

CE 536 - Human-Computer Interaction

Lecture #2

HCI Foundations:

Information Processing, Language, Mental Models, Human Factor

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Fundamentals

- The most fundamental assumption of the information-processing approach is that the human is a complex system that can be analyzed in terms of subsystems and their interrelation (Posner, 1986).
- Human factors and ergonomics (HFE) in general, and HCI in particular, begin with the fundamental assumption that “a human-machine system can be decomposed into machine and human subsystems, each of which can be analyzed further”.
- Young et al. (2004) emphasized that the most basic distinction between three processing stages (***perception, cognition, and action***), as captured in a block diagram model of human information processing, is important even for understanding the dynamic interactions of an operator with a vehicle for purposes of computer-aided augmented cognition.

Information Processing

Information-processing Methods

- Chronometric Methods
- Speed-accuracy Methods
- Psychophysiological And Neuroimaging Methods

Chronometric Methods

- Time-based, or chronometric, methods are the most widely used tools for studying human information processing.
- Thus, it is not surprising that reaction time (RT) has been the main dependent measure of the information processing approach (Lachman et al., 1979).
- Although many other behavioral, physiological, and neural measures are used, RT still predominates because of its sensitivity and the sophisticated techniques that have been developed for analyzing and modeling RT data.

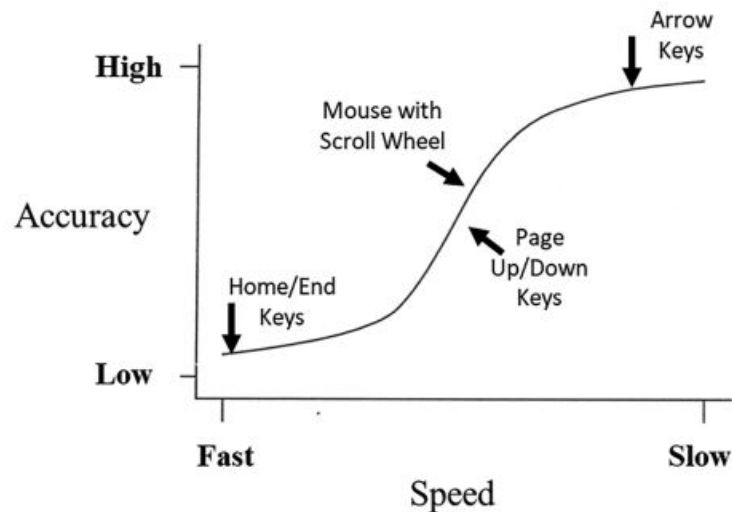
Speed-accuracy Methods

- The function relating response speed to accuracy is called the speed-accuracy tradeoff (Heitz, 2014; Pachella, 1974).
- For example, if the task is to scroll down a document to find an anomaly (see Figure 3.1a), the use of different input devices can yield different performances with respect to speed and accuracy.

Task: Scroll down the pages of this long document to find a gap in the line.



(a)



(b)

FIGURE 3.1 (a) Task of scrolling through pages of a document to find a gap in the line using four different input methods to navigate: home/end keys, page up/down keys, mouse/scroll wheel, and up/down arrow keys. (b) Speed-accuracy operating characteristic curve with where performance is estimated to be with the different navigation methods. Fastest task completion is expected to occur with the use of the home/end keys at the cost of lowest accuracy.

Psychophysiological And Neuroimaging Methods

- Psychophysiological and neuroimaging methods have been increasingly used to evaluate the implications of information-processing models and to relate the models to brain processes. This area of research is called **cognitive neuroscience** (Gazzaniga et al., 2019).
 - Such methods can provide details regarding the nature of processing by examining physiological activity as a task is being performed.
- Although imaging techniques have been increasingly used, a psychophysiological method that involves the measurement of electroencephalograms (EEGs) is still widely used.
- EEGs are recordings of changes in brain activity as a function of time as measured from electrodes placed on the scalp (Mangun, 2014).
 - Different frequency bands of EEG rhythms are correlated with subjective states and the processes underlying task performance.

Information Processing Stages

- Information processing can be studied using choice-reaction tasks in which each stimulus is assigned to a unique response to examine the effects of variables on three stages of processing: **stimulus identification**, **response selection**, and **response execution** (Proctor & Vu, 2023).
 - The stimulus-identification stage involves perceptual processes that are primarily dependent on stimulus properties.
 - The response-selection stage concerns cognitive processes involved in choosing which response to make to each stimulus.
 - Response execution refers to motor processing involved in programming and execution of motor responses. Of relevance to HCI, several principles and laws capture how human information processing is influenced by the task environment and task demands.

