The Things We Do

USING THE LESSONS OF BERNARD AND DARWIN TO UNDERSTAND THE WHAT, HOW, AND WHY OF OUR BEHAVIOR

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To William T. Powers,
for having led me to Bernard's lesson,
and to the memory of Donald T. Campbell,
who introduced me to Darwin's

Preface

For as long as I can remember I have been fascinated by the behavior of living things. Although I grew up within the urban confines of New York, that did not prevent me from acquiring a variety of animal specimens for study, including newts, snakes, lizards, parakeets, gerbils, rabbits, and various tropical fish. My interest in living behavior led me to study psychology as an undergraduate in the early 1970s at Queens College of the City University of New York, and then to graduate study in experimental psychology in the mid and late 1970s at McGill University in Montreal.

As an undergraduate at Queens, I was much impressed by the theories of B. F. Skinner and saw in his radical behaviorism what I considered to be a truly scientific and grand theory of behavior; simply put, that animals and people alike do what they are rewarded for, with no need to be concerned about their desires, wants, or purposes. But my studies in language acquisition and bilingualism at McGill with Wallace Lambert and G. Richard Tucker, together with the influence of Donald Hebb (whose last year at McGill coincided with my first), led me to cognitive theories that, in contrast to Skinner's behaviorism, focused on the role of mental and neural processes in determining behavior.

Impressive developments in the so-called cognitive revolution accompanied my tenure at the University of Illinois at Urbana-Champaign during the 1980s and 1990s. But in spite of these developments, I sensed two important gaps in psychology's account of animal and human behavior. First, I felt that psychological theory provided no convincing explanation for the obvious purposefulness of behavior. Although cognitive psychology emphasized the role of internal mental processes in explaining behavior, these processes were seen as transforming input (stimuli, sensations, perceptions) into output (responses, behavior). But we observe that behavior is purposeful when actions are varied to achieve a certain outcome, and I could not see how any input-output or cause-effect model, behaviorist or cognitive, could account for this.

Second, the psychological theories I knew provided no explanation for the goals and preferences that animals and humans have. Behaviorism tries to explain animal and human actions as resulting from reinforcement in the form of rewards (for example, food for a hungry rat, money for a person). Cognitive psychology uses more complex theories of motivation. But why are things such as food, money, and sex rewarding or motivating in the first place?

These basic questions about behavior remained unanswered in my mind when, in 1989, I met two fascinating and very approachable men: the late Donald T. Campbell and William T. Powers. Don Campbell introduced me to Charles Darwin (actually, to Darwin's theory of evolution and its implications for psychology) and to his former associate and co-teacher Powers. Bill Powers in turn led me to a fascinating theory of purposeful behavior having its roots in the work of Claude Bernard.

It would take several more years before all the pieces started coming together, during which time my first book, *Without Miracles*, appeared. But by taking heed of the discoveries of two giants of biology and modern developments of their theories, I began to find answers to my very basic questions about animal and human behavior.

Although I consider myself extremely fortunate to have met Campbell and Powers when I did, I can't help feeling somewhat cheated by my undergraduate and graduate education in psychology, which completely ignored both Bernard and Darwin, whose revolutionary contributions to the life sciences create an essential foundation for understanding animal and human behavior. Consequently, the purpose of this book is to introduce the lessons of Bernard and Darwin to those interested in understanding the *what*, *how*, and *why* of animal and human behavior.

Campbell, Powers, Bernard, and Darwin are not the only individuals who had an important influence on the evolution of this book. Richard Marken and Hugh Petrie provided comments that greatly improved the book, as did several anonymous reviewers of the manuscript. Greg

Williams not only provided a thorough and detailed list of insightful and helpful comments, but also served as a rapid-turnaround copy editor and, with his wife Pat (the other half of the Gravel Switch Typesetting Team), transformed the manuscript into the formatted print and illustrations you now hold in your hands. I thank Michael Rutter of the MIT Press for his editorial assistance and for his company during a great day of mountain biking near Tucson in June 1997. The red pencil of Sarah Jeffries did wonders to transform my often wordy, loquacious, redundant, superfluous writing style into something more closely resembling readable modern English prose (this is the one sentence she didn't get to see). Fellow music lover Rich Palmer provided an invaluable service by somehow being able to "undue" the hundred or so overdue books I had in my possession from the vast stores of the University of Illinois library. And I must also recognize the stimulating environment, freedom, and support that the University of Illinois at Urbana-Champaign and its Department of Educational Psychology have provided over the last twenty years.

Last but certainly not least, I am truly appreciative of the love, support, and tolerance of my wife, Carol, who once again had to share me for an extended period with the demanding mistress that a book-in-progress becomes. I promised her it was just a temporary fling. But I am sure she will understand that some habits are hard to break.

1

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.

I

Theories of Behavior: From Psychic and Purposeful to Materialist and Purposeless

2

Philosophical Perspectives on Behavior: From Animism to Materialism

I notice something and seek a reason for it: . . . I seek an intention in it, and above all someone who has intentions, a subject, a doer: every event a deed—formerly one saw intentions in all events, this is our oldest habit. Do animals also possess it?

—Friedrich Nietzsche (1901/1967)

As we observe the world around us, our attention is drawn to things that move and change. The sun makes its journey from east to west across the sky each day, and by night the moon, stars, planets, and occasional comets and meteors trace their luminous paths across the heavens. Drops of rain fall to the earth, collecting into rivulets and then streams that join together to form rivers that rush or leisurely meander to a sea that never seems to tire of sending waves crashing against the shore. Over many years, a fragile seedling grows into a towering oak and a helpless human infant somehow manages to transform itself into a musician, Olympic athlete, airline pilot, or neurosurgeon. Birds circle overhead while squirrels scamper among the branches of trees, and bees and butterflies busily collect nectar and pollen from flowers that open their brightly colored petals to the warm sun. In our cities we see a constant blur of movement as streams of people move along its sidewalks and vehicles clog its streets.

We humans are both affected by and constitute an important part of this movement and change as we go about our daily activities. So it is not surprising that we should be interested in the what, how, and why of the behavior of both nonliving objects and living organisms, including ourselves. In our attempts to understand, three major types of theories of motion and change have been developed. The first type appeals to immaterial, nonphysical explanations, including what may be called psychic, animist, supernatural, spiritual, or mystical entities and forces. The second type rejects such nonphysical explanations and sees all motion and change—whether of objects, plants, animals, or humans—as the result of processes involving only matter, energy, and physical laws that govern them and their interactions. The third type takes a dualist middle ground, combining both physical and spiritual entities and processes to account for all forms of behavior.

In this chapter we examine these three types of theories from a philosophical perspective, saving a psychological perspective for the next chapter. But before doing so, I have to provide some definitions.

Although the words *behave* and *behavior* are often meant to refer to actions of living organisms, they are also commonly used to refer to changes and movements that nonliving objects undergo. This more inclusive meaning is consistent with the definition of *behaviour* provided by the *Oxford English Dictionary*: "The manner in which a thing acts under specified conditions or circumstances, or in relation to other things." So though we speak of the behavior of a dog or child, we also consider how one chemical behaves in the presence of another and how the stock market behaved yesterday. Indeed, a better understanding of the differences underlying the behavior of inanimate objects on the one hand and living organisms on the other is a major goal of this book, and so I will use the unqualified term behavior and its derivatives to refer to either living or nonliving entities. When more specificity is required, the terms *inanimate behavior* and *animate behavior* will be used, recognizing that the discipline that refers to itself as *behavioral science* deals only with animate behavior (with physics usually restricting itself to the study of nonliving objects and systems; that is, inanimate behavior). To avoid the necessity of the adjective *nonhuman* when referring to animals other than *Homo sapiens*, the word *animal* is used, with its more usual meaning that excludes our own species (although, of course, our species is technically just another animal, if a rather special and peculiar one).

Mind Over Matter: Psychic Philosophies of Behavior

That humans possess self-awareness, consciousness, intentions, and desires that are not easily explained in terms of physical processes is a major motivator for immaterial theories of behavior, theories that have been extended by some to include all animals and plants and even inanimate objects. To explain motion and change, these theories appeal to nonphysical entities and forces that remain beyond the domain of physical sciences as we know them.

Such theories of behavior are often referred to as *psychic* or *animist*, *psyche* being the Greek word for "mind" or "soul" that also forms the root of our modern terms *psychology* and *psychiatry*; *anima* is its Latin equivalent. Those theories that go the entire distance in using psychic explanations to account for all behavior involving humans, animals, plants, and objects are referred to as *panpsychic*. Panpsychic theories do not necessarily deny the existence of a physical world and mechanical processes, but see materialist explanations as insufficient to explain any of the phenomena occurring in the universe.

Animism

It has been stated that animist explanations of behavior characterized humankind's earliest attempts to make sense out of the world, a world containing other human beings, animals, and plants, as well as physical forces emanating from fire, wind, water, and the earth itself. At some point in the evolution of our species, our ancestors developed awareness of their own existence and desires as well as the strange and powerful force of life present in all living animals and humans, but obviously absent in the bodies of dead animals and humans. Therefore they developed belief in a soul or spirit that gave life to bodies and also accounted for human consciousness, thought, desires, and behavior. The phenomenon of dreams, in which one has experiences that seem detached from the physical location of one's body, would also suggest a life-giving spirit that normally inhabits the body but can also leave it. Belief in an immaterial, life-giving soul is consistent with belief in a spiritual life after death of the physical body, a creed that is characteristic of religions throughout the world.

But human imagination is such that it has also developed a belief in souls residing in apparently nonliving objects. In his *Natural History of Religion*, Scottish philosopher David Hume (1711–1776) attempted to make sense of the belief in the souls of objects (1757; quoted in Tylor 1871/1958, p. 61):

> There is an universal tendency among mankind to conceive all beings like themselves, and to transfer to every object those qualities with which they are familiarly acquainted, and of which they are intimately conscious. . . . Nor is it long before we ascribe to them thought and reason, and passion and sometimes even the limbs and figures of men, in order to bring them nearer to a resemblance with ourselves.

Such animistic interpretations of the behavior of objects and physical forces allowed (and still allow) prescientific peoples to make better sense of their surroundings. Ascribing motives and intentions to other people and animals is the first step in this process. If I eat when hungry, flee when fearful, fight when angry, perform nurturing acts when loving, hunt to eat, and find or make shelter to stay warm and dry, it would not require much imagination to suppose that other humans and animals perform similar acts for similar reasons and purposes. It is but one more step to reason that kindness of the air and sun results in favorable weather and good crops while anger and jealousy of the spirits of water, earth, and fire bring floods, droughts, volcanic eruptions, landslides, earthquakes, wildfires, and other natural disasters. The next step is to attempt to influence these natural physical events by acts of propitiation, that is, by attempting to appease and favorably influence the spirits of the physical world through prayer, sacrifice, atonement, and other rituals (Kelsen 1946).

Sir Edward Burnett Tylor (1832–1917), one of the founding fathers of anthropology, provided the first systematic survey and description of animism throughout the world, describing animistic belief as a necessary first stage in the emergence of more fully developed religious systems (Tylor 1871/1958). That such beliefs serve the purpose of understanding and attempting to control natural events is demonstrated by their relative rarity in societies with modern science and technology and their persistence in societies that have had little or no contact with science and technology. However, as we will soon see, ignorance of science is not required for belief in an animistic world.

Ancient Panpsychism

It is also not the case that psychic theories of behavior are limited to "primitive" illiterate peoples not possessing sophisticated, carefully examined philosophies. Serious panpsychic theorizing goes back at least as far as the Greek pre-Socratic philosophers. Plato (428–348 B.C.) considered souls necessary to explain both the movements of heavenly bodies and the behavior of animals and humans. Concerning the former, Plato was struck by the orderly movements of stars, planets, sun, and moon and considered it evidence of a type of "world soul" provided by the Creator.

> The primary cause of movement must be that which can move both itself and other things, and this he [Plato] identified as soul. Soul carries around the sun, moon, and stars but he leaves it doubtful whether this is because soul is present in the sun as it is in man or because soul pushes the sun from outside or because the sun is moved from outside by soul in some other way. (Kerferd 1967, p. 157)

Plato's rationale for rejecting purely materialist, mechanistic explanations of human behavior is offered in his *Phaedo* dialogue in which Socrates is about to be put to death. Here, Socrates insists that materialist explanations simply cannot provide satisfactory answers to the why of human action, such as why he decided to stay in Athens and face death rather than flee and save his life.

Among ancient Greek thinkers it was Plato's student Aristotle (384–322 B.C.) who provided the most ambitious account of motion and change in the universe, dealing explicitly with both inanimate objects and living organisms. Somewhat paradoxically, Aristotle's panpsychism seems to have been motivated by a rather mechanical notion of movement. For him, all movement had to be caused by a mover, so that if object B moves, it was because object A had moved it. But then what had caused object A to move? To avoid an infinite regress, Aristotle posited the existence of an unmoved mover that was eternal and immaterial. Whereas he referred to this unmoved, transcendent mover as the "outermost heaven," Christians later conceived of this prime mover as an all-powerful and personal God.

For Aristotle, even the actions of animals were ultimately due to outside causes. Alhough it might appear as if animals move themselves spontaneously, he explained that "many motions are produced in the body by its environment and some of these set in motion the intellect or the appetite, and this again then sets the whole animal in motion" (*Physics*, book VIII, chapter 2, p. 337).

> Thus an animal is first at rest and afterwards walks, not having been set in motion apparently by anything from without. This, however, is false: for we observe that there is always some part of the animal's organism in motion, and the cause of

the motion of this part is not the animal itself, but, it may be, its environment. (*Physics*, book VIII, chapter 2, p. 337)

Aristotle's cause-effect reasoning led to the notion of a *stimulus* that played such an important role in later psychological theory. But whereas Aristotle considered the environment ultimately responsible for the behavior of organisms, he also realized important distinctions between inanimate objects and living organisms and therefore attributed a soul to all forms of life, including plants, animals, and humans. His conception of soul was somewhat less mystical and spiritual than either Plato's or later Christian conceptualizations, and for this reason some scholars might well object to describing his philosophy as panpsychic. Nonetheless, it is clear that he saw the soul as that which gave life to living things.

Aristotle believed that plants had nutritive and reproductive souls that caused them to take in nourishment from the sun, air, and ground, and allowed their growth and reproduction. Animals had souls that were similarly nutritive and reproductive, but in addition allowed them to sense the world around them, move, and have desires so that they would seek some things but avoid others. The souls of humans, in addition to possessing all the abilities of those of plants and animals, were intelligent, making humans capable of thought and rational action. Through their rationality, they could develop plans and rules to impose on their cruder animal desires. Aristotle saw the human soul as quite distinct in its rational powers from the souls of plants and other animals, but his placing plants, animals, and humans on the same continuum showed an appreciation of the relationship existing among all living organisms that was not seen again until the time of Charles Darwin some twenty-two centuries later.

Even a cursory treatment of Aristotle's view must mention its strong teleological flavor. *Telos* in Greek means "end" or "goal," and a teleological explanation is one that attempts to explain a phenomenon as directed by its ultimate outcome. To quote Aristotle, "Nature, like mind, always does whatever it does for the sake of something, which something is its end" (*On the Heavens*; quoted in Peters & Mace 1967, p. 3). That such a view considers nature an intelligent, purposeful agent with a grand plan for the universe is additional evidence of the essentially panpsychic nature of Aristotle's thought.

Modern Panpsychism

Anyone acquainted with the success of modern science might suspect that panpsychic theories of behavior have long since disappeared, together with other obsolete scientific theories, such as the earth-centered theory of the solar system, the ether theory of space, and the phlogiston theory of fire. But this is actually far from the case. Although the success of the physical sciences and technology (especially Newton's physics and the technology of the industrial revolution) did help materialist theories of behavior eventually win out over psychic ones, panpsychic views of nature have been entertained by many influential thinkers of the nineteenth and twentieth centuries. Among prominent post-Newtonian panpsychists we find psychologist G. T. Fechner; philosophers G. W. Leibniz, Arthur Schopenhauer, C. S. Peirce, and A. N. Whitehead; and biologists Pierre Teilhard de Chardin, C. H. Waddington, and Sewall Wright.

A set of passages that vividly illustrates one nineteenth-century panpsychic perspective comes from Schopenhauer (1788–1860) who commented on the "strong and unceasing impulse with which the waters hurry to the ocean, [the] persistency with which the magnet turns ever to the North Pole, [the] readiness with which iron flies to the magnet, [the] eagerness with which the electric poles seek to be reunited, and which, just like human desire, is increased by obstacles [as well as] the choice with which bodies repel and attract each other, combine and separate, when they are set free in a fluid state, and emancipated from the bonds of rigidity." He noted that when we lift a heavy object we notice how it "hampers our body by its gravitation towards the earth" and that we "feel directly [how it] unceasingly presses and strains [us] in pursuit of its one tendency." He further observed how the stars and planets "play with each other, betray mutual inclination, exchange as it were amorous glances, yet never allow themselves to come into rude contact" (1818, 1836; quoted in Edwards 1967, p. 25).

Schopenhauer's observations appear amusing because he invokes well-understood physical phenomena as evidence of nonphysical psyches. Gravity and magnetism are understood today (indeed, as they were in his day) as mindless physical forces, and although we may still not completely understand why they act as they do, scientists today feel no need to invoke spirits, souls, ghosts, or other supernatural entities to account for their effects.

More recent, and perhaps more reasonably proposed, was the panpsychism of English embryologist and geneticist C. H. Waddington (1909–1975). Waddington felt that the voluntary and purposeful nature of our actions was evidence of an immaterialist cause of human behavior, arguing that "the experiences to which we give the name of free-will cannot depend wholly on the particular type of nervous activity which, when it is expressed in action, appears as a purpose, but most essentially involve a phenomenon of self-awareness in addition to this" (1962, p. 118).

He also held that biological evolution, together with the fact that human beings have self-awareness, logically leads to the view that all other organisms as well as inanimate objects also have at least some degree of self-awareness. In addition, since humans are undoubtedly aware of themselves and evolved from simpler forms of life, these simpler forms—indeed all forms of life—must also have some degree of self-awareness. And since, according to the theory of evolution, life arose from previous nonliving matter, all nonliving things must also have at least some degree of self-awareness.

So we see that panpsychic theories of behavior have a long history in philosophical attempts to make sense of the movements and changes of the world's objects and organisms. Arguments vary, but common to all of them is the belief that actions appearing to be deliberate and goal directed cannot be explained by completely mindless physical processes.

Having One's Ghost and Feeling It, Too: Dualist Philosophies of Behavior

In contrast to panpsychic philosophies, psychophysical dualism restricts an immaterial soul or mind to certain entities, typically not attributing a psyche to inanimate objects and perhaps also not to plants and animals. For dualists, certain behaviors can be explained as the results of purely physical processes and others are determined (or at least influenced by) a nonphysical soul or mind. Any theory that is not either panpsychic or purely materialistic must embrace psychophysical dualism to some degree.

Descartes: Putting the Ghost in the Machine

Influential French philosopher and mathematician René Descartes (1596–1650) is considered by many to be the father of modern philosophy.

Accordingly, his dualist philosophy had a great and continuing impact on Western thought.

Descartes's dualism has two major characteristics. The first concerns where he drew the line on the existence of souls. This line was very clear: only humans had souls; inanimate objects as well as plants and all animals were purely physical machines with no consciousness, desires, or purposes of any kind. It is reported that Descartes was amused at the howls, cries, and whimpers of live animals he dissected in his research, since he considered these to be but the hydraulically caused noises of unfeeling machines (Jaynes 1973, p. 170).

This may seem to be an absurd and downright inhumane attitude to take today, but it should be mentioned that during Descartes's time English physician William Harvey (1578–1657) showed that the heart, formerly thought by many to be the seat of the passions, was "only" a mechanical pump for the blood. Also, during that time hydraulically animated mechanical models of people and animals were popular fountain decorations. These developments likely encouraged Descartes's belief in the purely mechanical nature of animals.

The second defining characteristic of Descartes's dualism was his theory of the interaction between the physical machine of the living human body and the soul it somehow contained. It should be noted first that whereas he believed that all humans had a soul, he nonetheless considered the physical human body to be a machine in the same way that animals were machines. Accordingly, many human actions were purely physical phenomena that occurred without involving the soul, as when we reflexively pull our hand away from a hot object. This Descartes explained as the action of a mechanistic and automatic one-way cause-effect reflex from sensation to behavior. He believed erroneously that these automatic behaviors involved transmission of a fluid from sensory organs to brain to muscles. But his conceptualization of the reflex arc as a one-way physical connection between perceiving senses and acting muscles had a lasting effect on psychology's one-way cause-effect conception of animal and human behavior as consisting of responses to stimuli.

But actions involving human will involved the functioning of the soul. Descartes believed that the pineal gland at the base of the brain was the site of interaction between the spirit of the soul and the machine of the body. He chose the pineal gland for this function because it appeared to him that it was the only part of the brain that did not exist in other animals (we now know that it does). So unlike stimulus-response reflexes that took place without involvement of the soul, willful action involved the soul receiving information from the senses and determining action by moving the pineal gland, which set in motion "animal spirits" ultimately resulting in muscle movements and overt human behaviors. Although he had the physiological details wrong, his belief that willful or deliberate action involves mediation of a mind acting between stimulus and response anticipated the basic structure of later psychological theorizing, including modern cognitive psychology.

Some rather serious problems plague Descartes's dualism, and many post-Cartesian philosophers have based their careers on describing them. Even in his own day, many could not understand how a soul—which by Descartes's account possessed no physical properties such as shape, volume, position, or mass—could manage to move a physical organ, even one as small as the pineal gland. (The same problem, often unrecognized by cartoon and movie makers, arises for ghosts who are able to pass unimpeded through walls and doors but still somehow manage to make things go bump in the night and have other effects on physical objects.) But it should be recognized that Descartes did pursue a materialist philosophy of behavior as far as it seemed to him prudent to go. All animal behavior was a mechanical reaction to the environment, as is the behavior of a machine. Similar were certain types of human behavior, such as automatic reflexes we make when we are startled by a loud noise or sneeze when dust enters our nose.

But Descartes recognized something quite different about the purposeful behavior that humans consciously want to perform and do so by the exercise of their will. He did not see how a purely mechanical account could be sufficient to explain such actions in which humans do not merely *react* to their environment but instead autonomously and willfully *act* on their environment. In this respect, he was convinced that a human being was fundamentally different from a machine, no matter how cleverly designed such a machine might be.

Vitalism

Descartes's philosophy is just one of the many forms that dualism has taken in the history of human thought. Another form, still very much with us in popular thought if not in science, is known as *vitalism*, which recognizes a fundamental difference between living and nonliving entities. Whereas both inanimate objects and living organisms are subject to the materialist laws of physics and chemistry, vitalism posits a nonphysical entity that gives an organism life and powers that no inanimate body can possess. So whereas panpsychists see all objects possessing a nonphysical soul, and Descartes reserved souls for humans only, vitalism makes what most of us today would likely find to be a more reasonable distinction between objects and organisms, with a nonphysical life force, or *élan vital*, possessed only by the latter.

One of the best-known vitalists of the twentieth century was German physiologist and philosopher Hans Driesch (1867–1941). He defined vitalism as "the theory of the autonomy of the processes of life" (quoted in Beckner 1967, p. 255). For him, the life of an organism depended on "an autonomous, mindlike, nonspatial entity that exercises control over the course of organic processes" (Beckner 1967, p. 255). Driesch admitted that laws of physics and chemistry applied to living organisms and their behavior, but he found such mechanistic principles insufficient to account for an organism's stages of development. The development of a fertilized egg into an embryo and then into a viable, independent organism could be explained after the fact by laws of physics and chemistry. However, such mechanistic laws by themselves could not determine this development, but only put limits on the range of possibilities. It was the special life-giving entity that Driesch referred to as "entelechy" that determined the actual course of development from egg to mature organism.

A description of Driesch's most famous experiment will provide a useful illustration. In the late nineteenth century it was generally believed that a fertilized egg cell contained within it a miniature likeness of the mature organism that it used as a plan for the developing embryo, a theory known as *preformationism*. But in 1891 Driesch separated the two cells of the first division of a sea urchin's egg and was surprised to find that each separate cell developed into a normal, whole sea urchin. For Driesch, this was proof that the egg was more than a machine governed by ordinary laws of physics and chemistry, since no machine divided in half could still make what it had been designed to produce. He saw here evidence of a type of living agency—a regulatory, goal-based process that could not be explained mechanically.

Similarly, Driesch felt that a person's voluntary actions could not be accounted for mechanically, and here we see that he shares company with Descartes. As an example, take a moment to decide whether you want to raise your hand above your head and then act on your decision. If you did raise your hand, this behavior could be accounted for after the fact as the result of contracting muscles that had been stimulated by motor neurons carrying impulses from the brain. But Driesch thought that laws of physics and chemistry were inadequate to explain your *decision* to raise your hand or not.

Although Driesch's vitalism differs from Descartes's dualism concerning where the soul/no-soul line is drawn, they do share two important features. First, like Descartes's mind-body dualism, Driesch's vitalism runs into the problem of how an immaterial, vital entity could direct the physical processes of a living organism without being a physical entity itself. Second, both theories were inspired by the phenomenon of apparently purposeful, goal-driven life processes. Descartes saw such purpose only in the willful action of human beings; Driesch recognized it even in the development of a sea urchin egg that successfully overcame the disturbance of being divided into two parts by developing into two complete organisms. Neither man saw how such purposeful, goal-directed behavior could be accounted for mechanically and so had to reach outside the physical sciences to search for a spiritualist explanation.

Getting Extremely Physical: Materialist Philosophies of Behavior

Although dualist views of behavior are problematic on several counts, forms of dualism are surely the most widely held views of behavior today. Dualism is also an integral part of the world's major religions, which all make distinctions between body and soul, flesh and spirit. But many individuals throughout history, including most philosophers and scientists today, see no need to go beyond physics and chemistry to explain behavior. In contrast to both psychic and dualist theories, such materialist theories attempt to explain the behavior of objects and organisms using only physical explanations based on matter, energy, and their interactions, rejecting all immaterial entities and forces. According to materialism, "there are no incorporeal souls or spirits, no spiritual principalities or powers, no angels or devils, no demiurges and no gods (if these are conceived as immaterial entities). Hence, nothing that happens can be attributed to the action of such beings" (K. Campbell 1967, p. 179).

Ancient Materialists

Although the doctrine of materialism is often associated with modern science, materialism has a long history and has been in competition with psychic and dualist theories since at least the time of ancient Greek philosophers. Among classical Greek thinkers, Leucippus (fifth century B.C.) and his student Democritus are best known for the development of materialism. They were the first to come up with the notion of atomism, the belief that the universe consisted of nothing but bits of tiny, indivisible matter and empty space between them—atoms and void. For Leucippus and Democritus, all that happened in the universe was the result of the mechanical action of these atoms as they collided with and exerted pressure on each other, with all movement and changes due to the combination and separation of atoms. As is consistent with our current theory of the conservation of matter and energy, these pioneering materialists asserted that nothing can arise out of nothing, and nothing can be destroyed. Thus they excluded from their system all teleology of the type embraced by Plato and Aristotle.

Three other early Western philosophers who developed materialistic theories should also be mentioned. Empedocles (fifth century B.C.) divided all matter into the four elements of earth, wind, water, and fire, a system that was also used by Aristotle. Epicurus (342–270 B.C.) saw all motion and objects as the result of an infinite number of atoms falling through infinite space during unlimited time, with resulting collisions leading eventually to every possible arrangement of atoms, including those in living organisms. Lucretius (c. 99–55 B.C.) was the only notable Roman to expound a materialist theory of behavior. These last two thinkers were similar in wanting to liberate people from religious anxieties and so argued with vigor against an immaterial soul and for the mortality of human existence.

Materialists of the Seventeenth Century and Later

Due to renewed popularity of Aristotle's philosophy and the power of the Roman Catholic Church, materialism did not form an important part of European thought until the Renaissance of the seventeenth century. One person who helped to bring about its revival was the well-known English philosopher Thomas Hobbes (1588–1679).

Influenced by the physics of Galileo (whom Hobbes met during a visit to Italy in 1636) and the notion of inertia, according to which objects in motion tend to stay in motion, Hobbes attempted to provide a purely materialist, mechanistic account of human sensation and behavior. Like other materialist theorists we have encountered, he understood all change in the universe as the result of physical bodies in motion and all movement as caused by contact of one moving body with another. He also considered the human body to be a complicated machine as did Descartes, although devoid of Descartes's immaterial soul.

But unlike classical materialists, Hobbes rejected the idea of empty space, believing instead that all space was filled with an intangible material substance. Accordingly, he rejected all notions of souls, angels, and a purely spiritual God, but instead saw God as making up the physical matter that filled what only appeared to be empty space.

A bit later on the European continent, French physician and philosopher Julien Offroy de La Mettrie (1709–1751) was promoting materialist ideas (and getting into trouble for doing so, such as being exiled in Holland). After a bout of serious illness during which La Mettrie experienced his mental powers declining along with his physical health, he became convinced that thought is nothing but the physical functioning of the brain and nervous system. His books *L'histoire naturelle de l'âme* (*The Natural History of the Mind*) and *L'homme machine* (*Man the Machine*) described humans as self-energized machines whose body parts functioned in purely mechanical ways. He also explained perception and learning as the results of changes in the brain, a concept that although wrong in its specific details is similar to the modern view of the essential relationship among brain, mind, and behavior. By showing that muscles and bodily organs could continue to function when removed from a living body, La Mettrie believed he had demonstrated that a soul was not necessary for life. But in contrast to Descartes's passive, purely reactive view of the functioning of animal and human bodies, La Mettrie conceived of the living body "as a purposively self-moving and self-sufficient system, consisting of dynamically interrelated parts" (Popkin 1967, p. 381).

In the *Système de la nature* published in 1770 by German-born Frenchman Paul Heinrich Dietrich d'Holbach (1723–1789), we find a well-developed and thoroughly atheistic materialism. Holbach saw all events in the universe as the result of the redistribution of matter and its energy. Human behavior, which might appear spontaneous and uncaused by physical forces, was for him the result of motion already existing within the body. He also explained emotional feelings and personality as dependent on arrangements of internal states of matter and explained behavior that appeared to be based on free will as the result of spontaneous modifications of the brain.

Progress in science, notably in physics, chemistry, and biology from the seventeenth century to the present day, has done much to make materialism more appealing and respectable. The influence of Galileo on the materialism of Thomas Hobbes has been noted. But it was the remarkable breakthrough in physics achieved by Sir Isaac Newton that had the most significant and lasting effect on these theories. Newton's grand achievement was a precise, mathematical understanding of the motion of bodies through space.

Kepler had derived laws of motion for the planets, and Galileo had developed laws describing the motions of bodies on earth. Newton's system of three laws (described in chapter 1) was more general than either and applicable to all objects, terrestrial and celestial. In Newton's system, all physical objects are fundamentally inert and can only move or change as a reaction to outside forces such as gravity, or by coming into contact with another moving object. This is very unlike Aristotle's teleological system of physics in which, for example, a heavy object falls toward the center of the earth not because of the influence of an external force but rather because of the object's own goal to be as near the center of the earth as possible. By convincing scientists that the behavior of all physical bodies could be understood as quantifiable reactions to external forces, Newton had an enormous impact on science, philosophy, and even psychology.

But whereas the success of Newton's mechanics eliminated the full-time job that angels had of pushing the planets around the sun, Newton himself did not believe his laws of physics completely eliminated the need for God. Instead, God was still required to prevent the stars from collapsing into one giant heap of mass under the force of gravity and to maintain the regular motion of the planets that would otherwise be disrupted by gravitational attraction as they passed close to each other in their orbits around the sun. Thus he maintained a decidedly dualist philosophy of the universe.

The same could not be said for French astronomer and mathematician Pierre Simon de Laplace (1749–1827). One of the advantages Laplace had over Newton was the improved calculus developed by his colleagues, especially that of Italian-French mathematician Joseph Louis de Lagrange (1736–1813). With this tool in hand, Laplace went about polishing up Newton's system of mechanics, eliminating from it all known problems and anomalies, such as the varying speeds of Saturn and Jupiter. He was therefore convinced that no divine intervention was necessary to maintain the observed regular motion of the planets. His confidence in the adequacy of a purely mechanical and deterministic account of the motions of objects was such that when Napoleon questioned him about the absence of God from his theory, Laplace confidently replied that he had no need of that hypothesis!

To illustrate the power of his new and improved Newtonian mechanics, Laplace proposed a thought experiment involving superhuman intelligence that knew the position of every particle of matter in the universe and all the forces currently acting on each of them. To a being with this knowledge of initial conditions, together with the now-understood laws of motion, "nothing would be uncertain and the future as the past, would be present to its eyes" (Laplace 1814/1902, p. 4).

Laplace's materialist theory of the universe's behavior, based entirely on the idea of moving particles of matter interacting with each other, is clearly reminiscent of the classical materialist views of Leucippus, Democritus, Empedocles, Epicurus, and Lucretius. But one important difference is that he had mathematics and empirical results to back up his claim, at least with respect to the regular behavior of inanimate matter such as the motion of planets around the sun. And although it is less clear that even improved Newtonian mechanics could do much to explain the more complex behavior of living organisms, we will see that the one-way cause-effect perspective was eventually to become—and remains—the principal model on which psychological theories of animal and human behavior are founded.

The world today is divided along many lines. One of the most obvious is the line dividing the wealthy, industrialized countries of Europe, North America, and Oceania from the poorer, less industrialized countries of much of the rest of the world. Perhaps less obvious, but just as striking, is the line separating materialist (physical, natural) methodologies and beliefs of science and scientists from overwhelmingly psychic (spiritual, supernatural) or dualist methodologies and beliefs of the rest of the world's human population. While science is now thoroughly materialistic in orientation and methodology, most individuals doubt that life, its origin, its meaning, and its experiences can be accounted for by physical properties of matter, energy, and their interaction, and hence believe in a God or gods, spirits, angels, paranormal happenings, and other supernatural entities and phenomena. In the next chapter we will see that there is good reason to doubt the adequacy of widely held materialist explanations of animate behavior.

3

Psychological Perspectives on Behavior: From Purposeful to Purposeless

From a purposeful perspective on behavior . . .

The pursuance of future ends and the choice of means for their attainment are thus the mark and criterion of the presence of mentality *in a phenomenon. We all use this test to discriminate between an intelligent and a mechanical performance. We impute no mentality to sticks and stones, because they never seem to* move for the sake of *anything, but always when pushed, and then indifferently and with no sign of choice. So we unhesitatingly call them senseless.*
—William James (1980, p. 8)

. . . to a purposeless one (one hundred years later) . . .

It is possible to step back and treat the mind as one big monster response function from the total environment over the total past of the organism to future actions.
—Allen Newell (1990, p. 44)

In moving from philosophical to psychological perspectives on behavior, we should first consider what distinguishes them from each other. Both are concerned with many of the same issues, such as the nature of perception, thought, and consciousness; what and how we are able to learn from our environment; and the underlying causes of behavior. So it is not so much their contents that differentiates the two disciplines as their methodologies. Philosophy relies primarily on verbal reasoning, logic, and sometimes mathematics to understand the world, our perception of it, and our actions within it; psychology for the most part claims to be an empirical science based on data derived from both laboratory-based and naturally occurring data.

Wundt's Voluntaristic Psychology

It is fitting that Wilhelm Wundt (1832–1920), who founded in Leipzig the first laboratory for experimental psychology in 1879, is widely considered to be the father of psychology. Wundt believed that psychology, like the older and respected science of physics, should rely on experimental methods to test and refine its theories. But Wundt saw the domain of "raw," immediate human experience, comprising both feelings and sensory perceptions unmodified by reflection or abstraction, as the primary subject matter of psychology. Relying on introspective reports of trained subjects who would report their experiences to controlled stimuli such as a ticking metronome, Wundt attempted to understand human psychological experience by relating it to its basic elements, an approach that has been described as a type of mental chemistry. As part of this project, he developed his tridimensional theory of affect, by which all emotions can be classified according to the three dimensions of pleasantness-unpleasantness, strain-relaxation, and excitement-calm.

Wundt held that a careful analysis of immediate experience would reveal to the psychologist the basic properties of the human mind, including its lawful changes from one state to another, a principle he referred to as "psychic causality." But whereas he made a distinction between psychic and physical causality, he nevertheless recognized the psychological importance of the physical function of the brain and nervous system, stating that "there is no psychical process, from the simplest sensation and affective elements to the most complex thought-processes, which does not run parallel with a physical process" (1912, p. 186). Wundt's contrasting of psychic and physical processes might make him appear to be a mind-body dualist, which indeed is the usual description of him in psychology textbooks. But that is not an accurate characterization. Instead, he maintained that there were both psychological and physical aspects to thought, perception, and animate behavior, and both had to be studied in order to understand the underlying phenomena (see Blumenthal 1988, p. 196).

Still, he felt that there were serious limitations in restricting oneself to physical approaches to studying animate behavior:

> Wundt acknowledged . . . the theoretical possibility of reducing psychological observations to physiological or physical descriptions. Still, he argued, these physi-

cal sciences would then describe the act of greeting a friend, eating an apple, or writing a poem in terms of the laws of mechanics or in terms of physiology. And no matter how fine-grained and complicated we make such descriptions, they are not useful as descriptions of psychological events. Those events need be described in terms of intentions and goals, according to Wundt, because the actions, or physical forces, for a given psychological event may take an infinite variety of physical forms (Blumenthal 1988, p. 198).

We see here that he recognized the importance of purpose in understanding animate behavior and that many different behaviors can be effective in achieving the same goal. Indeed, the notion of purposeful animate behavior played such a central role in his psychology that he referred to his psychological theory as "voluntaristic," based on the Latin word *voluntas* meaning "will." For Wundt, such purposeful behavior required central control processes that were fundamentally different from mechanistic processes of physical causality.

William James: Varying Means to a Fixed End

At the end of the nineteenth century and beginning of the twentieth, no one had a greater influence on psychological theory in the United States than William James (1849–1910). James was (and still is) widely respected for his two-volume *Principles of Psychology* that took him twelve years to complete before being published in 1890.

In the opening chapter of the *Principles*, James took great pains to make what he considered to be an important distinction between the behavior of physical objects and that of living organisms. First, he described the behavior of iron filings in the presence of a magnet and the behavior of air bubbles blown into the bottom of a pail filled with water. We observe the filings "fly through the air for a certain distance to stick to its [the magnet's] surface" and the air bubbles "rise to the surface and mingle with the air" (1890, p. 4). But if obstacles are introduced, such as a card placed on the magnet or a water-filled jar inverted over the bubbles, neither the filings nor the bubbles will end up as before. Instead, now the filings will stick to the intervening card and the bubbles will remain trapped inside the jar.

James went on to contrast the behavior of the iron filings with that of Romeo in the presence of Juliet and the behavior of the bubbles with that of a frog, and showed how living organisms can circumvent such obstacles, achieving their goals in spite of disturbances.

> Romeo wants Juliet as the filings want the magnet; and if no obstacles intervene he moves towards her by as straight a line as they. But Romeo and Juliet, if a wall be built between them, do not remain idiotically pressing their faces against its opposite sides like the magnet and the filings with the card. Romeo soon finds a circuitous way, by scaling the wall or otherwise, of touching Juliet's lips directly. With the filings the path is fixed; whether it reaches the end depends on accidents. With the lover it is the end which is fixed, the path may be modified indefinitely.

Similarly, the frog will not, like the bubbles,

> perpetually press his nose against its [the jar's] unyielding roof, but will restlessly explore the neighborhood until by re-descending again he has discovered a path around its brim to the goal of his desires. Again the fixed end, the varying means! (1890, p. 4)

Thus living things distinguished themselves from nonliving objects in their purposeful behavior and intelligence in obtaining fixed goals by varying their actions. A nonliving thing showed only "a mechanical performance" and naturally "we impute no mentality to sticks and stones, because they never seem to move for *the sake of* anything, but always when pushed, and then indifferently and with no sign of choice" (1890, p. 5).

It would seem that James was a soul-body dualist in dismissing the possibility that the apparently purposeful behavior of living organisms could have mechanical explanations. But he also considered mental phenomena and the behavior of humans and animals to be aspects of the same natural world in which we find nonliving objects. So in keeping with the provisional and undogmatic character of his treatment of complex and controversial topics, he admitted that brain and mind "hang indubitably together and determine each other's being, but how or why, no mortal may ever know" (1898, p. 119).

The Rise of Behaviorism

In addition to the immediate impact that James's *Principles* had on psychological thought, other events in Russia and the United States a short time later had an even greater influence on the growth of the still-young field of psychology, leading to the rise of what eventually became known as *behaviorism*.

In St. Petersburg, physiologist Ivan Pavlov (1849–1936) was studying the digestive system of dogs in the 1890s when he and his assistants noticed a curious phenomenon. The animals would secrete gastric juices not only when food was placed in their mouths but also at the mere sight of food and even at the sight of anyone who regularly fed them. Pavlov explained this change in behavior (now known as Pavlovian, classical, or respondent conditioning) as modification of a stimulus-response reflex. This involved linking a new stimulus (for example, the sound of a bell that regularly preceded the introduction of food into a dog's mouth) to an old response (in this case, salivation).

It is interesting to note that Pavlov's student, Anton Snarsky, who had done the original research on Pavlovian conditioning, attempted to explain this change in behavior by appealing to the dog's higher mental processes involving feelings, expectations, and thoughts. But Pavlov rejected this interpretation, wishing to remain "in the role of a pure physiologist, that is, an objective observer and experimenter" (quoted in Boakes 1984, p. 121). He therefore rejected all mentalistic interpretations, preferring to consider all animate behavior as the result of one-way stimulus-response reflexes, and all changes in animate behavior as the result of environmentally caused modifications of these reflexes.

While Pavlov restricted his research to dogs, American psychologist John B. Watson (1878–1958) applied Pavlov's theory to both animals and humans. In an influential paper published in 1913 entitled "Psychology as the Behaviorist Views It," Watson criticized the method of introspection used by Wundt and his followers, and declared that psychology should abandon all study of consciousness and mental processes, and be concerned only with publicly observable behavior and its causes. He even went so far as to hold that thinking was actually a form of silent speech that involved tiny, imperceptible movements of the larynx.

Pavlov and Watson explained animal and human behavior as the functioning of stimulus-response reflexes and learning as the pairing of new stimuli with old behaviors. Edward Thorndike (1878–1949), however, was interested in understanding how new behaviors were learned and spent considerable time observing how animals such as dogs and cats managed to escape from a box that required a new action, such as pulling on a loop of string, to open the door. Based on this and other animal research, Thorndike concluded that all learning in all animals (including humans) followed certain fundamental laws. The most well-known of these is his law of effect, stating that behaviors that are followed by "satisfaction to the animal" will most likely recur, while actions followed by "discomfort to the animal" will be less likely to recur.

Thorndike was the first psychologist to propose that all new learned behavior results from the selective reinforcement of random responses. It was fellow American B. F. Skinner (1904–1990) who made behaviorism widely known among both psychologists and the larger public in the second half of the twentieth century. Skinner called such learning "operant conditioning" since it involved organisms learning new ways of operating on their environments. Like Thorndike, he saw such new, useful behaviors as resulting from the reinforcement of those actions that were followed by a rewarding consequence. So, for example, if a hungry rat's push of a lever resulted in the delivery of a food pellet, the rat would soon learn to push the lever repeatedly. In addition to his extensive technical research on animal learning, Skinner, who had originally intended to be a novelist, wrote several popular books about behaviorism and its application to social and educational problems (1948, 1971, 1974). Skinner's name remains most firmly connected to the theory of *radical behaviorism*, a perspective that denies a causal role to internal mental states, purposes, and thought processes, and instead sees animate behavior and all changes in animate behavior as determined by the environmental consequences of actions.

It is important to realize that Skinner did not deny that human thinking and consciousness existed. But, like Watson, he did not see how such mental phenomena could offer any useful explanation of animate behavior, stating that "behavior which seemed to be the product of mental activity could be explained in other ways" (1954, p. 81). And consistent with his stimulus-response view of learned behavior, he denied that motives, desires, or purposes could provide an explanatory account for animal or human behavior. He argued instead that "a person disposed to act because he has been reinforced for acting may feel the condition of his body at such time and call it 'felt purpose,' but what behaviorism rejects is the causal efficacy of that feeling" (1957, p. 224).

Behaviorism can be seen as a bold attempt to make the study of animal and human behavior as objective and as scientific as the physical sciences.

It was reasoned that since behavioral scientists cannot have objective access to the subjective experiences of another animal or person, such mental states must be omitted from study. Instead, what could be studied objectively were overt behaviors of organisms and environmental factors that caused them. As described by Gardner (1987, pp. 11–12):

> A strong component of the behaviorist canon was the belief in the supremacy and determining power of the environment. Rather than individuals acting as they do because of their own ideas and intentions, or because their cognitive apparatuses embody certain autonomous structuring tendencies, individuals were seen as passive reflectors of various forces and factors in their environment. . . . It was believed that the science of animate behavior, as fashioned by such scholars as Ivan Pavlov, B. F. Skinner, E. L. Thorndike, and J. B. Watson, could account for anything an individual might do, as well as the circumstances under which one might do it. (What one thinks was considered irrelevant from this perspective—unless thought was simply redefined as covert behavior.) Just as mechanics had explained the laws of the physical world, mechanistic models built on the reflex arc could explain human activity.

In other words, the behaviorist approach could be characterized as an attempt to extend Newton's one-way cause-effect mechanics to living organisms. From this perspective, animate behavior is not autonomous or purposeful in any way but is composed of mechanically determined reactions to physical forces, with the reflex arc as a type of connecting rod between environmental inputs (causes or stimuli) and consequent behavioral outputs (effects or responses).

Such a characterization may be an accurate description of Pavlov's and Watson's classical conditioning in which one stimulus (such as the sound of a bell) becomes substituted for another (such as food). But it does not do complete justice to Thorndike's and Skinner's view of learning in which new, adapted behaviors are acquired. For an animal to learn a new response, behaviors that have not occurred before must occur spontaneously. These random behaviors, as shown by cats and dogs in Thorndike's puzzle boxes, and rats and pigeons in Skinner boxes, are not reactions to environmental stimuli but are rather emitted by an active organism seeking food, water, or escape from an unpleasant situation. So an essential component of Thorndike's law of effect and Skinner's operant conditioning is behavior that is essentially *uncaused* by the environment. In this way this view of animate behavior departs from a one-way cause-effect model.

But whereas operant conditioning requires such spontaneous, random behavior, this does not make it any less mechanistic or more purposeful for the behaviorists. Although neither Thorndike nor Skinner speculated on the precise cause of such emitted behavior, it could be readily accounted for by some type of random behavior-generator within the organism that performed the equivalent of tossing a die or selecting a value from a table of random numbers and acting on the result. Nonetheless, for both men the environmental consequences of a random action—for example, the degree to which it was successful in obtaining food for a hungry animal—determined the likelihood that such an action would be repeated in similar circumstances. So Gardner is essentially correct in the quotation concerning behaviorists' "belief in the supremacy and determining power of the environment." Living organisms, unlike inanimate pieces of matter, emit spontaneous behaviors uncaused by their physical environment, and it is from this repertoire that some behaviors are selected. But the environment nonetheless determines the behavior that is learned during this process in much the same way that environmental factors determine the motions of nonliving objects.

Skinner saw a striking analogy between his theory of operant learning and the theory of natural selection for biological evolution, remarking that "in certain respects operant reinforcement resembles the natural selection of evolutionary theory. Just as the genetic characteristics which arise as mutations are selected or discarded by their consequences, so novel forms of behavior are selected or discarded through reinforcement" (1953, p. 430). In the same way that Darwin's materialist and mindless theory of natural selection replaced a purposeful God in providing a scientific explanation for the evolution of species, Skinner considered the mechanical and mindless selection of animate behavior by the environment to be a replacement for the notions of mind and purpose operating at the level of individual organisms. We will return to his theory of learning and its curious mix of Newtonian and Darwinian causality in chapters 7 and 11.

Tolman's "Purposeful Behaviorism"

Skinner and the earlier behaviorists removed all consideration of mind and purpose from their analysis of animal and human behavior. This was possible, however, only by ignoring what Wundt and James had earlier emphasized—that animate behavior often varies markedly while its consequences remain constant. A rat does not take the exact same steps every time it runs through a maze, nor does it push a lever exactly the same way each time to obtain food. Neither does a man move the steering wheel of his car exactly the same way each time he drives from home to work. Skinner showed that he was aware of this phenomenon by defining the term "operant" as a class of animate behaviors that all had the same effect on the environment. But he provided no explanation as to how reinforcing individual actions could serve as a reinforcement for the infinity of actions not performed that also produced the same environmental effects. For example, if individual actions are selected by their consequences, how would reinforcing a rat with food for pushing a lever with its right paw lead it subsequently to push the same lever with its left paw or with its nose?

Edward C. Tolman (1886–1959) identified this problem in Skinner's behaviorism and recognized the goal-directed nature of animate behavior. He made a distinction between what he called *molar* and *molecular* descriptions of animate behavior. A molar description referred to the consequences of the behavior, and a molecular description referred to the specific muscular and limb movements performed by the organism. As examples of molar descriptions of behavior he offered (1932, p. 8)

> a rat running a maze; a cat getting out of a puzzle box; a man driving home to dinner; a child hiding from a stranger; . . . my friend and I telling one another our thoughts and feelings—*these are behaviors* (qua *molar*). And it must be noted that in mentioning no one of them have we referred to or, we blush to confess it, for the most part even know, what were the exact muscles and glands, sensory nerves, and motor nerves involved.

To demonstrate that rats do not learn specific, fixed responses when learning new tasks, Tolman and his associates at the University of California in Berkeley conducted a number of ingenious and influential experiments from the 1920s to 1950s. Among the best-known was one conducted by Tolman's student D. A. Macfarlane in which rats learned to swim through a maze to obtain a food reward (see Tolman 1932, pp. 79–80; Boakes 1984, p. 232). After they had learned to do this well, a raised floor was installed in the maze so that the rats now had to wade through the maze to get to the box containing the food. It was hypothesized that if the rats' learning consisted of acquiring specific swimming behaviors (that is, specific responses to specific stimuli), they would have to relearn the maze in the wading condition, as the movements and stimuli involved in wading are very different from those involved in swimming. It was found instead that after a very brief period of adjustment to the new situation (just one run through the maze), the rats performed as well in the wading condition as they had in the swimming condition. This was a clear demonstration that what the rats learned while swimming the maze could not be described as the formation of stimulus-response connections. Rather, the acquisition of a more abstract form of knowledge about the location of the goal box and how to get there was involved, since it made no difference to the rats whether they swam or waded to their destination. Similarly, once a person knows how to reach a specific location by driving a car, he can also go there by bicycle (if he knows how to ride one) or by walking (if it is not too far). The destination can be reached despite the fact that stimuli and responses differ greatly from one mode of transportation to another.

But in spite of these findings and many others like them, Tolman was never able to eliminate the concept of stimulus-response connections from the very core of his theory of purposeful behavior. Indeed, his attempt to explain how animate behavior can vary and yet reach a consistent goal involves imagining long, complicated chains of such connections existing within the organism in the form of intervening variables, and conceiving of responses not as specific muscular contractions but rather as a "performance." With respect to the latter, Tolman wrote (1959, p. 100):

> It is to be stressed . . . that for me the type of response I am interested in is always to be identified as a pattern of *organism-environment rearrangements* and not as a detailed set of muscular or glandular activities. These latter may vary from trial to trial and yet the total "performance" remains the same. Thus, for example, "going towards a light" is a *performance* in my sense of the term and is not properly a response (a set of muscular contractions).

But substituting the word "performance" for "response" does nothing to explain how an organism is able to accomplish a repeatable "organism-environment rearrangement" by responding to stimuli; it simply states that it somehow happens. If "behavior may vary from trial to trial and yet the total 'performance' remains the same," how is it that the organism is able continually to adjust its behavior to arrive at a desired goal?

Tolman made an important initial step toward solving this problem in his realization that sensory feedback was important; that is, the rat's behavior changed the stimuli it perceived and this feedback was essential in guiding the organism toward its final goal (1959, p. 103). But he never provided an explicit model for how such a system could work, so he never managed to break free of the behaviorist tradition of regarding stimuli as causes of animate behavior.

Hebb's Bridge from Behaviorism to Cognitive Psychology

Another important and influential North American psychologist who attempted to overcome the shortcomings of behaviorism was Donald O. Hebb (1904–1985) of McGill University in Montreal. Hebb was particularly interested in applying newly discovered principles of brain functioning to understand better how the brains of humans and animals worked to influence behavior. Watson and Skinner considered the brain as a type of black box whose inner workings were both invisible and irrelevant for understanding animal and human behavior. In contrast, Hebb dared to try to peer inside the brain and was convinced that it was only by understanding details of the brain's operations that animal and human behavior could be explained. He called his brain-based approach to animate behavior "neuropsychology."

He saw animal and human behaviors as varying along a continuum with respect to the amount and type of brain processes involved in the behavior. At one end of this continuum were behaviors that appeared to involve automatic, rapid reactions to stimuli, such as the startle response to a loud, unexpected sound, or withdrawing a hand from a hot surface. At the other end of the continuum were behaviors requiring a great deal of brain, or cognitive, processes between stimulus and response, such as finding the answer to a complex problem in mathematics or making a difficult decision. Since these brain processes occurred between stimulus and response, he referred to them as "mediating processes" in which thought, ideas, and images were involved. Toward the middle of this reflex-cognitive continuum were activities that were more than automatic responses to stimuli but did not require a great deal of mental activity, such as easy arithmetic tasks.

Hebb was thus able to build a bridge between the stimulus-response behaviorist psychology that was beginning to wane in the second half of the twentieth century and the "cognitive revolution" that was gaining momentum. In addition, he considered the neural mechanisms by which such cognitive processes could work. The behaviorists' conception of the brain was that of a one-way telephone switchboard that directly connected incoming stimuli to outgoing responses (with learning being a modification of these direct connections based on experience). Hebb instead imagined more complex brain processes that could account for cognitive processes such as thought, motivation, and attention (1949, 1972). In so doing he replaced the stimulus-response model of behaviorism with what has been described as a stimulus-organism-response model of animate behavior.

Hebb's major contribution in this regard was his theory of the "cell assembly," a group of brain cells (neurons) that formed a closed circuit in the brain and could remain active for quite some time after an initial stimulus by a type of nervous reverberation. These reverberations, which he believed were the basis of all higher cognitive processes, mediated or intervened between incoming sensory information and outgoing motor responses. An example he used involved presenting a schoolboy with the words "please add" followed five seconds later by the words "four, seven" (1972, pp. 85–86). The schoolboy's response of "eleven" is evidence that the initial stimulus of "please add" was somehow being kept active in the brain until the words "four, seven" were heard. Even though there was no immediate response to the initial words, they influenced behavior regarding the words subsequently heard and thus mediated the response to the numbers (the response would have been different if the instructions "please subtract" had been given instead). Thus all cognition could be understood as such mediating brain processes between stimulus and response.

This neuropsychological-based stimulus-organism-response account of animate behavior had important advantages over the direct stimulus-response theories of the behaviorists, but it still encountered difficulties in accounting for voluntary and purposeful animate behavior. This is because animate behavior was still ultimately determined by sensory stimulation, either directly (as in reflexes) or through mediating cognitive processes involving the reverberation of circular neuronal circuits in the brain. As Hebb put it (1972, p. 84):

The typical problem of higher behavior arises when there is a delay between stimulus and response. What bridges the S-R gap? In everyday language, "thinking" does it: the stimulus gives rise to thoughts or ideas that continue during the delay period, and then cause the response.

But if "higher behavior" involves stimuli eliciting thoughts with thoughts in turn causing responses, how can this mechanistic, one-way cause-effect system account for the goal-directed nature of animate behavior in which behavior varies as it must to produce a consistent outcome? If, as Hebb believed, "all behavior is under sensory guidance, through the switchboard of the central nervous system" (1972, p. 92), it would appear that animate behavior could not be any more purposeful or voluntary than the behavior of wind-blown clouds or falling drops of rain.

The Cognitive Science Approach to Behavior

Hebb recognized the mechanistic implications of his neuropsychological theory of animate behavior and consequently dismissed the notions of will and voluntary behavior, stating that "in modern psychology the terms 'volition' and 'will' or 'will power' have disappeared" (1972, p. 92). He could have easily added "purpose" to his list. Although cognitive psychology in the 1980s and 1990s developed in ways that he could not have foreseen, it has remained purely materialistic and for the most part continues to see animal and human behavior as the mechanical product of sensory stimulation processed by a brain that consequently produces behavioral outputs.

