When atoms are travelling
straight down through empty
space by their own weight, at
quite indeterminate times
and places, they swerve ever
so little from their course,
just so much that you would
call it a change of direction.
If it were not for this swerve,
everything would fall down-
wards through the abyss of
space. No collision would take
place and no impact of atom
on atom would be created.
Thus nature would never have
created anything.

—Lucretius

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A THOUSAND YEARS OF NONLINEAR HISTORY

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Contents

Sandstone and Granite

The concepts of "meshwork" and "hierarchy" have figured so prominently in our discussion up to this point that it is necessary to pause for a moment and reflect on some of the philosophical questions they raise. Specifically, I have applied these terms in such a wide variety of contexts that we may very well ask ourselves whether some (or most) of these applications have been purely metaphorical. There is, no doubt, some element of metaphor in my use of the terms, but there are, I believe, common physical processes behind the formation of meshworks and hierarchies which make each different usage of the terms quite literal. These common processes cannot be fully captured through linguistic representations alone; we need to employ something along the lines of *engineering diagrams* to specify them.

A concrete example may help clarify this crucial point. When we say (as marxists used to say) that "class struggle is the motor of history" we are using the word "motor" in a purely metaphorical sense. However, when we say that "a hurricane is a steam motor" we are *not* simply making a linguistic analogy; rather, we are saying that hurricanes embody the same diagram used by engineers to *build* steam motors—that is, we are saying that a hurricane, like a steam engine, contains a reservoir of heat, operates via thermal differences, and circulates energy and materials through a (so-called) Carnot cycle.[79] (Of course, we may be wrong in ascribing this diagram to a hurricane, and further empirical research may reveal that hurricanes in fact operate in a different way, according to a different diagram.)

I wish to argue here that there are also abstract machines (as Deleuze and Guattari call these engineering diagrams) behind the *structure-generating processes* that yield as historical products specific meshworks and hierarchies. Particularly instructive among hierarchical structures are social strata (classes, castes). The term "social stratum" is itself clearly a metaphor, involving the idea that, just as geological strata are layers of rocky materials stacked on top of each other, so classes and castes are layers—some higher, some lower—of human materials. Is it possible to go beyond metaphor and show that the genesis of both geological and social strata involves the same engineering diagram? Geological strata are created by means of (at least) two distinct operations. When one looks closely at the layers of rock in an exposed mountainside, one is struck by the observation that each layer contains further layers, each composed of pebbles that are nearly *homogeneous* with respect to size, shape, and chemical composition. Since pebbles do not come in standard sizes and shapes, some kind of *sorting mechanism* must be involved here, some specific device to take a multiplicity of pebbles of heterogeneous qualities and distribute them into more or less uniform layers.

Geologists have discovered one such mechanism: rivers acting as veritable *hydraulic computers* (or, at least, sorting machines). Rivers transport rocky materials from their point of origin (an eroding mountain) to the bottom of the ocean, where these materials accumulate. In the course of this process, pebbles of various size, weight, and shape react differently to the water transporting them. Some are so small they dissolve in the water; some are larger and are carried in suspension; even larger stones move by jumping back and forth from the riverbed to the streaming water, while the largest ones are moved by traction as they roll along the bottom toward their destination. The intensity of the river flow (i.e., its speed and other intensities, such as temperature or clay saturation) also determines the outcome, since a large pebble that could only be rolled by a moderate current may be transported in suspension by a powerful eddy. (Since there is feedback between pebble properties and flow properties, as well as between the river and its bed, the "sorting computer" is clearly a highly nonlinear dynamical system.)[80]

Once the raw materials have been sorted out into more or less homogeneous groupings deposited at the bottom of the sea (that is, once they have become sedimented), a second operation is necessary to transform these loose collections of pebbles into a larger-scale entity: sedimentary rock. This operation consists in *cementing* the sorted components together into a new entity with emergent properties of its own, that is, properties such as overall strength and permeability which cannot be ascribed to the sum of the individual pebbles. This second operation is carried out by certain substances dissolved in water (such as silica or hematite, in the case of sandstones) which penetrate the sediment through the pores between pebbles. As this percolating solution crystallizes, it *consolidates* the pebbles' temporary spatial relations into a more or less permanent "architectonic" structure.[81]

Thus, a double operation, a "double articulation" transforms structures on one scale into structures on another scale. In the model proposed by Deleuze and Guattari, these two operations constitute an engineering diagram and so we can expect to find isomorphic processes (that is, this same "abstract machine of stratification") not only in the world of geology but in the organic and human worlds as well.[82] For example, according to neo-Darwinians, species form through the slow accumulation of genetic materials and the adaptive anatomical and behavioral traits that those genetic materials yield when combined with nonlinear dynamical processes (such as the interaction of cells during the development of an embryo). Genes, of course, do not merely deposit at random but are sorted out by a variety of selection pressures, including climate, the action of predators and parasites, and the effects of male or female choice during mating. Thus, in a very real sense, genetic materials "sediment" just as pebbles do, even if the nonlinear dynamical system that performs the sorting operation is completely different in detail. Furthermore, these loose collections of genes can (like accumulated sand) be lost under drastically changed conditions (such as the onset of an ice age) unless they consolidate. This second operation is performed by "reproductive isolation": when a given subset of a population becomes mechanically or genetically incapable of mating with the rest. Reproductive isolation acts as a "ratchet mechanism" that conserves the accumulated adaptation and makes it impossible for a given population to "de-evolve" all the way back to unicellular organisms. Through selective accumulation and isolative consolidation, individual animals and plants come to form a larger-scale entity: a new species.[83]

