Beyond representations: towards an action-centric perspective on tangible interaction

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Abstract: In the light of theoretical as well as concrete technical development, we discuss a conceptual shift from an information-centric to an action-centric perspective on tangible interactive technology. We explicitly emphasise the qualities of shareable use, and the importance of designing tangibles that allow for meaningful manipulation and control of the digital material. This involves a broadened focus from studying properties of the interface, to instead aim for qualities of the activity of using a system, a general tendency towards designing for social and sharable use settings and an increased openness towards multiple and subjective interpretations. An effect of this is that tangibles are not designed as representations of data, but as resources for action. We discuss four ways that tangible artefacts work as resources for action: (1) for physical manipulation; (2) for referential, social and contextually oriented action; (3) for perception and sensory experience; (4) for digitally mediated action.

Keywords: action-centric perspective; interaction design; practice turn; representations; tangible interaction; theoretical foundations.

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1 Introduction

Throughout the history of tangible interaction research, certain issues have continuously been put to the fore. A fundamental concern in the discussions have been the relationship between physical and computational materials, such as how digital information can be represented as physical objects, and how actions in the physical world can be mapped to computational action.

In 1997, Ullmer and Ishii set the agenda for much of the research on tangible interaction, providing not only a vision for the field (formulated as 'tangible bits'), but also a conceptualisation for how to think of tangible artefacts as parts of an interactive system. The intention behind the model was to conceptualise the relationship between the representation and control of digital information through tangible user interfaces. This conceptualisation has been used to make explicit how tangible digital devices diverge from the conventional view of user interfaces, which until then was based mainly on graphical user interfaces and screen-based models of human–computer interaction.

In parallel with this development, contemporary studies on human interaction with technology have increasingly stressed the fundamental role of social and situated dimensions of human activity. This includes research in social and cognitive sciences that emphasises how human action is practically carried out by people in real and actual use settings. This development is sometimes referred to as the 'turn to practice' (Schatzki Knorr-Cetina and Savigny, 2001). Suchman (1987) was one of the first scholars to bring the practice turn perspective to the study of interactive artefacts, showing for instance how some of the established metaphors in artificial intelligence and human-computer interaction (HCI) collapsed when applied to the design and study of people's actual use of interactive artefacts. Related to this development is also the development towards conceptualising HCI as a design-oriented field of study (Löwgren and Stolterman, 2004; Bødker, 2006; Vetting Wolf et al., 2006), drawing on, e.g. Schön's (1983) account of *reflective practice* as an essential aspect of professional labour. The philosophical grounds of the practice turn have also become a major source of inspiration in areas such as context aware applications (Dourish, 2004), computational linguistics and robotics (Zlatev, 1997; Pfeifer and Bongard, 2006).

Research on tangible interaction has to some degree incorporated these theories, resulting in various frameworks and approaches to understand physical interaction (Dourish, 2001; Hornecker and Buur, 2006; Klemmer, Hartmann and Takayama, 2006; Jacob et al., 2008). From an industrial design perspective, the members of the Designed

Intelligence Group at Eindhoven University have recently published extensively on this matter (Buur, Jensen and Djajadiningrat, 2004; Djajadiningrat et al., 2004; Jensen, Buur and Djajadiningrat, 2005). Among the core concepts that this research have raised are the importance and values of taking on an 'action-centric' perspective on tangible interfaces, as an alternative to the more conventional 'data-centric' approach in HCI. However, none of these have made explicit how these conceptualisations differ from a data-centric perspective, and how it may work as an alternative model of interaction at large.

In this paper, we elaborate on how the understandings described in terms of the *practice turn* could be used to define a shift in perspective from a data-centric to an action-centric perspective on interaction. As a starting point, we will briefly review some basic aspects of a data-centric view of interaction, as exemplified in the well-known models proposed by Ullmer and Ishii (1997). Thereafter follows a few concrete examples of how the data-centric model has become criticised as insufficiently targeting some of the values that become salient in interaction with tangible interfaces. As an alternative, we discuss how the notion of *resources for action* could be used to frame the essential qualities of tangible systems within a practice-oriented rather than an information-processing perspective. We end with a short example of how an action-centric view involves a renewed understanding of the visions of tangible interfaces and their potentials in the design of new technology. Importantly, this could be seen as applicable not only in the development of tangible interfaces, but also in the designing of interactive technologies in general.

2 Background

As user interfaces have turned into increasingly diverse physical forms, it becomes relevant to discuss how this shapes the way we look at user interaction, and especially the models that we use to describe such forms of interaction. With conventional graphic user interfaces, a standard way of conceptualising the functionality of a computer system has been through notions of information processing, where data or signals are inserted to the system via various input devices, then processed, and finally returned to the user via some form of output device. Researchers have over the years pointed out a range of shortcomings of this model for describing interaction, and especially when used to describe interaction with tangible user interfaces.

