

terrae fracti

MORGAN V COURAGE

Euclid's *Elements*, first published in 300 BCE, is the most studied and edited book after the Bible. The definitions, axioms, theorems, and postulates remain unchanged today in study and use in modern practical applications such as biochemical modeling, medical imaging, sequence alignment, and nanotechnology. Euclidean geometry defines integer dimensions using the Pythagorean theorem, pi, and formulas for surface area and volume. The Earth's multi-dimensions cannot be confined to classical geometry - lines, planes, and solids; it is fuzzy, dynamic, and chaotic in the complex numbers and fourth dimension.

“In the whole of science, the whole of mathematics, smoothness was everything. What I did was to open up roughness for investigation.”

– Benoit Mandelbrot

The Development of the Fractal Concept

Describing this continuous non-integer dimension and non-differentiable functions started to formalize as recursion with Richard Dedekind (1888) and continued with Giuseppe Peano's five axioms for positive integers (1891). Louis Pierre Joseph Fatou wrote his thesis on integration of complex function theory setting the groundwork for iterations: the values and all nearby values behave similarly under repeated iterations of the function. Julia Gaston (1918) wrote “Mémoire sur l'itération des fonctions rationnelles” focusing on the iterative properties of a general expression:

$$z^4 + z^3/(z-1) + z^2/(z^3 + 4z^2 + 5) + c$$

The formula for the Julia set is $Z_{n+1} = Z_n^2 + C$ where C is always constant during the generation process and the value of Z_0 varies. Each point of the complex plane, the value of C, is associated with a particular Julia set. This mathematical ingenuity died with Julia until the advent of computing machinery with the ability to visually express the beauty and express the fourth dimension.

In the 1960s, Benoit Mandelbrot, an IBM employee, originated the term fractal to solidify the past

one hundred years of mathematical development in endless self-similarity iterations of equations describing roughness and irregularity on all systems and life on Earth.

The famous Mandelbrot set is graphically represented by something similar to a black beetle and is generated from an algorithm based on Julia's recursive formula: $Z_{n+1} = Z_n^2 + C$. Unlike the Julia set, C is migrated across the plane from the initial point of the iteration process. The points of the complex plane are separated into two categories and the color scheme is denoted by the value of the point.

The formula's starting point is zero and generates what may appear to be random and a somewhat meaningless set of numbers, but the graphic portrayal shows the self-similar reclusiveness over an infinite scale. The formula is a summary of the fourth dimension — the real world that includes an infinite set of fractal dimensions which lie in intervals between zero and the first dimension, the first and second dimension and the second and third dimension. Fractal geometry describes, in algorithms, the non-integer dimensions. Fractal generators are computerized paint-by-numbers, a stimulating combination of math, computations, and art.





