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# D2.2 Tangible User Interfaces

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| *Abstract* | In this deliverable we propose a model of tangible user interfaces that will be used to guide the design and evaluation of tangible interfaces for PuppyIR. We also describe some examples of interfaces that we developed for the museum and hospital context. |

## Table of Contents

# Executive Summary

Tangible user interfaces have a wide potential to support children's interactions with technology, because they exploit the innate ability of humans to act in physical space and to interact with physical objects. Research is needed on how tangible user interfaces can be used to solve known problems children have when using information retrieval systems. How tangible interfaces can make information accessible and understandable for children is a new challenge for researchers in the domains of information retrieval and human-computer interaction. This challenge is a research topic in WP2 (task 2.2) and this deliverable is the result of our work on that task.

In this deliverable we first describe the state of the art of tangible user interfaces, reviewing the currently available techniques. However, the main part of this deliverable focuses on users: on how users interact with tangible interfaces and on how to design tangible user interfaces for children. We treat models of tangible user interfaces and derive a new model that will be useful to guide the design and evaluation of tangible user interfaces for the PuppyIR project. We present examples of tangible interactions and describe an experimental application that we developed for and tested in the museum context as well as an application that is under development for the hospital context.

Collaboration is one of the aspects that is important for tangible interaction hence it will come up in the models and examples we describe in this document. A more extensive treatment of collaborative interaction models can be found in deliverable D2.1 (Collaborative interaction models/interfaces).

This deliverable is also related to D3.3 (Report on information extraction and mining techniques). Using information extraction techniques metadata about the dataset can be extracted, allowing the interface to select and use the search results in elaborative ways; e.g., showing results with a positive affective value, adjusted to the emoticon the child used to search (Cf. Chapter 4 of this deliverable).

Finally there is a relation with D4.3 (Report on implementation and documentation). Connection between a (tangible) interface and the PuppyIR framework is done using the OpenSearch protocol. Moreover, by extending the used xml-namespace, extra children-specific metadata can be communicated from the framework to the interface. To retrieve only tangible information (i.e., the output-side of a tangible user interface), the PuppyIR framework is used. Before a search request is posited, the framework can already be informed of the skills of the user (see Section 4.2.2). Moreover, the search results can be filtered on their complexity and suitability for children.

# 1 Introduction

The topic of this deliverable, tangible user interfaces, refers to an interface making information (retrieval) available to its user. The key part of the topic is *tangible*. Something tangible is defined as (American Heritage Dictionary, 2009)

1. *"a. Discernible by the touch; palpable: a tangible roughness of the skin. b. Possible to touch. c. Possible to be treated as fact; real or concrete: tangible evidence.*
2. Possible to understand or realize: the tangible benefits of the plan".

The above definition of tangible shows two important uses. The first part of the definition implies the user interface is to be touched or felt; i.e., having real substance. The second part of the definition is of a higher abstraction, and can be implied as making the (access to) information clear and understandable. As we will show, there is a synergy between these two uses of the word tangible, towards retrieving information useful to the user.

Van der Sluis and Van Dijk (2010) identified four categories of problems children have when using Information Retrieval (IR) systems: an insufficient mental model, a vocabulary problem, a chaotic search behaviour, and the used relevance judgments. The interface is able to address these problems. In particular, a tangible user interface can address the problem of an insufficient mental model by making the interaction intuitive and the vocabulary problem can be addressed by reducing the need for a (free recall) vocabulary. Making information retrieval *tangible* can thus be regarded as particularly helpful for children.

Information retrieval eases the opportunity of life-long learning. Supplying access to the internet in public spheres such as classrooms enhances learning to an even greater extent: unsupervised use in a social surrounding can foster even the deep learning of hard topics such as mathematics (Mitra, 2005). This idea is, at the time of writing, gaining momentum: e.g., recently a British primary school introduced an Apple iPad[1] for every student, reporting responses such as: "*last week, we couldn't get the Primary 3 pupils to stop doing maths and go for lunch*" (Speirs, 2010).

It is in this great potential of information retrieval for children where the novelty of tangibility is most salient. Making information retrieval tangible and consequently making the (access to) information clear and understandable is a new perspective for information retrieval in general, and for information retrieval for children in specific. This deliverable will highlight both the novelty and the usefulness of this approach in the following chapters: Chapter 2 treats the state of the art, giving a system-oriented perspective to tangible interfaces by reviewing the currently available techniques. In Chapter 3 we treat models of the use of tangible user interfaces from a user-oriented perspective. What are the benefits of the tangibility for information retrieval by children? This chapter ends-up with a model of tangible user interfaces that we will use in the PuppyIR project. Chapter 4 presents use case scenarios of tangible interactions that might be useful for the PuppyIR project and, in Chapter 5, we describe a tangible user interface that has been developed for the museum context (for experiments in Museon in Den Haag) and a tangible interface for the hospital context (for children in the Amsterdam Emma Kinderziekenhuis) that is under development.

[1] Apple iPad: http://www.apple.com/ipad/, last checked 1st October 2010

# 2 State of the Art

This chapter outlines the currently available techniques, including the restrictions and possibilities they pose. The techniques are divided in two categories: multi-touch (i.e., touch-based interfaces) and tangibles (i.e., object-recognition interfaces). We conclude the chapter with a well-known conceptual framework and a taxonomy that can be useful to characterize, examine and compare tangible user interfaces from a system-oriented perspective.

## *2.1 Multi-Touch Techniques*

There are numerous technical solutions with which multi-touch surfaces can be constructed. Here, we provide an overview of the most common techniques, most of which can be constructed with relative ease. Many do-it-yourself solutions rely on cameras as the sensor with which touches are detected. To discern between touches and no-touches, these systems mostly illuminate the surface from the top, bottom or side and allow that light reflects of objects such as the fingers. Recognizing the resulting blobs as hands or objects is beyond the scope of this overview.

### 2.1.1 Frustrated Total Internal Reflection (FTIR)

Infrared light is shining into the side of an acrylic panel (most often by shining infrared LEDs on the sides of the acrylic) (Han, 2005). The light is trapped inside the acrylic by internal reflection. When a finger touches the acrylic surface this light is "frustrated" causing the light to scatter downwards where it is picked up by an infrared camera. A silicone rubber layer is often used as a "compliant surface" to help improve dragging and sensitivity of the device. One must press hard or have oily fingers in order to set off the FTIR effect on bare acrylic. Compliant surfaces (e.g., silicone rubber) increase sensitivity greatly. See Figure 1 for a schematic picture of Frustrated Total Internal Reflection. The figures in this section (2.1) are all from http://nuigroup.com/forums/viewthread/1982.

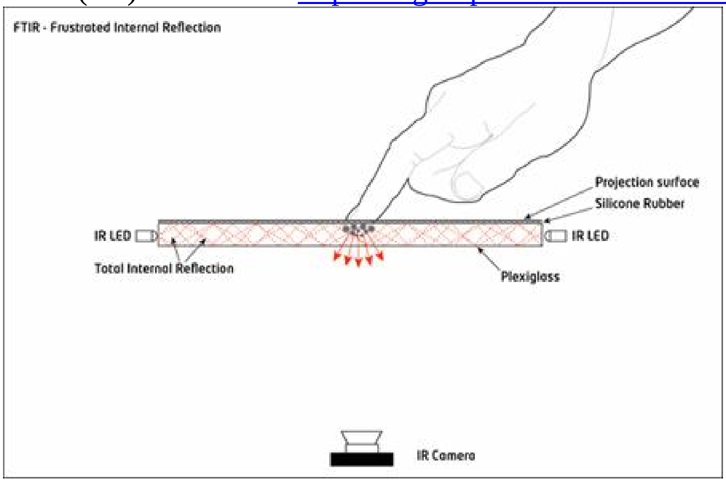



**Figure 1. Frustrated Total Internal Reflection**

Active markers, also called fiducials (see section 2.2.1 for more explanation), for example, with infrared LEDs built into them, are possible with FTIR (Malik and Laszlo, 2004). FTIR has been shown to scale up successfully but it cannot support passive fiducials, because they do not frustrate the internal reflection (Gross et al., 2008). FTIR has strong contrasted blobs, it can detect blob pressure with results in different sizes and very small objects such as pens can also be used when using a compliant surface. The choice for this compliant surface is rather precise, making it hard to construct.

### 2.1.2 Diffused Illumination (DI)

There are two types: front and rear DI. For rear-DI (see Figure 2), infrared light is shining at the screen from below the touch surface. A diffuser is placed on top or on bottom of the touch surface. When an object touches the surface it reflects more light than the diffuser or objects in the background; the extra light is sensed by a camera. Depending on the diffuser, this method can also detect hover and objects placed on the surface. Unlike FTIR, rear-DI supports passive markers (Kaltenbrunner et al., 2006, Benko et al., 2006). Rear-DI requires an enclosing box for it to work properly.

The front-DI version mostly does not need an infrared light source. Often the ambient surrounding can provide sufficient lighting from above the touch surface. A diffuser is placed on top or on bottom of the touch surface. When an object touches the surface, a shadow is created in the position of the object. The camera senses this shadow. There are no known front-DI fiducial systems.

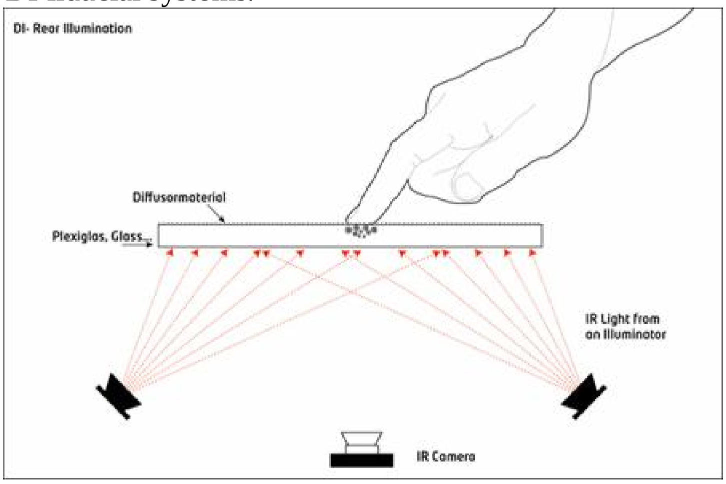



**Figure 2. Diffused Illumination, rear-DI is depicted**

DI systems do not require a compliant surface, making them relatively easy to construct. Any transparent material is suited as a touch surface. No LED frame is required for illumination. Rear-DI can detect both hovering over the panel and fiducials, front-DI cannot. DI systems are more likely to detect false positive touches than other techniques.

### 2.1.3 Laser Light Plane (LLP)

Infrared light from one or more lasers is shining just above the surface. The laser plane of light is about 1mm thick and is positioned right above the surface. When the finger just touches it, it will hit the tip of the finger which will register as an infrared blob (see Figure 3). LLP displays have been argued to provide a cheap alternative to capacitive coupling solutions (see section 2.1.5) that flood the market (Park and Han, 2010).

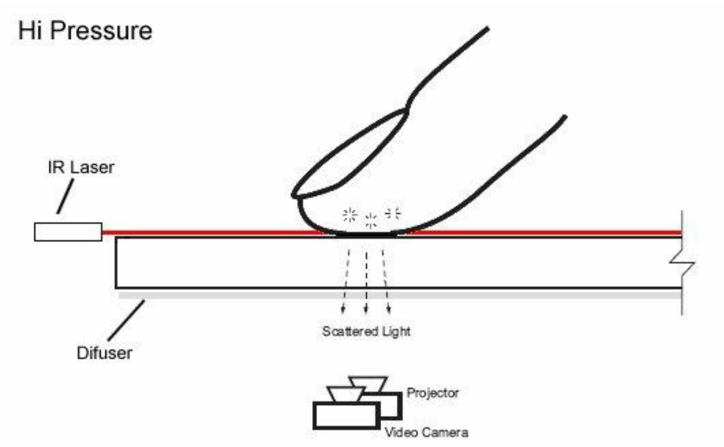



Figure 3. Laser Light Plane

LLP systems do not need a compliant surface, can use any transparent material for a touch surface, do not require an enclosing box and generally provide the simplest set-up of all multi-touch techniques. Existing surfaces can be transformed to multi-touch sensitive ones using this technique. LLP cannot detect fiducials nor can it distinguish between any object and fingers. When using just 1 or 2 lasers, LLP is sensitive to occlusion with two or more touches because the laser is obstructed behind an object.

