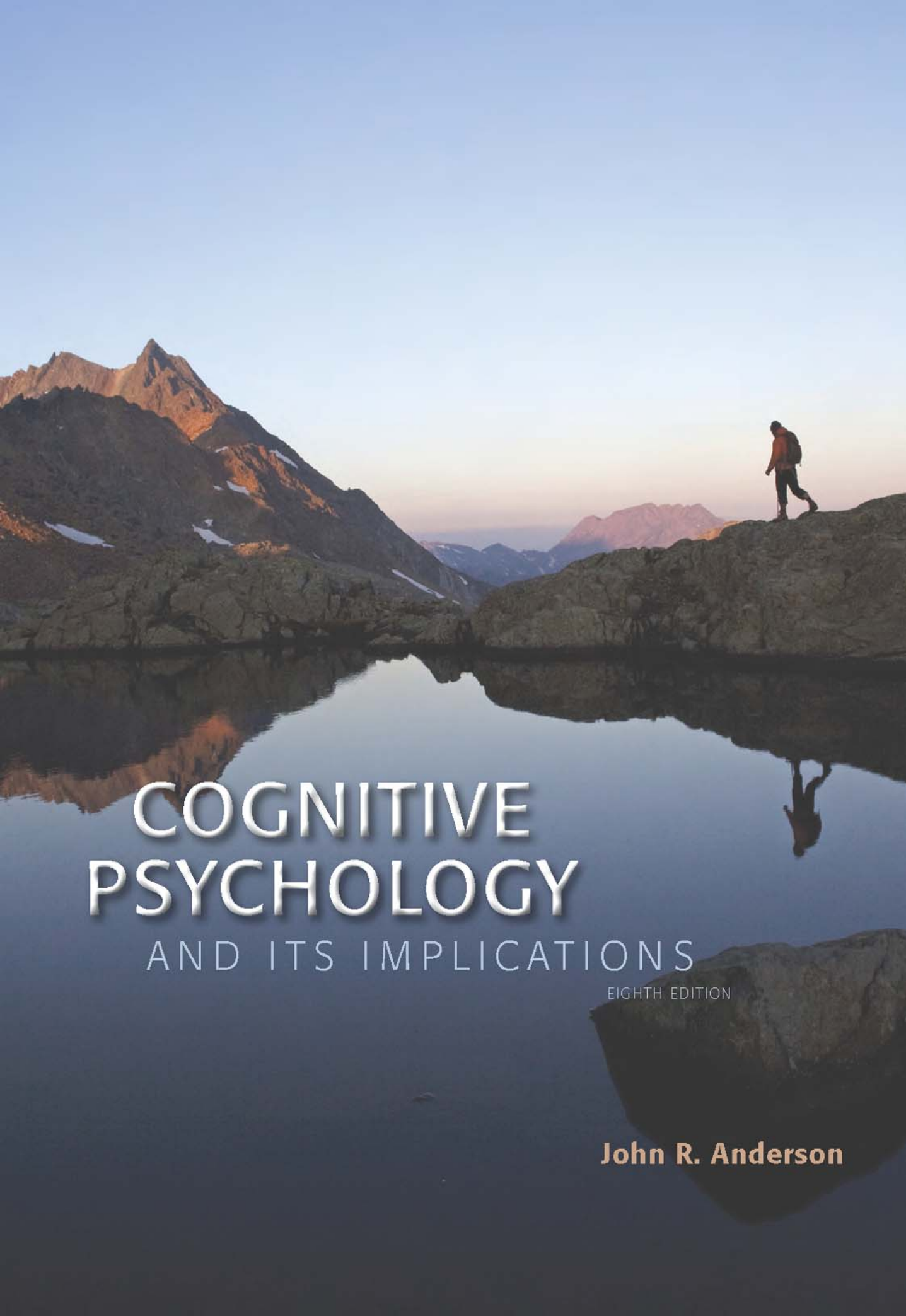

COGNITIVE PSYCHOLOGY

AND ITS IMPLICATIONS

EIGHTH EDITION

John R. Anderson

Cognitive Psychology and Its Implications

Eighth Edition

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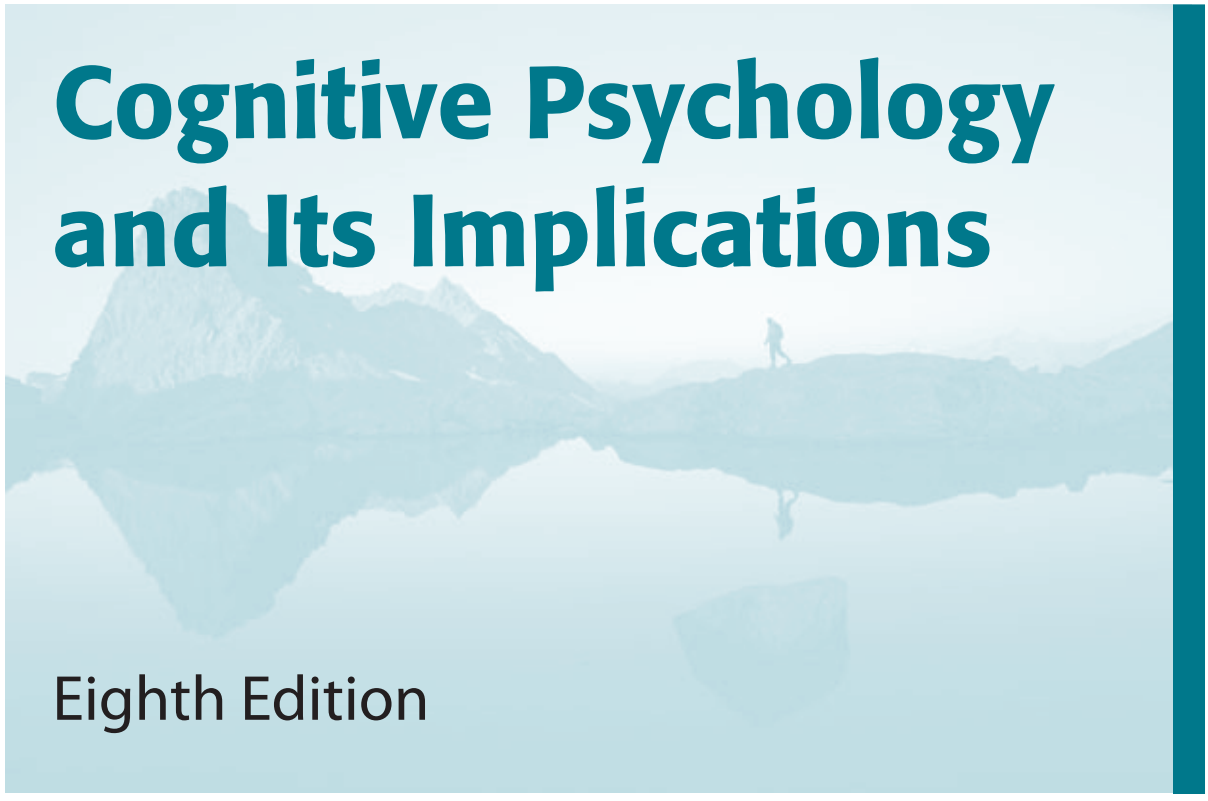
Cognitive Psychology and Its Implications



Eighth Edition

John R. Anderson
Carnegie Mellon University

WORTH PUBLISHERS

A Macmillan Education Company

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Composition: MPS Ltd.
Printing and Binding: RR Donnelley and Sons
Cover Painting: Mario Colonel/Aurora/Getty Images

Library of Congress Control Number: 2014938514

ISBN-13: 978-1-4641-4891-0
ISBN-10: 1-4641-4891-0

Printed in the United States of America

First Printing

Worth Publishers
41 Madison Avenue
New York, NY 10010
www.worthpublishers.com

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John Robert Anderson is Richard King Mellon Professor of Psychology and Computer Science at Carnegie Mellon University. He is known for developing ACT-R, which is the most widely used cognitive architecture in cognitive science. Anderson was also an early leader in research on intelligent tutoring systems, and computer systems based on his cognitive tutors currently teach mathematics to about 500,000 children in American schools. He has served as President of the Cognitive Science Society, and has been elected to the American Academy of Arts and Sciences, the National Academy of Sciences, and the American Philosophical Society. He has received numerous scientific awards including the American Psychological Association's Distinguished Scientific Career Award, the David E. Rumelhart Prize for Contributions to the Formal Analysis of Human Cognition, and the inaugural Dr. A. H. Heineken Prize for Cognitive Science. He is completing his term as editor of the prestigious *Psychological Review*.

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Brief Contents

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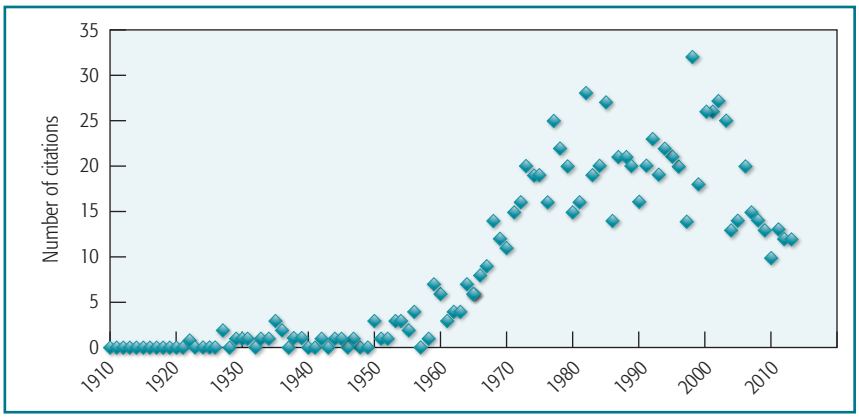
Preface

