A Brief History of Emergence

Frederick Turner, Robert Stern, and Roger F. Malina

THE CASCADING CRISES OF OUR times—climate change, pandemic, mass extinctions, a major war, political chaos, ideological conflict, a profound questioning of truth itself, the descent of the social media into rival righteous mobs, to name a few—require a better framework of understanding. Things have not just changed: change has *accelerated* on all fronts. Are all these crises just a coincidence, or are they actually symptoms, or byproducts, of some deeper process? In many academic disciplines, new models of how things happen are offered, that share a crucial insight into the nature of change. Disciplinary boundaries have often hindered researchers and analysts in different fields from seeing parallel developments in the new ideas cooked up next door. All of these changes and crises are best understood as due to a process often called "emergence," though other terms have been proposed. We suggest that constant change, resulting in periodic crisis, is a feature, not a bug, of the world's operating system; that emergence is that system; and that relief from rapid change is impossible unless or until civilization completely collapses. We have to live with it. But to live with it, we must know what emergence is, and its history in the evolution of the world.

Emergence is the propensity for any high energy, far-from-equilibrium system to self-organize in ways that cannot be predicted from knowing its individual components.[1] Emergence is closely related to self-organization and complexity, and is synonymous with evolution. Spiral galaxies, hydrothermal systems, animals, ecosystems, oceanic currents and tides, hurricanes, civilizations, political systems, economies, and war are some of the many examples of emergent phenomena, in which low-level rules give rise to higher-level complexity. Entirely new properties and behaviors "emerge," without direction and with characteristics that cannot be predicted from knowledge of their constituents alone. The whole is truly greater than the sum of its parts. In a book-length survey, H. L. Morowitz outlines the emergence of 28 phenomena, beginning with the Big Bang and ending with civilization.[2] There is no theory of emergence; our conceptualization of it is itself emergent.

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1 See R. Ablowitz, "The Theory of Emergence," *Philosophy of Science* 6 (1939), 1-16; and D. Pines, "Emergence: A unifying theme for 21st Century Science," *Foundations and Frontiers of Complexity* 28:2 (2014), medium.com/sfi-30-foundations-frontiers/emergence-a- unifying-theme-for-21st-century-science-4324ac0f951e.

2 H. L. Morowitz, *How the World Became Complex: The Emergence of Everything* (Oxford University Press, 2002).

Reductionist logical positivism conflicts with the very nature of emergent phenomena.

The biggest emergence is the universe itself, as which and from which everything emerged and is emerging. Within the universe, three emergences in particular stand out: first is the emergence of matter, stars, galaxies, and the elements. Second is the emergence of life and the evolution of ecosystems. Third is the emergence of human civilization, culture, and science. Let's follow this river of emergence from the beginning.

Out of nothing, about 13.8 billion years ago, emerged pure energy, which combined into charged particles shortly afterwards. This was the "Big Bang." Charged particles in turn combined to make the lightest atoms, hydrogen and helium; this gas collapsed into molecular clouds.
Mass concentrated increasingly and at fractal scales, leading to galaxies filled with stars of hydrogen and helium. No Earth-like planet could exist at this time, because the heavier elements like silicon and oxygen and magnesium needed for rocks and water didn't yet exist; they were yet to be made. The great pressures in star cores forged heavier and heavier elements up to element 56, iron. Elements heavier than iron were created during supernovae, when the more massive stars collapsed, jamming more neutrons into atomic nuclei. Collapsing stars spectacularly exploded, each time creating a new molecular cloud, each cloud collapsing into new stars and new planetary system with more heavy atoms than before. Molecular clouds formed, coalesced, collapsed into stars and planets; star bellies created heavier atoms and large stars exploded, repeating the cycle again and again. About 4.5 billion years ago, one of these clouds formed from the ashes of a supernova in an outer arm of the Milky Way galaxy. It was our solar nebula, which began spinning like a flattened top around a new star, our sun.[3]

