Exploring End User Programming Needs in Home Automation

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Exploring End User Programming Needs in Home Automation

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Home automation faces the challenge of providing ubiquitous, unobtrusive services while empowering users with approachable configuration interfaces. These interfaces need to provide sufficient expressiveness to support complex automation, and notations need to be devised that enable less tech-savvy users to express such scenarios. Rule-based and process-oriented paradigms have emerged as opposing ends of the spectrum; however, their underlying concepts have not been studied comparatively. We report on a contextual inquiry study in which we collected qualitative data from 18 participants in 12 households on the current potential and acceptance of home automation, as well as explored the respective benefits and drawbacks of these two notation paradigms for end users. Results show that rule-based notations are sufficient for simple automation tasks but not flexible enough for more complex use cases. The resulting insights can inform the design of interfaces for smart homes to enable usable real-world home automation for end users.

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CCS Concepts: • **Human-centered computing** → **Empirical studies in interaction design**; *Ubiquitous and mobile computing systems and tools*; • **Software and its engineering** → Software notations and tools;

Additional Key Words and Phrases: Configuration interfaces, contextual inquiry, qualitative analysis, smart home

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1. INTRODUCTION

Home automation as a concept has been around since the 1960s, while the term "smart house" was coined in 1984 [Aldrich 2003]. The purpose of home automation is to support inhabitants in their daily lives via technological means. Areas of interest include security functions like access control and surveillance systems, resource management with regard to water and electricity, multimedia functions for ubiquitous content streaming, and comfort functions like light and heat management [Bartram et al. 2011; Ur et al. 2013; Takayama et al. 2012; Yang and Newman 2013]. The profiles of smart home users are naturally diverse. With regard to technical interest and investment, the spectrum ranges from highly involved Do-It-Yourselfers to pure consumers of the Plug'n'Play mentality. Related to this, solutions for various budget sizes have been developed. Since the state of a building is an impacting factor for home automation,

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home automation systems exist in various degrees of building integration, ranging from fixed home installations for new buildings to lightweight wireless solutions that can be added without modifying the actual infrastructure. With regard to age and ability of inhabitants, the specialized segment of Assisted Living [Chan et al. 2008; Kleinberger et al. 2007] deals with the additional requirements of senior users or in-home patients.

This diverse user profile makes interaction design and development for smart homes challenging. On the one hand, solutions should be ubiquitous and refrain from impacting the user's life; on the other hand, people expect a certain degree of control over what is going on in their own homes [Bernheim Brush et al. 2011; Costanza et al. 2014; Mennicken and Huang 2012a; Mennicken et al. 2014; Rodden et al. 2013]. A number of commercial home interfaces have thus opted to expose the underlying technology in staggering detail to enable users full access to the home's functions [HomeSeer 2016; Insteon 2016; Loxone 2016; myGEKKO 2016]. This however conflicts with the reality that only part of the user population is both tech-savvy and interested enough to program their home from the ground up [Bartram et al. 2011; Bernheim Brush et al. 2011; Poole et al. 2008; Rodden et al. 2013; Rode et al. 2005; Yang and Newman 2013]. Home automation interfaces thus need to provide control solutions that also cater to the requirements of less tech-savvy users that still want to enjoy the benefits of an automated home. Current attempts for simplified interfaces usually provide home configuration in the form of if–then rule-based approaches [De Russis and Corno 2015; Dey et al. 2006; IFTTT 2016; Ur et al. 2014; Zamora-Izquierdo et al. 2010]. Other works have tried process-oriented approaches in the hope of providing increased expressiveness while still retaining easy-to-comprehend visualizations [Dahl and Svendsen 2011; Rietzler et al. 2013; Walch et al. 2013]. In their strictest form, these two paradigms can be seen as opposing ends of the home programming spectrum, and provide cornerstones for interaction research focused on end user needs. The fundamental principles underlying these two paradigms have however not yet been studied with regard to their effects on expressiveness and usability. Also, it is yet unclear how far-reaching end users' automation needs truly are. Research focused on the benefits and drawbacks of these basic paradigms can help to identify useful features and strategies for usable home automation interfaces targeting end users.

We conducted a contextual inquiry study with 18 participants in 12 households in order to gain a better understanding of end user needs for home automation and respective configuration. Through a process consisting of multiple home visitations and semi-structured interviews, we encouraged participants to think of and model home automation use cases in the context of their own home and daily activities. In a between-subjects design, participants either used a rule-based or a process-oriented notation to record automation tasks in order to study practical expressiveness, complexity, and ease of use of the two approaches. We opted for a pen and paper study to encourage creativity and the identification of automation use cases relevant to their own daily routines and household devices, without artificially restricting the elicitation process to a specific user interface implementation of either notation. Additionally, we also investigated general notions and perceptions on home automation in order to identify real-world deployment issues and requirements. Our results show that rule-based notations are generally sufficient to express simple automation tasks but are not flexible enough to support more complex use cases. Participants that used the process-oriented notation valued its expressiveness and presented us with more complex use cases involving more devices in their homes. We further discuss how our results can inform the design of end user configuration interfaces for smart home technology in order to enable usable real-world home automation for end users.

The remainder of this article is structured as follows. First, we discuss related work dealing with the acceptance and requirements of home automation by end users.

Furthermore, we detail various projects that have developed configuration interfaces following the rule-based and process-oriented paradigms. From this analysis, we derive the research questions that were addressed in our study. We then outline the particulars of our study and present the resulting insights.

2. RELATED WORK

Several previous studies aimed to elicit relevant factors for the adoption of smart home technology. We first discuss their results before focusing on proposed rule-based and process-oriented configuration approaches.

2.1. Requirements for Successful Home Automation

As the adoption of home automation in the general populace has been reluctant, research has been conducted over the years to better understand the requirements of potential users.

2.1.1. Notable Characteristics of Home Automation. To provide designers with an easy and reusable means of grouping home automation solutions targeting certain routines, Crabtree et al. [2002] expand on Alexander's approach of architectural design patterns inspired by social behavior [Alexander et al. 1977]. They designed a pattern-based approach to structure the domestic behavior of home automation study participants and introduced the notion of activity centers as the basis of domestic routines involving technology. Zhang et al. [2009], in their work on home automation interface complexity, identified home automation tasks as belonging to one of three categories, namely skill-based (e.g., turning on the lights), rule-based (e.g., If it is dark outside, close the blinds), and knowledge-based tasks. The latter comprises a more complex network of rule-based tasks and requires choices to be made depending on more than one context condition. With regard to the static nature of task automation, several works have pointed out how home automation will have to deal with irregular behavior or user routines changing over time [Davidoff et al. 2006; Chan et al. 2008; Kaasinen et al. 2012; Costanza et al. 2014].

2.1.2. Diverse Target Population. Davidoff et al. [2006] put their focus on researching the requirements of families with regard to home automation. They found flexibility of the system to be paramount as participants expressed a need for their system to accommodate their ever-changing routines. According to Davidoff et al., automation systems should provide users with capabilities to easily create and modify automation behavior. The survey conducted by Kaasinen et al. [2012] concerns itself with the general notion of user acceptance and expectations in intelligent environments. Among other things, they point out the importance of ease of use and giving the user a sense of being in control. They define the user as an active *co-crafter* in intelligent environments rather than a passive consumer and advise designers of intelligent environments to create technology that fits into their users' routines. Furthermore, smart technology should be designed for all kinds of users and neither exclusively for experts nor novices. With similar results, Mennicken and Huang [2012a] conducted an in-the-wild study that followed home automation professionals and end users in the process of establishing and inhabiting smart homes. Their findings include the notion of supporting and involving end users through all phases, from smart home conception to daily use. Regarding the latter, they also point out that capabilities need to be present to support both users with a high interest in modifying the home on a technical level as well as more passive users of the infrastructure. Pierce and Paulos [2012] reviewed HCI literature with a focus on energy-related home automation approaches. They found that upcoming smart grid technology will have a huge impact on home users who previously had little contact with energy technology due to the centralized nature of current provider systems. Aside from the persuasive aspect of getting users to reduce or shift energy consumption commonly associated with smart energy technology, they found that interaction research also needs to account for cultural aspects surrounding energy usage in the home. Special attention will have to be payed to the reconciliation of users' personal energy needs and routines with requirements characteristic of smart grids, such as peak avoidance. Further suggestions point toward automating everyday appliances like thermostats and dishwashers—a notion that has since been taken up by the industry. Pierce and Paulos further encourage research on new interactions to empower end users and leading them into their new role of energy supplier and distributor facilitated by an increasingly flexible energy grid. Costanza et al. [2014] conducted an in-the-wild study to research the impact and reception of an agent-based system designed to help users organize their laundry sessions in the context of smart grid technology. They found that doing laundry is an especially delicate use case illustrating the area of potential conflict between user routines and automation technology as users have rituals as well as necessities surrounding the laundry task that cannot easily be shifted to accommodate, for example, the goals of energy-aware appliances.

2.1.3. Barriers to Adoption. Harper [2003] identified cost and outdated building structures as potential impediments. Chan et al. [2008] point toward the large variety of connection technology and protocols. They also address legal and ethical issues relevant for the eHealth sector. Newman et al. [2008] identify "piecemeal interaction" as a central problem, i.e., that functionality is often scattered across various devices, services, and interfaces with narrowly defined responsibilities. Eckl and MacWilliams [2009] have found smart homes to be either too complex to use (stemming from the intention to be a general purpose system), too restricted in their functions (specialized niche products) or too "clever" by trying to take the user out of the control loop. They also note cost as a relevant factor. Brush et al. [2011] conducted an in-the-wild study with DIY households and more consumer-oriented households that had outsourced their home automation technology to specifically identify potential barriers for the widespread adoption of home automation technology. They identified four barriers, namely high cost of ownership, inflexibility, poor manageability, and difficulty achieving security. Poor manageability in particular addresses how complex user interfaces can confuse and irritate users. While their participants successfully incorporated home automation into their lives, they had to overcome diverse challenges that might keep less enthusiastic end users entirely from adopting home automation technology.

2.1.4. Interface Considerations. Several studies have found that full automation is not necessarily in the interest of users [Koskela et al. 2004; Koskela and Väänänen-Vainio-Mattila 2004; Hwang and Hoey 2012; Leitner et al. 2013], because they may fear losing control over the technology. Instead of full and invisible automation, end user configuration of automation behavior is proposed. Harper [2003] however found the usability of interfaces lacking and criticized the missing involvement of users in the design process. In the context of Assisted Living, Chan et al. [2008] also advocate user involvement at the design stage. Zhang et al. [2009] studied the effect of interfaces varying with regard to presented complexity on the completion metrics of home automation tasks and found that skill-based tasks as described above can be accomplished more effectively with a less complex, direct control style interface, while rule-based tasks are better supported by a more complex, task-oriented interface. They recommend the use of both approaches in home automation interfaces to adequately support the variety of tasks. Mennicken et al.'s [2014] survey compiles further challenges from related work. They identify the need to provide users with the ability to model what they find useful instead of what is technically feasible or interesting from the researcher's point of view. However, information needs to be visualized in a reduced way so even less tech-savvy users can make sense of it. They further point out the opportunities that could arise from users sharing their automation ideas and behaviors. They emphasize the importance of studying home automation interaction in the wild to uncover user requirements in more detail. In relation to this, Costanza et al. [2014] point out that interaction touching upon user routines needs to be designed in a way that allows users to incorporate the technology into their everyday lives instead of building their life around the automation system.

