Role of Prior Knowledge in User Interface Design: How Metaphors Help and Hinder the Adobe Photoshop CS6 Graphic User Interface

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Introduction

Human cognition involves a number of highly interrelated mental operations, including perception, attention, and memory (Anderson, 2005). These operations are influenced by both bottom-up, data-driven mechanisms and top-down, conceptually-driven processing (Mcmains & Kastner, 2011). Top-down processing utilizes an individual's expectations—developed through past experience and formal education—to efficiently process and understand the world (Gazzaniga, 2004). Termed "prior knowledge," this experiential and semantic information is stored in long-term memory, where it can be retrieved for future use (Hurtienne & Langdon, 2009). Prior knowledge facilitates the learning of new systems and, when incorporated into product design, can make an interface simpler and easier to use (Hsu, 2006). If a user lacks the prior knowledge and, therefore, mental model, with which to interact with a product, they will simply apply the closest fit available (Wilson & Rutherford, 1989). This mental model may or may not be appropriate, accurate, or complete (Johnson-Laird, 1989; Norman, 1983). Therefore, designers have a responsibility to create supportive interfaces that utilize prior knowledge and guide the user to either apply, or create, the appropriate mental model. One tool for accomplishing this is the metaphor (Lakoff & Johnson, 1980; Carroll & Thomas, 1982).

This paper will discuss the role of prior knowledge in user interface design, beginning with an overview of human information-processing theory and memory systems. Various theoretical models of knowledge storage, organization, and retrieval will be reviewed. The paper will then discuss how metaphors can be utilized to harness prior knowledge, and will evaluate their usage in the main tool bar of the Adobe Photoshop CS6 GUI (Figure 1).

Figure 1

Adobe Photoshop CS6 GUI. Main toolbar outlined in red (left). Detail view of select icons (right)

Information-Processing Theory and Memory Systems

Modern cognitive psychology took form during the cognitive revolution of the 1950s, 60s, and 70s (Anderson, 2005). Psychologists cast aside behaviorism in favor of information theory, which posited that humans process, rather that merely respond to, stimuli (Ashcraft, 1998). This information-processing approach was further influenced by the development of artificial intelligence, prompting many cognitive psychologists to draw parallels between the structure of the brain and that of computers (Anderson, 2005).

Information-processing theory divides memory into three systems: sensory memory, working or short-term memory, and long-term memory (Wickens, 2004). While sensory and working memory can only hold and process respectively large and small amounts of information for only brief periods, long-term memory is capable of storing unlimited amounts of information indefinitely (Cowan, 2001; Baddeley, 1990; Norman, 1968). It is here where knowledge is stored, organized, and retrieved (Wickens, 2004).

Long-term memory is classified as declarative, which involves the conscious or explicit retention of information (e.g. a social security number), or nondeclarative, which is implicit or unconscious (e.g. how to button a shirt) (Buckner and Schacter, 2004; Squire, Clark, and Bayley, 2004). While nondeclarative memory includes forms of perceptual and motor memory, declarative memory refers to facts and personal experiences (Squire & Zola-Morgan, 1988). As such, declarative memory can be further classified as either semantic (i.e. memory of general conceptual and world knowledge) or episodic (i.e. memory of events and personal experience) (Tulving, 1993). It is useful to note that many believe semantic knowledge is derived from episodic memory, such that humans can learn new concepts as a result of their personal experiences (Ashcraft, 1998).

Representations of Conceptual Knowledge in Long-term Memory

Since the neurological underpinnings of higher cognitive processes, such as memory, are highly complex and have yet to be fully understood, cognitive psychologists have proposed a number of theoretical models to explain the structure and retrieval of knowledge (e.g. Rumelhart and Ortony, 1977; Schank & Abelson, 1976; Collins & Quillian, 1969; Craik, 1943). These include schemas, scripts, semantic networks, and mental models. While the specifics of these models vary, they are linked by the common assertion that knowledge is stored in associative networks that tend to be highly organized, deeply interconnected, and constantly evolving (Sternberg, 1996; Anderson, 2005).

Schemas and Scripts

Two well-known frameworks for knowledge organization are schemas and scripts (Rumelhart and Ortony, 1977; Schank & Abelson, 1976). Introduced by Bartlett (1932) and popularized by Piaget (1952), schemas are cognitive frameworks that enable multiple elements to be grouped as a single conceptual unit (Sweller, 2005). Scripts are a subclass of schema and describe sequences of actions, such as how to check into a hotel (Schank & Abelson, 1976).