This is the eighth edition of my textbook—a new edition has appeared every 5 years. The first edition was written more than half of my life ago. In writing this preface I thought I would take the opportunity to reflect on where the field has been, where it is, where it is going, and how this is reflected in the book. One piece of evidence to inform this reflection is the chart showing number of citations to publication in each of the last 100 years. I have not felt the need to throw out references to classic studies that still serve their purpose, and so this provides one measure of how research over the years serves to shape my conception of the field—a conception that I think is shared by many researchers. There are a couple of fairly transparent historical discontinuities in that graph and a couple of not so apparent changes:

- There are very few citations to papers before the end of World War II, and then there is a rapid rise in citations. Essentially, the Greatest Generation came back from the war, broke the behaviorist grip on psychology, and started the cognitive revolution. The growing number of citations reflects the rise of a new way of studying and understanding the human mind.
- The number of citations basically asymptotes about the time of the publication of the first edition of this textbook in 1980. Being a baby boomer, when I came into the field, I was able to start with the framework that the pioneers had established and organize it into a coherent structure that appeared in the first edition.
- The relatively stable level of citations since 1980 hides a major development in the field that began to really establish itself in the 1990s. Early research had focused on behavioral measures because it seemed impossible to ethically study what was in the human brain. However, new techniques in neural imaging arose that allowed us to complement that research with neural measures. This is complemented by research on animals, particularly primates.
- There is a dip over the last 5 years. This reflects the need to properly digest the significance of the most current research. I could be wrong, but I think we are on the verge of significant change brought about by our ability to mine large data sets. We are now able to detect significant patterns in the huge amounts of data we can collect about people, both in terms of the activity of their brains and their activities in the world. Some of this comes out in the textbook's discussion of the most recent research.

