Bridging the Gap: Attribute and Spatial Metaphors for Tangible Interface Design

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ABSTRACT
If tangible user interfaces (TUIs) are going to move out of research labs and into mainstream use they need to support tasks in abstract as well as spatial domains. Designers need guidelines for TUIs in these domains. Conceptual Metaphor Theory can be used to design the relations between physical objects and abstract representations. In this paper, we use physical attributes and spatial properties of objects as source domains for conceptual metaphors. We present an empirical study where twenty participants matched physical representations of image schemas to metaphorically paired adjectives. Based on our findings, we suggest twenty pairings that are easily identified, suggest groups of image schemas that can serve as source domains for a variety of metaphors, and provide guidelines for structuring physical-abstract mappings in abstract domains. These guidelines can help designers apply metaphor theory to design problems in abstract domains, resulting in effective interaction.

Author Keywords
Metaphor, image schemas, tangible user interfaces, intuitive interaction, population stereotypes, design guidelines.

ACM Classification Keywords
H5.2. User Interfaces: Theory & Methods.

General Terms
Design, Human Factors, Experimental.

INTRODUCTION
The tangible and embodied interaction research community continues to thrive [9]. The Do-It-Yourself (DIY) tangibles community is also vibrant (e.g. [19]). However, few commercial applications of tangibles exist. If tangibles are to be taken up outside of the research and DIY communities, it is critical that interactions with them are "intuitive" or "natural". Interactions are "intuitive" or "natural" when actions result in expected outcomes or effects [16], or when the mappings between actions and effects are easily discovered or learned through salient feedback [2]. In a recent online article, Norman and Nielsen observe that despite the "naturalness" of gesture, the poor design of gestural interaction for devices such as iPhone, Android, and iPad is creating a new usability crisis [15]. They lament that designers are neglecting to apply well-tested and understood standards of interaction design to gestural interfaces. To avoid poor usability and better understand what "natural" interaction entails, we need to develop guidelines for gesture and tangibles based on how people attach meaning to gesture and physical actions on objects.

TEI 2012, Kingston, Ontario, Canada, February 19 – 22, 2012.
© 2012 ACM 978-1-4503-1174-8/12/0002 $10.00

A promising design approach for mapping tangible input actions to system effects is the application of Conceptual Metaphor Theory (CMT) [3,10]. CMT suggests that simple mental structures based on repeated patterns of physical action (image schemas) are elaborated through metaphor to structure our understanding of abstract concepts. This type of relation or pairing between image schemas and concepts has been successfully leveraged in analogue as well as in tangible and whole-body interaction design. For example, the pairing between an up and down input action (e.g. moving a vertical slider, a simple object, or an arm up and down) and controlling the volume of music (i.e. louder-softer) is easily understood through the pre-conscious application of the metaphorical schema-concept pairings: UP IS MORE and DOWN IS LESS.

Until recently, this approach has been largely limited to the design of action-control mappings. Hornecker and Buur suggest that the approach of using simple one-to-one mappings (e.g. involving up-down or on-off) misses out on opportunities provided by tangibles [8]. We agree with this observation. Tangibles provide a whole range of physical properties (e.g. size, shape, texture, temperature, weight). These properties may be linked to digital representations to convey a wide range of information rather than just using physical properties as controls. For example, Antle et al. applied CMT to the design of relations between physical actions of balancing and abstract meanings of balance in the context of an installation about social justice [1]. Results indicated that many participants used the abstract concept of balance, to interpret and describe the visual and auditory contents of the installation. With the exception of Hurtienne et al. [11] and Antle et al. [1,3] these metaphorical pairings remain largely unexplored. Their potential is tremendous. Physical-abstract pairings that are consistent with image schema-metaphor structures appear "natural" or "intuitive" to use and interpret [11]. Hurtienne calls these mappings "metaphor population stereotypes" since they are understood by a majority of users [11]. We will continue to use this terminology.

