Integrating the Smart Home into the Digital Calendar

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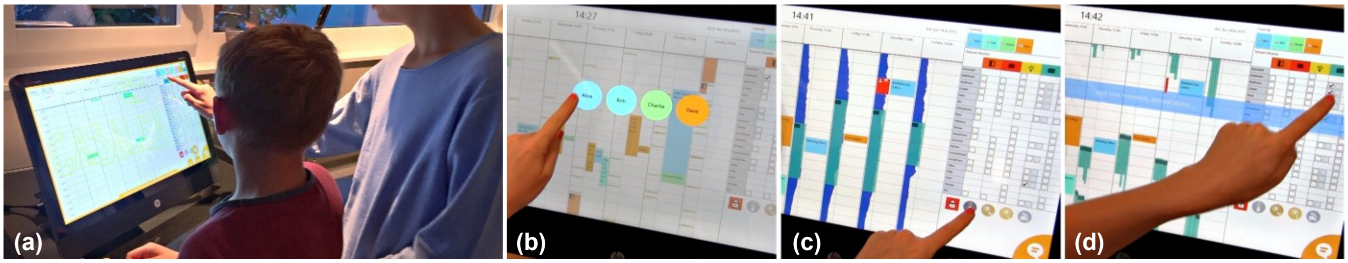

Figure 1: (a) The smart home digital calendar touch interface allows easy access for all household members at a central location at home; (b) each user can retrieve a tailored view of the smart home data via one-touch login; (c) the 7-day week view allows users to see behavior patterns of the home at a glance; (d) smart home and personal calendar events are shown side-by-side on each timeline and users can filter entries based on the device category and location.

ABSTRACT
With the growing adoption of smart home technologies, inhabitants are faced with the challenge of making sense of the data that their homes can collect to configure automated behaviors that benefit their routines. Current commercial smart home interfaces usually provide information on individual devices instead of a more comprehensive overview of a home's behavior. To reduce the complexity of smart home data and integrate it better into inhabitants' lives, we turned to the familiar metaphor of a calendar and developed our smart home interface *Casalendar*. In order to investigate the concept and evaluate our goals to facilitate the understanding of smart home data, we created a prototype that we installed in two commercial smart homes for a month. The results we present in this paper are based on our analysis of user data from questionnaires, semi-structured interviews, participant-driven audio and screenshot feedback as well as logged interactions with our system. Our findings exposed advantages and disadvantages of this metaphor, emerging usage patterns, privacy concerns and challenges for information visualization. We further report on implications for design and open challenges we revealed through this work.

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INTRODUCTION AND BACKGROUND
A variety of data on behavior in homes is collected as a result of the increasing adoption of connected sensors and actuators in domestic environments. Most currently available smart home interfaces allow inhabitants to view the state of individual devices or functions and access log files about past events or sensor values. Much of this data, such as numerical values for temperature and brightness or binary values for motion triggers, is presented in raw form as numbers and text in log entries that are not helpful for most inhabitants for forming a useful mental model of one's automated home [28]. However, having a proper understanding is crucial for being able to control such a system and develop trust in it [1], which ultimately affects how satisfied people can be with their most personal space – their home [12].

The way data is represented can also impede accessibility to the technology for household members without the required background or training. We previously found that people sharing a home not only differ in technical background, but also in motivation to actively engage with the smart home, and responsibility for such tasks [37]. There are particular groups of users with little interest in engaging with the home, who have more issues with current UIs, as well as users who actively take charge in maintaining the technical infrastructure of the home [25] and who often even consider smart homes their hobby [38]. The tools used to configure an automated home or to visualize collected sensor data are not tailored to the various user groups, which often results in low accessibility. This negatively impacts the overall user experience and leaves opportunities for automation untapped [39]. Especially for users without strong technical skills, this can lead to frustration over the lack of transparency and control of things happening in the home. Given the data that is already captured in the home, there is an opportunity to alleviate this issue with a better presentation that reveals behavior patterns of the home and the household. This could facilitate the understanding of the home's behavior and provide a more accessible interface that lowers the barrier to access to the technology and data within smart homes.

Once a smart home is set up and programmed, its installation is rather inflexible [29] and acts according to a set of preconfigured automation rules and its own schedule. In some ways, it could be seen as an entity of its own in the household, which could be incorporated in the planning and coordination of all household members' routines. A tool that has already proven successful for managing routines, communicating and coordinating with others in typical households is the calendar; often, a family calendar that all members have access to (e.g. many households use a paper calendar in the kitchen or another common area [22]).

In this paper, we investigate the suitability and value of calendars as a familiar interface metaphor to visualize a smart home's behavior and its collected sensor data, to facilitate understanding of its actions. We designed a prototype called *Casalendar* (Figure 1) to investigate potential benefits and drawbacks of calendars and deployed it in two real-world smart homes to gauge its value over a period of a month. The findings are intended to inform our future work, with the long-term goal to support a better inclusion of all different user groups and their routines and exceptions in the home. Our contributions in this paper are: (i) to provide an evaluation of the shortfalls of current smart home interfaces and uncover new opportunities for calendars in this context; (ii) to consider the key factors for designing a tool for communication and coordination between the home and its inhabitants and control of the automation technology; (iii) the design and development of the *Casalendar* interface and prototype; and (iv) our findings about the emerged usage patterns, the appropriateness of the calendar metaphor and how it supported lowering barriers to access within smart homes, resulting in several design implications.