If a new experience fits within an existing schema, it is incorporated or assimilated into that conceptual unit (Mayer, 1981). Alternatively, if a new experience violates expectations formed through past experience, and cannot fit within an existing schema, a new schema is created to accommodate it (Anderson, 2005). It is through these processes of assimilation and accommodation, the hallmark of Piaget's constructivist theory, that humans learn and construct new knowledge (Mayer, 1981; Piaget, 1952).

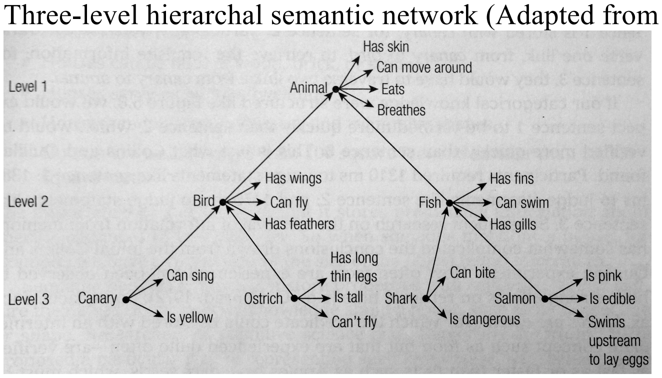
Semantic Networks

Schemas can also be organized into larger networks of interrelated concepts called semantic networks (Collins & Quillian, 1969). In semantic networks, knowledge is represented as a network of highly interconnected nodes, each of which can resemble a specific concept, word, or feature (Ashcraft, 1998; Collins & Quillian, 1969). Related nodes are linked via pathways, which communicate associations between ideas (Anderson, 1990). Activation of one node spreads to connected nodes, strengthening those associations in a process known as spreading activation (Collins & Loftus, 1975). As the activation signal spreads, it becomes weaker and more diffuse (Collins & Loftus, 1975). Additionally, activation decays over time, such that activated nodes will eventually return to a baseline level of inactivity (Ashcraft, 1998). In this way, semantic networks mirror the neural networks of the brain (Solso, MacLin & MacLin, 2005).

The semantic network model is also compatible with theories around knowledge retrieval wherein the ease with which a concept can be retrieved from long-term memory is determined by its strength and associations (Wickens, 2004). The more frequently or recently a concept is or was activated, the greater its retrieval strength and the easier it can be recalled (Kluge, 2014). Similarly, the greater the number of connections or associations a concept shares with others, the easier it is to retrieve (Kluge, 2014). While the number and diversity of the connections between concepts can positively impacts retrieval, it can also result in a slower rate of spreading activation, known as the fan effect (Anderson, 1974).

Figure 2

Three-level hierarchal semantic network (Adapted from Collins & Quillian, 1969)



The Teachable Language Comprehender (TLC) proposed by Collins & Quillian (1969) is one example of a hierarchal semantic network (Figure 2). Properties that are true of each category (e.g. has wings, can fly) are associated with that category (e.g. bird), while properties that are true of higher level categories (e.g. breathes) are also true for lower level categories (e.g. canary) (Collins & Quillian, 1969). Collins & Quillian (1975) later revised this model to incorporate weighted pathways, so as to account for the fact that humans respond faster to questions regarding more typical vs. atypical categories.

Mental Models

Mental models are schemas of dynamic systems, which describe a system's components, operation, and interaction possibilities (Wilson & Rutherford, 1989). Though Johnson-Laird (1989) is often credited with coining the term, mental models can be traced back to Craik (1943) who posited that humans construct mental models in order to hypothetically explore real world scenarios (Neressian, 2007). When human-computer interaction emerged as a field in the 1980s, mental models expanded beyond processing models of the mind—the primary area of interest for cognitive psychologists at the time—to models focused on how users interact with systems (Coovert, 1987). Norman (1983) was a major force in developing models for user interaction, distinguishing between the user's model of the target system, the system's model of the user, the conceptual model held by the target system's designer, and the designer's model of the user's model, which can be informed by user research (Van der Veer & Puerta Melguizo, 2003). The conceptual model, according to Neale & Carroll (1997), should demonstrate an understanding of the user's task, prior knowledge, requirements, capabilities, and limitations.

While the types of mental models vary, the key takeaway is that users do not come to a product with a blank slate, but rather apply their own, existing mental models, which are based on prior knowledge (Sease, 2008). When designers create products that map directly to a user's existing model, this can result in an intuitive but, sometimes, restrictive design (Condon, Perry & O'Keefe, 2007). They can also design for extreme innovation, which often propels product design forward (e.g. the iPod) (Sease, 2008). However, this type of design exerts higher cognitive load demands on the user, who must learn the new technology without the benefit of prior knowledge (Way, 1991). Alternatively, and the route often taken, designers can bridge the product's conceptual model with the user's model through the use of metaphor (Sease, 2008).

