Fractals take shape in the lab

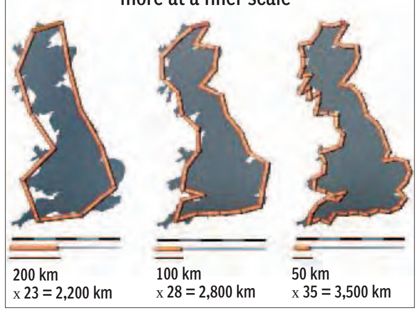
PATTERNS MADE UP OF PATTERNS THAT ARE THEMSELVES MADE UP OF PATTERNS, AND SO ON, ARE OF SPECIAL INTEREST, WRITES **S ANANTHANARAYANAN**

Waclaw Sierpinsky

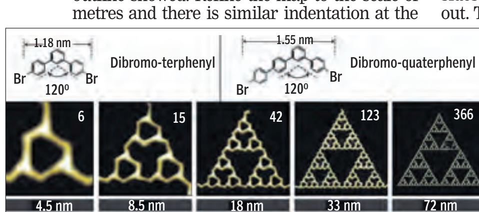
A kind of mathematical entity that is called a *fractal* is one where any small part of a pattern, if expanded, is seen to consist of the same pattern as the original whole. And then any small part of the pattern also shows the same pattern when expanded, and so on. These patterns occur in nature, in traditional decoration motifs, and are important in aesthetics, mathematics, science and engineering. Jian Shang, Yongfeng Wang, Min Chen, Jingxin Dai, Xiong Zhou, Julian Kuttner, Gerhard Hilt, Xiang Shao, J Michael Gottfried and Kai Wu of Peking University, Marburg, Germany, Heifei in China and Singapore report in their paper in the journal *Nature Chemistry* that they have got organic chemical molecules to self-assemble into the form of a well studied fractal, the *Sierpinsky* triangle, a fractal so far created only in theory by drawing lines on paper.

Instances of fractals that we encounter in everyday life are the branches of a tree or the capillaries of blood vessels, which keep dividing and showing the same pattern as we go to finer and finer scales. Another handy example is the profile of a coastline. At the usual scale of tens of kilometres, the outline shows indentation, but detail at the scale of tens of metres is not visible. If a portion is expanded to the scale of a kilometre, the detail in tens of metres comes into view, displaying the same kind of indentation as the first outline showed. Refine the map to the scale of metres and there is similar indentation at the level of centimetres! It is apparent that when the pattern that is seen at one scale is nearly the same as what is seen at other scales, the measurement of length at the finer scale would be much greater than what a longer yardstick could reveal.

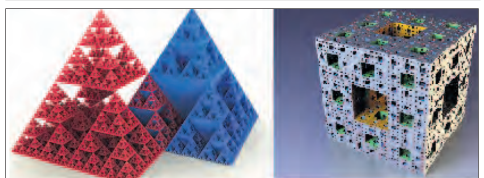
The coastline of Great Britain measures more at a finer scale



A more formal example is the so-called *Sierpinsky triangle*, named after Waclaw Sierpinsky, a Polish mathematician. This shape is constructed by dividing a triangle with equal sides into four similar triangles by joining the midpoints of the sides and then knocking the middle triangle out. The same operation is done with the three remaining, newly added triangles to yield nine new triangles. And the process is repeated with these new triangles, and so on. In fact, this figure could be created by starting with any triangle or even other shapes — a square, for example — and the result would be the Sierpinsky triangle. The triangle appears from any starting shape because the process amounts to iterations that retain points that belong to the fractal shape.



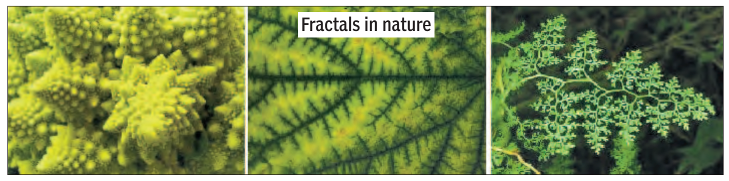
Structure of the dibromo-quaterphenyl molecule and the Sierpinsky triangles that it forms



Sierpinsky pyramid
Menger sponge

The process could equally well be carried out in three dimensions to yield the *Sierpinsky pyramd* or the *Menger sponge*, a cube that ends up with infinite surface area but zero volume!

