The Upcycled Home: Removing Barriers to Lightweight Modification of the Home's Everyday Objects

Kristin Williams[1], **Rajitha Pulivarthy**[1], **Scott E. Hudson**[1], **Jessica Hammer**[1,2]
[1] Human Computer Interaction Institute, [2] Entertainment Technology Center
Carnegie Mellon University, Pittsburgh, USA
krismawil@cs.cmu.edu, rpulivar@cs.cmu.edu, scott.hudson@cs.cmu.edu, hammerj@cs.cmu.edu

ABSTRACT
The Internet-of-things (IoT) embeds computing in everyday objects, but has largely focused on new devices while ignoring the home's many existing possessions. We present a field study with 10 American families to understand how these possessions could be included in the smart home through upcycling. We describe three patterns for how families collaborate around home responsibilities; we explore families' mental models of home that may be in tension with existing IoT systems; and we identify ways that families can more easily imagine a smart home that includes their existing possessions. These insights can help us design an upcycled approach to IoT that supports users in reconfiguring objects (and social roles as mediated by objects) in a way that is sensitive to what will be displaced, discarded, or made obsolete. Our findings inform the design of future lightweight systems for the upcycled home.

Author Keywords
Smart home; sustainability; personal inventories; upcycle; IoT; internet-of-things; division of labor; family coordination; intersectionality

INTRODUCTION
Internet-of-Things (IoT) devices promise to enhance even the most mundane of objects with computational properties by seamlessly coupling the virtual world to the physical. Yet, IoT research to date has largely focused on designing wholly new devices, while ignoring many of the existing objects in current households. Instead, we propose an upcycling approach. Upcycling is the process of reusing an object by transforming it into something of greater value or quality. An upcycled IoT would enable users to upgrade the home by transforming their possessions into IoT devices. This approach complements how users already acquire and relate to their objects. Even before the advent of personal computers, ethno-archaeological studies found that over one third of household objects enter the home in used condition [45]. More recent work on product lifecycles uncovered the importance of object attachment, appropriation, reuse, and lateral cycling for how people treat their possessions in the long term [38, 41, 51]. Upcycling can support family processes around re-configuring an object's role within the home and evolving the relationships owners have to their material possessions [52]. Recent innovations open the opportunity of this approach with battery-free, wireless sensing [32, 48, 25]. These studies demonstrate an opportunity to use the home's possessions as design material for IoT systems.

However, an upcycled approach to IoT introduces barriers. First, family members have unequal availability to participate in IoT decision-making [52]. They have different schedules, different skills, and different stakes in the process. Second, not all *families* have the same access to smart home systems. Structural factors, like renting a home, limit some families' power and autonomy when integrating these systems into their household [18, 33]. Third, IoT systems are not always compatible with the way families' manage and use their possessions. For example, families exercise room-level control of their objects (a bedroom TV is used differently than a living room TV), but most IoT systems homogenize how objects are treated across different home spaces [20, 21]. Finally, upcycling objects with IoT requires families to imagine new, technologically-augmented uses for their belongings. This type of creative reimagination is possible, but not always easy to achieve [7].

These barriers align with existing challenges for IoT systems. For one, existing systems struggle to incorporate meaningful collaboration especially when family members have different levels of contribution [8]. Most research to date studied relatively affluent families or other early adopters. As noted above, systems homogenize by residence rather than by room, undermining families' mental models of how home works. Finally, IoT requires novel ideation techniques when working with users to envision their future homes [17].

We seek to address these barriers to an upcycled IoT. We employed home tours and semi-structured interviews to uncover how households organize objects in their daily lives and the domestic roles sustained by them. Our findings contribute 1) 3 models for how families coordinate household labor and work, 2) a user study focused on the needs of families who experience forms of structural marginalization, 3) a characterization of room-level object management practices, and 4) a characterization of how families project their desired home onto their possessions. Our results demonstrate opportunities

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for IoT to support lightweight modification of existing object forms and, through those forms, existing social relationships.

RELATED WORK

Historically, smart home research has faced challenges with creating systems that (1) are sensitive to divisions of labor and routines, (2) account for structural marginalization of users, (3) can be easily managed, and (4) focus on creativity. We review this literature below.

Sensitizing New Devices to the Home's Organization

Upgrading to a smart home involves making critical decisions about which devices enter the home and how they are configured. End-users are unlikely to adopt smart home devices as a wholesale upgrade [20]. Instead, these devices will enter the household in piecemeal fashion as small improvements or reappropriations [12, 20, 40, 8]. This leads to a highly complex network of home technology that will be unlikely to conform to any single manufacturer domain/platform or even technical standard [12, 20]. Families work to weave IoT into their routines, and this process is critical for making these devices a success [49, 53]. Prior research finds that this adoption process is disruptive to the home. Household members will resist new devices becoming integrated if they perceive the process as too demanding [26]. Yet, households are better positioned to reconfigure the role of existing objects in their routines than newly acquired devices [16, 50]. Smart home adoption processes that focus on piecemeal integration and support lightweight modification of the home are better suited to the household ecosystem than processes that require upgrading to new devices.

Structural Marginalization Impacts Access

IoT devices are at risk of reinforcing undesirable social relationships within the home and across society. IoT will likely alter household routines, change control of living space, and even social conventions themselves, such as standards of cleanliness and good parenting [20]. Several studies found that screen-based technologies like video games, smart phones, and televisions undermine positive familial relationships when family members are unable to get the attention of others [2, 4]. Even when household routines are directly supported by new IoT devices, they may still reinforce traditional divisions of household labor that negatively impact specific classes and gender groups [53]. For example, middle and working class households differ in their uptake of new standards of good parenting that regulate children's use of devices [4, 15, 28, 36, 2, 54]. Similarly, family members frequently adopt gender-stereotypical roles with respect to who builds the home network and who learns to program the device [34, 43, 8]. The way IoT devices are incorporated in the home's division of labor can extend the reach of structural inequities like class or gender-based divisions in accessing and controlling devices.

