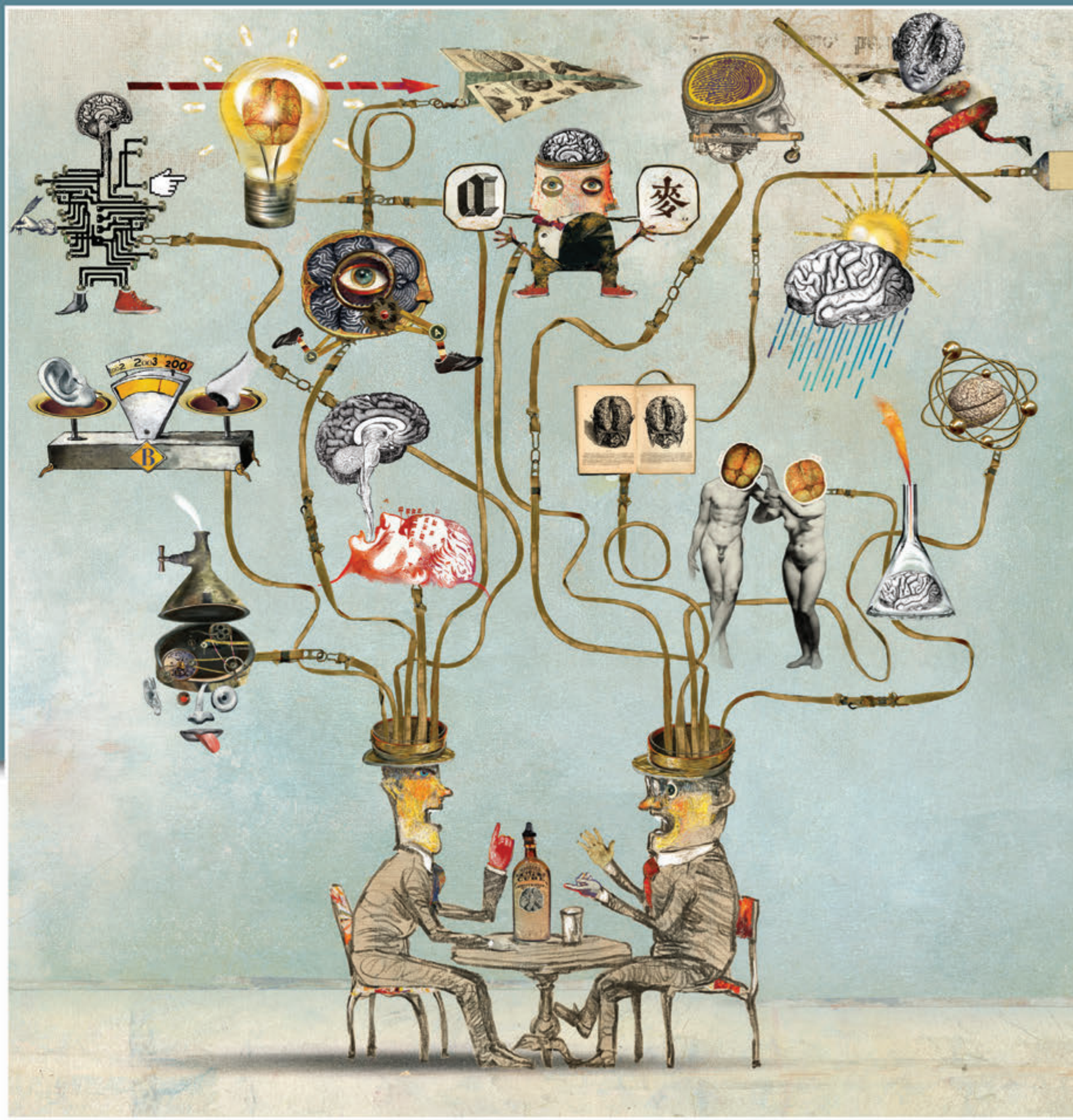

The Mind's Machine

Foundations of Brain and Behavior

SECOND EDITION

Neil V. Watson • S. Marc Breedlove

The Mind's Machine SECOND EDITION

COMPANION WEBSITE

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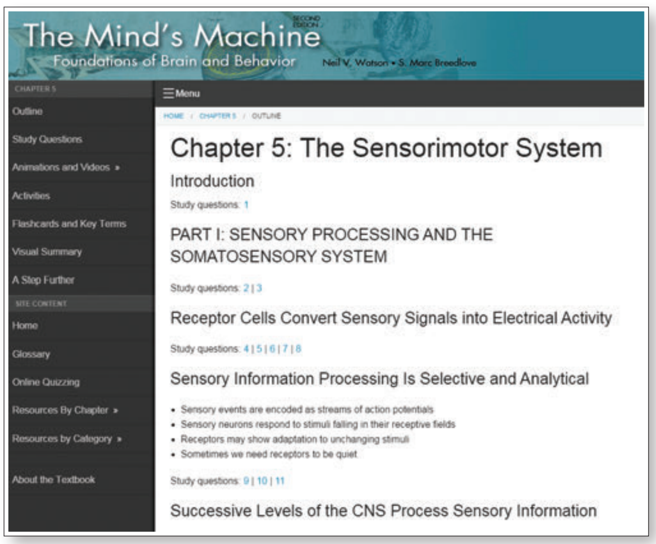
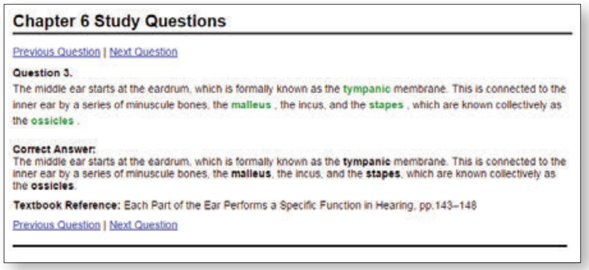
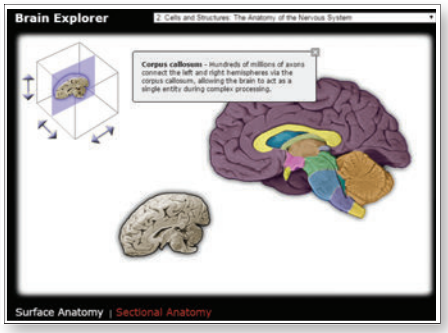


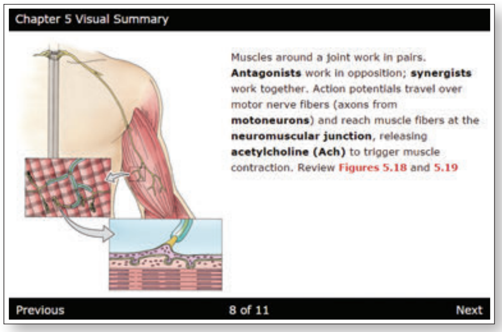
The Mind's Machine Companion Website is a free companion to the textbook that will help you learn the material presented in the book through a variety of study tools and multimedia resources. The website is tightly integrated with the text, with content corresponding to every section of each chapter and QR codes and direct Web addresses that link you directly to specific online resources. (See more at right.) Complex concepts and systems are made more accessible through the use of animations, videos, and activities, and key terms and concepts are reinforced through interactive study questions. The site also offers online quizzes that your instructor may assign. (Note that instructor registration is required in order for students to access the online quizzes.)



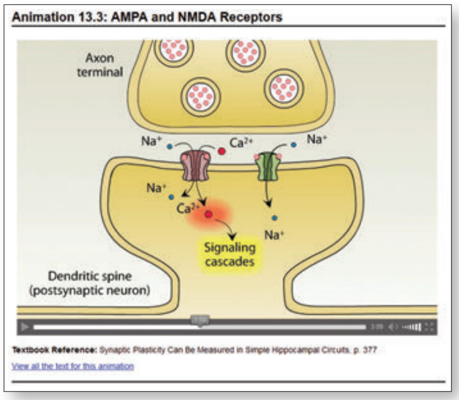
Study questions reinforce your knowledge of all the important facts and concepts covered in each chapter through interactive fill-in-the-blank questions that check your answers immediately.