In this paper, we report on a study that evaluated how readily people could identify the relations between 30 metaphor population stereotypes. We focused on physical-abstract pairings (e.g. HEAVY IS IMPORTANT or DOWN IS BAD). The physical aspects are related to object properties (rather than actions) and the abstract concepts are adjectives (words that describe nouns). Our approach validates and significantly expands previous work (e.g. [1,11]) and provides a focus on *meaning* in the design of tangible representations rather than just *control*. A third contribution is our key distinction between attribute and spatial physical properties. Attribute properties include size (small-big), weight (heavy-light), and texture (smooth-rough). Spatial properties include proximity (e.g. near-far) and orientation (e.g. up-down, front-back). Previous work has shown that people privilege spatial metaphors in interpretation [2]. We also explore this claim in our study.

Based on the results of this study, we identify a set of empirically validated metaphor population stereotypes. We focus on those in the form of physical-abstract pairings related to adjectives (i.e. used to represent meanings rather than as tangible controls). Designers can use such pairings to facilitate "intuitive" or easily understandable tangible user interfaces across a wide variety of domains and application areas.

HISTORY: METAPHORIC & INTUITIVE UI DESIGN

Using metaphors to inform graphical user interface design has been discussed within the HCI community for some time. Neale and Carroll describe the user interface metaphor as a mental model that can simplify the complexity of a computer interface systems [14]. They suggest that interface metaphors enhance learnability and usability [14].

Applying metaphors in tangible interface design is a relatively new area. Svanaes & Verplank suggest that metaphors for tangible user interfaces should move beyond rational mappings and towards phenomenon that facilitate intuitive interaction [17]. According to Spool, intuitive interaction is when users can immediately use an interface successfully and the interface does what people expect [16]. Hurtienne and Israel define intuitive interaction with computation as: "A technical system is intuitively usable if the users' unconscious application of pre-existing knowledge leads to effective interaction" [10].

Many early tangible interface designs were deemed intuitive by relying on isomorphic mappings of object properties and actions. An isomorphic mapping is one in which the input and output share the same structure or form. For example, Fitzmaurice et al. described a graspable user interface that uses physical bricks that isomorphically control digital objects in a tabletop application [6]. The bricks represent control points for objects (i.e. image, spline curve) on the tabletop. The location and orientation of each brick isomorphically controls the location and orientation of its associated control point. Underkoffler and Ishii described a tangible workbench for urban planning [18]. Physical objects represent the buildings in an urban landscape. The physical location of buildings represents their location in the digital space. However, using such literal physical-digital pairings is limited. This approach to tangible design misses out on the richness and diversity of meanings that may be conveyed by pairing physical properties of objects with digital representations through metaphorical mappings.

CONCEPTUAL METAPHOR THEORY

Theory

Conceptual Metaphor Theory posits that people understand abstract concepts by using mental structures formed from recurrent sensory-motor experiences [12,13]. These recurring patterns, or *image schemas,* can act as the source domain for metaphors that we use to understand abstract concepts [11]. For example, by observing water rise in a cup or a haystack grow in height, we make the connection

GROUP	IMAGE SCHEMAS
Attribute	**Heavy-Light**, Dark-Bright, **Big-Small**, Strong-Weak, Warm-Cold, **Rough-Smooth**
Balance	Axis Balance, Twin-Pan Balance, Point Balance, Equilibrium
Basic	Substance, Object
Containment	Container, In-Out, Surface, Full-Empty, Content
Existence	Bounded Space, Cycle, Object, Process, Removal
Force	Attraction-Compulsion, Balance, Blockage, Counterforce, Diversion, Enablement, Momentum, Removal or Restraint, Resistance, Source-Path-Goal
Identity	Face, Matching, Superimposition
Process	Cycle, Superimposition, Iteration
Spatial	**Up-Down**, **Front-Back**, Left-Right, **Near-Far**, Scale, Centre-Periphery, Contact, Path, Straight-Curved, Verticality, Location
Unity / Multiplicity	Merging, Collection, Splitting, Iteration, Part-Whole, Count-Mass, Linkage.

