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The Age of Imagination

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Galileo once said that one cannot understand the universe without comprehending its language: mathematics. Unfortunately, most individuals will approach physical sciences with dread, due in part to the difficulty with speaking the language of the universe, and for this reason may fail to perceive its breathtaking beauty. When we look deeper than the letter of reason, we encounter a flow of imagination that appears to be integral to the cosmos. The Enlightenment of the 18th century was an Age of Reason that deeply shaped our modern society. By following the movement of ideas from classical physics to quantum mechanics, passing by chaos theory and Einstein's special and general relativity, it is argued that a new Enlightenment might be in sight, an *Age of Imagination*, wherein the creatures that we are will consciously re-enter the flow of imagination. This exploration concerns classical physics and its repression of imagination; the difficult emergence of deterministic chaos is viewed as a return of what was left behind, so to speak: the shadow of reason.

> The one-after-another is a bearable prelude to the deeper knowledge of the side-by-side, for this is an incomparably more difficult problem.
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> —C. G. Jung (1970, par. 206)

In this article, I address an important question concerning physical exploration: Is there a place for imagination in the universe? To put the question another way, is imagination a spurious addition to the universe—some kind of dazzling makeup, which, when removed, would leave the universe fundamentally unchanged? Or is imagination integral to the cosmos?

The words *cosmos* and *cosmetic* share the same etymological root in the Greek word *kosmos*, which essentially means *order*. The verb *kosmein* means "to prepare" and also "to adorn, to dress." When using the word *cosmos*, we suggest that, like an attractive woman, the world is carefully ordered, prepared, adorned, and dressed, and we might wonder how this sophisticated order we discover around us came about and delight in the description of its magnificent forms. Physical science is about this: the consideration of the lawful, orderly structure of material things. But, as we will see, modern quantum mechanics increasingly reveals that the cosmos is in the making. To account for reality, we can no longer reduce the future to a recurrence of the past and must also imagine what might be observed in the present. This does not mean that *reason* fails entirely at this point of scientific exploration, only that that reason needs to be supplemented by a coherent form of imagination.

all the comets and other minor bodies were included at once? Might it be that one day, the regular motion of the planets would progressively and irremediably be skewed by small reciprocal gravitational perturbations? Would continual imperceptible gravitational interactions between planets lead to chaos and the destruction of the solar system after a long time? Newton briefly discussed this question in *Opticks* (1704/1952) and came to the surprising conclusion that "blind Fate could never make all the Planets move one and the same way in Orbs concentrick … Such a wonderful Uniformity in the Planetary System must be the Effect of Choice" (p. 402).

The stability of the cosmos and the only way to avoid chaos was to appeal to a *Deus ex machina*, a deliberate divine choice to preserve the stability of the solar system against the blind forces of nature that God Himself had created. The variant of *occasionalism* professed by Newton betrays his doubts that natural philosophy, with its extraordinarily successful mathematical principles, was enough to account for everything in the cosmos. In particular, genuine acts of creation as well as structural stability of organized bodies, like our own physical bodies, should also be the effect of a divine choice.

In the course of the following 150 years, accumulation of detailed astronomical data proved that planets such as Saturn and Jupiter were indeed subject to irregular motions, which raised serious concerns about the stability of the entire system and the possibility that another celestial orb would one day enter into collision with Earth (Laskar, 2012). At the same time, it was still unclear whether Newton's gravitational theory could account for these irregularities, since no scientist knew how to solve Newton's equations of motion for more than two bodies.

This is the context in which Poincaré rediscovered deterministic chaos. The circumstances of this discovery are themselves rather chaotic, as we will see. King Oscar II of Sweden decided to celebrate his sixtieth birthday by sponsoring an international mathematical competition, first announced in the journal *Nature* in 1885. The winner would be awarded a gold medal, as well as a prize of 2,500 Swedish crowns (Gray, 2012, p. 267). The winning submission would also be published in the prestigious *Acta Mathematica*. Four problems were submitted to the sagacity of the best mathematicians in the world, the first one being the problem of the stability of the solar system. Karl Weierstrass and Charles Hermite, two of the best mathematicians of the time, were part of the jury (Gray, p. 267).

Poincaré decided to take part in the competition and submitted the result of his exploration on the question of the stability of the solar system. He limited himself to the case of three bodies: the sun, Jupiter and a little orbiting asteroid. Poincaré started his article by stressing that his results were so incomplete that he hesitated to publish them (Gray, 2012, p. 270). Then he went on to determine the conditions under which stability of the three celestial bodies would be sustained, using mathematical methods he developed to map the trajectories of Jupiter and the asteroid. This method, now called *Poincaré map*, proved so valuable that it is still used in the treatment of chaotic systems. Poincaré's demonstration was a difficult one to follow, even for the esteemed jury members who privately asked him many questions (Gray, p. 277). The final conclusion, which went far beyond any other proof ever elaborated, affirmed without ambiguity that the solar system was indeed stable. Poincaré was declared the winner of the competition and awarded the gold medal and the money.

