Understanding Interactions in the Smart Home

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Understanding interactions with, and between, smart home technology is the key to better design

In this article we explore two issues that can lead to problems for smart-home systems; socio-technical interactions and cyclic interactions. Both issues threaten to obstruct the uptake of the vision for the smart home. At the heart of these problems is *interaction*; interaction between systems and interaction between people and systems. In its simplest form a smart home is one in which most electronic and electrical devises (including computer based systems) are connected to each other and the outside world via computer networks (Figure 1). At one extreme smart homes simply enable sharing of digital media across a home network or, at another extreme, enable collections of networked devices to coordinate their actions. They also enable the creation of so-called "virtual-appliance"[1] that work by deconstructing conventional appliances and applications into their elemental services and offering these back to the network user, so they may be recombined in various ways.

Figure 1: The Essex iSpace: An Experimental Smart Home

Socio-Technical Interaction

A key question is how non-technical people might be empowered to combine and program collectives of networked services to deliver the required functionality. Various approaches are possible such as the use of intelligent autonomous agent techniques to monitor, model, pre-emptively control the environment. Such approaches often employ life-long learning, in which they continually monitor and record the users habitual behaviour so as to adapt to the changing needs of the occupant and environment. However autonomous agents do not appeal to everyone as, if they are not appropriately applied, they can remove control, transparency and creativity from the system, thereby undermining the user's trust and liking of the system. This has led to people considering end-user programming[2]. Such approaches mostly try to disguise the process of programming by harnessing natural metaphors (eg jigsaw construction) and modes of interaction (eg speech dialogue). Thus, programming approaches range from highly automated to manual user-centred approaches; with various hybrid solutions lying between.

Various surveys have shown that user acceptance of technology in personal spaces is linked to issues of privacy, control and creativity. In terms of smart homes, control can be seen as a balance of technological autonomy versus user influence. In order to expose these concerns we created a conceptual Socio-Agent Framework (the 3C model) that graphically illustrates the issues (Figure 2). To capture the balance of automation we have included an 'autonomy axis' that shows the possibilities for configuration from manual (end-user) to automatic (agent based). In terms of sociology, reactions to technology vary from love to fear, thus we included an 'attitude' axis that shows user reaction (philia versus phobia) to the different possibilities. The quadrants show differing combinations of technology and attitude, identifying potentially significant positions within this space. For more detailed discussion readers are referred to other published work by the authors[3].

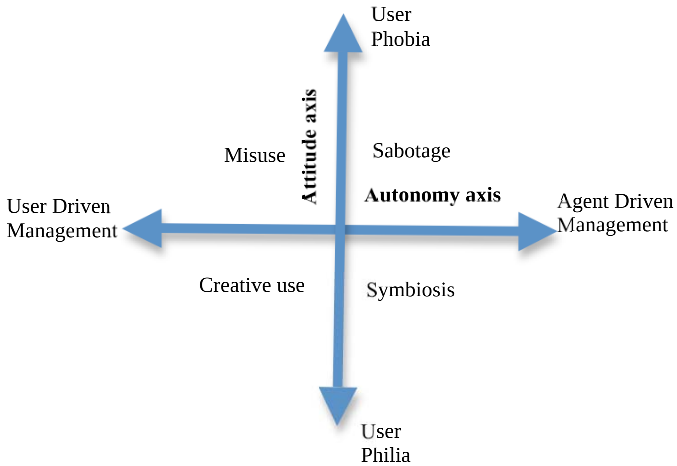

Figure 2: The 3C model - A Socio-Agent Framework

Cyclic Interaction

Another important interaction occurs between devices (or services). Networks enable smart-homes to coordinate actions, leading to interdependencies in the behaviour of the devices. Commonly behaviours are based on sets of rules formed by either autonomous agents or end-user programming. Potentially, there could be large numbers of interacting devices (eg 10-100s), programmed by different people or agents giving rise to complex system-wide interactions. This behaviour is further complicated by various sources of non-deterministic behaviour arising from sources such as users (sometimes behaving somewhat idiosyncratically), nomadic devices (including random malfunctions), and temporal delays (varying according to loads). Whilst much of the behaviour of these systems is what the users (or programmers) intended, the complex nature of these interactions means that, occasionally, unexpected and unwanted behaviour arises. Kolberg[4] produced a taxonomy for such destructive interactions, namely:

1. *Multiple Trigger Interaction* - two services are controlling the same appliance.
2. *Shared Trigger Interaction* - an event is sent to two different services that perform conflicting actions.
3. *Missed Trigger Interactions* - one service prevents a second one from operating.
4. *Sequential Action Interaction* - a service request to an appliance that, in turn, causes such appliance to send notifications to another service.

