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Brain Science for Humanity

When I meet people at parties, at family gatherings, on airplanes, or elsewhere, and tell them I do research on the brain, this evokes a range of reactions. Many people are particularly interested in some condition they have or know someone who has, such as attention deficit disorder, dyslexia, or schizophrenia, and hope that brain research can help us find a better treatment for it. Other people's imaginations are stirred by the exciting, but also frightening, possibility of designing machines that are truly intelligent (including the possession of consciousness and emotions). Once in a while, someone fears that my scientific work will lead to state control of people by means of drugs or psychosurgery — or, much more subtly, to suppression of people's spiritual side in the name of "reason."

Improved treatment for psychiatric, neurological, and behavioral disorders is one of the chief goals of neuroscience (theoretical as well as experimental), and a likely result of progress in brain research. So is the design of intelligent machines, for better or for worse. Once a process in nature is understood, it can be reproduced mechanically if the cost of the components is not too great.* Dehumanization and control are also possible results, but ones we can avoid if we act wisely. In fact, we can direct our scientifically based insights toward *increasing* our freedom. What we learn from brain science can help encourage the human spirit to develop much more fully, and the cooperative structures of human society to catch up to the rapid changes in our technology. For me, and for many other neural network theorists and neurobiologists, the greatest excitement in studying the brain comes from the insights it gives us about *our daily lives*.

* Since humans don't always perform cognitive functions optimally (see Chapter 4 in particular), the *best* machines we can design to do those functions won't necessarily duplicate the way we do them. But those seeking to design intelligent machines do try to at least understand brain processes in order to guide their search for principles of organization.

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Some of our common late Twentieth and early Twenty-First Century cultural patterns are common nonsense and need to be reevaluated (e.g., stereotyping, fixed trait attribution, divorcing reason from emotion). Others are common sense and need to be encouraged (e.g., cooperation, fair play, encouraging diversity, bringing out the best in others). Neuroscience and neural network theory need to be integrated with the social sciences to provide systematic clues about how to tell common sense from common nonsense, assuming some widely held human values.* This type of interdisciplinary investigation is now in its infancy, but I expect it to reach maturity before the middle of the Twenty-first Century.

Understanding Daily Life

What is really going on inside us, physically and chemically and biologically, when we have a conversation, watch a sunset, fall in love, get angry, or worship a god? We know surprisingly little about the answers to that question. As Kurt Vonnegut said, “Life! Who can explain even one minute of it?”¹

Some readers might object that more understanding will destroy the mystery of life. They fear that if we learn the processes behind art, love, and religion, it will dampen our strong feelings about these things. To me that is like arguing that sex education makes us enjoy sex less, which is absurd. Mystery is good but not *too much* mystery. We need to know in general what we are dealing with. Anyhow, the mystery will never be gone completely. Even if an event in life is understood biochemically, it is not *reduced* to biochemistry. There will always be a level of direct personal experience that can be approached best, if at all, by poetry, music, or religious worship.² And as we better understand the natural world, internal as well as external, we have available to us a greater range of patterns, connections (indeed, neural network

* In a talk at the 1994 World Congress on Neural Networks, Paul Werbos pointed out that Twentieth Century French existentialists ran into trouble when they tried to *rationaly deduce* universal values and the purpose of life. Werbos went on to say, and I agree, that values must be emotionally derived. Once values are defined, reason can provide strategies for living by these values.

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theory is sometimes called *connectionism*), and synchronicities. This can actually deepen our poetic appreciation instead of suppressing it.

How close are neuroscience and neural network theory to explaining daily mental life? In the early 2000s we're not there yet, but an explosion of results and theories just in the last decade has brought us much closer. For example, neuroscientists and modelers are now working on a distinction that the experimental psychologist Endel Tulving made between two types of memory: *semantic memory* and *episodic memory*.³ The technical meanings of these terms are pretty close to their lay usage. Semantic memory involves recall of stored facts and relationships (e.g., "Springfield is the capital of Illinois"), whereas episodic memory involves recall of specific events or episodes (e.g., "I ate pizza for dinner yesterday"). After an initial period of skepticism, neuroscientists and psychologists have come to believe that the semantic/episodic distinction is as important as the better known distinction between short-term and long-term memory. The two types of memory seem to have somewhat different mechanisms of action, since some mental and neurological disorders affect them differently. For example, in Alzheimer's Disease, episodic memory is impaired at an earlier stage of the disease than is semantic,⁴ although semantic is eventually affected as well.* The loss of episodic memory appears to be related to loss of neurons in the hippocampus, a brain area related to memory storage (see Figure 3.1). Semantic memory, by contrast, mainly involves association areas of the cerebral cortex, which also lose neurons in Alzheimer's but at a slower rate.