Each instructor will use a textbook in his or her own way, but when I teach from this book, I impose the following structure on it:

- The introductory chapter provides a preparation for understanding what is in the subsequent chapters, and the last chapter provides a reflection on how all the pieces fit together in human cognition and intelligence.



- The meat of the textbook is the middle 12 chapters, and they naturally organize themselves into 6 thematic pairs on perception and attention, knowledge representation, memory, problem solving, reasoning and decision making, and language.
- There is a major break between the first three pairs and the last three pairs. As I tell my class at that point: "Most of what we have discussed up to this point is true of all primates. Most of what we are going to talk about is only true of humans."

◆ New in the Eighth Edition

This new edition discusses current and exciting themes in cognitive psychology.

One of these themes is the increasing cognitive capacity of modern technology. Chapter 1 opens with discussion of Watson's performance on *Jeopardy,* Apple's Siri, and Ray Kurzwell's prophesy of the impending Singularity. Chapter 2 discusses new technological developments in character and face recognition. Chapter 4 describes new "mind-reading" research that uses fMRI to reconstruct the thoughts and images of people.

A complementary theme explores the bounds on human intellectual capacity. Chapter 5 describes new research on people with near-perfect autobiographical memory, as well as everyone's high capacity to remember images. Chapter 6 examines new research on the special benefits of self-testing, and new research on flashbulb memories for 9/11. Chapter 8 describes new research on the role of worked examples in acquiring problem-solving operators. Chapter 9 examines new research on the general cognitive benefits of working-memory practice and video-game playing, as well as the controversy surrounding these results. The final chapter explores new theories of the interaction between genetic factors and environmental factors in shaping intelligence.

A third theme is the increasing ability of neuroscience to penetrate the mind. Chapter 3 describes research relating visual neglect to deficits in conceptual judgments about number order and alphabetical order. Chapter 5 discusses the new work in neurosemantics. Chapter 6 describes new meta-analyses on the regions of the brain that support working memory. Chapter 11 describes the evidence connecting the response of the dopamine neurons to theories of reinforcement learning. Chapter 14 describes the research showing that single neurons are tuned to recognize specific numbers of objects.

Then there are introductions to some of the new theoretical frameworks that are shaping modern research. Chapter 7 describes the current state of research on retrieval-induced interference. Chapter 10 describes dual-process theories of reasoning. Bayesian analyses are playing an increasing role in our

field, and Chapter 12 describes one example of how the world's kinship terms are optimally chosen for communicative purposes. Chapter 13 describes the role of situation models in text comprehension.

◆ New Teaching and Learning Resources

Our newest set of online materials, *LaunchPad Solo,* provides tools and topically relevant content that you need to teach your class. *LaunchPad Solo for Cognitive Psychology* includes 45 experiments that helped establish the core of our understanding of cognitive functions. Taking the role of experimenter, you will work in a first-of-its-kind interactive environment that lets you manipulate variables, collect data, and analyze results.

Instructor resources include an Instructor's Manual, computerized test bank, and Illustration and Lecture slides.

Acknowledgments

There are three individuals who have really helped me in the writing of this edition. In addition to all of her other responsibilities, my Senior Acquisitions Editor Christine Cardone has provided a great set of reviews that helped me appreciate both how others see the directions of the field and how others teach from this text. The Development Editor, Len Neufeld, did a terrific job fact-checking every bit of the book and providing it with a long overdue line-by-line polishing. Finally, my son, Abraham Anderson, went through all of the text, holding back no punches about how it registers with his generation.

In addition to Chris Cardone and Len Neufeld, I also acknowledge the assistance of the following people from Worth: Kerry O'Shaughnessy, Project Editor; Catherine Michaelsen, Assistant Editor; Sarah Segal, Production Manager; Janice Donnola, Illustration Coordinator; Bianca Moscatelli, Photo Editor; Tracey Kuehn, Director of Editing, Design, and Media Production; Anthony Casciano, Associate Media Editor; Diane Blume, Art Director; and Vicki Tomaselli and Dreamit Inc., who designed the cover and the interior, respectively.