As mentioned, behaviorists thought the brain was analogous to a telephone switchboard that permitted only direct one-way connections between stimuli and their corresponding responses. To this switchboard Hebb added reverberating groups of neurons that he called "cell assemblies." Cognitive scientists of the second half of the twentieth century replaced the switchboard theory with one based on the digital computer, and used these electronic machines to attempt to simulate animal and human brains and the behavior they produce.

But a particularly intriguing development occurred around the middle of the twentieth century that promised to provide what had until then appeared unimaginable—a completely materialist, mechanistic model of purposeful animate behavior. In a 1943 paper with the title "Behavior, Teleology, and Purpose," Arturo Rosenblueth, Norbert Wiener, and Julian Bigelow proposed that machines designed in a certain way could demonstrate goal-directed behavior. It seemed that during the early decades of the twentieth century, while psychologists were not paying attention, engineers found a way to build machines called "control systems" that, like Shakespeare's Romeo and James's frogs, could vary their behavior as necessary to produce consistent outcomes.

We will save for the next chapter a more detailed account of the revolution begun by Rosenblueth, Wiener, and Bigelow. But it should be pointed out here that this new approach to understanding animate behavior constituted the first real break with the one-way cause-effect view that was a part of all previous theories. Instead of seeing external events as causes for animate behaviors, this new "cybernetic" approach recognized that the behavior of a living organism (or that of a machine designed as a control system) has an effect on its environment. Therefore its behavior must also affect what it senses or perceives of this environment. So instead of a one-way behaviorist stimulus-response, or a one-way cognitive stimulus-computation-response conception, cybernetics closed the loop by connecting response back to stimulus while maintaining the normal Newtonian cause-effect relationships for components within the overall system. But if it is the case that response influences stimulus and stimulus influences response, one can no longer speak of independent external causes for animate behavior. This is because the one-way causal chain has been turned into a closed loop in which stimulus and response both *cause* and *are caused by* each other. The familiar one-way, push-pull, cause-effect model inherited from Newton, in which an independent environmental stimulus causes a dependent behavior, was for the first time replaced by something quite different, a theory of animate behavior based on a closed loop exhibiting *circular causality.*

A number of other pioneering cognitive scientists were influenced by cybernetics (see Miller, Galanter, & Pribram 1960); however, this new field and its radically different view unfortunately had little lasting impact on behavioral and cognitive science. With few exceptions, behavioral scientists working in the last decades of the twentieth century stuck with the familiar one-way cause-effect approach.

This is not to say that important recent advances have not been made in understanding the brain, cognitive processes, and their roles in animal and human behavior. But the dominant view in behavioral and cognitive sciences remains consistent with—and seriously limited by—the input-output, stimulus-organism-response model developed by Hebb in the 1950s in which animate behavior remains dependent on past and present environmental influences. "Cognitive psychology comes in various forms, but all share an abiding interest in describing the mental structures and processes that link environmental stimuli to organismic responses . . ." (Kihlstrom 1987, p. 1445).

Conclusion to Part I: Embracing Materialism, Spurning Purpose

It is obviously not possible to provide a comprehensive account of 2500 years of human thought on inanimate and animate behavior in just two book chapters. But this summary does indicate two important trends.

The first trend is movement away from immaterial, psychic theories of behavior to materialist, physical ones. The animism of early nontechnological societies, including the panpsychic physics of Plato and Aristotle, gradually gave way to the materialist physics of Newton and Laplace that remains with us. And what is true for physics is also true of psychology, a discipline that became thoroughly and unashamedly materialist in both its behaviorist and cognitive versions in the twentieth century.

The second trend is movement away from a conception of behavior as goal-directed toward a view of it as being essentially purposeless. For the behavior of inanimate objects this is linked to the trend from psychic to materialist theories in physics. Whereas Plato and Aristotle shared a goal-directed view of the universe, Newton, Laplace, and their successors were able to purge all notions of purpose from the behavior of nonliving objects and systems. Concerning animate behavior, Wundt's voluntaristic psychology and James's emphasis on purposefulness were replaced by twentieth-century theories of purposeless animate behavior by psychologists, whether they be in the behaviorist or cognitive camp.

The result of these two long-term trends is that today mainstream philosophical and psychological theories of both inanimate and animate behavior are thoroughly materialist and overwhelmingly purposeless in orientation. One could make a strong argument that the popularity of materialism is justified by the success of our modern, materialist science that discovered physical mechanisms and forces underlying a broad range of phenomena—from sickness to supernovas—that could previously be understood only as actions of gods or angels or other forms of spirits and ghosts. Newton's physics relieved angels from their full-time jobs of pushing the planets around in their orbits and required only an occasional helpful shove from God himself; Laplace's improved mechanics did away with God completely. Even more amazing was Darwin's audacity and success a century later in accounting for the diversity and complexity of living organisms without God's help. Some scientists continue to include God or other spiritual entities in their science, but they constitute a small minority whose work is excluded from mainstream scientific journals.

But does a thoroughly materialist view of the universe necessarily lead to a purposeless view of all its behavior as well? One reason that this might appear to be the case has to do with a conception that requires purposeful behavior to be caused by a future event or state. In this view, if the purpose of rain is to allow trees, flowers, and grass to grow, the *future* growth of these plants would have to somehow influence the *present* actions of clouds and raindrops. According to our present conception of physics, effects cannot precede their causes, or causes follow their effects. So it may well be the case that attributing purpose to naturally occurring inanimate behavior is inconsistent with modern materialist science.

Can the same case against purposeful behavior be made for living organisms? Our everyday observations certainly suggest otherwise. What William James noticed in the behavior of Romeo and frogs—variable actions leading to consistent consequences—we see everyday in the behavior and achievements of animals and humans. Our experience as human beings—each with our own long-term financial, career, and family goals together with our more mundane daily trials against the unpredictable disturbances provided by traffic, illness, accidents, and often uncooperative family members and co-workers—makes it obvious that our behavior is goal directed and purposeful. This is the case even if such behavior can ultimately be reduced to the buzzing of neurons and the twitching of muscle fibers.

Fortunately, we do have a thoroughly materialist, physical explanation for the purposeful behavior of living organisms that does not involve spiritual agents or require that the future influence the present. Unfortunately, it is not widely known and appreciated by behavioral and cognitive scientists. Having its roots in nineteenth-century biology, we will see that in its modern and expanded form this theory provides a revolutionary framework for understanding the what, how, and why of animal and human behavior.

II

Purpose Without Spirit: From Constancy of the Internal Environment to Perceptual Control of the External Environment

4

A Biological Perspective on Purpose: The Physiology of Bernard and Cannon

We must therefore seek the true foundation of animal physics and chemistry in the physical-chemical properties of the inner environment. The life of an organism is simply the result of all its innermost workings. All of the vital mechanisms, however varied they may be, have always but one goal, to maintain the uniformity of the conditions of life in the internal environment.
—Claude Bernard (1878; quoted in Rahn 1979, p. 179).

Claude Bernard and the Internal Environment

The seven years from 1859 to 1865 are noteworthy for several revolutionary advances that took place in the life sciences. In 1859 Charles Darwin published *The Origin of Species* in which he convincingly argued for a common ancestor to all living organisms on earth and explained the great diversity of their forms as resulting from evolution by natural selection (the application of Darwin's insight to understanding behavior will be taken up in the next two chapters). From 1860 to 1865, French chemist Louis Pasteur (1822–1895) conducted a series of experiments that laid to rest the theory of spontaneous generation of life (showing, for example, that yeast and bacteria would not grow in decaying matter that had been sterilized and protected from exposure to air and dust) and laid the foundation for modern medicine with his germ theory of disease. In 1865 Austrian monk and pea gardener Gregor Mendel (1822–1884) discovered certain regularities of heredity that eventually led to the development of the fields of genetics and molecular biology. And also in 1865, Claude Bernard published his now classic *Introduction à l'étude de la medicine experimentale* (English translation 1927).

The contributions of Darwin, Pasteur, and Mendel are well known even among nonscientists. Bernard's name is much less familiar despite his numerous important contributions to our understanding of internal systems and their functioning, or physiology, of living organisms. Bernard's contributions include the following (Fruton 1975, p. 35):

1 The discovery of the role of the pancreatic secretion in the digestion of fats (1848)
2 The discovery of a new function of the liver—the "internal secretion" of glucose into the blood (1848)
3 Induction of diabetes by puncturing the floor of the fourth ventricle [of the brain] (1849)
4 The discovery of the elevation of local skin temperature on section of the cervical sympathetic nerve (1851)
5 Production of sugar by washed excised liver (1855) and the isolation of glycogen (1857)
6 The demonstration that curare specifically blocks motor nerve endings (1856)
7 The demonstration that carbon monoxide blocks the respiration of erythrocytes (1857)

It could be held, however, that Bernard's most important contribution to our understanding of the phenomenon of life is not included among any of these discoveries. Through his exhaustive research on internal systems of living organisms, Bernard came to understand that the function of physiological processes was to *regulate* or *control* the internal environment (*milieu intérieur*) of the organism. And he understood that this control, so essential to life, was achieved by normal laws of chemistry and physics, not by any special vitalist entities or processes.

As an example of control of the internal environment, let us consider the topic of the doctoral dissertation Bernard submitted in 1853. The countless living cells in a mammal's body require a continuous supply of food that must be present at all times in blood as glucose. If too little glucose is present, a condition known as hypoglycemia, the body's tissues will starve and, most important, the brain will no longer be able to function, leading to loss of consciousness and ultimately death. A very high concentration of glucose in blood, or hyperglycemia, is also dangerous since it may result in loss of consciousness and death, and less extreme hyperglycemia can cause thickening of capillaries and circulatory disease. So in healthy humans the level of blood sugar is maintained within quite narrow limits to 90 milligrams per 10 deciliters of blood. This control is maintained even if we go for many hours and even days without eating or if we instead stuff ourselves beyond reason over a few hours at a restaurant or holiday family meal.

How is this precise control of blood sugar level maintained? Bernard correctly identified the liver as a reservoir for glucose (where it is actually stored in a modified form known as glycogen), releasing it into the blood as necessary by the body's cells. He believed that the central nervous system played a direct role in the control of glucose levels, but we know today that the control center is located in the pancreas in clusters of cells called pancreatic islets or islets of Langerhans. Within these clusters are two types of cells, alpha and beta cells. Both have chemical sensors that are sensitive to the amount of glucose in the blood, but each has a different concern. Alpha cells become active when they detect blood glucose levels below 90 ml/10 dl and respond by producing glucagon, an enzyme whose principal effect is to stimulate the liver to release some of its store of glucose into the blood. Beta cells work in a complementary fashion, since they are sensitive to high levels of blood glucose and react by producing insulin, an enzyme that has the effect of removing glucose from blood. Through this complementary action of pancreatic alpha and beta cells, blood sugar level is controlled within narrow limits in spite of disturbances provided by fasting, eating, and physical activity. This vital control is conveniently accomplished automatically without awareness or conscious effort on our part.

Blood sugar is just one of the many aspects of our internal environment that must be closely controlled for the normal functioning of our cells. Other essential variables are body temperature, water and salt concentrations, oxygen and carbon dioxide levels, and acid-base balance. It is probably no coincidence that their control provides us with an internal liquid environment that in many respects is similar to the warm sea in which our first single-celled ancestors evolved. As Bernard wrote in 1878, the year of his death:

> The living organism does not really exist in the *milieu extérieur* (the atmosphere, if it breathes air; salt, or fresh water, if that is its element), but in the liquid *milieu intérieur* formed by the circulating organic liquid which surrounds and bathes all the tissue elements; this is the lymph or plasma, the liquid part of the blood, which

in the higher animals is diffused through the tissues and forms the ensemble of the intracellular liquids and is the basis for all local nutrition and the common factor of all elementary exchanges.

The *stability of the milieu intérieur* is the primary condition for freedom and independence of existence; the mechanism which allows of this is that which ensures in the *milieu intérieur* the maintenance of all the conditions necessary to the life of the elements (Bernard; quoted in Robin 1979, p. 258).

By "freedom and independence of existence," Bernard was not referring to metaphysical freedom of will. Rather he was describing the physical autonomy that allows organisms such as humans to survive in many different and often quite harsh environments despite the chemical and physical fragility of cells that make up our bodies. He saw this control of the inner environment as the primary distinguishing feature of life, what makes life possible and can be understood without recourse to vitalistic principles or phenomena.

It is intriguing to consider that although Bernard was an important proponent of a materialist view of life that made use of then-current knowledge of physics and chemistry, his conception of the organism as a regulator of its internal environment was in an important sense inconsistent with one-way cause-effect models of the physical sciences. If I pour sugar into a glass of water, the concentration of dissolved sugar in the water will increase. If I put a glass of cool water in the warm sun, the temperature of the water will rise. If I apply force to a chair by giving it a shove, it will either slide across the floor or fall over (depending on the amount of friction between chair and floor). These are all examples of the one-way, input-output causality of Newtonian physics in which a physical cause has a direct physical effect.

But Bernard pointed out that living organisms can and do react quite differently to such physical events. If I inject 200 milliliters of a 50% sugar solution into a vein in my arm, my blood sugar concentration may increase for a short while, but the activation of beta cells in my pancreas will soon produce enough insulin to restore my blood to its normal level of sugar. If I leave a cool room to sit in the warm sun (or vice versa), it will have little if any effect on my core body temperature (although the clothes I am wearing will slowly become warmer). And if I give another person a shove, it may well have no effect other than to have him stand his ground and shove me right back.

It seems as if the body actually "wants," "intends," "desires," or "wills" to maintain a certain concentration of blood sugar (90 mg/10 dl), temperature (98.6° F), and physical location (its current one). And it does what it has to to maintain these variables in spite of the types of physical disturbances that would have a noticeable effect on a nonliving object (for contrast, consider what effects these actions would have on a dead body). Although it would always be possible to apply a disturbance so large that the organism would lose control (such as a rapid intravenous injection of a liter of corn syrup, or an eight-hour stay in the sauna, or a shove from a bulldozer), control of important, life-sustaining variables is usually quite well maintained despite many typical disturbances we and other organisms continually confront.

In other words, although he did not describe it exactly this way, Bernard discovered that physiological systems are *purposeful and goal-directed*, designed to maintain constant conditions despite physical disturbances. In this sense, in their stubborn and active resistance, these systems were quite unlike anything that Newton or subsequent physicists had studied. Bernard's unprecedented knowledge of the materialist internal workings of organisms led to an appreciation that they functioned in a purposeful manner to maintain the physical conditions essential for life.

Walter Cannon and Homeostasis

It appears that Bernard's closest associates were much less impressed by this new understanding of the organism's control of its internal environment than they were by his experimental findings listed earlier. It was not until the twentieth century that this knowledge would be appreciated, expanded, and disseminated on the other side of the Atlantic, primarily by Walter Cannon (1871–1945) of Harvard University who, in his research on digestion, was the first to use X rays in the study of physiology. (Like Marie Curie, another pioneer in the use of X rays, Cannon's death was apparently due to the lethal accumulation of radiation he received while conducting his research.)

In his 1932 book *The Wisdom of the Body* (revised in 1939), Cannon published the results of his research team at Harvard's physiological laboratory on the functioning of many mammalian physiological systems, introducing a term that would become universally recognized in the field (1939, p. 24):

> The constant conditions which are maintained in the body might be termed *equilibria*. That word, however, has come to have a fairly exact meaning as applied to relatively simple physico-chemical states, in closed systems, where known forces are balanced. The coordinated physiological processes which maintain most of the steady states in the organism are so complex and so peculiar to living beings—involving as they may, the brain and nerves, the heart, lungs, kidneys and spleen, all working cooperatively—that I have suggested a special designation for these states, *homeostasis*. The word does not imply something set and immobile, a stagnation. It means a condition—a condition which may vary, but which is relatively constant.

In addition to making the concept of homeostasis widely known and continuing the line of physiological research begun by Bernard, Cannon made other important theoretical contributions. One of these was the evolutionary perspective that he brought to homeostasis through which he saw the evolution of "advanced" or "higher" organisms as involving attainment of more sophisticated systems of control. He recognized the influence here of Belgian physiologist Léon Fredericq who in 1885 wrote:

> The higher in the scale of living beings, the more numerous, the more perfect and the more complicated do these regulatory agencies become. They tend to free the organism completely from the unfavorable influences and change occurring in the environment.

Expanding on this idea and obviously influenced by Bernard as well, Cannon noted that "lower animals" such as the frogs can control neither the water content of their bodies nor their internal temperature and can therefore live only in and near water and at moderate temperatures. During cold winter months, a frog must burrow into the mud at the bottom of its pond or lake and remain there until warmer temperatures return. The "more highly evolved" lizard is able to control against loss of water and therefore can live in dry environments like deserts. But because reptiles are also unable to control their body temperature, they, like frogs, cannot remain active when the temperature falls. "Only among higher vertebrates, the birds and mammals, has there been acquired that freedom from the limitation imposed by cold that permits activity even though the rigors of winter may be severe" (Cannon 1939, p. 24). Evolutionary biologists usually refrain from using potentially misleading terms such as "lower," "higher," or "advanced" to compare organisms. Nonetheless, the notion that evolution can provide organisms with increasingly sophisticated control systems is an important insight to which we will return in a later chapter.

Cannon also understood that the mammalian nervous system was divided into two main parts, "one acting outwardly and affecting the world about us [today known as the somatic or 'voluntary' nervous system], and the other [the autonomic nervous system] acting inwardly and helping to preserve a constant and steady condition in the organism itself" (1939, pp. 25, 26). It is here that he appeared to come very close to recognizing that an organism's external actions, like its internal physiological ones, are also part of an essential process of control.

In retrospect, however, one can find serious limits to Cannon's understanding of the control achieved by biological systems. For instance, he provided no formal functional or mathematical analysis of the homeostatic systems he investigated, although he did implicitly recognize that such systems involved the functioning of a circle or loop. Notice, for example, how in the following sentence he begins and ends at the same place—the carbonic acid level of the blood (1939, p. 288):

> If the hydrogen-ion concentration of the blood is altered ever so slightly towards the acid direction, the especially sensitive part of the nervous system which controls breathing is at once made active and by increased ventilation of the lungs carbonic acid is pumped out until the normal state is restored.

On the other hand, Cannon did not explicitly recognize or appear to appreciate the essentially non-Newtonian character of physiological control processes, as is evident in his one-way, cause-effect, push-pull account of body temperature regulation that makes no mention of an internally specified goal state or purpose (1939, pp. 200, 201).

> If conditions are such that there is a tendency to tip the organism in one direction, a series of processes are at once set at work which oppose that tendency. And if an opposite tendency develops, another series of processes promptly oppose it. Thus quite automatically the remarkable uniformity of the temperature of the internal environment is preserved, in opposition to both internal and external disturbing conditions.

Nor did Cannon recognize that many mammalian physiological systems are not strictly homeostatic but rather are capable of achieving and maintaining themselves at different states according to changing needs. This phenomenon, called *rheostasis* (Mrosovsky 1990), is similar to changing the setting on a thermostat resulting in a cooler, though still controlled, room temperature. Despite these limitations, Cannon made a major contribution to understanding the body's "internal wisdom," and his concept of homeostasis eventually found its way into all modern physiology textbooks.

5

The Engineering of Purpose: From Water Clocks to Cybernetics

He devoted himself to alchemy, in which he claims to have uncovered miraculous things, and inventions of wonderful furnaces, among them one that will maintain the fire at any degree of heat desired, whether hotter or colder.

—N. C. Fabri de Peiresc (1624; referring to Cornelis Drebbel's thermostatic furnace; translated in Mayr 1970, p. 56)

Let us consider a car following a man along a road with the clear purpose of running him down. What important difference will there be in our analysis of the behavior of the car if it is driven by a human being, or it is guided by the appropriate mechanical sense organs and mechanical controls?

—Arturo Rosenblueth & Norbert Wiener (1950, p. 319)

The Use and Understanding of Feedback Control

Although Bernard and Cannon recognized the self-regulatory nature of the living systems they studied, an explicit, formal understanding of such systems did not develop from this physiological research but rather had to await the attempts of engineers to make purposefully behaving machines using what is now called *feedback control*.

Devices making use of feedback control go back at least as far as the Hellenistic period (Mayr 1970). The first documented device was designed by Ktesibios, a barber and mechanic living in Alexandria during the third century B.C. when that north African city was the scientific and intellectual center of the world (Euclid, Archimedes, and Eratosthenes were just three of Ktesibios's fellow Alexandrians whose names students of astronomy and mathematics will recognize).

Ktesibios's water clock required a steady, unvarying flow of water to measure accurately the steady, unvarying flow of time. But because water flows more quickly from a full container and more slowly when it is less full, Ktesibios had to devise a way to keep the vessel at a constant level while water was flowing from it into the clock mechanism. As he did this in a manner not unlike that of the modern flush toilet to which it is assumed the reader has handy access, I will use this more modern invention instead of the water clock as our first example of a feedback-control device.

The modern flush toilet must have a certain amount of water on hand for each flush to be effective. For this purpose, most residential toilets make use of a holding tank into which water accumulates between flushes. Since too little water in the tank does not allow adequate flushing and too much is wasteful (it will simply flow out through an overflow drain), a mechanism is used to maintain the water at the desired level. This mechanism consists of a float resting on the surface of the water that is connected to a valve. When the water level falls after a flush, the float falls with it and in so doing opens a valve, admitting water into the tank. But as the tank fills and the water level rises, so does the float, eventually closing the valve so that the tank does not overfill.

For the reader who has not already peered inside a flush toilet tank, it is well worth lifting the lid and taking a look. With the tank lid off and the flush lever activated, one can observe in live action the events described: the tank empties, the float falls, the valve turns on, the tank refills, and the valve shuts off. It is also informative to push lightly on the flush lever for a few seconds so that just a portion of the water in the tank escapes into the bowl. This will show that the tank need not be emptied completely before the float valve mechanism acts to refill the tank. If all is operating properly, the float-valve mechanism will not let the water remain very much below the desired level.

What is this desired level? Inside most tanks a line indicates the optimal amount of water for flushing the toilet. If the water level in your tank is above or below this line, it can be changed by adjusting the float's position on the link that connects it to the valve. By changing the distance between the float and the valve, you can control the water level that will be reached before the valve turns itself off.

Notice the phrase I used in the preceding sentence—"the valve turns itself off." Is this actually the case? Isn't it rather that the rising float causes the valve to close? Yes, of course. But what is it that causes the float to rise? Obviously, the water that is filling the tank. And why is the water entering the tank? Because the valve is open. And what will cause the valve to close? The rising water level. So the valve, through a series of events, does in a sense close itself, since the valve's opening eventually causes it to close again.

If it seems that we are going around in a circle here, it is because we are. All feedback-control devices make use of what is called a *feedback loop*, meaning that the effect the device has on its environment is *fed back* to the device. In the case of the toilet tank, the falling of the float causes the valve to open, but the resulting inflow of water causes the float to rise again. So the action of the float is fed back to itself, having the consequence that the float simultaneously *affects* the water level and is *affected by* the water level. And since a low water level results in opening the valve, which raises the water level, this is called a *negative*-feedback system. This contrasts with a *positive*-feedback system, which tends to drive itself to extremes, as when a microphone is placed too close to an amplifier's loudspeaker, resulting in an annoying howl or squeal as sounds are continuously amplified, picked up by the microphone, and reamplified. A positive-feedback toilet tank (if such a useless thing existed) would be one that filled itself when it already had too much water. Since all positive-feedback devices drive themselves to extremes, they cannot be used alone to establish control and so cannot be referred to as feedback-*control* systems (although it is possible to establish certain kinds of control by using a negative-feedback system to control a positive-feedback one).

All feedback control must therefore ultimately rely on negative feedback. We can see now why such a system is called a feedback-control device, since the effect (feedback) of the environment on the device is controlled by the device itself. The operation of the feedback loop should also make it clear that a type of *circular causality* is involved that is quite unlike the one-way, push-pull causality characteristic of physical objects and systems not organized as feedback-control systems.

The usefulness and convenience of the toilet tank feedback-control system becomes more apparent when the system malfunctions. If the valve no longer opens when the water level drops, the human user must then refill the tank manually after each use, taking care not to add too much or too little water. It can be appreciated that the float valve provides a very convenient form of automation that replaces irksome human labor.

Many other feedback-control devices have been designed and used since Ktesibios's water clock, from a Byzantine oil lamp of the third century B.C. that automatically maintains a proper level of oil for burning, to the "fantail" used in eighteenth-century England and Scotland to keep windmills facing the wind. But the device that first attracted worldwide attention and use was the speed governor for steam engines invented in 1788 by Scottish engineer and inventor James Watt (1736–1819).

The invention of the steam engine marked a turning point in human history since it provided a source of mechanical power that for the first time did not depend on the vagaries of wind or water, or the muscles of human or beast. But one problem with the early steam engine was that its speed was sensitive both to the amount of steam pressure generated in the boiler and to the work load placed on the engine. Watt's ingenious solution was to make use of a combination of centrifugal force and gravity acting on a pair of metal balls (called flyweights) spinning on each side of a vertical rotating shaft so that if the speed of the engine increased, the flyweights would spread apart due to centrifugal force. This operated a valve that decreased the flow of steam to the engine so that the slower speed would be restored. If instead the engine's speed decreased, the centrifugal force acting on the flyweights would decrease so that they would be pulled down by gravity, thereby increasing the amount of steam delivered to the engine. In this way, the engine's speed remained constant in spite of fluctuating steam pressure and work loads without requiring a human operator to monitor it and attempt to keep it constant by manually operating a steam valve or changing the amount of heat applied to the boiler. The negative nature of this feedback control is apparent since anything that would tend to decrease the engine's speed would result in an increase in steam delivered to the engine, thereby keeping its speed constant, whereas anything that would tend to increase the speed would result in a decrease in steam delivered to the engine, thereby maintaining its speed.

An early important application of feedback control to electrical systems was achieved by Harold S. Black, an engineer for Bell Laboratories in New Jersey. Black had been wrestling with the problem of designing amplifiers for a transoceanic telephone system. In 1927 he figured out how to use negative feedback to amplify telephone signals by a known amount in undersea cable amplifiers using vacuum tubes that aged and lost amplification year by year and had to be placed on the ocean floor where they were needed to function for perhaps twenty years without maintenance. Black achieved this by building amplifiers with much more amplification than required and then "throwing away" most of it by using negative feedback. The result was an amplifier whose characteristics were almost immune to changes in the vacuum tubes. As a bonus, the fidelity of amplification was greatly increased, changes in available electrical power had practically no effect on the telephone signal, and noise generated in the electronic circuits was markedly reduced relative to the signal (see Bode 1960 for details).

Black's electronic invention used different components from those in the mechanical control systems described above, but the two kinds of systems—the telephone amplifier with negative feedback and the electromechanical negative-feedback control devices—share fundamental similarities, and the same basic laws govern both. In addition, the practice of using schematic diagrams for designing electrical circuits made it clear to Black and other engineers just how feedback-control devices operated: through a feedback loop the system's varying output was used to control its input.[1]

The Birth of Cybernetics

Once the general principles of feedback control were understood, control systems (as engineers refer to them) found widespread use in engineering for automatically controlling processes that were previously not possible or that would otherwise require a constantly attentive human operator. And this brings us back to Walter Cannon, or rather to one of his associates, Mexican physiologist Arturo Rosenblueth.

Rosenblueth, who learned to appreciate the self-regulating nature of living physiological processes through his work with Cannon at Harvard, met and collaborated with MIT mathematician Norbert Wiener and engineer Julian Bigelow. Rosenblueth was knowledgeable about living physiological systems, and Wiener and Bigelow were familiar with new developments in engineering, having developed negative-feedback systems during World War II for aiming antiaircraft guns at enemy airplanes.

They realized that for a machine to behave as a human operator would, it had to be goal directed, and this could be achieved only by designing it as a negative-feedback-control system. This design constraint provided an important clue about the organization and behavior of living organisms. In their influential 1943 paper "Behavior, Purpose, and Teleology," the three men were the first to establish a clear link between animate behavior and that of feedback-control systems designed by engineers. In addition, they maintained that purposeful behavior, whether that of human or machine, did not require the usual impossible teleological assumption of a future cause having a present effect. Instead, purposeful behavior could be explained by present causes having present effects, although now with causation acting in a circular manner.

Pursuing these ideas further, Wiener published a groundbreaking book in 1948, *Cybernetics*, that promised to revolutionize the study of animal and human behavior. In *Cybernetics* (revised in 1961), Wiener continued his application of the principles of feedback control to living organisms and in so doing developed the first formal, mathematical analysis of the types of self-regulatory systems that Bernard and Cannon studied.

But Wiener went beyond physiology. One way of appreciating the breadth of his cybernetic work is to recall Cannon's division of the nervous system into inward-acting (autonomic, involuntary) and outward-acting (somatic, voluntary) systems. Cannon, like Bernard, realized that the function of the autonomic system was to ensure a stable internal environment, maintaining vital conditions such as blood pressure (by varying heart rate and blood vessel constriction and dilation), blood oxygen concentration (by varying respiration), and body temperature (by varying the rate of metabolism and by initiating perspiration or shivering). Cannon, being a physiologist and not a behavioral scientist, was not particularly interested in the function of the somatic or outgoing nervous system, the one that innervates muscles attached to limbs permitting locomotion and other voluntary actions on the external environment. But if the purpose of the autonomous, involuntary nervous system is to control the organism's *internal* environment, why not at least consider the possibility that the purpose of the somatic, voluntary nervous system is to control the organism's *external* environment?

This is essentially what Wiener proposed. Indeed, the word *cybernetics* can be roughly translated from its Greek origin as "steersmanship," referring to the process of steering a ship on a course to a desired destination. Recognition that such behavior was purposeful and was used to control aspects of an organism's external environment (in much the same way as physiological functions controlled aspects of an organism's internal environment) promised a radically new foundation for understanding animal and human behavior. This new perspective is diametrically opposed to the traditional one-way cause-effect view that the environment controls an organism's behavior, either directly through stimulus-response connections or indirectly by initiating intervening cognitive processes between stimulus and response. We will see in the next chapter that this new view has revolutionary implications for behavioral science.

6

A Psychological Perspective on Purpose: Organisms as Perceptual Control Systems

The analysis of behavior in all fields of the life sciences has rested on the concept of a simple linear cause-effect chain with the organism in the middle. Control theory shows both why behavior presents that appearance and why that appearance is an illusion. The conceptual change demanded by control theory is thus fundamental; control theory applies not at the frontiers of behavioral research but at the foundations.

—William T. Powers (1989, p. 127)

Two of the three necessary steps toward a thoroughly materialistic model of purposeful behavior have now been described. The first step was Bernard's and Cannon's discovery of self-regulation in the physiological processes controlling internal body conditions such as temperature and sugar level, acidity, and carbon dioxide concentration of the blood. The second was the cybernetic understanding of circular causality as it recognizes the essential role played by the closed loop of action and feedback in control systems designed by engineers and in self-regulating physiological processes and overt behavior of animals and humans.

But something is still missing: we have yet to come to a clear understanding of how *purpose* operates in such systems, including how it can be represented, where it comes from, and how it manages to bring about controlled consequences by varying actions in the face of unpredictable disturbances. In this regard it is noteworthy that in Cannon's influential book *The Wisdom of the Body* the word "purpose" is not even included in the index. And although it is featured prominently in the title of Rosenblueth, Wiener, and Bigelow's seminal 1943 paper, it again is conspicuously absent from the index of Wiener's *Cybernetics* except for its supporting role in referring to the pathological condition known as purpose tremor.

The Purposeful Behavior of a Cruise Control System

To address these crucial issues concerning purpose, we must go beyond our rather mundane toilet tank example and consider a somewhat more complex feedback-control device that will be familiar to many readers who drive cars. This is the cruise control system commonly found on automobiles that automatically maintains a steady speed with no assistance from the driver.

An automobile cruise control system is engaged by first turning it on and then pushing the “set” button after the car has reached the desired speed. This speed, say 65 miles per hour, somehow becomes the system’s goal or purpose (we will soon see how), and the system acts to increase or decrease the amount of fuel it delivers to the motor as necessary to maintain it. So if the car begins to climb a hill or a stiff headwind begins to blow, the system will sense a reduction in speed (being equipped with a speedometer that measures the rate of rotation of the wheels) and will provide more fuel to the engine through a mechanical link to the throttle. This will increase the engine’s power output so that speed is maintained despite the hill or wind. As the car begins to descend the other side of the hill or the wind subsides, the cruise control system will sense the increasing speed and close the throttle, reducing the amount of fuel delivered to the engine so that again the desired speed is maintained. Because it responds to too-high speeds by reducing the amount of fuel delivered to the motor and to too-low speeds by increasing the flow of fuel, the system can be easily recognized as a negative-feedback-control system, identical in function to Watt’s steam engine regulator.

Now that we have seen that a cruise control system automatically maintains a steady speed in spite of varying road conditions, let’s take a closer look at its internal functions to see how it manages to accomplish this. Figure 6.1 is an adaptation of Wiener’s control system diagrams from *Cybernetics* (Wiener 1961, pp. 112, 114). The three boxes indicate the three essential components of a feedback-control system: *sensor*, *comparator*, and *effector.* In a cruise control system, the sensor is a speedometer that converts the rate of wheel rotation to an electrical signal. The signal provided by the sensor is compared with another signal, here labeled “input,” which represents the desired or goal speed of the car.

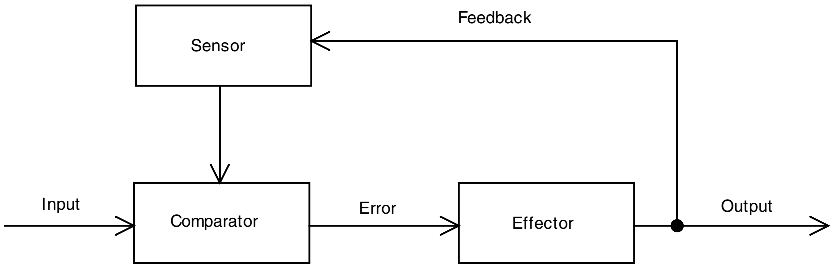

Figure 6.1
Wiener's feedback-control system

The comparator compares the actual speed indicated by the sensor with the desired speed represented by the input signal by subtracting the latter from the former. This comparison results in an error signal, which indicates not only the difference between actual and desired speeds but also the direction in which the actual speed must be changed to match the desired speed. So, for example, if the current speed is 70 miles per hour but the desired speed is 65, subtracting 70 from 65 yields negative 5, indicating that speed has to be reduced by 5 miles per hour. This error signal is then normally amplified and sent to the effector, in this case the throttle that will reduce the amount of fuel provided to the engine until the actual speed matches the desired speed, thereby closing the loop. It should be noted that this is once again a *negative*-feedback system, since the effector increases the amount of fuel sent to the engine if the sensed speed is less than the goal speed, but decreases the delivery of fuel if the measured speed is more than the goal.

It should now be a bit more obvious how the purpose of the system is represented and how it controls the speed of the car. In this diagram, the desired speed, or purpose, is represented by input into the system, which is an electrical signal that indicates the speed of the car when the "set" button is pushed. In this system, as in most engineered feedback-control systems, the desired level of the controlled variable is designed to be manipulable by the human operator. Setting the desired room temperature on a thermostat is another example. In these cases, the goal is provided to the system by a human operator, and is represented in the control system by a signal that is sent to the comparator. The system will then act in a purposeful manner, varying its output as necessary so that the two signals entering the comparator—the signal representing the vehicle's actual speed and the signal representing the desired or goal speed—are the same or very nearly so.

As mentioned earlier, one of the most important insights of the original cyberneticians was the realization that purposefully acting humans and engineered feedback-control systems are alike in certain essential respects. So let us now see how we can use Wiener's diagram to explain the behavior of a human driver controlling the speed of a car the good old-fashioned way, that is, without the assistance of a cruise control system.

We will start again with the sensor. The driver can sense the speed of the car in a number of ways. The speed at which the driver sees road surface approach the car and engine and wind noise (both loudness and pitch) can all be perceived as indicators of speed. But none of these perceptions provides a very precise measure of speed (although I did once know a musician with absolute pitch who claimed she could keep her car at a given speed by keeping the frequency of the engine noise close to a particular musical note!). Fortunately, all cars come equipped with a speedometer that provides the driver with an accurate visual indicator of speed. So the sensor is the driver's eyes and what is sensed is the speed indicated by the speedometer.

But this, of course, is not enough. The driver also has to have a target or goal speed to provide a purpose to his speed-controlling behavior. Let's assume that this goal is the legal speed limit posted as 65 miles per hour. Something within the driver's brain must compare the speedometer reading with the goal speed, subtract the latter from the former, and send the difference (error) to an effector to be acted on. The effector now consists of the muscles of the driver's right leg and foot that act to push down on the accelerator pedal if the perceived speed is less than the goal speed, release the pedal if the perceived speed is above the goal speed, or hold its current position if the perceived and goal speeds match (zero error). Of course, any movement of the accelerator will influence the speed of the car, and this result will be fed back to the speedometer, where the feedback loop from sensor through comparator to effector and back once again to sensor is completed.

So we see that Wiener's basic diagram of a feedback-control system can be readily applied to the purposeful behavior of both machine (cruise control system) and human (driver), even though the physical make-up of the two systems is quite different—electrical wires, sensors, and motors in the former, but living nerves, eyes, and muscles in the latter. However, there is one fundamental difference between machine and driver that seems to have escaped the notice of some early cyberneticians—the origin of what we referred to above as the desired speed or goal speed, but what control systems engineers usually refer to as the *reference level* of the system.

In Wiener's diagram, the reference level is supplied from outside the system and is therefore labeled as an input, since in engineered control systems the reference level can usually be set and manipulated by a human operator. For a cruise control system, the reference level can be changed by pushing the "accelerate" (faster) or "coast" (slower) button until the new desired speed is reached. But there are no "accelerate" or "coast" buttons to be found on the human driver. In fact, the only way to provide input to a human driver is through his senses, as when he sees a speed limit sign or his driving companion asks him to slow down. But there is no guarantee that he will observe such signs or requests. Indeed, our driver may instead decide to speed up when the legal speed limit drops or he is requested to slow down (for example, if traffic decreases or he wishes to annoy his passenger). Or he may slow down when the limit increases or he is requested to speed up (for example, if snow begins to fall or he again wishes to annoy his passenger). So in contrast to the reference level of an engineered control system that is typically provided from the outside by a human user, the reference levels that serve as human goals and purposes seem to originate somewhere inside the brain. If this is the case, it means that the goals of human beings (as well as all other living organisms) are not subject to direct environmental control, as is the case for engineered control systems.

Properties of Engineered and Living Control Systems

We will return shortly to the question of the origin of human reference levels, but only after we first consider some additional ways in which engineered and human control systems are similar. First, although both cruise control systems and human drivers must compensate for many disturbances that would otherwise change the car's speed, they need not perceive the disturbances themselves. The cruise control system has no way of determining whether the road is climbing or descending. Nor can it know if there is a stiff headwind or tailwind, that a heavy trailer was just attached to the car, that a tire is losing air and offering steadily increasing rolling resistance, or that a spark plug has fouled, causing the engine to lose power. All it can sense, and therefore control, is the car's speed. Yet despite its complete ignorance of a multitude of potential and actual disturbing factors, it nonetheless does a good job of maintaining the desired speed. Whereas a human driver may be able to perceive at least some of these disturbances (although wind speed, potentially a very important disturbing factor, is not usually one of these), the performance of the cruise control system suggests that he may not require or use any of this information as long as, like the cruise control system, he pays careful attention to the speedometer reading.

Second, a control system *does not control what it does*. Rather, it *controls what it senses*. The word *control* is used here in its technical sense of maintaining some variable at or near a specified fixed value or pattern of values despite disturbances. Both the cruise control system and human driver can control only what they are able to sense or perceive to be the speed of the vehicle, and they do so by changing output (behavior). Technically speaking, behavioral output is not controlled since the only way the car's speed can be kept close to the reference level speed despite disturbances is by varying the output (that is, changing behavior) as necessary. So we see that a feedback-control system, whether artificial or alive, controls its input (what it senses) and not its output (how it behaves). Consequently, maintaining a constant speed using either a cruise control system or an attentive human driver allows one to predict accurately how long it will take to cover a certain distance. But it will not let one predict how much fuel will be used to drive the distance because fuel consumption is not controlled, varying as it must to compensate for unpredictable disturbances. Since a control system controls what it senses, and since an organism's sensing of the environment is generally referred to as perception in behavioral science, application of control theory to the behavior of living organisms is called *perceptual control theory*. Including the word *perceptual* distinguishes this application of control theory to the behavior of living organisms from the control theory applied by engineers and physicists to artificial (that is, nonliving) control systems.

Third, it is important to realize that whereas a control system's behavior is clearly *influenced* by its environment, it is *not determined* solely by its environment. Rather, its behavior is determined by what it senses (or perceives) of the environment *in comparison with its goal or reference level*. It is worth emphasizing again the crucial difference between non-living control systems designed by engineers and living ones fashioned by biological evolution: an engineered control system is usually designed so that its reference level can be manipulated by the operator, for example, by pushing the "accelerate" button of the cruise control system or by turning up the room thermostat; however, no such direct manipulation of the reference levels of living control systems is usually possible. We can certainly ask a taxi driver to drive more slowly or tell a teenage child to be home by midnight, but we have no way to guarantee, other than by using overwhelming physical force, that either person will comply with our wishes.

Finally, both engineered and living control systems behave in a clearly *purposeful* manner, varying behavior as necessary in the face of unpredictable disturbances to control some perceived variable, in the same way that William James's frog purposefully sought to reach the surface of the water and Romeo sought to reach Juliet's lips (recall chapter 3). This is not achieved by some future state having present effects, but by having a goal state (reference level), comparing it with current conditions (perception), and acting on the difference (error) until it disappears or is made very small.

Note that nothing mystical, psychic, or spiritual is required for this to occur. It is certainly the case that specifying, perceiving, and controlling something like car speed, temperature, or water level in an engineered control system is orders of magnitude simpler than specifying, perceiving, and controlling something like building a house, writing a book, or having a successful career. Nonetheless, the fact that the former can be achieved in a completely mechanistic, materialist way using fairly simple wires, levers, valves, motors, and sensors suggests that the latter can also be achieved just as mechanistically and materialistically using the much more complex neural networks, sensory equipment, muscles, and limbs of the human body.

The cybernetic ideas of Wiener and his associates were greeted with considerable enthusiasm by several leading scientists around the middle of the twentieth century. Between 1946 and 1953 these ideas became the theme of a series of ten meetings sponsored by the Josiah P. Macy Foundation under the title “Feedback Mechanisms and Circular Causal Systems in Biology and the Social Sciences Meeting” that would later incorporate Wiener’s new term in the revised title “Cybernetics: Circular Causal and Feedback Mechanisms in Biological and Social Systems.” But although many leading figures in the biological, social, and behavioral sciences as well as prominent philosophers, physicists, and mathematicians attended these meetings,[1] the revolution in behavioral science that appeared so ready to occur never did.

One reason was that many participants of the Macy meetings were more interested in applying cybernetics to issues in information theory and communication than to biological, behavioral, and social sciences. Those who were eager to apply these new ideas to the life sciences often lacked basic technical knowledge concerning the design and operation of negative-feedback-control systems. One such individual, who later became president of the American Society for Cybernetics, stated that purposeful behavior could be explained in the same way that Newton’s theory of gravity explained the behavior of a drop a water sliding down an inclined plane, totally disregarding the closed-loop character of purposefully acting systems (reported by Powers 1989, p. 261)!

Another factor in cybernetics’ lack of lasting impact on the behavioral and cognitive sciences was the emergence of reliable and powerful digital computers in the middle of the century. The digital computer, with its binary zero-one mode of operation, was better suited to symbolic representations and their logical manipulation as practiced in what has become known as the artificial intelligence (AI) approach to investigating brain, cognition, and behavioral processes. Analog computers, with their use of continuously varying electrical currents that is more amenable to a cybernetic approach to modeling nervous systems, were largely replaced by their digital successors.

Many other reasons could be invoked for cybernetics’ failure to revolutionize the behavioral and social sciences (see Powers 1989, pp. 129–136). But a major factor that is still operating to impede acceptance of the basic cybernetic insight is the difficulty replacing the well-entrenched one-way cause-effect (stimulus-response, input-output) model of animate behavior with the more complex cybernetic notion of circular causality. And just such a replacement is needed to account for purposeful behavior in which causes are simultaneously effects and effects are simultaneously causes. It wasn't until the 1960s when another combination of two engineers and a medical researcher began to formulate a general feedback-control theory of human behavior.

Understanding Behavior as the Control of Perception

The Contributions of William T. Powers and His Associates

These three individuals were physicist and electrical engineer William T. Powers, physicist Robert D. Clark, and clinical psychologist Robert L. McFarland, who in the 1950s worked together at the Veterans Administration Research Hospital in Chicago. In 1960 they published a two-part article with the title "A General Feedback Theory of Human Behavior." Thirteen years later in 1973 Powers published the first book that focused exclusively on the application of cybernetic and control-system concepts to animal and human behavior. His book finally made good on the cybernetic promissory note issued by Rosenblueth, Wiener, and Bigelow thirty years earlier.

Powers made three important contributions in extending cybernetic concepts to animal and human behavior. The first was to appreciate fully the revolutionary implications that cybernetics had for behavioral science and to share this insight. As indicated by the title of his book, *Behavior: The Control of Perception*, he recognized that organisms, organized as living networks of negative-feedback-control systems, behaved as they do to control their perceptions. This was a blatant reversal of the then- and still-current mainstream view in behavioral science that perception (of environmental stimuli) controls behavior, either directly (as in behaviorist theory) or through intervening brain-based psychological processes (as in cognitive theory). By turning behavioral theory upside-down, Powers achieved what the preceding ninety-four years of psychological research and theory had not: liberation of psychology from the one-way cause-effect view that sees the behavior of living organisms, like that of inanimate objects, as determined by external forces.

Related to this liberation was Powers's realization—mentioned above in anticipation—that unlike engineered control systems such as thermostats, steam pressure regulators, and cruise control systems, reference levels specifying the goals of living control systems originate from *within* the organism and are neither provided nor directly manipulated by the environment. This raises the question as to what within the organism provides these reference levels and how and why they are provided, leading to Powers's second important contribution: a theory and working model of the *hierarchical* organization of control systems operating within the organism.

A Hierarchy of Perception and Control

To understand this hierarchical organization of control systems and its functioning, it will be useful first to take another look at a simple control system. But this time we will use a more complete diagram inspired by Powers's work that is more appropriate to living control systems than Wiener's diagram.

Figure 6.2 differs in several ways from Wiener's original diagram. First, the reader should take note of the purely cosmetic change from Wiener's horizontal orientation to a vertical one.

Second, a dashed horizontal line divides the control system from its environment. This makes it clear that the system is influenced by the environment only through its sensors (for a living organism this could be any sense organ such as eyes, ears, nose, or touch receptors in the skin), and it acts on the environment only through effectors such as those provided by muscles attached to limbs.

Third, input to the system on the left of Wiener's diagram has been replaced by an entity labeled purpose (6) which provides the reference signal (5) to the control system's comparator (4). Whereas in Wiener's diagram it appeared as if the reference signal came from outside the control system, here its source is clearly within the organism itself. We will return shortly to this important component labeled purpose (6) when we consider the hierarchical organization of living control systems.

Finally, three additional components have been added to the bottom environmental side of the diagram. Controlled variable (1) refers to the particular physical aspect of the environment that the organism is controlling. This can be anything that the organism can see, hear, smell, feel, or otherwise sense. In our example of maintaining driving speed, this envi-

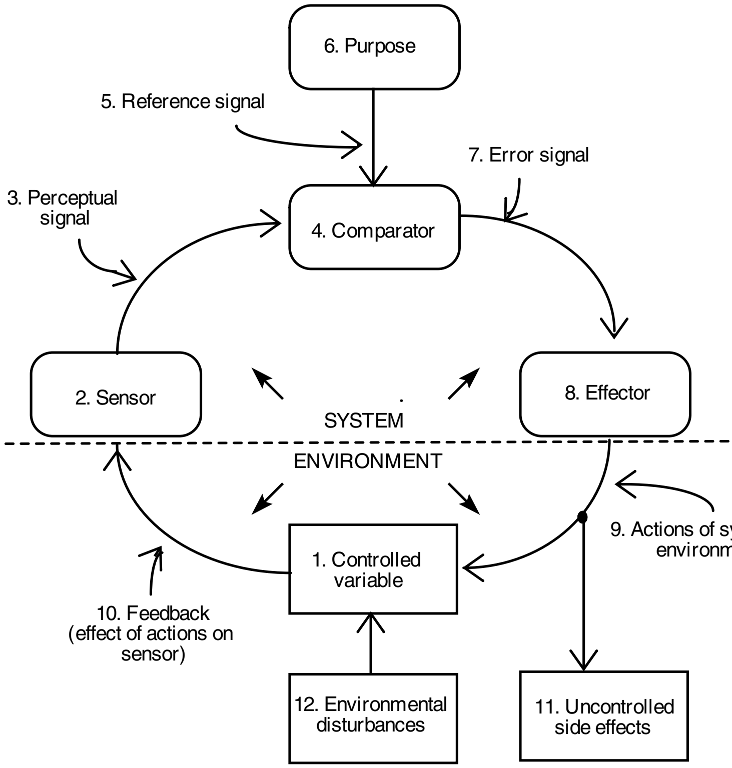

Figure 6.2
Elementary control system

ronmental variable is the position of the needle on the speedometer that the driver must be able to see in order to control the car's speed.

The box on the lower left, environmental disturbances (12), represents all the factors that influence the controlled variable other than actions of the control system itself. In our driving example these disturbances are factors such as wind speed and its direction, and the slope and condition of the road. These are influences for which the driver must compensate so that the car's speed remains under control.

The last addition is the box on the lower right that is labeled uncontrolled side effects (11). This box shows that the actions of a control system, whether engineered or living, will almost certainly have effects on its environment *other* than the desired effect on the controlled variable. Thus, delivering more fuel to the engine while climbing a hill will have effects beyond that of maintaining the speedometer needle at 65 mph. These effects include greater engine noise and vibration, increased use of fuel, higher engine temperature, and faster flow of emissions from the exhaust pipe. These are all unintended effects of maintaining the car's speed, and we will see later how the distinction between intended (purposeful) and unintended (nonpurposeful) consequences of an organism's behavior is crucial for understanding what a living organism is really doing.

Now that we have a more complete diagram showing what is involved in purposeful behavior, let's take a trip around the closed loop it illustrates to ensure that the functions of all its components, labels, and connections are clear. Staying with the example of a human driver maintaining a constant automobile speed of 65 mph, we will start at the controlled variable (1), which is a reading of 65 mph on the speedometer. But as this is an aspect of the driver's external environment (note that it is in the environment half of the diagram), it must be sensed by the driver to be controlled by him. This is done with his light sensor (2), or eyes. (Obviously, if the controlled variable were a sound, taste, smell, feeling, or some combination of these, other sensory systems would be involved.) The driver's visual system converts the speedometer reading into a perceptual signal (3) that is then provided to the comparator (4) that compares this signal with the reference signal (5) of 65 mph provided by the system's purpose (6). The difference between these two signals (3 and 5) constitutes the error signal (7) that causes the effector (8) to act, which in this case is the driver's foot acting on the accelerator pedal. The action of depressing or releasing the pedal (9) influences the driver's environment in many ways. The intended effect of the behavior is its influence on the car's speed and consequently on the driver's perception of the speedometer reading. This effect of behavior on perception through the system's environment is what is referred to as feedback (10). It is this feedback link from actions through the environment back to sensor that completes the loop from controlled variable (1) to sensor (2) to comparator (4) to effector (8) back to controlled variable (1). The box labeled environmental disturbances (10) represents all of the influences on the car's speed that must be compensated for by the driver. Finally, uncontrolled side effects (11) refer to all the unintended consequences of the driver's manipulation of the accelerator pedal (for example, engine and wind noise, fuel consumption, air pressure on the windshield, and engine and tire temperature).

We are now ready to consider where the all-important reference signal (5) comes from. And important it is, since changing this signal from 65 mph to 55 mph will result in an error if the car had been traveling at the previous goal speed of 65 mph, causing the driver to slow down to and maintain this lower speed. Similarly, increasing the reference signal to, say, 80 mph will cause an error in the opposite direction, leading the driver to accelerate to and maintain the higher speed, perhaps even resulting in a speeding ticket (which is probably one good reason why the reference signal will probably not be increased to 80 mph). Since this reference signal representing the control system's goal does not come from the environment (notice how figure 6.2 shows no connection from the environment to the reference signal), it must be provided as the output from some other component of the nervous system. This other component is a higher-level control system that, instead of sending its output to muscles, sends it to the comparator of a lower-level control system.

Powers hypothesized that the nervous systems of animals and humans are made up of many networks of control systems with the basic hierarchical arrangement shown in figure 6.3 whereby higher-level systems send their outputs as reference signals (and thereby constitute higher-level goals) to the comparators of lower-level ones (note that to save space in figure 6.3 comparators are indicated by the letter C, sensors by I for input, and effectors by O for output). For humans, Powers proposed eleven levels of perception. And since each higher-level control system must be able to sense what is happening in the control systems below it, the human control-system hierarchy also requires eleven levels of perception, with higher-level perceptions being made up of weighted combinations of lower-level ones.

Although combining many basic control systems in this hierarchical fashion adds much complexity (and capability) to the overall network, it should be kept in mind that each elementary control system compares its perceptual signal with its reference signal and acts on any difference to reduce it to close to zero. But instead of sending its output to a muscle or group of muscles to act on some aspect of the environment, a higher-level system sends its output to one or more lower-level control systems where it acts as a reference signal for the lower-level systems.

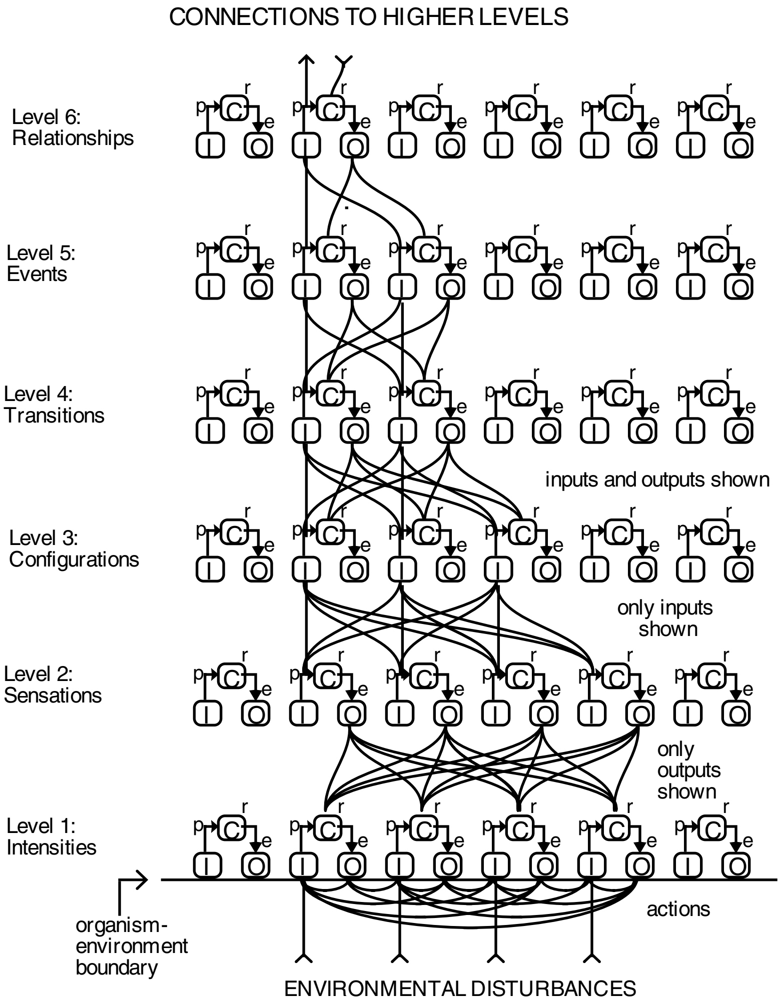

Figure 6.3
A hierarchical network of control systems

This model of the nervous system makes certain predictions about behavior, some of which can be easily demonstrated. But we will save this for a bit later in this chapter where several interesting demonstrations of perceptual control will be described. Instead, let us now consider how Powers's proposed organization provides a new perspective on the physiological control of an organism's inner environment as studied by Bernard and Cannon.

