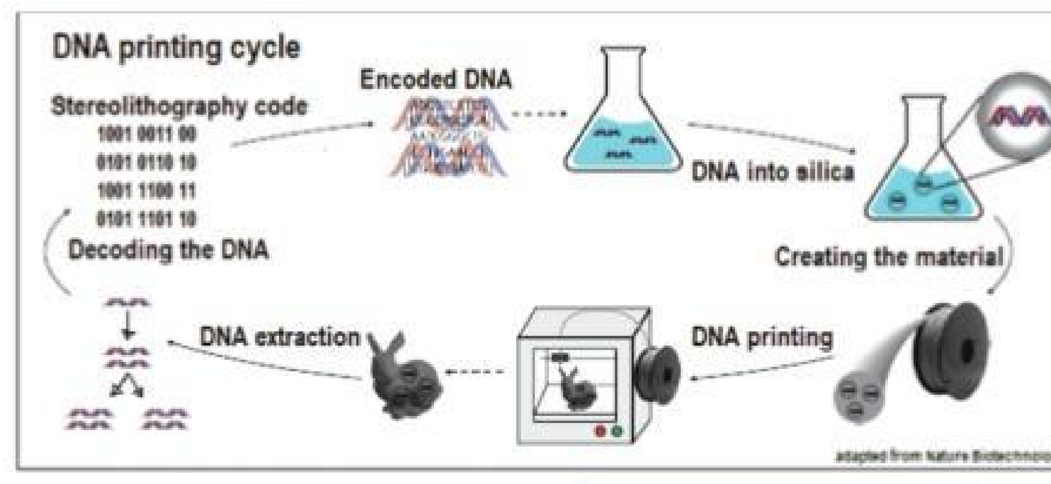
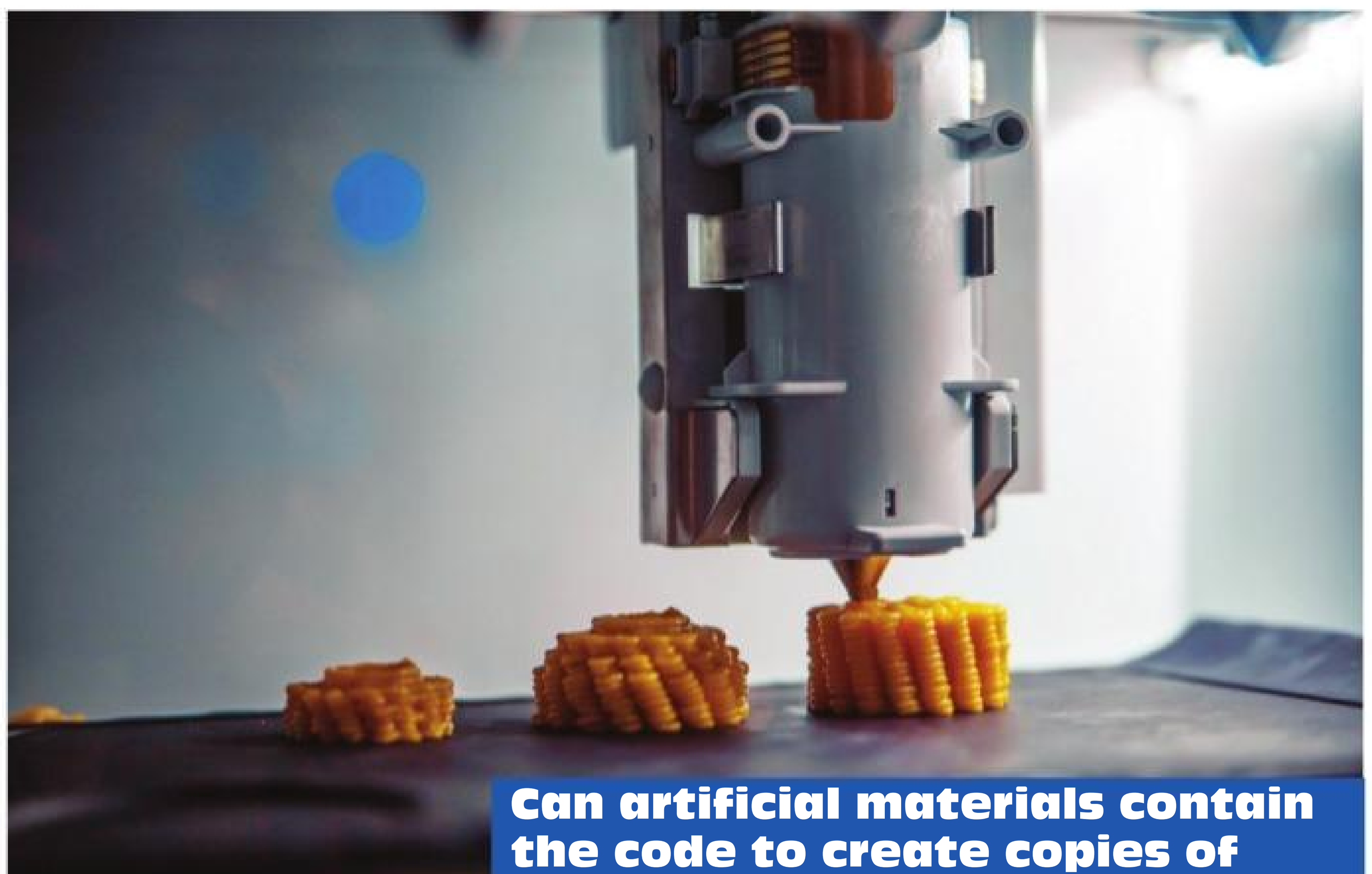
Data storage, Nature's way





