Embracing Complexity: An Exploration of the New Biology and Medicine

The list of accomplishments of Western medicine is impressive—organs transplants, a panoply of magic-bullet antibiotics, and the discovery of insulin to name a few. It is little wonder that the mystique surrounding it is so great. There is an ever-present air of enthusiasm for the new discoveries that seem to be just around every corner. Faith and expectation are pervasive.

Western medicine also has its weaknesses and problems. While powerful drugs and lifesaving technologies have improved the quantity and quality of life, these benefits have not come without costs.

To overcome the limitations of conventional biological science, some scientists and medical doctors are now thinking about fundamental problems in new and fresh ways. These “frontier” researchers have opened the way to new approaches in biology and medicine. The emerging ideas of the new biology, with its more “ecological” world view, offer exciting implications for medicine.

The Limits of Traditional Biology and Medicine

Western scientific medicine has had tremendous success in many areas. But its success in other areas has been more limited. For example, Western medicine has not dealt as successfully with chronic, degenerative disease as it has with illnesses of an acute, infectious nature. Its technological emphasis and molecular model of disease have separated medicine from the person behind the problem and severed the link to the timeless art of healing, an art that honors the innate capacity for self-healing and the value of caring and connection.

Another problem is the financial burden of technological medicine. The rising costs of medical care do not correlate with a rise in the health of the population: countries that spend more on high-tech medicine are not necessarily healthier. For example, despite its higher capta health care expenditure, the United States ranks eighteenth in infant mortality, well behind countries like Sweden, Finland, Spain, and the United Kingdom, and access to medical care for those in the lower rungs of the socioeconomic ladder is a major problem.

These issues, however, can be viewed in other ways than as fundamental problems with medicine. Access to medical care is a political issue, cost limitations are economic in nature, and the dilemmas of reproductive technologies like cloning fall in the realm of ethics. Yet deeper questions arise about the basic approach of the biomedical model. The success of biology and medicine has come by moving from anatomy to the world of the microscope and ultimately to the level of the molecule. Is the molecular cause-molecular cure model of Western medicine a handicap in the study of chronic, degenerative disease? Indeed, the history of science shows that breakthroughs come from the ability to think about problems in a new way. Harvey did not simply “discover” the circulation of blood, but thought about the problem in a way that overcame the limitations of past approaches.

While disease can be described in terms of the molecules involved—such as heart disease and the cholesterol molecule—there is always the question of context. The human mind-body system is complex, interacting with an equally complex social and physical environment. Set in this intricate web of interaction the molecular changes underlying disease processes are descriptions and not necessarily causes. Chemical drugs can powerfully and positively alter an illness, but the frequency of negative effects—so-called side-effects—shows the degree to which complexity remains a problem. Each patient is unique, making side effects difficult to predict, and the multitude of complex physiological interactions virtually ensures that powerful chemical agents will have more than their intended beneficial effect.
The Problem of Complexity

"Reductionism" in science means reducing things down to their smallest elements in an attempt to understand them. In a way, that's like trying to understand the Pacific Ocean by studying the sex organs of a shrimp. You can only go so far with it. —Jim Unger, in The Complete Herman, 1992

The tremendous success of science has come from a concept called "reductionism." This is an approach to science derived from the rational method of analysis developed in a flash of intuitive insight by Descartes, an approach whereby complex problems can be solved by breaking (or reducing) them down into simpler pieces. Wholes can be understood by breaking them into their parts and the parts can be understood by breaking them down into their parts, and so on. In biology, reductionism is combined with the notion that living organisms can be considered machines. Thus, "mechanistic reductionism," the dominant approach in biology, is an attempt to understand the physical and chemical mechanisms that comprise living organisms.

Over one hundred years ago the great British biologist Thomas Huxley (1825-1895) described the basic model of animal biology, which regards animal bodies as machines impelled by various forces and performing a certain amount of work which can be expressed in terms of the ordinary forces of nature. In its more modern form, the model is directed toward a complete understanding of the intricate chemical and physical mechanisms of living systems. Tremendous progress in describing the fundamental molecular machinery of life has been made, and many molecular biologists feel that the cause and cure of many chronic, degenerative diseases lies "in the genes."

Yet, despite such success, exclusive attention to molecular detail has left behind many interesting questions related to the complexity of living systems. In real life, narrowly considered solutions sometimes mask a quagmire of complication. In agriculture, for example, it would seem obvious that replacing a water buffalo with a tractor would be of great benefit. Yet in Sri Lanka this agricultural "improvement" unleashed a surprising chain of consequences. Buffalo create shallow pools (wallows) that serve as a home for fish during the dry season. The fish provide food for people and are voracious eaters of malaria-carrying mosquito larvae. Thick plant growth next to the wallows provides a home for rat-eating snakes and crab-eating lizards — rats and crabs are pests to the rice crop — and a source of roofing material for people. As natural rat, crab, and mosquito control is replaced with the use of chemical agents, another chain of ecological events is unleashed.

This agricultural example serves as an interesting metaphor for medical intervention. The human body, like an agricultural ecosystem, is a tightly coupled system. With all the parts so closely linked, it is limiting to think about parts without considering their interactions. Even a small change in one seemingly insignificant part can have a large impact on the system as a whole, an impact that cannot be predicted by studying parts in isolation.

Returning to a medical example, antibiotic therapy can unleash a surprising chain of events and lead to consequences hard to connect to their source. Antibiotics, which are bacteria-killing agents, can disrupt the natural microfloral ecology (the human body is a living garden of micro-critters, especially in the intestinal tract). If too many bacteria are killed, yeast can proliferate and the loss of beneficial bacteria can deprive the host of nutrients. If antibiotics are over-used, resistant strains of disease-causing bacteria develop.

