Journal of Political Science Research (2024)
Clausius Scientific Press, Canada

DOI: 10.23977/polsr.2024.050115
ISSN 2616-230X Vol. 5 Num. 1

Simulation of Hobbes' State of Nature Based on Cellular Automata

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Keywords: Hobbes, state of nature, spatial game, cellular automata

Abstract: The theory of the state of nature plays a significant role in Hobbes' political theoretical system. The fundamental characteristics of the state of nature lie in freedom and warfare, where individuals compete and pose threats to each other in the absence of common power constraints. This paper aims to explore the feasibility and utility of simulating Hobbes' state of nature using cellular automata modeling. It analyzes the advantages of cellular automata in simulating the evolution of complex systems and compares the alignments between the characteristics of cellular automata and the state of nature. By abstracting and simplifying the state of nature and conducting simulation experiments, this paper provides insights for studying the dynamic evolution of Hobbes' theory of the state of nature.

1. Introduction

Hobbes, the founder of modern political philosophy and the originator of social contract theory, delved deeply into the theory of the origin of the state in his work "Leviathan". By analyzing the process of people competing for self-interest in a state of nature and ultimately establishing a social contract under the guidance of natural law, he explored the origins of the state. Hobbes attempted to reconstruct and understand the emergence and operation of the entire system from the most basic components of complex social systems. Cellular automata, a grid dynamics model that operates according to predefined rules, employs a bottom-up modeling approach. Starting from the interaction of the basic constituent units of the system, it is suitable for simulating complex evolutionary phenomena.

2. The feasibility of simulating Hobbes' state of nature using cellular automata

2.1 Cellular automata are suitable for simulating the operation of complex systems

Hobbes believed that the state is a human creation. Before the emergence of the state, people lived in a state of nature where self-interest is inherent to human nature, and individuals were constantly in a state of mutual threat. In such a chaotic and disorderly environment, individuals could not preserve themselves and faced the fear of death at any moment. To escape this state, people followed the guidance of natural law, established a contract to build a state, and used public power to maintain order and protect individual interests. Therefore, in Hobbes' theory, the state can be seen as a complex

social cooperation phenomenon that emerges through long-term gameplay and repeated iteration among individuals within human society. The state of nature in his theory of the state can be viewed as a complex system with self-organization and emergence properties.

Cellular automata is an idealized model of complex systems, consisting of a large number of cells. Each cell interacts with only a few other cells, producing complex collective behavior through simple operational rules. Its computation method belongs to rule-based computation, employing a bottom-up modeling approach. By repeatedly applying simple preset rules or logically designed models, the complex behavior of the overall system emerges from the bottom up, achieving the purpose of simulating complex systems[3]. Using cells as the basic unit to describe the overall behavior of complex systems, and by setting evolution rules, conceptual models can be transformed into computer physical models. This allows micro-level decisions and mechanisms to exhibit distinct macro-dynamic effects, providing a strong intuitive understanding. Defining a system's state through the abstraction and modeling of complex systems not only reduces the difficulty of system analysis but also effectively improves the efficiency of problem-solving.

2.2 Cellular automata is suitable for simulating conflict dynamics

Hobbes believed that individuals in the state of nature need power to acquire and retain resources. He proposed a theory of human nature based on self-interest, arguing that people are inherently inclined to seek benefits and avoid harm. Each individual pursues an increase in their own power, making the pursuit of power competitive. In this state, people are constantly in competition. In the state of nature, resources are limited, and beneficial goods are scarce. Even individuals who possess nothing are seen as potential threats. The continuous demand for competition, the equal status of individuals, limited external resources, and uncertainty about personal safety make the state of nature a state of "war of every man against every man."