It will be recalled that Bernard wrote of the "constancy of the internal environment" and Cannon introduced the term homeostasis to describe the process by which the body maintains constant internal conditions in spite of the disturbances to which it is continually subjected. But it turns out that at least some of these internal conditions are not so constant after all, and vary in functional ways.

Human body temperature is a particularly interesting example. It is normally maintained close to 98.6° F regardless of ambient air temperature. But we have all experienced fevers during which body temperature increases to 100° or even 102° or 103° F. It used to be thought that these higher temperatures were the harmful effects of bacterial or viral infections. Research has shown, however, that the elevated body temperature characteristic of fever is actually an adaptation in that it helps the immune system eliminate harmful microorganisms. This is accomplished by setting a higher reference level (often called a set point by physiologists) that, like 98.6° F, is also defended against disturbances.

Consider the stages of a typical fever. First, your body temperature begins to rise. But even though it may already be higher than normal, you feel cold and may shiver and put on additional clothing or blankets. This is an indication that the reference level for body temperature has been reset to a higher setting by a higher-level control system. Until your body reaches this new temperature goal you feel cold despite the fact that your body may already be warmer than normal. When your temperature attains the new reference level, you are more comfortable but you feel very warm to anyone who touches you. Finally, your fever "breaks," which means that your reference level for body temperature has been reset once again to its normal temperature of close to 98.6° F. But since it takes a while for your body to cool down to the reference level of the new target temperature, you feel very warm during this time and may perspire profusely until your body temperature once again matches its normal reference level.

While it is not yet completely clear how the reference level for body temperature is manipulated, it is clear that homeostasis is not the best word to describe a control process that involves a changing reference level. Consequently, physiologist Nicholas Mrosovsky (1990) used the term rheostasis[2] to describe such changing reference levels, and he described many such varying reference levels, including those involved in body weight, calcium stores, blood acidity, blood gases, and blood pressure.

Control of body temperature holds further interest since for humans and many other animals it may involve voluntary overt behavior in addition to involuntary internal physiological processes. Shivering and constriction of blood vessels close to the skin are two automatic physiological responses designed to raise body temperature by generating and retaining heat. But a human may also act on the external environment to raise body temperature, as when a person puts on a sweater, adds another log to the fire, prepares and consumes a hot drink, turns up the room thermostat, or adds insulation to the attic. Behavioral means of regulating body temperature are particularly noticeable in cold-blooded animals (technically *ectotherms*) that have no internal physiological means of controlling body temperature. Lizards climb up the sides of rocks and walls in the early morning to catch the first warming rays of the sun. The desert iguana will move closer to a source of heat (such as an electric lamp in laboratory conditions) when infected with a pathogen, thus producing a reptilian version of fever that facilitates elimination of disease-causing microorganisms (see Mrosovsky 1990, p. 77).

Humans can control many variables that are much more complex than body temperature. Imagine for example that Mary, living in San Francisco, learns that her son has become ill in New York City and is being cared for in a hospital there. It is very likely that this situation would be disturbing to Mary in many ways and she would likely feel compelled to make arrangements to visit her son during his illness. We could invoke all kinds of reasons for why Mary is going off to New York, such as love for her son, concern for his well-being, or even that she was rewarded in some way for previous visits she made either to her son or to other individuals in similar situations. But another way of understanding Mary's actions is that she sees herself as a good and loving mother, and not visiting her son during his illness would constitute a serious disturbance to her self-perception.

This is surely a much more complex variable than body temperature or driving speed, but the basic principles of perceptual control are still applicable. For Mary to control her perception of herself as a good mother, she will have to manipulate many lower-level reference levels and control the many perceptions they specify. This is just another way of saying that she will have to accomplish many subgoals to accomplish her higher-level goal of visiting her son. To go from San Francisco to New York, she will have to obtain an airline ticket. To obtain her ticket, she must telephone an airline or travel agent. This involves pushing buttons on her telephone, accomplished by manipulating the tension of her arm muscles in a certain pattern. Only if all these (and many other) lower-level perceptual-control systems are successful in achieving their goals (each subject to unpredictable disturbances) will Mary be able to visit her son and thereby control her perception of herself as a good mother. Doing so, however, will likely cause disturbances to other goals she has, such as those related to her family and work in San Francisco. Thus goals can be related to each other within the same hierarchy as lower-level and higher-level, but can also be situated in different hierarchies, creating the possibility of someone being "of two minds" with accompanying stress and conflict.

The What, Why, and How of Behavior

Powers's model of a hierarchy of perceptual control systems provides a new way of understanding the what, how, and why of animal and human behavior and how this understanding is very different from views provided by other psychological theories.

We will first consider the what of behavior. When behaviorism came to dominate American psychology at the beginning of the twentieth century, one of its major goals was to make psychology a "real" science like physics, and *objective* measurement of behavior became an essential part of its methodology. The number of seconds taken by a rat to run through a maze, the rate at which a pigeon pecked at a key, and the number of times a child disrupted his class during a day at school are examples of behaviorists' objective measurement of behavior. But whereas many aspects of an organism's behavior can be measured by such apparently objective means, such an approach ultimately fails to be either objective or useful. This is because every behavior has very many consequences, and all that a behavioral scientist can ever do is describe one or more *subjectively selected consequences*.

Take the example of Mr. Smith walking down the street. By mentioning walking, I already described one of the consequences of his behavior, namely, that his legs are moving in such a way as to propel him over the ground. I could conceivably obtain more quantitative data about his behavior, such as the frequency of his gait, the speed of his travel, or the force with which he pushes his feet against the ground. But he is also doing many other things that I might have described. He may be out for exercise, calming himself after an argument with his wife, breaking in a new pair of shoes, or going to buy a newspaper at the corner store. He is probably also breathing, perspiring, and even slowly wearing out the soles of his shoes. These are all possible consequences of his behavior, but it is not at all obvious from simply observing Mr. Smith walk down the street which of these descriptions, if any, provides the best answer to the question, what is he doing?

So how does one provide an objective account of behavior when there are so many possible behavioral consequences from which to choose? Figure 6.2 provides a clue. Note that when a control system acts on its environment it has two major types of behavioral consequences. One is that some aspect of the environment, what we called the controlled variable (1), is affected. But many "uncontrolled side effects" (11) are also brought about. Objective observation and measurement do not themselves tell us which of the many effects that one's behavior has on the environment is being controlled—that is, which is the one for which there is a reference level and therefore matters to the individual.

A perceptual control system analysis informs us that one or more of these behavioral consequences matter to the behaving system, and others do not. But how do we find which consequences are being controlled by the individual's behavior and which are unintended side effects? Fortunately, the nature of perceptual control is such that it may be quite easy to find out which is the controlled variable because disturbances to this variable will be resisted whereas disturbances to uncontrolled aspects of the environment will not be resisted. This method of finding out what a particular behavior is intended to accomplish is called the test of the controlled variable by Powers, or more simply, the test.

Let us consider how we might apply the test to Mr. Smith. If we guess that he is out for exercise we might offer him a ride to wherever he is going. His refusal to accept would be consistent with the hypothesis, since a car ride would disturb his goal of getting exercise; but if he accepted, the hypothesis would not look good. If we suspected that he is out to buy a newspaper, we might tell him that the corner store is out of newspapers but the vending machine in the other direction still has some and then observe his actions. A change of heading toward the vending machine would be consistent with the newspaper hypothesis and no change of direction would be evidence against it.

In the case of human behavior, we might save ourselves considerable trouble by simply asking what someone is doing, or more accurately, what he or she is attempting to achieve by his or her actions. But although we may obtain useful information in this way, we have no guarantee that it will be accurate, particularly if the individual has some reason to conceal the real motives for his or her actions or is not conscious of them. And asking is not an option when dealing with very young children or animals.

So we see that perceptual control theory provides a new approach to understanding the what of behavior. Because an action on the environment is initiated when there is a difference (error) between a goal (as represented by a reference signal) and one's current perception, a useful answer to what one is doing is the intended consequence of the behaving organism. Jack may knock over a glass of wine into the lap of his dining companion while reaching for the salt, but a wine-stained skirt was not the intended consequence of his behavior, only the rather unfortunate unintended side effect of the combination of a reference signal for more salt on his steak and the location of the salt shaker behind his glass of wine. The goal-based analysis of behavior provided by perceptual control theory not only provides a new approach but in so doing provides, by the test, a scientific method for distinguishing between the intended (purposeful) and unintended (accidental) consequences of behavior, a distinction that is not even considered meaningful in the objective behaviorist approach. Indeed, the key to understanding behavior as the purposeful control of perception is to attempt to perceive the world from the perspective of the behaving organism. In this important sense, behavior is best understood from a subjective viewpoint, not an objective one.

From a control theory perspective, the answer to the question concerning the why of behavior partially overlaps with the answer to the what. To return to our example of Mr. Smith's walk, knowing what he is doing in terms of his goals (say buying a newspaper) is also to answer why he is walking down the street. But as every parent of a young, inquisitive child knows, one can always continue the why game to the next level and ask why he is getting a newspaper.

To answer this question we must make use of the hierarchy of control systems as shown in figure 6.3. As can be seen in this diagram, comparators receive their reference levels (goals) from the output of higher-level control systems. So obtaining the newspaper is a subgoal on the path to satisfying some higher-level goal, one specified in the reference signal to a higher-level perceptual control system. This higher-level goal could be to check the closing stock market prices. And why is Mr. Smith interested in the closing stock quotes? This brings us up one more notch to a yet higher-level perceptual control system that has as its goal the accumulation of wealth. Why accumulate wealth? Perhaps to be able to retire comfortably at age sixty. If, like the perpetually inquisitive child, we keep on asking why, we will eventually run out of reasonable higher-level goals and be tempted to answer with a simple unadorned "because." But the important point for the present discussion is not to provide an accurate list of higher-level goals for this particular example but rather to show that such why questions can in principle be answered by discovering what the next higher-level control system is controlling, and understanding all goals (except perhaps the one or ones at the very top of the hierarchy—more on that later) as being in the service of still higher-level goals.

The final question about behavior concerns how, and once again the hierarchy of control systems suggests an approach. Just as the why question can be answered by finding the reference level of the next-higher control system, the how question can be addressed by considering the reference levels of lower-level control systems. This is because higher-level goals typically require the control of many lower-level perceptual variables, and higher-level systems control their perceptions by manipulating reference levels they send as outputs to lower-level systems. If Mr. Smith discovers in the newspaper that he is not accumulating wealth according to his plan, he will have to modify certain lower-level goals so that, say, he will change his portfolio from 60 percent bonds and 40 percent stocks to 60 percent stocks and 40 percent bonds. Or, more drastically, he may have to modify his plans, postponing retirement from age sixty to sixty-five to ensure that he will have sufficient funds to retire in comfort.

We can now appreciate that answering a what question about behavior is actually more complicated than first suggested whenever we are dealing with a hierarchy of control systems. This is because the control of a variable such as buying a newspaper involves simultaneous control of many lower-level perceptions (such as reaching the store, taking the newspaper off the shelf, and putting a certain quantity of money on the counter). Yet buying a newspaper is itself a lower-level goal from the perspective of the higher-level goal that has set it, such as checking one's investments or preparing for retirement.

So it turns out that there is usually no one simple answer to a what question concerning behavior (e.g., what is he doing?) but rather the answer must be a description of a set of interrelated goals, some of which may be consciously accessible to the individual (if human) but others not necessarily so. Mr. Smith may be consciously aware of his goal to buy a newspaper, but he is certainly not consciously aware of the complex pattern of perceptual control that is involved in walking down the street (so complex, in fact, that no robot has mastered the bipedal gait). He may not even be conscious at the moment of his goal to retire at age sixty. The test, however, can still in principle be applied to any of these controlled variables, and answers to why questions of behavior can be answered only by moving up the hierarchy, whereas answers to how questions can be addressed only by moving down.

Demonstrations of Perceptual Control

We now come to Powers's third and final (as least as presented here) major contribution. Many behavioral scientists have produced block diagrams of their theories of behavior and perception of the types shown in figures 6.2 and 6.3, as well as verbal arguments to go along with them. But Powers took an important step beyond diagrams and words in producing several convincing demonstrations of the phenomenon of perceptual control and simulations of control-theory models of behavior. These models and demonstrations also inspired several other researchers to develop additional working demonstrations. Since they provide a useful hands-on approach to understanding perceptual control, we will explore several of them and see how they exemplify the concepts introduced above.

The Classic Rubber-Band Demonstration

Our first demonstration, developed by Powers (1973, pp. 242–244), only requires for equipment two rubber bands, a coin, a table, and a willing participant. The two rubber bands are knotted together as shown in figure 6.4 and the coin is placed on the table.[3] Seated across from you, your participant puts a finger through one of the two rubber-band loops and you do the same with the other loop. You then ask your participant to keep the knot that joins the two rubber bands centered over the coin while you gradually and repeatedly move your end of the rubber band toward and away from the coin, keeping it taut, but not so taut that it might break.

If your participant understood your request, you will see that the hand he is using to hold his end of the rubber bands mirrors the actions of your own hand. As you pull your end of the rubber bands away from the coin, he pulls in the opposite direction to keep the knot over the coin. And as you move your hand toward the knot, he does the same.

Since the movements of your participant's hand mirror those of yours, a third person observing this demonstration might well conclude that the participant was simply copying your actions with the position of your hand as the stimulus and moving his hand in response. But it is easy to show that this stimulus-response appearance is really just a seductive illusion (referred to by Powers as the behavioral illusion) and not at all what is really happening. This can be shown by blocking your participant's view of your hand by putting a large book (or magazine or newspaper) between your hand and the knot while taking care not to interfere with your participant's view of the knot and coin. You will then see that even with your hand hidden from your participant's view, he will have no difficulty keeping the knot over the coin in spite of your hand's movements. So contrary to what may appear to be happening, your participant is not responding directly to your hand's movements.

We can get a better idea of what is going on here by referring back to figure 6.2. In this demonstration, the participant is the control system above the horizontal system-environment boundary and you are acting as

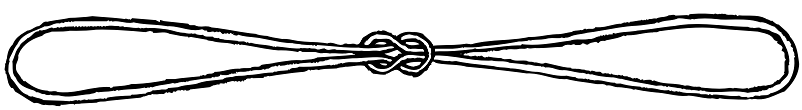

Figure 6.4
Knotted rubber bands

a source of environmental disturbances (12). The participant is able to keep the knot above the coin and achieves this by observing the controlled variable (1) with his eyes serving as sensors (2) that provide a perceptual signal (3) to the comparator (4) that compares the perceived position of the knot with the reference signal (5) provided by his purpose (6). The error signal (7), indicating the discrepancy between the intended perception and actual perception, is sent to the effector (8) that causes muscle contractions to increase or decrease tension on the participant's end of the rubber bands. So whereas your disturbances (12) do result in the participant counteracting them, the diagram makes it clear (as did blocking the participant's view of your hand) that he is responding to disturbances to the position of the knot only because of their effect on the controlled variable (1).

So is it not your movements in themselves but rather their effect on the position of the knot relative to the coin that causes the participant to move his hand. But then isn't it also the case that the participant's actions influence the position of the knot? So what is causing what? Is the position of the knot causing the participant to move his hand, or are his hand movements causing the position of the knot to change? The correct answer, which I hope is obvious by now, is that *both* are happening at the same time: changes in the position of the knot lead to movements of the participant's hand that simultaneously lead to changes in the position of the knot. Here we once again find circular causality operating in a closed loop from perception to action back to perception that defies a one-way, cause-effect analysis.

Computer-Based Demonstrations of Perceptual Control

Although the rubber-band example is a simple and useful demonstration of the phenomenon of perceptual control (and countless variations of it demonstrate other aspects), it does not permit a quantitative analysis of the relationships among disturbance, controlled variable, and action. For this reason, Powers developed a computer demonstration, called Demo 1, that runs on any IBM-compatible computer running DOS (or a DOS window) and that can be obtained on the Internet at *www.uiuc.edu/ph/www/g-cziko/twd*.

Demo 1, the phenomenon of control, provides a computer version of the rubber-band demonstration called a tracking task. The participant's task is to keep a short horizontal line, the cursor, between two target lines (see figure 6.5) by manipulating a computer mouse or trackball, referred to generically as the handle. Instead of pulling on the end of a rubber band, the participant moves a mouse or trackball up and down. Instead of keeping the knot centered over the coin, the participant keeps the cursor horizontally aligned between the two target lines. And instead of you as demonstrator providing disturbances by pulling on your end of the rubber band, disturbances are generated automatically by the computer program.

But now the similarities with the rubber-band demonstration end as the computer demonstration is able to store, display, and analyze relevant data. Figure 6.6 shows a typical run of step F of Demo 1 called compensatory tracking. Time is represented along the horizontal axis, which also serves as an indication of target lines. The positions of the handle, cursor (C. Var), and disturbance are represented by the three lines as they change over time during the course of the 30 or so seconds of the run.

The most striking pattern of this graph is the symmetrical relationship between the disturbance and handle, the latter forming a mirror image of the former. This corresponds to the symmetrical movement of the participant's and your hands in the rubber-band demonstration. This result is even more striking using the computer since we know that the participant never saw the disturbance but only its effect on the cursor while the cursor's position was simultaneously being influenced by the participant's movement of the handle. Yet the disturbance and handle movements are

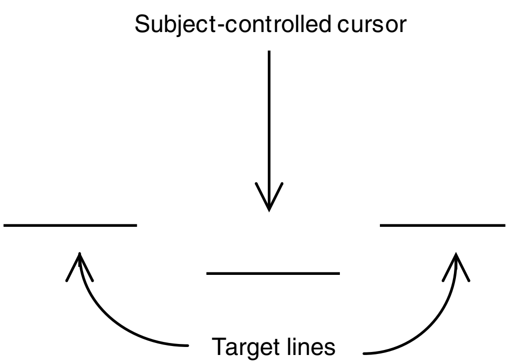

Figure 6.5
Cursor display for Demo 1, compensatory tracking task

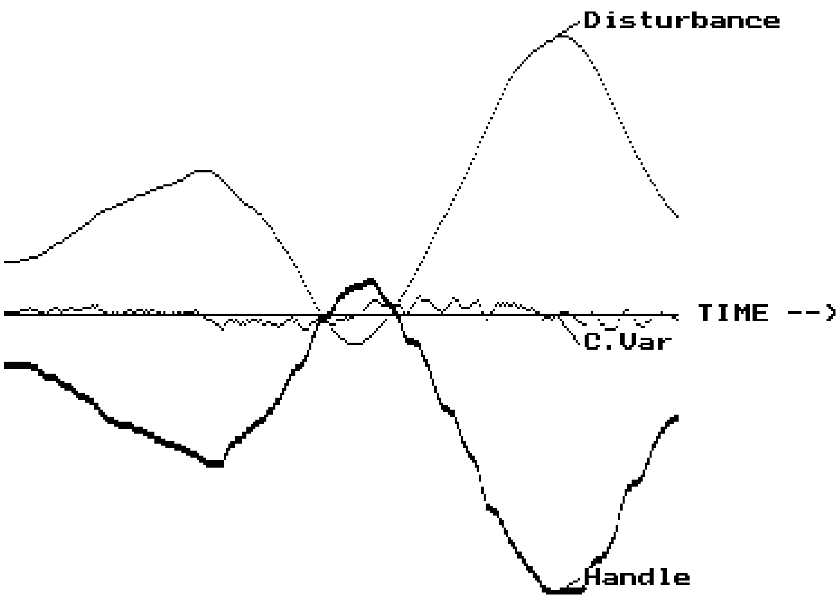

Figure 6.6
Results of Demo 1, compensatory tracking task

very highly corrrelated, with the program indicating for this particular run a correlation coefficient of negative 0.996 between the variables (see box 6.1 for an explanation of correlation coefficients).

Box 6.1
The Correlation Coefficient and Causality

To measure the direction and strength of the relationship between two continuous variables, behavioral scientists use an index called the *correlation coefficient* (usually denoted by the letter *r*), which was developed by Karl Pearson (1857–1936), a British applied mathematician and philosopher of science.

The value of the correlation coefficient varies from -1.00 to 1.00. Its sign (negative or positive) indicates the *direction* of the relationship between two variables, let's call them *x* and *y*. A positive sign indicates a direct relationship, so that as *x* increases *y* also increases and as *x* decreases so does *y*. A negative sign indicates an inverse relationship, so that as *x* increases *y* decreases, and vice versa. As examples, a positive correlation would most likely be found between the height and weight of a group of individuals (since taller people tend to be heavier than shorter people). A negative correlation would likely be found between weight and the number of pull-ups a person can do (since heavier people tend to be able to do fewer pull-ups than lighter individuals).

The *strength* of the relationship between *x* and *y* is indicated by the absolute value of the correlation coefficient, that is, its distance from zero and closeness to either negative one or positive one. Correlation near zero would likely be found between weight and intelligence since heavier people would not be expected to be more or less intelligent than slimmer people. A correlation around 0.7 would likely be found between the height and weight of a group of people, indicating a fairly strong but less than perfect relationship between the variables (it is not perfect since some people will be shorter but heavier than some other people). Perfect (or close to perfect) correlations are not usually found in the behavioral sciences, but can be found in Newtonian physics, such as for the relationship between the mass of an object and the force necessary to accelerate it at a given rate.

It is generally well understood among behavioral scientists that a strong correlation between variables *x* and *y* does not mean *x* is the cause of *y*. First, it may be that *y* is really the cause of *x*. For example, a strong positive correlation may be found for a sample of people between wealth and level of education. Although it may be that wealth leads people to pursue education, it could also be the other way around so that one's education level determines wealth (more highly educated people may earn more money than less-educated individuals). Second, it may be that another variable (or variables) may cause both *x* and *y*, so that wealthy people receive both wealth and educational opportunities from their wealthy parents.

But although a strong correlation does not imply causation, we nonetheless should expect to see a strong correlation between two variables if one of them *is* the cause of the other. For example, if smoking really does cause lung cancer, we should find a strong positive correlation between smoking behavior and incidence of this disease, and we do. This is why in Powers's Demo 1 it is of such interest to find a near-zero correlation between what the participant sees and what he does, since this is strong evidence that what the participant does (response) is *not* directly caused by what he sees (stimulus). Instead, what the participant does *controls* what he sees.

Less striking, at least initially, is the relationship between the cursor (which is what the participant saw) and his handle movements (what he did). The small movements of the cursor above and below the horizontal axis of the graph indicate that the participant was successful in keeping the cursor close to the target position but did not achieve perfect control. And the correlation between the cursor and handle in this run was only 0.179, which is quite close to zero as far as its strength is concerned. But it is this near-zero relationship that is remarkable since we might naively expect what the participant saw to influence what he did. Once we realize, however, that what he *did* also influenced what he *saw* (he was, after all, using his behavior to control his perception of the cursor), the lack of relationship makes more sense. The lesson being, once again, that the circular causality characteristic of perceptual control does not work according to rules of one-way cause-effect phenomena characteristic of the behavior of nonliving objects. In Demo 1 the indication that the participant is actually controlling his perception of the cursor is that there is virtually no measurable one-way relationship between what the participant saw and what he did.

This rather curious characteristic of perceptual control is demonstrated more clearly in step I of Demo 1, intentional vs. accidental effects. In this demonstration, there are now three cursors between the target lines (see figure 6.7). All three are influenced by the participant's movement of the handle, but each is affected by a different disturbance. This would correspond to a task in which three knotted pairs of rubber bands were looped around a participant's finger with three separate disturbers on the other ends. Although the participant's actions move all three cursors, having three disturbance patterns means that only one of the three cursors can be kept between the target lines. The participant's task is to pick one of the three cursors to control, and it is the computer's task to figure out which one it is.

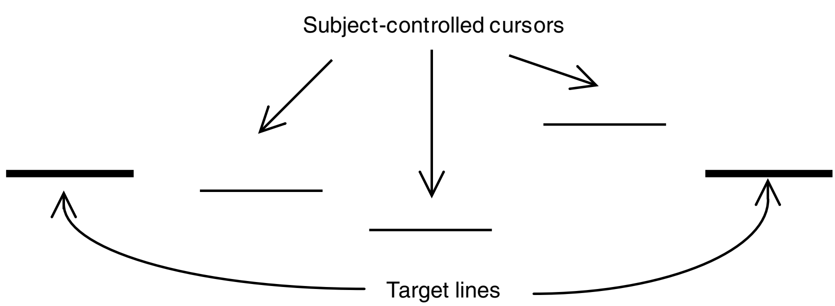

Figure 6.7
Screen display for Demo 1, Step I tracking task

Someone watching the participant do this task would have no difficulty deciding which cursor was being controlled since it is the one that remains close to the target position while the others wander up and down the computer screen. But this is not how the computer makes its decision. It does so by computing correlations between handle movements and all three cursors and picking the cursor that has the *weakest* (closest to zero) correlation with the handle. This counterintuitive approach works very well. In a typical run, correlations between 0.70 and 0.90 are obtained between the handle and the two uncontrolled cursors, while a virtually zero correlation (such as negative or positive 0.10) is obtained between the actually controlled cursor and the participant's handle movements.

An interesting variation of this method of distinguishing the intentional effects of actions from their unintended side effects was developed by psychologist Richard Marken. In his Mind Reading demonstration (developed for Macintosh computers and for Java-enabled Web browsers such as current versions of Netscape Navigator and Internet Explorer) on any computer platform, several numbers (boxes in the Java version) roam the computer screen, each continuously pushed around in two dimensions by its own disturbance. What is seen is not unlike a few scattered fallen leaves being blown around on the ground by its own gusts of wind. But the participant's computer mouse, along with the disturbances, also influences the movements of each number, pushing them all in the same way. By focusing on one number, the participant can control its position on the screen. The participant can decide to keep the chosen number stationary (counteracting its disturbances) while the other numbers continue to be buffeted by their disturbances. In this case it would easy for an observer to find the number being controlled, as it would be the only nearly stationary number on the screen.

But the participant could also decide to move his chosen number in any desired pattern, as in tracing out a circle, square, or figure eight, or even writing his name across the screen with the number. In these cases, since all the numbers will be moving around the screen in irregular patterns, an observer would be hard pressed to tell which one was being controlled by the participant. But the computer only has to find the weakest correlation between the movements of each number and the movements of the participant's mouse to determine which number the participant is intentionally moving. When found, the program indicates the controlled number by highlighting it in boldface. This mind reading of the participant's intentions works no matter what type of pattern the participant imposes on his number, as long as he has an intention concerning where he wants the number to be and varies his behavior to bring about the desired perceptions.

Another program developed by Marken called Find Mind allows the subject to do some mind reading of her own. Now we have numbers (boxes again in the Java version) roaming around the screen as before, but one of them is different from all the others, although this is not at first apparent from watching them move. All the numbers but one have been programmed to move around the screen not "caring" where they roam. If one of these numbers had been programmed to move one inch to the left while a disturbance pushed them all an inch upward, the number would simply move about an inch and a half toward the upper left corner by combining its own movement with that of the disturbance. But one of the numbers represents the actions of a control system with a varying reference signal specifying where it should be at any given instant and the means to counteract disturbances to achieve its goals. As in the previous demonstration all the numbers are influenced by the computer operator's mouse movements, but the one acting as a control system will go where it intends to go (the intention, of course, having been provided in the computer program by the programmer) and will resist disturbances to its movements. By trying successively to keep each number contained in a box at the center of the screen, the user will soon find the one number that has a mind of its own in not "wanting" to be in the box. This one number actually "feels" quite alive in its resistance to the user's mouse-induced disturbances.

These demonstrations were designed to give the user a better understanding of the phenomenon of perceptual control and to show some of its rather surprising characteristics, such as near-zero correlation between perception and action when one's actions are used to control one's perceptions. But Powers and his associates did not stop there. They wanted to show not only that perceptual control is a real phenomenon but that control systems can provide useful working models for animal and human behavior.

Powers's Demo 2, modeling compensatory tracking, leads the user step by step to the construction of a working control system whose behavior in a tracking task is compared with that of the user. In step F, closing the loop, the user sees how a working control system keeps the cursor centered on a target location and how changing the system's reference signal influences the consequences of its behavior. In step J, matching the model to real behavior, the user can compare his behavior to that of the model control system and make adjustments to the model until its behavior closely matches his own. In figure 6.8, the top diagram portrays the computer model's behavior (with plots of cursor, handle, and disturbance provided) and the bottom diagram is that of the human operator. The smaller

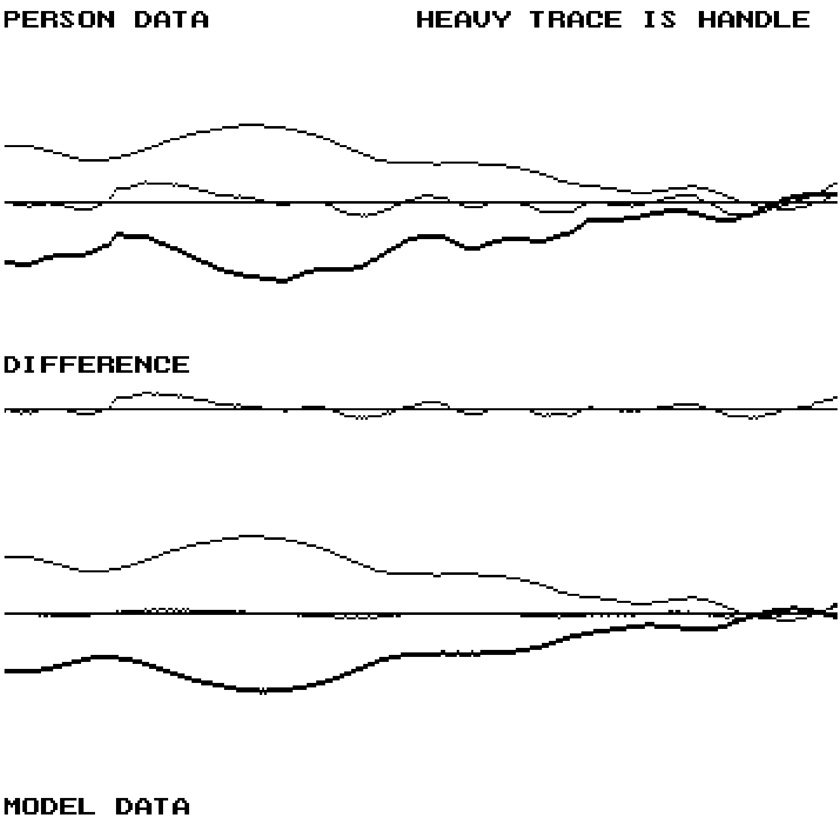

Figure 6.8
Matching person and model data in Demo 2

graphic separating the two shows the difference in their behavior. In the particular case shown, the difference was very small, with the correlation between the control system's behavior and the human's (in this case yours truly) equal to a very strong correlation of 0.986. This near-perfect correlation indicates that the control-system model fits the human's behavior extremely well (it should be noted that correlations stronger than 0.70 are quite rare in the behavioral and social sciences). Thus, Powers's Demo 2 goes well beyond the typical diagram of a psychological theory in that it can be turned into a working model that does what it was designed to do, that is, control some aspect of its environment as a purposeful human performs this same task.

Demonstrating a Hierarchy of Perceptual Control

Powers and his associates also developed a number of demonstrations of the hierarchical organization of human control systems that was described earlier and illustrated in figure 6.3. Recall that in a hierarchy of control systems, higher-level systems send their outputs as reference signals to lower-level systems. In this way the higher-level control systems do not tell the lower-level ones what to do but rather what to perceive as the consequence of their actions. This proposed hierarchical organization has at least two implications. First, it makes some interesting predictions about the performance of certain tasks. Second, it should prove useful in modeling certain types of animal and human behaviors.

Our first demonstration requires a human participant and you as experimenter. First, ask your participant to extend her arm fully toward the front so that her hand is at the same level as her shoulder, and to maintain it in this position. Now you apply disturbances to her extended arm by pushing her hand gently up and down and from side to side. If the participant indeed has the goal of maintaining her arm in this fixed position (as you have asked her to do), she will resist your disturbances, pushing back on your hand with the force required to keep her arm more or less stationary. This is a rather simple feedback-control system of the type shown in figure 6.2, with you acting as the environmental disturbance. You will notice that your participant's control of her arm is not perfect, but she should be able to keep her arm fairly close to her intended position as long as you don't apply too great a force to her hand or make very rapid changes in the force you apply.

Now as your participant maintains her extended arm position, place your own hand above and lightly touching hers and tell her that when given a certain signal she should bring her arm quickly down along her side. The signal will not be a verbal one, however. You will give it by pushing down on her extended hand (remember your hand is already touching hers) when you want her to change the position of her arm. When you provide the signal as described, you will notice a curious reaction from your participant. Instead of quickly bringing her arm down to her side as soon as you push down on it, she will at first resist your push for a fraction of a second. You can do this again and again, and each time this momentary resistance and hesitation will occur. This resistance seems at first rather odd since you are pushing her hand in the direction that she intends to move it. So why does she initially resist your push?

The hierarchical organization of control systems makes it clear why this must happen. By asking your participant to move her hand down when you push on it, you are actually asking her to change her reference signal (goal) for the position of her hand from straight out to down. But the only way this reference signal for hand position can be changed is by the output of the control system above it, the one that supplies the reference signals to the lower control system and is concerned with your participant's higher-level goal of complying with your request. It would be a disturbance to this higher-level system if your participant were to keep her arm and hand extended after you have pushed down on it, and so to correct for this error the higher-level system changes the reference level for the arm-position control system below. But before the higher-level system can perceive the push on her hand, the lower system has already sensed it (since it is lower in the hierarchy) and taken appropriate action to maintain the original position before the reference level can be changed to the new position by the higher-level system. So this momentary resistance and hesitation in bringing her arm down when pushed are exactly what a hierarchical control-system model of behavior predicts.

Many other manual demonstrations of the hierarchical organization could be described (see, for example, Robertson & Powers 1990, p. 21). But we will now move on to another interesting computer program developed by Powers known as Arm 1.

This computer demonstration (which again can be run on any IBM-compatible computer running DOS or in a DOS window) shows both how a hierarchy of control systems could be used to model human pointing behavior and how such a model could be used to create a robot arm. The task for the computer-simulated arm involves bringing its fingertip in contact with the center of a suspended triangular target and maintaining contact while the target is moved anywhere within reach in the three-dimensional space in front of the arm. This may seem to be a rather simple task for a robot arm to accomplish, but it turns out to be quite complicated, as least when pursued in the typical manner of using what the robot sees to compute what it should do. For this one-way cause-effect approach to work, the robot first has to see the target, determine its position in space, convert this position to the angles required at the shoulder and elbow joints for its fingertip to touch the target (this calculation is known in robotics as *reverse kinematics*), and finally calculate the forces required to bring the arm to this position without undershooting or overshooting the target using what is known as *reverse dynamics* (see Bizzi, Mussa-Invaldi, & Gisztér 1991 for evidence of the extreme complexity of this feed-forward approach to pointing to a target).

But this pointing behavior is actually quite easy to accomplish using seven simple control systems, with six of them organized into a two-level hierarchy. At the higher level are three visual control systems, each of which sees both the target and the robot arm's fingertip and also has a reference level of zero for the perceived distance between fingertip and target. One of these visual control systems controls horizontal distance between fingertip and target by sending its output as a reference signal to the comparator of a lower-level kinesthetic control system that controls the side-to-side angle of the shoulder joint. The second of the upper-level visual control systems controls the vertical distance between fingertip and target by sending a reference signal to another lower-level system that controls the up-and-down angle of the shoulder joint. And the third upper-level visual control system makes sure that the fingertip is not behind or in front of the target by controlling for zero perceived difference in the distance of the target and fingertip from the eyes by manipulating the reference level sent to the elbow joint. These six simple control systems, plus a separate seventh one that keeps the robot facing the target, are sufficient to keep the simulated robot pointing to the target as the user manipulates the position of the target in simulated three-dimensional space using the keyboard or a mouse (see figure 6.9). Powers's Arm 2 program does the same, but is more realistic (although slower) in that it includes the effects of gravity on the arm, real arm dynamics (related to the physical characteristics of human arms and muscles), and the possibility for the robot to learn to point more effectively over time (Powers 1999).[4]

Demonstrating Social Systems

Social systems composed of interacting purposeful individuals also were modeled using perceptual control theory. Powers, together with sociologists Clark McPhail and Charles Tucker (1992), developed a program called Gather[5] that models the movements of temporary gatherings of individuals (persons or animals). In these simulations, individuals are programmed as control systems that begin their existence at a certain point on the screen and move to satisfy the reference levels they are given for their locations. Each individual's location goal is either a fixed point on the computer screen or a certain proximity to another individual who also has a goal of either a fixed location or distance to another individual. Each individual also has reference levels for avoiding too-close proximity to other individuals and the fixed obstacles that are scattered across the screen. The user can manipulate the number of individuals, their goals, the number of obstacles present, and various other parameters

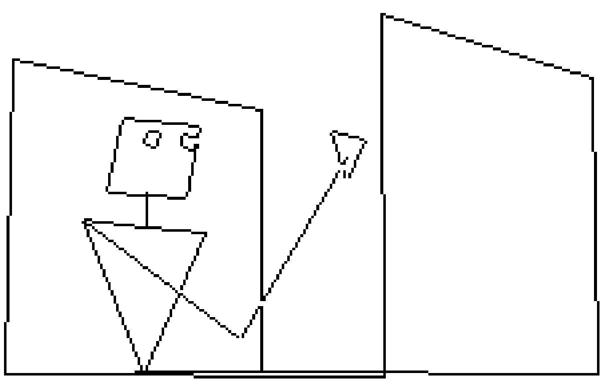

Figure 6.9
Pointing arm simulation

of the individuals' control systems, and see the effects on their collective behavior.

Figure 6.10 is the result of one run of Gather in which one individual, labeled M, moves from the left of the screen to its destination goal in the circle on the right side of the screen. The goals of the four individuals labeled G are not fixed locations but rather the intention to remain close to M without being too close to each other or run into any of the obstacles indicated by small circles.

With the choice of the right control-system parameters, all of the individuals are successful in achieving their goals (as the traces on figure 6.10 indicate) regardless of the distribution of the obstacles they must avoid. Their collective behavior is similar to that of a human mother being followed by her four children across a shopping mall while avoiding other individuals and objects, or a mother goose followed by her four goslings as they waddle from meadow to lake avoiding rocks and trees along the way. It is also of interest to note that the arc formed by the four Gs does not exist as a goal for any of the individuals but rather emerges as an uncontrolled (but reliable) side effect of the outcomes that the Gs are controlling, namely, maintaining a certain distance between themselves and M.[6]

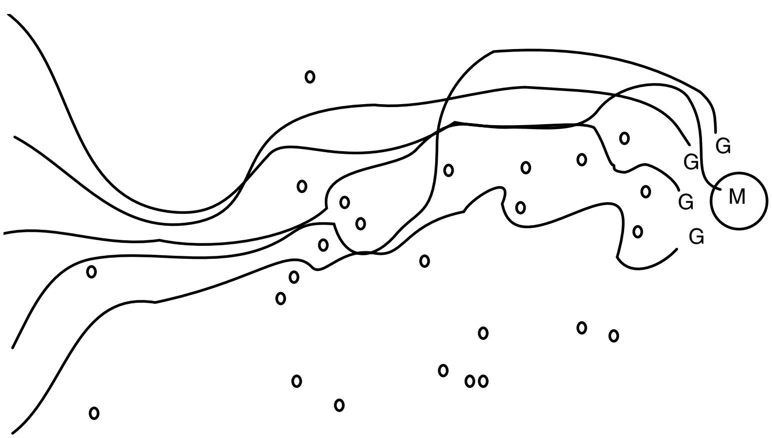

Figure 6.10
Gather simulation of four individuals (G) following another (M) (after McPhail, Powers, & Tucker 1992)

Three Final Demonstrations: Controlling Another Person, "Ballistic" Movements, and the Coin Game

Three final demonstrations, none requiring a computer, are worth describing since each shows another interesting characteristic of perceptual control. The first requires the same knotted rubber bands (see figure 6.4) used in the first demonstration, a table, two coins placed about 10 inches apart on the table, and, of course, our indispensable willing human participant. As in the first demonstration, you and your participant each grasp an end of the two knotted rubber bands, and you ask your participant to keep the knot over the coin that is farther from him. But this time as you watch the position of his hand, you move your hand so that he places his hand over the other coin.

What you have done is controlled the behavior of your participant by "making" him put his hand over the other coin. This control was achieved by knowing what perceptual consequence he was controlling and providing the disturbances that would lead him to put his hand where you wanted it to be. But this control of your participant's behavior works only as long as he maintains his goal of keeping the knot over the more distant coin and *does not care* (that is, has no higher-level goal or reference signal for) where his hand is located over the table. If either of these conditions no longer holds (your participant either no longer wishes to comply with your request to keep the knot over the one coin, or does not want to keep his hand over the other coin) you will no longer be able to control his behavior without recourse to overwhelming physical force. This indicates a general principle of the control of one person's behavior by another: Other than using irresistible physical force, an individual can control another individual's behavior (or more accurately, the *outcome* of his behavior) only by causing disturbances to goals that will elicit the desired behavior, and only if the desired behavior does not disturb the goals of higher-level control systems.

Another example shows the fallacy of the common belief that certain so-called ballistic behaviors take place too quickly for continuous sensory feedback to be involved in their execution. Two such behaviors are hammering and throwing a ball or stone. Neurobiologist William Calvin (1990, p. 239) made just such an argument and proposed it as a factor contributing to the evolution of the human brain:

> . . . ballistic movements [are] quite unlike the ones where an intention and feedback corrections suffice to get the job done: Brief movements have to be carefully planned in advance. Any trial and error has to be done while planning, checking a proposed movement against memory as you "get set," and discarding the plans that don't jibe.

To see if feedback can actually be used in these actions, one has to figure out how to apply a disturbance to the behavior while it is occurring and see if it is resisted to any extent. This can be easily done by attaching an elastic band to your participant's wrist (I use a large loop of rubber about an inch wide cut from an old bicycle inner tube) and have him throw or hammer while you apply a disturbance by pulling on the elastic band after his action has begun (still better would be to use two elastic bands with two disturbers pulling on one, or the other, or both, or neither so that the participant could not anticipate what the disturbance would be).

For throwing I have my participant throw a tennis ball underhand from a distance of about 15 feet against a chalkboard on which a target consisting of a circle of about 1.5 feet in diameter has been drawn. For hammering, I place a coin on a table and let the participant hammer on it with his closed fist (it's technically pounding, not hammering, but much easier on the table if not on the fist). While disturbances applied by the elastic band will likely have some effect on the accuracy of throwing or hammering, the effects are quite small compared with the magnitude of the disturbance. This is something you should also experience as the thrower or pounder with your participant attempting to disturb your actions, since you will experience how you automatically adjust your actions "on the fly" to compensate for the disturbances.

The fact that these disturbances can be corrected after the throwing or hammering action has begun indicates that negative-feedback control *is* involved in these supposedly ballistic behaviors. If they were the result of preplanned motor commands (as Calvin and many others believe), no real-time corrections would be possible at all. The results of these demonstrations are instead consistent with the operation of a hierarchy of control systems in which upper-level systems do not tell lower-level systems what to *do* (that is, provide motor commands) but specify what lower-level systems should *perceive*. The controlled perception is that of a certain sequence of joint angles (known as *proprioception*) that has been associated with the perception of previously successful throwing or pounding and that will itself be adjusted by still higher-level systems depending on the perceived outcome of each trial. It is important to note that a form of associative learning is occurring here. But it is not that of associating a stimulus with a behavior. Rather, it is associating higher-level controlled perceptions with lower-level ones.

The final demonstration is the coin game devised by Powers (1973, pp. 235–236). It shows how difficult it can be to figure out what perception another person is controlling, even when you have the opportunity to make repeated disturbances and guesses.

To play the game you need four coins, a table, and your human participant. Have your participant first arrange the coins in any configuration she wishes (for example, rectangle or square, or even something like two coins closer to each than the other two coins are to them or to each other) and ask her to write down in words on a piece of paper the configuration or condition that she has adopted as her goal. You as experimenter attempt to guess what your participant is controlling by disturbing the coins any way you wish and having the participant say "no error" or correct the error (by moving a coin or coins) that you have created. Once you are fairly certain that you know what the participant is controlling, test your hypothesis by making three moves, each of which you believe will be corrected by the participant, followed by three moves you believe will cause no error. If successful, you then describe what you believe to be your participant's controlled variable (such as, any three coins in a straight line) and compare it with what the participant wrote down.

Playing the coin game will reveal how difficult it can be to determine what the participant is "doing" (actually, what perception she is controlling) even though her actions are completely visible to you, and you can repeatedly disturb the configuration of coins and observe her reaction. Of course, the game is none other than a form of the test for the controlled variable mentioned earlier and provides an illustrative example of how the test can be used to understand another person's behavior.

I hope that I have provided useful descriptions of these demonstrations and what they reveal about the process of perceptual control. Verbal descriptions alone, however, cannot come close to providing the understanding and insights that hands-on experiences with these demonstrations can provide. For this reason, I strongly urge that readers take the time to do at least the rubber-band demonstrations, and that those with access to a personal computer and the Internet obtain and try out the computer demonstrations. Only in this way can one realize that seeing behavior as the control of perception is not just another cute slogan or cliché, and that cybernetic models of perceptual control are more than just boxes and lines on pieces of paper. Rather, perceptual control is a real and easily demonstrated phenomenon that cannot be understood from the traditional one-way cause-effect view of animal and human behavior, and networks of negative-feedback perceptual control systems can be fashioned into working models that behave remarkably like the purposefully behaving animals and humans that they were meant to simulate. Most important, however, is understanding that we now have a basic theory (and model) of animal and human behavior that can explain its purposeful nature in purely materialist and mechanistic terms, but which requires a rejection of the one-way cause-effect view of living behavior.

The Puzzle of the Ultimate Why Question

We have now seen how considering animate behavior as an organism's means to control aspects of its environment provides a new way of addressing questions concerning the what, how, and why of behavior. From this perspective, what questions are addressed by considering the perceptual variable that an organism is controlling, keeping in mind that any given action may have many uncontrolled side effects that are of no concern to the behaving organism, and that the behavioral consequences specified in reference levels need not be static but instead can be continually changing.

How questions are answered by considering the subgoals, or lower-level reference levels, that must be controlled for a higher-level perceptual variable to be controlled. From this perspective, a professional golfer is able to drive her ball onto the green not because her nervous system is able to send a certain fixed sequence of motor commands to her muscles, but because she has learned to control a sequence of lower-level perceptions involving the positions and velocities of her limbs, head, and trunk, as well as the relationship of these kinesthetic and proprioceptive perceptions to the visual perception of the green she is aiming at.

In contrast to behavioral how questions that focus our attention on lower-level control systems and their reference levels, why questions about behavior are addressed by moving up the hierarchy of control systems to find higher-level reference levels (or goals) that determine lower ones. Someone observing my behavior at this moment would notice that I am currently tapping keys on my computer. Why? To make certain letters and words appear on my computer screen (not to make the tapping sound that accompanies each keypress, although objectively my typing is creating noise as well as words). Why make these words appear? Because I want to write and publish a book. Why write and publish a book? Maybe to became famous and make lots of money from royalties (not very likely). Or perhaps so that I can make a lasting contribution to human knowledge (somewhat more likely?). But why bother contributing to human knowledge (I could be outside enjoying this beautiful late spring day rather than sitting in my office in front of a computer)? Good question. As we have noted earlier, as we continue to ask why questions about behavior we usually come to a point at which we no longer can easily imagine what words to put after "because."

But the hierarchy of goals posited by perceptual control theory provides at least a framework for considering answers to why questions. And the answers we find are very different from the ones proposed by one-way cause-effect theories that look for answers not within the organism but rather in the effects that the environment has on the organism. Because we attempt to answer these questions by searching for the next higher-level control system and its reference level, these can be considered the proximate causes of behavior.

But for any theory of behavior to be complete, ultimate causes of behavior must also be considered. We observe a robin pecking in the soft earth during a rainstorm and understand its behavior as a way of getting food in the form of earthworms into its stomach. But why earthworms and not the seeds that the sparrows and finches consume? A male robin pursues a female until she allows him to mount her. From where did this urge to copulate come? We later see the female robin regurgitating her food into the gaping mouths of her newly hatched chicks. But why should she share her hard-earned food with this chorus of seemingly insatiable little beaks?

Similar questions concerning the ultimate reasons for behavior could easily be posed for humans, but answers cannot be found by staying within an individual organism's hierarchical network of perceptual control systems. Instead, we have to consider the process responsible for life itself and its continued evolution.

III

Behavior and Evolution: Then and Now

7

The Evolution of Animal Behavior: The Impact of the Darwinian Revolution

Darwin's theory of natural selection came very late in the history of thought. Was it delayed because it opposed revealed truth, because it was an entirely new subject in the history of science, because it was characteristic only of living things, or because it dealt with purpose and final causes without postulating an act of creation? I think not. Darwin simply discovered the role of selection, a kind of causality very different from the push-pull mechanisms of science up to that time. *The origin of a fantastic variety of living things could be explained by the contribution which novel features, possibly of random provenance, made to survival. There was little or nothing in physical or biological science that foreshadowed selection as a causal principle.*

—B. F. Skinner (1974, p. 36; emphasis added)

People and animals are most remarkable for the things they do. Inanimate objects and forces certainly can impress us, as when a tornado plows through an American prairie town, a volcano erupts in Indonesia, an earthquake wreaks havoc on a Japanese city, or a comet pays a visit to our corner of the cosmos. But most of the objects that we encounter tend to stay in one place unless pushed or pulled in some way by an animal or person.

Living animals and people are different. They can burrow, crawl, walk, run, hop, climb, swim, and even fly to get where they want to go. Many animals engage in complex rituals for attracting mates and employ clever tricks for finding food, avoiding enemies, and raising their young. They build elaborate structures such as spider webs, beehives, coral reefs, bird nests, and beaver dams to provide shelter and to obtain food and store it for themselves and their associates. Some even make and use tools. One particular species, *Homo sapiens*, has transformed a considerable portion of the earth's surface, covering it with farms, highways, parking lots, houses, shopping centers, and skyscrapers.

Watching all this activity, the curious mind must wonder why all these organisms do what they do. Further reflection suggests that there are really two different types of why questions to consider about the behavior of animals and humans. One concerns immediate or *proximate* explanations. In the previous chapter we learned how seeing animate behavior as the means by which organisms control perceived aspects of their environment provides one set of answers to why questions. A cybernetic, control-system perspective allows us to understand purposeful behaviors in terms of the goals they achieve, such as attracting mates, obtaining food, finding (or building) shelter, avoiding enemies, or caring for offspring.

But we have also seen that this goal-based view does not address the ultimate questions having to do with why such goals (and the perceptual control systems that serve them) appeared in the first place. This is a particularly interesting question when we consider the many complex behaviors (and their consequences) of animals and humans.

This chapter focuses on these questions concerning animal behavior and chapter 8 deals with human behavior. We will see how the proposed answers go beyond the model inherited from Newtonian physics to arrive at a very different type of explanation first proposed by a reclusive English naturalist well over a hundred years ago.

The How and Why of Animal Instincts

When we observe the actions of animals we notice two rather distinct types of behaviors. One type consists of acts that every individual of a given species is somehow able to perform without first having to experience them performed by others, and without being in any way guided or instructed in them. Thus a mother rat will build a nest and groom her young even if she is raised in total isolation and has never seen other female rats engage in those acts (Beach 1955). The behaviors involved in the caterpillar's spinning a cocoon, the spider's weaving a web, the beaver's constructing a dam, and the honeybee's sculpting a honeycomb are additional examples of complex behavior that seem to be somehow built into these organisms.

The other type of behavior consists of acts that appear to be influenced by an animal's own particular experiences, and it is here that we notice striking differences in individuals of the same species. A circus performance shows us what dogs, bears, horses, lions, tigers, and elephants can do when provided with certain types of experiences. Dogs do not normally walk upright on their hind legs, bears are not to be seen riding motorcycles through the woods, or seals balancing beach balls on their noses in the Arctic. Yet these creatures can perform these and other unnatural acts if given a special type of environment provided by a circus and its animal trainers.

Similarly, whereas all normal, healthy children manage to breathe, laugh, cry, walk, and even talk without explicit instruction, such is not the case for reading, writing, mathematics, and music performance skills. The development of these latter abilities normally requires many years of explicit instruction coupled with many long hours of practice. Of the two types of behaviors, the first is typically referred to as *instinctive*, *innate*, or *inherited*, and the second as *learned* or *acquired*.

Two interrelated questions can be asked concerning instinctive behaviors of animals. The first deals with their origin and the second deals with their propagation. It is important to address the questions separately, but we will see that the most satisfactory answer we have to each turns out to be very much the same. We will also see that the answer to the ultimate why question provides an answer to the question of how these behaviors originally came about.

Instinct Through Divine Providence

One view of instinctive animal behavior came to us in the Western philosophical tradition through the writings of Aristotle, Thomas Aquinas, and Descartes, and remained popular and virtually unchallenged through the eighteenth century. This view attributes the source of instinctive behavior to an all-knowing creator. As Thomas Aquinas reasoned in the thirteenth century:

> Although dumb animals do not know the future, yet an animal is moved by its natural instinct to something future, as though it foresaw the future. Because this instinct is planted in them by the Divine Intellect that foresees the future. (1265–1273/1914, p. 470)

Later in the eighteenth century the views of followers of Aristotle and those of Descartes differed in many respects concerning animal behavior. But like Thomas Aquinas they agreed that complex animal behavior could be explained by an appeal to instincts that they understood as blind, innate urges instilled by God for the welfare of his creatures.

It is within this tradition of Christian thinking that we find William Paley (1743–1805), an English archdeacon, theologian, and philosopher. The Reverend Paley saw in the instinctive behavior of animals convincing evidence for the existence, goodness, and wisdom of God. He made his point by emphasizing those behaviors that could not possibly have been the result of learning during the lifetime of the organism. Thus he described (1813, p. 306) how moths and butterflies

> deposit their eggs in the precise substance, that of a cabbage for example, from which, not the butterfly herself, but the caterpillar which is to issue from her egg, draws its appropriate food. The butterfly cannot taste the cabbage—cabbage is no food for her; yet in the cabbage, not by chance, but studiously and electively, she lays her eggs. . . . This choice, as appears to me, cannot in the butterfly proceed from instruction. She had not teacher in her caterpillar state. She never knew her parent. I do not see, therefore, how knowledge acquired by experience, if it ever were such, could be transmitted from one generation to another. There is no opportunity either for instruction or imitation. The parent race is gone before the new brood is hatched.

Paley emphasized that if the animal has no opportunity to learn behaviors that are essential to the survival and continuation of a species, the originator of the behaviors must be God. From this supernatural perspective the question of transmission of behaviors to the next generation simply does not arise, since the behaviors are an integral part of the organism as designed by its creator.

Although such supernatural accounts are no longer held by behavioral scientists, providential thinkers such as Paley must be credited for noticing an important characteristic of these behaviors—that they are essential to the survival and reproductive success of the animal, even though it is unlikely that the animal is mindful of their ultimate function. The providentialists saw the mind of God as the explanation, but other scientists of the nineteenth century were seeking more naturalistic, materialist explanations.

Instinct Caused by the Environment

The work of Charles Darwin's grandfather, Erasmus Darwin (1731–1802), offers one materialist alternative to the providential view of instinct. Erasmus Darwin's annoyance with that view can be seen in his observation that from this perspective, instinct "has been explained to be a kind of inspiration; whilst the poor animal, that possesses it, has been thought little better than a machine!" (quoted in Richards 1987, p. 34). He and other "sensationalists" of the time emphasized the role of *sensory* experience. They believed that all behavior was based on the experience and intelligence of the individual organism, and described ways in which apparently instinctive behavior could be explained as such. But this explanation fared less well with behaviors performed immediately after hatching or birth. A French naturalist's theory appeared, at least initially, to do better.

Although early in his career Jean-Baptiste Lamarck (1744–1829) believed that all species had originally come into existence in much the same form as he observed them during his lifetime, he eventually accepted and promoted a theory of transformation by which over long periods of time organisms could change into new species. He also formulated a materialistic account of how the habits of animals of one generation could be changed into the instincts of their descendants, an account that bypassed Paley's God[1] and proposed instead mechanisms of environmental influence on organisms and their response to these factors.