Doris, a middle-aged mother with a serious case of the autoimmune disease lupus, illustrates the complexity of medicine. Her physician, writing in the popular science magazine Discover, described the relentlessness and devastation of lupus as "an empty and demoralizing vision of how far we have yet to go in treating and curing chronic disease." Hospitalized for complications of her illness, Doris was suddenly unable to lift her hands. Specialists were consulted and as her physician lamented, "No two seemed to agree.
about what was wrong." The rheumatologists felt that the inflammation associated with lupus was now affecting her nerves and blood vessels and recommended a higher dose of steroids, drugs that were already causing her skin to become "exceptionally fragile," and making her more susceptible to infection. The neurologists, in contrast, felt that the steroids themselves were causing the problem, advising that Doris be taken off steroids and subjected to further tests. The infectious disease experts thought some kind of bacteria or virus might be at work, suggesting appropriate tests and a prescription of antibiotics. Her physician persevered through this confusion of consultation, eventually locating the root of the problem: a side effect of one of the twenty-five drugs she was taking.

The Challenge of Infectious Disease

When the tide is receding from the beach it is easy to have the illusion that one can empty the ocean by removing water with a pail.

—René Dubos, Mirage of Health

Ever since the dawn of civilization—when humans began to gather into villages, towns, and cities—plague, smallpox, cholera, and other deadly infectious, communicable diseases swept through nations. Miraculously, during the nineteenth century the force of pestilence began to recede and by the later part of the twentieth century optimists proclaimed that the problem of infectious disease had been solved once and for all. This decline in sickness and death from infectious disease is commonly believed to be the crowning achievement of scientific medicine, the result of Pasteur and Koch’s germ theory and the development of vaccination, immunization, and antibiotics for prevention and treatment.

However, the curious thing is that medicine had only a small role to play in this defeat. Medical historians and others who have studied the decline in death from germ-based disease have discovered what has been called "a most fundamental heresy of our time." The decline in death from measles, typhoid, pneumonia, diphtheria, and a host of other dreaded diseases was already well underway by the time specific preventative or therapeutic interventions were developed. The most important factors in the decline were better living conditions, especially better nutrition, and specific sanitary measures introduced in the later part of the nineteenth century.7

Research suggests that in the United States only 3.5 percent of the decline in mortality since 1900 can be attributed to specific medical measures for major infectious diseases and about 92 percent the decline in mortality since 1900 had already occurred by 1950, the point when medical spending began to dramatically increase.8 This is not to strip medicine completely of its claim to fame—indeed, many lives were saved by medical intervention—but to acknowledge the ecological complexity of infectious disease and the crucial role played by factors like public health and good nutrition. The germ theory has come to dominate popular and medical thinking and this, coupled with an almost irrational confidence in antibiotic drugs, has meant the neglect of many important mysteries of germs: the environmental, social, and host factors related to their spread. As Dubos pointed out, "The more important reason for the stubborn persistence of infection lies in our lack of understanding of the interrelationships between man and his biological environment."9

The great Pasteur himself began his exploration of infection with the study of silkworm disease and he was painfully aware of the intricate web linking germ, silkworm, and environment. In reflection he wrote: "If I were to undertake new studies on the silkworm diseases, I would direct my effort to the environmental conditions that increase their vigor and resistance."10 Pasteur was keenly aware of the importance of the terrain, a concept encompassing those factors that pertain to the natural resistance of the host and a concept still important in French medicine. (While an American doctor might battle the germ, the French doctor might attempt to shore up the terrain with "terrain building" prescriptions or spa therapy.) Pasteur felt that improvement in a patient’s resistance should be an underlying
focus of therapy and even went as far as to suggest psychological factors played a role in the interplay between man and microbe. From an ecological perspective, poverty and filth can be as important in generating disease as the microbes themselves. The sanitation movement of the nineteenth century made a major contribution to the decline of infectious disease before the advent of the germ theory and even after the germ theory was developed some proponents of sanitation refused to accept its premises. The great German hygienist Max von Pettenkofer publicly drank a glass of water containing the cholera-causing bacteria in an attempt to disprove the germ theory. Pettenkofer was interested in what he saw as the disease-generating potential of foul air, peculiar soil conditions, and climate, a theory that led him to improve water and sewer systems. It is an irony of history that Pettenkofer and those in the sanitation movement who were opposed to the germ theory did so much to reduce mortality. (Of course, many in the sanitation movement did accept the germ theory and in doing so were all the more effective in enacting successful public health measures.)

Today in Canada, tuberculosis—to pick a dreaded disease from the past that still lingers in the population—occurs most commonly among native people who live in a First World country in Third World conditions with poor housing and poor nutritional status. The life expectancy of Canada's native people was 42.4 years in 1977. Contrast this with the parish of Hartland in the southwestern English county of Devonshire where people had a life expectancy of fifty-five years or more from the entire period from 1558 to 1837. The parish population had abundant food and good nutrition, infectious disease was rare because of the area's isolation, and the infant mortality rate was low for the time because of extensive breastfeeding. Sadly, the slow realization of the complexity of infectious disease has come at the expense of the lifesaving antibiotics that were to spell its end. Bacteria have a remarkable capacity to evolve, and have over decades of enthusiastic antibiotic (over)use learned to resist the best and brightest drugs. And their adaptive abilities are stunning.

Antibiotics act as magic bullets by affecting parts of bacteria that are different than anything found in human cells. (That way the drug can kill the bug without damaging the person.) Penicillin, for example, works through the action of a special enzyme which destabilizes the bacterial cell wall when the bacteria tries to divide—its way of reproducing. The “bugs” have evolved numerous strategies to counter this threat to reproductive success. They are able to generate a counter-enzyme, for example, or narrow their cell wall cavity to stop the penicillin enzyme from entering. Worst still is the fact that the bacteria can trade resistance genes—even exchanging genes with completely different kinds of bacteria! In this way, a dangerous germ
can pick up resistance from a harmless microbe that has become insensitive to antibiotics.

It was arrogant to declare the end of infectious disease. Since as one expert put it, "No magic bullet stays magic for long," the prospect for the future is not so clear. Some authors—such as Laurie Garrett in The Coming Plague—offer discomforting predictions and physicians are now struggling with resistant forms of many pathogens. But perhaps with a more ecological perspective accounting for host, bug, and environment, the magic bullets that still have some firing power can be used more wisely and their lifesaving potential will be with us for some time to come.

