I. b) ‘Science’ and ‘History’

From Wendell Berry: Life is a Miracle: an Essay Against Modern Superstition.

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Anybody who thinks that this "scientific" reduction of creatures to machines is merely an issue to be pondered by academic intellectuals is in need of a second thought. I suppose that there are no religious implications in this reductionism, for if you think creatures are machines, you have no religion. For artists who do not think of themselves as machines, there is one artistic implication: Don't be mechanical. But the implications for politics and conservation are profound.

It is evident to us all by now that modern totalitarian governments become more mechanical as they become more total. Under *any* political system there is always a tendency to expect the government to work with mechanical "efficiency"—that is, with speed and no redundancy. (Mechanical efficiency always "externalizes" inefficiencies, such as exhaust fumes, but still one can understand the temptation.) Our system, however, which claims freedom as its purpose, involves several powerful concepts that tend to retard the speed and efficiency of government and to make it unmechanical: the ideas of government by consent of the governed, of minority rights, of checks and balances, of trial by jury, of appellate courts, and so on. If we were to implement politically the idea that creatures are machines, we would lose all of those precious impediments to mechanical efficiency in government. The basis of our rights and liberties would be undermined. If people are machines, what is wrong, for example, with slavery? Why should a machine wish to be free? Why should a large machine honor a small machine's quaint protestations that it has thoughts or feelings or affections or aspirations?

It is not beside the point to remember that our government at times has seen fit to look upon the prosperity of many small producers and manufacturers as a political and economic good, and so has placed appropriate restraints upon the mechanical efficiencies of monopolists and foreign competitors. It is not mechanically efficient to recognize that unrestrained competition between an individual farmer or storekeeper and a great corporation is neither democratic nor fair. I suppose that our so-called conservatives have at least no inconsistency to apologize for; they have espoused the "freedom" of the corporations and their "global economy," and they have no conflicting inhibitions in favor of democracy and fairness. The "liberals," on the other hand, have made political correctness the measure of their social policy at the same time that they advance the economic determinism of the conservatives. Reconciling these "positions" is not rationally possible; you cannot preserve the traditional rights and liberties of a democracy by the mechanical principles of economic totalitarianism.

But for the time being (may it be short) the corporations thrive, and they are doing so at the expense of everything else. Their dogma of the survival of the wealthiest (i.e. mechanical efficiency) is the dominant intellectual fashion. A letter to the *New York Times* of July 8, 1999 stated it perfectly: "While change is difficult for those affected, the larger, more efficient business organization will eventually emerge and industry consolidation will occur to the

benefit of the many." When you read or hear those words "larger" and "more efficient" you may expect soon to encounter the word "inevitable," and this letter writer conformed exactly to the rule: "We should not try to prevent the inevitable consolidation of the farming industry." This way of talking is now commonplace among supposedly intelligent people, and it has only one motive: the avoidance of difficult thought. Or one might as well say that the motive is the avoidance of thought, for that use of the word "inevitable" obviates the need to consider any alternative, and a person confronting only a single possibility is well beyond any need to think. The message is: "The machine is coming. If you are small and in the way, you must lie down and be run over." So high a level of mental activity is readily achieved by terrapins.

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The reduction of creatures to machines is in principle directly opposed to the effort of conservation. It is, in the first place, part and parcel of the determinism that derives from materialism. Conservation depends upon our ability to make qualitative choices affecting our influence on the ecosystems we live in or from. Machines can make no such choices, and neither, presumably, can creatures who are machines. If we are machines, we can only do as we are bidden to do by the mechanical laws of our mechanical nature. By what determinism we *regret* our involvement in our mechanical devastations of the natural world has not been explained by Mr. Wilson or (so far as I know) by anybody.

But suppose we *don't* subscribe to this determinism. Suppose we don't believe that creatures are machines. Then we must see

the extent to which conservation has been hampered by this idea, whether consciously advocated by scientists or thoughtlessly mouthed about in the media and in classrooms. The widespread belief that creatures *are* machines obviously makes it difficult to form an advocacy for creatures *against* machines. To confuse or conflate creatures with machines not only makes it impossible to see the differences between them; it also masks the conflict between creatures and machines that under industrialism has resulted so far in an almost continuous sequence of victories of machines over creatures.

To say as much puts me on difficult ground, I know. To confess, these days, that you think some things are more important than machines is almost sure to bring you face to face with somebody who will accuse you of being "against technology"—against, that is, "the larger, more efficient business organization" that will emerge inevitably "to the benefit of the many."

And so I would like to be as plain as possible. What I am against—and without a minute's hesitation or apology—is our slovenly willingness to allow machines and the idea of the machine to prescribe the terms and conditions of the lives of creatures, which we have allowed increasingly for the last two centuries, and are still allowing, at an incalculable cost to other creatures *and to ourselves*. If we state the problem that way, then we can see that the way to correct our error, and so deliver ourselves from our own destructiveness, is to quit using our technological capability as the reference point and standard of our economic life. We will instead have to measure our economy by the health of the ecosystems and human communities where we do our work.

It is easy for me to imagine that the next great division of the world will be between people who wish to live as creatures and people who wish to live as machines.

6. Originality and the "Two Cultures"

If one of the deities or mythological prototypes of modern science is Sherlock Holmes, another, surely, is the pioneering navigator or land discoverer: Christopher Columbus or Daniel Boone. Mr. Wilson's book returns to this image again and again. He says that "Original discovery is everything" (p. 56). And he speaks of "new terrain" (p. 12), "the frontier" (pp. 39 and 56), "the mother lode" and "virgin soil" (p. 56), "the growing edge" (p. 39) and "the cutting edge" (pp. 99 and 201), and "virgin land" (p. 100). He speaks of scientists as "prospectors" (pp. 38 and 56), as navigators who "steer for blue water, abandoning sight of land for a while" (p. 58), and (in several places) as explorers of unmapped territory.

This figure of the heroic discoverer, so prominent in the mind of so eminent a scientist, dominates as well the languages of scientific journalism and propaganda. It defines, one guesses, the ambition or secret hope of most scientists, industrial technologists, and product developers: to go where nobody has previously gone, to do what nobody has ever done.

There is nothing intrinsically wrong with heroic discovery. However, it is as much subject to criticism as anything else. That is to say that it may be either good or bad, depending on what is discovered and what use is made of it. Intelligence minimally requires us to consider the possibility that we might well have done without

Three passages relating to the physics paradigm:

I. "Classical physics": Sir Isaac Newton (from *Opticks*. 1704)

> "God in the Beginning form'd Matter in solid. massy. hard. impenetrable. moveable Particles. of such Sizes and Figures. and with such other Properties. and in such Proportion to Space. as most conduced to the End for which he form'd them: and that these primitive Particles being Solids. are incomparably harder than any porous Bodies compounded of them: even so very hard. as never to wear or break in pieces: no ordinary Power being able to divide what God himself made one in the first Creation."

II. "New Physics:"

1. Max Planck:

> "Consciousness I regard as fundamental. I regard matter as derivative from consciousness. . . everything that we regard as existing postulates consciousness."

2. Henry Stapp. from a paper entitled "Quantum Theory and Human Values" [emphasis added]:

> "According to the orthodox quantum theory of nature. the actual things from which the universe is built are not persisting entitities. as in classical physics. but are rather sudden events called "quantum jumps . . .
>
> 5. About these jumps. or sudden changes in the 'Heisenberg State' of the Universe. "The first basic property . . . is that the selection. or choices. made by these jumps are not controlled by the mathematical laws analogous to the classical laws of motion. Those mathematical laws determine only the probabilities of the various alternative possible choices. they do not determine which . . . will actually be selected.
>
> 6. The second basic property is their non-local character: *the quantum jump is intrinsically a shift of the entire universe.*
>
> The natures of these two properties of quantum jumps induce a profound change in the conception of man's place in the universe. Man can no longer be seen as a deterministically controlled cog in a giant machine . He appears. rather. as an aspect of the fundamental process that gives form and definition to the universe.
>
> 8. The assimilation of this quantum conception of man into the cultural environment of the 21st century must inevitably produce a shift in values conducive to human survival. The quantum conception gives an enlarged sense of self ...[from which] must flow lofty values that extend far beyond the confines of narrow personal self interest."

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Quantum Physics and Human Values *

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Abstract

Address to the UNESCO–sponsored conference: Science and Culture in the 21st Century–Agenda for Survival.

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1. Introduction

Science created the problem addressed by this conference: it gave to man the power to pollute and ravage nature on an unprecedented scale, and to obliterate his species altogether. However, together with this potentially fatal power, science provided a compensating gift, which, though subtle in character, and still hardly felt in the minds of men, may ultimately be the most valuable contribution of science to human civilization, and the key to human survival.

Science is generally recognized as not merely the practical enterprise of subjugating nature to the will of man, but as also a part of man's unending quest for knowledge about the universe, and his place within it. This quest is motivated not solely by idle curiousity. Each of us, when trying to establish values upon which to base conduct, is inevitably led to questions about the universe and man's place within it. This link between the practical question of values upon which to base conduct and the abstract question of man's place in the universe is not just some airy philosophical invention. Concrete examples of the strong effect upon conduct of beliefs about the universe and man's place in it are legion. When the crusaders marched off to the holy land they were sacrificing their comfort, and were prepared to sacrifice their lives, in the name of their beliefs about the universe, its maker, and their place in that universe. When the Christians allowed themselves to be thrown to the lions, rather than uttering a few simple phrases, they were actually sacrificing their lives in the name of beliefs about the universe, and their place within it. The "kamikazes", the "muslim fanatics", and Bruno burning at the stake all bear vivid witness to the fact that no influence upon human conduct, even the instinct for survival itself, is stronger than the values that can be generated by firmly held beliefs about the nature of the universe and man's place within it.

It is sometimes claimed that science says nothing about values; that science can tell us how to obtain that which we value, but necessarily stands mute on the question of what is valuable. That claim is certainly incorrect. Scientific knowledge impacts strongly upon values. Perhaps the most striking example is the impact of scientific knowledge upon the system of values promulgated by the church during the middle ages. That system rested upon a credo about the nature of the universe, its creator, and man's connection to that creator. Science, by rendering that credo unbelievable, deflated the system of values erected upon it. Moreover, it put forth a credo of its own. In that "scientific" credo man was converted from a likeness of god, a spark of the divine creative power, endowed with free-will, to a simple automaton -- to a cog in a giant machine that grinds inexorably along a preordained path in the absolute grip of blind mathematical law.

Gone from this "scientific" picture of man is any rational basis for the notion of one's responsibility for his own acts. Each of us is asserted to be merely a mechanical extension of what existed prior to his birth. Over that prior situation one can have no control. Hence, over whatever emerges, preordained, from that prior situation one can bear no responsibility.

Given this conception of man, the rape of the environment becomes wholly rational. This conception provides no rational basis for any value but self interest. Hence behavior promoting the welfare of others, including future generations, becomes rational only to the extent that such behavior serves ultimately one's own interests. Thus science becomes doubly culpable: it not only gives man the power to destroy the ecosystem, but also denies him the basis of a rational system of values that can motivate sufficient moderation in the use of that power.

The mechanical picture of man described above is the picture presented by the "classical" physics of the seventeenth, eighteenth, and nineteenth centuries. In this century that classical picture has been found to be seriously flawed. Even the basic premises of the classical picture have been shown to be strictly incompatible with various phenomena associated with the atomic constitution of matter. The world is thus necessarily different, and, in fact, necessarily profoundly different, from the picture of it provided by classical physics.

This failure of the classical concepts has led physicists to a new approach to the understanding of nature. The new approach is based upon radically different concepts, and leads to a radically different conception of both the universe and man's place in the universe. The next section describes the main features of the quantum conception of nature; the subsequent section describes the associated quantum conception of man. The final section discusses the impact upon human values of this profound revision of the conception of man.

2. The Quantum Conception of Nature

In approaching the subject of this section the first point to be emphasized is that, strictly speaking, there is *no* quantum conception of nature, in the classical sense of these words. Niels Bohr, the principal architect of the orthodox philosophy of quantum theory, took great pains to make clear the fact that, from this orthodox point of view, the purpose of science in general, and of quantum theory in particular, is not to make claims about the nature of the physical universe itself; it is rather to allow the calculation of expectations pertaining to *results of observations* obtained under specified conditions. The character, or nature, of the universe that causes these expectations to be borne out is, according to this strictly orthodox point of view, not the proper subject matter of science.[1]

The basic reason for adopting this restricted point of view is that the only verifiable assertions about physical systems are, in the final analysis, assertions about observations: assertions about unobservable aspects of the universe are theoretical in character, and intrinsically less secure than testable and extensively tested assertions about results of observations.

The soundness of this orthodox viewpoint is supported today by the fact that there are, currently, three basically different conceptions of the universe that all purport to give the same predictions about observations. Insofar as this is indeed true, and remains true for all conceivable observations, there can be no empirical discrimination between these three radically different pictures of the universe.

This conference is not an appropriate place to describe all three possibilities. I shall discuss here only the "most orthodox" of these three pictures of the universe, namely the one promulgated by Heisenberg. This picture is the one favored by most quantum physicists, and is the one that conforms most closely to the quantum theoretical formalism as it is used in practice. I shall call this conception of nature "the quantum conception", in keeping with its favored status among quantum physicists.

According to this quantum conception of nature, the *actual* things from which the universe is built are not persisting entities, as in classical physics, but are rather sudden events, called "quantum jumps". These jumps are sudden changes in the so-called "Heisenberg state" of the universe. The Heisenberg state is something like the initial state of the classical universe. But whereas the initial state of the classical universe completely determines the well-defined values of all physical quantities for the entire history of the universe, the Heisenberg state determines, basically, only the relative probabilities of its various possible successor states. Thus we have a picture of the universe evolving by a sequence of discrete "quantum jumps", with each successive state determining only the probabilities of its various alternative possible successor states.

Certain Heisenberg states correspond to the fact that certain physical variables have, at some specified time, reasonably well-defined values. However, due to the Heisenberg uncertainty principle, a quantity that is well defined at one time often becomes less well defined as time progresses.

A typical quantum jump is assumed to be such as to make certain particular *macroscopic* qualitities reasonably well defined, at some particular time. Then the whole process of nature can be envisaged as a sequence of events that tends to work against the diffusive tendency induced by the uncertainty principle, and that, in particular, tends to keep the universe always reasonably well defined as regards the values of its *macroscopic*, and hence observable, degrees of freedom.

The laws that govern the probabilities of the quantum jumps are direct analogs of the laws of classical physics. This analogy between the quantum and classical laws ensures that the laws of classical physics will be approximately respected in the "classical" situations where the classical laws are known to work well.

Standing out against this background of events that act mainly to keep the macroscopic world in close accord to the laws of classical physics are the special "quantum-measurement-type" events. These are events that occur following a period in which there has been a great amplification of some atomic-level difference; i.e., in situations where small differences involving only a few "atoms" have become rapidly amplified to produce large differences in macroscopic, and hence directly observable, quantities.

These quantum–measurement–type events are associated, typically, with the quantum measuring devices that are used to study atomic phenomena, and they were the focus of Heisenberg's discussion of the conception of nature being described here. The functioning of these devices depends on the occurrence within the device of precisely the sort of amplification that was described above.

3. The Quantum Conception of Man

The impact of the quantum conception of nature upon the conception of man arises from the apparently close similarity between human brains and quantum measuring devices.[3] The function of a brain is to process various input data in order, first, to formulate some appropriate possible courses of action, next, to select one of the possible courses of action, and, finally, to supervise the execution of this chosen course of action. The mechanism for this processing is based upon the amplification by nerve cells of differences, within synaptic junctions where the nerve cells meet, that involve very small numbers of Ca^{++}ions. The brain process discussed above culminates in the reduction of the state of the brain to a quasi–stable state that supervises the chosen macroscopic response of the organism.

Computer studies[4] at the classical level show a very sensitive dependence of the final quasi–stable state into which the brain evolves upon the parameters that characterize the synaptic junction. Further studies are needed. But it seems likely that the analogy of brains to quantum measuring devices is appropriate, in that, as in quantum measuring devices, the choice of the final macroscopic state will be fixed by a "quantum jump" of the macroscopic system into one of the alternative possible macroscopic states.

If the brain is indeed analogous in this way to a quantum measuring device then the implications as regards man's place in the universe are profound. These implications follow directly from two basic properties of quantum jumps.

The first basic property of quantum jumps, within the quantum conception of nature, is that the selections, or choices, made by these jumps are *not* controlled by the mathematical laws analogous to the classical laws of motion. Those mathematical laws determine only the *probabilities* of the various alternative possible choices, they do not determine which of the various alternative possibilities will actually be selected.

These actual selections are, in fact, logically more akin to the choices of the *initial conditions* of classical physics, in that they stand outside of the mathematically determined process, and yet collectively determine the actual form of the macroscopic universe. The whole sequence of quantum events can thus be regarded as a selective processes that creates, or fixes, the actual form of the universe. However, in the quantum conception of nature this process is a gradual process, rather than, as in classical physics, an instantaneous initial choice that fixes *all at once* the entire history of the universe.

The second basic property of the quantum jumps is their nonlocal character. Each such jump is allowed to be associated in a special way with a local region of spacetime. Thus the quantum jumps that we have previously discussed act to fix either the locations of parts of a measuring device or the state of a human brain. However, each such jump induces also compensating changes in far-flung parts of the universe. The precise forms of these changes are specified by quantum theory, and their structure is such that the quantum jump must be fundamentally nonlocal: the quantum jump is intrinsically a shift of the entire universe, and it extends over all space. One cannot conceive of the quantum jump as simply the effect of the injection of some disturbance, or choice, into a localized region of space. The quantum jump, and the choice it represents, is inherently global in character.

The natures of these two properties of quantum jumps induce a profound change in the conception of man's place in the universe, vis-à-vis the place prescribed by classical physics. Man can no longer be seen as a deterministically controlled cog in a giant machine. He appears, rather, as an aspect of the fundamental process that gives form and definition to the universe. This aspect expresses itself through choices that are controlled by no known law of nature, and, although it expresses itself directly *through* the human body, it is intrinsically and immediately connected to the entire universe, in accordance with precise mathematical forms specified by quantum theory.

4. The Impact Upon Human Values.

The question is now: What impact, if any, does this altered perception of man have upon human values? Does not a completely rational approach still lead one to value only one's own self-interest? Probably so! But this conclusion leads on the the further question: What is the "self" whose interest one values?

Values arise from self-image. Generally one is led by training, teaching, propaganda, or other forms of indoctrination, to expand one's conception of the self: one is taught to perceive the self as an integral part of some social unit such as family, religions group, nation, or the like, and hence to enlarge one's self-interest to include the interest of this unit. In the present context it is not relevant whether this human proclivity for expanding one's self-image is a consequence of a natural malleability, an instinctual tendency, a spiritual insight, or something else. What is important is that we humans do have in fact the capacity to enlarge our image of "self", and that this enlarged self-image can become the basis of a drive so powerful that it becomes the dominant determinant of human conduct, overwhelming every other factor, including even the instinct for personal self-preservation.

Standing opposed to the social forces that work to broaden the concept of self is the force of reason. Reason demands evidence for beliefs. If we seek evidence for beliefs about the nature of the self, in relation to other parts of the universe, then science claims jurisdiction, or at least relevance. Physics represents itself as the basic science. However, physics in its classical form, provides no ground for any extended notion of the self. Each person is simply a localized gathering of atoms temporarily bound together in a quasi-stable configuration. Any notion that the self is basically more than just this collection of atoms, bound together by mathematically determined forces, is seen as a fantasy having no foundation in the empirical facts. Thus reason, acting on the basis of the evidence supplied and interpreted by classical physics, though it can promote an "enlightened" self-interest of the narrowly conceived personal self, provides no ground for any fundamental enlargement of the self. It therefore stands opposed to the social forces.

Transition to the quantum conception of man brings science into alignment with the social forces. Indeed, the scientific evidence, interpreted á la Heisenberg, enlarges the conception of self far beyond the simple ideas promoted by social forces: the self becomes enlarged not simply to an integral part of various social organizations, but to a nonlocalized intrinsic part of the formative process of the universe itself – to an agency that stands outside the grip of all known mathematical laws, and fills, in some small measure, a role akin to that of setting the initial conditions of the universe, a prerogative reserved in classical physics for some agency lying beyond physics.

This quantum conception of man resembles , in certain limited respects, the image set forth in various religions system. Hence it may be able to tap the powerful resonances evoked in humans by such beliefs. However, unlike those earlier beliefs, the quantum conception is in no way contrary to the evidence of science, but rather arises, almost automatically, from the most widely accepted conception of the universe compatible with the findings of modern science.

The assimilation of this quantum conception of man into the cultural environment of the 21st century must inevitably produce a shift in values conducive to human survival. The quantum conception gives an enlarged sense of self as architect of the universe. From such a self-image must flow lofty values that extend far beyond the confines of narrow personal self interest. The quantum conception, being based on scientific evidence available equally to all men, rather than arising from special historical situations peculiar to, and exploited by, particular social groups, has the potential of providing a universal system of values available and suitable to all men , without regard to the accidents of their origins. With the diffusion of this quantum conception of man science will have fulfilled itself by adding to the material benefits it has already provided to man a philosophical insight of perhaps even greater value.

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How to be in two places at one time

Quantum theory has some bizarre implications for the nature of reality which physicists have ignored for half a century in the hope that they might go away. Recent experiments have shown that the world really is as strange as quantum theory suggests

Nick Herbert

QUANTUM theory is the conceptual basis for computer chips, lasers and nuclear power plants, among other things. It has been flawlessly successful at all levels accessible to measurement. And yet, although physicists from London to Leningrad agree on how to use this theory, they disagree profoundly over what it means. After more than 60 years of controversy, there is still no scientific consensus on how to picture the "quantum reality" which underlies the everyday world.

Although he was one of its founding fathers, Albert Einstein was never comfortable with quantum theory. Most people remember that he objected to the fact that the predictions of quantum theory are fundamentally random. "I cannot believe," he said, "that God would play dice with the Universe". Randomness, however, was not the only feature of quantum theory that bothered Einstein. He could not accept the orthodox viewpoint that atoms, electrons, photons and all such quantum entities exist only when they are observed. They do not possess attributes of their own, but acquire them only in the act of observation. "I cannot imagine," he said, "that a mouse could drastically change the Universe by merely looking at it. . . . The belief in an external world independent of the perceiving subject," Einstein maintained, "is the basis of all natural science".

"Atoms are not things," retorted Werner Heisenberg, one of the founders of the orthodox view. Heisenberg compared "thing-nostalgic" physicists like Einstein to believers in a flat Earth. "The hope that new experiments will lead us back to objective events in time and space," said Heisenberg, "is about as well founded as the hope of discovering the end of the world in the unexplored regions of the Antarctic".

Einstein could perhaps have learned to live with these features of quantum theory. Sixty years of practical success have gradually accustomed most physicists to its randomness and thinglessness (or at least persuaded them not to think too deeply about these puzzles). But Einstein objected most strongly to a third peculiar aspect of quantum theory: the fact that, when two quantum entities, A and B, briefly interact and then move apart beyond the range of conventional interactions, quantum theory still does not describe them as separate objects, but continues to regard them as a single entity. If one takes seriously this feature, called "quantum

inseparability", then all objects which have once interacted are in some sense still connected.