Another example of a fractal shape is the Koch snowflake. This shape again starts from an equal sides triangle but adds a triangle, a third of the size of each side, on to each of its sides. Each side, thus, now has four straight segments, where it first had one. Now each of these segments adds a triangle equal to a third of the new segments, and so on. This pattern keeps adding on a third to the length of the outline and three new line segments to each existing one at each iteration. The length of the outline hence increases rapidly and approaches infinity.



The "self-similarity" quality of fractals makes these shapes fundamentally different from ordinary, orderly arrangements of entities. The difference is that the change of scale reveals a new level of complexity that is not there at a different scale. We know, for instance, that doubling the dimensions of any plane figure will increase its area by a factor of four, which is the factor by which dimensions are increased (ie, 2) to the power of the dimension of the space in which the figure lies (which is 2). In the case of a solid figure, the containing space is 3-D and the volume increases by the cube — eight times, if we double the dimensions. But if a fractal's one-dimensional lengths are doubled, the spatial content of the figure increases by a power that is ~~somewhere between 2 and 3,~~ It is this different "space filling" quality of fractals that characterises fractals and mechanical methods of measuring areas, like filling the closed figure with sand, would show different results as we change the size of the grains of sand. It is this *fractional nature* of the *dimension* that gives rise to the name *fractal*.

Construction of Sierpinsky triangle — create three identical triangles with the first triangle, create three similar triangles with a white triangle in the middle within each of these and so on

The same procedure, starting from a square also leads to the same Sierpinsky triangle

Doing it in the lab

The authors of the paper in *Nature Chemistry* observed attempts to use synthetic chemical compounds that combine in fractal shapes that did not met with any significant results. But for a first time they succeeded in getting the organic chemicals *dibromo-terphenyl* and *dibromo-quaterphenyl* to deposit as Sierpinsky triangles on a silver substrate, which provides leads on what kind of substances, on what bases and under what conditions can form fractals.

They noted that the chemical structure of the two bromo compounds had the correct angular orientation and was formed with bonds of bromine and hydrogen, which allow self-assembly into a network of triangular voids. The relative strength of the bonds allow mobility of the molecules to self correct and fall into the triangle pattern and also to remain stable in that form. The researchers also noted that the structure of the substrate should have threefold symmetry that matches the structure of the cyclic bromine-hydrogen bonds in the building blocks.

The method used was to create a single silver crystal with the appropriate orientation of silver atoms at the surface, and the bromine compounds were deposited by condensation of the vapour. As soon as the deposit formed, the assembly was cooled with liquid helium so that the carbon-bromine bonds in the film did not degrade. The patterns that the deposit took were measured using the Scanning Tunneling Microscope and the images acquired were processed with special software.

The result was a whole series of molecularly assembled and defect-free Sierpinsky triangles, the largest being with 48 participating molecules. Tests to assess the dimension of the figures, by counting pixels, showed a fractional value that confirmed that the figures were fractals. Fractals, apart from being theoretical marvels, represent the optimisation for economy and stability that is found in nature. Seashells, broccoli, the pinecone, leaf and petal formation, lightning bolts, ice crystals and biological tissue formation all follow fractal design. Techniques to harness fractal design by creating manmade fractals at the molecular level may lead to advances in material science, efficiency of chemical processes, nanotechnology and even new basic designs. "A full understanding of such amazing molecular fractals awaits sophisticated theoretical treatments at multiple scales and levels," the authors say.

