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COGNITION IN HCI: AN ONGOING STORY

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Abstract*: The field of human computer interaction (HCI) is deeply rooted in cognitive science. But can cognitive science still contribute to the newest developments? This article introduces the recent trends towards "embodied cognition." Then research on image schemas and their metaphorical extensions is reviewed as an example of how understanding a special branch of embodied cognition can be useful to HCI. Special emphasis is placed on the validity of the theory and its practicability in different phases of the user interface design cycle. It is concluded that cognition can still contribute to current HCI and that the dialogue between the different schools of thought is beneficial to the field.*

Keywords: *user-centered design, image schemas, embodied cognition.*

INTRODUCTION

New challenges require new solutions. Computers are becoming smaller, more powerful, and ubiquitous. They are no longer used exclusively for solving work tasks. They support communication and cooperation; they help with exercise and wayfinding; they entertain and educate. New design themes like user experience, emotion, and artistic expression emerge. The emphasis is shifting towards the analysis of context, embodiment, and values. New interaction paradigms, such as ubiquitous computing, tangible interaction, and ambient interfaces, have appeared that require new approaches to design well beyond those used for traditional graphical user interfaces. Design inspirations are drawn from phenomenological philosophy, ethnography, and industrial design. These new approaches to designing human–computer interaction (HCI) have been called third-wave HCI (Bödker, 2006), or the third paradigm (Harrison, Tatar, & Sengers, 2007) in the sense of Kuhn (1970).

Traditional HCI is rooted in cognitive science as well as in ergonomics and human factors engineering. From cognitive science it has inherited its focus on theory-based research, on experimental methods conducted in the laboratory (e.g., usability tests), and on information processing by humans and computers. From ergonomics and human factors engineering, it has inherited its focus on design for the workplace, emphasizing effectiveness

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and efficiency as design objectives. Traditional HCI, it is felt, cannot address the new developments adequately, hence the call for a paradigm shift.

Do these new developments mean that cognition and the scientific method are not needed anymore? Looking from the cognitive science perspective towards third-wave HCI, however, these approaches seem to be eclectic collections of fairly vague design philosophies; the insights generated by research are highly context dependant and lack generalizability; and subjective interpretation prevails, which does not contribute much to finding "objective truth."

Who is right and who is wrong? Is there really a paradigm shift going on? Does one approach have to dominate another? According to Kuhn (1970), a generally accepted set of theory, associated methods, and domains of applications characterize a scientific paradigm. A new paradigm can only exist after it has overthrown the old one by being better able to explain new and old phenomena. A paradigm shift only occurs by a process of scientific revolution.

Is this what is currently happening to HCI? I would say no. Grudin (2006) pointed out that several approaches to HCI are currently coexisting. There is not a sole paradigm; there is a multitude. It seems that, rather, we are in what Kuhn (1970) describes as the preparadigm phase, in which different schools of thought advocate different theories, approaches, and applications. In this phase there is no consensus on any particular theory, although the research being carried out can be considered scientific in nature. Current HCI then should be seen as a dialogue among members of different schools.

In this article I view cognition as one school of thought rather than a paradigm in the Kuhnian sense, and I will show what this school of thought has to contribute to the scientific dialogue in today's HCI.

TRADITIONAL AND EMBODIED COGNITION

The advent of computers influenced cognitive science and cognitive science influenced how computers were built. The computer brought a powerful idea to psychology: understanding the mind as an information processing device. Massaro and Cowan (1993) describe the defining properties of the information processing approach as follows: (a) The environment and cognition can be described in terms of input, process, and output; (b) Stages of processing can be broken down into substages; (c) Information is transmitted forward in time and all inputs necessary to complete one operation are available from the outputs that flow into it; (d) Each stage or operation takes some time; and (e) Information processing occurs in a physical system; representations are information embedded in states of the system, and processes are operations used to transform the representations. This idea of information processing means that one can trace the progression of information through the system from stimulus to response.

A high-level schematic of this approach is shown in Figure 1. The mind is seen as an information processing device consisting of independent modules for perception, cognition, and action. Often connected with the information processing view of cognition is the view of intelligence being explained by processes of symbol manipulation (Newell & Simon, 1976). Because symbols are abstract and amodal (i.e., not tied to perceptual representation), their processing can be implemented without difference in hardware, in software, in a brain, or in a

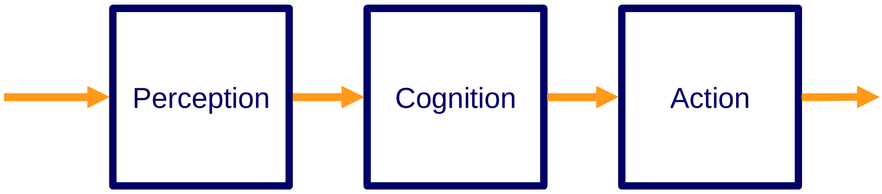

Figure 1. The traditional view of the mind, in which cognition forms a module separate from perception and action.

brain in a vat. Knowledge is equated with symbols, and thinking is equated with the application of algorithms. Theories of cognition are interchangeable with algorithmic programs. Indeed, a large part of the field of artificial intelligence was occupied with testing theories of human cognition that were formulated as computer programs.