We also find these two operations (and hence, this abstract diagram) in the formation of social classes. We talk of "social strata" whenever a given society presents a variety of differentiated roles to which individuals are denied equal access, and when a subset of those roles (to which a ruling elite alone has access) involves the control of key energy and material resources. While role differentiation may be a spontaneous effect of an intensification in the flow of energy through society (e.g., when a Big Man in prestate societies acts as an *intensifier* of agricultural production[84]), the sorting of those roles into ranks on a scale of prestige involves specific group dynamics. In one model, for instance, members of a group who have acquired preferential access to some roles begin to acquire the power to control further access to them, and within these dominant groups criteria for sorting the rest of society into subgroups begin to crystallize.[85]

Even though most cultures develop some rankings of this type, not in all societies do these rankings become an *autonomous dimension* of social organization. In many societies differentiation of the elites is not extensive (they do not form a center while the rest of the population forms an excluded periphery), surpluses do not accumulate (they may, for instance, be destroyed in ritual feasts), and primordial relations (of kin and local alliances) tend to prevail. Hence, for social classes or castes to become a separate entity, a second operation is necessary beyond the mere sorting of people into ranks: the informal sorting criteria need to be given a theological interpretation and a legal definition, and the elites need to become the guardians and bearers of the newly institutionalized tradition, that is, the legitimizers of change and delineators of the limits of innovation. In short, to transform a loose ranked accumulation of traditional roles (and criteria of access to those roles) into a social class, the latter needs to become consolidated via theological and legal codification.[86]

No doubt, this characterization of the process through which social strata emerge is somewhat simplified; even geological strata are more complicated than this. (For example, they grow not only through sedimentation but also through accretion and encroachment. Species and social classes may also involve these mechanisms.) But I will retain here the simplified diagram for its heuristic value: sedimentary rocks, species, and social classes (and other institutionalized hierarchies) are all historical constructions, the product of definite structure-generating processes that take as their starting point a heterogeneous collection of raw materials (pebbles, genes, roles), homogenize them through a sorting operation, and then consolidate the resulting uniform groupings into a more permanent state. The hierarchies to which I have referred throughout this chapter are a special case of a more general class of structures, stratified systems, to which not only human bureaucracies and biological species belong, but also sedimentary rocks. (And all this *without metaphor*.)

What about meshworks? Deleuze and Guattari offer a hypothetical diagram for this type of structure, too, but its elements are not as straightforward as those involved in the formation of strata. Perhaps the most-studied type of meshwork is the "autocatalytic loop," a closed chain of chemical processes, which must be distinguished from the simple self-stimulating dynamics to which I referred many times in my description of turbulent urban growth. Unlike simple autocatalysis, a closed loop displays not only self-stimulation but also self-maintenance; that is, it links a series of mutually stimulating pairs into a structure that reproduces as a whole.

The physical basis for either simple or complex self-stimulation are catalysts, that is, chemical substances capable of "recognizing" a more or less specific material and altering that material's molecular state so that it now reacts with certain substances with which it would not normally react. This act of recognition is not, of course, a cognitive act but one effected through a lock-and-key mechanism: a portion of the catalytic molecule fits or meshes with a portion of the target molecule, changing its internal structure so that it becomes more or less receptive to yet another substance. In this way, the catalyst *provokes a meeting of two substances*, facilitating (or inhibiting) their reaction and, therefore, the accumulation (or decumulation) of the products of that reaction. Under special conditions, a set of these processes may form a closed loop, where the product that accumulates due to the acceleration of one reaction serves as the catalyst for yet another reaction, which in turn generates a product that catalyzes the first one. Hence, the loop becomes self-sustaining for as long as its environment contains enough raw materials for the chemical reactions to proceed.

Humberto Maturana and Francisco Varela, pioneers in the study of autocatalytic loops, distinguish two general characteristics of these closed circuits: they are dynamical systems that endogenously generate their own *stable states* (called “attractors” or “eigenstates”), and they grow and evolve by *drift*.[87] The first characteristic may be observed in certain chemical reactions involving autocatalysis (as well as cross-catalysis) which function as veritable “chemical clocks,” that is, the accumulations of materials from the reactions alternate at *perfectly regular intervals*. If we imagine each of the two substances involved as having a definite color (say, red and blue), their combination would not result in a purple liquid (as we would expect from millions of molecules combining at random) but in a rhythmic reaction with states in which mostly blue molecules accumulate followed by states in which mostly red molecules are produced. This rhythmic behavior is not imposed on the system from the outside but generated spontaneously from within (via an attractor).[88]

The second characteristic mentioned by Maturana and Varela, growth by drift, may be explained as follows: in the simplest autocatalytic loops there are only two reactions, each producing a catalyst for the other. But once this basic two-node network establishes itself, new nodes may insert themselves into the mesh as long as they do not jeopardize its internal consistency. Thus, a new chemical reaction may appear (using previously neglected raw materials or even waste products from the original loop) that catalyzes one of the original reactions and is catalyzed by the other, so that the loop now becomes a three-node network. The meshwork has now grown, but in a direction that is, for all practical purposes, “unplanned.” A new node (which just happens to satisfy some internal consistency requirements) is added and the loop complexifies, yet precisely because the only constraints were internal, the complexification does not take place *in order for* the loop as a whole to meet some external demand (such as adapting to a specific situation). The surrounding environment, as source of raw materials, certainly constrains the growth of the meshwork, but more in a proscriptive way (what not to do) than in a prescriptive one (what to do).[89]

The question now is whether we can derive from empirical studies of meshwork behavior a structure-generating process that is abstract enough to operate in the worlds of geology, biology, and human society. In the model proposed by Deleuze and Guattari, there are three elements in this diagram. First, a set of heterogeneous elements is brought together via an *articulation of superpositions*, that is, an interconnection of diverse but overlapping elements. (In the case of autocatalytic loops, the nodes in the circuit are joined to each other by their *functional complementarities*.) Second, a special class of operators, or *intercalary elements*, is needed to effect these interconnections. (In our case, this is the role played by catalysts, which insert themselves between two other chemical substances to facilitate their interaction.) Finally, the interlocked heterogeneities must be capable of endogenously generating stable patterns of behavior (for example, patterns at regular temporal or spatial intervals).[90] Is it possible to find instances of these three elements in geological, biological, and social structures?

