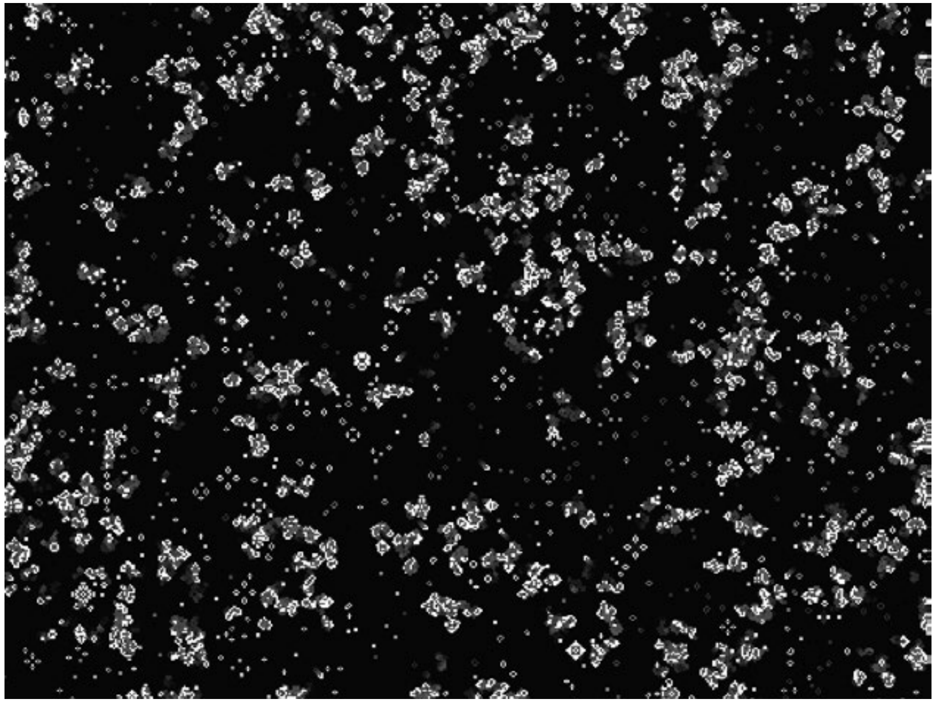

MARE K FISER, CONWAY'S GAME OF LIFE (2013)

SEXUAL PARADOX

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The Sensitivity of Chaos
The Mythology of Chaos

Chaos Gk. kaos abyss – to "yawn" or "gape."
In the Britannica Dictionary chaos is "a condition of utter disorder or confusion as the unformed primal state of the universe" citing either utter disorder and confusion or an unfathomable abyss as definitive. The Concise Oxford speaks of "formless void or great deep of primordial matter, this personified as the oldest of the Gods, utter confusion." The Grollier Encyclopedia notes that in Greek mythology, Chaos was the unorganized state, or void, from which all things arose. Proceeding from time, Chaos eventually formed a huge egg from which there issued Heaven, Earth, and Eros (love). According to Hesiod's Theogeny, Chaos preceded the origin not only of the world, but also of the gods. In Hebrew myth tohu wabohu is the universe without form and void, as in Genesis 1:2:

> *And the earth was without form, and void; and darkness was upon the face of the deep.*

Barbara Walker likens chaos to the undifferentiated raw elements occupying the womb of the world-goddess between destruction and recreation of the universe.

The eternal religious war of light and dark is very much the battle of chaos as the dark "force" and order as the principle of light. This is enacted in diverse myths of origin. In Babylon, Tiamat the feminine primal abyss and ancient mother is overthrown by Marduk the youthful male slayer of chaos, in the name of civic and world order. The same theme extends to classic male combat myth in the cosmic Zoroastrian war of dark and light which became in Jewish and later Christian thought the battle between God and Satan which leads to Armageddon and the unveiling tumult of apocalypse. This opposition between chaos and order is a fundamental misunderstanding of the natural condition.

