In Touch with Representation: Iconic, Indexical and Symbolic Signification in Tangible User Interfaces

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Abstract

In this paper, we discuss the value of semiotics to inquire tangible user interfaces (TUI) in human-computer interaction (HCI). Drawing on Peirce's three types of representation – icon, index, and symbol (Peirce, Houser, & Kloesel, 1998) – we analyze signification processes in the design of tangible UIs. As a case study, we draw on several prototypical interfaces and analyze their semiotic structure. We focus specifically on three different significations for a similar application on a mobile phone: Displaying a new event on a mobile phone (e.g. an unread text message or a missed incoming call). The aim is to establish a basis in semiotics for TUIs that can inform the mapping between physical and virtual parameters. Taking semiotics as basis can help to enhance interface design as the interface 'specifies the optimal set of signs for the interaction between two entities' (Nadin, 1988, p. 273).

Keywords

tangible user interfaces, semiotics, representation, interface design, design research.

Tangible UIs is an emerging research field as the value of haptic perception in HCI is getting more and more into the focus of research and development endeavours. At the same time, easy handling and low-cost availability of prototyping tools for physical interaction (e.g. the Processing environment or the Arduino board (Cuartielles, Banzi, Mellis, & Igoe)) opened up new opportunities for interaction design. Today, it is possible to design prototypes for new digital products rapidly, making the interaction concept explicit and developing it further in fast iterations. Therefore, the production cycle for tangible UIs became shorter, and prototypes in the status of 'perpetual beta' are increasingly popular in interaction design. This practice can be described as *thinking through prototyping,* as the design of the actual prototype plays a major role in the whole research process.

Therefore, it appears crucial to provide a theoretical foundation for the interactive processes that are enabled through these interfaces. We propose that combining the *efficient practice of tangible interaction* with the *analytical potential of communication theory* might provide a basis for findings beyond a purely practice-based approach in HCI. Therefore, we argue that it is worthwhile to investigate the underlying *semiotic principles* of tangible UIs – principles that are derived from the study of signs in communication processes and applied to interactive communication between humans and computers. Physical representations of the virtual can be designed in various ways for TUIs, and semiotics can provide a valuable guide to find the right signification for a given purpose, including parameters like function, context, user, and interaction.

Background

In this section, we discuss relevant findings in *semiotics* and *tangible interaction design*, in order to provide a foundation for the semiotic analysis and contextualization of the three tangible UIs presented in this paper.

Icon, Index and Symbol in Semiotics

Charles Sanders Peirce introduced three basic semiotic categories that describe the relation between Object, Representamen, and Interpretant (Peirce, Houser, & Kloesel, 1998). The *icon* 'is a sign fit to be used as such because it possesses the quality signified.' [p. 307] Peirce gives the example of a geometrical figure drawn on a piece of paper that resembles a triangle. The *index*, the second category of signs, is a sign that is 'in real reaction with the object denoted' [p. 307]. His example is a weathercock that is physically connected with the wind, and, being a sign, is an index of the wind. The third category, the *symbol*, is defined as a sign that ‘determines the interpretant sign’ [p. 307]. Peirce’s example is language itself, as it has a fundamental symbolic relation between letter, word and meaning. These categories had a deep impact on describing all processes of signification, especially when it comes to visual and iconic representation as in visual rhetoric or semiotics.

If we understand all design production as rhetorical action, as Richard Buchanan states (Buchanan, 1985), we can also apply these semiotic categories to interface and interaction in HCI. If we want to understand the communicative purpose of an interface and its semiotic structure, we can refer to *icon, index,* and *symbol* as basic categories. Hence, it is now aimed to understand the relation between the semiotic representation, the communicative function and the tangible UI. Mihai Nadin applied Peirce’s semiotic paradigm to interface design in the late 1980s with a fundamental conclusion for interface design as such: ’Since the technology upon and for which we build interface changes very rapidly, pan-logical semiotic principles, in their breadth and depth, provide a foundation for improved interface design’ (Nadin, 1988, p. 283). In his article, he investigated Command-Line Interfaces as well as GUIs. In this paper we argue that the basic assumptions and semiotic categories can also be applied to tangible UIs.