According to Lamarck, changing environmental conditions forced organisms to change their habits. These changed habits involved increased use of certain body structures and organ systems along with the decreased use of others, with resulting organic changes being passed on to succeeding generations. Since behavior is clearly influenced by biological structures including internal organs and appendages, the inheritance of such modified structures would result in the instinctive behavior dependent on the structures in succeeding generations. In this way Lamarck attempted to provide explanations both for the origin and transmission of new instinctive behaviors.

This materialist theory was well in keeping with the growing scientific naturalism of the nineteenth century, as was its one-way cause-effect character. The latter can be seen in its three necessary components. First, the environment causes a change in an animal's behavior (imagine a bird's environment becoming drier, so that it now has to find, crack open, and eat bigger and harder seeds than it did when smaller, softer seeds were more readily available).[2] Second, this change causes structural changes in the animal, both a result of the new behavior and facilitator of it (the bird develops a larger, more powerful beak, better able to crack bigger and tougher seeds). Third, these changes in structure and behavior are transmitted to the animal's offspring who thereby inherit the new high-performance beak and the (now instinctive) behaviors for using it. As Lamarck explained (1809; quoted in Løvtrup 1987, p. 53),

> Everything which has been acquired . . . in the organization of the individuals in the course of their life, is preserved through the reproduction, and is transmitted to the new individuals which spring from those who have undergone these changes.

In his view the environment causes changes in behavior, which cause changes in body structures, which in turn cause changes in the germ (egg and sperm) cells, which cause instinctive behavior in offspring. This causal chain from environment to behavior to bodily structure to germ cells to offspring has the ultimate effect of producing new organisms that possess as instincts the acquired habits of their parents.

But although Lamarck's theory successfully avoids a supernatural creator, it runs into serious problems of its own. First, how is it that a changing environment causes animals to assume adaptive behaviors? If soft seeds are no longer available, how does the environment cause the bird to search out and attempt to eat larger, tougher seeds? Particularly problematic in this regard are behaviors that cannot be imagined as the result of individual learning, as the egg-laying behavior of the moth and butterfly (in Paley's observation quoted above).

Second, according to Lamarck's principle of use and disuse, body parts that are used a great deal will develop and become more adapted to such use, whereas those that are not used will shrink and atrophy. But, to remain with our example, how will a bird's attempting to crack a seed that is too big and tough for its beak cause its beak to become bigger and stronger? We all know from our attempts to repair things that using a tool that is too small or weak will usually ruin the tool (and often what we are trying to fix), not make it bigger and stronger. As another example, consider that our shoes do not grow thicker soles the more we walk in them, nor do they become thin by being left unused in the closet. On the contrary their soles wear out from extended use and maintain their original condition only if not used. Now it is clearly the case that among living organisms we see what appear to be Lamarckian effects of use and disuse, as when someone begins to exercise and develops larger muscles and then stops and loses them again. But something more than a direct physical cause-effect phenomenon must be involved here because these adaptive results are not what we see happening in the objects we use where continued use leads to wear and tear and eventual breakdown, but disuse results in preservation.

Third, we must consider if the structural and behavioral changes an organism undergoes during its lifetime actually cause similar changes in its offspring. Lamarck was so convinced that such acquired changes were passed on to offspring that he wrote that the "law of nature by which new individuals receive all that has been acquired in organization during the lifetime of their parents is so true, so striking, so much attested by facts, that there is no observer who has been unable to convince himself of its reality" (1809; quoted in Burkhardt 1977, p. 166).

Indeed, the belief that acquired characteristics were inherited by one's offspring was well accepted in Britain and Europe throughout most of the nineteenth century, yet it turns out that there was never any good evidence for it whatsoever. A man and a woman who develop large and strong muscles either through hard physical labor or sport do not have a son or daughter who is born with similarly well-developed muscles. A man and woman who both become proficient pianists will not produce a child who can instinctively play the piano. And as German embryologist August Weismann (1834–1914) rather gruesomely demonstrated, chopping off the tails of several generations of mice does not produce successive generations of tailless mice or even mice with shorter tails. Weismann consequently made an important distinction between those cells of the body that are passed on to the next generation in reproduction (germ cells) and other cells that are not (somatic cells). He held that changes to somatic cells could in no way cause corresponding changes to germ cells. Separation of these two types of cells remains today as a generally recognized barrier to Lamarckian inheritance of physical or behavioral characteristics so that the habits acquired by one generation cannot become innate instinctive behaviors in a later one.[3]

So we see that while Lamarck attempted to provide a naturalistic, non-providential account of instinctive behavior, his theory (referred to by some as *instructionist*, since it assumes that the environment can somehow directly cause or instruct adaptive changes in behavior) failed at every posited cause-effect relationship, from environment to behavior, from behavior to somatic cells, and from somatic cells to germ cells. Clearly, a radically different explanation was needed.

Instinctive Behavior as Naturally Selected

Just such a radically different explanation was proposed by Charles Darwin. Darwin's initial attempt to explain instincts had much in common with Lamarck's theory. He believed that beneficial habits that persisted over many generations would make heritable changes in the organism leading to instinctive behavior in later generations. Gradually, however, he became dissatisfied with the idea of inherited habits as the sole explanation for instinctive behaviors, particularly when he realized (as Paley had before him but Lamarck apparently had not) that many of these behaviors (such as the moth laying eggs in cabbage) could not have originated as habits. Another example is provided by British natural theologian Henry Lord Brougham who wrote in 1839 about the female wasp who provides grubs as food for the larvae ("worms") that will hatch from its eggs "and yet this wasp never saw an egg produce a worm—not ever saw a worm—nay, is to be dead long before the worm can be in existence—and moreover she never has in any way tasted or used these grubs, or used the hole she made, except for the prospective benefit of the unknown worm she is never to see" (quoted in Richards 1987, p. 136). We know that Darwin was intrigued by this observation since he wrote in the margin of Brougham's book "extremely hard to account by habit." It was, in fact, more than "extremely hard" since "an act performed once in a lifetime, without relevant experience, and having a goal of which the animal must be ignorant—this kind of behavior could not possibly have arisen from intelligently acquired habit" (Richards 1987, p. 136).

So in keeping with his theory of natural selection for the origin of species, Darwin began to see instincts not as results of inherited useful habits but as consequences of the reproductive success of individuals already possessing useful habits (although he never completely abandoned the former idea). Natural selection thus provided an explanation for instinctive behaviors that never could have originated as habits, such as the wasp's egg-laying behavior.

Darwin's selectionist theory of instinct differs fundamentally from Lamarck's one-way cause-effect (or instructionist) theory of evolution. For Lamarck, the environment somehow caused (directed, instructed) adaptive changes in organisms that were passed on to future generations. It is this direct, causal effect of environment on organism that constitutes the one-way push-pull character of Lamarckian theory. But in Darwin's selectionist theory, individuals of a species naturally vary their behavior, with the environment playing no active, instructive role in causing this variation. Instead, the environment's role is restricted to that of a type of filter through which more adaptive behaviors pass on to new generations and less adaptive ones are eliminated. Darwin's selectionist explanation is distinctly different from Lamarck's in that the behaviors offered to the scrutiny of natural selection are not caused by the environment but are rather generated spontaneously by the organisms.[4]

An example may be useful here. Among Darwin's finches in the Galápagos Islands, one particular species, appropriately called the vampire finch, foregoes the vegetarian diet of seeds and nuts of other finches and prefers instead the taste of blood, obtaining it by perching on the back of a booby (a larger bird) and jabbing it with its pointed beak until it draws blood (see Weiner 1994, p. 17). Since this is the only bloodthirsty finch on the islands, it is reasonable to assume that the species descended from birds that did not drink blood. But because of natural variation in the behavior of its ancestors, some of these finches must have tried pecking at other birds and found some nutritional advantage from the practice, producing more offspring than birds that tried pecking at other objects. Within any one generation, these birds would show natural variation in feeding behavior; and after many generations of variation and selection the vampire finch that we know evolved. So unlike Lamarck's theory, which assumed that an animal's learned behaviors were inherited by its offspring, Darwin's selectionist account of instinctive behavior can work only with a *population* whose individuals already vary in their behavior, selecting behaviors leading to greater survival and reproductive success. Darwin, unfortunately but understandably, hadn't a clue as to why individuals of a species varied in form or behavior, or how these variations could be inherited by following generations. Our current knowledge of genetics and the molecular basis of mutation and sexual reproduction provides answers to these questions and strong support for Darwin's conclusion.

But one particularly thorny problem remained for Darwin concerning instinct, that of the evolution and behavior of neuter insects. The *Hymenoptera* order of insects includes bees and ants together with some wasps and flies. Many of these insects live in well-structured societies where survival depends on a specialized division of labor among the members that is reflected in different castes, such as the queen, drones, and workers in a beehive. Particularly intriguing and troublesome for Darwin's theory of natural selection was the fact that worker castes are often made up of insects that are sterile and therefore have no genetic means of passing on their instinctive behaviors to the next generation of workers. This posed a serious threat to Darwin's theory, as he was well aware.

A solution came after he learned how cattle were selected for breeding to produce meat with desirable characteristics. As described in a book by William Youatt published in 1834 and read by Darwin in 1840, animals from several different families would be slaughtered and their meat compared. When a particularly desirable type of meat was found, it was, of course, impossible to breed from the slaughtered animal. But it was possible to select for breeding cattle most closely related to it to produce the desired meat. In like manner, a colony of insects that produced neuters that helped the survival of the community (say, by taking care of young, providing food, or defending against enemies) would be naturally selected to continue to produce such neuter insects even if the neuter insects themselves could not reproduce. Darwin concluded that "this principle of selection, namely not of the individual which cannot breed, but of the family which produced such individual, has I believe been followed by nature in regard to the neuters amongst social insects" (1856–1858/1975, p. 370).

The concept of kin and community selection became powerful in understanding the evolution of altruistic behavior (to which we will return shortly) and it provided Darwin with an explanation for complex and useful instinctive behaviors that could not be explained by Lamarckian inheritance. But where the inheritance of acquired habits seemed conceivable, particularly when Darwin could see no selective advantage for the behavior, he made use of Lamarckian principles. And since for some reason Darwin was unable or unwilling to see survival or reproductive advantages accruing from the expression of emotions, he explained these as inherited useless habits that existed only because they accompanied more useful ones.

Despite the enormous impact that Darwin had on the life sciences during his own lifetime, he had relatively little immediate impact on the scientific study of animal behavior. One reason for this has to do with methodological difficulties of both naturalistic and experimental research on animal behavior. Another was the heavy use of anecdotal evidence and anthropomorphic interpretation practiced by George Romanes (1848–1894), Darwin's young disciple and defender who wrote extensively about animal behavior and mind from a Darwinian perspective while maintaining belief in the inheritance of acquired habits.

It was not until the 1930s that a serious attempt to study animal behavior from evolutionary and selectionist perspectives was begun. Konrad Lorenz (1903–1989) grew up sharing his family's estate near Vienna with dogs, cats, chickens, ducks, and geese. His observations in this setting eventually led to the founding of the field of ethology, which he defined as "the comparative study of behaviour . . . which applies to the behaviour of animals and humans all those questions asked and methodologies used as a matter of course in all other branches of biology since Charles Darwin's time" (1981, p. 1).

As suggested by this definition, Lorenz was primarily interested in finding evolutionary explanations for instinctive behavioral patterns characteristic of a species. For example, it was brought to his attention that greylag geese reared by humans would follow the first person they had seen after hatching in the same way that naturally hatched goslings waddled after their real mother. Lorenz confirmed these findings and extended them to several other species of birds. This pattern of behavior, resulting from a type of bonding with the first large moving object seen by the hatchling, he called imprinting, and it is for this finding that Lorenz is still best known.

By extending Darwin's theory of natural selection to animal behaviors observed in the field, Lorenz posited a genetic basis for specific behaviors that was subject to the same principles of cumulative variation and selection that underlie the adapted complexity of biological structures. In the case of the greylag goose, goslings that maintained close contact with the first large moving object they saw (which would normally be their own mother) would be in a better position to enjoy her protection and nurturance. Consequently, they would be more likely to survive and to have offspring that would similarly show this behavioral imprinting than goslings lacking this behavioral characteristic. In much the same way that we now understand how a tree frog can become so well camouflaged over evolutionary time through the elimination by predators of individuals that are less well camouflaged, we can understand how instinctive behavior can be shaped through the elimination of individuals whose behaviors are less well adapted to their environment.

Another example of Lorenz's conception of instinctive behavior is the egg-rolling behavior of the greylag goose. When the goose sees that an egg has rolled out of her nest, she stands up, moves to the edge of the nest, stretches out her neck, and rolls the egg back into the nest between her legs, pushing it with the underside of her bill. Lorenz called this a "fixed motor pattern" (1981, p. 108), that is, a sequence of actions generated in the central nervous system of the goose that is released or triggered by the sight of an egg (or other egglike object) outside the nest. In other words it is a fixed sequence of actions released by a specific type of stimulus. The purpose of this instinctive act is clearly to return the egg to the security of the nest, and it is easy to appreciate its value for the continued survival of the species.

But a serious problem with this concept becomes apparent when one realizes that an invariant pattern of actions will not be successful in returning a wayward egg to the nest unless all environmental conditions are exactly the same for each egg-rolling episode. This is, of course, the same problem with all one-way cause-effect theories. Instead, for the goose to be consistently successful in returning an egg to her nest she must be able to modify her behavior not only from episode to episode but also within each episode to compensate for variability in conditions and disturbances that she inevitably encounters, such as differences in the distance between herself and the egg at the beginning of the behavior, and irregularities in the terrain between the egg and the nest. This is another instance of consistent outcomes requiring variable means that William James described as the essence of purposeful behavior. And it is for this reason that Lorenz's stimulus-response analysis ultimately fails to explain the typical success of instinctive actions.

Many good examples of the variability of instinctive behaviors that are directed to fixed, consistent outcomes can be found in a book published in 1945 by E. S. Russell entitled *The Directiveness of Organic Activity*. Here are just three.

1. The larva of the caddis fly (*Molanna*) builds itself a protective case made of grains of sand. If this case is overturned, it will try a remarkable range of behaviors to right it. It will normally first extend its body out of the tube of the case and grip the ground with its forelegs in an attempt to flip the case over sideways. If this does not work, the larva will reverse its position and make a hole in the tail end of the case. Then it will either extend its body out the rear of the case and attempt to twist the case around the long axis of its body, or reach under the case and flip the case over its head. If the ground is very fine, loose sand, the larva will produce silk to bind grains together to make a firmer platform for righting its case. Or it may try to pull its case to another spot where the ground provides better traction. If all this fails, the caddis larva may bite a piece off the roof of the case and use that as a platform for its righting attempts, or even remove an entire wing of the case to flip it over. If the larva is still unsuccessful after several hours of work, it will abandon its case and build a new one somewhere else (Russell 1945, pp. 123–124).

2. The burying beetle (*Necrophorus vestigator*) is so called because it buries small dead animals on which it deposits its eggs. These insects often cooperate in this endeavor, working together to remove soil from under the animal so that it sinks into the earth. If the corpse lies on grass-covered soil, they will bite through the impeding stems and roots. If a mat of woven raffia is placed under the corpse, the beetles will cut through that as well. If a dead mole is tethered to the ground by raffia strips, the beetles will start their usual digging, but when the mole does not sink they will crawl over it, find the tethers, and cut them. If a small mouse is suspended by wires to its feet, the beetles will bite through the mouse's feet. If the suspended mouse is large, the beetles will be unsuccessful, although they may work for nearly a week before abandoning the project. Russell also

reported that when a dead mouse was placed on a brick covered with a thin layer of sand, the beetles spent a few hours trying unsuccessfully to bury it. Then they spent several more hours pulling the mouse in various directions until it was finally dragged off the brick and buried (1945, pp. 125–126).

3. The shore crab (*Carcinus maenas*) moves its legs in a fixed progression when walking forward. If one or more legs are amputated, it is still able to move about, but the order of movement of the remaining legs is changed, clear evidence that locomotion is not achieved by a fixed motor pattern that is inherited and unmodifiable. Similarly, "an insect which has lost a leg will at once change its style of walking to make up for the loss. This may involve a complete alteration of the normal method, limbs which were advanced alternately being now advanced simultaneously. The activities of the nervous system are directed to definite end, the forward movement of the animal—it uses whatever means are at its disposal and is not limited to particular pathway" (Adrian; quoted in Russell 1945, pp. 127).

So it appears that Lorenz was mistaken in insisting on innate fixed motor patterns as the basis for instinctive behavior. But he must nonetheless be acknowledged as the first to attempt to provide a Darwinian account of species-specific behavior patterns, and he was recognized for his achievement in 1973 when he shared a Nobel prize with fellow ethologists Nikolaas Tinbergen and Karl von Frisch. In the same way that biologists constructed evolutionary trees (phylogenies) by comparing the anatomical similarities and differences among living organisms and fossils, Lorenz used patterns of instinctive behavior, basing his comparative study "on the fact that *there are mechanisms of behavior which evolve in phylogeny exactly as organs do* (1981, p. 101). His evolutionary perspective also led him to emphasize that understanding animal behavior involved appreciating its purposefulness in preserving the species, its role in the entire repertoire of the animal's activities, and its evolutionary history.

Whereas Lorenz was successful in going beyond a one-way cause-effect view of the origins of instinctive behaviors, he nonetheless maintained a rather stimulus-response view of the actual behaviors performed. He concluded that evolution works in a selectionist manner, resulting in the emergence of those organisms with adaptive stimulus-response systems that contribute to survival and reproductive success. He was apparently unaware of the need for and existence of an alternative to this account that was as necessary as his selectionist explanation of its origins. And he would have no doubt been intrigued by the type of behavior generated by the Gather computer simulation described in chapter 6 that provides a striking simulation of the mother-following behavior of his beloved geese.

Foundations and Misconceptions

Lorenz placed the study of instinctive animal behavior within a thoroughly Darwinian framework, but his work initially had rather limited impact, especially in the United States. One reason for this was his association with the Nazis during World War II (see Richards 1987, pp. 528–556). Another reason was the then-dominant behaviorist paradigm in North America that was much more interested in learned behavior of rats and pigeons in artificial experimenter-controlled laboratory settings than in naturally occurring behavior of a variety of animals in their natural habitats. But Lorenz's Darwinian initiative eventually had an important impact on both sides of the Atlantic.

Before discussing this impact, it will be useful to outline in a bit more detail the necessary components of a standard evolutionary view of instinctive animal behavior. For evolution by natural selection to occur, three conditions must be met. First, there must be variation in the population of organisms making up a species. Although we may be most accustomed to thinking of this in terms of the physical make-up of organisms (morphology) such as size or coloration of body parts, variation in species-typical behavior can also be observed among individuals of a species, such as in feeding and mating behaviors.

Second, this variation in behavior must have consequences for reproductive success. Measured as the number of viable offspring produced, it requires both survival to the age of reproductive maturity (for which obtaining food and avoiding predators and serious diseases are essential) as well as the ability to find mates and, for some species such as birds and mammals, feed and protect one's offspring.

Finally, variation in behavior influencing reproductive success must be heritable; that is, it must be able to be passed on to the next generation.

Although this inheritance of behavior need not be limited to genetic inheritance (since forms of cultural learning are also possible for many animal species), evolutionary accounts usually emphasize the genetic component.

The importance that a Darwinian view of instinct ascribes to survival and reproductive success should come as no surprise for two reasons. First, if variation in behavior exists and behavior can be inherited by the next generation, clearly those behaviors that were not conducive to survival and reproduction would eventually be eliminated from the species. Any male squirrel that attempted to mate only with pine cones or engaged only in oral sex with other squirrels would simply not have any descendants to continue these innovative (for squirrels) sexual practices. Similarly, any mammal (other than humans or mammals raised by humans) that refused to nurse at its mother's breast would not survive long enough to find a mate and produce nipple-avoiding offspring of its own.

Second, the survival or reproductive function of many striking instinctive behaviors that we see among animals are rather obvious. The spider spins an intricate web. Why? If we watch what happens after the web is complete the answer becomes obvious—to obtain food. A wasp paralyzes a caterpillar with her venom and buries it alive with her eggs. Why? So that her hatched larvae will have fresh food (and not decayed, putrid flesh) when they emerge from their eggs. The male ruff, a European shore bird, spreads its wings, expands the collar of feathers around his neck, and shakes his entire body when a female ruff comes in sight. Why? To attract a mate. The parasol ant carries bits of freshly cut leaves back to its nest. Why? To grow a certain type of fungus that it uses for food. Countless other examples could be given, and indeed much of the appeal of books, films, and television programs about nature lies in their portrayal of such instinctive behaviors that have obvious survival and reproductive functions. And although we certainly need not assume that these animals are in any way conscious or aware of the survival, reproductive, or evolutionary consequences of their actions, the survival or reproductive role that most instinctive behaviors play is either initially obvious or made clear by further research into the life and habits of the particular species.

An evolutionary perspective on behavior can be misleading in at least three ways, however. The first has to do with Lorenz's original conception of instincts as fixed motor patterns. As we saw in the previous chapter, invariant sequences of actions cannot be adaptive in an environment containing unpredictable disturbances. An assembly-line robot may be able to assemble an automobile part by repeating the same motion over and over again, but it is successful only to the extent that its environment is carefully controlled to prevent disturbances from affecting the production line. The real world of living organisms, with its changing weather conditions and the presence of many other (often competing and hostile) organisms, is anything but a carefully controlled production line. In its natural environment an animal's action patterns cannot remain invariant if they are to be functional; rather its behavior must compensate for such disturbances. It is now recognized by at least some ethologists that animal instincts are modifiable by feedback received during execution of behaviors (see Alcock 1993, pp. 35–37).

We saw in chapter 6 how organisms organized as networks of hierarchical perceptual control systems can be effective in producing repeatable, reliable outcomes despite unpredictable disturbances. For an evolutionary perspective on instinctive behavior to make sense, we have to discard the commonly accepted notion that specific behaviors can evolve and be usefully inherited, and instead recognize that it is perceptual control systems and reference levels that are selected and fine-tuned for their survival and reproductive value across generations. We also have to be on guard against the behavioral illusion demonstrated in the previous chapter that makes it seem as though environmental factors (or stimuli) cause behavior, when in fact organisms vary their behaviors to control aspects of their perceived environment.

The second potential danger lurking in evolutionary accounts of instinctive behavior is the tendency to regard genes as *determiners* of instincts and consequently to regard instinctive behaviors as essentially inborn or innate. We know that genes do influence an organism's behavior, as it has been shown repeatedly and clearly that certain genetic differences are associated with striking behavioral differences. For example, changing a single gene in the fruit fly *Drosophila melanogaster* results in male flies referred to as *stuck* since they do not dismount from females after the normal period of copulation (Benzer 1973). Another single-gene difference affects the daily activity cycle of fruit flies. Normally this period is twenty-four hours long, but flies with a particular variation of a gene (referred to as an *allele*) have no fixed activity cycle. Flies with a second type of allele have shortened nineteen-hour activity cycles, and flies with a third allele have lengthened cycles of twenty-nine hours (Baylies et al. 1987).

But whereas individual genes and groups of genes have an important influence on behavior, they alone cannot determine behavior since all development and consequent behavior depend on the interaction of genes and environmental factors, the latter including physical factors such as nutrition and temperature as well as various sensory experiences. In this respect, genes can be thought of as a type of basic recipe for building an organism, while the environment provides the necessary materials and additional crucial information in the form of certain sensory experiences. When viewed in this way, questions concerning whether a given behavior depends more on nature or nurture can be seen to be meaningless, as would be asking whether the appearance and taste of an apple pie depend more on the recipe or on the ingredients. Of course, both are crucially and 100 percent important, since without the recipe (or equivalent knowledge of apple-pie baking) the ingredients are useless, as would be the recipe without the ingredients.

Some striking examples of the necessary interaction of genetic and environmental factors in determining behavior have been provided by the common laboratory rat. A mother rat will normally build a nest before bearing offspring and then groom her newborn pups. That she performs these behaviors even if she is raised in total isolation from other female rats, and so has never seen other rats engage in such behaviors, is the reason that such activities are referred to as instinctive. Nonetheless, certain experiences are necessary for these behaviors to take place. For example, when provided with appropriate nesting materials a pregnant rat will not build a nest if she had been raised in a bare cage with no materials to carry in her mouth. Also, a mother rat will not groom her young if she had been raised wearing a wide collar that prevented her from licking herself (Beach 1955). And failure to groom her babies can have serious consequences, since a newborn rat cannot urinate until its genital area has been first so stimulated, resulting in burst bladders for the unfortunate unlicked pups (Slater 1985, p. 83).

These and other findings indicate that instincts are not behaviors that are somehow completely specified in the genome of an animal, as stated by Lorenz. Rather, they are species-typical behaviors that emerge from the interaction of an animal's genes with the usual environmental conditions. As research shows, a change in either genes or environment can result in a change in instinctive behavior.

A final danger to guard against in taking an evolutionary view of animal instincts is thinking that all instinctive behaviors must be well adapted to the organism's present survival or reproductive needs. Although most instincts appear to have current survival or reproductive value, it does not follow from evolutionary theory that *all* such behaviors do. Certain behaviors may be neutral or even maladaptive side effects of other adaptive behavior. Reasons have been advanced for how certain forms of homosexual animal behavior can improve reproductive success; for example, cows mounting other cows may signal to nearby bulls that the cows are sexually receptive (see also Bagemihl 1999 for a comprehensive review of animal homosexuality). Research suggests, however, that at least some forms of homosexuality, such as that among female macaque monkeys, serves no clear direct or indirect reproductive function and may be simply a side effect of natural selection of animals with high sex drives (see Adler 1977). Such "useless" behavior may be tolerated by natural selection if it has negligible effects on ultimate reproductive success. But we should not expect it to persist for long if it has negative effects on survival and reproduction unless it appears as an unavoidable side effect of some other adaptive behavior that compensates for the effects of the maladaptive one.

In addition, because of the long periods of time required for evolution to shape adaptive instinctive behaviors, there is no guarantee that such behaviors are still adaptive today. Moths used the moon and stars to navigate during their nightly forays for millions of years when these celestial bodies were the only nocturnal sources of light. But the appearance of countless sources of artificial illumination in areas inhabited by humans now has moths spending the night flying in dizzy circles around electric light bulbs, into flames, or onto the electrocuting grid of bug zappers. The distinction between the environment in which a behavior evolved and the current environment where it may be less well suited will become particularly important when we consider human behavior in the next chapter.

The Problems of Altruism and Cooperation

Keeping in mind these potential problems of evolutionary accounts of behavior, we can now turn to some other aspects of animal behavior that first challenged and then showed the value of such an approach. The role of instincts in promoting the survival and reproduction of individual organisms (and therefore continued existence of copies of their genes in future generations) puts a distinctive selfish spin on instinctive behavior. It would initially seem that any behaviors that were helpful to others but costly to the originator should simply not evolve as instincts.

So-called *altruistic* acts, such as sharing food or putting oneself at risk by crying out to warn others of an approaching predator, would appear to reduce the ultimate reproductive success of the altruistic donor while increasing that of its recipients and genetic competitors. Yet these and other apparently altruistic behaviors are commonly observed among animals. A ground squirrel emits an alarm call upon noticing a predator, thereby warning other squirrels but putting itself at greater risk of predation (Alcock 1993, p. 517). A vampire bat regurgitates blood for a neighbor that was unsuccessful in finding its own meal (Slater 1985, p. 178). It was this problem of accounting for the evolution of altruistic acts that attracted the attention of a new generation of British and American biologists in the 1950s, 1960s, and 1970s who were interested in solving this and other evolutionary puzzles about animate behavior.

Among these scientists was British geneticist, biometrician, and physiologist J. B. S. Haldane (1892–1964) who in 1955 provided an important clue. He noted that a gene predisposing an animal to save another animal from some danger, with the potential "hero" running a 10 percent risk of being killed in the attempt, could spread in the population through natural selection if the animal thus saved were a close relative of the hero, such as an offspring or sibling. This is because a closely related individual would have a good chance of sharing the same altruistic gene as the hero, so that a copy of the gene in question would likely be saved even if the hero were to perish by his actions. Haldane also noted that such a gene could even spread, although not as quickly, if the saved individual was more distantly related to the hero, such as a cousin, niece, or nephew. "I am prepared to lay down my life for more than two brothers or more than eight first cousins" (reported in Hamilton 1964, 1971, p. 42) was his way of summarizing this phenomenon.

This was the beginning of the formulation of what is known as *kin selection*, the idea that a gene is not "judged" by natural selection solely on its effects on the individual who carries it, but also on its effects on genetically related individuals (that is, kin) who are also likely to carry a copy of the gene. From this perspective, altruistic behavior toward kin can be understood as a form of selfishness on the part of the gene necessary for the behavior, since the related individuals who receive assistance are likely to carry a copy of the same gene and pass it down to their offspring.

As there are different degrees of relatedness (the closest being identical twins; followed by offspring and full siblings; then half siblings, grandchildren, nieces, and nephews; followed by first cousins, etc.) it would make evolutionary sense for altruistic behavior to be scaled according to the degree of relatedness so that it would most likely be directed toward the closest relatives. British biologist William Hamilton developed these ideas in papers published in 1963 and 1964, noting that evolution should be expected to bias altruistic behavior toward close relatives and therefore also select for the ability of altruistic animals to discriminate close relatives from more distantly related individuals so that their acts could be preferentially directed toward the former and not the latter.

But whereas kin selection is an important factor in the evolution of behavior, we also see apparently altruistic acts directed toward unrelated individuals.[5] How can evolution account for this?

The modern answer was first hinted at in 1966 by American biologist George C. Williams in *Adaptation and Natural Selection*, a book that became a classic in evolutionary biology. Williams suggested that beneficent behavior toward another unrelated individual that was initially costly for the donor (for example, giving away food) could in the long run be advantageous if the favor was later returned.

This idea was further developed and refined in 1971 by American biologist Robert Trivers with the theory of *reciprocal altruism*, as in "I'll scratch your back if you'll scratch mine." Here, cooperative and seemingly altruistic behavior can evolve among individuals who are not closely related. Indeed, it can also account for mutually advantageous relationships observed between different species, such as that between cleaner-fish and the larger fish that they clean. During cleaning, the cleaner-fish obtains a meal and the cleaned fish gets rid of troublesome parasites, but only as long as it refrains from gobbling down the much smaller cleaner-fish. Through such symbiotic behavior both cleaner and cleaned profit in ways that would not be possible without mutual co-operation (see Trivers 1971).

Another topic much studied by researchers taking an evolutionary approach to animal behavior is sex differences. No matter how successful an animal is in finding shelter and food and defending itself from disease and enemies, none of these achievements can have evolutionary significance if the animal does not reproduce and have offspring that survive until they in turn reproduce. For sexually reproducing species, reproduction means finding a mate, and offspring of many species require some form of parental care.

The importance of finding a mate and factors determining mate selection were first pointed out by Charles Darwin in *The Descent of Man and Selection in Relation to Sex*, published in 1871. Darwin observed that males often compete with each other for access to females and that females in contrast tend to be choosy in their selection of partners, often preferring males with alluring courtship displays or some physical characteristics that could well interfere with their day-to-day survival. Darwin understood that such selection pressure was responsible for the elaborate "ornaments" possessed by males of many species, such as the bright and striking plumage of the paradise bird and peacock, and deer antlers.

But sexual selection and its consequences for animal behavior were largely ignored for the next century until Robert Trivers's 1972 paper, which drew attention to the fact that sex cells (gametes) produced by males (sperm) are much smaller and more numerous than those produced by females (eggs). An individual male may well provide enough sperm cells (many millions) during a single mating theoretically to impregnate every female of the species. This is in sharp contrast to the females of most species who produce a much smaller number of much larger eggs (in birds, a single egg may equal from 15 to 20 percent of the female's body weight). This marked discrepancy in potential reproductive potential (being much greater for males) should have important consequences for differences in sexual behavior, and as we will soon see, it does.

Making Darwinian Sense of Animal Behavior

Darwin's theory of evolution by natural selection turned out to be remarkably successful in providing answers to many ultimate why questions about animal behavior. Animal behavior scientists have repeatedly found that behaviors appearing at first quite puzzling often make good sense when seen from the Darwinian perspective, especially when principles of kin selection, reciprocal altruism, and sexual selection are taken into account. Let us take a brief look at some examples that can be understood using these evolutionary principles.

Since Hamilton's formulation of kin selection, many studies of animal behavior yielded results that are consistent with the theory. Parental care for offspring, such as that often observed in birds and mammals (and also practiced by certain species of insects and fish) is one obvious form. In one setting where it might appear difficult for parents to recognize their offspring, the communal cave nurseries of the Mexican free-tailed bat that may contain many thousands of crowded young pups, mothers find and feed their own offspring greater than 80 percent of the time (McCracken 1984). For certain birds whose young receive assistance from nonparents, these helpers are typically closely related individuals such as siblings (Harrison 1969; Brown 1974).

It was mentioned earlier that insects of the order *Hymenoptera* live in societies with a strict division of labor. Particularly intriguing are workers who diligently care for the queen's offspring and yet are sterile and therefore unable to have offspring of their own—certainly an extreme form of altruism. It turns out that these species are *haplodiploid*, meaning that each female receives the normal half of its mother's genes but *all* of its father's genes. Because of this genetic quirk, sterile female workers are actually more closely related to their siblings than they would be to their own offspring!

Similar societies in which most individuals are sterile and raise the offspring of their mother have been found that are not haplodiploid, for example, the naked mole-rat. Kin selection theory would predict that these altruistic individuals should show a very high degree of genetic relatedness to each other so that the altruistic genes they carry have a high probability of also being present in the individuals they assist even though they have no descendants of their own. This fact was found for the naked mole-rat (Reeve et al. 1990).

Examples of reciprocal altruism in which one individual assists another that is not closely related in order to receive some benefit in return (either at the same time or later) are widely reported in studies of animal behavior. The relationship between cleaner-fish and their cooperative hosts was mentioned earlier. Another interesting example is provided by olive baboons (*Papio anubis*). Sexually receptive females of this species are usually closely attended by a single male consort on the lookout for opportunities to mate. A rival male, however, may solicit the aid of an accomplice male who engages the consort in a fight. While distracted, the rival has uncontested access to a female. What is in this for the accomplice who fights but does not mate? He will likely get his chance at mating the next time when his buddy will take his turn in distracting another consort (Packer 1977).

What about differences in male and female behavior related to the roles they play in reproduction, with males' billions of tiny cheap sperm and females' much fewer, much larger, and much more costly eggs? The huge quantity of sperm cells that a male produces means that gaining access to as many mates as possible increases his reproductive success. But this is usually not the case for a female, whose reproductive success depends more on the fate of her fertilized eggs. This would lead us to expect that males should be more eager to mate and less discriminating in their choice of mates than females, who should be more restrained and more choosy in their selection of mates. And this is just what was found across a very wide range of animal species including insects, amphibians, reptiles, birds, and mammals.

A good example of discriminative mate choice is provided by female insects that demand a "nuptial gift" from the male before allowing copulation to take place. The female black-tipped hangingfly (*Bittacus apicalis*) will reject the advances of any male that does not first offer a morsel of food. And the larger the male's gift, the better the male's chances of inseminating the female, since a quickly consumed tidbit may lead the female to cut short the mating process and seek another gift-bearing male (Thornhill 1976). Such behavior puts selection pressure on males to provide larger bits of food since males with little or no gifts are not likely to have their "stingy" genes represented in the next generation, whereas those with larger gifts are more likely to reproduce.

This is just one example of many in the animal world of eager males having to provide resources to females for sperm to gain access to eggs. But it is not always food that is offered. Many female birds will mate only with males that control a food-producing territory. Female bullfrogs prefer mating with the largest males (as indicated by the strength and pitch of their singing), and it is not likely coincidental that the largest males usually control the breeding locations that are best suited to the development of fertilized eggs. Female birds often select males based on their song repertoire, plumage, size, or courtship ritual, which are indicators of health, strength, and parental ability as well as the likely mating success of male offspring fathered by the male (see Alcock 1993, chapter 13, for many similar examples).

But there are some fascinating exceptions to these typical male-female differences in reproductive strategies. In some species we find a complete reversal of the typical sex roles. Among pipefish of the species *Syngnathus typhle* the male receives from the female the eggs he has fertilized and keeps them in his brood pouch until they hatch. Since females can produce eggs more quickly than males can rear them, brooding pouches are in great demand among females. So as one would expect, it is the male pipefish who is picky about his mates, preferring large, well-decorated females who appear to be able to provide many high-quality eggs for him to carry.

Another interesting example of sex role reversal is the Mormon cricket (which, curiously, is neither a cricket nor Mormon but rather a katydid with no known religious preference). The male produces for his mate a large, nutritious meal in the form of what is called a *spermatophore*. Since the spermatophore may weigh as much as 25 percent of his body weight, he can usually produce only one in his short lifetime, thereby limiting his mating opportunity to just one female. Since he invests so much in his single mating, he is choosy, preferring to mate with large females who carry a greater number of eggs, and females compete for access to him.

These examples are of particular interest since they demonstrate that it is not gender itself or any intrinsic property of egg or sperm cells that normally makes males competitors for and females selectors of mates. Rather it is the gender with the higher reproductive costs that is choosy in selecting a mate, whereas the gender with the lower costs is less discriminative and more competitive. The fact that exceptions are so nicely accounted for by the struggle for survival and maximization of reproduction is an indication of the power of the Darwinian perspective on animal behavior.

A particularly striking example that can be explained from an evolutionary perspective involves the grisly act of infanticide. Hanuman langurs are monkeys found in India that live in bands consisting of one sexually active male and a harem of females with their young. Occasionally, the resident male is expelled from the group by another male after a series of violent confrontations. When this occurs, the incoming male attacks and kills the infants that were fathered by the previous resident male.

Many reasons could be proposed for this behavior. Perhaps high testosterone levels left over from fighting result in heightened aggression and attacks on easy victims. Or maybe the new male makes use of the infants as a source of high-protein food after a period of great physical exertion. Or it could be that infanticide is a pathologial reaction to the high stress accompanying the artificially high population densities of langurs in the many locations where they are fed by humans.

An evolutionary explanation, however, would look first at the reproductive consequences of langur infanticide, and these turn out to be considerable. Nursing females provide resources to the offspring of the previous male. In addition, lactating females do not ovulate and so cannot be impregnated by the new male. So by killing the infants the incoming male both eliminates the reproduced genes of his male rival and makes the females sexually receptive once again. That male langurs have never been observed to eat the infants they kill and that infanticide occurs also in areas of low population density lend support to the hypothesis that infanticide is a means of achieving reproductive advantage (Hrdy 1977). Also consistent with this interpretation is the observation of infanticide in similar conditions by other animals including the lion (Pusey & Packer 1992) and the jacana (Emlen, Demong, & Emlen 1989), a water bird.

Of course male langurs need not be conscious of the reasons for their killing ways, any more than they are conscious of why they have a tail or fingers. It is extremely unlikely that they have figured out that lactating females do not ovulate and that killing infants will make their mothers fertile and sexually receptive. It is more reasonable to suppose that incoming males simply have an instinctive desire to eliminate from their band all infants, a goal (or reference level) that was repeatedly selected in past generations because of the reproductive advantages it conveyed.

These are just a few examples of how an evolutionary perspective focusing on reproductive success provides answers to the ultimate why questions concerning a wide range of animal behaviors. Many other examples could be given showing the survival and reproductive function of behaviors animals use to find and make places to live, obtain food, defend themselves from predators, cooperate with other animals, mate, and care for offspring (see Alcock 1993, and McFarland 1993). Indeed, it can be said that evolutionary theory now provides the core explanatory framework for studies of animal behavior in natural settings. In addition, it is strongly supported by countless experiments in both field and laboratory settings (again, see Alcock 1993, for descriptions of many such studies).

But when invoking evolutionary answers to these ultimate why questions, we must be on guard against the tendency to see specific behaviors as being selected for their survival and reproductive benefits. Instead, we know that what are selected and inherited are not fixed patterns of action but rather goals in the form of reference levels and the physical means to achieve them despite continual and unpredictable disturbances provided by an uncaring Mother Nature.

To illustrate this essential point, let's consider a spider spinning its web. The webs of any given species of orb-weaving spider are all of the same basic design, but actual dimensions must vary because of variations in the locations where they are installed, such as branches of a tree or bush. So it is obvious that no invariant sequence of actions will be successful in installing a web in all locations. Instead, each web must be custom-designed for the site it is to occupy.[6]

The spider is able to fit web to site not by engaging in a fixed pattern of actions but by *varying* its behavior for each stage of web building until certain goals are met before it proceeds to the next stage. First, the spider, perched on a branch, releases a strand of silk into the wind until it catches on another branch. Since the distance to the other branch will be different for each site, the spider cannot release a fixed length of silk each time and therefore it has no fixed sequence of behavior. Instead, it must continually let out silk until it feels that its sticky end is attached to another branch (probably not unlike the way an angler fishing for bottom fish lets out line until he feels the weighted hook come to rest on the bottom of the lake). The amount of silk it will then pull back in for the proper tension must also vary from one web to another, depending on the distance between the branches and the stiffness of the branches themselves. After tying the near end to its branch, the spider uses this first strand to drop a looser second strand and then a third to form a Y configuration with three stands meeting at what is to become the center of the web. The spider then begins to construct additional radials, like the spokes of a bicycle wheel, checking angles between the radials with its outstretched legs and continuing to add radials until the angle between each spoke and its neighbor falls below a certain value. Each radial is also carefully cinched in so that it has the proper tension.

Next, the spiral portion of the web is constructed. Using a temporary nonsticky strand as a scaffold, the spider works first from the center outward and then from the periphery back toward the center, laying down permanent, sticky silk that will trap its future meals. The spider again carefully controls the spacing between spirals, since too much space would allow insects to pass through the web and too little would be wasteful of precious silk. Finally, the spider determines how much the web sways in the breeze. If sway is excessive, it may attach weights in the form of small pebbles or twigs to one of the web's lower corners. If after all this work the spider judges the web to be unsatisfactory, it will abandon the site and construct another web elsewhere.

Due to the nature of web building and the varied conditions in which it occurs, sensory feedback is essential to all stages of construction. It is only by varying its behavior as required to achieve each subgoal that the spider is successful in recreating the same basic design that evolved over millions of years for its prey-catching ability. As noted by William James (1890, p. 7): "Again the fixed end, the varying means!" In the case of the spider's web, the fixed end can be brought about only by achieving a number of subgoals in a particular order. It is these subgoals and the means for achieving them, not the spider's actions themselves, that evolved because of their value in providing the spider with a means for its livelihood.

Learned Behavior

We have seen that instinctive animal behaviors are (and must be) more flexible than originally understood by Lorenz for them to remain adaptive in a world of unpredictable obstacles and disturbances. But these behaviors nonetheless have real limits to their flexibility. A spider's web catches prey, and the spider must custom-build each web to fit its site. But the design it uses is the same basic one that has been successful over many thousands of years. If this design now turns out to be unsuccessful for a particular spider in securing food, the spider cannot make another kind of web, like the more productive one being used nearby by another species. It is stuck with the design of its species in much the same way that it is stuck with having eight legs, a hairy body, and an appetite for juicy insides of insects.

Other animals show more flexibility, being capable of learning. Whereas an insect-eating spider will eat only insects, rats will nibble on just about anything that might be edible and learn to distinguish what is nutritious from what is not (more on this type of rat learning later). Thus individual rats of the same species may have very different diets and food preferences according to their dining experiences. The circus examples given at the beginning of this chapter of dogs walking on their hind legs, bears riding motorcycles, and seals balancing beach balls on their noses are particularly striking cases of animal learning that appear unrelated to such naturally occurring instinctive behaviors as barking, scratching, and catching fish. But these unnatural acts arise only in a specially arranged environment where they are instrumental in obtaining food and achieving other goals. Although psychologists recognize several different forms of learning, we will focus here on the kind that involves acquisition of what appear to be novel behaviors as a result of the animal's particular experiences.

One way of looking at such learning is to see it as a behavioral adaptation to environmental changes that happen too quickly to be tracked by natural selection. Gradual changes in climate or the gradual appearance and extinction of pathogens, prey, and predators can affect instinctive behavior through the differential survival and reproduction of organisms with adaptive behaviors. But more rapid environmental changes taking place from one generation to the next or even within a generation cannot be tracked by evolution. As Skinner (1974, p. 38) observed, "contingencies of survival cannot produce useful behavior if the environment changes substantially from generation to generation, but certain mechanisms have evolved by virtue of which the individual acquires behavior appropriate to a novel environment during its lifetime." These "mechanisms" refer to ways of learning that allow animals to adapt their behavior to unpredictably changing environments.

We considered several approaches to learning theory in chapter 3, including classical conditioning theories of Pavlov and Watson as well as instrumental and operant conditioning theories of Thorndike and Skinner. But since that chapter came before the discussion of perceptual control theory in chapter 5 and before the evolutionary perspective presented in this chapter, it will be worth while to take another look at learning and modification of animal behavior from these new perspectives, focusing on the type of learning that Skinner was interested in.

As described in chapter 3, Skinner included both one-way cause-effect and selectionist components in his theory of how animals acquire new behaviors, in much the same way that Lorenz included both of these in his account of instinctive behavior. The selectionist component for Skinner had to do with the learning process itself; that is, how new behaviors are first emitted (random variation) with certain ones selected by the environment according to their consequences. It is for this reason that Skinner emphatically rejected the frequently applied characterization that his was a stimulus-response theory because of the "unstimulated" nature of the originally emitted novel behaviors.

But despite his protests, an important one-way cause-effect component of Skinnerian theory comes into play after a new behavior has been learned. This is because the new behavior is then elicited or caused by sensory stimuli that are the same as or similar to environmental stimuli experienced when the behavior was originally selected. The rat may stumble upon pushing the lever to obtain food in a haphazard, random way, but after it learns this new way of feeding itself it will immediately approach and push the bar (if hungry) when placed into the same or similar box in which the behavior was learned. It is for this Newtonian-inspired one-way cause-effect conception of performance of already learned behaviors that Skinner's theory was and still is characterized by many behavioral scientists as a stimulus-response theory. This characterization is understandable, if not completely justified, when it is realized that Skinner repeatedly referred to the "stimulus control" of behavior. Although he understood stimulus broadly as the cumulative effects of all previous sensory stimuli experienced by the organism, he emphasized that "the environmental *history* is still in control" (Skinner 1974, p. 74). By control he actually meant cause. This view of behavior is in striking contrast with the circular causality of perceptual control theory, which sees organisms purposefully varying their behavior to control perceived environmental consequences of those behaviors. In other words, instead of Skinner's selection *by* consequences we have Powers's selection *of* consequences.

A good way to contrast the difference between these theories of how organisms modify their behavior is to consider an intriguing pattern of behavior Skinner observed. He found that he could obtain very high rates of a behavior (such as a hungry pigeon pecking at a key to obtain food) by gradually *decreasing* the rate of reinforcement. These high rates could be obtained by starting out with a relatively generous reinforcement schedule that provided a grain of food for each key peck, and then using progressively more stingy schedules requiring more and more pecks (for example, 2, 5, 10, 30, 50, 75, and 100) for each reward. Skinner was thereby "able to get the animals to peck thousands of times for each food pellet, over long enough periods to wear their beaks down to stubs. They would do this even though they were getting only a small fraction of the reinforcements initially obtained" (Powers 1991, p. 9).

But if, according to this theory of operant conditioning, reinforcement increases the probability of the behavior that resulted in the reinforcement (note that this describes a *positive*-feedback loop) how could it be that *reducing* the reinforcement leads to an *increase* in the rate of behavior? This puzzle is solved when we see reinforcement not as an environmental event but rather as a goal the organism achieves by varying its behavior as required. If circumstances are arranged so that the hungry Skinner-box-trained rat must perform more bar presses to be fed, and it has no other way to obtain food, it will adapt its behavior by increasing the rate of bar pressing. If the rate of reinforcement is increased to the point at which the rat can maintain its normal body weight, a control-system model of behavior based on circular causality would predict that further increases in reinforcement should lead to decreases in the rate of behavior. This is exactly what happens (see Staddon 1983, p. 241, figure 7.18).

Skinner also believed that any behavior an animal was physically capable of could be brought about through contingencies of reinforcement. He took particular delight in demonstrating the games that he taught pigeons to play, such as the one in which the bird used its beak to roll a midget bowling ball down a miniature alley to a set of tiny pins (Skinner 1958).

But other research on animal learning has discovered clear constraints on the types of behaviors that animals can learn, and that instinctive behaviors can often interfere with learning new ones. Keller and Marian Breland, who worked for many years training animals for commercial purposes, reported several such examples in their informative and entertaining 1961 paper "The Misbehavior of Organisms." Included in their report are accounts of chickens that could not learn to stand on a platform for twelve to fifteen seconds without vigorously scratching it; raccoons that could learn to put one coin in a container but when given two coins would spend minutes rubbing them together and refuse to deposit them; and pigs that, after having learned to pick up and place large wooden coins in a piggy bank, would after several weeks or months begin repeatedly to drop the coin, push it with their snout (called "rooting"), and pick it up again, taking up to ten minutes to transport four coins over a distance of about six feet. Other researchers reported that male three-spined sticklebacks (a North American fish) were successfully trained to swim through a ring to gain access to a female, but they could not learn to bite a glass rod for the same reward since they attempted instead to mate with the rod (Sevenster 1968, 1973)! In all these cases we see the animal's normal instinctive behaviors related to eating and reproduction interfering with the new behavior the researcher wanted it to learn, a phenomenon referred to by the Brelands as "instinctive drift."

Other interesting evolutionary constraints on learning were investigated in the laboratory rat. For example, rats are quite handy with their front paws and so a hungry rat normally learns quite quickly to press a bar to obtain food. But it is very difficult to get a rat to press a bar to avoid a shock (Slater 1985, p. 87). This seems due to the rat's freezing in response to fear, an instinctive behavior incompatible with bar pressing.

Rats also can make certain associations between stimuli and their effects, but not others. If a rat is made sick after consuming a food with a certain taste, it will consequently avoid all foods having the same taste. And if a sound or visual stimulus regularly precedes an electric shock, a rat will associate this as a signal of the impending shock and will learn to make an appropriate avoidance response. But rats cannot learn to associate taste with electric shock or use auditory or visual cues to learn that a food is noxious (Garcia & Koelling 1966; Garcia et al. 1968).

These findings may be puzzling for the psychologist who has no appreciation of the evolutionary past of the rat, but they make quite good sense from an evolutionary perspective. For rats, which often scurry about in dark places and eat an amazing variety of foods, taste is a better indicator of the quality of food than its visual appearance or the sounds they make while eating. In contrast, physical dangers are usually accompanied by visual and auditory signals, not gustatory ones. So it makes sense that evolution would have selected rats that learn what is bad to eat by taste and what is physically dangerous by sight and sound.

That rats can learn food aversion based on taste is itself a quite remarkable adaptation that led psychologists to seriously revise their theories about learning. It was once widely believed (based on Pavlov's and other studies of classical conditioning) that two stimuli had to be presented several times and within a very short time if one was to become associated with the other. But in 1955 John Garcia and his associates fed rats a harmless substance with a characteristic taste and later made the animals sick using radiation (Revusky & Garcia 1970). Contrary to expectations, rats would learn to avoid the new food even if they were made sick several hours after ingesting it. And this food-avoidance learning appeared permanent.

The findings of this and several similar studies were quite surprising to psychologists at the time, although this type of learning ability again makes good evolutionary sense. Rats live in a wide variety of rapidly changing (now usually human-made) environments and consume a wide range of foods, often those intended for humans or discarded by them. Since they cannot know beforehand whether a new food is toxic or nutritious, they are very cautious and at first take only a small quantity of it. And since it may take a few hours for food poisoning to take effect, they have evolved a learning mechanism that can operate over an interval of hours so that they forever avoid the taste of a food that has made them ill just once. This well-adapted learning is why rat poisons have limited success. On the other hand, a rat whose normal diet is deficient in an essential nutrient (such as the B vitamin thiamine) has a stronger inclination to try a new food. If the new addition happens to be followed by recovery from the dietary deficiency, the rat will develop a marked preference for it (Rodgers & Rozin 1966).

These examples of how the learning ability of animals is adaptively constrained by evolution show that whereas theories of learning may be able to provide some answers to proximate why questions about animal behavior (such as why is that pigeon pecking that key? Answer: Because it is hungry and has discovered that it can obtain food by doing so), learning alone cannot provide answers to ultimate why questions. Ultimate questions must consider the evolutionary origin of the animal's learning abilities.

But what exactly is learned when an animal escapes from a puzzle box of the type Thorndike used, presses a bar to obtain food in a Skinner box, or develops a preference for a food that contains some essential nutrient? We saw in chapter 6 and from the preceding discussion of instinctive behavior that fixed patterns of behavior cannot remain adaptive in a world characterized by variable circumstances and unpredictable disturbances. Learning can be adaptive only if learned behaviors remain flexible and permit the organism to obtain its goals in the face of these disturbances.

The hierarchy of controlled perceptions introduced in chapter 6 provides a quite different perspective on learning. It will be recalled (see figure 6.3) that it shows how higher-level goals are achieved through manipulation of combinations of lower-level goals (subgoals). A spider is able to catch prey only by achieving a rather large number of subgoals that involve spinning a web (which itself requires achieving additional subgoals as described earlier), catching prey, and injecting its venom to kill or paralyze it. Fortunately for the spider, it inherits a control system hierarchy in which these goals and subgoals are specified, and so it requires no learning to be able to feed itself. This is what is referred to as instinctive behavior.

But other animals are more adaptable. A rat inherits certain taste preferences, and as long as it can find sufficient quantities of these foods, it may live its entire life without having to try new ones. But a starving rat must try new foods if it is to survive. It will then come to prefer tastes associated with feelings of wellness and avoid those associated with sickness. The rat is not learning specific new eating behaviors, but rather to reset reference levels for lower-level perceptions based on consequences for higher-level goals.

The rat placed in the Skinner box also demonstrates learning, but this involves learning which patterns of proprioceptive, auditory, and visual perceptions lead to the delivery of a food pellet (another perception). A rat's behavior is more flexible than that of a spider in that the rat is able to reset reference levels based on experience, whereas the spider's reference levels are less modifiable. However, we saw that evolution allows certain types of flexibility but not others; recall that a rat quickly learns in a single trial which taste leads to nausea and which sounds are followed by skin pain. In perceptual-control-theory terms, the rat learns to set a very low or zero reference level for these tastes and sounds to avoid the nausea and pain that follow them. But its behavioral flexibility is limited in that it cannot change its reference level for taste based on sound or for a certain sound based on nausea.

Learning from a hierarchical-perceptual-control-theory perspective is actually finding out, by a form of trial and error, which combinations of lower-level perceptions are successful in bringing about a higher-level goal. Powers refers to this process as *reorganization* (1973, p. 179):

> Reorganization is a process akin to rewiring or microprogramming a computer so that those operations it can perform are changed. Reorganization alters behavior, but does not produce *specific behaviors*. It changes the parameters of behavior, not the content. Reorganization of a perceptual function results in a perceptual signal altering its *meaning*, owing to a change in the way it is derived from lower-order signals. Reorganization of an output function results in a different choice of means, a new distribution of lower-order reference signals as a result of a given error signal.

This way of looking at what is normally considered learning combines the two alternative causal processes that provide the major themes of this book. First there is cybernetic circular causality in recognizing the purposeful nature of animal behavior and learning. Animals act on their world based on what they perceive and thereby change their environment and what they consequently perceive of it. Animals also change how they act on the world when old ways are no longer effective in getting what they want. But this change in behavior is based on a Darwinian process involving spontaneous variation and selection; not variation and selection of specific behaviors as conceived by Skinner and his behaviorist followers, but rather variation and selection of goals as the organism discovers which new combinations of controlled lower-order perceptions lead to the attainment of higher-level goals.

We will consider in more detail this notion of within-organism evolution and its purposeful nature in chapters 9 and 10 after we consider the evolutionary bases of human behavior in the next chapter.

8

The Evolution of Human Behavior: The Darwinian Revolution Continued

The challenge of Darwinism is to find out what our genes have been up to and to make that knowledge widely available as a part of the environment in which each of us develops and lives so that we can decide for ourselves, quite deliberately, to what extent we wish to go along.

—Richard Alexander (1979, pp. 136–137)

A fast-food restaurant is a little monument to the diet of our ancient ancestors.

—Leda Cosmides (quoted in Allman 1994, p. 50)

Oh, yo' daddy's rich, an' yo' ma is good look-in'

So hush, little baby, don' yo cry.

—"Summertime" (G. Gershwin, D. & D. Heyward, & I. Gershwin 1935)

Hey, Joe. Where you goin' with that gun in your hand?

