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On Complex Systems and Structure of Emergence in Games- A Survey

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Abstract

Many different complex systems display emergent behavior, and quite a few of these systems have been studied in the past. The science of complexity, popularly known as chaos theory, deals with emergent systems in other fields. Designing emergence is something of a paradoxical task because one of the defining aspects of emergent behavior is that it occurs only after a system is put into motion. In this paper, we begin with the definition of complex systems. Then, we describe the continuum between strictly ordered systems and entirely chaotic ones and show that emergence takes place somewhere between the two. After that, we survey and show how gameplay emerges from the complex system. Our survey points out that three structural features of complex systems contribute to emergence: (a) active and interconnected elements; (b) feedback loops; and (c) interaction at different scales. To show the active and interconnected elements, we explain cellular automata as an example of simple systems that can produce emergence in games. Moreover, we described how a system can be stabilized/destabilized by feedback loops and how different behaviors may emerge in a system at different scales, along with particular games. In this survey, we identified seven classes of emergence that can be considered in games. These classes are Simple, Weak, Multiple, Strong, Cluster, Hub, and Complex Emergence. These classes are produced by different combinations of feedback loops and interactions among the elements of a system at different scales.

***Keywords**:* Complexity, Complex Systems, Emergence, Games, Gameplay.

1.Introduction

A complex system is a system with a large number of smaller components that have interactions with each other and phenomena outside the system, and that is why they are called complex 0. One of the complex systems is computer games, with which most of us grew up and our personality was formed along with them. Games sometimes had attractive gameplay or narrative regardless of today's stunning graphics and visual effects.

Since emergence would be an ambiguous term, it must be defined clearly. A system is emergent if it is not a property of any of its fundamental elements. Emergence is the manifestation of emergent properties and structures at the higher level of an organization or complexity [26]. Emergence is not only appearing in the field of games, but also many complex systems exhibit emergent behavior0. Few studies have been devoted to complex systems, in the last decades. Complexity science, commonly known as chaos theory [16], involves emergent systems in other contexts.

Emotions and interactions are important in games. In game emotion design, deliberate design shows the emotional impact of interaction in the gameplay from time to time. Pitchmain et al. (2022) in a study provided an overview of the research on this aspect of game design[19]. They analyzed more than 200 articles and research sources and then classified their content based on game design goals. The results of this research showed three different areas of the

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intended player's experience in the gameplay. These three areas are physical, strengthening and supporting.

The concept of gameplay is expressed as the challenges that a game creates for players and the actions that the players can take in the game [3]. It can be considered one of the emerging features of games. Although some actions, like varying the color of a car in the racing game, for example, possibly are not related to challenges, many actions support the players to overcome challenges. In games, the actions related to challenges are controlled by their mechanics [13]. For example, an avatar can only jump when a mechanic associated with jumps is implemented in the game.

Games can be programmed in such a way that each challenge within them has a unique action to overcome it. Classic progression games, like text-adventure games, are designed and implemented with this approach. In these games, there are several challenges and actions. Moreover, every challenge is a single puzzle and every puzzle has a single action to tackle it.

However, sometimes a limited number of actions and challenges are created differently in most games. In Tetris [17], for example, no one programmed “Tetris blocks”, in which all possible sequences and combinations of falling Tetrominoes are performed. This game simply discharges Tetrominoes, randomly, and a challenge is produced by a specific combination of a random arrangement of Tetrominoes. Additionally, the player's actions in the previous step are considered in the challenge. This combination varies each time, and the player has some control over the challenges he/she encountered. The game goes with a limited number of actions to overcome the challenges. The games of “Solitaire card” do the same way.

Some other mechanisms may be designed and implemented in the games. These mechanisms allow the players to act in unexpected ways. In some games, game systems need to be set up so that the players have some opportunities to act in a wide variety of expressive ways. To provide this possible opportunity, game designers need to move away from specific resolutions to individual, pre-designed challenges and towards simple, stable game mechanics that may be combined in some ways, even if they lead to interesting results. Rocket shooting is one of these examples. Since an exploding missile applies force to neighboring objects in most first-person shooters, smart players use this extra force to jump higher and farther. The research in [4] presented these emerging not only for the player tactics as a problem but also as an opportunity. In the future, more games must be designed about the creativity and freedom that dramatic systems permit.

It is important to be consistent with realism, in games. For example, Rocket Jump is an unintentional and rather odd gameplay that is equally as unrealistic as it is entertaining. Steven Poole's argument in [2] that compatibility is more important than realism in games. Poole debates that playing a game is immersing the player in an artificial world produced by the game mechanics. The players don't want these mechanics to be completely realistic. A real “Formula 1 racing game”, for instance, would require players to experience many times to become skilled adequate to race, and that wouldn't be amusing whatsoever for many players in practice. The players suppose all space shooter weapons to act like “Star Wars” blasters. It is not like real lasers where the beam travels at the speed of light and is not visible unless the player hit it. The players can do some things that are unsafe or terrible to do in the real life, and weird effects like rocket jumps are all portions of the fun. The players, however, expect consistent game mechanics. When the mechanics perform randomly, like when a missile can kill a strong enemy but it fails to abolish a light wooden door, the players are frustrated.

This paper is motivated to clarify the relationship between emergence and gameplay and identify the structural qualities of complex systems that contribute to emergence. Moreover, it tries to describe the cellular automata as a model of simple systems that can yield emergence. The remaining sections of this paper are structured as follows. In Section 2, we will discuss the fundamental concepts. In Section 3, we present the structural qualities of complex systems. In Section 4, we classify emergence in the games. Finally, Section 5 is considered for the conclusion and future research.

2.Background

The complex system exhibits behaviors that cannot be deduced from the behavior of the components alone. To understand this behavior, we must examine the overall behavior of this system in a holistic view instead of the classical view of the past, not the individual behavior of each of its components. Modeling the behavior of these systems is inherently difficult. The dependence of each component on the other and the interaction of the system with the surrounding environment present complex conditions. The non-linear system, convexity, complex adaptive systems, spontaneous order, and feedback are examples of these behaviors0. In this section, we described the most important concepts, namely complex systems, experiencing emergence, and emergence in games.

2.1.Complex Systems

If we mention complex systems, it does not mean that systems are very difficult to know. Here when we refer to the word complex, it means that the system comprises many elements. With looking at the systems studied by complexity science, understanding and modeling these elements individually is repeatedly too simple. When these elements are arranged in some ways, most complex systems exhibit unpredictable and surprising behaviors so it is difficult to describe the system by just looking at the elements individually. In the scientific literature on complex systems, games are generally classic examples. In these games, the rules are relatively understandable and simple, but the outcome of a game is unpredictable.

To distinguish between chaos and order, we can classify the behavior of complex systems into chaos and everything in between, respectively. We can predict ordered systems, easily while prediction of chaotic systems is very difficult, even when we fully understand their components and how they work. Emergence thrives somewhere between chaos and order.