The Nature of Chaos

Far from being the nemesis of order, or the primal ooze in which order is imposed, chaos is also the genesis of new form. Most complex systems arise from the mutual interaction between chaos and order, through bifurcation – abrupt change of form under continuous underlying transformation. Bifurcation takes its name from "forking" but really applies to all discrete transformation under continuous change. It is typified by the onset of opposing flight or fight reactions, and sudden transformations, such as a wave breaking, or a bubble bursting. Bifurcations can introduce new structure and hence increasing complexity, particularly in transition from chaos to order, in dynamics occurring at the "edge of chaos."

The failure to appreciate the generative nature of chaos has led to it being one of the last scientific frontiers to be discovered, over fifty years after relativity and quantum theory. This has happened because the human will to impose order, even among scientists, is so strong that somehow, in their rush to fit every phenomenon into a mechanistic world view, they ignored the fact that virtually all interesting natural phenomena involve chaos, from the waves on the beach, to the beauty of a forest, from our seemingly regular heartbeat to the patterns of our brain waves in the moment of "eureka"!

Mathematicians distinguish dynamical chaos from a random, or stochastic process, in which critical events are determined by probabilities. Dynamical chaos is not simply disorder or randomness, but an internally unstable process. Chaotic systems may have well-defined dynamical formulations and may even be deterministic as classical systems, but this dynamic is one which doesn't settle down either into equilibrium or any particular periodicity or resonance but wanders erratically over time in an unpredictable way which is deceptively similar to randomness.

Although chaotic systems may be precisely defined by a recursive formula or feedback process, they combine erratic behavior with long-term unpredictability which gives them just the character those seeking orderly prediction might fear. Chaotic bifurcations and a closely-related phenomenon called self-organized criticality are also frequently associated with crises such as cyclones, floods, avalanches, earthquakes and other catastrophic natural interventions.

The essential characteristics, or "axioms", of classical chaos are threefold:

1 *Sensitive dependence:* Lorenz, the father of chaos theory, was first to note the key characteristic of chaos in the "butterfly effect," that the eddies of the wings of a butterfly flying in Hawaii could later become the seed of wild unpredictable fluctuation of a tropical cyclone hitting Fiji. This is "sensitive dependence on initial conditions" in which arbitrarily small changes can later become amplified by a chaotic process or flow into global fluctuations.

2 *Topological mixing:* Any small open region will eventually become mixed over any other. This means the dynamics is very tangled, so any orbit goes almost everywhere in the "phase space" of configurations of the system. This is precisely what happens in an egg-beater. This mixing property sometimes referred to as ergodicity makes the orbits or trajectories of a chaotic process appear random.

3 *Dense periodicities:* Chaotic dynamics is densely permeated with repelling periodic oscillations, often of infinitely many types, making for a great deal of hidden complexity.

Another way of encapsulating the latter two properties is to find a dense orbit single trajectory in the system which comes arbitrarily close to every point in the space of states. These three combine to mean the dynamic is complex, unstable and unpredictable.

Sensitive dependence causes chaotic systems to eventually become fundamentally unpredictable even when they are deterministic. They cannot be accurately computed, since arbitrarily small errors in the computation rapidly escalate into global inaccuracies. This unpredictability is at the core of the difficulties of weather prediction and it also lies at the root of diverse phenomena, from the stock market, to the risk of nuclear holocaust. […]

Chaotic systems arise naturally from positive feedback processes because the positive feedback amplifies small differences, causing the instability we see in the butterfly effect. We shall see shortly that sexual selection is a potentially chaotic positive feedback process, prone to exponential runaway. In this respect it is complementary to the stabilizing ordered constraints imposed by natural selection.

Many apparently periodic phenomena are actually chaotic. The heart beat appears periodic, but the healthy heart is actually tuned by chaos. This allows the brain and heart pacemakers and the heart cells themselves all to keep in feedback resonance with one another and thus respond to changing circumstances. No two heartbeats have exactly the same interval between, but vary in a chaotic manner, similar to a dripping tap. […]

Chaos occurs in a surprising variety of phenomena, many of which appear at the surface to be periodic. Both the heart beat and the dripping of a tap, although apparently periodic have chaotically intermittent variations in the beat period. The rings of Saturn and objects still remaining in the asteroid belt are governed by mode-locking chaos. Only those whose orbital periods have no rational (fractional) relationship remain, because all the fractionally-related orbits have long ago been thrown into the planets by a repeated sling-shot effect. When orbits of two astronomical bodies become mode-locked they interact strongly on a regular basis and the cumulative effect may throw the smaller one out of orbit. The asteroids remaining today are in a belt where the periods do not mode lock and have thus been left behind. More generally a large variety of systems from the weather through earthquakes, movement of the continental plates, chemical and electronic oscillations, secretion of enzymes, fluctuations in the stock market and collision of successive billiard balls, through to brain waves and possibly cognition itself, involve chaos or chaotic phases.

