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COGNITION

THEORIES AND APPLICATIONS

Stephen K. Reed

Cognition

Tenth Edition

To the memory of my parents:

Kenneth D. Reed (1919 – 2007)

Anita M. Reed (1921 – 2012)

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Theories and Applications

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Stephen K. Reed

San Diego State University

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SAGE

For information:

SAGE Publications, Inc.
2455 Teller Road
Thousand Oaks, California 91320
E-mail: order@sagepub.com

SAGE Publications Ltd.
1 Oliver's Yard
55 City Road
London, EC1Y 1SP
United Kingdom

SAGE Publications India Pvt. Ltd.
B 1/I 1 Mohan Cooperative
Industrial Area
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India

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Chelsea Neve

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PREFACE

I began writing the first edition of *Cognition: Theory and Applications* in 1979 when I was a visiting associate professor at the University of California, Berkeley. Cognitive psychology was then a relatively new field of study, and I was disappointed by the lack of cognition textbooks that could inform students about this emerging field. My goal in writing a textbook was to share my own excitement by introducing students to the research, theories, and applications of cognitive psychology. Eight revisions of that first edition show its continued development.

I had not planned to write a new edition when I retired from teaching in 2014. I instead focused on writing journal articles on integrating ideas in cognitive psychology. I referred to this project as searching for the big pictures (Reed, 2020a). When I ran out of ideas for big pictures, I returned to writing books (Reed, 2021) and enthusiastically began this tenth edition.

Both my new publisher (SAGE) and I approached the tenth edition as if it were a new book. It had been nine years since the publication of the ninth edition, and the time in between editions provided an opportunity to introduce changes. It also produced a need to extensively update the content, and my search for the big pictures provided a head start on adding new content to the tenth edition of *Cognition*.

Another head start was my recently completed book *Cognitive Skills You Need for the 21st Century* (Reed, 2020b). The motivation for that book was the World Economic Forum's *Future of Jobs Report 2018* based on interviews of some of the world's largest employers regarding the latest needed skills and human investment trends across their industries. The report indicated that by 2022, trending skills would include active learning and learning strategies, reasoning, analytical thinking and innovation, complex problem solving, and creativity. I discuss these skills (and many others) in greater depth in this new edition of *Cognition*, making it especially relevant and useful to instructors and students in cognitive psychology courses.

You do not, however, need to wait for graduation to apply these skills. Applications are tailored to align with student interests, and they are useful in our daily lives, as shown in the photographs of people performing these activities throughout the book. The emphasis on real-world applications and the visually appealing art program that brings them to life, along with the balanced coverage of classic and contemporary theories and research, reflects my attempt to maintain the best features of previous editions while introducing new features to substantially enhance that content.

CHANGES IN THE TENTH EDITION

The most visible change in the tenth edition is that it is in full color. I have enjoyed the task of finding colorful figures and photos to make this edition more engaging and informative than previous editions. As you might imagine, a delay of 10 years between the publication of the ninth and tenth editions also provided an opportunity to include extensive new material that has appeared in the past decade.

One of these changes was the addition of a new chapter on action. Many cognitive psychologists now believe that much of cognition—perception, memory, learning, language, decision making, and problem solving—occurs to support action. It now appears counterproductive to describe these cognitive processes without considering how we use them to support action. Another change was finishing the book with the chapter on "Expertise and Creativity." Placing that chapter after the one on "Decision Making" enables discussion of both decision making and problem solving within the context of expertise.

A frequent request by reviewers of previous editions was to include more material on cognitive neuroscience. We therefore relied on the expertise of contributing author Paul Merritt to help add that content to the book. Paul had an additional influence on content. Many of the students who enrolled in his cognitive psychology course at Georgetown University and Colorado State University were not psychology majors. I therefore attempted to make this book more user-friendly to those students by eliminating or rewriting material that appeared too difficult for a more general audience. The result is a text that undergraduate students will find very readable and accessible.

APPROACH

I have continued to use three criteria for selecting material. The first is whether the material makes an important contribution to cognitive psychology. The second is whether it is accessible to students. Will they understand it and find it interesting? The third is whether it can be easily integrated with other material in the book. There must be a clear flow of ideas to tell a coherent story.

Three themes appear throughout the book: research, theories, and applications.

1. Research

Research is the foundation of any field of science. Cognitive psychologists have developed many innovative research paradigms to make inferences about cognitive operations. Their measures include accuracy, response times, verbal reports, brain waves, and blood flow to identify cognitive operations and discover their locations in the brain. This book describes experiments in sufficient detail to help students understand these research paradigms. The detailed descriptions typically occur early in each chapter to provide a basis for understanding the remainder of the chapter. Most chapters have a chronological flow that illustrates how contemporary research has built on the findings of classical research.

2. Theories

Research would consist only of a collection of measurements if theories did not organize and provide interpretations of the findings. The chapters begin with the initial theories that established a foundation for cognitive psychology, such as the information-processing models developed by Broadbent for speech and Sperling for vision, Miller's description of short-term memory, the Atkinson and Shiffrin model of learning, levels of processing and encoding specificity, Paivio's dual coding theory, Rosch's work on categorization, variations of semantic memory models, Kintsch's model of text comprehension, Newell and Simon's theoretical framework for problem solving, and the Kahneman and Tversky study of heuristics in decision making. The chapters then show how these theories have evolved, either as others continued to develop the initial ideas or proposed competing theories. This emphasis on the evolvement of theoretical understanding is a central feature of this book.

3. Applications

Although research and theories are key components of science, both can appear rather abstract without illustrations of how they are useful. Previous editions of *Cognition: Theory and Applications* have always included applications, but the applications received less emphasis than the theories. The tenth edition places more emphasis on applications by adding a section on applications at the end of each chapter. Identifying visual disorders, misusing cell phones, managing cognitive overload, improving learning strategies, creating better memory codes, identifying clinical imagery, understanding dementia, producing concept maps, assessing comprehension, designing helpful decision aids, resolving conflicts, and enhancing creativity are a few of the many examples.

ORGANIZATION

The 14 chapters in the book cover a wide range of topics, and instructors can expand on whatever topics interest them. The book is divided into three parts: Cognitive Components, Cognitive Representations, and Cognitive Skills.

Part 1 on Cognitive Components consists of chapters on pattern recognition, attention, working memory, long-term memory, and action. Theories of pattern recognition seek to specify how people recognize and store descriptions of patterns in memory. Theories of attention are needed to explain how we select perceptual information. Working memory enables us to combine information retrieved from long-term memory with information that arrives from the environment. But its limited capacity and fast decay rate make it necessary for us to enter into long-term memory any new information we want to remember over a long interval. Action is needed to put this information to use.

Part 2 on Cognitive Representations contains chapters on memory codes, visual images, categorization, and semantic organization. The first two chapters describe qualitatively different memory codes because our ability to remember depends on the kind of memory code that we create. The study of memory codes also has important implications for how efficiently people retrieve information from memory and perform spatial reasoning tasks. The next two chapters emphasize how knowledge is organized into categories and how categories are organized into hierarchies. This organization can be studied by measuring how quickly people make classification decisions and retrieve semantic information.

Part 3 on Cognitive Skills consists of chapters on language, decision making, problem solving, and expertise and creativity. Language involves not only the meaning of individual words but the combination of words to form sentences that are both grammatically correct and convey intended meanings. The study of decision making has often focused on how people combine information when evaluating alternatives. The term *risky decision making* is used to describe situations in which there is uncertainty regarding possible outcomes. The study of problem solving describes the skills needed to solve different kinds of problems, identifies general strategies, and examines the role of memory in problem solving. The concluding chapter on expertise and creativity discusses how people use prior knowledge in reasoning and solving problems. The final section of this chapter describes recent theoretical and empirical approaches to the study of creativity.

In addition to the organization of chapters into three parts, the material in each chapter is organized into manageable sections and subsections: You should review the outline at the beginning of each chapter for an overview of the topics. You should also study the Learning Objectives at the beginning of each chapter to preview some of the major theoretical constructs that you will encounter during your reading.

ACKNOWLEDGMENTS

I wrote the first edition of this book while spending a sabbatical year at the University of California at Berkeley. I am grateful to Case Western Reserve University and the Group in Science and Mathematics Education at Berkeley for providing financial support during that year. The Group in Science and Mathematics Education also furnished me with a stimulating environment, and the Institute of Human Learning provided an excellent library. Shortly after arriving at Berkeley, I had the good fortune to meet C. Deborah Laughton, a psychology editor at the time. She expressed confidence in the book long before it was deserved and, with the assistance of excellent staff and first-rate reviewers, helped in the development of the text.

I am grateful to Abbie Rickard, Chelsea Neve, Jessica Miller, Lara Parra, Veronica Stapleton Hooper, Karin Rathert, and all the others at SAGE, who have contributed to the Tenth Edition. Paul Merritt played a major role as contributing author by explaining the neuroscience of the cognitive components described in Part 1. I would also like to thank the following reviewers for their helpful suggestions:

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The comments of others are always welcome, and I would appreciate receiving suggestions from readers.

ABOUT THE AUTHOR

Stephen K. Reed is currently an emeritus professor of psychology at San Diego State University and a visiting scholar at the University of California, San Diego. He has also taught at Florida Atlantic University (1980–1988) and at Case Western Reserve University (1971–1980). His research on problem solving has been supported by grants from NIMH, the National Science Foundation, and the Air Force Office of Scientific Research. He is the author of numerous articles and books including *Psychological Processes in Pattern Recognition* (Academic Press, 1973), *Word Problems: Research and Curriculum Reform* (Erlbaum, 1999), *Cognitive Skills You Need for the 21st Century* (Oxford University Press, 2020) and *Thinking Visually,* 2nd ed. (Routledge, 2021).

Getty Images/DrAfter123

1 INTRODUCTION

LEARNING OBJECTIVES

1. Explain the growth of cognitive psychology as a field of study, including the differences between behaviorism, the information-processing perspective and the early development of artificial intelligence.
2. Discuss the benefits of close cooperation between the fields of cognitive psychology, cognitive neuroscience, and artificial intelligence.

Cognition can be defined simply as the study of the mental operations that support people's acquisition and use of knowledge. Both the acquisition and the use of knowledge involve a variety of mental skills. If you glanced at the table of contents at the beginning of this book, you saw a list of some of these skills. Psychologists who study cognition are interested in topics such as how people recognize patterns, store information in memory, use language, solve problems, and make decisions.

The purpose of this book is to provide an overview of the field of **cognitive psychology**. The book summarizes experimental research in cognitive psychology, discusses the major theories in the field, and relates the research and theories to situations that people encounter in their daily lives—for example, reading, driving, studying, designing products, solving problems in the classroom, and making decisions.

