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COGNITIVE PSYCHOLOGY: REVOLUTION OR EVOLUTION?

ZEITGEIST: World War II

World War II indirectly stimulated the rebirth of a new kind of cognitive psychology. Among the causes of the war were expansionist agendas by Hitler in Germany and Tojo in Japan. In 1937 Hitler annexed Austria and the Czechoslovakia's Sudetenland and Japan invaded China. The war broke out on September 1, 1939 after Germany's invasion of Poland; Britain and France declared war on Germany in response. The Soviet Union, having signed a non-aggression pact with Germany, invaded eastern Poland, adding to its territory. In 1940 Germany invaded Belgium and France and very soon forced their surrender. Britain's troops on the continent were evacuated at Dunkirk with the loss of nearly all of their heavy equipment. Later in 1940, Germany and Britain fought the aerial Battle of Britain; that British victory prevented an invasion across the English Channel.

Despite these events antiwar sentiment in the United States still ran high and president Franklin Roosevelt could only use indirect measures such as the Lend-Lease program to provide needed assistance to Britain. The Japanese surprise attack on Pearl Harbor on December 7, 1941 flooded away American anti-war qualms and galvanized public sentiment toward punishing Japan. But, most Americans still wished to keep the country out of another European war. Hitler made that desire moot when he declared war on the United States a few days after Pearl Harbor. Roosevelt and Pentagon military planners directed most of the American war effort towards keeping Britain in the war and eventually defeating Hitler in Europe. The United States Navy and Marine Corps along with some Army units would fight Japan on the islands in the Pacific until Hitler was defeated. After, all efforts by the United States and its allies (principally Britain and the Soviet Union, now an ally following Hitler's invasion of their country in 1941) focused on Japan. It took nearly four years to defeat Germany and to ready the plan to invade Japan. Only the use of atomic bombs on Hiroshima and Nagasaki ended the war quickly and prevented the invasion of Japan and a prolonged war.

After Pearl Harbor many American men rushed to enlist in the armed forces. American psychologists were ready for them thanks to the earlier efforts of the American Psychological Association and the American Association for Applied Psychology. Their 1939 joint meeting took place only three days after Germany invaded Poland. The psychologists planned to create methods for evaluating recruits anticipating the United States' eventual entry into the war. Based on World War I's effects on soldiers one of their main concerns was "shell shock" or what is today diagnosed as post traumatic stress syndrome (PTSD). But, they were also concerned about how to select apt recruits for specialized skills such as airplane piloting, navigating, and bombing. The tests they developed did predict successful completion of the training courses but did not predict actual success in combat (National Research Council, 1991) Nevertheless, after the war those kinds of tests became the basis for a new and widespread testing movement within psychology. Thus, the war planted some of the first seeds of what would become modern cognitive psychology. Among those seeds were the first digital computers along with advances in cryptanalysis and coding and new models of cognition based on advances in computer science. Other seeds included new ways of studying memory, the analysis of human problem solving, a new paradigm in understanding language, and renewed effort in understanding the links between cognition and neurophysiology in humans and other animals. After the war these areas grew into a new and different conception of cognition, one that did not depend on introspective accounts or the positing of an incorporeal mind.

[Insert Border with Social Science here: Standardized Tests]

PREVIEW

After World War II *digital computers* were slowly integrated into business and later in to daily life. The *codebreaking* breakthroughs during the war led to the creation of *software* to run on the rapidly evolving computer *hardware* and led to a more sophisticated understanding and use of *information.* A new way of looking at cognition evolved redefining old terms such as *memory* and *problem solving,* the *information processing model*. In that model, *algorithms* and *heuristics* were repurposed as concrete methods for researching cognitive topics. *Language,* too, became a topic of intense interest to psychologists. The ancient goal of understanding cognition through its underlying *neurophysiology* also saw breakthroughs in human and *animal cognition.*

INTRODUCTION

The Slow Move to Cognitivism

The first psychologists were cognitivists too, but their methods were reliant on introspective reports. By the early part of the 20th century it was clear that such methods were faulty (see chapter 6). As a result, Watson's Behaviorism and later Neobehaviorism came to dominate American psychology during the last half of the 20th century (see chapters 9 and 10). But, that domination was never complete. Greenwood (1999) argued that Neobehaviorism and the emerging modern cognitive psychology did not really compete with each other or claim exclusive control of psychology. Behaviorists (from here on in this chapter "Behaviorism" will be used as a term encompassing all of its forms), for the most part, used operational definitions as a tool to understand behavior but overstated the importance of conditioning and were too strict in their prohibitions against any type of mental construct. Meanwhile, new topics such as sensory registers, types of memory, and heuristics were explored by the earliest modern cognitive psychologists. Behaviorists and Cognitivists shared a passion for experimental data collection, its analysis, and interpretation but their goals were different. Behaviorists interpreted their results in the light of S-R theory while Cognitivists interpreted theirs as evidence of cognitive processes (Carroll, 2017). By the mid 1950s psychologists began to craft theories of cognition in the areas of memory, problem solving, and language. Many of those were based on the model provided by computers using such terms as inputs, outputs, and storage. Miller (2003) described the cognitive revolution as a counterrevolution. He wrote (p. 142):

> Whatever we called it, the cognitive counter-revolution in psychology brought back the mind into experimental psychology. I think it important to remember that the mind had never disappeared from social or clinical psychology.

Regardless if it was an evolution or a counterrevolution, the mind was back as a topic in experimental psychology. The new cognitive psychology was not a revolution in the usual sense as a rapid change over a short time period. Plus, it did not intend to replace Behaviorism. There was no rapid conversion from Behaviorism to Cognitivism. The mind was back in psychology but the pace was evolutionary not revolutionary. Still, it was a revolution in terms of its approach to some of psychology's new questions:

- Is the brain a kind of computer?
- What was memory and how did it affect behavior?
- How did people solve problems?
- What was language and how was it acquired?
- What are the physiological underpinnings of cognition?

Those five areas, the computer model, memory, problem solving, language, and neurophysiology became the doors by which cognition re-entered psychology. But, those new areas, their methods, and their theories and did not displace Behaviorism. Rather, they became a parallel part of a larger and evolving psychology.

COMPUTERS AND PSYCHOLOGY

The first digital computer in the world was the Atanasoff-Berry computer, a nonprogrammable machine built at Iowa State University. It foreshadowed later and more advanced programmable World War II computers such as Colossus which was used by American and British

[Insert Photo 13.1 Here: Colossus]

codebreakers to decode the German Enigma code machine. That work was known as the Ultra Secret and its decrypts were very highly classified. In the Pacific theatre, American code breakers had already decrypted the Japanese diplomatic code before the war and had begun to solve the Japanese Navy's code, JN-25. In May 1942 Navy codebreakers anticipated the Japanese plans to attack Midway Island. Convinced by his codebreakers, Admiral Nimitz sent his three remaining aircraft carriers to intercept the Japanese fleet off Midway Island. The resulting battle was a United States victory, one of its first and a turning point in the war. But other than in codebreaking, electronic computers did not play any other important roles during the war.

After the war, however, computers played an important part in nearly all phases of life, including psychology. There, the electronic computer served as a concrete metaphor for cognition. Its programs or software could be thought of as the equivalent of thoughts and plans; its hardware could be considered analogous to the brain. Software and hardware could be exploited experimentally and eventually led to the founding of the field of Artificial Intelligence, the attempt to create intelligent machines. Unlike psychology's earlier introspective attempts to understand human cognition the software in the computer model operationalized thinking. In other words, there was now a concrete way to think of the mind in terms that could be studied experimentally. Human thinking could be thought of as a complicated kind of computer code operating in an extremely powerful biological computer, the brain. Furthermore, such a model offered researchers new ways to consider animal cognition too. Animals possessed their own software operating in simpler brains. Karl von Frisch's (1967) experiments with honeybees could be explained as relatively simple software codes operating in a small computer, the bee's brain. Bees could communicate the type of flowers and the distance and direction to find them. Thinking, redefined in this manner, mapped nicely onto the Darwinian model of evolution.

