THE
DIALECTICAL
BIOLOGIST
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Conclusion: Dialectics

Scientists, like other intellectuals, come to their work with a world view, a set of preconceptions that provides the framework for their analysis of the world. These preconceptions enter at both an explicit and an implicit level, but even when invoked explicitly, unexamined and unexpressed assumptions underlie them. The attempt to analyze evolution as an interaction between internal genetic causes and external environmental causes makes the distinction between organism and environment explicit. Yet underlying that distinction is the unexamined and implicit principle that organism and environment are indeed separate systems with their own autonomous properties.

We too have our own intellectual preconceptions. If we differ from most scientists, it is in our deliberate attempt to make these preconceptions explicit where we can. The earlier chapters in this book were written largely from a Marxist perspective. They reflect the conflict between the materialist dialectics of our conscious commitment and the mechanistic, reductionist, and positivist ideology that dominated our academic education and that pervades our intellectual environment. We have nowhere, however, attempted to define the dialectical method or set forth its principles in an explicit list. These chapters were not based on some clearly enumerated list of “dialectical principles.” Rather, they reflect certain habits of thought, certain forms of questioning that we identify as dialectical. Nevertheless, it seems necessary, in order to pursue the intellectual program of this collection, to attempt some explicit discussion of this way of thinking.

Formalizations of the dialectic have a way of seeming rigid and dogmatic in a way that contradicts the fluidity and historicity of the Marxist world view. This is especially the case when it is set out as “laws,” by analogy with the laws of natural science. Yet most scientific laws establish quantitative relations among variables and serve as a basis for pre-
diction. The "laws" of dialectics are clearly not analogous to, say, Einstein's equation $e = mc^2$, but rather are analogous to prior principles, the constancy of the speed of light in all inertial frames, and the conservation of momentum. Perhaps the principles of dialectics are analogous to Darwin's principles of variation, heritability, and selection in that they create the terms of reference from which quantifications and predictions may be derived.

A second reason for our reluctance to formulate the dialectic in terms of laws is that it creates the illusion that dialectics are rules derived simply from nature. They are not. A dialectical view of dialectics would emphasize that the principles and vocabulary taken over from philosophers have been transformed and invoked polemically in opposition to, as a negation of, the prevailing ideological framework of bourgeois science, the Cartesian reductionist perspective. The value of the dialectic is as a conscious challenge to the major sources of error of the present, and our own description of dialectical principles is specifically designed to help solve the problems we work with in both our scientific and our political lives.

Given the remarkable flexibility and capacity for novelty that characterize human thought, it is at least possible that any conclusion about the world could be reached by anyone, irrespective of the person's previous commitment to an ideology or world view. Newton, who accepted the supernatural world of religious belief, nevertheless conceived of a world of uncompromising mechanical necessity. But it is not necessary to insist that construction of a particular model of nature needs a particular world view to argue that ideology strongly predisposes us to see some things in the world and not others. It would have been very extraordinary indeed if a naturalist traveling with Columbus or Magellan around the turn of the sixteenth century had returned home with the same views that Darwin held when he stepped off the Beagle. Indeed, one can hardly imagine even sending a naturalist on a trip around the world in 1519. Ideas of cause and effect, subject and object, part and whole form an intellectual frame that delimits our construction of reality, although we are barely aware of its existence or, if we are, we affirm it as a self-evident reality that must constrain all thought. We do not and cannot begin at square one every time we think about the world. Knowledge is socially constructed because our minds are socially constructed and because individual thought only becomes knowledge by a process of being accepted into social currency. So dominant ideologies set the tone for the theoretical investigation of phenomena, which then becomes a reinforcing practice for the ideology itself.

Inevitably some problems of understanding the world cannot be solved in the commonly accepted ideological framework. These are either considered "fundamentally" undecidable or discreetly ignored in the triumphant march of discovery. The growth of knowledge is then akin to the conquest of land by a medieval army. Cities are laid siege to, and most surrender, but a few hold out indefinitely. The army sweeps around these, leaving behind some of its troops, who settle down to a long and frustrating encirclement. This has certainly been the case in biology, where the extraordinary progress made in molecular studies has been the consequence of a straightforward reductionist program, while the understanding of embryonic development and of the functioning of the central nervous system have remained in a rudimentary state. Even evolutionary biology, which is widely accepted as a triumph of modern science, has swept a lot of problems under the rug of undecidability.

The dominant mode of analysis of the physical and biological world and by extension the social world, as the social "sciences" have come into being, has been Cartesian reductionism. This Cartesian mode is characterized by four ontological commitments, which then put their stamp on the process of creating knowledge:

1. There is a natural set of units or parts of which any whole system is made.
2. These units are homogeneous within themselves, at least insofar as they affect the whole of which they are the parts.
3. The parts are ontologically prior to the whole; that is, the parts exist in isolation and come together to make wholes. The parts have intrinsic properties, which they possess in isolation and which they lend to the whole. In the simplest cases the whole is nothing but the sum of its parts; more complex cases allow for interactions of the parts to produce added properties of the whole.
4. Causes are separate from effects, causes being the properties of subjects, and effects the properties of objects. While causes may respond to information coming from the effects (so-called "feedback loops"), there is no ambiguity about which is causing subject and which is caused object. (This distinction persists in statistics as independent and dependent variables.)