Moreover, this lingering quantum connection is "non-local". Unlike gravity or electromagnetism, it is not mediated by fields of force, but simply jumps from A to B without ever being in between. Because nothing really crosses the intervening space, no amount of interposed matter can shield a non-local connection. Since non-local connections do not actually stretch across space, they do not diminish with distance. They are as potent at a million miles as at a millimetre. Just as a non-local connection takes up no space, so it likewise takes up no time. A non-local influence leaps between A and B immediately, faster than light. For some observers, as a consequence of Einsteinian relativity, this instantaneous connection appears to go backwards in time, a performance peculiar by any standards.

This sounds more like magic than solid science. Voodoo practitioners, for example, work in a world criss-crossed with non-local connections. By acting on a part—something a person once touched or wore—they believe they can influence at a distance the whole man, in a manner unmediated and immediate. Whatever witchdoctors may think, physicists from Galileo to Gell-Mann have unanimously rejected such voodoo-like place-to-place leaps as a basis for explaining what goes on in the world.

In the early 1930s, the Austrian physicist Erwin Schrödinger was particularly fascinated by quantum inseparability. He called it quantum theory's most distinctive feature, the place where quantum theory deviates most from classical expectations. Quantum inseparability, with its unsavoury non-local connections, undoubtedly exists mathematically in the quantum formalism, Schrödinger conceded. But do these connections actually exist in the real world? Einstein's special theory of relativity forbids all faster-than-light signals, so we can be reasonably sure that if non-local connections really exist they cannot be used for sending signals.

Since it postulates pure randomness at the heart of things, quantum theory renounces precise predictions and gives only the probabilities of the outcomes of a particular experiment. Actual calculations show that even though quantum theory is connected non-locally inside, these connections never get out to the level of quantum probabilities—the only aspect of quantum theory that can be put to direct test. Any measurable influence, in terms of transmission of information, still travels at the speed of light or slower. Thus despite its non-locality, quantum theory does not predict a single non-local effect—as Philippe Eberhard, of the University of California at Berkeley first showed. In line with quantum theory's perfect predictive success, no non-local connections have ever been observed, either in the wild or in the laboratory. The perfect locality of all quantum predictions suggests that non-local connections are a theoretical artifact with no more reality than the dotted lines that outline the constellations on star maps.

All experiments at the quantum level result ultimately in discrete events—a flash, click, bubble, or pulse in some detector. In common with other statistical theories, quantum

In 1964, John Bell finally proved that reality is every bit as strange as quantum mechanics had predicted. Some people, such as David Bohm (right), find this situation easier than Einstein did theory does not deal with individual events but with patterns—average values—of individual events. Because they are the very bricks from which all phenomena are constructed, I shall call these individual events "real events", or simply "reality", a usage initiated by Einstein.

Since Eberhard's result requires that all statistical averages should be locally connected, one might reasonably expect that each of the individual real events which make up these averages would also be locally connected. John Stewart Bell, of the European centre for particle physics, CERN, achieved the remarkable feat of showing that such a reasonable expectation is impossible to fulfil. Although the quantum averages are local for all systems, for certain quantum-inseparable systems these averages cannot be simulated by locally-connected real events. Bell's theorem proves, in short, that reality must be non-local, but at a level beneath detection in terms of the usual statistical measurements.

Bell proved this theorem for a particular experimental set-up, involving two photons rendered quantum-inseparable (in their mathematical representation, at least) by virtue of being emitted from the same calcium atom. This type of two-particle system was first considered by Albert Einstein and his Princeton colleagues, Russian-American Boris Podolsky, and Brooklyn-born Nathan Rosen. The intent of Einstein, Podolsky, and Rosen (EPR) was to attack the orthodox "thinglessness" interpretation—the doctrine that unobserved quantum entities do not possess intrinsic attributes called "elements of reality" by Einstein. EPR originally considered a pair of particles with correlated momenta, but their argument (and Bell's subsequent proof) is more easily understood in terms of two photons with correlated polarisations, a system first suggested by David Bohm, of Birkbeck College, London.

In Bohm's version of the experiment, a calcium atom emits a pair of photons which, for the sake of clarity, we will label "blue" and "green". They travel in opposite directions to two calcite crystals where they are deflected either up or down. Calcite is a transparent mineral which bends light polarised along its optic axis up, and bends light polarised at right angles to its axis down.

Three facts sum up the behaviour of Bohm's version of EPR (opposite):

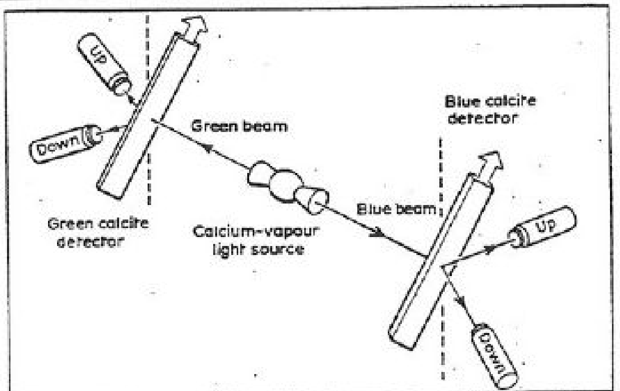
- Each crystal's output is always 50/50 random, with half the photons polarised "up" and half "down".
- When crystals are aligned, blue output is identical to green for every pair of photons emitted.
- When crystals are misaligned, the fraction of identical events is observed to decrease with angle Θ between calcite axes like $\cos^2\Theta$.

These facts remain true no matter how far the blue and green calcite/detectors are from the light source or from one another.

EPR's argument that a photon possesses intrinsic attributes is based on the fact that there is perfect correlation when crystals are aligned—plus the assumption (which seemed reasonable to everyone in 1935) that the real events occurring at the blue and green detectors are locally connected, so that no connections tie them together faster than light.

The assumption of locality means that something done to one system cannot influence the behaviour of another if the systems are so far apart that a light signal cannot connect them. In particular, how the green photon's calcite is set when traversed by its photon cannot affect the blue photon's "decision" (to go up or down) as it traverses its calcite. Since these photons are travelling back-to-back, each at the speed of light, and we can set the green calcite at the last instant, information concerning green's setting could influence blue's decision only if it travelled faster-than-light.

Einstein ridiculed the notion that non-local quantum influences might really exist, calling such influences "spooky" and "telepathic". EPR developed their argument as follows: Move the green calcite/detector close to the source so that it triggers first. Now we know that when the blue calcite is aligned at the same angle as the green, then the blue photons will exactly mimic the behaviour of the green photons. So we can predict with certainty the polarisation of the blue photon at any angle by setting the green calcite at that angle. If the green photon goes up or down, then the blue photon will do likewise. But, by the locality assumption, each blue photon's real situation cannot be influenced by the setting of the green calcite, so the blue photon must already possess a definite polarisation before it hits its calcite crystal and is actually observed. EPR conclude that here is an unobserved quantum entity—the blue photon—that possesses a definite attribute: its polarisation in a particular direction.



David Bohm's version of the celebrated experiment first dreamt up by Einstein, Podolsky and Rosen

Einstein, Podolsky and Rosen's original four-page paper triggered hundreds of articles on the "EPR paradox", none of which either refuted the argument nor shed further light on the alleged intrinsic attributes of the photon. In 1964 the EPR stalemate was broken by John Bell who proved that the locality assumption is untenable. Bell's theorem is most easily understood by construing the series of real events at each calcite/detector as a "message"—a particular binary sequence of Us and Ds, marks on a data tape. When both calcites are aligned, these messages are identical: no errors. When the calcites are misaligned, the messages diverge: errors creep in.

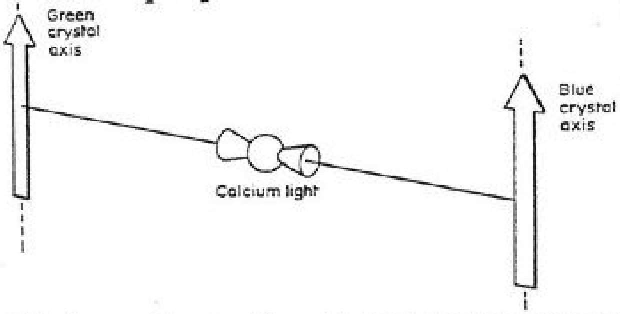
Start with both calcites aligned. Now consider the angle α for which the errors are 25 per cent (1 in 4). Whenever you move either calcite by α degrees, in either direction, one error bit appears, on average, in every four data marks. When you move the calcite back, these errors all disappear. The proof of Bell's theorem begins with the locality assumption—that moving the green calcite can change only the green mark. Locality means that green's move cannot change blue's mark.

Move blue calcite by α degrees: errors are 25 per cent (1 in 4). Return blue calcite: errors vanish. Move green calcite by $-\alpha$ degrees: errors are 25 per cent (1 in 4). Return green calcite: errors vanish. Now move both calcites by α degrees (in opposite directions). Calcites are now misaligned by 2α degrees. What is the new error rate?

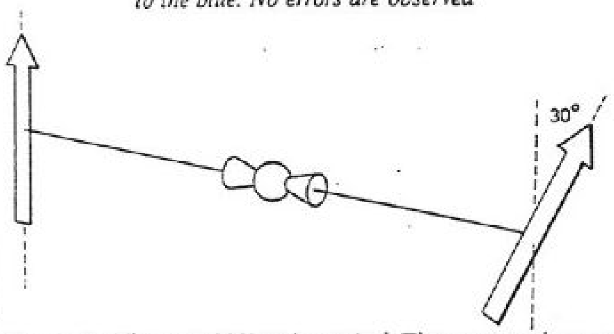
Since moving the blue calcite puts 1 in 4 errors in blue marks, and moving the green calcite puts 1 in 4 errors in green marks, we might hastily conclude that moving both calcites would produce 2 total errors in 4 marks. But this argument neglects the possibility that a few blue errors might cancel green errors, leading to a rematch. Allowing for such accidental error-correction, the locality assumption predicts that when the calcites are misaligned by 2α degrees the error-rate will be no more than 2 errors in 4 marks—that is, in the range of 0-50 per cent. This prediction, a direct consequence of the locality assumption, is an example of a "Bell inequality".

For calcium light, the angle for which the error rate equals 25 per cent is 30°. Hence the Bell inequality predicts an error

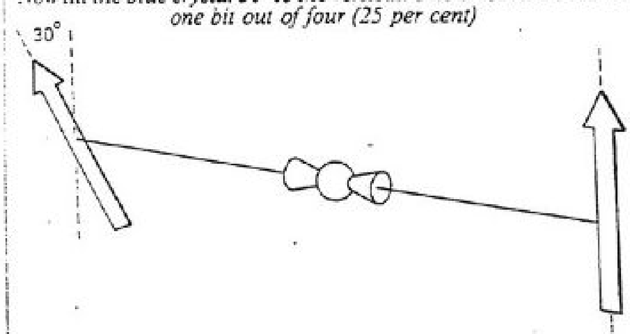
A simple proof of Bell's theorem



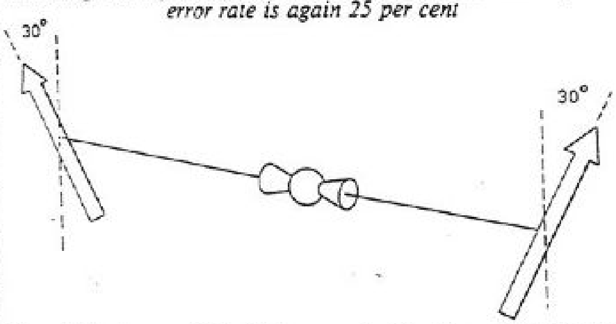
In the first case, illustrated above, the green crystal is oriented in the same direction as the blue. The green "message" is identical to the blue. No errors are observed



Now tilt the blue crystal 30° to the vertical. The error rate becomes one bit out of four (25 per cent)



Tilt the green crystal by minus 30° (with the blue vertical). The error rate is again 25 per cent



Now tilt both crystals by 30° in opposite direction so that the total misalignment is now 60°. What is the error rate? If we believe in locally connected real events, the error rate should be fewer than 2 out of 4 (0-50 per cent). The quantum prediction is an error rate of 3 out of 4 (75 per cent). This is what is actually observed

We have to conclude that no local model of how the events are produced can explain the observed variation of error bits with calcite angle. Hence, for this experiment, reality must be non-local. Even if quantum theory is one day supplanted by a better one, the experimental facts still show that the locality prediction is in error. □

rate of no more than 50 per cent at 60°. However, quantum theory predicts, and experiment confirms, an actual error rate of 75 per cent at 60°. This experimental result generously violates the Bell inequality. Hence the locality assumption is wrong.

Bell's theorem proves that, for these correlated pairs of photons, a local reality, with no influences travelling faster than light, cannot explain the experimental facts. Bell's result shows that the much-dreaded non-local connections are present not merely in the quantum formalism but in the real world. These connections exist, however, not at the level of quantum averages, but at the level of individual quantum events. This discovery of the necessary non-locality of real events resolves the Einstein-Podolsky-Rosen paradox, in Bell's words, "in the way Einstein would have liked the least".

Bell proved his theorem in 1964, by showing that the predictions of quantum mechanics violate the Bell inequality. But no one had measured the quantum facts at that time. Within a few years, however, John Clauser and Stewart Freedman at Berkeley actually performed the experiment and showed that Bell's inequality was violated. Important variations on the experiment were carried out by Clauser and others, culminating in the delicate work of Alain Aspect and his colleagues in Paris, in the early 1980s (*Physical Review Letters*, vol 49, p 1804).

These experiments are important because they show that not only is Bell's inequality (locality) violated by quantum theory, it is also violated by quantum fact. Though it originated in disputes about "quantum reality", Bell's theorem is actually more general than quantum theory. Someday, quantum theory may fail, joining caloric, ether and phlogiston in the junkyard of physics. But because it is based only on facts and arithmetic, Bell's theorem is here to stay.

Bell's theorem was originally formulated in terms of "hidden variables", hypothetical attributes of unobserved quantum systems. But in the past two decades Bell's theorem has been generalised by Bell himself, Clauser, Eberhard, and another physicist at Berkeley, Henry Stapp. Bell's theorem can be formulated entirely in terms of macroscopic phenomena—marks on a data tape; moves of a calcite crystal—with no reference whatsoever to the attributes of hypothetical microentities. In its thoroughly macroscopic form, Bell's theorem requires blue's mark to be linked non-locally to green's move. Bell's theorem now takes non-locality out of the inaccessible microworld and locates it squarely in the everyday world of calcites, cats, and bathtubs.

Bell's demonstration of the necessity of non-local connections raises the question of whether we can use these connections to send signals faster than light. Many ingenious attempts have been made to exploit the EPR set-up to send such messages, but all have failed. What blocks attempts at faster-than-light telegraphy is the uncontrollable randomness of real quantum events. One may move the green calcite and change the blue sequence faster than light, but on close inspection one succeeds only in exchanging one inscrutable random sequence for another. Howsoever green's calcite is set, blue's sequence of data is always 50/50 random.

Special relativity prohibits all signals that travel faster than light. Because the non-local connections are uncontrollable, they cannot be used for signalling, so they evade this relativistic prohibition. These Bell-mandated connections are not open to human manipulation, but are private lines accessible to nature alone.

To me, Bell's theorem suggests an alien design-sense loose in the Universe. We live in a world that seems strangely overbuilt. Why, for instance, does nature need to deploy a faster-than-light subatomic reality to keep up merely light-speed macroscopic appearances? □

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The New Biology

Discovering the Wisdom in Nature

ROBERT AUGROS & GEORGE STANCIU

Illustrations by Michael Augros

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Introduction

In the first quarter of this century, relativity and quantum physics demonstrated the limits of Newtonian mechanics. These momentous innovations transformed forever the science of physics. Parallel events have yet to occur in the life sciences, however. Biologist Edmund Sinnott, for example, acknowledges the modern progress in his field but notes that "there has been no revolution here as that which shook the physical sciences so profoundly."[1] Physicist Henry Margenau agrees: "Biologists have not yet experienced the transcendental leaps beyond customary ideas which Einstein and Heisenberg forced physicists to take."[2] For the most part, contemporary biology is still working within the paradigm of Newtonian mechanics. As biologist Ludwig von Bertalanffy puts it, "Today biology is still in its pre-Copernican period."[3]

At the turn of the century, who could have suspected that some of the most fundamental assumptions of physics were about to be reversed, that the very concepts of matter, gravity, time, and space—all things taken for granted everywhere and hardly ever reflected on—would soon be radically modified? Today, mounting evidence calls for a revision of the most fundamental principles in the life sciences, including the definition of life, how biology relates to the other sciences, the role of evolution in biology, the place of man in nature, what is meant by a scientific explanation, and the very concept of nature.

The search for a new paradigm has already begun in some disciplines. Bertalanffy comments: "The numerous attempts appearing today to find a foundation for theoretical biology point to a fundamental change in the world picture which is taking place now that the view based on the classical physics has reached its limits."[4] Current upheavals in evolutionary theory illustrate the point: conventional Darwinian mechanisms are under attack. Steven Stanley, paleobiologist of Johns Hopkins University: "Today the fossil-record is forcing us to revise this conventional view."[5] Even the synthetic theory of evolution developed by Ernst Mayr and others is being severely criticized from within biology. Paleontologist Stephen Jay Gould of Harvard declares, "The synthetic theory ... as a general proposition, is effectively dead, despite its persistence as textbook orthodoxy."[6] But if evolution is the single theory that unifies all biology, any major revision in it would require a readjustment in virtually every biological science and a reassessment of the whole framework of the life sciences.

In addition, within the past few decades several new fields have arisen in biology, some of them yielding profound discoveries that do not fit into the Newtonian program. For example, the modern science of animal behavior, founded in the 1930s by Konrad Lorenz, Niko Tinbergen, and Karl von Frisch, is not based on the machine models of classical physics. Similarly, several ecologists, including Daniel Simberloff and Paul Colinvaux, are challenging the notion that nature is a competitive struggle.

In this context, Mayr has declared, "It is now clear that a new philosophy of biology is needed."[7] Our goal in the present book is to make a contribution toward formulating the new biology, by unifying and synthesizing the work already done in disparate fields and supplementing it with our own work, using the new physics as a guide throughout. For example, the revolutions of relativity and quantum theory forced physics to outgrow the narrow confines of mechanism. In some areas of current biology mechanical models work beautifully, but in others they fail miserably. We shall carefully distinguish between these areas and, where necessary, suggest alternatives to the mechanistic approach.

Though self-contained, this book is the second in a series. It continues and further develops the same themes as our previous work, *The New Story of Science*, in which we examine the origins of the new world view in physics and neuroscience. The present work is not a comprehensive survey of general biology, nor does it treat exhaustively even those subjects it touches on. Our intention is merely to outline, by examples, arguments, and expert testimony, the contours of the new paradigm for biology, illustrating its implications in a few key areas. We hope this will prove useful both to the biologist and to the nonbiologist.

Finally, it is impossible in one volume to give the reader an adequate notion of life's vastness and overwhelming splendor. If our meager representation at least intimates these qualities of nature

and perhaps evokes the reader's wonder, we shall consider our efforts successful. We apologize to Mother Nature, as it were, for our inability to do justice to her richness, her beauty, and her wisdom.

1

Physics As the Paradigm

Most biologists today consider biology to be an extension of physics. Biologist Peter Medawar writes: "Biology is not 'just' physics and chemistry, but a very limited, very special and profoundly interesting part of them. So with ecology and sociology."[1] Biologist E. H. Mercer agrees: "Most scientists in practice behave as if they believed that only matters of convenience or convention separate physics from biology; or to put it another way, they act on a belief that there is really only one science."[2]

This view rests on the argument that science is analysis and analysis requires the resolution of a subject into its simplest elements. Such a procedure generates a scheme that relates the sciences to each other (see Figure 1.1).[3] Within this scheme, the laws that govern crowds, classes of persons, and societies are based on the qualities and characteristics of the individual. The causes of an individual's actions arise from anatomy, physiology, and the biochemistry of brain mechanisms. These subjects are in turn resolvable to the laws of chemistry and physics. This process of analysis finally stops with high-energy physics, which studies the ultimate particles.

Mercer assigns the origin of this scheme for the sciences: "Inevitably the idea spread that all the sciences could be brought together and integrated in terms of particle dynamics using Newtonian methods, and a universal scientific materialism came into being."[4] According to the materialist program, once the simplest particles are reached, all else can be understood by composition. Physicist Heinz Pagels writes:

"In its crudest form, material reductionalism maintains that there is a series of levels. At the bottom level are the subatomic particles, and from these the chemical properties of atoms and molecules are obtained. Molecules form living and nonliving things, and from the behavior of molecules and cells it is possible to determine the behavior of individual humans. They in turn establish a social order and institutions. Finally at the top level of the ladder are historical events. The claim is that in principle, history is materially reducible to subatomic events."[5]

Because the principles of physics have universal application in living and nonliving things, the other natural sciences are thought to be connected to physics by deduction. Mercer speaks of "the prevailing view that biology is a derived science whose principles can be deduced from the basic laws of physics and chemistry."[6]

This schema is as old as modern science itself; Descartes affirms that all disciplines are really one continuous science: "Philosophy as a whole is like a tree whose roots are metaphysics, whose trunk is physics, and whose branches, which issue from this trunk, are all the other sciences. These reduce themselves to three principal ones, viz., medicine, mechanics, and morals."[7] Descartes proposes this conception of the sciences together with a completely mechanistic account of living things. Speaking of the motion of the blood and of local motion in animals, he says, "The laws of mechanics ... are identical with those of Nature."[8] Hobbes also resolves politics and psychology to physics.[9] And later the British Royal Society was founded with the same program in mind. Its first secretary, Henry Oldenburg, describes the Society in a letter to Spinoza:

"In our Philosophical Society we indulge, as far as our powers allow, in diligently making experiments and observations, and we spend much time in preparing a History of the Mechanical Arts, feeling certain that the forms and qualities of things can best be explained by the principles of Mechanics, and that all the effects of Nature are produced by motion, figure, texture, and the varying combinations of these."[10]

Newton gave new impetus to the mechanistic program and laid its foundation in physics. Without Newton's laws of motion the program would have been just a dream. In the preface to his *Principia*, Newton speaks of the ideal of the mechanistic program: "I derive from the celestial phenomena the forces of gravity with which bodies tend to the sun and the several planets. Then from these forces, by other propositions which are also mathematical, I deduce the motions of the planets, the comets, the moon, and the sea. I wish we could derive the rest of the phenomena of Nature by the same kind of reasoning from mechanical principles, for I am induced by

many reasons to suspect that they may all depend upon certain forces by which the particles of bodies, by some causes hitherto unknown, are either impelled toward one another and cohere in regular figures, or are repelled and recede from one another."[11]

Pursuing Newton's ideal, mathematician Pierre Laplace enunciated the logical consequence of atomic determinism: "An intelligence, which at a given moment knew all of the forces that animate nature, and the respective positions of the beings that compose it, and further possessing the scope to analyze these data, could condense into a single formula the movement of the greater bodies of the universe and that of the least atom: for such an intelligence nothing could be uncertain, and past and future alike would be before its eyes."[12]

The mechanistic program persists today, not in physics, but in biology, psychology, and the social sciences. The difficulty of applying it to particulars in these areas is attributed to the complexity of the Laplacian calculation, not to any inherent flaw in the program itself. Mercer writes: "The sheer magnitude of the reductionist proposal is not an objection to its validity; in fact no one seriously believes it can or will be carried out—indeed it may be beyond us; a demonstration of its theoretical possibility, it is felt, would suffice to establish its truth in principle. The insistence that all biology, psychology, sociology, and history be interpreted deterministically has stimulated an enormous amount of research and continues to influence both private, scientific, and even national policies."[13]

There have been many famous attempts to implement the mechanistic program in various disciplines. In economics Malthus clearly uses a mechanical model taken from physics. He writes that in economics we must "consider man as he really is, inert, sluggish, and averse from labour unless compelled by necessity."[14] This is a paraphrase of Newton's first law of motion: "Every body continues in its state of rest ... unless it is compelled to change that state by forces impressed upon it."[15] Malthus conceives man after the manner of a Newtonian mass, adding, "The first great awakeners of the mind seem to be the wants of the body.... The savage would slumber for ever under his tree unless he were roused from his torpor by the cravings of hunger or the pinchings of cold." Most people, he says, need "stimulants to exertion."[16] The model is from mechanics: Man is an inert mass that must be activated by external forces.