Card, Moran, and Newell (1983) introduced this traditional view of cognition to HCI in their influential book, *The Psychology of Human Computer Interaction*. For an audience of computer scientists, they described the human mind as an information-processing system with memories, processors, cycle times, and specific laws of operation. They described it as *the model human processor* and proposed it as a general-purpose thinking device. This view of cognition and the model human processor was very successful in HCI. Card et al. summarized many principles, like the power law of practice, Fitts' law, and Hick's law, that enabled engineers to predict—within limits—human performance when interacting with computers. The GOMS (goals, operators, methods, and selection rules) analysis and the keystroke level model were powerful tools for modeling human–computer interaction. The model human processor concept influenced many milestone textbooks in HCI, among them Deborah Mayhew's (1992) *Principles and Guidelines in Software User Interface Design*. Cognitive modeling (or cognitive engineering) is the subfield in HCI that tries to replicate users' cognitive processes within the computer in order to better predict user behavior (Byrne, 2003; Norman, 1986). Different stages of information processing can still be found in today's human factors or usability engineering textbooks (Rosson & Carroll, 2002; Wickens & Hollands, 2000).

The metaphor of the mind as an information-processing device soon attracted criticism. Winograd and Flores as well as Dreyfus, Dreyfus, and Athanasiou (both in 1986) maintained that the traditional cognitive view on the mind is flawed and that artificial intelligence will not go far, based on this model. They backed their arguments with philosophical theories by Heidegger and Merleau-Ponty that bring in the ideas that thinking is dependant on perception, action, and experience; that having a human body thoroughly influences and constrains human cognition; and that human experience must be studied using a phenomenological approach. The mind cannot be viewed as a device operating on bits of information according to formal rules. Much of human intelligent behavior and expertise relies on intuition and subconscious processes, rather than conscious symbolic manipulation captured in formal rules. Works in robotics supported this criticism, showing that many everyday behaviors involving balance, motion, and navigation do not need high-level symbolic manipulation to be successful, because "the world is its own best model" (Brooks, 1990, p. 5).

The view that conscious symbol manipulation is, at best, only a small part of our intelligence is gaining ground in cognitive science. Evidence shows that cognition cannot be separated from sensory and motor processes. Language understanding, for instance, involves simulations of sensorimotor experiences rather than manipulating amodal symbols (Glenberg

& Kaschak, 2002). Sensorimotor input directly affects cognitive judgments about time (Casasanto & Boroditsky, 2008). Categorical knowledge is grounded in sensorimotor regions of the brain (Barsalou, 1999). And thoughts about abstract things, like the self, the mind, morality, emotions, causality, or mathematics, are grounded in the sensorimotor experience of the world (Lakoff & Johnson, 1999; Lakoff & Núñez, 2000).

Such evidence led to the view that cognition is embodied. Embodiment emphasizes that cognition is dependant on its concrete implementation in a human body, with specific sensory and motor capabilities. Connected to it is the idea that cognition takes place in the real world, that is, that cognition is situated, time-pressured, action-oriented, and emerges in interaction with the environment (Wilson, 2002). Hence, the clear demarcation between perception, action, and cognition cannot be sustained any longer, and large overlaps between these faculties exist (Figure 2).

Many of the general ideas in embodied cognition have entered third-wave HCI (cf. Dourish, 2001). As mentioned above, not all of them are clear-cut enough to be easily applied to human–computer interaction. Here, I will follow a notion of embodied cognition that describes how much of our thinking is influenced by past embodied experience. This idea is expressed by Zwaan and Madden (2005, p. 224): “Interaction with the world leaves traces of experiences in the brain. These traces are (partially) retrieved and used in the mental simulations that make up cognition. Crucially these traces bear a resemblance to the perceptual and action processes that generated them…and are highly malleable.” In the remainder of the article, a theory will be introduced that is concerned with these “traces of experiences” and that calls these traces *image schemas*. Research will be presented that shows how image schema theory is valid and useful in a context of user–interface design.