The cellular automata model, with its homogeneity, parallelism, and adaptability, is an ideal tool for simulating such complex conflict dynamics. Within the cellular space, the changes of each cell obey the same laws and evolve according to the same predefined rules. The state changes of each cell at each time step are parallel and do not require queuing according to a unified standard. By defining the interaction rules between cells, the competition and game between individuals can be simulated. These rules determine how the cell state changes based on its current state and the states of its neighbors [4]. At each time step, cells can update their own state and strategy based on the game results with neighboring cells. If a certain strategy yields lower benefits, the cell will adjust its strategy in the next time step to pursue higher benefits, thereby simulating the game and conflict between individuals. After updating the state according to the rules, the cellular automata will present a new configuration, reflecting the results of the game and conflict between cells.

2.3 Cellular automata and individuals in their natural state have characteristic compatibility

In Hobbes' theoretical assumptions, individuals in the state of nature possess the fundamental characteristics of an infinite desire for power and equality among themselves, which aligns with the dynamic and homogeneous nature of cellular automata.

Hobbes conceives the state of nature as a dynamic system. As the first mechanical materialist in modern European philosophy, Hobbes borrowed Galileo's principle of conservation of motion to explain human motives and behaviors[2]. According to Hobbes, similar to the continuous motion of objects, there exists within humans an infinite desire for security, freedom, and more resources. To satisfy and achieve these desires, people need the guarantee of power. Therefore, the first common desire of humanity is the infinite pursuit of power. In the state of nature, people are constantly driven by this relentless desire for power and continuously adjust and update their behavioral strategies based

on environmental conditions, ultimately influencing the overall changes in the state of nature. Cellular automata constitute a dynamic system evolving in discrete time dimensions, defined by a cellular space composed of cells with discrete and finite states. Dynamicity is a fundamental characteristic of this system, with local rules guiding the state updates of cells. The state of each cell evolves continuously over time, revealing the characteristics of the entire model during the dynamic evolution process.

As an idealized system model, cellular automata exhibit homogeneity, meaning that the distribution, size, and shape of cells are consistent, with a regular and orderly spatial layout. Each cell in the model holds the same status and function. When using cellular automata to simulate natural and human social phenomena, it often involves various presuppositions. Through extensive abstraction and simplification of actual situations, the research object is made to conform to the basic characteristic of equality between cells, so as to construct an applicable model. However, this approach is prone to losing some information and characteristics of the actual situation, thereby weakening the authenticity of the simulation and affecting its effectiveness. Hobbes' assumption of equality between individuals in the state of nature mitigates the adverse effects of this simulation process. Hobbes believed that individuals in the state of nature are equal. This equality encompasses not only equal rights to the same things, meaning that everyone has the right to pursue their own happiness and interests, but also roughly equivalent physical and mental capabilities, implying that everyone's psychological qualities and physical strength are similar, and anyone has the ability to engage in activities such as competing for property and attacking others. The assumption of equality ensures that when simplifying individuals in the state of nature into cells during the simulation process, excessive information and characteristics are not lost.

2.4 The decentralized control feature of cellular automata aligns with the anarchic nature of the natural state

The natural state envisaged by Hobbes is essentially a state without government, meaning that before the formation of a state, there is no unified authority superior to all individuals to command or regulate their behavior. Without the intervention of public power, the existence of law is unimaginable, and there is no concept of justice or injustice. Each individual acts autonomously based on their own interests, guided by the natural law discovered through reason. The behavioral choices of individuals are entirely based on their own judgments and considerations of interests. Individuals spontaneously obtain order under certain environmental conditions through internal interactions, without externally imposed specific interventions or formations based on external specific instructions, exhibiting distinct self-organization.

The absence of central control is a crucial characteristic of cellular automata operation. The behavior of cellular automata emerges from the evolutionary behavior of individual cells. All cells enjoy equal status and evolve according to preset rules. The update of each cell's state is only related to its surrounding cells, apart from its current state. All cells engage in self-organized decentralized control without central control, thereby emerging various complex behavior patterns collectively. The decentralized control mechanism endows cellular automata with robustness, resilience, and autonomy, enabling them to simulate extremely rich and complex dynamic behaviors and patterns. The decentralized control characteristic of cellular automata aligns with the stateless and self-organizing nature of Hobbes' natural state, making cellular automata a suitable tool for simulating such natural states.

