More Than Meets the Eye: Transforming the User Experience of Home Network Management

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ABSTRACT
As computing migrates from the workplace to the home, householders must tackle problems of home network maintenance. Often they lack the technical knowledge or motivation to complete these tasks, making the user experience of home network maintenance frustrating. In response to these difficulties, many householders rely on handwritten reminders or interactive networking tools that are ill-suited for the home environment. In this paper, we seek to understand how to design better home network management tools through a study of sketches created by 40 people in 18 households. In our study, we obtained information about householders' knowledge, practices and needs with respect to home networking. Based on our results, we present guidelines for transforming the user experience of home network management.

Categories and Subject Descriptors
H5.m. Information interfaces and presentation: Miscellaneous.

General Terms
Human Factors.

Keywords
home networks, sketching, troubleshooting

1. INTRODUCTION
Recently, a growing body of research in the human-computer interaction community has focused on the user experience difficulties of home networking (see, as recent examples, [4,7,9,17,21,26,36]). As computer networking has migrated from managed environments to the home, householders—whether they want to or not—are having to tackle problems of network setup, maintenance, and repair. These users are confronted with protocols, tools, and terminology that were created during a time when networks were architected and maintained by skilled (and paid) network administrators; the result is that home network management is a frustrating and tedious experience for most householders.

Much of this body of research presents the results of fieldwork designed to highlight the difficulties faced by home network users, and unpacks the root problem areas that are the sources of trouble. These impediments include (but are not limited to) factors such as unequal distribution of network knowledge in the home, the "invisibility" of the settings and configuration information required to properly set up the network, poor strategies for diagnosis and troubleshooting, and tensions between individual and household ownership of devices. Although this fieldwork has identified many of the problems of home networking, it has illuminated relatively few solutions to those problems. How can designers create tools that help (largely disinterested) householders to more easily set up, manage, maintain, fix, and even *understand* their networks? Further, how can these tools calmly accommodate and support the practices and routines of the home, while at the same time allowing for householders to complete "housekeeping" chores of network management?

Addressing the problems of home network management poses a difficult design challenge, as there is a gap between the data we can elicit from householders and the specific insights required for designing new technologies for the home network. For example, as noted by Grinter et al. [21], householders are often unable to verbally articulate accurate information about their networks, meaning that conventional interviews and think-aloud techniques may yield few specific design insights beyond "it should just work."

In this paper, we seek to bridge this gap by providing insight on how to design home networking management tools matching the knowledge, needs, and practices of ordinary householders. Our approach to gaining such insight is a set of studies analyzing the sketches householders drew of their own home networks. Our results suggest that sketching is a promising technique for uncovering the (often unspoken) details about technology that may otherwise be invisible in practice. We report our analysis of 40 sketches from 18 households. The sketches yield not only low-level data about how users conceive of the home network, but also data about the usage and evolution of individual home networks. Our findings highlight and reaffirm insights by Brand [6], Star [33], and others about the relationship of humans to the various infrastructures in the home environment.

In the next section we examine more closely why we chose sketching as a method for gaining insight into users' conceptions of networking. Following this discussion, we examine two bodies of work that relate to our own research. The first body of research focuses on studies of the networking in the home, and the second focuses on technical attempts at addressing some of the challenges posed by network management (and why these attempts have not succeeded in the home). We then present our methods and the results of our studies, organized along key findings. Finally, we conclude with a set of design implications drawn from our analyses.

2. Why Sketching?
Due to unfamiliarity with networking terminology, householders are often unable to verbally describe the current

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state of their network, detailed information about an intended ideal state, or their own internal conceptions of how the network works. Faced with this conundrum, we were encouraged by several pieces of research that relied on sketching to elicit information about peoples' conceptions of complex topics. For example, Vosniadou and Brewer used sketching to uncover children's perceptions about the world [38]. Elementary school students were asked to sketch what they thought the earth "looked like," in order to elicit details about their internal models of the earth (Is it flat or round? Do people live inside it or on it?). Similar methods have also been used in behavioral psychology to find how children reason about the Internet [41]. In a study with adults, Hendry used sketches to elicit mental models of search engines and created a set of mappings from user sketches to abstractions that may be useful in the search engine domain [23]. Other studies have examined users' conceptions of their email structure [16]. Given these prior results, we believed that sketching could be employed to uncover householder conceptions about home networks, at a level of detail that would support in-depth analysis in a way that interviews might not.

Beyond the uncovering of internal models, however, researchers have also relied on user sketches to elicit more reflective feedback as input to design. Tohidi, for example, reports on a design process for a house climate control system [35], in which users sketched their ideal thermostat design as a method to gather design ideas for interfaces that went beyond what could be collected using think-aloud and interview data. In Tohidi's study, sketches allowed quick analysis and visual comparisons as well as deep interpretation by the researchers. More closely related to the topic of networking, Friedman et al. [20] studied the use of sketching to uncover users' conceptions of web security. Researchers asked users to draw and explain concepts such as a "secure connection" on the web, and analyzed subjects' drawings to categorize them into several groups, based on the representations they sketched.