The **Brain Explorer** offers an interactive way to explore the brain anatomy discussed in each chapter, in both surface and sectional views.



Online versions of the **visual summaries** provide a thorough review of each chapter and include links to figures, animations, videos, and activities.



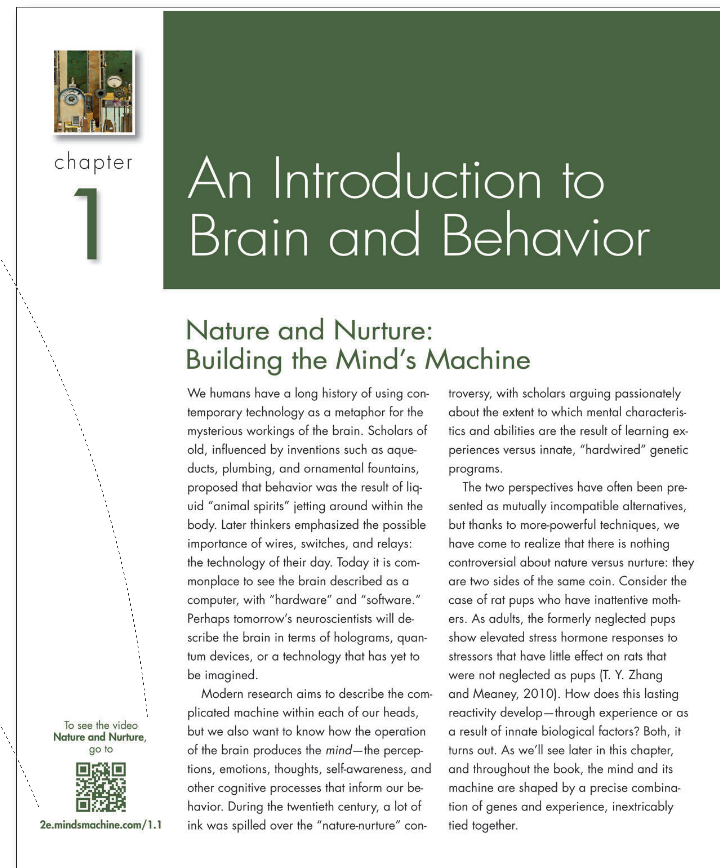
Animations present complex concepts in a clear, easy-to-follow narrative, using a visual style that closely matches the textbook's figures.

Additional Features

- **Activities**, which help you learn and review key structures and important processes.
- **"A Step Further"** topics, which expand on the material covered in the textbook.
- **Flashcards** for each chapter offer a convenient way to learn and review the many new terms introduced in the textbook.
- A complete **glossary** for quick access to definitions.

QR Codes

Using your smartphone or tablet, scan the QR codes that appear throughout the textbook (or type in the Web address shown) to instantly access animations, videos, and visual summaries on the Companion Website. (QR code reader app required. These are available for free from your device's app store.)



chapter 1

An Introduction to Brain and Behavior

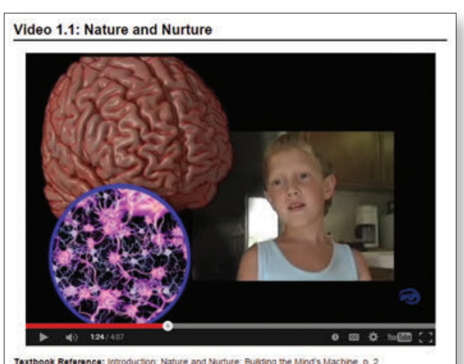
Nature and Nurture: Building the Mind's Machine

We humans have a long history of using contemporary technology as a metaphor for the mysterious workings of the brain. Scholars of old, influenced by inventions such as aqueducts, plumbing, and ornamental fountains, proposed that behavior was the result of liquid "animal spirits" jetting around within the body. Later thinkers emphasized the possible importance of wires, switches, and relays: the technology of their day. Today it is commonplace to see the brain described as a computer, with "hardware" and "software." Perhaps tomorrow's neuroscientists will describe the brain in terms of holograms, quantum devices, or a technology that has yet to be imagined.

Modern research aims to describe the complicated machine within each of our heads, but we also want to know how the operation of the brain produces the *mind*—the perceptions, emotions, thoughts, self-awareness, and other cognitive processes that inform our behavior. During the twentieth century, a lot of ink was spilled over the "nature-nurture" controversy, with scholars arguing passionately about the extent to which mental characteristics and abilities are the result of learning experiences versus innate, "hardwired" genetic programs.

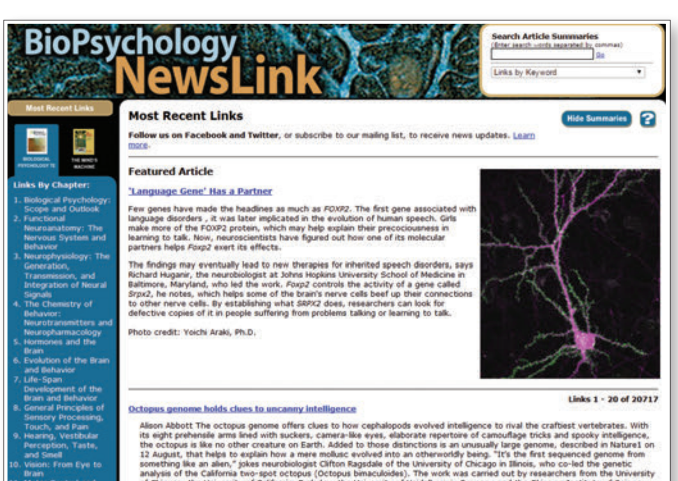
The two perspectives have often been presented as mutually incompatible alternatives, but thanks to more-powerful techniques, we have come to realize that there is nothing controversial about nature versus nurture: they are two sides of the same coin. Consider the case of rat pups who have inattentive mothers. As adults, the formerly neglected pups show elevated stress hormone responses to stressors that have little effect on rats that were not neglected as pups (T. Y. Zhang and Meaney, 2010). How does this lasting reactivity develop—through experience or as a result of innate biological factors? Both, it turns out. As we'll see later in this chapter, and throughout the book, the mind and its machine are shaped by a precise combination of genes and experience, inextricably tied together.

To see the video Nature and Nurture, go to 2e.mindsmachine.com/1.1



Videos

Videos present real-world examples of some of the key concepts and conditions discussed in the textbook.



BIOLOGICAL PSYCHOLOGY NewsLink

2e.mindsmachine.com/news

This invaluable online resource helps you make connections between the science of biological psychology and your daily life, and keeps you apprised of the latest developments in the field. The site is updated 3–4 times per week, and contains thousands of news stories organized both by keyword and by textbook chapter.

Find us on Facebook (Biopsychology).

COMPANION WEBSITE Resources (2e.mindsmachine.com)

The Mind's Machine Companion Website includes animations, videos, and activities for each chapter (listed below) as well as an interactive version of each chapter's visual summary. Animations and Videos are referenced throughout the book with QR codes and direct Web addresses. Activities are referenced in each chapter's summary.