The Unsolved Problems of Biology and Medicine

By reducing biological functions to molecular mechanisms and active principles in this way, biomedical researchers necessarily limit themselves to partial aspects of the phenomena they study. As a consequence they can achieve only a narrow view of the disorders they investigate and the remedies they develop.

—Fritjof Capra, The Turning Point

The history of biological and medical science is a steady progression from whole to parts, from parts to subparts, eventually ending at the level of the molecules. Because of the success of this program of reduction, all biological and medical problems are often thought to begin and end in the molecules themselves. Behavioral patterns, intelligence, and chronic diseases are all thought to be "in the genes." Taken to its extreme, organisms do not really exist—there are only "selfish" genes.

While the study of the molecules of living systems can offer essential insight, many unanswered problems of biology remain, problems surrounding the exquisite organization of living systems. In physics, all systems move from order to disorder. But biology moves in the opposite direction—from disorder to order. How do these molecules work together to form an organism? What are the regulatory and organizational principles of living systems? How do ecosystems—complex webs of interaction between living and non-living things—function, and what part does humankind play in the global ecosystem? What is mind and what is its connection to the physical basis of life? What are the relationships between chronic disease and social and environmental factors like climate, diet, activity level, and stress? These tough questions have been, for the most part, swept under the rug, although not entirely out of sight and out of mind.

Organizational understanding is needed to better describe the evolution of living systems. The conventional model of evolution envisions random changes in genes causing favorable or unfavorable traits in organisms, traits which are then "selected" according to their contribution to the organism's survival and reproduction. In this theory of "natural selection" a creature without wings could in principle evolve a pair through a series of small gradual changes; bits and pieces would emerge and eventually add up to a functional wing. It is easy to see the survival advantage of a wing, but the problem lies in the fact that many changes would be needed over a long period of time before a useful wing evolved. It is hard to imagine the selective advantage of a still useless half-wing, and so, while the theory of natural selection can explain changes in simple traits like the wing color of a moth, it lacks the ability to explain major organizational shifts and the emergence of complex parts like wings. (Such problems with the theory of natural selection do not, of course, represent support for "creationism," but rather point to the need to evolve the understanding of evolution.)

Evolution, the big picture of life, is framed around the little picture of life—the molecular stuff from which organisms are made, and both suffer from a lack of organizational understanding. Genes, molecular sources of biological information, contain the blueprint for the proteins found in living systems and despite the popularity of genetic determinism—the idea that practically everything is "in the genes"—genes are only part of the story. Biologists distinguish
between the genotype—an organism's genes—and the phenotype—the actual organism that results from those particular genes. While an organism's potential is restricted by its genotype, what it actually turns out to be—its phenotype—is shaped and molded by its environment. Some critics of determinism, such as the Harvard biologist Richard Lewontin, deny that human behavior is "in the genes," and argue that the role of genes in complex biological processes is not as straightforward as claimed by enthusiastic molecular biologists. (Lewontin is one of the authors of the 1984 book Not in Our Genes.)

Cystic fibrosis is a genetic disease that affects the lungs and pancreas and causes a potentially life-threatening build-up of mucus in the lungs. By the 1930s it became clear that the disease was inherited. Armed with the powerful tools of molecular biology, scientists hoped to find the gene that was the "cause" of the disease—the first step toward a cure. In 1985, the chromosome harboring the cystic fibrosis gene was located and in 1989 the actual gene was found and copied. Cystic fibrosis patients can have mutations in at least several hundred sites in the gene, some of which cause a severe form and others a more benign form of the disease. Still other mutations can result, not in cystic fibrosis, but in lung diseases like asthma and chronic bronchitis or even infertility resulting from a congenital malformation of the reproductive organs in males. Stranger still is the fact that some mutations do not result in any apparent symptoms, while other mutations may cause cystic fibrosis in some people but not in others.18

With the June, 2000 announcement that a rough draft of the human genome had been completed ahead of schedule, the public was left with a sense that cures for many diseases are now just around the corner. But scientists still only have a vague idea of how many genes exist in the more than 3 billion letters of the genome, or of what purpose the vast majority of this code serves. Few diseases appear to be the simple consequence of a single, malfunctioning gene. Rather, it appears that most diseases result from multiple genes, interacting together in complex non-linear ways and with the environment. Clearly, just as infectious disease will continue to plague humans for some time to come, chronic disease is not likely to yield to simple ideas. Genes, like germs, are a complex story that will occupy the human intellect for a long time to come.

The Search for a New Biology

Our vision of nature is undergoing a radical change toward the multiple, the temporal, and the complex.
—Ilya Prigogine and Isabelle Stengers, Order Out of Chaos19

The evolutionary biologist Stephen J. Gould once remarked that: “We debase the richness of both nature and our own minds if we view the great pageant of our intellectual history as a compendium of new information leading from primal superstition to final exactitude.”20 As Gould suggests, the quest for knowledge is much more complex than a steady accrual of facts moving us relentlessly from ignorance to certainty. Old ideas are not automatically wrong or “superstitious” if they cannot easily be explained “scientifically.” Science itself is a process of creating models to be used as tools for exploration and understanding. New models replace old ones not only because they might work better, but also for their aesthetic appeal and their resonance with the spirit of the times.

Thomas Kuhn, philosopher and historian of science, explained the progression of science in terms of ordinary and extraordinary phases. In a period of ordinary science, scientists in a particular discipline work from within the framework of a particular model—a broadly accepted collection of facts, assumptions, and methods that Kuhn called a “paradigm.” The model delineates what is true from what is untrue, the acceptable from the unacceptable, and contains a large number of “puzzles” that keep the scientists busy. This, said Kuhn, is what most of the scientists do most of the time.