RELATED WORK

Facilitating the understanding and control of environments equipped with sensors and capabilities to actuate devices has been a longstanding interest in research [19]. One big aspect of this is to inform inhabitants about the collected data, the carried out actions, and underlying reasons for this automated behavior [1]. In the following, we describe related work on the visualization of such data and how it inspired us to explore the metaphor of calendars further.

Feedback and Control in Smart Homes

In research, related work on visualizations of logged sensor data in the home often has a specific application focus, such as increasing awareness of energy consumption [21], network usage [4], or water consumption [9]. Related work for smart home interfaces often focuses on improving end-user programming of context-aware environments [8,30] or exploring different means of input [3,14]. Commercial interfaces usually simply offer users an interface (e.g. on a tablet PC, mobile phone, or in a web browser [13]) they can use to access the controls for the various devices and functionalities in the home, however, without support for specific higher-level activities, such as preparing the house for a party or a longer vacation. Our *Casalendar* interface is similar in this respect and does not afford a specific use case or promote a specific functionality. Its primary aim is to elicit data on inhabitants' interests and the way they intend to apply the knowledge they may gain in order to learn about advantages and disadvantages of the metaphor we chose to investigate.

Visualization of Data in Calendars

The calendar has been used as a canvas for visualizations in many areas of application. Costanza et al. [5] made use of calendars to allow people to better understand varying costs of energy in the context of smart grid applications, while Laschke et al. [15] provided an in-situ visualization in the shower using the calendar metaphor to increase awareness for water consumption. Informative data were also integrated in Huang et al.'s [11] work that visualized step counts from activity trackers next to people's calendar entries in order to increase awareness of such data and lower the threshold for engaging with them. Our prototype aims to incorporate the multiplicity of different devices comprised in a home and offer an overview of the provided functions. The goal is to learn whether aspects of the calendar metaphor have a different meaning when representing smart home data opposed to personal events and how suitable it is for allowing people to improve their understanding of their home's behavior.

Calendar Usage

Besides providing a strong metaphor for time-related data, calendars are a well-established tool for coordination, communication, and collaboration between people [24]. In the context of families, this has been looked at in depth by Neustaedter et al. [22]. Calendars have proven to be helpful for families in managing routines and manage conflicts [7]. Motivated by this, we explore whether similar benefits can be transferred to interactions between the home and its inhabitants.

Tullio et al. [31] created a shared calendar augmented with additional information and explored its use in the work context. This calendar interface contained predictive information for users, aiming to facilitate interpersonal communication. In our interface and case study, we explore the usefulness of the calendar metaphor mostly by looking at the participants' interaction with past smart home data, but we included potential predictions of smart home behavior in order to allow us to preliminarily probe on potential uses of such information. However, the contribution of our studies and the insights derived aim to add to the understanding of how to facilitate interactions with a smart home and are less about advancing the research on calendar interaction itself.

DESIGNING SMART HOME INTERFACES

Previous studies [25,26] provide us with motivations to improve the visualization of smart home behavior to support the inclusion of inhabitants with less technical background, both in terms of understanding and controlling the home. Common commercial smart home interfaces are usually designed with a focus on a few specific use cases, such as (1) **viewing the current state**, (2) **configuring settings** of a specific device at a specific known location, and (3) **getting a spatial overview** of the current state of a subset of functions.

Categorical Menu. Interfaces for the first use case are usually organized in categorical, often hierarchical, menus based on the device category or location. They usually contain specific control elements for each device type, which allows one to see the current state of each device and change its configuration. The main advantage of such menus is quick access to the settings, assuming one already knows what one is looking for. Moreover, the interface of each device type typically takes up the entire screen and can display detailed state information and options for control.

Spatial Map. Interfaces that are based on spatial maps provide a hierarchy-less overview of the entire home or selected floors. They allow users to locate the control element for a specific device based on their knowledge of the home's spatial layout, and thus provide direct access to a specific set of functions or devices. Such floor plan-like interfaces provide glanceability, allowing users to spot any irregularities of device states at a glance, for example by indicating any open windows with a red circle.

Log list. Log list interfaces are often included alongside the two other interface types described above and all three are based on the same underlying data. These lists are most practical when one is interested in viewing the event history and filtering for past events that happened within a specific timeframe.

The interface types described above suffice when a user is interested in changing simple settings or when she can specify what data she wants to access. However, they are not suited for developing a causal understanding of the complex interactions between multiple devices and programs running within a smart home. This is mainly due to the lack of an appropriate way to meaningfully present interactions and interdependencies between devices, rules, and users that occur over time.

There are further usage scenarios that are often overlooked but could contribute to a better inclusion of the different user groups through a more appropriate presentation of temporal data across the entire home. For example, (4) **finding the reason** for an unexpected actuation of a device that has multiple potential sources, (5) **discovering new opportunities** for automation and potential conflicts by detecting behavior patterns, and (6) **adapting the home's behavior** to the user's own personal schedule (i.e. routines and exceptions, as opposed to manually overriding the program every time or putting up with a sub-optimal configuration).

The above-mentioned interface types are most commonly used in current interfaces for smart homes. Yet, they are not ideal for addressing these scenarios, as they either require users to already know which devices, category of device, or location they want to look for, or they isolate the various devices without the option to view multiple devices and their behavior in the same view.

