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# Semantic connections: A new interaction paradigm for smart environments

## Abstract
As the environments we inhabit contain a growing number of networked, interactive products, both users and designers need a better understanding of how these products can potentially work together. User interaction is changing from interaction with single products into interaction with a larger system of products. This trend faces designers with a challenge: to create meaningful interactions for users to deal with the complexity of the larger ecosystem of technologies users function in. In this article we introduce an interaction paradigm, where we view smart environments in terms of connections and associations between the actors and artefacts within the environment. In this notion of Semantic Connections, meaning is pivotal. We report on a search for a theoretical foundation for our approach in existing semantic theories. We attempt to use and extend these theories beyond their traditional focus on the appearance of objects and interaction with them in isolation, towards designing for systems of interoperating products. We illustrate our contribution by providing examples of products and design prototypes that implement our ideas. Although our research is ongoing and the theory unfinished, we believe that sharing our work can fuel the discussion on how designers may deal with the challenges in contemporary interaction design.

## Keywords
Product semantics, interaction design, smart home.

## 1 Introduction
The environments that people inhabit are occupied by a growing number of digital devices and gadgets. Many of these devices may be connected to the Internet, wireless networks or other devices. Interaction with networked devices is changing from interaction with a single device, to interaction with a larger system of devices. Some of these devices are becoming portals to information stored somewhere else (e.g. online services). Others have the potential to share information like multimedia content, data, device capabilities and services. However, we have not yet succeeded in seamlessly operating among these devices. Especially when we consider the way user interaction was envisioned in paradigms like Ambient Intelligence [1], Pervasive Computing, Ubiquitous Computing [2] and the more recent notion of an Internet of Things [3]. The key goal of ubiquitous computing[1] is "serendipitous interoperability", where devices which were not necessarily designed to work together (e.g. built for different purposes by different manufacturers at different times) should be able to discover each others' functionality and be able to make use of it [4]. Future ubiquitous computing scenarios involve hundreds of devices, appearing and disappearing as their owners carry them from one room or building to another.

[1] In this article we adopt the paradigm of ubiquitous computing, as this matches our understanding of a smart environment the closest.

Therefore, standardizing all the devices and usage scenarios a priori is an unmanageable task.
Besides the technological challenges, there also lies a challenge ahead for designing user interactions with these ecosystems of interconnected devices. When moving away from interaction with a single device towards interactions with systems of devices, designers need to find ways to communicate the relationships between the devices and the larger system they are part of. Additionally, designers need to find ways to communicate the action possibilities of new, "emergent functionalities", that emerge when devices are being interconnected. As Bill Buxton stated at the 2010 Design by Fire conference:

*The real problems are not with any single device, but in the complexity, the potential complexity of the larger ecosystem of technologies that we function in. [...]*
*It's about how this device works with that device, whether it's from the same or a different manufacturers; it's the complexity of the ecosystem. Why aren't those things about the interoperability taking more of a point? It's about the society of appliances and how they work together, which is the new frontier [5].*

An important problem that arises when designing for these systems of interactive objects is their highly interactive and dynamic nature [6]. The inherent ever-changing nature of these systems and the severely limited overview of the ecosystem in its entirety is one of the most important challenges a designer faces when designing for such systems. Additionally, such a system comprises many different "nodes" that the designer, at the time of designing, has no control over. Yet, when designing and adding new nodes to the system, making them interoperable is crucial for success.
In this article we introduce an approach to systems, focusing on the inter-device relations and connections that exist or may potentially exist. We see these relations 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. The context of the connections and the things that they connect are pivotal for their meaning. Previous work has resulted in similar approaches. Newman, Sedivy, Neuwirth, Edwards, Hong, Izadi, et al. have developed an approach, which they named recombinant computing [7].

How objects of design acquire meaning throughout their use has been the subject of design research for many years. The process of making sense of artefacts is described by theories such as product semantics [8], product language [9], semiotics [10] and the theory of affordances (a term originally coined by Gibson, but introduced to the design community by Norman [11]). While these theories provide handles for designers when designing (simple) products and to some extent also for designing interactive products, they have not yet shown their potential for providing handles for the design of systems of interoperating devices.
In this article we present an approach to designing for user interaction in smart environments called Semantic Connections [12]. Central to this approach is the focus on the semantics – or meaning – of the connections between artefacts in such a smart environment. We report on a search for a theoretical foundation for our approach in existing design and semantics theory, and re-apply the theories to our notion of connections or associations between artefacts.