IMAGE SCHEMA THEORY

Image schemas are abstract representations of recurring sensorimotor patterns of experience (Johnson, 1987). They are formed by and directly structure our experience with the world. The *container* image schema, for example, forms the basis of our daily experiences with houses,

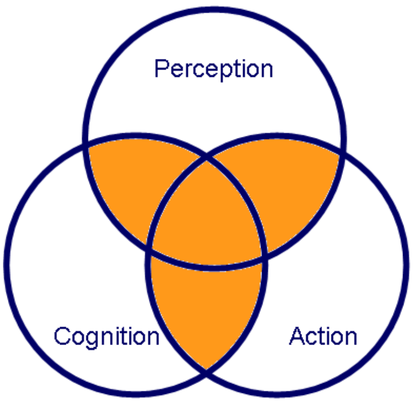

Figure 2. Embodied view of the mind, with large overlaps between cognition, perception, and action.

rooms, boxes, teapots, cups, cars, and so on. A container is characterized by an inside, an outside, and a boundary between them. Consider the many container events encountered in simple activities: “Take for example a child in a red dress who watches her mother put cookies into a jar. The child takes the lid off the jar and looks inside to search for the cookies. She reaches into the jar,…down into the cookies,…grasps a cookie (so that the cookie is now in her hand), and takes it out. She wraps the cookie in a napkin. She walks with the cookie through a door into another room, where she is picked up in her mother’s arms and put into a high chair. She watches the mother pour milk into a glass. She then dunks her cookie into the milk (which is itself contained in the glass), and puts the cookie into her mouth” (Dewell, 2005, p. 371–372). These examples show that containers can have different forms and consistencies: They can be instantiated by fluids (the milk), collections of things (the cookies), or flexible wraps (the napkin). (See also the experimental evidence in Feist, 2000; Garrod, Ferrier, & Campbell, 1999). One of the entailments of the container image schema is that the content of a container is separated from what is outside the container. The container image schema and its entailments are reused when thinking about abstract categories. It surfaces in conventions when we talk about “being in Florida” or that someone is persuaded “to enter into the contract.” Both expressions connote abstract containers without physical instantiations in the real world.

Table 1 lists a set of image schemas that are found in the cognitive science literature (Baldauf, 1997; Clausner & Croft, 1999; Hampe, 2005; Johnson, 1987; Talmy, 2005). The image schemas in Table 1 are separated into groups of *basic*, *space*, *force*, *containment*, *process*, *multiplicity*, and *attribute* image schemas.

Although most of these image schemas were derived from linguistic and philosophical analyses, they are proposed to stem from physical interaction with the world. As mentioned above, they can be transferred to the thinking about abstract, nonphysical entities. This transfer is called a *metaphorical extension* of the image schema. Metaphorical extensions are often grounded in bodily experience. For example, experiencing the level of liquid rising in a container when more liquid is added or seeing a pile of paper shrink when sheets are taken away leads to the metaphorical extension *more is up–less is down*. This correlation between amount and verticality is subsequently generalized to abstract entities like money or age, as can be seen

Table 1. List of Image Schemas.

Group	Image Schemas
BASIC	object, substance
SPACE	center–periphery, contact, front–back, left–right, location, near–far, path, rotation, scale, up–down
CONTAINMENT	container, content, full-empty, in-out, surface
MULTIPLICITY	collection, count–mass, linkage, matching, merging, part–whole, splitting
PROCESS	cycle, iteration
FORCE	attraction, balance, blockage, compulsion, counterforce, diversion, enablement, momentum, resistance, restraint removal, self-motion
ATTRIBUTE	big–small, dark–bright, heavy–light, smooth–rough, straight, strong–weak, warm–cold

in expressions like "My income rose last year," "Rents are going up," or "He is underage." Other metaphorical extensions of the up–down image schema are (Lakoff & Johnson, 1980):

> *Good is up–bad is down*: "Things are looking up"; "We hit a peak last year, but it's been downhill ever since."
>
> *Happy is up–sad is down*: "I'm feeling up"; "That boosted my spirits"; "He is really down these days"; "I'm depressed."
>
> *High status is up–low status is down*: "She'll rise to the top"; "He's at the bottom of the social hierarchy."

There are more than 40 image schemas, and each image schema gives rise to several metaphorical extensions: More than 250 metaphorical extensions have been documented in the literature (Hurtienne, Weber, & Blessing, 2008). Although much of this research was done on linguistic data, cognitive linguists claim that these metaphorical extensions are only expressions of underlying conceptual metaphors. Because this claim is very strong, research is necessary that provides evidence beyond pure linguistic analysis. (This is addressed more fully below.)