Most students are surprised to learn how much of their everyday lives is driven by cognitive processes. One major area of interest to both students and cognitive psychologists is how to improve learning—a topic that will run throughout several chapters in the text. Another important area of interest is marketing applications of cognitive psychology. For example, manufacturers spend a great deal of time trying to make their products visually distinctive and therefore easier to

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cognitive psychology The study of the mental operations that support people's acquisition and use of knowledge find on a store shelf—a direct extension of research conducted in *visual attention*. Further business applications include manipulating pricing and discounts to influence *decision-making* in purchasing—in fact, a great deal of economics is based on decision-making research.

A great deal of law and public policy has also been formulated directly from research in cognitive psychology. In a dramatic instance of law extending from cognitive research, the New Jersey Supreme Court set down a decision outlining the only legal ways in which police officers can interrogate eyewitnesses that is based entirely on research regarding the fallibility of memory (*State v. Henderson,* 2011). In the 21st century, cognitive psychology research has had other wide-ranging impacts, from the operation of airport screening checkpoints to the safe operation of subway systems to the design of roadways and sidewalks. A section on the applications of cognitive psychology occurs at the end of every chapter.

In addition to the important ways in which cognition influences our everyday lives, how we live our lives has equally important implications for our cognitive functioning. We are learning more every year about how our diet, exercise, and sleep influence critical cognitive functions such as memory and our risk for cognitive decline as we grow older. Stress, anxiety, and depression are all influenced by our lifestyles, and these in turn can have negative effects on cognition. Similarly, both prescribed and recreational drugs can influence cognition in a variety of ways that are both positive and negative.

Cognitive skills are needed in a wide variety of professions that I discuss in my book *Cognitive Skills You Need for the 21st Century* (Reed, 2020b). The book begins with the World Economic Forum's *Future of Jobs Report 2018* that asked executives at some of the world's largest employers to report on the latest skills and human investment trends in their industries (www.weforum.org). The industries include advanced materials and biotechnology, consumer and financial services, healthcare, information and communication technologies, infrastructure and urban planning, mining and minerals, transportation, travel and tourism, and professional services. Skills that will be trending in 2022 include analytical thinking and innovation, learning strategies, creativity and originality, critical thinking and analysis, reasoning, and complex problem solving. I analyze these skills in greater depth in this text. Before delving into these topics, let's take a brief look at the history of cognitive psychology.

THE GROWTH OF COGNITIVE PSYCHOLOGY

It is difficult to pinpoint the exact beginning of any field of study, and cognitive psychologists would likely offer a wide variety of dates if asked when cognitive psychology began. James's *Principles of Psychology*, published in 1890, included chapters on attention, memory, imagery, and reasoning. Kohler's *The Mentality of Apes* (1925) investigated processes that occur in complex thinking. He and other Gestalt psychologists emphasized structural understanding—the ability to understand how all the parts of a problem fit together (the Gestalt). Bartlett's book *Remembering: A Study in Experimental and Social Psychology* (1932) contained a theory of memory for stories consistent with current views. There are some other important articles or books that seemed modern but did not cause a major shift in the way cognitive psychology is currently studied.

One book that had a major impact on psychological research was Watson's *Behaviorism* (1924). The book's central theme was that psychologists should become more objective by studying only what they could directly observe in a person's behavior. Watson's argument lent support to a **stimulus-response (S-R)** approach, in which experimenters record how people respond to stimuli without attempting to discover the thought processes that cause the response. The S-R approach is consistent with Watson's view because the stimulus and the response are both observable. Watson's book contributed to basing psychology on a more objective foundation of scientific observations. A limitation of the S-R approach, however, is that it does not reveal what the person does with the information presented in the stimulus.

By contrast, the information-processing approach seeks to identify how a person transforms information between the stimulus and the response. The acquisition, storage, retrieval, and use of information comprise separate stages, and the information-processing approach attempts to identify what happens during these stages (Haber, 1969). Finding out what occurs during each stage is particularly important when a person has difficulty performing a task because the psychologist can then try to identify which stage is the primary source of the difficulty. Information-processing models continue to have a major impact on our understanding of cognitive processes (Jarecki et al., 2020).

Information Processing Gathers Momentum

Changing allegiance from a behavioral to a cognitive perspective required taking risks, as Miller (2003) points out in his personal account of the early years of the cognitive revolution. Miller (1951) wrote in the preface to his own book on language (*Language and Communication*) that the bias of the book was behavioristic. In 1951, he still hoped to gain scientific respectability by swearing allegiance to behaviorism. His later dissatisfaction with behaviorism resulted in the 1960 creation, with Jerome Bruner, of the Center for Cognitive Studies at Harvard. The cognitive emphasis at the center reopened communication with distinguished psychologists abroad, such as Sir Frederic Bartlett in Cambridge, England; Jean Piaget in Geneva, Switzerland; and A. R. Luria in Moscow, Russia. None of these three had been influenced by the behaviorism movement in the United States and therefore provided inspiration for the cognitive revolution.

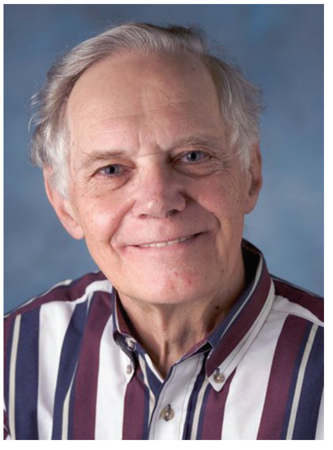


PHOTO 1.1 Ulric Neisser's 1967 book *Cognitive Psychology* contributed to establishing the field of cognitive psychology.

Credit: Cornell University

Ulric Neisser's 1967 book *Cognitive Psychology* provided a clear explanation of the information-processing perspective. He defined cognitive psychology as referring "to all processes by which the sensory input is transformed, reduced, elaborated, stored, recovered, and used." This definition has several important implications. The reference

stimulus-response (S-R) The approach that emphasizes the association between a stimulus and a response, without identifying the mental operations that produced the response to a sensory input implies that cognition begins with our contact with the external world. Transformation of the sensory input means that our representation of the world is not just a passive registration of our physical surroundings but an active construction that can involve both reduction and elaboration. Reduction occurs when information is lost. That is, we can attend to only a small part of the physical stimulation that surrounds us, and only a small part of what we attend to can be remembered. Elaboration occurs when we add to the sensory input. For example, when you meet a friend, you may recall many shared experiences.

The storage and the recovery of information are what we call memory. The distinction between storage and recovery implies that the storage of information does not guarantee recovery. A good example of this distinction is the "tip of the tongue" phenomenon. Sometimes we can almost but not quite retrieve a word to express a particular thought or meaning. Our later recall of the word proves the earlier failure was one of retrieval rather than one of storage. The word was stored in memory; it was simply difficult to get it back out. The last part of Neisser's definition is perhaps the most important. After information has been perceived, stored, and recovered, it must be put to good use—for example, to make decisions or to solve problems.

Neisser's *Cognitive Psychology* (1967) brought many of these ideas together into a single source; other books on cognition followed as cognitive research and theories began to gather momentum in the 1970s. For instance, research on categorization in the 1960s had focused on a concept identification paradigm in which categories were defined by logical rules, such as category members consist of all geometric forms that are either circles or large.

The predominant criticism of the concept identification paradigm was that real-world categories, such as clothes, tools, and vehicles, are unlike the categories studied in the laboratory. A dramatic change in how psychologists viewed real-world categories had to wait until the 1970s when Eleanor Rosch (Photo 1.2) and her students at the University of California, Berkeley, began to study the characteristics of real-world categories (Rosch, 1973). Her ideas and research were so important that they deserve the extensive coverage they receive in Chapter 9 on Categorization.

PHOTO 1.2 Eleanor Rosch made major contributions to our understanding of the organization of real-world categories.

Source: Photo of Eleanor Rosch available at https://en.wikipedia.org/wiki/Eleanor_Rosch#/media/File:Eleanor_Rosch.jpg, licensed by CC0 1.0 Universal (CC0 1.0) Public Domain Dedication

Cognitive psychology currently has widespread appeal among psychologists. Almost all psychologists studying perception, attention, learning, memory, language, reasoning, problem solving, and decision-making refer to themselves as cognitive psychologists, even though the methodology and theories vary widely across these topics. A caveat is that most of the initial contributions to the cognitive revolution were made by men because of the lack of women psychologists in academia during the time this revolution occurred. There are important exceptions, such as Eleanor Gibson's (1969) contributions to perception discussed in Chapter 2 on Pattern Recognition and Anne Treisman's (1960) theory discussed in Chapter 3 on Attention (Photo 1.3).

As a whole, the psychology field has also historically lacked racial and ethnic diversity. American Psychological Association data from 2015 showed 86% of psychologists in the U.S. workforce were white. In contrast, only 14% were from other racial or ethnic groups. Psychology is becoming more diverse as more racial and ethnic minorities enter the field, and cognitive psychology in particular is diversifying as it becomes more international, but more progress needs to be made.

PHOTO 1.3 Anne Treisman's theory of attention advanced the information-processing approach for studying cognitive processes. Here, she is pictured receiving the National Medal of Science from President Obama.

UPI / Alamy Stock Photo

Higher Cognitive Processes

The information-processing analysis of perception and memory was accompanied in the late 1950s by a new approach to more complex tasks. The development of digital computers after

World War II led to active work in **artificial intelligence**, a field that attempts to program computers to perform intelligent tasks, such as playing chess and constructing derivations in logic (Hogan, 1997). A seminar held at the RAND Corporation in the summer of 1958 aimed at showing social scientists how computer-simulation techniques could be applied to create models of human behavior. The RAND seminar had a major impact on integrating the work on computer simulation with other work on **human information processing**.

One consequence of the RAND seminar was its influence on three psychologists who spent the 1958–1959 academic year at the Center for Advanced Study in the Behavioral Sciences at Stanford University. The three—George Miller, Eugene Galanter, and Karl Pribram—shared a common dissatisfaction with the then-predominant theoretical approach to psychology, which viewed human beings as bundles of S-R reflexes. Miller brought with him a large amount of material from the RAND seminar, and this material—along with other recent work in artificial intelligence, psychology, and linguistics—helped shape the view expressed in their book, *Plans and the Structure of Behavior* (Miller et al., 1960).

The authors argue that much of human behavior is planned. A **plan**, according to their formulation, consists of a list of instructions that can control the order in which a sequence of operations is to be performed. A plan is essentially the same as a program for a computer. Because the authors found it difficult to construct plans from S-R units, they proposed a new unit called TOTE, an abbreviation for Test-Operate-Test-Exit. A plan consists of a hierarchy of TOTE units. Consider a very simple plan for hammering a nail into a board. The goal is to make the head of the nail flush with the board. At the top of the hierarchy is a test to determine whether the goal has been accomplished. If the nail is flush, one can exit. If the nail sticks up, it is necessary to test the position of the hammer to determine which of two operations, lifting or striking, should be performed.