The digital computer itself also took up space on psychology's expanded stage. In the hands of researchers such as Allen Newell and Herbert Simon (1956) they brought psychology closer to the Artificial Intelligence (AI) paradigm. AI studied cognition itself as a subject and later led to the creation of a semi-independent discipline, Cognitive Science. Nuñez, et al., (2019) contended that (p. 788):

> Indeed, bibliometrically, affiliation and publication patterns in the flagship journal of the *Cognitive Science Society* show that the field has been essentially absorbed by psychology, and the journal does not directly contribute to advances in brain research, or to many (if any) advances in anthropology or philosophy. In general, (cognitive) neuroscientists choose to publish outside of cognitive science journals.

Today, the cognitive revolution in psychology has essentially re-absorbed many of cognitive science's original disciplines (philosophy, linguistics, anthropology, and neuroscience). The two other original disciplines, psychology and computer science have also diverged from each other as well. That is the situation at present. How did psychology move into cognition in its modern form? One of the keys to that change was the study of memory.

[Insert Then and Now here: A World without Computers]

MEMORY

The study of memory is ancient and goes back to Plato and Aristotle at least. But, memory as a psychological topic dates to the last quarter of the 19th century. Wundt, for instance, believed memory was a subject beyond the reach of laboratory study. As noted in chapter 6, Hermann Ebbinghaus, nearly singlehandedly, brought memory into psychology and it has remained there since. Recall that Ebbinghaus studied memory using himself as his only subject and invented the nonsense syllable or consonant-vowel-consonant (CVC) combination in order to study memory in what he considered its purest form. He wanted to study memory under ideal laboratory conditions and his work set the stage for much of subsequent research in memory. His methods were original and have survived the test of time. His work later led to a large body of laboratory-based research in human memory, verbal learning. That research will be covered below. Before doing so, however, attention must be paid to another pioneer in memory research Frederic Bartlett whose research began in the 1930s. Roediger and Yamashiro (2019) described that British psychologist's contributions as anthropological in contrast to Ebbinghaus' laboratory approach. Bartlett was more interested in the errors people made while trying to remember and he also analyzed how people used meaning to help them remember. Bartlett, thus, was more interested in memory in natural contexts. He sought to discover the process by which people reframed and reconstructed memories. He was less interested in verbatim recall and more interested in recall of the meaning of the complex stories he posed to his respondents. The most famous of those stories was his “War of the Ghosts” (Bartlett, 1932) In that story (see below) he asked his respondents to read it and later to retell it. For Bartlett, memory was more than simple recall. He contended that people reconstructed their memories from own experiences and recombined those with the new materials they learned. He was one of the first to use **schemas** as an explanation for memory and thinking. In his book he had his British students read the “War of the Ghosts” story and then retell it later. He found (Deese, 1967, p. 223) that “Cambridge undergraduates, when they repeated the story, tried to make it

[Insert Marginal Definition: schema]

conform to their own language habits and to things with which they were familiar.” For instance, many students substituted “fishing” for “hunting seals” and “boats” for “canoes” presumably because those were more familiar experiences and terms for them. Bartlett found that the longer the interval between reading the story and repeating it the less detail was recalled. However, the meanings and experiences (recruitment, war party, arrows, and fighting) in the story were preserved in the retellings. Here is the original story (Bartlett, 1932, p. 65):

> One night two young men from Egulac went down to the river to hunt seals and while they were there it became foggy and calm. Then they heard war-cries, and they thought: "Maybe this is a war-party". They escaped to the shore, and hid behind a log. Now canoes came up, and they heard the noise of paddles, and saw one canoe coming up to them. There were five men in the canoe, and they said:
>
> "What do you think? We wish to take you along. We are going up the river to make war on the people."
>
> One of the young men said, "I have no arrows."
>
> "Arrows are in the canoe," they said.
>
> "I will not go along. I might be killed. My relatives do not know where I have gone. But you," he said, turning to the other, "may go with them."
>
> So one of the young men went, but the other returned home.
>
> And the warriors went on up the river to a town on the other side of Kalama. The people came down to the water and they began to fight, and many were killed. But presently the young man heard one of the warriors say, "Quick, let us go home:

> that Indian has been hit." Now he thought: "Oh, they are ghosts." He did not feel sick, but they said he had been shot.
>
> So the canoes went back to Egulac and the young man went ashore to his house and made a fire. And he told everybody and said: "Behold I accompanied the ghosts, and we went to fight. Many of our fellows were killed, and many of those who attacked us were killed. They said I was hit, and I did not feel sick."
>
> He told it all, and then he became quiet. When the sun rose he fell down. Something black came out of his mouth. His face became contorted. The people jumped up and cried.
>
> He was dead.

Bartlett's work was seminal in the area of memory in natural contexts and led to the distinction between *surface structure* (the actual words) and *deep structure* (the meaning) in subsequent memory research. His work, however, lay dormant for many years until revived by Neisser (1967) and others in the 1970s. Before that happened many Behaviorists gradually began to study memory in the laboratory. They studied memory in humans under the banner of verbal learning.

[Learning Objective 1: Deep structure of Bartlett's Egulac story.]

Verbal Learning

The study of memory in the verbal learning tradition goes back to Calkin's (1894) a method later known as paired associates, a technique she developed near the end of the 19th century. By contrast, Ebbighaus's methods were termed serial or learning one thing after another. The power of the paired associates method was that respondent's memory could be assessed independently of the order of original learning. Paired associates consisted of a combination of a cue item and a response item. The paired items could be words, nonsense syllables, or even graphic items. To illustrate the difference between serial and paired associates here is a serial list of words:

Boy→Horse→Mother→House→Car→Lamp→Ball

Respondents would learn the list and then attempt to repeat it. Note that except for the first and last items on the list all of the other items serve as cue and response. For example, “horse” is the response to “boy” and the cue for “mother.” Almost invariably three things became evident. The first item and the last item were recalled more easily than the items in the middle of the list. Primacy was the term assigned to the ease of remembering the first item, recency was assigned to the ease of remembering the last item, and the difficulty of remembering items in the middle of the list was labelled the serial position effect. In the paired associate task, respondents might learn a paired list (A-B) such as the one below:

Cue Item (A)	**Response Item (B)**
Rug	Boy
Blue	Horse
Dog	Mother
Highway	House
Doll	Car
Bed	Lamp
Bowl	Ball

Table 13.1. Sample Paired Associate List

The first item (A) was the cue and the second, paired item (B) was the response. Notice that, unlike the serial method, the cues and the responses do not overlap. Researchers could then give any of the cue items in any order to a respondent and expect the correct answer. (So, the answer to “bed” would be “lamp.”) Over the years, the technique of paired associates was used in a wide variety of ways to investigate human verbal memory. Serial techniques were used too as were free recall items. In free recall, respondents were shown a list of words or an array of items for a period. After, they were asked to recall as many items as possible. Verbal learning researchers used these methods to create a large body of knowledge related to human memory and to its opposite, forgetting.

The earliest theories of forgetting simply assumed that the passage of time caused forgetting. Eventually, memories rotted away so they were classified as decay theories. But, subsequent research showed that model to be too simple and simply wrong. Many memories persisted, some over very long periods. Verbal learning researchers created interference theory to explain forgetting. They posited two types of interference: retroactive and proactive. In retroactive interference, the learning of new material interfered with the memory of older, previously learned material. In proactive interference, the opposite occurred. Previously learned material interfered with the learning of new material. Interference theory nicely explained the primacy, recency, and the serial position effect. In the case of primacy, there was no or little proactive interference. In the case of recency, there was no or little retroactive interference, and for the items in the middle both types of interference affected those items.

The paired associate technique was widely used to demonstrate both types of interference in the lab. in the figure 13.1 below the letter A designates the cue items and the letter B designates the response items. C designates the new response items to be learned to the original A cue list. E is the experimental group and C is the control group. Notice that the control group only learns the A-C list and thus has little or no proactive interference. In the experimental group the A-B list interferes proactively with the learning of the A-C list (meaning it takes longer for that group to learn the A-C list).

✔

Proactive Interference

E	A-B	A-C	A-C
C		A-C	A-C

Figure 13.1 Proactive Interference

The setup for retroactive interference is similar (see Figure 13.2)

To demonstrate retroactive interference researchers would first have both groups learn the same list of paired associates, A-B. Then, the experimental group would learn another list, A-C. Both would be tested on the A-B list. The group that had to learn the A-C list had more difficulty in recalling the A-B list.

