# Biology Under the Influence

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## Dialectical Essays on Ecology, Agriculture, and Health

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# *Dedication*

Five Cubans are now serving long sentences in U.S. prisons because they were monitoring the activities of Cuban émigré terrorist groups in Miami. From their cells they have been active both in helping to make prison life more bearable for the other inmates in their immediate community and continuing to be full participants in the life of the Cuban revolution. We admire their steadfastness and creativity in resistance, and we dedicate this book to Antonio Guerrero, Fernando González, René González, Gerardo Hernández, and Ramón Labañino, and to people all over the world struggling for their release.

# Introduction

*Biology Under the Influence* is a collection of our essays built around the general theme of the dual nature of science. On the one hand, science is the generic development of human knowledge over the millennia, but on the other it is the increasingly commodified specific product of a capitalist knowledge industry. The result is a peculiarly uneven development, with increasing sophistication at the level of the laboratory and research project, along with a growing irrationality of the scientific enterprise as a whole. This gives us a pattern of insight and blindness, of knowledge and ignorance, that is not dictated by nature, leaving us helpless in the big problems facing our species. This dual nature gives us a science impelled both by its internal development and the very mixed outcomes of its applications to understand complexity as the central intellectual problem of our time. But it is held back by the philosophical traditions of reductionism, the institutional fragmentation of research, and the political economy of knowledge as commodity.

This means we have to be engaged on two fronts: 1) we stand against the obscurantist anti-science, which ranges from direct manipulation of the EPA and FDA by the government and the hype of the drug companies, to creationism and the mystification of mathematical chaos; 2) we also reject scientism, the claim that other people's ideas are superstition while ours are uniquely objective knowledge verified by numbers. We reject the postmodern view that, still reeling from having discovered the fallibility of science, comes to deny the validity of knowledge or, overwhelmed by the uniqueness of the particular, refuses to see patterns even of uniqueness. Scientism focuses mostly on the last stages of research, hypothesis testing, thus ignoring the questions of the origins of the hypotheses to be tested and of the source of the rules of validation. We challenge both the mystical holism that sees everything as so much "all one" that it becomes a shifting blur without parts, and the reductionism which claims that the most fundamental truths are found in the smallest parts of things. We trace how this works out in agriculture, health, ecology, and evolution. Then we step back and look at the processes of abstraction and model building, and return to examining the present-day obstacles to an integral, complex, dynamic view of the world.

We come to this project as participant observers. Both of us have been active in overlapping though somewhat different areas of population genetics, ecology, evolution, biogeography, and mathematical modeling. As participants we have been engaged in the nuts and bolts of our sciences in lab and field and before the computer. In our scientific work we have attempted to apply the insights of dialectical materialism that emphasizes wholeness, connectedness, historical contingency, the integration of levels of analysis, and the dynamic nature of "things" as snapshots of processes. Although we have variously worked with enzymes, fruit flies, corn, ants, gene frequencies, and orange trees, our point of view was always influenced by how we see the world as a whole.

We also step outside of the specific scientific problems to become observers and examine the nature of science and the uses of mathematics and modeling. In this, we step into what usually fits within philosophy of science. Occasionally we have worked jointly. At other times our separate work was strongly or loosely influenced by our ongoing dialog of almost forty-eight years.

We have also been political activists and comrades in Science for the People; Science for Vietnam; the New University Conference; and struggles against biological determinism and "scientific" racism, against creationism, and in support for the student movement and antiwar movement. On the day that Chicago police murdered Black Panther leader Fred Hampton, we went together to his still bloody bedroom and saw the books on his night table: he was killed because of his thoughtful, inquiring militancy. Our activism is a constant reminder of the need to relate theory to real-world problems as well as the importance of theoretical critique. In political movements we often have to defend the importance of theory as a protection against being overwhelmed by the urgency of need in the momentary and the local, while in academia we still have to argue that for the hungry the right to food is not a philosophical problem.

The essays in this book were written over a 20-year period and were directed at different audiences, some academic colleagues and some activists with little technical knowledge. Not all chapters will be equally relevant to everyone. Redundancy is usually undesirable in books, but here it is justified by two considerations: the removal of repetition would destroy the coherence of some chapters, and since the approach is largely unfamiliar, its repetition in different contexts may not be amiss.

Some of the entries are short essays from our column "Eppur´ Si Muove" that ran in the journal *Capitalism, Nature, Socialism*. These include "Are We Programmed?" about genetic determinism, "The Politics of Averages" about statistics, "Schmalhausen's Law" about vulnerability, "Life on Other Worlds," "Evolutionary Psychology," as well as several others. Longer pieces, some previously published, discuss uncertainty, the political economy of agriculture, Cuba, systems theory, model building, the organism/environment relation, and chaos. And, of course, there is Isador Nabi's contribution, "Greypeace," through which in a jest we spend our rage.

There are also important topics we do not discuss. We do not have any essays specifically on feminist analysis, cultural criticism or the role of subjectivity in social life, design plans for a better world, or questions about how to get there. Here we are consumers of the work of our comrades. This can lead some critics to the mistaken conclusion that we are indifferent to these questions and are mechanistic materialists.

We have followed the same rule as in the previous book, *The Dialectical Biologist*: we do not say anything where we have nothing to add.

# PART ONE

## 1

## The End of Natural History?

Biologists in the present century find themselves in a deeply contradictory position on questions of diversity and change. They are the inheritors of a nineteenth-century natural historical and evolutionary tradition in which the immense diversity of organisms and the long-term change that has occurred in the living world were at the very center of interest. There are millions of distinct species now extant representing less than 0.1 percent of all the species that have ever lived, and these too will become extinct. Yet only a minute fraction of all the kinds of organisms that might be imagined have ever or will ever exist. No two individuals within a species are identical, the species composition is always changing, population sizes vary markedly from year to year, and the physical conditions of life are in constant flux.

In the late eighteenth and nineteenth centuries, the ideology of change, central to the bourgeois revolutions and the social upheavals necessary for the growth of capitalism, was transferred easily onto the natural world. Herbert Spencer declared change to be "a beneficent necessity," and although it made Tennyson sad, he heard nature cry, "I care for nothing, all shall go." But the bourgeois revolutions succeeded and the Whig interpretation of history has become Whig biology. We are at the End of Natural History. The world has settled down, after a rocky start, to a steady state. Constancy, harmony, simple laws of life that predict universal features of living organisms, and the self-reproduction and absolute dominance of a single species of molecule, DNA, are the hegemonic themes of modern biology. Biologists suffer from a bad case of physics envy, and no branches of biology have been more ruthless in their search for a Hamiltonian, a single equation whose maximization will characterize the entire biosphere, than ecology and evolution. Indeed, the price of admission into "real science" for these natural historical fields has been to give up their concentration on change and contingency and to prove their status as science, rather than mere butterfly collecting, by producing some universal predictive laws. If there must be change, at least let it be caused by some simple law-like force.

On the model of Newtonian physics, change and diversity, rather than being the natural state of things, become deviations from the natural state of rest or regular linear motion, deviations that must be explained by externalities. But there's the rub. In classical physics, systems are sufficiently isolated from each other so that their ideal motion can be studied in isolation, taking into account the effect of an external impetus. The moon will continue in its utterly predictable course around Earth unless some very large object intrudes from outer space. But every population, species, and community, indeed the whole damned biosphere, is constantly changing in what appear to be unpredictable ways. Nor are the boundaries between the system and outer space so clear. How are we to explain system change as a result of unpredicted externalities if we are not sure what is external?

There have been two responses, one from a prescientific tradition, and one from the bowels of physics itself.

The first kind of response denies the constant turnover and instability of living organisms while it alienates the human species from the rest of nature and reasserts the reality of the distinction between artificial and natural. Human technological society, disturbing the natural world from its normal state of harmony and balance, becomes the externality. In a transformation of quantity into quality, what was in the early stages of its evolution just another part of the harmonious balanced whole, escapes into another sphere of action and becomes an autonomous actor dominating and exploiting the rest of nature from the outside. It does this, of course, at its peril, since, like any exploiter, it may extinguish both itself and the system that supports it by imprudent exploitation. Under this model, the task of science is to uncover the laws of behavior of the unperturbed natural world and to use these laws to hold in check the effects of the external perturbing force.

The other response does not attempt to identify externalities that cause unpredictable irregularities in an otherwise simple law-like system, but denies the very existence of the irregularities and asserts the predictability of the biosphere from simple generating principles. There have been three such attempts in the last twenty-five years, whose names are metaphors for the anxiety of meaninglessness that has engendered them. They are catastrophe theory, chaos theory, and complexity theory. All are attempts to show that extremely simple relationships in dynamical systems will lead to what seem at first sight to be unpredictable changes and extraordinary diversity of outcome, but which are, in fact, utterly regular and law-like.

Catastrophe theory—developed in the 1960s by the mathematician Rene Thom—shows that in some systems, which are changing in time according to quite simple mathematical laws, the changes observed may be continuous and gradual deformations of the state at a previous instant, and at a critical point the entire shape of the system will undergo a "catastrophic" change and then continue its development along a totally new pathway. Many physical deformations under continuously increasing force will reach a critical point at which they will break like a bent branch. The classic example, known by sometimes painful experience to the denizens of the Malibu beach, is the breaking wave. As a swell develops into a deep convex curve there is a continuous deformation of shape whose tubularity is suddenly and catastrophically lost at a critical point in its roll, and the wave comes crashing down. The practitioners of catastrophe theory hoped that it would provide the explanation of changes in shape during the development of individual organisms, and of the extinction of species, among other things, but there is currently no trace of this theory in biological practice. Indeed, the externalities view has more recently triumphed in the claim that truly "catastrophic" events, meteor impacts, rather than mathematical catastrophes, have been responsible for a major part of species extinctions. The fascination with the possibility of these external catastrophes has resulted in a complete neglect of the question of why every species goes extinct, with or without meteors.

In the 1980s, chaos theory was introduced to show that some very simple dynamic systems may go to equilibrium or undergo regular oscillations in one range of parameters and in other ranges will pass from one state to another in what appears to be a totally random fashion, but which in fact can be exactly predicted, moment by moment, from the equations of motion. So an uncertain and diverse world is really the solution to a trivially simple equation. In particular, mathematically chaotic regimes were offered as an explanation for the unpredictably varying population sizes that species typically display from generation to generation. Where chaos theory reigns, historical contingency disappears. The entire demographic history of a population from its initial condition is already immanent in the deterministic equation of its growth and is completely fixed by processes internal to the organisms that make up the population. No reference need be made to historical processes in the outside world or to random variation that arises from the finiteness of real populations. Thus far, biologists have been unable to make use of chaos theory outside of the speculative realm, because no one knows how to reconstruct these hypothetical ahistorical equations of motion from data that appear as random.

Most recently the thinkers at Santa Fe Institute have begun to develop a theory of complexity which, they promise us, will generate the dazzling variety of life histories from the behavior of networks of simple entities with lots of simple connections. Not wanting to break with previous speculations, they also claim that living systems are "at the edge of Chaos." There will be "laws" of complexity of which life will be one example, but only one. Complexity theory is yet another attempt to produce a theory of order in the universe, though one that is vastly more ambitious than astrophysics. Not only was the entire history of the stars immanent in that millionth of a second when the universe began but the history of life as well. It is not simply that we have reached the end of history, there never was any history to begin with.

None of these theories, all meant to tame diversity and change, and most important, to expunge historical contingency, envisions the alternative, that living beings are at the nexus of a very large number of weakly determining forces so that change and variation and contingency are the basic properties of biological reality. As Diderot said, "Everything passes, everything changes, only the totality remains."

# 2

# The Return of Old Diseases and the Appearance of New Ones

A generation ago, the commonsense position of public health leaders was that infectious disease had been defeated in principle and was on the way out as an important cause of sickness and mortality. Medical students were told to avoid specializing in infectious disease because it was a dying field. Indeed, the Epidemiology Department at the Harvard School of Public Health specialized in cancer and heart disease.

They were wrong. In 1961, the seventh pandemic of cholera hit Indonesia; in 1970, it reached Africa, and South America in the 1990s. After retreating for a few years, malaria came back with a vengeance. Tuberculosis has increased to become the leading cause of death in many parts of the world. In 1976, Legionnaires' disease appeared at a convention of the American Legion in Philadelphia. Lyme disease spread in the Northeast. Cryptosporidiosis affected 400,000 people in Milwaukee. Toxic shock syndrome, chronic fatigue syndrome, Lassa fever, Ebola, Venezuela hemorrhagic fever, Bolivian hemorrhagic fever, Crimean-Congo hemorrhagic fever, Argentine hemorrhagic fever, hanta virus, and, of course, AIDS, have confronted us with new diseases. The doctrine of the epidemiological transition was dreadfully wrong. Infectious disease is a major problem of health everywhere.

Why was public health caught so completely by surprise?

Part of the answer is that science is often wrong because we study the unknown by making believe it is like the known. Often it is, making science possible, but sometimes it is not, making science even more necessary and surprise inevitable. Physicists in the late 1930s were lamenting the end of atomic physics. All the fundamental particles were already known—the electron, the neutron, and the proton had been measured. What more was there? Then came the neutrinos, positrons, mesons, antimatter, quarks, and strings. And each time, the end was declared.

But the explanation demands something more than the obvious fact that science will often be wrong. Before we can answer why public health was caught by surprise, we have to ask: What made the idea of the epidemiological transition seem so plausible to the theorists and practitioners of health?

There were three main arguments:

1. Infectious disease had been declining as a cause of death in Europe and North America for nearly a hundred and fifty years, since the causes of mortality were first systematically recorded. Smallpox was almost gone, tuberculosis was decreasing, malaria had been driven out of Europe and the United States, polio had become a rarity, and the childhood scourges of diphtheria and whooping cough were on their way out. Women were no longer dying of tetanus after giving birth. Just look ahead: the other diseases would go the same way.

2. We had ever better "weapons" in the "war" against disease: better laboratory tests to detect them, drugs, antibiotics, and vaccines. Technology was advancing, while the germs had to rely on their only ways of responding—by mutations. Of course, we were winning.

3. The whole world was developing. Soon all countries would be affluent enough to use the advanced technologies and acquire a modern health portrait.

Each of these arguments was loosely plausible, and each of them wrong. The problem is that although they seem to be historical arguments, they completely lack an understanding of historical contingency or the way in which historical changes alter the conditions of future change.