At some point the model fails. Too many unexplainable or contradictory facts accumulate, precipitating a practical, intellectual, and even emotional crisis. This is extraordinary science, a period when old models dissolve and new ones are forged. Often it is the young
scientists and those from other disciplines that rise to the challenge of creating a new model because they are less indoctrinated in the old way of doing things and more open to new ways of thinking. Some older scientists remain intransigent, refusing to work with a new model even long after it becomes widely accepted.21

Physics, usually seen as the exemplary science for its precision and mathematically predictive theories, underwent a major shift in its underlying model as the twentieth century dawned. The Newtonian approach, with its material bodies acted upon by the force of gravity, proved inadequate to describe the physical universe at the level of the atom and quantum physics—with its legendary figures such as Albert Einstein, Erwin Schrödinger, Niels Bohr, and Werner Heisenberg—was born. The usefulness of the quantum model, a strange one of probability waves, uncertainty and non-local connections, is unquestioned; its implications remain a fascination and challenge.

Conventional mechanistic biology is based on the idea that living systems can be understood completely in terms of the laws of physics and chemistry. Since, as the argument goes, quantum physics is only needed when exploring unimaginably small things like electrons and protons, biology—which deals only with big things—remains firmly in the framework of centuries-old Newtonian physics.

At the dawn of the twenty-first century, biology is poised for a shift in framework equal in magnitude to that of physics a century earlier. Facing a collection of thorny problems, intractable and largely ignored in the old biology, frontier scientists have begun to initiate a period of extraordinary science. A model centered on the reduction of living systems to their basic structures using old physical ideas is giving way to a new biology, one focused on the complexity and organizational features of life. In this new biology the quantum theory is being applied to the understanding of biological organization, and a new theory of complex, dynamical systems is offering completely new perspectives on embryology, evolution, and the centuries-old mind-body dilemma. The new biology is based on a much more appealing conceptual framework, a framework attuned to the ecological spirit of the times. And there are now hints of what this new biology will mean for medicine.

From a Dead to a Living Universe: The Philosophy of Organicism

Life is an offensive, directed against the repetitious mechanism of the Universe.

—Alfred North Whitehead, Adventures of Ideas

Mechanistic biology, based on Newtonian physics, always suffered from a serious problem. The physical world of Newtonian physics was dead, uniform, and predictable. Living systems, in contrast, were alive, diverse, and unpredictable. Ironically, Newton himself was loath to accept that the ideas he pioneered to describe a dead physical world could completely describe living systems. While Descartes described animals as machines, Newton recoiled at the thought. The richness of the world could not have arisen from the mechanical interaction of uniform matter: it required a vital agent, an agent that for Newton connected the world to the divine. This divine vital agent was what Newton sought in his alchemical research, research that was to occupy much of his time and energy.22

Although Newton helped forge science in to its modern form—with a dead, material world replacing a timeless, organic vision—his work also helped to split biology into two camps. The intellectual battle between mechanists and vitalists became a dominant theme of biology, and even into the early part of the twentieth century the spark of vitalism burned brightly. Champions of vitalism, like biologist Hans Driesch (1867-1941) and philosopher Henri Bergson (1859-1941), did not deny the material basis of life, but added to it a vital organizing agent. For Driesch this was “entelechy,” for Bergson the “élan vital.”23

Despite the vitalists’ penetrating critiques of mechanistic biology, vitalism could not offer a concrete and useful alternative to mechanism. Vague talk about mystical-sounding “vital agents” responsible
for the organization of matter in living systems could not compete with the spectacular insights of the mechanistic molecular biologists. The mechanists soon claimed victory and declared their hated enemy, vitalism, dead and buried. For modern students of biology vitalism is but a historical curiosity, a heresy of earlier times.

Yet the victory party was premature. Despite the success of molecular biology, the problem of understanding biological organization remained and a third conceptual thread, a bold new perspective beyond the perennial mechanism-vitalism debate, emerged to challenge the primacy of mechanistic dogma. This third way, the philosophy of organicism, has spawned a concrete and viable approach to the study of living systems. And its champions have included eminent thinkers like Joseph Needham, a converted mechanist and the great chronicler of Chinese science and civilization.

Alfred North Whitehead (1861-1947) played a central role in describing the basic ideas of organicism. The remarkable British mathematician and philosopher, who spent his later professional years teaching at Harvard University, rebelled against the materialism of science and shifted the focus from matter to process. The essence of the universe was not matter, immutable and eternal, but structures of activity which he termed organisms. Mechanists saw the universe as dead, and were comfortable thinking of living things as machines, while vitalists accepted the idea of a dead universe, simply adding that a mysterious vital agent was needed to account for life. For Whitehead, the whole universe was alive. His “organisms” were not only animals, plants, and cells but also minerals and molecules. As he put it: “Biology is the study of the larger organisms, whereas physics is the study of the smaller organisms.”

In the philosophy of organicism, each organism has properties that arise from the relationships and interactions of its parts, parts which are themselves organisms at another level, and which, in turn, are composed of further parts, organisms at yet another level. Thus, there is a hierarchy of levels, each with organisms possessing unique properties that emerge as a result of the relationships among its components. Animals are composed of cells, which are composed of molecules, which are composed of atoms, which are composed of subatomic particles and so on.

Ant colonies, for example, have properties that emerge from the relationships between individual ants. In an ant colony, as in its human counterpart, there is a spectrum of work effort: some individuals are lazy, others are ambitious. This is more a property of the colony arising from the social dynamics of the group than a property that can be reduced to a feature of individual ants. If the hard-working ants are separated from their lazy brothers, two colonies are produced with the same spectrum of working characteristics as in the original colony. For a complete understanding of its properties a system must be studied in its entirety. Ant colonies cannot be fully understood by the study of individual ants. Plants and animals cannot be understood by the study of cells in isolation, nor solely in terms of their individual molecular constituents.

Organisms as Complex Systems

From the perspective of organicism, organisms are wholes with properties that emerge from the relationships of their parts. An organism is thus appropriately described as a “system,” a word with Greek origins suggesting “a composite whole” and “to bring together.” The new biology is thus a “systems biology” that uses “systems thinking” and the effort of those working in the new biology has been to understand the properties and organization of complex systems.

Two pioneers of systems theory were the Austrian biologist Ludwig von Bertalanffy and Alexander Bogdanov, a Russian whose interests roamed from medicine to philosophy and economics. Bogdanov developed a theory of the organizational principles of both living and nonliving systems, which he called “tektology” and described as a step toward a “universal science of organization.” Many of his ideas were precursors of important features of systems thinking that only became more widely incorporated into the new biology many years later. A German edition of Bogdanov’s Tektology
was published in 1928, over a decade after the Russian original. Von Bertalanffy described decades of systems research in his 1968 book *General System Theory*.

