Cellular Automata and Their Applications: A Review

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Abstract: **This paper reports a detail study on the convergence of the one-dimensional two-state 3-neighborhood asynchronous cellular automata (ACA) under null.**

Keywords: Asynchronous cellular automata (ACA), classification, convergence, fixed point attractor, multi-state attractor

I. INTRODUCTION

Cellular Automata (CAs) are among the oldest model of natural computing, dating back over a half century. The journey of cellular automata were originally proposed by Jon Von Neumann in the late 19400 s as formal models of biological self-reproduction, the goal was to design self-replicating artificial systems that are also computationally universal. The framework studied was mostly based on one and two dimensional infinite grids though higher dimensions were also considered. At the beginning, CA was only focus on the concept of computer science and mathematics. However, gradually it is used in different fields such as Physics, Biology etc. In the present era, CAs are being studied from many widely different fields, and the relationship of these structures to existing problems are being constantly sought and discovered. A Cellular Automaton (CA) is a discrete dynamic system comprising of an orderly network of cell, where each cell is a finite state automaton. The next state of a particular cell is decided by its previous state and its neighbors (left and Right most neighbors) cells following a local update rule. Wolfram in [52] said that CA is an infinite 1 Dimensional, where each square box called a cell. In CA there are two possible state 1 and 0, where 1 is considered as black cell and 0 is considered as white cell. The next of each cell depends on the state of itself and its two neighbors (left and right). The CA cannot only model biological self-reproduction but also computationally universal. The beauty of a CA is simple local interaction and computation of cell results in a huge complex behaviour when the cells add together. Since the inception, CAs have captured the attention of a large number of researchers already working in this field as well as new entrants to this field. There are different variations of CAs which have been suggested by different authors to ease the design and modelling of Complex Systems. They are Linear CA, Complement CA, Additive CA, Uniform CA, Hybrid CA, Null Boundary CA, Periodic Boundary CA, Programmable CA, Reversible CA, Non-Linear CA, Generalized Multiple Attractor CA, Fuzzy CA. Cellular automata are a collection of cells that each consists of a finite number of states. Single cells change in states by following a local rule that depends on the environment (i.e., neighbors) of the cell. The environment of a cell is usually taken to be a small number of neighboring cells i.e., 1 or 2 neighbors for 1-Dimensional as well as 2-Dimensional CAs [19]. Fig. 1. shows two typical neighborhood options i.e., for 1-Dimension as well as 2-Dimension, (a) One Way CA (b) Two Way CA are 1-Dimensional CAs and (c) Von Neumann Neighborhood (d) Moore Neighborhoods are 2-dimensional CAs. Basically, a cellular automaton (CA) consists of a graph where each node is a finite state automaton (FSA) or cell. This graph is usually in the form of a two dimensional lattice whose cells evolve according to a global update rule (CA Rule) applied uniformly over all the cells. As arguments, this update rule takes the cells present state and the states of the cells in its interaction neighborhood (left and right most cells) [8] as shown in Fig. 2.

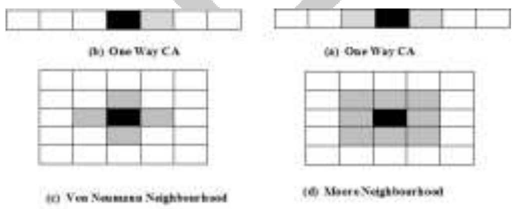

Fig. 1. 1(a) and 1(b) are 1-dimensional CAs, and 1(c) and 1(d) are 2-dimensional CAs

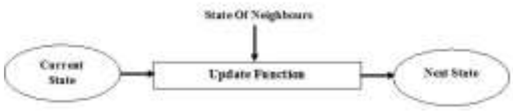

Fig. 2. State Transition depends on neighborhoods States

Over the years, the computational model of CAs has been suggested to study the general phenomenological aspects including Communication, Construction, Growth, Reproduction, Competition and Evolution [22]. In the rest of this Paper we have discussed CA applied in different applications such as Image Processing, Fractals, Pattern Recognition and classification, Bio-Informatics, VLSI, Cryptography, The Games of life, Economic Systems, Biological Systems, Environmental Systems, Ecological Systems, Edge Detection, Traffic Systems, Machine Learning and Control, Crystallization Process and the like. In CAs [40][50], are defined by a lattice of cells and a local rule by which state of a cell is determined as a function of the state of its neighbor of length greater than 1 (multi-state attractors). The researchers have also classified the CA following their convergence property [55]. However, all such works have dealt with synchronous CA, where all the CA cells are updated simultaneously.

Among the huge applications of CAs, here we briefly discuss some of the applications of CAs such as Image Processing, Fractals, Pattern Recognition and classification, Bio-Informatics, VLSI, Cryptography. This paper is coordinated as follows:

The section II consists survey about CAs in Image Processing, Section III contains the survey report of CAs in Pattern Recognition and Classification, Section IV contain CAs in Fractal, Section V is detail about CAs in Cryptography, Section V I consists of CAs in Bioinformatics, Section V II have review about CAs in VLSI, Section V III displays the conclusion of this paper and Final section i.e., Section IX shows the Reference part of this paper.

