Configuring 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. 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 part of this we have developed a tablet-based editor that discovers available ubiquitous components and presents these to users as jigsaw pieces that can be dynamically recombined. We conclude by considering the broad implications for the design of interactive domestic environments suggested by our approach.

1. Introduction

Developing ubiquitous technologies for the home has become a growing focus for many HCI researchers. New technologies have been suggested ranging from novel forms of interactive device [2] to a wide range of information appliances [1]. Many of these developments have been supported by purpose built domestic environments. These range from the development of domestic spaces [4] to the construction of purpose built homes [14]. These environments have tended to be used as "living labs" to support the development new interactive devices and explore how these can be placed within a domestic setting. The construction of these spaces has been complemented by an empirical exploration of domestic spaces where researchers seek to understand the everyday nature of the homes we inhabit. A number of different research approaches are being used to seek to understand the domestic. These include ethnographic studies [15, 17], the development of technology models [22], the use of cultural probes [10], and patterns [5]. Despite the diversity of these studies one common and important issue emerges: namely, that the home is open to continual reconfiguration by those who inhabit it.

More recently, researchers have started to develop domestic technologies "in the wild" by constructing and placing technologies within domestic settings in partnership with users. This includes 'technology probes' [13] where development takes place in partnership with a number of distributed families and the development and placement of lightweight media space technologies [11]. Not only has this work highlighted the importance of the inhabitants becoming involved in the design process it has confirmed the need for technology to be open to reconfiguration within the home. Similarly, architectural historians, such as Brand [3], have highlighted the importance of change to allow inhabitants to appropriate and adapt domestic spaces to meet their evolving needs. Researchers have extended this work to consider ubiquitous computing and domestic technologies [18]. A key feature is the relationship between the technologies within the

home and the underlying services needed to support them. This paper builds upon this previous work by considering how inhabitants can reason about supporting services and dynamically reconfigure technology in the home.

We explore the potential to support reconfiguration through the development of a lightweight component model that allows household members to manage the introduction and arrangement of interactive devices. Part of this has involved the development of an inhabitant's editor to allow the reconfiguration of interactive devices that has been briefly reported elsewhere [12]. In this paper we focus on how the development was directed by a series of focused user studies that exploited a paper-based 'mock up' approach [9] married to 'situated evaluation' [21]. This provided a means of engaging domestic inhabitants with ubiquitous computing at their own level of complexity. We were able to develop the component model in partnership with users and allow them to be involved in the identification of new components that made sense from their perspective.

2. Making the Infrastructure Available

A central issue in supporting the reconfiguration of innovative ubiquitous devices for the home is the relationship between devices and the supporting infrastructure. Essentially users must be able to easily place devices in the home, understand this placement and rapidly reconfigure devices. Furthermore, as Edwards and Grinter point out the networked home of the future will not be custom designed from the start but "it seems more likely that new technologies will be brought piecemeal into the home" [7]. As ubiquitous devices enter the home in the 'piecemeal' way predicted, they need to be made part of the broader infrastructure of the home. Consequently, the underlying supporting infrastructure needs 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.

To allow digital devices to be treated as 'everyday stuff' [20] we need to open up access to the supporting infrastructure that connects devices and provide users with a simple model that allows them to mange the introduction and arrangement of new interactive devices. While existing infrastructures such as Jini [23], UpnP,[1] and the Cooltown infrastructure,[2] among others provide services and component based abstractions for ubiquitous computing. However, few researchers have explored the rapid composition of applications through the dynamic configuration of these components. Two notable examples are the Speakeasy system [8], which has adopted a composition model based on typed data streams and services, and iStuff [2] that knits together a number of ubiquitous devices via a state based event-heap. Both tend to focus on the *developer* rather than the eventual *inhabitant* of a ubiquitous environment. 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 to allow the rapid composition of devices to support the everyday interactive arrangement of the home.

