# DNA Computation Based Approach for Enhanced Computing Power

Kashif Hammed

Department of Computer Science
The Islamia University of Bahawalpur
Bahawalpur, Pakistan

*gnetle_kashif@yahoo.com*

**Abstract.** DNA computing is a discipline that aims at harnessing individual molecules at the nano-scopic level for computational purposes. Computation with DNA molecules possesses an inherent interest for researchers in computers and biology. Given its vast parallelism and high-density storage, DNA computing approaches are employed to solve many problems. DNA has also been explored as an excellent material and a fundamental building block for building large-scale nanostructures, constructing individual nano-mechanical devices, and performing computations. Molecular-scale autonomous programmable computers are demonstrated allowing both input and output information to be in molecular form. This paper presents a review of recent advancements in DNA computing and presents major achievements and challenges for researchers in the coming future.

**Keywords:** DNA Computation, Computing Power, Evolutionary Computing

## 1. INTRODUCTION

Ever since scientists discovered that conventional silicon based computers have an upper limit in terms of speed, they have been searching for an alternative media with which to solve computational problems. The search led to DNA.

DNA computing is a method of solving computational problems with the help of biological and chemical operations on DNA strand. It was introduced by Adleman [1]. Since then more and more researchers are motivated by the promising future of this area and start working on it.

DNA is a basic storage medium for all living cells. The main function of DNA is to transmit or absorb the data of life for billion years. Roughly 10 trillion DNA molecules could fit into a space the size of a marble. Since all these molecules can process data simultaneously, you could have 10 trillion calculations going on in a small space at once.

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 byproduct of the reactions. The scientists tell the devices what to do by controlling the composition of the DNA software molecules. 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.

### 1.1. DNA Computation

DNA computing has the potential to overcome the limits imposed on the processing power on silicon based computers. This paper sets the stage for considering this topic to solve computational problems. It focuses on DNA computing in all its varieties and considers the benefits and possible problems of this different form of computing.

The advent of DNA computing also opened doors for collaboration among computer scientists, chemists, biologists, and mathematicians. With the arrival of Adleman's experiment [1], computer scientists and biologists now have the opportunity to study and conduct research in fields completely different from their own. Such collaborative efforts broaden the scope of research in these fields and lead to new insights and perspectives that otherwise would not be discovered. "It's nice to see that computer scientists are getting to know a lot about DNA, and that molecular biologists are getting to know a lot about computer science." [2]

### 1.2. Limitations in Silicon Based Technology

Computer processing power [3] follows a rule of Moore's Law that is the power will be doubled after every 12 months. This is achieved by decreasing the size of transistors and increasing their number in processor. But in coming years this size is reduced to such extent that the only way to make them small is to construct them with atoms. But this size will effect on the transmission of information. So there is a lower size limit on silicon based computer. Also these chips are made of toxic components. Silicon based computers waste a lots of energy in the form of heat they generate and energy they consume.

## 2. DNA COMPUTING

DNA molecule has a double helix structure composed of two sugar phosphate backbones formed by the polymerization of deoxy-ribose sugar. Placed between two backbones are pairs of nucleotides Adenine, Cytosine, Guanine and Thymine. DNA computers use single strands of DNA to perform computing operations.

DNA computing focuses on the use of massive parallelism, or the allocation of tiny portions of a computing task to many different processing elements. The structure of the DNA allows the elements of the problem to be represented in a form that is analogous to the binary code structure. Trillions of unique strands of DNA are able to represent all of the possible solutions to the problem. 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.

### 2.1. The Genesis of DNA Computing

The first major breakthrough in the field of DNA computing occurred in 1994, when Adleman use DNA computing to solve the traveling salesman problem [1] which is also known as Hamiltonian problem. In a Hamiltonian Path problem, a series of towns are connected to each other by a fixed number of bridges.

A hypothetical salesman has to find the shortest path through the set of towns so that he visits each town once before arriving at his final destination. When the number of cities is small, the question can be tackled analytically by figuring out all possible combinations for itineraries and then choosing the shortest path. As the number of cities grows, the problem generates too many possible paths for brute force solving, so a computer is needed to solve it. However, even with a computer, a Hamiltonian Path problem can easily become too complicated to solve.

