

# The History of Reasoning Research

## KEY THEMES

- The study of reasoning made remarkable progress in the 20th century.
- This field moved from being primarily a philosophical area of inquiry to a psychological one.
- The methods of experimental psychology enabled researchers to examine the role of context in reasoning accuracy and speed. Additionally, these methods enabled researchers to find consistencies across people forming principles of reasoning.
- Early studies of reasoning were carried out in Europe by the Gestalt school of psychology. These researchers focused on the role of insight in problem solving.
- In the first half of the 20th century behaviorism dominated psychological inquiry in the United States. With a primary focus on observable states of learning and conditioning, behaviorism limited the progress on understanding reasoning.
- Early studies of deductive reasoning were carried out in the early 20th century. These studies clarified the importance of familiarity with materials on the process people used for deduction.
- Modeling cognitive phenomena requires a sensitivity to both the architecture of the nervous system and the interactivity of information within the mind.
- Technological advances in brain imaging opened up a wide array of new avenues for linking neuroscience principles with reasoning research.

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## HISTORY OF REASONING

### Introduction

There is a rich and interesting history that preceded the current research approaches that we use to study reasoning. This chapter explores views on reasoning that date back to the early periods of human history.

There were times of intense inquiry where philosophers pursued the meaning of existence. There were also long periods of relative dormancy in which the study of the mind did not advance significantly. Over time, knowledge grew and was distributed much more widely. The methods of psychology gradually replaced introspection and purely thought-based experiments. It is remarkable how much of this development has occurred within the past century. The rapid advancement of reasoning research has co-occurred with the advancement of education and increased ease of sharing of ideas made possible by technological growth.

We will begin with an examination of some of the early approaches to the study of reasoning. There are some early clues as to when reasoning abilities began to advance and take hold for humans. The developments of technology and writing enabled people to preserve a record of their thinking about reasoning and cognition. These early times were mostly limited to thought experiments and philosophical writing. Despite the limitations in the methodology available early on, the roots of many important ideas can be traced quite far back to earlier periods in human history.

The late 1800s saw radical increases in intellectual development. This was the time during which Charles Darwin published his landmark book *On the Origin of Species* spelling out the theory of evolution by natural

selection (1859). The book and the ensuing debate radically changed the perspective of the biological world, or natural philosophy, as it was referred to at the time. Neuroanatomical knowledge was growing at a rapid pace and advances in microscope technology led to new understanding about the characteristics of the nervous system and its relationship to thinking. Alongside the new perspectives developing in biology, the first psychology labs began enabling principled empirical studies of the mind. These approaches would provide the means to address many of the challenges that had previously hindered the field. Such challenges included subjectivity and a lack of systematic research.

We will next consider the growth in reasoning research that took place over the 20th century. This century saw unprecedented advances in thinking, methodology, knowledge, and technology. Many critical ideas about reasoning were grappled with in the early 1900s, as the first psychologists gathered their thoughts about thinking, reasoning, and deciding and began to carry out studies. Some of these studies would fit within the Gestalt school of psychology (Box 2.1), which was centered largely in Europe. The Gestalt psychologists were keenly interested in the nature of insight, and problem solving was one of their well-researched areas of emphasis. In the United States, the behaviorist approach came to dominate the field in the first half of the 1900s, and this had a profound impact on reasoning research, as certain topics were relatively underexplored due to the restrictive nature of the behaviorist methods.

The mid-20th century saw key developments take place that would shape the rest of the century. Among these was the development of cognitive psychology, an approach that led to the development of new methods. These methods could be used to explore the contents of the mind and led to further studies of reasoning and decision making. The development of the computer was also occurring at this time. With that technology as a reference point, an intellectual position evolved maintaining that we are information processors and that our brains may operate similar to computers. Radical increases in knowledge about physiology and neuroscience also led to new ways of thinking about how we reason.

The developmental psychology perspective thrived in the 20th century as well. Cognitive development became a major interest within the discipline and remarkable progress occurred in both theoretical views of development and experimental approaches to the study of children's cognition. Reasoning ability emerged as a major component of the theories and methods that were applied in developmental studies. Studies of cognitive development also led to models of infant and child reasoning abilities. These developments have practical implications for parenting practices, early child care, and education.

As the 20th century came to an end, remarkable new technological developments were changing the face of the fields of cognition, neuroscience, and biology. The emergence of brain imaging techniques had a major impact on the types of questions that investigators were able to ask. Advancing knowledge about the brain and nervous system also led to new theories and perspectives on the way that reasoning is accomplished within the nervous system. The ability to compare cognition across species was also advancing.

As we look toward the future, there is reason to believe that our capabilities in thinking and reasoning will advance through the knowledge gained and the technologies that are currently in development. Over the past 50 years people's Intelligence Quotient (IQ) has been rising steadily. This is referred to as the Flynn Effect after James Flynn (1987). One theory is that we now reason about such abstract content that we actually have enhanced our capabilities for reasoning to meet these demands. Also relevant to this topic is the rapidly expanding information search abilities that have become possible in the past 20 years. Never before have people had so much knowledge available at such a rapid pace. Our capabilities for reasoning will likely change as we move into the future, and we conclude this chapter with a discussion about the future of reasoning, which is a major topic of Chapter 13 of this text.

## EARLY APPROACHES TO STUDYING REASONING

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### Reasoning Through Human History

At what point did people begin to reason? This is an intriguing question that follows from some of the discussion of the introductory Chapter 1. As modern humans evolved, we developed the capacity to represent the world in ways that were not apparent in previous ancestors. Humans have an advanced capability to represent information abstractly and elaborately. Abstract reasoning involves storing and manipulating representations that are removed from concrete perceptual information and actions. Abstract information can be replayed in sequences through mental simulation. Such information can be manipulated and changed. We can also selectively recall abstract information in a manner that helps to inform us about future possibilities.

Some brief discussion of human evolution is warranted before we examine some of the features of modern humans that are linked to our advanced reasoning capacity. There are several factors that impact our reasoning ability. Among these are brain size and the ability to manipulate factors in the environment. Little is known about either of these for much of our history.

## BOX 2.1

## GESTALT PSYCHOLOGY

The Gestalt school of psychology was a movement that took place in the field centered primarily in Europe in the early 1900s. Gestalt refers to a *whole* being different than the sum of its parts. Gestalt psychologists were interested in how people perceived incoming information, how they interpreted that information, and how they solved problems. The Gestalt psychologists started in Germany and were important historically, as they conducted research at the same time as behaviorism had taken hold in the United States. The behaviorist model of psychology placed strong limitations on the study of topics such as reasoning and decision making.

The Gestalt psychologists were interested in how situations or structures could be viewed as being unified. This idea applies throughout modern psychology. We perceive a face to be a whole entity, rather than merely a collection of features. We can group information into meaningful units, such as when a chess expert perceives a line of figures as being a “pawn chain,” because he has seen this formation so many times before. In many situations in life, numerous independent items can take on a singular overall meaning of its own. Gestalt psychologists were interested in how people group information perceptually. Fig. 2.1 shows a series of grouping principles that had been observed and noted by Gestalt psychologists. The arrangement and perceptual features of dots or lines can lead us to group those features into predictable arrangements. Gestalt psychology noted the regularities in grouping that people will tend to carry out and these came to represent Gestalt principles.

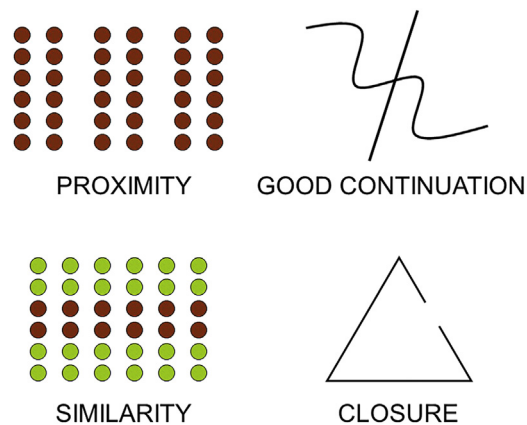
The Gestalt school emphasized rigorous research methods. Earlier experimental psychologists interested in mental representations included Wilhelm Wundt and

Hermann Ebbinghaus, who had used the introspection method and subjective interpretations of thought as the basis for developing views on mental representations. The Gestalt psychologists, by contrast, emphasized conducting experiments with naïve human subjects who had not previously encountered the experimental materials before. This emphasis enabled the experimenter to take on a more detached and objective viewpoint. These methods allowed researchers to draw conclusions that could be more widely generalized across populations.

Gestalt psychologists were interested in how people solved problems. There was a particular interest in the process of *insight* in problem solving (Sharps & Wertheimer, 2000). Gestalt psychologists, such as Karl Duncker, noted that there appeared to be several distinct steps that occurred in problem solving. These included four separable stages in problem solving:

1. *Preparation*: recognize the problem and make a first-pass attempt
2. *Incubation*: if at first you don’t succeed ... try again later, but possibly continue to work on the problem at an unconscious level
3. *Illumination*: insight is achieved and this is accompanied by a level of confidence that the answer has been found
4. *Verification*: confirm that the solution works

The Gestalt psychology school made enduring contributions that helped to shape our understanding of both perception and problem solving. Their methods and research interests foreshadowed much of what would follow, as cognitive psychology emerged in the 1950s.



**FIGURE 2.1** The principles of Gestalt grouping. Proximity: objects close to one another are grouped. Similarity: objects that are similar are grouped. Good Continuation: people tend to see two intersecting lines as continuing rather than being four separate pieces. Closure: people see a gap in a shape and tend to close that gap in their minds.

Notable Gestalt Psychologists (Fig. 2.2):

Max Wertheimer (1880–1943)—Developed an interest in apparent movement in perception. He also focused on the distinction between *reproductive thinking*, concerning learning by repetition, conditioning, and habit formation, and *productive thinking*, which is characterized by insights and the development of new ideas.

Kurt Koffka (1886–1941)—Articulated the distinctions between levels of learning. For example, Koffka

claimed that *sensorimotor learning* occurs when our actions are linked to outcomes. This is different from his concept of *ideational learning*, which deals with language concepts. Koffka also contributed to developmental psychology.

Wolfgang Kohler (1887–1967)—Kohler worked with Wertheimer and Koffka on perception and apparent motion. He also studied problem solving and was keenly interested in the similarities and differences between chimpanzees and humans.



**FIGURE 2.2** Considered by many to be the founders of Gestalt psychology, Max Wertheimer, Kurt Koffka, and Wolfgang Kohler (pictured left to right) were studying mental representations and the process of insight problem solving at a time when much of the psychological community was restricting itself to the study of stimulus–response based learning. Max Wertheimer (1880–1943) By Anonymous [Public domain], via Wikimedia Commons. Kurt Koffka (1886–1941) Courtesy of Smith College Archives; photograph by Katherine E. McClellan C. 1928. Wolfgang Köhler, from (*Reval*, January 21, 1887–*New Hampshire*, June 11, 1967).

