at the risk of also admitting a host of fringe theories that will consume time and energy to debunk. This is why the border of the fringe is policed so assiduously with wastebaskets.

For Wertheim, physics, like art, should be open to all, not the exclusive domain of experts (a status she grants to brain surgery). She recognizes that this could allow the entertainment of creationism as a candidate for a scientific theory. Yet Wertheim considers the risk marginal, noting that whereas creationists "reject much of academic science, fringe physicists love science and are thrilled by its power." Some creationists might hate science, but if you spend 30 minutes with the writings of George McCready Price, the architect of flood geology, or those of his latter-day disciple Henry Morris, you will find discussions of sedimentary columns and hydrodynamics, and indeed all the hallmarks of sincerity and passion for inquiry you could wish for. Should AIDS-HIV denialism and Immanuel Velikovsky's cosmic catastrophism also have their day in court? These theories likewise ignore the large edifice built by science (just as Carter ignores the history of vortex atoms) and attempt to erect new structures. This neglect of all the potential constraints on a theory make scientists' hostility more than blatant prejudice. Fringe physicists can do their physics, but they cannot demand that they be heard. Neither can establishment scientists, many of whom also toil in obscurity.

Wertheim shows us just how muddy the waters are on the border between what is classed as "legitimate" and what as "fringe." However, a murky boundary does not imply that one might just as well drink from any part of the river.

Michael D. Gordin is professor of history at Princeton University, where he teaches the history of modern science. He is the author of, among other books, Red Cloud at Dawn: Truman, Stalin, and the End of the Atomic Monopoly *(Farrar, Straus and Giroux, 2009) and* The Pseudoscience Wars: Immanuel Velikovsky and the Birth of the Modern Fringe *(forthcoming from University of Chicago Press).*

NEUROSCIENCE

Trust in Neurons

Robert J. Richards

BRAINTRUST: What Neuroscience Tells Us about Morality. Patricia S. Churchland. xii + 273 pp. Princeton University Press, 2011. $24.95.

Charles Darwin had human beings on his mind from the very beginning of his theorizing about species descent. He was especially concerned to give an account of their highest trait—not their reasoning ability, but their moral capacity. From the perspective of the British empiricist tradition, even the lowly ant might display a small dollop of reason, whereas moral judgment remained an exclusively human affair. A few days after he had formulated the elements of his principle of natural selection, Darwin began speculating on the origins of morality. He initially sought an explanation through inherited habit, because he could not puzzle out how natural selection, which operates on traits that benefit self, might give rise to traits that benefit others even at cost to self. It was only in solving another problem—the origin of the distinctive features of social insects—that he found the key. Since worker ants and bees are neuters and thus have no offspring to inherit their beneficial traits, natural selection seemed precluded from explaining the particular anatomical features of those insects or their several different kinds of instinct. Only in the throes of the composition of the *Origin of Species* (1859) did he hit upon the solution: Natural selection operates not directly on the individual but on the whole community. Those hives, for instance, that by chance produced individuals displaying the defensive instincts of the soldier bee would have the advantage over others that lacked such individuals, and so, over the course of ages, these instincts would continue to be sharpened. But in the solution to this puzzle, Darwin also found an explanation for altruistic behavior, which he regarded as the core of moral behavior.

In the *Descent of Man* (1871), Darwin gave over several chapters to developing his theory of the evolution of conscience. He argued that the fundamental, altruistic impulse originated in the community selection of those protohuman clans that by chance had individuals who, because they possessed "the spirit of patriotism, fidelity, obedience, courage, and sympathy, were always ready to give aid to each other and to sacrifice themselves for the common good." Such groups would prosper as their altruistic instincts became ever keener. Darwin believed this biological evolution would be abetted by cultural evolution, as groups began to learn that superficial characteristics of skin color and other racial features overlay a common humanity. They would continue to widen the moral circle of response to include other groups whom they would gradually come to recognize as "one of us." Darwin quite proudly declared that no one else had approached the problem of morality exclusively from the point of view of natural history. He believed he could accomplish what Kant had desired: an explanation for the moral sense, which "has a rightful supremacy over every other principle of human action."

In *Braintrust*, Patricia Churchland, a philosopher at the University of California at San Diego, seems intent on advancing a project comparable to Darwin's through the application of the most recent science, as the subtitle of her book suggests: *What Neuroscience Tells Us about Morality.* Readers may, however, decide instead to stick with that old-time evolution.

Churchland does not think that moral behavior can be reduced to any special kind of activity, as Darwin believed; rather, in her view, the term "moral" hovers over a variety of social behaviors, behaviors that might attract the same term but vary considerably across different cultures and individuals. Such behaviors, she argues, are not usually governed or motivated by explicit rules but are constituted by habits and emotionally guided decisions. She seeks to understand those habits and emotionally fed values as consequences of our neurobiology. She thus undertakes in several chapters to lay out the terrain of the brain, its regions and functions, and the kinds of hormones important for fertilizing the flowering of social relationships.