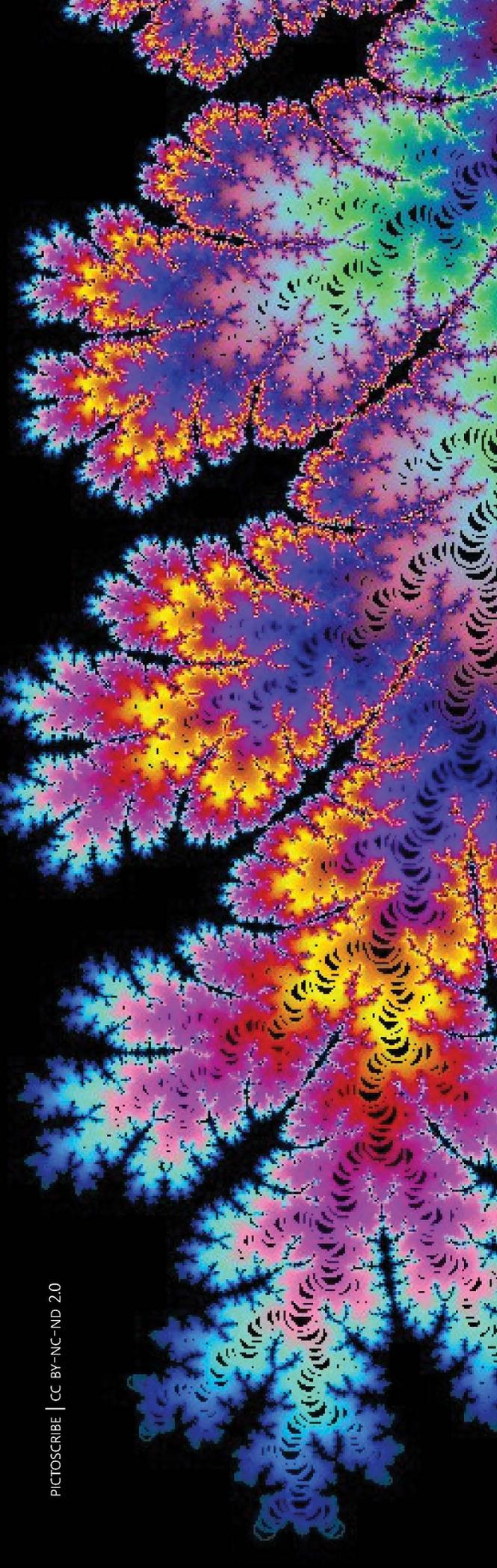
Fractals in Nature

The branches of a deciduous tree stark against the winter sky clearly show the natural fractal pattern: the repetition smaller copies of itself from the trunk to the tips of twigs. This structure with a seasonal and intricate process of photosynthesis serves the purpose of respiration. The leaves on branches absorb carbon dioxide from the air and return oxygen into the atmosphere. Remarkably, a lung's bronchiole tubes and arteries resemble a self-repeating branch pattern whose purpose in the body is also respiration. In reverse to trees, the lungs breathe in oxygen and exhale carbon dioxide. Almost as a reflection in the eyes looking at the trees or in a microscope at lung tissue, this same tree pattern repeats in retinal blood vessels that provide oxygen to the eyes.

Fractals are a natural phenomenon in everything seen and unseen by the unaided eye, ranging from the spectacular to the interesting.

The Miller School of Medicine at the University of Miami is using fractal analysis of the retina to determine the health of the retina's capillary network and provide microvascular changes associated with diseases such as stroke, hypertension and diabetes. A Retinal Functional Imager is used to scan the eyes' capillaries without the use of injecting a dye to highlight the blood vessels to produce clear images. These retinal images are uploaded into a proprietary software developed by Miller School researchers to produce high-resolution, non-invasive capillary perfusion maps (nCPMs), which reveal more information about small vessels. Fractal analysis of the nCPMs may be more effective to determine the health of the retina's capillary network with a natural descrip-





FRACTAL EVENTS

Have you ever heard of
First Fractal Friday?

Well, if not, today is your lucky day!
The first Friday of every month at the
New Mexico Museum of Natural History & Science,
an event known as First Fractal Friday is
hosted by Jonathan Wolfe, PhD.

FRIDAY FRACTAL : showings at 6pm & 7pm.
This is an education show centered around
learning about fractals.

FRACTALS ROCK! : showings at 8pm & 9pm.
This planetarium show is more about zooming
into fractals and music than talk.
This show is so addicting, you will not want to
leave when the show ends!

These shows are so popular, they always sell out.
The museum states their shows have sold out all
286 times! So far their shows have taught over
38,383 children and 28,354 adults!

New Mexico Museum of
Natural History and Science
1801 Mountain Road, NW
Albuquerque NM

