Between the Dazzle of a New Building and its Eventual Corpse: Assembling the Ubiquitous Home

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ABSTRACT
This paper presents the development of a lightweight component model that allows user 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 or interior layout and Stuff or artefacts placed within the fabric of the home. Interaction techniques developed through user-participation enable household members – rather than designers – to configure and reconfigure interactive devices and services to meet local needs. As a result, we have developed a tablet-based editor that discovers available ubiquitous components and presents these to users as 'jigsaw pieces' that can be dynamically assembled and recombined.

Keywords
Ubiquitous computing, domestic environment, ethnography, user participation, component model, interaction techniques.

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 [2] to explore the potential of ubiquitous computing for domestic environments [21]. 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). This paper seeks 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 [4, 5, 6, 7]. 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 [24]. 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 [13].

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., 11, 12], the majority of research concerning the potential of ubiquitous computing for the home is currently conducted in 'lab houses' [e.g., 15, 18]. As Edwards and Grinter [9] 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.

INTERACTION BETWEEN SPACE-PLAN AND STUFF

A range of ethnographic studies [8] 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 [27, 16, 20]. More recent studies have examined the 'ecological' character of technology use in more detail [4, 5, 6, 7]. 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 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, noticeboards where appointment cards are displayed, etc.

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.[1] 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.

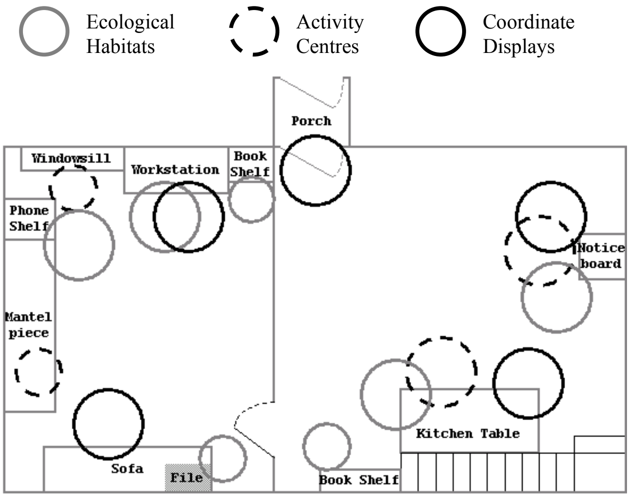
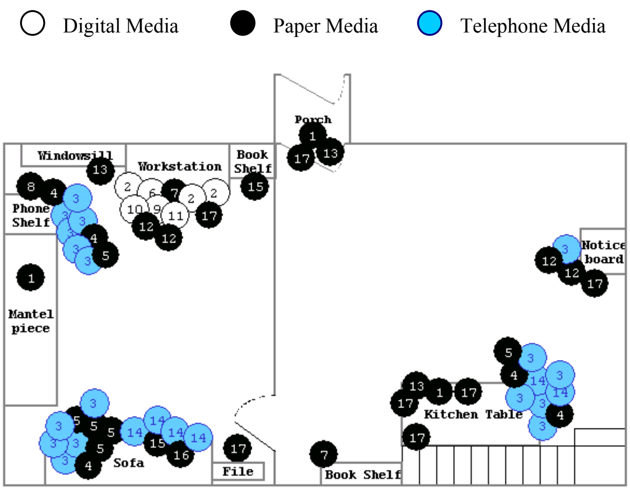


Figure 1. Functional Nature of the Space-plan

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 fulfill 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.



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	

Figure 2. Bricolage of Stuff at Functional Sites

[1] Figure 1 shows the various functional sites 'at work' in a particular household by way of illustration.

The Space-plan and Stuff of the home are interrelated and tied together then, through the ongoing *configuration* and *reconfiguration* of artefacts and media [5].[2] 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.

- **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 [7]. In this paper, we want 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 [24]. In the following section we consider some technical ways in which this might be achieved.

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 increasingly prominent and available to users. In fact, we would argue that this underlying infrastructure needs to become sufficiently visible 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.

A number of existing infrastructures directly address these challenges include Jini [28], UpnP [26] and the Cooltown infrastructure [3] 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 [19], which has adopted a composition model based on typed data streams and services, and iStuff [1] 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.

