

# The 1st Equator Workshop on Ubiquitous Computing in Domestic Environments

The School of Computer Science and Information Technology

The University of Nottingham

13th - 14th September 2001

The central goal of The 1st Equator Workshop on Ubiquitous Computing in Domestic Environments was to explore the integration of the physical with the digital in the context of the home in order to improve the quality of everyday life. Meeting this objective requires that designers address fundamental and long-term research challenges, particularly how ubiquitous computing technologies and concepts relate to everyday domestic environments. The digital world is increasingly present in our everyday lives and the spread of ubiquitous and mobile computing and communication devices means that home, work and leisure activities are interwoven in ever more complex ways. The workshop investigated ways in which the merging of physical and digital worlds may enhance home life. Researchers, designers and developers attending the workshop were especially concerned to understand the relationship between technologies and domestic environments, the use of ubiquitous computing to support activities within domestic environments, and the development of new forms of information appliance. The workshop brought researchers from a range of academic and industrial backgrounds together, who in various multidisciplinary ways share an interest in developing technologies for home. The multidisciplinary character of the workshop has fostered an ongoing dialogue between technology developers, designers, social scientists, artists and other researchers who seek to develop new technologies and new forms of application to support and enhance the quality of everyday life in the home.

Editors: Andy Crabtree, Terry Hemmings and Mark Rouncefield. ISBN 0853581002

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# The Millennium Home: Domestic Technology to Support Independent-living Older People

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**Abstract.** The number of older people in the population is increasing, and the problem of supporting a good quality of life for an ageing population is greatest in developed countries such as the USA, Japan and Britain because of the demographic structures of these countries. In Britain, improvements in quality of life and lower birth rates have resulted in those over 65 years of age representing 16% of the population, with this figure expected to rise to 19% in the first quarter of the 21st century. Many of these older adults, for reasons of personal choice and economics, will continue to live independently with a large number of them living alone. However, the elderly are far more prone to accidents in the home and often lie injured and undiscovered should one happen. It is in the interest of society in general that some way be found to detect early manifestations of problems they may have and provide some kind of a response to resolve the problem or summon external aid as quickly as possible. This also needs to be done in a way that the resident is comfortable using, is useful to them, and is usable. This paper provides details on the work to date of the Millennium Home project, which uses a combination of unobtrusive sensors, linked to a computer to monitor the well being of the elderly resident. Should a situation arise where the residents well-being may be threatened, the system will communicate with them in an attempt to resolve the situation or contact an outside party for assistance.

**Keywords.** Interface design, domestic technology, independent living, seniors.

Paper presented at The 1<sup>st</sup> Equator IRC *Workshop on Ubiquitous Computing in Domestic Environments*, The School of Computer Science and Information Technology, The University of Nottingham, 13-14<sup>th</sup> September 2001. <http://www.equator.ac.uk/>

## **Introduction**

Most people are aware of the effects of ageing but few fully appreciate the extent to which it changes the way in which older adults live. General biological ageing occurs, resulting in problems with strength, dexterity, gait and mobility. Eyesight and hearing deteriorate leading to difficulties communicating with others. Psychological ageing also occurs leading to diminished cognitive abilities. Its effects include memory deficits and difficulty with tasks where attention is divided or there are unexpected forms of presentation. Any one of these problems can have a severe disabling effect and in most cases, older adults have more than one problem to contend with. The very old (over 85 years of age) can be particularly frail and have little ability to cope with minor health and environmental challenges. This increased frailty exposes them to a greater number and degree of challenges in everyday independent living. They are, not unexpectedly, one of the groups of the population most vulnerable to accidents, particularly in and around the home. Those living alone are particularly at risk with falls presenting the greatest danger. Approximately 75% of domestic accidents for people aged 75 and over were falls (Wright 1994). Furthermore, accidents such as these may lead to a decline in self-confidence and increasing social isolation.

A team of researchers and industrial partners led by Professor Heinz Wolff at Brunel University are currently involved in the Millennium Home (MH) project which aims to provide a solution to the problem. The MH system will be retro-fitted to existing homes as well as incorporated into new homes, and will use existing technology in order to monitor the state of the resident in order to identify potential or immediately threatening conditions. Our team is developing the resident/house interface to facilitate communication between the elderly occupant and in-house computer system. The human computer interface, or more precisely, the resident-house interface, integrates the various technical and social elements of the project and allows the resident to interact with the house/ MH computer. At the core of the project, we are using speech-based interaction, which is critical because of the ubiquitous technology environment, but also, its novelty provides us with problems in that it is a radical departure from existing systems. There are a number of difficulties faced in the development of interfaces for the elderly. These include physical difficulties, in their hearing, their vision, in

terms of their speech/vocalisation, which may be impaired, as well as reduced mobility. They may also face a general degradation in their cognitive abilities. Cognitive impairments include the following factors: a tendency for reduced adaptability to novel situations, divided attention and distraction problems, and possible Alzheimer's disease, including senile and pre-senile dementia (covering memory loss, paranoia). There are often problems of compound impairment, where problems of physical well-being interact with limited cognitive problems.

### **The MH project**

The MH concept was formulated by Professor Heinz Wolff and his team at the Brunel Institute of Biotechnology in Brunel University. It was conceived in response to the increasing numbers of older people in the general population and the associated social and financial difficulties that entails. The concept envisioned a home environment that would be equipped with simple and cheap sensors to monitor the state of the resident. Information from these sensors would be interpreted by an in-house computer that will only communicate with the outside world if there is a situation that cannot be resolved by interacting with the occupant. Any outside communication will be routed to a newly developed local support group, and a volunteer will respond by visiting the tenant.

### **THE MH TECHNICAL INFRASTRUCTURE**

The MH project is intended to provide its users (residents) with an intelligent alarm. This will have a degree of intelligence, and will allow the resident the ability to communicate and interact with it. When appropriate, it will ring out of the house for assistance. A primary aim of the MH project is that it should use existing affordable technology where possible. We are constrained by budgetary considerations, as this is intended to be used as an affordable commercial system at the end of the development process. While the final decision on the specific technologies to be used will not be made until later in the project (work is ongoing at Brunel on sensory technology and configuration as well as interface design), it is likely that some of the following will be used to monitor the state of the tenant:

- ❑ Passive infra-red sensors (PIRs) to detect movement
- ❑ Custom made pressure sensors which will be placed underneath the legs of chairs and beds to detect whether the user is sitting or lying down
- ❑ Burglar alarm style sensors on windows and doors
- ❑ A simple custom-made body count sensor on the main entrance to the property so that the system will know how many people are in the property at any one time.

Work is ongoing on a number of accessory devices, such as special door locks that will normally only work with the users own key but will, in an emergency, respond to a special passkey used by appropriate outside help.

In addition, the house will have to interact with the tenant. This will be performed through a multimodal interface, based around speech, because of the users expected limited computer skills and the context within which the system will be used. This multimodality has led to a number of interesting issues in linking different media (e.g. menu navigation across the different media). The system will communicate to the resident through:

- ❑ Loudspeakers placed in all rooms
- ❑ The television screen (activated though a computer)
- ❑ The telephone, which can ring the resident (activated though a computer)
- ❑ The resident will also communicate with the system through:
  - ❑ Voice recognition
  - ❑ The activation of environmental sensors (e.g. shutting a door)
  - ❑ A yes/ no button for simple communications

In order to enable voice recognition, we have the ability to shut off some noisy domestic equipment from the mains using the X10 protocol.

Dialogues with the resident are rarely a simple matter of yes/no answers, but will often involve extended dialogues. These will depend on the complexity of the required interaction, the location of interactive events, as well as the residents verbal/hearing limitations. Designing speech interfaces provides us with a challenge from three directions: the technological concerns (e.g. recognition accuracy); the psychological concerns (e.g. an ephemeral signal); and interactional concerns (e.g. issues of navigation). If we link these with the problems of the

MH users (the acceptability of technological intrusion into peoples lives; the psychological limitations of its residents, such as limited memory issues or confusion; and interactional problems, such as little previous experience with technology), we can see that designing the system will be more complex than it may initially appear.

## **Previous work**

The notion of an intelligent home is not new. A “house of the future” has been developed at the Massachusetts Institute of Technology which has sensors embedded “into the fabric of the home” (Larson 2000). A research initiative named the *Aware House* (Kidd *et al.* 1999) at the Georgia Institute of Technology is on-going. This is not a not a retro-fit but a house built for \$700,000. It perceives and assists occupants, with sensors in chairs and furniture, video motion detectors, and even a “smart floor” which can identify the occupant by their footprints.

In addition to smart house technology, this has been applied to an extent to the elderly in the Gloucester Smart House,<sup>1</sup> which supports residents with dementia. It monitors the bath temperature, cooker, ambient temperature, and provides night-time toilet guides (via lighting), as well as other assistive technologies such as a picture-phone, and forget-me-not technologies (e.g. to help find keys).

## **PROBLEMS IN THE TECHNOLOGY-LED DESIGN PROCESS**

Prior to the start of the project a prototype MH system was developed. The design, however, was technology-led and the functionality of the system was based on what the small team of developers and engineers involved thought would constitute an adequate system to meet the needs of older people. However, choosing a particular technology and then working backwards by trying to use it to meet user requirements is fraught with problems. There is a general tendency to try and make the users requirements fit the technology, when the focus of a user-centred design should be on ensuring that any technology used is *appropriate* for the particular needs and requirements of the target users (Norman 1986). There has been no exception to this in the Millennium Homes project. From the moment we joined the project we have had to

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<sup>1</sup> <http://www.bath.ac.uk/Centres/BIME/projects/smart/smart.htm>

challenge the existing design and designers with reasons as to the importance of this user led approach. We have therefore taken a standard user-centred approach to system development, rather than a radical approach to accommodate the concerns of the rest of the design team. User centred design (Newman and Lamming 1995; Schneiderman 1992) places the users at the heart of the design process. As older adults represent a very large user group with a diverse range of physical and cognitive abilities it is vital that we begin the development process by focusing on their specific needs and continue to maintain that focus throughout development.

### **Approach to design**

The first consideration of our team was to continue development of a functional specification that would build upon the work completed as part of the initial prototype. Previous work on design for the elderly and disabled has been based on user centred principles (Hypponen 1999) but acknowledges that choosing suitable methods to accommodate these users into the design process is not clear cut. We have chosen methods that are similar to those used in the field of Human Reliability Assessment (Kirwan 1990) because this discipline shares many of the key goals of protecting human life and health with the MH project. The aim of this aspect of the research is to describe the functionality of the MH system in terms of inputs (events or behaviour to be detected) and outputs (e.g. communication with the resident). This began by defining all tasks and activities that constitute independent living and for each of these, assessing the consequences if they are not performed correctly. These consequences may result in situations that arise within the home that have negative consequences for the resident and thereby endanger their well-being (by situation we mean any activity, occurrence or state of affairs in the home that might affect the residents ability to continue living independently). Potential elderly users and their carers were then consulted to decide which of the identified situations should be further analysed. The system behaviour for each of these situations will then be defined in terms of communication protocols between the resident and the MH system. These protocols are discussed in a later section.

## Requirements gathering

As part of the user centred design process it was vital that we had the involvement of independent living older adults and their carers in determining early system requirements. A series of focus groups were conducted to elicit information on the list of situations thought to make up the tasks of daily independent living. The aims were:

- To ensure that the identified tasks of independent living were valid and complete
- To discover which of these the participants would like the MH system to detect
- To categorise each situation in terms of seriousness and the time frame for concern, where participants specified how long they would expect to wait before an outside party was notified of the problem.

The results revealed a series of situations that we have classed as Level 1 and Level 2 inputs. Level 1 inputs indicate that a serious negative outcome has occurred in the home that would require outside assistance within minutes.

1) Incapacity in the resident as a result of:

- Injury
- Falls

2) Intruders in the home

Level 2 inputs indicate events that could lead to serious negative outcomes (detailed in Level 1 inputs) if not addressed properly. An aim of the system is to deal with these inputs wherever possible to prevent Level 1 inputs occurring.

- 1) Temperature regulation of the home environment
- 2) Management of existing medical conditions – ensuring medication is taken
- 3) Management of sudden onset medical conditions – where the resident would require prompt medical assistance
- 4) Home security – appropriate monitoring of all entry and exit points.

This initial data collection has helped to more clearly define the functional requirements of the MH system. Further requirements gathering will take place as part of user testing and evaluation.

## The design process

This will involve multiple iterations and regular user testing and evaluation with each iteration becoming progressively more refined. The first step in this first iteration of the process was an analysis of the situations highlighted in data collection (these will be referred to as alarms or alarm states from this point forward) and is described in the next section. Based on this initial analysis the resident/home interaction for each different alarm was modelled using flow charts. These flow charts attempt to provide a generic guide to the house response for different classes of alarm as well as sufficient fine-grained detail to allow the various stakeholders to provide input concerning aspects such as the timing, number and type of communication with the resident. This is discussed further in the section on protocol design.

### PRELIMINARY ANALYSIS AND IMPLICATIONS FOR HIGH LEVEL DIALOGUE DESIGN

Having determined what situations the MH system should aim to detect, this next stage involved determining what the system should actually do after detecting a given situation. There are many factors that can influence the interaction between the resident and the MH system. What follows are examples of typical questions raised and the answers suggested during this analysis phase. An alarm state indicating the resident had a fall is used. Basic factors that influence how an interaction is conducted include:

- *Time of Day*: Should not have that much bearing on this interaction. We can assume that the resident is awake. Even if resident fell out of bed while sleeping we will assume that the fall would wake them.
- *Resident Activity*: What is the resident doing? There should not be any activity because the MH has already detected a fall. We assume that if there is activity, it will be minimal and will not be detected by MH.
- *Resident Location*: The location of the resident dictates which devices (microphones, speakers, visual displays etc.) will become active to facilitate the interaction.
- *Level of Urgency*: This relates to the previous incidence of alarm states within the home and how they affect the urgency with which the system considers the current

alarm (default condition will be nil, or predetermined by carer). The factors above may also influence this (weighting and factoring to be determined).

These will then dictate the constraints on the communication with the resident so again, using falls as an example, we must consider:

- *Which mode of communication will be employed by MH system?* Speech will be used for first communication with resident. It is a quick method of alerting the resident to the fact that the system is aware of the alarm state and may also be the only possible mode of communication, given that they may not be able to move. If the resident does not provide feedback (i.e. a response that the system can understand) then the system should continue to use speech throughout the interaction. If resident does provide feedback and it is not understood speech will continue to be the dominant mode.
- *Which mode of communication to be employed by the resident as feedback?* Speech or tactile (such as the press of a button). Environmental action (the detection of a door or window being opened or closed) will not count as feedback. Only manual feedback will return system to safe state – manual communication indicates that the resident is conscious, has motor control (maybe not fully mobile but feels that they can deal with it themselves without the aid of the system) and is aware of what the implications of returning system to safe state are (i.e. no further help from system unless they request it)
- *How long should the system wait between each act of communication before attempting a subsequent communication?* It is suggested that a period of 3 to 5 minutes plus system processing time. This is an extremely urgent alarm state and it is reasonable to assume that if the resident is fine they will be able to provide feedback within 3 – 5 minutes, even if they have to locate a device for tactile input.
- *How many times should the system communicate with the resident to obtain feedback?* There should be some method, such as a timeout feature, whereby the system will automatically request outside assistance if the alarm is not satisfactorily resolved within a certain period of time (which would not be very long in this case). The number

of communications would then be dictated by the interaction timeout length and the timing gap between system communications specified in the previous question.

- *Can incoming data from the MH or other alarm states terminate/change current communication?* Once a fall has been detected and communication with the resident has begun, the interaction must go through all relevant stages before returning to safe state unless, another alarm state has been detected of equal or greater importance. The alarm state can be terminated by appropriate manual feedback from the resident or a call or visit from a carer
- *When will a call be initiated by the MH system to the call centre?* In the case of a fall, when system terminates communication with the resident (see above) or when the resident provides feedback that they are not ok and need assistance
- *When a call has been initiated by the system – does the system communicate further with the resident?* Yes. The system should provide reassurance and inform the resident that a carer has been notified.
- *How many times should reassuring messages be communicated by the system to the resident after a call has been made for outside assistance?* If unconscious the resident will not hear the message. If conscious, however, they may find repeated system communication exacerbates what is already an extremely stressful situation for them. The presence and timing of these messages will need to be dictated by the individual resident and their carers.
- *How will the system terminate communication with the resident?* On arrival of the carer or detection of a phone call being made by a carer (if this is possible) and the resident answering the call. The system should inform the resident about who is calling or letting themselves into their home (this will be detected by the lock system being developed for the MH). If the resident provides tactile feedback that they are okay, the system should acknowledge this and inform the resident that it will return to safe state.

## PROTOCOL DESIGN

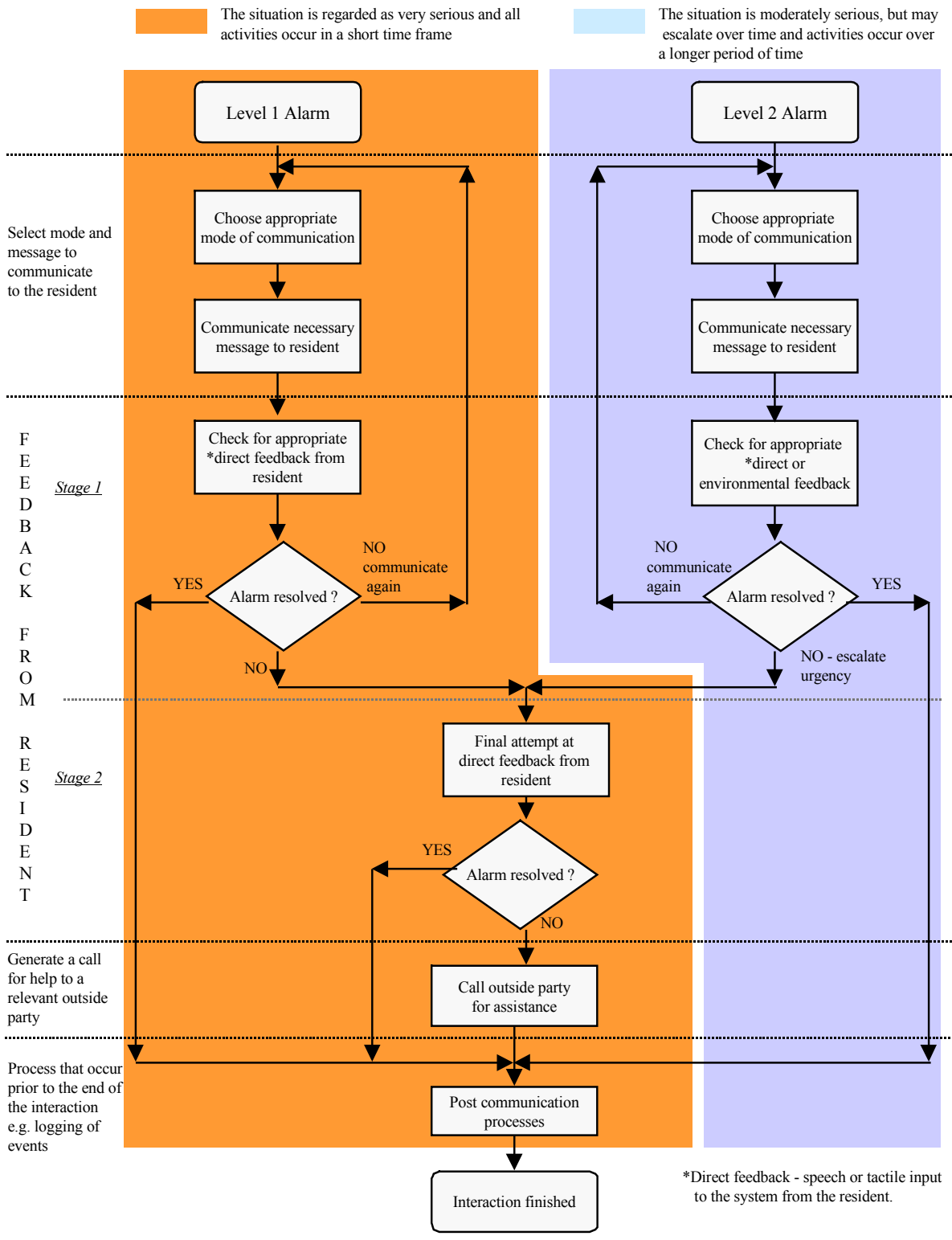
After the initial analysis was conducted it was felt that the next step should be to attempt some form of graphical representation of the sequence of events and flow of activities that made up each alarm state. Many of the questions raised during the analysis phase remained without conclusive answers. The various stakeholders would need to be consulted at this stage and to do this a representation of the proposed design was needed that would not require any prior technical knowledge on their behalf. It should also be capable of communicating some of the more fine-grained aspects of this phase of the design process. It was not just the stakeholders that were taken into consideration when choosing a suitable representation. The design team contained individuals that were not from a technical background, so this choice had to accommodate their lack of practical design experience.

Flow charts were chosen as the method of representation because of their relative simplicity and the ease with which they can be learned. While they may not necessarily continue to be utilised in later design iterations, they proved to be an excellent common language for all concerned at this early stage of the process. Figure 1 shows a high level flow chart of the two classes of alarms identified in requirements gathering. At this high level of detail the different classes are almost identical. Both alarm classes attempt to get feedback from the resident in two stages. Stage 1 involves a number of cycles of communication (the difference between the two here is the acceptance of environmental feedback from the resident in certain Level 2 alarms). If this fails to gain appropriate feedback there is a second stage that is a final attempt at gaining feedback before the system notifies an outside party. The most significant differences between the two classes, however, concerns the levels of urgency and the time frame within which activities occur. These will most likely be different for each alarm state. Figure 2 shows a table detailing some the communication, feedback and timing issues that need to be addressed for the different alarm scenarios.

## **Current and future progress**

Detailed flow charts of each different alarm situation are currently being developed. The generic interaction structure shown in Figure 1 will be used to help develop the various context-targeted interactions with resident. These will be shown to all stakeholders for assessment and the necessary changes will be made in a second series of flow charts. Another issue currently being considered is how urgency management should be incorporated into the design. This is an important aspect and will need to be dealt with carefully. Spiralling danger levels in the home will need to lead to modified interaction with the resident. There should be increased urgency in dialogues in these cases and possibly fewer warnings before an outside party is contacted.

Much work still needs to be done and there are still some basic design issues that have yet to be resolved. The prototype system being developed will have difficulties if there is more than one individual in the home. A suitable way of sensitively assessing house occupancy will be required. A body count sensor on entry points has been developed but can have problems if two people enter side by side. It only sees one person instead of two. An alternative way of determining if there is more than one individual in the home is required and will most likely be another form of verbal interaction between the MH system and the occupant. Interaction scenarios for all contingencies (alarm-related scenarios and non-alarm related) will need to be developed and an iterative evaluation process is planned. A heuristic evaluation of the first flow charts will be conducted to ensure that the basic design adheres to the tenets of interface design. The second phase of evaluation will most likely involve the use of the developed flow charts as verbal prototypes that can be evaluated by stepping through each interaction scenario to check that all eventualities have been accounted for. The next stage will involve implementing the design in the form of software prototypes. Development will be an iterative process with subsequent prototypes becoming more refined. Various pilot homes, where the MH system can be tested in a real life environment, have been established and considerable user testing is expected to take place here.



**Figure 1. High-level alarm flow chart**

ALARM	Mode of first communication	Max number of subsequent communications	Is feedback from resident required?	Type of feedback required (Stage 1)	Input device used for feedback (Stage 1)	Type of feedback required (Stage 2)	Input device used for feedback (Stage 2)	Max time from alarm start to alarm end or callout
<b>Fall</b>	Speech	4	Yes	Direct (Speech)	Microphone	Direct (Tactile)	Telephone	30 minutes
<b>Inactivity</b>	Speech, Visual display, Telephone	4	Yes	Direct (Speech)	*Input Box	Direct (Tactile)	Telephone	31-60 minutes
<b>Medication reminder</b>	Speech, Visual display, Telephone	4	Yes	Direct (Speech)	*Input Box	Direct (Tactile)	Telephone	31-60 minutes
<b>Temperature too low</b>	Speech, Visual display, Telephone	3+	Yes	Environmental	Thermostat	Direct (Tactile)	Telephone	60+ minutes
<b>Window open</b>	Speech, Visual display, Telephone	3+	Yes	Environmental	Window sensor	Direct (Tactile)	Telephone	60+ minutes
<b>Door open</b>	Speech, Visual display, Telephone	3+	Yes	Environmental	Door sensor	Direct (Tactile)	Telephone	60+ minutes
<b>Door shut But not locked</b>	Speech, Visual display, Telephone	3+	Yes	Environmental	Door lock sensor	Direct (Tactile)	Telephone	60+ minutes
<b>Intruder</b>	Visual display & Telephone	N/A	Yes	N/A	N/A	N/A	N/A	N/A

Figure 2. Alarm look-up table

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## Investigating Ubiquitous Computing in the Home

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**Abstract.** In this paper, we describe a series of workshops which were carried out in homes of five families in Scotland. The aim of the workshops was to explore the requirements that people have for new technologies in a household environment. The workshops were video-taped, transcribed and analysed from a number of perspectives. In this paper we concentrate on an analysis of the transcripts from the perspective of ubiquitous computing. The designs of possible future technologies will also be examined. Conclusions as to the applicability of the methods used here for future ubiquitous computing research and research in households are presented.

**Keywords.** Ubiquitous, households, families, HCI, technology.

Paper presented at The 1<sup>st</sup> Equator IRC *Workshop on Ubiquitous Computing in Domestic Environments*, The School of Computer Science and Information Technology, The University of Nottingham, 13-14<sup>th</sup> September 2001. <http://www.equator.ac.uk/>

## **Introduction**

One of the main challenges of ubiquitous computing is to meet the needs of real people living in the real houses rather than meeting the needs of a fuzzy idea of ‘users’ in ‘smart homes’ which have been purpose built. The majority of the population live in homes, which are more than twenty years old. Therefore it is imperative that designers and researchers investigate existing homes and families and try to understand their needs and thoughts.

The majority of recent approaches to design of interactive technologies have been developed for work environments. However, with technology migrating into the home, we need to consider the methodological challenges and opportunities in the home environment with respect to tools and methods for design of household technology. At present a number of studies of the use of household technologies have been conducted (O’Brien *et al.* 1999; Petersen and Madsen 1999; Kraut *et al.* 1998). However, few have looked into tools and methods specifically for the design of future household technologies. We describe in the following section the tools and methods we used in a series of home workshops.

## **Workshops**

There is a general lack of relevant literature and research in the area of requirements and design in household settings with a few notable exceptions i.e. (Venkatesh 1996; Kraut *et al.* 1998; O’Brien *et al.* 1999). As O’Brien *et al.* pointed out, the new focus by manufacturers on consumers in the home has important implications for HCI in particular. The problem for us as researchers was to what extent can HCI ideas and methods used to understand work environments would transfer to investigations in the home. As O’Brien commented Compared to work environments, how and in what ways domestic environments may be best investigated for the purposes of design remain little explored.

Methods of requirements gathering such as observation, simple interviews and so on do not transfer well to a domestic setting (Kjaer *et al.* 2000). Accordingly it was felt that a series of design workshops was appropriate. HCI researchers in the past have used design workshops as a way of establishing creative and collaborative settings for design (Petersen and Madsen 1999; Buur and Bødker 2000; Bødker *et al.* 2000). Therefore we decided that this may be a

way of gaining insight into the home and finding out more about how people use and interact with their technologies. We therefore carried out some situated ‘requirements determination’ workshops. The overall aim of the workshop series was two fold; (i) to explore the effectiveness of methods for gathering contextualised requirements for information and communication technologies in the home and (ii) invite participants to conceptualise in the form of a paper prototype their ideas for a home device. As argued by Druin (1999), we need to take into account who the users of the technology we are designing for are. While Druin’s work concentrated on designing technology with children, in these sessions, we sought to engage with the whole family. The series consists of three sessions with each family, at home, with approximately three weeks in between each session. As illustrated in the following table, the focus of the sessions developed through the course of the engagement with the families.

	<b>Session 1</b>	<b><i>Inter-session activities</i></b>	<b>Session 2</b>	<b>Session 3</b>
<b>Focus</b>	Investigate current problems and future possibilities	<i>Collection of data in-between sessions</i>	Contextualise ideas in home and daily life	Discussion, critique and iteration
<b>Methods</b>	1. Technology tour 2. Representations of emerging technologies 3. Materializing ideas for future technologies	1. <i>Post-it notes</i> 2. <i>Annotations on devices or drawings.</i>	1. Informal interview 2. Scenario analysis. 3. Positioning the technology physically in the home	Sharing ideas across families Modifying and elaborate on proposals.

**Table 1.** The Focus and Methods in the three sessions held in each family

Venkatesh (1999) conceptualised the household in terms of Home as Living Space, consisting of three key ‘spaces’: the social space, the technological space, and the physical space. In our first session we decided to focus initially but not exclusively on what Venkatesh (1996) termed

‘The Technological Space’, which represents the nature of the technological environment within the household.

Five families in Scotland agreed to participate in the workshops. The families cover a spectrum ranging from the family with two young children to a single 80-year-old woman (see Table 2). Each session lasted approximately one and a half hours.

Code	Who	Sex	Age	Occupation	House	Technologies
Cook	Rob father	M	48	Lecturer	Victorian, large, 4 bedrooms, dining room, drawing room, lounge kitchen, 2 bathrooms, cellar.	A mixture of old and new, games consoles, computers, Television.
	Sue mother	F	47	House Wife		
	Dianne daughter	F	10			
	Tarquin son	M	7			
Petric & Naysmith	Catherine partner	F	27	Recruitment Consultant	Semi-detached, newly acquired, 2 bedrooms, lounge, kitchen, bathroom	Mainly new technologies games console, mobile phones, etc
	Gordon partner	M	31	Admin Officer		
Suttons	Emily wife	F	68	Retired teacher	Victorian, large house, converted for their lifestyle e.g. converted, 2 bedrooms into 1 large room for entertaining.	low tech, standards technologies, TV, Hi-Fi etc
	Peter husband	M	70	Semi-retired builder (own business)		
Smiths	Simon Father	M	45	Joiner	Local authority flat, 2 bedrooms, lounge, kitchen, bathroom	High tech, lots of new technologies e.g. digital TV, PC, Mobile phones etc
	Barbara mother	F	43	Catering Asst		
	Mike son	M	15			
Reilly	Agnes	F	74	Retired Cook	Local authority, 2 bedrooms, lounge, kitchen, bathroom	Low tech, portable tv, small Hi-Fi

**Table 2.** Households in the study (pseudonyms have been used).<sup>1</sup>

<sup>1</sup> For a fuller description of the families and their homes see Baillie *et al.* (2001).

## TECHNOLOGY TOURS AND USER STORIES

After a brief introduction to the purpose of the sessions – to investigate people’s use of technology in the home – members of the family were asked to take the researcher on a tour of their technology. Typically the tours were quite unstructured with members of the family coming and going, commenting and cutting in as appropriate. Although this led to some difficulty in the analysis (see below), it was certainly grounded in the situation! Several researchers have pointed out how the way the technology is integrated in the physical and social organisation of the house provides useful clues of understanding the use of these technologies (O’Brien *et al.* 1999; Stolzoff *et al.* 2000; Abowd and Mynatt 2000; Venkatesh *et al.* 2000). Thus we maintained this focus in the technology tours. For example, Sue pointed out a radio cassette that she had:

Sue: I have got this umm... tape and radio but I am afraid only the radio works now.

Researcher: Right

Sue: As you can see it has seen better days

Researcher: Why have you still got it?

Sue: Well it comes in handy when I am moving round the house doing different things, the other one [she points to the new music system in the corner] has to stay where it is.

In these rounds we asked about possible conflicts in ownership of physical space (O’Brien *et al.* 1999; Venkatesh 1996) as well as the history, flexibility and motivation for the physical organisation of the space. We further asked them to describe problematic situations they had experienced with the technology and we asked people to show us how they used the technology. This prompting produced some particularly interesting accounts, focusing on specific incidents and breakdowns. For example, Emily had to change the batteries in her phone: the phone had instructions as to where the positive and negative symbols should be facing on the phone but no instructions as to how to insert or place the batteries, therefore Emily spent several frustrating hours trying to fix the phone only to find that when she threw the phone down in disgust the batteries slipped into place. Stories are valuable in that they are repositories of accumulated wisdom (Brown and Duguid 1996), provide accounts of the social,

## Understanding Existing Smart Environments: A Brief Classification

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**Abstract.** In recent years, smart environments have emerged as a key target area for ubiquitous and pervasive computing research. As technologists contemplate moving the focus of their research from proprietary laboratories into 'real living spaces', such as the domestic environment, it becomes important to gain an understanding of existing work and experiences in this area. As part of our work within the 'Domus' strand of the Equator IRC, we have conducted an extensive survey of existing smart environment computing research; we have discovered a rich and diverse set of work drawn from many disciplines. In this paper we present an initial design space for domestic focused technologies and highlight areas that we believe require further work. In addition, we highlight a number of design opportunities drawn from the existing work in this area.

