**Jeroen Peeters, Bram van der Vlist, Gerrit Niezen, Jun Hu, Loe Feijs**
j.p.a.peeters@student.tue.nl, {b.j.j.v.d.vlist, g.niezen, j.hu, l.m.g.feijs}@tue.nl

# A study on a tangible interaction approach to managing wireless connections in a smart home environment

## 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. Design has an important role in facilitating users to make sense of the many connections between devices in a networked environment. Two design solutions based on a tangible interaction approach have been developed, that allow users to manage wireless connections between devices in a smart living room context. One design (Interaction Tiles) 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, to gain insights into the mental models users construct when using the methods. Findings suggest that users' mental models of the Nodes design are more accurate representations of the actual structure 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 increased usability or increased perceived value.

## Keywords
Gestalt, Product Semantics, Interaction Design, Smart Home

## 1 Introduction
Technological advances in computational, networking and sensing abilities are changing the domain of interactive product design. Visions of the future, such as Ambient Intelligence [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, or to form a new, Internet of Things. 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, in isolation. 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 [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 the physical world with the information world" [8]. In the context of this project, we have previously designed the Interaction Tile [9]. The Interaction Tile is a design based on tangible interaction that allows users to explore 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.

We created the Nodes design 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 an organized way. In this design they are employed to visualize the otherwise invisible wireless 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 Interaction Tile and the Nodes design? And if so, what is this difference?

It was expected that the Nodes design would provide users with a mental model that more accurately resembles the underlying structure of the network, compared to the Interaction Tile. 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 requiring users to take a large step in semantic abstraction.

## 2 Design

Both designs presented in the research are designed to allow users to explore, make and break wireless connections between media devices in a smart home environment.

### 2.1 Interaction Tile

The Interaction Tile [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 Fig. 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 as well as 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.

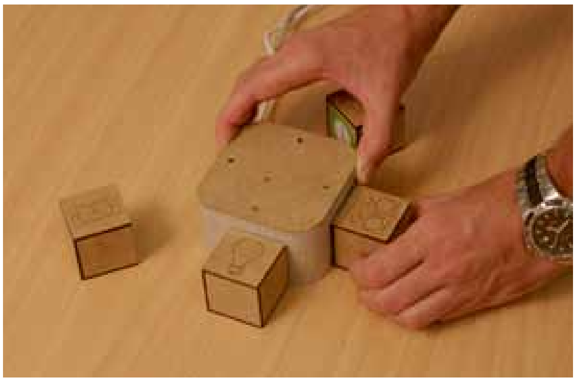

**Fig. 1. Interaction Tile.**

When an object is placed next to the tile, the lights give immediate feedback when the object is recognized (Fig. 2c). When multiple objects are placed near the interaction tile, it immediately shows the connection possibilities (feed forward) through lighting colour and dynamics. The lights' colour coding is simple and straightforward. Red colour means no connection and no connection possibility (Fig. 2d); green colour means there is an existing connection between the devices present (Fig. 2a/e) and green pulsing means that a connection is possible (Fig. 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 (Fig. 2c). By 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.

We rely on the symbolic meaning of colour – green colour meaning "proceed" and red meaning the

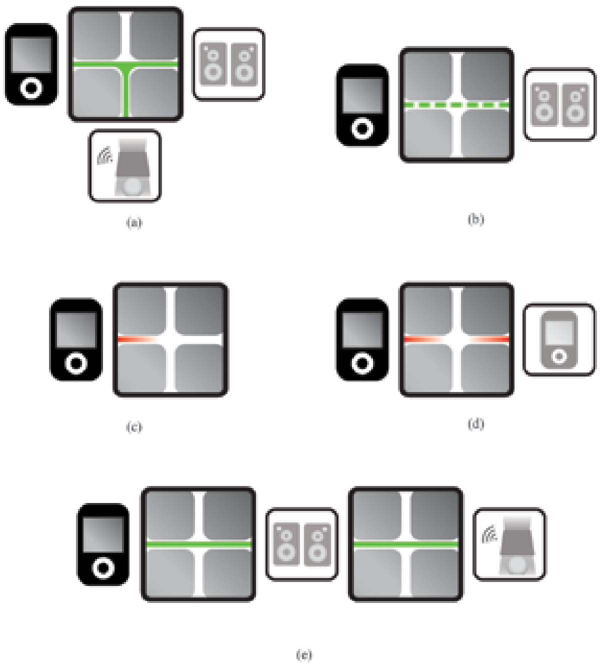


**Fig. 2. Meanings of lighting colour and dynamics.**

opposite. Using the association of solid colour and pulsing colour (indicated with solid and dashed lines) we aim to refer to the "existence" of something and the "possibility" of something. This something is a connection, being invisible but with noticeable results (functional feedback; i.e. 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.

