Image Schemas and Their Metaphorical Extensions – Intuitive Patterns for Tangible Interaction

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ABSTRACT
One of the goals of tangible interaction is to build more intuitive interfaces. This paper gives a definition of intuitivity and presents a continuum of knowledge serving as a classification for intuitive interaction. Against the background of the continuum recent taxonomies for tangible interaction are reviewed. A new approach for classifying tangible interaction will be presented: image schemas and their metaphorical extensions. Motivated by linguistic studies of meaning this taxonomy is able to overcome some limitations of previous approaches. The taxonomy is illustrated with examples of using image schemas and their metaphorical extensions in potential TUI applications. A more complex example, the Tangible Memories Box, shows how our taxonomy and earlier approaches may complement each other.

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Tangible User Interfaces, Intuitivity, Image Schemas, Metaphor, Embodiment.

ACM Classification Keywords
H5.2. Information interfaces and presentation (e.g., HCI): User Interfaces: Theory and methods.

INTRODUCTION
What is it that Tangible User Interfaces are for? One of the aims of this relatively new approach of designing computer user interfaces is to go beyond the predominantly visual paradigm of screen based WIMP interaction and make use of people’s experience of interacting with real world objects. Enhancing the richness of communication between the user to the computer, making use of physical constraints in interaction, and joining input and output space are other goals frequently found in the literature. The agenda of designing tangible user interfaces has been summarized very well in the seminal paper of Ishii and Ullmer [10, p. 240-241]: “Current GUI-based HCI displays all information as ”painted bits” on rectangular screens in the foreground, thus restricting itself to very limited communication channels. GUls fall short of embracing the richness of human senses and skills people have developed through a lifetime of interaction with the physical world. Our attempt is to change ”painted bits” into ”tangible bits” by taking advantage of multiple senses and the multimodality of human interactions with the real world. We believe the use of graspable objects and ambient media will lead us to a much richer multi-sensory experience of digital information.” Hornecker and Buur [9, p. 437] are widening the perspective by putting down “embedded computing in the everyday environment and supporting intuitive use” as the shared goals of TUI and other novel approaches to HCI.

In this paper we would like to elaborate the goal of “intuitivity”, give a definition of this concept and present a continuum of knowledge serving as a classification for intuitive interaction. Against the background of the continuum recent taxonomies for tangible interaction will be reviewed. A new approach to classifying tangible interactions will be presented, which draws on the sensorimotor level of the continuum: image schemas and their metaphorical extensions. Being rooted within the meaning of objects in the world rather than mechanical features (which are usually highlighted by TUI researchers), we believe this to be a promising approach for designing tangible user interaction. We will illustrate the use of the taxonomy of image schemas together with more traditional approaches using an example application for connecting tangible and digital memories: the Tangible Memories Box.

INTUITIVE INTERACTION AND THE CONTINUUM OF KNOWLEDGE
Intuitive interaction seems to be the most widely used concept both in HCI and product marketing brochures. However, the authors of these texts seem to assume that everyone has an intuitive understanding of the concept since formal definitions are hard to find. Only two groups of researchers seem to have been tackling the problem recently: Thea Blackler and her colleagues in Australia [1] and our IUUI (Intuitive Use of User Interfaces) research.
group in Germany [15]. Empirical work, theoretical considerations, and discussions with internal and external experts lead us to the following definition of ‘intuitivity’: *A technical system is intuitively usable if the users’ unconscious application of pre-existing knowledge leads to effective interaction.*

**Figure 1. Continuum of knowledge in intuitive interaction**

*Pre-existing knowledge* may stem from different sources. These knowledge sources can be classified along a continuum (see figure 1). The first, and lowest, level of the continuum consists of *innate* knowledge - ‘acquired’ through the activation of genes or during the prenatal stage of development. Generally this is where reflexes or instinctive behaviour draw upon. Purists will see this as the only valid level of knowledge when talking about intuitive interaction, because it assures universal applicability and unconscious processing. The next level is *sensorimotor*. It consists of general knowledge, which is acquired very early in childhood and is from then on used continuously through interaction with the world. Children learn for example to differentiate faces; they learn about gravitation; they build up concepts for speed and animation. Scientific notions like affordances [6] and the later discussed image schemata [11] are residing at this level of knowledge. The next level is *culture*. At the culture level we find tools commonly used by people, like ball point pens for writing, pocket lamps for lighting, or cell phones for communication. At the last stage there is the knowledge acquired from using tools in one’s area of expertise, for example image editing tools, enterprise resource planning (ERP) systems, or CNC machines. Even within the same domain of expertise (e.g. graphic design) there may be differing knowledge on the tool level of the continuum, depending on the kind of tools used (e.g. Corel Paint Shop vs. Adobe Photoshop).

