Course: CS30A1570 Complex Systems

Assignment 6: Cellular Automata

Completion Date: 27 April 2024

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Title: An Exploration of the Game of Life and Elementary Cellular Automata Rules

Introduction

Cellular automata are mathematical models used to simulate complex systems using simple rules. This report explores various aspects of cellular automata, focusing on the Game of Life, a well-known cellular automaton, and elementary cellular automata (ECA) rules. The Game of Life, invented by mathematician John Conway, is a zero-player game that evolves over time based on its initial state. ECAs are the simplest class of cellular automata, consisting of a one-dimensional array of cells with binary states and rules that depend on the nearest neighbor cells.

Research Objective and Questions

The objective of this research is to investigate the behavior of cellular automata under different conditions and rules. Specifically, the research aims to:

1. Understand the common patterns observed in the Game of Life with random initial patterns and how these patterns evolve over time.
2. Investigate the effects of rule changes on the behavior of the Game of Life.
3. Explore the behavior of different ECA rules and their corresponding Wolfram classes.
4. Analyze the behavior of a segregation model based on individual preferences.

The research question related to this investigation are as follows:

1. Task 1.1: What are the common patterns observed in the Mini-Life.nlogo model when run with random initial patterns? How do these patterns evolve over time?
2. Task 1.2: How does changing the rules of Life (specifically, a cell turning black if it has less than 4 black neighbors) affect the behavior of the cellular automaton? Does this rule change still produce interesting behavior?
3. Task 1.3: What effects do different rule changes have on the Game of Life model? How do these changes impact the behavior of the model on various random initial lattices?
4. Task 1.4: Is the asynchronous system deterministic, i.e., does it always calculate the same resulting patterns from the same initial conditions? How does the behavior of this new system compare with that of the original Game of Life cellular automaton?
5. Task 2.1: How does the base 10 Wolfram code number of an elementary Cellular Automata (CA) rule relate to its behavior and classification within the Wolfram classes?
6. Task 2.2: How does the Lambda value of an Elementary CA rule, such as rule 90, influence its behavior?

7. Task 2.3: Does Langton's hypothesis hold true when comparing the behaviors of different ECA rules with varying Lambda values, such as rule 32 and rule 90, or rule 24 and rule 30?
8. Task 2.4: Among the Elementary CAs with a Lambda value of 1/2, which ones exhibit chaotic behavior (Wolfram class 3) when tested on several initial configurations?
9. Task 3:
    a. What are the key components and dynamics of the Segregation.nlogo model from the Models Library?
    b. What hypotheses can be formulated about the behavior of the Segregation.nlogo model based on its initial conditions and rules?
    c. What experimental design can be used to test these hypotheses and what findings might be expected?
    d. How can the findings from the analysis of the Segregation.nlogo model be effectively communicated in a detailed report?

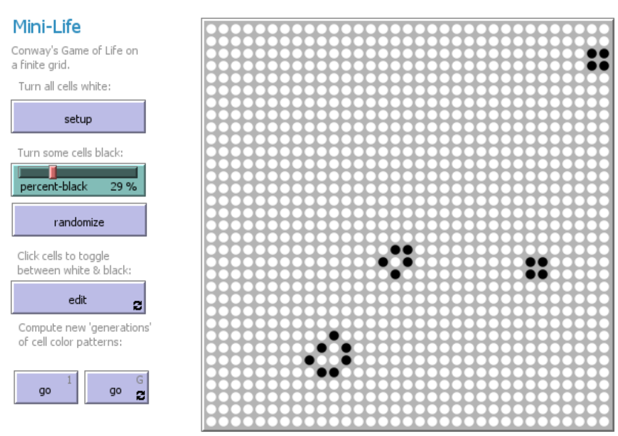
Experiment Design:

The experiments were designed to address each research question. For the Game of Life, the Mini-Life.nlogo model was run several times with random initial patterns. The rules of Life were then modified, and the behavior of the cellular automaton was observed. For the ECAs, the Wolfram code number and class were determined for specific rules, and the behavior of different ECAs with a Lambda value of 1/2 was tested. Finally, the Segregation.nlogo model was analyzed to understand the effects of individual preferences on societal segregation.

Results:

Task 1.1: Mini-Life.nlogo was run several times with varying black percentages (13, 55, and 81). The result can be seen in appendix (Image 2, 3 and 4).