First, public health professionals had too short a time horizon. If instead of counting only the last century or two they had looked at a longer period of human history they would have seen a different picture. The first confirmed eruption of plague—the Black Death—hit Europe in the time of the Emperor

Justinian when the Roman Empire was in decline. The second plague spread in fourteenth-century Europe during the crisis of feudalism. What the relation of economic and political events was to these outbreaks is unclear, but when the historical record is more complete the causal paths are easier to follow. The great plague of northern Italy at the beginning of the seventeenth century was directly consequent to the famine and widespread movement of armies during the dynastic wars of the period. And the most devastating epidemiological event we know of accompanied the European conquest of the Americas, when a combination of disease, overwork, hunger, and massacre reduced the Native American population by as much as 90 percent. The Industrial Revolution brought the dreadful diseases of the new cities that Engels wrote about in relation to Manchester in his *The Condition of the Working Class in England.*

So instead of the claim that infectious disease is in decline forever, we have to assert that every major change in society, population, use of the land, climate change, nutrition, or migration is also a public health event with its own pattern of diseases.

Waves of European conquest spread plague, smallpox, and tuberculosis. Deforestation exposes us to mosquito-borne, tick-borne, or rodent-carried diseases. Giant hydroelectric projects and their accompanying irrigation canals spread the snails that carry liver flukes and allow mosquitoes to breed. Monocultures of grains are mouse food, and if the owls and jaguars and snakes that eat mice are exterminated, the mouse populations erupt with their own reservoirs of diseases. New environments, such as the warm, chlorinated circulating water in hotels, allow the Legionnaire's bacteria to prosper. It is a widespread germ, usually rare because it is a poor competitor, but it tolerates heat better than most, and it can invade the larger but still microscopic protozoa to avoid chlorine. Finally, modern fine-spray showers provide the bacterium with droplets that can reach the furthest corners of our lungs.

Second, public health was narrow in another way: it looked only at people. But if veterinarians and plant pathologists had been consulted, new diseases would have been frequently seen in other organisms: African swine fever, mad cow disease in England, the distemper-type viruses in North Sea and Baltic mammals, tristeza disease of citrus, bean golden mosaic disease, leaf-yellowing syndrome of sugarcane, tomato Gemini virus, and the variety of diseases killing off urban trees would have made it obvious that something was amiss.

The third way public health was too narrow was in its theory: not paying any real attention to evolution or the ecology of species interactions. Theorists of public health did not realize that parasitism is a universal aspect of evolving life. Parasites usually don't do too well in free soil or water and so they adapt to the special habitats of the inside of another organism. They escape competition (almost) but have to cope with the partly contradictory demands of that new environment: where to get a good meal, how to avoid the body's defenses, and how to find an exit and get to somebody else. The subsequent evolution of parasites responds to the internal environment, external conditions of transmission, and whatever we do to cure or prevent the disease. Large populations of crops, animals, or people are new opportunities for bacteria and viruses and fungi, and they keep trying.

A deep problem is the failure to appreciate the evolutionary change that occurs in disease organisms as a direct consequence of the attempts to deal with them. Public health theorists did not consider how the bugs would react to medical practice, even though drug resistance had been reported since the late 1940s and pest managers already knew of many cases of pesticide resistance. The faith in magic bullet approaches to disease control and the widespread use of military metaphors ("weapons in the war on . . . "; "attack"; "defense"; "come in for the kill") made it harder to acknowledge that nature, too, is active, and that our treatments necessarily evoke some responses.

Finally, the expectation that "development" would lead to worldwide prosperity and major increases in resources applied to health improvement is a myth of classical development theory. During the Cold War, challenges to the World Bank/IMF approach to development were marginalized as communist. In the actual world of dominance of already formed rich economies, the poor nations obviously could not close the gap with the rich, and even when their total economies grew it did not mean that the mass of people prospered or more resources were devoted to social need.

More deeply, social processes of poverty and oppression and the actual conditions of world trade were not the stuff of "real" science that deals with microbes and molecules. So a cholera outbreak is seen only as the coming of cholera bacteria to lots of people. But cholera lives among the plankton along the coasts when it isn't in people. The plankton blooms when the seas get warm and when runoff from sewage and from agricultural fertilizers feed the algae. The products of world trade are carried in freighters that use seawater as ballast that is discharged before coming to port, along with the beasts that live in that ballast water. The small crustaceans eat the algae, the fish eat the crustaceans, and the cholera bacterium meets the eaters of fish. Finally, if the public health system of a nation has already been gutted by structural adjustment of the economy, then the full explanation of the epidemic is, jointly, *Vibrio cholerae* and the World Bank.

So, at one level of explanation, the failure of public health theory identifies mistaken ideas and too narrow a vision. But these in turn require further explanation. The doctors who looked only at the last 150 years were educated people. Many studied the classics. They knew that history did not begin in nineteenth-century Europe. But earlier times somehow did not matter to them here. The rapid development of capitalism led to ideas about the unique novelty of our own time, immortalized by Henry Ford as "History is bunk." They share American (and less extremely, European) pragmatism, an impatience with theory (in this case evolution and ecology). Therefore they did not see the commonality of plants and people as species among species. Ministries of health do not talk to ministries of agriculture. Agriculture schools are rural and state supported, their students often drawn from farm communities. Medical schools are urban and usually private, and their students come from the urban middle class. They do not fraternize or read the same journals. The pragmatism of both groups is reinforced by the sense of urgency to meet an immediate human need.

The development of a coherent epidemiology is thwarted by the false dichotomies that permeate the thinking of both communities: the either/ors of biological/social, physical/psychological, chance/determinism, heredity/environment, infectious/chronic, and others that we will discuss in other chapters.

One more level of explanation helps us understand the intellectual barriers that led to the epidemiological surprise. Narrowness and pragmatism are characteristic of the dominant ways of thought under capitalism, where the individualism of economic man is a model for the autonomy and isolation of all phenomena, and where a knowledge industry turns scientific ideas into marketable commodities—precisely the magic bullets that the pharmaceutical industry sells people. The long-term history of capitalist experience encourages those ideas that are reinforced by the organizational structure and economics of the knowledge industry to create the special patterns of insight and ignorance that characterize each field and make inevitable its own particular surprises.

# 3

# False Dichotomies

Our understanding of nature is deeply constrained by the language we need in talking about it, a language that is itself the result, as well as the replicator, of long-standing ideological practice. All of science, even "radical" science, is plagued by dichotomies that seem unavoidable because of the very words that are available to us: organism/environment, nature/nurture, psychological/physical, deterministic/random, social/individual, dependent/independent. A remarkable fraction of the radical reanalysis of nature that we ourselves have engaged in has revolved around a struggle to cut through the obfuscations that have arisen from those false oppositions.

One aspect of the dichotomies of general/particular and external/internal is the relation between averages and variations around those averages. A major divergence in explanation, especially in political struggles over the causes of disease and social dislocation, concerns the determinative importance of overall average conditions as opposed to the role of preexistent individual variation. Where one locates the causes of tuberculosis or domestic violence—whether in social and environmental stresses or in intrinsic physical and psychic variation among individuals—has powerful political consequences.

All environments vary in space and time, from the widespread and long lasting to the extremely local and transitory events that we often call random. All organisms vary, both in response to the intricate patterns of environment and because of their own internal dynamic. For most medical, epidemiological, and social research, that variation is a nuisance, and much ingenuity goes into removing the variation experimentally or statistically in order to detect average or "main" effects. For understanding the processes of evolution, in contrast, variation between organisms within a species is the necessary ingredient for evolution by natural selection and an object of interest in its own right. Ecology, a science that developed in part as an extension of physiology, and in part as an aspect of evolution, has been somewhat confused about the importance of average conditions affecting "typical" individuals, as opposed to variation in those conditions and in the responsive properties of individuals. We need to consider the relation among the population average, its range of variation, and the extreme values that occur within the population, all aspects of the interpenetration and mutual determination of variation in organisms and their environments.

First, different traits of the same organism differ in the consequences of variation. For some traits, such as body temperature, blood sugar, or the oxygen supply to the brain or heart, a constancy of the trait itself is critical. When internal or external fluxes displace them, mechanisms come into play that bring them back within the tolerable range. For these traits, increased variation may mean either that they have been subjected to more environmental buffeting or that the self-regulatory mechanisms have been weakened. Individuals differ in their self-regulating systems, but under the "normal" conditions in which individuals have evolved outcomes are essentially the same—all the temperatures of blood sugars or brain oxygen levels are within the tolerable range. Under more extreme conditions of temperature or nutrition or elevation, the individual differences become more important, as some manage to keep the physiology in the tolerable range but for others a critical threshold is crossed resulting in death. Finally, in even more extreme conditions, none of the individuals have enough regulatory capacity and variation disappears along with the population.

Other traits are part of the regulatory system itself, and therefore are themselves varying. Changing metabolic rates stabilize temperature. Varying food intake and insulin levels buffer blood sugar. Redistribution of blood keeps the brain breathing. Varying activities seem to be important for human well-being. For these traits, variation indicates that things are working well. If malnutrition prevents us from raising metabolic rates, if labor discipline prevents us from varying our activity or eating as part of self-maintenance, then our physiological state can move out of the tolerable range, and we have the heart disease, muscle pains, headaches, and depression of alienated labor. We avoid here the added complexity that the same traits are both regulated and regulators.

Second, although many traits are continuously variable, often critical thresholds distinguish between good and bad outcomes. But the numbers of individuals who are across the threshold changes as a consequence of the average level of conditions and, as a result, the manifest variation in the trait changes. Differences in susceptibility to disease, and especially mortality, are magnified at low nutritional levels. Measles, a disease that consumes protein, did not kill students in New York City elementary schools when we were children, although everyone contracted the disease. During the same era measles was the leading cause of child mortality in already malnourished West Africa, so that differences in individual metabolism and resistance would have been of the greatest importance.

The same phenomenon applies to the incidence of casual violence or the prevalence of rape. Not everyone who watches TV violence commits murder; not all sexist men are rapists. But if the average systemic validation of violence increases, then perhaps 1/1,000 instead of 1/10,000 will so act. A serious error in the analysis of causes arises when we fail to take into account the dialectic of average conditions and variations in response to those conditions, and instead take variability as an independent causal force having an intrinsic magnitude. When urban rebellions broke out in American cities in the 1960s, one response was to say that when people are sufficiently deprived by others of social power and economic security while the consciousness of their deprivation becomes heightened, they will rebel. The reaction by the right to this explanation was to point out that everyone in the inner cities did not burn and loot, but that these activities were the work of a small group. This group, it was claimed, had a biological predisposition to violence. Thus the explanation is relocated from the average level of conditions to an intrinsic preexistent variability among individuals. Putting the issue of biological causes aside, it is certainly true that individuals differ in their willingness to put up with insult and injury, and also in how they choose to express their unwillingness. But whether a significant number will find inaction intolerable surely depends on the level of that insult and injury. So the level of oppression that leads to rebellion depends upon the pattern of variation in response among individuals, but that variation in response depends upon the level of the challenge.

Third, quite aside from the effect of average level on the proportion of individuals falling over a threshold, differences in average conditions have a magnifying or reducing effect on the quantitative response of organisms to small variations in environment. An old problem in plant breeding is whether the difference between new varieties and old ones is most easily observed under stress conditions or under the optimal conditions of growth. The arguments were partly a reflection of *a priori* ideological views about social relations. Is the true test of individual merit one's behavior "under fire," in the most challenging circumstances that separate the sheep from the goats, or will the conditions allowing the greatest flowering of intrinsic abilities magnify differences that are small in depauperate circumstances? Partly, the argument is about which traits of the organism are at issue. Consider, for instance, infant deaths in poor communities. They are not spread out uniformly in the community but tend to cluster in those households with a low educational level, little social support, poor nurturing skills, etc., whereas in an affluent community these deficits may be merely inconvenient, rather than leading to mortality.

But the analysis of the causes themselves continues in the same way. Illiteracy or poor skills are not givens. Perhaps a slight visual deficiency made the blackboard blurry in a poorly lighted, overcrowded school room. Poor vision leads to a learning deficiency, discouragement, and dropping out. The individual variation was a consequence of the lack of means (attention, lightbulbs, glasses) and the predominance of a deviation-enhancing mechanism, low vision, that would mobilize the restorative (deviation-reducing) self-regulation in more fortunate circumstances. At the next level we come back to the individual variation. After all, not all children arrive in school with poor vision, a personal misfortune. Ah, but poor vision is often associated with vitamin A deficiency in poor communities. True, but not everyone. . . . Thus, we cycle back and forth between a focus on the systemic, average conditions that make people vulnerable and the range of variation that guarantees that some will fall over some critical value. A correct analysis and program for action demands that average and variant, systemic and individual explanations, are not seen as mutually excluded alternatives, but as codeterminants of the same reality.

## 4

# Chance and Necessity

Since the major breakthroughs of quantum physics in the 1920s and 1930s and the discovery of random mutation as an evolutionary force, people have been asking whether the world is determinate or random. The usual implication of *random*, whether it be a "random" number or a "random" mutation, is that some event has arisen that could not have been predicted no matter how much information was available about the prior state of the world. The spontaneous disintegration of a radioactive nucleus is said to be "random" because there is no difference in state between the nucleus and other nuclei up until the instant that it disintegrates. Randomness has been associated with lack of causality, and with unpredictability and thus of irrationality, a lack of purpose, and the existence of free will. It has been invoked as the negation of lawfulness and therefore of any scientific understanding of society. It then becomes a justification for a reactionary passivity. As the bumper sticker says, "Shit happens." So stop complaining.

For the most part, however, randomness and causation, chance and necessity, are not mutually exclusive opposites but interpenetrate.

First, the fundamentalist approach to randomness that equates it with lack of any causation excludes a large domain of events to which the notion of randomness applies. If, hurrying to a meeting, you rush out into the road and are struck by a "random" car whose driver was on his way to work, it is nevertheless clear that both your path and that of the car were determined and even planned well in advance. What makes the encounter "random" is that the causal pathways of the colliding objects were independent of each other. Opponents of the Darwinian mechanism of evolution have sometimes accused evolutionists of believing that complex organisms have come into existence by purely random processes. After all, don't biologists claim that all mutations are random? But this confuses the two concepts of randomness. It may indeed be true that some mutations are the result of indeterminacy at the quantum mechanical level, but that is beside the point. The essence of Darwinism is that the processes that produce the variation among organisms in the first place, the mutations, are causally independent of the processes that lead to the incorporation of these variations into the species. Mutations are random *with respect to* natural selection. Unless we are dealing with phenomena at the deepest level of quantum mechanics, randomness means causal independence, not the lack of causation.