2.1.5. Device Integration. Another issue for the successful adoption of home automation is centered around the issue of first bringing smart devices into the home. While this has been pointed out by research for some time [Poole et al. 2008; Mennicken and Huang 2012a; Chong et al. 2014] and various approaches have been proposed, it has not been fully addressed. Recently, Jewell et al. [2015] conducted usability studies on how to design configuration interfaces for the integration of smart devices aimed at less tech-savvy users. They found that end users require the interfaces to be unobtrusive, self-explanatory, and primarily robust.

Summarily, the following areas can be identified from the related work as critical for the successful adoption of home automation by end users. External factors related to the *infrastructure* deal with the potentially high cost and effort to turn current buildings into smart homes. In conjunction with this, surrounding infrastructure like high-speed internet and smart grid access need to be up to par. Furthermore, current smart home solutions are often niche products advertised for assisted living, entertainment, or security rather than holistically integrated systems. This also leads to issues with *installing and managing* home automation systems that serve multiple purposes as their combination tends to be complex and comprised of heterogeneous technologies. Setting up a smart home requires expertise that either needs to come from an external contractor or be acquired by end users themselves. In this regard, it needs to be kept in mind that not all end users are interested in managing the technology; often they "just want it to work." Systems should thus make sure to appeal to users with different levels of expertise. Also relating to technology is the issue that most current systems fail to embody multi-user settings that regularly occur in reality. And finally, for internal factors like *acceptance and trust*, home automation systems have to be reliable, inform users about their inner workings, and be flexible enough to be integrated into users' routines and everyday lives. The quality of user interfaces is paramount for the adoption of highly complex, distributed systems like home automation—users need to be able to monitor and interact with the automation system; however, the available information needs to be condensed and presented in a usable fashion.

In our study, we approach the issue of requirements for successful home automation from the user's perspective. We are interested in how prospective end users themselves evaluate the potential of home automation for their personal lives and what they perceive as inhibiting or facilitating factors of the technology. This can help to either verify and strengthen the points addressed in the related work and help identify additional areas of concern. Based on our results, both researchers and industry can gain a better understanding of how to take home automation from interesting novelty to broad adoption in the general population.

In addition, we found it beneficial to study more closely the design of current smart home configuration interfaces as the related work presented so far has highlighted that empirical research targeting the underlying interaction paradigms is missing. Related work pertaining to smart home configuration interfaces in general, and rule-based and process-oriented approaches in particular, is presented in the following.

2.2. Smart Home Configuration Interfaces

Prior work on end user configuration of home automation has uncovered interesting aspects with regard to programming metaphors and user requirements. Rode et al. [2004] define device programming as an extension of direct manipulation. They identified "ahead of time" (i.e., scheduling the execution of an activity) and "repeats easy" (i.e., the automation of recurring tasks) as main programming functions. They also find that users only choose programming over direct manipulation if there is a powerful necessity for it. Truong et al. [2004] studied how users conceptualize automation applications without a pre-given model. Their participants tended to specify desires by abstracting from devices and adopt a more task-centric perspective. They presented CAMP, a configuration interface introducing the fridge magnet metaphor. Newman [2006] and Newman et al. [2008] collected information on the adequacy of classic programming constructs for use by non-tech-savvy users and came up with the notion of digital recipes for their OSCAR interface, which encapsulate *scenes* in which users may specify device settings to be executed in combination. Koskela et al. [2004], Koskela and Väänänen-Vainio-Mattila [2004], and Leitner et al. [2013] also focused on scene-based end user configuration. Both approaches initially focused on time triggers for the execution of scenes, Koskela et al.'s participants however suggested the addition of context event-based triggers. They further uncovered two distinct activity patterns desired by users: *pattern control* and *instant control*. Pattern control denotes cases where users create automation settings, whereas instant control refers to remote control options. Participants preferred to use computers for pattern control and mobile phones for instant control. Eckl and MacWilliams [2009] also propose a system where users can invoke scenes; however, the respectively available selection of scenes depends on the current context. They advocate that the user should make a conscious choice instead of invisible background automation. Both Brush et al. [2011] and Leitner et al. [2013] find existing commercial home automation interfaces lacking in usability. Even computer science (CS) students had difficulties mastering the evaluated programming interfaces [Leitner et al. 2013].

In summary, the related work has identified that automation interaction can constitute either direct manipulation/remote control functionality, or occur in the form of programming. Both are demanded by users, the more complex programming variant is however only attractive if it offers clear additional value over the remote control alternative. With regard to abstraction, users tend to be task-oriented rather than focusing on the specific smart device. Scenes constitute a common automation construct that has also been adapted in the industry; thereby, a combination of related settings can be triggered at a given time or via determined context. This is however a very basic form of automation; its characteristics are closer to remote control functionality than to home programming. We will focus instead on the latter to gain a better understanding of the human computer interaction required to create more complex automation scenarios. With regard to user involvement, related work from this paragraph and the section before both find that fully hidden background automation can be detrimental to user acceptance and trust. Instead, end users want and need to be involved with the automatic processes happening in their homes. For users to be involved in the configuration of their smart homes, however, interfaces need to be easy to understand and usable even for less tech-savvy users.

2.2.1. Rule-Based Configuration. Many recently developed end user configuration interfaces of home automation systems focus primarily on rule-based approaches following the if–then paradigm (also referred to in the related work as trigger-action or event-action paradigm). The Stick-e Note architecture [Pascoe 1997] early on combined context conditions as annotations with desired actions "written" on Post-It notes to raise awareness for context-aware computing. The iCAP system [Dey et al. 2006] provides a visual programming interface for context-aware applications, which allows the specification of if–then rules that are triggered by certain context configurations. An iCAP rule may combine up to three conditions to trigger one action. The interface of the DOMOSEC prototype home [Zamora-Izquierdo et al. 2010], among other things, enabled users to configure scenarios in which a number of device actions could be executed under certain conditions. While those scenarios were not termed as rules, they exhibit if–then semantics. García-Herranz et al. [2010] developed a system-level rule engine to provide an application-independent mechanism for end user specification of rules. They intended to ameliorate the trade-off between flexibility and simplicity for users, with the vision of generating situation-specific interfaces for the underlying rule system. In addition to the if–then rules, they introduced triggers (a *when* condition) and timers for time-dependent functions. This can be considered a hybrid approach combining aspects from both conventional rule-based and process-oriented notations as introduced in the next section. The HomeMaestro application [Salzberg 2011] for Microsoft's HomeOS [Dixon et al. 2012] extends the explicit programming concept by enabling users to record rules from interaction within their actual environment. Ur et al. [2014] examined the capabilities of rule-based programming for end user configuration in the smart home context. They asked participants to freely submit desired smart home behaviors and extracted those that could be expressed as rules via *one trigger–one action* or *multiple triggers–multiple actions* patterns. They found end user configuration to be feasible as well as necessary due to the high variety in desired behaviors. A recent analysis of 200,000 rules defined by users of the web service IFTT [2016] shows the real-world proliferation and acceptance of rule-based programming [Ur et al. 2016]. De Russis and Corno [2015] developed HomeRules to test a set of guidelines for rule-based programming derived from related work. HomeRules is a tangible interface similar to HomeMaestro that combines real-world device interaction with rule-based programming. They evaluated the concept in a qualitative study and found participants both capable of and enthusiastic about rule-based programming.

To summarize, rules are constructed of conditions comprised from context and resulting automation actions, following the structure of "if THIS, then THAT." In addition to this basic version, several variations have been proposed where the number and combination of conditions can vary, where an additional "when" construct has been introduced or where actions can be triggered by a timer. As large rule systems can become complex and difficult to oversee, some projects have conceived workarounds like context filters or recording functionality. All in all, rule-based configuration is the most widespread home automation programming paradigm in research and industry and has been well-received by users. However, as rules follow a strict pattern and are not naturally adequate for automation chains, another paradigm has evolved—process-oriented configuration.

2.2.2. Process-Oriented Configuration. Process-oriented notations have emerged for the expression of temporal and loosely time-synchronized activities. However, the expressiveness of process-oriented notations is often coupled with complex user interfaces. Although some of the above mentioned rule-based solutions support sequences of actions, it is not an inherent characteristic of rule-based notations as defined by Ur et al. [2014] and employed in many current home automation systems where one or more trigger events are directly responsible for the execution of one or more actions.

Humble et al. [2003] propose a more process-oriented approach based on a jig-saw metaphor to enable users to create multi-stage connections of sensors and devices as an information flow pipeline. In accordance with the source-to-sink control flow paradigm, this introduces a timing aspect as a device's action and subsequent state change trigger the next action in the process. Dahl and Svendsen [2011] investigated the jig-saw metaphor, filtered lists, and wiring diagrams to elicit usability factors for end user configuration. Filtered lists constitute a basic rule-based interface where users specify a trigger and resulting action in strict order. Wiring diagrams allow for the placement and connection of component blocks via directed arrows and the subsequent specification of the desired behavior. While they find that filtered lists were rated as most effective, participants found the more process-oriented notations to be more enjoyable. Rietzler et al. [2013] and Walch et al. [2013] propose a process-oriented graphical end user configuration approach for smart homes, similar to wiring diagrams, which reduces the complexity of process-oriented notations while retaining their expressiveness. However, the work reports only preliminary usability results of this approach based on a prototype implementation of the homeBLOX system.

In summary, processes-oriented configuration can be seen as the creation of multi-stage automation chains where one set of conditions and actions can trigger one or more following sets. Process-oriented configuration introduces a temporal aspect by nature and allows conditional branching. While some interesting approaches for the paradigm have been proposed, it has not been thoroughly explored from an interaction research perspective. It is yet unclear whether the benefits of process-oriented configuration warrant a more complex user interface from an end user's point of view.

2.2.3. Discussion of Configuration Approaches. It can be concluded that existing home automation configuration approaches have a number of drawbacks. Scene and schedule programming [Koskela et al. 2004; Koskela and Väänänen-Vainio-Mattila 2004; Leitner et al. 2013; Newman et al. 2008; Rode et al. 2004], which is used by the commercial Control4Home [2016] and e-Domotica [2016] systems, is limited in expressiveness. Existing interfaces also tend to suffer from Newman et al.'s "piecemeal interaction," e.g., users have to control settings for lights, thermostats, etc., separately. Rule-based interfaces further tend to be rather programming-oriented (e.g., Leitner et al. [2013] or Loxone [2016]), which may introduce barriers for less tech-savvy users. More visual systems like Ninja Blocks [2016] and If-This-Then-That [IFTTT 2016] lose clarity when an automation task requires multiple rules. Rule-based approaches have also been found to limit the user's overall creativity and expressiveness [Dahl and Svendsen 2011; García-Herranz et al. 2010], whereas process-oriented notations need to focus more on supporting clarity of control flow mechanics [Dahl and Svendsen 2011].

With regard to programming notations rather than scene setting, both rule-based and process-oriented configuration seem to have the potential to be employed for effective end user programming. The respective advantages and drawbacks of the two paradigms have however not formally been researched. Doing so can lead to a sound understanding of end user interaction requirements and inform the design of future home automation interfaces. The next section gives a summary of our rationale and details the research questions we derived from our analysis of related work.

3. RESEARCH QUESTIONS

While home automation has been extensively researched and many home automation systems and configuration interfaces have been proposed, the concept has not yet penetrated the consumer market on a larger scale [Bernheim Brush et al. 2011; Kaasinen et al. 2012; Newman et al. 2008]. Current solutions are marked by high costs, high complexity, low flexibility, and low usability [Bernheim Brush et al. 2011; Harper 2003]. To further the adoption of smart home technology by end users, home automation systems need to offer intuitive, easy-to-use configuration capabilities and interfaces that enable users to tailor their home's behavior to their individual needs. However, home automation interfaces are faced with the challenge of presenting highly technical automation procedures in a way that is intelligible to non-expert users, yet being expressive enough to support their automation needs.

