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DNA Computers

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***Abstract* – The paper discusses the concept of DNA computing, its advantages over silicon-based computing and the future it holds for the mankind. It showcases the limitations of present technology and the promises DNA computing hold for the future. The paper looks on the future we shall be living in and how this new technology can sweep away all the notions of how we perceive and live in our world.**

***Keywords* – DNA, nucleotides, parallel computing, DNA bases, Hamiltonian Path Problem, Transcriptor, nucleic acids.**

I. INTRODUCTION

Computer chip manufacturers are furiously racing to make the next microprocessor that will topple speed records. Sooner or later, though, this competition is bound to hit a wall. Microprocessors made of silicon will eventually reach their limits of speed and miniaturization. This is because if we pack the cells much closer together electrical interference between them shoots up, affecting the device's performance.Thus, Chip makers need a new material to produce faster computing speeds.[2]

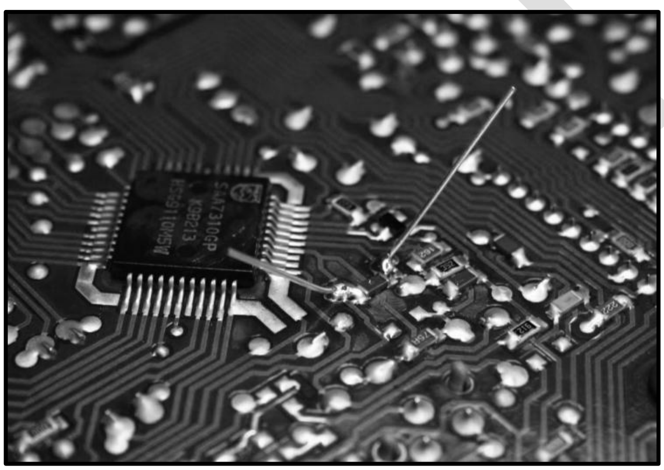

Fig. 1 Conventional Silicon Chip

Scientists have found this new material, they need to build the next generation of microprocessors, inside living organisms. And the material is DNA molecules, the material our genes are made up of. These have the potential to perform calculations many times faster than the world's most powerful human-built computers.[2]

Although DNA computing is in its infancy, and its implications are only beginning to be explored, they have already been harnessed to perform complex mathematical problems.[9]

II. WHAT IT IS?

In its simplest sense, a computer is just a machine capable of performing computations. It doesn't have to be electronic. Tom Ran, of the Weizmann Institute of Science in Israel, works with computers made out of strands of DNA."Working this way, we can get three trillion computers, working in parallel, in a space the size of a water droplet," he says. The 0s and 1s of conventional computers are replaced with the four DNA bases: A, C, G and T. Operations can be translated into strands of DNA using these bases, and the way the DNA strands interact with each other produces new strands which can be decoded as output values.[10]

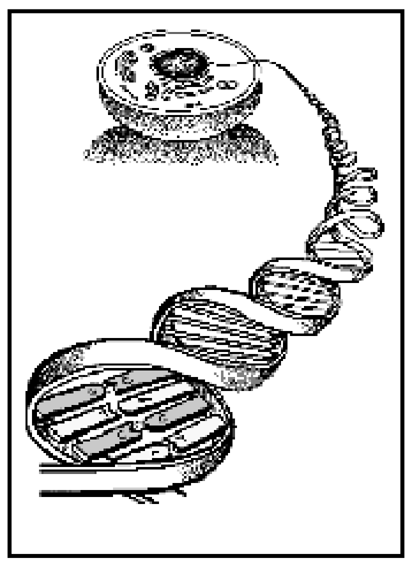

Fig. 2 Next Generation Computing Technology

Thus, DNA computing can be defined as a form of computing which uses DNA,biochemistry and molecular biology, instead of the traditional silicon-based computer technologies. It is fundamentally similar to parallel computing in that it takes advantage of the many different molecules of DNA to try many different possibilities at once.[1]

III. EVOLUTION

The technology is still in development, and didn't even exist as a concept a decade ago. The idea that individual molecules (or even atoms) could be used for computation dates to 1959, when American physicist Richard Feynman presented his ideas on nanotechnology.[6] However, DNAcomputing was not physically realized until 1994. In 1994, Leonard Adleman showed how to use DNA to solve complex mathematical problems. Adleman, a computer scientist at the University of Southern California, came to two conclusions. One, that DNA has computational potential and second, that DNA is very similar to a computer hard drive in how it stores permanent information about your genes.[2]His contribution in the field of bio-computing won him the Turing Award in 2002.[8]