Timelines. In contrast to spatial maps, a timeline view consists of past events and allows users to see emerging temporal behavior patterns at a glance. This enables the user to retrace the actions executed by the home (e.g. light turned on) for multiple devices or functions on the same timeline, even for automation that does not have a specific location (e.g. time-based triggers or sending alerts). The view can also include information on the sensors that triggered them (e.g. brightness sensor) and reveal potential chains of causality.

Calendar as a Smart Home Interface

A calendar represents a specific type of timeline interface that allows routines, repetitive behavior and exceptions to be easily visible. In the context of smart homes, such events could reflect state changes of devices. Events that recur daily or weekly are often effects of pre-programmed rules of a home that are in turn based on the household's routines (e.g. heating that is based on sleeping and waking up times). We found the calendar to be a suitable metaphor for our purposes as it is an accessible and already widely used tool that would allow users to view and match both the household's and the home's routines within the same interface.

Existing calendar views are currently not used as the main smart home interface, but just for visualizing the data of a single device or function, such as heating or air conditioning [35]. Thus, we seek to learn about the suitability of interfaces that focus on the use of the calendar metaphor and aim to explore it in the context of smart home interaction with the longer-term goal to support a better inclusion of all user groups and their routines in the home.

DESIGN AND IMPLEMENTATION OF CASALENDAR

Based on the goals and the usage scenarios we set out earlier, we designed an interaction concept and developed a working prototype that would allow us to collect insights about the everyday use of our concept in real homes.

Interface Design

The general design of our prototype is primarily based on the week view of a digital calendar containing seven vertical timelines, one for each weekday. The content consists of calendar entries added by the smart home and the inhabitants, each with an icon or text headline indicating the entry type, and color-coded to indicate who or which function it pertains to.

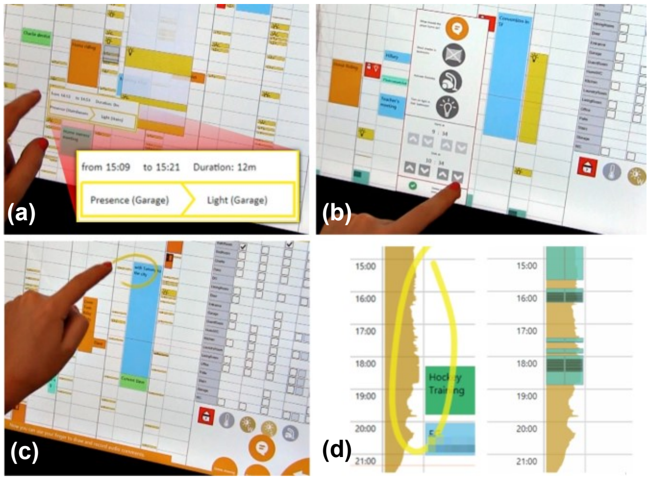

Figure 2: (a) Detail view of a *light* calendar entry. Shows the time, type and location of the light trigger (*presence* sensor); (b) user programs a smart home function in the calendar; (c) smart home and personal events are shown side-by-side and can be annotated; (d-left) H1H's annotation of an unusual peak in the brightness sensor data; (d-right) between 5 and 7 pm: unwanted behavior of shades observed by H1W

Timeline Layout. Our prototype emphasizes personal events, as it aims to recreate a calendar, which has the additional benefit of providing integrated access to additional information on and control of the smart home. To provide a clear visual distinction: smart home's events are displayed in left third of the timeline while household members' personal events use the remaining two thirds of the timeline (Figure 2c and 2d).

Dealing with Visual Clutter. A potential danger of providing a one-week overview of events across multiple devices of the same and different types, in addition to calendar events of household members, is visual clutter and information overload which would defeat our purpose. Therefore, we allowed users to view calendar entries of only certain household members and specific types of devices in specific locations which can be selected through a filter panel on the side of our interface (Figure 1d). We anticipated different viewing preferences for each participant and added a one-touch login mechanism (Figure 1b) that allowed household members to identify themselves and to retrieve and store their individual view settings. A future version could incorporate an automatic face-recognition-based login mechanism to simplify the identification process further.

*Representation of Smart Home Entries***.** We preselected a set of sensor and actuation devices to be displayed on the calendar based on their importance and potential impact on the inhabitants of the smart home. Our selection included: window shades (see turquoise calendar entries in Figure 1c and 2 d-right), lights, sensors detecting the door/window state (as open or closed), heating, temperature, brightness, music player and a vacuum-cleaning robot. Discrete events and data are visualized as rectangular blocks (e.g. shades down or door open) whose vertical height depends on their duration. Continuous sensor data, such as temperature and brightness, is displayed as graphs that span the entire timeline (see blue graphs in Figure 1c or yellow graphs in Figure 2d).

Additional Details and Control on Demand. Our interface allows inhabitants to retrieve additional details for an event, such as a list of possible causes that might have triggered it, exact duration of the event (Figure 2a) and other contextual sensor data (e.g. brightness and temperature). To elicit usage data beyond only consumption of information, we enabled inhabitants to perform simple control actions, e.g. locking specific motion triggered lights or controlling their vacuum-cleaning robot directly through calendar entries (Figure 2b).

Technical Implementation

We deployed our prototypes on 23″ all-in-one multi-touch PCs that allowed users to access the calendar interface comfortably via touch. The smart home infrastructure of our participants used *KNX*[1], a standardized network protocol for smart home devices. To easily communicate with KNX, we used a software controller called *nomos System*[2] which can be installed on a Raspberry Pi mini-computer and facilitates retrieving messages as well as sending commands from or to the connected KNX devices. The prototype was implemented in C# and WPF and is able to import iCal streams of our participants' personal digital calendars.