Previous studies of home networking have shown that users *already* use drawings and other self-created visual representations to help them with managing the network [9,36]. Further, all these studies demonstrate the promise of end-user produced sketches as a tool for eliciting information about how users conceive of entities that may be difficult to verbalize otherwise. Thus, we believed that a more systematic collection and analysis of householder-created sketches could yield insights into how better to design tools to support these users

We therefore developed a study design in which end-users would create sketches of their own networks. In multi-person households, we asked each householder to create separate sketches without consulting one another. The sketches were later analyzed for key commonalities and themes. The analysis technique is described in depth in the Methods section.

3. RELATED WORK

Here we describe two threads of prior research on network usability: studies of the problems of networking in the home, and technical solutions intended to make networking easier.

3.1 Home Networking

In the last few years, researchers have become increasingly interested in usability issues associated with home networking. As the complexity of the home network increases, so do the difficulties of configuring, upgrading, and troubleshooting. Envisioned "smart home" and ubiquitous computing applications (such as [10,30,40]) require more devices and more complex network topologies; these in turn lead to more burden on the householder to understand and maintain the network [7,26]. Yet, even in homes that could hardly be considered a ubiquitous computing "smart home," many occupants have significant difficulty setting up and troubleshooting their existing networks [4,9,13,21,36].

Some researchers—from both the networking and the HCI communities—have argued that these user experience problems are in fact inherent in the design of the core Internet technology (such as TCP/IP, and basic end-to-end architectural principles) that is the basis of current home networking (see [3,8] and [31] for a more complete discussion of this issue). Similar arguments are, in part, impetus to a host of efforts aimed at "redesigning" the Internet to provide better security, manageability, and so forth (see, for example, the National Science Foundation's GENI initiative in the US). Such "clean slate" approaches have the potential to lead to a greatly improved user experience for networking in the home; however, there is much inertia in the current infrastructure, leading to path dependencies that make the current technology hard to replace [29]. Without such wholesale revamping of the Internet architecture and protocols, users will likely be faced with some degree of network maintenance for the foreseeable future.

Focusing on homes using the current Internet-based technology, Grinter et al. [21] found that networks are difficult for even sophisticated householders to understand and manage. One of the reasons for this difficulty is the effective *invisibility* of the network, meaning that the configurations of individual machines, parameters needed for communication with the network, and patterns of traffic flow are all hidden unless one explicitly looks for them. Looking for this information may require skill with arcane tools and seldom-used configuration panels. One result of this effective invisibility is that householders are often confused about how to pursue fixes to problems, often relying on a strategy of systematically rebooting devices [4]. To compound this difficulty, oftentimes householders do not even know which devices are on their networks. Networking equipment may be added or removed by one occupant without the others knowing that this change had occurred. Furthermore, some householders may not know that certain devices exist at all if they have been placed in hard-to-see areas because of aesthetic concerns [9,21].

Other researchers have found that in response to the difficulties of home networking, some people create visual reminders—such as Visio diagrams, post-it notes and instructions—to help them understand and manage their networks [9,36]. These aids, however, are of limited usefulness; Chetty et al. [9] remark that householders need aids that go beyond simple post-it notes to more interactive tools that allow them to "see" the dynamic state of the network within their homes. Tolmie et al. [36] note that householder network diagrams are good for a local understanding of the home network but not as useful for external service providers.

Although a number of researchers have called for better management tools for the home network [9,17], the form these tools should take is unclear. We have little data explaining how users conceive of their home networks, nor do previous research efforts suggest how to use this information to influence the design of tools to support home network management. Further, given that home network management occurs around other daily routines and practices [12,34,37], it is not clear which aspects of the network may need to be represented in any visually-oriented tool. For instance, both simple network oriented details as well as intricate depictions of the network as

they relate to the physical and social dynamics of the household may have merits and limitations.

3.2 Existing Tools for Network Management

The research and commercial spheres have developed a number of network management tools. Most of these tools, however, were designed for workplace network management, where there are different constraints and assumptions than one would see in the home environment. First, many of these tools are designed for use by people with advanced technical knowledge of networking [5]; tools such as HP OpenView[1], for example, provide a complete network management suite intended for use by entire professional technical support departments. In contrast, most householders who manage home networks today tend to have informal knowledge of networking at best, and little motivation to learn and use complex management suites [9,21]. Second, many of these tools—such as VISUAL and EtherApe, and a range of 3D tools—focus on highly scalable visual representations that are necessary for large networks (*e.g.,* thousands of nodes) [1,24]. Home networks are typically orders of magnitude smaller, and thus visual representations that put scalability in a position of primacy over other considerations may be inappropriate in this context. Third, tools such as Ethereal[2], and a wide range of command line programs including *ping*, *netstat*, and *traceroute*, generally provide low-level details on latency, traffic patterns and bandwidth consumption, leaving the user to interpret data and make the necessary conclusions about possible causes of problems; the home network—with its less experienced or motivated users—is likely better served by tools that provide more directed troubleshooting guidance.

Recently, several tools designed for a context of use other than the workplace and non-expert users have appeared. For example, one of the only tools that specifically targets home network management is Pure Networks' *Network Magic*[3] software. The program provides a map of devices on the home network, capabilities to monitor network intruders, and views of shared files and printers. Although it provides a much simpler view than the enterprise or expert oriented tools described above, Network Magic omits a number of details that appear even on householders own self-created diagrams, including detailed configuration settings of individual devices, as well as other aspects of dynamic state such as network activity.