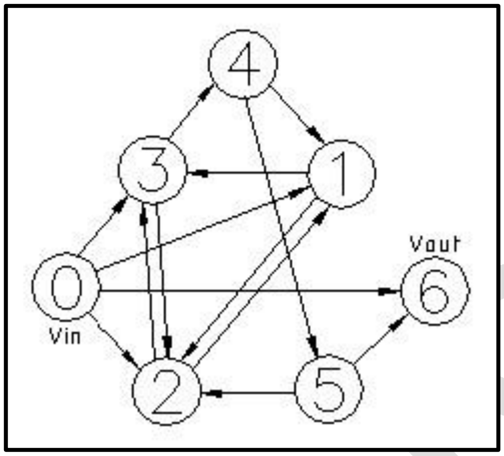

Fig. 3 Hamiltonian Path Problem

Three years after Adleman's experiment, researchers at the University of Rochester developed logic gatesmade of DNA. Instead of using electrical signals to perform logical operations, these DNA logic gates rely on DNA code. In 2003 Israeli scientists devised a computer working on DNA that can perform 330 trillion operations per second, more than 100,000 times the speed of the fastest PC. In January 2013, researchers were able to store a JPEGphotograph, a set of Shakespearean sonnets, and an audio file of Martin Luther King, Jr.'s speech on DNA digital data storage.[1]In March 2013, researchers created a transcriptor (a biological transistor).As of now, DNA computers that we have can only answer yes or no to a question, i.e., they cannot be currently used for applications like emailing.[3]

IV. ADLEMAN'S EXPERIMENT

Adleman's experiment involved finding the shortest route through a network of "towns" (labelled "1" to "7") connected by one-way "roads." The problem specifies that the route must start and end at specific towns and visit each town only once. This is known to mathematicians as the Hamiltonian path problem. He solved this problem using DNA to do the computations.[6]

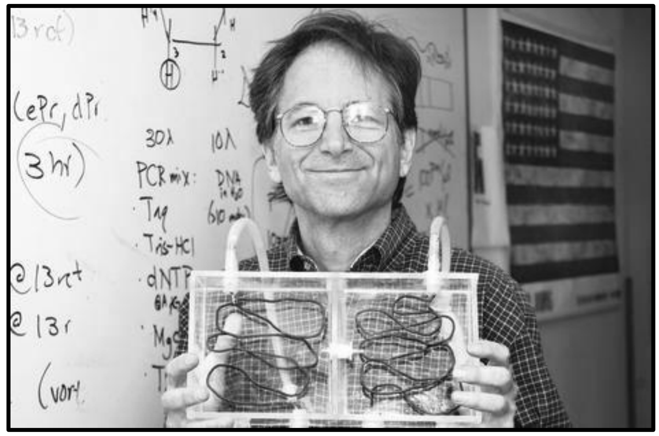

Fig. 4 Leonard Adleman

There was nothing remarkable about the problem itself. Nor was there anything special about how long it took Adlemanto solve it — seven days — substantially greater than the few minutes it would take an averageperson to find a solution. What was exciting about Adleman's achievement was that he hadsolved the problem using nothing but deoxyribonucleic acid (DNA) and molecular chemistry.

