

## Discovering Our Selves

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## Discovering Our Selves

**Biological Learning and Control: How the Brain Builds Representations, Predicts Events, and Makes Decisions.** Reza Shadmehr and Sandro Mussa-Ivaldi. MIT Press, 2012, 385 pp., illus. \$40.00 (ISBN 9780262016964 cloth).

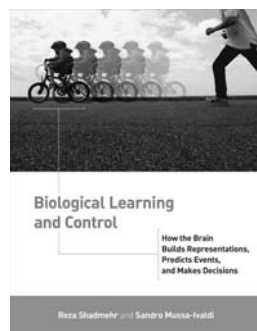
**The Good, the True, and the Beautiful: A Neuronal Approach.** Jean-Pierre Changeux (Laurence Garey, trans.). Yale University Press, 2012. 400 pp., illus. \$35.00 (ISBN 9780300161397 cloth).

**The Brain: Big Bangs, Behaviors, and Beliefs.** Rob DeSalle and Ian Tattersall. Yale University Press, 2012, 368 pp., illus. \$29.95 (ISBN 9780300175226 cloth).

In July 1990, George H. W. Bush signed Presidential Proclamation 6158 in support of House Joint Resolution 174. The proclamation designated the decade (beginning 1 January 1990) as the “Decade of the Brain.” Much of the targeted research conducted over that period benefited from the development and refinement of methods for imaging the brain: magnetic resonance imaging (MRI; particularly functional [fMRI] and real-time MRIs), PET (positron emission tomography) scans, and EEGs (electroencephalography). Employing those tools, neuroscientists and cognitive psychologists have been able to compare brain structures and to examine the activity of the brain during specific mental tasks in human subjects, as well as in other species. The insights gained during the 1990s greatly influenced the trajectory of brain research conducted in the first decade of the twenty-first century, and the books reviewed here feature various aspects of that research.

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The title of this article and its overall theme are based on a conference organized for the public entitled “Discovering Our Selves: The Science of Emotion,” which was held at the Library of Congress in May 1998. The meeting was the direct result of the increased interest in and funding for neuroscience. Although it was sponsored by the private Charles A. Dana Foundation, the gathering was organized by the Library of Congress and the National Institute of Mental Health with the purpose of providing informative talks for scientists and the public. Describing neuroscientific research for a wide audience is difficult, because the general public does not typically possess the background knowledge required to fully appreciate the insights described. Each of the books considered here assumes a working knowledge of math, chemistry, anatomy, and molecular biology at the level of an undergraduate science major. These three texts have broad-reaching views of different aspects of neuroscience, but all three consider what it is about the brain of *Homo sapiens* that makes us human.



Neuroscience and mathematics are integrated in *Biological Learning and Control: How the Brain Builds Representations, Predicts Events, and Makes Decisions* by Reza Shadmehr and Sandro Mussa-Ivaldi. An introductory examination of the book reveals many pages

of somewhat daunting, complex mathematics; however, the text explains the mathematical applications thoroughly and, often, delightfully. For example, chapter 4 (“Sensorimotor integration and state estimation”) begins with a discussion of motor control through a familiar example: taking a glass from a tray held by a waiter or waitress. The reader is asked to consider the act of reaching for the glass, the act of taking it from the tray, and the compensation that the waiter or waitress must make to adjust the forces applied by his or her arm muscles in order to maintain stability as the weight suddenly changes, although in a predictable way. From this, we are led to the idea that the brain not only directs motor activity but also incorporates sensory inputs to predict the outcome, even as external circumstances are changing rapidly. The authors suggest that the brain not only evaluates what is actually sensed but predicts what should be sensed.

A brief history of how the earliest scientists believed that we perceive and respond to our surroundings (going back to the eleventh century) is followed by very comprehensive descriptions of current research. This engaging introduction to the engineering concept of *estimation theory* leads naturally to the development of the mathematical framework, using a hike in the woods as an example of a biological problem processed by the brain that requires *model building* (what the senses should tell us) and *integration* (the formation of an estimate of the current state using prediction and observation).

Chapter 5 (“Bayesian estimation and inference”) discusses how our prior knowledge informs the way in which we interact with objects in our environment, from a Styrofoam coffee cup to a Big Gulp. Our expectation of the weight of an object influences the forces that we apply when we pick

up that object (e.g., the grip force necessary when lifting a full cup versus an empty one). This discussion then leads into the research conducted on astronauts who experience changes in gravity and must anticipate the rate at which a ball falls in order to catch it. Perhaps my favorite example in the entire book is the explanation of how successful baseball pitchers depend on their ability to foil the expectations of the batter by altering the trajectory of the ball using backspin and topspin.