I am grateful for the many comments and suggestions of the reviewers of this eighth edition: Erik Altman, *Michigan State University;* Walter Beagley, *Alma College;* Kyle Cave, *University of Massachusetts;* Chung-Yiu Peter Chiu, *University of Cincinnati;* Michael Dodd, *University of Nebraska, Lincoln;* Jonathan Evans, *University of Plymouth;* Evan Heit, *University of California, Merced;* Arturo Hernandez, *University of Houston;* Daniel Jacobson, *Eastern Michigan University;* Mike Oaksford, *Birkbeck College, University of London;* Thomas Palmeri, *Vanderbilt University;* Jacqueline Park, *Vanguard University;* David Neil Rapp, *Northwestern University;* Christian Schunn, *University of Pittsburgh;* Scott Slotnick, *Boston College;* Niels Taatgen, *University of Groningen;* Peter Vishton, *College of William & Mary;* and Xiaowei Zhao, *Emmanuel College.*

I would also like to thank the people who read the first seven editions of my book, because much of their earlier influence remains: Chris Allan, Nancy Alvarado, Jim Anderson, James Beale, Irv Biederman, Liz Bjork, Stephen Blessing, Lyle Bourne, John Bransford, Bruce Britton, Tracy Brown, Gregory Burton, Robert Calfee, Pat Carpenter, Bill Chase, Nick Chater, Micki Chi, Bill Clancy, Chuck Clifton, Lynne Cooper, Gus Craik, Bob Crowder, Ann Devlin, Mike Dodd, Thomas Donnelly, David Elmes, K. Anders Ericsson, Martha Farah, Ronald Finke, Ira Fischler, Susan Fiske, Michael Gazzaniga, Ellen Gagné, Rochel Gelman, Barbara Greene, Alyse Hachey, Dorothea Halpert, Lynn Hasher, Geoff Hinton, Kathy Hirsh-Pasek, Buz Hunt, Louna Hernandez-Jarvis,

Robert Hines, Robert Hoffman, Martha Hubertz, Lumei Hui, Laree Huntsman, Lynn Hyah, Earl Hunt, Andrew Johnson, Philip Johnson-Laird, Marcel Just, Stephen Keele, Walter Kintsch, Dave Klahr, Steve Kosslyn, Al Lesgold, Clayton Lewis, Beth Loftus, Marsha Lovett, Maryellen MacDonald, Michael McGuire, Brian MacWhinney, Dominic Massaro, Jay McClelland, Karen J. Mitchell, John D. Murray, Al Newell, E. Slater Newman, Don Norman, Gary Olson, Allan Paivio, Thomas Palmieri, Nancy Pennington, Jane Perlmutter, Peter Polson, Jim Pomerantz, Mike Posner, Roger Ratcliff, Lynne Reder, Steve Reed, Russ Revlin, Phillip Rice, Lance Rips, Roddy Roediger, Daniel Schacter, Jay Schumacher, Miriam Schustack, Terry Sejnowski, Bob Siegler, Murray Singer, Ed Smith, Kathy Spoehr, Bob Sternberg, Roman Taraban, Charles Tatum, Joseph Thompson, Dave Tieman, Tom Trabasso, Henry Wall, Charles A. Weaver, Patricia de Winstanley, Larry Wood, and Maria Zaragoza.

1 The Science of Cognition

Our species is called *Homo sapiens,* or "human, the wise," reflecting the general belief that our superior thought processes are what distinguish us from other animals. Today we all know that the brain is the organ of the human mind, but the connection between the brain and the mind was not always known. For instance, in a colossal misassociation, the Greek philosopher Aristotle localized the mind in the heart. He thought the function of the brain was to cool the blood. **Cognitive psychology** is the science of how the mind is organized to produce intelligent thought and how the mind is realized in the brain.

This chapter introduces fundamental concepts that set the stage for the rest of the book by addressing the following questions:

- Why do people study cognitive psychology?
- Where and when did cognitive psychology originate?
- How is the mind realized in the body?
  - How do the cells in the brain process information?
  - What parts of the brain are responsible for different functions?
  - What are the methods for studying the brain?

◆ Motivations for Studying Cognitive Psychology

Intellectual Curiosity

As with any scientific inquiry, the thirst for knowledge provides much of the impetus to study cognitive psychology. In this respect, the cognitive psychologist is like the tinkerer who wants to know how a clock works. The human mind is particularly fascinating: It displays a remarkable intelligence and ability to adapt. Yet we are often unaware of the extraordinary aspects of human cognition. Just as when watching a live television broadcast of a distant news event we rarely consider the sophisticated technologies that make the broadcast possible, we also rarely think about the sophisticated mental processes that enable us to understand that news event. Cognitive psychologists strive to understand the mechanisms that make such intellectual sophistication possible.

The inner workings of the human mind are far more intricate than the most complicated systems of modern technology. For over half a century, researchers in the field of **artificial intelligence (AI)** have been attempting to develop programs that will enable computers to display intelligent behavior. There have been some notable successes, such as IBM's Watson that won over

human contestants on *Jeopardy* and the iPhone personal assistant Siri. Still, AI researchers realize they are a long way from creating a program that matches humans in generalized intelligence, with human flexibility in recalling facts, solving problems, reasoning, learning, and processing language. This failure of AI to achieve human-level intelligence has become the cause of a great deal of soul-searching by some of the founders of AI (e.g., McCarthy, 1996; Nilsson, 2005). There is a resurging view that AI needs to pay more attention to how human thought functions.

