

Species and Ecosystems

We would do well to pause now for a moment to consider some of the philosophical questions raised by the flow of genes and biomass, as well as by the structures that emerge from those flows. As I argued in the previous chapter, there is a sense in which species and ecosystems are the product of structure-generating processes that are basically the same as those

which produce the different types of rocks that populate the world of geology. A given species (or, more accurately, the gene pool of a species) can be seen as the historical outcome of a sorting process (an accumulation of genetic materials under the influence of selection pressures) followed by a process of consolidation (reproductive isolation), which gives a loose accumulation of genes a more or less durable form by acting as a "ratchet device." The most familiar form of reproductive isolation considered by biologists has an external cause: geographical changes in the habitat where reproductive communities belonging to that species live. For instance, a river may change its course (over many years) and run through the middle of a previously undivided territory, making contact between members of a reproductive community difficult or impossible. In that situation, the two halves of the community will start to accumulate changes independently of each other and hence begin to diverge, until the day when mating between their respective members becomes (mechanically) impossible, or produces only sterile offspring.

However, the process of reproductive isolation (and thus, of *speciation*) may be more complex than that; in particular, it may have *internal* causes as well as external ones. One well-studied example of an internal cause is the "specific mate recognition system," or SMRS.⁸⁷ This is the system of traits and signals (which can be behavioral or anatomical, or both) that members of a sexually reproducing species use to recognize potential mates. Genetic changes that affect the SMRS (mating calls, courtship rituals, identifying marks and decorations, smells) may indeed act as a barrier to interbreeding even if the two divergent daughter species could potentially mix their genes. In this case, sexual selection (that is, selection pressures exercised on an individual by its potential mates) can cause a small initial difference to be amplified into a major barrier to the exchange of genes and, hence, result in the creation of a new species.⁸⁷

Thus the flow of genes (which one might imagine as potentially continuous) becomes encapsulated via these isolating barriers into separate packets, each defining a different stratified system. However, there is a risk of

exaggerating the strength of these barriers, particularly if we pay attention only to the world of relatively large animals, to which we belong. Indeed, other living creatures may not be as genetically "compartmentalized" as we are. Many plants, for example, are able to hybridize with plants of other species (that is, the isolating barriers retain a measure of permeability), while many microorganisms freely exchange genes with other species during their lifetimes. (As we shall see, this seems to be the way many of the bacteria that cause infectious diseases have acquired resistance to antibiotics.) In short, the flow of genes in the biosphere as a whole may not be as discontinuous (as stratified) as one would imagine by looking at large animals alone. In fact, in some special circumstances, even animals in total reproductive isolation may exchange genetic materials via inheritable viruses (called *retroviruses*).⁸⁹

Taking all this into account, the picture of evolutionary processes that emerges resembles more a meshwork than a strict hierarchy, a bush or rhizome more than a neatly branching tree:

There is substantial evidence that organisms are not limited for their evolution to genes that belong to the gene pool of their species. Rather it seems more plausible that in the time-scale of evolution the whole of the gene pool of the biosphere is available to all organisms and that the more dramatic steps and apparent discontinuities in evolution are in fact attributable to very rare events involving the adoption of part or all of a foreign genome. Organisms and genomes may thus be regarded as compartments of the biosphere through which genes in general circulate at various rates and in which individual genes and operons may be incorporated if of sufficient advantage.⁹⁰

Even with this added complication, the two abstract machines discussed in the previous chapter (one generating hierarchies, the other meshworks) are adequate to account for living structures, particularly if we make allowance for varying mixtures of the two types. However, I would like to argue that there is another abstract machine involved in the production of biological entities which has no counterpart in the geological world, therefore distinguishing species from sedimentary rocks. This other abstract machine, however, may be found in other nonbiological realms (in human culture, for instance) and therefore does not constitute the "essence" of living creatures.

Darwin's basic insight was that animal and plant species are the cumulative result of a process of descent with modification. Later on, however, scientists came to realize that *any variable replicator* (not just genetic replicators) coupled to *any sorting device* (not just ecological selection pres-

tures) would generate a capacity for evolution. For instance, in the 1970s, the computer scientist John Holland devised a small computer program that self-replicated by following a set of coded instructions and transmitting a copy of those instructions to its progeny. Holland's program did very little other than generate variable replicating copies of itself. However, if a *population* of these replicating programs was submitted to some selection pressure (for example, if the user of the program were to weed out those variants that did not seem an improvement, letting only the more promising variants survive), the individual programs developed useful properties after many generations. This is the basis for Holland's "genetic algorithm," which is widely used today in some computer-based disciplines, as an effective problem-solving device.⁹¹ Richard Dawkins independently realized that patterns of animal behavior (such as birdsongs or the use of tools by apes) could indeed replicate themselves if they spread across a population (and across generations) by *imitation*. Birdsongs are the most thoroughly studied example of these replicators ("memes," as Dawkins calls them), and they do indeed evolve new forms and generate different dialects.⁹²