Metaphor

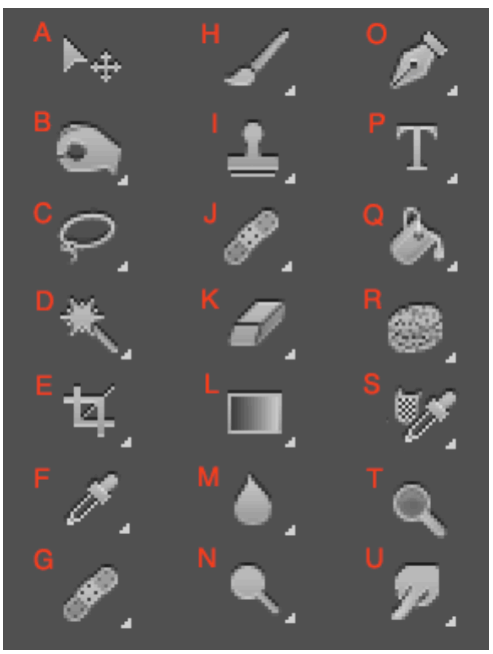
Discussed at length by Lakoff and Johnson in their classic 1980 book, metaphors transfer knowledge from a familiar domain to an unfamiliar one, enabling humans to use prior knowledge and experience to understand novel concepts (Holyoak & Thagard, 1995; Lakoff, 1994). According to Richards (1936), metaphor consists of four components: where it is taken from (the vehicle), what it applies to (the tenor), the common factors between the two (the ground), and the effort demanded to match one to the other (the tension). Metaphors allow a user to map information known about the vehicle onto the tenor, providing the user with a level of knowledge and comfort without them necessarily comprehending the underlying system (Paivio, 1979; Barr, Noble, & Biddle, 2003). As such, metaphors have the potential to significantly improve product usability or, as in the case with the desktop metaphor in computing, revolutionize an entire industry (Carroll, Mack & Kellog, 1988). However, when metaphors are misapplied, they can project misleading attributes or restrictions onto the tenor, limiting the product's functionality as well as confusing and frustrating users (Carroll & Thomas, 1982; Sease, 2008). For that reason, metaphors must be thoughtfully and skillfully deployed.

Design Evaluation of Adobe Photoshop CS6 Graphic User Interface

Adobe Photoshop CS6 is a popular brand of digital imaging software used by both consumers and photo/design professionals alike. Due to its impressive functionality and large number of tools, Photoshop must utilize the limited screen real estate wisely. To this end, graphical icons are employed throughout the user interface, particularly in the main tool bar, which contains many of the most essential editing tools (Figure 3). These icons rely on visual metaphors, the majority of which resemble real-life objects and artist tools. These visual metaphors operate with varying degrees of success, particularly when analyzing them from the perspective of the average consumer, who may lack prior knowledge about traditional photography tools and practices.

Figure 3

Select metaphorical icons in Photoshop GUI



Among the successful GUI metaphors are those that are not only visually recognizable, but map well from vehicle to tenor, aligning with the user's prior knowledge and expectations. For instance, both the paintbrush (Figure 3H) and paint bucket (Figure 3Q) resemble their tangible counterparts and function similarly to how they would in the real world. The paint brush can be used to apply strokes of color, while the dripping paint can, angled as if to splash paint onto a metaphorical wall, may be used to apply color in large volumes. Though both tools are "painting" in pixels rather than paint, the metaphors succeed in communicating the icons' respective uses.

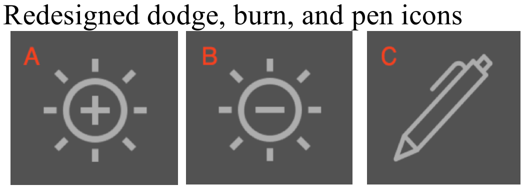
Other GUI metaphors, such as the arrow (Figure 3A) and letter "T" (Figure 3P) have been repurposed from different, but related environments (e.g. word processors). These conventionalized metaphors succeed in Photoshop since they are ubiquitous in computing and are familiar to most users. Additionally, they operate exactly as they would in other contexts (i.e. the arrow can be used to select and drag objects while the "T" enables text insertion). Utilizing previously established metaphors can be advantageous, since designers can capitalize on prior learning, "saving" the user cognitive effort which can then be applied elsewhere (e.g. learning a novel icon such as the magic wand selection tool (Figure 3D), which has no real-world equivalent.