Goin' down to shoot my old lady. You know I caught her messin' around with another man.

—"Hey Joe" (Billy Roberts 1966)

As we saw in the previous chapter, the evolutionary approach pioneered by ethologists provides answers to many ultimate why questions concerning animal behavior. The basic notions of survival and reproductive success, further refined by concepts of kin selection and reciprocal altruism, have time and again provided compelling answers concerning why animals naturally do the things they do and are able to modify their behavior in adaptive, functional ways.

But what about our own species? The Darwinian conclusion that human beings are also a product of biological evolution is scientifically inescapable, meaning that our behavior must also be compatible with and explainable by natural selection. But we humans are undisputably different from all other known organisms in the remarkable flexibility and variability of our behavior and the planning, consciousness, emotions, awareness, and moral sense that often accompany what we do.

In this chapter we will consider both the successes and problems of attempts to use natural selection to understand human behavior since the time of Darwin.

Darwin and His Critics on Animate Behavior

Although Darwin was the first scientist to consider in print the implications of natural selection for human behavior, he took a rather long time to do so. In *The Origin of Species* (published in 1859), in which he introduced the theory of natural selection, he made no explicit mention of human evolution or behavior. It was, however, quite clear from the central argument of this revolutionary book that he believed humans, like all other living organisms, gradually evolved to their present form from nonhuman ancestors. It was this unwritten but clear implication of his work that raised the most criticism and debate. As the wife of the Bishop of Worcester is reported to have worried, "Descended from monkeys? Let us hope that it is not true. But if it is true, let us hope that it does not become widely known" (quoted in Giddens 1991, chapter 2).

Unfortunately for the good bishop's wife, the theory of natural selection turned out to be both true and widely known. But it wasn't until over a decade later (after first publishing two revisions of the *Origin* followed by a book on orchids and another on domesticated animals) that Darwin tackled the emotionally charged and highly controversial issue of human evolution in *The Descent of Man and Selection in Relation to Sex*, first published in 1871 (see Darwin 1874, 1952). Here he maintained that human behavior was in some respects like that of other animals, while in other respects it was unique. He attempted to explain both the similarities and differences as arising naturally from the evolutionary process.

Like all other sexually reproducing animals, humans are (as were our nonhuman ancestors) subject to sexual selection of males by females and of females by males. Darwin saw in human sexual selection an explanation for human racial differences. Since he saw no obvious survival advantages for racial differences in physical attributes such as stature, hair, skin color, and body shape,[1] he reasoned that these variations were the results of differences in perceived sexual attractiveness among different races and the resulting selection of mates.

But more interesting from a behavioral perspective are his conclusions concerning the evolutionary basis for differences in behavioral and mental dispositions of men and women. Here he forged a bold link between humans and the sexual differences found in other animals (1874, pp. 583–584):

> No one disputes that the bull differs in disposition from the cow, the wild-boar from the sow, the stallion from the mare, and, as is well known to the keepers of menageries, the males of the larger apes from the females. Woman seems to differ from man in mental disposition, chiefly in her greater tenderness and less selfishness. . . . Woman, owing to her maternal instincts, displays these qualities towards her infants in an eminent degree; therefore it is likely that she would often extend them towards her fellow-creatures. Man is the rival of other men; he delights in competition, and this leads to ambition which passes too easily into selfishness. These latter qualities seem to be his natural and unfortunate birthright.

He also used sexual selection to explain what he saw as the more violent, aggressive nature of the male sex (1874, p. 583):

> There can be little doubt that the greater size and strength of man, in comparison with woman, together with his broader shoulders, more developed muscles, rugged outline of body, his greater courage and pugnacity, are all due in chief part to inheritance from his half-human male ancestors. These characters would, however, have been preserved or even augmented during the long ages of man's savagery, by the success of the strongest and boldest men, both in the general struggle for life and in their contest for wives; a success which would have ensured their leaving a more numerous progeny than their less favored brethren.

It was rather straightforward to provide evolutionary accounts of the human male's more aggressive characteristics. In contrast, understanding the evolutionary origins of the ethical, moral, and religious aspects of human nature was not so easy. Even Darwin's friends and supporters of his theory of evolution (including geologist Charles Lyell, cousin and gentleman scientist Sir Francis Galton, and fellow discoverer of natural selection Alfred Russel Wallace) could not imagine how survival and reproductive success could be at the origin of the kinder and gentler characteristics that often distinguish humans from other animals. According to Richards (1987, p. 206),

> Lyell could not conceive that man's intellect and moral sensibility naturally grew by slow degrees from animal stock. Galton and Greg isolated another crucial

problem for the Darwinian approach to man: as soon as protomen formed social bonds and through sympathy became solicitous for their mutual welfare, natural selection ought to be disengaged; for sympathy would prevent the salutary elimination of mentally and morally inferior individuals. Wallace . . . pressed these difficulties home. He urged that man's great intellect and refined moral sense far exceeded what was required for mere survival in the wild; hence, natural selection could not have produced them.

Darwin's three responses to these challenges are remarkable for their keen insight and anticipation of theories that became widely appreciated and accepted only much later the next century. First, he imagined that as their reasoning powers increased, our early ancestors would have realized that aiding another individual would increase their chances of being helped later by that individual in return. We saw this idea in the previous chapter, now referred to as reciprocal altruism.

Second, Darwin proposed that natural selection occurring at the level of the *group* could result in the evolution of behavioral traits that, although possibly of no use or even detrimental to the survival and reproductive success of the individual possessing them, would confer a selective advantage to the individual's community. As he reasoned (1874, p. 137):

It must not be forgotten that although a high standard of morality gives but a slight or no advantage to each individual man and his children over the other men of the same tribe, yet that an increase in the number of well-endowed men and an advancement in the standard of morality will certainly give an immense advantage to one tribe over another. A tribe including many members who, from possessing in a high degree the spirit of patriotism, fidelity, obedience, courage, and sympathy, were always ready to aid one another and to sacrifice themselves for the common good, would be victorious over most other tribes; and this would be natural selection.

Finally, he recognized the powerful influence that social praise and blame had on the behavior of individuals (1874, p. 136), an influence that would have been obvious to anyone living in Victorian England. Otherwise, individuals who refused to act for the good of the group (for example, by refusing to fight in the group's wars or not sharing food or other valuable resources) and instead acted only for their own and their family's interest would have greater survival and reproductive success than those who acted for the good of the larger social group. This would prevent the natural selection of altruistic behavior.

All this is not to imply that Darwin's views on the evolutionary origins of human behavior were unproblematic. For one thing, he did not seem to recognize the important role that the environment could play through social and cultural factors in influencing human behavior. This is evident in one of his descriptions of differences between men and women. He noted that "if two lists were made of the most eminent men and women in poetry, painting, sculpture, music (inclusive both of composition and performance), history, science, and philosophy, with a half-a-dozen names under each subject, the two lists would not bear comparison" and therefore "the average of mental power in man must be above that of woman" (1874, p. 504). It seems inexcusable to us today that he ignored the limited educational and employment opportunities afforded to women in his day and their impact on their lives and career options.

Also evident from this conclusion concerning male-female differences was Darwin's reliance on anecdotal observations of human behavior. This approach may have served him well in his research and conclusions on animal behavior, but animal behavior has much less variation than human behavior. The fact that a male peacock spreads and shakes his tail before a peahen to encourage her to mate is in itself suggestive that other peacocks act similarly. Observing that a panda bear eats bamboo leaves provides a good clue concerning the dining habits of all pandas. But seeing a single instance of human behavior tells us very little indeed about the behavior of humans in general, since humans have so many distinct ways to feed themselves (from hunting and gathering to writing computer programs), dress themselves, shelter themselves, and procure mates. (We will take a look at the large apparent variation in human behavior from another perspective later in this chapter.)

Darwin was also completely unaware of the genetic basis of heredity and so could not understand how traits were passed down from one generation to another, even though Mendel's ground-breaking work on genetics (based on the 30,000 pea plants he had grown) was published in 1865. Without this knowledge, Darwin could not understand how kin selection could be such a powerful force in the evolution of altruistic and cooperative behavior among humans.

Finally, he never abandoned the Lamarckian notion of the inheritance of acquired characteristics in his belief that habits learned during an individual's lifetime could show up as unlearned instincts in one's descendants. He made extensive use of this notion in his book *The Expression of the Emotions in Man and Animals* (1872/1955).

In spite of these limitations, Darwin must be credited for insisting on and providing thoroughly naturalistic explanations for the evolution of human behavior that did not require the divine intervention insisted on by both his harshest critics and some of his closest friends and supporters, such as Lyell, Wallace, and American botanist Asa Gray.

The Post-Darwinian Gap

Because Darwin's theory of evolution had such a great and immediate impact on the scientific world (the entire first edition of the *Origin* was sold out the first day it was put on sale), one might well expect that it would have had a great impact on those social and behavioral scientists interested in accounting for human behavior. But that impact was delayed for quite some time.

One reason for this lack of immediate effect on human psychology was that in spite of Darwin's arguments as summarized above, many simply could not see how evolution by natural selection could account for the emergence of the human mind. Among those who, like Darwin, sought thoroughly naturalistic explanations for the origin of the human species, many remained unconvinced of the theory, preferring instead Lamarck's notion of the inheritance of acquired characteristics. Why was natural selection rejected as the motor of evolution? There were at least three reasons.

First, since natural selection requires gradual accumulation of small variations appearing in each generation, it would take a very long time before an organism as complex as a giraffe or human could evolve from the simplest one-celled organisms. But the best estimates of the age of the earth available in the nineteenth century (provided by Lord Kelvin) were between 10 and 15 million years, far too young even by Darwin's reckoning to have allowed enough time for the evolution of all known extinct and extant species. Lord Kelvin's estimates were based on the temperature of the interior of the earth and rate of decrease of the sun's energy output. However, both radioactivity (which plays a major role in maintaining the earth's high interior temperatures) and nuclear fusion (which is the source of the sun's energy) were unknown phenomena in the nineteenth century. So although the earth is now considered to be about 4.5 billion years old, providing ample time for evolution to do its stuff, the best estimates during Darwin's time were considered incompatible with his theory of natural selection.

Another reason to doubt the effects of natural selection was the problem of inheritance. Darwin and other naturalists and biologists of his day (except Mendel) believed that inheritance in sexual species involved *blending* characteristics of male and female parents. Reasoning from this assumption, Scottish engineer Fleeming Jenkin pointed out that any new favorable variation would be diluted as the organism possessing it bred with other organisms. Over time, this repeated dilution of new traits meant that little or none of the originally advantageous variation would be retained by succeeding generations, making the emergence of new species impossible.

As noted, Darwin was unaware of Mendel's pioneering experiments in genetics that showed that inheritance did not involve a blending of male and female characteristics but rather was *particulate*; the fact that the offspring of a male-female couple is either male or female and not a blend of the two sexes is just one obvious example of the particulate nature of inheritance. Indeed, the basic notion of the gene that Mendel developed is that of an indivisible unit of biological inheritance that does not blend or dilute itself in the process of reproduction. The modern particulate theory of genetics is therefore thoroughly compatible with Darwin's theory of evolutionary change arising through natural selection of spontaneous variations produced by genetic mutation and sexual recombination of genes. Unfortunately, commonly held but erroneous ideas about inheritance in Darwin's own time were not entirely compatible with the concept of natural selection as the motor behind the evolution of species and emergence of new ones.

The third widely respected argument had to do with how the initial stages of a complex adaptation could become established. It was maintained by one of Darwin's harshest foes (the converted, and later excommunicated, Catholic zoologist St. George Mivart) that a complex adaptation such as a bird's wing was of no use to the animal that possessed it as a tool of flight unless it was fully formed and functional. From this line of reasoning it would seem that if natural selection were a gradual process involving accumulation of very small changes from one generation to the next, there would be no way that such a complex adaptation could ever begin to evolve.

Darwin had a good rebuttal to this objection, and one that is still considered valid today. He recognized that a complex adaptation may have had its beginning in a form that served a quite different function than its current one. For example, it is now believed that wings did not originally emerge as organs of flight but rather as protuberances allowing insects and birds to regulate their body heat. Nonetheless, this was seen by many as another valid argument against natural selection and is still used today by creationists and other opponents of evolution.[2]

But if Darwin was not swayed by Mivart's argument, he was troubled by those of Kelvin and Jenkin. So much so that by the sixth and final edition of *Origin* he considerably softened his position on natural selection, putting more emphasis on the role of the Lamarckian inheritance of acquired characteristics that he incorporated into his ill-fated theory of *pangenesis*.

His concessions to the antiselectionists did nothing to help his theory gain acceptance. The result was that, beginning in the years shortly before his death in 1882 until well into the twentieth century, biological evolution involving descent with modification was widely accepted among scientists but natural selection was not. Instead, the inheritance of acquired characteristics was seen as the primary motor of evolution, in spite of now obvious fatal flaws of Lamarckian theory.

But whereas the theory of natural selection was rejected by biologists and zoologists, it was embraced by many prominent philosophers and psychologists in Europe and America who saw in the process of variation and selection a mechanism to elucidate the functioning of the human mind. This application of Darwinian theory to the mental realm is part of what I call the "second Darwinian revolution" that is discussed in the next chapter.

Sociobiology's Search for Ultimate Causes

We saw in chapter 7 how biologists such J. B. S. Haldane, William Hamilton, George Williams, and Robert Trivers applied Darwinian concepts in the 1950s through 1970s to find answers to many perplexing ultimate why questions about animal behavior—including instances of cooperative social behavior—using theories of kin selection and reciprocal altruism. They also applied evolutionary reasoning to human behavior, but since their work was often couched in the complex mathematics of population genetics and directed to other evolutionary biologists, it had little impact at the time on behavioral science. This changed dramatically with the appearance of a book in 1975 that brought a broad Darwinian perspective to the behavior of a remarkable variety of organisms, from microorganisms and slime molds to gorillas and human beings.

The book was *Sociobiology: The New Synthesis* written by Edward O. Wilson, a Harvard entomologist recognized as one of the world's leading experts on ants and other social insects. Defining sociobiology as "the systematic study of the biological basis of all social behavior" (1975, p. 4), Wilson provided many fascinating examples from the world of insects and other animals of the types of behaviors and evolutionary reasoning described and formulated by Hamilton, Williams, and Trivers. Due to the accessibility of his writing and attractive illustrations, *Sociobiology* quickly attracted widespread attention. Although only the last of the twenty-seven chapters dealt with human behavior, it made it clear that Wilson's evolutionary, genetic, and essentially selfish account of the origins of social behavior was fully intended to be applicable to our species as well.

Wilson's book earned him both popularity and notoriety. Many biological and behavioral scientists appreciated the grand scale and synthesis of his work, but others (including some of his Harvard colleagues) accused him of being a racist, sexist, imperialist, right-winger, and genetic determinist. His public appearances were boycotted and disrupted, and he was even doused with a pitcher of ice water at one of his lectures.

But this negative reaction did not stop additional applications of Darwinian theory to human behavior. One year after the publication of Wilson's book, Oxford zoologist Richard Dawkins published *The Selfish Gene*, the first in what was to become a series of popular and influential books on evolution. Dawkins also explored the evolutionary and genetic bases for behavior, including the apparently altruistic behavior of humans toward their fellows. Like Wilson and the new generation of behavioral Darwinians, he emphasized the inherently selfish genetic nature of what may appear to be the kind, altruistic behavior of both animals and humans.

Why did this new application of a Darwinian perspective to human behavior meet with such resistance from so many behavioral scientists and indifference from others? To understand this reaction, we must take a closer look at some of the assumptions, reasoning, and conclusions of Wilson and his sociobiologist colleagues.

The first assumption is that the human species, like all other species of living organisms, evolved from simpler forms of life by natural selection. The second assumption is that since the evolution of a species is directed by the survival and reproductive success of individual organisms (including the survival and reproductive success of new generations), and that this success is influenced by an organism's behavioral characteristics, various human behaviors can be understood as adaptations that promote (or at least promoted in the past) survival and reproductive success. The third assumption is that there is a genetic basis for human behavior in the same way that there is an inherited, genetic basis for the behavior of other animals and for the physical structure of both.

All three of these assumptions are quite in keeping with modern biological theory and clearly consistent with what was learned from studies of animal behavior as discussed in chapter 7. So why all the fuss about applying them in an attempt to discover ultimate explanations for human behavior?

At least part of the resistance was (and is) due to misinterpretation of certain aspects of sociobiological theory. Perhaps the most common charge is that of *genetic determinism*, the idea that humans inherit genes that in effect force them to behave one way or another. It is true that Wilson and other sociobiologists discussed the possibility of human genes underlying such human behavioral characteristics as homosexuality and social conformity (for example, see Wilson 1975, pp. 555, 562). But it is also clear that these scientists were aware that genes must interact with environmental factors for them to have any effect on the structure or behavior of an organism, human or otherwise. As Wilson explained (1975, p. 26):

> Blue eye color in human beings can be proved to be genetically different from brown eye color. But it is meaningless to ask whether blue eye color alone is

> determined by heredity or environment. Obviously, both the genes for blue eye color and the environment contributed to the final product. The only useful question . . . is whether human beings that develop blue eye color instead of brown eye color do so at least in part because they have genes different from those that control brown eye color. The same reasoning can be extended without change to different patterns of social behavior.

Wilson also included a section in the last (human) chapter of *Sociobiology*, entitled "Plasticity of social organization," in which he presented the hypothesis "that genes promoting *flexibility* in social behavior are strongly selected at the individual level" (1975, p. 548; emphasis added).

However, he and other sociobiologists were on occasion less careful in describing the role of genes in human behavior. For example, Wilson asserted in his Pulitzer prize-winning book *On Human Nature* that "the question of interest is no longer whether human social behavior is genetically determined; it is to what extent" (1978, p. 19). The use of the word "influenced" (which implicitly recognizes the effect of other factors) instead of "determined" (which can be easily taken to mean that genes are the *only* cause of human behavior) would have given his opponents less cause for criticism.

Another charge is that sociobiologists often infer a specific genetic basis for apparently universal human behaviors without considering how such behaviors could have arisen from more general aspects of the form and abilities of the human organism interacting with the environment. For example, Wilson stated that "in hunter-gatherer societies men hunt and women stay at home. This strong bias presents in most agricultural and industrial societies and, on that ground alone, appears to have a genetic origin" (1975; quoted in Lewontin, Rose, & Kamin 1984, p. 255). But it is quite easy to imagine how this division of labor could be the indirect effect of physical differences between men and women such as men's greater size, strength, running speed, and throwing ability, which are characteristics best suited to hunting, and women's ability to bear and nurse babies, which is better suited to staying at or near one's home and taking care of children. As three of sociobiology's harshest critics remarked, Wilson's "argument confuses the observation noted, with the explanation. If its circularity is not evidence, one might consider the claim that, since 99 percent of Finns are Lutheran, they must have a gene for it" (Lewontin, Rose, & Kamin 1985, p. 255).

Another example is that all normal able-bodied humans use their hands to eat. This could therefore be considered a universal, species-specific aspect of human behavior (and a social behavior insofar as it is done with other humans). But does this then indicate that a specific human gene or group of genes causes us to use our hands to eat, which if changed would result in a human who did not use his or her hands to eat? This appears unlikely, as it is obvious that a hungry human who has learned to use his or her hands for manipulating objects would also use them to place food in his or her mouth. Of course, there is a genetic basis for the human behavior of eating with one's hands, since without human genes a human would not have hands to begin with, or the neurological system to achieve fine motor control of its fingers. But it is simply unconvincing to argue that a specific gene or set of genes must exist for a particular behavior simply because all (or nearly all) humans do it. Philosopher Daniel Dennett has made this same point using yet another example (1995, p. 486):

> Showing that a particular type of human behavior is ubiquitous or nearly ubiquitous in widely separated human cultures goes *no way at all* towards showing that there is a genetic predisposition for that particular behavior. So far as I know, in every culture known to anthropologists, the hunters throw their spears pointy-end-first, but this obviously doesn't establish that there is a pointy-end-first gene that approaches fixation in our species.

None of this is to deny that using one's hands to eat, dividing labor between the sexes, and throwing spears pointy-end-first may well be adaptive behaviors that facilitated the survival and reproduction of individuals who practiced them. But given the structure and abilities of human brains and bodies together with the environments in which they live, it seems implausible that any such universal human behaviors have a *specific* determining genetic basis. Instead, it is more likely that such behaviors are the outcome of the more general problem-solving abilities our species possesses that are themselves products of the interaction of our genetic endowment with our environment. As will be proposed later in this chapter, the entire enterprise of attempting to separate genetic from environmental (or social) causes of behavior is itself an indication of confusion.

These criticisms and problems notwithstanding, the evolutionary approach taken by sociobiologists has been of considerable value in addressing certain ultimate why questions about human behavior. The major contribution to our understanding is the realization that human behavior, like the behavior of all organisms, was shaped over evolutionary time as a function of its survival and reproductive consequences. As for any other species, a human behavior having an inherited basis that increases an individual's survival and reproduction, or the survival and reproduction of closely related individuals, will over time spread through the population. In contrast, heritable behaviors with less positive effects will over time be eliminated.

The Darwinian approach taken by sociobiologists to study human behavior yielded interesting hypotheses, predictions, and answers. We will now consider some of these as they relate to male-female differences and parental care of children.

Men and women differ in many obvious ways, but an important one that is not immediately apparent is their capacity for reproduction. With each ejaculation a man can provide up to 100 million sperm that are then quickly replaced. In contrast, a woman produces only about 400 eggs during her entire lifetime. In addition, a woman must make a very large investment in producing and rearing a child. The fetus develops in her body from which it draws its nourishment, the woman gives birth to the child at considerable risk to her own health, and the child must be nursed and cared for a considerable length of time. In contrast, a man needs do nothing more than copulate to produce a child, although, of course, many men (but certainly not all) also make substantial investments in their children. Thus a man's potential reproductive capacity is much greater than a woman's.

As in other animals, these striking differences in reproductive functions and capacities should, from an evolutionary perspective, lead to similarly striking differences in certain behaviors. Since the limiting factor for male reproductive success is the availability of fertile women, we should expect to find keen competition among males for fertile female mates, and evidence shows that such competition exists in all human societies. In fact, many cases of homicide are related to men competing for women (Daly & Wilson 1988).

Also, since each copulation by a man with a fertile woman has the potential of producing one or more children carrying half of the man's genes even with no further involvement by him, we would expect men to be more easily sexually aroused and more interested in mating with many different women. Because women have much less to gain from multiple partners (only one man at a time can father a child), they should be less easily sexually aroused and less interested in having several sex partners. The facts that married men are much more likely to engage in sex outside of marriage than their wives (Symons 1979), that many men pay women for sex but women do this much more rarely, and that a huge worldwide pornographic industry is supported by men who are willing to pay to just look at images of young scantily clad and nude women, are all consistent with evolution-based predictions by sociobiologists concerning male-female differences in sexual behavior. These findings are also consistent with male-female differences in animal behavior as discussed in chapter 7.

Men and women also differ in mate choices. A man may maximize his reproductive potential by establishing a relationship with a younger woman with many reproductive years ahead of her. So we should expect men to prefer younger mates, especially as they grow older. In contrast, a woman may maximize her reproductive success by finding a man with sufficient material resources to provide for her and her children, and such a man is likely to be older than she. As expected, men's preference for younger women and women's preference for older men were found in at least thirty-seven countries (Buss 1989; Kenrick & Keefe 1992). A rather blunt way to summarize these findings is to note that men tend to see women as sex objects (preferring mates and wives who are young and physically attractive), and women tend to see men as resource objects (preferring older and wealthier men with less concern for physical attractiveness).

But youthfulness is just one factor involved in female reproductive capability, with health and fertility being others. One indicator of female health and fertility is the ratio of waist to hip size. Healthy women in their prime childbearing years (early teens to middle age) have waist-to-hip ratios between 0.67 and 0.80, although conditions such as hypertension, diabetes, gallbladder disease, and (obviously) pregnancy tend to increase this ratio. A small waist-to-hip ratio is also indicative of high levels of the female hormone estrogen and therefore of fertility. We should thus expect men to find young women with low waist-hip ratios to be most attractive. This was in fact found in the United States and many other cultures where a ratio of 0.7 is considered most attractive by men (Singh 1993, 1997).

The care that parents invest in raising children has also been a subject of considerable interest among sociobiologists, using as their basic working hypothesis that men should invest less in their mate's child if they know or suspect that the child was fathered by another man. Perhaps one of the most interesting findings concerning parental care of children has to do with the Ifaluk people of the Caroline Islands in the South Pacific. Their society is characterized by a relatively high degree of sexual permissiveness so that a man has little certainty that he is the father of his wife's children. Evolutionary analysis would predict that a man in this situation would withhold at least some parental support from his wife's children. In the case of the Ifaluk, a man provides support not for his wife's offspring but rather for his sister's, to whom he is more likely to be related, by becoming their "uncle-father" (Alexander 1979). In the somewhat less exotic setting of the Canadian city of Hamilton, Ontario, children over the age of four living with a step-parent were forty times more likely to suffer some form of parental abuse than those living in families with both biological parents (Daly & Wilson 1985).

A final example of the value of a sociobiological approach to human behavior deals with two major practices that are used throughout the world to help one's child obtain a desirable spouse. Because a man's reproductive capacity is limited primarily by his access to fertile women, we would expect that a man and his parents would be willing to give up some material resources to obtain a wife, the payment of which to the woman's family is often referred to as a *bride price*. This was the custom among the inhabitants of southern Sudan when I made several visits there in the early 1980s. I found it interesting to compare prices for brides in different localities, with a typical price being in the neighborhood of fifteen goats. But when I explained to my male Sudanese hosts that in other places such as India it is the bride's family that provides money and other goods (that is, a *dowry*) to the groom's family, they were incredulous. Why on earth would a young woman's parents pay an unrelated man's family in addition to giving away the services of their daughter?

At the time I could provide my African friends with no reasonable explanation for the Indian custom of the dowry. Since then I learned that providing a bride price is much more common than paying a dowry throughout the world (Murdock 1967). Paying for a bride is particularly prevalent in societies where men often take more than one wife (polygyny) since this practice increases competition for wives (if some men have more than one wife, other men must have none) and hence their worth to men. In contrast, the woman's family providing a dowry is about fifty times more likely to be found in socially stratified, monogamous societies than in nonstratified, polygynous societies (Gaulin & Boster 1990). In such societies men's wealth and earning potential vary greatly, and because a man's resources cannot be diluted by the acquisition of many wives, it pays for a woman's family to find her a wealthy husband, even if considerable cost is incurred in doing so. So these strikingly different practices of bride price versus dowry can be understood as different ways of achieving the common goal of maximizing reproductive success in two different cultural contexts.

Evolutionary Psychology's Search for Proximate Causes

The work of sociobiologists provides interesting hypotheses and useful explanations for aspects of human behavior by focusing on the survival and reproductive consequences of behaviors in different social contexts. It must be kept in mind, however, that uncovering the ultimate, evolutionary origins of certain preferences and behaviors does not explain proximate here-and-now reasons for a behavior. To use an analogy, studying and understanding the history of the invention and development of the automobile does not provide an explanation for why my car (usually) accelerates when I step on the gas.

This is perhaps made most clear by an example of animal behavior. The European cuckoo is a bird that is referred to as a *brood parasite*, meaning that the female lays each of her eggs in other birds' nests and then abandons them. The cuckoo egg hatches before those of the host bird, and the intruding hatchling proceeds to dump the other eggs out of the nest by balancing each egg on its back between its extended wings while walking backward up the side of the nest.

Coming up with an ultimate, evolutionary explanation for the young cuckoo's egg-dumping behavior is not difficult. By eliminating the eggs of its genetically unrelated hosts, the cuckoo monopolizes the care and food given to it by its duped adoptive parents. Since today's cuckoos descended from cuckoos that practiced egg dumping, they continue the practice. But eliminating its nestmates to have more food for itself is not likely what the cuckoo has in mind when it sends its hosts' eggs tumbling out into the void. Its actual proximate goal is almost certainly something much simpler, such as to remove all objects of a certain size, shape, and color from the nest with no knowledge that achieving this immediate goal will have a longer-term positive effect on its survival and later reproductive success. That this behavior had the effect of increasing the survival and reproduction of cuckoos in the past provides no proximate explanation at all for why the individual cuckoo still does what it does. The latter can be determined only by empirical testing of various hypotheses by introducing objects of varying shapes, colors, and sizes into the cuckoo's adoptive nest and observing its behavior to determine what perceptual variables it is controlling. In this way, the young cuckoo's immediate behavioral goals can be determined, goals that evolution selected because of their ultimate side effects of facilitating survival and reproductive success.

Now let us consider an example of human behavior. It was noted that men throughout the world, particularly older men, prefer women who are considerably younger than themselves. The ultimate, evolutionary explanation for this preference that was offered was that younger women are fertile and have many reproductive years ahead of them. Men who in the past chose younger mates left more descendants than those who chose older, less fertile mates, so this inherited preference for younger women spread throughout the population of human males.

But this ultimate, evolutionary explanation does not necessarily provide information concerning the proximate reasons as to why an individual man prefers and pursues younger women. In the case of the cuckoo, the ultimate, evolutionary explanation for any behavior or preference need not correspond to the proximate explanation. But since humans can plan ahead and consider the long-term consequences of behaviors, choices, and preferences, the proximate reason may be that older men prefer younger women because they really do consciously desire to have many children and see a younger woman as a means to this goal. But a more likely explanation is that men have evolved a preference for young women because our male ancestors who had such a preference left more descendants than those who did not, and that preference may have nothing to do with any perceived reproductive advantages. Again, the ultimate, evolutionary explanation for a behavior need not necessarily provide information concerning proximate mechanisms. This is particularly clear for nonhuman organisms that are unable to consider the long-term survival and reproductive consequences of their behavior. But the distinction between ultimate and proximate explanations is valid for humans as well.

Sociobiologists have not always been careful to distinguish between the two types of behavioral explanations, sometimes taking ultimate, evolutionary explanations as proximate ones. As John Tooby commented (quoted in Allman 1994, p. 49):

> Many sociobiologists have this view of people as *fitness maximizers*. They assume that since evolutionary biology says "We all evolved to propagate genes," the purpose of humans is to propagate genes. They believe that beneath all of our complicated human behaviors there is an underlying hidden logic of "gene propagation." So when you are being nice to your child, they say, all you are *really* doing is selfishly trying to propagate your own genes. A lot of sociobiological work carries this cynical interpretation of human behavior—a view of the world for which sociobiologists have been rightly criticized. The problem is that sociobiologists confuse the mechanisms of the mind with the *process* that built the mind, and in fact these are two separate things. Evolutionary biology is not a theory of human nature. Rather, it is a theory for how human nature *came to be*—and a useful tool for discovering what human nature actually is. A mother really does love her child—it's not that somewhere deep inside her mind there is a selfish motive to spread her genes. In fact, it's really the other way around: Human beings love their children because those ancestors who loved their children had more surviving children, and we're descended from them and not the others who didn't love their kids. So in the "grand evolutionary biological" sense of *Why do you love your kids?* You love them because it is part of your human nature that evolved as part of our ancestors' brain mechanisms. There is nothing in those brain mechanisms that says *That kid has your genes; he's propagating your genes, and so you should love him*.

John Tooby and his wife, Leda Cosmides, two founders of the new field of evolutionary psychology, are primarily interested in discovering psychological mechanisms that serve as the proximate causes of human behavior while looking to evolutionary theory for clues to these mechanisms and their ultimate origins. This Darwinian approach is still in its beginning stages, but it has already made two important theoretical contributions. The first, as mentioned, is the distinction between ultimate (evolutionary) and proximate (psychological) causes of human behavior. The second is the realization that almost all human evolution took place while our species lived in small groups of hunter-gatherers, long before the development of agriculture, large urban communities, and modern technology. This means that many behaviors and preferences that were adaptive in their original evolutionary contexts may no longer be adaptive today.

An example is our taste preference for sugar, salt, and fat—which are, coincidentally, the main ingredients of concoctions served in fast-food restaurants that have invaded almost all corners of the world. During the Pleistocene epoch, which ended 10,000 years ago, such nutrients were difficult for our hunter-gatherer forebears to obtain, yet vital for their survival. So individuals who consumed as much sugar, salt, and fat as they could when available would have had survival and reproductive advantages over those who did not. Because there was little danger during this time of consuming too much of these nutrients (being in such scarce supply), humans evolved a strong craving for the taste of foods with these nutrients.

But today millions of people live where they have virtually unlimited access to foods containing all the sugar, salt, and fat they can eat, and the associated health problems of obesity, diabetes, hypertension, and heart disease are all too common in modern industrial societies. So whereas a craving for these nutrients was adaptive in early human environments, recent changes in the environment for many modern humans rendered these dietary preferences less adaptive if not downright maladaptive. This distinction between what evolutionary psychologists call the "environment of evolutionary adaptiveness" (often abbreviated EEA) and our current environment is important in understanding how certain human preferences and behaviors that appear nonadaptive today may nonetheless have an adaptive evolutionary origin.

Changes in survival and reproductive consequences of certain behaviors and preferences in modern environments not anticipated by evolution often give useful clues to the proximate mechanisms of human behavior. For example, behaviors and preferences that in the past typically resulted in many offspring were selected by evolution. But what was actually selected? Is it a basic human desire to have many children? Or is having many children a side effect of achieving other proximate goals?

The finding that over the last century family size declined in Western societies and that today it tends to be smaller for wealthier families

(Vining 1986) suggests the latter. This decline and its negative correlation with wealth is one consequence of the availability of contraceptive methods that permit heterosexual couples to copulate while limiting the number of children they have or avoiding having children altogether. The fact that contraception is widely used, particularly by wealthier couples who in the past would have been expected to produce the most children and grandchildren, is a good indication that having many children is not a universal human goal resulting from natural selection, but is rather a side effect of other inherited preferences, notably the desire for frequent sexual intercourse, particularly with young, attractive females (for men) and wealthy, high-status men (for women).

The picture that emerges is one in which evolution selected organisms who had goals (and the means to achieve them) that resulted in better than average survival and reproductive success. But survival and reproduction are not the goals per se that the organism pursues. Rather, organisms, humans included, evolved preferences (and the means to achieve them) that in past environments led to survival and reproductive success with no guarantee that they will do so today. Overconsumption of sugar, salt, and fat and the practice of birth control are two examples of the lessening fit of evolved preferences and behaviors to survival and reproduction.

But humans do differ from other organisms in the flexibility they show in achieving their goals. A farmer can change the crops he plants depending on weather and economic conditions. In contrast, the leaf-cutting ant, having discovered agriculture millions of years before humans did, is limited to its crop of leaf-based fungus and cannot change its way of feeding if for some reason cultivating fungus is no longer practical or possible. In other words, humans have higher-order goals that are achieved by manipulating lower-order goals as necessary. Other organisms also provide evidence of a hierarchy of goals in their behavior (recall the examples of flexible insect behavior in chapter 7), but their hierarchies are not as extensive as those of humans. Thus certain goals (such as what to eat) cannot be varied to the extent that humans can adaptively modify their goals (which is why you will never find a vegetarian dog or a cat on a self-imposed diet).

This emphasis on the flexibility of human behavior is another way in which evolutionary psychology distinguishes itself from sociobiology. In the terminology of Robert Wright whose book *The Moral Animal* (1994) introduced evolutionary psychology to a large audience, we can look at human nature as made up of "knobs and tunings." Knobs are basic preferences selected by human evolution, and tunings are influenced by environmental factors. The preference for a variety of sex partners may be a basic knob that all human males inherit as part of their evolutionary legacy. But the extent to which this preference is realized (tuning) may well depend on the particular experiences of the particular man. Learning that other men who are sexually promiscuous pay no obvious penalty for their adventures and are able to maintain a stable family life and high social status may result in the knob being set on the high end of the scale. In contrast, living in a society where male sexual promiscuity is punished (for example, by exposure as scandalous, leading to loss of social status and esteem) may result in a much lower setting of that specific knob.

Such variation in tunings of basic inherited preferences may well explain much of the cultural diversity that is found among human societies, a diversity that has led many anthropologists and sociologists to reject the notion of universal human behavioral characteristics that were shaped by our evolutionary past. But we have seen that whereas the cultural practices of bride price and dowry are superficially very different, both can be understood as having positive effects on reproductive success in their social contexts. Still, these positive reproductive consequences are likely only a side effect of men competing for wives in polygynous societies and women attempting to secure high-status, resourceful husbands in monogamous, stratified societies.

When one looks under the surface in this way, similarities among diverse human societies are more striking than differences. Donald Brown, in his book *Human Universals* (1991), described characteristics that appear to be universally present in all human cultures. Steven Pinker (1994, pp. 413–415) outlined some of them, summarized here.

With respect to oral language, all human societies have:

> Gossip. Lying. Verbal humor. Humorous insults. Poetic and rhetorical speech forms. Narrative and storytelling. Words for days, months, seasons, years, past, future, body parts, inner states (emotions, sensations, thoughts), behavioral propensities, flora, fauna, weather, tools, space, motion, speed, location, spatial dimensions, physical properties, giving, lending, numbers (at the very least "one," "two," and "more than two"), proper names, possession. Kinship categories,

defined in terms of mother, father, son, daughter, and age sequence. Binary distinctions, including male and female, black and white, natural and cultural, good and bad. Measures. Logical relations including "not," "and," "same," "equivalent," "opposite," general versus particular, part versus whole. Conjectural reasoning (inferring the presence of absent and invisible entities from their perceptible traces).

Concerning nonlinguistic vocal communication, all human communities have:

Cries and squeals. Interpretation of intention from behavior. Recognized facial expressions of happiness, sadness, anger, fear, surprise, disgust, and contempt. Use of smiles as a friendly greeting. Crying. Coy flirtation with the eyes. Masking, modifying, and mimicking facial expressions. Displays of affection.

With respect to emotions we find all human communities having:

Sexual attraction. Powerful sexual jealousy. Childhood fears, especially of loud noises, and, at the end of the first year, strangers. Fear of snakes. "Oedipal" feelings (possessiveness of mother, coolness toward her consort).

Concerning activities, humans everywhere have:

Dance. Music. Play, including play fighting.

Aspects of universal human technology include:

Manufacture of, and dependence upon, many kinds of tools, many of them permanent, made according to culturally transmitted motifs, including cutters, pounders, containers, string, levers, spears. Use of fire to cook food and for other purposes. Drugs, both medicinal and recreational. Shelter. Decoration of artifacts.

For social conventions, we find in all human communities:

A standard pattern of time for weaning. Living in groups, which claim a territory and have a sense of being a distinct people. Families built around a mother and children, usually the biological mother, and one or more men. Institutionalized marriage, in the sense of publicly recognized right of sexual access to a woman eligible for childbearing. Socialization of children (including toilet training) by senior kin. Children copying their elders. Distinguishing of close kin from distant kin, and favoring of close kin. Avoidance of incest between mothers and sons. Great interest in the topic of sex. Exchange of labor, goods, and services. Reciprocity including retaliation. Gifts. Social reasoning. Coalitions. Government, in the sense of binding collective decisions about public affairs. Leaders, almost always nondictatorial, perhaps ephemeral. Laws, rights, and obligations, including laws against violence, rape, and murder. Punishment. Conflict, which is deplored. Rape. Seeking of redress for wrongs. Mediation. In-group/out-group conflicts. Property. Inheritance of property. Sense of right and wrong. Envy.

Concerning sex and age differences, found universally are:

> Division of labor by sex and age. More child care by women. More aggression and violence by men. Acknowledgment of differences between male and female natures. Domination by men in the political sphere.

As discussed, universal human behavioral patterns and preferences cannot in themselves be used as evidence that they have a specific genetic basis. Instead they may be the result of the interaction of more general abilities and desires with physical and social environments that are similar enough in all cultures to produce these behaviors. But this essential interaction of genes and environment does not in any way detract from a Darwinian approach to explaining their origins since any behavior, preference, or trait depends on an interaction of genes and environment, of nature and nurture.

Sociobiologists and evolutionary psychologists respect this essential gene-environment interaction insofar as they usually refrain from stating that any human trait or behavior is either solely genetically or environmentally determined, but they make other errors as a result of not adequately respecting this interaction. For instance, it is not unusual for a Darwinian-inspired behavioral scientist to state that some behavior or trait is more due to genes than environment, or vice versa. E. O. Wilson commented on the extent to which human social behavior is genetically determined. A more blatant and potentially pernicious example of such thinking can be found in Herrnstein and Murray's controversial book *The Bell Curve* (1994). The authors used a maze of statistical analyses to argue that differences between American blacks and whites in performance on general intelligence tests are almost exclusively due to genetic racial differences and not to striking differences in environments in which individuals of these two races typically grow up and remain. Yet if all behavior and psychological abilities result from an interaction of genes and environment, what can it actually mean to say that either genes or environmental factors are more important for a behavior or trait?

One way of simplifying this issue is to consider the surface area of a rectangle, which is a function of both its length and width. Specifically, its length and width interact in a multiplicative fashion so that its area in square units is its length multiplied by its width. The way in which the length and width interact in determining area means that the effect of length on area depends on width. Similarly, the effect of width on area depends on length. So increasing a rectangle's width from 5 to 6 units will have more of an effect on its area if it is 16 units wide rather than 15 units wide. Increasing width from 16 to 17 units will have more effect on area if it is 6 units rather than 5 units long. Note that this interactive relationship makes it nonsensical to ask whether a rectangle's length or width is more important in determining its area.

Consider the implications of a similar multiplicative gene-environment interaction for human abilities and behaviors, such as those related to a child's success in school. If genes and environmental factors interact in determining school achievement, it makes no sense to consider whether nature or nurture is more important or which contributes more to the observed differences in this regard among a group of children.

Here's another example, a hypothetical case I call "The Case of the Stuttering Triplet," like the surface area example above, inspired by psychologist Donald Hebb's important 1953 paper on the roles of heredity and environment in behavior. Two psychologists, Dr. A and Dr. B, are interested in the causes of stuttering. Dr. A finds a boy named Stu who stutters and learns that Stu has a fraternal (dizygotic) twin living in the same house who does not stutter. Dr. A concludes from these findings that Stu's stuttering is genetically determined, since his brother, who has a different genome but shares the same home environment, does not stutter.

Meanwhile, Dr. B discovers a boy, also named Stu, who stutters. During his investigation Dr. B learns that this Stu has an identical (monozygotic) twin who was separated from Stu at birth, lives with a different family, and does not stutter. Dr. B concludes that Stu's stuttering is due to environmental factors since Stu's identical brother, who has an identical genome but lives in a different environment, does not stutter.

The punch line is that Dr. A and Dr. B have both found and studied the very same stuttering boy but have learned different things about him. Stu is actually one of *triplets*, two of them identical (one of them being Stu) and one fraternal. Dr. A's knowledge of Stu's nonstuttering fraternal twin living in the same home led him to conclude that Stu's stuttering had a genetic cause. In contrast, Dr. B's discovery of Stu's nonstuttering identical twin in a different home led to a very different conclusion, that Stu's stuttering must be due to his environment. What is really going on (obvious to us since we know of both Stu's identical and fraternal nonstuttering brothers) is that a certain *combination* of environmental and genetic factors led to Stu's stuttering, with neither genes nor environment being more or less important than the other in bringing about this phenomenon.

But there is yet another way in which genes and environment interact to influence behavior that goes beyond the multiplicative model suggested by the rectangle example. Research indicates that certain environmental factors can cause chemical changes in the body that affect certain genes that in turn produce proteins that ultimately influence the brain. Since changes in the brain influence behavior and the resulting environment, we have another circle of causality that defies one-way cause-effect analysis. We will see in the next chapter a particularly striking example of how at least a portion of a person's genes are not fixed at birth but rather continue to evolve throughout life in response to certain environmental conditions. To return briefly to the rectangle, it is as if changing its length also influences its width, which then influences its length, and so on.

What all this means for a Darwinian approach to human behavior is that neither genes nor environment (including culture) can be considered in isolation. Even to ask the question as to whether nature or nurture is more important in determining a human structural or behavioral trait is an indication of confusion. Since so much of humankind's environment is a function of human behavior and preserved for succeeding generations in the form of culture (which includes homes and schools), we must consider coevolution of both to make sense of human behavior. As the noted Ukrainian-born American geneticist Theodosius Dobzhansky remarked (quoted in Wilson 1978, p. 21), ". . . in a sense, human genes have surrendered their primacy in human evolution to an entirely new, nonbiological or superorganic agent, culture. However, it should not be forgotten that this agent is entirely dependent on the human genotype." And, of course, the human genotype has from its very beginning also been dependent on human culture.

This interaction of nature and nurture also blurs the distinction that is still often made between innate and learned behavior. We noted in the preceding chapter how the learning capabilities of animals were shaped by natural selection. That is, the ability to modify behavior in useful ways as a result of experience is inherited. Insofar as such learning abilities have survival and reproductive consequences, they in turn help to shape further evolution of the organism.

Strengths and Dangers of a Darwinian Approach to Human Behavior

The Darwinian approach to human behavior that emerged in the 1990s in the form of evolutionary psychology has begun to offer new insights into the behavior of our species.[3] Like its sociobiological forerunner, evolutionary psychology recognizes the importance of Darwinian evolution, including kin selection and reciprocal altruism, to provide ultimate explanations. In addition, it attempts to discover proximate psychological mechanisms underlying various human actions, recognizing that certain evolved behaviors and preferences may no longer be adaptive in a world so very different from the physical and social world in which we evolved.

But this approach has potential dangers that must be guarded against. One is the tendency to analyze human behavior by attempting to separate genetic from environmental factors, when these factors interact so that any such separation is meaningless at best and seriously misleading at worst.

Another potential danger is application of basic human universals or observed group differences (such as those based on sex or race) to individuals. By way of illustration, let us consider a proposed human universal from the preceding list where it was noted that all human societies make use of music and dance for various social functions. But finding music and dance in all human societies does not mean that all individual humans engage in musical behavior. Rather, since evolution depends on variation in traits and abilities, we should expect to find individual variation in participation in and abilities for such activities. Similarly, not all mature humans engage in sexual activities (while others do so frequently) and not all individuals participate in gift giving (while the great majority of us do). It is therefore important to keep in mind that human universals suggested by an evolutionary perspective are universal only in the sense that they are found in all human cultures and societies, and not in the sense that they apply to every human being on earth.

We must also guard against applying observed group differences to individuals. For example, consideration of human spatial abilities from an evolutionary perspective led to the hypothesis that since our male ancestors were primarily hunters of mobile, far-ranging game while our female forebears were mostly foragers of immobile, nearby vegetable foods, there should be sex differences in those abilities that are most important for hunting (where men should show an advantage) and foraging (where women should be superior). As predicted, men as a group are better in tasks involving mental rotations of objects, map reading, and maze learning, whereas women as a group show superiority in recalling objects and their locations. To take an ability where women show an advantage, a test for object memory, a group of 115 women correctly recalled on average 1.9 more objects from a diagram containing 27 objects than a group of 63 men (Silverman & Eals 1992, p. 539).

But in spite of this statistically significant difference favoring women ($p < 0.01$), the variability of individuals in each group (pooled standard deviation 4.03) resulted in a large enough overlap between men and women in this ability so that one cannot predict with confidence that a given woman will actually have a better memory for objects than a given man. Instead, since the mean difference between the groups is less than half the difference between a typical individual and his or her group's mean, a given man has close to a 7 out of 10 chance of being either above the woman's mean or not being more below that value than would be expected for a typical woman.

Even when group mean differences equivalent to one standard deviation are found (which is not common in psychological studies; an example would be a difference in means between two groups of 15 IQ points), it is still the case that a given individual in the lower group has an even chance of being either above the mean of the higher group or not farther below it than a typical individual of the higher group.

The lesson to take away from this is that a Darwinian approach to human behavior may lead to the discovery of interesting pancultural human universals and group differences, but such findings rarely if ever allow one to make accurate or useful predictions concerning the abilities or behavior of a given individual. So even if it is true, as Herrnstein and Murray claim, that American blacks score on the average 15 points below American whites on measures of general intelligence, such a group difference would be of virtually no use for making predictions about the intelligence of an individual white or black American.

Evolutionary psychology, unlike behaviorism, also recognizes the central importance of desires and goals in explaining human behavior. But, curiously, its practitioners have yet to discover proximate psychological mechanisms that can explain how such goals and desires influence behavior. This is because the mechanisms they propose continue to be one-way cause-effect models in which sensory input is transformed (that is, cognitively processed) into behavioral outputs. To illustrate this perspective, here are Cosmides and Tooby stating their view of the proximate psychological mechanism (1987, p. 282):

> Behavior is not randomly emitted; it is elicited by information which is gleaned from the organism's external environment, and, proprioceptively, from its internal states. Natural selection gave us information processing machinery to produce behavior, just as it gave us food processing machinery to produce digestion. . . . The evolutionary function of the human brain is to process information in ways that lead to adaptive behavior; the mind is a description of the operation of a brain that maps information input onto behavioral output. . . . Behavioral output differs with informational input; the information processing machinery that maps informational input onto behavioral output is a psychological mechanism.

But we saw in chapter 6 how such a one-way cause-effect mechanism is simply incapable of accounting for purposive behavior. If such a model cannot explain how a person can maintain the knot joining two rubber bands at a certain spot in spite of continuous disturbances, or keep a car centered in a highway lane despite curves and gusting winds, it certainly is inadequate to the task of accounting for how we are able to find food, procure mates, protect our children, defeat our enemies, and further our careers and reputations in complex, constantly changing, disturbance-filled environments.

This continued reliance on a one-way input-output mechanism of behavior leads to other problems. One is that evolutionary psychologists are susceptible to the behavioral illusion described in chapter 6 in which the covariation between some observable aspect of the environment and a person's behavior makes it appear as if a stimulus is causing behavior when in fact behavior is being used to control a perception that may not be apparent to the researcher. A second problem is that the one-way cause-effect model of behavior cannot distinguish between the intended consequences of human action and its unintended, accidental side effects. And a third problem is that an input-output view of behavior cannot account for the way in which certain desires or goals serve as subgoals, that is, as a means of achieving other goals, and how these subgoals are varied in response to disturbances to achieve the higher-level goals.

Perceptual control theory, with its hierarchy of perceptions and goals, provides an explicit, working model for these important characteristics of human behavior. But it is able to do so only by rejecting a one-way cause-effect view and replacing it with a hierarchy of closed loops, each involving the simultaneous functions of perception, comparison with a reference level, and action.

Whereas evolutionary psychologists recognize the Darwinian *origin* of many human desires and goals, as a group they have not yet escaped the grasp of one-way cause-effect reasoning in their attempts to understand the proximate *mechanisms* of behavior. Neither do they recognize the existence and importance of Darwinian processes occurring within the brain as humans constantly adapt their behaviors and desires to new environmental challenges for which our evolutionary past could not have prepared us. This application of Darwinian theory to adaptive processes occurring during the lifetime of organisms constitutes a veritable second Darwinian revolution that is the subject of the next chapter.

9

Evolution Within the Body: The Darwinian Lesson Extended

Evolution builds brains using evolution itself as a design tool. As it matures, a brain literally adapts to its body.

—Terrence W. Deacon (1997, p. 194)

Our present understanding of Darwinian evolution offers some answers and suggests others to many ultimate and proximate why questions concerning behavior. However, it must be recognized that the natural selection of organisms has a serious adaptive limitation. Natural selection can lead only to the evolution of organisms whose structure and behavior are adapted to *past* environments, with no guarantee that they will be adapted to the environment in which they live today and will inhabit tomorrow.

To the extent that an organism's environment is similar to that in which its predecessors evolved, we can expect its physical structures, physiological systems, and behavior to fit the demands of its current environment. But if the environment is significantly different in any way from that of its ancestors, we should not be surprised to find the organism maladapted in some way to the demands of living and reproducing. Changes in climate or in a species' food supply, or the arrival of a new predator or parasite may lead to extinction. The consequences of this inability of natural selection to prepare organisms for future environments can be quite serious, as indicated by the fact that the normal fate of a species is extinction; there are many times more extinct species than extant ones.

Psychologist Henry C. Plotkin referred to this as the "uncertain futures problem" (1994, p. 135), and it poses a serious challenge for all living organisms. Obviously, an organism's chance of surviving and reproducing would be improved if it could somehow solve the uncertain futures problem by changing its behavior to adapt to changes in the environment. Indeed most, if not all, organisms can adaptively modify their behavior to at least some degree, although some species are much better at this than others. In this respect, the human species is distinguished by remarkable flexibility that permits us to survive in a range of environments unmatched by any other species yet encountered (excluding parasites and bacterial companions for which we serve as host), from tropical forests and deserts to arctic tundra and, thanks to modern technological advances, from the ocean floor to the lunar surface.

The ability to change one's behavior (and thoughts, in the case of humans) as a result of environmental experiences is generally referred to as *learning* by psychologists and animal scientists. We surveyed in chapter 3 several attempts to understand how humans and other organisms are able to make adaptive changes to their behavior. But we also noted how these proposals—from behaviorist theories of Pavlov, Thorndike, Watson, and Skinner to cognitive theories of learning—fail to account for the purposeful nature of behavior, relying as they do on one-way stimulus-response or stimulus-computation-response mechanisms.

This chapter considers a more satisfactory materialist understanding of how it is that human behavior and thought can be adaptively modified as a result of experience. In keeping with the book's major themes, the mechanism offered will most assuredly not be one in which environmental stimuli cause behavior, but rather one that extends Darwin's selectionist lesson to processes occurring *within* organisms.

The Immune System as Within-Organism Darwinian Selection

Although it may seem odd to begin our discussion of learning with a look at the mammalian immune system, there are actually very good reasons for doing so. They will not become apparent, however, until we consider some basic facts about the functioning of the immune system.

The human immune system's primary function is to protect our bodies from microscopic pathogens such as bacteria, viruses, and chemical toxins that are collectively known as *antigens*. It does this by producing cells called *antibodies* that are able to recognize invading antigens and bind with them so that other cells produced by the immune system can find and neutralize or destroy them. What is both striking and essential about antibodies is that they have a very close physical match to the antigens to which they bind. An effective antibody fits an antigen in much the way that a jigsaw puzzle piece fits its neighboring piece (although for antibodies and antigens the fit is in three dimensions, not just two).

For over 100 years scientists puzzled over how antibodies managed to achieve this close fit with antigens. During the 1890s the first important immune system researcher, Paul Ehrlich (1854–1915) of Germany, theorized that mammals were born with a large innate set of antibodies, at least one of which was able to bind to any possible antigen. In this view, information essential for the production of all possibly needed antibodies is contained in the animal's genes (see Ehrlich 1900). Ehrlich's theory was therefore known as a *germ-line theory* of antibody production, with germ line referring to the entire set of genes (or *genome*) that is passed from parents to offspring.

But this theory soon encountered a major difficulty. During the 1900s Karl Landsteiner (1868–1943) of Austria demonstrated that antigens could be produced in response to the introduction of completely new artificial substances. This indicated that the germ-line theory is inadequate since an animal could not possibly possess in its finite genome the information required to produce an infinite number of all possibly needed antibodies. In effect, Landsteiner showed that the immune system somehow manages to solve the uncertain futures problem by producing new antibodies able to bind with antigens never before encountered in its host's life or evolutionary past.

The theory that first attempted to account for the immune system's ability to generate antibodies in response to novel antigens was the *template theory* that appeared in Europe in 1930 and was further developed by Nobel prize-winning chemist Linus Pauling (1901–1994) in the United States. According to the template theory, antigens themselves are used by the immune system to construct well-fitting antibodies, similar to the way that a cookie cutter makes cookies out of dough. Since antibody formation is considered the result of the direct action of antigens on antibodies, this can be referred to as an *instructionist* theory with antigens somehow directly causing or "instructing" adaptive changes in the production of antibodies. In this way the template theory is similar to Lamarck's instructionist theory of evolution that saw the environment as directly causing adaptive changes in organisms (see chapter 7).

Also like Lamarck's theory, the template theory of antibody production ultimately failed. As British-Danish immunologist Niels Kaj Jerne (1911–1994) pointed out in the 1950s, it could not account for several key immunological findings. These include the increasing rate of antibody production during the initial immune response, the system's memory of previously encountered antigens, and the fact that antibodies produced during the latter stages of an immune response are more effective in binding with antigens than antibodies initially produced.

