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Controlling smart home environments with semantic connections: A Tangible and an AR approach

Abstract
In the transition from a device-oriented paradigm towards a more task-oriented paradigm with increased interoperability, people are struggling with inappropriate user interfaces, competing standards, technical incompatibilities and other difficulties. The current handles for users to explore, make and break connections between devices seem to disappear in overly complex menu structures displayed on small screens. This paper tackles the problem of establishing connections between devices in a smart home environment, by introducing an interaction model that we call semantic connections. Two prototypes are demonstrated that introduce both a tangible and an augmented reality approach towards exploring, making and breaking connections. In the augmented reality approach, connections between real-world objects are visualised by displaying visible lines and icons from a mobile device containing a pico-projector. In the tangible approach, objects are tagged and can be scanned to explore connection possibilities and manipulate the connections.

Keywords
Product semantics, interaction design, smart home.

1 Introduction
When Weiser wrote his vision of ubiquitous computing about 20 years ago [1], he postulated that we will be surrounded by networked displays of various sizes, and that we will use them to explore and access our information and computerized infrastructure. They would simply be there, around us, like a piece of scrap paper or a blackboard, their use woven into the fabric of everyday life. It would be easy to switch between actively using them and barely noticing their mere existence. People would concentrate on their everyday activities, unaware that they are using possibly more than a hundred computers within their vicinity to carry out these activities.
In today's reality, although there are rooms accumulating almost comparable amounts of computers in the form of smart phones, web tablets, TV screens, netbooks, personal computers and so on, we have not yet achieved seamless operation among them. Each and every one of these devices demands our attention, uses a different user interface and allows access to none of the other components (or only to very few other components within the room). While many of the devices are, or can be networked, the process of making the actual connections and exchanging the information between them is painful without extensive networking knowledge. Configuration details and connectivity settings are hidden, deeply nested within menu structures. Even with the connections in place,

exchanging the actual information is cumbersome, and users have to dig into the file structures to find the files to be exchanged. In contrast, from a user's perspective, the devices should be easy to connect since they are physically close to each other (and can thus be touched or pointed at). The information to be shared might have been on the screens moments ago and could form part of the interaction, depending on the user's intention. Consider a seemingly simple task, like listening to your music stored on your PC or home stereo system from your mobile phone's headphones in the kitchen. It is practically impossible for many users, despite the principal technical ability of the involved devices and available network technologies. Part of the problem may be attributed to the fact that user interfaces are still highly focused on device-oriented operation. Competing standards and technical incompatibilities exist at the service-level, contributing to the problem and making it impossible for non-experts to take full advantage of today's technology.

Some of the irritations that users face today are a consequence of the mechanisms of the market, that imply different goals for the stakeholders. Developers of devices need to have a strong device-oriented view, whereas users' goals are often more easily resolved within a system-oriented view. Developers are concerned about the functionality and usability of the device at hand, possibly harmonizing its usage over the range of products provided by this specific manufacturer. Users, on the other hand, find themselves with a set of devices and services from different manufacturers, or even different industries. As an example: users still have to set the integrated clocks of many devices, even if they are all connected to each other. Although a scanner and a printer make up a nice copier, only selected models offer this combined functionality. If you would want to directly print the image that the video camera is currently sampling, you need a PC and install specific software to do so. Seemingly easy tasks (for an unbiased observer) are not possible, because at development time, nobody thought about it, and only minimal cross-device capabilities have been implemented.

One possible solution to solving the interoperability problem at the infrastructure-level is a software platform developed within the SOFIA[1] (Smart Objects For Intelligent Applications) project. SOFIA is a European research project within the ARTEMIS framework that attempts to make information in the physical world available for smart services – connecting the physical world with the information world.
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. Such a platform may be used to support semantic interaction in a smart home environment, as is described in [2].
Building on the SOFIA software platform, we propose a user interaction model and two interface solutions. One user interface solution we propose uses a projected augmented reality approach, based on a concept called Spotlight Navigation [3], [4]. Here, a mobile device containing a pico-projector visualizes connection possibilities between devices in the environment.
By using direct pointing gestures with the device in the user's hand, users can intuitively explore and manipulate the virtual network connections as if they are part of the user's real world environment. The second user interface solution is a tangible interaction approach, enabling users to physically select devices in their environment and directly view and manipulate the connections in a simple, universal way. In this paper we illustrate both interaction approaches to manipulate semantic connections in a smart home setting, where the tangible UI solution and Spotlight Navigation can be used interchangeably.