## 2 Semantic Connections

To address the problems as outlined in the introduction, this section introduces an approach to interaction with a system of devices in which the connections and associations between the devices play a central role. Before we give an extensive review of existing semantic theories and discuss their implications for our approach, we first introduce our semantic connections interaction model.
Semantic connections is a term for meaningful connections and relationships between artefacts and entities in an ecosystem of interconnected and inter-operating devices. These connections can be viewed as both the real, physical connections (e.g. wired or wireless connections that exist between devices) and mental or conceptual connections that seem to be there from a user's perspective. The context of the connections (what things they connect) is pivotal for their meaning. The term "semantic" refers to the meaningfulness of the connections. We consider the type of connection, which currently often has the emphasis when interconnecting devices (e.g. WiFi, Bluetooth, USB) not to be the most relevant, but what the connection can do for someone – its functionality (e.g. stream music, share files) – even more. Semantic connections exist in both the physical world and the

digital domain. They have informative properties, i.e. they are perceivable in the physical world and have sensory qualities that inform about their uses. However, these physical qualities might be hidden at some times, or only accessed on demand. We envision semantic connections to exist between objects, people and places. Not only objects and devices have meaning in a system of networked devices. According to [13], physical location within the home and device ownership (or usage) are of central importance for understanding and describing home networks by users. Amongst places, people and objects, we specifically consider semantic connections to exist between:

- artefacts;
- smart objects;
- sensors;
- UI elements;
- places;
- (smart) spaces; and
- persons.

Semantic connections have properties like directionality, transitivity and modality (i.e. what things they carry). Connections can be one-to-one, one-to-many, many-to-one and many-to-many. Connections can be persistent or temporary.

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 feedforward to strengthen the meaning of the connections and the emerging functionality [14].

The interactions with the connections and the objects that are connected are the carriers of meaning. This meaning may be supported or augmented with informative concepts like symbols, icons and indication functions [15]. We may need to rely on metaphors and symbolic and iconic meaning, because they provide the flexibility and expressiveness of language. Affordances are crucial but limited. They invite for a certain action, but only communicate the purpose of the action to a certain extent. Communicating what will be the result of an action – feed-forward – is the real challenge as the action itself is not the goal of the user.

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 steps (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.

### 2.1 Semantic Connections Interaction Model

A user interaction model for semantic connections is shown in figure 1. It describes the various concepts that are involved in the interaction in a smart space and shows how these concepts work together.

The interaction model was inspired by the Tangible Interaction model (MCRpd) by Ullmer and Ishii [16], which in turn was based on the Model View Controller (MVC) model. We distinguish between the physical part of the user interaction and the part that takes place in the digital domain. A user cannot directly observe what is happening in the digital domain (and should not) but experiences the effect it has in the physical world, by interacting with the various smart objects and the (semantic) connections that exist in-between them. In doing so, users create a mental model of the objects/system they are interacting with, which only partly (or not at all) includes the digital part. Digital information manifests itself in the physical world as data, media and services. When a user interacts with a smart object connected to the smart space, he/she senses feedback and feedforward, directly from and inherent to the controls of the device (inherent feedback), digital information augmented onto the physical world (augmented feedback) and perceives the functional effect of the interactions (functional feedback). The terminology, inherent, augmented and functional feedforward and feedback is adopted from [14]. The user actions in the physical world are transformed into interaction events and events/state changes, using semantic transformations. This interaction data in terms of user intentions is stored in the smart space[2], possibly together with user preferences, defaults and context information.

[2] The notion of smart space means that data is stored centrally, and can be accessed by the various smart objects in the smart space. For more information on these concepts refer to [17].