Chaos presents us with new properties of nature which are connected with the development of complexity. A chaotic system contains within it a fractal structure with diverse dynamics, including a dense set of infinitely many periodicities.

The Edge of Chaos and the Complexity of Nature

Out of chaos comes order.
Friedrich Nietzsche

A system which can bifurcate between chaos and order over time can enter a mixing phase of chaos and then retrieve structures hidden within chaos by bifurcating back into order. A chaotic system can likewise be tuned to display its hidden periodicities. Many types of system develop complex evolving structures in the transition region between order and chaos, sometimes called the "edge of chaos." The edge of chaos thus represents the region of sexual paradox between chaos and order where complexity becomes emergent.

Nature and evolution are both described as complex systems evolving at the edge of chaos. Many of the most beautiful aspects of nature arise from their fractal structures and textures. Climax forests are chaotic systems, both in terms of their species diversity and their fluctuating population dynamics. Climax forest also displays a fractal dynamic which is central to its diversity. Natural disturbances from fire and flood, wind and storm damage, to large falling trees are fractal disturbances to which diverse species become adapted in disseminating seed in an ever more complex arrangement of species diversity. The forest

is colonized in up to five strata from the top canopy to the floor each with their own ecosystemic complexity.

Both plants and animals are derived from fractal algorithms in nature and it is from these fractal algorithms that most of our understanding of form and diversity in nature comes. Evolution and its increasing complexity is a central instance of edge-of-chaos dynamics, as is our dynamical brain state, in both perception and problem-solving, especially when perceiving the chaotic diversity of nature itself for which we are highly adapted. It is the very sensitive dependence of chaos which ensures the brain remains completely adaptable to arbitrarily small differences.

An intriguing illustration of frozen chaos permeating biological organisms is the incidence of the golden mean as a ratio or angle in both animal and plant form. The twin spirals observed in plant forms, including the pineapple, pine cones, sunflowers and cacti occur at the golden mean angle 2p/g and generally have two related Fibonacci numbers. This prevents any ordered pattern of mode-locking which would prevent the seeds of the sunflower packing together properly.

Similarly many human proportions, from successive digit bones, the relative distance from the navel to the head and feet, the widths of successive incisors and the nose, mouth and eyes all conform to the golden mean. This is the last, most irrational number to submit to mode locking, as do the orbits of the remaining asteroids in relation to the orbit of Jupiter. Mode locking can also be seen in the 13 arms of the Mandelbrot portion above, where the dynamic is making 1/13 of a revolution.

The lynx is a species with regularly, yet erratically oscillating numbers. It was once believed that lynxes were partners in a dynamically unstable association with their main prey, the snowshoe hare. Recently it has been recognized that the cycle is driven by the interaction between hares and their food plants, with the lynxes being carried along more or less passively by changes in the abundance of hares.

In addition to this, the potentially chaotic population dynamics we have seen in the logistic function is displayed in many natural populations making population dynamics unstable from season to season and sensitively dependent on changes in the environment. For this reason, we have to be very careful when considering the major impacts we are making on natural ecosystems, lest chaos and bifurcation compound the problems we initiate.

It is important to note that population dynamics may cause paradoxical situations to arise. For example, we usually think of a predator-prey relationship as exploitative. However a predator acts to reduce the growth rate of a population and thus protects it from boom and bust population crisis in which the prey multiplies so fast that it eats all the available food and dies *en masse* through starvation. Thus, predator and prey are caught in a kind of prisoner's dilemma relationship which is both destructive and protective at the same time.

