Cellular automaton results

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INTRODUCTION

In this project, we created and analyzed three different cellular automaton models: a 3-neighbor automaton, a 5-neighbor automaton, and a 3-state automaton. As a team, we implemented these models, observed their behavior, and visualized their evolution to better understand how simple rules generate complex patterns.

A cellular automaton is a discrete computational system consisting of a grid of cells, where each cell updates its state based on a predefined local rule and the states of its neighbors. Even though each individual rule is simple, the repeated application of these rules over time can lead to highly complex, structured, or chaotic global behavior.

Cellular automata serve as powerful models for studying emergent behavior, pattern formation, complexity, and self-organization. By modifying the number of neighbors or the number of possible states, we can observe a wide range of behaviors—from simple repetitive patterns to fractal-like structures and chaotic dynamics.

In this work, we explore how different rule sets and neighborhood sizes influence the evolution of patterns in cellular automata, allowing us to compare their complexity and visual diversity.

The experiments were performed using three different one-dimensional cellular automaton models:

1. **3-neighbor binary automaton**
2. **5-neighbor binary automaton**
3. **3-state automaton with 3 neighbors**

Although each model uses a different neighborhood size or state structure, all simulations demonstrate how complex global patterns can emerge from simple local rules.

1. Results of the 3-Neighbor Automaton

The 3-neighbor model produced a variety of patterns depending on the chosen Wolfram rule.

The results include:

- highly symmetrical triangular structures,
- classical fractal formations,
- chaotic regions expanding from a single active cell,
- wave-like repeating patterns for specific rules.

The evolution clearly shows how sensitive the system is to the rule number: a small change in the rule leads to completely different global behavior.

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Введите правило (0 – 4 294 967 296): 555
Правило 555 в двоичном виде: 00000000000000000000001000101011
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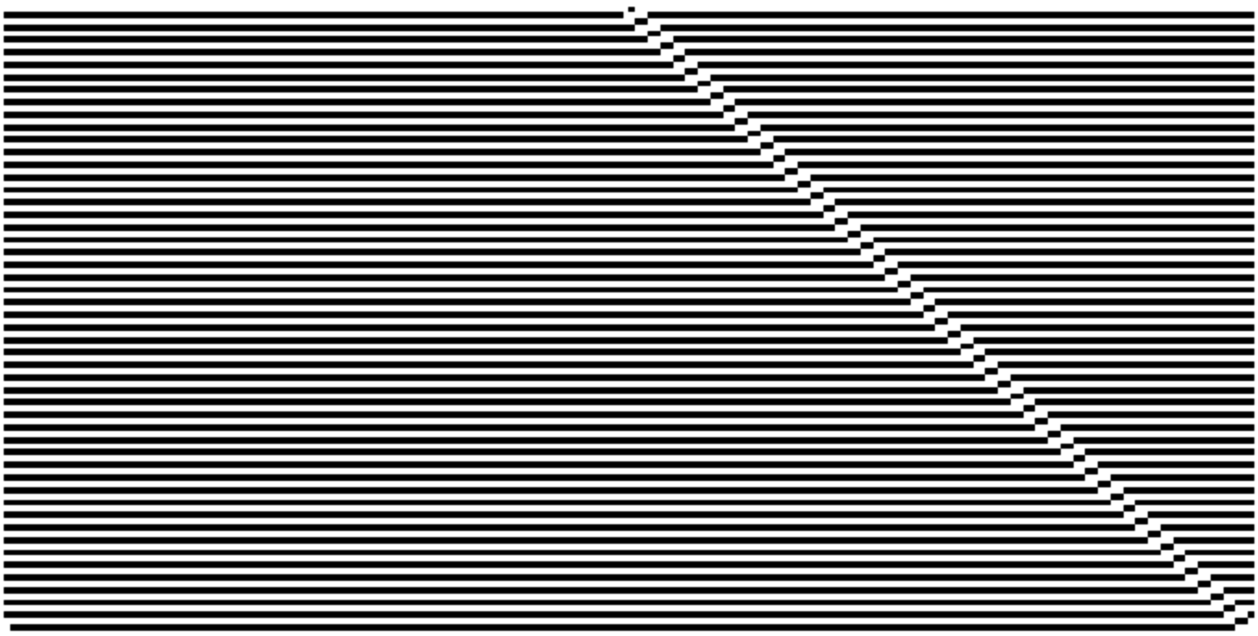