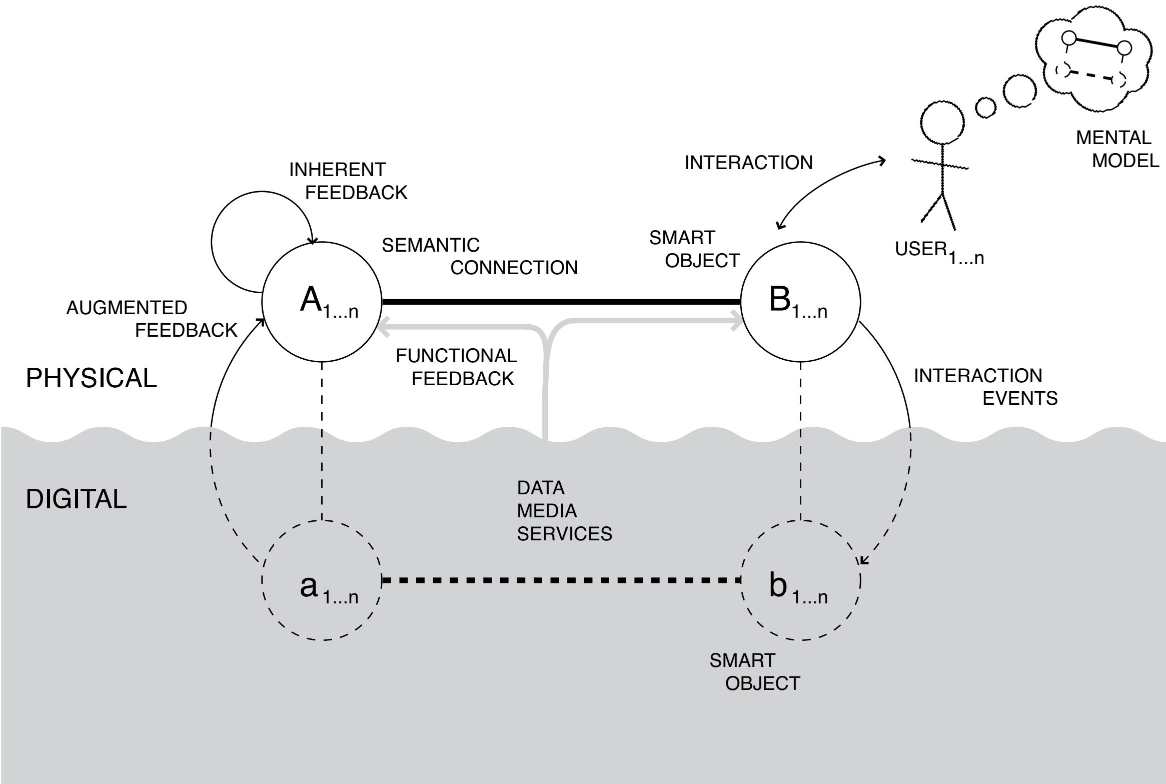


**Fig. 1. Semantic Connections user interaction model.**

## 3 Design Semantics Theory

### 3.1 Direct Approach – Interaction Frogger Framework

The Frogger framework, as was introduced by Wensveen [18], describes user interaction in terms of the information a user perceives, (like feedback and feedforward) and the nature of this information. It distinguishes between inherent, augmented and functional information. These types of information can serve as couplings between user actions and the products' functions in time, location, direction, modality, dynamics and expression. Although the framework was designed to describe the interaction with electronic devices and their interfaces, many of the concepts in the framework are applicable to our semantic connections concept as well.

When a user performs an action and the device responds with information that is directly related to the function of that product (lighting switching on when a light switch is operated), we speak of functional feedback. When a device has more than one functionality, functional feedback should be viewed with respect to the users' intentions and goals when performing the action. If there is no direct link between a user's action and the direct function of the product, or when there is a delay, augmented feedback can be considered to confirm a user's action. This feedback is usually presented in the form of lights, sounds or labels. Inherent feedback is directly coupled (inherently) to the action itself, like the feeling of displacement, or the sound of a button that is pressed.