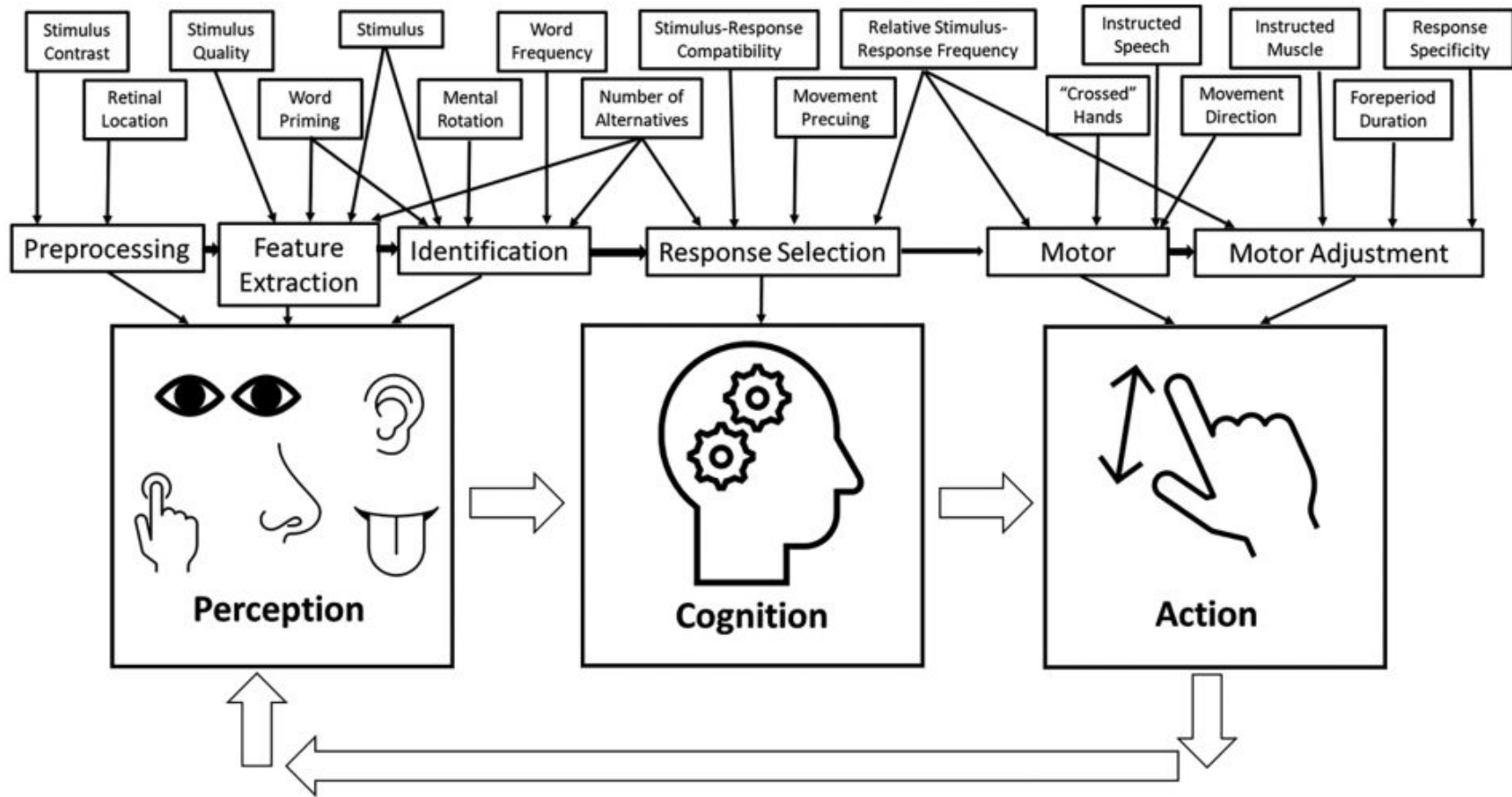


FIGURE 3.2 Information-processing stages and variables that affect them, based on Sanders' (1998) taxonomy.

Stimulus Identification

- The speed with which stimuli can be identified depends on several factors. As stimulus contrast, or intensity, decreases, reaction time (RT) increases.
 - For example, Miles and Proctor (2009) had participants make left and right key press responses to the non-spatial or spatial feature of centrally presented location words.
 - The discriminability of the spatial feature of the word, or of both the spatial and non-spatial features, was manipulated.
 - When the spatial feature of the word was task-irrelevant, decreasing the discriminability of this feature reduced the typical benefit for correspondence of the word meaning with the keypress response to the relevant stimulus feature.
 - This correspondence benefit was restored when the discriminability of both the task-relevant and task-irrelevant features was reduced together, slowing the processing of both the relevant and irrelevant information.
 - These results suggest that the reduction of discriminability slows the processing of the perceptual information but does not alter the response-selection processes that operate on that information.

Response Selection

- Response selection refers to those processes involved in determining what response to make to a particular stimulus.
 - It is affected by the number of alternatives, stimulus-response compatibility, and precuing (providing advance information about a forthcoming event).
- The influence of the number of alternatives on performance is captured by Hick's law, or the Hick-Hyman law, which states that RT increases as a logarithmic function of the number of stimulus-response alternatives (Hick, 1952; Hyman, 1953).

Response Selection

- For N equally likely alternatives, the following formula is used:

$$RT = a + b \log_2 N,$$

where a is the base processing time, and b is the amount that RT increases with increases in N .

Response Initiation and Execution

- Motor programming refers to the specification of the physical response that is to be made.
- This process is affected by variables such as **relative stimulus-response frequency** and **movement direction**.
- One factor that influences this stage is **movement complexity**.
 - Even in a simple RT task, the longer the sequence of movements that is to be made upon the occurrence of a stimulus, the longer is the RT to initiate the sequence (Henry & Rogers, 1960; Sternberg et al., 1978).

Response Initiation and Execution

- One of the most well-known relations for response execution is Fitts' Law (Fitts, 1954; MacKenzie, 2018), which describes the time to make aimed movements to a target location:

$$\text{Movement time} = a + b \log_2(2D/W),$$

where a and b are constants, D is distance to the target, and W is target width.

Memory

Memory In Information Processing

- Working memory (WM) refers to representations that are currently being used or have recently been used and last for a short duration.
- For many HCI applications, items in WM are often considered to be where the focus of attention is directed. In this view, because attention is a limited resource, WM is also limited in capacity.

Memory In Information Processing

- The best-known model of WM is that of Baddeley and Hitch (1974), which partitions WM into three main parts: **Central executive**, **phonological loop**, and **visuospatial sketchpad**.
 - The central executive is closely tied to the focus of attention, where information is being actively processed to achieve task goals.
 - For example, the central executive is involved in performing manipulations or computations on the items being held for processing, as well as in controlling and coordinating the actions of the two other subsystems, the phonological loop and visuospatial sketchpad.
 - The phonological loop is composed of a **phonological store** that is responsible for holding the to-be-remembered items and an **articulatory control process** that is responsible for recording verbal items into a phonological form and rehearsal of those items.
 - The items stored in the phonological store decay rapidly unless kept active by rehearsal from the articulatory control process.
 - The visuospatial sketchpad retains information regarding visual and spatial information, and it is involved in mental imagery and mental rotation.

Memory In Information Processing

- The WM model has been successful in explaining several memory phenomena (Baddeley, 2003).
 - However, the model cannot explain why memory span for visually presented material is only slightly reduced when subjects engage in concurrent articulatory suppression (such as saying the words “the” aloud repeatedly).
 - Articulatory suppression should monopolize the phonological loop, preventing any visual items from entering it.
- In this context, it means that if you're speaking or making sounds, your phonological loop is "busy," so you can't convert visually presented words (like written text) into verbal memory as easily.
- This makes it harder to remember visual items that you would normally process through inner speech.

Memory In Information Processing

- To account for such findings, Baddeley revised the WM model to include an **episodic buffer**.
- The buffer is a limited-capacity temporary store that can integrate information from the phonological loop, visuospatial sketchpad, and long-term memory (LTM).
 - By attending to a given source of information in the episodic buffer, the central executive can create new cognitive representations that might be useful in problem solving.