In addition to making strong arguments against the template theory, Jerne offered an alternative for which he received a Nobel prize in 1984. His natural selection theory of antibody production held that a mammal initially possesses a relatively small number of antibodies. Successful binding of an antibody to an antigen—which fortunately does not require an exact fit between them—triggers the antibody to produce a large number of copies of itself. In this way a preexisting antibody is effectively *selected* by the antigen that in turn stimulates the chosen antibody to produce a multitude of clones. Australian virologist Sir Frank Macfarlane Burnet (1899–1985), yet another Nobel laureate, further developed this theory, calling it the *clonal selection theory* of antibody production.

Whereas this rather sketchy account of antibody production has omitted much (for a more detailed summary see Cziko 1995, chapter 4), it nonetheless reveals its essentially Darwinian operation. Indeed, the clonal-selection production of antibodies is a veritable microcosm of Darwinian evolution with the three major principles of overproduction, variation, and selection each playing an essential role. Overproduction is evident in the production of far more antibodies than are effective in binding with an antigen; variation is achieved by the random recombination and mutation of antibody genes; and selection occurs as only those antibodies that bind with an antigen can reproduce and thus be represented in the next generation.

It should be now somewhat clearer why this chapter on learning and cognitive development began with an introduction to the mammalian immune system. It is because the immune system is an adaptive system that has overcome the uncertain futures problem by employing its own version of Darwinian evolution. This evolution takes place not over long periods of geological time, but rather over the much shorter lifetime of individual organisms as certain antibodies are naturally selected for reproduction and others are eliminated. Whereas adaptive biological evolution proceeds by cumulative natural selection occurring *among* organisms, we now understand that the immune system is able to adapt to new, unpredictable pathogenic threats by cumulative variation and selection occurring *within* organisms. Might it also be the case that organisms are able to devise behavioral and mental solutions to problems posed by uncertain futures using a similar process of within-organism variation and selection?

Darwinian Theories of Behavioral and Cognitive Change

Just such a Darwinian approach to cognitive functioning and behavior played an important role in psychological theory, particularly at the end of the nineteenth century and beginning of the twentieth. In the late nineteenth century, theories involving mental or cognitive variation and selection were used to attempt to understand how scientific discoveries are made. Scottish philosopher and psychologist Alexander Bain (1818–1903) emphasized that scientific discoveries required the generation of a great number of ideas and then trying them out (1868, pp. 593 ff.). Another early cognitive Darwinian was English economist and logician W. Stanley Jevons (1835–1882) who stated that "in all probability the errors of the great mind exceed in number those of the less vigorous one. Fertility of imagination and abundance of guesses at truth are among the first requisites of discovery; but the erroneous guesses must be many times as numerous as those which prove well founded" (1874; quoted in Campbell 1974, p. 428).

Other respected nineteenth-century writers who were quick to apply Darwinian selectionism to the understanding of human thought and behavior included American psychologist James Mark Baldwin (1861–1934), Austrian physicist and philosopher Ernst Mach (1838–1916), and

French mathematician Henri Poincaré (1854–1912). Central to all these men was the notion that useful thoughts (beliefs, ideas) could be found only if the thinker generated a large number of varied guesses that were somehow filtered so that only the better ones were retained and the others discarded.

In the United States, mathematician and philosopher Chauncey Wright (1830–1875) was so taken by the theory of evolution that he visited Darwin in England in 1872 and went on to apply concepts of natural selection to the workings of the human mind. Instead of Darwinian competition among organisms, Wright described a process of mental competition among beliefs, with both other current beliefs and the environment acting to eliminate less fit beliefs and leaving better-adapted ones.

Wright's ideas apparently also had some influence on America's first great psychologist, William James. James, who recognized the purposeful character of animal and human behavior (recall his description of the frog seeking air and Romeo striving to place his lips on those of Juliet), applied the ideas of Darwinian random variation and selection to the psychological realm (1880, pp. 456–457).

> . . . new conceptions, emotions, and active tendencies which evolve are originally *produced* in the shape of random images, fancies, accidental outbirths of spontaneous variation of the excessively unstable human brain, which the outer environment simply confirms or refutes, preserves or destroys—selects, in short, just as it selects morphological and social variation due to molecular accidents of an analogous sort . . .

But the rise of behaviorism in the United States during the first half of the twentieth century put a rather abrupt end to James's cognitive Darwinism and replaced it with a Darwinism oriented to overt behaviors. The theory of operant conditioning introduced by Thorndike and further developed and advocated by Skinner was described and critiqued in chapters 3 and 7. It will be recalled that Skinner's dismissal of purpose and his emphasis on the environment's role in determining an organism's behavior resulted in a theory in which external factors cause the organism's behavior and cannot account for the way in which the organism acts to control aspects of its environment. Skinner saw behavior as determined by its consequences (reward and punishment), however, a true appreciation of the purposeful nature of animate behavior must include understanding behavior as a means of controlling consequences.

In retrospect, it is unfortunate that Skinner used an evolutionary analogy for his theory of animate behavior and learning, since this provided a reason for those involved in the cognitive revolution of the second half of the twentieth century not only to reject his narrow focus on overt behavior and environmental control but to purge all Darwinian thinking from psychology as well. The Skinnerian image—organisms (including humans) emitting random behaviors with the environment providing consequences to determine which of these behaviors should be repeated—was (and still is) considered simplistic, unrealistic, and even repugnant to cognitive scientists. They instead attempt to understand behavior and its change by focusing on mental and neural processes that underlie what often appears to be initially highly intelligent behavior, not the randomly emitted fumblings Thorndike and Skinner described.

Perhaps the best example of this anti-Skinnerian and anti-Darwinian attitude among cognitive scientists is that of linguist Noam Chomsky and his innatist theories of language structure and acquisition. Indeed, Chomsky's 1959 review of Skinner's book *Verbal Behavior* is typically taken as the beginning of the cognitive revolution in psychology. Curiously, his anti-Darwinism goes so far as even to deny Darwinian evolution an important role in the evolution of the human capacity for language.[1]

Donald T. Campbell's Cognitive Darwinism

At least one behavioral scientist was able to reject Skinner's narrow focus on overt behavior while recognizing the power of the Darwinian process working within organisms. Donald T. Campbell (1916–1995), who spent most of his academic career at Northwestern University near Chicago, is best known among behavioral and social scientists for his development of research methods (see, for example, Campbell & Stanley 1966; Cook & Campbell 1979). But although this work remains important and influential, Campbell was actually more interested in developing a general theory of knowledge processes that used as its engine the Darwinian mechanism of variation and selection.

Campbell made three major accomplishments in this area. First, he documented and described Darwinian theories of thought and behavior of philosophers, psychologists, and other scientists since the time of Darwin (Campbell 1974). Second, over more than thirty-five years he provided strong arguments that Darwinian variation and selection underlie all processes by which adaptation of some type is achieved. These include the fit of our perceptions to aspects of the environment they represent, the fit of our thoughts and mental processes to real-world problems we confront and solve, and the fit of our scientific theories and predictions to the universe they describe. Finally, he devised a hierarchy of knowledge processes to explain how the development of all forms of knowledge—whether over long periods of evolutionary time or during the relatively short lifetime of a single organism—can be accounted for by the general Darwinian process of variation and selection.

For the purpose of this chapter, it is Campbell's description of what he called "vicarious blind variation and selective retention" that is of most interest. Campbell saw such vicarious processes as adaptive mental processes "substituting for overt locomotor exploration or the life-and-death winnowing of organic evolution" (1974, p. 421). Let us turn to a concrete example for a better idea of what he had in mind.

Imagine that a desired object, such as a piece of food, is placed in view behind a fence so that an animal can obtain it only by first moving away from it to go around the intervening barrier. This is known as the *Umweg* (German for "detour") task and has been used to test the problem-solving abilities of chimpanzees, chickens, and other animals (see Boakes 1984, pp. 184–196).

It turns out that chickens and chimpanzees differ markedly on the Umweg task. Whereas chickens can solve the problem only if their frantic movements bring them by chance to a spot where they can see the path around the obstacle, chimpanzees can more calmly examine the situation and then simply walk around the barrier to obtain the object. So chickens must rely on the variation and selection of overt behaviors, but larger-brained chimps are able to substitute the variation and selection of mental processes for overt behavior.

Here's another example that you can try yourself. Examine the maze shown in figure 9.1 and by visual examination alone (using no pen or pencil or tracing actions) try to find the path from the upper left corner to the lower right one. You should try this now before reading further.

Notice how you were able to solve the maze problem with no overt behavior at all (other than moving your eyes, if you consider that overt). To find the path, you almost certainly made a number of mental errors,

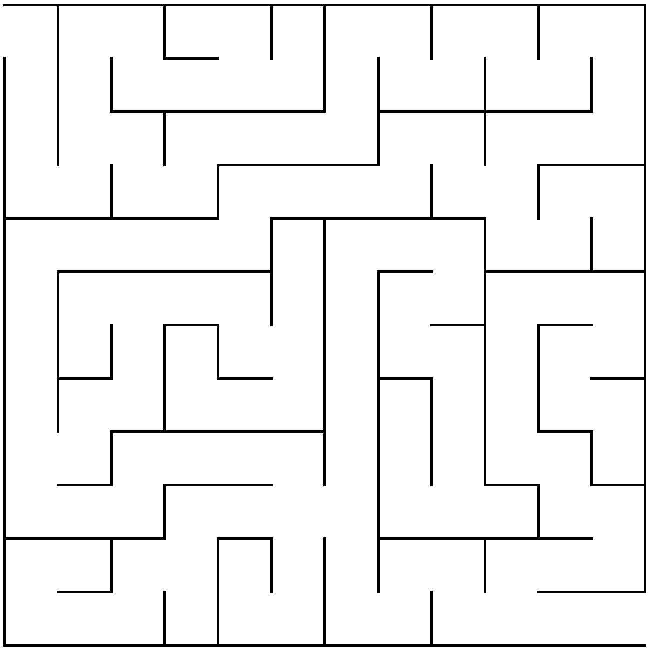

Figure 9.1
Maze

running into cul-de-sacs and backtracking to find an alternative successful route. This is an example of the vicarious variation and selection of mental processes that in humans—and presumably other "higher" animals such as apes and perhaps even dogs and cats—can substitute for the overt variation and selection of behaviors that Skinner emphasized.

As a final example, imagine trying to rearrange the furniture in your living room to accommodate a piano. In looking over the room as currently furnished, you could readily imagine other possible arrangements. You might think, "The sofa could be moved from the back wall to under the window freeing up wall space for the piano, and the armchair currently next to the window could be moved to the empty corner." On second thought, this plan may not prove to be feasible, as the piano would block access to the built-in bookcase. But other arrangements could easily be imagined as you observe the room's current configuration and contents and think about other ways it could be arranged.

The usefulness of this variation and selection of mental processes as a substitute for more costly (in terms of time and energy) and potentially dangerous overt behaviors provides what may be an important clue in understanding the evolution of consciousness itself. While the topic of consciousness and its purpose continues to intrigue and mystify both philosophers and cognitive scientists (for example, see Dennett 1991; Searle 1992), one important use of consciousness is the vicarious mental variation and selection it makes possible. This perspective on consciousness does not provide answers to the question of why we have the particular conscious experiences we have, but it does suggest an important functional role for consciousness. Consciousness as vicarious variation and selection allows us to try out possible solutions mentally using a type of simulated or virtual reality as a substitute for more effortful and possibly dangerous overt behavioral trials.

It is largely because of Campbell's writings that a general Darwinian approach to human knowledge, thought, and behavior survived through both the behaviorist and cognitive phases of twentieth-century psychological theory. Campbell coined the term *evolutionary epistemology* that is still widely used, at least among philosophers, for a general Darwinian account of the emergence of knowledge. For more than thirty-five years he provided important philosophical, logical, historical, and anecdotal reasons for seeing creative thought, problem solving, technological advances, and scientific progress as involving the cumulative blind variation and selection of thought trials. But he did not undertake empirical research to provide evidence for his claims and so his Darwinian account of knowledge processes has not had much impact on mainstream psychological theory. But we will see in the following sections that there is increasing evidence from both behavioral and neuroscientific research for Campbell's cognitive extension of Darwin's lesson.

Evidence for Cognitive Darwinism

When Campbell first proposed his extension of Darwinian theory to psychology, he anticipated difficulty finding empirical support, noting "the unfavorable ratio of hypothesized unobservable processes to observable input-output variables" (1960, p. 397). Thoughts and ideas do not leave fossils that can be dug up and examined, nor are they readily accessible to other means of scientific observation and measurement. But now, forty years later, a growing body of evidence suggests that some cognitive processes do involve the Darwinian variation and selection of thought trials. These findings are not only consistent with Campbell's theory but are difficult to account for otherwise. Much of this research deals with human creativity and invention and was reviewed by Simonton (1999b). We will now take a look at some of these studies, as well as some others not discussed in Simonton's book.

If it is true that problem solving and other adaptive forms of human creativity depend on blind variation and selection of thought trials, we should expect them to be enhanced by factors that increase the variability and number of such thoughts. This was found in a number of experimental studies. Subjects in one study were provided with shapes and forms to create objects having certain functions (Finke, Ward, & Smith 1992). They came up with the best and most imaginative inventions when both the forms they were given and the target function were randomly selected from a large set of possibilities. In another study, randomly generated associations facilitated problem solving on a marketing task (Proctor 1993).

Other investigations, known as psychometric studies, examined relationships between certain psychological traits and creativity. They found that above a certain basic level, IQ is not related to creative ability (Simonton 1985). Instead, creative individuals tend to produce many varied ideas (see, for example, Eysenck 1993, 1994, 1995). Accordingly, tests that attempt to measure creativity typically do so not by replicating the types of items found on intelligence tests but rather by assessing an individual's ability to generate many diverse ideas. The Remote Associations Test (Mednick 1962) assesses creativity by measuring one's ability to create associations between dissimilar ideas. Other tests assess an individual's ability in what is called divergent thinking, that is, the ability to generate many novel and diverse responses to a problem or question. An example is the Alternate Uses Test in which one attempts to come up with as many different uses for an object as one can.

Other aspects of personality that are associated with creativity also support a within-organism Darwinian view of cognition. Simonton (1999a) summarized this research by noting that:

> . . . creative personalities tend to possess those characteristics that would most favor the production of ideas both numerous and diverse. In particular, creative individuals tend to be independent, non-conformist, unconventional, even bohemian; they also tend to have wide interests, greater openness to new experiences, and a more conspicuous behavioral and cognitive flexibility and boldness.

Also of interest are studies of creativity and invention that use historical measures. Historiometric studies conducted by Simonton (1979, 1987, 1997) showed that individuals who are most prolific are also the most successful in creative achievements. This relationship between quantity and quality holds across as well as within individuals and thus provides some evidence that creativity is a function of variations. The more an individual produces, the more likely he or she is to be successful in some creative endeavor, not unlike biological evolution in which organisms that produce the most offspring are most likely to produce a variation that will be better adapted to survival and reproduction. Of particular interest is the finding that the proportion of produced variations that are successful does not increase as an individual gains experience in his or her field. Rather, individuals appear to be most creative around the age of 40, which is when they produce the greatest number of variations. In addition, a Darwinian view of creativity can account for the output of scientific communities (Kantorovich 1993).

Finally, in the field of cognitive development, Siegler (1996) found a high degree of variation in the problem-oriented thinking of children and held that "variability and selection functions seem essential to any developing system. Thus, they may be a basic part of many, if not most, mechanisms of cognitive development" (1989, p. 376).

These are just a few of the studies from the considerable (and growing) body of empirical research that supports a within-organism Darwinian theory of creative thought and behavior as suggested by Campbell. The reader is referred to Simonton's recent book (1999b) for a thorough treatment of this topic.

The Rise of Neural Darwinism

In addition to evidence from psychological studies of thought, personality, and behavior, the rapidly developing field of neuroscience has uncovered findings having clear Darwinian implications for our understanding of the development, structure, and functioning of the human brain.

One of the principal puzzles in the neurosciences is understanding how something as complex as the human brain can develop from a single fertilized egg cell. The adult human brain contains about 11 billion specialized nerve cells, or *neurons*, and each neuron may have up to 10,000 connections, or *synapses*, with other neurons. It is widely believed by neuroscientists, psychologists, and even some philosophers that all knowledge that the brain contains—from knowing how to walk to being able to perform abstract mathematical reasoning—is a function of neurons and their interconnections. Therefore, understanding how the functional complexity of the brain develops is a major goal of behavioral and brain sciences.

It was thought at one time that the brain's complex organization was fully specified in the genome as a result of many millions of years of natural selection. Research findings now cast doubt on such a view. For one thing, it is estimated that the human neocortex alone (the most recent addition to our brain) has about 10^{15} (1 followed by 15 zeros, or 1 thousand million million) synapses (Eccles 1989, pp. 1, 4). Since the entire human genome has only about 3.5×10^9 (3.5 billion) bits of information stored as nucleotide base pairs, some scientists (for example, Deacon 1997, p. 197) have concluded that our genes simply do not have enough storage capacity to specify all these connections, in addition to including information on the location and type of each neuron plus similar information for the rest of the body.

How then is the brain able to achieve the very specific and adaptive wiring required to function in so many remarkable ways? For example, how does a motor neuron know to which particular muscle fiber it should connect? How is a sensory neuron in the visual system able to connect itself to the correct cell in the visual cortex of the occipital lobe of the brain? If this detailed neuron-to-neuron wiring plan is not provided by the genes, from where does it come?

It turns out that the precise wiring of the brain and nervous system is accomplished by a process that *eliminates* many neurons and synapses. As far back as 1906 it was known that some embryonic neurons did not survive birth (Changeux 1985, pp. 216, 217), with later research finding that of the 20,000 neurons present in a particular location of a chicken embryo's spinal cord, only 12,000 remained in the adult bird (Hamburger 1975).

In addition to entire neurons, countless synaptic connections are eliminated during the development of the mammalian nervous system. But how does the nervous system know which connections to retain and which to eliminate? The work of David Hubel and Torsten Wiesel in the 1970s (who shared a Nobel prize in 1981) provided an important clue. They conducted their ground-breaking experiments by sewing closed the lid of one eye of newborn cats and found that even one week without sight altered the connections of the eyes to the brain (layer 4 of the occipital cortex, to be more precise). Neurons carrying nervous signals from the closed eye made fewer connections with the cortex, whereas those from the open eye made many more connections than was normal. This finding suggests that visual system neurons engage in a form of Darwinian competition for space in the visual cortex, with the result of the competition dependent on the amount and type of sensory stimulation carried by the axons.

We know that normal development of the brain is a function of interaction between genetic inheritance and environmental experience. The genome provides the general structure of the central nervous system, and nervous system activity and sensory stimulation provide the means by which the system is fine-tuned and made fully operational. But this fine-tuning does not depend on adding new components and connections in the way that a radio is normally assembled in a factory. Instead it is achieved by eliminating much of what was originally present. It is as if the radio arrived on the assembly line with twice as many electrical components and connections than it needed. If such an overconnected radio were plugged in and turned on, nothing but silence, static, or a hum would be heard from its loudspeaker. However, careful removal of unnecessary components and judicious snipping of redundant wires would leave just those components and connections that result in a functioning radio. This snipping is analogous to the elimination of synapses in the human brain as part of its normal development.

Psychologist William Greenough of the University of Illinois at Urbana-Champaign has studied in microscopic detail the process by which brain connections change over time as maturing animals interact with their environments. Using sophisticated techniques to determine the numbers of neurons and synapses in specific regions of the rat's brain, he and his associates found a rapid spurt in the growth of synapses during the first months of the rat's life that occurs regardless of the amount or type of sensory experience (Greenough & Black 1992). This period of synaptic "blooming" is followed by a sharp decline in the number of synapses. That is, elimination or "pruning" of synapses takes place based on the activity and sensory stimulation of the brain, ultimately resulting in the pattern of connections characteristic of the mature rat's brain.

Greenough refers to this initial blooming and pruning of synapses as *experience-expectant* learning, since the initial synaptic overproduction appears to be relatively independent of the animal's experiences. It is as though the brain is expecting important things to happen during the first months of life and is prepared to profit from these experiences with an overabundance of synapses, only a fraction of which will be selectively retained. The work of Greenough and his associates has been limited to rats and monkeys, but autopsy studies of human cortex have also found a decrease to about 60 percent of the maximum number of synapses as the human brain matures (Huttenlocher & Dabholkar 1997, p. 167).

In a recent book on the evolution of language, neuroscientist and biological anthropologist Terrence Deacon (1997, p. 199) summarizes the role of within-organism Darwinism for brain development:

> In the same sense that Darwinian processes have created new design information for building organisms during the course of the evolution of life, Darwinian-like processes in brain development are responsible for creating the new information required to adapt large brains to themselves and to their bodies.

Greenough's work also gives a Darwinian explanation for how the adult brain is able to learn new skills, form new memories, and adapt to new environments. According to this theory, experience-dependent learning involves both addition and elimination of synapses. Addition involves growth of new synapses in response to the animal's attempt to control aspects of a new, complex environment. Although the brain does appear to know what part of itself has to be involved in this construction project, it need not (and most likely could not) know which particular individual connections to make. By forming a large variety and number of new connections, the brain can select the combinations that work best, in the same way that the immature, developing brain retains useful connections from its initial oversupply. The long-term result is an overall addition to the number of synapses.

But the actual selection process that fine-tunes the connections is a subtractive one in which useful connections are selectively retained and less useful ones eliminated. Although clear evidence exists for synaptic increase in learning, as I write this we still have no such evidence in mature learning for overproduction of synapses that are pruned away. However, evidence has been found for overproduction of dendrites in mature rats during readaptation of the brain after injury, suggesting that overproduction of synapses may be involved as well (Jones & Schallert 1992, 1994; Schallert & Jones 1993). These findings fit very nicely with the subtractive synapse findings on brain maturation and provide an elegant solution to the puzzle of how the brain could know exactly which new synaptic connections to establish to enable it to acquire new knowledge, skills, and memories.

Several years ago only a relatively small number of neuroscientists subscribed to the view that the adult brain develops and learns through a Darwinian process of cumulative neural variation and selection. Today, however, such a view is starting to be considered mainstream, although much debate remains (see Quartz & Sejnowski 1997 and following commentaries and response). Neuroscientist William Calvin has referred to the brain as a "Darwin machine" that follows the plan of making lots of random variants by brute bashing about, then selecting the good ones (Calvin 1987; see also Calvin 1996a, b). Gerald Edelman, who shared a Nobel prize in 1972 for his research on the chemical structure of antibodies in the immune system, has written several books describing aspects of his neuronal group selection theory of brain development and learning that he refers to as "neural Darwinism" (Edelman 1987, 1988, 1989, 1992).

Research is underway to find physical evidence for overproduction and elimination of newly formed synapses in the adult mammalian brain as the mechanism underlying learning. New imaging techniques such as magnetic resonance imaging are also being used to gain insights into the functioning of the human brain, the universe's most complex known object. Finding clear evidence for Darwinian processes in its structural modification and functioning would place the brain alongside the immune system as a second striking example of how the process of cumulative variation and selection during the lifetime of an organism makes it possible to adapt to new and changing environments.

The Complementarity of Among- and Within-Organism Selection

The discovery of within-organism Darwinian processes involving cumulative variation and selection offers some clear answers and suggests others to a number of vexing problems concerning the functioning of the immune system, the processes involved in human thought and creativity, and the development and modification of the brain. Since these phenomena all require the adaptation of one system to another, we should not be too surprised to learn that Darwinian processes are involved. In effect, through the process of among-organism variation and selection, mechanisms of within-organism variation and selection have evolved to solve the uncertain futures problem that all organisms face.

But this does not mean that all physiological and neural functioning involves variation and selection of some kind. We should be grateful that the human heart does not have to learn to pump blood by within-organism trial and error elimination. And although processes of neural Darwinism may be involved in the development of the human auditory system, once developed, it appears to be able to analyze the sounds of human speech directly and quickly with remarkable accuracy with few if any errors from guessing. The among-organism variation and selection of human evolution (along with, in the case of the auditory system, some fine-tuning involving selective neuronal and synaptic elimination) may have provided us with some systems that are able to function quite well without current variation and selection. But other systems that face continual challenges and new environments, such as other aspects of the mammalian nervous and immune systems, must rely on variation and selection to adapt to these new circumstances.

A clearer understanding of the roles of among-organism and within-organism selection can be achieved by considering figure 9.2, which is a simplified illustration of what is hypothesized to be the relative importance of the two processes for three different types of adaptations.[2] To the extreme left we have what are usually considered inborn instincts, such as a spider weaving a web or a newly hatched gosling following the first large moving object it sees (Konrad Lorenz's imprinting, mentioned in chapter 7). Such behaviors are adaptations that may be entirely due (or nearly so) to among-organism selection of biological evolution.

In the middle of figure 9.2 we have adaptive behavior that is not innate but acquired during the individual's lifetime. One obvious example is a rat in a Skinner box learning to push a lever to obtain bits of food. Here we have what appears to be within-organism selection of behaviors emitted by the rat. But better examples for our present purposes are the types of learning studied by Köhler (1925) in apes, such as learning to stack two or more boxes to reach a suspended banana, or use a stick to pull in a banana placed outside the cage. Such learning often appears insightful; that is, after what appears to be a period of incubation, the apes proceed directly to the solution with no overt variation and selection of behaviors. Thanks to Donald Campbell, we can understand such learning as the result of

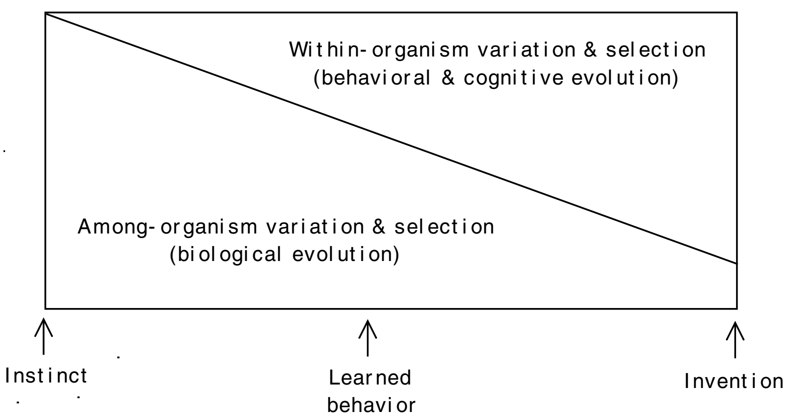

Figure 9.2
Complementarity of among-organism and within-organism variation and selection for three different types of adaptations

within-organism variation and selection involving the generation, evaluation, and selection of thought trials that substitute for overt behaviors.

Note, however, that among-organism evolution still plays an essential part in such learned behavior, as it is responsible for the ape having the necessary equipment (eyes, hands, arms, legs, brain) and motivation (a taste for bananas) for solving the problem. But among-organism (biological) selection is clearly not sufficient since, unlike instincts, what emerges is a new behavior that could not have been naturally selected in the ape's evolutionary past. Such acquired behavior also requires within-organism (cognitive or behavioral) variation and selection.

A useful way of conceptualizing the relative importance of among-organism variation and selection in learning is the degree to which it provides constraints for the blind variations of within-organism variation and selection. For example, young children readily learn the meanings of words spoken to them by their caretakers (as rapidly as one word per waking hour). Although biological evolution cannot in itself provide the child the meanings of these words (in the way that it may provide the meaning of a scream), it appears to set rather narrow (and very useful) limits on the possibilities that a child is willing to entertain. So whereas a child may have little difficulty in learning the meanings of *hand*, *arm*, and *forearm* (the latter referring to both the hand and arm up to around the elbow), she would not expect a single word to refer to both shoulder and hand, or to both knee and foot, or to both red and blue. Such constraints, the results of among-organism evolution, have the effect of usefully constraining or guiding the necessary within-organism variation and selection that must take place to acquire language.

Now we move to the extreme right of figure 9.2. Here we find certain forms of behavioral and/or cognitive adaptations that appear to rely primarily on within-organism variation and selection. Of course, among-organism variation and selection must still play a role since biological brains and limbs are involved (which is why in figure 9.2 the line separating among-organism from within-organism selection never makes it all the way to the lower right corner). But at this end there are fewer useful biological constraints on within-organism variations. Human invention is an example of such an adaptation, since there are apparently few useful biological constraints for the variations that must be considered for inventing steam engines, light bulbs, transistors, or nuclear fusion reactors.

A second important distinction exists between prior and current variation and selection. Obviously, from the viewpoint of the living organism, among-organism variation and selection of biological evolution is prior, but within-organism variation and selection can be seen as either prior or current. An ape confronted for the first time with boxes and a suspended banana must engage in some form of current behavioral and/or cognitive variation and selection to create a solution for reaching the banana. But the ape who solved the task yesterday requires little or no current variation and selection of behavioral or thought trials since the knowledge gained from that experience remain to guide the ape today. Such prior variation and selection can be of use even if the task is modified so that the boxes are different (such as being open on one end) or a desired object other than a banana (such as a favorite toy) is suspended out of reach. In other words, prior within-organism variation and selection results in knowledge that can be used to constrain current variation and selection for similar types of tasks.

Figure 9.3 indicates the complementary role of prior and current variation and selection for different types of behaviors or abilities. At

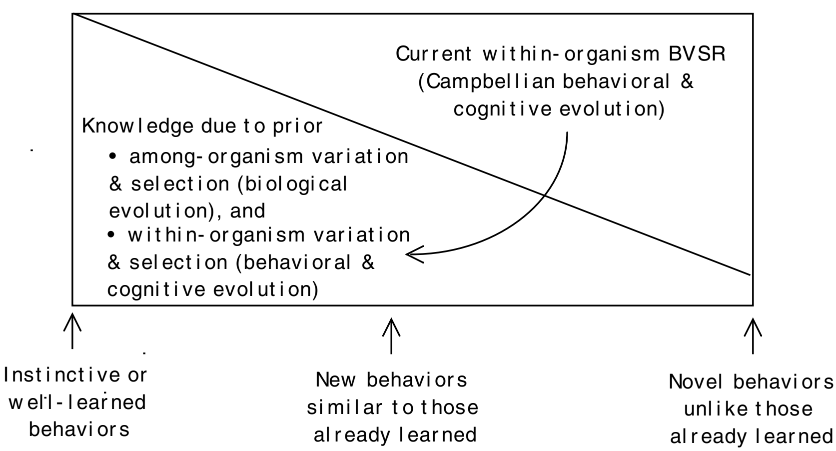

Figure 9.3
Complementarity of prior and current variation and selection for three different types of behaviors

the left end we find both instinctive (for example, bird nest building) and well-learned behaviors (as in a pianist's playing a familiar piece). For such behaviors, no current variation and selection may be necessary. For instincts, among-organism variation and selection supplies the necessary knowledge. For well-learned noninstinctive behaviors, it is a combination of among-organism variation and selection and prior within-organism variation and selection that provides the knowledge necessary for the new behavior or ability.

Moving toward the middle of figure 9.3 we find behaviors and abilities similar but not identical to acquired ones. Prior within-organism variation and selection provides some of the knowledge necessary for these behaviors, but it is not sufficient, thereby making additional current variation and selection necessary. Having created one successful musical composition or invention, one may find creating the next one quite a bit easier. But some additional current variation and selection will be necessary if the next work is not to be just a copy or imitation of the previous one.

Toward the right of figure 9.3 we find novel behaviors unlike those already learned. To learn such behaviors or develop new abilities, current variation and selection must play a major role since little has been learned to constrain or guide new variations that must be generated and tested. The arrow between "current within-organism variation and selection" and "prior within-organism variation and selection" indicates the transformation of current variation and selection to knowledge that may be used to constrain future within-organism variation and selection. This perspective on the complementary role of biological natural selection (that is, among-organism variation and selection) and continuing evolutionary processes (that is, within-organism variation and selection) suggests the universality of the Darwinian process of variation and selection as responsible for all instances of adaptation, indeed, for all knowledge processes broadly conceived (see Cziko 1995; Dennett 1995). If an animal appears to be born already knowing when and how to perform complex behaviors, such as finding food, defending itself, and mating, that knowledge is the result of the among-organism variation and selection of biological evolution. If, however, new behaviors are learned as a result of environmental demands (such as a seal learning to balance a ball on its nose to obtain food from its trainer, or a physicist developing a new superconductive material), this new learning or knowledge must also rely on a form of variation and selection, but now it is occurring within the organism.

This extension of Darwinian thinking to within-organism processes provides a major conceptual advance for many fields of inquiry, but it is not complete. For among-organism variation and selection, the environment (including other organisms) provides the selective filter to winnow the fit from the less fit. But what provides the selective filter for the within-organism selection of thoughts and ideas and new behaviors? Although biological evolution has no purpose in mind, the within-organism evolution of thoughts, ideas, and behaviors *is* purposeful. So to complete our understanding of how new knowledge and skills evolve within organisms, we have to pay heed once again to Bernard's lesson and combine it with this within-organism extension of Darwin's.

IV

Bernard and Darwin Meet Behavioral Science: Implications and Applications

10

Understanding Adaptive Behavior and Thought as Purposeful Evolution: Combining Bernard and Darwin

It is wonderful what the principle of selection by man, that is the picking out of individuals with any desired quality, and breeding from them, and again picking out, can do. Even breeders have been astounded at their own results. . . . Man, by his power of accumulating variations, adapts living beings to his wants—may be said to make the wool of one sheep good for carpets, of another for cloth, &c.

—Charles Darwin (from an 1858 letter to American biologist Asa Gray; reprinted in Bajema 1983, pp. 191–192)

Three Lessons of Biology for Behavioral Science

A major theme of this book as elaborated in the preceding chapters can be summarized by extracting a few important lessons about what biology has taught us about the what, why, and how of animate behavior.

The lesson inspired by Claude Bernard and introduced in chapter 4 is that the functioning of physiological systems can be understood as the means by which an organism controls its internal environment. But since physiological control is achieved by internal processes normally hidden from view, this lesson is more relevant to physiology and medicine than it is to behavioral science.

Instead, it is the *extended* Bernardian lesson that makes sense of observable behavior, grounded on Bernard's basic insight, further developed in the mid-twentieth century by cyberneticians, and systematized into a unified working theory of animate behavior by William T. Powers and his associates. Presented in chapters 5 and 6, the extended Bernardian lesson informs us that a living organism acts to control aspects of its external environment. And since an organism can know its environment only through its perceptual systems (including vision, hearing, touch, and other sensory modalities), animate behavior can be understood as the *control of perception*. The extended Bernardian lesson is concerned with the proximate (here and now) causes of behavior, and when augmented by perceptual control theory it establishes working models of behavior that are both physical and purposeful.

But controlling a perception requires the existence of an *intended* perception, that is, a goal, standard, or reference level with which to compare perception. This is where the basic Darwinian lesson becomes relevant. Chapters 7 and 8 informed us that the goals an organism pursues are not chosen at random. Neither are they determined in any direct, one-way causal manner by the organism's current environment. Instead, an organism's basic goals were selected during its evolutionary past for the effects they had on survival and reproductive success. It is not just a lucky coincidence that a male robin does all it can to maximize its distance from hawks while minimizing its distance from earthworms and female robins, since previous robins that didn't do likewise left few if any descendants. Human behavior is much more complex than that of other animals. But there are nonetheless good Darwinian reasons why men are much more inclined than women toward casual sex with a variety of partners, and why fast-food restaurants are able to attract millions of paying customers with their offerings of quick and conveniently packaged sugar, fat, and salt. Where the extended Bernardian lesson is concerned with the proximate causes of behavior, the basic Darwinian lesson has to do with the ultimate, evolutionary causes of behavior.

The third lesson of biology for behavioral science is the extended Darwinian lesson, presented in chapter 9. The basic Darwinian lesson draws its explanatory power from the cumulative variation and selection of organisms over long periods of phylogenetic time, resulting in the evolution of adaptive structures and behaviors. In contrast, the extended Darwinian lesson points out processes of cumulative variation and selection occurring *within* organisms over the much shorter span of their lives. Although the best currently understood example of cumulative within-organism variation and selection is the functioning of the mammalian immune system, growing evidence suggests that the brain also employs cumulative variation and selection to arrive at creative thoughts, innovative behaviors, and problem solutions.

How Evolution Can Be Purposeful

All three lessons (extended Bernardian, basic Darwinian, and extended Darwinian) are essential for making sense of animate behavior. But by combining the extended Bernardian and extended Darwinian lessons we gain special insight into why and how the goals of an organism change during its lifetime and how an organism is able adapt its perceptual-behavioral systems to achieve these new goals.

Last month a teenage boy was spending several hours a week in the gym trying to get in shape for the upcoming football season; today he no longer pumps iron but spends hours with his guitar. Last year a middle-aged housewife was content to remain at home performing domestic tasks, but now works long days selling real estate and has developed impressive computing, financial, and interpersonal skills that she did not have before. These changes in goals and abilities, resulting from the process we referred to as reorganization, require a directed, purposeful Darwinian process involving the cumulative variation and selection of lower-level goals to achieve higher-level ones. This combined lesson includes aspects of Bernard's and Darwin's insights and involves proximate and ultimate causes of behavior.

But to refer to a Darwinian process as "purposeful" or "directed" might seem to indicate a basic misunderstanding of the process itself. After all, Darwin proposed his theory of evolution by natural selection to explain how species could change over time and new ones appear without the involvement of a supernatural designer or preordained cosmic plan. This is why Richard Dawkins (1986, p. 5) described biological evolution as a blind watchmaker:

> All appearances to the contrary, the only watchmaker in nature is the blind forces of physics, albeit deployed in a very special way. A true watchmaker has foresight: he designs his cogs and springs, and plans their interconnections, with a future purpose in his mind's eye. Natural selection, the blind, unconscious, automatic process which Darwin discovered, and which we now know is the explanation for the existence and apparently purposeful form of all life, has no purpose in mind. It has no mind and no mind's eye. It does not plan for the future. It has no vision, no foresight, no sight at all. If it can be said to play the role of watchmaker in nature, it is the *blind* watchmaker.

Biological evolution may have no goal or ultimate purpose and in this sense it *is* blind. But this does not mean that cumulative variation and selection cannot be used by organisms in purposeful ways. It could even be argued (as some do) that natural selection was (and still is) God's way of creating and modifying life on our planet. A truly omniscient God would be able to foresee the organisms that would evolve from such a process even if we (and Richard Dawkins) cannot, making the emergence of our species part of the God's overall plan. Still, the great strength of Darwin's theory (and what makes it a scientific theory) is that it provides an explanation for life in all its diverse forms without requiring the involvement of any such supernatural designer or the occurrence of miracles.

But it doesn't require a god to use the Darwinian process in a purposeful way. In fact, even one of the simplest forms of life is able to do so. *Escherichia coli* is a bacterium that lives in a liquid environment (such as the contents of your stomach) and can either swim in a more or less straight line or tumble randomly in one spot. If it senses that it is getting closer to food it will continue on its straight course. But if it finds that it is not getting closer to food, it will stop, tumble a while, and head off in a new, randomly generated direction. If the new heading brings the bacterium closer to food it will continue on this course; but it will stop and tumble again if the direction turns out to be no better than the previous one. Although this method of locomotion may initially appear quite crude, it turns out to be a remarkably adept and virtually foolproof way for the bacterium to get where it needs to go (see Koshland 1980, pp. 14–15). The reader can see just how effective it can be by trying out the *E. coli* program for either IBM-compatible or Macintosh personal computers available on the Web at *www.uiuc.edu/ph/www/g-cziko/twd/*.

E. coli's method of locomotion is of particular interest as an example of one form of purposeful evolution. What evolves in this sense is not a new organism but rather a sequence of swimming directions that is effective in leading the bacterium to food. When the heading is not taking it closer to a food source, it has no clue which way to turn since it has no sense of vision or other means of determining the location of food at a distance. So it simply varies its orientation randomly and tries a new heading. Although it has no guarantee that the new direction will be any better than the previous one, if it isn't better the bacterium can try yet another one and another, until eventually it is able to home in on a meal. So by randomly varying its direction, quickly eliminating those that do not take it closer to food and selecting those that do, *E. coli* is able to use a simple yet effective process to accomplish its goal. This is a form of purposeful behavior that combines Bernardian (control) and Darwinian (cumulative variation and selection) processes.

Not to be outdone by the lowly bacteria tumbling in our tummies, humans have also made use of various forms of purposeful evolution. One of the first was breeding plants and animals. Ever since the development of agriculture, humans have been selecting plants and animals with desirable characteristics for propagating more plants and animals. Since breeders usually have no idea what genes are responsible for the characteristics they desire in crops and livestock, all they can do is select and breed those plants or animals that are in some way better than others. Natural selection may have no purpose, but artificial selection of plants and animals involves a purposeful selector.

The last decade of the twentieth century has seen the development of some very promising high-tech forms of purposeful evolution. Computer scientists have developed a technique called *genetic programming* in which pairs of randomly generated computer programs "mate" with each other, and their resulting "offspring" (programs that resemble but are not identical to their parents) are either selected for another round of mating or eliminated according to how close they come to fulfilling the criteria of the human programmer (see Koza 1992, 1994).

In chemistry, techniques referred to as *directed molecular evolution* (Joyce 1992) and *combinatorial chemistry* (Hall 1997; Plunkett & Ellman 1997) have been developed in which a multitude of different molecules are generated and screened for desired properties, such as their ability to bind to other molecules or be biologically active in medicinally useful ways. Thus new drugs can be created using a form of purposeful variation and selection without having to know the structure of the compound or why it behaves the way it does (see Cziko 1995, chapters 13 & 14, for additional information on these and other forms of purposeful evolution).

In each of these cases, a type of directed or purposeful evolution is used to achieve a goal that cannot be achieved with already acquired knowledge. This requires a search using blind variation and selection, as you would have to do if you wanted to open a lock and possessed a large set of keys but didn't know which one fit the lock. Opening the lock is your goal, but since you don't know which key will work, you have no choice but to proceed by the trial-and-error-elimination method of the evolutionary process. Even if you are able to eliminate certain keys that are obviously too large, too small, or of the wrong shape, you will still have to employ blind variation and selection among the remaining keys. Although I refer to this process as a form of guided or purposeful evolution, it is important to recognize that the variations (trials) generated are not guided (although they may be usefully constrained). Rather, the process is purposeful insofar as a reference level serves as a selection criterion for which certain variations (trials) are retained and others are eliminated.

As we understand the normal process of biological evolution, there is no reference level, no selection by a purposeful agent. Rather, organisms that are more successful in surviving and reproducing come to dominate their populations while those that are less successful are eventually eliminated. Darwin referred to this as *natural* selection to contrast it with the *artificial* selection made by agriculturists in selecting plants and animals for breeding. But whereas artificial selection is purposeful (believe it or not, someone really did want to produce those grotesque goldfish you can see at any pet shop, with the swollen bodies and puffy sacks for eyes, and went through a lot of trouble to do so), natural selection is not, although it resulted in the evolution of purposeful behavior, such as artificial selection performed by humans. Still, artificial (purposeful) and natural (nonpurposeful) selection are similar in that the same processes of cumulative blind variation and selection (either by a purposeful agent or by inanimate physical processes) combine to generate entities that are adapted to some selection criteria (faster wild antelopes as lions and other predators eliminate slower ones; more productive domestic dairy cows as farmers purposefully breed animals that produce the most milk).

Problems of Learning

This concept of purposeful evolution based on the combination of Bernardian and Darwinian processes provides a key for understanding how it is that organisms change their behavior over time in adaptive ways, what is usually referred to as learning.

What does a theory of adaptive behavioral change have to explain? First, it must explain how an organism can come to perform an adaptive behavior that it could not do previously. This could be as simple as a rat learning to push a lever to obtain food in a Skinner box, or as complicated as a college student learning to solve differential equations. It may involve long hours of practice and gradually improving performance, such as learning to play a musical instrument or speak a foreign language. Or it may appear quite suddenly with no previous observable behavior or practice, as as when someone suddenly comes up with a new idea for an invention. We will refer to this as the new knowledge problem.

Second, we must account for how it is that new behaviors can remain adaptive under changing environmental conditions. We saw in chapter 6 that these changing conditions and the new disturbances they impose mean that learning cannot be the acquisition of invariant motor responses to stimuli. Instead, an organism's actions must continually vary to bring about desired results. No matter how many times you may have driven your car from home to your place of work, you cannot make the trip using the same pattern of arm and leg movements that you used on any previous trip. Continually changing traffic, weather, and road conditions would make any such fixed pattern of actions ineffective in getting to work (not to mention dangerous if not fatal). This behavioral flexibility in the achievement of goals is not limited to humans but is characteristic of all animate behavior (recall from chapter 7 the varied behaviors undertaken by the burying beetle to bury small animal corpses on which to lay its eggs). We will refer to this as the behavioral flexibility problem.

There are two general approaches to dealing with the new knowledge problem as it relates to learning. The first is to appeal to innate knowledge as the source of what appears to be new knowledge. For example, during the first four years of life a human child makes amazing progress in acquiring the language of its caretakers. This involves learning the sounds of the language (phonology), its grammatical structure (syntax), and the meanings of words and phrases (semantics). The most widely accepted account of this remarkable feat (although one that is contested by many, including yours truly) is that this knowledge is essentially innate, or "hard-wired" into the child's brain. This innatist approach to the problem as it applies to humans essentially denies that new knowledge is actually acquired or created by an individual, so what looks like the acquisition of new knowledge is actually the growth or maturation of old knowledge. This is essentially the position taken by the influential linguist Noam Chomsky, to whom we return in chapter 11, where we examine more closely his decidedly un-Darwinian view of innate knowledge.

The other approach is to recognize that the acquisition of genuinely new knowledge is possible and that real learning does take place. Some attempts to solve the new knowledge problem, as noted in chapter 9, made explicit use of variation and selection, but to date they appear at best incomplete and at worst misguided and misleading. Among them is Skinner's theory of operant conditioning.

As discussed in chapters 3 and 7, that theory had at least three major flaws. First, it considered animate behavior as caused by the environment instead of the means by which aspects of the environment are controlled by the behaving organism. Second, all learning involved overt responses that were varied and then selected (or not) depending on whether or not the responses were followed by a reinforcing event (such as the presentation of food). The theory thus had no room for learning based on mental or internal processes that were not accompanied by overt behavior. Third, Skinner denied that internal purposes had a real role in behavior. He therefore could not account for how organisms were able to vary their behavior to achieve repeatable effects on their environment. He did recognize the power of variation and selection to account for new knowledge as reflected in new adaptive forms of behavior. But his inability to see behavior as purposeful, and his obsession with overt behavior to the exclusion of cognitive processes, made his attempt to incorporate within-organism Darwinism into a theory of learning a rather resounding (if nonetheless quite influential) failure.

Among incomplete Darwinian approaches to learning are theories of cognitive and neural variation and selection we have seen in the previous chapter. These attempts to apply Darwinian thinking to the new knowledge problem recognize that truly new, adaptive forms of knowledge (cognitive, perceptual, and behavioral) must rely on some process of cumulative variation and selection. Cognitive theories describe the variation and selection of ideas or thought patterns, and neural theories attempt to account for adaptive changes in the structure of the brain that are believed to underlie all forms of learning. But these theories are incomplete not only because of current limitations to our knowledge of the structure and functioning of the brain, but also because they fail to account for the purposeful nature of these Darwinian-based changes. Since all such adaptive changes allow the organism to control some aspect of its environment that it could not control before (or at least not as efficiently or precisely), such changes have to be understood as purposeful rather than as effects directly caused by environmental factors. In other words, these theories respect the extended Darwinian lesson, but they do not take into account the extended Bernardian lesson.

Moving on, it turns out that none of the major learning theories or their variations successfully deals with the behavioral flexibility problem. This is because they all embrace simple one-way causality from stimulus to response or (as more fashionable these days) from stimulus to cognitive computation to response. But any theory that posits behavior as an end product (output or response) that is elicited by an input (stimulus or perception) with or without intervening cognitive processes is inherently incapable of accounting for the continuous variations in behavior that we observe in the service of achieving goals in the face of continually changing disturbances. Thus a theory that attempts to explain learning as acquisition of a repertoire of responses must fail.

But by combining the insights of Bernard and Darwin we can arrive at an account of learning that solves both the behavioral flexibility and new knowledge problems.

With respect to the behavioral flexibility problem, chapter 6 showed how perceptual control theory gives us a working model for how organisms are able constantly to vary their behavior to achieve goals despite disturbances. An experienced driver can keep his car on the road and in the proper lane while maintaining a relatively constant speed, in spite of varying wind, road cambers, curves, and hills. He must constantly vary his behavior with respect to the steering wheel and accelerator pedal (and perhaps brake pedal) to achieve these effects, and he is able to do this because he has developed, through experience, the necessary perceptual control systems.

Now imagine that a teenager, having learned to drive during the summer, encounters winter driving conditions for the first time. These conditions present new disturbances for which his skills are inadequate. The first time on snow, he will likely accelerate, brake, and make turns too abruptly, resulting in skidding and (one hopes temporary) loss of control of the car. To maintain control of his vehicle in these new conditions, he must adapt his existing control systems, that is, reorganize them in ways so that he will be able to drive safely on winter roads.

Our driver can reorganize his currently existing network of driving-related control systems in a number of ways. The first involves resetting one or more reference levels. For example, under dry conditions negotiating a street corner at 15 mph may be quite safe. But this speed could be dangerous or even impossible to maintain safely while turning on a snow- or ice-covered street. Assuming that the driver's higher-level goal is to negotiate the turn successfully, he will have to reset his lower-level reference level to a lower speed. But since he doesn't actually know what speed is possible to maintain while turning on snow, this resetting will necessarily involve some degree of trial and error (variation and selection).

Another way that control systems can be modified is by reorganizing perceptual functions. This can occur in one of at least two ways. Trying out various combinations of lower-order perceptions can create new higher-level ones. For example, our driver will have to learn to recognize conditions that require reduced speed while turning. During warm weather he may have paid attention only to whether large objects (such as a person or another vehicle) lay before him in the road; now he must become perceptive to indications of the presence of snow or ice on the road surface. The second way to change one's perceptual function is to make it more or less sensitive to certain aspects of the environment. This is technically known as the *gain* of the perceptual function. The driver may have to learn to develop greater sensitivity to the beginning of the car's skid to take prompt corrective actions.

The third major way in which the reorganization of control systems can take place involves modification of their output functions. First it must to be recalled that outputs of an internal control system are not motor commands resulting in a specific action or muscle twitch. Instead, they serve as reference levels for lower-order control systems, and the particular action that results will depend on both this specified reference level and current environmental conditions. Like perceptual input functions, output functions vary with respect to their gain, so that a given error signal (that is, the discrepancy between a reference level and perceptual signal; see chapter 6) may result in output signals of different strengths. In our driving example, we might expect that certain output gains would have to be reduced to avoid too-quick steering, accelerating, or braking behaviors that could cause the car to skid on snow or ice.

Output functions may also change with respect to the particular lower-level reference signals they influence. Consider someone who has always driven a car with an automatic transmission but who now wants to drive one with a manual stick shift. Previously, accelerating from standing to highway cruising speed simply required depressing the accelerator with the right foot and waiting for the desired speed to be attained. Now it requires accomplishing additional lower-level goals involving the left foot and right hand as they operate the clutch and change gears until cruising speed is reached.

This account of learning as the reorganization of perceptual control systems leads to an interesting concept of learning. All traditional learning theories see learning as a modification of one-way cause-effect (stimulus-response or stimulus-computation-response) associations. Recall from chapter 3 that Pavlov understood learning as the association of new stimuli with old responses, as when his dog learned to salivate to the sound of a bell after the bell had preceded several times the introduction of food into the animal's mouth. Skinner (and Thorndike before him) was interested in how new responses to old stimuli were acquired, as when a rat learns to press a lever to obtain food. In marked contrast to both Pavlov and Skinner's stimulus-response theories of learning (and contrasting as well to stimulus-computation-response learning theories of current cognitive science), perceptual control theory sees learning as involving modification of *perceptual* associations, not stimulus-response associations.

To explore this idea, consider a chef who wants to develop a new shrimp entrée to serve at his restaurant. He has a definite goal in mind of what he is trying to achieve in terms of taste, appearance, and consistency (these are the higher-level perceptual goals), but he doesn't yet know what combination of lower-level goals (that is, perceptions) will lead to his higher-level goals. How many shallots should he mince (should the amount fill four or six tablespoons?)? How long to sauté (how much time should be seen to elapse on the timer?) and at what temperature (how high should the flame be under the pan?)? How well should the shrimp be cooked before adding the wine (offering little resistance to a probing fork or a bit more?)? His cooking experience may well suggest answers to many of these questions. But if he is developing a new dish, the chef is going to have to spend some time experimenting to find the right combination of lower-level perceptions that leads to the desired higher-level perception of a new culinary masterpiece. From this perspective, learning involves discovering new relationships among perceptions (and, of course, being able control them against disturbances), *not* the association of new stimuli with old responses (as in Pavlovian classical or respondent conditioning) or the association of new responses to old stimuli (as in Skinner's operant conditioning).

This culinary experimentation is, of course, an instance of Darwinian variation and selection. Since the chef does not yet know what combination of lower-level perceptions will lead to his desired dish, he will have to use some cumulative trial and error elimination to find out. Four tablespoons of shallots made the dish too bland when first tried, and six made it too spicy on the second attempt. So try five tablespoons and see what happens. Or perhaps stay with six and add a bit more wine. This process of within-organism variation and selection provides an answer to how new knowledge is possible. It does not involve variation and selection of specific overt responses as Skinner believed, but rather the variation and selection of controlled lower-level perceptions, eliminating those that do not lead to the desired higher-level goal and retaining those that do.

In further contrast to Skinner's theory, variation and selection of lower-level perceptions in the service of higher-level ones need not involve overt behavior, at least not with humans and some other primates. Instead, we can use our mental models of how our physical and social worlds work to try out combinations of lower-level reference perceptions and imagine their effects on higher-level ones. So if I am having a dinner party and inviting ten guests—some of whom get along well together while some others don't—I can imagine different seating plans (variations) before the guests arrive and eliminate potentially troublesome arrangements (those that put suspected antagonists within striking distance of each other) until I come up with a plan that seems best (selection). This process is an instance of Donald Campbell's vicarious variation and selection described in chapter 9.

A good deal of what we call thinking—at least thinking that involves problem solving, invention, and creativity—may actually be vicarious variation and selection of perceptual control systems. Such a concept lets us understand how cognitive processes involved in thinking can be purposeful even when they are not accompanied by concurrent purposeful behavior. And if thinking alone cannot generate solutions, we can assist it with other forms of substitute variation and selection: writing down our ideas on paper, using computers to run simulations of candidate solutions, or discussing the problem (proposing solutions, eliminating bad ones, and keeping the best) with other individuals.

A New Conception of Learning

By combining the extended Bernardian lesson (that organisms vary their behavior to control their perceptions) and the extended Darwinian lesson (that organisms make use of variation and selection to gain control of aspects of their environment) we arrive at a new conception of learning. Learning is no longer the association of new stimuli to old responses, or acquisition of new responses to old stimuli, but rather acquisition of new means of perceptual control by reorganizing existing perceptual control systems by within-organism variation and selection. In much the same way that *E. coli* randomly changes its direction when it senses that it is not moving closer to food, all learning requires an organism to make some change to its current organization of perceptual control systems when there is some chronic error between perception and reference level. And whereas previous learning experiences may usefully constrain the variations that are tried (an automobile mechanic is not likely to change the air pressure in a car's tires to see if doing so will make it start), acquisition of new knowledge requires at least some blind variation to explore and discover new useful relationships between combinations of perceptual variables.

The knowledge gained by such a process is discovering what combinations of lower-level perceptions are successful in bringing about desired higher-level perceptions controlling these lower-level perceptions against disturbances. A chef does not measure a cup a water by holding a container under an open faucet for a fixed amount of time, as this would lead to varying amounts of water due to the fluctuating pressure of the water supply line. Instead, he keeps the container under the faucet until the water level reaches the one-cup mark, no matter how long it may take. By successfully controlling this and other lower-level perceptual variables, he is able to prepare the entrée he has in mind, that is, match his higher-level reference perception. By extending this form of purposeful evolution to the mental realm when no overt behavior is involved, we obtain a new framework for understanding cognitive processes. Cognition is no longer seen as planning responses to certain stimuli, but rather as Darwinian reorganization of Bernardian perceptual control systems to control new aspects of the environment.

This view can be used to develop a general framework of knowledge and its acquisition. Within such a framework are three principal types of knowledge. First is the biologically based knowledge that we and all other organisms are essentially born with. This may be all the knowledge that a single-cell organism will ever have and it is reflected both in its structure and instinctive behavior. The way we see colors (or how we see at all) is a form of this knowledge and it cannot be changed, although certain experiences are necessary for it to develop, such as growing up and interacting in a world with visible light. This knowledge is derived from the cumulative among-organism selection of the fittest, as originally proposed by Darwin.

