Out of step but in tune

RHYTHMS AND PART-RHYTHMS IN NATURE LEND A HELPING HAND IN THE FIGHT AGAINST CLIMATE CHANGE, WRITES
S ANANTHANARAYANAN

Being periodic and regular is everywhere in nature — sound and light waves, movement of the planets, the seasons, generations of people. There are also regular patterns in art, architecture and music, and in the way atoms combine to form crystals. And then nature has examples of things that are precisely non-periodic, and useful for that very reason because they prevent things from repeating.

A third form of regularity that has been studied of late is partial periodicity — things that are not periodic but also not random, a form known as *quasi-periodic*, and this is found to have applications, too, one area being in herding and sorting the components light, which is useful in studies of optical transmission, photoluminescence, laser action and so on.

Materials with this kind of part-periodicity are also found useful in light-trapping for solar energy. This last property would have great application, but fabricating the right patterns is expensive. Alexander J Smith, Chen Wang, Dongning Guo, Cheng Sun and Jiaxing Huang, a multidisciplinary team from North Western University, Illinois, report in the journal *Nature Communications* that the now common *Blu Ray movie disc* carries a code that has a quasi-periodic character that is good for optimising light-trapping in the solar spectrum.

Examples of things that are periodic are legion in nature and in life. A whole great part of electronics and communications depends on periodic electric or radio waves. The complex shades and patterns on the wings of birds or insects arise not from dyes or chemicals but from the effect of periodic striations, on waves of white light. The crystal structure of materials is the regular place of atoms, repeated unchanged and in three dimensions, and the regularity gives materials a mechanical strength or useful electric or optical properties.

An example of being specifically non-periodic is the position of successive leaves around the stem of a plant as it grows. If there was anything periodic in the way the leaves sprouted, then sooner or later one leaf would find itself directly below another, which is no good for getting the best of sunlight. It is found that the way leaves grow follows a remarkable pattern, reflected in a series of numbers, known as the *Fibonacci series,* in which the ratio of any pair of successive numbers is always different from that of other pairs. Because of this nature of the spiral growth of leaves, no leaf ever grows exactly above another one, which makes for the best benefit of sunlight for the plant.

Another example is the way certain hibernating animals time the years when they emerge for breeding. If there were a pattern in the way this happened, their predators would be there to get them. The animals keep predators guessing by varying the gap between successive breeding seasons so that a pattern can never be discerned!

Quasi-crystals

As opposed to such planned regularity, or the converse in the non-repeating series, we have the quality of randomness or lack of any scheme or design. A crystal with specific periodicity would provide scattering centres that would specifically pick out some given frequencies of light and the crystal would reflect or transmit these frequencies. The same material in an amorphous, or non-crystaline form, would be the case of randomness and it would have no selectivity. But yet another, a third form of crystal structure, has now been discovered and this is the *quasi-crystal*, where atoms are packed in patterns, but such that they *do not repeat themselves!*

For long, it was thought that matter simply could not exist in such a form because the pockets of low energy into which atoms tend to align themselves all appeared in regular, repetitive structures. Daniel Shechtman, who discovered this structure in an aluminium-manganese alloy in 1982 and received the Nobel Prize in 2011, had to battle ridicule in the initial years — Linus Pauling is said to have commented, "There is no such thing as quasi-crystals, only quasi-scientists."


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A number of quasi-crystals have since been created in the lab and instances have been found in the natural world. Quasi-crystals that exist in some steels have been found to reinforce the material surface and commercial applications are being developed. Quasi-crystals, with their non-repeating regularity, or *long-range order*, show special properties of elasticity and propagating heat or sound. And in the field of photonics, or manipulation of light, these crystalline structures have shown the capacity to be efficient collectors of light of all or a wide range of frequencies.

This last property is seen as having great potential to improve the efficiency of solar cells. With all the attention paid to this source of non-polluting energy, the best solar cell panels can do is about 20 per cent efficiency, and many of them are at about 10 per cent. If a quasi-crystal structure could be built onto the silicon thin film solar cell, this would maximise energy absorption and efficiency of the solar cell. The trouble, however, is that quasi-crystals for specific applications cannot be made to order as there are no design or fabrication tools to create non-repeating patterns.