Animations & Videos

Activities

The Mind's Machine

Foundations of Brain and Behavior

SECOND EDITION

The Mind's Machine

Foundations of Brain and Behavior

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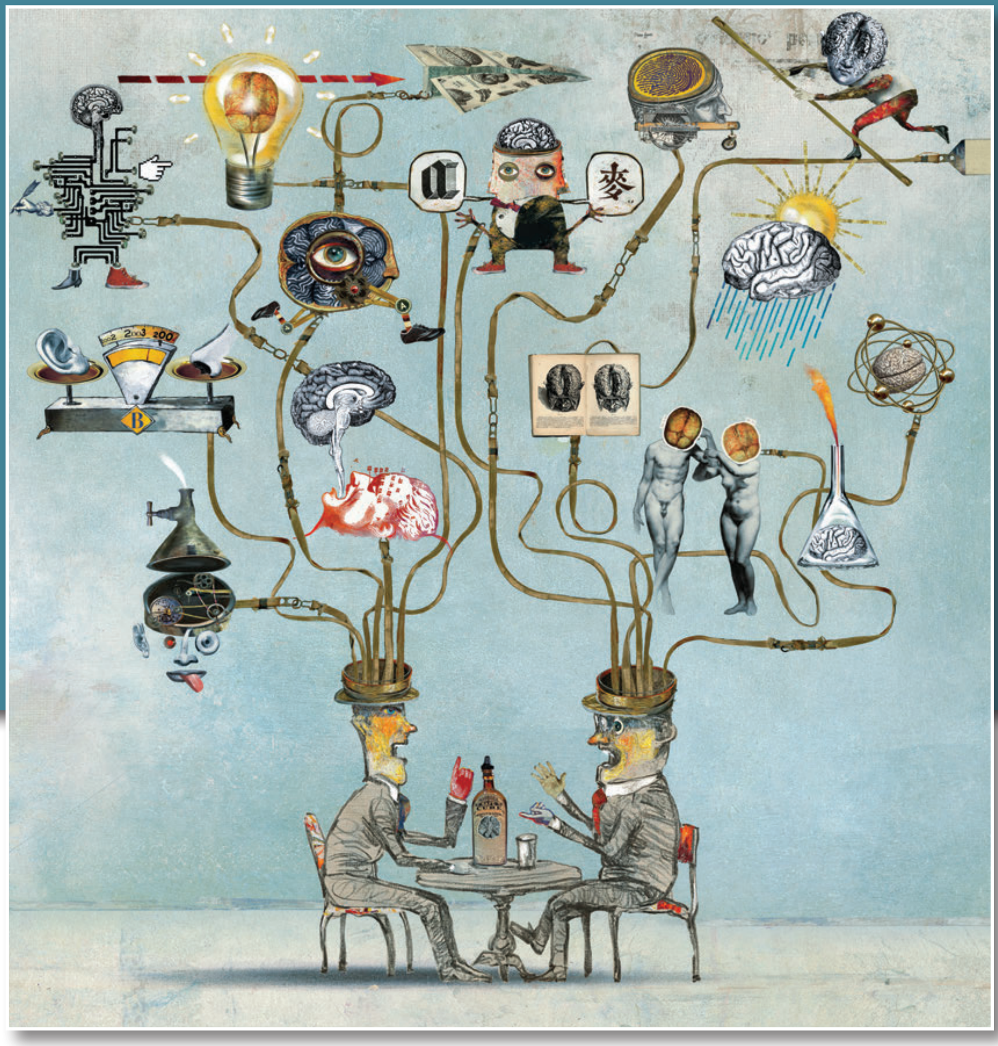

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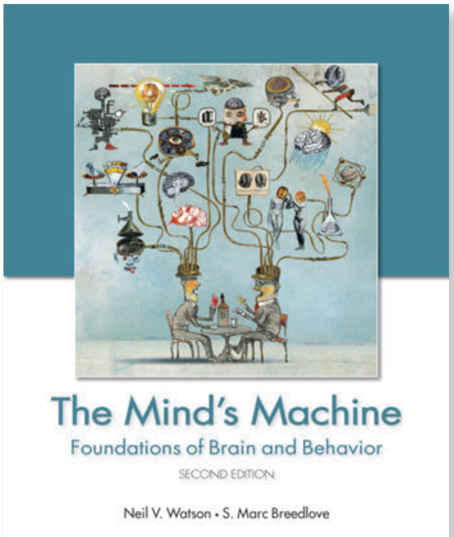
Sinauer Associates, Inc. Publishers

Sunderland, Massachusetts, USA



About the Cover and Chapter Opener Images

Bruno Mallart is one of the most talented European artists, his work having appeared in some of the world's premier publications: The New York Times, The Wall Street Journal, and the New Scientist, to name a few. A freelance illustrator since 1986, Mallart first worked for several children's book publishers and advertising agencies, using a classical realistic watercolor and ink style. Some years later he began working in a more imaginative way, inventing a mix of drawing, painting, and collage. His work speaks of a surrealistic and absurd world and engages the viewer's imagination and sense of fun. Despite the recurring use of the brain in his art, Mallart's background is not scientific—though his parents were both neurobiologists. He uses the brain as a symbol for abstract concepts such as intelligence, thinking, feeling, ideas, and knowledge. Attracted to all that is mechanical, Mallart's art frequently includes machine parts such as gears and wheels that imply movement and rhythm. These features together, in their abstract representation, beautifully illustrate the topics discussed in *The Mind's Machine*, Second Edition. To see more of Bruno Mallart's art, please go to his website: www.brunomallart.com.

The Mind's Machine: Foundations of Brain and Behavior, Second Edition

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N.V.W.
For my little brother, Pete

S. M. B.
For Sage William

Brief Contents

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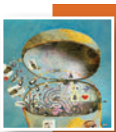

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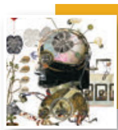

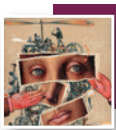

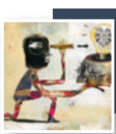

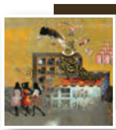

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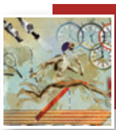

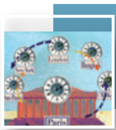

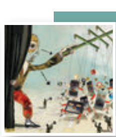

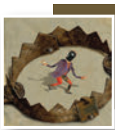

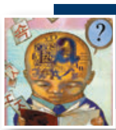

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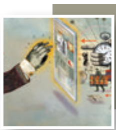

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Preface

It's getting difficult to browse the internet, open a newspaper, or flip through a magazine without encountering reports of astonishing discoveries about the brain's structure, function, and—alas—malfunction. The main reason for all this coverage is that the subject matter is intrinsically fascinating; who has not pondered their own consciousness, marveled at their many sensory experiences, or wondered how a small and lumpy organ can process so much information? But another reason neuroscience is in the news so frequently is simply that it has become one of the most active branches of science. The pace of discoveries about brain and behavior has increased at an exponential rate over the last few decades.

Every new edition of one of our books requires substantial updating because so much is happening all the time. (It's exciting, but boy, do we read a lot of reports and articles!) In fact, by far the hardest part of our job as authors lies in deciding which discoveries to include and which to (reluctantly) leave out: As the Red Queen remarked to Alice in Wonderland, "it takes all the running you can do, to keep in the same place." Our website (2e.mindsmachine.com/news) boasts a collection of more than 20,000 news stories, all drawn from the mainstream media, that relate to the topics covered in the book. You can follow updates on the website, via email, or Facebook (www.facebook.com/biopsychology.

While we are sampling from this almost boundless scientific smorgasbord, we have to watch our weight. Our goal for *The Mind's Machine,* Second Edition is to introduce you to the *basics* of behavioral neuroscience in a way that focuses on the foundational topics in the field—with a generous sprinkling of the newest and most fascinating discoveries—and leaves you with an appetite for more. Whether you are beginning a program of study centered on the brain and behavior, or are just adding some breadth to your education, you will find that behavioral neuroscience now permeates all aspects of modern psychology, along with related life sciences like physiology, biology, and the health sciences. But that's not all. The tools and techniques of behavioral neuroscience are also creating new ways of looking at questions in many nontraditional areas, such as economics, the performing arts, anthropology, sociology, computer science, and engineering. Researchers are beginning to probe mental processes that seemed impenetrable only a decade or two ago: the neural bases of decision making, love and attachment, memory and learning, consciousness, and much of what we call the mind. A few examples of formerly mysterious questions that are being answered with cutting-edge research include:

- Do prenatal events influence the probability that a child will develop a heterosexual or homosexual orientation?
- Does the brain make new neurons throughout life, in numbers large enough to make a functional difference?
- Can we improve memory performance with some drugs, and use other drugs to erase unwanted, traumatic memories?
- What happens in the brain as we develop trust in another person?
- Does strong liking for sweet foods involve the same brain mechanisms as addiction to drugs?
- How can we share so many genes with chimpanzees and other primates, and yet be so different from them?
- How can recent discoveries about the neural control of appetite help us to curb the obesity epidemic?
- Does a gene that predisposes for Alzheimer's disease in old age actually improve cognitive functioning earlier in life?

