Chapter 2
Semantic Cognition and the Ontological to Epistemic Transformation: Using Technologies to Facilitate Understanding

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2.1 Introduction

In this chapter, we present the term "semantic cognition" as a way of introducing semantic systems. Semantic cognition involves the study of top–down, global, and unifying theories that explain observed social cognitive phenomena consistent with known bottom–up neurobiological processes of perception, memory, and language. It forms a foundation for explaining why some technologies work well and others do not. For instance, the problem of information, or cognitive, overload has become all too familiar. For example, cognitive overload can create unneeded stress and hurdles to effective decision-making in the workplace, thus hindering productivity (Adams 2007). Technologies have become quite good in terms of gathering and providing information to human consumers, but they have tended to worsen the information overload problem depending on their construction and use.

The development of technologies informed by semantic cognition emphasizes manipulating form to fit the task and function in terms of the design, development, and implementation, and in the evaluation of technologies relative to goal-oriented outcomes. Form to fit has many implications for how systems will be developed and utilized in the near future to improve human performance.

Structure, Structuration, and Agency

Agency in a structuration sense is anyone who acts within the formalized social structure of an organization. Thus, our use of the term "agency" represents individual behaviors that operate within a broad network of socio-structural influences

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(Chomsky 1996) that can be within or outside the formally defined organizational structures. Bandura et al. (1977) defined this triadic phenomenon as “agentic transactions, where people are producers as well as products of social systems” (p. 1). Agency exists then on three levels: direct personal agency (an individual’s actions), proxy agency, which relies on others to act on one’s behalf to secure individually desired outcomes, and collective agency, which is exercised through socially coordinative and interdependent effort (Bandura et al. 1977; Chomsky 1996). The notion of agency from this perspective contrasts with nondeterministic (chaotic) and nonrational “natural” processes that create the environments in which people operate either formally or informally (Table 2.1).

The reciprocal relationships between agentic action and social structures are referred to as the “duality of structure” by Giddens (1984). In these terms, structure is defined by the regularity of actions or patterns of behavior in collective social action, which become institutionalized. Agency is the human ability to make rational choices, and to affect others with consequential actions based on those choices that may coincide with or run counter to institutionalized structures.

Structuration, on the other hand, is a dynamic activity that emerges from social interaction. Particularly, social action relies on social structures, and social structures are created by means of social action. The existence of each and the interdependence of social action and social structures can thus be thought of as a constantly evolving dynamic. Thus, structures derive the rules and resources that enable form and substance in social life, but the structures themselves are neither form nor substance. Instead, they exist only in and through the activities of human agents. For example, people use language for communication with one another, and language is defined by the rules and protocols that objectify the concepts that people convey to each other (Chomsky 1996). The syntax structure of language is the arrangement of words in a sentence, and by their relationships of one to another (e.g., subject–predicate noun–verb phrase). The sentence structure establishes a well-defined grammar that people use to communicate.

However, language is also generative and productive and an inherently novel activity, allowing people to create sentences using the syntax rather than to simply memorize and repeat them (Chomsky 1979). In similar fashion, institutionalized

Table 2.1 Agentic attributes

Autonomy	The ability to pursue an individual set of goals and make decisions by monitoring events and changes within one’s environment
Proactivity	The ability to take action and make requests of other agents based on one’s own set of goals
Reactivity	The ability to take requests from other agents and react to and evaluate external events and adapt one’s behavior and make reflexive decisions to carry out the tasks toward goal achievement
Social cooperation	The ability to behave socially, to interact and communicate with other agents
Negotiation	The ability to conduct organized conversations to achieve a degree of cooperation with other agents
Adaptation	The ability to improve performance over time when interacting with the environment in which an agent is embedded

structures regulate agentic behavior, but agents may also disrupt institutionalized structures. The defining features within structuration theory that explain how these processes work are: signification, legitimation, and domination. Signification concerns how meaning is cocreated and interpreted by agents, legitimation encompasses the norms and rules for acceptable behavior, and domination refers to power, influence, and control over resources (Giddens 1984). Collectively, the signification, legitimation, and domination constitute the institutionalized structuration processes. Agentic interaction with these processes creates the communicative structure, authoritative structure, and allocative structure, respectively.

It is important to note that agency behaviors can be modeled in adaptive information systems to act more like human beings so that they can be more compatible with how human beings work and solve problems. For example, modeling these sociobiological artifacts in software have led to the development of epigenetic systems (Bjorklund 1995) in which linear models have become supplanted by more dynamically organized computational models that perform multiple operations simultaneously and interactively with the environment in which it operates (Bandura et al. 1977). The software, or machine, is thus evolving and operating by learning from its environment in an open-ended fashion. Thus, epigenesis from a sociobiological perspective asserts that new structures and functions emerge during the course of developmental interaction between all levels of the agentic biological and environmental conditions (Bjorklund 1995). The notion of agency from this perspective contrasts with nondeterministic (chaotic) and nonrational "natural" processes that create the environments where people are embedded (Beck et al. 1994).

Agency and Agent Systems

Big data analytics draw from mining patterns out of data warehouses or distributed stores. This is a closed system, that is, information is pulled out of an environment and stored away in a large database where it is later examined for patterns by using various analytics. Much may have changed in the dynamic environment since the time the data were extrapolated into the closed system. The closed-system static model of pattern discovery is inherently limited. Moreover, with data warehousing analytics, the user must provide the problem context. By way of using the Web as an analogy, a user must "drive" the search for information with the assistance of a technology such as a crawler or bot. This has widely recognized limitations.