The information processing model is insufficient for describing a tangible user interface was discussed already by Ullmer and Ishii (1997). This became especially apparent through the notion of 'atoms and bits', which has then been a common way of conceptualising the relationship between physical and digital artefacts and materials. Central to this notion is that it points out that computational artefacts are essentially not made of physical matters (atoms), but of the stream of signals that controls the hardware of a digital device (bits). What this emphasises is that while the physical world has some persistency in its corporeal manifestation, the digital 'material' is dynamic, made up of actions and instructions, without any real physical substance. The fundamental difference between digital and physical are thereby made explicit, emphasising several challenges that interaction designers are in constant struggle with, such as connecting properties of static-dynamic, physical-intangible, persistent-fluid and so on. Other aspects that challenges the model developed for graphical user interfaces have been observed in situations where tangibles could be understood as devices that may simultaneously work as 'input' and 'output' to a computational system, blurring the distinction between 'input', 'output' and 'data' (Ullmer and Ishii, 1997).

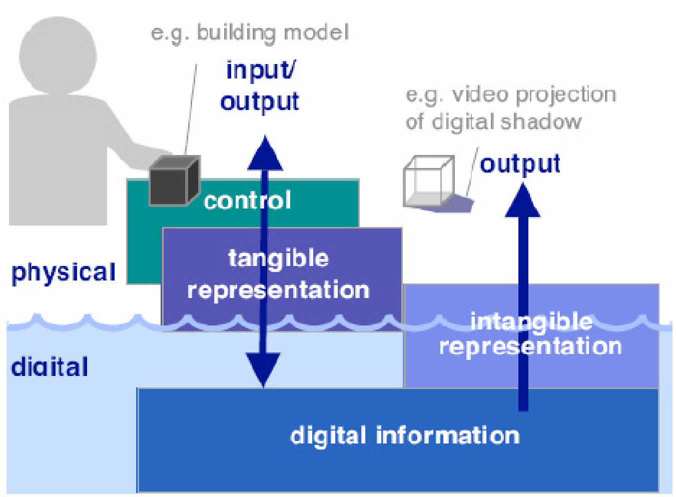
As a response to these kinds of problems, Ullmer and Ishii (2001) presented the MCRit interaction model for tangible computing systems. This model aimed to illustrate the various and shifting roles that tangibles may have in an interactive system, as an alternative to the interaction models designed for graphical user interfaces. The model shows a computational system manifested in the physical world via two different types of representations; the first takes the form of mediated digital information typically made available through a screen or as audio, and the second are physical representations in the form of tangible artefacts.

The relationship between the physical and computational parts of the system was described in terms of 'mappings', where different styles of mappings were identified between the physical configuration of objects and the computational interpretations projected upon them. Another aspect concerned the perceptual coupling between the physical objects and the dynamic intangible representations that is mediated through computer screens and audio. In this respect, the tangibles were seen as complementary representational forms. This could be exemplified for instance in the notions of 'tangible bits' and 'physical pixels', which both reflect a view of tangible interface as alternative representations of digital information.

The model borrows concepts from graphical user interfaces, such as icons, which can represent pieces of information such as documents, as well as functions, such as opening an application. This was conceptualised as *phicons* (Ullmer and Ishii, 2001), which are physical objects performing a similar function as icons in a graphical user interface.

Over the last years, the MCRit model has been elaborated and reflected upon in several publications, the most recent presented by Hiroshi Ishii in 2008 (see Figure 1). The general idea is however still the same, to model different aspects of representation, and how meaningful mappings may be created between the physical configuration and a corresponding computational model (Ishii 2008).

Figure 1 The most recent model for tangible user interfaces provided by Ishii (2008) (see online version for colours)



In several respects, and as discussed, e.g. by Djajadiningrat et al. (2004), this and similar models could be interpreted as stemming largely from an information-, or data- centric perspective on interaction. The model is also explicitly intended to be read as a modified version of the standard model of information processing, which originally was set up to describe graphical and text-based user interfaces, and the prominent role of the different channels for input and output. What is still missing in these models of user interaction, and which has increasingly been discussed lately, is that they do not explicitly address aspects related to the physical and social context of the interaction, nor do they address sensory or experiential aspects of interacting with the tangible system. Given that much of the argumentation for, as well as empirical studies of tangible user interfaces emphasise exactly those aspects, it is relevant to explore conceptualisations of tangible user interfaces where these aspects are more naturally incorporated.