We characterize the world described by these principles as the alienated world, the world in which parts are separated from wholes and reified as things in themselves, causes separated from effects, subjects
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separated from objects. It is a physical world that mirrors the structure of the alienated social world in which it was conceived. Beginning with the first glimmerings of merchant entrepreneurship in thirteenth-century Europe, and culminating in the bourgeois revolutions of the seventeenth and eighteenth centuries, social relations have emphasized the primacy of the alienated individual as a social actor. By successive acts of enclosure, land was alienated from the peasant cultivators, who formerly were tied to it and it to them. Individuals became social atoms, colliding in the market, each with his or her special interests and properties intrinsic to their roles. No individual person, however, is confined to a single role in bourgeois society. The same people are both consumers and producers, owners and renters, bosses and bosses. Yet bourgeois social theory sees society as constructed of homogeneous interest groups. "Consumers" have their interest, "labor" its interest, "capital" its interest, the whole of society taking a shape determined by the action of these categories on each other.

The alienated world is both ideological and real. Clearly, the claim that the social order is the natural result of the adjustments of demands and interests of competing groups is an ideological formulation meant to make the structure seem inevitable, but it also reflects the reality that has been constructed. Workers as individuals do sell their labor power in a market whose terms have been made by struggles between workers and employers generally. Consumers do have an interest in the commodities offered them that is antithetical to the interest of the producers. But these interest groups have been created by the very system of social relations of which they are said to be the basis.

In like manner, the alienated physical world is not only a structure of knowledge, but a physical structure imposed on the world. Which one of a chain of intersecting causes becomes the cause of a given effect is determined in part by social practice. For example, medical research and practice isolate particular causes of disease and treat them. The tubercle bacillus became the cause of tuberculosis, as opposed to, say, unregulated industrial capitalism, because the bacillus was made the point of medical attack on the disease. The alternative would be not a "medical" but a "political" approach to tuberculosis and so not the business of medicine in an alienated social structure. Having identified the bacillus as the cause, a chemotherapy had to be developed to treat it, rather than, say, a social revolution.

Sometimes problems are created in part by the very solutions invented to cope with them. The competition of certain weed species with crop plants is a serious problem for farmers, a problem that is now "solved" by wholesale application of herbicides. But not all weeds are bad for crops, and weed species compete among themselves. By using broad-spectrum herbicides, beneficial weeds, those that compete with harmful weeds, are destroyed along with the harmful weeds they displace, so the "weed problem" is partly created by the very operation that is supposed to cope with it. The same is true for insects, which are selected for genetic resistance to insecticides by the very insecticides used to control them. As a consequence, the greater the cure, the greater the problem.

No way of thinking about the world of phenomena can provide a total description of the infinitely complex set of interacting causes of all events. It is our contention that the alienated world view captures a particularly impoverished shadow of the actual relations among phenomena in the world, concerning itself only with the projections of multidimensional objects on fixed planes of low dimensionality. Indeed, it is an explicit objective of Cartesian reductionism to find a very small set of independent causal pathways or "factors" that can be used to reconstruct a large domain of phenomena. An elementary exercise in design courses is to make an object that is circular in one projection square in a second projection and triangular in the third. (We leave the solution as an exercise for the reader.) Alienated science deals with the alienated world of these projections, while a dialectical view attempts to understand the object in its full dimensionality. Of course, some objects, like spheres, are the same in all projections, so the reductionist strategy succeeds.

The error of reductionism as a general point of view is that it supposes the higher-dimensional object is somehow "composed" of its lower-dimensional projections, which have ontological primacy and which exist in isolation, the "natural" parts of which the whole is composed. In the alienated world things are at base homogeneous; indeed, the object of reductionist science is to find those smallest units that are internally homogeneous, the natural units of which the world is made. The history of classical chemistry and physics is the epitome of this view. In classical chemistry microscopic objects were made of a mixture of molecules, each of which was homogeneous within itself. With the development of the atomic theory of matter, these molecules were seen to be made of mixtures of atoms of different sorts, so the molecules were then seen as internally heterogeneous. Then it appeared that the very atoms defied their name (atomos, indivisible), because they too
were internally heterogeneous, being composed of elementary
neutrons, protons, and electrons. But even that homogeneity has dis-
appeared, and the number of "elementary" particles has multiplied
with each creation of a more powerful particle accelerator. Physicists believe
that the present theory predicts all particles that can exist, but since that
theoretical apparatus is only half a dozen years old, the cautious person
may reserve judgment.