Episodes, and remembering about them, are the stuff of daily mental life. The neural network theorist John Taylor has suggested that episodic memory is a basis for consciousness:

* Other researchers have noticed a third type of memory, different from either semantic or episodic, that is almost unaffected in Alzheimer patients. This is *procedural* memory, the knowledge (much of it unconscious) of how to perform tasks, motor or otherwise.

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... consciousness arises due to the active comparison of ongoing brain activity, stemming from external inputs in the various modalities, with somewhat similar past activity stored in episodic memory. The “mental” content of an experience was defined as the set of relations of that experience to stored memories of relevant past experiences. Thus the consciousness of the blue of the sky, as seen now, is determined by the stored memories of one’s past experience of blue skies, say on hillsides, at the seaside stretched flat on the sands, or out in the back garden sunbathing in a deck chair. It is the relational structure contained in the growing episodic memory of each individual that gives that individual the richness of their everyday conscious experience.⁵

Biological understanding of the brain is starting to approach the difficult territory of episodes and consciousness. The role of the hippocampus in episodic memory has been noted; this same brain region seems to be involved in comparing emotional reactions to two different events⁶ and in recognizing novelty.⁷ Another brain structure in the limbic system, the amygdala, seems to be involved in registering the emotional value of single events.⁸ The frontal lobes seem to be involved in choosing what sensory events, or what aspects of objects that are perceived, are most important for the current episode.⁹ Also, parts of the thalamus, which lies just under the cerebral cortex and above the midbrain (see Figure 1.1), seem to play major roles in focusing attention.¹⁰

I am giving this quick overview because our knowledge of conscious process is still fragmented. How all these brain areas might perform the functions ascribed to them, and how these areas interact for coherent mental function, is still not well understood, physiologically and chemically. Neural network theory should be one of the tools researchers use to unlock this. Other tools include modern non-invasive brain imaging techniques with humans, such as positron emission tomography and magnetic resonance imaging, and more traditional techniques with animals such as single-neuron electrical recording and selective brain

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lesioning.* Computer and mathematical models, while still very primitive compared to actual physiology and anatomy, are starting to mimic many processes that form parts of the overall picture of memory, attention, and consciousness. John Taylor for example, developed a model for roles of the hippocampus and thalamus in consciousness.¹¹ David LaBerge, Marc Carter, and Vincent Brown modeled roles of the thalamus in attention to visual stimuli.¹² Stephen Sloman and David Rumelhart modeled interactions of the frontal lobes and hippocampus in episodic memory.¹³ Stephen Grossberg and John Merrill modeled how the hippocampus enables us to measure time.¹⁴ Randolph Parks and I modeled the time courses for deterioration of episodic and semantic memory in Alzheimer's disease.¹⁵

All of these models of consciousness, episodic memory, et cetera, build on network architectures originally designed by the same research groups to model more primitive processes, such as perception, pattern recognition, and conditioning. The same principles of network design that are useful for low-level processes are likely, when combined into much larger structures, also to model more complex processes. For example, Sam Leven's and my "Coke" neural network (see Chapter 6) mimics some effects of context on human decision making by suitably combining smaller subnetworks designed to do simpler things. These subnetworks include the gated dipole, designed to process novelty or changes in reinforcement, and the adaptive resonance theory (ART) network, designed to classify sensory patterns. Neural network researchers study large-scale cognitive functions by analyzing them if possible into subcomponents that have already been modeled. Recombining these simpler networks is a hard task that doesn't always succeed — as an old cliché says, the "whole is greater than the sum of its parts." But it's a start toward making sense out of how larger processes might be organized in the actual brain.

All these simpler networks are based on mathematical dynamical systems. Mathematical results on these systems tell us that certain kinds of neural structures in the brain tend to lead to certain kinds of mental functions. Once these functions are understood they can be embedded in larger cognitive and

* There is now a strong animal rights movement that objects to such techniques which kill or severely cripple experimental animals. That group hopes that brain imaging and computer modeling will provide sufficient information to make animal experimentation unnecessary, or at least sharply reduce it.