**Keywords.** Domestic environment, smart home, technology, classification.

Paper presented at The 1<sup>st</sup> Equator IRC *Workshop on Ubiquitous Computing in Domestic Environments*, The School of Computer Science and Information Technology, The University of Nottingham, 13-14<sup>th</sup> September 2001. <http://www.equator.ac.uk/>

## Introduction

The ‘Domestic Space’ as a research topic, social issue, and commercial market has grown over the past few years. As a part of our work on the Domus project of the Equator IRC we have embarked on an extensive survey of the technical contributions that have taken place in the field of ‘intelligent environments’ over the past decade. Intelligent environment research spans a broad range of research domains from sheltered housing to home control applications. One of the emergent issues from this survey work has been the importance of developing technologies that are specifically *designed for* the domestic space, rather than simply a transplantation of office focused technologies. To illustrate this point further, consider the now defunct Interval Corp. (Hindus *et al.* 2001). Initially, Interval took their office media space prototype (Hindus *et al.* 1996), and conducted a field trial, which placed it directly into the home environment. The researchers found the media space was not well used in this environment, people often found them to be an intrusion on their privacy due to the lack of control information that was available about them. As a consequence of this lack of acceptance, Interval engaged in an in-depth study of the home environment as a setting for technology. As a result of this study, Interval developed a product called ‘the presence lamp’, a very different product from their initial office focused starting point, but one suited the target environment. The Interval Corp. have learnt that the home is very different from the office, in terms of the physical and the social aspects, but we have found many other institutions using the home as a secondary validation for technologies that they have already created. It is rare to find a technology that has gone through a complete revision process after being tested in the home.

In considering the placement of new technologies in a domestic setting, we believe it’s important to gain a thorough understanding of the placement of existing research and technologies. To this end, in this paper we present our formative work in developing a classification of existing domestic technologies - allowing us to form a structured view of the field; a ‘design space’. To be able to create such a space we must choose classifiers that can capture the diverse range of work that is being carried out under the banner of ‘domestic technologies’. In conducting our investigation we felt it appropriate to draw on research that

has been conducted in related areas that are, on the surface, similar to domestic spaces. Several technologies often used in augmenting meeting rooms have multimodal interfaces, which would clearly have a lot in common with a shared multimodal interface in the home. To be able to provide of more complete map of domestic research we feel that these fields are worthy of inclusion.

### **Creating the design space**

The partitioning of such a diverse research area can be seen as somewhat clumsy and imprecise. As seen in Dix *et al.* (2000) design space for mobile computing, the absolute categorisation of devices or technologies is not necessarily possible, nor even feasible. Several technologies that we have investigated can cover more than one classification point, making them difficult to pigeonhole. To disentangle the space we have created three dimensions in which to regiment domestic technologies. They are: *control*, *binding to people*, and *interface*. We shall first consider the relationship of the point of control to the controlled device. Over the last 50 years, the point of control of a television (the switches and knobs) has moved from being *embedded* in the device itself to being *disconnected*, most televisions have infrared remote controls. A remote control still requires the user to be co-located with the television, but domestic research is pushing control further out, such that it can be done *remotely* via a web page or WAP phone. The migration of the control point of a technology, from *embedded*, though *disconnected*, to *remote* forms our first categorisation.

Our next dimension is taken from Dix *et al.*'s mobile taxonomy; 'the extent to which a device is bound to a particular individual or group'. This breaks down into three categories, *personal*, *group* and *public*. Personal devices only support one person, whereas public devices are available to a wide group of people. In between these two extremes is the group category, in which a device supports several people. Dix *et al.* highlighted the fuzzy nature of this category by making explicit two types of 'groupness': groups together and groups over time. The television can be seen as a device that serves a group of people sitting around watching it, whereas a noticeboard on a fridge serves a group of people over time (they don't have to be temporally co-located in order to read the messages on the board).

Our final dimension is based on the interface to the device or service, which we have segmented into *natural*, *familiar* and *artificial*. The usability of a domestic product is crucial to its commercial success, although several research projects are investigating alternative interfaces. Most often an ‘alternative interface’ is a web or WAP page allowing the remote control of the device. The device relies on another device or technology to mediate the interface, e.g. a web browser to display information and capture user input. The majority of current smart environment research regards the desktop metaphor as inappropriate for the home, prompting research groups to look for interfaces or interface metaphors that are more *familiar/simple* in this context. The far extreme of this dimension is the *natural* interface, where the interface can be seen to be pervasive and interaction is possible using different modalities, examples being speech, gesture or gaze.

### **Populating the space**

Having segmented the space we can begin now to populate it using surveyed work. Shown below is a matrix of the space using the classification above criteria (see Figure 1). One of the most obvious trends in domestic research is the augmentation of control of a device, to allow a processor to change the state of a device. The gradual introduction of technology into the process of boiling water, from a boiling pan, to a specialised vessel that notifies you when the water is boiling (whistling kettle), to a vessel which turns itself off once the water has boiled (kettle with a bi-metallic switch), is an example proving that this type of evolution is nothing new. The technology is taking an increasing role in the process, yet becomes embedded and as familiar as domestic routine. Several projects around the UK use this approach for designing smart infrastructures for the elderly, disabled or dementia sufferers.<sup>1</sup>

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<sup>1</sup> CUSTODIAN - Conceptualisation for User Involvement in Specification and Tools Offering the Efficient Delivery of System Integration Around Home Networks:

<http://www.rgu.ac.uk/subj/search/Research/SustainableHousing/Custodian/Home.html>

Smart Homes: The Application of Home Automation and Assistive Technologies Within Social Housing:

<http://www.sussex.ac.uk/spru/imichair/projects/template.cfm?content=smarthomes.cfm>

Integrated control and communication systems for distributed sheltered housing in the community. The Queen's University of Belfast. <http://www.qub.ac.uk/tbe/arc/research/projects/equal.html>

Astrid: A Social and Technological Response to meeting the needs of Individuals with Dementia and their carers. <http://www.astridguide.org/>

		Device Binding			
		Personal	Group	Public	
Point of Control	Embedded	Artificial	PC Network Card	Shared PC Peripherals (Home PNA)	
		Familiar	Kitchen Appliances	Game Console Fridge Messageboard	Door Bell
		Natural			Creative Multimodal Spaces
	Disconnected	Artificial	'Follow Me' Info	Shared PC Peripherals (Home PNA)	<b>Intelligent Rooms</b>
		Familiar	Kitchen Appliances	Game Console Fridge Messageboard	
		Natural	Utilities Monitor	Electronic Whiteboard	
	Remote	Artificial	WAP services Web Services	Heating Control Fridge Messageboard	Security Lights
		Familiar			
		Natural			

**Figure 1.** A design space matrix for the home

Experiments with multimodal interfaces are also being performed in the home, as further recognition that a desktop interface is not always possible or desirable in a domestic context. Much of this research is based around business meeting rooms; using natural forms of interaction to allow a group of people to control a shared device (the Group-Disconnected-Natural cell in our matrix) or collaborate more effectively. The capture of these natural interactions is often performed by voice recognition,<sup>2</sup> or video processing.<sup>3</sup> Novel devices and displays are also used to display information in a shared environment. Solutions can range from the embedding of PC-style displays in furniture,<sup>4</sup> or on public display boards (McCarthy *et al.* 2001) to more ambient methods as seen in the Presence Lamp (Hindus *et al.* 2001;

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Smart Homes in Portsmouth: <http://www.envf.port.ac.uk/arc/research/index.htm>

The Gloucester Smart House: <http://www.bath.ac.uk/Centres/BIME/projects/smart/smart.htm>

<sup>2</sup> IBM: Natural Interactivity: <http://researchweb.watson.ibm.com/natural/>

<sup>3</sup> Microsoft EasyLiving project:  
<http://research.microsoft.com/easyliving/>

FXPal Smart Media Spaces Group:  
<http://www.fxpal.com/smartspace/index.htm>

AVIARY Audio-Video Interface for Intelligent Environment. CVRR Lab, San Diego, California:  
<http://swiftlet.ucsd.edu/~kimng/research/dimi.html>

<sup>4</sup> Ambiente. Work Spaces of the Future. GMD.:<http://www.darmstadt.gmd.de/ambiente/home.html>

Domisilica: Bring people and places together. GaTech: <http://www.cc.gatech.edu/fce/domisilica/index.html>

Schmidt *et al.* 1999). In the Group-Remote-Artificial cell, ringed in Figure 1, we can see a good example of a technology that spans across multiple classifications – where an interface within the home is also being coupled with a remote interface. These interfaces may be presented via web pages, WAP decks or even using augmented reality in wearable computing and allow the control of domestic services, particularly air and water heating. The mobility of access to services is being investigated by Project Aura amongst others.<sup>5</sup>

#### GAPS IN THE DESIGN SPACE

Some cells in the matrix denote research areas yet to be explored. The Public-Remote-Artificial cell, a remote web/web style controller for a device or service that is bound to the home and those outside it, has ‘Security Lights’ as a technology – realised by using X10 home automation equipment and an always on network connection.<sup>6</sup> This public display of information, turning on lights in the home to make it look as if you are in, is an interesting use of technology. Work done by Interval reports that devices that make public information about what is happening in the home can force a inhabitant into commitments which they do not want to make (Hindus 1999). Hence the only Public-Remote-Artificial device, which can currently fit into this category, is the one that supplies misinformation to the outside world.

The whole bottom row of Figure 1, the Remote-Natural section is completely blank. We have touched on natural interfaces for workspaces above, but the hardware and software requirements of natural user interfaces make their portability an issue, indeed whole infrastructures have to be created and fitted into the home in order to be able to dependably capture multimodal input. This is also why we have blank areas for Personal-Embedded-Natural (a personal device which you can speak to, although it could be argued that voice dialling in mobile phones could be classified in this section), and Group-Embedded-Natural (a standalone device that to which a group of people could talk at).

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<sup>5</sup> Project Aura: Distraction-free Ubiquitous Computing. Carnegie Mellon University:  
<http://www.cs.cmu.edu/~aura/>

<sup>6</sup> <http://www.x10.com>

## **Conclusions**

The design space has proved a useful tool in placing current research into some sort of context in addition to identifying new research opportunities. Across nearly all of the technical work that we looked at the research was technologically driven. The two exceptions to this rule are those research activities that are concerned with augmenting homes to support ‘care in place’ and the work done by the Interval Corporation. Many of the technologies that have been sold for the home have migrated from the workplace, be it automated building security, networking, or the Personal Computer itself. There are several pitfalls to this migration, which we shall discuss in our presentation, together with a classification of the emerging work within the Equator IRC project with respect to our design space.

## Acknowledgements

This work has been performed as part of the Equator IRC, ESPRC Project GR/N15986/01.

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## Domestic Legacy and Design

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**Abstract.** A great many approaches to the design of domestic technologies are revolutionary in character, seeking to construct the home anew. By way of contrast we articulate a post-revolutionary perspective, which seeks to build the future on top of the domestic legacy. Treated as a legacy problem, design for the domestic environment is seen to rely on an appreciation of the social organization of the domestic space, within which systems are embedded and used. We address the methodological problem of making the domestic legacy available to design, advocating the adoption of a pattern language framework derived from the architectural evaluation of the uses of buildings. We consider the role of patterns of technology usage in a design context.

**Keywords.** Home, domestic legacy, patterns of technology usage, ethnographic studies.

Paper presented at The 1<sup>st</sup> Equator IRC *Workshop on Ubiquitous Computing in Domestic Environments*, The School of Computer Science and Information Technology, The University of Nottingham, 13-14<sup>th</sup> September 2001. <http://www.equator.ac.uk/>

## Introduction

The domestic environment is currently receiving a great deal of attention from commercial and academic computing sectors alike. Many approaches to design in a domestic context adopt what might be called a “revolutionary” approach to redesigning the domestic space through technological innovation. By this we mean that many approaches to design treat the home as something to be constructed anew. By way of contrast, we suggest that this “year zero” mentality ignores domestic legacy. The home is not a new institution but an ancient one whose organization changes gradually over time to meet the quotidian needs of its inhabitants. We suggest that rather than ignore this organization design should instead strive to build upon it (Mitchell 2000), not least for the reason that future technologies will inevitably be answerable to that domestic legacy. Indeed, the success or failure of technological innovations for the home might be seen to rely on their fitting into and adding value to the quotidian organization of domestic life that is our domestic legacy (Keeley 2001).

We are suggesting, then, that rather than construe of the home as a site for radical “revolutionary” innovations, a “post-revolutionary” perspective, which construes of the design of domestic technologies as a legacy problem and seeks to build evolutionary solutions “on top of” existing organizations of home life, is more appropriate to the challenge. Readily intelligible examples of legacy problems include the “millennium bug” and the introduction of the “euro”. On each of these occasions designers were compelled to get to grips with the requirements of future technologies by addressing *the constraints of the past and the present*, which are not purely technical in character (Gold 1998). Whatever technical characteristics computers may possess, they are embedded in an organizational context, which is essentially social in character. Naturally, the home is no exception, being a socially organized setting regardless of its non-commercial character (Venkatesh 1996). In dealing with domestic legacy issues we need not only to attend to technical matters then, but also, to the social organization of the home, which sets the constraints and elaborates requirements for technology usage.

We take it that addressing domestic legacy is a methodological problem. A problem, that is, as to how we might explicate, or make available to design, the quotidian social organization of the domestic environment? Workplace study methods appear to be highly inappropriate for

the task. The products of domestic life – people - are exceptionally valuable and their rationalities of production, efficiencies, labour costs, material needs, and the rest, cannot be adequately appreciated in terms of workplace criteria of production. Developments in evaluating the use of buildings in architecture seem more promising and have attracted considerable attention in a design context of late (Bayle *et al.* 1998, Erickson 2000; Hughes *et al.* 2000). At the heart of the matter lies the notion of a “pattern language” (Alexander 1979). Below we briefly address the architectural notion of patterns and our own adaptation of that notion to include the social organization of domestic technologies. We consider the role of socially organized *patterns of technology usage* in a design context prior to drawing our conclusions.

### **The emergence of a pattern language**

The notion of a pattern language for design has its origins in architecture’s efforts to reconstruct itself through taking the adaptation and use of towns and buildings into account (Brand 1994). It specifically emerges from the work of the architect Christopher Alexander (1977). Alexander observes that towns and buildings are orderly places organized through reoccurring “patterns of events” that people take part in over and over again. Being in bed, having a shower, having breakfast in the kitchen, sitting in the study writing, walking in the garden, cooking and eating a common lunch, going to the movies, taking the family to eat at a restaurant, having a drink at a friend’s house, driving on the freeway, going to bed again are examples used by Alexander to illuminate the point. Although such patterns of events are implicated in the daily lives of individuals, a great many of them are not individualistic but organize “our lives together” as members of society –

they are the rules through which our culture maintains itself, keeps itself alive, and it is by building our lives out of these patterns of events, that we are people of our culture. (Alexander 1979)

Thus, and for example, each morning people get up, shower, eat breakfast, and drive down the freeway to work, where they together engage in other patterns of events, such as checking their

mail, attending meetings, or going for lunch, etc. A great many of the patterns whereby towns and buildings are organized are thoroughly social in character then. Patterns thus make available the social organization of towns and buildings.

Importantly, patterns of events are *tied to particular places* within a society: showering in a morning to the bathroom, eating breakfast to the kitchen, driving to the freeway (and not the sidewalk), for example. As Alexander puts it, patterns are always “anchored in space” –

I cannot imagine any pattern without imagining a place where it is happening. (ibid.)

Furthermore, the patterns out of which any particular place – a bathroom, a kitchen, a freeway, etc. – is made up are “rather small” or finite. The finite and architecturally-bounded character of patterns provides for their generalization. The notion of obeying red and green signals at traffic lights provides a widely intelligible example of the generality of patterns within a society. Gross generalities of the kind that typify a great deal of work in the human sciences are eschewed then. What is generalized and generalizable are the particular patterns of events which occur in particular situations located in particular places in particular societies.

The preliminary aim of pattern analysis in a domestic context is to identify the finite pattern of events that occur in and define particular places. In kitchens, living rooms, studies, and the other sub-environments that taken together comprise the home. Thus patterns provide a rich portrait of the social organization of the home, within which future technologies will inevitably be embedded and in various ways be answerable to. Identifying patterns of events is not the primary focus of pattern analysis, however, but the starting point for the explication of the domestic legacy. The primary aim of pattern analysis is to identify the socially organized *pattern of relationships* that obtain between events and the material arrangements of place: between cars and pedestrians crossing the road, between a person entering a building and the physical entrance, between people doing individual activities in a communal living room, etc. (Alexander 1979).

We extend the notion of material arrangements of place to include household technologies, which we construe of in the broad sense of the word to include such things as the humble pen and paper as well as sophisticated computing systems. As Venkatesh and Nicosia

(1997) put it, we need to look at a whole range of technologies in the home no matter how mundane,

[for] in order to understand the adoption/use issues of computers, one must view the total technological space of the household ... very little insights will gained by looking at computers alone.

Thus, and for example, in the course of “making breakfast” certain pragmatic day-to-day patterns of relationships become apparent and make technologically mediated organizations of domestic life involving kettles, toasters, microwaves, radios, TVs, newspapers, and the rest, available to design. Patterns of relationships reveal *patterns of technology usage* then. We take the explication of these patterns to be the goal of pattern analysis in a design context as they make the real world, real time social organization of the sub-environments that comprise the home available to consideration in the design of future technological arrangements of place.

### **Identifying patterns**

It is one thing to theorize the characteristics of patterns, another to identify them as real world, real time features of the domestic legacy. How are real world patterns of events to be located and how are we to explicate the patterns of relationships that obtain between events and technology in real time? Being designed for the needs of architecture, Alexander’s observational framework is not adequate for the task. One potential solution is articulated by Venkatesh (1996). While agreeing with the ethnographic approach to the study of “actual patterns of use”, we have certain reservations regarding the analytic emphasis placed on the sociological functions of technology in the household/ technology model however. We are specifically concerned with the substitution of members’ formulations of meaning for analytic formulations of functional value. As Venkatesh and Nicosia (1997) quite rightly point out

technologies are not passive objects in the technological space, they are live, full of meanings for the members ... who use them.

The meanings members attach to technologies drive adoption and use. The use of desktop computers in the home, for example is motivated and regulated by the meanings members' attach to it - that the computer is an "educational" or "communication" tool or something that the kids "waste time" on, for example. It is not that the computer either assumes one of these meanings or the other but rather, at different times for different members it assumes all of these meanings, and its use is thus woven into the milieu of domestic activities: into the doing of homework, sending emails to friends and relatives, playing games and being turned off to stop the playing of games, etc. Members come to adopt technology and organize its use through the meanings *they* attach to it in the course of conducting their daily affairs. Thus, it seems to us, that analytic attention ought to be paid to members' formulations of meaning rather than be substituted for professionally defensible versions that gloss over the real world, real time social organization of technology usage.

#### LOCATING REAL WORLD PATTERNS OF EVENTS

Rather than develop a model of the home, we prefer instead to conduct, through ethnographic inquiry, ethno-methodological studies of work (Garfinkel 1986; Crabtree *et al.* 2000). While it may appear strange to talk of studying "work" in the home, we do so in the sense that domestic environment is a site characterized by ongoing practical activity: of getting up and ready for work in a morning, of taking the children to school, of receiving guests, making dinner, doing schoolwork, and all the other mundane socially organized events that "go on" in and "make up" the domestic environment. We take it that it is the sense of ongoing practical activity rather than paid labour in particular that the home may be characterized as a site of "work" then; that the work that takes place in the home is part and parcel of and elaborates the domestic legacy; and that design should, therefore, attempt to be responsive to that work as technologies will in various ways be embedded within the socially organized activities of the home and their use be constrained by them.

In undertaking studies of work in the home we are particularly concerned to locate the work implicated in the *routine construction* of domestic life. The construction of domestic routines enables household members to coordinate and (thus) conduct their daily activities in

an orderly rather than a haphazard way. In getting up in a morning, household members may take the same routine turns in using the bathroom for example, thus ensuring that they get to work on time. As the example indicates, routines are distributed around the various sub-environments that comprise the home and interwoven with the use of technology: the technologies of the bathroom (showers, razors, toothbrushes, etc) and the kitchen (toasters, kettles, radios, etc.) are implicated in daily routines of getting up and getting ready for work, for example (O'Brien *et al.* 1999). In this respect it might be said that routines articulate large or primary patterns of events that define particular places within the home, each of which is composed of smaller component patterns. The purpose of work study is to locate the primary patterns of events that occur in various sub-environments and compose a “base map” making those patterns and their components available to design (Alexander *et al.* 1977).

In our own work we have located patterns of technology usage through “video ethnography”.<sup>1</sup> Specially adapted digital cameras were placed in sixteen volunteer households and used to record everyday domestic interaction. Several key sub-environments (the kitchen, living room, and study where available) were “wired up” to facilitate continuous video and audio recording and constitute the locus of our current inquiries. Up to five miniature, low-light, variable focus remote cameras and video recorders were installed in each of the key areas and up to eight hours of video footage per day, per camera installation, was recorded. Recording equipment was installed in each of the households for a minimum of ten consecutive days per year over two-years. Camera positions and appropriate times for recording were decided following discussions with the families in their homes and with their agreement.

In both practical and procedural terms family members provided invaluable help. In many respects household members acted as adjunct researchers, determining when and where observations should be made. A member of each family was nominated “technical assistant” in order that the quality of the video could be monitored and that tapes could be changed daily. As the location of cameras was determined by members’ intimate “insider” knowledge of the

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<sup>1</sup> <http://virtualsociety.sbs.ox.ac.uk/projects/morrison.htm>

setting, then so too, in their capacity as technical assistants, members' decided on appropriate times for scheduling recording. In addition to these activities, each household took part in individual and family wide interviews and viewings to explore ambiguities in the recordings and foster our understanding of their daily activities. Thus, in situations where the meaning of domestic activities was unclear, clarity was established through collaborative examination of the video materials in question.

The volunteer families came from a range of socio-economic brackets in the UK, although neither exceptionally poor nor wealthy families were included in the study (as none volunteered). The result of the "video ethnography" resulted in the capture of some 6000 hours of household activity, which is free from intrusion and bias to a remarkable degree. All but one of the families conducted their affairs without undue concern as to the presence of the video, being concerned to get their activities done rather than worry about what was going onto the video. In practical day-to-day details of "getting activities done", video ethnography furnishes investigators with fine-grained and phenomenally intact *in vivo* recordings of everyday family life. In contrast to a mass of notes, anecdotes, vignettes, and disembodied conversations which characterize traditional ethnography, video footage becomes the primary resource enabling direct investigation of the domain.

Importantly, and in the manner of Sacks' (1984) concern with audio recordings, video has the virtue that it is a "good enough" record of what actually happens in the home (and elsewhere), it can be replayed and so it can be studied in an extended way over a period of time, and others can look at what the researcher studies and make of it what they will should they disagree with the findings. Thus, not only can the researcher inspect the domestic environment in interactional details of actual lived events, anyone else can go and see whether what is said about those events by the analyst is actually so, and that, as Sacks reminds us, "is a tremendous control on seeing whether one is learning anything".

#### IDENTIFYING REAL TIME PATTERNS OF TECHNOLOGY USAGE

The approach we take to "learning anything" or extricating patterns from the video footage is descriptive rather than theoretical in character. Specifically, we seek to furnish "thick

descriptions” of the actual interactional events that have been recorded (Ryle 1971). Thick description stands in contrast to “thin description”, signifying the difference between mere behavioural accounts that describe only what can literally be seen and those characteristics which identify action as the practical action it recognizably is for members. As Ryle puts it,

[the] thinnest description of what the person is doing, e.g. pencilling a line or dot on paper ... requires a thickening, often a multiple thickening, of a perfectly specific kind before it amounts to an account of what the person is trying to accomplish, e.g. design a new rigging for a yacht.

In order to get beyond the thinnest level of description of what members’ are doing we are obliged to thicken the thin features captured on tape (audio and video alike) and we may do this by attending to and describing the “accomplishment levels” (ibid.) implicated in the production and recognition of meaningful practical action.<sup>2</sup>

The *prima facie* accomplishment level made available by the molecular sequences of interaction on an audio or videotape is 1) a grossly observable layer of talk and, more specifically, a layer of *conversational formulations* over the unfolding course of which members articulate what it is that they are doing, what event is going on, or what practical project of action they are together engaged in. This grossly observable layer of formulations constitutes the starting point for thick description of the practical actions that are occurring on the tape. The analyst’s first task is to describe those conversational formulations as they are hearably produced and recognized by parties to the talk (as questions, answers, objections, challenges, agreements, and the rest). While special methods of description may be employed (e.g. Jefferson 1978; Jordan and Henderson 1995) they are not required as formulations do not,

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<sup>2</sup> Analytic attention to the accomplishment levels implicated in the production and recognition of meaningful action distinguishes our work from Geertz’s (1973) popular misreading of Ryle. Geertz employs the notion to inscribe generic conceptual or theoretical “structures of signification” upon everyday settings and activities. Like so many approaches to the study of social life, Geertz’s is a top-down approach whereas ours is a ground-up one that attempts to identify formal structures of practical action (patterns, processes, structures of signification, etc.) in the practical actions of members, rather than impose such structures upon action regardless of local orders of work.

in themselves, display the orderly work through which practical actions come to assume the recognizable character that they do for members (Garfinkel and Sacks 1970).

In order to explicate the meaningful character of practical action, the analyst need attend to a second accomplishment level and describe 2) the routine *work performed* by members' formulations. This is a feature of naturally occurring interaction that is partially eclipsed through the use of specialized methods of description, which focus on the way in which members' organize their formulations through various "turn-taking" mechanisms at the expense of the work done by members in taking-turns (Lynch 1993; Garfinkel 2001). Describing the routine work performed through members' formulations makes available for description a third accomplishment level, which consists of 3) the *reoccurring courses of practical action* or the "work-practices" whereby members order their work and which furnish the work its recognizable character (Button and Harper 1996). A fourth and final accomplishment level is made available by members' work-practices, namely 4) the *patterns of technology usage* constituted in the reoccurring courses of practical action through which members' order their work so that it comes to assume its recognizable character time and time again: as practical actions implicated in "making breakfast", "doing schoolwork", "entertaining guests", "watching TV", and all of the rest.

The notion of thick description of accomplishment levels is not to be taken as a claim to have furnished a complete and exhaustive description of all the factors that constitute the interactional dynamics of technology usage. As Ryle reminds us, "there is no top step on the stairway of accomplishment levels", hence there is a possibility to extend any description, infinitely. For purposes of our research, we believe that description of the four orders of accomplishment level outlined above are practically adequate however, as they serve to make visible just how and with just what material technologies domestic routines are "put together" or constructed in the real world, real time actions of members. Thick description of these accomplishment levels are adequate, then, as they make available for consideration in design the real world, real time interaction and concomitant patterns of technology usage glossed over and missed by analytic accounts that substitute members' formulations of meaning for professionally defensible ones (Button and Harper 1996).

Although essentially simple, this compact methodological account might be more readily appreciated by practical example. Take the following molecular sequence of interaction, for example.

### ***1. Conversational Formulations***

The mother of a young child (age three approx.) is cleaning the kitchen. She sits the child (Levi) at the kitchen table and gives her some junk mail to open.

Mum: Look, you've left your apple.

*Levi is grumbling unintelligibly.*

Mum: Stop making all that noise.

Levi: Will you get me some piece of paper?

Levi: Will you get me some piece of paper?

Levi: Will you get me some piece of paper?

Mum: Go and get your own up stairs.

Levi: No, I want you to get me some.

Mum: Oh wait a minute, I've got some down here.

Mum puts a couple of sheets of paper on the table along with a pencil. Levi picks the pencil up and starts drawing on the paper. Mum carries on with the housework.

Levi: Can I paint?

Levi: Can I paint?

Mum: No, not today 'cause we've got to keep the house clean.

Levi: I want to paint.

Mum: Not today.

### ***2. The Work Performed by the Formulations***

This simple interactional sequence begins with mum issuing a mild admonishment to Levi for not eating the apple she has been given. Levi responds in grumbling in an annoying childish way, which her mum instructs her to stop. Levi complies with the request and soon after asks in a very insistent way for some paper. Her mum instructs her to go and get her own paper but Levi refuses to comply, instructing her mother to get her some paper instead. Mum notices some paper close to hand and passes to Levi along with a pencil. After drawing quietly for a few minutes while mum gets on with the housework, Levi makes a request to paint, which is denied.

### ***3. The Work-Practices Ordering the Work***

The work is ordered, as one might expect given the age of Levi, through several rudimentary practices. First off, Levi is 1) sat at the table and given something to occupy her in order that mum can get on with the housework. Levi soon tires of the junk mail and 2) makes a request of her mum to get her some paper. Mum 3) turns down the request and Levi 4) restates it. Mum 5) complies with request and hands Levi some sheets of paper and a pencil. Levi starts 6) doodling while mum carries on with housework. Levi then 7) makes another request this time to paint, which is 8) denied. The work is basically ordered through issuing and responding to a series of rudimentary requests, a technique of interaction that many three-year old children have mastered.

### ***4. The Pattern of Technology Usage***

Although exceptionally simple and very unsophisticated, this simple molecular sequence of interaction makes a common pattern of technology usage observable. The kitchen table is a technology in the home and one *used as an activity center*. Rather more specifically, the kitchen table is a device *employed to coordinate activities* in the home. In the case above it is used to coordinate the actions of mother and child, being employed as a place to do drawing, and on other occasions, painting while mum gets on with cleaning the kitchen. Importantly, in this respect, the placing of the child at the kitchen table allows mum to monitor the child and so *maintain awareness* of the child.

Coordination and awareness are integral features of various patterns of table use in the kitchen. Other sequences of routine interaction make patterns of mail use visible and show that tables are used to display new mail and mail requiring action to household members, for example. Alternatively, the table is often used for doing schoolwork, enabling parents to assist, coordinate, and monitor the actions of children. In short, the table is an activity center around which many patterns of usage revolve. In attending to the molecular sequences of interaction that take place in and latch together to make up the various sub-environments of the home, a

corpus of empirical patterns may be assembled locating design in the quotidian patterns of socially organized events and technology usages that comprise the domestic legacy. The development of a common format for the presentation of patterns will enable the sharing of patterns across various “work” domains within a culture and across cultures.<sup>3</sup>

### **Patterns and design**

In the context of software engineering patterns assume a prescriptive significance, directing the work of design (Gamma *et al.* 1995). We place patterns in a different part of the design process – the requirements phase – where they come to assume a different order of significance. Used to identify functional requirements for future technologies, patterns work as *resources* with which we may think about design. Used as resources rather than prescriptions for design, patterns play two roles or functions in the design process. On the one hand, they identify discrete *domains for design*. In the context of the home and our own work to date, the identification of patterns has enabled us to identify a number of discrete domains for the design of domestic technologies. These include: household management, security, awareness and coordination, education, and children’s activities. We have no doubt that as our investigations proceed further domains will be identified.

On the other hand, patterns work as resources for design in some very familiar ways, being easily assimilable into design practice in supporting *the construction of scenarios*. Take the pattern provided above, for example. As part of our work we have sought to design an arrangement of technology that is sensitive to the core needs of the pattern. A central feature of the pattern is the role of the surface as a place of coordination and activity. The children sought to play on the kitchen table (or the floor near the table). The location of the surface was a significant feature of this pattern and the surface played an important everyday role in the routine work of the home. The challenge then for designers is how to provide technology

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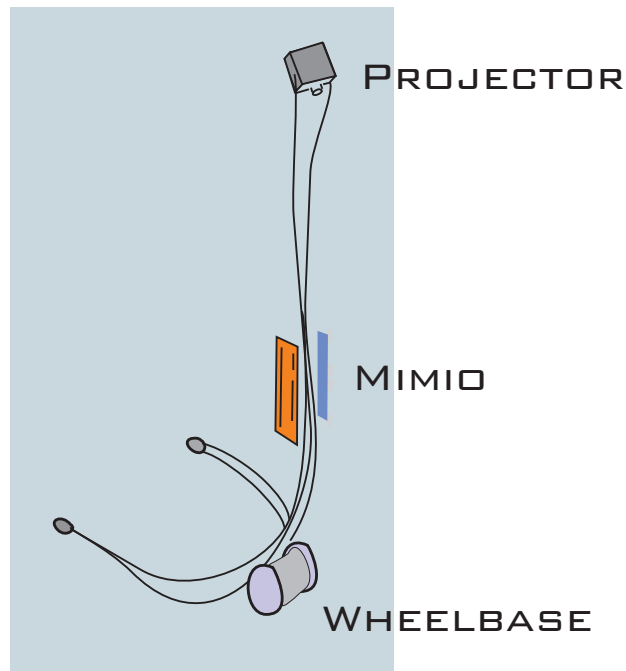
<sup>3</sup> See Hughes *et al.* (2000) or Martin *et al.* (to appear) for example. We are currently devising a similar format for the presentation of patterns.

which is sensitive to this legacy and which can be readily interwoven with the routine work of the home.