The continuum of knowledge has an inherent dimensionality. The frequency of encoding and retrieval of knowledge increases from the top to the bottom of the continuum. Then, the further we rise towards the top level of the continuum, the higher the degree of specialization of knowledge and the smaller the potential number of users possessing this knowledge gets. But still, on each level of the knowledge continuum we may assign ‘intuitive use’ according to the above definition – as long as it is *unconsciously* applied by users. The application of knowledge may be *unconscious* from the beginning on (as with reflexes) or may have become unconscious due to frequent exposure and reaction to stimuli in the environment: the more frequent the encoding and retrieval was in the past the more likely it is that knowledge in memory is applied without awareness by the user.

**REVIEW OF TAXONOMIES**

Over the past decade, several taxonomies have been proposed for classifying tangible interfaces. As stated above, the early goals of tangible interaction have been to enrich user input from low bandwidth keyboard and mouse manipulation to use the knowledge and skills the users have from their embodied interaction with the world. The next section will review approaches which are in sync with this idea – namely relying on knowledge on the first two levels of the knowledge continuum. The section following this will look at taxonomies that go beyond the original approaches.

**Taxonomies on the ‘innate’ and ‘sensorimotor’ levels of the continuum**

When inventing graspable user interfaces, Fitzmaurice et al. coupled physical and digital media by using small *bricks* as *physical controls* for purely *virtual objects*, emphasizing the space-multiplexed character of these interfaces. They relied very much on one-to-one mappings between physical controls and digital objects or widgets, but also introduced first approaches for dynamically creating and releasing physical-digital couplings [4]. As advantages of their philosophy they propose that it “leverages off of our well developed, everyday skills of prehensile behaviors for physical object manipulations” and “takes advantage of our keen spatial reasoning skills” [4, p. 443].

Ullmer and Ishii interpreted tangible interfaces as being of *spatial, relational, constructive, and mixed* type and outlined several classes of couplings, including *static* and *dynamic couplings* between physical and digital objects [18]. They later added the *token+constraints* approach to design implicit syntax and to guide interaction in tangible
interfaces by providing physical tokens and constraints for presence, position and orientation, sequence, proximity, connection and adjacency. In order to increase complexity of tangible interfaces, they proposed nested (recursive) configurations of token-constraints. [19]. Strengths of the token-constraints approach are that human perception and manipulation of objects is facilitated by external representation, support of object aggregates and kinaesthetic / haptic feedback.

Holmquist introduced a taxonomy which differentiated between containers, tokens and tools as objects used to move, store, access and manipulate digital data [8]. For fitting tokens to the task he refers to affordances [6] as a central criterion for design and evaluation.

Shaer et al. extended Ullmer’s taxonomy towards the TAC paradigm which is based on coupling, relative definition, association, computational interpretation, and manipulation, in order to develop a high level description language for tangible interfaces in terms of pyfos (objects), token, constraints, variables (digital information and functions), and actions (possible manipulations of the object) [16]. Actions, for instance, are on a very basic level and include manipulations like add, remove, slide, or draw.

Taxonomies using other levels of the continuum
In traditional HCI, metaphors play an important role in the design of user interfaces (e.g. the desktop metaphor in GUIs). Metaphors have also been discussed in the context of tangible interaction, e.g. metaphors of optics, light and shadow [10] and magic or paranormal metaphors [17]. However, metaphors often make use of knowledge at the levels of tool, expertise, or culture.