The ideas expressed by Miller, Galanter, and Pribram were influenced by earlier work in two areas outside psychology. The work of Newell et al. (1958a) in the area of artificial intelligence identified strategies that people use to perform complex tasks such as playing chess. A second major influence came from linguist Noam Chomsky, who argued that an S-R theory of language learning could not account for how people learn to comprehend and generate sentences (Chomsky, 1957). His alternative proposal—that people learn a system of rules (a grammar)—was consistent with Miller, Galanter, and Pribram's emphasis on planning.

COGNITION'S RELATION TO OTHER FIELDS

Cognitive psychology is part of a broader field of study labeled cognitive science. **Cognitive science** is the study of intelligence in humans, computer programs, and abstract theories, with an emphasis on intelligent behavior as computation (Simon & Kaplan, 1989). It attempts to unify

artificial intelligence The study of how to produce computer programs that can perform intellectually demanding tasks

human information processing The psychological approach that attempts to identify what occurs during the various stages (attention, perception, short-term working memory) of processing the stimulus

plan A temporally ordered sequence of operations for carrying out some task

cognitive science The multidisciplinary study of cognition through such fields as psychology, philosophy, artificial intelligence, neuroscience, linguistics, and anthropology views of thought developed by studies in psychology, linguistics, anthropology, philosophy, artificial intelligence, and the neurosciences (Hunt et al., 1989).

There are several landmarks in the development of the field (Nunez et al., 2019). The journal *Cognitive Science* began publication in 1977, and the Cognitive Science Society was formed in 1979. In 1986, the first PhD-granting cognitive science department was created at the University of California, San Diego. Don Norman played a major role in the creation of the journal, the Cognitive Science Society, and the first PhD-granting cognitive science department.

Nunez and his coauthors nonetheless argue that the field as a whole has lost impetus, focus, and recognition. Instead of becoming an interdisciplinary field, it has become a multidisciplinary field. A multidisciplinary field makes use of the theoretical perspectives of the different disciplines without integration. In contrast, interdisciplinary theories are more coherent and integrated. A multidisciplinary field refers to a collection of disciplines without cohesive interaction among them (Nunez et al., 2019).

PHOTO 1.4 Don Norman at the University of California, San Diego, helped establish the multidisciplinary field of cognitive science.

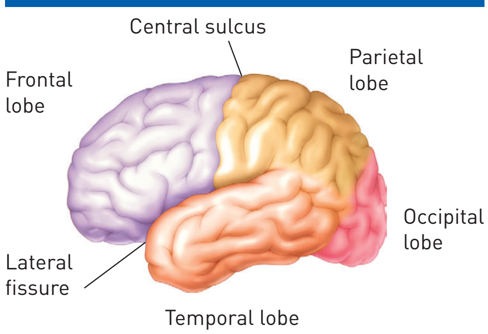
Don Norman.

Gentner (2019) agrees that the field has not converged on unified theories but argues that this is not a departure from the goals of its founders. She applauds the multidisciplinary approach to cognitive science and believes that it should be preserved and celebrated. Both the multidisciplinary and interdisciplinary approaches have made valuable contributions to cognitive science, as documented in the remainder of this chapter.

Cognitive Neuroscience

An exception to a lack of integration among fields within cognitive science is the field of cognitive neuroscience, which combines the methodology and theories of cognitive psychology with the methods of neuroscience. Throughout the text, we will examine the relationship between specific brain areas and cognitive functions. Much of this will focus on the **neocortex**, which consists of the four lobes of the brain shown in Figure 1.1. Processing of visual information occurs in the *occipital lobe*, which is the sole function located in this brain region. The *parietal lobe* is specialized for dealing with the body and spatial information (where things are in the world, including the body). Damage to this area can result in difficulty with movement as well as loss of attention. The *temporal lobe* is essential for understanding language and contributes to recognizing complex visual patterns, such as faces. The *frontal lobe* receives sensations from all the sensory systems and contributes to planning motor movements. Damage to this area can also interfere with memory.

FIGURE 1.1 ■ Some Major Subdivisions of the Left Hemisphere of the Neocortex.

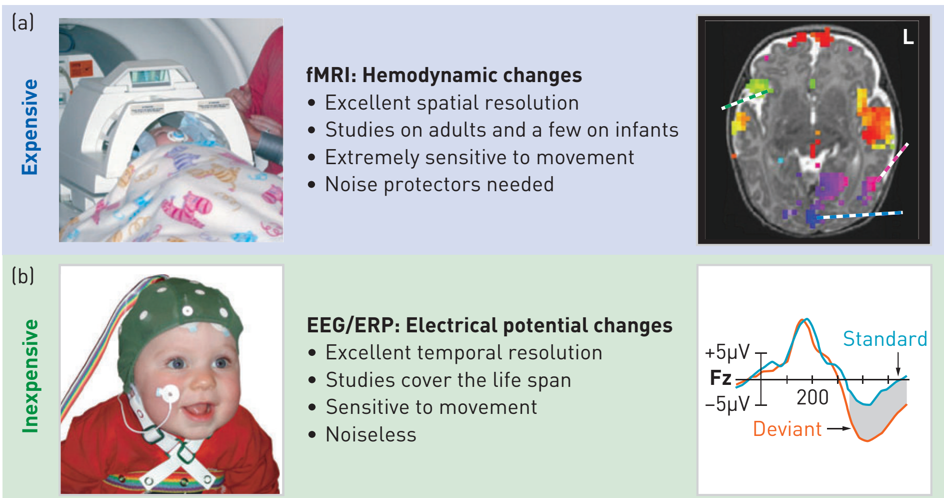


Source: Garrett, Brain and Behavior 5e, Figure 3.8: Lobes and Functional Areas on the Surface of the Hemispheres.

neocortex Layers of the cerebral cortex that are involved in higher-order brain functions, such as perception, cognition, motor commands, and language

As technology has advanced, the ability of scientists to measure brain activity has also advanced. **Positron emission tomography (PET)** uses radioactive tracers to study brain activity by measuring the amount of blood flow in different parts of the brain (Posner & Rothbart, 1994). A more recent and widely applied method, **functional magnetic resonance imaging (fMRI),** uses magnetic fields to measure blood flow (Figure 1.2a). It is a popular method of neuroimaging in adults because it provides high spatial-resolution maps of neural activity across the entire brain. However, the loud noises and sensitivity to movement limit its use with infants (Kuhl & Rivera-Gaxiola, 2008).

FIGURE 1.2 ■ Functional Magnetic Resonance Imaging (fMRI) and Event-related Potentials (ERP) Provide Spatial and Temporal Measures of Brain Activity.



Source: From "Neural substrates of language acquisition," by P. K. Kuhl & M. Rivera-Gaxiola, 2008, *Annual Review of Neuroscience, 31*, 511–534. https://www.annualreviews.org/doi/10.1146/annurev.neuro.30.051606.094321. Figure 1 on page 514 (row 1 and 3)

A limitation of spatial imaging techniques such as PET and fMRI is that they do not provide the precise temporal information that is necessary for analyzing many cognitive processes in which fractions of a second are theoretically important. Recording electrical activity from the scalp provides temporal precision on the order of milliseconds. The use of these **event-related potentials (ERPs)** allows scientists to study the time course of mental operations. The vertical axis of the graph in Figure 1.2b displays voltage changes and the horizontal axis displays time in milliseconds (Kuhl & Rivera-Gaxiola, 2008).

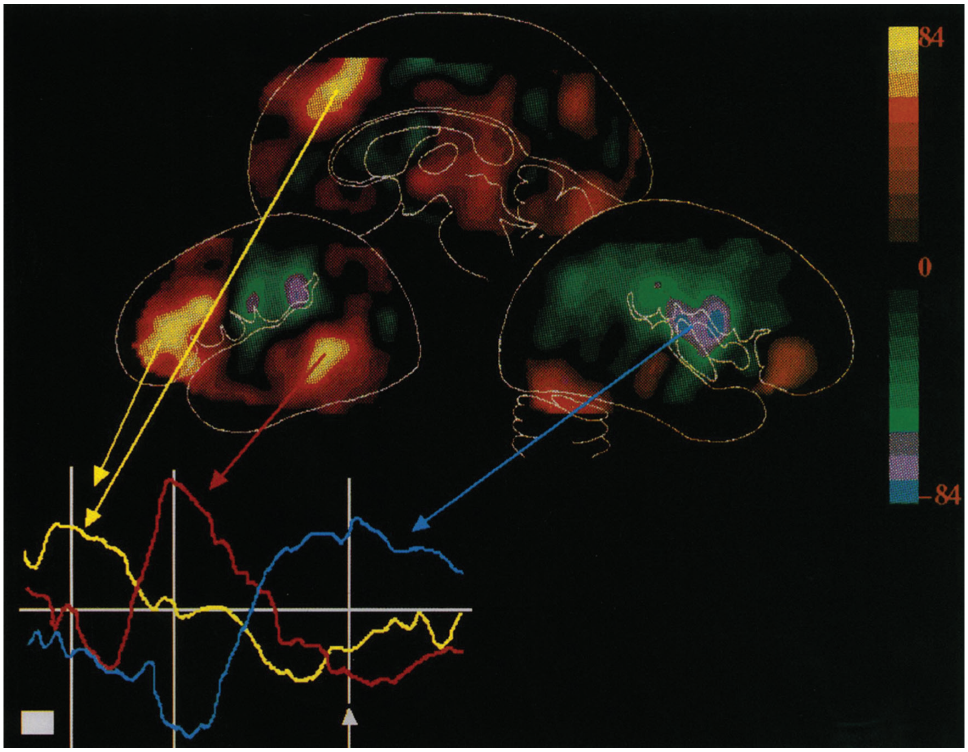
positron-emission tomography (PET) A diagnostic technique that uses radioactive tracers to study brain activity by measuring the amount of blood flow in different parts of the brain

functional magnetic resonance imaging (fMRI) A diagnostic technique that uses magnetic fields and computerized images to locate mental operations in the brain

event-related potential (ERP) A diagnostic technique that uses electrodes placed on the scalp to measure the duration of brain waves during mental tasks

By combining PET and ERP studies, it is possible to take advantage of the more precise spatial localization of imaging techniques and the more precise temporal resolution of electrical potentials (Posner & Rothbart, 1994). Figure 1.3 illustrates how both techniques help scientists comprehend how people understand written words (Snyder et al., 1995). The red and yellow areas show increases in blood flow, indicating that the frontal and temporal areas of the left hemisphere are important for understanding the meaning of the words.