[1] Universal Plug and Play - http://www.upnp.org

[2] Cooltown - http://cooltown.hp.com/cooltownhome/

2.1 A Compositional Approach to Home Environments

Our starting point has been the development of a component model for ubiquitous devices in home environments suitable for further elaboration by inhabitants. 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 and 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*** take physical effects and transform them into digital effects.
- ***Digital to Physical Transformers*** make digital information physically manifest in the real world.
- ***Digital Transformers*** act upon digital information and effect digital information.

In the associated toolkit the different transformers are realized as JavaBeans which exposes the properties they wishes to share through a distributed dataspace. This model is analogous to the one proposed within iStuff 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 further extends this approach 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. Consequently, our emphasis is on the development of user-oriented techniques that allow the dynamic assembly of devices.

2.2 Components and Jigsaw Pieces

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 is based on the everyday familiarity of the 'jigsaw piece' and the intuitive suggestion of assembly through connection. 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 1). 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 [19]. 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 undertaken using a user-oriented approach. Through a series of focused user studies we sought to:

- ***Understand*** the intuitive availability and efficacy of the jigsaw-based approach from inhabitant's point of view.

- ***Uncover*** inhabitants understanding of abstraction in order that we might keep the level of complexity in reach of the practical reasoning of inhabitants.
- ***Develop*** insights into what sorts of devices might fit into real home environments and so inform continued development of new devices and components.

Figure 1. The physical jigsaw editor

In order to undertake these studies we exploited a paper-based 'mock up' approach [9] married to 'situated evaluation' [21] where a series of physical jigsaw pieces were made available to users practical considerations. These session where recorded on videotape to promote a later 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 complexity of configuration, and the nature of ubiquitous computing in the context of their everyday lives. The seed scenarios were drawn from earlier ethnographic studies [5], and some initial prototype development within a lab based domestic environment [12].

3. Learning from Potential Users

In order to bring users' expertise to bear on development – both to establish the veracity of our technological concepts and to elaborate future avenues of technical work - we undertook a series of mockup exercises. Mockups are early expressions of potential technological futures and they are essentially incomplete, thereby providing an opportunity to engage end-users early on in the design process in a formative process of *mutual* learning. Mockups enable users to get 'hands on' experience of potential technological futures, providing a tangible basis for users to reason about and elaborate technological possibilities. The mockups are embedded in seed scenarios, which furnish a context for users' reasoning, sensitizing them to design concepts and visions. These scenarios are not specifications to be assessed by users but 'triggers' designed to engage them in an open-ended design dialogue. They provide a concrete entry point for users and designers to work out what the future might amount to in detail, prompting reflections on and, importantly, projections of technological possibilities which in turn drive development work. We marry mocking-it-up with situated evaluation, which exploits ethnographic study to support the learning exercise and identify salient issues to design. The focus of the study is the designers and users talk, specifically the conversational formulations triggered by the seed scenarios which articulate technological possibilities [6]. When analysing the mockup sessions and presenting findings we do so in terms of designers and users talk and in relation to a number of relevant development criteria [16].

- ***Seeing 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?
- ***Recognising the Relevance of the Technology.*** 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?
- ***Appropriating the Technology.*** 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 mockup 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 series of vignettes to convey a flavour of the main issues to emerge from the mockup exercise in relation to the criteria laid out above.

3.1 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. 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.

Vignette #1

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?

Figure 2. Assembling seed scenario #1

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.

Figure 3. Sean's assembled 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.

3.2 Recognising 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.

Vignette #2

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. Indeed, like our other participants, 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.

Figure 4. Making relevant *ad hoc* assemblies

Jack: Right. Yeah, that's great.

3.3 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.

Vignette #3. The Doorbell

In this segment of conversation 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!