Fishkin introduced a taxonomy which describes tangible interfaces in the two dimensions embodiment and metaphor with four levels each [3]. The dimension embodiment describes the spatial configuration of the interface, how closely input focus and output focus are linked, and “to what extent the users think of the state of the system as being inside the object they are manipulating”. [3, p. 348]. With full embodiment, output and input objects are identical. Output may also take place nearby the input object, in the environment around the user, or at a distant place (e.g. remote control). The dimension metaphor means: “is the system effect of a user action analogous to the real-world effect of similar actions?” [3, p. 349] For Fishkin, the physical properties of an object may invoke metaphorical links which support the understanding of its digital meaning. It is grouped around metaphors of noun, which appeal to the shape of an object, and metaphors of verb, which appeal to the motion of an object. On the lowest end, a tangible interface (or particular aspects of it) may have none metaphorical analogies to the real world. If its shape, the permitted actions, or both have metaphorical analogies to real world examples, they are described as metaphors of noun, verb, or noun and verb, respectively.

Chapter 3 - THE EXPRESSIVE CHARACTER OF INTERACTION

**Full** is the highest metaphorical level, here, the user sees the virtual system as identical with the physical system and needs to make no analogies at all. Fishkin’s metaphors can relate to any of the levels of the knowledge continuum.

Although Fishkin’s taxonomy uses the notions of embodiment and metaphor, they are not to be confused with the meaning of these terms we are associating with them. Embodiment in Fishkin’s sense refers to how much the user feels that digital events are happening within the tangible objects he is manipulating. Or in his own words: “To what extent does the user think of the state of computation as being embodied within a particular physical housing?” [3, p. 348]. Embodiment in the knowledge continuum has to do with how much human thinking and knowledge is shaped by our direct sensory-motor (embodied) interaction with the world. Also, as will be seen below, our use of the term metaphor does not imply mimicking the real world as closely as possible (as in Fishkin’s taxonomy). By metaphor we mean the transfer of schematic structures of real world phenomena to abstract concepts in thought. We then try to use these cognitive phenomena to build more intuitive user interfaces.

A comprehensive framework of four themes for tangible interaction was recently introduced by Hornecker and Buur [9]: tangible manipulation, as the most basic quality of tangible interfaces, is given by their material representation; spatial interaction describes tangible interaction as movements in space; embodied facilitation refers to constraints and access points which guide and stimulate interaction; and expressive representations emphasize the importance to provide tangible access to the salient parts of the digital model in order to perceive the coupling by the user. Hornecker and Buur also “warn of stopping at simple, direct mappings” and “feel that too many tangible interfaces aim for direct one-to-one mappings, remaining literal and missing out opportunities” [9, p. 440] For increasing the complexity of tangible systems, they suggest to incorporate full body interaction, performative actions, social expressions and gestures in the concept of tangible interaction, interpreting the human body as involved tangible instance.

Focus of the present work
As we have seen by the comment of Hornecker and Buur above there seems to be too strong a reliance on physical one to one mappings in the majority of current tangible interfaces. Also, in their review of TUI applications Ullmer and Ishii state that “the most popular application of tangible interfaces has been using physical objects to model various kinds of physical systems.” [19, p. 82] Contrast this with the demand for user interfaces for manipulating abstract data like financial variables in enterprise resource planning (ERP) systems, personal profiles on online-dating platforms or evaluation data of online questionnaires. What solutions do TUI have to offer? Our analysis of image schemas and their metaphorical extensions below shows a way (in
principle) how physical manipulations can be mapped for manipulating abstract data.

Often TUI taxonomists tend to look at things from a purely geometrical or mechanical point of view. They for instance derive possible interactions by looking at what constraints are provided by physical objects and containers or by physical movements of the human body. An example for the former is the token+constraint approach [19], the latter is illustrated by a quote from Svanaes and Verplank: “What will constitute a useful set of interaction elements for the TUI domain? What should be its Windows, Icons, Mouse and Pull-Down menus (WIMP)? [...] One way of approaching the problem could be to start out with basic hand operations like placing, picking up, moving, pointing, collecting, assembling, de-assembling, stretching, pushing, pulling, touching, rubbing, and shaking. From this there might emerge a tacit interaction language, and a set of objects.” [17, p. 129]. Instead of focusing on objectively possible patterns we would like to propose a taxonomy of subjectively meaningful patterns in the hope to provide with it a more direct way to finding the most intuitive design for tangible interfaces.

And finally with our approach we would like to stick to the original intention of using TUI and stay at the sensorimotor level of our continuum of knowledge. For this we explore an approach from the field of cognitive linguistics: image schemas and their metaphorical extensions.