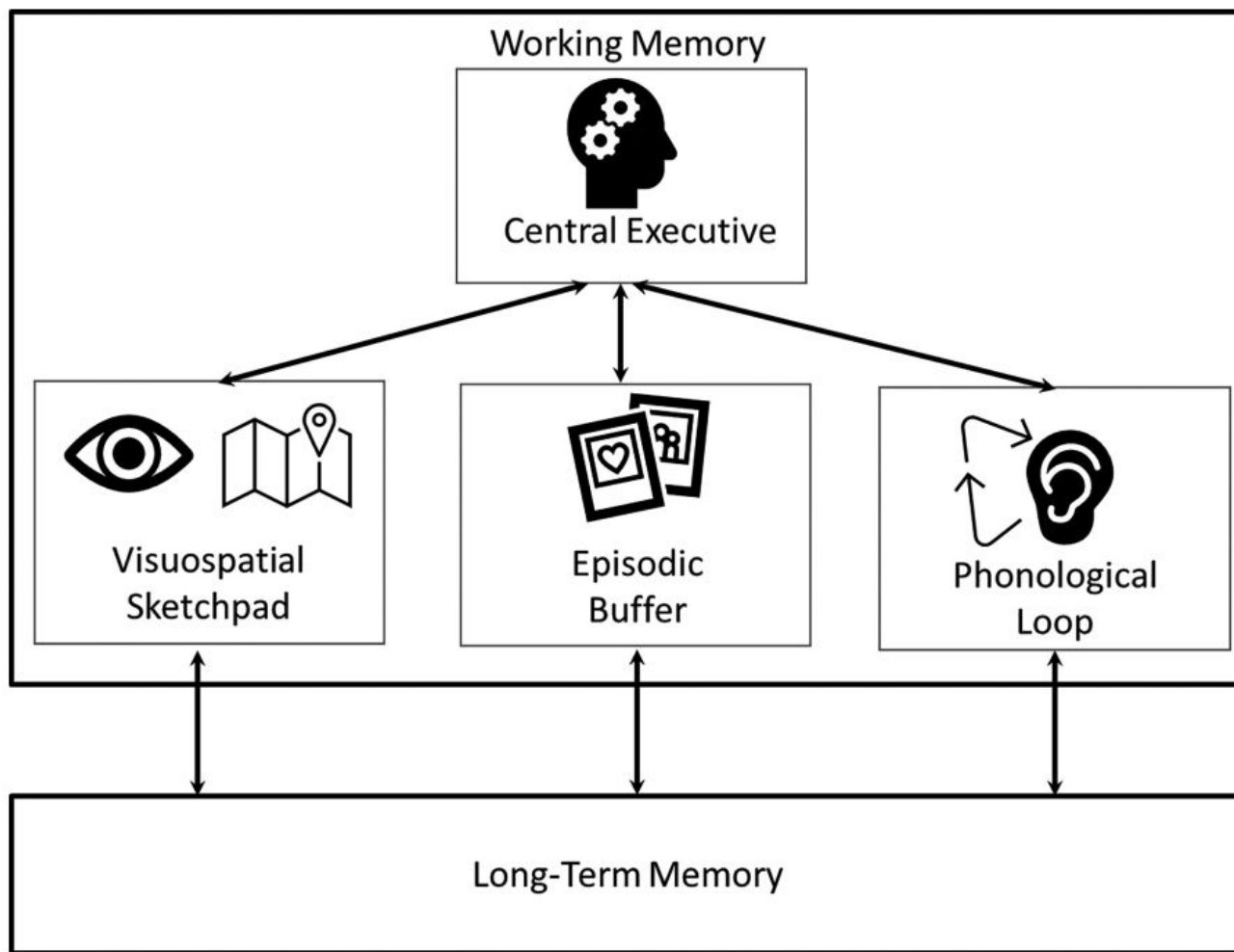


FIGURE 3.4 Depiction of Baddeley's (2000) revised working memory model.

Long-Term Memory

- LTM refers to representations that can be remembered for durations longer than those that can be attributed to WM.
- LTM can involve information presented minutes ago or years ago.

TABLE 3.1**Long-Term Memory Principles and Their Implications for HCI**

Principle	Description	Implications for HCI
Depth of processing	Items can be processed along a continuum of shallow to deep processing. The greater the depth of processing, the better the memory (Craik & Lockhart, 1972)	Repetition is not sufficient for good memory. Relating to be remembered items to prior knowledge can improve memory
Encoding specificity	The probability that a retrieval cue results in recollection of an earlier memory is dependent on the match between encoding and retrieval (Tulving & Thomson, 1973)	Memory is often context-dependent. If the encoding and retrieval environments match, memory can be improved
Transfer appropriate processing	Deep-level processing produces better performance than shallow on standard recall or recognition memory test. However, when the memory test required judgments based on visual features; shallow processing of visual features was more beneficial (Morris et al., 1977)	Retention will be evident to the extent that the procedures engaged in during study or training are reinstated at the retention test (Healy et al., 2005)
Spaced practice is better than massed practice	Massed repetition (repeating the same item in a row) is less effective than spaced repetition (repeating the same item with one or more intervening items; Hintzman, 1974)	With spaced practice individuals have the chance of determining which study strategies are more effective and can use those strategies to benefit memory (Bahrick & Hall, 2005)
Generation effect	Recall is better when participants have to generate the items that they need to remember rather than just studying them (Slamecka & Graf, 1978)	Have users generate passwords rather than assign a password to them (Vu et al., 2007)
Testing effect	Recall is better for items that were previously tested than new items (Karpicke & Roediger, 2008)	Provide intermittent quizzes for important information
Mnemonic techniques	Connecting the items to be remembered with an established organizational structure that can facilitate later recall (Wood & Pratt, 1987; Verhaeghen & Marcoen, 1996)	Passwords generated from a mnemonic technique can be more memorable (Vu et al., 2007)

Automaticity and Practice

- Attention and WM demands are high when a person first performs a new task. However, these demands decrease, and performance improves as the task is practiced.
- Because the quality of performance and attentional requirements change substantially as a function of practice, it is customary to describe performance as progressing from an initial cognitively demanding phase to a phase in which processing is automatic (Anderson, 1982; Fitts & Posner, 1967).
 - That is, when a user first learns a task, the individual must hold task components in WM and verbalize the steps (**declarative phase**).
 - As the user continues performing the task, the components become linked or connected through practice (**associative phase**).
 - Finally, after extensive practice, the steps are proceduralized and performed automatically, with little or no attention (**autonomous phase**).

