

# The State-of-art Applications of Game Theory in Computer Science

Jingzhen Wu \*

Department of School of Computer Science, University of Birmingham, Birmingham, United Kingdom

\* Corresponding Author Email: JXW1390@student.bham.ac.uk

**Abstract.** From the ancient game theory thought to the increasingly advanced game theory, the concept of game theory has always played an important role in human development. Nowadays, computer technology has become increasingly mature, and there are many applications of game theory among them. This study will introduce the use of three game theories in computer science. Firstly, in the field of machine learning, game theory can model agent interactions, ultimately finding Nash equilibrium, and providing the best solution for each agent. Additionally, in network security, the application of game theory is also very common. Game theory can model the interaction of attackers and defenders, thereby obtaining the best strategy for defense systems for defenders. In the field of social networking, game theory can help community administrators predict user behavior, analyze data, and design better algorithms or mechanisms to help establish a more complete community and create a better environment for the community. Game theory is a powerful tool, and its application has created more powerful systems, not only making great contributions to the development of computer systems, but also playing a significant role in ensuring the information security of all the computer users.

**Keywords:** Game theory; computer science; machine learning; network security; social network.

## 1. Introduction

The idea of game theory first appeared in the chess game confrontation in ancient China [1]. People always use this type of thinking to think about the current situation and make judgments, so as to make the best choice for themselves. At that time, people called this kind of thinking as strategic theory. In Sun Tzu's Art of War which is the world's earliest military strategy book dedicated by Sun Tzu to the King of Wu in the later Spring and Autumn Period, some basic characteristics of the game theory were reflected [1]. As time passed by, in 1928, John von Neumann, a famous mathematician, computer scientist and economist, published a paper on "two-person zero-sum game", which proved the basic principles of game theory and took the first step to establish game theory [2]. Later, von Neumann found a like-minded Austrian economist, Morgan, for long-term cooperation. In 1944, von Neumann and Oskar Morgenstern jointly wrote the famous economics book "Theory of Game and Economic Behavior" was first published [2]. This book is the foundational work of game theory, marking the formation of game theory, and also marking the new stage of economics. Game theory has deeply influenced various fields since its emergence, from economics, finance to biology, and even international relations and military strategy [1]. Now, from the fact that AlphaGo, a Go AI program developed by Google's company DeepMind, has defeated many human professional Go players, including Lee Sedol, the world champion of Go [3]. It can be seen that game theory also has an undeniable impact on computer science.

Game theory offers a valuable toolkit of methods and ideas for constructing, scrutinizing, and optimizing intricate systems that involve strategic interactions among several agents. With the continuous development of science and technology, game theory has been applied to numerous aspects of computer science. First of all, game theory has been applied to the rapidly developing artificial intelligence, and machine learning, as a key element in building artificial intelligence models today, is also inseparable from the support of game theory [4]. In addition, game theory can be applied to network security. Researchers can simulate the interaction between attackers and defenders and model them as games, then, analyze their behavior to ultimately determine the best defense strategy

[5]. Moreover, the application of game theory in algorithmic game theory is also very powerful. Game theory can provide researchers with optimal or near optimal solutions, enabling them to design the most efficient algorithms [6].

In general, game theory has developed at an alarming rate and has been applied to various branches of computer science. Game theory has not only changed the way humans think, but also the thinking mode of computers. Game theory allows computers to analyze the advantages and disadvantages of different strategic decisions in different situations, enabling them to always find the optimal solution or approximate optimal solution to a problem most efficiently. By referring to different strategies, computer scientists can create smarter artificial intelligence, more rigorous system structures, or more efficient algorithms, making the development of computers and even the world more rapid.

## 2. Description of Game Theory

Game theory mainly studies and formulates the strategic interaction between rational individuals or teams, and is a mathematical theory and method for studying phenomena with the nature of struggle or competition [7]. Game theory considers the predicted and actual behavior of individuals in a game, and studies their optimization strategies.