In each of these cases, the coupling of variable replicators with a selection pressure results in a kind of "searching device" (or "probe head") that explores a space of possible forms (the space of possible organic shapes, or birdsongs, or solutions to computer problems). This searching device is, of course, blind (or more exactly, shortsighted), following the key principle of neo-Darwinism: *evolution has no foresight*.⁹³ (It is, nevertheless, highly effective, at least in certain circumstances.) This probe head is the abstract machine we were looking for, the one that differentiates the process of sedimentary-rock formation from the process that yields biological species. And yet, although the new machine is characteristic of life-forms, the same basic diagram applies to memes and genetic algorithms. It would be incorrect to say that evolutionary concepts are used *metaphorically* when applied to computer programs and birdsongs, but literally when talking about genes. It is true that scientists first discovered this diagram in the world of living creatures, and it may even be true that the living world was the first physical realization of the abstract machine on this planet. However, that does not make the abstract machine any more "intimately related" to DNA than to any other replicator. Hence, it does *not* constitute an "essence" of life, in the sense of being *that which makes life what it is*.⁹⁴

The flow of genes through replication is indeed only a part of what life is. The other part is constituted by the flow of biomass. Individual animals are not just members of a species, but members of a particular

reproductive community inhabiting a particular ecosystem and thus participate in the exchange of energy and materials that makes up a food web. As with any physical system, the intense flow of energy moving through an ecosystem pushes it far from equilibrium and endows it with the ability to generate its own dynamic stable states (attractors). The same dynamic holds true for the individual organisms evolving within that ecosystem. Consequently, the space that the probe head blindly explores is not completely unstructured but already populated by various types of stable states (static, cyclical, chaotic, autopoietic). This prestructuring of the search space by intensifications of the energy flow may indeed facilitate the job of the abstract machine (blind as it is). For example, since one possible endogenously generated stable state is a periodic attractor, which would automatically draw gene activity and gene products into a cycle, the searching device may have *stumbled upon* the means to generate a primitive metabolism very early on. Further evolutionary complexification may have been achieved as the probe head moved from attractor to attractor, like so many stepping-stones.

When search spaces (or "adaptive landscapes") were first postulated in biology in the 1930s, they were thought to be prestructured by a single equilibrium, a kind of mountain with one peak, which selection pressures forced the probe head to climb. According to this schema, the top of the mountain represented the point of maximum fitness, and once a population had been driven there, selection pressures would keep it locked into this optimal equilibrium. However, recent explorations of adaptive landscapes, using sophisticated computer simulations, have revealed that these search spaces are anything but simple, that they may comprise many mountains of different heights (local optima), clustered in a variety of ways, the valleys and peaks related not directly to fitness but to underlying dynamical stable states. Moreover, once the question of coevolution is introduced (as when an improvement in a prey's armor puts pressure on its predator's fangs and claws to further sharpen, which in turn stimulates a thickening of the armor), it becomes clear that interacting species in an ecosystem have the ability to *change each other's adaptive landscapes*. (This is just another way of saying that in a predator-prey arms race there is not a fixed definition of what counts as "the fittest.")⁹⁵

Although the notion of unique stable states did some damage to evolutionary biology (by imposing an oversimplified version of evolution which disregarded energy flow and the far-from-equilibrium conditions the flow of energy generates), the idea of the "survival of the fittest" had much more damaging effects when it was applied to human culture. That misapplication degenerated almost immediately into Social Darwinism and

the eugenics movement and, later on, inspired the racial cleansing policies of Nazi Germany. Coming as it did after centuries of intense colonialism, Social Darwinism naturally fostered the idea that the Caucasian race was superior to all others. Of course, in addition to the mistaken notion of a single, optimal equilibrium, these social movements were nurtured by the belief that genes determine culture, that is, that there is but a single probe head (whereas, as we just saw, even birds embody at least two).