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behavioral tasks. Later we will return to the study of dynamical systems and what they can tell us about mental structure and function. Before that, we will assume this methodology and deepen our intuitive understanding about the integration of human personalities. This will help us draw some conclusions about how to structure institutions to maximize human potential. As the linguist and cognitive scientist Ray Jackendoff said:

... human nature has a rich and complicated organization that is largely inaccessible to conscious introspection. It reveals itself only upon careful study. If we are trying to develop social policy, it pays to attend to what such study can reveal, instead of relying on oversimplified truisms about what people want or need.¹⁶

The Social Brain and the Frontal Lobes

The challenge Jackendoff outlined, of theorizing about social institutions based on what the brain-related sciences say about human nature, has been taken on by many neuroscientists. One of the boldest is Michael Gazzaniga, a pioneer of “left and right brain” research. Unfortunately, he used neuroscience and psychology to justify some common nonsense about the ineffectiveness of social structures, in particular government programs, to change human behavior.

In a book called *The Social Brain*, Gazzaniga contrasted two common views of human nature and society. One view, which he called *externalist*, is that “in order to handle the multiple problems of this life ... society should set up structures, agencies, institutions to help manage the individual’s affairs. Things and people can be fixed by the external administration of circumstances and goods.”¹⁷ Opposed to that is the *internalist* view, which recognizes that “personal beliefs are the proper guides for personal action and that by placing responsibility on the person, social groups function better. A key idea is that responsibility for action is an individual responsibility, not the responsibility of the social system.”¹⁸

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Gazzaniga argued in favor of the internalist position. His evidence for this came partly from neuroscience (the brain's division into subsystems) and partly from experimental psychology (certain effects of external manipulation on cognitive dissonance). But combining his evidence with ideas about the plasticity of neural connections, I come to a different conclusion than he did. My conclusion is a synthesis of the externalist and internalist positions. It asserts that personal beliefs *are* primary but institutions can and should be structured to selectively encourage some beliefs more than others.

Gazzaniga cited some results of psychological experiments on cognitive dissonance (see Chapter 7). These experiments showed that external rewards have little effect on people's beliefs. In particular, he cited a study by Arthur Cohen in which Yale University students were asked to express opinions on how the New Haven police had handled a student riot.¹⁹ These students all disapproved of the police's actions but were asked to write an essay in support of the police (a behavior dissonant with their beliefs). They were offered varying amounts of money, ranging from fifty cents to ten dollars, to write this essay. Then after writing, these students were again asked their opinions about the riot. Cohen found that those students offered the *most* money changed their beliefs the *least* after writing the essay.

Gazzaniga explained the Yale student results on the basis of the brain's *modularity*, that is, organization into distinct and somewhat independent subsystems. If one subsystem generates behaviors in response to external rewards or punishments, it can remain largely separate from another subsystem which generates internal beliefs. The greater the external rewards for an action, the more the person can attribute the action to the reward and not to his or her own beliefs. The person can say to himself or herself "I didn't really mean to do it" or "I didn't believe in what I was doing."

Gazzaniga used the separateness of behavior and beliefs as a generic explanation for why "externalist" social programs often don't work. He didn't take an explicit political stand, but argued in a general way for greater individual and family responsibility for people's welfare, and less governmental and social responsibility. In one example — treatment of elderly people with mental problems — he used this to argue for more care by family members instead of building more nursing homes.

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These insights about brain modularity support the idea of the artificial intelligence pioneer Marvin Minsky that the human brain is not a single intelligent organism but a *collection* of intelligent organisms.²⁰ For this Minsky coined the term “Society of Mind.” Both Gazzaniga’s and Minsky’s theories support, for example, this book’s distinction between the subsystem that “wills” and the subsystem that “does” (“The good I will I do not, the evil I will not I do.”). However, I draw a different conclusion about social programs than Gazzaniga does. My conclusion is not that we should have fewer programs. It is that we *should* have programs that are *participatory* rather than imposed from above.

