Network and Complex Systems
ISSN 2224-610X (Paper) ISSN 2225-0603 (Online)
Vol 2, No.2, 2012

Bio Inspired Approach as a Problem Solving Technique

Harini Chakravarthy* Pomil Bachan Proch Roshini Rajan K. Chandrasekharan

Department of Computer Science and Engineering, National Institute of Technology Karnataka, Surathkal, Mangalore, Karnataka 575025, India

* E-mail of the corresponding author: harinijc@gmail.com

Abstract

This paper describes the "biologically inspired methodology" as a computing and problem solving technique. Bio-inspired methods have recently gained importance in computing due to the need for flexible, adaptable ways of solving engineering problems. Bio-inspired algorithms are based on the structure and functioning of complex natural systems and tend to solve problems in an adaptable and distributed fashion. An example of a bio-inspired approach to solving the problem of location search has been taken up and discussed in this paper. The bio-inspired methodology has several merits and demerits, which are also discussed in the paper.

Keywords: Bio-inspired approach, Merits and Demerits, Haptotaxis, Competitive and Cooperative Interactions

1. Introduction

Computers have grown from rudimentary calculation machines to sophisticated complex machines that can perform detailed and precise computations and store huge amounts of data. However, the capacity of computers is still limited by the physical limits imposed by the raw material used to make computers. (Nancy Forbes 2000)

Several computation techniques have been introduced to enhance computation beyond the physical limits of computers to solve complex problems. One such approach is biologically inspired computing, also known as Bio-Inspired approach.

Despite the numerous advances in computing technologies, we continue to be humbled by the way nature operates. The variety, sophistication of nature has always amazed the human kind. A problem solving methodology derived from the structure, behaviour and operation of a natural system is called a Bio-Inspired approach. Several systems such as the ant-colony system, bee foraging, bird flocking etc. have been used as the basis for developing models and algorithms to solve various issues such as peer-to-peer network communication and optimal resource allocation. Bio-inspired algorithms have gained importance in the field of computing for their remarkably flexible and adaptable nature.

2. What is Bio-Inspired Computing?

Computing has evolved to help us solve problems with increasing ease. Several complicated problems can be solved using engineering approaches. However classical approaches to solve such problems lack in flexibility and require rigorous mathematical analysis. In direct contrast to these approaches are new methodologies inspired by the natural world that provide simple solutions to complex problems that would be hard by traditional computing approaches.

Biologically inspired algorithms or bio-inspired algorithms are a class of algorithms that imitate specific phenomena from nature. Bio-inspired algorithms are usually bottom-up, decentralized approaches (Ding 2009) that specify a simple set of conditions and rules and attempt to solve a complex problem by iteratively applying these rules. Such algorithms tend to be adaptive, reactive and distributed. (Rocha 2011)

2.1 Importance of Bio-inspired Approach

The study of biological organisms has recently gained importance in computing. Biological organisms deal with environmental demands using ingenious solutions that differ greatly from engineering solutions that are traditionally used to solve similar problems. Such biological solutions are commonplace and easily available to study.

Inspiration has been drawn from biology since the time of early computing. The first digital computer by von Newmann was based on the human brain. (Nancy Forbes 2004) However the use of algorithms directly mimicking the behaviour of natural organisms is a recent development and these algorithms are proven to be significantly more robust and adaptive than traditional algorithms while not compromising much on performance.

Bio-inspired algorithms imitate a biological system in terms of their component behaviour. Biological systems heavily depend on individual components of the system. Thus the first step in building a bio-inspired algorithm is to build individual simplistic components that imitate the behaviour of their biological counterparts. These components then try to reach the overall goal that is defined for them. The components can then be tailored to meet specific problem requirements such as performance or adaptability.