Out of this spinning cloud of gas and dust condensed the earth, the planets, their moons, and all of the materials we use today. Incredibly, we have samples of this primitive concentrate in the form of meteorites, which land on earth every so often. This meteorite-stuff made all the planets and moons. The planets closest to the sun were rocky, unbelievably hot, and inhospitable, and the ones farther away were gassy or icy giants; all were constantly being bombarded by meteorites large and small. One of these rocky planets—our Earth—was a "Goldilocks planet" —far enough away from the sun that liquid water could persist on its surface, and big enough that its gravity could hold on to its water and atmosphere. We might add some other constraints of the same kind: the right axial tilt of the planet, the right period and kind of meteorite bombardment, a big moon to stir things up and create a range of conditions, the right mix of elements in the crust and mantle, et cetera.

Earth's surface water—its oceans—fostered the second great emergence—life. Life started early in earth's history—maybe 4 billion years ago—and started simply. Somehow a microscopic self-enclosed capsule began to take energy from chemicals in seawater to keep itself going—the first metabolism—and a short strand of

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3 This history ignores the 95% of the universe that did not participate (except for its mass) in the emergent process of physical evolution: the dark energy and dark matter that remained behind as the 5% went on to its extraordinary destiny. Perhaps we can learn from what dark energy and dark mass do not do, and thus what it is about the light-emitting minority that leads to emergence.

RNA that could replicate itself came into being. Simple bacteria and other single celled organisms called archea were the only life forms on the planet for three billion years. One of these single-celled organisms figured out how to use sunlight to turn water and carbon dioxide into food plus a dangerous waste gas: oxygen. Oxygen was poison to the organisms that existed then, but there wasn't much of it at first. With time, lifeforms that could use the extraordinary chemical power of oxygen came into being. Individual cells evolved to cooperate in multi-cellular organisms. From this point on, the distinction between lifeforms that use sunlight to create food—plants—and those that eat them—animals—became greater and greater. Animals evolved to eat and avoid being eaten and plants evolved to better capture sunlight, nutrients, and water and to avoid being eaten.

Single-celled organisms got bigger and more complicated, but it wasn't until about 800 million years ago that multicellular organisms with specialized functions and advanced sensory organs appeared. These animals proliferated in the sea and on the shallow seafloor, diversifying into the thirteen basic body-plans that persist today, from sponges to chordates. One of these chordates—a primitive worm—evolved into fish, some of which crawled out of the sea after a few hundred million years and began to live on land: first amphibians, then reptiles, and mammals. One group of reptiles began to fly and became birds. Other earth systems were co-emerging with life, most importantly the way the hot earth interior convected. Plate tectonics emerged, affecting the distribution of land and sea as well as climate like nothing before.

Species evolved to exploit the new niches that were being opened by the continued pressure to increase and multiply, built into the multiplicative habit of the DNA molecule. Ecosystems emerged from interactions between plants, animals, Earth's watery skin and climate. Plants and animals colonized land, making soil.
While individual species slowly adapted, their interactions with myriad other, also-changing species changed and ecosystems co-emerged. Periodic extinctions wiped out many species, creating opportunities for new species to evolve. After about 350 million years of evolving on the land, a remarkable animal—human beings—came into being, leading to the third great emergence: civilization.

What triggered the third great emergence was the combined result of the human species' uniquely powerful communication and tool-making skills. Maybe our civilization needed several other rare "Goldilocks" conditions to happen, plate tectonics being one, to have just the right mixture of stability, gradual change, and sudden change.

