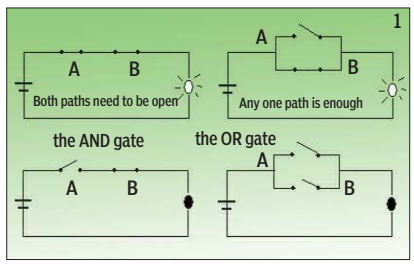
Simplifying a complex challenge

ONE LONG STRIDE HAS BEEN TAKEN ON THE MARCH TO QUANTUM COMPUTING, WRITES **S ANANTHANARAYANAN**

The physics of very small objects has features that make uncanny things possible. One of these is that outcomes of interactions are not clearly one or another, but a probability of each of different possible ways. A particle within a nucleus, for instance, has a probability of being outside the nucleus as well, which is why radioactivity is possible. The undisturbed state of the particle, in fact, is both within and outside, till a measurement is made. This quality, of things being in more than one state at once, unlike the usual condition of one or the other, suggests a new mechanism that can consider different possible values of the same variables in a calculation and a number of computations, all at once.



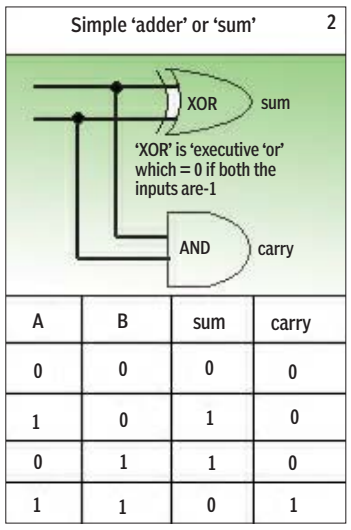
It was the legendary Richard Feynman who, as early as in 1982, had the insight to think of such a device. The idea was of using an object, like an electron, which could have a spin "up" or "down", in the same way as an electronic gate, which could be "open" or "shut", to represent the digits "0" or "1" of binary arithmetic. The idea held promise as the electron could be in both states at once, unlike the electronic device, but for many years there was no method to actually use this property for computation.

Finally, there was progress, first in proposed computational methods and then in actual devices, but the devices are rudimentary. Raj B Patel, Joseph Ho, Franck Ferreyrol, Timothy C Ralph and Geoff J Pryde of the Center for Quantum Dynamics, Griffith University and the University of Queensland in Australia and the Université of Bordeaux in France report in the journal *Science Advances* the development of a more complex unit to process quantum states that would simplify the challenge of implementing an actual quantum computation of reasonable complexity.

The way the regular computer deals with binary digits is with electronic gates, or devices that can pass electricity, or not, which are the two states to represent "0" or "1". Pairs of such devices can then make logical decisions, or "OR" or "AND" and pairs of these devices could be connected to add binary numbers.

In quantum computing, in place of electronic components or gates we use states of atomic assemblages, or properties like the nuclear spins in molecules, which can be either aligned or counter-aligned to represent the numbers "0" and "1", and each such unit is called a *qubit*. The qubits are manipulated using magnetic fields, radio frequency pulses or Nuclear Magnetic Resonance. Qubits, however, are very sensitive to disturbance, which destroys the condition of being in "all possible states at once", as disturbance acts as a measurement that causes the qubit to "commit" to one of its possible states and thenceforth in that state.

The physical qubit is, hence, a great challenge in implementing quantum computing. In principle, if we set up a system of, say, 100 particles to be in either of two states then we can mimic the action of a conventional computer with 2^{100} components. 2^{100} is a number with 30 zeros or an unimaginably huge number and our quantum computer of 100 particles would be able to do the most complex computation in a trice. But the best that we have been able to do with sophisticated arrangements is a four-particle system, which can manipulate $2^4 = 16$ states.