The Web is filled with a sea of electronic texts and images. When you look for something of interest, unless someone provides you with a URL link where you can find relevant material, you will then have to resort to a search engine that gathers up links to everything that it thinks is related to my topic. It is then necessary for you to begin an extensive hunt, sifting through the links looking for possibilities. When you find a page that sounds interesting and begin reading through the material, you will likely discover that it is not what you had in mind. Many of the pages in the Web are cluttered with a multiplicity of subjects, and they are littered with links tempting you to divert your limited attention to another realm, causing you to abandon the original quest in favor of a newly piqued interest (Palmer 2001). Because of their agentic and social attributes, agent-based systems have the potential to help alleviate some of these problems by seeking goals and making evaluations. For example, you may be working in an office in Florida when your boss calls and asks you to attend a meeting with a customer in Dallas to present the company's technical strategy. You then give instructions to an agent to gather intelligence on the customer so that you can frame the presentation for the audience. You may instruct him/her to find published strategies with which to compare so that the customer will see that you have come prepared, and you may also instruct the agent to book the trip, finding the best plane fares for the flights you would want to take, and a hotel near the customer site. To perform these functions, the agent cooperates with other agents (in multi-agent systems, or MAS) to exchange information, resources, and tasks.

The ecosystem in which agents operate is organic. The systems generate descriptions of things and events in the system (called models) and the rules (also in the form of a model) for other agents to use when operating on these models. The systems are not only self-describing, but because the models are dynamically generated within the ecosystem, they are self-defining. Furthermore, models may be advertised and discovered by agents. An agent may even traverse the places where models are advertised and "look" for things and do things. Such a system would be self-renewing, because it can import and export resources. Self-defining, self-renewing, and self-organizing characteristics define an organic system (Bertalanffy 1968).

Goal-Directed Agents

Many systems such as found in many contemporary network and application monitoring use simple stationary agents. In a semantic sense, agents take on more complex behaviors including mobility (Usbeck and Beal 2011). From a semantic perspective, a software agent is an "independent software program with real-time decision-making abilities that acts intelligently and autonomously to deliver useful services" (Agentis Software 2008, p. 1). Goal-directed agents are a special case (cf. BBN Technologies 2004). These agent frameworks are able to adapt in dynamic environments by allowing them to deviate from predefined plans according to their situational awareness (Fig. 2.1).

Goal-directed agents perform a series of steps to carry out a plan, while the agent monitors its environment for substantive changes relative to achieving its defined goals. An agent may choose a different plan, set new goals, and update its "understanding" if it encounters impediments. This ability to "infer" based on changes in the ecosystem is what distinguishes goal-directed agents from their more static predecessors. With goal-directed agents, new plans may be added without affecting the existing plans because plans are independent of one another. Moreover, because agents assemble their execution contexts at run-time, execution paths and error recovery procedures are not required during their design and development (Agentis Software 2008).

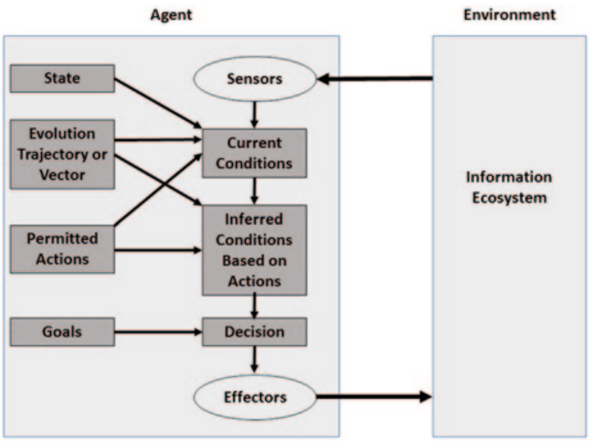

Fig. 2.1 Goal agent architecture

The Problem of Meaning

Building semantic systems stems from human cognition and perception. Thus, a discussion is warranted here to explain what follows.

At the heart of semantic systems is the definition and derivation of meaning. Even with the promise of these more organic technologies, "meaning" is a human construction. If you say, tear, what does this word mean? To answer this question, we need to know the relationship of this word to other words. We need it in context. The word means something different if you say: You have a tear in your shirt versus you have a tear in your eye. One word with two meanings is one level of the semantic problem.

We also have the inverse—many words with one meaning. The antonym and synonym issues are still only half the semantic picture. There are other problems we put in the category of transformational grammar (Chomsky,1979). A door may be opened, or it may be open. We also have the issue of some words operating as verbs in one context and nouns in another—wave, for example—look at the wave versus wave at the crowd. To begin to address this problem, we need some way to describe an entity. The first part of the semantic problem deals with the antonym and synonym problem, and hence the relationships between things are important. However, it is not as simple as that, attributes that define objects can be different, such as with the following:

Teacher: Teacher Name, College, Discipline.
Teacher: Teacher ID, Teaching Philosophy, Degree

The two entities called Teacher consist of different attributes. Some of these attributes may be the same, such as Discipline and Philosophy, but maybe not. A real example is found at the Coca-Cola Corporation where they use independent distributors and bottlers worldwide. Not only do these entities use different languages but also each has different notions of entities as defined by their attributes.

A customer in Bulgaria is not the same as a customer in Montreal. They cannot be equated in business terms.

How might semantic and Web 3.0 technologies help? Most systems are not able to make associations among information because they do not have the structures needed to analyze the relationships among the data; they are only able to process information and perform the functions written into programmatic logic. However, with ontologies, the structures carry part of the semantic association inherent in the data structures themselves. That is, they provide relationships among data that enable systems to make associations from the information based on predetermined rules. The relationships are moved out of the program code and placed inside the documents that programs read and interpret, and reason over. According to Lassila and Swick (1999), "The World Wide Web was originally built for human consumption, and although everything on it is *machine-readable,* this data is not *machine-understandable*." This is among the core of the issues being resolved. To understand how, we need to present an overview of human cognition.

2.2 Cognition Overview

There are (at least) two schools of thought on memory processing and cognition—the Information Processing Approach, where an analogy between the mind and a digital computer is made, and the Ecological Perspective, where the focus is on the dynamics of the environment a person is in, including with machines and people. Informational Processing is conceptualized as where the mind is more "computational" using memory to access memory and form a representation with meaning to a stimulus, whereas the Ecological Perspective relies on a person's perception of the environment around them and their actions form the basis of the conscious mind. The information processing perspective is based on mind–environment dualism, while the ecological perspective is based on mind–environment duality (Cooke et al. 2004).