Igneous rocks (such as granite) are formed in a process radically different from sedimentation. Granite forms directly out of cooling magma, a viscous fluid composed of a diversity of molten materials. Each of these liquid components has a different threshold of crystallization; that is, each undergoes the bifurcation toward its solid state at a different critical point in temperature. As the magma cools down, its different elements separate as they crystallize in sequence, and those that solidify earlier serve as containers for those that acquire a crystal form later. The result is a complex set of heterogeneous crystals that *interlock* with one another, and this is what gives granite its superior strength.[91]

The second element in the diagram, intercalary operators, includes, in addition to catalytic substances, anything that brings about local articulations from within—"densifications, intensifications, reinforcements, injections, showerings, like so many intercalary events."[92] The reactions between liquid magma and the walls of an already crystallized component, nucleation events within the liquid which initiate the next crystallization, and even certain "defects" inside the crystals (called "dislocations") which promote growth from within, are all examples of intercalary elements. Finally, some chemical reactions within the magma may also generate endogenous stable states. When a reaction like the one involved in chemical clocks is not stirred, the temporal intervals generated become spatial intervals, forming beautiful spiral and concentric-circle patterns that can be observed in frozen form in some igneous rocks.[93]

Thus, granite (as much as a fully formed autocatalytic loop) is an instance of a meshwork, or, in the terms used by Deleuze and Guattari, a *self-consistent aggregate*. Unlike Maturana and Varela, who hold that the quality of self-consistency exists only in the biological and linguistic worlds, Deleuze and Guattari argue that "consistency, far from being restricted to complex life forms, fully pertains even to the most elementary atoms and particles."[94] Therefore we may say that much as hierarchies (organic or social) are special cases of a more abstract class, strata, so autocatalytic loops are special cases of self-consistent aggregates. And much as strata are defined as an articulation of homogeneous elements, which neither excludes nor requires the specific features of hierarchies (such as having a chain of command), so self-consistent aggregates are defined by their articulation of heterogeneous elements, which neither excludes nor requires the specific features of autocatalytic loops (such as growth by drift or internal autonomy). Let's now give some biological and cultural examples of the way in which the diverse may be articulated as such via self-consistency.

A species (or more precisely, the gene pool of a species) is a prime example of an organic stratified structure. Similarly, an ecosystem represents the biological realization of a self-consistent aggregate. While a species may be a very homogeneous structure (especially if selection pressures have driven many genes to fixation), an ecosystem links together a wide variety of heterogeneous elements (animals and plants of different species), which are articulated through interlock, that is, by their functional complementarities. Given that the main feature of an ecosystem is the circulation of energy and matter in the form of food, the complementarities in question are alimentary: prey-predator or parasite-host are two of the most common functional couplings in food webs. *Symbiotic relations* can act as intercalary elements, aiding the process of building food webs (an obvious example: the bacteria that live in the guts of many animals, which allows those animals to digest their food).[95] Since food webs also produce endogenously generated stable states, all three components of the abstract diagram would seem to be realized in this example.[96]

We have already observed several examples of cultural meshworks which also fit our description of self-consistent aggregates. The simplest case is that of small-town markets. In many cultures, weekly markets have been the traditional meeting place for people with heterogeneous needs. Matching, or interlocking, people with complementary needs and demands is an operation that is performed automatically by the price mechanism. (Prices transmit information about the relative monetary value of different products and create incentives to buy and sell.) As Herbert Simon observes, this interlocking of producers and consumers could in principle be performed by a hierarchy, but markets "avoid placing on a central planning mechanism a burden of calculation that such a mechanism, however well buttressed by the largest computers, could not sustain. [Markets] conserve information and calculation by making it possible to assign decisions to the actors who are most likely to possess the information (most of it local in origin) that is relevant to those decisions."[97]

Of course, for this mechanism to work prices must *set themselves*, and therefore we must imagine that there is *not* a wholesaler in town who can manipulate prices by dumping large amounts of a given product into the market (or by hoarding). In the absence of price manipulation, money (even primitive forms of money, such as salt, shells, or cigarettes) functions as an intercalary element: with pure barter, the possibility of two exactly matching demands meeting by chance is very low; with money, those chance encounters become unnecessary and complementary demands may find each other at a distance, so to speak. Other intercalary elements are also needed to make markets work. As we have repeatedly noted, not just material and energetic resources change hands in a market, property rights (the legal rights to use those resources) do too. Hence we typically do not have to model simple exchanges but more complex transactions that involve a host of other costs, such as those involved in enforcing agreements. If these transaction costs are too high, the gains from trade may evaporate. In small-town markets, informal constraints (such as codes of behavior enforced through peer pressure in dense social networks) are also needed to reduce transaction costs and allow the interlocking of complementary demands to take place.[98] Finally, markets also seem to generate endogenous stable states, particularly when commercial towns form trading circuits, as can be seen in the cyclical behavior of their prices, and this provides us with the third element of the diagram.