There does not appear to be anything magical about human intelligence that would make it impossible to model in a computer. Scientific discovery, for instance, is often thought of as the ultimate accomplishment of human intelligence: Scientists supposedly make great leaps of intuition to explain a puzzling set of data. Formulating a novel scientific theory is supposed to require both great creativity and special deductive powers. But is this actually the case? Herbert Simon, who won the 1978 Nobel Prize for his theoretical work in economics, spent the last 40 years of his life studying cognitive psychology. Among other things, he focused on the intellectual accomplishments involved in "doing" science. He and his colleagues (Langley, Simon, Bradshaw, & Zytkow, 1987) built computer programs to simulate the problem-solving activities involved in such scientific feats as Kepler's discovery of the laws of planetary motion and Ohm's development of his law for electric circuits. Simon also examined the processes involved in his own now-famous scientific discoveries (Simon, 1989). In all cases, he found that the methods of scientific discovery could be explained in terms of the basic cognitive processes that we study in cognitive psychology. He wrote that many of these activities are just well-understood problem-solving processes (e.g., as covered in Chapters 8 and 9). He says:

> Moreover, the insight that is supposed to be required for such work as discovery turns out to be synonymous with the familiar process of recognition; and other terms commonly used in the discussion of creative work—such terms as "judgment," "creativity," or even "genius"—appear to be wholly dispensable or to be definable, as insight is, in terms of mundane and well-understood concepts. (Simon, 1989, p. 376)

In other words, a detailed look reveals that even the brilliant results of human genius are produced by basic cognitive processes operating together in complex ways to produce those brilliant results.[1] Most of this book will be devoted to describing what we know about these basic processes.

■ ***Great feats of intelligence, such as scientific discovery, are the result of basic cognitive processes.***

Implications for Other Fields

Students and researchers interested in other areas of psychology or social science have another reason for following developments in cognitive psychology. The basic mechanisms governing human thought are important in understanding the types of behavior studied by other social sciences. For example, an appreciation of how humans think is important to understanding why certain thought malfunctions occur (clinical psychology), how people behave with other individuals or in groups (social psychology), how persuasion works (political science), how economic decisions are made (economics), why certain

[1] Weisberg (1986) comes to a similar conclusion.

ways of organizing groups are more effective and stable than others (sociology), and why natural languages have certain features (linguistics). Cognitive psychology is thus the foundation on which all other social sciences stand, in the same way that physics is the foundation for the other physical sciences.

Nonetheless, much social science has developed without grounding in cognitive psychology, for two main reasons. First, the field of cognitive psychology is not that advanced. Second, researchers in other areas of social science have managed to find other ways to explain the phenomena in which they are interested. An interesting case in point is economics. Neoclassical economics, which dominated the last century, tried to predict the behavior of markets while completely ignoring the cognitive processes of individuals. It simply assumed that individuals behaved in ways to maximize their wealth. However, the recently developed field of behavioral economics acknowledges that the behavior of markets is affected by the flawed decision-making processes of individuals—for example, people are willing to pay more for something when they use a credit card than when they use cash (Simester & Drazen, 2001). In recognition of the importance of the psychology of decision making to economics, the cognitive psychologist Daniel Kahneman was awarded the Nobel Prize for economics in 2002.

■ ***Cognitive psychology is the foundation for many other areas of social science.***

Practical Applications

Practical applications of the field constitute another key incentive for the study of cognitive psychology. If we really understood how people acquire knowledge and intellectual skills and how they perform feats of intelligence, then we would be able to improve their intellectual training and performance accordingly.

While future applications of psychology hold great promise (Klatzky, 2009), there are a number of current successful applications. For instance, there has been a long history of research on the reliability of eyewitness testimony (e.g., Loftus, 1996) that has led to guidelines for law enforcement personnel (U.S. Department of Justice, 1999). There have also been a number of applications of basic information processing to the design evaluations of various computer-based devices, such as modern flight management systems on aircraft (John, Patton, Gray, & Morrison, 2012). And there have been a number of applications to education, including reading instruction (Rayner, Foorman, Perfetti, Pesetsky, & Seidenberg, 2002) and computer-based systems for teaching mathematics (Koedinger & Corbett, 2006). Cognitive psychology is also making important contributions to our understanding of brain disorders that reflect abnormal functioning, such as schizophrenia (Cohen & Servan-Schreiber, 1992) or autism (Dinstein et al., 2012; Just, Keller, & Kana, 2013).

At many points in this book, Implications boxes will reinforce the connections between research in cognitive psychology and our daily lives.

■ ***The results from the study of cognitive psychology have practical implications for our daily lives.***

◆ The History of Cognitive Psychology

Cognitive psychology today is a vigorous science producing many interesting discoveries. However, this productive phase was a long time coming, and it is important to understand the history of the field that led to its current form.

Early History

In Western civilization, interest in human cognition can be traced to the ancient Greeks. Plato and Aristotle, in their discussions of the nature and origin of knowledge, speculated about memory and thought. These early philosophical discussions eventually developed into a centuries-long debate between two positions: **empiricism,** which held that all knowledge comes from experience, and **nativism,** which held that children come into the world with a great deal of innate knowledge. The debate intensified in the 17th, 18th, and 19th centuries, with such British philosophers as Berkeley, Locke, Hume, and Mill arguing for the empiricist view and such continental philosophers as Descartes and Kant propounding the nativist view. Although these arguments were philosophical at their core, they frequently slipped into psychological speculations about human cognition.

During this long period of philosophical debate, sciences such as astronomy, physics, chemistry, and biology developed markedly. Curiously, however, it was not until the end of the 19th century that the scientific method was applied to the understanding of human cognition. Certainly, there were no technical or conceptual barriers to the scientific study of cognitive psychology earlier. In fact, many cognitive psychology experiments could have been performed and understood in the time of the ancient Greeks. But cognitive psychology, like many other sciences, suffered because of our egocentric, mystical, and confused attitudes about ourselves and our own nature, which made it seem inconceivable that the workings of the human mind could be subjected to scientific analysis. As a consequence, cognitive psychology as a science is less than 150 years old, and much of the first 100 years was spent freeing ourselves of the misconceptions that can arise when people engage in such an introverted enterprise as a scientific study of human cognition. It is a case of the mind studying itself.

