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Frozen Accidents

Quoted at length from
Murray Gell-Mann

....The importance of accidents in the history of the universe can thus hardly be exaggerated. Each of us human beings, for example, is the product of an enormously long sequence of accidents, any of which could have turned out differently. Think of the fluctuations that produced our galaxy, the accidents that led to the formation of the solar system, including the condensation of dust and gas that produced Earth, the accidents that helped to determine the particular way that life began to evolve on Earth, and the accidents that contributed to the evolution of particular species with particular characteristics, including the special features of the human species. Each of us individuals has genes that result from a long sequence of accidental mutations and chance matings, as well as natural selection.

Now, most single accidents make very little difference to the future, but others may have widespread ramifications, many diverse consequences all traceable to one chance event that could have turned out differently. Those we call frozen accidents. I give as an example the right-handed character of some of the molecules that play important roles in all life on Earth though the corresponding left-handed ones do not. People tried for a long time to explain this phenomenon by invoking the left- handedness of the weak interaction for matter as opposed to antimatter, but they concluded that such an explanation wouldn't work. Let's suppose that this conclusion is correct and that the right-handedness of the biological molecules is purely an accident. Then the ancestral organism from which all life on this planet is descended happened to have right-handed molecules, and life could perfectly well have come out the other way, with left- handed molecules playing the important roles.

Another example can be chosen from human history. For instance, Henry VIII became king of England because his older brother Arthur died. From the accident of that death flowed all the coins, all the charters, all the other records, all the history books mentioning Henry VIII; all the different events of his reign, including the manner of separation of the Church of England from the Roman Catholic Church; and of course the whole succession of subsequent monarchs of England and of Great Britain, to say nothing of the antics of Charles and Diana. The accumulation of frozen accidents is what gives the world its effective complexity.

The effective complexity of something is the length of a brief description of its regularities. Those regularities can come from only two sources: the fundamental laws, which are very simple and briefly describable, and frozen accidents.

As time goes on, systems of greater and greater effective complexity appear. That's true for nonadaptive systems, such as galaxies, stars, and planets, as well as for complex adaptive systems, as in biological evolution. Of course, I don't mean that each individual system becomes more complex. Some things get simpler; they may even disappear altogether, as in the case of vanished civilizations. Instead of a steady march toward greater complexity everywhere, there's a tendency for the envelope of effective complexity to expand. We can understand why. With the passage of time, more and more accidents occur, and frozen accidents accumulate. In fact, at any time, there are many mechanisms at work producing self-organization, which results in local order, even though the average disorder in the universe is increasing in accordance with the second law of thermodynamics. Self-organization gives rise, for example, to the arms of spiral galaxies and the myriad symmetrical shapes of snowflakes.

In the case of complex adaptive systems, their schemata have consequences in the real world, which exert selection pressures back on the competition among the schemata, and those schemata that produce favorable results in the real world have a tendency to survive, or to be promoted, and those that are less successful in the real world have a tendency to be demoted or to disappear. In many situations, complexity may offer a selective advantage. It is a challenge to evolutionary biologists, for example, to understand when that is the case.

Light can be thrown on many such questions by making use of computer-based complex adaptive systems, which can be used (1) to provide crude models of natural complex adaptive systems, (2) to supply interesting examples of complex adaptive systems for study, (3) to evolve new strategies for playing games or for solving problems, or (4) to solve problems by means of "adaptive computation."

The study of computer-based complex adaptive systems is already burgeoning, especially as a mathematical discipline concerned with the relation between simple rules and the emergence of complex behavior. That's something worth pursuing in its own right, but even more exciting is the possibility of useful contributions to the life sciences, the social and behavioral sciences, and even matters of policy for human society.

The favorite activity of some of my colleagues, especially my younger colleagues, at the Santa Fe Institute and of their friends around the world is to construct computer models with very, very simple rules — carefully chosen, stripped-down sets of rules that permit complex behavior to emerge. It's a remarkable and somewhat addictive experience to watch that emergence. We have people who are very good at stripping down rules for computer models — the political scientist Bob Axelrod, for example. He also has a flair for persuading his colleagues in political science that such a simplified model is somehow relevant to reality. If I came up with a model of that kind and presented it in a lecture to political scientists, they'd laugh me off the platform. Bob, however, presents it in such a way that social scientists can accept it. For example, imagine a circle of little polities occupying the coast of a Polynesian island with a huge volcano in the middle. The polities interact with one another either by forming alliances or making war. Each one can attack only an immediate neighbor or one that can be reached through an uninterrupted sequence of allies. Somehow Axelrod manages to extract interesting lessons from such a trivial, one- dimensional model.

Someday we'll have a full-fledged mathematical science, with theorems and proofs, that will make it clear, for instance, when new rules merely complicate the picture without adding anything essential to the emergent patterns. The construction of that science lies at one end of the spectrum of efforts to use computers to help us think about complicated systems. At the other end of the spectrum are attempts to think about policy problems that humanity faces in the real world, in connection with human society, the rest of the biosphere, and the relation between the two. In the middle, we have attempts to understand better the operation of complex adaptive systems in the life sciences and in the behavioral and social sciences. When we get away from the mathematical end of the spectrum, the accumulation of accidents of history enters in a very important way. The stripped-down computer models are typically ones that apply, in a general way, to complex adaptive systems on any planet in the universe. They don't contain any historical information about the planet Earth, or about the organisms that inhabit the planet Earth, or about human beings and the institutions we've built.