II. CA IN IMAGE PROCESSING

Over the last fifty years a variety of well known researchers such as John von Neumann, Stephen Wolfram and John Conway have explored the properties of cellular automata [32]. Particularly in the 19600s and 19700s significant activity was done towards developing special purpose hardware (e.g. CLIP) along-with developing rules for the application of the CAs to image analysis tasks. By the 19900s CAs could be applied to achieve a range of computer vision tasks, such as: calculating properties of binary regions such as area, perimeter, convexity, gap filling and template matching and noise filtering and sharpening [32]. In this modern world, parallel algorithms for solving any image processing task is a highly demanded approach. CAs are the most simple and common model of parallel computation. So, CAs have been successfully used in the domain of Image Processing for the last couple of years [31]. In Image Processing, the parallel algorithms are much more important than serial algorithms. Many standard algorithms for most of the Image Processing tasks have already been introduced by different researchers in the last few decades. But some researchers later have used CAs to solve the same problem and found to be better than conventional methods [31]. From this review it has been found that most of the researchers used Linear CA for solving different Image Processing tasks and very few of them using Hybrid and Non-Linear CA. Application of Hybrid CA and Non-Linear CA is a challenging task for researchers in this field. In CA, the states of the cells are updated synchronously at a discrete time step. So the time complexity to do any Image Processing task is the least.

In Image Processing mainly 2-Dimensional CAs are involved. The pixels of the images represent as cells of the CA and they update their state based on the states of the neighboring cells (pixels). Multiple states of CA cells allow the processing of Grey Scale Images or Color Images. Identifying the rules that apply to cells in order to answer a certain request in Image processing in nether less a non-trivial task [4]. The simplest use of CA for Image Processing is given by the application of specific rules for different tasks of Image Processing, for example B-rule, 2-Cycles CAs, Totalistic Rule, Majority Rule, Linear Rule, Optimal Rule, Hill Climbing, Grow-Cut Algorithm, Seed Grow Cut Algorithm by Vezhnevets no different from Ford Bellmann Algorithm (That computes shortest paths from a cell to all other cells in the CA) and other methods such as Genetic Algorithm, Swarms Optimization, Genetic Programming and the like [4]. In particular, for filtering salt and pepper noise the CA performed better than Standard Median Filtering. At the beginning the CA focus on the Binary Image Processing i.e., the image formed from 00s and 10s and gradually it moved to Digital Images and then Intensity Images. Digital Image Processing acting a vital tasks in daily life applications such as Satellite Television, Computer Tomography and Magnetic Reverberation imaging also in the area of Research and Technology like Geographical Information Systems and Astronomy [35]. CA has been applied in Image Processing with various advantages in 1-D as well as 2-D CA. The increased number of cell states leads to a vast increase in the number of possible Rules. Therefore, a reduced intensity representation is used, leading to a three state CA that is more practical [35]. CA are successfully used in many Image Processing tasks including Image Denoising, Edge Detection, Image Compression, Segmentation, Geometric Transformation, Noise Filtering, Feature Detection and the like [4].

III. CA IN PATTERN RECOGNITION AND CLASSIFICATION

Cellular Automata (CAs) are Spatio-Temporal Discrete Systems (Neumann 1966) that can model Dynamic Complex Systems. For elementary pattern recognition a special type of Generalized Multiple Attractor Cellular Automata (GMACA) has been introduced. It is a promising pattern classifier using a simple local network of Elementary Cellular Automata (ECA) (Wolfram 1994) called attractor basin that is a reverse Tree Graph. For the Purpose of ordering the CA Rules GMACA utilizes a Reverse Engineering Technique and Genetic Algorithm (GA). This leads to a major disadvantage of Computational Complexity as well as Recognition Performance [41]. Due to the major drawbacks of Complexity and Recognition Performance stated previously, the binary CAs based classifier called Two-Class Classifier-GMACA with artificial point (2C2-GMACA) is presented. In [41] hence it is finally concluded that Two-Class Classifier GMACA with Artificial Point (2C2-GMACA) for pattern recognition reports 99.98% recognition rate superior to GMACA which reports 72.50% when it is the case of Associative Memory. In case of Non-Associative Memory Two-Class Classifier GMACA with artificial point (2C2-GMACA) reports 95.00% superior to GMACA which reports 72.50%. So, Therefore Two-Class Classifier GMACA with Artificial Point 7 to 14 times faster than GMACA. So, in [41] it suggests the extension of 2C2GMACA to other pattern recognition tasks.

In [6] describes a pattern recognition method which will allow for a combination of approaches based on prior analysis and Contextual Information with those based on Artificial Neural Networks. [6] Develops a new iterative Neural Network Skeleton or groundwork which allows the incorporation of Knowledge-Based reasoning in to the network topology. In order to solve any set of problems related to pattern recognition the Artificial Neural Networks (ANNs) is the simplest version, which proceeds by assigning positive and negative weights to links between processing nodes and then an appropriate algorithm is suggested. For Example, the Hop-Field Network can implement an associative memory of any input pattern. The Network can then recognize a given pattern, if the presented pattern is ”close” in some sense to one of the stored pattern. From the study of desirable features in a pattern recognition it arises a Neural Network implementation of a probabilistic CA (Cellular Automaton) and that has the following properties such as By the help of correlation and possible noise into a parallel iterative algorithm, integrates the information about the structure of the object to be recognized, As the connection are local: Only nearby processors interacts etc [6].