Table 1. Consolidated list of image schemas by group (image schemas used in this study are highlighted in bold).

between height and quantity. The image schema of "up" is metaphorically paired with the abstract concept of "more". We subsequently, and often unconsciously use "up" to mean "more" in a variety of contexts (e.g. turn up the volume, fill up the gas tank).

Image schemas are foundational to understanding and working with CMT. Previous literature provides different lists of common and universal image schemas [7,12,13]. Table 1 combines Hurtienne and Israel's [10] and Evans and Green's [5] consolidations of these lists. In the table, image schemas are grouped by their physical nature.

Application in Tangible Interface Design

Various researchers have used CMT in tangible or embodied interface design and evaluated effect on interaction [3,10,17]. Antle et al. used CMT to map out interface controls for an interactive audio space [2]. Participants interpreted control mappings based on image schemas from the spatial group more frequently than mappings based on image schemas from the basic group (e.g. music as a moving substance). These and other studies showed how the theory could be used to create predictable relationships between human action and system responses [3]. Hurtienne and Israel used conceptual metaphors as taxonomy for describing the interactions within a tangible interface [10]. Hurtienne et al. compared the strength of various metaphors made from the attribute group in order to develop a list of attribute-based metaphors that designers can use to represent information in TUIs [11]. Their study identified benefits of using conceptual metaphors in information representation, but did not examine a wide variety of image schema groups (i.e. space, force).

BIG IS ...	SMALL IS ...	HEAVY IS ...	LIGHT IS ...	ROUGH IS ...	SMOOTH IS ...
Powerful: She's working against the big boys in industry.	**Weak:** He's just a small fry.	**Constrained:** I have more pressing matters to attend to.	**Unconstrained:** That's a load off my shoulders!	**Impolite:** His way of talking is rough.	**Polite:** She calmed the man with a smooth explanation.
Important: That's a big discovery!	**Unimportant:** He only had a small role in the play.	**Important:** The weight of his words stuck with her.	**Unimportant:** Don't attach any weight to those rumours.	**Dangerous:** Don't play so roughly with the baby.	**Safe:** It should be smooth sailing from here on out.
Valuable: She's making the big bucks now.	**Valueless:** I only have small change.	**Expensive:** That wedding ring must cost a hefty sum.	**Inexpensive:** My wallet feels light after Christmas.	**Unpleasant:** She's a little rough around the edges.	**Pleasant:** The drink went down smoothly.
Significant: I have big dreams.	**Insignificant:** it was only a minor spelling error.	**Sad:** Her heart is heavy with grief.	**Happy:** He's light hearted and full of spirit.	**Interrupted:** It was a staggeringly rough path to my degree.	**Continuous:** The ride was smooth and uneventful.
More: This is such a big class!	**Less:** That quiz was shorter than usual.	**More:** My course load is pretty heavy at this time.	**Less:** She is a light drinker.	**Problematic:** We are going through some rough times.	**Unproblematic:** The rest of the study should go smoothly.

Table 2. Attribute image schemas and metaphors tested in this study.

