The Ins and Outs of Home Networking: The Case for Useful and Usable Domestic Networking

REBECCA E. GRINTER, W. KEITH EDWARDS, MARSHINI CHETTY, ERIKA S. POOLE, JA-YOUNG SUNG, JEONGHWA YANG

School of Interactive Computing, Georgia Institute of Technology, Atlanta, Georgia, United States of America.

AND

ANDY CRABTREE, PETER TOLMIE, TOM RODDEN, CHRIS GREENHALGH, STEVE BENFORD

School of Computer Science and IT, Unversity of Nottingham, Nottingham, United Kingdom.

Householders are increasingly adopting home networking as a solution to the demands created by the presence of multiple computers, devices, and the desire to access the Internet. However, current network solutions are derived from the world of work (and initially the military) and provide poor support for the needs of the home. We present the key findings to emerge from empirical studies of home networks in the UK and US. The studies reveal two key kinds of work that effective home networking relies upon: one, the technical work of setting up and maintaining the home network, and the other, the collaborative and socially organized work of the home in which the network is embedded and supports. The two are thoroughly intertwined and rely upon one another for their realization, yet neither is adequately supported by current networking technologies and applications. Explication of the 'work to make the home network work' opens up the design space for the continued integration of the home network in domestic life and elaboration of future support. Key issues for development include the development of networking facilities that do not require advanced networking knowledge, that are flexible and support the local social order of the home and the evolution of its routines, and which ultimately make the home network visible and accountable to household members.

Categories and Subject Descriptors: H5.m [**Information Interfaces and Presentation**] – User Interfaces – *Miscellaneous*

General Terms: Human Computer Interaction

Additional Key Words and Phrases: Home Networking

ACM File Format:

This research was supported by the National Science Foundation CNS-#0626281 and the EPSRC, through the Equator project. Rebecca E. Grinter, and W. Keith Edwards were resident at the University of Nottingham when this research was conducted.

Authors' addresses: School of Interactive Computing, College of Computing, Georgia Institute of Technology, Atlanta, Georgia 30308, United States of America. E-mail: {beki, keith, marshini, erika, jsung, jeonghwa}@cc.gatech.edu. School of Computer Science and IT, University of Nottingham, Jubilee Campus, Wollaton Road, Nottingham, United Kingdom. E-mail: {axc, pdt, tar, cmg, sdb}@cs.nott.ac.uk.

1. INTRODUCTION

In the last decade, Human Computer Interaction (HCI) research has moved out of the office and into the home. While much is different between the two domains, empirical and technical interest in computer networks is not, either on the part of product developers, end-users, or IT researchers. Simply put, the home is an increasingly *networked entity*, comprising a multitude of connected devices and services distributed throughout the home. This trend towards the home network is being driven by a number of needs: sharing a single computer in a single location is an increasingly unrealistic proposition for household members; other devices in the home have to share access to the Internet; devices also and increasingly need to communicate with each other as well. Consequently the networked home has rapidly become a part of domestic computing.

The purpose of this paper is to present the results of a series of research studies that explore the work householders engage in to embed computing in domestic life and thus 'make the home network work'. These studies were conducted in two countries, the United Kingdom (UK) and the United States (US). Each focused on the work required to integrate the network into everyday life in the home [Chetty, et al. 2007;Grinter, et al. 2005;Tolmie, et al. 2007]. Prior to presenting our studies, we review research related to four key features of technology uptake and use in the home: adoption of domestic technology, communication, computing, and networking. We then describe our methods, and the households that participated in our research. Our reflection on these studies is presented in two sections each with a distinct focus. First we describe the work it takes to set up a network and the devices on it and then, second; we consider the practical work required for ongoing maintenance, which we characterize as 'digital housekeeping'. Finally, in discussion, we turn to our main point which is that the work of domestic networking relies a) on technical work to construct the network which is *poorly supported by design* at this point in time and b) on collaborative work that embeds the home network in everyday life and opens up *new possibilities* for design. We conclude that our studies suggest the need for HCI involvement in a more radical reconsideration of the nature of the networked domestic infrastructure.

2. RELATED WORK: STUDIES OF THE DOMESTIC

Over the last ten years HCI research has built a significant corpus of knowledge about domestic technology. In this section we review key literature from the HCI community, as well as work that pre-dates HCI but speaks to questions of technology in a domestic context. We caveat this section by noting two things. First, much research has focused on industrialized nations—therefore it is important to state that this research (our own included) makes certain assumptions may not follow in other parts of the world where domestic technologies are beginning to take hold, such as, for example, the so-called "Global South." Second, given that our empirical work took place in the UK and the US, we also also focused on related work that gave us context for understanding the history of domestic technology adoption in these two nations. Nevertheless, while we recognize that the ways in which technology is woven into everyday life exhibits distinct cultural differences, the current limitations of network technology and the collaborative character of the work that use necessarily relies on speak to broad concerns. After all, whether we live in New York or Yemen we still have to create and maintain the home network and incorporate it into the cultural milieu. *Creating and maintaining the local home network*, and *incorporating the network into the immediate social environment*, are issues that cut across a great many cultural distinctions and divides.

2.1 Adopting Domestic Technologies

Although a relatively new focus for HCI, the study of the history of the adoption of domestic technologies is an established concern. For example, at the turn of the 20th Century domestic scientists focused on studying a variety of technical systems and their role in supporting 'housework'. In the 1950s Lillian Gilbreth applied scientific management techniques, and time and motion studies in particular, to redesign both domestic practice and the physical layout of the home to make housework more efficient [Gilbreth, et al. 1954]. The results of Gilbreth's 'domestic engineering' influenced the built structure of the home, shaping the 'magic triangle' kitchen layout that became widespread throughout the Western world. Indeed, the 1950s was a boom time for domestic engineering as white goods and a host of novel labour-saving devices flooded the market. Their uptake was accompanied by a growing understanding of the systems that comprise the home: new indoor plumbing facilities and how they supported the movement of water in to, and waste out of, the home [Leavitt 2002].

The inter-relation between these emerging technologies and home life became a subject of some interest. In the 1940's and 1950's, in both Canada and Sweden women-led groups focused on consumption and its relationship to homemaking emerged to tackle debates about what consituted enough work [Parr and Ekberg 1996]. In the 1960's feminist scholars took up the question of gender and domestic technologies [Ravetz 1965]. More recently, Cowan's seminal study of housework, for example, focuses on the gap between the promise of domestic technologies and the reality of housework [Cowan 1983]. She notes that while domestic technologies such as washing machines were marketed to women as 'labour saving' devices, their adoption did not save as much time as promised. Rather, it triggered a change in expectations about how often people would change their clothes. So although washing was no longer a fully manual chore, the amount to be washed increased significantly. More generally Cowan argued for a broader analysis of what it means for technology to be adopted and that there is a particular need for us to explore the *patterns of action and interaction that actually surround a system*. This, in turn, may enable us to establish whether initial visions of labour saving (or any other promissory note) inherent within a technology actually exist in practice, or whether work shifts from one type of activity to another.

Surveys of labour in the home continue to suggest that women bear the chief responsibility for housework tasks such as cooking and cleaning. However, other studies also point to different kinds of home labour (such as Do It Yourself), and include activities such as the assembly and maintenance of home electronics including audio-visual (AV) systems [Gelber 1997]. In our work we took a broad view of what constituted digital housekeeping, focusing on the work being done.

Whatever the actual status of domestic work with respect to its gendered character, it is clear that the study of domestic technologies has a long history of looking at the relationship between infrastructure (including the built environment), the technology within it, and the work involved in using it. A dominant analytic perspective has emerged that focuses on the relationship between gender and technology, particularly on understanding who is doing the work and accounting for the role of technology in terms of the broader social order. The research reported here suspends a concern with gender in the study of technology [Chetty, et al. 2007;Grinter, et al. 2005;Tolmie, et al. 2007] and focuses, for reasons of design, on the practicalities of technology use in the home. We are less concerned at this point in time with whom as we are with what, though we take seriously the advice that we should look at the actual patterns of action and interaction or 'work' that surround technology. In this respect we suggest that our research may offer scholars of domestic life concrete insights into the nature of domestic work, how technology supports or hinders that work, and what the relationship between technology and housework encompasses.

2.2 Domestic Communications

Ever since the widespread adoption of the home telephone people have asked questions about the impact of communication technologies on domestic life. In the early 1900s, for example, executives of the Bell System (which was growing in dominance in the US telephone industry) worried about the recreational uses of the telephone. Indeed they went as far as to actively discourage the use of the telephone for social calls through advertising. Nonetheless it was the sociability of the phone, and its use in the domestic context in particular, that drove uptake and use and ultimately shaped the adoption patterns associated with this technology in the US at least [Fischer 1997]. Studies of communication technologies in the home have and are perennially accompanied by concerns with its effects on people, children and teenagers included. With respect to the home telephone researchers have suggested that the technology 'depersonalizes' communication and has been responsible (at least in part) for the increased sexual liberation of American teenagers [Lynd and Lynd 1929]. Similar concerns, and moral panics, have permeated analyses of successive communications technologies, including radio, television, mobile phones, and computers [Millwood Hargave and Livingstone 2006]. Discussion of the impacts of communications technologies on the inhabitants of the home is now a standard part of social commentaries on what it means to communicate from within the home and, in turn, what it means to use digital technologies for that purpose.