Figure 1 shows five classes of the behavior of complex systems: (a) Order, (b) Periodic Systems; (c) Emergency Behavior, (d) Chaos, and (e) Ultra Chaos. For each class, several examples are provided. Between the extremes of order (the first class) and ultra-chaos (the fifth class), there are three stages. These stages are periodic systems, emergency systems, and chaos.

Periodic systems evolve over a certain number of steps in a continuous and simply predictable sequence of operations. On a large scale, the climate system and the seasonal cycle work this way. Depending on where we are on an airplane or a planet, we have a certain number of seasons every year. In some regions, the rhythm of the seasonal cycle is very tough, and every year a certain season starts on approximately the same day. Although there are some variations in seasonal temperatures and the start dates of the seasons, the climate system is largely in equilibrium, going through a cycle many times. Global warming appears to make some changes in the climate system already, but there is extensive debate about whether this is an invariant or changing in the segment of a much longer cycle.

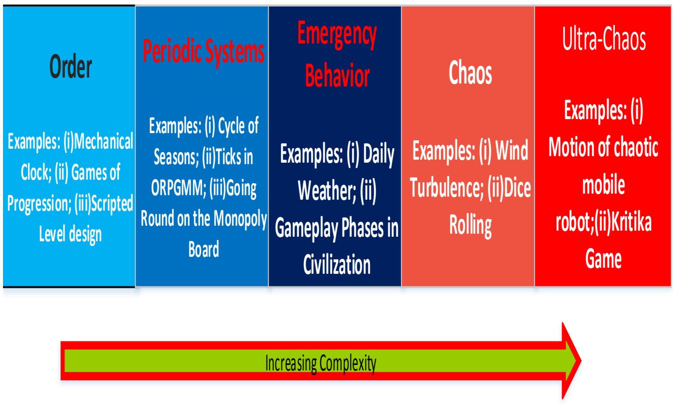

Fig.1. Four classes of the behavior of complex systems (Partially taken from [3])

Since the possible actions and challenges during the play of the game are different each time, emergency games have high replay value. In each period of time, an exclusive result of cooperation between the games and their players will appear. However, it is very difficult to predict whether attractive gameplay will appear in an individual game, basically by looking at its rules. In games, creating emergence is not just about having a lot of rules. In reality, the relationship between the complexity of rules and that of game behavior is nonlinear. Adding more rules may not create a specific game to be more interesting. In fact, occasionally reducing the number of rules is more effective to make really innovative and interesting gameplay.

Emergent systems have a lower level of order with more chaos than those of periodic systems. Often, emergent systems exhibit stable behavior patterns, but their behavior may change suddenly and unpredictably from one pattern to another. The patterns in the weather system are good examples. It is difficult to predict the weather for a particular year, although the cycle of seasons has general measures in a particular region. Accurately predicting the date of the next hard freeze or winter snowfall is nearly impossible due to the complex interactions between air temperature, ocean temperature and weather pressure. It is still possible to specify assumptions and develop rules of thumb based on statistical measures, such as "Peas on Good Friday", but these rules will not be constant each year.

The ultra-chaos is a new concept that emerged recently[27] and it widely exists in practice. The ultra-chaos is a higher-level disorder and fluctuations, compared with the chaos. The motion of chaotic mobile robots, for example, is placed into ultra-chaos. In these robots, little instabilities would cause huge deviations in the motion of robots, even in sensing and statistical meaning. Another example of ultra-chaos is in Kritika games[28]. This game is a very beautiful and graphic game that is very exciting because this game has the style of action games and also role-playing. In this game, the story is that there is a group of enemies who want to spread justice against what the player wants. The players in this game use cold weapons in their hands to fight them and must destroy them one after another. In this game, the players experience the best Android role-playing game with their actions. In fact, with high power, they restrain the attacks of the enemies and meet all kinds of heroes, and on the other hand, they are immersed in the graphics and the deep story of the game and entertain themselves for hours.

2.2.Experiencing Emergence

Through a simple experiment, we can classify four complex behaviors. In this experiment, all we need is a faucet. When we open the faucet very slowly, at some point, water drops start to drip at a slow and regular rate (the first behavior). Although this experiment works better with some faucets than others, sometimes this is easier to achieve by opening the faucet and then slowly closing it. No water flows when a faucet is closed (the second behavior). It is predictable and regular behavior. A dripping faucet is in periodic mode. When we slowly turn on the faucet, it starts to drop faster and faster (the third behavior). Nevertheless, at a certain point, not too long before we get a complete flow of water, the water flow pattern becomes erratic (the fourth behavior). At this point, we rapidly drive the system into a chaotic state.

We may be able to get more complex periodic patterns, somewhere between chaos and periodic drops, such as two rapid drops in a row tailed by a longer pause. Occasionally the faucet alternates between rapid drips and slow, irregular drips. After opening the faucet, it will rapidly return the faucet to steady and regular water flow.

When looking for patterns of behavior in many games, multiple patterns simultaneously can be recognized. Progress games are custom systems since all sequences of possible actions and challenges are designed in advance. Although the players cannot forecast what will be happened next, a designer regarding the mechanics can regulate it. In the board games, turn-taking produces a periodic but more elegant system. In most online role-playing games with massively multiplayer (ORPGMM- See Figure 1) [11], the discrete unit of time (tick) can make affect player strategies. The importance of the behavior of users in massively-multiplayer online games (MMOGs) was studied in [37], and then this research identified five broad classes including: "gamer modeling", "gamer experience modeling", "gamer incentive modeling", "social relationship analysis", and "human gamer behavior and automated agents (hots) detection".

There are several good examples of emergent behavior in games. For instance, we have the clear development phases, namely (a) expansion; (b) consolidation; (c) war; (d) colonization; and (e) space race in “Sid Meier's Civilization”. Finally, the dice or random number generator and other player’s actions can produce a chaotic element in the game. To produce an emergent, the designer must ensure that all elements in the game balance each other in some way so that the overall behavior of the game falls into the emergent class.

2.3.Emergence in Games

In complex systems, emergence can happen only after their elements are set in motion. This point illuminates why the game design is so much dependent on prototyping and playtesting. Only way to ensure the gameplay is enjoyable, interesting and balanced is to make several prototypes and to play it in some ways.

Usually, the design is considered as a process where the designers know how the process works and what they want to make. Designing an emergency system is a paradoxical process since the designers may not know exactly when the system goes to a final state, but they design the experience of getting there. However, "Designing Game Mechanics" takes certain structures into account so that they tend to produce certain types of outcomes. Identifying and knowing these structures help designers to produce the effects they want, even though the process still involves a lot of experimentation.

3.Structural Qualities of Complex Systems

Complexity science usually deals with complex and extensive systems. To explain it, the climate system is a typical example. In this system, a small change can lead to large effects over time, which is identified as the butterfly effect. In these effects, a butterfly flapping its wings on one side of the earth may supposedly activate a movement of air that gathers into the storm on the faraway side of the earth. Several other systems such as stock markets, traffic, pedestrian flow, bird aggregations, and the motion of astronomical objects are studied by complexity science. The complexity of these systems is usually much more than those identified in games.