Systems theory is distinctly different from mechanistic biology. Instead of dissecting wholes into parts as a means of understanding, parts are examined in the context of the whole. This sense of context suggests a network or web of relationships that characterize a system at each level, a web of relationships that combine to produce a unique pattern of organization. Fritjof Capra, who presented an overview of the emerging new biology in his 1996 book *The Web of Life: A New Scientific Understanding of Living Systems*, notes that the pattern of organization of a system is distinct from its structure. The pattern of organization is “the configuration of relationships among the system's components that determines the system’s essential characteristics,” while the structure refers to the actual components themselves.

Cybernetics, the study of regulation and control in living and non-living systems, is an important facet of the new systems biology. Organization is achieved with the help of regulatory networks of positive and negative feedback. If A affects B and B affects C, feedback exists when C affects A. This means that something A does is transmitted in a circular fashion back to itself. Positive feedback can be harmful, like an ultimately self-destructive device that increases the volume of a speaker when it records an increase in sound. Negative feedback, on the other hand, is important for achieving balance, like a thermostat which turns a furnace off when the temperature exceeds a set value and turns it on when the temperature goes below that value.

One of the interesting and important things about networked systems with multiple loops of communication and feedback is the blurring of cause and effect. Analyzing things in terms of cause and effect is a hallmark of traditional science. Yet in complex systems the causes and effects can become blurred into a chicken and egg scenario: it is hard to distinguish which came first. Multiple factors can be involved in the breakdown or disruption of a complex system. Breakdowns can be described in terms of the factors involved and the system's altered pattern of organization.

Networks of interacting components with multiple feedback loops are a challenging mathematical problem, one that has required many years and the help of powerful modern computers for solutions to emerge. For most of its history, science has concentrated on simple cases and ignored the more complex problems. These simple cases are described as “linear” and have basic mathematical relationships, often existing only as the exception rather than the rule in the “real world.” Complex systems, in contrast, exhibit non-linear relationships and, although the non-linear mathematics describing these systems is hard to solve, they are much more relevant to biological problems.

While linear systems exhibit simple and predictable behavior, non-linear systems are complex and unpredictable. In the linear case, a small input will generate a small change in the system and a large input, a large change. In the non-linear case, small inputs can give rise to large changes, while stability of the system can sometimes be maintained in the face of a large input. Non-linear systems can also experience catastrophic, a sudden and often unpredictable change after a period of stability.

The complex systems that are relevant for biology are also characterized as “open” and “non-equilibrium.” Open means that the system is in constant connection with its environment, taking in and giving off or “dissipating” matter and energy. Non-equilibrium means that the system is not in balance with its environment. The human body, for example, is maintained at a constant temperature despite the changing and varied temperature of the surroundings, a feat that is accomplished by various heating and cooling mechanisms. After a plant is pulled out of the ground, it will quickly wilt and die. Cut off from a supply of water through its roots, the plant is unable to maintain the “turgor pressure” that generates its stiffness and structure. The plant is in effect maintaining itself in a non-equilibrium state.
The Russian-born scientist Ilya Prigogine is famous for his studies of open, non-equilibrium systems. Prigogine, who, as Scientific American put it, “oscillates between the international Solvay Institute in Belgium and the University of Texas at Austin,” has explored how in such systems order can arise from chaos. The order and complex pattern of organization that can arise in random, disordered systems offers a hint of the exquisite organization seen in living systems. The Bénard cell, for example, is an ordered, dynamic structure that arises in an open, non-equilibrium system. If a thin layer of fluid is heated, heat will flow by conduction from the bottom to the colder top. In conduction, the fluid does not move, but heat is carried by the bumper car effect of adjacent molecules. As more heat is applied, conduction alone cannot transmit sufficient heat and convection begins, with heat-carrying currents of fluid moving in a random, disordered way. Strangely, as more heat is applied, the random convection currents form a beautifully ordered hexagonal pattern that allows cold fluid to descend and hot fluid to rise.

Prigogine, who called these dynamic patterns of organization “dissipative structures” because their existence is related to the dissipation of matter and energy, won a Nobel Prize for his work in 1977. Prigogine emphasizes the importance of fluctuations and feedback in these complex systems. While the system can maintain stability in this non-equilibrium state, internal fluctuations are amplified through feedback and the system can reach a “bifurcation” point, a point of instability from which it evolves to one of several possible new patterns of organization.

Dissipative structures are an example of self-organization, a spontaneous ordering that occurs in the face of a transfer of energy and matter and that offers a glimpse of a fundamental characteristic of living systems. Living systems share other characteristics with such complex, self-organizing systems, including the need for a constant input of matter and energy, internal feedback and fluctuation, and system evolution. The basic units of biological systems which interact to produce organisms with these characteristics are processes, not structures, for biological structures emerge from the web of interacting processes of each organism. The structures that comprise the human body, for example, are constantly being broken down and built up. Yet, despite this constant recycling and replacing there is an evolving pattern of organization with enough constancy to create at least the illusion of a fixed sense of self.

Organism and Environment, Mind and Body: The Relationship Between the Part and the Whole in the New Biology

We know today that both the biosphere as a whole as well as its components, living or dead, exist in far-from-equilibrium conditions. In this context life, far from being outside the natural order, appears as the supreme expression of the self-organizing processes that occur.

—Ilya Prigogine and Isabelle Stengers, Order Out of Chaos

An organism is a dynamic pattern of organization with a tension between its individuality and its role as part of whole. A cell, for example, is a distinct entity, yet its activity is constrained and shaped by its role as part of a multicellular organism. A liver cell can be studied in terms of its components and functions, but these only make sense in the context of the liver’s physiological role in an animal body. At another level, an animal’s behavioral pattern only makes sense in the context of the animal’s relationship to its environment.