3 Foundations for conceptualising tangibles as resources for action

During the last decade, several scholars have brought to discussion an alternative perspective on tangible user interfaces, which instead of data representation is based upon a perspective on tangibles as *resources for action*. Klemmer, Hartmann and Takayama (2006), for instance, discuss tangibles in terms of bodily action, and point to a range of new challenges that this may bring to the designers of interactive artefacts. The recent framework of reality-based interaction (Jacob et al., 2008) also emphasises a number of aspects related to bodily practices and skills as central considerations in the design of 'post-wimp' user interfaces. Similarly, Dourish (2001) and Hornecker and Buur (2006), ground their perspectives on tangibles on the idea of interactive systems as resources for shared human sense-making. Instead of proposing yet another modified version of the information-processing model of interaction, all these descriptions could be interpreted as proposing a shift in focus to instead base the understanding of tangible artefacts on notions of action and activity.

To put a finger on the general problem that all of these scholars in one way or the other address, we here summarise what has elsewhere been referred to as the 'practice turn' perspective on tangible user interaction (Fernaeus, Tholander and Jonsson, 2008). Perhaps, the most prominent and well-known way that the practice turn has manifested itself in HCI could be seen in the increased focus on context, mobility and physical settings, and the current interest in systems for social, shared and collaborative activity. Another central dimension of the practice turn perspective is the rejection of the separation of mind from body, the inner from the outer, practice from theory, knowledge from knowing and instead, as put by Lave (1988, p.1) ' "Cognition" observed in everyday practice is distributed – stretched over, not divided among – mind, body, activity and culturally organised settings (which include other actors)'. We see this as highly relevant to tangible interaction research, wherein a common theme has been to emphasis the 'gap' between physical and digital, hardware and software, and (at least in a metaphorical sense) mind and body, and the increased focus on tangibles in social settings.

We discuss this development based around three important aspects that over the past decade repeatedly have put the data-centric perspectives of interaction to test:

- social and physical context as essential parts of the interaction
- problem defining the 'data' in sensory experiences and manual actions
- the interplay of tangible and virtual artefacts and materials.

3.1 Social and physical context as essential parts of the interaction

Social and shared aspects of interaction have in HCI traditionally been viewed as new and difficult steps to take from previously individually-oriented designs (implicit in special sub-fields such as CSCW and CSCL). This has been the case also in the field of tangible interaction, as illustrated by some of the often quoted systems (e.g. the marble answering machine), primarily addressing the interaction of individual users, emphasising, e.g. sensory experience of touch, and the cognitive benefits from working hands on with physical objects (Patten, Griffith and Ishii, 2000). This focus could be understood as stemming from a view where values of an interface are regarded primarily as a communication channel between the user and system.

However, from a practice-oriented perspective, collaborative, social and shared use is instead viewed as the natural mode of being with artefacts, which has also been supported by ethnographic and ethnomethodological studies in a range of different settings (Suchman, 1987; Heath and Hindmarsh, 2000; Wyeth, 2006; and so on). A central dimension in reformulating the design space then concerns how social and collaborative aspects are not viewed as extraordinary use situations, but as the basic ones. 'Interaction' thereby needs to be understood as taking place with the system and between participants around it, and how users act together around the technology. This becomes increasingly relevant as a growing number of researchers are now explicitly emphasising the qualities of tangibles in terms of social, affective and collaborative activity (Sundström, Ståhl and Höök, 2005; Hornecker and Buur, 2006; Hengeveld et al., 2008; Kalanithi and Bove, 2008). While these social and contextual aspects have been noted as important qualities of user's interaction with technology (Cohen, Withgott and Piernot, 1999; Patten and Ishii, 2000; Benford et al., 2005), they do not fit naturally within a model of systems designed only for responding to user input.

This relates also to the current strive in research towards a participants' perspective on action and interaction with technology. The participant's perspective emphasises that designers and analysts should attempt to understand how an activity is viewed by its participants – not to search for evidence that may serve to label the activity based on pre-imposed categories of what is wished for or expected. Instead, the goal is to document how the participants go about doing and organising the activity, e.g. what aspects they are oriented towards, what they make central and peripheral and how they make the activity meaningful for themselves and for their peers (Heath and Luff, 2000). With respect to this theme, a new goal in design and evaluation of interactive systems is to, instead of postulating what characterises a 'good' or usable system, seek to understand how users make meaning through the interaction, and what aspects they orient themselves towards and use in their specific interactional practices (Sengers and Gaver, 2006). Generally, social and contextual factors then become important to address.

3.2 Problem defining the 'data' in sensory experiences and physical actions

Fundamental to the practice turn perspective is its grounding in theories of cognition that acknowledge the prominent role of bodily and subjective experiences, with emphasis on how knowledge, sense-making and creativity occurs through its embedding in, and dependence upon, our social and material environment (Goodwin, 2003; Murphy, 2005). This perspective also includes aspects of how perception becomes intertwined with interaction, with the world and the artefacts within it. This is of immediate relevance for tangible interaction research, as much argumentation for tangible interfaces has concerned sensory experiences of manual actions such as pulling, shaking and squeezing (see, e.g. Buur, Jensen and Djajadiningrat, 2004).