Although the solution to Adleman's seven‒city Hamiltonian Path problem was relatively straightforward (since all possible routes can be written by hand in a reasonable amount of time), his experiment showed that DNA could be useful as a computational tool.

### 2.2. Different Forms of DNA Computing

One form is DNA computing in which information is processed by making and breaking bonds between DNA components. DNA computers can solve variety of problems and it has proved its worth by solving some complicated problems like "Sales man problem" [1].

Another form is DNA chip which is being used by scientists in their research for self treatment of diseases. Efforts are under way to create tiny robots that could reside in cells and interact with different processes of living organisms.

Researchers are developing genetic 'computer programs' that could be introduced into and replicated by living cells in order to control their processes. Research has already produced engineered sequences of genetic material that can cause the living cell in which it is implanted to produce one of two possible genes. This would be effectively analogous to the computer programs and can serve as 'switches' to control the chemicals that living organisms synthesize [5].

Another variant is to combine living organisms with silicon based technology because brain of living organisms has ability to understand such problems that no amount of silicon based computers will be able to handle.

### 2.3. Benefits of DNA Computing

Following are major benefits of using the DNA computing.

**Parallelism.** "The speed of any computer, biological or not, is determined by two factors: (i) how many parallel processes it has; (ii) how many steps each one can perform per unit time. The exciting point about biology is that the first of these factors can be very large: recall that a small amount of water contains about 1022 molecules. Thus, biological computations could potentially have vastly more parallelism than conventional ones." [6]

**Gigantic Memory Capacity.** They provide extremely dense information storage. For example, one gram of DNA, which when dry would occupy a volume of approximately one cubic centimeter, can store as much information as approximately one trillion CDs.

**Low Power Dissipation.** DNA computers can perform 2 x 1019 (irreversible) operations per joule. Existing supercomputers aren't very energy-efficient, executing a maximum of 109 operations per joule. Here, the energy could be very valuable in future. So, this character of DNA computers can be very important.

**Suitable for Combinatorial Problems.** Much of the work on DNA computing has continued to focus on solving NP-complete and other hard computational problems. In fact, experiments have proved that DNA Computers are suitable for solving complex combinatorial problems, even until now, it costs still several days to solve the problems like Hamiltonian Path problems [4]. But the key point is that Adleman's original and subsequent works demonstrated the ability of DNA Computers to obtain tractable solutions NP-complete and other hard problems, while these are unimaginable using conventional computers.

**Clean, Cheap and Available.** Besides above characteristics, clean, cheap and available are easily found from performance of DNA Computer. It is clean because people do not use any harmful material to produce it and also no pollution generates. It is cheap and available because you can easily find DNA from nature while it's not necessary to exploit mines and that all the work you should do is to extract or refine the parts that you need from organism.

### 2.4. Problems with DNA Computing

A number of problems with DNA computing must be resolved before it can reach its full potential.

1) First, in some cases the type of genetic sequences that would have to be synthesized to make fully functional genetic robots would be expensive using current methods.
2) Second, despite their capability for massively parallel calculations, the individual operations of DNA computers are quite slow in comparison to those of their silicon based computers.
3) Third, DNA computing requires quantity of DNA that can only be used once as reuse can contaminate reaction vessels and lead to less accurate results.
4) Finally, DNA computing is prone to errors at a level that would be considered unacceptable by silicon based computer industry.
5) The DNA molecules can fracture. Over the six months you're computing, your DNA system is gradually turning to water. DNA molecules can break – meaning a DNA molecule, which was part of your computer, is fracture by time. DNA can deteriorate. As time goes by, your DNA computer may start to dissolve. DNA can get damaged as it waits around in solutions and the manipulations of DNA are prone to error.

### 2.5. Future of DNA Computing

The current state of DNA computing research does not suggest that DNA computers will provide a successor to silicon within the next few decades if at all.

We do not believe that DNA computing should be written off completely however since whilst a DNA computer in the traditional sense may be a pipedream, there are niche application areas where the technology may play a part.