In contrast, in the dialectical world view, things are assumed from
the beginning to be internally heterogeneous at every level. And this
heterogeneity does not mean that the object or system is composed of
fixed natural units. Rather, the "correct" division of the whole into
parts varies, depending upon the particular aspect of the whole that is
in question. In evolutionary reconstructions the problem is to identify
the anatomical, behavioral, or physiological units of evolution. Is the
hand a unit in evolution, or is it the entire forelimb or, on the contrary,
each finger or each joint of each finger the appropriate unit? The an-
swer depends upon the way genes interact with each other to influence
the development of the hand and the way in which natural selection op-
erates. But gene interactions themselves evolve, and the nature of the
force of natural selection varies from time to time and species to spe-
cies, so the hand may be a unit of evolution at some times but not oth-
er times. Moreover, the degree of functional integration or independence of
fingers, hand, and forelimb will itself evolve; a unit of evolution may,
by its own evolution, annihilate itself as a unit of future evolution. It is
a matter of simple logic that parts can be parts only when there is a
whole for them to be parts of. Part implies whole, and whole implies
part. Yet reductionist practice ignores this relationship, isolating parts
as preexisting units of which wholes are then composed. In the dialecti-
cal world the logical dialectical relation between part and whole is tak-
en seriously. Part makes whole, and whole makes part.

It seems clear that all bits of the physical world are in interaction
with each other to some degree. Yet in practice much of that interaction
is irrelevant. It may be that "thou canst not stir a flower without trou-
bling of a star," but in fact, our gardening does not have any effect on
the sun, because gravitation is a weak force that falls off as the square
of the distance. The growth of our flowers, on the other hand, is affect-
ed by the sun because photons travel across 80 million miles without
losing their energy. The community in ecology does not lose its meaning
as a unit of analysis nor its effectiveness as a level of interaction just be-
cause it is possible to connect every species in the world with every oth-
er one by some long chain of remote biotic interactions. The problem
for the ecologist is not to divide up the world of organisms once and for
all into communities, but to look for groups of species within which
there are strong interactions and between which there are weak rela-
tions in particular circumstances. A single species may be part of two
communities without thereby joining those communities into one. The
owl as a predator belongs to one community; as a defector it is part of
a quite different one.

The first principle of a dialectical view, then, is that a whole is a rela-
tion of heterogeneous parts that have no prior independent existence as
parts. The second principle, which flows from the first, is that, in gen-
eral, the properties of parts have no prior alienated existence but are ac-
quired by being parts of a particular whole. In the alienated world the
intrinsic properties of the alienated parts confer properties on the
whole, which may in addition take on new properties that are not char-
acteristic of the parts: the whole may be more than the sum of its parts.
But the ancient debate on emergence, whether indeed wholes may have
properties not intrinsic to the parts, is beside the point. The fact is that
the parts have properties that are characteristic of them only as they are
parts of wholes; the properties come into existence in the interaction
that makes the whole. A person cannot fly by flapping her arms, no
matter how much she tries, nor can a group of people fly by all flapping
their arms simultaneously. But people do fly, as a consequence of the
social organization that has created airplanes, pilots, and fuel. It is not
society that flies, however, but individuals in society, who have ac-
quired a property they do not have outside society. The limitations of
individual physical beings are negated by social interactions. The
whole, thus, is not simply the object of interaction of the parts but is
the subject of action on the parts.

The dialectical emphasis on wholes is shared by other schools of
thought that rebel against the fragmentation of life under capitalism,
the narrowness of specialization, the reductionism of medical and agri-
cultural theory. Holistic health movements stress the inseparability of
psychological and physiological processes; the relevance to health of
nutrition, exercise, and emotions; and the complex interactions of dif-
ferent nutrients. The ecology movement emphasizes the unity of na-
ture, which includes us.

We agree with these criticisms of current practices, but we differ
from these groups in two major ways. Most of the alternative health
movements focus on the individual, without integrating that individual
into social processes either in analysis or program. And their organizing principle is harmony, balance, or “oneness” with nature. In the dialectical approach the “wholes” are not inherently balanced or harmonious, their identity is not fixed. They are the loci of internal opposing processes, and the outcome of these oppositions is balanced only temporarily.

A third dialectical principle, then, is that the interpenetration of parts and wholes is a consequence of the interchangeability of subject and object, of cause and effect. In the alienated world objects are the passive, caused elements of other active, causal subjects. In evolutionary theory organisms are usually seen as the objects of evolution: through natural selection, autonomous changes in the environment cause adaptive alterations in the passive organism. As we argued in Chapter 3, however, the actual situation is quite different. Organisms are both the subjects and the objects of evolution. They both make and are made by the environment and are thus actors in their own evolutionary history.

The separation between cause and effect, subject and object in the alienated world has a direct political consequence, summed up in the expression, “You can’t fight city hall.” The external world sets the conditions to which we must adapt ourselves socially, just as environment forces the species to adapt biologically. The ideology of “being realistic” manifests itself in theories of human psychic development, such as Piaget’s (1967) claim that “equilibrium is attained when the adolescent understands that the proper function of reflection is not to contradict but to predict and interpret experience.” To this we counterpose Marx’s (1845) eleventh thesis on Feuerbach: “The philosophers have only interpreted the world in various ways; the point, however, is to change it.”

Two other schools of thought also recognize the heterogeneity of the world, but in different ways. Liberals are fond of urging that situations “are not all black or white,” that each course of action has its advantages and disadvantages, costs and benefits. Their solution is to see the world as shades of gray, to weigh costs and benefits on some scale that comes with a single resultant—net profit or loss—or to insist that, given two extremes, “The truth lies somewhere in between.” In each case the differences are quantitative, and contradictions are resolved by compromise.