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. 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.

- *Physical to Digital Transformers.* These take physical effects and transform them into digital effects.
- *Digital to Physical Transformers.* These make digital information physically manifest in the real world.
- *Digital Transformers.* These act upon digital information and effect digital information (see [13] 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

[2] Figure 2 shows the various configurations 'at work' in a particular household by way of illustration.

wish to share through a distributed dataspace. We exploit our own dataspace EQUIP, which provides semantics that are similar to dataspaces such as Tspace. This model is analogous to the one proposed within iStuff [1] 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 paper 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.

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. 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.

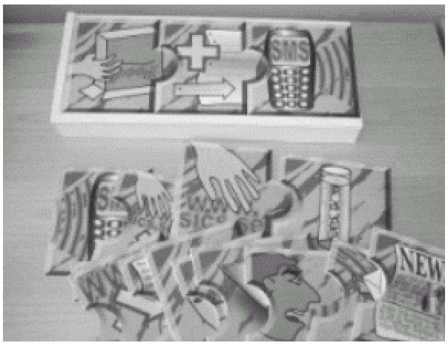


Figure 3. The Physical Jigsaw Editor

It is worth stressing that within this approach we are constraining the potential for development. For example, we do not have the richness of programming expression allowed by iCap [23]. However, the benefit to be accrued from reducing complexity of assembly is that inhabitants might more readily understand the environment.

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 [10] married to 'situated evaluation' [25] where a series of physical jigsaw pieces were made available to users 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 [5], and some initial prototype development within a lab based domestic environment (the scenarios are described in [13]).

LEARNING FROM POTENTIAL END-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 [17] 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 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 vignettes conveying the main issues emerging from the mock-up exercise.

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. 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 (one of designers) 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, a member of the design team, 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) is configuring it here?

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) goes there and then a list is sent to

Sean: Me.

Jack: Yeah, this is your list.

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.

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 lets 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**). Like that you see.

Jack: Right. Yeah, that's great.

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.

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?

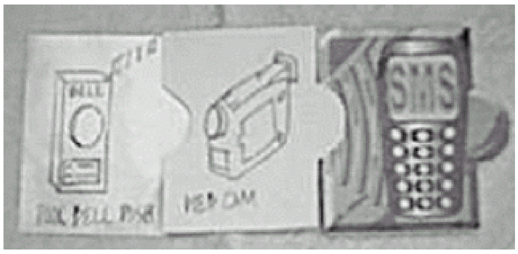
Bill: A video camera or webcam or something like that.

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? (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) and that shows me just who's at the door!



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

Bill: Yeah.

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.

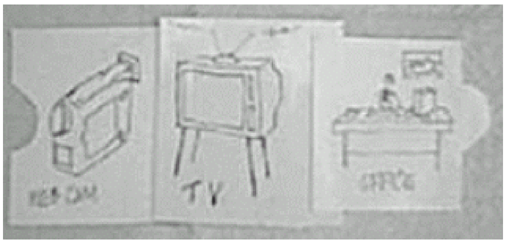
Jack: So you capture pictures with the webcam which sends them to a TV display (sketches a **TVDisplay** icon on a blank jigsaw piece and connects it to the **Webcam** icon).

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 …"

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).



Kate: Yeah, that's it.

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?

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.

The Jigsaw Editor Tablet

Responding to the request for a main point of access we constructed the Jigsaw Editor Tablet [13]. The jigsaw editor (Figure 4) is made available to users on a tablet PC that uses 802.11 to talk to the dataspace. The editor discovers the dataspace and is 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.

Figure 4. The Tablet Editor and Editor Screen

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 [22], 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.

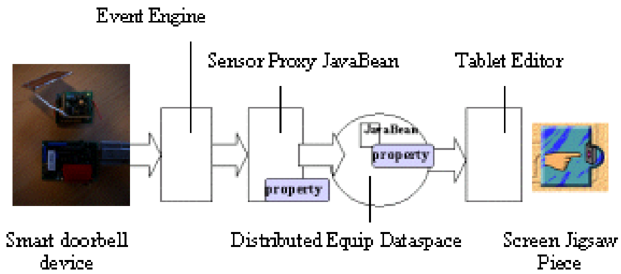


Figure 5. Making Lightweight Sensors Available

Once made available to the dataspace it 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.