Limitations of the Deployable Prototype

Our interaction concept for *Casalendar* included several features that we were not able to implement in our prototype, such as determining the root cause of certain events with absolute certainty. For instance, the actuation of shades in the participating homes was determined by a complex decision structure involving a weather station whose internal logic unit we could not access. Direct control of devices through our interface was somewhat limited, as it would not have been feasible to break apart the existing smart home configuration and reprogram all involved sensors and actors. Due to the complexity of this task and potential liability issues that could result from a breakdown of our research prototype, we decided to do this for only a limited subset of the home's functionalities. To make up for this restriction and to elicit further data on active usage, we allowed users to create "fake events" and record short audio clips that let them express their interest in particular smart home features missing in *Casalendar*. We would have liked to implement several features known to be important for the adoption of calendar interfaces, such as mobile access from multiple locations [20]. However, we were not able to address them in this first case study due to technical constraints.

FIELD-RESEARCHED CASE STUDY

Living in a smart home and using its functionalities in everyday life differs considerably from staged usage

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[1] knx.org/in/knx/association/what-is-knx/index.php

[2] nomos-system.com/

Figure 3: Locations in which our participants set up our prototype. Kitchen in H1 (left), living area in H2 (right).

scenarios in lab settings. We conducted an in-the-wild deployment of our prototype design for an entire month (June 2015) to assess its applicability to real homes.

Procedure

Recruiting of Participants. Two smart home households, which originally had been recruited via a smart home forum for previous studies [18], were recruited again for this study for two reasons: firstly, we had to ask them for full access to all of their smart home as well as their personal calendar data, thus, we wanted participants with whom we had already established a trust relationship. Secondly, we were familiar with their installations and several specifics about their configurations that would allow us to smoothly integrate our prototype into their existing systems. Both households were willing to participate without any compensation but were given an equivalent of USD 320 as an incentive to maintain their participation over the course of the month.

Preparation for Deployment. As the integration of our prototype involved major individual customizations, we had two meetings with one member of each household beforehand. In these meetings, we retrieved their configuration files that were required to prepare our prototype for each home. We also discussed specifics of their respective installations and gave our participants the opportunity to express any concerns or questions they had regarding our deployment and evaluation. Even with careful preparation prior to the on-site installation, it took several hours to fully deploy our prototype in the actual setting.

The prototypes were placed in locations chosen by the households. These locations were highly frequented spots that allowed family members easy access and promoted shared awareness [22]: in the kitchen (Figure 3 left) and in the open space for living and dining (Figure 3 right). After the prototypes were running, we introduced all family members to the interface, and explained the features of our system to them, including the feature for recording feedback. We also provided a manual that repeats these explanations visually.

Participating Households

For our case studies, we intentionally recruited two households with different characteristics, apart from similar age and family composition, to gain broader insights about our concepts. The first household (H1) consisted of two parents in their early 40s and their three children between 8 and 14 years old. The second household (H2) also consisted of two parents in their early 40s and two teenagers, ages 14 and 15. In both cases, the husbands were working full-time and the wives part-time. The wives had less interest in engaging with the smart home and less technical skills compared to the husbands, who considered smart homes a hobby.

H1 built their house with integrated smart home technology and moved in approximately two years ago, while H2 installed their smart home functionalities during a major renovation almost eight years ago. While in H1 both parents used digital calendars extensively and maintained digital calendars for their kids, in H2 only the father used a personal digital calendar and maintained a minimal shared calendar to which other family members were subscribed. The mother maintained a traditional paper calendar for the entire family which was placed at a central location that could be easily accessed by everyone in the family.

Data collection

We gave participants questionnaires that inquired about their opinions and attitudes towards smart home technologies before and after the study. The questions intentionally left out any items related to our prototype in order to isolate and learn about changes in the participants' general perception of their own smart home and interactions with it. In addition, we also asked them to complete a questionnaire which contained items specifically targeting our interface. The questionnaire was an adapted UTAUT [33] survey, which is a standardized set of questions that assesses the technology acceptance by probing users' expectations and intentions for use. While our intention was to learn about potential usability or user experience issues that could affect other collected data from our case study participants, we did not use this data to make general claims about the ease of use of our interface. All questionnaire items were statements and participants rated their agreement with each on a Likert scale between 1 for 'I fully disagree' to 5 for 'I fully agree'. All participants, except two children, answered the surveys.

During the study, we logged interactions with the interface and participants captured additional qualitative feedback through the 'feedback mode' of the interface (Figure 4). Once invoked, this mode captures a screenshot of the interface and allows users to add freehand annotation on the screen by using their finger to draw on the touchscreen (see yellow annotation in Figure 4) and/or record an audio file. Feedback and snapshots of the calendar entries are instantly stored on a password-protected cloud data storage, which can be directly accessed by the researchers. This way, we were able to review participants' screenshots and audio feedback and prepare follow-up questions for the final interview while the study was still running. These interviews, which were conducted at the participants' homes, also contained more general questions such as whether there were any unusual events during the duration of the study that might have affected the use of the calendar, whether *Casalendar* was a topic of family conversations and if their experiences with the interface inspired ideas about what they would have liked