While feedback is information that occurs after or during the interaction, feedforward is the information provided to the user before any action has taken place. Inherent feedforward communicates what kind of action is possible, and how one is able to carry out this action. Inherent feedforward is in many ways similar to the concept of affordances, revealing the action possibilities of the product or its controls [18]. When an additional source of information communicates what kind of action is possible it is considered augmented feedforward. Functional feedforward communicates the more general purpose of a product. This type of information often relies on association, metaphors and the sign function of products, which are described by theories such as product semantics [8] and product language. Good practice in creating inherent feedforward is making the functional parts of a product visible, informing users about the functionality of the product [11].

**Implications for Semantic Connections.**
If we view semantic connections in terms of the Interaction Frogger framework, the following interesting insights emerge:

*Feedback:* When we consider multiple interconnected devices and the functionalities and services they provide, information like feedback and feedforward gets spatially distributed. A user may operate a device, receiving inherent feedback locally, but receiving augmented and/or functional feedback remotely. In figure 1, the several types of feedback are indicated. As inherent feedback is inherent to the operational controls of the device, these reside only in the physical world and are local to the device. Augmented feedback is feedback that is augmented from the digital domain onto the physical world. This type of feedback is subject to change when devices get connected to other devices. In the domain of networked digital artefacts, functional feedback is of a digital nature. Data, media and services that exist in the digital domain become available in the physical world, through the various devices and their connections. Although many functionalities of digital devices can be regarded as (displaying) media, data or services, for some simple functionalities this seems problematic. If we, for example, look at functional lighting, it seems that the presence of light as the functionality of a lighting device is not a very digital concept. However, if we view a lighting device as a networked smart device, the presence of lighting, based on some sensor data, can be considered the functionality of a digital service.
But what about the semantic connections themselves, do they have these types of feedback as well? When we approach the connections as if they were physical entities with which one can interact, be it through an interaction device, they do provide these types of information as well. However, how this happens and what kind of information it is, is slightly more complicated. Inherent feedback is feedback that is mediated through an interaction device, as one cannot manipulate a connection directly. This inherent feedback may however be closely related to the action of making or breaking a physical connection, like a snap or click when the connection is made or broken. Augmented feedback to indicate a connection may be in the form of lights, or in the form of projected or displayed lines. Functional feedback is information about the actual function of the connection, like the sound from a speaker that was just connected to a media player. This type of feedback always reaches the user through the devices being connected. Figure 2 shows examples of these types of feedback in designs that were created for this research.

*Feedforward:* Inherent feedforward, conceptually similar to the notion of affordances, provides information about the action possibilities with the devices or the individual controls of an interface. Similar to this are also informatives [8, p. 117] and partially also indication or marking functions as defined in the theory of product language [15]. Inherent feedforward is always physical and locally on the device. However, when devices or objects are part of a larger system, feedforward also emerges where interaction possibilities between objects exist (e.g. a key that fits a lock, a connector of one device or cable that fits another). The same holds for augmented feedforward, lights, icons, symbols and labels that provide additional information about the action possibilities. These may concern the action possibilities locally at the device, as well as action possibilities that concern the interaction with other devices in the environment. While inherent and augmented information are primarily concerned with "the how", functional feedforward communicates "the what", the general function of the device or the function of a control. This type of information often relies on association, metaphors and the sign function of products, and is described in theories such as product semantics and product language. With multifunctional digital artefacts, and even more with networked artefacts, this becomes increasingly difficult. Introducing the concept of semantic connections tries to address these problems; therefore the functional feedforward is the main challenge when designing semantic connections. Functional feedforward should give information about the function of the semantic connection before the interaction takes place. Properly designing functional feedforward is therefore the crucial part of understanding semantic connections, smart services and smart environments.