These chapters quite nicely introduce the novice to the fundamental geography of the brain and its basic operations, especially to the roles of the hormones oxytocin and vasopressin. Oxytocin is a peptide that seems to flow freely through the mammalian phylum. It is released in abundance during childbirth; it helps to form a bond between mother and infant, promotes lactation, and makes the helpless female feel safe and secure with a mate. Churchland quotes studies to show that oxytocin, when sprayed in the nostrils of game players, increases trust and cooperation. An added bonus is that it also speeds the healing of wounds. (Too bad the military hasn't devised an aerial dispersal agent with this hormone as the main ingredient—a real love bomb.)

Churchland regards oxytocin as fundamental to morality, since it enhances that complex of social behaviors that often fall under the rubric of the moral. This warming elixir is found in a variety of other mammals—voles, for instance—in which it also stimulates maternal behavior, pair bonding and group equanimity; consequently, Churchland feels no reluctance to recognize lower animals as moral. Here she parts company with Darwin, who did not wish to jeopardize his own moral theory by making, say, squirrels our moral cousins. (Such a move would likely have also inhibited him as an avid hunter.) In addition to social instincts, Darwin thought a moral individual had to have sufficient intelligence and language to allow the elaboration of such innate behaviors and to establish the codified instantiations of altruism distinctive of different cultural groups.

Although it is informative to know that oxytocin has many functions in mammals, it remains unclear what its role might be when we debate about, for instance, the morality of capital punishment, abortion or myriad other ethical questions that our society regards as unsettled. The heat of argument among disputants might even pressure oxytocin to leak away. And although oxytocin may have a significant role in certain behaviors we regard as moral, so would many other hormones, neurotransmitters and the brain itself. Does oxytocin have any decisive function in a decision to send a $50 check to Oxfam? One could hardly classify this peptide as a criterion of the moral, just because it makes us and voles feel good about the world.

Churchland investigates other neurological features that might plausibly be offered as part of the scaffolding of moral behavior. She considers, for example, the possibility that there is an innate and heritable impulse to behave morally (Darwin's view) and the hypothesis that moral behavior is grounded in mirror neurons, so that we might effortlessly imitate empathetic behaviors. Churchland chips away at these as possible neural structures for moral behavior. For instance, she attempts to undermine the concept of innate behavior generally by requiring a specification of the relevant genes and their relation to brain circuitry—a criterion beyond reach even for highly heritable traits, such as height. Indeed, by that criterion Darwin's general theory of heritable adaptations, for which he had no reliable genetic foundation, would be but a passing fancy for the delectation of Intelligent Designers.

Churchland concludes her volume with a vague appeal to the phenomenon of trust, which she says "has much to do with oxytocin and vasopressin, their receptor distributions, and the complex circuitry in the limbic structures, the brainstem, and the structures of the prefrontal cortex." The essential message of the book seems to be that trust, a main ingredient of morality, stems from parental care and nurture, which become elaborated through social learning into the habits and common wisdom of a decent society. This is a view of morality that hardly depends on a deep knowledge of the brain. By contrast, Darwin's more definite conception of morality finds an articulated account in his evolutionary proposals. His theory specifies explicit grounds either for dispute or for further development, as is proceeding in many areas of evolutionary psychology and behavioral economics. The answer to the question "What does neuroscience tell us about morality?" turns out to be "Not much."

Robert J. Richards is Morris Fishbein Distinguished Service Professor of the History of Science and Medicine; professor of history, philosophy and psychology; and director of the Fishbein Center for the History of Science and Medicine at the University of Chicago. His most recent book is The Tragic Sense of Life: Ernst Haeckel and the Struggle over Evolutionary Thought *(University of Chicago Press, 2008).*

COMPUTER SCIENCE

Murkiness in Numerical Computing

Brian Hayes

HANDBOOK OF FLOATING-POINT ARITHMETIC. Jean-Michel Muller, Nicolas Brisebarre, Florent de Dinechin, Claude-Pierre Jeannerod, Vincent Lefèvre, Guillaume Melquiond, Nathalie Revol, Damien Stehlé and Serge Torres. xxiv + 572 pp. Birkhäuser, 2010. $129.

The digital computer was originally conceived as a machine for doing arithmetic, and so you might think it could add, subtract, multiply and divide without error. After all, these are skills we teach to young children. But arithmetic is a subtler art than it seems. For some problems, a computer cannot possibly give an exact numerical answer, because irrational quantities such as the square root of 2 cannot be represented in a finite number of digits. The most you can reasonably ask of the computer is that it always calculate the best approximation to the true answer, within the constraints of finite precision. But even this goal is sometimes exceedingly difficult to achieve.

In the empyrean world of mathematics—as distinct from the material world of computation—arithmetic has rules you can count on. For example, the relation $a+1>a$ holds true for every finite value of a on the real number line. But if you try a few experiments with computer software, you can readily find values of a for which $a+1=a$. A spreadsheet program on my computer gives this preposterous result when a is set equal to 9,007,199,254,740,992. Another familiar rule that computer arithmetic flagrantly violates is the associative law of addition, which states that $(a+b)+c=a+(b+c)$. In the spreadsheet, when I assign the values $a=10^{17}$, $b=-10^{17}$ and $c=1$, I find that $(a+b)+c$ returns a result of 0.0, whereas $a+(b+c)$ yields the value 1.0.

These anomalies are not the result of programming errors or hardware malfunctions, and they are certainly not confined to this one spreadsheet pro-