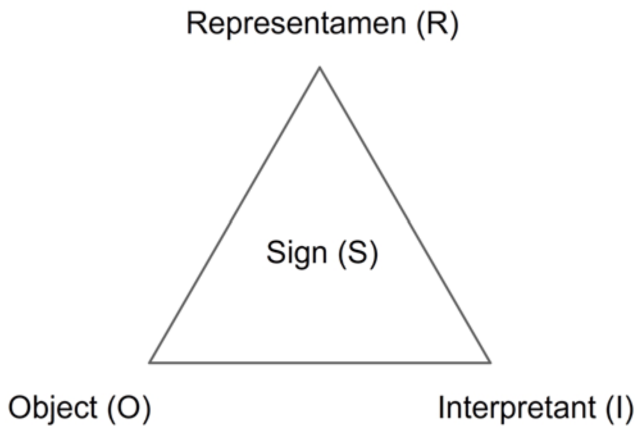

Figure 1, Peirce’s definition of Sign.

Iconic, Indexical, and Symbolic Representations in Interface Design

Gui Bonsiepe defined the interface as a device turning ’Vorhandenheit‘ into ‘Zuhandenheit’, drawing on Heidegger’s terminology. Therefore, he stressed the tool character of the interface as such and shed light on the aspect that an interface is more a relation between user, tool, and artefact than a simple input and output device. Nadin also enhanced the definition of the interface by defining every point of contact between user and computer system as part of the interface. As a result, there are many interfaces between the whole computer corporation and the market with users and potential users (Nadin, 1988, p. 274). We follow this broad definition of the interface when looking at tangible UIs. Furthermore, we stress aspects of time and physical space of interaction that draw on concepts of embodiment as being a specific quality of tangible interaction. Ishii and Ullmer, in 1997, proposed this style of interaction that couples ‘bits and atoms’ (Ishii & Ullmer, 1997).

Regarding the semiotic categories for interface design, the question is how object, representation and interpretant relate to each other in order to form a sign in the communication process between the entities. It is crucial to understand that the interpretant is not equal to a single user, but rather it characterizes the process of interpretation in which various users can be involved. All these significations (iconic, indexical, symbolic) are actualized through the interpretant and its human agency. Without this process of actualization there *is no* sign. Therefore, the interaction between object, representamen and interpretant in human-computer-interaction puts the signification into place.

The question is how iconic, indexical, and symbolic signification is used in interface design and in which forms they occur. Nadin gives the example of a virtual calculator that can be represented in all three forms – from an iconic representation of a physical calculator to a symbolic representation of the mathematical operations of calculating. In tangible UIs, the physical dimension comes into play and expands the realm of signification. The relation between object, representamen, and interpretant changes as there is no physical object being represented, but rather a function or action that is represented by the interface. This representation is actualized through the process of usage.

Signification in Tangible UIs

Iconic representations can be found in mappings based on *resemblance.* The icon resembles its representation in a certain way, although it can be an abstraction like we learned it from Peirce's example of the geometrical figure. When we look at Graphical User Interfaces (GUIs), we encounter some common examples of iconic representation, like e.g. the trash bin for the function of 'deleting files'. For TUIs, it is much harder to find examples as we are facing physical representations of virtual concepts.

In the LucidTouch project, Wigdor et al. (Wigdor, Forlines, Baudisch, Barnwell, & Shen, 2007) introduced a 'pseudo-transparent' device that displayed the user's fingers, interacting at the back of the device, on its display. The fingers on the device's back are filmed by a camera, and then shown on the display, as for enabling them to be used in the interaction with the GUI. The interaction with the device is, as the Wigdor et al. demonstrated, intuitively understandable, flexible in terms of its applications, yet limited to 'fingers represented by fingers'. The signs on screen resemble the fingers that touch the back of the device, and therefore, we can call it an iconic representation. In this example, we see a hybrid interface being a GUI with graphical display, and at the same time a tangible interface, because of its rich integration of the fingers into the virtual space (on the screen).