Language

Language

- To introduce the discussion on language and communication in HCI, we begin with a semiotic definition of language (a language is a set of signs with defined selective and associative rules used to convey meaning) and refer to a pair of concepts in Structural Linguistics defined by de Saussure (2005): **langue** and **parole**.
- Roughly translated into English as “language”, a langue is an abstract system composed of conventional rules and signs; a parole (“speech”, in English), on the other hand, is a concrete oral or visual instance of the langue a person uses to express their thoughts.
 - Therefore, when one is talking about the language of computer interfaces, it is fundamental to specify whether the intended meaning refers to the abstract system of signs in computer interfaces (langue) or to the use of signs in a specific interface (parole).

Elements of Language

- The Phonological,
- The Morphological,
- The Syntactic,
- The Semantic, and
- The Pragmatic elements.

Elements of Language

- In a natural oral language, **Phonology** is the study of its sound system,
 - comprising the description of individual phonemes (abstract representation of a sound),
 - contrastive features (what differentiates the sound /p/ from the sound /b/, for example), and
 - the systematic phenomena of sound combination (such as the fact that the last sound of third person singular verb forms in English always sound as /s/ if the preceding sound is a voiceless consonant, as in “thinks”, “cuts” or “stops”, but they sound as /z/ if the preceding sound is a voiced consonant or a vowel, as in “begs”, “goes” or “loves”).
- A phoneme is the smallest unit of a language that can change meaning, although it does not have a meaning on its own

Elements of Language

The four possible alignments on the page are visually conveyed by iconic representations that differentiate from one another by contrastive traits: line lengths (short versus long) and distribution in the horizontal axis.



FIGURE 4.1 Phonological differences in Google Docs buttons.



FIGURE 4.2 Phonetic variations of the refresh button across different browsers.

Elements of Language

- **Morphology** is the study of word form and structure, focusing on the theoretical construct of morphemes, the minimal distinctive units of grammar (Crystal, 2008).
- In natural languages, morphology studies word formation and how grammatical categories such as number (singular, plural, etc.), verb aspects (simple, progressive, perfect, etc.), gender (masculine, feminine, etc.) and many others are expressed by morphemes.

Elements of Language

- Computer interfaces also convey meaning morphologically, that is, through systemic contrasts of meaning that arise from systemic contrasts of form.
- When it comes to buttons, the opposite meanings of “selected” and “not selected” may be expressed by opposite uses of color, as in “colored” and “not colored” in Google Docs buttons, as seen in Figure 4.3



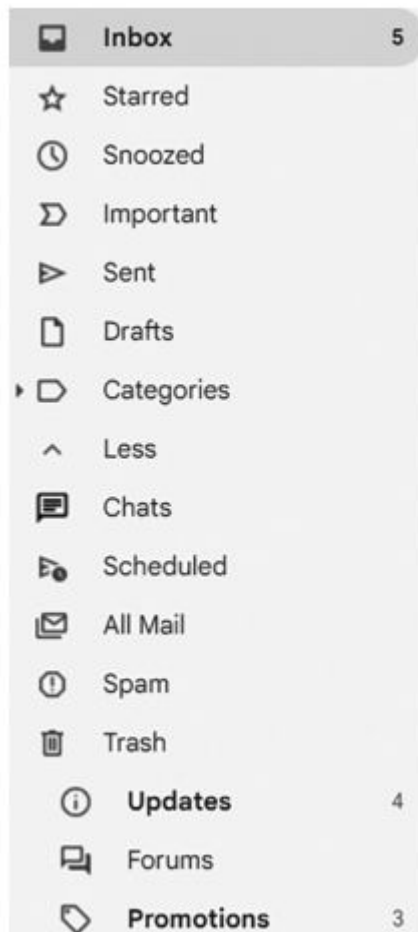
FIGURE 4.3 Morphological differences in Google Docs buttons.

Elements of Language

- In the Linguistics of natural languages, **Syntax** refers to the study of the combinatory rules of words within a sentence.
- Every language has its own constraints on word *order* (e.g., that subjects often come before verbs in English), *subordination* (e.g., that adverbs modify verbs, adjectives, and other adverbs, but not nouns in English), *agreement* (e.g., that adjectives do not take plural inflections in English even if they modify plural nouns, as in “blue cars”) and *collocation* (that a certain word can only take specific prepositions, as in “compare X to Y”, or “compare X with Y”, but not “compare X for Y” in English).

Elements of Language

- In computer interfaces, syntactic hierarchies of coordination (structures of the same level) or subordination (structures of different levels, in which there is a main structure and subordinate structures) are often expressed visually by means of alignment in the horizontal or vertical axis.
- In the figure, a Gmail screenshot shows that the alignment in the horizontal axis means that Updates, Forums, and Promotions are subordinate categories of Trash, whereas Trash is on the same level as (or coordinate with) Inbox, Starred, Snoozed, and others.



Elements of Language

- In Linguistics, **Semantics** can be broadly understood as the study of meaning, which borrows contributions from *Structural Linguistics* (as in mapping out meaning relations such as synonymy, antonymy, hyperonymy, etc.), *Logics* (as in truth conditions, and logical consequences of statements), and *Psychology* (as in highlighting cognitive processes underneath linguistic phenomena, such as metaphors or conceptual blending).
- In HCI, a Semantics-oriented approach sheds light on the well-known desktop metaphor (Hartson & Pyla, 2018), in which an image is drawn from a source domain very familiar to users (that of a physical office, with common objects and stationery on a desktop) to help conceptualize a more abstract domain (that of computer processes).
- These metaphors are both verbal and nonverbal, so that deleted files are moved to a folder called “trash”, and its visual representation is often an icon for an office trash can.

Elements of Language

- Finally, **Pragmatics**, the highest level linguistic stratum, is related to language in use in real contexts, especially focusing on the relation between the addresser, the addressee, and the message they get across considering the rules and constraints of different contexts of social interaction (Crystal, 2008).
- Among other discursive phenomena, Pragmatics studies deixis, the cooperation principle between speakers, the dynamics of conversation, speech acts, and implicatures (implicit information, more or less deducible from context or statements).
- As Pragmatics is, among the language levels herein presented, the one that is more often nowadays explored in the convergence between Linguistics and HCI.

