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Design Semantics of Connections in a Smart Home Environment

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Design Semantics of Connections in a Smart Home Environment

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智能家居环境中的连接性设计语义

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摘要： 借助日趋电脑化的力量，我们的居家环境越来越智能化，居住环境中设备与设备之间的嵌入式传感器及网络连接很可能会让使用者感到茫然。用户交互从一开始操作单一的设备转变为了一系列生态事件组成的庞大系统。人们变成了现实世界与不可见的数码世界之间的调解员。本文主要通过展示部分正在进行中的研究调查，该调研是关于如何利用简洁的设计语义来传达明智居家环境中设备连接的抽象概念，使使用者理解并且构建有意义的智能环境，与之进行相应的互动。我们将通过示范来让用户在一个居家娱乐案例中掌握这种不可见的无线仪器连接。

Abstract: As the environments in which we live become more intelligent— through more computational power, embedded sensors and network connections between the devices that reside in the environment—there is a risk of leaving its users clueless about what is going on. User interaction changes from interaction with a single device into interaction with a larger system— an ecology of things. Physical things are becoming mediators between the physical world and the digital, invisible world that is inside and behind them. The work we present in this article is part of ongoing academic research on using explicit design semantics to convey abstracted models of connections between devices in a smart home environment. This enables users to understand and construct meaningful mental models of the smart environment and interact with it accordingly. We illustrate our findings by presenting a demonstrator that gives users physical control over invisible, wireless connections between devices in a home entertainment scenario.

关键词：产品语义学；用户互动；智能居家；互动设计
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1. Introduction

As computers are disappearing into smart environments, like envisioned by the "Ambient Intelligence" paradigm [1], novel human-computer interactions will be needed to deal with the complexity of such hybrid environments, merging the physical with the digital. Ambient Intelligence envisions digital environments to be sensitive, adaptive, and responsive to the presence of people, and will change the way people will interact, not only with the environment itself, but also with the interactive multimedia through the environment [1]. Over a decade of research has lead to several interesting interaction paradigms such as tangible interaction, augmented reality and mixed reality. Already in 1997, Ullmer and Ishii [2] introduced their vision on a new interaction paradigm for Ubiquitous Computing. By providing physical handles for digital information, users can use the senses and skills that people developed during millennia of interacting with physical objects [2]. Other related work presents solutions for simplifying configuration tasks of in-home networks by creating virtual "wires" between physical objects like memory cards [3] that can interconnect devices. Others propose to introduce tags, tokens and containers [4, 5] for tangible information exchange. Concepts like "pick-and- drop" [6] and "select-and-point" [7] are used to manage connections and data exchange between computers and networked devices, and augmented reality solutions are considered [8]. The introduction of near field communication, using a near field channel like radio-frequency identification or infrared communication, allows for direct manipulation of wireless network connections by means of proximal interactions [9]. Related work is not limited to the network configuration tasks themselves. Visual metaphors to show the progress of making short distance wireless connections, such as Bluetooth pairing, and the affordances and aesthetics of making connections by physical contact between devices are investigated in [10]. What sets the work presented in this article apart from many of the earlier "Tangible User Interface" concepts is our focus on connections. Instead of giving digital information physical containers/representations as done in many tangible user interfaces,

we allow for exploration and manipulation of the connections "carrying" digital information (pipelines instead of buckets). We see these connections as both real "physical" connections (e.g. wired or wireless connections that exist in the real world) and "mental" conceptual connections that seem to be there from a user's perspective, and their context (what things they connect) is pivotal for their meaning. We aim to enable users to explore and make configurations on a high semantic level without bothering them with low-level details. We believe this can be achieved by making use of Semantic Web technologies and ontologies in an interoperability platform as proposed by the SOFIA project (http://www.sofia-project.eu/). Such a platform could be used to support semantic interaction in a smart home environment [11].

For users to truly benefit from smart environments it is necessary that users are able to make sense of such an environment. One way of facilitating this "sense making" is through design. Things make sense to users in different ways, by use and functioning, by appearing in language and human communication and social use [12]. If we look at meaning from an Internet of Things point-of-view, physical connections between artefacts, and conceptual and metaphorical connections play an important role. Artefacts can be physically connected by wired or wireless communication,but people also tend to group artefacts that are not physically connected together by finding resemblances in their meaning. In smart environments with many interconnected and interoperable objects—hiding their physical connections—these conceptual and metaphorical connections become even more valuable, and maybe even crucial for the understanding of a smart environment. Without this understanding there is the risk of engendering a mismatch between the system's model of interaction and the user's mental model of the system. In these conditions, using explicit design semantics can be used to help users to construct helpful mental models, in order to minimize system and user model mismatches.

Our research is centered around developing visualization and interaction techniques for semantic connections/interactions, to support information presentation and to increase information and service awareness. Additionally, focus will be on user conceptual models, and developing ways to represent the configuration of, and information exchanged within a smart home environment. It is key is to make proper abstractions of the network configuration, information exchange and available services, helping users to construct helpful mental models to understand a smart environment. When having a proper understanding of the smart environment and an increased awareness and manageability of available services, we envision a better user experience and a higher user acceptance. Design theory like product semantics is utilized to find handles for these new interactions [13, 14], and will be used to design meaningful objects and interactions. This will enable users to interact with a smart environment, through interaction with interactive objects.

2. Product semantics

Product semantics is a theory about how products acquire meaning. Product semantics was defined by Krippendorff and Butter in [14] as being both:

"A systematic inquiry in how people attribute meanings to artefacts and interact with them accordingly." and

"A vocabulary and methodology for designing artefacts in view of the meanings they could acquire for their users and the communities of their stakeholders."

Product semantics shares many concepts with semiotics, the theory of signs [15]. Within the context of smart environments, an increasing amount of automation and increasing interconnectedness will have a negative impact on the meaningfulness of products. Of course, our understanding of products, and the way they acquire meaning, will also change. Nevertheless, in the envisioned smart environments, we need to provide users with handles and clues to make them under-stand what is happening and allow them to be and feel in control.

The origin of many of the problems that arise lies in the difference in nature of, or more precisely in the incompatibility of the physical world we live in, and the invisible world within our products. In order to understand products and systems, we develop a conceptual model of how we believe things work and how they should be used. These User Conceptual Models (UCMs) as defined in [20] are usually an approximation or simplification of reality. This means that these models are often incomplete and different from reality, but as long as they work for the users they do not need to be true. As long as the underlying mechanisms of the working of products are simple and reside in the physical world, they have a bigger chance to be understood and to make sense, and thus have meaning to their users. Traditionally, product semantics is mainly concerned with physical objects. But meaning arises at different levels. In order to design for sense making, we need to look for references and resemblances between the new and known concepts. We distinguish between first usage (ratio facilis) and second usage (ratio difficilis) [16]. If we want to understand the semantics of the desktop computer, as it exists nowadays, we need to look back to the context in which it was originally introduced.

