Chaos & An Unpredictable Tomorrow | Issue 114

Philosophical Science

Peter Saltzstein finds that Chaos Theory yields unexpected philosophical results.

The future is not what it used to be. I mean, an intriguing implication of the branch of mathematics called *chaos theory* is that the future states of complex dynamical systems such as the weather, the human brain, the stock market, evolution, and history itself, are not what we once thought them to be. Specifically, chaos theory suggests that the behavior of complex systems can follow laws and yet their future states remain in principle *unpredictable*. The behavior of complex systems is exquisitely sensitive to conditions, so that small changes at the start can result in ever larger changes over time. Hence, chaos theory implies that the future is not predictable based on past events, as it used to be thought to be. Or in words that have been attributed to both physicist Niels Bohr and baseball manager Yogi Berra, "Prediction is very difficult, especially about the future."

In this vein, we should also take a moment to consider the wisdom of comedian and philosopher *extraordinaire* George Carlin: "No one knows what's next, but everybody does it." This is important as well as funny because it reminds us that the future is not independent of us, following in a straight line from the past, but is constituted by what we and everyone and everything else does, in a hodgepodge mixture of human actions and biological and physical happenings that feed back into each other. Our lived reality is one in which effects exist fleetingly in the process of becoming causes. That there be a ‘what’s next’ is inevitable, but what actually comes next is not thereby predictable, according to chaos theory.

Chaos At Work

Computer simulations show that complex systems are extremely sensitive to initial conditions: that *exactly* where you start determines how the system manifestly unfolds. This is what mathematician and metereologist Edward Lorenz discovered in repeated runs of a computer simulation of weather, in which the starting points of the program varied only by tiny decimal point differences, and yet the consequences for weather outcomes were dramatic. In an academic paper in 1972 he called this the *butterfly effect*, saying that the flapping of a butterfly’s wings in one location could potentially affect the weather patterns in other locations.

The initial conditions of a complex system can never be pinned down accurately enough to make precise predictions about its behavior. The measurements can never in principle be accurate enough. Compare the situation to a number line. Imagine taking even the sharpest of probes and using it to pinpoint a place on the line. Since a number line is continuous, with there being no place on the line that is not further divisible into increasingly fine numbers, the area pinpointed on the number line would reflect the size of the probe not a discrete point. Similarily, determining the initial conditions of a natural complex system will always depend on the accuracy of the measuring instruments used, and they can never be sharp enough for absolute accuracy. We might wonder whether the behavior of a complex system could indeed be so sensitive as to depend on the behavior of a single subatomic particle. Consider Brownian motion. In 1905 Albert Einstein showed that the apparently random motion of pollen grains suspended in water can be accounted for by collisions with individual water molecules. However, while the particles’ movements are subject to Newton’s laws of motion, and thus in principle deterministic, the forces acting on them can never be precisely measured, and so their paths cannot be accurately predicted.

Of course, for most purposes, approximations are good enough. Temperature, for example, is a good approximation of the energy of ambient air molecules. So when it’s 75 degrees outside, I know I won’t need a jacket (unless it’s raining). But air temperature is an average over the variety of energies of the surrounding air molecules, and although the average is all I need to determine whether to wear a jacket, averages can obscure differences in the motions of individual molecules that might be significant in the behavior of a chaos-driven system such as the weather.

Further complicating the situation, as a complex system evolves over time, each iteration of the system – each of the system’s cycles or outputs – provides a new condition that feeds back into the system. This is what J.A. Scott Kelso in *Dynamic Patterns* (1995) refers to as 'circular causation'. We are only now coming to see that many significant natural processes, such as those involved in climate change, do not proceed in a linear fashion, but instead turn in upon themselves, amplifying or dampening their own effects, and redirecting themselves. Each new iteration sets the context for the next iteration. New phenomena may be created.

A good illustration of circular causation is given in Iain McGilchrist's account of the brain as complex system:

> "Events anywhere in the brain are connected to, and potentially have consequences for, other regions, which may respond to, propagate, enhance or develop that initial event, or alternatively redress it in some way, inhibit it, or strive to re-establish equilibrium. There are no bits, only networks, an almost infinite array of pathways" (*The Master and His Emissary*, 2010).

Indeed, the interactions between the parts within a complex system can occur at different levels within the system, creating multi-level relationships of great sensitivity to each other. Consider Enrico Coen's account of the human respiratory system:

> "Our ability to breathe depends on the interplay between our nervous system, muscles, skeleton, and lungs. The function of our lungs depends on the composition of the mucus that lines its walls. The composition of the mucus depends on the proteins that transport negatively charged chloride ions. Changes in just one element of the integrated system can have disastrous consequences. Patients with cystic fibrosis have difficulty breathing because they carry a mutation in the gene needed for chloride transport. It only takes one change out of the three billion base pairs in our genome to cause the disease. The functioning of every individual depends on the integration of many different components" (*Cells to Civilization*, 2012).

