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# On the Applications of Cellular Automata and Artificial Life

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***Abstract*— Cellular automata are dynamical systems which emulate natural evolution. Cellular automata is a part of Artificial Life. The paper explains the basics of Artificial Life and Cellular Automata. It also examines the basic building block of such systems that is Langton's Loops. The paper discusses various applications of Artificial Life and Cellular Automata and also intends to present a brief review of the work that has been done so far and the gaps there in. The last section of the paper discusses the applicability of Artificial Life in other spheres.**

***Index Terms*— Artificial Life, Cellular Automata, Langton's Loop, Theory of Reproduction.**

## I. INTRODUCTION

Artificial Life (AL), as the name suggests, examines the evolution of life via simulations and modelling. It is an interdisciplinary subject which finds its applications in various fields like computational biology, robotics and computer science.

AL can be classified into hard, soft and wet AL. The soft AL consists of cellular automata (CA) and neural network based techniques. The Hard AL mainly deals with robotics and the wet AL synthetic biology and biotechnology.

A CA is a dynamical system that is discrete in space and time, and operates on a regular lattice. They are characterized by local interactions. A CA is a system that generates patterns that have the capacity of replicating themselves [1]. A Neural network is a massively parallel distributed processor made up of simple processing units that has a natural propensity for storing experiential knowledge and making it available for use [2]. Synthetic biology refers to the synthesis of complex, biologically based systems, which display functions that do not exist in nature [3]. Robotics is the branch of technology that deals with the design, construction, operation, and application of robots, as well as computer systems for their control, sensory feedback, and information processing [4]. Fig. 1 shows the above classification.

The discipline now finds its applications in wide variety of tasks including the management of water distribution system [5] and software testing [6-9].

The work chiefly deals with the soft AL parts and its applications. The organization of the paper is as follows. The second section of the paper deals with the theory of reproduction and its relevance to AL. The applications of AL have been discussed in the third section. The possibility of inclusion of related fields and future scope has been discussed in the fourth section of the paper. This section of the paper concludes.

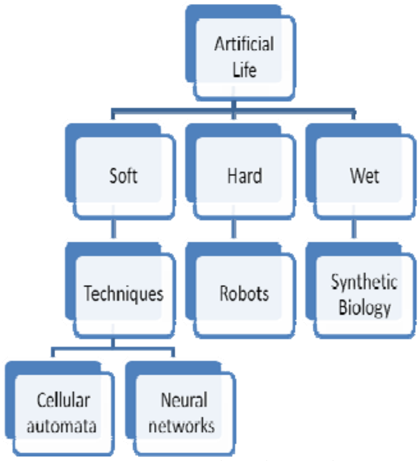

Fig. 1. Types of Artificial Life

## II. THE CONCEPT OF REPRODUCTION

AL is the study of life like processes based on synthetic methodology [10]. The term was coined by Christopher Langton, who also gave the concept of reproduction of pattern by simple rules. This concept of self reproduction was conceptualised by John Von Newman, who gave the theory of self reproducing automata.

The self regulatory processes and CA form the basis of AL. It has been observed by many observers that the statistical mechanic model of physics and mathematics are helpful in quantitative analysis of the system [11]. The dynamical hierarchy is based on the interaction of entities at the lower level which follows definite rules. However, what transpires cannot be guessed. An excellent example of which is John Conway's "Game of life" [12]. The concept of reproduction can be understood by considering the Langton's Loop.

### *A.Langton's Loop*

Langton's Loop was one of the pioneering works in AL. The section discusses the implementation of Langton's Loop. In order to implement Langton's Loop the whole plane is divided into cells and initialized with zeroes. The process starts from the point at the centre who's all four neighbours, initially are zeroes. The next state of the cell is decided as per the rules of Langton's Loop. It may be stated at this point that the next state of a cell is generated by a function which takes the state of the four neighbouring cells and the cell under consideration as its input and generates the next state as the output. There are rules which govern the emergence of patterns. Fig. 2 depicts the application of rules in the patterns. The implementation of Langton's Loop results in repetition of pattern as shown in the Fig. 3.

