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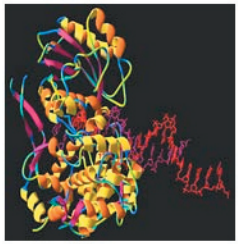
Computer Made from DNA and Enzymes

Stefan Lovgren
for National Geographic News
February 24, 2003

Israeli scientists have devised a computer that can perform 330 trillion operations per second, more than 100,000 times the speed of the fastest PC. The secret: It runs on DNA.

A year ago, researchers from the Weizmann Institute of Science in Rehovot, Israel, unveiled a programmable molecular computing machine composed of enzymes and DNA molecules instead of silicon microchips. Now the team has gone one step further. In the new device, the single DNA molecule that provides the computer with the input data also provides all the necessary fuel.

The design is considered a giant step in DNA computing. The Guinness World Records last week recognized the computer as "the smallest biological computing device" ever constructed. DNA computing is in its infancy, and its implications are only beginning to be explored. But it could transform the future of computers, especially in pharmaceutical and biomedical applications.



Israeli scientists have devised a computer composed of DNA and enzymes. The enzyme FokI breaks bonds in the DNA double helix, causing the release of enough energy for the system to be self-sufficient.

Photograph courtesy of Kobi Benenson/Adapted from PDB ID: 1FOK
D.A. Wah, J.A. Hirsch, L.F. Dorner, I. Schildkraut, A.K. Aggarwal. Structure of the Multimodular Endonuclease FokI Bound to DNA.
Nature *388 pp. 97-100 (1997)*

Following Mother Nature's Lead

Biochemical "nanocomputers" already exist in nature; they are manifest in all living things. But they're largely uncontrollable by humans. We cannot, for example, program a tree to calculate the digits of pi. The idea of using DNA to store and process information took off in 1994 when a California scientist first used DNA in a test tube to solve a simple mathematical problem.

Since then, several research groups have proposed designs for DNA computers, but those attempts have relied on an energetic molecule called ATP for fuel. "This re-designed device uses its DNA input as its source of fuel," said Ehud Shapiro, who led the Israeli research team.