Elements of Language

- **Deixis** is a linguistic term that refers to the indexical relation between more general words, especially adverbs and pronouns, such as “now”, “here”, and “he/she/they”, and specific references to time, space, or person in context (Hanks, 2017; Stapleton, 2017).
- Differently from nouns, adjectives, and verbs, which have intrinsic context-independent meanings that can be pinned down in dictionaries, such as in the noun “computer”, the adjective “computational”, and the verb “to compute”, adverbs and pronouns often point to temporal, spatial and/or personal references that vary in the context of real-time communication.
 - For example, if the chair of a conference says “I am happy to see you all here today” on November 15th, in New York, the pronouns “I” and “you”, and the adverbs “here” and “today” point out to entities different from the ones referred to by a high school teacher who greets their class in San Francisco on April 2 saying “I am happy to see you all here today”.
 - That is because the referents of these pronouns and adverbs are indexical.

Communication

Communication

- With the goal of improving the efficiency of telecommunication systems, Shannon (1948) defined a mathematical theory of communication involving the **transmission, reception, and processing of information**.
- Shannon and Weaver (1949) recognized three levels of communication problems:
 - **technical**, concerned with how accurately symbols can be transmitted (as signals);
 - **semantic**, concerned with how the transmitted symbols convey the desired meaning (i.e., the relation between the receiver's interpreted meaning and the sender's intended meaning); and
 - **effectiveness**, concerned with how effectively the received meaning affects conduct in the desired way.

Communication

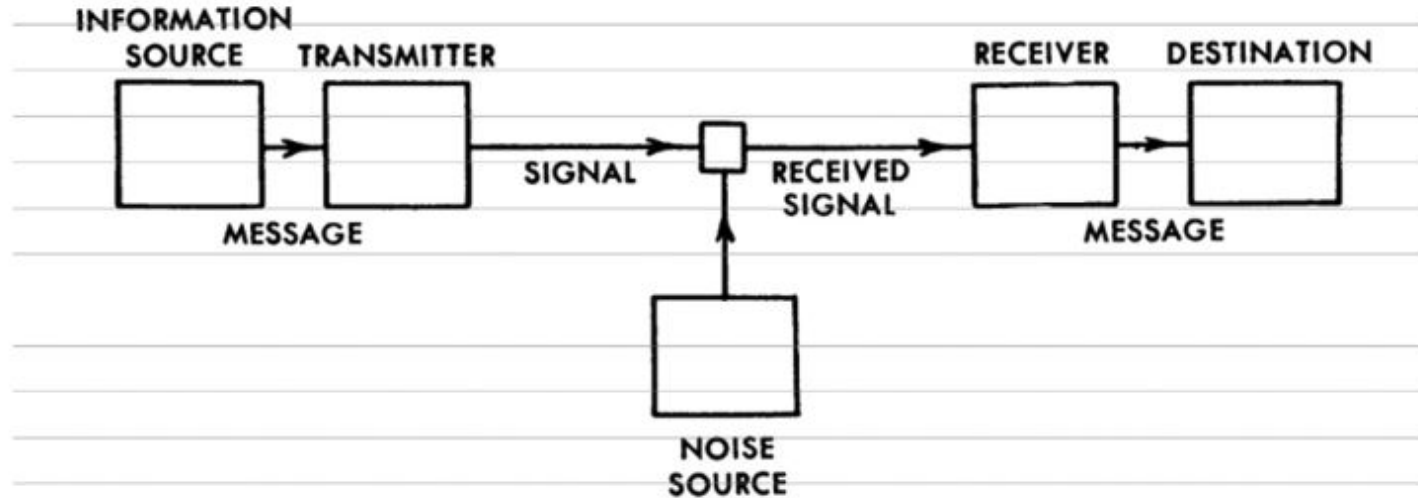


FIGURE 4.7 Schematic diagram of a general communication system (Shannon & Weaver, 1949, p. 34).

Communication: Jakobson's Language Functions



- When asked to relate poetics to linguistics, Roman Jakobson (1960) discussed six functions of language, based on a model of verbal communication that bears some superficial resemblance to Shannon's schema.

*“The **addresser** sends a **message** to the **addressee**. To be operative, the message requires a **context** referred to, seizable by the addressee, and either verbal or capable of being verbalized; a **code** fully, or at least partially, common to the addresser and addressee (or, in other words, to the encoder and decoder of the message); and, finally, a **contact**, a physical channel and psychological connection between the addresser and the addressee, enabling both of them to enter and stay in communication.”*

Communication: Jakobson's Language Functions

- Jakobson defines six functions of language, one associated with each of the factors in his model. He clarifies that messages usually fulfill more than one function, but that the messages' (verbal) structure depends primarily on a predominant function, as decided by the addresser.
- The language functions are the following:
 - **referential function**: focused on the context, describing a situation, object, or mental state;
 - **emotive (or expressive) function**: focused on the addresser, direct expression of the speaker's attitude toward what they are speaking about, tending to produce an impression of a certain emotion;
 - **conative function**: oriented to the addressee, as in vocative or imperative sentences;
 - **phatic function**: related to the channel, "serving to establish, to prolong, or to discontinue communication, to check whether the channel works, to attract the attention of the interlocutor or to confirm their continued attention";
 - **metalingual (or metalinguistic) function**: associated with the code, for instance, to check whether the addresser and addressee are using the same code; and
 - **poetic function**: focused on the message "for its own sake", on how something is said.

Semiotics: Signs, Signification, Communication, And Semiosis

- Semiotics investigates signs, signification, and communication processes (Eco, 1978). Peirce (1893–1913 (1998), p. 13) defines:

“A sign [as] a thing which serves to convey knowledge of some other thing, which it is said to stand for or represent. This thing is called the object of the sign; the idea in the mind that the sign excites, which is a mental sign of the same object, is called an interpretant of the sign.”