■ ***Only in the last 150 years has it been realized that human cognition could be the subject of scientific study rather than philosophical speculation.***

Psychology in Germany: Focus on Introspective Observation

The date usually cited as the beginning of psychology as a science is 1879, when Wilhelm Wundt established the first psychology laboratory in Leipzig, Germany. Wundt's psychology was cognitive psychology (in contrast to other major divisions, such as comparative, clinical, or social psychology), although he had far-ranging views on many subjects. Wundt, his students, and many other early psychologists used a method of inquiry called **introspection**, in which highly trained observers reported the contents of their own consciousness under carefully controlled conditions. The basic assumption was that the workings of the mind should be open to self-observation. Drawing on the empiricism of the British philosophers, Wundt and others believed that very intense self-inspection would be able to identify the primitive experiences out of which thought arose. Thus, to develop a theory of cognition, a psychologist had only to explain the contents of introspective reports.

Let us consider a sample introspective experiment. Mayer and Orth (1901) had their participants perform a free-association task. The experimenters spoke a word to the participants and then measured the amount of time the participants took to generate responses to the word. Participants then reported all their conscious experiences from the moment of stimulus presentation until the

IMPLICATIONS

What does cognitive psychology tell us about how to study effectively?

Cognitive psychology has identified methods that enable humans to read and remember a textbook like this one. This research will be described in Chapters 6 and 13. The key idea is that it is crucial to identify the main points of each section of a text and to understand how these main points are organized. I have tried to help you do this by ending each section with a short summary sentence identifying its main point. I recommend that you use the following study technique to help you remember the material. This approach is a variant of the PQ4R (Preview, Question, Read, Reflect, Recite, Review) method discussed in Chapter 6.

1. Preview the chapter. Read the section headings and summary statements to get a general sense of where the chapter is going and how much material will be devoted to each topic. Try to understand each summary statement, and ask yourself whether this is something you knew or believed before reading the text.

Then, for each section of the book, go through the following steps:

2. For each section of the book, make up a study question by looking at the section heading and thinking of a related question that you will try to answer while you read the text. For instance, in the section Intellectual Curiosity, you might ask yourself, "What is there to be curious about in cognitive psychology?" This will give you an active goal to pursue while you read the section.

Hanquan Chen/Getty Images

3. Read the section to understand it and answer your question. Try to relate what you are reading to situations in your own life. In the section Intellectual Curiosity, for example, you might try to think of scientific discoveries you have read about that seemed to require creativity.
4. At the end of each section, read the summary and ask yourself whether that is the main point you got out of the section and why it is the main point. Sometimes you may need to go back and reread some parts of the section.

At the end of the chapter, engage in the following review process:

5. Go through the text, mentally reviewing the main points. Try to answer the questions you devised in step 2, plus any other questions that occur to you. Often, when preparing for an exam, it is a good idea to ask yourself what kind of exam questions you would make up for the chapter.

As we will learn in later chapters, such a study strategy improves one's memory of the text. ▲

moment of their response. To get a feeling for this method, try to come up with an association for each of the following words; after each association, think about the contents of your consciousness during the period between reading the word and making your association.

coat book
dot bowl

In this experiment, many participants reported rather indescribable conscious experiences, not always seeming to involve sensations, images, or other concrete experiences. This result started a debate over the issue of whether conscious experience could really be devoid of concrete content. As we will see in Chapters 4 and 5, modern cognitive psychology has made real progress on this issue, but not by using introspective methods.

■ ***At the turn of the 20th century, German psychologists tried to use a method of inquiry called introspection to study the workings of the mind.***

Psychology in America: Focus on Behavior

Wundt's introspective psychology was not well accepted in America. Early American psychologists engaged in what they called "introspection," but it was not the intense analysis of the contents of the mind practiced by the Germans. Rather, it was largely an armchair avocation in which self-inspection was casual and reflective rather than intense and analytic. William James's *Principles of Psychology* (1890) reflects the best of this tradition, and many of the proposals in this work are still relevant today. The mood of America was determined by the philosophical doctrines of pragmatism and functionalism. Many psychologists of the time were involved in education, and there was a demand for an "action-oriented" psychology that was capable of practical application. The intellectual climate in America was not receptive to the psychology from Germany that focused on such questions as whether or not the contents of consciousness were sensory.

One of the important figures of early American scientific psychology was Edward Thorndike, who developed a theory of learning that was directly applicable to classrooms. Thorndike was interested in such basic problems as the effects of reward and punishment on the rate of learning. To him, conscious experience was just excess baggage that could be largely ignored. Many of his experiments were done on animals, research that involved fewer ethical constraints than research on humans. Thorndike was probably just as happy that such participants could not introspect.