### 2.1.4 Diffused Surface Illumination (DSI)

DSI uses a special acrylic to distribute the infrared evenly across the surface[2]. Basically a standard FTIR setup can be used with an LED Frame (no compliant silicone surface needed), and a special acrylic. This acrylic uses small particles that are inside the material, acting like thousands of small mirrors. When infrared light shines into the edges of this material, the light gets redirected and spread to the surface of the acrylic. The effect is similar to DI, but with even illumination, no hotspots, and same setup process as FTIR. See Figure 4.

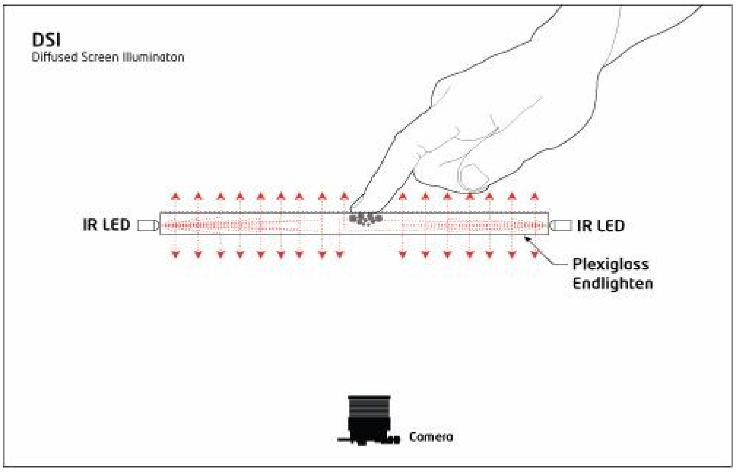



Figure 4. Diffused Surface Illumination

DSI is the more expensive hardware to construct a multi-touch panel with. With DSI one can easily switch between FTIR and DI making it capable to detect objects, hovering and

[2] DSI: last checked 30th September 2010

fiducials. DSI does not require a compliant surface and it is pressure sensitive. There are no illumination hotspots due to the even illumination throughout the surface. Blobs do have a lower contrast than with FTIR and DI systems, making them harder to detect robustly.

### 2.1.5 Capacitive Coupling (CC)

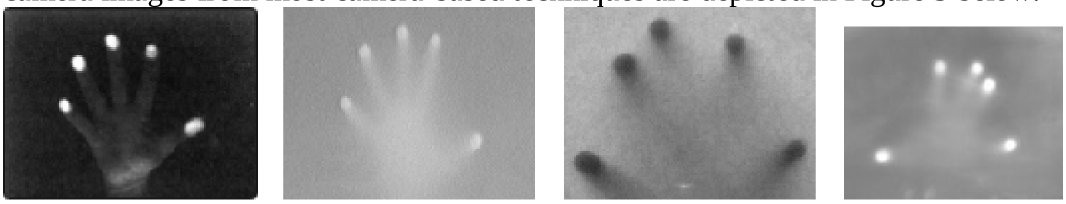
The Apple iPhone is a well-known example of a capacitive coupling touch screen. This technology relies on the conductive properties of the human skin and it is, due to its complexity, hard and expensive to manufacture. A grid of electrically polarized transmitters and receivers is required to detect the small changes in capacitance triggered by a touch. Implementations vary: the iPhone is based on mutual capacitance, SmartSkin (Rekimoto, 2002) has its receivers and transmitters under right angles and the DiamondTouch (Dietz and Leigh, 2001) touch panel contains two arrays of only transmitters with users standing on receiver mats. By design, the SmartSkin cannot distinguish between users but it can detect conductive objects (i.e. capacitive tags) on its surface. The DiamondTouch can distinguish between its users through the receiver mats enabling explicit turn taking (Forlines and Lilien, 2008; Ryall et al., 2006). The signals received by the DiamondTouch are code division multiplexed which results in ambiguity of $n^2$ possibilities for $n$ touches of the same user.
CC systems require a complex hardware set-up making them hard to construct yourself. The only commercial CC-based multi-touch panel, the DiamondTouch, panel suffers from a lack of synchronization between its x and y touches, making it hard to accurately detect what the exact touch locations are.

### 2.1.6 Challenges for Multi-touch

Multi-touch displays are potentially powerful interfaces with many open challenges. This section identifies a number of these challenges in random order. The finger is quite large and will reduce input resolution. Touch precision will need to be increased. Depending on the hardware implementation, user touch ambiguity might occur, so that the system has no information to which user the hand (or even individual touch points) belongs. Multi-touch users need be enticed to use the interface: users can be hesitant to touch the table simultaneously due to social proximity to other (unfamiliar) users (Ryall et al., 2006). This appeared to be more the case for adult users than for children. However, when multiple users operate a table at the same time their actions can easily conflict with one another (Ryall et al., 2006). The floor can be given to a user until she stops interacting, as in (Forlines and Lilien, 2008) or users might cooperatively operate the table (Morris et al., 2006). The table can be cluttered easily with visualizations when multiple users operate it. In cooperative settings users on the opposite side of the table cannot read text that is upside down for them requiring easily accessible rotation (Kruger et al., 2003) or another way (e.g., multiple versions of the text) to make the text readable. Touchlight (Wilson, 2004) shows that stereo-vision systems increase touch resolution and enable the detection of hovering over the surface (Tse et al., 2006).

### 2.1.7 Comparison between Techniques

In most cases, an adequate box enclosing the hardware is needed to prevent light seeping in from the surroundings, possibly interfering with the camera images. The resulting camera images from most camera-based techniques are depicted in Figure 5 below.



FTIR rear DI front DI DSI

**Figure 5. Camera images from most camera-based techniques**

DSI is the most resilient solution in terms of possibilities and robustness although its blobs suffer from a lower contrast. LLP can be used to turn any surface into a touch-sensitive one although it needs to overcome occlusion issues. CC allows for multi-user recognition which is arguably valuable in settings where multiple users work together around a tabletop.

## *2.2 Tangible Techniques*

Next to the detection of touch, the detection of objects is a related method of making interaction tangible. It is through these technologies that a normal, tangible, object can turn into an interface. Two major methods will be described: fiducials and RFID tags.

### 2.2.1 Fiducials

Fiducials are markers used to recognize an object. These markers are commonly “seen” by a sensory system; e.g., camera-based systems such as most tabletops. Two types of fiducials can be discerned, active and passive ones.

Passive fiducials are commonly images which are easily recognizable and discernable through computer vision techniques. Example images are shown in Figure 6. The aim of such images is to give a unique marker to an object. The concept of passive fiducials has been proven to work fairly well, depending on camera and lighting conditions (Costanza and Robinson, 2003), and is particularly useful because of the easiness of tagging objects with a visual marker.

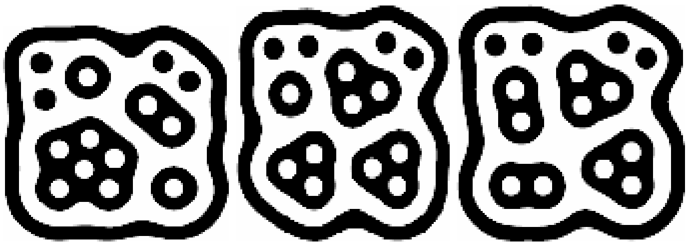


**Figure 6. Three examples of passive fiducials.**

A special type of passive fiducials is a data matrix (Stevenson, 2005). Data matrices are also called 2D bar codes and as such encode data in them; e.g., a URL. These data matrices are greatly gaining momentum, showing themselves in ever more public places to add digital data to something non-digital. Most newer telephones are equipped with

(often open-source; e.g., the ZXing library for Android[3]) software to recognize and decode data matrices, making it a popular method to pair digital information with a tangible object.
An example data matrix is given in Figure 7, encoding the web-address of the PuppyIR project. A data matrix consists of cells, either containing a value of 1 (black) or 0 (white). Data matrices can be between 8 x 8 cells till up to 144 times 144 cells in size. At the left-bottom there is a finding marker, a solid black line, allowing the user to find and orient the matrix. At the right-top there is a timing marker, allowing the user to count the number of rows and columns. Alternative implementations of data matrices exist as well: e.g., the QR code implementation, commonly used in Japan, and the Microsoft Tag[4], allowing for more elaborate and sophisticated designs of tags.

**Figure 7. Data matrix encoding the web-address of the PuppyIR project.**

Active fiducials are markers which act; e.g., markers which send out coloured or infrared light. Often, such markers are given the possibility to handle input as well, thus changing their output based on their environment. For example, an active marker might encode its current location based on a GPS sensor. In some sense, RFID tags (described in the next section) are a form of active fiducials: an RFID tag responds to an external stimulus with its identifier.

### 2.2.2 Radio-Frequency Identification

Radio-Frequency Identification (RFID) is the use of radio signals to identify an object. It uses a tag (or label) to be identified by a reader (or interrogator). There are three types of tags: passive, which use no battery and require an external source (e.g., signal) to provoke a response; active, which have a battery and transmit a signal as soon as an interrogator has been spot; and battery assisted passive which is similar to a passive one but with a longer transmission range. In general tags can be identified up to two meters and are very cost effective. Readers, however, are more expensive, up to a few thousand euros (Finkenzeller, 2010).
The different elements of the tag are key to an RFID system. A passive tag consists of three parts: a chip, an antenna, and a substrate (i.e., material that holds it all together). The chip contains the data and executes commands. Commonly, a chip contains 96 bits of information, used to identify itself with. A substrate is mostly a Mylar or plastic film, to which both the antenna and chip are attached.
The antenna is perhaps the most innovative element of the RFID tag. It absorbs radio frequency waves and broadcasts a signal in responsive. Through a technique called coupling it retrieves energy from the radio frequency waves (a technique based on Gauss'

[3] ZXing: http://code.google.com/p/zxing/
[4] Microsoft Tag: http://tag.microsoft.com

law). In general, the bigger the antenna, the greater the coupling, the further the range. Moreover, low-frequency and high-frequency antennas are similar to coils; ultra-high frequency antennas are similar to classic radio antennas.
An RFID tag is used in ways similar to a (visual) fiducial: with a limited amount of data it can identify objects or encode (manipulate) small amounts of data. As the next section will illustrate, these concepts can be applied in multiple interactive settings.