A	B	sum	carry
0	0	0	0
1	0	1	0
0	1	1	0
1	1	0	1

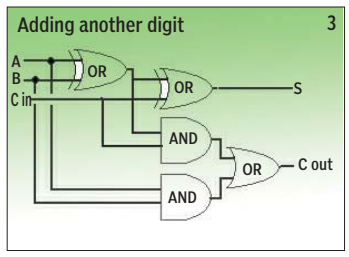
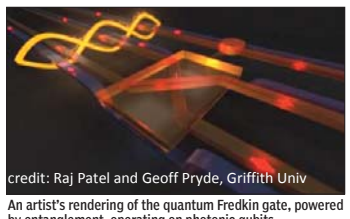


Figure 1 shows two kinds of gates and figures 2 and 3 show how the two kinds of gates can add two binary digits, and also "carry over" a digit to the next place, if the sum needs another digit to be expressed. In figure 1, the sum of A and B, for their four possible values, is 0, 1, or 2, which is written as "10" in binary arithmetic. The table then shows the rightmost digit of the answer under "sum" and the carry over of "1", in the fourth case. If there is a carry digit to be added from a previous addition, this is done by using another two gates, as in figure 3.

Algorithms

But even if we find ways to manage qubits, it is misleading to suppose that quantum computers would directly lead to high computing. Let us take a typical problem, say comparing two sets of 1,000 numbers to find duplicates. In the normal way, this would take 1,000 x 1,000 = 1 million comparisons. But with a quantum computer, we could have two components in 1,000 states each at the same time and carry out the comparison at once! True, but the system will still carry out a million comparisons and would not pick out the match, when found, and present it to us.



An artist's rendering of the quantum Fredkin gate, powered by entanglement, operating on photonic qubits.

The possibility of quantum computing looked promising only after clever methods were discovered to extract actual information from the "massive parallel" process of the quantum system. A famous one is the *Shor algorithm* for finding the two factors of a number generated by multiplying together two large prime numbers. This is a formidable task when the primes are, for instance, 64 binary digits long and the product is 128 digits long. One way of doing this is by dividing the number by all primes from the number, 2 onwards, to see which one produces no remainder. Conceivably, a quantum computer could carry out this check in reasonable time but, as in the case of finding duplicates, there is no way to say which division resulted in no remainder.

The Shor algorithm essentially restates the problem so that the result of quantum computing is not all the possible solutions together but only the one of interest. It first relies on an old result that was known since the 18th century, about cycles in division of a series of powers of the number 2. Let us consider a series like this: 2, 4, 8, 16, 32, 64, 128, 256, 512, 1,024...

Now we list out the remainders when we divide each of these numbers by the number 15, which is the product of prime numbers 3 and 5. We get: 2, 4, 8, 1, 2, 4, 8, 1, 2, 4…

What do we notice? That the remainders form a sequence of four numbers that repeat. Well, the 1760s result is that the number of remainders that repeat must be a divisor of the product of one less than the two prime numbers involved. In our case, the primes were 3 and 5. Now 2 x 4 = 8, and we see that the number 4, in the sequence of remainders, is a divisor of the number 8.

The reader could try it out with the number 21, which is the product of the primes 3 and 7.

The number of remainders that repeat are 6 and (3-1) x (7-1) = 12, which is a multiple of 6. In the case of the factorising problem, then, a quantum computer could quickly find the periodicity of remainders and, hence, a divisor of the product of the two primes, less one. This is still not the answer, but a step closer. The Shor algorithm then relies on the properties of quantum mechanical states that result in remainders and finds that all these "wrong answer" states would cancel and not appear in the solution, which would then contain only the correct answer!

Fredkin gate

The work of the *Science Advances* authors is regarding an arrangement like the quantum mechanical "AND" or "OR" gate in the actual computation. These gates are challenges by themselves and for a problem of any complexity we would need a very large number of them. There is, hence, an advantage in creating single, more complex modules to reduce the total numbers required in practice. "Similar to building a huge wall out of lots of small bricks, large quantum circuits require very many logic gates to function. However, if larger bricks are used the same wall could be built with far fewer bricks," says Dr Raj Patel, from the Griffith's Centre for Quantum Dynamics at Brisbane.

