DEM Cubes: Meaning & Abstraction Through Embodied Interaction

Brendan Matkin
Simon Fraser University
250-13450 102nd Avenue
Surrey, BC V3T 0A3 Canada
bmatkin@sfu.ca

Alissa Antle
Simon Fraser University
250-13450 102nd Avenue
Surrey, BC V3T 0A3 Canada
aantle@sfu.ca

Abstract
Image schemata are simple mental structures based on early, repetitive bodily experiences, such as up-down or big-small. They help us to understand and structure abstract concepts through metaphor, and are key to exploiting embodied interaction. We can apply these concepts to tangible interaction design as physical or spatial properties. One way to determine how people map designed, image-schematic properties of tangibles to specific metaphors is through metaphor population stereotypes. This type of study has been done using multiple objects to represent each image-schematic property, but we have little understanding of how people will interpret these properties when they change dynamically (e.g. shape change). In this paper we describe a prototype system of several small cubes, each with a dynamic, image-schematic property. Using this system to determine metaphor population stereotypes will lead to specific design guidelines to create and represent abstraction and meaning in tangible interaction.

Author Keywords
Embodied interaction; image schema; population stereotypes; metaphor; tangible interaction.

ACM Classification Keywords
H.5.2. User Interfaces: Theory & Methods.

Introduction

Embodied interaction is a promising approach to support meaning and abstraction in tangibles. Although it is often cited as a critical component of tangible interaction, there are few guidelines on how to design for it. Hornecker and Burr [9] suggest that one-to-one control mappings, the current trend in tangibles, miss out on the greatest potential of tangible user interfaces (TUIs). The system we have developed emphasizes several theme components outlined in their framework: Tailored Representation, Representational Significance, and Perceived Coupling.

Designers still have trouble implementing embodied metaphors, yet metaphor and bodily experience are key to embodied interaction. Bakker et al. [3] summarize embodied metaphors: "A metaphor allows us to understand or experience one concept (target domain) in terms of another (source domain). When the source domain involves schemata that have arisen from bodily experiences, we call them *embodied schemata* and the metaphors, *embodied metaphors*." These embodied, or *image schemata* help us to structure our understanding of abstract concepts and are often studied in the context of Conceptual Metaphor Theory (CMT). "CMT suggests that simple mental structures based on repeated patterns of physical action (i.e. image schema[ta]) are elaborated through metaphor to structure our understanding of abstract concepts" [13]. Although CMT has long been used for interaction design, the approach has been largely limited to action-control mappings (i.e. one-to-one control such as up-down to control on-off).

It is clear that application of embodied metaphors through image schemata can be used to support meaning and abstraction in tangible interaction design, but it is still not clear *how* to do that. Macaranas el al. [13], Hurtienne et al. [10], Antle et al. [1], and Bakker et al. [3] have all begun to explore techniques to implement embodied metaphors at a conceptual level. One successful method has been to evaluate how populations stereotypically map opposing, image-schematic properties of objects to conceptual metaphors (metaphor population stereotypes). So far, these studies have been limited to pairs of static objects [10,13]. Physical transformation, or shape-change, has long been an area of study in Tangibles and is still current (e.g. Radical Atoms [12]). It is also typically used for one-to-one control or output, or is based on speculative materials and technology. To our knowledge, there has yet to be any experimental research involving actuated, or shape-changing tangibles to study image-schematic conceptual metaphors. This has led us to develop the following research questions:

RQ1: Do people consistently identify the relations between metaphor population stereotypes based on dynamic, image-schematic *physical* properties (e.g. rough-smooth, heavy-light, big-small, temperature, color) of objects mapped to abstract concepts?

RQ2: Do people consistently identify the relations between metaphor population stereotypes based on dynamic, image-schematic *spatial* properties (e.g. up-down, front-back, left-right, path, location) of objects mapped to abstract concepts?

RQ3: Are the results consistent with the results from previous studies of metaphor population stereotypes for

Figure 1: The Up-Down Cube (top: up state, bottom: down state)

static physical and spatial properties? If not, in what ways are the results different?