The universal character of image schemas, their—in the course of life—extremely frequent encoding in and retrieval from memory, and their subconscious processing make them interesting as patterns for designing user interfaces. A *left–right* image schema (along with an up–down image schema), for example, may be represented by a joystick on a toy car's remote control. When the joystick is moved leftward, the toy car turns left. A rightward move of the joystick lets the toy car turn right, thus a simple physical mapping. Metaphorical extensions of image schemas can be used to represent abstract concepts, such as using up–down in a vertical slider for controlling the intensity of the speaker volume (more is up) or to rate the attractiveness of a new car (good is up). This use of image schemas for representing abstract concepts is one of the major promises for user–interface design, because, in the mind of users, they subconsciously tie the location, movement, and appearance of user interface elements to their functionality. Thus they can provide an extra layer of meaning to physical properties of interfaces. The next section describes research into how image schema theory has been applied to user interface design.

IMAGE SCHEMAS IN HCI

As in any theory useful for HCI, image schema theory needs to fulfill the requirements of (a) making valid predictions in a context of user interface design, and (b) being useful in practice. Research that has addressed these requirements is reviewed here.

Validity

Image schema theory originates from the fields of cognitive linguistics and philosophy. In language, image schemas are found to motivate grammatical forms, underlie the meaning of prepositions, motivate verbs and adverbs, and motivate many metaphorical extensions of abstract concepts like causation, death, and morality (Baldauf, 1997; Gibbs & Colston, 1995;

Hampe & Grady, 2005; Lakoff & Johnson, 1980, 1999). The question is whether they are also valid outside a purely linguistic context.

Psychological experiments show that image schemas are mediating between perception, language, action, and cognition. Mandler (1992, 2004, 2005) describes research that shows how image schemas are involved in building up a sensorimotor representation of the world in the young infant and how they scaffold the acquisition of early concepts and language. Other studies show that nonverbal image schema instantiations interfere with sentence understanding when the sentence implies a different image schema (e.g., left–right instead of up–down) and facilitate understanding when the image schema orientation is consistent. These effects could be shown with visual, acoustic, and motor instantiations of a number of different image schemas (up–down, left–right, *front–back*, *near–far, rotation*; see Hurtienne, 2009, for a review). How image schemas are plausible from a neurocognitive standpoint was shown by Barsalou (1999).

The psychological reality of a number of metaphors of the up–down image schema was shown by Meier and Robinson (2004), Casasanto and Lozano (2006, 2007), and Schubert (2005). The metaphor *similar is near–different is far* was validated by Casasanto (in press). He found that people judge abstract words more similar when they are presented close together than when they are presented further away from each other. Meier, Robinson, and Clore (2004; Meier, Robinson, Crawford & Ahlvers, 2007) experimentally confirmed the relation between affective state and instances of the *bright–dark* image schema (e.g., *happy is bright–sad is dark*). Metaphors of time perception were investigated by Boroditsky (2000; Boroditsky & Ramscar, 2002), also under a complete avoidance of verbal material (Casasanto & Boroditsky, 2008). Metaphorical expressions in gesture replicate those found in speech (Cienki & Müller, 2008; McNeill, 1992, 2005). Neurological evidence for conceptual metaphor is discussed in Kemmerer (2005) and Rohrer (2005).

Despite the multiplicity of studies in linguistics and psychology, only a few studies validate the claims of image schema theory in the domain of HCI. The idea is that user interfaces consistent with metaphorical extensions of image schemas will be more effective (i.e., less error prone), more efficient (i.e., less time consuming), and more satisfying to use (i.e., they receive better ratings by participants) than inconsistent user interfaces.

Two studies (Hurtienne & Blessing, 2007) investigated metaphorical extensions of the up–down image schema with arrangements of buttons and sliders. In these, efficiency was measured by response times and satisfaction by subjective suitability ratings of different arrangements. In the first experiment, participants evaluated hotels along different dimensions. They did this with a simple two-button interface, with one button in the upper position and the other in the lower position (Figure 3). The results show that participants significantly preferred button arrangements consistent with the metaphors more is up–less is down, good is up–bad is down, and *virtue is up–depravity is down* over button arrangements that were inconsistent with these metaphors. In the case of good is up and virtue is up, response times were significantly lower when the buttons were arranged in a manner consistent with the metaphor than when they were inconsistent. No statistical difference in response times was found for the metaphor more is up.

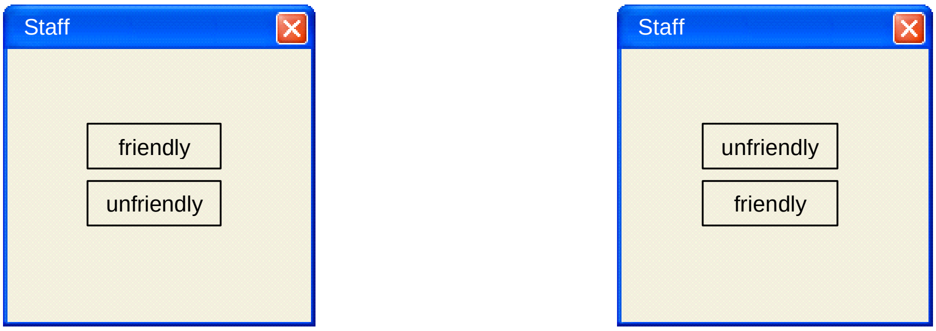

Figure 3. Button labels in a hotel evaluation task. Button labels on the left are compatible with the metaphor virtue is up; labels on the right are incompatible (Hurtienne & Blessing, 2007).