The telephone still plays a central role in domestic communications [Anderson, et al. 2002;Anderson, et al. 1999;Palen and Salzman 2002;Palen, et al. 2000] and despite the intentions of those early telephone executives, it remains a device in use to promote and reinforce familial and social ties [Anderson, et al. 2002;Anderson, et al. 1999]. However, the last decade has seen the wholesale arrival of the mobile phone and computer in the home, both of which have come to be used within the context of domestic communication. Examination of Short Messaging Service (SMS)—a text-based communications system originally available on Groupe Spéciale Mobile (GSM) networks but subsequently replicated on other wireless systems—provides some insight into the roles that domestic communications fulfil. SMS research has often focused on teenagers across Europe and Asia because they were among the earliest adopters of this technology for communications purposes [Grinter and Eldridge 2001;Harper, et al. 2005;Ito, et al. 2005;Ling 2000;Taylor and Harper 2002]. These studies report a variety of findings that uncover how SMS fits into the everyday circumstances that teenagers find themselves in: being able to transcend the physical limitations of circumstance, for example, and talk to friends at a distance; working around the schedule constraints imposed by the family; and using SMS to coordinate activities in real-time as opposed to having to arrange events and meetings in advance, etc.

Just as mobile phones have been rapidly appropriated into domestic communication, then so too have computers. In addition to email, bulletin boards, chat rooms, and Instant Messaging have all found a place within the home [Grinter and Palen 2002;Livingstone 2002;Turow and Kavanaugh 2003;Wellman and Haythornthwaite 2002]. Indeed in a comparative study that sought to answer the question of what drives people to use computing, Kraut *et al.* [1999] found that householders tended to be drawn to communication activities over information activities. Recent surveys in the UK similarly revealed that over 75% of computer use in the home revolves around communication, with 99% of survey respondents saying they use it to read and send email; 56% for instant messaging; 26% for chat rooms, and 13% for Internet telephone [OII 2009]. For over a century the landline telephone has been one of the primary technologies of communication for householders. However, in the last 20 years other

technologies, mostly noticeably the mobile phone and the computer have augmented it. Further, some of these new digital technologies and means of communication have been built on the telephone's infrastructure. Today, modems, Digital Subscriber Line (DSL) routers and WiFi piggyback on a global communications infrastructure and are rapidly populating the home to make new forms of communication possible. For example, research in Ubiquitous Computing has explored a range of ambient as well as direct communications devices, such as the InterLiving Project's InkPad system that allows family members to draw on a computer surface and by so doing share notes between houses [Lindquist, et al. 2007] or the Digital Family Portrait that supports the sharing of activity movement [Rowan and Mynatt 2005], or PlantDisplay that visualises how much time people spend communicating [Kuribayashi and Wakita 2006].

2.3 Domestic Computing

Mirroring previous interests surrounding other technologies, the growing popularity of personal computing throughout the 1980s led to the emergence of domestic computing as a distinct research focus. One of the earliest studies of domestic computer use highlighted the role of computers in telecommuting—using a modem in the home to connect to the corporate network. In the mid 1980s telecommuting was in its infancy and being positioned as a new mode of working. An initial survey of 282 homes [Vitalari, et al. 1985] highlighted the makeup of these early adopters of computers revealing (somewhat unsurprisingly) that 96% of telecommuters were male with a higher than average education level, that 63% of respondents reported being in a technical profession, and that the computer was used for purposes of work. More significantly, they noted that time spent on the computer was a trade-off against other activities that take place in the home, and that having a computer at home was a significant commitment, requiring technical knowledge to set up, run, and maintain. Ten years later Alladi Venkatesh [1996] saw different uses of the computer in the home. The rapid adoption of Internet technologies—in particular email and the web—had changed what was possible to accomplish with a computer at home. Domestic computer use was becoming increasingly diverse (a trend that continues today, and has been well captured by HCI research). Studies showed that in addition to telecommuting, recreational uses were also emerging which focused on using the resources of the Internet in support of home leisure activities [Kraut, et al. 1996;Lally 2002;Venkatesh 1996]. In the UK, a 2005 national survey reported that 77% of respondents reported using the Internet to plan and make travel arrangements, 54% for downloading music, 48% for playing games, and 18% for managing their photo collections. 50% used it for online shopping, 45% for banking, and 30% for paying bills [OII 2009]. Outside of this, 40% used it for accessing central and local government services. Creative use such as developing web pages and blogs was reported as being engaged in by 20% of the survey population and surfing the net, particularly in relation to local concerns (such as weather, traffic, and local news information) was reported by almost all respondents.

While communication remains at the forefront of computer use in the home, domestic computing has clearly burgeoned over the last decade. This has been accompanied by a growing interest in domestic computing by the HCI community to explore the possibility of designing applications for the home [Mateas, et al. 1996;O'Brien and Rodden 1997] or understand the full spectrum of domestic activity [Taylor, et al. 2008;Wyche and Grinter 2009]. One major line of domestic research has focused on understanding the *routines* of the home, including those implicated in technology use. This research has sought to explicate the ways in which householders collaboratively organize and conduct all aspects of domestic life. Through detailed attention to the nature of household routines, this line of research has sought to understand the barriers to

technology adoption in the home [O'Brien, et al. 1999], provide insight into what it means to design technologies that can be incorporated into everyday life in the home [Tolmie, et al. 2002], and highlight opportunities for richer domestic technology design that resonates with the demands of the home [Crabtree and Rodden 2004;Rodden, et al. 2004;Taylor and Swan 2005]. Another line of research has focused on the use of novel methods that suspend a concern with rationality, functionality and utility to explore domestic values, often in playful and provocative ways [Gaver, et al. 1999;Gaver and Martin 2000;Hutchinson, et al. 2003;Lindquist, et al. 2007]. Given the centrality of communication within the home, a number of systems have also been built and deployed in homes to explore new types of technologies to support communication. Some systems have explored the possibility to extend explicit communications—for example, providing new mechanisms for holding conversations [Hindus, et al. 2001]. Another approach has focused on facilitating communications by raising awareness of the whereabouts of family members [Brown, et al. 2007]. Instead of being designed for communication directly, this class of systems helps householders take advantage of potential opportunities to communicate as needed.

Behind much of this research is the presence or assumed presence of a *network connection*, both to connect the home to the digital world beyond the front door and to connect to an increasing array of devices and services distributed around the home. Network access is increasingly central to the computer's domestic utility, so much so that a great many households have expanded the network from a simple Internet connection for a single computer, to an intra-household network that shares the network connection across multiple machines and devices (such as Personal Video Recorders and dedicated game consoles), and supports services *within* the home (such as networked music players and home file servers). And it is the desire of householders to have networked applications and services that is driving commercial broadband and wireless service growth. And yet, although the infrastructure underpinning intra-home networks holds much promise, research already shows that the realization of the home network does not come without complications.

2.4 Domestic Networking

Given existing interest in both communication and computing use in the home, the explosive growth of the network during the early 1990s raised questions about how the spread of networking beyond a technologically sophisticated minority would impact the household. As early as 1996 research was showing that domestic networking was proving difficult. Franzke and McClard [1996] and Kiesler *et al*. [2000] reported how difficult users found creating even the simplest network case: connecting one computer to the Internet. Their findings stressed how participants needed technical knowledge to diagnose and deal with networked technologies, and that they turned to friends and family for help, a finding also observed in more recent research [Poole, et al. 2009]. Over a decade since, two things have changed. First, the field of Ubiquitous Computing has emerged with strong visions and an aggressive research agenda to build 'smart homes' and then leverage that intelligence to provide new classes of applications to support domestic life [Intille 2002;Kidd, et al. 1999]. Second, an increasing number of homes have adopted more complex networks that connect large numbers of devices inside the home together [Horrigan and Rainie 2002]. However, these two developments point to a serious tension or gap [Shehan and Edwards 2007]: the promise of future applications rests on the ability of *householders to manage the home network*, something that our collective research shows has not become easier since the first reports of connecting computers to the Internet.

We are not the first to comment on the complexity of technology demanded by the Ubiquitous Computing agenda [Harper 2003]. In a seminal study of the Orange Smart Home, Randall [2003] identified that even in use, the smart home creates a paradoxical situation for its residents. He learned that for the residents, albeit temporary ones in a research setting, the control system designed to provide householders with increased ability to manipulate the home was creating sufficient confusion as to leave them feeling out of control. Others have focused on the work needed to understand what it means for householders to be able to participate in or completely own the experience of making their home smart. Edwards and Grinter [2001] observe that for most people, and unlike most laboratory-built smart homes, making the home 'smarter' means adding technologies to *an existing structure*, rather than commissioning a builder to design a house that is smart from the ground up. This theme was further taken up by Rodden and Benford [2003] who applied Stuart Brand's [1994] architectural framework to analyse the complex relationship that potentially exists between the structure of the home and the technologies associated with domestic Ubiquitous Computing and then further extended to including networked technologies by Chetty *et al.* [2007]. Beckmann *et al.* [2004] focused on the complexity inherent in sensor networks designed to help computers determine the presence and activity of users through an array of devices that can detect movement, temperature, and so forth. They found, perhaps not surprisingly, that people struggled to install these types of networks and questioned whether it was appropriate to gather certain types of data in their homes at all.