2 Semantic connections

We defined the term semantic connections [5] to refer to meaningful connections and relationships between entities in an ubiquitous computing environment. These connections are invisible by default, but can be viewed and manipulated on demand, using a special-purpose device or application. We envision 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. Their context (what things they connect) is pivotal for their meaning. The term "semantics" refers to the meaningfulness of the connections. We consider the type of connection, which often has the emphasis now (e.g. WiFi, Bluetooth

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

or USB) not to be the most relevant, but that what the connection can do for someone – its functionality – even more. Semantic connections exist in both the physical and the digital world and can exist between objects, people and places.

Semantic connections have properties like directionality, transitivity and modality (i.e. what things they carry). The rationale behind semantic connections is to rely on:

- the meaning of existing objects to provide meaning for the relationships between the objects and the resulting meaning of the networked objects.
- the power of natural mapping and locality, using real objects and locations to provide meaning for the connections that are created between the objects and (object) locations.
- inherent, augmented and functional feedback and feed-forward (using terminology as proposed in [6]) to strengthen the meaning of the connections and the emerging functionality.

Crucial to our approach is to make the gap between user goal and action smaller. If we consider streaming music from one device to another, "streaming" now consists of multiple actions that do not necessarily make sense. In our view, this single high-level goal, should have one (or at least as few as possible) single high-level action(s). That single action should carry the meaning of its goal. By using the physical world as interaction space and using the real location of the objects, we are reducing the need to identify the devices from a list with names or rely on other forms of representation.

3 The Connector: A Tangible Approach

As a portal to the semantic connections, we introduce our tangible user interface approach which we called the connector. The Connector can be used to explore and manipulate semantic connections between different devices in the home environment. It is a handheld device that identifies devices, by scanning RFID tags that are located on the devices themselves. By holding the Connector on top of the tag, users can explore the connection possibilities that are visualized with lights on top of the Connector. After holding the device in the RFID field for a moment, the device-ID is locked and the other device to be connected can be selected in a similar fashion. With a push-to-click action a connection between two devices can be established. For removing an existing connection, the ring on the lower part of the device should be pulled until it clicks.

Fig. 1. The Connector prototype and a smart phone used as a media player.

3.1 Design

The cylindrical shape of the connector (figure 1) is loosely inspired on that of a loupe or hand lens. By moving the connector over a tag, the connection possibilities can be "read" from the top of the cylinder. The display consists of two rings (made up of LEDs), each divided into four segments. The connector supports several actions. You can move it over an object or tag to see whether it is active. A device or object can be selected by holding the connector close to or on a tag until the selection sequence is completed. The connector can be compressed by pushing the top and the lower part together, and it can be pulled, by pulling the lower part and the top part away from one another until it clicks. When the tag is in the range of the Connector's RFID field, it reads the tag and the first (yellow) light segment on top of the Connector will light up, serving as feedback that the Connector recognises the device. After holding the Connector over a device tag for a moment, a sequence starts, lighting up the second, third and fourth segment of the inner ring. This can be seen as feedforward to hold the Connector over the tag until it has been selected and all four segments are lit. After the device is recognized and selected, another device may be selected in a similar fashion. Now, the second ring of lights will start lighting up in sequence and one should wait until both rings are fully lit. Removing the Connector from the tag prematurely cancels the selection process.