Can artificial materials contain the code to create copies of themselves?

S ANANTHANARAYANAN

The hallmark of living things is cell division, where a cell becomes two and each daughter cell is the same as the parent. And then, living cells contain the intelligence to arrange themselves so that a cell can grow into a copy of the parent organism.

Julian Koch, Silvan Gantenbein, Kunal Masania, Wendelin J Stark, Yaniv Erlich and Robert N Grass, from Zurich in Switzerland and Raanana, in Israel, write in the journal, *Nature Biotechnology*, that they have embedded the code for the shape of the Stanford bunny, a model object in the field of 3D printing, into the material of the bunny, so that it can be rebuilt with the help of a speck of its own material.

Of course, this is not Nature's way of cell division and spontaneous reconstruction. It is, however, the use of the technology that resides in living cells for the material of an object to contain the blueprint for the object's own reconstruction.

An early way of reproducing shapes was the tracer lathe, where the cutting tools were guided by a stylus that moved along a template. A development was the CNC, or Computer Numerical Controlled machine, where a blueprint was converted into numbers that guide the cutting or grinding tools. With refinement, many three-dimensional objects can now be shaped from a block of material with the help of a programme that directs what parts will be chipped away.

This is clearly unlike how living things are shaped by Nature. In Nature, things are built up from a microscopic beginning, by adding material, to build it up, rather than chipping material away, to reduce to the shape. But now, with special materials and computer programmes, this has also become possible, by the process of 3-D printing.

In the case of a 2-D object, like a picture, a scanner extracts the information of the colour and brightness at each location on the picture, and stores the information in a digital form. The stored information can then be used to reproduce the picture, on a screen or through a printer. In 3-D printing, a 3-D object is scanned in the same way, to generate a set of numbers that contain the shape information of the object. With this information, a computer controlled machine deposits layers of material according to the shape that has been recorded, to build up a replica of the original object.

The process may be faster and more economical than coming down to the shape from a larger block of material, and would certainly be less wasteful.

Nature also builds organisms up by adding cells, from a single celled beginning. Here, however, the growth is not by external deposition, but by building cells up from the substances in the environment, with the help of a programme of construction that the cells contain. This programme is the DNA, the record that is there in the nucleus of every cell.

When the cell replicates, the DNA splits into two complementary halves and the halves become two separate wholes by rebuilding their missing counterpart halves. The new cells hence have the DNA, with instructions that decide the structure and function of the cell, as well as instructions that tell the cell when and how, in turn, to replicate.

In this way, a living organism is able build itself and to reproduce. A significant aspect of the process, however, is that a very complex set of instructions, all that is needed for the functioning of a living animal, is encoded in every cell, so that the instructions are available everywhere, and all within the microscopic nucleus of the cell. And, in an artificial system, even if the whole process of natural growth and reproduction is not feasible, so far, the work reported in *Nature Biotechnology* represents an important application of DNA storage and retrieval, albeit in a different context.