Computers needed instructions; in the time of the first personal computers instructions to them were given by text input. That is why keyboards are so close to typewriters. To be able to output something we gave them a possibility to write back; having a display, as we knew it from early TVs seemed logical. But also in the interaction with computers, the desktop metaphor was introduced, and our hand to "physically" move things on our digital desktop was represented by the pointer of a computer mouse, the digital extension of our hand. Metaphorical connections are strong and welcome if we need to shape new, unknown concepts. But there might be different and better ways of making sense (p. 5 of [17]): "The essence of a metaphor is understanding and experiencing one kind of thing in terms of another."

If we have a look at the innovation smart environments promise, the step forward would be improved interoperability and the added value this interconnectedness and information exchange offers. Important to note is that this added value is an addition to the existing, basic functionality of the devices. An example of this can be found in [18], where interoperability between existing applications (exercise monitor, computer game, phone and media player) enables a scenario where a game called SuperTux would award extra lives for exercising (using an exercise monitor), a mood renderer embedded in a media player would play music depending on the game's state, and the game and media player would react accordingly if the person received a call. Additionally, connecting smart devices to one another makes it possible to support high-level services that would usually involve multiple steps on multiple devices. From a user's point of view, streaming music from a mobile device to a home

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entertainment system is a single high-level task. In practice there are multiple steps involved, and if the devices involved are from different manufacturers, the user needs to learn the operational details of each device interface in order to perform the task.

But how will these additional, high-level services make themselves known to their (prospective) users?How will users discover the newly enabled functionality and how will they decide what they want, but most important, what they do not want? In order to make sense of the added functionality and new services the smart space brings the users, they should be able to manage it. And in order to manage it, they should be able to, to a certain degree, understand it. For example: in order to use a vacuum cleaner one should know how to use it and understand that the power cord needs to be connected to a working power socket for it to function. One does not need to understand how an electromotor works; neither does one need to understand the physics of electricity.

We can find meaning in different layers. We can find meaning in the appearance of a product, informing us about the function of the product. But there is also meaning in the appearance of artefacts in language (e.g. vacuum cleaner; meaning something that cleans using a vacuum, or suction). This type of meaning has its roots in conventions and metaphors, and can be analyzed with the study of semiotics. At interaction level we find another level of semantics; concepts like feedback, feedforward and ecological perception (affordance) [24] play an important role here. Affordance is the property of an object that appeals to our sensory-motor skills, like a doorhandle that "affords" to be grabbed and a chair that "affords" to be sit on. When the insights of ecological perception were introduced into design, it fueled the design community to try and solve many usability problems. It was also adopted as a key element for what was called a direct approach. In this view, the meaning of things is created in action and feedforward and inherent feedback are considered key in making the abstract concepts in consumer products accessible to users [25].

But we can also discriminate between different physical layers of meaning. The appearance of a vacuum cleaner itself informs us about its usage: wheels to make it mobile, a hose and a telescopic tube with an ending that seems suitable for moving it over the floor's surface while standing upright. But when we open it to replace the dust-bag, there are physical clues about how it fits in there. However, these clues are hidden during normal usage, as it is not of your concern when using t to clean. Now, how can we use this semantic design knowledge in order to design meaningful interfaces for smart environments? Or how do we reveal new possibilities in a meaningful way, when a new smart device enters a smart space?

3.Design case

To illustrate the above-mentioned concepts and ideas, we developed a demonstrator. This interaction tile (figure 1), inspired by Kalanithi and Merrill's "Siftables" [26], was designed to explore the connections and connection possibilities and enable direct manipulation by making simple spatial arrangements. The interaction tile visualizes the various connections by enabling users to explore which objects are connected to one another and what can be connected to what. Coloured lighting and light dynamics visualize the connections and connection possibilities between the various devices. This is done by means of putting devices, or for non-mobile devices their representations, close to one of the four sides of the tile. A user can check whether there is a connection and if not, whether a connection is possible. By simply picking up the tile and shaking it, a user can make or break the connection between the devices present at the interaction tile. The design of the demonstrator allows for an "on-demand" visualisation and manipulation of the connections. When there are many connections in a smart home this is especially desirable, since users will only be dealing with the connections that matter to them at that moment.

We also expect that the rather active approach in exploring the connections might help to explore the smart space—and build a mental model of it—step by step.

3.1 The scenario

"Mark is relaxing at home when his friend Dries arrives. Dries comes with a portable music player loaded with his favourite songs. He wants to play some of his recent collections for Mark. Mark's home is equipped with a sophisticated surround sound system. They decide to enjoy the music from the music player on the sound system. Mark uses his Interaction Tile to see if he can connect Dries's music player to the sound system, which is connected to the home network. The interaction tile indicates that a connection is possible and Mark picks up the tile and shakes it to make the connection.

All the smart devices in the home have a cube-like representation that can be used with the interaction tile. The interaction tile shows the connection possibilities with a high level of semantic

Fig. 1. The demonstrator in action

Additionally, it keeps the interaction simple and information load for the users limited and therefore might allow for a more aesthetic and pleasing interaction. A video of the demonstrator in a simple home enter tainment scenario is available at http://www.youtube.com/watch?v=vdZcjqkgfRQ.

abstraction, hiding the complexity of the wired or wireless networks. By interacting with the objects, semantic connections can be built, redirected, cut or bypassed. Dries starts streaming his music to the environment. Now the room is full with Dries's music and they both enjoy listening to it. Recently Mark has installed an ambient lighting system that can be connected to the sound system and renders the mood of the music by dynamic colour lighting in the room. Mark uses the objects again to create another connection and now the room is filled with Dries's music and colourful lighting effects. Mark's roommate Sofia comes back from work and decides she wants to watch a movie on the TV. She seems somewhat annoyed by the loud music. Mark and Dries do not want to bother her and they again use the objects to re-arrange the music stream. Now the music is streamed to Mark's portable music player while also playing back at Dries's. It is also connected to the ambient lighting system directly, bypassing the sound system. They both are enjoying the same music using their own favourite earphones (and the colourful lighting effects), but without loud music in the environment.Now Sofia can enjoy her movie without any disturbing music.

From this scenario one can see that there are multiple ways and different levels of interacting with the smart devices in the environment. There are high-level semantic interactions with the interaction tile (explore/ make/break connections) and also lower-level interactions with the music player (play/pause/stop music).