Adults \$10
Seniors \$8
Children (3 to 12) \$6

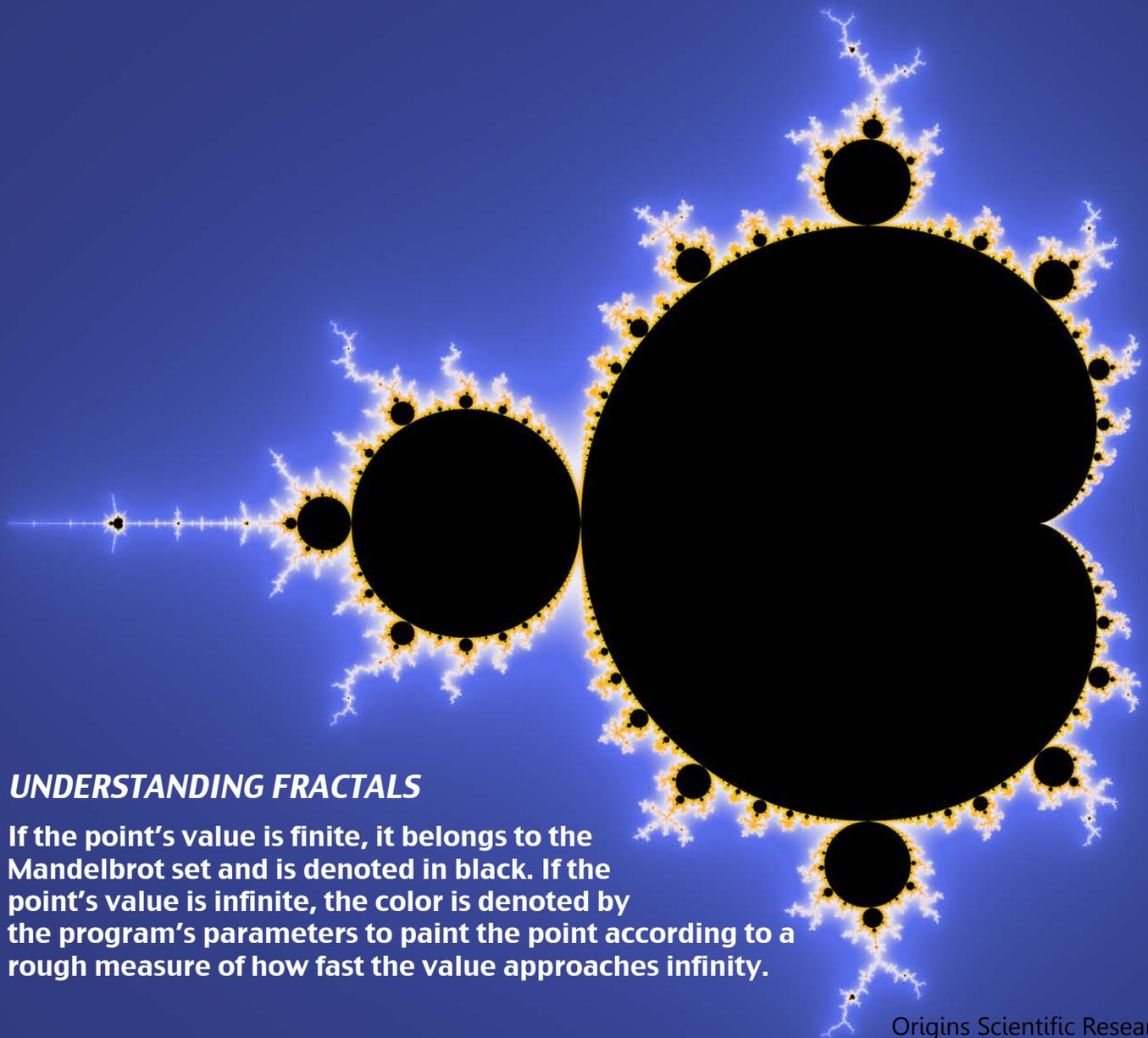
Tickets can be purchased at the
box office or online at MuseumTix.

More info:
www.fractalfoundation.org

tion of the complex branching structure.

The types of fractal analysis include box counting, lacunarity analysis, and multifractal analysis. Differing from fractal art, any of these methods have fractal generating software that set the necessary benchmark patterns needed to assess the outputs. Box counting breaks the data set into consecutive smaller pieces, usually box-shaped, and analyzes the pieces at each smaller scale by use of algorithms that find the optimized way of cutting a pattern to reveal the scaling factor. Lacunarity is a measure of "gaps" in patterns. Difficult to perceive or quantify, lacunarity is calculated with

computer aided methods such as box counting. A multifractal system needs a continuous spectrum of components to describe its dynamics. Datasets are extracted from patterns and then distorted to generate a multifractal spectra that illustrates how scaling varies over the entry dataset. Geophysics, stock market time series, heartbeat dynamics and natural luminosity are all examples of natural multifractal systems. Fractal geometry is the math, or language, that enables the description and understanding of nature, scientific concepts that led and continuing leading to breakthroughs in biology, healthcare, and the process of respiration.