THE WRITER CAN BE CONTACTED AT
simplescience@gmail.com

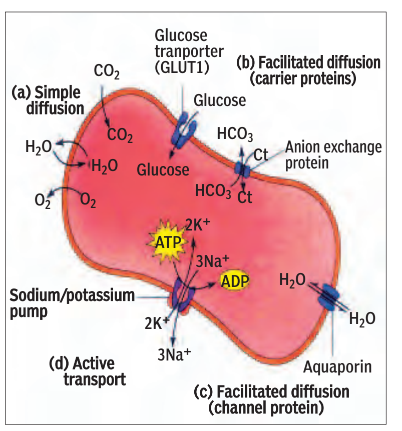
SIMPLE DIFFUSION

TAPAN KUMA MAITRA ELABORATES ON THE UNASSISTED MOVEMENT DOWN THE GRADIENT

The most straightforward way for a solute to get from one side of a membrane to the other is by simple diffusion, which is the unassisted net movement of a solute from a region where its concentration is higher to a region where its concentration is lower. Because membranes have a hydrophobic interior, simple diffusion is a relevant means of transport only for small, relatively nonpolar molecules. Such molecules simply permeate, or move into the phospholipid bilayer on one side, diffuse passively across the bilayer and emerge on the other side, again in aqueous solution.

There are several types of transport (see figure) that are vital to erythrocyte function, namely: (a) *Simple diffusion:* Oxygen and carbon dioxide diffuse across the plasma membrane in response to their concentrations inside and outside the cell; (b) *Facilitated diffusion mediated by carrier proteins:* The movement of glucose across the plasma membrane is facilitated by a glucose transporter called GLUT1 that recognises only D-glucose and the D-isomers of a few closely related monosaccha-rides.

An anion exchange protein facilitates the reciprocal transport of chloride (CI") and bicarbonate (HCOj) ions on a 1:1 basis; (c) *Facilitated diffusion mediated by channel proteins:* Aquaporin channel proteins facilitate the rapid inward or outward movement of water molecules, although water can also cross the membrane by simple diffusion; and (d) *Active transport:* Driven by the hydrolysis of ATP, the Na^+/K^+ pump moves three sodium ions outward and two potassium ions inward, thereby establishing an electrochemical potential across the plasma membrane for both ions.



Oxygen is an example of a small, nonpolar molecule that traverses the hydrophobic lipid bilayer readily and therefore moves across membranes by simple diffusion. This behaviour enables erythrocytes in the circulatory system to take up oxygen in the lungs and release it again in body tissues. In the capillaries of body tissues, where oxygen concentration is low, oxygen is released from haemoglobin and diffuses passively from the cytoplasm of the erythrocyte into the blood plasma and from there into the cells that line the capillaries.

In the capillaries of the lungs, the opposite occurs: Oxygen diffuses from the inhaled air, where its concentration is higher, into the cytoplasm of the erythrocytes, where its concentration is lower. Carbon dioxide is also able to cross membranes by simple diffusion; however, most CO_2 is actually transported in the form of bicarbonate ion (HCO_3^-). Not surprisingly, CO_2 and oxygen move across the erythrocyte membrane in opposite directions, with CO_2 diffusing inward in body tissues and outward in the lungs.

No matter how a population of molecules is distributed initially, diffusion always tends to create a random solution in which the concentration is the same everywhere. Diffusion is always movement toward equilibrium.

Another way to express this is to say that diffusion always tends toward minimum free energy. Chemical reactions and physical processes always proceed in the direction of decreasing free energy, in accordance with the second law of thermodynamics. Diffusion through membranes is no exception: Free energy is minimised as molecules move down their concentration gradient and as ions flow down their electrochemical gradient.

Several properties of water cause it to behave in a special way. First, water molecules are not charged, so they are not affected by the membrane potential. Moreover, the concentration of water is not appreciably different on opposite sides of a membrane. What, then, determines the direction in which water molecules diffuse? When a solute is dissolved in water, the solute molecules disrupt the ordered three-dimensional interactions that normally occur between individual molecules, thereby increasing the entropy and decreasing the free energy of the solution. Water, like other substances, tends to diffuse from areas where its free energy is higher to areas where its free energy is lower. Thus, water tends to move from regions of lower solute concentration (higher free energy) to regions of higher solute concentration (lower free energy).