## *2.3 Possibilities with Multi-Touch and Tangibles*

Interactions with interactive tables are influenced greatly by the application and its setting. Is the interaction time crucial (Tse et al., 2006)? Do users collaborate or do they compete with each other (Gross et al., 2008)? Do users casually interact with the table in passing (Scott et al., 2004) or do they perform complex and more time-consuming tasks (Forlines and Lilien, 2008)?
The Reactable* (Kaltenbrunner et al., 2006) is built for musical performances; objects marked with passive fiducials are placed and manipulated on the surface to create the composition. These tangible objects make the interface highly engaging but require additional computational power that can slow the interface down.
The TikTegel (Van de Wouw, 2009) is an RFID-based tangible interface created to support educational activities for children. It has no normal display; it uses a surface on which activity-specific overlays (i.e., pictures) are put. By placing RFID-tagged objects on the overlay, the children interact with the system. The system gives feedback via audio. The location-aware RFID reader technology is patented.
Wu and Balakrishnan (Wu and Balakrishnan, 2003) used a room furniture layout application for exploring interaction techniques that take advantage of multi-touch and hand shape input on table displays. Two users on opposite sides of the table would fit furniture in a room in the RoomPlanner application. Private information could be projected on hands and objects (e.g. a piece of paper) by virtue of using a top-projection table.
Scott et al. (Scott et al., 2004) observed three types of interactive table territories in their observations of both casual and formal interaction settings. The personal territory allowed users to perform independent activities, the group territory served as a joint blackboard and the storage territory held unused icons in out-of-the-way spaces on the table.
By placing multi-touch surfaces on the floor, the feet can be used to interact with visualizations on the floor (Augsten et al., 2010). The Multitoe system can recognize its users by detecting and identifying the soles of their shoes. A trend can be seen in these systems that focus on ever-larger displays that span whole walls. These wall-sized displays can also be made interactive through mobile devices (Mistry and Maes, 2009) but also through adding to them touch-sensitive surfaces such as the ones we described earlier.
Commercial systems such as the Apple iPad[5] and many similar tablet PCs are flooding the market. The availability of these mobile, small and mass-market multi-touch panels allows many new opportunities in creating multi-touch interactions in public environments. An example is the Touch Projector where a mobile phone is used to control out-of-reach displays (Boring et al., 2010). The interactive components of the

[5] Apple iPad: http://www.apple.com/ipad/, last checked 1st October 2010

display contents are projected on the phone so that the user can operate them through touch. The SixthSense system uses camera-based control of arbitrary interactive surfaces (Mistry and Maes, 2009). Any surface can be transformed into an interactive visualization through projecting on that surface with a small, mobile projector. The Skinput system is similar to SixthSense but it appropriates the human body for acoustic transmission, allowing the skin to be used as an input surface (Harrison et al., 2010).

Similar popular attention and broad public interest as with the release of Apple's popular iPhone and iPad and Nintendo's Wii[6] can be expected later in 2010 when Microsoft releases its Kinect system[7]. The Kinect system can detect gesturing not only on surfaces but its time-of-flight camera enables the detection of hovering over a surface and gesturing in mid-air. This is similar to the TouchLight system described earlier (Wilson, 2004).

Spherical displays are also used as interactive surfaces (Benko et al., 2008). In "Sphere" this surface type is used to interact with mostly 3D globe-like structures such as the earth and other astronomic bodies. Alternative surfaces are water-based[8], mud-based[9] and pressure sensitive touch-panels. The later display type is currently in full development[10].

## *2.4 Models of Tangible User Interfaces*

A few decades ago, Human-Computer Interaction was largely restricted to traditional graphical user interfaces on computers with rectangular screens and mouse and keyboard as input devices. In that time Ishii and Ullmer (1997) proposed to make computing truly ubiquitous and invisible and they introduced tangible user interfaces as a way to make digital information tangible. In these interfaces physical objects play a central role both as physical representations and as physical controls of digital information. This allows people to take advantage of their experience in the real world with multimodal human interactions. Several models, taxonomies and frameworks have been proposed. In the following subsections we treat two models that focus on typical characteristics of tangible user interfaces and that can be used to determine the tangibility of an interface.

### 2.4.1 Towards a Conceptual Framework – Ullmer & Ishii

Ullmer and Ishii (2001) present an interaction model for tangible user interfaces. Central in this model is the integration of physical representation and control. Whereas in graphical user interfaces input (control) by mouse and keyboard is strongly separated from the output (digital representation) provided by the graphical display, in tangible user interfaces physical representations embody mechanisms for interactive control and the distinction between input device and output device disappears. Ullmer and Ishii distinguish four key characteristics of tangible user interfaces:

1. Computational coupling of physical representations to underlying digital information
2. Physical representations embody mechanisms for interactive control

[6] Nintendo Wii: http://us.wii.com/
[7] Mircosoft Kinect: http://www.xbox.com/kinect/, last checked 1st October 2010
[8] Multi-touch water screen: http://sassexperience.org/multitouch/water.html, last checked 1st October 2010
[9] Mud-tub: http://tomgerhardt.com/mudtub/, last checked 1st October 2010
[10] http://bits.blogs.nytimes.com/2009/12/30/multi-touch-screens-could-enable-many-new-devices/, last checked 1st October 2010

3. Perceptual coupling of physical representations to actively mediated digital representations
4. The physical state of interface artifacts partially embodies the digital state of the system

In their model, Ullmer and Ishii (2001) strongly focus on the role of physical representation, though they do not intend to exclude systems with less emphasis on graspable physical objects from the design space of tangible user interfaces.

### 2.4.2 Taxonomy with Dimensions Embodiment and Metaphor - Fishkin

Fishkin (2004) relaxes this focus on physical objects and the elimination of the distinction between input and output devices. He presents a taxonomy with two dimensions: embodiment and metaphor. The characteristic embodiment has four levels: full, nearby, environment and distant. In case of full embodiment input device and output device are the same. In case of distant embodiment the output is at another place than the input, on another screen, or even in another room. Metaphors are frequently used in language and interaction design, to conceptualize abstract or hard-to-imagine concepts and interactions in more concrete terms and as graphical visualizations at the interface (Sharp, Rogers and Preece, 2007). Fishkin chose metaphor as one of the axes of his taxonomy because of the obvious relationship between the physical tangibility of parts of an interface and physically afforded metaphors. The place on this axis shows how analogous the system effect of a user action is to the real-world effect of similar actions. The metaphor dimension has four levels as well, based on the grouping of metaphors in two types called “metaphor of noun” and “metaphor of verb”. A metaphor of noun appeals to the *shape* of an object and a metaphor of verb appeals to the *motion* of an object. The four levels on the metaphor axis are: none, noun or verb, noun and verb and full. In case of “none”, physical representation and manipulations are not connected to any real-world analogy; in case of “full”, in the mind of the user the virtual system *is* the physical system.

The higher a system scores on the level of embodiment and the level of metaphor, the more tangible it is. This taxonomy is useful for examining and comparing existing systems, but it can also be used by designers, to think about and choose a level of embodiment and metaphor (Mazalek and Van den Hoven, 2009). Tabletop interaction (with and without tangible objects) fits here as well – better than in the model of Ullmer and Ishii. Figure 8 shows the taxonomy printed as a matrix with the artifacts computer keyboard, normal joystick, joystick shaped like steering wheel, greeting-card with audio, and car-seat controls shaped like car seats within it.

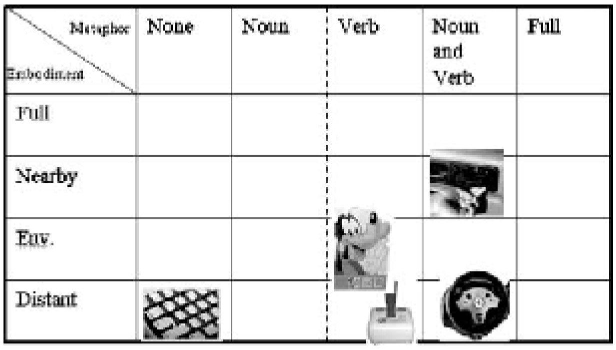



Figure 8. Industrial design artifacts placed in the taxonomy. Source: Fishkin 2004.

### 2.5 *Conclusion*

This chapter mainly treated the system characteristics of tangible user interfaces, with their possibilities and restrictions. In Chapter 3 we will focus entirely on the user: how the user will interact with tangible interfaces and how to design tangible user interfaces for children.

# 3 Tangible User Interfaces for children

Many models, taxonomies and frameworks for tangible user interfaces have been proposed in the past decade. Two system-oriented models have already been treated in Chapter 2. In this chapter we treat user-centered models: models that mainly focus on user experience and on how to design interactions. See Mazalek and Van den Hoven (2009) for an overview of existing models. Only one of the models we found focuses especially on tangible interfaces for children. In this chapter we first describe three well-known existing models. Then we relate these models and derive a model that will be used in the PuppyIR project, to guide design and evaluation of the experimental applications and the demonstrators

### 3.1 *Heuristics to Exploit Human Spatiality – Sharlin et al.*

Sharlin et al. (2004) argue that the success of tangible user interfaces depends on how well they exploit spatiality, human's innate ability to act in physical space and interact with physical objects. They propose three heuristics that can guide tangible user interface design.

1. *Physical/digital mappings must be successful spatial mappings.*
   A spatial mapping is successful if the spatial relationship between a physical object and its digital use is natural and intuitive and exploits spatial abilities known innately or learned early in life.
2. *Physical/digital mappings must unify input and output space.*
   When we play with a physical object the action space (our hands moving the object) and perception space (view and weight of the object) are perceived in the same time and place. Tangible user interfaces designed to maximize input and output unification have a tight action-perception coupling leading to increased user identification between physical interface components and digital application objects.

3. *Physical/digital mappings must enable trial-and-error activity*.
   Good physical tools enable people to perform goal-oriented activities as well as trial-and-error activities meant to explore the task space. They make sure that the cost of trial-and-error explorations is low. To allow unconstrained exploration of digital problems in physical space, designers of tangible user interfaces should try to provide as many one-to-one couplings between physical interface objects and digital application as possible. Transient many-to-many or one-to-many mappings should be avoided, when possible.

## 3.2 Framework Focusing on Interaction Experience – Hornecker & Buur

The model presented above and the ones presented in Chapter 2 define tangible user interfaces as interfaces that utilize physical representation and manipulation of digital information: physical and digital objects are computationally coupled. Hornecker and Buur (2006) call this the *data-centered view* on tangible interaction. They extend this view with an *expressive-movement-centered view* that emphasizes bodily interaction with objects and a *space-centered view* that focuses on interactive spaces that combine physical space and objects with digital displays and sound installations. For PuppyIR the data-centered view is most important, hence these extensions will not always be relevant. Nevertheless the paper of Hornecker and Buur is interesting because they introduce a framework of tangible interaction that focuses on the user experience of interaction. The models we presented until now focused mainly on categorizing and characterizing systems and representations. The framework of Hornecker and Buur consists of four interrelated themes that offer different perspectives on tangible interaction. The use of these themes allows for systematic shifts of focus in analysis and offers conceptual guidance for design. The themes and the related concepts that elaborate each theme are presented in Figure 9.

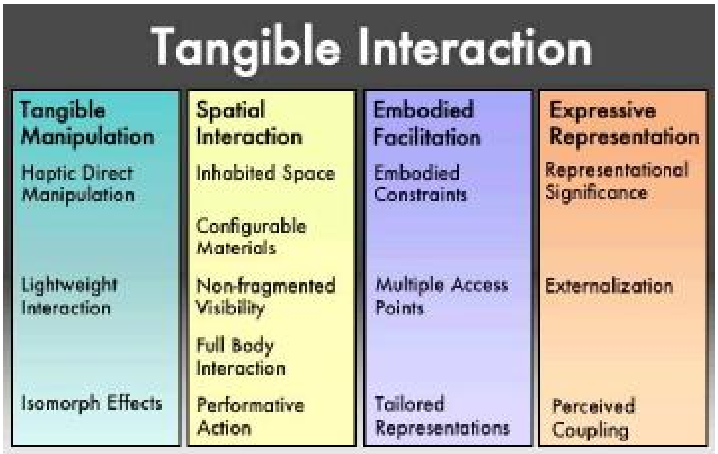



**Figure 9. Themes and related concepts. Source: Hornecker and Buur 2006**

From left to right in the figure, the themes become more general. The most specific theme *Tangible Manipulation* refers to the interaction with physical objects and can be characterized by the concepts:

- Haptic direct manipulation: can users grab, feel and move the interaction objects?