Thus, much as sedimentary rocks, biological species, and social hierarchies are all stratified systems (that is, they are each the historical product of a process of double articulation), so igneous rocks, ecosystems, and markets are self-consistent aggregates, the result of the coming together and interlocking of heterogeneous elements. And just as the diagram defining the "stratifying abstract machine" may turn out to require more complexity than our basic diagram of a double articulation, so we may one day discover (empirically or through theorizing and computer simulations) that the diagram for the meshwork-producing process involves more than the three elements outlined above. Moreover, in reality we will always find mixtures of markets and hierarchies, of strata and self-consistent aggregates. As Simon says, it may seem prima facie correct to say that

> whereas markets figure most prominently in coordinating economic activities in capitalist countries, hierarchic organizations play the largest role in socialist countries. But that is too simple a formula to describe the realities which always exhibit a blend of all the mechanisms of coordination. The economic units in capitalist societies are mostly business firms, which are themselves hierarchic organizations, some of enormous size, that make only a modest use of markets in their internal functioning. Conversely socialist states use market prices to a growing extent to supplement hierarchic control in achieving inter-industry coordination.[99]

There is one final aspect of meshwork dynamics I must examine before returning to our exploration of the "geological" history of human societies. We may wonder why, given the ubiquity of self-consistent aggregates, it seems so hard to think about the structures that populate the world in any but hierarchical terms. One possible answer is that stratified structures involve the simplest form of *causal relations*, simple arrows going from cause to effect.[100] According to Magoroh Maruyana, a pioneer in the study of feedback, Western thought has been dominated by notions of linear (nonreciprocal) causality for twenty-five hundred years. It was not until World War II that the work of Norman Wiener (and engineers involved in developing radar systems) gave rise to the study of negative feedback and with it the beginning of nonlinear thinking.

The classic example of negative feedback is the thermostat. A thermostat consists of at least two elements: a sensor, which detects changes in ambient temperature, and, an effector, a device capable of changing the ambient temperature. The two elements are coupled in such a way that whenever the sensor detects a change beyond a certain threshold it causes the effector to modify the surrounding temperature in the opposite direction. The cause-and-effect relation, however, is not linear (from sensor to effector) since the moment the effector causes a change in the surrounding temperature it thereby affects the subsequent behavior of the sensor. In short, the causal relation does not form a straight arrow but folds back on itself, forming a closed loop. The overall result of this circular causality is that ambient temperature is maintained at a given level.

Maruyana opposes negative feedback with "positive feedback" (a form of nonlinear causality that we have already encountered in the form of autocatalysis). While the first type of reciprocal causality was incorporated into Western thought in the 1950s, the second type had to wait another decade for researchers like Stanislav Ulam, Heinz Von Foerster, and Maruyana himself to formalize and develop the concept.[101] The turbulent dynamics behind an explosion are the clearest example of a system governed by positive feedback. In this case the causal loop is established between the explosive substance and its temperature. The velocity of an explosion is often determined by the intensity of its temperature (the hotter the faster), but because the explosion itself generates heat, the process is self-accelerating. Unlike the thermostat, where the arrangement helps to keep temperature under control, here positive feedback forces temperature to go out of control. Perhaps because positive feedback is seen as a destabilizing force many observers have tended to undervalue it relative to negative feedback. (In the so-called Gaia hypothesis, for instance, where stabilizing negative feedback is postulated to exist between living creatures and their environment, positive feedback is sometimes referred to pejoratively as "anti-Gaian.")[102]

Maruyana sees the question in different terms. For him the principal characteristic of negative feedback is its homogenizing effect: any deviation from the temperature threshold at which the thermostat is set is eliminated by the loop. Negative feedback is "deviation-counteracting." Positive feedback, on the other hand, tends to increase heterogeneity by being "deviation-amplifying": two explosions set off under slightly different conditions will arrive at very different end states, as the small original differences are amplified by the loop into large discrepancies.[103] We have already observed the many roles that positive feedback has played in the turbulent history of Western towns. However, it is important to distinguish between simple autocatalytic dynamics and complex autocatalytic loops, which involve not only self-stimulation but self-maintenance (that is, positive feedback and closure).

Another way of stating this distinction is to say that the increase in diversity that mutually stimulating loops bring about will be short-lived unless the heterogeneous elements are interwoven together, that is, unless they come to form a meshwork. As Maruyana writes, "There are two ways that heterogeneity may proceed: through *localization* and through *interweaving*. In localization the heterogeneity between localities increases, while each locality may remain or become homogenous. In interweaving, heterogeneity in each locality increases, while the difference between localities decreases."[104] In other words, the danger with positive feedback is that the mere production of heterogeneity may result in isolationism (a high diversity of small cliques, each internally homogeneous). Hence the need for intercalary elements to aid in articulating this diversity without homogenization (what Maruyana calls "symbiotization of cultural heterogeneity").