**IMAGE SCHEMAS AND THEIR METAPHORICAL EXTENSIONS**

**Image schemas**

Image schemas are abstract representations of recurring dynamic patterns of bodily interactions that structure the way we understand the world [11]. The CONTAINER schema, for example, forms the basis of our daily experiences with houses, rooms, boxes, tea pots, cups, cars etc. A CONTAINER is characterized by an inside, an outside, and a boundary between them. Image schemas are much more abstract than images. So it is easy to form a mental image of an hour glass. However, image schemas are much more basic: the hour glass consists of two CONTAINER schemas connected via a LINK and both CONTAINERS are half FULL with a SUBSTANCE.

Image schemas are schematic in nature and as they capture the structural contours of sensory-motor experience they are not just symbols. They exist beneath conscious awareness. They integrate information from multiple modalities and could thus be represented visually, haptically, kinesthetically or acoustically. Depending on the author about 30 to 40 of such image schemas are distinguished [7, 11]. Table 1 organizes them into eight groups. Their universal character, their - in the course of life - extremely frequent encoding in and retrieval from memory and their unconscious processing makes them interesting for using them as pattern for tangible user interfaces. A simple example for the UP-DOWN schema is, when the tangible token is moving upwards and the digital representation, e.g. of a house, will follow.

<table>
<thead>
<tr>
<th>Group</th>
<th>Image Schemas</th>
</tr>
</thead>
<tbody>
<tr>
<td>BASIC SCHEMAS</td>
<td>SUBSTANCE, OBJECT</td>
</tr>
<tr>
<td>SPACE</td>
<td>UP-DOWN, LEFT-RIGHT, NEAR-FAR, FRONT-BACK, CENTER-PERIPHERY, STRAIGHT-CURVED, CONTACT, PATH, SCALE, LOCATION</td>
</tr>
<tr>
<td>CONTAINMENT</td>
<td>CONTAINER, IN-OUT, CONTENT, FULL-EMPTY, SURFACE</td>
</tr>
<tr>
<td>IDENTITY</td>
<td>FACE, MATCHING</td>
</tr>
<tr>
<td>MULTIPLICITY</td>
<td>MERGING, COLLECTION, SPLITTING, PART-WHOLE, COUNT-MASS, LINKAGE</td>
</tr>
<tr>
<td>PROCESS</td>
<td>SUPERIMPOSITION, ITERATION, CYCLE</td>
</tr>
<tr>
<td>FORCE</td>
<td>DIVERSION, COUNTERFORCE, RESTRAINT REMOVAL, RESISTANCE, ATTRACTION, COMPULSION, BLOCKAGE, BALANCE, MOMENTUM, ENABLEMENT</td>
</tr>
<tr>
<td>ATTRIBUTE</td>
<td>HEAVY-LIGHT, DARK-BRIGHT, BIG-SMALL, WARM-COLD, STRONG-WEAK</td>
</tr>
</tbody>
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Table 1. List of image schemas, grouped by similarity.

**Metaphorical Extensions**

Although image schemas describe human experiences with the physical world their actual strength lies in their metaphorical extension for structuring abstract concepts [11, 12]. Metaphor is a notion originating in linguistics and thus is mostly used when talking about language. In their seminal book *Metaphors we live by* Lakoff and Johnson extend the meaning of metaphor to “understanding and experiencing one kind of thing in terms of another.” [12, p. 5]. They claim that metaphor is not only a device of language but also one of thinking and experience. Consequentially they talk about ‘conceptual metaphors’. Linguistic analyses have shown that image schemas can serve as source domains of countless metaphors.

In the following sections we would like to show how image schemas are metaphorically used in language to conceptualize more abstract domains. As language reflects thought, image schemas and their metaphorical extensions should also be working in non-linguistic reasoning. In fact there is growing evidence of this coming from the field of cognitive psychology [2, 5, 13, 14]. If image schemas and their metaphorical extensions are common primitives of thought (as the theorists claim and the empirical evidence suggests) then they might be exploited for designing intuitive tangible interaction. In the following sections we try to outline the application of image schemas for the analysis and the design of tangible interfaces.
APPLICATIONS OF IMAGE SCHEMAS AND THEIR METAPHORICAL EXTENSIONS

In the following we will discuss examples of selected image schemas, review the linguistic evidence for their metaphorical extensions to abstract domains, and show how they might be used in the design of tangible user interfaces. Because of the scarcely available space we can only give a rough overview and some triggers for using image schemas in tangible user interfaces.

