Assembling Connected Cooperative Residential Domains

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1 Introduction

Between the dazzle of a new building and its eventual corpse ... [lies the] unappreciated, undocumented, awkward-seeming time when it was alive to evolution ... those are the best years, the time when the building can engage us at our own level of complexity.

– Stewart Brand

Researchers have recently drawn on the work of the architectural historian Stewart Brand (Brand 1994) to explore the potential of ubiquitous computing for domestic environments (Rodden and Benford 2003). Of particular relevance is Brand's evolutionary model, characterised by the interplay between the Six S's – Site (where the home is situated), Structure (the architectural skeleton of the building), Skin (the cladding of the building; stone, brick, wood, etc.), Services (water, electricity, waste, etc.), Space-plan (the interior layout of the home, including walls, doors, cupboards, shelves, etc.) and Stuff (mobilia or artefacts that are located within the Space-plan). We seek to complement prior research inspired by Brand's model. We focus particularly on the interplay between the Space-plan and Stuff in terms of human interaction. The supposition underlying this line of inquiry is that computing devices will be situated within the Space-plan and Stuff of the home and that the effort to develop new technologies for domestic settings may be usefully informed by considering the relationship between the two from the point of view of use.

We explore the relationship between the Space-plan and the Stuff of the home firstly by considering the results of a number of ethnographic studies (Crabtree and Rodden 2002; Crabtree et al. 2002a, 2002b, 2003). These studies draw attention to the ways in which household members routinely exploit the Space-plan and the Stuff of the home to meet their practical day-to-day needs. The studies suggest that there is a need to make interactive devices and associated services available to members and to allow these to be configured and reconfigured in order that ubiquitous computing might become part and parcel of the "everyday stuff" of the home (Tolmie et al. 2002). We explore the potential to support the dynamics of interaction through the development of a lightweight component model that allows household members to manage the introduction and arrangement of interactive devices. Interaction techniques developed through "mock-up" sessions with end-users enable members to configure ubiquitous computing in the home via a simple "jigsaw" editor (Humble et al. 2003).

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The component model and editor are not only responsive to the findings of ethnographic studies and end-user requirements, but also to one of the major research challenges in the area. With few exceptions (e.g., Gaver et al. 1999; Hindus et al. 2001), the majority of research concerning the potential of ubiquitous computing for the home is currently conducted in "lab houses" (e.g., Kidd et al. 1999; Mozer 1998). As Edwards and Grinter (Edwards and Grinter 2001) point out, however,

> *... while new homes may eventually be purpose-built for smart applications, existing homes are not designed as such. Perhaps homeowners may decide to "upgrade" their homes to support these new technologies. But it seems more likely that new technologies will be brought piecemeal into the home; unlike the "lab houses" that serve as experiments in domestic technology today these homes are not custom designed from the start to accommodate and integrate these technologies.*

These real world constraints make it necessary for us to complement lab-based research and consider how users might bring ubiquitous computing into the home in the "piecemeal" fashion predicted. Our component model and editor provide a means of exploring and responding to this challenge and of engaging users with ubiquitous computing at their own level of complexity.

2 Interaction Between Space-Plan and Stuff

A range of ethnographic studies (Crabtree 2003) conducted in the home from the mid-1980s forwards have emphasized the importance of the spatial and temporal nature of technology use in the home (Venkatesh 1985, Mateas et al. 1996; O'Brien et al 1999). More recent studies have examined the "ecological" character of technology use in more detail (Crabtree and Rodden 2002; Crabtree et al. 2002a, 2002b, 2003). These studies show how the Space-plan and Stuff of the home are organizational features of interaction. Specifically, that organization consists of the following features:

- **Ecological[1] Habitats.** These are places where artefacts and media live and where household members go to locate particular resources. They include such places as shelves where phones and address books reside, desks where PCs are situated, tables where mail pending action lives, etc.
- **Activity Centres.** These are places where artefacts and media are manipulated and where information is transformed. They include such things as porches and hallways where mail is organized, sofas where letters are discussed, tables where phone calls are made from, etc.
- **Coordinate Displays.** These are places where media are displayed and made available to residents to coordinate their activities. They include such things as bureaus where mail is displayed for the attention of others, mantelpieces where cards are displayed for social and aesthetic reasons and to remind the recipient to respond, notice boards where appointment cards are displayed, etc.

[1] The term 'Ecological' refers here to the physical environment in which work takes place and how that environment and its composite features are integral features of the cooperative accomplishment of work

While discrete, these places often overlap, assuming different functions at different times. For example, the kitchen table may at one time be an ecological habitat where mail pending action lives, at another an activity centre where mail is acted upon (e.g. writing a cheque to pay a bill), and at another time still, it might be a coordinate display where mail is placed for the attention of others. The Space-plan does not simply "contain" action then, but is interwoven with action in various functional ways. In the interweaving it is furthermore apparent that an essential feature of the Space-plans functionality consists of the manipulation of the Stuff of the home.