Still other tools provide awareness of network activity, but are not aimed at management. For example, Etherpeg[4] provides network users with collages of image files that are flowing over a network. Natalie Jeremijenko's LiveWire system, described by Weiser and Brown [39] is an ambient display of network traffic in which the movement of a hanging string is proportional to the amount of traffic on the network. In addition to these examples, there are tools that can provide some visibility of hidden aspects of networking, such as software indicators revealing strength of wireless signals [14].

All of these tools, however, provide only a narrow window into the state and activity of the network, and provide no support for understanding the nuances of the network that may be useful for overall management. In effect, a collection of narrow, ambient displays for network status – in the form of the indicator lights on routers, cable modems, and access points – is what most householders rely on at present. In reaction to these impoverished interfaces, a number of researchers have called for better interoperability standards, a set of usability principles intended for connected consumer products [22,25,28,32], and animated instructions for device setup [19]. While these recommendations are certainly a step in the right direction, most of this work focuses on improving the setup and use of single devices, rather than the holistic experience of setting up and using the complex constellations of devices normally found on entire networks.

[1] http://h20229.www2.hp.com/

[2] http://www.ethereal.com

[3] http://www.networkmagic.com/

[4] http://www.etherpeg.org/

4. METHODS

We collected data for this work during two studies focused on exploring householders' use of complex home networks. We have previously reported some findings from these studies [9,21], but in this paper our attention is on the data that was generated in a sketching exercise we asked the participants to undertake. Although we focus on the sketch data collected, our studies employed three primary instruments. The first instrument was an inventory form designed to filter out homes that did not have networks of sufficient complexity for investigation—those without devices connected together or to the wider Internet via a wired or wireless network. In this instrument, we also collected demographic information about each participant, including any professional IT experience, advanced degrees in technology-related fields (e.g. engineering, information systems), and role in setting up and maintaining the home network.

The second instrument was a sketching exercise in which occupants drew their home networks. During the course of the studies, 40 people from 18 homes in two metropolitan areas in the United States completed an exercise in which they independently drew visual representations of their home computer networks (routers, modems and other computing devices), audio/visual (AV) networks (televisions, receivers, VCRs and other AV equipment primarily for recreation), as well as their "ideal" home network—one that they would like to have independent of any constraints on time, finances, or reality. The sheets of paper provided for the sketches informed study participants that they could use boxes and lines for representations. Participants were also verbally instructed to draw their networks in whatever form or shape they desired. All participants worked independently, and were not allowed to view or discuss each others' sketches until completion of the exercise.

The third instrument used was a home tour followed by semi-structured interviews. The tour provided us with additional details about the uses of technology in the home, and surfaced the occupants' problems in trying to control, use, and adapt technology to their needs. Study participants' sketches served as a prop and a pre-home-tour primer for the researchers. First, seeing the sketches helped the researchers gain a sense of the layout of the home network so that they were prepared for which equipment to seek or be on the lookout for on the home tour. Further, the sketches themselves served as a tool for eliciting discussions about the home network. For instance, householders could point to items in their drawings as they spoke with the researchers. (Likewise, the researchers could also point to items drawn by householders and inquire about them). As each householder explained his or her sketches, issues such as how the network was connected and who was responsible for various devices surfaced.

We analyzed the sketches by coding every single item in every drawing, using a technique similar to those used in previous sketch-based studies [23,35]; our scheme resulted in over 100 codes in three groupings. The first group of codes referred to how networking devices—including end-user devices, peripherals, audio/visual equipment, and infrastructure devices—were drawn and labeled. Several sketches also included old or broken devices that were once on the network but were not necessarily connected to the network at the time of the study. For each device, we noted whether representations were depicted pictorially (for example, a small picture of a laptop) or abstractly (such as a box representing a particular laptop). We also noted how items in the drawings were labeled. For instance, we coded whether labels referred to the person who owned the item ("Bob's laptop"), brand ("TiVo"), location ("Living room PC"), or other nomenclature such as technical terms.

The second group of codes referred to how connected items—including the network as a whole—were represented in sketches. For example, we examined the representations of links between items drawn by users. For example, these links usually were depicted as lines, waves or a textual label such as 'wireless' or 'wired'. In this part of the coding, we also noted whether householders mentioned groupings of items or networks external to the home, such as 'the Internet' or perhaps a neighbor's wireless access point.

The third group of codes referred to how householders drew aspects of the physical infrastructure of their homes—for instance, whether they drew rooms in their houses, icons to represent furniture, or parts of the house such as cable/phone jacks or electrical outlets.

Finally, in addition to analyzing the sketch data, we compared the themes emerging out of this data with other information collected from our interviews and home tours as well as from studies conducted by other groups on householder needs and routines surrounding home network management [4,9,21,36].

5. RESULTS

In this section, we describe the results of our sketching analysis. First, we discuss the different ways that people organized their networks in their sketches. Second, we highlight how for some of our participants, elements of the network conceptually blurred together. Third, we review the types of labels householders used to talk about their networks. Throughout our discussion, we categorize study participants based on their degree of engagement with the home network (i.e. as users, or also as people who actively worked to set up, maintain and repair the network). Based on suggestions contained in previous research, we sought to make this distinction among people to see whether differences manifested themselves in the sketches based on the different roles that householders had with respect to the network.