3. An Example

There have been several papers in this area targeting specific real world problems. Researchers have tailored generic bio-inspired approaches such as genetic engineering and ant-colony optimisation to specialized computing problems such as developing self-organizing systems and dynamic resource allocation. One such application is the use of the Haptotaxis phenomenon to perform a location search in an unstructured p2p network. (Kulkarni, Ganguly, Canright & Deutsch 2006)

3.1 Introduction to Haptotaxis

Tissue development, inflammation, tumour metastasis and wound healing in the body takes place by a phenomenon called Haptotaxis. Cell migration to a wounded area or to an inflamed area in the body must maintain a defined direction and speed. This is achieved by cell adhesion proteins that are present in the cell walls. Adhesion ligands are present in the extra-cellular matrix (ECM). The ECM is a layer that surrounds cells in a tissue. The ECM creates a gradient of cell adhesion causing the cells to move towards higher adhesion between ECM ligands and cell receptors. The magnitude of adhesion affects the speed of cell movement while the gradient of adhesion affects direction of cell movement. The Haptotaxis phenomenon is an example of making cells move closer to the destination. This concept can easily be applied to any guided search problem where at any given point of time, the entity should be directed closer to the destination.

3.2 Application

The paper "A new bio-inspired location search algorithm for peer to peer network based Internet telephony" (Brownlee 2005) describes a method of applying the concept of Haptotaxis to the general problem of guided search and specifically to p2p internet telephony systems such as Skype. This technique is called the Hapto-search algorithm.

The authors assume a key based network, where the aim of the system is to retrieve location information of other nodes in the system. Each node is assigned a key, which it distributes to a fixed number of nodes in the network. We say that a node A knows the location information of a node B if it knows the key of B. Thus, if a node A wants to find the location information of a node B, it tries to reach a node C which has a key of node B. Once it finds node C, it extracts B's location information from it.

Figure 1 depicts an instance of the use of the Hapto-search algorithm in a key based network. Assume that a node X distributes its key to nodes C and D. A node G tries to find location information of node X. It first searches the keys it contains to determine if it itself contains the location information of the node X If node G does not contain the key of node it searches its neighbours to find the neighbour that is closest to the destination. To do this, it goes through the keys that each of its neighbours contains. If any of its neighbours contain the key of the destination node, the location information is downloaded from that node. Otherwise, the Hamming distance between each of the keys they contain and the destination is calculated to find the neighbour with the least distance from the destination. The closest neighbour becomes the current node.

This process is repeated until one of the nodes C, D or X is found. The location is downloaded from the node thus found.

3.2.1 Structure of the network

Every node distributes its key to a fixed number of nodes in the network. Thus every node in the network contains keys from other nodes in the network. For any node to get the location information of a node, it is enough if they traverse to any of the nodes that the node has distributed its key to.

3.2.2 The concept of Closeness

The Hamming distance between keys is used as a measure of closeness of one key to the other. A node A is said to be closer to the destination than a node B if A has a key closer to the destination than B in terms of Hamming Distance. If a node does not have the required key, it routes the query to a neighbour that is the closest to the destination.

3.3 Problems with the algorithm

A major problem with the algorithm is when a local minimum is reached. This means the current node is the closest to the destination than any of its neighbours. This problem arises because of the way the algorithm is designed rather than a problem with the biological method used to model the situation. The problem however is overcome by recognizing minima when they occur and continuing the solution using the neighbour farthest from the destination as the current node. A minimum can be recognized easily when all neighbours of the current node have been evaluated to have a higher Hamming Distance than the current node.

4. Bio-Inspired Approach as a Problem Solving Technique

As described in section 2, bio-inspired algorithms depend heavily on component behaviour. They take a bottom-up decentralized approach to solving any problem. They are called computationally intelligent with respect to the field of artificial intelligence. This is because the system is not told how to achieve an overall goal. Instead, through iterative individual component behaviour, the system produces an emergent, overall behaviour. This emergent behaviour is then utilized for solving the problem.