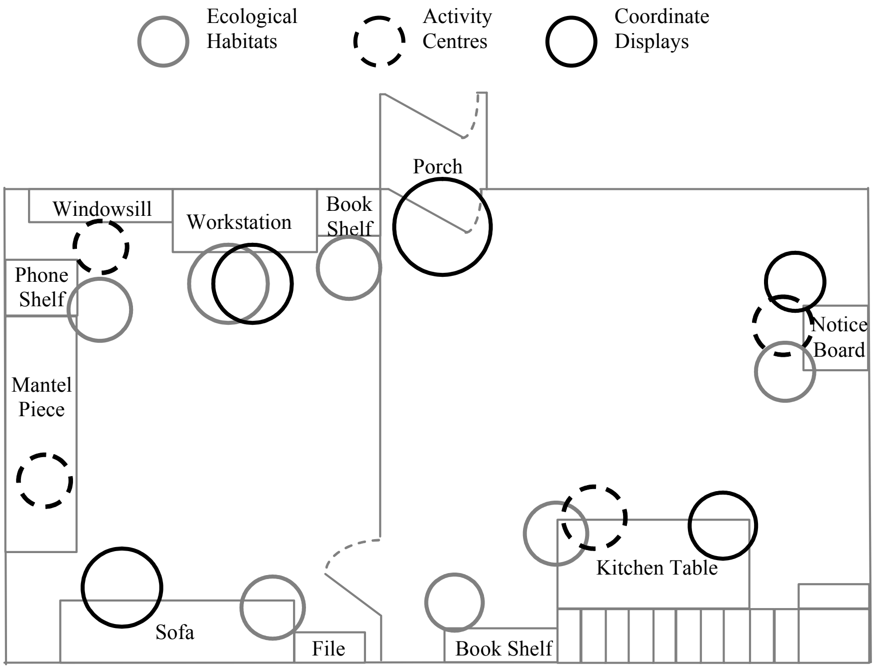
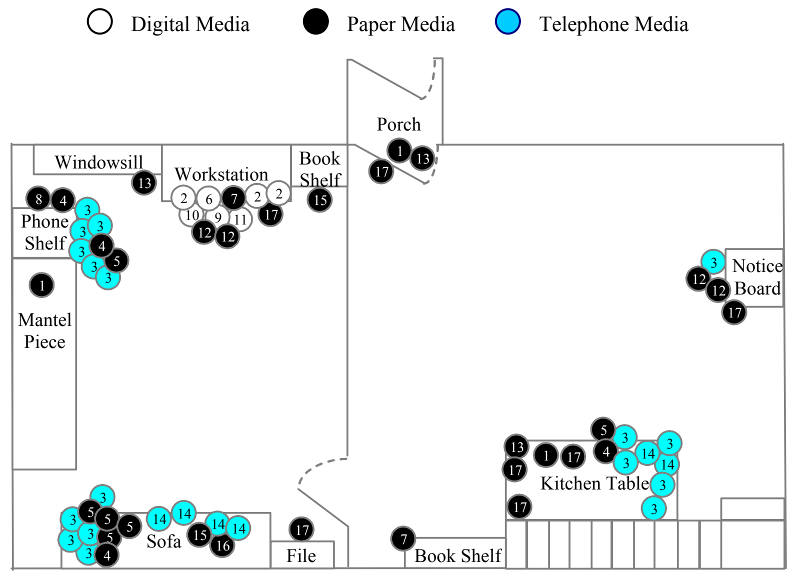


Fig. 1. Functional Nature of the Space-plan

Ethnographic studies inform us that the Stuff of the home is dynamic, coalescing around different sites at different times for the practical purposes of the activities to hand. The places that household members employ to fulfil various functions are places where the Stuff of the home – a range of artefacts and media, such as phones, address books, calendars, letters, emails, etc. – are contingently assembled and used. The Space-plan and the Stuff of the home are tied together in and by interaction and the interplay between the two consists of and relies upon the assembly and manipulation of a bricolage of artefacts and media at various functional sites.

The Space-plan and Stuff of the home are interrelated and tied together then, through the ongoing configuration and reconfiguration of artefacts and media (Crabtree et al. 2002). The functional and configurational character of the interplay between the Space-plan and Stuff of the home draws attention to two basic requirements for the development of ubiquitous computing in domestic settings.



1. Cards	7. Paper recipes	13. Postcard
2. Email	8. Answer machine	14. Text message
3. Phone	9. Electronic documents	15. Books
4. Address Book	10. Hyperlinks	16. Magazine
5. Paper notes	11. Digital images	17 Mail (bills etc.)
6. Internet	12. Paper documents	

Fig. 2. Bricolage of Stuff at Functional Sites

- **Placement.** When designing new technologies for the home there is a need to be sensitive and responsive to the local organization of the Space-plan and enable new technologies to be situated at functional sites within the home.
- **Assembly.** It is not sufficient to simply place new technologies at functional sites in the home, users must be able to configure and reconfigure devices and services across functional sites to meet the day-to-day needs of the household.

We have previously addressed ways in which designers might develop a sensitivity to the local organization of the Space-plan and identify important functional sites for situating ubiquitous computing in the home (Crabtree et al. 2003). We want to concentrate on the second requirement. Enabling users to assemble and manipulate a bricolage of ubiquitous devices is a real challenge for design. If successful, it will not only enable users to manage the introduction of devices in the piecemeal fashion predicted, but also, to dynamically assemble and reassemble arrangements of devices to meet local needs and make ubiquitous computing part and parcel of the "everyday stuff" of the home (Universal Plug and Play). In the following section we consider some technical ways in which this might be achieved.

3 Configuring Ubiquitous Stuff

Essentially the challenge here is to enable users to easily place devices in the home, to understand this placement and to rapidly reconfigure those devices. As interactive devices become increasingly ubiquitous the underlying infrastructure supporting them will need to become prominent to a degree and available to users. In fact, we would argue that this underlying infrastructure needs to become sufficiently apparent to users to make it part and parcel of their everyday practical reasoning about the nature of their home. Consequently, we need to develop a flexible infrastructure that reduces the cost of introducing new devices and allows users to control and evolve their use within the home. However such an infrastructure need not be intrusive, but form part of the collective of the Space-plan.

A number of existing infrastructures that directly address these challenges include Jini (Waldo 1999), UPnP (www.upnp.org) and the Cooltown infrastructure (http://cooltown.hp.com/cooltownhome/) among others. While these tackle the above challenges directly, they do so for the developer of new devices rather than the eventual inhabitant of a ubiquitous environment. The focus of these infrastructures has by necessity been on the development of appropriate protocols and techniques to allow devices to discover each other and make use of the various facilities they offer. Limited consideration has been given to how inhabitants may see these devices or how they may exploit them to configure novel arrangements meeting particular household demands.