The second experiment investigated the metaphors more is up and good is up. Participants received a context-free task with vertical analogue sliders and they were to indicate in which direction they would push the slider when asked to adjust the slider to display more, less, better, or worse. The results validated the metaphors, showing that preferences were significantly higher and response speeds were significantly lower for the metaphor-consistent sliders than for the metaphor-inconsistent sliders. In both experiments, alternative explanations of the findings could be ruled out by control conditions in which the buttons and sliders were arranged horizontally.

Measures of all three usability indicators—effectiveness, efficiency, and satisfaction—were taken in an experiment that investigated the influence of the near–far image schema in judging the similarity of display values in pointer and number displays (Hurtienne, 2009). Well-known design principles like the proximity compatibility principle (Wickens & Hollands, 2000) state that values that are processed together during a task should also be placed near each other on the display. This principle, however, is in contrast to the metaphor similar is near–different is far, evident in expressions like "A and B are close, but they are by no means identical" or "the difference between A and B is vast." This metaphor would predict that two displays showing differing values should be placed further apart, even if they belong to the same task. In these experiments it could be seen that in a comparison task in which display similarity varied along one dimension (display value) more errors were made and reaction times were slower when following the proximity–compatibility principle. Following the metaphor similar is near was more beneficial to performance. However, subjective suitability ratings were less distinctive between the two principles.

Across all three experiments (Hurtienne & Blessing, 2007; Hurtienne, 2009) effect sizes d (Cohen, 1988) were measured. Response times as efficiency measures show small- to medium-sized effects (average d = .45). Error rates as effectiveness measures were sometimes not available because the tasks were too easy. If there were error effects, they were in the medium to high range (d = .74). Expressed in percentages, this means up to 14% gains in speed and 50% fewer errors in the metaphor consistent conditions. Suitability ratings as measures of satisfaction show very large effects (average d = 2.28) and could swing from a strong rejection of the inconsistent to a strong acceptance of the consistent interfaces.

Image schemas are useful not only for conveying functional information, but they also can be used for conveying aesthetic information (van Rompay, Hekkert, Saakes, & Russo, 2005). The expression of the image schemas up–down, container, and *balance* was manipulated in jugs and alarm clocks. Up–down, for instance, was varied by manipulating the height of the objects. Participants rated the expression of the objects on nine dimensions, for example, secure–insecure, introvert–extravert, and constricting–liberating. The results showed that the image–schematic variations in product appearance influenced the ratings on the abstract dimensions. Unfortunately, the study was not based on specific metaphorical extensions derived from theory, so it provides no evidence for or against the validity of specific metaphors.

In a recent study, 29 metaphorical extensions of five attribute image schemas (big–small, bright–dark, *warm–cold*, *heavy–light*, and *smooth–rough*) were investigated (Hurtienne, Stößel, & Weber, 2009). Participants received simple objects (Lego bricks of different sizes, colors, and textures; small bottles filled with hot and cold water; or a light and a heavy match box) and were given an abstract word for which they should find the one object that best represents this word. For example, they received black and white Lego bricks and should say which best represented the word *happy*. Here, the metaphor happy is bright–sad is dark predicts that people will choose the white brick as an answer (indeed, 88% did). Other examples of metaphors under investigation are *important is big–unimportant is small*, *good is bright–evil is dark*, *emotional is warm–unemotional is cold*, *problematic is heavy–unproblematic is light*, and *polite is smooth–impolite is rough*. Averaged over all 29 metaphors, 78% of the participants' answers were consistent with the metaphors' prediction, a value that lies significantly above chance agreement (50%). There were, however, great variations in strength between the metaphors and the presentation styles of image schemas. The metaphor good is bright–evil is dark, for example, received 100% agreement when using black and white Lego bricks, but only 67% agreement when using light-blue and dark-blue bricks, suggesting that the specific instantiation of image schemas plays a great role in whether metaphors are valid or not.

Altogether, the evidence on the validity of image schemas and their metaphorical extensions inside and outside the context of user interface design is promising. Further research will be necessary to replicate these findings under different circumstances, to detect the effects of context and conflicting metaphors, and to refine the theoretical predictions. Much of the potential has not been tapped so far and many hypotheses are still hidden in the 250 metaphorical extensions that have been documented by cognitive linguists.