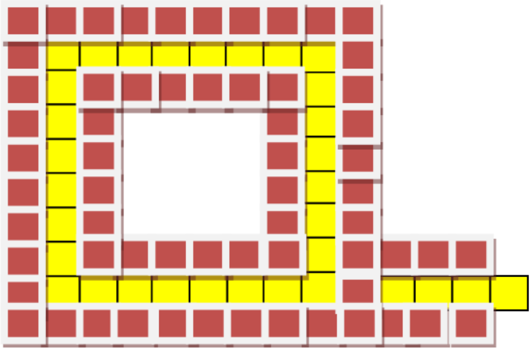

Fig. 2. Langton's Loop

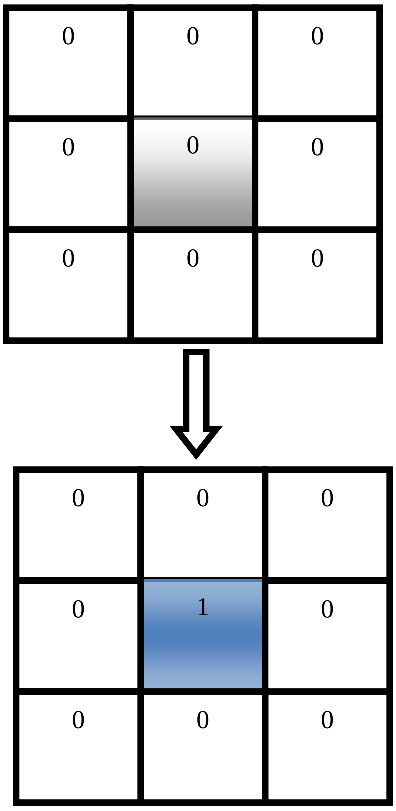


Fig. 3. Applications of rules in order to generate Langton's Loop

The rules governing the formation of Langton's loop are as follows.

- A single white signal propagates through one side and adds one cell to the side.
- Two consecutive white signals extend the data path by two squares.
- Two consecutive green signals change the direction towards left.
- Signals/squares continuously cycle around the data path forming a loop, a kind memory (storage room). Replica of these signals propagate through the tail (path) continuously extending its data path.
- A sequence of six white and two green signals propagate together repeatedly, extending and bending the path till it encloses back forming a new loop.
- It takes 151 time steps in the formation of new identical off spring (Replica of first loop).
- Each loop goes on to produce further off springs (loops), thus reproducing themselves, as long as there is space to create and accommodate new off springs.

When one loop encounters another and limits the space of loop to extend further then the loop has to withdraw its construction arms, thus finally becoming a Dead or Empty loop. This process continues producing a growing colony of such loops.

## III. Applications of Artificial Life

CAs have been used in diverse fields ranging from cryptography, test data generation, biological simulations, parallel processors, cryptanalysis and to solve NP hard problems.

### *A. Cryptography and Cryptanalysis*

CA has been used to design symmetric key cryptography by Franciszek Seredynski et. al.[13]. The work applies CA to generate pseudo random number sequences. The work generates new set of rules by cellular programming, as per the author the set provides high quality encryption.

Cellular programming is an evolutionary computing technique and was introduced to discover the rules of non uniform CAs by M.Sipper [14]. It is capable of evaluating non uniform rules. First of all an initial configuration is set and the CA begins to evolve according to the rules. The statistical quality of the rules is calculated by evaluating the entropy. The entropy used in the work is given by Formula 1.

$$E_h = -1 \times \sum_{k=0}^{n} P_{h_j} \log_2 P_{h_j}$$ : Formula 1

Here $p_{hj}$ is the probability of the occurrence of a sequence $h_j$ in a pseudo random number generator. The rules of the type r=1 and r=2 have been operated upon by selection crossover and mutation. In order to apply genetic operators an evolutionary mechanism is used. The paper proposes a new methodology off crossover and mutation. Uniform CAs having 50 cells evolved in 65, 536 steps with each rule were divided into 4-bit cells. The statistical tests were then applied on the sequence generator.

It may also be stated here that CA has been applied for cryptography since 1985, Wolfram was one of the first persons [15, 16] to use CA for cryptography.

Non uniform CA rules 90 and 150 have also been used in cryptography by S.Nandi et. al. [17]. It may also be stated here that P.D Hortensius et. al.[18] proposed pseudo random generator using CA which became the basis of many works that follow. CAs with r=1 and rule number 90, 105, 150 and 165 have also been used by M. Tomassini et. al.[19] as early as 2000.

In the secondary review by P. Sarkar [20]. It has been noted that CA can be treated as a substitute for the present cryptography systems. The mathematical modelling and the analysis of the conventional cryptography system that have been used till now can be found in the book by Schneier [21].

AL is also important in computer science and Artificial Intelligence. In computer science the methodology used in Genetic Algorithm and agent based system is similar to that of AL.

*B. Test Data Generation*

CAs have also been used in Test Data generation by Bhasin et. al [8]. In the work CAs have been applied for Test Data generation keeping path coverage in view. The work proposes an algorithm for automatic Test Data generation using ERP systems. The extension of the work takes the process further and proposes rule selection and path generation algorithms which covers loops and switch case also [9].