Osmotic movement of water across a membrane is always from the side with the higher free energy (that is, with the lower solute concentration) to the side with the lower free energy (that is, with the higher solute concentration). For most cells, this means that water will tend to move inward because the concentration of solutes is almost always higher inside a cell than outside. If not controlled, the inward movement of water would cause cells to swell and perhaps to burst.

THE WRITER IS ASSOCIATE PROFESSOR, HEAD, DEPARTMENT OF BOTANY, ANANDA MOHAN COLLEGE, KOLKATA, AND ALSO FELLOW, BOTANICAL SOCIETY OF BENGAL, AND CAN BE CONTACTED AT tapanmaitra59@yahoo.co.in

A rather messy trail

MARK BRANDON EXPLAINS WHAT HAPPENS WHEN AN ANTARCTIC ICEBERG THE SIZE OF A COUNTRY BREAKS AWAY

You never forget the first time you see an iceberg. The horizon of a ship at sea is a two dimensional space and to see a three dimensional piece of ice appear in the ocean is quite something. But, in truth, the first iceberg you see is likely to be small. Most icebergs that make it far enough north from Antarctica to where they are a danger to shipping are sometimes many years old and at the end of their lives. They are small fragments of what once left the continent. Once in a while, however, a monster breaks free from the edge of Antarctica and drifts away. Tens of kilometres long, these bergs can tower perhaps 100 metres above the sea and reach several hundred more below the surface. These are called tabular icebergs — and while it is rare for people to see something on such a scale they are part of the normal cycle of glacial ice in Antarctica.

Everyone knows Antarctica is an ice-covered continent, but the ice is not static. To a scientist, it is a dynamic environment — it's just a question of the timescale you are looking at. Snow falls on the continent and over time it has built up layers of ice that flow in glaciers towards the coast. On reaching the sea, these glaciers fracture and release icebergs or form large regions of floating ice known as ice shelves. In a few special places glaciers can extend tens of kilometres into the ocean – giant fingers of ice several hundred metres thick, pointing out into the sea. Just like a wall, they shield what is in their lee, and rather than the ocean being covered by drifting sea ice it can remain open throughout the year to form what is called a polynya. A new research article in the journal *Nature Communications* by a French team working in Antarctica has looked at the history of the polynya in the lee of the Mertz Glacier going back 250 years.

An iceberg in Ilulissat, Greenland: researchers have been studying the phenomena of the melting glaciers and their long-term ramifications for the rest of the world.

This glacier forms one of these fingers of ice reaching out from the continent and the polynya in its lee can be up to 6,000 square km. What they did was take a core sample of sediment from the sea bed in the lee region and look back in time using climate proxies such as the titanium content — which can be considered a proxy for how much of the sediment comes from the land.

The proxies tell us which species of plankton dominated the region in a particular period: if the sediment is dominated by species that live in open water then they can infer that the polynya existed and so the Mertz Glacier had a long tongue extending north. If the sediment is dominated by species that live in the sea ice, then the polynya and the glacier tongue were absent. It is quite an elegant way to investigate glacier flow.

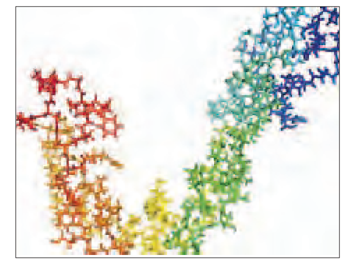
What they found was that every 70 or so years the Mertz polynya was absent for tens of years. Given that the glacier is advancing about one kilometre per year, this means a super-iceberg tens of kilometres in length has regularly formed in this region. In February 2010 an iceberg containing almost 900 billion tonnes of fresh water broke free. You may think it would drift north, away from the continent, but icebergs this big don't have an easy path. They crash and bounce along any relatively shallow region of the sea floor and wipe out anything in their way. Imagine the trail of damage 900 billion tonnes of ice scraping on the sea floor can leave.

