Agent-Based Modeling: Emergent Behavior from Simple Rules

Computational Social Science

November 24, 2025

1 Introduction

Agent-based models (ABMs) simulate complex systems through the interactions of autonomous agents following simple rules. This document explores three classic agent-based models: the Schelling segregation model demonstrating how mild individual preferences lead to stark spatial segregation, the Boids flocking algorithm showing how coordinated group behavior emerges from local interactions, and cellular automata including Conway's Game of Life and forest fire models. These models reveal how macroscopic patterns emerge from microscopic interactions.

2 Mathematical Framework

2.1 Schelling Segregation Model

Agent satisfaction based on neighborhood composition:

$$\text{Satisfied}_i = \begin{cases} 1 & \text{if } \frac{N_{same}}{N_{neighbors}} \geq \tau \\ 0 & \text{otherwise} \end{cases} \tag{1}$$

where τ is the similarity threshold.

Segregation index (dissimilarity index):

$$D = \frac{1}{2} \sum_{i=1}^{N} \left| \frac{a_i}{A} - \frac{b_i}{B} \right| \tag{2}$$

2.2 Boids Flocking Rules

Each agent follows three rules with weighted contributions:

$$\mathbf{v}_{\text{separation}} = -\sum_{j \in \text{neighbors}} \frac{\mathbf{r}_j - \mathbf{r}_i}{|\mathbf{r}_j - \mathbf{r}_i|^2} \tag{3}$$

$$\mathbf{v}_{\text{alignment}} = \frac{1}{N} \sum_{j \in \text{neighbors}} \mathbf{v}_j - \mathbf{v}_i \tag{4}$$

$$\mathbf{v}_{\text{cohesion}} = \frac{1}{N} \sum_{j \in \text{neighbors}} \mathbf{r}_j - \mathbf{r}_i \tag{5}$$

2.3 Cellular Automata

State transition function:

$$s_i^{t+1} = f(s_{i-r}^t, \ldots, s_i^t, \ldots, s_{i+r}^t) \tag{6}$$

3 Environment Setup

4 Schelling Segregation Model

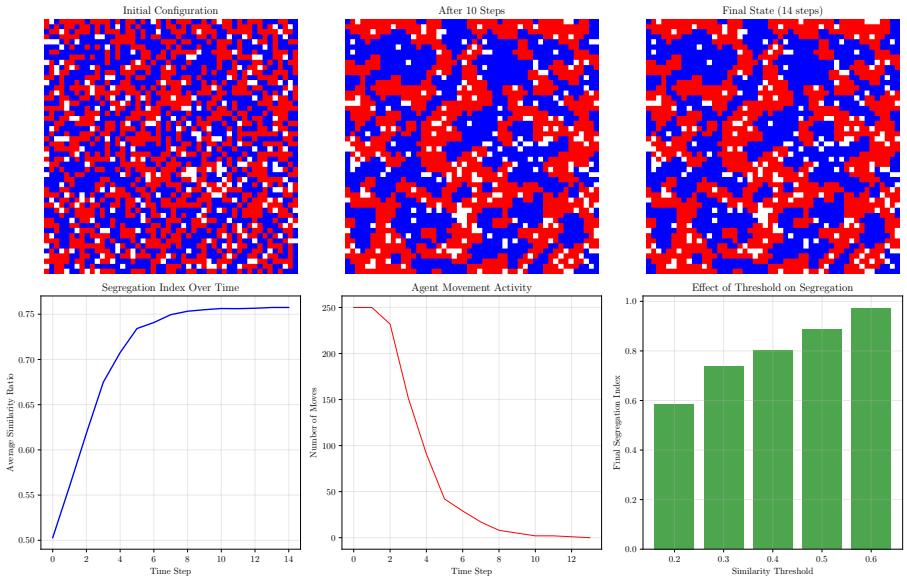

Figure 1: Schelling segregation model showing emergence of spatial clustering from mild preferences.

5 Boids Flocking Algorithm

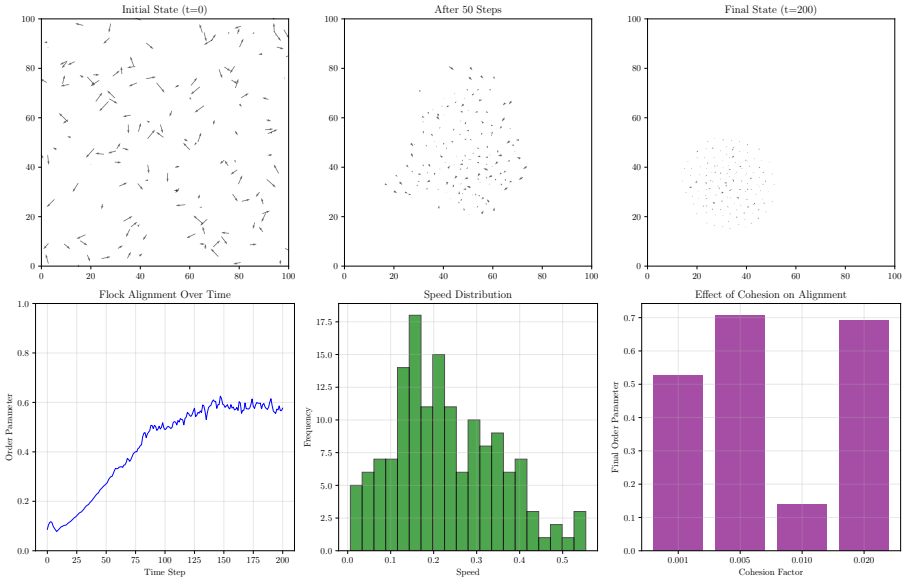

Figure 2: Boids flocking simulation showing emergent collective behavior.