Image 1: Mini-Life.nlogo (with 29% black)



Task 1.2: The Mini-life.nlogo model was modified so that a cell turns black if it has less than 4 black neighbors or white if otherwise (Appendix: Attachment 1). This change gave some interesting results (Appendix: Image 9 and 10). Initially, for the first few steps (3/4 steps), the entire patches became white and started to alternate between all the patches being white or black. But when the percent of black was set at 50%, an interesting pattern emerged. After certain steps there were certain patches having colors

different than the rest, and with each step it was alternating as if someone was turning on/off the cells (Image 6).

Image 5: Modified Mini-life.nlogo with 34% black (step 3)

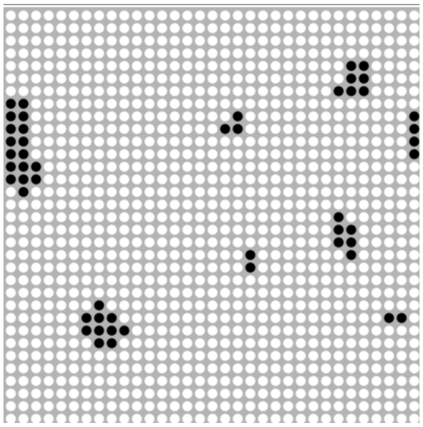
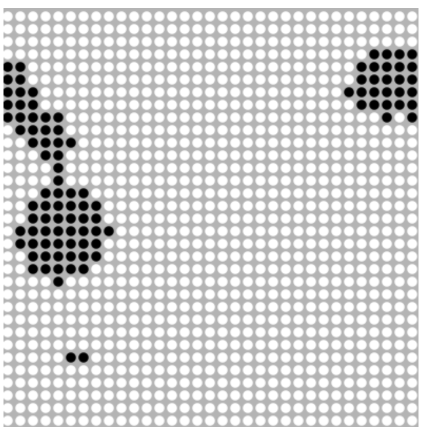
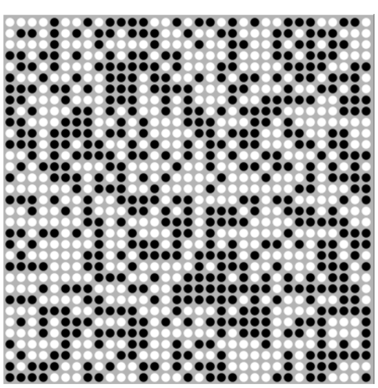


Image 6: Modified Mini-life.nlogo with 50% black (step 8)



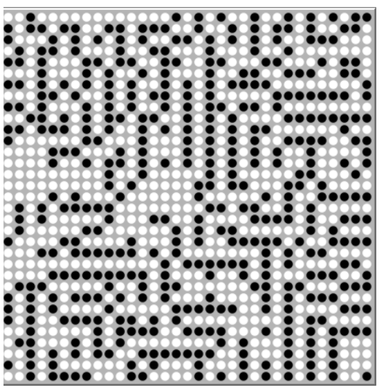
Task 1.3: The Mini-life.nlogo model was modified so that a cell will turn black if it has an even number of black neighbors, and it will turn white otherwise (Appendix: Attachment 2). The result was such that no matter what was the percent of black, the simulation always oscillated between white and black at each step.

Image 7: Modified Mini-life.nlogo with 57% black (step 445)



Task 1.4: The Mini-life.nlogo model was modified (Appendix: Attachment 3) and it results in an asynchronous update of the cells, where each cell changes its color immediately after counting its neighbors. This is a significant departure from the original synchronous update rule in Conway's Game of Life, where all cells simultaneously update their states based on the previous generation (Image 8). In terms of determinism, the new system can still be deterministic, but it depends on the implementation. If the order in which cells are updated is random and varies from one generation to the next, then the system will not be deterministic. This is because the outcome could differ even with the same initial conditions, due to the randomness in the update order. However, if the update order is fixed then the system would still be deterministic, as the same initial conditions would always lead to the same outcome. The asynchronous update can lead to different patterns and dynamics. In the new asynchronous system, the evolution of a cell will depend on the states of other cells in the current generation, which can lead to different patterns. This result in more complex or unpredictable behavior compared to the original Game of Life.

Image 8: Modified Mini-life.nlogo with 50% black (step 231)



Task 2.1: The Wolfram code number in base 10 of the elementary cellular automaton (ECA) rule 1 0 1 0 0 1 0 1 is 169. This rule belongs to Wolfram Class 4, which is characterized by complex, long-lived structures.

