NANOTECHNOLOGY

AUTHORS:

R.VENKATESH
M.RAVINDREN

SREE SOWDAMBIKA COLLEGE OF ENGINEERING
ARUPPUKOTTAI

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Abstract:

"Small Science to be big in 21st century"

This paper deals with a multidisciplinary, innovative, progressive, precise technology, the ***'nanotechnology'***. We are particularly going to deal with ***DNA nanocomputers***. Devices that convert information from one form into another according to a definite procedure are known as automata. One such hypothetical device is the universal Turing machine which stimulated work leading to the development of modern computers. The Turing machine and its special cases including finite automata operate by scanning a data tape, whose striking analogy to information-encoding biopolymers inspired several designs for molecular ***DNA nanocomputers***. Laboratory-scale computing using DNA and human-assisted protocols has been demonstrated but the realization of computing devices operating autonomously on the molecular scale remains rare. Here we describe a programmable finite automaton comprising DNA and DNA-manipulating enzymes that solves computational problems autonomously. The automaton's hardware consists of arestriction nuclease and ligase, the software and input are encoded by double-stranded DNA, and programming amounts to choosing appropriate software molecules. Upon mixing solutions containing these components, the automaton processes the input molecule via a cascade of restriction, hybridization and ligation cycles, producing a detectable output molecule that encodes the automaton's final state, and thus the computational result. In our implementation 10^{12} automata sharing the same software run independently and in parallel on inputs (which could, in principle, be distinct) in 120 ml solution at room temperature at a combined rate of 10^9 transitions per second with a transition fidelity greater than 99.8%, consuming less than 10^{-10} W.

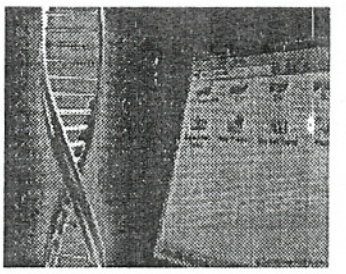
Keywords: Nanocomputer - Genetic gate - biochips - two-state two-symbol finite automaton

1.Introduction:

One of the paramount goals of nanotechnology is the creation of nanocomputers. While nanocomputers could have numerous applications, the one that stirs the imagination the most is the launching of nanocomputers inside the human body on an *in vivo* mission to identify malfunctions and fix them. Will such a "fantastic voyage" ever be possible? And if so, what steps can we take to expedite embarkation? We believe this vision is realizable. Molecular machines inside the living cell already posses a full repertoire of operations required to implement a universal computer and science's understanding of the cell's molecular machinery is improving by the day. But, as the ability to create a molecular machine "from scratch" may be several decades away, one approach is to hunt nature's "mines" for existing molecular machines that can be stitched together and coerced to compute, even if in a somewhat cumbersome way.

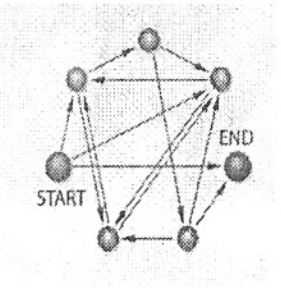
2.DNA Nano-Computer:

2.1 Basics of DNA Nano-computer:



A nanocomputer that uses DNA to store information and perform complex calculations. The technology is still in development, and didn't even exist as a concept a decade ago. In 1994, Leonard Adleman introduced the idea of using DNA to solve complex mathematical problems. Adleman came to the conclusion that DNA had computational potential after reading the book "Molecular Biology of the Gene". In fact, DNA is very similar to a computer hard drive in how it stores permanent information about our genes

2.2 Adlemen's contribution:



Adleman is often called the inventor of DNA computers. He used DNA to solve a well-known mathematical problem, called the **directed Hamilton Path problem**, also known as the "traveling salesman" problem. The goal of the problem is to find the shortest route between a number of cities, going through each

city only once. As you add more cities to the problem, the problem becomes more difficult. Adleman chose to find the shortest route between seven cities.