### 2.2 Nodes

While the Interaction Tile is a centralized design – the connections are made by interacting with a central device, irrespective of the location of the actual devices being connected – the rationale with the Nodes design was to explore a different approach to allow users to understand and manage connections between devices in the same context. As opposed to a centralized solution such as the Interaction Tile, which abstracts the network and takes the connections out of their context, the Nodes design is distributed and localized.

The Nodes design revolves around physical objects that represent nodes within the virtual network. The physical nodes are small circular platforms that are distributed in the environment, meaning they are placed close to or onto the actual devices a user wants to connect. Placing the nodes near devices does not yet establish the connections between the devices. To establish connections, users need to determine the start and end points of connections between the nodes. These are determined by placing flat shapes that resemble an arrow (start point) or negative arrow (end point) vertically onto the nodes. (Fig. 3) By aiming a start point on one node directly at the end point of another node, the connection between two nodes is visualized and established (Fig. 4).

**Fig. 3. Placing a Node on a device (left), placing a network start point on a Node (middle) and placing a network end point on a Node (right).**

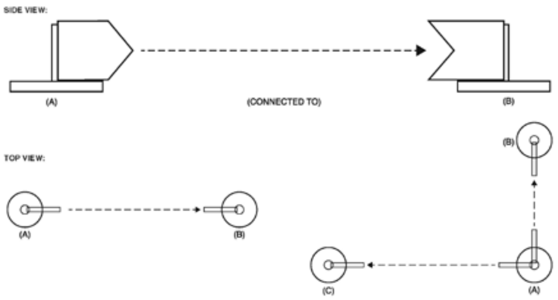


**Fig. 4. The side view shows how to aim the Nodes to connect device A to device B. The top view shows two networks: one in which device A is connected to device B, and another in which A is connected to both devices B and C.**

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 (Fig. 5) 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 represent 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 each other and form networks.
- Law of Good Continuation – the mind continues visual patterns. Used in the design to communicate connections that cross one another.

## 3 Evaluation

A user experiment was designed to answer the research question proposed earlier in this article. The experiment was set up to collect data about differences in participants' mental models, when presented with two design

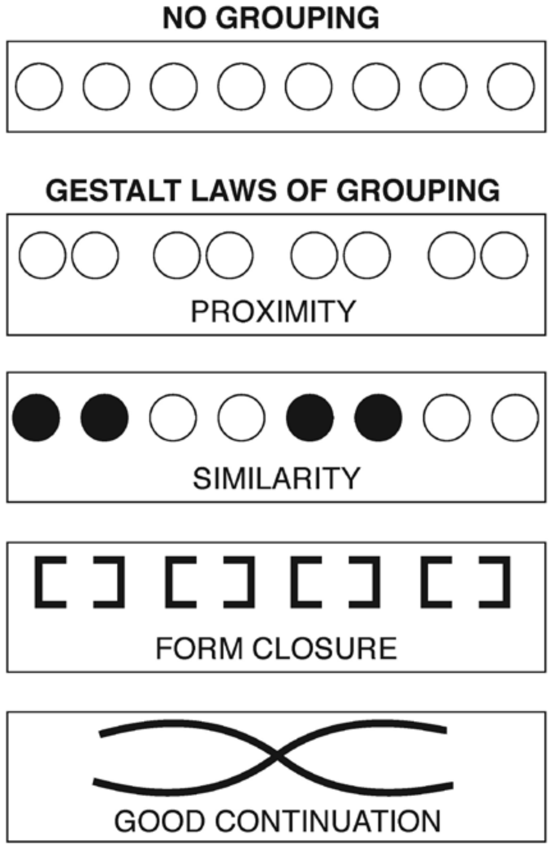


**Fig. 5. Examples of the Gestalt laws of prägnanz.**

solutions to create networks of devices in a smart living room environment. Two pilot tests were conducted to identify and repair problems concerning the set-up of the experiment.

### 3.1 Participants

Fifteen participants in the target demographic of 45+ were recruited. This demographic was used 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, eight females and seven males were recruited. All participants indicated that they use multiple electronic products with varying regularity. The educational background for the participants ranged from low to high.