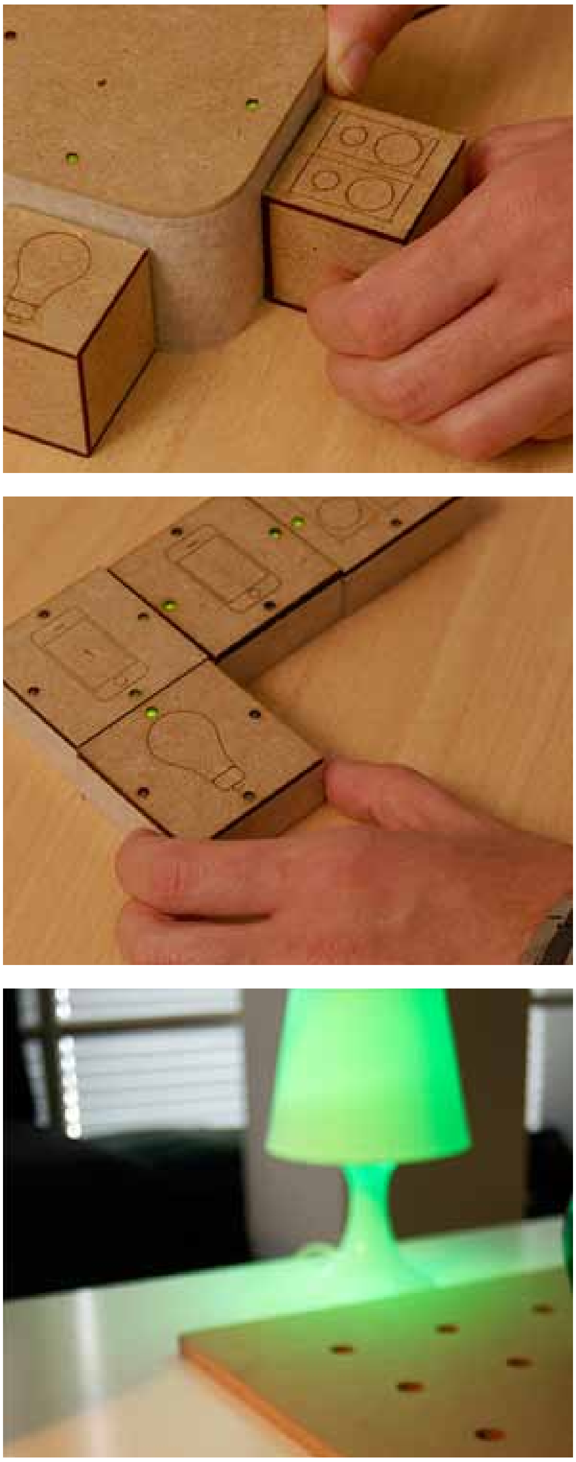

**Fig. 2. Examples of the different types of feedback: (a) Augmented feedback; (green) lights showing a connection currently exists. (b) Inherent feedback; the feeling of a "snap" when two tiles are aligned. (c) Functional feedback; a light rendering the mood of the music when a music player is connected to it.**

Wensveen [14] further proposes that in interaction, these types of information can link action and function together in time, location, direction, modality, dynamics and expression. Strengthening these couplings between action and function will lead to richer and more intuitive interactions [18]. We can also view semantic connections in the Frogger framework in more general terms. Although semantic connections are not a physical device or product, but rather describe the structure or configuration of a system of devices, the Frogger framework can teach us important lessons. When we look at the link between action and functional information in time or location, a strong link would mean they coincide in time and location. For location this would mean that the connection that is made between devices corresponds to the location of the actual devices in physical space. Additionally, the direction of the action of connecting/disconnecting devices, being moving devices towards or away from each other, would strengthen the coupling in terms of direction. Also, the direction of the action could have a link to the directionality of the semantic connection that is made. This is similar to the couplings in dynamics.

### 3.2 Product Semantics

As discussed previously (to some extent), the theory of product semantics describes and analyzes the meaning of products in terms of what a product is and to a certain extent how it can be operated. Product semantics is a theory about how products acquire meaning. Krippendorff states in his work The Semantic Turn [8]: "Humans do not see and act on the physical qualities of things but on what they mean to them" [8, p. 47] and "One always acts according to the meaning of whatever one faces. [...] It always concerns sets of possibilities and presupposes human agency" [8, p. 58].

Krippendorff [8] thus differentiates between the intended meaning of the designer, leading to the design, and the meaning it eventually acquires after interpretation and reinterpretation by the user during use. These two meanings are different things and the meaning that a design has for its user may be a different one than the meaning the designer intended. This concept of meaning is in accordance with information theory, where the designer is viewed as a communicator of a message in the form of a product and the user as a receiver of that message [19].

