SEMANTIC RESOURCES

A STUDY ON A TANGIBLE INTERACTION APPROACH TO MANAGING WIRELESS CONNECTIONS IN A SMART HOME ENVIRONMENT

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ABSTRACT

Technological advances in computational, networking and sensing abilities are leading towards a future in which our daily lives are immersed with interactive devices that are networked and interoperable.

It is imperative that users are able to understand such complex intelligent and interactive environments. Design has an important role in facilitating users in making sense of the many connections between devices in a networked environment.

Two design solutions based on tangible interaction have been developed that allow users to manage wireless connections between devices in a smart living room context.

One design (SCD) is a centralized approach based on a high-level of semantic abstraction. The second design (Nodes) employs a distributed and localized approach, building upon laws of grouping from Gestalt psychology.

A user experiment (N=15) was conducted, comparing both design solutions in the form of video prototypes. The goal of the research was to gain insights into the mental models users construct when using the methods and how they differ.

Findings suggest that users' mental models of the Nodes design are more accurate representations of the actual architecture of the network and that it allows for the projection of different mental models. Furthermore, findings also suggest that this does not necessarily lead to better usability or increased perceived value.

INTRODUCTION

Technological advances in computational, networking and sensing abilities are changing the domain of interactive product design.

Visions of the future, such as Ambient Technology [1], Pervasive Computing [2] and Ubiquitous Computing [3] predict a future in which our daily lives are immersed with devices that are networked and interoperable.

Other discourses on the future of technology, such as the "Internet of Things" [4] and "Shaping Things" [5] predict all devices to be connected to the internet. This allows individual products and their location in space and time to be identified.

In such worlds, interactive products no longer function, or are interacted with, on their own. Rather, they become part of a larger network of products. This changes the field of design from a one person - one product paradigm into that of a world in which many products and systems form complex networks [Frens et al, 6].

For these highly interactive and intelligent systems to have any merit, it is imperative that users are able to understand and manage their content. Design plays an important role in allowing users to make sense of this content - the devices and connections within the network - and to help bridge the gap between virtual and physical worlds.

Various approaches have been developed that aim to bridge this gap. One example is Tangible Interaction [7], which builds upon perceptual motor-skills by presenting users with physical entities that can be manipulated to interact with virtual data.

The European research project SOFIA targets to *"make "information" in the physical world available for smart services - connecting physical world with information world"* [8].

In the context of this project, G. Niezen and B.J.J. van der Vlist have designed the Semantic Connections Demonstrator [9] at the Department of Industrial Design at Eindhoven Technical University. The Semantic Connections Demonstrator (SCD) is a design based on tangible interaction that allows users to understand and manage wireless connections between devices in a smart living room context. The design employs a centralized approach and builds on high-level semantic abstractions.

The Nodes design has been created to explore an alternative design direction in the same setting. The Nodes design employs a distributed and localized approach and builds on Gestalt psychology's laws of perception. These hypothetical laws dictate expected perception of visual information in a organized way. In this design they are employed to visualize the otherwise invisible virtual network.

In order to gain insights into the use of Gestalt laws to aid in designs that bridge the virtual and real, a user experiment was conducted. The two designs were compared in order to answer the following research question:

- Is there a difference in the user constructed mental models between the Semantic Connections Demonstrator and the Nodes design? And if so, what is this difference?

It is expected the Nodes design provides users with a more accurate mental model compared to the Semantic Connections Demonstrator.

The Nodes design places physical objects that suggest the real architecture of the system directly in the environment. This allows users to perceive the network as it exists within the context, without a large step in semantic abstraction.

BACKGROUND

Semantic Connections Demonstrator

The Semantic Connections Demosntrator (SCD) [10] allows users to explore, make and break connections between devices in the smart home environment. It revolves around a high-level of semantic abstraction based on icons that represent the devices in the environment.

The design [see Figure 1] is based around a central, cube-like object, the Interaction Tile. The Interaction Tile features 4 LED lights that provide feedback to the user about possible connections and active connections. Smaller, cube-like objects each represent a device in the living room. An icon on top of the small cubes communicates what device they represent.

By aligning a smaller cube with the Interaction Tile, the user can explore connections: A possible connection means a green LED will blink. By placing another icon next to a different side of the Interaction Tile and shaking the Interaction Tile, a connection can be made between the devices. The green LEDs will now glow continuously. A red LED means a connection is not possible, or that another device must be added to the cube to create a connection.