While some GUI metaphors map well from vehicle to tenor, they are ultimately less successful due to their visual ambiguity. For instance, the function of the sponge icon (Figure 3R) mirrors that of an actual sponge, absorbing color when applied to an image. However, since the icon itself is visually ambiguous, the user must consider both prior knowledge stores and context in order to identify it (e.g. Photoshop is a brand of artistic software, so this circular block, dotted with holes is likely a sponge, not a scone). This can result in misidentification and error, as well as exert unnecessary cognitive load on the user. While hovering over the icon will trigger a lexical prompt with the icon's name to aid identification, designers should not solely rely on these prompts as they can undermine the visual economy of using icons, and call the suitability of certain visual metaphors into question.

Other GUI metaphors fail due to bad mapping, in which misleading characteristics are attributed to the tenor, based on prior knowledge of the vehicle. One example of this is the band-aid icon or healing brush tool (Figure 3G). For many users, a band-aid implies healing and repair. To this end, one might expect the healing tool to function much like an "undo" button in a word processor. However, the actual function of the healing tool is to sample parts of an image and meld them with the areas to which the tool is applied. So, contrary to what the metaphor may suggest, the tool does not restore a prior state but rather creates a new and different one. The tool, therefore, possesses functionality different from, and beyond, that of a "healing band-aid." However, due to the misapplied metaphor, this is not apparent to the user. If a more appropriate metaphor cannot be found, the best route might be to design a novel icon and term, which the user can learn. While this would initially demand cognitive effort, in the long-run, it could be beneficial to both the user and the product as a whole.

Figure 4

Redesigned dodge, burn, and pen icons



Lastly, some GUI metaphors fail due to their reliance on specialized, prior knowledge. One example of this is the dodge icon (Figure 3N). The dodge icon is rendered as a traditional dodge tool (i.e. a circular piece of cardboard attached to a wire) used in photographic dark rooms to selectively limit light exposure to sections of light sensitive, photo-printing paper. Dodge tools essentially enable photographers to consciously "lighten" sections of a photo print. While the metaphorical dodge icon functions similarly, it requires prior knowledge to understand. Also, since traditional photo dark rooms have become a rarity with the advent of digital processing, the percentage of users able to correctly identify the name and purpose of this icon is likely small. The same holds true for the burn icon (Figure 3B), which is used to darken sections of a photo and mirrors the way a photographer would shape their hand in order to "burn" sections of a photo in a traditional darkroom. A better solution would be to generate new icons that clearly communicate their utility and draw on more general semantic knowledge (Figure 4A & B). One could further justify this redesign by virtue of the metaphorical representations being out of date (i.e. darkrooms are mostly a thing of the past). This could also be said of the dated visual representation of the pen tool (see Figure 3O for original, 4C for redesign), which bears little resemblance to the gel and rollerball pens commonly used today.

Conclusion

Prior knowledge has a profound impact on cognition, enabling humans to make predictions and efficiently process, understand, and learn new information (Gazzaniga, 2004). Theoretical models of how this knowledge is stored, organized, and retrieved in long-term memory differ in structure, yet share common features, such as high levels of organization, interconnectedness, and adaptability (e.g. Rumelhart and Ortony, 1977; Collins & Quillian, 1969; Johnson-Laird, 1989).

When a user encounters a new interface, they search their long-term memory for an appropriate model with which to interact with the system, based on prior knowledge (Wilson & Rutherford, 1989). While prior knowledge has been shown to positively influence the rate and accuracy of learning new systems, the mental models constructed from it are sometimes inaccurate or incomplete (Murphy & Medin, 1985; Schank, Collins, & Hunter, 1986; Johnson-Laird, 1989). Therefore, designers must carefully consider the role of prior knowledge when designing an interface, and guide the user to either apply or create the appropriate model. One tool for harnessing this knowledge is the metaphor (Lakoff & Johnson, 1980).

Photoshop successfully employs metaphor in select sections of its graphic user interface (e.g paintbrush and arrow). However, more often than not, the visual metaphors in the main tool bar merit visual clarification (e.g. sponge icon), updating (e.g. pen), or complete abandonment due to poor mapping (e.g. healing/band-aid tool) or the need for specialized prior knowledge (e.g. dodge & burn). When Adobe designs the next iteration of this popular software package, it should carefully evaluate the use of visual metaphor, balancing metaphor usage with innovation, which may ultimately lead to better product performance and usability.

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