Understanding the research probing these sorts of questions requires some familiarity with the physiology of behavior and experience. Our aim in *The Mind's Machine,* Second Edition is to provide a foundation that places these and other important problems in a unified scientific context.

We've found that students enrolled in our courses have diverse academic backgrounds and personal interests. In this book, we've tried to avoid making too many assumptions about our readers, and have focused on providing both behavioral and biological perspectives on major topics. If you've had some high-school level biology you should have no trouble with most of the material in the book.

For those readers who have more experience in science—or who want more detail—we have peppered the chapters with embedded links to more advanced material located on our website. These links, called A Step Further, are just one of several novel features we have included to aid your learning. Throughout the book you will find QR codes (small square bar codes) that will link your smartphone to animated versions of many figures, video clips, and more. (You'll need to download an app to read the codes; a variety of free or inexpensive Code Readers are available for the major smartphones like iPhone, Android, and Blackberry.) Or you may use your computer to go to the web address provided below every QR code.

Each chapter also features a segment called Researchers at Work, which illustrates the nuts and bolts of experimentation through real-world examples, and a new segment called Signs & Symptoms that relates a real-world clinical issue relevant to the chapter topic. Every few pages, you will find a feature called How's it Going?, with self-test questions that will help you to gauge your progress. And every chapter ends with a Visual Summary, an innovative combination of the main points and figures from the chapter, which you can also view in an interactive format on the companion website. We encourage you to explore the website for the book (2e.mindsmachine.com), which contains a free comprehensive set of study questions. This website is a powerful companion to the textbook that enhances the learning experience with a variety of multimedia resources.

The chapter lineup in this edition of *The Mind's Machine* encompasses several major themes. In the opening chapters, we trace the origins of behavioral neuroscience and introduce you to the structure of the brain, both as seen by the naked eye and as revealed by the microscope. We discuss how the cells of the brain use electrical signals to process information, and how they transmit that information to other cells within larger circuits. Along the way we'll look at the ways in which drugs affect nerve cells in order to change behavior, as well as some of the remarkable technology that lets us study the activity of the conscious brain as it perceives and thinks.

In the middle part of the book we look at the neural systems that underlie fundamental capabilities like feeling, moving, seeing, smelling, and hearing. We'll also consider biological and behavioral aspects of "mission-critical" functions such as feeding, sleeping, and sexual behavior. And we'll look at how the endocrine system acts as an interface between the brain and the rest of the body, as well as the reverse—ways in which the environment and behavior alter hormones and thus alter brain activity.

In the latter part of the book we turn to some of the high-level emotional and cognitive processes that color our lives and define us as individuals. We'll survey the systems that allow us to learn and remember information and skills, and the brain systems dedicated to language and spatial cognition. Research on processes of attention has made great progress in recent years, and we'll also consider consciousness and decision-making from a neuroscientific perspective. Finally, we'll review some of the consequences of brain dysfunction, ranging from psychopathology to behavioral manifestations of brain damage, and some of the innovative strategies being developed to counter these problems.

As you make your way through the book, you'll learn that one of the outstanding features of the brain is its ability to remodel. Every new experience, every piece of information that you learn, every skill that you master, causes changes in the brain that can alter your future behavior. The changes may involve physical alterations in the connections between cells, or in the chemicals they use to communicate, or even the addition of whole new cells and circuits. It's a property that we neuroscientists refer to as "plasticity." And it's something that we aim to exploit—if we've done our job properly, *The Mind's Machine*, Second Edition should cause lots of changes in *your* brain. We hope you enjoy the process.

Neil V. Watson

2e.mindsmachine.com/watson

S. Marc Breedlove

2e.mindsmachine.com/breedlove

We welcome feedback on any aspect of
The Mind's Machine, Second Edition.
Simply drop us a line at mindsmachine@sinauer.com.

Acknowledgments

This book bears the strong imprint of our late colleagues and coauthors Arnold Leiman (1932–2000) and Mark Rosenzweig (1922–2009). Arnie and Mark prepared the earliest editions of our more advanced text, *Biological Psychology*, and many illustrations and concepts in *this* book originated in their minds' machines.

In writing this book we benefited from the help of many highly skilled people. These include members of the staff of Sinauer Associates: Syd Carroll, Editor; Kathaleen Emerson, Production Editor; Christopher Small, Production Manager; Joanne Delphia, Production Specialist; Jason Dirks, Media and Supplements Editor, and Mara Silver, Production Editor for Media and Supplements. Copy Editor Lou Doucette skillfully edited the text, and Photo Researcher David McIntyre found many of the photographs. Mike Demaray, Craig Durant, and colleagues at Dragonfly Media Group transformed our rough sketches and wish list into the handsome and dynamic art program of this text.

Our greatest source of inspiration (and critical feedback) has undoubtedly been the thousands of students to whom we have had the privilege of introducing the mysteries and delights of behavioral neuroscience, over the course of the last couple of decades. We have benefited from wisdom generously contributed by a legion of academic colleagues, whose advice and critical reviews have enormously improved our books. In particular we are grateful to: Duane Albrecht, Anne E. Powell Anderson, Michael Antle, Benoit Bacon, Scott Baron, Mark S. Blumberg, William Boggan, Eliot A. Brenowitz, Chris Brill, Peter C. Brunjes, Rebecca D. Burwell, Aryn Bush, Catherine P. Cramer, Betty Deckard, Brian Derrick, Karen De Valois, Russell De Valois, Tiffany Donaldson, Rena Durr, Thomas Fischer, Julia Fisher, Loretta M. Flanagan-Cato, Francis W. Flynn, Lauren Fowler, Michael Foy, Kara Gabriel, John D. E. Gabrieli, Jack Gallant, Kimberley P. Good, Diane C. Gooding, Janet M. Gray, James Gross, Ervin Hafter, Mary E. Harrington, Ron Harris, Christian Hart, Chris Hayashi, Wendy Heller, Mark Hollins, Dave Holtzman, Rick Howe, Richard Ivry, Lucia Jacobs, Janice Juraska, Dacher Keltner, Raymond E. Kesner, Mike Kisley, Keith R. Kluender, Leah A. Krubitzer, Joseph E. LeDoux, Diane Lee, Robert Lennartz, Michael A. Leon, Simon LeVay, Jeannie Loeb, Stephen G. Lomber, Jeffrey Love, Donna Maney, Stephen A. Maren, Joe L. Martinez, Jr., John J. McDonald, Robert J. McDonald, James L. McGaugh, Robert L. Meisel, Ralph E. Mistlberger, Jeffrey S. Mogil, Randy J. Nelson, Chris Newland, Miguel Nicolelis, Michelle Niculescu, Lee Osterhout, Linda Perrotti, James Pfaus, Eleni Pinnow, Helene S. Porte, George V. Rebec, Thomas Ritz, Scott R. Robinson, David A. Rosenbaum, Lawrence Ryan, Martin F. Sarter, Jeffrey D. Schall, Stan Schein, Frederick Seil, Dale R. Sengelaub, Victor Shamas, Matthew Shapiro, Arthur Shimamura, Rachel Shoup, Rae Silver, Cheryl L. Sisk, Laura Smale, Robert L. Spencer, Jeffrey Stowell, Steven K. Sutton, Harald K. Taukulis, Jessica Thompson, Sandra Trafalis, Lucy J. Troup, Meg Upchurch, Franco J. Vaccarino, David R. Vago, Cyma Van Petten, Charles J. Vierck, Robert Wickesberg, Christoph Wiedenmayer, Walter Wilczynski, S. Mark Williams, Richard D. Wright, Mark C. Zrull, and Irving Zucker.

A dedicated group of proofreaders pored over the text under severe time constraints; thanks to Will Vickerman and Maria Watson for catching errors we repeatedly missed. The following external reviewers read and critiqued the draft chapters of the Second Edition of *The Mind's Machine*; their contributions and corrections really honed the final product. Any errors that remain are thus entirely our fault.