It was as if the planet had provided a niche for an efficient biped with a good temperature control system, spare forelimbs suitable to for climbing and then manipulating, a large brain adapted to respond to ecological constraints but also for complex social interaction, excellent binocular vision, enhanced longevity, long infancy, transformative adolescence, and an otolaryngeal system capable of a wide waveband of expression and communication. This was a basin of attraction into which one group of ape lineages eventually found its way.[4]
A threshold of emergence had been

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4 The distinction between a basin of attraction and a niche is between a broad term and a narrow one. A basin of attraction is a phenomenon that is characteristic of any field of varying probabilities, ranging from math and physics through biology and economics. A niche is a basin of attraction in a living landscape. In both cases, the general and the specific, the terms imply an assumption that there can be a mutual forcing between the basin and its occupants, between the ecosystemic niche and its dwellers.

gradually approached, and then crossed with enormous and instant consequences.

In what geologists would call a blink of an eye, the surface and biosphere of the planet were transformed. Language for knowing and communicating came to dominate the physical world it named. Agriculture led to extra food, which allowed for larger families and concentrations of people in villages, then towns. Townspeople began to develop special skills. Cities emerged in river valleys where agriculture was especially productive, often with a characteristic social hierarchy that reconciled in one way or another the conflicting pulls of group and individual interests, the efficiency of authority versus the creativity of freedom, the regulation of the law against the productivity of the market. That dynamism had its characteristic architectural expression in the pyramid or raised platform, its slope and relative mass nicely expressing the degree of specialization, power, consent, and coercion in each society. Religions emerged as these talented apes tried to explain where all this came from, what was expected of people, and what happens to us when we die.

We learned how to find new energy sources: fire, slaves, animals, and wind at first; then coal, oil, and electricity. Technology, mathematics, and scientific knowledge flourished. We began refining metals and making new materials. Money was invented, first bits of gold and silver, then paper, then plastic, and eventually zeroes and ones on a computer. The night sky was scrutinized for what it could tell us about time and direction. Markets and forms of ownership required laws to regulate them, and specialists to enforce and interpret the law. Writing was invented to record transactions, rituals, stories, heritage, law, and history. Every civilization created or was created by a grand story, an epic, that would include in its narrative the characteristic conflicts and various group interests of its constituent clans and tribes. Those epics often became the basis of the region's religion. Trade between city-states also resulted in sharing of new plants, tools, materials, and techniques. Regions with different languages and cultures unified into nations and empires. War became increasingly deadly. We began to explore other lands, then the oceans, then space.

This summary implies that the density of significant changes (as opposed to mere stasis, cyclic repetition, or chaotic violence) increases with time. More new stuff gets packed into each millennium, century, year and day, partly because all previous forms of change don't cease, even as they are subsumed into new forms of change such as ecosystems, sociobiological evolution, economics, sociopolitical interaction, and culture. So brief summaries get harder and harder, the closer we get to today.

But human culture and its crystallization as civilization were certainly aware of the processes of emergence that surrounded and included them. They named those very forces. The small ones they called spirits (literally, "breaths"), and the big ones they called gods—or deities, from an Indo-European root sounding like "dewos" (literally, "shining"). An ecosystem such as a river, a self-organizing weather phenomenon such as a storm or hurricane, an animal species, an autocatalytic human system such as language, the marketplace, the system of motherhood, the system of political power—even a great hero or heroine, if their actions were sufficiently original—each of these could be a god.

Paradoxically, if we discard any vocabulary for talking about such emergent entities, and dispense with the respect, poetry, mysticism and communal celebration that recognizes them, we also dispense with most of the "non-western" culture that, for both political and moral reasons, we need to include in our worldview. The inspiration that built and is restoring Notre Dame de Paris, the fertile divine stories that generated the Taj Mahal and Mozart's Requiem, and the Balinese temple culture that points the way to a sustainable ecological future, are examples of the "shining," "breathing" forces that we recognize in our experience of the world's continuing evolution. Poets find it hard not to celebrate those larger systems, systems that we cannot fully embrace because they embrace us.