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 Figure 6 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.

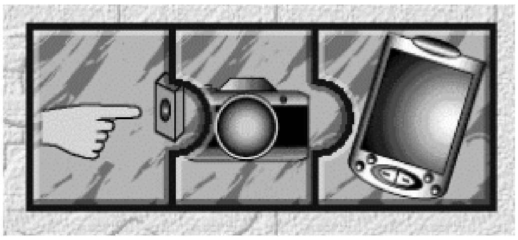


Figure 6. The Doorbell, Webcam and Portable Display

Exploiting Applications: The Weblog

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 (Figure 7b) that results in a lightweight sensor (a Smart-It motion sensor (Figure 7a) triggering a device (a webcam) and making the output from the device available to an application (a weblog – Figure 7c).

Figure 7. Combining a Lightweight Sensor, a Device, and an Application to Monitor a Space

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 weblog. Users away from the home can access the weblog (www.accord.blog) and view the domestic space remotely, thereby realising the monitoring envisioned by users during the mockup sessions.

REFLECTIONS

We have presented the development of a lightweight component model that allows user 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.

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.

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.

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 new sensors and cameras being connected to older devices such as mobile phones or placing material on the World Wide Web.

Linking Outside the Home

While the home offers new challenges for designers and developers and suggest new values for design, such as playfulness [11], 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 [14] and by Hindus et al on the Casablanca project [12]. 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 sought to support these through the development of communication facilities including the weblog application.

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. We are currently in the process of placing the toolkit in a number of domestic environments for prolonged assessment and continued elaboration. 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 ubicomp from the research lab into real users homes.

The current 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.

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REFERENCES

1. Ballagas, R., Ringel, M., Stone, M. and Borchers, J. (2003) "iStuff", *Proceedings of the 2003 CHI Conference on Human Factors in Computing Systems*, pp. 537-544, Florida: ACM Press.
2. Brand, S. (1994) *How Buildings Learn*, New York: Viking.
3. Cooltown, http://cooltown.hp.com/cooltownhome/
4. Crabtree, A. and Rodden, T. (2002) "Technology and the home", CHI Workshop, *Proceedings of the 2002 CHI Conference on Human Factors in Computing Systems*, Minneapolis: ACM Press. www.cs.umd.edu/hcil/interliving/chi02/
5. Crabtree, A., Hemmings, T. and Rodden, T. (2002) "Pattern-based support for interactive design in domestic settings", *Proceedings of the 2002 Symposium on Designing Interactive Systems*, pp. 265-276, London: ACM Press.
6. Crabtree, A., Rodden, T. and Hemmings, T. (2002) "Supporting communication in domestic settings", *Proceedings of the 2003 Home Oriented Informatics and Telematics Conference*, Irvine, California: International Federation for Information Processing. www.crito.uci.edu/noah/HOIT%20Papers/Supporting%20Comm%20Domestic.pdf
7. Crabtree, A., Rodden, T., Hemmings, T. and Benford, S. (2003) "Finding a place for UbiComp in the home", *Proceedings of the 5th International Conference on Ubiquitous Computing*, pp. 208-226, Seattle: Springer.
8. Crabtree, A. (2003) *Designing Collaborative Systems: A Practical Guide to Ethnography*, London: Springer.
9. Edwards, K. and Grinter, R. (2001) "At home with ubiquitous computing: seven challenges", *Proceedings of the 3rd International Conference on Ubiquitous Computing*, pp. 256-272, Atlanta, Georgia: Springer.
10. Ehn, P. and Kyng, M. (1991) "Cardboard computers: mocking-it-up or hands-on the future", *Design at Work: Cooperative Design of Computer Systems* (eds. Greenbaum, J, and Kyng, M.), pp. 169-195, Hillsdale, New Jersey: Lawrence Erlbaum Associates.
11. Gaver, W., Dunne, A. and Pacenti, E. (1999) "Design: cultural probes", *Interactions*, vol. 6 (1), pp. 21-29.
12. Hindus, D., Mainwaring, S.D., Leduc, N., Hagström, A.E. and Bayley, O. (2001) "Casablanca: designing social communication devices for the home", *Proceedings of the 2001 CHI Conference on Human Factors in Computing Systems*, pp. 325-332, Seattle: ACM Press.
13. Humble, J., Crabtree, A., Hemmings, T., Åkesson, K-P, Koleva, B., Rodden, T. and Pär Hansson (2003) "'Playing with your bits': user-composition of ubiquitous domestic environments", *Proceedings of the 5th International Conference on Ubiquitous Computing*, pp. 256-263, Seattle: Springer.
14. Hutchinson, H., Mackay, W., Westerlund, B., Bederson, B.B, Druin, A., Plaisant, C., Beaudouin-Lafon, M., Conversy, S., Evans, H., Hansen, H., Roussel, N. and Eiderbäck, B. (2003) "Technology