- Lightweight interaction: a conversational style of interaction with rapid feedback, allowing users to proceed in small experimental steps.
- Isomorph effects: how easy is it to understand the relation between the manual actions of users and their effects? For instance because they are close in time, visibly nearby or of the same shape. However, they warn not to stop at simple direct mappings.

The theme *Spatial Interaction* refers to the inherent property of tangible interfaces that they are embedded in space and take up real space. Concepts like full-body interaction and the things that can be communicated by body movements are part of this theme but will not be treated here because we do not expect to use these concepts in the PuppyIR system. Other concepts in this theme are:

- Inhabited space: Is the place where people interact meaningful? How is the positioning of the objects in relation to the body of the user (which is the reference point for perception)? Do users and objects meet?
- Configurable materials: Does moving significant objects around (in order to control or explore the environment) have meaning?
- Non-fragmented visibility: can everybody see what is happening and follow the visual references?

The third theme *Embodied Facilitation* is characterized by the following concepts and main questions:

- Embodied constraint: Does the physical set-up (such as size, form or location of objects) lead users to cooperate by easing some activities and limiting others?
- Multiple access points: to distribute control such that all users can get their hands on objects of interest. Can all users see what is going on?
- Tailored representation: are the representations built on the user's experience and skills and do they invite them into interaction?

The most general theme *Expressive Representation* refers to the interrelation of physical and digital representations and to how users perceive them. Often hybrid representations combine physical and digital elements. These representations have different representational qualities. The concepts in this theme are:

- Representational significance: are physical and digital representations equally strong and salient? Are they meaningful and of long-lasting importance?
- Externalization: can users use the objects as props to act with or think and talk with or through? Are tangible interactions salient to the overall use process?
- Perceived coupling: are physical and digital representations seemingly naturally coupled?

## *3.3 Tangible Systems for Children – A Conceptual Framework - Antle*

Antle (2007) developed a preliminary conceptual framework for the design of tangible and spatial interfaces for children. The framework is based on conceptual understanding of how and why the features of tangible and spatial interactive systems support cognitive processes in children over the age of four and under the age of twelve. In her definition of tangible systems, Antle follows the broad definition of Hornecker and Buur (2006). She defines tangible systems as systems that rely on tangible manipulation and physical representation of data, interactions that take place in real physical spaces or digitally augmented physical spaces. Tangible and spatial interactions may be haptic, gestural, full bodied or spatial. The framework of Antle can be used to inform tangible systems design and it can serve as an analytical framework for resulting interactions. The framework considers notions from both cognitive development and educational theory. In the design of tangibles to support abstract thinking, designers should be aware of the strengths of action-based cognition and the limitations of children's mental representational abilities. Therefore the framework uses concepts from the area of embodied cognition but also from information processing approaches to cognition.

The child tangible interaction (CTI) framework of Antle (2007) is presented in five themes, each relating to a feature or aspect of tangible systems. The first theme: *space for action*, refers to the spatiality of tangible user interfaces which was also central to the theory of Sharlin that was treated in section 3.1. The suitability of tangible systems to use children's developing repertoire of physical actions and spatial abilities for direct system input and control can only be applied successfully if design is based on an understanding of how and why children's actions in space relate to changes in cognitive development. Direct physical interaction with the world, by means of bodily engagement with physical objects, facilitates active learning and is a key component of cognitive development in childhood. The repertoire of physical actions that can be used in design should be age appropriate, based on existing knowledge about children's development. Children use epistemic actions to facilitate development of understanding of how things work. An example is the repeatedly connecting and disconnecting of Lego blocks to better understand how different configurations relate to stability of the construction. External scaffolding (aids that include interactions with other children, adults, or aspects of the environment) is often used when executing epistemic actions. This theme is related to the theme actions and effects

The second theme, *perceptual mappings*, refers to the various kinds of mappings between physical and digital space that are afforded by tangibles. The mapping between the perceptual properties of the physical and digital aspects of the system can rely on perceptual affordances or designed affordances. Designs that rely on perceptual affordances allow even very young children to explore these mappings. Designed affordances are opportunities for actions which are created through mindful design of artificial objects and environments. These affordances may be meaningful for adults, but for children age appropriate perceptual, cognitive and motor abilities and limitations need to be considered.

The *behavioural mappings* theme refers to the mapping between the input behaviours and output effect of the physical and digital aspects of the system. Choices regarding these behavioural mappings will have to take children's understanding into account. Experiential cognition is a mode of cognition that gives children the opportunity to explore new concepts, environments and activities. Reflective cognition gives the opportunity to search for understanding and explanations and is required to learn complex structures and concepts. Children need support to ensure that they switch from an active, experiential mode to a reflective mode where they can acquire new understandings. Design choices can actively promote a switch to a reflective mode, for instance by introducing uncertainty and unexpectedness in system events (Rogers and Muller, 2006).

Children apply several cause-and-effect principles with varying degrees of accuracy at different ages. A few important "common sense" principles used by young children are that they think causes precede their effects or occur simultaneously; causes and their effects covary systematically and causes and effects must be contiguous in time. Design of behavioural mappings requires understanding of how young children apply these principles.

*Semantic mappings* refer to the mapping between the information carried in the physical objects and the digital aspects of the system. Young children (under seven) have difficulty relating physical manipulatives to other forms of representation. The ability to understand that one object can have multiple representations develops slowly. Several design concepts result from the semantic mappings theme:

- Reveal representational mappings
- Facilitate exploration of relationships between entities and representations
- Facilitate the development of reciprocal mappings between physical and mental representations
- Leverage children's understandings of bodily-based concepts to help them understand abstract concepts
- Leverage children's understanding of concrete spatial schemata to help them understand abstract concepts

The first two design concepts need no further explanation. The third concept is based on theory of the development of spatial cognition. Tangible interfaces provide both a model and a control for physical space which is subsequently mapped to virtual space. Hence the mapping between representations is important. As children age, their conceptions of space and mental abilities to visualize, transform and change perceptions in space improve which results in a better understanding of maps. This is reciprocal: in turn, the children's developing conceptions of maps improve their ability to conceive space and understand spatial information. An example to explain the fourth concept: children use their fingers to learn to count. A similar example for the last concept: children may conceptualize counting as adding to a pile of objects.

The last theme is called *space for friends* and refers to the fact that tangible user interfaces have both the space and affordances for multiple users. This gives the opportunity to facilitate collaboration and imitation. Since collaboration and imitation are important ways for children to develop schemata level knowledge acquisition, it is important for designers of tangible user interfaces to understand the importance and mechanisms of imitation in experiential learning and to understand how to facilitate children's collaboration. Tangible systems have space and handles for co-located collaboration without the need to share input devices. Since collaborative interaction was the subject of deliverable D2.1 of PuppyIR, we do not elaborate on that topic here. Another topic belonging to this theme is imitation. Learning through imitation is very important for young children. When young children observe another person using unfamiliar objects they try to discern what the other person is using the artifact for. Tangible user interfaces are very suitable to foster imitative learning processes because of the physicality of tangibles combined with space for others and digital feedback.

Though engagement is a critical aspect of interaction design the CTI framework does not pay attention to affective and motivational factors (Antle, 2007). Neither do the other models in this chapter. For PuppyIR, this theme is of importance and will therefore be added.

## 3.4 Engagement and Fun

Three perspectives on engagement and fun will be described: presence, motivation, and user experience.

Presence is the feeling of being in a mediated world; i.e., being fully engaged in a mediated activity. Accordingly, the degree of presence can be seen as the degree to which normal (psychological) processes are applied to a mediated world (Nunez, 2003). Tangible interfaces have the ability to heighten presence by this definition: it allows using normal (physical) processes to interact with a mediated world.

Motivation is an important user state, influencing the effort exerted and the persistence shown in solving a problem. It has been found to be a strong predictor of problem-solving success (Jonassen, 2000). Motivation is often divided in intrinsic motivation; i.e., a genuine interest, and extrinsic motivation; i.e., some external incentive. An interface can be made extrinsically motivating by making it more game-like; i.e., with fantasy, challenge, rules and goals, sensory stimuli, mystery and active user control (Garris et al., 2002). Intrinsic motivation can be explained by two determinants: a task performance that leads to a sense of mastery and competence, and a novelty that leads to a sense of curiosity, attention, and interest (Reeve, 1989). The implications of these two aspects for tangible interfaces are described in depth in Section 4.2. Moreover, it should be noted that feedback on and an overview of the progress with the activity are a key element of intrinsic motivation which should be supported by an interface (Csikszentmihalyi, 1991).

The final perspective, user experience, takes a holistic view on engagement and fun. User experience is a rather fuzzy concept, often defined as technology use beyond its instrumental value (e.g., topicality for IR). In other words, stating that it is the whole experience of an interactive system, contrary to only the instrumental, which creates value. Hence, the focus on user experience is broader than merely heightening the enjoyment of a system; the experience has many facets joining together. Several aspects of user experience have been identified; e.g., usability, beauty, affect, temporality, and situatedness. Together, these aspects explain part of the eventual user experience (Hassenzahl and Tractinsky, 2006). Hence, an interface should be usable (i.e., intuitive), support positive emotions (See Section 4.2), and be aesthetically appealing.

## 3.5 Comparison of the Models and a Model for PuppyIR

Comparison of the models and taxonomies shows that Ullmer & Ishii (see Chapter 2) give key characteristics of tangible user interfaces, focusing on *what* makes a system tangible. The models of Sharlin et al., Hornecker & Buur and Antle in this chapter focus more on *how* to design successful tangible user interfaces: Sharlin et al. give heuristics to make full use of spatiality, the innate ability of humans to act in physical space and interact with physical objects; Hornecker & Buur focus on the user experience of interaction and give several design concepts and questions that can guide design; and Antle relates features of tangible systems to cognitive processes in children. Since these three models are more prescriptive we will only use these models to derive a model for PuppyIR.

The taxonomy of Fishkin (see Chapter 2) does not derive heuristics or design principles but uses two dimensions: level of embodiment and level of metaphor on which tangible user interfaces can be compared to determine their tangibility. The dimensions embodiment and metaphor have many relationships with several of the design heuristics and concepts of the models described in this chapter. Still they will not be incorporated directly into the model but can be used to determine the extent to which certain heuristics will be followed. We use an example here to explain how it can be used. Sharlin proposes the heuristic: unify input and output space and Hornecker has the related concept of haptic direct manipulation: can users grab, feel and move the interaction objects. If we relate that to the dimensions of Fishkin, full embodiment and full metaphor would mean that input and output device would be the same physical, digitally enhanced, object. In PuppyIR we would like to consider virtual representations of the same object as output as well, for instance on a multi-touch table with tangibles used for interaction. If the tangibles have a virtual representation on the table this would fall into the category nearby embodiment and noun and verb metaphor in the taxonomy of Fishkin. For practical reasons, in PuppyIR the tangible physical objects will often be replaced by virtual objects on a multi-touch table. The taxonomy of Fishkin is useful for tabletop interaction without tangible objects as well.

In the model we propose for PuppyIR, the design concepts and heuristics are grouped in four themes: (1) Physical and digital representations; (2) Actions and effects; (3) Exploration and collaboration; and (4) Engagement and fun.

The theme *Physical and digital representations* refers to the appearance of the physical objects and the relation with the digital representation of the objects. Are representations naturally coupled? Are they meaningful and built on the user's experience? Do they invite them into interactions? This theme is related to several design concepts treated in Hornecker and Buur and to the perceptual mappings theme of Antle. See Table 1 for the related concepts. Concepts in brackets are related to the theme but probably less important for the design and evaluation of PuppyIR applications.