While introspection was being ignored at the turn of the century in America, it was getting into trouble on the continent. Various laboratories were reporting different types of introspections—each type matching the theory of the particular laboratory from which it emanated. It was becoming clear that introspection did not give one a clear window into the workings of the mind. Much that was important in cognitive functioning was not open to conscious experience. These two factors—the "irrelevance" of the introspective method and its apparent contradictions—laid the groundwork for the great behaviorist revolution in American psychology that occurred around 1920. John Watson and other behaviorists led a fierce attack not only on introspectionism but also on any attempt to develop a theory of mental operations. **Behaviorism** held that psychology was to be entirely concerned with external behavior and was not to try to analyze the workings of the mind that underlay this behavior:

> Behaviorism claims that consciousness is neither a definite nor a usable concept. The Behaviorist, who has been trained always as an experimentalist, holds further that belief in the existence of consciousness goes back to the ancient days of superstition and magic. (Watson, 1930, p. 2)

> The Behaviorist began his own formulation of the problem of psychology by sweeping aside all medieval conceptions. He dropped from his scientific vocabulary all subjective terms such as sensation, perception, image, desire, purpose, and even thinking and emotion as they were subjectively defined. (Watson, 1930, pp. 5–6)

The behaviorist program and the issues it spawned pushed research on cognition into the background of American psychology. The rat supplanted the human as the principal laboratory subject, and psychology turned to finding out what could be learned by studying animal learning and motivation. Quite a bit was discovered, but little was of direct relevance to cognitive psychology. Perhaps the most important lasting contribution of behaviorism is a set of sophisticated and rigorous techniques and principles for experimental study in all fields of psychology, including cognitive psychology.

Behaviorism was not as dominant in Europe. Psychologists such as Frederick Bartlett in England, Alexander Luria in the Soviet Union, and Jean Piaget in Switzerland were pursuing ideas that are still important in modern cognitive psychology. Cognitive psychology was an active research topic in Germany, but much of it was lost in the Nazi turmoil. A number of German psychologists immigrated to America and brought **Gestalt psychology** with them. Gestalt psychology claimed that the activity of the brain and the mind was more than the sum of its parts. This conflicted with the introspectionist program in Germany that tried to analyze conscious thought into its parts. In America, Gestalt psychologists found themselves in conflict with behaviorism on this point. However, they were also criticized for being concerned with mental structure at all. In America, Gestalt psychologists received the most attention for their claims about animal learning, and they were the standard targets for the behaviorist critiques, although some Gestalt psychologists became quite prominent. For example, the Gestalt psychologist Wolfgang Kohler was elected to the presidency of the American Psychological Association. Although not a Gestalt psychologist, Edward Tolman was an American psychologist who did his research on animal learning and anticipated many ideas of modern cognitive psychology. Tolman's ideas were also frequently the target for criticism by the dominant behaviorist psychologists, although his work was harder to dismiss because he spoke the language of behaviorism.

In retrospect, it is hard to understand how American behaviorists could have taken such an anti-mental stand and clung to it for so long. The unreliability of introspection did not mean that a theory of internal mental structure and process could not be developed, only that other methods were required (consider the analogy with physics, for example, where a theory of atomic structure was developed, although that structure could only be inferred, not directly observed). A theory of internal structure makes understanding human beings much easier, and the successes of modern cognitive psychology show that understanding mental structures and processes is critical to understanding human cognition.

In both the introspectionist and behaviorist programs, we see the human mind struggling with the effort to understand itself. The introspectionists held a naïve belief in the power of self-observation. The behaviorists were so afraid of falling prey to subjective fallacies that they refused to let themselves think about mental processes. Current cognitive psychologists seem to be much more at ease with their subject matter. They have a relatively detached attitude toward human cognition and approach it much as they would any other complex system.

■ ***Behaviorism, which dominated American psychology in the first half of the 20th century, rejected the analysis of the workings of the mind to explain behavior.***

The Cognitive Revolution: AI, Information Theory, and Linguistics

Cognitive psychology as we know it today took form in the two decades between 1950 and 1970, in the cognitive revolution that overthrew behaviorism. Three main influences account for its modern development. The first was research on human performance, which was given a great boost during World War II when governments badly needed practical information about how to train soldiers to use sophisticated equipment and how to deal with problems such as the breakdown of attention under stress. Behaviorism offered no help with such practical issues. Although the work during the war had a very

practical bent, the issues it raised stayed with psychologists when they went back to their academic laboratories after the war. The work of the British psychologist Donald Broadbent at the Applied Psychology Research Unit in Cambridge was probably the most influential in integrating ideas from human performance research with new ideas that were developing in an area called information theory. Information theory is an abstract way of analyzing the processing of information. Broadbent and other psychologists, such as George Miller, Fred Attneave, and Wendell Garner, initially developed these ideas with respect to perception and attention, but such analyses soon pervaded all of cognitive psychology.

The second influence, which was closely related to the development of the information-processing approach, was developments in computer science, particularly AI, which tries to get computers to behave intelligently, as noted above. Allen Newell and Herbert Simon, both at Carnegie Mellon University, spent most of their lives educating cognitive psychologists about the implications of AI (and educating workers in AI about the implications of cognitive psychology). Although the direct influence of AI-based theories on cognitive psychology has always been minimal, its indirect influence has been enormous. A host of concepts have been taken from computer science and used in psychological theories. Probably more important, observing how we can analyze the intelligent behavior of a machine has largely liberated us from our inhibitions and misconceptions about analyzing our own intelligence.

The third influence on cognitive psychology was **linguistics,** which studies the structure of language. In the 1950s, Noam Chomsky, a linguist at the Massachusetts Institute of Technology, began to develop a new mode of analyzing the structure of language. His work showed that language was much more complex than had previously been believed and that many of the prevailing behaviorist formulations were incapable of explaining these complexities. Chomsky's linguistic analyses proved critical in enabling cognitive psychologists to fight off the prevailing behaviorist conceptions. George Miller, at Harvard University in the 1950s and early 1960s, was instrumental in bringing these linguistic analyses to the attention of psychologists and in identifying new ways of studying language.