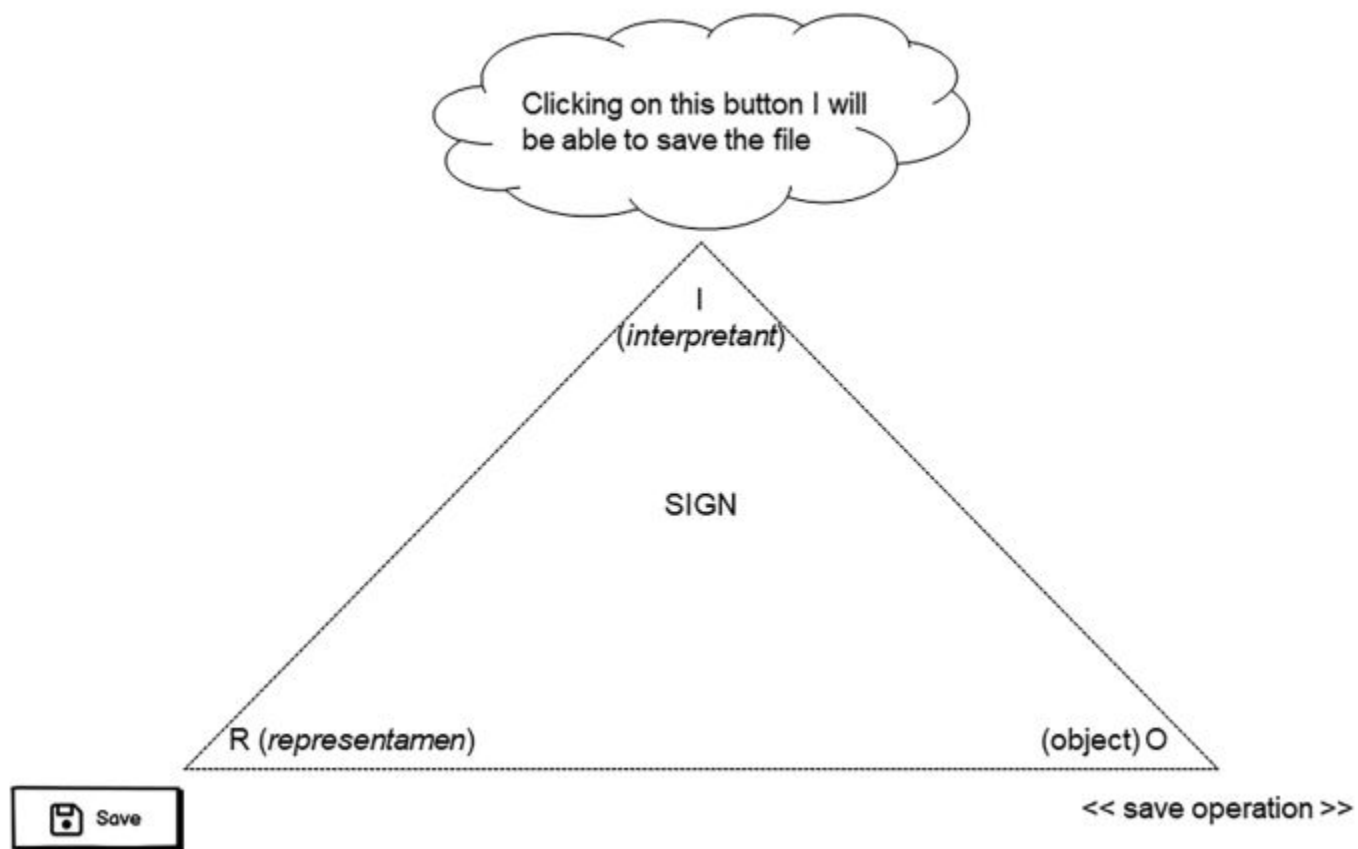
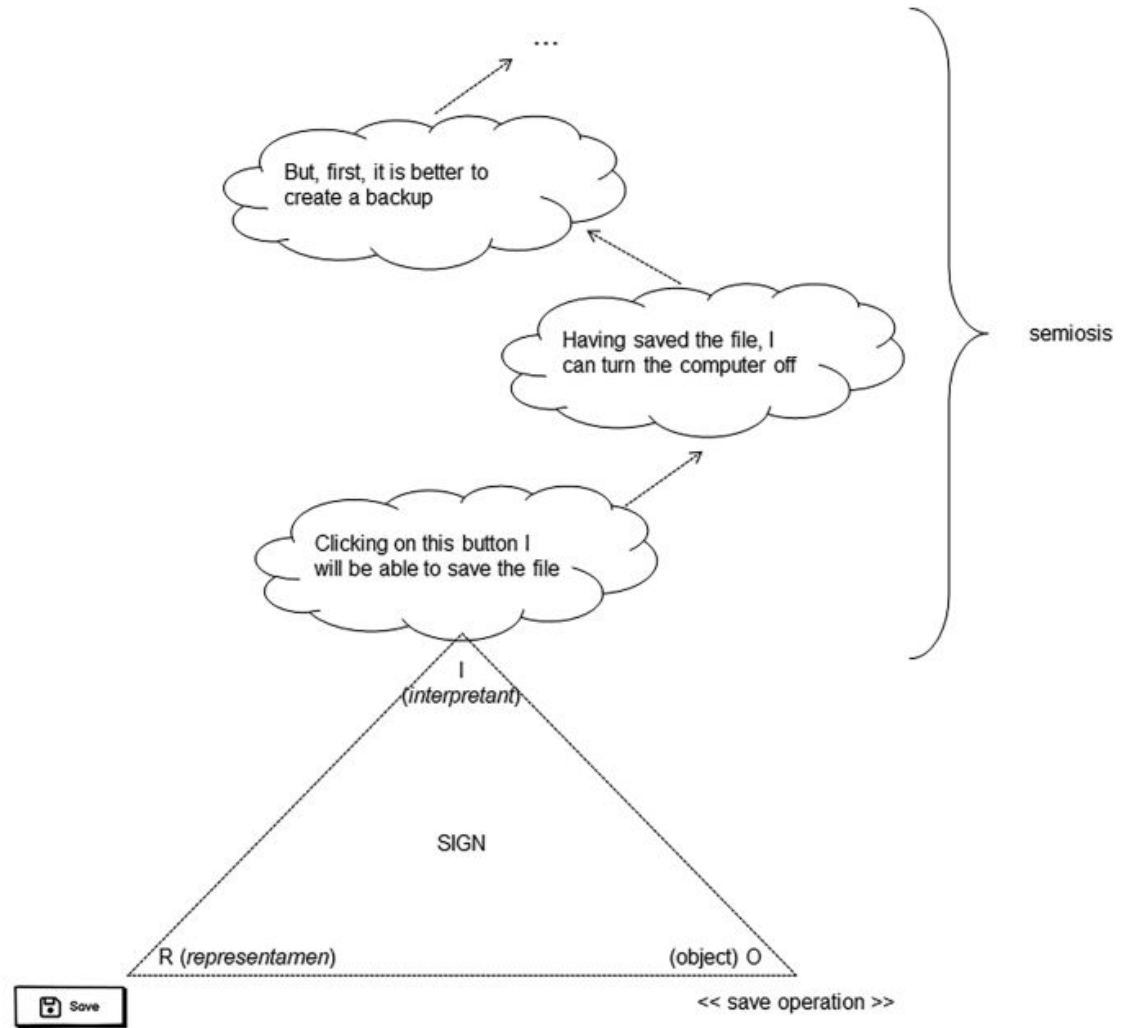


FIGURE 4.15 A sign that represents an operation of saving a document.