Memory and Cognition

It is widely recognized that while the capacity of long-term memory is, in theory, virtually unbounded, attentional or working memory is severely limited (Halford et al. 2005). Nevertheless, human brains have the ability to process some kinds of information in simultaneous and nonlinear ways. For example, one may be deeply engrossed in a conversation with her friend and suddenly feel a spider crawling on her hand. Her sensory systems perceive the tiny legs of the spider on her skin and alert her attention; her hypothalamus releases neurochemicals that elicits a fear response to the potential spider bite, she sweeps the spider from her hand and continues her conversation. The person in this situation reacts unconsciously before her schematic knowledge structure stored in memory has processed the behavior (Gioia and Poole 1984). This type of “multiprocessing” indicates that working memory acts as an event receiver, where stimuli compete for “time slices” of attention (Anderson 1983, 2000).

To highlight this point, Dennett (1997) presented the multiple drafts of consciousness theory in which he posited that our conceptions and perceptions of reality are formed in working memory by receiving “snapshots” of the activities processed in different parts of our brains. “Pasting” these snapshots together is somewhat analogous to how photo frames are strung together to make motion pictures (movies). Interestingly, these “realities” are not as contiguous as they might seem in a movie; instead, they are more akin to showing chunks of several different movies in an alternating fashion. However, this does not mean that our attention oscillates between different static frames of apprehension as I might have implied with the simple movie analogy—rather, our brains process information and stimuli with varying degrees of conscious attention in a very fluid and dynamic fashion (Anderson 2000; Bargh and Morsella 2008).

Examining these features reveals the notions of implicit and explicit cognition (Hutchins et al. 2013). Implicit cognition is defined as those processes which are automatic, effortless (in terms of working memory), unconscious, and involuntary, whereas explicit cognition is defined as the intentional use of working memory (Schacter 1995). Given these distinctions, we may also consider “thought” as a memory retrieval process, whereas “thinking” is a creative reconstruction from what has been learned or experienced, or as a process of imagination or concentration (Jensen et al. 1997).

While many functions are specifically performed in well-defined parts of the brain, such as speech and language (most often located in the left hemisphere called Wernicke’s and Broca’s areas), many portions of the brain are malleable insofar as they “rewire” neural connections, a property known as plasticity. It is intriguing to note that owing to neuroplasticity, the more one attends to a particular stimulus, generally the more readily one comes to recognize or focus on it (Bransford and Johnson 1972). One reason for this is because more frequently used neural pathways are more readily primed, along with their associated cognitive schema (Barnhardt 2005). As Bargh and Morsella (2008) noted, “cognition research on priming and automaticity effects have shown the existence of sophisticated, flexible, and adaptive unconscious behavior guidance systems” (p. 78).

Priming effects and automaticity may be crudely thought of as water following the paths of least resistance—in other words, neural pathways that have been recently or intensively utilized are more easily charged or activated (Craik and Lockhart 1972; Khemlani and Johnson-Laird 2013). Cognitive schema may be thought of as a network of concepts, rules, and protocols (McNally et al. 2001). To illustrate, a procedural schema for ordering food when primed with the word “restaurant” causes people to retrieve a specific set of expectations for their prototype of the restaurant concept. When a prime is modified, such as in the phrase “fast-food restaurant,” the schema is also modified (Schacter 1995).

Nevertheless, despite this cognitive flexibility (Shabata and Omura 2012), people tend to lean either toward implicit or explicit cognitive dominance, especially when under time pressure to solve complicated or subjective problems (Barnhardt 2005; Gawronski and Bodenhausen 2006; Richardson-Klavehn et al. 2002). Moreover, since working memory is limited, people develop "habits" because they are cognitively economical (Halford et al. 2005). According to Biel and Dahlstrand (2005), habits derive from deeply embedded and richly encoded thoughts and behaviors built up over time, whereas explicit cognition (including the use of newly learned problem-solving strategies or principles used for making judgment calls) must be remembered and intentionally used.

Moving from the concepts of implicit and explicit cognition, we look at metacognition, which is "knowing what you know." In other words, metacognitive processes create awareness and help coordinate cognition involved in acquiring perceptual, conceptual, and thinking feedback, and monitoring progress toward task solutions (Sternberg 1977). Improving metacognition enables individuals to be better equipped to attend to and interpret relevant information, and use this information to decide how to act and perform effectively (Blume et al. 2013; Engonopoulos et al. 2013). The utilization of metacognitive strategy is also a key difference between expert and novice learners, where the expert learner plans cognitive strategies, monitors them, and will revise strategies to meet goals (Goldstein and Ford 2002). This use of metacognitive strategizing can be useful when dealing with information overload.

Next, when people are inundated with information or when information becomes extremely complex, they experience cognitive information overload (Killmer and Koppel 2002; Watson and Tharp 2013). Since durable information is stored in the form of organized schemata in long-term memory, semantically enriched information helps free up working memory resources and hence allows the limited capacity of working memory and explicit cognition to address anomalies or attend to the more novel features in the information conveyed, and permit cognitive processes to operate that otherwise would overburden working memory (Hutchins et al. 2013; Paas et al. 2003; Seitz 2013; Shabata and Omura 2012). There are emotional and physiological reactivity effects associated with subjective job overload of workers leading to burnout caused by demands made upon them in the work environment and the resources available to them (Shirom 2003).

Information Structure and Semantics

Consider that the bulk of the information with which we are presented and utilize comes to us in a linear form, such as lines on a page that you are reading. One can imagine that this does not capitalize on the brain's natural ability to process information in simultaneous and nonlinear ways. As an example of this linearity, if we asked the question, "What does the word tear mean?" It is unlikely that someone would not be able to tell unless we stated that you have "a tear in your eye" versus you have "a tear in your shirt." We rely on this dependable and relational information structure so that we can "make sense."