Some Articles like [46] refers specialized class of 1-Dimensional CAs, called Linear/Additive CA which has gained the primary attention of many researchers as well as new entrants to this field. Many CAs applications were successfully developed by the utility of ease characterization Linear/Additive CA such as VLSI Design, Cryptography, pattern recognition etc. To get effective solution for pattern recognition it uses Multiple single -Length cycle Attractors around CAs which is more demand-able at the current work. For pattern recognizer, an appropriate scheme has been developed to sympathize the Single-Length Cycle Attractor CA, avoiding Multiple-Length Cycles [46].

The Internet-Worked society has been suffering a explosion of data that is acting as an barrier in acquiring knowledge. The meaningful perception of these data is increasingly becoming difficult [1]. For the purpose of knowledge extraction, consequently Researchers, Practitioners, Entrepreneurs from diverse fields congregate together to develop sophisticated technique [1]. Study of data classification model forms the basis of such research. A pattern classification normally comprises of two basic operations such as Classification and Prediction. The evolving CAs based classifier derives its strength from the different types of features. They are:

(a)To arrive at the derived model of CAs based pattern classifier a special class of CAs referred to as MACA is evolved with the help of GA [1].

(b)In the prediction phase the classifier is capable of accommodating noise based on distance metric [1].

(c)The classifier Employs simple computing model of three neighborhood additive CAs having very high throughput that results in simple, regular, modular and local neighborhoods sparse network of CAs suits ideally for low cost VLSI implementation [1].

In [22] a special class of CAs has been focused referred as Fuzzy CAs (FCA) is employed to design the pattern classifier. FCA introduced in CAs more than 30 years ago. It is a natural extension of conventional CAs which operates on Binary string employing Boolean Logic as next state function of a cell. For the purpose of analysis and synthesis of FCA a metric algebraic formulation has been developed. Extensive experimental results confirms the scalability of the proposed FCA based classifier to handle large volume of datasets irrespective of the number of classes, tuples and attributes. The FCA based pattern classifier has established excellent classification accuracy as an efficient and cost effective solution for the pattern classification problems. In [22] it is mentioned that FCA have been considered by several researchers in both theory and applications. By using rule supporting OR and NOR function as next state logic the FCA is configured.

In [18] a scalable evolutionary design for pattern recognition using Multiple Attractor CAs (MACA). By using Hamming distance based attractors MACA helps to impart Non-Linearity in the classifiers. In order to make the large classification problem involving Non-Linear boundaries method more scalable Isomorphism in MACA was exploited. In Satellite Image analysis problem the pattern classifier may be applied. Linear Classifier are not suitable for all problems. A data dependent non-linear metric is more versatile as it help in capturing and imparting non-linearity to classifiers inherently [18]. MACA is a special class of CAs that help us to lower the complexity by using Hamming Distance Metrics. Lowering the complexity has helped us in making the pattern classifier more scalable. The pattern classification have been utilized in many real life applications. The MACA classifier which is of great importance to the Data Mining Community. The current MACA based classifier shows a promise of simple binary classifier and an inferencing mechanism on the dataset which can be used to solve many real life problems [18].

In [9] a theoretical skeleton has been improved to devise scheme for blending a Single Length Cycle Multiple Attractor CAs with the specific set of PseudoExhaustive Bits (PE-Bits). In order to make a cost effective solution of real life applications and Multiple Single Length CAs with PE-Bits can be used. The said synthesized CAs is effectively utilized to design efficient pattern classifier [9].

In [23] the proposed classifier is designed around a special class of Sparse Network referred to as CAs which can be applied in their diverse field such as Data Mining, Image Compression and Fault Diagnosis. Data or Pattern Classification is the method of identifying common properties among a set of objects or data in a Database. It determines the objects into different classes. The essential requirements of developing the pattern classifier for current information age are high throughput and low storage requirements. Further, a low cost hard-wired for the implementation of such specific scheme is becoming very important criteria for on-line real time applications [23]. The various Conventional techniques developed for pattern classification are Bayesian Classification, Neural Network whose decision are too complex to meet such requirements. So, there is a pattern classifier built around a special class of Sparse Network which reduce the complexity of the CAs based algorithm from O(n3) to O(n) [23].

IV. CA IN FRACTAL

The first fractals were discovered by a French Mathematician named ”Gaston Julia” who discovered them decades before the advent of computer graphics. Julias work was rediscovered by Benoit Mandelbrot Fig. 3.. The term ”Fractal” was coined by ”Benoit Mandelbrot” in 1975. The term Fractal is derived from the Latin word ”Fractus” which means ”Broken” or ”Fractured”. ”Mandelbrot Set” is most famous among all fractals. Basically a fractal is a ”Rough” or ”fragmented” geometric shape that can subdivided into parts, each of which is atleast approximately a reduced-size copy of the whole. This is one type of special property related related to fractal called ”Self-Similarity”. A Fractal is a mathematical object that has two specific properties such as (a) Self-Similarity and (b) Chaos.

