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Chance

The Stoic Chrysippus (200 B.C.E.) said that a single uncaused cause could destroy the universe (cosmos), a concern shared by some modern philosophers, for whom reason itself would fail.

> Everything that happens is followed by something else which depends on it by causal necessity. Likewise, everything that happens is preceded by something with which it is causally connected. For nothing exists or has come into being in the cosmos without a cause. The universe will be disrupted and disintegrate into pieces and cease to be a unity functioning as a single system, if any uncaused movement is introduced into it.

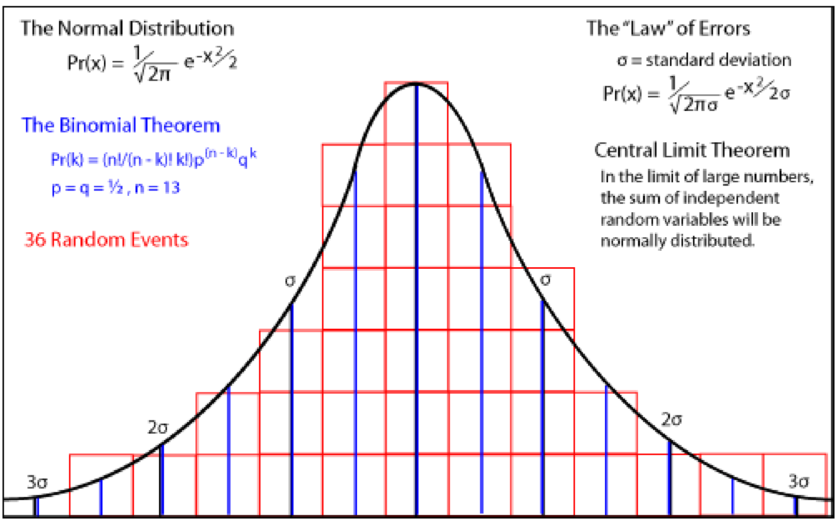
The core idea of chance and indeterminism is closely related to the idea of causality. Indeterminism for some is simply an event without a cause, an uncaused cause or *causa sui* that starts a new causal chain. If we admit some uncaused causes, we can have an adequate causality without the physical necessity of strict determinism - which implies complete predictability of events and only one possible future.

An example of an event that is not strictly caused is one that depends on chance, like the flip of a coin. If the outcome is only probable, not certain, then the event can be said to have been caused by the coin flip, but the head or tails result itself was not predictable. So this “soft” causality, which recognizes prior uncaused events as causes, is undetermined and the result of chance alone.

Even mathematical theorists of games of chance found ways to argue that the chance they described was somehow necessary and chance outcomes were actually determined. The greatest of these, Pierre-Simon Laplace, preferred to call his theory the “calculus of probabilities.” With its connotation of approbation, probability was a more respectable term than chance, with its associations of gambling and lawlessness. For Laplace, the random outcomes were unpredictable only because we lack the detailed information to predict. As did the ancient Stoics, Laplace explained the appearance of chance as the result of human ignorance. He said,

> "The word 'chance,' then expresses only our ignorance of the causes of the phenomena that we observe to occur and to succeed one another in no apparent order."

Decades before Laplace, Abraham de Moivre had discovered the normal distribution (the bell curve) of outcomes for ideal random processes, like the throw of dice. Perfectly random processes produce a regular distribution pattern for many independent trials (the law of large numbers). Inexplicably, the discovery of these regularities in various social phenomena led Laplace and others to conclude that the phenomena were determined, not random. They simply denied chance in the world.



Chance is closely related to the ideas of uncertainty and indeterminacy. Uncertainty today is best known from Werner Heisenberg's principle in quantum mechanics. It states that the exact position and momentum of an atomic particle can only be known within certain (sic) limits. The product of the position uncertainty and the momentum uncertainty is equal to a multiple of Planck's constant of action. Irreducible chance in physical processes was first clearly identified by Albert Einstein in 1916, who saw it as a "weakness in the [quantum] theory."

But real chance and uncertainty had already entered physics fifty years earlier than Heisenberg or Einstein, when Ludwig Boltzmann showed in 1877 that random collisions between atomic particles in a gas could explain the increase in entropy that is the Second Law of Thermodynamics.

In 1866, when Boltzmann first derived Maxwell's velocity distribution of gas particles, he did it assuming that the physical motion of each particle (or atom) was determined exactly by Newton's laws. In 1872, when he showed how his kinetic theory of gases could explain the increase in entropy, he again used strictly deterministic physics. But Boltzmann's former teacher Josef Loschmidt objected to his derivation of the second law. Loschmidt said that if time was reversed, the deterministic laws of classical mechanics require that the entropy would go down, not up.