Second is the knowledge that some organisms acquire during their lifetimes. It results from the interaction of one's biological endowment with one's particular experiences, and it is limited in important ways by one's biologically provided knowledge. Humans can learn only certain types of languages. We cannot learn to make visual distinctions between two ultraviolet patterns the way bees can. Rats fail to learn certain tasks requiring visual discrimination, but can learn similar tasks involving their keen sense of smell. Such knowledge is similar to biologically based knowledge in that it also depends on variation and selection. But it is different in two key respects: it involves the within-organism variation and selection of modifications to perceptual control systems, and it is driven by the organism's internal goals. So unlike biological evolution, the knowledge that an organism acquires during its lifetime results from a purposeful form of continuing variation and selection.

Finally, some organisms, especially, humans, seem to acquire knowledge from others. But this is actually a special case of the second form since it is acquired as the result of one's individual experiences interacting with biological knowledge. We may be able to make use of the trial-and-error experience of others by observing their (successful and unsuccessful) behavior, or talking with them or reading their books. But we cannot simply absorb this knowledge in the way that a blank computer diskette can receive the information stored on another. Instead, it could be reasonably argued that the knowledge we derive from others' experiences also requires some degree of within-organism variation and selection (see Cziko 1995, chapter 10). I may observe how an expert skier moves his skis and holds his body as he descends the slope. He may even give me instructions and sell me his book and video on skiing. But although this information may facilitate my development as a skier, it cannot replace the need for me to reorganize my perceptual control systems, eliminate those modifications that leave me sitting in the snow, and retain those that keep my posterior above my skis.

The view of learning provided by combining the extended Bernardian and extended Darwinian lessons has important implications for all forms of education and training, a topic to which we will return in the final chapter.

11

Behavioral Science and the Cause-Effect Trap

The cognitive and biological sciences have discovered a lot about vision and motor control, but these discoveries are limited to mechanisms. No one even thinks of asking why a person looks at a sunset or reaches for a banana, and how such decisions are made. The same is true of language. A modern generative grammar seeks to determine the mechanisms that underlie the fact that the sentence I am now producing has the form and meaning it does, but has nothing to say about how I chose to form it, or why.

—Noam Chomsky (1996, pp. 9–10)

The scientific investigation of animate behavior began just about 120 years ago, using the founding of Wilhelm Wundt's psychological laboratory in 1879 as its date of birth. That is a short period of time compared with the other well-established sciences such as chemistry, physics, and even biology. Yet the science of animate behavior is arguably more complex than these older sciences. So it should not be too surprising that behavioral science has not had significant breakthroughs comparable with those of other sciences, such as the periodic table in chemistry, quantum theory in physics, or cracking the genetic code in biology.

But just such a breakthrough may now be within view as a small but growing group of behavioral scientists have started to explore the behavioral implications of Darwin, and a still smaller but also growing group has begun to take into consideration the implications of Bernard for understanding behavior. Indeed, for the first time we now have within our grasp a fundamental materialist understanding of the what, how, and why of animate behavior.

To a reader not well acquainted with the academic and professional literature in psychology and cognitive science, the synthesis provided here might well appear reasonable and uncontroversial. Of course a living organism controls aspects of its physical surroundings. If it did not, it would not be able to survive and reproduce in an uncaring and often hostile world. Clearly, its behavior is purposeful, whether or not the organism itself is consciously aware of its purposes. Its evolutionary past provides important clues as to what aspects of its environment it controls, and why and how it does so. And even the use of purposeful within-organism variation and selection by living organisms to solve problems for which biological evolution could not have prepared them in advance might seem a reasonable hypothesis, especially when growing evidence such as that reported in chapter 9 is considered. But, as noted throughout the previous chapters, this Bernardian and Darwinian view of behavior is not widely accepted among behavioral scientists for whom the one-way cause-effect perspective continues to dominate theory and research.

We will see in this chapter just how pervasive and dominant this simple cause-effect perspective remains. This will be accomplished by surveying several of this century's most cited and influential behavioral scientists and theorists and showing how their theories of behavior are in one way or another fundamentally incompatible with insights that originated with Bernard and Darwin. We will see that each of these individuals has either ignored or rejected one of the three lessons that biology has for behavioral science that were described at the beginning of the previous chapter, namely, the basic Darwinian, extended Darwinian, and extended Bernardian lessons.

Rejecting the Three Lessons: From Piaget to Pinker

Piaget's Disdain of Darwin

With the possible exception of Sigmund Freud, no twentieth-century European psychologist is better known and has had more impact on psychology than Jean Piaget (1896–1980). Prolific in research and writing from the age of ten until shortly before his death (with more than thirty books published as author or co-author), Piaget began his career as a biologist specializing in mollusks, like the snails inhabiting the lakes of his native Switzerland. But a job in Paris administering intelligence tests to children sparked a life-long interest in the development of human mental abilities and knowledge. He called this study "genetic epistemology," with *genetic* referring not to the genome but rather to a concept of the development of thought as internally guided cognitive growth.

Piaget employed a mélange of in-depth questioning and ingenious experiments to probe the perceptual and thought processes of young children, discovering that they are different not only in degree from that of adults, but in kind. He also concluded that each child goes through an invariant series of cognitive stages, each stage requiring a major overhaul of the preceding one. For example, from the perspective of a young infant an object exists only if it can be presently seen, felt, heard, or smelled. At this age, removing a desired object from the child's senses usually results in the infant abandoning all efforts to find and obtain it. But the child soon develops "object permanence," so that she is now able to seek and find objects that were hidden while she was watching. From a Piagetian perspective, the child is like a little scientist who is constantly developing and testing new theories about the world, rejecting old theories when a new one is discovered that is better at making sense of the world and meeting her needs.

It might be expected that Piaget's early training as a biologist, combined with his interest in the development of human cognitive abilities, would lead him to embrace the basic and extended Darwinian lessons of biology for psychology. Au contraire, his disdain of Darwinian ideas was such that he rejected natural selection as accounting for biological evolution. In the year that he received his *doctorat* in natural sciences he wrote (1918/1976, p. 40):

> But natural selection cannot explain evolution. . . . The heredity of acquired traits is an experimental fact. . . . Hachet Souplet, by training cats, formed habits that were transmitted to later generations. . . . We can then decide in favor of Lamarckism without any qualms, without excluding natural selection as a secondary or accidental factor.

Fifty-eight years later, when Lamarckian evolution had been thoroughly discounted and evolution by Darwinian natural selection had become the central pillar of biology, Piaget remained unimpressed (1976; quoted in Vidal, Buscaglia, & Vonèche 1983, p. 87):

> Either chance and selection can explain everything or else behavior is the motor of evolution. The choice is between an alarming waste in the shape of multitudinous

and fruitless trials preceding any success no matter how modest, and a dynamics with an internal logic deriving from those general characteristics of organization and self-regulation peculiar to all living beings.

And yet while he rejected Darwin's theory of evolution, he did, if unwittingly, make use of Darwinian ideas. For example, in discussing instinctive behavior, the following passage is one that could have been written today by an ethologist, sociobiologist, evolutionary psychologist, or behavioral ecologist (1967/1976, p. 844):

Instinct is always at the service of the three fundamental needs of food, protection against enemies, and reproduction. If, with migration or various modes of social organization, instinct seems to pursue secondary ends, they are only secondary as being interests grafted onto the three main ones and still dependent upon them, so that in the last resort they are subordinated to the survival of the species and, as far as possible of the individual.

The major themes of Piaget's theory of cognitive development can also be understood from a Darwinian perspective. He stated that the two major ways in which children (as well as adults) interact with their world are through assimilation and accommodation. Assimilation refers to incorporation of sensory experience into a preexisting thought structure called a schema. For example, a child having seen sparrows and robins and able to recognize them as members of the category *bird* would likely include the first blackbird she sees in this same category. She might also attempt to assimilate the first observed butterfly into her bird schema since it shares certain similarities with other members of this category. However, calling a butterfly a bird would likely result in a correction by an adult or older child, "That's not a bird, it's a butterfly!" This would lead to accommodation of the child's thought so that butterflies and birds would be treated as different concepts, each with its own label and distinguishing characteristics. Assimilation thus is a process that involves the adjustment of perceptions to fit already developed knowledge, whereas accommodation involves modification of previously existing knowledge to fit new perceptions better.

But a parent cannot simply transmit the meanings of new words to a child. Instead, the child can only know that some sort of error has been made and that, according to her parent, the current object in view is not a bird but a butterfly. The parent's remark does not tell the child *why* it is a butterfly and not a bird. Is it because it is yellow and the other flying creatures she has seen are brown and black (but then what of canaries?)? Is it because it stops to sip nectar from flowers, while the other flying animals do not (but then what of hummingbirds?)? Or is it because the child has only seen birds in the afternoon, and it is now morning (but then what of the bird that gets the worm?)? Clearly, the child must make some sort of guess as to how to modify her bird schema and create a new butterfly one. This guess may well be initially wrong, but by continuing to generate and test additional hypotheses, she will eventually come to the notions of bird and butterfly that are shared by the adults of her speech community. Such necessary cumulative variation and selection (or trial and error elimination) is, of course, a form of within-organism selection, even if Piaget did not recognize it as such.

But why should a child even bother to change her way of thinking or using language to bring it closer in line with how others around her think and speak? Why should it bother her if what she calls a bird others call a butterfly? Why should she care if, when a ball of clay is rolled and stretched into a skinny sausage, she sees the sausage as containing more clay than it did as a ball because it is longer? Surely, she must have certain basic developmental goals selected by evolution because of their usefulness for living in a physical environment that includes other humans. One of these is to use words the same way others use them so that she can both understand and be understood. Another is to have a consistent, noncontradictory understanding of the environment.

Piaget referred to this process of keeping mental schemas and perceptions consistent with each other as equilibration. Equilibration is a form of cognitive regulation or control in which the competing processes of assimilation and accommodation are used to achieve the goal of cognitive *coherence*. As he explained (1958/1976, p. 833):

> . . . it must be stressed that the equilibration process which thus constitutes an intrinsic characteristic corresponds, in living beings, to specific needs, tendencies, or functions and not merely to an automatic balance independent of the activities of the subject. Thus, in the case of higher cognitive functions, there exists a tendency to equilibrium which manifests the need for coherence.

We see therefore that for Piaget, human cognitive development is driven by a basic human need for cognitive coherence, not by external environmental factors in the form of stimuli or rewards. He also recognized the circular nature of the causality required by his theory (1975/1976, pp. 840–841):

> In biological or cognitive equilibrium . . . we have a system in which all parts are interdependent. It is a system which could be represented in the form of a cycle. *A* has its influence on *B*, which has its influence on *C,* which has its influence on *D*, which again influences *A*. It is a cycle of iterations among the different elements. It also has a special feature of being open to influences from the outside.

But Piaget did not seem to have an accurate extended Bernardian understanding of animate behavior, stating that "It is true, of course, that stimuli give rise to responses" (1970/1972, p. 5), explaining that (1970/1972, pp. 5–6):

> The stimulus unleashes the response, and the possibility of response is necessary for the sensitivity to the stimulus. The relationship can also be described as circular which again poses the problem of equilibrium, an equilibrium between external information serving as the stimulus and the subject's schemes or internal structure of his activities.

Although Piaget used the word circular to describe the relationship between stimulus and response, he nonetheless appeared to be saying that stimuli lead to responses as mediated by the individual's internal cognitive structure. He did not recognize that it is not a stimulus that leads to response but rather the difference between the perceived stimulus (perception) and intended stimulus (reference level). Elsewhere, he referred to the process of self-regulation as providing "internal reinforcements" for behavior (quoted in Evans 1973, p. 67), further evidence for his misunderstanding of the nature of self-regulating feedback-control systems that do not "reward" specific actions but rather vary actions to control their perceptual inputs.

Despite Piaget's disdain of selectionist mechanisms and incomplete understanding of feedback-control systems, he does appear to have recognized to some degree the importance and power of combining Bernard with Darwin to derive a mechanism capable of a form of directed or purposeful evolution in changing old knowledge to fit new perceptions (that is, accommodation). This is indicated by his statement ". . . accommodation is carried out by gropings, and these are a prime example of feedbacks in which an action is corrected in terms of its results" (1967/1977, p. 847).

It is not surprising that a biologist turned developmental psychologist would find biological ideas of use in his psychological research and theorizing, and Piaget did just that. What is surprising is that while he drew on the lessons of Bernard and Darwin, he did so without recognizing their full importance.

His view of cognitive growth appears to recognize the goal-directed nature of development that can only be accounted for by a form of circular causality. But although his theory of cognitive development can certainly be seen from extended Bernardian and extended Darwinian perspectives, he never provided explicit working models as to how such development is goal-directed. Neither did he discuss the concept of an internally specified reference level and how it operates to maintain what he called cognitive equilibrium. He often pointed out how young children behave in a groping manner when learning skills and modifying their mental schemas to control aspects of their environment, but he provided no evidence of having understood animate behavior as the control of perception, or of having recognized the necessity of within-organism Darwinian selection for cognitive development.

Piaget was able to take some important preliminary steps leading out of the cause-effect trap, but he did not come close to escaping it completely.

Skinner's Skewed Selectionism

B. F. Skinner, introduced in chapter 3 and discussed further in chapter 7, remains one of the best-known psychologists of the twentieth century, and he certainly ranks as the most influential American psychologist of all time. His theory of radical behaviorism is no longer in vogue among psychologists and cognitive scientists, but his theory of behavior and how it is modified continues to be highly influential, especially among applied psychologists who attempt to change or otherwise control the behavior of other animals or people.

Skinner, unlike Piaget, had no qualms about accepting evolution by natural selection as the process responsible for life in all its varied forms. Nonetheless, he did not look to evolutionary theory for clues concerning animal and human behavior, and in this respect he rejected the basic Darwinian lesson. For him, evolution provided animals and humans with a general learning mechanism, namely, operant conditioning, by which behaviors were selected (or eliminated) as a result of their consequences for the organism. Thus an animal could be taught to do just about anything that was physically possible if reinforcement for the desired behavior was appropriately applied. That Skinner was not particularly concerned about behavioral differences among species, or even those between humans and animals, is indicated by the fact that he "conducted most of his research on animals and wrote most of his books about people" (Kohn 1993, p. 6). But we recognized in chapter 7, in discussing the phenomenon of instinctive drift, that different species clearly behave differently, and that an organism's evolutionary past plays an important role in influencing behavior and determining how and the extent to which the organism's behavior can be modified.

Although Skinner ignored the basic Darwinian lesson with respect to species-specific behavior, he was nonetheless keenly interested in extending the lesson to account for his theory of operant conditioning that involved spontaneous generation of behavior and its selection (or elimination) as determined by its consequences. But his exclusive concern with observable behavior led him astray. Since he denied the importance of internal mental events in accounting for behavior, he could not apply the extended Darwinian lesson to the variation and selection of mental processes or thought trials (Campbell's vicarious or substitute selection processes described in chapter 9).

As for the extended Bernardian lesson—animate behavior is the purposeful control of perception—Skinner rejected it outright. Chapter 3 described how he denied the central role of purpose in animate behavior, believing instead that "motives and purposes are at best the effects of reinforcements" (1974, p. 56). In other words, in keeping with the one-way cause-effect perspective, purposes were somehow caused by the environment rather than being generated from within the organism as a reference level or a standard for a perception. In keeping with his view that behavior is caused by environmental factors, he went so far as to even deny that he himself had feelings of personal involvement and purpose in his own work. He commented that after finishing his book *Beyond Freedom and Dignity*, "I had the very strange feeling that I hadn't even written the book. . . . [It] just naturally came out of my behavior not because of anything called a 'me' or an 'I' inside" (quoted in Kohn, 1993, p. 7).

Further evidence that he did not appreciate the importance of the extended Bernardian lesson is indicated by his serious misunderstanding of the operation of control systems, as shown in his discussion of the behavior of a "homing device" (1974, p. 56):

> Goals and purposes are confused in speaking of purpose in a homing device. A missile reaches its target when its course is appropriately controlled, in part by information coming from the target during its flight. Such a device is sometimes said to "have purpose built into it," but the feedback used in guidance (the heart of cybernetics) is not reinforcement, and the missile has no purpose in the present sense."

This statement may provide an important insight into Skinner's way of thinking about behavior, control, reinforcement, and purpose. By stating that "a missile reaches its target when its course is appropriately controlled, in part by information coming from the target during its flight," he sees the missile as an object being controlled by external factors, including the "information from the target," which is analogous to perceptual input in living organisms. He shows no recognition that the missile is actually varying its course as necessary to *control* its perception (or sensing) of the target. He then rejects the notion that such a control system "has purpose built into it," using the curiously circular reasoning that the negative feedback used by the system "is not reinforcement," and since purpose is always the result of reinforcement, the missile can have no purpose! Succumbing to the behavioral illusion of believing the missile's behavior is caused by environmental disturbances, he could not appreciate that such a homing device does in fact display purposeful behavior in varying its actions as necessary to reach its goal. This is exactly what it was designed to do, and in this respect the heat- (and therefore target-) seeking missile engages in purposeful behavior just like that of James's air-seeking frog and Shakespeare's Juliet-seeking Romeo.

Skinner's influence on behavioral science remains considerable. He was the principal influence in promoting a version of the behavioral illusion that can be described as the reinforcement illusion—the belief that an organism's behavior is controlled by environmental reinforcement. Although he is gone and his brand of behaviorism is not nearly as popular as it once was, the reinforcement illusion remains as one of the most influential and pernicious ideas from behavioral science, giving testament to the continued legacy of one-way cause-effect thinking as applied to animate behavior (see Kohn 1993).

Chomsky's Baseless Biologizing

Noam Chomsky not only revolutionized the study of language but also had a major impact on the cognitive and behavioral sciences. In his 1959 review of Skinner's book *Verbal Behavior*, he pointed out that just about every sentence a person produces is a novel combination of words that neither the speaker nor anyone else has ever uttered before. Therefore, language behavior cannot, as Skinner proposed, be the result of a fixed repertoire of utterances that were somehow reinforced in the past. Instead, language competence must be the result of a set of mental instructions or rules that permit the speaker to produce (and understand) an infinite number of novel sentences using the finite resources of the human brain. His convincing argument for a cognitive theory of human language helped to make it respectable once again to go beyond observable behavior and consider the types of mental knowledge and processes involved. For this achievement he is considered to be one of the founders of the cognitive revolution in psychology.

Chomsky also maintained that human language competence is essentially innate because every normal child rapidly develops competence in his native language without requiring formal instruction. Given the apparently large gap between what a child hears (the "poverty of the stimulus") and what he eventually comes to know about his language, such knowledge ("universal grammar") must be innate. The child uses experience only to guide him in deciding which variety of language is used in his environment.

Such an innatist view might lead one to expect Chomsky to accept a Darwinian account of the evolution of human language. But instead he has remained quite unimpressed by Darwinian accounts of evolution of any kind, saying (1988, p. 23):

> evolutionary theory appears to have very little to say about speciation, or about any kind of innovation. It can explain how you get a different distribution of qualities that are already present, but it does not say much about how new qualities emerge.

This is quite a remarkable statement, since it shows that one of the most influential intellectuals of our time appears blind to the basic Darwinian lesson of how, through the evolutionary process of cumulative variation and selection, innovations of all types are generated, tested, selected, and refined.

But there is probably a good (for Chomsky) reason why he rejects a Darwinian account of human language. Recall the "poverty of the stimulus" view that a child's language knowledge must be innate since there is no way that a child could attain complete knowledge of his language based solely on what he hears spoken. But the very notion of a stimulus implies a one-way cause-effect view of learning in which what the child hears somehow transmits knowledge of the language. This is made quite clear when he states (1997, p. 13):

> Evidently each language is a result of the interplay of two factors. One of them is whatever the genetically determined initial state is, and the second is the course of experience. We can rephrase that observation without changing anything by thinking of the initial state of the language faculty as a kind of device which operates on experience and turns it into the language that is attained, which we can think of as being just a state of the language faculty. Looked at that way, which just rephrases the observation, the initial state of the language faculty you can think of as kind of an input/output device, the kind one knows how to study: an input/output device where the input is the course of experience, and the output is the language obtained, that is, the state of the language faculty obtained.

If Chomsky were to recognize that language is an adaptive human ability and that the only reasonable nonmiraculous explanation for its emergence is a Darwinian one, he would have to confront the possibility that a process of learning involving within-organism variation and selection (the extended Darwinian lesson) might make it possible for the child to acquire language in a creative, evolutionary manner without the need for an innate universal grammar. So from this perspective it is not surprising that he rejects both the basic and extended Darwinian lessons. But it does put him in the rather odd position of advocating an innate biological basis for human language while rejecting the only understood process by which it could have evolved.

What about the extended Bernardian lesson? Whereas Chomsky indicated in his review of Skinner (1959, p. 554) that he believes people's wants, likes, and wishes have an influence on behavior, he has provided no theory to explain how these factors operate. In fact, he has always insisted that the study of the structure of human language (syntax) has little to do with the meaning (semantics) and communicative use of language. In all of his prolific writing about language that revolutionized the field of linguistics, he never recognized human language as an important form of purposeful behavior or one of the most powerful tools our species has developed for controlling our environment. He has not only restricted his own linguistic research to investigation of the formal structural properties of language (syntax), but as shown in the opening quotation of this chapter, he believes that explanations for questions concerning the why of human behavior are simply outside the realms of science.

Chomsky should then be surprised to learn that at least some behavioral scientists *are* asking why (and how and what) questions concerning animal and human behavior and answering such questions using Darwinian- and Bernardian-inspired explanations. It cannot be denied that Chomsky has made important contributions to our understanding of the structural aspects of language. But the next revolution in the science of human language will have to await someone of his intellectual powers who recognizes the evolutionary (Darwinian) nature of language's origin and acquisition, the purposeful (Bernardian) nature of its use, and the control-system mechanisms that account for the latter.

Dennett's Dangerous Darwinism

Daniel Dennett, director of the Center for Cognitive Studies at Tufts University near Boston, may well be the most widely read philosopher alive today. His 1991 book *Consciousness Explained* sold over 200,000 copies, an amazing number for a book written by a philosopher about the nature of human consciousness and related puzzling phenomena of the human mind. This was followed in 1995 by *Darwin's Dangerous Idea*, in which the theory of natural selection was explained, defended, and applied to a wide range of phenomena, many of them outside the bounds of biological evolution.

Dennett finds Darwin's theory to be not only dangerous since it demolishes many of our traditional beliefs about the origin and meaning of life, but also fascinating and extremely useful for explaining instances of apparent design. Darwin's idea is a "universal solvent, capable of cutting right to the heart of everything in sight" (1995, p. 521).

Dennett also recognizes that our evolutionary past played an important role in shaping the types of behaviors and mental characteristics that we share as a species, although he is cautious about attributing to evolution what is more likely the result of cultural and other environmental influences. He clearly has learned the basic Darwinian lesson that biology has to offer behavioral and cognitive science.

But Dennett goes further with this dangerous idea than most cognitive scientists, behavioral scientists, and philosophers would care or dare to go by seeing in Darwinian natural selection a model for the actual operation of the human brain. He refers to humans as "Popperian creatures" (1995, p. 375) since we can generate varied thoughts and hypothesis and test them mentally using within-organism selection. He might just as well have used the descriptor "Campbellian creatures" since his view of cognitive problem solving is similar to that of Donald T. Campbell, who (as discussed in chapter 9) considered human creative thought and problem solving to involve variation and selective retention. (It is curious that Dennett makes no reference to Campbell's important works that describe human thought as a Darwinian process.) So Dennett is clearly mindful of the extended Darwinian lesson and remains perhaps the best-known living philosopher to appreciate the importance and power of within-organism cognitive selection.

Dennett appears to have learned at least a part of the extended Bernardian lesson, too. He realizes that there is something special about systems that act as "agents" having goals they pursue and achieve by their actions. He refers to these as "intentional systems" and defines them thus (1996, p. 34):

> *Intentional systems* are, by definition, all and only those entities whose behavior is predictable/explicable from the intentional stance. Self-replicating macromolecules, thermostats, amoebas, plants, rats, bats, people, and chess-playing computers are all intentional systems—some much more interesting than others.

But this smacks of circularity since it defines an intentional system as one whose behavior appears to be intentional! Better would be to define an intentional system as one whose actions serve to control some aspect of its environment, varying its behavior as necessary in the face of disturbances. But it does not appear that Dennett fully appreciates that an intentional system (what we have been calling a control system) uses circular causality to control its inputs by varying its behavior, and that consequently the purposeful (intentional) behavior of living organisms can be understood as the control of perception.

So although he appears to have some appreciation of the extended Bernardian lesson, Dennett makes no mention of its most important modern applications, such as those provided by William Powers (see chapter 6). Neither in *Darwin's Dangerous Idea* nor in *Kinds of Mind* (1996) does he make explicit mention of Bernard, cybernetics, feedback control, control theory, or perceptual control theory to account for the purposeful behavior of his intentional agents.

Nonetheless, among all the individuals reviewed in this chapter, Dennett comes closest to fully recognizing the lessons of biology for behavioral and cognitive science. The basic and extended Darwinian lessons he has both learned well and taught to many others through his lectures and his writings. And he at least partly appreciates the extended Bernardian lesson. When he fully appreciates it, Dennett will see that Bernard's big idea ranks with Darwin's dangerous one in importance for understanding the behavior of living organisms.

Picking on Pinker

Steven Pinker, director of the Center for Cognitive Neuroscience at the Massachusetts Institute of Technology, is one of today's most influential and popular cognitive scientists (for an informative profile of Pinker, see Hayashi 1999). His first book for general readers, *The Language Instinct* (1994), offered a scientific yet entertaining account of the wonders of human language and became a best seller. In its sequel with the bold title *How the Mind Works* (1997), he attempted to describe the workings of the human mind as physical processes occurring within the brain, a brain whose design can be understood only by taking into account its evolutionary past.

It is clear from *How the Mind Works* that Pinker has embraced the basic Darwinian lesson that our fundamental goals, preferences, and mental abilities—including human language—were shaped by natural selection. In this respect he differs from his MIT colleague Chomsky who, we noted, rejects the basic Darwinian lesson as it applies to human language. His paper written with Paul Bloom, "Natural language and natural selection" (1990), is a thorough and convincing argument for a Darwinian view.

In chapters 5 through 8 of *How the Mind Works,* Pinker moves beyond language matters and tackles many issues in evolutionary psychology using his characteristically engaging and entertaining style. That a recent book about the mind by a leading cognitive scientist should devote so many pages to evolution and its role in shaping human cognition and behavior is a hopeful sign that the basic Darwinian lesson will finally be accepted by many mainstream behavioral and cognitive scientists. But what about the other lessons—the extended Darwinian and extended Bernardian lessons—that biology has to offer these fields of study?

Being such a knowledgeable and influential proponent of the basic Darwinian lesson, we might well expect Pinker to embrace or at least give fair consideration to the extended Darwinian lesson. After all, if the process of cumulative variation and selection among organisms can produce such marvelously adapted creatures (such as ourselves) and organs (such as our eyes and brains), we might expect a similar process to be used within organisms to adapt to changing conditions for which biological evolution could not have prepared them.

Surprisingly, Pinker completely ignores the considerable theorizing and research on selectionist processes within the brain as summarized in chapter 9, and this despite numerous references throughout his book to Dennett, who is an important proponent of the extended Darwinian lesson. Instead, Pinker appears quite hostile to the notion that some form of cumulative variation and selection might be employed by human brains in the form of the variation and selection of synapses or ideas, or that cultural evolution (as in the development within societies of traditions, technology, or science) could also involve Darwinian processes.

For example, he dismisses the perspective offered by psychologists Elizabeth Bates and Brian MacWhinney, who "view the selectional processes operating during evolution and the selectional processes operating during [learning] as part of one seamless natural fabric" (quoted in Pinker 1997, p. 206). "The implication," Pinker commented, "is that there is no need for specialized mental machinery" (1997, p. 206). But why does the existence of Darwinian mental processes imply no need for specialized mental machinery? The types of variations produced, the mechanism by which they are produced, and the criteria and mechanisms for selection and retention would most certainly be different (and involve different parts, or modules, of the brain) for different types of learning, such as learning how to ice skate versus learning vocabulary in a foreign language. We know that our immune system uses variation and selection of lymphocyte cells to produce new antibodies, but this does not mean that selectionist brain processes must also employ lymphocytes! Pinker should be relieved to know that the extended Darwinian lesson is not incompatible with the modular view of the mind-brain that he and many other cognitive scientists embrace.

He concludes his chapter 4 with another argument against the extended Darwinian lesson, using the example of the stomach (1997, p. 210):

> The stomach is firmly grounded in biology, but it does not randomly secrete variants of acids and enzymes, retain the ones that break down food a bit, let them sexually recombine and reproduce, and so on for hundreds of thousands of meals. Natural selection already went through such trial and error in designing the stomach, and now the stomach is an efficient chemical processor, releasing the right acids and enzymes on cue.

But despite Pinker's straw-man argument, the extended Darwinian lesson does not tell us that all within-organism processes have to be Darwinian, only those that result in new solutions to new problems that our evolutionary ancestors did not confront (such as writing symphonies, breaking the genetic code, or ice skating). Through among-organism selection, biological evolution may have discovered some very useful processes, such as the production of digestive enzymes or the ability to see colors, that may be completely non-Darwinian in their current operation (see figure 9.3). But this does not mean that there are no within-organism Darwinian processes whatsoever. The obvious counterexample to Pinker's digestion example is once again the human immune system since it functions almost exactly as Pinker says the stomach does not, producing each day millions of new antigens by genetic recombination and mutation, selecting the ones that work best, and using them to generate still more novel antibodies over many generations. This within-organism Darwinian process allows the immune system to come up with adaptive solutions to the new problems posed by viruses and bacteria never encountered before. So whereas some mental processes may well be comparable with digestion in their directness, others are undoubtedly much more similar to antibody production, namely, those that we use to create new solutions to new problems. Pinker rightly exposes as a non sequitur the belief that the products of evolution have to look like evolution. But he counters with a non sequitur of his own that since *some* products of evolution do not look like evolution then *none* of them do.

But perhaps he is actually somewhat less hostile than even he realizes to the extended Darwinian lesson. In his discussion of creative geniuses such as Mozart, Einstein, and van Gogh, he made the following observations (1997, p. 361).

> Geniuses are wonks.
>
> [Geniuses] are either discriminating or lucky in their choice of problems. (The unlucky ones, however talented, aren't remembered as geniuses).
>
> They work day and night and leave us with many works of subgenius.
>
> Their interludes away from a problem are helpful . . . because they are exhausted and need the rest (and possibly so they can forget blind alleys).
>
> The epiphany is not a masterstroke but a tweaking of an earlier attempt.
>
> They revise endlessly, gradually closing in on their ideal.

Here Pinker is trying to get across the idea that geniuses are really not that different from more ordinary people like (probably) you and me. In doing so, he must emphasize the errorful, gradual, and groping nature of their achievements, coming quite close to what could be considered a selectionist, extended Darwinian account of creativity, not unlike that considered in chapter 9.

Turning to the extended Bernardian lesson, it is interesting that in chapter 2 of his book, Pinker uses the same passage from William James quoted in chapter 3 of this book, about Romeo wanting to put his lips on those of Juliet and his circumventing all obstacles to do so. He follows this quotation with the statement that "intelligence . . . is the ability to attain goals in the face of obstacles" (1997, p. 62). This certainly appears to be preparing the stage for the extended Bernardian lesson.

But nowhere in his book does he describe a model that can account for the very type of purposeful behavior that he takes as an indispensable indication of intelligence. He makes no mention of feedback control, cybernetics, Wiener, or control systems. No discussion of how a mechanical system (which he adamantly insists the brain is) can be designed to possess a goal and continuously act on the world so that its perceptions match the internally specified reference level that contitutes the goal. No explanation of how an organism's purposeful behavior serves to control perception. Pinker's ignorance, avoidance, or rejection of such concepts pushes him perilously close to embracing a dualist mind-body philosophy (1997, p. 315):

> Goals and values are one of the vocabularies in which we mentally couch our experiences. They cannot be built out of simpler concepts from our physical knowledge in the way "momentum" can be built out of mass and velocity or "power" can be built out of energy and time. They are primitive or irreducible, and higher-level concepts are defined in terms of them.

It's enough to make one wonder if Pinker ever used a thermostat or drove a car with cruise control.

One of the major themes in *How the Mind Works* is that the brain is a computing device, orders of magnitude more complex than any electronic computer yet created, but a computing device nonetheless. So how does the brain get involved in behavior? According to Pinker, not by using the means at its disposal (such as muscles attached to bones) to manage its environment by controlling the perceptions provided by its sensory systems, but rather by using inputs to control its outputs, the interpretation of behavior based on one-way causality. This is especially clear in the most detailed example he provides of behavior (1997, pp. 11–12):

> Controlling an arm presents a new challenge. Grab the shade of an architect's lamp and move it along a straight diagonal path from near you, low on the left, to far from you, high on the right. Look at the rods and hinges as the lamp moves. Though the shade proceeds along a straight line, each rod swings through a complicated arc, swooping rapidly at times, remaining almost stationary at other times, sometime reversing from a bending to a straightening motion. Now imagine having to do it in reverse: without looking at the shade, you must choreograph the sequence of twists around each joint that would send the shade along a straight path. The trigonometry is frightfully complicated. But your arm is an architect's lamp, and your brain effortlessly solves the equations everytime you point. And if you have ever held an architect's lamp by its clamp, you will appreciate that the problem is even harder than what I have described. The lamp flails under its weight as if it had a mind of its own; so would your arm if your brain did not compensate for its weight, solving a near-intractable physics problem.

Pinker's later mention of inverse kinematics and inverse dynamics (1997, p. 31) makes it clear that he views the brain's role in behavior as specifying outputs in the form of joint angles and muscle forces based on sensory inputs. But he might have had second thoughts about his analysis if he had paused to consider how the angles of the architect's lamp were computed. Of course, they were not computed at all, their resulting angles and velocities being determined automatically by simply moving the lamp to where you wanted it to be! This is basically how a control system analysis would account for how you are able to move your hand to where you want it to be, automatically compensating for the combined weight of hand and arm. And this is exactly what Powers's "Arm 1" demonstration does (described in chapter 6), using interconnected control systems to permit a robot to point to a target anywhere in reachable space (and even allowing the user to turn gravity on and off to see how the system so quickly and easily compensates). Pinker and others who may be skeptical that such seemingly complex behavior can be generated without having to solve a "near-intractable physics problem" required by the input-output Newtonian analysis of the behavior have only to download the program at *www.uiuc.edu/ph/www/g-cziko/twd* and run it on an IBM-compatible personal computer (even a slow, outdated 286 machine with no math coprocessor will suffice). Or simpler still, he can attempt to touch with his finger a small faintly glowing object in an otherwise completely darkened room (so that he cannot see his finger). He will then realize that without continuous visual feedback provided by seeing the target, his finger, and the space between them, the act of reaching for an object cannot be reliably performed.

But although he does not heed the extended Bernardian lesson, Pinker at least recognizes the importance of desires and beliefs (the latter we can understand as higher-level perceptions) in understanding human behavior (1997, pp. 63–64):

> In our daily lives we all predict and explain other people's behavior from what we think they know and what we think they want. Beliefs and desires are the explanatory tools of our own intuitive psychology, and intuitive psychology is still the most useful and complete science of behavior there is. . . . It is not that common sense should have any more authority in psychology than it does in physics or astronomy. But this part of common sense has so much power and precision in predicting, controlling, and explaining everyday behavior, compared to any alternative ever entertained, that the odds are high that it will be incorporated in some form into our best scientific theories. . . . No science of mind or brain is likely to do better. That does not mean that the intuitive psychology of beliefs and desires is itself science, but it suggests that scientific psychology will have to explain how a hunk of matter, such as a human being, can have beliefs and desires and how the beliefs and desires work so well.

This is, of course, exactly what modern developments of the extended Bernardian lesson provide in the form of perceptual control theory and its working models of behavior as described in chapter 6. Pinker clearly understands the need, but it appears that the allure of the cause-effect trap is such that even a mind as keen as his fails to see the Bernardian-inspired materialist solution to the puzzle of purposeful behavior that he is seeking.

Finally, he has made some comments concerning the combination of the extended Bernardian and extended Darwinian lessons, that is, how by combining within an organism both Bernardian and Darwinian processes, a very useful form of directed or purposeful evolution can emerge. Here his words indicate a belief that biological evolution cannot be purposeful, as well as a failure to recognize the distinction between among-organism (basic Darwinian) and within-organism (extended Darwinian) selection.

Pinker correctly points out that "felt need," such as a giraffe's "need" for a long neck, has no role in the among-organism selection of biological evolution and that to believe otherwise would be Lamarckian (1997, pp. 206, 207):

> They [needs] are met only when mutations appear that are capable of building an organ that meets the need, when the organism finds itself in an environment in which meeting the need translates into more surviving babies, and in which that selection pressure persists over thousands of generations. Otherwise the need goes unmet. Swimmers do not grow webbed fingers; Eskimos do not grow fur.

True enough. But swimmers might well begin to evolve webbed fingers (and Eskimos fur) if some human had the bizarre desire and means to breed swimmers and Eskimos for these characteristics in the way that farmers have been breeding animals and plants for hundreds if not thousands of years to meet their needs to produce more food for less cost and labor.

Pinker then moves on to within-organism selection (1997, p. 207):

> I have studied three-dimensional mirror-images for twenty years, and though I know mathematically that you can convert a left shoe into a right shoe by turning it around in the fourth dimension, I have been unable to grow a 4-D mental space in which to visualize the flip.

He seems to be concluding here that since he cannot achieve a certain mental ability, *no* mental abilities can arise as the result of the needs of the owner of a human brain. Not only is his logic obviously faulty, but the reader has only once again to refer to chapter 9 to see how within-organism selection of antibodies, ideas, images, and synapses can meet new needs when embedded in a control system that contains an internal goal, a means to try out new actions on its environment, and a way to compare the continuing consequences of its actions with its goal.

How the Mind Works is well worth reading. In addition to Pinker's engaging treatment of the basic Darwinian lesson, his discussion of both the potential and problems of connectionism as a model of brain functioning (see his section "Connectoplasm" in chapter 2) should be of considerable interest to cognitive scientists and others interested in the inner workings of the human brain.

But the book falls far short of its ambitious title by ignoring or rejecting the extended Darwinian and Bernardian lessons and their combination. As a result Pinker neither accounts for how the mind is able to use behavior to satisfy its desires nor explains its remarkably adaptive ability to come up with creative solutions to problems. With this impoverished view of the mind as an input-output computing device, it is perhaps not surprising that Pinker's final message is a rather negative one, doubting that the human mind will ever be able to truly understand itself. In this respect he may be right. But the extended Bernardian and Darwinian lessons provide renewed hope. Given the strong desire (that many humans have) to understand the puzzle of our own minds, plus a remarkable Darwinian computational engine (that all humans have in the form of a human brain) capable of generating and testing many possible solutions to this puzzle, it may just be a matter of time—perhaps just another generation or two—before such understanding is ours. After all, as Dennett has observed (1995, p. 377), "we today—every one of us—can *easily* understand many ideas that were simply unthinkable *by the geniuses* in our grandparents' generation!"

The Cause-Effect Trap

I cannot pretend to have done justice to the important work of these five influential behavioral scientists by my cursory summaries and interpretations of their theories about human behavior. I hope nonetheless to have shown that none of them completely embraces all three of biology's lessons

Table 11.1
Acceptance of Bernardian and Darwinian lessons for animate behavior

Behavioral Scientist	Basic Darwinian Lesson	Extended Darwinian Lesson	Extended Bernardian Lesson	Score
Piaget	No	No	Partly	0.5
Skinner	No	Partly	No	0.5
Chomsky	No	No	No	0.0
Dennett	Yes	Yes	Partly	2.5
Pinker	Yes	No	No	1.0

for behavioral science. Table 11.1 provides a summary of the extent to which each man gave evidence of understanding the basic Darwinian, extended Darwinian, and extended Bernardian lessons. In addition, I could not resist (although I probably should have) assigning each one an overall score based on their demonstrated appreciation of biology's three lessons for behavior. Dennett comes closest to having learned all the lessons (scoring 2.5 out of 3), but Chomsky, considered by many to be the most important intellectual figure of the second half of the twentieth century, winds up with a big fat zero since he appears to have learned not a single one!

William T. Powers, whose perceptual control theory was discussed in chapter 6, comes closer than Dennett in appreciating the three lessons, but he has reservations about the basic Darwinian lesson. This is at least partly due to his belief that Darwin's theory of evolution by natural selection is incomplete, since organisms may have means of controlling their rate of mutation in response to environmental stresses (Powers 1995). So while I chide him for having only partly accepted the basic Darwinian lesson, it could turn out that his view of evolution as a feedback-control process is actually more complete and accurate than current Darwinian theory (see Rutherford & Lindquist 1998 for evidence consistent with Powers's view of evolution).

It therefore appears that Powers and perhaps some others influenced by him are the only behavioral scientists who have been able to free themselves completely from the one-way cause-effect trap. While they constitute only a tiny minority of today's behavioral scientists, I hope that this book will encourage others to join them.[1]

I conclude this chapter with a list of quotations from other influential scholars and scientists from the second half of the twentieth century to provide evidence that it is not only the five prominent individuals discussed above who have ignored or rejected biology's three lessons for behavioral science and therefore remain in the cause-effect trap.

> The typical problem of higher behavior arises when there is a delay between stimulus and response. What bridges the S-R gap? In everyday language, "thinking" does it: the stimulus gives rise to thoughts or ideas that continue during the delay period, and then cause the response. (Donald Hebb 1972, p. 84)

> It is possible to step back and treat the mind as one big monster response function from the total environment over the total past of the organism to future actions . . . (Allen Newell 1990, p. 44)

> If the external environment is represented in the brain with high-dimensional coding vectors; and if the brain's "intended" bodily behavior is represented in its motor nerves with high-dimensional coding vectors; then what intelligence requires is some appropriate or well-tuned *transformation* of sensory vectors into motor vectors! (Paul M. Churchland 1995, p. 93)

> Behavior is not randomly emitted; it is elicited by information which is gleaned from the organism's external environment, and, proprioceptively, from its internal states. . . . *the mind is a description of the operation of a brain that maps information input onto behavioral output*. (Leda Cosmides & John Tooby 1987, p. 283)

> Learning must be a matter of finding the right connection strengths so that the right patterns of activation will be produced under the right circumstances. (James L. McClelland, David Rumelhart, & Geoffrey E. Hinton 1986, p. 32)

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Applying the Lessons of Bernard and Darwin to Behavioral Theory, Research, and Practice

. . . any system based on the control of behavior through the use of rewards (or, of course, punishments) contains the seeds of its own destruction. There may be a temporary period, lasting even for many generations, during which some exciting new system concept so appeals to people that they will struggle to live within its principles, but if those principles include incentives, which is to say arbitrary deprivation or withholding at the whim of human beings, inexorable reorganization will destroy the system from within: nature intervenes with the message, "No! That feels bad. Change!"

—William T. Powers (1973, p. 269)

Having reached this final chapter, it is time to summarize what we have learned from the lessons of Bernard and Darwin about the what, how, and why of animate behavior, and to consider the application of these lessons to behavioral theory, research, and behavior-related issues and problems.

The What of Behavior

The question of the what of animate behavior might not at first appear to be particularly interesting, at least not for the purpose of applying Bernard's and Darwin's lessons and for distinguishing the behavior of living organisms from that of inanimate objects and systems. A falcon's dive to seize a sparrow in midflight can be objectively described in terms of acceleration and trajectory in much the same way that a stone falling to earth can be described adequately without applying Bernard's or Darwin's lessons. But closer examination reveals an important difference between raptor and rock: the falcon, by varying the configuration of its outstretched wings, continually adjusts its path so as to strike its evading prey, whereas the falling stone can do nothing but follow the path of least resistance to the earth's surface. So although the actions of living organisms can be described from the viewpoint of an objective observer, such a description misses the most striking characteristic of animate behavior: its orientation toward some goal or purpose. Such goals and purposes, whether they be conscious or not, are revealed by disturbing the suspected desired outcome and seeing if the organism takes action to compensate for the disturbance.

The answer to the question, "What is animate behavior?," that is provided by Bernard's extended lesson can be no better expressed than by referring to the title of Powers's 1973 book and responding that animate behavior is best understood as the *control of perception*. That is, by varying its behavior an organism maintains control over certain important aspects of its environment. This does not mean that an organism can control all aspects of its environment, or that the control that is achieved is always perfect. It does mean, however, that all living organisms use behavior as a means to control what they can. Or as William James observed a century ago (1890, p. 7), "the fixed end, the varying means!"

This answer to the question of the what of behavior means that a satisfactory account of observed animate behavior must specify the particular perception that the organism is controlling. Answering this question requires a methodology that is very different from standard methods used in behavioral sciences, whereby behavior is seen not as the control of perception but rather as being controlled by or caused by perception. This latter Newtonian perspective attempts to establish a one-way causal link between stimulus and response (with or without mediating cognitive processes) using statistical methods to uncover relationships between independent and dependent variables.

In contrast, a Bernardian approach applies what Powers refers to as "the test of the controlled variable," or more simply just "the test." A summary of this approach as applied to people was provided by Runkel (1990, pp. 14, 15):

1 Select a variable that you think the person might be maintaining at some level. In other words, guess at an input quantity. (Examples: light intensity, sensation of skin temperature, admiration in another person's voice.)

2 Predict what would happen if the person is *not* maintaining the variable at a preferred level.

3 Apply various amounts and directions of disturbance directly to the variable.

4 Measure the actual effects of the disturbances.

5 If the effects are what you predicted under the assumption that the person is *not* acting to control the variable, stop here. The person is indeed not acting to control it; you guessed wrong.

6 If an actual effect is markedly smaller than the predicted effect, look for what opposition to the disturbance that, by its own varying, can counterbalance variations in the input quantity. That may be caused by the person's output. You may have found the feedback function.

7 Look for the way by which the person can sense the variable. If you can find no way by which the person could sense the variable, the input quantity, stop. People cannot control what they cannot sense.

8 If you find a means of sensing, block it so that the person cannot now sense the variable. If the disturbance continues to be opposed, you have not found the right sensor. If you cannot find a sensor, stop. Make another guess at an input quantity.

9 If all of the preceding steps are passed, you have found the input quantity, the variable that the person is controlling.

Working computer demonstrations of this method are provided by Powers's "Demo 1" (DOS program) and Marken's "Test of the Controlled Variable" (Java program), available at *www.uiuc.edu/ph/www/g-cziko/twd*. What is most remarkable about the test for determining the variable that is being controlled by behavior is lack of an apparent relationship (as in a near-zero correlation coefficient) between the controlled variable and behavior. It must be recognized that this refers to lack of a systematic *one-way* relationship between stimulus and response. But this is just what is to be expected from understanding the circular causality characteristic of both living and artificial control systems, in which perception and behavior reciprocally and simultaneously influence each other to maintain some perception close to a goal or standard (reference level).

Use of the test for analyzing animate behavior contrasts with all other research methods of behavioral science. Whether behaviorist or cognitive, traditional methods attempt to establish causes (independent variables) for aspects of behavior (dependent variables) as objectively defined from the viewpoint of the researcher. This approach has two serious weaknesses. First, it is not focused on determining the perceptual variables being controlled by the behaving organism. At best it may discover disturbances that appear to cause behavior, but by ignoring perceptual variables that the organism is actually controlling, such an analysis is incomplete at best and misleading at worst. For example, imagine driving west on a straight road with winds gusting out of the north. A traditional one-way cause-effect analysis of your steering behavior will find that the gusts of wind (independent variable) cause you to turn the steering wheel to the right. Your act of turning the steering wheel can be measured objectively to the nearest millimeter if desired and correlated with wind speed and direction. But this analysis completely misses the fact that you are varying the angle of the steering wheel *to maintain your perception of keeping the car centered in its lane*.

This crucial knowledge of the variable you are controlling by varying your behavior allows us to make predictions as to what will happen if other factors act to disturb the position of the car. For example, if the road begins to slope to the right as it changes from a four-lane highway to a two-lane road with a high crown, knowledge of the controlled variable permits us to predict correctly that you will now turn the steering wheel to the left to maintain the car's position. In contrast, knowing only that there is a correlation between wind speed and steering behavior provides no clues at all as to what will happen when other disturbances to the car's position are encountered.

The second weakness of the traditional cause-effect analysis of animate behavior is that it cannot distinguish between the goals of behavior and its incidental, unintended side effects. If behavior is described objectively from the viewpoint of the impartial observer, there can be no significant difference between reaching for the salt and knocking over a glass of wine into the lap of your dining companion. Something must have caused you to reach for the salt, and something must have caused you to knock over the wine. A one-way cause-effect analysis provides no way to distinguish between the two behaviors, despite the fact that your apologies (and your companion's consequent forgiveness) indicate that an important difference does exist between intentions and accidents (a distinction also made in courts of law). In contrast, using Bernard's extended lesson to focus on the intended consequences of behavior makes a clear and important contrast between perceptions being controlled by behavior (such as the appearance of these letters on my computer screen as I type) and incidental, uncontrolled consequences of behavior (such as the clicking sounds made by the computer's keys as I type that are disturbing my wife trying to sleep in the next room).

The How of Behavior

The next question to consider concerns the how of behavior. For example, how is it that wanting some fresh bread results in the appearance of a steaming loaf in the kitchen a few hours later?

The extended Bernardian lesson, as developed by Powers, provides a clear non-Newtonian answer: we are able to achieve goals by setting and accomplishing prerequisite subgoals. The recipe for bread lists water, flour, sugar, salt, and yeast as ingredients. If these are not readily available, a trip to the grocery store is in order. Once obtained, the ingredients must be measured (four cups of flour, two cups of water, a tablespoon of sugar, one teaspoon each of yeast and salt), combined in a certain way (mixed and kneaded until a certain consistency is reached), and baked in the oven at a certain temperature until the crust is golden brown. Actually, many more subgoals are involved than can be conveniently listed here, all of which must be achieved in order to bake a loaf of bread, and with each one likely requiring its own subgoals (subsubgoals?).

In addition, each subgoal must be attained despite the inevitable real-world disturbances that will be encountered. We considered the disturbance of not having all the necessary ingredients on hand, and how that led to a visit to the grocery store. But many other disturbances are also likely to be encountered (such as variations in water pressure while measuring the water, or an oven that must be set at 475° Fahrenheit to reach 425°), and the only way to ensure that they will be successfully countered is by implementing a control system for each subgoal. It is this hierarchy of goals and the setting of lower-level reference levels by higher-level control systems that provide an accurate and useful answer to the how of behavior (introduced in chapter 6 and illustrated in figure 6.3). A useful working model of such a hierarchy of goals and subgoals is Marken's "Spreadsheet Model of a Hierarchy of Control Systems" (1990) for both Macintosh and IBM-compatible personal computers that is available at *www.uiuc.edu/ph/www/g-cziko/twd*.

Traditional cause-effect psychologists have a very different answer to how questions, believing that behavior is able to achieve what it does by generating necessary outputs. Pinker's example of reaching for an object, described in chapter 11, is a good example of this approach, which requires exceedingly complex computations of behavior as output based on inverse kinematics and inverse dynamics. But such computations are not only unnecessary, they are also incapable of producing animate behavior that remains functional despite continuous and unpredictable disturbances. An industrial robot that picks up automobile parts from a conveyor belt and places them in a box by repeating the same sequence of fixed actions over and over again can be effective in a disturbance- and surprise-free environment. But it will fail if the conveyor belt changes speed, or the spacing between the parts changes, or the receiving box is moved a few inches. For humans, it is only by seeing both one's hand and the desired object that one is able to reduce the distance between them to zero and grasp the object. Such behavior remains successful despite disturbances such as muscle fatigue, bulky clothing, or someone attempting to deflect your hand from the desired object. Computed behavioral outputs are simply incapable of achieving such goals in a real world subject to disturbances, and can be useful only in the tightly controlled, disturbance-free environment of a manufacturing plant or a computer simulation.

Questions concerning the how of behavior can be continued to levels of explanation beyond the domain of behavioral science as we ask for what could be considered to be more and more reductionist explanations. One of the answers to how you open a book involves understanding how specific reference levels are generated and sent to the control systems that govern the muscles of your arms and hands. How these reference levels are actually generated and transmitted by your nervous system to the appropriate lower-level control systems brings us to the domain of neuroscience. How the resulting error signals cause muscular contractions involves molecular biology and eventually chemistry and physics. So integration of knowledge from all these disciplines is necessary to answer all the many how questions we can formulate.

The how question is also relevant to the question of learning. How is it that we are able to do something today (such as hitting a tennis ball or playing a musical piece) that we could not do yesterday? A traditional approach sees such learning as the acquisition of new responses; a Bernardian approach sees it as the purposeful, goal-driven, within-organism evolution of new perceptual, reference, and/or motor functions (see chapter 10).

The Why of Behavior

Answering questions about the how of animate behavior leads us down the hierarchy of control systems to lower levels of control. But questions about the why of behavior are addressed by going up the hierarchy to higher levels of control.

Returning to our bread-baking example, we pick up the action as you begin to move your hand toward the kitchen faucet. Why are you changing the position of your arm and hand? Clearly, to turn on the water. Why turn on the water? To put sixteen ounces of it in your measuring cup. Why collect two cups of water? To add to the flour and other dry ingredients to make dough. Why make this dough? To bake a loaf of bread. The answer to each successive why question specifies the higher-level goal for which the current goal is a necessary subgoal.

So far, the answers to these why questions are rather obvious. Even so, they demonstrate how the answers to repeated why questions lead us to higher and higher levels of perception and control. But at a certain point things become more difficult. Why bake a loaf of bread? Perhaps you are hungry and just want something to eat. Or maybe you plan to share the bread with your family at your next meal. Or it could be you intend to give the loaf to a friend who has been sick. We cannot know the answer without further investigation. If your bread making ceased after receiving a phone call informing you that no one would be home for dinner tonight, that would suggest it was for the family to enjoy. If you made your bread despite the call, this would be consistent with the explanation that you intended to eat it yourself or give it to someone.

But in any case, continued why questions (such as why do you want to share a loaf of bread with your family, or give it to a friend, or eat it yourself?) eventually require a shift in perspective from what we have been calling the proximate explanations of behavior involving continuing processes of perceptual control to ultimate explanations involving the natural selection of organisms with adapted goals (discussed in chapters 8 and 9). The ultimate reason why we eat food rich in carbohydrates such as bread is because those who did so in the past were more successful in surviving and left more offspring (including us) than their contemporaries who did not eat such food. And there are good reasons why goals related to providing food for family and helping friends were also favored by evolution.

Humans evolved to prefer bread, whereas dung flies (having a quite different evolutionary history) prefer cow poop. But not all humans eat bread (although none eat cow poop). To answer the question of why an individual eats bread and not rice or potatoes or pasta, we must consider environmental factors, both physical and sociocultural. That all human beings eat foods containing carbohydrates is a universal characteristic of our species. Marriage, caring for children, and male sexual jealousy also appear to be universal features of humankind. But the particular foods we eat (as well as how we prepare them and with whom we eat them) vary widely from culture to culture, depending on what foods are available and what we have learned from others about their preparation and consumption. Similarly, a man's response to a mate's sexual infidelity will be influenced by local culture, with possible outcomes ranging from complete forgiveness to murder.

Universal human goals and desires interact with local conditions resulting in the quite varied proximate behavioral goals we see across human societies. A bride in India provides a dowry to her husband's family, whereas in Africa it is expected that the man make a generous contribution to his future in-laws. These behaviors may seem quite distinct, but they are in fact two different culturally adaptive solutions to the universal human concern of obtaining a high-quality mate and ensuring the survival and reproductive success of one's children.

Do all behaviors have ultimate evolutionary reasons? There is currently much debate about this. Ethologists, sociobiologists, and evolutionary psychologists tend to believe that such explanations exist for all behavior, and they point to the impressive success this approach has in making sense of animal behavior. Other behavioral scientists do not agree, particularly those who emphasize the importance of physical and cultural environments.

But if, as evolutionary psychologists are quick to point out, environmental factors do play an important role in influencing human behavior, this itself can be considered an adaptive trait that has an evolutionary origin. Humans' unmatched ability to engage in forms of within-organism purposeful evolution (see chapter 10) to modify goals and behaviors has made us the most widespread and adaptable species on the planet. This ability is so well developed that we are capable of behaviors that may even seem to be at odds with the basic concerns of survival and reproduction.