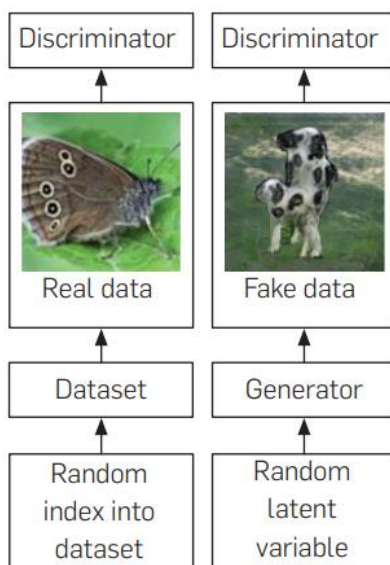
There are several important elements in game theory. First of all, players, also known as agents, have the ability to make their own decisions on the premise of rationality. The game played by two players is called a two-person game, while the game played by more than two players is called a multiplayer game. Secondly, strategies, refer to the methods or practices that each player can choose when making decisions, different strategies will lead to different results. Thirdly, payoffs, which are the results of the end of the game. Players' strategies often affect payoffs, not only their own strategies, but also the strategies of the other players in the game. Fourth, orders, players will give their strategies in a prescribed order, generally in a one in one loop. If someone uses the strategy more than once, which will lead to a Payoff error in the game results and affect the judgment of researchers. Lastly, equilibrium, which refers to a stable state, although the payoff to both players is different. However, this stable state is beneficial to both players and is the most ideal strategy pursued by both players.

Game theory can be divided into various types of games, including cooperative and non-cooperative games. Cooperative games refer to games in which players can negotiate and ultimately make relative strategies through mutual conversation. Non-cooperative games, on the contrary, are characterized by the inability of players to make strategies through mutual conversation and cooperation. Prisoner's Dilemma is the most typical static non-cooperative game in which the rules are two prisoners who cannot communicate with each other, There are two options for playing a game of betrayal or silence, and there are four corresponding game outcomes. First, if both players do not disclose each other, both of them will only be imprisoned for 2 years. If either player discloses, the whistleblower will be directly released and the person in silence will be sentenced to 10 years in prison. If both players choose to betray, each party will be imprisoned for 5 years. If the prisoner's dilemma is conducted in a cooperative game, most people will definitely choose the best strategy for both sides, which is both sides are silent, while conducting it in a non-cooperative game requires deeper consideration of the advantages and disadvantages of each strategy [8]. Secondly, there are simultaneous and sequential games, in which players independently and simultaneously make decisions. Ultimately, players' strategies bring them ultimate benefits. At the same time, games are represented by a formal matrix. Unlike sequential games, players do not make decisions at the same time, but instead make decisions separately. Player 1 makes decisions first, while Player 2 can choose decisions that are beneficial to them based on the strategies chosen by Player 1. This game is usually represented by the tree shape of an extended game. In addition, zero-sum game and non-zero-sum game. Zero sum game refers to a game in which the total income of all players is always zero. For example, poker game is a typical zero-sum game, because the money won by the winner is always equal to the money lost by the loser. The opposite is true for non-zero-sum games, where the result

is either less than 0 or greater than 0, and never equal to 0. There are many other types of games, including complete/incomplete information games, symmetric/asymmetric games, etc. [9].

### 3. Applications of Game Theory in Machine Learning

Many concepts that appear in game theory have been used in machine learning, and Nash Equilibrium (NE) is one of them. This refers to a state in a game. In this situation, while other players' decisions remain unchanged if any player changes their current decisions, they cannot obtain more payoffs, which is similar to the optimal solution of machine learning. Generative adversarial networks (GAN) also embody this concept of game theory. GAN consists of two parts, namely, a generator and a discriminator. The task of the generator is to attempt to generate false samples and deceive the discriminator, while the discriminator does its best to determine whether the samples are generated by the generator. The Fig. 1 shows how the generator network and a discriminator network work [10, 11]. Both the generator and the discriminator want to maximize their utility, the generator wants to maximize the authenticity of the sample, and the discriminator wants to identify the false samples generated by the generator, which is similar to a two-player game. The goal is to find the Nash equilibrium of the game because both players are trying to achieve the maximum expected payoffs.