Negative feedback, as a system of control and reduction of deviation, may be applied to human hierarchies. Decision making in stratified social structures does not always proceed via goal-directed analytic planning but often incorporates automatic mechanisms of control similar to a thermostat (or any other device capable of generating homeostasis).[105] On the other hand, social meshworks (such as the symbiotic nets of producers whom Jacobs describes as engaged in volatile trade) may be modeled on positive-feedback loops as long as our model also incorporates a means for the resulting heterogeneity to be interwoven. Moreover, specific institutions will likely be mixtures of both types of reciprocal causality, and the mixtures will change over time, allowing negative or positive feedback to dominate at a given moment.[106] The question of mixtures should be also kept in mind when we judge the relative *ethical value* of these two types of structure. If this book displays a clear bias against large, centralized hierarchies, it is only because the last three hundred years have witnessed an excessive accumulation of stratified systems at the expense of meshworks. The degree of homogeneity in the world has greatly increased, while heterogeneity has come to be seen as almost pathological, or at least as a problem that must be eliminated. Under the circumstances, a call for a more decentralized way of organizing human societies seems to recommend itself.

However, it is crucial to avoid the facile conclusion that meshworks are *intrinsically better* than hierarchies (in some transcendental sense). It is true that some of the characteristics of meshworks (particularly their resilience and adaptability) make them desirable, but that is equally true of certain characteristics of hierarchies (for example, their goal-directedness). Therefore, it is crucial to avoid the temptation of cooking up a narrative of human history in which meshworks appear as heroes and hierarchies as villains. Not only do meshworks have dynamical properties that do not necessarily benefit humanity (for example, they grow and develop by drift, and that drift need not follow a direction consistent with a society's values), but they may contain heterogeneous components that are themselves inconsistent with a society's values (for example, certain meshworks of hierarchies). Assuming that humanity could one day agree on a set of values (or rather on a way of meshing a heterogeneous collection of partially divergent values), further ethical judgments could be made about specific mixtures of centralized and decentralized components in specific contexts, but never about the two pure cases in isolation.

The combinatorial possibilities—the number of possible hybrids of meshworks and hierarchies—are immense (in a precise technical sense),[107] and so an *experimental and empirical* attitude toward the problem would seem to be called for. It is surely impossible to determine *purely theoretically* the relative merits of these diverse combinations. Rather, in our search for viable hybrids we must look for inspiration in as many domains as possible. Here, we have looked to a realm that would normally seem out of bounds: the mineral world. But in a nonlinear world in which the same basic processes of self-organization take place in the mineral, organic, and cultural spheres, perhaps rocks hold some of the keys to understanding sedimentary humanity, igneous humanity, and all their mixtures.

Arguments and Operators

I have argued that structures as different as sedimentary rock, animal species, and social classes may be viewed as historical products of the same structure-generating processes. (Or more accurately, of different concrete processes embodying the same abstract machine or engineering diagram.) Does language embody an abstract machine too? The accumulations of linguistic materials that are sorted into homogeneous sets and cemented together through isolation are examples of stratified systems, and, hence, language can be said to embody this (double-articulation) abstract machine. Similarly, insofar as the sounds, words, and constructions of a language are viewed as replicators, languages also embody an abstract probe head, or searching device. But the question we must address now is this: Is there an abstract machine that is specific to language? In other words, do the processes responsible for the generation of phrases and sentences embody an engineering diagram that distinguishes the structure of language from the structure of rocks, plants, and animals?

Chomsky believes that this diagram defines an *abstract robot* embodied in our brains, an automaton capable of producing every valid sentence in a given language. In 1959, Chomsky postulated the existence of four different types of abstract automata which differ in their degree of complexity: finite-state automata are the simplest type, followed by context-sensitive robots, context-free robots, and finally Turing machines.[69]

Chomsky argued that a language could be seen as made up of two components, a dictionary (or reservoir of words) and a *set of rules* determining how those words may be combined to make legal sequences (well-formed sentences). Thus, given a set of sentences, the robot (a context-free automaton) could tell whether they belonged to a given language simply by applying the rules. To the robot, a sentence was no more than a *string of inscriptions* (whether the inscriptions were on clay, paper, or air was immaterial to it), and the rules were recipes to test these strings for membership in the set of valid strings. This model was supposed to capture the grammatical intuition that allows speakers of English to tell the difference between "Colorless green ideas sleep furiously" and "Sleep green colorless furiously ideas" (one a grammatically valid string, the other invalid), even though both strings are semantically meaningless.

When it came time to *produce* new strings (as opposed to checking them for validity), the rules were divided into two types: one set generated the basic logical skeleton of a sentence (its deep structure), while several other sets transformed this naked sentence, fleshing it out with the materials of a real language. (These two components of a grammar are called "generative" and "transformational," respectively.) The generative component of the automaton was assumed to be inborn and to capture all that is universal about language (that is, all that remains constant across different languages and is unaffected by their particular histories). Could we consider this robot the abstract machine of language? Deleuze and Guattari, among others, answer this question negatively:

> Our criticism of these linguistic models is not that they are too abstract but, on the contrary, that they are not abstract enough, that they do not reach the *abstract machine* that connects language to the semantic and pragmatic contents of statements, to collective assemblages of enunciation, to a whole micropolitics of the social field. . . . [T]here is no language in itself, nor are there any linguistic universals, only a throng of dialects, patois, slangs, and specialized languages. There is no ideal speaker-listener, any more than there is a homogeneous linguistic community. Language is, in Weinreich's words, "an essentially heterogeneous reality." There is no mother tongue, only a power takeover by a dominant language within a political multiplicity.[70]

In essence, what Deleuze and Guattari oppose is the postulation of a "universal core" (or synchronic dimension) of language, since this relegates social processes (such as pidginization, creolization, or standardization) to a secondary role, affecting at most the transformational component of the grammar. What they propose instead is to give historical processes a more fundamental role by modeling the abstract machine of language not as an automatic mechanism embodied in individual brains but as a diagram governing the dynamics of collective human interaction. The main problem to be solved if we are to implement their proposal lies in finding a valid means of transferring the *combinatorial productivity* of the automaton, its ability to produce an infinite number of sentences out of a finite stock of words and combination rules, to the patterns of behavior generated by different social dynamics. One possible solution may be to assume that the postulated grammatical rules do not exist in our brains but are instead embodied in social institutions. The problem with this solution is that, as is well known, human beings do not learn their mother tongue as a set of rules. Indeed, it was the well-documented ability of children to learn language by being exposed to adult conversation (that is, without being explicitly told what the rules are) that motivated the postulation of an inborn automaton in the first place. But if a set of rules is not the source of the combinatorial productivity of language, then what is?