In reaction to this position, a number of anthropologists (including Franz Boas, Margaret Mead, and Ruth Benedict) developed during the first decades of the twentieth century a countertheory that not only gave human culture its deserved autonomy from genetic determination, but denied that biological evolution had any effect whatsoever on the development of human societies. According to these anthropologists, human nature was completely malleable and flexible, and human behavior determined by culture alone. In the short run, "cultural relativism" (as it came to be known) did us the considerable service of fostering a greater tolerance of cultural differences (a welcome antidote to the racist ideas and policies of the Social Darwinists and eugenicists), but later on it hardened into dogma, and in some cases it even degenerated into empty clichés (such as the slogan "everything is socially constructed").⁹⁶

Fortunately, anthropologists seem to be moving away from dogmatic positions and developing a new *interactionist* approach, wherein both organic and cultural evolution are considered simultaneously. One version of this new approach (the one developed by William Durham) seems particularly close to the view we are exploring here: that both organic and cultural change involve replicators and that new structures arise by selective retention of variants. Moreover, Durham agrees that this does not involve a metaphorical use of biological concepts. (He calls this Campbell's rule: the analogy to cultural accumulations is not from organic evolution but from a general model of evolutionary change, of which organic evolution is but one instance.)⁹⁷

Before describing the five different ways in which genetic and cultural replicators interact according to Durham, we must first address the question of just what genetic effects we are considering here. Although a few individual genes have been added to the human gene pool in historical times (such as the gene that causes sickle-cell anemia but protects its carriers against malaria), genetic evolution is so much slower than cultural evolution that its influence in human affairs is marginal. As Stephen Jay Gould points out, "While the gene for sickle-cell anemia declines in frequency among black Americans [since they are not subjected to the malarial selection pressure], we have invented the railroad, the automo-

bile, radio and television, the atom bomb, the computer, the airplane and spaceship."⁹⁸ Thus, the genetic effects we are considering are the organic limitations imposed on us by our own bodies which can be called "human universals" as long as we do not attach any transcendental meaning to this term. (Organic constraints, like cultural constraints, are contingent historical products, though they operate over longer timescales.)

One way in which genetic and cultural replicators interact (or act on one another) is as sorting devices. On the one hand, genes, or rather their bodily (or phenotypic) effects, may act as selection pressures on the accumulation of cultural materials. Durham discusses the example of color perception, and its relationship with color words, partly because its anatomical basis is relatively well known (both the pigment-based system of light absorption in the eye and the processing of sensory input by the brain) and partly because much anthropological research on this subject already exists. Crucial evidence on the "universality" of color perception was gathered in the 1960s by the anthropologists Brent Berlin and Paul Kay in the course of an experiment designed to prove the opposite hypothesis: that each language performs the coding of color experience in a different manner. Berlin and Kay showed a large sample of color chips to subjects belonging to twenty different linguistic communities and asked them to locate in the grid of chips both what the subjects would consider to be the focal point of the referent of a given color word as well as its outer boundaries. On the basis of the linguistic relativity hypothesis (that there is no "natural" way to cut up the spectrum), these researchers expected their experiments to elicit widely scattered focal points and discordant outer boundaries, but instead they recorded a very tight clustering of focal points (and concordance of boundaries) regardless of how many color terms existed in a given native vocabulary. More recent research has supported (and refined) Berlin and Kay's results and has further shown that even though different cultures have accumulated a different number of color labels, the *order that this accumulation follows* exhibits some definite regularities, with terms for "black" and "white" always appearing first, followed by terms for primary colors in certain sequences (red-green-yellow-blue, for example). One possible interpretation is that the first labels that accumulate ("black" and "white") designate broad, composite categories ("dark-cool" and "light-warm," respectively), which slowly differentiate as new labels are added to the repertoire, each one entering the set in a specific and highly constrained fashion. On this basis, Durham has concluded that this is an example of genetic constraints on perception guiding the accumulation of cultural replicators (color words).⁹⁹

Cultural materials, in turn, may act in the opposite direction and influence the accumulation of genes. Unlike the accumulation of color terms, however, the accumulation of genetic materials happens so slowly as to be virtually unobservable. Hence, hard evidence is much more difficult to obtain in this case, and we are forced to discuss hypothetical scenarios on the basis of indirect evidence, such as that provided by myths. The example Durham discusses in detail is the gene that allows some Indo-European races to digest raw milk as adults. First of all, variation for this gene does exist and is highly correlated with certain cultural patterns. High prevalences of this gene exist only in populations that today consume comparatively large amounts of fresh milk and possess ancient mythologies that both record and encourage adult fresh-milk consumption. In turn, these genetic and cultural materials are associated with environments of low ultraviolet radiation, where vitamin D and metabolic calcium are chronically deficient, that is, with environments where fresh-milk consumption can have positive health effects. Durham reviews several possible scenarios that may explain these correlations and concludes that the most plausible one (as well as the one more consistent with the history coded into myths) is as follows:

As genes for LA [lactose absorption] were favored at high latitudes, more people could drink milk after weaning, thereby spreading the benefits of milk production and improving the local cultural evaluation of the memes behind the practice. The increased availability of milk, in turn, would have continued the genetic selection of LA genotypes, thereby augmenting the frequency of adult lactose absorption, the benefits of milking, the cultural preference for milk, and so on in perpetuity. . . . The cycle may have started as a continuation of routine infant feeding practices. Early on, the milk of dairy animals may have been tried as a supplement to mother's milk, increasing the volume of lactation, its duration, or both. By virtue of the (initially rare) LA genotypes, some recipients would have maintained lactose sufficiency beyond its normal lapse, continuing to drink milk and thereby avoiding rickets in their early years. . . . In particularly rachitogenic areas, the advantage to fresh milk consumption would have extended into adolescence and adulthood.¹⁰⁰

In addition to these two ways of interacting directly with each other, culture and genes may enter into other, more indirect relations. In particular, Durham points out that once certain cultural materials have accumulated, they may harden into institutional values, which in turn act as selection pressures for further cultural accumulations. Hence, some cultural repli-

cators may, in a sense, be *self-selecting*, and this gives them a degree of autonomy in their evolution. Under these conditions, cultural adaptations may come to have relations of enhancement, opposition, or neutrality with respect to genetic adaptations.

Incest taboos are an example of enhancement. Zoologists have convincingly demonstrated that inbreeding has deleterious genetic effects and that many animals have evolved an instinctive avoidance of it. Humans may indeed share this built-in constraint, as studies of aversion to sexual intercourse among adults who were reared together in kibbutzim seem to show. However, as Durham points out, taboo prohibitions are not necessarily the same as avoidance of inbreeding. He observes that "there can be nonincestuous inbreeding (as when sexual intercourse between certain categories of kin is not prohibited) and noninbred incest (as when prohibitions apply between parents and their adopted children)."¹⁰¹ Given the range of variability of the incest prohibitions, which only partially overlap with inbreeding, Durham concludes that the sets of regulations that constitute the taboo in different societies evolved under cultural selection pressures (although it is possible that instinctive avoidance may have played a role in their accumulation early on in human evolution).

The relative autonomy with which self-selection endows the evolution of cultural replicators allows them to follow a direction that is neutral relative to organic adaptations. For the same reason (i.e., cultural replicators' relative evolutionary autonomy), various aspects of culture may turn out to have maladaptive consequences relative to our biology. For example, many civilizations in the past carelessly intensified the exploitation of their soils, failing to implement available techniques (such as terracing) that could have protected this valuable resource from eroding away. Consequently, those societies inadvertently set a limit on the number of times they could pass their genes down through the generations. (An upper limit of seventy generations existed for most cultures, according to one historian's calculations.) In this case, the bounded rationality of many elites and the prospect of short-term gains promoted the accumulation of habits and routines that, in the long run, destroyed the conditions under which the gene pools of those civilizations could reproduce themselves. Durham also finds these maladaptive cultural materials accumulating in contemporary communities of El Salvador and Honduras, their landscapes "littered with telltale signs of maladaptation. Slopes of forty or fifty degrees . . . were being cultivated in perpetuity . . . with steadily declining yields. Corn was cultivated in rock outcrops, animals grazed in steep gullies, and the erosive force of tropical rains carried off ever more of the leached and worn-out topsoil."¹⁰² In this case, however, the

problem is not the local peasant culture. Rather, the manipulation of land tenure policies by the landed elites and the government's support for export agriculture had imposed these maladaptive conditions on the peasants. From this and other cases, Durham concludes that a major cause of opposition between genetic and cultural replicators is the imposition from above of habits and customs (or living conditions leading to certain habits and customs) that are maladaptive.

However, one must not assume that the power to impose a set of values on a population (and hence to influence the direction of that population's cultural evolution) is always strong enough to eliminate the selective effect of individual choice. (Herein lies another weakness of "cultural relativism": not only does it emphasize the exotic at the expense of the unremarkable, which is where human universals are to be found, but it tends to focus on the norms of a society while ignoring the actual behavior of individual agents, who may or may not always adhere to those norms. Perfect obedience cannot be taken for granted.¹⁰³) According to Durham, absolute imposition and free individual choice need to be taken as idealized poles of a continuum, with most actual behavior falling somewhere in between, as a mixture of the two.

