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Introduction and Overview

But if a thing is a product of nature . . . then this second *requisite is involved, namely, that the parts of the thing combine of themselves into the unity of the whole by being* reciprocally cause and effect *of their form.*

—Immanuel Kant (1790/1952, p. 556; second emphasis added)

As we enter the third millennium, we can look back at a century of unprecedented scientific and technological progress. We have learned to split and fuse atoms and in so doing convert minuscule amounts of matter into huge amounts of energy. We have walked on the moon and sent space probes to distant planets. We have discovered nature's clever trick for storing biological information in the double helix of DNA molecules and learned how to manipulate the genes of living organisms for our own agricultural, industrial, and medical purposes. Advances in chemistry and material science have provided new substances such as plastics, synthetic fibers, and metal alloys that have given us unbreakable shampoo bottles, inexpensive panty hose, jumbo jets, and superconducting materials. Progress in electrical engineering and computer science goes on at an accelerating pace so that the computer and software bought just a year or two ago is obsolete. Medical research has lengthened human life and improved its quality for those fortunate individuals having the means to take advantage of new drugs, equipment, and surgical techniques.

These accomplishments in physics, biology, chemistry, engineering, and medicine contrast sharply with our still limited scientific knowledge of the human mind and human behavior, the domain of those disciplines usually referred to as social, psychological, behavioral, and cognitive sciences. The field of psychology is fragmented into scores of different schools and theories, with those in one camp either ignorant of or openly hostile to the researchers, methodologies, theories, and findings of other camps. The very existence of the discipline of sociology is currently being threatened as it continues to lose turf to psychology, biology, and anthropology (Ellis 1966). And although expectations were great in the 1970s as psychologists, linguists, philosophers, anthropologists, neuroscientists, and computer scientists joined forces to create the new field of cognitive science, the ambitious goal of understanding how the human brain gives rise to intelligent behavior, thought, and consciousness remains largely unfulfilled.

The lack of clear progress in applied behavioral science becomes particularly evident when we examine the behavior-based ills of today's societies. In the United States, arguably the world's richest and most technologically advanced country, prisons are overflowing with people convicted of murder, rape, armed robbery, domestic violence, and drug dealing. Metal detectors are now commonly used to keep deadly weapons out of urban public schools where teachers are often more concerned with survival than with teaching. Throughout the world, ethnic, racial, and religious tensions regularly explode in horrifying acts of violence, leaving widespread suffering and misery in their wake. The AIDS virus, whose spread depends on human behaviors resulting in the transfer of bodily fluids from one individual to another, continues its deadly worldwide spread. And the increasing rate of global population growth poses a menacing danger to the earth's resources and continued survival of many species, including our own. So while stunning advances have been made in many fields of science and technology, we are still unable to solve the many serious social problems stemming from certain types of human behavior.

It is perhaps not surprising that our attempts to understand ourselves and solve these problems should be met with very slow progress if not outright failure. The fact that we humans can formulate questions concerning the things we do and feel, including why and how we do them and feel as we do, reveals a degree of intelligence that is not found in other species and may paradoxically lie beyond our ability to comprehend fully. The fact that the human mind is affected by studying itself, as pointed out by eighteenth-century philosopher Immanuel Kant, provides an additional difficulty that does not arise when we study physical phenomena or other species.

But there is another—and fortunately, correctable—reason for the slow progress of human behavioral and cognitive sciences. Simply put, certain essential findings from biology concerning the origin, evolution, and functioning of *all* forms of life have been largely ignored. Instead, for reasons to be explored in the following chapters, behavioral scientists have with few exceptions followed Sir Isaac Newton in applying the findings and methods of seventeenth-century classical physics to the study of life, disregarding the findings of two revolutionary nineteenth-century biological scientists—French physiologist Claude Bernard on the self-regulating nature of living organisms, and English naturalist Charles Darwin on the origin and evolution of species.

Newton's Legacy

Few individuals had as much impact on science and its continued development as Sir Isaac Newton (1643–1727). Among his many scientific achievements, he demonstrated that the movements of all bodies, whether on earth or in space, could be understood by his now famous three laws of motion.

Newton's first law is the law of inertia or momentum, stating that a body at rest will remain at rest and a body in motion will maintain its speed and direction unless acted upon by an external force. His second law, $a = F/m$, gives the acceleration that results from application of a force (F) on a body of a given mass (m). Newton's third law states that for every force (action) there is an equal and opposite force (reaction).