Virtually all religious art, especially that of creation myths, depicts emergence as imagined by peoples with a pre-rationalist (not pre-rational) vocabulary. We enlightened Westerners are actually *rediscovering* emergence after three centuries of rationalist determinism, the thermodynamic idea of the clockwork universe running down through the increase of disorder. Our culture's present yearning for other religious ideas, rituals, meditative practices, etc, is an implicit rejection of the Platonized religion of the Enlightenment. But our artists and poets—Sandro Botticelli, William Blake, Goethe, and Gauguin are good examples—never bought into the clockwork.

Browsing through the multifarious visual imagery of the world's religions, one notices many forms of emergence: the emergence of consciousness or personality out of an inanimate object; the emergence of a cosmos out of an explosive center; the transformation of an adept's mind in a state of contemplation; the emergence of meaning out of a script or glyph or ikon; the integrity of an object in which the whole is greater than the sum of its parts; the mandala, which presents a diminishing or increasing series of figure-ground reversals; fractal self-similarity or scaling, implying a kind of recursive process of emergence now clarified by Benoit Mandelbrot; transformation, as in the theriomorphic images of divinities or human ritual practitioners; branched candelabra resembling Darwin's early drawing of the branching tree of species; the World Tree as is found in many cultures—Yggdrasil, the Tree of Life, the Mayan Ceiba, the Hindu Ashvattha and Buddhist Bodhi—symbolizing the emergence of the new from the old, of the many from the one. In the parable-poem of Jesus of Nazareth, the kingdom of heaven is like a mustard seed, whose very principle is emergence. (Sad how these dynamic playful images of emergence often gave rise over time to ossified institutions and systems of compulsory theology!)

Postmodern science, with its interest in systems, emergence, and wholes that are greater than the sum of their parts, is finally beginning to put some solid foundations under the intuitive recognitions that constituted humanity's ancient lore of spirits. One key concept, auto-poesis, is well summarized by R. Rogowski:

> *Autopoiesis describes the capacity of an entity to reproduce itself. As a concept it was first introduced in theoretical biology to explain cognition and the essence of life (see Maturana and Varela 1980, 1987) and was then further developed in general systems theory (for example, von Förster 1984). It has been widely applied in mathematics, in the study of cognition, and in studies of the nervous system as well as in information systems, cognitive science, and artificial intelligence (see Mingers 1995).*[5]

One key feature of auto-poesis is that it arises from interactions between small elements of a system and is rarely part of any top-down strategic planning process. In

5 International Encyclopedia of the Social & Behavioral Sciences, 2001; www.sciencedirect.com/referencework/9780080430768/international-encyclopedia-of-the-social-and-behavioral-sciences.

human and animal communities, individual agency, the possession of control over actions and their consequences, is essential. Without a sense of agency at the lower levels of a social system, it is unlikely that desirable phenomena will emerge. In this sense, an auto-poetic system is more like a market or an ecology than a dictatorship or a monoculture.

Before the emergence of the science of complex systems, cybernetics—the science of control and communications in animals and machines—laid out a number of fundamental premises. A triad of essential principles may be a useful starting point. They are purpose, context, and feedback. These work something like a musical trio. For instance, in an ecosystem or an orchestra, the purpose of a species is to reproduce itself, while the purpose of a performer is to help create a musical piece. The context of an ecosystem is its geology and climate; the context of an orchestra is the aesthetic and economic world of musical performance. The feedback of an ecosystem is its survival, flourishing, or decline in abundance. The feedback of an orchestra is the attention, applause, and return of its audience.

Once a reflective observer enters a cybernetic system, a "fourth order" emerges. Summarizing its principles, fourth order cybernetics considers what happens when a system redefines itself. It focuses on the integration of a system within its larger, co-defining context. Ultimately, fourth order cybernetics is difficult or, perhaps, impossible to conceive—it unavoidably defies certain principles that make sense at the "lower" orders. Fourth order cybernetics acknowledges the complex system's emergent properties of a greater complexity, properties that reduce knowability and predictability. It also implies that a system will "immerge" into its environment, of which it is part. Immergence means "submergence" or "disappearance in, or as if in, a liquid."