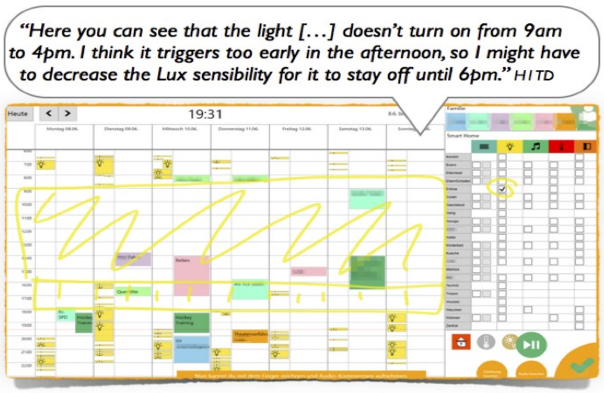

Figure 4: Freehand annotation (yellow) on a screenshot of the current calendar view and transcribed audio feedback.

to change about it. We further sent three reminder emails to participants over the course of the study to maintain their participation and prompt feedback.

FINDINGS

First, we evaluated the UTAUT survey to learn whether issues with the usability or acceptance of the system could have severely influenced the use of the system. Then we looked at differences between the pre- and post-deployment surveys about participants' opinions and attitudes regarding smart home technologies. As the data sample was too small for statistically significant results, we instead focused on looking at noticeable differences among individuals, between households, or user types. We classified changes as noticeable if the answer before the study differed by at least two points from the answer given after the study, or if multiple participants' answers changed in the same way. As those changes might have occurred by chance, we checked for consistency with the qualitative feedback from interviews and feedback given through *Casalendar*, which was partially transcribed and analyzed using open coding. We only considered insights from our quantitative analysis that were consistent with the qualitative feedback.

In the following sections, we present what we learned about the appropriateness of the calendar metaphor in the smart home context, emerging usage patterns with our interface, and social implications we observed. We refer to the participants by using the household number and H for husband, W for wife, and C# for their children (e.g. H1C1 describing the oldest child of H1W and H1H).

Appropriateness of the Calendar Metaphor

The use of our interface we observed and feedback we collected revealed several benefits and limitations regarding the suitability of a calendar metaphor for smart home user interfaces.

Beneficial for Providing an Overview of Behavioral Patterns

Participants reported that the weekly overview that incorporated multiple functions and sensors was good for giving an overview of behavioral patterns of the home and the family. H1W described this as *"You quickly have an overview [of] what my family is up to"* and *"[I can] see the whole week, how the home has behaved."* As mentioned earlier, many commercially available smart home interfaces displayed the various functions in individual, isolated visualizations. While this allows one to choose the best-fitting representation of the data, it makes it more difficult to draw insights about the overall behavior of the home.

We found that visualizing the data on a timeline provided an easy way to spot issues in the configuration, as when one event causes another, they are often close together in time. In some cases, it also facilitated the definition of actionable changes to the existing configuration. For example, H1W noticed that the shades were not acting as she wanted them to in the afternoon and early evening. By visual inspection of the calendar, her husband was able to identify unexpected brightness changes and the effects to the currently set threshold values as one potential cause (Figure 2d), which he could use to update the configuration. Additionally, this is an example of the calendar offering a means to facilitate communication between family members to solve suboptimal configurations of a smart home.

Establish Trust in the Home Through Temporal Anchors

Participants' responses to several questionnaire items about trust and understanding were slightly increased after they had used *Casalendar* for a month. For example, their average agreement on *"If something happens automatically in the home, I know why it happened"* increased consistently by 0.5 points for all participants. H2H, who was previously wondering about a specific function in his home further reported: *"It's visually obvious to me now that there are no malfunctions. Till now, I've assumed that the light in the basement is periodically turned on without any reason."* One potential explanation could be that the familiarity of the calendar metaphor, with calendar entries being associated with events taking place, increased feelings of trust. However, even in a personal calendar it can be uncertain whether personal entries actually took place [31]. We assume that participants may think of the home's events as a defined schedule rather than a dynamically adapting calendar. This understanding may be challenged by a future version of *Casalendar,* which could include future event predictions that are automatically inserted by the home and continually adjusted over time.

Usage Patterns Around Smart Home Events

Two primary use cases emerged in our deployment: *checking on the home's behavior retrospectively* and *verifying the configuration*.

Retrospective Check

Our participants reported enjoying having a familiar tool to turn to when they wanted to check on what was happening at home while they were absent. This included information on the family and the home's functions. For example, H1W wanted to know what her kids had been up to, while H2W wanted to learn about the Roomba's activities. The information they retrieved from *Casalendar* also became a conversation topic and a tool for reflecting on the patterns, not only for the adults but also for the kids, as expressed by H1C2: *"We just saw for how long the light was on, or whether we forgot to turn it off, or whether we forgot and left the music playing."*

Configuration Verification

Participants appreciated having visual feedback that allowed them to confirm that the home had worked as expected. For example, H2H wondered whether the motion-triggered lights in the basement were working properly, and H1W wanted to verify whether the configuration changes that her husband had carried out actually worked.

While these usage patterns seem similar, their intentions are slightly different: In case of the *retrospective check*, the inhabitants' focus was on learning about details of the automation technology's behavior or other household members' behaviors without a specific expectation. In case of the *configuration verification*, they focused on whether or not something worked as expected, and compared their expectation with what was visualized.