Cognitive psychology has grown rapidly since the 1950s. A milestone was the publication of Ulric Neisser's *Cognitive Psychology* in 1967. This book gave a new legitimacy to the field. It consisted of 6 chapters on perception and attention and 4 chapters on language, memory, and thought. Neisser's chapter division contrasts sharply with this book's, which has only 2 chapters on perception and attention and 10 on language, memory, and thought. My chapter division reflects a growing emphasis on higher mental processes. Following Neisser's work, another important event was the launch of the journal *Cognitive Psychology* in 1970. This journal has done much to define the field.

In the 1970s, a related new field called cognitive science emerged; it attempts to integrate research efforts from psychology, philosophy, linguistics, neuroscience, and AI. This field can be dated from the appearance of the journal *Cognitive Science* in 1976, which is the main publication of the Cognitive Science Society. The fields of cognitive psychology and cognitive science overlap. Speaking generally, cognitive science makes greater use of such methods as logical analysis and the computer simulation of cognitive processes, whereas cognitive psychology relies heavily on experimental techniques for studying behavior that grew out of the behaviorist era. This book draws on all methods but makes most use of cognitive psychology's experimental methodology.

■ ***Cognitive psychology broke away from behaviorism in response to developments in information theory, AI, and linguistics.***

Information-Processing Analyses

The factors described in the previous sections of this chapter have converged in the **information-processing approach** to studying human cognition, and this has become the dominant approach in cognitive psychology. The information-processing approach attempts to analyze cognition as a set of steps for processing an abstract entity called "information." Probably the best way to explain this approach is to describe a classic example of it.

In a very influential paper published in 1966, Saul Sternberg described an experimental task and proposed a theoretical account of what people were doing in that task. In what has come to be called the **Sternberg paradigm,** participants were shown a small number of digits, such as "3 9 7," to keep in mind. Then they were shown a probe digit and asked whether it was in the memory set, and they had to answer as quickly as possible. For example, 9 would be a positive probe for the "3 9 7" set; 6 would be a negative probe. Sternberg varied the number of digits in the memory set from 1 to 6 and measured how quickly participants could make this judgment. Figure 1.1 shows his results as a function of the size of the memory set. Data are plotted separately for positive probes, or targets, and for negative probes, or foils. Participants could make these judgments quite quickly; latencies varied from 400 to 600 milliseconds (ms)—a millisecond is a thousandth of a second. Sternberg found a nearly linear relationship between judgment time and the size of the memory set. As shown in Figure 1.1, participants took about 38 ms extra to judge each digit in the set.

Sternberg's account of how participants made these judgments was very influential; it exemplified what an abstract information-processing theory is like. His explanation is illustrated in Figure 1.2. Sternberg assumed that when participants saw a probe stimulus such as a 9, they went through the series of information-processing stages illustrated in that figure. First the stimulus was encoded. Then the stimulus was compared to each digit in the memory set. Sternberg assumed that it took 38 ms to complete each one of these comparisons, which accounted for the slope of the line in Figure 1.1. Then the participant had to decide on a response and finally generate it. Sternberg showed that different variables would influence each of these information-processing stages. Thus, if he degraded the stimulus quality by making the probe harder to read, participants took longer to make their judgments. This did not affect the slope of the Figure 1.1 line, however, because it involved only the stage of stimulus perception in Figure 1.2. Similarly, if he biased participants to say yes or no, the decision-making stage, but not other stages, was affected.

Sternberg Memory Search

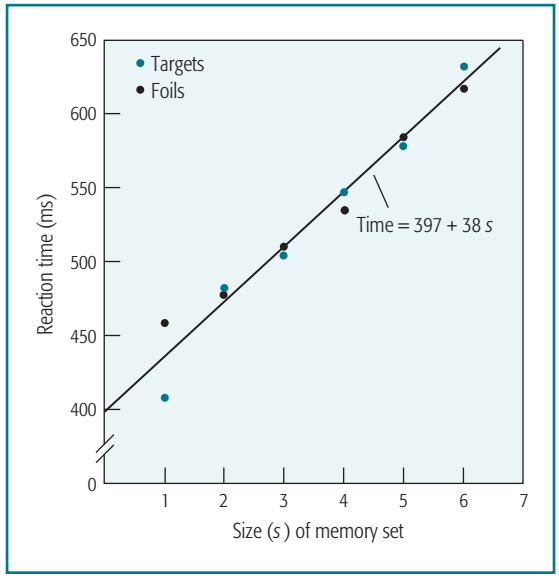


FIGURE 1.1 The time needed to recognize a digit increases with the number of items in the memory set. The straight line represents the linear function that fits the data best. *(Data from S. Sternberg, 1969.)*

It is worth noting the ways in which Sternberg's theory exemplifies a classic abstract information-processing account:

1. Information processing is discussed without any reference to the brain.
2. The processing of the information has a highly symbolic character. For example, his theory describes the human system as comparing the symbol 9 against the symbol 3, without considering how these symbols might be represented in the brain.
3. The processing of information can be compared to the way computers process information. (In fact, Sternberg used the computer metaphor to justify his theory.)
4. The measurement of time to make a judgment is a critical variable, because the information processing is