Fig. 3. Benoit Mandelbrot

(a) Self-Similarity: According to this property as you will break an Object or Image into small parts, you can able to see the original Object or Image over and over again in its parts i.e., when you look at a single sub-part it just look like the whole.
(b) Chaotic: Fractals are infinitely complex i.e., the object generated is complex in nature. Generally, Chaotic can be defined as: (1) Sensitive to Initial Conditions, (2) Topologically Mixing and (3) Dense Periodic Orbits. Amazingly, these beautiful complex objects are generated by using simple mathematical processes (rule) called CAs local rule. To know the fractal character of an object we have to check the dimension of the particular object i.e., the dimension of the object should not be an integer like 0, 1, 2, ... but it must be like 0.1, 1.2, 0.63....etc. A fractal often has the following special types of features such as:
(i) It has fine structure at arbitrarily small scales, (ii) To be easily described in traditional Euclidean Geometric Language, Fractal is too irregular, (iii) It is Self-Similar as well as Chaotic in Nature and (iv) It has simple and recursive definition.
Fractal Dimensions: Everyone knows the dimensions of a Line, Square, and a Cube and how they can be measured. They are One, Two and three respectively. And, we can measure the Distance, Area, and Volume of those objects as well. However, what is the dimension of the inside of a Kidney or the Brain or Heart and do we measure their Surface Area, Volume etc? How about a piece of Cauliflower and other object with irregular shape? This is where fractal dimension can help us out. Fractal Dimension allow us to measure the complexity of a object as pattern wise measurement. There are two different types of fractal Dimension which is said in [16]. They are: a Self-Similarity Dimension. And b Box-Counting Dimension.

In recent years, CAs have been found of computing complex behavior or system by using simple CAs local rule (Mathematical Processes) with local interaction. On simple initial configuration, the generated pattern might be Fractal or Self-Similar. Hence in [15] regular evolution of Totalistic Linear CAs is investigated i.e., Capable of generating fractal object or not. Based on Statistically observed long-term simple behavior CAs, Wolfram in [53] suggested a classification of CA. He discovered that the CAs appears to fall into four classes. Majority of CA rules falls in third class in which the evolution leads to a Chaotic Pattern. Not all the CA rule generate chaotic pattern even some of them generate self-similarity pattern or figure. Wilson has studied the generation of fractal pattern by additive CAS, that have Mod 2 addition (XOR) CA Local Rule, when the initial seed is single 1. In [15] shows the fractal behavior (i.e., Self-Similarity as well as Chaotic) of Linear Totalistic CAs as well as for Trellis Automata.

In [26] proposed a specific method to develop ”Fractal Pattern” by utilizing simple computation known as CAs. However, the problem of Fractal Pattern generation is done by using Linear CAS recently rather than Classical CAs. Here in [26] describe how to generalize cellular space of greater dimension by using some basic techniques for the construction of the transition function, which draws a Cantor set. Then, further a specific method is developed for embedding the configuration into a closed interval to obtain fractal patterns. A sequence of error also appears by fractal during the transmission of data. The problem related to prove the fractal behavior of CAs is studied by Wolfram [53], Culik [15], Wilson [51] and Haesler et al. [10]. These authors often accord with linear modulo-2 uni-dimensional CAs whose main occasion is the Pascal Triangle, which can be developed finitely by algebraic means. Haesler et al. [10] claimed that the production of fractal pattern in the long time evolution of CAs poses three major problems such as: (1) When and in What sense for the evolution of CAS there is an limit-set? (2) How can the Self-Similarity feature of a limit-set be formally designed and deciphered? (3) Which class of CAs out of four class (According to Wolfram) of CAs can generate fractal structure? Therefore, where Wilson [51] discuss and solve the first problem, Takahashi [47] did it for second problem and Haesler et al. consider for all the three problems. In [26] introduce another specific method for the generation of fractal structure by involving CAs mostly based on Cantor Sets and Products of Cantor Sets (ExampleThe Sierpinski carpet or Sierpinski-Menger Sponge). In [26] it work with an congregate of some configurations into a continuous space and we can restrict ourselves to a subsequence of the configurations in the discrete space to make computations. Hausdroff measure also an best method applied to generate Fractal Pattern using CAs. In [17] said that the Space-Time Diagram of some CAs rules generates Fractal structures. Since from several decades the fractal structure or pattern of CA has been proved to be an interesting topic for many researchers already working in this field as well as for the new entrants into this field. In many works of Linear CA, the authors in many paper present various ways to calculate the fractal dimension of a pattern or to predict the state of an arbitrary cell at an arbitrary time step, with very much low complexity then by running CA step by step in order to check the dimension of the image pattern wise to prove the self-similarity and chaotic property of that generated pattern. In [17] it consider 1-Dimension of Linear CAs whose alphabet is an Abelian group. The recursion relation empower us to compose the evolution of the Space-Time Diagram as a matrix substitution method, which in-turn gives us the medium to calculate the fractal dimension of Space-Time Diagram of CAs rules. There are various types of methods which are utilized to prove the generation of fractal structure or pattern by CAs (Space-Time Diagram) such as Elementary Graph Theory (EGT), Matrix Substitution System with CAs etc. The study of Clifford Quantum Cellular Automata (CQCAs) is tha stem to our interest in the fractal structure of CAs on Abelian Groups. In [17] shows that every CA (Cellular Automaton) including a morphism of Abelian Groups produces a Space-Time Diagrams that converge to Self-Similar patterns that are superposition of elementary patterns dragged for groups of prime power order. In [17] it includes only 1-Dimensional CA to generate fractal structures but it can be extends to higher dimensions in-order to generate fractal structures.