When acknowledging sense-making as a phenomenon rooted in subjective and bodily experiences, this also has implications for how information and representations are to be understood and designed for. Bodily forms of expression, such as physical manipulation of tangible objects, always bring about some ambiguity in terms of what kinds of sensor readings, or 'information' that is actually transmitted to the system. Benford et al. (2005) conceptualise this problem in terms of a demarcation between sensing and sense-making. From a phenomenological perspective, all interpretations are understood through active personal bodily experiences of being in the world. We choose to direct our eyes towards certain objects and when we examine objects with our hands we do not only touch them but also turn them around in our hands and stroke them with our fingers. The reading of a thermometer used to determine the warmth of water before taking a bath becomes meaningful because we have been able to interact with the device over time and thus been able to create mappings between numbers on the thermometer with our bodily experiences from touching the water. A representation thereby only becomes meaningful for a person through the way it manifests itself to that person.

From an understanding of all experience as being subjectively and bodily perceived, it may not be obvious how information and representations are practically shared between people (and between users and digital devices). The phenomenologist explanation is that as we do share a common 'life world', we can assume that other persons have got similar experiences as ourselves, and that they will make sense of certain phenomena in a similar way as we do. By interacting with each other and by sharing a common environment we are able to agree on the symbols, representations and language that we use to describe properties of the world. The existence of different temperature representations (Celsius, Kelvin and Farenheit) has, e.g. to be understood in relation to the activities and social settings in which they have been developed and maintained. Similarly, the view of tangibles as representing digital data, and especially some static and specific data, may be problematic, given the multitude in experiences that they may give rise to. This becomes especially evident in settings where several physical actions are continuously and simultaneously traced and responded to, and where the interaction is closely tied to experiential factors outside of the immediate interface.

3.3 The interplay of tangible and virtual artefacts and materials

So far, the main focus in the area of tangible user interfaces has only to a limited extent been directed towards making the most of the digital and physical forms of 'materials' in combination, as to bridging, transferring, or, as repeatedly put in this field: to 'make digital data tangible'. This perspective of interaction is evident in a general focus on the actions that a system should react to, how processed data get manifested in feedback to the user, and the distinction between 'input' and 'output' as primary properties of interaction. At a conceptual level, this perspective is present also in many of the central concepts that are often discussed in this area, such as the notions of coupling, manipulation and perhaps most notably through the focus on various forms of representations.

As has been pointed out by Jordà et al. (2007), a key characteristic of most non-computational artefacts that we have around us, such as a piano or a white board with felt pens, is that they in a quite effortless fashion allow for the sharing of 'control'. This view is also reflected in their own design of Reactable, a collaborative digital music instrument designed to be played by a varying number of users simultaneously. The system consists of a tabletop interactive surface on which physical blocks representing different 'sounds' are placed and different actions can be performed to manipulate and combine the sounds. A key dimension of the Reactable is how it supports the *sharing of control* over computational actions, rather than the sharing of data or information. Currently, there is a range of other systems where the main values of the tangibles are phrased in terms of similar qualities (see, e.g. Bischof et al., 2008).

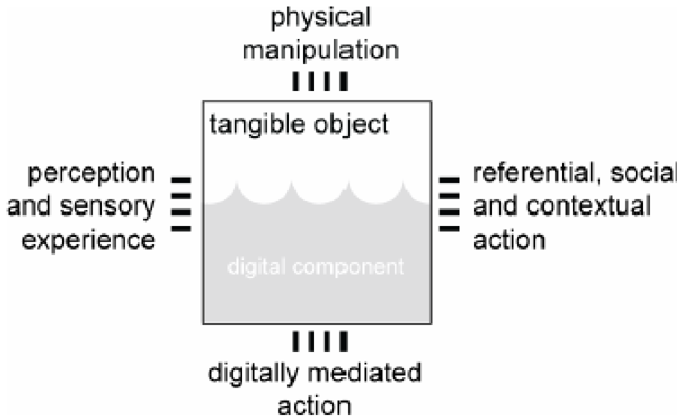
With very much the same arguments, the relationship between conventional crafting and design with digital materials has been extensively discussed for instance by Malcolm McCullough (1997), highlighting how physical properties of interaction are central to media production even in conventional computing settings. Just as with any other design material, designing with mouse and keyboard has to do with joint achievements of multiple senses, such as vision and touch, of spatial relationships explored through bodily action, and of visual affordances combined with manual skill. From this perspective, the difference between physical and digital are not understood as a 'gap' where a goal is that one must be represented in the other. Instead, the physical and digital are understood as two equally fundamental properties of interaction with digital artefacts. The goal instead gets directed to what the users are actually doing, and how the various resources together may support those practices.

