DNA Computing

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Abstract—*In this paper, we intend to present the computing technology that has a great future – DNA. DNA (Deoxyribose Nucleic Acid) computing, also known as molecular computing is a new approach to massively parallel computation based on ground-breaking work by Adleman. DNA computing is a form of computing which uses DNA, biochemistry and molecular biology, instead of the traditional silicon-based computertechnologies .The main idea behind DNA computing is to adopt a biological (wet) technique as an efficient computing vehicle, where data are represented using strands of DNA. This massive parallelism of DNA processing is used in solving NP-complete or NP-hard problems. DNA computers will be capable of storing billions of times more data than your personal computer. The total execution speed of a DNA computer can outshine that of a conventional electronic computer. DNA computer is thus suited to problems such as the analysis of genome information, and the functional design of molecules where molecules constitute the input data.*

I. DNA COMPUTER

A DNA computer, as the name implies, uses DNA strands to store information and taps the re-combinative properties of DNA to perform operations. DNA molecules, the material our genes are made of, have the potential to perform calculations many times faster than the world's most powerful human-built computers. DNA might one day be integrated into a computer chip to create a so-called biochip that will push computers even faster.

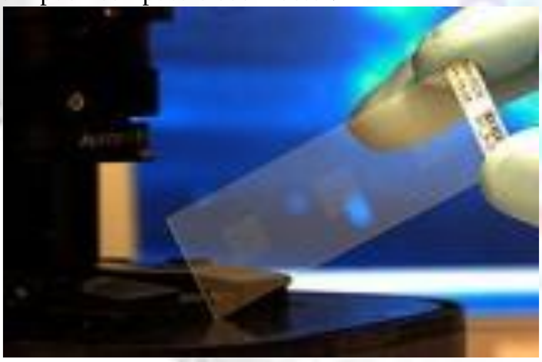

Fig. 1: Test Tube of DNA Strand

A small test tube of DNA strands suspended in a solution could yield millions to billions of simultaneous interactions at speed faster than today's fastest supercomputers. DNA computer uses the re-combinative property of DNA to perform operations. The main benefit of using DNA computers is that it can solve complex problems having different possible solutions all at once. This is known as parallel processing.

II. PRINCIPLES OF DNA COMPUTING

DNA is the major information storage molecule in living cells, and billions of years of evolution have Tested and refined both this wonderful informational molecule and highly specific enzymes that can either duplicate the information in DNA molecules or transmit this information to other DNA molecules. Instead of using electrical impulses to represent bits of information, the DNA computer uses the chemical properties of these molecules by examining the patterns of combination or growth of the molecules or strings. DNA can do this through the manufacture of enzymes, which are biological catalysts that could be called the 'software', used to execute the desired calculation.

III. REASON FOR DNA COMPUTING:

There are two reasons for using molecular biology to solve computational problems.
(i) The information density of DNA is much greater than that of silicon: 1 bit can be stored in approximately one cubic nanometre. Others storage media, such as videotapes, can store 1 bit in 1,000,000,000,000 cubic nanometre.
(ii) Operations on DNA are massively parallel: a test tube of DNA can contain trillions of strands. Each operation on a test tube of DNA is carried out on all strands in the tube in parallel.

IV. DNA: A UNIQUE DATA STRUCTURE

Just like a string of binary data is encoded with ones and zeros, a strand of DNA is encoded with four bases, represented by the letters A, T, C, and G. The bases are spaced every 0.35 nanometers along the DNA molecule, giving DNA a remarkable data density of nearly 18 megabits per inch. In two dimensions, if you assume one base per square nanometer, the data density is over one million gigabits per square inch.

Another important property of DNA is its double stranded nature. The bases A and T, and C and G, can bind together, forming base pairs.

Therefore every DNA sequence has a natural complement. For example if sequence S is ATTACGTCG, its complement, S', is TAATGCAGC. Both S and S' will come together (or hybridize) to form double stranded DNA. This complementarity makes DNA a unique data structure for computation and can be exploited in many ways. Error correction is one example. Errors in DNA happen due to many factors. Occasionally, DNA enzymes simply make mistakes, cutting where they shouldn't, or inserting a T for a G. DNA can also be damaged by thermal energy and UV energy from the sun. If the error occurs in one of the strands of double stranded DNA, repair enzymes can restore the proper DNA sequence by using the complement strand as a reference.