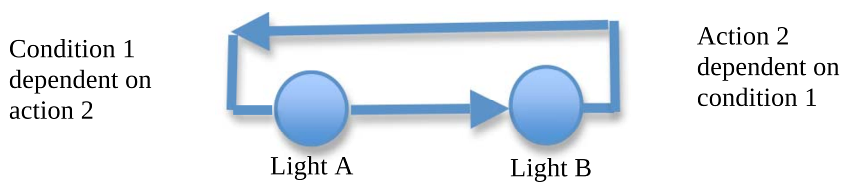

Figure 3: Simplified Illustration Of Cyclic Instability

Researchers found solutions for all cases apart from cyclic interaction (part of the Sequential Action Interaction category). A simple way of understanding cyclic interaction in smart homes is to consider two interacting light control agents (Figure 3). Here it is clear that if the rules are set such that 'light A' being 'on' is dependent 'light B' being 'off', but that 'light B' being 'off' is dependent on 'light A' being 'off' we have a mutually-exclusive condition with a resulting oscillation (flashing lights) with a period determined by the temporal properties of the system. Further, if more devices are involved in a loop, loops overlap (nodes are shared) or the network is perturbed (by users, nomadic devices and variable loading) this quickly becomes an intractable problem. This is especially difficult to solve because complex systems theory[5] has shown that, in general, it is not possible to predict theoretically whether a given rule-based system will suffer from unwanted cyclic instabilities. However, whilst it is not possible to say with certainty that a given system will suffer such instability, we have been able to devise methods that identify the potential for such instabilities and to "inoculate" the system against the occurrence of cyclic interactions by developing the following mathematically based tools:

1. *Interaction Network (IN)* - This is a mathematical framework based on directed graph and set theory that provides a means to represent and reason about rule-based systems.
2. *Instability Prevention System (INPRES)* - a mechanism that uses IN analysis to generate an optimal locking strategy.
3. *Multi-dimensional Model for Visualization (MDM)* – a graphical model that enables time, devices, and their binary state to be visualised. It is especially useful for understanding the system dynamics.
4. *Cyclic Density Metric* - a practical metric related to the usability of the system.

By way of an example, some cyclic interactions occurring in a small 4x4x4 benchmark we developed are shown below (Figure 4).

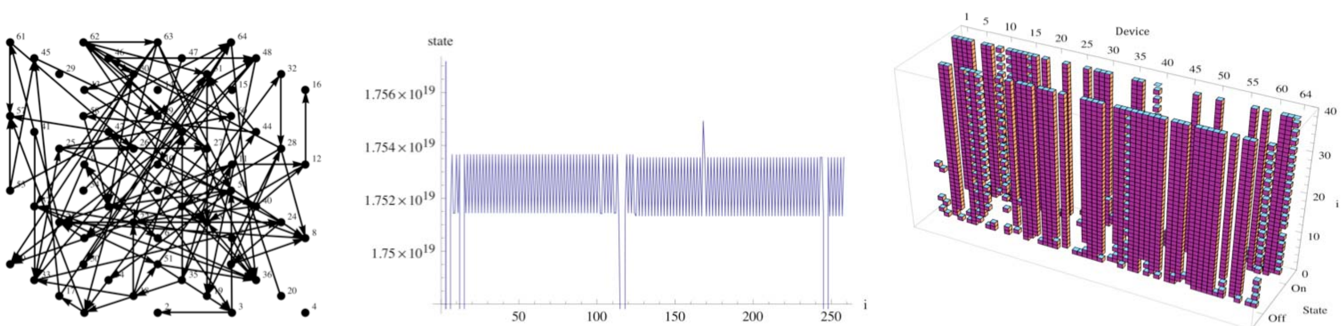

Figure 4: (a) 4x4x4 (64 node) interaction benchmark featuring random connections containing 81 loops. (b) Unlocked response of the random system showing system-wide oscillations. (c) Multidimensional model for visualization

In summary, Interaction Networks, the Instability Prevention System and the Multidimensional Model of Visualization work in a unified way, providing a formal description of the problem, a graphical representation of the dependencies of the rules, a mechanism to prevent periodic behaviour, and a micro visualization of the dynamics of the system. For more detailed discussion readers are referred to other published work by the authors [6].

In this article we have described tools that can be used to overcome problems relating to interaction between systems, and interaction between people and systems, in the design of smart home technology. For our future work we intend to explore applying these techniques to wider set of applications such as economic and social systems.

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References

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