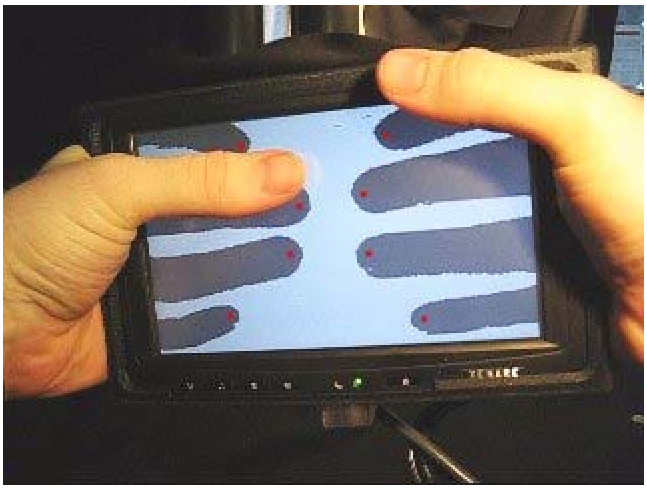

Fig. 2: The LucidTouch device.

Indexical representations can be observed in devices that draw on a *causal relationship* between digital entity and physical counterpart. In the FeelSpace project (Nagel, Carl, Kringe, Märtin, & König, 2005), Nagel et al. augmented users' perception with 'orientation information, obtained by a magnetic compass, via vibrotactile stimulation around the waist'. Here, the vibrotactile stimulation indicated the direction of north.

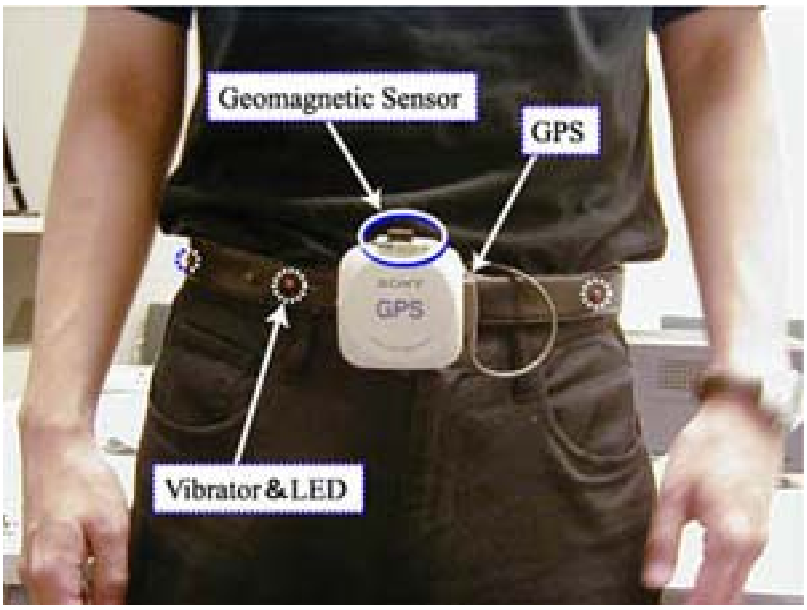

Fig. 3: The FeelSpace belt.

The actual digital data (zeroes and ones, respectively magnetic measurements data) is not represented in an iconic way here. Rather, it is interpreted, brought into connection with the belt's orientation, and then *linked* to a vibration into the direction of north. Therefore, we find an inherent link between the information and its representation within the TUI, an indexical representation. This kind of interpretation and reduction to a simple physical signal can be found more often in tangible interfaces. As the output channels are in many examples primarily used to provide a physical cue about the digital contents to the user, the representation is indexical. The model therefore is to have an output signal to the user that s/he can perceive in a haptic manner

Symbolic representations can be of use in many encoded physical representations. The *Marble Answering Machine* by Durrell Bishop (1992) is an example for such a type of representation. Here, a marble represents a message left on an answering machine. The user can interact with this object: Putting the marble into a hollow plays back the message. In this example, we find a *symbolic representation* of the digital content – a left message – that is translated into a tangible object, a marble. This mapping is not inherently obvious, as the data entity 'message' does not relate directly to the concept of 'marble'. In this symbolic representation, two semantic fields are connected that were separated before: a voice message that is related to the functionality and logic of an answering machine and to the usage of phones in general – and the marble, that is associated with child play.