Karl Marx attempts a similar materialistic scheme to account for all human activities: "In the social production which men carry on they enter into definite relations that are indispensable and independent of their will; these relations of production correspond to a definite stage of development of their material powers of production. The sum total of these relations of production constitutes the economic structure of society—the real foundation, on which rise legal and political superstructures and to which correspond definite forms of social consciousness. The mode of production in material life determines the general character of the social, political, and spiritual processes of life. It is not the consciousness of men that determines their existence, but, on the contrary, their social existence determines their consciousness."[17]

Freud models his psychology on mechanistic biology. He begins with an assumption that "mental processes are essentially unconscious,"[18] the unconscious being an uncontrollable mechanical force. It follows that "man is a creature of weak intelligence who is ruled by his instinctual wishes."[19] The mechanical model is evident when Freud speaks of "the premises upon which psychoanalysis rests—the existence of unconscious mental processes, the special mechanisms which they obey, and the instinctive propelling forces which are expressed by them."[20] And he argues that there is an aggression instinct in man by using "biological parallels."[21]

Behaviorism, in attempting to resolve all human behavior to biological factors or conditioning, makes the sharpest denial of man's agency. B. F. Skinner: "A scientific analysis of behavior must, I believe, assume that a person's behavior is controlled by his genetic and environmental histories rather than by the person himself as an initiating, creative agent; but no part of the behavioristic position has raised more violent objections. We cannot prove, of course, that human behavior as a whole is fully determined, but the proposition becomes more plausible as facts accumulate."[22]

Though controversial and unprovable, determinism appears to be the only available scientific approach to man. This leads Skinner to a denial of consciousness in man, a denial even more radical than Freud's: "Mental life and the world in which it is lived are inventions. They have been invented on the analogy of external behavior

occurring under external contingencies. Thinking is behaving. The mistake is in allocating the behavior to the mind."[23]

Malthus, Marx, Freud, and Skinner agree on one thing: man is not an agent in his own right, but is acted upon by inner and outer forces beyond his control. In the full rigor of the mechanistic scheme, man cannot act for a conscious purpose.

Zoologist Edward Wilson attempts to implement part of the schema in Figure 1.1 by resolving social behavior to biological principles through what he calls "the new discipline of sociobiology, defined as the systematic study of the biological basis of all forms of social behavior, in all kinds of organisms, including man."[24] Wilson expects in the future that "the mind will be more precisely explained as an epiphenomenon of the neuronal machinery of the brain."[25] He describes how the more basic disciplines will absorb the derivative ones:

"The discipline abuts the antidiscipline; the antidiscipline succeeds in reordering the phenomena of the discipline by reduction to its more fundamental laws; but the new synthesis created in the discipline profoundly alters the antidiscipline as the interaction widens. I suggested that biology, and especially neurobiology and sociobiology, will serve as the antidiscipline of the social sciences. I will now go further and suggest that the scientific materialism embodied in biology will, through a reexamination of the mind and the foundations of social behavior, serve as a kind of antidiscipline to the humanities."[26] Thus, "having cannibalized psychology, the new neurobiology will yield an enduring set of first principles for sociology."[27]

Lastly, ethologist Richard Dawkins, in *The Selfish Gene*, proposes that man is not a cause but an effect, and that life and mind are merely the outcome of genes that "swarm in huge colonies, safe inside gigantic lumbering robots, sealed off from the outside world, communicating with it by tortuous indirect routes, manipulating it by remote control. They are in you and in me; they created us, body and mind; and their preservation is the ultimate rationale for our existence. They have come a long way, those replicators. Now they go by the name of genes, and we are their survival machines."[28]

There have been many other attempts to implement the mechanistic scheme of the sciences, but the above illustrate the program with some of its expectations and consequences. When a biologist

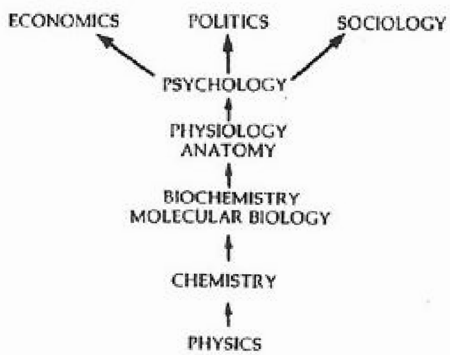

Figure 1.1. The materialistic scheme of the sciences. The sciences are seen as studying various structures and properties of matter. Biology investigates those particular arrangements of matter that cause living phenomena; psychology, politics, and sociology examine the behavior that results from the configurations matter takes in the human brain. All sciences are conceived to be ultimately reducible to physics.

seeks to make his science an extension of physics, it pertains to the physicist to judge whether the attempt is well advised. But physicists long ago passed judgment on the mechanistic program within physics itself. Einstein wrote: "Science did not succeed in carrying out the mechanical program convincingly and today no physicist believes in the possibility of its fulfillment."[29]

Nevertheless the mechanistic program is still pursued in biology. Physicist Henry Margenau: "It is still widely believed that a complete

knowledge of physics, chemistry, and biology will ultimately explain the phenomena of life and account for consciousness and the mind. The later are said to 'reduce' to the former when all details are understood. Reductionism is the philosophy that affirms this view. Its simplest form is materialism, the doctrine asserting that all human experience is ultimately understandable in terms relating to physics of matter, more specifically the theories of prequantum physics."[30]

This belief creates an incongruity between contemporary physics and the life sciences. Zoologist William Thorpe: "Physicists are implying that, fundamentally and in its totality, inanimate matter is not mechanical; whereas molecular biologists are saying that whenever matter is recognized as being alive, it is completely mechanical (that is, it is reducible to a rather superficial nineteenth-century type of physical chemistry).... [Physicist David] Bohm issues a timely warning that molecular biologists should consider the fact that, in the nineteenth century, physics theories were far more comprehensively and accurately tested than is possible for current theories of molecular biology. Despite this, classical physics was swept aside and overturned, being retained only as a simplification and approximation valued in a certain limited macroscopical domain. It is not improbable that molecular biology, undoubtedly magnificent though its achievements are, will sooner or later undergo a similar fate."[31]

The mechanistic model in biology does break down at the most basic level. Physicist Freeman Dyson explains: "Every student of molecular biology learns his trade by playing with models built of plastic balls and pegs. These models are an indispensable tool for detailed study of the structure and function of nucleic acids and enzymes. They are, for practical purposes, a useful visualization of the molecules out of which we are built. But from the point of view of a physicist, the models belong to the nineteenth century. Every physicist knows that atoms are not really little hard balls. While the molecular biologists were using these mechanical models to make their spectacular discoveries, physics was moving to a quite different direction.

"For the biologists, every step down in size was a step toward increasingly simple and mechanical behavior. A cell is more mechanical that a bacterium. But twentieth-century physics has shown that further reductions in size have an opposite effect. If we divide a DNA molecule into its component atoms, the atoms behave less mechanically than the molecule. If we divide an atom into nucleus and electrons, the electrons are less mechanical than the atom."[32]

The failure of the mechanistic program in physics ushered in a new world view. Physicist Richard Feynman declares that if you believe that atoms are like little solar systems, "then you are back in 1910."[33] The same profound changes open the possibility today for a new biology. The entire mechanistic scheme rests on Newton and presupposes a certain conception of matter. Newton describes the ultimate particles of matter as "massy, hard, impenetrable, moveable particles of [various] sizes and figures." He assigns the properties of these particles as "extension, hardness, impenetrability and inertia."[34] We note that atoms are imagined as existing in the same manner as large bodies like apples or billiard balls.

The new understanding of matter is dramatically different. The most profound innovations came from quantum physics. Werner Heisenberg: "It is true that quantum theory is only a small sector of atomic physics and atomic physics again is only a very small sector of modern science. Still it is in quantum theory that the most fundamental changes with respect to the concept of reality have taken place, and in quantum theory in its final form the new ideas of atomic physics are concentrated and crystallized."[35] After years of experiment and analysis it was discovered that "it was not possible to formulate the laws of quantum mechanics in a fully consistent way without reference to the consciousness," in the words of Eugene Wigner.[36] This is called the principle of observership. Max Born defines it more completely: "No description of any natural phenomenon in the atomic domain is possible without referring to the observer, not only to his velocity as in relativity, but to all his activities in performing the observation, setting up instruments, and so on."[37]

Dyson amplifies the point: "When we are dealing with things as small as atoms and electrons, the observer or experimenter cannot be excluded from the description of nature.... The laws of subatomic physics cannot even be formulated without some reference to the observer.... The laws leave a place for mind in the description of every molecule."[38]

This new understanding of matter does not lead to universal

skepticism or relativism since the contribution of the observer is significant only at the smallest scale where "observing" the particle necessarily means doing something to it. Weizsäcker explains how we must speak of the atom's indeterminacy: "Hence I may not say: 'The atom is a particle' or 'It is a wave,' but 'It is either particle or wave, and I decide by the disposition of my experiments, in which of the two ways it manifests itself.'"[39] It is crucial to note that the indeterminacy inheres in the atom itself, not just in our understanding of it.

Atoms do not have the kind of existence that we find in apples and billiard balls. Heisenberg notes: "In the experiments about atomic events we have to do with things and facts, with phenomena that are just as real as any phenomena in daily life. But the atoms or the elementary particles themselves are not as real; they form a world of potentialities or possibilities rather than one of things or facts."[40] Potentiality, the key concept, resolves these apparent contradictions in experimental results. The atom, of course, is not at the same time a wave and a particle, but the experimenter can actualize this dual potentiality of the atom in either direction.

Given a particle's intrinsic potency and indeterminacy, it is a mistake to imagine it as a body moving through space. That would confer on it a being it does not have. Margenau offers an example: "The word 'orbit,' still used for simplicity, must of course not be taken literally. It refers to a certain probability distribution for the electron's position which has the spatial shape of a diffuse ring or shell about the proton."[41]

Insistence on a sensible or imaginable model was a great attraction of the old physics and at the same time a serious limitation. Weizsäcker writes: "The physical world view of the nineteenth century...took the forms of our perception, in so far as they correspond to classical physics, as absolute, and therefore thought that a process which was not perceptible to the senses had been understood only after it had been reduced to a model after the pattern of the perceptible. We recognize how this conception, too, derives from the thought of a unified picture of the world. This picture was a grandiose attempt, and it was natural that physics should follow it as far as possible. But the advance of our knowledge has decided against it."[42]

Pagels explains that the new physics is understandable though not picturable: "Grasping quantum reality requires changing from a reality that can be seen and felt to an instrumentally detected reality that can be perceived only intellectually. The world described by the quantum theory does not appeal to our immediate intuition as did the old classical physics. Quantum reality is rational but not visualizable."[43]

The distinction between the picturable and the nonpicturable serves to illustrate the division between the macroscopic and the microscopic worlds. Pagels describes how quantum indeterminacy is negligible in large objects but reigns at the lowest level: "For a flying tennis ball, the uncertainties due to quantum theory are only one part in about ten million billion billion billion (10^{-34}). Hence a tennis ball, to a high degree of accuracy, obeys the deterministic rules of classical physics. Even for a bacterium the effects are only about one part in a billion (10^{-9}), and it really doesn't experience the quantum world either. For atoms in a crystal we are getting down to the quantum world, and the uncertainties are one part in a hundred (10^{-2}). Finally, for electrons moving in an atom the quantum uncertainties completely dominate and we have entered the true quantum world governed by the uncertainty relations and quantum mechanics."[44]

Atomic materialism from Democritus down to the present day has always assumed that the ultimate particles exist in the same manner as large scale objects. Heisenberg comments: "The ontology of materialism rested upon the illusion that the kind of existence, the direct 'actuality' of the world around us, can be extrapolated in the atomic range. This extrapolation is impossible, however."[45] On this impossible extrapolation rests the entire reductionist schema of the sciences outlined above. Consequently, deriving laws for plants, animals, or human beings from the laws of ultimate particles is impossible in principle.

The consequences of quantum theory reaffirm the priority of the everyday world we all experience, as Heisenberg points out: "Previously, physics had attempted to treat processes accessible to our senses as secondary and derived and to explain them in terms of events on an atomic scale. These events were considered to be the 'hidden' objective reality. However, we now recognize that events accessible to our senses (with or without the aid of scientific apparatus) can be considered to be 'objective.'"[46]

With atomic materialism matter was the source of all action and mind was a passive by-product. The new physics reverses this perspective: matter is passive, potential, and incomplete while mind is a source of action. This leads Dyson to declare that "Our consciousness is not just a passive epiphenomenon carried along by chemical events in our brains, but is an active agent."[47]

Built into the new physics is the recognition that the agent has free will. So, far from being "unscientific," acknowledging free choice in man is necessary for the study of matter, and indeed for all experimental science. Weizsäcker points out that "freedom is a pre-requisite of the experiment. Only where my action and thought are not determined by circumstances, urges or customs but by my free choice can I make experiments."[48] Though we may in some cases act automatically and without reflection, there remains an area where free choice operates and this is an ultimate datum.

Thus modern physics asserts that the human mind is an agent, an independent, irreducible source of action. We must therefore revise the schema of the sciences, taking into account this recognition of mind as a cause. Historically, the mechanistic model has been fruitful in the strictly physical sciences such as chemistry, astronomy, and geology. Here the mechanistic program has the greatest area of legitimacy, recognizing, of course, the limits set by relativity and quantum theory.

Concerning man, the new physics implies that mind and choice are irreducible elements. They are real causes of human action and cannot be resolved to material forces. Because man performs actions that matter cannot share in, namely, understanding and willing, the human sciences are autonomous and cannot take their first principles from physics and chemistry. Heisenberg cautions: "If we go beyond biology and include psychology in the discussion, then there can scarcely be any doubt but that the concepts of physics, chemistry, and evolution together will not be sufficient to describe the facts."[49] Man's understanding and will belong to the independent realm of the human sciences: psychology, politics, ethics, and economics.

The revised schema of the sciences shown in Figure 1.2 takes into account the two ultimate realities, matter and mind. All the sciences must incorporate or acknowledge these two realities, albeit in varying degrees. As we have seen, matter cannot be understood

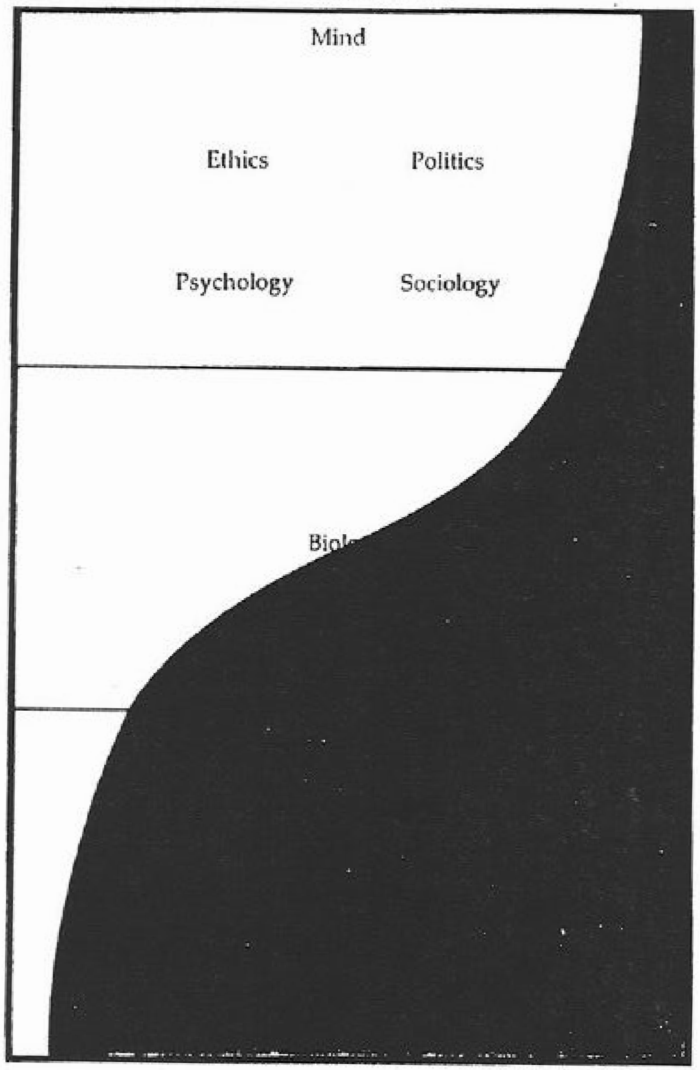

Figure 1.2. The new schema of the sciences. Both ultimate realities, matter and mind, are incorporated in varying degrees into all the sciences. Biology occupies a middle ground between physics and human sciences.

without introducing mind. Hence, physics, the science of matter, must necessarily include mind, not, of course, as part of its subject matter but as an indispensable precondition for certain of its fundamental principles.* And since man is composed of matter and mind, the human sciences must include reference to matter, although their chief subject is the mind and its works.

Biology occupies a middle ground between physics and the human sciences. This suggests that some of the principles of biology are reducible to physics and others are not. So while the skeletal structure of a hummingbird is understandable in terms of physics, its mating behavior is not. The rules of grammar apply to all great works of literature, but one cannot deduce Shakespeare or Milton from them. Nor is grammar alone sufficient to distinguish tragedy from comedy, the epic from the novel and other forms. In a similar way, living things in all their variety cannot be deduced from physics and chemistry, nor are the actions of plants and animals reducible to physical and chemical laws alone, even though they never violate those laws. Biologist François Jacob puts it succinctly: "Biology can neither be reduced to physics, nor do without it."[50] In the revised schema of the sciences, biology will incorporate in some way an equal mix of matter and mind. The exact nature of this mix will be worked out in the chapters that follow.

*For example, we have argued in *The New Story of Science*, chap. 4, not only that mind is central to relativity and quantum theory, but that a Mind is responsible for the origin of matter and that reference to the human mind as a goal of the universe can explain many physical constants, from the subnuclear to the cosmological, that are otherwise inexplicable.

lacks the higher kinds found in living things. Therefore, if matter is taken as the basis for understanding all nature, reductionism must necessarily result. And yet materialism uses the machine model for analyzing the agency of all natural beings; the plant, the animal, and man. Only a nonmechanical model—the observership principle—encompasses the full range of agency found in nature. For matter, growth, reproduction, sensation, emotion, intellect, and will are all found in man.

4
Cooperation

The paradigm of modern biology depicts nature as a ruthless struggle between opposing forces. In 1858 Charles Darwin set the tone when, in a paper delivered to the Linnean Society, he made public for the first time his theory of evolution. Darwin opens the paper with a stark image of nature: "All nature is at war, one organism with another, or with external nature. Seeing the contented face of nature, this may at first well be doubted; but reflection will inevitably prove it to be true."[1] The co-discoverer of natural selection, Alfred R. Wallace, in a paper presented simultaneously with Darwin's, employs the same imagery, describing animals and plants as locked in "a struggle for existence, in which the weakest and least perfectly organized must always succumb."[2] Biologist Thomas Huxley, Darwin's friend and defender, speaks in the same vein: "The animal world is on about the same level as a gladiator's show. The strongest, the swiftest and the cunningest live to fight another day... no quarter is given."[3] To describe this brutality Tennyson coined the now-famous phrase "Nature, red in tooth and claw with ravine [violence]."[4] In *The Origin of Species,* Darwin maintains that "all organic beings are exposed to severe competition" and to "the universal struggle for life." He argues that this conflict of living things follows inevitably from the tension between limited resources and unlimited population growth.[5]

This paradigm has dominated biology since Darwin's day. But paradoxically, it does not square with observation. Ruthless struggle between species can be induced artificially in the laboratory, but it is difficult to point out clear examples of mutual harm between natural species undisturbed by man. Many ecologists and others experienced in field studies of animals candidly admit that the theoretical expectations are not borne out by the observed facts. Daniel Simberloff writes: "It is rare to see two animals, particularly animals of different species, tugging at the same piece of meat. And even when competition is observed, it often appears inconsequential. Perhaps a fiddler crab scurries into a hole on a beach only to come running out again, expelled by the current inhabitant. But the crab simply moves off to find another hole. Competition between species—interspecific competition—thus appears to be little more than a minor, temporary inconvenience."[6]

After a three-year study of breeding bird communities in the North American plains and shrubsteppe, John Weins and John Rotenberry discovered that "variations in the population size of one species in an area are largely independent both of the presence or absence of other species and of variations in habitat features. Coexisting species appear to use resources more or less opportunistically. We find little evidence that they are currently much concerned about competition with one another or that competition in the past has led to an orderly community structure."[7] They conclude that "competition is not the ubiquitous force that many ecologists have believed" it to be.[8] Weins and Rotenberry began their observations with the conventional assumption that interspecific strife is the central factor in determining how the natural communities are put together. They confess that "as the research progressed, however, these expectations proved to be naive."[9]

Entomologist P. S. Messenger also writes that "Actual competition is difficult to see in nature."[10] Ecologist E. J. Kormondy asserts that competition in natural conditions is rare.[11] And biologists Allee, Emerson, Park, Park, and Schmidt in a collaboratively produced text declare, "Instances of direct mutual harm between species are not known to us."[12]

Because of this conflict between the accepted paradigm and what is actually observed in natural communities of species, discussion of competition in biology is fraught with confusion and contradiction. Evidence that undermines the premises of competitive struggle is presented as the *result* of competitive struggle. Some claim to see competition operating in the very mechanisms that enable animals to *avoid* competition. As ecologist Robert Ricklefs says, "Competition is perhaps the most elusive and controversial of all ecological phenomena."[13]

The Ways Nature Avoids Competition

A careful review of the many strategies nature employs to prevent competition* will bring light to this controversy and help to dispel some of the confusion. (Whether the cooperation present in nature now is the result of prior competition we will address in Chapter 6.)