A way around fabrication of actual quasi-crystals has been the development of other structures, like a plane with closely separated rulings placed above another plate with slightly different rulings, which are able to mimic the quasi-crystal ability to address a range of frequencies of light. The way quasi-crystals and structures seem to work is based on a principle that a complex wave can be represented as a series of simple waves, each of these component waves being weaker or stronger. A regular structure, like a crystal, then, corresponds to a small set of wavelengths, and a random structure to all wavelengths. But quasi crystal, and equally the quasi-random structure, are found to map to a spectrum of wavelengths and, hence, their value in channeling solar energy.

But creating artificial structures with architecture at the scale of wavelengths of light, which is routine in natural objects like crystals, is challenging and expensive. This difficulty may thus have been the limiting factor in the use of quasi-random nanostructures in the solar panel industry. At least, till the serendipitous discovery of the Illinois researchers.

Blu Ray movie discs

The *Blu Ray* is a convention of coding compact discs that superseded the DVD standard. The digital optical recording principle is to record data, audio or video, with the help of indentations known as *pits*, in a spiral track on a circular plastic disc. The DVD standard improved on the coding used in the CD, but it was limited by the wavelength of the red laser that was used for reading the code. The Blu Ray uses shorter wavelength, blue laser, which allows smaller "pits" and a finer track pitch, along with improvements in data compression and checks to detect errors.

In the quest for more accessible quasi-random nanostructures, the research team in Illinois has discovered that the pattern of "pits" and "lands", which is where there are no "pits", in the Blue Ray disc is a full-fledged quasi-random pattern, which is able to do for solar cells what was planned with the expensive original. The "pits" in the Blu Ray disc are of the order of 150 nanometres, which compares well with the wavelengths in visible light — 390 to 700 nanometres. As Blu Ray discs are mass produced, the cost of their use in harnessing solar energy would be little more than material cost once the recordings have been marketed.

The Illinois group found that the quasi-random pattern of "pits" on the Blu Ray discs, after encoding, regardless of the normal content of the discs, was well suited for photon management over the full solar spectrum. The team extracted the pattern on the discs and imprinted it on to polymer solar cells and found that there was an increase in absorption and power conversion. The team was also able to prove that the same method would work with other photoactive materials. "This new insight opens up promising areas for repurposing a low-cost consumer product for a high-end, value-added application," the team says in the paper in *Nature Communications*.

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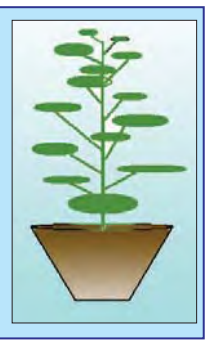
Fibonacci numbers

1, 1, 2, 3, 5, 8, 13, 21, 34, 55, 89, 144, 233… each is the sum of the last two. The ratios of the successive pairs in the series are:
1/1=1 2/1=2 3/2=1.5 5/3=1.666 8/5=1.60
13/8=1.625 21/13=1.615 34/21=1.619
55/34=1.6176 89/55=1.6182 144/89=1.61797
233/144=1.61806

And we can see that the ratio gets closer and closer to 1·61803 39887… but is never the same.