NEAR IS ...	FAR IS ...	FRONT IS ...	BACK IS ...	UP IS ...	DOWN IS ...
Similar: That point of view ties closely with my beliefs.	**Different:** That book is far from perfect.	**Active:** Step forward and cast the first stone.	**Passive:** Step back and let me handle this.	**Good:** Her intentions are on the up and up.	**Bad:** He's fallen from grace.
Present: It is still too close to the break up to move on.	**Past or Future:** Relax! The deadline is still far away.	**Significant:** The test was at the forefront of my attention.	**Insignificant:** That deadline is in the back of my mind.	**Healthy:** His health is looking up.	**Sickly:** She's coming down with a cold.
Wanted: That cat is close to my heart.	**Unwanted:** Keep that thing away from me!	**Progressive:** He told her to go ahead with the plan.	**Regressive:** Sam went back a grade.	**Happy:** Cheer up!	**Sad:** I'm feeling kind of down.
Significant: You two seem to have gotten close.	**Disconnected:** I feel like we have grown apart.	**Predictive:** I'm looking ahead to the future.	**Reflective:** I'm thinking back on the past.	**More:** Gas prices are going up.	**Less:** Please turn down the volume.
Aware: Please keep a close watch on her.	**Unaware:** She's out of my sight and out of my mind.	**Successful:** She's ahead of the game.	**Failure:** You are falling behind on your studies.	**High Status:** We look up to him.	**Low Status:** He's at the bottom of the corporate ladder.

Table 3. Spatial image schemas and metaphors tested in this study.

METAPHORS AND REPRESENTATIONS EXAMINED IN THIS STUDY

Image Schemas and Metaphors

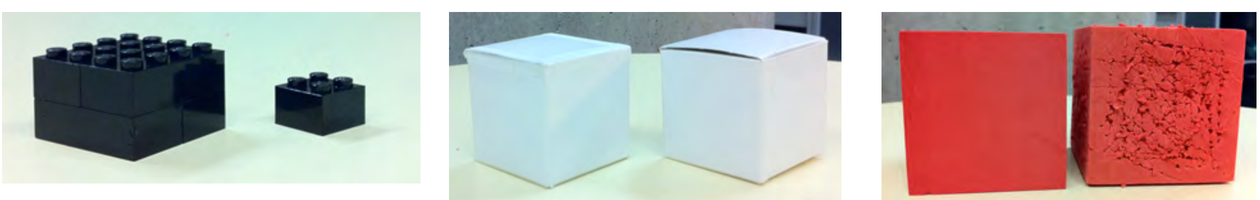
We suggest that metaphors based on both attribute and spatial image schema groups are important for tangible interface design since tangibles involve physical objects with physical attributes, and are located in space. In this study we focused on metaphorical pairings based on three attribute image schemas (taken from [11]) and three spatial image schemas (shown as privileged in [2]). Each image schema was represented as an opposing pair (e.g. up-down, near-far). We used image schematic metaphors involving adjectives, that is, abstract concepts that describe nouns (e.g. significant, expensive). We also considered these as opposing pairs (e.g. significant-insignificant, expensive-cheap). We then investigated which attribute-adjective pairings (e.g. heavy is expensive) and space-adjective pairings (e.g. near is significant) are recognized by the majority of users (i.e. are metaphor population stereotypes). Frequently identified pairings can form the basis for reliable design guidance. For each image schema, five conceptual metaphors were defined, each with an adjective pair. Tables 2 and 3 list the metaphors tested in the study, along with sentences that illustrate their use within everyday English language. Some adjectives give quantitative descriptions (*more-less*) while others give qualitative descriptions (*significant-insignificant, valuable-valueless).* All metaphors from the attribute group were taken from a similar study done by Hurtienne et al. [11] in order to validate this work with different objects and population sample. The adjectives for the spatial group were taken from Lakoff and Johnson's metaphors examples [13] or derived from our analysis of their use in the English language.

Objects' Physical Representations

The image schemas were depicted using the properties of simple everyday objects. For each image schema pair (e.g. heavy-light), two identical objects were used, differing only in the attribute or spatial properties associated with the image schema. See Figure 1 (Attributes) and Figure 2 (Spatial) for image schematic representations. The objects used to represent each image schema differ from those used by Hurtienne et al. [11]. We did this to see if changing the object (but using the same representation) would result in similar findings to those of Hurtienne et al. [11].