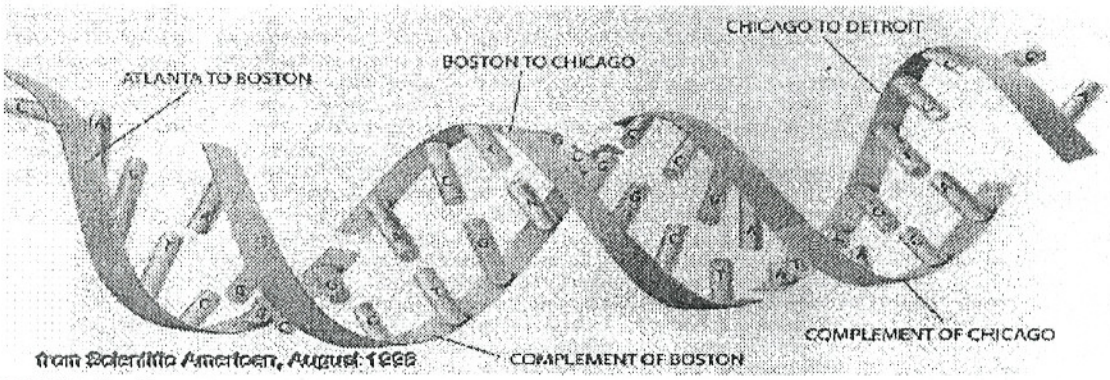
2.2.1 Adleman's approach:

One could probably draw this problem out on paper and come to a solution faster than Adleman did using his DNA test-tube computer. Here are the steps taken in the Adleman DNA computer experiment:

1. Strands of DNA represent the seven cities. In genes, genetic coding is represented by the letters A, T, C and G. Some sequence of these four letters represented each city and possible flight path.
2. These molecules are then mixed in a test tube, with some of these DNA strands sticking together. A chain of these strands represents a possible answer.
3. Within a few seconds, all of the possible combinations of DNA strands, which represent answers, are created in the test tube.
4. Adleman eliminates the wrong molecules through chemical reactions, which leaves behind only the flight paths that connect all seven cities.

The success of the Adleman DNA computer proves that DNA can be used to calculate complex mathematical problems. However, this early DNA computer is far from challenging silicon-based computers in terms of **speed**. The Adleman DNA computer created a group of possible answers very quickly, but it took days for Adleman to narrow down the possibilities. Another drawback of his DNA computer is that it requires **human assistance**. The goal of the DNA computing field is to create a device that can work independent of human involvement.

Three years after Adleman's experiment, researchers at the University of Rochester developed logic gates made of DNA. Logic gates are a vital part of how your computer carries out functions that you command it to do. These gates convert binary code moving through the computer into a series of signals that the computer uses to perform operations. Currently, logic gates interpret input signals from silicon transistors, and convert those signals into an output signal that allows the computer to perform complex functions.



from Scientific American, August 1998

2.3 DNA logic gates:

The Rochester team's DNA logic gates are the first step toward creating a computer that has a structure similar to that of an electronic PC. Instead of using electrical signals to perform logical operations, these DNA logic gates rely on DNA code. They detect fragments of **genetic material** as input, splice together these fragments and form a single output. For instance, a **genetic gate** called the "And gate" links two DNA inputs by chemically binding them so they're locked in an end-to-end structure, similar to the way two Legos might be fastened by a third Lego between them. The researchers believe that these logic gates might be combined with DNA microchips to create a breakthrough in DNA computing.

DNA computer components -- **logic gates** and **biochips** -- will take years to develop into a practical, workable DNA computer. If such a computer is ever built, scientists say that it will be more compact, accurate and efficient than conventional computers. In the next section, we'll look at how DNA computers could surpass their silicon-based predecessors, and what tasks these computers would perform.

2.4 Advantages of DNA:

There are several advantages to using DNA instead of silicon:

- As long as there are cellular organisms, there will always be a **supply** of DNA.
- The large supply of DNA makes it a **cheap** resource.
- Unlike the toxic materials used to make traditional microprocessors, DNA biochips can be made **cleanly**.
- DNA computers are many times **smaller** than today's computers.

DNA's key advantage is that it will make computers smaller than any computer that has come before them, while at the same time holding more data. One pound of DNA has the capacity to store more information than all the electronic computers ever built; and the computing power of a teardrop-sized DNA computer, using the DNA logic gates, will be more powerful than the world's most powerful supercomputer. More than 10 trillion DNA molecules can fit into an area no larger than 1 cubic centimeter (0.06 cubic inches). With this small amount of DNA, a computer would be able to hold 10 terabytes of data, and perform 10 trillion calculations at a time. By adding more DNA, more calculations could be performed.