I believe in social programs because the brain’s modularity doesn’t mean our mental life is anarchy. Our mental life is more like democracy. Each of its subsystems has a “voice,” and frequently some of the subsystems “argue” with each other. The brain can often arbitrate between different subsystems’ claims. Based on many results already discussed in this book, the frontal lobes, which are sometimes called *the executive of the brain*,²¹ seem to be the main “arbitrator.” Because the frontal lobes can communicate with all three parts of the triune brain (the instinctive, emotional, and rational brains), we can (unfortunately we don’t always!) make thoughtful decisions that integrate knowledge of both current rewards *and* preexisting beliefs.

All analogies between nervous systems and social systems are extremely speculative, so far. But the importance of an active frontal “executive” suggests to me that governments should be activist as well. The frontal executive is more like a president or a democratic coordinator than a dictator. It operates through feedback connections with other “participants” such as the emotional areas of the limbic system, rational/semantic areas of the cerebral cortex, and instinctual areas of the midbrain. This suggests by analogy that an activist government should work closely with and, when possible, cooperate with the people directly affected by its programs.

So I agree with Gazzaniga that *top-down, bureaucratically imposed* social programs, no matter how benevolent their organizers, often work badly. Not only do such programs take away individual responsibility, but the bureaucrats administering them often make decisions without considering local conditions that they don’t know much about. Bureaucratic ignorance of real conditions is one reason the

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American welfare system (before the 1996 law “reformed” welfare by gutting it) was such a mess, for example. Such ignorance is also a cause for the downfall of centrally planned utopias, real and fictional.* Finally, it bedeviled American urban renewal programs in the middle of the Twentieth Century. For instance, as the social critic Jane Jacobs discussed, well-meaning city planners in Boston made policies that led to bulldozing most of an immigrant neighborhood, the West End. These planners decided the West End was a “bad neighborhood” by some quantifiable standards, namely, it had a high population density and a lot of dirt in the streets.²² These planners neglected other facts about the neighborhood that were much more favorable. It was stable, had little crime, many people lived close to family and friends, and children played in the streets under watchful adult eyes. The loss of their neighborhood led to community disruption, as people who formerly lived close together were scattered to other parts of the city. Gradually, planners learned their lesson: in the 1960s and 1970s, good community organizing saved a similar Boston neighborhood, the North End, from the same fate.

But Gazzaniga’s discussion of beliefs left something out: attitude inconsistencies. He tacitly assumed that people either do or don’t believe something: the Yale students were either for or against the police, white Americans either do or don’t want to live with African-Americans, et cetera. In reality, each of us has many areas of ambivalence in his or her attitudes. That means we have some beliefs, opinions, and feelings that are somewhere in between two opposites, so they can go either way depending on circumstances. Psychologists have found that when people’s attitudes are ambivalent, external inducements to engage in a behavior sometimes can change people’s attitude in the direction of that behavior, instead of in the opposite direction as in the Cohen study. For example, most white Americans are quite conflicted in their attitudes toward blacks. They tend to see blacks both as unfairly hurt by past discrimination and as not doing enough to help themselves.²³ In psychology experiments designed to study racial ambivalence, white subjects who valued freedom and equality highly but were only weakly in favor of black civil rights felt uncomfortable

* Please see Chapter 8 for a brief discussion of recent novels about utopias that are more decentralized and likely to be more appealing.

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when made aware of their contradictions. The more discomfort these subjects expressed, the more they were likely to change their behavior to be more supportive of blacks (such as by joining the NAACP).

The results on white racial attitudes hint that sometimes people sincerely want to be generous to another person, or a different group, but are waiting for the opportunity to do so without excessive self-sacrifice. For this reason, government programs don't always replace individual responsibility. Just as often, they make it easier for people who want to act responsibly to do so. For a personal example, in the 1970s my grandfather was over eighty years old and could no longer care for himself. He lived in Toronto but wanted to move to California to be with his daughter, my mother. She thought it would be too difficult to move him into her own house, but would have been happy to move him into a managed apartment or retirement home in her area. However, he ended up staying in Toronto because the Ontario provincial health insurance system paid for 90% of his care at a retirement center there. It was not a conventional nursing home but a well-run, cheerful, Jewish-oriented home with many activities. If the United States or the state of California had been sponsoring a comprehensive government health insurance system, my grandfather would have been able to get the same care in California. My mother could then have been more actively involved in seeing to his day-to-day welfare.