4 An action-centric view on tangible interaction

The themes outlined above all point in a direction that suggests an action-centric perspective, as opposed to a data-centric perspective on interaction with technology. More specifically, what the observations suggest is that the information-processing model, modified or not, will not sufficiently work to describe the qualities of tangible user interfaces. We conceptualise and generalise this understanding through the notion of the tangibles as *resources for action*, and how this perspective may get reflected in design. Figure 2 illustrates four separate ways that a tangible artefact may work as a resource for action:

1. for digitally mediated action
2. for perception and sensory experience
3. for physical manipulation
4. for referential, social and contextually oriented action.

Figure 2 A tangible object working as a resource for multiple kinds of actions



4.1 Resources for digitally mediated action

An alternative for emphasising the value of tangibles as representations of data is to look upon them as resources providing an expanded and potentially richer range of actions and manipulations of digital materials. The specific qualities of the digital material could be illustrated by the forms of visual expression afforded by computer screens and other digital display surfaces. Much can happen on a computer screen that is not possible to achieve with physical materials; things can be made to animate, objects may change shape and size, they may be copied, deleted, modifications can be undone and much more. Computer screens also allow for online sharing of information, rich possibilities for animation, and precision in manipulation in ways that are not possible with ordinary hands on manipulation of physical objects. The qualities of the tangibles are instead characterised by providing specific sensory and multimodal qualities, and that the artefacts are in some sense being persistent, static and constrained by the laws of physics.

As resources for digitally mediated actions, the tangible artefacts are then understood to provide new means for control and performance with a computational system. Physical objects incorporating sensing and actuation technologies like haptics, accelerometers and gyros may for instance allow for increased possibilities and precision in manipulation and navigation in virtual spaces. Mobile positioning systems and sensors of varying kinds may facilitate performance and access to media and functionality that is tied to a specific physical object or place. Tangible systems and devices can also in various ways be tailored to provide increased access to computational power for children, people with physical disabilities and others with special physical requirements.

Tangibles as resources for digitally mediated action thereby concerns the facilitation of actions through a digital material, as taking effect, e.g. on a computer screen, in the form of audio, or through actuated movement of robotic devices. These are also the kinds of actions that are generally the primary focus of investigation in data-centric perspectives of tangible interaction research, i.e. how the system data gets mediated through tangibles, making them work as input and output devices. In the conceptualisation of ‘phicons’ for instance, the tangibles are described to make a difficult fit as something in between physical representations of data and as input devices (Ullmer and Ishii, 1997). Compared with, e.g. typing text into a command line interface, or clicking on an icon on a screen, the character of the data that is sensed and supposed to be understood as 'input' or 'representation' becomes rather difficult to grasp, as is the notion of how information is being processed, and also the character of the supposed 'output' of that process. Note that this problem is here overcome by focusing on the tangibles as resources for *human* action and performance with and through the system, rather than how the system gets manifested through its physical devices.

4.2 Resources for increased sensory experiences and perception

This function of tangible interfaces refers to their commonly discussed potential of making the interaction richer and more personally engaging, addressing our various sensory experiences of touch, as well as learning of skills through bodily engagement. The expanded space for using technology provided by physical dimensions also includes other aspects that are central to everyday interactions, such as ownership, attachment and personalisation. Of relevance to this is again the users' subjective and personal ways of participating and contributing to an activity, allowing users to manipulate the objects in accordance with the changing circumstances of their use situation.

The relationship between representation, interpretation and sensory experience has become one of the major obstacles and matters of debate, especially within the area of context aware applications (Dourish, 2004). In this area, a general attempt has been to build systems that adapt their behaviour based on inferences made from available sensor data. There are currently several examples of systems that are designed to give users more control with respect to how meaning is extracted from sensor information, where the process of rendering the sensor data meaningful requires more active engagement with the system (Espinoza et al., 2001; Jonsson, 2007). Similar approaches have also been found to be the most successful also in other areas relying on sensor readings, such as mobile robot applications (Pfeifer and Bongard, 2006). This suggests that data, such as sensor information in this case, has an instrumental rather than representational function in these cases. This again emphasises the need of understanding the actual use of the physical and digital resources together and in context, and not just treat the tangible resources as input/output channels that can be analysed and understood on their own.

4.3 Resources for physical manipulation

Physical materials are often more flexible than digital ones in that they are practically endlessly open-ended in how they may be combined and used, they may be seamlessly brought to and used in a range of different settings and activities, without needing a mediating digital hardware to become visible. Physical artefacts all hold the qualities of allowing for action and interaction to be performed concurrently, with both hands, and that physical manipulation can be conducted jointly as well as individually.