It is Newton's second law (of which the first is a special case) that is the most important, as it defines mathematically the effect that a force will have on a body, whether it be to cause a stationary object to move or a moving object to stop or change its speed or direction. And although Newton believed that the hand of God was required to stabilize the motion of the planets, further refinements of his theory, most notably those of Pierre-Simon Laplace (1749–1827), showed that his laws were sufficient to account for all observed motions of the planets (the anomaly of Mercury's orbit, which could not be explained without relativity theory, was unknown during Laplace's time).

Newton's second law remains a classic example of a *one-way cause-effect* theory that can be expressed as C —> E. The force applied to the object is the cause and the change in motion of the object is the effect. It is a one-way theory since while force determines acceleration, acceleration has no influence on force. For example, imagine a spaceship coasting at a constant speed between Earth and Mars. By igniting the engines and thereby applying a force to the rear of the vessel, the spaceship will accelerate at a rate determined by the amount of thrust provided by the engines and its own mass. In contrast, force provided by the engines is independent of the spaceship's mass, velocity, or acceleration. Thus we have a one-way cause-effect model in which force is the *independent variable* and acceleration is the *dependent variable*.

The laws that Newton discovered and formulated had a profound effect on science. This was not because they explained everything about the movements of inanimate bodies (for example, Newton didn't even attempt to formulate an explanation for how the gravity of one body could influence the movement of a distant body), but rather because they allowed for *prediction* and *control* of moving objects. Newtonian principles are still used to predict where the international space station will be at a given time and to control the trajectory of the space shuttle as it ferries supplies and passengers from Earth to the station.

It therefore seemed that a similar perspective could be applied to the behavior of living bodies. That is, if inanimate bodies react to forces in predictable ways, we should be able to predict (and consequently control) the behavior of living organisms once we uncover the cause-effect principles that apply to that behavior.

This is essentially what the field of psychology has been trying to do for the last hundred years or so. But although it could be argued that we have continued to make impressive gains since the time of Newton in predicting and controlling the behavior of inanimate objects and systems, we have made much less progress in predicting and controlling animate behavior, and little real progress in predicting and controlling human behavior where desires, goals, intentions, and purposes play such an important role.

The one-way cause-effect model that became Newton's legacy was also unable to provide scientific explanations for the origin and evolution of life forms and the physiological processes and purposeful behavior of living organisms. What was the cause that resulted in the emergence and evolution of living organisms? How is it that animals are able to maintain relatively constant conditions inside their bodies despite many disturbing environmental forces? How are organisms able to act purposefully in spite of these disturbing forces to achieve outcomes favorable to their survival and reproduction? To answer these questions, a different perspective on causality is required.

Bernard's Internal Environment

One nineteenth-century biologist whose work challenged one-way cause-effect models was Claude Bernard (1813–1878). As we will see in chapter 4, Bernard made many important discoveries concerning the internal processes of living organisms. But his most important contribution was a conceptual one in his recognition that these processes serve to maintain a relatively constant internal environment in spite of disturbing forces, and this regulation or control of the *milieu intérieur* is an essential condition for all forms of life. In other words, a necessary requirement for life is the achievement of a degree of independence or autonomy from the external environment so that the normal cause-effect relationships found in non-living systems no longer hold. A glass of warm water placed in a refrigerator will quickly chill to the temperature of its new environment. The cooler temperature is the cause and the cooled water the effect. But placing a bird in a cooler environment will have little or no effect on its body temperature, at least not while it remains alive. This phenomenon of the control of internal body temperature initially appears to violate the usual laws of physics in which external forces or causes have predictable effects.

Similarly, living organisms are able to control aspects of their external environments. A newly hatched gosling will stay in close proximity to its mother, scurrying around obstacles and avoiding its nestmates to do so. A mature salmon will fight strong currents and even jump up waterfalls in its drive to return to the stream in which it was hatched, to mate before it dies. And humans engage in an amazing variety of behaviors to provide food, comfort, and security for themselves and their families in an often uncaring and hostile world. What we see in these and all instances of purposeful behavior are not reactions to environmental forces, but rather actions that *compensate* for environmental forces to achieve the organism's goal, using behavior that appears outside the scope of Newton's laws of motion.