One possible answer is that words carry with them, as part of their meaning, "combinatorial constraints" that allow them to restrict the kinds of words with which they may be combined. That is, in this view individual words carry information about their frequency of co-occurrence with other words, so that, as a given word is added to a sentence, this information exerts demands on the word or kind of word that may occur *next*. (For example, after adding a definite article to a string, the following position is constrained to be occupied by a noun.) Combinatorial productivity would not result from a centralized body of rules, but from a decentralized process in which each word *locally restricts* the speaker's choices at each point in the construction. One version of this alternative way of handling the production of sentences was proposed long ago by the linguist George K. Zipf, who was perhaps the first to study language as "stuff," that is, as a large body of material inscriptions exhibiting certain statistical regularities. Zipf called the tendency of words to occur next to each other their degree of crystallization: "To illustrate the comparative degrees of dependence of words in sentence-structure, let us perform an imaginary experiment. We may take as material a vast number of English sentences, just as they are spoken, say a million of them. Figuratively speaking we shall now dash these sentences on the floor with such force that they will break, and pieces of them will scatter. Of course, some of the words, being more crystallized in arrangement than others, will cohere. Definite and indefinite articles will adhere to their nouns, auxiliaries to their verbs, prepositions to following objects."[71]

The linguist Zellig Harris, who introduced the notion of "transformation" into linguistics in the early 1950s (and so is no stranger to the Chomskyan paradigm), has developed a way to take metaphorical descriptions like this and transform them into a mathematical theory of language that comes very close to the abstract machine we are looking for. According to his theory, the constraints or demands that words place on one another are transmitted as socially obligatory information. ("Information" is being used here in the sense of "physical information," the kind measured in bits, *not* the semantic information used in dictionary definitions.) Harris explicitly develops his model of the social transmission of combinatorial constraints in evolutionary terms, with different constraints (or rather, the sentences constructed with their help) competing for the same "informational niches."[72] He rejects the concept of an unchanging, homogeneous core of language, and therefore his theory allows us to approach the question of dialectal variation (and the essential heterogeneity of language) directly: not only is language in constant change, with the strength of the constraints varying along a continuum from optional to obligatory, but the rates of change themselves may be different from dialect to dialect. His view of language is completely historical; the source of the constraints themselves is the gradual standardization (or conventionalization) of customary usage. Thus, despite the fact that changes in syntax may occur much more slowly than changes in other aspects of language, the syntactical element is not isolated from semantics and pragmatics.[73]

Harris classifies three main types of combinatorial constraints. The simplest one is what he calls "likelihood constraints," information carried by words about the words with which they tend to combine *more frequently* as a matter of actual usage. That is, a word like "tiger" carries information to the effect that it typically co-occurs with other words (such as "fierce" or "hunting") but not others ("polite" or "dancing"). Not that there is a specific rule barring these combinations; rather, as a matter of *statistical fact*, in a given speech community these words occur in certain combinations much more frequently than in others. (The phrase "dancing tigers" does occur in children's books, but compared with the overall usage of those two words in actual speech, this combination is rare.) For a given word, the set of its most frequently co-occurring words (a fuzzy set since it is in constant change, contracting and expanding) is called its "selection," and in Harris's model it is this selection set that forms the "core meaning" of the word. (Hence, the meaning of words would be determined by their combinability, not their identity. Formal dictionary definitions and informal stereotypes emerge from conventionalization of likelihood constraints.)[74]

A second type of constraint, the most fundamental to the structure of language, according to Harris, is the operator-argument constraint, which models the action that verbs, adverbs, adjectives, prepositions, and other linguistic modifiers have on their objects. Unlike the likelihood constraint, the operator-argument constraint binds together not individual words but classes of words. A given operator, once included in a sentence, *demands* an argument of a certain class. This constraint, too, adds information to the sentence: the more unfamiliar the argument supplied for a given operator, the more informative it will be. Of all the different linguistic functions that this constraint may be used to model, Harris stresses the operation that verbs perform on the nouns that serve as their subjects and objects, since this operation yields the basic structure of sentences. As is well known, sentences afford their users the means to perform two different functions: to *identify* for an audience the objects or events to which the speaker is referring and to say something *about* those objects or events. The operator-argument constraint, when used to link verbs and nouns, adds to a sentence the meaning of "aboutness," the ability to refer not only to individual objects and events but also to complex *situations*.[75]

Finally, Harris postulates a third type of constraint, which he calls "reduction." Whenever the likelihood that two words will co-occur becomes very high, the amount of physical information their co-occurrence adds to a sentence is correspondingly low; that is, it adds very little information that cannot be supplied by the speaker or listener. In those conditions, one of the two words may be reduced in form (becoming a suffix or prefix attached to the other word) or even eliminated altogether. However, even when a word has been "zeroed," the little information it used to carry is still there (or may be reconstructed by the speaker or listener), so that after successive reductions the resultant simpler forms may carry (in a very compressed way) a rather complex meaning. Harris uses this third kind of constraint to explain the origin of some classes of words (such as adverbs, pronouns, and some conjunctions) as well as of the different affixes.[76] In other words, the reduction constraint allows Harris to give a historical account of the origin of the main word classes, classes which are taken as given (as unexplained primitives) in the Chomskyan theory.[77]