To allow digital devices to be treated as "everyday stuff" we need to open up access to the supporting infrastructure that connects devices and provide users with a simple model that allows them to manage their introduction and arrangement. While existing infrastructures such as Jini provide service and component based abstractions for ubiquitous computing, few researchers have explored how users may be involved within the dynamic configuration of these components. Two notable examples are the Speakeasy system (Newman et al. 2002), which has adopted a composition model based on typed data streams and services, and iStuff (Ballagas et al. 2003) which knits together a number of ubiquitous devices via a state based event heap.

As in the case of iStuff we allow a number of different devices to be composed within a ubiquitous environment. However, our challenge is to allow users to view these compositions and rapidly reconfigure them to meet their changing needs. Below we present a simple user-oriented component model that seeks to allow the rapid composition of devices to meet the everyday interactive arrangement of the home.

3.1 A Compositional Approach to Home Environments

Our starting point has been the development of a component model for ubiquitous devices in home environments. The basis of our component model is the notion of a shadow digital space that acts as a "digital" representation of the physical environment (Fig. 3). Devices can use this shared digital dataspace to become aware of their context, to represent this contextual information to other devices, and to make this manifest in the physical world. The aim of devices within the physical environment is either to make information from the physical available within the digital or to make digital information have a corresponding physical manifestation.

The fundamental aim of components in our arrangement is to ensure the convergence of the physical and the digital environment. There are three main classes of components.

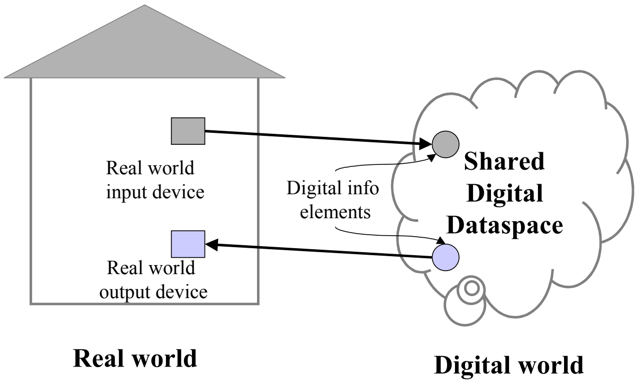


Fig. 3. The component model

- **Physical to Digital Transformers**. These take physical effects and transform them into digital effects. Any particular device may make use of a number of transformers. Essentially each transformer measures a physical effect and transforms it into a corresponding digital property that is shared through the data space.
- **Digital to Physical Transformers**. These make digital information physically manifest in the real world. This class of components transforms the values of shared properties to drive some sort of physical device.
- **Digital Transformers**. These act upon digital information and effect digital information. This class of components provides a way to present deeper semantic reactions to changes in the environment to users. For example, data gathered from temperature sensors might be interpreted to herald ambient descriptions, such as warm or cold (see (Humble et al. 2003) for a more detailed description of these component classes).

In the associated toolkit the different transformers are realized as JavaBeans which exposes the properties they wish to share through a distributed digital space or *dataspace.* We exploit our own dataspace called EQUIP (http://www.equator.ac.uk/technology/equip) which provides semantics that are similar to dataspaces such as TSpace. We decided on the Java bean model because of the added benefit of separating individual component development from the infrastructure itself. Our dataspace provides an export facility that introspects the Java software component (i. e. bean) and publishes the relevant component properties associated with the bean. This allows us to incorporate existing and new software components into the infrastructure without the necessity of reengineering the code. Other processes listening to the dataspace can link with the property in the dataspace and be notified when it changes. This model is analogous to the one proposed within iStuff (Ballagas et al. 2003) which provides developers with a set of discrete devices that can be assembled through publication of state information within a dataspace called the event heap.

This project extends this work by focusing on how components – such as the devices in iStuff – and the ways in which they are configured might be exposed to inhabitants for them to reason about and exploit. Consequently, our emphasis is on the development of user-oriented techniques that allow the dynamic composition and assembly of arrangements of devices.

3.2 Interacting with the Component Model

The first issue we had to address concerned how we might present underlying device configurations to users. A number of candidate representations to support practical reasoning within the domestic environment were already available, including variants of electronic wiring diagrams and plumbing schematics currently in use. However, our initial explorations suggested that these were heavily loaded with existing interpretations and their use required a significant degree of technical competence. Consequently, we sought a more neutral approach based on the notion of assembling simple jigsaw-like pieces.

Fig. 4. The Physical Jigsaw Editor

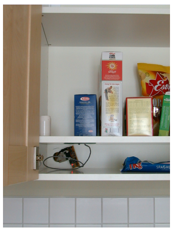
Our choice of the "jigsaw piece" metaphor is based on the familiarity evoked by the notion and the intuitive suggestion of assembly by connecting pieces together. Essentially, we wanted to allow users to connect components and so compose various arrangements through a series of left-to-right couplings of pieces. The "jigsaw" provides a recognizable interaction mechanism for connecting services together. The benefit of this simplified editing mechanism is that inhabitants might more readily understand the environment they are configuring, despite the reduced complexity of assembly.

Our exploration of the applicability of this jigsaw-based approach to reconfiguration was explored through a user-oriented approach. Through a series of focused user workshops we sought to:

- *Understand* the intuitive availability and efficacy of the jigsaw-based approach from inhabitants' point of view.
- *Uncover* inhabitants understanding of abstraction in order that we might keep the level of complexity with in reach of their practical reasoning.
- *Develop* insights into what sorts of devices might fit into real home environments and so inform continued development of new devices and components.

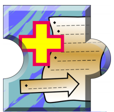
In order to undertake these studies we exploited a paper-based “mock-up” approach (Ehn and Kyng 1991) married to “situated evaluation” (Twidale 1994) where a series of physical jigsaw pieces were made available to users for their practical considerations and recorded on videotape to promote in-depth analysis. We also presented users with a set of initial seed scenarios elaborating various transformers and their potential arrangement. These reflect different levels of abstraction and provide a starting point allowing users to reason about the editor, the complexity of configuration, and the nature of ubiquitous computing in the context of their everyday lives. The seed scenarios were drawn from previous ethnographic studies (Crabtree et al. 2002), and some initial prototype development within a lab based domestic environment. An illustrative selection of scenarios and potential components are presented below.