The conventional reductionist approach to biology draws a sharp line between the organism and its environment. The various characteristics of an organism are thought to be shaped by distinct innate and external factors and the problem is thought to be one of determining what percentage of a particular characteristic is biologically determined (“in the genes”) and what percentage is the result of the influence of the environment. Yet from a systems perspective the line between the organism and its environment is not so clear. The organism and its “environment” interact in a dynamic way—the organism affects the environment and the environment affects the organism...
affects the organism. They co-determine each other as part of a broader evolving process, making it difficult to think about one or the other in isolation.

The complex and intimate relationship between organism and environment is demonstrated by the behavior of bacteria, who actively choose their environment by moving toward a sugar-rich region. The bacteria will “eat” the sugar and excrete waste products, eventually altering the environment to the point where it becomes hostile. Finding themselves in a poisoned environment of their own making, the bacteria leave to find more hospitable territory. The “environment” is not a fixed external reality in which an organism must struggle to survive, but an evolving set of conditions with which organisms interact, shaped in part by the activity of the organisms themselves.29

This intimate intermingling of organism and environment reaches to the level of the entire planet. Indeed, one of the most profound revelations of twentieth century science has been the realization that the planet is a complex, self-organizing system—an organism. James Lovelock, a British scientist and inventor, first noticed that the atmosphere of the Earth was not in equilibrium. Searching to explain this startling fact, he concluded that the Earth’s special atmosphere was connected with the existence of life on the planet. As he put it: “Could it be that life on Earth not only made the atmosphere, but also regulated it—keeping it at a constant composition, and at a level favorable for organisms?”30

Working with American biologist Lynn Margulis, Lovelock traced a variety of complex cycles, complete with feedback loops, that link the planet’s living and non-living systems so that conditions favorable for life are maintained. The startling conclusion is that living things play a central role in producing the very conditions upon which their existence depends. Lovelock called this self-organizing planetary system Gaia after the Greek goddess of the Earth. The Gaia theory shows that the miracle of life is literally and not just figuratively a planetary phenomenon, and changes the view of evolution from one where only the fittest organisms survive against the hostility of their environment to a complex, co-evolutionary process involving organism and environment as parts in a larger whole. It also offers an ecological vision of human place in the biosphere that contrasts sharply with the values of growth-oriented technological society.31

Systems theory not only sheds light on the relationship between organism and environment, but also it offers a fresh perspective on the age-old problem of mind and body. Since the birth of modern science and Descartes’ pronouncement “I think, therefore I am,” Western civilization has felt uncomfortable about its conception of mind and the relationship between mind and body. Descartes took a “dualist” position, arguing that while mind could influence body through the pineal gland, they were separate and distinct. Today, confusion reigns. Descartes’ dualism lingers alongside a strictly materialistic perspective that simply denies the existence of mind by reducing mental and emotional phenomena to brain events. An understanding of mind is equated with an understanding of the brain: emotions like anger, for example, are reduced to brain chemistry.

From a systems perspective, mind is not synonymous with brain. Mind is not a thing at a specific location, but an intimate and interwoven feature of complex, self-organized systems. As Fritjof Capra explains in The Web of Life:

According to the theory of living systems, mind is not a thing but a process—the very process of life. In other words, the organizing activity of living systems, at all levels of life, is mental activity. The interactions of a living organism—plant, animal, or human—with its environment are cognitive, or mental interactions. Thus life and cognition become inseparably connected. Mind—or, more accurately, mental process—is immanent in matter at all levels of life.32

Seen in this way mind is fundamentally inseparable from the physical basis of life. Mental activity is reflected in the physical embodiment of a living system, while the physical reality of the
system shapes and constrains its mental reality. This is far more than simply suggesting that mind affects body and body affects mind. Mental responses to the environment are also physical responses; physical responses to the environment are also mental responses. Such a new understanding of mind and its relationship to the body has profound implications for health and healing and is congruent with a plethora of new research showing the fundamental connections between the nervous system—with its organ the brain—and the hormonal and immune systems.

**Fields of Organization**

A “field” is a special concept widely used in physical science to describe the distribution of a physical property in time and space. Think of a flowing stream. At each position in the stream the water is moving with a particular speed in a particular direction. The speed and direction of flow at each position also changes in time. A “flow field” describes the pattern of movement of the stream by specifying the velocity of the water at each point in space and how it changes in time. This flow or velocity field is a useful way of describing the organized pattern of moving water.

Biological systems also display a pattern of organization across space and time. The human form, for example, begins with the meeting of sperm and egg, moves through a startling sequence of forms during the development of the embryo, and continues with a series of changes in form through childhood to adulthood and old age. Regeneration—the ability of creatures like starfish and salamanders to regrow parts—also shows the remarkable ability of organisms to organize themselves in space and time.

The maintenance and evolution of an organism’s form over the course of its life has always been a mystery to biologists. Every cell in the human body, for example, contains the same genetic information. Yet some genes are switched on and others off to form particular cells, like liver cells or skin cells, and all these different cells are organized to form a whole person. Vitalists used the idea of a mysterious vital force to “explain” the exquisite organization that characterizes life. Instead of a vital force, conventional mechanistic biology talks about an equally mysterious genetic “program” as the source of biological organization. Searching for a more concrete understanding, organismic biologists have applied the field concept to the understanding of form and pattern in living systems. These organizing fields are called morphogenetic fields because they shape an organism’s form and pattern of development over the cycle of its life.

University of Toronto biophysicist Lynn Trainor and his colleagues have successfully applied the morphogenetic field concept to a simple, single-celled organism called tetrahymena. Their morphogenetic field model describes the dynamic changes associated with the growth and replication of the organism. Tetrahymena is a strange critter. Two of these miniature, single-celled creatures can fuse together into one, and in the course of doing so they change from a form with two complete “mouth parts” to a form with only a single mouth part. That by itself is not so strange, but during this conversion process a configuration with three mouth parts occasionally appears. Trainor’s mathematical model of the morphogenetic field explains “why 3 is between 2 and 1,” making detailed predictions about the location and orientation of the mouth parts. Trainor has also used biological fields to gain insight into regeneration in the salamander, a creature with a spectacular ability to regrow its legs and tail. This research shows that fields can describe and even predict biological patterns, making them an exciting part of the new biology.

