When Three Worlds Collide: A Model of the Tangible Interaction Process

Marc Hermann
University of Ulm
89069 Ulm, Germany
marc.hermann@uni-ulm.de

Michael Weber
University of Ulm
89069 Ulm, Germany
michael.weber@uni-ulm.de

ABSTRACT
The design of Tangible Interfaces has already evolved since the first projects were developed. Frameworks and taxonomies have helped to understand the field of Tangible Interaction. But nevertheless the mental models of the interaction process with Tangible Interfaces seems to be surprisingly diverse. In this paper we present a comprehensive and generic model for interaction with the digital world through physical objects. Our goal is to model the complete process of interaction, to analyse existing design approaches using the model, and to gain a generic design aid for Tangible Interaction.

Author Keywords
Design, Action Research, Tangible Interaction.

ACM Classification Keywords
H5.2. Information interfaces and presentation (User Interfaces).

INTRODUCTION
Thirteen years ago, Brygg Ullmer and Hiroshi Ishii (Ullmer, 1997) shaped the term Tangible Interaction. Inspired by antique scientific tools, their aesthetics and the intuitive usage, their intention was to reintegrate the physical world into Human Computer Interaction. Their early definition distinguished three concepts of Tangible Interaction Systems. *Ambient Media* are aesthetic objects for output that work in the periphery of perception, allowing access to virtual information in the background, without disturbing the user in other tasks. *Physical-Digital Objects* are everyday graspable objects like cards, books or models that are linked to virtual information. The information can be observed and manipulated with the object. *Interactive Surfaces* are surfaces like walls, desks or floors that can be used for interaction with computer systems e.g. by pressure-sensitivity or projection of output onto the surfaces.

A huge number of research projects shows the potential of this interaction technique. A couple of relevant work already supports the understanding and development of Tangible Interfaces. Early works (Ullmer, 1997, Holmquist, 1999 and Shaer, 2004) especially attended to the physical context and the technical coupling of real and virtual elements. Facets of psychology and design influenced frameworks which examined the properties of the coupling between object and data (Koleva, 2003 and Fishkin, 2004). Terms like Affordances (Gibson, 1986) and Constraints (Norman, 1988 and 1999), well known in the product design area, were adopted for tangible interfaces. New approaches like the framework of Hornecker (Hornecker, 2006) or the ISH project of Hummels (Hummels, 2004) gaze at the user and her social surroundings. The fact *how* the interaction is done comes to the fore in the research of Wensveen (Wensveen, 2004) and van den Hoven (Hoven, 2007). Also, philosophy and psychology hold new aspects for the research on Tangible Interfaces, e.g. in Hurtienne's work on using image schemas in the design process of Tangible Interfaces (Hurtienne, 2007). All those works and many more have helped us to comprehend the complex area of Tangible Interaction.

On this basis we tried to create a model of Tangible Interaction, both figurative and generic. A complete model of the interaction process will allow the discovery of critical transitions in the process, reveal missing areas in projects, can be useful as an evaluation instrument and is a premise for developing design guidelines.

In the next section we give an overview on related work before we introduce our model illustrating the process of Tangible Interaction.

MODELING INTERACTION - SEVERAL APPROACHES
In 1988 Don Norman presented the human action cycle (Norman, 1988). He gave an easy to understand model of the interaction between people and the physical world surrounding them. The model covers the whole cognitive process of a person (or user) interacting with the world. Fig. 1 shows the seven stages of the human action cycle.