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Patrick Steffen, *Brigham Young University*
Bruce Svare, *State University of New York at Albany*
Beth Wee, *Tulane University*
Carmen Westerberg, *Texas State University*

Finally, we would like to thank all our colleagues whose ideas and discoveries make behavioral neuroscience so much fun.

Media and Supplements

to accompany

The Mind's Machine

Second Edition

For the Student

Companion Website *2e.mindsmachine.com*

The Mind's Machine, Second Edition Companion Website contains a wide range of study and review resources to help students master the material presented in the textbook and to help engage them in the subject with fascinating examples. Access to the site is free and requires no passcode. (Instructor registration is required in order for students to access the online quizzes.) Tightly integrated with the text, with content corresponding to every major heading in the book, this online resource greatly enhances the learning experience. Key resources are linked throughout the textbook via QR codes and direct Web addresses, making access to animations and videos easy from any smartphone, tablet, or computer.

The Companion Website includes:

- Chapter outlines
- Extensive study questions
- Animations, videos, and activities
- Online, interactive versions of the visual summaries
- Online quizzes (multiple choice and essay)
- Flashcards
- "A Step Further," additional coverage of selected topics
- Complete glossary

Biological Psychology NewsLink *2e.mindsmachine.com/news*

This invaluable online resource helps students make connections between the science of biological psychology and their daily lives, and keeps them apprised of the latest developments in the field. The site includes links to thousands of news stories, all organized both by keyword and by textbook chapter. The site is updated 3–4 times per week. Find us on Facebook (facebook.com/Biopsychology).

For the Instructor

Instructor's Resource Library

(Available to qualified adopters)

The Mind's Machine Instructor's Resource Library includes a variety of resources to aid in planning the course, developing lectures, and assessing students.

The Instructor's Resource Library includes:

- *Figures and Tables*: All of the illustrations, photos, and tables from the textbook are provided as both high-resolution and low-resolution JPEGs, all optimized for use in presentation software (such as PowerPoint).
- *PowerPoint Resources*: Two PowerPoint presentations are provided for each chapter of the textbook:
  - All figures, photos, and tables
  - A complete lecture outline, including selected figures
- *Animations*: These detailed animations help enliven lectures and illustrate dynamic processes
- *Videos*: A collection of video segments that illustrate interesting concepts and phenomena
- *Instructor's Manual and Test Bank* in Word format (details below)
- *Computerized Test Bank*: The entire Test Bank is provided in Diploma format (software included), making it easy to quickly assemble exams using any combination of publisher-provided and custom questions. Includes the Companion Website quiz questions.

Instructor's Manual & Test Bank

(Included in the Instructor's Resource Library)
The Mind's Machine, Second Edition Instructor's Manual & Test Bank includes useful resources for planning the course, building lectures, and creating assessments. For each chapter of the textbook, the Instructor's Manual & Test Bank includes the following:

- Chapter overview
- Complete chapter outline
- Detailed key concepts
- Additional references for lecture and course development
- Key terms
- Comprehensive test questions, including multiple choice, fill-in-the-blank, matching, short answer, and essay questions. The Companion Website quiz questions are also included.

Online Quizzing

The Companion Website includes online quizzes that can be assigned by instructors or (at the instructor's discretion) used as self-review exercises by students. Instructors can create custom quizzes with any combination of their own questions and publisher-provided questions. Results of the quizzes are stored in the online gradebook. (Instructors must register in order for their students to be able to access the online quizzes.)

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The Mind's Machine

Foundations of Brain and Behavior

SECOND EDITION

chapter 1

An Introduction to Brain and Behavior

Nature and Nurture: Building the Mind's Machine

We humans have a long history of using contemporary technology as a metaphor for the mysterious workings of the brain. Scholars of old, influenced by inventions such as aqueducts, plumbing, and ornamental fountains, proposed that behavior was the result of liquid "animal spirits" jetting around within the body. Later thinkers emphasized the possible importance of wires, switches, and relays: the technology of their day. Today it is commonplace to see the brain described as a computer, with "hardware" and "software." Perhaps tomorrow's neuroscientists will describe the brain in terms of holograms, quantum devices, or a technology that has yet to be imagined.

Modern research aims to describe the complicated machine within each of our heads, but we also want to know how the operation of the brain produces the *mind*—the perceptions, emotions, thoughts, self-awareness, and other cognitive processes that inform our behavior. During the twentieth century, a lot of ink was spilled over the "nature-nurture" controversy, with scholars arguing passionately about the extent to which mental characteristics and abilities are the result of learning experiences versus innate, "hardwired" genetic programs.

The two perspectives have often been presented as mutually incompatible alternatives, but thanks to more-powerful techniques, we have come to realize that there is nothing controversial about nature versus nurture: they are two sides of the same coin. Consider the case of rat pups who have inattentive mothers. As adults, the formerly neglected pups show elevated stress hormone responses to stressors that have little effect on rats that were not neglected as pups (T. Y. Zhang and Meaney, 2010). How does this lasting reactivity develop—through experience or as a result of innate biological factors? Both, it turns out. As we'll see later in this chapter, and throughout the book, the mind and its machine are shaped by a precise combination of genes and experience, inextricably tied together.

To see the video **Nature and Nurture**, go to

2e.mindsmachine.com/1.1

There are now almost 7.5 billion of us, and while we can debate whether to fear or celebrate that number, there is no doubt that each of those billions of human brains will at times contemplate its own existence and meaning. How does the operation of a three-pound organ generate our sense of self, express our unique personalities, record information, and guide our actions? Evolution has shaped our bodies and brains so that we closely resemble one another, yet our brains remain malleable throughout life, continually remolded by our environments, experiences, and interactions with other people. So, through a remarkable intersection of genetic heritage and environmental influences, 7.5 billion unique individuals have been formed, and we literally change each other's minds on a daily basis.

Our goal in this book is to introduce you to some of the many ways in which the structures and actions of the brain produce mind and behavior, and also the reverse: some of the many ways in which experiences change the brain. We hope to kindle in you the same interest and excitement that we experienced as students (and still feel today) when reading and thinking about the biology of behavior. Let's start by considering the aims and scope of the science called *biological psychology* or *behavioral neuroscience*.

FIGURE 1.1 How Biological Psychology Relates to Other Fields

What's in a Name?

neuroscience The scientific study of the nervous system.

biological psychology Also called *behavioral neuroscience*, *brain and behavior*, and *physiological psychology*. The study of the biological bases of psychological processes and behavior.

To see the **Brain Explorer**, go to

2e.mindsmachine.com/1.2

The general field of **neuroscience**—the scientific study of the nervous system—is divided into many subdisciplines because the topic is so vast. The first scholars to study the relationships between brain and behavior called themselves philosophers, because it was philosophy that established the scientific method as our best tool for finding new knowledge. Philosophers had long been concerned with the sources of human behavior, so **biological psychology**, the field that relates behavior to bodily processes, naturally evolved from those beginnings. The names *behavioral neuroscience*, *brain and behavior*, and *physiological psychology* are all synonyms for *biological psychology*, but whichever name is used, the main goal of this field is to understand the brain structures and functions that respond to experiences and generate behavior.

Researchers with dramatically varied backgrounds—psychologists, biologists, physiologists, engineers, neurologists, psychiatrists, and many others—together make up the field of biological psychology. It is a field that spans both academia and industry, with focus that ranges from pure research on basic processes to entirely applied work directly translating findings into goods and services (Hitt, 2007). The diverse branches of science that overlap with biological psychology are mapped in **FIGURE 1.1**.