FIgure 1 - The Semantic Connections Demonstrator being used.

The SCD is a centralized design; the connections are made by interacting with a central device, irrespective of the location of the actual devices being connected.

Nodes

The rationale between the Nodes design was to explore a different approach to allowing users to understand and manage connections between devices in the same context. As opposed to a centralized solution such as the SCD, which abstracts the network and takes the connections out of their context, the Nodes is distributed and localized.

The Nodes design revolves around physical objects that represent nodes within the virtual network. The physical nodes are distributed in the environment, meaning they are placed close to the actual devices being connected. Start and end points of connections are attached to the nodes and aimed at their counterparts at other nodes in the network, effectively visualizing the virtual network as it exists between the devices [see Figure 2, 3].

Figure 2 - The Nodes design being used: A user places a node fitted with a receiver (end point of a connection) at the base of a TV.

Figure 3 - The Nodes design being used: A user makes a connection between two Nodes by aligning the sender (starting point of a connection) with the receiver on another device (speakers)

The Nodes design is based on laws of *prägnanz*, the main principle in Gestalt psychology. Gestalt psychology revolves around the principle that the human mind is holistic and that it has self-organizing tendencies in its perception [11].

The laws of *prägnanz* [See Figure 4] are a set of hypothetical laws that allow for prediction as to how visual information is grouped according to certain characteristics. Specifically, the Nodes design builds upon the Law of Closure: The mind has a tendency to complete incomplete forms, effectively seeing something for which it does not receive stimuli. In this design, this principle is used to visualize something that is invisible (the virtual network) through physical objects that represents parts of it (the nodes and start/end points).

The design also employs other *prägnanz* laws: The Law of Proximity: objects that are close to one another are perceived to belong together. Used in the design to communicate a node belonging to a specific device.

The Law of Similarity: objects that are similar in form are perceived to belong together. Used in the design to communicate the nodes belonging to the each other and form networks.

And finally, the Law of Good Continuation: the mind continues visual patterns. Used in the design to communicate connections that cross one another.

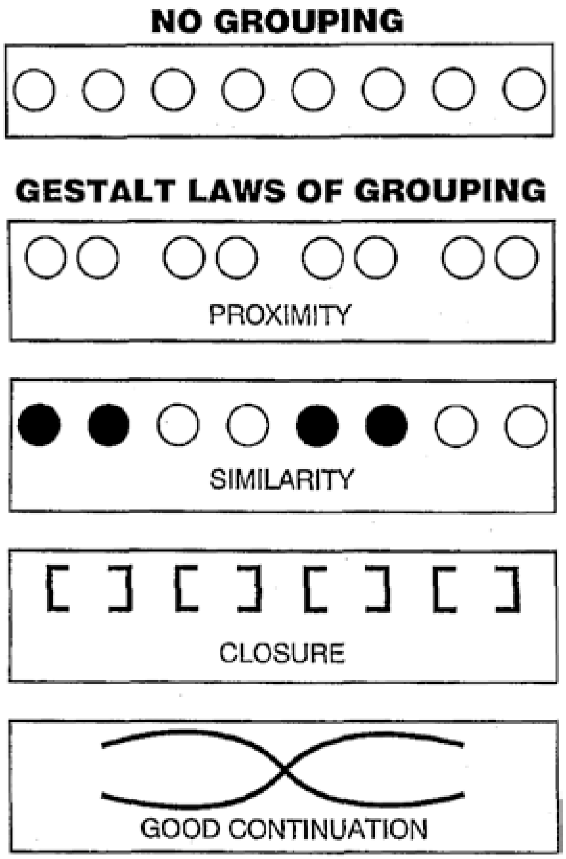

Figure 4 - An overview of the Gestalt Laws of Grouping, taken from [Irvin Rock et al, 11]

METHOD

A user experiment was designed to answer the research question proposed earlier in this report. The test plan for the experiment was developed in co-operation with a usability test expert, the researchers that created the SCD and the project supervisor.

PARTICIPANTS

Fifteen participants were recruited based on their willingness to participate. The requirements for the selection were their vicinity to the location of the experiment and their ability to participate in the experiment in the short term. Furthermore, the target demographic for the experiment was age 45+, in order to gain insights into the mental models of users that are expected to be less familiar with the networking of interactive products than generations that grew up with such technologies emerging.

In total, 8 females and 7 males were recruited. All participants indicated they use multiple electronic products with varying regularity. The educational background for the participants ranged from low to high, but all except one participant had completed a mid to high level education.