Task 2.2: The Wolfram code number in base 10 of the ECA rule 0 0 1 0 1 1 0 0 is 44. This rule belongs to Wolfram Class 2, which is characterized by chaotic, seemingly random behavior.

Task 2.3: The Lambda value of ECA rule 90 is 0.5. The Lambda value is a measure of the rule's complexity, with a value of 0.5 typically indicating a balance between order and chaos.

Task 2.4: Langton's hypothesis suggests that ECAs with a Lambda value close to 0.5 should typically exhibit more complex behavior than those with a much lower Lambda value. When comparing the typical behavior of rule 32 (Lambda = 0.25) and rule 90 (Lambda = 0.5), rule 90 indeed exhibits more complex behavior, supporting Langton's hypothesis. Rule 32 tends to produce simple, periodic structures, while rule 90 can generate complex, fractal-like patterns.

Image 11: ElementaryCAs.nlogo model simulation (rule 32)

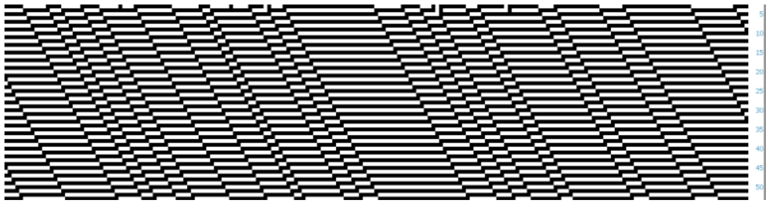


Image 10: ElementaryCAs.nlogo model simulation (rule 90)

Task 3: Analysis of Netlogo Segregation.nlogo Model

The NetLogo Segregation model (Reference 3) is a simulation based on the work of Nobel laureate economist Thomas Schelling (Reference 1). It simulates residential segregation in a simplified environment. The model demonstrates how small individual preferences for one's neighbors to be of the same color can lead to large-scale societal segregation. In the model, there are two types of agents, often referred to as "turtles", which are colored either red or green. Each turtle prefers to live in a neighborhood where a certain percentage of its neighbors are of the same color. If this preference is not met, the turtle will move to a random empty location. The entities of the model are:

- **Agents:** Turtles representing individuals with a specific ethnicity (red or green).
- **Environment:** A square grid where turtles reside.
- **Behavior:** Turtles move around the grid. They evaluate their satisfaction based on the number of same-ethnic neighbors. Dissatisfied turtles might relocate to a new location with a higher desired neighbor percentage.

This model explores how individual preferences for similar neighbors can lead to emergent patterns of segregation at the population level. Despite individuals having only a slight preference for living among others of the same color, the aggregate effect is a significant level of segregation at the societal level. The following hypothesis can be formulated:

H1: Increased Discontent Threshold: Even a small preference for one's neighbors to be of the same color can lead to significant societal segregation. As the minimum percentage of desired same-ethnicity neighbors increases, the model will show a stronger tendency towards segregation. With a higher threshold for satisfaction, it becomes harder for individuals to find suitable locations, leading to clusters of similar ethnicities (Reference 2).

Experiment and Findings: The model was run with different values for the "PERCENT-SIMILAR-WANTED" parameter (20%, 40%, 60%, 80%). The findings are presented in Table 1 (Appendix: Image 12,13,14 and 15).

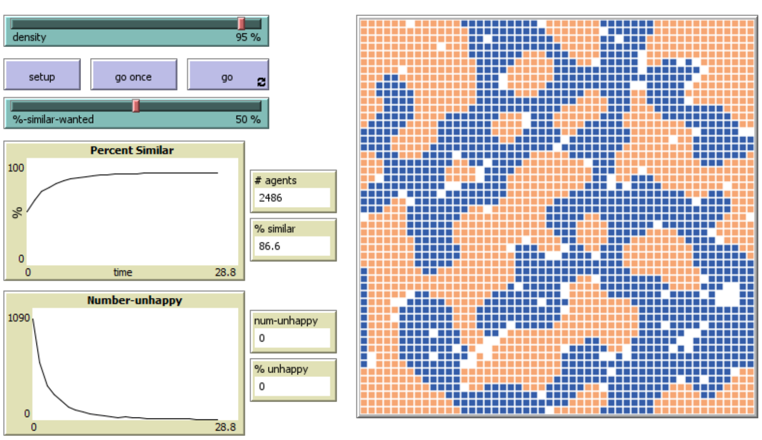
Table 1: Finding of Segregation.nlogo simulation