Although our sample size is limited, participants' feedback indicated that the duration of habitation in a home may have affected the benefits an interface can provide. We hypothesized before the study that H1, who had been living in their home for less than two years and was still frequently changing the home's configuration, would consider *Casalendar* more useful than H2 who had been living in their home for more than eight years and who reached a phase of stability in which they had already fixed many issues of its behavior through many iterations. This was confirmed by their responses in our questionnaire: H1's perception of whether *Casalendar* increased the chance to set the home in the way they wanted it to be was higher than H2's. Similarly, H1 agreed that *Casalendar* could help identify and understand problems quickly, while H2 disagreed. H2 reflected on the usefulness of our interface in the early stages of the smart home adoption. H2H: *"I had to change so many things over and over again, and then it still wasn't like the way you had thought. The temporal sequence [of actions] took a lot of adjustments [to get it right]."* H2W: *"You could have simply looked at the whole week [in Casalendar] to see how the home has behaved."* They considered the calendar-based interface to be useful to see patterns and exceptions in the weekly overview at a glance. H2W was generally happy with the interface she was using after several adjustments had been made and she reported having gotten used to interacting with these tools. However, she noted that she would have adopted *Casalendar*, if she had been given this option earlier, since *"[with Casalendar] you simply have it all, [the different devices and calendar] in one [interface]."*

Usage Patterns Around the Integrated Calendar

When designing the interface, we considered scenarios in which the context of the personal calendar could potentially be connected to the smart home's behavior (e.g., by having the robot vacuum clean the house before a visit that is entered as a personal event, or deactivating the shades to the garden when guests come over for dinner in order to not disturb them). Yet, neither in the annotated screenshots collected nor in the follow-up interviews did examples like this, or any other specific interest in connecting personal calendar entries with smart home behavior, come up. However, participants mentioned the usefulness of seeing their calendar entries collocated with the behavior of the home. E.g., H1W expressed the wish to define exceptions for the shades when seeing that a school holiday was coming up. Despite having the potential to be a promising approach, stronger evidence for the usefulness of such functionality has yet to arise. This idea might be worthwhile reevaluating when our prototype a) offers control over various devices and b) when calendar entries have more automatically generated contextual information, such as locations of events or commute times.

In general, our participants felt that they had lost interest in the smart home's actions after living there for a while. They believed that the true purpose of a smart home should simply be to *"function optimally in any situation, so the user wouldn't need to worry about questions like 'will the shades go up and when will they go down?'"* (H1W). H2 had substantially less interaction with the interface than H1. We attribute that to the fact that there is generally little need and interest in the smart home data most of the time. This makes sense: smart home inhabitants want to enjoy peace of mind [2] and worry about fewer things, not more. H1W expressed interest in using one single interface for both smart homes functions and the family's calendar and said: *"I would like to also be able to edit the [personal] calendar entries [in Casalendar], so that I could get rid of the iPad entirely."* The same household also reported how they were using *Casalendar* exclusively to look at their own calendars when they had a very busy week during our study. Therefore, we propose integrating informative data about the smart home's behavior into an interface that is frequently used in the user's everyday life. The integration should be carried out in such a way that it only draws the user's attention when it is needed and otherwise stays in the background or can easily be ignored.

H1 used their digital calendars extensively and we observed a more natural integration of their interaction with *Casalendar* into the daily habits of the family compared to H2. We argue that the acceptance of such an interface will be highest if a) users already habitually use digital calendars and b) are still in a phase with frequent adjustments to their home's configuration.

Tradeoff Between Completeness and Visual Clutter

The challenge of designing usable interfaces which incorporate dense information is certainly not new. One of the many guidelines for good design states that "the display should be designed to convey 'just enough' information" [17]. Although we tried to address this issue with user-specific information and view filters beforehand, we observed a frequent tension between having access to more information and viewing less data in our participants' feedback. Our participants reported sometimes being overwhelmed by the amount of information presented. H1H reported: *"[...] I simply selected all shades [...] and now there's a bunch of individual bars and that's all very confusing."* At the same time, they also expressed the wish to include more data in the interface. H1H and H2H would have liked to see numerical values next to the temperature and brightness graphs on the timeline. Ideally, the interface would manage high information density and create a view that is useful and actionable for the user.

More Reflection and Context Needed Over Time

We observed that our interface was only interesting for a short period for the participants who have been living in their smart home for a longer time and who were already familiar with their home's behavior. H2H commented: *"In the beginning [Casalendar] was very interesting, however, over time it wasn't [...] interesting to look at it over and over again because in the end it doesn't really change a lot."* He felt that his trust in the home's behavior was confirmed after a while and he *"doesn't check all the time whether it still runs correctly as [when he checked it] last time.*" He stated that he would instead be interested in learning about certain trends in the home's behavior and recent changes to the configuration. Strengers [28] made a similar observation of saturation on inhabitants who have been provided with eco-feedback for some time.

Presenting information that is relevant to the user at a specific moment is essential. Related work looked at various techniques on how to prepare information for people in context-aware environments to make it useful [34]. This concerns events that actually took place, but also events that did not, because people will also still wonder why expected events did not take place [16]. For example, H2W stated a strong interest in these questions and other unusual behavior. She wanted answers to questions such as *"did the iRobot really run, or was there a black out?"*

Other participants stated that they would not only want to see entries that would allow them to understand the home better, but also support them in spotting exceptions in the sensor data or home's behavior. H2H described it as: *"[It would be helpful] if you could see [...] 'was that only an exception?' or is that the typical course of action. At the moment, I always have to figure out, was it an exception or my mistake [in the configuration]?"*

Lower Barrier to Access for Smart Home Interactions

Mennicken and Huang [41] revealed that many common smart home technologies require people to have technical skills to gain access to all information and control functionalities. We were therefore interested in how our approach would be perceived by user of different technical abilities.