Both in industry and research, primarily *if-this-then-that rules* are used to specify home automation behavior: Based on time- or event-based triggers, certain automation actions are performed, e.g., *"when the alarm clock rings, turn on the lights."* While rule-based approaches allow for accessible automation of simple tasks, more complex automation scenarios—that need to assume the form of extensive rule systems—are both difficult to create and potentially difficult to understand or recognize upon revisitation. Recent research has proposed to employ a more *process-oriented* approach to smart home end user configuration [Dahl and Svendsen 2011; Rietzler et al. 2013; Walch et al. 2013] in order to enhance the expressiveness of automation tasks.

To unearth the inherent benefits and drawbacks characteristic of the rule-based and process-oriented configuration paradigms, we designed a contextual inquiry study in which participants worked with notations designed to be representative of each of the paradigms for one week in a natural setting surrounded by their own devices and everyday routines. We felt that this would yield more meaningful results than evaluating the notations in a lab setting with artificial use cases that were of no personal relevance to participants. Also, we hypothesized that we could gain more in-depth feedback if we let participants engage with the notation for a longer period of time. In addition, we also investigated the general attitude of our participants toward home automation to identify real-world deployment issues and requirements for the successful adoption of home automation by the general population. The underlying research questions of our study are as follows.

Potential of Home Automation: Both as a survey of the current technological state of households and to get participants to start imagining home automation in their own life, we were interested in recording device inventories. In these inventories, we collected information on both appliances and electronic devices that participants already owned or that they desired to have. We further noted whether participants owned devices that were already network-enabled to estimate how much and what kind of home automation could potentially be established in current households. We used the compilation of these inventories further to get participants to think about use cases for the devices they mentioned in combination with their daily routines. The aim of this was to potentially reveal common use case clusters that should be the target of home automation industry efforts in the future.

Acceptance of Home Automation: To be able to put our results into perspective, we inquired about participants' general feelings toward home automation, as we expected a variety of attitudes, ranging from highly enthusiastic to very reserved. Related to this notion, we wanted to determine the conceptual and technological prerequisites necessary for end users to embrace home automation.

Rule-Based vs. Process-Oriented Notation: As the main focus of our study, we presented participants with either a rule-based notation for home automation or a process-oriented one to determine which features and strategies of each can be employed to create usable home automation interfaces. We expected rule-based notations to be sufficient for simple automation scenarios but were interested in whether participants would feel limited by it. Vice versa, we expected that process-oriented notations were more difficult to grasp but yield a higher expressiveness. Related to this, it was our goal to determine whether users even feel the need for complex home automation scenarios.

4. STUDY PROCEDURE

To address the research questions, we devised the following study design. We visited participants in their home to conduct a home tour and spark their creativity toward home automation by letting them formulate use cases in an unrestricted manner,

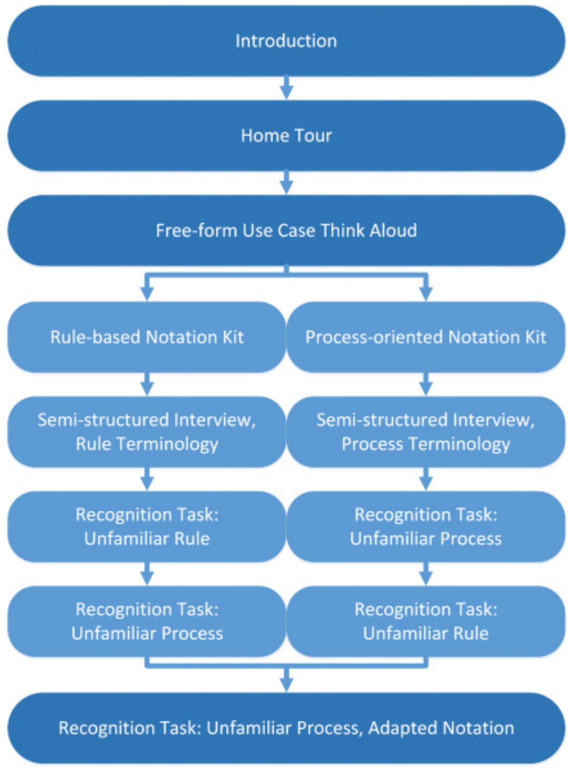

Fig. 1. Distribution of the research tasks between the two study conditions.

including those devices, appliances, and objects identified during the home tour as well as any other kind of sensor, device, or actuator they could imagine. Afterwards, we exposed them to a pen and paper notation kit following either the rule-based or process-oriented paradigm. Participants were instructed to try out the notation with one think aloud use case, while the experimenters were present to help with misunderstandings and getting participants acquainted with the respective notation. We would then leave participants alone with the notation for one week to allow them to think about and create desired automation procedures as they noticed them in their daily lives. In this, they were not restricted to the devices or sensors they owned; we encouraged them to model whatever behavior they would want their ideal smart home to have. During a subsequent visit, participants were encouraged to present their devised use cases followed by a semi-structured interview. The interview was basically the same for both conditions aside from the terminology of rules and processes. Condition-specific were those questions that dealt with the particulars of each notation as detailed below. To conclude, participants were given a recognition task. This task comprised three interpretation exercises, i.e., participants were given one unfamiliar use case recorded in the notation that was previously introduced to them, one from the respective other study condition and one use case recorded in an adapted process notation for additional results. Participants were then instructed to tell the experimenter what home behavior they thought would result from each of the automation procedures. This task was added to examine the understandability of the notations. The distribution of the research tasks between the two study conditions can be seen in Figure 1.

In the following, we first present the definitions of rule-based and process-oriented notations that were employed in this study. Furthermore, we introduce the methods and materials that were used during the study to gather information from participants relating to the research questions formulated above. To conclude, we present the recruitment process and participant demographics.

4.1. Definition of Notations

Our goal was to gain a deeper understanding of the characteristic benefits and drawbacks of rule-based and process-oriented notations in relation to end user configuration of smart homes. For this purpose, we first derived the relevant characteristics of each notation approach based on our analysis of existing research and commercial interfaces. We then proceeded to define generalized notations being representative for the respective approach. This was done to be able to focus on the underlying principles distinctive of each paradigm and to avoid implementation-specific issues that would have been introduced by comparing existing notations. While for example rule-based notations can be extended with "when" constructs or chaining of rules to serve similar purposes as process-oriented notations, we wanted to explore the fundamental conceptual differences between the paradigms and thus chose to present participants with a strict version of rule-based notations in our study.

4.1.1. Rule-Based Notation. In strict rule-based notations, automation behavior is defined in an *if THIS, then THAT* form. The if-clause may contain points of time (e.g., *8 a.m.*), device events (e.g., *bedroom lights on*), or contextual events (e.g., *Alice entered living room*). The then-clause describes device actions (e.g., *turn on the radio*) to be executed after successful evaluation of the if-clause. The vocabulary for the elements of rule notations varies. We defined the if-clause as a *trigger* and the then-clause as resulting *actions*, similar to Ur et al. [2014]. Commonly, triggers can be constructed by combining several events via the use of AND-operators. OR-constructs are represented by separate rules with a complementary set of trigger events. Actions can be combined with AND-constructs, i.e., a trigger results in the execution of multiple actions. We did not include additional timing elements, like those suggested by García-Herranz et al. [2010], as they constitute specific extensions not found in most rule-based configuration interfaces for home automation. Similarly, we did not include chaining of rules (e.g., *if THIS, then RULE X*), because it constitutes a timing-dependent pre-condition for rule x—a feature found in some rule-based notations, but not common in existing configuration interfaces and thus not representative of the underlying paradigm.

An example of our generalized rule-based notation can be seen in Figure 2. In the upper left corner, a name for the respective rule has to be specified. Triggers and actions can then be specified in dedicated columns. The AND semantic is used implicitly on both sides, i.e., if more than one trigger is specified, then all triggers need to evaluate true to trigger the action column; similarly, all actions in the action column are activated in parallel. For the OR semantic, a new rule has to be created. Both triggers and actions are device-specific and need to be specified in the format *device (event)* or *device (action)*. Sensors, which are essential for smart environments, are not necessarily treated as dedicated devices in our notation; instead, they have been abstracted into the concept of *context*. This adheres to the task-centric perspective of end users as postulated by Truong et al. [2004] and is deemed to be easier to understand for non-tech-savvy users. Context events are to be assigned either to their respective sensing devices as understood by the user like *clock (between 6 and 8 am)* for time or *thermometer* ($>32^{\circ}C$) for temperature or they can be labeled with their associated variable, i.e., *humidity (high)*. More advanced sensing is supported but is dependent on the respective technical knowledge of the user. In general, participants are free to come up with any

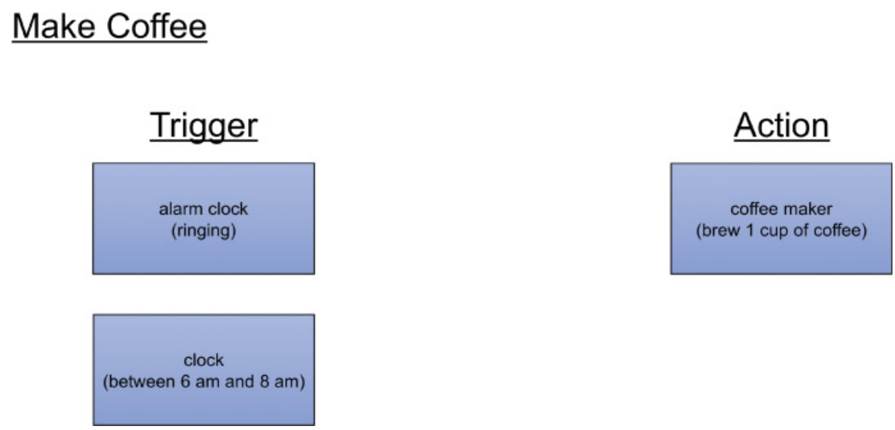

Fig. 2. Example of rule-based notation.

kind of context they can imagine—regardless of technical understanding or feasibility. Additionally, we included a timer construct where events in rule A could trigger the virtual device *timer (set to x minutes)* and *timer (elapsed)* could in turn trigger the actions in rule B. This is a feature used in most current rule-based approaches and does not break the integral "if THIS, then THAT" structure of the paradigm.

4.1.2. Process-Oriented Notation. Process-oriented notations allow for the specification of control graphs. Devices and context elements can be depicted as nodes, while edges denote control flow. For every connection, triggering event and resulting action have to be specified. Logical operators (AND and OR) can be used between the nodes to create arbitrarily complex automation processes. Since the control flow is dependent on the triggering and completion of previous elements, time dependencies are introduced. Thus, a chain of events and actions accrues a growing context description statement for later elements. Consider the process "*When I wake up in the morning, brew a cup of coffee. On weekends, turn on the radio when coffee is ready, otherwise the TV news channel. If my partner is still asleep 20 minutes later, open the bedroom blinds*." The coffee maker action is triggered every time the user wakes up, while the blinds action requires the respective aggregated context to be executed. It is further possible to fully or partially encapsulate processes as reusable subprocesses, which corresponds to the concept of rule chaining.