✔

Retroactive Interference

E	A-B	A-C	A-B
C	A-B		A-B

Figure 13.2 Retroactive interference

Eventually, interference theory was supplemented by data showing that respondents in laboratory settings could learn material more easily when either they or the researcher organized the material in some way. Miller (1956) in his influential article showed that people had a limited

[Insert Photo 13.2 Here: George Miller]

capacity for holding items in short term memory (see more about memory's stages below) and that organizing items in some way made remembering easier. He called those larger units chunks and noted that words are chunks of phonemes. Sentences, of course, are chunks of words and paragraphs are chunks of sentences. Most people could easily remember seven items (words, numbers, syllables) but had trouble remembering more than nine. Miller's work set the stage for a move to a new way to study memory, information processing.

[Learning Objective 2: Memorize paired associate list]

Information Processing

Miller's article presaged a shift to information processing psychology, a shift marked by reliance on the computer model of cognition. After World War II computers gradually moved from being room-sized machines to being pocket sized. By 1980 the personal computer had become available to the public and eventually transformed society. Today, nearly everyone carries around a general purpose computer with them all day long, the smartphone. In the face of this process it was logical for psychologists to incorporate the terms of computing into their theorizing about cognition. Thus, words such as software, hardware, storage, memory, retrieval, and coding came into common usage. Before that, however, two psychologists had already formalized such thinking into psychology, the Atkinson-Shiffrin model of memory (Atkinson & Shiffrin, 1968). They proposed three stages of human memory: the sensory register, short-term memory, and long-term memory. In their model all perceptions entered the visual and auditory sensory registers, but most of those were quickly lost. Those that remained passed into short-term memory for a period of seconds to minutes. Finally, what remained of the original perceptions were encoded into long-term memory where they could remain from hours to years (including a lifetime). The study of memory moved from being a thing to being a process.

[Insert Photos 13.3 (Atkinson) and 13.4 (Shiffrin) Here]

The first step in the process was input from sensation into one of the sensory registers. Fairly quickly, psychologists realized that the visual (or iconic) sensory register and the auditory sensory (or echoic) register operated differently. Sperling (1960) showed that the contents in the visual sensory register only lasted a few fractions of a second before they disappeared. However,

[Insert Photo 13.5 Here: Sperling]

the contents of the auditory sensory register lasted as long as four seconds. Still, nearly all of the sensory input received by either register was lost. Short term memory (STM) was the next step and it was researched extensively. Psychologists found that STM lasted less than 30 seconds unless a person made an effort (termed rehearsal) to keep the item in STM. Mentally repeating the item to oneself was one example of rehearsal. Forcing respondents to carry out distractor tasks such as counting backwards out loud by threes from 100 eliminated rehearsal. The final step in Atkinson and Shiffrin's original model was long-term memory (LTM). The length of LTM could be as short as a few hours or as long as a lifetime. Additionally, LTM seemingly possessed unlimited capacity. Retrieval was the process by which people accessed and reported the contents of their LTMs. In summary, the information processing model in its simplest form contained three processes: input, storage, and retrieval that acted as kinds of filters for sensory input. The sensory registers accepted that input, losing most of it. What was left went into STM, where again most of that was lost too. Finally, the remainder was stored in LTM. Some items in LTM could be easily retrieved but others depended on the respondent finding the right cue at the right time. Such data led to the notion of retrieval failure, meaning that the memory existed in LTM but the person could not retrieve it automatically or reliably. Countless students have experienced retrieval failure during a test only to remember an answer later, perhaps as soon as leaving the building where they had been tested.

Subsequent modifications to the information processing model included Craik and Lockhart's (1972) levels of processing model. They proposed that the effort people expended in memorizing items made a difference in subsequent recall. Items that underwent shallow processing (e.g., counting the number of letter Es in a list of words) would lead to less recall

[Insert Photos 13.6 (Craik) and 13.7 (Lockhart) Here]

while items that were processed more deeply (e.g., deciding whether a word was pleasant or unpleasant) would lead to higher levels of recall. Both types were compared to people in control groups who were told to memorize the same lists but not given any further instructions. Tulving (1972) proposed a distinction between episodic and semantic long term memories. Episodic memories were autobiographical and time-tagged. They included the events in one's life such as high school graduation, marriage, or the loss of a loved one. Semantic memories were akin to knowledge. So knowing that the capital of the country Burkina Faso was Ouagadougou might be an arcane bit of semantic memory. Notice that in this model all the knowledge in one's head was once a bit of episodic memory. For example, nearly everyone knows that 3 x 7 = 21 (a semantic memory) but very few would remember the instant they first learned that mathematical fact (an episodic memory). Baddeley and Hitch (1974) added details to STM including a phonological loop that helped listeners understand the sounds of language and visuospatial sketchpad that aided the understanding of images or when people pointed or made faces. Tulving (1983) proposed the encoding specificity principle where retrieval from LTM was more likely when people were in the same state or physical context as they were when they encoded the

[Insert Photos 13.8 (Baddeley), 13.9 (Hitch), and 13.10 (Tulving) Here]

information in the first place. The information processing approach and its modifications led to much research on human memory and eventually led psychologists to consider memory as a series of processes instead of kind of mental construct. Problem solving was another simultaneous approach to a revived cognitive psychology.

[Learning Objective 3: Indicate which of the following capitals are already in your semantic memory.]

PROBLEM SOLVING

Mental Set or *Einstellung*

Problem solving too, was explored using new non-mentalistic approaches. Abraham Luchins, an American Gestalt psychologist used the metaphor of water jars to pose problems and to analyze the results. He was interested in setting up a mental set or *Einstellung* (see chapter 8) by allowing participants to solve a series of problems using hypothetical water jars labelled *a, b,* and *c*. He posed a series of problems involving where jars held different quantities of water and asked his respondents to come up with a procedure to obtain a given quantity of water Luchins (1942) The first problem was a demonstration and could be solved by the formula: $a - 3b$ (See Table 13.2 below). The next five problems were presented so that a solution worked out early in the process, $b - a - 2c$ would work for all five. The next four problems could be solved using the same equation, but they could also be solved much more simply ($a - c$ for Jars 7 and 9, and $a + c$ for Jar 8 and 10). Most participants adhered to the original and longer tried-and-true method they had learned and failed to perceive the easier solution, thus demonstrating the mental set or *Einstellung* effect. A final problem had to be solved in a completely new way. Using today's computer terminology, Luchins was analyzing the **algorithms** used by his respondents. Note that he could use their solutions to the problems he posed to analyze their thinking without needing to ask them about their thinking.

[Insert Photo 13.11 Here: Luchins]

[insert Margin Text: algorithm about here]

Here are Luchins' Original Problems

How would you use the 3 jars with the indicated capacities to measure out the desired among of water?

Problem	Jar A	Jar B	Jar C	Desired
1	29	3		20
2	21	127	3	100
3	14	163	25	99
4	18	43	10	5
5	9	42	6	21
6	20	59	4	31
7	23	49	3	20
8	15	39	3	18
9	28	76	3	25
10	18	48	4	22
11	14	36	8	6

Table 13.2 Luchins Water Jar Problems (Luchins, 1942)