We can understand this by drawing an analogy with Eugene Roberts' neurochemical theory of disinhibition (see the last chapter). My mother's love for and natural generosity to her aged father were *inhibited* by the difficulty of caring for him, and would have been *disinhibited* by a good health insurance plan. As Roberts and the neuroscientist Gerald Edelman both argued, the same person holds within himself or herself a repertoire of competing behavioral patterns.²⁴ This is not just true of external behaviors but also of beliefs. Many of us are, to varying degrees, both racist and racially tolerant, both selfish and altruistic, both relaxed and intense, and so forth. If a white person has both generous and prejudiced feelings toward blacks, she or he will react well to external factors that make it easier to express the generous side of her or his feelings.

Participatory Democracy

I also believe, though, that the people who benefit from government programs should be participants in running the programs. This idea isn't a monopoly of the anti-government political right. In the 1960s, the American left wing organization called Students for a Democratic Society (SDS) used the words *participatory democracy* as one of their slogans. They were reacting to the elitism and paternalism of top-down handouts by liberal government. Unfortunately, SDS had no well-thought plan for what to replace the handouts with. Since the focus of SDS's leaders was ideologically opposed to the pragmatic liberalism of John Kennedy's presidency, they shunned making suggestions about nuts-and-bolts policies. They more or less practiced participatory democracy within their own power structure. But they had no sense of how they would govern if they came to hold wider power; nor did they ever have enough power to innovate successfully.

The most exciting experiments on participatory government programs may not have been tried yet. A 1994 article by the biologist and futurist Mary Clark does, however, review some local communities and some larger societies where participatory institutions seemed, at the time she wrote, to be functioning well.²⁵ Among these are the state of Kerala in India (which has living standards and literacy comparable to the West), the Mondragon Cooperatives in northern Spain, and the Dudley Street Neighborhood Initiative in Boston. Of all the Western democracies, Sweden has the best developed network of voluntary organizations, some representing labor, some management, and some a variety of other constituencies (running the gamut from consumers to women to bicycle riders). Communication back and forth between these organizations and government departments is ongoing and more frequent than in most other countries. Many people involved in these organizations, however, feel that they have no real influence on government decision making, as Marvin Olsen has documented.²⁶ This is because these activists believe the communication system serves more to co-opt the divergent interests in the country than to integrate them into policy making.

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The kind of genuine “participatory pluralism,” with decentralized decision making, that Olsen advocates²⁷ seems so far to be easier to implement at the level of cities rather than countries. The administration of Harold Washington as mayor of Chicago (between 1983 and 1987) saw some bold experiments in involving communities in delivery of human services and neighborhood economic development.²⁸ Similar progressive programs have also appeared in smaller American cities such as Burlington, Vermont, and Berkeley and Santa Monica, California.

Social systems, like individual neural systems, can seek to optimize one of many criteria.²⁹ Authoritarian systems with a strong central government are optimal in some respects: if well run, they provide order and a sense of everyone knowing his or her place in society. Laissez-faire, libertarian, decentralized systems are optimal in other respects: they often provide a range of opportunities and a sense of freedom. Either of these types of organization can be “disinhibited” by social customs and policies favoring one set of values over another. But extreme libertarianism is a “gated dipole” reaction (see Chapter 5) to authoritarianism (the American rebellion against the British monarchy is a good example), and much of the rhetoric of either extreme is common nonsense. Let’s take a lesson from the earlier network model of self-actualization, which functions best when the largest number of needs are met.* The lesson is to try to create a political system that combines the best features of *both* authoritarian and libertarian systems.

Detailed political theory is outside the scope of this book. For general system design, though, the political scientist Christian Bay made a useful distinction between two types of freedom.³⁰ Bay argued that modern American society has a great deal of *social freedom*, which he defined as the ability to act or refrain from acting as one desires (freedom from compulsion). But that type of freedom can often be oppressive because we lack what he called *psychological freedom*, that is, the capacity to recognize and act upon one’s full range of needs. Some more traditional societies, he argued, have more psychological freedom

* At the level of societies, this is perhaps analogous to John Stuart Mill’s notion (*Utilitarianism*, 1861) of “the greatest good for the greatest number.”

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(arising from a sense of community and common purpose) but much less social freedom. Bay argues that true participatory democracy requires the elusive combination of both types of freedom.