Randomness by causal independence has powerful implications in biology. Biological objects differ from other physical systems in two important respects. They are intermediate in size and they are internally functionally heterogeneous. As a consequence their behavior cannot be determined from a knowledge of only a small number of properties, as one can specify the orbit of a planet from the planet's distance from the sun, its mass, and its velocity, without being concerned about what it is made of. Biological objects are at the nexus of a very large number of individually weak forces. Although there are indeed interactions among these forces (and the interactions are often of the essence), it is also the case that there are very large numbers of subsystems of causal pathways that are essentially independent of one another, so that their effects on an organism appear as random with respect to one another. Variations in nutrients over a meadow are causally independent of genetic variations among windborne seeds that fall in different parts of the meadow, so the interaction between environment and genotype that determines the growth of the plant is an interaction of factors that are random with respect to one another.

Individual local events that are the intersection of large numbers of specific causal pathways impinge on society as if they were random. The death of Franklin Roosevelt was surely not an accident with respect to the president's own body, circulation, and general state of health. But it was an accident at the level of international politics.

Second, determinacy can arise out of randomness, even the abyssal randomness of quantum physics. The most accurate clocks in the world, measuring time to nanoseconds with no cumulative error, are based on random radioactive decay. Whether individual events are random in the quantum sense or only in the sense of independent causes, the cumulation of large numbers of independent occurrences in averages, sums, and probabilities allows extremely accurate and repeatable prediction. Moreover, the statistical regularities can be altered by determinate processes. Although we cannot predict which mutation will occur in a gene when we change the temperature or expose an organism to a mutagenic chemical, we know the average effect of increasing temperature, of ionizing radiation, of toxic chemicals, and even of the presence of other genes, on both the average mutation rates and on how drastic those mutations may be in their effect.

The Chernobyl meltdown was both an accident and a caused event. Some months before the catastrophe the director of that nuclear power plant gave a reassuring interview in which he said that the safety backup system was so good that we would not expect a serious accident more often than once in 10,000 years. The chilling aspect of this is not that he was wrong, but that even if he overestimated his own plant's safety, he was right. There are more than 1,000 reactors in Europe, so the chance of something happening to one of them is about 1 in 10 years. It happened to happen at Chernobyl. For the director it was an unlikely accident, but for Europe it was not so improbable. A chance event with low probability becomes a determinate certainty when there are a large number of opportunities.

Third, randomness can arise from determinacy. A standard technique in the computer simulation of real world processes is the generation of so-called random numbers. But these numbers are more properly called *pseudo-random* numbers because they are generated by some extremely simple deterministic numerical rule: for example, by using the middle 10 digits of the successive powers of some starting number. If I know the starting number I can exactly reproduce the pseudo-random sequence. Nevertheless the numbers are "random" as far as the process I am simulating is concerned, because the rule of generating them is utterly unrelated to the rest of the process.

Fourth, random processes are causally constrained. "Random" does not mean "anything goes." Random changes in organisms are nevertheless changes in the neighborhood of the preexistent state. A mutation in green peas or in fruit flies results in the alteration of the development of green peas or fruit flies. The flies will not produce vines that climb trellises nor will the peas fly around and lay eggs. The dangerous "mutants" of early science fiction are fictional precisely because they are impossible in the light of the organization of the body in which they occur, not because they are rare. Random changes are then unpredictable only within the domain of the allowable, and one of the major unsolved problems of ecology and evolution is how to delimit the allowable domain for organisms and communities within which random processes can operate. It is precisely the problem of historical materialism: Where can you get from here?

The interpenetration of chance and determination bears on the problem of how there can be a scientific approach to society when individual human behavior and consciousness seem unpredictable. Those who despair point out that people are not machines, that there are subjective processes in the making of decisions, that it is not classes but individuals who make choices. Terms such as "the human factor" or "subjective factors" with their implication of chance and unpredictability are invoked as the negation of regularity and lawfulness. And indeed it is true that individual behavior and consciousness are the consequences of the intersection of a large number of weakly determining forces. But it does not follow that where there is choice, subjectivity, and individuality there cannot also be predictability. The error is to take the individual as causally prior to the whole and not to appreciate that the social has causal properties within which individual consciousness and action are formed. While the consciousness of an individual is not determined by his or her class position but is influenced by idiosyncratic factors that appear as random, those random factors operate within a domain and with probabilities that are constrained and directed by social forces.

# 5

# Organism and Environment

Nothing is more central to a dialectical understanding of nature than the realization that the conditions necessary for the coming into being of some state of the world may be destroyed by the very state of nature to which they gave rise. As it is in nature, so it is in the study of nature. Darwin's most powerful contribution to the development of modern biology was not his creation of a satisfactory theory of evolutionary mechanism. Rather, within that theory, it was his rigorous separation of internal and external forces that had, in previous theories, been inseparable. For Lamarck, the organism became permanently and heritably transformed by its willful striving to accommodate itself to nature and so incorporated that outer nature into itself. By totally confounding inner and outer forces in an unanalyzable whole, premodern biology was in fetters that made further progress impossible. Darwin's division of forces into those that were completely internal to organisms and determined the variation among individuals and those that were external, the autonomous forces molding the environments in which organisms found themselves accidentally, "burst those fetters asunder." For Darwinian biology the organism is the nexus of the internal and external forces. It is only through natural selection of internally produced variations, which happen to match by chance the externally generated environmental demands, that what is outside and what is inside confront each other. Without such a separation of forces the progress made by modern reductionist biology would have been impossible. Yet for the scientific problems of today, that separation is bad biology and presents a barrier to further progress.

The development of an organism is not an unfolding of an internal autonomous program but the consequence of an interaction between the organism's internal patterns of response and its external milieu. Many experiments have demonstrated and a great deal has been written about codetermination of the organism by the interplay between gene and environment in development. Even there, however, the environment is treated as external impingement on an autonomous program or as necessary resources for its realization. But aspects of the environment that are regular occurrences become themselves part of the developmental process. When a seed germinates only after a soaking rain, it is not merely responding to a signal that conditions are suitable. The rain becomes a factor of development as much as the proteins of the seed coat. The development of our ability to see presupposes light, the development of our muscles presupposes movement.

What has received far less attention, both in concept and in practice, is the reciprocal codetermination, the role of the organism in the production of the environment. Darwinism represents the environment as a preexistent element of nature formed by autonomous forces, as a kind of theatrical stage on which the organisms play out their lives. But environments are as much the product of organisms as organisms are of environments. The Darwinian alienation of the environment from its producer, though a necessary condition for the formation of modern biology, stands in the way both of the further development of the sciences of evolution and ecology, and of the elaboration of a rational environmental politics.

There is no organism without an environment, but there is no environment without an organism. There is a physical world outside of organisms and that world undergoes certain transformations that are autonomous. Volcanoes erupt, the earth precesses on its axis of rotation. But the physical world is not an environment, only the circumstances from which environments can be made. The reader might try describing the environment of an organism that he or she has never seen. There is a noncountable infinity of ways in which the bits and pieces of the world might conceivably be put together to make environments, but only a small number of those have actually existed, one for each organism. The notion that the environment of an organism preexists the organism is embodied in the concept of the "ecological niche," a kind of hole in ecological space that may be filled by a species, but it may also be empty, waiting for an occupant. Yet if one asks an ornithologist to describe the "niche" of, say, a phoebe, the description will be something like, "The phoebe flies south in the fall, but returns to the northern mixed forest early in the spring. The male marks out a territory that it patrols and over which it forages for insects, while the female, arriving two weeks later, builds a nest of grass and mud on a horizontal ledge into which she deposits four eggs. Usually insects are caught in flight but nestlings are fed by regurgitation of insects caught near the ground." The entire niche is described by the sensuous life activities of the bird, not by some menu of external circumstances. Organisms do not experience or fit into an environment, they construct it.

First, organisms juxtapose bits and pieces of the world and so determine what is relevant to them. The grass growing at the base of a tree is part of the environment of a phoebe that uses it to make a nest, but not of a woodpecker who makes an unlined nest in a hole in the tree. A stone lying in the grass is part of the environment of a snail-eating thrush that uses it as an anvil, but is not part of the world of the flycatcher or woodpecker. Temperature would seem like an externally given, fixed condition, but every terrestrial organism is surrounded by a shell of warm moist air produced by its own metabolism, a shell that constitutes its most immediate "environment." When we ask, "What is the temperature tolerance of an ant?" we discover many different meanings. What temperature can an ant tolerate for a few minutes or hours while foraging? What temperature can an ant nest in a tree tolerate for a complete life cycle? What temperatures allow for sufficient vegetation and prey to permit a population of ant colonies to persist in contact with other ant species?

Even the relevance of fundamental physical phenomena is dictated by the nature of the organism itself. Size is critical. Although gravitation is an important force in the immediate environment of large objects like trees and human beings, it is not felt by bacteria in a liquid medium. For them, because of their size, Brownian motion is a dominant environmental factor, while we are not buffeted to and fro by bombarding molecules. But that size disparity is a consequence of genetic differences between life-forms, so just as environment is a factor in the development of an organism, so genes are a factor in the construction of the environment.

Second, organisms remake the environment at all times and in all places. Every organism consumes resources necessary for its survival, and produces waste products that are poisonous to itself and others. At the same time organisms create their own resources. Plant roots produce humic acids that facilitate symbiotic relations and these change the physical structure of the soil in ways that promote absorption of nutrients. Ants farm fungi and worms construct their own housing. Many species change the conditions of their surroundings in such a way as to prevent their own offspring from succeeding them. That is what it means to be a weed. Every act of consumption is an act of production and every act of production is an act of consumption. And in the dialectic of production and consumption the conditions of existence of all organisms are changed. At the present no terrestrial species can evolve unless it can survive an atmosphere of 18 percent oxygen. Yet that oxygen was put into the atmosphere by early forms of life that lived in an atmosphere rich in carbon dioxide that they made unavailable to later forms by depositing it in limestone and in fossil hydrocarbons.

Third, organisms by their life activities modulate the statistical variation of external phenomena as they impinge on the organisms. Plants average their productivity over diurnal and seasonal variation in sunlight and temperature by storing the products of photosynthesis. Potato plants store carbohydrate in tubers. We appropriate that storage in our body fat, in warehouses, and in money.

Finally, the organism transduces the physical natures of the signals from the outer world as they are made part of its effective environment. The rarefaction of the air that strikes my eardrums and the photons that strike my retina when I hear and see a rattlesnake are transformed by my physiology into elevated levels of a chemical signal, adrenaline, and that transformation is a consequence of my mammalian biology. Were I a rattlesnake a very different transformation would occur.

A consequence of the codetermination of the organism and its environment is that they coevolve. As the species evolves in response to natural selection in its current environment, the world that it constructs around itself is actively changed. At present, because of the narrow problematic of both evolutionary biology and ecology that envision a changing organism in a static or slowly changing autonomous outer world, we know little beyond the anecdotal about the way in which changing organisms lead to changing environments. We know rather more, but still far too little, about how, through their life activities, organisms are the active makers and remakers of their milieu. But a rational political ecology demands that knowledge. One cannot make a sensible environmental politics with the slogan "Save the Environment" because, first, "the" environment does not exist, and second, because every species, not only the human species, is at every moment constructing and destroying the world it inhabits.

# 6

# The Biological and the Social

Struggles for legitimacy between political ideologies eventually come down to struggles over what constitutes human nature. At present, in its starkest form, the struggle is between a vulgar biological determinism, typified by sociobiology, and an extreme subjectivity. For determinism, all social phenomena are merely the collective manifestation of individual fixed propensities and limitations coded in human genes as a consequence of adaptive evolution. At the opposite pole, subjectivity claims that all human realities are created by socially determined consciousness, unconstrained by any prior biological and physical nature, all points of view being equally valid. At best, liberal thought attempts to combine the biological and the social in a statistical model that assigns relative weights to the two, allowing for some component of interaction between them. But the division of causality between distinct biological and social causes that then may interact misses the real nature of their codetermination.

Like any other species, human beings clearly have certain biological properties of anatomy and physiology that both constrain and enable them, properties that are partly shared with other organisms as a consequence of being living systems, and that are partly unique as a consequence of the particular genes possessed by our species. We all have to eat, drink, and breathe; we are all susceptible to attack by pathogens; there are limits to the external temperatures that our naked bodies can survive; and we will all die. No historical contingency or change in consciousness can remove those necessities. But at the same time, the central nervous system of human beings, combined with their organs of speech and manipulative hands, leads to the formation of social structures that produce the historical forms and transformations of those needs. Whereas human sociality is itself a consequence of our received biology, human biology is a socialized biology.

At the individual level our physiology is a socialized physiology. The time course of blood pressure or serum glucose with age, the integrity of the epithelial interfaces between the insides and outsides of our bodies, the ways in which we perceive distance or pattern, the availability of our immune systems for confronting invasions by other organisms, and the formation and disruption of linkages in our brains—all are variably dependent on class position, the nature of work, the social status of our ethnicity, the commodities that circulate in our society, and the techniques of their production.

At the next level we select our environments actively or they are selected by others for us, sometimes on a moment-to-moment scale as when one is forced to work in the heat of the midday sun, or sometimes through less frequent decisions about where to live, what work to do, with whom to associate, when and how to reproduce. But an environment for settlement or work has many more properties than those that guided the selection. A site on a river may be chosen as a political center for the ease of collecting tribute there, but can also be a breeding place for snails that transmit schistosomiasis.

The socially conditioned construction and transformation of our environments determine the actual realization of biological limits. The boundaries of human habitation do not correspond to the geographical extremes of temperature or oxygen or food availability that could support us in a socially untransformed world, but correspond to those places where economic activity and political power provide the means to regulate our temperature, provide oxygen, and import food. In so doing we also change the determinants of the boundaries of other organisms. The northern boundary of wheat in North America is not the limit of where wheat plants can mature successfully, but where the profitability of wheat in good harvest years makes up for the poor ones so that an average profitable return on wheat is greater than for alternative crops.

As technology provides cultural mediations between ourselves and physical conditions, new environmental impacts are created. A severe winter in an urban environment does not produce frostbite but hunger—when the poor divert resources from food to fuel. Racism becomes an environmental factor affecting adrenals and other organs in ways that tigers or venomous snakes did in earlier historical epochs. The conditions under which labor power is sold in a capitalist labor market act on the individual's glucose cycle as the pattern of exertion and rest depends more on the employer's economic decisions than on the worker's self-perception of metabolic flux. Human ecology is not the relation of our species in general with the rest of nature, but rather the relations of different societies, and the classes, genders, ages, grades, and ethnicities maintained by those social structures. Thus, it is not too far-fetched to speak of the pancreas under capitalism or the proletarian lung.

