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Nature and the optimal

Nature manages nearly 100% efficiency in energy conversion through photosynthesis, says S.Ananthanarayanan.

Life on earth owes its existence to plants which use sunlight to change carbon dioxide into carbohydrates. This powers life and also draws out carbon dioxide, the greenhouse gas, from the atmosphere. If we could harness sunlight in this way, we could solve our growing energy needs and also stave the scepter of global warming. But more enticing is the near perfect efficiency of natural photosynthesis. Gregory Scholes at Toronto and Rienk van Grondelle at Amsterdam report in ***Nature*** a major development of the understanding nature's secret of efficiency

Tapping sunlight

All energy sources we have, of course, are based finally on sunlight. Coal based energy is to recover the sun's energy stored in coal deposits and hydroelectric energy also taps the sun's energy, which moves water from the seas to mountains and river valleys. But these are indirect routes to recover energy and the efficiencies are low. The coal powered steam engine does no better than 30-40% and in hydro projects there is much waste in the mechanical processes involved.

Nature's method, on the contrary, where green plants or some bacteria snare sunlight and transfer energy to their internal store, is found to be over 95% efficient. Not only have molecular devices, to trap sunlight in different stages, been evolved, but the process has design features that practice optimization principles that are the very base of the laws of science.

The apparatus

The actual trapping of photons happens at light harvesting proteins that plant tissue contains. The solar photons excite electrons in pigment molecules and the energy is guided to another set of proteins which drive chemical processes that collect and store the energy, typically as carbohydrates. But the process of transfer, from the photon to the carbohydrate has evolved, in photosynthetic systems, to manage with the highest possible thermodynamic efficiency.

A first design issue is that the energy of one photon is not sufficient to activate economical storage. Collection, then, has to be extensive and fine-grained. Next the transfer path needs to be efficient, with the least intermediate steps and the transfer from different collectors needs to be coordinated, for efficient reception and conversion.

Nature has thus provided an extensive array of photon gatherers, absorbing and feeding electronic excitation to the reaction centre. Having this arrangement also distributes the comparatively simpler, photon sensing terminals and limits the number of complex energy processing factories. And then, the photon gatherers can be of different types, to cater for different colours of incident sunlight and also for different conditions of light and shade.

The evolution of the system has optimized the orientation and spacing of these components for the best efficiency. Even the orientation of the leaves of a plant, each of which contains countless photosynthesis arrangements, is seen to follow remarkable mathematical patterns, to optimize the amount of sunlight that the whole plant can collect (see box).

Quantum computing

But the most amazing fact that has been revealed of late is that the actual transfer, from the photon collectors to the reaction centre, is coordinated to happen with perfect efficiency with the practical use of quantum computing, a concept that promises the ability to instantly perform calculations that may otherwise take years or centuries. The concept is still very much only in the minds of scientists and has been realized, with elaborate arrangements, only for the simples problems. And yet, photosynthesis is seen to be using this every second to capture and store solar energy.

The first great advances of science, which led to understanding the solar system, the steam engine, the automobile, wireless and electricity, had their basis on Isaac Newton's formulation of the laws of motion. But these laws proved deficient when faced with radioactivity and the nature of the atom, or the exact way a hot object radiated heat.

Physics then had to be reformulated, to provide that energy could not be transferred continuously, or in a stream, but had to be passed in discrete parcels, known as ***quanta***. Light itself was not viewed as a wave, but as a train of packets called ***photons*** and the smallest particles, like electrons, showed wave-like properties. This way of thinking solved the difficulties in understanding radiation, the unique colours of light from different elements, the structure of the atom and nuclei, and all else that is understood in modern times.

A consequence of this new formulation is that as particles have a wave-like nature, their location cannot be specified beyond a limit and there would always be some ***blur*** or uncertainty. There would then be not one but a series of possible of outcomes of interactions and even some traditionally impossible outcomes become feasible. An instance is radioactivity, where a particle that is locked inside an atom by an energy barrier is still able to '***leak***' through.