As someone who is fascinated by the circuitry of the brain, I was particularly interested in the chapters addressing learning and adaptation in the nervous system. Most of the experiments described involve reaching and arm control, with or without visual feedback, or movement under various loads that require modification of motor activity for success. Although the mathematical modeling is more tenuous here, the text provides a different view of learning than what I have encountered elsewhere: Motor learning will occur more rapidly if the learner becomes more sensitive to prediction errors (due to perturbations), because that is when the brain works to generate a model to optimize the odds for successful motor activity, and ultimately, success in performing a task. Cerebellar circuitry is described with regard to motor learning, time-scales of memory, and changes in synaptic strength associated with motor memory. The carefully chosen clinical studies included in *Biological Learning and Control* are particularly informative, because what is lost following damage to a specific region of the brain can provide functional information that cannot be obtained otherwise in humans.

The authors provide another familiar example to lead the reader into a discussion of the “Cost and rewards of motor commands” (chapter 10)—the life history of the sea squirt, a distant chordate relative of humans. The adult sea squirt is a sedentary filter feeder, but the larva is motile and searches for an appropriate location to settle.

The brain of the sea squirt consists of approximately 300 cells, which allows the sea squirt to swim and sense components of the environment that are most favorable for a permanent home. Succinctly put by the authors, “Once it finds a surface, it buries its head, absorbs most of its brain, and never swims again” (p. 279). Their point is that the earliest neural circuits were associated with movement, and sensory systems that evolved in the earliest animals served to direct movement. They also suggest that movement is ultimately about obtaining a rewarding outcome while expending the least energy, thereby maximizing the gain. This introduction is followed by a fascinating consideration of how human eyes move to most efficiently investigate the key features of a scene.

*Biological Learning and Control* ends with a discussion of feedback control and a final example of motor learning, for competitive high jumps. The current, reclining technique (the Fosbury method) was developed during a single high school track meet by an athlete who had been having limited success. The young man altered his approach to the bar on consecutive jumps to gain additional height each time, ultimately gaining 6 inches over any of his previous jumps. The human capacity for behavior modification is hard to put into a mathematical formula, but modeling small changes in specific behaviors is not an insurmountable task. Like the clever examples provided throughout this book, the insights into brain function provided by Shadmehr and Mussa-Ivaldi have broad applications. I believe this book would be a great choice for an undergraduate special topics course; it just might inspire greater interest in the biomedical applications of mathematics.

A unique view of neuroscience is taken by Jean-Pierre Changeux in *The Good, the True, and the Beautiful: A Neuronal Approach*, translated and revised from the original French (*Du Vrai, du Beau, du Bien*, 2008) by Laurence Garey (who also translated *Neuronal Man* by Changeux in 1985). The title is based on Plato’s universal

questions of the natural world and on Socrates’s description of the *good*, the *true*, and the *beautiful* as independent celestial essences that are intertwined and inseparable. To truly appreciate the details presented by Changeux in this volume, a knowledge of the complex organization of the central nervous system is useful, as is an understanding of molecular biology. The book begins with Changeux’s considerations of the *beautiful* and ends with his considerations of the *true* and the molecular biology of the brain.



Changeux’s *beautiful* includes *neuroesthetics*, the neural basis of our appreciation for various art forms and music, which he suggests originates in the human ability to feel empathy and sympathy. The successful artist or musician symbolically expresses an idea or a feeling that can be perceived and understood by other humans. The use of symbols is considered an important step in the evolution of the mind, because ideas are symbolic by their nature, although they originate in neural activity. Changeux develops the concept of a *conscious neuronal workspace* in the cerebral cortex. This workspace is equivalent to correlated neuronal activity across association areas in the brain, which allows insight and planning based on sensory input and stored memories. A bit of insight into the author is provided by his own philosophical view on the beauty of science: “Beauty is perceived in explaining much from little, finding patterns, especially in simple relations, within apparent complexity and disorder” (p. 41).