FIGURE 1.3 ■ A PET Scan Showing Changes in Blood Flow in the Left Hemisphere During a Cognitive Task. Brain Waves Show When Activation Occurs.

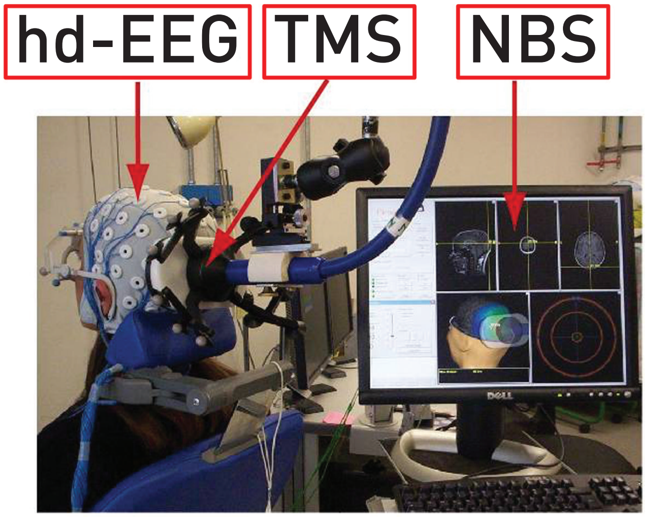


Source: From "Scalp electrical potentials reflect regional cerebral blood flow responses during the processing of written words," by A. Z. Snyder, Y. G. Abdullaev, M. I. Posner, & M. E. Raichle, 1995, *Proceedings of the National Academy of Sciences USA, 92*, 1689–1693. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC42585/

The arrows connect PET blood-flow changes with the ERP waveforms recorded at the nearest overlying electrode on the scalp. The activation in the frontal part of the left hemisphere (yellow) leads the activation in the temporal part (red) by several hundred milliseconds. These findings imply that the earlier frontal activation is important for encoding the meaning of individual words and the later temporal activation may be more important for the integration of word meanings to understand phrases and sentences (Snyder et al., 1995). This hypothesis is consistent with the finding that damage to the temporal area of the left hemisphere often produces a language deficit that leaves the person unable to combine words to produce meaningful ideas.

Remarkably, it is possible to not only record ERPs but to directly change them (Widhalm & Rose, 2019). Transcranial magnetic stimulation produces a high-intensity magnetic field that passes through the scalp and causes neurons to fire. The effects of the stimulation are observed not only through changes in behavior but through changes in brain activity that reflect cognitive processes that contribute to that behavior (Widhalm & Rose, 2019). Figure 1.4 displays a brain stimulation system that navigates and targets **transcranial magnetic stimulation** on a 3D construction of the participant's brain. An EEG cap measures the electric field induced by transcranial stimulation and estimates its intensity on the cortical surface (Rosanova et al., 2012).

FIGURE 1.4 ■ A Navigation Brain Stimulation System (NBS) Measures Brain Waves (EEG) Produced through Transcranial Magnetic Stimulation (TMS).



Source: From "Combining transcranial magnetic stimulation with electroencephalography to study human cortical excitability and effective connectivity," by M. Rosanova, S. Casarotto, A. Pigorinni, P. Canali, A. G. Casali, & M. Massimini, 2012, *Neuromethods, 67*, 435–457. https://doi.org/10.1007/7657_2011_15

Cognitive neuroscience is particularly interesting to cognitive psychologists when it helps them evaluate cognitive theories (Yarkoni et al., 2010). For instance, we will see in Chapter 8 that one of the classic debates in cognitive psychology is the role of visual imagery in cognition. How do we know when people are using visual imagery to perform a task? Cognitive neuroscience has helped answer this question by allowing psychologists to study which part of the brain is active when

transcranial magnetic stimulation (TMS) A brain stimulation technique in which electrical pulses produced by a magnetic field cause neurons to fire in a focused region of the brain people perform spatial reasoning tasks. Evidence for the use of visual imagery occurs when the same part of the brain is activated (the occipital lobe) as is activated during visual perception.

Artificial Intelligence

In their chapter on artificial intelligence (AI) in *The Cambridge Handbook of Intelligence,* Goel and Davies (2020) propose that, from an AI perspective, the construct of intelligence is not limited to humans or even animals but includes any type of intelligent system including computers. AI implements information-processing theories that describe intelligence in terms of the content, representation, access, use, and acquisition of information. It is helpful for exploring the benefits and limitations of different ways of representing and organizing knowledge in memory. It is also helpful for exploring how robots interact with the physical world through perception and action.

There are two major paradigms for designing intelligent computers, according to the authors. Engineering AI attempts to design the smartest possible intelligent systems regardless of whether the systems reflect intelligence found in people. The vast majority of AI research on robotics and machine learning falls into this category. In contrast, psychological AI attempts to design systems that think like people.

Goel and Davies (2020) describe a paradox in which tasks that are relatively easy for computers, such as producing logical proofs and playing chess, are difficult for humans. Tasks that are relatively easy for humans, such as perceiving, walking, and talking, are difficult for computers. The goal of general AI is to make computers proficient at a wide range of tasks, including those that are easy for humans.

There are at least three benefits of close cooperation between cognitive psychologists and people working on AI (Reed, 2019). The first is that computational programs in AI can serve as potential theoretical models in cognitive psychology. An early collaborative effort between a cognitive psychologist (Alan Collins) and a computer scientist (Ross Quillian) resulted in the hierarchical network model described in Chapter 10 to represent semantic organization in human memory (Collins & Quillian 1969). But it was human problem solving (Newell & Simon, 1972) that introduced many new ideas into cognitive psychology that is described in Chapter 13.

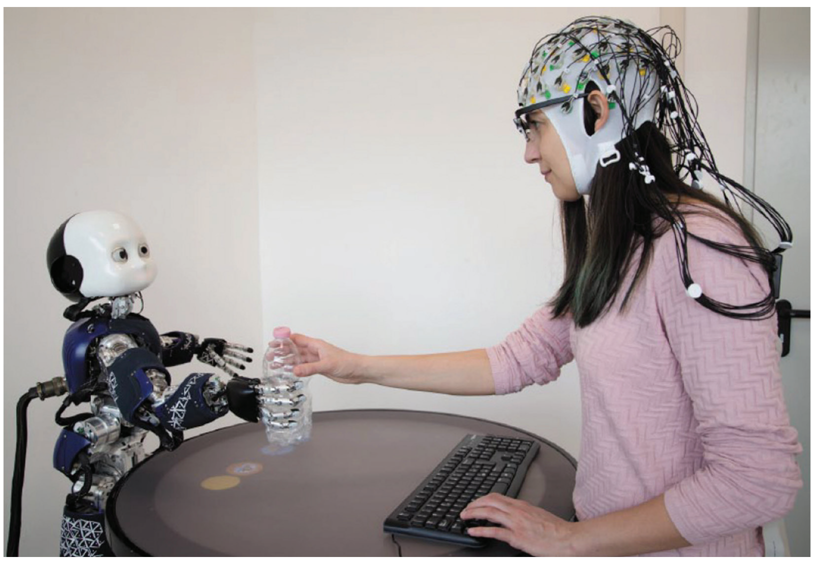
A second benefit is that AI and cognitive psychology share common interests, such as developing methods for categorizing patterns. In his book *The Master Algorithm: How the Quest for the Utimate Learning Machine Will Remake Our World,* computer scientist Pedro Domingos (2015) explains different methods used in machine learning. Cognitive psychologists have developed similar methods to evaluate models of how people categorize patterns (Reed, 2019). The *Master Algorithm* asks how these different methods can be combined to improve performance, a challenge for both AI and cognitive psychology.

A third benefit of building bridges between AI and cognitive psychology is that the increasing impact of AI in our lives requires understanding how technology and people can work together. For instance, it is likely that robots will soon enter our lives as assistants in workplaces, shops, airports, healthcare, and classrooms (Wykowska, 2021). They will also serve as tools for

PHOTO 1.5 Alan Newell (left) and Herb Simon (right) at Carnegie Mellon University applied concepts in artificial intelligence to model human cognition.

Getty Images/Bill Pierce

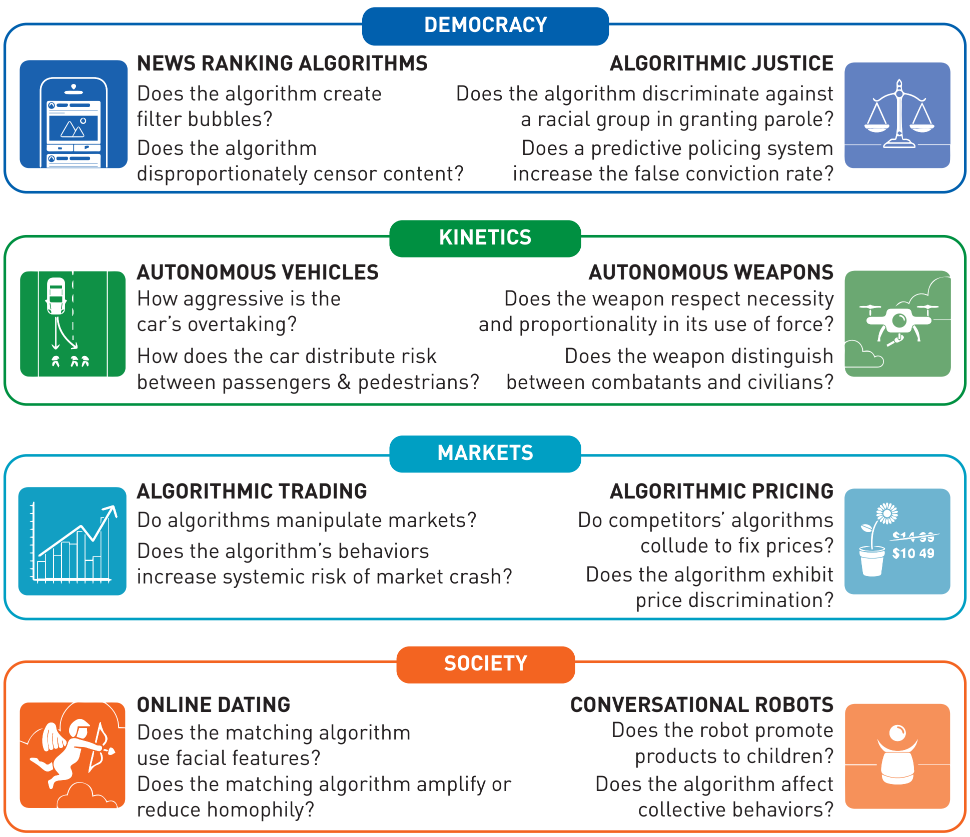
FIGURE 1.5 ■ An Experiment that uses Behavioral Measures, Evoked Potentials, and Eye Tracking to Record the Interactions between a Participant and the Robot iCub.