In the simple exercises that are so popular, one starts with a caricature of one level of organization, and then one often sees a higher level of organization emerge. Starting with highly simplified individuals, you may see the emergence of a society. Starting with highly simplified polities, you may see confederations emerge. Suppose, however, you want a simplified description of human society as it exists on this planet, with all its polities and the various levels — federations, confederations, and so on — that exist, and their various relations with one another, the results of a huge number of historical accidents. These entities are all historical and peculiar to this planet and to human beings. You're forced to start complicating the stripped-down models by adding in other things — especially, new levels of organization — without waiting for them to emerge. You don't wait for the individuals in your model to develop a city or a business firm, and you don't depend on the cities and the firms to invent a nation, and the nations to invent a U.N. You have to put a lot of that in, along with some of the special properties that human beings and their firms, cities, ethnic groups, nations, and international organizations exhibit on this planet. You can no longer be content with the thrill that my friends get when they see one level of organization emerging from another, as simple rules give rise to complex behavior.

If you want to put in too many special properties, whether at the level of the individual human being or at higher levels of organization, you'd be going far beyond the capacity of any model. First, the model would become too difficult to handle mathematically, and second, once the model ran you'd find it very difficult to understand the results. There's always a trade-off between the advantages of stripping down the rules — so that you get caricatures of human beings, let's say, but you also get operations you can carry out mathematically — and the advantages of putting in something more complex, more sophisticated, more applicable to this planet and to the human race. Of course, as computers get better and better, the whole game will become more sophisticated, but there will still be such a trade-off.

An interesting question about the behavior of complex adaptive systems is, What is required to move from one level to another? In Tom Ray's little artificial world of digital organisms, there are significant jumps, and with more elaborate models we'll be able to see even more significant changes in level of organization.

The tendency of the researchers is to crowd over at the mathematical end of the spectrum, where the rules are simple and they get enormous pleasure out of seeing complexity emerge, but that work will be difficult to use for scientific or policy purposes, and rather easy to misuse. One has to invest some effort in the other parts of the spectrum as well.

Furthermore, one has to proceed with caution, in that much mischief has been done in the world by exaggerating the role of scientific metaphor in human affairs. The science of economics provides an example: people have tried to apply a stripped-down version of economics to human affairs, omitting a great many values, a great many things of importance. You get society in the service of economics, instead of economics in the service of society. The Nazi racial theories are, of course, a horrible example of misapplying metaphors from science. Nineteenth-century ideas of social Darwinism are another example. We have to be careful when we use these stripped-down models — and even when we use more complicated models — not to take them too seriously but rather to use them as prostheses for the imagination, as sources of inspiration, as acknowledged metaphors. In that way I think they can be valuable.

I've never been eager to sell a particular kind of activity to others just because I'm engaged in it myself. I never tried to sell elementary-particle physics to people as a career, and I wouldn't try to sell the study of complex adaptive systems to anybody either. I think what is exciting is human culture as a whole. People may want to be painters or poets or historians or scientists of various kinds — field biologists or archaeologists or plectics theorists or elementary-particle experimentalists or astronomers or whatever. It is noteworthy, though, that people who work on simplicity and complexity — on plectics — are often capable of carrying out practical activities in a great many different fields.

Nevertheless, people doing transdisciplinary work have a lot of problems finding suitable employment, especially in academic life. The reason isn't merely prejudice but also the fact that all the mechanisms for judging excellence are set up in the narrow traditional disciplines. Peer reviewed journals, academic departments, Ph.D. exams, professional societies, and so on, are typically organized along disciplinary lines. Of course, there are always phonies who cower on the boundaries between fields, so people aren't altogether unjustified in being wary of transdisciplinary work. Clearly, we need effective mechanisms for judging it.

In discussing plectics with audiences, I encourage people to see one panorama rather than a lot of separate disciplines: the various meanings of simplicity and complexity; complex nonadaptive systems in the physical sciences; the modern interpretation of quantum mechanics; the simplicity of the fundamental laws of physics — that is, the unified theory of all the particles and their interactions plus the boundary condition at the beginning of the expansion of the universe; complex adaptive systems in the life sciences, in the behavioral and social sciences, and in practical human affairs; computer-based complex adaptive systems, some of which can serve as crude models for natural complex adaptive systems; and so forth.

Also, I have found it necessary to discuss the notion of reductionism. People scream epithets at one another over this issue of reduction. I take what I think is the only sensible position, which is that of course the basic laws of physics are fundamental in the sense that all the other laws are built on them, but that doesn't mean you can derive all the other laws from the laws of physics, because you have to add in all the special features of the world that come from history and that underlie the other sciences. Physics and chemistry stem from the fundamental laws, although even there, in the complicated branches of physics and chemistry, the formulation of the appropriate questions involves a great deal of special additional information about particular conditions that don't obtain everywhere in the universe. In the center of the sun, there is no solid-state physics. In the very early universe, when matter was still mostly a quark soup, there was not even nuclear physics. So even those subjects involve, in a sense, more than just fundamental laws.

All the rest of the sciences depend heavily on particular accidents in the history of the universe: astronomical accidents, geological accidents, biological accidents, accidents of human history, and so on. There's a huge body of information that has to be supplied in addition to the fundamental laws before you get the details of biology on Earth, for example. Just because elementary-particle physics is fundamental doesn't mean you can reduce biology to it, even in principle, unless you adjoin that additional information. Furthermore, in practice, it's essential to study biology at its own level, and likewise psychology, the social sciences, history, and so forth, because at each level you identify appropriate laws that apply at that level. Even though in principle those laws can be derived from the level below plus a lot of additional information, the reasonable strategy is to build staircases between levels both from the bottom up (with explanations in terms of mechanisms) and from the top down (with the discovery of important empirical laws). All of these ideas belong to what I call the doctrine of "emergence."

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A Syber Group reprint
Philosophy & Linguistics Classics