The Taoist tradition in China shares with dialectics the emphasis on wholeness, the whole being maintained by the balance of opposites such as yin and yang. Although balanced, yin and yang do not lose their identities in some puddled intermediate. Chinese medicine recognizes excess of yin and deficiency of yang as distinct pathologies. However, balance is seen as the natural, desirable state, and the goal of intervention is to restore balance. Therefore Taoist holism is a doctrine of harmony rather than development.

Because elements recreate each other by interacting and are recreated by the wholes of which they are parts, change is a characteristic of all systems and all aspects of all systems. That is a fourth dialectical principle. In bourgeois thought change occupies an apparently contradictory position that follows from the history of the bourgeois revolution. The triumph of capitalism was accompanied by an exuberant, arrogant, and liberating iconoclasm. What was, need not be; ideas do not have tenure. Change, in Herbert Spencer’s words, was a “beneficent necessity.” People could change their status; success came by innovation. But with the eventual dominance of bourgeois institutions, bourgeois society itself was seen as the culmination of social development, the final release of humanity from the fetters of artificial feudal restraints into the natural state of economic man. From that point on, change was to be restricted within narrow boundaries: making technical innovations, improving laws, balancing, adjusting, compromising, expanding, or declining. Legitimation of bourgeois society meant denial of the need for fundamental change, or even the possibility of it. Stability, balance, equilibrium, and continuity became positive virtues in society and therefore also the objects of intellectual interest.

Change was increasingly seen as superficial, as only appearance, masking some underlying stasis. Even in evolutionary theory, the quintessential study of change, we saw the deep denial of change. Evolution was merely the recombination of unchangeable units of idioplasm; species endlessly played musical niches; the seemingly sweeping changes through geological time were only prolongations of the microevolution observed in the laboratory; and all of it was merely a sequence of manifestations of the selfish gene in different contexts of selfishness.

In choosing among alternative possibilities, priority has been given to the null hypothesis that no change has occurred. Until recently, models of dynamics focused on conditions for stable equilibrium. This diverted attention from the many varied ways in which systems could be unstable. Since stability requires the simultaneous satisfaction of a large number of different criteria (twice as many as there are variables
in the system), systems can be stable in only one way, but they can be unstable in many ways. Only recently has attention shifted to the richness of nonequilibrium processes.

In bourgeois thought change is often seen as the regular unfolding of what is already there (in principle in the genes, if not physically preformed); it is described by listing the sequence of results of change, the necessary stages of social or individual development. This shift from process to product also contaminates socialist thought when the dynamic view of history as a history of class struggle is replaced by the grand march of stages, from primitive communism through slavery, feudalism, capitalism, socialism, and on into the glorious sunset. Thus even where deep change cannot be ignored, it is acknowledged reluctantly and denied with the world-weary aphorism, "the more things change, the more they are the same." In the alienated world there are constants and variables, those things that are fixed and those that change as a consequence of fixed laws operating with fixed parameter values.

In the dialectical world, since all elements (being both subject and object) are changing, constants and variables are not distinct classes of values. The time scales of change of different elements may be very different, so that one element has the appearance of being a fixed parameter for the other. For example, the formulations of population genetics take the environment as constant for long periods in order to calculate the trajectories of gene frequencies and their equilibria. But as the environment changes slowly, the equilibria themselves may be changing more slowly. Reciprocally, population ecology assumes that species are not changing genetically in order to calculate the demographic trajectories of age classes, although the equilibria will slowly change as the genotypic composition of populations changes. Finally, community ecology takes both the demographic and genetic properties of species as constants in order to predict the equilibrium of species numbers in a community, although these may slowly change as genetic changes occur in an evolutionary time scale.

Unfortunately, the time scales of these processes are often not different, so the assumption that one process can be held constant while the other changes is in error. Fisher's (1930) derivation of the Malthusian parameter for following the genetic changes in a population made the error of supposing that age distribution would remain constant during the selective process. It was not until forty years after the publication of *The Genetical Theory of Natural Selection* that the demographic and genetic processes of change were finally treated simultaneously (Charlesworth 1970). Another manifestation of the same error is to treat the fitnesses of genotypes in populations as independent of the frequencies of those genotypes, relegating so-called "frequency-dependent selection" to the category of a special and unimportant case. Yet most selective processes are necessarily frequency dependent, especially if they involve competitive or cooperative interactions.

There are, of course, physical constants like the mass of the electron, the speed of light, and Planck's constant, which we regard as fixed and insensitive to the systems of which they are a part. Yet their constancy is not a law derived from yet other, more primitive principles, but an assumption. We do not, in fact, know that the mass of the electron has been the same since the beginning of matter nor, even if it has been so constant, that its value is not an accident of the history of matter. Whether such values are indeed changing and, if they are, at what rate, is a contingent question, not to be answered from principle. The difference between the reductionist and the dialectician is that the former regards constancy as the normal condition, to be proven otherwise, while the latter expects change but accepts apparent constancy.