Seed Scenario #1. A common grocery item is missing from a kitchen cupboard



Using the pieces shown below, **GroceryAlarm** is connected to **AddToList,** which is then connected to **SMSSend**. **GroceryAlarm** reports the missing item after a certain time interval and the missing item is added to an electronic list and then sent via SMS to a mobile phone on request.

GroceryAlarm: Generates names of missing groceries in the cupboard. It detects groceries moving in and out and if one is away more than 30 minutes it is said to be out.



AddToList: Takes an element string and adds it to the list it publishes into the data space.

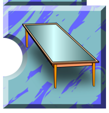
SMSSend: Takes a message string and sends this as SMS to the given phone.

Seed Scenario #2. A way to access information services from the internet which ties in to common practices, such as reading the newspaper at the breakfast table. Physical icons (Phicons) of various abstract shapes are used to manipulate a web based news feed displayed on the table itself.

Connecting the pieces below, the **TableCommands** receives commands (e.g. “next”, “previous”) from a physical interaction object (e.g. a “shaker”, see arrow in figure opposite) and controls a **News** service, which in turn is displayed on the **KitchenTableDisplay**.

TableCommands: Reads a physical “shaker” phicon and generates corresponding commands, such as NEXT, PREVIOUS, etc.

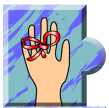
News: Takes a command string and outputs a new URL to a news web page.



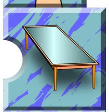
KitchenTableDisplay: Takes a URL and displays the associated web page.

Seed Scenario #3. Reminders can be directed to a number of outputs

A reminder application lets the user enter textual or auditory reminders (birthdays appointments, schedules, etc.) using a touch display and microphone. This can be connected to a display with speakers, sent to a mobile, etc. The **Reminder** piece can be connected to the either the **KitchenTableDisplay** or **SMSSend** to allow users to receive reminders where they are most appropriate.



Reminder: Corresponds to a reminder application that provides an input GUI, manages the reminder alarms, and publishes reminders as URLs when reminders are due.



KitchenTable Display: Takes a URL and displays the associated web page.

SMSSend: Takes a message string and sends this as SMS to the given phone**.**

4 Learning from Potential Users

We sought to engage potential users in the development process at an early stage in order that we might establish the veracity of our technological reflections and concepts, and also elaborate future avenues of technical work. Mock-ups provide an opportunity to engage end-users in a formative process of mutual learning. They enable users to get “hands on” experience of potential technological futures, and provide a tangible basis for users to reason about and elaborate technological possibilities. When analysing the mock-up sessions and presenting findings we do so in relation to a number of relevant development criteria (Mogensen 1994) that are concerned to establish whether users can:

- **See the sense of the technology.** On encountering a novel technology, users can rarely see the sense of it. It is not, at first glance, intelligible to them and its potential use must therefore be explained. This involves guiding users through technological functionality and may be accomplished via mockups, prototypes or both. Whatever the medium, the first question is, given that course of explanatory work, will users see the sense of the technology or will it remain unfathomable?
- **Recognise the relevance of the technology to practical activities and practical circumstances.** That users may come to see the sense of the proposed technology does not mean that they will recognize it as relevant to their everyday activities. If users are to engage in any meaningful analysis of the technology's potential utility, and further elaborate functional demands that may be placed on it, then they need to be able to recognize the relevance of the technology to their everyday lives. The question is, will users recognise the relevance of the proposed technology and, if so, in what ways?
- **Determine ways in which the technology might be appropriated.** That a new technology may be recognized as relevant by potential users does not necessarily mean that they wish to appropriate that technology. Naturally there are many reasons for this, though in the early stages of development concerns are likely to be expressed about the available range of functionality. The question is in what ways, if any, will users conceive of appropriating the technology and what will those conceptions be concerned with?

Six mock-up sessions were conducted with eight participants aged from their early twenties to late fifties in six homes. The length of the sessions varied between one and four hours. Below we present a number of session transcripts or *vignettes* conveying the main issues emerging from the mock-up exercise.

4.1 Seeing the Sense of the Technology

Even at this early stage in design it was possible for participants to see the sense of the technology. Although the specific details of participation changed from case to case, the following vignette nevertheless illustrates the way in which our participants generally came to achieve this outcome. It is a transcript excerpt from one of the workshop sessions hosted by Jack, one of our project member ethnographers. We can be sure that participants see the sense of the technology when, as in this case, they make the imaginative leap beyond our initial scenarios to incorporate new elements into the design dialogue. Thus, and by way of example, the vignette shows Sean makes an imaginative leap from Jack's working of the mock-up, making sense of the technology in the context of his own unique domestic arrangements. Accordingly, Sean speaks of preparing and sending a shopping list to his partner, arriving at concrete sense of the technology by envisioning how it can be incorporated into and tailored to support his life and personal relationships. All our participants came to see the sense of the technology and all did so in similar ways by making the technology relevant to the practical circumstances of their everyday lives. This is of the utmost importance as it in turn moves beyond particular design visions, and the sense others might see in them, to consider ways in which potential users recognise the relevance of the technology to their practical concerns.

Jack is sat at the kitchen table with one of our participants, Sean. The jigsaw pieces are spread out on the table in front of them and Jack is working through the seed scenarios with Sean.

Jack: OK, so each one of these pieces when they are put together would set up a series of connections (Jack assembles the pieces involved in Seed Scenario #1). So this piece (points to **GroceryAlarm**) connects to this (**AddToList**) and this (**AddToList**) to this (**SMSSend**) and that would then send a message to you, OK?

Sean: So this (pointing to the pieces Jack has connected – see Fig. 5) is configuring it here?

Fig. 5. Mock-up of grocery alarm to SMS service (video frame image)

Jack: Yeah.