Ideally, the experiment would also include an equal amount of participants from a younger demographic with a equally varying background. This would allow the research to provide insights into differences in mental models constructed by a demographic that can be expected to be more familiar with the use and networking of electronic devices.

Two pilot tests were conducted to identify and repair problems concerning the set-up of the experiment.

EXPERIMENT DESIGN

A within-subjects design was used to design the experiment. The set-up was experimental, but employs an established technique that allows researches to gain insights into the mental models constructed by users, the Teach-Back Protocol [12].

Video-prototypes [13] were used to convey the interaction and functionality of both designs to participants, using the exact same use scenario.

Video-prototypes allow the researcher to have much more control over the behavior of the system, minimizing the interference of prototyping design flaws or technical instability. This influences the construction of mental models participants constructed, as the humans learn differently when seeing as opposed to doing. To minimize this difference, an adaptation to the Teach-Back Protocol was implemented; Users interacted with cardboard models of the designs to approximate their actual use in context. This stimulates users to form their own mental models despite of the lack of functionality in the cardboard prototypes.

APPARATUS

The following apparatus was used in experiment:
- A video-prototype of the SCD design
- A video-prototype of the Nodes design
- A laptop computer to present the video-prototypes to participants
- A non-functioning model of the SCD design
- A non-functioning model of the Nodes design
- A digital camera mounted on a tripod to record the experiment
- Six non-functioning devices that represented the devices in the scenario (a VCR, a TV, a table light, a set of speakers, a CD-player and a small radio)
- An Iphone to record audio during the experiment.

PROCEDURE

The experiment was set-up to collect data about differences in participants' mental models when presented with two design solutions to create networks between devices in a smart living room environment.

Location and set-up

The experiment was conducted in a controlled environment. A entertainment room at a residency was furnished to resemble a living room, the context in which both designs would be used (see Appendix A).

Participants were presented with a video-prototype of the design and asked to complete a number of tasks using cardboard models as well as writing and drawing. To emulate the spatial dimension of the Nodes design, the six devices used in the task descriptions were positioned in the environment. The devices were turned off and to avoid unnecessary confusion they were clearly marked.

Every session was recorded from a wide-angle using a video camera and the audio was recorded using an Iphone. The moderator lead to session and made notes.

Methodology

Qualitative data was collected on the mental models of participants using the Teach-Back Protocol.

Participants were divided into two groups. One group started by going through the test cycle using the SCD design after which they repeated the cycle for the Nodes design. The other group went through the cycles vice-versa.

After an introduction to the experiment, participants were asked to read and sign an informed consent form (translated and adapted from [14], see Appendix B) and to fill in a short pre-test questionnaire (see Appendix C). The pre-test questionnaire aimed to gain general demographic and background data from the participant, including some general insights into their use of electronic products.

Starting the test, the participants were first presented with a video prototype of the design. This video prototype shows a user making and breaking connections between devices using the method. In the videos, the designs appear to be fully functional. Both video-prototypes revolved around the same person, in the same context and managing the same connections.

The participant was then asked to use cardboard models of the method to manage connections for two specific task scenarios. The participant was asked to think out loud and explain why and what they were doing, including what they expected the system to do as they performed certain actions.

Secondly, the participant was asked to write down a short general description of the design they were using (See Appendix D).

Thirdly, the participant was asked to explain to an invisible friend how they see the connections in a two specific task scenarios, using the drawings. (See Appendix E).

This cycle was repeated for the other design.
Eight different task scenarios were created for the experiment. Every participant was presented with each task scenario, but the order was randomized for each participant. Each task scenario was presented on a card, allowing users to review the task if necessary [see Appendix F]. In addition to a simple description of the devices to be connected, the card also communicated the connections in context (i.e. The music from the CD-player plays on the speakers), in order to facilitate the participants understanding of the type of connections needed.

Finally, the participants were asked for anything they would like to share about either design and their preferences, and the moderator followed up on problems or observations. This post-test discussion ended with a short debriefing by the moderator.