The issue of network complexity, and how householders might come to manage it for themselves—thereby embedding computing in, and adapting it to, the ongoing circumstances of domestic life—is the principal concern of this paper. We begin by noting that, despite the difficulties, households are taking up a networked domestic life. Accordingly we seek to examine current practices surrounding the networked home and, from those practices, learn about possible solutions to issues of complexity. Our research shows not only the practices and routines that have emerged around home networking, but also the ways in which home networking remains non-trivial for even the most qualified of people—even those with advanced degrees in Computer Science. The research sheds light on the Ubiquitous Computing agenda and the real world character of 'intelligence' in the networked home, revealing what householders are seeking to do with their home networks and how they are making them 'fit into' the infrastructures—technical, physical, and social—that inhabit the domestic setting.

3 METHODS AND PARTICIPANTS

In this section we describe the methods we used to collect and analyse data, and the participants from whom we collected that data. Our studies took two somewhat different forms. In the United Kingdom (UK) our research took an ethnomethodologically-informed ethnographic approach. In the United States (US) we employed a qualitative approach using several different techniques to draw out the experiences of our participants. We describe each of these in turn.

3.1 Methods and Participants in the United Kingdom

The study in the UK focused upon tracking over time the efforts of three different households to install and maintain home networks. The study ran from May to December 2006 and involved a mixture of direct observations and 'catch-up conversations' designed to offer participants an opportunity to report on their ongoing experiences with the network between observations. Both the ethnographic capture of data and subsequent analysis were conducted from an ethnomethodological perspective [Suchman 1987], which is to say that we sought to describe in fine detail the social organization of the

home network as it was given in the methodical ways that members encountered and managed the network in the course of their day-to-day actions and interactions. Participants in the study included:

- *Household A*, consisting of two adults, one male, one female, 44 and 30 years old respectively, both computing professionals, living in a large two-bedroom apartment.
- *Household B*, a family consisting of 2 adults, one male, one female, 38 and 36 years old respectively, and 3 children, one 9 (a girl), one 7 (a boy), and one 15 months (another girl), living in a semi-detached house; one of the adults is a computing professional, all other members of the household have very limited technical experience.
- *Household C*, a family consisting of 2 adults, one male, one female, both 43 years old, and 2 children, one 12 (a girl) and one 9 (a boy), also living in a semi-detached house; once again one of the adults is a computing professional but all of the others in the household have no specialized experience of technology.

Whilst at least one member of each household was involved in computing in some sense, none of the households involved in the study could really be described as having 'advanced technology set ups'. Instead, as became quickly evident to us, each of the computing professionals involved were very reluctant to get too heavily involved in computing activities at home. The principal reason cited for this was that working with computers already consumed a significant part of their day. Having someone technical in the house does not, it would seem, by any means result in rapid technology adoption. Rather, it transpired that any technical undertaking in the home was and is accountable to a whole range of other everyday household concerns. The building of a home network wasn't driven by technical interest then, but was instead motivated by household members' concern to develop a solution to burgeoning technological complexity: multiple computers, multiple devices, and multiple demands being placed on them by various household members warranted and drove the construction of home networks for the participants in our study. With broadband connections amounting to over 70% of all Internet connections in the UK and a rapid uptake of wireless technologies, it is hard to maintain the notion of home network building being about experimentation done by 'geeks'. Instead people are installing home networks because it makes sense for them to do so in the face of computing technology that is increasingly *distributed throughout* the home and used by a variety of equally distributed different household members. Construction of a home network is a members' solution to the problem of distribution.

Our study of network construction and maintenance was conducted through monthly site visits, which were complemented by regular catch-up conversations over the telephone. The site visits were a critical part of being able to witness and understand the reasoning involved in a range of situated activities associated with building and maintaining the networks. However, as is apparent in the following sections, it transpired that network set-up and maintenance rapidly becomes an *ongoing and routine feature* of the broader pattern of household activities. We therefore kept in regular contact with the households in order to capture some of what that ongoing work involved as part of the participants' day-to-day experience. The site visits were conducted through direct ethnographic or participant observation [Crabtree 2003]. This entailed shadowing participants as they went about their activities in order to produce a fine-grained or 'thick description' [Ryle 1971] of the actions and interactions involved in setting up and maintaining their home networks. The aim of the approach was and is to uncover and explicate the various ordinary, *in situ*, and frequently tacit competences and collaborative

activities through which everyday courses of action (such as network maintenance) are accomplished and organized. Data capture here is comprehensive as there is no prior presumption as to what might or might not be significant. Instead the ethnographer aims to become party to the gamut of lively action and reasoning applied to situated circumstances as they arise. In this way matters such as network set-up and maintenance are seen as a practical accomplishments done by social actors performing their activities in the face of a host of local contingencies that inhabit their work [Garfinkel 1967].

The record of practice that emerges is similarly subject to ethnomethodological analysis where the focus is upon what can be learnt about recurrent patterns of action and reasoning through the inspection of particular 'instances' [Sacks 1984] in which the members of particular settings engage with and display their orientation to the ongoing and *organized work* of those settings [Button 1992]. Thus, whilst findings may be articulated through specific fieldwork vignettes, it should not be understood that what is being said is only of relevance to the particulars of each observed instance. Instead we are interested in broad characteristics of practical action and practical reasoning that make 'homes', 'households', 'housework', 'network maintenance', etc., recognizable as the organized accomplishments of members—that is, as accomplishments that you or I as well as those studied might recognize as organized accomplishments too. Thus, as people engage with concerns such as where to put technology, where to plug things in, how to organize furniture, what to tell children about using things, and so on, we are interested in both how the particular arrangements and characteristics shape how technology is 'made at home' in some particular setting, and how the *social organization* of practical action and practical reasoning is of broader relevance to our understanding of home networks and the potential for their continued development.

3.2 Methods and Participants in the United States

In the US we conducted two studies that followed the same protocol. The protocol consisted of two steps. First, we asked potential participants to fill out an inventory of their technology. The inventory was organized into three parts. Part one focused on technologies, in particular infrastructure technologies such as home control, security, cable, satellite systems, and network type (*e.g.*, WiFi, Ethernet). Part two asked the participants to locate technologies in each room of their house. Part three focused on those technologies that do not tend to be associated with a specific room, but rather with a particular householder. The goal of this inventory was to get a sense of the technologies that we were likely to encounter during the interview and to customize our interview for that particular household.

The second step of our home protocol consisted of a home visit, which was scheduled for a time when all members of the household would be present and available. This was limited to all 'typically occupant' householders—we did not attempt to schedule times when sons and daughters would be home from university or military service for example. The home visit itself was broken into three distinct parts. First, we asked our participants to each independently sketch their current Audio-Visual (AV) and Computer networks, and then draw what they thought they would ideally like (for more details see [Poole, et al. 2007]). The current network sketching exercise allowed us to understand what individual participants thought their network comprised (and from this we were able to identify differences among householders). We asked about their ideal to see what people aspired to, particularly where it differed from visions that we might hold in HCI or Ubicomp research. It also turned out that the sketches also served as a useful tool for 'warming up' the participants: being forced to think explicitly about their network helped them to reconnect to sometimes 'invisible' infrastructure technologies [Star 1999;Tolmie, et al. 2002]. After sketching we asked the participants to take us on a

guided tour of their home, to visit the locations where they had home networking or AV equipment. We included AV networks in this study for two reasons. First, AV represents a predecessor network in the home, meaning that such networks represent, for most people, an earlier instantiation of a complex constellation of interconnected devices. We anticipated that AV networks might have some influence in how people handled their computer networks. Second, AV and computer networks are increasingly converging with devices requiring the services of both (i.e., a MP3 player that gets content from the computer but plays it out through the speakers of the stereo). At each location we visited in the home, we asked the householders to describe what was going on, and prompted them to talk about their network. Again, we found proximity to some of the devices triggered memories about victories and disasters associated with networking. When the home tour was complete, we returned with the participants to the living room to finish asking questions.

We recruited participants in two metropolitan areas of the United States: San Francisco and Atlanta. In San Francisco our sample consisted of 8 households that were made up of two people (a man and woman) with dual-incomes and no-children. Our sample in this city intentionally focused on early adopter home network users, with complex network needs and configurations, in order to reveal both possible futures for home networking, and to understand how relatively expert users approach the challenges of networking in the home. Thus, these couples all had at least one householder with some formal or practical knowledge of networking, which took the form of an advanced degree in Computer Science, or many years of systems administration experience. In Atlanta, our sample consisted of 11 households, with a total of 28 individual participants. We sampled to broaden the types of household we visited beyond simply early adopters. Six of the households we visited included parents and children. Despite broadening our sample, all of our participants had higher than average household incomes (pointing to the costs of home networking, and of the reality of a "smart home"). More details about the participants and the methods are available in our earlier reports of these studies [Chetty, et al. 2007;Grinter, et al. 2005].