The first and easiest way to prevent two species from harming each other is geographical isolation. Scattered across the globe are many species that could eradicate others in a short time, but this does not happen because they inhabit separate continents. In 1876, Wallace distinguished six biological land realms on the earth, each characterized by plants and animals unique to it and that naturally occur nowhere else (see Figure 4.1). Wallace's six realms, roughly corresponding to continental divisions, are still valid and recognized by biologists today. Hundreds of miles of ocean or vast deserts or huge mountain ranges like the Himalayas isolate the six realms from each other, effectively preventing competition and allowing the earth to support a much richer diversity of animals and plants than it did before the continents were separated from each other. This is why man's introduction of a species into a region where it does not naturally occur often brings ecological disaster and sometimes the extinction of native species.

But what about organisms in the *same* habitat? How can similar organisms avoid competing with each other if food and other resources are limited in supply? Similar species living together avoid competition by dividing the habitat into ecological niches. The habitat is where an organism lives; the niche is its profession. The presence of one species no more harms another species with a different livelihood than "the practice of a doctor harms the trade of a mechanic living in the same village," to use a comparison of Lorenz.[15] Niche means not only the physical space the plant or animal uses, but also how it fits into the community: whether it is a food producer, consumer, or decomposer; how it uses energy

*Colinvaux points out that "'Competition' is a word with a clear meaning, valid and hallowed in English usage. There is competition whenever two or more individuals or groups 'strive together' (the literal meaning of the Latin roots) for something in short supply. Men compete for prizes, and only one man, or one group of those competing, can win a prize."[14]

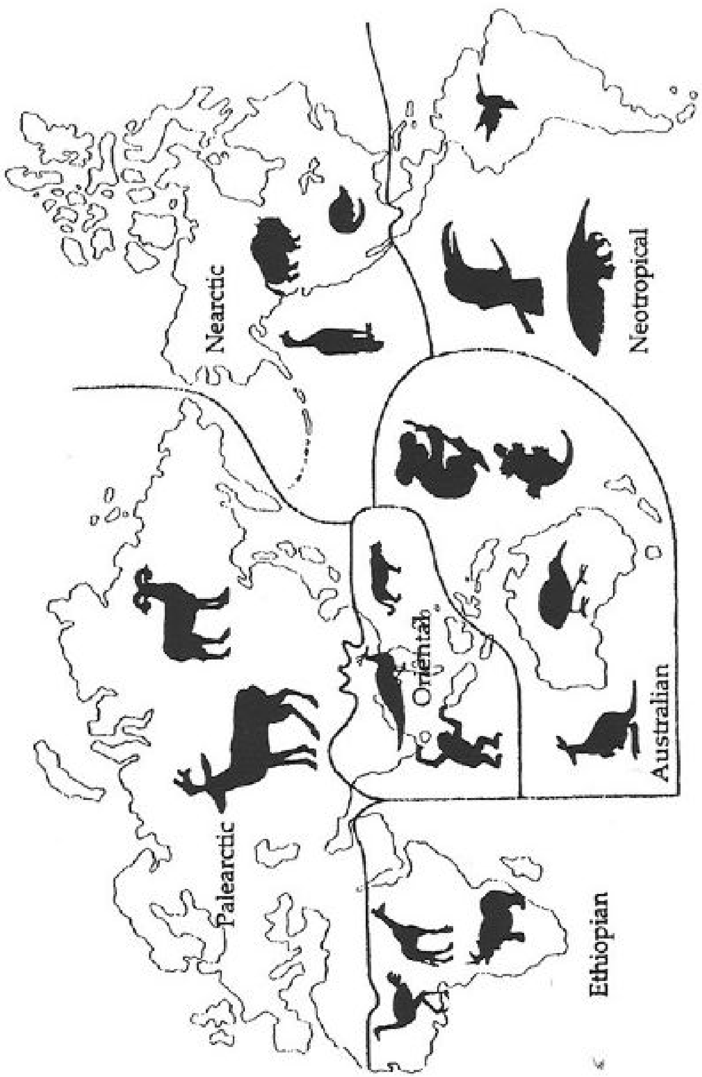

Figure 4.1. Wallace's six realms with a sample of the fauna unique to each. Natural geographical barriers prevent competition and allow the earth to support a rich diversity of plants and animals.

sources; what predators and prey it may have; its period of activity; and what changes it makes in the environment.[16]

Among the most thoroughly documented principles in the science of ecology is the dictum that two species never occupy the same niche. Thousands of examples are known where similar animal species coexist without competing because they eat different foods or are active at different times or otherwise occupy different niches. Each plant species also occupies a distinct niche: some specialize in sandy soil, others in rich humus; some prefer acid soil, others alkaline; still others require no soil, such as the lichens; some exploit the early growing season, others the late; some get by only because they are tiny, others only because they are huge. Experiments have shown, for instance, that two species of clover can flourish together in the same field. Of the two species investigated, "*Trifolium repens* grows faster and reaches a peak of leaf density sooner. However, *T. fragiferum* has longer petioles and higher leaves and is able to overtop the faster growing species, especially after *T. repens* has passed its peak, and thus avoids being shaded out."[17] Herbs and grasses have shallow roots to absorb moisture from light rains. Thus they do not compete with trees like oaks that have deep roots to tap more permanent sources deep in the soil water table. Also, in a deciduous forest many plants bloom and complete their yearly growth *before* trees have formed enough leaves to shade out the needed sunlight. Other plants require the shade and higher humidity that the forest canopy provides.

Plant physiologist Frits Went writes: "There is no violent struggle between plants, no warlike mutual killing, but a harmonious development on a share-and-share basis. The cooperative principle is stronger than the competitive one."[18] Went exemplifies this principle with the growth of seedlings. Even if several thousand per square yard spring up together they do not kill each other. They simply do not grow to full capacity while sharing the available water, nutrients, and sunlight. He points out that weeds sometimes crowd out desirable garden plants only because the latter have been planted out of season or in the wrong climate. The cooperative principle operates even in harsh environments: "In the desert, where want and hunger for water are the normal burden of all plants, we find no fierce competition for existence, with the strong crowding out the weak. On the contrary, the available possessions—space, light, water and food—are shared and shared alike by all. If there is not enough for all to grow tall and strong, then all remain smaller. This factual picture is very different from the time-honored notion that nature's way is cut-throat competition among individuals."[19] The same is true of the jungle: "The forest giants among the trees do not kill the small fry under them. They hold back their development, and they prevent further germination. In a mountain forest in Java it was observed that the small trees living in the shade of the forest giants had not grown after 40 years, but they were still alive."[20] Thus in garden, desert, and forest the paradigm for plants is not competition but peaceful coexistence.

Food specialization is one of the simplest ways that animal species avoid competition. Along the shore of Lake Mweru in Central Africa, three species of yellow weaver birds live side by side without struggle. They do not fight over food since one species eats only hard black seeds, another eats only soft green seeds, and the third only insects.[21] Many caterpillars will eat only one kind of plant. In some cases the plant's toxins render it inedible to all but one specialist herbivore, as with milkweed and the monarch butterfly larva. Twenty different insects feed on the North American white pine without competition because five species eat only foliage, three species concentrate on buds, three on twigs, two on wood, two on roots, one on bark, and four on the cambium.[22] Experiments show that newly hatched, inexperienced garter snakes pursue worm scent by preference over cricket scent. Baby green snakes that live in the same regions have just the opposite preference, though clearly both kinds of snake could eat both kinds of prey.[23]

Two species of cormorant found in Britain look very much alike, occupy the same areas of the shoreline, and feed and nest in similar ways. The competitive paradigm predicts that these animals must be locked in a ruthless struggle, each trying to supplant the other. Close investigation, however, reveals that one eats mostly sand eels and sprats, the other a mixed diet but no sand eels or sprats. One fishes out at sea, the other in shallow estuaries. One nests high on the cliffs or on broad ledges, the other low on the cliffs or on narrow ledges.[24] No struggle. No competition at all. The birds, in fact, occupy different niches.

Size of food is a major factor in determining food preferences. Carnivores, for example, must prey on animals small enough to

overpower, but not so small as to be of negligible nourishment for the time and energy invested in the hunt. Man is the only animal not restricted to certain foods by size requirements. G. D. Carpenter, who studied the tsetse fly in the region of Lake Victoria, Africa, found it could suck the blood of mammals and birds whose blood cells vary from seven to eighteen microns in diameter but could not draw blood from the lungfish because its blood cells (forty-one microns wide) are too large to pass into the proboscis of the fly.[25]

Sometimes spatial division of the habitat is sufficient to prevent competition. Five species of cone-shelled, carnivorous snails live segregated from each other in five parallel strips along the shores of Hawaii, where within each strip each species attacks with poison darts a unique group of prey.[26] The niche of many fresh-water fish is circumscribed by their oxygen requirements. Catfish can inhabit the lower, slow-moving regions of a stream where there is little oxygen but brook trout, which require much more dissolved oxygen, can live only where the water is aerated by rapids and waterfalls. Figure 4.2 illustrates the differing tolerances for salinity in estuarine animals. Thus the clam does not compete with the mussel because it cannot live in the same places. The space that defines a niche need not be large or far away from others: three different species of mite occupy three different areas of the honey bee's body as their niches.[27]

Dividing the habitat according to time is another strategy nature uses to prevent competition. Most habitats support two ecological communities, the diurnal and the nocturnal. During the day, bees, butterflies, weasels, most lizards, and most birds are active. At dusk they retire and the night shift takes over, including cockroaches, moths, mice, bats, and owls. Moths feed on white or pale yellow flowers that open only at night, thereby avoiding competition with bees and butterflies. Ecologist Charles Elton describes the noncompetitive use of the habitat by diurnal and nocturnal animals: "Not only is one kind of animal replaced by another, but one kind of food-chain is replaced by another, and certain niches which are unused by any animal during the day become occupied at night. The weasel-bank vole industry is changed into a tawny owl–wood mouse industry. The woodpecker-ant connection has no equivalent at night, while the moth-nightjar or bat chain is almost unrepresented by day. In fact, one food-cycle is switched off and another starts up

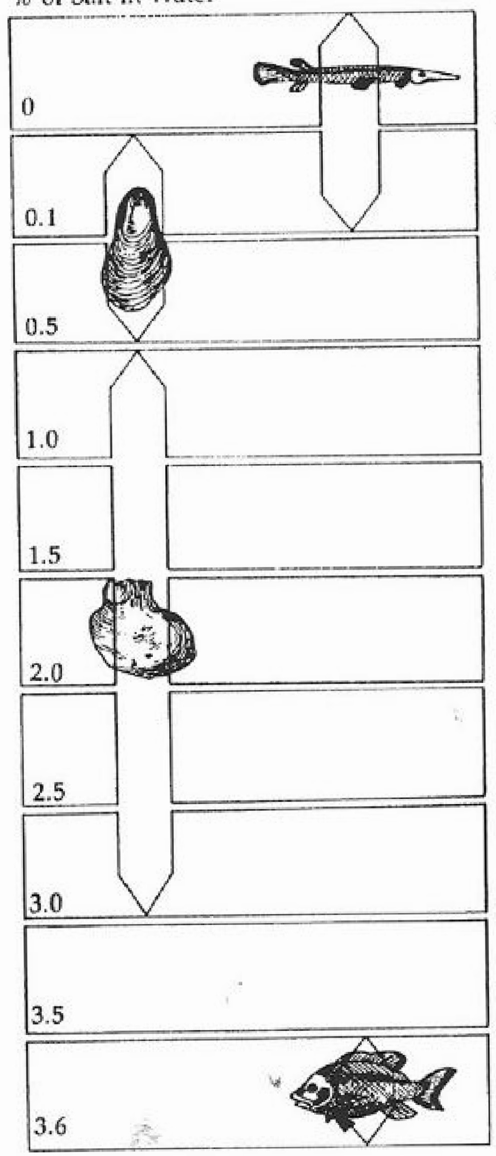

Figure 4.2. Differing degrees of saltiness establish invisible but rigid barriers between estuarine animals. The mussel, since it cannot tolerate more than 0.5 percent salinity, never competes with the oyster, which cannot live in water with less than 0.5 percent salt. For the same reason, the gar is incapable of trespassing into the snapper's niche, and vice versa. Spatial division of this sort is one way animals of similar species avoid competition.

to take its place. With the dawn the whole thing is switched back again."[28] Elton offers the unusual example of the gerbille that inhabits the South African veld. This rodent often shares the same underground tunnels with the carnivorous mongoose but is never attacked because "while the gerbilles come out exclusively at night, leaving their burrows after sunset and returning always before dawn, the mongoose . . . feed only during the day, and retire to earth at night."[29]

Biologists Leyhausen and Wolf discovered that with "domestic cats living in free open country, several individuals could make use of the same hunting ground without ever coming into conflict, by using it according to a definite time-table. . . . An additional safeguard against undesirable encounters is the scent marks which these animals . . . deposit at regular intervals wherever they go. These act like railway signals whose aim is to prevent collision between two trains. A cat finding another cat's signal on its hunting path assesses its age, and if it is very fresh it hesitates, or chooses another path; if it is a few hours old it proceeds calmly on its way."[30]

Similar species sometimes escape struggling with each other over resources by periodic migration. For example, the white storks and the black storks that winter in Africa spend the rest of the year in Europe. They "thus have avoided competition with their tropical relatives, not by radiating into unique food niches but by leaving the area," says zoologist M. Philip Kahl.[31] Other animals that migrate—some as far as twelve thousand miles—include caribou, bats, whales, birds, dragonflies, butterflies, fish, eels, and turtles.

The migration strategy is not open to plants, of course. Flowering plants avoid interspecific competition for pollinators by flowering sequentially, each species in its turn, as commonly occurs in the Arctic, the temperate zones, and in the tropics.[32] To these differences of timing correspond the active periods of pollinators such as bats, hummingbirds, and insects. Ricklefs points out that of the four species of honey bee that occur in England, *Bombus pratorum* coexists peacefully with *Bombus agrorum* because the former is active earlier in the season. The other two species do not fight over the same flowers because they restrict themselves to woods rather than open fields, and *B. hortorum* has a much longer tongue, so it feeds only at flowers with long corollas that the other three short-tongued species do not visit.[33] In a similar way, miconia trees of several species on the island of Trinidad fruit at different times, thereby avoiding competition for birds to eat the fruit and scatter the seeds.[34]

But how can different grass species living blade against blade in the same turf, using the same water and nutrients, avoid competition? There would seem to be no room for a division into different niches. The answer is the cropping principle, described by Darwin: "If turf which has long been mown, and the case would be the same with turf closely browsed by quadrupeds, be let to grow, the more vigorous plants gradually kill the less vigorous, though fully grown plants; thus out of twenty species growing on a little plot of mown turf (three feet by four) nine species perished, from the other species being allowed to grown up freely."[35] Stated the other way around, constant browsing allowed nine more species of grasses to thrive than would otherwise be possible. Here the browser eating the grasses prevents the competitive elimination of some species from the turf. Herbivores also have their preferences, and this leads to a kind of cooperation. In a mountain meadow goats will keep down the population of the plants they like best to eat. This gives other plants more chance to grow. These other species may be preferred by an elk or a big horn sheep, leading to a rich variety of plant species and food for all without competition. Part of the niche of a grass species in a meadow is being inedible or at least unpalatable to all but a particular herbivore; the plant accomplishes this by growing thorns or by producing special toxins such as nicotine, digitalis, or hypercin. As a general rule, the larger the mammal herbivore, the longer the list of plant species it eats, taking only a little of each one to minimize the effects of toxins and at the same time producing a balanced crop.

The herbivores also have special habits and equipment that preclude fighting over the same foods. Colinvaux explains how three browsers coexist on the African savanna: "Zebras take the long dry stems of grasses, an action for which their horsy incisor teeth are nicely suited. Wildebeest take the side-shoots of grasses, gathering with their tongues in the bovine way and tearing off the food against their single set of incisors. Thompson's gazelles graze where others have been before, picking out ground-hugging plants and other tidbits that the feeding methods of the others have both overlooked and left in view. Although these and other big game animals wander over the same patches of country, they clearly avoid competition by specializing in the kinds of food energy they take."[36]

The zebra, the wildebeest, and the gazelle in their turn are the common prey of five carnivores: the lion, the leopard, the cheetah, the hyena, and the wild dog. These predators can coexist because there are five different "ways which do not directly compete to make a living off three prey species," according to ethologist James Gould. He explains: "Carnivores avoid competition by hunting primarily in different places at different times, and by using different techniques to capture different segments of the prey population. Cheetahs are unique in their high-speed chase strategy, but as a consequence must specialize on small gazelle. Only the leopard uses an ambush strategy, which seems to play no favorites in the prey it chooses. Hyenas and wild dogs are similar, but hunt at different times. And the lion exploits the brute-force niche, depending alternately on short, powerful rushes and strong-arm robbery."[37] And these five predators are far from significantly reducing the three prey species. For there are in East Africa's Serengeti-Mara region alone approximately 170,000 zebras, 240,000 wildebeest, and 640,000 Thompson gazelles.[38]

The elimination of competition by division of the habitat into niches is so universal in the plant and animal kingdoms that it has become a principle of prediction and discovery for field studies. Colinvaux writes: "Whenever we find rather similar animals living together in the wild, we do not think of competition by tooth and claw, we ask ourselves, instead, how competition is avoided. When we find many animals apparently sharing a food supply, we do not talk of struggles for survival; we watch to see by what trick the animals manage to be peaceful in their coexistence."[39]

In a classic study, ecologist Robert MacArthur set out to learn how five species of warbler, similar in size, shape, and diet, could live together in the same coniferous forest of Maine. What factor was "preventing all but one from being exterminated by competition"? After months of painstaking observations, MacArthur discovered that each species had defined a subtle niche for itself based mainly on behavior: "The birds behave in such a way as to be exposed to different kinds of food. They feed in different positions, indulge in hawking and hovering to different extents, move in different directions through the trees, vary from active to sluggish, and probably have the greatest need for food at different times corresponding to the different nesting dates. All of these differences are statistical, however; any two species show some overlapping in

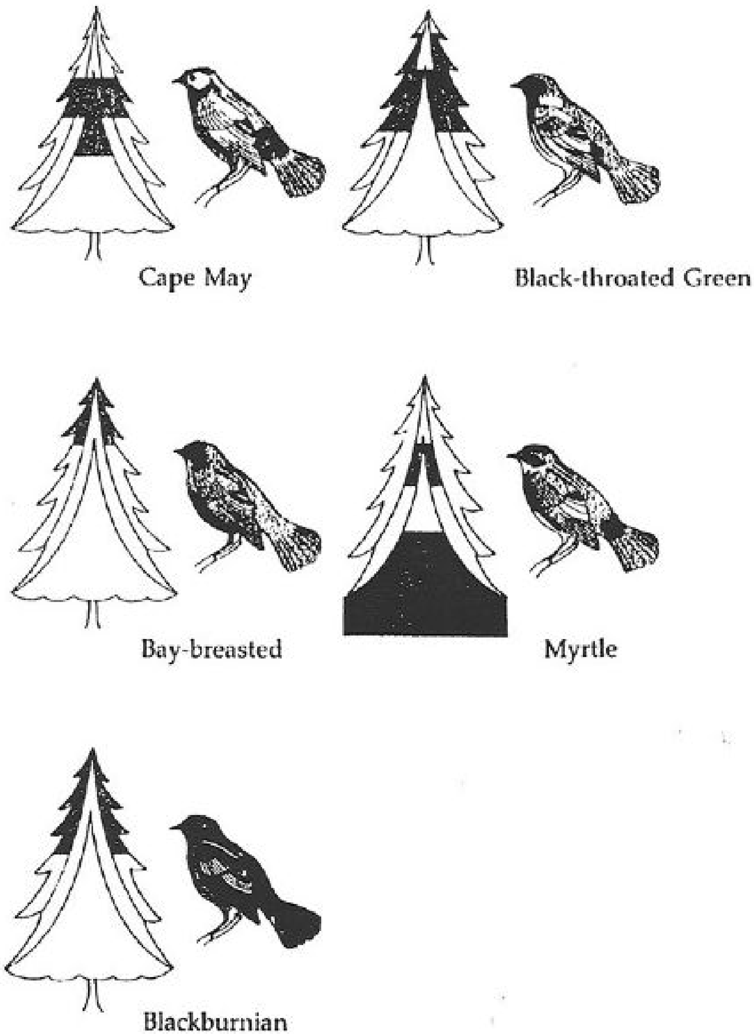

Figure 4.3. Derived from a classic study by ecologist Robert MacArthur, this diagram illustrates how five species of warbler, similar in size and shape, feed on bud worms in the same spruce trees. They avoid competition by occupying subtly different niches. The shaded areas indicate where each species spends more than half its time. The birds also use different methods of hunting. This pattern of noncompetition is typical of naturally coexisting species. (From MacArthur)

all of these activities."[40] (See Figure 4.3.) Colinvaux concludes that "Nature is arranged so that competitive struggles are avoided," and adds that "peaceful coexistence, not struggle, is the rule."[41]

Where food and other necessities are abundantly available many species may coexist in the same area without conflict. Herbert Ross found that six species of leafhopper in Illinois thrive side by side on the same trees without competition.[42] Such aggregations of similar species are called guilds. Hundreds of cases are known of large numbers of similar species coexisting without interference. An investigation of fourteen species of coexisting hummingbirds revealed that the birds feed differently according to flower density, height of flowers, and time of nectar renewal, with small overlap between species.[43] In the same forest log there are diverse niches for seven species of millipede.[44] Ricklefs reports that "The shallow waters of Florida's Gulf Coast can harbor up to eight species of large predatory snails.... Lake Malawi in Africa has more than 200 species of cichlid fish, which appear to have similar ecological characteristics."[45] Nature engages all her ingenuity in developing techniques to forestall strife among species. It is not surprising, then, that even careful and experienced investigators trying to document the paradigm of competition come up with disappointing results. Andrewartha and Birch comment on David Lack's paper "Competition for Food by Birds of Prey":[46] "We have discussed Lack's studies of birds in some detail because this work is so well documented. But we are forced to conclude that his interesting results do not in any way demonstrate that 'competition' between birds in nature is at all commonplace or usual. On the contrary, his results seem to show that it hardly ever occurs. Where he finds species together, there is evidence that their food is 'superabundant,' or else they live on different foods. When they are separated, there is no evidence that they do invade one another's territories."[47]

Because each species has its own niche and its own task, fights between animals of different species are exceedingly rare, if they occur at all. Lorenz after many years of studying fish remarks, "Never have I seen fish of two different species attacking each other, even if both are highly aggressive by nature."[48] Lions often steal the kills of cheetah, but there is never a struggle. The cheetah, much too wise to take on an opponent more than double its weight, abandons its prey without a fight.[49] The same prudent retreat occurs if a monarch eagle intrudes on a smaller eagle's meal of carrion, for instance. The smaller bird withdraws without protest and waits until the monarch eats its fill. As mentioned above, Allee and his collaborators did not know of any "direct mutual harm between species."[50] Colinvaux puts it succinctly: "A fit animal is not one that fights well, but one that avoids fighting altogether."[51]

Predation also is best understood not as a struggle but rather as a kind of balanced coexistence. In natural populations predators do not exterminate prey species. As a particular prey animal becomes more scarce, the predator turns to more abundant substitutes.