Detailed scenario for the experiment:

Introduction (5 minutes)
- Welcome participants
- Participants are explained the importance of their involvement in the experiment
- Participants are explained the moderator's role
- Participants are explained the room configuration and audio/video recording equipment
- Participants are explained the set-up and order of the experiment

Pre-test arrangements (5 minutes)
- Participants review and sign an informed consent form (see appendix C)
- Participants fill in a short questionnaire (see appendix D)

Test (20 minutes)
- Participants are shown a video-prototype of the first design, the moderator explains what is happening in the video scenario. Participants are allowed to ask questions for clarification or re-watch the video if necessary
- Participants are asked whether they think they understand the design presented in the video.
- Participants are presented with two task scenario cards. Participants are asked to act-out how they would use the design to create the connections as described in card, while thinking out loud.
- Participants are asked to write down a short general description of how they view the system's connections using the design.
- Participants presented with two task scenario cards. They are asked to explain how they view the connections using the design in to an invisible collegue, using pen and paper and being encouraged to draw.

The test is repeated for the second design.

Post-test discussion (5 minutes)
- Participants are asked whether they would like to add or mention anything.
- Moderator follows up on observations or problems during the test
- Participants are asked to state which design they prefer.

Measures

To answer the research question as presented previously in this report, qualitative data was collected on the mental models participants construct. The data was collected using drawings and descriptions made using the Teach-Back Protocol, as well as from observations by the moderator. In the post-test discussion, general preference data towards the designs was also collected through informal questioning of the participants.

Moderator Role

The moderator sat next to the participants while conducting the session. The moderator welcome the participants, introduced them to the experiment, supported the video-prototypes with an explanation and led the participant through the two test cycles. The moderator took notes on the behavior and comments of participants, answered participants' questions and asked follow up questions relating to observations and problems that arose during the test.

RESULTS

The text and drawings created by the participants during the test and observations made during the test as well as during review of the video were collected to start the data analysis.

The collected data was transferred to small cards and analyzed using the Affinity Diagram method. [see Figure 5). Cards were clustered based on their relation to each other, resulting in six categories of interest, three for each design, presented in the Discussion section of this report. The results for each technique are discussed below.

Figure 5 - Processing the data using Affinity Diagrams

ACTING OUT

Participants were asked to act out how they would manage connections with the designs using cardboard models to execute task scenarios.

Using the SCD, three users forgot to shake the Interaction Tile, a required action to establish a connection between the devices which icons have have been aligned with the Tile. Instead, they assumed simply placing the icons would establish a connection. This had no influence on the mental models of the participants, as they still perceived a networked to be formed, and were able to explain how they viewed the network.

Some participants were also confused by the meaning of icons as they acted out using the SCD. This did not influence their mental models of the network, as their perception of the network and the devices in it remained the same.

Using the Nodes design, five users made mistakes in their use of sender/receiver combinations (e.g. making a connection by pointing two senders at each other, as opposed to a sender and receiver). Two participants quickly recovered from this initial mistake. One participant realized his mistake as he attempted to describe the system. Two participants did not realize their mistake of not using the sender/receiver forms. One of them only used senders to connect devices.

All participants understood the importance and implemented the aiming of two start or end points at different nodes towards each other.

One participant placed two nodes at the same device to establish connection to two other devices, all other participants placed the correct number of nodes at the correct devices (one for each device). This did not influence her perception of the network and connected devices.

Roughly half of the participants required a few moments to decide what nodes were required to send and what nodes were required to receive. The other half was able to realize this instantly.

Two participants wondered whether the placement of nodes relative to the device, i.e. whether they should be on top of the device or could also be in front of it. Most participants placed the nodes in front of the device, some mixed nodes on top of and in front of devices. None of the participants expressed worries about height difference in placement of the nodes.

Participants were observed to created similar networks in different ways. I.e. when connecting an Ambient Light that reacted to music, some participants connected it to the source of the audio (CD-player, radio), most connected it to the speakers that made the audio from the source audible.

DESCRIPTION

Roughly half of the participants expressed that they found it difficult to write down a short general description of the designs. Two participants were only able to describe one system (once Nodes, once SCD) and two participants were unable to write a description at all. When participants were observed to be uncomfortable by their inability to describe the system, this step was skipped by the moderator.

For the SCD, almost all participants described a Central Unit that is used to connect everything, and which automates the establishing of connections.

For the Nodes, almost all participants referenced the existence of two elements: a sender and a receiver.

TEACH-BACK PROTOCOL

All participants were able to use a drawing to explain how they perceive the connections in a certain scenario using a particular design.

Concerning the SCD design, almost all participants clearly indicated all connections to be mediated by the "Central Unit". They perceived all devices as being connected to the Central Unit, and that this Central Unit managed the connections for them. Two participants thought the Central Unit managed the connections through instructing the main device in the network to form connections to other devices by itself.