When a connection between the selected devices is possible, both rings start flashing green. When no connection is possible, they will turn red. When a connection between the devices you scanned already exists, the rings will turn green. To make the connection, the Connector is compressed by pushing the top and lower part together, or by pushing the Connector down on the device it is touching, until it clicks. To remove an existing connection between two scanned devices, the ring on the lower part of the Connector should be pulled until it clicks. The rings will show a red light to indicate that the connection has been broken. The segments will turn off once the Connector is moved away from the device. Performing the opposite action of what is required to make or break a connection, cancels the procedure.

3.2 Prototype

The Connector prototype is made out of four separate pieces that are 3D printed. The lower part and the top part of the Connector can be moved inward and outward serving as a two-way spring-loaded switch. The prototype packages all the necessary components into one integrated device, which is wirelessly connected to a computer using a Bluetooth connection.
The Connector contains the following main components:
- Arduino Stamp 02
- Innovations ID-12 125kHz RFID reader
- SparkFun BluetoothMateGold
- 8 bi-colour LEDs
- Switches
- 3.3v LiPo battery (850 mAh)

4 Spotlight Navigation: An Augmented Reality Approach

Spotlight Navigation can be used to explore and manipulate connections between smart devices. With Spotlight Navigation, connection information contained in the smart space is projected into the real world, augmenting the real environment with virtual information, making it intuitively perceivable for users. Spotlight Navigation projects icons close to the actual devices in physical space. It allows for the creation of new connections simply by drawing lines between these icons, using a "pick-and-drop" action with a push-button on the prototype (press and hold the button when pointing at one device, move over the second device and release the button). Additionally the connection possibilities are projected between devices that allow for a connection, by changing the colour of the projected line (while the connection is being drawn) from yellow to green when the line's end is moved over the frame of the targeted device. When a connection is impossible, the connecting line will turn red and disappear as soon as the button is released.

4.1 Design

Spotlight Navigation was invented as an intuitive way of accessing large data spaces through handheld digital projection devices. Rather than directly projecting the equivalent of a small LCD display, Spotlight Navigation continuously projects a small portion of a much larger virtual pane or data space. It is the device's orientation that defines which part of the larger pane is selected for display. This is done in such a way that the virtual data appears to have a fixed location in the real world. By moving the projector's light spot over the wall, users make portions of the data space visible through intuitive, direct pointing gestures. This intuitiveness stems from the fact that the projected content always stays roughly at the same physical place, regardless of the orientation of the device. It becomes visible depending on whether it is in the projector's light cone or not. In other words, users have the impression that they are illuminating a part of a conceptually unbounded virtual data space, just as if they would be looking at hieroglyphs on a huge wall in a tomb with a flashlight. As people are familiar with operating flashlights, the operation needs no or little training. When accessing a data space with the device, users can zoom in and out of the data space by using a scroll wheel control, resulting in a pan-and-zoom user interface. To visualise the semantic connections in physical space, we rely on the symbolic meaning of colour, where green colour means "proceed" and red means the opposite. Using green, yellow and red lines we aim at referring to the "existence" of a connection, the "possibility" of a connection or to indicate that a connection is not possible. Figure 2 shows the projection when connecting two devices together.
With Spotlight Navigation, devices are identified by their physical location, relying strongly on natural mapping. Connections are created simply by drawing lines between the devices. An erasing gesture with the Spotlight Navigation device pointed at an existing connection, breaks the connection.

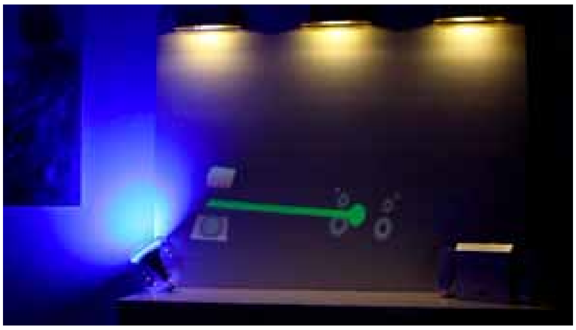

Fig. 2. Projection when connecting two devices together.