In prose, our ability to gain and share knowledge in this way can be described as transformational grammar (Chomsky 1979). Vocabulary rules help to convey semantics because they determine the objective measures by which people draw conclusions and make inferences about ideas. Transformation grammar involves two levels—a deep structure and a surface structure. The deep structure is essentially that of meaning (or intended meaning) encoded with the surface structure, which is that of syntax. To formulate a conception of meaning, or to draw conclusions and make inferences about an intended meaning, the rules and relationships among the words or concepts must be known (Shiffrin and Schneider 1977). Transformational grammar, therefore, is the system of rules and relationships that transform ideas from one structural level to another (Kozma 1991; Trafton and Trickett 2001).

Beyond sense making from information structure, another important aspect of semantic cognition is situational awareness. Endsley et al. (2003) described situational awareness as cognition on three levels: (1) comprehending or perceiving relevant elements in a situation, (2) understanding the meaning of the elements, and (3) the application of the understanding such as to be able to project future states and make inferences. Consequently, situational awareness is a type of "cognitive map" that people develop as they receive information.

While information may be received in many forms (e.g., sound or touch), the majority of information with which people presently work is visual (Card et al. 1999). We have concentrated on visual information so far because this has been the dominant form of information representation in business to date, especially that of written texts. At this juncture, however, we note that visual information has other conveyances, such as with images and drawings. If we consider how these are perceived by our visual sensory systems, and our apprehension of meaning, we might take, for example, a painting we appreciate. The painting conveys information to us in a holistic and simultaneous manner (Langer 1957), but it may leave us with a vague subjective impression of what the painter intended with his or her rendering and what we determined it to mean. The reason why we may not be able to objectively interpret the meaning of the painting is that it lacks transformational grammar. Although some experimentation has been done using graphical linguistics, cuneiforms, symbols, and various forms of isotypes (cf. Lidwell et al. 2003), there has yet to be a consolidation in terms of principles that could enable generalized and objective interpretations.

Indeed, despite a large stream of cognitive and neuroscience theory and literature on visual perception, attention, memory, and linguistics, this is one area where human factors research has traditionally lagged behind the underlying work related to information storage and retrieval theory (Gavrilova and Voinov 2007). This is an interesting issue because underlying storage and retrieval research (cf. McBride 2004) have been utilizing semantic and cognitive theory to drive the development of markup such as RDF and OWL for more than two decades.

The disparity between the semantically rich underlying description logics and the representation of the information models in visual displays of information begs for more theory-driven implementations based on semantic cognition. An interesting feature of these description logics is that the typical linear or hierarchical data structures, such as found in XML, are supplanted by richer embedded relational structures (as in the case of RDF) with some of the rule features of transformational grammar (as in the case of OWL). These are interesting features because the data structures more closely resemble cognitive schema, inherently.

2.3 Visual Perception

In the previous section, we presented an overview of cognition and introduced that the ways information can be structured may either aid or complicate the extraction of meaning from the available data or information. We discussed linear representations of information, and presented that the rules and relationships among components enable our understanding. The purpose of this section is to describe the processes of visual perception and visual perceptual memory in order to understand the human factors and visual communication issues involved in effective design, implementation, and utilization of semantic technologies that best facilitate visual apprehension of information rendered by them. We take a quick physiology tour of vision before we get into some practical points with implications for semantic information display especially of high-density data that are time sensitive.

Vision and Visual Perception

Visual perception is the way in which we interpret the information gathered (and processed) by the eyes. We first sense the presence of a visual stimulus, and we perceive what it is. Light waves enter the eye where images are inverted by the lens. The light waves are then projected onto the reactive surface of the eye, called the retina. The retinal surface consists of three layers of neurons: rods and cones, bipolar cells, and ganglion cells. The rods and cones form the back layer of the eye, and these are the neurons that are first stimulated by the light. Only a fraction of the original light energy is registered on the retina, the rest is absorbed and scattered by the fluid and structures within the eye.

Patterns of neural firing from the rods and cones are forwarded to the bipolar cells, which collect the messages and pass them along to the ganglion cells. These have extended axons (stems) that converge at the rear of the eye in the optic nerve. The image that is captured in the eye has a blind spot (called a scotoma) which is “filled in” by other cognitive and perceptual processes. The optic nerve exits the eye and continues onto the visual cortex in the occipital lobe in the back of the brain, first crossing midbrain between the left and right hemispheres such that the left eye’s image is projected to the right side in the occipital lobe and vice versa. The image that is projected to the back of the brain is upside down, and must be set upright by our mental processes. By the time these processes transform, analyze, and summarize the visual input, the message that finally reaches the visual cortex represents preprocessed and compressed record of the original visual image.

When we read, we get the sense that our eyes consume visual information in a continuous fashion. However, the eye actually sweeps from one point to another in movements called saccades, and then pauses or fixates, while the eye encodes the visual information. While this eye movement is fairly rapid (about 100 ms), it takes about twice that long to trigger the movement itself. During the saccade, there is suppression of the normal visual processes, and for the most part, the eye only takes in visual information during the fixation period, roughly 20 ms (Thomas and Irwin 2006). This means that there is enough time for about three complete visual cycles of fixation-then-saccade per second. Each cycle of the process registers a distinct and separate visual image, although, generally speaking, the scenes are fairly similar and only a radical shift in gaze would make one input completely different from the previous one (Urakawa et al. 2010).

Studies (e.g., Haber 1983) show that there are differences in visual perception between viewing a natural environment versus a computer screen. For one thing, the focus of our field of vision is narrower when working with a computer screen than when we are attending to visual stimuli in our natural environment. Also, there are differences in what is called dimensionality.

No matter how an image may appear on a computer screen (even if rendered in three dimensional—3D), the screen can only display on a flat surface. Another important characteristic is that visual information is only briefly stored in memory. The duration of time that an image persists in memory beyond its physical duration depends on the complexity of the information that is absorbed during the encoding process.