An example of our process-oriented notation can be seen in Figure 3. In the upper left corner, a name for the respective process has to be specified. Every process has a designated starting point. Arrows start at that point and connect to the first order of devices. More devices can be added by adding more arrows, both horizontally and vertically. Each device has events and actions, e.g., alarm clock has the action "set alarm" and the event "ringing." Events and actions need to be specified in the format *device (event)* or *device (action)*. Mirroring the rule-based notation, context events are to be assigned to their respective sensing devices like *clock (between 6 and 8 am)* for time or *thermometer (*$>32^{\circ}C$*)* for temperature. Based on the same argumentation as before, advanced sensing is possible but depends on the user's technical understanding. AND and OR operators can be placed at the appropriate positions of a process. All incoming edges of an AND operator need to be fulfilled for progression while for an OR operator one suffices. We also included a timer device with the action "set to x minutes" and the event "elapsed." Processes can further be reused as subprocesses, referred to with their name.

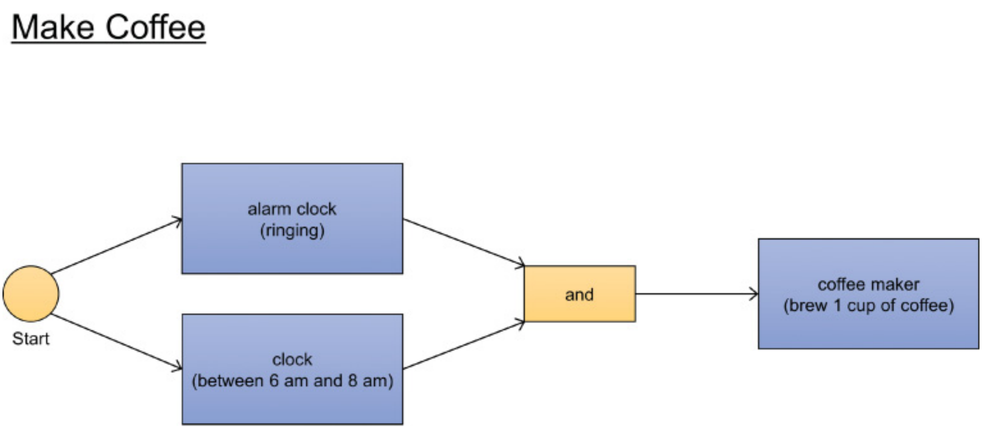

Fig. 3. Example of process-oriented notation.

4.2. Methods and Materials

To address the research questions regarding acceptance and potential of home automation as well as interaction with the programming notations, we opted for a qualitative study design. We created a number of supporting materials that are introduced in the following. Originally, all materials were in German to accommodate our participants.

4.2.1. Home Tour. To start off the study, we introduced participants to the general idea of home automation and gave them an example to familiarize themselves with the concept. We chose the example of "When the alarm clock rings in the morning, coffee is automatically made." Participants were informed that they could stop participating at any time but that they would receive the compensation of 30 Euros only upon completion of the entire study. They had to consent to audio recordings of the interviews as well as to having pictures taken of their handwritten notations. Subsequently, they were given the opportunity to ask questions before signing a consent form.

Following the formalities, participants were asked to guide the experimenters through their home. For this, we devised a supporting questionnaire for the experimenter to note the participating household's ID, what kind of appliances and electronic devices already existed in the household or were desired and what use cases the participants could imagine in their environments.

For the device inventory, we devised a matrix of the most common rooms (e.g., living room, kitchen, bathroom, home office, etc.) and potentially automatable devices (e.g., lights, windows, stove, multimedia equipment, door locks, etc.) with extra fields for additional rooms or devices so the experimenter could note existing devices quickly without disrupting the natural flow of the home tour. The experimenter could also note whether devices (1) *exist*, whether they (2) *exist and are already network-enabled*, or whether they (3) *do not exist but are desired* by the participants.

As for the use cases, participants were encouraged to formulate these in a free form manner while disregarding any technical constraints. They should state whatever behavior they would want from an automation system—including additional devices, sensors and actuators—and not be limited by what they thought feasible. Experimenters could point out existing devices to elicit further use cases but should not suggest any; i.e., they could ask participants if they would find it useful to automate a particular device x, but not tell them what automation in that case could look like so as not to prime them towards the experimenter's notion of home automation.

The home tour was generally conducted with two experimenters present, so one could lead the tour while the other took notes. Exceptions were made when necessary. If the participating household consisted of two participants, the home tour was conducted together. During the tour, audio data was collected for later use case analysis.

4.2.2. Notation Kits. Afterward, the participants were introduced to the notation kits and given the opportunity to ask questions. For both notations, we devised paper-based notation kits. Paper-based approaches are especially helpful in the early stages of interaction research to ensure that participants can complete tasks in a way that feels intuitive to them. Rodden et al. [2013], building upon the work of Tohidi et al. [2006], determine the advantages of sketches to be that they are (1) *disposable*—which encourages participants to criticize aspects without fear of insulting a researcher's work as could be the case with fully developed interfaces, (2) *minimalist*—which helps both researchers and participants to focus on the core aspects of the research questions instead of having to deal with additional aspects introduced by technology, (3) *explorative*—which allows participants to come up with creative solutions that are not fenced in by what is possible or not in a specific prototype, and last (4) *ambiguous*—in a way that participants can appropriate the sketched content more easily and make it their own. It has to be noted that paper-based notations can only go so far to support the design of future interfaces. While conclusions can be drawn concerning the applicability of certain interaction metaphors, implementations of the notations will have to prove their merits by themselves. Usability testing will then reveal whether a given interface is indeed capable of conveying its underlying interaction paradigm to end users in a usable way both with regard to clarity and efficiency. This will be especially crucial once features from different paradigms are combined in the hope of capitalizing on their varying advantages. Paper-based research is however helpful to include the intended end user in the design process early on and then guide the initial design choices of future implementations. In the following, we will describe the notation kits that were devised for this study in detail.

The rule-based notation kit consisted of a 1-page manual detailing the notation as laid out above, a pen, large sheets of paper, yellow sticky notes, and an adhesive tape. Participants were instructed to use one sheet of paper per rule and think of meaningful names same as those that would have to be used in an actual home automation interface to identify the rule. Devices with triggers and actions were to be noted on the sticky notes and placed on the large sheets of paper. The manual illustrated the rule notation with an exemplary picture but also stated that the layout shown was merely a suggestion. A translation of the manual can be found in Appendix A.1.

The process-oriented notation kit consisted of a 2-page manual detailing the notation as laid out above, a pen, large sheets of paper, three colors of sticky notes (green, pink, and orange), and an adhesive tape. Participants were instructed to use one sheet of paper per process and think of meaningful names the same as those that would have to be used in an actual home automation interface to identify the process. Devices with triggers and actions were to be noted on green sticky notes, logic operators should be noted on pink sticky notes, and for subprocesses, the re-used process's name should be written on an orange sticky note. All notes should be placed on the large sheets of paper and connected with arrows to form an automation process. The manual illustrated the notation with an exemplary picture but also stated that the layout shown was merely a suggestion. A translation of the manual can be found in Appendix A.2. Instructions were designed so that participants understood the presented notations but were neither expressly instructed to follow them strictly nor forbidden to deviate from them.

Participants then—each, in case of a household with two participants—had to complete one predetermined use case with the notation plus one to three of the ideas they expressed during the home tour. Experimenters deliberately did not try to "correct" the notation to match the instructive materials as it was also of interest to see how participants would change their respective notation to make it their own. Deviations were noted and discussed during appointment 2 in the semi-structured interview. To conclude the appointment, experimenters would take pictures of the participants' use cases but leave the originals for the time being. Before leaving, they would encourage participants to record more use cases until appointment 2 one week later.

4.2.3. Think Aloud and Interviews. The beginning of appointment 2 then depended on whether participants had recorded more use cases on their own. If so, they were asked to explain their mental processes retrospectively. If not, they were asked to record use cases using the think aloud approach. Participants could either decline or accept this request. If they accepted, they had to come up with their own ideas and work through the notation on their own. The goal of this section was to explore participants' mental model while creating processes and rules. Two things were of interest there: Is there a potential dissonance between the instructive material and the participants' understanding of it and is the noted down use case the same as the one participants originally envisioned? This phase was used to gather information for the subsequent interview to unearth which observed effects were due to the differing notations and which were due to misgivings in the mental model they constructed of the notation.

Following the think-aloud task, the semi-structured interview was conducted. The interview dealt with the efficiency of the given notation for participants' use cases first: How fast did they feel they were in noting down single or complex use cases with their notation? Could they come up with meaningful names? In what ways did the notation support or not support clarity of overview for complex scenarios? Did participants feel they were given enough information to work with the notation? Afterwards, condition-specific questions were asked to elicit participants' opinion on the elements specific to their given notation and their opinion on the notation as a whole. If they had created potential conflicts in their use cases, e.g., one rule that turns the lights on after 8 pm and one that turns them off when no-one is home, they were asked if they were aware of this and if so, what stopped them from solving the problem. The same was done if they modeled potentially unintended side effects like one behavior closing the blinds when the TV is on and one behavior to turn on the lights when the blinds are closed. Subsequently, participants should evaluate whether they felt that the given notation supported all their envisioned use cases. We were also interested to see whether participants would use in-between steps, i.e., more than one order of trigger and action. In the rule condition, this would constitute a violation of the notation that could lead us to potential deficiencies of rule-based notations for home automation. Vice versa, if participants in the process group saw no need for in-between steps, process notations might be unnecessarily complex for automation scenarios. To conclude the interview, general questions about home automation were posed: Do participants feel as if they would use home automation in their everyday lives and what would their requirements for home automation software be like? The complete interview script can be found in Appendix B.

Afterwards, the recognition task was conducted. All participants were shown a use case modeled by a different participant of the same condition, as well as one use case from the other condition. In addition, an alternative of the process notation was shown that lacked a starting point and placed the event information on the edges instead of the device nodes. This notation came up in previous user testing with the homeBLOX user interface [Rietzler et al. 2013; Walch et al. 2013], and we were interested in how it would compare with the standard notations. An illustration of the adapted process notation can be seen in Figure 4. With this task, we wanted to find out how

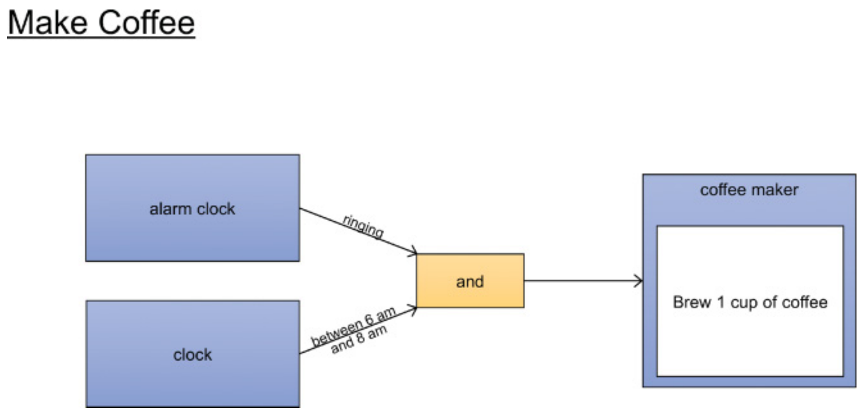

Fig. 4. Example of adapted process notation.

well participants could reconstruct unknown use cases, both from the notation they were familiar with as well as the respective other paradigm. The recognition task was designed to gain insight into the understandability of each notation but also served as a point of comparison where participants could discuss the benefits and drawbacks they perceived in each notation. Use cases for process and rule notation were chosen by the experimenters in each case from the available pool of use cases created by the participants and transferred into a digital representation. Important in this case were similar complexity and also, that use cases were chosen that did not stray too far from the initially devised notations. The use case for the adapted process notation was "*If the TV is turned on, close the blinds. If then a movie is being played and someone leaves the room, pause the movie until the person returns*."