One participant described the connections as moving *around* the Central Unit; i.e. every device connecting directly to another, unmediated by the Central Unit. This participant did not realize the necessity for some kind of connection to exist between the devices and the SCD in order for it to be able to instruct devices.

Despite some participants making mistakes in their use of sender/receiver elements in the acting out tasks, all participants implemented this differentiation correctly and consistently in their drawn explanations of connections in the Nodes design.

POST-TEST DISCUSSION

During the post-test discussion, some participants expressed that they wondered what was happening inside the SCD's Interaction Tile. They perceived it as being automated.

One participant explained that he found it difficult to understand the system because he was unaware of what happened inside the Interaction Tile.

DISCUSSION

In this study, two designs were compared to gain insights into the mental models constructed by users when using the SCD and Nodes designs to manage connections between devices in a smart living room context. The research aimed to find out whether the mental models differ between the SCD and Nodes design, and what this difference is.

It was expected the Nodes design provides users with a mental model that is more accurate towards the actual architecture of the system than that of the mental model created when using the SCD.

Analyzing the data using Affinity Diagrams, six categories of results emerged from the data. The six categories mirrored each other across the two designs, and were merged to contrast the differences between the two designs:

ON MENTAL MODELS

For the SCD, almost all written descriptions of the system by the participants revolved around a central device that is connected to all devices and manages the connections automatically. Participants often referred to the Interaction Tile as the "central unit", "the interface to all devices" or "a magic box".

Almost all participants also indicated in their drawings [see Figure 6] that they perceived all connections to go through the Interaction Tile, where the Interaction Tile "did something" to the signals and created the network.

This lead to the conclusion that the SCD system creates a mental model with a centralized hierarchy; all devices are connected to and controlled by a central object, the Interaction Tile.

For the Nodes design, almost all participants wrote about "senders and receivers" to make connections and placement of nodes near devices that need to be connected to determine the content of the network.

In their drawings, all participants created hierarchical connections between devices, where some devices send data and others receive it (see Figure 7). Participants created different mental models of the same type of networks, and were able to adapt the use of the system to fit their mental model without compromising the functionality of the network. For example: In a network of three devices, music from a CD-player plays on the speakers and an ambient light responds to the music. Most participants directed the signal from the CD-player to a receiver on the speakers, and relayed the signal from the speakers to a receiver on the light. Some participants sent two signals from the CD-player, one towards the speakers and one towards the light. This shows a powerful characteristic of the Nodes design: it supports users in projecting different mental models on the system.

It can be concluded that the hypothesis is supported by the results from the study. The Nodes design provides users with a more accurate mental model towards the actual architecture of the system in the sense that devices are directly connected to each other without the network being mediated by a centrally. However, as the design allows for different mental models to be projected onto it, not every mental model of the Nodes design is the exactly the same as the network's real architecture.

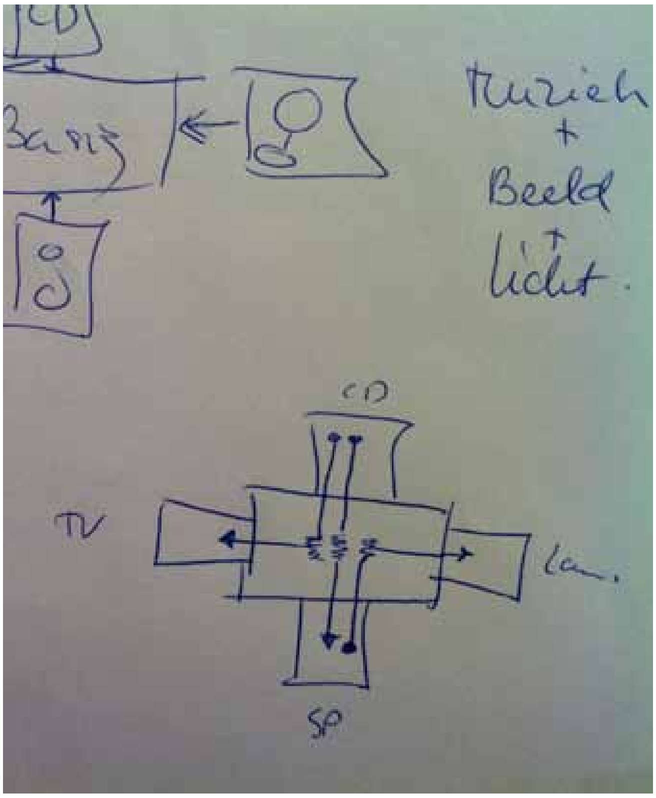

Figure 6 - One of the participant's drawings to explain the SCD system, clearly showing the mental model which revolves around all connections being mediated through a central object.