Sean: So the computer's in the background somewhere?

Jack: Yeah. Alternatively, you might want a list to be generated and sent to the kitchen table (points to **KitchenTable** jigsaw piece). There could be a display in this table (runs his hand over the table they are sat at) and you could then transfer the list from the table to, say, your PDA. Or you might decide that you want each family member to have an icon (takes an identity card out of his wallet and places on the table). This is you; it's your Identity icon. You could be the administrator for the household - so each person in the house has an Identity icon and they have certain privileges - so you might want to put that down first (puts Identity icon down on table) and that (connects **GroceryAlarm** piece to Identity icon) goes there and that (connects **AddToList** to series – see Fig. 6) goes there and then a list is sent to …

Sean: Me.

Jack: Yeah, this is your list.

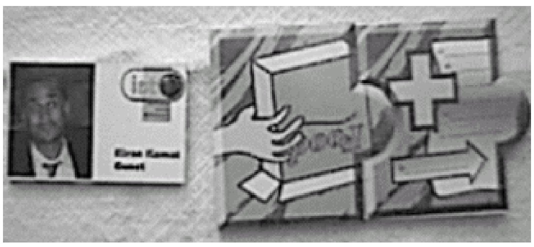


Fig. 6. Mock-up of grocery alarm with identity (video frame image)

Sean: Right, OK. Or you could send it to somebody else, say Charlotte, and make sure she does the shopping instead of me if I'm late home from work.
Jack: Exactly.

4.2 Recognizing the Relevance of the Technology

Recognition of the relevance of the technology follows from the understanding developed of the basic working of the technology – of the assembly of various pieces to produce particular outcomes – and the embedding of that understanding in the participants' practical circumstances. As this vignette makes visible, participants come to recognize and articulate the potential relevance of the technology by continued working of the pieces to meet specific needs, such as the paying of household bills. The vignette, like many others, also instructs us in the participant's grasp of complexity and their ability to handle abstraction, where they take over the assembly of pieces to produce outcomes that are greater than the individual functions of the pieces making up any particular assembly. In other words, in recognizing the relevance of the technology, participants demonstrate the efficacy of the jigsaw metaphor and that reasoning about complexity in this manner is readily intelligible to them. At the same time, and reflexively, in making their own assemblies of pieces, participants articulate areas of activity that they see the technology as being relevant to: paying bills, doing the shopping, organizing the collection of children from school, managing appointments and schedules, monitoring the children, controlling domestic services and appliances, making the home more secure, etc., etc., etc. Participants come to recognise the relevance of the technology by getting their hands on the mock-ups and tailoring their use to address salient issues in their own lives.

Jack has worked through the seed scenarios with Sam and she is getting increasingly more curious and articulate about the jigsaw pieces and their potential use. She is starting to "run" with the ideas articulated by Jack, as the following vignette shows:

Sam: What's that? (Points to a piece on the table).
Jack: This is the bubble tower. Say someone's accessed your website – it could be indicated in the water tower with a change in the bubbles or changes of colour.
Sam: Hmmm.
Jack: You can decide what sort information is communicated. So this could be in the corner of the room and its Sunday and
Sam: Actually that's quite a good idea. Let's says you were at work. I know we're talking about home right now but let's say you were at work. Rather than having something like Outlook, you have say a task manager with a list of things (points to the **AddToList** piece then moves her finger, motioning across and down as if to indicate rows and columns). Then say at home, you have bills on your list and you want to be reminded to pay them. So you could have a little sort of nudge in your house, you know, you could see the bubble tower constantly in the corner of the room and you could also be reminded by SMS to your mobile to pay the gas bill or pick the kids up from school.
Sam: By the same token you could have your lamp change to blue after that list has been prepared. Effectively you can have your lamp change from amber say to blue when you run out of X number of items of food (connects **GroceryAlarm** to **AddToList** to **BubbleTower** – see Fig. 7). Like that you see.

Fig. 7. Mock-up of grocery alarm to bubble tower (video frame image)

Jack: Right. Yeah, that's great.

4.3 Appropriating the Technology

In the course of recognizing the potential relevance of the technology participants begin to articulate ways in which the technology might be appropriated. As the sessions unfold, users become more and more familiar with the technological possibilities to-hand and users begin to project the technology into their everyday lives and configure it to meet their particular requirements. These projections go beyond existing design conceptions and engage users and designers in a creative dialogue that conveys participants' practical concerns and reflexively articulates future avenues of work that provide direction for a continued and iterative course of development. User projections elaborated a wide range of practical concerns including being able to survey visitors to the home both from inside and outside the environment, of being connected to family and friends through a variety of devices, of accessing and controlling devices in the home from outside the home. These and a host of other practical concerns elaborate the design domain and real user needs, paramount of which is the ability to configure ubiquitous computing to meet the local, contingent and unique needs of potential users, several of which are articulated in the following vignettes.

4.3.1 The Doorbell

In this sequence of talk we see a specific suggestion emerge that requires the addition of a new component (a doorbell), which the user then exploits to assemble an arrangement of devices to monitor access to the home.

Bill: I might want to see who's coming to the house during the day while I'm at work. So I might want to have this (picks up a blank jigsaw piece) as a doorbell, yes?
Jack: Yes (sketches a Doorbell icon on the blank piece). And when the doorbell is activated it links to?
Bill: A video camera or webcam or something like that.
Jack: Yes a camera, good idea (takes another blank paper jigsaw piece and sketches a Webcam icon).
Bill: Even better. If we have that (points to the newly sketched Webcam icon) and the doorbell rings, OK? Then the image from the webcam goes to

Jack: A web page?[2] (Jack places jigsaw piece showing **WebToText** icon next to jigsaw pieces bearing sketches of Doorbell and Webcam).

Bill: Or even a picture text message. I suppose you could have a picture flashed up on my mobile (points to his Sony Eriksson T300 and then replaces the **WebToText** piece with the **SMSRecieve** piece – see Fig. 8) and that shows me just who's at the door!