UNDERSTANDING FRACTALS

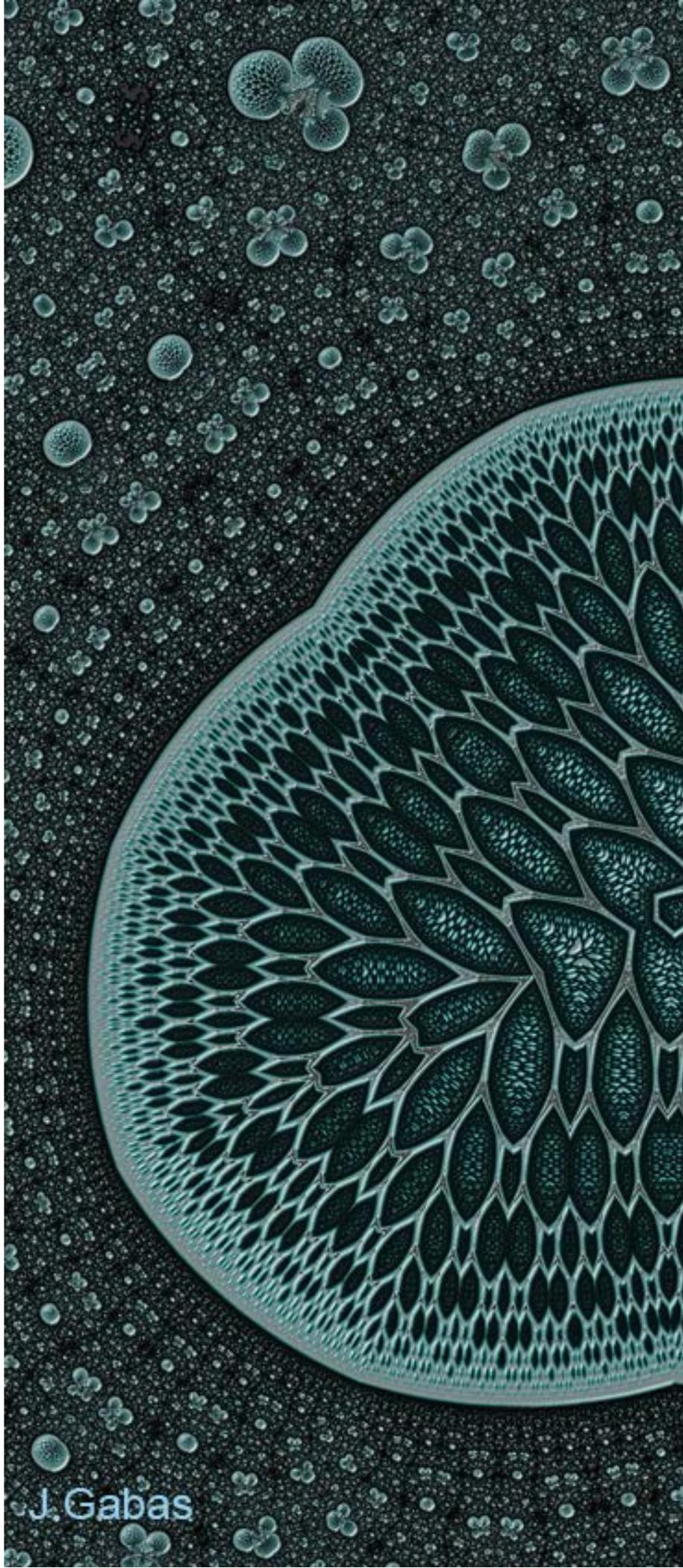
If the point's value is finite, it belongs to the Mandelbrot set and is denoted in black. If the point's value is infinite, the color is denoted by the program's parameters to paint the point according to a rough measure of how fast the value approaches infinity.