Visual Memory Processing

Just as we have the ability to remember a phone number, our visual sensory system has the ability to persist information. There are also individual differences in relation to three types of intelligence posited by Carroll (1993). Visual spatial reasoning is a type of intelligence measure of one's ability to see foreground, back, distance, and speed. In terms of computer image processing, Averbach and Sperling (1961) performed a series of interesting experiments that showed, on average, people have deterioration in visual recollection as the information complexity increases. For example, when up to four items were presented in their studies, subjects' recollection was nearly complete, but when up to 12 items were presented, recollection deteriorated to only a 37% level of accuracy. Furthermore, they found that this poor level of accuracy remained essentially the same even for exposures of the visual stimuli lasting for a long time—in a visual sense, as long as 500 ms.

Consequently, in general, people have a span of visual apprehension consisting of approximately four or five items presented simultaneously, although there is some variability relative to visual image persistence based on the contrast and background upon which images were rendered (Greene 2007; Irwin and Thomas 2008). When dark fields were presented before and after a visual stimulus (consisting of

18 letters), visual memory was enhanced (just as a lightning bolt is more visible in a nighttime storm than a daytime storm because of the contrast illumination). More specifically, Averbach and Sperling (1961) found that more than 50 % of the letters presented were recalled well after a 2-s delay when dark fields were used, but in contrast, accuracy dropped to 50 % after only a quarter of a second when light fields were used.

Research (e.g., Logan and Cowan 1984) has shown that a later visual stimulus can drastically affect the perception of an earlier one. This effect is called backward masking. The masking stimulus, if it occurs soon enough after the display of the original, interferes with the perception of the earlier stimulus presented at the same position. In some studies of backward masking (e.g., Becker et al. 2000), subjects literally claim that they see only the subsequent (masked) stimulus even though their other performance indicators (such as timings in recognitions of previously seen versus unseen items) suggest that the sensory system did indeed register the first stimulus (Irwin and Thomas 2008; Thomas and Irwin 2006). When the contents of visual sensory memory are degraded by subsequent visual stimuli, the loss of the original information is called erasure. Studies (Shabata and Omura 2012; also see the seminal work: Stroop 1935, and long lineage of confirmatory work, e.g., Sternberg 1977) have shown that the information stored in working memory of visual images may not simply erase or distract from information that was recently presented, but rather can facilitate the anticipation of information that might appear next, called proactive interference.

A final point for our purposes in this section is that visual information processing involves feature detection. A feature is a simple pattern or fragment or component that can appear in combination with other features across a wide range of stimulus patterns. Studies (Neisser 1967) of unelaborated features (those without surrounding context) suggest that we read printed text by first extracting individual features from the patterns, then combining the features into recognizable letters, and then combining the letters to identify the words. With surrounding context, we use the cognitive heuristic of "likeness" to infer correct from misspelled words if there is enough context from which to make the inference. As an example, most people are unable to see that a single word is misspelled such that "slevin" might be unintelligible, unless we write that "four score and slevin years ago." The influences of surrounding information along with a person's own previous knowledge are critically important to understanding visual information.

2.4 Memory and Attention

In the previous section, we spent some time on visual perception because this is an exciting new area of applied research and development that semantic technologies will soon leverage. Structuring visual data, especially high-density data, has been and will continue to be one of the major bottlenecks to comprehension of complex data and situational awareness. Many human factors experts (along with popular bloggers, display design consultants, and other laypeople) have tried to show how to design cognitively economical data displays, but most have failed because they merely take one display media, such as a pie chart, and show it in a different form without any understanding of human vision or semantic cognition. Semantic technologies are poised to be a game changer in that regard. In this section, we devote some time to cognitive processes, and how working and long-term memory work, relative to attention.

It is interesting that we seem to be able to do so many things at once, but that we can only seem to concentrate on a single thing at a time, and still some of our behaviors are habitual and operate without any conscious attention at all (Halford et al. 2005). We perceive our attention as a central controller of sorts (cf. Anderson 1983, 2000), and that it directs all of our other cognitive activities, but this is an illusion (Brünken et al. 2002). Working memory and attention act more like event processors—they respond to stimuli that stream in from all of our perceptual–sensory and mental activities going on in various parts or our brains (Bargh and Morsella 2008; Barnhardt 2005; Hazeltine et al. 2006). In this section, we briefly cover some of the underpinning theories that explain our "attentional" cognition and draw some implications for the design and implementation of technologies as these relate to human performance.

Working Memory

Colloquially (because the term was applied in early research), we often refer to our *short-term memory*. The term "short-term memory" is no longer used because we have come to understand that this cognitive activity is much more than a simple storage system (Baddeley and Hitch 1974). The term working memory has replaced short-term memory in the academic lexicon because the cognitive function it comprises involves information, concepts, percepts, and operations. Researchers originally thought that short-term memory consisted of only that which we are consciously aware. More modern research into metacognition (the term applied to knowing what we know) has indicated that some mental processes occur in working memory that are not revealed to consciousness—and, in fact, they are performed automatically (Brünken et al. 2002). People may be aware of the contents of their working memory, but they are not necessarily aware of the processes that occur to retrieve information and operate on them (Zaccaro et al. 2001).

The early work of Miller (1967) showed that people are able to store an average of seven items (plus or minus two) in working memory. Subsequent research (Cowan 2000; Halford et al. 2005) has shown that this greatly depends on the complexity of the information and the number of operations that people perform at a given time—and that the number is somewhere below seven items. However, techniques such as "chunking" information into groups (e.g., a phone number may be chunked as a single item), and creating associations between concepts (such as by using rhymes or peg words) can augment this limited faculty.

Augmenting is often called recoding—because groups of concepts are used to form an associative network, which makes newly formed units more "meaningful" and hence, at least partially, automatic—akin to grabbing a link in a chain and pulling on it brings other links with it. Thus, working memory as explained is different from long-term memory, and this has been observed physiologically (Bargh and Morsella 2008; Barnhardt 2005). Working memory involves anatomical components deep in the central part of the brain, whereas long-term memories are stored in the outer cortex. The interesting aspect of this, however, is that cognitive functions "blur" because cognition is a symphony, but there is nothing analogous to a conductor except by way of the term attention.