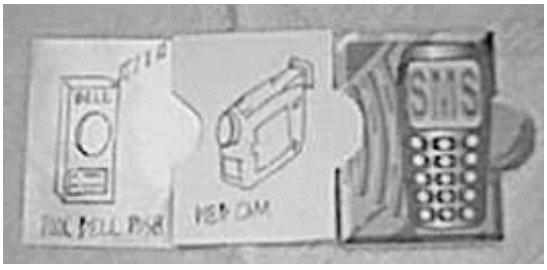


Figure 5. Bill's doorbell assembly

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

Bill: Yeah.

Vignette #4.The Office

This segment of conversation suggests the need for more abstracted concepts (in this case the office) to be reflected in the set of components available 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).

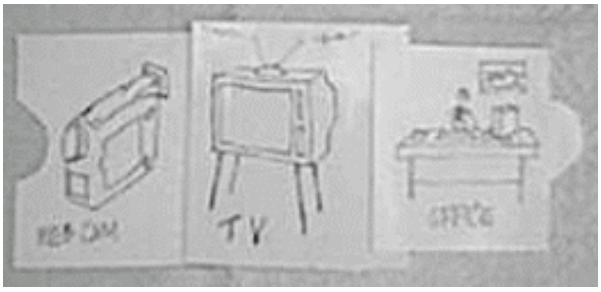


Figure 6. Kate's home-office assembly

Kate: Yeah, that's it.

Vignette #5. Main Access Point

In this final segment 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?

4. Responding to User Projections

Users' projections do not furnish requirements for design – there is not a necessary one-to-one correspondence between users' 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 that 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. Thus, we have developed an electronic jigsaw editor and a range of other devices in response to users projections.

4.1 The Jigsaw Editor Tablet

Responding to the request for a point of access we constructed the Jigsaw Editor Tablet [12]. The Jigsaw editor is made available to users using a tablet PC that uses 802.11 to talk to the dataspace (Figure 7). 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 or workspace. The editing canvas serves as the work area for connecting pieces together and visualizing their activities.[3]

Figure 7. The tablet editor and the editor screen

[3] Commercial partners in the ACCORD project have also developed a paper jigsaw editor, which utilizes paper-based identification technology. Each component is represented in the same way as on the graphical editor (Figure 7) as a jigsaw piece but this time it is a physical jigsaw piece. Users can create services by connecting physical pieces together in a left-to-right order. Unfortunately we are constrained by the commercial sensitivity of the underlying technology and so can say little more about this particular development here.

4.2 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,[4] 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. Once made available to the dataspace it appears on the jigsaw editor and users can connect the sensor device to other components (Figure 8). 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.

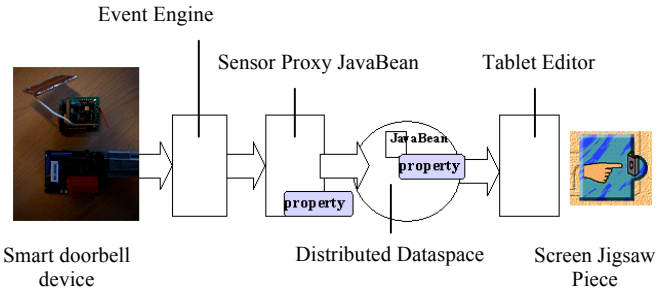


Figure 8. Making lightweight sensors available

4.3 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 Figure 9 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.

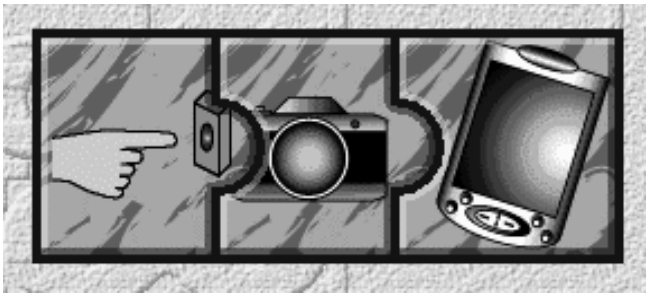


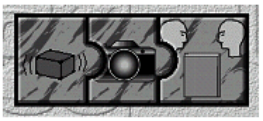
Figure 9. The doorbell, the webcam and the portable display

4.4 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.