SPACE schemas

Space schemas are especially interesting for designing tangible interaction since interaction with physical tokens will take place in 2D or 3D space. Also, since space schemas reflect the vast experience people have with navigating space; their metaphoric extensions are especially rich. Only two of the space schemas will be introduced in detail to point out the opportunities for TUI design.

UP-DOWN

The UP-DOWN schema, together with the spatial schemas LEFT-RIGHT and FRONT-BACK, has been used in virtual all tangible user interfaces at least for physical mappings. UP-DOWN can be used either in a static (i.e. placing objects above or below another) or in a dynamic fashion (moving objects vertically on a wall or on a table in 2D space). Physical UP-DOWN placement and movements of objects may lead to analogous placement and movements in virtual space.

Linguistic analysis points to metaphorical extensions of the UP-DOWN schema to conceptualize abstract domains like

- Quantity, as in: The number of books printed each year is going up. My income rose last year. The number of errors made is incredibly low. He is underage. (MORE IS UP, LESS IS DOWN)
- Quality, as in: Things are looking up. He does high-quality work. We hit a peak last year, but it's been downhill ever since. (GOOD IS UP, BAD IS DOWN)
- Status, as in: She’ll rise to the top. He has little upward mobility. He’s at the bottom of the social hierarchy. (HIGH STATUS IS UP, LOW STATUS IS DOWN)
- Control, as in: I have control over her. I am on top of the situation. His power is on the decline. (HAVING CONTROL IS UP, BEING SUBJECT TO CONTROL IS DOWN)
- Happiness, as in: I’m feeling up. That boosted my spirits. He is really down these days. I’m depressed. (HAPPY IS UP, SAD IS DOWN)
- Other dichotomies like HEALTH AND LIFE ARE UP - SICKNESS AND DEATH ARE DOWN, CONSCIOUS IS UP - UNCONSCIOUS IS DOWN, RATIONAL IS UP - EMOTIONAL IS DOWN, VIRTUE IS UP – DEPRAVITY IS DOWN, [see 12, p. 14-21 for more examples].

These metaphorical extensions can be transferred to tangible user interfaces: moving a tangible brick upwards might be used to intensify the loudness of speakers (using the metaphor MORE IS UP) when controlling an mp3-player or indicate happiness within a networked social communication platform (using HAPPY IS UP). One also might think of arranging bricks on a time line when using a project planning application (FORESEEABLE FUTURE EVENTS ARE UP).

PATH

A second important space schema is path. A path involves physical or metaphorical movement from place to place and consists of a starting point, a terminal point, and a series of contiguous locations [11]. Since the path schema is so ubiquitous in experience there is a rich collection of metaphorical extensions:

- PURPOSES ARE DESTINATIONS: He’s headed for great things. I’ve got quite a way to go before I get my Ph.D.
- ACTORS ARE TRAVELERS: As we travel down life’s path...
- STATES ARE LOCATIONS: He saw teaching as just a stopover on his way to bigger things.
- THE MEANS FOR ACHIEVING PURPOSES ARE ROUTES: If this doesn’t work, I’ll just try a different route.
- DIFFICULTIES ARE IMPEDIMENTS TO TRAVEL: He’s lost his way. He has a rocky road ahead of him.
- PROGRESS IS DISTANCE TRAVELLED: We’ve come a long way.
- MAJOR CHOICES ARE CROSSROADS: She’s at a crossroads in her life.

All of these metaphorical extensions may be employed for instance to design a tangible project planning and tracking application. Sub-projects may be different routes, time is mapped to linear space, tokens are representing project teams, milestones can be placed, certain routes can be opened or blocked etc.

CONTAINMENT schemas

This group of image schemas includes the aforementioned CONTAINER which is characterized by a physical or metaphorical boundary, an enclosed area or volume, and / or an excluded area or volume. Subjectively, i.e. experientially, a container also involves differentiation and separation; protection from and resistance to external forces; enclosure and thus restriction and limitation of forces within the CONTAINER. The consequences of this are a certain fixity of location, accessibility or inaccessibility of the CONTENT to view, and transitivity (i.e. when nesting CONTAINERS within others). Part of a container is a SURFACE giving support to the CONTENT. Associated actions are IN and OUT movements that result in the CONTAINER being FULL or EMPTY.