Validation

We validated the physical-abstract pairings as follows. Three researchers, familiar with CMT, rated the appropriateness of each object's physical representation of an image schema, and each physical-abstract pairing. The rating scale was a 7-point Likert scale (+3 being a good match, -3 being a bad match). Representations and pairings that had a mean rating of +2 or less were revised based on feedback. For example, we changed the adjective "cheap" to "inexpensive" and "problematic-unproblematic" to "constrained-unconstrained" as suggested by the raters. The revised representations and pairings were then presented to a different set of three people unfamiliar with CMT. These people rated the revised representations and pairings using the same scale. All representations and pairings received a mean rating above +2, except for two pairings (one



Big-Small (Big: four 2x4 Lego blocks joined together to make a 2-layer 4x4 Cube. Small: one 2x2 Lego block.)

Heavy-Light (Heavy: 5 cm. cubed box filled with coins taped down to make no sound; Light: empty 5 cm. cubed box.)

Smooth-Rough (Smooth: 7.5 cm. cubed foam block; Rough: 7.5 cm. cubed foam block with scratches.)

Figure 1. Image schematic representations of attribute properties.

Near-Far (Near: Two 10x1 flat Lego planes joined together by two 2x1 Lego blocks at the centre. Far: Two 10x1 flat Lego planes joined together by one 2x1 Lego block located at each end) and)

Front-Back (Front: yellow car taped on a 5x7.5 cm ground, the front half off the ground. Back: yellow car taped on a 5x7.5 cm ground, the back half off the ground.)

Up-Down (Up: 3-layered 2x1 tower made from three 2x1 Lego blocks, gray piece on top. Down: 3-layered 2x1 tower made from three 2x1 Lego blocks, gray piece on bottom.)

Figure 2. Image schematic representations of spatial properties.

attribute, one spatial), which received a mean rating of 1.33. Since each belonged to a different group, we decided to proceed with the study as all conditions were balanced.

METHODOLOGY

Study Design

We used an experimental, comparative design with two groups: attribute and space. The within-subjects design minimized effects of individual differences. All participants rated all pairings in each category.

Participants

Twenty adults (7 m 13 f) from the greater Vancouver area in western Canada volunteered to participate in the study using a university online recruiting system. Their age ranged from 19 to 49 years (M=24.9 SD=7.5). Eighty-five percent (n=17) were students from the university (14 undergraduate, 3 graduate). The remaining 15% (n=3) held degrees and were working in industry. The participant group was a convenience sample. Although, image schemas are universal [12,13], metaphors may differ across cultures. In our sample, 35% (n=7) listed English as their first language, 60% (n=12) stated it as their second, and one person stated it as her third. None were familiar with CMT or image schemas. Findings from our participant group will likely be applicable to other English speaking populations.

Tasks

Each participant completed thirty metaphor identification tasks. For each task, participants were presented an object pair and an adjective that was paired to one of the objects. For example, they were given two foam blocks, one representing rough, and one representing smooth (see Figure. 1) and shown the word "dangerous" (dangerous-safe adjective pair). They were asked to choose which of the objects more closely resembled the adjective. They were given 30 seconds to make their choice. This time period was chosen to encourage participants to base their decisions on first impressions. This process was repeated for a total of thirty adjectives using the six object pairs.

Each object pair was presented in an open-faced paper box. Participants were instructed to take the items out of the box and inspect them before making their choice. This was done to minimize choices based on the objects' orientation or presentation. Each participant was shown the same number of adjectives with positive and negative meanings. They also had the same number of adjectives mapped to attribute and to spatial image schemas. The order of adjective presentation and valence (positive or negative) was randomized for each participant. Thus no two participants had an identical list of schemas presented to them. We did this to avoid order effects.

Data Collection and Analysis

For each metaphor identification task, participants' choices were scored as a match or not. A match is when a choice identified the metaphorical mapping between physical property and adjective. For example, when presented with the two foam blocks (one rough, one smooth) and the adjective "dangerous", choosing the rough block was scored as a match. This choice matched the conceptual metaphor ROUGH IS DANGEROUS. Participants also filled out a post-task questionnaire.