Quantum mechanics thus describes an independent particle or a system as not in one or other of its permitted states, but in all of them, including the unlikely ones, at the same time. If the particle or system interacts, or is measured (which is the same thing), it will slip into one of the possible states, the more probable ones more often, but till it is measured, it is all of them!

This idea, of a system being in many states at once suggests a method of making massive, sequential calculations all at the same time. Answers to many problems in industry and management cannot be found analytically but only by trying out combination after combination, till the one that works is found. There could be dozens or even thousands of variables, and each could have many possible values. The number of trials could then run into billions and more and grow out of reach.

The idea of physical systems, like a collection of atoms, that represent the variables, with each one being in all its possible states at once, then suggests algorithms (or methods of computation) to carry out massive parallelism. To realize the idea, however, has been elusive, as it is difficult to maintain the systems in the undisturbed and 'coherent' state long enough to make the calculation and the only success has been at Yale University, with two groups of aluminum atoms to occupy one of two states – which amounts to making four comparisons at once.

Photosynthesis does it

But the photon gathering terminals in plants and some bacteria seem to exist for long periods in this state where each and all are in all states and have not committed, till they can pass on electron excitation to the collection centre with the least energy loss. The various conventional, 'random decay' models of energy transfer all result in efficiency less than what is seen and it is only with quantum parallel processing that what is seen can be explained.

In 2007, Graham R Fleming of California, and colleagues reported a periodic, 'wave' behavior, so called 'quantum beats', of the energy transfer in a bacterium that showed photosynthesis. The persistence of variations in signal intensity for several femtoseconds (a billion billionth of a second, a long time for atomic systems) was characteristic of coupling of the different electronic states, to decay through the easiest path to the reaction centre.

This study did show that there was quantum computing going on, but it was conducted at low temperature, about 200˚C below freezing, where atomic motions are slow. It was hence still academic and could be compared to the Yale quantum computer of Aluminum atoms. But the result now reported by Scholes and Grondelle is of a system working at room temperature. In this study, photosynthesizing organisms were excited using a pair of laser pulses, to create a population of excited electronic states. The system was then exposed to a delayed, third pulse, and the response studied, to reveal the state of coupling of the different electronic states.

The study revealed lifetimes of coherent states well beyond what is normally expected, and is explicable only as the result of quantum effects. Being a study at room temperature, this is more convincing evidence that quantum computing exists in the real world conditions of chlorophyll and plants.

Plants, numbers and sunshine

There is a category fractional numbers known as 'irrational numbers'. These are numbers that cannot be expressed exactly in the form of x/y, or ratio of two whole numbers.

Any fraction of the form x/y can be solved, either exactly or in the form of a recurring decimal sequence. But numbers, like the square root of 2, or the exact value of π (pi), the ratio of the circumference of a circle to its diameter – the value, 22/7, is only an approximation) are such numbers.

A mathematician called **Fibonacci** discovered a series of numbers like this:

1, 1, 2, 3, 5, 8, 13, 21, 34, 55, 89, 144, 233……………..

In this series, each number is the sum of the previous two numbers. We can see that 2=1+1, 3=2+1, 5=3+2, 8=5+3…. 233=144+89 and so on.

The interesting thing is that the ***ratio*** of successive terms tends to become the same, as we go higher into the series

1/1=1	2/1=2	3/2=1.5
8/5=1.60	13/8=1.625	21/13=1.615
55/34=1.6176	89/55=1.6182	144/89=1.61797

The ratio gets closer and closer to **1·61803 39887**..., and it can be shown that the final ratio can never be expressed as a fraction of whole numbers.

But what is more interesting is that the leaves of a plant, arranged in a rising spiral, naturally not one above the other, are actually arranged according to the Fibonacci numbers. This seems to be to ensure that no leaf will ever come exactly above another leaf and the plant always gets the best of sunshine!!