The patterns produced by CAs gives a special sequence of set in Euclidean Space. In [49] fractal structure do not depends on Time-Parameter. Generating Self-Similar fractal figure is an interested application of CA which has ability to drag the attention of many researchers already working in this field as well as the attention of the new entrants to this field Wilson studied the generation of fractals by Linear CAs when the initial seed was a short finite configuration and computed the fractal dimension for several such cases where method based on the Time-Parameters. So, we can get only (d+1) dimension where d denotes the Space Dimension and 1 is the Time-Parameter. A suitable pattern is produced by all CA class is chooses and integrated into Euclidean Space by appropriately rescaling the set sequence leads to a limit which might be a fractal structure. By this method all classical fractal can be gained in particular , Self-Similar sets [49]. In [16] shows an example of fractal pattern generation using CAs i.e. a cancer growth cell inspired from the Conway's Game of Life and each of the cell grid represents the location of the living cell.

V. CA IN CRYPTOGRAPHY

The term "Cryptography" has derived from a Greek word, which means "Secrete Writing". In the age of Global Electronic Connectivity to secure data storage and transmission against the possibility of message eavesdropping and electronic scam a basic technique is used which is called as "Cryptography". However, current global network are characterized by an very large growth of digital information storage and transmission needs. Especially to promise security and authenticity in the field of electronic commerce transactions and for classified material many public and private organizations have become increasingly depend on cryptographic techniques. In [25] describes a single key cryptographic system based on One and Two-Dimensional CAs randomizers obtained by artificial evolution. CAs in cryptography was first introduced by Wolfram [54], and by Nandi et al. [38], Gutowitz [14], and Guan [13]. In [24] [25] [27] describes that the proposed encryption scheme is depend on the generation of Pseudo-Random Bit sequence produced by One and Two-Dimensional Non-Uniform CAs.

The basic objective of cryptography system is to secure the message that passing through an insecure medium. The security of data is provided by the Cryptography Algorithms. The message to be sent over the insecure medium is known as plain text, which is encrypted before sending over the medium. The encrypted message is called cipher text which is received at the other side and then it is decrypted back to the original plain text message. Cryptography is a mathematical process to perform encryption as well as decryption. Cryptographic algorithm with CAs is broadly classified into three categories such as : (a) Symmetric Algorithm, (b) Asymmetric Algorithm and (c) Authentication. In case of Symmetric Algorithm same key is used for encryption and decryption process, whereas for Asymmetric Algorithm different keys are used for encryption and decryption process and for Authentication Algorithm mean that the receiver should be sure about sender identity. A CAs used in cryptography ia an organized lattice of cells and each cell have finite number of states such as "True" (T) or "False" (F). In [27] focused on security key for encryption and decryption with CAs as well as 256 bit CAs encryption and decryption is designed and synthesized. The CAs in cryptography is applied in different area such as Security, Defence, Medical, Business and Many other application Areas. The effective measure of cryptography Algorithm is how long it run encrypt and decrypt with out breaking the security key. in [3] it focus on symmetric algorithm where the sender as well as the receiver utilize the same key for encrypt and decrypt process. This key used by the sender to encrypt the message called as cipher text and then the same key is used by the receiver to decrypt the message called as plain text in order to get the original message [3].

Application of CAs in stream cipher cryptography was discovered by Wolfram [54] with Non-Linear CAs. In [38] describe the theory and application of additive CAs as the basic data encryption hardware module. For communication privacy or Concealment of data in data bank essentially required cryptography whose encryption may be achieved by building two types of ciphers such as Stream cipher as well Block cipher. A Block cipher is one in which the message is broken into successive blocks and they are encrypted or decrypted by a single key or multiple keys. On the other hand, in a stream cipher a message is broke into stream and then is encrypted by a key stream. In [38] present schemes for a class of Block cipher and Stream cipher around the regular structure of CAs. In [20][39] shows that Reversible CAs (RCAs) as effective encryption and decryption devices. Their effectiveness is due to their inherent parallelism. In both classical secrete key cryptosystems as well as a public key the reversible CAs can be used. During the practical implementation of cryptosystem are built it often causes big problem due to low speed of encryption and decryption method. This is valid especially in connection with public key cryptosystem, but in some framework higher speed of security key systems would be necessary as well. Generally, the solution of the above said problem is to alter software with hardware. Another alternative method to solve the problem is parallelization, in order to get considered speed up, but a big amount of dedicated hardware is required, which can make the cost of implementation of the system astronomical. So, in [20][39] propose the use of reversible CAs as very fast cryptosystem. CAs are inherently parallel which makes their parallel implementation natural. Due to the simplicity and locality property of CAs their operation with cryptosystem make it possible to build cheap and fast devices containing even hundreds or thousands of cells (processors) working in parallel.

