Introduction to DNA Computing

Shivam Saxena

M Tech Computer Science & Engineering
Rampur Uttar Pradesh, India

Abstract

With increase in the size of computational complexities of classical computing methods, human is looking forward for other models of computation. Processors made of silicon have a definite limit on speed and computability. We are searching for other alternatives. It was Feynman who suggested constructing computer from molecules in 1964 [1]. And biological computation inspired Adleman proved it is possible to use DNA(deoxyribonucleicacid) to solve complex problems like Hamiltonian path problem in 1994 [2]. DNA computers are big alternatives to classical computers. Aim of this paper is to introduce DNA computation, its scope, approaches to solve problems and challenges.

Keywords—*DNA Computing, molecular computation, Bio-inspired computation.*

I. INTRODUCTION

Billions of Super computers are present in each and every living organism in the form of DNA (Deoxyribonucleic acid). Up to now DNA were seen as transmitters of data of lives. But scientists of 20th century identified the hidden potential of DNA molecule which can be utilized to perform very complex computations which classical computers cannot. It was breakthrough by Adleman who performed calculation on DNAs to solve Hamiltonian path problem in 1994 [2]. While this technology is not readily available but it has a vast potential to emerge as a strong alternative to the way computers work today.

II. DNA

DNA or Deoxyribonucleic acid is a molecule that carries genetic information is present in almost each and every cell of living organisms. It contains biological information that passes from one generation to another. It contains instructions to needed for an organism to develop, survive and reproduce.

The information stored in DNA is in the form of four chemical bases: adenine (A), guanine (G), cytosine(C) and thymine (T). Human DNA contains about 3 billion bases. DNA bases pair up with each other forming base pairs A with T and C with G (A-T and C-G).

The structure of DNA is double helix which is a two stranded chemical structure. This shape looks like a twisted ladder, where sugar and phosphate forms two strands of ladder shaped DNA. The hydrogen bond between phosphates causes the DNA strand to twist. This model is called Watson and Cricks model [3].

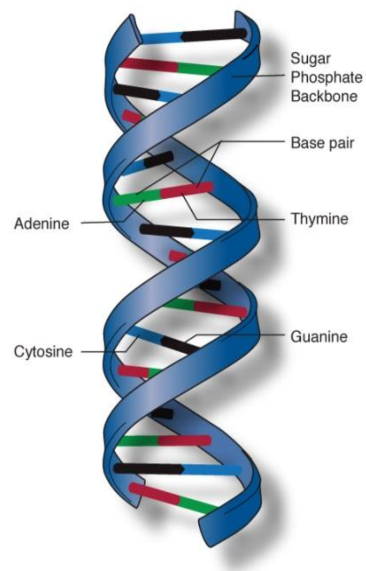

Fig 1. Structure of DNA

III. BASIC OPERATIONS ON DNA

1. ***DNA synthesis***: it is a very common operation to get variable length strands of DNA
2. ***Mixing***: to combine content of two test tubes to third test tube obtain union.
3. ***Melting***: to break double strand of DNA to single strand by process of heating.
4. ***Copying***: to make copy of DNA strands by polymerase chain reaction (PCR).
5. ***Separating***: Separating strands of DNA by process of gel electrophoresis.
6. ***Annealing***: Bonding two strands of DNA by cooling.

7. ***Ligating***: Pasting sticky DNA ends by using DNA ligases.
8. ***Detection and Reading***: using genetic engineering tools.

IV. DNA COMPUTATION

DNA computation means usage of DNA strands to store information and use it to perform mathematical calculations using basic DNA operations. DNA computer is a collection of specially selected DNA strands whose combinations will result in solution to some problem. The biggest benefit we get from DNA computation is parallel processing by billions of interactions, and we get all possible results. Unlike classical storage DNA can store huge data in very small space, about 100000 times of classical storage devices.

The speed of DNA interaction is as fast as twice the speed of fastest super computer. Speed along with parallel operations in addition to high density storage is the only thing human needs.

V. APPROACHES OF DNA COMPUTING

Concept of DNA computing came in real after Leonard Adleman solved an instance of Hamiltonian Path problem by using strands of DNA annealing to each other [2]. He took 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 path. 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. Within a few seconds, all of the possible combinations of DNA strands, which represent answers, are created in the test tube.Adleman eliminates the wrong molecules through chemical reactions, which leaves behind only the flight paths that connect all seven cities.

Using Adleman techniques Lipton showed that SAT problem can also be solved using DNA computation. [4].

Rozenberg divided DNA computation into two aspects theoretical and practical [5]. Though actual DNA Computers will take time to become reality, but their algorithms for specific complex problems are widely developed. Other approaches including breaking of cryptographic algorithms using DNA computations. Most of the NP Complete problems which are too difficult to be solved by silicon based classical computers in polynomial time can be solved with great accuracy with DNA computers.

In 1997, researchers at the University of Rochester developed logic gates made of DNA. In October 2006 Researchers at Columbia University Medical Center in New York and the University of New Mexico claimed that they have developed a DNA-based computer for diagnosing West Nile Virus and bird flu. In May 2010, IBM and the California Institute of Technology have actually built a computer chip utilizing synthesized DNA molecules.

VI. SCOPE OF DNA COMPUTING

Because of high speed and parallel processing approach, DNA computing has a very wide scope. DNA computing is an interdisciplinary field where biologists, computer scientists, physics, mathematicians, chemists, etc. find a lot of interesting problems which can be applied to both theoretical and practical areas of DNA computing. DNA can be seen as a store house of information for a very long time since it is carrying human genetic information for millions of years. Since supply of DNA is costless, hence economic burden of development of this technology is very less. Energy dissipation is also very low in this technology. Optimization problems can be easily solved using DNA computers. Many organizations throughout the planet are brainstorming in development of DNA computing technology.

VII. CHALLENGES OF DNA COMPUTATION

The speed of calculation by DNAs is still not known. Since Genetic engineering is not much developed Annealing errors and hydrolysis of DNA molecules may occur causing loss of data. Even it is difficult to detect and read information from DNAs. DNA computers are not programmable, so it may not be that efficient as we need. DNA molecules works like isolated computing units and there is lack of communication among molecules this limits their flexibility.

VIII. CONCLUSION

Though there exists some loop holes in concept of DNA Computation but one can never discard this fact that DNA computers are promising high speed, large storage and parallel processing approach. NP Complete problems which are very hard for classical computers to solve are far easy for DNA computers to solve in less time. Cost effectiveness and No energy requirement are plus points of DNA computing over classical silicon based computing. With each milestone we achieve in genetic engineering we are coming closer to the day when DNA computer would be a reality.

IX. REFERENCES

[1] R.P. Feynman, Miniaturization, New York, Reinhold, pp.282-296, 1961

[2] L.M. Adleman, Molecular computation of solutions to combinatorial problems, Sciences, vol. 266, no.5187, pp. 1021-1024, 1994

[3] J.D.Watson, P.H.C. Crick, The structure of DNA, 123-131, 1953

[4] Richard J. Lipton, DNA Solution of Hard computational problems, Science, vol. 268, no. 5210, 542-545, 1995

[5] G. Rozenberg, A. Salomaa, DNA Computing: New ideas and paradigms, Lecture Notes in computer science, springer-verlag, vol.7, pp. 188-200,2006