**Table 1. PuppyIR model of tangible user interfaces related to two other models**

Concepts in brackets belong to the themes but are probably less important in PuppyIR

| Theme | Related concepts of Hornbecker & Buur (2006) | Related concepts of Sharlin et al. (2004) | Related themes of Antle (2007) |
|---|---|---|---|
| Physical and digital Representations:<br><br>The appearances | Perceived coupling<br>Representational signific.<br>Tailored representation<br>(Inhabited space – partly) | | Perceptual mappings<br>Semantic mappings |
| Actions and effects:<br><br>How tightly are they related? | Isomorph effects<br>Externalization<br>Haptic direct manipulation<br>(Inhabited space – partly)<br>(Configurable materials) | Successful spatial mappings<br>Unify input and output space | Space for action<br>Behavioural mappings<br>Semantic mappings |
| Exploration and Collaboration:<br><br>How are they facilitated? | Lightweight interaction<br>Embodied constraint<br>Multiple access points<br>Non-fragmented visibility | Enable trial-and-error activity | Space for friends<br>Semantic mappings |
| Engagement and Fun: Are presence, motivation and user experience positively affected? | | | |

The theme *Actions and effects* refers to the relation between the manual actions of users and their effects. Are they easy to understand, for instance because they are close in time, visibly nearby or of the same shape? Is the spatial relationship between a physical object and its digital use natural and intuitive? Does it exploit spatial abilities known innately or learned early in life? Is there a tight action-perception coupling leading to increased user identification between physical interface objects and digital application components? Can users use the props to act with or think and talk with or through? Again we refer to Table 1 for the related concepts, heuristics and themes in the other three models treated in this chapter.

The theme *Exploration and collaboration* refers to the suitability of tangible user interfaces to facilitate exploration and collaboration. To facilitate exploration the user interface should enable users to perform goal-oriented activities as well as trial-and error activities, meant to explore the task space. Does the interface offer a conversational style of interaction with rapid feedback to allow users to proceed in small experimental steps? Is the cost of trial-and-error explorations low? Are there many one-to-one couplings between physical interface objects and digital application? To facilitate collaboration the interface should offer distributed control (multiple access points) such that all users can get their hands on objects of interest. Can everyone see what is happening and follow the visual references? Does the physical set-up (such as size, form or location of objects) lead users to cooperate by easing some activities and limiting others? Table 1 shows the related concepts in the models of Hornecker & Buur, Sharlin et al. and Antle.

The theme *Engagement and fun* refers to the suitability of tangible user interfaces to increase presence, to be intrinsically and extrinsically motivating, and to create a positive user experience. Presence is closely related to the first two themes, where a decrease between *action and effect* and between *physical and digital representations* increases the use of normal psychological processes. Moreover, this also applies to other modalities (e.g., interaction through speech and sound) (Van der Sluis et al., 2006). Is the interface intrinsically motivating? Does it offer timely feedback on and overview of the progress? Is the interface extrinsically motivating, for instance by making it game-like? How do users experience the interface? Does it support positive emotions? Is it enjoyable and fun to use? Is it usable, intuitive, and aesthetically appealing? This theme does not occur in the other models treated in this chapter but is added because of its anticipated importance.

This model will be useful to guide the design of PuppyIR prototypes and demonstrators and it will also be used to develop measures for user-centered evaluation.

# 4 Children and Tangible Interaction in PuppyIR

As described in chapter 3, tangibles have a wide potential to support children's interactions and enrich their possibilities of using technology. In the first part of this chapter we present examples of tangible interactions of children in scenarios that are interesting for PuppyIR. In the second part of this chapter we will elaborate on tangible output in relation to the themes of the PuppyIR model.

## *4.1 Scenarios of Tangible Interactions*

Referring to the themes identified in chapter 3 and presented in Table 1 we present three use case scenarios of tangible interactions and models in PuppyIR.

### 4.1.1 Using Tangible Objects to Support Children's Group Decision Making

Although children can benefit from group learning and working, they are not necessarily able to organise collaborative situations on their own (Crook, 1998; Inkpen et al., 1999). Since multi-touch tables are primarily designed as interfaces that highly aim at providing collaboration we have to ensure that PuppyIR will provide suitable interfaces for both, collaborative and non-collaborative situations. Referring to D2.1 where we have described interaction paradigms and models for collaboration, helping children to organize a task is also important when tangible interaction is combined with tabletop devices. Scripting can help children to effectively work together (King, 2007). In

classrooms teachers are often implicitly scripting tasks for pupils and when children come together to play, games also follow special rules and are thereby implicitly “scripting” a process.
Starting collaboration on a multi touch table can be distracted by the fact that children might not be able to find a common topic they are all interested in or they could at least agree to work on together. Therefore, a tool is currently under development to support children’s decision making when they want to start a collaborative search task after they gathered different topics of interest, e.g. during a tour through a museum. In a first screen the children get a presentation of all personal topics of interest (maybe limited to a sensible selection if the size of the table requires this). The idea is to ask the children to “vote” for their preferred topics by using tangible objects with fiducial markers which can be positioned on top of a topic on interest on the table. This voting process follows a game based approach and refers to both the theme of *engagement and fun* and *actions and effects* from Table 1, whereas the latter possibly plays an minor role.
To implement the voting process, different objects can be used depending of the children’s age, gender and their concept of what value or “weight” a special object may have. One possible setting can be that each child has three different coins in gold, silver and bronze and has to place each of the coins on a topic regarding how much he/she is interested in this topic. Alternatively there can be other items used representing different values. Finally children can have items with equal values and place a different number of items on each topic to express their interest. Figure 10 shows how the initial interface could look like.

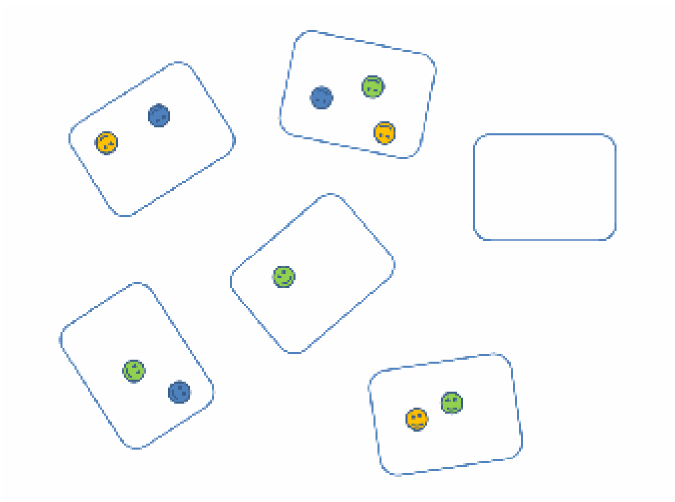


**Figure 10. Voting for interesting topics**

After each child finished the “voting” task the system can generate a ranking and suggest topics to the children, that probably no child will refuse to work with. That way a collaborative search can successfully be started without frustrating or disappointing the children. The tool will be tested and a related publication will be planned for the first quarter of the third project year. Figure 11 shows how the “voting” might influence the appearance of the topics.

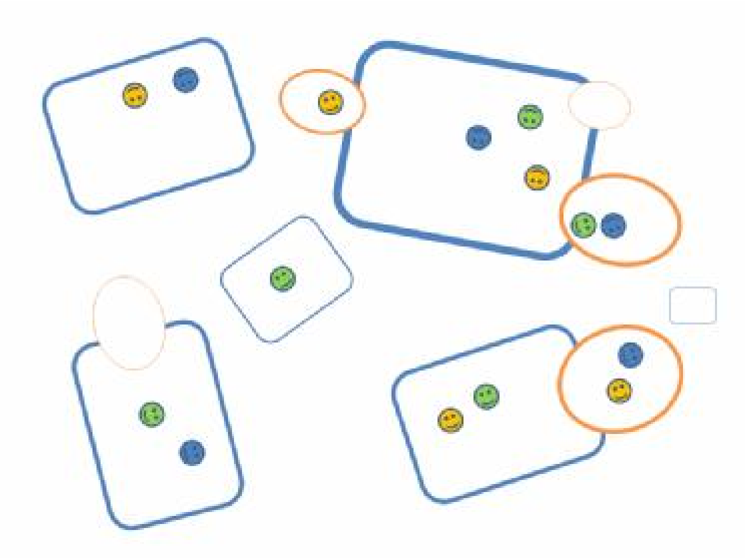


Figure 11. Tokens placed in different topics and interest is visualized

After the children have expressed their interest, the system calculates the ranking of topics and fades out topics which are less important. This could be done by automatically resizing objects or highlighting more important objects. While objects without a tag shrink and will probably fade out and disappear completely, the other objects will grow depending on the number of children who are interested in the topic. In a next step the system could start to search for more related objects/topics in the background and attach these new objects to the related content. If the children like the new objects, they can also tag them with their personal identifier. If a new objects gets no attention for a certain time it might start to fade out and disappear and new objects could come up. Thereby collaborative search can be scripted by using tangibles and help children making decisions.

### 4.1.2 Using Tangible Objects and Books for Retrieval of Books

Despite the fact that children grow up using computers and the Internet frequently and despite efforts to make search engines more child-friendly, children have problems using information retrieval (IR) systems that require textual keyword input (Druin et al., 2009). We studied an alternative input method, using tangible objects to search for books (Jansen et al., 2010). To investigate how tangible user interfaces can make IR easier for children, we built and evaluated TeddIR. TeddIR is a fully functional prototype that allows children to search for books by placing tangible objects or books in boxes. The target age group is 6-8 years. The complete prototype, consisting of two boxes, a display and a set of tangibles, is shown in Figure 12.

Figure 12. The prototype in the set-up used during evaluation. Source: Jansen et al. (2010)

The two boxes are red and green, with a happy smiley on the green box and a sad smiley on the red box. If children place a tangible or book in the green box that means they like it and want to look for books matching the tangible representation. If they place a tangible in the red box they dislike it and want to avoid books that match the tangible representation. The children can insert or remove tangibles at any time.

The tangible objects represent concepts that may be either concrete (e.g., a dog stands for books about dogs; a car stands for books about cars) or abstract (e.g., a spider stands for books with scary subjects in general; a heart stands for love). If children have read a book they like/dislike they can put it in the green/red box.

The moment a tangible is inserted to or removed from a box this is shown on the display between the boxes. The display shows the contents of the boxes in two virtual "boxes" at the bottom of the screen. The biggest part of the screen shows the search results: the covers of the twelve most relevant books, in order of decreasing relevance. See Figure 13 for a screenshot of the display.


**Figure 13. Screenshot of the GUI shown on the display. Source: Jansen et al. (2010)**

Every action with a physical tangible object triggers a reaction in the virtual world on the display. Display updates are visualized using animated transitions.

To test how well children understand the concept of a tangible interface for browsing and searching a collection of books, TeddIR was evaluated with seventeen children aged 6-8 years at a primary school. Six boys and eleven girls attended the test. Special care was given to the test procedure and set-up, to make it suitable for children and to use methods that would make it possible to gather as much information as possible from the children interacting with the prototype. The children did the test in groups of two or three children. For more details about the procedure and set-up we refer to Jansen et al. (2010).

During a closing interview the children all reported that interacting with the system was a lot of fun and it was like playing a game. They often continued playing with the system or tangibles after they completed the tasks. All children understood the relation between the physical boxes and the virtual “boxes” on the screen. They often repeatedly inserted tangibles into a box and removed them again while looking at the screen to watch the animation.

The children understood the meaning of the tangibles. Even the meaning of the abstract tangibles was clear. The mix of concrete and abstract concepts did not confuse them, which is proofed by their remarks while playing and by their answers during the interview. All children were able to use of the green box to select books (e.g., for the task select on soccer) and they could explain how to accomplish that task. The use of the negative red box was more of a challenge to most of the children. Although the screen used was not a touch screen, in multiple occasions the children touched the screen in an attempt to interact with the system, for instance to get to know more about a certain book. This seems to indicate that touch screen interaction is quite intuitive for these children. The results show that tangible user interfaces are promising for IR tasks for children, as an alternative to textual input by keyboard.