The socialization of the environment also determines which aspects of individual biology are important for survival and prosperity. Melanin metabolism, no longer of much relevance for heat balance, has become a sign of social location that affects the way in which people have access to resources and are exposed to toxicities and insults. But an organism under stress along one axis of its conditions of existence will be more vulnerable to stresses along other axes as its conditions of homeostasis are taxed. Thus, there will be a clustering of harmful outcomes to health and well-being in households or families under deprivation or stress, even when the conditions that precipitate the cluster seem physiologically trivial. It is the social mediation of individual biological phenomena that turns a single day's incapacity from the flu into the loss of a job for an already marginalized worker, with consequent catastrophic economic failure and a disintegration of health and the general conditions of life.

Beyond the transformation of biological needs into forms that are specific to different times and places, the kind of social interaction that is biologically possible for the human species has an even more powerful property, the property of negating individual biological limitations. No human being can fly by flapping his or her arms, nor could a crowd of people fly by the collective action of all flapping together. Yet we do fly as a consequence of social phenomena. Books, laboratories, schools, factories, communications systems, state organizations, and enterprises are the means of production for airplanes; fuel, airports, pilots, and mechanics make it possible for any of us to do what

Leonardo could not. Nor is it "society" that flies, but individual human beings who go from one place to another through the air. No human being can remember, unaided, more than a few facts and figures, but a social product, the *Statistical Abstract of the United States,* as well as the library that contains it, constitutes a negation of that limitation. But the social process leading to such a negation begins only when a condition of existence is perceived as a *limitation,* that is, when an alternative world is deemed possible. Although it may indeed be a generalized biological property of the human central nervous system to be able to make mental constructs of things that do not exist and to plan actions in advance of their willful realizations, the domain of what we imagine to be changeable is socially constructed. Indeed, the vulgar reductionist claim that human beings are inevitably driven by their biology to behave in certain ways is self-fulfilling for it takes those behaviors out of context and places them in the domain of unquestionable "facts of life," part of the substrate of unexamined conditions of existence. That is why the present ideological struggle over the biological and the social is the elementary political conflict between those who wish to change the nature of human existence and those who prefer to keep it in its present state.

# 7

# How Different Are Natural and Social Science?

A caricature of the study of "nature" and "society" sees social science as deeply corrupted by the subjective elements introduced by the observer, whereas natural science is carried out by objective means. And it is not only the positivist natural scientist, scornful of social science, who propagates this view.

It is often argued, especially by social scientists, that dialectics is fundamentally different in natural science than it is in social science. The difference is said to come from the active participation of human beings in the dynamics of society and especially from the unique role of subjectivity. It is not fruitful, however, to debate whether nature and society are different despite similarities or similar despite differences. Much of the dispute depends on the level of analysis. Obviously, each domain of study is different. In particle physics, quantum mechanical randomness is a central feature. In most ordinary chemistry vast numbers of relatively few kinds of atoms allow for a statistical averaging that masks micro-scale randomness. But macromolecules such as DNA are represented only once or a few times in each cell and behave mechanically. The physiology of individual organisms can be understood in part as goal directed, while the metaphor of the organism is misleading in the study of ecological communities. Societies also have their unique properties, not the least of which is the emergence of labor, culture, ideology, and subjectivity. But the question remains: Is the uniqueness of the social different in kind from the uniquenesses of other domains?

Those who argue that it is point out that the observation of social processes is itself a social process. They emphasize that social processes involve the subjectivity of the objects of study, and sometimes talk casually about "the human factor," which presumably makes uncertainty inevitable and duplication impossible. (The terms "human factor" or "human condition" are not analytic terms. They do not refer to the role of labor in our formation, to the use of language or symbols, or to sexual reproduction. Rather it is most often a term of exasperation or despair.) They add that in natural science we can design experiments and observe a large number of repetitions that cancel out many sources of error. Therefore, they claim, natural science can be objective in ways that social science cannot. They add that it would be futile to expect to have predictive equations for society, whereas even the complex patterns of the earth's atmosphere can, in principle, be thought of as obeying a very large set of as yet unspecified equations. Who could even conceive of writing equations that would predict the emergence and content of postmodernism?

This argument is fallacious for a number of reasons. First, it accepts too much of the natural scientists' self-description. Writing equations, and even prediction from them, is only one activity of science. Formulating a problem, the definitions of relevant variables, the choices of what to include or leave out, the decision as to what is an acceptable kind of answer, the interpretation of results, the rules of validation, and the linking of the conclusions from different studies into a theoretical framework are all the results of social processes, some very idiosyncratic ones, interacting with the natural phenomena being studied. Science has become very sophisticated in correcting for the idiosyncratic subjectivities of its practitioners but not for the shared biases of communities of scholars. A long tradition of the Marxist study of the scientific process is lost when Marxists take scientists at their word and accept the self-description of scientific objectivity, or indeed when postmodernists imagine that the critique of science began with Thomas Kuhn.[1]

Second, science is not the same as quantification or experiment. There have been situations where numerical results have been vital in making theoretical decisions. In tests of relativity theory, the overthrow of parity, the confirmation of the Mendelian 3:1 ratio in genetics, and the prediction of the existence of the planet Neptune from anomalies in the orbit of Uranus precise measurement has been critical. But even here the important conclusions have not been quantitative but rather qualitative or semi-quantitative: that gravitation can affect light, that genetic traits segregate, that there is something else out there beyond Uranus. Statistical tests are often used to decide that some phenomenon has or has not had a "significant effect" on some process or is more or less important than some other phenomenon. Such tests can be used to demonstrate the relation between health and class, the association between poverty and the suicide rate, and the growing concentration of wealth.

But in other discoveries, numerical results played a much smaller role: the recognition of the *Australopithecine* fossil Lucy as close to human ancestry, the formulation of the structure of DNA, the confirmation that mosquitoes transmit pathogens, the role of plaque formation in coronary heart disease, the patterns of continental drift and the expanding universe. The various roles of precise measurement separate different branches of natural and social science rather than natural and social science from each other.

Large-scale computer programs can simulate important aspects of a process, but in the end what we are left with are more numbers. These are often useful for projections as long as nothing important changes. And they are certainly essential in design, where quantitative precision can be crucial. But there is no substitute for qualitative understanding, the demonstration of a relation between the particular and the general, that requires theoretical practice distinct from the solving of equations or the estimation of their solutions.

Nor is experimentation a necessary ingredient of science. Though processes of the very small can be duplicated in the laboratory, we certainly cannot replicate supernovae or epidemics or species formation or continental drift. Here we need other methods of verification. The study of large-scale social phenomena shares with ecology, evolution, epidemiology, and biogeography the characteristic that the number of examples of each kind available for study is small compared to the number of relevant *kinds* of objects that actually exist or are possible. Therefore, replication is not possible. We cannot compare 150 socialist revolutions stratified by the degree of sexism in their societies to compare outcomes, or fifty isolated continents with and without large mammals to see how they affect the development of agriculture or the evolution of birds.

In contrast, there are relatively few kinds of atoms or fundamental particles or stars, each present in extraordinarily large numbers of essentially identical replications. But there are a reasonably large number of small businesses and local officeholders for comparative study. Here prediction is performed not on controlled experiments but on sets of data not used in making the prediction. These differences certainly affect the methodologies of the sciences and the kinds of questions they deal with, but they do not separate natural from social science.

Thus the lack of equations or of controlled experiments in social science does not make it fundamentally different from natural science as such. Nor does the question of predictability. While the classical examples of physical science showed the glorious confirmatory power of accurate prediction, the modern theory of dynamical systems reveals many situations, even rather simple ones, in which precise prediction is not possible. (Weather prediction is a notorious example. The modern interest in "chaos" was stimulated by Lorenz's attempt to solve a model of the atmosphere with only three variables and his discovery that even arbitrarily small changes in a variable could result in drastically different outcomes, and arbitrarily small errors of estimation could make the predictions extremely uncertain.) Yet even chaotic systems have regular as well as seemingly random aspects. We may not be able to project the trajectory of a self-regulating population and yet we know that it will most likely oscillate between certain bounds, and that on one of the downswings it might become extinct. The structure of capitalism makes class struggle inevitable; the uniqueness of each historical configuration makes the particular forms of class struggle and even the outcome uncertain from the perspective of that structure alone.

Thus there are two kinds of uncertainty in science: all systems, no matter how complex, have an outside from which influences not included in the theory may penetrate and have major effects; and the dynamics of complex systems themselves may result in chaos, a combination of predictable and unpredictable aspects of the process. Neither of these is unique to social science.

Subjectivity is subjective only from the inside; our theories do not describe how it feels. But subjectivity can also be studied objectively. Beliefs and feelings have causes, and are themselves causes. They may become more or less common. We can, for example, include fear or despair as links in the progress of an epidemic, responding to the prevalence of a deadly disease and the availability of effective treatment, and affecting the contagion rate that feeds back into prevalence. Changing subjectivities must be included for any realistic assessment of the AIDS pandemic. The study of many different subjectivities reveals patterns of subjectivity that make psychosocial therapies possible.

Thus there is no basis for arguing that dialectics is all right in natural science, where predictability and lawfulness prevail, but not in social science, where the erratic operation of capricious subjectivities thwarts science. Or alternatively, that dialectics is all right in social science where contradictions play themselves out before our eyes, but not in natural science where nature is deterministic and mechanical or statistical. Both dialectical materialism and the more limited insights of systems theory are relevant to understanding both natural and social processes.

# 8

# Does Anything New Ever Happen?

The tired, discouraged author of the Book of Ecclesiastes, writing in the second or third century BCE, assures us that "there is nothing new under the sun" and that "all is vanity." More recently, the arch-Whig Francis Fukuyama allowed that perhaps things *used* to happen, but now history has ended. In the time between the two, many quaint sayings repeated the same theme, including "You can't change human nature" and "Plus ça change, plus c'est la même chose."

Claims that phenomena are radically new or only the same old story do not arise from some general ideology but are meant in each instance to do specific work. In some instances, those who prefer that there be no change, as well as those who have tried to promote change only to see their efforts frustrated, join in picking out ways in which different times are similar in order to deny difference. For instance, to support an argument that entrepreneurship is a basic and unchangeable aspect of human nature, any kind of exchange of goods is seen as "trade," and all trade is interpreted as a form of capitalist exchange. So, a Stone Age male corpse found in the Alps with more flints than he could use himself, or a couple of Cubans exchanging rationed goods to meet their different needs, are lumped into a universal human propensity for commerce (presumably on the same chromosome as the genes for the propensity to cheat on exams and distrust strangers). From such a perspective the Soviet Union was merely a continuation of the czarist empire with superficially changed rhetoric, and all revolutions are alike in that they merely replace one group of rulers with another. Yet, in a seeming reversal of ideology, bourgeois apologists have asserted that capitalism has undergone a revolutionary change, replacing domination by the owners of capital with that of technocrats as a result of "the managerial revolution," while it falls to Marxist theorists to remind us that "plus ça change, plus c'est la même chose."

It is always possible, of course, to find similarities and differences among phenomena. Darwin's tracing of evolution depended on both: the similarities betrayed common ancestry and accounted for the constraints within which divergences occurred, while the differences indicated historical divergence. If there were only differences, with each kind of organism unique and showing no common features with any others, then special creation would be a better explanation of the observations than evolution.

Depending upon the work to be done, it is appropriate to stress similarity or change. In looking at contemporary capitalism, we see the continuation of exploitation, the extraction of profits, and the changing means of production as the main source of wealth, the commodity relation penetrating everywhere. From the perspective of challenging the whole system these elements of continuity are more important than the new: the rise of information industries, the increasing independence of financial instruments several steps removed from production seen as major investment opportunities that offer the highest rate of turnover of capital, the endemicity of unemployment, and the rise of the transnational corporation. But when we plan strategies, then we have to increase the magnification and examine the novel features that affect organizing, the need for across-the-board solidarity, the increasingly dangerous position of the Untied States as a declining economic power with a first-rate military, now facing the problem of how to use its military in the service of the economy.

In looking at similarities it is important to note that two "similar" objects or events may have quite different significance and may be on quite different trajectories of development because they are in different contexts. For instance, voting is now widespread in many societies. But voting has had quite different roles: the confirmation of an existing power relation (all Germans were allowed to vote in Hitler's 1934 plebiscite, giving him the authority to rule by decree); the choice between political parties, within which the populace at large has little voice; a referendum ratifying the results of extensive prior popular consultation, as in voting on budgets in New England town meetings; a popularity contest driven by advertising technicians—all are "votes."

When conservatives emphasize the absence of change they speak of "ethnic conflict" and "ancient enmities" rather than nationalistic conflict, which represents a political choice. But if conservatives underline similarity when it is spurious, anarchist thought often emphasizes continuity, as in the belief that the catharsis of revolution creates "new people," ready and willing to live collective lives in equality and solidarity, freed from previous consciousness. The real experience of building socialism shows otherwise. Some social relations are extraordinarily tenacious, and as Rosa Luxemburg pointed out, we are attempting to build a future with the materials of the past.

The claim that nothing new is happening is a common device for opposing social and political action, either on the grounds that no action is possible because the present situation is an unchangeable constant of nature or that no new action is required because things are not materially different than they have always been. The most active current manifestations of these conservative moves oppose demands for radical action in two spheres where public consciousness has been raised to a threatening degree—social inequality and environmental deterioration. The problem of inequality has been a dominant social agony of bourgeois life since the revolutions of the eighteenth century, revolutions claiming equality as their legitimizing principle. The response to a demand that is unrealizable within bourgeois society has been to claim that really new social relations are biologically impossible because human nature is continuous with a competitive, aggressive, self-oriented, and self-aggrandizing nature built into our nonhuman ancestors by evolution. Nothing really new arose in the evolution of the human species. We are simply "naked apes" possessed of our own species-specific form of unchanged and deeply entrenched animal natures, so attempts to change social arrangements are delusory.

Our anxiety that the present form and scale of transformation of resources will soon make a materially decent life untenable for human beings has been met with the claim that nothing new is happening. Doesn't Marx remind us in the *Grundrisse* that every act of production is an act of consumption and every act of consumption is an act of production? And not only for human beings. Every species of organism consumes the resources necessary for its life and, if unchecked by predation or competition, would undergo unlimited growth. Every organism produces waste products that are poisonous to itself. And why all the fuss about extinction? After all, 99.999 percent of all species that have ever existed are already extinct and, ultimately, none will escape extinction. Time and chance happeneth to all. Moreover, no species of vertebrate or flowering plant has become extinct in Britain in the last hundred years despite the toxic outpouring from the "dark satanic mills." The Greeks had already completely deforested their land in Classical times and there hasn't been any prairie in North America for more than a century, but that didn't stop either the Greeks or the Americans from becoming dominant in their time.