AL has also been used in Test Data generation by Bhasin et. al [6]. The work uses Langton's Loop to generate test cases. The work has been verified by using a professional software. The extension of the work model based on module state diagram [7].

*C. NP complete hard problems*

CA has also been applied to solve NP class of problems. Many researchers have proved that CA out performs heuristic algorithms.

The work by Margensterna et. al. defines CA on a grid of the hyperbolic plane that is based on the tessellation obtained from the regular pentagon with right angles. It shows that 3-SAT can be solved in polynomial time in that peculiar setting; then it extends that result for any NP problem. On this ground, several directions are indicated [23].

NP complete problems have also been dealt with by CA. Bhasin et. al. used CA to solve Travelling Salesman Problem (TSP). The work uses CA along with Genetic Algorithms to solve TSP. The verification shows that the technique outperforms other techniques[24].

Table 1 depicts some of the applications of CA. it is not difficult to infer that CA has already been used in diverse fields and there is a possibility of it being used in many other fields as well.

TABLE I. APPLICATIONS OF CELLULAR AUTOMATA

| | | |
|---|---|---|
| Jaydeb bhaumik, Dipanwita Roy chowdhury, Indrajit Chakrabarti [22] | Error correction coding | The work proves that CA based VLSI implementation error correcting code is superior to Reed-Solomon code. The work overcomes limitations of the Reed- Solomon code. |
| Tommaso Toffoli [25] | CA For Modelling Physical systems | This paper discusses the problem of encoding the state-variables and evolution laws of a physical system. The paper also discusses rules for interpreting the model's behaviour. |
| Stephen Omohundro [26] | CA For Modelling Physical systems | A system of 10 coupled nonlinear partial differential equations is exhibited in the work which simulates an arbitrary two-dimensional, nine-neighbour, square-lattice CA. The work discusses various implications of the result and techniques used in its construction as well as possible practical consequences. |
| G.Bard Ermentrout, Leah Edelstein-Keshet [27] | Simulation of Biological Processes | This paper reviews a number of CA that arise in developmental biology, in neurobiology, population biology along with models of oscillatory media, fibroblast aggregation, branching networks, trail following, and neural maps. |
| Aalpen A. Patel,Edward T. Gawlinski,Susan K. Lemieux,Robert A. Gatenby[28] | Simulation of Cancer cells growth | A hybrid cellular automaton model is described and used to simulate early tumor growth and examine the roles of ihost tissue vascular density and tumor metabolism in the ability of a small number of monoclonal transformed cells to develop into an invasive tumor. |
| Ioannis Karafyllidis Adonios Thanailakis [29] | Simulation of Forest Fires | This paper provides a model that can predict the spreading of fire in both homogeneous and inhomogeneous forests and can easily incorporate weather conditions and land topography. |
| Andrzej Nowak,Maciej Lewenstein [30] | Simulations of Social Movement | This work discusses computer simulations of social processes as models of qualitative understanding. The paper proposes a CA based model of dynamic social impact and its applications in the areas of the formation of public opinion and social change as an example of a model of qualitative understanding. |
| Hortensius, P.D. McLeod, R.D.Card, H.C.[31] | VLSI Application | The work proposes random number generator for fine-grained parallel processing. The author has applied these RNGs in special purpose accelerators. |
| M. Sipper [32] | Distributed Computing | The paper proposes the concept of Cellular computing based on entirely different principles. The concept provides new means for doing computation more efficiently-in terms of speed, cost, power dissipation, information storage, and solution quality. |
| Dave Burraston Ernest Edmondsa [33] | Art | This paper reviews electronic music and sonic art applications CA in a historical and technical context. |

## IV. CONCLUSION AND FUTURE SCOPE

AL imitates the process of natural evolution. The above work brings forth the point that the concept of AL has not been explored, in many disciplines, as yet. There is an immense scope of concepts like Langton's Loop being used in Software Testing. It was also observed that these concepts have not been used in analysing software behaviour. Although, AL is a natural contender for a system that is capable of analysing the behavioural pattern of a software. It may also be stated here, that the paper focuses on the soft techniques of AL and that too CAs. Neural networks have already been used and analysed extensively. They have already been explored in software design and testing. The major point that cropped up during the research was that the basic building blocks like Langton's Loop have seldom been used in Cryptography, Cryptanalysis and Software testing. The future work will focus on whether Langton's Loop can be used to accomplish the above tasks. AL can be used to generate dynamic environment, which would help in diploid genetic algorithms. Such environments are being created and tested for dynamic TSP [34].

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