Just as there are the "AND" and "OR" gates, there is also the *Fredkin gate*, whose action is to switch the states of two qubits depending on the state of a third qubit. In binary arithmetic, switching states of binary units like qubits is a real arithmetic operation, as also a logical one. The Fredkin gate is, thus, a useful unit in more complex computations and it takes the place of a number of other devices. Implementing a Fredkin gate is, thus, a means of eliminating many others and, hence, simplifying the whole task.

"Although the salient features of quantum computing have been shown in proof-of-principle experiments, difficulties in scaling quantum systems have made more complex operations intractable. This is exemplified in the classical Fredkin (controlled SWAP) gate, for which, despite theoretical proposals, no quantum analog has been realised," say the authors. The team has now demonstrated the quantum Fredkin gate using photons, or particles of light, which can be in two distinct states of polarisation, or planes of vibration of electro magnetic waves. The team is able to generate stable three-photon states, where the state of a two-qubit system can be controlled. This "paves the way for larger controlled circuits to be realised efficiently", the authors say.

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EFFECTIVE CONTROLLERS

TAPAN KUMAR MAITRA HAS THE LOWDOWN ON TWO BACTERIAL AGENTS THAT HINDER THE PROLIFERATION OF INSECTS

The main way of artificially causing bacterial diseases in insects is by overall application of pathogenic bacterial agents. Insects, comprising over 90 species, are killed by bacteria among which are obligate and facultative parasites. The greatest practical successes have been achieved by applying spore-forming bacteria of the group *Bacillus thuringiensis* on the leaf-eating species of *Lepidoptera*. A feature of these bacteria is the formation in the cells — in addition to spores — of crystalline inclusions containing substances toxic to insects. The spore-forming bacteria *Bacillus popiliae* and *Bacillus lentimorbus* are used successfully for controlling the Japanese beetle.

Positive results have been obtained in tests involving the use of bacteria of the genus *Pseudomonas* on leaf roller and gypsy moths, the *Bacterium prodigiosum* to control turnip moths, beet weevils, pine moths, and the *Enterobacter Cloacae* for locusts. To date, however, practical recommendations for the use of these bacteria have not yet been worked out. Let's take a look at two such bacterial agents for controlling insects.

Entobacterin, which is an active ingredient consisting of live spores and toxic protein crystals in the endotoxin of the bacterium *Bacillus thuringiensis var galleria*. The culture of the bacterium was separated from the bee moth and the formulation may be stored for two years at a temperature between -30 and +30°C. Entobacterin is very sensitive to an increase in humidity and therefore, it must be kept with a relative air humidity not exceeding 60 to 70 per cent especially at high positive temperatures. It must be stored away from pesticides.

The formulation is ingested into an insect's body together with its food. If the amount of absorbed protein endotoxin is sufficiently high, the insect rapidly dies. At smaller doses, only paralysis is observed, but the insect stops feeding and therefore causes little harm to plants. In the intestine bacteria begin to reproduce from the spores, fill the tissues, and the insect dies because of general infection. As a result of weakening of the insect under the influence of the endotoxin, the usual intestinal microflora also becomes active and pathogenic. The resistance of various species of insects to entobacterin varies and depends on the composition of the intestinal microflora. This is why various rates of use of the substance are needed for different species of pests.

Entobacterin is effective against more than 50 species of leaf-eating pests of vegetable, fruit, and berry crops in gardens, parks, and forests. Ermine and smoky moths, loopers, and white butterflies are the least resistant to it. Noctuid moths have a relatively high resistance.

Entobacterin may be applied during any period of vegetation, including blossoming and harvesting. The rates of use of the formulation and the concentration of the suspension depend on temperature, pest species, crop, and also, on the apparatus used. The optimal temperatures are from 20-30°C.

A prepared working suspension must be used immediately because its effectiveness lowers when stored for two or three hours. Cold water should be used when possible to prepare the suspension and ensure that non-germinating spores get onto the plants. Spraying is performed in the period of development of actively feeding caterpillars, preferably of the younger ages. Treatment should be carried out in the same hours as conventional chemicals and any time of day is suitable.