The *good* (subtitled “Neuroscience and ethical normativity”) is described as the human brain’s ability to recognize intent and emotions in others, to develop the capacity for empathy and sympathy, and to internalize moral rules and social conventions. For example, Changeux considers the importance of facial expression in nonverbal communication, including the recognition of expressions in others and empathy that develop as the brain matures during the first years of life in humans. Empathy and sympathy were likely to have been important attributes of early humans, with a strong positive selective advantage, along with the recognition of other social cues (e.g., anger) that allowed humans to live in cooperative groups and to exhibit reciprocity. The neural basis for many of these emotions can be localized to the temporal cortex and the limbic system.

Changeux also presents evidence that the origins of higher consciousness coincided with the evolution of the frontal lobes, particularly the prefrontal areas. In addition, he discusses the work of Jonathan Cohen, wherein different cerebral activity patterns occurred when a human subject reacted to a test situation as either morally acceptable or unacceptable, which seems to reveal a neural basis for moral judgment and sympathy. Although acceptable behavior within each society is learned, Changeux argues that the capacity to identify social cues and categorize them must be inherent in some aspect of brain circuitry. Further evidence for inherent emotional categories is provided by clinical cases in which patients are incapable of recognizing emotion in others.

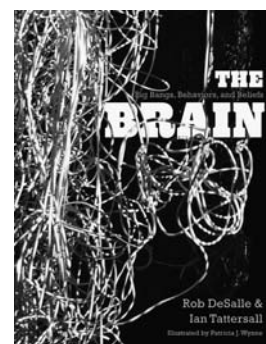
The *true* for Changeux refers to the brain’s capacity to represent the outside world and the internal state of the body. Within this category, the author discusses the neurobiological correlates of consciousness, cognition, and the production of written language. He considers the electrical activity of the brain during wakefulness, sleep, and paradoxical sleep.

There also is a historical perspective of pain reduction (analgesia) and anesthesia, culminating in what the states of anesthesia reveal about the chemistry of consciousness. From this consideration of individual mental activity, Changeux transitions into a discussion of the rise of social groups during the evolution of humans and the cognitive changes that must have occurred as the nonhuman primate brain acquired new neural connections and functions that eventually produced humans’ ability to use signs to express ideas. The earliest written communications were population-specific combinations of pictograms or ideograms, which, over thousands of years, evolved into symbols representing syllables or phonemes and eventually into various alphabets. According to Changeux, the evolution of writing is one of the best-documented examples of cultural evolution. In his consideration of the neural correlates for writing, the information gained from clinical cases is again most instructive as to how specific regions of the brain are tasked with producing and understanding the written word and the streams of words that represent ideas.

*Mirror* neurons (in the promoter area of the frontal lobe) are suggested as important components of circuits for empathy and also in circuits for speech recognition. The activity of individual mirror neurons “reflects” the observation of a conspecific performing a specific motor activity. Mirror neurons have been documented in humans and in some other primates. Changeux suggests that homologues of mirror neurons in the neighborhood of Broca’s speech area (revealed by fMRI) may be important for the visual component of imitation that facilitates learning language. A particularly interesting discussion of the paleontological evidence for the development of language is given a Darwinian slant by the author. Different languages spread and intermingled, regional dialects developed, new words evolved, and, according to Changeux, because of the limit of human memory, words within a language become extinct.

Reading this section of the book, I was reminded that Merriam-Webster’s Collegiate Dictionary annually adds new words, phrases, or definitions on the basis of current usage and removes others that are no longer used. The evolution of learned language could be considered more Lamarkian (e.g., inheritance of acquired social characteristics) than Darwinian, in that only the language that is used is passed along to the next generation.

*The Good, the True, and the Beautiful* concludes with a summary of how much has been learned about the molecular biology of the brain since the publication of *Neuronal Man*. The seventh chapter (“Epilogue”) is an assortment of ideas, including the social aspects of death that are peculiar to *H. sapiens*. Belief in supernatural agents beyond human control, an immortal soul, and resurrection of the dead are discussed as “remarkable inventions of the human brain” (p. 354). This unusual chapter is followed by a conclusion, in which Changeux states that his aim in writing this book was to “give a free hand to ideas about the molecule and about the soul... in the context of our brain” (p. 355). It is an unusual approach but also an interesting one.