4.2 Prototype

On a technical level, the operation is achieved through continuously measuring the orientation, and optionally also the position, of the device. Our prototype is using an inertial navigation module, also called an inertial measurement unit (IMU), that directly measures the orientation by means of accelerometers, gyroscopes and an electronic compass.

Fig. 3. Spotlight Navigation prototype.

The Spotlight Navigation prototype is a fully embedded setup integrated into a 3D printed casing. The design of the casing was targeted at getting the smallest possible setup that could run on the integrated batteries.
A dummy ring was added to the prototype to strengthen the semantics of a mobile projector. Figure 3 shows the prototype. Our current setup consists of the following components:
- OMAP3530 board (IGEP module)
- Pico projector (Microvision SHOWWX)
- Orientation sensor (Sparkfun 9DOF Razor IMU)
- scroll wheel (with button press functionality)
- two additional buttons
- two 3.7v li-ion batteries (Nokia BL5J)

The OMAP3530 processor contains a 3D-graphics core (PowerVR) that is capable of rendering the connection visualizations and device icons in real-time. Our current prototype still requires the object positions to be manually configured in space, as it did not contain a camera. By using a camera, as is planned for future versions, our intention is to recognize the identity and physical location of each device, so that it is no longer necessary to align the projected object icon with the location of its associated device.

5 Pilot Evaluation

Both our prototypes were evaluated in a pilot user study. This pilot was composed of demonstrators made by the different partners in the SOFIA project and was conducted with users in a setting that resembles a real home. In order to get enough insights to improve the system, seven groups consisting of three people each were asked to interact with the system, during which their experiences were recorded. The two interaction prototypes presented in this article were part of a larger test setup, which was evaluated during a full week of experiments. In this paper we focus on the results, which are relevant for evaluating the interaction concepts. During the pilot, users experienced a smart space with various automated and interactive appliances and devices, which we refer to as smart objects. The appliances in the smart space are interoperable, sensitive to changes in their environment and exchange information with one another. There exist several explicit and implicit relations between the smart objects, of which some can be explicitly viewed or manipulated with the Spotlight Navigation device (available in the study room of the pilot setup) or the Connector device (available in the living room of the pilot setup).

5.1 Participants

Twenty-one participants were recruited in seven groups of three friends. Selection was based on age (between 20 and 35), availability during the week of the pilot and their mutual friendships. Of the recruited 21 participants that successfully completed the trials, 13 were male and eight were female. Their age ranged from 23 to 34, with an average age of 28.5. Nine participants were living alone and 11 were cohabiting. The median score of self-report familiarity with interactive systems was 6 on a 1-through-7 scale.

5.2 Materials

Figure 4 shows a brief overview of the different parts of the system. The experiment took place in two rooms, the study and the living room of the Experience Lab on the High Tech Campus in Eindhoven. The facilities and infrastructure of the Experience Lab were used to set up the demonstrator system and to collect observation data (video and audio recordings).

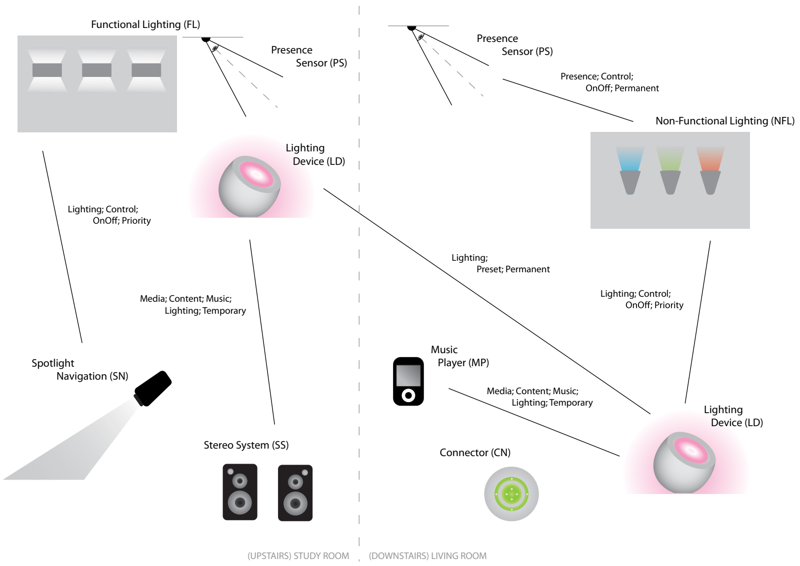

Fig. 4. The devices and their connections as used in the system.