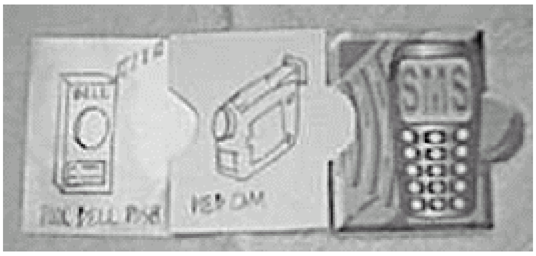


Fig. 8. Mock-up of doorbell-camera-SMS service (video frame image)

Jack: So you'd have an image of who and how many people have been to your home.

Bill: Yeah.

4.3.2 The Office

This sequence of talk suggests the need for more abstracted concepts (in this case the office) to be reflected in the set of components available in the home and for these to be linked with other components to build an arrangement for monitoring the home.

Kate: Let's say you were interested in whose calling at night, as a security measure. If you were in, it could be displayed on your TV screen

Jack: So it goes to your TV at home?

Kate: Yes, or in a little TV monitor that flashes up on your TV, or that's waiting on your TV when you come in from work.

Jack: So you capture pictures with the webcam which sends them to a TV display (sketches a **TVDisplay** icon on a blank jigsaw piece and connects it to the **Webcam** icon).

Kate: You could see the display when you're at home and if you don't want to answer the door you can ignore it. It could come up with a picture of the person at the door automatically in a little insert screen in the corner of the screen while your watching. Or when you come in and turn on your TV you might have a list - a "rogues gallery" of people who have come to your house during the day or night. So when someone says, "I've been and I've tried to deliver this …" (articulates holding a parcel)

Jack: Yeah, that's a good idea.

Kate: Could you have it sent to work?

Jack: (Sketches an Office icon and then connects the pieces together – see Fig. 9).

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[2] Web pages and message boards are ongoing topics and comments from earlier segments, merely suggesting a continuation on the same dialogue theme.

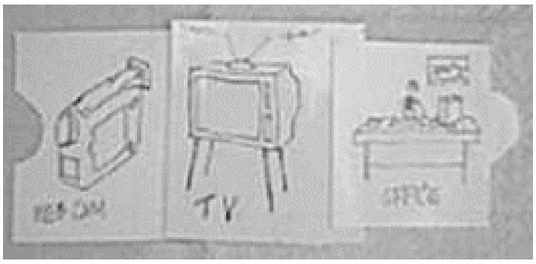


Fig. 9. Mock-up of home surveillance from the workplace (video frame image)

Kate: Yeah, that's it.

4.3.3 Main Access Point

In this final sequence the user requests a main point of access to allow her to edit and manipulate the assembly of components.

Jo: Anyway, I don't want to play with your bits anymore (pushes jigsaw pieces away and laughs).
Jack: That's all right.
Jo: You know, my dream is to have one screen which you can access everything through.
Jack: Yeah.
Jo: It's like your main access point - you can access everything through it. That's my thing and I don't think you have a picture of it here?

5 Responding to End-User Projections

Users' projections do not furnish requirements for design – there is not a necessary one-to-one correspondence between user visions and future design work. Rather, users' projections provide inspiration for design. The point might be more readily appreciated if we consider the notion of a "main access point", for example. While intelligible, that notion does not tell us what a main access point might look like, it does not tell us what to build. What it does do is provide a grounded form of inspiration for design which is intimately connected to the development of specific technological concepts through direct user participation. Design work is directed towards developing, in this instance, a single, coherent interface where users can access the technological environment and configure the components therein to meet their particular needs. Below we briefly describe an electronic jigsaw editor and a number of other devices we have developed to articulate the relation between users' projections and design work.

5.1 The Jigsaw Editor Tablet

Responding to the request for a main point of access we constructed the Jigsaw Editor Tablet (Humble et al. 2003). The jigsaw editor (Fig. 10) is made available to users on a tablet PC that uses 802.11 wireless connectivity to communicate with the underlying dataspace. The editor contacts the dataspace through a discovery mechanism of the framework and is initially notified of the components available within the dataspace. The editor is composed of two distinct panels, a list of available components (shown as jigsaw pieces) and an editing canvas. Jigsaw pieces can be dragged and dropped into the editing canvas. The editing canvas serves as the work area for connecting pieces together and visualizing their activities.