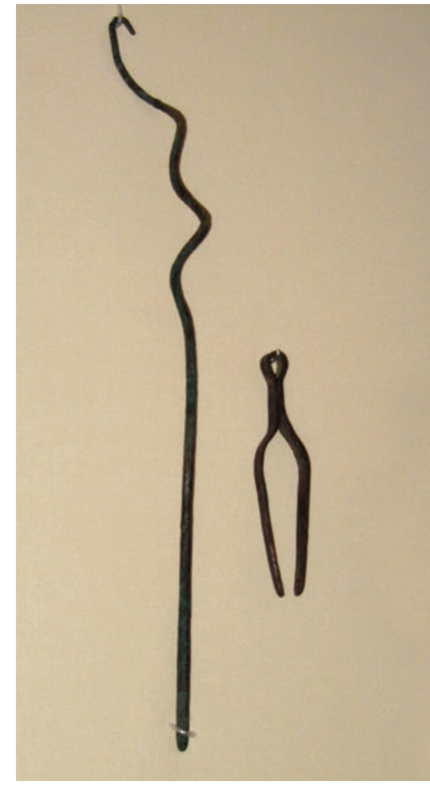
The Science of Brain and Behavior Spans Past, Present, and Future

An early textbook famously opened with the observation that, as a science, "psychology has a long past but only a short history" (Ebbinghaus, 1908). That's certainly an apt description of biological psychology. The modern era of biological psychology—characterized by objective experimentation and use of the scientific method to test hypotheses—has a formal history of only 100 years or so. But curiosity about the genesis of behavior reaches much further into the past, shaped by religious ideas, folk knowledge, and ancient observations about the biology of humans and nonhuman animals. Where does behavior come from?

The behavioral role of the brain was uncertain to early scholars

The elaborate preparation of tombs and careful mummification of important people in ancient Egypt (especially about 1500–1000 BCE) reflected the belief that the dead would enter an afterlife that entailed both struggle and—for the adequately equipped individual—great reward. So, in addition to embalming the body with special salts and oils, the usual practice was to preserve four important organs in alabaster jars in the tomb: liver, lungs, stomach, and intestines. The heart, being especially esteemed, was preserved in its place within the body. The brain, however, was plucked out and unceremoniously discarded; apparently it was considered to be of no particular value in the afterlife.

There is little or no mention of the brain in the Quran, and it is likewise never mentioned in either the Old Testament or New Testament of the Bible, but the heart is mentioned hundreds of times, along with several references each to the liver, the stomach, and the bowels as the seats of passion, courage, and pity, respectively. Aristotle (about 350 BCE), the most prominent scientist of ancient Greece, likewise considered mental capacities to be properties of the heart. When we call people *kindhearted*, *openhearted*, *fainthearted*, *hardhearted*, or *heartless*, and when we speak of learning *by heart*, we are using language echoing this ancient notion. Aristotle thought the brain was little more than a cooling system for hot blood from the heart. But Aristotle's near contemporary, the great Greek physician Hippocrates (about 400 BCE), already suspected that Aristotle's view was—ahem—wrongheaded, and he instead ascribed emotion, perception, and thought to the functioning of the brain.



Brain Removal Kit It seems the ancient Egyptians had little regard for the brain. During the mummification process, embalmers used specialized tools, like these examples in the British Museum, to first break up the small bones behind the nose and then extract the brain through the opening. Unlike other major organs, the brain was discarded, and the cranium was stuffed with linen or straw. (Photograph by Neil Watson.)

A Brain on the Ceiling of the Sistine Chapel? Between 1508 and 1512, Michelangelo painted the Sistine Chapel in the Vatican. In one panel of Michelangelo's masterpiece, God is depicted reaching out to bestow the gift of life upon humanity, through Adam. But neuroscientists have noted that the oddly shaped drapery behind God, and the arrangement of his attendants, closely resembles the human brain (Meshberger, 1990); compare it with the sagittal view in Figure 2.16. A keen student of anatomy, Michelangelo probably knew perfectly well what a dissected human brain looks like. So, was Michelangelo having some fun, making a subtle commentary about the origins of human behavior? We probably will never know. But we can all agree that our uniquely human qualities—language, reason, emotion, and the rest—are products of the brain.

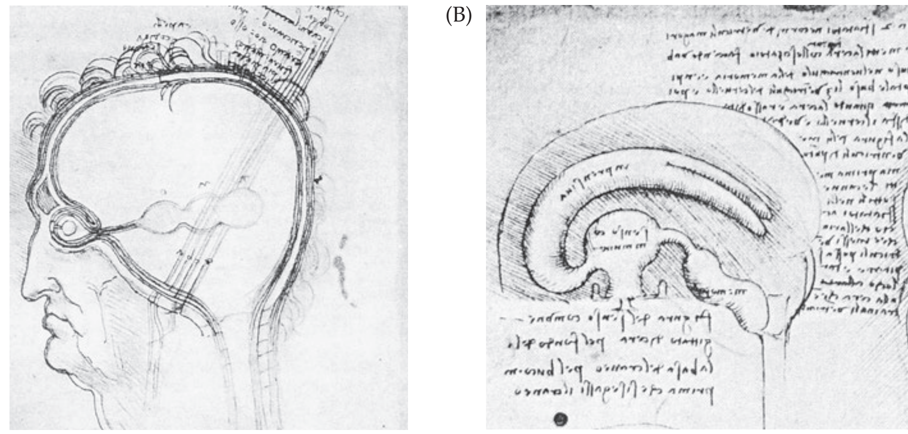


FIGURE 1.2 Leonardo da Vinci's Changing View of the Brain

(A) In an early sketch, Leonardo simply copied old drawings that bore little resemblance to the actual structure of the brain, showing the fluid-filled ventricles as a balloon connected to the eye.

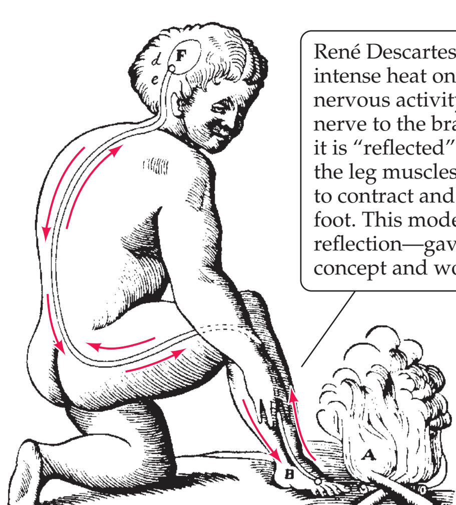
(B) Leonardo's later drawings, made from direct observations, were much more anatomically correct.

dualism The notion, promoted by René Descartes, that the mind has an immaterial aspect that is distinct from the material body and brain.

By the second century CE, this brain-centered view of mental processes had become more entrenched, appearing in the writings of the Greco-Roman physician Galen (the "Father of Medicine"). Galen's experiences in treating head injuries of gladiators lead him to propose that behavior results from the movement of "animal spirits" from the brain through nerves to the body, but his understanding of the relevant anatomy was poor. Not until much later were techniques developed for making highly detailed anatomical studies of the fine structure of the brain.

Skillfully applying newly developed innovations in drawing technique, Renaissance painter and scientist Leonardo da Vinci (1452–1519) produced exquisite neuroanatomical illustrations of nerves and brain structures (**FIGURE 1.2**). Religious dogma dominated Renaissance science—just ask Galileo—with the result that scientific writing from that era often presents the brain as a mysterious and intricate gift from God. But perhaps some thinkers of the day secretly held a more secular view of neuroscience; for example, it has been observed that the depiction of God on the ceiling of the Sistine Chapel, painted by Michelangelo (1475–1564) (see the photo on the previous page), bears a striking resemblance to a midline view of the human brain (Meshberger, 1990). It is believed that Michelangelo was conducting dissections of cadavers at about the time that the painting was created.

In any event, weighing religious notions of the soul against increasingly mechanistic views of the brain became a major preoccupation for later scholars. Among his many contributions to math and science, René Descartes (1596–1650) tried to explain how the control of behavior might resemble the workings of a machine, proposing the concept of spinal reflexes and a neural pathway for them (**FIGURE 1.3**). But Descartes also argued (perhaps in order to deflect criticism) that free will and moral choice could not arise from a mere machine. So Descartes asserted that humans, at least, had a nonmaterial soul as well as a material body and that the soul governed behavior through a point of contact (possibly the pineal gland) in the brain. This notion of **dualism** spread widely and left other thinkers with the task of trying to explain how a nonmaterial soul could exert influence over a material body and brain. Today, biological psychologists reject dualism in favor of the much simpler view that the workings of the mind can be understood as purely physical processes taking place in the material brain.