Audio data was recorded all through appointment 2 and upon completion, experimenters took all recorded use cases and leftover material. Participants were thanked for their participation and received the compensation. If the household consisted of two participants, then appointment 2 was conducted with each in private.

4.3. Recruitment

We recruited potential participants through a number of channels, i.e., Twitter, Facebook, and various university channels. Due to the potentially sensitive nature of the study that required participants to invite the experimenters into their own home and show them around, we also chose to recruit potential participants from our own social circles to reduce that barrier. However, we ensured that, whenever logistically possible, participants later would not be interviewed by the team member they knew personally.

We aimed for a diverse group of participants in our study showing different levels of interest in home automation and technological affinity to be able to deduce what characteristics home automation interfaces need to have to be appealing to the general populace. To be able to select a balanced pool of participants for our study, we used a demographic questionnaire on our pool of potential participants first. The characteristics that were of interest to us were: Computer Science (CS) background (yes/no), age, living situation (alone, shared apartment, or living as a couple), self-proclaimed level of tech-savviness on a 5-point Likert scale, and self-proclaimed level of technophilia on a 5-point Likert scale. Based on this, we chose pairs with similar characteristics from the pool and randomly assigned them to the two conditions. Family households could not be included in this sample as none volunteered. The specifics are detailed in the following section.

Table I. Overview of the 18 Participants and Their Respective Characteristics

ID	Condition	Background	♀/♂	Age	Living situation	Tech-savviness	Technophilia
R24b	Rule	CS	♂	25	Shared	4	5
R24a	Rule	Not CS	♂	25	Shared	4	4
R31	Rule	Not CS	♀	26	Shared	1	4
R23	Rule	Not CS	♀	21	Shared	4	4
R29a*	Rule	Not CS	♀	66	Couple	2	2
R29b*	Rule	Not CS	♂	65	Couple	4	5
R26a*	Rule	Not CS	♀	23	Couple	3	3
R26b*	Rule	Not CS	♂	24	Couple	5	5
R27*	Rule	Not CS	♂	24	Alone	5	5
S19a	Process	CS	♂	25	Shared	5	5
S19b	Process	Not CS	♀	22	Shared	3	3
S22	Process	Not CS	♀	23	Shared	2	2
S11*	Process	Not CS	♀	22	Shared	4	4
S28a*	Process	Not CS	♀	54	Couple	1	2
S28b*	Process	Not CS	♂	57	Couple	3	4
S30a*	Process	Not CS	♂	25	Couple	3	5
S30b*	Process	Not CS	♀	28	Couple	1	5
S8*	Process	Not CS	♂	21	Alone	3	3

Starred entries denote participants that were interviewed by someone they knew personally.

4.4. Demographics

We chose 12 households with one or two members each to participate in our study. The demographics of our 18 participants total are detailed according to the characteristics mentioned before and can be seen summarized in Table I. The irregular participant IDs are remnants from the recruitment pool.

Of the 18 participants, 9 were female and 9 male. Their age ranged from 21 to 67 years. All participants were German. Each group contained 1 one-person household, 4 participants living in a shared apartment, and 2 couples living together. The rules condition comprised 4 women and 5 men with an average age of 33 years (Mdn = 25, SD = 17.3). The process condition comprised 5 women and 4 men with an average age of 31 years (Mdn = 25, SD = 13.4). Only one person in each condition had a CS background, the others had academic as well as non-academic backgrounds. Regarding tech-savviness and technophilia, participants in the rule condition had an average savviness rating of 3.8 and technophilia rating of 3.8; participants in the process condition had a savviness rating of 3.1 and technophilia rating of 3.0. Post-study analysis showed that low technophilia or little interest in home automation did not have a significant impact on participants' engagement with the study in terms of the number of modeled use cases.

Post-study analysis further showed that having a familiar interviewer did not significantly impact the number of use cases modeled in the study nor skewed participants towards a certain opinion on home automation. Both groups gave equal praise of their respective notation; however, participants that did not know their interviewer personally were more reluctant to criticize the notations.

5. STUDY RESULTS AND DISCUSSION

In the following, we present our method of analysis and the results of the study clustered by the respective research questions. Results are shortly discussed where appropriate, while an overarching summary of the resulting insights for home automation interfaces is given in the next section.

Table II. Interview Categories Resulting From Coding

Use cases	Home automation	Notation
Comfort/home control (18)	General interest, yes (18) / no (8)	Criticism (18)
Security (7)	Desire for automation (12)	Praise (18)
Energy saving (6)	Desire for remote control (8)	Recognition task (18)
Pets (2)	Desire for remote access (3)	Deviations (14)
Plants (2)	Desire for notifications (3)	Problems with own use case (1)
Remote access (1)	Preferred interface device smartphone (10)	
Health (1)	Preferred interface device tablet (9)	
Other (3)	Preferred interface device laptop (9)	
	Preferred interface device desktop (4)	
	Preferred interface device other (7)	
	Presumed software requirements (17)	
	Aspect concerning deployment (10)	

Numbers indicate how many of the 18 participants made a mention in this category.

Table III. Device Types Participants Would Like to Automate

Lights	Audio playback	Central heating	Stove/oven control	Refrigerator
12	12	12	11	11
Window automation	Coffee maker	TV	Smartphone	
11	9	9	8	

Numbers indicate how many of the 12 households mentioned this type.

5.1. Method of Analysis

From the home tours, we analyzed the device inventory sheets compiled for each household, as well as the collection of 249 freely formulated use cases to determine clusters. With regard to the notation modeling, we analyzed 65 rule and 64 process recordings, including use cases modeled at the end of the first session. We recorded 13 hours of interview audio from the second sessions.

Qualitative analysis of the interview recordings was conducted by three coders in an iterative coding process. Inter-rater reliability was determined using Fleiss' Kappa coefficient. The coding taxonomy was iteratively refined to obtain a taxonomy consistent across groups. We iterated over one randomly selected rule and process participant each to make sure categories were applicable for both. After each coding, the annotators discussed and reconciled annotation discrepancies. Eventually, we settled on three major categories: Use Cases ($\kappa = 0.70$), Home Automation ($\kappa = 0.74$), and Notation ($\kappa = 0.60$).

Corresponding subcategories and number of mentions can be seen in Table II.

In the following, we detail the results of our study with regard to potential and acceptance of home automation as well as the comparison of notations.

5.2. Current Potential of Home Automation

Overall, households named on average 21 (SD = 5.9) device types, e.g., lighting, heating, media devices, and so on. During the hometour, households came up with 6–43 informal use cases (avg. 20.8, SD = 9.9) and 249 in total. As for the notation modeling task, participants recorded 3–12 use cases on their own (rules avg. 7.2, SD = 2.9; processes avg. 7.1, SD = 2.6) with 65 rule and 64 process recordings in total.

The device inventories revealed what device types participants would like to automate. The results can be seen in Table III. All households were interested in automating lights, to either illuminate the house in the evening or when needed upon entering a specific room or location within a room. Household 19 explained that their combined home office/bedroom would benefit from selective lighting where one inhabitant could go to bed and have this area darkened, while the other could continue working at the

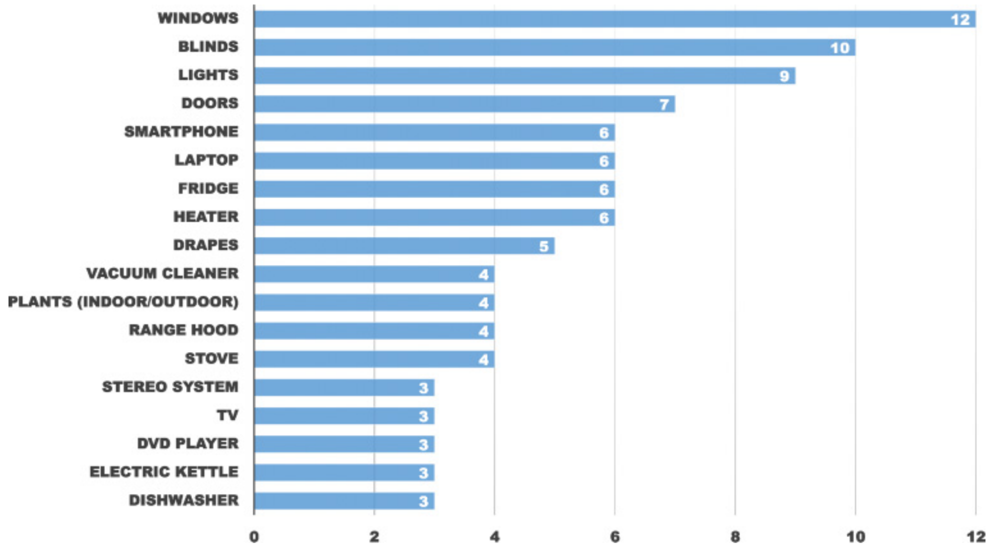

Fig. 5. Distribution of devices that interviewers prompted in more than two households during home tours.

desk. Audio playback also played a dominant role with use cases focusing on media streams following the user around the home or accompanying activities like relaxation or cooking with characteristic music. S30b suggested the idea of creating a shower setting where a relaxing light setting was complemented with the sounds of the rain forest. Automated central heating was also mentioned by all households, either to simplify thermostat routines like heating the bathroom before taking a bath or to save energy more efficiently with heating schedules based on user presence. Eleven households wanted to automate windows, either to control the quality of air in the house with regard to staleness and humidity or to make sure that all windows were closed when no one was home. Unfavorable weather conditions like heat, rain, or strong winds were also a concern. With regard to the kitchen, households mostly favored stove and oven control, which would allow for automated cooking, and smart fridges able to manage their contents and compile grocery lists. Interesting ideas were fridges capable of detecting spoiled goods and a calories management system for the household. Automated coffee makers were also high on the list, usually in combination with breakfast-making routines triggered by inhabitants getting out of bed or finishing their bathroom routine. Automating TVs received moderate attention with a variety of use cases; media streaming was a topic, but also the use of the TV as part of a surveillance/door opening system and also as an additional display for content otherwise displayed on smaller laptop screens. Smartphones mostly played a role with regard to functioning as a universal remote for the home or as a source of sensor and context information. As participants mentioned that they would prefer notifications over full automation in some use cases, the smartphone was deemed the best fit for receiving and displaying these in a timely manner.

In addition to letting participants name devices on their own during the home tours, we sometimes prompted them about whether common devices were to be found in their home as well or when we could see devices that they had neglected to mention. A distribution of the devices most commonly prompted can be seen in Figure 5. It has to be mentioned though that from their reaction alone we cannot tell for sure whether participants simply forgot mentioning a device or whether they neglected it because they thought it was not suitable for home automation. However, participants were often very outspoken in telling us when they did not want a specific device to be automated or could see no use in it. All in all–while not being conclusive–these results can help indicate which devices participants currently associate intuitively with home automation and which would need to be promoted more.

In general, participants showed a large interest in automating kitchen, bathroom and cleaning equipment (96 of 249 mentions). We identified kitchen, bathroom, front door, the living room couch, and pets and plants as respective activity centers of the home using the approach devised by Crabtree et al. [2002]. This classification can help designers find reusable automation solutions for common use cases aggregating around these activity centers.