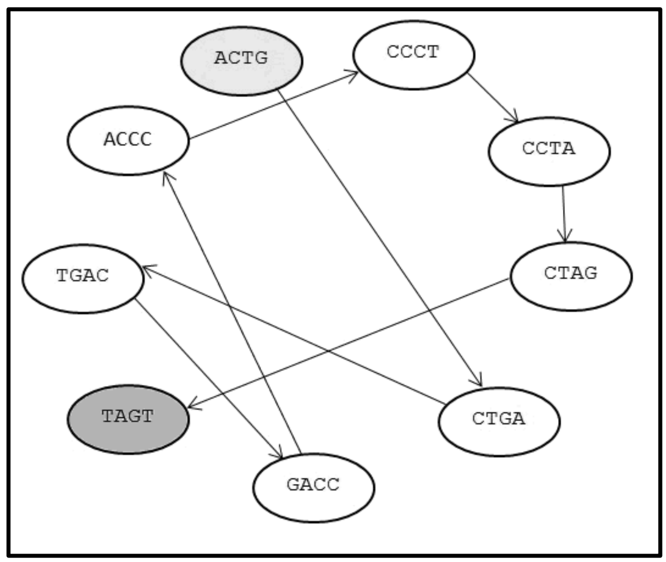

Fig. 5 Adleman's DNA encoded Hamiltonian Path Problem

He designed short strands of DNA to represent towns and roads such that the road strands stuck the town strands together, forming sequences of towns that represented routes (such as the actual solution, which happened to be "1234567"). Most such sequences represented incorrect answers to the problem ("12324" visits a town more than once, and "1234" fails to visit every town), but Adleman used enough DNA to be reasonably sure that the correct answer would be represented in his initial pot of strands. The problem was then to extract this unique solution. He achieved this by first greatly amplifying (using a method known as polymerase chain reaction [PCR]) only those sequences that started and ended at the right towns. He then sorted the set of strands by length (using a technique called gel electrophoresis) to ensure that he retained only strands of the correct length. Finally, he repeatedly used a molecular “fishing rod” (affinity purification) to ensure that each town in turn was represented in the candidate sequences. The strands Adleman was left with were then sequenced to reveal the solution to the problem.[6]

V. HOW IT WORKS?

A. About DNA

DNA (Deoxyribonucleic acid) are the molecules that carry genetic information and pass it from one generation to the next. It is the way genetic information is encoded in the DNA that makes each and every organism different from one another.

An organism (be it bacteria, rosebush, ant or human) has some form of nucleic acid which is the chemical carrier of its genetic information. There are two types of nucleic acids, deoxyribonucleic acid (DNA) and ribonucleic acid (RNA) which code for all the information that determines the nature of the organism's cells.

Strands of DNA are long polymers of millions of linked nucleotides. These nucleotides consist of one of four nitrogen bases, a five carbon sugar and a phosphate group. The nucleotides that make up these polymers are named after the nitrogen bases that comprise it, namely, Adenine (A), Cytosine (C), Guanine (G), and Thymine (T). These nucleotides only combine in such away that C always pairs with G, and T always pairs with A.

Fig. 6 DNA Strand

The particular order of the bases arranged along the suger-phosphate backbone is called the DNA sequence and the combinations of the four nucleotides in the estimated millions long polymer strands results in a billions of combinations within a single DNA double helix. These massive amounts of combinations allow for the multitude of differences between every living thing on the plane-from the large scale (for example, mammals as opposed to plants) to the small scale (differences in human hair colour).

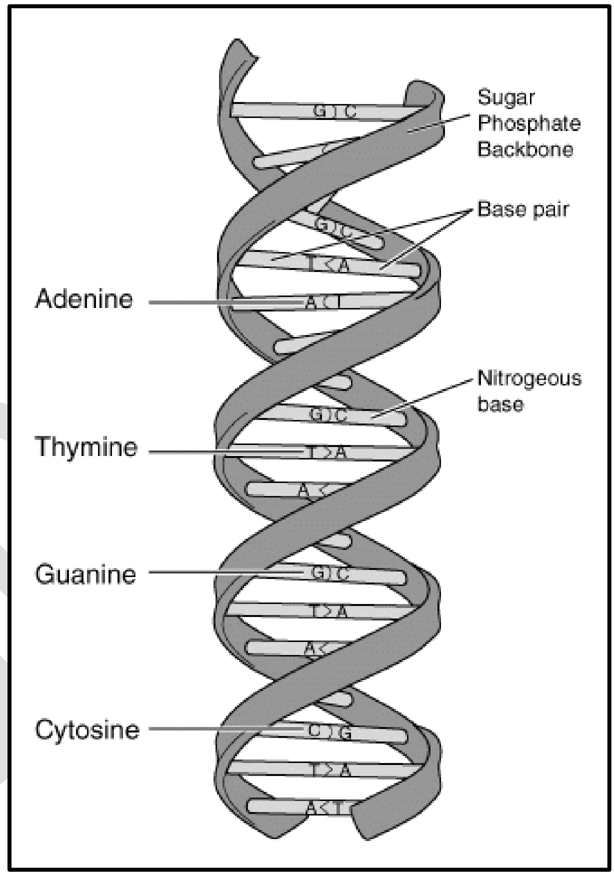

Fig. 7 DNA Labelled Structure

B. About DNA computers

DNA computers basically deals with two different applications, one – computational work and second – storage facility. We’ll be looking into these two one by one.