Fortunately, many other simpler systems exhibit emergent behaviors. To study these systems, the extraction of the relevant structural qualities that contribute to emerging behaviors is easy. A couple of reinforcement learning methods, including Markov Decision Process (MDP) [38] and Cellular Learning Automata (CL) 0 can be used to show the emergence in games. In this section, we choose CLA, due to its advantages over MDP. The main advantage of cellular automata models is that they do not aggregate individuals into compartments, thus allowing each modeling unit to be heterogeneous based on certain attributes. After explaining the relevant structural qualities, we elaborate on how a system can be stabilized/destabilized by feedback loops and how different behavioral patterns emerge at different scales.

3.1.Cellular Automata: An Active and Interconnected Elements

At the border of sciences between computer science, mathematics, and games, there is a particular field known as cellular automata 0. A cellular automaton is a set of simple rules over spaces or cells on a grid or in a line. Every cell in the grid may be white or black. The rules control how a cell alternates from white (black) to black (white) and how a cell's color affects the cells around it. Typically, the rules for determining the color of a cell consider only three factors: (a) the current color of the cell; (b) its eight neighbors on a 2D grid; and (c) its two neighbors on a line. Generally, scientists of mathematics consider such a set of rules as a hypothetical machine that works alone without any intervention by a human. That is the main reason to name these machines automata.

A cellular automaton begins with its cells in a certain configuration in which there are some black cells and some white cells. Then the rules are executed to determine whether the color of each cell should be changed or not. The color of a cell is not changed immediately. At the first iteration, all cells in the grid are checked and marked as those that need to be changed. The necessary changes are performed for all cells before the next iteration. The process is repeated for each iteration, which is called a generation. Wolfram Stephen, a British scientist has produced a simple cellular automaton with a cell line that exhibits emergent behaviors [1]. In this cellular automation, the color of the cells is considered as states. Obviously, the next state for a cell is specified by the former state of that cell and its two immediate neighbors. Since the cells are either in white or black color as only two possible states in each generation, there are eight possible combinations.

A set of possible rules with the resulting complex is shown in Figure 2. The rules are presented at the bottom of this figure. A surprising pattern is produced by printing each new generation of the system under the previous generation. It starts with only one black cell and the remaining cells have white color. The rules for changing the color of a cell are shown at the bottom of Figure 1. The left rule means that "if a black cell is surrounded by black cells on both sides, in the next generation, the cell will become white". The fourth rule means that if a white cell has only one black cell to its left, that cell will be black in the next generation. Although we have nothing random in the rules, a pattern with distinct and seemingly random features is generated by the cellular automaton shown in Figure 2.

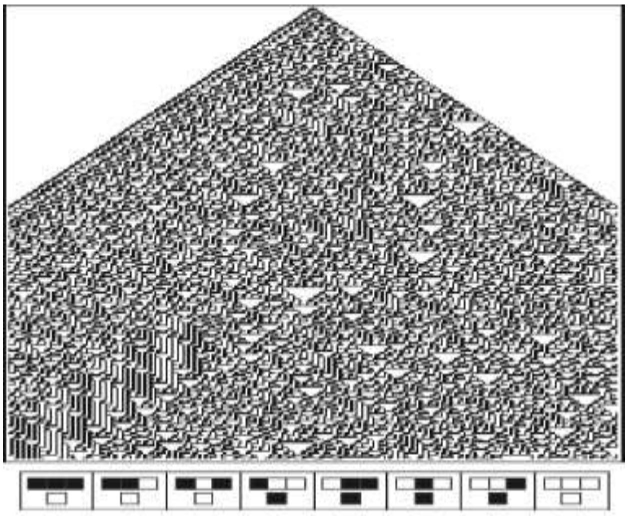

Fig.2.Stephen Wolfram’s cellular automaton [4]

We can identify three critical characteristics of systems that show dynamic behavior [1]:

- **Simple Cells with local rules:** The first characteristic is that the system should be composed of simple cells and its rules are defined locally. With these characteristics, the system must be composed of elements that can be reasonably and easily described. For example, in Wolfram's cellular automata, there are eight simple rules to determine the behavior of each cell.

- **Long-Distance Communication:** The second characteristic is that the system should have long-distance communication. In fact, changing the state of a single element of a complex system must be capable to lead some changes in elements far away in space or time. This capability is a Long-distance communication that makes the butterfly effect possible. Communication between the elements in Wolfram's cellular automata occurs, because every cell directly affects its immediate neighbors. The reason that the neighbors of each cell also have neighbors, every cell is connected indirectly to every other cell in the system.

- **Activity Level of the Cells:** The third characteristic is that the activity level of the cells is a good indicator of the complexity of the system's behavior. In a system with only a small number of active cells, interesting and complex behavior is unlikely to appear. In the Wolfram automata, activity is considered as a change in the state of a cell. A cell goes to the active state when a rule changes its color from white to black or from black color to white.

Fascinatingly, some of these features can be "read" from the rules governing the behavior of each cell. The fact that all cells are connected and every cell receives input from itself and its two neighbors. These inputs indicate a good chance of long-distance communication. Additionally, four of the eight rules in Figure 2 cause to change the color of the cell, indicating that likely a large number of activities in the system.

Cellular automata show that the complexity threshold is surprisingly low. As long as there are enough elements, activities, and connections in systems, relatively simple rules can generate complex behavior. Most games are made similarly. Games are composed of various elements that are governed by relatively simple mechanics.

Some particular elements in games may have many possible interactions. Although the player is an essential source of activity in the system, but as the cellular automata demonstrate, emergence can happen even without any intervention by a human. For example, “Tower defense game” demonstrates the following features well in Figure 3.

- The game consists of many relatively simple elements and enemies follow a pre-designed path to the castle of the player.
- Each enemy has many hit points and a certain speed with a few mechanisms to make the game more interesting.
- The player places the towers to defend his position.
- Each tower fires bullets at enemies at a certain speed at a certain range.
- Some towers may be damaged while others create other effects such as slowing down enemies.
- Occasionally the towers enhance the neighboring towers in their performance.

Fig.3. Tower Defense Game [9]

In a “Tower Defense Game”, many elements are outlined by towers and local mechanisms of enemies. Similar to cellular automata, these elements are active and interconnected. The active elements are such as: (a) towers respond to enemies and (b) enemies move. The interconnection refers to something like towers firing at enemies and the towers can enhance each other's performance.

There are some helpful indicators to distinguish emergent games from progressive games. These indicators can be the number of connections between elements and the level of activity. In a typical progression game, every element including characters, puzzles, and so on only interact with the player's avatar, without any interaction with each other. In fact, they are only activated when they are displayed on the screen. The elements that are not currently visible on the screen in a progressive game are usually disabled. In a similar manner, the number of connections between the elements is small. The game elements can only interact with each other in a limited number of pre-designed ways. These interactions provide the designer with a lot of control over the events when a game progresses, but more predictable games also result when all pre-designed options have been explored. They are no longer fun [18].