### 3.2 Experiment Design

A within-subjects design was used. We employed the Teach-Back Protocol [12], an established technique that allows researchers to gain insights into the mental

models constructed by users. Because users' mental models consist of both semantic and procedural knowledge about the system they are interacting with, teach-back questions can be subdivided into "what is?" questions focusing on semantic knowledge, and "how to?" questions focusing on procedural knowledge [12]. Using such questions, adjusted to our specific situation and research goal, we aimed to extract the semantic and procedural concepts that are relevant for our users. Participants were asked to explain to an imaginary peer 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 the participants to explain to an imaginary peer how to perform a specific task with the system, we aimed 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. The data was collected by examining the drawings and descriptions made by participants, as well as from observations and recordings made by the moderator. In the post-test discussion, participants were asked for their feedback and preferences for the two designs. Video prototypes [13] were used to convey the interaction and functionality of both designs to participants, using the exact same usage scenario. Video prototypes allow the researcher to have much more control over the behaviour of the system, minimizing the interference of prototyping design flaws or technical instability of the networked devices and networks formed.
The use of video prototypes instead of real prototypes influences the construction of mental models by the participants, as 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 act out their use of the systems within context and were asked to vocalize their thoughts and ideas during this step. This stimulates users to form their own mental models despite the lack of functionality in the cardboard prototypes.

### 3.3 Materials

The following materials were used in the experiment:

- video prototype of the Interaction Tile design
- video prototype of the Nodes design
- laptop computer to present the video prototypes to participants
- non-functioning model of the Interaction Tile design
- non-functioning model of the Nodes design
- 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, an ambient light that reacts to sound, a set of speakers, a CD-player and a small radio)
- a voice recorder to record audio during the experiment.

### 3.4 Procedure

The experiment was conducted in a controlled environment. An entertainment room at a residence was furnished to resemble a living room, the context in which both designs would be used. Participants were presented with a video prototype of the design and asked to complete a number of task scenarios (see next section) 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. The moderator sat next to the participants while conducting the session. The moderator welcomed 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 behaviour and comments of participants, answered participants' questions and asked follow-up questions relating to observations and problems that arose during the test. Every session was recorded from a wide angle using a video camera and the audio was recorded using a separate audio recorder. The moderator led the session and made notes.

*Tasks.* Eight different tasks were created for the experiment:

- Connect the CD player and the speakers: The music from the CD plays back on the speakers.
- Connect the radio and the speakers: The music from the radio plays back on the speakers.
- Connect the CD player, the speakers and the ambient light: The music from the CD-player plays back on the

speakers and the ambient light responds to the music.
- Connect the CD player, the speakers, the TV and the ambient light: The music from the CD player plays back on the speakers, and the TV screen and the ambient light respond to the music.
- Connect the CD player, the speakers and the TV: The music from the CD player plays back on the speakers and the TV screen responds to the music.
- Connect the TV and VCR. Also connect the CD player and the speakers: The VCR plays back on the TV. The music from the CD player plays back on the speakers.
- Connect the TV, the VCR, the speakers and the ambient light: The VCR plays back on the TV, the sound from the VCR plays back on the speakers, and the ambient light responds to the sound.
- Connect the radio, the speakers and the ambient light: The sound from the radio plays back on the speakers, and the ambient light responds to the sound.

Every participant was asked to perform all of the tasks in an order that was randomized for each participant. Each task was presented on a card, allowing users to review the task if necessary. 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 back on the speakers), in order to facilitate the participants' understanding of the type of connections needed and their purpose.
Participants were divided into two groups. One group started the test using the Interaction Tile design, after which they repeated the cycle for the Nodes design. The other group went through the procedure in the reversed order. After an introduction to the experiment, participants were asked to read and sign an informed consent form, and to fill in a short pre-test questionnaire. 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.
Participants were first presented with a video prototype of the design. This video prototype showed a user making and breaking connections between devices using the respective designs. In the videos, the designs appear to be fully functional. Both video prototypes involved the same person, in the same context and managing the same connections. The participant was then asked to use cardboard models of the design to manage connections for two of the task scenarios. The participant was asked to think out loud and explain what they were doing and why, including how they expected the system to respond to their actions.
Then, employing the Teach-Back Protocol, participants were asked to write down a short general description of the design they were using, as well as to explain to an invisible friend how they conceptualized the connections in two of the tasks, using drawings. This procedure was repeated for the other design. Finally, the participants were asked for anything they would like to share about either of the designs and their preferences, and the moderator followed up on problems or observations. This post-test discussion ended with a short debriefing by the moderator.

## 4 Results

The collected data was transferred to small cards and analyzed using the Affinity Diagram method. Cards were clustered based on their relation to each other, resulting in three categories of interest, presented in the Discussion. The results of each technique are described in the following sections.