Again, I think neuroscience — both experimental and theoretical — will contribute to this debate by telling us more about the human “raw material” in sociopolitical systems. Further knowledge about the frontal lobes, and other brain “command centers”³¹ involved in selective disinhibition, can be used to strengthen arguments for more progressive social and political arrangements. After all, we want to design social, political, and economic systems that are compatible with the mental material we bring to them. As it becomes further refined, the neural network model for self-actualization can approximate the interplay of different needs in the brain.³² Functional principles arising from this type of model network, we hope, can have analogues that are applicable at the level of social systems.

Understanding how to organize neural and social systems is enhanced by language and concepts from mathematical dynamical systems theory. Let us now look at the potential benefits to humanity from knowledge of this branch of mathematics.

The Lessons of Dynamical Systems Theory

This book has stressed that a complex dynamical system generally has more than one possible equilibrium (see Figures 4.1, 7.1, and 10.3). This has been demonstrated in many mathematical theorems about systems describing neural networks.³³ It has also been demonstrated in some dynamical systems applied to economics.³⁴ This is a property of these systems that comes from the fact that they are *nonlinear*. What does that mean? A mathematical system represents some interactions within the physical or mental world: the system has an input (influences from the outside environment) that it converts to an output (response of the system itself). The system is defined as *linear* if the system’s output increases or decreases gradually in proportion to the strength of the input. Many simple physical systems can be studied using linear system theory; examples include a spring or a simple electrical circuit. In a nonlinear system, by contrast, increasing the input to the system a small amount may possibly lead to a large increase in the output.

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Nonlinear systems are less predictable, and harder to control, than linear systems whose response is proportional to the amount of input given the system. This very unpredictability, though, is in other ways a blessing. If a human personality were a linear system, well-established mathematical theories tell us it would have only one stable attractor. That is, the personality could only sustain one set of operating traits. A “linear” person who had developed the habits of petty crime and dropping in and out of jobs and schools couldn’t learn different habits of hard work and honesty. The same is true of societies. If a society were a linear system, it wouldn’t have the dynamic flexibility to change from sustained dictatorship to sustained democracy.

The nonlinear, flexible nature of dynamical systems holds out much more hope for change in each of us. Our stuck points, the “way things have always been” are in fact only local, not global, attracting states. A sufficient amount of energy or disruption, like the noise in my self-actualization network (Figure 7.2), can knock us out of the most entrenched habits. The most confirmed couch potato, for example, will get up from his couch when his house is on fire.

There’s the catch: the energy that knocks us out of established habits is often related to something dangerous (like a house on fire) or at least unpleasant (like a relationship gone sour). The fear of such unpleasant events is one thing that keeps people stuck in bad habits. When temporary unpleasant changes occur, there is no guarantee they will ultimately lead to successful results. But the other side of the coin is that in nonlinear systems, including neural and social systems, *pleasant* surprises can also happen abruptly! For example, in the 1970s, the apartheid system in South Africa seemed solidly entrenched. Sporadic marches and other forms of black protest were suppressed by violence on the part of a white power structure rich enough to enforce its will. But in less than twenty years, the gradual buildup of stresses, internal and external, increased the number and power of South African blacks as well as whites who wanted to change the system. In time the unthinkable, a multiracial government with a black President, happened.

The unthinkable is also happening in many other international trouble spots: peace accords between Israelis and Palestinians; non-Communist governments in Eastern Europe; a partial cease-fire in Northern

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Ireland (even though, as of this book's writing, all these advances are still in serious danger). All have been achieved through few people's determined leadership, many more people's quiet dissatisfaction with the old ways, and a fair amount of suffering by everyone involved

In spite of all the convulsive changes in many parts of the recent world, people persist in cynicism about the world as a whole. Our common nonsense is that people are "naturally" greedy, and that hierarchies of dominance and submission are the only way to run societies (or organizations, or families).^{*} The lesson of the mathematics of nonlinear dynamical systems is that there can be more than one "natural" state at a time. Even if greed is natural, cooperation is also natural. This means a society where people nurture and empower each other is not an impossible dream. Mary Clark's examples of current cooperative societies discussed earlier hint at what can happen; so do the times of resurgent partnership movements discussed by both Riane Eisler and Ralph Abraham,³⁵ such as the early Christian era, medieval troubadour period, parts of the Renaissance, and the late 1960s in the West. A cooperative society is not inevitable, since the attraction to an authoritarian equilibrium still exists. But it is possible. And to get there, we will have to accept some temporary loss of comfort. I will return to this at the end of the book.