Source: From "Robots as mirrors of the human mind," by A. Wykowska, 2021, *Current Directions in Psychological Science, 30*, 34–40. doi:10.1177/0963721420978609 generating new hypotheses, predictions, and explanations regarding human cognition. Robots offer the possibility of greater experimental control over initiating and responding to interactions with people (Figure 1.5).

Although AI is already having a major positive impact on our lives, it can also have a negative impact, which has raised concern about its ethical usage. Many of the questions raised in Figure 1.6 are concerns about the social consequences of algorithms (Rahwan et al., 2019). Do they disproportionally censor content? Do they discriminate against racial groups? Do weapons use appropriate amounts of force? Do competitors collude to fix prices? These types of questions are increasingly being asked in and out of courtrooms.

FIGURE 1.6 ■ AI Algorithms that Impact People's lives.



Source: From "Machine behavior," by I. Rahwan et al., 2019, *Nature*, *568*, 477–486. https://doi.org/10.1038/s41586-019-1138-y

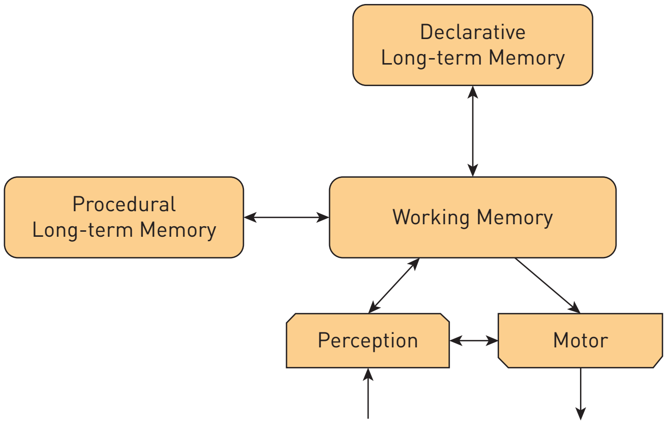
Cognitive Architectures

A landmark in the history of artificial intelligence was a book published by Alan Newell (1990) titled *Unified Theories of Cognition*. Unified theories should ideally be able to explain all aspects of cognition, including perception, learning, memory, problem solving, and decision-making. Such explanations require specifying interactions among the various components of cognition. Newell proposed a theory of how these components interact by developing a **cognitive architecture** called Soar (Newell, 1990).

Soar continues to be developed by the AI community (Laird, 2012), but its greatest contribution to cognitive psychology has been its influence on the development of ACT-R (Anderson, 1983)—a cognitive architecture for modeling human cognition. ACT-R assumes that cognitive architectures should be a theory of how behavior is generated through information processing that includes perception and action (Ritter et al., 2019). It has demonstrated how many aspects of cognition are intertwined, such as perception, memory, and problem solving. A manual, summer school, and workshops have supported building a community of cognitive scientists who have used the architecture to model cognition.

A limitation of ACT-R is its complexity; hence the need for summer school and workshops. Participants in a 2013 symposium on integrated cognition, sponsored by the Association for the Advancement of Artificial Intelligence, therefore met to develop a standard model of the mind based on a stripped-downed cognitive architecture. A standard model would be helpful because artificial intelligence, cognitive psychology, cognitive neuroscience, and robotics all contribute to our understanding of intelligent behavior but each from a different perspective. A standard model would provide a common framework for unifying these disciplines and guide practitioners in constructing a broad range of applications.

FIGURE 1.7 The Standard Model of the Mind.



Source: From "A standard model of the mind: Toward a common computational framework across artificial intelligence, cognitive science, neuroscience, and robotics," by J. E. Laird, C. Lebiere, & P. S. Rosenbloom, 2017, *AI Magazine*, *38*, 13–26. https://doi.org/10.1609/aimag.v38i4.2744

cognitive architecture An integrated system of cognitive components for modeling cognition

Figure 1.7 shows the components of the proposed standard model (Laird et al., 2017). Perception converts sensory stimuli into representations that can be stored in working memory or directly converted into actions by the motor component. Attention limits the amount of available perceptual information in both situations. Working memory provides a temporary storage space where perceptual information can be integrated with information from long-term declarative and long-term procedural memory. Declarative memory is the store for facts and concepts. Procedural memory contains knowledge about actions. The motor component uses the body to execute the actions.

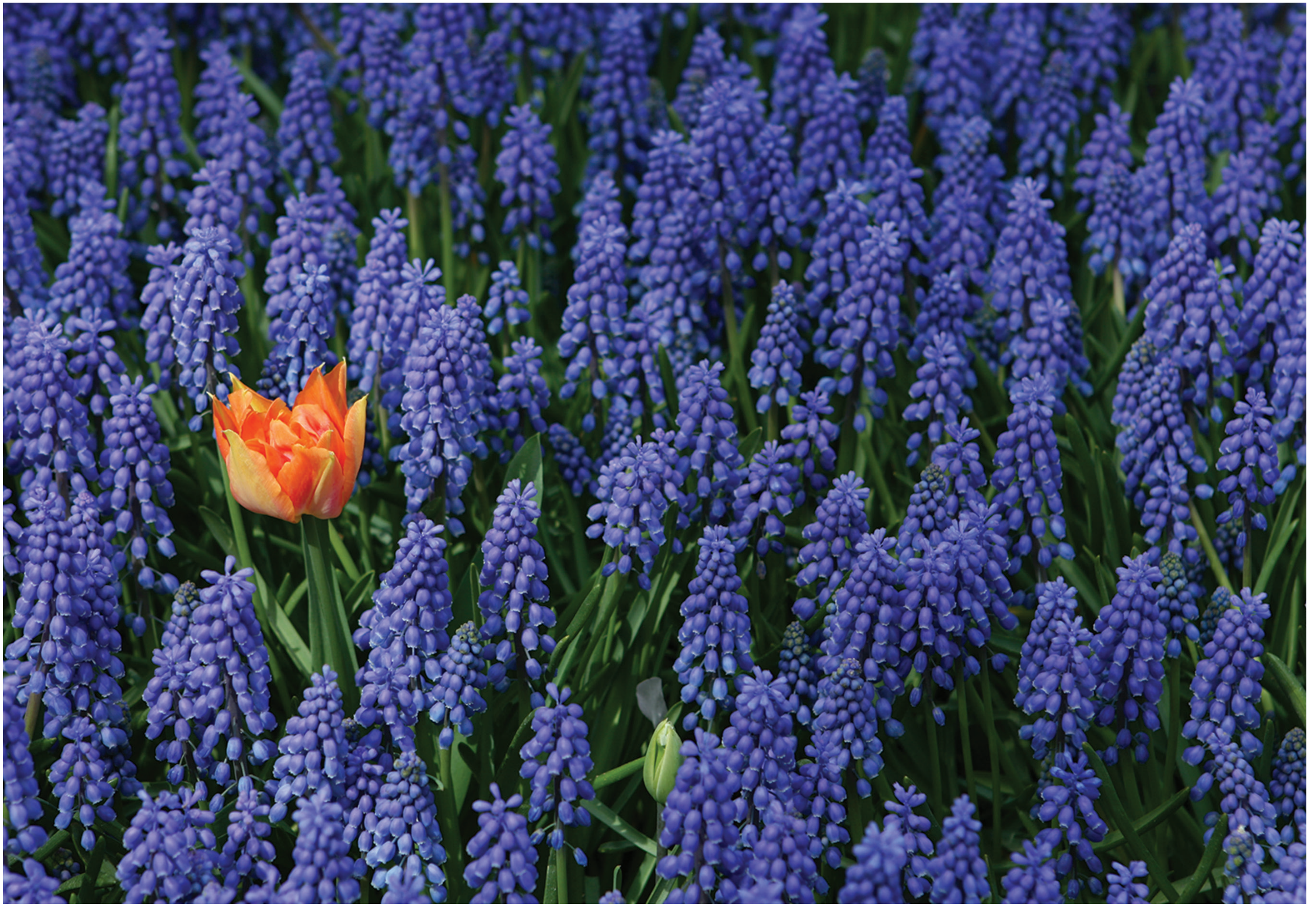
You will learn much more about each of these components as you progress through the book, and the standard model will help relate these components. The authors of the standard model propose that it has the potential to provide a platform for the integration of theoretical ideas across different disciplines. I hope that including it in this text will help fulfill that goal.

SUMMARY

One reason for studying cognitive psychology is that cognitive processes influence many aspects of our lives. It differs from behaviorism by its emphasis on mental representations and procedures, such as replacing stimulus-response associations with hierarchical plans. Cognitive psychology is a member of a multidisciplinary field labeled "cognitive science," which also includes linguistics, anthropology, philosophy, artificial intelligence, and cognitive neuroscience. The interaction between cognitive psychology and cognitive neuroscience is the best example of an attempt to create an interdisciplinary field in which disciplines interact with each other. The objective of the standard model of the mind is to encourage more interdisciplinary interactions based on a shared cognitive architecture. The next five chapters discuss the components of this architecture—perception, working memory, long-term declarative memory, long-term procedural memory, and action.

RECOMMENDED READING

Readers interested in how major theoretical approaches influenced the history of psychology should read Heidbreder's (1961) *Seven Psychologies.* The book contains chapters on prescientific psychology, the beginning of scientific psychology, the psychology of William James, functionalism, behaviorism, dynamic psychology, Gestalt psychology, and psychoanalysis. *The Mind's New Science: A History of the Cognitive Revolution* (Gardner, 1985) and *How the Mind Works* (Pinker, 1997) provide very readable accounts of the evolution of cognitive psychology. The article "A framework for building cognitive process models" (Jarecki et al., 2020) demonstrates how information-processing models continue to influence the field. Chipman's (2016) introduction to cognitive science appears in the *Oxford Handbook of Cognitive Science*, which she edited. *Cognitive Skills You Need for the 21st Century* (Reed, 2020b) contains 20 short chapters on themes related to this topic. *How We Learn: Why Brains Learn Better Than Any Machine… for Now* (Dehaene, 2020) an overview of many issues discussed in this textbook.



Getty Images/JurgaR

2 PATTERN RECOGNITION

LEARNING OBJECTIVES

1. Contrast feature and structural theories of pattern recognition.
2. Explain how Sperling's partial-report technique contributed to understanding characteristics of the visual sensory store.
3. Explain how the word superiority effect determines why a letter in a word is better recognized than a letter by itself.
4. Discuss the goals of understanding scenes and the applications of deep neural networks.
5. Describe how visual disorders have increased our knowledge of neural pathways.