Bernard himself did not propose a formal alternative to the one-way cause-effect perspective, but those who continued this line of work on the self-regulating nature of living organisms eventually developed models incorporating what can be described as *circular causality* in which causes are also effects and effects are also causes. Also referred to as *closed-loop*, *cybernetic*, or *control* systems, models incorporating circular causality provide useful working models for both internal physiological processes and overt behavior of living organisms. In short, understanding circular causality is key to understanding how the behavior of living organisms, unlike that of nonliving entities, can be purposeful and goal directed whereas the underlying processes are physical and naturalistic.

Darwin's Selectionism

Bernard was interested in the internal mechanisms of living organisms, but Charles Robert Darwin (1809–1882) was most interested in why and how organisms emerged and evolved into the countless species that once lived or still do on our planet. And although Newton certainly had an influence on him (Depew & Weber 1995), Darwin had to break free of the one-way cause-effect model to provide a scientific theory of evolution. According to his theory of natural selection, the offspring of organisms spontaneously vary in form and behavior, resembling their progenitors, but not always exactly (never exactly for sexually reproducing species). By sheer luck, certain organisms are more successful in surviving and reproducing than their contemporaries, and these variations are inherited by *their* offspring, who also vary and enjoy differential survival and reproductive success, and so on. As Darwin theorized, and as understood by today's biologists, the environment does not cause these variations, but only winnows out less fit from better fit organisms.

Consider a tree frog whose back looks astonishingly like the bark of the tree on which it spends so much of its time. This remarkable camouflage is an adaptation that hides the frog from those who would have it for a meal. A one-way cause-effect analysis would attempt to explain this phenomenon as somehow transmitted from the environment (the tree's bark) to the organism (the frog's back), much as one can account for transmission of information from environment to film in the making of a photograph. But while the frog's back may appear to be analogous to a photograph of the tree's bark, the mechanism by which it evolved is quite unlike the one-way cause-effect process of taking a photograph. To take a photo, light reflecting from the object being photographed enters the camera through its lens and strikes the film, causing chemical changes in the film. The frog's camouflage arose only after many generations of frogs with varying backs enjoying differing rates of survival and reproduction. The environment did not cause these variations. Rather, these variations were spontaneously and randomly (and, of course, unknowingly) created by the frogs themselves, with the environment serving only as a type of filter selecting variations best suited to camouflage and eliminating the rest.

In a system operating according to Newton's second law, forces may interact in complex ways, but nothing truly new or creative emerges. Set the balls of a frictionless billiard table in motion and they will continue to bounce and collide, but that is all they will ever do. In contrast, in a system operating according to Darwin's principles of cumulative variation and selection, new complex and adapted entities—such as bacteria, bananas, beetles, baboons, and babies—can arise that are utterly unpredictable by Newton's or anyone else's one-way laws of cause and effect. One could argue that the physical processes underlying biological evolution are still Newtonian at their core. This may well be the case, but the fact remains that a one-way cause-effect model (such as that which explains how a photograph is made or where a thrown object will land) cannot account for the emergence of new, complex, and adapted forms (such as the back of the tree frog).

Circular causality is also an important part of evolution, acting in ways that we have only recently begun to understand and model. Since selection pressures are brought about by competing organisms of both the same and different species, selection influences evolution at the same time that evolution influences selection, each being both cause and effect of the other. For example, because cheetahs hunt and feed on gazelles, there is selection pressure on gazelles for running speed. But as gazelles evolve to be faster, this puts selection pressure back on the cheetahs for more speed, and so on. Unlike the circular processes studied by Bernard in which internal physiological conditions are tightly controlled, the runaway nature of evolutionary "arms races" tends to push organisms to extremes, as in California redwoods growing to over 300 feet in their quest to reach sunlight beyond the shadows of their giant neighbors.

The explanatory power of Darwin's discovery is not limited to biological evolution. As described in my previous book, *Without Miracles* (Cziko 1995), the process of variation and selection underlies the emergence of all sorts of complex, adapted entities. These entities include antibodies, brains, languages, computer programs, drugs, and other aspects of culture and technology, as well as the primary concern of this book—the behavior of living organisms. But, as we will also see, Darwin's more complex selectionist causality is not widely embraced by behavioral scientists, who still overwhelmingly prefer one-way cause-effect models consisting of independent variables (environmental causes) impinging on dependent ones (behavioral effects).

The central argument of this book is that when the revolutionary biological principles discovered by Bernard and Darwin are considered, updated with the best of our scientific knowledge, and applied to animal and human behavior, certain long-standing theoretical and practical problems in behavioral science disappear and new methods and topics for research in mind and behavior present themselves.