This is one of the reasons why Deleuze and Guattari view the Chomskyan automaton as "not abstract enough." The robot is capable of explaining the production of one set of forms (those of sentences) but only by assuming another set of forms (those of rules and primitive word classes). In Harris's model, on the other hand, language is a thoroughly historical product (the cumulative result of restrictions in the occurrence of words relative to one another), and combinatorial constraints are truly morphogenetic: as new constraints emerge from conventionalization of customary usage, changing the probabilities that words will co-occur, language structure self-organizes as a process involving *successive departures from equiprobability* (i.e., randomness) in the combinations formed by replicating norms.[78]

This scenario meshes well with some of the ideas we developed earlier. In particular, the emergence of language may now be seen as the result of a double articulation: an accumulation formed by a sorting device consolidated through an act (or succession of acts) of conventionalization or institutionalization. However, this diagram may be too simple even to account for sedimentary rocks, which also grow and develop through *accretion,* that is, the amassing of further materials and the proliferation of existing structure. Language, too, in Harris's view, is an accretionary structure.[79] In particular, once certain high frequency co-occurrences have become obligatory constraints, speakers begin to construct new patterns *by analogy* to previously institutionalized ones. Prior structures could also proliferate by *recursion*: operator-argument pairs, for example, themselves could be made the argument of a higher-level operator. Hence, positive-feedback loops develop where structure (consolidated accumulations) favors accretions, which in turn generate further structure. Moreover, the creation of new patterns by analogy to previously accumulated ones (or by recursive application of existing constraints) is what generates a system that, in retrospect, may appear to consist of a set of rules.[80] (Of course, some languages, such as standard English or French, *are* sets of rules, and they are taught to grammar school children as such. The question is whether the language that those children learn at home in an untutored way is also a set of rules or rather a set of normative combinatorial constraints.)

Another feature of Harris's theory may help us meet Deleuze and Guattari's demand that the abstract diagram be "abstract enough." Ideally, the abstract machine postulated to account for the generation of linguistic forms should not be the abstract machine *of language* (in which case it would be hard to distinguish it from an "essence" of language), much as the abstract probe head we discussed before is not the abstract machine *of life* (since it may be "incarnated" in any population of replicators, not only genes). Similarly, an "abstract enough" diagram that explains the generation of strings of linguistic inscriptions should ideally explain the morphogenesis of other (nonlinguistic) strings. In other words, language may not be the only structure that can be viewed as a system of demands or of required repetitions. While the structure of language is unique, the constraints that generate it are not. (Being the subject of a verb is uniquely linguistic; having the occurrence of certain things depend on the occurrence of other classes of things, is not.)

Harris shows how by making the combinatorial constraints more rigid we can generate strings of inscriptions like those belonging to systems of logic or mathematics, while by making them more flexible we can produce musical strings. For example, weak conversational (or discursive) demands constrain the successive order of sentences in ordinary language. If we strengthen those demands, so that sentences must now follow one another in a prescribed manner (and if we further demand that the sequence begin with self-evident truths and conclude with a sentence as true as the previous ones), the result is a logical or mathematical proof structure. If we change the operator-argument hierarchical constraint and demand that only the operator carry constraint-based information, we thereby transform the argument into a *variable* and the operator into a *function*. (That arguments in mathematics exercise no constraints is what makes it a science of relations, that is, of operators.)[81] On the other hand, if instead of fixing the operator-argument relation we make it variable, so that "many varied relations exist between a longer musical line and its subsegments," we can generate structures like those exhibited in musical compositions.[82] This is not to deny that explicit rules exist in mathematical or musical systems, much as they do in standardized languages. The question is whether mathematics or music could have originally developed as a decentralized system of constraints that only later was formalized as a centralized body of rules.

In addition to providing us with an "abstract enough" diagram of language, Harris's theory also meets the other requirement we found lacking in Chomsky's robot: that the abstract machine be directly connected to a social dynamics. Specifically, the core of Harris's model involves a process through which statistical regularities in usage are gradually transformed through standardization into required constraints. But these institutional requirements would have no reality if there was no mechanism through which social obligations could be enforced. It may be argued that to be complete Harris's theory demands some kind of norm-enforcement mechanism, such as that provided by social networks. We saw before that, in sociolinguistics, the degree of density of a network (roughly, the degree to which, for every member of a community, the friends of his or her friends know each other) and its degree of multiplexity (the degree to which his or her life-support activities depend on those friends and friends of friends) are viewed as the parameters that define its efficacy as a norm-enforcement device. In a sense, these parameters define the *intensity of our attachment* to a given community or group, and the norms enforced within a network draw the boundaries that define the identity of that community or group. Thus, a view of language in terms of constraints on word combination directly involves questions of the effects that group-membership has on individuals, and, in that sense, it meets Deleuze and Guattari's requirement that "collective assemblages of enunciation" be made an intrinsic component of the abstract machine of language.