3.2 Design semantics

The design semantics of the demonstrator are simple and straightforward. The tile-shape shows clear clues about orientation, e.g. what side should be placed up. The four sides clearly show four possibilities for placing objects near the tile; the size of each side restricts the number of objects one can place close to the tile. When an object is placed next to the tile, the lights give immediate feedback when the object is recognized (figure 2c). When multiple objects are placed near the interaction tile, it will immediately show the connection possibilities (feed forward) by lighting colour and dynamics. The lights' colour coding is simple and straightforward. Red colour means no connection and no connection possibility (figure 2d); green colour means there is an existing connection between the devices present (figure 2a/e) and green pulsing means that a connection is possible (figure 2b). To indicate that the interaction tile did sense the first object a user places near, it shows a red colour at the side the object was detected (figure 2c). Placing a second, third and fourth object, the interaction tile shows the lighting effect corresponding to their connection capabilities. By simply picking up the tile, and shaking it, the user can make or break the connection between the devices present at the interaction tile. The result of this action depends on the connection's current state, and the devices present; if the tile shows a connection possibility, the action will result in a connection event.

The same action performed when the tile shows an existing connection will break the connection. Although the expressiveness of the current demonstrator is limited because of its neutral shape and the use of single, multi colour Led lights, we see opportunities for further development.

We aim to enable users to explore and manipulate the connections within the smart space without having to bother with the lower-level complexity of the architecture. We envision this "user view" to be a simplified view (model) of the actual architecture of the smart space. Conceptually, the connections are carriers of information; in this case they carry music. Depending on the devices' capabilities (e.g. audio/video input and/ or output) and their compatibility (input to output, but no output to output), the interaction tile will show the connection possibilities. In our current demonstrator we do not distinguish between different types of data since we are only dealing with audio, but it will be inevitable in more complex scenarios. We rely on the symbolic meaning of colour, green colour meaning,

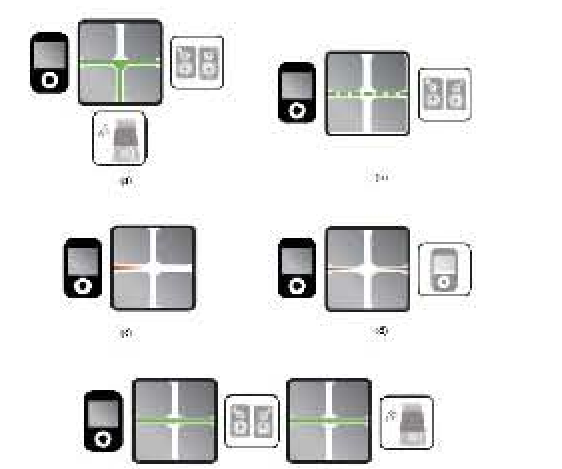

Fig. 2. Meanings of lighting colour and dynamics: (a) Green solid light means the devices present are connected; (b) Green, pulsing light means the devices are currently not connected, but can be connected; (c) Red solid light means device recognized, a second device is necessar y to show connections or connection possibilities; (d) Red solid light means the devices are recognized, but no connections or connection possibilities exist; (e) Shows the possibility to use multiple interaction tiles to look into connections in a more detailed manner, however both (a) and (e) have the same meaning.

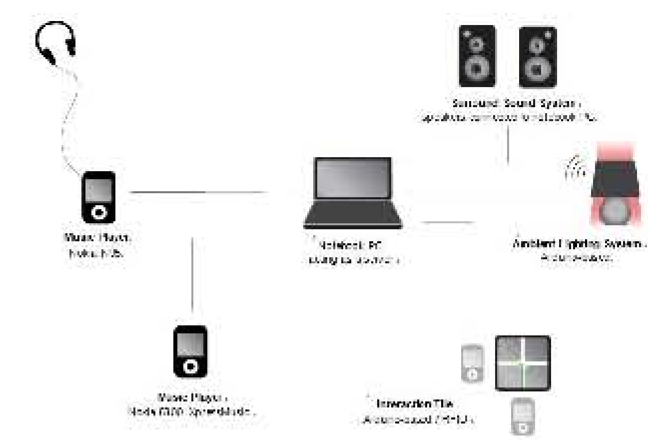

Fig. 3. An over view of the demonstrator

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"proceed" and red meaning the opposite. Using the association of solid colour and pulsing colour with solid and dashed lines we aim at referring to the "existence" of something and the "possibility" of something. This something is a connection, being invisible but with noticeable results (the sound of music out of a loudspeaker that you just connected to your MP3 player). We rely on iconic representation for the cube-like objects representing a stationary non-mobile device and on meaning resulting from direct manipulation of these objects we just described, representing other objects. People seem to be able to work with all these different (in fact rather complex) relationships at the same time, and our expectation is that we need the richness of all these mechanisms to successfully interact with our complex environments and the envisioned smart environments of the future.

3.3 Realisation

The interaction tile acts as an independent entity, connected to the home-network. Figure 3 shows the system architecture of the current setup.

The interaction tile consists of the following components:

- Arduino board;
- RFID reader (MiFare);
- multi-colour Leds;
- accelerometer;
- vibration motor;
- piezoelectric speaker;
- magnetic switches.

The demonstrator consists of the following devices:

- media players (Nokia N95 and 5800 XpressMusic smart phones);
- ambient lighting system (Bluetooth based);
- sound system (speaker-set connected to notebook PC);
- notebook PC;
- interaction tile.

4.Discussion

With the design presented in this article we made the invisible wireless connections visible. We also took it a step further by enabling users to physically explore and manipulate the connections. With this demonstrator we are exploring intuitive and appropriate ways to interact with the hidden digital world by enabling users to explore and control connections between devices.

The current demonstrator helps us in defining more specific research questions and identifying key issues in using product semantics theory, to design for bridging the digital with the physical. Although simple, this demonstrator does show that making high-level semantic abstractions of normally low-level tasks has the potential to allow for semantic interaction in home- network configuration tasks.

Building this demonstrator also identified possibilities for improvements and extensions. As previously discussed, it currently does not distinguish between different types of information exchanged, nor does it show directional properties of the connections. By replacing the single Led lights with Led arrays we could show the dynamics of information flow. Using additional colour coding could show different types of connections (e.g. audio/ video/ text), or it could have separated modes of operation, where it only shows one type of connection at a time. Although currently all devices are represented by cubes, due to technological constraints, the cubes representing the mobile devices could easily be replaced with actual devices in future versions. When networking complexities increase and the connections among more than four devices should be explored/manipulated, multiple interaction tiles can easily be combined. Besides these observations, the demonstrator shows that even the slightest and simple ways of giving feedback (lighting colour and dynamics) can reveal meaningful information. To what extent users can extract meaningful information from the interactions with the smart space, and how they can use it to build a suitable mental model for understanding, is currently being evaluated.