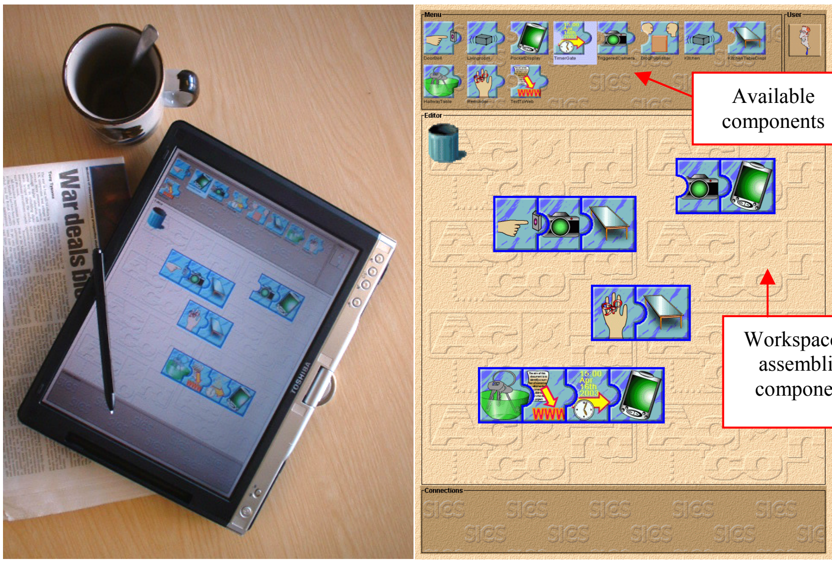


Fig. 10. The Tablet Editor and Editor Screen

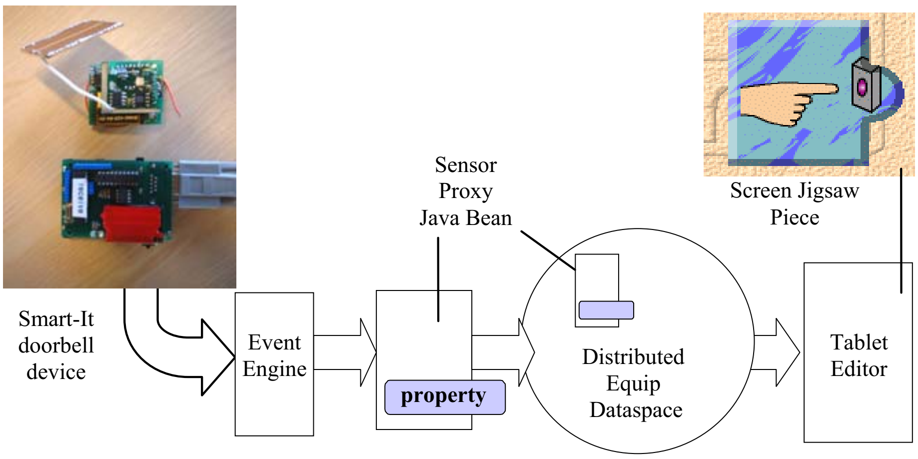


Fig. 11. Making Lightweight Sensors Available

5.2 Adding Simple Sensors: The Doorbell

Responding to the doorbell projection, we extended the set of components to provide a simple touch sensitive component. This component utilizes the Smart-Its toolkit (Smart-Its), a general-purpose hardware toolkit for ubiquitous devices. A component acts as a proxy for the sensor device allowing it to expose the state information in the dataspace (Figure 11).

Once made available to the dataspace the component appears on the jigsaw editor and users can connect the sensor device to other components. For example, the sensor can be used to drive larger scale devices connected to the dataspace. Two such devices are the web camera and a portable display.

5.3 Integrating Larger Devices: The Webcam and Display

The arrangement used to add larger devices to the system is similar to the approach for lightweight sensors. Essentially the device is "wrapped" as a component allowing the associated property to be shared across the dataspace. This means that the device can be combined with the inputs provided by the lightweight sensors. For example, the arrangement shown in Fig. 12 shows the pushbutton being used to signal a webcam to take a picture. Linking the webcam jigsaw piece to a portable display means that this picture is then directed to that display. In this case the display is a driver that sends the image to a mobile phone using MMS.

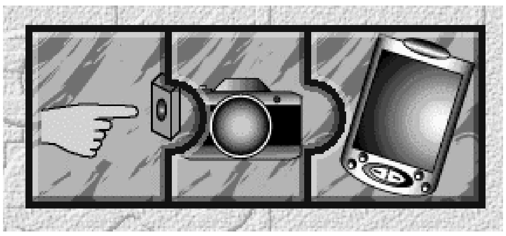
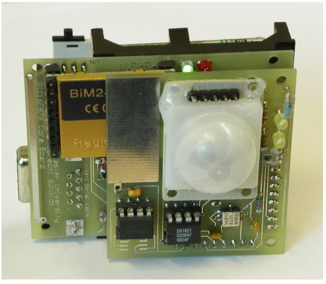


Fig. 12. The Doorbell, Webcam and Portable Display

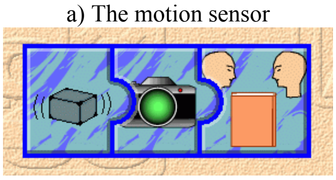
5.4 Exploiting Applications: The Blog

Responding to the office projection suggested by users requires us to consider how to ingrate the sensors and devices with more abstract entities. In this case the user suggested that they wanted to be able to monitor the home while at the office. We address this issue by exporting the properties representing larger applications. This allows users to combine these with lightweight sensors and devices.

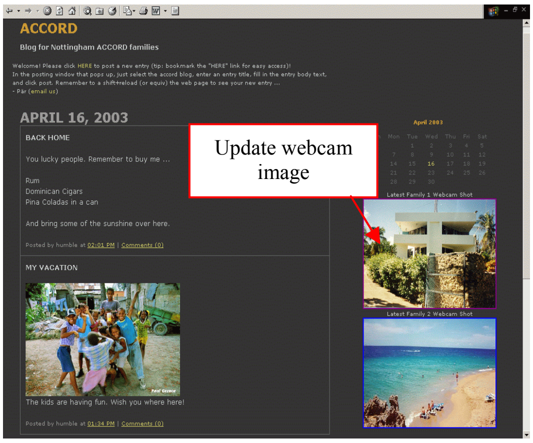
In order to address the link between the home and the office we see a combination of jigsaw pieces (Fig. 13b) that results in a lightweight sensor (a Smart-It motion sensor (Fig. 13a) triggering a device (a webcam) and making the output from the device available to an application (a blog – Fig. 13c). This configuration means that whenever motion is detected within a space it is used to take a picture that is then automatically added to the blog. Users away from the home can access the blog and view the domestic space remotely, thereby realising the monitoring envisioned by users during the mockup sessions.



a) The motion sensor



b) The jigsaw assembly



c) The web blog

Fig. 13. Combining a Lightweight Sensor, a Device, and an Application to Monitor a Space

5.5 The Linker Device

The linker device takes an alternative approach to the composition and linking of devices. Rather than provide an overview display that shows the devices and transformations in the home as an abstract graphical representation, the linker device seeks to use physical manipulation within the setting as a means of exploring the properties devices make available to the dataspace and as a means of linking properties on one device with properties on another.

The basic device consists of a PDA which communicates directly with the shared dataspace and a barcode reader that can read barcodes placed on interactive devices (Fig. 14). When the user scans a barcode the linker device queries the dataspace for software properties pertaining to the software component of the physical device (the

Fig. 14. The linking device

physical to digital transformer). For example, an SMS sender component might publish both a phone number and a message property in the dataspace.