### 4.1 Acting Out

While using the Interaction Tile, three users forgot to shake the tile, a required action to establish a connection between the devices which icons have been aligned with the tile. Instead, they assumed that simply placing the icons next to the tile would establish a connection. This had no substantial influence on the mental models of the participants, as they still perceived a network to be formed, and were able to explain how they viewed the network. The meaning of the icons also confused some participants while they were using the tile. 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 out of the 15 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). Ten participants succeeded in using the right combination of senders and receivers consistently. 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 of aiming two senders or receivers at different nodes towards each other. One participant placed two nodes at the same device to establish connection to two other devices, but this did not influence her perception of the network and connected devices. The 14 other participants placed the correct number of nodes at the correct devices (one for each device). About 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 decide instantly.

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

Participants were observed to create similar networks in different ways. For example, when performing a task scenario that involved connecting an ambient light that reacted to music, some participants connected the light to the source of the audio (CD player, radio), but most connected it to the speakers that made the audio from the source audible.

### 4.2 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 (the one only Nodes, the one only Interaction Tile) and two participants were unable to write a description at all. When participants were observed to become uncomfortable by their inability to describe the system, the moderator skipped this step. For the Interaction Tile, almost all participants described a central entity 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.

### 4.3 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 Interaction Tile design, almost all participants clearly indicated all connections to be mediated by the central entity. 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 underlying necessity for some kind of connection to exist between the devices and the Interaction Tile in order for it to be able to instruct devices to form connections.

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.

### 4.4 Post-test Discussion

During the post-test discussion, some participants expressed that they wondered what was happening inside the 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.

## 5 Discussion

The study aimed to determine whether users' mental models differ between the Interaction Tile and Nodes design, and what exactly this difference is. It was expected that 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 Interaction Tile.

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

### 5.1 On Mental Models

For the Interaction Tile, 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 Fig. 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 leads to the conclusion that the Interaction Tile 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 Fig. 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 results of our study support our hypothesis that the Nodes design provides users with a more accurate mental model towards the actual configuration of the network in the sense that devices are directly connected to each other without the network being mediated by a central unit. However, as the design allows for different mental models to be projected onto it, not every mental model of the Nodes design is exactly the same as the network's real architecture.

### 5.2 On Symbolism and Interaction

For the Interaction Tile, some participants were confused about the meaning of the graphical icons on top of the blocks (i.e. which device was being represented by which icon). Also, participants wondered whether the location of the icons relative to each other

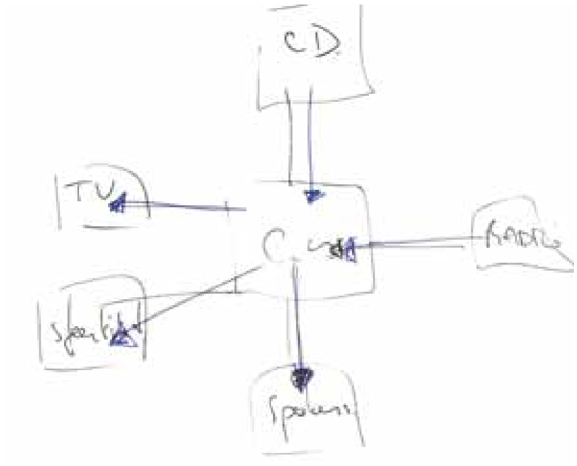


**Fig. 6. A typical mental model drawing of the network when using the Interaction Tile: all connections go through a central unit.**


**Fig. 7. A mental model drawing of the perceived network when using the Nodes design: Data is sent from the radio towards the speaker-set, which acts as a relay to an ambient light.**

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 arrow-shape to send or receive a signal. In their drawings, however, all participants used the sending/receiving principle correctly in explaining connections. This indicates that the system could benefit from a better form design to allow differentiation between the sending and receiving shapes. 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 Interaction Tile 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.

### 5.3 On Value Judgment

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 Interaction Tile method over the Nodes method.

They described the Interaction Tile 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 therefore 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 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 Interaction Tile design (ease of use, perceived value).

## 6 Conclusion

The study compared the mental models created by users when using both a centralized and a distributed approach as a tangible interface for configuring networks 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 artefacts can acquire meaning in an ecology of objects, and how they can help to bridge the gap between real and virtual worlds.

**Jeroen Peeters, Bram van der Vlist, Gerrit Niezen, Jun Hu and Loe Feijs**
Department of Industrial Design
Eindhoven University of Technology
Eindhoven, Netherlands

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