Adding constraints, as in limiting functionality, or not using the full technological potential, is not necessarily a bad thing. These constraints are essentially guides and handles for users to understand what is possible and what is not, or what should be done in alternative ways. An example can be found in our implementation. When there are more than two devices present at the tile, indirect connections are also shown; in fact there is no difference in the visualisation between direct and indirect connections (as explained in figure 2a/ e). To explore these connections in more detail, one has to explore and change the configuration to see how things are connected. It is a constant trade-off between the richness of complexity vs. simplicity. Recent work [21] shows the ongoing pursuit of making digital information and content physical, to allow for a natural way of accessing and controlling such data. Bridging the digital and physical has been a topic of research for over a decade. Although there is rich potential in tangible interaction concepts, shortcomings and tradeoffs are inevitable. One problem that emerges is the trade-off between "generic" versus "task-specific". When introducing physical objects to represent digital data, we need many physical objects that will have a more or less fixed physical shape. Very expressive physical objects will inherently have a very specific use. While very generic ones—like many objects featuring graphical displays and buttons—are not very expressive, and appeal less to our perceptual motor skills.

Another disadvantage of tangible computing is the introduction of many new physical objects into the environment. Leaving information in the digital world has advantages—we do not always want to have physical representations of all the information that we generate in the virtual world, which would mean overcrowding the physical space. A relatively unexplored approach is to use the existing physical (electronic) objects and devices in our interaction with the virtual world, going beyond using their (touch) screen and or buttons to interact with the information world. We propose to use the physicality of the objects e.g. their context, position and our usage of these object to generate new interaction concepts. We also expect that the physicality of the objects themselves and the context in which they are used, are the main providers of meaning. The connection created between a MP3 player and a stereo set has a meaning in itself, because of the resemblances in meaning of the two devices (being able to play music). Putting a photo camera close to a smart phone could mean the user would like to exchange all, or maybe the most recent image between the two devices. It is our challenge to not only make it happen technically, but to enable users to express their desires in a meaningful way.

5.Future work

This research is to be considered a work-in-progress. We will continue to develop research prototypes to investigate new interaction mechanisms. We have developed a more robust version of the interaction tile and an alternative variation, which are currently being evaluated in a user experiment.

Furthermore we will need to identify whether this way of interaction

can be generalized and applied in different contexts in the home. Further research will attempt to answer questions like:

How do we handle increased complexity? How should information about the information/content that is exchanged be revealed and how is control over the content provided? How can the design of physical objects (appearance and behaviour) enhance the creation of suitable mental models in users? Where smart systems or environments try to predict what the user is trying to accomplish, by being adaptive and anticipatory, we need to identify ways to give the users appropriate means to express themselves.

The possibilities, available services and information that exist in the smart environment need to be communicated in a meaningful way. Only if this is done correctly will users be able to build helpful mental models of the functionality the environment has to offer, set goals and make plans on how to act.

By developing novel and meaningful interaction devices, the user can then perform the necessary actions and the system can in turn try to understand the user's goals and make the match to its internal models. We see a vital role here for the theory of product semantics, the study of how artefacts acquire their meaning and use its theories to define common concepts and semantics.

We are currently also working on making the match from the other side—the side of the smart environment. By using technologies originating from the Semantic Web vision and ontologies, to define common concepts and relations, we might be able to make a better match between system's internal models of interaction and the user's mental model.

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对话 Dialogue
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译文：

一、简介

随着电脑逐渐转化为智能环境，正如"情景智能"表所预料的那样，新颖的人机互动需要解决复杂的混合环境问题，将自然与数码有机融合在一起。"情景智能"预测数码环境应该是敏捷的，可调节的，并能对人的出现做出反应。它还能改变人们是如何进行互动，不仅仅对于环境本身，也对于通过环境的多媒体互动。

对于使用者而言，他们能够明白他们所处的环境才能真正地从中受益。其中的一条途径便是通过设计，让使用者理解的方法有很多，如通过操作和运行，付诸于语言与交流及社会推广。

我们的研究围绕着为语义联系而开发可视化和互动化技术，从而帮助信息展示并增加人们对信息与服务的关注。此外也将关注使用者的概念雏形、开拓方式来展示智能居家环境的构造与信息转换。对互联网构建，信息交换和服务做抽象的概述至关重要，它能帮助使用者建立概念雏形从而理解智能环境。

二、产品语义学

产品语义学是关于产品是如何得名的理论，它与符号学有很多相似的概念。置身智能环境之中，自动化和内部连接设备的增加将对产品的意义产生负面影响。当然，我们对产品的理解以及它们得名的方式也会随之改变。虽然如此，在理想的智能环境下，我们需要提供给使用者以简明的操作和提示，让他们了解发生了什么，使得它们感觉到智能系统是可驾驭的。

三、设计案例

运用上述的概念和想法，我们研发了一种示范模型，这种互动显示视窗（图 1）的设计，在简易的空间准备后用于发现更多的连接和连接可能性。互动显示视窗通过让操作者发现哪些物件是连接在一起的，哪些物件可以相互连接，从而使各种连接变得可视。

从案例中我们可以看到，智能环境中可以有诸多方式和不同水平层次的互动，有与互动显示窗进行的高层次语义互动，也有与音乐播放器之类的低层次互动。

显示视窗的产品语义是简单的，直接的。这个显示窗方向的摆放有明确的指示，比如哪一侧要放在上面。物品可以放在显示屏的任何一侧。当有物品靠近显示屏并被识别时，显示屏的灯会马上亮起来给用户反馈信息（图 2）。这种可以与用户互动的显示屏可以独立充当一个实体，与家庭网络相连接。图 3 显示了系统架构。

四、案例分析

通过文中展示的设计，我们使无形的无线连接变得可见。我们也进一步采取措施使用户亲身体验和操纵这种连接。我们也正在探索直观的、适宜的途径。通过它，用户可以与不可见的数字世界互动，以及控制各种设备之间的联系。在解释更多具体的研究问题，确定在运用产品语义学过程中的关键问题这些方面，当前的示范仪上的显示屏例帮助我们搭建了一座用户和虚拟的数字之间的桥梁。尽管简单，这个示范案例的确显示了将普通低级别的任务创造成高级别语义的抽象概念，使得产品语义互动出现在家庭网络布局变得可能。

五、未来工作

这项研究被认为是一种我们会继续研发的新的人机互动机制。目前，我们已经开发了一个更健全的互动的显示视窗和另一种备选方案，用户体验实验正在对这两者进行评估。此外我们还需要判断这种互动机制是否可以广泛推广和运用在家庭生活的各个方面。进一步的研究要尝试回答一系列的问题，比如我们如何处理越来越复杂的人机关系？如何显示信息交流的过程？如何通过信息控制实物？实物的设计（包括外观和使用）如何能促进用户构建出适当的概念雏形？通过开发新颖的、富有意义的互动设备，用户可以发出特定的指令，与此同时系统可以理解用户的指令并与内部模型相匹配。我们看到产品语义学具有重要的作用，它揭示了人工制品是如何实现自身价值的。目前，我们也在智能环境方面做研究。通过利用产生于语义网络和实体论的技术给共同的概念和关系下定义，我们也许能使系统内部的互动模型和用户的概念雏形相匹配。

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信息可视化中的交互设计研究及应用实例

文 / 程时伟 罗玉蓉 Cheng Shiwei Luo Yurong

Research on Interaction Design of Information Visualization and Its Application Example

摘 要：本文主要研究信息可视化中的交互设计方法，从可视化结构设计、图形用户界面组件设计、任务驱动的交互操作设计三个方面阐述具体的交互设计方法框架。采用 Prefuse 可视化开发工具，设计了一个互联网数据可视化系统，通过该实例说明交互设计方法在信息可视化中的具体应用。

Abstract: This paper focus on the interaction design of information visualization, and sets up the design framework, which includes visual structures design, graphic user interface components design, and task driven interaction operations design. To describe the applications of our proposed design method, we design and develop one Internet data visualization system based on the toolkit Prefuse.