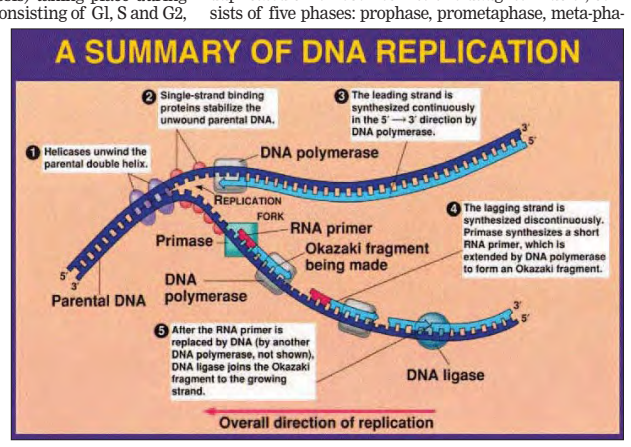
The leaves of a plant, as one goes up from the lower lot to the higher ones, are arranged not one above the other but each a little to the side. It seems to be way to help each leaf catch as much sunlight as possible and to make each leaf most useful in channeling rainwater to the roots. It is found that the extent of the turn, as one goes from one leaf to the next, are Fibonacci numbers. The purpose seems to be to make the ratios different all the time so that no leaf is ever exactly below another.



WONDROUS MECHANISM

TAPAN KUMAR MAITRA
EXPLAINS CELL CYCLE, DNA REPLICATION AND MITOSIS

The eukaryotic cell cycle is divided into four main phases — Gl, S, G2 and M — with chromosomal DNA being replicated during the S phase and cell division (mitosis and cytokinesis) taking place during the M phase. The interphase, consisting of Gl, S and G2, is a time of cell growth and metabolism mat typically occupies about 95 per cent of the cycle time. Cultured mammalian cells usually divide once every 18-24 hours, but cells in multicellular organisms differ greatly in generation time, ranging from stem cells that divide rapidly and continuously to differentiated cells that normally do not divide at all.



DNA is replicated by a semi-conservative mechanism in which the two strands of the double helix unwind and each serves as a template for the synthesis of a complementary strand. Bacterial chromosome replication is initiated at a single point and moves in both directions around the circular DNA molecule. In contrast, eukaryotes initiate DNA replication at multiple replicons, with replication proceeding bidirectionally in each replicon. DNA synthesis is catalysed by DNA polymerases, which add nucleotides to DNA chains in the 5' to 3' direction. DNA synthesis is continuous along the leading strand, but discontinuous along the lagging strand, generating small Okazaki fragments that are later joined together by DNA ligase.

DNA replication is initiated by an enzyme called primase, which synthesises short RNA primers that are later removed and replaced with DNA. During DNA replication, the double helix is unwound through the action of helicases, topoisomerases and single-stranded DNA binding proteins. As replication proceeds, a proofreading mechanism based on the 3' to 5' exonuclease activity of DNA polymerase allows incorrectly base-paired nucleotides to be removed and replaced.

In eukaryotes, the problem of replicating the ends of linear chromosomal DNA molecules is solved by telomerase, an RNA-containing enzyme that uses its RNA as a template for creating short repeated DNA sequences at the ends of each chromosomal DNA molecule. A mechanism known as licencing also allows eukaryotes to ensure that DNA molecules are replicated only once prior to mitosis.

DNA damage arises both spontaneously and through the action of mutation — causing chemicals and radiation. Some types of DNA damage are tolerated by DNA polymerases that carry out a translesion synthesis of new DNA across regions where the template DNA is damaged. Alternatively, damaged regions can be repaired by nucleases that remove damaged stretches of DNA followed by replacement of the missing nucleotides by DNA polymerase.

Excision repair pathways are used to correct mutations involving abnormal bases, while mismatch repair removes and replaces improperly base-paired nucleotides that have escaped the proofreading mechanism. Finally, double-strand breaks are repaired by nonhomologous end-joining or homologous recombination.

Mitosis, the process that distributes the two sets of duplicated chromosomes into two daughter nuclei, consists of five phases: prophase, prometaphase, metaphase, anaphase, and telophase. During prophase, replicated chromosomes condense as sister chromatids that are still joined together. Meanwhile, the cell's two centrosomes move apart and initiate the assembly of the microtubules (MTs) of the mitotic spindle. In prometaphase, the nuclear envelope breaks down and the chromosomes then become attached to kinetochore MTs and move toward the spindle equator. At metaphase, the chromosomes line up at the metaphase plate. Anaphase begins with the separation of the sister chromatids and continues with their movement, as daughter chromosomes, toward the spindle poles. During this process, the kinetochore MTs shorten, the polar MTs lengthen and the cell starts to elongate. At telophase, the separated chromosomes decondense and a nuclear envelope is reformed around each daughter nucleus.