The wolf does not compete with the caribou but depends upon it. The caribou in its turn does not struggle with the lichens it consumes but depends on them for its livelihood. It is in the predator's interest that the prey thrive. Andrewartha and Birch state flatly, "There is no competition between the predator and its prey."[52] Odum notes that "where parasites and predators have long been associated with their respective hosts and prey, the effect is moderate, neutral, or even beneficial from the long term view."[53]
90 98 Predation does not benefit the individual that is eaten but it can benefit the rest of the prey population in several ways. After a three-year study of the wolf population on Isle Royale, an island in Lake Superior, L. David Mech writes: "The wolves appear to have kept the moose herd within its food supply, culled out undesirable individuals, and stimulated reproduction. Wolves and moose probably will remain in dynamic equilibrium."[54] After a similar study of the wolves of Mount McKinley National Park in Alaska, Adolph Murie states of the Dall's sheep indigenous to the area: "Wolf predation probably has a salutary effect on the sheep as a species. At the present time it appears that the sheep and wolves may be in equilibrium."[55]

One benefit of predation is that in certain cases more diversity in prey species is allowed than would otherwise obtain because competitive exclusion is prevented. The addition of a single predator can *increase* the number of prey species that can live side by side in a given habitat. For example, biologist David Kirk writes: "One of the most important effects of predator-prey interactions is the reduction of competition between prey species that share a common predator. For example, the sea star *Pisaster* is a major predator on sedentary mollusks and barnacles of the intertidal zone. If the sea

star is excluded from the community, one or two of the sedentary species soon crowd or starve out the other sedentary species because of their competitive advantage in feeding and reproduction. However, if the sea star is allowed access to the simplified community, it removes many individuals in these successful sedentary populations, leaving space for immigration of individuals of several other species. In other words, the addition of a single predator species can lead to an increase in the total number of prey species."[56] L. B. Slobodkin has obtained similar results with different species of hydra in laboratory cultures.[57] In the same way different insects preying on specific seeds and seedlings prevent or reduce tree competition.

The predator is not the enemy of its prey in the sense of hating it or being angry with it. Lorenz clarifies the relation: "The fight between predator and prey is not a fight in the real sense of the word: the stroke of the paw with which a lion kills his prey may resemble the movements that he makes when he strikes his rival, just as a shotgun and a rifle resemble each other outwardly; but the inner motives of the hunter are basically different from those of the fighter. The buffalo which the lion fells provokes his aggression as little as the appetizing turkey which I have just seen hanging in the larder provokes mine. The differences in these inner drives can clearly be seen in the expression movements of the animal: a dog about to catch a hunted rabbit has the same kind of excitedly happy expression as he has when he greets his master or awaits some longed-for treat. From many excellent photographs it can be seen that the lion, in the dramatic moment before he springs, is in no way angry."[58]

Even the unavoidable struggle is minimized. Mech reports that the fifty-one moose kills he examined were composed of the very young, the old, and the diseased. *None* of the animals killed by the wolves was in its prime.[59] A wolf pack sensibly seeks out prey that will offer the least fight. Murie found the same thing with wolf predation of Dall's sheep.[60] Finally, predators do not practice wanton killing, and even the pain seems to be minimized. Rodents attacked by snakes commonly go into shock before being killed and devoured. A wildebeest surrounded by attacking lions does not even resist but falls into shock.

The same principles hold regarding the parasites found universally among animals and plants. Authorities agree that parasitism is rarely harmful to the host. "It is the exceptional parasite that is deleterious," writes Thomas Cheng.[61] For example, "The Okapi, which lives in the tropical forests of central Africa, harbours at least five kinds of worms simultaneously and some of these may be present in numbers of several hundreds; the host does not seem any the worse for this and can feed itself as well as cater for the fauna it contains," according to parasitologist Jean G. Baer.[62]

Some parasites have intricate life cycles requiring one or more secondary hosts. The larvae of the brain worm that parasitizes the white-tailed deer live in slugs and snails that the deer inadvertently ingest when grazing. The larvae then penetrate the deer's stomach and enter the spinal column, eventually migrating to the spaces surrounding the brain. Here they mate and lay eggs that pass via the bloodstream to the deer's lungs where they are coughed up, swallowed, and passed out with fecal waste to reinfect another snail. But the damage to the host animal is minimal. Ecologist Robert L. Smith remarks, "As with most parasites and hosts, the deer and the brain worm have achieved a mutual tolerance, and the deer does not suffer greatly from the infection."[63]

The host's continued health and well-being are clearly in the interest of the parasite. This is why, as Cheng observes, "recent evaluations of the nature of the host-parasite relationship have intentionally avoided employing 'the infliction of harm' as a criterion in distinguishing parasitism from other categories of symbiosis."[64] Harm results only when parasites are present in excessive numbers. In fact, several controlled experiments have proven that certain parasites enhance the growth and vigor of the host, either by providing nutrients or by modifying the host's metabolism.[65]

Competition can be induced between species artificially in the laboratory. But the experiments of Gause[66] and others prove that such competition cannot persist with stability. Either the two species find subtly different niches and thereby avoid competition or one species replaces the other. This confirms the one species, one niche principle found in nature. Mathematical models, laboratory experiments, and field studies all show that competition between species cannot be sustained. The competition between paramecia in an aquarium, or between flour beetles in a jar is unnatural since migration, the natural means of avoiding competition, is prevented.

Furthermore, these laboratory experiments imply that if all nature were at war, one organism with another, then only one species would survive. If life is not to destroy itself, competition must be avoided. Thus competition is not the paradigm.

Cooperation between Species

A recognition of the peaceful coexistence among animals and plants is only half the story. The Darwinian images of struggle and war have led biologists to seek competition everywhere and to overlook or downplay cooperation. Biologist William Hamilton writes, "Cooperation per se has received comparatively little attention from biologists."[67] Zoologist Robert M. May notes that "mutualism has remained relatively neglected—in field, laboratory, theory and textbooks."[68] And Lynn Margulis writes, "Although they are often treated in the biological literature as exotic, symbiotic relationships abound; many of them affect entire ecosystems."[69] Nature's manner is not merely peaceful coexistence, but cooperation. Kirk declares: "It is doubtful whether there is an animal alive that does not have a symbiotic relationship with at least one other life form."[70] A few examples will give some idea of the magnitude of this mutual interdependence among living things.

One organism can be helpful to another in several ways: by providing food, protection from predators, a place to live, or transportation, or by ridding the other organism of pests, or by preparing some necessary condition for its life or welfare. The innumerable cooperative associations between different species constitute one of the most intriguing subject areas in all natural science. The variety and subtlety of interdependence is astounding.

The simplest service one organism can offer another is providing a place to stay. The sea worm *Urechis caupo* is nicknamed "the innkeeper" because it regularly harbors various fish, mollusks, arthropods, and annelids—up to thirteen species—in the U-shaped burrow it makes in California's coastal mudflats. Though able to live independently, the lodgers reside in the worm's tube for protection, some of them feeding on whatever *Urechis* brings in but does not consume.[71] Certain crabs live within the rectums of sea urchins, others within the shells of live oysters.[72] The horseshoe crab is also host to many guests. Clarke notes, "Anyone who has an opportunity to catch an elderly horseshoe crab (*Limulus polyphemus*) in the shallow waters off the New England coast is likely to find several species of mollusks, barnacles, and tube worms attached to the shell and a number of more motile commensals living in the 'book gills' or other anatomical nooks of this strange animal."[73] In fact, any sea animal with a shell or available space of any sort will serve as a home for other species. Farb adds that "the porous body of a sponge provides a home for a wide variety of sea creatures. One large specimen found growing off the Florida Keys served as a habitation of 13,500 other animals—some 12,000 of these were small shrimps, but the other 1,500 included 18 different species of worms, copepods and even a small fish."[74] Plants called epiphytes use other, established plants for a place to live. Tropical orchids, mosses, bromeliads, and vines grow along the horizontal branches of trees or hang down from them. These epiphytes are thus able to find a place in the sun and yet do not have to make the enormous investment in growing tall support structures.

It would be impossible to list all the animals that use plants for shelter and breeding. But some animals have formed close mutual relationships with certain plant species. Kirk writes of the *Acacia* of Central America: "Ants of the genus *Pseudomyrmex* live in the swollen thorns of the plant, gain their sugar from nectaries on the leaves, feed their larvae with modified leaflet tips that are rich in proteins and steroids, and have a nearly continuous food supply because these species of *Acacia* remain green during the dry season (in contrast to other *Acacia* species not associated with ants). The ants, in turn, drive away plant-eating insects and prune back vines and shrubbery that might crowd out the *Acacia*. This activity is of immediate benefit to the ants because it keeps the *Acacia* strong and healthy and ensures a more continuous and abundant food supply. The larger the ant colony, the more effective the continuous protection that it provides for the plant; thus, both ants and *Acacia* can maximize their growth through this close mutualism."[75] (See Figure 4.4.) Many other trees, shrubs, and plants carry on cooperative associations with ants. The aspen sunflower of the Rocky Mountain area secretes extrafloral nectar rich in sugar and containing eighteen different amino acids needed for ant nutrition. Ants feed on the nectar and protect the flower's seeds from devastating parasites.[76]

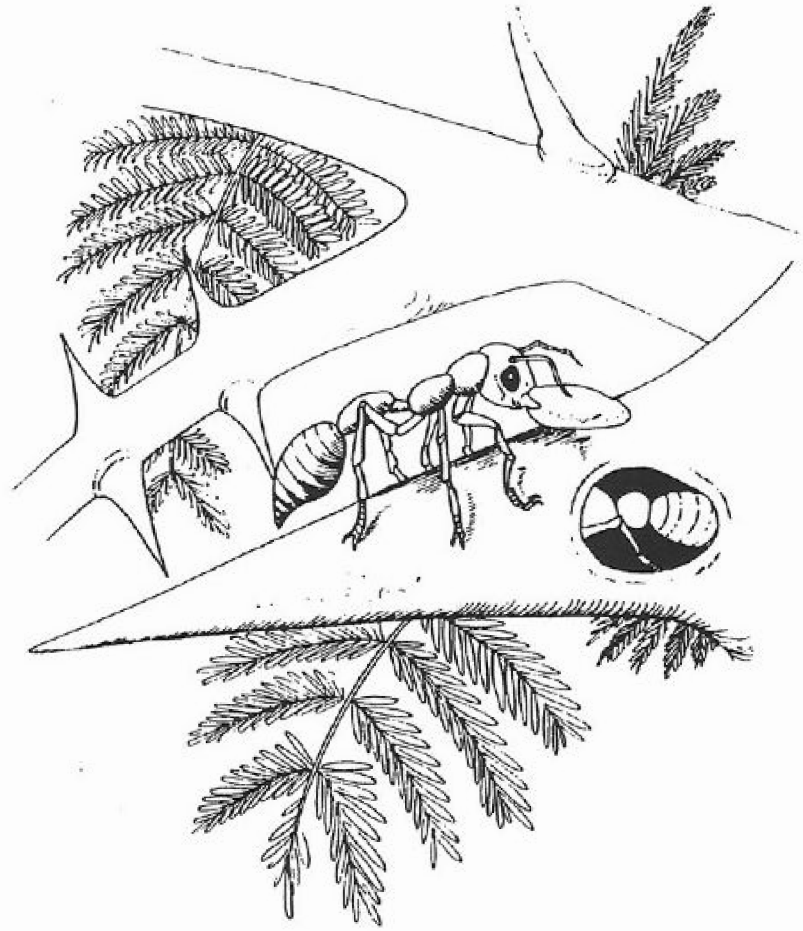

Figure 4.4. The cooperative arrangement between the *Acacia* of Central America and the ant *Pseudomyrmex*. The ant lives in the hollow thorns of the plant and feeds on its nectar. The ant, in turn, drives away plant-eating insects and prunes back vines that might crowd out the *Acacia*.

Other ants grow and maintain cultures of fungi for food. Still others nurture aphids to the same end. Wood-boring beetles live in association with wood-softening fungi. The female beetle carefully smears each egg she lays with fungus to guarantee that the partnership will continue in the next generation.

Many animals use the help of other species to obtain food. The blue jay can open acorns, but the bobwhite cannot. The blue jay is a sloppy eater, however, and leaves much meat uneaten in the opened shells. The bobwhite then feeds on a source it could not exploit itself. Eating the leavings of others is a widely exploited niche in every ecosystem. Hyenas frequently scavenge from lion kills that include animals the hyena could never kill by itself. The Arctic fox lives largely on the remains of kills made by polar bears.

Farb describes the amazing mutual assistance between a small African bird called the honeyguide and the badgerlike ratel: "Both the bird and the ratel seek the beehive—the ratel because of the honey and the larvae it contains, the bird because it is a wax eater. The honeyguide, however, cannot attack and break open a hive, so it needs a partner like the ratel, which is nearly impervious to stings because of its tough, furry skin that hangs loosely on its body. In return, the honeyguide aids the ratel in the forest, it attracts its attention by a loud chattering; the ratel follows it, issuing a series of grunts as if to reassure the bird that it is right behind it. Once the hive is located, the ratel tears it apart while the outraged bees furiously try to imbed their stingers; the bird waits on the sidelines and is content to eat the empty waxen combs after the ratel has finished with them."[77]

Another service one species can perform for another is to provide transport, either of the whole organism or of its seeds. To disperse themselves, stationary creatures often take advantage of mobile ones in remarkable ways. The mantle of one fresh-water mussel, *Lampsilis ventricosa*, is modified to look like a small fish. Clarke writes: "When a real fish, attracted by this mimic, swims over the mussel, casting a shadow, the mussel discharges its glochidial larvae. Some of these larvae reach the gills or fins of the fish to which they attach and live as parasites until they are ready to metamorphose into adults. Certain fishes thus parasitized wander upstream where the young mussels drop off and begin a new life as independent bottom animals. In this way these sessile forms are distributed against the current to the upper reaches of the stream."[78]

Barnacles attached to whales and anemones attached to crabs get free transport and an opportunity to obtain food otherwise unavailable. The anemones also provide the crabs with camouflage and probably prevent predation by octopus. There are hundreds of insects and worms that use other organisms for transportation and dispersal to more promising habitats. This practice of hitchhiking, called phoresis, has been going on for at least twenty-five million years, as is proven by amber fossils of various mites and nematodes clinging to beetles and wasps.[79]

Flowering plants use bees, moths, hummingbirds, and bats to achieve cross-fertilization, rewarding the workers with nutritious nectar. Many of these associations have developed into obligatory mutualism between plant and animal, so that they allow prediction. For example, when Darwin first examined *Angraecum sesquipedale*, a Madagascar orchid with a foot-long tubular nectary, he knew from experience that orchids usually have a single insect pollinator. But to reach the inch of nectar at the bottom of this orchid's whiplike nectary, the insect would need an incredibly long proboscis. Darwin made a bold prediction: there exists in Madagascar an insect with a proboscis twelve inches long![80] Entomologists scoffed at the idea of such an insect. But the scoffers were silenced when, several years later, *Xanthopan morgani praedicta*, a previously unknown Madagascar moth, flew into a collector's net, foot-long proboscis and all. Subsequently, this story repeated itself in reverse, when in South America a moth with a twelve-inch proboscis was first discovered; then, after a considerable time, a corresponding flower with a foot-long nectary was found.

Fruits are another way plants disperse their seeds with the aid of animals. The animal eats the fruit and, sometime later and some distance away, excretes the undigested seeds, which are thus provided with their own supply of rich fertilizer. Fruits commonly have a mild laxative effect just to ensure that the job is well done. For example, certain portions of *Amelanchier*, *Rosa*, and *Goultheria* seeds have been demonstrated to germinate after passing through the digestive tract of the black-tailed deer.[81] Certain seeds germinate better after being subjected to the forces of digestion. The *Calvaria* tree of Maritius Island in the Indian Ocean has not been able to germinate for over three hundred years—ever since the extinction of the dodo bird, which once inhabited the island. The dodo, in eating the *Calvaria* fruit, ground and abraded the hard shell of the pit in its powerful gizzard, such that when excreted, the seed was able to penetrate the shell and grow. Without the dodo's help the *Calvaria* seed could not break through its own shell. There are now on Mauritius only a few *Calvaria* trees, all dying, and all over three hundred years old.[82] (See Figure 4.5.)

Various algae form symbiotic partnerships with a wide range of animals: protozoa, snails and other mollusks, infusorians, coelenterates (including the hydra), rotifers, and many kinds of worms. Corals, for example, significantly increase their growth rate by forming cooperative associations with certain algae. The two partners make use of each other's waste products: the alga benefits from the carbon dioxide and nitrogenous wastes of the coral, and the coral benefits from the oxygen produced by the alga. The balance is so finely tuned that coral polyps with alga can live for two weeks in sealed glass containers filled with sea water.[83] Several species of ciliated protozoa, including the *Paramecium*, contain large numbers of small algal cells that live unharmed within the cell tissue, contributing the products of photosynthesis and enjoying a medium conducive to growth. A similar relationship is found in many species of flatworms; some even become green because of the many alga cells they harbor in their tissues.[84] The giant clam cultivates alga on the rim of its mantle. On the long, grooved hairs of the South American sloth, a green alga grows in such abundance that it gives the animal a greenish appearance, affording it a degree of camouflage while it sleeps in the treetops.[85]

Algae form intimate symbiotic relationships with many fungi, producing what amounts to a new organism, the lichen, that can grow under conditions where neither the alga nor the fungus alone could survive. Found all over the world, lichens represent a significant part of the earth's flora. Margulis states: "About one quarter of all fungal species enter lichen symbioses—some 25,000 species!... Lichens are remarkable examples of innovation emerging from partnership: they possess many morphological, chemical, and physiological attributes that are absent from either partner grown independently. The association is far more than the sum of its parts."[86]

Another plant-plant partnership is that of mycorrhizal fungi that live in association with the roots of most forest trees such as pines, oaks, hickories, and beeches, and many other plants also. Odum

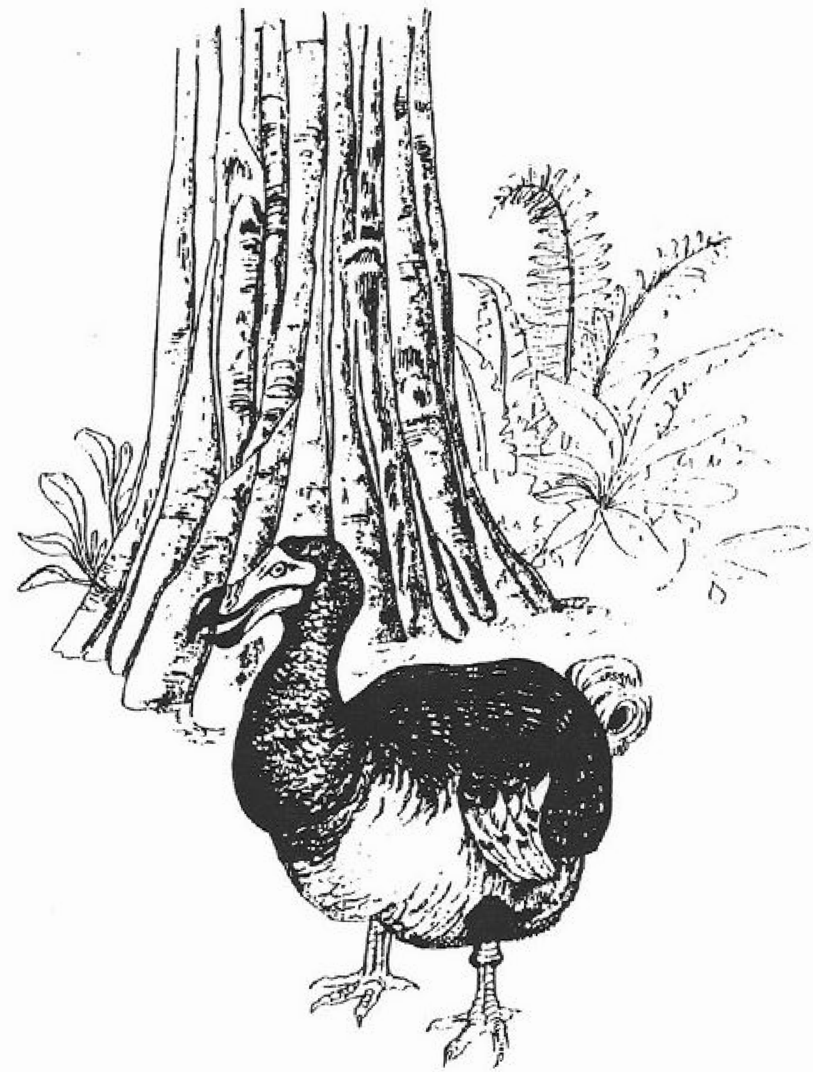

Figure 4.5. The cooperation between the dodo and the *Calvaria* tree. The *Calvaria* furnished the dodo with fruit, and in turn the bird ground and abraded the hard pit of the *Calvaria* seed so that it could germinate.

explains the relationship: "Many trees will not grow without mycorrhizae. Forest trees transplanted to prairie soil, or introduced into a different region, often fail to grow unless inoculated with fungal symbionts. Pine trees with healthy mycorrhizal associates grow vigorously in soil so poor by conventional agricultural standards that corn or wheat could not survive. The fungi are able to metabolize 'unavailable' phosphorus and other minerals."[87]

Another service is provided to certain plants by nitrogen-fixing bacteria. These microbes take up residence within the roots of legumes such as alfalfa, clover, and beans, and are able to fix atmospheric nitrogen to produce nitrates and nitrites, thus enriching the soil. Curtis gives an illustration: "A striking example of the capacity of the nitrogen-fixing bacteria to improve the fertility of the soil was seen in an experiment carried out by the U.S. Forest Service near Athens, Ohio. A planting of cedar trees was set out in an area of very poor soil. In one part of the area, a number of locust trees were set among the cedars. Locusts, which are legumes, carry nitrogen-fixing bacteria on their roots. Eleven years later, the cedar trees that had been planted alone averaged 30 inches high, while those planted among the locusts had grown to an average of 7 feet."[88] There are about 500 genera and 13,000 species of legumes that fix 100 million tons of nitrogen every year. Without this constant enrichment, the earth's soil would become too poor to sustain the quality and variety of plants, trees, and shrubs that we now witness.