关键词：交互设计；信息可视化；可视化结构；用户界面
Key words: interaction design; information visualization; visual structure; user interface
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一、信息可视化概述

信息可视化（Information Visualization，简称 InfoVis 或 IV）是利用计算机实现对抽象数据的交互式图形表示，从而增强人们对这些抽象信息的认知。[1] "一图值千言"，相比文本而言，可视化利用视觉通道的快速感知能力，提高人们观察、识别和加工信息的效率。信息可视化是伴随商业数据的大量计算和数据仓库的大规模应用而兴起的，它处理的数据是诸如金融、商业、医疗、通信、互联网、社会管理等领域的抽象数据。

信息可视化是一个从抽象数据到可视化形式的映射过程，在绘制数据对象的可视化属性过程中，需要将非空间的抽象信息映射为有效的可视化形式，并通过人机交互机制来提高人的感知能力。[2] 为了建立数据的可视映射，Card 等人提出了可视化参考模型（Reference Model for Visualization），该模型描述了原始数据、数据表格、可视化结构和视图之间的转换关系，以及用户根据任务通过人机界面进行数据变换、可视化映射、视图变换等操作。

二、信息可视化的交互设计框架

信息可视化需要解决两个关键问题：1、将数据转化成视觉图形；2、用户控制转化过程的各个阶段以获取信息。[3] 而信息可视化的最终对象是用户，为用户的认知和操作提供支持，必须实现以用户为中心的设计理念。为此，本文从交互设计（Interaction Design）的角度进行考虑，建立面向信息可视化的交互设计框架（如图 1 所示）。

该框架主要包括三个部分：

1. 可视化结构设计

可视化结构（Visual Structures）是指能够被人的视觉有效处理的图形系统，一般具有三个基本组成部分：图形空间、标记及其图形属性。[4] 可视化结构在一个图形空间中用标记和图形属性对信息进行编码。标记是图形空间中的可视化对象，包括点、线、面、体等，标记的图形属性包括形状、大小、位置、排列、分辨率、透明度和各标记之间的相互关系等。将原始的抽象数据映射成一定的可视化结构，需要分析数据本身的特征，如计算机文件目录、图书类目录等数据都普遍存在层次化结构，就可以采用二维或三维空间中的树型结构来表示这一特征。

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Design Semantics of Connections in a Smart Home Environment

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Abstract. As the environments in which we live become more intelligent—through more computational power, embedded sensors and network connections between the devices that reside in the environment—there is a risk of leaving its users clueless about what is going on. User interaction changes from interaction with a single device into interaction with a larger system—an ecology of things. Physical things are becoming mediators between the physical world and the digital, invisible world that is inside and behind them. The work we present in this article is part of ongoing academic research on using explicit design semantics to convey abstracted models of connections between devices in a smart home environment. This enables users to understand and construct meaningful mental models of the smart environment and interact with it accordingly. We illustrate our findings by presenting a demonstrator that implements our ideas in a home entertainment scenario.

Keywords: Semantic Web technology, product semantics, user interaction, smart home

1 Introduction

As computers are disappearing into smart environments, like envisioned by the Ambient Intelligence (AmI) paradigm [2], novel human-computer interactions will be needed to deal with the complexity of such hybrid environments, merging the physical with the digital. AmI envisions digital environments to be sensitive, adaptive, and responsive to the presence of people, and will change the way people will interact, not only with the environment itself, but also with the interactive multimedia through the environment. [1]

Over a decade of research has lead to several interesting interaction paradigms such as Tangible Interaction (TI), *augmented reality* and *mixed reality*. Already in 1997, Ullmer and Ishii [9] introduced their vision on a new interaction paradigm for Ubiquitous Computing. By providing physical handles for digital information, users can use the senses and skills that people developed during millennia of interacting with physical objects [9].

Other related work presents solutions for simplifying configuration tasks of in-home networks by creating virtual “wires” between physical objects like memory

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cards [3] that can interconnect devices. Others propose to introduce tags, tokens and containers [21],[7] for tangible information exchange. Concepts like "pick-and-drop" [18] and "select-and-point" [13] are used to manage connections and data exchange between computers and networked devices. The introduction of near field communication (NFC), using a near field channel like radio-frequency identification (RFID) or infrared communication, allows for direct manipulation of wireless network connections by means of *proximal interactions* [19].

What sets the work presented in this article apart from many of the earlier Tangible User Interface (TUI) concepts is our focus on connections. Instead of giving digital information physical containers/representations as done in many TUIs, we allow for exploration and manipulation of the connections "carrying" digital information (pipelines instead of buckets). We see these connections as both real "physical" connections (e.g. wired or wireless connections that exist in the real world) and "mental" conceptual connections that seem to be there from a user's perspective, and their context (what things they connect) is pivotal for their meaning. We aim to enable users to explore and make configurations on a high semantic level without bothering them with low-level details. We believe this can be achieved by making use of Semantic Web technologies and ontologies in an interoperability platform as proposed by the SOFIA[1] project. Such a platform could be used to support semantic interaction in a smart home environment.[16]

For users to truly benefit from smart environments it is necessary that users are able to make sense of such an environment. One way of facilitating this "sense making" is through design. Things make sense to users in different ways, by use and functioning, by appearing in language and human communication and social use [11]. If we look at meaning from an *Internet of Things* point-of-view, physical connections between artefacts, and conceptual and metaphorical connections play an important role. Artefacts can be physically connected by wires or wireless communication, but people also tend to group artefacts that are not physically connected together by finding resemblances in their meaning. In smart environments with many interconnected and interoperable objects—hiding their physical connections—these conceptual and metaphorical connections become even more valuable, and maybe even crucial for the understanding of a smart environment. Without this understanding there is the risk of engendering a mismatch between the system's model of interaction and the user's mental model of the system. In these conditions, using explicit design semantics can be used to help users to construct helpful mental models, in order to minimize system and user model mismatches.

We believe it is crucial to have an overview of, and preferably a high-level of control over, networked connections between smart devices. New additional services that come into being by interconnecting several independent devices/agents will have to find appropriate ways of introducing themselves and their whereabouts to the user. Enabling users to actively explore connections and connection possibilities may contribute to the understanding and transparency of the smart environments and their services.