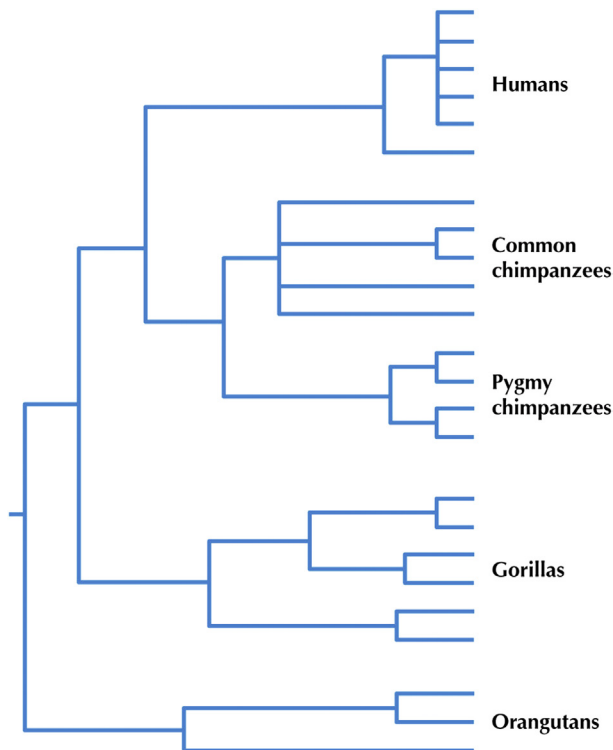
We can roughly estimate the likely size of the brains of our primate ancestors, and brain size is observed to have increased over time. The difficulty is that fossils can only give limited clues as to the reasoning abilities of our ancestors. What we can say is speculative and can only be viewed through the lens of comparison to modern humans.

Increases in brain size point toward the capacity for more complex behavior and the tendency to engage in social groups. Modern humans appear to have developed larger brains relative to earlier hominids. We have a relatively long postnatal growth period, and we require considerable parental care. Coupled with these features, people have relatively few offspring and have to invest considerably in those progeny. Fig. 2.3 shows a tree indicating the relatedness of different extant species of primates.

One of the closest ancestors of the modern human is *Australopithecus*, a name meaning southern ape. There are several different fossil discoveries of *Australopithecus* that vary to some degree in their size and characteristics. These early hominids lived between 2.5 to 3 million years

ago and were smaller on average than modern humans, weighing approximately 40–140 pounds depending on the specific variant of *Australopithecus*. Perhaps the most famous fossil is named “Lucy,” a female *Australopithecus afarensis* who measured three-and-one-half to four feet in height and appears to have engaged in bipedal locomotion. Other fossils of *Australopithecus* have been found over the past century. The skulls of these fossils indicate that *Australopithecus robustus* and *Australopithecus africanus* would have had estimated brain volumes of approximately 550 cc. The precise lifestyle of *Australopithecus* is a matter of some speculation, but based on the traits of these fossils it appears that considerable evolutionary change was occurring (Strickberger, 1996).

Our closest ancestors are of the genus *Homo*. Fossils of these hominids originate from Africa dating between 2.2 and 1.8 million years ago. *Homo habilis* was a relatively short species estimated to be roughly the size of *Australopithecus*. The brain volume of *H. habilis* is estimated to have been between 600 and 700 cc, an enlargement over the earlier hominids (Fig. 2.4). *H. habilis* also appears to have used stone tools for hunting and butchering large



**FIGURE 2.3** A tree diagram indicating the relatedness of different species of primates. *Ruvolo 1994 figure on human ancestry. Copyright (1994) National Academy of Sciences, U.S.A.*

carcasses. These skills imply a level of social organization that would have been needed in order to take down large prey and to invent tools. Both of these lifestyle properties are characteristic of a complex species. Other members of the genus *Homo* include the larger *Homo erectus*, whose brain volume ranged from 750 to 1000cc and dating to approximately 250,000 years ago. Meanwhile *Homo sapiens* who appeared around 50,000 years ago are our direct ancestors having the largest hominid brain volume of approximately 1300–1500cc (Strickberger, 1996). There is a further distinction between the *Homo sapiens sapiens* (modern humans) and the *Homo sapiens neanderthalensis*, who are commonly known as Neanderthals, hominids possessing a somewhat smaller skull than *H. sapiens sapiens*, a shorter and more squat body plan, but otherwise bearing high similarity to modern humans.

While we cannot solidly establish the reasoning capacities of these earlier hominids, the scientific community has established several important features that they possessed. Among these is bipedalism, the ability to walk on two legs. Bipedalism likely allowed for improvements in the ability to detect predators due to a height advantage, as well as the ability to carry food over long distances (Lovejoy, 1981). The ability to use fire as a tool likely led to a reduction in digestive load, as cooked meat could be more easily digested. Such a capacity could have led to less time spent sleeping and enhanced productivity. Lastly,



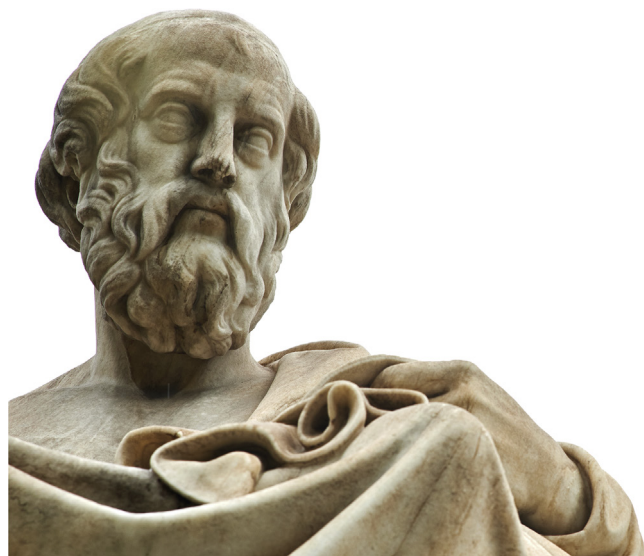
**FIGURE 2.4** A skull of the primate *Homo habilis*. From Wikimedia Commons.

hunting appears to have been cooperative at this point and likely involved the use of tools such as flaked stone hatchets and spears. These advances in hunting are characteristic of advancements in reasoning ability. As we will discuss in Chapter 4 on animal reasoning, we can learn about the complexity and capabilities of a species based on its capacity to obtain food in novel and flexible ways.

There are some other clues to the development of the human ability to think abstractly. One clue is cave art. A species that is capable of producing detailed drawings has a well-developed level of dexterity that enables this activity. Perhaps more importantly producing cave art demonstrates an elaborated capacity for memory. The act of creating art requires a brain that has great flexibility, as situations must be learned in a single trial. Emotionally salient situations are good examples of such one-trial learning. If the artist wishes to convey the dynamics of a hunt, then the ability to store a sequence of events surrounding the hunt that evolved over time is needed. Modern humans have an impressive ability for storing and recalling episodic memories. This refers to the ability to store situations that occur over an extended period of time. The act of representing a scene, such as a cooperative hunt, is made possible by the ability to store episodes in time. Memory psychologist Alan Baddeley (2000) has referred to our ability to recall and examine episodes in time as an episodic buffer within our working memory system. We do not see cave art in any other existing species, which may suggest that they do not possess the type of memory for episodes that humans do.

## Philosophy of Reasoning

Since the dawning of consciousness, there has likely been a human desire to understand the nature of thinking



**FIGURE 2.5** Plato (427–326 BCE) wrote about different types of knowledge and how certain we should be about the conclusions yielded by different forms of reasoning. *From Shutterstock.com.*

and reasoning. It would take many years to develop the experimental methods and tools to measure reasoning abilities. There are few clues about the earliest periods of inquiry into knowledge and reasoning, as few cultures wrote down their thoughts and few writings survived to the present day.

One of the early impressive contributions to human reasoning came from the Greek philosopher Plato (427–326 BCE) (Fig. 2.5). Plato wrote about different types of knowledge, how it was obtained, and how certain we should be of different forms of reasoning. The writings took the form of a dialogue between Plato and a student. In one such writing, Plato discusses knowledge of the subject of geometry. He draws a square in the sand and asks a student how many sides it has and whether they are equal. The boy responds appropriately. Plato then asks his students to imagine that the sides had been doubled in size. He asks how much larger this new imagined square would be than the one that had been drawn in the sand. The student responds that the new larger square would be equal in size to four squares of the original size. Plato points out that ideas can emerge innately and without the person consciously planning out the rules, or using any sophisticated formal geometry. While this demonstration is a far cry from later psychological experiments, it indicates that scholars such as Plato had a keen interest in the nature of our mental representations and how they may be applied toward reasoning.

Other notable philosophers of the mind would emerge later in history. Around the time of the Italian Renaissance, thinkers such as Rene Descartes (1596–1650) were active (Fig. 2.6). The Renaissance was a time of great curiosity and creativity. Alongside remarkable



**FIGURE 2.6** Rene Descartes (1596–1650) studied physiology, physics, geometry, and language. Some of his most notable observations were on the relationships between the mind and body. *From Wikimedia Commons.*

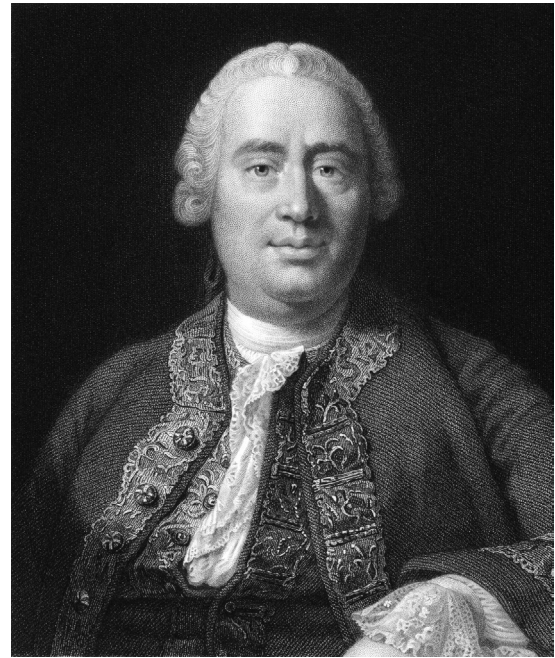
artworks, philosophers were once again striving to understand the nature of the mind and how it interacted with the body. The contributions of Descartes were myriad, as he studied physiology, physics, geometry, and language. Some of his most notable observations were on the relationships between the mind and body. Descartes believed that geometry represented the purity of thought and that when each person considered a particular shape, such as a square or triangle they would be certain to agree upon the properties of the representation. These thoughts were considered to be the essence of reasoning for Descartes, a subject matter that was not open to the challenges of interpretation that plagued other aspects of human judgment. For Descartes, the complexities of judgment extended to how people perceive information from the senses. It was clear to philosophers for some time that illusions could occur. People could experience distortions under different lighting conditions, or when facing comparisons between objects of different sizes. Even the interpretation of marks on paper varied depending upon one's vantage point and the lighting of the room. Indeed, Descartes concluded that the substance of the mind was different and in some sense more pure than the translation of physical stimuli onto the senses and subsequent perception by the mind.

Descartes is famous for claiming that the mind and body were separable. He believed that the human mind was unique, and that it transcended the physiology of the rest of the body. This would include the brain, which

he regarded to be separable from the mind at a core level. In some cases, people still hold such views, as the subjective nature of introspection appears to be in some way separate from the body and the rest of the physical world. This view also implied to Descartes that there was a strong difference between humans and the rest of the natural order. This implied that humans were special and differed fundamentally from other species due to their ability to think in pure terms. Descartes was aware of the ventricles of the brain. He believed that they were important for enabling movements of the body and this led him to form an early, though inaccurate, theory about the relationship between the brain and body. Since humans bleed when cut, Descartes claimed that the mind was able to force fluid from the brain via the pineal body to the muscles of the body. He claimed that movement was achieved through hydraulic pressure. This theory was in part informed by the actions of mechanical statues that existed in Paris at the time, which could be controlled via hydraulic pressure when visitors stepped upon pressure plates.