In the remainder of this paper, we refer to three distinct groups of householders. We call people who took responsibility for setting up, maintaining, and fixing the network *gurus* (n=19). Three households had two gurus, two had none, and the rest had one. Our second group, *assisters*, consists of people who assisted with network maintenance, but did not lead these activities; we encountered nine of them in our study. Finally, those individuals who used the network, but did not engage in any network administration we call *consumers* (n=12). We made these distinctions based on self-reports by the participants, and confirmed our hypotheses about the roles that they played through the home visit, since during these visits all participants provided great detail about their level of responsibility and engagement with the devices that comprised the home network. Note that we do not wish to imply any value judgments associated with these distinctions—rather we attempted to capture each household's division of labor.

5.1 Layout: Organizing Schemes

One of the most striking differences among the sketches coincided with the roles householders played in network administration. Perhaps unsurprisingly, *gurus* especially and some *assisters* tended to draw the home network following "traditional" networking conventions—those learned through the type of training (such as a computer science or electrical engineering degree, or learned through a career in systems administration) still largely required to own a home network today [21]. Specifically, our *guru* and *assister* participants often opted for diagrams that illustrated how devices were connected together: a "logical" view of the network that illustrated its topology without any reference to any other type of organizational scheme. In our data this represented 43% of our gurus and assisters—and is illustrated by the top sketch in Figure 1.

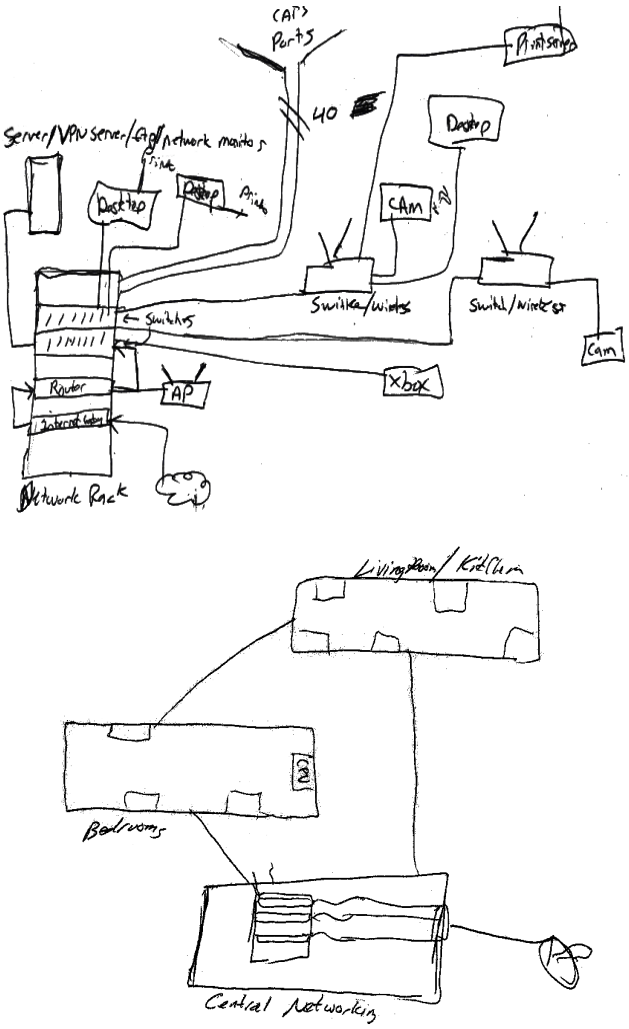

Figure 1: Two sketches of the same network. The guru (top) depicts individual technical components of the network infrastructure, whereas the consumer (bottom) describes the backbone of the network as a single entity called "central networking".

Another 21% of our *gurus* and *assisters* drew diagrams that were largely logical, but included elements drawn from another organizational scheme for describing the network—a physical/spatial organizational scheme that reflects spatial orientations and placements within the home, rather than simple connectivity. This style is illustrated in the top sketches in both Figures 2 and 3, which both include physical and spatial elements. In Figure 2 the wall appears and is shown connected to the cable modem. In Figure 3, the diagram makes reference to the "upstairs audio" implying that the device has a physical position within the house. This scheme—a hybrid of logical and physical—was particularly used by a subset of our *assister* population who identified as not having formal or practical network training.

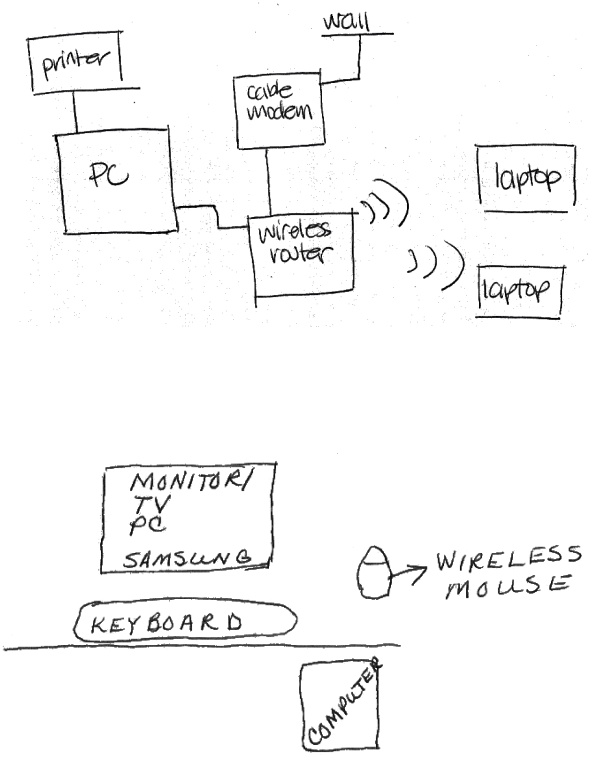

Figure 2: Inclusion of physical/spatial information: Top drawn by guru and bottom drawn by consumer.