The Unforeseen Death of Predictability

Why are we tempted to think that we're heading for a set future? Let me suggest that we are tempted because things around us are not random but have a regular pattern. Day follows night; one season follows another; an object at rest tends to stay at rest, and an object in motion tends to stay in motion. Our world has what the mathematician John Casti, in his book *Complexification* (1994) calls 'structural stability' – a stability which makes life on this planet possible, and which confers a good degree of predictability. More specifically, we have found that for one thing to happen, something else must happen before it in a chain of events. This is standard cause and effect. Thus it is tempting to see inevitability to the course of events. In philosophy this view is known as *determinism*: we may not *know* the future, but the future will nevertheless follow in lockstep as the outcome of a chain of events, with one thing mechanically bringing about another thing. After all, a few minutes after putting bread in a toaster and turning the toaster on, I can reliably predict that I will soon have nice warm toast.

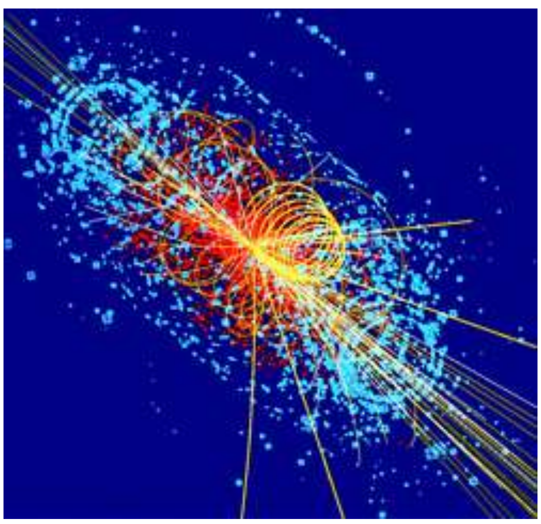
Newton's laws of motion represent a triumph in predicting the future based on the past. The Newtonian perspective views the world as a complicated system like a machine. Specifically, the paradigm is a clock. Newton's laws can be used to make some impressive predictions. They did get us to the Moon, after all.

It's no surprise that for much of human history observed regularities made people believe that the world was the result of an intelligent designer, and that he, she, or it organized the world in a meaningful way, and preordained the fate of everything starting from an initial act of divine creation. After all, it was reasoned, if we live in a clockwork universe, it would seem to require the existence of a clock-maker. Even today science tends to proceed on the assumption that with deeper research, more precise measurements, and more powerful mathematics, regular, predictable patterns will be discovered in those areas where regularity and predictability are not yet readily apparent. Indeed, as Dr David Kernick notes, in the past science has often viewed predictive limitations “as data or processing inadequacies, omissions, bias, or randomness” (*Complexity and Healthcare Organizations*, 2004).

Einstein famously quipped, “God does not play dice with the universe.” However, electrons, it appears, never met Einstein’s non-gambling God, since, like all subatomic particles, electrons appear to be able to travel every possible path between here and there, and it seems entirely random where they end up. The path of an electron is best understood as a matter of probability, not deterministic certainty. Sub-atomic particles, it appears, do indeed play dice, in the very active casino down at the micro level of reality. This is the first element of absolute unpredictability to spoil our confidence in the world being a predictable mechanism.

An interesting philosophical consequence of chaos theory is that it creates a second crack in the notion of a regular, predictable universe, but now at the level of our everyday experience. In the past we expected causation to result in repeatability, and repeatability to result in predictability. But chaos theory tells us that since complex dynamic systems are exquisitely sensitive to initial conditions, any attempt to perform repeated runs of such a system will be stymied if there is even the tiniest difference in the starting conditions of the system. Thus while one thing still follows another, this does not mean the result will be the same, even if the future is determined by the past.

History Is Mystery



Chaotic quantum collisions
Collisions © Julian Bunn/CERN/Harvey Newman/Caltech

We can also no longer view history as merely “one damn fact after another,” as Henry Ford is reputed to have called it. That the unfolding of complex systems depends on sensitivity to their initial conditions means that history may be no better known than the future. Since past events are themselves the result of chaotic behavior, their succession is going to be just as difficult to reconstruct as the future is to construct. As the poet Paul Valery puts it: “the difficulty of reconstructing the past, even the recent past, is altogether comparable to that of constructing the future, even the near future; or rather, they are the same difficulty. The prophet is in the same boat as the historian" (*Crisis of the Mind*, First Letter, 1919).