One of the other major contributions of Descartes to the science of the mind was his interest in mental representations. Descartes referred to these as *models*, and he was also aware that we can think in images and symbols. The models could be manipulated and transformed by the mind. For instance, a model of a chair could be rotated in different ways to imagine the view from the top or underside. Additionally, Descartes contributed to the methods of introspection, or self-referential thinking, which would be a cornerstone method for early psychologists in the centuries to come. Not all of Descartes ideas have stood the test of time, and indeed many are considered to have been refuted many years ago. We cannot, however, overlook his contributions to inquiry on the nature of mental representations, and how they relate to the physical world through our physiology. His writings continue to influence the directions of both philosophy of the mind and experimental psychology.

Other important philosophical contributions to the study of reasoning came from David Hume (1711–1776) (Fig. 2.7). Hume was a pioneer of many ideas that would form the basis for cognitive psychology. Hume claimed that there existed both an external world and an internal one. He claimed that humans were capable of reasoning by combining simple ideas by comparing them. For example, Hume believed we could develop new knowledge by making comparisons between objects. The comparison between two shades of red, for example, led to the concept of identity, a new and abstract form of knowledge (Haberlandt, 1994). This relational comparison ability forms the basis of many later studies of reasoning that took place in the 20th century. Many psychologists still consider relational thinking to be at the



**FIGURE 2.7** David Hume (1711–76) claimed that there existed both an external world and an internal one. He claimed that humans were capable of reasoning by combining simple ideas by comparing them. From Shutterstock.com.

top of a hierarchy of our reasoning abilities (Hummel & Holyoak, 1997).

Hume was also keenly aware of the associations that could be made between sensory events or objects. As an example, he noted that lightning preceded thunder, and thus people would be likely to draw the inference that lightning actually caused thunder. Causal inferences are particularly powerful relational comparisons. Whether we understand the mechanisms of cause ultimately determines whether we are correct in how we attribute cause, but Hume's thinking foreshadows much of the interesting psychology of causal reasoning that we will describe later in Chapter 8. The concept of association would also form the basis of many early programs of psychological research in the late 19th and the 20th century.

Immanuel Kant (1724–1804) was another important philosopher who made enduring contributions to the study of reasoning (Fig. 2.8). Kant was interested in describing the types of knowledge that could exist. He was an early proponent of distinguishing between innate mental abilities and those that were acquired by experience. For Kant, experience was a major driving force that led people to possess knowledge. Kant proposed multiple forms of knowledge. Among these were *dimensions*, *categories*, and *schemas*. Dimensions were the concepts of space and time which people's minds understood innately. Categories meanwhile were the tools of reasoning. Kant described 12 innate categories of reasoning



Immanuel Kant.

**FIGURE 2.8** Immanuel Kant (1724–1804) made enduring contributions to the study of reasoning. Kant was interested in describing the types of knowledge that could exist. He was an early proponent of distinguishing between innate mental abilities and those acquired through experience. *From Shutterstock.com.*

including aspects such as quality and quantity of information. Lastly, schemas referred to units of knowledge. A schema was a general form of knowledge such as animals or trees and did not necessarily refer to particular specific examples. While these are not the modern terms that we would apply to mental representations, the ideas are quite similar to ones that psychologists would later propose. Kant did not believe that one could understand the nature of knowledge without examination of the mind, a concept very similar to the proposals made later by physiologists and psychologists.

### What We Can Learn From the Philosophical Approach

We can benefit greatly by examining some of these historical precursors to the study of reasoning that would flourish later in the 20th century. Many of the ideas contributed by early philosophers of the mind would form the basis for experimental procedures that would develop later. We can see from writings as early as those produced by Plato the concept that the mind was somehow different from the physical aspects of matter and of the world. Plato, Descartes, and others believed that the contents of the mind were in some ways more pure and reliable than aspects of perception

or sensation. The idea that mental representations were important and critical for reasoning can be traced throughout the works of those interested in the philosophy of the mind. We see in the later ideas of Hume and Kant a strong desire to understand and categorize knowledge structures and a realization that reasoning is directly linked to the acquisition and manipulation of knowledge structures. Also foreshadowed by the philosophers of the mind was a realization that events that occurred closely in space and time would come to be associated. These events may even lead to causal inferences, which help us to make sense of the world by enabling predictions to be made between events and their possible outcomes. This idea would continue to influence the psychology of the mind long after these philosophers were gone.

### Limitations of Philosophical Inquiry

While philosophers of the mind were busy describing how things may work in the world and more intimately, within our minds, the approach was still missing something critical. There were no strong methods to test the ideas of Hume, Kant, and others. Introspection or thinking about one's own thinking is an important aspect of psychological theorizing. The challenge is that we cannot distinguish objectively between different theories unless we are able to test these under controlled conditions. This is certainly a challenge as subjectivity cannot help but enter into our deductions, as we are limited to using the mind and brain in order to study these same subjects. A variety of experimental approaches would later enter into popular usage enabling people to be more objective about their conclusions and to be able to test their theories. In order for this to happen, the field had to transition to using a psychological approach to inquiry about the nature of the mind and human reasoning.

## EARLY PSYCHOLOGY OF REASONING

### Reasoning in Early Psychological Research

The late 1800s saw the emergence of psychology as an independent discipline. The earliest psychologists were trained as medical doctors. They became interested in aspects of the mind and were keenly interested in mental representations, memory, and how these processes linked to emerging biological knowledge about the brain.

Wilhelm Wundt (1832–1920) is often considered to be the first experimental psychologist (Fig. 2.9). Wundt founded the first psychology lab in Leipzig, Germany, in 1879. Wundt was trained originally in medicine and physiology, and he was interested in turning the study of the mind into a rigorous discipline that would have the

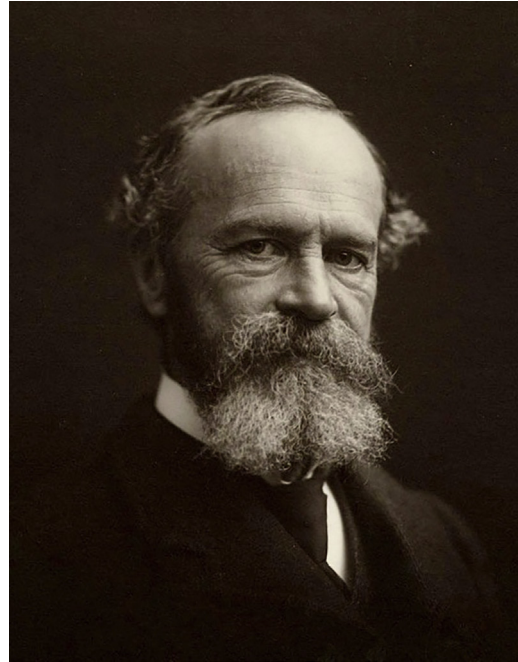


**FIGURE 2.9** Wilhelm Wundt (1832–1920) is often considered to be the first experimental psychologist. He founded the first psychology lab in Leipzig, Germany, in 1879. [Public domain], via Wikimedia Commons.

same inferential power as physiological study. Wundt practiced a style of research that is known as structuralism. He was interested in the structure of how mental events occurred and the regularity of such events.

Introspection was the experimental approach employed by Wundt in order to study the mind. He would ask his research subjects to think inwardly about situations that were described by the experimenter. Ideas that came to the minds of the subjects were reported and scrutinized by the experimenter.

Wundt had a clear impact on the methods used in order to understand the mind, but one of his other decisions would prove challenging for the study of reasoning. Wundt claimed that there were two classes of psychological phenomena, one of them being higher cognition, which depended on language and culture, while the other had more to do with stimulus and response properties. Wundt believed that the higher psychological phenomena that depended upon variables such as culture and language could not be adequately studied using the limited methods that were possible at that time. Rather, he claimed that such thinking could only be adequately characterized by viewing an entire culture. This points out the challenges that early psychologists would face when trying to study abstract processes such as those involved in reasoning. Indeed the evolution of measurement and methodology has had a profound impact upon the success and the nature of theorizing that has accompanied the study of reasoning.



**FIGURE 2.10** William James (1842–1910) is credited with writing the first text of psychology entitled *Principles of Psychology* in 1890. By Notman Studios (photographer)—[1]MS Am 1092 (1185), Series II, 23, Houghton Library, Harvard University, Public Domain, Wikimedia Commons.

William James (1842–1910) is often considered to be the founding father of psychological research in the United States (Fig. 2.10). James is credited with writing the first text of psychology entitled *Principles of Psychology* in 1890. This influential book encapsulated many of the ideas that would make up the fabric of psychological research in the 20th century. James wrote with a visionary quality outlining his views on topics ranging from development to emotion. James even anticipated the Hebb rule of learning and memory, even speculating that pathways within the brain that were regularly activated would become strengthened. Clearly this was almost pure speculation at the neuroscience level, as there were no data or methods by which to determine what was actually occurring at a cellular level in physiology. The ideas could be traced to the nature of human habit formation, which would have been evident to a keen observer. James, like Wundt, was also a prolific mentor of trainees. Many modern researchers can trace their academic training lineage directly back to either Wundt or James. Some of his famous students include physiology pioneer Edward Thorndike, Walter Cannon, who famously described the “fight or flight” response, memory researcher Mary Calkins, and writer Gertrude Stein.

William James described an array of viewpoints on many topics in psychology. Among those was reasoning. James was not exhaustive in his treatment of the topic and ignored many critical distinctions among classes of reasoning, its development in childhood, and deduction

versus induction. James was highly concerned with some critical aspects of reasoning however. Among these was whether humans possessed reasoning abilities that were not present in other species. James was an associationist, like others before him, such as David Hume. James did not view the retrieval of memories in response to sensory stimuli as being unique to humans. When we smell a certain odor and call to mind a particular experience, or concept linked directly to the smell, we are not likely exhibiting anything other than mere association. This type of association, James believed, was akin to what other species may do. James indicated that inferences were perhaps unique to human reasoning in instances when people draw together a new association, particularly one between concepts, or ideas, that had not previously been considered to be related in the past. He referred to reasoning as being *productive* in this regard, rather than merely reproductive, which would describe the simpler associations that had been experienced together repeatedly in past instances (Nickerson, 1990). James also claimed that reasoning enabled people to deal with novel data. This was one of the properties that marked reasoning as being different from other mental processes and perhaps constitutes what is unique about human thinking.

Another feature of reasoning that William James discussed at length was the ability of people to abstract or symbolize concepts or ideas. He claimed that “key to abstraction is the ability to take away the essence of an object, rather than storing the object as a literal copy.” “Every possible case of reasoning involves the extraction of a particular partial aspect of the phenomena thought about,” “whilst empirical thought simply associates phenomena in their entirety, reasoned thought couples them by the conscious use of this extract” (p. 967). James was aware of the differences between perception and conceptualization. He also emphasized that those people who are effective in reasoning are able to focus on the relevant properties of objects and ignore the irrelevant ones. Deciding on relevance is another matter, but assuming one has a clear goal in mind, this would be a capability that is reminiscent of modern researchers’ focus on the role of the frontal lobes in reasoning, as being important for filtering the associations needed for accomplishing a task. An appreciation of similarity and the ability to communicate ideas were other areas of emphasis for James when describing the processes of human reasoning. His influence can still be felt over 100 years later in the work of modern cognitive psychologists, cognitive scientists, and neuroscientists of reasoning.

## The Emergence of Knowledge About the Brain

The 1800s saw the dawning of many important insights about the brain and its physiology. These ideas

would lay the groundwork for much of the remarkable growth and progress in neuroscience observed in the 20th century. Among the key figures in physiology were those studying early animal models, examining the microstructure of the nervous system, and those involved in treating patients who had sustained brain damage.