Unlike conventional computers, DNA computers perform calculations **parallel** to other calculations. Conventional computers operate linearly, taking on tasks one at a time. It is parallel computing that allows DNA to solve complex mathematical problems in hours, whereas it might take electrical computers hundreds of years to complete them.

The first DNA computers are unlikely to feature word processing, e-mailing and solitaire programs. Instead, their powerful computing power will be used by national governments for cracking secret codes, or by airlines wanting to map more efficient routes. Studying DNA computers may also lead us to a better understanding of a more complex computer -- the human brain.

2.5 Finite automaton:

An effort has been recently reported to construct such a simple computer. The computer's input, output, and "software" are made up of double-strand DNA molecules. Two naturally occurring enzymes that manipulate DNA form the "hardware." These are FokI, an enzyme that cuts DNA, and Ligase, an enzyme that seals two DNA molecules together.

When mixed in solution, the input molecule is processed by software and hardware molecules to create the output molecule, which contains the result of the computation. This simple mathematical computing machine is known as a finite automaton.

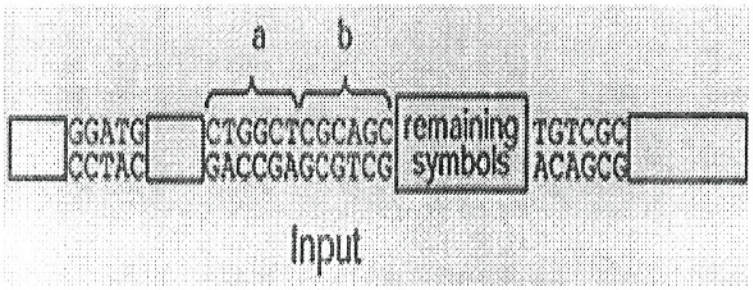
By choosing different software molecules to be mixed in solution, this nanocomputer can be programmed to perform several simple tasks. For instance, it can detect whether, in an input molecule encoding a list of 0's and 1's, there are an even number of 1's. The software molecules can be used to create a total of 765 software programs.

2.5.1 Programs tested:

A number of these programs were tested in the lab, including the "even 1's checker" mentioned above, as well as programs that check whether a list of 0's and 1's has all the 0's before all the 1's, whether it has at least (or at most) one 0, and whether it both starts with a 0 and ends with a 1.

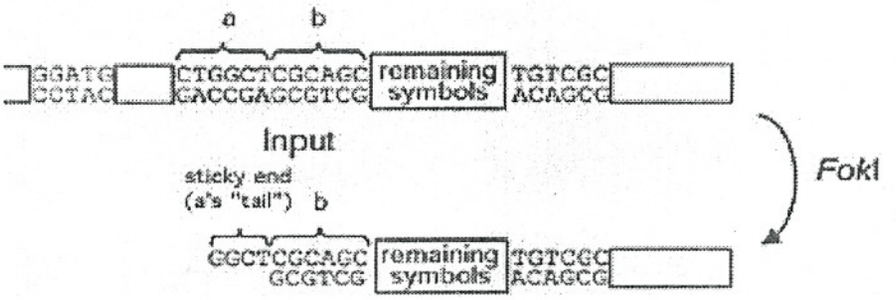
2.5.2. Two-state, Two-symbol finite automaton:

How can DNA strands to contain the symbols 0 and 1? DNA strands are usually depicted as a scroll of recurring "letters, " in varied combinations, that represent DNA's constituents (four chemical bases). The team decided that the letter pattern "CTGGCT" in the input molecule would signify "1" (*a* in the diagram below) and "CGCACG" would signify "0" (*b* in the diagram).



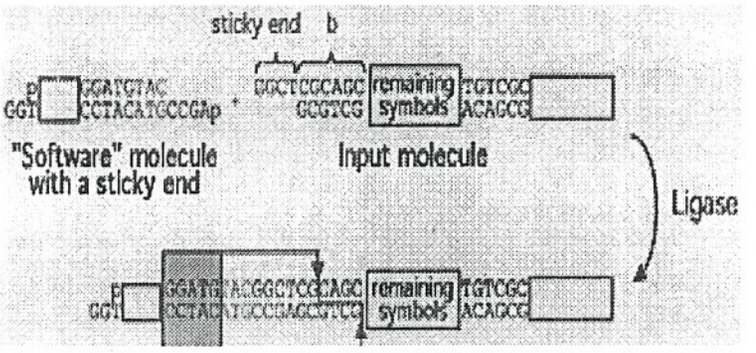
The input molecule, when mixed with hardware and software molecules, also two "states". When the hardware molecule FokI, recognizing a symbol, "cuts" DNA, it leaves it with one strand longer than the other, resulting in a single-strand overhang called a "sticky end" (see diagram below). Since FokI makes its incision at the site of the symbol, the "sticky end" is what remains of the symbol. FokI may leave the symbol's "head" or "tail" attached. These are the two possible "states."