#### DESIGNING DEVICES FOR LEGACY SETTINGS

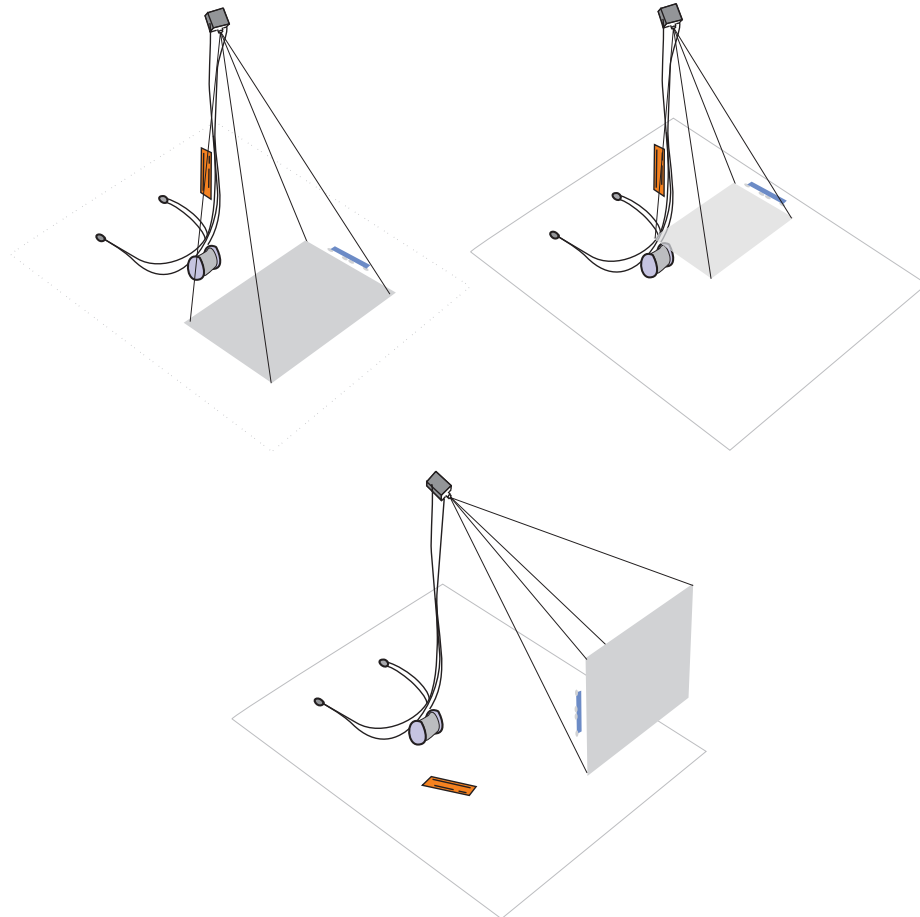
We have addressed this by considering how we may develop technological arrangements that can be readily configured to augment existing surfaces and spaces. Thus rather than develop a new table that incorporates some digital technology we articulate the problem as “how to we provide tools that allow people to augment their existing environment with new possibilities”. Rather than directly change the environment the shift to augmentation layers new functionality on top of the existing domestic legacy and aims to support the process of change by users.

In terms of the particular arrangements described in the pattern of the previous section we have designed and prototyped a device that allows users to make existing surfaces interactive. The device takes the form of a portable projector which can be moved around the home and which has an associated mimio device that allows existing surfaces to be made interactive (Figure 1).



**Figure 1.** The interactive projector

This device seeks only to augment existing surfaces and exploits the legacy inherent within these surfaces. It builds upon the kitchen tables place within the domestic setting rather than replace it. The device is designed to be portable and to be readily configurable to add interaction to a range of different surfaces including floors and walls (Figure 2).



**Figure 2.** Different arrangements of the projector

By being sensitive to domestic legacy the projector represents a different class of device for the home. Existing information appliances are self contained artifacts to be added to the home. These include electronic notice board, smart fridges and electronic picture frames. In contrast the project builds upon the legacy of the home by adding to the existing practices that are anchored to the places and artifacts within the home. The projector makes no sense within the existence of the kitchen table and the practices surrounding it and seeks to support and augment these established routine practices that make up the domestic environment.

## **Conclusion**

In this paper we have presented a approach to understanding domestic environments in order to inform design. We have presented an adapted pattern language framework to help in understanding the domestic environment. We have also developed a set of simple methodological policies to aid in the analysis of material drawn from the home. We have applied this approach to a series of video material from a range of domestic environments. As part of our on-going work we have started to design a range of devices that are sensitive to the notion of domestic legacy and are designed to augment our domestic arrangements rather than revolutionize these. In this paper we have presented one of these devices in the form of an interactive projector that can add computational features to existing surfaces within the home. The design and development of this devices represents a shift in the nature of devices for the home to consider the development of devices that are to be used as resources in the design of the domestic space by users themselves.

## Acknowledgements

The research on which this paper is based was funded by the Equator IRC, EPSRC GR/N15986/01. <http://www.equator.ac.uk>

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# The Process of Designing Appropriate Smart Homes: Including the User in the Design

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**Abstract.** Information and Communication Technology (ICT) has recently been relocated from an external entity brought into the home, to an internal feature of the domestic environment extending the range of the home beyond the 'bricks and mortar'. Whilst other European countries such as Germany and Sweden have embraced the technology for its environmental and functional properties, the UK has been slow to adopt smart home technology except as a toy for the rich and famous. A number of research projects have considered the use of smart home technology within a range of social spheres, demonstrating the technology for a wide range of people with differing levels of disabilities and older people whilst developing a software suite that enables people to design smart homes that reflect people's needs. Smart homes can be useful; enhancing the quality of life for people whose life is limited by their domestic environment. This paper seeks to consider how smart home technology can be incorporated appropriately within the design process, exploring the difficulties in determining the most appropriate type of technology to meet the needs of people. The paper concludes with a set of guidelines to inform future designs within this area.

**Keywords.** Smart home technology, home automation, appropriate design, disability, older people.

Paper presented at The 1<sup>st</sup> Equator IRC *Workshop on Ubiquitous Computing in Domestic Environments*, The School of Computer Science and Information Technology, The University of Nottingham, 13-14<sup>th</sup> September 2001. <http://www.equator.ac.uk/>

## Introduction

Information and Communication Technology (ICT) has recently been relocated from an external entity brought into the home, to an internal feature of the domestic environment extending the range of the home beyond the ‘bricks and mortar’ (Dewsbury and Edge 2001). It is no longer solely confined to the conventional products such as lighting, washing machines or fridges but has begun to become situated within the fabric of the home through the introduction of and continual development of smart home technology. Smart homes are not a new phenomenon as the technology has existed for decades within the realm of the office block or shopping arcade, yet the technology has made slow impact within the UK domestic environment.

Whilst other European countries such as Germany and Sweden have embraced the technology for its environmental and functional properties, the UK has been slow to adopt smart home technology except as a toy for the rich and famous. Part of the reason for the lack of adoption is that the technology has not been entirely marketed the domestic sectors, as higher profits exist within the large commercial contracts. Correspondingly, the cost of the technology has tended to reflect its use in large-scale commercial projects, where profit levels can be much higher than in mass housing markets. Clear evidence suggests that smart home technology has a role within the household where its usage can extend beyond the ‘plaything of the rich’ into the area of enabling and empowering people how have disabilities or older people.

A number of research projects have considered the use of smart home technology within a range of social spheres. The ASTRID project clearly demonstrated that smart home systems could enable people with dementia to lead more empowered lives if used in the appropriate manner (Marshall 2000). The INCLUDE COST 219 project demonstrated the efficacy of smart homes for older people and people with disabilities.<sup>1</sup> The CUSTODIAN project demonstrated the technology for a wide range of people with differing levels of disabilities and older people whilst developing a software suite that enables people to design smart homes that reflect

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<sup>1</sup> <http://www.stakes.fi/include>

people's needs.<sup>2</sup> Smart homes can be useful; enhancing the quality of life for people whose life is limited by their domestic environment. However, technology for technology's sake can be debilitating and disempowering. This paper seeks to consider how smart home technology can be incorporated appropriately within the design process. It also considers that the process of design of smart homes for people with disabilities requires the designer to undertake a number of tasks to remedy the mismatch between need and technology. The paper also explores the difficulties in determining the most appropriate type of technology to meet the needs of people. The paper concludes with a set of guidelines to inform future designs within this area.

### **Smart homes?**

The domestic environment in the UK has undergone considerable modification in the last hundred years (Dewsbury and Edge 2001). At the start of the twentieth century, the home was the mainstay of the traditional family unit, acting as the locus of identity, position and external evaluation. Currently, more people live independently than they did in previous decades. Additionally, the UK, like much of the developed countries in the world, has seen an increase in life expectancy and better health care leading to a greater proportion of older people who are active members of the population. Older people are sometimes living in isolation, as most people no longer live in extended families. The UK has also seen the rise of the welfare state in which medical and social interventions by the state are recognised in order to maintain a minimum quality of life for people who are incapacitated physically or mentally (ibid). Consequently, health care providers are required to provide a high standard of care for older people in the community, and people with disabilities. The choice of how this care is provided and meets the needs of the users is of considerable importance to policy makers and the care providers.

Smart homes can be useful; enhancing the quality of life for people whose life is limited by their domestic environment. The design process is something that requires needs to be considered within a framework of barrier free design. However, technology for technology's

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<sup>2</sup> <http://www.rgu.ac.uk/subj/search/research/SustainableHousing/Custodian/Home.html>

sake like inappropriate design can be debilitating and disempowering. This paper seeks to consider how the process of designing smart home technology can be undertaken appropriately. It also considers that the design of smart homes for people with disabilities requires the designer to undertake a number of key decisions to remedy the mismatch between need and technology.

## The technologised home

A smart home is a harmonious home, a conglomeration of devices and capabilities working according to the Zen of Home Networking. (Briere and Hurley 1999)

Smart homes are just one example of a range of technologies that come under the heading of assistive or augmentative technologies. Smart home technology can be split into two main categories. *Active devices* such as control panels and switches, with which the home occupant will directly interact with and use. *Passive devices* such as sensors and receivers, over which the home occupant has no direct contact, function to enable and empower the living experience of the occupant. These devices and other technologies provide four main types of augmentative technology that can enhance independence, namely

1. Assistive Technologies, which are devices or systems allowing an individual to perform a task they would otherwise be unable to do or which increases the ease and safety with which the task can be performed;
2. Adaptive Technologies, through which any system or device can be modified according to the needs of an individual so that a task can be performed more easily and safely;
3. Inclusive Designs or 'Design For All' Technologies are developed on the principle that devices and systems can be used by as wide a range of the population as possible.
4. Medical Devices cover all products other than medicines, which are used in the healthcare environment for the diagnosis, prevention, monitoring, treatment or alleviation of illness or injury.<sup>3</sup>

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<sup>3</sup> Source: *Inclusion of Disabled and Elderly People in Telematics*: [www.stakes.fi/include](http://www.stakes.fi/include). Quoted in *The Parliamentary Office* (UK) 2000.

The manner in which devices interact and are interconnected provides the functionality that can enhance the quality of a person's life. The relationship between active and passive components enables a designer to build up a structured need derived system. Of considerable importance is the appropriate level at which to apply existing and new technologies to produce the defined system.

Intelligent health care systems in the home will utilise a myriad of technologies in their implementation. (Warren *et al.* 1999)

Smart technology is not the Holy Grail of the system of care for older people in the new millennium. But used sensitively alongside person centred care it can be a vital and valuable companion in a journey that will bring a happier, more fulfilling life to those of us about to join the silver generation. (Burley 1999)

Visions of what technology can do... are rarely based on any comprehensive understanding of needs and in some cases are blatant technology push. (Tweed and Quigley 2000)

As societal forces and technological push collide, the use of appropriate technology becomes increasingly more viable and cost effective. In determining the appropriateness of the technology it is easy to over compensate and become one sided within the debate.

The use of technology appears to present dramatic compromises in social activities, role definition, and identity. (Gitlin 1995)

Gitlin observes that technology becomes part of the self-concept. Just as technology can enable it can equally be the cause of disablement and low self concepts leading to greater needs being unmet. Sidsel Bjerneby (2000) notes that the reliability of the technology is essential.

Technology that does not function properly is extremely confusing and distressing to everybody, but exceptionally so for people with dementia and their carers. (Bjerneby 2000)

Reliability and robustness can have many facets, not just considering that a device acts in the appropriate manner, but considering the hidden effects related to the properties of the network.

With the increase of radio frequency devices and the advancement of technological protocols such as Bluetooth, and WAP integration, the networking properties become significant.

It is important to note that information surety (i.e., security, integrity, reliability, safety, and availability), plays an extremely important role in this architecture, since it is distributed by nature. (Warren *et al.* 1999)

Any technological system should be protected against potential hackers and people who might wish to compromise the integrity of the overall system, yet as the digital age progresses, technology increases apace whereas security systems to maintain reliability are often a secondary consideration. This could be problematic, should a house be configured to work using a standard protocol that falls into the hands of a person who wishes to burgle the home. If all that is required is that they emit the correct signals or Infrared sensor configurations for all the doors and security systems of the house to be deactivated there are clearly going to be a number of unhappy people and insurance companies will be considering whether to insure houses which have technology of this ilk within them.<sup>4</sup>

The design solution is not straightforward, often there is a balance to be struck where the designer has to weigh up the odds of the differing possibilities and discuss these with the relevant people before settling on a provisional design specification. To illustrate this, the graph (Figure 1) below is intended to demonstrate the cost / efficiency of two different smart home systems, the EIB (European Installation Bus) fieldbus and X10. Field bus systems such as EIB or Lon, it is contended have a high cost even for the most basic system whereas a basic X10 system can be installed very cheaply. However, fieldbus systems enable more devices to be integrated together to work with each other to create a rich functionality. Furthermore it is suggested that they are more reliable since they rely on more sophisticated bi-directional protocols.

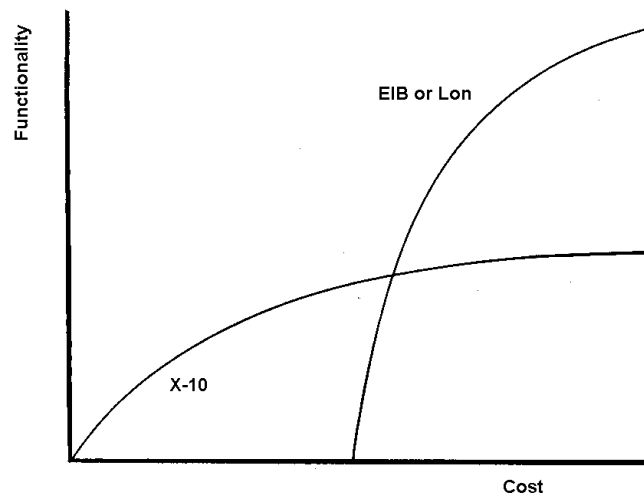
Configuration of a field bus system is the method by which an installer couples a command initiator to one or more command receivers. For simple systems such as BatiBUS and X10 configuration is achieved by

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<sup>4</sup> See <http://www.smarththinking.ukideas.com/>

setting hardware thumb wheel switches to identical address numbers. For complex systems such as LonWorks and EIB configuration is achieved using a PC connected to the bus and a graphical interface through which devices are set to communicate with one another. One such interface allows a configurator to enter the electrical points on architectural drawings and using the mouse group and assign luminaries to switches. (Allen and Dillon 1997)

The sophisticated protocols used infield bus systems means the devices are more complex and expensive (Berlo 1999). If in addition, strict compliance standards are enforced by an agency such as EIBA (European Installation Bus Association) this will further add to the initial cost of the devices but means that installation and commissioning of the system is straightforward. To summarise, it is contended that fieldbus systems are more expensive but have greater serviceability and reliability and can be integrated to achieve a wider spectrum of configurations than the unidirectional X10 (see Berlo 199; Dewsbury *et al.* 2001).



**Figure 1.** The efficacy of two types of smart home technologies

The above graph also demonstrates that at the bisection of the technologies, the designer is required to consider which is likely to be most appropriate for the greatest time. A number of factors will influence the decision. This does not mean that X10 systems are substandard, as there is clear evidence of their utility and appropriate applicability for a number of users.

Sacrificing high-end reliability for a cheaper but effective system might be the better course of action if the design enables the person to achieve the goals they desire.

Allen and Dillon (1997) compares a number of differing busline technologies and concludes that there are significant differences between EIB and X10 in terms of suitability for use with people with disabilities.

EIB bus is very suited to exploitation in the rehab field for the following reasons:-

- ❑ Availability of commercial products
- ❑ Technology is open to third parties for exploitation
- ❑ Development kits are available
- ❑ Established network of training centres
- ❑ Interface to M3S has been developed by FST in Switzerland

The one major drawback of the EIB bus is that the technology has so far only been applied in great measure to the twisted pair medium. This implies that if an existing home is to receive an EIB bus a certain amount of re-wiring will need to take place. However, the technology can be applied to other media and products do exist for Infrared and Power Line media. The EIBA is also carrying out development for the coaxial cable, optical fibre and radio frequency mediums...

X10 is suitable for simple environmental control applications in the rehabilitation field for the following reasons:-

- ❑ Availability of low cost commercial products
- ❑ Ease of configuration and installation

However it has the following major drawbacks:-

- ❑ Technology is propriety and unavailable to third parties
- ❑ Limited On/Off type protocol with no possibilities for improvement. (Allen and Dillon 1997)

The designer must decide on the appropriate reliability required from the smart home system that matches the needs, abilities and circumstances of the person. This is especially the case when financial constraints might make X10 the only viable system. Similarly, as Dewsbury (2001) and Taylor (2001) acknowledge, technological solutions can often be used in preference to conventional solutions, when the conventional would be more effective. It is all too easy to technologise solutions for the sake of using technology over conventional methods of design.

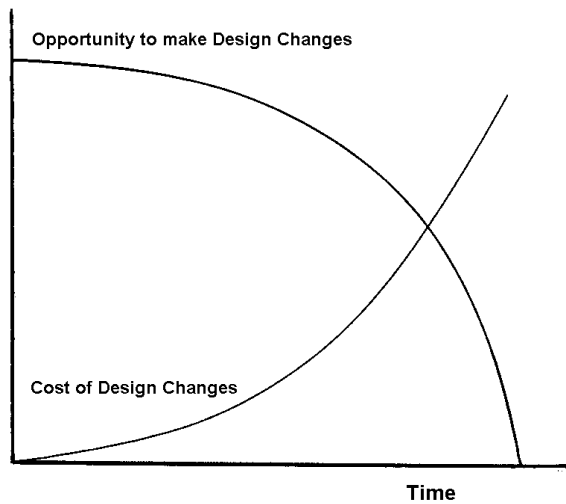
Today, we really do have the opportunity to tap into wires already in place in our homes for security and telecommunications purposes to enable constant monitoring, tracking, and transmitting of home care patient information to and from our homes. But we also really do have the opportunity to think carefully about what applications these collecting capabilities can have. (Kinsella 2001)

### **Appropriate design for smart homes**

It is known that many products are not accessible to large sections of the population. Designers instinctively design for able-bodied users and are either unaware of the needs of users with different capabilities, or do not know how to accommodate their needs into the design cycle. (Keates *et al.* 2001)

Historically, home automation has targeted those areas which already have a strong element of control in them, such as the automatic control heating and lighting. As with mainstream computer applications, some activities are more amenable to automation than others. Increasingly, however, the lofty goals of home automation are being eclipsed by the more modest ambitions of creating the on-line home, in which information appliances are appearing on the market that still rely heavily on human action to control them - they just provide more information about their status and how they might be used. (Tweed and Quigley 2000)

Designing smart homes for people with disabilities or older people is not different from designing the home for people without any form of impairment on the one hand. On the other hand, there is a perceptual shift that is required in order to ensure needs are met from all stakeholders. There is a need to determine the needs of the occupant(s) and reflect these needs within the overall design. The designer is required to interface with other professionals and trades, such as architects and electrical contractors etc to determine that the needs of the person are reflected in all areas of the design process. The entire design process is one of iteration. The initial design may be modified considerably in the process. However, the earlier that changes are made to the design, the less these changes should cost. The design should be frozen before installation work commences (see Figure 2 overleaf).



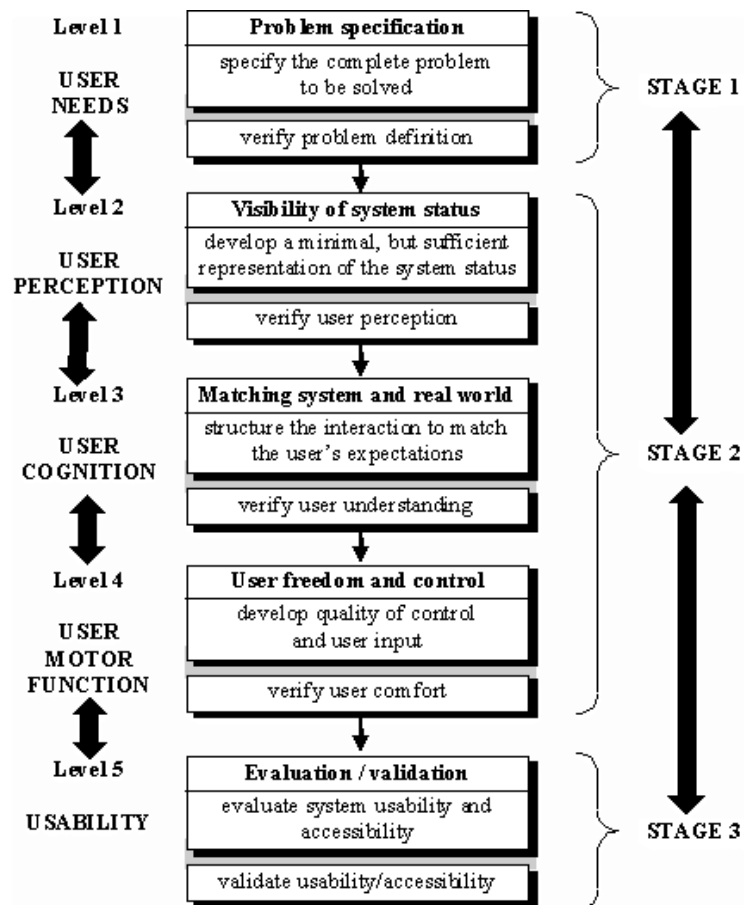
**Figure 2:** The opportunity to make changes in design vs. cost

It is fundamental that the designer is able to interpret qualitative information as well as qualitative data and reflect the determined needs into appropriate configurations and devices. Therefore, the designer of the smart home should be acquainted with the appropriate technology to match the clients disability/disabilities and possess knowledge of the disability, its aetiology, and its outcomes, as well as skills in inclusive design, basic electrical systems and the roles and nature of employment of the people they are likely to encounter in the design process.

It is useful to draw a number of case scenarios for different problems in order to determine how technology can benefit the person in different situations as well as ascertain where technology will be limited and ineffective. Often simple case scenarios can become more complex once the problem is considered properly. As an illustration, consider the case example of enabling a person with cognitive impairments to make a cup of tea. To design a system that enables the person to actively participate within the process and still enable the system to monitor and control for incorrect actions becomes extremely complex and almost impossible. How can it be determined that the person has put enough water in the kettle? How can it be ascertained that the person has not put the milk or sugar in the kettle or the teapot? The use of Case Scenarios allows the designer to consider every eventuality in order to

determine the most appropriate technological response (Taylor 2001). In the case of the cup of tea most likely technological response will be limited or no technology as the system would prove to be too complex to be rehabilitative or produce independence. Here the needs of stakeholders will inform the design process and determine the level of interaction that is required between the user and the technology.

The process of iteration is demonstrated by Clarkson and Keates (2001) who show the stages through which the designer needs to pass. The following adapted diagram attempts to illuminate this procedure further.



**Figure 3.** The methodological iteration of the design process (adapted from Clarkson and Keates 2001)

Evidently, designing appropriate smart home systems is complex and requires the designer to consider a number of qualitative and qualitative possibilities. The iterative process of design

and the Use Case Scenarios should enable a designer to work through most problems and eliminate others before they arise. Some problems cannot be followed through in this fashion and it is with this in mind that the following suggestions and considerations on the design process have been developed. These considerations will not always be applicable in every design, but as guidelines, they should prove to be a useful starting point.

### **Some Smart Home Design Considerations<sup>5</sup>**

1. Appropriate Inclusive design criteria are required before technology is considered.
2. A long-term view of a person's condition should be undertaken in the assessment. If a person's condition is to degenerate slowly than the technology will be useful for longer.
3. Undertaking a full user needs assessment is critical to determine if technology is appropriate to meet the needs of the person.
4. Assessments and judgements should consider how the person is to interact with the technology from a psychological, emotional, physical and social perspective.
5. Assessments should not just consider what the technology can do for the person but what it can do for all stakeholders.
6. The implementation of the user needs assessment by professionals requires that appropriate technology be used in the correct manner, with the correct devices undertaking the correct functions when and if they are supposed to do so
7. The long-term efficacy of the technological design should reflect the needs of all stakeholders, the person(s) with disabilities, carers, and others.
8. Seeing technology as enabling and empowering is essential to the design process, whilst it is important to recognise that inappropriate design is disabling, debilitating and disempowering.
9. Specifying devices to meet the needs of stakeholders must also include specifying how the devices will interact with each other.

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<sup>5</sup> Adapted from Dewsbury (2001).

10. Technology requires regular maintenance and it is essential that the system is regularly checked to ensure it still functions correctly and meets the needs it was designed to meet.
11. Technology should not be considered predominantly in terms of being cost saving or a labour saving intervention; social exclusion or dependency should not result from the design.
12. Technology should not be seen as the panacea for all ills in the world.

These guidelines have been developed through designing smart homes to meet the needs of specific people. They demonstrate the conflicting requirements that the designer faces and illuminate the decision making process that produce effective and robust designs. There can never be a standardised smart house that will meet the needs of all, the universal design process can only make certain considerations come to the fore, but the process of designing smart homes for people with disabilities does require the designer to undertake a dialectical approach in which people with disabilities or older people are the norm and able bodied people are marginalised to the periphery.

## **Conclusions**

Everything has become an operation, everything has to have a function and a use. (Fromm 1995)

When technology is incorporated within the home, the people who live with the technology on a day-to-day basis have tended to be overlooked (Tweed & Quigley 2000). Any attempt to produce definitive guidelines for the design of smart homes is likely to be deficient in some aspects. The process of design is complex and involves a number of extraneous factors that cannot be covered within the scope of a paper such as this. Instead, this paper has attempted to outline the main considerations and problems the designer has to take into account in the process of designing smart homes. The nature of the home is evolving and undergoing constant change in definition and as such is required to become responsive to the needs of people throughout their whole lifetime and in most circumstances.

The home as a fixed entity is unresponsive and unable to accommodate the new demands placed upon it. The social care/ housing sectors act as reactive bodies to situations such as this and provide mechanical aids to enable the individual to reside within the home, but here there are obvious limitations and constraints embedded in this process. The home, it is contended, should be considered as more than just a physical entity. Moreover, it is proposed that smart technology should be thought of as an essential part of the design process and not an after-thought. (Dewsbury and Edge 2001)

The home is the locus of esteem and self-concept that enables the isolated person to be less trapped and more independent. Any design process requires the designer to consider the home from a proactive and lifetime perspective. Ideally, smart homes should be a rehabilitative and therapeutic structure that augments the current care services and enables and empowers individuals who live within them.

The reality is that the home, even without intelligence is not so much bricks and mortar, but increasingly a series of personal care services. With the advent of the smart home the range of services that the home provides may be about to undergo a radical change. (Edge *et al.* 2000)

The investment in field bus systems is coming from the world's major electrical companies. If they are successful and succeed in penetrating the market, the result will have a direct positive effect on the lives of people who have disabilities. Rehabilitation companies will exploit the emerging technology and make available low cost environmental control systems. These systems will be truly integrated with a buildings electrical system and will provide much greater functionality than the "add-on" systems which are currently available. (Allen and Dillon 1997)

This paper has asserted some basic guidelines on the process of designing smart homes that meet the varied needs of people with disabilities or older people. Firstly, it has been put forward that it is necessary to consider all stakeholders within the design. Secondly, it is suggested that it is important to map the intended design on paper or computer and seek clarification for the User Case Studies from the stakeholders. Thirdly, it is contended that the designer must choose the best-fit technological solution to meet all stakeholder needs with an appropriate reliability and minimum cost. Fourthly, the paper has shown that the designer is required to be flexible and responsive to the changes that occur during the design process. The

design process is not stage processes but can be undertaken within the iterative process of appropriate design throughout the course of the overall design.<sup>6</sup>

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<sup>6</sup> For further information please visit the SMART Thinking website at: [www.smarthinking.ukideas.com](http://www.smarthinking.ukideas.com)

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# Embedding Intelligence: Research Issues for Ubiquitous Computing

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**Abstract.** In this paper we discuss the need for new technologies to enable the full benefits of ubiquitous computing to be realised in domestic environments. We argue that a key aspect of such new technology is that of embedding intelligence into devices. We do this by explaining the enhanced functionality that embedded-intelligence can provide to everyday products. In particular we describe how intelligence is the key to groups of artefacts learning to work together to achieve higher level, user-determined goals. We outline a scenario for an “Intelligent Domestic Environment” based on an Intelligent Student Dormitory (iDorm) being built at the University of Essex that will allow experimentation on “cognitive disappearance” of explicit control of devices arising from a networked system of intelligent artefacts. We explain the challenges facing those seeking to develop methods of embedding intelligent into computationally compact and distributed co-operating artefacts. Finally we summarise our arguments as to why “cognitive disappearance” requires intelligent artefacts and describe some of the projects we are working on that address these underlying research issues.

Paper presented at The 1<sup>st</sup> Equator IRC *Workshop on Ubiquitous Computing in Domestic Environments*, The School of Computer Science and Information Technology, The University of Nottingham, 13-14<sup>th</sup> September 2001. <http://www.equator.ac.uk/>

## **Introduction: the vision**

Today people's domestic spaces are becoming increasingly "decorated" by electronic or computer-based artefacts (gadgets) varying from, mobile telephones through CD players to transport systems and beyond. The variety of computer-based artefacts, and their capabilities, is growing at an unprecedented rate fuelled by advances in microelectronics and Internet technology. Cheap and compact microelectronics means most everyday artefacts (e.g. shoes, cups) are now potential targets of embedded-computers, while ever-pervasive networks will allow such artefacts to be associated together in both familiar and novel arrangements to make highly personalised systems. However, in order to realise this possibility, technologies must be developed that will support ad-hoc and highly dynamic (re)structuring of such artefacts whilst shielding non-technical users from the need to understand or work directly with the technology "hidden" inside such artefacts or systems of artefacts. How can this aim be achieved? The authors are part of the eGadgets project which is funded by the EU "Disappearing Computer" programme and in this paper we will describe how embedding intelligence into artefacts in the form of embedded-agents could provide one viable solution.<sup>1</sup>

## **Technology and domestic environments**

A typical domestic environment provides an environment where there is wide scope for utilising computer-based products to enhance living conditions. For instance, it is possible to automate buildings service (e.g. lighting, heating etc), make use of computer-based entertainment's systems (e.g. DVDs, TV etc), install work tools (e.g. robot vacuum cleaners, washing machines, cookers etc), or enhance peoples safety (e.g. security and emergency measures, appliance monitors etc). Some of these artefacts will be part of the building infrastructure and static in nature (e.g. lighting; heating, ventilation and air conditioning or HVAC etc.), others will be carried on the person as wearables or mobiles, or temporarily installed by people as they decorate their personal space (e.g. mobile phones, TVs etc). Environments in which computers are used to control building services are generally referred

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<sup>1</sup> <http://www.extrovert-gadgets.net>

to as “Intelligent Buildings” (Callaghan *et al.* 2000), a paradigm that developments such as the “Disappearing Computer” programme promises to transform radically.

### **Embedded-intelligence and artefacts**

Ideally, for the vision described above to be realised in domestic environments, people must be able use computer-based artefacts and systems without being cognitively aware of the existence of the computer within the machine. Clearly in many computer-based products the computer remains very evident as, for example, with a video recorder, the user is forced to refer to complicated manuals and to use his own *reasoning* and *learning* processes to use the machine successfully. This situation is likely to get much worse as the number, varieties and uses of computer based artefacts increase. Can technology, which is the cause of this problem, be harnessed to provide a solution? We argue that if some part of the reasoning, planning and learning normally provided by a gadget user, were embedded into the artefact itself, then, by that degree, the cognitive loading on the user would reduce and, in the extreme, disappear (i.e. a substantial part of the computer’s presence would disappear.). Put another way, the proportion of reasoning, planning and learning transferred to the gadget (collectively referred to as “embedded-intelligence”) is a “cognitive disappearance “ metric! Hence, we view *embedded intelligence as an essential property of artefacts for the cognitive disappearance of the computer* and necessary to the successful deployment of new technology in the domestic environment. Our work at Essex University is focused on the development of new technology in the form of computationally compact mechanisms for embedding intelligence into artefacts, which would form part of intelligent domestic environments. In the remainder of the paper, we discuss the issues involved, the techniques we have developed and describe an experimental test-bed, the iDorm.

### **Disappearance: the AI challenges**

Above we argued that transferring some cognitive load from the users into the artefact was a key element in achieving cognitive disappearance. However, this is far from easy as such “intelligent artefacts” operate in a computationally complex and challenging physical

environment which is significantly different to that encountered in more traditional PC programming or AI. Some of the computational challenges associated with creating systems of intelligent-artefacts are discussed below. As a precursor to this discussion we first overview some of the more general issues and terminology.