Krippendorff's semantic theory has, as briefly discussed before, a very human-centered approach; as he states: "meanings are always someone's construction [...] meanings are always embodied in their beholder" [8, p. 56]. He also argues for conceptual openness, as meaning emerges in the process of human interaction with artefacts. "Meanings are neither intrinsic to the physical or material qualities of things, nor can they be located within the human mind. [...] Meanings are constructed from previous experiences, expanded on them and drift, much like imagination does" [11, p. 56]. All meanings are context-dependent as usually many meanings are possible, but only few of them make practical sense. Artifacts may mean different things in different contexts and may mean different things to different people. Contexts limit the number of meanings as "artifacts mean what their contexts permit" [8, p. 59]. Contexts work in two directions, in the sense that one thing provides the context for the other and vice versa. For artefacts this means that "the meaning of an artefact's parts depends on the meaning of their arrangements, just as the meaning of its arrangements depends on that of its parts" [8, p. 61]. Krippendorff compares understanding complex artefacts with reading texts, with the distinction that one can interact physically with an artefact, in contrast with only visually perceiving a text.
Krippendorff [8] speaks of four main mechanisms of how artefacts acquire meaning: meaning of artefacts in use, meaning of artefacts in language, meaning in the lives of artefacts, and meaning in an ecology of artefacts. For our semantic connections, both the first and the last of these mechanisms invite a closer look.
Meanings of artefacts in use: Norman distinguishes between surface artefacts (what you see is all you get) and internal artefacts, of which the latter needs interfaces to represent and allow control over its internals. The majority of problems with usability and the constructions of meaning occur with internal artefacts. Krippendorff describes interfaces and states that: "Humans always act so as to preserve the meaningfulness of their interfaces" [8, p. 84]. When using a well-designed interface users go through the stages of:

**Recognition:** correctly identifying what something is and what it can be used for;
**Exploration:** figuring out how to face something, how it works, what to do to achieve particular effects, and
**Reliance:** handling something so naturally that attention can be on the sensed consequences of its use.

For recognition, (product) categories, (visual) metaphors and attractiveness play an important role. By finding resemblances in form and finding closeness to ideal types of a product category, people can recognise artefacts for what they are. Artefacts deviate from ideal types in dimensions, varying within certain boundaries of dimensions that define an artefact. They may also vary in features, dispensable additions to an artefact that do not alter its identity. As an example consider a smart phone. With or without many of its features it would still be a phone, as long as its core function is preserved. When we have to recognise new artefacts we can rely on the meaning of existing artefacts by using metaphors. Central to the stage of exploration are User Conceptual Models (UCMs), which are mental models of how artefacts could work, when to do what, and what to expect as a consequence of one's actions. Affordances and (physical) constraints are important mechanisms to invite users into actions and guide users in an artefact's possible use. Other conceptual handles for designing interfaces are informatives and semantic layering. Informatives are similar to the concept of "indication functions" in the theory of product language and essentially guide and inform users about the flow of the interaction. Informatives include: signals, state indicators, progress reports, confirmings, affordings, discontinuities, correlates, maps of possibilities, error messages and instructions.

*Meanings in an ecology of artefacts:* Looking at artefacts as a species, that are part of an ecology of things, is an interesting viewpoint. There is a crucial difference between ecologies of things and biological species however, as is pointed out by Krippendorff "biological species interact on their own terms; artefacts interact on human terms" [8, p. 195]. Technological artefacts do not know of each other but "interact with each other on account of the designer's specifications and/or users' desire to connect them" [8, p. 195]. Krippendorff [8] distinguishes between diachronic accounts and synchronic accounts to analyse ecologies of artefacts. While for a diachronic account artefacts are being traced according to their evolutions, a synchronic account "describes the network of concurrent

connections between artefacts that co-determine their use" [8, p. 197]. Important here are: causal connections (actual physical connections); family resemblances (belonging to the same product family, part-whole relationships); metaphorical connections (carry meaning between one, more familiar species of artefacts to another species) and institutional liaisons (different institutions are depending on the same species of artefacts).
Within the context of smart environments, an increasing amount of automation and increasing interconnectedness may have a negative impact on the meaningfulness of products. Artefacts can no longer be considered in isolation, as they are part of a larger ecosystem of technologies that we interact with.