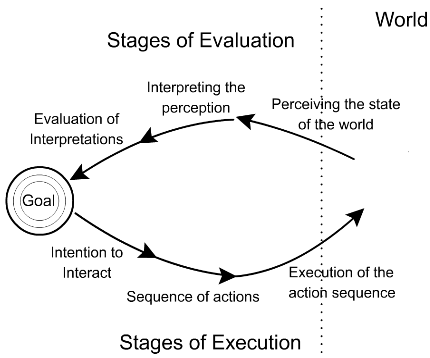

Fig. 1: The Human Action Cycle by Don Norman

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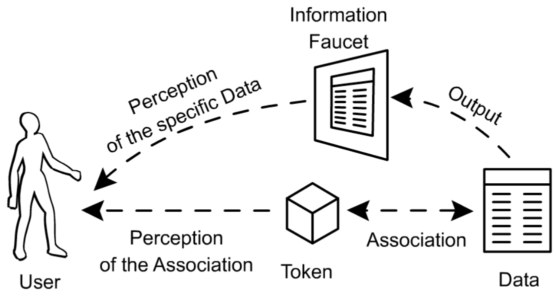

Fig. 2: Interaction with Tokens and Information Faucets as described in Holmquist, 1999.

Norman's model is very helpful to understand how the user of a product may change her goals while performing an action in the physical world.

An early framework of Holmquist, 1999, was created for a subset of Tangible Interaction systems, where the physical objects are placeholders, so-called *Tokens* for the digital information they are linked with. Some aspects of the information are perceivable through attributes of the object, e.g. colour or shape. To make visible the exact information, the object can be placed near an Information Faucet, some sort of display presenting the linked information. Fig. 2 shows our visualisation of their interaction process with Tokens and Information Faucets.

Jensen (Jensen, 2005) and van den Hoven (Hoven, 2007) distinguish between products and Tangible Interfaces by highlighting which world is being modified: products are built to modify the real world, Tangible Interfaces help to modify the digital, virtual world.

LINKING THREE WORLDS

In Tangible Interaction we can detect three layers of reality: the cognitive reality of the person (cognition, see human action cycle), the reality of the physical world (physical reality) and the virtual reality (virtuality).

Two main components are prerequisites for Tangible Interaction: the *Actor* and the *Tangible Interaction system* (consisting of physical and digital, virtual parts). Both of the components are related to two layers of reality, and both exist in the physical reality. The actor perceives information from the physical reality with senses, whereas the system receives information from the physical reality with sensors and interfaces. The cognition cannot exist without an actor, the virtuality's existence is bound to a system.

Fig. 3 shows the components, the layers of reality and the various areas of context of the Interaction Process. The actor interacts with the physical parts of the system, the interface, consisting of *physical objects* in the *system-dependent physical context*. The *virtual data* belonging to the *system-dependent virtual context* are linked to these objects. In many scenarios the actor is not alone. We call all human beings in the periphery of the actor the *social context* (which can also be none). Other optional physical components in Tangible Interaction systems are *sensors* providing the system with information of the surrounding. In every layer we can differ between system-dependent

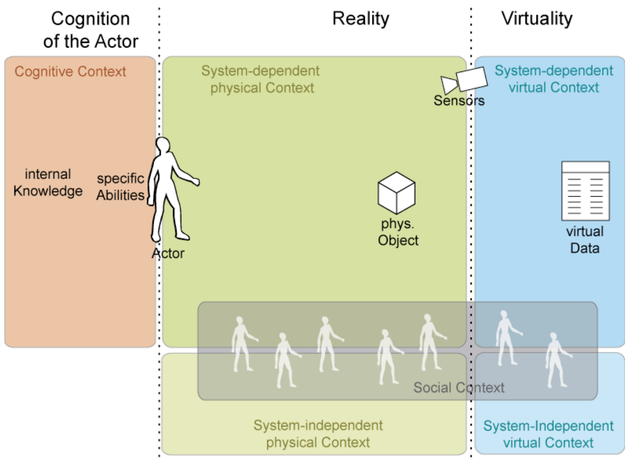

Fig. 3: Components, Layers of Reality and Context Areas of the Interaction Process

and system-independent context. The actor has *specific skills* including senses, physical abilities, and learning skills. In her life she collects *internal knowledge*, which she is able to recall (consciously and unconsciously).

In our model we expect some parameters to be already set, although during the interaction process they may change (Fig. 4).