Similar considerations apply to parasites and hosts. A central development of this dynamical relationship we shall see next is the idea that a prisoner's dilemma genetic "arms race" between parasites and hosts led to sexual evolution to promote genetic variety and hence resistance to disease. This mutual adaption arms race thus required each of the competing organisms to become capable of sexual recombination to survive the others changes.

Once sexuality became established, sexual selection began to become a fundamental driving force complementary to natural selection. Because natural selection

tends to operate as environmental or inter-species constraints on survival it is both stable and predominantly a negative feedback. In addition, the vast majority of mutations are deleterious.

The peacock's tail illustrates how sexual selection can become a runaway positive feedback process, leading to chaotic unpredictability. Once again, we see hints of Fibonacci golden mean spirals.

Sexual selection has very different characteristics from natural selection. Firstly, it acts not negatively on survival but positively on reproduction. It is also an iterative feedback process with strong positive feedback characteristics. Female reproductive choice acts as a capricious and variable positive feedback which, as it adapts to competing display by becoming more discerning, drives male evolution into potential runaway. Mutual mate selection can also have powerful effects. This leads to sexual selection becoming a potentially chaotic positive feedback force complementing the stabilizing effects of natural selection. These effects are again complemented by the opposing effects of mutations and recombination as genetic modifiers held in check by selection retaining only the viable options.

These effects result in a deep connection between sexual paradox and edge of chaos complexity. Broadly speaking the condition of sexual paradox induces sensitively unstable dynamics which lead to complex systems dynamics at the edge of chaos because the actions of each of the partially opposing forces are frustrated from imposing order. Loss of sexual paradox leads to degeneracy, with a dominant stable process and consequently reduced complexity and reduced viability. Thus, maintaining sexual paradox in evolution and climax diversity in planetary abundance and resilience go hand in hand. Although our gatherer-hunter origins appear to be sexually paradoxical, many aspects of human culture show loss of sexual paradox into degeneracies of patriarchal sexual and natural dominion involving boom and bust and rape of the planet's diversity. These are accompanied by very worrying instances of loss of complexity which need urgent correction to ensure human viability.

A final example of the interdependence of chaos and order in the development of complexity is illustrated in the brain which is not simply a digital computer but displays prominent dynamical behavior, illustrated in the broad-spectrum waves of excitation in the electroencephalogram. This excitation is distributed across the cortex in a manner consistent with parallel distributed processing. Both perception and cognition can be modeled as a transition from a state of chaos representing the unrecognized condition, or the unsolved problem, to a state of order. This process can be modeled as a transition: from high energy chaos, "exploring" its internal space without getting stuck in any "rut"; to order, as the energy is reduced so as to flow towards a minimum, through the capture of the system by a learned attractor in recognition, or the bifurcation of the system to form a new attractor. An insight "eureka" often happens instantaneously, from a state of relative confusion, indicating a single transition from chaos to new order representing the "knowing" state. The chaotic state is thus the progenitor of new order, rather than mere manipulation of order itself. Rather the order imposed by the problem becomes a boundary condition for chaotic resolution. [...]

A famous example of complexity with universal computation is Conway's "game of life" in which a given cell survives if two or three neighbors out of the possible eight are alive and is "born" if precisely three are alive. The "game of life" behaves in a similar manner to a complex dynamical system at the edge of chaos. Here successive states show increasing complexity, including drifters capable of logical computation. Such processes, including 2-D cellular automata simulations of the prisoner's dilemma, may thus become formally undecidable because of the Turing halting problem. Conway's "game of life" is equivalent to a prisoner's dilemma game where cooperation is incited by three cooperating neighbors and the status quo maintained by two, with other values leading to defection.

Unlike the "game of life," consciousness is not bound to a discrete classical logic. Ultimately, through chaotic sensitivity, the conscious brain may be able to access the quantum realm and putative forms of quantum computing and transactional space-time hand-shaking, manifestations of the weird properties of uncertainty, non-locality and entanglement, arising from quantum complementarity between wave and particle aspects. Consciousness appears to use these deeper complementarities within quantum chaos to anticipate potentially incomputable complexities and to affect physical outcomes through the application of conscious will. Here we come to the deepest expression of that complementarity in logical and existential paradox of which chaos and order are also a reflection. This is where sexual paradox enters its quintessence.