Entobacterin applied to plants retains its potency

for eight to 10 days, after which the activity gradually diminishes. The dose of entobacterin can be reduced by using it in combination with decreased doses of pesticides (carbaryl, trichlorfon, dicofol) thereby causing physiological weakening of insects. Another active ingredient called dendrobacillin consists of live spores of the crystal-forming bacterium *Bacillus dendrolimus* whose culture was separated from caterpillars of the pine moth. The control agent is a dry homogeneous powder of a light-gray or grayish-pink colour and its moisture content is up to 5 per cent. It must be stored in dry cool places away from insecticides and the storage period is 12 months.

Dendrobacillin gives good results when food is infected. It is effective on numerous insect pests such as cone moths and pine loopers, brown-tail and cabbage moths, large white butterflies, and a number of harmful *Lepidoptera* in gardens. It is mainly intended for controlling moths and worms on cotton — bollworms, turnip moths, and armyworms, and is used in combination with carbaryl. It is best to spray it early in the morning in good weather or in the evening. The toxicological and hygienic characteristics are similar to those of entobacterin.

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Walking up waterfalls

THE ANATOMY OF A SPECIES OF CAVE FISH COULD HELP US UNDERSTAND HOW OUR ANCESTORS EVOLVED, WRITES **DOUG BOLTON**

A species of cave fish has been documented "walking" up waterfalls like a lizard in a discovery that could have "major" implications for our understanding of evolution. A team of researchers from the New Jersey Institute of Technology travelled to Thailand to study *Cryptotora thamolica*, a species of blind fish found in a handful of caves. Only around 2,000 of them exist in the wild.

There are other types of fish that use their fins to "walk" across the sea bed, usually with a rudimentary hopping motion. The cave fish is very different, however, since it climbs up steep rock faces covered by fast-moving waterfalls using its fins, moving in a similar way to a salamander. Videos of the fish show this unusual movement — twisting its body from side-to-side, it uses its front and rear fins to take steps up the face of the waterfall. To the untrained eye, it looks more like a lizard than a fish.

A study detailing the team's discovery, which was contributed to by Thai researchers and includes the findings of a CT scan of a specimen, was published in the high-profile *Nature Scientific Reports* journal on 24 March. Speaking about the investigation, Brooke Flammang from the NJIT said she had never come across a similar creature in her entire career. "From an evolutionary perspective, this is a huge finding. This is one of the first fish that we have which is a living species, which acts in a way we think fish must have acted when they evolved from a fluid environment to a terrestrial environment at the very beginning of the fin-to-limb transition, when the first limbs evolved in our earliest ancestors."

In effect, the humble cave fish can offer biologists a glimpse of what life may have looked like around 400 million years ago, when the oldest ancestors of humans began to walk on land.

The *Cryptotora thamolica* uses its fins to walk like a lizard.

Since the fish are so rare, it's difficult to study them with conventional means and more investigations will need to take place to unlock its significance for evolution. The species' lack of eyes also throws up more important questions for researchers. "How do they find each other and make babies? How do they sense where their food is? All of these are interesting and important questions," Flammang said.

Meanwhile, according to a recent report, a snub-nosed monkey that sneezes when it rains, a walking fish and a jewel-like snake are among more than 200 new species discovered in the eastern Himalayas. It reveals that 133 new species of plants, 39 invertebrates, 26 fish and 10 amphibians have been found there since 2009 — a scale of discovery that confirms the region, spanning Bhutan, Northeast India, Nepal, north Burma and southern Tibet, as being among the most biologically diverse in the world. One new bird — the spotted wren-babbler — was also discovered in the region over the period, as well as one reptile and one mammal species — bringing the total new species discovered in the region in the past 15 years to 550.

The region's rich diversity — one in 10 of the world's bird species lives there — is largely put down to a landscape of steep mountains and valleys. This has created isolated habitats with many species that are unique to the area, according to the wildlife charity WWF, which produced the report.