Physiologic Fractals

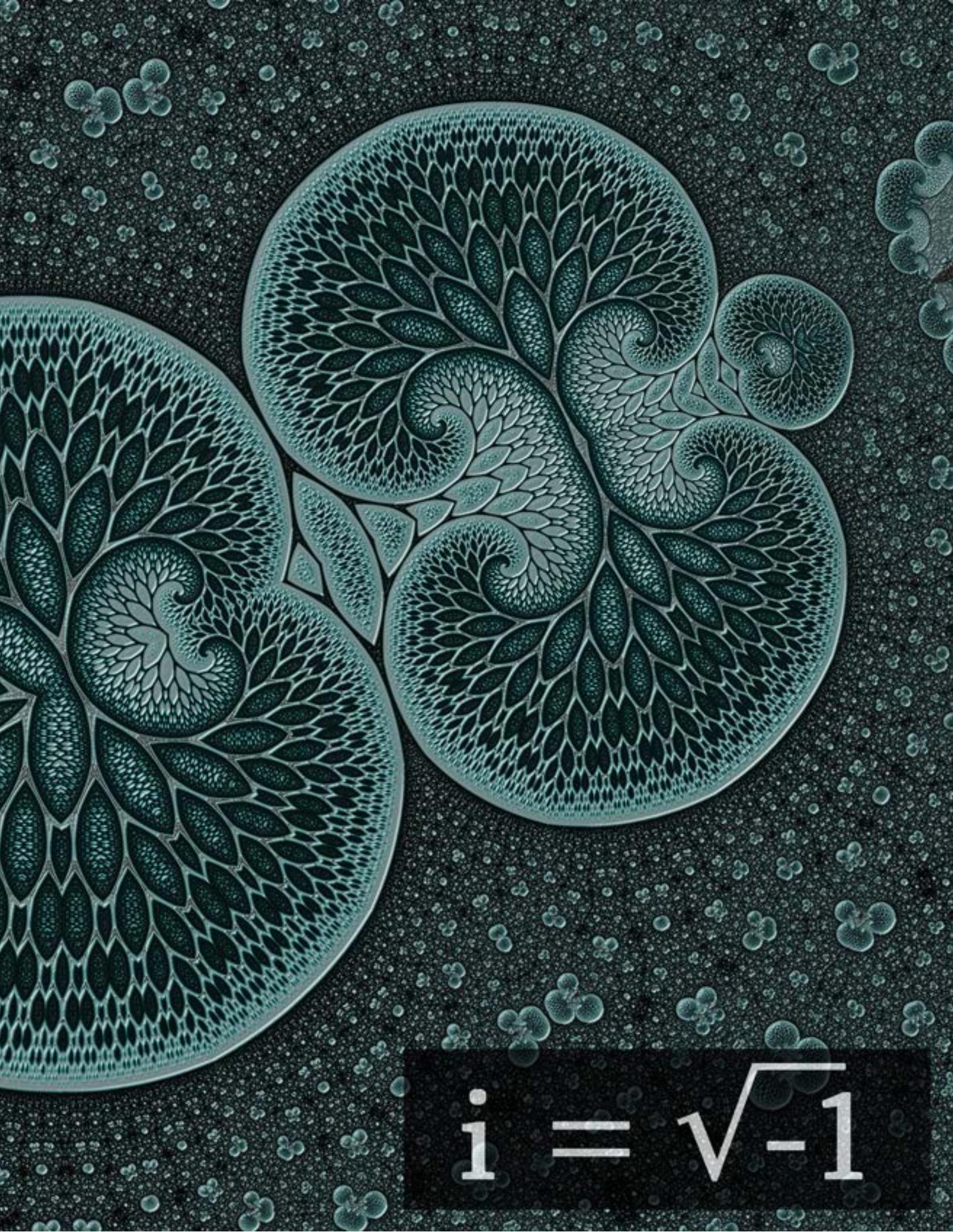
Blood is distributed throughout the body in a fractal pattern. Researchers are using ultrasound imaging to measure the fractal dimensions of blood flow and derive mathematical models to detect cancerous cell formations sooner than before. According to recent studies, a healthy human heart does not beat in a regular, linear rhythm, but rather that it fluctuates in a distinctive fractal pattern.

The heart has four chambers: two upper small chambers called the left and right atrium with two lower larger chambers called the left and right ventricle. The sinoatrial (SA) node, located in the back wall of the right atrium, initiates the heartbeat. Cells within the SA node, known as the pacemaker cells, spontaneously generate an electrical discharge at a rate of about one hundred spikes per minute, changing the electrical charge from positive to negative and back to positive. This intrinsic rhythm is strongly influenced by the autonomic or involuntary nerve. The vagus or parasympathetic nerve brings the resting heart rate down to 60-80 beats per minute and the sympathetic nerves speed up the heart rate. When the heart is relaxed, the cells are electrically polarized. The interior of each cell carries a negative charge and the exterior environment is positive. Cells depolarize as negative ions pass through the cell membrane, sparking a chain reaction and the flow of electricity from cell to cell within the heart.

A heartbeat is caused from the action potential generated by the SA node spreads throughout the atria, depolarizing them and causing contraction. The electrical impulse travels to the ventricles via the atrioventricular (AV) node, located in the wall between the atria, where specialized conduction pathways



J. Gabas



$$i = \sqrt{-1}$$



rapidly conduct the wave of depolarization throughout ventricles causing contraction. The depolarization wave must travel unimpeded and intact through the heart so the chamber contractions are coordinated to send blood efficiently to the lungs and the rest of the body. There are two types of fibrillation — an occurrence when the depolarization wave breaks up and the heart contracts in a totally disorganized way — atrial and ventricular. Atrial fibrillation is irregular and rapid contractions of the atria that work independently of the ventricles and are associated with around 10% loss of cardiac function. Ventricular fibrillation, similar to atrial, is the irregular contraction of the ventricles resulting in a complete loss of cardiac function causing death if not treated immediately.