3.2.Stabilizing/Destabilizing a System: Feedback Loops

In this section, we explain how a system can be stabilized/destabilized by feedback loops. A specific typical example of complex systems is ecosystems. These systems appear to be perfectly balanced. In an ecosystem, the different populations of animals do not change much over time. Moreover, nature activities seem to include a variety of mechanisms to keep and control the balance. The best way to explain mechanisms is by looking at the populations of prey and predators. When there is a lot of prey, predators can find some food easily. These foods increase the number of predators. However, as more and more predators survive, the population of prey declines. As this mechanism goes forward, there will be too many predators at a certain period of time at which the situation will reverse. In fact, in that situation, the predators will not find enough food so their population will decrease. Since that situation has fewer predators, more prey survives and produces offspring, which causes the population of predators to grow again.

In an ecosystem, a particular balance between predators and prey can be recognized. This balance can be created by something, which is called a feedback loop. This feedback loop is produced when the effects of a change in one element of the system, return to affect the same elements at a later time. For example, in the ecosystem, when an increase in the number of predators occurs, the number of preys will decrease. This decrease, in turn, causes a further decrease in the number of predators. In fact, the effects of changes in the number of predators literally feedback on their population size.

In some systems, there are feedback loops that cause a balance. These feedbacks are named as negative feedback loops and are generally used in the design of electrical and electronic devices. A typical example of a negative feedback loop is thermostat that detects the air temperature. This device activates when the temperature of a heating system goes too low. Then the heater causes the temperature to go up and again causes the thermostat to turn off the heater, in turn. A speed governor in machines is another device. When the speed of a machine goes up, for instance, if the load on the machine is reduced, the governor supplies a lower power to the machine to slow its speed down. When the speed of the machine slows down, the governor transmits more power supply to increase its speed.

This controls the speed of the machine to be stable. Therefore, the speed governors are employed to ensure that the machine operates efficiently. Moreover, it cannot be moved to dangerous speeds if its load is unexpectedly removed.

Negative feedback loop is often found in some games. In “Civilization”, for example (See Figure 4), not unlike the predator/prey example in ecosystems, the population of a city is changed by the negative feedback loop. When the city grows in population, it will need more food for life. This leads a sustainable growth in the city size that is held by the ground and the player's current level of technology.

There is the opposite of the negative feedback loop, naturally. This loop is called the positive feedback loop and reinforces the effects that caused it, rather than balancing it by operating against the changes, triggered by the feedback loop. Audio feedback is a good example. In this example, a process works in three steps: (a) the microphone picks up an input sound; (b) the amplifier amplifies the sound; and (c) the speakers reproduce a louder input sound. This process is repeated. The microphone receives a new sound from the speakers, which is amplified again and distributed. The result of the process is a loud sound. This sound can only be paused when the microphone is moved away from the speakers.

Positive feedback often happens similarly in games. In a game of chess, for example, if the player captures one of his/her opponent's pieces, it will be easy to capture another piece because at this time the player has more pieces than his/her opponent.

It shows that positive feedback can create volatile systems with rapid changes.

Fig.4.An image of *Civilization* [8]

To sum up, we can express that in most emergent games, several different feedback loops operate simultaneously. It is important to think that feedback loops can happen in complex systems. We must consider negative feedback loops to maintain balance in the system, whereas positive feedback loops can disrupt the system.

3.3.Emerging Different Behavioral Patterns: Different Scales

In this section, we explain different behavioral patterns that emerge at different scales. We begin with this axiom that the most famous cellular automaton is called the "Game of Life". It consists of cells placed on a two-dimensional grid that continues indefinitely, in theory in all directions with two attributes. The first attribute is that every cell on the grid has eight neighboring cells diagonally and orthogonally. The second attribute is that every cell can be in two different states, either alive or dead. In most samples, dead cells are stained in white color and living cells are stained in black color. In every iteration, the following rules are performed on every cell:

- A living cell dies of loneliness if it has less than two living neighbors.
- A living cell dies due to overcrowding if it has more than three living neighbors.
- A living cell survives if it has two or three living neighbors.
- A dead cell is revived if it has exactly three living neighbors.

To begin the "Game of Life", a grid is set up with a number of cells selected to be alive, initially. Figure 5 shows an example of the effects that arise from the application of these rules. However, to truly understand the emergency behavior of the "Game of Life", looking at one of the interactive versions available online 0, will be helpful.

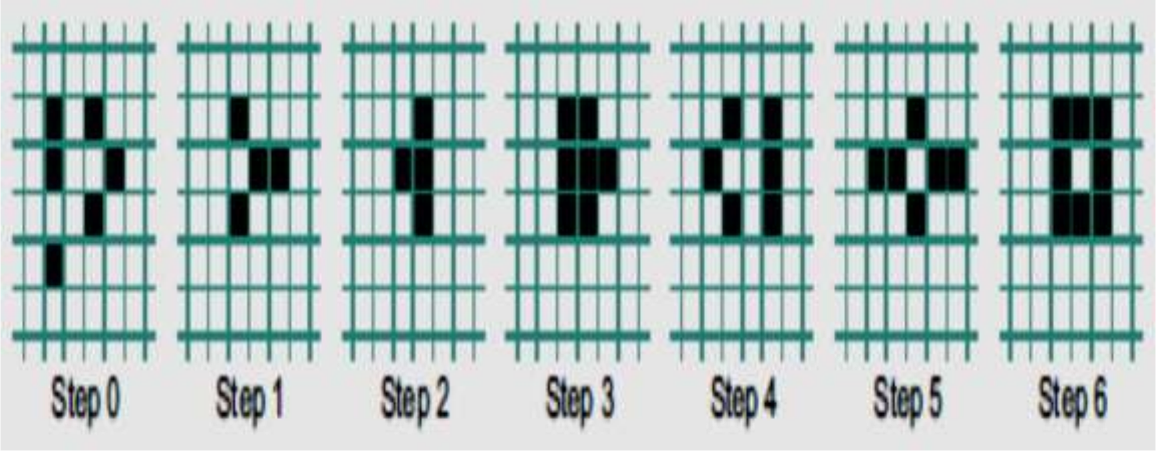

Fig.5.Several iterations of the "Game of Life"

When the "Game of Life" is set in motion, it generally has quite chaotic results, with many activities bursting out of their original living cells. Often after a few iterations, the "Game of Life" settles into a more or less stable configuration. From time to time, this game has many groups of cells moving from one state (white color) to another state (black color).
The main motivation for researchers to study the "Game of Life" could be to provide an answer to the question, "Is there an initial configuration of living cells that expands forever?". The researchers quickly began to catch configurations that exhibited surprising behavior[4]. One of these configurations is called Glider. In the definition [20], Glider is a group of five living cells that, after four iterations, reproduce themselves one tile away. A glider effect is the effect of a small creature that travels across the grid (See Figure 6). More fascinating patterns such as the glider gun can be found. For instance, a pattern that stays in one place on the grid can generate new gliders that move every 30 iterations.