A computer that has two possible states and two possible symbols is called a two-state, two-symbol finite automaton.



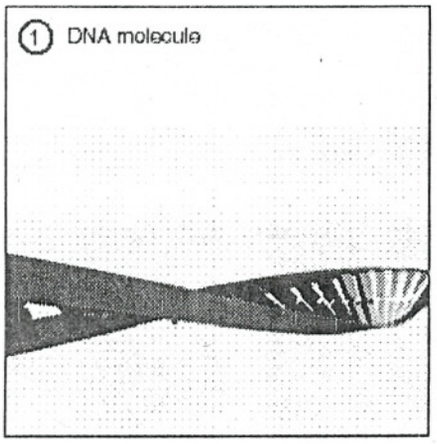
2.6 Hybridization:

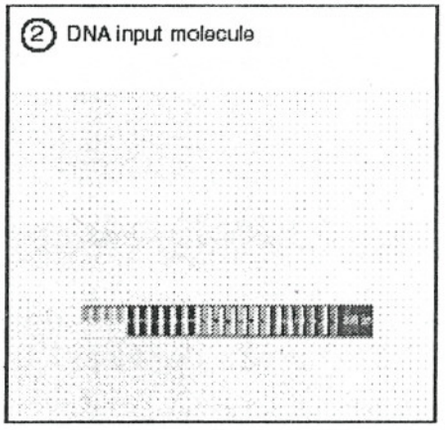
Two molecules with complementary sticky ends can temporarily stick to each other (a process known as hybridization). In each processing step the input molecule hybridizes with a software molecule that has a complementary sticky end, allowing the hardware molecule Ligase to seal them together using two ATP molecules as energy.

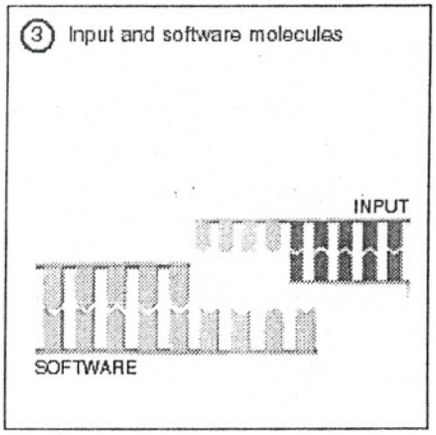


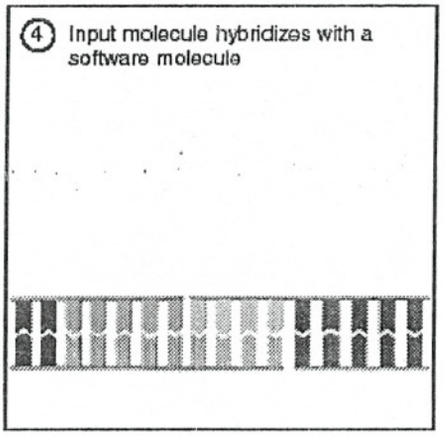
Then comes Fok-I, and cleaves the input molecule again, in a location determined by the software molecule. Thus a sticky end is again exposed, encoding the next input symbol and the next state of the computation. Once the last input symbol is processed, a sticky end encoding the final state of the computation is exposed and detected, again by hybridization and ligation, by one of two "output display" molecules. The resulting molecule, which reports the output of the computation, is made visible to the human eye in a process known as gel electrophoresis.