A common argument for tangible interfaces with respect to this has been that physical manifestations potentially allow users to make use of experiences from interaction with other everyday objects, allowing the resources to blend into existing activities in a natural way. An interactive tabletop surface may be usable as ordinary tables to put physical things on, a classic PC keyboard sometimes get used by several users at a same time. Mobile and tangible artefacts may be carried around and used in several different social contexts such as various work situations and settings that include family or friends, and ordinary physical artefacts are constantly appropriated and used in a range of unintended ways. What this illustrates is how an essential property of the physicality of digital devices can be used in more than one way, and in ways that may sometimes have little to do with their interactive properties or the actual software that runs on them.

Thus, this function of tangible objects refers to their role as resources for actions directed towards the physical objects in accordance with their specific physical affordances. The added value of representing a large set of database objects in physical form may for instance be the extended ability to sort, discuss and get an overview of the objects stored in the database. As with the sensor reading representations discussed before, this view focuses on what users can do with the resources, rather than only what the resources are meant to represent. Important is also that the manipulations are not considered to be performed only to modify an underlying digital model but how the manifestations allow for manipulation, i.e. how they may be physically acted upon in the context of use. This dimension of tangibles could be mapped to the notions of Tokens and Constraints (Ullmer, Ishii and Jacob, 2005), as emphasising how physical objects may be manipulated and combined.

4.4 Resources for referential, social and contextually oriented action

As resources for socially and contextually oriented action, this quality points to the potentials of tangibles in making easier references to objects by pointing, touching or accounting for one's own actions in more visible ways, the possibility to hide or store an object at a specific location for later use or even placing it in the hand of a specific person. As an example of this, Hengeveld et al. (2008) recently showed the results of a tangible play kit for children with multiple impairments. While the system was initially designed for individual use, an important quality of the design turned out to be how the physical artefacts could be used as a means for communication between the child and assistant. This indicates that an essential property of tangible objects is that they are shareable, and as such the setting must be framed as designing new artefacts that will be used also for social and shared interaction. Within our research field, this also suggests a shift from taking properties of the interface as the primary unit of analysis, to taking the context of use as the primary.

Systems designed for social and collaborative activity necessarily require a fundamental move towards new ways of looking at 'interfaces' in relation to computational and interactional processes. This is especially because physical and material manifestations may allow for expanded social and bodily engagement with and around technology, and that shared activity around computational systems always entails social interaction outside of the immediate context of interaction with the system. This development is well reflected by the current interest and incorporation of, e.g. industrial design and dramatic performance as part of the development of interactive systems. Rather than emphasising the tangible resources strictly as input/output channels, they are then looked upon as resources also for contextually oriented actions.

A consequence is that further emphasis must be placed on how systems, both in hardware and software, are designed to support users to act with the resources towards the system, as well as to account for one's actions in a group, to negotiate interaction and to act socially around the resources.

5 Example case: Patcher

To further illustrate some of the benefits of tangible interfaces viewed from an action-oriented perspective, we here present an analysis of some important reflections made from the development of Patcher, a set of tangible resources for children's collaborative construction of screen-based systems (as presented in Fernaeus and Tholander, 2006). We begin by analysing the system from an information-centric perspective inspired by the model provided in Figure 1, to highlight the difficulties of describing this system through such notions. While these reflections are closely coupled to a specific system, we see them as emphasising several issues that can be observed also in other systems that have recently been presented in the field.

5.1 Overview of the system

A primary reason for building a tangible interface for programming was to allow for a group of four to five children to act together upon the same material, in a similar fashion as children are commonly observed to act when playing with ordinary physical materials. A goal was in this case to let the children create media specific to the affordances of a computer screen surface, e.g. to create visual objects that could animate and interact in various ways. Figure 3 shows the physical setup of the system, made up of a collection of plastic play cards, a digitally enhanced floor surface, a screen display and wireless RFID readers. The floor surface takes the shape of a soft carpet made of green fleece fabric, upon which a grid has been marked by stitched lines of white thread. Underneath each of the tiles on the carpet is an RFID tag corresponding to a position on the screen. By placing a wireless RFID reader on the floor surface, a position on the screen gets highlighted, onto which pictures may be added, controlled and programmed.

Figure 3 The Patcher system in use (see online version for colours)

There are different kinds of programming cards, used to add behaviours and interactive properties to the pictures on the screen, and for controlling the system. Picture cards are used to place new objects at specific locations on the screen, while the behaviour cards are used to specify the functionality of the objects that have already been added. There are a number of cards that can be used to add behaviours for movement, collisions, user interaction and there are also cards that let you change 'properties', such as the size, rotation or colour of a picture. To add a new picture at a specific location, a picture card is placed on top of the creator block. Behaviours are added to existing objects by placing the reader block at the position of the object one wants to program and then putting a behaviour card on top of it. There are also control cards, which let users perform global actions to the system, such as playing, stopping and saving what has been created. Simple icons corresponding to the illustrations on the programming cards are used to indicate the behaviours and properties that are attached to each of the pictures on the screen. When the program is set to play, all the programming signs are hidden, and the pictures on the screen start to act according to the behaviours given to them.