With regard to reasoning, one particular case endures as one of the most famous instances of a change in biology that brought about a psychological change linked to thinking. Railroad worker Phineas Gage sustained a remarkable injury to his brain during an accident involving a tamping iron. Gage was struck by a 6-ft-long iron rod that had a pointed end. The rod was fired forcibly through his forebrain passing just under his left eye and emerging out of the middle of his frontal lobes. Remarkably Gage survived this catastrophic injury. While details are somewhat incomplete, Gage evidently regained consciousness shortly after the explosion had fired this rod through his brain. Onlookers were shocked that Gage was able to move around and speak shortly after the injury. While the case of Phineas Gage was not studied with the degree of precision that a modern brain injury would be, John Harlow, a local medical doctor did examine Gage and took a strong interest in his case. Phineas Gage apparently escaped with his life, along with many of his faculties remaining intact. Gage’s speech, motor action, and sensory processing were spared, but Harlow did note some rather surprising and ultimately devastating effects of the injury. There is little clear evidence of Phineas Gage’s behavior prior to the injury, but the limited reports of the day indicate that he was moderate, respectful, polite, and a family man prior to the injury. His life after the accident was strikingly different.

Gage underwent an apparent personality change after the tamping iron damaged his frontal lobes. The man who had once been a model citizen fell into difficult times. After the injury, he made poor financial decisions, acted impulsively, used vulgarity, and generally became difficult for others to be around. These same types of traits are also reported in modern day cases of brain injury, in which once highly successful and disciplined individuals fall into making decisions that are unwise, rash, and destructive (Bechara, Tranel, Damasio, & Damasio, 1996). While Phineas Gage did survive, he was apparently never quite the same and suffered from a form of insult to his intellectual faculties. He appears to have had a compromised ability to wisely and effectively plan for the future. He also exhibited difficulties in carrying out his plans, and became irritable and ill-tempered. Gage’s life ended some 14 years later, and he never appeared to have regained his former abilities (See Box 2.2).

## BOX 2.2

## THE REMARKABLE AND TRAGIC LIFE OF PHINEAS GAGE

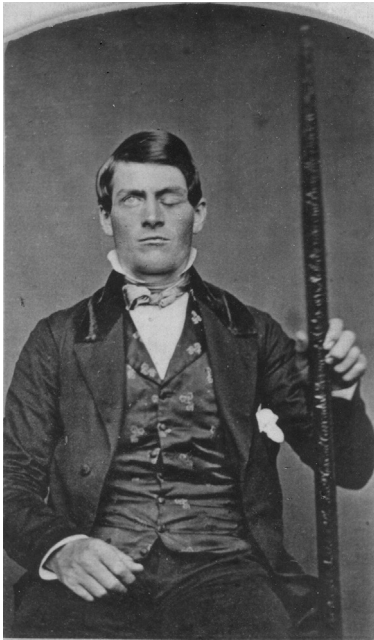
Phineas Gage (1823–1860) was a railroad worker who suffered a remarkable accident on September 13, 1848. Gage was involved in clearing rock for the railway by preparing for dynamite blasts. He worked as a foreman for the Rutland & Burlington Railroad south of the town of Cavendish, Vermont. One particular day he set to work placing a dynamite charge within a hole in the rock. Standard practice of the day was for the charge to have sand poured over it and then the charge could be tamped down further into the rock prior to detonation. The tamping was accomplished using an iron rod. In this case, Phineas Gage set to work using a tamping rod measuring approximately 6 ft in length with a diameter of roughly 3 in. across. One end tapered to a point, while the other was blunt. Gage was apparently ramming down the charge into the rock using the blunt end when a spark presumably detonated the charge prematurely, while Phineas Gage was still working over the hole.

What happened next was stunning to medical personnel at the time. The tamping iron shot upward piercing Phineas Gage just below his left eye. The rod shot through the eye socket passing directly through Gage's frontal lobes. The 3-inch diameter of the bar destroyed a large portion of his medial prefrontal cortex (see Fig. 2.11). The bar then passed up through the middle and dorsal portions

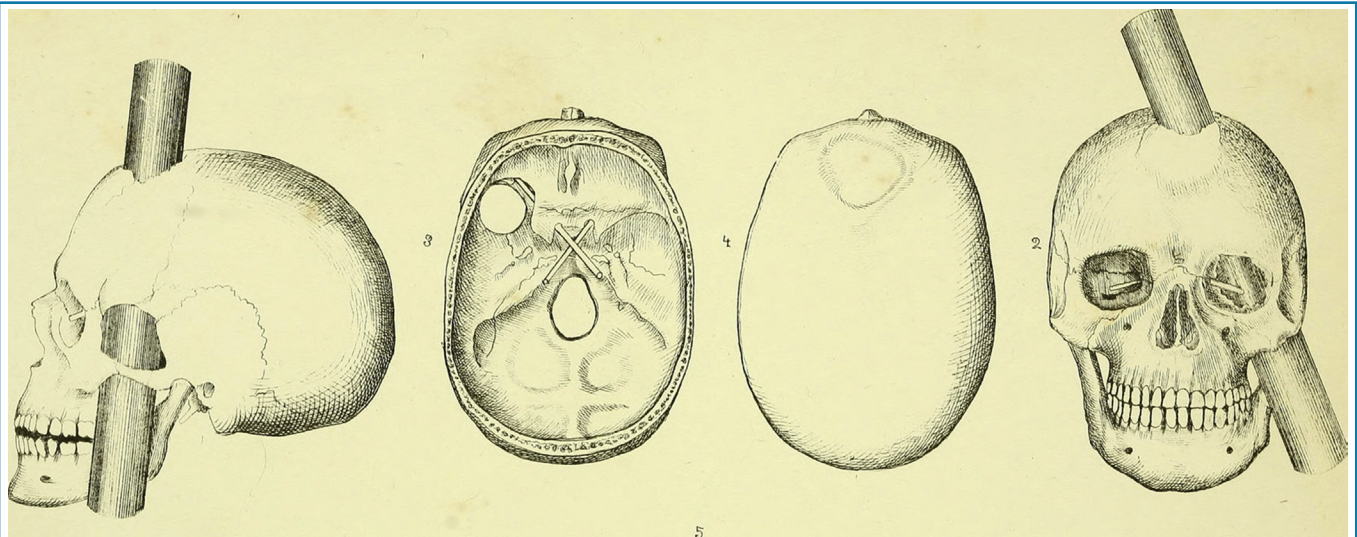
of his frontal lobes before launching out of the top of his head and into the air some 50 ft. Remarkably, Phineas Gage regained consciousness shortly afterward and was up and moving about. John Harlow, a Vermont doctor saw Phineas Gage and made a general examination of the wound. It is remarkable that Gage survived the initial effects of this traumatic injury to his brain and secondly that he did not succumb to an infection afterward. Harlow was fascinated by the injury and that Gage was able to survive.

Little is known for sure about the earlier life of Phineas Gage, but in the aftermath of the injury it became clear that he had acquired some difficulties with his ability to plan, carry out plans, reason, and decide. In modern terms, we would call this an executive function deficit. Executive functions are the mental abilities that allow us to both appreciate and devise plans and to carry them out without becoming distracted or losing focus. In the years following his frontal injury, Phineas Gage had great difficulty in life. He could no longer hold down a job due to problems controlling his temper. He engaged in profanity and was childlike and irritable. According to Harlow, Gage had also become capricious, devising many plans only to scrap them quickly afterward. Gage also had great difficulties with financial decision making and was unable to maintain a stable family life.

Over the course of the next 12 years Phineas Gage led an erratic and challenging life. He ended up finding work as a carnival performer in P. T. Barnum's Circus, in which he carried around and displayed the tamping iron that had so nearly ended his life. Eventually Gage found his way west and died in San Francisco in 1860 from complications related to epilepsy (O'Driscoll & Leach, 1998). He was buried there in a rather infamous cemetery, which would be dug up and relocated in the early 1900s. Realizing that Phineas Gage's body was to be exhumed in the cemetery relocation, researchers at Harvard Medical School asked permission from Gage's relatives to exhume the body. The folks at Harvard were able to acquire Gage's skull, which bears the marks of that incredible injury, as well as the tamping iron itself, which had been buried with Phineas Gage in a rather macabre twist to the story. Both of these items are on display at the Harvard Medical Library in Boston. Having visited this collection, I was amazed at the devastation that the tamping iron had caused to Gage's skull (Fig. 2.12). It is quite apparent that the bones had to fuse back together after massive cracking to enable the enormous width of the tamping iron to pass cleanly through the front of Gage's head.



**FIGURE 2.11** Phineas Gage experienced a devastating brain injury that changed his personality. *Author of underlying work unknown. (File:PhineasPGage.jpg) [Public domain], via Wikimedia Commons.*



**FIGURE 2.12** Researchers have tried to estimate the damage sustained by Phineas Gage using his skull and the tamping iron, which were recovered from his grave. By Piper, Richard Upton, 1816–97; Bigelow, Henry Jacob, 1818–90. *Anaesthetic agents, their mode of exhibition, and physiological effects* [No restrictions], via Wikimedia Commons.

As a side note, the medical community did not quite know what to make of Gage's injury for some time. Some felt the frontal lobes were not especially important in our daily functioning, as Phineas Gage was still able to speak

and move after the injury. Others pointed to Harlow's writings as an indication that damage to the frontal lobes can disrupt cognitive abilities including reasoning and decision making.

Other famous neurological case studies occurred in the 1800s. Two patients contributed significantly to the understanding of how language functioned in the brain. Like reasoning, language was another elusive property of the human mind that appeared to vary extensively in the comparison between humans and other species. Paul Broca was one of the intellectuals of the time. An anthropologist, surgeon, and anatomist in Paris, Broca had been pondering the claim that language functions were localized to the frontal lobes (Dronkers, Plaisant, Iba-Zizen, & Cabanis, 2007). This possibility had been hypothesized by the phrenology community in the middle of the 1800s.

Phrenology was a discipline that had proposed that the functions of the mind and brain could be determined by feeling the protrusions of the head and mapping the largest areas to traits that had been laid out in a map of the head (Fig. 2.13). The claims of phrenology were made prior to any formal analysis of the brain, thus the mapping of function to brain area was very crude and generally inaccurate. An opportunity to test this hypothesis presented itself for Broca in 1860.

Broca was asked to consult about the condition of a patient who had a striking and peculiar speech and language deficit. The patient in question was named Leborgne. He was 51 years old and had a variety of neurological problems. When Leborgne tried to speak or

answer a question, he was limited to the production of just one single repetitive syllable "tan." Leborgne was able to vary his monosyllabic statements by changing the intonation, but was not able to produce anything resembling normal speech and language. The patient did not survive long and upon autopsy, it was discovered that Leborgne had sustained damage to his left frontal lobe. Broca presented this case as evidence for the linkage between language and the frontal lobes (Broca, 1861). Broca confirmed this relationship between anatomy and speech function by examining other similar individuals who had sustained strokes and presented with similar symptoms (Broca, 1865). Broca's modern approach to neurological investigation with these patients advanced the state of the science dramatically from the speculative localization suggested by Franz Joseph Gall's phrenology approach of the early to mid-1800s. The left frontal region would come to be known as Broca's area, and people who sustain this type of injury are described as having Broca's aphasia.

From these early neuropsychology studies, it became clear that damage to different areas of the brain disrupted different functions. Though brain imaging was over 100 years away, the process of documenting the deficits acquired by the victim of an accident or stroke and then viewing the brain or skull after death enabled people to begin to understand how functions



the dogs found naturally interesting and rewarding. The dogs salivated in response to the meat powder, an unconditioned response, as they found the powder appetizing, without training. The presentation of the meat powder was paired with a tone, which initially lacked meaning for the dogs. This tone represented the conditioned stimulus, as conditioning was needed in order for the tone to acquire meaning. Over time, after repeated presentations of the tone, the dogs learned that the tone was predictive of the meat powder and they became conditioned to salivate in response to the tone alone (Fig. 2.15).