Not only do parameters change in response to changes in the system of which they are a part, but the laws of transformation themselves change. In the alienated world view, entities may change as a consequence of developmental forces, but the forces themselves remain constant or change autonomously as a result of intrinsic developmental properties. In fact, however, the entities that are the objects of laws of transformation become subjects that change these laws. Systems destroy the conditions that brought them about in the first place and create the possibilities of new transformations that did not previously exist. The law that all life arises from life was enacted only about a billion years ago. Life originally arose from inanimate matter, but that origin made its continued occurrence impossible, because living organisms consume the complex organic molecules needed to recreate life de novo. Moreover, the reducing atmosphere that existed before the beginning of life has been converted, by living organisms themselves, to one that is rich in reactive oxygen.

The change that is characteristic of systems arises from both internal and external relations. The internal heterogeneity of a system may produce a dynamic instability that results in internal development. At the same time the system as a whole is developing in relation to the external world, which influences and is influenced by that development. Thus
internal and external forces affect each other and the object, which is the nexus of those forces. Classical biology, which is to say alienated biology, has always separated the internal and external forces operating in organisms, holding one constant while considering the other. Thus embryology has always emphasized the development of an organism as a consequence of internal forces, irrespective of the environment. At most the environment is regarded as a signal that sets the interior developmental forces going. Developmental biology is consumed with the problem of how the genes determine the organism. On the other hand, evolutionary biology, at least as practiced in Anglo-Saxon countries, is obsessed with the problem of the organism’s adaptation to the external world and assumes without question that any favorable alteration in the organism is available by mutation.

There is abundant evidence, however, that the ontology of an individual is a function of both its genes and the environment in which it develops. Moreover, it is certainly the case that no tetrapod has ever, no matter what selective forces are involved, succeeded in acquiring wings without giving up a pair of limbs. The separation of the external and internal forces of development is a characteristic of alienated biology that must be overcome if the problems of either embryology or evolution are to be solved.

The assertion that all objects are internally heterogeneous leads us in two directions. The first is the claim that there is no basement. This is not an a priori imposition on nature but a generalization from experience: all previously proposed undecomposable “basic units” have so far turned out to be decomposable, and the decomposition has opened up new domains for investigation and practice. Therefore the proposition that there is no basement has proven to be a better guide to understanding the world than its opposite. Furthermore, the assertion that there is no basement argues for the legitimacy of investigating each level of organization without having to search for fundamental units.

A second consequence of the heterogeneity of all objects is that it directs us toward the explanation of change in terms of the opposing processes united within that object. Heterogeneity is not merely diversity; the parts or processes confront each other as opposites, conditional on the whole of which they are parts. For example, in the predator-prey system of lemmings and owls, the two species are opposite poles of the process, predation simultaneously determining the death rate of lemmings and the birth rate of owls. It is not that lemmings are the opposite of owls in some ontological sense, or that lemmings imply owls or couldn’t exist without owls. But within the context of this particular ecosystem, their interaction helps to drive the population dynamics, which shows a spectacular fluctuation of numbers.

What characterizes the dialectical world, in all its aspects, as we have described it is that it is constantly in motion. Constants become variables, causes become effects, and systems develop, destroying the conditions that gave rise to them. Even elements that appear to be stable are in a dynamic equilibrium of forces that can suddenly become unbalanced, as when a dull gray lump of metal of a critical size becomes a fireball brighter than a thousand suns. Yet the motion is not constrained and uniform. Organisms develop and differentiate, then die and disintegrate. Species arise but inevitably become extinct. Even in the simple physical world we know of no uniform motion. Even the earth rotating on its axis has slowed down in geologic time. The development of systems through time, then, seems to be the consequence of opposing forces and opposing motions.

This appearance of opposing forces has given rise to the most debated and difficult, yet the most central, concept in dialectical thought, the principle of contradiction. For some, contradiction is an epistemic principle only. It describes how we come to understand the world by a history of antithetical theories that, in contradiction to each other and in contradiction to observed phenomena, lead to a new view of nature. Kuhn’s (1962) theory of scientific revolution has some of this flavor of continual contradiction and resolution, giving way to new contradiction. For others, contradiction is not only epistemic but political as well, the contradiction between classes being the motive power of history. Thus contradiction becomes an ontological property at least of human social existence. For us, contradiction is not only epistemic and political, but ontological in the broadest sense. Contradictions between forces are everywhere in nature, not only in human social institutions. This tradition of dialectics goes back to Engels (1880) who wrote, in Dialectics of Nature, that “to me there could be no question of building the laws of dialectics of nature, but of discovering them in it and evolving them from it.” Engels’s understanding of the physical world was, of course, a nineteenth-century understanding, and much of what he wrote about it seems quaint. Moreover, dialecticians have repeatedly attempted to make the identification of contradictions in nature a central feature of science, as if all scientific problems are solved when the
contradictions have been revealed. Yet neither Engels' factual errors nor the rigidity of idealist dialectics changes the fact that opposing forces lie at the base of the evolving physical and biological world.