[1] http://www.sofia-project.eu/

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Our research is centered around developing visualization and interaction techniques for semantic connections/interactions, to support information presentation and to increase information and service awareness. Additionally focus will be on user conceptual models, and developing ways to represent the configuration of, and information exchanged within a smart home environment. Key is to make proper abstractions of the low-level architecture, information exchange and available services, helping users to construct helpful mental models to understand a smart environment. When having a proper understanding of the smart environment and an increased awareness and manageability of available services, we envision a better user experience and a higher user acceptance. Design theory like *product semantics* will be utilized to find handles for these new interactions [11],[6].

2 Product Semantics

Product semantics is a theory about how products acquire meaning. Product semantics was defined by Krippendorff and Butter [10] in 1989 as being both:

> "A systematic inquiry in how people attribute meanings to artefacts and interact with them accordingly."

and

> "A vocabulary and methodology for designing artefacts in view of the meanings they could acquire for their users and the communities of their stakeholders."

Product semantics shares many concepts with semiotics, the theory of signs. [4]. Within the context of smart environments, an increasing amount of automation and increasing interconnectedness will have a negative impact on the meaningfulness of products. Of course, our understanding of products, and the way they acquire meaning, will also change. Nevertheless, in the envisioned smart environments, we need to provide users with handles and clues to make them understand what is happening and allow them to be and feel in control.

The origin of many of the problems that arise lies in the difference in nature of, or more precisely in the incompatibility of the physical world we live in, and the invisible world within our products. In order to understand products and systems, we develop a conceptual model of how we believe things work and how they should be used. These User Conceptual Models (UCMs) as defined in [11] are usually an approximation or simplification of reality, which means it might not be true and it might not need to be true. As long as the underlying mechanisms of the working of products are simple and reside in the physical world, they have a bigger chance to be understood and to make sense, and thus have meaning to their users.

Traditionally, product semantics is mainly concerned with physical objects. But meaning arises at different levels. In order to design for sense making, we

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need to look for references and resemblances between the new and known concepts. We distinguish between first usage (ratio facilis) and second usage (ratio difficilis) [5]. If we want to understand the semantics of the desktop computer as it exists nowadays, we need to look back to the context in which it was originally introduced. Computers needed instructions, in the time of the first personal computers instructions to them were given by text input. That is why keyboards are so close to typewriters. To be able to output something we gave them a possibility to write back; having a display as we knew it from early TVs seemed logical. But also in the interaction with computers, the desktop metaphor was introduced, and our hand to "physically" move things on our digital desktop was represented by the pointer of a computer mouse, the digital extension of our hand. Metaphorical connections are strong and welcome if we need to shape new, unknown concepts. But there might be different and better ways of making sense (p. 5 of [12]):

> "The essence of a metaphor is understanding and experiencing one kind of thing in terms of another."

If we have a look at the innovation smart environments promise, the step forward would be improved interoperability and the added value this interconnectedness and information exchange offer. Important to note is that this added value is an addition to the existing, basic functionality of the devices. An example of this can be found in [8], where interoperability between existing applications (exercise monitor, computer game, phone and media player) enables a scenario where a game called SuperTux would award extra lives for exercising (using an exercise monitor), a mood renderer embedded in a media player would play music depending the game's state, and the game and media player would react accordingly if the person receives a call. Additionally, connecting smart devices to one another makes it possible to support high-level services, that would usually involve multiple steps on multiple devices. From a user's point of view, streaming music from a mobile device to a home entertainment system is a single high-level task. In practice there are multiple steps involved, and if the devices involved are from different manufacturers, the user needs to learn the operational details of each device interface in order to perform the task.

But how will these additional, high-level services make themselves known to its (prospective) users? How will they discover the newly enabled functionality and how will they decide what they want, but most important, what they do not want? In order to make sense of the added functionality and new services the a smart space brings the user, they should be able to manage it. And in order to manage it, they should be able to, to a certain degree, understand it. For example: in order to use a vacuum cleaner one should know how to use it and understand that the power cord needs to be connected to a working power socket for it to function. One does not need to understand how an electromotor works; neither does one need to understand the physics of AC electricity.

We can find meaning in different layers. We can find meaning in the appearance of a product, informing us about the function of the product. But there is also meaning in the appearance of artefacts in language (e.g. vacuum cleaner;

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meaning something that cleans using a vacuum, or suction). This type of meaning has its roots in conventions and metaphors, and can be analyzed with the study of semiotics. At interaction level we find another level of semantics; concepts like feedback, feedforward and ecological perception (affordance) [17] play an important role here. Affordance is the property of an object that appeals to our sensory-motor skills, like a doorhandle “affords” to be grabbed and a chair “affords” to be sit on it. But we can also discriminate between different physical layers of meaning. The appearance of a vacuum cleaner itself informs us about its usage: wheels to make it mobile, a hose and a telescopic tube with an ending that seems suitable for moving it over the floor’s surface while standing upright. But when we open it to replace the dust-bag, there are physical clues about how it fits in there. However, these clues are hidden during normal usage, as it is not of your concern when using it to clean. Now, how can we use this semantic design knowledge in order to design meaningful interfaces for smart environments? Or how do we reveal new possibilities in a meaningful way, when a new smart device enters a smart space?

3 Design Case

To illustrate the above mentioned concepts and ideas, we developed a demonstrator. This interaction tile (figure 1), inspired by Kalanithi and Merrill’s “Siftables” [15], was designed to explore the connections and interaction possibilities and manipulation by direct manipulation, and by making simple spatial arrangements. The interaction tile visualises the various connections by enabling users to explore which objects are connected one another and what can be connected to what. Coloured LED lighting and light dynamics visualize the connections and connection possibilities between the various devices. This is done by means of putting devices close to one of the four sides of the tile, a user can check whether there is a connection and if not, whether a connection is possible. By simply picking up the tile and shaking it, a user can make or break the connection between the devices present at the interaction tile. A video of the demonstrator a simple home entertainment scenario is available[2].

3.1 The scenario

“Mark is relaxing at home when his friend Dries arrives. Dries comes with a portable music player loaded with his favourite songs. He wants to play some of his recent collections for Mark. Mark’s home is equipped with a sophisticated surround sound system. They decide to enjoy the music from the music player on the sound system. Mark uses his Interaction Tile to see if he can connect Dries’s music player to the sound system, which is connected to the home network. The interaction tile indicates that a connection is possible and Mark picks up the tile and shakes it to make the connection.

