Fractals

by Sophie Cohen Bodenes (English Translation) From ABECEDAIRE DE LA BEAUTE, B42 Editions

From cubes, straight lines, circles, curves, spheres, or other regular polygons, we build skyscrapers, roads, computers, and objects of everyday life. Kandinsky painted elementary forms on a rectangular canvas with perpendicular edges. Atoms, too, are modeled as polyhedra. And yet... classical geometry, as taught in school and defined by Euclid 300 years before Christ, does not correspond to the geometry of nature!

Let us observe the structures that enchant us: coral reefs, the patterns and shapes of shells and animals, trees. Consider the structure of a rock: it is irregular, rough, fragmented in texture. Anyone attempting to draw its outline would approximate it with a continuous line—but that would only be a model, an idealization of the form of objects and matter that surround and constitute us, from the infinitely small to the scale of galaxies, all of which follow fractal geometry.

In 1975, when Mandelbrot introduced this new concept—whose etymology is linked to "fraction, fracture, fragile"—he caused a storm in the scientific world, metaphorically and literally. A tornado is itself a fractal form: like a Russian doll, it repeats a spiral shape at different scales; its parts resemble the whole.

However, fractal and Euclidean geometries are not antithetical. Fractals are simply a better approximation, a model that enriches the geometric representation of natural forms. In this sense, fractals are mathematical objects, like functions or matrices, with their own properties and rules that define whether a figure is fractal or not.

Fractals are also artistic objects, used by Hokusai in his waves, by Leonardo in his turbulence, or by Van Gogh in his clouds. Their scientific properties overlap with artistic expression, opening a window into the quest for universals of beauty. While Euclidean geometry introduces symmetry as a primary rule of beauty, fractals add other properties: self-similarity, repetition, recursion, and scale invariance—all essential to aesthetic experience.

To construct a fractal figure, like a snowflake or a Sierpinski carpet, one begins with a simple figure, such as a triangle. Then, through a recurrent or iterative process, one repeats the same figure at changing scales, creating subfigures within the "beautiful figure"—a process that can repeat infinitely.

It has been scientifically established that the human brain perceives fractal forms as aesthetically pleasing and beautiful (Taylor, ref.). Above all, scale invariance is considered a universal of beauty (Palmer, Schloss & Sammartino, 2013), a property of all fractals. A fractal image can be conceptualized as a "natural image."

In vision science, a major finding in the study of natural image statistics is that their power spectrum is inversely proportional to the square of frequency ($1/f^2$). The slope of this function on a logarithmic scale is -2. The power spectrum of fractal images closely resembles that of natural images. This spectrum shows how intensity is distributed across scales—levels of detail from large to small. Fractals display the same pattern recursively, with decreasing intensity from larger to smaller scales. Their power spectrum is, like that of natural images, a decreasing function of spatial resolution, with a negative slope close to -2.

Furthermore, the theory of efficient coding proposes that natural scenes are optimally encoded by the visual system (Olshausen, ref.). Cognitive science, under the "computational" conception of the brain, sees it as an information-processing machine: sensory input (visual stimulus) is processed by algorithms and produces an output (perception). For example, when we look at a fractal—complex in form—it is projected in 2D on the retina. Retinal neurons process the image by decomposing its components: varied brightness, irregular contours, rough texture. The information is transmitted as action potentials along axons to neural networks. In higher cortical areas, this processing yields object recognition: "this is a fractal figure." Recognition requires prior familiarity with the mathematical object and its features.
Yet, beyond recognition, other outputs are possible—such as aesthetic pleasure ("this fractal is beautiful"). According to neuroaesthetics, Ramachandran called one principle "grouping": decomposed and recombined fractal patterns align with biases of the visual system, becoming optimal stimuli efficiently processed by visual cortex cells. With less redundancy to remove, the system processes the information more fluently and with less cost.
Thus, efficient coding theory (Olshausen, Renoult 2016; Redies 2017) may explain why fractals—like Turing patterns on animal skin or "form constants" (spirals, tunnels, honeycombs in hallucinations)—are perceived as aesthetically pleasing (Cohen-Bodénès & Neri, 2021). The theory of fluency (Renoult 2016) expands on this: forms processed more fluently by the visual system are perceived as more beautiful.
Because fractals are complex and varied, fluency theory suggests beauty is not limited to simple, elementary forms (dots, curves, straight contours) that match receptive fields in the primary visual cortex. Physicist Richard Taylor, a specialist in fractal aesthetics, developed the notion of "fractal fluency." Using box-counting methods to measure fractal dimension, he analyzed Pollock's drip paintings and Escher's tessellations to quantify aesthetic intensity based on fractality (Taylor 1999, 2002, 2006).
But are all fractals equally beautiful, and are they judged similarly by all people? To approach this, we propose conceptualizing fractals as cognitive attractors. Since nature's geometry is fractal, it is conceivable that the brain's geometry—and the architecture of the visual system—is fractal as well (Kiselev 2003, Di Ieva).
There is an intuitive analogy between an attractor in a dynamic physical system (which fractals are) and a cognitive attractor: an aesthetic form that pleases the brain because it matches its structural biases and neuronal architecture. Complexity theory, chaos theory, and an organic (rather than purely genetic) conception of evolution all enter into this reflection.
For example, consider the excitable dynamic system of the skin of a cuttlefish (Sepia officinalis)—a master of camouflage. It encodes visual information from its environment in the optic lobe, transmits this through motor neurons, and activates chromatophores—pigment sacs that expand or contract—producing a range of 40 pattern combinations (dots, squares, curved lines) for camouflage. The cuttlefish's skin is thus a visible dynamic network, akin to a neural network. Laurent compares it to a pixelated screen where we can "read its thoughts."
During courtship, cuttlefish display Turing patterns: zebra-like stripes whose intensity and contrast seduce partners. Waves of color sweep across their skin, corresponding to underlying action potentials. These stabilized Turing patterns may act as attractors in the physical system, while also being judged beautiful—evolutionarily favored by sexual selection.
Spontaneous skin patterns in cuttlefish, analyzed in temporal sequences, also reveal fractal dimensions (Cohen-Bodénès & Neri, 2021). This supports the hypothesis that cuttlefish brains, like human brains, may be fractal in structure and geometry.

CONCLUSION

We have highlighted fractal properties—recursion, scale invariance, self-similarity—as rules of beauty. Recursion, in particular, underlies fractal construction. The human neural code itself may be recursive: the ability to process embedded structures could be an exclusively human cognitive faculty, linked to the evolution of language.
Thus, studying the perception of fractal attractiveness in humans and animals may illuminate whether animal neural codes also include recursive components—as explored, for example, in birdsong research.