Insight Learning

As described in chapter 11, Wolfgang Köhler discovered the phenomenon of insight learning while interned on the island of Tenerife during World War I. Working with chimpanzees he found that some of them were capable of linking two pieces of knowledge together suddenly after originally failing to solve the problem. He termed that quiescent period an impasse, meaning that the chimpanzees seemed to have given up on solving the problem. The chimpanzee, Sultan, for example, before he learned to move boxes directly under the bananas that Köhler had hung in the animal enclosure had demonstrated an impasse; he appeared to have given up on reaching the bananas. Suddenly, Sultan moved the box immediately under the bananas. (Note that unlike Thorndike's cats Sultan did not exhibit a gradual learning curve. Sultan put the box directly under the bananas.) Köhler interpreted Sultan's successful solution in the light of gestalt psychology. Sultan had reinterpreted the two separate situations, the hanging banana and the boxes in the enclosure into a new and related gestalt. Subsequently, gestalt psychologists argued that the suddenness of insight learning meant it was different from S-R learning. The quick solutions seen inferred that cognitive processes were taking place during the impasse's interim between problem perception and solution. Ash, Jee, and Wiley (2012) conducted experiments using undergraduates to study insight as a problem solving phenomenon using puzzles and arithmetic problems. They wrote (pp. 6-7, original italics), "very little modern research has been conducted to investigate the core concept of sudden *insight learning,* which was actually the primary phenomenon of interest to the Gestalt psychologists." They asked undergraduates to solve four puzzles and four mathematical problems after their participants initially rated the problem's components as to their importance in solving the problem. After, the participants worked two practice problems (one puzzle and one mathematical problem) and were coached in thinking aloud while attempting to solve the problems. Finally, the participants completed eight problems, four puzzles and four mathematical problems. They were allowed four minutes to complete each problem. Impasses were 2.77 times more likely for the puzzles than for the mathematical problems but many participants solved both types of problems without an impasse. A week later, participants once again attempted to solve the same problems. For the puzzles, the results were clear (p. 19), "the re-solution effects observed on the puzzle problems solved with impasse were not simply due to re-exposure to the problems." They added (p. 22), "this emphasis on internal representation is what motivated the resurgence of interest in cognitive psychology in response to the Behaviorist theories of the late 1950s." Ash et al. saw the research program of Newell and Simon (1972) and its emphasis on problem spaces and representation as the flip side of Gestalt psychology, one that studied problem solving representations (such as those of

Luchins and Ash et al.) but did not closely examine how those representations became internalized. Exactly what are representations and how do they fit into problem solving?

Representations

Roitblatt (1982, p. 353) defined representations as "a remnant of previous experience that allows that experience to affect later behavior." For him, representations contained five parts: a domain, specific content, a code, a medium, and were dynamic. The domain was the subject matter of the representation. For example, the domain of this book is psychology, not baseball. Consider the question: "What should I do on oh and two?" What domain does it come from? Knowing its answers depends on knowing its domain, baseball. The words "oh and two" refer to the count facing a batter (no balls and two strikes). For the batter, the answer is "swing on any pitch that might be a strike." (For those unfamiliar with baseball batters get three strikes per batting attempt; it is embarrassing to strike out without attempting a swing at a pitch that could be a strike.) For the pitcher, the answer is, "throw a pitch that is hard to hit but that could be a strike." (For a pitcher to throw an easy-to-hit pitch to a batter with two strikes risks letting that batter off the hook.) For anyone not familiar with the domain baseball any such questions would be difficult if not impossible to answer. Knowledge of the domain is an essential part of any representation.

[Insert Photo 13.12 Here: Roitblatt]

The contents of a representation were its descriptive features. Many convenience stores in the United States have a vertical strip near the door with the numbers 4, 5, and 6 printed on it. Should someone rob the store employees watch as the perpetrator exits the store. That strip allows them to estimate the height (in feet) of the robber. Later, when describing the robber they can reliably tell the police how tall the robber was. They can, of course, add other descriptors such as clothing, hair, and eye color. Every representation will have descriptive contents. Think of cats. They might have coats describable as: tabby, calico, piebald, short haired, or long haired.

The code of a representation is how the information is conveyed to others. The words of a language, written or spoken, are ubiquitous examples of such a code. The 6,000 or so languages in the world are each unique codes. Making sense of a representation described in an unfamiliar language is practically impossible. *Nyní přestaňte číst*. Did you follow the instructions of the last sentence? It said, "Stop reading now." But, it was in Czech. Slang, too, can be a kind of restricted code. Some readers might not agree that this is a "crunk" book, for example. (The slang word "crunk" has a variety of meanings ranging from a type of rap music to feeling good. Here, it means the book is a good read.) Codes can occur in any of the perceptual modalities. Asking someone to smell the two-week old milk would be an example of an olfactory code leading to a decision to drink the milk or throw it away. Icons are visual examples of codes. The design of easily understandable iconic signs in public places is an applied science. In 1974 the United States Department of Transportation (DOT) working with the American Institute of Graphic Arts created visual icons for use in airports and other public places. The idea was to convey content in pictures instead of words and to have that content be understandable to people from all around the world. Eventually, 50 such icons were created. Figure 13.3 shows a sampling of those icons. Can you interpret them correctly?

[Insert Figure 13.3 Here. Sampling of DOT icons (free, fyi)]

The medium of a representation can vary widely. This book is using a paper and ink medium, but it could also be represented as pixels on a computer screen. Computer media have changed rapidly since the 1980s. Data and programs were once stored on 5.25” floppy disks, then on 3.5” disks, later on CD-ROMs and DVDs. Today, hardly any modern computers have the necessary hardware to read those media. Any information stored on such vintage media is essentially lost. Other examples of media include movie film and the magnetic tapes of DVRs. Both of those media might contain the same information but each requires the appropriate hardware to display it. Now consider the problem preserving a medium over long periods of historical time, say 10,000 years. How might people today represent DANGER to people 100 centuries from now? Weichselbraun (2018) reviewed the film *Containment* that speculated about how difficult it will be to warn humans in the distant future about the deadly buried nuclear waste substances buried. What medium could possibly last thousands of years and still convey the message, “Stay Away?”

Representations change over time; they are dynamic. The poem *Beowulf* was written in Old English between 600 and 1100 CE and is not understandable by those who can read modern English. Here are the last lines from that epic poem in Old English: (Anomymous, nd).

> Swa begnornodon Geata leode
> hlafordes hryre, heorðgeneatas,
> cwædon þæt he wære wyruldcyninga
> manna mildust ond monðwærust,
> leodum liðost ond lofgeornost.

Here are the same lines in modern English (Tinker, 1912, p. 142).

> So the Geatish people, companions of his hearth, mourned the fall of their lord;
> said that he was mighty king, the mildest and kindest of men, most gracious to his people, and most desirous of praise.

Try picking out the modern meanings of those Old English words. Slang, too, is dynamic. In the 1920s "cat's meow" might mean the same as today's "lit." Both words referring to good times or enjoyment. Cultures, too, change; they are dynamic (Kashima, 2014). He suggested that cultures change via importation from other cultures, invention within a culture, ideas selected in or out of a culture, and via random processes (cultural drift). Questions about cultural dynamics include the nature and prevalence of a culture or how cultural changes come about. In other words, the dynamism of representations is an inherent feature so expecting a representation to stay constant is a mistake.

How and when did representations come to be part of cognitive psychology? One answer is they came via computer programming. Programmers needed to represent information digitally, to convert it into the ones and zeros that computers use. The earliest successful computers, the mainframes, were designed to handle the needs of business. So, representing profit or loss was easily done; the representation was arithmetical. In 1956, however, psychologists Allen Newell and Herbert Simon created Logic Theorist, a computer program that did what accomplished mathematicians did, it solved mathematical proofs on its own.

[Learning Objective 4: Represent yourself.]

Logic Theorist

Newell and Simon (1956) published Logic Theorist. That program successfully created proofs for 38 of the 52 theorems in Whitehead and Russell's (1910) groundbreaking book on mathematics. Gugerty (2006, pp. 882-883) paradoxically described Logic Theorist as an AI program and as a simulation of human cognition:

> In an article in the *Psychological Review* in 1958, Newell, Shaw and Simon pointed out that the elementary information processes in the Logic Theorist were not modeled after human thinking, and that the model was not shaped by fitting to quantitative human data. Also, the branching control structure and the list-based knowledge representation of the Logic Theorist were later determined to be psychologically implausible. These considerations support the conclusion that the Logic Theorist does not simulate human cognitive processes, and therefore, given its intelligent behavior, is an AI program.
>
> On the other hand, the higher-level information processes in the Logic Theorist – the methods instantiating the four heuristics – were explicitly modeled after the introspective protocols of Simon and Newell themselves. Newell and Simon explicitly claim that heuristics are a good way to model the quick but error-prone nature of human problem solving, and they used heuristics to model other kinds of problems solving (e.g., chess) around this time. In their 1958 *Psychological Review* article, Newell et al. point out a number of other similarities in how people and the Logic Theorist solve logic problems – e.g., both generate subgoals, and both learn from previously solved problems. These considerations suggest that in terms of higher-level information processes such as heuristics, subgoaling, and learning, the Logic Theorist was a simulation of human cognition.