The new understandings of the world as emergent demand deep philosophical changes in how we do science, scholarship, and philosophy. For example:

One of the underlying problems in existing academic disciplines has been the tendency of we humans to over-simplify in attempts to make sense of "things" or "phenomena." For instance, to an astronomer, the statement "Is it day or is it night?" oversimplifies the orbital mechanics that lead to gradual changes in light levels and that demand the further question of which time zone the question is asked in. Oversimplification can result from reductionism, formalized as the logical positivism that insists that existing things or states of affairs are definable in terms of directly observable objects, or sense-data.[6]

Reductionist logical positivism conflicts with the very nature of emergent phenomena. In the last century the science of complex systems, and the mathematics of complexity, have also complexified the very notion of "causality." New concepts of sensitive dependence on initial conditions that are by their very nature indeterminate (as popularly imaged in the "butterfly effect") force us to imagine cause not as a single train of events but as a branching tree of possible outcomes, several of which can take place at once and some of which will not happen to be realized though they are as possible as the ones that are. Cause is only fully ascribable after the fact. Auto-poesis sometimes happens with no precursor causalities; very rarely does "A cause B." More often, A causes B, but B is causing C, and C causes A, or A may cause B, if C happened before and D happens somewhere else. The reason why lab

6 "Reductionism," Britannica.com, online at www.britannica.com/topic/reductionism.

experiments are strictly isolated according to scientific protocols is in order to eliminate as many of the causal branches as possible—but the procedure itself makes the result less and less applicable to the messy real world.

This urge to over-simplification is combined with the untheoretical search for "symmetries," when in fact fractality is more common in the world. The success of Newton's theory of gravity has often misled our understanding of causalities that occur in complex systems. Statistical mechanics and quantum mechanics, as early as the 19th century, should have made us aware that focusing on individual atoms, or elements, could lead to falser conclusions than those derived by analyzing the collective thermodynamic behaviors of the individual agents. The simplification of complex information into binary zeroes and ones, that frames the way digital computers operate, means that the error is built into the operating system of our current economy and technological infrastructure. Emergent phenomena are rarely symmetric or right/wrong, left/right.

The postmodern arts, especially those with an environmental concern, are beginning to reflect this correction to the fundamental "operating system" of the world, transcending and partly replacing the Newtonian positivism of our former view. Our understanding of human organizations is being illuminated by agent-based models in game theory with its applications in modeling genetic competition, ecosystems, manufacturing, democratic lawmaking, and markets. In computer science, evolutionary algorithms, where programs compete or cooperate or share code to solve intractable problems, show similar advantages.
Such efficiencies are a nice pragmatic argument for the value of individual freedom, especially in this era, when adherence to collective identities is preferred to the open interaction (competitive/cooperative) of free persons. As universities and colleges begin to absorb the discipline-transcending implications of this succeeding grand narrative, the educational system will have the opportunity to begin a new phase of emergence.[7]

We live in an extraordinarily emergent world, with fundamental changes happening all around us. Is it possible to know what is emerging now, what will emerge next, and how to "steer" some of these emergences? If so, what is the role of the university in sensing, anticipating, and steering emergences? How do we foster the kind of top-down/bottom-up feedback and distributed agency that leads to the emergence of new ideas? A

7 Having provided a theoretical framing on emergence, we are working on observing our university, the University of Texas at Dallas. We are observing and noticing, but not meddling. But the nature of autopoesis is that there is a quantum mechanical observer effect where the act of observations meddles without premeditation. The occasion of this essay by three scholars in widely different fields is a good example of how university administrators can foster the kind of interdisciplinary research that leads to emergence. We would like to thank Nils Roemer, Dean of the Harry W. Bass, Jr. School of Arts, Humanities, and Technology, for his provision of a venue and lunches for the group that composed this piece.