The *coupling* (a) between an object in the real world and data in the virtual world is a prerequisite for Tangible Interfaces and thus the most important parameter of the system. In our model coupling represents technical coupling as well as associated coupling. This is not meant as one-to-one relationship. The coupling can be very complex, but in our model we only want to point out the existence of the coupling rather than how it is accomplished.

The object and the physical context have properties which give the actor information on usage and possible effects when she perceives the object and its physical context. We use the word *feedforward* (b) here for all distal stimuli (see Wensveen 2004).

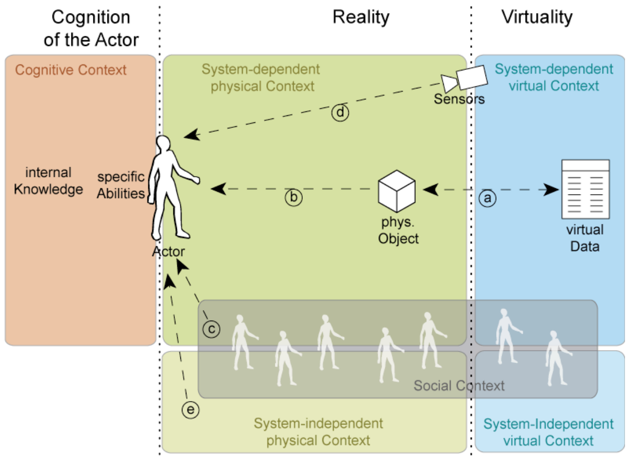

Fig. 4: Prerequisites for the Interaction Process:
(a) Coupling, (b) Feedforward, (c) Social Influence, (d) Virtual Influence, (e) External Interference.

We also detected some parameters that we think have been overlooked in other models by now: influences and interferences.

In the whole process the humans in the periphery influence the actor in several (positive and negative) ways. We call them *social influences* (c), as their source is the social context of the actor. The influences can lead to a mass of changes in the behaviour and activity of an actor (positive and negative effects).

The presence of sensors, especially visual ones, has influences on the behaviour of the actor, too. Actors feel observed when cameras are present. We chose to call them *virtual influences* (d), because in most cases the actor behaves like there is a virtual person present.

Whenever the actor is disturbed from anything other than humans or sensors, we talk about *external interference* (e). It is rather impossible to foresee all external interferences in the design process. Nevertheless, if the location and scenery is known, some of the possible interferences can be detected and should be considered in the design process.

With these prerequisites the interaction process can begin. The following eight steps form an interaction cycle (see Fig. 5). We have to point out that some of the steps happen (at least nearly) simultaneously, although in our model they seem to happen sequentially.

Perception (1): The actor perceives the object and its physical context.

Cognition (2): The actor interprets and plans her next action. The actor predicts the physical effects according to the feedforward and her knowledge of the world, e.g. of previous similar actions.

Action (3): The actor manipulates the object by any means. (1) to (3) are similar to the main steps of Don Norman's human action cycle mentioned earlier.

Physical Effect (4): The manipulation has a physical effect on the object.

Virtual Effect (5): The manipulation changes the data dependent on the coupling of physical and virtual.

Status Update (6): The virtual data eventually sends a status update to the object to inform of possible changes.

Remote Effect (7): The status update has an effect on the object and its physical context. This can e.g. be a remote-controlled manipulation of the object or an output in the physical context of the object.

Feedback (8): The change of the object and its physical context gives feedback to the actor. This feedback is given every time any changes occur. This means, the physical effect immediately gives feedback to the actor, even without a status update of the tangible system.