Other bacteria and protozoans have developed a mutualism with hundreds of mammalian herbivore species, including elephants, cattle, sheep, goats, camels, giraffes, deer, and antelopes. Sometimes called ruminants, these animals are cud-chewers and have a complex three-stomach or four-stomach digestive system. The domestic cow, for example, does not have the enzymes necessary to digest cellulose, the main constituent of its diet. Special bacteria within the cow's first two stomachs digest the cellulose and convert it to fatty acids digestible by the cow. In the third and fourth stomachs, the bacteria, which die naturally after twenty hours, are digested, giving the cow necessary proteins. These bacteria would die in the presence of oxygen. They need an anaerobic environment and constant cellulose. Hence they thrive, warm, protected, and well fed, in the first two stomachs. Since the cow cannot digest its food

without bacterial help, the existence of cattle in the world depends on the work of microbes. The action of the bacteria explains why vitamin B is found in a cow's milk but not in its feed. In human beings harmless intestinal bacteria similarly contribute vitamin B_{12} to the host.[89] Certain termites and cockroaches are able to digest wood only because of the help of flagellate protozoans that live in their digestive systems. The relation is mutually beneficial and obligatory. A termite without the protozoans in its gut will starve to death despite ingesting normal quantities of wood fiber.

A further service one organism renders another is protection. One strategy is to associate closely with a dangerous predator. Clown fish develop an immunity to the stings of a sea anemone and then live within its arms, acting as bait for other fish, and enjoying security from predators. The horse mackerel lives within the tentacles of the dangerous Portuguese man-of-war. Shrimp fish live among the spines of the sea urchin. Many birds build their nests near beehives. In Algeria a particular edible plant grows in close association with a thorny, inedible one. The former benefits, while the latter is unharmed.[90]

Many species take warning of danger from other species. Alarm calls in all prey birds are similar so that all species in an area are warned if one gives the alarm. Baboons frequently associate with gazelle and profit from their keen sense of smell, while the gazelles benefit from the superior vision of the baboons in detecting predators. Ostrich often herd with zebra for the same reasons.

Another service one animal can offer another is cleaning. This service is important for animals that are anatomically incapable of cleaning their own bodies. The arrangement is mutually beneficial since the client is rid of parasites and the cleaner gets fed. Among land animals the tickbird cleans the rhinoceros, egrets clean various cattle, and the Egyptian plover enters the mouth of the crocodile to feed on leeches and emerges unharmed. Biologist William Beebe observed red crabs removing ticks from the marine iguanas of the Galápagos Islands.[91] The existence of cleaning symbiosis among marine animals has come to light only since skin diving has allowed extensive observation of sea creatures. According to marine biologist Conrad Limbaugh, the cleaner-client association "represents one of the primary relationships in the community in the sea."[92] Known cleaners include some forty-two species of fish, six shrimps, and Beebe's crab. Cleaners establish fixed stations that are visited by countless species of fish. Limbaugh reports, "I saw up to 300 fish cleaned at one station in the Bahamas during one six-hour daylight period."[93] The client fish approaches the station and poses, allowing the cleaner to forage within its gills and even to enter its mouth without danger (see Figure 4.6). No one yet knows what prevents ordinarily voracious fish from eating the cleaners. Limbaugh found that the cleaners could prevent the spread of bacterial infections that would normally prove fatal to the client. He concludes, "The extent of cleaning behavior in the ocean emphasizes the role of cooperation in nature as opposed to the tooth-and-claw struggle for existence."[94]

An astounding example of cleaning is found in the bluebottle fly and the blowfly. These flies prefer to lay their eggs in the festering wounds of animals. At first thought this might appear to be one of nature's great cruelties. But when the larvae hatch, they feed on the pus and consume dead tissues. Even their excretions disinfect the wound! Far from being cruel, the fly larvae may be the animal's only chance to recover from a possibly lethal infection. Blowfly larvae were in fact used as wound cleaners in hospitals during the last century.[95]

Another mode of service occurs in ecological succession, the sequential replacement of a community's flora by other species. This is best understood as a kind of cooperation rather than as ruthless eradication by subsequent species. Succession occurs because the establishment of new species *modifies* the environment. The annual plants are like nomads. Their job is to prepare the soil, paving the way for the perennials, and then to move on. Permanence is not part of their niche: they are not equipped for it. The lichens are the most rugged pioneers of all. They do not *require* soil, they help *create* it, colonizing even bare rock, which they slowly break down into tiny amounts of humus, allowing mosses or other higher plants to gain a foothold. Succession continues until a stable climax stage is reached where new species can no longer change the community. In northern temperate forests, species such as hemlock, beech, and maple constitute the climax stage because only their seedlings can thrive in the shade of the mature trees. Cases of succession from bare ground to hickory climax within one hundred fifty years have been documented in North Carolina.[96] Ecological succession is

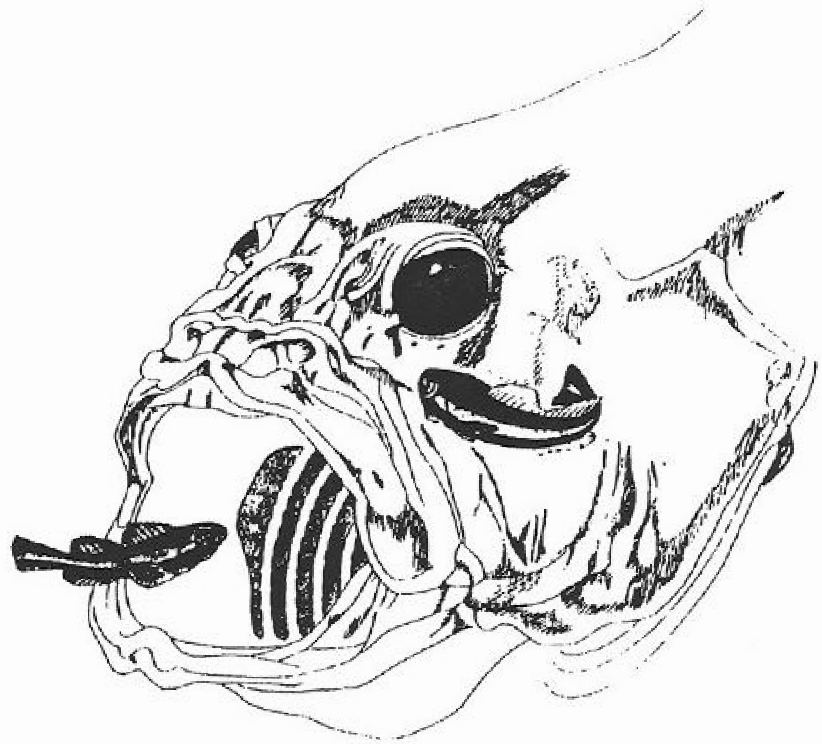

Figure 4.6. Two neon gobies cleaning a Nassau grouper. The cleaners forage within the client fish's gills and even enter its mouth without danger. Cleaning symbiosis is a common kind of cooperation.

merely nature's way of healing her scarred skin. Not all species are replaced in the succession: lichens grow on tree trunks, while the shady areas in dense forest are ideal for mosses and ferns.

In another form of interdependence, certain large animals support whole communities of species. A single hippopotamus, for example, is cleaned by twenty or so labeo fish and stirs up food for other fish, as it walks along under water. When it surfaces, a stork may ride on its back to hunt the snails it churns up. And its dung nourishes plants, bacteria, insect larvae, and crustaceans in the ponds and lakes it frequents. These organisms provide food for many species of fish, thereby greatly extending the food web. The aquatic life is always much richer in bodies of water that hippos inhabit.[97] The elephants of Sri Lanka are the foundation of a similar community. They are sloppy eaters and make much forage available to other browsers. In a single day ten elephants can deposit on the forest floor a ton of feces. None of that dung is wasted: butterflies and beetles feed on it; birds retrieve seeds from it; mushrooms and fungi thrive on it; insects lay eggs in it; and termites convert most of its cellulose into sugars. All these uses set up further food webs, including termite eaters such as the sloth bear and the pangolin. So what is a waste product for the elephant becomes an organic treasure for scores of other creatures.[98] In a community "every species . . . directly or indirectly, supplies essential materials or services to one or more of its associates," writes Dice.[99]

The exquisite cooperation between plants and animals in general is a marvel in itself. Each needs the products of the other. Plants use the carbon dioxide in the air and water from the soil to manufacture sugars, releasing oxygen as a by-product. Animals consume plant sugars and oxidize them to produce energy, breathing back carbon dioxide into the air and returning water to the soil as urine. The cycle is perfect and nothing is wasted. The following chart shows a simplified version of the chemistry involved.

PLANTS:	$6CO_2$ from air	+	$6H_2O$ from soil	+	Energy from sun	→	$C_6H_{12}O_6$ sugar	+	$6O_2$ returned to air
ANIMALS:	$C_6H_{12}O_6$ sugar eaten and absorbed into tissues	+	$6O_2$ from air	→	Energy	+	$6CO_2$ expired through lungs	+	$6H_2O$ returned to soil

Without this perfect cycle, life on the earth would have gone out of business long ago. Carbon dioxide is a rare gas on our planet. It constitutes only 35/1,000 of 1 percent of the atmosphere, less than argon. That amount of carbon dioxide, if not replenished, would support the present plant population of the world for only forty years.[100] Thus, respiration of animals and of certain bacteria is crucial for the continued life of plants. And without plants, no animals could live.

The same holds for nitrogen. Even though it constitutes almost 80 percent of the atmosphere, few plants can assimilate it directly. Plants must take nitrates from the soil to synthesize their proteins. So if plant and animal proteins were not recycled back into the soil, plants would have no source of nitrogen compounds and would eventually die out. Fortunately, various bacteria that specialize in decomposing organic matter routinely break proteins down to ammonia, while others change ammonia to nitrites, and others change nitrites to nitrates, making them available for plants. If there were no bacteria decomposers, all nitrogen would sooner or later get irretrievably locked into plant and animal bodies. Decomposition occurs only by the agency of specialized living beings, not by automatic chemical processes. Figure 4.7 summarizes the necessary interdependence of all living things for food.

"All organisms are dependent upon the varied activities of other organisms for the supplies of essential stuffs," writes Burkholder.[101] No single species could persist if it were alone on the planet. It would eventually exhaust all the available nutrients, and, having no way no convert its own waste products into food, it would die. Life is necessarily a cooperative venture. Lynn Margulis writes: "All organisms are dependent on others for the completion of their life cycles. Never, even in spaces as small as a cubic meter, is a living community of organisms restricted to members of only a single species. Diversity, both morphological and metabolic, is the rule. Most organisms depend directly on others for nutrients and gases. Only photo- and chemo-autotrophic bacteria produce all their organic requirements from inorganic constituents; even they require food, gases such as oxygen, carbon dioxide, and ammonia, which although inorganic, are end products of the metabolism of other organisms. Heterotrophic organisms require organic compounds as food; except in rare cases of cannibalism, this food comprises organisms of other species or their remains."[102]

The recognition of such universal, essential cooperation among animals and plants alters the conventional image of nature. Biologist Lewis Thomas writes: "One major question needing to be examined

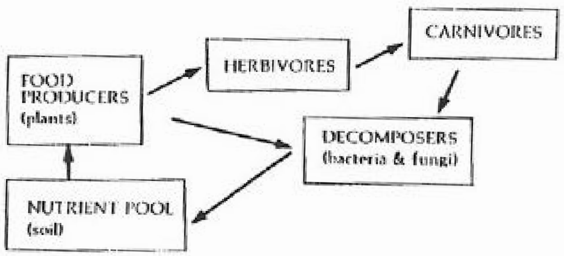

Figure 4.7. All living things necessarily depend on one another for food. Plants would eventually die out if decomposers did not make available to them a continuous supply of nitrogen compounds from decaying organic materials. Without plants, animals would die of starvation.

is the general attitude of nature. A century ago there was a consensus about this; nature was 'red in tooth and claw,' evolution was a record of open warfare among competing species, the fittest were the strongest aggressors, and so forth. Now it begins to look different.... The urge to form partnerships, to link up in collaborative arrangements, is perhaps the oldest, strongest, and most fundamental force in nature. There are no solitary, free-living creatures, every form of life is dependent on other forms."[103]

Cooperation within Species

Up to this point we have discussed only the relations between one species and another. Cooperation is also the ruling principle among members of the same species, despite Darwin's assertion that "The struggle will almost invariably be most severe between the individuals of the same species, for they frequent the same districts, require the same food, and are exposed to the same dangers."[104] How can members of the same species avoid competition if they all occupy the same niche? Nature is not at a loss for methods. One way is to have some technique to separate individuals from each other. This is accomplished in animals and plants by various dispersal techniques. Tinbergen explains: "These 'dispersion mechanisms' reduce competition to a minimum. Perhaps the simplest way to disperse is just to drift aimlessly about for a while, carried and scattered by the wind or water until the time for settling has arrived. The larvae of many marine animals, such as shellfish, starfish and crabs, do this; after a few days, weeks or even months of floating life they change their behavior, sink to the bottom and settle down. Many kinds of caterpillars would lose the effectiveness of their natural camouflage and become dangerously conspicuous if they stayed together in large groups. To prevent this, the moths of some species scatter their eggs when they lay them."[105]

Every living thing has a dispersal phase at some stage in its life cycle. Equal distribution prevents competition while maintaining a remarkable stability in populations. Curtis describes a striking example: "In one experiment, for example, a census of a particular species of butterfly was taken each year for eight years. Each fall, there were from 8,000 to 14,000 larvae of the species in a field in New England. In most years, about 30 larvae survived until spring; and most summers, there were about 20 butterflies. In autumn of the sixth year, the field was stocked with 20,000 additional larvae. Eighty spring larvae were present the following year, but by summer, there were only 22 butterflies in the field, about the usual number. That fall, only 400 autumn larvae could be found. Examination of the surrounding areas revealed that many more eggs than usual had been laid outside the field. In response to the overstocking of the field, the butterflies had emigrated, despite the fact that ample food was left for the larvae and ample space remained for the deposit of eggs."[106]

One way nature distributes members of a species evenly across the habitat is the territory principle. Animals that mark off and defend definite areas divide their niche into livable plots. Territories for mating or feeding, or both, are established by hundreds of species including limpets, lobsters, crabs, spiders, crickets, grasshoppers, many other insects, bony fishes, lizards, perching birds, raptors, oceanic birds, rodents, ruminants, and most other mammals. The power of territorial borders is surprising. Zoologist Hans Kruuk has seen hyenas break off the chase of a promising prey animal when they reach the border of neighboring hyena territory, even though no other predators are in sight. His field studies showed that "Fully 20 percent of unsuccessful wildebeest hunts could be attributed to hyena respect for one another's boundaries."[107] Kirk writes: "Territorial behavior leads to an optimum distribution of limited resources among a maximum number of individuals of a species."[108] For example, territory size appears to be regulated by innate factors. Song sparrows never establish territories greater than one acre, no matter how few are present. Nor do they defend territories below about half an acre, no matter how many other sparrows are present.[109] A study of four hundred coexisting howler monkeys in Central America revealed twenty-three different clans with definite territories.[110]

The defense of territory in all species is characterized not by battles to the death, but by highly stereotyped threats, aggressive displays, and appeasement gestures that rarely result in injury. Lorenz observes that these ritualized sign stimuli are as powerful as the impulses of hunger, sex, and fear in the animal.[111] (See Figure 4.8.) The encounter is more a ritualized contest than a real fight, with one animal eventually retreating unharmed. Territory boundaries tend to be respected. Kirk elaborates:

"Particularly when the territory is well established, the defender is usually successful in driving away an invader irrespective of differences in size, strength, development of specialized structures important in the aggressive display, and so forth. This is most clearly seen in the case of two individuals with adjacent territories. Here, each individual is usually successful in defending its own territory yet unsuccessful in attempts to encroach on its neighbor's domain. In every interaction each individual appears to be driven by opposing tendencies: fight and flight. The closer to the center of its own territory an individual is, the greater appears to be its motivation to fight. But the farther it is from the center of its home territory, the greater appears to be the tendency for flight."[112] This system can hardly be described as a brutal struggle or ruthless warfare if size and strength do not determine the outcome.

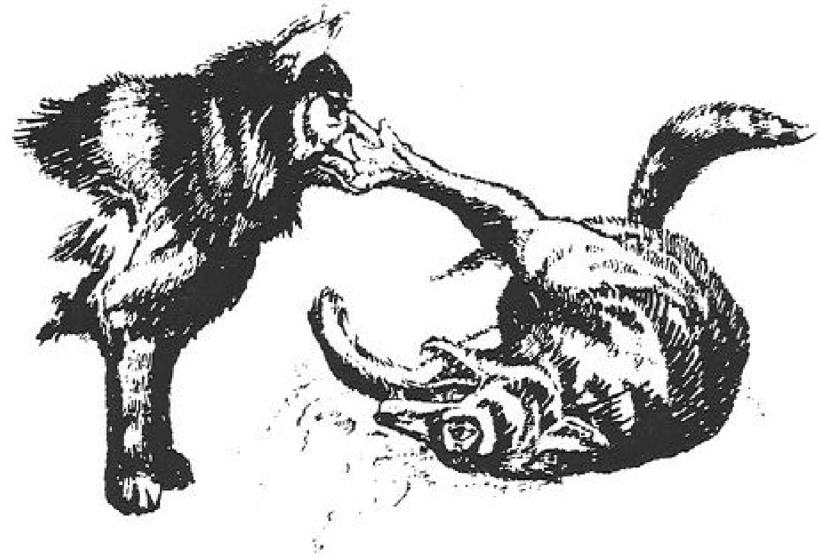

Figure 4.8. Intraspecies encounters between rival animals rarely result in injury because they are regulated by instinctual, stylized displays of aggression and by appeasement gestures. A wolf, for example, that feels it is no match for another wolf during an encounter avoids a fight simply by presenting its unprotected throat to the adversary. This stimulus never provokes attack by the other wolf. On the contrary, it causes the dominant animal to turn away, and the tension of the encounter is dissipated.

Zoologist Norman Owen-Smith notes: "Territoriality of the white rhinoceros may thus be described as a system for ordering specifically reproductive competition among males. Its primary function within the population seems to be to increase the reproductive efficiency of prime bulls by reducing the incidence of injury-inflicting combat. These statements can probably be broadened in scope to apply, with the exception of the Indian rhinoceros, to all other ungulates in which territoriality has been identified, and perhaps to any species in which territoriality is restricted to adult males."[113]

Some species maintain noncompetitive distribution without even encountering each other. Certain mammals accomplish this by leaving scent marks in their territory that other members of the same species then avoid. The male frogs of certain species distribute themselves evenly throughout the habitat by distancing themselves from the croaking of other males. Plants avoid competition with their own seeds by many dispersal techniques. A single crop spread over acres and acres of land is found only in man's artificial agriculture, never in nature.

Another means nature uses to prevent competition and fighting among gregarious animals is the dominance hierarchy, which minimizes aggression within the social group. First studied with pecking orders among birds, the dominance hierarchy prevents animals of the same group from wasting time and energy by constantly fighting over food and mates. Instead of fighting, the individual animal lower in the pecking order immediately concedes to the higher one, without any struggle. Kirk gives an illustration of what happens without this strategy: "For the group, dominance assures stability. Once the hierarchical order has been established, aggression over resources and mates is kept to a minimum. In one study, the investigator deliberately kept disrupting the dominance relationships in a flock of hens. The outcome was that the hens fought more, ate less, gained less weight, and suffered more serious injuries than the control flock in which the dominance relationship was stable."[114] Among Japanese macaques of Koshima Island, dominant males break up quarrels between females that have no dominance hierarchy of their own. Dominance hierarchies, found in many species of birds and mammals, show nature to be not only pacific but sensible. Why should a weaker individual fight a stronger one that would win anyway with probable injury to both?

On rare occasions injury results from territory defense or rival encounters, but the aim of aggression is never the extermination of fellow members of the same species. If it were, a species would destroy itself in a short time. Fights to the death and cannibalism do sometimes occur in unnatural circumstances, such as with birds in a cage, or fish in an aquarium where retreat is impossible. But such is

not nature's way. Animals with the most dangerous weapons also have the strongest instincts to prevent their use against conspecifics. Male giraffes that can dispatch a lion with a single kick save their lethal hoofs for predators only, using their stubby, harmless horns for encounters with rival giraffes. Lorenz points out: "Those inhibitions which prevent animals from injuring or even killing fellow members of the species have to be strongest and most reliable, first in those species which being hunters of large prey possess weapons which could as easily kill a conspecific; and secondly, in those species which live gregariously."[115] After a study of dominance in bison herds, ethologist Dale F. Lott concludes: "Because fighting is dangerous and demands so much time and energy, substitutes have developed. In animals that establish—and defend—territories . . . fighting is often avoided because individuals are separated by distance. But species whose social life is organized by dominance depend heavily upon the ability to predict each other's behavior from such signals as postures and vocalizations."[116]

An ecological niche can also be divided by learned behavioral differences within a species. For example, one species of oyster catcher found along English shores is divided into two behavioral groups, the "stabbers" and the "hammerers," each of which mates only with its own kind. Stabbers feed on mussels and cockels that remain under water in tidal pools at low tide. Such mussels leave their shells partially open to continue filtering food from the sea water. The bird thrusts its beak into the shell, cuts the abductor muscle, and opens the shell to eat the contents. Hammerers feed on mussels and cockels that remain closed at low tide by persistently beating on a vulnerable spot on the shells until the beak can be inserted to pry the shell open. In this way two groups within the same species live in the same area and eat the same foods, but, because of their different hunting techniques, they do not compete.

Within a species, we take for granted the profound cooperation of the family, the herd, the colony, the flock, and the school. But these also are founded on strong natural instincts. Lorenz speaks of the powerful inhibitions in male wolves, lizards, hamsters, gold finches, and many other species against biting females.[117] He adds: "The fact that mothers of brood-tending species do not attack their young is thus in no way a self-evident law, but has to be ensured in every single species by a special inhibition. . . . Every livestock breeder knows that apparently slight disturbances can cause the failure of an inhibition mechanism of this kind. I know of a case where an airplane, flying low over a silver-fox farm, caused all the mother vixens to eat their young."[118]

There are many advantages of flocking together. Many eyes are better than a simple pair in looking for predators, and a circle of musk oxen is more formidable to a wolf pack than is a single animal. Moving in schools and flocks also makes it difficult for a predator to single out one individual when dozens of others cross its field of vision, as anyone knows who has ever tried to catch a single bird among many in a cage. A certain population density is necessary for many animals: muskrats, for example, do not breed successfully below a density of one pair per mile of stream or eighty-six acres of marshland.[119] Many sea birds hunt in flocks because it is more efficient. All social insects live by cooperation. The individuals in a termite colony depend on each other absolutely, some being unable to feed themselves and others being unable to reproduce. Parental care, feeding, protection, and training of young is simply too extensive to summarize. We may point out, however, that for those species that reproduce sexually, at least some kind of cooperation between the sexes is unavoidable. After years of studying group life among animals, Allee declares, "No free living animal is solitary through its life history."[120]

Darwin's Argument

Having reviewed the extent of cooperation between species and within a species, we can now reexamine Darwin's reason for proposing competition as the paradigm for living things. He maintains that "a struggle for existence inevitably follows from the high rate at which all organic beings tend to increase."[121] Darwin begins by assuming that each living thing is trying to produce an unlimited number of offspring: "Every single organic being may be said to be striving to the utmost to increase its numbers."[122] He adds, "There is no exception to the rule that every organic being naturally increases at so high a rate, that, if not destroyed, the earth would soon be covered by the progeny of a single pair."[123] He offers the example of the elephant to illustrate the point: "The elephant is reckoned the slowest breeder of all known animals, and I have taken

some pains to estimate its probable minimum rate of natural increase; it will be safest to assume that it begins breeding when thirty years old, and goes on breeding till ninety years old, bringing forth six young in the interval, and surviving till one hundred years old; if this be so, after a period of from 740 to 750 years there would be nearly nineteen million elephants alive, descended from the first pair."[124] If, in fact, the earth is not swamped with elephants or any other species, there must be some check to their geometric growth rate. So he concludes: "Each species, even where it most abounds, is constantly suffering enormous destruction at some period of its life."[125] Darwin proposes four causes that check a species' natural tendency to increase without limit: predation, starvation, severities of climate, and disease.[126] In a word—death.