In [39] also describes a algorithm based on CAs built on a set of reversible rules which has the ability to construct unpredictable secret keys using MARGOLUS neighborhoods. To prove this algorithm [39] presents some test on encryption, decryption and diffusion and therefore the algorithm work only against the Brute Force Attack. The cryptosystem algorithms are implemented in Security Protocols, Electronic Chips etc. The most known symmetric cryptography systems are DES, AES, RC4, and RC5 which are utilized in a secure communication protocols as TLS whereas Asymmetric cryptography used in secured protocol such as SSL. In [43] CAs are used to design symmetric key cryptosystem based on ”Vernam Cipher”. During the encryption process CAs are applied to generate a Pseudo Random Number Sequence (PNS). The quality of the PNSs highly depends on the set of applied CAs rules where radius r = 1 or 2 for Non-Uniform one-Dimensional CAs have been considered. The applied CAs set provide high quality encryption and the system is very much resistant to attempt of breaking the cryptography key . At present there are two types of encryption system in the market such as Secret Key System and Public Key System. [43] describe one of the promising cryptography technique called CAs where CAs proposed for Public-Key cryptosystem by Guan [13] and Kari [20]. In such system two keys are required one for encryption and other one is for decryption i.e., where one held in private and other one is published.

In [44] represents a Symmetric key cryptosystem using rule 57 Asynchronous CAs. It is exploratory shown that after 32000 iterations the proposed cryptosystem achieves the avalanche effect. The exposure of the proposed scheme is discussed and note that, Brute Force Attack is practically beyond the bounds of possibility. The capability of the scheme is correlated with other cryptosystems, and finally, it is also conclude that the proposed cryptosystem can easily be implemented in hardware.

CAs have been utilized in cryptography because of some specific feature of CAs such as Complex Behavior, Simple Model (CA Local Rule) and able to generate complex and random patterns. Kari introduce the use of Reversible CAs in cryptography. Kari insists that due to ”the inherent parallelism, RCAs can be used as efficient and decryption devices”. However, all these research on cryptography are mostly converge on Synchronous CAs (deterministic) where all the cells are enforced to update. Till now, no work has been initiate in cryptography using Asynchronous CAs (ACAs). This has inspire [44] to engage in such type of research. In [44] adapt One-Dimensional, Two-States, and Three Neighborhood CAs that update fully Asynchronously i.e. At each discrete time step an arbitrary cell is selected randomly and uniformly to update. In [44] for block cipher encryption an ACAs based symmetric key cryptosystem have been addressed. In the proposed scheme of [44] it generates a cipher text by encrypting a plain text using a class of CAs under fully asynchronously update and then it again decrypt the cipher text using the same ACAs in order to obtain the plain text. Hence, [44] utilize ACAs with property of backward transaction for design of the cryptosystem as the encryption and decryption are opposite to each other. In view of the proposed target, [44] first analyze ACAs with capable of backward transactions. In One-Dimensional, Two-States and Three-Neighborhood system 256 local rules are present. [44] evolve all 256 rules to find the capability of ACAs with capable of background transaction. However, [44] find the ACAs with no fixed point from the list of ACAs with the capability of backward transaction. Hence, In [44] uses Fixed-Point Graph to find such ACAs from the list of ACAs. The security of the proposed scheme [44] mainly depends on the key used for the encryption. [44] used the proposed scheme to compare the new encryption with the existing system such as Data Encryption Standard (DES) and Advanced Encryption Standard (AES). For block cipher encryption [44] has proposed an ACAs based symmetric key cryptosystem. In [44] for design it utilize the ACAs with backward transaction and using reverse the property of update pattern. In [44] compare the cryptosystem ACAs with the existing cryptosystem and then report that the designed cryptosystem is competitive with other existing cryptosystem. The primary limitation of the designed cryptosystem is large key length. Finally, [44] realize the possible of cryptosystem in hardware.

VI. CA IN BIOINFORMATICS

Bioinformatics Encircle everything from data storage and recapture to the identification and presentation of features within data, such as finding genes within DNA sequence, finding comparability between sequences, structural predictions. The proposed algorithm may be very much useful to solve many other Bioinformatics problems like Protein Structure Prediction, RNA Structure Prediction, Promoter Region identification etc. [33] aims at introducing a contemplate on the problem that can be easily addressed by CAs in Bioinformatics. The application of CAs in Bioinformatics is a virgin field in research out of the various existed algorithm introduced by different authors for addressing some problems in Bioinformatics. Till day none of the researchers has tried to track the major problems in Bioinformatics and find a common solution. In [33] provides information towards relating various problems in Bioinformatics logically and tries to attain a common structure for addressing the same. In [33] mainly focus on problem related to Bioinformatics like Protein Coding , Promoter Prediction, and Protein Structure Prediction. In [33] CAs is introduced with AIS-MACAs (Artificial Immune System based Multiple Attractor Cellular Automata).