It may be possible that DNA computing technology can be integrated with more traditional approaches to create DNA/silicon hybrid architectures or within software. Since software is more flexible and suited to rapid adaptation than hardware, we may see DNA computing benefits being implemented and exploited by in software first, leaving hardware to play catch up [8].

Success hinges on the refinement of the DNA computing process to reduce the time taken to isolate the correct results from all the possibilities generated, and the addition of autonomy to allow DNA computers to arrive at their results with the minimum of human interference.

## 3. RELATED WORK

Researchers are developing genetic ‘computer programs’ that could be introduced into and replicated by living cells in order to control their processes. Research has already produced engineered sequences of genetic material that can cause the living cell in which it is implanted to produce one of two possible genes. This would be effectively analogous to computer programs and could serve as ‘switches’ to control the chemicals that living organisms synthesize.

Development efforts are underway to add data processing elements, memory storage elements, and communication elements, to produce tiny genetic “robots” that could reside in cells. This would allow a level of interface with living processes on a microscopic level that is not possible using strictly silicon-based computing technology. Such techniques could provide an unprecedented level of control over such processes.

Another variant of biological computing development seeks to unite living organisms with silicon-based computing technology. The purpose of this is to use living organisms to control technology. Such technology involves linking living neural cells to silicon-based computing components. The reason for doing this is that the brains of humans, and to a lesser degree, those of lower organisms, have abilities to understand complicated problems that no amount of silicon-based processing power will be able to handle. Further, they are able to solve problems correctly, even with only partial information.

This field is in an extremely early stage of development. For example, researchers at Georgia Tech have used leech neurons to perform mathematical operations, as shown in the picture above. Further, other researchers have managed to link the brain of a lamprey eel to a robot for the purposes of controlling it. The brain has already shown the ability to process information from the surrounding environment and direct the robot’s movements in response to the stimuli. Some researchers are quite interested in extending development work in this area to human beings, albeit in slow steps.

Recently, British cybernetics professor Kevin Warwick was the personal participant in an experiment in which a computer chip was attached to a main nerve in his arm. The chip remained in his arm for four months, allowing him to control a robot on wheels.

## 4. CONCLUSION

In this paper we reviewed current technologies that are available in DNA computing research field. DNA computing is a brand new research area which receives more and more attentions from both biologists and computer scientists. Some biological experiments has been performed which proved the possibility of DNA computing. Due to the highly parallel characteristics of DNA operations, the corresponding DNA algorithms scale well in the size of the problem. Therefore DNA computing shows potential advantages in solving the hard problems. As a conclusion, DNA computing is one of the newest exciting areas to be explored by researchers.

There are a lot of opportunities in expanding and manipulating DNA characteristics and operations to solve real application especially industrial engineering and management engineering problems. However there are still some obstacles in employing this method in its full motion.

## REFERENCES


1. Adleman, L. M. Molecular computation of solutions to combinatorial problems. Science, 266(11):1021-1024, 1994.
2. Zingel, T. Formal Models of DNA Computing: A Survey. Proc. Estonian Acad. Sci. Phys. Math., 49, 2, 90–99, 2000.
3. A .Narayanan and S.Zorbalas, DNA algorithm for computing shortest paths, Proc. of the Genetic Programming, Morgan Kaufman, p p.718-723, 1998.
4. J. C. Adams, on the application of DNA based computing, available online at: http://publish.uwo.ca/jadams/dnaapps1.htm, 14 Jan, 2008.
5. Details of some recent advances in DNA computers are available from NASA's web site at: http://www.jpl.nasa.gov/releases/2002/ release_2002_63.html
6. Nanotechnology will drive the evolution of the DNA molecule as functional components", Olympus TechnoZone, http://www.olympus.co .jp/en/magazine/TechZone/Vol54e/page5.html
7. Information about some of the DNA chip development work at the University of Houston can be found at: http://www.uh.edu/admin /media/nr/102001/biochip.htm
8. Will Ryu, "DNA Computing: A Primer", Ars Technica, 2002