5.2 Patcher through notions of representation, information and input/output

Based on the modified information-processing model in Figure 1, the various tangible artefacts in Patcher may be conceptualised as either representations of digital information, or as simultaneous devices for input and output. Table 1 presents an attempt to analyse the system components through these notions.

Table 1 Patcher analysed through information-oriented notions

	Reader blocks	*Programming cards*	*Tiles on mat*
Input device	Generates events when reading a card or a tile	When placed on a block, its ID is sent to the system	When placed under a block, its ID is sent to the system
Output device	Shows where cards could be placed (but no output from the system)	Presents available actions/commands (but no output from the system)	Shows where blocks could be placed (but no output from the system)
Representation of data	Position corresponds to screen position (but they do not represent data)	Represent available computational actions (not existing data in the system)	Positions correspond to screen positions

A first observation from this brief analysis is that considering the physical resources as simultaneously working as input and output devices seems inappropriate. A central function of the reader blocks is for instance that they work as 'sights', allowing users to locate a position on the screen before adding something there. They could in this sense be understood as devices for 'inputting' data to the system, but not quite in the same sense as conventional input devices, as this can only be done in combination with the mat and a programming card. Similarly the cards, although they are enhanced with identification tags, do not alone communicate anything to the computer. The cards do in this sense hold exactly the qualities that Ullmer and Ishii (1997) refer to as physical icons (or 'phicons'), as making an uneasy fit within the traditional user models of icons and conventional input and output devices. In this respect some of the cards take on roles that icons or representations otherwise displayed on the screen would take, yet they cannot be said to provide the user with any actual system output.

Also considering the physical resources as representing digital data becomes problematic. The dynamic character of what may get displayed on the screen does for instance mean that the idea of a physical picture card as representing a specific picture on the screen may only work temporarily (i.e. until the object on the screen starts to move, get deleted or copied, or when the physical card is carried away). Similarly the behaviour cards are not to be understood as 'programming code' of the system that is being constructed, but rather as tools for adding code to the system on the screen. Placing a card on a reader could also result in global actions, such as playing, stopping and saving a simulation or game that has been built, as well as working as devices for interacting with the created system while it is playing. Then the conception of the cards as representing data becomes even more difficult to follow. This suggests that notions of input, output and representations are highly limited for providing a rich understanding of the system and its use, and also they do not capture some of the core values and qualities strived for in the design.

5.3 Patcher elements described as resources for action

Table 2 presents an analysis of the Patcher system components in terms of the action-centric framework discussed before. In the analysis, we would like to draw attention to how the action-centric framework provides an understanding of the system components and their use in relational terms, including how users combine system components to achieve different computational actions as well as actions with social and collaborative purposes. The framework thereby facilitates a broader understanding of the system that integrates technical and design-oriented aspects with the social, bodily and contextual factors that is so commonly emphasised in the design of tangible systems.

Table 2 Patcher analysed through action-centric notions

	Reader blocks	*Programming cards*	*Tiles on mat*
Digitally mediated action	Select position on screen (with mat) Adding and controlling pictures on screen, etc. (with cards)	Adding and controlling pictures on screen, and starting, stopping, saving and opening a game (with block)	Select position on screen (with block)
Sensory experiences and perception	Recognise active screen positions Seeing where cards could be placed	Getting overview of available actions/commands	Seeing where blocks could be placed Sensing the physical boundaries of the interface
Physical manipulation	Placing and moving on the mat	Placing on block, sorting, arranging, two-handed manipulation	Sitting and walking, spreading cards across surface
Referential, social and contextually oriented action	Individual as well as collective action Group formation Account for one's actions in the group	Non-verbal negotiation, e.g. hand-over interaction elements to one another Planning Competing and playing	Draw someone's attention to something by physically relocating oneself Account for current state of the activity

With *digitally mediated action*, emphasis is put on what users are actually able to accomplish with the digital system using the tangibles, in this case providing means for programming and controlling objects displayed on a computer screen. Rather than emphasising the role of data and interface, this model emphasises the different qualities of physical resources and digital media, e.g. the importance of not letting digital manipulations get restricted by physical constraints, and to allow for concrete modification of dynamic content through various physical interaction modes. The interface manipulations are then understood as action upon the digital material, such as changing the size or colour of an object, to save or open a game, to play, stop and control a game or simulation.

With *sensory experience and perception*, we look at how the different resources facilitate perception and sensory experience of relevance to the interaction with the system. Except for the obvious increase in tactile qualities, an important function of the blocks was for instance to work as 'sights', which indicate for instance where a picture will end up on the screen if placed upon it. This also includes how the physical and graphical designs of the play cards help interpreting the functions that they provide.