Bio-inspired techniques have three common concepts to achieve the bottom-up emergent behaviour. (Brownlee 2005)

a) Emergent Effects: Desirable characteristics emerge from exposing the bio-inspired computational system to a particular problem. This phenomenon is due to individual component interaction and are easily observed and identified in systems. There are usually complex relationships among individual behavioural patterns that cause emergent effects.

b) Local Interactions: Local interactions are required for components to pass local information, synchronization etc. These interactions are simplistic and are easy to describe and implement.

c) Intermediate Dynamics: The activities of a system that describe how and why discrete units and local rules result in the desired emergent behaviours. These dynamics are complex and difficult to model or describe. Although these concepts are very hard to model exactly for engineering applications, each of these concepts can be optimized or modified to suit specific engineering problems. (Abbott 2005)

4.1 Component design

Components in biological phenomena can typically be classified into cooperative or competitive, depending on whether the components share information to reach the component-level goal or whether each component works competitively to reach the component-level goal. (Smistad 2010)

Consider, for example, Particle Swarm Optimizations (PSO). At the beginning of the algorithm, we randomize the location of individual members and the direction in which each member moves. Each member of the swarm then does a local study (environment variables such as location, velocity and distance from the original base camp). Usually in such algorithms, the individual aims to spread its information to its neighbours. This ensures that each member gets a relative idea about its neighbours and has sufficient information about where its individual performance stands relative to the group. This information helps the individual make decisions such as whether to keep moving in the same direction or not and whether to slow down or speed up. These environment variables are periodically checked by each component throughout the lifetime of the program.

If we compare this search technique to evolutionary algorithms we see that both are parallel search techniques. But, while evolutionary algorithms have competitive interactions, PSO has cooperative interactions among its individual components.

To illustrate competitive interactions, we take the example of Bird Flocking Algorithms. This category of algorithms are inspired by birds and fish that move together so that no individual in the flock can be singled out and eaten by predators. It is to be noted that as in particle swarm optimizations where the organism's tendency is to move towards achieving a common goal of the entire group. This may not apply in case of Bird Flocking Algorithms because here each individual's aim is to survive. This may come at the cost of life of the other members. In some cases, the individual is presented with a choice to leave the group during its migration if it senses that the group of which it is currently a part of is more susceptible to danger that some other group.

Craig Reynolds (1986) studied these algorithms in detail and was the first one to simulate the Flocking Behaviour on a computer. He suggested flocking behaviour is controlled by three simple rules:

a) Separation - avoid crowding neighbours (short range repulsion)
b) Alignment - steer towards average heading of neighbours
c) Cohesion - steer towards average position of neighbours (long range attraction)

The phenomena of cooperation and competition are driving forces for several complex biological systems in nature.

5. Merits and Demerits of Bio-inspired Approach

5.1 Merits

As we have discussed, bio-inspired algorithms present several merits because such a system is designed to be flexible, completely distributed and efficient. Bio-inspired systems can grow, organize, and improve themselves with little direction from humans. These systems consist of several, usually quite simple, individual components. The components usually follow some simple behaviour according to the local information they have or can perceive. This enables artificially intelligent systems that use these components and dynamics to do parallel processing. Each of the components can often operate separately.

A few other merits are presented in Table 1, comparing them to the methods adopted by conventional algorithms using the following criteria.

a) Flexibility
b) Performance
c) Scalability
d) Flexibility in decision making
e) Improvement Scope and innovation

5.2 Demerits

Although Bio-inspired approaches to problem solving seems almost ideal because of properties such as self-optimization, flexibility and simple set of ground rules, it has a few demerits.

1. Component Design: A major drawback in case of Bio-inspired algorithms is the conflict on whether to compromise on competitive interactions or cooperative interactions.
2. Lack of data: Biological systems are extremely hard to study, and the lack of data on a system may affect the design of the algorithm derived from the corresponding biological system. For example, not many measurements have been made for bird flocking, even with high speed cameras to film

flocks. The rules listed above have been found true for small groups but for large flocks the validity of the above rules remains questionable, especially the rule regarding cohesion in large flocks.

3. Lack of complete adaptability: Bio-inspired algorithms cannot be completely adapted to real world systems because of conflicts in scalability or performance issues. For example, in the Bird-flocking algorithm, achieving component safety from being singled out will require that we work out the path of each individual in an explicit manner. This is alright when the algorithm is small scale (similar to a flock of 15-20 birds). However, if we are dealing with a large number of components, this explicit programming will take a huge amount of time.
4. Low performance: Bio-inspired algorithms typically have low performance. This is because biological methods aim to behave well in a wide variety of situations as against aiming to reach the goal quickly. (Neumann & Witt 2010) However, we are free to improve on performance by compromising on the adaptability or flexibility of the algorithm if we know parameters about the environment that the algorithm will be working in.