4 RESULTS: CONSIDERING THE NETWORK FROM WITHIN AND WITHOUT

In this section we present the results of our collective research organised into two sections that broadly reflect the work of 'digital housekeeping' [Tolmie, et al. 2007]. First we wish to reflect on the work required to introduce new devices and services into the home and to make them fit into the network and the household. Second, we talk about the ongoing work required to keep the devices and services working once they have been configured. In both sections, we wish to stress two interrelated types of work, the work to understand and work with the network as a technical artefact, and simultaneously the need to manage it as a social artefact.

4.1 Setting Up Technology in the Home

A common theme that emerges across our research in both the UK and US is the complexities that households face in setting up their technology at home and making it part of their home network. This complexity manifested itself in positioning the technology, maintaining the wider order of the home, and planning for change. We describe each of these in turn.

Many, if not all, of the households we visited discussed issues of *locating technology in the home—i.e.*, where they installed the devices that made up their home networks and why they chose particular places. In these conversations, a number of properties that home networks must fulfil came to light. Some stemmed from the physical and infrastructural properties of the house itself, while others spoke to the domestic order of

the household, family members' patterns of action and interaction with each other, and quotidian 'logics' that organise the home and the work within it. The physical properties of the house required that householders reason about the network in a variety of ways. The presence of wireless networks, marketed in part to work around the constraints of the physical house, did not always mean that our participants did not have to think about their home. For example, participants described learning about the physical properties of their homes, such as the thickness of the walls, through their experiences of locating their wireless base station(s) within their home. Householders told us about the reach of their wireless networks, the strength of the signal, and the places where parts of their home hidden behind their walls (load bearing walls being attributed as being particularly thick) blocked or reduced their network connectivity. Wireless networks—both those belonging to the household, as well as those belonging to neighbours—appeared at various places in the physical environment of our participants' homes. Some families talked about not only where they could and could not connect to their own network, but also where they saw someone else's signal. Indeed, we saw evidence in the form of repositioned furniture to capitalise on 'free network access' in parts of the home that their own household wireless networks did not cover.

The need for power was a significant constraint on device location. Devices had to be situated by the wall jack, or power had to be "moved" to where householders wanted the technology. In older houses (where power outlets were less common), literally fulfilling the need for power required the development of complex schemes including plugging multiple extension cords into each other (forming a chain) in order to cope with a situation where there was a jack with at most two outlets serving between six and ten devices competing for power. In some cases infrequently used devices might be disconnected, but many components (*e.g.*, the television, the router) occupied such a central role that they had to be constantly plugged in. Participants recognised that the overloading of wall jacks with chains of extension cords was hardly the safest solution. As we discuss below, the presence of young children can make this type of arrangement unacceptable. Another problem we found with this solution was that the circuitry could not meet the power demands of the devices, leading to other difficulties. In one case, it took the householders several months of living with a problem before they figured out that when they turned on certain combinations of devices, their circuit would fail to provide enough power (brown-out), which in turn caused their router to lose its IP address thus disabling the network. After they finally determined the problem with their router, this put the household into the position of having to redesign their network to accommodate their electrical wiring.

Despite the obvious need to connect devices to a power supply, extension cords also served another purpose, to move devices so that they were positioned in the places that householders wanted. In these cases, we learned about locations that were grounded in our shared sense of where certain activities should happen. Discussions about the shape of the room, the possibilities of arranging furniture, and most importantly expectations about what types of activities took place where (which orientation, with access to what lighting, because the furniture would not fit any other way, because it was important to have access to other parts of the home, etc.) led our householders to arrange their rooms and in so doing configure their activities in particular ways. They then worked hard to ensure that devices could be connected into that space in ways that fitted into that usage plan.

Another type of consideration that emerged in our households focused on children, who often surfaced a set of logics concerned with physical safety of both children and household devices. Households confronted the challenges posed by children by putting devices in places where they could not be reached, and making sure that wires were

installed in such a way that they would not be tripped over. Decoration also mattered in the sense that tidiness and appropriate visibility/invisibility came up for our householders. We found cases of DSL modems being hidden under couches, because householders did not like to see the blinking lights in their living rooms. We saw 'nests' of wires behind the backs of televisions and other large devices in order to hide them from view. In one instance, having abandoned an attempt to hide these wires, one family had decided instead to decorate them, as if to acknowledge their presence and attempt to integrate them more aesthetically into the home. In another case potentially unsightly nests of cables were placed on a windowsill where pre-existing clutter would render them relatively invisible, stressing that invisibility for householders is often not about literal absence of perceptual availability but rather a matter of making features wholly commonplace [Tolmie, et al. 2002].

These *ecological placements*—which are rooted in the household's desire to have their network reflect their household order—turned on not just the power needs of devices but also on data requirements. Wireless networks provided some flexibility in this regard, but we also encountered other types of networks in use in order to allow data to reach a device. Both phoneline and powerline bridges, technologies that use the existing home phone and electrical wiring infrastructure, respectively, to pass data traffic, were present in some of the homes we visited. Participants explained that these technologies allowed the home network to evolve in ways that supported how they used their physical space.

Related to the work of positioning particular network elements, we also heard about the work of *making changes while retaining wider order* during installation. Installing a single device, or making more complex changes and/or enhancements to the network, we learned, was typically a complex activity involving disruption to the household. In most but not all households, we saw that this activity tended to fall to one individual—typically a person with some type of formal knowledge (either acquired through formal education in Computer Science and related disciplines and/or through professional experience of holding jobs that entailed some level of computing competence) took up the responsibility associated with making changes to the network. The fact that this pattern repeated itself across the homes in our collective studies immediately suggests one challenge for Ubiquitous Computing and related disciplines, the necessity of not requiring such specialized knowledge in order to set up, maintain and evolve home networks. This is particularly important if Ubiquitous Computing is to reach out to broader sections of the population.

The person responsible for these changes often described undertaking two kinds of related activities. First, the person thought about the addition of new technology, or the reconfiguration of the network, in its technical terms. By this, we mean that part of this job was to consider the entire network, and its topology, to make sure that the undertaken change not only provided the desired goal but also did not break existing services. For many of our householders this goal turned out to be surprisingly hard. Just knowing what services the network was providing was sometimes more complicated than it might appear. For example, households with teenagers—who reported making their own changes and modifications to the network—sometimes did not have a unified knowledge of what was on their network or the services it provided (and where it delivered those applications). In other cases, we heard about seldom-used services, easily forgotten when making changes, and discovered only after the change had been made.

This set of considerations was closely coupled to a broader, out of network, set of plans that also needed to be made. Additions and changes were often described as being very disruptive. The physical mess associated with the technology was often ungainly,

cluttering up space around the network. But this was not the only problem that these householders considered: they also described thinking about the network as a collection of services embedded in the broader routines of the home. Changes to the network frequently meant disruption to those routines. Additions of print servers might mean that printers would be offline; re-cabling an audio-visual network to include a Personal Video Recorder or iPod would mean that others could not watch television or use the receiver.

For all these reasons, making changes to the network was frequently described in terms that emphasized not only the modifications, but also the means by which order within the network and the home would be preserved. These changes were also sometimes framed in terms that highlighted the anxiety and apprehension about the complexities of maintaining order while making change. In fact, one family who had been trying to resolve a problem on their network described how it had been on their to-do list, in one form or another (referring to the different solutions that they had tried) for over 3 months, and because of that they saw any new change as one of great risk. One solution that some home administrators used was to minimize the disruption caused by change by waiting for an appropriate time such as when other householders were not present. In a more ambitious case, when a household had decided to install an Ethernet-based network, they waited until their home was undergoing renovations to make the change, leveraging a more intense change to the physical structure of the home as an opportunity to make this more minor modification.

In addition to making decisions about the location of devices, and thinking about how to make changes while maintaining order, other *planning* activities also took place. This planning work had two foci, first, the technical work of making the network work, and second, making the system fit into the domestic order of the household. The technical network focus manifested itself in at least two ways. First, we were amazed, particularly in households that had elaborate home networks (multiple machines and subnets, wired and wireless, powerline and phoneline, connections to one or more corporate network and so forth), by the sheer amount of equipment that was not in the network currently but on hand for supporting changes and upgrades. We found cupboards and chests of drawers devoted to wires and other network devices such as routers, servers, and hubs. When we asked why these householders had so many different types of cables and devices, we learned that their sense of change was that it was likely to be complicated enough to require specialized cabling, so they planned for needing it and kept it to hand. Indeed, it appeared to be analogous to not starting a home renovation project without all the appropriate equipment (a need to have all the "parts" so that the job could be finished in a timely manner).

Another way that network planning manifested itself was through the maintenance of homemade network diagrams (not to be confused with the ones that we asked the participants in the US studies to sketch in the course of our study). These diagrams reflected our participants' need to track what was on the network and how it was connected together. Some of the labels communicated the role that the device was serving, for example, whether it was just passing traffic or whether it was configured for Network Address Translation (NAT) and so forth. Others parts of the diagram communicated whether firewalls were present (even if they were in software and not in hardware) and sometimes listed the ports that were live. All of this served to help those householders in the work of planning change to the network (and again suggest the current level of complexity that home networking requires on the part of the household).