[Insert Margin Text Here: heuristic]

[Insert Photo 13.13 Newell and Simon]

That dichotomous description pointed to a fork in the road in the history of cognitive psychology. The AI branch eventually led to today's explosion of "intelligent" computers, the increasing use of algorithms, and machine learning. The psychological side addressed human problem solving in new ways focusing on "learning, concept formation, short-term memory phenomena, perception, and language behavior." (Simon & Newell, 1971, p. 148) Simon and Newell viewed their work as another facet of information processing psychology, one that added to the discipline's knowledge base and not one that competed with Behaviorism. They introduced terms, based upon well-defined processes, to explain human problem solving: heuristics, problem spaces and operators. Those, along with representation, provided a new way to look at human problem solving.

Simon and Newell noted (1971, p. 154), "There are many 'trick' problems… where selection of the correct problem space permits the problem to be solved without any search whatsoever." Restructuring is an operator that permits such a solution in many problems. In other words, restructuring involves choosing another, different problem space, one that yields a quick solution without search. Look at this classic problem: How are these numbers arranged?:

8, 5, 4, 9, 1, 7, 6, 3, 2, 0

Nearly everyone will begin to look for a mathematical rule, but there is no such simple rule. Now look at these numbers:

Eight, Five, Four, Nine, One, Seven, Six, Three, Two, Zero

What is different? Now look again:

Eight, **Fi**ve, **Fo**ur, **N**ine, **O**ne, **Se**ven, **Si**x, **Th**ree, **Tw**o, **Z**ero

Have you made the switch yet? Have you changed the problem space from mathematics to English? The numbers are arranged alphabetically in English.

Heuristics

Newell and Simon programmed four principal heuristics (Gugerty, 2006) into Logic Theorist: substitution, detachment, chaining forward, and chaining backward. Gugerty (p. 881) wrote, “Newell had learned about the importance of heuristics in problem solving from the mathematician George Polya. Simon and Newell discovered potential heuristics by noticing and recording their own mental processes while working on proofs.” Heuristics are problem solving strategies that, unlike algorithms, do not guarantee a solution. They are akin to “rules of thumb” and are usually based on experience and trial-and-error. The heuristics in Logic Theorist were useful in theorem proving and were similar to how humans solve logical problems and mathematical expressions. How did Simon and Newell (1971) redefine human problem solving? They saw the task environment of a problem as a god’s eye view of the problem, or the problem maker’s view. The problem space, on the other hand, was the constructed view of the problem solver. Once created, the problem space included the present state, the final desired goal state, and the operators that allowed the problem solver to move successfully through the problem space to the final desired state. That movement, they argued, was constrained by the fact that humans are serial processors, possess limited but quick short-term memories, and have essentially infinite but slow long-long term memories. Those inherent limits prevent parallel processing approaches or lengthy searches of large problem spaces; modern AI systems, of course, have no such limitations. Operators are cognitive tools, such as analogy, induction, or metacognitive process (Burns & Vollemeyer, 2000). Problem solvers applied heuristics in order to move through the problem space to a solution. The means-ends heuristic looks for the differences between the current problem state and the final desired solution. Subgoaling is where problem solvers breakdown the problem into a set of smaller interrelated problems. Working backwards is when problem solvers mentally place themselves at the final desired state and then look back from there to determine the steps necessary for a solution. Analogies, too, are prominent heuristic methods. Being able to see the analogical relationships between previous problems and the current one will often yield a solution.

Think of the following problem: getting from Magnolia, Arkansas to Little Rock. The distance between those two locations is 136 miles (219 kilometers). That distance is the basis for a means-ends analysis solution. The problem, stated in terms of that heuristic, is simply to reduce that distance to zero. If the two cities were islands on the hypothetical Sea of Arkansas, then sailing a heading of 30° would be sufficient. But, there is no sea so roads must be used. That solution requires a vehicle. If one is available so much the better. If not, one has to be obtained. It could be rented, borrowed, or stolen (not recommended). Once obtained, it must be fueled and a route mapped out. Once those preliminary steps are completed arrival in Little Rock could be two hours and fifteen minutes away. All of those steps are examples of subgoaling or breaking the problem into smaller and related problems: obtaining a vehicle, fueling it, selecting a route, obeying the speed limits, and finding the destination. Suppose the trip to Little Rock is a medical emergency and the goal is to get to a trauma center within an hour. Now roads and vehicles no longer suffice as operators, they are not fast enough. The operator may now be a medical helicopter. It could cover the distance in an hour or less (but at much greater expense).

The working backwards heuristic also helps with this problem. Suppose the final goal is to be in Little Rock at 5 pm and it is 7 am on that day. Here is a likely scenario for working backwards:

- Goal: Be in Little Rock by 5:00 pm today—Time = 5:00 pm (with 15 minutes to spare)
- Driving time: 150 minutes—Time = 4:45 pm
- Leave for Little Rock—Time = 2:15
- Fueling time: Fifteen minutes—Time = 2:15 pm
- Drive to gas station: Fifteen minutes—Time = 2:00 pm
- Leave home for gas station: Time = 1:45 pm
- Go home, have lunch, change clothes: 105 minutes—Time = 1:45 pm
- Office hours: 135 minutes—Time = Noon
- Teach class: Sixty minutes—Time = 9:45 am
- Go to work: Fifteen minutes—Time = 8:45 am
- Get showered and dressed: Sixty minutes—Time = 8:30 am
- Have breakfast: Thirty minutes—Time = 7:30 am
- Wake up: Time = 7:00 am

Analogy is another useful heuristic. In this example the necessary operators to solve the problem have already been learned: drive on the right side of the road, red traffic lights mean stop and green lights mean go, do not exceed the posted speed limits, on superhighways only use the left lane to pass, leave three seconds worth of distance from the vehicle in front, and many more. These operators came from experience. Student drivers do not drive on Interstate highways on their first day behind the wheel. Instead, they start their driving lessons in a safe location such as a large, empty parking lot. They slowly progress to driving on lightly traveled streets and work their way up to fast highways. Could a person make it to Little Rock without knowing how to drive? Yes, but someone else would have to drive. Imagine solving this problem in Great Britain instead of the United States. There, one part of previous driving experience would be useless; driving on the right side of the road is not allowed there. A new operator would need to be learned, and fast!

Are humans rational decision makers? Do they weigh the objective data about problems to make decisions? What kind of heuristics do humans use to make decisions? These kinds of questions emerged from the research on problem solving. It turns out that under certain conditions humans make decisions using heuristics that, "sometimes lead to severe and systematic errors." (Tversky & Kahneman. 1974, p. 1124)

Biased Judgments

Tversky and Kahneman (1974) described three heuristics people commonly use: representativeness, availability, and adjustment and anchoring. They demonstrated that the quick and facile use of those heuristics often led to biased judgments. In representativeness heuristic "probabilities are evaluated by the degree to which A is representative of B" (p. 1124). When using the representativeness heuristic people misjudged probabilities, sample sizes, chance factors, predictability, and statistical regression. Thus, Tversky's and Kahneman's participants were more likely to judge the person in the following description as a librarian than as a farmer, salesman, airline pilot, or physician. "Steve is very shy and withdrawn, invariably helpful, but with little interest in people, or in the world of reality. A meek and tidy soul, he has a need for order and structure, and a passion for detail." (p. 1124).

[Insert Photos 13.14 (Kahneman) and 13.15 (Tversky) Here]

In the availability heuristic participants judged probabilities of events on factors such as the ease to which they could be brought to mind, their salience, abstractness vs. concreteness, and imaginability. The adjustment and anchoring heuristic is a bias toward initial values (the anchor). When two groups of high school students were asked to estimate in five seconds the product of:

8 x 7 x 6 x5 x 4 x 3 x2 x 1

or the product of:

1 x 2 x3 x 4 x 5 x 6 x 7 x 8

their answers differed widely. The ascending group's average estimate was 2,250 while the descending group's estimate was 512. (The actual answer is 40,320.) The students did not have enough time to multiply all of the numbers and underestimated the product. The anchors in this case (the starting numbers of each sequence) played a strong role in the difference of the two estimates. Tversky and Kahneman concluded (p. 1131), "These heuristics are highly economical and usually effective, but they lead to systematic and predictable errors. A better understanding of these heuristics and of the biases to which they lead could improve judgments and decisions in situations of uncertainty." While algorithms and heuristics contribute much to the understanding of human cognition, the elephant in the room is language, a universal feature in all human groups.