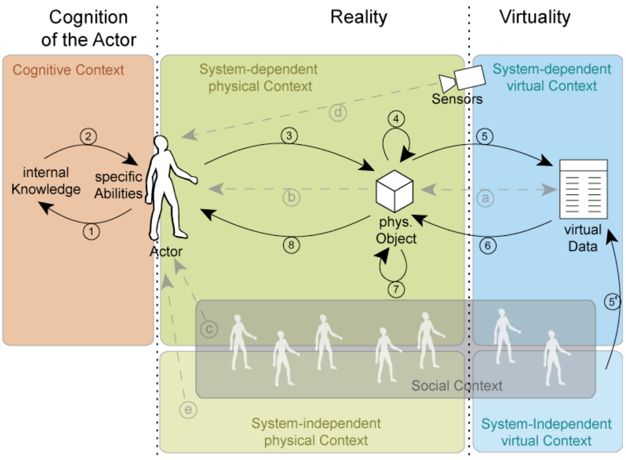

Fig. 5: The Tangible Interaction Process:
(1) Perception, (2) Cognition, (3) Action, (4) Physical Effect, (5) Virtual Effect, (5') External Effect, (6) Status Update, (7) Remote Effect, (8) Feedback

The interaction process seems to be complete, but some possible steps are missing. The model by now lacks a major advantage of Tangible Interfaces: A lot of projects rely on multi-user scenarios with more than one actor. So we need actions coming from other sources. The other actors can either interact in the same physical context or manipulate data in the same virtual context. We can add these two issues by inserting two steps:

If a human being from the social context manipulates an object in the physical context by any means, we call it *external action* (3'). This starts a separate interaction cycle, giving our actor feedback, even by perceiving the social context and the humans' action.

If the virtual data in the virtual context is changed from other sources than the actor himself, we refer to it as *external effect* (5'). This includes actualisation over time, by network or any other computerized effect, and also other actors located elsewhere with the ability to change the data. The external effect starts an interaction cycle by giving our actor feedback.

We could add more arrows, e.g. an arrow leading from the actor to the social context, as the actor also influences the thinking and doing of other persons. But this has no effect on the actor's interaction cycle. For the same reason we don't need the feedback or feedforward arrow pointing to the social context. Certainly, the persons also perceive these informations. We can compare these options with a multi-user scenario, where several interaction cycles take place at the same time. Every person is influenced by all other persons of the social context. Fig. 6 shows an example with two actors interacting with the same system, but on different physical objects. The social influence to the first actor now includes physical constraints caused by the second actor and vice versa. In this example we can see another possible external effect (5'), the changing of the virtual data coupled with the first actor's object as side effect of the data change by the second object. Thus a multi-user or even a multi-object scenario would not add more steps to the main model.

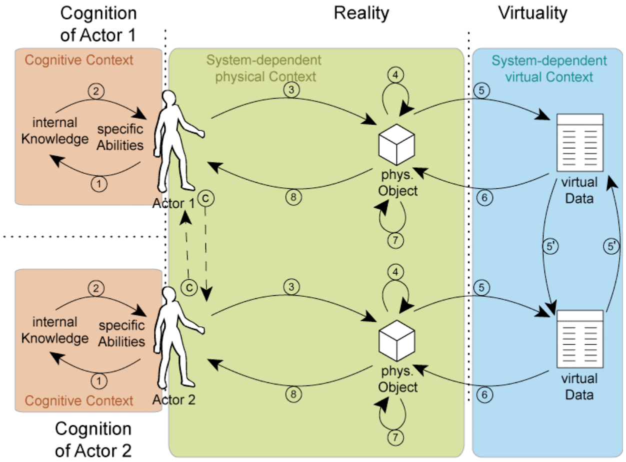

Fig. 6: Multi-user-scenario with two actors using different objects in the same context.

CONCLUSION

Currently, there is a high divergence in the mental models of Tangible Interaction people have. In this paper we presented a model for interaction with Tangible Interfaces. We tried to make the model as complete and as general as possible, but also keep it figurative. We detected the importance of influences on the interaction process.

Our main goal was to get an easy to use and understand instrument to aid the design process of Tangible Interfaces. Future work will include analysis of how the model can help to avoid failures in the design. This may lead to guidelines for the design of better Tangible Interfaces.

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