Embedded intelligence can be regarded as the inclusion of some of the reasoning, planning and learning processes in an artefact that, if a person did it, we would regard as requiring intelligence. An intelligent artefact would normally contain only a minimal amount of “embedded-intelligence”, sufficient to do the artefact task in question. Embedded-computers that contain such an intelligent capability are normally referred to as “*embedded-agents*” (Callaghan *et al.* 2000). Intelligent Artefacts would, in effect, contain an embedded-agent. Individually, such an embedded-agent can harness intelligence to undertake such tasks as:

- Enhancing Artefact functionality (enabling the artefact to do more complex tasks)
- Simplifying or automating the user interface (in effect, providing an intelligent assistant)
- Reducing Programming Costs (the system learns its own program rules)

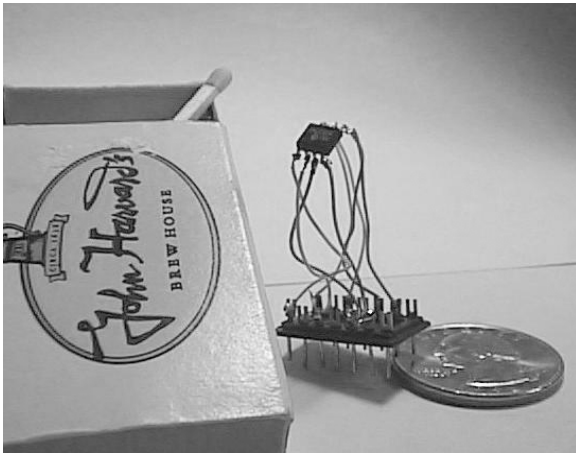
It is now common for such “*embedded-agents*” (as intrinsic parts of “*intelligent artefacts*”) to have an Internet connection thereby facilitating multi embedded-agent systems. In a fully distributed multi embedded-agent systems each agent is an autonomous entity co-operating, by means of either structured or ad-hoc associations with its neighbours. Each agent can reason or plan how it might work with those with which it is currently associated thereby supporting *evolving aims or emerging functionality*. Without autonomous learning and ad-hoc association it is difficult to see how emergent functionality could otherwise be achieved. Because of this we argue that autonomy and intelligence are important attributes for intelligent artefacts if emergent behaviour is going to be possible. It is important to understand that being autonomous and promiscuous (open to making associations with other artefacts) does not imply undirected or unsafe behaviour. Agents can have basic fixed rules built in to them that prevent them taking specified actions deemed unsafe.

An interesting and potentially productive application of intelligent-artefacts arises when they are assembled and operated in synergetic groups. Perhaps artefacts will most commonly find themselves as part of rooms people live in. Rooms are often highly personalised, decorated by artefacts carefully chosen to suit tastes and needs. Rooms can be regarded as the building block of many habitats from cars and offices to homes. Rooms usually have a function (e.g. living, sleeping, driving etc) and the group of artefacts within a room will invariably reflect in part at least this function and well as the characteristics of the person that “decorated” the room with the artefacts.

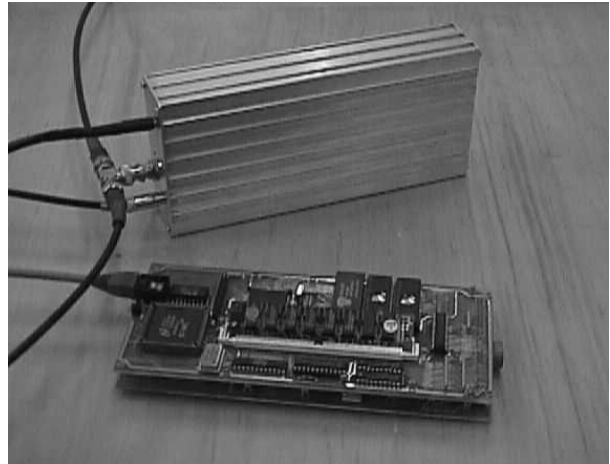
Most automation systems (which involve a minimum of intelligence) utilise mechanisms that generalise actions (e.g. set temperature or volume that is the average of many people’s needs). However, we contend that AI applied to personal artefacts and spaces needs to *particularise* itself to the individual. Further, subject to safety constraints, we contend that it is essential that any agent (or artefacts) serving a person should always and immediately carry out any requested action, no matter how perverse it may appear (i.e. people are always in control, subject to overriding safety considerations). The embedded-agent techniques we will outline are characterised by their ability to particularise their actions to individuals *and* immediately execute command, wherever that is a practical possibility. Elsewhere, the social and commercial issues of future widespread employment of agent-based artefacts are more exhaustively discussed (Clarke *et al.* 2000) and related work on applications such as intelligent-buildings are explored (Brooks 1997; Callaghan *et al.* 2000; Minar *et al.* 1999; Mozer 1998; Davisson 1998). Artefacts that include intelligent agents of the type we describe inherit all these above-mentioned capabilities

### **The issue of physical size and cost**

For physical disappearance artefacts will need relatively small low-cost embedded computers (possibly based on application specific micro-electronic fabrication). For example typical specifications might be Cost: £20-£50, Size:  $<2^2$ cm, Speed: 1-10MHz, Memory: 1-2 MB, I/O: 10-50 I/O channels. Examples of two real devices are shown in Figures 1 and 2 overleaf.



**Figure 1.** University of Massachusetts prototype embedded-internet device



**Figure 2.** University of Essex prototype building services agent

While it is inevitable that the “computing power / cost ratio” will continue to increase (i.e. more mega-everything per dollar), history has shown that functionality will always demand even faster computers. Thus available resources for a given cost always lag behind needs. The classic illustration of this dilemma is the defiance of the hard disk to become extinct despite 30 years of predictions of semiconductor memory becoming cheap and abundant. Of course the prediction that memory will become cheap and abundant has always proved correct but it seems functional demands have outpaced it. The lesson here is that although it is inevitable embedded-computers will become much more powerful, they will always be less powerful than the functionality demanded at that future point!

Traditional artificial intelligence (AI) techniques are well known for being computationally demanding and therefore unsuitable for ‘lean’ computer architectures. Historically most traditional AI system were developed to run on powerful computers such as workstations, whose specifications are at least two orders of magnitude removed from most embedded-computers. In addition, traditional AI techniques have proved too fragile to operate real time intelligent machines such as robots. As a result, even implementing simplified traditional AI systems on embedded-computers has proved virtually impossible. However, the

authors have techniques from developments of their earlier work in robotics that seem well suited to providing artefact intelligence which are discussed later in this paper (Callaghan *et al.* 2001; Hagaras *et al.* 2000; Hagaras *et al.* 2001).

### **The issue of intelligence**

Depending upon the way that the intelligence is deployed within and between artefacts we can see a wide variety of different ways in which the functionality of artefacts can be enhanced. At its simplest intelligence might be used to make the use of a specific artefact easier or in the case of environmental control more or less invisible. However, one argument is that there are a wealth of synergetic possibilities for the user-controlled association of devices into new collections of artefacts that may be able to deliver novel functionality. As things stand with a predominance of physical connections between artefacts the problem is one of wiring and physical plugs, but one can easily see that with wireless communications capabilities interoperability might be achieved across a much wider set of artefacts than is possible now. The following section attempts to roughly sketch out the sort of scope for including intelligence in artefacts and for the association of artefacts, it is drawn from the eGadget project and uses that terminology but could in theory be applied to any artefacts.

#### **GADGETWORLDS AND INTELLIGENCE IN GADGETS.**

A GadgetWorld is a collection of gadgets that are associated together to form some coordinated set of gadgets that operate together to carry out meaningful functions. The gadgets can be dumb, or intelligent to some degree, as can the mechanisms used for associating them together. Clearly from the table below you can also conclude that there are GadgetWorlds in which the gadget might have a variety of levels of intelligence and be associated in one of the three ways specified above, so dumb, automated and fully intelligent artefacts might form GadgetWorlds in which association is manual, or managed by an editor, or managed by onboard intelligence in each gadget for such a purpose.

<b>Intelligence of association</b> → <hr/> <hr/> <b>Intelligence in Gadget</b> ↓	<b>Manual association through hard or soft links. Physical manipulation of gadgets themselves.</b>	<b>Some form of Association Editor. Specifying hard links or setting up links through RF or other wireless connections</b>	<b>Intelligent Association using wireless or similar flexible form of setting associations, communication and transferring information</b>
<b>Dumb gadget – no intelligence in gadget itself</b>	A GadgetWorld where all the gadgets are dumb and all the associations are done manually	A GadgetWorld where all the gadgets are dumb but the associations are managed using an association editor. The actual associations might need to be made manually	A GadgetWorld in which all the gadgets are dumb but the associations are managed by intelligence in each gadget
<b>Some relatively limited form of intelligence or intelligent processing as with automation and the use of various forms of computer based controllers of individual artefacts e.g. washing machine.</b>	A GadgetWorld where gadgets with limited intelligence or automation of their functionality are manually associated.	A GadgetWorld where all the gadgets have some limited intelligence or automation and whose associations are managed using an association editor. The associations can be hard or soft.	A GadgetWorld where all the gadgets have some limited intelligence or automation but the associations are managed by intelligence in each agent.
<b>‘Fully’ intelligent artefact/gadget capable of learning and reasoning in some form e.g. gadget with an intelligent agent in it.</b>	A GadgetWorld in which all the agents are fully intelligent but they are associated together manually.	A GadgetWorld in which intelligent gadgets are associated together using an association editor and where the associations might be hard or soft.	A GadgetWorld in which intelligent gadgets make associations intelligently and maintain those associations through soft links

## SYNTACTIC AND SEMANTIC DIMENSIONS

The rules governing associations of gadgets have both syntactic and semantic dimensions. The syntactic aspect of association should specify the channel and type of connection that is possible for any specific gadget. In order to be able to use this channel any other gadget will have to have an appropriate channel and connection. In terms of the wider issues of how multiple artefacts associate a number of questions are raised. Does one gadget within a

GadgetWorld have to be able to associate directly with all the other gadgets in that GadgetWorld? Is an association with one other gadget enough to constitute a GadgetWorld? Could a GadgetWorld be constituted by a daisy chain of gadgets where they were working together to produce a meaningful response for the user? Or do we require that associations between gadgets in a GadgetWorld be very closely coupled, with all gadgets connected to all other gadgets? Do the forms of association largely depend upon the collective meaningful functionality of the ensemble? In general would the fewest connections consistent with the overall functionality required be the optimum solution? Could the network of associations between gadgets be compared to the connections between atoms in a molecule?

The semantics of associations between specific gadgets is potentially specifiable across a broad range of GadgetWorlds. However, it is unlikely that this will ever be an exhaustive description and the work involved may be unnecessary if new meaningful sets of associations can be learned through intelligent association mechanisms. The ability to physically associate various gadgets manually is of course the basis upon which any new meaningful and therefore semantically significant association of gadgets can take place. We are unlikely to ever have a complete semantics of association since this would exclude the possibility of emergent functionality.

#### THE NEED FOR INTELLIGENT ASSOCIATION

Whilst it may not currently be easy to see the importance of intelligent association between artefacts in a highly dynamic world of mobile agent, ubiquitous agents, and the global provision of services, the question of communicating and co-operating with other agents for the provision of necessary services at many different levels will be a continuing problem. Or, it will be if the necessary research isn't carried out now into solving the hard problems that dynamic intelligent association imposes. It is only with the benefit of such an infrastructure that the full potential for domestic users is going to be realised.

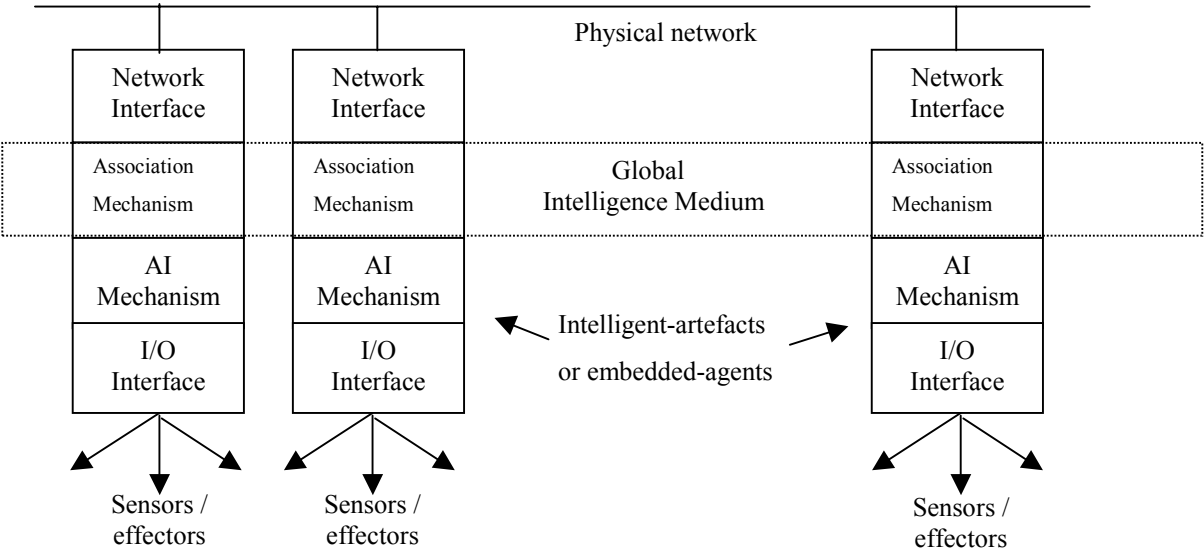
## The Issue of Distribution

In most disappearing computer style scenarios, computer based artefacts are able to form ad-hoc groupings which work together to achieve some higher-level purpose. From an AI viewpoint this raises questions such as:

1. How is AI (agent) functionality and computation distributed (e.g. what is the computational granularity of artefacts, are they computationally and functionally autonomous).
2. How are associations to other artefacts formed and recorded (i.e. does each artefact decide and record its own associations or is this centrally managed and recorded)? Such associations are critical to group co-ordination, synergy and learning.
3. How are the dynamics of artefact mobility and failure handled (how do artefacts choose between competing services or cope with the removal of a service)?
4. How is group control and contention arbitrated (is there a master artefact in overall charge or is this devolved)?
5. How do artefacts/embedded-agents communicate with each other (what is an appropriate and compact language to support the expression needed for generalised intelligent-artefact communication and co-operation)?

Figure 3 below shows a high-level diagrammatic view of a distributed intelligent-artefact architecture that goes some way to address these problems. In this diagram each artefact is responsible for determining which other artefacts (which might include sensors and effectors) to associate with and holding its own local record (no global record is maintained). The system is initialised with a set of associations deemed the artefacts "sphere of influence" (e.g. these associations may be set using a manual-editing tool). In the learning mechanism that is outlined later it will be seen that embedded-agents have the ability to evaluate which of the associations (and associated input stimuli) is important to its event based decision mechanism (discarding those that are not influential). The agent may also look beyond its prescribed associations for new associations that might provide input stimuli that improve its decision

making process (thus autonomously creating new associations). Through this combined mechanism of association formation and removal, the global association medium assumes an implicit and global learning intelligence. Records of association are fully distributed throughout the system with each artefact knowing only about its own associations. These may be interrogated and modified by a manual editor as well as the autonomous self-learning process of each agent.



**Figure 3.** A distributed intelligent artefact architecture (with implicit global intelligence)

In order to carry out this sort of co-ordination and communication, intelligent-artefacts need a language to communicate, and to request and provide a variety of services to other artefacts. This needs to operate securely and robustly in a dynamic environment using a minimum of computational resources. Much work has been done on agent communication languages such as KQML, FIPA, Jackal, JafMas, etc. (Finin 1994), the latter being frameworks that utilise JAVA. In a study we have completed we have shown that languages aimed at traditional AI applications are unsuitable in term of their computational demands and functionality. In our related “intelligent-buildings” work we have developed a language, DIBAL (Cayci 2000), which used a tagged hierarchical format to create a highly compact agent language that overcomes many of the problems associated with the more functionally rich traditional agent

communication languages such as KQML. It is possible that such a communication language might be adapted for inter-artefact communication based on the architecture described above.

### **The issue of mobility**

Artefacts can be mobile to differing degrees. For example, a mobile phone is highly mobile following the users movement. If it were to collaborate with sets of local agents then its presence in their group may be fairly short. At the other extreme there maybe fixed computer based artefacts in buildings (e.g. HVAC systems) which are effectively permanent and static in nature. There are also intermediate levels of mobility such as that of a CD player brought into a building by an owner which may be there for a number of weeks, or years, before being moved. Clearly, the technical infrastructure has to deal with these varying dynamics of mobility and association. The following table summarises these possibilities.

	<b>Centralised</b>	<b>Distributed</b>
<b>Static</b>	Orchestration of groups of fixed artefacts by a single centralised computer	Anarchical (co-operating, self-organising, non-hierarchical) collaboration of groups of fixed autonomous artefacts
<b>Semi-Static</b>	Orchestration of groups of temporally located artefacts by a single centralised computer	Anarchical collaboration of groups of temporally located autonomous artefacts
<b>Mobile</b>	Orchestration of groups of continuously moving artefacts by a single centralised computer	Anarchical collaboration of groups of continuously moving autonomous artefacts

### **The Issue of Dimensionality and Temporality**

The quality of agent decisions is limited by its knowledge of the world. It gets its knowledge from sensors directly attached to it and other agents (i.e. indirectly from their sensors). Which set of sensor information is sufficient for an agent to make a particular class of decision? Consider a simple heating controller, why does the room's occupant alter the heat value. Is it

to do with the current temperature, his current level of activity, what he is wearing, where he is in a room, where he has just been or what? We may decide that it is based upon current temperature and therefore could operate with only one sensor, but later discover that an agent that used only one sensor was not working very effectively. At the other extreme, we could decide we should sense ‘everything’ and then let the agent learn which of these sensed values was important. Clearly in this latter situation, the agent would be able to make better-informed decisions and adapt to changing criteria. In addition, this problem exposes a central dilemma, what is the best mechanism for selecting relevant sensory sets for agents? Is it the designer or the agents themselves? The problem with a designer is the assumption that people know best what the intelligent agent needs; but is this true? We would argue that it is better to provide a large set of sensory inputs to agents and let them resolve which of the stimuli is important for any given decision wherever possible. Whilst this latter argument may have some appeal it carries with it a penalty, the need to compute using large sensory input vectors. Thus, large sensory sets are an issue for intelligent-artefacts. One solution is the development of mechanisms that allow embedded-agents to “focus” on sub-sets of data relating to specific decisions or circumstances. An additional problem is that of time and sequences. Often the reason an action is taken is not simply related to the current state of the world, but to the sequence of states that led up to the most recent event. Thus, an effective embedded-agent would need to be able to deal with temporality. In general the foregoing are the most difficult problems to be addressed. In terms of temporality we are beginning to investigate state-machine based methods, whereas for dimensionality our methods largely rely on manual focusing although we are working towards more automated mechanisms based on constraint satisfaction methods.

### **The issue of non-determinacy, intractability and dynamism**

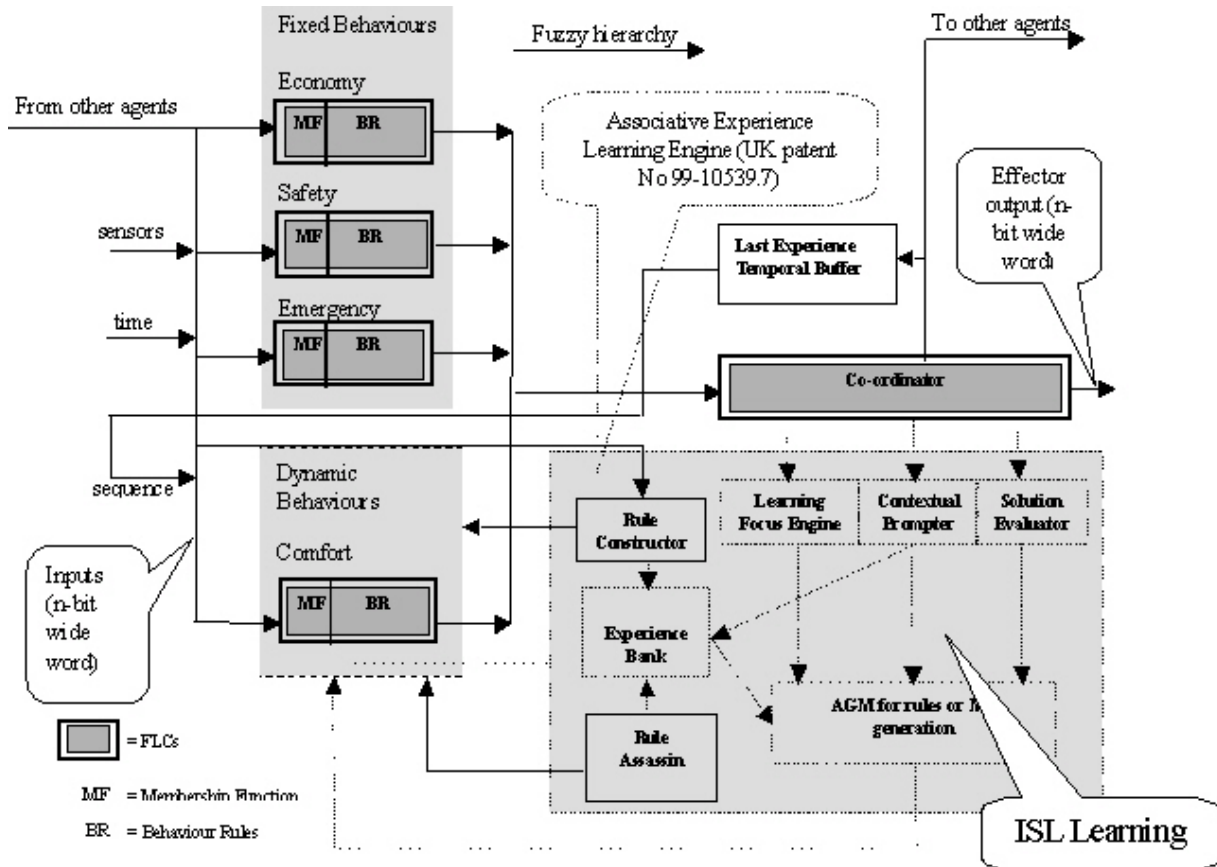
Traditional AI is based around the so-called Sense-Model-Plan-Act (SMPA) architecture. In this there is a presumption that the world the agent acts upon can be abstractly described by either a mathematical model or some form of well-structured representation. In addition, it is usually presumed that the state of the world can be sensed reasonably reliably and compared to

the abstract representation so as to reason or plan about the world. This approach works reasonably well for some forms of problem such as chess playing programs where many of these axioms hold true but completely fails in applications such as robotics and other applications that involve an intimate relationship with the physical world. The reason that traditional AI fails in such physical applications has been well described by others (Brooks 1991) but a simplified explanation would be that the assumption that the world can be accurately sensed and modelled (the key axiom of SMPA) does not hold. For example, a robot interacting with the world does so via imperfect and sparse sensing, monitoring physical phenomena and people which are either of intractable complexity or are essentially non-deterministic (e.g. people's actions aren't reliably predictable). In addition, it has proved virtually impossible to adequately represent the world, or to maintain a consistent representation in real-time of a highly dynamic world (e.g. objects and associations changing through deliberate actions or failures), resulting in loss of synchronisation between the model and the real world with associated catastrophic results.

We have argued elsewhere that intelligent-artefacts (containing embedded-agents) are equivalent to robots, experiencing similar problems with sensing, non-determinism, intractability, loss of synchronisation etc. (Callaghan *et al.* 2001). Thus whatever techniques are used to embed intelligence into artefacts will require these issues to be addressed. Fortunately, robotics has generated a potential solution for this type of problem that works by discarding the abstract model and replacing it by the world itself; a principle most aptly summarised by Rodney Brooks as, "the world is its own best model". This AI school is known as "new AI" or perhaps more meaningfully "behaviour-based AI". Our earlier work (Callaghan *et al.* 2001; Hagaras *et al.* 2000; Hagaras *et al.* 2001) was in the field of robotics, which has allowed us to recognise the underlying similarities between robotics and intelligent artefacts.

In our robot-based embedded-agents, which we have also used within an intelligent building environment, we encode behaviour based architecture principles via hierarchical fuzzy logic in which logic rules (programming) are formed by a novel real-time genetic algorithm. It is not the purpose of this paper to describe this agent mechanism although we include a high-level diagram in Figure 4 below and refer the interested reader to our other

papers which debate these principles in some considerable depth (UK Patent 99; Colley *et al.* 2001, Callaghan *et al.* 2001; Hagaras *et al.* 2000; Hagaras *et al.* 2001).



**Figure 4.** An embedded-agent architecture for intelligent-artefacts

In simple terms the operation of the agent in an intelligent building scenario is as follows: when an occupant changes an effector setting manually, the system responds by immediately carrying out the action, setting the building to the requested state, generating a new rule based on that instance and initiating a new learning sequence. In this case the learning sequence is the equivalent of one iteration of the forced-error learning in our mobile robot agent. At this point any further action is suspended until there is another interaction with the occupant. There is therefore no forced interaction with the occupant but rather the occupant's spontaneous interactions trigger a simple learning process. By spreading the iterations over an extended period, using the natural interactions of the user with the system for guidance, learning is made unobtrusive. For example, if we consider a temperature controller, each day the occupant

might make an adjustment to the system (i.e. one learning iteration) and complete a learning cycle in, say, 21 days (c.f. our experimental data reported in Callaghan *et al.* 2001 and Hagaras *et al.* 2000). We would argue that this is an acceptable time for an agent to learn to particularize its services to a person as, in a manual system, the user will always need to control the system, whereas in the agent-assisted system the manual load upon the occupant should reduce over time. In addition to providing a non-intrusive learning mechanism, this approach also places the user in prime control as it unfailingly and immediately responds to his commands.

### **The iDorm testbed**

We are constructing an intelligent-artefact space at the University of Essex to illustrate the kind of approach described above. More extensive descriptions of the technology involved in these rooms are given elsewhere (Callaghan *et al.* 2001; Colley *et al.* 2001; Hagaras *et al.* 2001]. We have chosen a student dormitory (see Figure 5 below) to be a demonstrator and testbed for some of the techniques involved. The dormitory constitutes a personal space populated by an assortment of personal computer-based artefacts, many of which are to be configured by the occupant. Being a student dormitory it is a multi-use space (i.e. contains areas with differing activities such as sleeping, working, entertaining etc). The occupant of the room (a student) would be free to decorate his room with whatever artefacts he chooses (computer and non-computer based, passive and active). Because this room is of an experimental nature we are fitting it with a liberal placement of sensors (e.g. temp. sensors, presence detectors, system monitors etc) and effectors (e.g. door actuators, equipment switches etc), which the occupant can also configure and use. Our expectations are that the occupant would chose to decorate his personal space (the room) with a variety of artefacts ranging from building service devices such as heaters to entertainment systems such as CD/TV. A possible scenario is as follows. The student moves into the dormitory, which contains some existing artefacts (mostly connected with the room infrastructure) but brings other more personal artefacts with him. He then runs a configuration program on his PC that allows him to set up associations between sensors and effectors.

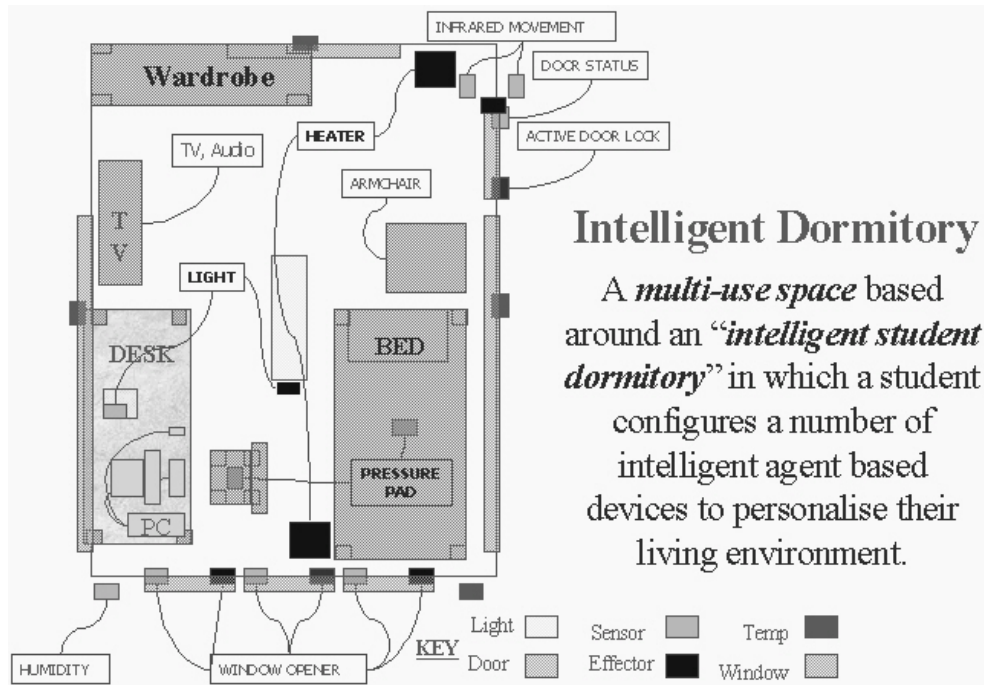


Figure 5a. Intelligent inhabited environment

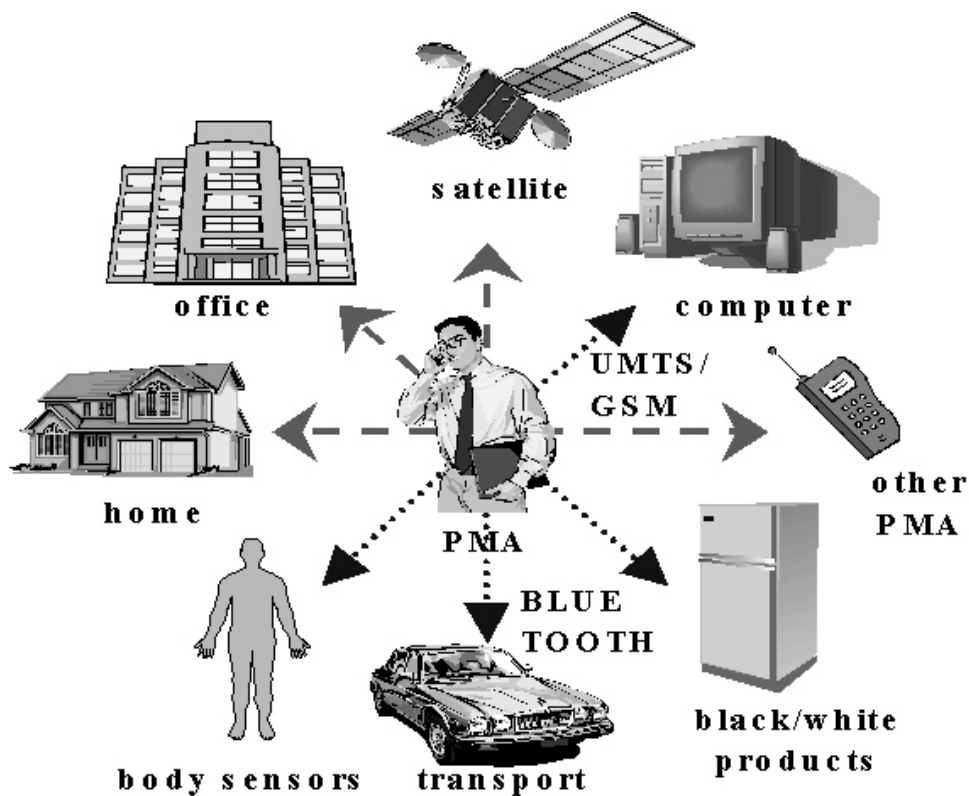


Figure 5b. A world of interacting artefacts

To take a mundane example concerning the room's infrastructure, the student might set an association between a light switch immediately inside the door and a number of room lights. In addition he could personalise this space by deciding to associate the same light switch sensor to his radio, so that the radio switches on whenever he enters the room. He then continues until he has associated together all the sensors, effectors and artefacts that interest him. Having set up a basic artefact association the occupant may then choose to switch the artefacts into an active online learning mode (or leave them as manually set). In general the room and artefacts function as non-agent based systems, interacting with the user through conventional controls (no special embedded-agent controls are necessary and the user is essentially unaware agents exist, or this is anything other than a normal environment). In the active mode artefacts monitor their use, in relation to the state of their local world, programming themselves to satisfy the occupant by doing what he habitually and persistently wants (i.e. not simply learning random whims of a user but rather learning long term persistent requirements, what we call 'learning inertia') in the embedded-agent research we have undertaken. At the same time as learning habitual and persistent user requirements, the embedded-agents also respond immediately to any command made by the occupant. Thus after some time has passed the intelligent-dormitory may have learnt how to configure and operate the constituent intelligent-artefacts to the benefit of the occupant. This description is not comprehensive in coverage, and clearly speculative in places, but we hope it helps expose some of the issues and gives a feel for they type of operational issues and possibilities involved.

### **Summary: the future**

In this paper we have argued that transferring some cognitive capabilities from people into artefacts is a natural way to facilitate the disappearance of computers as computers are increasingly embedded into our daily environment. We have also argued that embedded-intelligence can bring significant cost and effort savings over the evolving lifetime of product by avoiding expensive programming (and re-programming). In particular, if people are to use

collections of computer based artefacts to build systems to suit their own personal tastes (which may be unique in some sense) then self programming embedded-agents offer one way of allowing this without incurring an undue skill or time overhead. However, whilst this paper argues strongly that integrating embedded intelligent agents into artefacts is highly beneficial, it also exposes several significant problems, many of which remain as research challenges. For instance, dealing with the problems of non-determinism, dimensionality and temporality in computationally compact environments are very challenging topics.

We also presented an overview of an intelligent inhabited environment in the form of the iDorm that we plan to use as a test-bed for some intelligent artefacts in the eGadgets project and for the CareAgent project (part of a Korean-UK Scientific Fund Programme), which includes co-operation between fixed agents and mobile robots (Colley *et al.* 2001). We look forward to reporting results from this environment in a future paper. We note that previous papers from our group have reported on experimental results in a simpler environment that suggest that embedded-agents can significantly contribute to making effective computer based artefacts in which the computer has cognitively disappeared to a significant extent.