A few other demerits are presented in Table 2, comparing them to the methods adopted by conventional algorithms using the following criteria.

a) Initial thrust/Starting condition for the algorithm
b) Overhead involved
c) Checking of the environment variables

6. Comparison of Bio-Inspired Algorithms with Conventional Algorithms

Bio-inspired approach certainly differs from the conventional techniques. Biological techniques usually are results of efforts of generations for their struggle to survive harsh conditions. Bio-inspired algorithms are built on simple rules and the assumption that the organism stick to those rules. Also an important characteristic of Bio-inspired approach is the continuous checking of an individual's own performance, as compared to the group. Table 3 compares conventional algorithms to Bio-Inspired algorithms with respect to four criteria

a) Intelligence
b) Testing and Verifiability
c) Improvement
d) Adaptability to practical situations (Kulkarni, Ganguly, Canright & Deutsch 2006)

It is these very properties that are coming to the fore in emerging computer environments such as autonomic computing, pervasive computing, peer-to-peer systems, grid computing and the semantic web. These environments demand systems that are robust to failures, adaptable to changing requirements and deployment scenarios, composed of relatively simple components for ease of development and maintenance and are preferably decentralized and parallel.

7. Conclusion and Future Work

Bio-inspired approach is an emerging field in problem solving techniques. Bio-inspired algorithms have the unique feature of being highly decentralized, bottom-up, adaptable and flexible, thus providing elegant solutions to engineering problems that are constrained by rigid limitations that traditional approaches pose. These algorithms are being progressively used and adapted to various real life situations and problems.

In this paper, we have explored the Bio-Inspired approach and analysed its importance by way of an illustration. Bio-Inspired Algorithms can be used as a problem solving technique using the concepts of Emergent effects, Local Interactions and Intermediate Dynamics. The merits and demerits of using such an approach in real life problems are also shown. This paper addresses the difference between conventional approaches to problem solving and Bio-Inspired approaches.

Bio-Inspired approach to problem solving has immense potential for research especially in the field of Secure routing in Mobile Ad Hoc Networks. The specific challenges of secure routing in MANETs can be handled by using Bio-Inspired Algorithms. As future work, we intend to explore the possibility and feasibility of using an immune system inspired Bio-Inspired approach for secure routing in MANETs.

References

Abbott, R. (2005), "Challenges for Bio-inspired Computing", *The Proceedings of The BioGEC workshop, GECCO*, New York: ACM, pp. 12-22

Bongard, J. (2009), "Biologically Inspired Computing", *IEEE Computer* **42**(4), pp. 95-98 [online at http://www.cs.uvm.edu/ jbongard/papers/2009 IEEEComp Bongard.pdf [accessed 11 Sep 2011]

Brownlee, J. (2005), "On Biologically Inspired Computation a.k.a. The Field", Technical Report 5-02, Swinburne University of Technology

Cohoon, J. & Evans, D. (2003), "Biologically-Inspired Computing", http://www.cs.virginia.edu/evans/bio/ [accessed: 11 Sep 2011]

Craig Reynolds (1986), "Boids", http://www.red3d.com/cwr/boids/ [accessed 11 Sep 2011]

Ding, J (2009), *Advances in Network Management*, Taylor & Francis, p. 164

Forbes, N. (2000), "Biologically Inspired Computing", *Computing in Science and Engineering* **2**(6), pp. 83-87

Forbes, N. (2004), *Imitation of Life: How Biology Is Inspiring Computing*, Cambridge, Massachusetts: The MIT Press

Kulkarni, S., Ganguly, N., Canright, G. & Deutsch, A. (2006), "A new bio-inspired location search algorithm for peer to peer network based Internet telephony", *Proceedings of the 1st international conference on Bio-inspired models of network information and computing systems*, New York: ACM, Article 33.