3. Simulation of Hobbes' state of nature

3.1 Model construction

3.1.1 Grid partitioning of the system

(1) Cellular and its state set

Cells are the fundamental components of cellular automata, and in this model, individuals in the natural state are represented as cells. In Hobbes' social contract theory, to escape the natural state and establish public authority, people relinquish all their rights when entering into a contract. However, since the purpose of contracting is self-preservation, the right to resist aggression to defend their own lives is inalienable. Essentially, what people relinquish is the right to punish or harm others. Therefore, in Hobbes' natural state, the key variable for individual evolution lies in the retention or abandonment of the right to punish or harm others. Let c(i, j, t) represent the state of the individual located at (i, j) at time t. The state set of the cellular can be expressed as follows: c(i, j, t) = 0 represents the one who reserves the rights, and c(i, j, t) = 1 represents the one who abandons the rights.

(2) Cellular space

In practical applications, square grids offer the advantages of being visually intuitive, simple to use, and suitable for representation and display in existing computer environments. Therefore, this model employs a square grid to simulate the space occupied by individuals in the natural state, with a spatial scale of 100*100.

(3) Boundary condition

In theory, the cellular space can extend infinitely in all dimensions, but it is challenging to achieve this ideal condition in practical operations. Periodic boundary conditions are the closest to infinite space. This model chooses periodic boundary conditions for analysis and simulation.

3.1.2 Determine the initial state

The initial state refers to the determined and segmented initial values for the evolution of each cell, which serves as the source influencing the evolutionary layout of cellular automata and needs to be representative and comprehensive. In Hobbes' conception, the natural state is a state of all against all, implying that all individuals are initially right retainers and transform into right abandoners under the guidance of natural law. However, this violates the quiescent condition of cellular automata and is difficult to achieve in computer simulations. Therefore, in this model, we choose to pre-place 9 uniformly distributed right abandoners at the center of the cellular space, while all other cells are set as right retainers.

3.1.3 Determine the evolution rules

(1) Neighborhood form

The evolution rule is defined within a local scope, meaning that the state of a cell at the next moment depends on its own state and the states of its neighboring cells. This model adopts the commonly used Moore type in practical applications, which considers the 8 adjacent cells within a radius of 1 from a cell as its neighbors.

(2) Rule design

Hobbes believed that the state of nature, where everyone is an enemy to everyone else, makes it impossible for individuals to preserve themselves. The fear of death prompts individuals to seek a way out of this natural state. Reason helps people discover the laws of nature and use them as behavioral guidelines to preserve themselves and escape from the natural state. Hobbes proposed 22 natural laws, among which he emphasized the first three, namely: seek peace and abide by it, and

when peace cannot be obtained, defend yourself by all possible means; everyone should relinquish their rights to all things for the sake of peace and personal safety; one should fulfill contracts [1].

From this, we can simplify and abstract the rules governing individual state changes in the natural state. Seeking and observing peace implies that when there are more benefits for those who abandon their rights in the neighborhood, individuals should relinquish punishing or infringing upon the rights of others. When peace cannot be obtained, all possible means should be used to defend oneself, which means that when there are more benefits for those who retain their rights in the neighborhood, individuals should choose to retain their rights for defense. Contracts should be fulfilled, indicating that the state of an individual retaining or abandoning their rights cannot change continuously within a single time step, and they cannot simultaneously be in two contradictory states of retaining and abandoning their rights. The game payoff of each cell is the sum of the payoffs from its interactions with its neighboring cells. All cells participate in the game and calculate their payoffs simultaneously. If the payoff of the central cell is higher than all its neighbors, it maintains its current strategy; otherwise, it switches to the strategy with the highest payoff among its neighbors. After updating the strategy, the next round of the game begins.