A number of fields are now looking at using DNA for data storage. While data from programmes like space exploration or Cern's Large Hadron Collider is processed over months in dedicated facilities or through crowd sourcing, there is huge data that needs to be preserved. Records like civil documents, like land records, topographic data, layout of drainage or communication lines have become massive and need to be preserved in digital formats. There is thus need for huge capacity along with reliable and stable, long term storage.

The microscopic DNA, clearly, has the greatest capacity, and great economy of space. As for durability, we have instances of the genome of animals long extinct being found preserved in fossilised remains. DNA technology for data preservation could hence be the solution of choice.

Getting hold of sufficiently long DNA backbones, on which to code digital data, however, has not been an easy task. A decade ago, Microsoft Corporation engaged a California-based company, called Twist Bioscience to supply 10 million DNA strands to try out the medium. Using the currently available DNA strands, the current study developed a concept of "DNA of Things", where the information of the form of a 3-D object was recorded over 12,000 units of the DNA. The information for the model object used, the Stanford bunny, comes to 100 kilo bytes, which is some four times the size of text data in this article. With a compression technique, this was reduced to 45 kb. And then, the technique to transfer the information to the DNA strands allowed the data to be recorded more than five times over.

While DNA molecules can be freely twisted and crumpled, they would denature in heat and moisture when material for the construction of a model is prepared. The DNA was hence embedded in silica nanoparticles, called **S**ilica **P**article **E**ncapsulated **D**NA. Even with some loss of information, the five-fold redundancy in the encoding ensured that full data was available. The SPED was then combined in the material used in 3-D printing or casting, so that the DNA strands remained intact.

The process that followed is shown in the picture. The code that is used for 3-D printing the object is first encoded onto the DNA strands. These are then embedded in silica nanoparticles, to create SPED. SPED is then mixed into the material to be used for building the object, and the object is 3-D printed.

Now is where extracting the code from the object itself starts. As the material of the 3-D printed object contains silica nanoparticles, which contain DNA, a sliver that is chipped off from the 3-D printed object would contain DNA, from which the embedded code could be extracted. DNA that contains the code could then be generated in quantity and again embedded in silica nanoparticles, et al, to result in a second-generation DNA printed object.

A sliver could then be chipped off this object and the procedure repeated, to create a third-generation object. The authors of the paper report that they were able to go to five generations without loss of accuracy in the replications.

In the same way, the team was also able to encode and encapsulate the information for 1.4 MB video in a Plexiglas spectacle lens and retrieve the video from a tiny piece of the lens. "DoT could be applied to store electronic health records in medical implants, to hide data in everyday objects (steganography) and to manufacture objects containing their own blueprint. It may also facilitate the development of self-replicating machines," the paper says.

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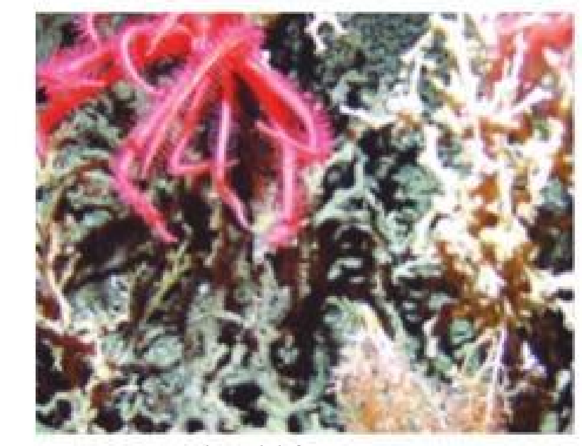
Breaking bunny

The Stanford bunny is a ceramic model of a rabbit whose form has been broken down into 69,451 triangles, using 3-D scanning. The set of data is widely used for testing techniques or algorithms that are used for data compression or rebuilding the original from the data. It is part of a repository of computer graphics resources at the Stanford University.

PLUS POINTS

All we have



Humanity should focus its attention on solving the climate crisis instead of far-fetched and unrealistic notions of escaping Earth for unspoiled planets, a scientist who won this year's Nobel Prize has said.

