Challenges and Opportunities for Intelligibility and Control in Smart Homes

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Abstract
Several studies have reported on interaction challenges users face when confronted with proactive context-aware technologies that take actions on their behalf. To address these challenges, techniques have been proposed to improve *intelligibility* (understanding) *of* and *control over* context-aware systems for end-users. Proactive context-aware systems have not only been featured in several smart home visions, but are also common in current solutions within the smart home space. In this position paper, we outline a number of challenges and opportunities with respect to intelligibility and control in smart homes that take into account the diversity and evolving needs of inhabitants.

Author Keywords
Intelligibility; smart homes; evolving needs.

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

Introduction
Context-aware systems use sensors to gain knowledge about and adapt to the *context*—the situation in which they are used [12]. However, as argued by Bellotti and

Edwards [1] (and several others), context-aware systems are not infallible: there are some aspects of the context that cannot reliably be sensed. This means that the system could perform an inappropriate action due to its incomplete model of the current situation. To address this problem, Bellotti and Edwards [1] suggest that context-aware systems should be *intelligible* by informing users about what they know, how they know it, and what actions they are taking based on that knowledge. Additionally, proactive context-aware applications should offer users control, so that they can intervene when the system makes a mistake.

Issues with intelligibility and control are also commonly observed in smart homes (e.g., [18]), and can be considered one of the important remaining challenges to address [4,10,11]. Indeed, a recent study of the Nest smart thermostat [17] uncovered that participants at times experienced difficulties in understanding the thermostat's behaviour and also felt out of control. One person mentioned they felt the Nest was behaving arrogantly, doing "whatever it thought was right".

Although several general techniques have been proposed to support intelligibility and control (e.g., explanations [8,16], feedforward [2,15], end-user programming [2]), this position paper focuses on specific challenges for intelligibility and control posed by the dynamics of a home environment, along with interesting opportunities to make significant advances in this area.

Intelligibility "In the Wild"

Most studies of techniques to improve intelligibility and control, have been confined to simulated scenarios or lab settings (e.g., [8,16]). Studies of deployed techniques in real smart homes could reveal new insights that open up further avenues for research on intelligibility and control. Platforms such as HomeOS [3] or SPOK [2] could enable large-scale deployment and studies of intelligibility and control techniques. This could answer essential questions—such as in what situations intelligibility is most important to smart home inhabitants, how intelligibility and control should be provided to different kinds of users, or whether they are interested in knowing about sensing details. For instance, Yang and Newman's study of the Nest [17] revealed that intelligibility was mostly important when something went wrong, and that users had little motivation for developing an understanding of the system's behaviour as an independent activity. Providing intelligibility and control not from a technology-centric perspective, but in a manner that is "contextualized" to the activities and routines of inhabitants in the home is a promising direction for future work [9,11,17].

An Intelligibility and Control Dialogue

We argue that it is important for the home to support *soft* failures, react slowly to improve awareness [14] and take the less dramatic option when confronted with multiple possibilities for action. An interesting avenue for future research is to study interfaces that blend support for intelligibility and control into a dialogue between the home and inhabitant [5,11]. Next to awareness of its actions and behaviour, the home could allow inhabitants to indicate exceptions from general rules or routines in the home (e.g., when a temperature change is a one-off event [17]). Spontaneous configuration and control could allow inhabitants to undo particular actions and specify why this behaviour was inappropriate—from which the home could learn [7]. This also avoids suboptimal solutions such as having to reset the learning algorithm to its initial state [17].

Multi-User Intelligibility

Most existing research on intelligibility primarily targets intelligibility for single-user scenarios. Future research is needed to broaden the scope to investigate intelligibility in social settings, and in particular in domestic environments. There are a number of issues that come into play when providing intelligibility involving multiple users. First, for multi-user systems that act autonomously based on the sensed context, it will be necessary to provide awareness about the actions of other users and who the system is responding to, or *accountability* [1]. Indeed, the home might mediate user actions that impact other inhabitants (e.g., "passive users" [10]). Moreover, privacy and security are important open issues for multi-user intelligibility. As a consequence of being intelligible, smart home technologies could reveal sensitive information that might not be suitable to be shared with other inhabitants, let alone visitors or passers-by [13].

User Diversity and Evolving Needs

An important challenge for intelligibility and control in smart homes is dealing with the diversity of different inhabitants (or guests) in the home, their different roles, and evolving needs over time. Next to the technical expertise of inhabitants [10], the different stages in their lives (e.g., children, adults, parents, elderly) can require different strategies to explain and control the home. Families with young children may want to restrict or lock certain technologies from their children, and provide specific privileges to trusted visitors such as babysitters. Cognitive decline at a later age could require modifications to the home's behaviour to avoid confusing the inhabitant (e.g., people suffering from dementia). Moreover, this could require passing "control" over to family members or trusted caregivers, which could happen gradually based on the inhabitant's interactions with the home. Caregivers will finally be the ones managing and configuring the home, and will have different needs than the inhabitant (e.g., monitoring, emergencies [6]). This means that intelligibility and control interfaces will have to be primarily provided to the caregivers, allowing them to be informed remotely and take control over the home if needed.

From a technological evolution perspective, it can be useful to introduce a grace period or sandboxing mode whenever new technology is introduced into the home. This mode would allow less autonomy for the component and make users explicitly aware of its future behaviour [14,15] and interactions with other technology components in the home.

About the Authors

Jo Vermeulen is a Research Fellow at the HCI Centre of the University of Birmingham, UK. He recently completed his PhD at Hasselt University, in which he explored the design space of techniques for control and intelligibility. He continues this line of research on context-aware systems in Birmingham, and is also interested in applying social theories in HCI to develop context-aware interventions for behaviour change.

Russell Beale is Director of the HCI Centre in the School of Computer Science at the University of Birmingham, UK. He is currently focussed on designing interactions for sustainable behaviour change. In addition to his work on pedagogies for MOOCs, he has conducted research on user-centred knowledge discovery and context-aware mobile applications. He also spends time talking about how technology impacts and affects our social structures and activities.

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