Pavlov's famous study is representative of a very different approach to psychological inquiry than that used by Wundt and Ebbinghaus. Pavlov's work had some strong advantages. First, it relied on careful experimental control. The dogs did not have prior experience with the tone. Second, the stimulus was concrete and could be delivered in the same manner across subjects. Third, the presence of a response such as salivation was concrete and uncontroversial. This experimental approach focusing on observable behaviors that could be linked to new stimuli became known as *behaviorism*. Behaviorism had its roots in associationism, which was advocated as a key psychological mechanism during the philosophical era by David Hume. The type of associationism demonstrated by behaviorists was powerful, as it enabled previously unprecedented levels of experimental control and the ability to manipulate single independent variables allowed for strong causal inferences about the outcomes of the experiments.

The widespread adoption of behaviorism across experimental psychologists in the United States came with a price. The focus on purely observable behavior limited the subject matter that could be plausibly studied

under the restrictions of the discipline. Behaviorist studies prevented the study of mental representations of any kind outside of the mechanisms of association. The approach also limited the ability of researchers to study the psychological processes that are involved in everyday life, which had been a key focus of individuals such as William James. The dominance of behaviorism from the early to mid-1900s largely limited the study of reasoning, an area of inquiry that is highly dependent upon understanding the nature of mental representations, semantic memories, and the use of explicit and conscious processing. In time, these limitations prevented American experimental psychology from making progress in critical areas within the field. Change would come in the World War II era, when psychologists began to focus on the practical problems of the war effort. This shifted the focus of experimental psychology in the United States squarely back toward the study of mental representations.

### Behavioral Views on Reasoning and Gestalt Psychology (1920s–1940s)

While behaviorism was dominant in the United States, there was a distinctly different approach to psychology being carried out in parts of Europe. As described earlier in this chapter (Box 2.1), Gestalt psychology was highly active in the study of mental representations. The Gestalt psychologists included Hermann Ebbinghaus, Kurt Koffka, and Wolfgang Kohler. These psychologists were interested in cognitive phenomena that did not involve explicit associationist learning. In fact, one of the most notable contributions of the Gestalt movement was the demonstration that certain types of perceptual phenomena operated almost universally across individuals and that these phenomena did not



**FIGURE 2.15** Pavlov's dogs were presented with a tone followed by meat powder. They would salivate in response to the meat powder. Over time, the dogs learned that the tone predicted the meat powder and therefore salivated simply at the presentation of the tone. Depicted is one of the many dogs Pavlov used in his experiments. Note the saliva catch container and tube surgically implanted in the dog's muzzle. By Rklawton—English Wikipedia, see below, CC BY-SA 3.0, <https://commons.wikimedia.org/w/index.php?curid=601191>.

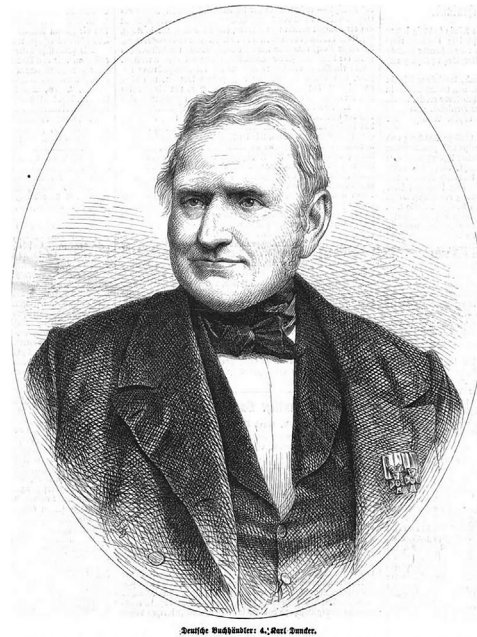
require instances of learning or association to occur. Phenomena such as grouping stimuli based on similarity or proximity were so commonly observed among experimental participants that they were termed principles. A key difference between Gestalt psychology and behaviorism is that the principles implied that the mind was not a blank slate that was merely populated by associations learned by stimulus-response conditioning. Rather, the fact that people so automatically and consistently experienced incoming information in the same manner implied that something structurally significant about our perceptual systems and cognitive abilities was enabling this phenomena to occur. The perceptual principles of Gestalt psychology did not require reward-based association to occur.

For the psychology of reasoning, some of the most noteworthy contributions of Gestalt psychology came about in the domain of insight problem solving. Gestalt psychologists such as Karl Duncker and Wolfgang Kohler were fascinated by the process by which people experienced a leap of insight as they solved a challenging problem. Further, there appeared to be distinct steps that occurred leading to insight. Duncker noted that we appear to undergo a phase of problem exploration. This is followed by a period of attempting a solution and possibly failing. After an incubation period in which the person takes a break from the problem, they may then experience a feeling of insight, an “aha” moment as they obtain a solution. Lastly, the problem solver verifies that his or her solution does indeed solve the problem (Wallas, 1926).

The Gestalt psychologist Karl Duncker (1903–1940) (Fig. 2.16) contributed several important ideas to the problem-solving literature. Behaviorists and earlier psychologists had maintained that problem solving arises from trial-and-error learning and from the experience that the problem solver had. By contrast, Duncker sought to investigate problem solving from an alternative viewpoint, that the solutions come about from the context or situation in which the problem occurs. This different point of view was important in driving Duncker’s research forward (Newell, 1980).

Duncker viewed problem solving in the following manner (summarized from Duncker, 1945):

1. A problem arises when one has a goal, but does not know how to reach it. When one cannot go from the given situation to the desired situation simply by action, then there has to be recourse to thinking.
2. The solution to a new problem typically takes place in successive phases, which takes on the character of a solution over several iterations.
3. The functional value of a solution is critical to the understanding of it being a solution. It can be called the sense, or the principle, of the solution.



**FIGURE 2.16** The Gestalt psychologist Karl Duncker (1903–1940) contributed several important ideas to the problem-solving literature. Created December 31, 1866 By Unbekannter Grafiker der Epoche. (Illustrirte Zeitung, Bd. 49 (1867), S. 108.) [Public domain], via Wikimedia Commons.

4. The final form of an individual solution is, in general, not reached by a single step from the original setting of the problem; on the contrary, the principle, the functional value of the solution, typically arises first and the final form of the solution in question develops only as this principle becomes successively more and more concrete.
5. In the transition to phases in another line of thinking, the thought process may range more or less widely. When every transition involves a return to an earlier phase of the problem, a new branching off from an earlier point in the family tree occurs. Sometimes one may return to the original setting of the problem, or just to the immediately preceding phase.
6. The essential nature of generating a solution is through thinking about sub-elements of the problem and how they meet the goal. Such relatively general procedures, are ‘heuristic methods of thinking’.
7. Every solution takes place, based on the substrates of its particular problem situation.

From this summary, we can get a sense of the thinking of the Gestalt psychologists and how their views differed from the behaviorist viewpoint. Note that the context of the problem was seen to be critical to its solution. The idea of heuristics, or general methods, that can be successfully applied toward solving problems appears. Problem solving is observed to occur in multiple phases and the problem solver may refer back to the original problem, or potentially other points in their

solution, in order to move forward. Many of these phenomena would appear in later forms in the second half of the 20th century when cognitive psychology began to take on these same challenges.

Karl Duncker's methodology was also noteworthy in distinguishing the Gestalt psychologists from the methods commonly used by behaviorists. Duncker frequently used "think aloud techniques," in which a subject was asked to state aloud all of the ideas that came to mind when solving a problem. This approach resembles the introspection analyses that had been popular in the late 1800s as psychological research was just getting started. Among the notable work of Karl Ducker was the introduction of his X-ray problem, in which someone is asked how radiation can be used to destroy a tumor, which is below the surface of the body. A key condition is that there could be no contact between rays and healthy tissue. We will revisit this radiation problem when we discuss reasoning by analogy in [Chapter 10](#).

### Reasoning Research (1930s–1950s)

There were several interesting approaches that did not squarely belong to either behaviorist or Gestalt psychology during the time periods in which those approaches were dominant. Steps were being taken toward understanding the mental processing that makes up reasoning.

One key area of interest centered upon the psychological distinction between inductive and deductive reasoning. These concepts will be the focus of [Chapter 9](#), discussing the differences between these two forms of reasoning and also tracing the full history of research into induction and deduction up to the present. For our purposes in the current chapter of tracing the history of reasoning, we need only discuss some of the developments in this field that took place in the early to mid-1900s.

The key differences between induction and deduction can be summarized on the basis of premises and conclusions. If we were to reason about the possibility of rain, we could do so deductively by evaluating a set of rules. For instance we could have a rule as follows:

If there are dark clouds, then it will rain.

When coupled with the premise *there are dark clouds*, we can conclude that it will rain. This is deduction in action. Notice that we can confidently reach a valid conclusion based on the rule. This rarely happens in our daily life reasoning, due to the probabilistic nature of events in the world and the fallibility of our perception. More commonly, we will make inductive arguments about a domain such as the weather that is determined by numerous complex and interacting factors. An inductive argument about rain could go as follows:

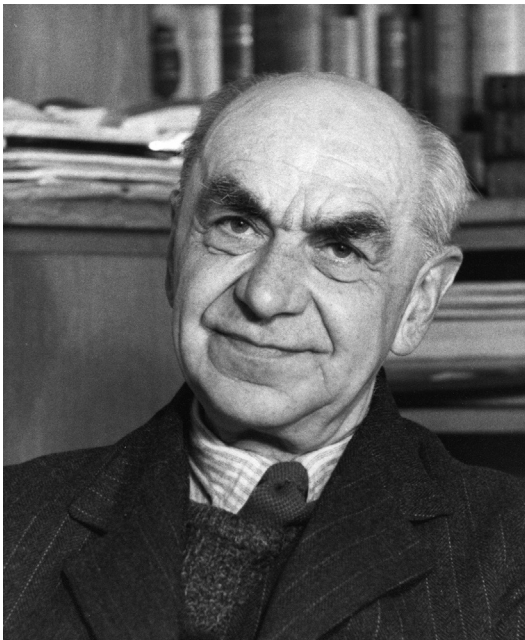
Most of the time that dark clouds are present, rain will follow

The thinker in this case will probably infer that dark clouds are linked to rain. The key difference is that this inference is not guaranteed to be valid. There is not a formal rule present in inductive cases, so they serve as a likely guideline that may prove true much of the time, but they are not necessarily valid. You will probably notice that the deductive case is different only if we can always rely on the rule linking dark clouds to rain. If we cannot (which is the state of affairs in daily life), then we are essentially in a similar place as we would have been with the inductive inference having to make do with some guesswork.