The article was in the process of being published in *Acta Mathematica*, when a young editor of the journal, a modest mathematician named Edvard Phragmén, pointed to several mistakes in mail exchanges with Poincaré. All the mistakes proved minor, features at once, rather than the exact detail of individual traits. The exact trajectory of heavenly bodies in the solar system was not as useful as grasping a stream of realistic trajectories, differing only by determined minuscule factors, and observing how these factors were amplified over time. The focus is now on imagining how things would be otherwise. This is a movement that Poincaré had initiated, but it took several more decades, after computers began to emerge in the 1950s, to pursue this qualitative road in a systematic way. Then, as the scales fell from the eyes, the new generation of mathematicians began to appreciate the intricate beauty of deterministic chaos—which suddenly was perceived everywhere around us and within us, from the ragged contours of coastlines, mountains, and leaves to complex weather systems; from the beating of our own hearts to the simultaneous firing of neurons in our brains.

This beauty corresponds to a geometry of roughness developed by Benoit Mandelbrot, called *fractal geometry.* The word *fractal*, coined by Mandelbrot, comes from the Latin *frangere*, which means "to break." Mandelbrot speculated that in the Roman mind, *frangere* evoked the action of breaking a stone, since it combined properties of broken stones, irregularity, and fragmentation. Fractals serve to describe "grossly irregular and fragmented facets of nature" (Mandelbrot, 1980, p. 172) and, together with Euclidian shapes such as triangles, circles, and other geometrical figures, they are important symbols in the great book of the universe. Mandelbrot also makes the analogy with numbers and situates fractals between the Euclidian shapes in the same way that fractions and rational numbers lie between whole numbers (p. 172). To get an intuitive image of what this means, we just need to look around us at the cubes, spheres, and other smooth shapes we use to build our homes and cities, and contrast them with complex shapes of trees, root systems, and clouds engineered by nature.

According to British physicist Freeman Dyson, when the mathematicians of the 19th century created their "'gallery of monsters' *akin to the cubist painting and atonal music that were upsetting established standards of taste in the arts at about the same time*," the aim was to prove that mathematics contained more variety than nature. It was to reach the supernatural. However, ironically, "Nature has played a joke on the mathematicians. The 19th-century mathematicians may have been lacking in imagination, but Nature was not. The same pathological structures that the mathematicians invented to break loose from 19th-century naturalism turn out to be inherent in familiar objects all around us" (Mandelbrot, 1977, pp. 3–4).

Wandering through the dark labyrinth of physical reality logically leads to the discovery of an infinite number of transient, irregular forms of being, which should not be viewed in any way as defective or pathological, since they consist of the rational extension of eternal forms. In this strange light, we might regard our individual human life, as short as it is, as rough and fragmentary as it feels, not so much as the corruption of a perfect, blissful state, but as a part of a complex interconnected whole, which includes both human and nonhuman worlds.

Concluding Reflections

Deterministic chaos developed in the shadow of classical science as a fragmented, splintered part of reason that could not (yet) be accepted by our fathers, but now ought to be. "The shadow," C. G. Jung writes, "is a moral problem that challenges the whole ego-personality, for no one can become conscious of the shadow without considerable moral effort" (Jung 1968, par. 14). Unfortunately, most of us still cling to antiquated forms of *occasionalism*, according to which God will always choose to keep our world balanced and stable, even though it is now clear that deterministic chaos set a perpetual flag on the Earth billions of years before the first human existed. How else could we make sense of the fact that we still cannot imagine that the repeated, imperceptible behavior of burning fossil fuels may result in the most destructive outcome on Earth? On a collective level, climate change confronts us with the destructive face of chaos and requires that we look beyond the short-sightedness affecting the reasoning of our fathers.

It might be that Poincaré's error and the way he dealt with it symbolically point to an alternative route that we will need to imagine. Realizing with distress that he was wrong, Poincaré paid back a prize he did not deserve and even put his hand in his pocket to take back the physical evidence of his blindness. Then he swiftly demonstrated the presence of chaos in the heavenly realm. It is already too late to deal with some of the destructive consequences of climate change—many natural species have been obliterated from the face of this planet—but the worst can still be avoided, provided we set our minds to confront the shadow cast by modern societies. This is the moral obligation of our time, which will determine the fate of our civilization.

Returning to the image of the road, deterministic chaos is nothing like the image of a smooth freeway, carefully scraped, graded, and artificially covered with asphalt, which I used to describe classical physics. A better analogy would be a dirty, bumpy road that winds in a nonlinear way according to the landscape. Such a road only differs from its natural surroundings by the repeated passages from which it emerged. Taking the road of chaos demands a slowing down to meet the unexpected as well as careful steering to stay on a safe course. It is a versatile road where we may make constructive encounters, but may also face destructive outcomes.

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