By contrast with the *assisters* and *gurus*, our *consumer* participants drew heavily on the physical organization of the home as a method for organizing their view of the network. Indeed, over two-thirds of our *consumer* participants used the physical layout of the home as a mechanism for showing where the home network was located. This is illustrated in the bottom sketches in Figure 1 and 2. Participants varied in their degree of expression about connectivity. In the bottom sketch of Figure 1, the participant draws a representation of connectivity among the rooms of the house, and a separate place that the participant referred to as "central networking"—her characterizations of the room in the house where the networking equipment was located.

Figure 3 (which was not the only sketch that included the whole house in cross-section) goes so far as to include pieces of furniture in the diagram, a couch in this case. In other cases, beds and desks were drawn. The addition of furniture, not "logically" related to the network, appeared in 42% of all the sketches we saw by consumers. Through conversation, we learned that these pieces of furniture were—in the minds of these participants—in fact a "part" of the network. Furniture, alongside rooms, represented settings for home network usage. The couch was the place where some networking activities occurred for the participant who drew the bottom sketch in Figure 3. In other words, this participant also used routines of activity as a conceptual scheme for thinking about the home network.

Routines-of-use also appeared in other sketches. In one sketch, we saw a laptop appear in multiple places in the physical-spatial diagram. Critically, it was the same laptop—and consequently a diagrammatic representation that would violate the logical view of the network. However, what it expressed for this participant, which we were immediately able to grasp, is the local mobility provided by this laptop within the domestic setting. This participant's view of the home network was coupled to different settings of use.

For some participants, it was not only their own usage that showed up in diagrams, but also that of other householders, notably children. For example, in Figure 4 we see a participant's description of how her daughter's computer is configured. It shows some network access; the computer could connect to the printer, but not to the Internet. As the householder explained, these restrictions were in place because the machine was in the child's bedroom, and thus would not easily allow supervision of online usage; thus, the PC was disconnected from the Internet, but could access the printer so that the daughter could complete homework assignments in her bedroom.

When asked to draw their networks, our participants used a variety of resources to organize their diagrams. For some, notably *gurus* but to a lesser degree *assisters* as well, a degree of logical connection was depicted and likely a reflection of their knowledge of the links between devices on the network. Also, we saw some of our participants' formal training emerge in their diagrams; indeed a few *guru* participants provided us with pre-drawn diagrams during the home visit that followed the traditional technical ways of organizing and depicting networked devices. Some turned to the built environment as a scheme, or included elements of the home infrastructure. Interestingly, this complements Rodden and Benford's [27] argument that the physical systems of the home (such as its geographical location, its walls and floors and the central systems) as well as their evolution should all be taken into account when considering the design of domestic computational technologies. We suggest that participants are already in part expressing connections between the network and their homes by representing elements of their physical home and its infrastructural systems in their diagrams. Our previous research suggests that people do confront the physicality of their homes when using the network, so perhaps it is no wonder that these relationships are made manifest in their diagrams [9]. We also saw sketches that made reference to the routines of use in the home, for instance where laptops are frequently used. Previous research has demonstrated the importance of understanding routines when considering the design of domestic technologies [11,12,34]. Sketching, as a mechanism for eliciting information about the network, appears to capture some of those routines and situate the network within that context by showing us where certain activities take place.

In conclusion, we found that householders drew on a variety of resources to conceptualize their home networks. In addition to drawings that exhibited properties associated with network education or training, some householders employed other schemes such the physical layout or routines of the home as