Things change because of the actions of opposing forces on them, and things are the way they are because of the temporary balance of opposing forces. In the early days of biology an inertial view prevailed: nerve cells were at rest until stimulated by other nerve cells and ultimately by sensory excitation. Genes acted if the raw materials for their activity were present; otherwise they were quiescent. Gene frequencies in a population remained static in the absence of selection, mutation, random drift, or immigration. Nature was at equilibrium unless perturbed. Later it was recognized that nerve impulses act both to excite and to inhibit the firing of other nerves, so the state of a system depends on the network of opposing stimuli, and that network can generate spontaneous activity. Gene action is regulated by repressors, repressors of the repressors, and all sorts of active feedbacks in the cell. There are no genetic loci immune to mutation and random drift, and no populations are free of selection.

The dialectical view insists that persistence and equilibrium are not the natural state of things but require explanation, which must be sought in the actions of the opposing forces. The conditions under which the opposing forces balance and the system as a whole is in stable equilibrium are quite special. They require the simultaneous satisfaction of as many mathematical relations as there are variables in the system, usually expressed as inequalities among the parameters of that system.

If these parameters remain within the prescribed limits, then external events producing small shifts among the variables will be erased by the self-regulating processes of stable systems. Thus in humans the level of blood sugar is regulated by the rate at which sugar is released into the blood by the digestion of carbohydrates, the rate at which stored glycogen, fat, or protein is converted into sugar, and the rate at which sugar is removed and utilized. Normally, if the blood sugar level rises, then the rate of utilization is increased by release of more insulin from the pancreas. If the level of blood sugar falls, more sugar is released into the blood, or the person gets hungry and eats some source of sugar. The result is that the blood sugar level is kept not constant but within tolerable limits. So far we are dealing with the familiar patterns of homeostasis, the negative feedback that characterizes all self-regulation.

However, the pancreas might respond weakly to a high sugar level, which could result in diabetic coma. Or the blood sugar level may fall so low that the person is incapable of eating.

The opposing forces are seen as contradictory in the sense that each taken separately would have opposite effects, and their joint action may be different from the result of either acting alone. So far, the object may seem to be the passive victim of these opposing forces. However, the principle that all things are internally heterogeneous directs our attention to the opposing processes at work within the object. These opposing processes can now be seen as part of the self-regulation and development of the object. The relations among the stabilizing and destabilizing processes become themselves the objects of interest, and the original object is seen as a system, a network of positive and negative feedbacks.

The negative feedbacks are the more familiar ones. If blood pressure rises, sensors in the kidney detect the rise and set in motion the processes which reduce blood pressure. If more of a commodity is produced than can be sold, prices fall, and the surplus is sold cheaply while production is cut back; if there is a shortage, prices rise, and that stimulates production. Or if a baby cries, this tells the responsible adult that something is wrong, and he or she initiates action to remove the cause of discomfort and stop the crying. In each case a particular state of the system—high blood pressure, overproduction, crying—is self-negating in that within the context of the system an increase in something initiates processes that leads to its decrease.

But systems also contain positive feedback: high blood pressure may damage the pressure-measuring structures, so that blood pressure is underestimated and the homeostatic mechanisms themselves increase the pressure; overproduction may lead to cutbacks in employment, which reduce purchasing power and therefore increase the relative surplus; the crying of the baby may evoke anger, and the abuse of the child can then result in more crying.

Real systems include pathways for both positive and negative feedback. Negative feedbacks are a prerequisite for stability: the persistence of a system requires self-negating pathways. But negative feedback is no guarantee of stability and under some circumstances can throw the system into oscillation. If there is a preponderance of positive feedback or if the indirect negative feedbacks by way of intervening variables are strong enough, the system will be unstable. That is,
own condition is sufficient cause of its negation. Thus systems are either self-negating (state A leads to some state not-A) or depend for their persistence on self-negating processes.

We see contradiction first of all as self-negation. From this perspective it is not too different from logical contradiction. In formal logic process is usually replaced by static set-structural relations, and the dynamic of “A leads to B” is replaced by “A implies B.” But all real reasoning takes place in time, and the classical logical paradoxes can be seen as A leads to not-A leads to A, and so on. For instance, consider Russell’s paradoxical barber who shaves any and all men who do not shave themselves. If we assume that the barber shaves himself, then he belongs to the set of those he does not shave. Therefore, he is eligible to be a shaver by himself, and so we go round and round, as each affirmation is in turn negated. (Logicians would exclude the feminist solution that the barber is a woman and does not shave herself.) Material and logical contradiction share the property of being self-negating processes.

The stability or persistence of a system depends on a particular balance of positive and negative feedbacks, on parameters governing the rates of processes falling within certain limits. But these parameters, although treated in mathematical models as constants, are real-world objects that are themselves subject to change. Eventually some of these parameters will cross the threshold beyond which the original system can no longer persist as it was. The equilibrium is broken. The system may go into wider and wider fluctuations and break down, or the parts themselves, which have meaning only within a particular whole, may lose their identity as parts and give rise to a qualitatively new system. Further, the changes in the parameters may be a consequence of the stable behavior of the system that they condition in the first place. As a result of the cycle of over- and underproduction, businesses fail, firms merge and expand, a permanent body of unemployed people is created, and political struggles culminate in the replacement of the capitalist system with its whole dynamic. If predator and prey are in demographic balance, this may hide the prey’s evolution toward better predator avoidance, thus eventually resulting in the extinction of the predator; or the predator’s efficiency at hunting may evolve beyond the threshold compatible with the survival of the prey, and both become extinct.