One of the most prominent advocates of the morphogenetic field concept has been the maverick British biologist Rupert Sheldrake. His popular book *A New Science of Life* generated a lively debate when it was published in 1981. An editorial in the British science journal *Nature* was titled “A Book for Burning?,” illustrating the radical character of his ideas. He has even discussed his ideas before a United States Congressional Clearinghouse on the Future. *A New Science of Life* and his subsequent book *The Presence of the Past* present an elaborate vision of the morphogenetic field concept. Sheldrake’s organizing
fields shape living and non-living forms ranging from protein structure to the shape of individual organisms as well as behavioral patterns, instinct, and learning. They also evolve and influence each other through a kind of resonance, a fundamental connection across space and time.

This “morphic” resonance, as Sheldrake calls it, is an important feature of his morphogenetic field model. An organism’s field is connected across space and time to those fields that bear the most similarity and the more often a pattern occurs in nature, the more likely it will occur in the future. Because of morphic resonance between similar patterns of behavior and learning, as rats in one location learn to negotiate a maze, rats in another locality will then find it easier to negotiate the same maze.34

Biological field research is still in its early stages, and Sheldrake’s effort is more speculation than science. Yet the idea of organizing fields associated with living systems has interesting implications for health and healing. Can one person help heal another with prayer because of the morphic resonance between their fields? Can healing take place, even without actual physical contact, through the interaction of the human bio-field?

Electricity and Magnetism in the New Biology

Now there is evidence that it is the informational aspect of biological systems that characterizes the essential view of life. And this is less reflected by biochemical findings but rather by a level beyond the domain of chemical reactivity, namely that of electromagnetic fields. Within the framework of electromagnetic bioinformation a basic explanation of biological processes, e.g., communication, health, aging, cancer, biological rhythms, regulation, and biochemical control may be found and not just their description.

—K. H. Ü, Electromagnetic Bioinformation35

Since the discovery of electricity and magnetism, scientists have wondered what role, if any, they play in the organization of living systems. Italian physiologist Luigi Galvani (1737–1798), for example, spent many years studying “animal electricity,” an electrical phenomena associated with the injury of tissue. Galvani was convinced that the biological electricity he observed was the long sought after vital force. But as the enthusiasm for vitalism waned, the idea that electricity might be relevant to biology fell out of favor. Even the electrical characteristics of the nerve signal were shown to result from the movement of charged ions (like sodium and potassium) across the nerve membrane.

In more modern times, the spectacular successes of chemical-based biology led to a pervasive view that any electromagnetic phenomena associated with living things were secondary to chemical events. Yet some scientists remained convinced of an important relationship between electromagnetism and biology. The Belgian scientist Georges Lakhovsky, for example, wrote The Secret of Life in the 1920s, in which he claimed that living things emit and receive electromagnetic radiation and that health was related to the oscillatory equilibrium of living cells.

Electromagnetic technologies improved as the twentieth century progressed and more scientists, especially in the former Soviet Union, became interested in bioelectromagnetic research. The Russian scientist A. S. Presman discussed the results of hundreds of experiments in his 1968 book Electromagnetic Fields and Life. Presman concluded that electromagnetic fields were important biologically. Organisms, he argued, could use fields for gaining information about their environment, for integration and regulation, or for communication with other organisms. Since the publication of Presman’s book, more has been learned about all three of these bioelectromagnetic phenomena.

Organisms ranging from bacteria and bees to salmon, pigeons, and dolphins use the earth’s magnetic field for navigation, a feat which they seem to accomplish with the help of a built-in magnetic “compass.” Joseph Kirschvink, a scientist at the California Institute of Technology, explains the interaction between magnetic fields and
organisms in terms of a special cellular structure containing magnetic material of biological origin. Kirschvink's group even announced in 1992 the discovery of magnetic particles in the human brain.

W. Ross Adey, another California-based scientist, has studied the role played by electromagnetic fields in cellular communication, describing cellular electromagnetic signals as the “whispering” of cells. Adey describes bioelectromagnetics as one of the most significant new scientific frontiers of this century and is quick to criticize other scientists for dismissing the biological importance of electromagnetic fields. He stresses that progress in understanding bioelectromagnetic regulation and communication will come from work on the highly cooperative nature of living systems using nonlinear, non-equilibrium concepts.

The German scientist F. A. Popp has explored the electromagnetic waves given off by living organisms—called biophotons by Popp. The conventional view holds that these electromagnetic waves are by-products of chemical reactions and of no biological importance. Popp, in contrast, feels that biophotons act as regulatory signals, controlling phenomena ranging from cell differentiation and growth to the activity of enzymes and the immune system.

Robert Becker, an American orthopedic surgeon interested in healing processes, picked up where Galvani (and others) had left off in their work on the relationship of electrical currents to injury. Beginning in the 1960s, Becker explored, in several decades of brilliant experimental work, the basic processes associated with healing and regeneration. He (re)discovered the electrical current generated in injured tissue and went on to describe a “second” nervous system, more primitive but more fundamental than the nerve impulse system. Becker found that very weak electrical currents could affect a cell’s DNA, stimulating a phenomenon called dedifferentiation. (All the cells in the body have the same genetic information. Some genes are turned on and others off to produce particular kinds of cells—“specialized” cells like skin cells or liver cells. This is called differentiation. In dedifferentiation, specialized cells revert back to their more primitive, undifferentiated state. Interestingly, Becker’s work on dedifferentiation foreshadowed the recent success in cloning, a controversial biotechnology which made use of dedifferentiation stimulated in part by electricity.)

Bioelectromagnetics, despite a long history, has only recently coalesced into an important field of study, one that will play a prominent role in the new biology. As suggested by the preliminary work of pioneering scientists like Becker, Popp, and Adey, electromagnetic phenomena are an important part of the regulatory and communication systems in organisms.36

The Medicine of Complexity

From the point of view of the new biology, each human is a unique and complex system with a network of internal and external interactions. Each organ system affects every other organ system. Mind and body are mutually interacting facets of a dynamic whole linked with the social and physical environments, themselves complex systems at another level. Disease—a disruption in the mind-body system—can at times be described and successfully treated in terms of narrowly defined causes and specific cures. This model has been particularly successful with infectious disease, allowing disease-causing microbes to be effectively treated with “magic bullet” antibiotics. This approach has proven less valuable for chronic diseases such as cancer and coronary heart disease, two of the plagues of modern industrial civilization.