5.3 Measurements

During the pilot, several measurement instruments were employed. Participants were asked to rate the pilot setup on three different scales; the HED/UT scale [7], the Perceived Control scale [8] and a questionnaire developed by the SOFIA project for internal use.

The mental models that users developed during their interaction with the system were recorded using the Teach-Back protocol [9], and the participants' attitudes towards the system were recorded with a semi-structured interview. Because the HED/UT scale and the Perceived Control scale were targeted at the entire system, we do not discuss their results in this paper. Mental models were extracted using the teach-back protocol. Because users' mental models consist of both semantic and procedural knowledge about the system they were interacting with, teach-back questions can be subdivided into "what is?" questions focusing on semantic knowledge, and "how to?" questions focusing on procedural knowledge [9]. Using such questions, adjusted to our specific situation and research goal, we aimed to extract the semantic and procedural concepts that were relevant for our users. Participants were asked to explain to the researcher what they thought the system was and was for, including listing all the components and the relationships and connections between the components they thought made up the system. By asking for the perceived connections and relationships between the components, we aim to gain a better understanding of how users conceptualize the cause-and-effect relationships between their actions and the responses of the various devices in the smart home. This includes the information that is exchanged between these devices. By asking the participants to explain to the researcher how to perform a specific task with the system, we aim to get insights into how well the participants understood the necessary steps and devices involved to achieve their goal. To support and communicate their answers to both types of questions to the researchers (and for recording purposes), participants were asked to make drawings, schematics or use a textual representation.

Interview. In order to gain a deeper insight into the things that occurred during the experiment sessions and record the users' general opinions, a semi-structured interview was conducted. Using a list of open questions as a structure, participants were evoked to share their experiences with the test setup and think along for possible improvements. During the interview, the researchers also asked questions based on specific behaviour or actions of the participants that they observed during the trial.

5.4 Procedure

Participants had already received written information about the experiment together with an official invitation by email. After the participants were welcomed in the Experience Lab and were briefed, they received and signed an informed consent form and were asked to fill out a pre-experiment survey. This survey included demographic questions and a self-report scale of familiarity with interactive systems like (tablet) PCs and smart phones.

The groups of 3 participants were split up into two groups of which two participants were led to the livingroom area to perform the role of Mark and Dries, and one participant was taken to the study to perform the role of Sofia (these names will be used later to identify the different treatment groups). All participants were introduced to the devices, which they had to interact with before the experiment started.

During the experiment, the participants were asked to perform a series of predefined tasks that revealed the functionality of the system. Every participant received these tasks on paper and was asked to think aloud, or for the participants in the living room (Mark and Dries), to share and discuss their thoughts during the whole experiment. After they performed the tasks, they were asked to freely explore the system to deepen their understanding and check their assumptions of its operation. They could continue this free exploration until they thought they understood the system's operation and would notify the researcher that they had finished. The researchers (one in the living room and one in the study) sat down in the back of the room during the entire session and were available in case anything went wrong.

After interacting with the demo, the participants were asked questions to elicit their mental models and were interviewed. The Mark and Dries characters were interviewed together, and they could openly discuss their opinions and mental models. Some of the participants agreed on their answers and agreed on one drawn representation of their shared mental model. Others disagreed, and created their own representation. The duration of each trial was approximately 50-60 minutes, including briefing, instructions, filling out the questionnaires and the closing interview.