Very large icebergs get identifying codes; this one became C28 as it was the 28th large iceberg from this sector of Antarctica. It took two months for C28 to reach the deep water before it shattered into two pieces (C28A and C28B) both still massive, and both went on to spawn further icebergs as they fractured into ever smaller pieces over the next few years. When still close to shore, these giant bergs are bad news for penguins, who suddenly have to travel much further — around the iceberg — to find open sea and their food. Chicks growing up near a massive iceberg may starve and die and some entire colonies may become unviable. As they drift away, these huge icebergs create their own habitat, cooling the seas, freshening the waters and also seeding the oceans with iron, which means more algae and plankton at the bottom of the food chain in remote locations such as South Georgia, where icebergs run aground and die.

Over the past 50 or so years, the robust cycle of growth and decay in the Mertz glacier has broken down. The researchers think this is due to largescale changes in the way the wind circulates over Antarctica — the so-called Southern Annular Mode. Other studies have shown that the way this mode has changed over recent decades has an anthropogenic footprint. It seems even in Antarctica we can identify human impacts on climate processes that are likely to have been operating for thousands of years.

THE INDEPENDENT

PLUS POINTS



Short, strong signals

Cellular signals transmitted via the protein Notch are critical for an array of developmental processes in animals, but, if poorly regulated, these signals can contribute to pathologies such as cancer. A report published in *Science Signalling* on 24 March reveals that part of the mechanism regulating Notch is the addition of methyl groups that boost the protein's activity — and hasten its demise.

"While other post-translational modifications have been found in the Notch intracellular domain before, this is a new type of modification, and the biological effects are intriguing," said geneticist Urban Lendahl of the Karolinska Institute in Sweden, who was not involved in the work.

Notch signalling is triggered when the protein's extracellular domain binds to its ligand — expressed on a neighbouring cell. In response to this interaction, the intracellular portion of Notch detaches and travels to the nucleus to activate transcription of target genes. Franz Oswald of the University of Ulm in Germany and his colleagues decided to investigate how this business-end of the protein was regulated.

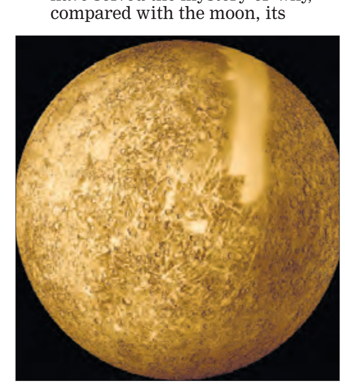
Using biochemical techniques, including mass spectrometry, the team identified a methyltransferase called Coactivator-Associated Arginine Methyltransferase 1 as a direct interaction partner of the Notch intracellular domain. As its name implies, Carm1 adds methyl groups to the amino acid arginine and the team confirmed that five arginines in the Notch intracellular protein were indeed methylated by Carm1.

RUTH WILLIAMS/THE SCIENTIST

Murky Mercury

The planet has long enjoyed a certain glamorous sheen, thanks to it being named after the fleet-footed messenger of the Roman gods, but now Mercury seems in danger of gaining an altogether less appealing association — as a celestial reminder of what happens if you don't keep up with the dusting.

American scientists believe they have solved the mystery of why, compared with the moon, its nearest airless neighbour, Mercury has a dark and decidedly non-silvery surface. The reason, they say, is that the planet is coated in billions of years' worth of carbon dust, after millennia upon millennia of being "dumped on" by passing comets. The repeated showers of dusty "stealth-darkening agent", they suggest, have in effect turned Mercury into "a painted planet".



Its dim surface of the planet closest to the sun has long puzzled astronomers. Since it has the thinnest atmosphere of all the planets in the solar system, one possibility was that it was darkened by the effects of solar winds and the impacts of micro-meteorites. Both processes, however, would leave a thin, dark coating of tiny, dark iron particles, and analysis found that there were in fact very few such particles on Mercury's surface.

Now research published in *Nature Geoscience* and conducted by Megan Bruck Syal at Brown University in Rhode Island, has produced another possibility. "It's long been hypothesised that there's a mystery darkening agent that's contributing to Mercury's low reflectance," she said. "One thing that hadn't been considered was that Mercury gets dumped on by a lot of material derived from comets."

ADAM LUSHER/THE INDEPENDENT