Participants especially liked the idea of automating devices for morning and coming home routines. They showed comparatively little interest in automating entertainment and access control (56). This contrasts starkly with the home industry's current focus on marketing automatable devices in this area like the seamless music solution Sonos[1] or Link Interactive's[2] door lock and glass-break monitoring.

In accordance with related work, participants did not aim for full-fledged building automation but rather placed emphasis on everyday appliances like water heaters, alarm clocks and coffee makers, which have largely been neglected by manufacturers both with regard to automation and integration with the home. Since we did not restrict participants to use cases that were feasible with current technology, we expected to encounter a number of futuristic ideas as well—especially from participants that had little technical knowledge; however, we only observed few futuristic ideas, namely "backpack packer," "cereal preparer," "mind remote control for TV and music," "completely automatic shaving where I don't have to do anything anymore," and a fridge that can move from one floor to the other to save inhabitants a trip down the stairs.

Overall, participants strongly favored *comfort / home control* use cases, e.g., automation that would spare them tedious, everyday tasks like turning things on or off, setting alarms or pushing device buttons. For example, participants would like to automate behavior such as "When I go to bed, remind me to charge my phone and set my alarm according to my next-day appointments. As soon as I'm asleep, make sure all lights are turned off and windows and doors are locked. When the alarm rings, open the blinds, turn on lights in the bathroom and brew me a cup of coffee." Participants were also of the opinion that automation should help manage personal preferences in multi-person households by tailoring for example lighting atmosphere, music taste, and room or bath water temperature. Household S30 expected the smart home to be aware of their preferences with regard to news interest, TV shows and music in order to present them with a personalized media mix that should also take their current mood into account. They also brought up the idea of interleaving their content streams when they were both present. The two participants from shared household R24 also added that they would like a smart home to help them schedule laundry and bathroom routines, especially when not only all inhabitants are present but also house guests. They imagined a solution where the smart home would coordinate based on everyone's waking time and morning appointments. S19b would like the smart home to manage her extensive library in a way that she could locate a book by searching for its title and having the shelf indicate its position by a blinking light. Pet owners S19 and R27 would like the smart home to take over the duty of feeding the animals. Plant owners would generally want their plants to be watered automatically. Two participants also showed concern for software updating needs. R29b wants device updates in the home to be installed seamlessly, in contrast to, for example, his current navigation system that

[1]http://www.sonos.com/.
[2]https://www.linkinteractive.com/.

needs to be taken out of the car, connected to the laptop to update, and then be brought back. S19b remarked that she would need an exception for energy saving routines to make sure that updating devices were not suddenly turned off when people left the home. Participants also showed concern for others; R29a and S28a wanted the home to automatically limit music or TV volume so as not to bother their partners, while households S19 and R24 were concerned about bothering the neighbors. S30b in turn wanted the home to help her take care of herself with regard to separating work from free time by managing her calls. Private calls during work hours or work calls during off time should be hidden, but notifications should be available upon explicit request. Exceptions should be made for private emergency calls, which should always be patched through until the user picks up the call.

Regarding *energy* use cases, the idea of "turn off appliances when we are away or sleep" was paramount. Participants were however also concerned about charging their devices. With regard to smartphones, many were worried about forgetting to do so, while with electric toothbrushes, participants were aware that always putting them back in the charger would damage the battery. Several participants would prefer to have the smart home take care of these issues. 19a wanted the smart home to provide him with detailed resource monitoring so that he could optimize his routines.

Participants had a general awareness of *security* issues; the prominent use case here focused on supporting access control via identifying sensors or by employing a combination of cameras and smartphones to implement a remote door opener. Participants also frequently brought up the need to be sure that automatic windows would reliably close again to prevent break ins. Both R29 and S30 additionally wanted "vacation settings" for blinds and lights that would make the home look inhabited even if the owners were away on a trip. Participants also thought of appliance surveillance; household S19 imagined an emergency stop and notification system for their washer in case of flooding, while S22 wanted to keep tabs on her gas-powered water heater to prevent dangerous carbon monoxide build-up. S30b also wants the smart home to take on an educational role: In general, she wants to remember to turn off devices like stove or lights by herself before she leaves the home; if she forgets, she wants the home to tell her that she did, even if no emergency was detected.

Overall, 70.5% of the modeled use cases fell into the *comfort/home control* category, followed by *energy saving* at 7.0% and *security* at 6.2%. These results should be mirrored by both research and industry which have both hitherto put their focus more on energy saving and security use cases and less on the convenience aspect of automation desired by current home owners.

5.3. Current Acceptance of Home Automation

With regard to the current acceptance of home automation, we present our participants' opinion on the perceived utility of home automation in general as well as their requirements for potential home automation software.

5.3.1. Perceived Utility of Home Automation. The majority of participants stated that they would use home automation in their own home (15). Prominent reasons were "saves time and frees me from tedious work" (9) and "is fun & entertaining" (3). R19a felt that "it would be very comfortable and I would get to be lazy." Also, S11 was enthusiastic: "I have a ton of use cases." Both S30b and 29a stated "It would make my life easier and I would feel safer." R27 liked the idea of both saving time and trips throughout the house. However, participants also voiced reservations, e.g., due to associated costs. Participant R29b noted that switching to home automation should not incur huge financial or structural imposition. Four participants saw home automation at best as a "nice to have." Most participants stated at some point—and regardless of their general opinion of home automation—that they felt they did not really need it in their lives. S8 stated that his household did not warrant automation due to its small size; he could however imagine things to be different with an increasing number of devices.

Reasons for wanting to use smart home technology were diverse in the areas *Automation*, *Remote Control*, *Remote Access,* and *Notification*. R29b summarized the advantages of home automation as (1) prevention of forgetfulness, (2) sparing people unnecessary trips just to start or stop something, and (3) enabling things to happen in the user's absence. S30b noted that she had previously had no desire for home automation but after contemplating it for a week, saw large potential for it in her personal life. Sixteen participants voiced specific automation needs, focused on comfort/home control, energy saving, and security in a way that matched results from the home tours. Participants would also like systems to be able to recognize different users and execute the corresponding set of preferences (music, lighting, temperature, etc.) when they are on their own, e.g., relaxing in the living room. Several would like a generic remote control to automate devices in the home, while R31 emphasized the use of remote control for entertainment purposes. S28a stated that a remote control would be her favorite for interacting with electronic devices in the home. S28b saw the benefit in "being able to control the home comfortably from the couch." Four participants liked the idea of remote access to the home's digital infrastructure, for example, to remotely monitor and control potential dangers like open windows or unattended stoves, or to request status messages from devices like the fridge or the answering machine. R26b found the idea of combining remote control capabilities with remote access to the house's functionality "amazing." Eight participants preferred notifications over automation, while three emphasized the importance of memory assistance, e.g., for reminding people about wallets or keys when leaving the home. Another three participants stressed that they wanted to be informed in case of potential security problems at home.

Statements against home automation (12) focused primarily on the notion that automation was unnecessary because tasks could be completed without. S11 for instance stated quite energetically "Some things [...] would just be silly. I can really do that on my own!" Participants often felt that things like flicking a switch just did not warrant the necessary overhead to create a smart home. Two participants also observed that their lives were more exception than regularity and could not imagine them expressed as automation behavior. S22 worried about forgetting "the non-automated bits" like refilling the water tank of the plant watering system. She felt that notifications were a better fit for her. Other rejections were grounded in the fear of becoming lazy, losing control, or a general dislike of technologized environments. S28a felt that an automated home would be "too sterile, too mechanical" for her. S30b disliked automatic decisions and would prefer a system of notifications and explicit user interaction. The participant described a scenario as critical where automation was set up for guests; in case of a break-in the automatic system might treat the intruder as a guest whereas the notification system would attract the inhabitant's attention to the intruder. R24a however conceded that contrary to his general dislike of home automation, he would "probably use it if it was installed anyway."

Participants also commented on perceived real-world deployment issues. S19b was worried that automation behavior intended for the inhabitants might accidentally be triggered by their dog. Conflicts and side effects, especially in scenarios with several inhabitants, would cause significant impairment and deduct from the overall usefulness of home automation. The preferred system behavior would be automatic correction or compromise, however participants conceded that a purely technical solution might not be feasible. S30b would like the automation system to be able to detect potential conflicts on its own and get back to the user to ask for help if that was the case. S19b and R31 would choose a pre-deployment collaborative approach with their cohabitants to manually balance automation desires of inhabitants and avoid conflicts later on. Five participants stated that they would be willing to correct or adapt automation specifications manually when noticing unwanted automation effects in the home's behavior. S30a felt that a thorough "debugging" phase of automation behavior might lead to additional work in the beginning but also improve the system's performance in the long run. R29a stated that depending on the severity of conflicts and side effects, she "might not make the effort" to correct the behavior and instead learn to live with it. The idea of technology not working as expected however frustrated her immensely.

All in all, participants supported the idea of home automation but were not overly convinced that home automation systems would work in a stable and predictable manner in real-world scenarios. This is an image issue both deeply rooted in end users' previous experiences with home electronics as well as their lack of knowledge of the inner workings of smart technology. For home automation to succeed in the general market, end users will have to be convinced that allowing additional technology into their homes will be more than an integration and device management nuisance.

5.3.2. Home Automation Interfaces. With regard to home automation interfaces, 14 participants would like to configure their homes manually. Two would only want to use configuration software "if it was really easy," and R29b preferred to have a remote control with programmable codes. R29a conceded that she would probably not use the software on her own, but rather ask her partner to do it for her.

When asked about requirements for a proposed user interface, participants came up with an abundance of ideas. With regard to first steps, six participants said that the picture of the notation example in the introductory material of the notation kit had been the biggest help. Four liked being tutored by the experimenter, three found the introductory text in the instruction sheet helpful. R23 however stated that the text was too long and too complicated. S8 expressed the need for a more detailed explanation of context events and special functions. This suggests the need for a variety of support levels and modalities in home automation interfaces.

With regard to clarity, participants remarked that colors helped to discern various elements (5); that a configuration interface has to be easy to use without programming experience (4); that devices, actions, events, or rooms need to have expressive names or should be nameable by the user (4); that icons instead of text would be helpful (four, in contrast to two participants preferring text), while two participants each favored easy (de-)activation of stored rules or processes, high clarity, and the abstraction from technical details. In addition, participants from the rule group stated that they did not expect large rule sets to get confusing after creating use cases. One however was of the opinion that he would only define one rule per device while another stressed the necessity to group related rules, e.g., for lighting or heating controls. S8, R24b, and S22 declared that a rule-based interface would not be sufficient for their automation needs: "If you're getting home automation, you want to do something complex. This notation [rules] would upset me." (S8) and "complex configurations should definitely be possible." (R24b and S22). Further desired characteristics included editing and updating previously defined rules or processes (3), freedom with regard to modeling direction on the canvas and the order of configuration steps (2), sufficient security (2) and privacy (1), and consistency across several devices (1). Two participants emphasized the importance of a visually appealing look. Interesting suggestions further included automatic detection of modeling mistakes, a simulation mode to test automation behavior before actual deployment, the ability to use standard functions like "turn device x on/off" in the form of templates that users could then extend, and intervention options to reset automation behavior at runtime.