For each adjective we calculated the percentage of participants who scored a match. We then calculated *Cohen's kappa coefficient* (K), a ratio that represents the percentage of participants who identified the metaphor while considering those who identified the metaphor by chance. For this study, chance agreement is 50% as there were only two objects to choose from for each adjective. The formula to calculate the coefficient is:

$$K = \frac{\%\text{ of Agreement} - \%\text{ of Chance Agreement}}{1 - \%\text{ of Chance Agreement}}$$

K values above 0.6 indicate identification by majority of participants taking chance into account. We next ran a paired t-test on the K values between the positive (i.e. pleasant) and negative meanings (i.e. unpleasant) for all adjective pairs. We found no significant difference, $t(29) = 0.12$, $p > 0.1$, and thus aggregated the scores.

RESULTS

Table 4 (Attribute Image Schemas) and Table 5 (Spatial Image Schemas) list each metaphor, the percentage of participants who identified it, and the K value. Metaphors not identified by the majority of participants are represented with light grey text.

Metaphor (Big is – Small is)	**%**	**K**
Powerful –Weak	90	0.8
Important –Unimportant	85	0.7
Valuable –Valueless	60	0.2
Significant –Insignificant	80	0.6
More –Less	100	1.0
Metaphor (Heavy is – Light is)		
Important –Unimportant	80	0.6
Sad – Happy	80	0.6
Constrained – Unconstrained	80	0.6
More – Less	95	0.9
Expensive – Inexpensive	80	0.6
Metaphor (Rough is – Smooth is)		
Impolite – Polite	95	0.9
Dangerous – Safe	95	0.9
Unpleasant – Pleasant	100	1.0
Interrupted – Continuous	95	0.9
Problematic – Unproblematic	100	1.0

Table 4. Identification results for attribute-based metaphors.

Metaphor (Near is – Far is)	%	K
Similar – Different	70	0.4
Present – Past or Future	85	0.7
Wanted – Unwanted	70	0.4
Connected – Disconnected	85	0.7
Aware – Unaware	65	0.3
Metaphor (Front is – Back is)		
Active - Passive	60	0.2
Significant – Insignificant	55	0.1
Progressive – Regressive	65	0.3
Predictive – Reflective	35	-0.3
Successful – Failure	70	0.4
Metaphor (Up is – Down is)		
Good - Bad	100	1.0
Healthy – Sickly	85	0.7
Happy – Sad	85	0.7
More – Less	70	0.4
High Status – Low Status	85	0.7

Table 5. Identification results for spatially-based metaphors.

Image Schemas

We calculated the number of metaphors each participant identified, categorized these metaphors by image schema, and converted these numbers into percentages. Figure 3 illustrates the mean number of metaphors identified for all participants grouped by image schema.

We ran a one-way within-subjects ANOVA to see whether there was a significant difference in the number of metaphors identified by participants for the different image schemas. We found a significant difference between groups, $F(5, 95) = 6.57$, $p < 0.0001$. Post-hoc comparisons using a Tukey HSD test indicated that the percentage of metaphors identified for the front–back image schema (M = 2.85, SD = 1.60) was significantly less than that identified for big–small (M = 4.15, SD = 1.10), heavy–light (M = 4.2, SD = 0.77), rough-smooth (M = 4.75, SD = 0.55), and up–down (M = 4.2, SD = 0.89). There was no significant difference between the near-far (M= 3.8, SD = 1.44) and front-back image schemas, and no significant difference between any other schemas.

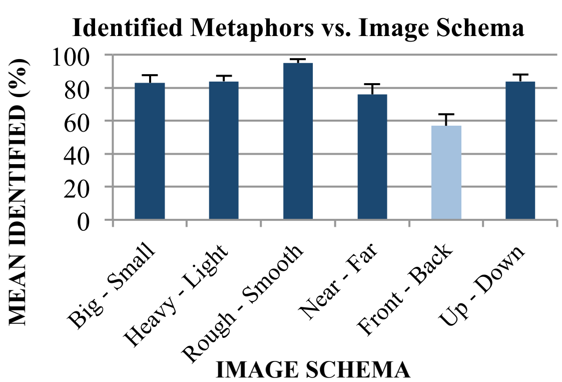


Figure 3. Percentage of metaphors identified by image schema group (bars are standard error).