The game payoff is as follows:

	Abandon	Retain
Abandon	1,1	0,b
Retain	b,0	0,0

In the natural state of "all against all," individual gains are minimized, industries cannot exist, labor achievements cannot be preserved, knowledge cannot accumulate, and human life is characterized by solitude, poverty, cruelty, and short lifespan. This is also the original intention of individuals to escape from the natural state. Therefore, when those who retain their rights encounter each other, their gains can be considered as 0; when those who abandon their rights meet, the gains from cooperation are greater than the gains from mutual opposition, so it is set as 1; when those who retain their rights encounter those who abandon their rights, those who retain the power to infringe upon and punish the rights of others can gain a greater advantage and obtain more benefits, so their gains are set as b ($b > 1$). The model only has the parameter b, which facilitates analysis, thus abstracting and simplifying the natural state into a spatial game model [6].

3.2 Computer simulation

Modeling and simulation were conducted using MATLAB. As shown in Figure 1: Evolution of cooperation level, with the passage of time, the level of cooperation, which represents the proportion of those who abandon their rights in the overall cell population, shows an upward trend. In the later stages of evolution, the cooperation level gradually stabilizes, indicating that those who abandon their rights can survive stably in the cellular space. When b is less than 1.6, the cooperation level in the later stages of evolution is greater than 50%, indicating that those who abandon their rights occupy a dominant position in the cellular space. As the value of b gradually increases, the average cooperation level in the later stages of evolution shows a downward trend, and the speed of expansion of those who abandon their rights slows down. When b is greater than 1.6, the average cooperation level decreases significantly.

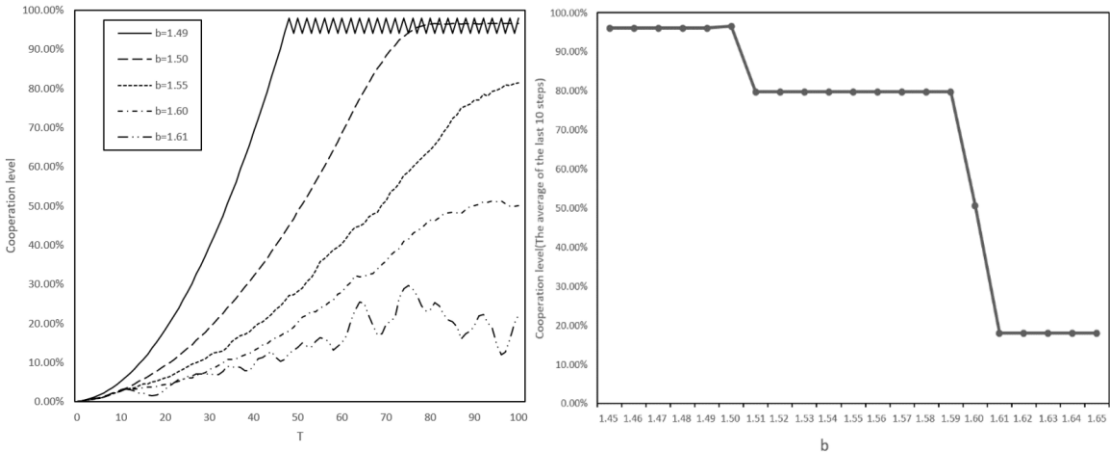

Figure 1: Evolution of cooperation level

As shown in Figure 2, when 1.5 < b < 1.6, the clusters of those who abandon their rights continue to expand from the initial state, occupying a dominant position in the cellular space at the end of evolution, and the cooperation level can reach a certain steady state.