Lacking detailed field studies of natural populations—they were done one hundred years later—Darwin buttresses this argument based on "mere theoretical calculations"[127] with examples of domestic animals "run wild,"[128] in other words, from man's artificial introduction of a species into a habitat where it did not occur before. Recent field studies of native animals by ecologists have yielded conclusions quite different from Darwin's. Elton and Andrewartha and Birch argue that starvation rarely acts as a direct influence on numbers of species; Lack says the same of disease.[129] What, then, are the factors? Take Darwin's example of elephants. Biologist Richard M. Laws reports that a study from 1966 to 1968 of over three thousand elephants in Kenya and Tanzania showed that "the age of sexual maturity in elephants was very plastic and was deferred in unfavorable situations. . . . Individual animals were reaching maturity at from 8 to 30 years."[130] The same study showed that the females do not continue bearing young until ninety, as Darwin thought, but stop becoming pregnant around fifty-five years of age. Thus the elephant population is regulated not by predation, starvation, or death, but by adjustments in the onset of maturity in the females, which lowers the birth rate whenever overcrowding occurs. Nor are elephants unique in having an internal mechanism for regulating population growth. Evidence from other field studies indicate that the birth rate or the age of first reproduction depends on population density in many large mammals, including white-tailed deer, elk, bison, moose, bighorn sheep, Dall's sheep, ibex, wildebeest, Himalayan tahr, hippopotamus, lion, grizzly bear, dugong, harp seals, southern elephant seal, spotted porpoise, striped dolphin, blue whale, and sperm whale.[131] Increases in population density alter birth rates in small mammals also. Kirk observes: "In experiments with rats, mice, and voles, definite physiological changes accompanied increases in population density. An increase in the size of a population confined to a constant space led to an increase in the weight of adrenal glands and a decrease in the weight of thymus and reproductive glands. The degree of the effect was inversely related to social rank. Dominant individuals were affected little if at all; subordinate individuals were strongly affected. These changes were accompanied by decreases in reproduction."[132] Under crowded conditions, female mice ovulate more slowly or stop ovulation altogether. In some species of birds, failure to gain a territory prevents the onset of sexual maturity.

In many animals, then, population growth is regulated by benign internal causes without any need for the periodic devastations Darwin supposed. Another fault in Darwin's argument is the assumption that "amongst animals there are very few which do not annually pair."[133] On the contrary, a large nonbreeding portion of the adult population is the norm in many species. In a five-year study of nearly two hundred white rhinoceros in Zululand, South Africa, Norman Owen-Smith found that only two-thirds of the adult population maintain territories, allowing subordinate males to graze in their territory but not allowing them to breed.[134] Many bird species keep a reserve of nonbreeders in the population. This was discovered accidentally in a study of the spruce bud worm and its predators. Experimenters Robert Stewart and John Aldrich attempted to eliminate the birds from a forty-acre tract of land in Maine by shooting.[135] The number of territorial males before the shooting took place was 148. Stewart and Aldrich shot and collected 302 males from the area, however, in less than a month. They write: "For most species, over twice as many adult males were collected on the area as were present before the collecting started."[136] The explanation was a large, surplus population of unmated males that quickly filled in vacated territories. The replacement of removed birds does not demonstrate competition but is a safety device to regulate the population. In other experiments it was found impossible to reduce the numbers of juncos in a given area because of immediate replacement by immigrants from the surrounding area.[137]

We may infer from these experiments that predation would not significantly affect the population growth rate in such species. According to Ricklefs, "Detailed removal-replacement experiments have had similar results, indicating that territorial limitation of breeding population is quite general."[138] This includes field studies on blackbirds, red grouse, voles, dragonflies, and pomacentrid fish. Not taking these facts into account, any argument for geometric increase in natural populations is based on "mere theoretical calculation," which, though mathematically correct, are biologically irelevant.

And it is also erroneous to assume that those adults that do mate produce the same number of offspring each season. A wide range of animals vary their litter size and clutch size according to the amount of food available. Elton observes: "The short-eared owl (*Asio flammeus*) may have twice as many young in a brood and twice as many broods as usual, during a vole plague, when its food is extremely plentiful."[139] Lack points out that nutcrackers normally lay only three eggs but increase the clutch to four eggs when there is a bumper crop of hazelnuts. He also mentions that the arctic fox is known to produce much larger litters when lemmings are abundant, and that lions bear more or fewer cubs per litter according to the availability of food.[140] By contrast, in lean years many species do not breed at all.

In some cases the herbivore population is controlled by the plant. For example, in years following a drought, sagebrush develops high concentrations of phytoestrogens that mimic reproductive hormones in the California quail. These hormones inhibit ovulation in the quail that consume the sagebrush, causing a sharp drop in the size of the quail population. When rainfall becomes more plentiful, the sagebrush has little or no estrogen mimics, and quail populations return to normal. Here the herb imposes birth control on the herbivore. Studies show also that ovarian activity is shut down in mountain voles in the late summer because of phytoestrogen buildup in the grasses they consume.[141]

Also false is the assumption that animals and plants produce as many eggs and seeds as physiologically possible. All bird species have a normal clutch size, but if eggs are removed, the female can be induced to lay many more. The domestic fowl, if left all its eggs, produces a clutch of about twelve, but if the eggs are removed daily, it can lay up to 360 per year.

The normal number of eggs varies greatly from one species to the next. Flamingos lay one egg, ostriches twelve to fifteen. Ecologist Y. Ito records that "Among the frogs an egg mass of *Rana nigromaculata* contains about 1,000 eggs but the number of eggs laid by *Flectonotus pygmaeus* ranges from four to seven, which is smaller than the clutch size of many birds or the litter size of rats."[142] The general rule is that the number of eggs is inversely proportional to parental care and protection. The female mackerel, which offers no care to its young, lays two to three million eggs, 99.9996 percent of which are eaten by predators within seventy days, leaving only two or three individuals that reach adulthood.[143] The sea catfish, on the other hand, lays only thirty eggs per season; almost all survive because the male protects them in his mouth. Producing enormous numbers of offspring is not proof of ruthless competition but rather of cooperation since the excess of eggs and seeds supports thousands of predators that could not otherwise subsist. If all species used the high-care, low-fecundity strategy, the vast numbers and varieties of animals we see in nature would not be possible. And this is not accomplished at the price of annihilating the prey species. There are still millions of mackerel in the sea every year.

No species strives to increase without limit, any more than an individual tends to grow to infinity. And animal populations are limited not by struggle, starvation, and death, but by restricting the number of breeders in various ways and by varying the number of offspring produced at a time by each female. Biologist V. C. Wynne-Edwards comments on Darwin's assumption that every living thing strives to increase its numbers geometrically:

"This intuitive assumption of a universal resurgent pressure from within held down by hostile forces from without has dominated the thinking of biologists on matters of population regulation, and on the nature of the struggle for existence, right down to the present day.

"Setting all preconceptions aside, however, and returning to a detached assessment of the facts revealed by modern observation and experiment, it becomes almost immediately evident that a very large part of the regulation of numbers depends not on Darwin's hostile forces but on the initiative taken by the animals themselves; that is to say, to an important extent it is an intrinsic phenomenon."[144]

That populations are self-regulating fits well with the notion of life as directed self-movement. Nature is not at war, one organism with another. Nature is an alliance founded on cooperation.

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GOOD NATURED

The Origins of Right and Wrong in Humans and Other Animals

Frans de Waal

Harvard University Press
Cambridge, Massachusetts • London, England

1
DARWINIAN DILEMMAS

> Be warned that if you wish, as I do, to build a society in which individuals cooperate generously and unselfishly towards a common good, you can expect little help from biological nature. Let us try to *teach* generosity and altruism, because we are born selfish.
>
> *Richard Dawkins*[1]

> Why should our nastiness be the baggage of an apish past and our kindness uniquely human? Why should we not seek continuity with other animals for our 'noble' traits as well?
>
> *Stephen Jay Gould*[2]

Famous in her country as the star of several nature documentaries, Mozu looks like any other Japanese monkey except for missing hands and feet and an arresting countenance that appears to reflect lifelong suffering. She roams the Shiga Heights of the Japanese Alps on stumpy limbs, desperately trying to keep up with more than two hundred healthy group mates. Her congenital malformations have been attributed to pesticides.

When I first visited Jigokudani Park in 1990, Mozu was already eighteen years old—past prime for a female macaque. She had successfully raised five offspring, none of whom showed abnormalities. Given the extended period of nursing and dependency of primate young, no one would have dared to predict such a feat for a female who must crawl over the ground, even in midwinter, to stay with the rest. While the others jump from tree to tree to avoid the ice and snow covering the forest floor, Mozu slips and slides through shoulder-high snow with an infant on her back.

One thing that the monkeys in Jigokudani Park have in their favor is hot-water springs, in which they temporarily escape from the glacial temperatures, grooming one another amid clouds of steam. Another factor that makes life easier is food provisioning. Modest amounts of soybeans and apples are distributed twice daily at the park. Caretakers say they give Mozu extra food and protect her when she encounters competition from other monkeys. They try to make up for the trouble she has obtaining food, yet stress that Mozu does not dally at the feeding site. She is really part of the troop. Like the rest, she spends most of her time in the mountain forest, away from people.

Survival of the Unfittest

My first reaction to Mozu was one of awe: "What a will to live!" The connection with morality came later, when I heard how much paleontologists were making of the occasional survival into adulthood of Neanderthals and early humans afflicted with dwarfism, paralysis of the limbs, or inability to chew. With exotic names such as Shanidar I, Romito 2, the Windover Boy, and the Old Man of La Chapelle-Aux-Saints, the fossil remains of a handful of cripples were taken to mean that our ancestors supported individuals who could contribute little to the community. Survival of the weak, the handicapped, the mentally retarded, and others who must have posed a burden was depicted as the first appearance on the evolutionary scene of compassion and moral decency. Cavemen turned out to be communitarians under the skin.

Accepting this logic, should we not also include Mozu's survival as an example of moral decency? One might counter that the artificial food provisioning at Jigokudani Park disqualifies her, since we do not know if she would have made it without the extra food. Moreover, if active community support is our criterion, Mozu can be eliminated right away because there is no shred of evidence that other monkeys have ever gone out of their way to assist her in her monumental struggle for existence.

Exactly the same arguments have been raised against the Shanidars and Romitos of the human fossil record. According to K. A. Dettwyler, an anthropologist, it is possible that these individuals lived in rich environments in which the sharing of resources with a few impaired community members posed no problem. In return, the handicapped individuals may have made themselves useful by collecting firewood, baby-sitting, or cooking. Dettwyler also argues that there is a wide gap between mere survival and being treated well. She describes cultures in which mentally retarded people are stoned, beaten, and jeered at for public amusement, or in which people afflicted with polio do not receive any special consideration ("adult women crawled on hands and knees with children tied to their backs").[3] As for Western society, we need only think of the filthy asylums of the not-too-distant past, and the chained existence of the insane, to realize that survival does not necessarily imply humane conditions.

Without knowing the precise similarities and differences between Mozu and the human fossils, I do not think these fossils prove moral decency any more than does Mozu's survival. Only a relatively tolerant attitude toward the handicapped can be inferred in both cases. Mozu is certainly well accepted by her group mates, a fact that may have contributed to her survival. If what happened in 1991 is any measure, Mozu may even enjoy a special level of tolerance.

In the spring of that year, the troop of monkeys at Jigokudani had grown so large that it split in half. As usual during fissioning, the dividing line followed the backbone of macaque society, the matrilineal hierarchy (female kin are closely bonded and united in their battles with nonkin, the result being a social order based on matrilineal descent). One piece of the troop consisted of a few dominant matriarchs and their families; the other included subordinate matriarchs and their families. Being of low rank, Mozu and her offspring ended up in the second division.

According to Ichirou Tanaka, a Japanese primatologist who has worked at the park for years, the fission posed a serious problem for Mozu. The dominant division began to claim the park's feeding site for itself, aggressively excluding all other monkeys. Faced with this situation, Mozu made a unique decision. Whereas female macaques normally maintain lifelong bonds of kinship, Mozu ignored the ties with her offspring and began making overtures to individuals in the dominant division. Despite occasional attacks on her, she stayed at the periphery, seeking contact with age-peers, females with whom she had grown up nineteen years before. She made repeated attempts to groom them (without fingers, Mozu's rather clumsy grooming still served to initiate contact). Eventually her peers began to accept her presence, and to return Mozu's grooming. Mozu is now well integrated into the dominant troop, once again enjoying the feeding site, yet having paid for this advantage with permanent separation from her kin.

In no society worthy of the name do the members lack a sense of belonging and a need for acceptance. The ability and the tendency to construct such associations, and to seek security within them, are products of natural selection found in members of species with better survival chances in a group than in solitude. The advantages of group life can be manifold, the most important being increased chances to find food, defense against predators, and strength in numbers against competitors. For example, it may be of critical importance during a drought to have older individuals around who can lead the group to an almost-forgotten waterhole. Or, during periods of heavy predation all eyes and ears count, especially in combination with an effective warning system. Each member contributes to and benefits from the group, although not necessarily equally or at the same time.

Mozu's case teaches us that even though primate groups are based on such give-and-take contracts, there is room for individuals with little value when it comes to cooperation. The cost to the others may be negligible, but their inclusion is remarkable, given the realistic alternative of ostracism.

Noting that Japanese monkeys can be quite aggressive, at times demonstrating what he calls murderous intent, Jeffrey Kurland described the following concerted action against a particular matriline at a site far from Jigokudani.

A female of the top matriline started a fight with a low-ranking female named Faza-71. The attacker and her supporters (a sister, a brother, and a niece) made so much noise that the alpha male (the troop's most dominant male) was attracted to the scene. By the time he arrived, Faza-71 was high in a tree, a position from which she was forced to jump 10 meters to the ground when the male climbed up and cuffed her. Fleeing from her pursuers, Faza-71 saw no escape other than an icy, fast-streaming river. Her attackers wisely stayed on land, but for a long time prevented the frantically swimming Faza-71 from coming back on the riverbank. In the meantime Faza-71's family, powerless to help, fled over a dam across the river.

But for a small pile of sand under a chilly waterfall, Faza-71 would have drowned. Bleeding and apparently in shock, she waited to join her family until the attackers had dispersed. The entire encounter lasted less than half an hour; but it took more than a week for Faza's matriline to rejoin the troop, and many months for them to relax in the presence of the dominant matriline.[4]

Biologicizing Morality

Social inclusion is absolutely central to human morality, commonly cast in terms of how we should or should not behave in order to be valued as members of society. Immoral conduct makes us outcasts, either here and now or—in the beliefs of some people—when we are turned away from the gates of heaven. Universally, human communities are moral communities; a morally neutral existence is as impossible for us as a completely solitary existence. As summed up by Mary Midgley, a philosopher, "Getting right outside morality would be rather like getting outside the atmosphere."[5] Human morality may indeed be an extension of general primate patterns of social integration, and of the adjustment required of each member in order to fit in. If so, the broadest definition of this book's theme would be as an investigation into how the social environment shapes and constrains individual behavior.

No doubt some philosophers regard morality as entirely theirs. The claim may be justifiable with regard to the "high end" of morality: abstract moral rules can be studied and debated like mathematics, almost divorced from their application in the real world. According to child psychologists, however, moral reasoning is constructed upon much simpler foundations, such as fear of punishment and a desire to conform. In general, human moral development moves from the social to the personal, from a concern about one's standing in the group to an autonomous conscience. While the early stages hardly seem out of reach of nonhuman animals, it is impossible to determine how close they get to the more rational, Kantian levels. Reliable nonverbal signs of thought in humans do not exist, and the indicators that we sometimes do use (staring into the distance, scratching the head, resting the chin on a fist) are commonly observed in anthropoids. Would an extraterrestrial observer ever be able to discern that humans ponder moral dilemmas, and if so, what would keep that observer from arriving at the same conclusion for apes?

Biologists take the back door to the same building that social scientists and philosophers, with their fondness for high-flung notions, enter through the front door. When the Harvard sociobiologist E. O. Wilson twenty years ago proclaimed that "the time has come for ethics to be removed temporarily from the hands of philosophers and biologicized,"[6] he formulated the same idea a bit more provocatively. My own feeling is that instead of complete reliance on biology, the best way to generate fresh air is simultaneously to open both front and back doors. Biologists look at things in a rather functional light; we always wonder about the utility of a trait, on the assumption that it would not be there if it did not serve some purpose. Successful traits contribute to "fitness," a term that expresses how well adapted (fitted) an individual is to its environment. Still, emphasis on fitness has its limitations. These are easily recognized when paleontologists hold up the fossil remains of an ancestor who could barely walk, declaring it a defining moment in human prehistory when the unfit began to survive.

To understand the depth of these limitations, one need only realize the influence of Thomas Malthus' essay on population growth that appeared at the beginning of the nineteenth century. His thesis was that populations tend to outgrow their food supply and are cut back automatically by increased mortality. The idea of competition within the *same* species over the *same* resources had immediate appeal to Charles Darwin, who read Malthus; it helped bring his Struggle for Existence principle into focus.

Sadly, with these valuable insights came the burden of Malthus' political views. Any help one gives the poor permits them to survive and propagate, hence negates the natural process according to which these unfortunates are supposed to die off. Malthus went so far as to claim that if there is one right that man clearly does *not* possess, it is the right to subsistence that he himself is unable to purchase with his labor.[7]

Although Darwin appears to have struggled more with the moral implications of these ideas than most of his contemporaries, he could not prevent his theory from being incorporated into a closed system of thought in which there was little room for compassion. It was taken to its extreme by Herbert Spencer in a grand synthesis of sociology, political economy, and biology, according to which the pursuit of self-interest, the lifeblood of society, creates progress for the strong at the expense of the inferior. This convenient justification of disproportionate wealth in the hands of a happy few was successfully exported to the New World, where it led John D. Rockefeller to portray the expansion of a large business as "merely the working-out of a law of nature and a law of God."[8]

Given the popular use and abuse of evolutionary theory (comparing Wall Street to a Darwinian jungle, for example), it is not surprising that in the minds of many people natural selection has become synonymous with open, unrestricted competition. How could such a harsh principle ever explain the concern for others and the benevolence encountered in our species? That a reason for such behavior does not follow readily from Darwin's theory should not be held against it. In the same way that birds and airplanes appear to defy the law of gravity yet are fully subjected to it, moral decency may appear to fly in the face of natural selection yet still be one of its many products.

Altruism is not limited to our species. Indeed, its presence in other species, and the theoretical challenge this represents, is what gave rise to *sociobiology*—the contemporary study of animal (including human) behavior from an evolutionary perspective. Aiding others at a cost or risk to oneself is widespread in the animal world. The warning calls of birds allow other birds to escape a predator's talons, but attract attention to the caller. Sterile castes in social insects do little else than serve food to the larvae of their queen or sacrifice themselves in defense of their colony. Assistance by relatives enables a breeding pair of jays to fill more hungry mouths and thus raise more offspring than otherwise possible. Dolphins support injured companions close to the surface in order to keep them from drowning. And so on.

Should not a tendency to endanger one's life for someone else be quickly weeded out by natural selection? It was only in the 1960s and 1970s that satisfactory explanations were proposed. According to one theory, known as *kin selection*, a helping tendency may spread if the help results in increased survival and reproduction of kin. From a genetic perspective it does not really matter whether genes are multiplied through the helper's own reproduction or that of relatives. The second explanation is known as *reciprocal altruism*; that is, helpful acts that are costly in the short run may produce long-term benefits if recipients return the favor. If I rescue a friend who almost drowns, and he rescues me under similar circumstances, both of us are better off than without mutual aid.

Wilson's *Sociobiology: The New Synthesis* summarized the new developments. It is an influential and impressive book predicting that all other behavioral sciences will one day see the light and convert to the creed of sociobiology. Confidence in this future was depicted in an amoebic drawing with pseudopods reaching out to devour other disciplines. Understandably, nonbiologists were piqued by what they saw as an arrogant attempt at annexation; but also within biology, Wilson's book provoked battles. Should Harvard be allowed to lay claim to an entire field? Some scientists preferred to be known as behavioral ecologists rather than sociobiologists, even though their theories were essentially the same. Moreover, like children ashamed

of their old folks, sociobiologists were quick to categorize earlier studies of animal behavior as "classical ethology." That way everyone could be sure that ethology was dead and that we were onto something totally new.

Sociobiology represents a giant stride forward; it has forever changed the way biologists think about animal behavior. Precisely because of their power and elegance, however, the new theories have lured some scientists into a gross simplification of genetic effects. Behavior that at first sight does not conform to the framework is regarded as an oddity, even a mistake. This is best illustrated by a single branch of sociobiology, which has gotten so caught up in the Malthusian dog-eat-dog view of the world that it sees no room for moral behavior. Following Huxley, it regards morality as a counterforce, a rebellion against our brutish makeup, rather than as an integrated part of human nature.[9]

Calvinist Sociobiology

At the Yerkes Regional Primate Research Center, one chimpanzee has been named Atlanta and another Georgia. It is impossible for me to forget where I am, as I see both individuals on a daily basis. I moved to the Star of the South, as the city likes to call itself, to resume my study of the species that surpasses every other when it comes to similarity to our own. My tower office has a large window that overlooks the outdoor enclosure of twenty chimpanzees. The group is as close-knit as any family can be; they are together day and night, and several of the adults were born into the colony. One of these is Georgia, the rascal of the group. Robert Yerkes, a founder of primatology, once declared it "a securely established fact that the chimpanzee is not necessarily utterly selfish."[10] From everything I know about Georgia, she is not the sort of character Yerkes had in mind when he made that declaration six decades ago.

When we provision the colony with freshly cut branches and leaves from the forest around the field station, Georgia is often the first to grab one of the large bundles, and one of the last to share it with anybody else. Even her daughter, Kate, and younger sister, Rita, have trouble getting food. They may roll over the ground, screaming in a pitiful tantrum, but to no avail.

No, Yerkes must have thought of individuals such as Mai, an older high-ranking female, who shares quite readily not only with her children but also with nonrelatives, young and old. Or he may have thought of adult male chimpanzees, most of whom are remarkably generous when it comes to food distribution.