A computation may be thought of as the execution of an algorithm, which itself may be defined as a step-by-step list of well-defined instructions that takes some input, processes it, and produces a result. [6]

Biochemical "Nano computers" already exist in nature; they are manifest in all living things. But they're largely uncontrollable by humans. DNA molecules, through its own in-built system, stores vital information that gets passed on to each successive generation and coordinates the making of itself as well as other molecules. The whole concept behind DNA computing is to somehow program DNA in our own way so that it can be used as we wish. 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 by-product of the reactions. The scientists tell the devices what to do by controlling the composition of the DNA software molecules.[2]

To understand DNA computing lets first examine how the conventional computer process information. A conventional computer performs mathematical operations by using electrical impulses to manipulate zeroes and ones on silicon chips. A DNA computer is based on the fact the information is "encoded" within deoxyribonucleic acid (DNA) as a patterns of molecules known as nucleotides. By manipulating how the nucleotides combine with each other the DNA computer can be made to process data.

In DNA computing, information is represented using the four-character genetic alphabet (A [adenine], G [guanine], C [cytosine], and T [thymine]), rather than the binary alphabet (1 and 0) used by traditional computers. This is achievable because short DNA molecules of any arbitrary sequence may be synthesized to order. An algorithm's input is therefore represented (in the simplest case) by DNA molecules with specific sequences, the instructions are carried out by laboratory operations on the molecules (such as sorting them according to length or chopping strands containing a certain subsequence), and the result is defined as some property of the final set of molecules (such as the presence or absence of a specific sequence).[6]

For the second application – storage facility - scientists have long been able to read DNA, a code comprising four "letters", but using it to store information has been difficult because it is prone to decoding errors when the same letter is repeated.[4]

In a study published in the Nature journal, the researchers demonstrated they could avoid the problem by translating computer files, made up of ones and zeroes, into a form of DNA code which did not allow letters to repeat themselves.[4]

VI. ADVANTAGES

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 madecleanly.
- DNA computers are many times smaller than today's computers 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. [2]

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.[2]

Some people believed that molecular computers could one day solve problems that would cause existing machines to struggle, due to the inherent massive parallelism of biology. Because a small drop of water can contain trillions of DNA strands and because biological operations act on all of them—effectively—in parallel (as opposed to one at a time), it was argued that one day DNA computers could represent (and solve) difficult problems that were beyond the scope of "normal" computers.[6]

VII. DISADVANTAGES

The success of the Adleman DNA computer proves that DNA can be used to calculate complexmathematical problems. However, this early DNA computer is far from challenging silicon-basedcomputers in terms of speed. The Adleman DNA computer created a group of possible answersvery quickly, but it took days for Adleman to narrow down the possibilities. Another drawback ofhis DNA computer is that it requires human assistance. The goal of the DNA computing field isto create a device that can work independent of human involvement.[2]

Also in most difficult problems the number of possible solutions grows exponentially with the size of the problem (for example, the number of solutions might double for every town added). This means that even relatively small problems would require unmanageable volumes of DNA (on the order of large bathtubs) in order to represent all possible answers.[7]

Another disadvantage is that the DNA molecules can fracture. Over the six months you're computing, your DNA system isgradually turning to water. DNA molecules can break – meaning a DNA molecule, which waspart of your computer, is fracture by time. DNA can deteriorate. As time goes by, your DNAcomputer may start to dissolve. DNA can get damaged as it waits around in solutions and themanipulations of DNA are prone to error. Some interesting studies have been done on thereusability of genetic material in more experiments, a result is that it is not an easy taskrecovering DNA and utilizing it again.[7]

Also, the model of the DNA computer is concerned as a highly parallel computer, with each DNAmolecule acting as a separate process. In a standard multiprocessor connection-buses transmitinformation from one processor to the next. But the problem of transmitting information from onemolecule to another in a DNA computer has not yet to be solved. Current DNA algorithmscompute successfully without passing any information, but this limits their flexibility.[7]

VIII. CURRENT SCENARIO

First demonstration of DNA computing used a rather unsophisticated algorithm, but as the formalism of DNA computing becomes refined, new algorithms perhaps will one day allow DNA to overtake conventional computation and set a new record.