## Acknowledgements

We are pleased to acknowledge the contribution of Malcolm Lear, Robin Dowling and Arran Holmes for their help building the intelligent dormitory and intelligent-artifacts. We would also like to thank Hakan Duman, Anthony Pounds-Cornish, Sue Sharples, Gillian Kearney, and Filiz Cayci for their indirect contributions arising from many stimulating discussions on intelligent-artifact and embedded-agent issues.

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## Unremarkable Computing: Routines and the Design of ‘Invisible in Use’

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**Abstract.** In this paper, we aim to move the Ubiquitous Computing agenda forward by focusing on one of its earliest, but most difficult, ambitions - making technology “invisible in use”. We draw on field studies of domestic life as this domain is becoming increasingly important for new technologies and challenges many of the assumptions we take for granted in the design of technologies for the workplace. In particular, we analyse some examples of domestic routines and identify a number of insights into what it means for the features of activities to be “unremarkable”. We conclude by using these insights to critique some of the current emphases in ubiquitous computing research, and suggest how we might better understand what will be required to develop technologies that really are “invisible in use”.

**Keywords.** Ubiquitous computing; calm computing; ambient intelligence; intimate computing; ethnography; ethnomethodology; field studies; domestic environments; technology for the home; routines; context.

Paper presented at The 1<sup>st</sup> Equator IRC *Workshop on Ubiquitous Computing in Domestic Environments*, The School of Computer Science and Information Technology, The University of Nottingham, 13-14<sup>th</sup> September 2001. <http://www.equator.ac.uk/>

Computing, the office has been the default domain:

Inspired by the social scientists, philosophers, and anthropologists at PARC, we have been trying to take a radical look at what computing and networking ought to be like. We believe that people live through their practices and tacit knowledge so that the most powerful things are those that are effectively invisible in use. This is a challenge that affects all of computer science. Our preliminary approach: Activate the world. Provide hundreds of wireless computing devices per person per office ... (Weiser 1998)

In our current research we have been considering the notion of Ubiquitous Computing in the context of another domain – the home. This has been motivated by changes in work practices and technology that have led to a significant growth in the numbers of people working from home, throwing into sharp contrast the office/home boundary and highlighting the different design approaches that have been traditionally adopted within these two domains. While much of the vocabulary of the office revolves around tasks, processes, productivity and functionality, the language of the home is often oriented towards lifestyle, aspirations, emotions aesthetics, form and so forth. Yet, as Ubiquitous Computing takes hold, we can expect that computing will increasingly expand from the work domain and become embedded within home appliances and domestic environments. Consequently these two technology and design traditions are on a potentially fascinating collision course. We are also motivated by a belief that the radical differences between the home and the office may cause us to re-evaluate many of the assumptions buried within prevalent views of Ubiquitous Computing. Alternative domains have a habit of challenging consensus and questioning engrained perspectives.

Despite our overall goal of understanding how ubiquitous computing might arrive and make its place in domestic everyday life, our first concern in examining home environments is ‘to let them speak for themselves’. Our approach has been one of ethnomethodologically-informed ethnography through which we seek to understand, pre-theoretically, the concrete lived details of phenomena and to bring out the *ethno-methods* (Garfinkel 1967) and tacit resources whereby things get to look the way they do.

## **The glue of domestic life**

As we set about looking at the everyday phenomena of life and work within the home it became evident to us that one of the most significant and ubiquitous ways in which this is managed is through routines. In fact the role of domestic routines was such that in home settings where work was also done we found that work routines were typically made subservient to domestic routines with work being seen as a thing that (within certain confines) can be done anytime within the day whilst breakfast has to be *now*, the children have to get to school *now* and so on. There is a sense in which routines are the very glue of everyday life, encompassing innumerable things we take for granted such that each new enterprise can be undertaken unhesitatingly. This is especially pertinent in the home where the highly disparate priorities of different family members have to be realised without the commonality of an orientation to some shared work objective to bind them together. Routines help provide the grounds whereby the business of home life gets done so that people can get out the door, feed themselves, put the children to bed etc. without having to eternally take pause and invent it anew or open up its every facet for inspection, comment, challenge or the generation of accounts.

## **PREVIOUS WORK ON ROUTINES**

Despite the significance of routines in domestic life there is, to date, little empirical understanding of their fundamental nature and no way has yet been found for such an understanding to directly impact the actual design of domestic technologies. In contrast the study of routines in the office environment has had a direct impact upon computer science in fields such as CSCW. The significance of the notion of ‘routines’ came to the fore in the late 1970s and early 1980s when technology developers began to explore ideas of ‘office automation’. It was the field studies of researchers like Wynn (1979) and Suchman (1987) which first demonstrated the rich and complex nature of allegedly repetitive activities and the

skilled and cooperative decision-making and negotiation necessary to ‘get the work done’.<sup>1</sup> Suchman in particular was able to suggest a radically different sense to ‘routine’ and illustrate the importance of an ethnographic orientation to the status of procedural plans, seeing them as accomplished products rather than as structures which stand behind the work. Embedding representations of routines within systems (such as workflow tools) was seen to change the status of those representations from being a resource for situated action to becoming something to be enacted programmatically. A focus upon supporting work with resources rather than automating it has now become a distinctive characteristic of Computer Science in CSCW, influenced by this understanding of the status of representations of routine processes and emphasizing ‘routineness’ as an accomplishment produced through the practised exercise of complex skills.

#### A FRESH LOOK IN THE HOME

We would certainly not wish to understate the significance of the above body of research. Indeed, the work of Suchman was motivated by the same core interest and approach as our own. However, this is now a well-worn path, where the primary focus has remained upon *work* practices and the *office*. So, rather than replay here the lessons of CSCW by applying them once more to the field of Ubiquitous Computing, we intend to put them aside for the time being and take a fresh look at routines and their significance in a new domain - the home. Domestic routines cover a wide range of phenomena with many research implications. Our aim in this paper is a modest one: we seek only to begin to identify, through empirical materials, some of the features that might serve to give things a *routine character* in the home.

#### **Instances of routines**

##### 1. PERCEPTUAL VISIBILITY AND PRACTICAL INVISIBILITY: THE ALARM CLOCK

Our first instance of interest is an extract from a study of a freelance translator working at home. The translator in question, Lucie,<sup>2</sup> lived in a small 3-bedroomed house with her 2

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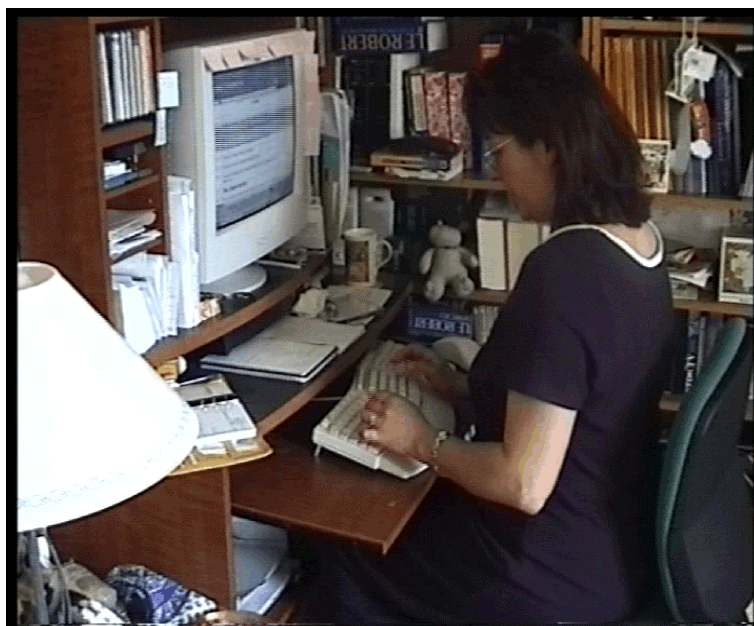
<sup>1</sup> See early Office Automation research in the late 1970s and early 1980s; e.g. Zisman (1977) and Ellis (1980)

<sup>2</sup> Proper nouns have been changed throughout to preserve anonymity.

children, a boy aged 12 and a girl aged 10. The previous year she had moved from doing translation work in an agency to 'going it alone' at home and had converted one corner of her living room into an office. Translation work turns chiefly upon the physical number of words one can translate in any one session, so she frequently started work early in the morning before her children had got up in order to get as much as she could done without interruption. This instance is drawn from observations of one such early morning session. Lucie has been sat at her desk, translating from English into French a text describing a new dieting aid, since about 6:00 a.m.

**Instance 1:**

Lucie flicks through some printed sheets on her desk and comments on how the table of contents doesn't match the text. She returns to the electronic document and continues to translate the next title, saying out loud a segment in square brackets. It is 7:00 a.m. and an alarm goes off upstairs which she totally ignores, continuing to key in as before. When she has completed that section of text she switches her monitor off and says 'it's been an hour'. She pushes in the leaf to her desk, stretches, then leans on the ledge under her monitor resting on her elbows, her hands to her cheeks, drinking coffee. Once she has finished her coffee she goes into the hall to call upstairs to the children: « Bonjour mon gros doudou, Bonjour mon lapin... »



**Figure 1.** Not noticing the alarm going off?

One feature we would particularly like to draw attention to here is the way she shows no response to the alarm going off upstairs at 7 o'clock, despite going to the foot of the stairs to

call up to the children a short while later. To the ethnographer the alarm going off is a notable enough event for it to be recorded in the fieldnotes. Yet, for Lucie it passes by without remark.

Yet, how would it have been had she paused to take note of it, perhaps saying something like ‘Oh, is it that time already?’, or even ‘whatever is that?’. In the first of these cases she would have preserved the actual going off of the alarm’s ordinariness by not seeking to account for why that had happened. Rather the event would have become a resource for commenting upon something distinct about the current situation. In the second of these cases an explicit drawing attention to the alarm by saying ‘whatever is that?’ would have marked out to anyone who was there to witness it the ‘unusualness’ of the occurrence, with an ‘ordinary’ next step being to seek out some account, for instance ‘the alarm has been set wrong somehow’. However, in Lucie’s very *disattending* to the alarm she displays her orientation to it as something wholly unremarkable. And by *visibly* failing to attend she provides for the sense of the going off of the alarm upstairs at seven o’clock in the morning as being a matter of routine, for who would comment upon a feature of their routine as though it were somehow special? So here we have some initial, orderly features of what routines might consist in:

- Routines are i) unremarkable in their realization; ii) can be disattended to, which renders them visibly unremarkable; and iii) For those who enact a routine, to remark upon the routine is itself something that is remarkable and accountable.

However, although the alarm going off is visibly unremarkable, that is not to say it is a thing without import. For a start it is a thing of import for her children. Its very mutual availability to Lucie and themselves makes ignoring it highly accountable. Consequently, it is a resource that can serve to initiate other features of the everyday morning routine, such as getting out of bed, going to the bathroom, getting dressed etc. So, despite having rendered the alarm unremarkable by ignoring it, were it to be ignored by *her children* Lucie could unproblematically hold them accountable. That makes it a resource for her as well. This is made visible by her subsequent movement to the foot of the stairs to call up to them. Similarly, though aspects of routines may never be directly remarked upon, a failure to attend to their implicativeness is accountable in the very terms of what is usually unremarked, e.g.

‘didn’t you hear the alarm going off?’ So, to answer the question under the above photograph, it is not the case that she is not noticing the alarm going off. Rather she is not *displaying* that she has noticed because to display that notice would be to make her accountable for her interest in its significance. Finally, one can imagine instances where she might display some interest in the alarm *not* going off, perhaps by noticing the time and realising the alarm has failed. This displays an orientation to the alarm as something ‘nodal’ upon which many other things may turn. So her disattention to its going off is certainly not dismissal. Furthermore, should it fail to go off that failure can itself be quite specifically attended to.

Alarms then can be perceptually visible yet practically invisible in use, as part of what has been made routine. What matters about the alarm is, in this case, not so much its perceptual character as its significance, a significance that can be made explicit should the alarm ever fail. So here we have some more orderly aspects of routines:

- iv) The features of routines serve as resources for the mutual co-ordination of unremarkable doings in that they are: a) mutually available resources, and b) mutually accountable resources to those who enact them; and v) Within many routines there are nodal occurrences that are implicative for everything else that follows;
- vi) Failure to enact a routine is held specifically accountable to the routine that failed, and vii) The failure of a routine is specifically remarkable;
- viii) Disattending to a routine is in no way equivalent to not noticing the routine; so ix) Artefacts implicated in routines can be perceptually available yet practically invisible.

The above instance begins to demonstrate how routines can serve as mutually available, mutually accountable resources for articulating particular courses of action, like getting up. However, it is also the case that routines can serve as that kind of resource for articulating courses of action *between* households. In the next example we see how ‘knowing the routine’ enables members of two separate households to accomplish a particularly fine-tuned course of action.

## 2. DONE IN THE DOING: THE KNOCK ON THE DOOR

The following abbreviated accounts are descriptions of two distinct but related instances drawn from observations of the domestic round of a family with two children, one aged 12 and

the other aged 9, collected on different days. Both of the instances occur at the time of the mother, Christine's, departure to pick up her youngest daughter, Susie, from school.

**Instance 2a:**

Christine has been sitting at the end of the garden in the sunshine drinking a cup of tea. It is 3:00 p.m. and she is heading back to the house to get ready to go and get Susie from school. She goes into the kitchen through the back door, shuts and locks it and closes the kitchen window. Then she puts away some shopping that she has left out before picking up her mobile phone and going through into the hall. She puts a few items on the stairs and goes into the living room. There is a knock at the door. She goes into the hall and half opens the door and, without looking to see who is at the door or giving any verbal response, goes back into the living room to finish what she is doing. Then she goes out onto the street, shutting the door behind her. Her next-door neighbour, Louise (who is also her sister-in-law), is walking slowly up the street and looks to Christine as she comes out. Christine heads over to Louise, commenting on the heat, and they walk up the road together towards the school.

**Instance 2b:**

It is a couple of minutes past 3:00 p.m. Christine has just gone into the house from the back garden and has been going round closing doors and windows. A moment later the door to both her house and Louise's house next-door, open and they come out down their respective paths. They look at one another and Christine says "That was good timing". Louise pauses at the end of her path and when Christine reaches her they walk off up the road together in the direction of the school.



**Figure 2.** "That was good timing"

As some additional background it is worth noting that Christine and Louise have never discussed this arrangement, it having 'just evolved'. Finding they were leaving at the same time, they had started to walk to the school together, with whoever comes out first knocking

on the other's door before heading off to the school. Neither of them waits if the other one doesn't come out.

### ***Knocking as a 'message'***

We might first of all wonder about what is accomplished through this knock on the door. Actions such as 'knocking on a door' can achieve various things beyond just making a sound on a door: they can be a statement that 'I'm here' or a means to 'check for absence prior to entry' or a confirmation of the ownership of a space and the rights of access to it. Clearly a knock such as this could be a 'summons'. However an ordinary thing about a summons is that the summoner waits for the summoned to answer, yet that is clearly not what is being oriented to here. In instance 2a, Christine could have answered the door as soon as Louise knocked on it but instead a thing happens that would be unusual in most other circumstances: Louise walks away without waiting for Christine to answer. This is not, however, some form of peculiar game. In fact, Christine in no way holds Louise accountable for that behaviour. The knock, then, is oriented to as not so much a summons as a *message*, the import of which is only locally intelligible where, for each of the mothers involved, it tells them that the other mother is about to walk to the school.

### ***Opening the door as a 'message'***

Another otherwise strange feature of instance 2a is the way Christine only half opens her front door and immediately returns to what she is doing without speaking to the person knocking at the door. One would typically expect that either a caller would be greeted or that a half opening of the door followed by walking away would be highly accountable, for instance by saying "sorry, I was just in the middle of something". Christine however clearly has a solid *expectation of the implicativeness* of this knock such that she can disregard the possibility that her actions might be held accountable. In order to understand the import of this half opening of the door it is necessary to recall the logic of this arrangement whereby, should the knocking individual get no response, they can treat that as licence to just walk off to the school on their own. So Christine's half-opening of the door is just enough to suffice as an acknowledgement

whilst she is involved in doing something else. The opening of the door, then, also serves as a message, whereby an announcement of imminent departure can be acknowledged.

### ***Context specific meanings***

We now want to move on to considering how it would have been if the knock on the door had taken place at some other time of day, somewhere else, or at 3:00 p.m. on a Saturday. Clearly the phenomenon here involves preparations to collect a child from school and only works and has intelligibility at a very specific time of day, and only on certain days for certain weeks of the year. Both Christine and Louise are able to mutually orient to that highly specific intelligibility in such a way as to enable the co-ordination of one specific commonality of routines between two families. The particulars of *how* it is realised serve as a resource for achieving that sense of having a shared routine that can be effectively co-ordinated. It turns upon neither of them specifically opening up the operation of it for comment or problematising its unique features (which, in relation to all the many things that knocking on a door and opening up a door might amount to, are quite distinctive). In instance 2b for example what is remarked upon is not the practice itself but rather the perfection of this particular realisation. The beauty of instance 2b is that, in that one moment where they walk out of the door together, the very need for there to be the originally observed phenomenon, a knock on the door, simply fades away and reveals that this is never simply about knocking on a door at all. That is only ever a resource to bring about what they are really after, which is to walk to the school together, rather than separately and alone. It provides for all of those occasions when they fail to walk out of their front doors at the same time as one another. But when they do, to still knock on one another's doors would be patently absurd.

The features of the realisation of this particular routine turn upon the mutual intelligibility of certain highly specific courses of action that in just about any other set of circumstances might be meaningful in other ways. They provide for a highly nuanced adaptation of wholly mundane physical and interactional resources such as knocks on doors, and openings of doors through the very unremarkable, dis-accountable, yet consistent regularity of their realization. They provide for this in such a way that some, at first sight strange, happenings at 3 o'clock on

a school day can add up to something meaningful and evidently unremarkable for two mothers from different houses who want to walk together to school. So, to summarise what we have discovered here:

- x) Specific meanings can accrue to certain activities such that they can serve to facilitate the coordination of certain routines which are only locally intelligible; and xi) these locally intelligible resources can also be used to coordinate routines across households.

In our final instance we seek to both delineate what we have said about what provides for some course of action having a *routine character*, but also to begin to demonstrate how ‘knowing other people’s routines’ can itself be a powerful resource for articulating and gearing together highly distinct orientations and goals, where it may be that one of the interactants is *never normally party to that routine at all*.

### 3. KNOWLEDGE OF OTHERS’ ROUTINES: GOING TO THE COFFEE SHOP

The instance is gleaned from an ethnographic study of the work of a freelance website designer and graphic artist, Michael Jones, who works at home. Michael likes to focus his business upon the local community and engages with many of his clients face to face at a local coffee shop. This particular sequence of events was prompted by Michael working through a To Do list he keeps on his desktop in MS Word, which he checks through at the beginning of each working day:

#### **Instance 3:**

Michael is greying out things he’s done on his To Do list – He says about needing to do something about ‘John’s’ opening times – [John is the proprietor of a local Farm Produce Shop] – He knows John wants them changed on his poster but doesn’t recall for sure what to. Michael goes to a folder on his PC titled ‘Posters’ and clicks on a document called Farm Shop which opens in Illustrator. Leaving the poster open he goes to phone John. However, John doesn’t answer. He notes that the time is about a quarter to ten – He says he thinks he will go to the coffee shop [a small coffee house just around the corner] where he thinks he’ll catch John because John usually goes in there for a coffee before opening up the Farm Shop at ten o’clock - When he gets to the

coffee shop he sees John waiting at the counter – He goes up to talk to him and says about the poster, checking what times John wants to go on it. While Michael queues they talk about John’s website and some advertising he wants done for some chocolate products he’s going to be selling. Just before ten o’clock John goes off to open the Farm Shop and Michael says he’ll pop in to see him later and talk about things in more detail.



**Figure 3.** Meeting at the coffee shop

Now, so far we have looked at examples of routines that are oriented to as resources for doings within a particular household, and across two households with certain common interests. However, this instance is quite distinct in a number of ways. There is no matter of course requirement upon Michael that he should specifically co-ordinate his routine with John’s and he has no particular accountability placed upon him that he should attend to that routine at all. In direct contradistinction to our previous observations Michael quite specifically *marks out* what he knows of John’s routine for comment – he knows that John goes to the coffee shop every morning before he goes to open up the shop. In this way, John’s activities have been made a matter of note for Michael in a way that John himself might not ordinarily take note of them. John would be unlikely to mention to, say, his partner before leaving the house that he was going to the coffee shop if that was a thing he did every day because the mentioning would invite that it be seen as something out of the ordinary and specifically *significant*. John

might make mention of that as a thing he did by habit to facilitate someone like a visitor finding him, but such a mentioning is a quite separate occasion to actually going to the coffee shop as a matter of routine.

All of these observations are not independent of one another but are, in fact, quite tightly related. It is exactly because Michael is not a member of the cohort governed by John's routine that it can be, for him, a matter of comment. As he is not accountable to it, so he is also not accountable for having made something notable and significant out of what, for members of John's family, is necessarily taken for granted. Furthermore, Michael is not engaged in a routine activity himself. His doings are notably occasioned: he needs to talk to John about the poster now because he wants to work on it, but John isn't there when he tries to phone him. As his actions are occasioned, so his motivations in those actions are open to quite explicit justification. So here we have someone not pursuing their own routine but using what they have explicitly noted about someone else's routine as a resource to bring off a particular course of action. This use of other people's routines as a resource for tailoring specific actions has been noted in a number of other studies, including studies of domestic telephone use where some pretty fine-tuned judgments can get made about 'when it's a good time to phone' (Lacohée and Anderson 2001).

What we are not saying, however, is that members are somehow oblivious to their routines just because they never remark upon them in the actual course of doing them. On the contrary, one can perfectly well bring forth an account of routines and justify them in the context of other occasioned activities, like being interviewed. In these cases, though, the mention of details of routines is specifically occasioned, and picking them out imbues these things with a certain significance. This is different from the actual realisation of routines where to give them some marked significance is wholly contrary to just taking them for granted. Indeed things that are taken for granted form the very background against which one might take note of other, distinctively occasioned and therefore notable activities.

So we can note here that there are perfectly accountable circumstances for explicitly remarking upon both one's own and other people's routines, but, importantly, these remarks are situatedly *occasioned*. Furthermore, one of the ways in which people's routines become

*discoverable* to others is through such *occasioned* circumstances where people explicitly provide details of their routines within accounts. However, in this particular case the availability of John's routine for Michael's own inspection was a matter of his own *noticing*, rather than through any particular account. It was a thing he had discovered through his own recurrent visits to the coffee shop – visits that, whilst not time-specific, were wholly a feature of his own routine. What marks out the above instance as something different is that he then makes use of that discovery in an *occasioned* rather than a *routine* visit to the coffee shop. So, to summarise:

- xii) There are accountably appropriate motives for displaying interest in someone's routines; and xiii) Such interests are specifically occasioned;
- xiv) People can provide accounts of their own routines, but such accounts are occasioned: discovering what is relevant within the routine is bound up with that occasion; xv) Through such occasioned accounts and noticings the routines of others can be discovered and made available for use; xvi) Knowing the routines of others can serve as a resource for a large number of other occasioned activities

### **Significance for ubiquitous computing**

We have then pointed to a number of features of things that have a routine character and the strong sense in which routines are deeply unremarkable. It seems then that, in their own terms, routines are invisible in use for those who are involved in them. Returning then to the agenda set by Mark Weiser and quoted at the beginning of the paper, we wish to consider what it is about the ways in which routines are unremarkably 'just there' that could help us develop Ubiquitous Computing that is invisible in use, that is in its own way unremarkable. The aim then is, again, well articulated by Weiser (1994):

For thirty years most interface design, and most computer design, has been headed down the path of the "dramatic" machine. Its highest ideal is to make a computer so exciting, so wonderful, so interesting, that we never want to be without it. A less-traveled path I call the "invisible"; its highest ideal is to make a computer so imbedded, so fitting, so natural, that we use it without even thinking about it.

Routines have then many of the qualities we may be aiming for in that they are tacit and calm in that they do not draw attention or demand attention except when they need to. They are seen but not noticed. They are themselves used as resources for action and the resources involved in them (doors, alarms, coffee shops and so forth) have been made unremarkable and routine. However, just how to go about making computing “so imbedded, so fitting, so natural” remains, we would suggest, unsolved. In fact a central point of this paper and the one to which we now wish to turn is that many of the ways in which solving this is being approached seem not to match with the features of routines and the use of resources within routines which we have observed.

#### USE AND INHERENT QUALITIES

Let us take as a first example the sense of computing as something that could ‘disappear’. Here we see an attempt to convey what this might mean from a research project on ambient computing.<sup>3</sup>



**Figure 4.** All sorts of computing devices (left) will disappear into the background of our everyday lives (right) Obviously this is an attempt to visually convey what might be meant and we are not unsympathetic to what is being attempted here. However these images can lead one to focus upon the *perceptual* visibility or invisibility of computing. We feel that perceptual invisibility is not necessarily the same as the achievement of invisibility in use. The alarm clock example described in instance 1 very much involves a perceptually demanding device yet one that has

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<sup>3</sup> Philips Research, <http://www.research.philips.com/generalinfo/special/ambintel/index.html>

been made routine. The alarm has not been made smaller or quieter or some how perceptually ambient but has rather, as a function of use, been made unremarkable. Perceptually the alarm remains an alarm but it is not attended too because its significance has been made unremarkable. Similarly, an alarm not sounding at all could very well be a remarked upon event.

The notion of “invisibility in use” is a difficult idea and the exact implications for the design of technology have not yet been thoroughly explored. However, it is all too easy to understand “invisible in use” as meaning literally (perceptually) invisible: the miniaturisation of computational technology, itself a driver of ubiquitous computing, has already enabled devices to become smaller and perceptually less visible (encountering a 1970s mainframe in your living room would be somewhat different from encountering a PDA.) However, we feel that a different, understanding is required for Ubiquitous Computing, and was, we believe originally envisaged as part of the ubicom program. However the most familiar examples are often misunderstood as pointing to perceptual issues. What we think is important about the well known example of “The Dangling String” (a piece of string connected to a motor that changes speed according to the network traffic (Weiser and Brown 1996)) are not the perceptual psychology issues (“periphery”, “attention”, “attunement”, “peripheral sensory processing” (ibid.)) but the features that enable it to become a resource in action.

Clearly, there *are* perceptual qualities which are critical to creating an “invisible-in-use” phenomenon:

- that the phenomenon can be “disattended to” implies that it must be “endurable” (the string would not work if it were designed as a loud siren of varying pitch)
- that the phenomenon can be attended to implies that it must be “available” within the context of the routine (an alarm is no use unless you can hear it).

Yet the question for us is not what perceptual qualities allow the device to be attended or disattended, but rather how do people embed these perceptual resources into their routines so that they can attend and disattend to them as needed. We feel that this notion of “invisibility in use” is already prefigured in Weiser in his attempt to turn attention away from the search for better ‘inherent qualities’ of computers. What is not sought is a computer that is more intimate

(Weiser 1993) or even more intelligent (Weiser 1994) but rather an altogether *unremarkable computer*: “Whereas the intimate computer does your bidding, the ubiquitous computer leaves you feeling as though you did it yourself. “ (1994a)

Similarly perceptually invisible is not the same as invisible in use. The point is not to adjust the perceptual qualities by, for example, making computers visually disappear, or producing notifications that are perceptually ‘softer’. These do not necessarily make the computer less present. The aim is not for a hidden computer. Indeed a computer that behaved as computers currently do and required the same form of interactions as computers currently do but which could not be seen or heard could be *more* remarkable, *more* present than before. The challenge for design is to go beyond focusing simply upon the perceptual qualities of devices and to make computational resources which can be embedded into routines and can augment action.

#### AUGMENT THE ACTION

Here then we wish to move onto our second point – that it is actions that we need to augment not artefacts per se. We may sometimes need to augment artefacts in order to augment actions but those artefacts are to be in service of the actions and their augmentation should be motivated by their role in those actions. If we consider for example fieldwork instance 2a, clearly everyday artefacts and actions are being used. The doors are offering hard surfaces which hands can knock on to make sounds, they are offering solid barriers which can be opened to allow entry, closed to prevent it or opened to varying degrees. These are then mundane features of the tangible world that are being manipulated using mundane competencies people have for touching and moving surfaces. However, as we have noted, much of the significance of the use of these doors comes from what is done in the doing of actions with them. The knock on the door is not only the action of lifting ones hand and connecting it to the physical door artefact so as to make a sound that can be heard by those on the other side of the door. It is, in this case, also a means to coordinate actions and to make others aware that you are ready to begin a routine. These are the significances of these actions. Furthermore as we have seen in instance 2b there are other ways of achieving these aims and

occasions where these artefacts need not be used at all and hence the actions are simply not taken.

This suggests to us then that a little caution is required about over hasty moves to augment tangible artefacts that are used in activities. Again we are sympathetic to what is being attempted in the tangible interface paradigm. Firstly when attempting to make computing “so embedded, so fitting, so natural” then augmenting physical artefacts is highly appealing in itself especially if these provide visible interaction mechanisms for perceptually invisible computer hardware. Secondly the tangible interface approach is a perfectly coherent HCI approach. After all, the manipulation of physical objects is (one of) people’s everyday competencies and one that is more generally available than, say, abstract computer commands and software applications. There is a logic behind developing tangible interaction mechanisms just as there is a logic to other interaction paradigms based on everyday competencies: spatially based systems<sup>4</sup>; graphical and visual-symbol based interfaces; and even languages with which to interact with computers (given that learning and using languages is an everyday human competence). These everyday competencies are however deployed *so as to* communicate, organize, coordinate and so forth. Augmenting a door artefact (e.g. to enable remote notifications) can only be a sensible design choice when one understands the significance that this artefact and the associated action of ‘knocking’ has.

In this context the point for us is not that interaction with computation may be mediated through tangible mechanisms (Brave and Dahley 1997) or that it is mediated through the augmentation of everyday tangible objects (such as the Media Cup (Gellersen *et al.* 1999)) or even that it is mediated through natural language, speech or gesture. Rather the point for us is that the computation is in service of actions – everyday actions – which themselves have a significance. The knock on the door is an *action that signifies*. To focus only upon the door artefact is to (literally) take a surface interpretation of what is going on and what people are doing. Augmenting artefacts needs to be in service of the actions done with those artefacts but also in service of what is “done in the doing” of those actions (what is achieved or conveyed

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<sup>4</sup> Such as the early ‘rooms’ interface (Henderson and Card 1986) and later work with virtual environments (Benford *et al.* 2001).

by the doing). Remember that in instance 2b the door is dispensed with completely as an artefact for coordination because that has already been done in other ways. One would not want to require someone to knock on a door to announce their departure to some one who was already standing next to them ready to depart. The design goal then is to augment the resources, tangible or otherwise, which are available to the action and to what is done in the doing of that action. Put simply, we need to embed computation within life not just in cups.

#### RIDING EXTRA SEMANTICS ON THE BACK OF TANGIBLE ARTEFACTS

A related error is, we believe, to assume that embedding computation within an existing tangible artefact is guaranteed to merely ‘augment’ that artefact in ‘natural’ and ‘intuitive’ ways rather than to fundamentally change (if not confuse) the semantics of exactly what that artefact is. We have suggested then that a fundamental issue for us in things that are ‘invisible in use’ is not the physical nature or particular perceptual qualities of these things but rather the significance which accrues to them within a particular course of action. The issue for us is then one of what one might call “user semantics” and here we target an area that is between and deliberately separate from system semantics (what entities know about themselves and others) and interaction mechanisms (how users interact with the system). User semantics is rather what the user knows about the world and how they understand, for example, what is available, what can be combined, what is configured already and so on. That is, while we are interested in and recognize the challenges both of novel interaction paradigms and of system-level problems in Ubiquitous Computing, we also see a middle area which can tend to be slipped over and which regards user semantics. Indeed issues of new user-level semantics can be mistakenly conflated with tangible computing interaction mechanisms.

Not explicitly recognizing this level can make it harder to conceive and evaluate designs in which changes to the semantics of objects are being introduced. For example, one might, as a design choice, choose to embed within a door a mechanism such that whenever it was knocked upon, it displayed a personalised newspaper, or debited a credit card or changed channels on a television. The point is not just that these may not be desirable additions to the functionality of the door but rather that they would change the semantics of what this door was

– perhaps usefully so and perhaps in ways that could be easily learned but still change nevertheless. Furthermore, we have seen in instances 2a and 2b that *this* knock on *this* door for *these* people at *these* times is not a request to enter, not a warning before entering, not a test to detect for presence but rather an announcement of imminent departure. That is, not only is more done in the doing than just the doing but it is also the case that what is done in the doing is ‘just that’ and not something else. Consequently while some doors and some uses of some doors by some people at some times might lead one to want to, say, augment those doors such that, for example, the doors capture details of all who called by while you were not there or which displayed whether the room behind them was occupied or not, that would not be the kind of augmentation of value for the doors, the actions with the doors and what was done in the doing of those actions with those doors in instance 2a.

The nature of the augmentation is not then simply one of computation. Computation is the mediator but the augmentation is one of the semantics. The assignment of augmentation, the assignment of semantics should then be a matter of careful consideration. That those extra semantics are being embedded in a tangible device is no saviour, it does not in itself mean that the orientation and use of *those* semantics are somehow natural. The existing semantics may be natural or at least known and understood but the assignment of extra semantics cannot be guaranteed to ‘ride on the back of’ the semantics of the initial artefact. This augmentation may then be a matter for careful design reflection and indeed the artefact may have to be redesigned so as to make its new semantics understandable.