The dialectical model suggests that no system is really completely static, although some aspects of a system may be in equilibrium. The quantitative changes that take place within the apparent stability cross thresholds beyond which the qualitative behavior is transformed. All systems are in the long run self-negating, while their short-term persistence depends on internal self-negating states.

The dialectical viewpoint sees dynamical stability as a rather special situation that must be accounted for. Systems of any complexity—the central nervous system, the national and world capitalist economies, ecosystems, the physiological networks of organisms—are more likely to be dynamically unstable. Even systems designed explicitly to be stable, such as nuclear power plants, have shown a remarkable propensity to behave in unplanned ways.

The important point here is that complex systems show spontaneous activity. Each of these systems responds to events from outside, but it is not necessary to look to external sources for the causes of movement. The capitalist business cycle does not depend on sunspots. Political “unrest” is not explained by outside agitators. Changing abundance of species is not evidence of human impact on the environment. And it is becoming increasingly apparent that the prevention of change in wildlife management, environmental protection, or society is, in the long run, an impossible goal.

Self-negation is not simply an abstract possibility derived from arguments about the universality of change. We observe it regularly in nature and society. Monopoly arises not as a result of the thwarting of “free enterprise” but as a consequence of its success: hence the futility of antitrust legislation. The freeing of serfs from feudal ties to the land also meant the possibility of their eviction from the land; freedom of the press has increasingly meant the freedom of the owners of the press to control information. The self-negating processes of capitalism are often expressed as ironic commentaries, as the realization of ideal goals turns out to thwart their original intent. Sometimes this self-negation is the consequence of quantitative changes that cross a threshold. For instance, at one time the Polish government established a policy of subsidizing the price of bread at a fixed level in order to guarantee the basic food supply. As inflation developed, the gap between the subsidized price of bread and the prices of other goods widened until one morning Warsaw was without bread: farmers had discovered that it was cheaper to buy bread to feed their livestock than to grow feed: the very mechanisms designed to guarantee the urban bread supply were turned into their opposite.

A second aspect of contradiction is the interpenetration of seemingly mutually exclusive categories. A necessary step in theoretical work is to
make distinctions. But whenever we divide something into mutually exclusive and jointly all-encompassing categories, it turns out on further examination that these opposites interpenetrate. In Chapter 3 we examined the interpenetration of organism and environment. Here we note briefly several more examples.

At first glance, "deterministic" and "random" processes seem to exemplify mutually exclusive categories. Many trees have been sacrificed to the cause of printing debates about whether the world, or species aggregates, or evolution, is deterministic or random. (The deterministic side implying order and regularity, the stochastic side implying absence of system or explanation.) In the first place, however, completely deterministic processes can generate apparently random processes. In fact, the random numbers used for computer stimulation of random process are generated by deterministic processes (algebraic operations). Recently, mathematicians have become interested in so-called chaotic motion, which leads neither to equilibrium nor to regular periodic motion but rather to patterns that look random. In systems of high complexity the likelihood of stable equilibrium may be quite small unless the system was explicitly designed for stability. The more common outcome is chaotic motion (turbulence) or periodic motion with periods so long as never to repeat during even long intervals of observations, thus also appearing as random.

Second, random processes may have deterministic results. This is the basis for predictions about the number of traffic accidents or for actuarial tables. A random process results in some frequency distribution of outcomes. The frequency distribution itself is determined by some parameters, and changes in these parameters have completely determined effects on the distribution. Thus the distribution as an object of study is deterministic even though it is the product of random events.

Third, near thresholds separating domains of very different qualitative behaviors, a small displacement can have a big effect. If these small displacements arise from lower levels of organization, they will be unpredictable from the perspective of the higher level. And in general the intrusion of events from one level to another appears as randomness.

Finally, the interaction of random and deterministic processes gives results in evolution that are different from the consequence of either type of process acting alone. In Sewall Wright's model, selection alone would lead all local populations to the same gene frequencies, so no selection among populations would be possible. The random drift that arises from small numbers within each population would result in the nonadaptive fixation of genes. The joint effect, however, is to allow variation among local populations, which provides the variability for new cycles of selection in different directions. People have long known that random search can be an important part of adaptive processes, the trial and error procedure leading to desired results by unexpected paths.

Similarly, the dichotomy between equilibrium and nonequilibrium systems is not absolute. When ecologists realized that nature changes, there was a rush to abandon equilibrium analysis as unrealistic. However, it is not at all obvious that a changing system is not also in equilibrium. The proportions of various ionic forms of phosphorus in a lake reach equilibrium in seconds, even though the total amount of phosphorus may change. Algae populations may equilibrate with the mineral level, which itself changes, changing the algae. Phenomena that are very much slower than those of interest can be treated provisionally as constant, while those that are very much faster can be treated as if already at equilibrium. In the long run it is important to see equilibrium as a form of motion rather than as its polar opposite. Our conclusion, borne out by the history of our science, is that such dichotomies are both necessary and misleading and that there is no nontrivial and complete decomposition of phenomena into mutually exclusive categories.