*The Brain: Big Bangs, Behavior, and Beliefs* by Rob DeSalle and Ian Tattersall was inspired by a popular museum display titled “Brain: The Inside Story” at the American Museum of Natural History in New York City, where both men are curators. The organization of their book follows a more evolutionary approach than do those of the other two texts, and

although an understanding of genetics and development is required, this book provides a helpful glossary of terms. *The Brain* begins with a discussion of the nature of science and an introduction to what constitutes a nervous system. In chapter 3 (“Hanging our brains on the tree of life”), they consider the question, what is a brain? Along with a comprehensive discussion of the various forms of neural tissue found in model organisms, the most recent work in gene expression during development is also presented in detail, revealing an astonishing continuity among very different phenotypes of invertebrates and vertebrates. For example, the genes expressed in organizing the most anterior parts of the invertebrate head (e.g., of a fly) are also responsible for the development of the forebrain in vertebrates—the site of our most advanced centers for sensory integration and planning behavior.

In “Making sense of senses” (chapter 4), the authors compare sensory systems among invertebrates (from the nematode to the fly) and vertebrates. Sensory receptors are described and compared in detail for the five senses we learn as children (vision, audition, olfaction, gustation, and touch), as well as the others that are often not considered until college-level courses (nociceptors, proprioceptors, and gravistatic receptors). Sea squirts are also referenced in this book, because their light receptors indicate that the ancestor of all vertebrates had at least two of the opsins found in the cones of extant vertebrates (involved in color vision) and the rhodopsin found in rods (light reception without color). As an example of the variety of opsins found among vertebrates, DeSalle and Tattersall include a discussion of the African cichlid fishes. The extensive speciation of cichlids is reflected in various, sometimes subtle variations in color patterns that are

critical for identifying conspecifics and facilitating reproductive isolation. The cichlid visual system is also impressive because the species examined to date have seven color opsins, each of which responds to a narrower range of wavelengths; therefore cichlids are able to distinguish different shades of color than humans can discern (e.g., more shades of green).

In their discussion of the evolution of the brain, the authors make the case that the physics and chemistry that determine the basic functions of brain tissue originated in our most ancient common ancestor, the sponge. Although we cannot know exactly how symbolic consciousness came about, DeSalle and Tattersall include a comprehensive discussion of evidence from the fossil record that indicates which ancestral humans are likely to have had cognitive capabilities beyond those attributable to non-human primates. For example, even though the widely distributed and obviously successful populations of *Homo heidelbergensis* built huts and hunted with a handmade, javelin-like spear over 1 million years ago, there is no evidence that they had symbolic capabilities. Symbolic thinking and creativity were apparent in the drawings, carvings, musical instruments, and decorative objects produced by Cro-Magnon man (early *H. sapiens*; 32,000–30,000 years ago), but nothing similar was produced by *Homo neanderthalensis*, whose populations overlapped those of *H. sapiens* temporally and perhaps spatially. From braincase studies, there is evidence that the brain of *H. neanderthalensis* was as large as the brain of *H. sapiens*; however, on the basis of what paleontologists can glean of their habits, Neanderthals lacked symbolic cognition and, therefore, are unlikely to have had language as we know it.

Parts of the human brain differ from the brains of nonhuman primates in

size and architecture, and it is in those regions that the authors suggest that the human brain processes information in a profoundly different way. DeSalle and Tattersall propose that there was a major genetic change that altered the development and connectivity of those brain regions in a small population of *H. sapiens* (most likely to have been early Cro-Magnons), which ultimately fostered symbolic thought processes and greater success for the individuals of that population. Exactly how those brain regions differed over the course of evolution in populations of *H. sapiens* is unanswerable, but the fact that human species overlapped for about 100,000 years (although likely in separate population centers) suggests that mental evolution provided a capacity to outthink the ancestors of *H. sapiens* in the ultimate game of *Survivor*.

The epilogue for *The Brain* is an overview of ideas and a final consideration of the human species as the smartest animal on the planet but also as an animal with limitations. The authors provide a final perspective worth sharing: “Every living species, no matter how simple it may look from our point of view, is in reality an endpoint, a terminal twig on the Tree of Life.... For all its unusual qualities, *Homo sapiens* is just another of those myriad endpoints on the Tree of Life...” (p. 303). “In a profound sense, every terminal twig on that Tree of Life is equally evolved” (p. 306).

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Peggy L. Edds Walton ([seewalton@gmail.com](mailto:seewalton@gmail.com)) is a sensory neuroethologist who has studied the behavior of baleen whales and auditory processing in teleost fishes. Currently, she is the director of Science Education and Enrichment in Riverside, California, and she is a guest investigator at the Woods Hole Oceanographic Institution, in Woods Hole, Massachusetts.