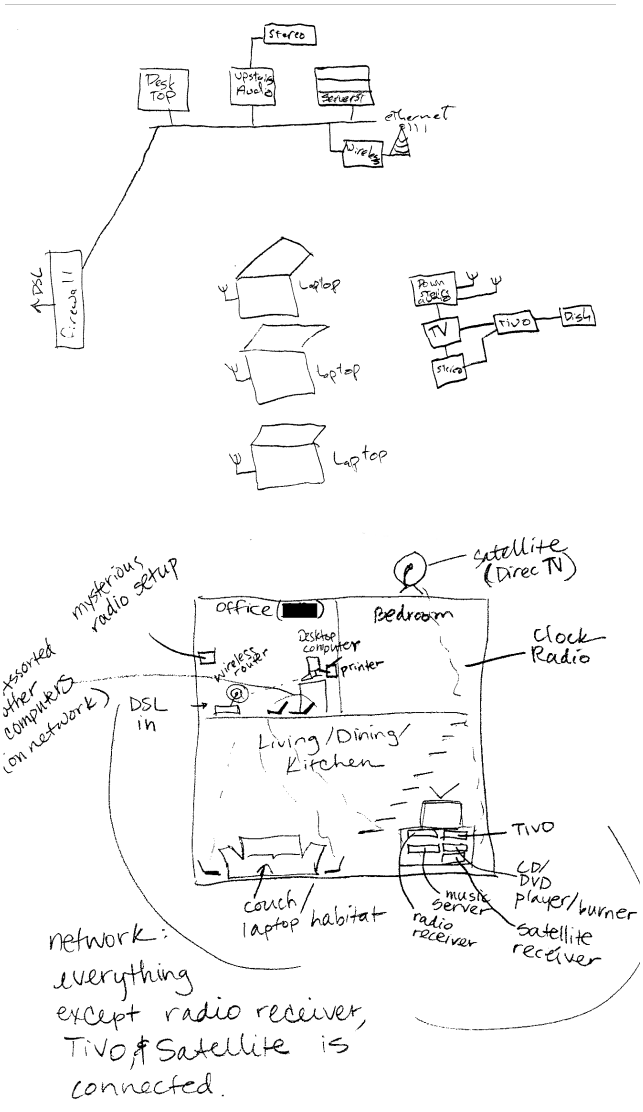

Figure 3: The home itself as a tool for organizing the view of the network. Top drawn by guru and bottom by consumer.

Figure 4: Access controls for a child's PC. The text reads "9-yr-old girl bedroom desktop wired to network for printer access, no Internet access (?), software block".

methods of organizing the network. Minimally, we suggest that these other mechanisms for ordering and making sense of the network present possibilities for tools to support all householders in networking tasks (for instance, by portraying the network in the familiar organizational schemes of physical home layout or routines of use). Such organizing schemes would be helpful during troubleshooting tasks, as they could, four instance, help householders pinpoint locations of malfunctioning devices.

5.2 What's On: Devices, Blobs, and Legacy

Another common difference among the participants' sketches was that *consumers* were much more likely to amalgamate certain types of networking devices in their sketches. In particular, consumers tended to merge infrastructure devices—such as modems, routers, cabling, and servers—essential for networking but not typically used directly by householders into one entity in their diagrams.

We wish to stress that our participants did not think that these devices were a single unit: in many diagrams they actually labeled the object in such a way that it was clear that multiple devices existed. For example, in Figure 1 (bottom sketch) the participant clearly draws a box with multiple lines, and labels it "central networking equipment". What is missing are distinctions among the devices that give each a unique function within the network, as well as the connections among each element. Again, Figure 5 refers to the presence of a "main network dealy (maybe several dealies)" that the participant drew next to the printer (which was where the "network dealies" were physically within the home), yet did not distinguish among them or express their connectivity.

Another common pattern among the *consumers* (and one that was in stark contrast to the *guru* participants in our study) was to omit any details about the connection type, for instance, seventy-five percent of *consumers* did not indicate the type of connection in use (Ethernet, Wifi, Bluetooth and so forth). Again, we do not suggest that this is because they do not know—conversations during the home tour suggested that they were aware of these connections—but rather that it was not the way that they thought about, or could easily depict, their network in diagrammatic form.

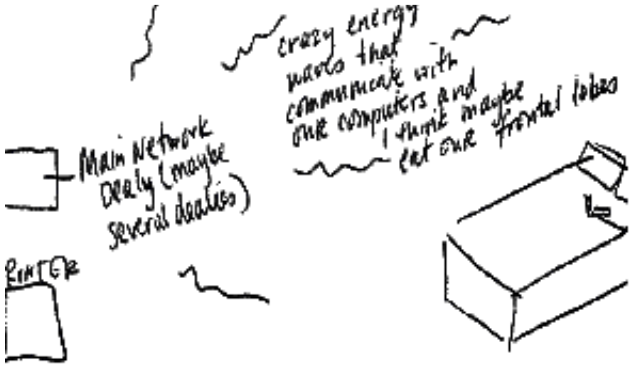

Figure 5: This consumer's sketch describes network infrastructure as "network dealy (maybe several dealies)" and "crazy energy waves that communicate with our computers".

A final type of difficulty that we saw was a breakdown in the physical organization scheme. In one case, a participant knew that a cable modem provided Internet connectivity to the home. However, when drawing the house in a spatial representation scheme, it was necessary to know where it was physically located in the home. This participant did not know the location

of the device, and instead noted on his sketch that the device existed, but he did not know where it was within the home.

As might be expected, both *gurus* and *assisters* generally provided more technically accurate diagrams. They included more devices and connection types, and by doing so their sketches provided critical information for understanding how the network functioned. Yet, even people with significant technical expertise, as well as day-to-day knowledge with their home networks, sometimes forgot core devices such as the network router (occurring in 37% of these drawings).

A final difference emerged around legacy devices. *Gurus* more than any other group were likely to include devices that no longer worked in their network diagrams. These typically showed up as connected into the network, but annotated with a comment about their offline nature (see Figure 6). Again, we suggest that this likely stems from the *guru's* administrative responsibility of knowing how all the devices – even those out of commission – fit into the network.