Home Networks Undermine the Mental Model of Home

The family's mental model of home often does not align with smart home networks. As a result, users have struggled to install and configure home networking without specialized knowledge. The skill level required approaches that of a systems administrator [20, 24]. In a *control paradox*, families create complex conventions to remind themselves of the network's configuration to gain control. Yet, they increasingly feel it erode as the complexity of the network grows, and household members specialize in managing it or making upgrades [12, 26]. In contrast, the family successfully uses the home's spatial layout to manage activities such as private consumption of sensitive material, religious commitments, or quiet (although this varies by culture) [5, 12, 31, 51, 54]. In the United States, a large percentage of housing stock consists of older homes designed for labor and housework to be accomplished as a backstage activity [5, 2]. Nonetheless, kitchens function as command centers where families congregate to catch up with one another, coordinate, do homework, and collaborate over bills or school notes [12, 15, 13, 5, 49]. Parents use bathrooms to socialize children into good habits like hygiene and cleanliness [5, 2]. Bedrooms are private spaces that may be free from electronics or the internet altogether, or allow for consumption of specific content [12, 5]. Technologies can impinge on these divisions by violating house rules (*e.g.*, giving kids internet access in their bedrooms), or in cases like the TV, directly organize spatial layout [5, 12, 31]. By treating internet connected devices homogeneously, IoT disrupts the home's implicit organization and management.

Creative Reuse Needs to be Supported

The desire to "disassemble, rearrange, and partially upgrade" IoT be explained by detractors of the ubiquitous computing vision (quote taken from [12]). When embedded systems seamlessly fade into the background, the moment to reflect on one's choices and do things differently is missing and can effectively erode agency [14, 44]. Alternatively, *engaged computing* develops embedded systems capable of extending human abilities to be constructive, creative, and ultimately, in control of the actions they take in the world [44]. Do-It-Yourself IoT could offer end users greater discretion and control over how smart home technologies are woven into routines and relationships [3, 8]. In short, a DIY IoT is likely to support greater self-expression [16]. When family members are empowered to re-purpose and build off one another's ideas using nearby objects, they are better able to foster creativity [16, 52]. Yet, incorporating the home's possessions must be done with care. Objects and their life-cycles carry layers of social meaning [22, 23, 27, 1, 2, 51]. In other words, they are polyvalent [46]. Some objects may be discarded or destroyed not because of the object, but to sever the relationships they are a part of [1]. In the United States, household objects realize family ideals such as nurturing growth, talent, creativity, self-expression, and identity [2]. Support for these ideals is currently missing from IoT [26]. By using the domestic objects as design material, an upcycled IoT supports reinventing the home's existing socio-material contexts to align with its values.

METHODS

We use ethno-archaeological and portraiture methods to uncover the relationships sustained by domestic objects in diverse households across race and ethnicity, gender, age, disability, and class differences. Ethno-archaeological methods examine a household's material culture by focusing on the presence/lack of artifacts [42] and the use of space [5]. Linking

patterns of objects distributed throughout a site with the human activities that are responsible for their accrual and decay allows unobserved behaviors to be inferred [5]. For example, the Garbage Project used ethno-archaeological methods to analyze living persons' decisions to advance an object forward in its life-cycle or to discard it [42, 45]. We are unaware of previous human-computer interaction work that uses these methods. Here, we use them to examine which objects family members would upcycle and which they would keep in their current state. We analyze our data using portraiture to address how technology design may be influenced by systemic and structural inequalities in society. Recent scholarship argues that when an analysis hinges on a single critical dimension (*e.g.*, gender), it obscures how structural inequities have compounded, marginalizing effects because it only considers a single structural factor [47]. Instead, portraiture sketches the connections between participants' individual personalities and organizational culture by portraying their authority, wisdom, and perspectives [30, 29]. This method centers their views within careful ethnographic description so they might be fully recognized, appreciated, respected, and scrutinized [30, 29].

Participants

We recruited 10 households for our study from a mid-sized American city (Pittsburgh, population 300,000). We sampled participants according to 6 criteria: gender, age, race, class, disability, and household structure, in line with persistent categories of concern [19, 47]. We excluded potential participants when, (1) working with them would require changing our study's protocol (*e.g.*, translator), (2) their household had changed over the past year (*e.g.* new baby), (3) their household had <2 people, or (4) we had recruited enough similar households. This shifts our population away from a representative sample. In our sample, 100% lived in the same home a year ago and averaged 2.9 persons per household compared with the city average of 77.8% and 2.1 persons [11]. We describe children <5 yrs. and those with severe intellectual disabilities as part of their households, but we did not interview or directly work with them. We recruited through NGOs and public organizations using word of mouth and flyers. We required participants commit to the entire duration of the study and all household members participate. We were unable to recruit many family types such as divorced families, or gender fluid households, though we recruited these types through related organizations. Their omission is a limitation.

Procedure

Our university's internal review board reviewed and approved our procedures before our study commenced. The study took place in participant homes, and sessions generally lasted between 1.5-2 hrs. One household lasted 3 hours due to disability related delays and interruptions from unexpected visitors. We consented participants according to our IRB protocols and assented children 5-18 years old with parental approval. We paid adult participants $15/hr and children >5 years, $5/hr.

Our study lasted 7 days. On the first day, participants completed a demographics questionnaire, gave a home tour, and completed a one-on-one semi-structured interview. Home tours and interviews were conducted in parallel. Those household members who were not being interviewed gave a home tour to a member of our research team. Thus, children gave home tours twice. In one family with 3 adults, the family gave 2 complete home tours and 3 one-on-one interviews.

Daily Activity Interviews

Building on prior work [2], we developed a semi-structured interview protocol asking adult participants how members divide the households' main activities and their awareness of others' activities. We separated members during this interview since participants are more likely to honestly disclose about their partners in their absence [6]. We asked them to describe a typical day, which activities take the most and least time, others members' activities, whether they participated, and activities they wished their household spent more time on.