**Fig. 3. Example from our research; using a spotlight metaphor to project connections into the physical world.**
**The Spotlight Navigation device (top); and projecting the wireless connections between devices (bottom).**

Therefore, designers need to provide users with handles and clues to make them understand and enable them to be effective in such an ecosystem of technologies, to understand what is happening and allow them to be and feel in control.

**Implications for Semantic Connections.**
Considering the theory of product semantics, and in particular Krippendorff's view on semantics, we can start defining what implications this has for our concept of semantic connections.
Building on Krippendorff's user-centred approach to meaning, we should be careful when indicating that a certain connection has a certain meaning. Although it might have a certain predefined functionality, what it will come to mean for its users is not entirely for the designer to control. By taking a second-order viewpoint, and using principles such as metaphor, affordances and informatives to support the phases of recognition, exploration and reliance, designers can, however, provide circumstances that increase the probability of the intended meaning to come across.
For semantic connections this might mean that we have to look for reliable metaphors like physical cables and the interactions with them. Or like using a spotlight metaphor to explore connections that are invisible without using it (figure 3).
Physical constraints and informatives like signals, state indicators, affordances or discontinuities in form might help to indicate where and how to act; how to make or break connections, and which devices allow (and which do not allow) to be connected. Additionally, the notion of causal connections that link artefacts together, like wired or wireless networks, that is known and understood, provide helpful clues. Also the notion of family resemblances, where portable media players, stereo sets and speakers belonging to the same product families, might provide practical understanding of what a connection, connecting products of this family (with music playing capabilities) together, might mean and what the emerging functionality will be. Looking from an ecological perspective the following should be considered:

- The meaning of a semantic connection depends on the meaning of the artefacts it connects.
- Semantic connections work in mutual cooperation. They depend on other species (smart objects) and also support them.

- Semantic connections might also have competitive interactions with other artefacts. Emergent functionalities through interoperability between artefacts could eventually lead to less objects around us. By combining the functionality of several artefacts, others might become obsolete (e.g. combining a printer and a scanner gives copying functionality).
- Semantic connections may also have a cooperative relationship with other artefacts, because more smart objects might result in more semantic connections being made.

### 3.3 Ecological Perception

Although the theory of ecological perception and the concept of affordance has been briefly discussed in some of the previous sections, we would like to discuss the theory and its implications a bit further. While many of the semantic theories discussed depart from a semiotic/ linguistic and communication perspective, the ecological approach to perception has an entirely different theoretical foundation. Despite these differences, it will also become clear that on a practical level, the resulting designs might rely on similar perceptual qualities. Affordance, which is a central concept of ecological perception theory, is the property of an object that appeals to our sensory-motor skills, like a door-handle that "affords" to be grabbed and a chair that "affords" to be sat upon. When the insights of ecological perception were introduced into design by Norman [11], it fuelled the design community to try and solve many usability problems. Whereas on a practical and application level not necessarily relevant, Norman's view of affordances is slightly different from the original thoughts of Gibson and many like-minded psychologists [11, p. 219]. Central to the notion of affordances is the inseparability of humans and their environments, as humans have always dealt with their environments going through evolution. Affordances can thus neither be seen independently from humans, nor can they be viewed independently from the environment. For affordances to be detected, they need to be available as information that can be perceived by the human perceptive system. Secondly, they need to be viewed in relation to the bodily properties of every individual. While chairs may afford seating for adults, it may afford something else for children that might play underneath it [20]. Furthermore, when designing complex products and interfaces, affordances often work well for inviting users to perform certain actions that the controls allow for. This does not necessarily indicate what the results of such an action will be. This is acknowledged by Djajadiningrat [21]; however, he also successfully shows that the notion of affordances can be used as a framework for design.