Attribute versus Spatial Groups

We took the total of identified metaphors for each participant, sorted them into attribute and spatial groups, and converted the total into percentages. The attribute group had a mean identification rate of 87.3%. The spatial group had a mean identification rate of 72.3%. We ran a paired t-test between the groups and found a significant difference between the attribute group (M=13.1, SD = 1.45) and spatial group (M = 10.85, SD = 2.56), $t(19) = 3.29$, $p < 0.01$.

DISCUSSION

Overall Results

Many (66.7%) of the thirty metaphors were identified by the majority of participants. Those successfully identified are called metaphor population stereotypes. Most of our findings are similar to those from the study by Hurtienne et al. [11]. For example, metaphors in their study that had K values above 0.6 also had K values above 0.6 in our study. Metaphors for the *valuable-valueless* adjective pair received K values of less than 0.6 in both studies. However, *pleasant-unpleasant*, which had the lowest K value from the rough-smooth image schema in the study by Hurtienne et al. (K = 0.42), was consistently identified in our study (K = 1.0). We suggest that metaphors with K scores above 0.6 can be used reliably to design physical-abstract mappings in tangible user interfaces. For example, the metaphor rough is problematic could be used when a designer wants to draw attention to digital information that requires attention (i.e. is problematic). The tactile qualities of an input object could dynamically become rougher when the object is moved nearer to the problematic information. However, since context is important, we suggest that such mappings should be verified in formal or informal user studies. In particular, the physical form and representation of the image schema can effect the user's identification of a related metaphor.

Image Schema Groups

In order to generate guidelines that go beyond individual metaphors, we analyzed identification rates for different metaphors that are based on the same image schema. In cases when participants identified the majority of metaphors based on a single image schema, then that image schema can be recommended as a strong source domain. On average, participants identified four out of five metaphors for each of the following image schemas: big-small, heavy-light, rough-smooth, near-far, and up-down. As a design guideline, we suggest that these image schemas are good candidates for a variety of metaphor population stereotypes.

In both our study and the study by Antle et al. [2] participants had some difficulty understanding the near-far based metaphors so we recommend near-far with caution.

Attribute versus Spatial Groups

We found that metaphors based on the attribute image schema group were identified more frequently than metaphors based on the spatial image schema group. This suggests that metaphors based on attribute image schemas are more readily identifiable. However, we also draw attention to the result that the up-down spatial image schema had strong results, which is consistent with findings in [1]. Although the study designs are quite different, we also compare our findings to previous ones. Antle et al. [2] suggested that spatially based metaphors (spatial group) were more easily identified than body movement-based metaphors (basic group) when used to control audio in a whole-body audio interactive environment. However, when comparing whole body actions to actions on tangible objects, Bakker et al. reported less evidence of this effect [4]. Based on our results in combination with these studies, we tentatively suggest a guideline that image schema groups can be ordered in terms of ease of identification as attribute > spatial > basic. This guideline may require further investigation.

Static versus Dynamic Representations

We suggest that the low identification rate of metaphors from the spatial group may be due to the difficulty of representing some spatial image schemas using static objects. For example, when choosing an object from the front-back pair for the adjective "predictive", many participants chose the "back" object because the car has yet to cross the road. Movement may be more important than the reference point in interpretation. When choosing an object from the up-down pair for the adjective "more", many participants chose the "down" object because it had more black blocks on top (Figure 2, right). This may be because the object representation did not have a clear frame of reference. Many spatial properties may be better represented through movements, such as stepping forward and going up, or by using multiple objects with one object serving as a frame of reference (e.g. one box inside another box for "in" as found in [4]).