René Descartes suggested that intense heat on the toe causes nervous activity to flow up the nerve to the brain, from which it is "reflected" back down to the leg muscles, causing them to contract and withdraw the foot. This mode of action—reflection—gave rise to the concept and word *reflex*.

FIGURE 1.3 An Early Account of Reflexes

Thanks in large part to systematic studies of the relation between various disorders and damage to regions of the human

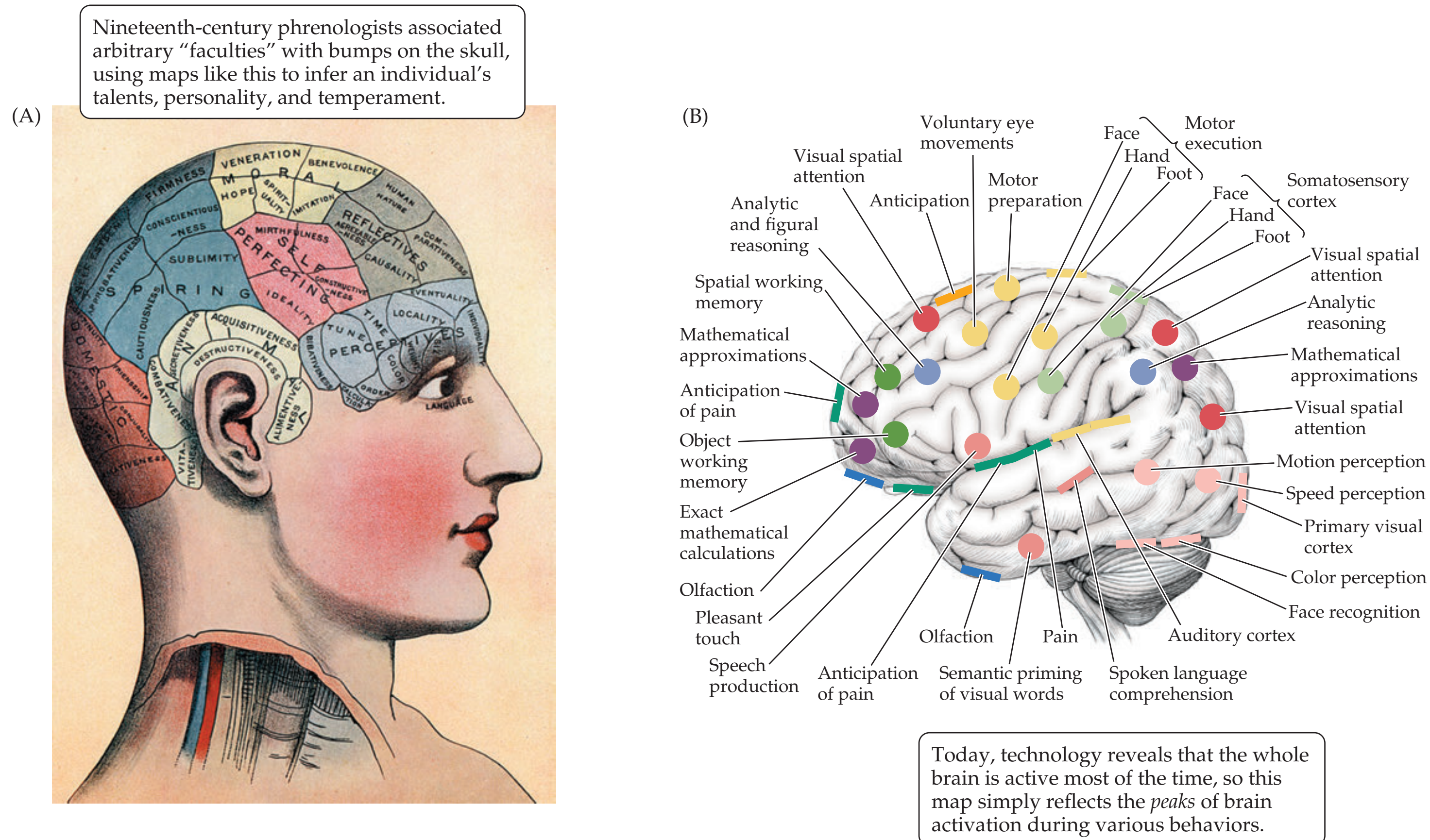


FIGURE 1.4 Old and New Phrenology (Part B after Nichols and Newsome, 1999.)

brain that were conducted by the English physician Thomas Willis (1621–1675), the notion that the brain coordinates and controls behavior eventually became widely accepted (Zimmer, 2004). A pseudoscientific fad of the early 1800s called **phrenology** (**FIGURE 1.4A**) capitalized on the emerging idea that specific behaviors, feelings, and personality traits were controlled by corresponding specific regions of the brain. Although phrenology was plainly wrong in several fundamental ways—for example, phrenologists believed they could "read" a person's character by feeling the bumps on that person's head—the field helped establish the concept of **localization of function**, which asserts that different brain regions specialize in specific behaviors.

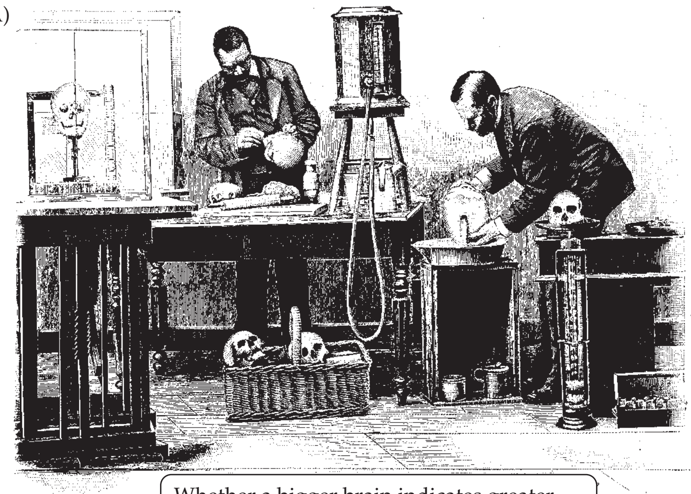
Later researchers found that damage to specific regions of the brain causes predictable impairments in people; for example, Paul Broca (1824–1880) noted that damage to a particular region of the left side of the brain reliably causes problems with speech production (see Chapter 15). Neuroscientists today accept that the localization of function within the brain is more or less true. Although the whole brain is active most of the time, when we are performing particular tasks, certain brain regions become *even more* activated, and different tasks activate different brain regions. So modern functional maps of the human brain track the locations where these *peaks* of activation occur (**FIGURE 1.4B**). A parallel concern that harks back to the phrenologists has been the importance of brain size to intellectual function. After a couple of centuries of study, the evidence indicates that while the overall size of your brain matters, it matters a lot less than you might expect (**FIGURE 1.5**).

In 1890, William James's book *Principles of Psychology* signaled the beginnings of a modern approach to biological psychology. In James's work, psychological ideas such as consciousness and other aspects of human experience came to be seen as properties of the nervous system. A true biological psychology began to emerge from this approach.

phrenology The belief that bumps on the skull reflect enlargements of brain regions responsible for certain behavioral faculties.

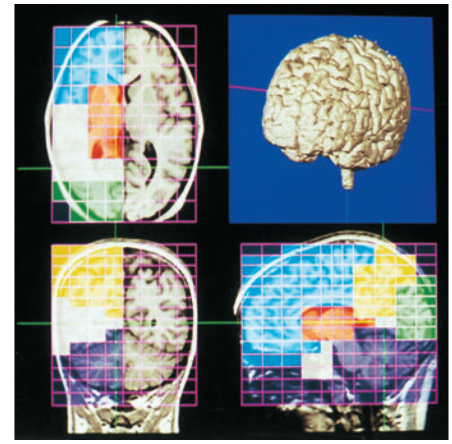
localization of function The concept that different brain regions specialize in specific behaviors.

(A)



Whether a bigger brain indicates greater intelligence is an old question. Investigators in the nineteenth century measured the volumes of skulls of various groups and estimated intelligence on the basis of people's occupations, teachers' guesstimates, and other doubtful criteria.