[Learning Objective 5: Deaths by animal attack.]

LANGUAGE

The study of language or linguistics has a long history. Plato and Aristotle each wrote about rhetoric, a predecessor of linguistics (see chapter 3). Also, recall how Renaissance philology, especially the study of ancient Roman texts, led to humanism (see chapter 4). By the early 20th century linguistics was an established social science. The study of language was another player in the emergence of cognitive psychology.

Origins of Language

The distant origins of language are an unsolved mystery. Donald (2020, p. 287) noted, "In a word, the language mechanism is bound up with culture." He argued that two preconditions preceded the evolution of language: a capacity to refine a wide variety of skills via practice and rehearsal and creation of long-lasting materials (e.g., stone tools) that required transmission from generation to generation to ensure preservation of the techniques required for their making. He argued that as humans became more skilled in the manufacture and use of tools and other material goods they needed to communicate more effectively about them. Mimesis, an embodied analogical representation such as those still seen in displays of grief and celebration, preceded language and evolved into voco-mimesis, the use of non-word signals. Merlin argued that language evolved slowly (p. 294):

> Thus, at least three very basic brain properties – voluntary access to procedural memory, improved metacognitive self-supervision, and greater developmental plasticity - were prominent among the modifications that the primate brain needed to evolve, before the preconditions needed for the genesis of language and symbolic invention were in place. These, along with other cognitive adaptations related to socialization and mindsharing, were necessary for the emergence of the highly variable knowledge networks unique to modern humans. It was the emergent properties of those kinds of networks that necessitated the invention of more complex languages, and the elaborate imaginative mental life they enabled.

The relatively recent mutation (200,000 to 400,000 years before present) of the FOXP2 gene points to a genetic component to the evolution of language. The mutated form of the gene has been found in modern humans and Neanderthals (Krause, et al., 2007). Zimmer (2011, pp. 22-24) summarized the role of the gene:

> FOXP2 didn't give us language all on its own. In our brains, it acts more like a foreman, handing out instructions to at least 84 target genes in the developing basal ganglia. Even this full crew of genes explains language only in part, because the ability to form words is just the beginning. Then comes the higher level of complexity: combining words according to rules of grammar to give them meaning.

Fisher (2019) called the FOXP2 (p. R67), "one piece of an extremely elaborate puzzle." Truer words have seldom been spoken. The evolution of language remains a mystery.

Language in Psychology

Noam Chomsky's book *Syntactic Structures* (1957) played a key role in making language a psychological topic. In that book he proposed that linguists should study a language's grammar first. He used the sentence, “Colorless green ideas sleep furiously.” As an example of an English sentence that is grammatically correct but meaningless and unlikely to ever be uttered. Chomsky’s view of language did much to change the direction of linguistics by putting syntax at

[Insert Photo 13.16 Here: Chomsky]

the forefront over morphology (the study of words) and phonology (the sounds of language). Chomsky’s (1959) critique of Skinner’s book *Verbal Behavior* (1957) contrasted his approach to language as a process involving (p. 47), “data-handling or ‘hypothesis-formulating’ ability of unknown character and complexity” to Skinner’s reinforcement based individual learning approach. Skinner, himself, never responded to Chomsky’s critiques, but MacCorquodale (1970)) did so. He focused on three aspects of Chomsky’s critique: verbal behavior was an untested hypothesis, Skinner’s use of technical terms were paraphrases of more traditional treatments of verbal behavior, and the complex nature of speech. MacCorquodale (p. 98) writing about Chomsky’s “revolution” notes:

> So far there have been no telling engagements in the revolution. The declaration of war has been unilateral, probably because the behaviorist cannot clearly recognize why he should defend himself. He has not hurt anyone; he has not preempted the verbal territory by applying his methods to verbal behavior…”

One fruitful area in the study of language has been how children come to learn language, the process of language acquisition.

Language Acquisition

In the 21st century more nuanced and well researched views of language and its acquisition have emerged. Kuhl (2000, p. 11856) lists six tenets of language acquisition:

- infants' initially parse the basic units of speech allowing them to acquire higher-order units created by their combinations;
- the developmental process is not a selectionist one in which innately specified options are selected on the basis of experience;
- rather, a perceptual learning process, unrelated to Skinnerian learning, commences with exposure to language, during which infants detect patterns, exploit statistical properties, and are perceptually altered by that experience;
- vocal imitation links speech perception and production early, and auditory, visual, and motor information are coregistered for speech categories;
- adults addressing infants unconsciously alter their speech to match infants' learning strategies, and this is instrumental in supporting infants' initial mapping of speech; and
- the critical period for language is influenced not only by time, but by the neural commitment that results from experience.

Infants, thus, are sophisticated learners of language who are already learning language *in utero*. Moreover, that learning reshapes the brain and warps the brain's perceptual processes. Animals share some aspects of these features of learning (categorical learning), but not others (the perceptual magnet effect). The alteration of the brain by language learning helps explain why second language learning in adults is difficult for them but not for children. Adults who learn a second language must depend on separate brain regions for those languages while children who learn two languages early in life do not (Kim, Relkin, Lee, & Hirsh, 1997). The study of language acquisition continues to be a complex and fertile area for cognitive psychology.

[Learning Objective 6: Human cognition without language.]

NEUROPHYSIOLOGY AND COGNITION

One of psychology's long term goals has been to understand the biological underpinnings of behavior. Aristotle linked body and soul (recall that in Latin the word *anima* may be translated as either soul or mind) tightly together and both, working together, were responsible for nearly all human functions. Descartes, in the 17th century, separated body and soul and provided his interactionist solution of the mind-body problem. His conception of humans as biological machines possessing both a mind and a body was revolutionary. He proposed that the link between those two separate parts was the pineal gland because it was not a paired brain structure. Berhouma (2013) analyzed whether Descartes knew of contradictory contemporary physiological evidence against his views about the pineal gland and concluded (p. 1670), "Descartes' neuroanatomical errors were intentional and do not result from Descartes' lack of knowledge. It seems that Descartes adapted his original neurophysiological concept to his metaphysical dualistic theory." Physiological explanations of behavior were rekindled in the late 19th century with the discovery of the neuron and the synapse, re-stimulating the search for links between neurophysiology and behavior. The next step was to describe how the 100 billion neurons in the human body form brains and peripheral nervous systems; that description is still a long distance away.

After World War II, theorists oriented toward psychobiology attempted to link behavior to biological processes. Karl Lashley's efforts to find the engram (1950) and Donald Hebb's (1949) cell assemblies were early examples of that type of research. Neither fully succeeded in finding causal links between the nervous system and behavior but they opened the door to later researchers including Nobel Physiology and Medicine Prize winners Roger Sperry and Eric Kandel.

[Insert Photos 13.17 (Lashley) and 13.18 (Hebb) Here]

Roger Sperry won the 1981 Nobel Prize (shared with David Hubel and Torsten Wiesel) for his research on “split-brain” human epileptic patients. Those surgeries, called corpus callosotomies, the severing of the corpus callosum, were treatments of last resort to inhibit grand mal epileptic episodes from crossing from one side of the brain to the other. Sperry recruited 11 such patients and discovered new findings about brain lateralization. After the surgery, one result was that patients could only name objects flashed on a screen that went to their right visual field. Gazzaniga (2014, p. 18094), then Sperry’s graduate student, recalled his excitement at the results from the first patient he ever tested:

> A circle is flashed to the right of fixation, allowing his left brain to see it. His right hand rises from the table and points to where the circle has been on the screen. We do this for a number of trials where the flashed circle appears on one side of the screen or the other. It doesn’t matter. When the circle is to the right of fixation, the right hand, controlled by the left hemisphere, points to it. When the circle is to the left of fixation, it is the left hand, controlled by the right hemisphere, that points to it. One hand or the other will point to the correct place on the screen. That means that each hemisphere does see a circle when it is in the opposite visual field, and each, separate from the other, could guide the arm/hand it controlled, to make a response. Only the left hemisphere, however, can talk about it. I can barely contain myself. Oh, the sweetness of discovery.