The diagrams also spoke to the second focus of planning, understanding how the network fitted into the domestic order. Devices, most notably computers, were given labels that also spoke to who tended to use them. Jan's computer, for example, implicated a particular member of the household in any intended change that involved or

affected that machine. The diagrams also served as a resource for understanding change within the context of the household itself. This concern—how change would affect the household—also manifested itself in household discussions about what constituted appropriate changes to the network and for what reasons. For example, most households with children talked about the plans that they had made to acquire new technology to support their children's educational needs. Other households talked to us about their differing views on network changes based on whether they thought it was appropriate to undertake computer-related activities in certain rooms in the home. Planning involved discussions about financial realities of the household, aesthetic considerations, and whether the new addition would provide services that were appropriate in context of device placement, and the routines of action and interaction within various rooms of the home.

In summary, throughout the broader 'setting up' activity we saw a constant attention to what we describe as *within* and *without* network concerns. The technical *within* network focus manifested itself in resolving technical constraints, in leveraging creative solutions to appropriate device placement, in thinking about how to preserve the technical functionality of the system while making changes, and in leveraging a variety of resources (cabling, networking equipment, diagrams) to ensure that changes to the network were successful. The broader *without* focus on the household order was apparent in and articulated through local logics of device placement based on routines, in householders' respect for those routines in planned disruptions, and in keeping track of who might be affected in updates.

4.2 Housekeeping of Digital Resources

Beyond the setting up of devices, we saw another kind of digital housekeeping associated with the smooth running of everyday network services for householders. Within this we saw that some routine management tasks require much more consideration in the domestic setting, that householders have to take up questions of access and security, and that digital media management presents a new challenge for the home.

Just as in office settings, our visits and interviews revealed that householders confront a range of routine network management tasks such as backups and systems upgrades. However, unlike the office setting where backups, systems patches and updates may happen automatically as a result of connecting to the corporate network (and taking advantage of the managed infrastructure typically available there), we did not see any evidence of such systematic automation at home. Instead, householders tended to do this work explicitly, when they decided to do it at all. Again, this work, like that of set up, also reflected the dual foci on the network itself as a technical entity and on the relationship between the network and the household. This work, the housekeeping of digital resources, also highlighted the tight interconnection between the technical and domestic work associated with home networking.

In most households, backup was also largely the responsibility of a single individual. This householder tended to think more about the consequences of backing up, and understood the technical intricacies of what it meant to lose data and attempt to restore a machine and its files. Other householders might participate in backup-related activities, such as emailing copies of important files to themselves, but they were not nearly as involved in this work. For the person who did consider, and sometimes implement backup schemes, their knowledge by necessity included some understanding of what the others might have done, and their machine usage patterns. While the former was used to support them in their decisions about when to back up, the latter helped them to know where files were likely to be stored (particularly if there were central and local options) as

well as finding a good time to do this type of work since it would likely preclude the person from using that device/files during that time.

We also learned that in some households, another set of technical and household concerns got bound together in ways that complicated and even confused assignment of responsibility for certain support tasks. In particular, in some households we learned about a strong distinction made between *device* support activities and *network* support activities. This distinction turned on a sense among the household that devices (especially computers) were considered to be owned by a member of the household. In these cases, we also saw the device *ownership in use* was coupled with device *ownership in maintenance*. The person who used the computer was expected to be able to do maintenance, despite the different levels of knowledge and ability to perform such tasks. In these cases, we also learned about tension among householders with some feeling that they had responsibility for things they couldn't and didn't want to do, while others felt the need to refuse to take on more work to make the home network work.

The dual questions of *access* and *security* also came up in terms of managing the digital resources that comprised the home network. Households with children exhibited some of the most explicit questions about access and security, and some solutions that used a variety of technical and social methods appeared to strike the right balance between access and security. Adults in our studies spent time and energy deciding how to balance their children's use of the Internet (and the resources that it made available for learning and recreation) against the uncertainties and threats that use of the Internet may pose. Some families installed specialized software, seeking a technical solution to the problem of security. But these solutions in turn ask families to explicitly state what is permitted and what is not, something that outside of the context of actual exploration and practice can be hard to know definitively. Worse still, these solutions tend to reify a standard (sites allowed, sites not allowed) set of expectations as if all households will respond to the same sites in the same ways, something that our households reported they did not align themselves with in all cases.

Alongside technical means for managing access and security, our families also developed strategies that leveraged other properties of the network, most notably its hardware and location, within the broader home. For example, one family determined that their children could use the network but only in 'public places' within the home such as the kitchen or dining room, but not the bedroom. These householders simply disconnected the bedroom computer from the network and then allowed their children to use it. A number of families had a public space like kitchen devoted to an Internet-connected computer, which was often used by children for homework while cooking took place, allowing parents to supervise their children's online computer use. These computers were positioned in such a way that adults in the kitchen had a 'good view' of the monitor in use by their children. Security then was accomplished by using their knowledge of their own routines within the home marrying adults' activities to the rules that governed children's Internet usage.

Access and security questions also came up with respect to wireless networks, and we observed both technical and social resources being used to manage the use of such networks. In almost every house, at least one householder was aware of the technical insecurity of most consumer wireless protocols (such as WEP), but still used these solutions because of the difficulty of using more secure systems (such as EAP-TLS). Other households coupled these Wi-Fi based security protocols with other network architectural decisions that increased network security, such as using NAT to ensure that inbound attacks could not easily access the internal network devices, and also enabling MAC address filtering, so that only certain machines could use the network. Other people left their networks open. Some people sought to invite 'good use' by their neighbours,

which meant that they did not mind if other people used their network as long as they didn't then engage in bandwidth intensive activities. In this mode, offenders would receive a physical visit from a member of the householder and be asked to refrain from downloading such bandwidth heavy material. Householders used social expectations about what constituted appropriate activity to manage this kind of access. Other people, despite having left their networks open, did not appear to invite their neighbours to access it. Indeed, in one case, where a household lived on a large plot of land, the householders determined that their wireless network did not exceed their property boundaries and consequently they decided that no one would be likely to trespass and use their network. A final irony was that in considering access and security, some of our households exhibited a rather inconsistent policy. A few households took technical security mechanisms to lock down their own wireless network, while simultaneously feeling little remorse if they ever used their neighbours' insecure networks. A few people even admitted to looking into their neighbour's networks, identifying devices and even opening files. But these same people spoke about a dilemma, while they wanted to tell their neighbours that they were insecure, householders valued being able to use that network, particularly when their own was down.

A final area that produced a variety of housekeeping tasks focused on the *management of digital media*. A common recurring theme in our studies was the complexity of managing the ever-increasing volume of digital media including digital images, music, and movies. Housekeeping around digital media often seemed to come up in conversation as being deeply unsatisfying for householders, a case of 'doing the best possible' in circumstances that were both technically and socially complicated. For example, one question that plagued our households was where to store digital images. Images taken off cameras often ended up on the hard drive associated with the machine to which they had been downloaded; much less frequently did we find images on a central machine that acted as a unified file store (in part, we think, because the notion of local versus central file shares seemed to be an abstract concept for some householders, one grounded in a technical understanding of networking that was not familiar or easy for some of our householders to understand). However, that led to situations where media was strewn around the individual machines of the household, making joint or household collections difficult to easily construct.

Music highlighted how this tension between individuality and collectivism was even designed into devices. For example, we found several households who had integrated an iPod into their AV network, so that they could play digital music through their home stereo system. However, iPods can only be associated with one computer at a time, meaning that the person who had the iPod controlled which music was playable at home via the AV network. The householders whose music was not stored on the iPod typically commented on the difficulties of not being able to play their preferred choices. More generally, we suggest that the increased emphasis on digital media is not well coupled to solutions for managing those files.

Day to day digital housekeeping–*i.e.*, the work of supporting the network and its resources—reveals how the technical and social concerns of domestic networking are tightly integrated. Householders engaged in a variety of technical strategies for managing back ups, some that would be familiar as back up even to computing professionals, and others that supported critical file recovery. At the same time, back ups also required understanding the patterns of use that householders engaged in on the network. Access and security illustrates how householders used technical and social solutions, sometimes in concert, to manage their resources while securing themselves from perceived threats. Simultaneously, we learned about some householders who could 'read' and exploit the

potential gaps in others' inability to manipulate access and security. Finally, digital media seemed to present a myriad of difficulties associated with making collective use of resources that by their very design are intended for individual use. Domestic digital housekeeping consists of working with not only the technical artefacts of the network, but also the social routines of action and interaction, in order to find working solutions to making the network at home on a day-to-day basis. And, in both countries, and in all 22 households that we collectively examined, finding these working solutions was a non-trivial activity, but one frequently required as the home network continued to evolve to meet the changing demands of the household.

