Will Future Computers Be Made of DNA?

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Your pentium is never going to be replaced with one made of DNA. But computers with DNA processors may shortly perform computations too large to be run on electronic supercomputers.

The basic motivation is simple. *The* purpose of life is to process information encoded in DNA. That is: life exists precisely to process information encoded in DNA. Accordingly, evolution has spent billions of years refining its information processing tools, tools such as a wealth of enzymes, copying mechanisms, proofreading mechanisms, etc. Over the past few decades, molecular biologists have begun to unravel many of these mechanisms– and what's more they have gained the ability to apply some of them in the lab.

So the idea of DNA Based computing is to subvert these mechanisms produced by evolution, and use them to do data processing we want to do. So we will encode in DNA information specifying some big computational problem we would like to solve, but maybe too big to be solved on a supercomputer, and then use the tools of molecular biology to process this information.

What do we hope to gain by this? Well, we'd be storing and manipulating information at a *molecular* level. In a hot-tub sized vat of DNA, at normal laboratory concentration, one might imagine having 10^{21} DNA molecules, each encoding potentially 400 bits of information. That's one hundred thousand billion times as much information as you can store in your 1 Gig Disk. And each of these molecules acts, in a sense, as a separate processor in a giant multi-processor machine. So we have, in effect, a thousand billion billion processors.

Sounds pretty exciting, not to say Saganesque. But there are some problems and hurdles, of course. One problem is that the algorithms proposed so far use molecular biological operations which are really slow. Remember how long it took to process O.J.'s blood? Ever have a blood test to see if you have Lyme disease? It takes days to come back from the lab. Each primitive operation in the DNA computer takes hours. That's a clock rate maybe 10^{11} times slower than your 100 megahertz pentium. That's why you don't have to worry about a DNA based computer replacing your pentium. It will never produce fast reponse on simple problems. What it might do is bring its 10^{21} processors to bear, to make up for its slow speed with pure parallel power or massive memory, on some problem too big to fit or run in a silicon machine. The hope is to do a computation in, say, six months of lab work, that would take millions of years on the most powerful supercomputer.

But there are other hurdles. For one thing, these processes take hours when you run them with a small test tube of DNA. When you scale up to the vast amounts of DNA we're talking about, they may slow up dramatically. Another problem is hydrolysis. Your DNA molecules can break- meaning a DNA molecule which was part of your computer is now fractured. So over the six months that you are computing, your DNA computer is gradually turning to water! Another problem is that every operation you want to do in your DNA computer, is somewhat random. Unlike the transistors in your pentium– which reliably compute what they're supposed to– the components in the DNA computer are probabilistic. If some little tiny subcircuit is supposed to give the answer 1, what you might actually get is 1 90% of the time and 0 10% of the time. So to make DNA computing work you have to figure out how to build a reliable computer out of noisy components. Another problem concerns the model of the DNA computer as a highly parallel computer- with each DNA molecule a separate processor. In a standard multiprocessor- say a Connection machine or a Cray- there are busses transmitting information from one processor to another. In the DNA computer- how do you transmit information from one molecule to another? This is not really solved. Current DNA algorithms succeed in computing without passing any information, but this limits the flexibility of the approach.

And finally, a big hurdle, what giant problem do you want to use DNA to compute? Noone has yet suggested a concrete problem, and a concrete algorithm for solving it using DNA, which you really want to solve, and couldn't solve faster some other way. What is the killer ap?

All these obstacles sound daunting. Any one of them might be enough to kill DNA computing if it can't be solved. But computer scientists are very inventive, and have all kinds of creative ideas for overcoming these problems and realizing the great potential of DNA. DNA computing is where silicon computing was the year after the transistor was invented. It doesn't do anything very useful yet, but who knows what might happen if you play with it a bit?

So the bottom line is, DNA computing is not a here and now practical technology- it is a blue sky research project. It has astounding possibilities- but its going to take a lot of good ideas, hard work, and luck, for its potential to be realized. My predictions? DNA computers will eventually be made to work on moderately large problems. But it will take long enough to get to this point, and the capabilities of the DNA computer will have to be scaled back enough to overcome the hurdles, that they will not compete successfully with traditional supercomputers. I hope this is too pessimistic, but its my best guess.

At a minimum, though, I think that having computer scientists think about using DNA for artificial computing is going to shed a whole new perspective on the computing DNA does in living creatures. To date only biologists have thought about these issues, and computer scientists have different and potentially critical insights to offer. If the purpose of life is to process information stored in DNA, then in trying to perfect DNA computing we are in a sense trying to create life. There's no better way to understand something than by trying to build it. I expect breakthroughs, I'm just not sure what they will be.