The patient could only verbally respond to stimuli sent to his left visual field (e.g., from the right eye). But, when the stimulus was presented to the right visual field he could not respond but he pointed to the location where the stimulus had been with his left hand. Blindfolded patients could name objects in their right hands but not in their left hands. Interestingly, they could use those objects correctly but still could not name them. For example, a comb placed in the left hand of a blindfolded patient would elicit no verbal response. But, when asked to use it, they combed their hair (and still could not name the object). These were the results that eventually led to Sperry's Nobel Prize.

[Insert Photo 13.19 Here: Sperry]

Eric Kandel won the Nobel Prize for Physiology and Medicine in 2000 (shared with Arvid Carlsson and Paul Greengard) for his research on the sea slug, *Aplysia californica,* (Castellucci & Kandel, 1976). Kandel and his coworkers showed that simple learned responses (habituation, sensitization, and dishabituation) were controlled by specific sensory and motor neurons. In other words, they were able to link behaviors to biological processes. That research led to insights about learning in animals with relative few brain cells (20,000 in *Aplysia* and 300,000 in *Drosophila,* the fruit fly), that the hippocampus contains a cognitive map, how short-term memories convert to long-term, that increases in synaptic strength lead to memory formation, while synaptic depression provides a parallel mechanism for memory storage (Kandel, 2009). Such pure psychological research has been paralleled by similar research in artificial intelligence (AI).

[Insert Photo 13.20 Here: Kandel]

On the AI side one goal is to build a brain, a biological neural network, in their parlance, but using computers. In AI, thus, the search is for an "artificial neural network" (ANN). The ANN goal is similar to what Feynman, the physicist, had written on the blackboard at his classroom at Caltech, "What I cannot create, I do not understand." Hiesinger (2021) has attempted to link neurobiology (his field), AI, developmental biology, and robotics together by pursuing each's notion of the concept of "information." Prior to writing the book he created a workshop with ten seminars attempting to bring developmental neurobiologists and AI researchers together. He found that the discussions in the seminars were useful but (p. 11):

> As I kept on going back to my own discussions and tried to distill their meaning in writing, it turned out all too easy to lose their natural flow of logic and the associations that come with different perspectives. So I decided to present the discussions themselves. And as any discussion is only as good as the discussants, I invented four entirely fictional scientists to do all of the hard work and present all of the difficulty problems in ten dialogs. The participants are a developmental geneticist, a neuroscientist, a robotics engineer, and an AI researcher.

The participants in those fields define and view information differently. The goal of his workshop was to enable better communication among these fields because they are all working on the same problems related to cognition, be that in living things or constructed devices. While Hiesinger indicated, (p. 37) "this seminar series is not about the applications of AI" much has been learned about the interaction of neurophysiology and neural engineering.

[Learning Objective 7: Produce a map of the human nervous system.]

Since the advent of the transistor in the 1950s scientists and engineers have forged a link between neurophysiology and neural engineering creating successful devices such as cochlear implants, cardiac pacemakers, and many other similar devices. Prochazka (2017, p. 1302) attributed the success of such devices to, “the development of materials, miniaturization, computerization, wireless communication surgery, and, last but not least, to the understanding of the underlying neurophysiological mechanisms.” Thus, there is benefit to science from the applied side too.

ANIMAL COGNITION

Bräuer et. al (2020) reviewed the field of animal cognition and concluded that in the past researchers had been too anthropomorphic and had neglected to take (p. 2) “ the biological context of behaviors” into account. They complained that all too often researchers assumed that one general and overall form of cognition was sufficient to explain all cases. While many researchers still consider humans as possessing the ultimate form of cognition, Bräuer et al. provide many counterexamples where animals outperform humans including the ability of many birds to classify objects and remember cached locations of food over long periods. They point to how researchers failed to use the proper sensory modality when testing for animal cognition. They cite the paucity of studies in dog behavior that assess that species’s (p. 12) “most relevant sense,” olfaction. Researchers, however, should take care to consider animal cognition in its own context to avoid anthropomorphic interpretations and be aware that they are not studying a general form cognition but rather are studying a wide variety of cognitions in a Darwinian sense. Bräuer et al. (p. 29) argued that considering each case by itself:

> allows us to reveal the evolutionary, developmental, and environmental conditions that foster the growth of certain unique abilities in the young of a species, or the convergence of skills shared among species.

Modern psychology animal cognition, too, is an active area of research and has re-emerged phoenix-like from Romanes's overtly anthropomorphic origins and it near-banishment by classical Behaviorism.

SUMMARY

The scientific study of the mind was the impetus that first led to the founding of psychology by Wundt. That early form of cognition foundered because of methodological problems and led to Watson's founding of Behaviorism, a slow-moving movement that eventually came to dominate much of American psychology well into the 1970s. But, as Miller (2003) noted, the mind had remained alive within social and clinical psychology. World War II helped revive interest in cognition through the need to rapidly assess and select personnel for the specialized tasks of warfare. After the war, that effort led to a massive revival of psychological testing in a wide variety of arenas including education and job placement. The work of codebreakers using the earliest digital computers also led to their introduction to the civilian world after the war was over. The rise of ransomware has demonstrated how completely the digital computer and its networks have come to dominate the current scene.

The study of memory was not a part of psychology's initial list of topics. It only gained prominence after Ebbinghaus published the results of the research he had painstakingly collected from himself using his new savings method. His results are still valid and appear in every general psychology text today. Bartlett was another early memory researcher but his goal was different from Ebbinghaus's. Bartlett looked for the errors his students made after reading stories he presented. He found that the longer the interval between reading and testing the worse was their recall of story details, or the surface structure. Plus, his students tended to change unfamiliar topics to more familiar ones. But, nearly all of his students recalled the meaning of the story, its deep structure.

Ebbighaus's methods were quickly adopted and modified and led to an interest in verbal learning by many psychologists. Calkins developed the paired associate method and it was used extensively in laboratory settings to study memory because it avoided the problems of serial methods. Recall methods were used too, as participants attempted to remember as many verbal of physical items following a brief presentation. Theories of forgetting were also part of the verbal learning movement. The earliest decay theories yielded to interference theories and later to theories that factored in biological constraints or the benefits of organization to memory. Miller's "magic number 7" and Atkinson and Shiffrin's information processing theory were examples of each respectively. Later modifications included Craik and Lockhart's levels of processing model, Tulving's distinction between episodic and semantic memories, and Baddeley and Hitch's working memory. The verbal learning researchers changed the idea of memory as a thing to memory as a process.

Luchins's water jar experiments demonstrated how once a solution was found to a problem it tended to persist even when a simpler solution was available. Köhler's insight learning showed how some problems were solved after an impasse and the linking of two separate gestalts together into one. The use and acceptance of representations also aided problem solving. Being able to switch from a representation that inhibited the finding of a solution to another where the solution was clearer aided problem solving. Roitblatt's elucidation of the components of a representation: domain, content, code, medium, and dynamism made it easier to understand how representations played a role in problem solving. Newell and Simon's Logic Theorist computer program demonstrated that computers, too, could be made to solve difficult problems through the use of formal logic and heuristics working together. Their definition of problems as consisting of a problem space, an initial set of conditions, a final desired goal, and operators to move through the problem space to the final goal has been widely adopted. While heuristics have proved helpful to problem solving, Kahneman and Tversky demonstrated how some heuristics led to biased judgments.

Language is an ubiquitous human phenomenon but one whose origins are lost in time. Biologically, the FOXP2 gene has been implicated in the evolution of language but many argue that human sociality also played a large role. In the 1970s Chomsky brought language into psychology as a major topic. Many studies have demonstrated the remarkably consistent process of language acquisition in children and in adults learning a second language.

The chapter concludes with a look at the relationship of neurophysiology and cognition. This old problem was revitalized in the late 20th century by Lashley's search for the engram and Hebb's idea of cell assemblies. Sperry's discovery of the "split brain" won him a Nobel Prize and showed in new detail the organization of the human brain. Kandel also won a Nobel Prize for his work on *Aplysia,* the sea slug. He demonstrated the neurobiology of many types of learning. Hiesinger, a neurobiologist, attempted to bring neuroscientists, developmental geneticists, robotics engineers, and AI researchers together to better understand how information is handled by all of those disciplines and to have them better communicate about it among each other. Prochazka noted the many successes of applied devices such as cochlear implants and cardiac pacemakers. He pointed out how the transistor and integrated circuits have made it possible to make daily life better through engineering. Bräuer argued that the cognition of non-human animals is another worthwhile area for future study. He believed that researchers should become less anthropomorphic and should take animal ecology into better account in the future.