When asked about the preferred device for smart home configuration, some participants explicitly preferred a laptop (4) or general computer (5) based software, since they already owned one or because it provides more structure and clarity compared to a mobile device (five in favor of laptop and three in favor of a PC). For R24a and R26b, this was the only conceivable option, under the premise that they would use a home automation interface at all. While a tablet was considered optimal by a larger group (8), participants would not want to buy one just for home automation (5). Three participants would like to have a dedicated tablet for home automation so that all inhabitants could share it without having to share someone's personal device. Nine participants could see advantages in utilizing a smartphone. However, six stated that the display size was too small. They advised to use the smartphone for special tasks (mostly remote access) in conjunction with one of the other options. S22 saw a benefit in using the smartphone for quick check-ups that do not merit the boot time of other devices. S30b expressed concern that a smartphone could be seized too easily by strangers and compromise home security. Notions beyond well-established devices included mind control (S11), a remote control with display (S11), touch-based wall displays (S28a and R29b) and hard-wired control boxes (S28b and R26a). Overall, participants stressed form factors that provided clarity and adequate display size; also, they preferred touch interaction.

5.4. Rule-Based vs. Process-Oriented Notation

This section details the results from the analysis of participants' use of the two notation variants.

5.4.1. Complexity of Modeled Automation Tasks. On average, the rule group used 3.3 devices per use case, while the process group used 4.5. A Mann–Whitney U test ($U = 14$, $z = -2.3$, $p < 0.05$, $r = -.55$) shows that the device count per use case was significantly lower in the rule group ($M = 2.8$) than in the process group ($M = 4.1$). Device count can be seen as an indicator of a use case's complexity. In this case and based on our results, it can be said that participants from the process group tended to model more complex behaviors than participants from the rule group.

Participants however also exhibited diverse modeling behaviors. The process group modeled automation behaviors with dedicated devices as instructed, while the rule group tended to describe vague contexts on a single sticky note instead of following the *device (event)* pattern for the trigger column. Therefore, we further evaluated the *simple behavior* count, which we defined as the number of behaviors with only one trigger and exactly one action. The rule group overall modeled 17 simple behaviors (26.2%, $M = 1.0$). In contrast, the process group only modeled 4 simple behaviors (6.3%, $M = 0$). Using a Mann–Whitney U test, this constitutes a significant difference ($U = 18.5$, $z = -2.1$, $p < 0.05$, $r = -.49$).

Both these metrics show that participants in the process group modeled more complex behaviors than the rule group, which supports the hypothesis that processes are more expressive.

Additionally, the process group had the opportunity to reuse already recorded processes as subprocesses. Yet, only two participants made use of this concept and one of them used subprocesses simply as triggers for other processes. The rule group was not primed to reuse already modeled behaviors; nonetheless, R29b modeled similar behavior for a vacation use case: "If on vacation, a 'show signs of habitation' (e.g., shutter- and light-control) behavior should be activated."

5.4.2. Participants' Perceptions of the Notations. During the semi-structured interviews, participants could comment on their respective notations. It has however to be noted that these perceptions relate to the notation as used by individual participants, which partially deviated from the given notation as detailed in the following section. Eight participants in the process group and four in the rule group indicated that their notation allowed for *neatly arranging simple use cases*; six of them confirmed this for complex processes, and three for complex rules. Rules were described as *simple and straightforward* by eight participants, processes by four. Both notations were perceived as *efficient* (seven from the process group, six from the rule group). Six participants described processes as *intuitive and easy to understand*, and two expressed the same for rules. The rules were considered as *structured* by four participants, while one participant voiced the same for processes. Five participants of the process group and three of the rule group stated they saw *no restrictions* in their notation. The statements of the rule group were weakened in two cases by adding the comment that this would involve "tremendous effort." These perceptions indicate that rules are sufficient for simple tasks but become confusing for more complex use cases, while processes remain comprehensible.

When asked to criticize their notations, half the rule group (4) stated they felt *restricted by their notation*. Two participants further described the rule notation as *inflexible, confusing and uncomfortable for more complex use cases*. Two participants described processes as *confusing when lines crossed, difficult, or unintelligible*; 2 noted that they lacked understanding concerning the logical joins. This indicates that both notations have potential drawbacks that need to be addressed in interfaces planning on employing these paradigms for home configuration.

We further asked participants to suggest improvements for their respective notation. In the process group, three participants felt that a defined start point is unnecessary. It was also mentioned twice that no arrows would be needed and lines would be sufficient, as directionality (derived from the western reading system from left to right) was intuitively clear. Individual suggestions were given about the design: conditions could be annotated on the lines, and the use of color or different types of strokes could help to distinguish one path from another.

In the rule group, four participants stated they would like to be able to group rules in different ways, e.g., by device, function, or room; three also reported that they would like to model temporal dependencies. They suggested to introduce an "after" column, to define order based on the vertical position, or to offer the possibility to chain rules.

5.4.3. Errors and Deviations From Notation. To assess how well participants could apply the given notations, we analyzed their created use cases for errors, inconsistencies, and deviations from the notation. Since participants were not restricted in their use of the given notation, errors can be interpreted as indicators for deviations between the recorded use case and what the participant had in mind. Deviations that clearly stray from general semantics are also seen as errors. In the process group, two participants had issues with the AND and OR semantics. This was to be expected as logic operators are an abstract construct whose application needs to be explicitly learned. In one case, joins were drawn with only one inbound arrow modeled, understood as sequential execution. Another participant misunderstood the semantics of arrows, and modeled start events that were independent from one another as a process. In the rule group, two participants did not grasp the separation of triggers and actions. For example, actions were entered into the list of triggers and vice versa.

We did not identify any unintentional side effects between the created use cases in either group. This was probably due to the relatively closed-off character of the use cases provided by participants with few overlaps and the relatively low number of modeled use cases per participant.

Distinct patterns however emerged in the participants' deviations from the given notation. In the rule group, one deviation could be observed for all participants:

Fig. 6. An example how lines were added to the rule notation (participant R26b).

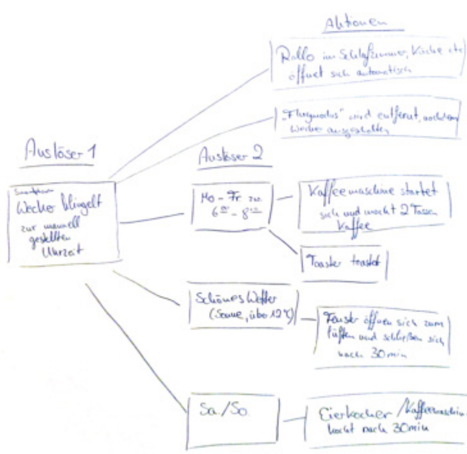

Fig. 7. A created rule as an example of how participants changed the notation (participant R26a).

Despite being instructed to use one sheet of paper per rule, rules that were considered to belong together were always modeled together, i.e., one below the other. A related variation was the use of arrows or lines to connect triggers and actions (which was not introduced as part of the notation), which were used to further distinguish between individual rules on a sheet with more than one rule (five participants). One example of this is shown in Figure 6. Observed difficulties related to the use of AND and OR operators (four participants), which were modeled as single elements or stated as a condition next to an arrow. In three cases, temporal and hierarchical dependencies were modeled which were represented by arrows or lines. See Figure 7 for an example of a more complex rule. These deviations show that participants of the rule group adapted their notation to express more complex use cases leaning toward the process-oriented notation—without being formally introduced to that notation paradigm. These results support the hypotheses that some real-world home automation use cases require capabilities beyond those of a strict rule-based notation. Four participants had difficulties in representing OR semantics. These participants

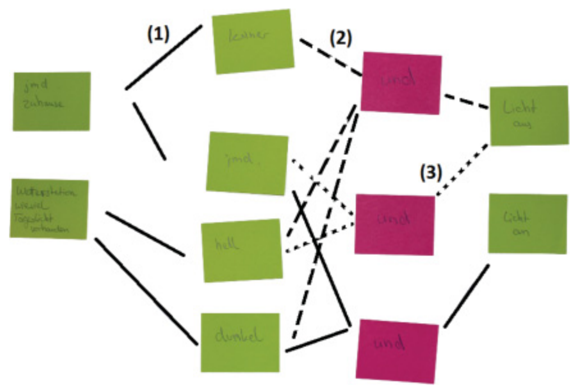

Fig. 8. Participant S30a modeled solid (1), dashed (2), and dotted (3) stroke types to distinguish the paths of the process; strokes were digitally redrawn for clarity.

were mostly unwilling to add additional rules (3) stating "it HAS to be possible to do it like this," while one did not think of modeling an OR relationship as multiple rules.

For the process-oriented notation, the start and end points of processes were repeatedly omitted by two participants; instead, the beginning of the process was perceived as its start, and the respective last actions as well-defined ends. In one case, arrows were entirely omitted, as it was assumed that the customary reading direction would suffice. Two participants tried to distinguish different paths of the process by using distinct types of strokes, an example of which can be seen in Figure 8. The implicit AND and OR-split, which was realized by several outgoing edges of a node, was explicitly used by one participant as a separate element. Elements without preconditions were modeled without an incoming edge by two participants. Two participants in this group were also unsure when to use the AND or the OR join during process creation.

5.4.4. Interpretation of Others' Use Cases. In the final recognition task, all 18 participants were shown a use case modeled by a different participant of the same condition, as well as one use case from the other condition. In addition, an alternative of the process notation was shown. The respective use cases were generally well interpreted. There were no differences between the respective notations, indicating that it is possible to interpret these notations even without prior knowledge.

These results allowed us to draw a number of insights that can be useful when designing an end user programming interface for home automation. The insights are presented in the following section.

6. INSIGHTS REGARDING END USER PROGRAMMING INTERFACES IN HOME AUTOMATION

Since smart home technology aims to be ubiquitous and unobtrusive, any kind of interaction should be tailored especially to less tech-savvy users. This notion conflicts with our participants' desire to understand and control their immediate environment to the fullest extent. Home automation interfaces will have to find a way to mediate this conflict. Our findings show that process-oriented notations for configuration could be a viable approach to achieve that. Davidoff et al. [2006] however state that strict routine models are insufficient for end users as domestic routines are subject to change over time; therefore, we propose to extend interface implementations in the fashion of Koskela et al.'s "instant control" [Koskela and Väänänen-Vainio-Mattila 2004], e.g., by additionally incorporating remote control aspects.

Our results indicate that while strict rule-based notations are sufficient for simple automation tasks and are perceived as well structured, participants from the rule group felt restricted when considering more complex automation tasks. In relation to that, García-Herranz et al. [2010] point out that limited capabilities could stress users. Participants provided us with real-life use cases that they could not model with the rule-based notation without extending it with features reminiscent of the process-oriented notation: grouping of rules, line connections, and temporal as well as hierarchical dependencies. Therefore, we propose to provide more expressive process-oriented notation for systems that are conducive of more complex automation tasks. Home automation interfaces should offer both simple and complex modeling options in order to capitalize on both clarity and expressiveness, as also suggested by Ur et al. [2014]. This could be achieved by allowing for simple rules to configure simple automation tasks with few triggers and actions, while a process-oriented approach could extend on this to support complex tasks with temporal dependencies. Alternatively, interfaces could offer tools and assistance for seamlessly expanding rules into processes. In our notation study, participants from the rule condition intuitively combined the two approaches in such a fashion by extending the rules notation with the additional features mentioned above—depending on the requirements of specific use cases.