Having established the different forms of direct and indirect interactions between cultural and genetic replicators, we must now address certain questions regarding the *kinds* and *number* of abstract probe heads at work in cultural evolution. For example, we observed that the flow of genes through large animals is quite different from the flow through microorganisms, the former following a rigid vertical form (from one generation to another) while the latter additionally involves a horizontal exchange of genes (from one species to another, via plasmids or other vectors). In terms of the number of channels for transmission, the flow of cultural materials in human societies is quite open, and in that sense akin to the flow of genes through bacteria. Cultural replicators flow vertically in a one-to-one structure (from parents to offspring) or in a many-to-one structure (as when the adults in a community exercise pressures on a child). Cultural replicators also flow horizontally, from adult to adult (one-to-one) or from leaders to followers (one-to-many).¹⁰⁴

Moreover, it may be argued that cultural evolution involves more than one searching device: while some materials replicate through *imitation* (and, hence, are analogous to birdsongs or, more generally, to memes), others replicate through *enforced repetition*: children do not simply learn to imitate the sounds and grammatical rules that make up a language, they *adopt them as a norm* or *repeat them as a rule*. (This is one minor shortcoming of Durham's analysis: he uses the term *meme* for all cultural

replicators, even though some of them are transmitted as norms [e.g., his "secondary values"].) Sforza observes that linguistic norms (except for individual words) do not easily replicate across different cultures but travel along with the bodies that serve as their organic substratum. (Hence the tight correspondences he finds between linguistic and genetic maps.) He attributes this conservative tendency to the first two (vertical) mechanisms of cultural transmission.¹⁰⁵ The flow through horizontal channels, on the other hand, does involve imitation and so may be considered a flow of memes.

A different process is involved when the transmission involves not formalized knowledge but embodied know-how. In this case, the information in question cannot travel by itself (through books, for example) but needs human bodies as its vehicle. This kind of transmission may be compared to that involved in epidemic contagion. Braudel argues, for example, that the printing press and mobile artillery did not create a permanent imbalance in the distribution of power in Europe because they spread too rapidly across the Continent, thanks to the mobility of their practitioners. Printers and mercenaries in the sixteenth and seventeenth centuries migrated continuously, taking their skills and know-how wherever they went, spreading them like an epidemic.¹⁰⁶

In thinking through the mechanisms of cultural evolution, we must take into consideration the *kinds* of entities that may be said to evolve in a given society. When studying societies that lack diversified politico-economic institutions, we may view cultural transmission in terms of replication of the whole set of values and norms which binds a particular society together. But in urban societies, institutions may also reproduce themselves with variation *individually*. The economists Richard Nelson and Sidney Winter, for instance, espouse an evolutionary theory of economics based on the idea that once the internal operations of an organization have become routinized, *the routines themselves constitute a kind of "organizational memory."*¹⁰⁷ For example, when an economic institution (e.g., a bank) opens a branch in a foreign city, it sends a portion of its staff to recruit and train new people; in this way, it transmits its internal routines to the new branch. Thus, institutions may be said to transmit information vertically to their "offspring." On the other hand, since many innovations spread through the economy by imitation, institutions may also affect each other in a manner analogous to infectious contagion.

Here we have been exploring exclusively the interactions between culture and genetics, but nonetheless we must never lose sight of the fact that the flow of replicators (whether genes, memes, norms, or routines)

constitutes only half the story. The flow of matter and energy through a system (which often means the flow of biomass, either living or fossil) is of equal importance, particularly during intensifications. The role of genetic and cultural replicators (or, more accurately, of the phenotypic effects of those replicators) is to act as catalysts that facilitate or inhibit the self-organizing processes made possible by intense matter-energy flows. It is these flows that determine the nature of the thermodynamic stable states available to a system; the catalysts act merely as control mechanisms, choosing one stable state over another. Another feature of catalytic action is that low expenditures of energy can bring about high-energy transformations. An enzyme, for example, may bring about a large accumulation of a given substance by accelerating a particular chemical reaction, without itself being changed in the process (i.e., without itself participating in the larger energy transfers).

Cultural replicators may be viewed as having phenotypic effects similar to catalysis. A command given by someone of high rank in a hierarchy, for example, can set off disproportionately large flows of energy, as in the case of a declaration of war. However, the military order itself is powerless unless backed up by a chain of command that has been kept in working order through constant drill and discipline (including physical punishment for noncompliance), all of which involves enormous expenditures of bodily energy. The history of Western society in the last few centuries evidences an increasing dependency on disciplinary force to secure obedience. Therefore, we cannot be content with a description of society expressed exclusively in terms of replicators and their catalytic effects, but must always include the material and energetic processes that define the possible stable states available to a given social dynamic.