(B)



IQ tests improved the objectivity of intelligence measurement. When carefully controlled, MRI studies like this one do find a correlation between brain size and IQ scores (Andreasen et al., 1993), and IQ seems to correlate better with the volume of the front of the brain than the back (Colom et al., 2009). So it seems that bigger is better, but the correlations are of only modest size, meaning that other factors must also contribute to IQ scores (Stanovich, 2009).

FIGURE 1.5 Does Size Matter? (Part A from the Bettmann Archive; B courtesy of Nancy Andreasen.)

Advances in experimental methodology propel modern biological psychology

By the beginning of the twentieth century, researchers were applying newly developed tools to study mental processes that had previously seemed unknowable. Rapid progress was made in developing techniques for measuring learning and memory in humans and animals, and Russian physiologist Ivan P. Pavlov (1849–1936) made his landmark discoveries of classical conditioning in animals—Nobel Prize–winning work that influences scientists to this day.

This rapid progress prompted a parallel interest in understanding the neural basis of learning, marked by one of the first true biological psychology research programs: the "search for the engram" by Karl Lashley (1890–1958). Although he would not accomplish his goal of linking a specific brain region to the formation of a specific long-term memory (an "engram"), Lashley gave us the idea (now well established) that memory is not localized to only one region of the brain.

One of Lashley's students, Donald O. Hebb (1904–1985), had a particularly profound impact on biological psychology. Hebb showed that cognitive processing could be accomplished by networks of active neurons, molded by repeated activation patterns into functional circuits. His hypothesis about how neurons strengthen their connections as a consequence of experiences led to the idea of the *Hebbian synapse*, a type of plastic (changeable) connection between neurons that remains a hot topic in neuroscience, as discussed in Chapter 13.

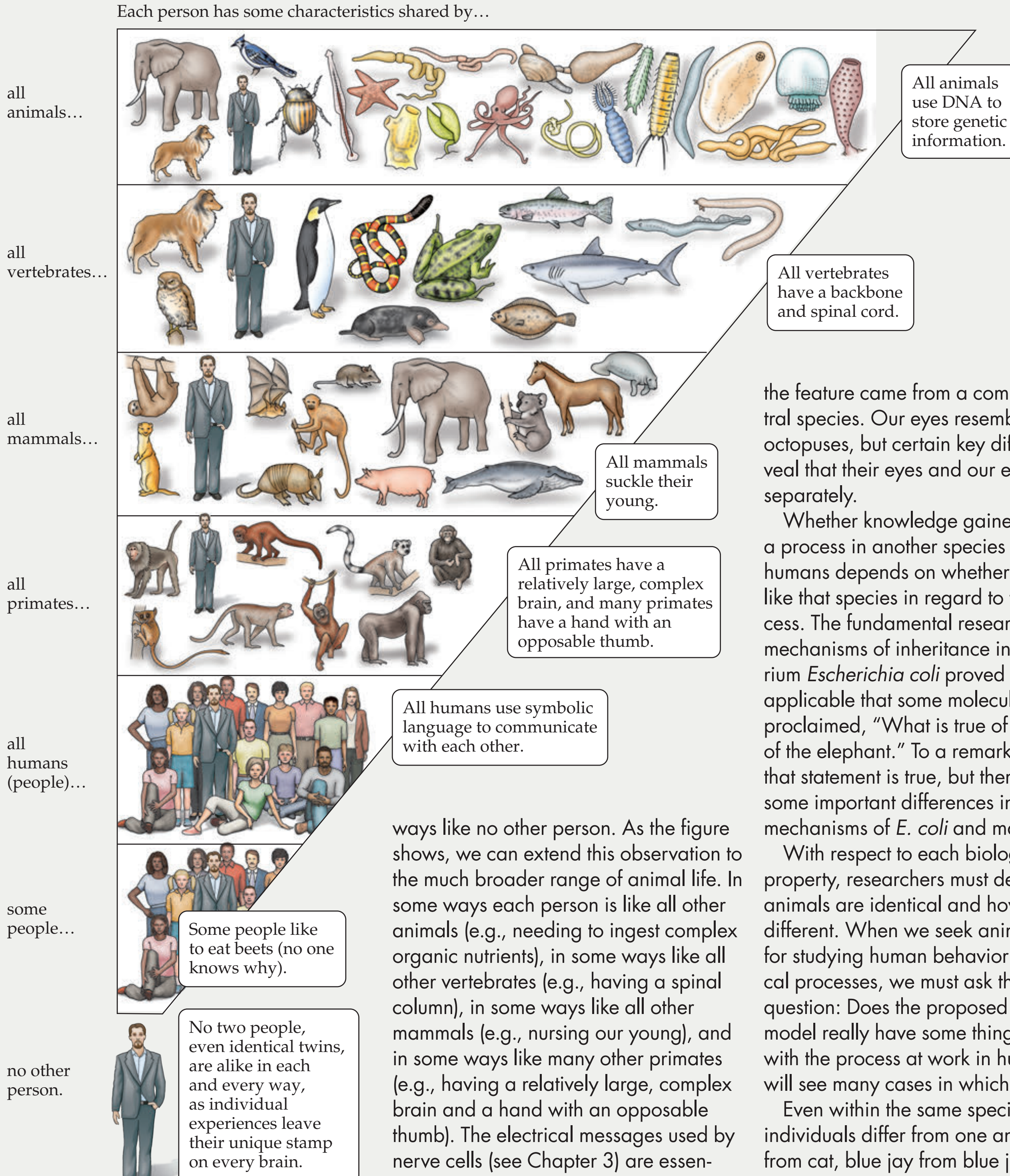
Present-day biological psychologists may draw on several different theoretical perspectives. Here are some of the major ones:

1. *Systematic description of behavior* Until we describe what we want to study, we cannot accomplish much. Depending on our goals, we may describe behavior in terms of detailed acts or processes, or in terms of results or functions. To be useful for scientific study, a description must be precise, using accurately defined terms and units.

2. *The evolution of brain and behavior* Darwin's theory of evolution through natural selection is central to all modern biology and psychology. Biological psychologists employ evolutionary theory in two ways: by evaluating *similarities* among species due to shared ancestry, and by looking for species-specific *differences* in behavior and biology that have evolved as adaptations to different environments (**BOX 1.1**). We will discuss many examples of both perspectives in this book.

conserved In the context of evolution, referring to a trait that is passed on from a common ancestor to two or more descendant species.

BOX 1.1 We Are All Alike, and We Are All Different



How do similarities and differences among people and animals fit into biological psychology? Each person is in some ways like all other people, in some ways like some other people, and in some ways like no other person. As the figure shows, we can extend this observation to the much broader range of animal life. In some ways each person is like all other animals (e.g., needing to ingest complex organic nutrients), in some ways like all other vertebrates (e.g., having a spinal column), in some ways like all other mammals (e.g., nursing our young), and in some ways like many other primates (e.g., having a relatively large, complex brain and a hand with an opposable thumb). The electrical messages used by nerve cells (see Chapter 3) are essentially the same in a jellyfish, a cockroach, and a human being, and many species employ identical hormones. Species share these **conserved** characteristics because the features first arose in a shared ancestor. But mere similarity of a feature between species does not guarantee that the feature came from a common ancestral species. Our eyes resemble those of octopuses, but certain key differences reveal that their eyes and our eyes evolved separately.

Whether knowledge gained about a process in another species applies to humans depends on whether we are like that species in regard to that process. The fundamental research on the mechanisms of inheritance in the bacterium *Escherichia coli* proved so widely applicable that some molecular biologists proclaimed, "What is true of *E. coli* is true of the elephant." To a remarkable extent, that statement is true, but there are also some important differences in the genetic mechanisms of *E. coli* and mammals.

With respect to each biological property, researchers must determine how animals are identical and how they are different. When we seek animal models for studying human behavior or biological processes, we must ask the following question: Does the proposed animal model really have some things in common with the process at work in humans? We will see many cases in which it does.

Even within the same species, however, individuals differ from one another: cat from cat, blue jay from blue jay, and person from person. Biological psychology seeks to understand individual differences as well as similarities. Therefore, the way in which each person is able to process information and store the memories of these experiences is another part of our story.