### 4.1.3 Using Physical Objects to Integrate Children's Experiences

Referring to the theme *Physical and digital representations* a system built with PuppyIR could make use of future technology for identifying places and objects through technology and web services. During the last years there were many different technologies introduced which can identify and detect natural objects, locations or even buildings. One of the latest in this line is Goggle, an image recognition service for Android mobile phones which can identify buildings, locations or other hot spots shown on pictures which are taken by mobile phone cameras. Since not only mobile phones are equipped with a GPS receiver but more and more digital cameras as well there is a huge potential in using this meta data to search for information by using digital images. For example, if children are on a field trip in a forest and take pictures of leaves or animals, the digital photo in conjunction with a location based recognition can help children to receive information about items they have found and photographed ("tell me what this is") and enable them to turn this into keys to search for information.

Supermarkets already work with camera attached scales to measure loose fruit and vegetables and let the customer weigh them by themselves without the need of selecting any buttons or remembering any codes but just by placing fruits like bananas on a scale and getting a price label printed (Bolle et al., 1997). It is imaginable that technology like this can enable children to identify objects like leaves or fruits found in a forest during a field trip and turn them into search keys.

Depending on other new technologies we will likely see affordable interfaces that can be used by developers building search interfaces and information services for children in various context using the PuppyIR system.

## *4.2 Tangible Output*

The definition of tangible in Chapter 1 highlights two perspectives through which the output of information can be made tangible as well: discernible by touch or *tactile information*; and possible to understand or *tangible information*. We will describe both perspectives in relation to both the user and system requirements already depicted in this deliverable.

### 4.2.1 Tactile Information

In August 2009, the title on the cover of *Communications of the ACM* was printed in Braille, in reference to its cover article on a blind person's interaction with technology (Shinohara and Tenenberg, 2009). Braille is the most common used form of relief print, already devised in 1821. It uses 6 dot positions to denote a character, leading to 64 possible characters, discernable by touch.

However, Braille is not the only system in use. Currently, there are three types of devices: mechanical energy, electric field, and thermal flow devices. The last, thermal flow is able to create temperature differences. Mechanical energy is the most used implementation and actually puts pressure or vibration on the skin. The electric field devices try to activate the nerves underneath, and by that merely create the perception of touch (Chouvardas et al., 2008).

Tactile interfaces are not only used to read information. Two notable examples are: giving informative tactile cues to warn the user in situations of high (work)load such as driving (cf. Cao et al., 2010), and enhancing one's user experience by adding tactile

stimuli, for example when watching video (cf. Nijholt et al., 2010). These examples fit in the theme *Action and effects* of the PuppyIR model in Table 1.
Referring to the themes ***Physical and digital representation*** is the fact that often a hybrid between tangible input and visual output is used. The merge of the two can be quite profound, in particular for object-based systems (i.e., using fiducials or RFID tags, see Section 2.2). An example of this hybrid approach is Siftables. A Siftable is a small object with a screen attached on top of it. Depending on the location of one Siftable relative to other Siftables, the screen can show different information (Merrill et al., 2007). Here the theme *Actions and effects* becomes relevant. As in the example with the Siftable, often a tangible user interface does not give tactile output (see Section 2). Accordingly, the focus will be primarily on the second definition of tangible in this section.

### 4.2.2 Tangible Information

To make information tangible is to make it possible to understand or realize (see Chapter 1). Implications for a tangible user interface are two-fold: it is both the information presentation and the information itself which can be made tangible.
The concept of tangible information and its presentation is best explained from a common theoretical framework of flow experience. The concept of flow was introduced by Csikszentmihalyi (1991), meaning a complete absorption in what one does. More particularly, it refers to something intrinsically motivating; i.e., the activity itself is seen as rewarding. This type of activity has also been coined autotelic activity, where auto can be substituted with self, and telic (from telos) with goal: an activity which is its own goal. The theme *Engagement and fun* is relevant here.
Chen (2007) concludes on two core components of a flow experience: a balance between one's skills and knowledge, and a continuous feedback or indication of progress towards the end-goal. Van der Sluis and Van Dijk (2010) indicate some of the bottlenecks for the flow experience of children: they in general have less cognitive skills, less meta-cognitive skills, and less literacy skills than experienced users.
Concerning the information presentation, this implies that the presentation should be adjusted to the user. When looking at children, the amount of information a child can process is dependent upon the (meta-)cognitive skills of the child. As these in general are low, an interface should give less information at once; i.e., less search results or less information per result should be visible. Moreover, the interface should indicate the progress of the information search: e.g., through giving a history of the search session.
Concerning the information itself, Van der Sluis and Van den Broek (2010b) focused on how attributes of an information object can influence the flow experience. Four directives were shown: readability, amount of information, coherence, and the overlap with the user's knowledge. Textual features indicative of each facet were successfully shown to be able to distinguish between simple text and normal text. Moreover, De Belder and Moens (2010) have developed a method (for PuppyIR WP3) to reduce the complexity of a sentence.
In conclusion, a tangible user interface also incorporates tangible output; i.e., tangible information. The interface can support them both in the way the information is presented and in the presented information itself. However, the full complexity of making information tangible is beyond what is shown here: it requires the interface to learn about (the knowledge and skills of) its user (Van der Sluis and Van den Broek, 2010a).

Moreover, it involves more aspects of the user experience; i.e., of the whole Information Retrieval eXperience (IRX) (Van der Sluis et al., 2010).

# 5 Development of Tangible User Interfaces

In this chapter we describe ongoing work on the development of prototypes for the museum context and the hospital context.

## *5.1 Museum Application*

In our former deliverable D2.1 on collaborative interaction interfaces, we presented a use case scenario for a museum. There we focused on the collaborative experience of children using a multi-touch table application. In the mean time, the application has been built and tested in Museon. In this section we will report on the details of the design of the interactive application and on the first experiences of children interacting with the multi-touch table application.

### 5.1.1 Introduction

In the museum the multi-touch table is used at the beginning and at the end of the museum visit, by groups consisting of two to four children. Often one or two parents are also part of the group. In the experiments we chose to work with groups no bigger than four persons. In the beginning the participants can choose subjects or categories of subjects they are interested in. These categories are used to determine a route through the museum that is presented in the form of a quest the participants do individually. After all members of the group have finished the quest, they go to the multi-touch table again to do the end game. In the following subsections we describe the design of the interactions at the multi-touch table and some observations of the behaviour of the participants. Although the interactions at the multi-touch table are only short (3-4 minutes), while the quest takes far more time because this is the actual visit to the exhibition of the museum, here we will focus more on the interactions at the multi-touch table for obvious reasons.

### 5.1.2 Registration and Initial Game

The main screen people see when they arrive at the table has the solar system as a background. When people touch this screen, particles appear with coloured backgrounds. See Figure 14 for a screenshot of this screen.

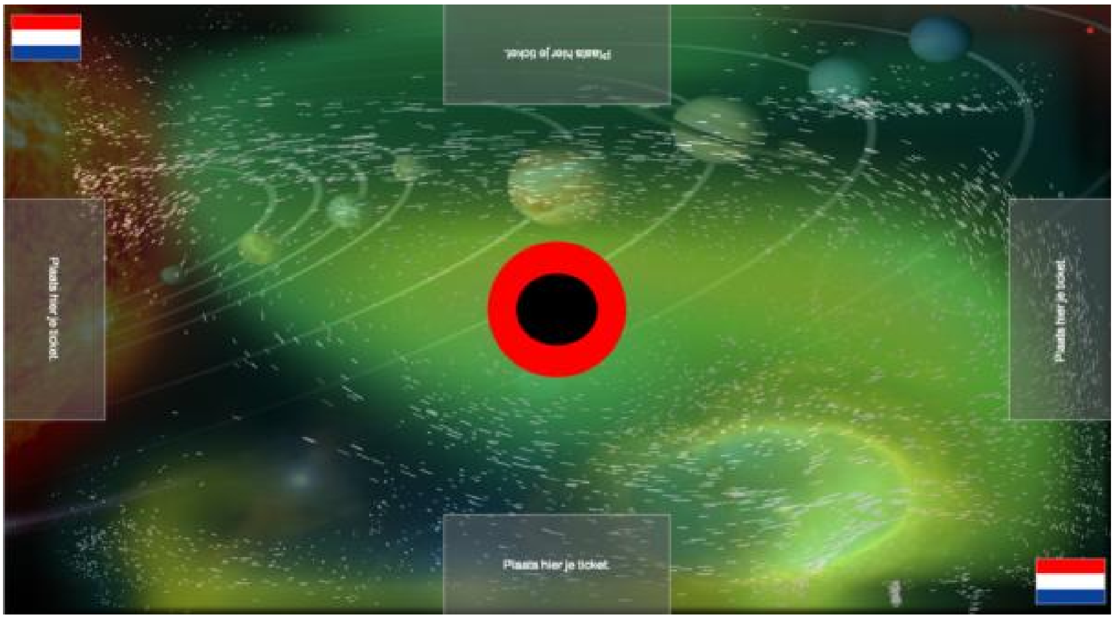



Figure 14. The main screen of the multi-touch table in Museon before interaction started.

In two corners of the table you can see a flag that can be touched to choose between two languages: English and Dutch. At the middle of each side of the table there are virtual boxes. These boxes can be used to register. People who agree to take part in the experiment get a ticket that fits in these boxes and that has a marker on one side that is recognized by the table. The other side of the ticket has a barcode on it that will be used in the quest (see Section 5.1.3). To start the initial game, people have to put the tickets in the boxes. Figure 15 shows the situation that two people already registered successfully (the red circle becomes partly green then) and two people are still busy registering.

Figure 15. Registration with the personal tickets.

When all group members have registered their tickets, the game can be started by pushing a start button in the middle of the table. Next, the participants get a screen with explanation about the game and after they have read this they can give their names. Figure 16 shows the screen where they drag the characters of their name to a bar on the table, in front of them.

**Figure 16. Putting in the name of the people in the game.**

After this registration process, the initial game starts with a screen where people choose categories of subjects they are interested in. There are twelve categories represented by round images. Everybody chooses six of these categories. Figure 17 shows the screen where the people can drag the images they choose to the circles near their registration ticket.

**Figure 17. Choice of categories of subjects people are interested in.**

After everybody finished choosing interesting subjects the quest in another part of the museum started.

### 5.1.3 Quest

Based on the results of the initial game the participants receive a personalized quest. During the quest children have to answer a question at each exhibit of the route of their quest before they get the instruction to go to the next exhibit. People can help each other whenever they want. They are near to each other and interacting with the other group members. To support the quest, a touch screen is placed near each exhibit. Here the tickets are used again, this time with the barcode, to transfer information from and to the table applications. The quest consists of twelve questions to be answered at twelve different exhibits. After each good answer, the children choose a virtual object they like. This way every group member collects twelve objects, since eventually every question is answered correctly, sometimes after several attempts. These virtual objects are used in the end game.

### 5.1.4 End Game

Coming back to the multi-touch table the children can login again, using their tickets. From the virtual objects collected during the quest (in total twelve per person) the group has to choose twelve different objects for the end game. The table shows twelve sets of two, three or four objects - dependent on the size of the group. The group chooses one object of each set. In the end game the twelve chosen virtual objects are in the middle of the table. Twelve boxes with words are positioned at the edge of the table. See Figure 18 for a screenshot of the table.