Because these metaphorical extensions are hypothesized to derive from correlations in basic sensorimotor experience, they should exhibit a high degree of universality across cultures. In a comprehensive survey of linguistic metaphors, Kövecses (2005) shows that metaphors about emotions, event structure, time, and the self are consistent across languages of different families (such as English, Chinese, Hungarian, Japanese, Polish, Wolof, and Zulu). Only minor variations occur, for example, in the word forms that are used (e.g., nouns instead of verbs) or in the different salience of parts of the metaphor. In our own studies (Hurtienne, 2009; Hurtienne, et al., 2009) participants with different native languages (Chinese, French, Polish, Spanish, Japanese) produced results that were not noticeably different from the majority of subjects whose mother tongue was German. Although such results are promising regarding the universality of conceptual metaphor in the HCI context, the issue awaits further study in the form of dedicated comparative studies.

Practicality

If image schemas are at the basis of much concrete and abstract thought, as the theory suggests, they might be usefully employed as a language to describe users' mental models, their tasks, and the user interfaces. Having established that image schema theory makes valid predictions, the concern now is how designers can use image schemas in their daily design work and how useful image schemas are. This section reviews previous research regarding a model of the human-centered design process, as proposed by ISO 13407 (International Organization for Standardization, 1999; see Figure 4). The process starts with a planning phase (goals, time, budget). Then the four core design activities are (a) understand and specify the context of use, (b) specify the user and organizational requirements, (c) produce design solutions, and (d) evaluate designs against requirements.

In the first phase of the cycle, the context of use typically is analyzed in situ. Characteristics of the task to be solved (including user goals), the current technological support, the characteristics of the target user group, and the general organizational context are analyzed. Several studies show that image schemas can be extracted from users' utterances, thus revealing parts of their mental models. Maglio and Matlock (1999), for example, analyzed users' mental models of the World Wide Web (WWW) using image schemas. Although the WWW is usually described as a *collection* of web sites (*locations*) that are connected via *links,* the users' utterances revealed many *self-motion*, container and *path* image schemas. The use of path metaphors increased in line with the participants' greater experience in using the WWW.

In other studies, the mental models of people were examined when navigating in airports (Raubal, 1997; Raubal & Worboys, 1999). Image schemas were extracted from the utterances

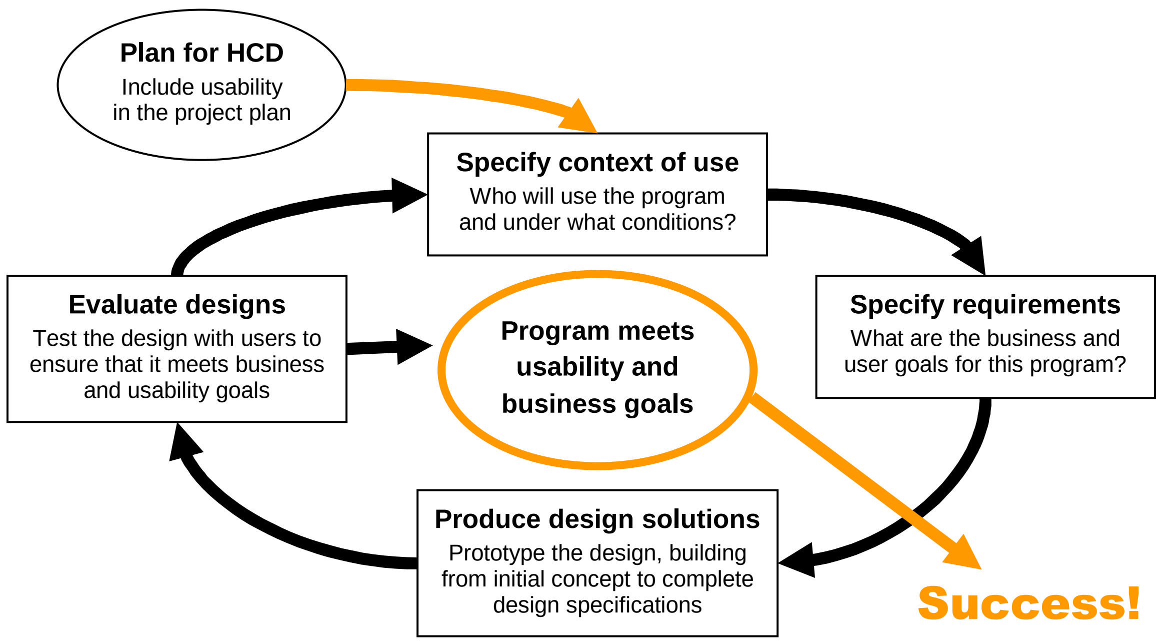

Figure 4. The human-centered design (HCD) process according to ISO 13407 (ISO, 1999).

the users made while finding their way through simulations of these airports. Image schemas could be extracted from almost all utterances of the participants, and suggestions for the redesign of the airport navigation system could be derived from the results by the researchers.