The study of **pattern recognition** is primarily the study of how people identify the objects in their environment. Pattern recognition, which is discussed in this chapter, and attention, in the next chapter, play lead roles in the perception component of the standard model of cognition

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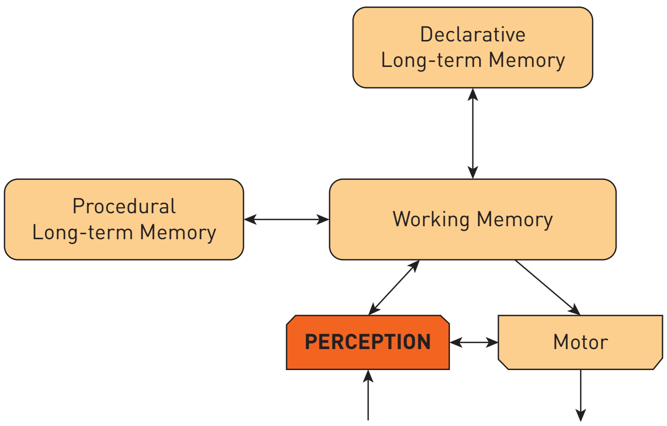
pattern recognition The stage of perception during which a stimulus is identified

(Figure 2.1). We focus on visual pattern recognition in this chapter to provide continuity. Other chapters, such as the next chapter on attention, contain material on speech recognition.

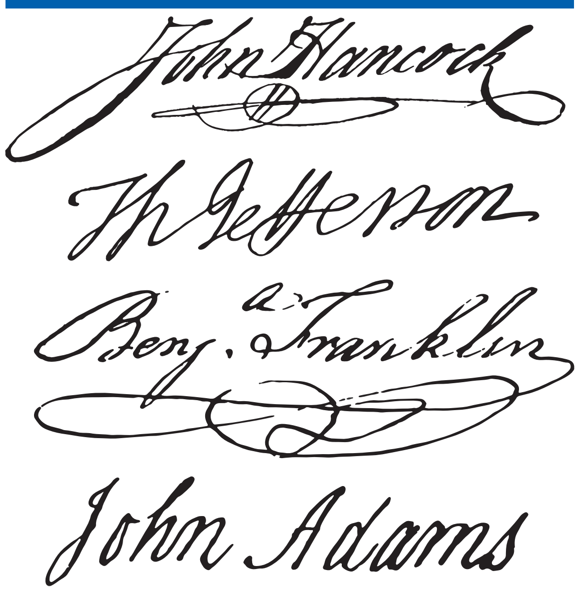
Our ability to recognize patterns is impressive if we stop to consider how much variation there is in different examples of the same pattern. Figure 2.2 shows various styles of handwriting.

FIGURE 2.1 ■ The Perception Component of the Standard Model of the Mind.



Source: Based on "A standard model of the mind: Toward a common computational framework across artificial intelligence, cognitive science, neuroscience, and robotics." by J. E. Laird, C. Lebiere, & P. S. Rosenbloom, 2017, *AI Magazine*, 38, 13–26.

FIGURE 2.2 ■ Variations in Handwriting.



Source: istockphoto.com/DNY59

Not all people have the same style of writing, and some handwriting styles are much less legible than others. However, unless it is very illegible, we usually are successful in recognizing the words.

Our superiority over computers as pattern recognizers has the practical advantage that pattern recognition can serve as a test of whether a person or a computer program is trying to gain access to the Internet. If you have spent much time on the Internet you might have encountered a situation that required you to identify a distorted word before you were allowed to enter a site. The mangled word is easy for people to identify but difficult for computer search programs.

A large part of the literature on pattern recognition is concerned with alternative ways of describing patterns. The first section of this chapter discusses three kinds of descriptions that represent different theories of pattern recognition. The second section is about information-processing models of visual pattern recognition. The next two sections focus on word recognition and scene recognition. The last section on visual agnosia describes how studying brain disorders has contributed to establishing the neural basis of recognizing patterns.

DESCRIBING PATTERNS

Consider the following explanation of how we recognize patterns. Our long-term memory (LTM) contains descriptions of many kinds of patterns. When we see or hear a pattern, we form a description of it and compare the description against the descriptions stored in our LTM. We can recognize the pattern if its description closely matches one of the descriptions stored in LTM. Although this is a plausible explanation, it is rather vague. For example, what form do these descriptions take? Let us consider three explanations that have been suggested: (1) templates, (2) features, and (3) structural descriptions.

Template Theories

Template theories propose that patterns are really not "described" at all. Rather, **templates** are holistic, or unanalyzed, entities that we compare with other patterns by measuring how much two patterns overlap. Imagine that you made a set of letters out of cardboard. If you made a cutout to represent each letter of the alphabet and we gave you a cutout of a letter that we had made, you could measure how our letter overlapped with each of your letters—the templates. The identity of our letter would be determined by which template had the greatest amount of overlap. The same principle would apply if you replaced your cardboard letters with a visual image of each letter and used the images to make mental comparisons.

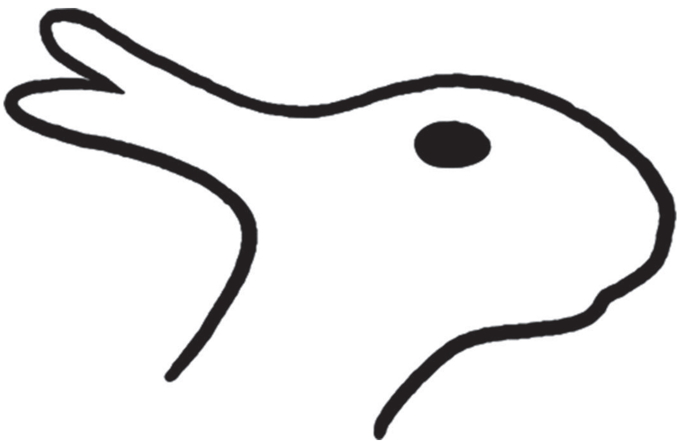
There are a number of problems with using the degree of overlap as a measure of pattern recognition. First, the comparison requires that the template is in the same position and the same orientation, and is the same size as the pattern you are trying to identify. Thus, the position, orientation, and size of the templates would have to be continuously adjusted to correspond to the position, orientation, and size of each pattern you wanted to recognize. A second problem is the

template An unanalyzed pattern that is matched against alternative patterns by using the degrees of overlap as a measure of similarity great variability of patterns, as was illustrated in Figure 2.2. It would be difficult to construct a template for each letter that would produce a good match with all the different varieties of that letter.

Third, a template theory doesn't reveal how two patterns differ. We could know from a template theory that the capital letters *P* and *R* are similar because one overlaps substantially with the other. But to know how the two letters differ, we have to be able to analyze or describe the letters.

A fourth problem is that a template theory does not allow for alternative descriptions of the same pattern. You may have seen ambiguous figures that have more than one interpretation, such as a duck or a rabbit in Figure 2.3. The two interpretations are based on different descriptions; for example, the beak of the duck is the ears of the rabbit. A template is simply an analyzed shape and so is unable to make this distinction. By contrast, a feature theory allows us to analyze patterns into their parts and to use those parts to describe the pattern.

FIGURE 2.3 ■ **An Ambiguous Figure that can be Perceived as Either a Duck or a Rabbit.**



Source: "What an image depicts depends on what an image means," by D. Chambers & D. Reisberg, 1985, *Cognitive Psychology, 24*, 145–174. https://doi.org/10.1016/0010-0285(92)90006-N

Feature Theories

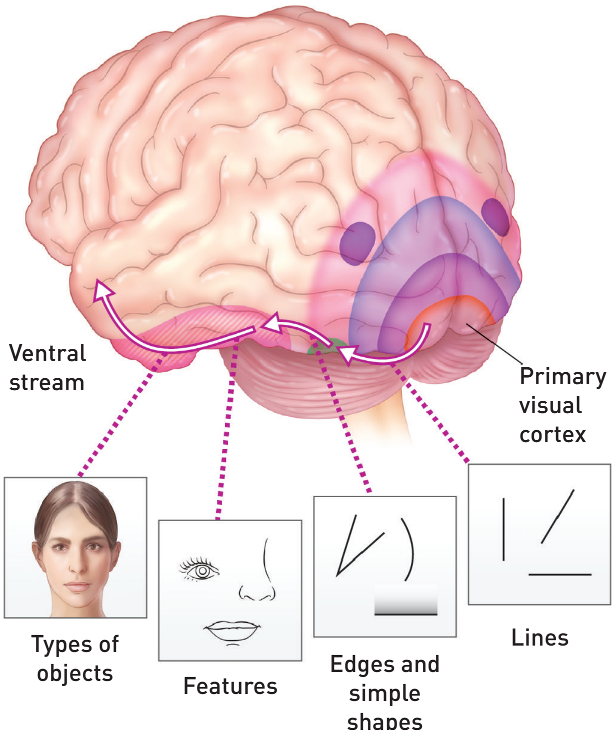
Feature theories allow us to describe a pattern by listing its parts, such as describing a friend as having long blond hair, a short nose, and bushy eyebrows. Part of the evidence for feature theories comes from recording the action potentials of individual cells in the visual cortex. By placing microelectrodes in the visual cortex of animals, Hubel and Wiesel (1962, 1963) discovered that cells respond to only certain kinds of stimuli. Some cells might respond to a line of a certain width, oriented at a correct angle and located at the correct position in its visual field.

feature theory A theory of pattern recognition that describes patterns in terms of their parts, or features

Other cells are even concerned about the length of the line. In 1981 Hubel and Wiesel received a Nobel Prize for this work.

Figure 2.4 shows the neural processing of visual information. Light is initially detected by photoreceptor cells in the retina to extract meaningful information about the visual world. This information is projected to the thalamus and areas of the primary visual cortex where the cells discovered by Hubel and Wiesel respond to features such as lines and simple shapes. These simple shapes are then combined in the ventral stream into more complex features to identify objects. We will learn more about visual features in the next section on perceptual learning and more about neural pathways in the last section on visual disorders.

FIGURE 2.4 ■ Neural Processing of Visual Features.



Source: Adapted from *INNATE: How the Wiring of Our Brains Shapes Who We Are,* by K. J. Mitchell, 2018, Princeton, NJ: Princeton University Press.

Perceptual Learning

Feature theories are convenient for explaining perceptual development, and one of the best discussions of feature theories is contained in Eleanor Gibson's (1969) *Principles of Perceptual Learning and Development.* Gibson's theory is that perceptual learning occurs through the discovery of features that *distinguish* one pattern from another.

Although most pattern recognition theorists make use of the feature concept, it is often a challenging task to find a good set of features. Gibson (1969) proposed the following criteria as a basis for selecting a set of features for uppercase letters:

1. The features should be critical ones and present in some members of the set but not in others to provide a contrast.
2. The identity of the features should remain unchanged under changes in brightness, size, and perspective.
3. The features should yield a unique pattern for each letter.
4. The number of proposed features should be reasonably small.

