Reference Frame

Models, Morals and Metaphors.

Leo P. Kadanoff

Games of chance are often used as conceptual models of random processes in nature. For example, an exhibit on the heart in Chicago's Museum of Science and Industry includes a kind of pinball machine. After the balls bounce somewhat randomly through this machine, they fall into bins symbolizing the different states of health of one's heart. One can bias the outcomes for better or for worse by turning knobs related to one's habits (smoking? eating too much?) and controllable risk factors. This device is a provocative metaphor for the mix of random and controllable processes that determine one's health.

Similar metaphors occur in the Field Museum of Natural History's exhibit "Life through Time." Here we find three different kinds of toys--wheels of chance, craps, and a horse race--all used to describe the stochastic nature of the evolutionary process. One of the toys invites the museum-goer to spin a wheel to gain characteristics that might enable an organism to prosper in a transition from an aquatic to a land environment. If the spin yields gills, that's bad. A strong tail won't help much either. A sturdy skeleton would be a boon, though. According to this display, survival is a matter of luck, depending on whether the traits developed in one environment might be useful in another. Another display shows various species of horses racing through the millennia until extinction drags them down, leaving only the modern horse. These toys are tabletop illustrations of the point made by David Raup in his book, *Extinction: Bad Genes or Bad Luck?* (W. W. Norton, 1991).

In his book on the evolution of natural history museums, *Stuffed Animals & Pickled Heads: The Culture and History of Natural History Museums* (Oxford U. Press, 2001), Stephen T. Asma describes the gambling displays at the Field Museum and then points us to a nearby board with Post-it® notes left by museum visitors. One thoughtful visitor, Alan, objects quite strongly to these toys, saying,

> [W]hat appears to the human mind as mere randomness, may from a divine perspective not be random at all. You may argue that this is a biased perspective, ridden with personal values and interpretations. However, seeing the principal cause and government of the universe as a roulette wheel is filled with the same personally subjective views as well as being morally bankrupt. Please pick a more objective and socially responsible means to convey your concept of evolution.

Alan sees these displays as having led us into a totally amoral universe. No creator, no greater good; the only goal is to survive. But the gambling displays only talk about the evolution of different species and groups. Is Alan's extrapolation an error?

Another Post-it commentator disagrees with Alan's specific conclusion. This person's note says, "Alan needs to understand that life is a gamble. Whenever he walks out his front door, Alan is gambling with his life." Both museum visitors recognize the evocative power of these little mechanical models and the metaphors they represent. While these displays are not precisely science, both observers see them as potential tools for extrapolation and generalization. They thus work in somewhat the same way as a literary metaphor.

As a specialist in statistical physics, I could offer Alan some comfort. I could point out to him that the observation of apparently stochastic features in some behavior does not imply that the underlying laws are themselves probabilistic. Often, deterministic motion is so complex or so sensitively dependent on initial conditions that the motion is indistinguishable from a set of random events. For example, the path taken by an individual molecule in a gas is very well modeled as a random walk, entirely probabilistic in its nature. The random walk model can be derived from more fundamental models of molecular scattering. The scattering events could be realized in at least three different ways: using classical mechanics (fully deterministic), using quantum mechanics (partially deterministic), or prespecifying the probabilities of scattering. Thus the probabilistic single-particle model, the random walk, can be equally well obtained from a many-particle model that is entirely deterministic, partially so, or not deterministic at all. Real gases will all show the same behavior independent of the detailed laws governing the scattering. We use the word "universality" to describe the rather commonly occurring physical situations in which a set of derived laws remains substantially the same over a wide range of alternative underlying fundamental laws. In these cases, the observable outcome cannot be used to select among the possible underlying laws.

The process of obtaining apparently probabilistic outcomes from deterministic laws has acquired its own name, the butterfly effect. This metaphor describes the magnification of small differences in initial data to ultimately produce a very large effect. To exemplify this process, meteorologist Edward Lorenz pointed out that the disturbance produced by the flapping of a butterfly's wings in South America has the potential to modify or produce a later storm in the United States.

Conversely, as every student of statistics well knows, if you put together many individual stochastic motions, you may well get an essentially deterministic situation. A dilute classical gas obeys the deterministic gas law, $PV = NkT$. Through the "miracle" of large numbers, many stochastic molecules have produced a deterministic gas.

These examples show that what one sees in a particular set of observations of the world will not and cannot determine what is happening at a deeper level. Thus statistical physics has not revealed whether the universe (or even a gas) is "really" stochastic or deterministic. We can only say that our models, stochastic and deterministic, have each caught some elements of what we see when we look at the gas. As we study the models, we better understand them and their close correspondence to behaviors of the real gas. But that is as far as we get.

So what can we tell Alan and his Post-it critic? In my view, we should say that even the best models we have seen in science are idealizations and abstractions of nature and must, of necessity, catch only a piece of reality. If Alan wants to believe that deep down the universe has a purpose that we have not caught in any of our scientific models, we have no evidence to convince him of the contrary. On the other hand, science does have some useful

information for Alan and other thoughtful people. There *is* strong evidence that the world is old and has been behaving the same way for a very long time. Evidence does indicate that the motion of the planets, the inheritance of biological characteristics, and everything we have observed follows well-defined laws. Wherever we have looked most seriously, we have seen phenomena that can be described by simple models of lawful behavior, endlessly repeated, without discernible purpose or goal. As Alan says, this is a cold and amoral description of reality. This view of the world as defined by law does have some support as a model of the Solar System and of other situations we have studied carefully. However, to apply this picture to the entire universe requires a tremendous extrapolation. Such an extrapolation can only have the strength of a metaphor.

As a scientist, I can say that we do not have (and probably cannot have) any evidence to show that nature is just a set of laws operating without purpose or goal. But as a person, I find the metaphor congenial. I believe that the world is like that.

Science gives us metaphors that we can use to organize and express our experiences in life. One powerful metaphor arises in my own subject of dynamical nonlinearity. We study many models that undergo a partially recurrent cyclic behavior in which the same basic thing happens through very many cycles. Then, in one or a few cycle times, there is a large and "unexpected" excursion to a very different behavior. In my thinking about the world, I follow the metaphor of these models and conclude that, in real life, one should expect "large changes" or perhaps even "disasters." Here I am extrapolating the scientific model results far beyond their range of scientific validity. Such extrapolations are not science. But they can be valuable.

I close with a final example: The Museum of Science and Industry contains another exhibit, on AIDS. Here there are several dice cages, which the visitor spins to represent dangerous behavior--for example, unprotected sexual contacts. One dice cage models an interaction in which the visitor would have a one in six chance of contracting HIV. Is this metaphor objective? No. It presents a particular picture of how things work. Is it immoral? That's for each individual to decide. I think it's quite moral indeed.

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