Three groups of motor proteins are involved in the chromosomal movements that take place during mitosis. Motor proteins at the kinetochores and spindle poles move chromosomes toward the spindle poles, accompanied by a disassembly of the MTs at their plus and minus ends. At the same time, motor proteins that crosslink the polar microtubules push overlapping microtubules in opposite directions, thereby pushing the spindle poles away from each other. Finally, a third set of motor proteins pull astral MTs toward the plasma membrane at the cell poles, thereby pulling the spindle poles apart.

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Into the interactome

MOLLY SHARLACH REPORTS ON A MASSIVE SCREEN THAT YIELDS THE MOST COMPREHENSIVE MAP OF BINARY HUMAN PROTEIN INTERACTIONS TO DATE

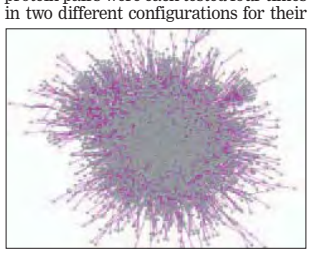
The completion of the human genome sequence more than a decade ago was an indisputable triumph for biomedical research and, more recently, efforts such as the Encyclopaedia of DNA Elements (Encode) project have sought to expand knowledge of functional elements within the genome.

But truly connecting genotype to phenotype will require a comprehensive view of how the protein products of genes operate and interact. Researchers at the Dana-Farber Cancer Institute's Center for Cancer Systems Biology and their colleagues have produced a new human interactome map (reported on 20 November) in *Cell*. It is based on a systematic screen of 13,000 human proteins that uncovered 14,000 pair-wise interactions.

This nine-year project likely represents about five per cent to 10 per cent of all the protein-protein interactions that exist, according to study co-author Fritz Roth of the University of Toronto. While still limited in scope, it is at least a five-fold improvement over previous interactome maps, Roth said.

"This is a long road, and we've never had a human interactome project to go with the Human Genome Project," he said. "But I think people are starting to appreciate that the genome is the beginning of the story… it's a parts list in an alien language that we're starting to figure out."

To identify these interactions, the researchers used a high-throughput yeast two-hybrid approach, in which 82 million protein pairs were each tested four times in two different configurations for their ability to activate a reporter gene in yeast. They also validated selected interactions using three independent methods, testing whether the protein pairs could reconstitute the parts of a fluorescent protein or a membrane-bound protein complex in mammalian cells, plus used an in vitro method.


A systematic map of nearly 14,000 binary interactions among 4,100 human proteins.

They compared its results to a list of protein interactions supported by multiple pieces of evidence garnered from a literature search in 2013 and found that their systematic strategy picked up a large swath of interactions that were missed by individual studies. "This kind of centralised approach has a much higher likelihood of finding interactions throughout the human proteome, rather than just finding interactions of the specific proteins that people have studied because of a disease process or because of the specific cellular function that they're interested in," said Stanley Fields of the University of Washington. Fields, who pioneered the use of the yeast two-hybrid system, was not involved in the present study but served on the advisory board for a National Institutes of Health grant that partially funded the research.

Notably, the new interactome map lends support to a long-held suspicion that proteins implicated in cancer participate in disproportionate numbers of interactions with other proteins. As scientists sequence tumor genomes, more extensive knowledge of these protein-protein interactions could help to distinguish "driver" mutations that cause cancer from "passenger" mutations that are simply along for the ride.

"Our goal is to help facilitate the expansion and robustness of the human interactome to the point that it can really provide insight into every chronic disease," said Joselp Loscalzo of Harvard Medical School, a cardiovascular researcher and long-time proponent of "network medicine" who has collaborated with study co-author Albert-László Barabási, but was not involved in the present work.