The 3-neighbor cellular automaton demonstrates how simple binary rules can generate structured and predictable patterns. When Rule **555** is applied, the system produces a highly regular configuration consisting of alternating horizontal stripes. A diagonal propagation line emerges from the initial active cell, showing how local rule interactions cause a steady directional shift in the pattern.

The resulting visualization illustrates a **stable, periodic behavior**, where each new row closely repeats the previous structure with a consistent diagonal displacement. This indicates that Rule 555 belongs to a class of automaton rules that generate ordered, non-chaotic, and non-fractal patterns.

Such results highlight the sensitivity of cellular automata to their rule sets and show how minimal local changes can lead to globally uniform and symmetric patterns.

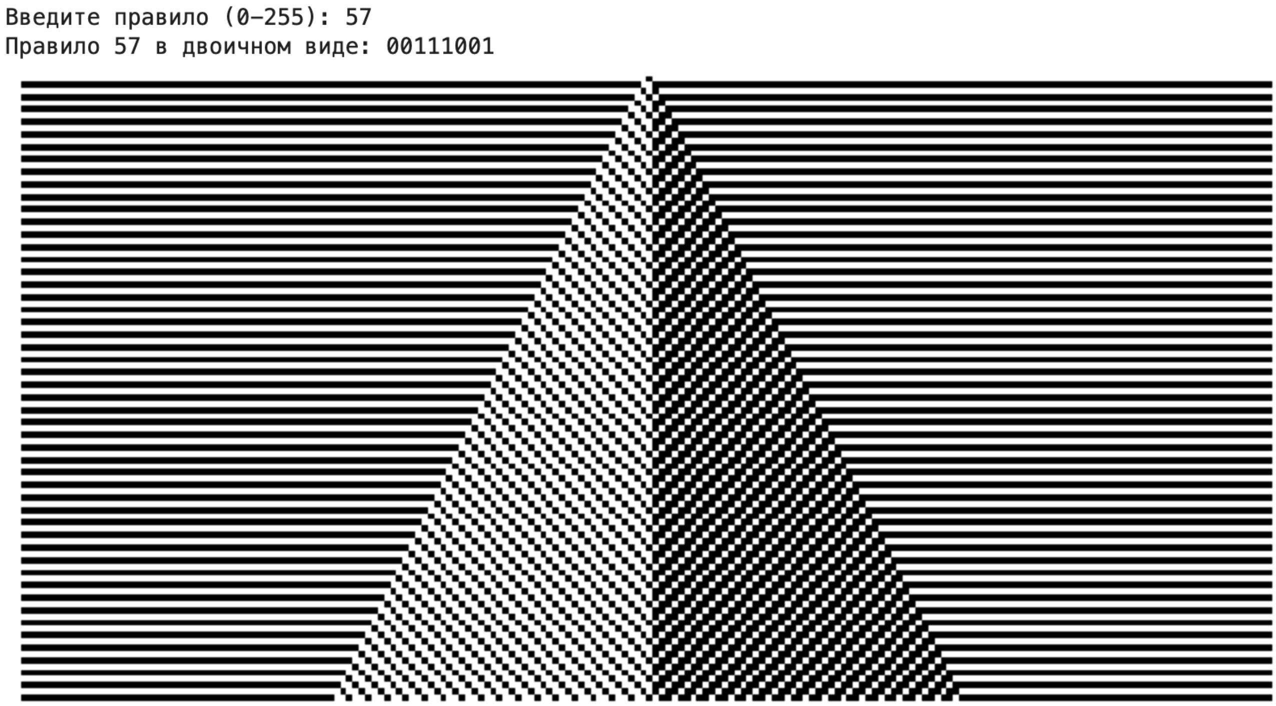
2. Results of the 5-Neighbor Automaton

Increasing the neighborhood from 3 to 5 neighbors significantly increases the complexity of the dynamics.