5. DISCUSSION

While the promise of homes populated by a heterogeneous collection of computational devices offering a range of "smart" services continues to motivate research and product development, the networking on which those visions rely remains neglected. Yet whether motivated by visions of 'smartness' or by more mundane concerns with technical complexity, households are beginning to assemble their own collection of devices and services in their homes. Our research argues that we need to examine *what* households are constructing and *how* they provide for the ongoing configuration and maintenance of the home network in order that we might better understand and respond to the real world challenges involved in making the home network into a routine feature of domestic life. Collectively our research begins to address this by examining home networks as they exist and by learning from householders about the rationale that guides their initial set up and ongoing maintenance activities. Critically, we have found that constructing and maintaining the home network relies two types of closely interlinked work. First, there is the technical work required to understand the network as a technical artefact, and with that knowledge make the technical changes required to preserve, enhance and evolve the infrastructure and services that it offers. Second, there is the work to understand how the network supports the households' routines.

Our studies show that the work required to implement home networking presents significant challenges. Some of these stem from the fact that networking technologies were designed for an entirely different context of use than the home. The Internet began as a research project (ARPAnet) funded by the U.S.'s Advanced Research Project Agency (the research arm of the military) [Abbate 1999]. As a consequence the design objectives focused on facilitating research (at a time when processing power was very expensive) and creating an internetwork that was reliable even in the event that parts of it were unavailable to route traffic. Design for this context led to the development of the protocols and principles that today's Internet architecture reflects. And now those design values have entered the home, appearing to have ruled out other possibilities for domestic networking even though some argue that it is precisely these conflicting principles that create the difficulty with home networking [Calvert, et al. 2007;Shehan and Edwards 2007].

For HCI, and related fields such as Ubiquitous Computing, this mismatch presents significant obstacles to success. Our research shows that design priorities rooted in the history of the ARPAnet have led to the loss of ease of installation, maintenance and evolution for domestic Internet users. In both the UK and the US, even people who have advanced computing knowledge struggle with home networking. And yet it is this very infrastructure that is at the root of many visions of domestic HCI. It returns us to Cowan [1983] who argues that technologies do not always save labor, but rather they may transform it. Home networks create a significant amount of work for their owner-operators, a work which we have collectively shown presents serious challenges and time commitments. These time commitments include the work that householders do to make

decisions about how to technically set up the network, position devices, configure security to balance the maintenance of access, decide how best to support backups, and so forth. In addition to having to implement these decisions in the network, our householders also took on a challenge that comes from the physical infrastructure of the house itself—a building not yet designed to support network infrastructure. In the case of device placement, features of the house itself, like the wall jacks and load bearing walls, influence the ways in which it is technically possible to set up the network and its devices. Indeed, in some households we saw that the problems associated with the house led to the adoption and use of other types of technologies intended to work around the difficulty of not having networking proximate to the devices. To make networking work, sometimes householders engineered very complex technical solutions.

Our emphasis on physical infrastructure also calls for further research. Our research suggests that older homes are more complicated to deploy home networks in, having less electrical outlets and failing to provide enough power. But the house itself is also a source of potential cultural difference. In the two US sites, San Francisco and Atlanta, differences in housing density played a significant role. All of our householders could see networks belonging to their neighbors in San Francisco, in Atlanta some of our householders owned property that completely contained their WiFi. As 802.11 networks continue to profilerate, for end-users they are embedded in physically different circumstances, range is not just a technical property, it is one that becomes mapped onto others including property boundaries that in turn may change whether people attempt to secure that network. The physical construction of the home was also something householders had to learn, to understand the possibilities (installing Ethernet, understanding signal strength, how much they could load their their electrical circuitry). And although we did not explicitly compare, we expect that differences in construction methods and regulations will be a part of how household solutions evolve. For example, homes in UK are typically built of brick, while wood is the common construction method in the US, and how the two pass signal is different.

This technical work is also intertwined with another type of work needed to make the home network work: something we have previously described as digital housekeeping [Tolmie, et al. 2007]. This is the work of fitting the network into a household's routines. And by bringing our two studies together we have shown the range of digital housework practices. We have described how the network needs to accommodate the routines of each household, such as having devices positioned in places that make sense in broader terms of who uses the room (children supervised by their parents, adults only) what the space is used for (watching television, surfing the web) and the configuration of furniture therein. We want to stress here that these routines belong to the household, and do not always transfer from one home to another. For example, we found a few households with occupants who had very strong views about the appropriateness of television in the living room. When framed in terms of statistics, the adoption of television has been profound, appearing in almost every home. Yet we saw differences, and very strongly held positions, on where television (and indeed the computer) could live in the home, and households differed in their decisions. It is, then, important to appreciate the *flexibility* and *evolution* of household routines and respect this when developing alternate solutions; indeed designing for flexibility and evolution would seem to be key. Here again, our collective studies highlight less of a national-cultural divide, and more of a household values diversity.

When designing for the routine, the network must be made to reflect the practical concerns of the home. We saw this manifest itself in a sense that the network should be made 'presentable' so that it fits in to the home. Some families put their networked

devices; particularly those that people did not interact with directly like modems and base stations, in surprising places. We found at least one modem under a couch, and found a wireless repeater worked into a flower arrangement. Minimally, we suggest that this argues for making not just the end-user technologies aesthetically pleasing, but also for giving thought to the potential to disguise or camouflage the other devices in the network so that they can be "hidden" in plain view. Beyond this simple design suggestion, our emphasis is on highlighting that *being tidy matters* to households, and the network must reflect these concerns. And again, this crossed studies, reflecting a common concern with keeping the home tidy, while also illustrating the myriad of possibilties for accomplishing tidiness.

A third aspect of the work that householders take on when they adopt and use networking technologies is *making the network accountable to the domestic order* that exists in the home. This manifests itself very visibly in planning for change. We learned about the strategies that our households have for trying to minimize disruption when the network is about to under go change, including waiting until people were not going to need the resources provided by the network, and in some cases, laying in supplies of cables and other equipment so that when projects started they would end as quickly as possible. Whatever strategy our householders used, their sensitivity to understanding the routine engagements of other people with the network was an integral part of planning any change. A fourth type of consideration that householders factored in, particularly with respect to the ongoing maintenance of the network, was balancing the time dedicated to network work against all of the other time commitments that existed within their home. In addition to making decisions about when and how often to do various types of network-related work, the household also had to decide when was an appropriate time to respond to something going on with the network, in much the same way that householders have to decide whether or not to answer a phone during meal-time.

Underpinning this discussion of the technical and socially organized work involved in making the network at home is a sense that householders are constructing unique networks. In the technical sense, we found very different architectures in the households that we visited. For example, we found some households with networks that consisted of multiple sub-networks, while others did not make such distinction. We also saw differences in the types of machines connected, the level of integration of the computer and A/V networks that many households had, and the types of services that the home network provided. These technical differences reflected important social differences among the households that we visited. The households varied in a number of important ways such as number of rooms, division of routine across those rooms, overall house size, number of occupants, the relationships among the occupants, and the types of infrastructure coming into the home that would support a home network. All of these in turn became reflected in the network itself, such as decisions about what device would be where, used by whom, when, and so forth. They also reflected external concerns, for example, one reason some of our American participants had separate networks was to do with tax law, the ability to separate home business from home personal network uses. Critically, the home network is not just designed as a technical entity, it is a reflection of a variety of individual, household and even national concerns.

This degree of variability has, we suggest, been under-examined, but presents a significant challenge for deploying the applications that are posited for the digital environment of our future homes. The degree of variability presents a challenge because it reflects households as a *local* and more global social order. Variability in the network reflects how each household uniquely decides and enacts an order that makes their concerns, their aspirations, the ideas about what it means to live together make sense and seem appropriate. Home networking, we suggest, has to accommodate these differences,

indeed its success relies upon it being answerable to the local social order at work in any home. Another observation is that this local understanding makes at least one possible trajectory for home networking, the standard scripted solution, complicated at best. Indeed, our householders described how people coming into their home to set up new devices would follow a set script for installation, assuming that their network was a generic entity. As soon as the installer left, the householders would then disassemble the device and connection and rebuild it so that it was actually compatible with their network. This local understanding and the need to make the network fit into *this* home also suggests the need for sophisticated types of home network management tools that work with people's technical needs and skills, and which make the ways in which they configure, use and maintain the network accountable and thus available to practical reasoning.

A final theme that binds the technical and social together is that of financing. In the US households we visited, we asked for estimates of the number of bills paid for the network, and in some cases we even learned about the rough monthly totals for the network. All of those on-going costs, and all the costs associated with purchasing devices (bar those that are provided by the corporations that our householders worked for) are born by the household itself. A consideration of financial costs also factored into what services the network was tasked to provide, such as whether a service, or a new a device, made sense for the household. Consideration of the financial implications of home networking, and domestic computing more generally, has also not received as much attention from the HCI community as they merit. We suggest that domestic computing and the domestic HCI agenda cannot avoid the consideration of the price-performance that applications provide, because very clearly householders do not ignore it; instead they bring it into their conversations about what is necessary and what might be deferred or simply rejected.