Both of these arguments emphasize the present operation of the same basic forces that were the motors of past history, and the continuity of the present with the past. But that emphasis misses essential features of dynamical systems that allow the occurrence of novelties despite continuity and a uniformity of underlying processes. First, domains of the world that had not previously been touched by the process may become incorporated. All species use resources, but human beings are unique among species in placing nonrenewable resources like fossil fuels and minerals at the center of their consumption. Second, domains of the world that were not previously in contact may be juxtaposed and interact. Most of the chemical reactions produced by humans have never before taken place because the reactants have never been in contact. Third, dynamical systems change their shape at critical values of the continuous variables, so-called catastrophe points, as when a stick, increasingly bent by continuously increasing forces, suddenly breaks. So, even for renewable resources, low rates of production and consumption of these resources may lie within a range of values that allows for a dynamic stability of the system, though exploitation outside this range may result in a collapse. But a mathematical "catastrophe" may also be a constructive novelty. As the central nervous system of human primate ancestors grew larger, with connections multiplying, parts of the brain began to perform new functions, among them linguistic functions that have no analogue in nonhuman primates. Fourth, nonlinear dynamical systems behave smoothly and predictably for some ranges of their parameters, but outside these ranges oscillate wildly and without any obvious predictability (so-called chaotic regimes). An economy of petty money-lending local producers, supplying a local market, does not have the same dynamic as globalized finance capital.

It is said that when Galileo, confronted by the nasty tools of the Inquisition, retracted his claim that the earth, like other heavenly bodies, was in motion, he murmured, "Eppur´ si muove!" (But it does move!) We do not know if he really said it, or only that he should have to satisfy the legend of progressive change. We adopted this phrase for the title of our column in *Capitalism, Nature, Socialism* at a low point in the history of our movement for a new form of social life, when the triumph of capitalism seemed irresistible and Margaret Thatcher's cry of "There is no alternative!" seemed to close off all possibilities. Dialecticians know better.

# 9

# Life on Other Worlds

From the earliest years of the American space program, the detection of extraterrestrial life has been on the agenda. When the *Viking* lander arrived on Mars in 1976 it carried a device for detecting Martian life, an apparatus that was the result of a development program begun with the very first plans for landing an unmanned vehicle on the Red Planet. It was assumed that no little green men would be running around the surface and that life, if any, would be microorganismal. At the beginning of the program there were two competing schemes for detecting life. One consisted of a long sticky tongue that would unroll onto the Martian surface where it would pick up bits of dust. The tongue would then retract, its surface would be passed under a microscope, and the resultant images would be transmitted back to earth-bound microbiologists who would presumably recognize a living organism when they saw it. We may call this the morphological definition of life: if it looks like a cell or wiggles, it's alive. The competing scheme, and the one finally adopted, seemed more objective and more sophisticated. The lander carried a reaction vessel filled with a soluble carbohydrate substrate for metabolism in which the carbon atoms had been radioactively labeled, a kind of radioactive chicken soup. Above the liquid level was a detector that would register the appearance of radioactive carbon dioxide. Dust was scooped up from the Martian surface and deposited in the soup. If there were living organisms, they would use the carbohydrate as an energy source, and radioactive carbon dioxide would be released. This is the physiological definition of life: no matter what it looks like, if it metabolizes it's alive.

The reader may imagine the excitement at Mission Control when, indeed, radioactive counts began to appear and they increased exponentially, as we expect from a culture of microorganisms dividing in an almost unlimited nutrient. But then things went awry. Suddenly no new radioactive counts were registered, although the apparatus was working. Normally a growing culture of microorganisms will slow down in its growth and reach stationary phase of population size, with a steady consumption of nutrients and a steady production of waste products for a long period, but the Martian bugs seemed to have shut down or disappeared completely—in an instant! After considerable debate and soul searching it was decided that life had not in fact been detected, and that the carbon dioxide had been produced from a catalytic breakdown of the carbohydrate on the finely divided clay particles from the Martian surface and that these particles had become saturated. A similar reaction has since been reproduced in the laboratory on Earth.

The morphological definition of life was regarded as too naive because, as a century of science fiction has convinced us, Martian life might be very odd-looking indeed. An extraordinary diversity of forms has arisen in the course of terrestrial evolution and quite different diversity may have appeared on other worlds. After all, organismal shapes are just the assemblies of molecules, and they may take on a bewildering variety, but they are all just different forms of the same underlying processes and laws. Shape is superficial and subject to the vagaries of history. It is the molecular processes that are the invariants of life subject to general physical principles. Molecules are the base; gross forms are the mere superstructure. So if we wish to search for extraterrestrial life we must not be led astray by the superficial specificities of living forms that happen to have occurred on Earth, but search at the molecular level for the constancies that underlie the variation at the higher levels.

The problem of detecting life on Mars, however, is more profound than the NASA scientists perceived it to be. The difficulty posed by historical contingency cannot be escaped by concentrating attention on function rather than form, or molecules rather than gross anatomy, because molecular function also evolves and betrays the effect of historical contingencies. What the *Viking* lander did was to present Martian life with an "environment" without having ever seen the life. But, as we have argued in Chapter 5, just as there is no organism without an environment, there is no environment without an organism. How, among the infinity of possible ways that the physical world can be put together, do we know which represents an environment, except by having seen an organism that lives in it? What the *Viking* experiment showed was that no life on Mars apparently lives in the environment of a restricted range of terrestrial microorganisms. The environment offered to potential Martian life was depauperate, both in what it provided and what it left out. First, it provided only a particular carbohydrate as a nutrient for energy extraction. Even supposing that Martian life is carbon based rather than, say, silicon based, how do we know that it uses carbohydrates rather than, say, hydrocarbons? After all, a bacterium that metabolizes raw petroleum has been produced on Earth. And even if Martian life does metabolize carbohydrate, perhaps it is a sugar that is not fermented by terrestrial bacteria. By mutation and selection experiments, strains of *E. coli* have been made experimentally that will not ferment lactose, their normal energy source, but they will ferment an altered sugar that is not found in nature. Terrestrial organisms have realized historically only a small fraction of the possible basic metabolic patterns.

Second, the Mars lander took no account of most of the complexity that characterizes terrestrial environments. The same experiment done on earth would have failed to detect the presence of most forms of microbial life already known. There is no general microbial culture medium and without a prior knowledge, for example, of the physical substrate specificity, or the inorganic trace elements that are necessary for some species or toxic for others, the search is blind. It would have failed to find sulfur fixing bacteria, nitrogen fixing bacteria that cannot live freely but must be associated with plant roots, fungi and algae that are associated in lichens, extreme thermophiles, halophiles, and so on. For some terrestrial fungi, single spores in isolation will not germinate, but need to be concentrated in a small volume so that their combined low-level metabolism brings the substrate to a critical state, allowing them all to break their dormancy. Is Martian life characterized by dormancy, and if so, what conditions are needed to break it? All of this rich variety of cellular metabolism is the result of historically contingent evolution and none of these forms need ever have existed.

The belief that at the molecular level we will find noncontingent characteristics of life is a consequence of the dominance of a simple model derived from the physical sciences. Biology is seen as a lesser science to the extent that it depends on contingent detail. Perhaps in studying metabolism we have not gone down far enough in the hierarchy of physical nature. What and how organisms eat may indeed be a product of a contingent evolution, but surely there must be some molecular universals that would characterize anything we would want to call "life." Informational molecules? But of course they need not be DNA. Nor does the information need to be concentrated in one sort of molecule. Instead, structures may be self-specifying and may be copied directly by the reproductive machinery, as in the case of cell walls in bacteria which have their own somatic inheritance and which cannot be manufactured without some previous cell wall primer. But why reproduction at all? Like any physical system, living matter necessarily suffers accidents, destructions, and decay, and if there were not some renewal process life would soon end. But why *reproduction*? Why send the old car to the junk heap and buy a new one, if the old one can be repaired indefinitely? All living systems we know of have repair mechanisms, including organ and tissue regeneration, the recovery of damaged cells, and correction of errors in DNA copying. And why individuals? Could not life elsewhere consist of a single physically contiguous object, varying from place to place in its physical extent and from time to time as a consequence of the turnover of its physical constituents? When a tree fell onto the rear part of the four-door sedan of one of our neighbors in Vermont, he converted the car to a pickup truck.

The problem that plagues the investigation of alternative independent lifeforms is the observation that science is necessary because things are different, but that science is only possible because things are the same. The search for life elsewhere that looks simply for a detailed replication of terrestrial life will miss most, if not all, of the events, for it neglects completely the overwhelming importance of historical contingency. However, contingency does not mean that anything goes. The problem cannot be solved by unbounded speculation. There must be something concrete to search for by concrete methods that take into account reasonable physical constraints. NASA does not understand the shape of the problem and is about to repeat the error of the *Viking* lander on a more ambitious scale. It has announced a program in astrobiology, to find life in other planetary systems. But this program is restricted entirely to experimental and engineering projects with no theoretical component. The result will surely be elaborate, with expensive machines designed to detect the simplest terrestrial life somewhere else.

The importance of a correct formulation of the problem is, of course, not in finding life on other planets, a project whose probability of success is exceedingly small. Rather, a proper model for its solution is a model for the management of terrestrial life. Things in the future cannot be exactly as they were in the past. Ecosystems will change and species will go extinct. Life "as we know it" cannot be maintained. But neither is a future possible that is bounded only by imagination and desire. Our methodological problem is to develop an approach to planning and agitation that takes into account both historical contingency and the limits to its possibilities.

## 10

# Are We Programmed?

Living organisms are characterized by two properties that make them different from other physical systems: they are medium in size and functionally heterogeneous internally. Because they are smaller than planets and larger than atomic nuclei, and because there are a large number of interacting processes occurring within them, organisms are at the nexus of a very large number of individually weak determining forces. Their behavior either individually or collectively cannot be described or predicted by reference to a few laws with a few parameters, unlike the laws of motion of the solar system or the laws of quantum physics that apply to very large and very small and rather homogeneous systems. The consequence for science, an enterprise that takes Newtonian mechanics as its model *par excellence,* has been to search for analogies and metaphors for living systems that will somehow reduce their bewildering variety of behaviors to some manageable system of explanation and prediction.

The history of these metaphors mirrors the history of science and technology and the ideologies of successive periods. The founding metaphor of modern biology is Descartes's machine model in which the organism is analogous sometimes to a clock with its gears and levers and sometimes to a mechanical pumping system. Descartes finessed the problem of the unpredictability of human behavior by a neat dualism, putting free will into an entirely nonphysical realm of soul. Problems of faith and morality were assigned to another department, where knowledge was revealed by the Church, leaving science with a free hand to describe the machinery of the body.

Since Descartes, the use of new technology and new ideology in modeling organisms and especially human beings has been the unvarying rule, and in each epoch the metaphor reflects the current state of science, technology, and ideology. The idea that the heart is a pump, that our bones and muscles are levers and pulleys, that our circulatory system is plumbing, and that spinal disks are shock absorbers belongs to the simple technology that dates to the seventeenth and eighteenth centuries. But the development of social ideology also enters. Hanging on the wall of one of our offices is a large educational chart from the late 1920s showing the internal operation of "The Human Factory," with rooms, machinery, and workers reminiscent of the last episode of Woody Allen's *Everything You Always Wanted to Know About Sex.* The gears, pulleys, conveyor belts, and chemical vats, and the workers who operate them, are all being signaled along wires that run through a telephone switchboard tended by women operators. The input to this switchboard comes literally "from the top"—three offices in the skull in which men in suits and ties perform the functions of Intelligence, Judgment, and Will Power.

As technology has changed, so the ruling metaphor has changed. The telephone exchange was clearly too simple to account for the central nervous system, so it became, briefly, a hologram in order to include the new observations that information is stored in a dispersed fashion. But the hologram model didn't do the needed work and we were rescued by the invention of the digital computer. The physical realization of the abstract Turing machine, a digital computer, is an arrangement of electrical and mechanical components, the entire function of which is to serve as the physical host for an abstract set of preexistent directions, the program, that will turn input data about the world into output. The computer itself is the mere electromechanical device, the muscle of the productive enterprise. It is the program, the blueprint, the plan, that is the essence of the productive operation. Nothing better manifests the ideology of the separation of physical and mental labor and the superiority of the mental to the physical than the computer and its program. The immense ideological power of the metaphor of the computer program has resulted in its spread from a model of the central nervous system to a model of the entire organism. The genes contain the program, the essence of the organism, while the cell machinery simply reads the blueprint and executes the directions.

The problem with analogies and metaphors is that we need them in order to understand nature, yet their power to illuminate nature is accompanied by great dangers. Each technological advance reveals a different aspect of our relations with nature, and new domains of technology often imply deeper understanding of nature. The insights can then be applied elsewhere. Nor is it useful to put an analogy under a microscope to see where it does or does not fit. Of course, there will be differences between the model and what is being modeled. As Norbert Wiener wrote, "The best model of a cat is another, or preferably the same, cat." The question is, what does the model do for us to deepen or weaken our understanding?

Let us look at what is implied by the computer analogy.

When somebody says that some behavior is programmed, the implication is that it is inevitable, determined in advance. For scientists, there is the pleasure of puncturing the self-important illusion that we make decisions and choose behaviors freely, with perhaps a touch of an anticlerical poke at the soul. Calling us programmed is a self-deprecatory expression similar to referring to posturing, pompous, and competitive men as "alpha male" or the elementary school claim that the human being is twenty-three cents' worth of chemicals, or that falling in love is a matter of "chemistry."

The technological analogies of the past all served useful purposes. The heart *is* a pump. Its contractions send blood through the body, the strength of the contractions and the amount it fills before contracting tell us how much blood is pumped. The atherosclerotic plaque on the walls of arteries *do* constrict the flow of blood and therefore oxygen to where it is needed. But it also *is not* a pump; plaque is far more dynamic than rust being deposited and removed from the arteries. An artery can be blocked by plaque but also constricted reversibly by stress. The plumbing analogy did not allow for the known possibility of reversal of heart disease or sensitivity to the intricate relation among cardiovascular state, emotional flux, and social location. The analogy of the brain to a circuit network is also helpful: functions are concentrated in specific regions and damage to those regions impairs function. But an activity is carried out in many parts of the brain at once, and when there is damage to one part, the activities may be relocated in other sections. Circuit connections do not guarantee transmission since neurotransmitters are required where the nerve cells meet. Nerves are continually remaking their connections and injured nerve cells can regenerate. Thus, the "hard wiring" of the brain is "soft" (dynamic). It develops during prenatal and post-natal development of the body and depends on the connections being used.