With *physical manipulation*, we point to the added values provided by the physical resources in terms of moving and manipulating interface elements, in a potentially richer way than would be possible if they were all represented only on screen. Examples include two-handed interaction, e.g. in sorting cards, turning and stacking them in different ways and the way the blocks can be moved on top of the mat surface.

With *referential*, *social and contextually oriented action*, emphasis is put on how the design works to support users in performing actions of importance for engaging in and driving the entire interactive situation further. A central quality of the tangible artefacts is that they support people's possibility to act individually as well as collectively, to arrange and to hand over interaction elements to one another, to draw someone's attention to something through physically relocating oneself and to account for one's actions in a group. In the case of Patcher, a central use quality of the design of the mat, the play cards, and the blocks was to work in different ways as resources for these kinds of actions.

6 Discussion

The research area of tangible user interfaces has generated a range of novel and intriguing design solutions, which have sometimes been found to theoretically challenge how we describe and what we value in people's interaction with technology. In particular, several examples in recent research, and also in commercial development, have raised questions concerning conventional notions such as the divide between digital and material, input and output, the role of data representation and the relationship between the context and interactive system. As a range of systems do not make a natural fit within such conceptual frameworks, it is relevant to further investigate the fundamental grounds for this situation and to potentially find alternative, hopefully more generally applicable ways of framing the important useful qualities of tangible user interfaces.

Along with several other researchers in the field, this paper has argued for how an action-centric perspective on interaction redefines the basic goals in terms of system functionality, to put further emphasis on what users will be able to do in the setting in which the interactive system plays a part. This suggests that the initial definitions of tangible interfaces get replaced by conceptualisations that put more value to human *action*, and less to representation and transformation of *information*.

This also implies that issues such as the separation between the locus of interaction and feedback (discussed extensively in, e.g. Ullmer, Ishii and Jacob, 2005) becomes less of an issue. In our example case for instance, all of the tangible artefacts were found to be more appropriately understood to be used to *create* and *control* objects, rather than as representational objects that could actually be displayed anywhere. Instead of emphasising the sensor readings and the way these are represented, the more central values of using the system became how computationally enhanced physical cards were used in the unfolding of social interaction, for instance through the possibilities of being organised in a stack for later use, get held up, hidden or handed between users as a means in the negotiation.

Most importantly, the choice of conceptual perspective for understanding a system governs also how design work is approached and how design problems are framed in this area. We argue that an information-centric view on physical interaction is inclined to generate solutions that emphasise process, transmission and sharing of data, before other useful qualities of the interactive systems. This may get reflected in a general focus in the design process to explore and design explicitly for sensory and cognitive use qualities, phrased for instance as the potential for tangibles to make digital data tangible and easier to understand. The work thereby concentrates on system functionality and interface, i.e. how the technology should be directly manipulated, with a risk of not sufficiently considering for instance social and contextually oriented user actions around the technology. Proponents of the practice turn argue, and which is also the message of this paper, that although such a perspective may be meaningful from a technical point of view, it does not necessarily generate solutions that fully target the activity that the users engage in.

Instead of focusing on aspects such as reasoning and data representation, an action-centric view aims for solutions that put further emphasis on aspects such as user control, performance and what should more practically be accomplished in the activity. The added value of, e.g. a Wii remote control above a joystick may then be phrased not as another form of *input device*, but a new interactional resource for performing and acting with the digital media, as well as with the surrounding social and physical contexts. Aspects of information processing may of course still be relevant in describing how a system is implemented. However, what may be accomplished through the manipulations, and how the activity is concretely experienced and made sense of is by the practice turn given a more fundamental position.

Implications for research based on an action-centric perspective are that emphasis moves from conceptualising tangibles as input and/or output devices, information processing, the gap between manipulation and effect and cognitive benefits of tangible representations. More focus gets instead placed on the design of shareable resources, bodily performance and experience, multiple uses and interpretations and the design of tangibles as resources for conducting specific practices and tasks. The qualities in the interaction do in this respect stretch beyond properties of the system and interface, to also include qualities of the entire interactive setting. Importantly, an action-centric perspective then includes action directed towards the computer as well as ‘offline’ socially oriented action, as well as sensory and experiential aspects.

For designers, the suggested perspective of tangibles as *resources for action* provides an integrated view of interaction in context, where offline activities play as much part in the 'user interaction' as do actions with more immediate effects on the computational system. An implication of this framework is for instance that many of the interface actions become directed to the social and physical setting, rather than only to the software 'inside' the digital devices. Thus, from an action-centric perspective, tangible interactive objects must be understood as having a broad range of interactional functions in a shared, collaborative space of physical and digital activity that users engage in.

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