Predicting Patterns in Cellular Automata

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Introduction:-

A Cellular Automaton is a discrete model that evolves in discrete time over a grid composed of cells[1]. The CA updates the states(in a finite space) of a cell according to some pre-defined rules that is related to the current state of the neighbouring cells. Even if the rules are simple, the configurations which a grid could take has a very high complexity level and beauty in its own. This beauty has urged researchers to find out the regularities and irregularities in the patterns which could have implications in real life problems.

The simplest CA is one-dimensional array of cells with two states(ON and OFF). Any three consequent set of cells form a neighbourhood and thus there could be 8 possible configurations for a neighbourhood and each cell has two states so there could be 2^8 posssible rules for this "simple CA". A rule is a set of constraints according to which the cell updation takes place at each generation. The phrase simple is kept in quotes to show the complexity of this CA as Wolfram[2] said in his book and classified the rules in different classes as follows:
1). Class-I: All the initial conditions finally lead to same state.
2). Class-II: The final configurations are periodic in nature in terms of the cells states.
3). Class-III: All initial conditions lead to chaotic state final state.
4). Class-IV: A mixture of Classes II and III in which simple tructures behave in a complex way[3].

Conway's Game of Life:-

Game of Life(also called Life) is one of the 2-dimensional cellular automata devised by a Mathematician John Conway. It is one of the 2^{512} rules in 2-D cellular automata that gives beautiful patterns after some generations of the grid. Examples of such patterns are still-lifes(that are still for all further generations), oscillators(are periodic in nature), spaceships(that translate across the grid) among many[4]. John Conway first claimed that there could be no initial configuration by which a population can grow indefinitely. But later it was disproved by Gosper when he introduced first Glider Gun that produced patterns that traverse through the grid. After that it became an interesting field of research area in Artificial Intelligence if one could find or predict patterns in future generations of cellular automata.

Implications:-

Cellular Automata has a wide field of applications:-
1). Random number generators- Game of life has been used to create patterns in the random number generators' outputs.
2). Mathematics- Mathematical functions and their growth can be modeled using patterns of cellular automata.
3). Physics- Quantum Physics computations take long time to get simulated by present time processors. It is thought that perhaps Game of life could simulate the living patterns using its binary and simpler nature.
4). Any Computation- It has been proved that Game of life is Turing-Complete and thus given a suitable initial configuration, we can perform any type of computation. Some these are used for prime number generations, twin prime calculations etc.
5). Cryptography- Cellular Automata are a potential alternative to prime number computation in Cryptography, due to backward prediction, i.e. predicting a past state from a future state being computationally expensive.

Proposal:-

We concern ourselves with forward prediction. There has been some recent research in this area. Toole and Page explored the predictive power of individual agents and groups of agents in one dimensional Cellular Automata[3]. They used individual agents that keep a count of possible final states and predict through a majority count. Also, they used groups of agents, each of which learns autonomously, and vote on the final state during prediction. The prediction of the group is the majority of the votes of each agent.

In single agent systems, majority count learning is the best way to learn how to predict the future state of a cell. But in multi-agent systems, the situation gets more complicated, as there exist various ways to place multiple agents and make them co-ordinate with each other. In [3], the placement of agents that they tried was random, and the weightages for votes during prediction was equal. We think that a more efficient way of learning might exist.

There are $2^\wedge(N^2)$ possible groups of agents in a grid of size NxN. Moreover, the vote weightages of each of these agents is potentially infinite. Our aim is to find an efficient learner. Genetic algorithms are really good at finding

solutions in huge search spaces, like this one. We will explore the possibility of using a genetic algorithm for producing an efficient learner and predictor of cellular automata.
We will try to evolve the group of agents and the way of learning by means of a genetic algorithm. We will represent the group of agents as a grid, and call it a candidate for our algorithm. There are two aspects to our genetic algorithm:
1. *To represent the candidate*- We will represent the candidate as a grid of a variable size, with bits representing the presence of agents at a particular cell. Placement mutations will involve agents randomly appearing or disappearing at a particular cell, or shifting to adjacent cells. Prediction mutations will involve randomly changing vote weightages for different agents.
2. *The fitness function*- Each candidate will go through a phase of training and testing. The fitness of a candidate depends upon the predictive power of the candidate on the test set we provide, the space required to store and express the candidate, and the time required for the candidate for prediction.

Repeating the algorithm on various rules of one dimensional and two dimensional cellular automata and examining the predictive powers of the fittest candidates we get will give us an idea of whether a good learner exists for that particular rule or not.

References:-

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[2] S. Wolfram, A New Kind of Science, Champaign, IL: Wolfram Media, Inc., 2002.

[3] J. Toole, S. Page, Predicting Cellular Automata, Complex Systems Publications, 2011.

[4] http://en.wikipedia.org/wiki/Conway's_Game_of_Life