Access for the Entire Household

Our interface was well received also by inhabitants with strong technical skills that already used existing interfaces as it was simpler to access and the calendar visualization was easier to parse, as reported by H2H: *"Well, I could go into the logs and see that there, but here in Casalendar it's visualized very comfortably."* A shared visualization that is usable by all family members, regardless of their technical skills, could help to support communication of problems and ideas for the configuration, and thus improve the initial configuration phase.

Our interface design was based on the metaphor of shared, physical calendars that can be accessed by everyone at any time, as opposed to tools on personal devices that are often access-restricted. In the participating households, some family members had limited access to the devices on which the control interfaces resided. For example, in case of H1 the data on sensor data (temperature, brightness) was only accessible through interfaces that were never introduced (or of any real interest) to most household members, and only installed on devices that had restricted access, as described by H1C2: *"On mama's [iPad] we can't do that because [the iPad] is locked."* Our prototype *Casalendar* was not access-restricted, which was well received, as described by H1W: *"The kids enjoy using the calendar view, but they also play around with the smart home functions in there because the iPad is locked."*

Emerging Questions of Privacy

Contrary to our expectations, our participants had no privacy concerns about *Casalendar* revealing information to other household members and only those with a strong technical background (H1H, H2H) agreed or strongly agreed they would not want information to be shared outside of their household. Those with less technical skills (H1W, H2W) disagreed or strongly disagreed and thus, did not share this concern. Privacy concerns did not come up in the interviews either, although we specifically probed for them. Only H1W commented that her children could potentially have concerns in the future: *"We could associate the fingerprints to the kids sometime in the future. We could check which kid got home at what time after they have been going out at night. Hm, they will probably not be overly happy about that."*

While data collected from individual devices (for motion-triggered lights in the basement or electricity measurements of the kitchen stove) might not instantly raise privacy concerns for the inhabitants, it could easily be turned into a sophisticated surveillance system just by being put in the context of the entire home [32]. This is not unique to calendar representations; however, the increased accessibility and the potential resulting awareness make careful design to maintain privacy especially important. From the patterns in the timeline, H1W was able to infer when the kids came home and whether they actually heated up their lunch or whether they went straight to the basement to play computer games. We found that our visual representation of data helped users to easily capture exceptions or outliers in certain patterns or events at unusual times. For example, H1W noticed an unusual entry located in the basement one night, which she recorded via an annotated screenshot in our feedback mode. After casually talking to her husband about it, he admitted having fallen asleep after watching TV for too long and then checking up on the cats before going to bed. In this case, both household members felt comfortable sharing; in other cases, a simple smart home calendar entry might violate a person's privacy or cause arguments.

DISCUSSION AND IMPLICATIONS

In this section, we discuss our findings and provide several implications that aim to support the design of future systems. Moreover, our discussion aims to raise emerging questions that take into account the limitations of our interface prototype and our case study.

Calendar or Smart Home Interface

We designed our interface primarily to look like a regular calendar interface, as reflected in our decision to give personal calendar events more space than smart home events. However, we noticed that the perception of whether our hybrid interface was primarily a calendar or a calendar-style smart home interface varied based on the usage and configuration, and the extent to which digital calendars were already in use in a household. As a consequence, the question arises whether and when it makes sense to present *Casalendar* primarily as a smart home interface in the form of a calendar and when to present it as a subtle integration into something that is primarily a calendar interface. Both would share similar properties, such as presenting smart home events on a timeline and providing an overview across devices and days that makes it easy to spot patterns, exceptions, and causalities. From our study, we learned that the smart home data and logs themselves are not interesting enough to justify a stand-alone interface most of the time. Additionally, work by Palen [24] revealed that simply replacing the calendar artifacts that people use can create major challenges with regard to their routines. Thus, we believe that integrating smart home data into frequently used tools will be the more promising approach compared to only focusing on visualizing the data – as long as it does not compromise existing practices with these tools or require extra effort from the user.

A calendar interface is without a doubt more familiar and accessible to the wider population than technical smart home interfaces or log files. In our study, we found that no one had trouble understanding our interface concept. However, we also reached the understanding that one interface cannot serve all purposes equally well. Although we only offered limited options to control features of the home (as this was not the primary focus of our study), it gave us some early insights about participants' opinions of the metaphor of a central calendar for control purposes. H1W raised concerns regarding the limited practicality for simple controls, such as letting the shades down. She expressed that she does not want *"to have to walk up to the calendar for this simple action."* This would be a problem for any interface that is not mobile and has to be accessed from a specific location. While this might be addressed by making *Casalendar* accessible from mobile devices, it also hints that immediate control of devices may not be well supported by this metaphor. Still, participants expressed that they want to be able to access specific control functions when they see events of this function in the interface. Hence, such a visualization interface should include the means to control the devices presented or their configuration, even if it will probably remain only a complementary tool to other means of control. When integrating means for control of multiple devices into a single interface, the design challenges that are known from previous approaches to "universal remotes" [23], such as preventing mode errors, will have to be taken into account.