One of the more unusual species discovered in recent years is Snubby, the nickname given to *Rhinopitecus Strykeri*, a black and white snub-nosed monkey that locals claim is easy to find when it is raining. This is because rainwater gets into their upturned noses causing them to sneeze — an eventuality they avoid if they can by sitting with their heads tucked between their knees.

The vibrant blue dwarf walking Snakehead fish is another unusual find. Amazingly, it is able to breathe atmospheric air and can even survive on land for up to four days. And while its movements on land may appear more cumbersome than a smoothly slithering snake, it can writhe and wriggle its way up to a quarter of a mile on wet land between bodies of water.

The newly discovered bejewelled lance-headed pit viper, meanwhile, is emblazoned with an ornate yellow, red and orange pattern that, at first glance, looks like a carefully crafted piece of jewellery.

THE INDEPENDENT

PLUS POINTS

Face-scanning car

A face-scanning police car has been developed by a Chinese university which could help in chasing and

arresting wanted criminals. The intelligent vehicle, developed by the University of Electronic Science and Technology of China in Sichuan Province, will be first tested in east Zhejiang Province in June, the university said.

The car is equipped with rooftop cameras that capture faces within a radius of 60 metres, even at a speed of 120 kmph. The images are then sent through the police database and, if matches are found, an alarm is sounded. Its other functions include detecting information on vehicles and identifying mobile phones in its proximity. Its engine also consumes less oil and discharges less carbon dioxide.

"The new car is not just a means of transportation. It is more like a smart law enforcement system on wheels," said Yin Guangqiang, director of the Police-use Advanced Technology Institute at the university. China's police cars are mostly refitted with commercial models according to the needs of local authorities.

Minimal genome

By stripping down the genome of a mycoplasma bacterium to the minimal genes required for life, Craig Venter and colleagues have created a new organism with the

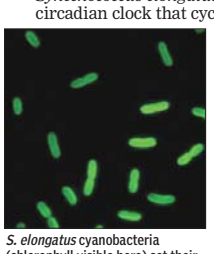
smallest genome of any known cellular life form. The work, published in *Science*, is the closest scientists have come to creating a cell in which every gene and protein is fully understood — but they are not quite there yet.

The quest to synthesise a minimal genome with only the essential genes for life is one researchers at the J Craig Venter Institute in San Diego have been doggedly pursuing for the better part of two decades. Clyde Hutchison, an investigator at the institute and lead author of the new study, explained the motivation, "We want to understand at a mechanistic level how a living cell grows and divides. There is no cell that exists where the function of every gene is known." Possession of such fundamental knowledge, he added, would also put researchers "in a better position to engineer cells to make specific products", like pharmaceuticals.

RUTH WILLIAMS/THE SCIENTIST

Sugar time

Like many organisms, the photosynthetic cyanobacterium *Synechococcus elongatus* has a circadian clock that cycles with



S. elongatus cyanobacteria (chlorophyll visible here) set their circadian clocks by metabolism rather than light.

light/dark rhythms. The timekeeper has just three core proteins — KaiA, KaiB and KaiC — making it the simplest circadian clock known to science. Given that researchers have failed to identify light-sensitive clock components in *S. elongatus*, but have demonstrated that Kai proteins respond to metabolic activity, some scientists suggest that cyanobacteria are synchronising to the downstream metabolites of photosynthesis, as opposed to light itself.

To tease apart light-dark cycles and metabolism, researchers led by Michael Rust at the University of Chicago engineered a strain of *S. elongatus* that could grow without photosynthesis by metabolising externally supplied glucose. The team found that these cyanobacteria's clock phases were essentially unresponsive to light cues in the presence of glucose, and that in constant darkness they could be entrained by a periodic glucose supply. The results establish metabolic activity as the primary clock driver in *S. elongatus*. "All you need is a metabolic cycle and the (clock) proteins will follow it," says Rust.

CATHERINE OFFORD/THE SCIENTIST