CONTAINERS have been used much in the field of TUI. We just remind of Holmquist’s classification of containers, tokens and tools [8] and Ullmer and Ishii’s
The metaphorical extensions of the CONTAINER schema are so large, that only a few examples are given here:

- **ACTIVITIES ARE CONTAINERS**: In washing the windows I splashed water all over the floor. How did Jerry get out of painting the fences?
- **STATES ARE CONTAINERS**: Whenever I’m in trouble, she always bails me out. He’s in love. She entered a state of euphoria.
- **GROUPS OF INDIVIDUALS ARE CONTAINERS**: He is an outsider. The proportion of females in the population has increased. It was bound to raise a serious debate in the party.
- **LAND AREAS ARE CONTAINERS**: There is a lot of land in Kansas. A clearing in the woods. What should I take with me for a walk in the South Downs?
- **TIME IS A CONTAINER**: in the 20th century. He did it in three minutes. In 1968. . . He’s like something out of the last century.

As CONTAINERS are ubiquitous in tangible computing this list just gives some impression, how CONTAINERS may be used to represent abstract data. For example, CONTAINERS in a TUI may represent different regions for simulating migration between countries or departments of a company. CONTAINERS may also be used in a TUI to represent time periods for shift planning where the assignment of shifts is done by putting employee tokens into different containers representing early, late, and night shifts. Media may be sorted into CONTAINERS according to place (photos from the trip to Berlin, New York, Prague), group of individuals (photos of relatives, friends, colleagues), time period (movies of the thirties, forties and fifties), emotional state (joyful music, music for being sad) etc.

Johnson [11] suggests that some elements of formal logic arise from our bodily experience of CONTAINMENT. The claim of S being either P or not-P can be seen as S being in a metaphorical category-CONTAINER P or outside it. Consequently not-not-P is identical to P: not being outside the CONTAINER means being inside it. Also the logical relation of transitivity might be experientially motivated by CONTAINMENT. The formal statement: if A is a member of B and B is a member of C then A must also be a member of C can be understood as: if A is contained by B and B is contained by C then A must also be contained by C. It seems to be quite bold to claim that our concepts of negation and transitivity are rooted within the experience of CONTAINMENT but taking it seriously opens up very interesting interaction possibilities for tangible interfaces.

**FORCE schemas**
The FORCE schemas (table 1) are mainly of a dynamic nature. In TUI they may be best used when force feedback devices are coupled to the objects of physical interaction. However, there are also metaphorical extensions worth thinking about like: OBLIGATIONS ARE FORCES (I was forced to do it) or EMOTIONS ARE FORCES (I was moved by the poem, He was wrestling with his feelings).

**ATTRIBUTE schemas**
ATTRIBUTE schemas are lacking the rich structure other image schemas possess. They are a collection of recurring experiential properties of things in the world like HEAVY-LIGHT, DARK-BRIGHT, BIG-SMALL, WARM-COLD, STRONG-WEAK. TUI might vary these properties in physical objects to vary abstract properties in virtual representations. Metaphoric extensions like POSITIVE IS LIGHT, NEGATIVE IS DARK (Jesus is the light of the world. Satan is the prince of darkness.), ARGUMENTS ARE HEAVY (They piled up some weighty arguments), or EMOTIONALITY IS WARMTH (She is a warm-hearted person. He is a cold-blooded murderer.) may be inspiring to designers.

**EXAMPLE: THE TANGIBLE MEMORIES BOX**
The connection between image schemas introduced in the previous sections and other taxonomies can be illustrated in the context of a simple fictitious tangible interface sketch: the Tangible Memories Box (figure 2).