The program model does not mean we always do the same thing. Rather, we have a sophisticated program that can respond differently to different situations, and by comparing the results of a behavior to whether it is good or bad for us, the program can learn. Computers can learn some things well, such as playing chess. In the famous case, Big Blue "learned" by scanning very large numbers of choices and evaluating their outcomes. Increasingly, computer programs are designed to simulate brain behavior. When they do, we are told, "See, the brain is like a computer."

But the notion that we are programmed is misleading in several important ways:

- Brains generate spontaneous activity. When sensory input is reduced, as in sleep or isolation, brain activity gives us dreams, fantasies, or hallucinations. Thus, unlike a computer program, the brain is not at rest when not called upon to act. *Therefore, the brain is never in the same state twice, so that the same stimulus need not evoke the same response.*

- Brain "programs" are influenced not only by the data that can be regarded legitimately as "input" to the program but by processes extraneous to the program that can distract, excite, depress, or otherwise alter the "program" in ways not part of the program. Neurons that are involved in computations may be influenced by hunger, noise, sexual arousal, worries from another sphere of life, exhaustion, or spontaneously generated internal activities. Computers can also do more than one thing at a time. But then it is through time-sharing—essentially having different programs at work that do not influence each other. *The brain is doing many things at once, and these things influence each other.*

- The "program" is not a separate physical entity from the body that is activated by the brain, whereas in a computerized machine or robot the output is conceptually distinct from the sensors and computers and the program itself. In an organism, these are made of the same material as the limbs and eyes. For example, the blood pressure sensors in the kidney can be damaged by high blood pressure and then alter the regulation of blood pressure. As against the hierarchical notion of a programmer aristocracy commanding the peasant body, we have the structures and activities of the body developing and controlling each other.

- The brain has some $10^9$ neurons, and these may have hundreds of connections each. Thus the number of circuit arrangements that are possible is vastly greater than the number of subatomic particles in the visible universe. The genome has only some $10^6$ to $10^9$ genes. Thus there cannot be a different specific genetic blueprint for the construction of each different brain. Rather, there are some more general patterns that are prescribed by the fluxes of proteins: localization of branchedness, probabilities of linkage, proportions of excitatory and inhibitory pathways, synthesis of neurotransmitters, and other very general properties out of which we produce ourselves through interactions with the environments of the uterus and later the wider world. In that interaction, the developing organism selects, transforms, and defines its environment and is transformed by it.

Very little is known about the neurological equivalents of particular behaviors even if we do know the regions of the brain involved. For instance, if people are given arithmetic problems, we can detect heightened activity in some cortical regions, but we have no idea how doing addition is different from long division. We might detect a region of the brain that is especially active as we contemplate works of art, but not separate neurological patterns for looking at expressionist and cubist art. We can identify pathways of neural and chemical activity associated with stress but not why some things are stressful and others not, or how fear of an oncoming automobile differs from fear of losing your job. What we can say is that there are stress responses, coordinated activities of nerves, glands, and muscles that form a more or less coherent cluster of behavior. But these clusters are loosely linked to each other and to cognition, to the processes that evaluate a situation as requiring that mobilization of bodily resources. Our total behavior is therefore a unique combination of more or less stereotyped subunits that makes behaviors look familiar. So, yes, our "printer" may be programmed to print letters as "instructed," but the text is created in a different arena.

How do we interpret the observation that male baboons who have "low social status" in a troop have cardiovascular patterns similar to those of low-status human males? Clearly, both are stressed by their social circumstances. This is not an argument for the universality of hierarchy, but rather a critique of our society that creates a status hierarchy attached to all kinds of privileges, the exclusion from which is stressful. The stress response itself is partly shared with other mammals. (Since we study the patterns in the laboratory, we pick out those aspects that can be compared and remain ignorant of aspects of the stress response that are uniquely human.) But what is stressful is clearly not the same; the stress cluster is linked to quite distinct phenomena. Although the metaphor of the computer program has some use and application when applied at the level of the translation of genes into specific proteins, that use becomes more and more problematic as we move away from that level toward higher and higher levels of organismic function. Genes may be a "program" for protein structure, but protein structure does not contain all the information needed to construct the physical body of an organism at birth, and the physical structure at birth does not predict the course of later development. Most remote of all from a program model is the specific formation, development, and the moment by moment functioning of the brain. To quote Wiener again, "The price of metaphor is eternal vigilance."

# 11

# Evolutionary Psychology

With the waning of religion as the chief source of legitimation of the social order, natural science has become the font of explanation and justification for the inevitability of the social relations in which we are immersed. Biology, in particular, plays a central role in creating an ideology of the inevitability of the structure of society because, after all, that structure is the collective behavior of individuals of a particular species of organism, a manifestation of the biological nature of *Homo sapiens.* Biology has been supposed to provide the answers for two major questions. First, why, despite the ideology of equality that seems an unquestioned fundamental of bourgeois social theory, is there so much inequality of status, wealth, and power? The biologistic answer has been that such inequalities are the consequence of unequal distributions of temperament, skill, and cognitive power, manifestations of genetically determined differences between individuals, races, and the sexes. But this claim leaves untouched the second question. Suppose it were true that there were such genetically determined individual and group differences. Those differences in themselves do not dictate a hierarchical society. Why not "from each according to ability and to each according to need"? What is required is a biologically based framework for human motivations and interactions that will explain, among other things, why unusually skillful basketball players get so rich and famous, but women players less so than men. That is, to complete its program of explaining human society, biology must have a biological theory of human nature.

A biological explanation of human individual behavior and social interactions cannot simply be a story of genetic determination. It must also incorporate an explanation of how the particular genes that are said to be the efficient causes of human behavior came to characterize the species, as opposed to the genes that govern behavior in, say, fish. A modern biological explanation, to be respectable, must be evolutionary. But a plausible evolutionary explanation must be more than a mere narrative, providing a reconstructed historical sequence of characteristics during the evolutionary history of a species. First, it must convince us that characteristic human behaviors, though specific to the human species, are nevertheless detectable alterations of general behavioral properties of other organisms. Somehow what humans do must be special cases of aggression or communication, or sexual competition, or problem solving, or a mechanism of cheating in a cooperative sharing of resources, or any of the other properties that all animals are supposed to exhibit. A unique behavior that cannot be derived from a related one in a related species is a serious embarrassment for the teller of evolutionary stories.

Second, given the ideological function of an evolutionary explanation as providing justification for a behavior, it must be possible to give an explanation of the evolution of the behavior as resulting from natural selection, so that the genes for behavior are not only present but superior to alternatives. It is the selective story that, along with the genetic determination, does the most important ideological work. If a behavior is genetically determined, or at least very strongly influenced by genes, then it will be seen as very difficult to change by merely social arrangements, or, even if it could be changed, the new behavior would be unstable and likely to relapse back to its "natural" state. If the genes for the behavior were established by natural selection, then the welfare of the species is at stake. The most popular view of evolution by natural selection, a direct inheritance from Adam Smith's "invisible hand," is that evolution is an optimizing process in which choosing the most fit individual will maximize a species' efficiency or stability or likelihood of survival. We change what has been established by natural selection at our peril.

Over the last twenty-five years there have been two widely disseminated versions of the evolutionary argument for human social behavior. The first, sociobiology, provided a specific adaptational explanation for every social manifestation that the theory's inventor, E. O. Wilson, could list, including religiosity, entrepreneurship, xenophobia, male dominance, the urge to conform, and ease of indoctrination. Sociobiological theory was an instant success in explanations of animal behavior, but it engendered, from within biology, a strong critical attack on both its pretensions and its status as well-supported natural science. As a consequence, though it remains part of the explanatory structure used by many economists, political scientists, and social psychologists, "sociobiology" has become a term of some opprobrium in biology and even Wilson has gone on to immerse himself in the more acceptable domain of species conservation. In its place there has arisen the subject of "evolutionary psychology," a somewhat more nuanced version of sociobiology that replaces the naive and easily attacked detailed claims of sociobiology with a more general adaptationist theory. The basic assertions of evolutionary psychology are expressed by its best-known proponents, Cosmides and Tooby:

> The brain can process information because it contains complex neural circuits that are functionally organized. The only component of the evolutionary process that can build complex structures that are functionally organized is natural selection. . . . Cognitive scientists need to recognize that while not everything in the design of organisms is the product of selection, all complex functional organization is.[1]

Unfortunately, we are not given helpful directions on how to know a "complex functional organization" when we see it. This general theory is then cashed out, in particular for human social behavior, by claiming that what has been selected are certain specialized mechanisms like "language acquisition device . . . mate preference mechanisms . . . social contract mechanisms, and so on." The list is much less specific than xenophobia and religiosity, but nevertheless covers the same territory. Like its predecessor, sociobiology, evolutionary psychology depends on poorly specified notions of complexity and adaptation and asserts without any hope of proof that traits judged to be adaptive can only have been established by natural selection as opposed to, say, learning by individuals and groups in a social environment. What characterizes evolutionary explanations of human behavior is the lack of any articulated social theory. The closest evolutionary psychology comes to a social theory is to claim that individuals have been selected who have the capacity to enter into "social contracts," that is, the willingness to go along with group norms. How those norms are arrived at, what their historical dynamic is, how individual socialization varies from group to group, between sexes, among individuals, are all outside the theory. It is, in fact, a theory without a social content.

Whereas evolutionary psychology and its parent, sociobiology, derive their appeal outside of science as bases of legitimation for political and economic structures, it should not be supposed that the drive to invent such theories comes from such justificatory needs. There is something else at stake for natural scientists and academic theorists of society. The model of a "real" science is one that is universal in the domain of its explanations. In evolutionary biology, the drive to apply the skeletal structure of evolution by natural selection to every aspect of living organisms is the drive to provide the science with its ultimate legitimation. After all, if the principles of evolution cannot explain the most significant aspects of human existence, our psychic and social lives, then what kind of a science is it? Moreover, the most prestigious domain of modern biology and the one that claims the greatest successful generalization is not evolutionary, but molecular biology. So evolutionary science, if it is to succeed, must not only be universal in its application, but must conform to the extreme reductionism of molecular biology. Social explanation is seen as obfuscatory.

In pursuit of a reductionist explanation some, but not all, of the recent discoveries of neurobiology are used. Gross regions of the brain can be identified that become more metabolically active (that is, consume more sugar or show more electrical activity) when memory, cognitive, or emotional processes occur. Neurotransmitter molecules have been identified that mediate specific kinds of activity such as motor control or memory, and disorders such as Parkinson's and Alzheimer's disease have been associated with their aberrant production. This encourages evolutionary psychologists to believe that the Human Genome Project will reveal genetic determination of neuroanatomy and neurochemistry and, hence, human behavior.

Yet, other discoveries are ignored, such as the ability of nerve cells to develop and reconnect throughout life and the impact of social experience on our whole physiology. The cerebral cortex, acting through its labile connections and by way of neurotransmitters, links social experience to our biology. For instance, the balance of the two branches of the autonomic nervous system, the sympathetic and the parasympathetic, in the regulation of heart function is different in working-class and middle-class teenagers. Thus, causation flows in both directions and a biological difference associated with a behavioral difference is not evidence for internal biological determination, nor do behavioral differences explain social organization.

The drive for intellectual legitimacy also compels psychology, sociology, and anthropology. That search for legitimation has demanded the creation of "social science" out of the "merely" humanistic study of history, anthropology, and sociology. Evolution is a form of history, and nothing is easier than to gain the respectability of a natural science by confounding history and evolution. But because evolutionary biology as the price of its own respectability is driven to an extreme reductionism, evolutionary social theory is no social theory at all.

# 12

# Let the Numbers Speak

After three centuries of reductionist science in Europe and its cultural inheritors, in which the problem of "What is this?" would be answered by "This is what it is made of," modern science increasingly confronts the problems of complexity and dynamics. Whereas the great successes of science have been largely discoveries about isolatable phenomena or small objects in which a small number of determinate causes are operating, the dramatic failures have arisen where attempts are made to solve problems of complex systems and dynamics. It is no exaggeration to claim that complexity is the central scientific problem of our time.

In preceding chapters we have criticized reductionist approaches in various fields, challenging the fundamental assumption of reductionist science that if you can understand the smallest parts of a system in isolation from one another, then all you have to do is to put them together correctly in order to understand the whole. As a research tactic this model certainly works, provided the system being studied is simple enough, and even for very complex systems, many of the bits and pieces are nearly independent of one another and can best be understood by a reductionist research strategy. Descartes's metaphor of the organism as a clocklike machine certainly works for clocks, or for the heart viewed as an isolated pumping machine, but not for whole organisms, or social and economic organization, or communities of species. Our criticism of the simple reductionist machine model has been based in an assertion about the actual nature of things, namely that, in general, their properties do not exist in isolation, but come into being as a function of their context. Thus, it is what philosophers call an *ontological* error to suppose that we can understand composite systems by dividing them into *a priori* parts and then studying the properties of those parts in isolation. But the reductionist research strategy for studying complex systems has also been abandoned for a different reason by many scientists who are ontological reductionists and believe that the world really is a large set of gears and levers with intrinsic, isolatable properties. They have abandoned it because they believe that, in practice, we cannot study all the properties and all the connections of very large systems made up of many different parts with many paths of interaction among them and in which the multiple causal forces are individually weak. These *epistemological* nonreductionists say that it is just too hard, that we do not have world enough and time, or that because of physical, political, or ethical constraints the ultimate power of the reductionist strategy is not available to us. Until relatively recently it was a criminal act to dissect a human corpse.

Laplace is famous for his statement that if he knew the position and velocity of all the particles in the universe, he could predict all future history. This was the strongest claim for reductionism that could be made in a deterministic material universe. But he also knew that the information could not be made available to him and so, using the notions of probability, he treated the effect of all the unexplorable causes as chance. The realization that the world may be too complex to study by dissection, even if in actuality it were machine-like, has given rise to a mode of study that, over the last century and a half, has come to be a major methodology for the analysis of causes in complex physical and social systems. That methodology is *statistics.* In the eighteenth century statistics was a purely descriptive set of techniques for characterizing assemblages of objects, especially human populations, as a political (statist) tool. Beginning in the late nineteenth century, through a union with the theory of probability, statistics became a major mode for the inference of causal relations when, for one reason or another, the preferred reductionist method of dissection and reconstruction is not possible.