## SUPPORTING ROUTINES THEMSELVES

As we turn towards augmenting actions and the sense of those actions within sequences of actions, then routines themselves become a topic of interest. Routines are a form of action sequences and, as we have noted, are generally unremarkable and provide the omnipresent glue of domestic life. The question is what will it really mean for Ubiquitous Computing to fit comfortably within routines and avoid losing the unremarkable qualities that make them what they are. We might expect ubiquitous computing components to fit into and augment everyday routines – for example how might a ubiquitous computing environment provide alternative

ways of serving the communication that is taking place around the knock on the door in instance 2. Or to draw on instance 3, what would it mean for Ubiquitous Computing systems themselves to draw upon knowledge of peoples' routines in order to be context-sensitive, to support a calm world of computing, to detect the intention for users, to seamlessly recombine computational resources, to perform low level connections and transformations and to just 'do the right thing'.

We have seen how in the office environment Office Automation systems did not appreciate the status of representations of routines by embedding them within systems. Similarly the status of user accounts of routines needs careful consideration. In particular we see accounts of routines as occasioned matters and separate from the actual doing of those routines. A consequence of this is that care will be needed to ensure that systems do not transform the unremarked nature of doing routines by marking them out through supporting them. That is the marking out of actions within routines can be the very thing that disrupts the doing of routine sequences of actions. Systems must be designed such that background is not made foreground, the routine is not made episodic, the taken for granted does not become notable, the matter of course does not become a matter of comment.

Is developing Ubiquitous Computing that supports or uses an understanding of routines therefore impossible? We would argue not. We have seen that routines are indeed resources for action and knowledge of others routines can also be resources for action and interaction. Routines are knowable, teachable and breachable. To some extent the same may be true for systems' comprehension of routines. However, we would suggest that attention needs to be paid to the distinction between, on the one hand, routines being visibly unremarkable in their realization and, on the other hand, accounts of routines being occasioned and the accounts of what is relevant within the routine being bound up with that occasion. We believe that there are deep challenges in trying to provide unremarkable computing for unremarkable routines. We are beginning to explore two potential topics within this area.

#### NODAL POINTS WITHIN ROUTINES

The first is that within many routines there are *nodal* occurrences that are implicative for things that follow (such as the alarm clock or the knocking on the door). These may be, for

example, utterances that open up conversations or close them down, actions that initiate sequences or conclude them. Not only may these points be useful points to detect but they may be points for potential augmentation and points where requiring that they are made more explicit in their marking out is less disruptive than other points. The challenge is to be able to identify such points, to understand the potential for augmentation through ubiquitous technologies and to understand requirements for these technologies so that they can realistically become part of a routine.

#### THE SYSTEM AS 'PARTICIPANT'

Weiser set himself the challenge of “could I design a radically new kind of computer that could more deeply participate in the world of people?” (Weiser 1995). We should of course not interpret this as a call to develop intelligent agents that are indistinguishable from people in their behaviour – for example, Suchman (1993) has clearly articulated the asymmetry in the sense making abilities of people and computers. Rather the challenge is to work out how the “sense making” that can reasonably be expected from a computational system can be of value in the support of human activities. It is not unreasonable to expect the system to be treated as an active participant in human routines so long as its inherent limitations are clearly understood. For example, how might the system help suggest John’s whereabouts in instance 3?

However, it might be more appropriate to think of the system as more akin an ethnographer than a participant. Participants have an *egocentric* view of other’s routines because knowing another’s routines is a practical matter, it is a resource and only needs to be adequate for the participant’s purposes. It is in this sense specific and partial as the purpose is not a passing abstract and general interest. For a system to “get it right” implies major challenges in access to and use of contextual information that are likely to be beyond what it is reasonable to expect. The accounts of the kind an ethnographer gives are more like the basis that might be appropriate for a system to embody – they are likely to contain a better articulation of the home’s routines than a participant will be able to produce easily, and by so

doing leave the more subtle issues of how this should be used in a particular situation to the human participant.

## **Conclusion**

We have demonstrated how lessons that challenge and can help develop the Ubiquitous Computing agenda in the direction of technologies being ‘invisible in use’ can be drawn from studying the domestic environment. In particular, acknowledging the subtleties of the often complex, yet unremarkable, details that surround our everyday routines places powerful requirements on any technology that might become embedded in such activities. We have demonstrated that social scientists can provide examples which help reveal what ‘invisible in use’ might mean. The move from this to design is clearly still a major challenge, but there are intriguing possibilities that ethnographically based accounts in this area might not only help clarify concepts, inspire design, or suggest requirements, but might be of value as part of the resulting system.

## Acknowledgements

Particular thanks are due to Jon O'Brien, latterly of XRCE and now of PA Consultancy, and Graham Button, Director of XRCE, both of whom contributed to the ideas we have worked up here in a number of discussions. We also acknowledge the support of the European project MIME.

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## **Cooperative Design of Communication Support for and With Families in Stockholm:**

Communication Maps, Communication Probes and Low-tech Prototypes

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**Abstract.** In this paper we describe how the work in the InterLiving project (“Designing Interactive, Intergenerational Interfaces for Living Together”) has started with families as design partners and we report some early experience. The project has its point of departure in “the user end” by letting the families themselves describe how communication comes into their living together by drawing communication maps and using communication probes.

**Keywords.** Co-operative design, intergenerational communication, family, design partner, design, communication probe, communication map, low-tech prototyping.

Paper presented at The 1<sup>st</sup> Equator IRC *Workshop on Ubiquitous Computing in Domestic Environments*, The School of Computer Science and Information Technology, The University of Nottingham, 13-14<sup>th</sup> September 2001. <http://www.equator.ac.uk/>

## **Introduction**

The most successful technologies are rarely the catchy ones that appear as short clips in the evening news; they are more often the subtle ones that people find they cannot live without. Talking cars have come and gone, but post-it notes are here to stay. Our goal in the InterLiving project is to develop artefacts that disappear into the fabric of everyday life; that are taken for granted, but are essential. Of course, such technologies are more difficult to evaluate, so we must also develop new ways of understanding their importance. Rather than developing technology on our own and presenting it to end-users in focus groups or laboratory settings, we will design new artefacts together with families and evaluate them *in vivo*, through long-term studies.

Thus, InterLiving wants to offer an alternative to today's technology-push and work-centred development of new computer artefacts. Rather than emphasizing productivity, InterLiving is about connections among human beings. We begin with real people, with complex family lives, and seek to understand how to integrate new technology in subtle, non-obvious ways.

New technologies often come at a cost. The much-appreciated car phone that lets you call to say you will be late picking up the children because of a traffic jam becomes a nuisance when it rings during dinner. Technology makes it too easy to place a higher value on strangers at a distance than family members in the same room. While useful, even essential at times, the telephone is an intrusive technology that disrupts as well as enhances daily life. In contrast, we hope InterLiving technologies will be less obtrusive and merge seamlessly into daily life.

## **Families as design partners**

We believe that co-operative design is critical throughout the design and development of all technologies and that the family members recruited for the InterLiving project should be treated as design partners, not subjects in an experiment. Our research team has extensive experience in partnering with users, both with professionals, as in (Bødker *et. al.* 1987; Sundblad and Tollmar 1995; Mackay *et. al.* 2000) and with children, as in (Druin 1999; Benford *et al.* 2000; Alborzi *et al.* 2000). See also Bødker *et al.* (2000). In the EU Future Emerging Technologies

(FET) research planning there is a strong awareness of the importance and value in bringing in end users as design and development partners (see Wejchert 2001). We expect the approach of working with families, as design partners, will provide a unique opportunity to explore and reinterpret new technologies in the context of their use. We are especially interested in emergent innovations and will encourage family members to reflect on their use-in-context throughout the co-design phase of the project.

#### THE INTERLIVING PROJECT

InterLiving is a cooperative project between researchers from different scientific disciplines; ethnology, psychology, industrial design and computer science, and six families, three in Sweden and three in France. InterLiving is coordinated by CID (Centre for User Oriented IT-Design) at KTH (the Royal Institute of Technology) in Stockholm, Sweden. Partners are INRIA (Institut Nationale de Recherche en Informatique et Automatique) in Paris, LRI (Laboratoire de Recherche en Informatique Université de Paris-Sud) and HCIL (the Human-Computer Interaction Lab) at the University of Maryland. InterLiving is funded for three years from 2001 by the EU IST FET research initiative “The Disappearing Computer”.

#### AESTHETICS

It is not only a matter of understanding what the artefacts the families are willing to place in their different homes should do and how they should work. We need to get the whole picture, which includes the products’ appearance and expression.

We surround us or not with all kinds of things. There are certainly practical reasons but we also have more subtle, symbolic reasons for doing so.” (Nippert-Eng 1996)

We need to be able to design the artefacts in such a way that the families will accept to have them in their homes. This can of course include all kinds of aspects like status, exclusiveness, etc. The results could even involve “invisible” design, where the technology is hidden. Since we only have to consider the situation when the artefact is in the home we can focus on the

“needs and desires” that the families express. We do not have to consider other aspects such as marketing, branding, manufacturing, distribution, disposal, recycling and price.

### **Finding and selecting three families in Sweden**

In February we advertised in Metro, a free morning tabloid that is available on all public transportations in Stockholm, and which claims to be read by around 500,000 people. It was a small advertisement with short information, including expectations of at least three generations and a three-year involvement. Around 40 people responded to the ad, most of them by phone. They asked questions about “rules” of commitment and also explained why they were interested in participating. We sent them all a letter with a more detailed description of the InterLiving project. Those that still were interested after reading the letter were asked to fill in a form with names, ages and addresses of the persons in the families willing to participate in the project. We got seven responses to select from. All the households included in the family must live reasonably near Stockholm to make it possible for us to serve the technology that we need to install in their homes later in the project.

The research group made a few more criteria for the participating families: We also wanted the three families to differ as much as possible from each other concerning ages, computer habits and geographical spreading, since different surroundings requires different communication practices. The three families that were chosen were distributed in ten different households. We are well aware of that this choice is not a selection of average Swedish families! It is more a choice of motivated and open-minded people that are willing to spend time working together with their family members and us.

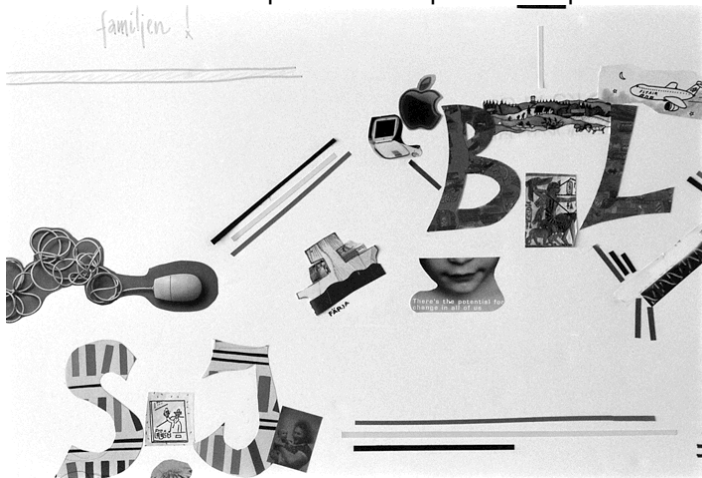
### **The first meeting**

One Saturday in March, 2001, we gathered the families at CID’s project agora for a rather informal meeting. We presented ourselves, the InterLiving project and other on-going research at CID. The families made a brief presentation of themselves. Their ages varies from nine months to 73 years in totally 10 households. We also handed out and described communication probes, described below, one probe for each household.

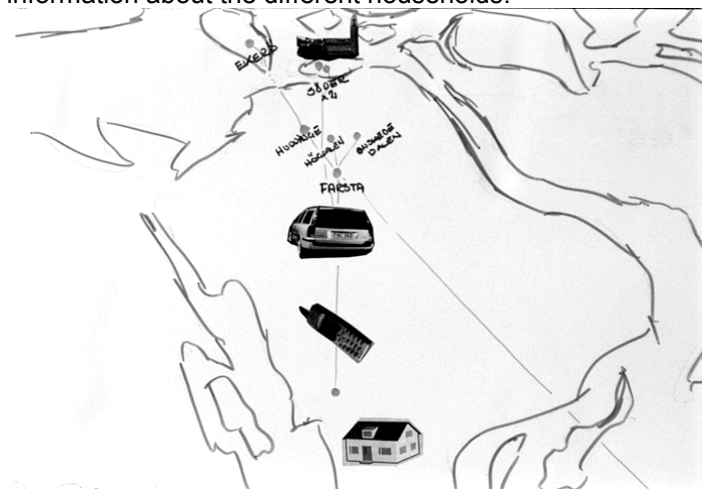




**Figure 2.** The father in the family above is often on travels. The contact is then kept with the help of mobile phone.



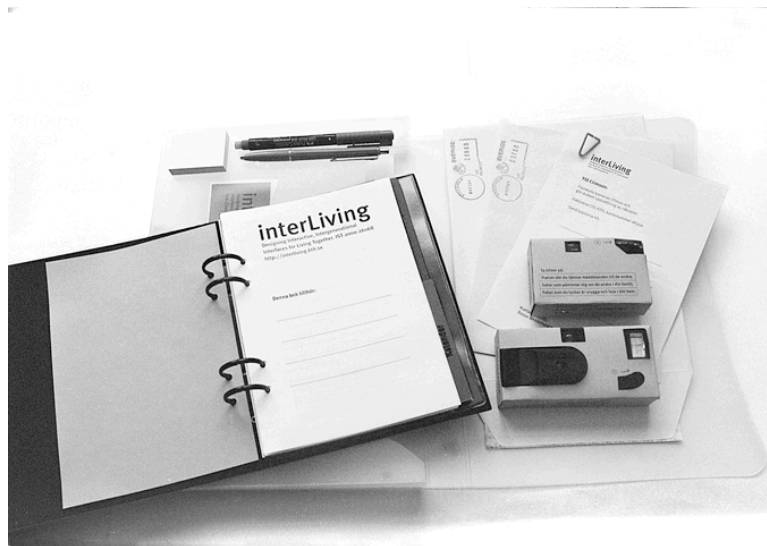
**Figure 3.** This communication map illustrates specific information about the different households.



**Figure 4.** This communication map emphasises locations and events.

## Communication probe (cultural probe)

The basic idea is that the families themselves describe their communication through the probe. A Cultural Probe is a package with different material “designed to provoke inspirational responses.” “Like astronomic or surgical probes, they are left behind and hopefully return fragmented data over time” (after Gaver *et al.* 1999). The kit, “communication probe”, that we gave each household contained a few items that we hoped would help the families give us researchers a good understanding of their communication. The material in our kit was chosen and produced so that the contents would have an integrated appearance. See Figure 5.



**Figure 5.** The material in the communication probes was chosen and produced so that the contents would have an integrated appearance. The binder contained the Communication Diary, the Note Book as well as some information about the project.

The families were given five weeks to enter information into the different probes and return them to us. Each kit included:

- A Communication Diary where the families should write down all their contacts during two weeks; one “ordinary” week and one holiday week. The idea behind this was to receive more data because of the supposed different pattern of communication during an ordinary week and a holiday.
- The pages in the diary were plain white without any headings or divisions. We did not want so restrict or press the families into filling any predefined space.

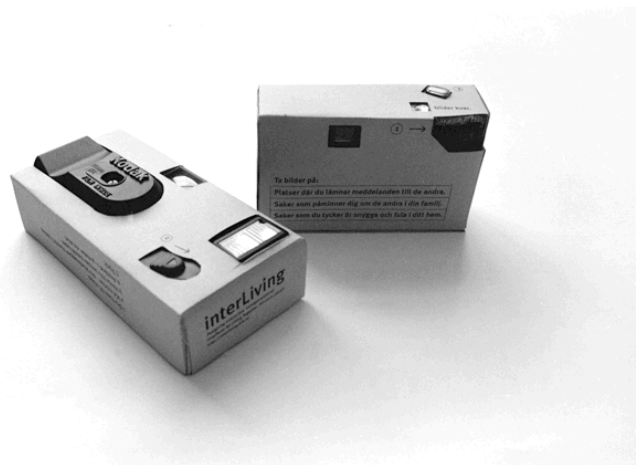
- A Note Book where they could write freely about contacts, appearance and the project. These pages were also plain white papers.
- A Binder where the Communication Diary and the Note Book were placed. In the binder we also put all the instructions, dates, contact information and the ethics statement. At the end there was also a plastic pocket, encouraging the people to even put small artefacts or other “stuff” to expand the notes.
- Two Disposable Cameras with instructions to take photos of:
  - Places where you leave messages to the others.
  - Things that remind you of the others in your family.
  - Things that you find neat in your home (or ugly).
- A pen, one permanent marker to make comments on the photos.
- An addressed envelopes with prepaid postage for development of the photographs (two copies) and sending commented photos and the other material to the researchers.

### ***Comments***

We decided to give each household just one type of camera for the three different tasks, instead of one for every task. The important part is when they get the photos back and write their comments on them with help of the questions. They are several people that will take pictures and it is better if the cameras get used up quickly so they will get the photos back quickly, which also makes it easier to remember who took the photo and why.



**Figure 6.** The folder that all the communication probes were delivered in.



**Figure 7.** The cameras had the three questions printed directly on them.

#### FOLLOW-UP VISITS TO THE FAMILIES

After a couple of weeks we visited each household for approximately an hour to answer new questions that had arisen since the first joint meeting. We also had a look around, so that we could put the probe photos into their context. It was also necessary for us to have an idea of what the family members meant when they wrote e.g. “home” or “in the kitchen” in their diaries and notebooks.

#### PROBES RETURNED

A month after the first meeting with the families the data from the probes started to arrive at CID. We studied the information and reflected upon the similarities and differences. This resulted in a set of questions that we thought would be interesting to ask all the households.

#### *Comments*

The probe method seems to have made the family members very aware of their different communications over time. It helped them to reflect and put words on some of their needs and ideas. Of course we know that nothing is objectively neat or ugly. But we consider design and expression as part of functionality and by asking such a basal question we hope to start a process where the family members reflect on artefacts’ appearance and character.

## Interviews

The households were visited a second time for interviews. These lasted about one hour and were videotaped. The data from the probes was used in the interviews as well as questions.

## ANALYSIS

The videos from the interviews were analysed and an eight minute long summary video was assembled. The video was to be used for giving all the households some common ground at the second workshop. Short video cuts from the interviews were sorted under different themes:

- ❑ Privacy / Reachability
- ❑ Blackboard / Calendar
- ❑ Play / Games / Music ...
- ❑ Help with homework / Company
- ❑ Expression / Characters



**Figure 8.** The second Swedish family workshop at CID's project agora.

## Second Workshop

The second workshop with the Swedish families took place at CID's project agora in mid June. The workshop was divided into three basic steps:

- ❑ Use scenarios, where the focus was on problem description.
- ❑ Brainstorming to generate ideas for solutions

- Finally the families developed one idea each further and produced simple low-tech prototype artefacts accompanied with design scenarios.

## USE SCENARIOS

The families got twenty minutes to formulate scenarios where colloquial situations illustrate how the family communicates and how things can go wrong and/or there is room to improve the communication. We stressed that they should be specific, describe something that is real to them and not try to generalize.

### *Comments*

All of the families came up with very interesting stories, rooted in their everyday life. The general theme was about misunderstandings due to incorrect assumptions about what others know. Children assume that what is told to one parent automatically also is known by the other. Parents assume that children can determine the degree of urgency of a phone call. An example is “See you as usual”: Grandfather had agreed with grandmother that he would pick her up by boat. He said: “See you as usual”, thinking of a certain landing stage. But she thought he meant another landing stage 100 meters away. It took an hour and much irritation and worry before they found each other.

All in all seven different use scenarios were presented. The results produced were great, just the sort of colloquial situations we think are good as starting points for the future work. The scenarios told by the families provide a very promising design material. They were detailed, founded in the patterns of everyday life. They were also clearly influenced by the families’ new awareness around communication issues, as a result from previous project activities. Within the scenario format the participants also expressed the emotional charge in the events accounted for: the frustration, longing and pleasure that underline communication activities.



Figure 9. One of the use scenarios was drawn in a storyboard manner.

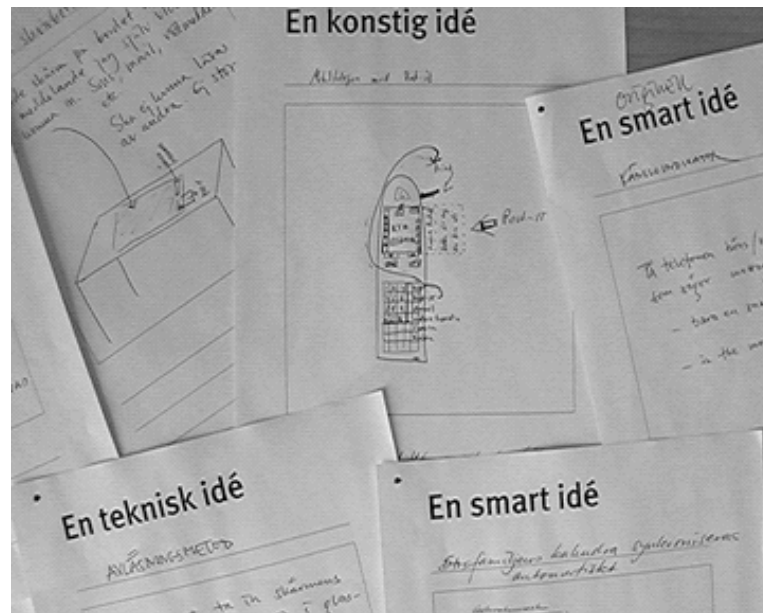
## GENERATION OF IDEAS

The families were then asked to generate ideas for solutions (“things”) with connection to one of the scenarios above. Guidance for the exercise was: fast, many ideas, do not reject anything. They had thirty minutes for this phase. As a help the families got printed forms where ideas could be filled in fast, in text and/or pictures. Seven different forms for seven different types of ideas:

- A cheap idea
- An original idea
- A strange idea
- A smart idea
- A funny idea
- A technical idea

## Comments

We prepared the forms in order to clarify the scope of this exercise both in matter of quantity (each family was given a pile of idea sheets) and quality. The labels helped to point out that no idea should be dismissed at this stage and to broaden the spectrum of solutions. The forms were also an invitation to playfulness, and we introduced them with a nonsensical example of a new innovation: the birthday cake fax machine. The forms were helpful, especially for the children that received a format for idea generation, which they could complete without adult assistance. The nutty labels also helped saving some ideas from an early dismissal as being “too boring”. On the other hand, for some of the participants the idea flow was stopped as they felt forced by the labelling on the forms to categorise finished ideas.



**Figure 10.** The ready labelled sheets of paper that were used for generating ideas.

## DESIGN SCENARIOS / LOW-TECH PROTOTYPES

In the next step the families were asked to choose one of the ideas (things) and continue with them in three different ways:

- Scenario: How the new thing will be used
- Prototype: Simple shape of the thing that can be used when presenting the scenario.
- Image-board: A collage with pictures and newspaper clips etcetera, that gives a feeling of the aesthetic qualities imagined: colour, expression, material etc.

For this part of the workshop the families worked for one hour.



Figure 11. Looking for pictures in magazines.

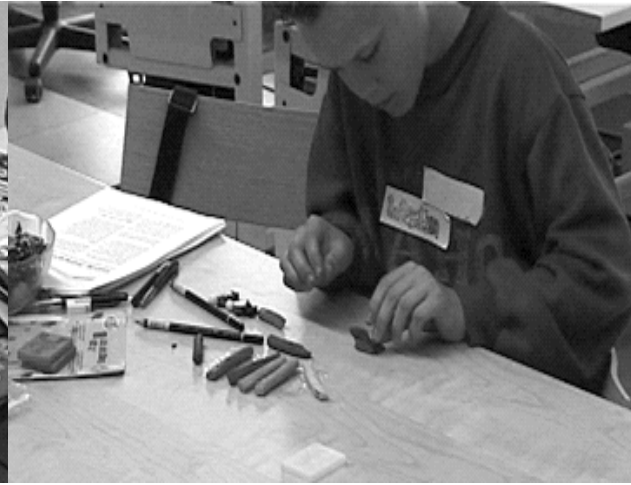


Figure 12. Building a prototype in clay.

### Comments

Four concepts were accounted for by the families. The results were well thought out and clearly developed from the ideas. Three of the proposals have substantial common parts, which indicate interesting paths to investigate. No group described their ideas also with the aid of an image-board (collage), probably because of lack of time and of lack of examples from us how it could look. All projects were described with the aid of simple and clear prototypes. See Figures 11-16.

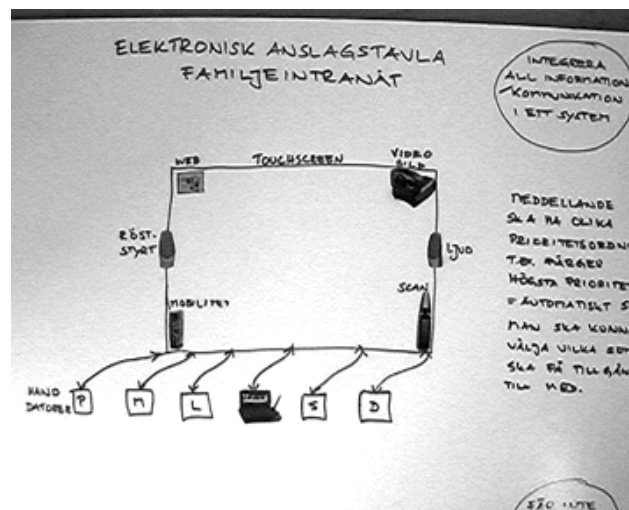


Figure 13. One illustration clearly showing how the proposed system should work.





**Figure 16.** A low-tech prototype used in the design scenarios above.

## Observations

The families have already produced a great deal of data during these first months that will be thoroughly analysed and used as input for upcoming workshops and other activities. The results from the workshop described above seem to more point to problems than solutions. We realise that we have to “dig further” in future workshops and other activities. We have experienced, again, that users show great inventiveness when given the opportunity to think and reflect over their needs in everyday situations. The three different and very fruitful aspects in the communication maps from the three families came with (and because of) the lack of more detailed guidance. The low-tech prototype design session produced interesting ideas. The family activities to support can be described with four C:s: Communication, Collaboration, Co-ordination, Company. Most of the ideas that came up as low-tech prototypes fall into the category Co-ordination and Communication, but we could observe ideas of Company type, mainly from the younger and older family members, that were not pursued because of the “power structure” in the families. All through the second workshop, participants kept working within their family group.

The four design concepts were presented: three of them coming “collectively” from the three families, the fourth one being presented by one of the children. The three collective

concepts all focused on co-ordination and communication, whereas the fourth concept focused on evasion (being able to fax oneself to another place). This highlights a fundamental question in working with families: How does the dynamics of the family structure influence on the proposals of the participants? What differences are there between collective proposals made by one family group, and individual proposals, or ideas developed by a cross-section of one type of family members (mothers, children, grand-parents)? These are questions that we will pursue in upcoming workshops. Thus it is important in the future work to divide the families into age / role groups for performance of idea and design sessions. Very important in the co-operative design practice is to have the researchers / developers involved as partners on equal footing with the users in the design groups. This involvement could and should be stronger than in the work with the families so far.

### **Future activities**

InterLiving is a three year project of which the activities here described only represent the first half year at one of the sites. The intention is to further deepen the understanding of communication patterns and needs within and between households in the families and gradually design and bring in supporting technology with the families as partners. Thus the activities described above are the first steps of work in progress. The next step will be a workshop in September where the families will be divided into age / family role groups forming design teams together with researchers. Elaboration and analysis of the previous results as well as first ideas of supporting technology will be discussed and developed. In parallel similar activities are conducted in Paris with the three French families. InterLiving researchers from France, Sweden and USA participate in all workshops collecting and exchanging experience. More long-term, supporting technology will be co-operatively designed and developed together with the families. The aim is that one result from InterLiving will be technology that supports intergenerational family communication, not just used as a transient new gadget, but used long-term as it fulfils real needs. The other main result will be better understanding of communication within and between intergenerational households in families.

## Acknowledgements

This work would not be possible without continuous discussions with our InterLiving project partners in Stockholm, Malmö (Interactive Institute/Narrativity studio), Paris and Maryland, i.e. Michel Beaudouin-Lafon, Ben Bederson, Hilary Browne, Allison Druin, Björn Eiderbäck, Åsa Harvard, Paul Ladeveze, Wendy Mackay, Catherine Plaisant, Guillaume Pothier and Helena Tobiasson. We also completely depend on, and are very grateful for, the enthusiasm and willingness to offer time and effort by our family partners in the Greater Stockholm area. The EU research grant for the InterLiving project, 2001-2003, is gratefully acknowledged.

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## End-User Programming in the Networked Home

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**Abstract.** Pervasive networking of domestic appliances provides a wealth of possibilities. Some of these possibilities will be anticipated by developers, but many will be novel and unexpected. Hence, the provision of end-user programming adds significant utility to a networked home. The work described investigates the design of end-user programming systems for a diverse user population, in the context of the Cambridge AutoHAN project.

**Keywords.** End-user programming, networked home, ubiquitous computing, tangible interfaces.

Paper presented at The 1<sup>st</sup> Equator IRC *Workshop on Ubiquitous Computing in Domestic Environments*, The School of Computer Science and Information Technology, The University of Nottingham, 13-14<sup>th</sup> September 2001. <http://www.equator.ac.uk/>

## **Introduction**

Computers have become increasingly integrated into everyday life. This is most evident in an office environment, where the paraphernalia conventionally associated with computers - keyboards, monitors and mice - pervade the environment. However, it is also true, although less obvious, in many other environments, with the advent of increased automation of a wide variety of tasks. Bar code readers, speed cameras and mobile phones all contain significant computing power. The home environment is particularly rich in terms of computation; a typical home may have dozens of devices, each with its own microprocessor. In most cases, all but the most sophisticated devices communicate with each other in only the most perfunctory way. Integrating these disparate devices to provide a coherent computing environment is an interesting research problem, encompassing many aspects; networking, high-reliability computing, security and human-computer interaction. This work investigates aspects of the latter area, in particular the possibilities for end-user programming in such an environment.

Historically, the users of computers were programmers. As the field developed, ready-made applications became increasingly common, and the need for users to program decreased. This trend continued, spurred on by developments in user interface technology such as the mouse (Engelbart and English 1968), direct manipulation (Sutherland 1963), and the desktop metaphor, giving rise to the current situation where the vast majority of computer users use nothing but ready-made applications and have no knowledge of programming. The users of an application are referred to as “end users”, to distinguish them from the application developers, or users who have direct contact with, and possibly influence over, those developers.

While this has undeniably given a far wider range of people access to computing facilities, and resulted in computers being used in application areas as diverse as desktop publishing and air traffic control, it has also served to limit the flexibility with which those computing facilities may be used. End user applications are, by and large, generic, and users apply these applications to their specific problems. This “leaves personal computer users in an ironic situation,” where they are performing repetitive actions to apply the generic application to the task at hand, despite the truism that “computers are good at performing repetitive activities” (Cypher 1993). Without access to end user programming, the only solution is to request

additional features more applicable to your problem, or, more commonly, to await the release of the next version of the application in the hope that it will contain such features.

The size and diversity of the end-user population can only increase with the advent of “ubiquitous computing”, where computers become an invisible, integral part of the environment, much as electric motors did during the early twentieth century (Weiser 1991). While much research in ubiquitous computing has been centered in the business arena, both in and out of the office, another important area of research is ubiquitous computing in the home. A basic tenet of this area is that domestic devices are augmented with a network interface, allowing them to communicate with, and be controlled by, other devices. The key difference between this situation and other ubiquitous computing projects is the population of users. While a business will almost invariably employ a trained professional to set up and maintain any computing system, a home network may be set up by an unskilled user, and day to day maintenance will almost certainly be carried out by such users. There is a similar disparity within the end user population. While the users of a business computing system tend to have at least some computer-related experience, have completed at least some formal education, and are capable of making abstractions. Conversely, in a home environment, none of these factors may be assumed. This presents an interesting human-computer interaction challenge.

Much of the current research effort in home automation is directed toward finding appropriate network technologies. In many systems, specialized network technologies are used for certain purposes, such as mobile use or multimedia. In this case, the problem of integrating disparate network technologies must be addressed.

As has been noted previously, the users of a home automation network cannot be assumed to have any computing background or training. Therefore, many home automation projects aim to provide a network with the ability to configure itself automatically. In particular, when a device is (physically) added to the network, it must be automatically detected, and the system’s model of the network updated accordingly. This involves both registering the device’s presence, and determining the functionality that the device provides. The latter is generally achieved in one of two ways. The majority of systems export a description of the devices interface, which provides sufficient information for other devices on the network to contact the

device and cause it to perform operations. This is the approach taken by, among others, the Universal Plug and Play standard.<sup>1</sup> Another approach is for the device to make fragments of executable code available. Other devices can then download and execute this code in order to access functionality. This is the approach taken by Sun's JINI architecture;<sup>2</sup> unsurprisingly, the code transmitted takes the form of Java objects.

### **End-user programming**

Office environments are the most common target for end-user programming systems. As with any design task, it is essential to define the population for which the design is intended. We have already described end users as users who do not necessarily possess any programming knowledge or experience; (Nardi 1993) offers an important addition to this definition:

End users are not "casual," "novice," or "naive" users; they are people such as chemists, librarians, teachers, architects, and accountants, who have computational needs and want to make serious use of computers, but who are not interested in becoming professional programmers.