Image schemas were also used to analyze and describe user interface metaphors (Kuhn & Frank, 1991). Zooming, for instance, instantiates both a near–far image schema that mediates a *part–whole* image schema. Similarly, desktops and clipboards are instances of the *surface* image schema; and folders and trashcans instantiate the container image schema. The results of a large number of image–schematic analyses, for example, of airplane cockpits, ticket and cash machines, tangible user interfaces, business software applications, or software widgets, have been collected in a database called ISCAT (Image Schema CATalogue; Hurtienne, Weber et al., 2008). The database was built to provide designers with examples of image schema uses and their effects on the usability of products.

Image schemas and their metaphorical extensions also have been proven effective in the design phase of prototypical applications. One application, SchemaSpace (Lund, 2003), is a collection of WWW bookmarks organized in a hierarchy (Figure 5). Semitransparent cones in an information landscape represent different categories of bookmarks, thus drawing on the metaphor *categories are containers*. The more bookmarks there are in one category, the taller the cone is (more is up). The relevance of single bookmarks in a category is conveyed by the metaphor *important is central*. Connections between cones (link) indicate the relations between subcollections of bookmarks. Higher level categories are located higher in the landscape (e.g., on a hill) and lower level categories are located lower in the landscape drawing on the metaphor *abstract is up–concrete is down*. Finally, similar categories (cones) are located near each other and dissimilar items are located far from another (similar is near–different is far).

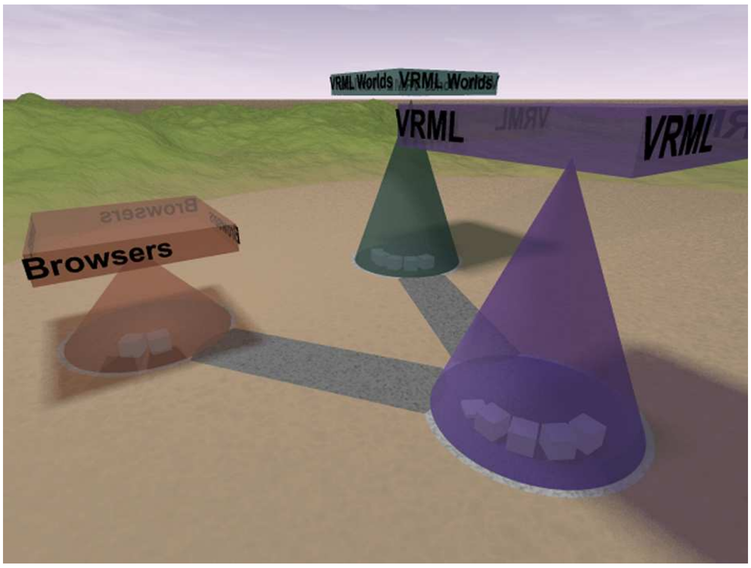

Figure 5. SchemaSpace, a personal information browser, illustrating the image-schematic metaphors categories are containers, more is up and connectedness is linkage (Lund, 2003, p. 150; used with permission).

The SchemaSpace prototype was evaluated by a number of users who solved information finding tasks; the same users also solved the same tasks with an information-equivalent hypertext prototype (Lund, 2003). The results showed that the SchemaSpace prototype elicited significantly more comments containing the image schemas center–periphery, container, link, near–far, part–whole, path, and up–down than the hypertext prototype. The hypertext prototype, in contrast, elicited only more comments containing the image schema surface. The author concluded that implementing metaphorical instantiations in user interfaces profoundly influences how users think about the interface.

The first application of image schemas covering all phases of the user-centered design cycle (i.e., from the context-of-use analysis via requirements specification, producing design solutions and evaluation) has been done in the redesign of a business application for accounting (Hurtienne, Weber et al., 2008). Image schemas were used to gather requirements from a context-of-use analysis of task steps, current user interfaces, and interaction steps, as well as the users' utterances. The strength of the image schemas was that they allowed a direct translation of requirements into design solutions.

For instance, in thinking aloud, users' often used front–back relations to describe their use of additional information, such as lists of contact persons in the company or additional order information. However, the current system presented this information either in left–right fashion on different monitor screens or *split* the information into several containers that had to be accessed separately. Consequently, putting any supplemental information into one container in a position behind the main screen (front–back) was posed as one of 29 image–schematic requirements.