Philosophers long noted that there were fundamental differences between inductive and deductive reasoning, but these differences had not been held up to the scrutiny of behavioral testing. Experimental psychologists began formal investigations into the nature of deduction and induction in the 1920s and 1930s. [Minna Cheves Wilkins \(1928\)](#) reported on a deductive reasoning task, in which participants were asked to evaluate deductive arguments about concrete situations (locations of geographical places) and abstract situations about arbitrary rules involving letters. She found that real-world problems enabled the best inferences. This finding demonstrated the value of human experiments, as the context of the problem contributed greatly toward whether someone could answer soundly. [Robert S. Woodworth and Saul B. Sells \(1935\)](#) followed up Wilkins research, finding further evidence that people struggled to assess the validity of deductive reasoning problems. These researchers noted that people had difficulty processing the specific direction that particular rules specify. They termed this directionality error *an atmosphere effect*, as the atmosphere of the premises appeared to influence how the problem was interpreted. [Irving Janis and Frederick Frick \(1943\)](#) found additional evidence of logical errors in deductive problems and emphasized that people's prior beliefs are one of the major reasons that they fail to reason accurately about validity. This phenomenon became known as the *belief-bias effect*. These early studies helped to inform later work on deductive reasoning carried out by Peter Wason and Philip N. Johnson-Laird in the 1960s and beyond. Less formal work would be carried out on the study of inductive inference in psychology labs until later in the 20th century. It should be noted however, that the scientific method of carrying out hypothesis testing to falsify a hypothesis relies considerably on inductive inference. The philosopher [Karl Popper \(1959\)](#) pointed out that scientists should carry out their research in order to falsify, rather than to confirm, their hypotheses.

Another important early contributor to the study of reasoning in the early 20th century is Sir Frederic Bartlett (1886–1969) of Cambridge University ([Fig. 2.17](#)). Bartlett was a famous British psychologist who is perhaps best known for his 1932 book entitled *Remembering: A Study in Experimental and Social Psychology*. Bartlett was widely interested in perception, reasoning, memory, and even

topics such as fatigue and skill learning as relevant to the World War II efforts of enhancing human performance (Roediger, 2000). Bartlett was a remarkable scholar and an accomplished mentor, giving him a wide influence in the field. Bartlett set up his lab in the 1920s placing him as a contemporary of the behaviorist approach in the United States and the Gestalt school of psychology in Europe. He was well acquainted with numerous researchers of the day, but his work had its own character that was ahead of its time. Like other early experimental psychologists, Bartlett did not employ a formal experimental method, in which one limits themselves to the manipulation of one or more independent variables and carefully measures the results. Rather, Bartlett's group conducted less constrained experiments, in which people were observed performing a task. It should be noted that Bartlett's significant achievements have been replicated under more formal conditions (Bergman & Roediger, 1999; Roediger, 2000). Perhaps Bartlett's most famous contributions about memory can be summarized by his description of a recall exercise entitled "the War of the Ghosts" (we will also discuss this study in more detail in Chapter 3). Participants in this experiment were presented with a relatively complex story about a story about Native American warfare (1932). They were asked to recall the story at a variety of later points in time. The attempts by participants indicated that memory is a reconstructive process, rather than a literal one. People changed details within the story in their attempts to recall it, but fundamentally did get the gist of the



**FIGURE 2.17** Sir Frederic Bartlett (1886–1969) was a famous British psychologist who is perhaps best known for his 1932 book entitled *Remembering: A Study in Experimental and Social Psychology*. Courtesy of the Department of Psychology Archive, University of Cambridge.

story consistently correct. Bartlett referred to the gist of a memory as a schema. The term schema would later become standard in cognitive psychology in the late 20th century, when researchers began to categorize semantic memory. Bartlett was a rare early psychologist who was able to take a broad perspective on human behavior, while also using experimental methods (Roediger, 2000). The enduring contributions of his work on schemas and the reconstructive nature of memory are likely due to his appreciation that numerous factors enable us to solve problems and view the world and that the complexity of human cognition cannot be easily reduced to simple stimulus–response pairings. Indeed, few studies conducted today approach the everyday realism of Bartlett's work from that time period in the 1930s.

Edward Chace Tolman (Fig. 2.18) (1886–1959) is another important transitional figure between the behaviorist and cognitive eras. While Tolman conducted numerous learning experiments on rodents, he was of the opinion that classical conditioning and purely stimulus–response-based learning could not explain all of behavior. Tolman indicated that he believed that the Gestalt psychologists such as Kurt Koffka, with whom he studied, were making important contributions to



**FIGURE 2.18** Edward Chace Tolman (1886–1959) was another important transitional figure between the behaviorist and cognitive eras. Tolman conducted learning studies and postulated that animals used mental representations of their environment. By <http://faculty.frostburg.edu/mbradley/psyography/edwardtolman.html> [FAL], via Wikimedia Commons from Wikimedia Commons.

psychology. Tolman wrote of “mental maps” and demonstrated through his experiments that rats can take shortcuts in maze running. Such behavior indicated to Tolman that the rat is capable of more than simply running through a learned pattern from memory, but rather acted as if it understood the location of a food reward, based on a map-like system of knowledge. He also indicated that rats could alter their behavior within a maze when their starting point had been changed. All of these findings contributed to his proposal that these animals had something analogous to a mental representation of the world in the form of a map. Later research would confirm that the hippocampus has spatially sensitive neurons, a finding that would later result in the awarding of a Nobel Prize for neurophysiologists John O’Keefe, Edvard Moser, and May-Britt Moser in 2014.

## COGNITIVE PSYCHOLOGY OF REASONING

### Cognitive Psychology and Reasoning Research (1950s to Present)

Trends in psychological research in the United States began to change with the experience of World War II. Amid great pressure to develop scientific technology for the war effort, American researchers were active contributors bringing about a stronger focus on information processing. This took the form of two dominant directions: the advancement of computer science and a renewed interest in studying the unobservable aspects of the mind that had been largely ignored in the United States during the era in which behaviorism was dominant. Ultimately, these changes led to the formation of cognitive psychology as a discipline that would change the type of research being conducted on human reasoning.

Computer science was emerging as an important discipline. This development was in part due to the need for computers in code breaking. The 1940s and 1950s saw an expansion of the capabilities for computing on a large scale due to both hardware development and the ability to program the large computing devices of the era. Over a relatively short period of time from the mid-1940s through the 1950s computers shrank in size and expanded in computing capability. The reduction in size was largely due to the changes in hardware. Early research computers such as the Colossus and the ENIAC relied upon vacuum tube technology to implement binary code. The vacuum tubes are similar to light bulbs and consist of a heated filament inside a glass surround. The vacuum tube was both unreliable and demanding of resources. The invention of transistors and then integrated circuits enabled computers to become much smaller, more computationally powerful, and cheaper to run (we discuss computer development further in [Chapter 13](#)). Meanwhile, computer scientists

were taking advantage of the new developing technology to write and execute ever more complex and useful software code. Fundamentally, the computer science movement was based on advancing new ways to store, process, and utilize information. People could not help but take notice that these same operations appeared to apply similarly to the operations of the brain as we carry out cognitive processes.

Experimental psychologists were active in helping with the war effort as well. The work of Donald Broadbent is illustrative of the way that psychologists were able to help ensure that new technological developments operated at maximal efficiency. [Broadbent \(1958\)](#) was interested in the basic perceptual and processing mechanisms of cognition ([Newell, 1985](#)). Broadbent noted that humans were guided by feedback, or information that was provided to them by machines ([Best, 1989](#)). An example of this occurred within aircraft cockpits in which numerous gauges and controls were available to the pilot. By analyzing pilot errors in working with the devices, Broadbent was able to determine that some arrangements of the cockpit were superior to others. The work indicated that there was not a single type of design that could be learned equally well by all pilots, as would be implied by behaviorist learning. According to behaviorist principles, success in flight should have been equally likely regardless of the arrangement of the cockpit, as all learning could be reduced to stimulus–response acquisition. Instead it appeared to Broadbent that different arrangements of the controls would yield different outcomes with the human pilot. Broadbent noted that limitations of attention were likely responsible for the awkward ways that pilots engaged with certain control devices.

Soon a variety of experimental psychologists were beginning to study mental representations. Some of the earliest cognitive psychologists included [George Sperling \(1960\)](#) and [Ulrich Neisser \(1967\)](#) who examined a form of memory known as *sensory memory*. Sensory memory is thought to be separable depending upon sensory modality. Iconic memory is the visual form of sensory memory which has a relatively large capacity of as many as nine items, but which lasted for a very brief duration of under 1 s and is almost constantly being overwritten by new information being taken in by the visual system ([Neisser, 1967](#)). These investigators were also interested in the auditory equivalent of sensory memory, which was a fleeting aftereffect of an incoming sound that lasts approximately 4 s ([Neisser, 1967](#)).

George Miller was another early cognitive psychologist who studied the capacity of short-term memory. This is the type of memory which lasts for a relatively short time, but can be rehearsed in the mind. A classic example of short-term memory occurs when someone reads out a phone number to you, and you say it to yourself several times until you can type it into your phone.

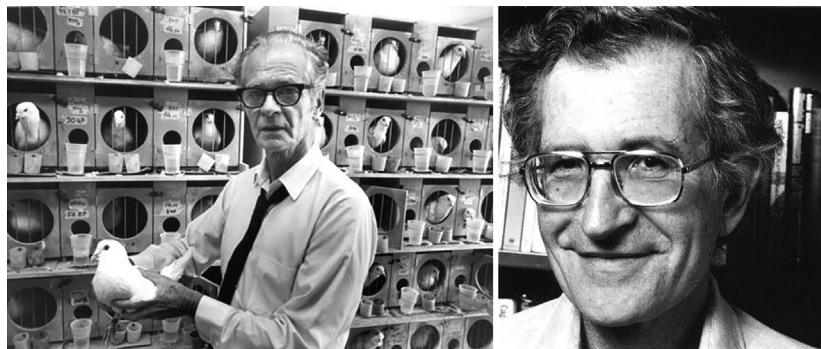
Miller estimated the capacity of short-term memory to be roughly seven items give or take two. His paper on this subject bears the now famous title “The Magic Number Seven Plus or Minus Two” (Miller, 1956). While short-term storage also had a clear upper limit on capacity, it also appeared to be relatively fleeting provided that an individual did not rehearse the items regularly. Other psychologists were interested in the conditions under which the contents of short-term memory would be lost. Waugh and Norman (1965) using a digit-span paradigm demonstrated that memory loss from short-term storage occurred primarily due to interference from other items, rather than purely disuse or decay over time.

Other researchers were interested in higher cognitive functions including reasoning and language. One of the most famous examples of early cognitive psychology was the debate between eminent behaviorist B. F. Skinner and the young linguist Noam Chomsky. In this case, Skinner had published a book entitled “Verbal Behavior” (1957). Skinner’s position was that language was able to be acquired using a classical conditioning method in which a small child looks to the parent or caregiver for reinforcement of each of his or her utterances. The adult would provide reinforcement for the correct behaviors by a head nod or look of approval. Skinner claimed full human language was possible through shaping by reinforcement over time. This position was widely refuted after Noam Chomsky provided a critical review of the book (Fig. 2.19). Chomsky would become well-known for advocating a nativist position on language that it would have to be learned in part by a biological propensity, which he referred to as a language acquisition device. Things had shifted solidly toward a cognitive approach to the study of psychology. Rather than emphasizing learning by context and reward, the field became much more interested in the nature of mental representations and the processes that we engage in to reason and decide.

## The Information Processing Approach to Studying the Mind

The study of psychology would move toward understanding the features of mental representation and mental processing. These features have led many to describe the research following the cognitive revolution as focusing on an information processing approach. From this point forward theories were formed around the types of operations that people carry out and the characteristics of our mental processing.