This makes two important points. Firstly, while end users do not possess computing knowledge, they may well possess a high degree of knowledge in their particular domain, be it history, economics or medicine. Secondly, these users do not *want* to acquire computing knowledge in and of itself - they are busy being historians, economists and doctors. Hence, the problem of end-user programming is that of making the power and flexibility of programming accessible with as little effort as possible on the part of the user.

Many attempts to solve this problem take the form of improved interaction techniques, which purport to render the question of programming irrelevant. One common example is natural language systems; why, it is argued, would people want to program, when they can simply state their intentions in natural language? In this scenario, the computer would act as an assistant. Nardi argue that this vision is misleading, chiefly because the *programmer* is still

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<sup>1</sup> Universal Plug and Play device architecture: [http://www.upnp.org/download/UPnPDA10\\_20000613.htm](http://www.upnp.org/download/UPnPDA10_20000613.htm)

<sup>2</sup> Jini technology architectural overview: <http://www.sun.com/jini/whitepapers/architecture.html>

providing the assistant's functionality. She argues that advances in interaction techniques do not obviate the need for programming, and proposes that end user programming solutions should focus on task-specific languages and environments, and take into account working practice and other sociological factors, in addition to exploiting advanced interaction techniques.

### **Programming by demonstration**

A common theme of both Programming By Demonstration and Visual Programming systems is to give a concrete representation of each concept in the programming environment. As Finzer and Gould (1993) put it:

Everything in the Rehearsal World is visible; there are no abstractions and only things that can be seen can be manipulated. Almost all of the designer's interactions with the Rehearsal World are through selection (with the mouse) of some performer [Smalltalk object] or of some cue [Smalltalk message] to a performer.

This is not to say that all state is visible to the eventual user of the script. The system discussed above includes an area known as the "wings"; objects placed in this area are visible to the designers, but not to the end users of the script.

Programming by example systems are distinguished from the simple macro systems present in many applications by the capability to *generalise*. A simple macro facility will allow the user a simple mechanism to repeat a sequence of actions exactly, without taking into account variations in context. More advanced macro facilities, such as those found in Microsoft Office (1997), allow the user to edit a generated macro to make it applicable in a range of contexts, but this still requires them to manipulate a traditional, textual programming language (in this case, Visual Basic).

In contrast, programming by example systems may generalise programs. One approach is to infer the required generalisation using artificial intelligence techniques. This method is attractive as it requires no effort on the part of the user, but is difficult to achieve in practice, and is best suited for systems dealing with limited problem domains. In particular, it is vital to include some way of rejecting incorrect inferences. Maulsby and Witten (1993) describe a

system, Metamouse, which uses AI techniques combined with user intervention. The tradeoffs associated with different degrees of intelligence in programming by example systems are addressed by Myers and McDaniel (2000).

```
Title:
/Nfs/buntingford/usr19/rgh22/work/docs/phd/toontalk.eps
Creator:
GIMP PostScript file plugin V 1.06 by Peter Kirchgessner
Preview:
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with a preview included in it.
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This EPS picture will print to a
PostScript printer, but not to
other types of printers.
```

**Figure 1.** ToonTalk (from Kahn 2000)

Another approach is to allow the user to indicate the way in which a program may be generalised. ToonTalk (Kahn 2000) is based on a “concurrent constraint programming language”, broadly similar to the logic programming language Prolog. The system is designed to appeal to school-age children, and to this end it is presented as a cartoon-like video game, with various components of the interface represented as animated characters (see Figure 1). Objects such as numbers and characters may be manipulated directly. To program, the user places a “robot” into the workspace, and tells it to watch while the user performs actions some input via direct manipulation. Once this training is complete, the robot will perform the specified actions whenever it sees objects identical to the original input. The user may watch the robot carry out the individual steps, to check that it is performing as expected, or instruct the robot to “fast forward” and only show the end result.

The system as described so far is equivalent to the simple macro recorders mentioned above. Its power is due to the simple yet expressive method of generalisation. It is possible to modify a robot to act on a wider class of inputs by removing concrete values from the “pattern” of recognised inputs, creating “wildcards” that may take any value. Facilities are also provided for conditionals, abstraction, encapsulation and communication, all presented in the

same cartoon-like way. Together, they allow children as young as five to create simple programs, while older children can create moderately complicated programs such as games.

ToonTalk programs, unsurprisingly, tend to be highly graphical, and make use of animation - the tool was designed to make the creation of such programs as easy as possible. However, for problems that do not have a strong graphical element, or require complex data structures, ToonTalk can become unwieldy. The pervasive use of metaphor, while arguably well suited for a pedagogical tool, would need to be examined carefully before being transferred to another application domain.

### **Visual programming**

A *visual language* is described in Marriot *et al.* (1998) as “a set of diagrams which are valid *sentences* in that language, where a diagram is a collection of *symbols* in a two or three dimensional space”. This is reminiscent of Chomsky’s definition of (spoken and textual) language as a set of valid *strings* of symbols. Hence, the key distinction drawn between visual and textual languages is that textual languages are linear (sequential, one-dimensional), whereas their visual counterparts are expressed in a two- or three-dimensional medium. Visual Programming (VP) systems use visual as opposed to textual languages to express programs.

Blackwell (1996) surveys and categorises the perceived benefits (termed *metacognitive theories*) of VP, and notes a “remarkable consistency of metacognitive concerns amongst VP researchers”. The theories identified are based in many areas, including introspection by researchers, cognitive theory and folk psychology. While VP is not, as is sometimes claimed, a panacea that is better in all respects to conventional programming methods, there is nevertheless convincing evidence that VP is beneficial in certain specific ways.

VP systems are often based around direct manipulation, a technique more commonly associated with activities not traditionally thought of as programming. The main characteristics of direct manipulation are (to paraphrase Schneiderman 1983) continuous representation of the objects of interest, “physical” actions, rapid incremental reversible operations whose impact is immediately visible, and a layered or spiral approach to learning that permits usage with minimal knowledge. Consequently, many of the lessons learnt in the

design of direct-manipulation based Graphical User Interfaces (GUIs) may be profitably applied to VP.

A common technique employed in GUI design is metaphor; the system is made to mimic another, real-world, system. The advantage of a metaphor is to allow users to “learn by analogy”. However, an inappropriate metaphor, in addition to hampering learning by analogy, may cause users to make incorrect assumptions about the system. Furthermore, in some cases, a visual analogy may not provide significant benefits to comprehension (Blackwell and Green 1999).

In general, the application areas in which VP has been used most successfully are those where the problem in question has a large visual/spatial component, a notable example being GUI design. Integrated Development Environments (IDEs) are now used almost universally for this task. These systems combine a textual programming environment with visual tools to define the layouts of GUI components. While early systems limited the user to specifying simple, absolute layouts, modern systems are considerably more flexible, allowing users to specify complex relationships between layout parameters in a visual manner.

### **End-user programming in the networked home**

While many research projects deal with *home automation*, few have considered end-user programming. As an example, the automated home environment created by Microsoft’s Easy Living research group includes a rule engine to allow the environment to act on sensor information; however, defining new rules involves writing or modifying a C program (Brummit 1999). A common view is that ubiquitous computing will obviate the need for programming; as mentioned earlier, this is at best a point of contention.

As mentioned above, it is imperative to form a clear picture of the intended users of any end-user programming system. In the case of an end-user programming system for an automated home, the users are the occupants of the home. This is a very wide group, encompassing a wide range of ages, occupations and levels of education. At first sight, it would appear that there are few, if any, useful generalisations that may be made about such a diverse population. However, closer inspections reveals important commonalities. In

particular, a user wishing to automate the control of a device *may be assumed to understand how to control that device directly*. This means that end-user programming languages for the home may profitably be built upon the basis of direct manipulation, such as the ToonTalk system mentioned above.

### **Graspable user interfaces**

There is a growing body of research into designing physical objects to allow improved human-computer interaction. Such physical objects, or props, have numerous advantages over virtual objects. They are familiar to users, and provide rich affordances in a way that the user is already comfortable with. Physical objects are also subject to physical constraints. This is advantageous, in terms of communicating valid actions to the user, but limits the flexibility of props compared to virtual constructs. For example, the contents of a real folder is limited by size, and placing one folder inside another is problematic at best. These problems are not an issue with virtual folders in desktop computing systems. Similarly, while virtual objects may be modified instantly, in any way imaginable, physical objects are limited in this respect by their mechanical capabilities.

The Tangible Media group at MIT have produced a number of demonstration systems exploring the possibilities using physical and virtual objects in conjunction, within everyday architectural spaces (Ishii and Ullmer 1997). The group is interested in both props for user manipulation, and the exploitation of “ambient media” such as airflow and background noise as a continuous data channel that users may monitor passively.

Rekimoto *et al.* (2001) describe one of these systems, in which physical tokens (DataTiles) are combined with a display for virtual objects in an effort to offer the advantages of physical objects while retaining some of the flexibility of virtual ones. Transparent tiles are placed within a tray incorporating a display and sensors to determine which tiles are where. The virtual portion of the tile may then be shown behind the physical tile, on the appropriate section of the display. This allows the tiles to be used as “graspable windows for digital information”

This technique may be used to combine high-resolution (printed) but static data, such as a map, with low-resolution dynamic data, such as the current location of objects. It may also be used to afford certain physical actions. The paper gives the example of a rotational control, that combines a circular groove acting as a guide for a stylus with an appropriate graphical component to allow an angle, which may be mapped to a value, to be entered. Simple aggregate effects may be achieved by placing tiles next to one another, but this area is as yet under-explored and offers much scope for further work.

### **AutoHAN infrastructure**

The AutoHAN project (Saif *et al.* 2001) is an ongoing project in the Computer Laboratory, working on technologies to enable a pervasive, self-configuring network in a home context. It provides a solid foundation to support a home network architecture, including support for user interaction devices. IP is used as the basis of the network architecture, allowing heterogeneous link-layer technologies to be employed. The technologies currently include Warren (Greaves 1997), a variety of ATM designed to allow simple end-point devices, and Ethernet. TCP and UDP are used as transport protocols.

Title:  
(AutoHAN.eps)  
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other types of printers.

**Figure 1.**The AutoHAN architecture

At the application level, communication is performed over several higher-level protocols. Chief among these is HTTP. At present, HTTP/1.0 is used in most applications, as this provides sufficient flexibility without the complexity of HTTP/1.1, which requires the

implementation of a large set of relatively complex features. HTTP/1.0 is a request/response protocol using the message format described in IETF RFC 822. This allows request and responses to have a *type* or *method*, describing the type of request or response, a set of arbitrary *name/value pairs*, and a *body* containing arbitrary data. Conventionally, HTTP methods `<SMALL>GET</SMALL>` and `<SMALL>POST</SMALL>` are used to retrieve documents from and send queries to a web server. These methods are used in AutoHAN to query and update DHAN, an XML based registry.

SOAP is a Remote Procedure Call protocol based around HTTP, using an extended set of methods. Objects that provide a SOAP interface necessarily run a server to listen for, and reply to, requests. GENA is a complementary HTTP-based protocol for eventing. Applications run a server, and then subscribe to certain classes of event by sending an appropriate request, containing the URL of their server to a Subscription Arbiter (SA). The SA then sends a request to the application whenever an appropriate event occurs. Both SOAP and GENA are used extensively in the Universal Plug and Play architecture, and are described in that specification.

XML is widely used as a data presentation format in AutoHAN.<sup>3</sup> Devices are described in XML, as are the payloads of SOAP and GENA messages. XML was chosen as it is flexible, portable and human readable, and, most importantly it may be extended to accommodate future changes in the data's structure.

To enable further research to utilise this infrastructure, the appropriate high-level protocols (notably GENA and HTTP) have been implemented in several languages. As may be inferred from the above descriptions, this involves supporting the implementation of both clients and servers. C++ and Java interfaces have been created and used extensively. The object-oriented scripting language Python (see van Rossum) may also be employed, as it has an extensive standard library that includes HTTP servers and clients and an XML parser. The language has proved to be useful for rapid development, but it lacks the runtime efficiency for some applications.

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<sup>3</sup> Extensible Markup Language (XML) 1.0 (second edition): <http://www.w3.org/TR/REC-xml>

Other members of the AutoHAN group are working on developing a general-purpose language, Iota, which has many features useful in developing AutoHAN software. It is a statically-typed impure functional language, similar to ML (Milner *et al.* 1997), with sophisticated fine-grain concurrency primitives based on the *Pi* calculus (Milner 1999). A major feature of the language is that XML data is a primitive datatype, with rich syntactic support, particularly pattern matching. In addition, Iota is intended to be used with a standard library tailored to a specific application domain. The initial version of the language, Iota.HAN, includes a library to support the development of AutoHAN infrastructure and applications, providing capabilities such as HTTP. Iota.HAN is primarily intended for use by device manufacturers in order to create AutoHAN applications to ship with consumer devices. However, it is sufficiently general to be useful in implementing AutoHAN infrastructure components. The design process of the Iota language is discussed in (Blackwell and Hague 2001).

## Media cubes

The part of the project being discussed here deals with designing a novel user interface that will enable end users to control networked devices, both directly and indirectly (automation/programming). The current approach centres on novel interaction devices dubbed Media Cubes, as shown in Figure 3.

```
Title:
/Nfs/buntingford/usr19/rgh22/work/docs/phd/oldcubes.eps
Creator:
GIMP PostScript file plugin V 1.06 by Peter Kirchgessner
Preview:
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with a preview included in it.
Comment:
This EPS picture will print to a
PostScript printer, but not to
other types of printers.
```

**Figure 1.** Prototype media cubes

The Media Cubes provide a concrete representation of abstract concepts; for example, a cube could represent the concept of reaction (“Do X when event Y happens”). This representational capacity also helps the user manipulate devices that are not physically present, such as devices in other rooms. Similarly, in the networked home, some devices may have no “front panel” user interface, or may be implemented as software objects. The Media Cubes are designed to provide an suitable tool for users to work with such devices. They may also be used as a physical representation of media streams or content, as in (Ullmer *et al.* 1998) and (Lamming *et al.* 2000).

Media Cubes are introduced to users as simplified remote controls, in the sense that, while familiar remote controls offer many functions for a single device, a Media Cube offers a small number of functions, but may be used to control any device. Once the user is comfortable with using the cubes in this way, the concept of placing cubes together and using them in combination is introduced, allowing the user to abstract functions over time and space. This provides a means for the user to progress smoothly from direct manipulation to programming.

Figure 3 shows the current prototypes of the media cubes, designed by Alan Blackwell and Daniel Gordon. Each cube has the following external features:

- A single tri-colour LED, mounted on the topmost face, allowing limited feedback regarding the state of the Media Cube.
- A single button, also mounted on the topmost face.
- An IR transmitter and receiver, providing two-way communication with a networked base station.
- Four coils, mounted on the vertical faces of the Media Cube. The coils are used to detect the proximity of other Media Cubes (see below).

Each cube contains a small microprocessor. This pulses each coil around sixteen times a second, and monitors the current through each coil when it is not being pulsed. If another cube is adjacent to the coil being pulsed, a current is induced in the corresponding coil of the second cube, and detected by its microprocessor. In this way, each cube can calculate the set of faces that are adjacent to other cubes. This information is relayed to an infrared base station, where it

is translated into a GENA event, and hence may be acted upon by software components in the AutoHAN architecture

Each cube has a hard-coded, unique ID; the cubes are identical in all other respects. A software layer maps meanings onto individual cubes. The cubes are labeled to indicate this meaning to the user. In some cases, the meanings of certain faces or cubes may change as they are used - in this case, re-writable labels are provided.

A piece of software known as the Cubes Proxy keeps track of the status of the cubes, and holds the representation the constructs created, via the cubes, in the Media Cubes language (see below). Like many AutoHAN software components, the Cubes Proxy communicates with the network at large solely via GENA events, meaning that it may be run on any machine with an IP connection to the network.

The Cubes Proxy subscribes to events from one or more base stations, and hence receives events corresponding to each of the transmissions from the cubes via HTTP. These events are then decoded to determine which cubes are interacting, and which of their faces are adjacent. Each individual cube is associated with a proxy, i.e. a software representation, via its ID. These representations are used to determine the semantic meaning of the particular interaction at hand, which may:

- ❑ Change the state of the Cubes Proxy, for example by defining a new script or changing the value of a cube.
- ❑ Cause one or more GENA events to be broadcast, allowing the cubes to control other software components and devices.<sup>4</sup>

Currently, the Cubes Proxy is written in C++, and runs on a Linux PC. Each physical cube recognised by the system has a corresponding C++ object, associated by the unique ID of the cube. The object is an instance of some class that implemented the “CubeProxy” interface, which defines methods to handle events where a button is pressed, and where the cube has been placed next to another. When an event is decoded, it is passed to the appropriate proxy object, along with the proxy object for the other cube in the latter case. As any class that

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<sup>4</sup> Of course, a single interaction may do both.

implements the appropriate interface may be used as a proxy for a physical cube, additional behaviours may be readily added to the system.

When used in combination, the **Media Cubes** constitute a medium in which a program may be expressed. Our aim is to construct a language that may be effectively used by end users to express home automation programs, or scripts, in that medium.

Currently, a minimal demonstration language has been implemented. This language is built on three types of cube; an *event cube*, which has a GENA event associated with each face, a *timer cube*, which has a delay (10 seconds, one minute, etc...) associated with each face, and a *contingency cube*, which has two active faces, labelled “Do...” and “When...”.

The event cube may be used as a direct manipulation device. The faces are viewed as an ordered sequence, and pressing the button on the cube causes the next event in the sequence to occur. For example, if the faces of the cube are associated with the events “Connect CD Player”, “Connect Radio Tuner”, “Connect DVD Audio”, and “Connect TV Audio”, pressing the button repeatedly would allow the user to cycle through the various audio sources. When used in combination with the other two cubes, very simple abstractions may be constructed. First, an event from the event cube is associated with the “Do...” face of the contingency cube by placing the appropriate faces together and pressing the buttons on the cubes. A delay is similarly associated with the “When...” face. Then, after the specified delay, the specified event occurs.

### **Future work**

The existing demo system may be profitably improved with a small amount of effort. Currently, contingencies only function correctly with delay events. A minor modification would allow events to be contingent on any other event, allowing programs such as “mute the audio when the phone rings” to be constructed. Also, the current system has only rudimentary type checking, which allows incorrect programs to be constructed. Again, minor modifications to the system would allow the integration of a more advanced type system. With these additions, the system will be more than sufficient to support the research into **Media Cubes** languages described below.

While working with the AutoHAN system, it has become apparent that the use of a full system, including hardware, is problematic, and much time is spent on maintaining this system at the expense of more productive work. To alleviate these problems, a number of software simulations of real devices will be developed. These will communicate via the standard GENA architecture, and hence a system developed with the virtual devices should communicate with physical devices with little or no modification. Virtual devices also have the advantage that they may be created and modified as required, allowing a variety of network configurations to be used. Simulations may also be created for devices that have not yet been implemented, allowing a far broader range of tasks to be addressed by users during testing.

#### A MEDIA CUBES LANGUAGE

Using the work mentioned previously as a basis, a language based around the Media Cubes will be designed. We are currently considering two alternative programming paradigms for this language (Blackwell and Hague 2001); the cubes can either be taken to be analogous to words in a spoken or written language (linguistic abstraction), or they can be taken to be representations of elements in the users world model (ontological abstraction).

The ontological paradigm associates cubes with “natural categories” in the user’s mental model of the system, and the faces of those cubes represent interpretations or interactions of those categories. For example, an Event cube represents a change in system state, such as a doorbell ringing, and supports interpretations such as “on” and “off”. Similarly, a Channel cube represents a media stream and has interpretations to support routing of the channel as desired. The intention is that, by providing users with a set of tokens that represent familiar or “sensible” ontological categories, the language provides support for reasoning about the abstract concepts involved.

The linguistic paradigm is similar to object-oriented textual and visual languages. Cubes have associated data, and have faces that allow access to and modification of this data. An example would be a cloning cube; this cube would have a face labelled “clone” that, when placed next to some face of another cube, stores the value of that face. Another face of the cube may then be used as if it were the cloned face of the second cube. An extension of this

cube would be a collection cube, which would allow a single cube face to take on the properties of multiple faces drawn from other cubes. For this to be practical, a type system may be necessary in order to ensure that cube faces are not combined in a nonsensical way.

An important feature common to both paradigms is the ability to associate a cube with a physical device, simply by placing a face of the cube adjacent to a sensor on the device. This allows physical objects to be referred to directly, reducing the level of abstraction necessary to construct programs.

Two initial language designs will be produced, one for each of these paradigms. These will then be implemented within the framework already created. The prototypes will then be tested on users, and the results of these tests will be used to produce a second version of the language. This revised language will be based on one of the possible paradigms, but is likely to include ideas from both initial prototypes. An orthogonal question that will also be addressed during the user testing stage is the degree of computational flexibility required by the language; specifically, is it necessary for the language to be Turing powerful? While current domestic device interfaces are not, it may be the case that it is beneficial for a more general interface to be. Conversely, a computationally complete language may prove confusing or otherwise inappropriate for this application area. A related issue is that of the provision of higher-order functions, which can fit into either paradigm.

## MULTIPLE END-USER PROGRAMMING LANGUAGES

In addition to the tactile language developed with the Media Cubes, other approaches to end-user programming in the home and other ubiquitous computing situations will be investigated. While the Media Cubes provide a rich input medium, their output capabilities are severely limited. In addition, the number of physical cubes available limits the vocabulary of the Media Cubes language. To overcome these limitations, a visual language for use with conventional displays such as televisions will be developed. One use of this language will be to view programs created via the Media Cubes, while another use may be to modify existing programs. The latter use will require some form of input. While a mouse may be used, pen or touchscreen input would seem to be more appropriate given the application area - this suggests a device

similar to the WebPads that are currently coming to market. A keyboard is unlikely to be readily available, so textual input should be made optional or avoided altogether. It is important to note that, while a visual programming language overcomes the stated limitations of the Media Cubes language, it does not possess some of the advantages of that language, such as the smooth transition from direct manipulation. The two languages are complementary.

Other types of media may be explored. Video-based systems, such as the In/Out board and BrightBoard described in Stafford-Fraser (1997) may be appropriate for certain areas of the home. These systems offer an unobtrusive input medium with a minimal hardware infrastructure, but must be carefully designed to ensure robustness. Locations-based systems such as those developed by the AT&T Sentient Computing project offer another possibility for a pervasive medium for programming in a home network. It is possible that several of the media may be fruitfully combined.

While Iota is being developed to enable software engineers to easily create AutoHAN applications, it may be profitable to consider an alternative textual language designed for a less skilled group of users. This language would be used to “plumb together” AutoHAN components in a home network. It is expected that this task would be performed either by a confident end user, or a technician brought in to install a device, much as today an electrician may be called in to install a wall socket by someone who is not confident doing the job themselves. In either case, it is not necessarily true that the end-user will have the degree of computer science knowledge required to fully understand a concurrent, statically typed functional language. A more accessible language would fill a similar niche to scripting languages such as Perl (Wall *et al.* 1996) in conventional system administration, in that ad-hoc solutions to problems may be produced quickly and easily. Like Perl, the language will not be designed for the implementation of large-scale or general applications, and is unlikely to be the best choice for such tasks.

## A FRAMEWORK FOR MULTI-LANGUAGE SYSTEMS

The previous section details a number of languages designed to allow end-users to program their home network. These languages each have different, but complementary, features. Hence, substantial gains may be made by allowing the languages to interoperate. A language-neutral representation will be developed, and used as the basis of the language implementations. Unlike portable executable formats such as Java bytecode, this representation should allow high-level source code to be generated. This will allow a program to be created in one language, and modified in another - a valuable capability when the preferred method of creating programs, e.g. the Media Cubes, does not provide a convenient interface for program modification. Ideally, systems languages such as Iota would be integrated into the framework, to allow seamless integration between provided applications and end-user programs. A significant problem to be addressed is that of translation between disparate languages with different paradigms a problem that has proved difficult in the past. For example, Microsoft's .NET architecture allows tight integration between a variety of languages, but requires all languages to fit into an object-oriented structure, at least where they interact with code in other languages.

XML may be used for the language representation. This would allow individual language implementations to leverage the large body of tools, libraries and knowledge regarding XML processing. In addition, presentation of the program may use technologies such as Cascading Style Sheets,<sup>5</sup> or XSLT,<sup>6</sup> to present the program in a conventional web browser. The latter technology may be used to transform one XML document into another in an arbitrary way. It would be straightforward to transform a program into SVG,<sup>7</sup> and XML based vector graphics format, allowing for easy and flexible graphical presentation.

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<sup>5</sup> Cascading style sheets level 2 specification: <http://www.w3.org/TR/CSS2/> .

<sup>6</sup> XSL Transformations (XSLT) version 1.0: <http://www.w3.org/TR/xslt>

<sup>7</sup> Scalable vector graphics (SVG) 1.0 specification: <http://www.w3.org/TR/SVG>

An execution engine for the language-neutral format would allow programs developed in any supported language to be executed. This engine would handle issues such as event subscription and reception, and handle received events according to the appropriate stored program. The programs would be submitted over the network by editors or proxies that implement specific language interfaces. Programs may also be retrieved for display or modification. HTTP offers an appropriate interface for submitting new programs and retrieving stored programs, but may not be suitable for modification of stored programs. The engine may be integrated with a general AutoHAN policy enforcement mechanism, allowing scripts created by different users, or in different circumstances, to have an appropriate level of access to the system. This would prevent, for example, a child creating a script that circumvented a spending restriction for pay-per-view TV, or anyone from creating a script that muted the burglar alarm.

Pervasive networking of domestic appliances provides a wealth of possibilities. Developers will anticipate some of these possibilities, but many will be novel and unexpected. Hence, the provision of end-user programming adds significant utility to a networked home. The AutoHAN project aims to provide a consistent framework in which everyone may be able to set up and use a home network in a convenient and accessible way.

## Acknowledgements

The AutoHAN project is led by David Greaves. Rob Hague is sponsored by AT&T Laboratories – Cambridge Ltd. Alan Blackwell’s research is funded by the Engineering and Physical Sciences Research Council under EPSRC grant GR/M16924 “New paradigms for visual interaction”.

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## Design and Digital Care

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**Abstract.** This paper is primarily about design and some of the difficulties of “appropriate” design in care settings. This is hardly a novel concern but this particular focus arises as a consequence of digital technologies maturing and transferring to the everyday domain. Domestic environments are becoming key sites for the consumption of information and communication technologies, embracing in the “care” domain various forms of “assistive” technologies and the design and provision of “smart” homes. This paper reports on the Equator IRC “Care in the Digital Community” project – a multidisciplinary research programme concerned with the development of enabling technologies to assist care in the community for particular user groups with different support needs. The general aim is to examine how digital technology can be used to support sheltered housing residents and their staff.

**Keywords.** Care in the community, ethnography, cooperative design.

Paper presented at The 1<sup>st</sup> Equator IRC *Workshop on Ubiquitous Computing in Domestic Environments*, The School of Computer Science and Information Technology, The University of Nottingham, 13-14<sup>th</sup> September 2001. <http://www.equator.ac.uk/>

The proper study of mankind has been said to be man. But I have argued that man - or at least the intellectual component of man - may be relatively simple, that most of the complexity of his behaviour may be drawn from man's environment, from man's search for good designs. If I have made my case, then we can conclude that, in large part, the proper study of mankind is the science of design. (Simon 1969)

## **Introduction**

This paper is primarily about design and some of the difficulties of 'appropriate' design in care settings: about the interaction between technologies, application domains, design methodologies and about some of the challenges of informing design. This is hardly a novel concern but this particular focus arises as a consequence of digital technologies maturing and transferring to the everyday domain; as the convergence of interactive digital systems, networks and mobile devices potentially transforms the ways that we carry out mundane, everyday activities. In recent years the increasing presence of computing technology in the domestic environment has emerged as an important new arena of study. Domestic environments are becoming key sites for the consumption of information and communication technologies - embracing, in the 'care' domain, various forms of 'assistive' technologies and the design and provision of 'smart' homes. This paper reports on a recently initiated research project - 'Care in the Digital Community' - begun under the EPSRC IRC Network project EQUATOR. The project aims to use a multidisciplinary research team to facilitate the development of enabling technologies to assist care in the community for particular user groups with different support needs. The general aim is to examine how digital technology can be used to support sheltered housing residents and their staff. Although only recently started the project anticipates exploring the affordances of a variety of technological configurations including the use of virtual environments replicating real world situations and the use of handheld and wearable digital technology to provide support.

## **Design and methodological challenges**

Much of the work in the care domain has been technology rather than 'needs' led - indeed gaining a comprehensive understanding of needs or a perspicuous view on user requirements in this domain poses a number of interesting methodological challenges. It is not just that

many of the important ethical and deployment issues concerning the development and evaluation of real systems remain unexplored, but that methods for eliciting needs in such a complex setting are relatively under-developed. The extent to which the relatively well tried and tested ideas and methods used to understand work environments can be transposed to investigation of domestic environments is an open question. Domestic environments in general and ‘care’ settings in particular are very different spaces from working environments and represent a very different set of challenges for those involved in the design of systems. This paper therefore considers some of the implications of the methodological options open to those working in the domestic domain, in particular, the translation of research into design recommendations and the attempt to uncover, elicit or validate ‘requirements’. Moving away from technology led applications and attempting to have a useful input into the development process requires an understanding of how technologies and their uses are integrated in a range of social contexts. The problem is that research in certain contexts is often regarded as difficult if not inappropriate. The deeply personal nature of many social activities limits just what can be investigated and reporting the interactional elements in a range of activities and contexts is difficult. Ethnographic studies claim to provide a ‘sensitising’ to the ‘real world’, ‘real time’ character and context of everyday life and the facilitation of what Anderson (1994) calls ‘the play of possibilities for design’. Much of our understanding of designing computer systems has been the product of ethnographic investigation of the workplace and we require significant shifts in our investigative techniques as well as in our understanding of design, to consider how technology relates to and supports everyday living rather than productivity.

These and other delicate issues represent potentially obdurate problems and methodological responses have taken a number of forms. At present the project research method for technology development includes ethnographic study, user-centred design and evaluation and the use of ‘cultural probes’. ‘Cultural Probes’ (Gaver *et al.* 1999), originating in the traditions of artist–designers rather than science and engineering are a way of supplementing ethnographic investigations, prompting responses to users emotional, aesthetic, and social values and habits as well as providing an engaging and effective way to open a dialogue with users.

Thus we were after “inspirational data” with the probes, to stimulate our imaginations rather than define a set of problems. We weren’t trying to reach an objective view of ... needs through the probes, but instead a more impressionistic account of their beliefs and desires, their aesthetic preferences and cultural concerns. (ibid.)

The eclectic approach adopted by this project attempts to meet some of the ethical and moral dilemmas through careful involvement and acknowledgement of users in the design process. ‘Process’ here encapsulates rather more than the requirements elicitation stage to include deployment, use and evaluation. It therefore incorporates possibilities for ‘innofusion’ (where getting devices to work in particular user settings produces useful innovations) and ‘domestication’ (the integration of a device into everyday practice) (Fleck 1987; Williams *et al.* 2000). In amongst the technical challenges, central to the project and the technology development effort are issues concerning generalisability, the transfer of skills to real world situations, and support for independent living in the community. This challenge highlights some of the moral and ethical components of the design enterprise, in particular the need to carefully think through and balance issues of ‘empowerment’ and ‘dependence’. The design challenge is to provide support for individuals in the move towards independent living, rather than create new, technological, forms of dependence. It involves an ethical awareness and recognition of the way that technology can impinge on individual care pathways and a sensitivity towards the implications of any such intervention. It further involves a recognition and understanding that the project, and any associated technical development, takes place within a particular political and moral framework (of deinstitutionalisation) and inevitably becomes embroiled in the various social science debates that surround this issue. Of particular relevance is the notion that ‘de-institutionalisation’ has been constituted through moral-ethical discourses about places, about good and bad places - about moral landscapes (Dear and Wolch 1987). The challenge for design in these settings therefore, is not just to recognise this dilemma but to steer a careful path through this moral minefield. Embodying a philosophy of care into design necessitates considering issues of empowerment and dependence and then thinking how these might usefully become incorporated into design guidelines.

### **Background and setting: hostel and semi-independent living**

The setting for the project is a hostel and nearby and associated semi-independent living accommodation (see Figure 1 below), managed by a charitable trust, for former psychiatric patients in a large Northern town. The hostel is the first step for patients leaving the psychiatric wards of local hospitals the hospital environment. Here they are provided with a room and are monitored and helped to develop independent living skills by a number of staff. Residents can then move on to the other, semi-independent living site, which is sheltered housing consisting of a number of flats and bed-sits, prior to moving out to flats in the local area, or, if they are deemed to need further and continuing support, back to the hostel. The overall aim of these facilities is to gradually introduce the patients back into the community and allow them to support themselves. Emphasis is on the learning of daily living routine and skills and any technology introduced should contribute to this goal. A technology that merely completes a task for residents does little in producing independence but merely shifts reliance onto the technology.