**Implications for Semantic Connections.**
Because connections/relationships between networked artefacts are not physical, and perhaps only mental constructions, affordances are a difficult concept in this context. We can create affordances for the control over these connections, but they will most likely only reveal how to manipulate the connections/relations, and not be very informative about the nature of these connections. Here, associations and meanings of the artefacts and their capabilities are important, which are learnt and rooted in convention and previous encounters with products. However, affordances can be used to invite users to perform certain actions, and these actions can carry meaning. To give a few examples of possibilities - the affordance of a control to make a connection can be shaped in such a way that it invites an action that may associate it with permanent or non-permanent connections, like a locking action after inserting a connector into a socket. Furthermore, there can be the affordance that invites the movement of a control in a certain direction (e.g. a sliding switch). This direction may in turn translate into the directionality of a connection. Some of these ideas have been implemented in the design of a digital camera and a VCR controller as described in [21].

## 4 Discussion

In this article we have discussed various theories of design and sense making. Much of the design theory described is, however, about the meaning of objects (or sometimes language) and originates from the era of non-interactive, mechanical and electric products and machines. With the introduction of microelectronics and digital electronics, many of these theories have been reconsidered to accommodate for interfaces and interactivity, and some have evolved into new ones. Now that we have entered the era of digital networked artefacts, which introduces additional concepts and complexity, these theories may need to be reconsidered; especially when considering that the networking technologies that connect these devices are

wireless and thus invisible. Even if we find ways to shape objects in such a way that they reveal their connectivity, how will they inform users about the possible connection types and the emerging functionality?
Today networked objects are often recognised by their LCD screens, as part of a product category of "smart objects", or desktop, portable or wearable computers. Developing a form language and interaction paradigms for such products is a challenge that a large part of the (interaction) design community is and has been working on. Despite these efforts, today's products remain mainly GUI-based and these GUI's are the most important means for controlling connectivity.
The semantic connections interaction model and underlying theory proposes to reveal these invisible connections and allow direct physical control over them, like we have control over many physical wired connections. To support this, part of our semantic connections interaction model also proposes a software architecture to solve the current interoperability problems to a certain extent. This software architecture enables networked devices to exchange information and share device capabilities. Together this is expected to enable users to interact with the various devices in the system on a higher, more goal-oriented level, moving away from the current device-oriented way of interaction. Even though our approach still has to prove itself in practice, our experimental prototypes and setups show potential.
Wensveen et al. [14] propose an approach they refer to as the direct approach, which departs from the idea that not only the physical appearance of a product, but also the actions it invites users to perform, are carriers of meaning. They argue for a strong link between the qualities of an action and the result of that action, as is described in the Frogger framework [18]. The notion of feed-forward is pivotal in this direct approach, especially functional feedforward (as described in section 3.1). For our notion of semantic connections, we rely on several mechanisms to provide this (functional) feedforward. First of all we rely on natural mappings [11]. The connections or associative links are created between devices, places, persons or interactive parts of devices, that all exist in the physical reality. Instead of relying on identifying networked devices by name or other types of representation, we identify them by their physical location, where users can perceive them, point at them and touch them. Secondly, we rely on the meaning of the devices that are being connected, in particular the resemblances in meaning of the devices being connected. Important here is the change in meaning that might occur, when users view the device no longer in isolation, but as part of a larger system. Krippendorff [8] discusses these part-whole relationships (as is described in section 3.2). Thirdly we rely on feedback and feedforward being provided by a mediating device or service, which has the special purpose to enable exploring and manipulating the – otherwise invisible – connections. We not only consider which things are connected, but also how these connections are made. This is where we have the freedom to carefully craft the way we discover and manipulate these connections, to provide additional information about what the connection will mean once it is made. Once the connection is active, in many cases the functional result in the physical environment will give additional feedback on the success and functionality of the connection that was made.
Although we believe that our approach will contribute to the necessary paradigm shift in user interaction, needed to accommodate interaction with systems of devices in contrast with single-device interactions, we realise our contribution is only a start. However, we are convinced that sharing this viewpoint and its theoretical foundation with the design community can be beneficial for starting the discussion amongst a larger audience than primarily the ubiquitous computing research communities and interaction designers working in that area.

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