Molecular computers evolving fast

Processing in future could be done using thin films of molecules exhibiting 'circuit evolution'

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A problem-solving layer of organic molecules that exhibits "circuit evolution," like nerve cells in the brain, has been developed by an international team of scientists. With this success, intelligent robots may be a little bit closer to reality.

The team — comprised of researchers from Japan's National Institute for Materials Science (NIMS) and National Institute of Information and Communications Technology, as well as Michigan Technological University in the U.S. — developed a monolayer of organic molecules that can be used for massive parallel computing. They published the research results in British science magazine Nature Physics in April this year.

Their technology is a kind of molecular computer. But the group's "molecular computer" is an assembly of molecules that shares only two things in common with conventional computers: the name "computer" and the fact that the system provides answers to input questions. Otherwise, the film looks nothing like a computer and is used in a completely different way. It is far from the conventional computer both in appearance and in use.

Whereas a normal computer is built from semiconducting devices, hard disks and the like, the new technology is nothing more than a thin film of organic molecules spread on a substrate. Each molecule is around 1 nanometer in diameter and the entire structure is a square matrix of 30 molecules on a side. The molecular layer itself is the computer. Too small to see with the naked eye, it is observed and manipulated using a scanning tunneling microscope.

Neighbor processing

Information is processed on this molecular layer, but not in any way like the digital processing of electronic signals. What happens is that each molecule changes the bonds it makes with its neighboring molecules. The "one-to-many interactions" made by each molecule can take eight different forms. Input and results output are not arrays of 0s and 1s, but are a pattern of figures. That is why this technology is called pattern-based computing.

Since nearby groups of molecules tend to adopt the same kinds of bond interactions, a mosaic pattern emerges in the film as different sections of the film compartmentalize. Each compartmentalized section of the film is treated as a different computer circuit. Since the molecules can interact with their neighboring molecules in any of eight different ways, the organic molecular layer can evolve many different possible circuits.

When a problem-solving task is entered to this molecular assembly, the shapes and sizes of the partitions (that is, the circuits) change as the molecules interact, and this is visualized by a change in the mosaic pattern. The changes are indicative of the ways the circuits have been reconfigured. In essence, one molecular computer has evolved into a different molecular computer. A "problem" is entered by using the STM to apply electrons and draw a pattern that will serve as the starting base for the eventual solution.

Testing for mutants

In one test, the research team used their molecular assembly to stimulate the mutation of normal cells into cancer cells when different tumor suppressors interfere with each other. When two concentric rings were drawn with the STM as the input, a pattern evolved to display a mass in the center representing the emergence of cancer cells.

Researchers expect molecular computers of this kind to be able to solve the kinds of problems that are very difficult to solve with regular computers, such as predictions of natural disasters and outbreaks of disease. The construct can be applied to studies of many-body systems like climate modeling, which even a supercomputer needs a huge amount of time to crunch through, and should also excel at image recognition tasks.

But what is also interesting is that emergent computing based on assemblies of molecules as demonstrated here shows evidence of intelligence. Simple data processing as performed by a computer is not the same as intelligence. Consider the task of separating a set of shapes into two groups, one for the shapes that share similarities and the other for all the other shapes. A person could simply look at the shapes and sort them with relative ease.

First step

But a conventional computer has a terrible time finding the shapes that are similar because it identifies even small differences. Meanwhile, the organic molecular layer is good at grouping tasks of this kind, providing the same answer for similar inputs. "The ability to classify like this is the first step toward intelligence," asserted Anirban Bandyopadhyay, a researcher at NIMS. Without that ability, higher intelligence probably would have never evolved, because things cannot be identified before being classified.

As an evolutionary computer, the molecular layer resembles the organization of the brain: the molecules are the neurons, the evolutionary circuits are the neural networks, and the molecular layer in its entirety is the brain — a step closer to the intelligent brain of humans. In the future, this kind of work may lead to the realization of robots with the intelligence to learn without being taught.