Quantitative versus Qualitative Concepts

All participants identified the metaphoric relationship between size (big-small) and quantity (more-less). Ninety-five percent (n=19) of participants identified the relationship between weight (heavy-light) and quantity (more-less). However, participants were less reliably able to identify relationships between size or weight and qualitative adjectives. For example, the metaphors for significance, importance, and expense had K values that just met the 0.6 threshold. Furthermore, the only attribute-based metaphor that did not meet the K value threshold involved connecting size with value (i.e. big-small is valuable-invaluable). This finding may reflect the way humans perceive and understand quantitative and qualitative values. Quantities are often directly perceivable through our senses and thus may be more objectively determined. Qualitative values are often formed through mental judgements or opinions and may be more subjective and open to interpretation.

In light of this distinction, we suggest that metaphors may actually be more beneficial for understanding abstract qualities in tangible user interfaces since quantities are somewhat self-evident, whereas qualities are more open to interpretation. Though less consistent, many qualitative-based adjectives (*powerful-weak, significant-insignificant)* were identified by the majority of participants and are suitable for metaphor population stereotypes.

Limitations

We tested each image schema only with one representation, and this choice may have affected the results. Further research is needed to validate the current findings within a wider range of contexts relevant for abstract domains. For example, the image schema front-back was represented with a car and ground (Figure 2, middle). When presented with the cars and the concept "predictive", many participants chose the car that did not cross the road because prediction is done prior to executing the action. In this case the spatial relation between the car and ground is ambiguous. Is the car in front or the ground in front? The poor identification rate of metaphors made from the front-back image schema reduced the overall effectiveness of conceptual metaphors from the space group. This highlights the importance of context, and warrants further study with a different representation where an object serves as a frame of reference for the spatial schema (e.g. front, top).

DESIGN IMPLICATIONS

We suggest the following metaphoric relations between physical properties and abstract concepts for TUI design as they have been shown to be reliably identifiable:

- The 20 specific metaphors identified in this study receiving a score of $K > 0.6$ (See Tables 4 and 5);
- The specific metaphors identified in the study by Hurtienne et al. receiving a score of $K > 0.6$ [11];
- A variety of metaphors unexplored in our study but based on the specific image schemas: big-small, heavy-light, rough-smooth, and up-down;
- A variety of metaphors unexplored in our study but based on a variety of attribute image schemas;
- A variety of metaphors based on spatial image schemas if the image schema can be well represented with clear reference frames (e.g. in-out as a box within a box [4]);
- A variety of metaphors based on spatial metaphors if action or movement can be used to clarify spatial relationship (e.g. up-down);

- A variety of metaphors that describe quantities only if the quantitative aspect is not "obvious", easily perceivable or understood outside of a metaphor;
- A variety of metaphors that describe qualities in cases where enhancing users' interpretation is desired and precise or objective descriptions are not mandatory.

We also suggest testing all mappings with end-users since context, such as the nature of the physical representation on an object, can affect interpretation of metaphors

CONCLUSION

From our study we provide validation for twenty conceptual metaphors that were identified by the majority of participants and can be used in tangible interface design as metaphor population stereotypes. We also identified individual image schemas that had high identification rates and can be used as the source domains for a variety of metaphors. We provide guidelines about specific metaphors as well as more general suggestions for groups of metaphors. We made distinctions amongst attribute, spatial, and substance image schema groups; between static and dynamic representations; as well as between quantitative and qualitative concepts. We propose guidelines, not hard and fast rules, to inform designs. We advocate testing all designs since the specifics of the context can affect identification rates. Future studies are needed to explore other image schemas, forms of representation, and to validate our findings in other contexts and user groups.

ACKNOWLEDGEMENTS

We would like to thank the researchers who participated in validating the metaphors and object representations, as well as the participants who took part in the study. This research was funded, in part, by a NSERC Discovery Grant.

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