As dynamical system ideas become more widely known, people will begin to associate mathematics, or at least this branch of it, with different parts of the human personality. Since the time course of a dynamical system over time can be described by a moving point in space, people will also associate dynamical systems with pretty pictures such as the very popular fractal designs.³⁶ In addition to revising our views of society, this will combat some common nonsense about mathematics itself. The conventional wisdom is that mathematics is a static, pure "left-brained" pursuit, and that its study dehumanizes people.^{**} In American slang, the word "number" is used either for a machine-like, soulless bureaucrat, or for a citizen

* An account of a recent conference on world population by Mary Clark (Social Issues, Volume 51, 1995) suggests that women in most countries have been less influenced by this particular piece of common nonsense than men.

** I wonder if the sound of the word "mathematics" contributes to this belief. The similarity of its first and third syllables gives the word a repetitive, sing-song quality. The word is supposedly derived from a Greek verb meaning "to learn," but did it originally mean rote rather than creative learning?

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enslaved by a bureaucratic system. This belief about mathematics appears to be stronger in the United States than elsewhere in the industrialized world, although in Rome in the 1920s, Enrico Fermi and his scientifically minded friends were looked down on as “logarithms” by his literary sister and her friends.³⁷ Related beliefs are that mathematical skill is rare, and that people who have that skill aren’t like down-to-earth or average people. The prevalence of these beliefs has contributed to the decline in American technology (see Chapter 10).

If the current American stereotypes about mathematics are examined, moreover, they are seen to be self-contradictory. On the one hand, mathematics is seen as soulless, mechanical, and humdrum. Math and science are seen by many as mundane in comparison to the more “romantic” pursuits of literature, art, and music. On the other it is seen as an esoteric, almost mystical, pursuit, an abstract game with symbols divorced from real life. Is math *too much* a part of the mundane world or *too little*? It can’t be both at once!

But mathematics is in fact dynamic as much as it is static. Also, while mathematical constructs often oversimplify the real world in order to be precise, they can be used as metaphors for a wide range of less precise ideas. The minister and mathematics educator Sarah Voss, for example, uses the *definite integral* from calculus (see Figure 11.1) as a metaphor for God, or for perfection in general.³⁸ This is because the integral is a means of estimating the area of an irregularly shaped region by approximating it by sums of smaller and smaller measurable rectangles. The definite integral, defined as the actual area of the region, can never be directly measured but can be approximated as closely as we wish. Similarly, Voss says, we can get arbitrarily close to God but never completely reach either God or perfection on this earth. What she says about God may also be true of a perfect society.

The message of the integral metaphor, like the message of dynamical systems, is one of hope. Mathematics can open up possibilities for us, in the natural sciences and in life, that we never knew existed. Also, because mathematics demands logical rigor, studying it can encourage us to look beyond appearances to the truth. The pursuit of truth is a powerful antidote to the tyranny of conventional beliefs. So if we

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develop skill in mathematics and apply that skill to the rest of life, it can help us resist common nonsense, whether in psychology, politics, religion, or elsewhere.

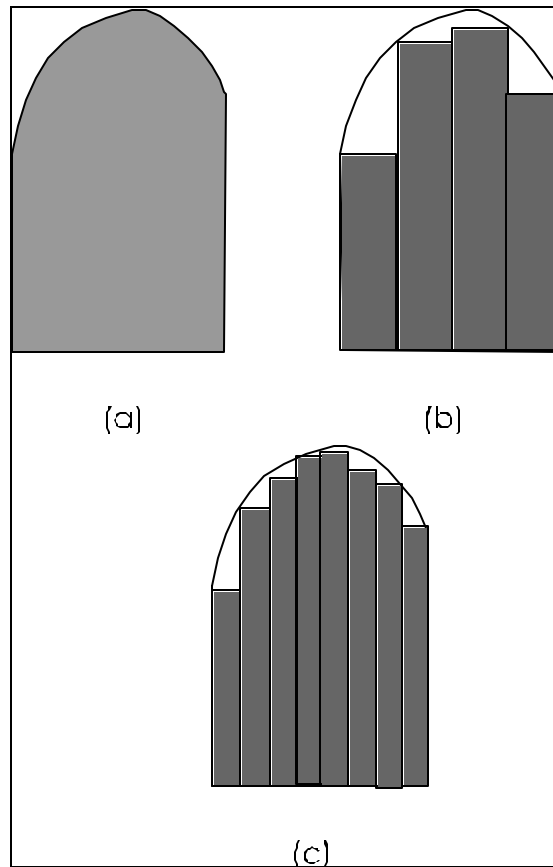


Figure 11.1. (a) The definite integral of a segment of a curve. It is represented by the shaded area under the curve, which can't be measured directly. (b) Approximation to the area in (a) by four rectangles, which *can* be measured directly. (c) Closer approximation to the area in (a) by eight rectangles.