6. CONCLUSIONS

We have presented the results of studies of home networking that took place in the United Kingdom and the United States. The focus of these studies was on understanding how householders are incorporating networking technologies and the services that they provide into their homes. The studies suggest that understanding domestic networking involves examining the complexities of the technical and the social work that must be accomplished for the network to fit into the home. Domestic home networking offers numerous opportunities for Human-Computer Interaction. Clearly, one take away from this research is that great potential exists for innovation in applications and interfaces that help householders with home networking. Today's situation suggests that adoption and use of home networks largely relies on the technological skill of one household member, which would seem to support current approaches to delivering networks to the home. However, studies of domestic networking offer a new lens through which to examine what it means for people to participate in and belong to the networked home. While set-up and maintenance may be largely fall to one individual in the home, the network itself reflects a host of quotidian concerns that occupy household members as individuals-in-a-collective. Understanding how those concerns are reflected in the ongoing set-up and maintenance of the home network opens up the design space for developing the home of the future.

We would suggest that the emergence of the domestic networking may require a more radical reconsideration of the network. Our studies offer significant evidence of the way in which the network is shaped by the localised needs and desires of the home. This included the physical setting of the home, the routines of the home and the everyday

activities that take place. However, the Internet has not been driven by these localised needs rather it has been driven by issues of scale and complexity where the network explicitly does not embody any notion of anticipated or expected use. This is an issue that require deep engagement by HCI and is much more than providing user-friendly interface to an infrastructure that does not reflect the nature of the home. Rather, we need to redress this schism by consider how we might reinvent the network infrastructure itself from a user driven perspective where usability plays a central role in reconsidering and reshaping the design decisions at the core of the network.

ACKNOWLEDGMENTS

We would like to thank all the people who took part in this research. We acknowledge the support of the Engineering and Physical Sciences Research Council (EPSRC) through the Equator and HomeWork projects and the National Science Foundation (NSF) NSF-CNS #0626281.

REFERENCES

ABBATE, J. 1999. *Inventing the Internet.* MIT Press, Cambridge, MA.

ANDERSON, B., GALE, C., GOWER, A.P., FRANCE, E.F., JONES, M.L.R., LACOHEE, H.V., MCWILLIAM, A., TRACEY, K. and TRIMBY, M. 2002. Digital Living—People-Centred Innovation and Strategy. *BT Technology Journal* 20, 2, 1-20.

ANDERSON, B., MCWILLIAM, A., LACOHEE, H., CLUCAS, E. and GERSHUNY, J. 1999. Family Life in the Digital Home - Domestic Telecommunications at the end of the 20th Century. *BT Technology Journal* 17, 1, 85-97.

BECKMANN, C., CONSOLVO, S. and LAMARCA, A. 2004. Some Assembly Required: Supporting End-User Sensor Installation in Domestic Ubiquitous Computing Environments. In *Proceedings of the Sixth International Conference on Ubiquitous Computing (Ubicomp 2004)*, Nottingham, UK, September 7-10, Springer-Verlag: Lecture Notes in Computer Science 3205, 107-124.

BRAND, S. 1994. *How Buildings Learn: What Happens After They're Built.* Penguin Books Inc., New York, NY.

BROWN, B., TAYLOR, A., IZADI, S., SELLEN, A. and KAYE, J. 2007. Locating Family Values: A Field Trial of the Whereabouts Clock. In *Proceedings of the 9th International Conference on Ubiquitous Computing (Ubicomp 07)*, Innsbruck, Austria, September 16-19, Springer-Verlag,

BUTTON, G. 1992. *Technology in Working Order.* Routledge Press, London, U.K.

CALVERT, K.C., EDWARDS, W.K. and GRINTER, R.E. 2007. Moving Towards the Middle: The Case Against the End-to-End Argument in Home Networking. In *Proceedings of the ACM Workshop on Hot Topics in Networks (HotNets-VI)*, Atlanta, GA, November 14-15, ACM Press,

CHETTY, M., SUNG, J.-Y. and GRINTER, R.E. 2007. How Smart Homes Learn: The Evolution of the Networked Home and Household. In *Proceedings of the 9th International Conference on Ubiquitous Computing (Ubicomp 07)*, Innsbruck, Austria, September 16-19, Springer-Verlag,

COWAN, R.S. 1983. *More Work for Mother: The Ironies of Household Technology from the Open Hearth to the Microwave.* Basic Books, Inc., New York, NY.

CRABTREE, A. 2003. *Designing Collaborative Systems: A Practical Guide to Ethnography.* Springer-Verlag, Heidelberg, Germany.

CRABTREE, A. and RODDEN, T. 2004. Domestic Routines and Design for the Home. *Computer Supported Cooperative Work (CSCW): An International Journal* 13,191-200.

EDWARDS, W.K. and GRINTER, R.E. 2001. At Home With Ubiquitous Computing: Seven Challenges. In *Proceedings of the UbiComp 01*, Atlanta, GA, September 30-October 2, (LNCS 2201) Springer-Verlag., 256-272.

FISCHER, C.S. 1997. "Touch Someone": The Telephone Industry Discovers Socialibility. In *Technology and American History: A Historical Anthology from Technology and Culture*, S.H. CUTCLIFFE and T.S. REYNOLDS Eds. University of Chicago Press, Chicago, IL, 271-300.

FRANZKE, M. and MCCLARD, A. 1996. Winona Gets Wired: Technical Difficulties in the Home. *Communications of the ACM* 39, 12, 64-66.

GARFINKEL, H. 1967. *Studies in Ethnomethodology.* Prentice Hall Inc., New York, NY.

GAVER, B., DUNNE, T. and PACENTI, E. 1999. Design: Cultural Probes. *Interactions* 6, 1, 21-29.

GAVER, W.W. and MARTIN, H. 2000. Alternatives: Exploring Information Appliances through Conceptual Design. In *Proceedings of the ACM Conference on Human Factors in Computing Systems, CHI '00*, The Hague, The Netherlands, April 1-6, ACM Press, 209-216.

GELBER, S.M. 1997. Do-It-Yourself: Constructing, Repairing and Maintaining Domestic Masculinity. *American Quarterly* 49, 1, 66-112.
GILBRETH, L., THOMAS, O. and CLMYER, E. 1954. *Management in the Home*. Dood, Mead and Co, New York, NY.
GRINTER, R.E., EDWARDS, W.K., NEWMAN, M. and DUCHENEAUT, N. 2005. The Work to Make the Home Network Work. In *Proceedings of the The 9th European Conference on Computer-Supported Cooperative Work*, Paris, France, 18-22 September, K. SCHMIDT Ed. Kluwer Academic Press, 469-488.
GRINTER, R.E. and ELDRIDGE, M. 2001. y do tngrs luv 2 txt msg? In *Proceedings of the Seventh European Conference on Computer-Supported Cooperative Work ECSCW '01*, Bonn, Germany, September 16-20, 2001, W. PRINZ, M. JARKE, Y. ROGERS, K. SCHMIDT and V. WULF Eds. Dordrecht, Netherlands: Kluwer Academic Publishers, 219-238.
GRINTER, R.E. and PALEN, L. 2002. Instant Messaging In Teenage Life. In *Proceedings of the ACM Conference on Computer Supported Cooperative Work (CSCW 2002)*, New Orleans, LA, November 16-20, M. TWIDALE Ed. New York, NY: ACM Press, 21-30.
HARPER, R. Ed. 2003. *Inside the Smart Home*. Springer, London, UK.
HARPER, R.H.R., PALEN, L. and TAYLOR, A. Eds 2005. *The Inside Text: Social, Cultural and Design Perspectives on SMS*. Springer, Dordrecht, The Netherlands.
HINDUS, D., MAINWARING, S.D., LEDUC, N. and BAYLEY, O. 2001. Casablanca: Designing Social Communication Devices for the Home. In *Proceedings of the Conference on Human Factors in Computing Systems CHI '01*, Seattle, WA, March 31 - April 4, New York, NY: ACM Press, 325-332.
HORRIGAN, J.B. and RAINIE, L. 2002. *The Broadband Difference: How Online Americans' Behavior Changes with High-Speed Internet Connections at Home*. Pew Internet and American Life Project.
HUTCHINSON, H., MACKAY, W., WESTERLAND, B., BEDERSON, B., DRUIN, A., PLAISANT, C., BEAUDOUIN-LAFON, M., CONVERSY, S., EVANS, H., HANSEN, H., ROUSSEL, N. and EIDERBACK, B. 2003. Technology probes: inspiring design for and with families. In *Proceedings of the Proceedings of the SIGCHI conference on Human factors in computing systems*, Ft. Lauderdale, Florida, USA, 5-10 April, ACM Press, 17-24.
INTILLE, S.S. 2002. Designing a Home of the Future. *IEEE Pervasive Computing* 1, 2, 76-82.
ITO, M., OKABE, D. and MATSUDA, M. Eds 2005. *Personal, Portable, Pedestrian*. MIT Press, Cambridge, MA.
KIDD, C., ORR, R.J., ABOWD, G.D., ATKESON, C.G., ESSA, I.A., MACINTYRE, B., MYNATT, E.D., STARNER, T.E. and NEWSTETTER, W. 1999. The Aware Home: A Living Laboratory for Ubiquitous Computing Research. In *Proceedings of the Second International Workshop on Cooperative Buildings (CoBuild'99)*, Pittsburgh, PA, October 1-2, 1999, N.A. STREITZ, J. SIEGEL, V. HARTKOPF and S. KONOMI Eds. Heidelberg, Germany: Springer-Verlag,
KIESLER, S., ZDANIUK, B., LUNDMARK, V. and KRAUT, R. 2000. Troubles With the Internet: The Dynamics of Help at Home. *Human Computer Interaction* 15, 4, 323-351.
KRAUT, R., MUKHOPADHYAY, T., SZCZYPULA, J., KIESLER, S. and SCHERLIS, W. 1999. Information and Communication: Alternative Uses of the Internet in Households. *Information Systems Research* 10, 4, 287-303.
KRAUT, R., SCHERLIS, W., MUKHOPADHYAY, T., MANNING, J. and KIESLER, S. 1996. HomeNet: A Field Trial of Residential Internet Services. In *Proceedings of the ACM Conference on Human Factors in Computing Systems CHI '96*, Vancouver, B.C., April 13-18, 1996, M.J. TAUBER Ed. ACM Press, 284-291.
KURIBAYASHI, S. and WAKITA, A. 2006. PlantDisplay: turning houseplants into ambient display In *Proceedings of the Proceedings of the 2006 ACM SIGCHI international conference on Advances in computer entertainment technology* Hollywood, California June 14-16, ACM Press, Article #40.
LALLY, E. 2002. *At Home With Computers*. Berg, Oxford, England.
LEAVITT, S.A. 2002. *From Catherine Beecher to Martha Stewart*. The University of North Carolina Press, Chapel Hill, NC.
LINDQUIST, S., WESTERLUND, B., SUNDBLAD, Y., TOBIASSON, H., BEAUDOUIN-LAFON, M. and MACKAY, W. 2007. Co-Designing Community Technology With and For Families — Methods, Experience, Results and Impact. In *The Disappearing Computer: Interaction Design, Systems Infrastructures, and Applications for Smart Environments*, N. STREITZ, A. KAMEAS and I. MAVROMMATI Eds. Springer-Verlag, Berlin, 99-119.
LING, R. 2000. *Norwegian teens, mobile telephony and text messages*. Technical Newsletter from Telenor Research and Development. 2-2000.
LIVINGSTONE, S. 2002. *Young People and New Media: Childhood and the Changing Media Environment*. Sage Press, London, UK.
LYND, R.S. and LYND, H.M. 1929. *Middletown: A Study in Modern American Culture*. Harcourt Brace Jovanovich, Orlando, FL.
MATEAS, M., SALVADOR, T., SCHOLTZ, J. and SORENSEN, D. 1996. Engineering Ethnography in the Home. In *Proceedings of the ACM Conference Companion on Human Factors in Computing Systems CHI '96*, Vancouver, B.C., April 13-18., M.J. TAUBER Ed. ACM Press, 283-284.