Swiss astronomer Didier Queloz, who shared the prestigious 2019 Nobel Prize for Physics for his role in discovering planets orbiting distant suns, denounced those who argue against fighting climate change because of the distant possibility that humanity "might leave the Earth at some point". "I think this viewpoint is irresponsible," Queloz said at a news conference in Stockholm. "The stars are so far away, I think we should not really have any serious hope to escape Earth." He also told the conference, which he was attending to collect his share of the £641,000 prize fund, that it is "better to spend our time and energy trying to fix it rather than trying to imagine we will destroy it and leave it".

Queloz appeared to be referencing the theory held by some scientists, including late cosmologist and theoretical physicist Stephen Hawking, that threats such a nuclear war and climate change could become so serious that humans will eventually have to depart the planet in order for the species to survive. In 2017, Hawking issued an apocalyptic warning as part of *BBC* documentary, *Expedition New Earth* saying humanity has as little as a single lifetime to leave and find a new planet to colonise.

Other prize winners also emphasised the need to urgently take action. Michael Stanley Whittingham, who was awarded the 2019 Nobel Prize for Chemistry alongside scientists John B Goodenough and Akira Yoshino for developing the lithium-ion battery, urged that a realistic approach to the crisis should take place. "We've got to do things stepwise and have some solutions in mind," Whittingham said. "The time is right now, but we have to be pragmatic… we can't just turn off all the CO_2."

Esther Duflo, one of the Nobel economics laureates, said tackling climate change "will require a change in behaviour, particularly in rich countries" who consume a lot of the world's resources.

The independent

Large diversity

An Asia-wide genome-mapping project has discovered at least 10 ancestral lineages within Asia, revealing a large genetic diversity far exceeding that of other areas such as northern Europe, which has a single ancestral lineage that traces back to one common ancestor.

This study offers the widest coverage of genetic diversity in Asia as it analysed the DNA of 1,739 people across 64 countries. The paper was published in the research journal, *Nature*. Asians make up more than 40 per cent of the world's population, yet only six per cent of the world's recorded genome sequences were from Asians prior to this study. A genome is the total sum of an organism's DNA.

The study was conducted by GenomeAsia 100K, a non-profit consortium launched in 2016 and hosted by Nanyang Technological University in Singapore. It comprises three industry members from South Korea, India and the United States. The consortium aims to sequence 100,000 genomes of people living in Asia.

This study is especially significant in the area of healthcare and personalised medicine, where drug combinations can be tailored to one's genes to ensure optimum treatment.

Climate differences and migration history have also been found to shape the genetic make-up of Asia. The database was formed from analysis of new blood and saliva samples as well as existing samples that were collected over the last three decades.

These samples include 598 genomes from India, 156 from Malaysia, 152 from South Korea, 113 from Pakistan, 100 from Mongolia, 70 from China, 70 from Papua New Guinea, 68 from Indonesia, 52 from the Philippines, 35 from Japan, and 32 from Russia.

The strait times/ann

Light is the answer

Lasers and toaster-sized satellites are being used to beam information faster through space

GOTTFRIED LECHNER

Satellites are becoming increasingly important in our lives, as they help us meet a demand for more data, exchanged at higher speeds. This is why we are exploring new ways of improving satellite communication.

Satellite technology is used to navigate, forecast the weather, monitor Earth from space, receive TV signals from space, and connect to remote places through tools such as satellite phones and NBN's Sky Muster satellites.

All these communications use radio waves. These are electromagnetic waves that propagate through space and, to a certain degree, through obstacles such as walls.

Each communication system uses a frequency band allocated for it, and each band makes up part of the electromagnetic spectrum, which is the name given to the range of all types of electromagnetic radiation.

But the electromagnetic spectrum we are able to use with current technology is a finite resource, and is now completely occupied. This means old services have to make room for new ones, or higher frequency bands have to be used.

While this poses technological challenges, one promising way forward is optical communication.

Communication with lasers

Instead of using radio waves to carry the information, we can use light from lasers as the carrier. While technically still part of the electromagnetic spectrum, optical frequencies are significantly higher, which means we can use them to transfer data at higher speeds.

However, one disadvantage is that a laser cannot propagate through walls, and can even be blocked by clouds. While this is problematic on Earth, and for communication between satellites and Earth, it's no problem for communication between satellites.