The observed results include:

- multilayer fractal patterns,
- dense chaotic clusters,
- intermittent order-chaos transitions,
- stable repeating bands and symmetry lines.

Because the rule space is much larger (32-bit rule), the automaton exhibits broader behavioral diversity compared to the 3-neighbor model.



The 5-neighbor cellular automaton reveals a significantly richer structure compared to the standard 3-neighbor model. When Rule **57** is applied, the system produces a highly symmetrical triangular formation that expands downward from the initial active cell. The pattern demonstrates a combination of **regular horizontal bands** and a **dense central region** where interactions between the extended neighborhood create a finely detailed texture.

The resulting visualization shows a clear separation between ordered and more densely populated regions. The left and right sides form uniform horizontal stripes, while the central area develops into a complex triangular structure composed of alternating black and white cells. This indicates that the increase in neighborhood size enhances the automaton's ability to generate multilayered and visually rich patterns.

Overall, the 5-neighbor rule produces more intricate global behavior, demonstrating how expanding local interactions leads to deeper structural complexity and greater pattern diversity compared to classical 3-neighbor rules.

3. Results of the 3-State Automaton

The 3-state automaton (with states 0, 1, and 2) produced the most colorful and visually rich outcomes.

Although the rule itself is binary (27 bits), the three visual states create complex textures such as:

- expanding concentric color waves,
- multi-layered chaotic regions,
- symmetrical color patterns,
- mixed periodic–chaotic behavior.

This model demonstrates how increasing the number of states enables richer emergent structures even when the rule format remains binary.

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Правило 5592405 в двоичном виде: 000010101010101010101010101
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The 3-state cellular automaton produces the most visually complex and expressive patterns among all tested models. Under Rule **5592405**, the automaton evolves into a highly structured triangular formation composed of repeating layered segments. Unlike binary automata, the presence of three possible states creates richer interactions, resulting in alternating color bands and densely packed geometric motifs.

The visualization reveals a combination of long horizontal regions and nested triangular waves that propagate symmetrically from the initial active cell. The central area exhibits a fractal-like arrangement, where small repeating units appear at multiple scales. This demonstrates how increased state complexity allows the automaton to generate deeper hierarchical patterns and more elaborate textures.

Overall, the 3-state automaton under this rule exhibits a mixture of order and complexity: the global shape remains clearly triangular, while the internal structure shows intricate oscillations and multilevel repetition. This highlights the expressive capability of multi-state cellular automata in modeling emergent geometric behavior.

Summary of Observations

Across all three automata, the following phenomena were observed:

- simple local interactions generate surprisingly complex global behavior;
- some rules lead to ordered fractal patterns, while others create pure chaos;
- expanding neighborhoods (3 → 5) increase structural richness;
- adding more states (0/1/2) enhances visual diversity even without changing the rule mechanism.

These results highlight the expressive power of cellular automata and their ability to model complex behaviors from simple rule sets.

CONCLUSION

Through this work, we demonstrated that simple local rules can generate highly complex global behavior in cellular automata. The 3-neighbor automaton produced classical fractal and chaotic patterns, while the 5-neighbor model showed even richer and more layered structures. The 3-state automaton generated the most visually diverse results due to its extended state space. Overall, we successfully implemented all three systems and clearly observed how neighborhood size and state complexity influence the evolution of patterns. These results confirm the power of cellular automata as a model for studying emergent behavior in complex systems.