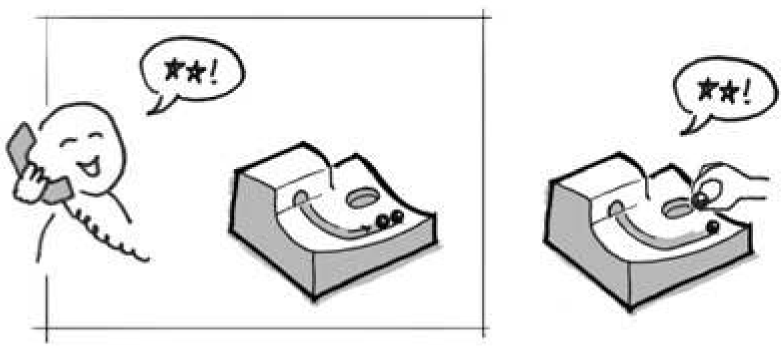

Fig. 4: The marble answering machine

Connecting these two fields adds a new semantic to both. The small, tangible children's toy gets an added functionality by representing a virtual voice message. The interaction with the marble still resembles the one of the children's toy: dropping it into a hollow, making rows of marbles, quite handy and easy. Therefore, this signification adds on the one hand a tangible interaction mode to a virtual message; on the other hand it applies the emotional value of a playful interaction to an answering machine. It should be noted that there is also an indexical component in this representation: The number of marbles 'waiting' on the device represents the number of messages waiting inside. In general, one finds often examples of a combination of different types of representations. As in the example of the answering machine, there are different layers of signification that form together the semiotic structure of the interface.

For now, we discussed examples for all three kinds of representation following Peirce's model. Therefore, we focused on the relation between a function and its semiotic translation within the interface. We discovered a higher degree of complexity in the semiotic structure of the three examples: an iconic and 'direct' representation of the user's fingers on the display; a tangible output signal representing certain information about directions; and a symbolic representation of missed calls adding a new layer of semantics to an answering machine.

In the following, we will draw on a case study of tangible UIs on mobile phones. We compare three different mappings for the same application: Displaying a new event on a mobile phone.

Case Study: Three Examples of Representation

We will now analyze from a semiotic point of view three research projects that we conducted in the past years: The *Dynamic Knobs* project (Fig. 5a), which employed an *indexical* representation, a project named *Weight Shifting Mobiles* (Fig. 5b), which also followed an *indexical* approach, and the *Ambient Life* project (Fig. 5c), which drew on *symbolic* representation.

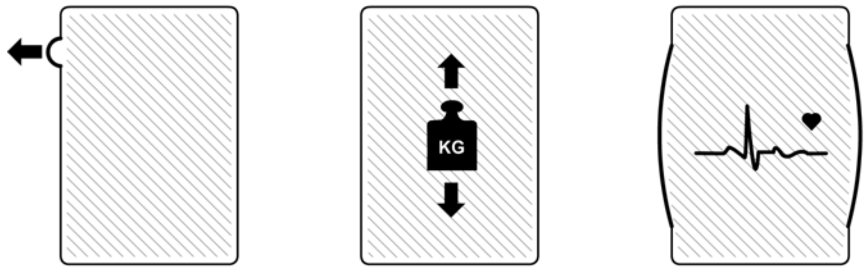

Fig. 5a-5c: Three prototypes, utilizing different means of user notification.

Dynamic Knobs: Indexical Representation

In common UIs of mobile phones, an event (e.g. new text message, missed call) is indicated on the display (GUI) as well as through a signal (vibration, ring tone). In the Dynamic Knobs project (Hemmert, Joost, Knörig, & Wettach, 2008), we utilized a physical representation of the mobile phone's internal events on its physical surface. A new event would result in a knob dynamically extending out of the phone's casing. Hence, the physical device itself changes its shape according to a change of status. The user can perceive an event in a tangible way by touching the physical shape of the device. The knob, a small entity sticking out of the rectangular shape of the phone's device, expands itself triggered by the internal event.

Fig. 6: The Dynamic Knobs prototype.

The principle is implemented through a servo motor in the phone's casing (Fig. 6), which moves a button out of the phone's case. On its surface, a pressure sensor is placed in order to measure the force exerted on it by a finger. The servo is strong enough to withstand most pressure a finger can exert, and the pressure sensor can measure weights between 10g and 10kg.