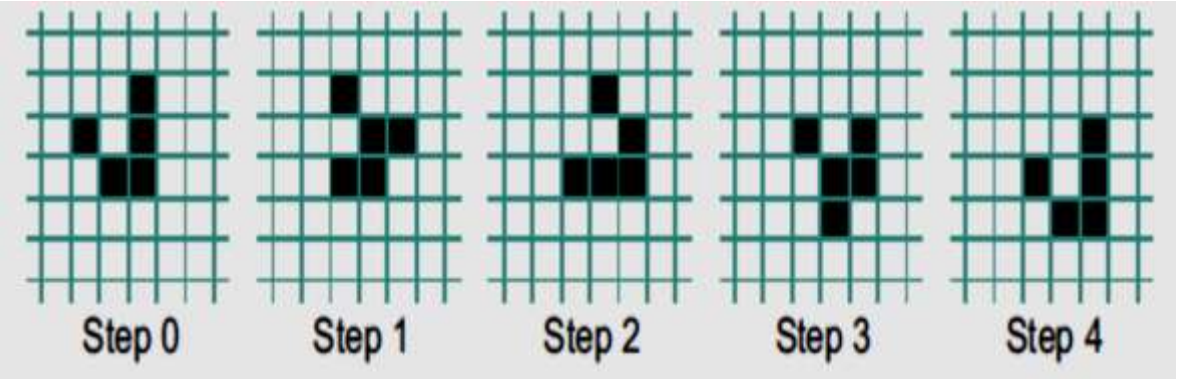

Fig.6.The Step 0 to Step 4 in a glider for the “Game of Life”

Gliders and glider guns demonstrate the most remarkable behavior in complex systems. To demonstrate this behavior, we can consider a group or a flock of birds, as a very good example that the birds move as one (Figure 7). The group as a whole appears to have a distinct shape, purpose, and direction. This behavior occurs not only at the scale of particular elements but also at the scale of groups of elements. In this example, the "rules" that guide birds operate at both scales. The flocking can be simulated by: (a) having the birds' movement balance by moving in the direction with their neighbors, (b) preventing the birds from getting too close to their neighbors, and (c) moving the flock toward the center of the group with a matching speed. This behavior can be seen in many other complex systems.

Fig.7.Flocking birds [7]

Similar effects can be seen in games. In Pac-Man 0, for example, the players have wondered over the years when the ghosts are intentionally grouped against them and set traps to capture the players. In this game, the ghosts do not cooperate so their whole behavior looks much more intelligent than that of usual situations. In fact, the ghosts are simple machines that performed with simple rules by which the game is played and alternates between two modes: from chase mode to scatter mode or vice versa.In scatter mode, the ghosts do not hunt the player, but every ghost seeks a different corner of the maze. However, the game is in chase mode most of the time, when ghosts hunt the player. When the ghosts want to hunt the player, they must decide at each intersection of the maze. This decision is performed by an algorithm that chooses which direction can bring the spirit closer to the player. The algorithm simply ignores the walls between the ghost and the player. The algorithm operates slightly differently for each ghost as follows:

(a) The red ghost (Blinky) attempts to reach the player's current position;
(b) The pink ghost (Pinky) attempts to get a position four tiles ahead of the player;
(c) The blue silhouette (Inky) decides where to go, based on the player's position and Blinky's position(d) The orange ghost (Clyde) chases the player when he is far away; and
(e) finally, Clyde attempts to reach the bottom left corner of the maze when he gets close to this corner.

Together, the motion effects look surprisingly clever. For instance, Blinky follows the player while Pinky and Inky attempt to outrun the player and Clyde adds some noise. The ghosts, as a group, are honestly effective hunters, even without knowing where the others are located. This combination of simple behaviors makes the players an impression that they are hunting together, having simple complementary strategies.

4.Classifying Emergence

We can distinguish different levels of emergence in complex systems. Some effects are more pronounced than others. In a complex system, the different scales and feedback loops together drive a long way in describing and explaining the different levels of emergence. In the literature ([4], [5], [12], [13], [18], [22], [25], [34]), we can identify the following classes of emergence in complex systems.

4.1. Simple Emergence

In its simplest form, there is feedback only between agents at the same level of a system. In the simple emergence, there is not any downward feedback with self-organization. As Figure 8 (top-left) shows, there is only a feedforward relationship between the elements of the system. Most man-made machines, for example, are put in this class, where the machine's performance is intentional in some ways and emergent features are designed in their elements. The behavior of machines that exhibit intentionality is predictable and deterministic, but suffers from adaptability or flexibility. A thermostat and a speed controller are good examples of this type of predictable feedback.

4.2.Weak Emergence

The second class of emergence behavior is weak emergence, where complex machines incorporate classic phenomena, including top-down feedback and self-organization. As Figure 8 (top-right) shows the main characteristic of this class is simple feedback, either positive or negative between the elements of the system. In this class, a further distinction is made between stable and unstable forms. In this class, there is top-down feedback between different levels in the system, in which either feedback can be agent-to-agent (ATA) or group-to-agent (GTA). For example, a bird reacts to the proximity of other birds (ATA) and simultaneously perceives the flock as a group (GTA). The whole flock constitutes a different scale than that of a particular bird. A bird observes and reacts to both, ATA and GTA. This behavior is not only limited to birds, but also sets of fish behave in a similar manner. The flocking can be extended to any type of unit that can understand both its neighborhoods and the mode of its group as a whole.

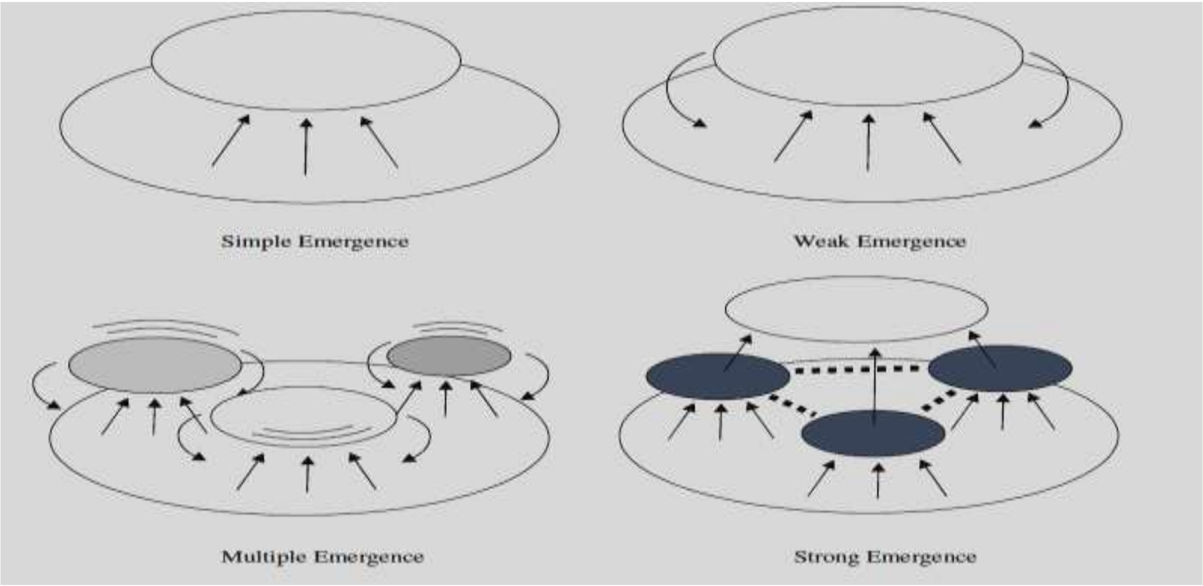

Fig.8.Four main classes of emergence in complex systems

4.3.Multiple Emergence

A rung up the complexity from weakly emergent systems are systems that reveal multiple emergencies. This class covers every form of emergence over multiple feedbacks and adaptations in more complex adaptive systems caused by evolution. As Figure 8 (down-left) shows this emergence arises in very complex systems through many feedback loops, or in complex adaptive systems with intelligent agents, and it is the class with a large number of externalities in the emergent process. In this class, multiple feedback passes through different levels of the association of the system. Forum [5] illustrates this class by illuminating how emergence can be established so that systems have either long-term negative feedback or short-term positive feedback. The stock market shows such behavior. In short-term positive feedback, when stocks are rising, people notice and buy more, causing the price to rise further.