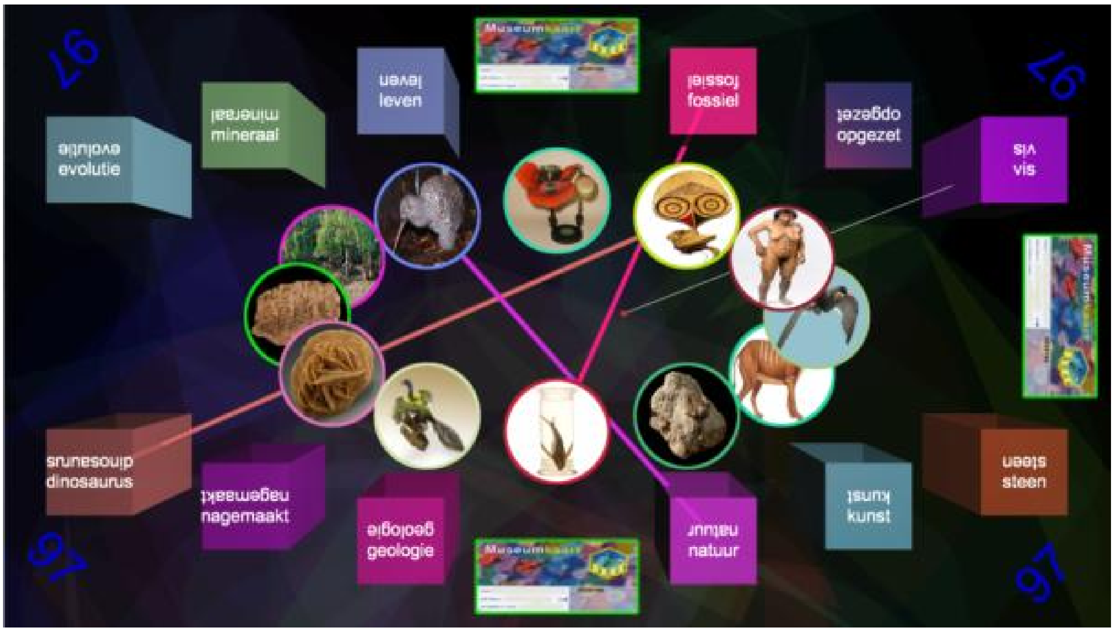



Figure 18. Boxes with words that have to be connected with virtual objects in the end game.

The task is to connect the words to the matching virtual objects by drawing lines. The children have limited time for this. After two minutes the connections are checked showing an animation: one by one the virtual objects are highlighted and the connecting lines become green when a connection is correct and red when it is not correct. After this animation the end score of the group is shown.

### 5.1.5 Observations and Conclusion

Interaction with the solar system on the main screen attracted many visitors and appeared to be engaging: children kept producing colours and stars for up to five minutes. While doing this they talked about fireworks, stars and imitating Harry Potter. Without much hesitation most children interacted with the table with both hands and together with other children. They cooperated while they tried to find out how the table worked. An often heard hypothesis was that the table reacted on heat. Some of the children discovered that the table already reacted when they hovered over it, which they found intriguing. Only some very young children (younger than six years of age) started to interact very cautiously, with one finger. Often children leaned on the table. This often resulted in an accidental choice of the language selection screen. The people who leaned often did not realize they caused this choice themselves but the other group members did. It was no problem for the groups to get back to the normal starting screen again.

Children were inclined to push buttons too quickly, for instance when not everybody was ready yet. Often their parents prevented this. The choice of characters and images appeared to be intuitive. Children did have more problems than adults to move the characters and images in a straight line and sometimes they used their whole hand to grab an object. This was not recognized properly by the table so nothing happened. However, all children persisted and were very patient when they did not succeed immediately.

In the end game children connect the words to the matching virtual objects by drawing lines. This appeared to be less intuitive than the other interactions on the table, especially for children under eight years old. With improved explanations and feedback, most children found out how it worked quickly. Once a line was drawn it could not be removed again. Nevertheless children often tried to remove lines, most of the time by making an erasing movement in the middeI of a line. During the animation that checked the connections drawn, nobody touched the table and the children were very attentive to see their results.

In conclusion, these preliminary results indicate that the interactions at the multi-touch table are *engaging and fun*, facilitate *exploration and collaboration* and most of the interactions are intuitive, hence *actions and effects* are tightly related. Only in the end game this relationship might be improved. Hence for three out of four themes of the PuppyIR model derived in Chapter 3 the interactions at the multi-touch table seem to be well-designed. In the multi-touch table interactions designed for Museon until now, no tangible physical objects are used (except for the registration tickets). Hemce the first theme, the appearance of the *physical objects in relation to the digital representation*, seems to be irrelevant here. Tightly related, however, is the representation of parts of the exhibition of Museon in the round images children use to choose subjects they are interested in. If this coupling was clear is one of the questions we hope to be able to answer after we studied all the results of the experiments we did in Museon.

## *5.2 Hospital Application*

This section describes work on a tangible interface for children in the Amsterdam Emma Kinderziekenhuis (children’s hospital).

### 5.2.1 Introduction

A special use case for information retrieval for children is for health information, considering health information is already difficult to retrieve and read for adults. Amongst others, this has inspired the application of readability formulae to get an indication of textual difficulty (Yan et al., 2006), in particular for paediatric health information (D'Allesandro et al., 2001); i.e., to make the health information *tangible* (See Section 4.2.2).

One the most salient problems with retrieving health information is in the recall and recognition of the right words to describe an information need; i.e., the vocabulary problem. Moreover, numerous studies show children have difficulties in choosing the right words (See Chapter 1).

A tangible interface can alleviate the vocabulary problem. Hence, this prototype will present a tangible, cross-media, retrieval interface. This interface reduces the need for the recognition of words through using images to represent easy recognizable body parts. Moreover, to make more complex concepts available, users can zoom-in on certain body parts to make their search more specific. Hence, children can explore health related information through visually exploring the different body parts.

The created user interface is shown in Figure 19. Two main functionalities clearly show from Figure 19: the visual search part and the results presentation part both will further be elaborated on next. Moreover, first the used data set and the open search interface between the user interface and data set will be described.

Figure 19. First prototype of hospital application.

### 5.2.2 Dataset

The paediatric information is in the library of the Emma's Children's Hospital in Amsterdam. Hence, the data set consists of meta-data of what is available in the library: e.g., books, DVDs, leaflets, colour pages, etc. All the information is tagged with its age-appropriateness, partly tackling the problem of the complexity of paediatric information (and, thus, of tangible information; see Section 4.2.2). Moreover, a short description, title, and an accompanying image are available for each item in the library.

Table 2 gives an overview of the body parts with the highest number of data set items available. As can be seen, a very detailed descriptor of a body part, the brain, has the highest number of related items. On the contrary, the least detailed descriptor ("body") has the second highest number of related items. This illustrates part of the complexity of describing the data set through the chosen search paradigm (see Section 5.2.3).

**Table 2. Top-10 frequencies per body part**

| Body Part | Frequency |
|---|---|
| Brain | 21 |
| Body | 17 |
| Nose | 12 |
| Lungs | 9 |
| Eyes | 7 |
| Small inte | 6 |
| Pancreas | 6 |
| Ears | 4 |
| Head | 4 |
| Heart | 4 |

### 5.2.3 Tangible Search

The search-part of the user interface uses an illustration of a body as a search metaphor. As Table 2 illustrates, selections can range from the whole body to the brain. This considerable difference in the level of detail creates the need for a zoom-in. We solved this need by using one image which contains a great level of detail, allowing for an image zoom-in to very specific parts (e.g., the ears). Moreover, the image changes when zooming in to highlight the relevant aspects at that level of details (e.g., the brains).

The interaction has been kept deliberately simple: a touch paradigm is used for both selecting and zooming in, using feedback to make the functionality intuitive. Certain parts of the image are highlighted at any time, indicating a touch on the highlighted part will give search results on that part. Moreover, when touching a highlighted area, the image will automatically zoom-in, leading to new highlighted areas.

In particular with children, keeping an overview of their search is difficult. This often leads to chaotic search behaviour (Van der Sluis and Van Dijk, 2010). Hence, giving feedback on where the search is (in terms of specificity) is likely to support the self-regulation (See also Section 4.2.2). This feedback is given through adding two common parts of a zoom-in interface: an overview of the total picture, including a highlight of the part currently viewed, and a scale indicating the amount of specificity and control buttons to zoom-in or zoom-out.

### 5.2.4 Results Presentation and Conclusion

As indicated in Section 4.2.2, the information presentation should be kept minimalist for children: too much information will increase (cognitive) load too much, leading to a negative IRX. Hence, for the presentation of the results a linear interface has been opted. After a search, only the first result will be visible; with the addition of a clearly visible button to go to the next result, and an overview of how many more results there are.

In conclusion, this prototype presents a novel way to solve a challenging retrieval problem: making often highly specialized health information searchable by less experienced users. However, the actual value of this design has yet to be proven in practice.

# 6 Conclusion

Tangible user interfaces allow children to take advantage of their experience in the real world with multimodal human interactions when interacting with digital information. In this deliverable we describe the state of the art of tangible user interfaces and propose a model that focuses mainly on the user experience during interaction. This model will be used to guide the design and evaluation of tangible user interfaces that are suitable to access and explore information in our ongoing project activities.

# 7 References

American Heritage Dictionary (2009). *The American Heritage Dictionary of the English Language, Fourth Edition.* Houghton Mifflin Company, 4 edition.

Antle, A. (2007). The CTI framework: Informing the design of tangible systems for children. In: *Proceedings of the 1st international conference on Tangible and embedded interaction ( TEI'07)*, pp. 195-202, ACM, New York.

Augsten, T., Kaefer, K., Meusel, R., Fetzer, C., Kanitz, D., Stoff, T., Becker, T., Holz, C., and Baudisch, P. (2010). Multitoe: high-precision interaction with back-projected floors based on high-resolution multi-touch input. In*: Proceedings of the 23rd annual ACM symposium on User interface software and technology (UIST '10)*, pp. 209–218, New York, NY, USA. ACM.

Benko, H., Wilson, A., and Baudisch, P. (2006). Precise selection techniques for multi-touch screens. In *Proceedings of the SIGCHI conference on Human Factors in computing systems (CHI '06)*, pp. 1263–1272, New York, NY, USA. ACM Press.

Benko, H., Wilson, A. D., and Balakrishnan, R. (2008). Sphere: multi-touch interactions on a spherical display. In *Proceedings of the annual ACM symposium on User interface software and technology (UIST'08)*, pp. 77–86.

Bolle, R.M., Connell, J., Haas, N., Mohan, R., and Taubin, G. (1997). VeggieVision: A Produce Recognition System. In: *Proc. 1997 IEEE Workshop on Automatic Identification Advanced Technologies (WAIAT-97)*, pp. 35-38.

Boring, S., Baur, D., Butz, A., Gustafson, S., and Baudisch, P. (2010). Touch projector: mobile interaction through video. In *CHI '10: Proceedings of the 28th international conference on Human factors in computing systems*, pp. 2287–2296, New York, NY, USA. ACM.

Cao, Y., van der Sluis, F., Theune, M., op den Akker, R., and Nijholt, A. (2010). Evaluating informative auditory and tactile cues for in-vehicle information systems. In: *Proceedings of the International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, to appear. ACM.

Chen, J. (2007). Flow in games (and everything else). *Communications of the ACM*, 50(4), 31–34.

Chouvardas, V., Miliou, A., and Hatalis, M. (2008). Tactile displays: Overview and recent advances. *Displays*, 29(3), 185 – 194.

Costanza, E. and Robinson, J. (2003). A region adjacency tree approach to the detection and design of fiducials. In *Video, Vision, and Graphics*, pp. 63–69.

Crook, C. (1998). Children as computer users: the case of collaborative learning. *Computers & Education, 30*(3-4), 237-247.

Csikszentmihalyi, M. (1991). *The Psychology of Optimal Experience.* Harper Collins, New York.

D'Alessandro, D. M., Kingsley, P., and Johnson-West, J. (2001). The Readability of Pediatric Patient Education Materials on the World Wide Web. *Arch Pediatr Adolesc Med*, 155(7), 807–812.