Home Tours

We elicited decisions on upcycling domestic possessions by adapting home tour methods capturing participant attitudes towards their home [2]. We asked participants to show us 5 rooms in their home. In each room, we asked participants to choose 3 objects to modify with computing abilities, and 3 objects that they would not want to modify. Next, we asked participants to explain their reasoning behind their choices.

Data and Analysis

Audio data from the home tours and interviews were professionally transcribed, and survey answers were digitized. We used grounded theory and portraiture to analyze our home tour data. On our first pass through the data we developed inductive codes and applied deductive codes when our data supported previous findings such as attachment [1, 38], parenting and technology [4, 36, 54], reuse [41, 42, 45], and ownership [5, 2, 1, 35]. On our second pass, two research team members discussed and clustered the 107 codes into 3 categories on domestic artifacts' role in division of labor, network management, and household acceptance. We proceeded to axial coding with the emergent 3 themes and 11 subthemes, collapsed overlapping codes, and developed new codes when fit was imperfect. Finally, one research team member uninvolved in coding thus far, used the 3 themes and their 11 subcodes to code two randomly chosen transcripts. They were then debriefed for coverage and characterization of the data.

We coded our one-on-one interviews according to our field notes and interview protocol. We used 10 daily activities co-constructed with each of the 20 interviewed participants and our protocol's 3 themes (one's day, awareness of others' day, and desired activities). We clustered and collapsed overlapping codes. This resulted in 15 activities. We then compared family members' responses to identify activity patterns across households. We present the results using thick description and use pseudonyms for families and their members.

FINDINGS

Working with 10 households, we found that household members bring society-level constraints home and work with other family members to renegotiate their approach to ongoing demands made from both inside and outside the home. We identify 3 division of labor patterns that illustrate how households

Indicators of Class

Income Ranges[a]	*American City*	*Study Pop.*	*Households*
<$10,000	12.4%	0%	0
$10-14,999	7.5%	0%	0
$15-24,999	12.5%	10%	1
$25-49,999	23.9%	10%	1
$50-74,999	16.5%	50%	5
$75-99,999	9.8%	10%	1
$100-149,999	9.8%	10%	1
$150-200,000	3.6%	0%	0
>$200,000	4.3%	10%	1
Education Level[b]	*American City*	*Study Pop.*	*Participants*
<High School	8.1%	0%	0
High School	27.6%	5%	1
Associates	7.9%	15%	3
College	21.3%	30%	6
Graduate	19.4%	35%	7

[a]For our 8 married households, the comparison for married couples may be more appropriate: 26.6% <$50k; 19.2% $50-<75k; 15.4% $75-<100k; 19.9% $100-<150k; 8.5% $150-200k; 10.3% >$200k

[b]Based on adults >25 years old; For the household of adults <25, comparisons with adults 18-24 years would be appropriate: 22.3% bachelor's or higher (in our study, 100% of this 1 household).

Table 1. The chart shows the representation of different classes in the local population relative to the households represented in the study's population. We used income and education to characterize the class structure of our population in line with standard conventions using income, education, and job type.

realize society's structural inequities. We thickly describe how these are embodied in home life. Against these background patterns, we found that family members use domestic objects and spatial layout to set and enforce the home's norms. They create boundaries in relationships and instruct others in domestic roles and responsibilities. Lastly, household members contend with existing, nuanced networks of ownership when making critical decisions to incorporate IoT into the home. We characterize these ways that households regularly reuse and appropriate domestic objects to create, sustain, and reconfigure their relationships. These findings inform what support is needed for IoT decision-making, and illustrate ways that upcycling could support piecemeal upgrades to the home.

Below, we first summarize participant demographics; then 3 division of labor patterns. Each are followed by a family portrait. Next, we present 6 family portraits that show how families use objects to develop shared mental models of home and how this can be in tension with current IoT. Objects are specialized to their containing room and are used in compliance with those rooms' norms. After each portrait, we draw lessons from each household to inform management and control over an IoT system and design support for family members integrating IoT in a way that makes progress towards their aspirational home.

Demographics

We recruited 29 household members and 26 participants (42.9% male and 57.1% female). We had slightly more female representation than the recruitment city (51% [11]). Participants ranged between 9 to 70 years of age (M=35.8 yrs., SD=20.2 yrs.; City MD=32.9 yrs., [9]). Our recruitment city had the following age distribution: 5% <5 yrs., 15.8% <18 yrs., 70.2% adults <65 yrs., and 14% adults >65 yrs [11]. Our study's age distribution approximated this with 8.7% <5 yrs., 34.8% <18 yrs., 65.2% adults <65 yrs., and 21.7% adults >65 yrs. Seven household members reported having a disability. This prevalence is at times higher than the city's: 9.1% <65 yrs. (compared to 9.9% for the city) and 83.3% >65 yrs. (compared to 13.6% for the city) [11, 9]. We summarize further in Tables 1, 2, and in prose (sources [9, 10, 11, 39]).

Division of Home Labor

When we compared households, we observed highly integrated morning and evening routines. All families were together for dinner, and almost all, during the morning routine. This does not mean that all families ate meals together. In many families with children, children ate on an earlier shift than parents. Morning routines tended to be asynchronous with points of contact between family members due to differing rising times, bathroom scheduling, or calculated prep times for children, pets, or others with a disability. We identified 3 patterns—*Cruise Control*, *Labor Specialization*, and *Balanced Awareness*—that we characterize these in more detail below.

Cruise Control

Cruise Control families listed under half of their routines in common. We call this style *Cruise Control* because, compared to other families, participants rarely mentioned household management. They do chores, but did not seem to manage the process. These families rarely, if ever, mentioned any hobbies or exercise. They worked through lunchtime and multitasked: doing homework or answering e-mail. Their life styles exhibited asymmetry. One family member described a single, additional activity omitted by their partner, while the other listed several (>3). In one family, many differences arose from the head of household living with a significant disability. In the others, one family member was stretched thin balancing many side jobs, while their partner worked long hours. These partners were employed professionals in a field requiring a graduate degree and had guaranteed, predictable and steady hours. For 2 families, one partner described the other as doing chores, while the other described the first as playing video games. These couples desired more time to relax together.