Keywords

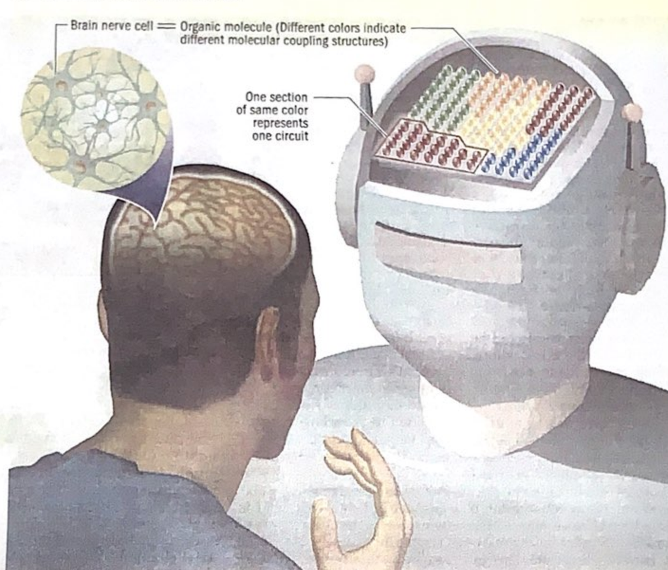
Evolutionary circuit

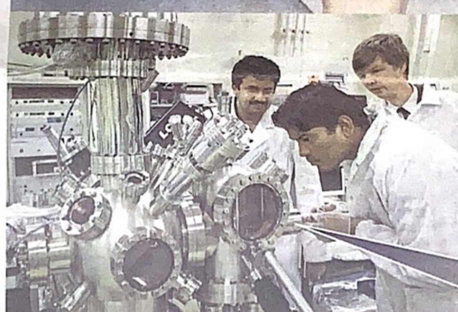
In a conventional computer built from semiconductor devices, once the circuits have been fabricated the architecture is pretty much fixed. In contrast, evolutionary circuits are reconfigurable. With evolutionary circuits, complex problems can be processed with flexibility by reconfiguring the circuit architecture. This resembles the self-evolutionary process of neural network reconfiguring that takes place inside the human brain.

Evolutionary circuits can be built even into a normal computer by preparing a number of different circuit structures ahead of time. But the selection of evolutionary paths is limited to six or seven different circuit structures at most. In comparison, the tiny organic molecular layer built from a matrix of just 30 x 30 molecules has a billion quadrillion different possible circuit structures (that is 1 septillion, a 1 followed by 24 zeros).

The term "evolutionary" here does not imply that the network of molecules in the layer can evolve to process information faster or perform better. Rather, it means that the molecules, like the neurons in the brain, can self-rearrange their interconnections and reconfigure their circuits in order to solve complex tasks.

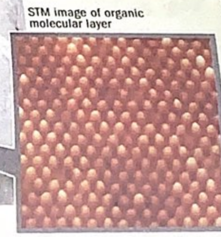
Dawn of intelligent robot
Structure of organic molecular computer



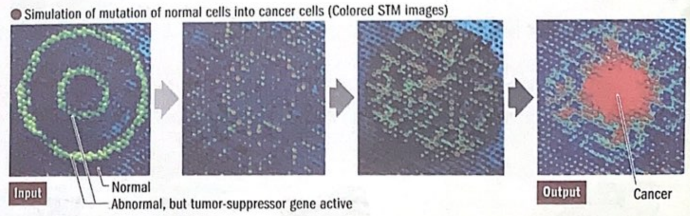


Researchers Bandyopadhyay, left, and Peper, right, work with a machine used for making and visualizing organic molecular layers.

STM image of organic molecular layer



● Simulation of mutation of normal cells into cancer cells (Colored STM images)



STM images, simulation images courtesy of Nature Physics magazine, National Institute for Materials Science

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