Not only is history difficult to reconstruct, then, its complexity makes counterfactuals – or in common parlance, 'what ifs' – even more of a stretch to speculate on. Historians, philosophers, and we regular folks ask ourselves, "What if such-and-such had happened instead?" Take the counterfactual scenario, "What if JFK had not been killed?" It is claimed by some historians that President Kennedy was very wary of committing more than advisors to South Vietnam during the early 1960s. Had he lived and resolved that American troops would not be used in a war in Vietnam, could America's Vietnam War have been prevented? And suppose Kennedy would have kept the U.S. out of war, what other events would have resulted? How could we tell? We don't even know what combination of events would have been necessary for him to have lived, let alone their probability of occurring. It's too easy to suggest that all he had to do was avoid the initial condition of being in Dallas on that fateful day. For what would have been involved in avoiding Dallas then; and what would have been the consequences of *that* for later history? Furthermore, even if Kennedy had not been killed, any policy he might have tried to adopt toward Vietnam would have been subject to strong countervailing forces, such as whether he would be reelected; whether he could count on the support of his own party; the interests of the military-industrial complex; concerns about the spread of communism; and the clandestine role of the Kennedy administration and the CIA in first supporting and then removing the South Vietnamese leader Ngo Dinh Diem; and this is to name just a few considerations that might have played a role in whether the Vietnam War would take place. Indeed, President Kennedy's and his advisors' role in supporting the 1963 coup that toppled Diem, has been credited by historian and national security analyst John Prados with making America responsible for the future of Vietnam.

Returning to the bigger picture of life itself, the fact that chaotic systems are extremely sensitive to initial conditions does suggest a certain creativity in nature, since such sensitivity makes possible a sort of 'elbow room', providing space for the results of natural processes to be unique, in the sense of non-repeatable in detail. The late paleontologist Stephen Jay Gould argued that historical contingency in this sense plays as great a part in evolution as does natural selection. In Wonderful Life (1990) he said that if we could turn back evolution on Earth to its beginnings and restart the process with slightly different initial conditions, the organisms on our planet would look radically different.

Historical contingency may also play a role in the very laws of nature. In his book *Time Reborn* (2013), physicist Lee Smolin argues that the laws of nature themselves "emerge from inside the universe and evolve in time with the universe they describe." He quotes favorably the renowned quantum physicists Paul Dirac and Richard Feynman on this point. Dirac notes that "At the beginning of time the laws of Nature were probably very different from what they are now. Thus, we should consider the laws of Nature as continually changing with the epoch, instead of holding uniformly throughout space-time." And Feynman observes that "The only field which has not admitted any evolutionary question is physics. Here are the laws, we say… but how did they get that way, in time?… So, it might turn out that they are not the same [laws] all the time and that there is a historical, evolutionary, question." The universe could be an evolving chaotic system, even down to its laws.

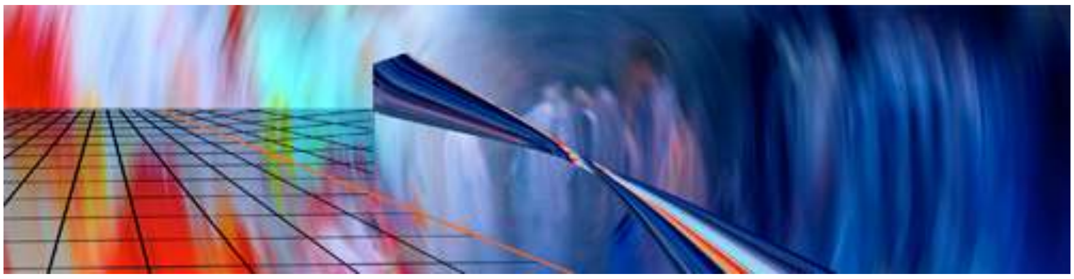
Cosmic Chaos

In her study of the social roots of school shootings, *Rampage* (2005), Katherine Newman warns that "When we are at a loss to explain something [like school shootings], we look for the most proximate or immediate cause" rather than seek to understand the more complex web of causal factors involved. However, chaos theory makes clear that complex system behavior cannot be understood by looking only at the proximate causes of the behavior; one must understand the system.