[Start Margin Texts Here]

schema: a dynamic cognitive unit based on previous knowledge that reconstructs memories and knowledge.

algorithm: an effective procedure that guarantees a result.

heuristic: a procedure that may likely yield a solution but not necessarily the best one, a rule of thumb.

[End Margin Texts Here]

[Start Then and Now Box Here]

THEN AND NOW

A World Without Computers

The word "computer" originally referred to a person who could add, subtract, multiply, and divide numbers. Later, devices such as the abacus were invented to help those human computers do a faster and better job in obtaining mathematical results. Pascal created the first successful mechanical calculator in 1642. Many improvements followed and mechanical calculators persisted well into the 20th century. When I first started graduate school in 1973 the chair of the department was proud to show us first-year grad students the calculator room. There sat a dozen Monroe rotary calculators (see Photo 13.21). The chair sternly warned us never to make the calculators divide by zero. Doing so would cause them to attempt to find infinity!

[Photo 13.21 insert Monroe calculator photo here]

Later in our graduate careers we filled large pieces of paper with the preliminary calculations necessary to achieve the final statistical results of our experiments. But change was afoot. Hewlett-Packard and Texas Instruments led the way when they introduced handheld digital calculators (see Photo 13.22) that could compute square roots and other necessary mathematical functions. Soon after, the personal computer came on the scene and, behind it, came the first

[Photo 13.22 insert Texas Instruments SR 10 calculator photo here]

software statistical programs. The computer age had arrived and the old mechanical calculators were junked. Today's grad students analyze their experimental results using sophisticated computer software such as: R, MATLAB, SPSS, or any of the many such offerings. Odds are those students have no idea about mechanical calculators, large sheets of paper, and computing intermediate results.

[End Then and Now Box Here]

[Start Border with Social Science Here]

BORDER WITH SOCIAL SCIENCE

Standardized Tests

Although standardized testing dates from imperial China some 18 centuries ago (Himelfarb, 2019) the modern form began in the 19th century. Francis Galton, Alfred Binet, Theodore Simon, Lewis Terman, James McKeen Cattell, Robert M. Yerkes, and Edward Lee Thorndike all developed tests from the late 1800s to World War I. But the modern testing movement was a product of the post-World War II era. Lemann (1995) describes the growth and development of the use of standardized tests in the United States. He noted the importance of the early years of the Cold War and the beginning of the Korean War as important factors in the rise of the testing movement. The scientists who had emigrated from Europe had been the ones mostly responsible for the success of the Manhattan Project and the creation of the atomic bomb. As the Cold War opened American politicians and educational leaders were concerned about maintaining a pipeline of American scientists, educated in the United States, to serve the nation with their brains and not their brawn. Thus, the Selective Service System, the government agency in charge of the draft, began to offer deferments to college students from military service. In 1957, the Soviet Union launched the first earth-orbiting satellite, Sputnik. That event strongly reinforced the idea that the United States needed more scientists marking the beginning of interest in promoting STEM (science, technology, engineering, and math) careers.

Today, American students are subjected to standardized tests throughout their careers in the K-12 grades and beyond. College admission, still in large part and despite moves by many universities to drop the SAT and ACT tests in response to the Covid-19 pandemic, depends on test scores and high school GPA. Beyond the traditional baccalaureate degree lie more standardized tests: the GRE (Graduate Record Exam), the MCAT (Medical College Admissions Test), the LSAT (Law School Admissions Test), just to name a few.

The bottom line is that universities, businesses, and governments want to have some method by which they can select students and employees rationally and efficiently. Unfortunately, human cognitive abilities are still beyond the reach of such tests and only give partial results as to who will become the top students or the best employees. Cognitive psychology has yet to reach that point and it may never do so. Time will tell.

[End Border with Social Science Here]

[Start Photos 13 here]

Photo 13.1 Colossus Computer in 1945

https://newatlas.com/colossus-70th-anniversary/30721/#gallery:1

Photo 13.2. George A. Miller

https://en.wikipedia.org/wiki/George_Armitage_Miller#/media/

File:George_Armitage_Miller_speaking_at_the_first_APS_convention_in_1989.jpg

Photo 13.3. Richard C. Atkinson

https://www.nsf.gov/about/history/bios/rcatkinson.jsp

Photo 13.4. Richard Shiffrin

https://images.sitehost.iu.edu/dams/xuffrhvbfr_actual.jpg

Photo 13.5 George Sperling

http://www.cogsci.uci.edu/~whipl/staff/sperling/sperling.html

Photo 13.6 Fergus Craik

https://royalsociety.org/people/fergus-craik-11280/

Pboto 13.7 Robert S. Lockhart

http://www2.psych.utoronto.ca/users/lockhart/welcome.htm

Photo 13.8 Alan Baddeley

https://en.wikipedia.org/wiki/Alan_Baddeley#/media/File:Alan_Baddeley.jpg

Photo 13.9 Graham Hitch

https://www.lancaster.ac.uk/staff/towse/GHF/Welcome.html

Photo 13.10 Endel Tulving

https://alchetron.com/Endel-Tulving

Photo 13.11 Abraham Luchins

https://alchetron.com/Abraham-S-Luchins

Photo 13.12 Herbert Roitblatt

https://www.joinideas.org/speaker/herbert-roitblat/

Photo 13.13 Herbert Simon and Allen Newell

https://www.computerhistory.org/chess/stl-431e1a07cf7a1/

Photo 13.14 Daniel Kahneman

https://en.wikipedia.org/wiki/Daniel_Kahneman#/media/File:Daniel_Kahneman_(3283955327)_(cropped).jpg

Photo 13.15 Amos Tversky

https://upload.wikimedia.org/wikipedia/en/2/2b/Amos_Tversky.jpg

Photo 13.16 Noam Chomsky

https://en.wikipedia.org/wiki/Noam_Chomsky#/media/File:Noam_Chomsky_portrait_2017_retouched.png

Photo 13.17 Karl Lashley

https://en.wikipedia.org/wiki/Karl_Lashley#/media/File:Photo_of_Karl_Lashley.jpg

Photo 13.18 Donald Hebb

https://en.wikipedia.org/wiki/Donald_O._Hebb#/media/File:Donald_Hebb.gif

Photo 13.19 Roger Sperry

https://en.wikipedia.org/wiki/Roger_Wolcott_Sperry#/media/File:Roger_Wolcott_Sperry.jpg

Photo 13.20 Eric Kandel

https://en.wikipedia.org/wiki/Eric_Kandel#/media/File:Eric_Kandel_01.JPG

Photo 13.21 Monroe Calculator

http://bp3.blogger.com/_0PDBIcmWb4c/R_sWm_FfvwI/AAAAAAAAABM/_ibKUwLVkFg/s1600-h/Monroe.jpg

Photo 13.22 Texas Instruments SR 10

http://bp2.blogger.com/_0PDBIcmWb4c/R_sY2vFfvxI/AAAAAAAAABU/Y0Ar6l0s4ko/s1600-h/sr10.jpg

[Numbered Figure Captions]

Figure 13.1 Proactive Interference

Figure 13.2 Retroactive Interference

Figure 13.3 DOT Icons

https://www.aiga.org/resources/symbol-signs

(pick some from the 50 available)

[Begin Learning Objectives]

Learning Objective 1: Describe the deep structure of Bartlett's Egulac story.

Learning Objective2: Memorize the paired associate list in Table 13.1 by putting the cue words on one side of a 3x5 card and the response words on the other. How many trials did it take you to learn the list without making any errors?

Learning Objective 3: Indicate which of the following capitals are already in your semantic memory by giving their countries: Ouagadougou, Kabul, Brazzaville, Stockholm, Ottawa, Montevideo.

Learning Objective 4: Illustrate the representations of you available on a driver's license or similar identification card. How many are there? What are their codes?

Learning Objective 5: Estimate the number of death per year due to shark attack or bee sting. What heuristic would predict a higher number for shark attacks?

Learning Objective 6: Imagine what human cognition would be like without language.

Learning Objective 7: Produce a map of the 100 billion neurons in the human nervous system and show all of the synapses between them. Award yourself the Nobel Prize for Physiology and Medicine upon completion. :-)

[End Learning Objectives]