The reality of what mathematics can yield is quite different from a lot of popular mythology about mathematics. The same is true of natural science.

Science Versus “Scientism”

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As we get more scientific knowledge about the brain, some people fear that we will impose on our view of the human personality the popular notion of what being “scientific” is. But that popular notion is really based on a Newtonian outlook and doesn’t incorporate many of the scientific advances of the last century (quantum mechanics, Heisenberg’s uncertainty principle, Gödel’s incompleteness theorem, and so forth). What people fear is the reductionist idea that values, consciousness, and spiritual experience are “nothing but” a certain sequence of biochemical events in the brain. The dynamical systems theorist Ralph Abraham calls this stance *scientism*.³⁹

Not just the general public but scientists themselves often fall into the common nonsense of rejecting concern for values as “soft” or “unscientific.” For example, when I first proposed writing this book, the response of my academic colleagues ranged widely. Some were enthusiastic, but others felt either that my spending time on this pursuit was a waste of time or a distraction from doing new research. Still others simply couldn’t appreciate the connections I was drawing between widely different fields.

But scientism isn’t where I believe further advances in neuroscience will ultimately lead us. Scientism is the extreme form of the traditional philosophical outlook of *materialism*. Materialism is roughly defined as the notion that everything that occurs can, and should, be treated as events in the palpable physical universe. In a strictly logical sense, as discussed by the contemporary philosopher John Searle,⁴⁰ materialism is compatible with the existence of mental states like consciousness, emotions, and subjective experience. But philosophers who take the materialist position have tended to stretch it further to a reductionist, “nothing but” stance. In other words, they tend to leave out the possibility that consciousness or subjective experience can exist.

Over the last several centuries, materialism has been one of the two traditional opposite positions in metaphysics. The other opposite is *dualism* (mainly due to Descartes), the notion that the physical and spiritual universes both are important but can be considered as largely independent. The extensive interplay of reason and emotion in the brain⁴¹ and between our mental and physical selves makes the dualist position untenable.

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But John Searle has argued that the “nothing but” strain of materialism is *also* untenable. This is because neuroscience has shown that there are measurable events in the brain that correlate with feelings, thoughts, and subjective perceptions. That doesn’t mean that feelings, thoughts, and perceptions are *reducible* to brain states. For example, if you and I both see that a tree is green, that doesn’t mean that your brain state on seeing the tree is absolutely the same as mine. But our brain states do have enough in common that it is useful to place our perceptions in the same category.

Searle believes, as I do, that new philosophical categories need to be developed.⁴² These would be categories that allow for multiple, interacting levels of understanding. Instead of the traditional belief in a single cause for events, we would interpret causality in the framework of dynamical systems in which each of many parts can influence all the others. In the case of the body and the mind, for example, while physical processes in the brain would be seen as causing mental events, mental events would also be seen as causing physical things to happen. (This is one reason why changes in beliefs can help change society!) The physical and the spiritual would once again become partners rather than adversaries. We would cultivate the capacity to describe events with accuracy — the traditional domain of science — as well as the capacity to value events with awe — the traditional domain of the arts or of religion.

This chapter has outlined some of the things brain science (theoretical and experimental) has to contribute to changes in society. I agree with most serious futurists that the world’s current problems demand basic changes in our attitudes and mental paradigms. The global population crisis, and the disruptions caused by the communications revolution, will force such changes. But the changes that actually happen could be good or bad, and all of us have a role in directing their evolution. If we work very hard and play our cards right, some writers say, we will usher in the next and most glorious revolution in the history of human thought. This would not only save our planet but enhance the quality of our lives around the world to a point never attained before in history. Building on the previous chapters, I now conclude the book with a description of how the world can look in the near future if we meet these challenges successfully.

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Chapter 11: Brain Science for Humanity

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