As soon as a call has been missed, the knob is extended out of the phone's casing. Therefore, we drew upon an indexical relation between an event (a missed call) and its representation (the physical knob). We argue that there is a physical relation between the sign 'protruding knob' pointing to the missed call (the event). Through interaction of the user by e.g. pressing the knob to listen to a voicemail, the sign is constituted. This interaction between tangible UI and user sheds light on the role of the interpretant. Through his or her interaction the process of signification is completed and the signs relates to its semantics.

This interface allows for direct interaction with the underlying virtual entities. In this particular example, the *being-there* of the message is particularly important, as its representation physically stands out of the phone's casing. Physical pressure can be applied to the – otherwise virtual – text message, like we discussed in the example of the marble answering machine. In further implementations, the length of a voice mail message was mapped to the length of the extended knob, so that the message could be 'squeezed' out of the phone while holding it next to one's ear. In this signification we find again a strong physical relation between sign and event when mapping the length of message with the extension of the knob. An indexical mapping with a physical representation allowed for convenient interaction with the digital content as the user had a direct hint how to interact with the interface.

User reactions

We conducted an informal user study with 6 users (2f, 4m, Ø32.2 yrs.), presenting them the prototype and asking them for their impressions. When confronted with this system and explained the concept of physical representation, they understood the pop-out knob as a *logical* representation of the digital entities. The approach was facing issues, however, when *more* than one event should be displayed, also *more knobs* would be required, as would other types of physical display for other types of virtual contents. Users emphasized that the principle proposed was *easily understandable*, yet *limited in its extendibility*. Nevertheless, the indexical representation was understood by most participants intuitively as being a reference to physical interfaces. Therefore, the signification seemed to be appropriate for the purpose.

Weight-Shifting Mobiles: Indexical Representation

In the second project, Weight-Shifting Mobiles (Hemmert, Hamann, Löwe, Wohlauf, & Joost, 2009), a moving weight was explored as a means of display in mobile phones. In one application, a new text message is displayed through the phone's centre of gravity being moved to the top of the screen. The message's placement inside the phone is physically *simulated*.

Fig. 7: Weight Shifting Mobiles Prototype

The proposed prototype employs a weight on a servo motor, which is affixed on the inside of a box. This weight-actuated box is then mounted underneath a mobile phone, which serves as the screen and button means for the 'weight actuated mobile'.

Interacting with a mobile device that employs an actuated centre of weight involves fine sensitivity for how the device *feels* in the hand. Its kinaesthetic behaviour changes with a moving centre of weight, and so, often, the information is perceived only in an ambient way, a circumstance that fitted the system's character of a non-visual information display. The event, e.g. a text message on the mobile phone, is signified in an indexical manner as it relates to a physical weight and location. A virtual event is therefore mapped to physical space and gravity. Interacting with the message, e.g. accessing it or browsing through a list of messages is assigned with physical parameters that are related to the interaction. This indexical mapping suggests a tactile sensing of navigation as well as a physical space and gravity of the mobile phone's informational space.

User reactions

A user test with 12 users (5f, 7m, Ø25.2 yrs.) was conducted. Users were engaged in a study regarding the accuracy at which they were able to estimate the weight's position, and also in a semi-structured interview that assessed their experiences. They appreciated the subtleness of the approach – they would be displayed additional information non-visually, yet perceivable while interacting. The idea of *information with weight as a sign of presence* in the device was considered intuitive, and was easily integrated with the users' interactions. However, users asked for *more realism* of the same interaction, e.g. to move the weight around in the phone by tilting it, instead of through the usage of buttons.

Ambient Life: Symbolic Representation

In the Ambient Life project (Hemmert, 2008a), a mobile phone is augmented with a permanent tactile heartbeat. Other iterations of the system (Hemmert, 2008b) included a 'breath'-like deformation of the phone's casing, following the same 'life-like' principle. In case of a new text message, the phone's heartbeat would then switch from the normal 'calm' heartbeat to an 'excited' pattern. This draws on the assumption that humans are inherently well-trained in the perception of life. It uses a *metaphorical signification*.