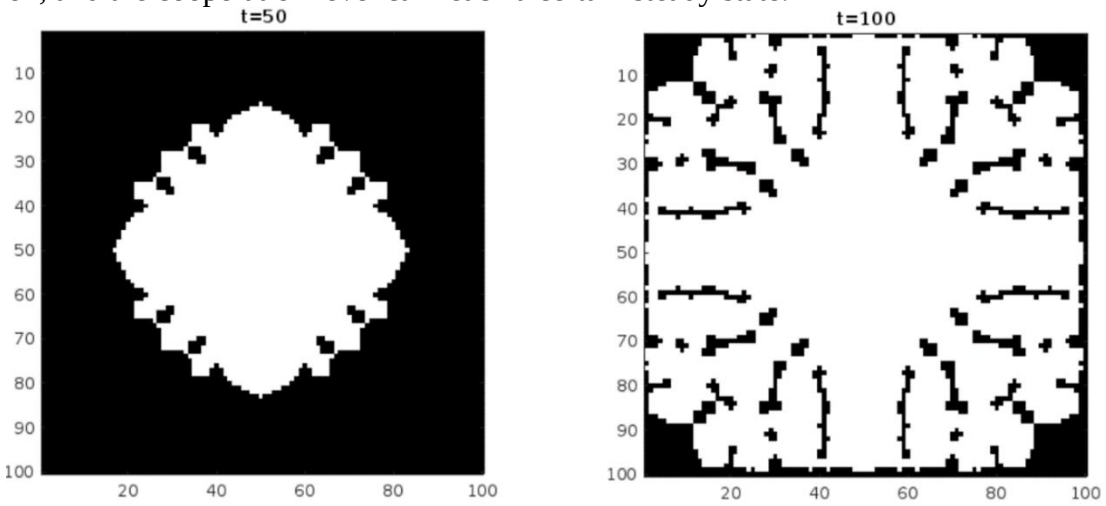

Figure 2: Evolution screenshot

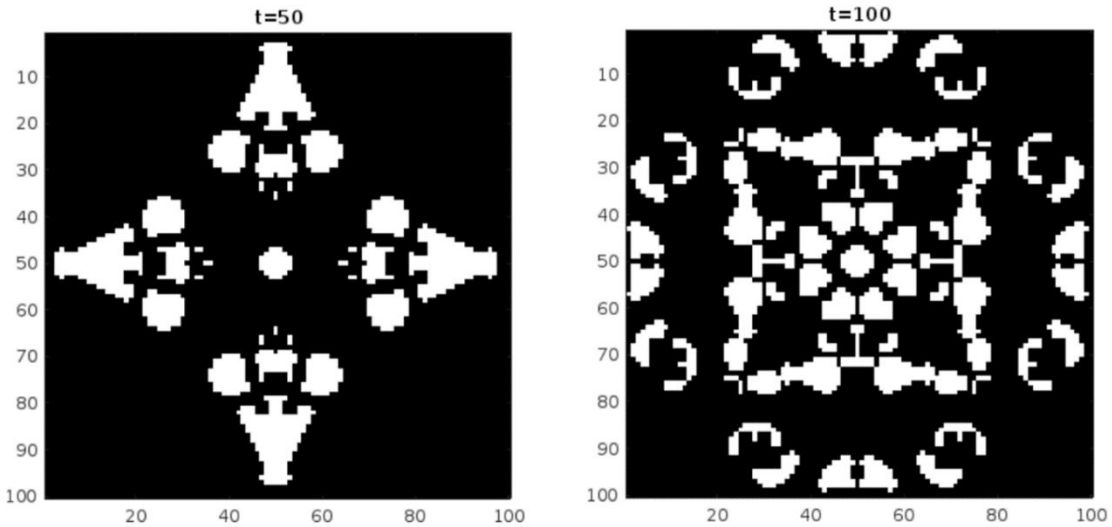

Figure 3: Evolution screenshot

As shown in Figure 3, when b > 1.6, those who abandon their rights and fail to form clusters are invaded by those who retain their rights. In the later stages of evolution, those who abandon their rights occupy a relatively low proportion in the cellular space, but they still achieve a relatively stable state of survival. This shows that this model can simulate, to some extent, the mutual game between individuals in the natural state, as well as the survival and expansion of groups formed by those who abandon their rights.