MILLWOOD HARGAVE, A. and LIVINGSTONE, S. 2006. *Harm and Offence in Media Content: A Review of the Evidence.* Intellect Press, Bristol.
O'BRIEN, J. and RODDEN, T. 1997. Interactive Systems in Domestic Environments. In *Proceedings of the Conference On Designing Interactive Systems (DIS 97)*, Amsterdam, The Netherlands, August 18-20, ACM Press, 247-259.
O'BRIEN, J., RODDEN, T., ROUNCEFIELD, M. and HUGHES, J. 1999. At Home with the Technology: An Ethnographic Study of a Set-Top-Box Trial. *ACM Transactions on Computer-Human Interaction* 6, 3, 282-308.
OII 2009. The Oxford Internet Institute: The Internet in Britian Today. *The Oxford Internet Survey* www.oii.ox.ac.uk/research/oxis/oxis2005_report.pdf,
PALEN, L. and SALZMAN, M. 2002. Beyond the Handset: Designing for Wireless Communications Usability. *ACM Transactions on Computer-Human Interaction* 9, 2, 125-151.
PALEN, L., SALZMAN, M. and YOUNGS, E. 2000. Going Wireless: Behavior and Practice of New Mobile Phone Users. In *Proceedings of the ACM Conference on Computer Supported Cooperative Work (CSCW 2000)*, Philadelphia, PA, December 2-6, 2000, D.G. DURAND Ed. New York, N.Y.: ACM Press, 201-210.
PARR, J. and EKBERG, G. 1996. Mrs Consumer and Mr Keynes in Postwar Canada and Sweden. *Gender & History* 8, 7, 212-230.
POOLE, E.S., CHETTY, M., EDWARDS, W.K. and GRINTER, R.E. 2007. Designing Interactive Home Network Maintenance Tools. In *Proceedings of the ACM Conference on Designing Interactive Systems (DIS 2008)*, Cape Town, South Africa,
POOLE, E.S., CHETTY, M., MORGAN, T., GRINTER, R.E. and EDWARDS, W.K. 2009. Computer Help at Home: Methods and Motivations for Informal Technical Support. In *Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI 09)*, Boston, MA, April 4-9, ACM Press, to appear.
RANDALL, D. 2003. Living Inside a Smart Home: A Case Study. In *Inside the Smart Home*, R. HARPER Ed. Springer-Verlag, London, UK, 227-246.
RAVETZ, A. 1965. Modern Technology and Ancient Occupation: Housework in Present Day Society. *Technology and Culture* 6,256-260.
RODDEN, T. and BENFORD, S. 2003. The Evolution of Buildings and the Implications for the Design of Ubiquitous Domestic Environments. In *Proceedings of the ACM Conference on Human Factors in Computing (CHI '03)*, Fort Lauderdale, FL, April 5-10, ACM Press, 9-16.
RODDEN, T., CRABTREE, A., HEMMINGS, T., KOLEVA, B., HUMBLE, J., AKESSON, K.-P. and HANSSON, P. 2004. Between the Dazzle of a New Building and Its Eventual Corpse: Assembling the Ubiquitous Home. In *Proceedings of the ACM Symposium on Designing Interactive Systems*, Cambridge, MA, Sept 1-4, ACM Press, 71-80.
ROWAN, J. and MYNATT, E.D. 2005. Digital Family Portrait Field Trial: Support for Aging in Place. In *Proceedings of the ACM Conference on Human Factors in Computing (CHI '05)*, Portland, Oregon, 2-7 April, ACM Press, 521-530.
RYLE, G. 1971. The Thinking of Thoughts. *University Lectures* 18, University of Saskatchwan: Canada.
SACKS, H. 1984. Notes on Methodology. In *Structures of Social Action*, J.M. ATKINSON and J. HERITAGE Eds. Cambridge University Press, Cambridge, UK, 21-27.
SHEHAN, E. and EDWARDS, W.K. 2007. Home Networking and HCI: What Hath God Wrought? In *Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI 07)*, San Jose, California, ACM Press, 547-556.
STAR, S.L. 1999. The Ethnography of Infrastructure. *American Behavioral Scientist* 43, 3, 377-391.
SUCHMAN, L. 1987. *Plans and Situated Actions: The Problem of Human-Machine Communication.* Cambridge University Press, Cambridge, UK.
TAYLOR, A. and HARPER, R. 2002. Age-old Practices in the "New World:" A Study of Gift-Giving Between Teenage Mobile Phone Users. In *Proceedings of the Conference on Human Factors in Computing Systems CHI '02*, Minneapolis, MN, April 20-25, New York, NY: ACM Press, 439-446.
TAYLOR, A., WYCHE, S.P. and KAYE, J.J. 2008. Pottering by Design. In *Proceedings of the NordCHI 2008 the 5th Nordic conference on Human-computer interaction*, Lund, Sweden, ACM Press, 363-372.
TAYLOR, A.S. and SWAN, L. 2005. Artful Systems in the Home. In *Proceedings of the ACM Conference on Human Factors in Computing (CHI '05)*, Portland, Oregon, 2-7 April, ACM Press, 641-650. Best Paper Nominee.
TOLMIE, P., CRABTREE, A., RODDEN, T., GREENHALGH, C. and BENFORD, S. 2007. Making the Home Network at Home: Digital Housekeeping. In *Proceedings of the The 10th European Conference on Computer-Supported Cooperative Work*, Limerick, Ireland, September 24-28, Springer-Verlag,
TOLMIE, P., PYCOCK, J., DIGGINS, T., MACLEAN, A. and KARSENTY, A. 2002. Unremarkable Computing. In *Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI 2002)*, Minneapolis, MN, April 20-25, ACM Press, 399-406.
TUROW, J. and KAVANAUGH, A.L. Eds 2003. *The Wired Homestead: An MIT Press Sourcebook on the Internet and the Family.* MIT Press, Cambridge, MA.

VENKATESH, A. 1996. Computers and Other Interactive Technologies for the Home. *Communications of the ACM* 39, 12, 47-54.
VITALARI, N.P., VENKATESH, A. and GRONHAUG, K. 1985. Computing in the Home: Shifts in the Time Allocation Patterns of Households. *Communications of the ACM* 28, 5, 512-522.
WELLMAN, B. and HAYTHORNTHWAITE, C. Eds 2002. *The Internet in Everyday Life.* Blackwell Press, Oxford, UK.
WYCHE, S.P. and GRINTER, R.E. 2009. Extraordinary Computing. In *Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI 2009)*, Boston, MA, ACM Press,

Received February 2008; revised February 2009; accepted ???