Example of semiosis, a chain of signs generated through interpretation processes.



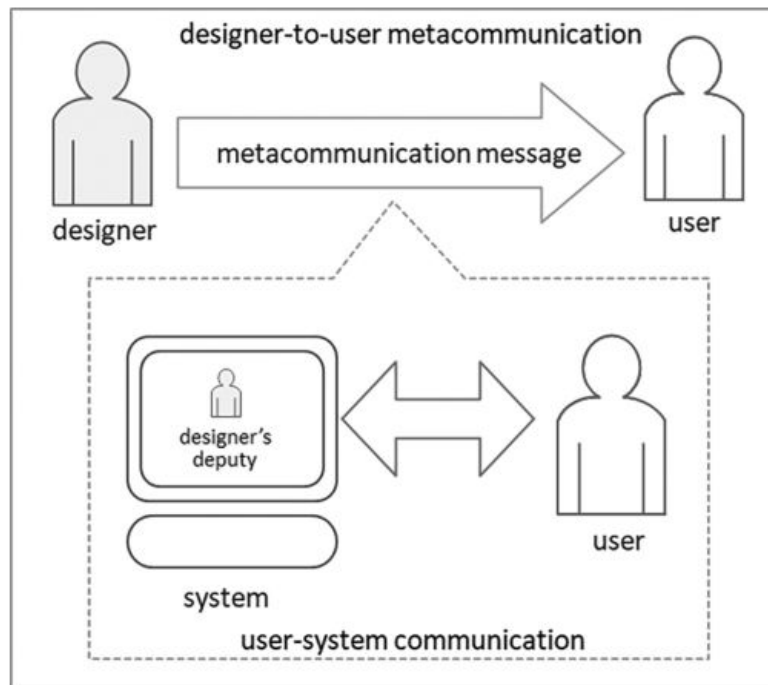


FIGURE 4.17 Designer-to-user metacommunication and user-system communication (interaction).

TABLE 4.1

Metacommunication Message Associated to Analysis and Design Activities

Analysis	Here is my understanding of who you are, what I've learned you want or need to do, in which preferred ways, and why
Design	This is the system that I have therefore designed for you, and this is the way you can or should use it in order to fulfill a range of purposes that fall within this vision

Semiotics: Signs, Signification, Communication, And Semiosis

- Semiotic Engineering asks the designer to answer the following questions about each element of the model (de Souza, 2005a, p. 87):
 - **Who is the sender (designer)?** What aspects of their own constraints, motivations, beliefs, and preferences should be communicated to the user for the benefit of metacommunication?
 - **Who is the receiver (users)?** What aspects of the user's constraints, motivations, beliefs, and preferences, as conceived by the designer, should be communicated to the actual users to support their role as the system's interlocutor?
 - **What is the context of communication?** What elements of the user's expected spectrum of interactive contexts (psychological, sociocultural, technological, physical, etc.) must be processed by the system's semiotic computations, and how?
 - **What is the communication code?** What computable codes may or must be used to support effective metacommunication? Should this include alternative, complementary, and redundant codes?
 - **What is the channel?** What channels of communication are available for designer-to-user metacommunication and how they should or could be used?
 - **What is the message?** What does the designer want to tell users, and to what effect i.e., what is the designer's communicative intent?