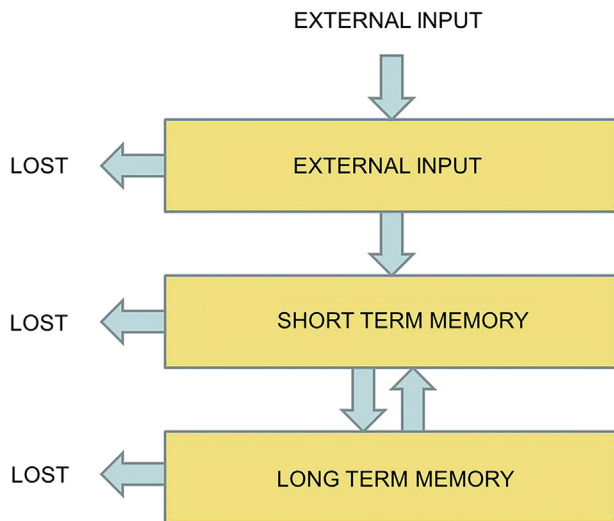
The Atkinson-Shiffrin modal model of memory is an excellent example of the information processing approach in psychology. Richard Atkinson and Richard Shiffrin organized a viewpoint on memory types into a “boxes and arrows” model. The model specified that we have a *sensory store*, as had been studied by researchers such as Sperling (1960) and Neisser (1967). Information within the sensory store was commonly lost, as depicted in Fig. 2.20. Alternatively, the information could be passed on to another box in the model referred to as *short-term storage*. This box differed in quality, compared to the sensory store, as by this point the capacity and duration of storage was believed to vary in comparison to sensory storage. Lastly, a separate box for *long-term memory* represented all of the information that a person maintains indefinitely. This store could both accept new information from short-term storage and place older information back into short-term memory. This model captures the essential qualities of the information processing approach. Rather than describing memory as one unitary process, this model represents the position that multiple types of memory exist, that these forms of memory vary in their duration and capacity, and that information can move interactively from one to another within the set of modules. Other cognitive psychological theories also included these properties. Soon, other models began to



B. F. SKINNER

NOAM CHOMSKY

**FIGURE 2.19** B. F. Skinner and Noam Chomsky had a famous dispute in 1956 over how language was acquired. Skinner was a behaviorist and advocated for a reinforcement learning approach, while Chomsky claimed that children acquire language through biological guidance. Professor B.F. Skinner, (1904–90). Photo: [https://psychbehaviorism.wikispaces.com/CC By-SA](https://psychbehaviorism.wikispaces.com/CC%20By-SA). Noam Chomsky from [wikispaces.com/CC By-SA/3.0](https://wikispaces.com/CC%20By-SA/3.0).



**FIGURE 2.20** Atkinson-Shiffrin modal model of memory demonstrated many of the principles of the information processing approach to cognition.

be programmed formally into computerized simulations called *computational models*, which took the information processing approach to a degree to which actual information processing within a computer could be used to examine and simulate psychological processes.

## Cognition and Reasoning

Alan Newell, J. C. Shaw, and Herbert Simon described some of the early influential cognitive psychology processes believed to be important in reasoning. In a comprehensive paper published in 1958 they emphasized several key components that are necessary for a theory of problem solving. This paper emerged from the authors' observation that no strong theory adequately explained how people solve problems. Their work centered upon the idea that the human mind is an information processing system and that it can be likened to the operations of a computer. Below is a quote from that original paper describing a set of properties that should be able to be specified in order to understand problem solving.

What questions should a theory of problem solving answer?

First, it should predict the performance of a problem solver handling specified tasks. It should explain how human problem solving takes place: what processes are used, and what mechanisms perform these processes. It should predict the incidental phenomena that accompany problem solving, and the relation of these to the problem-solving process... It should show how changes in the attendant conditions - both changes "inside" the problem solver and changes in the task confronting him - alter problem-solving behavior. It should explain how specific and general problem-solving skills are learned, and what it is that the problem solver "has" when he has learned them. [p. 151].

Notice the set of observations contained within this passage. The specification of "how" a problem is to be solved should occur. To get at the larger "how" question, the authors went on to specify that the processes and mechanisms need to be understood. Let's imagine this occurring as you grapple with the problem of entering your first floor apartment after having misplaced your key. The mechanisms and process imply an understanding of the physiology of the brain and what types of information processing will be accomplished along the way toward solving a problem. In our example, relevant internal factors may include your perception of the situation, being stuck outside of a locked apartment, memory in the form of what you know about the building, and perhaps what you know about the security of the building.

In addition to this neurobiological and cognitive specification, the authors indicate that "incidental phenomena" must be specified. In modern terms, we might call this the context under which the problem must be solved. For example, if it is the middle of the night and the neighbor is a light sleeper, then this may indicate that stealth is needed to avoid alerting the neighbor. Furthermore, imagine that it is raining in our example. Perhaps some greater urgency is needed to accomplish the goal and enter the apartment quickly.

The next specification indicates that a dynamic set of circumstances needs to be accounted for. This includes not only the changes that occur within the brain (learning or possibly changes in perception), but also the changes occurring within the situation itself. For example, if you recall that you may have left your bathroom window unlocked, but find that it appears to be jammed, then you have achieved two things: learning that your window is stuck and realizing that this is probably a dead end for the problem. Lastly, assuming that you realize you have a loose window pane that can be pried slightly in order to open the latch and enter the apartment, then you have learned something about yourself and how to approach this problem. You are likely to have more confidence that you can enter your apartment through some means other than the front door. Further, you may now realize that you will be able to accomplish this under other similar circumstances in the future. These features of information processing became the keys to a program known as the general problem solver (GPS).

The GPS idea became influential for two reasons. First, it presented a clear approach offering concrete guidelines and objectives. Second, Newell and Simon programmed an early computer to carry out the GPS in an attempt to duplicate human thinking and in doing so learn about human reasoning. The programmers could give the GPS program a description of the problem to be solved. This is somewhat different than what a human problem

solver would do, as the computer did not have to perceive the problem or specify the goal state and context. This simplified the task of the GPS dramatically. Next, the program would carry out information processing by applying some heuristics and a decision tree could be formed with points for evaluation. The program could implement a *means-ends analysis*, a method that the program could employ to reduce the difference between the current state and end state. This program added depth to the theory and allowed these psychologists to demonstrate several important features of problem solving. Among these features was a correct representation of the problem space, the limitations of our search capabilities, and that the limitations of human problem solving can directly stem from our limitations in formulating the correct representation of the problem (Best, 1989).

Another influential early cognitive psychology approach to reasoning was occurring in the domain of deduction. Philip Johnson-Laird and Peter Wason were interested in how we go about applying rules to achieve outcomes. Wason and Johnson-Laird were studying how deductive arguments are processed. This work followed from the earlier investigations of researchers including Wilkins, Sells, and Woodworth. Johnson-Laird proposed that we use *mental models* to solve such problems. For Johnson-Laird, mental models are representations of the world that can include both visuo-spatial information stored in an analog code, as well as propositional knowledge that is stored in the form of words or symbols. Johnson-Laird et al. claimed that mental models underlie reasoning performance and rely on general knowledge and other relevant representations that move beyond what is explicitly asserted in a set of premises (Johnson-Laird, 1983). In an example representing this approach, Ehrlich, Mani, and Johnson-Laird (1979) provided participants with a set of information involving spatial relations among objects as follows:

The knife is in front of the spoon.  
The spoon is on the left of the glass.  
The glass is behind the dish.

This set of propositions can be linked (in the following order: knife, spoon, glass, dish). A mental model can be constructed additively in this case, unlike an alternative version in which the order was scrambled such as:

The glass is behind the dish.  
The knife is in front of the spoon.  
The spoon is on the left of the glass.

Participants were asked to draw the appropriate spatial layout of these propositional descriptions. Participants with this later set of scrambled

propositions presented out of order would have to construct two mental models and then combine them after receiving the third proposition. Sixty-nine percent of participants' drawings based on continuous premises were correct compared to 42% of the drawings based on the scrambled order of descriptions. This result indicates that people build mental representations of space within their minds in order to solve problems and that the formation of these models can be facilitated or hindered based on the manner in which information is presented.

## A Cognitive Approach to Human Judgment and Decision Making

The psychology of judgment and decision making is a multidisciplinary field that seeks to understand how and why people decide the way that they do. Philosophers, economists, legal scholars, and psychologists have actively studied the nature of our decisions. The study of decision making flourished within the framework of cognitive psychology. Two of the most notable psychologists active in the study of how people make decisions in their daily lives were Daniel Kahneman (born 1934) and Amos Tversky (1937–1996) (Fig. 2.21). Kahneman and Tversky approached the study of judgment and decision making from the perspective that people were not always rational decision makers. This was a challenge for the field of behavioral



**FIGURE 2.21** Daniel Kahneman and Amos Tversky are highly influential researchers in the area of judgment and decision making. Amos Tversky and Daniel Kahneman toast to their partnership in the 1970s. From *Vanity Fair*, Courtesy of Barbara Tversky.

economics, as actual behavior of people out in the world is nonrational. People make errors, decide inconsistently from one context to another, and often respond differently when information is varied or deviates from their prior beliefs. These two researchers revolutionized the study of decision making by demonstrating that people are both nonrational and tend to act differently under different circumstances.

One of Tversky and Kahneman's most notable contributions was the development of Prospect Theory (1981). This served as a general model of how people approach decisions with regard to their perceived gain or loss. Notably, Kahneman and Tversky had established that people tend to behave in a more risky fashion when they are faced with the possibility of a loss compared to when they are faced with the possibility of a gain through extensive experimentation. The gain can be equivalent to the loss, but for most people the loss will be felt with a greater psychological magnitude than the gain. In accordance with this theory, people will take greater risks in order to avoid a loss than they will in order to obtain a gain. This theory also accounts for the finding that people demonstrate an endowment effect, in which they will insist upon a higher selling price for an item that they own than an equivalent item that they are attempting to attain (Kahneman, Knetsch, & Thaler, 1990).

Kahneman and Tversky's work on decision making centered upon mental representations. These researchers demonstrated that contexts matter, as they will influence the way in which a person sees his or her options. This emphasis on mental representations was key to establishing a variety of rules of thumb, referred to as heuristics, by which people see the world and operate on information. The fields of economics, law, and ultimately neuroscience have been dramatically influenced by this approach. This work led to the Nobel Prize for Daniel Kahneman in 2002. Amos Tversky died at the relatively young age of 59 and therefore could not share in this prize, which Kahneman shared with economist Vernon Smith.

## THE EVOLUTION OF COGNITIVE MODELING

### Modeling the Cognitive Processes Involved in Reasoning (1980s–Present)

Computational modeling is an important movement in the evolution of cognitive psychology. Modeling represents the ultimate convergence between the information processing approach, as applied to the mind and that same approach instantiated within machines. Early computational models of reasoning include the general problem solver (GPS) of Alan Newell and Herbert Simon. Experimental psychologists have employed cognitive

modeling as a method for furthering our understanding of human cognition for over five decades. Some of the best instances of the approach combine computational models with human experiments that can test the predictions made by the model. This approach bears strong resemblance to artificial intelligence (AI), an endeavor in which people attempt to build a computer that captures and carries out aspects of intelligent behavior. The major difference between computational models of cognition and AI models is that computational cognitive models are usually intended to simulate aspects of the human nervous system and are therefore constrained by biological characteristics of the human brain. AI models, by contrast, can at times exceed the capabilities of biological cognition, or carry out operations in a completely different manner.

### Parallel Distributed Processing

One of the most influential approaches employed within cognitive modeling is known as parallel distributed processing (PDP). PDP modeling originated with simulations by David Rumelhart and James McClelland (1986). These researchers wanted to build computational models of cognition that aligned with the biology of the mind. They set out a series of principles by which PDP models should operate. One of the most important of these principles was the dense interconnectivity of processing nodes within the models. This interconnectivity is intended to simulate the axons, which relay neural impulses within biological neural systems. These critical connections have also led PDP models to be referred to as *connectionist models*.