While a distinction between sharing and keeping means a lot in human society, it is sometimes lost in the language of a particular brand of sociobiology that takes the gene as absolute king. Gene-centric sociobiology has managed to reach a wide audience with its message that humans and other animals are entirely selfish. From this standpoint, the only difference between Mai and Georgia is in the *way* they pursue self-interest; whereas Georgia is just plain greedy, Mai shares food so as to make friends or receive return favors in the future. Both think only of themselves. In human terms, this interpretation amounts to the claim that Mother Teresa follows the same basic instinct as any inside trader or thief. A more cynical outlook is hard to come by.

Gene-centric sociobiology looks at survival and reproduction from the point of view of the gene, not the individual. A gene for bringing home food for one's children, for example, will ensure the survival of individuals likely to carry the same gene.[11] As a result, that gene will spread. Taken to its logical extreme, genes favor their own replication; a gene is successful if it produces a trait that in turn promotes the gene (sometimes summed up as "a chicken is an egg's way of making other eggs"). To describe such genetic self-promotion, Richard Dawkins introduced a psychological term in the title of his book, *The Selfish Gene*. Accordingly, what may be a generous act in common language, such as bringing home food, may be selfish from the gene's perspective. With time, the important addition "from the gene's perspective" was often forgotten and was eventually left out. All behavior was selfish, period.

Since genes have neither a self nor the emotions to make them selfish, one would think this phrase is just a metaphor. True, but when repeated often enough, metaphors tend to assume an aura of literal truth. Even though Dawkins cautioned against his own anthropomorphism of the gene, with the passage of time, carriers of selfish genes became selfish by association. Statements such as "we are born selfish" show how some sociobiologists have made the nonexistent emotions of genes into the archetype of true emotional nature. A critical article by Mary Midgley compared the sociobiologists' warnings against their own metaphor to the paternosters of the Mafiosi.

Pushed into a corner by a witty philosopher, Dawkins defended his metaphor by arguing that it was *not* a metaphor. He really meant that

genes are selfish, and claimed the right to define selfishness any way he wanted. Still, he borrowed a term from one domain, redefined it in a very narrow sense, then applied it in another domain to which it is completely alien. Such a procedure would be acceptable if the two meanings were kept separate at all times; unfortunately, they merge to the extent that some authors of this genre now imply that if people occasionally think of themselves as unselfish, the poor souls must be deceiving themselves.

It is important to clear up this confusion, and to emphasize once and for all that the selfish gene metaphor says nothing, either directly or indirectly, about motivation, emotion, or intention. Elliott Sober, another philosopher interested in the semantic trappings of sociobiology, proposes a distinction between *vernacular egoism*, our everyday usage of the term, and *evolutionary egoism*, which deals exclusively with genetic self-promotion. A plant, for example, is able to further its genetic interests yet cannot possibly be selfish in the vernacular sense. A chimpanzee or person who shares food with others acts altruistically in the vernacular sense, yet we assume that the behavior came into existence because it served survival and reproduction, hence that it is self-serving in an evolutionary sense.[12]

There is almost no point in discussing the evolution of morality if we let the vernacular sense of our terminology be overshadowed by the evolutionary sense. Human moral judgment always looks for the intention behind behavior. If I lean out of a window on the fifth floor and unknowingly nudge a flowerpot, thereby killing a pedestrian on the sidewalk below, I might be judged awkward or irresponsible, but not murderous. The latter accusation would surely be heard, however, had someone watched me grab the pot and throw it at the person. The effect is the same, but the motives are absolutely crucial. Jury and judge would want to know which emotions I showed, the degree of planning involved, my relationship with the target, and so on. In short, they would want to fathom the psychology behind the act.

These distinctions are largely irrelevant within a sociobiology exclusively interested in the effects of behavior. In such a framework, no different values are attached to intended versus unintended results, self-serving versus other-serving behavior, what we say versus what we mean, or an honest versus a dishonest mistake. Having thus denied themselves the single most important handle on ethical issues, some sociobiologists have given up on explaining morality. William Hamilton, the discoverer of kin selection, has written that "the animal in our nature cannot be regarded as a fit custodian for the values of civilized man," and Dawkins urges us to cultivate pure, disinterested altruism because it does not come naturally. "We, alone on earth, can rebel against the tyranny of the selfish replicators."[13] By thus locating morality outside nature, these scientists have absolved themselves from trying to fit it into their evolutionary perspective.

An even more alarming position was adopted by George Williams in a commentary on Huxley's celebrated "Evolution and Ethics" lecture. Calling nature morally indifferent, as Huxley had done, was not enough for Williams, who preferred "gross immorality" and "moral subversiveness." He went on to demonstrate that "just about every . . . kind of sexual behavior that has been regarded as sinful or unethical can be found abundantly in nature." This conclusion was accompanied by a depressing enumeration of animal murder, rape, and wretchedness.[14]

Can we really pass judgment on other animals any more than we can on the flow of a river or the movement of nuclear particles? Does doing so get us beyond age-old stereotypes such as the hard-working bee, the noble horse, the cruel wolf, and the gluttonous pig? Granted, animals may possess standards of behavior, perhaps even ethical standards. Yet Williams was not measuring their behavior against their own standards, but against those of the culture of which he happens to be part. Since animals failed to meet his criteria, he declared nature, including human nature, our foe. Note, again, how vernacular egoism slips into a statement about the evolutionary process: "The enemy is indeed powerful and persistent, and we need all the help we can get in trying to overcome billions of years of selection for selfishness."[15]

By now, I am sure, the reader must have smelled the perfume Egoïste (an actual Chanel creation) to the point of either conviction or stupefaction. How in the world could a group of scientists come up with such a pale view of the natural universe, of the human race, of the people close to them, and of themselves (because we must assume that their theory knows no exceptions)? Do they not see that, to paraphrase Buddha, wherever there is shadow, there is light?

Underlying their position is a monumental confusion between process and outcome. Even if a diamond owes its beauty to millions of years of crushing pressure, we rarely think of this fact when admiring the gem. So why should we let the ruthlessness of natural selection distract from the wonders it has produced? Humans and other animals have been endowed with a capacity for genuine love, sympathy,

and care—a fact that can and will one day be fully reconciled with the idea that genetic self-promotion drives the evolutionary process.

It is not hard to find the origin of the proposed abyss between morality and nature. The conviction is well established outside science. The image of humanity's innate depravity and its struggle to transcend that depravity is quintessentially Calvinist, going back to the doctrine of original sin. Tension between civic order and our bestial ancestry, furthermore, is the centerpiece of Sigmund Freud's *Civilization and Its Discontents*. Freud argues that we need to control and renounce our baser instincts before we can build a modern society. Hence, we are not dealing with a mere biological theory, but with a convergence between religious, psychoanalytical, and evolutionary thought, according to which human life is fundamentally dualistic. We soar somewhere between heaven and earth on a "good" wing—an acquired sense of ethics and justice—and a "bad" wing—a deeply rooted egoism. It is the age-old half-brute, half-angel view of humanity.

It must be rather unsatisfactory, to say the least, for gene-centric sociobiologists to be obliged to exclude one domain from their Theory of Everything. And not a trivial domain, but precisely the one many of us consider to be at the core of being human. Failure to account for morality in terms of genetic selfishness is the logical outcome of such reductionism. If we shrug off attempts to attribute love to hormones or hatred to brain waves—knowing that these attributions are only part of the story—it is good to realize that these are tiny jumps compared with the reduction of human psychology to gene action.

Fortunately, the current pendulum swing is away from such simplifications. It is toward attempts to explain living systems in their entirety, integrating many different levels. In the words of a recent task force of the National Science Foundation, "The biological sciences are moving away from the era of analytical reductionism . . . from taking biological systems apart to see what the pieces are and how they work, to putting the pieces back together to understand how the totality works together."[16]

One does not need to follow this holistic swing all the way to Gaia (the idea that the biosphere acts as a single organism) to agree that the current development indicates greater scientific maturity. In the New and Improved Sociobiology, animals still do everything to survive and reproduce, yet take their circumstances into account so as to choose the best course of action: from "survival machines" they have become "adaptive decision-makers." With so many degrees of freedom added, selfish-gene thinking can now safely be relegated to history as "classical sociobiology."

Have I been kicking a dead horse, then? I do not think so. Gene-centric sociobiology is the type best known to the general public. It is still widespread in certain academic circles, particularly those outside biology that have battled hard within their respective disciplines to stake out and defend an evolutionary approach. Furthermore, as a corollary to the belief in a natural world red in tooth and claw, there remains tremendous resistance, both inside and outside biology, to a terminology acknowledging beauty in the beast.

The sociobiological idiom is almost derisive in its characterization of animals. Given the image of biologists as nature buffs, it may be shocking for outsiders to learn that the current scientific literature routinely depicts animals as "suckers," "grudgers," and "cheaters" who act "spitefully," "greedily," and "murderously." There is really nothing lovable about them! If animals do show tolerance or altruism, these terms are often placed in quotation marks lest their author be judged hopelessly romantic or naive. To avoid an overload of quotation marks, positive inclinations tend to receive negative labels. Preferential treatment of kin, for instance, instead of being called "love for kin," is sometimes known as "nepotism."

As noted by economist Robert Frank (referring to a problem common to the behavioral sciences):

> The flint-eyed researcher fears no greater humiliation than to have called some action altruistic, only to have a more sophisticated colleague later demonstrate that it was self-serving. This fear surely helps account for the extraordinary volume of ink behavioral scientists have spent trying to unearth selfish motives for seemingly self-sacrificing acts.[17]

As a student of chimpanzee behavior, I myself have encountered resistance to the label "reconciliation" for friendly reunions between former adversaries. Actually, I should not have used the word "friendly" either, "affiliative" being the accepted euphemism. More than once I was asked whether the term "reconciliation" was not overly anthropomorphic. Whereas terms related to aggression, violence, and competition never posed the slightest problem, I was supposed to switch to dehumanized language as soon as the affectionate aftermath of a fight was the issue. A reconciliation sealed with a kiss

became a "postconflict interaction involving mouth-to-mouth contact."

Barbara Smuts ran into the same resistance when she chose "friendship" as an obvious label for intimate relationships between adult male and female baboons. Can animals really have friends? was the question of colleagues who without blinking accepted that animals have rivals. Given this double standard, I predict that the word "bonding" will soon become taboo as well, even though it was initially coined by ethologists as a neutral reference to emotional attachment. Ironically, the term has since entered common English with precisely the meaning it tried to circumvent, as in "mother-child bond" and "male bonding." It is rapidly becoming too loaded for students of animal behavior.

Animals, particularly those close to us, show an enormous spectrum of emotions and different kinds of relationships. It is only fair to reflect this fact in a broad array of terms. If animals can have enemies they can have friends; if they can cheat they can be honest, and if they can be spiteful they can also be kind and altruistic. Semantic distinctions between animal and human behavior often obscure fundamental similarities; a discussion of morality will be pointless if we allow our language to be distorted by a denial of benign motives and emotions in animals.

An intriguing expression of emotion occurred once when, in the middle of the day, our entire chimpanzee colony unexpectedly gathered around Mai. All the apes were silent, staring closely at Mai's behind, some of them carefully poking a finger at it and then smelling their finger. Mai was standing half upright, with her legs slightly apart, holding one hand between her legs. Remarkably, an attentive older female mimicked Mai by cupping her hand between her own legs in exactly the same fashion.

After approximately ten minutes, Mai tensed, squatted more deeply, and passed a baby, catching it in both hands. The crowd stirred, and Atlanta, Mai's best friend, emerged with a scream, looking around and embracing a couple of other chimpanzees next to her, one of whom uttered a shrill bark. Mai then went to a corner to clean the baby and consumed the afterbirth with gusto. The next day Atlanta defended Mai fiercely in a fight, and during the following weeks she frequently groomed Mai, staring at and gently touching Mai's healthy new son.

This was the very first time I witnessed a chimpanzee birth. I have seen several macaque births, though, and the big difference is that other macaques do not approach the mother. It is hard to tell if they are even interested; there is no obvious excitement or curiosity about the delivery. Positive interest occurs only after the amniotic sac has been removed and the infant has been cleaned. For macaques are extremely attracted to newborns. Our chimpanzees responded much earlier; they seemed as much taken with the process as with its outcome. It is entirely possible that the emotional reaction of Atlanta (who has had quite a few infants of her own) reflected ***empathy,*** that is, identification with and understanding of what was happening to her friend.[18]

Needless to say, empathy and sympathy are pillars of human morality.

A Broader View

A climbing orangutan grasps a branch with one hand, holding on tightly until the other hand has found the next branch. Then the roles are reversed, and the first hand releases its grip in order to get hold of another branch. Elias Canetti, in *Crowds and Power,* noticed a connection between the ancient arboreal function of one of our most versatile organs and the universal human ritual of barter and trade: climbing through the trees may have predisposed us for economic exchange, since both activities depend on the careful coordination of grasp and release. With his goods held out in one hand, the tradesman reaches with the other for his partner's goods, mindful not to release anything before his grip on the desired goods is secure. Failure to perform this sequence in the right order or with the right timing may have fatal consequences in the trees in the same way that it may leave the human trader empty-handed. Material exchange has become second nature to us; most of the time we reflect as little on the risks as does a monkey racing through the canopy.

Canetti's is a fascinating parallel, yet there exists of course no causal connection. Otherwise the octopus would be the champion merchant of the animal kingdom, and animals without hands, such as dolphins and bats, would be excluded as possible traders. It is precisely bats, mammals with front limbs transformed into wings, who provide us with some of the first evidence for give-and-take relations in animals. Gruesome as it may sound, vampire bats trade meals by regurgitating blood to one another. At night these bats

stealthily lap blood from a small patch of flesh exposed by razor-sharp teeth on a sleeping mammal, such as a horse or cow. With their bellies full, the bats return to the hollow tree in which they spend the day. We know about their blood economy because the bats sometimes share their roost with a scientist who spends hours on his back, legs outside and torso inside an opening at the base of the tree, peering upward to collect behavioral information along with the inevitable bat droppings.

Having tagged his subjects with reflective bands in order to recognize them in the dark, Gerald Wilkinson noticed that mother bats often regurgitate blood to their offspring. While this is not too surprising, the investigator saw other combinations share on twenty-one occasions—mostly individuals who often associated and groomed. There appeared to be a "buddy system" of food exchange, in which two individuals could reverse roles from night to night, depending on how successful each had been in finding blood. Because they are unable to make it through more than two nights in a row without food, it is a matter of life or death for vampire bats to have such buddies. Although the evidence is still meager, Wilkinson believes that these animals enter into social contracts in which each occasionally contributes part of a meal so as to be able to solicit a life-saving return favor during less favorable times.

Petr Kropotkin would have loved these little bats, as they exemplify the evolutionary principle advocated in his famous book *Mutual Aid,* which was first published in 1902. Though bearded and an anarchist, Kropotkin must not be thought of as a wild-eyed zealot. Stephen Jay Gould assures us, "Kropotkin is no crackpot."[19] Born a Russian prince, and very well educated, he was a naturalist and intellectual of great distinction. He was offered the position of secretary to the Imperial Geographical Society in Saint Petersburg, and later, during his exile in England, a chair in geology at Cambridge University. He declined both positions inasmuch as they would have interfered with his political activities, which aimed, according to a comrade, at opposing with an ecstasy of expiation the very injustice of which fate had made him the involuntary beneficiary.

Animals, Kropotkin argued in *Mutual Aid,* need to assist one another in their struggle for existence; a struggle, not so much of each against all, but of masses of organisms against the adversity of their environment. Cooperation is common, as when beavers together dam off a river or when horses form a protective ring against attacking wolves. Kropotkin did not stand alone in his emphasis on sociality and communion among animals: an entire generation of Russian scientists was uncomfortable with the primacy given in evolutionary thought to competition. Daniel Todes, in a fascinating treatise on Russian natural science aptly entitled *Darwin without Malthus,* argued that there may have been geographical reasons for this different outlook.

Whereas Darwin found inspiration in a voyage to rich, abundant tropical regions, Kropotkin at the age of nineteen set out to explore Siberia. Their ideas reflect the contrast between a world where life is easy, resulting in high population densities and intense competition, and one where life is harsh and filled with unpredictable dangers. When discussing evolution, Kropotkin and his compatriots always had their sparsely populated continent in mind, with its rapidly changing weather and extreme seasonality. He described climatic calamities that could render a territory as large as France and Germany combined absolutely impracticable for ruminants, in which horses could be scattered by the wind, and entire herds of cattle could perish under piles of snow.

> [These calamities] made me realize at an early date the overwhelming importance in nature of what Darwin described as "the natural checks to over-multiplication," in comparison to the struggle between individuals of the same species for the means of subsistence, which may go on here and there, to some limited extent, but never attains the importance of the former. Paucity of life, under-population—not over-population—being the distinctive feature of that immense part of the globe which we name Northern Asia, I conceived since then serious doubts as to the reality of that fearful competition for food and life within each species, which was an article of faith with most Darwinists, and, consequently, as to the dominant part which this sort of competition was supposed to play in the evolution of new species.

Kropotkin objected vehemently to the depiction of life as a "continuous free fight" and a "gladiator's show" made popular by the same Huxley who five years later, just before his death, partially reversed and softened his position to introduce morality as humanity's saving grace. Playing down Huxley's competitive principle, Kropotkin instead saw a communal principle at work: cooperation and mutual assistance among animals arose in response to the common enemy. The idea of a common enemy is perhaps the most significant

of all of Kropotkin's ideas. In his mind it referred to the hostile environment in which many animals try to exist and multiply.

Kropotkin's analysis had serious flaws, and he sprinkled *Mutual Aid* with highly selective, often dubious examples to make his case. He had a (not so) hidden revolutionary agenda, and read political preferences into nature to the point that he totally overlooked its nasty side. He stated that "in the face of free Nature, the unsociable instincts have no opportunity to develop, and the general result is peace and harmony." Kropotkin, however, was writing in direct response to people who reduced everything in nature to savage, unmitigated combat.[20] Their position too could hardly be considered free from ideological bias. Russian scientists of that period saw the gladiatorial view as a concoction of the British upper class to defend the status quo.

Kropotkin cast his arguments in terms of survival of the group, or the species as a whole. Rejection of this view, known as group selection, marked the rise of sociobiology. Contemporary biologists in general do not believe that behavior evolved for a greater good. They assume that if bats, bees, dolphins, and other animals help one another, there must be benefits for each and every participant or their kin, otherwise the trait would not have spread.[21]

Old ideas never die completely, and group selection has been staging a gradual comeback.[22] It is also good to realize that Kropotkin was in excellent company in his belief that the success of the group matters: Darwin himself leaned toward group selection when tackling the issue of morality. He literally saw one tribe gain advantage over another:

> At all times throughout the world tribes have supplanted other tribes; and as morality is one element in their success, the standard of morality and the number of well-endowed men will thus everywhere tend to rise and increase.[23]

I should not leave the impression that Darwin and Kropotkin were in the same league as thinkers about evolution. Darwin argued his case much more systematically and coherently, and with vastly greater knowledge, than did the Russian naturalist. *Mutual Aid* was no match for Darwin's powerful exposé of the principles of natural selection, and Kropotkin, despite profound disagreements with Darwin's followers, never wavered in his admiration for the master himself.

Nevertheless, scientists retain a tendency to claim the primacy of one head or the other, and ethologists have been no exception. Virtually every existing moral principle has by now been biologically explained, a dubious genre of literature going back to Ernest Seton's *Natural History of the Ten Commandments,* published in 1907. Other biblical titles have followed, principally in the German language, spelling out how moral principles contribute to survival of the species.[33] If law and religion prohibit the killing of fellow humans, the reasoning goes, it is in order to prevent extinction of the human race. Supported by the then-prevailing opinion that no animal ever lethally attacks a member of its own species, this argument sounded logical enough. But we know now that we are by no means the only murderous species, not even the only "killer ape." In the Arnhem chimpanzee colony, for example, one male was killed and castrated by two others in a fight over sex and power. The steadily growing list of species in which lethal aggression occurs—even if rarely—illustrates the weakness of species-survival arguments.[34]

Much of this literature assumes that the world is waiting for biologists to point out what is Normal and Natural, hence worth being adopted as ideal. Attempts to derive ethical norms from nature are highly problematic, however. Biologists may tell us how things are, perhaps even analyze human nature in intricate detail, yet there is no logical connection between the typical form and frequency of a behavior (a statistical measure of what is "normal") and the value we attach to it (a moral decision). Lorenz came close to confusing the two when he was disappointed that the perfect goose marriage, with the partners faithful unto death, was actually quite rare. But perhaps Lorenz was only titillating his readers with his favorite birds' "shortcomings," because he also gave us his student's wonderful retort: "What do you expect? After all, geese are only human!"[35]

Known as the *naturalistic fallacy,* the problem of deriving norms from nature is very old indeed. It has to do with the impossibility of translating "is" language (how things are) into "ought" language (how things ought to be). In 1739 the philosopher David Hume made these points in *A Treatise of Human Nature:*

> In every system of morality, which I have hitherto met with, I have always remarked that the author proceeds for some time in the ordinary way of reasoning, and establishes the being of God, or makes observations concerning human affairs; when of a sudden I am surprised to find, that instead of the usual copulation of propositions, *is,* and *is not,* I meet with no proposition that is not connected with an *ought,* or an *ought not.* This change is imperceptible; but is, however, of the last consequence. For as this *ought,* or *ought not,* expresses some new relation or affirmation, it is necessary that it should be observed and explained; and at the same time that a reason should be given, for what seems altogether inconceivable, how this new relation can be a deduction from others, which are entirely different from it.[36]

To put the issue of ethics back into ethology in a more successful manner, we need to take note of the chorus of protest against previous attempts. Philosophers tell us that there is an element of rational choice in human morality, psychologists say that there is a learning component, and anthropologists argue that there are few if any universal rules. The distinction between right and wrong is made by people on the basis of how they would like their society to function. It arises from interpersonal negotiation in a particular environment, and derives its sense of obligation and guilt from the internalization of these processes. Moral reasoning is done by *us,* not by natural selection.

At the same time it should be obvious that human morality cannot be infinitely flexible. Of our own design are neither the tools of morality nor the basic needs and desires that form the substance with which it works. Natural tendencies may not amount to moral imperatives, but they do figure in our decision-making. Thus, while some moral rules reinforce species-typical predispositions and others suppress them, none blithely ignore them.[37]

Evolution has produced the requisites for morality: a tendency to develop social norms and enforce them, the capacities of empathy and sympathy, mutual aid and a sense of fairness, the mechanisms of conflict resolution, and so on. Evolution also has produced the unalterable needs and desires of our species: the need of the young for care, a desire for high status, the need to belong to a group, and so forth. How all of these factors are put together to form a moral framework is poorly understood, and current theories of moral evolution are no doubt only part of the answer.

In the remainder of this book, I will investigate the extent to which aspects of morality are recognizable in other animals, and try to illuminate how we may have moved from societies in which things were as they were to societies with a vision of how things ought to be.