[2] http://www.youtube.com/watch?v=vdZcjqfq8RQ

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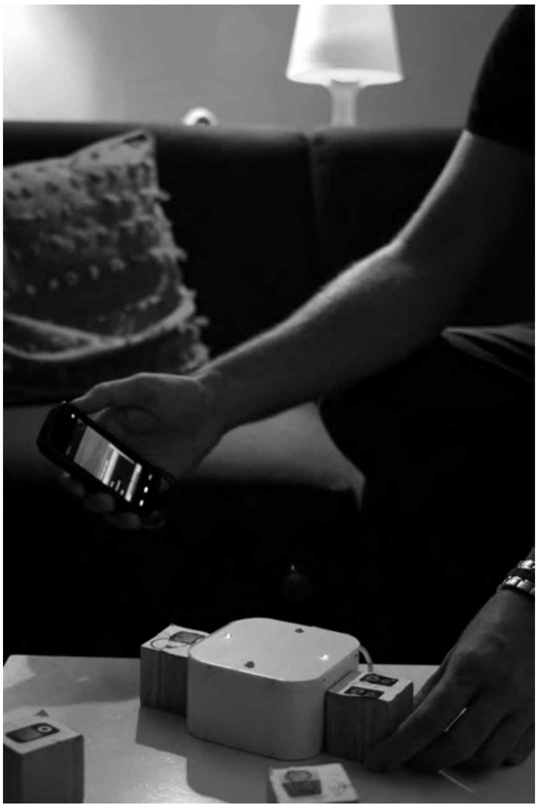

Fig. 1. The demonstrator in action

All the smart devices in the home have a cube-like representation that can be used with the interaction tile. The interaction tile shows the connection possibilities with a high level of semantic abstraction, hiding the complexity of the wired or wireless networks. By interacting with the objects, semantic connections can be built, redirected, cut or bypassed.

Dries starts streaming his music to the environment. Now the room is full with Dries's music and they both enjoy listening to it. Recently Mark has installed an ambient lighting system that can be connected to the sound system and renders the mood of the music by dynamic colour lighting in the room. Mark uses the objects again to create another connection and now the room is filled with Dries's music and colourful lighting effects.

Mark's roommate Sofia comes back from work and decides she wants to watch a movie on the TV. She seems somewhat annoyed by the loud music. Mark and Dries do not want to bother her and they again use the objects to re-arrange the music stream. Now the music is streamed to Mark's portable music player while also playing back at Dries's. It is also connected to the ambient lighting system directly, bypassing the sound system. They both are enjoying the same

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music using their own favourite earphones (and the colourful lighting effects), but without loud music in the environment. Now Sofia can enjoy her movie without any disturbing music."

From this scenario one can see that there are multiple ways and different levels of interacting with the smart devices in the environment. There are high-level semantic interactions with the interaction tile (explore/make/break connections) and also lower-level interactions with the music player (play/pause/stop music). A more detailed description of the interaction tile and the demonstrator is available in [20].

3.2 Design semantics

The design semantics of the demonstrator are simple and straightforward. The tile-shape shows clear clues about orientation, e.g. what side should be placed up. The four sides clearly show four possibilities for placing objects near the tile; the size of each side restricts the number of objects one can place close to the tile. When an object is placed next to the tile, the LED's gives immediate feedback when the object is recognized (figure 2c). When multiple objects are placed near the interaction tile, it will immediately show the connection possibilities (feed forward) by lighting colour and dynamics. The LED colour coding is simple and straightforward. Red colour means no connection and no connection possibility (figure 2d); green colour means there is an existing connection between the devices present (figure 2a/e) and green pulsing means that a connection is possible (figure 2b). To indicate that the interaction tile did sense the first object a user places near, it shows a red colour at the side the object was detected. Placing a second, third and fourth object, the interaction tile shows the lighting effect corresponding to their connection capabilities. By simply picking up the tile, and shaking it, the user can make or break the connection between the devices present at the interaction tile. The result of this action depends on the connection's current state, and the devices present; if the tile shows a connection possibility, the action will result in a connection event. The same action performed when the tile shows an existing connection will break the connection.

3.3 Realization

We want to enable users to explore and manipulate the connections within the smart space without having to bother with the lower-level complexity of the architecture. We envision this "user view" to be a simplified view (model) of the actual architecture of the smart space. Conceptually, the connections are carriers of information; in this case they carry music. Depending on the devices' capabilities (e.g. audio/video input and/or output) and their compatibility (input to output, but no output to output), the interaction tile will show the connection possibilities. In our current demonstrator we do not distinguish between different types of data since we are only dealing with audio, but it will be inevitable in more complex scenarios.

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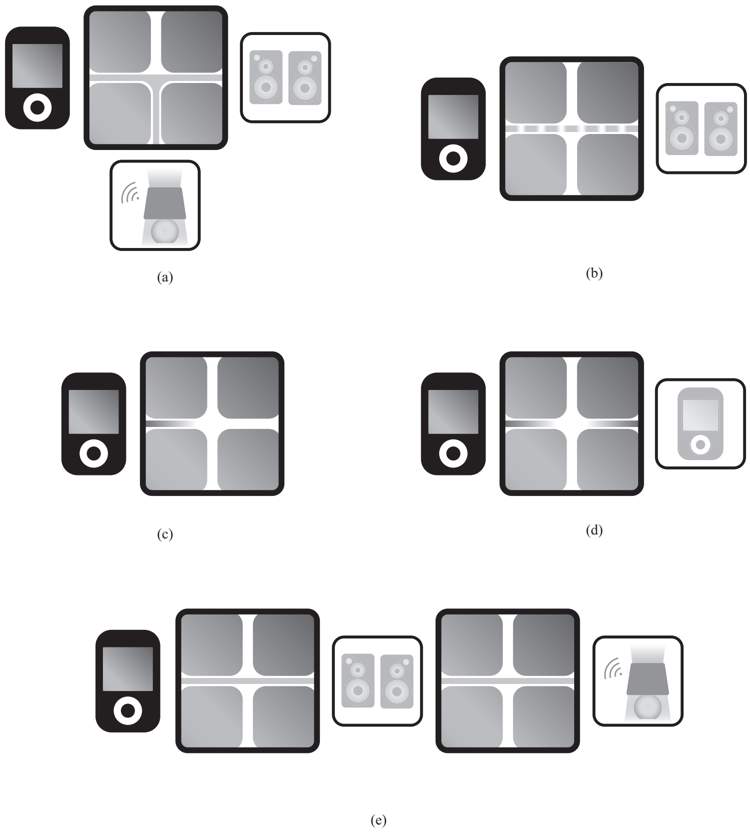

Fig. 2. Meanings of lighting colour and dynamics: (a) Green solid light means the devices present are connected; (b) Green, pulsing light means the devices are currently not connected, but can be connected; (c) Red solid light means device recognised, a second device is necesary to show connections or connection possibilities; (d) Red solid light means the devices are recognised, but no connections or connection possibilities exist; (e) Shows the possibility to use multiple interaction tiles to look into connections in a more detailed manner, however both (a) and (e) have the same meaning.