In long-term negative feedback, people take advantage of their experience that stocks will ultimately peak, and they plan and will sell their stock at its high, thereby leading the price down. This phenomenon also operates in reverse so that people tend to sell a stock when they see it going down, but tend to buy when they know it has bottomed out and is a bargain. John Conway's play life also presented this type of emergence [4]. The "Game of Life" consists of both positive and negative feedback. In positive feedback, there are rules that govern the birth of cells, and in negative feedback, there are rules that govern the death of cells. The "Game of Life" also demonstrates different scales or points of an organization in which there is the scale of individual cells at the lowest level. At a higher level of an organization, we can identify stable behaviors and patterns such as gliders and glider guns.

4.4.Strong Emergence

The fourth class is strong emergence which covers all forms of robust emergence in evolution. The strong emergence is independent and free from any supernatural or unscientific meaning. Two main examples of this class are life as an emergent feature of the genetic system and culture as an emergent feature of language as well as writing. Strong Emergence is a multi-level emergence in which the consequence of emergent behavior at the highest level can be separated from factors at the lowest level of the system, As Figure 8 (down-right) shows strong emergence is characterized by multi-level emergence and a large diversity in the created system, that is, due to the combinatorial explosion, the possible states of the emerging system. This is the emergent form responsible for producing structures of higher-order complexity, which cannot be reduced, even in principle, to the direct influence of the properties and laws of the fundamental constituents.

In fact, this class of emergence is recognized as the large difference between the scales on which the emergence acts and the presence of intermediate scales in the system. For example, a network of cells used for the “Game of Life” can be configured to act at a higher level as a computer that can perform simple calculations, and from that new complex systems to be used, it is possible to make. In this case, the causal relationship between the behavior shown by the computer and the “Game of Life” itself is minimal.

4.5.Hub Emergence

The fifth class of emergence is defined based on Barab´asi–Albert (BA) scale-free model as a complex network to designate interactions among nodes. The production of this network is performed by employing BA model with preferential attachment ([23],[24]). Initially, a BA network is created and the operations begin with the initial connected network in which there are a known number of links. New nodes are inserted into the network one at a time. Each new node is connected to the number of existing nodes that specified by the number of links, chosen according to linear preferential. At each iteration of the time step, a node and a link are chosen randomly. If the degree of the selected node is greater than that of the selected link’s head node, then the link is reconnected to a node with a higher degree. Otherwise, the link is left as is. The principle, therefore, is to reconnect a randomly selected link every time it increases the degree of a high-degreed node.

Figure 8 shows a network of ten nodes and thirteen links. It can be viewed in three hubs. Hub emergence appears in public good games[25] (PGG), in which the network comprises a set of connected agents[25]. Each agent is located in one node, and there are links between an agent and others nodes linked to its neighbors. The principle is that each agent with its neighbors makes a group of play of PGGs when the number of neighbors (the degree of the node) is higher than a specific threshold. Each agent contributes to its group of play, and in the groups connected with its neighbors. Some specific applications of PGGs, as examples, are organizational structures, environmental policy, workplace, justice, and legal issues.

4.6.Cluster Emergence

The sixth class is cluster emergence which is defined based on the clustering coefficient and measures the cliquishness of a typical neighborhood of each node in a network. In this class, the network works as follows. After generating the BA network, a random node and a random link are selected, at each time step. We reconnect the link to a new random node when the overall cluster coefficient leftovers the same or is greater than before. As a consequence of the reconnection when the clustering coefficient decreases, the topology of the network is turned to the previous time step. For instance, the network in Figure 8 can be turned into four clusters, based on the information from the previous step.

In cluster emergence, the entities in the system interact directly, leading to the construction of clusters, which in turn affect the behavior of the entities themselves. Examples of cluster emergence appear in packs of wolves, flocks of birds, herds of mammals, swarms of bees, and shoals of fish. In these examples, the nodes (as players) can give and receive payoffs from all the groups with which they are connected. Moreover, every node/player contributes similarly to the groups connected with its direct neighbors.

Figure 8 shows the effect of hub and cluster emergencies on a network structure. Hub emergence takes together the network in large groups, but cluster emergence creates the network more clustered and the get-together of the nodes in a form of triangles.

These classes show that there are also different levels of emergent behavior, often operating simultaneously, in the games. More significantly, they also show the structural features of game mechanics, such as the presence of different scales and feedback loops. They play a vigorous role in the emergence of interesting and complex behavior.

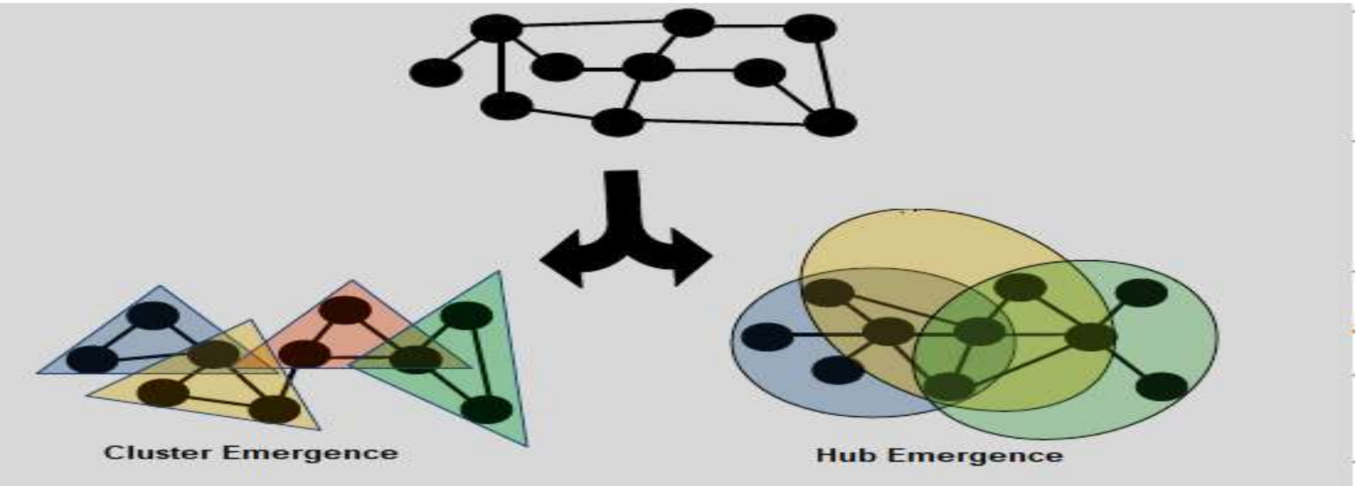

Fig.8.Cluster and Hub Emergence

4.7.Complex Emergence

A system usually starts with very simple emergent properties and an initial equilibrium. As the system progresses, it proceeds further from the initial equilibrium and then it will reach a point where not only the nature of equilibrium does not exist, but the nonlinearity of the system increases and thereby leading to reduced self-organization in the system. This point is where complex emergent properties of the system appear and the system becomes complex. This progress is usually in the form of transition or symmetry breaking bifurcation ([29],[30]).