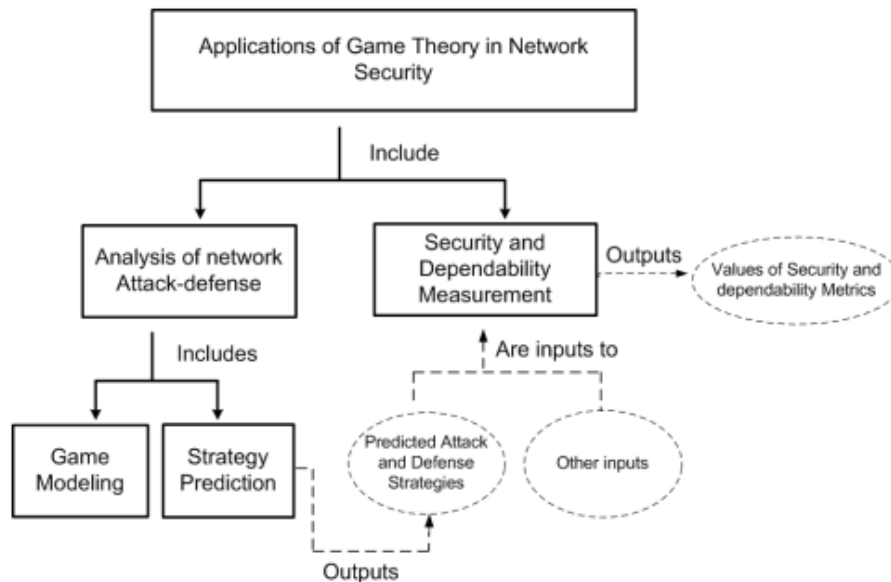
**Fig 1.** The generator network and a discriminator network in GANs [11].

Reinforcement learning, another important branch of machine learning, is the interactive behavior between an agent and the environment. It is based on the rewards or penalties obtained from the environment, repeated trial and error, and continuous learning from it, thereby formulating a set of optimal action strategies [12]. Game theory has been widely used in various aspects of reinforcement learning. Game theory can study the behavior of agents in various environments, thereby analyzing and optimizing the behavior of agents, and ultimately designing more effective resource allocation mechanisms. A key application of game theory in reinforcement learning is the development of algorithms for multi-agent systems. Game theory provides a framework for modeling interactions between agents and designing strategies to bring good results to all agents. For example, with the development of autonomous driving technology and the emergence of more and more autonomous vehicles on the road, intelligent algorithms to ensure the safety of these vehicles have become important. Game theory can model vehicle interactions in an environment, such as an intersection or a congested road, and each vehicle on the scene needs to make a decision on whether to drive or yield based on the behavior of other vehicles, thereby reducing the probability of accidents and improving road congestion. Cooperative adaptive cruise control (CACC) is an autonomous driving algorithm that helps drivers minimize driving time and ensure their safety by modeling with other vehicles in the system and formulating optimal strategies [13].

Overall, game theory has played an important role in machine learning, especially in the development of GAN, reinforcement learning and multi-agent systems. By using principles from game theory, including Nash Equilibrium, modeling agent interactions, and developing the most effective tactics. In order to improve a variety of elements of daily life (e.g., autonomous driving), researchers have been able to develop more effective and efficient machine learning algorithms.

#### 4. Applications of Game Theory in Network Security

Network security refers to the technology used to protect digital systems, networks, and data from unauthorized access, theft, and attacks. The goal of network security is to ensure the confidentiality, integrity, and availability of digital systems and data. With the continuous development and popularization of the Internet, the biggest problem facing network security today is network crime, such as hacker attacks, data theft, and so on. To address these issues, researchers must adopt the latest and best technology to analyze attackers to protect the system and data security [14]. Game theory provides a framework for modeling and analyzing the behavior of attackers and designing optimal strategies for security systems. The Fig. 2 shows two examples of game theory used in network security [15].