Fig. 8: Ambient Life Prototype

In the prototypes, the breathing is simulated through a servo motor that moves similar to a lung in a corpus. The heartbeat, as a second application, is simulated through a regular vibration motor, which is common to many current mobile phones on the market. The prototype of a mobile phone proposed in the 'Ambient Life' project informed the user about its state through instinctive cues. Interacting with it may, at first sight, be compared to interacting with a living being like a small animal. The metaphor would be a 'hamster in the pocket', as it simulates the mobile phone to be a living being, especially with an occasional need of attention. However, it is controlled through buttons and menus – not, as a real 'hamster' would – empathically, through touch and voice. It is, besides the pulse, purely technical. Therefore, the signification is symbolic as it maps two separated semantic fields – the one of living beings and its bodily functions and the one of virtual events on a mobile phone. The concept behind is to draw upon human ability to sense living being in an ambient way, like subtle breathing or heartbeat, and using it to inform about the status of a technical device. This mapping reminds of the children's toy 'Tamagotchi' from the 1990s were the user had to take care of a (non-functional) device like it would be a living being. This triggers a higher emotional involvement as it links to personal relationships in the real world. This prototype of 'Ambient Life' was, being a research prototype, not meant to explore new features of mobile phones for market use, but rather should trigger discourse on the question about our relationship to mobile devices today.

User Reactions

In a study, users (3f, 4m, Ø 27.1 yrs.) were handed the device and asked to carry it for two days. The phone randomly switched from 'calm' mode to 'excited' mode randomly several times per hour between 9:00 and 19:00. Users were instructed to 'take care' of the device, calming it down through a button press whenever it switched to 'excited' mode. The reactions to the heartbeat-augmented phone were mixed: In general, all users introduced to the phone fell into one of two groups: They would either perceive the device as 'cute', or perceive it as 'disgusting' – interestingly, none of the users was emotionally untouched by the device (which might have led to a perception of 'just a rhythmic vibration pattern'). The usage of the instinctive cue of the heartbeat allowed for a metaphorical *projection* of the phone into an *emotionally rich* context: living beings that need to be taken care of.

Along with that projection, it emerged that users *assumed more* than the functionalities that were actually implemented. For example, they assumed that the phone would be 'hungry', 'lonely', or 'in the need to be spoken to and caressed' – they attributed pet-like behavioural components (in this case: basic needs and emotion) to the phone.

Discussion

Analyzing different tangible UIs we formed the hypothesis that an iconic representation is hard to find. This is true due to the fact that there is always a semiotic translation between actions and physical representation within the interface. Therefore, an iconic representation based on resemblance is not likely to be implemented in TUIs. This category might be better applicable to GUIs – but this is a tentative finding that has to be investigated further.

In the first example, Dynamic Knobs, a functional event in mobile communication was represented by a physical sign in an indexical representation. Pressing the knob to trigger a function can be defined as an indexical representation, too. The second example, Weight-Shifting Mobiles, shows a physical representation of an action, in a dynamic way. The action of scrolling or navigating in space is represented via a similar movement that involves physical weight and movement. In a way, this representation is also partly symbolic as it attaches a symbolic weight to an operation in digital space. The third example, Ambient Life, is highly symbolic, as it refers to the metaphor of (artificial) life.

All these mappings draw on prior knowledge about conventions of interface design. One of these conventions is representing functions via specified elements like knobs or keys on a device. The indexical mapping applies an inherent logic connection between function and representation as we learned from Peirce's example of the weathercock. This connection can be logically derived when interacting with a device. Therefore, in the example of Weight-Shifting Mobiles, this mapping is likely to be understood by the users through experiencing the interface. The symbolic mapping, in spite of this, is the most abstract one, where the representation is highly abstract.

Conclusion

In physical interaction design, the mapping between the physical and the virtual needs to be chosen with care – the pointed out semiotic translations can provide a valuable basis for this choice. We see from the discussion above that interface- and interaction design requires knowledge about the semiotic action that comes with it. Therefore, it is crucial to understand the kind of representation that is chosen to represent functionality. We suggest using the three semiotic categories, icon, index, and symbol, in order to describe the communicative function of the mappings that are made. We discussed several examples from HCI that involved different kinds of mappings for different interaction purposes. Further work has to be done on measuring user acceptance for these mappings according to the context of use. Furthermore, the applicability of these categories to interaction design has to be validated through alternative examples from interaction design. For such endeavours, we suggest to consider the aspects of flexibility, inherent logic, emotional richness as well as the necessary prerequisite knowledge.

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