[4] Smart-Its - http://smart-its.teco.edu.

a) The sensor



b) The jigsaw assembly

c) The weblog page

Figure 10. Combining a lightweight sensor, a device and an application to monitor a space

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 10b) that results in a lightweight sensor (a Smart-It motion sensor (Figure 10a) triggering a device (a webcam) and making the output from the device available to an application (a weblog – Figure 10c). This configuration means that whenever motion is detected within a space this 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 image realising the remote monitoring envisioned by users during the mockup sessions.

5. Reflections and Conclusions

In this paper we have presented the evolution of a simple component model in partnership with users. The model supports user configuration of ubiquitous computing environments. The use of jigsaw pieces allows users to develop functions through a process of left to right assembly. A formative user-centred approach has underpinned the elaboration of the component model. A key element of our approach has been the use of mock up sessions with users that have highlighted that:

- Users can readily understand components as jigsaw pieces and understand the concepts involved in building assemblies of devices
- Users can reason about simple interconnections of devices and handle the complexities involved in building simple connections
- Users can make assemblies of components to meet their local needs and can suggest additional devices that can fit into the overall framework and metaphor.

In addition to confirming the overall veracity of our approach and allowing users to engage in the development of our component model these studies have also highlighted some broader lessons in designing technologies for domestic settings.

5.1 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.

5.2 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.

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

5.3 Linking Outside the Home

While the home offers new challenges for designers and developers and suggest new values for design, such as playfulness [10], 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 [13] and by Hindus et al on Casablanca [11]. 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.

5.4 Future Work

The process of user-based development is ongoing, with each iteration leading to the further refinement of 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 users' domestic environments for prolonged assessment and continued elaboration. We envisage these trials raising significant issues of collaborative access and control as the toolkit is exploited cooperatively by families to meet their day-to-day needs.

6. Acknowledgement

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7. References

1. Abowd, G. and Mynatt, E. (2000) "Charting past, present, and future research in ubiquitous computing", *ACM Transactions on Computer-Human Interaction*, vol. 7, (1), pp. 29-58.
2. 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.
3. Brand, S. (1994) *How Buildings Learn*, New York: Viking.
4. Brumitt, B., Meyers, B., Krumm, J., Kern, A. and Shafer, S. (2000) "EasyLiving: technologies for intelligent environments", *Proceedings of the 2nd International Symposium on Handheld and Ubiquitous Computing*, pp. 12-29, Bristol: Springer.
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. (2003) *Designing Collaborative Systems: A Practical Guide to Ethnography*, London: Springer.
7. 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.
8. Edwards, K., Newman, M., Sedivy, J. and Izadi, S. (2002) "Recombinant computing and the speakeasy approach", *Proceedings of the 8th Annual International Conference on Mobile Computing and Networking*, pp. 279-286, Atlanta: ACM Press.
9. 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.
10. Gaver, W., Dunne, A. and Pacenti, E. (1999) "Design: cultural probes", *Interactions*, vol. 6 (1), pp. 21-29.
11. 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.

12. 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*, October 12th-15th, Seattle: Springer.

13. 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.

14. 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 2nd International Workshop on Cooperative Buildings*, pp. 191-198, Pittsburgh: Springer.

15. 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.

16. Mogensen, P. (1994) *Challenging Practice*, DAIMI PB 465, Dept. of Computer Science, Århus University.

17. 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.

18. 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.

19. 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.

20. 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.

21. 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.

22. Venkatesh, A. (1985) "A conceptualization of household-technology interaction", *Advances in Consumer Research*, vol. 12, pp. 189-194.

23. Waldo, J. (1999) "The Jini architecture for network-centric computing", *Communications of the ACM*, pp. 76-82, vol. 42 (7), pp. 76-82.