I recognize that this notion will not be an easy sell since it flies in the face of over 100 years of psychological theory and research based on one-way cause-effect theories. Also, the lessons of Bernard and Darwin are old news to biologists, at least with respect to the origin, evolution, and basic life functions of living organisms. But the case nonetheless can and must be made that further progress in behavioral and cognitive sciences can be achieved only by moving away from Newton and toward Bernard and Darwin.

This basic thesis is developed in the following parts and chapters. Part I presents philosophical (chapter 2) and psychological (chapter 3) overviews of past and current theories of behavior, and recounts how the progression from yesterday's psychic and spiritual to today's naturalistic and materialist[1] theories has thrown the purposeful baby out with the psychic, spiritualistic bath water.

The three chapters of part II show how a purely naturalistic and materialist theory of purposeful behavior is indeed possible and is being developed and applied by a small but growing group of behavioral scientists and practitioners. This theory, known as perceptual control theory, has its roots in the insights of Bernard (chapter 4) and the work of twentieth-century control systems engineers and cyberneticians (chapter 5), and was molded into its present form by William T. Powers and his associates (chapter 6). Chapter 6 provides both demonstrations and working models of animal and human behavior based on perceptual control theory. These demonstrations and simulations (many available on the World Wide Web at *www.uiuc.edu/ph/www/g-cziko/twd*) show and explain living organisms as purposeful systems demonstrating circular causality that behave to control their perceptions of the environment. They offer a new perspective for understanding what, why, and how living things, including humans, do what they do.

Part III applies Darwinian evolution to understanding animal and human behavior as well as to the human thought processes that underlie human behavior. Chapter 7 considers animal and chapter 8 human behavior from the evolutionary perspective provided by Darwin in an attempt to answer the ultimate, "big" question of why we and our animal cousins do what we do. Chapter 9 relates how the process of cumulative variation and selection that underlies biological evolution has been extended to provide new understandings of the maturation and functioning of the human organism, in particular, the human brain. On this view of the brain as a Darwinian machine operating under selectionist causality, variation and selection of organisms is replaced by variation and selection of synaptic connections, mental processes, and thoughts, giving rise to our uniquely human abilities in problem solving, imagination, and creativity, and indeed to consciousness itself.

Finally, part IV attempts to integrate the biologically inspired perspective of the three preceding parts with current theoretical and applied work in behavioral science. Chapter 10 shows how, by combining Bernard's and Darwin's lessons, we can understand how certain evolutionary processes, most notably those that occur within organisms, can be directed and purposeful, and provide the human brain with powerful mechanisms for lifelong adaptation to new environments and solutions to new problems.

Chapter 11 focuses on the problems of current psychological theory, showing that outdated one-way, push-pull theories of how the environment causes animate behavior are not only still widely held among behavioral and cognitive scientists but that their stubborn persistence is a major factor in the slow progress of these fields. Chapter 12 discusses theoretical advantages and practical uses of a theory of behavior that moves away from one-way cause-effect models to selectionist and circular models and to appreciation of the creative and self-regulating properties of life first recognized by Bernard and Darwin. (Readers wanting to see now a summary of the book's main conclusions can turn to the last section of chapter 12, "Toward a Unified Theory of Behavior.")

This book was written for both general readers interested in understanding what and how we (and animals) do what we do and why we do it, as well as for professional behavioral scientists, both theoretical and applied. I suspect that the main theses may actually be easier to grasp by readers with little or no formal study of behavioral, cognitive, and social sciences who are therefore "uncontaminated" by the orthodox perspective of viewing animate behavior as an organism's output (effect) determined by environmental input (cause). Behavioral scientists may well have a harder time suspending what they already believe about behavior and psychological theory, but once they do they may be better able to appreciate the full significance of Bernard's and Darwin's insights for understanding animate behavior and grasp the implications of demonstrations and computer simulations introduced in chapter 6.

My principal hope for this book is that it will help bring to completion two long overdue revolutions in behavioral and cognitive sciences that are already underway but still quite limited in their impact. Another hope is that the book will help interested readers see more clearly certain essential features of life; namely, how and why living organisms behave as they do. Such knowledge is of value not only for its own sake, but it also has important practical applications as we enter the twenty-first century and confront the behavioral challenges and problems of the third millennium.