The Walker Family Portrait: Celine and Mia are a young and energetic, married couple who own their 2 story house in a suburban neighborhood on the edge of the city. They make twice the median income of their surrounding neighborhood (average for the city). It is over 85% white and has >75% home ownership. Their home has brightly colored walls lined with meditative sayings or photos of the couple together and is populated by several dogs. Mia describes her and Celine's routine a year ago when Mia had a single 9 to 5 job. They had a date night when they would go to a show together or go for a walk on the waterfront. Now, Celine is busy with 3-4 jobs and caring for her relative with a cognitive disability.

Often, Celine and Mia's schedules do not align, so they cherish their weekends and dinners together (after Mia comes home and before Celine goes back to work). Celine spends the most time preparing for these:

	Race & Ethnicity								
	Citizen	*English 2nd Language*	*Hispanic*	*Amer. Ind./ Alaskan*	*Asian*	*Black/ Afr. Amer.*	*Hawaiian/ Pac. Isl.*	*White*	*Two/More Races*
City Pop.	91.5%	10.8%	2.8%	0.2%	5.5%	24.3%	0.0%	66.3%	3.2%
Study Pop.	75.9%	24.1%	13.8%	3.4%	10.3%	27.6%	0.0%	37.9%	6.9%
Households	8	2	1	1	1	3	0	5	2
	Household Structure								
	Female Headed	*Male Headed*	*Married Opp. Sex*	*Same Sex Couples*[1]	*Children*	*Neither Par. Employed*[2]	*Mother not Employed*	*Father not Employed*	*Both Par. Employed*
City Pop.	29%	8%	63%	1.4%	44.1%	3.8%	26.3%	7%	62.9%
Study Pop.	20%	0%	70%	10%	40%	25%	25%	0%	50%
Households	2	0	7	1	4	1	1	0	2

[1]Same sex couples city comparison figures are for the entire US. [2]Employment city comparison figures are for the entire US.

Table 2. The representation of different racial and ethnic groups, household structures, and working parents in the local population relative to the study's population. The number of households present in our study for that subpopulation is given below the percentage.

> *We're always trying some different diet that—I'll be in the kitchen for four hours a day. The worst one was when we did raw veganism, and I was literally in the kitchen food prepping for five or six hours every single day, because everything has to be fresh.* (Celine)

Upon arrival home, Mia is drained: *"Emotionally... I bring it home.... There's a lot of really horrible things that happen to people."* Alone in the evenings, Mia watches TV while researching home renovation. The Walkers consulted a contractor about installing a dishwasher, but halted their plans when the level of structural change meant renovating the kitchen.

Pattern Lessons. Cruise Control family members often work on the home or prepare for collaborative activities in isolation from one another. Their asynchrony limits familiarity with each others' activities. Job demands constrain their availability and energy to invest in collaborative decisions. An upcycled IoT should support these families by enabling hand-off of prep work and minimizing project creep into deeper structural changes to decrease coordinated decision making.

Labor Specialization

Labor Specialization families listed half their routines in common. They described little exercise and few to no hobbies. Unlike Cruise Control families, they had a high division of labor. One member functioned as the 'manager'. They tracked the home's state and directed attention to critical needs. Breakdowns occurred if this person forgot since others did not always recognize when they should contribute. Although most family members mentioned chores, the manager described the check-in process when chores would be divided. Family members knew each others' habitual chores (partner verified), yet, felt they were never-ending. Their activities frequently diverged and included multiple activities omitted by others (>2). Labor Specialization parents wanted their children to do more chores, eliminate cleaning up after them, and hasten house work. Families without children had tight schedules accommodating a particular life stage's needs like school or rehabilitation. These families desired a shared effort at cleaning and organizing their home.

The Martinez Family Portrait: The Martinez family lives in a rented townhouse in a wealthy suburb occupied by >90% white families, >$75,000 median household income, and >75% home ownership. Their neighborhood is clean and friendly. Located across from a golf course's lushly manicured lawns, it is near a park offering several recreational options. Julio is college educated and commutes to his IT job in the city. His wife, Carmen, describes herself as a stay-at-home mom, but confesses to sometimes working remotely for her privately owned business in her country of origin. Carmen regularly prepares the family's breakfast and dinner, walks the pets, does laundry, picks up her kids from after-school activities, grocery shops, and helps with homework. Carmen describes how there are breakdowns when she loses track of the household.

> *With the day to day, trying to work and cook and take care of them, sometimes I forget. It just seems that they never take—if I don't walk the dogs, feed the cats and the dogs, it seems something very common. If I'm not here, if I'm not on top of it, nobody feeds them.*

Carmen describes Julio as proactive in helping around the house, but she is responsible for knowing what needs to be done. Julio earns the majority of the household income and often comes home after everyone has eaten dinner. His family will sit and catch up with him while he eats. When dinner is finished, Carmen and Julio load the dishes and put food away together. Then they join their kids watching a Netflix[3] show.

Pattern Lessons. Labor Specialization families take a divide and conquer approach to house work. Doing so enables the family to parallelize tasks and complement each others' contributions. To leverage this collaborative process, an upcycled IoT should enable setup and maintenance tasks to be subdivided into parallel processes and make each members' role transparent and easy for others to learn. Thus family members could rotate a managerial role or swap roles so that task specialization does not become an entrenched routine.

Balanced Awareness

Balanced Awareness families substantially overlapped their activities (7 or more). Family members checked-in daily at a prearranged time. They delegated errands to a specific time to correct for likely forgotten items. Chores were swapped. Or, the one person who regularly did a chore—cooking or

[3]Netflix is an online television streaming service.

networking their home—specifically enjoyed it. These families had significant hobbies, like gardening or singing, that grounded members' self-conception. Yet, they didn't try to do too much and described only 1-2 unique hobbies. This allowed time for household upkeep, work in parallel, or to be available when needed. These families desired spontaneous or unstructured time to get outdoors and break with their routines.