In this paper we first provide some theory and related work on image schemata, metaphor population stereotypes, and shape-changing displays. From this we derive our design goals and requirements for a prototype that can be used in a metaphor population stereotype study to address our research questions. We follow this with a description of our prototype: ***D****ynamic,* ***E****mbodied* ***M****etaphor Cubes (DEM Cubes)*, with a focus on key design rationale. We present a brief description of our future study, and discuss the design tradeoffs and assumptions that arose creating DEM Cubes.

The outlined study will result in guidelines to help designers identify how *dynamic* physical or spatial image-schematic property changes of tangible objects can be used to create and represent abstraction in, and add meaning to, tangible user interfaces. Implementing these guidelines will make tangibles feel more intuitive and easier to learn.

Theory & Related Work

Image schemata: are deeply engrained in the way that we perceive and explain the world around us. They are mental structures which develop from bodily experiences from before we can speak [8]. By tapping into this existing, low-level cognitive domain, our findings could lead to tangible user interfaces with deeper meaning than is possible with current designs; systems which feel more natural/intuitive [2], and are capable of portraying abstract concepts. Although schemata and metaphor have long been used in HCI [2], the embodied nature of tangible interaction is an ideal application for this way of framing our world through bodily experience.

Metaphor Population Stereotypes: One challenge of embodied interaction research is to correctly map deeply embedded image schemata to meaningful metaphors in the system. For tangibles, this can easily occur via the physical or spatial properties of an object. Two previous studies have successfully mapped interpreted meanings through metaphor population stereotype studies [10,13]. In both cases, researchers used pairs of physical objects (e.g. a large cube and a small cube) to represent an opposing pair of image-schematic properties (e.g. large-small) and asked users which of an opposing pair of adjectives (e.g. powerful or weak) mapped to which property. Although conceptually valuable, tangibles often require the ability to provide feedback, input/output, etc., without forcing the user to switch which object s/he is grasping. We suggest that objects which are capable of *dynamically* changing their image-schematic physical or spatial properties will provide opportunities for creating & representing co-located ranges of meaning and abstraction, while building upon the principles laid out in previous studies.

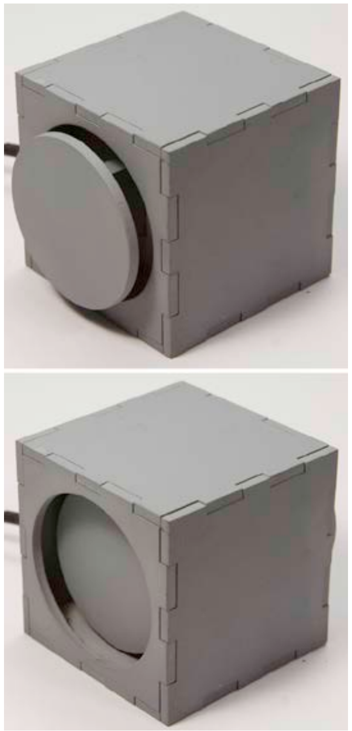

Figure 3: The Front-Back Cube (top: front state, bottom: back state). The back appears identical to the front, only with opposite behavior.

Shape Change & Actuation in Tangibles: Shape change/actuation has been studied in tangible interaction for many years, typically as a way to embody digital information [6,16]. It is used for information display [4,15], direct data manipulation [7,11], translation [14,15], and haptics [5]. Tangible interaction designers have been seeking for a way to convey information with physical output [11], but they are still focused on one-to-one mappings. Our findings will afford physical system output beyond one-to-one.

System Design and Implementation

Design Goals & Requirements: Two goals motivated the design of DEM Cubes: (G1) Extend previous metaphor population stereotype studies by using a single object for each opposing-pair (physical or spatial) property. (G2) Improve upon previous studies by minimizing the salience of extraneous properties. This led to the following *key* design requirements: (Req1) Limiting image schematic properties to physical and spatial. (Req2) Objects must be consistent between each other and as neutral as possible. (Req3) Must be a set of like objects, each with a single *dynamic* output component which effectively represents one image-schematic property. We have also developed the following secondary requirements: (Req4) Control of dynamic property configurable for either user or researcher.