For example, we can vow, as Catholic priests and nuns do, to abstain from sexual activity and reproduction. We can, despite our long evolutionary history as omnivores, refrain from eating meat. We can endure great hardships and persecution, including torture and death, for our religious and political beliefs. We can even (which I suppose is the ultimate paradox) make a conscious effort to learn about the evolutionary origins of our desires, preferences, and consequent behaviors and decide to lead an austere life in opposition to the predilections of our selfish genes. Such flexibility can make it very difficult to apply an evolutionary perspective to all forms of human behavior. But priests, nuns, vegetarians, and religious martyrs are the exceptions rather than the rule, and I have no doubt that the general "rules" of human behavior will continue to make more sense as we continue to investigate them from an evolutionary perspective.

These Bernardian and Darwinian answers to why questions contrast sharply with answers provided by behavioral scientists using behaviorist and cognitive approaches. Skinner was not concerned with the evolutionary past of organisms whose behavior he studied, and he believed in spite of considerable evidence to the contrary (see Breland & Breland 1961) that under the proper conditions (contingencies of reinforcement) any organism could learn to perform just about any type of behavior that was physically possible. For him and other behaviorists, organisms do what they do for the simple reason that they were reinforced for such behaviors in the past.

Although cognitive scientists put less emphasis on reinforcement and more on mental processes, they also have traditionally shown little interest in adopting an evolutionary perspective to answer why questions. Exceptions, of course, are the relatively small group of cognitive psychologists who refer to themselves as evolutionary psychologists. But whereas evolutionary psychologists such as Tooby and Cosmides have learned the basic Darwinian lesson, they have not yet accepted the extended Darwinian and extended Bernardian lessons. For them, ultimate explanations for behavior are to be found in the evolutionary past of an organism. But proximate explanations are still cast in perceptual-input-causes-behavioral-output terms as used by all other cognitive scientists, rather than in behavioral-output-controls-perceptual-input terms as is consistent with the extended Bernardian lesson.

Applying the Bernardian and Darwinian Lessons

A biologically inspired approach to the what, how, and why of behavior has important implications for theory and research in behavioral science. But what does it mean for practice? Can this new approach, which takes heed of Bernard's and Darwin's lessons, provide new and effective solutions to the many serious issues and problems involving human behavior?

Skinner's Cause-Effect Approach

It was not so long ago that the application of a "truly scientific and objective approach" promised to solve such problems. By judicious application of operant conditioning techniques involving the establishment of proper contingencies of reinforcement and/or punishment as described by Skinner and his adherents, it was believed that one human could control another's behavior. In fact, this notion seems to have become the institutional policy in all societies where those in power provide rewards in the form of money and other benefits to motivate workers while meting out punishment in the form of imprisonment and hard labor to reform criminals.

It is generally accepted as common knowledge that this policy can work, but it has some serious problems. In his book *Punished by Rewards* (1993), Alfie Kohn described many disappointments encountered by those applying Skinnerian principles in a wide range of settings including the workplace, home, and school. After reviewing hundreds of such studies, Kohn concluded that attempts to control people by rewarding them for desired behaviors is not effective for a number of reasons. First, the quality of one's work suffers when emphasis is put on incentives such as money and grades. Second, the effect of reinforcement rarely generalizes to other settings (a child who is enticed to read a certain number of books over the summer to earn a pizza cannot be expected to continue reading books when no pizza is offered). Third, providing rewards for completing a task can turn what was previously an enjoyable activity pursued for its own sake into one that is perceived as disagreeable (as in the case of a child who used to read for pleasure, but now sees reading as inherently unpleasant work to be done only for a reward).

Although punishment was never actually advocated by Skinner, as it points out only what should not be done rather than what should be done, it remains a common means for controlling behavior in all societies despite considerable evidence that it is ineffective and counterproductive in the long term. Punishment may result in initial compliance to cease the offending behavior, but it also leads to resentment in the one punished and to devising ways to continue the behavior while avoiding punishment or retaliating against the punisher. Decades of research have shown consistently that children subjected to physical punishment turn out to be more aggressive and violent than other children and are more likely to use physical punishment on their own children (see Kohn 1973, p. 167). As to the effectiveness of punishment as institutionalized in the American penal system, James Gilligan (1996, p. 95) observed:

> The murder rate in the United States is from five to twenty times higher than it is in any other industrialized democracy, even though we imprison proportionately five to twenty times more people than any other country on earth except Russia; and despite (or because of) the fact that we are the only Western democracy that still practices capital punishment (another respect in which we are like Russia).

The ineffectiveness of Skinnerian methods of behavior modification should come as no surprise to one who has carefully examined the basic premises of behaviorism. According to principles of operant conditioning, the probability of certain behaviors is increased by providing a reinforcement after the behavior is completed. Reinforcement is seen as strengthening the connection between the stimulus preceding the behavior and the behavior itself. So according to reinforcement theory, if a child is given a treat after reading a book, this should increase the frequency of future book reading *even if the student knows that no treat will be given the next time a book is read*.

It may well be that providing rewards will expose an otherwise reluctant child to the intrinsic pleasures of reading and thus be successful in encouraging the child to continue to read. But you can be sure that a child who does not find reading enjoyable and does it only to obtain extrinsic rewards will not continue to read books if he or she knows that rewards are no longer in the offing. And, as already noted, a child who initially found joy in reading may well come to consider it a disagreeable task when offered extrinsic rewards.

It is not the provision of *past* rewards and punishment that influences behavior, but rather anticipation of *future* rewards and punishment. Public hangings can be quite effective in getting the population to think twice about performing acts that are punishable at the end of a rope (it is, of course, completely effective in preventing such actions in the future by the punished individual). Promises of future rewards can also increase the likelihood of certain activities (which is how most religions operate to modify the behavior of their adherents, not to mention the threat of hell as future punishment). The reason why rewards and punishment often appear to be effective in modifying or controlling another person's behavior is not because their application in the past controls current behavior. Instead, humans vary their present behavior to obtain (or avoid) that which they want to obtain (or avoid). That is, rewards do not control behavior. Rather, behaviors are used to control rewards.

Another aspect of trying to use rewards to control behavior is often overlooked and may actually go a long way toward explaining why it is ineffective in the long term. For me to use reinforcement in an attempt to control your behavior, I must be able to control the resource that will serve as the reinforcement and make sure that you are in a state of *deprivation*. That is, I must make sure that you have less of the reinforcement than you want. I cannot use food as reinforcement if you are able to obtain all the food you want from other sources. Whereas such an arrangement may work well for a rat or pigeon that cannot question the fairness of such a situation, you as an intelligent adult human being will almost certainly find such a situation unfair if not intolerable. As Powers (1973, p. 268) noted:

> Food rewards *will* cause modification of behavior, but how do you set up the conditions that give you sole control of the food supply? That is the step which Skinner and those who admire his methods have completely overlooked. That is the step that leads directly to violence.

This action of the would-be controllee against the would-be controller was recognized by Skinner who referred to it as "countercontrol," although it is seldom if ever mentioned now by advocates of his approach. In fact, anyone attempting to use Skinner's technique on another intelligent human being makes himself or herself susceptible to countercontrol. For example, a father may tell his teenage son that he must improve his high school grades to earn the right to use the family car. The teenager can then engage in countercontrol by making it known that if he can't use the car whenever he wants, he will simply not study at all! This is only one form that countercontrol can take, as more violent outcomes are also possible.

Bernard's Biological Approach

If reward and punishment fail to solve the problems caused by human behavior, why do those with political, military, and economic power persist in using them? One reason is that, as mentioned, the promise of reward and the threat of punishment can modify others' behavior, at least until ways are found to defeat the system (as in escaping from the situation or using violence to overcome the reinforcer-punisher). Another reason is the assumption of a one-way cause-effect view in which reinforcement causes desired behaviors and punishment eliminates undesirable ones.

In contrast, applying the extended Bernardian lesson leads to a very different approach. It differs from a cause-effect behaviorist approach in at least two main respects. This is due to Bernardian (as further developed by Powers) recognition that perceptions (such as the perception of stimuli as reward or punishment) do not control behavior. Rather, individuals vary their behavior as necessary to control their perceptions and thereby obtain desired outcomes and avoid unwanted ones.

A school discipline process based on Powers's perceptual control theory suggests that application of the extended Bernardian lesson can be quite effective in bringing about desired changes in behavior. The Responsible Thinking Process, developed by Edward E. Ford, was first implemented in Clarendon Elementary School in Phoenix, Arizona (1994, 1996). Ford, a social worker and counselor who discovered the work of Powers in 1981, conceived an approach to school discipline based on the Bernardian lesson that human beings act to control aspects of their environment.

No extrinsic reward or punishment (or promises or threats of them) are used, and teachers are not held responsible for the behavior of their students. Instead, students engaging in disruptive behavior are asked a series of questions by the teacher designed to have students reflect on their behavior and its consequences if continued. Students who need help learning how to behave responsibly (that is, in a way that does not disturb the learning activities of the classroom) go to a "responsible thinking classroom" where a full-time teacher-counselor helps them develop a plan for change to submit to the classroom teacher for approval.

From this all-too-brief description of Ford's process (for more information see *www.respthink.com*), it may seem that it is just another way of using rewards and punishment to control students' behavior, with reward being the privilege to remain in the regular classroom and punishment being sent to the responsible thinking classroom. But this is not an accurate assessment, since the student is always in control of his or her own situation in accordance with the rules that have been accepted by the school's students and teachers concerning acceptable behavior.

Nowadays it is almost always the case that a teacher responds to a disruptive student with the threat of punishment (if the disrupting behavior continues) or the promise of a reward (if the disrupting behavior stops). In contrast, teachers in Ford's process do not use threats, bribes, or commands in such situations. Instead, they ask a series of questions like the following: "What were you doing?" "What are the rules?" "What happens when you break the rules?" "Is that what you want to happen?" "Is what you are doing getting you want you want?" "Do you want to work at solving your problem?"

At no time is a student told what to do or not to do, or asked to explain his or her behavior. But the rules of the school are enforced in a clear and consistent way, and the student has the choice of following them and participating fully in school activities or being excluded from them until he or she comes up with a satisfactory plan to change the disruptive behavior.

Although easy to describe, the Responsible Thinking Process is not so easy to implement for the simple reason that it goes against the belief commonly held by teachers that they are responsible for the behavior of their students and that rewards and punishment can be used to control students' behavior. Ford found that it takes a serious, determined effort on the part of teachers to cease threatening and bribing their students, and he devotes considerable time and effort to help them change their reaction.

But once achieved, the results, as I personally witnessed in an elementary school near Chicago, are quite amazing. That is why in just a few years the Responsible Thinking Process has spread to more than forty schools in the United States and Australia.

Ford's work in public schools and other institutions (he has also worked in juvenile detention centers) is a clear demonstration of the potential of a Bernardian approach to behavior to solve behavior-related problems. Contingencies of reinforcement or punishment, or their associated bribes and threats, are not necessary. There is no risk of escalating control and countercontrol. Most important, it removes from teachers the onus of attempting to control students' behavior and allows them to devote their energies to teaching. As one sixth-grade teacher remarked, "We've waited for a program to come along that allows me to teach! We have finally found it!" (quotation on the back cover of Ford 1994).

Darwin's Biological Approach

If the application of Bernard's extended lesson to animate behavior has been effective as applied to education, what about applications of the basic and extended Darwinian lessons?

It is not easy to find applications to education of Darwin's basic lesson. The notion that our evolutionary past had a role in shaping the human mind and thereby influences our abilities, emotions, goals, desires, and fears does not appear to be popular among educators. This is particularly so in the United States, where the fact of biological evolution itself is not popular (and is often attacked by religious fundamentalists), and where the role of the current environment, not one's evolutionary past, is usually considered the determining factor in shaping cognitive skills and personalities. But at least some attempts have been made to use Darwin's basic lesson to change schools to optimize learning and to understand difficulties children have in learning certain concepts.

An example of the former is Gary Bernhard's book *Primates in the Classroom* (1988). Bernhard drew primarily on studies of the world's remaining hunter-gatherer groups (including the Semang of Malaysia, Mbuti Pygmies of the Congo's Ituri forest, !Kung of the Kahalari Desert, Aborigines of Australia, and Eskimos of Canada's Arctic) to understand how learning naturally occurs in groups that live in environments similar to the one in which our species evolved; that is, before the development of agriculture and industry. Bernhard (1988, pp. 178–179) pointed out many similarities among these groups and described their implications for education, stating that

> Learning by discovery in a democratic social context is one of the characteristics of our species, and we are kidding ourselves if we think that a longer school year, more rigorous basic-skills instruction, higher academic standards, and all of the other suggestions that have come out of studies such as A Nation at Risk will solve the "education problem" in this country. An evolutionary perspective also makes it clear that, in order for children to learn naturally, they need to have consistent yet varied adult models. Thus we are equally foolish if we believe children will be well served in an environment in which the only adults around are trying to get out of the children's way. Finally, an evolutionary way of looking at education issues is grounded in the need that all humans have to belong to a group and to be acknowledged as individuals by the other members of the group. It is thus hardly surprising that the more removed children are from their conception of who is in the "band," the greater their distress.

Some will question Bernhard's method of applying what has been observed in hunter-gatherer groups to urban children in modern schools, but many innovative changes taking place in education are consistent with his Darwinian perspective. Such progressive approaches typically give students more responsibility for their own learning, integrate many types of knowledge and skills in pursuing projects of interest to the students, employ adults not as authoritarian transmitters of information but rather as facilitators and role models, and have multiage classrooms in which children and teachers remain together for several years. All these, and many other progressive changes in education, are compatible with how human children appear to learn best "naturally."[1]

But many skills that we expect children to learn did not exist in the evolutionary past. Reading and writing are considered basic to all formal education, yet they are relatively recent cultural inventions that had no role in our evolution as a species. Mathematics is another branch of knowledge unknown to our early human forebears but occupies an important role in education. What might the basic Darwinian lesson have to say about learning in these areas?

Psychologist David Geary studied children's learning of various subjects and observed an important distinction between what he calls "biologically primary" and "biologically secondary" cognitive abilities. The former appear to have evolved largely by means of natural or sexual selection, whereas "biologically secondary cognitive abilities reflect the co-optation of primary abilities for purposes other than the original evolution-based function and appear to develop only in specific cultural contexts" (Geary 1995, p. 24).

A good example of this distinction is the contrast between oral language ability (listening and speaking) and literacy skills (ability to read and write language). Normal children require no special instruction to learn to speak and understand language. As long as they are exposed to a spoken language in interaction with older individuals, they will acquire this ability with little apparent effort and no formal instruction. Human evolution obviously shaped our species to excel at the acquisition and use of language (see Cziko 1995, chapter 11; Pinker and Bloom 1990).

But no evolutionary pressure existed for learning to read and write or understanding mathematics, as these skills are relatively modern cultural inventions. Accordingly, they take special concentrated effort to acquire. Geary concluded that learning secondary biological abilities must involve extensive practice, and since this may not be particularly enjoyable, ways must be found to encourage children to undertake it.

Considerable controversy exists among educators about how this should be done and what should be practiced (as in the phonics versus whole-language approaches to reading). Nonetheless, Geary's evolutionary analysis of biologically primary and biologically secondary cognitive abilities creates a useful framework for understanding the success and difficulties our children experience in school and shows one way that the basic Darwinian lesson can be applied.

What about applications of the extended Darwinian lesson? We saw in chapter 9 how within-organism variation and selection functions within the mammalian immune and nervous systems, and how the process permits these systems to adapt to new circumstances in the form of immune responses and learning new behaviors and abilities. Can this lesson be applied in practical settings? It turns out that does have important behavioral applications in at least the field of education, despite the fact that educators have for the most part ignored it.

An important exception is Henry Perkinson, a philosopher and historian of education. He observed important connections among the extended Darwinian lesson, the philosophy of Karl Popper, and major developments in educational theory and practice, notably those motivated by the work of Piaget, Skinner, Maria Montessori, A. S. Neill (of *Summerhill* fame), and Carl Rogers (Perkinson 1984). The approaches to educational theory and practice advocated by these five influential individuals certainly have important differences. But what they all have in common is rejection of the traditional cause-effect notion of education as the transmission of knowledge from teacher to student, and appreciation of education as a process of change that involves continuous modification of previous knowledge by trial and error elimination.

This essentially Darwinian approach can be summarized by the title of Perkinson's book: education involves learning from our mistakes. This means that it is facilitated by an environment in which learners are free to try out their knowledge and skills without fear of making mistakes. But it also means that the environment must provide critical feedback permitting students to discover the inadequacies of their knowledge and skills so that they can continually improve. This approach rejects the view of students as passive recipients of knowledge and sees them instead as active creators of their own knowledge. It is consistent not only with the essential core of the educational theories of Piaget, Skinner, Neill, Montessori, and Rogers, but with other progressive changes occurring in education, even if reformers are unable or unwilling to recognize the Darwinian roots of these changes (see Cziko 1995, chapter 12, for a more thorough Darwinian discussion of education).

Toward a Unified Theory of Behavior

Applying the lessons of Bernard and Darwin to the what, how, and why of behavior provides the building blocks for a unified theory of behavior drawing on biology, psychology, physiology, and ultimately physics. The concerns and contents of such a theory should be obvious from the preceding chapters. But it will be useful to conclude this book with an outline of such a theory and a consideration of its limitations.

The basic Darwinian lesson informs us that our evolutionary past provided us and all animals with certain basic preferences. We prefer certain foods, odors, and tastes and are repulsed by others. We prefer environments that are not too hot and not too cold. We look for certain characteristics in mates, which differ depending on our sex. We do what we can to assist the well-being of our children, close relatives, and other individuals from whom we can expect such assistance in return. We prefer the company of family members and others who are most like us, and are wary of others whom we perceive as physically, racially, or culturally different. But these preferences, naturally selected for their past survival and reproductive consequences, are not necessarily advantageous in these respects in the modern environment we inhabit.

The extended Bernardian lesson provides an explanation for how such preferences, existing as reference levels within feedback-control systems, influence our behavior, and how we are able to purposefully vary our behavior to make our perceptions match these reference levels. The extended Bernardian lesson, in its cybernetic formulation as perceptual control theory, shows how goals, desires, intentions, likes, and dislikes are emergent properties of thoroughly materialistic systems, having no need for spirits, souls, or other supernatural entities or processes.

But we humans have many goals and preferences that cannot be traced back to our evolutionary past. Thus we need the extended Darwinian lesson to explain how new goals can evolve in the service of more basic ones. An Eskimo spears seals and whales to make a living. A farmer in Illinois plants hundreds of acres of corn and soybeans for his livelihood. A musician in Paris supports herself by producing certain sounds with her flute. Such behaviors require preferences and control systems that cannot be provided by our evolutionary past, but they can be created by within-organism variation and selection as a process of purposeful evolution.

I have no doubt that a biologically inspired view of behavior that uses the insights of Bernard and Darwin is far superior to the one-way cause-effect approach currently embraced by mainstream behavioral scientists. But I also recognize that this new approach has certain inherent limitations of its own concerning our understanding, prediction, and control of animate behavior.

First, our search for the ultimate, evolutionary accounts for behavior are hampered by unavailability of fossil records of behavior (although certain extremely rare fossil finds, such as that of a dinosaur apparently guarding her eggs and newly hatched offspring, do provide some behavioral evidence). So whereas we can provide all sorts of evolutionary accounts of the emergence of our preferences and abilities (such as language), we cannot know for sure which if any of these comes close to what actually took place.

Also, compared with other species, our behavior is remarkably diverse, reflecting our varied physical and cultural environments. Pandas eat only bamboo shoots, and robins always make a nest of a certain shape in which to lay eggs; but we humans engage in a wide variety of tasks to accomplish whatever basic goals evolution has provided us. This diversity makes it especially difficult to find universal human behavioral characteristics. Nonetheless, a Darwinian approach offers clues as to what fundamental universals may exist. Furthermore, recognition of the hierarchical nature of human perceptual control systems is a way of recognizing similarity in the underlying goals of human behavior in spite of their apparent superficial diversity.

Considering first the extended Bernardian lesson that organisms act to control their perceptions, we must recognize that the actual behavior implemented by an organism has to compensate for disturbances that are encountered. To the extent that these disturbances are unpredictable, the organism's behaviors will also be unpredictable. For example, even if I know that you are driving down a straight road to travel from your home in Eastville to a friend's home in Westville, I cannot know in advance how you will move the steering wheel, since I cannot predict the wind, traffic, and road conditions you will encounter. Nonetheless, knowledge of your goal (that is, the perceptual variable that you are controlling) will allow me to predict the outcome of your behavior (arriving in Westville), even if the precise actions you make while driving remain unpredictable.

The extended Darwinian lesson of within-organism variation and selection also poses challenges to understanding and predicting behavior. Through reorganization, organisms acquire control over new variables in new situations. Since this process has an essential random component in the generation of variation (mathematicians refer to it as a *stochastic* process), it is in principle impossible to know exactly what type of reorganization will take place. A boy who is deprived of attention at home will look for it elsewhere. Whether he will attain it by excelling in academics, sports, or by committing a violent crime will be determined by the results of control system reorganization, whose outcome is by its very nature impossible to predict.

All of these are important limitations to a unified theory of behavior based on the Bernardian and Darwinian lessons. But this biologically inspired framework allows us to ask many new, interesting questions about behavior, and conceive of a methodology for answering them that avoids the push-pull straightjacket of cause-effect behavioral science, taking into account our evolutionary past and present (the latter in the form of within-organism variation and selection).

We have no guarantee that applying the lessons of Bernard and Darwin will ultimately allow us to answer all the important and interesting questions about animal and human behavior. Nor can we be certain that they will lead us to solutions for the major behavior-based problems our species is facing, such as failing schools, violence, pollution, overpopulation, spread of disease, and the growing division of the world's population into haves and have-nots.

What is clear is that the currently accepted one-way cause-effect model, successful in explaining much of the workings of the inanimate world, cannot account for the purposeful, goal-directed behavior by which living organisms control important aspects of their environment. It is also clear that attempts to modify human behavior based on the push-pull approach inherited from Newton have failed both as a theoretical account for animate behavior and as an applied tool for behavior change.

Major revolutions have taken place in the fields of astronomy, geology, physics, and biology, with important consequences for our understanding of the universe and our ability to predict and control important aspects of our environment. It is not unreasonable to expect that the consequences of a major revolution in the much younger discipline of behavioral science may have consequences as great as or greater than those of these earlier revolutions.

When the lessons of Bernard and Darwin become widely understood by behavioral scientists, the life, behavioral, and physical sciences will have achieved an integration that future scientists will find so obvious, satisfying, and useful that they will have difficulty understanding why, after Bernard's and Darwin's revolutionary breakthroughs in the nineteenth century, it was not until the twenty-first century that their lessons were widely learned and applied.

Notes

Chapter 1

1. *The American Heritage Dictionary* (1992) defines materialism as "the theory that physical matter is the only reality and that everything, including thought, feeling, mind, and will, can be explained in terms of matter and physical phenomena." "Physical phenomena" include forms of energy such as electricity and magnetism.

Chapter 5

1. This paragraph and the preceding one were written with the assistance of William T. Powers.

Chapter 6

1. Some of the better-known participants were social scientist Gregory Bateson, engineer Julian Bigelow, sociologist Paul Lazarsfeld, social psychologist Kurt Lewin, neurophysiologist Rafael Lorente de Nó, anthropologist Margaret Mead, neuropsychiatrist Warren McCulloch, mathematician Walter Pitts, physiologist Arturo Rosenblueth, information theorist Claude Shannon, electrical engineer Heinz von Foerster, mathematician John von Neumann, and, of course, cybernetician Norbert Wiener.

2. Apparently after rheostat, a device that resists the flow of electricity and whose resistance can be varied by mechanical means.

3. Figure 6.4 was provided by Bryan Thalhammer.

4. Another approach to modeling hierarchical networks of control systems is by Marken (1990), who created a three-level control hierarchy in the form of a computer spreadsheet that can be obtained from *www.uiuc.edu/ph/www/g-cziko/twd*.

5. Gather, a program for IBM-compatible personal computers, is also available from *www.uiuc.edu/www/ph/g-cziko/twd*.

6. Additional control system simulations of social behavior have been developed by Bourbon (1990).

Chapter 7

1. Although Lamarck did not see God as directly involved in the creation of currently existing forms of life, he nonetheless referred to God as "the supreme author of all things" (quoted in Burkhardt 1977, p. 185).

2. See Weiner (1994) for a fascinating account of the work of Peter and Rosemary Grant on the evolution of Darwin's finches on the Galápagos Islands.

3. Unfortunately, Weismann's research did nothing to dissuade Soviet biologist Trofim Denisovich Lysenko (1889–1976) from his doomed attempt to increase the productivity of Soviet agriculture based on Lamarckian principles. Stalin's receptivity to and imposition of Lysenko's Lamarckian beliefs crippled the development of Soviet biology and genetics until the 1960s (see Medvedev 1969, and Joravsky 1970, for accounts of the life and times of Lysenko).

4. It is the case that certain environmental factors (such as radiation and chemical substances known as *mutagens*) can increase mutation rates in organisms and thereby cause an increase in behavioral variation. However, these variations are like those that arise spontaneously in their being unrelated to the environmental factors that caused them and completely blind to the adaptive needs of the organism.

5. Since evolutionary theory recognizes all organisms as having descended from a common ancestor, all organisms are in this sense related to each other. I use the word "unrelated" in its more common definition of applying to two organisms with no close kin relationship and who are therefore unlikely to share a new or relatively uncommon gene.

6. This account of web building is taken primarily from Dawkins (1996, chapter 2) and Hoagland and Dodson (1995, pp. 140–141).

Chapter 8

1. Since Darwin's time, adaptive explanations have been provided for some human racial differences. For example, sunlight is an important factor in human health since skin exposed to sunlight permits the production of vitamin D, a vital nutrient. But because overexposure to the sun has damaging effects and may lead to skin cancer, the color of human skin is an adaptation to the intensity of sunlight. Tropical races have dark skin for protection against the sun's harmful effects, and temperate and Arctic races have light skin to allow more of the available solar radiation to enter the skin to be used for synthesis of vitamin D.

2. See Behe (1996) for a modern version of the same misguided argument.

3. See Buss (1999) for a valuable recent compilation of these findings. See also Johnston (1999) for a fascinating evolutionary account of human emotions.

Chapter 9

1. See Cziko (1995, pp. 186–187) and Dennett (1995, pp. 384–393) for two critiques of Chomsky's anti-Darwinian views.

2. Both figures 9.2 and 9.3 give a simple quantitative portrayal of the two complementary entities in question; however, their interaction is undoubtedly much more complex.

Chapter 11

1. For more information about these behavioral scientists and their work, see the Website of the Control Systems Group at *www.ed.uiuc.edu/csg*.

Chapter 12

1. For an example of a school consistent with such principles, see the video *A Learner-Centered School* about Williston Central School in Vermont (Burrello 1995).

References

Adler, T. (1997, January 4). Animals' fancies: Why members of some species prefer their own sex. *Science News*, *151*, 8–9.

Alcock, J. (1993). *Animal behavior: An evolutionary approach* (5th ed.). Sunderland, MA: Sinauer Associates.

Alexander, R. D. (1979). *Darwinism and human affairs*. Seattle: University of Washington Press.

Allman, W. F. (1994). *The stone age present*. New York: Simon & Schuster.

Aquinas, T. (1914). *The "Summa Theologica" of St. Thomas Aquinas* (Part II). London: W. & T. Washbourne. (Original work written 1265–1273)

Aristotle. (1952). *Physics* (*Great books of the Western world*, Vol. 8, pp. 257–355). Chicago: Encylopaedia Britannica.

Bagemihl, B. (1999). *Biological exuberance: Animal homosexuality and biological diversity*. New York: St. Martin's Press.

Bain, A. (1868). *The senses and the intellect* (3rd ed.). London: Longmans, Green.

Bajema, C. J. (Ed.). (1983). *Natural selection theory*. Stroudsburg, PA: Hutchinson Ross.

Baylies, M. K., Bargiello, A., Jackson, F. R., & Young, M. W. (1987). Changes in abundance or structure of the *per* gene product can alter periodicity of the *Drosophila* clock. *Nature*, *326*, 390–392.

Beach, F. A. (1955). The descent of instinct. *Psychological Review*, *62*, 401–410.

Beckner, M. O. (1967). Vitalism. In P. Edwards (Ed.), *The encyclopedia of philosophy* (Vol. 8, pp. 253–256). New York: Macmillan.

Behe, M. J. (1996). *Darwin's black box: The biochemical challenge to evolution*. New York: Free Press.

Benzer, S. (1973, December). Genetic dissection of behavior. *Scientific American*, *229*, 24–37.

Bernard, C. (1927). *An introduction to the study of experimental medicine* (H. C. Green, Trans.). New York: Macmillan. (Originally published 1865)

Bernhard, J. G. (1988). *Primates in the classroom: An evolutionary perspective on children's education*. Amherst, MA: University of Massachusetts Press.

Bizzi, E., Mussa-Invaldi, F. A., & Giszter, S. (1991). Computations underlying the execution of movement: A biological perspective. *Science*, *253*, 287–291.

Blumenthal, A. L. (1988). A reappraisal of Wilhelm Wundt. In L. T. Benjamin, Jr. (Ed.), *A history of psychology: Original sources and contemporary research* (pp. 195–204). New York: McGraw-Hill.

Boakes, R. (1984). *From Darwin to behaviourism: Psychology and the minds of animals*. Cambridge: Cambridge University Press.

Bode, H. W. (1960). Feedback—The history of an idea. In R. Bellman & R. Kalaba (Eds.), *Mathematical trends in control theory* (pp. 106–123). New York: Dover.

Bourbon, W. T. (1990). Invitation to the dance: Explaining variance when control systems interact. *American Behavioral Scientist*, *34*(1), 95–105.

Breland, K., & Breland, M. (1961). The misbehavior of organisms. *American Psychologist*, *16*, 681–684.

Brown, D. E. (1991). *Human universals*. Philadelphia: Temple University Press.

Brown, J. L. (1974). Alternative routes to sociality in jays—With a theory for the evolution of altruism and communal breeding. *American Zoologist*, *14*, 61–78.

Burkhardt, R. W., Jr. (1977). *The spirit of the system: Lamarck and evolutionary biology*. Cambridge: Harvard University Press.

Burrello, L. C. (Executive Producer). (1995). *A learner-centered school* [video]. (Available from Phi Delta Kappa, P.O. Box 789, 408 N. Union Street, Bloomington, IN 47402-0789.)

Buss, D. M. (1989). Sex differences in mate preferences: Evolutionary hypotheses tested in 37 different cultures. *Behavioral and Brain Sciences*, *12*, 1–49.

Buss, D. M. (1999). *Evolutionary psychology: The new science of the mind*. Boston: Allyn & Bacon.

Calvin, W. H. (1987). The brain as a Darwin machine. *Nature*, *330*, 33–34.

Calvin, W. H. (1990). *The cerebral symphony: Seashore reflections on the nature of consciousness*. New York: Bantam.

Calvin, W. H. (1996a). *The cerebral code: Thinking a thought in the mosaics of the mind*. Cambridge: MIT Press.

Calvin, W. H. (1996b). *How brains think: Evolving intelligence, then and now*. New York: Basic Books.

Campbell, D. T. (1960). Blind variation and selective retention in creative thought as in other knowledge processes. *Psychological Review*, *67*, 380–400.

Campbell, D. T. (1974). Evolutionary epistemology. In P. A. Schilpp (Ed.), *The philosophy of Karl Popper* (Vol. 1, pp. 413–463). La Salle, IL: Open Court.

Campbell, D. T., & Stanley, J. C. (1966). *Experimental and quasi-experimental designs for research*. Chicago: Rand McNally.

Campbell, K. (1967). Materialism. In P. Edwards (Ed.), *The encyclopedia of philosophy* (Vol. 5, pp. 179–188). New York: Macmillan.

Cannon, W. B. (1939). *The wisdom of the body* (rev. ed.). New York: Norton.

Changeux, J.-P. (1985). *Neuronal man: The biology of mind*. New York: Oxford University Press.

Chomsky, N. (1959). A review of B. F. Skinner's *Verbal behavior*. *Language*, *35*(1), 26–58. (Reprinted in Fodor, J. A., & Katz, J. J. (Eds.). (1964). *The structure of language: Readings in the philosophy of language* (pp. 547–578). Englewood Cliffs, NJ: Prentice-Hall)

Chomsky, N. (1988). *Noam Chomsky on the generative enterprise: A discussion with Riny Huybregts and Henk van Riemsdijk*. Dordrecht, The Netherlands: Foris Publications.

Chomsky, N. (1996). *Powers and prospects*. Boston: South End Press.

Chomsky, N. (1997). *Language and mind* (transcript of video). Los Angeles: Into the Classroom Media.

Churchland, P. M. (1995). *The engine of reason, the seat of the soul: A philosophical journey into the brain*. Cambridge: MIT Press.

Cook, T. D., & Campbell, D. T. (1979). *Quasi-experimentation: Design and analysis issues for field settings*. Boston: Houghton-Mifflin.

Cosmides, L., & Tooby, J. (1987). From evolution to behavior: Evolutionary psychology as the missing link. In J. Dupré (Ed.), *The latest on the best: Essays on evolution and optimality* (pp. 277–306). Cambridge: MIT Press.

Cziko, G. (1995). *Without miracles: Universal selection theory and the second Darwinian revolution*. Cambridge: MIT Press.

Daly, M., & Wilson, M. (1985). Child abuse and other risks of not living with both parents. *Ethology and Sociobiology*, *6*, 197–210.

Daly, M., & Wilson, M. (1988). *Homocide*. Chicago: Aldine de Gruyter.

Darwin, C. (1874). *The descent of man and selection in relation to sex* (2nd ed.). New York: Thomas Y. Crowell.

Darwin, C. (1952). *The descent of man and selection in relation to sex*. (*Great books of the Western world*, Vol. 49, pp. 253–639). Chicago: Encyclopaedia Britannica. (Originally published 1871)

Darwin, C. (1955). *The expression of the emotions in man and animals*. New York: Philosophical Library. (Originally published 1872)

Darwin, C. (1975). *Charles Darwin's natural selection, being the second part of his big species book written from 1856–1858*. (Edited by Paul Barrett, 2 vols.). Cambridge: Cambridge University Press.

Dawkins, R. (1976). *The selfish gene*. Oxford: Oxford University Press.

Dawkins, R. (1986). *The blind watchmaker*. New York: Norton.

Dawkins, R. (1996). *Climbing mount improbable*. New York: Norton.

Deacon, T. W. (1997). *The symbolic species: The co-evolution of language and the brain*. New York: Norton.

Dennett, D. C. (1991). *Consciousness explained*. Boston: Little, Brown.

Dennett, D. C. (1995). *Darwin's dangerous idea: Evolution and the meanings of life*. New York: Simon & Schuster.

Dennett, D. C. (1996). *Kinds of minds: Towards an understanding of consciousness*. New York: Basic Books.

Depew, D. J., & Weber, B. H. (1995). *Darwinism evolving*. Cambridge: MIT Press.

Eccles, J. C. (1989). *Evolution of the brain: Creation of the self*. London: Routledge.

Edelman, G. M. (1987). *Neural Darwinism: The theory of neuronal group selection*. New York: Basic Books.

Edelman, G. M. (1988). *Topobiology: An introduction to molecular embryology*. New York: Basic Books.

Edelman, G. M. (1989). *Remembering the present: A biological theory of consciousness*. New York: Basic Books.

Edelman, G. M. (1992). *Bright air, brilliant fire: On the matter of the mind*. New York: Basic Books.

Edwards, P. (1967). Panpsychism. In P. Edwards (Ed.), *The encyclopedia of philosophy* (Vol. 6, pp. 22–31). New York: Macmillan.

Ehrlich, P. (1900, July 24). Croonian lecture: On immunity with special reference to cell life. *Proceedings of the Royal Society of London*, *66*(432), 424–448.

Ellis, L. (1996). A discipline in peril: Sociology's future hinges on curing its biophobia. *American Sociologist*, *27*, 21–41.

Emlen, S. T., Demong, N. J., & Emlen, J. (1989). Experimental induction of infanticide in female wattled jacanas. *Auk*, *106*, 1–7.

Evans, R. I. (1973). *Jean Piaget: The man and his ideas*. New York: Dutton.

Eysenck, H. J. (1993). Creativity and personality: Suggestions for a theory. *Psychological Inquiry*, *4*, 147–178.

Eysenck, H. J. (1994). Creativity and personality: Word associations, origence, and psychoticism. *Creativity Research Journal*, *7*, 209–216.

Eysenck, H. J. (1995). *Genius: The natural history of creativity*. Cambridge: Cambridge University Press.

Finke, R. A., Ward, T. B., & Smith, S. M. (1992). *Creative cognition: Theory, research, and applications*. Cambridge: MIT Press.

Ford, E. E. (1994). *Discipline for home and school: Teaching children to respect the rights of others through responsible thinking based on perceptual control theory*. Scottsdale, AZ: Brandt.

Ford, E. E. (1996). *Discipline for home and school: Book 2: Program standards for schools*. Scottsdale, AZ: Brandt.

Fruton, J. S. (1975). Claude Bernard the scientist. In E. D. Robin (Ed.), *Claude Bernard and the internal environment: A memorial symposium* (pp. 35–41). New York: Marcel Dekker.

Garcia, J., & Koelling, R. A. (1966). Relation of cue to consequence in avoidance learning. *Psychonomic Science*, *4*, 123–124.

Garcia, J., McGowan, B. K., Erwin, F. R., & Koelling, R. A. (1968). Cues: Their effectiveness as a function of the reinforcer. *Science*, *160*, 794–795.

Gardner, H. (1987). *The mind's new science: A history of the cognitive revolution* (paperback ed.). New York: Basic Books.

Gaulin, S. J. C., & Boster, J. S. (1990). Dowry as female competition. *American Anthropologist*, *92*, 994–1005.

Geary, D. C. (1995). Reflections on evolution and culture in children's cognition: Implications for mathematical development and instruction. *American Psychologist*, *58*(1), 24–37.

Giddens, A. (1991). *Introduction to sociology*. New York: Norton.

Gilligan, J. G. (1996). *Violence: Our deadly epidemic and its causes*. New York: Putnam.

Greenough, W. T., & Black, J. E. (1992). Induction of brain structure by experience: Substrates for cognitive development. In M. Gunnar & C. Nelson (Eds.), *Developmental behavioral neurosciences*, Vol. 24: *Minnesota symposia on child development* (pp. 155–200). Hillsdale, NJ: Erlbaum.

Haldane, J. B. S. (1955). Population genetics. *New Biology*, *18*, 34–51.

Hall, S. E. (1997). The future of combinatorial chemistry as a drug discovery paradigm. *Pharmaceutical Research*, *14*(9), 1104–1112.

Hamburger, V. (1975). Cell death in the development of the lateral motor column of the chick embryo. *Journal of Comparative Neurology*, *160*, 535–546.

Hamilton, W. D. (1963). The evolution of altruistic behavior. *American Naturalist*, *97*, 354–356.

Hamilton, W. D. (1964). The genetical evolution of social behavior (Parts 1 & 2). *Journal of Theoretical Biology*, *7*, 1–54.

Hamilton, W. D. (1971). The genetical evolution of social behavior, I. In G. C. Williams (Ed.), *Group selection* (pp. 23–43). Chicago: Aldine. (Reprinted from *Journal of Theoretical Biology*, 1964, *7*, 1–16)

Harrison, C. J. O. (1969). Helpers at the nest in Australian passerine birds. *Emu*, *69*, 30–40.

Hayashi, A. M. (1999, February). Pinker and the brain. *Scientific American*, *280*(2), 32–33.

Hebb, D. O. (1949). *The organization of behavior: A neuropsychological theory*. New York: Wiley.

Hebb, D. O. (1953). Heredity and environment in mammalian behavior. *British Journal of Animal Behaviour*, *1*, 43–47.

Hebb, D. O. (1972). *Textbook of psychology* (3rd ed.). Philadelphia: Saunders.

Herrnstein, R. J., & Murray, C. (1994). *The bell curve: Intelligence and class structure in American life*. New York: Free Press.

Hoagland, M., & Dodson, B. (1995). *The way life works*. New York: Times Books.

Hrdy, S. (1977). *The langurs of Abu*. Cambridge: Harvard University Press.

Huttenlocher, P. R., & Dabholkar, A. S. (1997). Regional differences in synaptogenesis in human cerebral cortex. *Journal of Comparative Neurology*, *367*, 167–178.

James, W. (1880, October). Great men, great thoughts, and the environment. *Atlantic Monthly*, *66* (276), 441–459.

James, W. (1890). *The principles of psychology* (Vol. 1). New York: Holt.

Jaynes, J. (1973). Animate motion in the 17th century. In M. Henle, J. Jaynes, & J. J. Sullivan (Eds.), *Historical conceptions of psychology*. New York: Springer.

Johnston, V. (1999). *Why we feel: The origin and function of human feelings*. Reading, MA: Perseus Books.

Jones, T. A., & Schallert, T. (1992). Overgrowth and pruning of dendrites in adult rats recovering from neocortical damage. *Brain Research*, *581*, 156–160.

Jones, T. A., & Schallert, T. (1994). Use-dependent growth of pyramidal neurons after neocortical damage. *Journal of Neuroscience*, *14*, 2140–2152.

Joravsky, D. (1970). *The Lysenko affair*. Cambridge: Harvard University Press.

Joyce, G. F. (1992, December). Directed molecular evolution. *Scientific American*, *267*(6), 90–97.

Kant, I. (1952). *Critique of judgement*. (*Great books of the Western world*, Vol. 42, pp. 461–613). Chicago: Encyclopaedia Britannica. (Originally published 1790)

Kantovorich, A. (1993). *Scientific discovery: Logic and tinkering*. Albany: State University of New York Press.

Kelsen, H. (1946). *Society and nature: A sociological inquiry*. London: Kegan Paul.

Kenrick, D. T., & Keefe, R. C. (1992). Age preferences in mates reflect sex differences in reproductive strategies. *Behavioral and Brain Sciences*, *15*, 75–133.

Kerferd, G. B. (1967). Aristotle. In P. Edwards (Ed.), *The encyclopedia of philosophy* (Vol. 1, pp. 151–162). New York: Macmillan.

Kihlstrom, J. F. (1987). The cognitive unconscious. *Science*, *237*, 1445–1452.

Köhler, W. (1925). *The mentality of the apes* (2nd rev. ed., E. Winter, Trans.). New York: Harcourt, Brace.

Kohn, A. (1993). *Punished by rewards*. Boston: Houghton Mifflin.

Koshland, D. E., Jr. (1980). *Bacterial chemotaxis as a model behavioral system*. New York: Raven Press.

Koza, J. R. (1992). *Genetic programming: On the programming of computers by means of natural selection*. Cambridge: MIT Press.

Koza, J. R. (1994). *Genetic programming, II: Automatic discovery of reusable programs*. Cambridge: MIT Press.

Laplace, P. S. de. (1902). *A philosophical essay on probabilities* (F. W. Truscott & F. L. Emory, Trans.). New York: Wiley. (Originally published 1814)

Lewontin, R. C., Rose, S., & Kamin, L. J. (1984). *Not in our genes: Biology, ideology, and human nature*. New York: Pantheon.

Lorenz, K. (1981). *The foundations of ethology*. New York: Simon & Schuster.

Løvtrup, S. (1987). *Darwinism: The refutation of a myth*. London: Croom Helm.

Marken, R. S. (1990). Spreadsheet analysis of a hierarchical control system model of behavior. *Behavior Research Methods, Instruments, & Computers*, *22*, 349–359. (Reprinted in Marken 1992, pp. 133–156)

Marken, R. S. (1992). *Mind readings: Experimental studies of purpose*. New Canaan, CT: Benchmark.

Mayr, O. (1970). *The origins of feedback control*. Cambridge: MIT Press.

McClelland, J. L., Rumelhart, D. E., & Hinton, G. E. (1986). The appeal of parallel distributed processing. In D. E. Rumelhart, J. L. McClelland, & the PDP Research Group (Eds.), *Parallel distributed processing: Explorations in the microstructure of cognition, Vol. 1: Foundations* (pp. 3–44). Cambridge: MIT Press.

McCracken, G. F. (1984). Communal nursing in Mexican free-tailed bat maternity colonies. *Science*, *223*, 1090–1091.

McFarland, D. (1993). *Animal behaviour* (2nd ed.). Harlow, Essex: Longman.

McPhail, C., Powers, W. T., & Tucker, C. T. (1992). Simulating individual and collective action in temporary gatherings. *Social Science Computer Review*, *10*(1), 1–28.

Mednick, S. A. (1962). The associative basis of the creative process. *Psychological Review*, *69*, 220–232.

Medvedev, Z. A. (1969). *The rise and fall of T. D. Lysenko* (L. G. Lawrence, Trans.). New York: Columbia University Press.

Miller, G. A., Galanter, E., & Pribram, K. (1960). *Plans and the structure of behavior*. New York: Holt, Rinehart & Winston.

Mrosovsky, N. (1990). *Rheostasis: The physiology of change*. New York: Oxford University Press.

Murdock, G. P. (1967). *Ethnographic atlas*. Pittsburgh: Pittsburgh University Press.

Newell, A. (1990). *Unified theories of cognition*. Cambridge: Harvard University Press.

Nietzsche, F. (1967). *The will to power* (W. Kaufman & R. J. Hollingdale, Trans.). New York: Random House. (Originally published 1901)

Packer, C. (1977). Reciprocal altruism in *Papio anubis*. *Nature*, *265*, 441–443.

Paley, W. (1813). *Natural theology* (14th ed.). London: S. Hamilton.

Perkinson, H. J. (1984). *Learning from our mistakes: A reinterpretation of twentieth-century educational theory*. Westport, CT: Greenwood Press.

Peters, R. S., & Mace, C. A. (1967). Psychology. In P. Edwards (Ed.), *The encyclopedia of philosophy* (Vol. 7, pp. 1–27). New York: Macmillan.

Piaget, J. (1972). *The principles of genetic epistemology* (W. Mays, Trans.). London: Routledge & Kegan Paul. (Originally published 1970)

Piaget, J. (1976). Biology and war. In H. E. Gruber & J. J. Vonèche (Eds.), *The essential Piaget* (pp. 38–41). New York: Basic Books. (Originally published 1918)

Piaget, J. (1976). Equilibration processes in the psychobiological development of the child. In H. E. Gruber & J. J. Vonèche (Eds.), *The essential Piaget* (pp. 832–837). New York: Basic Books. (Originally published 1958)

Piaget, J. (1976). Problems of equilibration. In H. E. Gruber & J. J. Vonèche (Eds.), *The essential Piaget* (pp. 838–841). New York: Basic Books. (Originally published 1975)

Piaget, J. (1976). The various forms of knowledge seen as differentiated organs of the regulation of functional exchanges with the external world. In H. E. Gruber & J. J. Vonèche (Eds.), *The essential Piaget* (pp. 842–859). New York: Basic Books. (Originally published 1967)

Pinker, S. (1994). *The language instinct*. New York: Morrow.

Pinker, S. (1997). *How the mind works*. New York: Norton.

Pinker, S., & Bloom, P. (1990). Natural language and natural selection. *Brain and Behavioral Sciences*, *13*, 707–784.

Plotkin, H. (1994). *Darwin machines and the nature of knowledge*. Cambridge: Harvard University Press.

Plunkett, M. J., & Ellman, J. A. (1997, March). Combinatorial chemistry and new drugs. *Scientific American*, *276*(4), 68–73.

Popkin, R. H. (1967). La Mettrie, J. O. de. In P. Edwards (Ed.), *The encyclopedia of philosophy* (Vol. 4, pp. 379–382). New York: Macmillan.

Powers, W. T. (1973). *Behavior: The control of perception*. Chicago: Aldine.

Powers, W. T. (1989). *Living control systems*. Gravel Switch, KY: Control Systems Group.

Powers, W. T. (1991, February). Skinner's mistake. *Control Systems Group Newsletter*, pp. 7–14.

Powers, W. T. (1995). The origins of purpose: The first metasystem transitions. *World Futures*, *45*, 125–137.

Powers, W. T. (1999). A model of kinesthetically and visually controlled arm movement. *International Journal of Human-Computer Studies*, *50*(6), 463–479.

Powers, W. T., Clark, R. K., & McFarland, R. L. (1960). A general feedback theory of human behavior (Parts 1 & 2). *Perceptual and Motor Skills*, *11*, 71–88, 309–323. (Reprinted in Powers 1989, pp. 1–45)

Proctor, R. A. (1993). Computer stimulated associations. *Creativity Research Journal*, *6*, 391–400.

Pusey, A. E., & Packer, C. (1992). Infanticide in lions. In S. Parmigiani, F. vom Saal, & B. Svare (Eds.), *Infanticide and parental care*. London: Harwood Academic Press.

Quartz, S. R., & Sejnowski, T. F. (1997). The neural basis of cognitive development: A constructivist manifesto. *Behavioral and Brain Sciences*, *20*, 537–596.

Rahn, H. (1979). Acid-base balance and the *milieu intérieur*. In E. D. Robin (Ed.), *Claude Bernard and the internal environment: A memorial symposium* (pp. 179–190). New York: Marcel Dekker.

Reeve, H. K., Westneat, D. F., Noon, W. A., Sherman, P. W., & Aquadro, C. F. (1990). DNA "fingerprinting" reveals high levels of inbreeding in colonies of the eusocial naked mole-rat. *Proceedings of the National Academy of Sciences*, *87*, 2496–2500.

Revusky, S. H., & Garcia, J. (1970). Learned associations over long delays. In G. H. Bower (Ed.), *Psychology of learning and motivation* (Vol. 4, pp. 1–83). New York: Academic Press.

Richards, R. J. (1987). *Darwin and the emergence of evolutionary theories of mind and behavior*. Chicago: University of Chicago Press.

Robertson, R. J., & Powers, W. T. (1990). *Introduction to modern psychology: The control-theory view*. Gravel Switch, KY: Control Systems Group.

Robin, E. D. (1979). Limits of the internal environment. In E. D. Robin (Ed.), *Claude Bernard and the internal environment: A memorial symposium* (pp. 257–267). New York: Marcel Dekker.

Rodgers, W., & Rozin, P. (1966). Novel food preferences in thiamine-deficient rats. *Journal of Comparative Physiological Psychology*, *61*, 1–4.

Rosenblueth, A., Wiener, N., & Bigelow, J. (1943). Behavior, purpose, and teleology. *Philosophy of Science*, *10*, 18–24.

Rosenblueth, A., & Wiener, N. (1950). Purposeful behavior and non-purposeful behavior. *Philosophy of Science*, *17*, 318–326.

Runkel, P. J. (1990). *Casting nets and testing specimens: Two grand methods of psychology*. New York: Praeger.

Russell, E. S. (1945). *The directiveness of organic activities*. London: Cambridge University Press.

Rutherford, S. L., & Lindquist, S. (1998). Hsp90 as a capacitor for morphological evolution. *Nature*, *396*, 336–342.

Schallert, T., & Jones, T. A. (1993). "Exuberant" neuronal growth after brain damage in adult rats: The essential role of behavioral experience. *Journal of Neurotransplantation and Plasticity*, *4*(3), 193–198.

Searle, J. R. (1992). *The rediscovery of the mind*. Cambridge: MIT Press.

Sevenster, P. (1968). Motivation and learning in sticklebacks. In D. Ingle (Ed.), *The central nervous system and fish behavior* (pp. 233–245). Chicago: University of Chicago Press.

Sevenster, P. (1973). Incompatibility of response and reward. In R. A. Hinde & J. Stevenson-Hinde (Eds.), *Constraints on learning: Limitations and predispositions*. London: Academic Press.

Siegler, R. S. (1989). Mechanisms of cognitive development. *Annual Review of Psychology*, *40*, 353–379.

Siegler, R. S. (1996). *Emerging minds: The process of change in children's thinking*. New York: Oxford University Press.

Silverman, I., & Eals, M. (1992). Sex differences in spatial abilities: Evolutionary theory and data. In J. H. Barkow, L. Cosmides, & J. Tooby (Eds.), *The adapted mind: Evolutionary psychology and the generation of culture* (pp. 533–549). New York: Oxford University Press.

Simonton, D. K. (1979). Multiple discovery and invention: Zeitgeist, genius, or chance? *Journal of Personality and Social Psychology*, *37*, 1603–1616.

Simonton, D. K. (1985). Intelligence and personal influence in groups: Four nonlinear models. *Psychological Review*, *92*, 532–547.

Simonton, D. K. (1987). Multiples, chance, genius, creativity, and zeitgeist. In D. N. Jackson & J. P. Rushton (Eds.), *Scientific excellence: Origins and assessment* (pp. 98–128). Beverly Hills, CA: Sage.

Simonton, D. K. (1997). Creative productivity: A predictive and explanatory model of career trajectories and landmarks. *Psychological Review*, *104*(1), 66–89.

Simonton, D. K. (1999a). Creativity as blind variation and selective retention: Is the creative process Darwinian? *Psychological Inquiry*, *10*, 309–328.

Simonton, D. K. (1999b). *Origins of genius: Darwinian perspectives on creativity*. Oxford: Oxford University Press.

Singh, D. (1993). Adaptive significance of female physical attractiveness: Role of waist-to-hip ratio. *Journal of Personality and Social Psychology*, *65*, 293–307.

Singh, D. (1997, June 7). *In search of the most alluring female waist-to-hip ratio: Quantifying female physical attractiveness*. Presented at the annual meeting of the Human Behavior and Evolution Society, Tucson, AZ.

Skinner, B. F. (1948). *Walden two*. London: Collier-Macmillan.

Skinner, B. F. (1953). *Science and human behavior*. New York: Free Press.

Skinner, B. F. (1954). Behaviorism at fifty. In T. W. Wann (Ed.). *Behaviorism and phenomenology: Contrasting bases for modern psychology* (pp. 79–97). Chicago: University of Chicago Press.

Skinner, B. F. (1958). Reinforcement today. *American Psychologist*, *13*, 94–99.

Skinner, B. F. (1971). *Beyond freedom and dignity*. New York: Knopf.

Skinner, B. F. (1974). *About behaviorism*. New York: Knopf.

Slater, P. J. B. (1985). *An introduction to ethology*. Cambridge: Cambridge University Press.

Staddon, J. E. R. (1983). *Adaptive behavior and learning*. Cambridge: Cambridge University Press.

Symons, D. (1979). *The evolution of human sexuality*. New York: Oxford University Press.

Thornhill, R. (1976). Sexual selection and nuptial feeding behavior in *Bittacus apicalis* (Insecta: Mecoptera). *American Naturalist*, *110*, 529–548.

Tolman, E. C. (1932). *Purposive behavior in animals and men*. New York: Century.

Tolman, E. C. (1959). Principles of purposive behavior. In S. Koch (Ed.), *Psychology: A study of a science* (Vol. 2, pp. 92–157). New York: McGraw-Hill.

Trivers, R. L. (1971). The evolution of reciprocal altruism. *Quarterly Review of Biology*, *46*(4), 35–57.

Trivers, R. L. (1972). Parental investment and sexual selection. In B. Campbell (Ed.), *Sexual selection and the descent of man*. Chicago: Aldine.

Tylor, Sir E. B. (1958). *Religion in primitive culture*. New York: Harper & Brothers. (Originally published 1871)

Vidal, F., Buscaglia, M., & Vonèche, J. J. (1983). Darwinism and developmental psychology. *Journal of the History of the Behavioral Sciences*, *19*, 81–94.

Vining, D. R., Jr. (1986). Social vs. reproductive success. *Behavioral and Brain Sciences*, *9*, 167–186.

Waddington, C. H. (1962). *The nature of life*. New York: Atheneum.

Watson, J. B. (1913). Psychology as the behaviorist views it. *Psychological Review*, *20*, 158–177.

Weiner, J. (1994). *The beak of the finch: A story of evolution in our time*. New York: Knopf.

Wiener, N. (1961). *Cybernetics: Or control and communication in the animal and the machine*. Cambridge: MIT Press.

Williams, G. C. (1966). *Adaptation and natural selection: A critique of some current evolutionary thought*. Princeton, NJ: Princeton University Press.

Wilson, E. O. (1975). *Sociobiology: The new synthesis*. Cambridge: Belknap Press of Harvard University Press.

Wilson, E. O. (1978). *On human nature*. Cambridge: Harvard University Press.

Wright, R. (1994). *The moral animal: Evolutionary psychology and everyday life*. New York: Pantheon.

Wundt, W. (1912). *An introduction to psychology* (R. Pinter, Trans.). New York: Macmillan.

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