The user can select a property through the PDA interface and see what transformer (hence device) the property is linked to. The user can choose to link the property to a property pertaining to another transformer. In order to do this the user can find all of the digital transformers available which have compatible and connectable properties in the system and link the selected property to one of them. Alternatively, the user can scan a second physical device bringing up the compatible properties of the new device. The user can then select the destination property, thus creating the link.

6 Reflections

We have presented the development of a lightweight component model that allows users to manage the introduction and arrangement of new interactive services and devices in the home. The model is responsive to ethnographic studies of the interplay between the Space-plan (interior layout) and Stuff (artefacts) of the home, which emphasize the need to support the dynamic assembly and recombination of ubiquitous Stuff across various functional sites in the home. A tablet-based editor which exploits a jigsaw interaction mechanism has been developed through user-participation and enables household members both to introduce interactive devices in the piecemeal fashion predicted by researchers in the field and to rapidly configure and reconfigure them to meet local needs. In addition to confirming the overall veracity of our design concepts our work with users has also highlighted some broader lessons in designing technologies for domestic settings.

6.1 Inhabitants as Designers and Developers

A key feature of our exploration is that once user became familiar with the broad approach they sought to compose assemblies that met their needs and desires. Essentially, they wished to further refine our existing seed suggestions to interleave with the practicalities of their everyday lives. For example, users would seek to redirect output to more appropriate devices or even suggest new classes of input and output device. Shifting to consider how we might design for appropriation suggests an interesting relationship between those who seek to design technologies for the home and the inhabitants. Rather than consider design as a problem solving exercise where designers seek to develop a technology to meet a particular need our aim has been to furnish inhabitants with the tools of design. We wish to help users design and develop their own arrangements of technologies just as they design many aspects of their home. We have sought to do this through the provision of a simple editor to allow the direct composition of device assembles.

The jigsaw editor has been improved to allow as much flexibility into the paradigm as possible. For example, among other enhancements it includes features to insert self-authored graphics, images or annotations into the each jigsaw icon, as well as the capability of combining several pieces (or transformers) into a single one to introduce simpler representations of complex behaviours. It is worth stressing that within this approach we are still constraining the potential for development. For example, we do not have the richness of programming expression allowed by iCap (Sohn and Dey 2003).

However, the benefit to be accrued from reducing complexity of assembly is that inhabitants might more readily understand the environment.

6.2 Reasoning with Diverse Elements

It is worth reflecting on the diversity of the components users wished to connect together. It was not unusual to see users develop assemblies that combined lightweight sensors with more traditional computer devices and larger applications and services. For example, users would link something as small as a doorbell with something as complex and varied as “the office”. This form of reasoning is somewhat in contrast to how developers might normally consider components where they would seek to understand elements at similar levels of abstraction. It appears from our exploration that inhabitants are less concerned with the variability of the complexity of these components than they are with the interactions between them. We have addressed the need to interconnect components of varying complexity by allowing components to make properties available to a distributed dataspace. This arrangement allows different types of component to offer a very simple state based interface, which can be presented to users to allow them to construct assemblies to meet their particular needs.

6.3 Interleaving the New and the Old

One of the most notable aspects of our sessions with inhabitants was the desire to interleave new devices and facilities with older more established devices and services. For example, users would wish to direct output to their TV or to their mobile phone. Similarly, users would wish to take output from web pages and display this on a local display or to link with their existing alarm systems. Although providing difficult technical challenges links of this form are essential if devices are to be interleaved into the everyday activities of the home. In fact many of our assemblies provided just this function with newer sensors and cameras being connected to more traditional devices such as mobile phones or placing material on the World Wide Web.

6.4 Linking Outside the Home

While the home offers new challenges for designers and developers and suggest new values for design, such as playfulness (Gaver et al. 1999), our explorations also stress that the domestic is interleaved with many activities outside the home. Indeed, these confirm the importance of communication suggested by the Interliving project (Hutchinson et al. 2003) and by Hindus et al on the Casablanca project (Hindus et al. 2001). Many of the assemblies of devices developed by inhabitants sought to access the outside world from the home or to make the home more accessible from outside. For example, inhabitants sought to send messages to the office or to household members away from the home. We have also aimed to support these through the development of communication facilities including the blog application.

6.5 Future Work

The component model and editor are the product of an ongoing period of interdisciplinary research. Working in cooperation with potential end-users, we continue to iterate and refine the technical infrastructure and toolkit of devices, software, and applications that embed ubiquitous computing in the domestic environment to meet real user needs. Although development is ongoing, our work to date makes a valuable contribution to foundational research in ubiquitous computing for domestic environments, identifying and exploring significant challenges that underpin the migration of ubiquitous computing technology from the research lab into real users homes.

The ACCORD version of the toolkit, including the Jigsaw editor, is publicly available and may be downloaded from the project's website: www.sics.se/accord. This allows developers to wrap their particular sensors, devices or applications as JavaBeans, to provide an iconic representation of the device, and to publish them to our dataspace. Once within the dataspace they become available for use through a number of editors including the Jigsaw editor. Our aim is to allow users more control over the assembly of the ubiquitous devices that share their environment in order that home users can readily situate and exploit ubiquitous technologies within the space they live in.

The ACCORD legacy has provided the launch pad for future home technology research endeavours, such as the Equator Domestic Experience initiative (http://www.equator.ac.uk). It has provided the basic design methodologies and software tools for current ubiquitous technology assemblies. Development is carried on as part of the Equip Component Toolkit ECT (Greenhalgh et al. 2004), which in turn serves as a digital resource for rapid prototyping in academic assignments, design and research collaborations. ECT features vast improvements in the core design of the infrastructure as well as introducing numerous sets of features facilitating third party development and deployment in domestic settings. We are currently in the process of placing a version of the toolkit in a number of domestic environments for prolonged assessment and continued elaboration.

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