Similar Wanted	Percent Similar	Percent Unhappy	Steps
20	55	0	8
40	84.4	0	15
60	99	0	847
80	50-52	90-95	continues

The "PERCENT-SIMILAR-WANTED" parameter in the model represents the percentage of neighbors that each agent wants to be of the same color as itself. The "Percent Similar" is the percentage of agents that are actually living next to neighbors of the same color. "Percent Unhappy" is the percentage of agents that are unhappy with their current location, i.e., those who have fewer similar neighbors than they want. "Steps" is the number of iterations it took for the model to reach a stable state where no more agents are unhappy. The results demonstrate that, when 20% preference, agents are quite tolerant and only require 20% of their neighbors to be similar. The system quickly reaches a stable state (in 8 steps) where 55% of an agent's neighbors are similar and no agents are unhappy. At 40% preference, agents are slightly less tolerant, requiring 40% of their neighbors to be similar. The system still reaches a stable state relatively quickly (in 15 steps) where 84.4% of an agent's neighbors are similar and no agents are unhappy. At 60% preference, agents are less tolerant, requiring 60% of their neighbors to be similar. The system takes much longer to reach a stable state (847 steps), but eventually, all agents are surrounded entirely by similar neighbors (99%) and no agents are unhappy. However, at 80% preference, agents are very intolerant, requiring 80% of their neighbors to be similar. The system does not reach a stable state within the timeframe of the experiment. The percentage of similar neighbors fluctuates between 50% and 52%, and a high percentage of agents (90-95%) remain unhappy.

These results illustrate how increasing intolerance (higher "PERCENT-SIMILAR-WANTED") can lead to more segregation (higher "Percent Similar"), but also more dissatisfaction ("Percent Unhappy") and longer times to reach stability ("Steps"). This suggests that a society with high levels of intolerance may struggle to reach a state where all individuals are satisfied with their surroundings.

Image 11: Segregation netlogo model with 50% similar wanted



The NetLogo Segregation model demonstrates how individual preferences, even if they are relatively mild, can lead to significant societal segregation. This highlights the importance of understanding the aggregate effects of individual behaviors in a society. It also suggests that efforts to reduce societal segregation need to address individual preferences and behaviors.

Discussion

The experiments revealed interesting behaviors of cellular automata under different conditions. In the Game of Life, even minor rule changes could significantly alter the behavior of the cellular automaton. For the ECAs, the experiments confirmed that the complexity of the behavior is related to the Lambda value, with a value close to 1/2 typically indicating more complex behavior. The analysis of the segregation model demonstrated how individual preferences, even if relatively mild, can lead to significant societal segregation.

Conclusion:

This research provided valuable insights into the behavior of cellular automata. It demonstrated the sensitivity of cellular automata to initial conditions and rule changes, and highlighted the complexity that can arise from simple rules. The findings underscore the potential of cellular automata as powerful tools for modeling and understanding complex systems. Future research could explore other types of cellular automata and investigate the effects of different rule changes in more depth.

References:

1. Schelling, T. (1978). Micromotives and Macrobehavior. New York: Norton.
2. Rauch, J. (2002). Seeing Around Corners; The Atlantic Monthly; April 2002;Volume 289, No. 4; 35-48. https://www.theatlantic.com/magazine/archive/2002/04/seeing-around-corners/302471/
3. Wilensky, U. (1997). NetLogo Segregation model. http://ccl.northwestern.edu/netlogo/models/Segregation. Center for Connected Learning and Computer-Based Modeling, Northwestern University, Evanston, IL.

Appendices:

Image 2: Mini-life.nlogo with 13% black

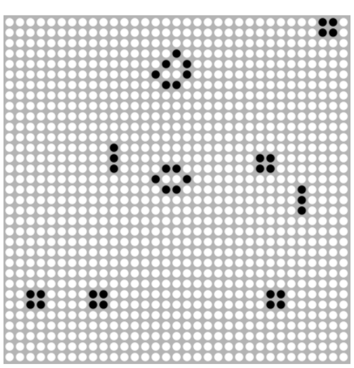


Image 3: Mini-life.nlogo with 55% black

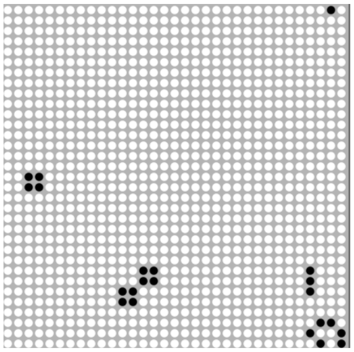


Image 4: Mini-life.nlogo with 81% black

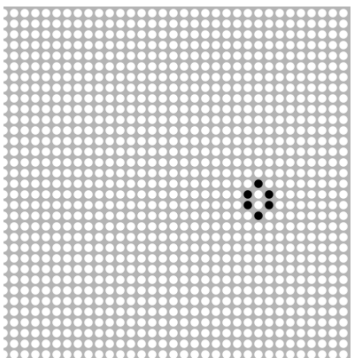


Image 9: Modified Mini-life.nlogo with 81% black (step 5)

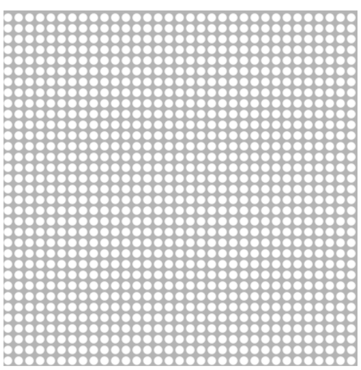


Image 10: Modified Mini-life.nlogo with 81% black (step 6)

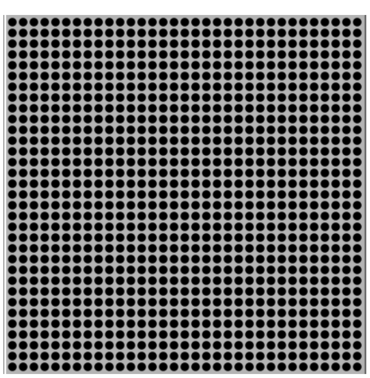


Image 12: Segregation.nlogo with 20% similar wanted (step 8)

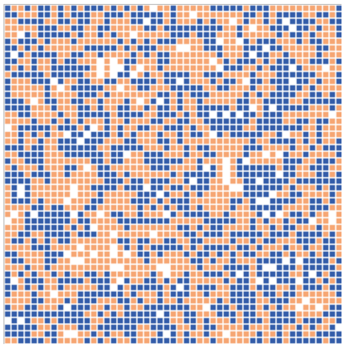


Image 13: Segregation.nlogo with 40% similar wanted (step 15)

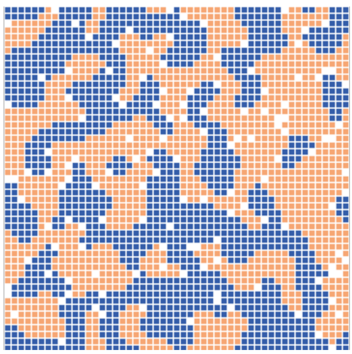


Image 14: Segregation.nlogo with 60% similar wanted (step 847)

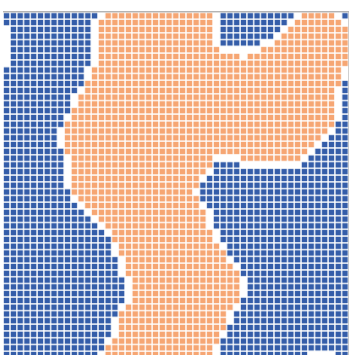
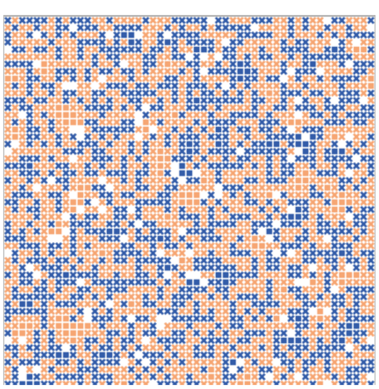


Image 15: Segregation.nlogo with 80% similar wanted (step 847)



Attachment

1. **https://github.com/ahsan-sami-turzo/complex-system-code/blob/main/CS_Assignment_6/Mini-Life_v_6.1.2.nlogo**
2. **https://github.com/ahsan-sami-turzo/complex-system-code/blob/main/CS_Assignment_6/Mini-Life_v_6.1.3.nlogo**
3. **https://github.com/ahsan-sami-turzo/complex-system-code/blob/main/CS_Assignment_6/Mini-Life_v_6.1.4.nlogo**