Conventional medicine has searched for the cause of coronary heart disease by examining the biomolecular processes involved, and has centered much of its attention on the cholesterol molecule. A number of drugs have been developed to lower the cholesterol level in the blood, and these drugs, together with techniques like bypass surgery, have been used with limited success to treat the disease.

As a medical student in Houston, Texas, Dean Ornish became discouraged by what he saw as “the limitations of technological approaches that literally and figuratively bypassed the underlying causes of the problem.” Instead, he looked for more fundamental
causes of heart disease and found research suggesting many factors were involved. A high fat and high cholesterol diet could increase blood cholesterol, something that was widely implicated in the development of heart disease, and stress, smoking, and (lack of) exercise were other clearly important factors. It was surprising to Ornish that no one had studied whether a program combining potentially positive lifestyle changes could affect the processes underlying heart disease. 37

Ornish developed a comprehensive program combining dietary change (see Chapter 8), stress management, exercise, smoking cessation, and group support. He borrowed many elements of his program from ancient Indian yoga, incorporating yoga-based techniques of relaxation, visualization, and meditation as used by modern researchers like Herbert Benson, Jon Kabat-Zinn, and Carl Simonton. Program participants stretched, meditated, and ate their way to health.

Ornish's results were very impressive. Over 80 percent of program participants showed an actual reversal of their coronary artery blockage and the more rigorously they followed the program the greater the improvement. Data suggested that all parts of the program are important, but according to Ornish each participant might benefit more from some parts than others. Stress management might be very important for someone with a high-stress life; dietary change might be crucial for someone else with a history of poor eating habits.

Ornish emphasizes the importance of taking a multi-factorial perspective. Cholesterol is an important part of the heart disease puzzle, but by itself it does not form the whole picture. The same thing can be said about blood pressure, smoking, and exercise. Ornish was surprised his research demonstrated little link between change in blood cholesterol level and improvement in arterial blockage, but explains that cholesterol is simply not the critical factor because other factors—such as stress, poor social support, and negative emotions—also play a significant part in the development of coronary heart disease. “The farther back in the causal chain of events we can address a problem,” says Ornish, “the more powerful the healing can be.” 38

Ornish is not averse to conventional treatments and makes use of appropriate drugs and lifesaving measures when they are needed for the short term. Yet over the long term the goal is to activate the innate healing power by correcting the myriad factors that disrupt the system in the first place. Side effects from this approach are positive ones: participants lose weight, experience a decrease in blood pressure, and have more energy. Such success with a multi-factor model of cause and cure in dealing with an important chronic disease demonstrates that a “systems approach” can indeed be an effective means of medical therapy. In this interesting example of the new medicine, conventional treatments and the full power of science are combined with ancient insights into health and healing to create a comprehensive therapeutic regimen that is cost effective and empowering rather than invasive.

Like heart disease, cancer has also proven challenging. In the traditional model, cancer is an entity separate from the person with a specific cause and a specific cure. Despite the enormous amount of money spent to study cancer from this perspective, no specific cause has yet been found nor is there a magic bullet on the horizon. Like heart disease, many factors seem to be involved in the disease and the development of magic bullet cures is hampered by the difficulty of killing the cancer without harming the patient.

In a pessimistic 1997 study of cancer death rates, published in the New England Journal of Medicine, University of Chicago researcher John Bailar concluded that little progress has been made in the treatment of the disease. “In 1986, we concluded that some 35 years of intense effort focused largely on improving treatment must be judged a qualified failure,” claimed Bailar, adding “Now, with 12 more years of data and experience, we see little reason to change that conclusion.” 39

One group of researchers is working to forge a completely new approach to the cancer problem based on systems thinking. The team, led by Harvey Schipper at the University of Manitoba, argues
it is time to throw out the old cancer model—a model that has been used for over one hundred years and one that has clearly reached its limits—and begin looking at the problem in a new way. Cancer is not composed of cells with any great difference from normal cells and trying to kill the cancer cells can even make the problem worse since invasive therapies depress the immune system.

Cancer is really a problem of cellular regulation and communication involving the interactions of a complex system. Cancer cells are normal cells that are not doing what they should. The problem is not the cancer itself but the distorted channels of regulation and communication. Rather than trying to kill cancer cells, the solution is to restore the natural regulatory environment so that the pathological growth processes that characterize cancer are brought back under normal control. This means a wider focus on both the cancer and its surrounding environment—what the researchers describe as “a complex, multi-component non-linear system.” Rather than using cancer-killing drugs and radiation, this new approach is based on the use of agents designed to “reregulate” in the effort to reverse or at least stabilize the pathological, unregulated processes that characterize the illness.

Critics of organicism have often argued that it is nothing more than a different way of talking about complex physical and chemical machines. Organicism might be philosophically appealing, but it does not lead to anything distinct from the mechanism model. Yet as Ornish’s work on heart disease shows, thinking about the complex interactions of humans themselves, rather than just the molecules, can lead to success in the treatment of disease. And Shipper and his colleagues make it clear that the real breakthrough in cancer research might simply be thinking about the problem in a new way: “We now have data that suggest a subtler paradigm based on cellular and intercellular communication and biologic control. The upshot will be an approach to cancer that is distinctly different from that to microbial and viral diseases, in which we recognize an intruder and kill it. In

the case of cancer, we may come to recognize aberrancy in our normal self and reassert control.”

Technological medicine is a mixture of miracle and muddle, promise and peril. Within this contradiction it is possible to celebrate the accomplishments of Western medicine while acknowledging limitations that both engender the evolution of its theories and therapies and leave room for complementary approaches. As a new biology and medicine eclipses the old, progress will come from looking at problems in fresh ways while building on the accomplishments of the past—accomplishments of both technological medicine and other ancient and evolving traditions.