Neumann, F. & Witt, C. (2010), *Bio inspired Computation in Combinatorial Optimization Algorithms and Their Computational Complexity*, (Natural Computing Series) Springer [online at http://bioinspiredcomputation.com/self-archived-bookNeumannWitt.pdf]

Ridge, E., Kudenko, D., Kazakov, D., Curry, E. (2005), "Moving Nature-Inspired Algorithms to Parallel, Asynchronous and Decentralised Environments", In Czap, H., Unland, R., Branki, C., Tianfield, H. (eds), *Proceeding of the 2005 conference on Self Organization and Autonomic Informatics*, IOS Press, pp. 35-49.

Rocha, L. (2011) "I485/H485/I585: Biologically Inspired Computing", http://informatics.indiana.edu/rocha/i-bic/. August 31, 2011 [accessed 11 Sep 2011]

Smistad, E. (2010) "Competitive and cooperative interactions in biological inspired AI", http://www.thebigblob.com/competitive-and-cooperative-interactions-in-biological-inspired-ai [accessed 11 Sep 2011]

Wikipedia (2011), "Bio-inspired Computing", http://en.wikipedia.org/wiki/Bio-inspired computing. [accessed: 11 Sep 2011]

Notes

Note 1. The basic requirement of all bio inspired algorithms is that they always need some kind of initial thrust or some kind of competition or some condition from which something has to be gained. If there is nothing to be gained or there is no competition then these types of algorithms should not be preferred.

Note 2. Movement of every member (node) is not simply randomized but is guided by some specific set of rules which are programmed into the system.

Table 1. Merits of Bio-Inspired algorithms compared to conventional algorithms

Criteria	Bio-inspired Algorithms	Conventional Algorithms
Flexibility	Strength through flexibility, or strength in numbers	Start with a fixed size or population in mind and hence are not very flexible
Performance	Work well even when the task is poorly defined	Reach a saturation limit in their performance
Scalability	Scalability is not really a challenge	Scalable, but only to a certain degree
Flexibility in decision making	Tend to find the alternate best available solution	Depends on programmer's understanding of the program
Improvement Scope and innovation	Largely unexplored field	Conventional algorithms are optimized and developed almost to their limits

Table 1. Challenges while dealing with Bio-Inspired algorithms

Criteria	Bio-inspired Algorithms	Conventional Algorithms
Initial thrust/Starting condition for the algorithm	Require some kind of initial thrust	No other initial thrust required for the program to run than its specified input
Overhead involved	Overhead involved in assigning a fitness value	Overhead involved is comparatively less
Checking of the environment variables	They form feedback mechanisms. Thus they need to continuously check environment variables.	Do not require any environment variables other than specified input and result.

Table 2. Comparison of Bio-Inspired Algorithms to Conventional Algorithms

Criteria	Bio-inspired Algorithms	Conventional Algorithms
Intelligence	They are built on simple rules. They take a bottom-up approach.	Strictly top down approach.
Testing and Verifiability	Improvements have to be tested on generations success rate of the organisms has to be compared with the previously existing success rates	Any modifications to the algorithm can be tested and results can be verified almost immediately
Improvement	Improving of the Bio-inspired algorithms is not that easy because verifiability	Can be improved whenever the programmer finds a better approach to problem
Adaptability to practical situations (Brownlee 2005)	Cannot be applied to practical problems directly, but have to be customized to the problem	Built keeping the practical situations and the end result in mind

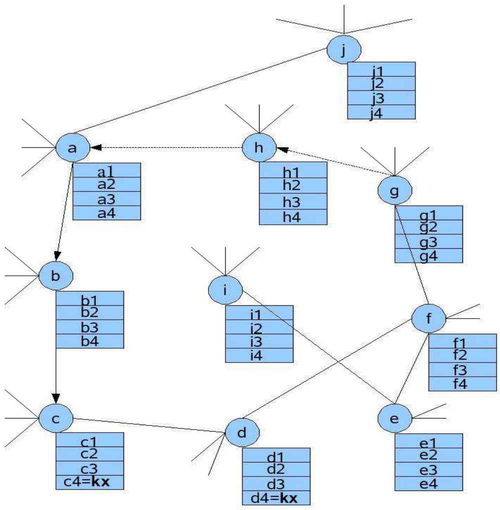

Figure 1. Sketch of a sample location information search.