4. Deficiencies and reflections

4.1 Discreteness and spatiotemporal locality constraints

As a discrete model, cellular automata feature discrete sets for time, space, and state variables. The evolution of cellular automata models proceeds in equal time intervals, where the state configuration at time t only affects the state configuration at time (t+1). Cells are scattered across discrete grid points divided according to certain rules, forming a regular and orderly spatial layout, and their state parameters can only be selected from a few preset discrete values. Cellular automata also exhibit spatio-temporal locality, meaning the state update of each cell depends solely on the states of its neighboring cells at the previous time step, primarily reflecting local interactions. Conversely, the natural state postulated by Hobbes, as a social phenomenon in human society, bears distinctly different characteristics. Time in human society is continuous, unlike the discrete time steps in cellular automata. The distribution of individuals in space is natural and does not exhibit the regular grid layout found in cellular automata. Individuals may exhibit a superposition of multiple states or hold ambiguous attitudes in their interactive activities. Their interactions are not limited to local areas; individuals are constantly mobile and can establish broad connections through various means such as long-distance information transmission. These characteristics are challenging to simulate using cellular automata.

4.2 Difficulty in simulating the operation of public authority

Hobbes believed that natural law could not ensure that people would adhere strictly to the peace treaty. Therefore, a public authority above individuals, namely the state, is needed to ensure peace by deterring everyone. Hobbes argued for the origin of the state from the perspective of contracts. To resist external aggression and prevent internal mutual infringement, people entrust all their power and strength to a representative to exercise uniformly, unifying all individuals into one personality, namely the state. The state can use all its power and means to take actions in a way that it deems beneficial to the peace and security of all. Hobbes used the term "Leviathan" to symbolize the state, emphasizing that the state possesses a terrifying power to deter everyone. Thus, in Hobbes' theory, the state needs to have the function of defending and maintaining peace. However, in cellular automata, simulating complex collaborative behavior is more difficult due to the independence of cells. Although such cooperative behavior can be simulated by adding mechanism settings, such as giving additional benefits or reductions to the central cell when a certain number of surrounding cells adopt a strategy of relinquishing rights. However, in practical operations, determining the threshold for the number of those who relinquish rights and the specific values of benefit changes are challenging aspects of the simulation process. The definition of these variables lacks theoretical support and empirical analysis, making it difficult to ensure the accuracy and effectiveness of the simulation.

4.3 Rule design and configuration representation are subjective

In the process of using cellular automata for simulation, designing rules to meet specific simulation requirements is often an intuitive process that relies on the designer's experience. This model takes the three natural laws emphasized by Hobbes as a benchmark and simplifies the complex natural state into a spatial game model of prisoner's dilemma between individuals. However, the rules formulated through abstract simplification omit many details and assumptions about the natural state, and the model's operation may not fully conform to Hobbes' theoretical framework [5]. Furthermore, in the natural state, the outcome of individuals' mutual game is the emergence of the state. In this model, this process is simplified to the expansion of clusters of rights abandoners within the group of rights holders and the consolidation of their dominant position, i.e., when b is less than 1.6, abandoners account for more than 50% of the cellular space in the later stages of the evolution process. However, when b is greater than 1.6, such as b=1.61, the strategy of relinquishing rights can also stably exist, and clusters formed by abandoners can occupy a certain proportion in the cellular space. There is still some uncertainty regarding what proportion of individuals who choose to relinquish the right to punish and harm others and engage in cooperation is required to conform to Hobbes' theoretical assumptions, and whether the configuration at the end of the model's evolution can fully represent the birth of the state. Further research and refinement are needed.

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