Cellular Automata: Artificial Intelligence (AI) is the survey of impersonating human mental ability in a computer. Current AI methods most importantly focus on two general categories. They are: Explicit Modeling (Words, Images), Implicit Modelling (Numerical Techniques).

(a) Explicit Modeling: (Words, Images) This model has been successfully used in many domains based on rules, frames and case based learning. This model doesn't have capability to handle unseen cases.

(b) Implicit Modeling: (Numerical Techniques) Based on perception and experience this methodology addresses this issue by advancement of the model dependent. And therefore, this model have capability to handle unseen cases because CAs based classifier can learn Associations.

(1) Cellular Automata: CAs consists of a grid of cells with each cell contain finite number of states. CAs is a computing model which afford a best platform to carry out complex computations with the available local information.
CA can be defined by four tuples (G, Z, N, F). where, G = Grids (Sets of Cells), Z = Set of possible cell states, N = Set which describe cells neighborhoods, F = Transition function (CAs local rule).
Basically, A CAs expose three basic characteristics such as : Locality, Infinite Parallelism, and Simplicity.
(i) Locality: CAs is defined by local interactions of its cells. The connectivity among the cells are defined on the basis of locality. Each cell can interact with the adjacent cells in which, the transitions derived between cells carry only small amount of data. None of the locally connected cells will have a global view of the complex system.
(ii) Parallelism: Most of the complex computing problem is demanded to address by parallel computing environment. In most parallel computers include more than a few dozen of processors. CAs can gain parallelism on a scale greater than massively parallel computers. On a spatially extended grid CAs performs its computations in a distributed fashion. It distinct from the conventional approach to parallel computation in which a problem break into independent sub-problems, each sub-problem is being solved by different processor, the solution of each sub-problems are subsequently integrate to yield the final solution.
(2) Wolfram's Two-state three neighborhoods CAs: In Fig 4,5; display Wolfram's two state and three neighborhoods CAs, which consists of 8 different possible present state combination. [33] presents Rule 254 for defining the transitions between the neighbors which is shown at Table 1.. Each CAs cell in he grid must be a memory element (D-Flip-Flop) with some combinational logic such as XOR and XNOR gate (Additive). The transition of each cell depends on the immediate neighbors.

Table 1. Rule Representation

Possible Combinations	Binary Equivalent of Rule-254 (Next State)
111	1
110	1
101	1
100	1
011	1
010	1
001	1
000	0

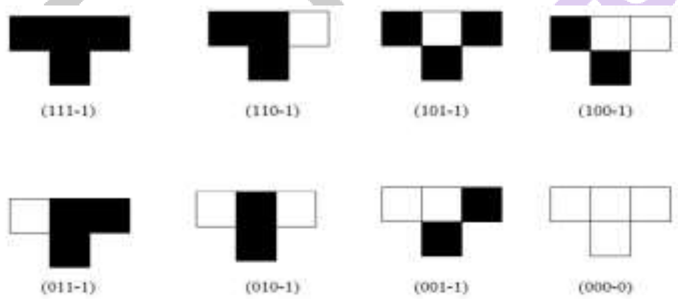

Fig. 4. Neighborhood Representation

In CAs Rules plays an important role in developing a good classifier.
(3) AIS-MACAs (Artificial Immune System Based Multiple Attractor Cellular Automata): Since thirty year ago a Multiple Attractor CAs which is special class of Fuzzy CAs has introduced. MACAs utilizes Fuzzy Logic to handle real value attributes. Genetic Algorithm (GA)structure is used to represent the corresponding CA rule infrastructure. So [33] have named this special classifier as AIS-MACAs. AIS-MACAs can represent many problems in Bioinformatics.
There are different types of problems related to Bioinformatics which are focused by [33] such as: Protein Coding Regions, Promoter Region Prediction and Protein Structure Prediction. There is a special tool which is utilized for predicting Protein Coding and Promoter Region called as CAs based Integrated Tool [34].

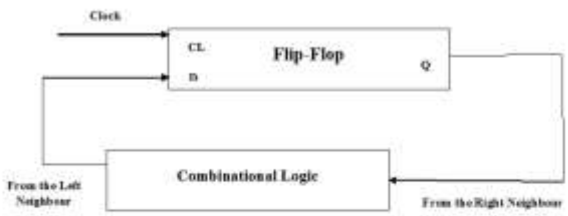

Fig. 5. Wolfram Representation of Flip-Flop Circuit

Human body built up of lot of cells, each cell resides of Deoxyribonucleic Acid (DNA). But determining the coding regions is more complicated job compared to the former. Distinguishing the protein which absorb little space in genes is really a challenging task. In order to understand the gene coding region analysis plays a vita role [37][29].Proteins are molecules which has macro structure that are chargeable for a wide range of vital Bio-Chemical functions, which includes acting as Oxygen, Antibody Production, Nutrient Transport, Cell Signaling, and Building up Muscle Fibers. At current time Promoter Region Identification and Protein Structure Prediction has gained a remarkable attention. Even though there are few existing identification techniques addressing this problem where the approximate accuracy in recognizing the promoter region is closely 68% to 72%. But [37] have developed a tool that is based on CA build with Hybrid Multiple Attractor Cellular Automata (HMACAs) classifier for Protein Coding Region, Promoter Region Identification, and Protein Structure Prediction which predict the Protein Coding Region and Promoter Region with an accuracy of 76% as well as the Structure of protein with an accuracy of 80%. Bioinformatics is a concept that contains how to store data, presenting the feature within the data and retrieval of the data also.