While this latest map is a valuable resource, it provides a static view of the proteome, said Loscalzo. "Looking at dynamic changes will be another important part of this… it would also be useful to look at adaptive responses of the proteome to stresses in the environment."

Roth and his collaborators are already at work on the next interactome map, which will expand the screen to 17,000 proteins. While large, this expanded map will still be far from comprehensive. "One thing we know is that not every interaction can be detected by every assay, so it's unlike genome sequencing," he said. "It's an asymptotic problem."

PLUS POINTS

Plastic bricks

Bricks made from soft plastic waste that can each withstand six tonnes of pressure and relentless rain could replace the clay bricks currently used to build rural homes in monsoon-prone countries such as India. Clay is susceptible to rain, but the new waste-made material, which is both strong and lightweight, could solve a nagging problem, says Lise Fuglsang Vestergaard, who developed the idea during her design Master's at the Technical University of Denmark.

Earlier this month, as a winner of a DTU student competition called the Green Challenge, she was handed around $2,500 that will help her develop her concept. She got the idea while spending three months in 2013 as part of her studies developing a waste collection system in Joygopalpur, West Bengal. Back home, she experimented by melting plastic — including foil-covered snack bags, a huge part of India's domestic waste — into moulds in an ordinary oven. This resulted in prototypes that remained strong despite containing up to 60 per cent snack bags.


Lise Fuglsang Vestergaard presenting her plastic bag bricks during an exhibition in Copenhagen, Denmark.

But as electricity is limited in places such as Joygopalpur, Vestergaard has come up with a way to melt plastic using a solar-powered grill. She plans to do more testing on her next trip to India. However, not everyone in poor areas of India understands the importance of recycling, says Vestergaard. "They are used to waste such as banana skins that disappear."

According to Waste Warriors, an NGO that seeks to clean up India, many people in the country suffer from pollution-induced diseases that are the result of waste. "India has a very serious garbage problem that could be managed with a bit of effort, (but) it needs to stop being at the bottom of everyone's agenda," says Jodie Underhill, Waste Warriors' co-founder.

One way forward could be to offer cash for collecting refuse and delivering it to recycling stations, says Sashi Sivramkrishna, an economist at the Narsee Monjee Institute for Management Studies, India. "We get a decent price selling old newspapers. So why not for plastic waste and even organic waste if it can be put to use?" he adds.

Although the plastic bricks idea seems "fantastic", says Sivramkrishna, it should be aimed at more than just low-income communities. "If plastic bricks are targeted at the poor, (the project) will definitely fail because the poor want a concrete house just like everyone else in India," he says.

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Pain in a dish

Scientists have created a miniature model of human pain in the form of nerve cells growing in a laboratory dish that respond to the discomfort of hot chillis and other kinds of physical distress. They may not yet say "ouch" when pinched, but the living nerve cells show they are just as sensitive to painful stimuli whether they come in

the form of high temperatures or the chemical ingredient that make chillis feel so hot.

Harvard University researchers said they had generated the human nerve cells that normally send painful stimuli to the brain by reprogramming ordinary skin cells experimentally so that they could develop into fully mature, adult pain neurons. The result is "pain in a dish", which they believe could be used to discover new kinds of analgesics and other forms of pain relief, as well as helping to find out why some people are more prone to feeling chronic pain than others.

"Pain is arguably one of the most important of our sensory applications. It warns us of danger in the environment and we're exposed to a lot of things that can damage our sensitive biological systems," said Clifford Woolf of the Harvard Stem Cell Institute in Cambridge, Massachusetts, who led the study. "We've made neurons (nerve cells) that retain the key aspects of the pain system. They act like a fire alarm but instead of detecting a fire they detect tissue damage."

The nerve cells created at Harvard, he said, responded to immediate physical injury, the acute "ouch" pain, as well as the more subtle forms of chronic, longer-term pain caused by things like tissue inflammation or the side-effect of chemotherapy drugs.

STEVE CONNOR/THE INDEPENDENT