Though we ordinarily think of statistics as an analysis of populations, the basis of the statistical approach to inferring causes is a model of the *individual*, and it is an explanation of the properties of the individual that are being sought. The properties of each individual are assumed to be the consequence of a nexus of variable causes whose magnitudes are, relative to one another, insufficient to have an unambiguous effect on each individual object. Every tree that is cut will fall because the single force of gravitation overwhelms all other minor perturbations, but every tree is of a different size and shape because growth is the consequence of the interaction of a very large number of individually weak genetic and environmental causal pathways as well as of microscopic variable molecular events within cells. We do not need statistics to infer gravitation, at least for large objects, but statistical methods are the reigning techniques for inferring the causal relations of genes, environment, and molecular "noise" in nature, because every individual differs in the effects of these variable causes. In order to overcome the difficulty posed by large numbers of causes, each with a weak effect, large numbers of individuals are agglomerated into statistical populations and average values of causes and effects are studied. It is in the formation of these populations and the calculation of the averages that all action occurs.

There are essentially only two techniques of statistical inference. In one, contrast analysis, individuals are sorted into two or more populations based on some *a priori* criteria: males and females, different ethnic groups, age categories, social class. Some kind of average description of some characteristic of interest is then calculated within each group and if these averages are sufficiently different between the groups, then the criterion used for setting up the groups is deemed to be of causal significance. The average that is calculated may be simply the numerical average (mean) of the characteristic, say the mean family income, or it may be the proportion of the population falling into some class, say the proportion of families with incomes above $50,000, or it may be some measure of the variability of the characteristic from individual to individual.

The alternative technique, correlational analysis, is to assemble all the individuals into a single population, to measure two or more characteristics, again chosen *a priori*, and then to look for trends in one or more of these characteristics as other characteristics vary. Does some measure of ill health tend to increase as family income decreases? A commonly chosen variable is time. For all people who have died in the last hundred years, does the proportion of those dying of lung cancer increase as the date of birth is later and later? When some relationship between variables is seen then some inference about causation is made.

Whereas it is often claimed that statistical techniques are ways of letting the objective data speak for itself, in both of these modes of statistical inference all the real work is done by the *a priori* decisions imported into the analysis. What *a priori* categories will be used, in the first mode, to create the contrasting populations? Is gender relevant, or social class, or ethnicity? These decisions must be made before the data are even collected. American sociology is well known for ignoring theory-laden social class as a variable and substituting theory-laden social economic status as a numerical and therefore "objective" measurement. In both contrast and correlational analysis what characteristics are to be measured: mean family income, which is heavily weighted by a small number of very-high-income families, or median family income, which is not biased in this way; days of work lost which, for a given cause of ill health, may be greater for the more affluent than for those who must go to work even sick? Which characteristics should be held constant while others are compared? Do blacks and whites differ in health status if the data is filtered in such a way as to equalize occupational status and income between the two groups? And, finally, which is cause and which is effect? Is low income the cause of ill health, or ill health the cause of low income? At every juncture in the analysis, from the gathering of data to the final analysis, an *a priori* theoretical model of causal relations guides the "objective" statistical methodology. Therefore it is necessary to recognize that causal relations inferred from statistical comparisons may be artifacts of the set of assumptions that enter in the "objective" statistical evaluation of data.

In what remains of this chapter, let's briefly explore the problem of directionality of causation and the relationship between cause and effect, on the one hand, and dependent and independent variables, on the other. A variable that is said to be "independent" is one that is assumed to be determined by conditions outside of, and autonomously from, the effects being studied. The distinction between independent and dependent variables is a fundamental theoretical construct of much correlational statistical work. In environment studies, the level of pesticide treatment may be the "independent" variable and the prevalence of brain cancer the "dependent" variable. In economics the tax rate may be the independent variable and investment the dependent variable. In the new field of "policy," a policy choice such as allocation of resources to health programs can be treated as the independent variable and health outcomes the dependent variable. Then statistical calculations are performed using these *a priori* variables and inferences about causes and effects. One or another statistical rule is used to decide if the putative causal relation is supported by the relation between the independent (causal) and the dependent (effect) variables.

But what happens if cause flows in both directions? What happens if health outcomes of policies result in public action to change policy, if disability affects income? In the last century, Engels wrote of the interchanging of cause and effect, physiologists described self-regulation, and engineers were designing self-correcting industrial processes. In systems of any complexity there are feedbacks, and these affect the relationship between statistical outcomes and causal pathways.

In negative feedback, a change in one element of a system leads to changes in others that eventually negate the original change. The negation may be partial, complete, or even overshoot, so that dumping nitrogen in a pond may reduce the nitrogen level if a radical change in species composition occurs, or applying pesticides may increase pest load by removing more pesticide sensitive competitors of the pest or, frequently, by killing off predators of the pest species. The predators are poisoned directly by the pesticide, but both a negative and positive branch of a feedback loop are involved. Along the positive branch predators are decreased because their food supply, the pest species, is decreased by the pesticide. Along the negative loop the pest carrying insecticide molecules poisons the predator, which results in an *increase* in prey. It is not that predators are more sensitive physiologically to insecticide, but that their location in the loop makes them more vulnerable ecologically. The important point for statistical analysis is that every negative feedback loop has a negative and a positive branch. Along the positive branch, prey increase the predator population, high blood sugar increases insulin, addition of nutrient increases algal growth, high farm prices encourage production. Along this branch both variables increase or decrease together: this is formalized as a positive correlation between the dependent and independent variables. But along the negative branch of the feedback loop, predators decrease their prey, insulin reduces blood sugar, high algal growth creates a mineral shortage, increased production reduces farm prices. Then the two variables move in opposite directions and show a negative correlation.

These feedback loops are embedded in larger contexts and other influences may impinge upon the loop at any point, moving first along the positive or negative branch. Then the same pair of variables, predator/prey, insulin/sugar, production/price, nutrient/algae, may show positive correlations in some situations and negative ones in others. Finally, if influences of other variables percolate along both positive and negative branches there may be no correlation at all, even if the variables are interacting strongly. This may lead to the erroneous conclusion by students that correlation is not the same as causation. Then why do they carry out correlational analyses at all?

# 13

# The Politics of Averages

It is commonplace knowledge that different sorts of averages give very different information about populations and thus can suggest different conclusions from the same basic data. The mean or arithmetic average household income, for example, simply takes the total income of the entire population and divides by the number of households so that one very rich family makes up for a large number of poor ones. If one wants to emphasize how well off people are the mean is the number to use. The median family income, in contrast, is the value below which half of all families fall, thus taking account of the proportion of families in different income categories and providing a more realistic view of the situations in which families find themselves. In the United States the median family income is about two-thirds of the mean. If Bill Gates and other rich entrepreneurs all double their incomes, the average family income in the United States will increase but not the median. Measures such as the income of "the top 10 percent" or "the bottom 20 percent" or their ratios grasp the distributional aspects better while averages are more suitable for how well "we" are doing.

What is not so well known is that all ratios, such as those commonly used in ecology, population studies, and economics, provide the same ambiguity as simple averages and the same opportunity to obscure or reveal the actual situation. This ambiguity arises because the average of a ratio of two variables is not, in general, equal to the ratio of the averages, and this discrepancy is quite large when the variation is large for both the numerator and denominator. There is no application in which this discrepancy is more apparent and more distorting than in the characterization of population and resource density. For example, the population density of a country or region is usually calculated as the total number of individuals divided by the total area. For the United States, according to the 1990 census, the population density was:

$$\frac{248{,}709{,}873 \text{ people}}{3{,}539{,}289 \text{ sq. miles}} = 70.3 \text{ persons/sq. mile.}$$

But this is clearly a gross underestimate of the effective density at which people are living because the estimate takes the large, dense urban populations and treats them as if they were uniformly spread over the vast deserts of the Great Basin. In fact, the effective density at which people are living in the United States turns out to be about 3,000 people per square mile.

The density of a population can be calculated in two ways. In both cases we begin by dividing the entire extent of the population into small areas within which the population is more or less evenly spread, say counties or ponds or patches, depending on the organism. We then measure the area of each patch and count the number of individuals in each to calculate a local density. The question now arises how we are to combine these individual local ratios to characterize the population as a whole. One way is to weight each ratio by the proportion of the entire *area* that is in the local patch to produce a so-called *area-weighted density.* This turns out to be what is actually calculated by the usual ratio of total population to total area. But such an area-weighted density gives great weight to all those areas with few or no individuals in them and thus badly underestimates the real density at which most individuals live. For instance, suppose there are three people living on a one-acre plot and one person on three acres. There are four people on four acres so that the average population density is one per acre. But three people are living at a density of three per acre and one person is living at one-third person per acre. The alternative is to weight each local ratio by the proportion of the entire *population* that is included, and sum these up to produce an *organism-weighted density,* giving a realistic picture of the density at which individuals are actually living. In our simple example, the average effective density is then

$$\frac{3 \times (3/1) + 1 \times (1/3)}{4} = 2.33 \text{ people/acre}$$

The person-weighted density is always larger, and often many times larger than the area-weighted density, with consequences that are inconvenient for a national government or the World Bank. However, if, as ecologists, we ask the question, "What is the average pressure of human activity experienced by a patch of land?" then the area-weighted measure would be quite appropriate, although it would still leave out the information that some pieces of land are much more highly exploited than others.

As an example we consider the pattern of farm size in Panama in 1973 for which we have a census. Since the total farm population was 575,153 occupying a total farm area of 2,098,062 hectares, it was a mere 0.27 people per hectare by the conventional measure or, inversely, 3.65 hectares per person, not a very high density on a world scale. However, as one might expect, the most crowded 20 percent of the population occupied only 0.2 percent of the farm area and the most crowded one-third of the farmers had only 1 percent of all the land. At the other end of the distribution a tiny 0.1 percent of the farmers occupy a total of 10 percent of the farmland. The effective density of farm occupation, calculated from the person-weighted density, turns out to be 22.07 people per hectare or, inversely, only .045 hectares per person, clearly inadequate to support people even at the highest yields achieved anywhere. The person-weighted density, which is 80 times the conventional calculation, gives a quite different picture of the causes of poverty in the Panamanian countryside.

Just as there are different ways of calculating density, so, reciprocally, there are different ways of calculating average wealth, that is, the average amount of resource available to each individual. The conventional measure, as in per capita income, is to take the aggregate wealth and divide it by the total number of individuals, which is exactly the reciprocal of the conventional measure of density. But again this leaves out of account the effect of the uneven distribution of resources. By analogy with the measure of density we can calculate a *resource-weighted wealth* and an *organism-weighted wealth.* The conventional measure, which is simply the reciprocal of the area-weighted density, turns out to be the organism-weighted wealth and gives an overestimate of how much wealth individuals typically have because it takes no account of the uneven distribution of resources. Once again it is not a complete surprise that this is the measure used in public statistics.

In ecological questions the choice of a measure of density or resource availability depends upon whether one takes the standpoint of the resources or the consumer. Consider, for example, a fairly uniformly spread food plant consumed by an insect with a patchy and clumped distribution, a common situation when there is larval feeding. From the standpoint of the insect as a consumer, most individuals are densely packed on their resource so the organism-weighted density is an appropriate measure for the population. From the standpoint of the food plant, however, most individuals are free of predators, or nearly so, and it is the resource-weighted wealth that counts. Evolutionary arguments about the force of natural selection depend on the organism-weighted density for pressure to adjust the search behavior of the predator, but on the resource-weighted wealth for pressures on the plant to develop secondary poisonous compounds that will resist the insect. Thus the predator and the prey respond to two quite different measures of density arising in the same predator-prey interaction.

There is, then, no single "correct" measure of average density or wealth either in ecology or political economy. The question is: Whose side are you on?

# 14

# Schmalhausen's Law

Ivan Ivanovich Schmalhausen was a Soviet evolutionary biologist working at the Academy of Sciences in Minsk. In the 1940s his book *Factors of Evolution* appeared and was denounced by T. D. Lysenko, whose neo-Lamarckian theories of genetics were then on the ascendancy. At the close of the 1948 Congress of the Lenin Academy of Agricultural Science it was revealed that Stalin had endorsed Lysenko's report in which it was affirmed that the environment can alter the hereditary makeup of organisms in a directed way by altering their development. Schmalhausen was one of the few who affirmed his opposition to Lysenko and spent the rest of his life in his laboratory studying fish evolution and morphology.

In the West, Lysenko's views were simply dismissed. But Schmalhausen could not ignore the Lysenko agenda, which insisted on a more complex interpenetration of heredity and environment than genetics generally recognized. Along with Marxist and progressive scientists in the West, such as C. H. Waddington in the United Kingdom, he accepted the challenge. As a result, he developed a more sophisticated approach for understanding these interactions and helped explain the observations of some of the better studies cited by Lysenkoists.

Schmalhausen argued that natural selection was not only directional, producing new adaptations to new circumstances, but stabilizing. That is, if a characteristic of a species causes it to be well adapted, then random variation in the characteristic caused by external or internal disturbances would reduce the fitness of the organism, so natural selection will operate to prevent such disturbances. The development and physiology of the species will be selected to be *canalized,* that is, insensitive to such random disturbances. These disturbances come not only from the environment but also from genetic variations from individual to individual. Genes are selected which work in such a way that most genetic combinations produce more or less viable and similar offspring. Thus individual genetic variation remains hidden because of the canalization of development.

The selection to produce canalized development and physiology operates over a restricted range of natural conditions that characterize the usual or normal environmental range to which the species is subjected during its evolution. However, under unusual or extreme conditions where selection has not had the opportunity to operate, these genetic differences show up as increased variation. This claim provided an alternative explanation to the observation that populations that are apparently uniform under normal conditions show a wide range of heritable variation under new or extreme conditions. Whereas Lysenko argued that these populations were uniform genetically and that the environment created new genetic variations, Schmalhausen argued that the environment revealed latent genetic differences which could then be selected.

Waddington developed this line of reasoning further with his idea of genetic assimilation. Suppose that there is some threshold condition in the environment for the development of a particular trait. Much below threshold none of the individuals show it, much above threshold they all do. But under some intermediate conditions some will be above and some below threshold. If environmental conditions change so that it is advantageous for all individuals to manifest the trait, then those with the lowest threshold will be favored by natural selection. The average threshold in the population will decrease and eventually produce organisms whose threshold is so low that the trait always appears under any conditions in which the organism can survive. Then the trait has become "assimilated": an environmentally induced condition has become fully genetic.