It showed that image schemas were able to prescribe the structure of the interface without constraining the creativity of the designer in how image schemas become instantiated. For example, if main and supplementary information should be shown as an instance of the front–back image schema, the designer is free to creatively develop different forms of front–back appearance (Figure 6). Concrete design solutions were developed in the same way for other image–schematic requirements and the most suitable solutions were selected and combined to form the complete user interface concept. To show the flexibility of image–schematic requirements, the same set of requirements was used to develop a graphical user interface solution (Hurtienne, Weber et al., 2008) and a tangible user interface (Hurtienne, Israel, & Weber, 2008). In the subsequent evaluation with users, both solutions were rated as significantly higher in hedonic and pragmatic quality compared to the current solution.

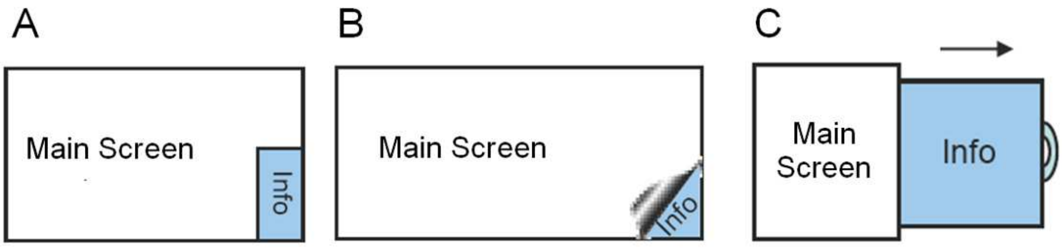

Figure 6. Design variants of front-back arrangements of main (front) and supplementary information (back).

SUMMARY: WHAT HCI CAN LEARN

First, although originating from research in cognitive linguistics, many image schemas and their metaphorical extensions are also valid within a user interface design context. Metaphorical extensions can provide design rules that were unknown until recently. They can point out the limits of current design principles, like the proximity compatibility principle and provide alternative explanations instead.

Second, as the practicability studies show, image schemas enhance insights during a user-centered design process. They allow the description of tasks, mental models, requirements, and design solutions to be conceived in a common language. They facilitate the transfer from requirements to design solutions by providing the structure of the prospective user interface.

Third, analyzing image schemas in user interfaces may lead to insights into implicit design rules and can help make them explicit. For instance, specific interactions and dependencies between image schemas emerged during the analyses for the ISCAT database. Among these are

- rules of image schema co-occurrences (e.g., *blockage* needs to be followed by *restraint removal*; *attraction* is resulting in *diversion*);
- image schema transformation rules (e.g., up–down is readily substituted by front–back relations); and
- typical problems (e.g., user interface elements that belong to the same task are often far away from each other without communicating their relation via a link or a common container image schema).

Fourth, there are a number of metaphorical extensions that are able to capture the “softer” aspects of human–computer interaction. Because computers today are increasingly used as tools for human–human communication, aspects such as social relationships, emotions, and personality traits need to be expressed through user interfaces. Metaphorical extensions of image schemas show how this could be done. Metaphors—*social relationships are links, intimacy is closeness, sinning is diversion from a path, affection is warmth, desire is attraction, intelligent is bright*, or *problems are heavy*—point to interesting ways on how one could build user interfaces for intangible domains of use.

Finally, image schemas have been used for building graphical and tangible user interfaces alike. This shows that they are flexible enough to be useful also for designing newer forms of interaction. Indeed, my present research extends the application of image schemas towards the design of haptic force-feedback interaction employing the group of force image schemas.

CONCLUSION

Cognition certainly is not and will not be the only discipline contributing to HCI. This review shows at least two contact points to the other schools of thought.

One point of contact with ergonomics and human factors engineering is the concept of population stereotypes. Population stereotypes describe ways in which people, often subconsciously, expect user interface elements to function. The ergonomics literature, however, documents only a few population stereotypes that were derived from user surveys. With image schema theory, however, the current number of documented stereotypes can be increased tenfold with known metaphorical extensions. This number may even be higher with further analysis (Hurtienne et al., 2009) inspired by the theory.

Another point of contact is with applications of third-wave HCI. Metaphorical extensions of image schemas provide a way to map the abstract realms of emotion and experience, which are more important in nonwork user interfaces, to spatial and physical properties of user interface elements. In the discussion of the validity, it has been shown that design with image schemas can enhance classical measures of effectiveness, efficiency, and satisfaction, as well as convey aesthetical attributes (van Rompay et al., 2005). Other studies have shown that image schemas are easily applied to third-wave user interface paradigms such as tangible interaction. Indeed, the image schema language is general enough to be useful in the design of other user interface styles as well (including artistic installations that intentionally violate common image schema usage).

Finally, this review shows that new theories of embodied cognition, when applied to HCI, can make cognitive science productive and interesting again. Cognition can still deliver theories with concrete predictions on what will be useful in design, methods that can readily be applied to the design process, and concrete design rules. As long as cognitive science develops, and someone in HCI listens, the story may go on.

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