One way to imagine this is via an interesting phenomenon called the serial position effect in which information that is first seen (primacy) or is most recently presented (recency) is most readily recalled. We see in the serial position effect the interactions among working memory, attention, and long-term memory. It is also interesting to realize that memories are handled differently by the brain depending on whether they are learned skills and procedures, or experienced, or derived as a cognitive process such as performing calculations, or processes such as doing mental image rotations.

Types of Memory

Based on what we have covered thus far, we might consider that there are "types" of memory processes that we may label as *procedural, episodic, semantic,* and *declarative* memory. Procedural memory involves "how to do something" such as the processes invoked when we, for example, drive an automobile, or balance our checkbooks. Episodic memory is autobiographical, that is, a memory of personal experiences, and semantic memory, which refers to a recollection about meaningful events or our "world knowledge." Declarative memory (representations of learned knowledge) includes both semantic and episodic memory components (Schacter et al. 2011; Tulving 1972).

As indicated earlier, our experiences are wrapped up with the tasks and skills that we learn and are stored away for future reference in a relational manner in what is called a cognitive script or schema. Thus, our memory system stores separate groups of information together to the extent that those separate groups are related to each other. To understand new experiences, we use what we already know in a conceptually driven fashion. We call these conceptual groupings schemata, or general world knowledge. Those new experiences then become part of our elaborated knowledge structures, and continue to assist in later cognitive cycles of conceptually driven processing. These integrative memory tendencies have a feature known as encoding specificity, which refers to a phenomenon that when people learn a task or other information, they also encode (integrate and store) information about their surroundings. For example, students perform better on a test when they take the test in the same classroom in which they learned the materials rather than if they take the test in a different classroom.

Information is more durably stored and more readily recalled from long-term memory when the information is semantically enriched compared to when those items were learned in a less meaningful way. Elaboration is a technique to semantically enrich information by adding context to concepts. For example, in a series of experiments, Morris et al. (1999) showed that the concept “bear” was recalled 86 % of the time when it was memorized in a sentence such as, “The bear ran through the woods,” compared to 63 % of the time when “bear” was memorized in a list of rhyming words such as “bear, hair, care,” and fell to only 33 % when “bear” was memorized merely as part of a random list of words. This shows that elaborative rehearsal occurs when people do not merely read text, but rather search for connections and relationships that make the text more memorable. In addition, retention of information persists longer when given certain features that make the words in a list more distinctive, such as underlined, in a different font, or a different color.

Cognitive Processing

Conscious information processes are open to our awareness and occur only with our intention; that is, they are deliberately performed. Because of this, conscious processes require and consume some of our available resources in working memory. On the other hand, automaticity is the property that some cognitive functions have to operate automatically, and is central to how attention, pattern recognition, and memory work.

Three characteristics define an automatic process as indicated earlier: (1) the process occurs without a person’s intention, (2) the process is not revealed to consciousness (attention), and (3) it does not consume working memory (“attentional”) resources (Schacter 1995). A clever mechanism to discover how all our cognitive processes function together in concert is through what is called a dual-task test. A dual-task test divides conscious from automatic processes by giving the research subject a primary (intentional) task to perform, and then measuring the time it takes for him or her to react to a secondary cue or task (an automatic response). In one form of this type of test, a subject is given a timed writing task to perform, while simultaneously listening to a narrative on headphones. Subjects are able to perform the writing task virtually as fast as if they had no auditory accompaniment—filtering out the auditory narrative. However, when the subject’s name is said in the narrative, it interrupts his or her performance. This indicates that there are cognitive processes, operating below the level of consciousness, that are attending to sounds in one’s environment. This is a specific example of our ability to attend to information and cues on levels below that of consciousness.

Illustrating this concept with visual information, Stroop’s (1935) seminal research showed words to subjects such as “RED,” “GREEN,” “BLUE,” and “YELLOW” in colors other than the words (e.g., the word “RED” might be written in blue ink). Subjects were required to name the ink color rather than the printed words as quickly as possible. Stroop found significant timing delays (interference) when the color name and ink color were different. This indicates that accessing the meaning of the written symbols, such as RED, is automatic—it happens whether subjects wanted it to or not. We refer to this effect as "priming"—a word automatically activates a given meaning in memory, and as a consequence, primes or activates meanings closely associated with it. Priming makes related meanings easier and faster to retrieve because the information is cognitively networked together by association. Automatic processes, such as priming, do not consume working memory resources, so then why would priming interfere with conscious functioning relative to the Stroop test? Consciously naming ink colors is interrupted because while cognitive access to the meaning of the word is performed automatically, the interference occurs at a later stage in our cognitive processing.

The Stroop test shows that interference is created because of the incompatibility of responses that are competing simultaneously for working memory resources: saying the ink color word when the automatic reading process has primed a different color word. We find no such interference when different ink colors are used to print words such as "PEN," "TABLE," "CHAIR," "COMPUTER," and so on. The automatic and conscious processes interfere with each other only when they compete for the same cognitive response mechanism. Thus, we can see that relationships we form among concepts, even if processed in different parts of the brain, are crucially important to human performance because of the brain's integrative tendencies.

As we mentioned before, thinking is a creative process, whereas having a thought is basically a memory retrieval process. Underpinning the theories of attention and cognitive processing is the idea of implicit and explicit cognition. Implicit cognition results from automatic cognitive processes, as we have stated. Recall that automatic cognitive processes are effortless, unconscious, and involuntary. It is rarely the case, however, for all three of these features to hold simultaneously, but it should be pointed out that *ballisticity* (Logan and Cowan 1984), a feature of a cognitive process to run to completion once started without the need of conscious monitoring, is common to all implicit processes (Bargh and Morsella 2008).