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Think of DNA as software, and enzymes as hardware. Put them together in a test tube. The way in which these molecules undergo chemical reactions with each other allows simple operations to be performed as a byproduct of the reactions. The scientists tell the devices what to do by controlling the composition of the DNA software molecules. It's a completely different approach to pushing electrons around a dry circuit in a conventional computer.
To the naked eye, the DNA computer looks like clear water solution in a test tube. There is no mechanical device. A trillion bio-molecular devices could fit into a single drop of water. Instead of showing up on a computer screen, results are analyzed using a technique that allows scientists to see the length of the DNA output molecule.
"Once the input, software, and hardware molecules are mixed in a solution it operates to completion without intervention," said David Hawksett, the science judge at Guinness World Records. "If you want to present the output to the naked eye, human manipulation is needed."
Don't Run to the PC Store Just Yet
As of now, the DNA computer can only perform rudimentary functions, and it has no practical applications. "Our computer is programmable, but it's not universal," said Shapiro. "There are computing tasks it inherently can't do."
The device can check whether a list of zeros and ones has an even number of ones. The computer cannot count how many ones are in a list, since it has a finite memory and the number of ones might exceed its memory size. Also, it can only answer yes or no to a question. It can't, for example, correct a misspelled word.
In terms of speed and size, however, DNA computers surpass conventional computers. While scientists say silicon chips cannot be scaled down much further, the DNA molecule found in the nucleus of all cells can hold more information in a cubic centimeter than a trillion music CDs. A spoonful of Shapiro's "computer soup" contains 15,000 trillion computers. And its energy-efficiency is more than a million times that of a PC.
While a desktop PC is designed to perform one calculation very fast, DNA strands produce billions of potential answers simultaneously. This makes the DNA computer suitable for solving "fuzzy logic" problems that have many possible solutions rather than the either/or logic of binary computers. In the future, some speculate, there may be hybrid machines that use traditional silicon for normal processing tasks but have DNA co-processors that can take over specific tasks they would be more suitable for.
Doctors in a Cell
Perhaps most importantly, DNA computing devices could revolutionize the pharmaceutical and biomedical fields. Some scientists predict a future where our bodies are patrolled by tiny DNA computers that monitor our well-being and release the right drugs to repair damaged or unhealthy tissue.
"Autonomous bio-molecular computers may be able to work as 'doctors in a cell,' operating inside living cells and sensing
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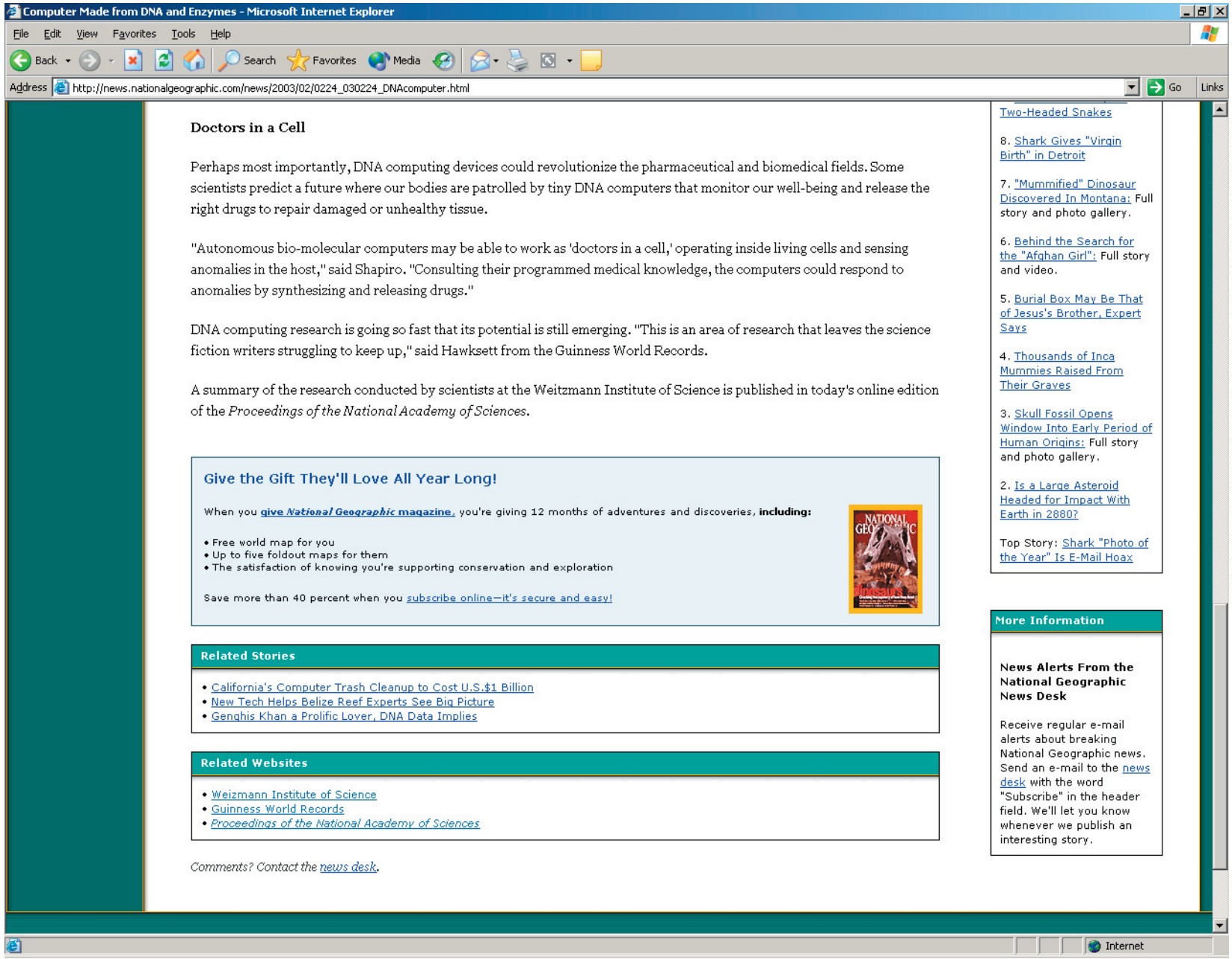
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Doctors in a Cell
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"Autonomous bio-molecular computers may be able to work as 'doctors in a cell,' operating inside living cells and sensing anomalies in the host," said Shapiro. "Consulting their programmed medical knowledge, the computers could respond to anomalies by synthesizing and releasing drugs."
DNA computing research is going so fast that its potential is still emerging. "This is an area of research that leaves the science fiction writers struggling to keep up," said Hawksett from the Guinness World Records.
A summary of the research conducted by scientists at the Weitzmann Institute of Science is published in today's online edition of the Proceedings of the National Academy of Sciences.
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