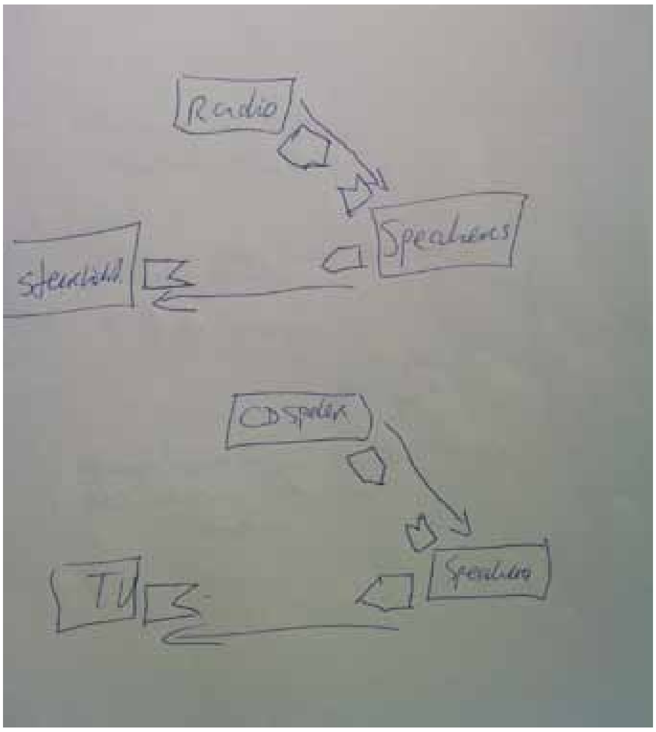

Figure 7 - One of the participant's drawings to explain the connections in the Nodes system, clearly showing the mental model which revolves around direct connections between devices in a hierarchy, mediated by senders and receivers at the ends.

ON SYMBOLISM & INTERACTION

For the SCD, some participants were confused about the meaning of the icons (i.e. what device was represented by which icon). Also, participants wondered whether the location of the icons next to the Interaction Tile was important, although they assumed it was not.

For the Nodes design, similar problems surfaced. It was difficult for some participants to immediately apply the sending/receiving concept in their acting out tasks, and some did not realize the importance of using the right shape to send or receive a signal. In their drawings however, all participants used the sending/receiving principle correctly in explaining connections. Furthermore, two participants wondered about whether the location of the nodes relative to the device was important, although they assumed that it only had to be in close proximity.

These issues for both the SCD and Nodes designs are similar and occurred (roughly) equally often and for a minority of the participants. They did not influence the mental models, as these were observed from the Teach-Back Protocol to be consistent for all participants whether they identified these issues or not. They do however point out important design issues that can be limitations to both systems. This suggests that further research into the semantics of sign and form in both designs could lead to a better understanding of the interaction required for the device, as well as increased usability.

ON VALUE JUDGEMENT

From the observations and post-test discussions, some data concerning the participant's preference for either method surfaced as well. When asked about their opinions on both designs, almost all participants indicated they preferred the SCD method over the Nodes method.

They described the SCD method as being very easy to use, as they only had to add icons of the devices and did not need to determine what the role of each device was. The system was perceived as being automated and therefor experienced as the most user friendly. Furthermore, they liked the fact that they were able to manage the connections without getting up and moving about the space.

Most participants indicated they found the Nodes design easy to understand, but that it required too many actions. Furthermore, some participants indicated that they would not like having to place additional objects in their living room, for which they did not see specific merit.

This suggests that although the Nodes design provides a more accurate mental model of the network, this is not necessarily also a better mental model and does not necessarily lead to better usability. Further research could explore design directions that merge the merits of the Nodes design (accuracy and clarity of the mental model, flexibility towards different mental models) with those of the SCD design (ease of use, perceived value).

CONCLUSION

The study has compared the mental models created by users when using a centralized and a distributed approach to tangible interface for networking of devices. A clear difference has been found in the way users perceive the network and suggests some speculation as to how this could impact understanding and usability of such networks.

The success of the Nodes design in allowing users to create and apply mental models to networks suggests that Gestalt laws of prägnanz can be powerful tools in the way in which physical artifacts can acquire meaning in an ecology of objects and how they can help to bridge the gap between real and virtual worlds.

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