Concerning end user configuration in general, Newman et al. [2008] state that designing for future states is easy for programmers, yet introduces a certain level of insecurity in end users. Several approaches [Newman et al. 2008; Dahl and Svendsen 2011; Leitner et al. 2013] support the notion to provide a simulation mode for home automation interfaces that was also voiced by our participants. Simulation modes provide a safe environment where users can get to know automation technology or try out new ideas. The difficulty with this will be how to represent the potentially large number of devices in a household in a comprehensive manner. To be meaningful, simulation modes would have to reflect the individual home situation to at least a certain degree—by mirroring the floor plan or representing a throng of devices with different capabilities. Light automation alone would require a number of devices positioned all across a room, all of which can differ with regard to brightness, color, area of illuminance, and dimming capabilities. The amount of data increases exponentially as soon as several rooms or more device types should be considered for automation. It is yet unclear how home automation interfaces could acquire this information without requiring the user to manually map their entire home. And even if users would be willing to do this once, it has to be kept in mind that home arrangements change over time with devices being replaced or rearranged. We envision that home interface designers will have to draw upon visualization techniques that were developed for depicting large datasets in other domains to make this amount of data manageable and intuitive to understand for end users.

Furthermore, the strong desire for a veto right to automatic adaptations also confirms prior work [Koskela et al. 2004; Davidoff et al. 2006; Mennicken and Huang 2012b]. In a home automation interface, this could be realized in various ways. One of our participants stated that he would be satisfied if the system allowed him to turn the lights back off after the automation had determined to turn them on. On part of the software, this does however require additional logic and some sort of memory. Otherwise, the system would just revert back to the automated settings the next time conditions were evaluated. Along a similar notion, haptic interaction could be conceived; for instance, users could place a decorative element in a certain position to override automation for a specific room. This could also be used to solve conflicts, e.g., one inhabitant could declare priority over the others in terms of current media choices or room settings. Another participant would like the system to ask questions if unsure how to proceed; this can however raise the issue of having to find a satisfactory compromise between smart ubiquity and continuously prompting the user.

The number of deviations from the given notation also indicates that due to the complex nature of some automation tasks, home automation interfaces need to provide extensive assistance, especially for initial use. As expected, we observed a need for support especially for more advanced features of the process-oriented notation, i.e., logic operators. However, our results also indicate that one-size-fits-all solutions would likely not be effective due to our participants' different ways of approaching configuration tasks. Instead, diverse assistance should be provided, such as instructions at different levels of granularity and software support for certain notation features, such as logical joins. Here, ideas can be drawn from classical software engineering. Introductory information can be presented as text, video or step-by-step clickable tutorials. Information shown in the beginning should however always be retrievable; either as an integrated compendium or in the form of tool tips. Our usability testing in previous work also revealed that configuration interface users employ different interaction strategies and appreciate the redundant implementations of features, for example, that a device icon can be deleted via an explicit garbage can area or simply by being dragged off the screen [Rietzler et al. 2013; Walch et al. 2013]. Senior users also voiced additional requirements, such as adjustable font size and zoom capabilities.

With regard to the general acceptance of home automation, participants voiced concerns over feasibility, cost, reliability, and security. Since home automation operates in a user's personal territory, concerns for security and privacy are understandable and valid. Building user trust by informing inhabitants about the underlying rationale of the home automation system, offering effective veto options and making sure that private information is sufficiently protected will be paramount to the success of home automation technology. In addition, feedback from participants living in multi-person households suggests a need for moving away from the single-user paradigm which is often assumed as a default setting in home automation technology. While easier to deal with, it is not representative of real-world user requirements. Home automation interfaces will need to find a way to deal with conflicts and offer strategies to arbitrate between the preferences of multiple users.

7. STUDY LIMITATIONS

A potential limitation of our study is the sample size of 12 households and 18 participants. However, it provides a sample of typical size for qualitative studies and our results provide rich insights on home automation needs and the design of configuration interfaces. We further aimed to balance our groups in terms of their demographics and recruited participants with diverse living situations, i.e., single households, shared flats, and couple households. Although the rule group showed slightly higher technical interests and skills, we could not find indications that it influenced our results. While our participants were likely not fully representative of the general population, especially since family households were missing from the sample, we believe that our results carry valuable insights for the design of home automation interfaces that are likely generalizable beyond our sample population and should be validated for different demographics. However, we have to point out that all our participants came from the same cultural background. Results may vary for different cultural settings.

Concerning the study design, participants provided use cases with a wide range of complexity; therefore, we conclude that the instructive examples did not prime participants toward a certain complexity.

A limiting factor is that participants merely thought about potential use cases rather than using real-world home automation. While they did this in the context of their own home, participants still could only have a limited idea of what living with home automation would truly look like. Coming into contact with the actual benefits and drawbacks of the technology could change their perception of it. Furthermore, implementations of home automation configuration interfaces will presumably never be able to accommodate all mental models or configuration strategies of which our participants have likely just shown a few; this will lead to usability issues that will have to be studied for each solution. This holds especially true when concepts from the two paradigms we researched separately are to be combined. Furthermore, some participants created only a few use cases during the week between assignments; however, the majority provided multiple use cases, which suggests that they took our assignment seriously and were engaged in the study. It has to be kept in mind though that this does not allow for making any assumptions about how seriously they would engage with real-world home automation which as-of-yet is a lot harder to set up and maintain than a piece of paper. Overall however, our results suggest that not bringing them in contact with actual home automation technology allowed them to be more creative in how they approached home automation and potential use cases for it, which matched our intention of eliciting their everyday requirements with no regard for current technological constraints. The insights we gained in this study can thus be a first step in the design of home automation interfaces to better support end users in the programming of their homes.

8. CONCLUSION AND FUTURE WORK

Home automation faces the challenge of providing ubiquitous, unobtrusive services while also supporting end users with approachable programming interfaces. As these interfaces further need to provide sufficient expressiveness to support complex automation behaviors, proper notation styles for less tech-savvy users need to be devised. Over the last years, rule-based and process-oriented paradigms have emerged; however, their underlying concepts had not been studied in a comparative manner. We reported on a contextual inquiry study that collected qualitative data from 18 participants in 12 households in their own homes. We gathered information on the current potential and acceptance of home automation in general, as well as explored the benefits and drawbacks of the two programming notation paradigms for end users. Our results show that rule-based notations are sufficient to express simple automation tasks but can be limiting for more complex use cases. Participants that used the process-oriented notation valued its expressiveness and presented us with more complex use cases involving more devices in their homes. We identified benefits and drawbacks of the two paradigms that suggest that providing end users with a mix of the two approaches might be beneficial to address a broad variety of automation desires. We discussed how our results can inform the design of end user configuration interfaces for smart home technology in order to enable usable real-world home automation for end users.

As a next step, approaches that bridge the analog–digital divide could be used to provide users with small-scale functional home automation that still retains the benefits of intuitive, experimental pen and paper interaction. Hess et al. [2012] describe an approach for business process modeling where informal pen input can be combined with a rudimentary software, providing feedback similar to full-scale solutions. In the home context, this could lead to prototypes that enable configuration input in the form of sketched rules or processes that are then transferred into actual sensing and actuation commands in the home. Compared to pen and paper approaches, this would allow participants to get a better grasp on what living with home automation will actually be like and improve their assessment. Researchers could leverage this to get new insights regarding programming metaphors without the need to develop fully functional, high-fidelity interfaces for the participants to interact with the home automation prototypes. With regard to developing interfaces, once promising configuration strategies have been identified, McCurdy et al.'s [2006] approach of mixed-fidelity prototypes can be used to break down the task of developing complex automation software into manageable units by iteratively focusing on various dimensions of interest. Transitioning from the fully analog to the fully digital approach with these intermediary steps will help to ensure that the resulting interfaces for the home automation market fulfill end user requirements on a number of different levels. Traditional usability testing can then be used to evaluate how successful each interface solution is in conveying its underlying programming paradigm to the user.

APPENDIXES

A. NOTATION KIT MANUALS

The manuals given to participants of the study to detail the characteristics and intended workflow of the respective notation are presented here. The materials were originally devised in German and are presented in translation.

A.1. Instructions for Rule-Based Notation

—Use one sheet of paper per rule.
—Put a meaningful name for the rule in the upper left corner.
—Rules consist of triggers (stemming from events) and resulting actions. Both triggers and actions are assigned to devices. Devices should be written down on the sticky notes and put on the paper.
—A rule is executed when all triggering events happen. To use a device as trigger, you need to specify its appropriate event, e.g., the alarm clock has the event "ringing."
—To execute an action, you need to specify the desired action on the device sticky note, e.g., coffee maker has the action "make one cup of coffee" or alarm clock has the action "set alarm,"
—Additionally, you may use a timer as device to model temporal dependencies. To do this, you may specify a rule A where the action "timer(set × minutes)" is executed after a given event and another rule B where "timer from rule A elapsed" is used as triggering event.
—An example for a rule is "if the alarm clock rings and it is between 6 and 8 am, then make one cup of coffee." (This was illustrated with a picture similar to Figure 2.)
—The layout shown in the picture is presented merely as a suggestion.

A.2. Instructions for Process-Oriented Notation

—Use one sheet of paper per process.
—Put a meaningful name for the process in the upper left corner.
—Every process consists of interconnected devices; devices should be put on green sticky notes. Each device has events and actions, e.g., alarm clock has the action "set alarm" and the event "ringing." Connect devices with arrows and note what events trigger what actions.
—Every process has a designated starting point. Arrows start at that point and connect to the first order of devices. More devices can be added by adding more arrows.
—To execute an action, you need to specify the desired action on the device sticky note, e.g., coffee maker has the action "make one cup of coffee."
—To combine events and actions, you can put "and" and "or" on pink sticky notes and place them at the appropriate position in your process; "and" means that all events need to happen to execute an action, "or" means that one of them suffices.
—Additionally, you may use a timer as device to model temporal dependencies. You can incorporate this element in your processes the same way you would include a device. For this, note the time that you want to postpone the following action execution for.
—You can reuse already recorded processes as subprocesses. For this, note the name of the previously recorded process on an orange sticky note and incorporate this in your new process where appropriate.

—An example for a process is “if the alarm clock rings and it is between 6 and 8 am, then make one cup of coffee.” (This was illustrated with a picture similar to Figure 3.)
—The layout shown in the picture is presented merely as a suggestion.

B. INTERVIEW SCRIPT

The script of the semi-structured interview is detailed in the following. The questions were originally devised in German and are presented in translation.

—Efficiency of the notation for use cases: How fast could you create processes/rules for single and complex use cases? Could you come up with meaningful names?
—Clarity of overview: If so, what did you like? If not, what was problematic? How was clarity for simple processes/rules? How for complex ones?
—Were you provided enough information to work with the notation? What helped, what did you miss?
—(Condition-specific) Did you encounter difficulties working with the notation? (ask about all elements)
—What did you like about the system?
—What did you dislike about the system?
—Where there functionalities you missed?
—(if they created potential conflicts in their use cases) Were you aware that this might cause problems? If yes: What were the reasons for not rectifying it (did not know how, did not find it necessary, ...)?
—(if they modeled potentially unintended side effects) Were you aware that this would trigger behavior other than intended? If yes: Would that bother you? If yes, what were the reasons for not rectifying it? If no, why not?
What would you need from the system in terms of support to handle these situations?
—Did you feel that the notation supports all of your envisioned use cases? If yes: how does it support? If not: how does it inhibit?
—In-between steps:
If used: Why and what for? (in case of rule condition: Did you explicitly ignore the given notation?)
If not used: Why not? (in case of rule condition: Because it was not in the given notation or because it did not feel necessary?)
—Do you feel as if you would use home automation in your daily life? If so: Why? If not: Why not?
—Do you feel as if you could use this system in the form of an automation software? Why/why not? What would you wish this software to be like? What device would you like to use that software on?

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