Gibson used these criteria, empirical data, and intuition to derive a set of features for uppercase letters. The features consist primarily of different lines and curves that are the components of letters. Examples of lines include a horizontal line, a vertical line, and diagonal lines that slant either to the right or to the left as occur in the capital letter *A*. Examples of curves include a closed circle (the letter *O*), a circle broken at the top (the letter *U*), or a circle broken at the side (the letter *C*). Most letters consist of more than one feature, such as a closed circle and a diagonal line in the letter *Q*.

A set of features is usually evaluated by determining how well it can predict **perceptual confusions,** as confusable items should have many features in common. For example, the only difference in features for the letters *P* and *R* is the presence of a diagonal line for the letter *R;* therefore, the two should be highly confusable. The letters *R* and *O* differ in many features, and so they should seldom be confused.

One method for generating perceptual confusions is to ask an observer to identify letters that are presented very rapidly (Townsend, 1971). It is often difficult to discriminate physically similar letters under these conditions, and the errors provide a measure of perceived similarity. Holbrook (1975) compared two feature models to determine how successfully each could predict the pattern of errors found by Townsend. One was the model proposed by Gibson and the other was a modification of the Gibson model proposed by Geyer and De Wald (1973). The major change in the modification was the specification of the number of features in a letter (such as two vertical lines for the letter *H*) rather than simply listing whether that feature was present.

A comparison of the two models revealed that the feature set proposed by Geyer and De Wald was superior in predicting the confusion errors made both by adults (Townsend, 1971) and by four-year-old children (Gibson et al., 1963). The prediction of both models improved when the features were optimally weighted to allow for the fact that some features are more important than others in accounting for confusion errors. Because the straight/curved distinction is particularly important, it should be emphasized more than the others.

---

perceptual confusion A measure of the frequency with which two patterns are mistakenly identified as each other

Distinctive Features

Children learn to identify an object by being able to identify differences between it and other objects. For example, when first confronted with the letters *E* and *F*, the child might not be aware of how the two differ. Learning to make this discrimination depends on discovering that a low horizontal line is present in the letter *E* but not in the letter *F*. The low horizontal line is a **distinctive feature** for distinguishing between an *E* and an *F;* that is, it enables us to distinguish one pattern from the other.

Perceptual learning can be facilitated by a learning procedure that highlights distinctive features. An effective method for emphasizing a distinctive feature is to initially make it a different color from the rest of the pattern and then gradually change it back to the original color. Egeland (1975) used this procedure to teach prekindergarten children how to distinguish between the confusable letter pairs *R-P, Y-V, G-C, Q-O, M-N*, and *K-X.* One letter of each pair was presented at the top of a card with six letters below it, three of which matched the sample letter and three of which were the comparison letter. The children were asked to select those letters that exactly matched the sample letter.

One group of children received a training procedure in which the distinctive feature of the letter was initially highlighted in red—for example, the diagonal line of the *R* in the *R-P* discrimination. During the training session, the distinctive feature was gradually changed to black to match the rest of the letter. Another group of children viewed only black letters. They received feedback about which of their choices were correct, but they were not told about the distinctive features of the letters. Both groups were given two tests—one immediately after the training session and one a week later. The "distinctive features" group made significantly fewer errors on both tests, even though the features were not highlighted during the tests. They also made fewer errors during the training sessions.

Emphasizing the distinctive features produced two benefits. First, it enabled the children to learn the distinctive features so that they could continue to differentiate letters after the distinctive features were no longer highlighted. Second, it enabled them to learn the features without making many errors during the training session. The failure and frustration that many children experience in the early stages of reading (letter discrimination) can impair their interest in later classroom learning.

Focusing on distinctive features might aid in distinguishing among faces, as it does in distinguishing among letters. To test this, Brennan (1985) used computer-generated **caricatures** that make distinctive features even more distinctive. For instance, if a person had large ears and a small nose, the caricature would have even larger ears and an even smaller nose than the accurate drawing. When students were shown line drawings of acquaintances, they identified people faster when shown caricatures than when shown accurate line drawings (Rhodes

---

distinctive feature A feature present in one pattern but absent in another, aiding one's discrimination of the two patterns

caricature An exaggeration of distinctive features to make a pattern more distinctive et al., 1987). Making distinctive features more distinctive through exaggeration facilitated recognition.

Combining Features

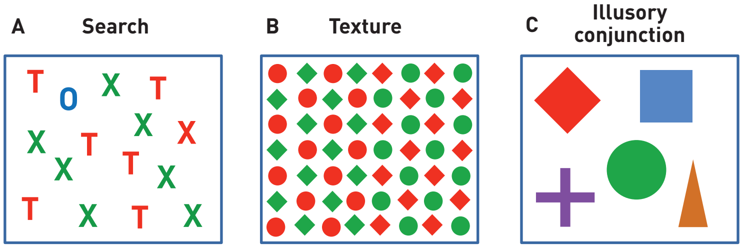
Distinctive features are a key component of our ability to locate an object in our environment. If you ever waited for your luggage at an airport, you may have noticed many people tie colorful ribbons to their luggage to help find their bags more easily because they "pop out" from the crowd. This phenomenon, as illustrated by the red flower at the beginning of the chapter, is a major prediction of feature integration theory (Treisman & Gelade, 1980).

According to this theory, all features across the entire visual landscape are represented simultaneously and pre-attentively. Thus one need only monitor the relevant feature to locate a distinctive item. Treisman and Gelade (1980) found that reaction times to find an object in a *single feature search* were independent of the size of the display, indicating that searching for a single feature is accomplished all at once. However, when two or more features must be combined in a *conjunction search*, each object in a visual scene must be examined for the combined features, which requires using attention. Returning to the airport example—if you have a standard black bag, you will now have to examine each black bag for size, shape, and so forth.

Many of the Treisman's experiments on feature integration theory explored the problem of how a perceiver combines color and shape, as these two features are analyzed by separate parts of the visual system. Figure 2.5 shows several demonstrations of how color and shape interact (Wolfe, 2018). In Panel A, it is easier to find the blue *O*, defined by the unique feature blue, than to find the red *X*. Finding the red *X* requires attending to the conjunction of red and *X* because there are also red *T*s and green *X*s in the display. Treisman found that it did not matter how many other letters were in the display, if people searched for a letter defined by a unique color or shape. The uniqueness made the letter pop out from the rest of the display, as occurs for the blue *O*. However, adding more red *T*s and green *X*s to the display would increase the time to find the red *X* because it requires attending to a conjunction of features.

Panel B illustrates another finding that is predicted by the attention requirements of feature integration theory. It is not immediately obvious that the left half of the display differs from the right half because attention is necessary for perceiving conjunctions of color and shape. The circles and diamonds switch colors, which you can observe by closely attending to the shape and color combinations. Another important implication of Treisman's theory is referred to as the "illusory conjunctions." Following a brief glimpse of the display in Panel C, observers may report seeing an incorrect combination of color and shape, such as a green square. Feature integration theory states that it requires attention to combine features such as color and shape. Insufficient attention, therefore, causes incorrect combinations of features.

FIGURE 2.5 ■ Visual Displays used to Evaluate Feature Integration Theory.



Source: "Ann Treisman (1935–2018)" by J. M. Wolfe, 2019, *Current Biology*, 28, R329–R341 (2018). https://doi.org/10.1016/j.cub.2018.03.009

Structural Theories

A limitation of feature theories is that descriptions of patterns often require that we specify how the features are joined together. Describing how features join together to create a structure is a guiding principle of Gestalt psychology. To Gestalt psychologists, a pattern is more than the sum of its parts. Providing precise descriptions of the relations among pattern features was initially formalized by people working in the field of artificial intelligence who discovered that the interpretation of patterns usually depends on making explicit how the lines of a pattern are joined to other lines (Clowes, 1969).

Structural Descriptions

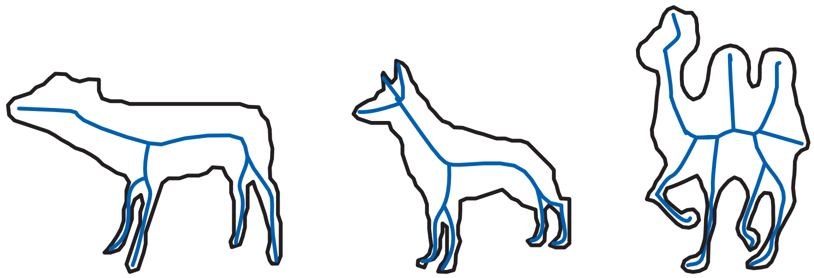
Structural theories describe the relations among the features by building on feature theories. Before we can specify the relation among features, we have to specify the features. A structural theory allows specification of how the features fit together. For example, the letter **H** consists of two vertical lines and a horizontal line. But we could make many different patterns from two vertical lines and a horizontal line. What is required is a precise specification of how the lines should be joined together—the letter **H** consists of two vertical lines connected at their midpoints by a horizontal line.

Figure 2.6 illustrates shape skeletons for different animals that are based on structural descriptions originally proposed by Blum (1973) as a method for distinguishing among biological forms. Wilder et al. (2011) adapted Blum's methods to make predictions about how people would classify novel shapes into categories, such as *animal* and *leaf.* Their successful predictions support the argument that people use these kinds of descriptions to make classifications. The skeleton shapes of animals have relatively curvy limbs compared to the fewer, straighter limbs of leaves.

Moving from a two-dimensional world to a three-dimensional world creates additional challenges for identifying and describing the relations among features. Figure 2.7 illustrates the problem of identifying features by the relative difficulty of perceiving the three patterns as cubes (Kopfermann, 1930). The left pattern is the most difficult to perceive as a cube, and the pattern in the middle is the easiest. Try to guess why before reading further. (Hint: Think about the challenge of identifying features for each of the three examples.)

structural theory A theory that specifies how the features of a pattern are joined to other features of the pattern

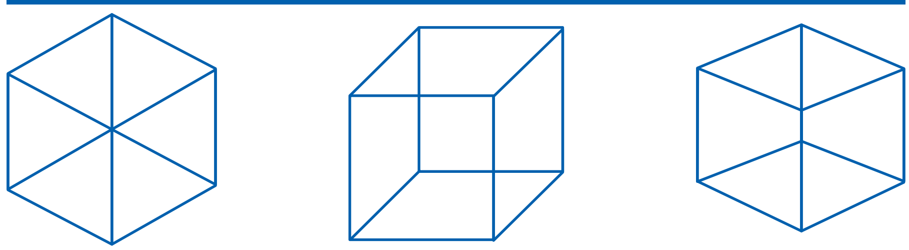
FIGURE 2.6 ■ Examples of Skeleton Structures of Animals.