The Baker Family Portrait: Janel and Joshua Baker own their 2 story house in a racially diverse suburb of the city. Their street is lined with tall trees and yards with children playing. Making well over the median income for their surrounding neighborhood (a little below the city average), they are from the city and so, have family nearby. Janel and Joshua were high school sweethearts and had their first child when they were just out of school. They recently had a second child—a daughter—ten years later. Five days a week, Janel and Joshua work full time outside of the home and are home together in the evenings. They divide dropping off and picking up their children while commuting to work.

At the end of each day, the Bakers check in to see whether dinner is on track. Did they remember to defrost what they had planned? Should something be picked up from the store? When they arrive home, Janel multitasks in the kitchen. She does this during the interview—feeding the baby as she speaks—and explains that transitioning to dinner takes time.

> *I come home after sittin' in traffic, and once I get home we can talk about our days—"Hey. How's your day? How've you been?" Talk to the baby. Then I get ready to make dinner... once I make dinner, then we feed her.*

Janel sometimes socializes with friends or attends board meetings for a local association rather than return home directly after work. Likewise, Joshua goes to the gym and will periodically bring their son Caleb with him. Describing his weekends, Joshua smiles, *"So cutting grass isn't supposed to be relaxing; but sometimes it is, because you're just outside."* He finds ways to enjoy even chores.

Pattern Lessons. Balanced Awareness families have integrated routines or management strategies that are resilient to breakdowns and surprises. Making time to coordinate and accomplish housework is not a problem. Yet, these processes are so established, they undermine spontaneity and experimentation. To support these families, an upcycled IoT should nurture creative ideation and role play. Then household members could try new household arrangements to stretch the family to grow.

Summary.
We identified 3 patterns for coordinating housework within the confines of family roles and commitments. Cruise Control families invest in the home asynchronously and need an upcycled IoT to support project hand-off and limit scope creep. Labor Specialization families have a manager who directs members to work in parallel and complementary roles, and need support with swapping roles and assuming responsibility. Balanced Awareness families switch roles and scheduling as needed, but need support in escaping routine. These typologies characterize how families currently allocate time and attention to jointly accomplish housework. To complement these, we developed pattern lessons an upcycled IoT should use to support families with trying out new arrangements.

Negotiating Social Boundaries through Ownership

Family members use objects to instruct other members in household norms. During their home tour, participants emphasized their relationships to their objects or their object-mediated relationships with others. Most household objects are functionally shared between all family members. Yet, ownership and authority are regularly used to cue, negotiate, or control relationships between household members. Objects are used by households with children to construct and enforce rules of behavior as part of nurturing child development. Even in households without children, objects are used to set boundaries, signal consideration, and coordinate tasks. Acquiring and discarding objects presents a cost, as displaced or discarded objects disrupt these time-earned negotiations.

Owners have Imaginative Authority
Knowing how to behave towards other family members' objects and rooms is part of knowing the rules of the home. Many objects are shared, but a select few belong to a single person. Eighteen participants identified objects specifically belonging to themselves or others in the home, and 12 participants emphasized when objects were shared.

The Jameson Family Portrait: Janice and Tameeka live in a rented townhouse in a neighborhood occupied by over 90% African American residents with a median income of <$25,000. Janice is Tameeka's grandmother and is unable to work due to a disability. Janice is relatively young for her grandmother status and glows when talking about Tameeka's projects and involvement in a neighborhood program for at-risk youth. Tameeka, age 12, proudly shows off 'her room' with 'her TV'. When adding computing abilities to her room she explains, that she would start with the *"simpler things"* such as her floppy-eared, stuffed rabbit, or her giant bear. Tameeka would add IoT services that could enable her stuffed animals to talk. For her, IoT could help her bedroom's imaginative world come alive. Tameeka and Janice have a relationship that Tameeka describes as *"awesome"*. However, she is careful to consider when she has crossed the threshold into her grandmother's domain. When giving a tour of the house, Tameeka giggles at the opportunity to violate household norms by making unsupervised use of her grandmother's room: *"Finally I choose her room!"* Tameeka does not want to upcycle her grandma's closet. She explains, *"her closet is perfect for me to play hide and seek in if she would let me."* Her grandma's closet nurtures Tameeka's imagination, but her freedom to enact her fantasies in that space is limited by ownership.

Object Lessons: Personal objects, like Tameeka's stuffed animals, realize and sustain their owners' imaginative ideas. The personal process of adding computing to these objects enables owners to project their fantasies onto their world. Upcycling should enable owners to encode their imaginative ideas into upcycled objects during setup.

Room Lessons: Rooms have owners. Through ownership, family members have authority to make the room's rules and use its boundaries to instruct others in its norms. An upcycled

IoT could respect this practice by enabling the home setup to be subdivided and customized at the room level.

Claiming and Enforcing Territory

Owners personalize and claim territory to signal their wishes. Conflicts over objects arose during 7 home tours. However, ownership conferred authority to enforce a person's preferences to resolve conflict.

The Carroll Family Portrait: Nicholas and Sara Carroll are both college educated. They married after going to school together, and then relocated to the city because of a job opportunity for Nicholas. Sara quit her job as a school teacher to stay home and raise their three children: Josh, Caleb, and Tyler. On the home tour, Josh and Caleb decide that it is important to keep the lettering of their names on their bedroom wall untouched by IoT. When asked about their reasons, Caleb declares "Territory!" Josh, who shares the room, echoes the sentiment and provides more explanation:

> *It claims territory when our friends come over. . . Also if my brother's about to touch [my things], I can say stuff like, "Do you see that name above there; that's there for a reason!" and he'll back away.*

These territorial claims are not unique to children. Sara claims territory too. She unhappily explains that her lamps should remain unaltered by IoT, but they are currently broken. They were a casualty of Josh and Caleb playing football in the house. Sara uses the football and lamps to reinforce her point to Josh and Caleb as she gives the tour: the football belongs outside the house, and the lamps were not Josh's and Caleb's to break. Josh and Caleb violate the home's rules by misusing her belongings. Sara recounts how Josh and Caleb buried her wedding silverware in the backyard dirt as treasure for their game of pirates. She still feels the loss, as no one has been able to locate the buried silver in the yard of their rented house.