So in 1877 Boltzmann reformulated his derivation, assuming that each collision of gas particles was not determined, but random. He assumed that the directions and velocities of particles after a collision depended on chance, as long as energy and momentum were conserved. He could then argue that the particles would be located randomly in "phase space," based on the statistical assumption that individual cells of phase space were equally probable. Boltzmann's H-Theorem produced a quantity which would go only up, independent of the time direction. Laws of nature became statistical.

In particular, the macroscopic and phenomenological laws of thermodynamics were now based on a microscopic randomness that Boltzmann later called "molecular disorder." Classical mechanics became "statistical mechanics." Ontological chance appeared to play a role in physics, but it would be forty years before Albert Einstein clearly saw the existence of chance, and it greatly bothered him.

Boltzmann's student Franz S. Exner defended the idea of absolute chance and indeterminism as a hypothesis that could never be ruled out on the basis of observational evidence, just as determinism can never be *proved* by any number of experiments.

Exner did this in his 1908 inaugural lecture at Vienna University as rector (two years after Boltzmann's death), and ten years later in a book written during World War I. But Exner's view was not the standard view. Ever since the eighteenth-century development of the calculus of probabilities, scientists and philosophers assumed that probabilities and statistical phenomena, including social statistics, were completely determined by some as yet undiscovered underlying laws. They thought that our inability to predict individual events was due simply to our ignorance of the details.

In his 1922 inaugural address at the University of Zurich, What Is a Law of Nature?, Erwin Schrödinger said about his teacher,

> "It was the experimental physicist, Franz Exner, who for the first time, in 1919, launched a very acute philosophical criticism against the taken-for-granted manner in which the absolute determinism of molecular processes was accepted by everybody. He came to the conclusion that the assertion of determinism was certainly possible, yet by no means necessary, and when more closely examined not at all very probable.
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> "Exner's assertion amounts to this: It is quite possible that Nature's laws are of thoroughly statistical character. The demand for an absolute law in the background of the statistical law — a demand which at the present day almost everybody considers imperative — goes beyond the reach of experience."

Ironically, just four years later, after developing his continuous and deterministic wave theory of quantum mechanics, Schrödinger would himself "go beyond the reach of experience" searching for deterministic laws underlying the discontinuous, discrete, statistical and probabilistic indeterminism of the Bohr-Heisenberg school, to avoid the implications of absolute chance in quantum mechanics. Planck and Einstein too were repulsed by randomness and chance. "God does not play dice," was Einstein's famous remark.

A major achievement of the Ages of Reason and Enlightenment was to banish absolute chance as unintelligible and atheistic. Newton's Laws provided a powerful example of deterministic laws governing the motions of everything. Surely Leucippus' and Democritus' original insights had been confirmed.

In 1718 Abraham De Moivre wrote a book called *The Doctrine of Chances*. It was very popular among gamblers. In the second edition (1738) he derived the mathematical form of the normal distribution of probabilities, but he denied the reality of chance. Because it implied events that God could not know, he labeled it atheistic.

> Chance, in atheistical writings or discourse, is a sound utterly insignificant: It imports no determination to any mode of existence; nor indeed to existence itself, more than to non existence; it can neither be defined nor understood.

As early as 1784, Immanuel Kant had argued that the regularities in social events from year to year showed that they must be determined by general laws of nature.

> "No matter what conception may form of the freedom of the will in metaphysics, the phenomenal appearances of the will, i.e., human actions, are determined by general laws of nature like any other event of nature...Thus marriages, the consequent births and the deaths, since the free will seems to have such a great influence on them, do not seem to be subject to any law according to which one could calculate their number beforehand. Yet the annual (statistical) tables about them in the major countries show that they occur according to stable natural laws."[1]

In the 1820's, Joseph Fourier noticed that statistics on the number of births, deaths, marriages, suicides, and various crimes in the city of Paris had remarkably stable averages from year to year. The mean values in a "normal distribution" (one that follows the bell curve or "law of errors") of statistics took on the prestige of a social law. Quételet did more than anyone to claim these statistical regularities were evidence of determinism in human affairs.

In 1835, Quételet published his book *Sur l'homme et le développement de ses facultés, ou Essai de physique sociale*. Quételet argued that these regularities in what he called "social physics" prove that individual acts like marriage and suicide must be determined by natural law.

Individuals might think that marriage was their decision, but since the number of total marriages was relatively stable from year

1 *Idea for a Universal History*, 1784

to year, Quételet claimed the individuals were determined to marry. Quételet used Auguste Comte's term "social physics, to describe his discovery of these "laws of human nature," forcing Comte to rename his work "sociologie," a social science with a continuing penchant for finding determinstic laws of human nature.

Quételet's argument for determinism in human events is quite illogical. It appears to go something like this:

- Perfectly random, unpredictable individual events (like the throw of dice in games of chance) show statistical regularities that become more and more certain with more trials (the law of large numbers and the central limit theorem).
- Human events show statistical regularities.
- Therefore, human events are determined.