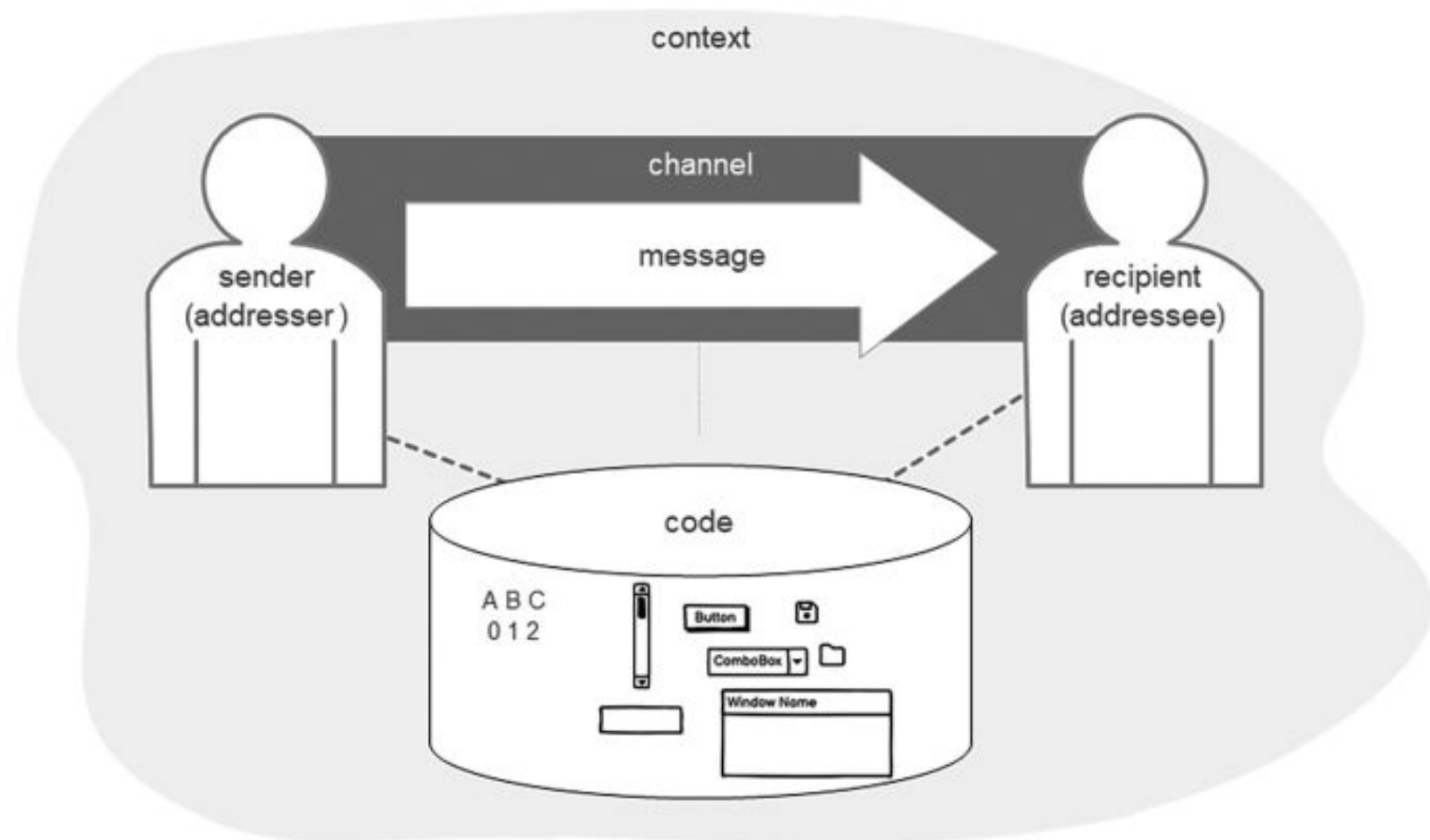


FIGURE 4.18 Semiotic Engineering's HCI design space (de Souza, 2005a, p. 65), based on Jakobson's model (1960).

Mental Models

Mental Models

- They are perceived as “a key and even a panacea for successful design and development” by many researchers and practitioners from the domain of human factors.
- Properly leveraging mental models can improve the user experience.
 - First, mental models help unveil the different understandings of IT among users, designers, software engineers, human factor analysts, and cognitive psychologists (Carroll & Olson, 1987).
 - Awareness of these differences might help improve collaboration among practitioners from various backgrounds and departments to lay a common ground for discussion.
 - Second, mental models go beyond the limitations of attitudes, values, and beliefs and could help unveil the motivations of human behaviors (Jones et al., 2011).
 - In other words, mental models dig deeply into why certain behaviors occur, which may apply to users with diverse characteristics.
 - Third, mental models may influence interaction performance.
 - Particularly when users are confronted with complex information architectures, better mental models contribute to better performance (Xie et al., 2017). Furthermore, comparing the mental models of designers and users between the mental models of experts and those of novice users would help identify directions for improvement.
- Despite these merits, the power of mental models to explain the human mind and behavior should not be exaggerated (Wilson & Rutherford, 1989).

Mental Models

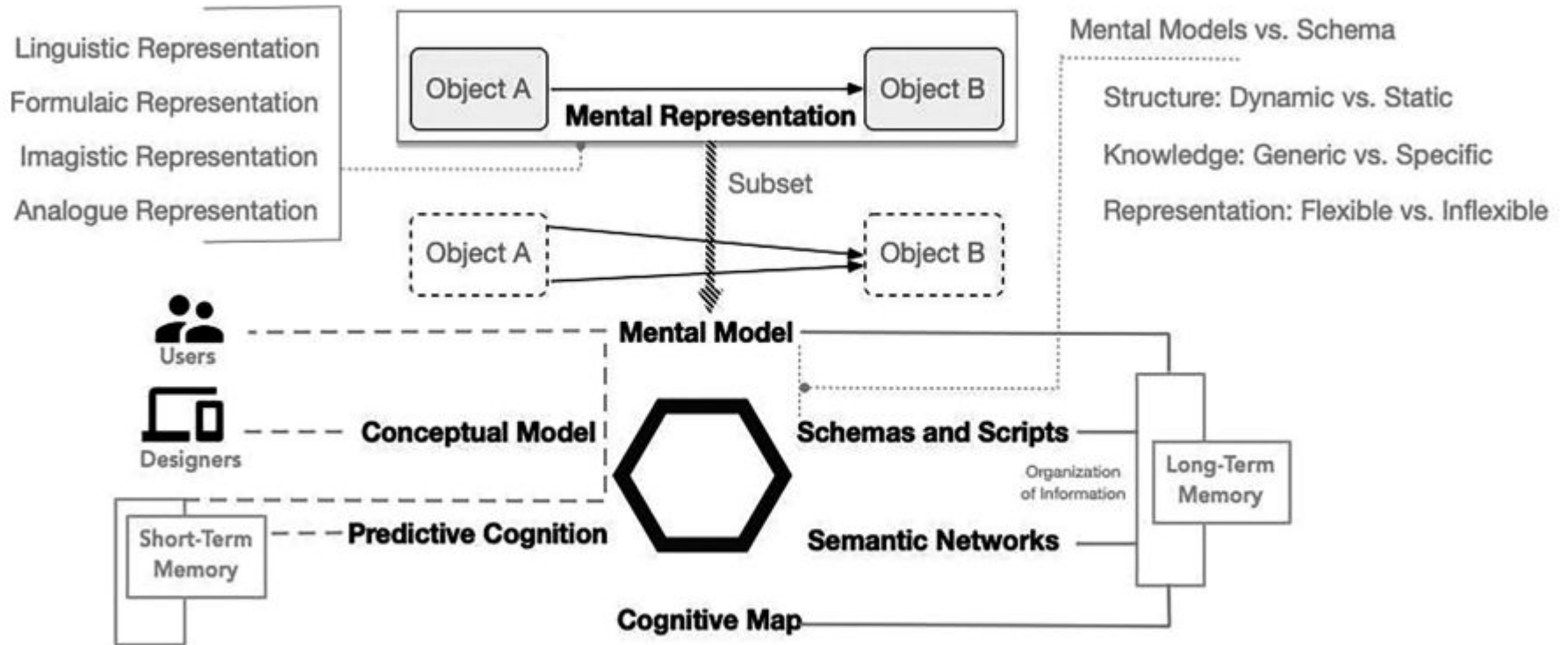


FIGURE 5.1 Mental models and six related concepts.

Further Reading

- Read Chapter 02, Human-Computer Interaction: An Empirical Research Perspective, MacKenzie, I. S. (2024). Morgan Kaufmann.
- Review Vol. 01, Chapters 02 through 11, Human-Computer Interaction: Foundations and Advances, Stephanidis, C., Salvendy G. (2024). Taylor & Francis.