Nonlinear systems can only have complex emergence when they are out of equilibrium through large energy inputs. There are numerous natural systems of this type and many of them are explained as complex systems. Since self-organized systems involve a relatively constant energy input to maintain order, the complex emergence of these systems also requires continuous energy inputs. Thus, since complex systems must be self-organized, only nonlinear systems can produce complex emergence.

There are some simple examples of complex emergence are the emergence of regular hexagonal convection cells [29], the emergence in the selection of shortest paths in ant swarming systems [30], and the emergence of the dynamic instability of a population of microtubules involved in the center of microtubule organization in a cell [32]. Other more complex examples are ecosystems, emotions, and weather patterns. In examples such as self-awareness and consciousness, it is assumed that there is nothing drastic and fundamentally mysterious about their origin. In other words, as with other less esoteric systems, if there is sufficient knowledge of biology, chemistry, physics, and other related sciences, it is easy to understand their emergence from the behavior and interaction of all related elements. As systems become more complex by moving the emergence continuum further toward the extreme of complex emergence, complex emergence appears at more than one level, possibly through frequent bifurcation symmetry breaking[29]. Such systems are hierarchical and have multiple levels, and computing system-level emergent properties from the element level quickly become unpredictable and possibly intractable. Indeed, we cannot reveal these systems—the shortest algorithm for describing such systems is the systems themselves [33].

A very complicated example of complex emergence is COVID-19 virus. In 2020, the emergence of this virus imposed terrible conditions and effects on human society. The research [35] and [36], benefiting from the comprehensive approaches of criminal policy and the hypothesis of chaos theory, tried to explain the necessary elements in controlling and reducing harmful and incompatible social phenomena. During the outbreak of the COVID-19 virus, many games ranging from childhood games to adult games as well as educational games were designed and entertained people at home.

Table 1 summarizes the seven types of emergencies found in complex systems. The types of emergence, main features and some examples for each one are specified in the first, second and third columns of this table, respectively.

Table 1
A summary of types of emergencies found in the complex systems

Type of Emergence	Main features	Examples
Simple	• Roles of elements are fixed. • The system is predictable and closed with passive elements • There are abundant in the real world	Most man-made machines. Thermostats Speed controllers
Weak	• Roles of elements are flexible. • The system is predictable with principle. • The system is open with active. • There are too many in the real world	Flocking of birds Sets of fish
Multiple	• Roles of elements are fluctuating. • The system is unpredictable or chaotic. • The system is open with multiple levels. • There are common and unusual in the real world.	Game of Life Stock market
Strong	• Roles of elements are well-defined. • The system is unpredictable in principle. • A New system is produced or includes many subsystems. • There are rare in the real world.	Life with emergent features of the genetic system. People's Culture or Nation's culture
Hub	• Each agent contributes to its group of play, and in the groups associated with its neighbors.	Most public good games
Cluster	• Topology of the network is changed in each time step, based on the clustering coefficient.	Packs of Wolves, Flocks of Birds, Swarms of Bees, Herds of Mammals, Shoals of Fish
Complex	• Happens only in nonlinear systems driven far from the equilibrium by the input of energy.	Regular hexagonal convection cells, Shortest pathways in ant mass recruitment systems

5.Conclusion and Future Research

In this paper, we explained that games are one type of complex systems. The games can not only produce unpredictable results but also should provide some goals in terms of experience and knowledge for their players. To achieve these goals, game designers need to understand the nature of emerging behaviors, in general, and a well-designed and natural user experience game, in particular.

In this paper, three structural features were specified in complex systems. They were active and interconnected elements, feedback loops, and interactions at different scales. These features are the first step to building a theoretical framework, which is called Mechanisms. This framework emerges in the games and gives the game designer, greater control over the elusive process of building quality games that exhibit emergent behaviors. As a direction for future research, studying games with supplementary detail will reveal more features of complex systems.

We considered many active elements and related them together with feedback loops, and different scales as structural features of the games. The structural features play a fundamental role in the production of emergent gameplay. As a second direction for future research, studying game mechanics will reveal these structures (and others) with much greater detail. The game designers should make the appearance of the harness in the games.

We found seven types of emergencies in complex systems. It is important to consider that **e**mergence across scales and levels is a key issue in the study of complex systems. This issue is represented by the two lofty mountains of the origin of life and the origin of consciousness. In recent years, emerging theories and tools, such as causal emergence theory, machine learning renormalization technology, and self-referential dynamics, appeared. As a third direction for future research, studying these theories and tools are expected to reveal the emergence law of complex systems.

Although some complicated phenomes, such COVID-19, can be explained and interpreted by the chaos theory, the vicious experience of contracting this virus shows that in analyzing the phenomena, the human being needs new tools and deep views to reduce their ignorance and misguidance from complex systems and their intra-network relationships. With serious doubt about the current and former policies to manage this virus, the policies adopted in the fields of industry, environment, health, and treatment, and even the education system must be reviewed. Certainly, the results of such reviews will provide priorities to the intrinsic and fundamental value of human dignity and the fair distribution of welfare, security, health, education, and peace for everyone.

The theory of chaos and the organized view of criminal politics (identified in games) seeks to change the very complex relationships of social phenomena from a detailed, one-dimensional, and simplistic linear view to a deep, coherent, and multifaceted view and analysis within the network, and to improve forgiveness. Obviously, discovering new approaches in the analysis of social and human phenomena is considered a great revolution in understanding the issues of human society, especially in the cross-field of human sciences and engineering, as a fundamental approach in guiding the performance of humanity.

References

[1] Wolfram S. (2002), *A New Kind of Science*. Champaign, IL: Wolfram Media.

[2] Poole S. (2000), Trigger Happy: The Inner Life of Videogames, London, UK: Fourth Estate.

[3] Adams E., (2013), *Fundamentals of Game Design, Third Edition*. Berkeley, CA: Peachpit Press/New Riders.

[4] Adams E., Joris D., (2012), Game Mechanics: Advanced Game Design, New Riders Pub.

[5] Fromm J. (2005), Types and Forms of Emergence, Cornell University Library website at http://arxiv.org/abs/nlin.AO/0506028.