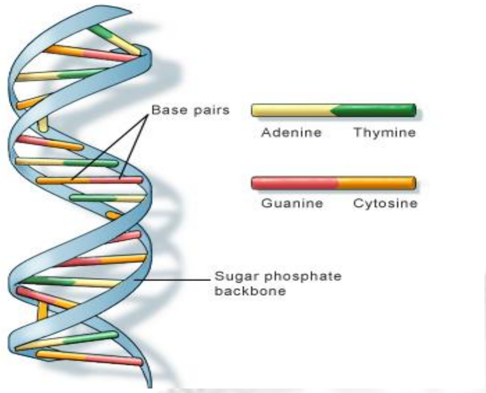

Fig. 2: DNA Strand

V. OPERATIONS IN DNA

In the cell, DNA is modified biochemically by a variety of enzymes, which are tiny protein machines that read and process DNA according to nature's design. There is a wide variety and number of these "operational" proteins, which manipulate DNA on the molecular level. For example, there are enzymes that cut DNA and enzymes that paste it back together. Other enzymes function as copiers, and others as repair units. Molecular biology, Biochemistry and biotechnology have developed techniques that allow us to perform many of these cellular functions in the test tube. It's this cellular machinery, along with some synthetic chemistry, that makes up the palette of operations available for computation. Just like a CPU has a basic suite of operations like addition, bit-shifting, logical operators (AND, OR, NOT NOR), etc. that allow it to perform even the most complex calculations, DNA has cutting, copying, pasting, repairing, and many others. And note that in the test tube, enzymes do *not* function sequentially, working on one DNA at a time. Rather, many copies of the enzyme can work on many DNA molecules simultaneously. This is the power of DNA computing, that it can work in a massively parallel fashion.

VI. SOFTWARE STRUCTURE OF DNA

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

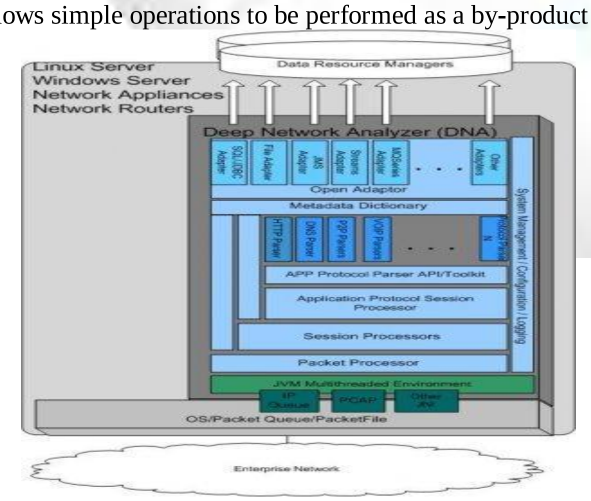

Fig. 3: Software Structure of DNA

the reactions. 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.

VII. INFORMATION STORAGE USING DNA

A DNA computer could hold 10 terabytes of data and perform 10 trillion calculations at a time. Calculations in a traditional computer are performed by moving data into a processing unit where binary operations are performed. In a traditional computer, data are represented by and stored as strings of zeros and ones. DNA is also digital, but it is not limited to positions 0 and 1. DNA uses 4 possible bit positions and is therefore a quaternary digital system. By convention, a binary digital byte is 8 bits in length, providing 256 possible different values per byte. A “byte” of DNA is called a codon. A codon is 3 bits long (e.g., AAA or GCT). Each bit can be one of 4 possible values (0, 1, 2 or 3) and so the DNA quaternary encoding system provides 64 possible values per codon. In a different perspective, more than 10 trillion DNA molecules can fit into an area no larger than 1cubic centimetre. With a DNA computer, a sequence of its four basic nucleotides - adenine, cytosine, guanine, and thymine **-** is used to represent and store data on a strand of DNA. Essentially, the operations turn miniaturized circuits off or on corresponding to the zeros and ones that represent the string of data.

VIII. ADVANTAGES

The advantages of DNA Computing are listed down:

- Perform millions of operations simultaneously (Parallel Computing).
- Generate a complete set of potential solutions and conduct large parallel searches.
- Capable of storing billions of times more data.
- Over 100 times faster than fastest computer.
- Minimal storage requirements.
- Minimal power requirements.
- They are inexpensive to build, being made of common biological materials.
- The clear advantage is that we have a distinct memory block that encodes bits.
- Using one template strand as a memory block also allows us to use its compliment as anothermemory block, thus effectively doubling our capacity to store information.
- More powerful than the world's most powerful supercomputer.
- DNA computers smaller than any computer.
- Perform millions of operations simultaneously.
- Generate a complete set of potential solutions and conduct large parallel searches.
- Efficiently handle massive amounts of working memory.

- They are inexpensive to build, being made of common biological materials.
- The clear advantage is that we have a distinct memory block that encodes bits.
- Using one template strand as a memory block also allows us to use its compliment. As another memory block, thus effectively doubling our capacity to store information.
- DNA itself provides the added benefits of being a cheap, energy-efficient resource.

IX. Conclusion

Before you trash your silicon-based computer and start trying to process words with DNA, remember that it'll be a while before the wet computers show up in showrooms. DNA computers can't be found at your local electronics store yet. The technology is still in development. The current applications of DNA chips are restricted to the field of medicine. DNA chips or arrays have been used to solve many problems in the field of medicine.

These DNA computers can be used in fluids, such as a sample of blood or in the body, and make decisions at the level of a single cell. DNA computers could conceivably be implanted in the body to both diagnose and kill cancer cells or monitor and treat diabetes by dispensing insulin when needed.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. 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.

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