Object Lessons: Fixed objects, like Caleb and Josh's wall lettering, create stable rules for a room. In contrast, roaming objects (*e.g.*, football, wedding silver) move throughout the home and so the room rules governing them vary. An upcycled IoT could work with a spectrum of object types by supporting fuzzy object properties that range from stationary, fixed behavior to roaming, in flux behavior.

Room Lessons: A room's owner uses its objects to signal the room's rules. Shared spaces without clear owners (*e.g.*, living rooms or dining rooms) are sites of conflicting values since the room's rules are negotiated among the household's members. An upcycled IoT should defer room level policies to the negotiated arrangements and provide for dynamic change over time. To do so, policies could be set by the objects at the focus of attention and prioritized according to social hierarchy.

Negotiating Boundaries

Objects successfully or unsuccessfully enforce social boundaries by expressing the owner's identity or limiting sharing in a relationship. 9 participants used objects to support their self-image, their household role, and interaction with others.

The Gilmore Family Portrait: Tyler and Chloe Gilmore are a retired couple who own their three-story house in a low income neighborhood of the city. Retired now, Tyler worked as a computer programmer in the military. He protects his home by wanting to upcycle his current alarm system by adding more security features to the window using IoT. The Gilmores *"do a lot of cruising"*, and he worries an intruder *"might come in and break the window while [they're] gone...[or they] might forget to lock the windows"* Tyler portrays himself as a protector who safeguards the family and home. He worries when Chloe and their daughter are home alone. Chloe recently recovered from surgery and is limited in her ability to get around. The Gilmores installed a motorized chair on their stairwell to enable Chloe to move between floors on her own. Showing it off as she descends the stairs, she exclaims, *"Thank God for the stairlift."* It inspires many of her IoT modification ideas. She would add IoT to her possessions so that she could use them independently or remain in her own home as she ages. Chloe would add IoT to her bath so that she can bathe alone:

> *For those of us who have disabilities...It would just make it more friendly and [sic] wouldn't have to call on other family members or somebody to keep you company. You'll [sic] more independence...it also does something great for you when you are able to do it by yourself.*

Chloe's husband frequently assists her bathing, but she feels a sense of accomplishment and dignity when doing it herself.

Object Lessons: Objects—like Chloe's stairlift—mediate family relationships by modifying a room's norms. When objects cannot be used independently, they breach these norms and create asymetrical relationships as household members require others' help. An upcycled IoT could address these failures of objects to sustain independence by recommending augmentations of those objects so that they can be used independently.

Room Lessons: Rooms are perceived as hospitable or inhospitable. They can signal the home's boundaries to outsiders by using surveillance to cue transgression. Rooms alienate insiders when they breach household norms. This becomes more salient the more personal the space such as a bathroom. An upcycled home can incorporate these norms by taking advantage of the privacy gradations implicit in the home's spatial layout. Greater control over the IoT system could be made available in insider spaces where only a privileged few have access and access could be limited in spaces available to outsiders.

Summary.

The home's spaces are both private and shared. Their norms structure family interactions and discriminate insiders from outsiders. Owners have the authority to set norms for how their part of the home or possessions are used. These possessions mediate the relationships and ground their dynamics. They can be fixed to a room or roam between room-level jurisdictions. An upcycled IoT should defer to negotiated norms for the home's spaces and possessions. It could do so by aligning system access with spatial privacy, recommending object modification patterns, supporting a spectrum of fixed to roaming object types, and enabling room-level partitions and policies.

Modifying Objects to Create the Aspirational Home

Domestic possessions carry prior expectations from the way they already work in the home. Some of these possessions

are regarded as essential to peoples' lives and so, are non-negotiable. New IoT capabilities compete with these prior arrangements and must engage with them. For many households, the home and its construction is a given. These assumptions constrain what the home can accommodate or adapt to. Yet, new computing modifications enable new arrangements that evolve the household closer to its members' ideal home.

Making a Household Work

The home's objects are sorted according to those that function reliably and those needing continual upkeep and repair. Family ideals for the home praise functioning items, because they *"[do] what [they're] supposed to"* (Miguel Martinez). Seventeen participants thought computing-enhanced objects could disrupt or restore their ideal home by introducing greater fragility to routines or automating upkeep like to-do lists.

The Olson Family Portrait: The Olsons are a technology-savvy, retired couple who outfitted their 2 story house in a residential neighborhood with cloud storage and remote access to their music collection. During her career, Sheila managed a database system and is considered *"the techie"* (Gordon's description). Sheila creates many custom bill-pay, medication management, and party planning systems for their home. Though retired, Sheila feels she works most days.

> *Processing stuff, trying to keep up with stuff, trying to understand things that come in... we got a new car at the end of May and I asked [the company] to send me the booklet. And I never got it, so I call her and she said "Oh, I'll send it again", and I never got it, so that folder sits on the table, waits, so I have to call her again. (Sheila)*

Sheila's systems process household information and automate housework. She teaches Gordon how to use them, and he knows exactly how to input his part so that he can hand the bill payment off to Sheila. He is wary of modifying household objects with IoT knowing the amount of time they already spend on maintenance. He explains, *"we're very fearful of Windows 10"* because they are forced to upgrade Sheila's custom systems. He worries about investing in these costs.

Object Lessons: Workplace object practices extend work to the home by sustaining management routines. Even when experts successfully teach them to other family members—like a bill pay system—these practices nurture unwelcome psychological strain like exhaustion. Domestic IoT should disguise computing techniques borrowed from the workplace to help household members distance themselves from their jobs.

Room Lessons: Even when IoT supports information access across room boundaries, spatial arrangement—like a folder on a table—is still used to cue family members on the state of the information system and next steps. Thus, an upcycled IoT can use place and spatial layout to provide system affordances that are idiosyncratic to each household's social dynamics.