Is it possible to extend (or complement) Harris's model so that a similar abstract diagram explains not only the form and function of individual sentences but also the historical origin of larger linguistic structures, such as discourses? Or more specifically, is there an abstract machine that can explain in sociodynamical terms the emergence of discourses expressing worldviews (coherent sets of values and beliefs)? A model created by the anthropologist Mary Douglas comes close to defining such an abstract machine, and it may be linked with Harris's theory of language since in Douglas's model the intensity with which individuals are attached to a group also defines an important feature of "collective assemblages." Another equally important trait of group dynamics defines not whom we interact with, but *how* we interact; it does not bestow group-membership but controls behavior in the wider social context within which the group functions. Douglas, who calls these two aspects of social dynamics "group" and "grid," one measuring the intensity of group allegiance, the other the intensity of centralized regulation, has created a theory of the self-organization of worldviews, in which the kind of cosmologies that emerge in different communities depend directly on the values of the "group" and "grid" parameters. When applied to specific social groups (Douglas's model does not apply to entire societies), these two parameters define an abstract diagram with four possible stable states that act as "attractors" for beliefs and values as they organize into a coherent set. Or rather (since she models not the dynamics of beliefs but the dynamics of *groups of believers*), the two parameters define a lifestyle (more or less hierarchical, more or less group-dependent) and people *coerce one another* to fully develop the implications of that lifestyle. The resultant worldviews act as attractors in the sense that "the four extreme grid/group positions on the diagram are liable to be stable states, steadily recruiting members to their way of life, which is at the same time inevitably a way of thought."[83]

When both the group and grid parameters have high values, the community in question not only has a strong sense of self-identity (the group may spend much energy policing boundaries and elaborating rules of admission) but it is also well integrated into larger social groups. Life within a government military institution such as the army or navy would serve as a good example of this lifestyle, but so would the culture of any hierarchical bureaucracy. Keeping the value of group allegiance high but lowering the value of regulation (and integration into a larger whole) results in sectarian lifestyles with strong group identity but a weak sense of responsibility to conform to any norms that hold outside the group. If both parameters are set at a low intensity, group members refrain from drawing strong boundaries around them (they rather engage in networking; given the loose group demands, everything seems open for negotiation), and they tend to participate in those areas of public life that are less centralized and hierarchical. (A small-business entrepreneur would be a good example here, but not the manager of a large corporation, particularly if he or she participates in the corporate culture.) Finally, there are those who do not belong to closed groups but nevertheless have little room to maneuver around regulations and are, indeed, burdened by them:

> As I see it, three corners exert a magnetic pull away from the middle; individualists extolling a culture of individualism tend to become more and more uncommitted to each other and more committed to the exciting gamble for big prizes. Egalitarian idealists committed to a sectarian culture strongly walled against the exterior, become more and more enraged against the outside society and more jealous of each other. The supportive framework and intellectual coherence of a hierarchical and compartmentalized society nurses the mind in cogent metaphysical speculations vulnerable to disorder and independence.... The fourth corner, the fully regulated individuals unaffiliated to any group, is plentifully inhabited in any complex society, but not necessarily by people who have chosen to be there. The groups [bureaucracies or sects] expel and downgrade dissenters; the competition of individualists ... pushes those who are weak into the more regulated areas where their options are restricted and they end by doing what they are told.[84]

Although Douglas's model may have to be enriched in several ways, even in this simple form (with two parameters generating four possible states) it meshes well with the ideas we have explored in this book. First of all, it attempts to capture some of the features of group dynamics behind the *genesis of form* at the level of coherent discourse. That this morphogenetic process may turn out to be more complex does not deprive her hypothetical model of validity as a first approximation, particularly if the model is given a nonlinear dynamic formulation so that the first three corners of the diagram become true attractors. (A catastrophe theory version of Douglas's model does exist and points in the direction that this reformulation would have to take.[85]) Additionally, the model is intended to be used in a bottom-up way, to be applied to the study of specific communities, where the constraints that the holders of a worldview exert on one another can be fully specified. In other words, the scheme is not supposed to apply to societies as a whole but only to smaller subsets thereof, with cities or nation-states modeled as complex mixtures of several types of worldview.[86] On the other hand, Douglas's model has limitations: it only captures processes that take place *within* organizations or collectivities, and hence cannot account for the effects of the transmission of ideas and routines between the members of an ecology of institutions or, indeed, for any effect on the form of discourses which the interactions between institutions may have (e.g., the interactions between hospitals, schools, prisons, and factories).

Returning to the question of the abstract machine of language, both Harris and Douglas have contributed crucial insights into the essentially *collective character* of this machine. In both linguistic evolution and worldview development there are, no doubt, many contributions and innovations by individuals. But in many cases it is the position of an individual in a communication network that determines the fate of his or her contribution. Consequently, the accumulation and consolidation of languages and worldviews is a collective enterprise, not the result of individual self-expression. Moreover, to the extent that the resulting linguistic and discursive forms are transmitted to new generations (or new members) through enforced repetition, these forms are replicators; hence we need to use "population thinking" to describe their evolutionary dynamics. This, too, forces on us the need to approach the subject in terms of collectivities rather than individuals. On the other hand, the collective dynamics may be such (low group/low grid) that individuals may play significant roles in the fate of these accumulations. But even so, it may be argued that this extra room to maneuver is afforded to individuals by the stable state governing the collective dynamics, and in any case those individuals owe their surplus freedom to the fact that they are connected to decentralized structures (such as markets), which are every bit as collective as the most routinized hierarchy.[87]

We may now picture the structure-generating processes behind individual sentences as embodying an abstract machine operating on the basis of combinatorial constraints transmitted as replicators. The process of transmission itself involves collective mechanisms of enforcement, which are also part of the abstract machine of language and which may be used to account for the emergence of coherent structures made out of many sentences (discourses embodying specific worldviews). Now we must return to the historical development of both these components of the abstract machine and examine the history of their multiple and complex interactions.