Quételet might more reasonably have concluded that individual human events are unpredictable and random. Were they determined, they might be expected to show a non-random pattern, perhaps a signature of the Determiner.

Franz Exner was not alone in defending chance long before quantum chance. In the nineteenth century in America, Charles Sanders Peirce coined the term "tychism" for his idea that absolute chance was the first step in three steps to "synechism" or continuity.

Peirce was influenced by the social statisticians, Quételet and the English Thomas Henry Buckle, by French philosophers Charles Renouvier and Alfred Fouilée, who also argued for some absolute chance, by physicists James Clerk Maxwell and Ludwig Boltzmann, but most importantly by Kant and Hegel, who saw things arranged in the philosophical triads that Peirce so loved.

> Quételet and Buckle thought they had established an absolute deterministic law behind all statistical laws. Renouvier and Fouillee introduced chance or indeterminism simply to contrast it with determinism, and to discover some way, usually a dialectical argument like that of Hegel and indeed of Peirce, to reconcile the opposites. Renouvier argues for human freedom, but nowhere explains exactly how chance might contribute to that freedom, other than negating determinism.

There is evidence that Maxwell may have used the normal distribution of Quételet and Buckle's "social physics" as his model for the distribution of molecular velocities in a gas. Boltzmann also was impressed with the distribution of social statistics, and was initially convinced that individual particles must obey strict and deterministic Newtonian laws of motion.

Peirce does not explain much with his Tychism, and with his view that continuity and evolutionary love is supreme, may have had doubts about the importance of chance. Peirce did not propose chance as directly or indirectly providing free will. He never mentions the ancient criticisms that we cannot accept responsibility for chance decisions. He does not really care for chance as the origin of species, preferring a more deterministic and continuous lawful development, under the guidance of evolutionary love. He called Darwinism a "greedy" theory. But Peirce does say clearly, well before Exner, that the observational evidence simply does not establish determinism.

Perhaps better than any other philosopher, Peirce articulated the difference between *a priori* probabilities and *a posteriori* statistics. He knew that probabilities are *a priori* theories and that statistics are *a posteriori* empirical measurements, the results of observations and experiments.

For Peirce, necessity and determinism were merely assumptions. That there is nothing necessary and logically true of the universe, Peirce learned from discussions of the work of Alexander Bain in the famous "Metaphysical Club" of the 1860's, although the ultimate source for the limits on logic was no doubt David Hume's skepticism.

It remained for William James, Peirce's close friend and his lifetime supporter, to assert that chance can provide random unpredictable alternatives from which the will can choose or "determine" one alternative. James was the first thinker to enunciate clearly a two-stage decision process, with chance in a present time of random alternatives, leading to a choice which selects one alternative and transforms an equivocal ambiguous future into an unalterable determined past. There are undetermined alternatives followed by adequately determined choices.

> "The stronghold of the determinist argument is the antipathy to the idea of chance...This notion of alternative possibility, this admission that any one of several things may come to pass is, after all, only a roundabout name for chance...
>
> What is meant by saying that my choice of which way to walk home after the lecture is ambiguous and matter of chance?...It means that both Divinity Avenue and Oxford Street are called but only one, and that one either one, shall be chosen."2

Chance is critically important for the question of free will because strict necessity implies just one possible future. Absolute chance means that the future is fundamentally unpredictable at the levels where chance is dominant. Chance allows alternative futures and the question becomes how the one actual present is realized from these potential alternative futures.

Of those thinkers who have considered these aspects of chance, very few besides William James have also seen the obvious parallel with biological evolution and natural selection, with its microscopic quantum accidents causing variations in the gene pool and macroscopic natural selection of the fittest genes evidenced by their reproductive success.

As we noted in chapter 4, Bertrand Russell thought the law of causation may be *a priori*, a necessity of thought, a category without which science would not be possible. Although he felt some claims for causality might be excessive, Russell was unwilling to give up strict determinism, saying "Where determinism fails, science fails."[3]

In agreement, Henri Poincaré said

> "Every phenomenon, however trifling it be, has a cause, and a mind infinitely powerful and infinitely well-informed concerning the laws of nature could have foreseen it from the beginning of the ages. If a being with such a mind existed, we could play no game of chance with him ; we should always lose. For him, in fact, the word chance would have no meaning, or rather there would be no such thing as chance."

We know that even in a world with microscopic chance, macroscopic objects are determined to an extraordinary degree,

2 "The Dilemma of Determinism," in *The Will to Believe*, 1897, p.155

3 *Determinism and Physics*, p.18

because large objects average over enormous numbers of quantum events which cancel out and produce macroscopic regularity. Newton's laws of motion are deterministic enough to send men to the moon and back. Though if the lunar mission had failed it might have been the consequence of a quantum event in the Apollo computers that was not correctable by their error detection and correction systems.