Contradiction also means the coexistence of opposing principles (rather than processes) which, taken together, have very different implications or consequences then they would have if taken separately. Commodities embody the contradiction between use value and exchange value (reflected indirectly in price). If objects were produced simply because they met human needs, we would expect the more useful things to be produced before less useful things, and we would expect objects and methods of production to be designed to minimize any harm or danger and maximize durability or reparation. The amounts produced would correspond to the levels of need; any decline in need would allow either more leisure or the production of other objects. If objects had no use value at all, of course, they couldn't be sold; use value makes exchange value possible. But the prospect of exchange value leads to results that often contradict the human needs that called forth the commodities in the first place. Commodities will be produced, for example, only for those who can afford them, and priority will be given to the production of those commodities with the highest profit margins. Productive innovations which make commodities easier and cheaper to make may create unemployment or ill health for workers
and consumers. Thus the process of supplying human needs by the creation of commodities whose exchange value is paramount actually creates new hardship.

A single proposition may have opposing implications. Consider, for example, the statement that more than half the population of Puerto Rico receives food stamps. This serves as a basis both for the party in power to justify the continuation of American rule and for the opposition to criticize that rule. On the one hand, eighty-six years after the United States occupied Puerto Rico, the island’s economy is more dependent and less able to support its population than before. Some $5 billion are extracted annually by United States businesses in the form of profits and interest, preventing Puerto Rico from accumulating what it needs for autonomous development. On the other hand, food stamps are not available in Honduras and the Dominican Republic. For the recipient of food stamps, the direct experience is of American benevolence. It requires an intellectual detour to perceive also that the necessity for food stamps is a result of being absorbed into the American economy, that the United States is the cause of the problem that it partly ameliorates. Much of the political conflict around the status of Puerto Rico derives from the contradictory implications of the same fact.

The principles of materialist dialectics that we attempt to apply to scientific activity have implications for research strategy and educational policy as well as methodological prescriptions:

**Historicity.** Each problem has its history in two senses: the history of the object of study (the vegetation of North America, the colonial economy, the range of *Drosophila pseudoobscura* and the history of scientific thinking about the problem, a history dictated not by nature but by the ways in which our societies act on and think about nature. Once we recognize that state of the art as a social product, we are freer to look critically at the agenda of our science, its conceptual framework, and accepted methodologies, and to make conscious research choices. The history of our science must include also its philosophical orientation, which is usually only implicit in the practice of scientists and wears the disguise of common sense or scientific method.

It is sure to be pointed out that the dialectical approach is no less contingent historically and socially than the viewpoints we criticize, and that the dialectic must itself be analyzed dialectically. This is no embarrassment; rather, it is a necessary awareness for self-criticism. The preoccupation with process and change comes in part from our commit-

ment to change society. An alertness to the fallacies of gradualism derives from a challenge to liberalism. An insistence on seeing things as integrated wholes reflects a belief that much of the suffering, waste, and destruction in the world today comes from the operation of patriarchal capitalism as a world system penetrating all corners of our lives rather than from a list of separable and isolatable defects. And the emphasis on the social interpretation of science comes from a political commitment to struggle for an alternative way of relating to nature and knowledge that is congruent with an alternative way of organizing society. One practical consequence of this viewpoint is that the study of the history, sociology, and philosophy of science is a necessary part of science education.

**Universal interconnection.** As against the alienated world view that objects are isolated until proven otherwise, for us the simplest assumption is that things are connected. The ignoring of interconnections, especially across disciplinary boundaries, has been the main source of error and even disaster in complex fields of applied biology such as public health, agriculture, environmental protection, and resource management and the cause of the stagnation of theory in these areas. Therefore we urge that an early stage of any investigation should be to trace out the indirect, speculative, and even far-fetched connections among phenomena of interest and to justify any ignored connections.

**Heterogeneity.** The internal heterogeneity of all things and all populations of things is the complementary perspective to universal connections: different things combine into greater, heterogeneous wholes. This perspective leads us to focus on quantitative and qualitative variability as objects of interest and sources of explanation. Then certain problems become especially appealing, such as the organization of phenotypic variability in plants and animals, the differentiation of classes in society, the recognition that plants which bear the same species name can be quite different to the herbivores that eat them, or that the same species may have different ecological significance in different places. When faced with an ensemble of things of any sort, we are suspicious of any apparent homogeneity.

**Interpenetration of opposites.** The more we see distinctions in nature, and the more we subdivide and set up disjunct classes, the greater the danger of reifying these differences. Therefore, complementary to any process of subdividing is the hypothesis that there is no nontrivial and complete subdivision, that opposites interpenetrate and that this interpenetration is often critical to the behavior of the system.
Integrative levels. As against the reductionist view, which sees wholes as reducible to collections of fundamental parts, we see the various levels of organization as partly autonomous and reciprocally interacting. We must reject the molecular euphoria that has led many universities to shift biology to the study of the smallest units, dismissing population, organismic, evolutionary, and ecological studies as forms of "stamp collecting" and allowing museum collections to be neglected. But once the legitimacy of these studies is recognized, we also urge the study of the vertical relations among levels, which operate in both directions.

We do not know whether or not these elements of a research and educational program will in fact result in solutions to long-standing problems of biology. Dialectical philosophers have thus far only explained science. The problem, however, is to change it.