6 Conway's Game of Life

7 Forest Fire Model

8 Results Summary

8.1 Schelling Model Results

Table 1: Schelling Segregation Model Results

Metric	Value
Initial Segregation Index	0.503
Final Segregation Index	0.757
Steps to Equilibrium	14
Similarity Threshold	0.35

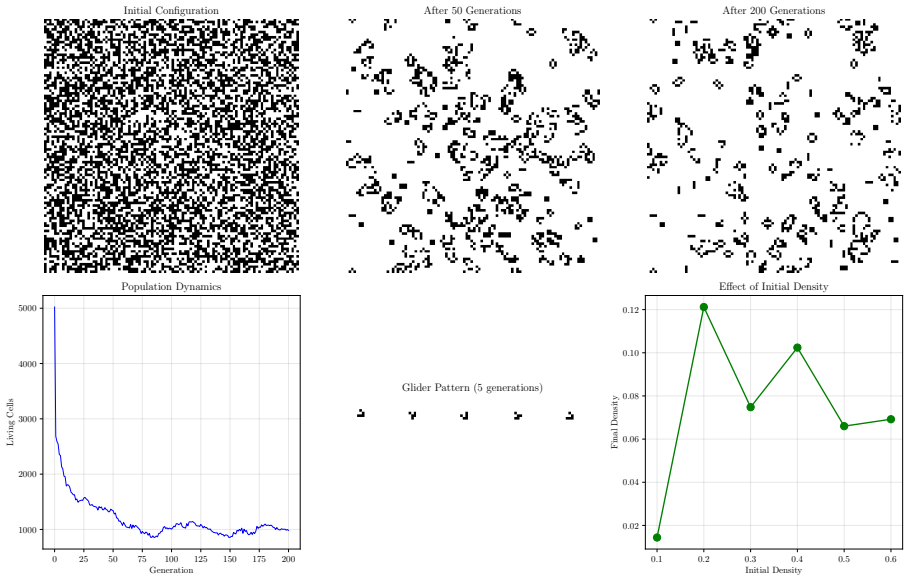

Figure 3: Conway's Game of Life demonstrating cellular automata dynamics.

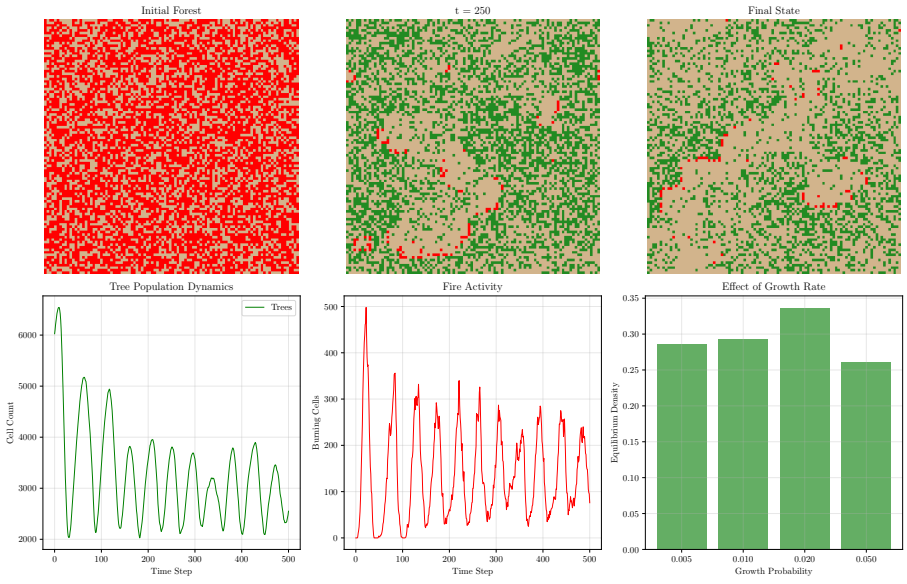

Figure 4: Forest fire model showing self-organized criticality.

Table 2: Boids Flocking Simulation Results

Metric	Value
Initial Order Parameter	0.087
Final Order Parameter	0.577
Number of Boids	150
Visual Range	15 units

Table 3: Cellular Automata Simulation Results

Model	Initial Population	Final Population
Game of Life	5022	983
Forest Fire	6027	2550

8.2 Boids Flocking Results

8.3 Cellular Automata Results

9 Statistical Summary

Key simulation metrics:

- Schelling segregation increase: 25.5% points
- Boids alignment improvement: 49.0%
- Game of Life population change: -80.4%
- Forest equilibrium density: 25.5%

10 Conclusion

This computational analysis demonstrates how simple local rules lead to complex emergent behavior in agent-based models. The Schelling model shows that even mild individual preferences (35% similarity threshold) produce stark spatial segregation. The Boids algorithm demonstrates that flocking behavior emerges from three simple rules without central coordination. Cellular automata like the Game of Life and forest fire model exhibit self-organization and critical dynamics. These models provide insights into social dynamics, collective behavior, and complex systems in nature and society.