The interaction tile acts as an independent entity, connected to the home-network. Figure 3 shows the system architecture of the current setup.

The interaction tile consists of the following components:

– Arduino board (Duemilanove);
– 13.56MHz RFID reader (ACS/MiFare);
– multi-colour LED’s;
– accelerometer;
– vibration motor;
– piezoelectric speaker;
– magnetic switches.

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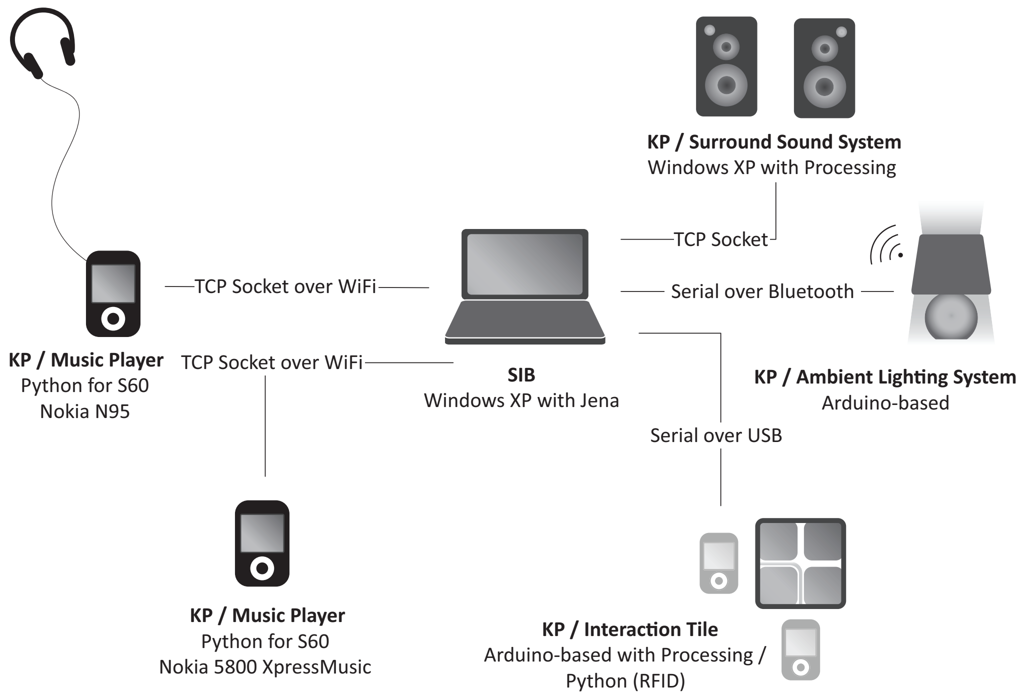

Fig. 3. An overview of the demonstrator

The demonstrator consists of the following devices:

- media players (Nokia N95 and 5800 XpressMusic);
- ambient lighting system (Arduino BT based homebrew lamp with RGB LEDs);
- sound system (speaker-set connected to notebook PC);
- notebook PC (acting as SIB[3]);
- interaction tile.

4 Discussion

The current demonstrator helps us in defining more specific research questions and identifying key issues. Although simple, this demonstrator does show that making high-level semantic abstractions of low-level events has the potential to allow for semantic interaction in home-network configuration tasks.

Building this demonstrator also identified many possibilities for improvements and extensions. Like discussed before, it currently does not distinguish between different types of information exchanged nor does it show directional

[3] Semantic Information Broker (SIB) is a terminology used in the context of the SOFIA project.

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properties of the connections. By replacing the single LEDs by LED arrays we could show the dynamics of information flow. Using colour coding could show different types of connections (e.g. audio/video/text) or it could have separated modes of operation where it only shows one type of connection at the time. Although currently all devices are represented by cubes due to technological constraints, the cubes representing the mobile devices could easily be replaced by the real ones in future versions.

Besides these observations, the demonstrator shows that even the slightest and simple ways of giving feedback (LED colour, dynamics) can reveal meaningful information. To what extend users can extract meaningful information from the interactions with the smart space and how they can use it to build a suitable mental model for understanding is currently being evaluated evaluated.

Recent work [15] shows the ongoing pursuit of making digital information and content physical, to allow for a natural way of accessing and controlling such data. Bridging the digital and physical has been a topic of research for over a decade. Although there is rich potential in tangible interaction concepts, shortcomings and tradeoffs are inevitable. One problem that emerges is the trade-off between “generic” versus “task-specific”. When introducing physical objects to represent digital data, we need many physical objects that will have a more-or-less fixed physical shape. Very expressive physical objects will inherently have a very specific use. While very generic ones—like many objects featuring graphical displays and buttons—are not very expressive, and appeal less to our perceptual motor skills.

A disadvantage of tangible computing is the introduction of many new physical objects into the environment. Leaving information in the digital world has advantages—we do not always want to have physical representations of all the information that we generate in the virtual world, which would mean overcrowding the physical space. A relatively unexplored approach is to use the existing physical (electronic) objects and devices in our interaction with the virtual world, going beyond using their (touch) screen and or buttons to interact with the information world. We propose to use the physicality of the objects e.g., their context, position and our usage of these object to generate new interaction concepts.

Adding constraints, as in limiting functionality, or not using the full technological potential, is not necessarily a bad thing. These constraints are essentially guides and handles for users to understand what is possible and what is not, or what should be done in alternative ways. An example can be found in our implementation. When there are more than two devices present at the tile, indirect connections are also shown; in fact there is no difference in the visualisation between direct and indirect connections. To explore these connections in more detail, one has to explore and change the configuration to see how things are connected. It is a constant trade-off between the richness of complexity vs. simplicity, as is discussed in [14].

Where smart systems or environments try to predict what the user is trying to accomplish, by being adaptive and anticipatory, we need to identify ways to give the users appropriate means to express themselves. The possibilities,

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available services and information that exist in the smart environment needs to be communicated in a meaningful way. Only if this is done correctly will users be able to build helpful mental models of the functionality the environment has to offer, set goals and make plans on how to act. By developing novel and meaningful interaction devices, the user can then perform the necessary actions and the system can in turn try to understand the user's goals and make the match to its internal models. We see a vital role here for the theory of *product semantics* [6], the study of how artefacts acquire their meaning and use its theories to define common concepts and semantics.

5 Future work

This research is to be considered a work-in-progress. We will continue to develop research prototypes to investigate new interaction mechanisms. We have developed a more robust version of the interaction tile and an alternative variation which are currently being evaluated in a user experiment.

Furthermore we will need to identify whether this way of interaction can be generalized and applied in different contexts in the home. Further research will attempt to answer questions like: How do we handle increased complexity? How to reveal information about the information/content that is exchanged? How to provide control over the content? How can the design of physical objects (appearance and behaviour) enhance the creation of suitable mental models in users?

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