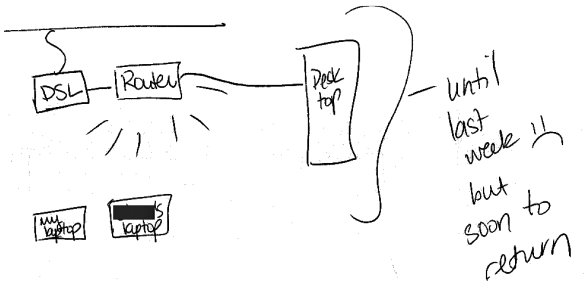

Figure 6: This guru's sketch includes a broken device that was available "until last week but soon to return".

Of course, the fact that users—even *gurus*—forgot devices could partially stem from the nature of the sketching exercise, since the participants were asked to produce a diagram in a constrained period of time with a stranger present in their home. (We did not tell householders in advance that they would be asked to produce a sketch, in order to avoid having householders discuss the network, and potentially learn about the network from each other in preparation for the exercise.) But the more systematic difficulties that *consumers* had in articulating some of the fundamentals that make their home network function suggest possibilities for the design of home network management tools.

In particular, where this sort of knowledge becomes critical is in troubleshooting. As we have previously described [9,21], *consumers* sometimes ended up in a situation where the network failed when the householder typically responsible was not available to troubleshoot the problem. We learned that *consumers* had considerable difficulty tracing the problems—even simply rebooting devices gets complicated if their presence on the network is not known. Tracing the problem back through the network turns on understanding its logical connectivity.

However, visualizations of home networks—particularly those that could be generated automatically—offer householders another resource to remember the structure of the network. Visualizations to support *consumers*, *assisters*, and even *gurus* are becoming more of a necessity as visions of a ubiquitous computing future come to pass where the number of connected devices is ever increasing; particularly when these technologies provides little end-user interaction but must be present for the network to function. In this we are reminded of Star's [33] observation that a challenge with infrastructure—into which home networking clearly falls—is that in use it often fades into the background (hence becoming invisible or, in other words, unremarkable, to paraphrase Tolmie et al. [37]).

5.3 Labels: Networks in the Object World

Thus far, we have largely described the sketching diagrams themselves with little reference to the labels. However, the labels merit attention for they also speak to the ways that our participants saw their networks and constituent devices – both through issues of physicality, spatiality, and ownership, as well as technical properties of the network. In labeling, many of the *gurus* in our study abandoned technical terminology in their diagrams. While *gurus* were most likely to label connections by using technical nomenclature (Ethernet, Wifi, and so forth), they often used other types of names to refer to objects on the network. No one in our *guru* group, for example, labeled any devices by their Internet Protocol (IP) addresses, or their hardware or Media Access Control (MAC) addresses. Rather, both *gurus* and *assisters* labeled devices on the home network by householder ownership. Over half of those participants referred to devices using terms like "Bob's laptop" or "Jill's desktop" (for example, see Figure 6). Indeed, this scheme was ubiquitous and it speaks to two observations associated with the network. First, it shows how dominant the nature of ownership is in computing. Devices, even those that support multiple users, were often "owned" by one person. This was not to say that that person had purchased it, but rather that that device was dominantly used by that person.

Second, labeling also reflects the object's status within a broader context of the world of goods that our participants have and consume in their home. Drawing on Douglas and Isherwood's [15] idea that individuals do not just purchase goods for psychological needs, objects become a part of identity, a way to make sense of and participate in the world. Hence the labels tell us about who owns a device, expressing a relationship that tells us something about the person and their participation in a world which has home computing being something that makes sense, that is valued, that is to be consumed, and that is to be known. Taking this second view of labeling also helps in considering those devices that are not associated with a particular person, but with a room, such as "kitchen computer." These labels invite us to explore the household's "value" system. Labels remind us that kitchens are now, for some, appropriate places to consume networked computing technology within the home.

In our study of labels, we found information about the objects on the network and through this information we could see the place of computers as "things in the home." Labels suggest that individual ownership and room usage are ways that people orient to these objects in the home: some objects belong to individuals, yet others invite new purposes for old rooms. More pragmatically, we suggest that flexibility in labeling in any form of network management tool will be essential for the home. People have adopted these objects, and categorized them for people and places: rather than asking them to take up new terms that may reflect technology, we think allowing people to continue to sort and manage their devices on their terms will prove more useful and usable in the domestic context.

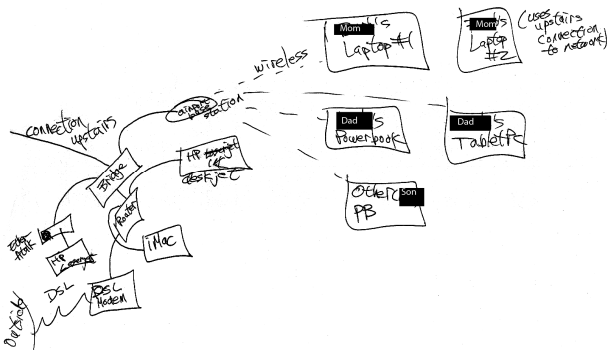

Figure 7: This guru's sketch labels devices by ownership.

6. DISCUSSION

Based on our results, we discuss design implications for home network management tools. We present three themes to consider when implementing various types of tools to support householders. These themes include: (1) designing for time, (2) designing for space, and (3) designing for household routines.