Which Objects Should Be 'Smart'?

Fourteen participants want computationally modified objects to give them peace of mind, realize their commitments, and provide reassurance. Objects that are successfully interwoven in the home supply this support, and are valued as a result.

The Taylor Family Portrait: Dave and Katie Taylor are a young, married couple who met in college and relocated to the city so that Dave could pursue a graduate degree. They live in a recently built, one bedroom apartment located in a rental complex as part of a suburban, shopping district with a population that is 80% white. Dave and Katie personalize their home with an extensive collection of games they regularly play together and decorate it with posters from their favorite books and movies. Before Dave gets home from school, Katie begins cooking dinner. When he arrives, he chops the vegetables or washes the dishes while the food simmers as she directs him to. Many times Katie worries. Has she left the stove on? What about the toaster oven? She wishes she could remotely cut off power to parts of her home. She describes a recent storm occurring while the couple was away from home: *"We lost power a couple nights ago. We were worried—did we fry our TV? Did we fry our game system?"* She worries about damage to the entertainment hub they've invested in and that support the family's leisure time together. Similarly, Dave worries about damage. He wants to ensure they keep the apartment to the company's standards. He wouldn't add computing abilities to the floor, walls, and doors. They should remain exactly as acquired so that they do not have to pay the rental company.

Object Lessons: Play and leisure support personalization, customization, and connection with others. In doing so, they enable families to create ownership of rental and temporary spaces. By centering play and leisure, upcycling could enable families to customize a temporary space into a smart home.

Room Lessons: Families do not have full control over the rules governing temporary or rented spaces. These rules constrain the structural depth to which computing can be integrated. Yet, families desire room-level management of computing capabilites, and need those same affordances available through their possessions. To support this, upcycled objects could set room boundaries and so, function as a room's walls.

Mental Models of Home

Family members develop nuanced models of their objects' roles within their household's flow. These models limit members' ability to explain decisions to add IoT to some objects over others. For 8 participants, the decision was obvious: part of how they conceive of the object categorically.

The Crane Family Portrait: Lisa and Kevin are a married couple on the brink of retirement. Both have graduate degrees that they used in their professions. Lisa already retired, but Kevin still works full time at a nearby hospital. They own their 3 story house in a wealthy, residential neighborhood (median income >$120,000). Kevin enjoys music. When entering the Cranes' house, visitors walk by his 3.5 feet drums in the foyer. The Cranes learned how to audiocast music to their decades old, classic speaker system with the help of their son. They arrange and modify their household to nurture their interests. Lisa loves to cook and spent the past three years planning and remodeling her kitchen. She wouldn't want to alter her cookbooks with computing abilities because she dislikes online recipes and prefers the physical cookbook.

Because it's a book. You can handle it. You can mark it. You can see it. You've got history there. It tells a story. There are stains from the recipes you've used a lot. You mark it—this works, or that—change that. I can leave something for my kids. (Lisa)

For Lisa, upcycling the cookbook with IoT implies a digital screen that she couldn't spill things on, or use to record the recipe's history. The Cranes treasure the object forms that they have selected and shaped over the years.

Object Lessons: Families nurture their interests by investing in domain-specific possessions like drums or a cookbook. These objects ground creativity and talent. Upcycling's added value should sustain these investments and entrenched uses, yet encourage domain growth like audiocasting did for the speakers.

Room Lessons: Owners use their control over the home's rooms to structure support for inventive activities such as playing music or cooking. In this way, the home itself buttresses identity building and formation.

Adaptable Objects and Essential Objects

Participants' life stage informed which objects should be upcycled and how (9 participants). Some objects shouldn't be learned anew during early and late life stages, demanded too much time, would quickly be outgrown, or required too much responsibility. These objects needed to compromise with big life changes like babies, graduate school, or a new disability.

The Chaterjee-Basu-Mistry Family Portrait: Roommates Yasmeen, Meethu, and Neha live in a two bedroom apartment in university housing. All three are college educated and currently pursuing graduate studies. Neha has lived in the apartment for longer than Yasmeen and Meethu and occupies the solo bedroom. She describes the kitchen's continuous disarray: *"It gets really messy, and there's a lot of space crunch. Since we're students, we leave the house early in the morning."* The family has limited time and space at home. They neglect kitchen objects to accommodate demands made from outside the home, or reconfigure their livingroom to accommodate guests such as a family member or boyfriend. They desire more control over their apartment:

This window is really small. It blocks all the sunlight, usually. It feels like I'm trapped at times...It just pisses me off. That's the reason why I can't get an air conditioner, because I do not have the window space. (Yasmeen)

Yasmeen learns to accept the window as is and instead, would upcycle its decor. Modifying the blinds would *"be a fun thing to do."* and liven up the window she resents. The family feels empowered when they successfully work within the apartment's constraints. Beaming at their ingenuity, Meethu shows off the shelf the family assembled to hold their foodstuff.

Object Lessons: Adaptable possessions, like reconfigurable furniture, give owners control over their home's constraints. Since many families, like roommates, are together for a short time, their shared objects do not carry timeworn negotiations. Upcycled objects should use adaptation to harmonize competing desires for household norms (*e.g.*, kitchen upkeep) by supporting changeable functions throughout their lifecycle and making them intelligible so that they may be renegotiated.

Room Lessons: Rented rooms can result from compromising housing with growth needs for specific life stages. As non-ideal, they emotionally impact inhabitants and undermine aspirations for home (*e.g.,* Yasmeen's window). An upcycled IoT could nurture positive associations by helping owners' reinvision their aspirations for home through customization.

Summary

Families invest in objects and rooms to nurture their creativity and growth in varying degrees based on control over their space. Family members want to structure their space using IoT to better nurture their growth. Yet, because of their limited control, they need the ability to use object-level infrastructure to function as room-like to accomplish these goals. It should adapt to rented spaces to honor renters' commitments to owners, have affordances capable of harmonizing multiple owners' wishes through reconfiguration, and sustain inventive processes rather than migrate workplace management into the home to ensure the home is restorative and relaxing.

