Cellular Automata Control with Deep Reinforcement Learning

Emanuel Becerra Soto

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Contents

Chapter 1

Cellular Automata Control with Deep Reinforcement Learning

1.1 Abstract

1.2 Acknowledgments

Chapter 2

Introduction

2.1 Motivations

Since antiquity the idea of building a thinking machine has always been in the minds of philosophers, artists, sciencemen, kings and commoners alike, filling us with wonder, terror and contemplation. A human creation capable of human feats, would turn us, at least in an allegorical sense, into gods.

2.2 Objectives

2.2.1 Main Objectives

- To propose a novel environment for Reinforcement Learning algorithms, based on Cellular Automata, that could be used as an alternative benchmark instead of Atari games.
- Characterize the proposed environment by solving it by state of the art methods.

2.2.2 Specific Objectives

- Select the a Cellular Automaton model for the environment and program it, in this case the forest fire cellular automaton.
- Propose a RL task to be realized on top of the CA.
- Program the RL environment, following the Open AI gym API.
- Apply Dual? Q-networks with its variants.

Chapter 3

Cellular Automata

Cellular Automata are mathematical systems that are mainly characterized by (Ilachinski 2001):

1. A discrete lattice of cells: A n-dimesional arragement of cells, usually 1-D, 2-D or 3-D.
2. Homogenity: Cells are equivalent in the sense that they share an update function and a set of possible states.
3. Discrete states: Each cell is in one state from a finite set of possible states.
4. Local Interactions: Cell interactions are local, this is given by the update function being dependant on neighbouring cells.
5. Discrete Dynamics: The system evolves in discrete time steps. At each step the update function is applied to simultaneously (synchronously) to all cells.

3.1 Mathematical Definition

The following is adapted from the book Probabilistic Cellular Automata (Louis and Nardi 2018).

The main mathematical aspects of a CA are:

- The network G: A graph G.

  $$G = (V(G), E(G))$$

  The set of vertices $V(G)$ represents the location of the automata (cells). The set of edges $E(G)$ describes the interaction between automata.

- The alphabet S: Defines the states that each automata can take. In the majority of setting S is a finite set. It is also called *local space* or *spin space*.
- The configuration space $S^{V(G)}$: This is the set of all posible states of the CA. An specific configuration is denoted as

$$\sigma = \{\sigma_k \in V(G)\}$$

3.2 History

Jonh von Neumann following a suggestion from mathematician Stanislaw Ulam introduced Cellular Automata (CA) on 1948 to study self replicating systems, particularly biological organisms (Von Neumann and others 1951) (Von Neumann, Burks, and others 1966). The basic idea was to build a lattice in $\mathbb{Z}^2$ capable of copying itself, to another location in $\mathbb{Z}^2$. The solution, in spite of being elaborate and involving 29 different cell states, was modular and intuitive. Since then more constructions capable of the same feat have been found with a lesser number of states (Codd 1968). Some earlier precusor ideas can be traced back to 1946 cibernetics models by Wiener and Rosenbluth (Weiner and Rosenblunth 1946).

A key moment came with the invention of 2-D CA Game of Life. Pure mathematician J.H. Conway created "Life" as a solitaire or simulation type game. To play "Life" a checkboard was needed, then counters or chips were put on top of some cells. This represented an initial alive population of organisms and the initial configuration would evolve following reproduction and dying rules. The rules were tweaked by Conway to produce unpredictable and mesmerazing patterns. The game was made popular when was published as recreational mathematics by Martin Gardner in 1970 (Gardner 1970). Despite its name and interesting properties "Life" has little biological meaning and should be only interpreted as a methapor (Ermentrout and Edelstein-Keshet 1993).

During the 80s the notoriety of CA was boosted to the current status and CA studies became quintessential examples of complex systems and useful modeling tools. Is in this decade that the first CA conference was held at MIT (Ilachinski 2001) and that the seminal review article of Stephen Wolfram was published (Wolfram 1983).

Since then applications have been coming in a variety of domains. In the biological sciences models of exitable media, developmental biology, ecology, shell pattern formation and immunology, to name a few, have been proposed (Ermentrout and Edelstein-Keshet 1993). CA can be applied in image processing for noise removal and border detection (Popovici and Popovici 2002). For physical systems fluid and gas dynamics are well suited for CA modeling (Margolus 1984). Also they have been proposed as a discrete approach to expresing physical laws (Vichniac 1984).

Table 3.1: Key events in the history of Cellular Automata and Complex Systems. Table taken from the book Cellular Automata A Discrete Universe (Ilachinski 2001).

Year	Researcher	Discovery
1936	Turing	Formalized the concept of computability, universal turing machine.
1948	von Neumann	Introduced self-reproducing automata.
1950	Ulam	Insisted on the need of more realistic models for the behavior of complex extended s
1966	Burks	Extended von Neumann's work.
1967	von Bertalanffy, et al	Applied System Theory to human systems.
1969	Zuse	Introduced the concept of "computing spaces".
1970	Conway	Introduced the CA "Game of Life".
1977	Toffoli	Applied CAs to modeling physical laws.
1983	Wolfram	Authored a seminal review article about CAs.
1984	Cowan, et al	The Santa Fe Institute is founded for interdisciplinary research of complex systems.
1987	Toffoli, Wolfram	First CA conference held at MIT.
1992	Varela, et al	First European conference on artificial life.

3.3 Motivation

Rolando's Directrices 1. Sell the idea originality 2. Sell that automata are general 3. Show that are useful

CA are one of the simplest representations of complex systems (dynamical systems with nonlinearly interacting parts) [Ilachinski]

3.4 Complex Systems

CA are specilly useful for modeling discrete time and space.

The origins of Cellular Automata can beJonh von Neumanm
The origins of Cellular Automata can be traced back to a 1948 seminal paper by von Neumann and Ulam *Probabilistic CA, 174, 208*

Cellular Automata are lattices of interconnected finite-state automata (cells), which evolve synchronously in discrete time steps according to deterministic rules. invoving the states of

When the updating rules of CA are allowed to be made A natural extension of CA are Probabilistic Cellular Automata(PCA)

3.4.1 Tips for paraphrasing

1. Translate to own words.
2. Flip sentence. Move the beginning to the end.
3. Add a signal phrase. First the source.
4. Citation afterward. At last the source.

```
# Current
rate <- 3.3/6e6
epoch <- 2e6
exp(-rate*epoch)
```

```
## [1] 0.3328711
```

```
# Proposed New
rate <- 5.5/6e6
epoch <- 3e6
exp(-rate*epoch)
```

```
## [1] 0.06392786
```

Chapter 4

Reinforcement

We describe our methods in this chapter.

Chapter 5

Results

Some *significant* applications are demonstrated in this chapter.

5.1 Example one

5.2 Example two

Chapter 6

Conclusion

We have finished a nice book.

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