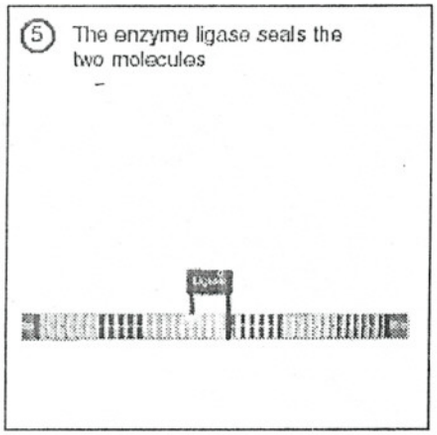
The steps involved in DNA computation are:

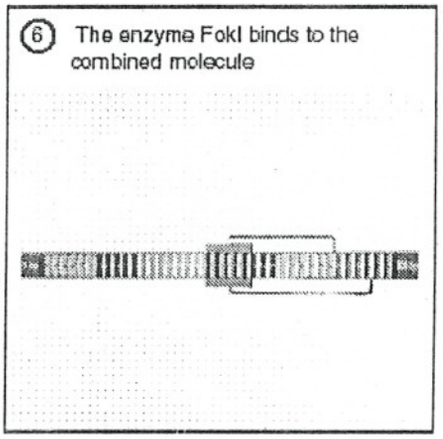


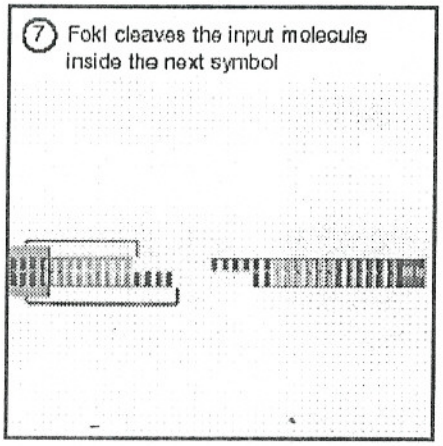


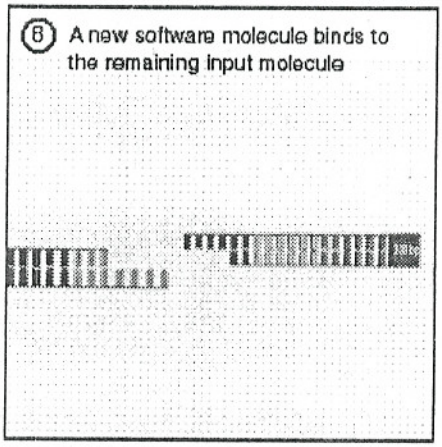


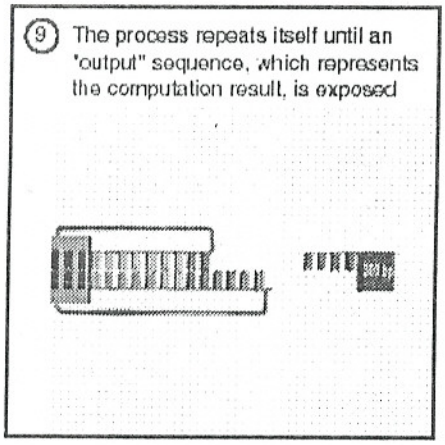


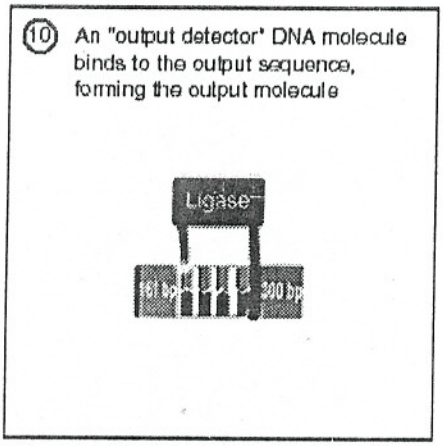












2.7Features of automaton:

The automaton is so small that 10^{12} automata sharing the same software run independently and in parallel on inputs (which could in principle be distinct) in 120 ml solution at room temperature. Their combined rate is 10^9 transitions per second, their transition fidelity is greater than ***99.8%,*** and together they consume less than a billionth of one Watt.

As science's understanding of the cell's molecular machinery is rapidly improving, there is no reason to expect an insurmountable obstacle to transforming this dream into a reality. Eventually, one will be able to harness nature's building blocks and techniques to construct a molecular machine to specification.

3. Conclusion:

The nanocomputer created is too simple to have immediate applications, however it may pave the way to future computers that can operate within the human body with unique biological and pharmaceutical applications. ***"The best way to predict the future is to invent it."*** Hence, by implementing the theoretical concepts and predictions of this technology into practical real world application, we can hope for a revolutionized future, in which almost every field will have the impact of this technology, which is only a decade off.

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