DISCUSSION AND LIMITATIONS

We found that families use objects to adapt the home's space by setting and enforcing norms. Modifying domestic possessions allows them to project their ideals onto the household and adapt rooms to nurture creativity and growth. To support this, families need IoT infrastructure to range from room-centric to object-centric change. It should accommodate norm setting that dynamically changes across spatial jurisdictions and temporary owners (*e.g.*, renters or borrowers). At times, participants were wary of of IoT's disruptive costs like displacing routines, discarding functioning items, or making skills obsolete. To minimize these, an upcycled IoT could support lightweight modifications of the home's relationships by preserving object forms and using them to ground infrastructure.

Preserving Form and Managing Displacement

At the outset, we argued that family members do not have equivalent availability to integrate IoT, and IoT impinges on mental models of home. We showed how an upcycled IoT could leverage families' object-practices instead. Doing so could enable households to tailor IoT and make it more accessible to mental models of home. By contributing to family members' self-conceptions and their relationships to others, existing possessions are accessible to preconceptions for how they, as objects, should work when modified with IoT. As a result, differing family members could make IoT decisions according to their control and understanding of an upcycled artifact. Households evolve idiosyncratic arrangements over time and construct family roles through object-norms. Introducing new IoT devices risks displacing these negotiated relationships. In our study, objects were strong boundary markers—especially in families with children—for household customs. Lamps regulated children's behavior indoors, and a cookbook's material properties crafted a family legacy. New IoT interactions could respect these customs by preserving both existing object forms and relationships (*e.g.*, with others, object attachments, etc. [52]).

Yet, family members are not always happy with the home's current arrangements. Objects can reify problematic relationships and remind members of painful history. For example, objects obligate family members to others or require help to effectively use. IoT costs are not simply monetary. Instead, costs incur from the disruption IoT brings. With the new interactions made possible by IoT come displaced processes, requirements to upgrade or reconstruct past practices, and the work of configuring the new technology to the household.

Upcycling domestic possessions could aid in redefining the home. Modifying objects with IoT could support constructing new relationships and crafting ideals. For example, upcycled objects could re-allocate family members' time and attention. Domestic possessions would not obligate the family 'manager' if they could convey their own priority, proper use, or messages from other family members. An object could even reassure a person that it is not, in fact, a priority. Earlier studies found that married heterosexual women have a heightened awareness of household chores and could benefit from diminishing expectations for household organization and cleanliness [6, 2, 36]. Upcycled home objects could change household conventions, like cleanliness standards, by shifting responsibility, providing a check on perceived needs, and avoiding increased standards associated with new technology. For example, Sheila Olson's folder could be upcycled with messaging capabilities by piggybacking on a standard protocol like e-mail through the wireless communication afforded by an RFID lightbulb as described in [25]. Cleanliness is one convention of many embedded in day to day life, but it illustrates how upcycling could shift entrenched household norms.

Customization Instead of Discarding

Earlier, we claimed that an upcycled IoT should support family members with reimagining their possessions with computing capabilities. We found that participants' concern with discarding objects in working condition creates an opportunity for an upcycled IoT to address household values of minimizing waste by envisioning a new life for those possessions. Many participants were reluctant to acquire new objects and thought IoT would require discarding those they currently enjoyed or were "perfectly good". In many cases, these object worked just fine and participants thought it wasteful to discard it. Domestic possessions were investments families weren't willing to ignore or write off. By including these objects, an upcycled IoT alleviates some of these worries and could support making improvements on objects that merely "function well enough". For example, the Cranes were delighted their classic speaker system could be part of new, audiocasting cabilities. In contrast, the forced upgrade to Windows 10 undermined the previous investment the Olsons had made in building their custom, organizational systems. Often boredom with an aesthetic genre, or a want of agency, novelty, and self-expression results in a desire to rearrange domestic environments [1]. Enabling customization of an upcycled IoT would support making deliberate decisions about which properties to discard while keeping those that are satisfactory. These could be added at any point during an object's life cycle to refresh older objects with new capabilities just as rearranging furniture or adding a new coat of paint renews and recreates a room [1].

An upcycled home could support personalizing objects that are inherited, rented, or passed on from their previous owners. In out study, many domestic possessions saw second and third owners through family inheritance or changing roommates. Households used personalization techniques to adapt objects to their new owners or current point in time such as claiming a side of the room, manipulating a recipe's tastes, or expanding food storage space. An upcycled IoT could use these techniques to help new owners adapt previously owned objects to their own tastes or needs. Just as recipe modifications and wall-mounted lettering were used by our participants to personalize their possessions, upcycling could facilitate digital naming and annotation. Or, it could enable object versioning to allow users to modify an upcycled object's parameters but retain previous owners' choices. These techniques leverage the IKEA effect by enabling owners to use modular configuration or assembly of pre-designed adaptations to household possessions [37, 8]. Users can then adapt pre-designed IoT modifications to their objects to reinvision local constraints.

Limitations

We investigated 10 households in one American city, but this is not enough to fully characterize needs for lightweight modification. Other cultures should be examined. They will undoubtedly use objects and space differently [51, 8]. It remains an open question whether our division of labor typologies and family portraits would adequately speak to these alternatives.

CONCLUSION

We worked with 10 diverse households to shape an upcycled IoT to minimizes risks of destabilizing domestic relationships and values, and to characterize the home's object focused practices. We portrayed 3 patterns of how households divide labor to meet competing demands made from both inside and outside the home. These patterns show how societal level constraints are embodied in home life and prefigure potential costs of IoT. Across households, we found that domestic objects are used to negotiate social boundaries, nurture growth and adaptation to constraints, and make progress on an aspirational home. Our results identify several household niches where IoT could support lightweight modification of existing object forms and social relationships through upcycling. An upcycled home would support customization to give users control over which object properties will be modified and how disruptive the modification will be. Further, it would give family members the ability to manage the costs of newness such as what will be displaced, discarded, or made obsolete. We contribute portraits of household niches amenable to upcycling.

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