Explicit cognition results from intentional processing that are effortful and conscious (Jacoby 1991). Conscious monitoring in this context refers to the intentional setting of the goals of processing and intentional evaluation of its outputs. Thus, according to this conceptualization of cognition, a process is implicit if it (due to genetic "wiring" or routinization by practice) has acquired the ability to run without conscious monitoring, whereas intentional cognition requires conscious monitoring and relies on working memory (Richardson-Klavehn et al. 2002). Taking this into account, Baddeley and Hitch (1974) proposed a model of working memory consisting of a number of semi-independent memory subsystems that function implicitly, which are coordinated centrally by a limited capacity "executive" that functions explicitly. Their model suggests that there are separate stores for verbal and visual information; for example, a "visuospatial sketch pad" is responsible for temporary storage of visual–spatial information, with the central executive being responsible for coordinating and controlling this, and other peripheral subsystems (Barnhardt 2005). Their model also highlights the effects of explicit cognitive processing of information encoded serially. Human cognition works in this fashion essentially as a linear scanning system (Halford et al. 2005).

For instance, in an auditory channel, people use an "articulatory loop" to rehearse and elaborate on information they hear to form cognitive schema. In a visual channel, people make brief scans across the series of symbols and then fixate momentarily (saccades), while they encode the information into cognitive schema (Smith and Jonides 1995). These encoding processes consume working memory resources, and the effect on performance is a product of the available working memory resources. As information complexity increases, there is greater serialization of information increasing cognitive load, which drains cognitive resources, and task performance deteriorates (Hazeltine et al. 2006).

Next, Anderson's (2000) model of human cognitive architecture asserts that only the information to which one attends and processes through adequate elaborative rehearsal is spread to the long-term memory. Long-term memory can store schemata and subsequently retrieve them with varying degrees of automaticity (Reder and Schunn 1996). The capacity of long-term memory is, in theory, virtually unbounded, but people are not directly cognizant of their long-term memories until they retrieve the schema into their working memory, which is greatly limited—with seven concepts (plus or minus two) being the upper bound (Cowan 2000; Halford et al. 2005; Miller 1956).

Since durable information is stored in the form of organized schemata in long-term memory, rendering information effectively to people can free up working memory resources and hence allow the limited capacity of explicit ("attentional") cognition to address anomalies or attend to the more novel features in the information conveyed, and as these schemata allow for enriched encoding and more efficient information transfer and retrieval from the long-term memory, they allow cognitive processes to operate that otherwise would overburden working memory. From research (e.g., Lord and Maher 2002) into our understanding and processing of concepts—the essence of semantics—we find that a distinguishing feature of semantic memory is based on acquired knowledge about the relatedness of concepts. Episodic memory, in contrast, represents empirically acquired experience and later evaluated as we face new situations. This highlights the difference between remembered versus constructed meaning.

When already-known information influences our memory for new events, we call it conceptually driven processing. In addition, there are alternative models which have been proposed to deal with a more individual-centered method of information processing consisting of rational, limited capacity, expert, and cybernetic models (Lord and Maher 1990). The rational model assumes that individuals process all relevant information for an outcome. The limited capacity model explains the use of cognitive simplification methods, such as satisficing and the use of heuristics, to reach a decision. The expert model is when a person uses existing knowledge structures that are highly organized and developed of a content domain to supplement simplified processing. Finally, the cybernetic model proposes that the processing of information and actions associated with it are dynamic over time, and uses simple heuristics procedures, just as the limited capacity model does, but is affected by feedback.

Semantic Relatedness and Cognition

In order for us to make plans and decisions, we need to collect information and draw inferences about causes and effects. This function relies on the semantic aspects of cognition. From the previous subsections, we have gotten a sense of how semantic memory operates, and have gathered the importance of relationships among concepts in the construction, storage, and retrieval of meaning. From the earliest studies of memory, it has been shown that nonsense words are less memorable than meaningful words, and that contextual stories are more understandable than non-contextual ones. It is the association among concepts that gives them their meaning.

Collins and Quillian (1972) developed a model of how information is mentally grouped together into meaningful units as part of a network of concepts. They described the structure of semantic information as an "interrelated set of concepts, or related body of knowledge where each concept in the network is represented as a discrete element with associative pathways to other discrete elements." For example, a bird might be semantically linked with "flying," "feathers," and "eggs." We refer to the phenomenon spreading activation, which is the mental activity of assessing and retrieving information from this network. With spreading activation, retrieving one nodal concept leads to the activation of all the other interconnected nodes. The spreading of these nodes leads to almost simultaneous thinking of other mental representations (Fig. 2.2).

Research (Sternberg 1977) has shown that the network of semantic concepts also contain property and superordinate pathways, as well as ordering concepts in subject and predicate terms such that the less related the concepts (called semantic distance), the more difficult the retrieval of the information. For example, in experiments, "a robin is a bird" is retrieved more readily than is "a robin is an animal." Of course, these categorizations and their subsequent retrieval depend on learning, both as a process of being taught and from experience, such as "a bee stings."