Schmalhausen's realization that natural selection operates to change the sensitivity of physiology and development to perturbations, but that it only operates under the usual and normal range of environmental and genetic variations experienced by the species in its evolution, leads to a result with wide implications. This result is known as "Schmalhausen's Law." It indicates that when organisms are living within their normal range of environment, perturbations in the conditions of life and most genetic differences between individuals have little or no effect on their manifest physiology and development, but under severe or unusual general stress conditions even small environmental and genetic differences produce major effects.

Two examples of the application of Schmalhausen's Law are in the determination of species distribution and in the effect of toxic substances on population health. Both show the danger of predicting the outcome of perturbations in natural populations using the results of experiments on single factors under controlled conditions.

**In Biogeography.** At almost any location on the earth, the ecological community is made up of species near the boundary of their distribution and species that are in the middle of their range. When the environment changes, this has a major impact on the species near their boundary. Some may become locally extinct, others may experience great expansions of their abundance and range, and still others will remain more or less as they have been. Further, populations near their boundaries are especially sensitive to changing conditions and are more likely to show big differences from year to year. Thus simple predictions about the effect of climate change are bound to err if they take into account only the direct physiological impact of the environmental change on species one at a time, out of the context of their community interactions. In contrast, species in the middle of their range are likely to show less effect from an environmental change. Therefore, when we ask how a 1°C change in temperature will affect the distribution of malaria, we have to ask how close to their boundaries not only the vector mosquito but also its natural enemies and competitors are located. Different localities near the boundary will respond differently for no obvious reason, just because of extreme sensitivity to even undetectable changes of circumstance.

**The Thresholds of Toxicity.** Tolerable levels of toxic substances are often set on the basis of experiments with animals. Usually the work is done with standardized healthy animals under well-controlled conditions to minimize "error" due to individual differences or variation in the environment. However, this methodology underestimates the impact of a toxin for a number of reasons. If an organism is exposed to a toxic substance of external or internal origin, it has various mechanisms to detoxify that substance. But the toxin is still present. If there is a constant level of exposure, the toxin will reach some level of balance between new absorption of toxin and the rate of removal. This equilibrium depends on the level of exposure and the maximum capacity of the detoxification system to remove the poison.

Of course, we know that the environmental exposure is not constant for all members of a population or even for any one individual over time. And we also know that different members of the population differ in their detoxification capacity and that it may vary over time for the same person. Furthermore, this variability matters and cannot be averaged away.

What good is a model that assumes constant conditions? Here we see one of the powerful ways in which models are both useful and dangerous in science. In physical and engineering sciences it is often possible to isolate a problem sufficiently to ignore external influences, assume that all switches are the same in what is relevant, that all salt molecules are interchangeable, and so on. Then we can measure accurately and get equations that are as exact as we need. But in ecological and social sciences this is not possible—the populations are not uniform, conditions change, and there is always an outside impinging on the system of interest. We cannot even believe the equations too literally. But we can still study these systems. First, we find the consequences of models under unrealistic conditions that are easily studied and give precise results. Then we ask, how do departures from those assumptions affect the expected outcomes? In this case, the standing level of toxicity, a measure of damage done to an organism, is a mathematical function of $d - e$, the maximum detoxification capacity minus the exposure (see Figure 14.1). The maximum removal rate has to be greater than the exposure or else, according to the mathematical model, the toxicity will accumulate without limit. In reality, it will accumulate to the point where other processes, which were negligible in the original model, take over. These might involve any of the consequences of toxicity such as cell deaths. In relatively unstressed conditions, when $d$ is greater than $e$ the graph of toxicity plotted against $d - e$ decreases from zero as capacity exceeds exposure by greater and greater amounts. Furthermore, it is concave upward.

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Figure 14.1

That is, it is steeper the closer we are to $d = e$ and flattens out when detoxification capacity is much greater than exposure. If we measure the dose response curve in the range where capacity is much bigger than exposure the results will show little effect of the poison and we will be reassured by claims that there is no detectable effect. Testing is often conducted under optimal conditions on uniform populations of experimental animals in order to get uniform results, reduce the error, and avoid "confounding factors."

If different stressors are confronted by the same detoxification pathways, they can be added at the level of exposure and act synergistically at the level of toxicity. Therefore, if we look at only one insult at a time, the other "confounding factors" increase the damage beyond what we expected.

In the United States, exposure varies with location and occupation. The poor, excluded, and marginalized communities such as inner cities, *colonias,* and reservations are often subject to multiple exposures due to incinerators, *maquiladoras,* poor water quality, malnutrition, and unsafe jobs. Therefore even toxic substances that meet EPA standards will prove more harmful than expected. But these effects will be hard to detect since we will observe an array of health impairments rather than a single harm appearing to different degrees.

Similar arguments hold if the capacity to detoxify varies among individuals: because of the shape of the curve relating toxicity to detoxification capacity, the average toxicity in the population is greater than the toxicity at average detoxification capacity. Once again, if detoxification capacities are reduced each unit of insult has a bigger effect than expected.

We suspect that detoxification capacities are undermined in the course of life for all of us after the first two decades, but that adverse conditions accelerate this erosion so that vulnerability increases more rapidly and life expectancy is reduced, for example, by some five years for African-American women and seven years for African-American men.

**The Variability of Results.** Under stress, when $d - e$ is small, small differences in either one can have big effects. A population at a disadvantage will show big differences among people for reasons we cannot explain, and different poor communities will differ widely in the rates of adverse outcomes. This can easily be misinterpreted: it appears as if under the "same" conditions some do well and others poorly, and that we can then blame the latter. But what really is happening is that under conditions of any kind of stress, small differences have big effects.

Schmalhausen's Law focuses our attention on the historical relation of a population with its environment, the responsiveness of the physiology to familiar and to new stressors, and the inherent variability of both organisms and environments.

# 15

# A Program for Biology

Recent internal developments in biology and social science urge the necessity to confront the rich complexity of the phenomena of interest at the same time that the large-scale practical problems of greatest concern—eliminating poverty, promoting health, and equity and sustainability—call for more integral, multilevel, and dynamic approaches than those to which we are accustomed. Both areas of knowledge are grappling with ways to escape from the unidirectional causation, *a priori* categories, hierarchies of "fundamentalness," and rigid disciplinary boundaries that have dominated thinking and have led to some of the big mistakes of recent times. Most of these, such as the green revolution, the epidemiological transition, sociobiology, the reification of intelligence testing, and the current fetishism of the genome, err by posing the problems too narrowly, treating what is variable as if it were constant and even universal, and offering answers on a single level only.[1]

Cumulative research in each area points toward a dialectical, dynamically complex alternative, but theoretical and philosophical traditions within the sciences, institutional arrangements of disciplines, and economic interest combine to resist this rather obvious development. Single causes are more readily patented than are complex webs of reciprocal determination and make better headlines. Scientists are rewarded or excluded according to whether their work fits comfortably into the departmental boundaries or definitions of funding programs, since narrower, more conventional projects are more likely to reach publishable conclusions within the time limits of the rehiring and promotion cycle. Therefore, while there exist interdisciplinary, transdisciplinary, or nondisciplinary programs and all institutes are set up to study complexity, the sciences as a whole still stumble over the obstacles that we all recognize.

The major theoretical achievement of the genome project was the refutation of its greatest expectation—that a mapping of the DNA base sequence would also be a map of all the interesting characteristics of the organism, disease vulnerability, individual and group behaviors, and the origin of life. The source of the error lies in the continued repetition of the mantra that "genes determine organisms," because genes "make" proteins and proteins "make" organisms. Even putting aside the overwhelming importance of organisms being the consequence of processes that depend in an interactive and dialectical manner on genes, on environment, and on random events in development, the error begins at the molecular level. No DNA sequence contains all the information necessary for the specification of a protein. A DNA sequence contains a recipe for the sequence of amino acids in a polypeptide. But that polypeptide must fold into a three-dimensional structure, a protein, and there are multiple free-energy minima for such a folding. The particular folding that occurs depends on cellular conditions, on the presence of so-called chaperones and other molecules and cellular structures. But the DNA sequence of a gene does not always have the full information sufficient to determine the sequence of amino acids in the polypeptide. In some organisms, such as flagellates, there is editing of the RNA message that is transcribed from the DNA, a message that does not contain all the information on the amino acid sequence to be assembled. This editing may involve the insertion of many missing nucleotides into the RNA sequence or it may result in a shuffling of blocks of messenger RNA sequence into a final sequence that is then translated into an amino acid sequence. More generally, before an amino acid sequence becomes a protein with a role in cell structure and metabolism, individual amino acids may be chemically modified, the sequence trimmed, or have other amino acid sequences attached to it (post-translational modification).

The alternative to the unilinear sequence is the feedback loop in which all elements on a pathway have equal rank. Even the distinction between the genome and the soma, useful for transmission genetics, is misleading in the discussion of development and evolution. Rather, we have to confront a more complex, multilevel system in which the genome, the proteome, the traitome, the behaviorome, and the societome exist in reciprocal feedbacks of a complex nonlinear dynamics instead of the simple sequence DNA→RNA→protein→trait.

In the context of genetics, the first feedback takes place at the cellular level, where RNA, protein, and metabolites interact with DNA sequences to regulate the timing, rate, and location of the cell's conversion of DNA sequence information into protein. Much of this feedback is a consequence of physical changes in the organism that flow from developmental events themselves. Changes in cell number, shape, and location, and the production of proteins within these cells affect the processes within neighboring cells. But these changes within the organism alter the external environment, which in effect then feeds back into the development and metabolism of the organism itself.

At the same time, experimental results and new technologies of functional mapping of the brain show the surprising plasticity of the central nervous system and the spread of almost all interesting activities throughout the brain. This does not negate gross regional specialization but it casts doubt on the rigidity of regional boundaries and the repeated invocation of "hard-wiring" as explanation and the repeated claims that each newly evolved region of the brain leaves the previous ones intact and limited to their previous functions. The limbic area of humans is not the fossil of the Mesozoic era, the reptilian brain that is supposed to be the deepest part of ourselves in a more than anatomic sense. The modern amygdala receives signals from the cortex, is confronted with new patterns of stimulation, and has evolved in its new context. Nowadays all biologists agree in principle that the organism depends on both the internal processes and the environment. But the distinction between internal and external is permeable. "Environment" reaches inside the organism: each part is environment to all the other parts. Even within the uterus, monozygotic twins sharing the same interior of the same mother may be in importantly different environments if they are attached to separate chorions and are more different than if they shared a chorion. The voice of the mother affects the fetus in ways that make "innate" quite different from "genetic."

C. H. Waddington wrote about genetic assimilation, a process whereby a trait that depends on an external stimulus becomes "genetic" by a lowering of the signal threshold for its appearance to the point where that signal is present in all circumstances compatible with life. Thus calluses appear on the feet of ostriches at birth, before any stress from walking could induce their formation. Natural selection has favored this unconditional appearance of calluses, which then protect the young bird from the damage that would be done during the development of calluses from external stress.

The complementary view of this process is that a part of the "external," which is almost universal, can become incorporated into the developing system as a sort of external yolk. Then its consequences would be seen as "hard-wired." Sensory stimulation is needed to form certain near-universal traits of the brain, such as the organization of the visual cortex, and in the case of social animals the activity of adult caretakers plays a vital role in the development of the young.

Finally, it raises questions about the emergence of the nervous system from apparently passive input-output reflex mechanisms to networks capable of spontaneous activity. The stability and dynamics of such a network depend on relations among long and short positive and negative feedback loops (excitatory and inhibitory pathways). In order for the nervous system to work, the excitatory activity must prevail first and then be damped by the inhibitory slower pathways in order to contain the activity. But a large number of synapses is needed for more complex activity, to make more distinctions in the environment and initiate more differentiated and complex responses. Therefore a system that can do a lot of things in response to external inputs will have many inhibitory pathways. If the connectivity of the network is great enough and the total number of neurons big enough, then the very conditions that maintain boundedness also lead to local instability, that is, spontaneous activity.

In examining the Green Revolution, we see that a view based on unidirectional causation leads to the expectation that since grasses need nitrogen, a genotype that takes up more nitrogen would be more productive; since pesticides kill pests, their wide use would protect crops; and since people eat food, increased yields would alleviate hunger. In each case, the linear inferences were plausible. The counterintuitive outcomes came about because of branching pathways from the starting point: the increase in wheat yield was partly achieved by breeding for dwarf plants that are more vulnerable to weeds and to flooding; the killing of pests was accompanied by the killing of their natural enemies, their replacement by other pests, and the evolution of pesticide resistance. The successful yield increases encouraged the diversion of land from legumes. The technical package of fertilizers, pesticides, irrigation, and mechanization promoted class differentiation in the countryside and displacement of peasants.

When a complex system is perturbed—for instance, by adding a medication to a physiological network—the impact percolates through many pathways. It may be buffered along some pathways, amplified along others, even inverted on some pathways, giving the opposite result from what is expected. (Ritalin is used both to arouse and to calm.) And the stronger the medication, the more effective in its intended effect, the more likely it is also to have big unexpected effects.

A strategy for avoiding the kinds of errors we have been discussing would start from the following propositions:

1. The truth is the whole. Of course, we cannot really see the whole, but it warns us to pose a problem as bigger than we would have, with further reaching ramifications. For instance, we can write an equation for a prey population:

   $$\text{Prey population} = a - b\ (\text{predator population}).$$

   Here the predator is the independent variable and the prey, the dependent variable. If we measure them carefully, we could find the regression coefficient $b$ and "account for" a large fraction of the variance. But the predator is simply given from outside the model. We always have to ask, where is the rest of the world? In this case we could start by having the predator determined by the prey and have a negative feedback loop. This gives a richer understanding because it shows mutual determination and allows us to see the covariation pattern of predator and prey when the rest of the world enters mostly by way of one of the two species. The first equation is not "wrong." It fits the prey population to the level of the predator as accurately as we possibly can, but it is also an impoverished way of looking at nature.

2. Recognize that everything in the world is not relevant to everything else. The death of a single butterfly does not have palpable effects on the rest of the living world. We must find the boundaries of subsystems within which there are effective interactions and between which there is effective independence. This process of "dissecting nature at its joints" is one of the most difficult tasks in biology because the same material objects, molecules, cells, individuals, and populations belong to multiple functional subsystems, depending on the process being considered.

3. Things are the way they are because they got that way, have not always been that way, need not always be that way. History matters—at the short-term

> level of the development of specific individuals, at the medium-term level of the assemblages of individuals into populations and ecosystems, and at the long-term level of evolution.

We ask three questions: Why are things the way they are instead of a little bit different (the question of homeostasis, self-regulation, and stability)? Why are things the way they are instead of very different (the question of evolution, history, and development)? And what is the relevance to the rest of the world?