**Figure 1.** Semi-independent living accommodation

### **Supporting various forms of awareness: security and medication**

Although our research is at an early stage, a number of issues/requirements have already arisen. Initial introductory and debriefing meetings at the hostel and the semi-independent living accommodation and the early ethnographic fieldwork (Hughes *et al.* 1994) currently indicate some major preoccupations of both residents and care workers - all of which centre on supporting various forms of 'awareness'. Firstly, there is an absolutely overwhelming preoccupation with security. Situated on what is acknowledged to be a 'difficult' council housing estate both residents and staff have been subjected to frequent physical and verbal attacks. A number of meetings to address this issue have been held with the local community and the police and four CCTV cameras and nine foot iron railings have been installed to protect the semi-independent living accommodation. The house is also protected by burglar alarms and an entry control system. Paradoxically, these now mark out the residents as being somehow 'different' and make them the natural and unfortunate victims of ill-informed, media induced, moral panics about 'paedophiles' or 'community care'. Attacks and verbal abuse by children has resulted in the gates being locked at four o'clock each day and some residents will only travel outside the accommodation by taxi and residents are increasingly cut-off from the outside community.



**Figure 2.** The need for security: common sites of attack

The main locations for the attacks are the road between the hostel and the semi-independent living accommodation and the park next to the accommodation which is used either as the quickest way into town or to avoid the abuse and attacks associated with the other route (see below). In these circumstances a security/monitoring system that would allow staff to monitor residents travelling between sites in order to increase the sense of safety, reduce anxiety and reassure residents. Such a system may also contribute to greater community awareness amongst both residents and staff.

In order to encourage residents to feel safer while traveling between sites we are investigating the potential for issuing personal panic alarms. When activated such alarms would alert staff as to the identity and location of the person in distress. The alarm needs to be lightweight (possibly wearable) and should not have any significant commercial value because of fears of encouraging theft and possible assaults. In addition, the device needs to be highly dependable both in terms of location accuracy and the ability to communicate the distress call in a timely manner. In order to respect residents' rights to privacy, their location will not be tracked constantly, instead their location will only be communicated when the alarm is activated. In terms of location sensing, one approach that might be suitable in the future would be to use a system such as E-OTD. However, this solution is not currently viable because the modifications required to the base station infrastructure are not yet in place. The approach that we are currently considering is to deploy a device that incorporates a GPS receiver and transmits the user's current coordinates via a GSM connection whenever the alarm button is pressed. We have considered using SMS as the transport for sending the GPS information, however, we discounted this approach because of its lack of dependability. In more detail, SMS traffic is only sent when the network is under a low loading and so if the GSM network happened to be under a high loading at the time, then the successful transmission of the panic call could be delayed by a significant period of time.

One of the most significant benefits of the proposed panic alarm device is that it need not be incorporated into a mobile phone and consequently is less likely to be perceived as worth stealing. The potential drawback of this device is that in certain areas of the town the so called 'canyon effect' could prevent a GPS fix from being obtained. However, tests in the area

between the two sites revealed that the view of satellites by the GPS receiver is very good. However, if residents did wander into an area where a GPS fix could not be obtained then this would clearly present a real problem. For these reasons, we are designing the unit in order to provide its user with simple but immediate feedback if there is any problem with obtaining a location fix and/or communicating the distress call.

A second concern of both residents and staff focuses on issues surrounding the routine taking of daily medication. At the initial project meetings a number of residents expressed their concerns about the possible consequences of them forgetting to take their medication. In both informal interviews and via the postcards issued as part of the 'cultural probes' residents expressed an almost overwhelming interest and concern with issues of medication, its importance, availability and effectiveness. Medication issues - dosage, delivery of 'medi-pacs', reminders, re-assuring residents about delivery and so on also feature heavily in the everyday work of the staff. At the hostel medication is kept in a locked drug cabinet, distributed by the staff when required with records kept in a written log. At the semi-independent living site patients must manage their own medication and it is a source of continuing anxiety for the residents. Although provided with a week's supply of packaged daily doses by the pharmacy - 'medi-pacs' - there is some concern that they may either forget to take their medication or accidentally overdose. Technical devices that may prove useful in these circumstances are various medication reminders that help patients manage their own medication, i.e. when to take it, record acknowledgements of reminders and so on allied with a system to automate the recording of drug information. The functionality of any technology provided must be carefully considered and sensitively deployed. The devices are intended to act as 'reminders' to residents to take their medication and are not indicators that any medication has been taken and obviously such devices must be dependable as failure of the technology could have potentially disastrous consequences.

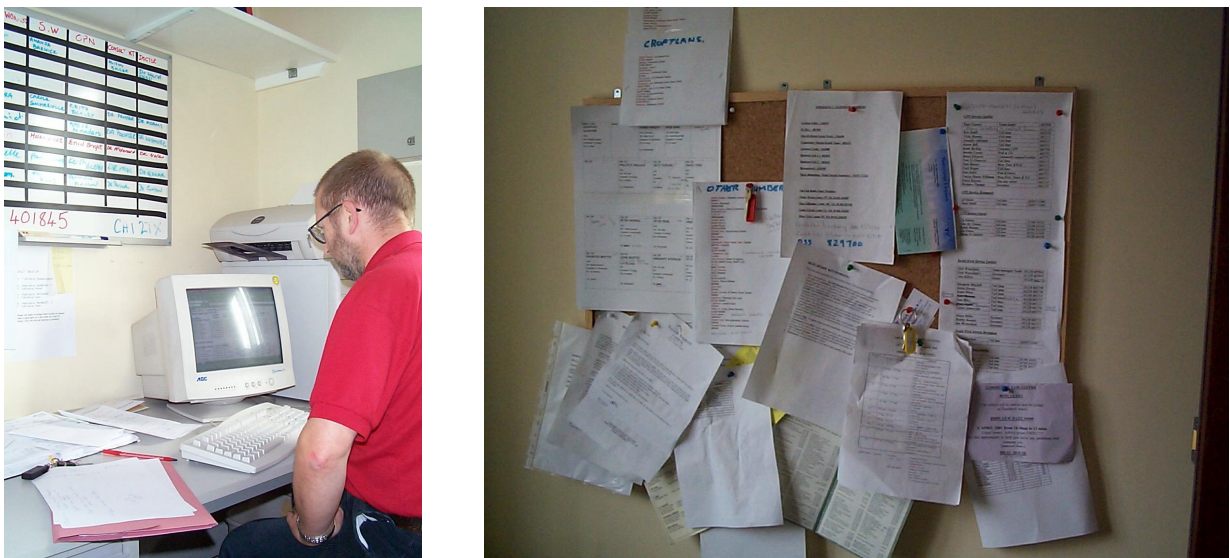
Where residents are responsible for taking their own medication, this fact has significant implications for the way in which medication is monitored and tracked. For example, the use of a bar-code scanning approach would place an inappropriate burden on the resident. One possible approach is to use RFID-based smart labels in order to ascertain whether a resident

has taken their medication from the medication store - as used in the Magic Medicine Cabinet system (Wan 1999). Another possibility worth exploring is to build certain reminder and recording features into the 'medi-pacs' themselves. Again, this will not control the medication regime to prevent deliberate overdosing, but it may contribute to the prevention of accidental overdosing. Some instances from the early fieldwork - coincidentally occurring on the same day - illustrate this point. In one case the care worker, following a phone call from the resident's doctor was concerned to intercept the delivery of a 'medi-pacs' in order to replace one dosage of tablets with another. In another incident there was some concern that an elderly resident was accidentally overdosing as a consequence of the design and delivery system for the 'medi-pacs'. As the 'medi-pacs' are delivered from the pharmacy at about 6:30pm the resident was required to take only the evening dose for that day, leaving the two earlier doses to be taken the next week. Problems were arising both because the resident, used to emptying each daily dose, was accidentally overdosing by taking all the medication for the delivery day, but also was being left with no morning or afternoon medication for the same day on the following week.

The 'medipack' used by the residents at the Botcherby site is a blue vinyl folder with seven plastic containers each with four compartments. Each container is used to hold a day's medication and the whole pack is issued to the residents every week with medication for the next seven days. Our interest is in how to augment the medipack in order to aid the residents' management of their medication. Any device must help the residents manage their own medication rather than managing it for them. The main problem is establishing the dosage and timing of any medication. Such a device may also offer a level of reassurance to residents, by providing indications that they are following their medication regime correctly. As the residents rarely carry the containers or pack with them, and are rarely away from the Botcherby site for lengthy periods of time, the device is not required to be mobile, and any device constructed can be installed in a resident's flat. Size of the device is therefore not a constraint. However, the device must hold a weeks supply of drugs and it would be useful to make it simple to restock. Within these constraints a prototype device is currently under discussion. This would consist of a 'lightbox' frame, into which a transparent box with internal

compartments could be placed. The base of the frame would contain LEDs to indicate the correct dosage for the time of day. It may also be useful to construct the frame with sensors to that would allow the controlling software to monitor when a dose has been removed.

One final issue about control of medication arose when one of the residents deliberately overdosed by taking all the medication in the newly delivered ‘medi-pac’. This incident highlighted other issues to do with medication and the recording of, access to and integration of information as the care worker sought to give information on the resident and the medication regime to the ambulance service. Such information has four possible locations, a whiteboard that has details of each resident, their key worker, consultant, social worker and community psychiatric nurse; a noticeboard that details who is living in each flat or bedsit; the computer and the filing cabinet that contains the resident’s records (see below). Ways of integrating, up-dating and displaying this information are currently being investigated.



**Figure 3.** Medi-pac information: distributed awareness and coordination

### **Summary and concluding remarks**

This paper has sought to identify and address some of the challenges faced when trying to meet the requirements of the ‘real life, real time’ concerns of community care. The driving aim of our project is to explore the extent to which the requirements of a community care trust can

be met by technology whilst staying within the political and ethical boundaries imposed by the given application domain. Over the coming months we will be deploying the chosen solutions within the trust itself. This deployment process will itself raise a whole series of important and necessary issues including tailorability, mobility, and the trade-off between generic and specific devices. Following deployment a period of evaluation will commence which (in addition to raising further issues) will no doubt lead to refinements in our initial set of requirements and therefore modifications to our adopted approach as an aspect of cooperative design. Users need the opportunity to explore fully the possibilities for adopting, and adapting to the new technologies. As assistive technologies are developed and penetrate more and more into this domain, the real problem becomes not so much the creation of devices as their effective integration with the everyday demands of the particular setting and 'design in use' becomes achievable.

## Acknowledgements

This work is funded by the UK Engineering and Physical Sciences Research Council, EQUATOR and Dependability (DIRC) Interdisciplinary Research Collaborations. We particularly acknowledge the support of the Croftlands Charitable Trust. This is a revised version of a paper given at the EDRA conference, Edinburgh 2001.

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physical and technological space of the situation (Venkatesh *et al.* 2000) and as a collection contribute significantly to the systems requirements (Imaz and Benyon 1999).

## REPRESENTATIONS OF FUTURE DEVICES

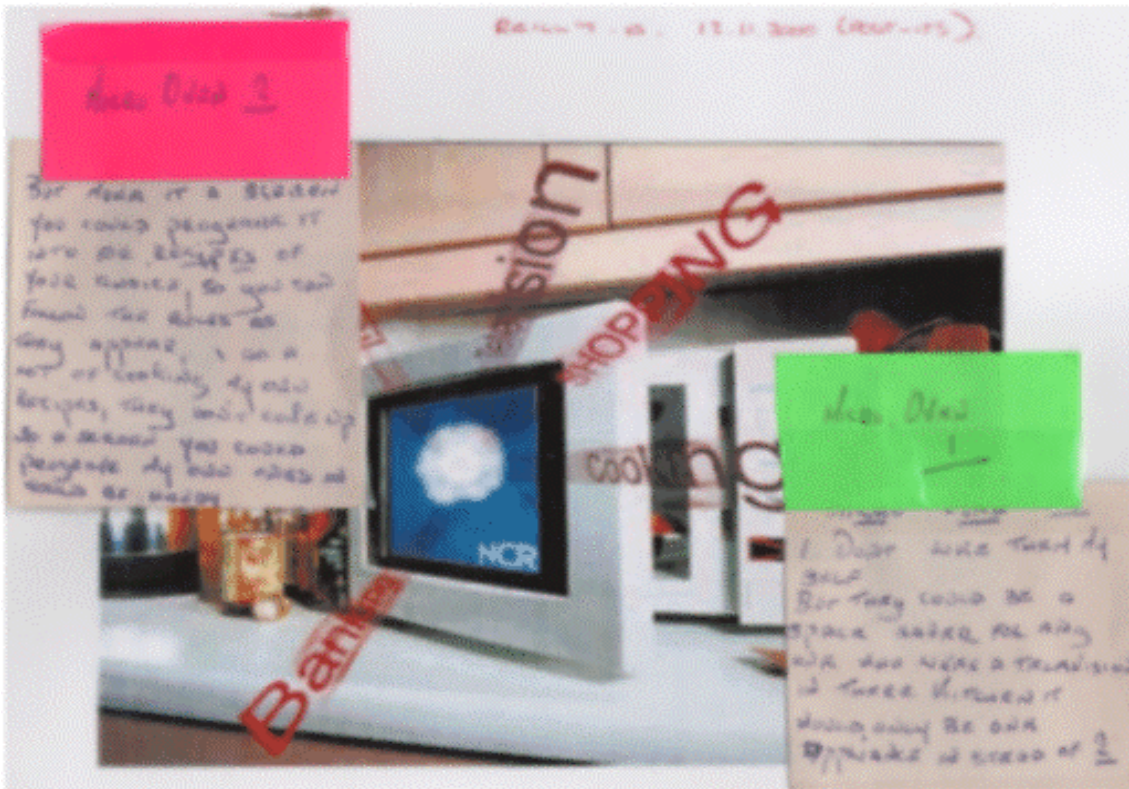
After the technology tour, people were given pictures of a number of emerging technologies; things such as the fridge that 'knows' when it is out of milk, the microwave with e-mail and so on. The researcher then discussed with the families how they make use of the technology, how it might constrain or liberate them and so on. Through the technology tour and the discussion on emerging technologies, ideas often arose for new devices that the members of the families would be interested in having. Some were happy to take one of the examples shown and elaborate on the idea. Others, who did not want any of the examples, were asked to materialise their suggestions in the form of preliminary paper prototype. For example, one woman wanted an automatic food record system which would contain: what food she had in her kitchen, suggestions of recipes for what she had in the kitchen and a general recipe book. But whether they designed their own or selected one of the examples of future devices or services, they were asked to leave the representation in the households, and live with it, until the next workshop.

## POST-IT NOTES

Researchers in the past have experimented with limited success with short questionnaires as a way of gaining insights into interesting cases of technology use in between visits and with getting people to video themselves when the researcher was absent (Kraut *et al.* 1998). Neither of these had proved successful and yet it was important to capture data between visits. It was decided to leave some blank post-its with the participants, encouraging them to write any comments on the post-its and stick them onto an existing device or their newly envisioned device. When the researcher returned for the next workshop session, some of the participants had been moving the mock up device around their house. For instance, some people had recorded the extra facilities they would like from the device on post-its, others had annotated

the picture of the device itself. This provided an effective method of gathering people's reactions to devices when *they* felt ready, and not when the researcher was ready.

For example Reilly, a computer literate eighty-year-old woman, had attached notes to a picture of a microwave oven that included a TV screen (Figure 1). Subsequently she re-designed the device as something she would have in her living room which had TV, e-mail DVD, internet and so on, on it, touch screen and voice activation.



**Figure1.** Post-its (Agnes Reilly).

## SCENARIOS

In the second session, after discussion about the post-its, the families were invited to imagine how they would go about an activity based on a scenario of some people arriving for a meal. This scenario had been generated by the researchers with the aim of getting people to think about future devices and services that could help them with such a situation. Unfortunately, this produced little useful data as far as requirements for devices were concerned; the researcher had imposed too many assumed concerns onto the users. The scenario *concept* was

useful and the families started to develop their own, based on their own interests. It was the *particular* scenario – that failed to ground activities within their context — that was the problem.

## DESIGN

The participants were asked to develop a design solution in the form of a paper prototype. The participants were asked to either design a solution to a current problem or to envision a new device that would be of benefit to them in their home. Some of the older participants were hesitant about drawing their own device therefore in one instance one of the research team drew the device as it was dictated to them by one of the participants, all the other participants managed to draw their own devices. The only problem that arose during this session was that some of the participants felt that their ideas weren't good enough. The researcher reassured them that their ideas were good enough.

## **Workshop 1&2: Emerging themes**

In this section we discuss issues raised by the participants during the workshops which we felt were of particular relevance to ubiquitous computing. These themes arose in some ways accidentally, that is to say, the researcher was not concentrating on ubiquitous computing per se. Our focus for the workshops was based more around the concept of single technologies in the home. However, people were asked for their ideas and opinions and from their comments three main themes emerged: smart homes, control of physical space, and control of social space.

## SMART HOMES

When talking to the families about 'smart homes' the idea provoked favourable images. Many of the families felt that these homes would be especially good for the disabled or more senior citizens. Two small excerpts from the workshops are given below:

Peter: There wont be lines outside or inside (he is talking about wireless technology).

Researcher: Well this is what they are talking about for the home, wireless technology, everything will be mobile.

Emily: A picture will just hang in the air. They have had it on Tomorrows World (television programme)

Researcher: Yes, h::m would you like that, wireless technology I mean?

Emily: Of course ((she is smiling broadly and Peter is nodding his head in agreement))

Another participant said he would like a smart home to do the following:

Mike: Run the lighting in the home, run the bath, do other household tasks, heating and such like, run a bath for you and take the temperature of the bath (he is smiling broadly and points at the walls, floor, and ceiling of the room)).

It can be seen from the above that the participants seemed to welcome the concept of ubiquitous and digital homes. However some of the families felt that if everyone had a ‘smart home’ it may make people lazy as they would have everything done for them.

#### CONTROL OF THE PHYSICAL SPACE

Three of the families in the study owned their own homes and had modeled them and added to them over time to suit there lifestyles (see table two). However, two families lived in local authority housing were the control of the home and its fixtures and fittings belong to the local authority. Mrs. Reilly found this extremely frustrating when workers from the local authority came round and change the electrical points in her home, she made the following comments about her kitchen:

Researcher: So is this your ideal set up for your kitchen?

Agnes: No, you can see it’s all been set up for the sockets

Researcher: Yes

Agnes: See they are stupid there (Agnes is pointing to some sockets right next to her back door).

Researcher: So if you had been designing this room you would not have had those sockets there?

Agnes: No. They were just put there, they never used to be there, it’s only in the last year that those sockets have been put in.

Researcher: So did you have any input into were the sockets where going to be?

Agnes: No. I wouldn't have put them there.

It can be seen from these comments that Mrs. Reilly would have been happier with her house if the Local Authority had asked her where she wanted new sockets installed instead of presuming that they knew best. Both of the families who lived in the local authority homes felt that they were not in control of what happened to their own homes. The comments from these families make it clear that they wish to be consulted about any changes to their homes. It also shows how our concerns as designers must go well beyond what we would normally consider 'the technology'.

#### CONTROL OF SOCIAL SPACE

This section emerged from the issues of control within families. One of the main issues raised by families was control over the technology this had two main themes:

1. Parents or children?
2. Householders or the technology/ system?

O'Brien *et al.* (1999) when carrying out a study of television set-top boxes in the home found that interaction with technology is in complex ways, a managed activity in domestic environments, and this management is closely linked with relationships within the home. Therefore we would suggest that designers need to take into account issues of management and control within families when designing a new system for the home. This issue became more apparent during the workshops when the idea of voice activation was raised. The participants in one family in particular were keen on voice activation. The father in the family seemed to be quite positive about the idea of voice activation and wanted to be able to tell a screen on the wall in his home to carry out most household task, for example: run a bath, change the television channels, and so on. However when discussing voice activation with two of the other families they were more negative about the possibilities thinking that voice activation may cause arguments one of the participants made the following comment:

Researcher: Can you see yourselves using voice activation?

Emily: Oh that would just cause arguments. It's bad enough pressing buttons but if he could activate it with his voice it would be much worse.

In another family the father was concerned about who had control of the system him or his children and seemed quite adamant that he should be the one controlling any home system. The main problem with voice activation did not seem to be anti the technology more anti the problems it would cause for the way technology and family relationship were managed in the home.

### **Workshop 2&3: Designing your own device**

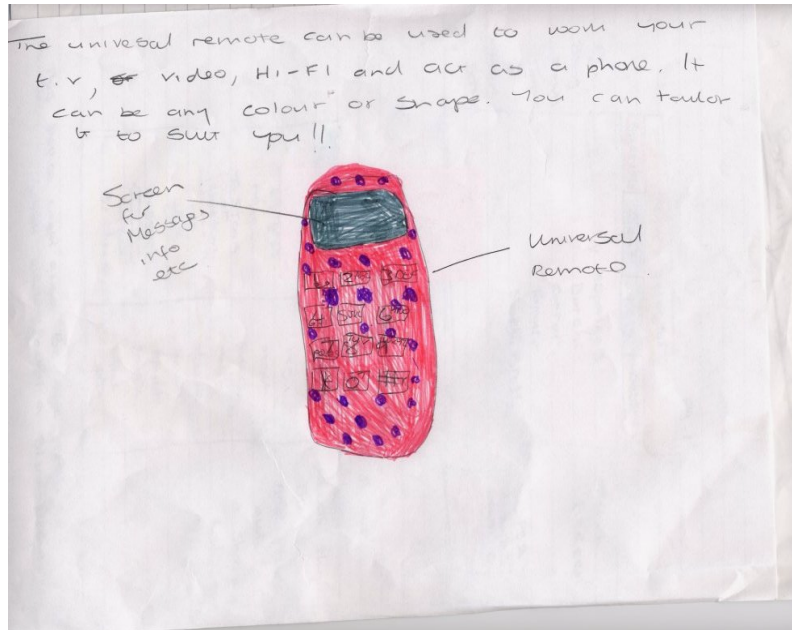
We as researchers are sometimes guilty of feeling that people cannot articulate their ideas for the future without help from us. We can also sometimes assume that they cannot come up with novel solutions or ideas for the future. During the course of the workshops it became clear that people can indeed come up with novel ideas for future homes/devices, if not practical at the present time. The devices discussed here were never intended to be seen as finished designs but were in fact intended to be seen as visualisations of possible future homes or devices which the participants wished they could have. We have not included all the designs here as there are twelve designs in total, instead we have instead picked out the designs, which seemed to be most relevant to ubiquitous computing and its ideas and concepts. Some of the devices are explained and shown in the subsequent sections.

#### **HOME DEVICE REMOTE CONTROL**

Catherine briefly explains her design:

Catherine: it is a remote control that does everything switches on your lights, fire, central heating, hot water, television, video, stereo...

The remote control (see Figure 2 below) has a small screen and a tracker ball (Catherine did not draw on the tracker ball as her design had spots on it) for ease of use. She felt that it was important that people were able to choose their own colours and design.



**Figure 2.** Universal remote (Catherine Naysmith).

The idea emerged when Catherine was trying to think of an idea for a device, she was sitting in her living room at the time and was anxiously looking round for an idea, her gaze fell upon one of her remotes (television) and she picked it up, she then looked around the room and focused for a few seconds on each of her remotes, she has ones for the video and stereo as well as the television remote. Her mobile phone is also sitting nearby. Being in her own living room and seeing the remotes in context seemed to help Catherine find the idea for the universal remote concept.

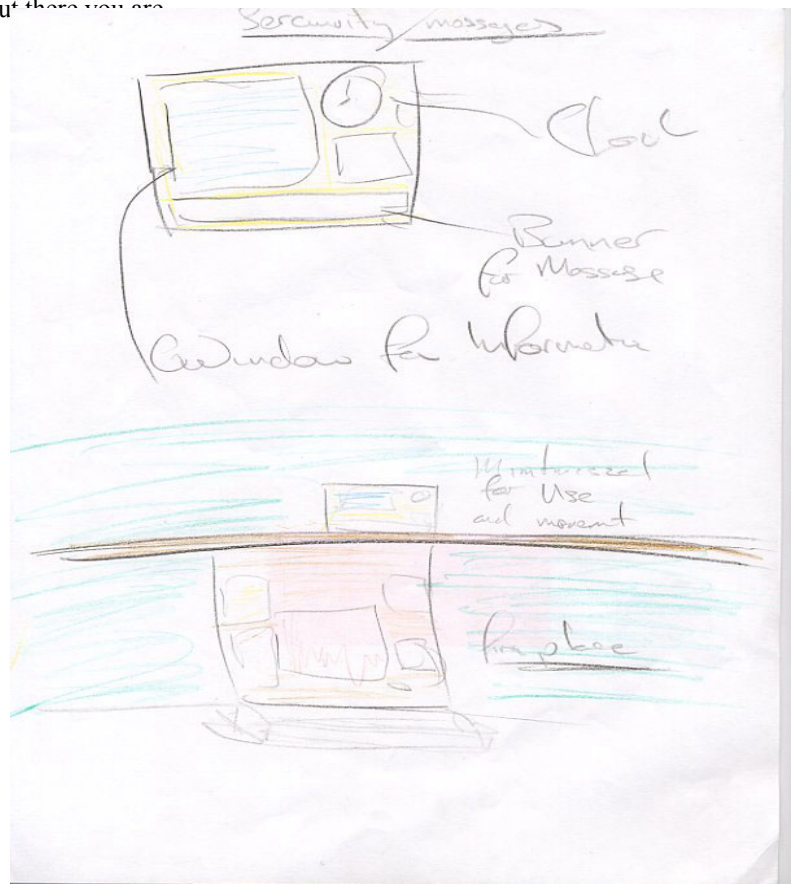
#### HOME SECURITY DEVICE

This device will let you know if anyone is in the home who shouldn't be. It will send you a text message to update you on the houses 'well being'. The device can also be accessed by the emergency services in the case of an emergency i.e. if there is a fire, who is in the house and where they are located.

## HOME WARNING DEVICE

This is a panel that would hang on your wall and would have a family picture, painting, or drawing displayed when not in use (see Figure 3). Peter felt very strongly that he did not want a screen taking up space and dominating the room, he wanted something pleasurable to look at and that would merge into the background of the room. Peter is explaining his device:

Peter: It would flash up, A light would flash if the doorbell rings, in case you cant hear it, or a light would flash if you had left the oven on to long. It would have to be somewhere in the room that it would catch your eye and then you would go up to it and see the individual light and see what has happened. I would want the light to flash and for the display to pop up, it could be in your lounge, bedroom, kitchen, it could also be in the toilet also, but there you are

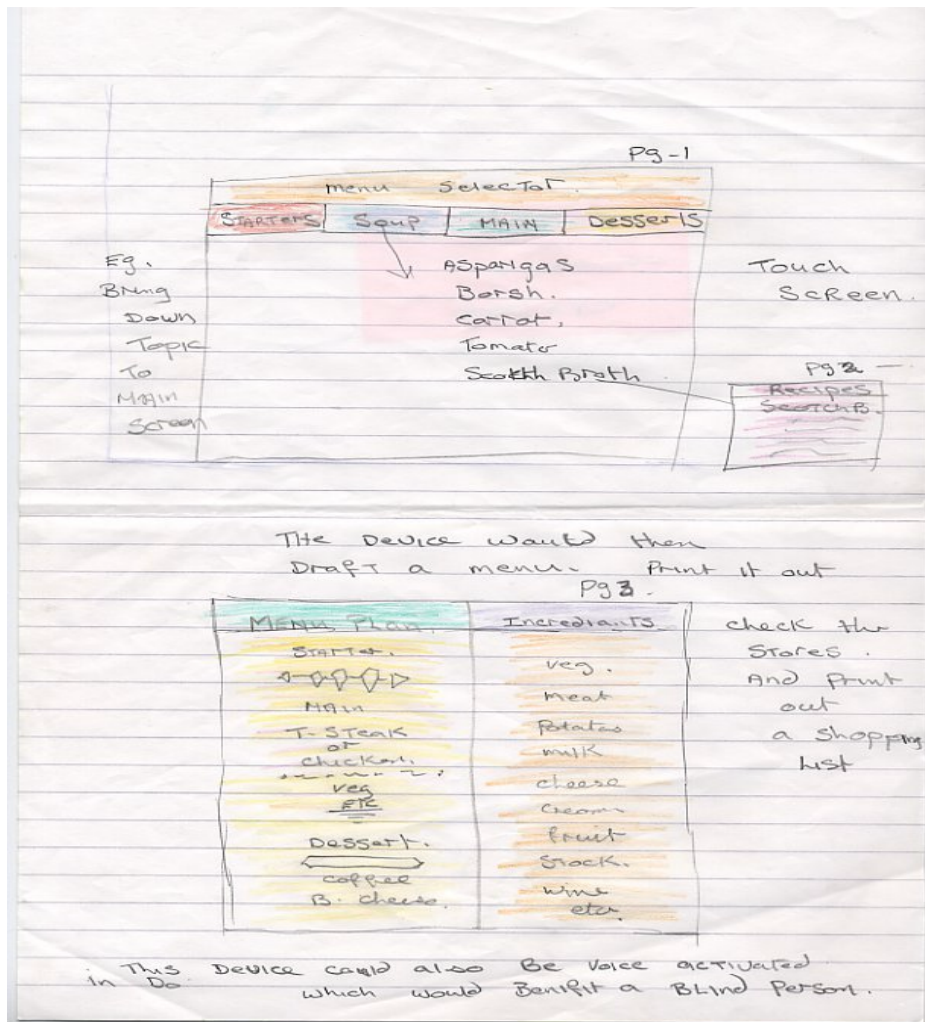


**Figure3.** Home warning device remote (Peter Sutton).

This idea seems to be one that would be relatively easy to implement. It is interesting that Peter only wants the device to be visible when it is required and disappear into the background when not in use.

## THE RECIPE AND KITCHEN STORE DEVICE

Barbara designed a device (see Figure 4) that would provide recipes and would keep track of the food contents of her fridge, freezer, and cupboards. If she chose a recipe she wanted the device to check what she had in stock against the recipe list. She also wanted the device to print her a general shopping list when required. She did not want the device to carry out any of the shopping for her, when asked why, she said: "I enjoy shopping".



**Figure 4.** Home recipe and kitchen store (Barbara Smith).

## **Discussion**

### **METHODS**

Reflecting on the methods used, the Technology Tour was effective and provided the richest set of data. In orientating people to the issues of technology and requirements it proved successful. The post-its seemed to work very well except for our error in giving people post-its that were too small! This led to people drawing on the drawing or picture of the device itself (on the back as well as the front). Scenarios should be collected from the families themselves rather than being imposed from the outside. The most appropriate scenarios should be grounded in the users stories of failing or inadequate technologies from the first session. When asking people to design a device for their home we were pleasantly surprised at the ability of people to generate their own ideas. However some of the more elderly participants were at first more reluctant to take part in this session. They did, however, overcome this initial reluctance with the aid and encouragement of the researcher. The children seemed to like this session the best and were happy to use all the craft materials brought by the researcher.

### **THEMES**

The idea of living in a smart home in general provoked positive images from the families, for instance, many thought that the elderly or disabled would benefit from living in such homes. Some families, however, could not envisage themselves living in such a home, this was perhaps because of the groundedness of being in their own home and yet asking them to envisage a completely different type of home. Perhaps when asking questions of this nature it would be helpful to have some mock-ups or pictures of such a home so, that the participants can imagine themselves in such a home. Control over physical space was the second theme to emerge this manifested itself in the negative feelings of the families toward the lack of control, real or perceived, they had over their homes. This lack of control led one of the participants to point out the poor positioning of sockets in her home, which meant that she had no choice over the positioning of sockets and therefore devices. We found that people had strong feelings towards their physical environment with two of our families having either built additional

rooms or remodeled rooms in their homes. Therefore when studying people in their homes particular attention should be paid to this space. 'Control of Social Space' continued as an important theme throughout the course of the workshops, in the early sessions this manifested itself in the different uses of rooms and the technology within them at different times. This issue was also raised when participants were critiquing other peoples designs i.e. one or other of the parents would ask: who has control over the device? is there an override? Therefore it can be seen that interesting issues were raised by the families as pertains to the social space of the home.

## DESIGNS

Abowd and Mynatt (2000) when looking at the possibilities for future research in ubiquitous computing said that people may want: computers that they wear, or have embedded in their environment, or the ability to alter their perception of the physical world, or they may wish to have information at their fingertips. During our studies we found that people did want computing embedded in their environment as can be seen by Barbara's recipe and kitchen store device, or Peter's home warning device. Ubiquitous computing is involved in looking at how we can change the physical interactions between humans and computers, instead of the current keyboard/mouse/display paradigm, in the future it will be more like the way we interact as humans with the physical world i.e. speech, gesture, touch, pen and pencil. It is evident from what the participants designed and said, i.e. Mike wanting to talk to a device and ask it to run a bath for him in a smart home, or the universal remote, or the house warning system, that they wish to have a device or system that they can talk to, or touch, or point/gesture at. It can be seen therefore that the way participants are thinking about the home is moving away from the current computer paradigm to a physical world paradigm of voice, touch, gesture.

## Conclusions

As technologies become more ubiquitous and invisible, it is essential that the people who will use these devices have an input into the design and functionality of such products so as to

improve the usability and acceptability of those devices for all. It can be seen from above that people are more than willing to give up their own time and ideas so as to be able to contribute to future designs and ideas for ubiquitous and future technologies.

From our experiences to date, it appears that a suitable combination of grounded methods of data gathering and analysis can highlight important contextual issues in the household setting. We are looking for methods that focus on issues concerned with information and communication technology-based product design. It is important that the analyst is open – to surprising ideas, to different configurations of households and to alternative views of technology, but it is also important that they focus on concerns related to the social, technological and physical space. In addition to contributing to the debate about what methods for examining context transfer between work and household, we have come to understand more about the issue of usability of household technologies and indeed about the concept of household itself.

## Acknowledgements

We wish to thank the HCI group at Napier University for their support and helpful comments they provided on previous versions of this document.

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