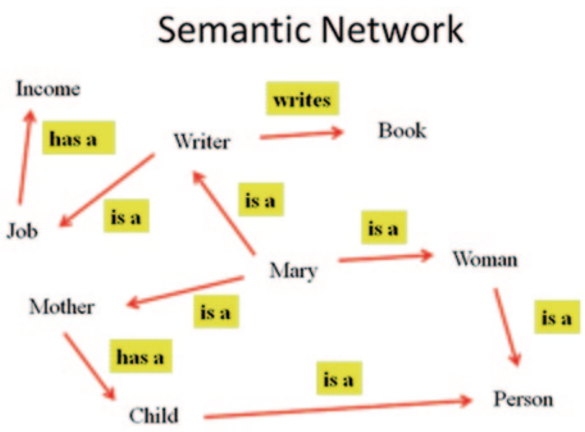

Fig. 2.2 Cognitive schema and semantic network

What we perceive from our visual sensory system is based on detecting "features." Earlier, we read that looking at information on a computer screen is different from seeing information in our natural environment. When we perceive a thing, we classify it, but we find that people perceive natural versus artificial categories differently. Artificial categorization tends to be more discrete, whereas natural categorization tends to be "fuzzier." This is a property of "structure"—artificial categories (a circle is round) are generally given more structural features than natural, real-world categories (the Earth is round, sort of). People formulate perceptual categories based on structure, and also based on analogous structures experienced in nature. For example, in one set of studies (Rosch 1975), subjects were asked to rate a list of category membership based on their representativeness or typicality for a given class of objects, such as: "which is a better member of the 'dog' category, a Collie or Poodle?" It was found that categorization used to classify a member of a set (e.g., a Poodle is a dog) depends on the rated typicality from the subject's own experience. This research shows that real-world category membership is not a collection of bundles of independent and objective features, nor are they classified into categories only because of the presence or absence of certain features (e.g., is it square? Is it shaded? Is it on the left?).

Instead, real-world categories indicate ill-defined and uncertain membership for a variety of instances: Is a "sled" a toy or a vehicle? Because concepts and categories that occur in the natural setting of our experience have a complex internal structure, "fitness" is important. That is, the category "dog" has an internal structure in which some members are better fits or are more representative than others. The fit comes from the frequency of association that people have, and hence differ depending on various factors such as geography and culture. For example, people in Mexico are more likely to associate Chihuahua with "dog" than Poodle, whereas in France, the opposite is true. We have a central meaning for each category and concept, and these can be represented, in a semantic distance sense, in terms of prototypical similarities and dissimilarities based on our experience.

Semantic Priming

Any stimulus that is presented first such that it leads to anticipation and hence influences some later process is called a *prime* as we have learned. Priming is dependent upon connections between ideas/concepts and is for the most part an automatic process. The stimulus that follows the prime is called the *target*. Sometimes this influence is beneficial, as when a prime makes the target easier or faster to process. This kind of positive influence on processing is called facilitation. Occasionally, the influence is negative, as when a prime is misleading. When the prime slows down performance to the target, the negative influence on processing is called inhibition, backward masking, or suppression. Priming is an automatic cognitive process and fundamental to retrieving information from semantic memory, thus the key to facilitation versus inhibition is semantic relatedness, as we have learned. For instance, Loftus and Loftus (1975) found that human performance was significantly better when a known concept was used as a prime (e.g., fruit—apple) than when that letter or adjective was used as the prime (D—mammal; red—fruit). The category name activates its semantic representation and then primes other members of the category.

When letters or adjective targets are presented in an experiment, priming from the category name makes it easier to access a memory of the category, because the memory had already been primed. Conversely, receiving a letter or adjective as a prime has little effect. No relevant activation of potential targets is available with such primes, so there is no facilitation of the word naming. It is not necessary for people to access the meanings of words in a lexical decision task; instead, they need only look up the words in a "mental dictionary" or lexicon, determining if the word has been retrieved from long-term memory—this is a fully automatic process. The network of interpretations reveals the relationship between our semantic concepts and the words we use to name them, that is, between the semantic and the lexical entries in memory. There are some complications in this process, however. Lexical feature complexity can affect the speed of processing (latency) in priming concepts, and lexical ambiguity also leads to retrieval difficulties—they can interfere or inhibit. Spreading activation of semantically related information connects all the meanings of an ambiguous word.

The potency of spreading activation depends on at least two factors: the dominance of a particular meaning for a given concept that has different meanings (e.g., wave), and the degree of surrounding context ("wave at the crowd"). With little or no context, meanings are activated to the level that depends on their associative dominance. With richer context, the meaning receives additional automaticity effects from activations, which has a strong influence on information retrieval speed from semantic memory.

Content and Technical Accuracy

On the one hand, a negative effect of our integrative memory tendencies is that the separate bits of information we store away may not exactly match our existing knowledge, leading to certain kinds of distortions when we attempt to remember things. Later memory retrieval may be technically inaccurate because when we re-create memories; they are a product of both integration and summarization, and not a verbatim recollection. When in a more thoughtful and controlled process, a person may actively suppress and reject information that they retrieve, believing it to be irrelevant. This can present a problem when people must re-create an experience (an episode) exactly, such as demanded in court cases using eyewitness testimonies.

On the other hand, an overwhelming positive aspect of this tendency is that it enhances content accuracy, that is, we can understand and remember the essence of complex meaningful events and episodes. Tasks involving episodic memory generally rely only on performance with the items presented as stimuli. This is a very data-driven process. Subjects involved in episodic task research, in which nothing like the connected meaningfulness of a paragraph is presented to them, recall what they are shown. We call this technical accuracy—subjects must recall or recognize to some degree of accuracy, where accuracy is defined as recalling or reconstructing exactly what was experienced. In more semantic tasks, we find very little emphasis on what people remember exactly about what was presented, but instead focus on remembering the material in terms of its overall meaning.

2.5 Summary

We have now given a broad view of concepts of previous and current research into cognition, and how we have to think of harnessing this knowledge to create systems that work better with human use in the future. When we think of the human and how innovation should center on how the human mind and body works, better products with better efficiencies will be gained. The journeys ahead to alleviate human–computer interaction hurdles, such as cognitive overload, lies in an intimate understanding of who we are, what make us "tick," and what are the best ways to compliment the user and not hinder their natural processing abilities. The human and the machine should act in as much a symbiotic state as possible. Who is to say where we will be in 20, 30, or even 200 years from now in regard to how we interact with technologies. The potential is only as far as we can dream, as we have seen with past conceptualizations in science fiction and other dreams of storytellers that have become a reality in our everyday lives.

The focus of the following chapters is on semantic cognition and what it means for development of computing technology. There will be much discussion and debate, but one thing is clear: We can move forward, and by a basic understanding of human functioning on a cognitive scale, that progression is made easier.

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