Fractal Dimensions in the Medical Practice

The electric fields generated by the depolarization and contraction of the atria and ventricles are detectable throughout the body. Placement of electrodes on the chest, ankles, and wrists record the continuous and successive heartbeats, known as an electrocardiogram (ECG). Ventricle contraction sends out the most prominent spike and the interval between the large spikes is the heartbeat.

The first successful ECG in the 1800s on a test subject was attempted on a frog; however, the heart had to be exposed to the testing equipment. Willem Einthoven (1903) invented the first practical ECG. In 1980, Boston's Beth Israel Hospital (BIH) and the Massachusetts Institute of Technology (MIT) finished the MIT-BIH Arrhythmia Rhythm Database containing 48 half-hour excerpts of two channel ambulatory ECG recordings for clinically significant arrhythmias and the MIT-BIH Normal Sinus Rhythm Database containing 18 excerpts of no significant arrhythmias.

The World Health Organization (WHO) listed ischemic heart disease as the number one cause of death (2011) with seven million people. A recent research study in detecting heart disease early has shown a significant clinical advantage in using fractal analysis ECGs for three major heart diseases — Atrial Premature Beat (APB), Left Bundle Branch Block (LBBB), Premature Ventricular Contraction (PVC) — and the healthy heart Normal Sinus Rhythm (NSR). The rhythms were taken from the MIT-BIH arrhythmia database and a rescaled range method was used to determine the specific range of fractal dimension for each disease and NSR.

Fractals in the Earth System

Lightning is an electrical current. Earth's electrical balance is maintained by thunderstorms. A steady current of electrons flow upwards from the Earth's negatively charged surface into the positively charged atmosphere until lightening from thunder-

storms transfer the negative charges back to the Earth. Lightning is generally negative; however, on occasion, it is dangerously positive. An invisible channel of electrical charge, called a stepped leader, zigzags downward mostly in forked pattern segments to the ground and connects to an oppositely charged stepped leader and a powerful electrical current starts flowing. A flash is about twenty rapid return strokes, at 60,000 miles per second, back towards the cloud. Lightning is visible when this process repeats itself several times along the same path.

Each step goes in a slightly different direction along that path creating the jagged pattern in lightening. One typical lightning flash alone carries around 500,000+ million Joules with temperatures between 20,000 and 30,000 degrees, far hotter than the surface of the sun. The air expands during this sudden increase in temperature resulting in a shockwave heard as thunder.

Did You Know

From the space station, fog filling river valleys in Ohio and West Virginia look like lightning.

ball of plasma in a strong magnetic field. This lightning appears as a glowing ball and has been known to pass through walls or ceilings. Dry lightning occurs without a thunderhead and precipitation. Volcanic activity or wildfires create pyrocumulus clouds from ash and debris creating a hazardous cycle of fires.

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This spectacular light show visible at any time of day is a natural occurring fractal pattern and has different shapes. Forked lightning has a branch shape when two or more return strokes follow slightly different paths. Ribbon lightning is formed when string winds spread out the plasma channel of the lightning strike. Bead lightning occurs when small segments of lightning remain after the rest of the lightning disappears leaving spread out "beads" of light in the sky. St. Elmo's Fire, named after the patron saint of sailors, is a blue to green colored light appearing around metal conductors in a high electrical field. Metal bands on the tops of high masts of sailing ships, lightning conductors on tall buildings, airplanes, and even blades of grass during very strong thunderstorms produce this phenomena. Ball lightning is perhaps a trapped

The most deadly is positive lightning, known as bolts of blue, that form when positive strokes form from the very top of a cloud and travel longer distances giving them 10x more power than regular cloud to ground lightning. The sky can be clear and there is no warning when this type of lightning will strike.

The tree of life can be a description of many branch patterns that have become visible with the study of fractal geometry to study them in depth. We learn from Euclid how to think in logic and build cities, roadways, and homes within these dimensions but cannot see the world's roughness without describing the complexity. ♦