System Description: DEM Cubes currently consists of four components: one control box and three cubes (Figure 2). Each cube should map to a set of conceptual metaphors via a single, dynamic, image-schematic property. For the proof of concept, we have selected one physical and two spatial image schemata from the study by Macaranas et al. [13]. They are: Rough-Smooth (physical), Up-Down (spatial), and Front-Back

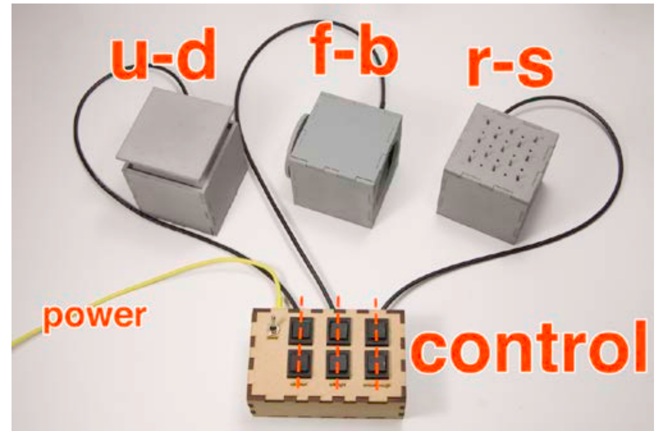

Figure 2: DEM Cubes, system overview. Up-Down (u-d), Front-Back (f-b), Rough-Smooth (r-s). Vertical dashed lines on controller indicate button grouping.

(spatial). The controller has six buttons; two per cube (Figure 4). Each button triggers one of the two states for each cube. Actuation of an output component (e.g. a face of the cube) represents the state. For the Up-Down cube, the top button moves the top face of the cube up (up), the bottom button moves it back flush with the sides (down), see Figure 1. The Front-Back cube has an output surface on the front and one on the back. In one state, the front surface protrudes out of the cube, and the rear surface is sunken into the cube (front); the other state is opposite (back), see Figure 3. The Rough-Smooth cube has thirteen pins connected to the actuator as its output component. In one state, the pins are hidden inside of the cube (smooth), in the other, they protrude out through the surface (rough), see Figure 5.

Objects with one dynamic physical or spatial property, rationale (Req1): Macaranas et al. chose spatial and

Figure 4: The Rough-Smooth Cube (top: rough state, bottom: smooth state)

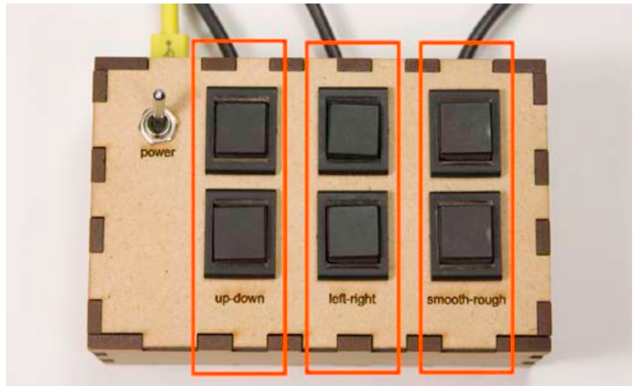

Figure 5: DEM Cubes controller. Buttons are grouped into pairs, two for each cube. The "left-right" section actually controls the "front-back" cube (future update).

physical image-schematic properties because tangibles are physical objects are manipulated in space [13]. Although dynamic property change capability might afford other image schema groups like Force or Balance, we determined that it was important to first focus on extending the successful components of previous studies before branching into new areas. Other research has suggested that spatially-based metaphors are more readily interpreted than other categories [2,3], yet Macaranas et al. found that metaphors related to physical image-schematic properties we more frequently identified than spatial. However, they identified issues with some spatial category research artifacts & suggested further investigation [13]. Therefore, we placed higher priority on designing cubes with a dynamic spatial property, in order to develop a refined prototype before running a full study. By isolating a single property at a time, we reduce the number of variables that we need to control.