Our interface helped our participants get a better idea of the temporal behavior of their home, and they could create focused views of it using the different filter functionalities. Yet, for use cases in which only the current state is of interest, a spatial metaphor might serve better. For example, when leaving the home and trying to find out which windows are still open, a spatial interface such as a map would only require one view. In our interface, users would first have to orient themselves within the timeline and then see whether there were events related to all the devices of interest. As mentioned earlier, we believe that the visualization of smart home data we propose here will probably not suffice as a stand-alone application. Integration with another interface might offer other advantages as well. For example, by integrating temporal and spatial interfaces the use of a selected location could customize the calendar view and reduce visual clutter. Offering multiple metaphors could also allow for a more versatile use of the system.

Calendar as a Sensor and Tool to Facilitate Future Controls

Despite the small sample size, our deployment of *Casalendar* in real households indicated that a familiar representation of information that is usually captured but hidden in log files can be useful for inhabitants. But capturing this information could also serve another purpose: in addition to offering automated behavior that remains rather static and inflexible after the initial setup [29], the house could use it to play a more active role in the household. By aggregating information about the context of everyone's whereabouts through the calendar, the home could better understand the dynamics of the household and adjust to them. Prior work by Davidoff [6] demonstrated how such information on people's routines can be used to create more valuable ubiquitous computing systems. Other work used calendars as sensors to collect information, in order to automatically annotate images with context information [10]. People already use calendars for tracking past actions [24], and annotations on the calendar have been used to support awareness within the family [20]. A smart home could potentially do the same thing: it could use the information about interactions with the building infrastructure to allow a better adaptation to the family or to create a means for the inhabitants to more easily set their home to a specific state. For example, the home could look back at personal events (such as "Spring break", "Dinner party", etc.) and try to correlate them with the changes to its configuration to learn about how it could interpret them. Then, it could offer "autocomplete"-style suggestions when adding or changing a device or configuration or when adding a new personal calendar event. This could permit a more optimized use of the technologies and reduction of manual overrides, assuming that the reconfiguration was previously too demanding for the user.

The only potential future events we showed was manually generated information about the behavior of the shades. Therefore, we could not gain much insight about how people would interact with predictive events from our study. Yet, participants expressed interest in having the various scheduled events of different devices or functions included in the calendar interface. For example, H1W believed it would be helpful if she could see the starting time of her stove in *Casalendar* when she programmed it in the morning. That way she could react to potential conflicts during the course of the day by adjusting the preprogrammed time or canceling it. H2W wanted to include the weekly cleaning schedule of the robot vacuum in the calendar for the same reasons. She also wished to include contextual information that was potentially relevant to the home, like the weather forecast, so that she could easily change the home's settings accordingly. Merging all this data into one interface could help create a mutual understanding of what the home bases its actions on. Yet, when introducing uncertain and potentially changing data, a challenge that is already known for shared calendars will have to be considered: how does the inhabitant stay ahead of changes that occur throughout the day [20]?

Transparency vs. Privacy

Our interface has the potential to provide more transparency, to act as a base for communication and to allow the less technical household members to understand and refer more easily to certain behaviors of the automation technology. In the case of H1, we also observed how the home can act as an extended monitoring system that provides a more tangible way for parents to address some behavior patterns of their children.

Our interface raised an additional question regarding privacy, besides the general questions of collecting such data: what does it imply if smart home data is offered in an accessible tool that makes it very visual, and thus easily consumable for all household members? Should the entirety of the data collected be available to all household members? Even regular calendar entries can make users vulnerable to external judgment [24]. What will happen when a teenager misses curfew by a couple of minutes, leaving a distinct visual pattern on the calendar? Will a tolerated "white lie" become intolerable because of the calendar entry it creates? This scenario has been studied by Ur et al. [32], revealing attitudes of parents and teenagers. One of their recommendations is to make the logs less granular, such as showing "around 11pm" instead of the exact timestamp. A calendar interface that visualizes logs would therefore need to be able to offer a suitable representation for such fuzzy entries.

Privacy issues in smart homes are not new; the data in such homes has always been available but accessible only by one or few members of the household and buried in a list of log entries. In some ways, this has created an imbalance in access to information about other family members. If interfaces like *Casalendar* suddenly make previously obscure data usable and lower barriers to access, new privacy issues and questions regarding the rights to access smart home data will be exposed. Who should know about what in a household? Who should be able to filter this information? Behavioral patterns can be spotted easily in the calendar interface as they have a specific visual appearance. There are several approaches in privacy research, such as adapting information to context in ambient calendar displays [27] that could be considered, even for interfaces situated in a more private context. Most importantly, these questions need to be recognized as major challenges that will require sensible design choices, in order to avoid negative social implications on family dynamics.

CONCLUSION

Casalendar is a first attempt to provide a combined, holistic view of a home's and inhabitants' events and routines through a temporal interface containing actual smart home logs and participants' calendars. Based on a one-month deployment in two households, we presented several observations and insights, such as how the metaphor of a calendar supported building trust in the home's behavior and how such an interface can lower barriers to accessing smart home information. We reflected on the usefulness of the calendar metaphor for giving an overview of the home's and family's behavioral patterns. However, we also learned that with the current state of our interface such information is mostly of interest if changes to the home's configuration were still being made. We further found that the proposed visualization of smart home data would most likely be useful if integrated into existing tools rather than considered as a stand-alone application. By discussing the limitations of our work, we identified remaining challenges that need to be addressed.

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