Unlike common photo boxes, this version stores collected items which are placed in trays within the box. Each item is linked to a collection of digital media of events, people, places etc. which can be displayed on a screen. In this example, the box stores items collected in the year 2006: an elephant for the visit to the zoo in January, a shelf for the holiday trip in March, a dice representing a games evening with friends in April, a sad toy football player for the defeat in the world cup in June, a toy brick for the refurbishment of our flat in August etc. (figure 3). The media collections were previously separately uploaded by connecting box and digital camera to the computer and placing the new items in one of the holes.
When connecting the box to the computer, folder icons for each item group appear on the screen (figure 4). When a special cylinder is put in one of the smaller trays above, the display shows icons of each digital file which belong to the items in the tray beneath (figure 5). Rotating the cylinder moves a cursor from one icon to the other. Placing the cylinder upright displays the currently selected file in full screen (figure 6). Rotating the upright cylinder one way or the other toggles the display to the previous or subsequent file, respectively.

Figure 4. Folder icons for each item group.

Analysis of Interaction Elements

The Tangible Memories Box presents a mixture of physical as well as metaphorical uses of image schemas, and constraints. The Tangible Memories Box itself is a CONTAINER with a COLLECTION of tangible memories inside. The box is MATCHED to another CONTAINER on the screen, the file folder, which also holds a COLLECTION of digital media. The trays in the box are CONTAINERS for objects which correspond to CONTAINERS holding media files on the screen. The tray CONTAINERS are metaphorically extended by the metaphor TIME IS A CONTAINER, since single trays each represent a period of two months. Because the memories are ordered in a time sequence from the first two months of the year on the left to the last two months of the year on the right the image schema SCALE also applies. Other assignments of trays to objects can be imagined following metaphors like GROUPS OF INDIVIDUALS ARE CONTAINERS (putting the objects in trays representing friends, relatives or colleagues) or LAND AREAS ARE CONTAINERS (trays representing places, e.g. Berlin, London, Paris). Placing the cylinder into a small tray above an item tray invokes the MATCHING schema which is confirmed when seeing the media items on the screen which belong to the tangible items in the corresponding tray. Via a physical LEFT-RIGHT movement of the cylinder a physical LEFT-RIGHT movement of the cursor is invoked. This provides a mental model of a LEFT-RIGHT ordering of the media items which will be applied by the user in the full screen mode as well when LEFT-RIGHT rotation of the upright cylinder calls up new images in the sequence.

Figure 5. Browsing through the collection of digital media associated with shell and dice.

The analysis of the positions of the cylindrical token is more interesting. Although the UP and DOWN positions of the cylinder in figures 5 and 6 might be seen as instances of the UP-DOWN schema, UP-DOWN is neither physically nor metaphorically transferred to the screen. Their relative effectiveness for steering the zoom actions lies in matching the constraints of the cylinder to the constraints of the display. Both have two degrees of freedom. Position of the cylinder (UP or DOWN) is mapped to the zoom modes on the display (first degree of freedom) and movement of the cylinder (LEFT-RIGHT rotation) is mapped to the sequential navigation between images on the display (second degree of freedom). Since the navigation is already communicated via the LEFT-RIGHT schema being present in the box and on screen there is only one possibility what the UP and DOWN positions of the cylinder could mean: zooming the image.

Figure 6. Magnifying a picture by raising the cylinder.
DISCUSSION AND CONCLUSION
The value of our taxonomy is threefold:

- It provides a catalog of basic perceptual-motor patterns that are meaningful to human experience and that can be used for designing physical TUI interaction. This catalog is a new approach because by using image schemas and their metaphorical extensions it focuses on subjective meaning instead of mere theoretical possibility.
- The use of metaphorical extensions opens up new areas of applications for TUI which go beyond simple one to one physical mappings.
- Relating to the sensorimotor level of our knowledge continuum, intuitive interaction is greatly facilitated.

Our taxonomy does not contradict other approaches. As the example has shown they complement each other. Exploiting constraints is a useful approach to find possible interactions not provided by image schemas. Also, metaphors may also be used to utilize knowledge from other levels of our continuum of knowledge (e.g. Ishii’s flashlight metaphor which operates at the tool level).

However, this does not mean that the application of image schemas for designing tangible user interfaces has been fully understood yet. As we have seen it might be interesting to find out what use can be made of the FORCE schemas when the provision of force feedback to physical objects is possible. Much opportunity for exploration remains for going beyond simple one to one physical mappings into the realm of abstract data manipulation. The utility of this taxonomy for the design of new tangible interaction then needs to be empirically validated.

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