The principles of connectionist models are listed below. These models can be built to simulate a variety of processes within cognition. The principles align with the idea that simple binary on/off processing units can be built up into organized networks that can then carry out sophisticated processing such as that observed in human thinking and reasoning. These principles align with those described years earlier by Oliver Selfridge's (1959) *Pandemonium* architecture. An advance by McClelland and Rumelhart was developing the principles into a programming method that could be used to simulate numerous areas of cognition. PDP models include the following elements:

1. Primitive processors with an on/off binary code
2. Processors are stacked in layers
3. The layers connect via inhibitory and excitatory connections
4. Energy is transmitted through the connections
5. Iterations can simulate information processing

Note that each of these aspects simulates a property of the nervous system. The on/off primitive processors

correspond to the action potentials, or spike trains of neurons that activate in an “all-or-none” fashion. The stacked layers correspond to topographic functional units of cortical neurons that carry out a similar aspect of processing. The connections simulate the axons of a nervous system, while energy simulates the movement of information transmitted through the connections of neurons. Lastly, the modification of the network strength by iterative tuning simulates the principle that neural connections can be modified by experience.

Fig. 2.22 presents a diagram of a PDP connectionist architecture. In this case, the layers simulate the visual processing needed in order to recognize words. The connections among the layers enable more complex behavior to be derived from the system of simple primitive processors. PDP models were prevalent in cognitive psychology in the 1980s and 1990s. By the early 2000s the emphasis had shifted to include neuroimaging experiments to test aspects of connectionist models and PDP simulations of how a system degrades after brain injury.

### Hybrid Models

An excellent example of a connectionist inspired model of thinking and reasoning is the Learning and Inference with Schemas and Analogies (LISA) model by Hummel and Keith Holyoak (1997). The connectionist principles can be highly effective for building up toward

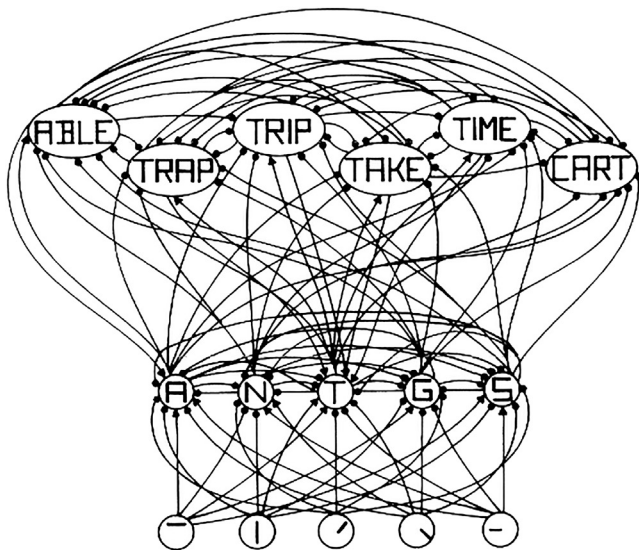
complex representations such as words or concepts. Reasoning involves building those complex representations into even more complicated entities and matching patterns at a hierarchical scale. The LISA model uses a connectionist style architecture to simulate knowledge at the level of simple semantic information, sub-propositional (language based) representations, and propositional representations (of the sort used in analogies and schemas). The combination of propositional representations (made up of words) and the use of connectionist principles enabled this model to simulate basic results in human cognition using a modeling process that was compatible with features of the human nervous system (Krawczyk, Holyoak, & Hummel, 2004).

## DEVELOPMENTAL PSYCHOLOGY OF REASONING

### Studies of Infant Cognition

There are important contributions to the study of reasoning that can be traced to early infancy and childhood. The work of Jean Piaget (1986–1980) is particularly noteworthy in this area. Piaget will be discussed in much more detail in Chapter 5 when we cover the development of reasoning. For Piaget, the child was seen as an active learner. Piaget specified a series of cognitive stages that children pass through from the preschool years through age 12. These stages traced the competencies of children as they aged. The child was originally seen as being limited to sensory and motor processing in infancy through age two. By the early preschool period Piaget claimed that children begin to exhibit reasoning about the world around them, but that they are limited to a self-centered viewpoint. As the elementary school years begin, Piaget argued that children move toward a phase in which they are capable of more abstract and symbolic thinking. Lastly, Piaget claimed children moved toward a period of formalized cognitive operations. This period includes the development of skills that enable young people to test hypotheses about the world around them and carry out principled deductive and inductive reasoning.

Piaget worked on many notable features of development. He explained the hypothesis that children move away from egocentric thinking as they age. Another major contribution by Piaget was the idea that children move from perceptual to abstract representations as they age. The stages proposed by Piaget are somewhat approximate and much work has been carried out in the subsequent decades testing the predictions of Piaget’s developmental stages. Piaget had a long and productive career testing his ideas experimentally,



**FIGURE 2.22** A schematic example of a PDP connectionist model. In the model, lines are represented in one layer. These pass activation up to a letter recognition layer. Lastly, a word recognition layer receives activation from the relevant letters one layer down. Rumelhart, D. E., McClelland, J. L., & PDP Research Group (Eds.) (1986). *Parallel distributed processing* (vol. 1). Cambridge, MA: M.I.T. Press, A Bradford Book. *Psychological Review*, 88(5), 375–407. Reprinted (or adapted) with permission.

and he also mentored numerous individuals who would go on to become leading developmental psychologists themselves. For several decades researchers have continued to test Piaget's ideas. Many of his proposals about child development have held up under decades of experimental scrutiny. His influence on the cognitive development of thinking and reasoning is far-reaching.

## NEUROSCIENCE OF REASONING

### The Emergence of Cognitive Neuroscience (1990–Present)

The formation of the field of cognitive neuroscience has led to new perspectives on the study of reasoning that were primarily driven by the availability of new methods. The term *cognitive neuroscience* was coined around 1980 by Michael Gazzaniga, a neuroscientist, and cognitive psychologist George Miller who was known for his work on memory. Gazzaniga is widely known for the study of the cognitive effects of split-brain surgery, in which the two hemispheres of the brain are disconnected in order to control epilepsy. The split-brain surgery afforded researchers an experimental preparation in which they could examine the largely independent contributions of the two cerebral hemispheres. We will discuss the work of Gazzaniga on split-brain patients in greater detail in [Chapter 8](#).

The development of neuroimaging methods enabled new ways to study a range of cognitive phenomena including reasoning, decision making, social cognition, and deduction. The first functional imaging experiments were conducted using a technique called positron emission tomography (PET). PET scanning involves the injection of a radioactive tracer into a person's bloodstream. The participant is then placed within a scanner that is able to detect the presence of the tracer in the brain. As neurons become active, there is an associated increase in glucose metabolism that results in greater amounts of tracer being taken up into different areas of the brain. Attention psychologist and neuroscientist John [Duncan et al. \(2000\)](#) published an intriguing functional neuroimaging study of reasoning and intelligence. In the study, Duncan et al. had presented participants with problems associated with high degrees of fluid reasoning engagement, resulting in lower accuracy and higher response times, and ones that were simpler pattern matching problems. These researchers were able to isolate a larger degree of brain activity in the left middle frontal gyrus associated with more effortful reasoning performance. PET enabled researchers to begin to map the cognitive processes involved in reasoning and other cognitive phenomena to their associated brain areas. This is an

ongoing effort that continues to become more sophisticated as new methodologies emerge. We will discuss this technique in further detail in [Chapter 3](#).

By the middle of the 1990s magnetic resonance imaging (MRI) had largely replaced PET as a preferred method for functional imaging. Functional MRI (fMRI) scanning allowed researchers to carry out experiments that addressed locating the cortical areas that are associated with behavior and mental processing. For the study of reasoning, the technology was initially useful for specifying the neural correlates of executive functions in working memory ([D'Esposito et al., 1995](#)). In the late 1990s researchers began to apply neuroimaging toward understanding fluid reasoning abilities and the neural basis of intelligence. This is one of the major topics discussed in [Chapter 3](#). Functional MRI enabled investigators to better determine what regions were most associated with different forms of reasoning. Soon researchers were able to carry out neuroimaging studies to compare different forms of reasoning including deductive and inductive reasoning ([Goel & Dolan, 2000](#)), analogical reasoning ([Wharton et al., 2000](#)), relational reasoning ([Prabhakaran, Smith, Desmond, Glover, & Gabrieli, 1997](#)), and spatial reasoning ([Vartanian & Goel, 2005](#)). The capability of neuroimaging was obvious and the technology proved useful in adding another form of analysis toward categorizing and understanding the processes involved in reasoning.

The limitations of neuroimaging are also evident after over two decades of functional MRI studies of reasoning. While fMRI allows a reasonably fast sampling rate, it relies largely upon blood oxygen changes for its marker of neural activity. Blood travels slower (on the order of seconds) than neurons can produce action potentials (on the order of milliseconds), thus there is a delay in the response relative to the actual speed of neural transmission. Additionally, fMRI studies provide limited access to the mental representations that are being processed within a cortical area. We still do not understand the neural codes that are being transmitted to other brain areas when an area of the brain is active in a neuroimaging study. Thus, the fundamental representational units of a reasoning task are still largely unspecified. Additionally, neuroimaging tends to lead to localizationist theories, as some regions of interest appear as active in a particular task. The emerging picture facilitated by fMRI studies is that widespread networks are involved in complex cognitive tasks such as reasoning and deciding. While fMRI can also reflect the activity of networks associated with reasoning ([Shokri-Kojori, Motes, Rypma, & Krawczyk, 2012](#)), the precise way that regions of interest interact with larger neural networks remains a major target of current and future investigation.

## SUMMARY

The study of reasoning has a long and fascinating history. We have examined many of the approaches that have led to our current understanding of this field. In summary, there was remarkable progress made in the 20th century. This moved the field from a philosophical area of inquiry in which the only experiments were primarily involving intuition and introspection about one's mental processes. The methods of experimental psychology enabled researchers to examine the role of context in reasoning accuracy and speed. Additionally, these methods enabled researchers to find consistencies across people forming principles of reasoning.

Psychology continues to participate strongly in the multidisciplinary field of reasoning research. As we will see in the coming chapters, important contributions to reasoning research are being made from neuroscience, comparative psychology, cognitive development, aging research, neurology, psychiatry, and behavioral economics. Social psychologists, as well as technological innovators, including game developers, computer modelers, and software developers are playing increasingly large roles in this research area. Reasoning has come a long way and has a bright and exciting future, thanks in large part to the continuing development of methods and technological advances.

## END-OF-CHAPTER THOUGHT QUESTIONS

- Psychological inquiry made remarkable progress in the 20th century. Had philosophers begun to use experimental methods earlier on, how much progress do you think they would have made prior to advances in physiology?
- This field moved from being primarily a philosophical area of inquiry to a psychological one. Is there still a strong role for philosophy in the study of reasoning? How are these disciplines related?
- The methods of experimental psychology enabled researchers to examine the role of context in reasoning accuracy and speed. How far can the field of reasoning get based only upon these behavioral methods? What other data may be important?
- Early studies of reasoning were carried out in Europe by the Gestalt school of psychology. These researchers focused on the role of insight in problem solving. How much progress have we made in understanding insight since those early times?
- In the first half of the 20th century behaviorism dominated psychological inquiry in the United States. How would you study reasoning using behaviorist methods of stimulus-response observation?
- Early studies of deductive reasoning were carried out in the early 20th century. Why do you think these studies managed to emerge despite moving strongly against the restrictions of behaviorism?
- Modeling cognitive phenomena requires a sensitivity to both the architecture of the nervous system and the interactivity of information within the mind. How do cognitive models relate to the advancing field of AI?
- Technological advances in brain imaging opened up a wide array of new avenues for linking neuroscience principles with reasoning research. What are some of the limitations of MRI as a tool for studying the nervous system?

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