De Belder, J. and Moens, M.-F. (2010). Integer linear programming for Dutch sentence compression. In: Gelbukh, A.(ed.) *Computational Linguistics and Intelligent Text Processing, Lecture Notes in Computer Science, volume 6008*, pp. 711–723. Springer Berlin / Heidelberg.

Dietz, P. and Leigh, D. (2001). Diamondtouch: a multi-user touch technology. In *Proceedings of the 14th annual ACM symposium on User interface software and technology (UIST ’01)*, pp. 219–226, New York, NY, USA. ACM Press.

Druin, A., Foss, E., Hatley, L., Golub, E., Guha, M.L., Fails, J. and Hutchinson, H. (2009). How children search the internet with keyword interfaces. In *Proceedings of the 8th International Conference on Interaction Design and Children* (IDC '09), pp. 89-96. ACM, New York, NY, USA.

Finkenzeller, K. (2010). *RFID Handbook: Fundamentals and Applications in Contactless Smart Cards and Identification*. John Wiley & Sons, Inc., New York, NY, USA, 3 edition.

Fishkin, K. (2004). A taxonomy for and analysis of tangible interfaces. In: *Personal and Ubiquitous Computing, 8(5)*, 347-358.

Forlines, C. and Lilien, R. (2008). Adapting a single-user, single-display molecular visualization application for use in a multi-user, multi-display environment. In *Proceedings of the working conference on Advanced visual interfaces (AVI ’08)*, pp. 367–371, New York, NY, USA. ACM.

Garris, R., Ahlers, R., and Driskell, J. (2002). Games, motivation, and learning: a research and practice model. *Simulation & Gaming* 33(4), 441–467.

Gross, T., Fetter, M., and Liebsch, S. (2008). The cuetable: cooperative and competitive multi-touch interaction on a tabletop. In *CHI ’08 extended abstracts on Human factors in computing systems*, pp. 3465–3470, New York, NY, USA. ACM.

Han, J. (2005). Low-cost multi-touch sensing through frustrated total internal reflection. In *Proceedings of the 18th annual ACM symposium on User interface software and technology (UIST ’05)*, pp. 115–118, New York, NY, USA. ACM Press.

Harrison, C., Tan, D., and Morris, D. (2010). Skinput: appropriating the body as an input surface. In *CHI ’10: Proceedings of the 28th international conference on Human factors in computing systems*, pp. 453–462, New York, NY, USA. ACM.

Hassenzahl, M. and Tractinsky, N. (2006). User experience - a research agenda. *The American Journal of Psychology*, 25(2), 91–97.

Hornecker, E. and Buur, J. (2006). Getting a grip on tangible interaction: a framework on physical space and social interaction. In *Proceedings of the SIGCHI conference on Human Factors in computing systems (CHI ’06)*, pp. 437-446, ACM, New York NY, USA.

Inkpen, K. M., Ho-ching, W.-ling, Kuederle, O., Scott, S. D., Shoemaker, G. B. D., & Shoemaker, B. D. (1999). This is Fun! We’re All Best Friends and We're All Playing: Supporting Children's Synchronous Collaboration. In *Proceedings of the 1999 conference on Computer support for collaborative learning* (CSCL '99), pp. 252-259. Christopher M. Hoadley and Jeremy Roschelle (Eds.). International Society of the Learning Sciences.

Ishii, H. and Ullmer, B. (1997). Tangible bits: towards seamless interfaces between people, bits and atoms. In *Proceedings of the SIGCHI conference on Human Factors in computing systems (CHI ’07)*, pp. 234-241, ACM, New York NY, USA.

Jansen, M., Bos, W., Van der Vet, P., Huibers, T. and Hiemstra, D. (2010). TeddIR: Tangible information retrieval for children. In: *Proceedings of the 9th International Conference on Interaction Design and Children (IDC’10)*, pp. 282-285, ACM, New York, NY, USA.

Jonassen, D. H. (2000). Toward a design theory of problem solving. *Educational Technology Research and Development*, 48(4), 63–85.

Kaltenbrunner, M., Jorda, S., Geiger, G., and Alonso, M. (2006). The reactable*: A collaborative musical instrument. In *Proceedings of the 15th IEEE International Workshops on Enabling Technologies: Infrastructure for Collaborative Enterprises (WETICE '06)*, pp. 406–411, Washington, DC, USA. IEEE Computer Society.

King, A. (2007). Scripting collaborative learning processes: A cognitive perspective. In P. Dillenbourg, M. Baker, C. Bereiter, Y. Engeström, G. Fischer, H. Ulrich Hoppe, et al. (Eds.), *Scripting computer-supported collaborative learning* (Vol. 6, pp. 13-37). Springer US.

Kruger, R., Carpendale, S., Scott, S., and Greenberg, S. (2003). How people use orientation on tables: comprehension, coordination and communication. In: *Proceedings of the 2003 international ACM SIGGROUP conference on Supporting group work (GROUP '03)*, pp. 369–378, New York, NY, USA. ACM.

Malik, S. and Laszlo, J. (2004). Visual touchpad: a two-handed gestural input device. In *Proceedings of the 6th international conference on Multimodal interfaces (ICMI '04)*, pp. 289–296, New York, NY, USA. ACM Press.

Mazalek, A. and Van den Hoven, E. (2009). Framing tangible interaction frameworks. In: *Artificial Intelligence for Engineering Design, Analysis and Manufacturing, 23*, 225-235.

Merrill, D., Kalanithi, J., and Maes, P. (2007). Siftables: towards sensor network user interfaces. In*: Proceedings of the 1st international conference on Tangible and embedded interaction (TEI '07)*, pp. 75–78, New York, NY, USA. ACM.

Mistry, P. and Maes, P. (2009). Sixthsense: a wearable gestural interface. In *SIGGRAPH ASIA '09: ACM SIGGRAPH ASIA 2009 Sketches*, pp. 1–1, New York, NY, USA. ACM.

Mitra, S. (2005). Self organising systems for mass computer literacy: Findings from the 'hole in the wall' experiments. *International Journal of Development Issues*, 4(1):71–81.

Morris, M., Huang, A., Paepcke, A., and Winograd, T. (2006). Cooperative gestures: multi-user gestural interactions for co-located groupware. In *Proceedings of the SIGCHI conference on Human Factors in computing systems (CHI '06)*, pp. 1201–1210, New York, NY, USA. ACM.

Nijholt, A., Dijk, E. O., Lemmens, P. M., and Luitjens, S., editors (2010). *Proceedings of the EuroHaptics 2010 Special Symposium: Haptic and Audio-visual Stimuli: Enhancing Experiences and Interaction*. Number WP10-01 in CTIT Workshop Proceedings Series WP10-01. Centre for Telematics and Information Technology, University of Twente, Enschede.

Nunez, D. (2003). *A connectionist explanation of presence in virtual environments*. PhD thesis, University of Cape Town.

Park, J.-H. and Han, T. (2010). Llp+: multi-touch sensing using cross plane infrared laser light for interactive based displays. In *SIGGRAPH '10: ACM SIGGRAPH 2010 Posters*, pp. 1–1, New York, NY, USA. ACM.

Reeve, J. (1989). The interest-enjoyment distinction in intrinsic motivation. *Motivation and Emotion*, 13(2):83–103.

Rekimoto, J. (2002). Smartskin: an infrastructure for freehand manipulation on interactive surfaces. In *Proceedings of the SIGCHI conference on Human factors in computing systems (CHI '02)*, pp. 113–120, New York, NY, USA. ACM Press.

Rogers, Y. and Muller, H. (2006). A framework for designing sensor-based interactions to promote exploration and reflection in play. *International Journal of Human-Computer Studies, 64,* 1-14.

Ryall, K., Morris, M., Everitt, K., Forlines, C., and Shen, C. (2006). Experiences with and observations of direct-touch tabletops. *TableTop 2006. First IEEE International Workshop on Horizontal Interactive Human-Computer Systems*, pp. 89–96.

Scott, S., Sheelagh, M., Carpendale, T., and Inkpen, K. (2004). Territoriality in collaborative tabletop workspaces. In *Proceedings of the 2004 ACM conference on Computer supported cooperative work (CSCW '04)*, pp. 294–303, New York, NY, USA. ACM.

Sharlin, E., Watson, B., Kitamura, Y, Kishino, F. and Itoh, Y. (2004). On tangible user interfaces, humans and spatiality. In: *Personal and Ubiquitous Computing, 8(5)*, 338-346.

Sharp, H., Rogers, Y. and Preece, J. (2007). *Interaction Design: Beyond Human-Computer Interaction.* Second Edotion. John Wiley & Sons, Chichester.

Shinohara, K. and Tenenberg, J. (2009). A blind person's interactions with technology. *Commun. ACM*, 52(8), 58–66.

Speirs, F. (2010). The ipad project. Last retrieved from http://speirs.org/blog/tag/theipadproject on 05-11-2010.

Stevenson, R. (2005). Laser marking matrix codes on pcbs. *Printed Circuit Design & Manufacture*, 12:32–36.

Tse, E., Shen, C., Greenberg, S., and Forlines, C. (2006). Enabling interaction with single user applications through speech and gestures on a multi-user tabletop. In *Proceedings of the working conference on Advanced visual interfaces (AVI '06)*, pp. 336–343, New York, NY, USA. ACM Press.

Ullmer, B. and Ishii, H. (2001). Emerging frameworks for tangible user interfaces. In: Carroll J.M. (ed.) *Human-Computer interaction in the new millennium*, pp. 579-601. Addison-Wesley, New York.

Van de Wouw, D. (2009). Design of the 'tiktegel'. Master's thesis, Delft University of Technology.

Van der Sluis, F. and Van den Broek, E. L. (2010a). Modeling user knowledge from queries: Introducing a metric for knowledge. In An, A., Lingras, P., Petty, S., and Huang, R., editors, *Active Media Technology*, *Lecture Notes in Computer Science*, volume 6335, pp. 395–402. Springer Berlin / Heidelberg.

Van der Sluis, F. and Van den Broek, E. L. (2010b). Using complexity measures in information retrieval. In *Information Interaction in Context (IIiX) Symposium*, New York, USA. ACM.

Van der Sluis, F., Van den Broek, E. L., and Van Dijk, E. M. A. G. (2010). Information Retrieval eXperience (IRX): Towards a human-centered personalized model of relevance. In *Third International Workshop on Web Information Retrieval Support Systems August 31, 2010 (Toronto, Canada)*.

Van der Sluis, F., Van den Broek, E. L., Stam, L. M., and Abrahamse, E. L. (2006). Subjects taught in VR. *Deliverable of the EU Network of Excellence INTUITION, Cluster 1, Workpackage WP1.C, No. D1.C_5* (pp. 53).

Van der Sluis, F. and Van Dijk, E. M. A. G. (2010). A closer look at children's information retrieval usage: Towards child-centered relevance. In *Proceedings of the Workshop on Accessible Search Systems held at the 33rd Annual International ACM*

*SIGIR Conference on Research and Development in Information Retrieval*, New York, USA. ACM.

Wilson, A. (2004). Touchlight: an imaging touch screen and display for gesture-based interaction. In *Proceedings of the 6th international conference on Multimodal interfaces (ICMI ’04)*, pp. 69–76, New York, NY, USA. ACM Press.

Wu, M. and Balakrishnan, R. (2003). Multi-finger and whole hand gestural interaction techniques for multi-user tabletop displays. In *Proceedings of the 16th annual ACM symposium on User interface software and technology (UIST ’03)*, pp. 193–202, New York, NY, USA. ACM Press.

Yan, X., Song, D., and Li, X. (2006). Concept-based document readability in domain specific information retrieval. In *CIKM ’06: Proceedings of the 15th ACM international conference on Information and knowledge management*, pp. 540–549, New York, NY, USA. ACM.