probes: inspiring design for and with families", *Proceedings of the 2003 CHI Conference on Human Factors in Computing Systems*, pp. 17-24, Florida: ACM Press.
15. Kidd, C.D., Orr, R.J., Abowd, G.D., Atkeson, C.G., Essa, I.A., MacIntyre, B., Mynatt, E., Starner, T.E. and Newstetter, W. (1999) "The aware home: a living laboratory for ubiquitous computing research", *Proceedings of the 2^nd^ International Workshop on Cooperative Buildings*, pp. 191-198, Pittsburgh: Springer.
16. Mateas, M., Salvador, T., Scholtz, J. and Sorensen, D. (1996) "Engineering ethnography in the home", *Proceedings of the 1996 CHI Conference on Human Factors in Computing Systems*, pp. 283-284, Vancouver: ACM Press.
17. Mogensen, P. (1994) *Challenging Practice*, DAIMI PB 465, Århus University, Dept. of Computer Science.
18. Mozer, M. (1998) "The neural network house", *Proceedings of the AAAI Symposium on Intelligent Environments*, pp. 110-114, Palo Alto, California: AAAI.
19. Newman, M.W., Sedivy, J.Z., Neuwirth, C.M, W.K. Edwards, Hong, J.I., Izadi, S., Marcelo, K., Smith, T.F., Sedivy, J. and Newman. M. (2002) "Designing for serendipity: supporting end-user configuration of ubiquitous computing environments", *Proceedings of the 2002 Symposium on Designing Interactive Systems*, pp. 147-156, ACM Press.
20. O'Brien, J., Rodden, T., Rouncefield, M. and Hughes, J.A., (1999) "At home with the technology", *ACM Transactions on Computer-Human Interaction*, vol. 6 (3), pp. 282-308.
21. Rodden, T. and Benford, S. (2003) "The evolution of buildings and implications for the design of ubiquitous domestic environments", *Proceedings of the 2003 CHI Conference on Human Factors in Computing Systems*, pp. 9-16, Florida: ACM Press.
22. Smart-Its, http://smart-its.teco.edu.
23. Sohn, T. and Dey, A. (2003) "iCAP", Interactive Poster, *Proceedings of the 2003 CHI Conference on Human Factors in Computing*, pp. 974-975, Florida: ACM Press.
24. Tolmie, P., Pycock, J., Diggins, T., Maclean, A. and Karsenty, A. (2002) "Unremarkable computing", *Proceedings of the 2002 Conference on Human Factors in Computing Systems*, pp. 399-406, Minneapolis: ACM Press.
25. Twidale, M., Randall, D. and Bentley, R. (1994) "Situated evaluation for cooperative systems", *Proceedings of the 1994 ACM Conference on Computer Supported Cooperative Work*, pp. 441-452, Chapel Hill, North Carolina: ACM Press.
26. Universal Plug and Play, www.upnp.org
27. Venkatesh, A. (1985) "A conceptualization of household-technology interaction", *Advances in Consumer Research*, vol. 12, pp. 189-194.
28. Waldo, J. (1999) "The Jini architecture for network-centric computing", *Communications of the ACM*, pp. 76-82, vol. 42 (7), pp. 76-82.