On the side of the "hardware", improvements in biotechnology are happening at a rate similar to the advances made in the semiconductor industry. With the amount of government funded research dollars flowing into genetic-related R&D and with the large potential payoffs from the lucrative pharmaceutical and medical-related markets, this isn't surprising. Just look at the number of advances in DNA-related technology that happened in the last five years. Today we have not one but several companies making "DNA chips," where DNA strands are attached to a silicon substrate in large arrays. Production technology of MEMS isadvancing rapidly, allowing for novel integrated small scale DNA processing devices. The Human Genome Project is producing rapid innovations in sequencing technology. The future of DNA manipulation is speed, automation, and miniaturization.

And of course we are talking about DNA here, the genetic code of life itself. It certainly has been the molecule of this century and most likely the next one. Considering all the attention that DNA has garnered, it isn't too hard to imagine that one day we might have the tools and talent to produce a small integrated desktop machine that uses DNA, or a DNA-like biopolymer, as acomputing substrate along with set of designer enzymes. Perhaps it won't be used to play games or surf the web -- things that traditional computers are good at -- but it certainly might be used in the study of logic, encryption, genetic programming and algorithms, language systems, and lots of other interesting things that haven't even been invented yet.

IX. FUTURE

Future 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.[9]

These inherently biological computers can interact directly with living cells. One goal is to programme DNA-based computers to work inside the body to combat disease. Take cancer as an example – chemotherapy drugs currently target all rapidly dividing cells, including, for example, hair cells; a DNA computer could be programmed to identify and kill only cancerous cells.[10]

The possible applications of this emerging technology will have an impact on many areas, including intelligent medical diagnostics and drug delivery, tissue engineering, energy, and the environment.[6]

Fig. 8 DNA Robots

Other than using tiny DNA computers as medication this technology can also be used as monitoring devices inside living cells. The transcriptor can be used for this purpose. Like the transistor, one main function of the transcriptor is to amplify signals. Just as transistor radios amplify weak radio waves into audible sound, transcriptors can amplify a very small change in the production of an enzyme to produce large changes in the production of other proteins. Amplification allows signals to be carried over large distances, such as between a group of cells.[5]

The new technology offers some electric possibilities: sensing when a cell has been exposed to sugar or caffeine, for example, and storing that information like a value in computer memory. Or telling cells to start or stop dividing depending on stimuli in their environment.[5]

Further advancements can lead to storing of large amount of data in a tiny space of volume. This is because it has been established that one pound (0.45 kilogram) of DNA has the potential to store more data than every computer ever built added together.[1]

X. CONCLUSION

DNA computing is becoming one of the most exciting fields. It is importing notions of electrical and electronics engineering – digital logic, memory and oscillators – into the realm of biology. With the pace this field is evolving it won't be long when molecular computing will surpass silicon-based technologies and thus in turn opening up spectacular possibilities and realizing scenarios that still belong to the realms of science fiction. The DNA computing technology is definitely on the verge of shattering our notions of how we perceive our world and it is certain that a major breakthrough for the same is around the horizon. It may well not be understatement to state that DNA computing is the future of computers.

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REFRENCES

[1] Wikipedia - the free encyclopaedia. Available: *https://en.wikipedia.org/wiki/DNA_computing#Capabilities*

[2] How Stuff Works-how DNA computers will work. Available: *http://computer.howstuffworks.com/dna-computer1.htm*

[3] National Geographic website. Available: *http://news.nationalgeographic.co.in/news/2003/02/0224_030224_DNAcomputer.html*

[4] The Telegraph website. Available: *http://www.telegraph.co.uk/science/science-news/9821895/Computer-files-stored-accurately-on-DNA-in-new-breakthrough.html*

[5] Fox News website. Available: *http://www.foxnews.com/science/2013/03/29/digital-evolution-dna-may-bring-computers-to-life/*

[6] Encyclopaedia Britannica website. Available: *http://www.britannica.com/EBchecked/topic/941575/DNA-computing*

[7] Oracle Education Foundation-Think Quest website. Available:*http://library.thinkquest.org/3037/dna.htm*

[8] Youngzine website. Available: *http://www.youngzine.org/article/dna-computing-meet-dr-adleman*

[9] Matt Over Matter website. Available: *mattovermatter.com/2011/03/the-future-dna-computers/*

[10] The Guardian website. Available: *http://www.theguardian.com/nanotechnology-world/the-future-of-computing-power-from-dna-hard-drives-to-quantum-chips*