6 Results

6.1 Mental models

Of the 21 participants who participated in the pilot, we collected 18 mental models. The teach-back protocol with the Sofia characters (n=7) resulted in seven unique mental models, while for the Mark (n=7) and Dries (n=7) characters we obtained 11 mental models, of which three were shared. We will first give an overview of the overall results of the mental models, followed by a more detailed description of the mental models recorded from Sofia characters and the Mark and Dries characters (which we treated as one group).

Completeness. Out of all the mental models, 15 did not note that presence detection was used; seven out of seven for the Sofia characters and eight out of 11 for the Mark and Dries characters. Of the three that included presence detection in their drawings, one was a shared model and the other two were from the same session. A few other components of the system that were in the study and the living room were occasionally not included in the mental models. This includes the non-functional lighting (NFL) in the living room, the relation between the NFL and the Living Colour (LC) light (the NFL would dim down when the LC was active), the functional lighting (FL) in the study upstairs, and the dimming of the FL when the Spotlight Navigation was in use. The NFL was missing in two mental models, as was the connection between the NFL and the LC. These two mental models were from the same session. For the mental models of the Sofia characters, one out of seven missed the FL and two were missing the connection between the FL and the Spotlight Navigation.

Semantic Connections Concepts. During the user experiments some of the participants noticed and discussed interesting networking concepts like transitivity and directionality. These concepts were also considered in the semantic connections interaction model, but were not implemented in the pilot. Despite the absence of these concepts, participants did intentionally (or sometimes perhaps unintentionally) draw them in their mental models or discuss them. Among the concepts of our interest are directionality, transitivity, priority and the temporary or persistent nature of the connections.
Transitivity was noted in three of the mental models and directionality in nine of them. Two mental models indicated a notion of priority in their mental models, concerning one out of multiple conflicting connections to have priority over the others. Two persons discussed the persistence of connections, wondering when connections would stop existing (for instance when the person would take a mobile device out of the house) or indicating, what they described as a permanent connection, distinctively from the other non-permanent connections.

Organisational Layout. We identified three types of organisational layouts in the way people draw their mental models. The majority used a physical/spatial way of describing their mental model, of which we identified eight as being fully spatial (the main structure of the network is based on the physical location of the components) and another eight mental models have what seems to be an arbitrary mapping, using the physical appearance of the components to identify them in the drawing. Some of these representations include spatial information but it is not used as their main structure. We label these hybrid layouts. There are two mental models that show a logical way of representing the network and its components using blocks and labels to identify the components. Similar ways of organising mental models were found in [10].

Network Structure. For the mental models of the Mark and Dries characters, we observed three main trends in the structure of the networks they drew. We distinguished between network structures that define a central entity (which is close to the actual network architecture), network structures that have a mainly peer-to-peer structure, and a mixed infrastructure which both have peer-to-peer connections and connections going through a central entity (the Connector object). All of these mental models of the network are compatible with the actual situation in the pilot. We observed five mental models with a central entity, four with mainly peer-to-peer connections and two with a mixed structure.
For the Sofia characters we mainly observed two different network structures: A daisy-chained one (every component connects to one or two others in a serial manner) found in five mental models, and a parallel structure (where connections had a more parallel nature), which occurred two times. What is interesting to note was that the Spotlight Navigation device was often seen as an entity that was not connected to the network, while the Connector object was in all cases considered part of the network (and in some cases even as being the central entity).

6.2 Interviews

From the interviews we observed a few trends. Some of which were to be expected, while others were more surprising. Many participants were disappointed in the limited functionality of the current setup. Although the participants were enthusiastic about the ease of which the connections between devices could be made, they were disappointed that they could only control the connections between two devices, despite the fact that there were many more devices and appliances available (especially in the livingroom e.g. TV, stereo set, other light sources and luminaries). Most participants were enthusiastic about the "simple way" of making connections. However, they did indicate that they wanted to be more in control of what would actually happen when the connection was made. Some participants indicated that this lack of control was not crucial, because they figured that the connections could be undone in the same fashion when they did not like the effects of the connection. With regard to the overall functionality participants also indicated that they would like to see more "practical applications" that would make their daily life easier. These remarks were mostly in the direction of concepts known from the home automation domain.