The different type of Problems related to Bioinformatics are:

(1) Protein Coding Region:

Genes hold the instructions for making proteins that are available in a cell as a specific sequence of nucleotides that are present in DNA molecules. In [29] introduce a unsupervised Fuzzy Multiple Attractor Cellular Automata (FMACAs) depends on pattern classifier to recognize the coding region of a DNA sequence. [29] propose a specific algorithm called as distinct K-Means Algorithm for designing FMACAs classifier which is simple , efficient and produces more accurate classifier than that of existed model been obtained for a range of various sequence length experimental result of handling large volume of dataset irrespective oof the number of classes, tuples and attributes confirms that the scalability of proposed unsupervised FCA based classifier. By using distinct K-Means Algorithm [29] establish good classification accuracy.

(2) Promoter Region Prediction:

Determining the promoter regions plays an important role in understanding human genes. [45] Introduce a new CAs based Text Clustering Algorithm for indicating these promoter region in genomic DNA. Experimental result confirm the applicability of CAs based Text Clustering algorithm for identifying these promoter region which note an increase in accuracy of fining these promoter region by 12% for DNA sequences in case of shorter length [45]. The algorithm was accomplished to identify promoter regions in mixed and overlapping DNA sequences. When the length is greater than 54 in that case the proposed algorithm fails to identify the promoter regions. The proposed algorithm will also used to signify the RNA structure. Identifying the promoter regions is tough because genomes are small as well as not continuous (0.1 10.1 bp) [45]. When the cell gets ready to divide the proteins attached to the DNA and help the DNA strands coil up into a chromosome. The very important point to this research is adding of protein to the strands. It also need to search the closest neighborhood strides which is the primary reason for the cause of dynamism in the research project [45]. [45] utilize trust region method for concluding the optimized stride [28]. Once [45] found neighboring strides it utilizes parallel scan algorithm for processing the sequence to find the coding region. It was also involved to signify the structure of RNA. On small DNA sequence, [45] proposed algorithm was found to be very proficient. [45] proposed algorithm can further extended to find protein coding region in genomic DNA also.

(3) Protein Structure Prediction:

In recent years protein structure prediction from sequences of Amino Acid has gained a remarkable attention. Even though there are a lot of prediction techniques addressing this problem, the approximate accuracy in predicting the protein structure is closed to 75%. For predicting the structure of the protein an automated procedure was evolved with MACAs. Most of the existing approaches are sequential which classify the input into four different classes which are designed for identical sequences to identify ten classes from the sequences that share twilight zone similarity and identity with the training sequences a PSMACAs model is designed. [30] designed which consists of 10 feature selection methods and 4 classifier to develop MACAs based classifier that are build for each of the ten classes. [30] practiced the proposed classifier with twilight zone and 1-high -similarity benchmark dataset with other three dozens of modern competing predictors and conclude that PSMACAs provides the overall best accuracy that ranges between 77% and 88.7% depending on the dataset. The three-Tiered structural hierarchy possessed by proteins is typically referred to as primary and tertiary structure. Tremendously the trend of genome sequencing projects are increasing as well as the SWISS-PORT databases of primary protein structures are expanding. There are difficulties in finding the levels of the structure because the protein data banks are not improving at a faster rate. Structure identification procedure experimental results have very serious disadvantages such as very expensive, time consuming, require more labor and may not be applicable to all the proteins. Major research are dedicated to protein prediction of high level structure using computational technique by keeping in view of shortcoming laboratory procedure in predicting the structure of the protein. Anfisen has predicted the protein structure from Amino Acid sequences. This is normally called as protein folding problem which is a tremendous challenge in the field of Bioinformatics. However, the topology of a particular chain can be characterized by predicting the structure of protein. The Tree-Dimensional arrangement of Amino Acid sequence can be illustrated by tertiary structure. Structure involves in the identification of membrane proteins, location of binding sites and identification of homogeneous protein in order to list few of the benefits and thus headlining the usefulness of knowing this level of structure. This is the primary reason why considerable effort has been dedicated in predicting the structure only. Knowing the structure of protein is highly important and can also exactly enhance the accuracy of tertiary structure prediction. Further, the proteins can be derived according to their structural elements such as their Alpha Helix and Beta sheet content. [30] Has proposed scheme such as PSMACAs provides the good overall accuracy that ranges from 77% to 88.7% depending on the dataset.

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