On Earth, optical communication via fibre optic cables connects continents and provides enormous data exchanges. This is the technology that allows the cloud to exist, and online services to be provided.

Optical communication between satellites doesn't use fibre optic cables, but involves light propagating through space. This is called "free space optical communication", and can be used to not only deliver data from satellites to the ground, but also to connect satellites in space.

In other words, free space optical communication will provide the same massive connectivity in space we already have on Earth.

Some systems such as the European Data Relay System are already operational, and others like SpaceX's Starlink continue to be developed.

But there are still many challenges to overcome, and we're limited by current technology. My colleagues and I are working on making optical, as well as radio-frequency, data links even faster and more secure.

CubeSats

So far, a lot of effort has gone into the research and development of radio-frequency technology. This is how we know data rates are at their highest physical limit and can't be further increased.

While a single radio-frequency link can provide data rates of 10Gbps with large antennas, an optical link can achieve rates 10 to 100 times higher, using antennas that are 10 to 100 times smaller.

These small antennas are in fact optical lenses, and their compact size allows them to be integrated into small satellites called CubeSats.

CubeSats are not larger than a shoebox or toaster, but can employ high speed data links to other satellites or the ground.

They are currently used for a wide range of tasks including earth observation, communications and scientific experiments in space. And while they're not able to provide all services from space, they play an important role in current and future satellite systems.

Another advantage of optical communication is increased security. The light from a laser forms a narrow beam, which has to be pointed from a sender to a receiver.

Since this beam is very narrow, the communication doesn't interfere with other receivers and it's very hard, if not impossible, to eavesdrop on the communication. This makes optical systems more secure than radio electromagnetic systems.

Optical communication can also be used for Quantum Key Distribution. This technology allows the absolute secure exchange of encryption keys for safe communications.

What can we expect from this?

While it's exciting to develop systems for space, and to launch satellites, the real benefit of satellite systems is felt on Earth.

High speed communication provided by optical data links will improve connectivity for all of us. Notably, remote areas, which currently have relatively slow connections, will experience better access to remote health and remote learning.

Better data links will also let us deliver images and videos from space with less delay and higher resolution. This will improve the way we manage our resources, including water, agriculture and forestry.

They will also provide vital real-time information in disaster scenarios such as bushfires. The potential applications of optical communication technology are vast.

Banding knowledge together

Working in optical satellite communication is challenging, as it combines many different fields and research areas including telecommunication, photonics and manufacturing.

Currently, our technology is far from achieving what is theoretically possible, and there's great room for improvement. This is why there's a strong focus on collaboration.

In Australia, there are two major programmes facilitating this — the Australian Space Agency run by the federal government, and the SmartSat Cooperative Research Centre, also supported by the federal government.

Through the SmartSat CRC programme, my colleagues and I will spend the next seven years tackling a range of applied research problems in this area.

The writer is associate professor and director of the Institute for Telecommunications Research, University of South Australia.
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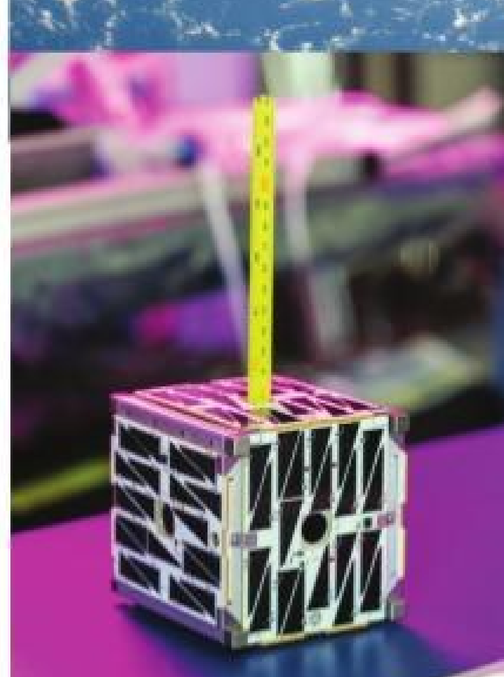
The electromagnetic spectrum we can access with current technologies is completely occupied. This means experts have to think of creative ways to meet our rocketing demands for data



The first CubeSats were launched in 2003 on a Russian Rocket launch vehicle