Several remarks were made concerning the user interaction with the Spotlight Navigation and Connector device. For the spotlight navigation, remarks were often made about the icons that were projected. The icon for the Living Colour lamp was not always clear to users. Remarks were also made about the (mis)alignment of the icons and the physical devices, and many participants indicated that the icons could be omitted or be replaced by boxes around the physical objects. Additionally, remarks were made about the inaccuracy of the pointing gesture and difficulties in operating the button on the device. For the connector device, the low speed of the selection procedure was often mentioned. The effort required to physically select a device was often mentioned as a downside, while others mentioned it as a positive point as it was considered playful. Remarks were also made about the limited pairwise selection -participants indicated that they would want to have the possibility to select and connect more devices at the same time.

7 Discussion

Spotlight Navigation and the Connector are two alternative user interface approaches to configuring ubiquitous computing infrastructure. Although we cannot directly compare the mental models elicited during the user experiment, which would have asked for a more controlled setting (e.g. having the same setup and having an equal number of participants for both treatments), we did make some interesting observations.

The most striking difference between the way users described the setup was the perception of the users that the Connector was part (if not the central part) of the system, while the Spotlight Navigation was often considered outside of the system. We hypothesise that this is due to the different roles that the Spotlight Navigation and the Connector have in the interaction with the connections. The Connector is used to conceptually "carry" the content between the two devices and in itself represents the relation between these two artefacts. The Spotlight Navigation is, in contrast, perceived as a "remote control" that visualises the connections in physical space. This might lead the users to conclude that the projected lines are the connections, directly between the devices, and leave the Spotlight Navigation itself outside of this network.
The results show that devices and appliances that automatically act and react to people's behaviour are often not considered in the mental models, compared to the devices and relations that users interact with explicitly. However, the results also show that some participants noticed these relations, and incorporated them in their mental models. More interestingly, some of the participants expected that they could manipulate these relationships (e.g. between sensor and light) in the same way as they could manipulate the other connections. This result is promising and might indicate that people project their experience with one part of the system to the rest of it. This also became apparent when participants started looking for tags on other devices they thought could also be connected.

An interesting observation is the rather direct impact of the interaction device's design on the mental models. For instance, the design and interaction of the Spotlight Navigation reminded them of a remote control, and consequently they used and described it as such. One participant even thought it was connected to the speaker set because it controlled the music (i.e. making or breaking a connection between the Living Colours lamp and the speaker set started and stopped the music playback).

Another observation was the complicated conceptions the participants had about the connections and their properties. Although there was no explicit directionality on the interactions or the connections, participants conceived the connections that for instance carried music to have a direction, travelling from its source to a destination. Directionality was also indicated where one device seemed to control the behaviour of the other. By allowing users to use this sense of directionality in their interaction to establish the connection, we could easily give them more control over the connections. Transitivity was another, less obvious, concept that emerged from some of the mental models. Transitivity of a connection is a logical property that emerges when a network node A is connected to B, and in turn B is connected to node C. Transitivity then defines A to be connected to C as well. We observed participants to erase connections they indicated to exist before because they "were no longer needed" because of transitivity. And, in another case, worried about (hypothetically) removing a device from the network when it was in a chain of multiple connected devices, because it would lead to removing the transitive connections as well.

8 Conclusion

The SOFIA project provides a platform and therewith the possibilities to improve the interoperability among devices. In this context, two prototypes were developed to experiment with tangible and augmented reality approaches to manage semantic connections. Both show their potential in moving the interaction with devices from a device-oriented paradigm towards a more task-oriented paradigm with increased interoperability. Although we are still exploring the possibilities of our approach, promising results and insights have been achieved already. The results obtained during this evaluation will be used to further define our semantic connections interaction model, and may hopefully help other interaction designers to deal with design opportunities and challenges that emerge when designing for interoperability.
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