We call this kind of determinism "adequate determinism." Quantum uncertainty leads some philosophers to fear an undetermined world of chance, one where Chrysippus' imagined collapse into chaos would occur and reason itself would fail us.

The Discovery of Quantum Chance

The scientist Ludwig Boltzmann and the philosopher Charles Sanders Peirce both felt the need for the fundamental existence of chance in the universe, but it was Albert Einstein in 1916 who discovered the microscopic source of ontological chance.

Einstein found that when light is radiated away from a material particle, each individual light quantum must go in a specific direction, even though the average over large numbers of light particles is spherically symmetric (isotropic).

Einstein saw that these quantum events are fundamentally, and we can say metaphysically, statistical.

Einstein found that the direction of the light particle (later called a photon) must be a matter of chance. He noted that Ernest Rutherford had recently found that when a radioactive nucleus decays, the time of the decay appears to be completely random. Rutherford could provide only the probability of decay, the time when half the nuclei would have decayed, the so-called "half-life."

Einstein now realized that both the time and the direction of emission of a photon must be fundamentally a matter of chance.

> It speaks in favor of the theory that the statistical law assumed for [spontaneous] emission is nothing but the Rutherford law of radioactive decay.[4]

4 Einstein, Collected Papers, vol.6, p.216

Here for the first time we have a metaphysical underpinning for the concept of physical possibility, which for centuries was thought to be a matter of human ignorance.

Einstein himself did not like the idea at all. The inability to predict both the time and direction of light particle emissions, said Einstein in 1917, is "a weakness in the theory..., that it leaves time and direction of elementary processes to chance (*Zufall*)."[5] It is only a weakness for Einstein because his "God does not play dice."

Besides carrying away energy $E = h\nu$, the light particle must also carry a momentum $p = h\nu/c$, Einstein reasoned. Conservation of momentum requires that the momentum of the emitted photon will cause an atom to recoil with momentum $h\nu/c$ in the opposite direction. However, the standard theory of spontaneous emission of radiation is that it produces a spherical wave going out in all directions. A classical spherically symmetric wave has no preferred direction. It produces no recoil. Einstein asked:

> Does the molecule receive an impulse when it absorbs or emits the energy ε? For example, let us look at emission from the point of view of classical electrodynamics. When a body emits the radiation ε it suffers a recoil (momentum) ε/c if the entire amount of radiation energy is emitted in the same direction. If, however, the emission is a spatially symmetric process, e.g., a spherical wave, no recoil at all occurs. This alternative also plays a role in the quantum theory of radiation. When a molecule absorbs or emits the energy ε in the form of radiation during the transition between quantum theoretically possible states, then this elementary process can be viewed either as a completely or partially directed one in space, or also as a symmetrical (nondirected) one. *It turns out that we arrive at a theory that is free of contradictions, only if we interpret those elementary processes as completely directed processes.*

If the direction of the photon is random, it is the source for the ontological randomness in the universe. And it is not just for radiation. If a material particle, an electron or atom, recoils randomly whenever it interacts with radiation, this can be the source of Ludwig Boltzmann's "molecular disorder," the reason that mechanics is not classical," but statistical.

5 Einstein, Collected Papers, vol.6, p.216

This can give us a solution to the central problem in statistical physics. The question is how macroscopic *irreversible* behavior can arise if the motions of atoms and molecules are microscopically *reversible*. Reversibility requires that the path information in each atom is preserved duting collisions. We can now say that path information is destroyed in any collison that involves a photon.

In a deterministic univese, information is conserved. Ontological chance not only destroys older information, it creates new information. It was this deep insight that led Einstein to describe quantum mechanics as a statistical theory, if an "incomplete" one.

And this is not the "statistical" of the mathematicians and scientists who hoped for an underlying determinism ensuring macroscopic regularities.

This is quantum, ontological, and metaphysical chance. It is the chance acausality that Heisenberg quantified in his uncertainty principle ten years after Einstein's and twenty-five years after Rutherford's discovery of chance.

Sadly, for some years Einstein led the chorus of deniers who decry quantum jumps and the collapse of the wave function. A significant fraction of working physicists and perhaps most philosophers of science, especially those claiming to explore the "foundations of quantum mechanics," long for the return of classical determinism.

They all have what William James called "antipathy to chance."

> "The stronghold of the determinist argument is the antipathy to the idea of chance...This notion of alternative possibility, this admission that any one of several things may come to pass is, after all, only a roundabout name for chance..."[6]

Without metaphysical chance, there is no metaphysical possibility and the metaphysics of possibility lies at the heart of the possibility of metaphysics.

6 The Dilemma of Determinism," in *The Will to Believe*, 1897, p.155