Grey and constructed, rationale (Req2): To minimize salience of extraneous properties, we decided to reduce or eliminate unnecessary properties which may convey additional meaning, emotion, memories, etc. Rather than using found objects or complex shapes, we chose to construct a simple geometric form for every object. Grey was selected as an inherently neutral color for the same purpose. Colour can be image-schematic; we reasoned that, in North America, a neutral grey is least likely to invoke metaphorical meaning.

Small cubes, rationale (Req3): Selecting a cube as the shape for each DEM Cube allowed us to isolate a single property variation across the entire system, rather than between a variety of object pairs as in previous studies. Cubes have several surfaces to manipulate (e.g. as opposed to a sphere or cylinder), can be made hollow to house electromechanical components (unlike LEGO [10,13]), and are simple to design and construct (unlike other polyhedrons). We chose to make each cube 2.5 inches per side as it is reasonably small without requiring extensive electronic or mechanical engineering to make everything fit. We feel this is still easily graspable by the majority of users, and it allowed us to develop this proof of concept quickly. One challenge we came across during early testing is that a cube has no inherent orientation, which can be troublesome for spatial property objects. For now, we've addressed this by installing rubber feet on the bottom of each one, but may need to determine an alternate solution in the future.

Dedicated Controller, rationale (Req4): We have yet to determine if our study will allow user or researcher control of the objects. Rather than control DEM Cubes by computer or automatic behavior, we built the dedicated controller in order to run preliminary evaluations to decide which condition will be most appropriate.

Technical implementation: DEM Cubes is controlled by a Teensy 3.2 (Arduino-compatible programmable microcontroller), and is powered by 5V over USB. The six control buttons are linked to programmable logic on the Teensy, which is easily reconfigurable to modify or tweak the system's behavior. In the case of these three exemplars, each cube is actuated by a small hobby servo inside. The servo moves a laser-cut, wooden linkage (faced with acrylic strips to reduce friction), which is tied to the output component. The cube and controller enclosures are laser cut wood (MDF). Currently, each cube is tethered with a power/control umbilical wire, but future iterations will be controlled by ESP8266 WiFi modules (also Arduino-compatible) and powered by rechargeable lithium batteries.

Future Work

We plan to run a metaphor population stereotype study closely following the study performed by Macaranas et al.; a comparative experiment with two groups: physical & spatial [13]. Each DEM Cube will represent an image schema (e.g. up-down) via its physical or spatial property states. Participants will choose which conceptual metaphor adjective from each of five pairs is best represented by each of the cube's two possible states. For example, the adjective pairs for Up-Down are: good-bad, healthy-sickly, happy-sad, more-less, high status-low status. Which property state is good and which is bad? They will be presented in random order and valence (positive-negative). The study will be run with 20-30 native English speaking, adult participants with a balanced gender representation.

DEM Cubes will be used to replace the object pairs used in the reference study in order to answer RQ3. To answer RQ1 and RQ2, participants will be allowed to see (and possibly trigger) the transition between states of each object. The dynamic property change results will be compared to previous studies. The consistent and controlled form and function of DEM Cubes is our way of isolating the dynamic physical or spatial property as our independent variable. The other design characteristics will help us to improve the quality of these results as much as possible. Further studies may have participants rate how well each metaphor (adjective pair) maps to each cube's image-schematic property state using a Likert Scale or similar.

Discussion

Because this is a novel attempt at implementing image-schematic actuations, DEM Cubes was designed with a few assumptions that will need to be tested and tweaked in preliminary evaluations. Most critical is that we can't be sure if people will interpret these movements as the correct image schema! We used the objects from previous studies as inspiration, but the forms are so different that they couldn't be directly copied. For example, although Macaranas et al. had trouble with front-back [13], our font-back cube is also not always interpreted correctly. It is often seen as in-out. We may need to run a set of population stereotypes on a large group of cubes in order to assess and refine the accuracy of each motion, or work hard to create clear contexts.

One of our design trade-offs is the inconsistency of output elements; up-down & rough smooth are both square, while front-back is round. This was done to explore different forms. The future version will better match the rest of the system.