In fact, their extreme sensitivity to initial conditions means that complex systems are not isolatable but are connected to everything else that happens. This makes setting definitive boundaries between individual complex dynamic systems not simply arbitrary, but perhaps a fiction. So it would seem that in the search for the definitive initial condition for a complex system, one would need to start with the creation of time itself, because the Big Bang represents the discrete point into which all of the universe's matter and energy was compressed. Chaos theory holds that, from that point forward, the smallest changes in events would lead to large differences in the future states of galaxies. (As Einstein's Theory of Relativity makes clear, large masses shape space and time, and are in turn themselves directed in their orbital paths by the distortions in time and space their masses create. So we would need to add in the causal input the galaxies have on each other's development – a very large circle of causation indeed.)

Indeed as we think more deeply about boundaries in nature, we see that boundaries are artificial. Although we have a tendency to reduce systems to their component parts, there is good reason to believe that component parts are not the units of relevance to nature itself, at either the micro or macro level. Nature itself seems rather to be about the relationships and patterns in which the parts stand. Bohr, Heisenberg and the other pioneers of quantum physics showed this to be true at the subatomic level, since the observations we make of quantum phenomena must take into account the observer as an integral part of the results obtained. At the macro level, Einstein has shown that time itself is relative to one's frame of reference. Perhaps, then, macro level phenomena are also ultimately connected as a whole. In their recent book *Heart of Darkness* (2013), Jeremiah Ostriker and Simon Mitton summarize, with dismay, a conclusion reached by Steven Hawking and Richard Ellis: "Local physical laws are determined by the large-scale structure of the universe. This means that cosmology must be understood, not as an entertaining afterthought, but as at the foundation of laboratory physics, which is an unsettling thought." Unsettling for Ostriker and Mitton – but great for the train of my argument, since it supports the idea that seemingly merely local events may not be separable from the greater happenings of the cosmos.

To take this argument one step further, there is evidence that the behavior of sub-atomic particles can be instantaneously connected at unlimited distances – a phenomenon known as *non-local quantum entanglement*. This phenomenon defies the common-sense notion that separation in space and time makes events independent of each other. Einstein described this so-called entanglement disdainfully as "spooky actions at a distance." While many non-scientists have instantaneously jumped to conclusions about what non-locality means and how it can be used – anything from *Star Trek*-like teleportation to speculation about a conscious universe – we could at least responsibly agree that particle entanglement does raise the issue of the extent to which events can be considered independent occurrences, or rather should be seen as the component parts of wholes.



Infinity or Heat Death by Jacqueline Marks, 2016
Please visit fineartamerica.com/profiles/jacqueline-marks

Quantum Consciousness

Finally, what are we to make of the Copenhagen interpretation of quantum physics? According to the Copenhagen interpretation, our very choice of which atomic behavior to observe determines what exists. As Pascual Jordan, one of the founders of quantum theory, succinctly puts it, “Observations not only *disturb* what is measured, they *produce* it.” On this interpretation, a clear boundary does not seem to exist between observers and the observed, between consciousness and the atomic phenomena measured. This conclusion bothered Einstein more than even the random behavior of atoms, because it calls into question the existence of a physical reality apart from the observer. In the words of physicist John Wheeler, “Useful as it is under everyday circumstances to say that the world exists ‘out there’ independent of us, that view can no longer be upheld. There is a strange sense in which this is a ‘participatory universe’.”

All of this raises a most interesting question: Do we need to rethink our notions not only of the future, but of who we are? To the extent that we identify with our consciousness, this seems to mean that each of us is more intimately connected with the world than we ordinarily imagine. But like other complex dynamic systems, what we are is unbounded – even if we can be distinguished from other things for many purposes, such as death, taxes, and marriage. Whether we see our connection to the universe as a whole as metaphysically spooky depends on whether (as in the tale of the blind monks) we characterize the elephant by feeling its individual parts; or instead we see that the parts have arisen in relationship to each other and to the greater environment as a whole, and so can identify the whole thing.

Clearly, chaos theory has uncovered powerful natural processes that we’re only beginning to understand. So, what are we to conclude about the future? Given chaos theory’s contention that complex systems act deterministically but are not thereby predictable, we can say that soothsayers and all such pundits are overpaid! But to be serious, there is a sense in which the future is open. Since complex systems are extremely sensitive to initial conditions, to circular feedback, and to interactions with other complex systems, what is going to happen in the world seems to depend on how all the world’s complex systems behave from moment to moment. The future, then, is self-organized, but to no particular end, purpose, or plan.

A student about to conduct a science experiment once asked his professor, “What’s supposed to happen in this experiment?” expecting, as students do, a predetermined answer. The wise professor replied, “What’s supposed to happen is what happens.” Sounds like a good account of the future to me.

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