Source: "Superordinate shape classification using natural shape statistics" by J. Wilder, J. Feldman, J., & M. Singh, 2011, *Cognition*, 119, 325–340. https://doi.org/10.1016/j.cognition.2011.01.009

The theme of Hoffman's (1998) book on visual intelligence is that people follow rules in producing descriptions of patterns. The first of the many rules described in his book is to always interpret a straight line in an image as a straight line in three dimensions. Therefore, we perceive the long vertical line in the center of the right pattern in Figure 2.7 as a single line. However, it is necessary to split this line into two separate lines to form a cube because the lines belong to different surfaces. It is particularly difficult to see the figure on the left as a cube because you also need to split the two long diagonal lines into two shorter lines to avoid seeing the object as a flat pattern.

FIGURE 2.7 ■ Perceiving Cubes.



Source: *Visual Intelligence,* by D. D. Hoffman, 1998, New York: Norton.

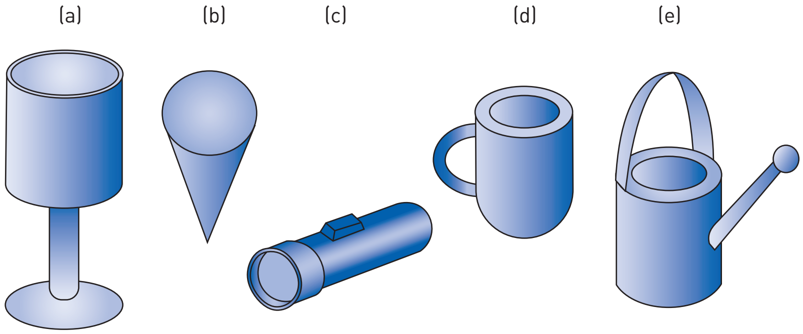
The pattern in the middle is easy to perceive as a cube, which you may have recognized as the famous Necker cube. The Necker cube is well known because your perception of the front and back surfaces of the cube changes as you view it (Long & Toppino, 2004). It is yet another example that a structural description can change when the features do not change!

Biederman's Component Model

Descriptions of three-dimensional objects would be fairly complicated if we had to describe each of the lines and curves in the object. For example, the cubes in Figure 2.7 each consist of 12 lines (which you may find easier to count in the left and right cubes after splitting the lines than in the reversing Necker cube). It would be easier to describe three-dimensional objects through simple volumes such as cubes, cylinders, edges, and cones than to describe all the features in these volumes.

The advantage of being able to form many different arrangements from a few components is that we may need relatively few components to describe objects. Biederman (1985) has proposed that we need only approximately 35 simple volumes (which he called **geons**) to describe the objects in the world. Some objects contain the same geons, but the geons are arranged differently. The mug (d) in Figure 2.8 would become a pail, if the handle were placed at the top rather than at the side of the container. Add two additional geons, and the pail becomes a watering can (e).

FIGURE 2.8 ■ Different Arrangements of Geons Produce Different Objects.



Source: Schwartz, Sensation and Perception 2e: Figure 5.25

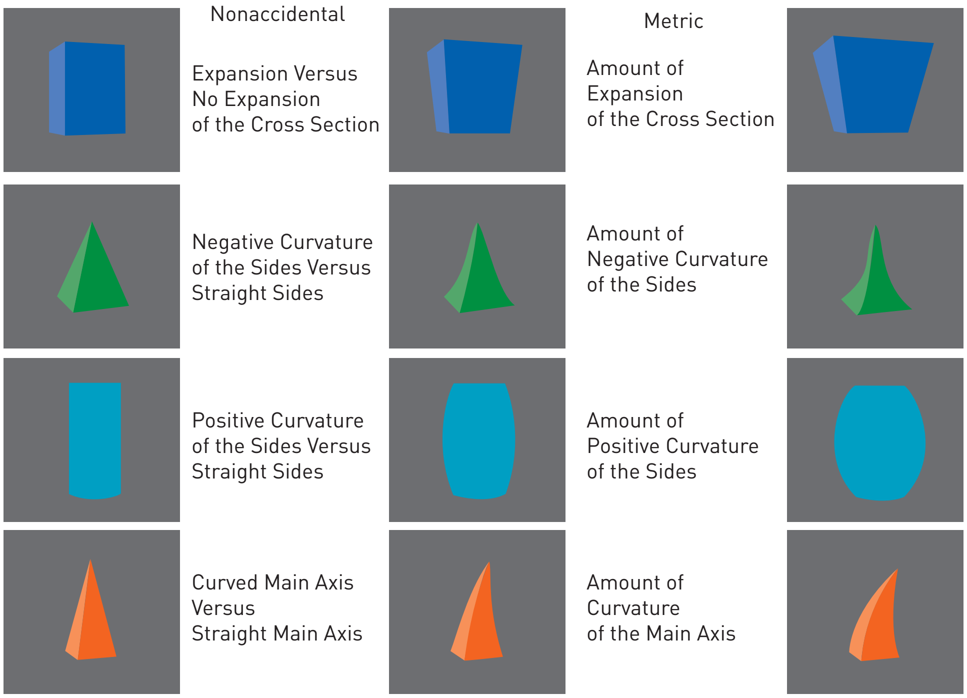
Research by Biederman et al. (2009) established that it is easier to discriminate one geon from a different geon than to discriminate two variations of the same geon. For example, U.S. college students can more easily discriminate the middle object in Figure 2.9 from the left object (a different geon with straight sides) than from the right object (a variation of the same geon with greater curvature).

A question raised by these findings is whether there are cultural differences in people's ability to discriminate among geons. The distinction between straight lines and curves is fundamental in western culture, as we have already discovered, for discriminating among letters of the alphabet. In contrast, there is less of the need to discriminate between lines and curves by the Himba, a seminomadic people living in a remote region of Namibia. Nonetheless, the Himba also are more able to distinguish different geons from each other (the left two objects) than variations of the same geon (the right two objects).

If pattern recognition consists mainly in describing the relations among a limited set of components, then deleting information about the relations among those components should reduce people's ability to recognize patterns. To test this hypothesis, Biederman removed 65% of the contour from drawings of objects, such as the two cups shown in Figure 2.10. In the cup on the left, the contour was removed from the middles of the segments, allowing observers to see how the segments were related. In the cup on the right, the contour was removed from the vertices so observers would have more difficulty recognizing how the segments were related. When drawings of different objects were presented for 100 msec, subjects correctly named 70% of the objects if the contours were deleted at midsegments. But if the contours were deleted at

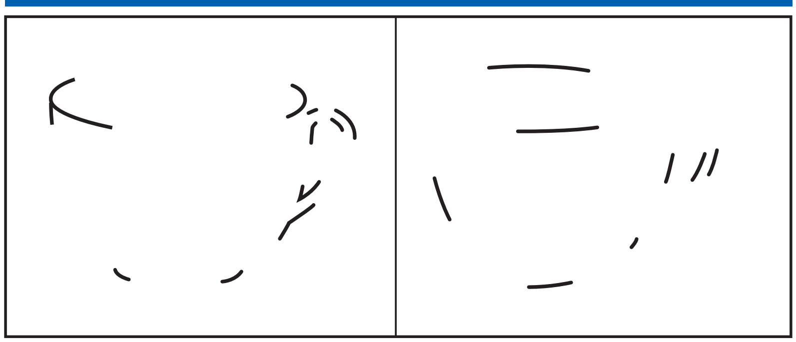
geons Different three-dimensional shapes that combine to form three-dimensional objects the vertices, subjects correctly named fewer than 50% of the objects (Biederman, 1985). As predicted, destroying relational information was particularly detrimental for object recognition.

FIGURE 2.9 ■ Discriminating between Different Geons (Middle and Left) is Easier than Discriminating between Different Variations of the Same Geon (Middle and Right).



Source: "Representation of shape in individuals from a culture with minimal exposure to regular, simple artifacts" by I. Biederman, X. Yue, & J. Davidoff, 2009, *Psychological Science*, 20, 1437–1442. https://doi.org/10.1111/j.1467-9280.2009.02465.x

FIGURE 2.10 ■ Illustration of 65% Contour Removal Centered at Either Midsegments (Left Object) or Vertices (Right Object).



Source: "Human image understanding: Recent research and a theory," by I. Biederman, 1985, *Computer Vision, Graphics, and Image Processing*, *32*, 29–73. https://doi.org/10.1016/0734-189X(85)90002-7

In conclusion, structural theories extend feature theories by specifying how the features are related. Sutherland (1968) was one of the first to argue that if we want to account for our very impressive pattern recognition capabilities, we will need the more powerful kind of descriptive language contained in a structural theory. The experiments in this section show that Sutherland was correct. We now look at how pattern recognition occurs over time.

INFORMATION-PROCESSING STAGES

The Partial-Report Technique

To completely understand how people perform a pattern recognition task, we have to identify what occurs during each of the information-processing stages (pattern recognition, attention, working memory) discussed in Chapter 1. George Sperling (1960) is responsible for the initial construction of an information-processing model of performance on a visual recognition task. We discuss his experiment and theory in detail because it provides an excellent example of how the information-processing perspective has contributed to our knowledge of cognitive psychology.

Subjects in Sperling's task saw an array of letters presented for a brief period (usually 50 msec) and were asked to report all the letters they could remember from the display. Responses were highly accurate if the display contained fewer than five letters. But when the number of letters was increased, subjects never reported more than an average of 4.5 letters correctly, regardless of how many letters were in the display.

A general problem in constructing an information-processing model is to identify the cause of a performance limitation. Sperling was interested in measuring the number of letters that could be recognized during a brief exposure, but he was aware that the upper limit of 4.5 might be caused by an inability to remember more than that. In other words, subjects might have recognized most of the letters in the display but then forgot some before they could report what they had seen. Sperling, therefore, changed his procedure from a **whole-report procedure** (report all the letters) to a **partial-report procedure** (report only some of the letters).

In the most typical case, the display consisted of three rows, each containing four letters. Subjects would be unable to remember all 12 letters in a display, but they should be able to remember four letters. The partial-report procedure required that subjects report only one row. The pitch of a tone signaled which of the three rows to report: the top row for a high pitch, the middle row for a medium pitch, and the bottom row for a low pitch. The tone sounded just after the display disappeared, so that subjects would have to view the entire display and could not simply look at a single row (Figure 2.11). Use of the partial-report technique is based on the assumption that the number of letters reported from the cued row equals the average number of letters perceived in each of the rows because the subjects did not know in advance which row to look at. The results of this procedure showed that subjects

whole-report procedure A task that requires observers to report everything they see in a display of items

partial-report procedure A task in which observers are cued to report only certain items in a display of items