[6] Game of Life, Available from https://playgameoflife.com/, Last visited: 8 Nov 2022.

[7] Zandie Rohola, Available from https://betterprogramming.pub/boids-simulating-birds-flock-behavior-in-python-9fff99375118, Last visited: 11 Nov 2022.

[8] Tomb Builder, Available from https://forums.civfanatics.com/threads/tomb-builders-egypt-cultural-deity-pangaea-all-standard.411077/ , Last visited: 11 Nov 2022.

[9] Kingdom Rush- Tower Defense TD, Available from https://play.google.com/store/apps/details?id=com.ironhidegames.android.kingdomrush&hl=en_US&gl=US&pli=1, Last visited: 11 Nov 2022.

[10] PAC-Man Game, Available from https://thereader.mitpress.mit.edu/how-pac-man-revolutionized-gaming/ , Last visited: 11 Nov 2022.

[11] Pałosz, R. (2022), How Do Base Rules Constitute a Virtual World? International Journal for the Semiotics of Law 35(5), pp. 1879-1901

[12] Boumaza, K., Tolba, C., Ober, I. (2021), Formal verification of emergent properties, Informatica (Slovenia) 45(3), pp. 463-475

[13] Chen, Y., Liu, J. (2020), Social Capital Games as A Framework for Social Structural Pattern Emergence, Proceedings of the 2020 IEEE/ACM International Conference on Advances in Social Networks Analysis and Mining, ASONAM 2020 9381448, pp. 309-316.

[14] Simon, J.P. (2018), Triggering the emergence of digital ecosystems: the role of mobile and video games in emerging economies, Digital Policy, Regulation and Governance 20(5), pp. 449-478

[15] Wolfram S. (1983). "Statistical Mechanics of Cellular Automata". Reviews of Modern Physics. 55 (3): 601–644. Bibcode:1983RvMP...55.601W. doi:10.1103/RevModPhys.55.601. Archived from the original on 21 September 2013. Retrieved 28 February 2011.

[16] Gleick J. (2008), Chaos: Making a New Science, Penguin Book.

[17] Tetris, Avaiable from https://tetris.com/play-tetris/, Last visited: 11 Nov 2022.

[18] Wang Z., Li R., Jin X., and Ding. H., (2022), "Emergence of Social Norms in Metanorms Game with High-Order Interaction Topology," in IEEE Transactions on Computational Social Systems, doi: 10.1109/TCSS.2022.3144978.

[19] Pichlmair M. and Johansen M. (2022), "Designing Game Feel: A Survey," in IEEE Transactions on Games, vol. 14, no. 2, pp. 138-152, doi: 10.1109/TG.2021.3072241.

[20] Randall D. (2014), The Cognitive Domain of a Glider in the Game of Life, Artificial Life (2014) 20 (2): 183–206. https://doi.org/10.1162/ARTL_a_00125

[21] Sayama H., Introduction to The Modeling and Analysis of Complex Systems, Binghamton University, State University of New York, LibreTexts, 2022.

[22] J. E. Bahbouhi and N. Moussa, "Impact of emergence on the evolution of cooperation in public goods games," 2019 1st International Conference on Smart Systems and Data Science (ICSSD), 2019, pp. 1-5, doi: 10.1109/ICSSD47982.2019.9003111.

[23] Perc, M., and Szolnoki, A. (2012). Self-organization of punishment in structured populations. New Journal of Physics, 14(4), 043013.

[24] Szolnoki, A., and Perc, M. (2013). Effectiveness of conditional punishment for the evolution of public cooperation. Journal of theoretical biology, 325, 34-41.

[25] Bahbouhi J.L, Moussa N. (2022), Impact of Emergence on the Evolution Of Cooperation in Public Goods Games, IEEE Conference on Dec 24, 2022.

[26] Fromm J. (2021), Types and Forms of Emergence, University of Kassel, Germany, Technical report.

[27] Yu Yang, Shijie Qin, Shijun Liao (2023), Ultra-chaos of a mobile robot: A higher disorder than normal-chaos, Chaos, Solitons & Fractals, Volume 167, 13037, ISSN 0960-0779, https://doi.org/10.1016/j.chaos.2022.113037.

[28] Kritika: The White Knights, Available at https://apps.apple.com/us/app/kritika-the-white-knights/id865958296, Last Visit Jan 9 2023.

[29] Ball, P. (2001), The Self-Made Tapestry; Oxford University Press: New York.

[30] Goodwin, B.C. (1994), How the Leopard Changed its Spots. The Evolution of Complexity; Scribner's: New York.

[31] Aron, S.; Deneubourg, J.-L.; Goss, S.; Pasteels, J.M. (1990), Functional self-organisation illustrated by inter-nest traffic in ants: The case of the Argentine ant. In: Lecture Notes in Biomathematics. Biological Motion. Alt, W.; Hoffman, G., Eds.; springer: Berlin, pp 533–547.

[32] Gerhart, J.; Kirschner, M. (1997), Cells, Embryos, and Evolution; Blackwell: Cambridge, MA.

[33] Davies, P.C.W. (2004), Emergent biological principles and the computational properties of the universe. Complexity, 10, 1–9.

[34] Halley, Julianne & Winkler, David. (2008). Classification of emergence and its relation to self-organization. Complexity. 13. 10-15. 10.1002/cplx.20216.

[35] Shamloo, B. (2020), Rereading preventive crime policy in the light of the Covid-19 pandemic and chaos theory (in Persian), Legal Research Quarterly - Special issue of Law and Corona, Volume 23, pp. 11-142.

[36] Acikalin S.N, Ercetin S.S. (2022), Understanding COVID-19 with Chaos Theory: Dynamics and Implications for Societies, World Scientific Publishing Europe Ltd., https://doi.org/10.1142/9781800611450_0001

[37] Rezvani M. H. and Khabiri D. (2018), "Gamers' Behaviour and Communication Analysis in Massively Multiplayer Online Games: A Survey," 2018 2nd National and 1st International Digital Games Research Conference: Trends, Technologies, and Applications (DGRC), Tehran, Iran, 2018, pp. 61-69, doi: 10.1109/DGRC.2018.8712055.

[38] Naghdehforoushha M., Dehghan Takht Fooladi M.,Rezvani M.H., Sadeghi Gilanian M.M. (2022) "BLMDP: A new bi-level Markov decision process approach to joint bidding and task-scheduling in cloud spot market," Turkish Journal of Electrical Engineering and Computer Sciences: Vol. 30: No. 4, Article 17. https://doi.org/10.55730/1300-0632.3857, Available at: https://journals.tubitak.gov.tr/elektrik/vol30/iss4/17.

[39] McCaskill, J.S., Packard, N.H. (2019). Analysing Emergent Dynamics of Evolving Computation in 2D Cellular Automata. In: Martín-Vide, C., Pond, G., Vega-Rodríguez, M. (eds) Theory and Practice of Natural Computing. TPNC 2019. Lecture Notes in Computer Science, Vol 11934. Springer, Cham. https://doi.org/10.1007/978-3-030-34500-6_1.