Conclusions

DEM Cubes will lead to guidelines for tangible interaction designers to be able to create interfaces with deep, meaningful, cognitive connections. By exploiting the powerful ability that image schemata have to represent and structure abstract concepts and metaphors, designers will have clear ways to create TUIs which embody specific ideas, meanings, and information consistently and to with variable strength. Utilizing carefully designed dynamic, image-schematic properties in tangibles allows the connected metaphors to be exploited as the primary outputs, or as secondary information in hybrid systems. Users will benefit from interfaces which are easier to learn, feel more intuitive, and utilize already familiar concepts. Tangibles with dynamic, image-schematic properties are the next step of embodied interaction and move us closer to fully exploiting the potential of tangible interaction.

References

[1] Antle, A.N., Corness, G., and Bevans, A. Springboard: Designing Image Schema Based Embodied Interaction for an Abstract Domain. In D. England, ed., *Whole Body Interaction*. Springer London, 2011, 7–18.

[2] Antle, A.N., Corness, G., and Droumeva, M. Human-computer-intuition? Exploring the cognitive basis for intuition in embodied interaction. *International Journal of Arts and Technology 2*, 3 (2009), 235–254.

[3] Bakker, S., Antle, A.N., and Van Den Hoven, E. Embodied metaphors in tangible interaction design. *Personal and Ubiquitous Computing 16*, 4 (2012), 433–449.

[4] Blackshaw, M., DeVincenzi, A., Lakatos, D., Leithinger, D., and Ishii, H. Recompose: Direct and Gestural Interaction with an Actuated Surface. *CHI '11 Extended Abstracts on Human Factors in Computing Systems*, ACM (2011), 1237–1242.

[5] Brave, S. and Dahley, A. inTouch: A Medium for Haptic Interpersonal Communication. *CHI '97 Extended Abstracts on Human Factors in Computing Systems*, ACM (1997), 363–364.

[6] Coelho, M. and Zigelbaum, J. Shape-changing interfaces. *Personal and Ubiquitous Computing 15*, 2 (2011), 161–173.

[7] Frei, P., Su, V., Mikhak, B., and Ishii, H. Curlybot: Designing a New Class of Computational Toys. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, ACM (2000), 129–136.

[8] Gibbs Jr., R.W., Costa Lima, P.L., and Francozo, E. Metaphor is grounded in embodied experience. *Journal of Pragmatics 36*, 7 (2004), 1189–1210.

[9] Hornecker, E. and Buur, J. Getting a Grip on Tangible Interaction: A Framework on Physical Space and Social Interaction. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, ACM (2006), 437–446.

[10] Hurtienne, J., Stößel, C., and Weber, K. Sad is Heavy and Happy is Light: Population Stereotypes of Tangible Object Attributes. *Proceedings of the 3rd International Conference on Tangible and Embedded Interaction*, ACM (2009), 61–68.

[11] Ishii, H. Tangible Bits: Beyond Pixels. *Proceedings of the 2Nd International Conference on Tangible and Embedded Interaction*, ACM (2008), xv–xxv.

[12] Ishii, H., Lakatos, D., Bonanni, L., and Labrune, J.-B. Radical Atoms: Beyond Tangible Bits, Toward Transformable Materials. *interactions 19*, 1 (2012), 38–51.

[13] Macaranas, A., Antle, A.N., and Riecke, B.E. Bridging the Gap: Attribute and Spatial Metaphors for Tangible Interface Design. *Proceedings of the Sixth International Conference on Tangible, Embedded and Embodied Interaction*, ACM (2012), 161–168.

[14] Nowacka, D., Ladha, K., Hammerla, N.Y., et al. Touchbugs: Actuated Tangibles on Multi-touch Tables. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, ACM (2013), 759–762.

[15] Pangaro, G., Maynes-Aminzade, D., and Ishii, H. The Actuated Workbench: Computer-controlled Actuation in Tabletop Tangible Interfaces. *Proceedings of the 15th Annual ACM Symposium on User Interface Software and Technology*, ACM (2002), 181–190.

[16] Poupyrev, I., Nashida, T., and Okabe, M. Actuation and Tangible User Interfaces: The Vaucanson Duck, Robots, and Shape Displays. *Proceedings of the 1st International Conference on Tangible and Embedded Interaction*, ACM (2007), 205–212.