6.1 Designing for Time

Chetty et al. found that home networks are frequently evolving do-it-yourself projects, with alterations and upgrades as part of the norm [9]. The sketches created by *gurus* and *assisters* in our study reflected the dynamic character of the home network. Several sketches depicted broken or legacy devices (for example, old laptops that were stored in a closet but not used). For home network tools that depict devices on the network (visually or otherwise), it may be useful to keep track of what once was on a network or what is temporarily missing. Having the ability to visualize the evolution of the network over time using a tool, as well as having the ability to roll back to previous configurations may help householders resolve problems. Additionally, interactive tools that can show how a network has evolved over time could be used by home networking researchers as a probe for discussion in interviews with householders. Combined with visualizing how devices and their configurations have changed over time, tools might also depict network events that have occurred in the past. For example, householders may wish to keep a record of when an intruder accessed the home network while no one was present in the house. Displaying changes over large periods of time, however, can result in information overload if not carefully designed. Using techniques from information visualization such as dynamic sliders [18] or magic lenses [2] to assist with representing large amounts of data may result in more manageable, understandable interfaces.

6.2 Designing for Space

Participants in our study drew their networks in three types of organizational layouts: spatial, logical or hybrid. When developing home network management tools focused on visualizing data, there are tradeoffs that come with depicting the network in terms of its logical structure or its spatial structure. Visual representations that are true to the logical structure of the network may be better candidates for in-depth, focused troubleshooting, as they provide more detailed information about how the network infrastructure is connected. On the other hand, such representations are deeply technical, may not correlate well with non-expert users' understanding of the network, may not readily provide an overall sense of network health, and may be inappropriate for activities other than focused troubleshooting.

Using a purely spatial representation of a home network in a visualization tool, however, exemplifies the opposite set of tradeoffs. A spatial representation maps onto the physical structure of the home, and correlates with how *consumers* seem to conceive of the network. On the other hand, it obscures important details about the network structure that are essential for problem solving. The underlying logical network topology, for instance, is hidden in this approach; further, diagrammatical depictions of details such as traffic flows—which may be straightforward and clean in a logical view—are cluttered and messy in a spatial view. For example, traffic between two nearby devices may wind their way through infrastructure components in other rooms and back again in a spatial representation.

Although spatial views are comfortable to most householders, logical views may be necessary for problem solving because they can reveal whether links are broken between devices for example. Additionally, detail is needed for problem solving, but quickly becomes overwhelming when there are no breakdowns (or the steady-state case) and may obscure more important aspects of overall network health by providing too much information. Moreover, designing tools that 'know' the spatial layout of a home are difficult to implement – each home is different; hence having visualizations that show a house's structures require significant input from the users themselves to 'build' an accurate picture of their houses in the visualization. Moreover, spatial depictions make the placement of mobile devices problematic. Since these devices may roam from room to room (and even outside the house completely), it is infeasible to expect that users will manually update the positioning of these devices.

6.3 Designing for Household Routines

Underlying many householder problems with network breakdowns is a fundamental issue inherent in digital networking: home networks are, by-and-large, *invisible* to their users. Even though users may see the wires, routers, access points, and other devices, the *logical topology* that sits above this physical infrastructure layer is hidden, and data about network function remains unseen unless explicitly examined with arcane networking tools. Even researchers studying home computing can find that obtaining accurate, complete technical information about individual networks is difficult. For example, it may be impossible to obtain information about every service, configuration detail and so forth of every machine on the home network or to get information about physical topology that is largely invisible even from the networking point of view without being extremely disruptive to householders.

Through use of householder sketching, however, we were able to obtain certain useful pieces of information about the home network that would otherwise be unobtainable by physical or other technical means of inspection. Although sketches provided by our study participants did not provide a 'ground truth' from a technical perspective of the structure and function of the network, these householder-created sketches provide insight into the values and routines that are embedded into home networking technology. For example, in households with children, parents were often concerned with restricting access to some networked resources in the home (e.g. the Internet at large on a child's bedroom computer). This suggests that network management tools for the home need to take into consideration (and possibly notify householders or people helping them with network setup or maintenance tasks) the social aspects of the household affecting home networking. At the same time,

however, the domestic ecology is a setting of subtle interplay among the routines of its occupants, and privacy is a core concern. Any tool, for instance, that visualizes network traffic in the home has privacy implications. In order to support troubleshooting, tools must provide substantial detail about the network and the traffic over it; and yet, such detail may compromise individual privacy preferences of householders.

7. CONCLUSION

Addressing the user experience problems of home network management poses a difficult design challenge. Householders are often unable to verbally describe accurate information about their networks, meaning that conventional interviews and think-aloud techniques may yield little information. To better understand the needs, knowledge, and practices of home network management, we analyzed sketches created by 40 people from 18 homes. Our results suggest that sketching is a promising technique for uncovering the details about networked technology that are difficult for householders to verbalize. We believe that this technique may be useful for eliciting information related to the design of other complex technologies.

Based on the results of our analysis, we have discussed implications for design of the user experience of home network management. Network management tools for the home should take into consideration issues of time, space, and householder routine. By creating appropriate tools for home network management, designers are taking essential steps to empowering householders to understand and manage their digital devices.

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