**Fig 2.** The general applications of Game Theory in Network Security [15].

Game theory can be used to design intrusion detection systems (IDS) that can withstand zero-day attacks [14, 15], while traditional intrusion detection systems cannot detect zero-day attacks because traditional IDS relies on known attack patterns or behaviors, and zero-day attacks are attacks that utilize unknown vulnerabilities carefully designed by system designers [16]. Since these vulnerabilities are not yet known, no features or patterns can detect them. However, game theory can help model the interaction between attackers and defenders into an attack and defense game, where attackers attempt to attack, while defenders attempt to detect and prevent attacks. Both have a series of strategies, and the use of each strategy will affect the final payoffs [17]. Designers can use game theory to analyze the best strategies of both, thereby designing IDS that can prevent zero-day attacks

In cloud computing systems, game theory can be used to determine strategies to minimize the impact of attacks such as data leakage and resource hijacking. This can be achieved by modeling the interaction between attackers and cloud computing systems as a game in which attackers attempt to disrupt the system while the system attempts to maintain availability and protect data [18]. By analyzing the game, researchers can determine the best strategy for the system and apply it to today's cloud computing systems. Game theory can be used to pinpoint tactics for cyber-physical systems (CPS) that maximize system resilience and reduce the likelihood of catastrophic failures [19]. This

can also be done by simulating the interactions of attackers and defenders as a game in which the attacker tries to bring about a system failure and the defense tries to stop it. It is possible to determine the best defensive tactics by studying the game, such as employing redundancy controls, diversifying the system architecture, or utilizing dynamic defense mechanisms that change their tactics depending on the attacker [20].

To sum up, game theory can be used to protect systems by determining the best strategy for defenders based on a strategic analysis of the interaction between attackers and defenders. By modeling these interactions as games, you can determine strategies to maximize the expected return of defenders while minimizing the expected return of attackers, thereby improving the security and resilience of computer systems.

## 5. Applications of Game Theory in Social Networks

Game theory has become an important tool for analyzing strategic interactions in social networks. In these networks, users often face decisions that involve balancing their own interests with those of others. For example, users may need to decide whether to share information or opinions with others, or whether to compete or collaborate with other users. Game theory provides a framework for analyzing these decisions and predicting the possible outcomes of strategic interactions.

Game theory can be applied to the analysis of online reputation systems in social networks. Reputation systems are used to motivate users to act in a way that benefits the community, reward users with high reputations, and punish users with low reputations [21]. Game theory can be used to model the strategic behavior of users in these systems and predict the possible outcomes of different reputation mechanisms. For example, game theory can be used to analyze how users decide whether to leave feedback to others, and how this decision is influenced by other user behaviors [22].

Another application of game theory in social networks is cooperative game theory, which refers to a game in which a group of people cooperate to obtain common interests. In this case, one can use game theory to analyze individual strategies under cooperative games, allowing them to know how to coordinate everyone's actions and how to allocate benefits, in order to achieve the collective optimal results and ensure the stability and efficiency of cooperation [23]. Game theory is also used to analyze strategic interactions between users in social networks, e.g., online communities and social media platforms. For example, game theory can be used to analyze how users decide to collaborate or compete with other users in social networks, and how this decision is influenced by the behavior of other users. Game theory can also be used to analyze the strategic behavior of users in online auctions and markets, and predict the possible outcomes of these markets based on the behavior of buyers and sellers [24].

Overall, game theory plays an important role in analyzing strategic interactions in social networks, which can be used to predict the possible outcomes of these interactions based on user behavior. By understanding the strategic behavior of users in social networks, game theory can help designers and decision makers design more effective social network algorithms and mechanisms, encourage positive user behavior, and benefit the entire community.

## 6. Limitations & Prospects

Although the concept of game theory is an important part of the development of computer science, its application in this field still has some limitations. Firstly, the premise of game theory is that all players must be rational. Though computers are absolutely rational, in real life, the opposite is often true. When people make decisions, they are also affected by factors such as emotions, social environments, and cognitive biases. Under the influence of these factors, it is impossible for people to be 100% rational [25]. For example, in the cooperation strategy mentioned above, it is necessary to ask people to provide strategies. However, due to the above environmental or emotional reasons,

the modeling is inevitably inaccurate, resulting in incorrect results. Therefore, in some cases, game theory models cannot fully reflect the behavior of participants.

Additionally, game theory models are usually based on the assumption that all participants have complete information. Each participant knows the policies and information of the other participants. However, in real life, in many cases, people often have different information, even incorrect information, leading to information asymmetry. In online communities, this phenomenon is more common. For example, some community stars tend to have more attention, leading to their strategies being accepted and adopted, while the strategies of ordinary users tend to be ignored. Therefore, based on such asymmetric information, it is difficult for researchers to model it, which can also lead to inaccurate data. Moreover, the application of game theory also faces difficulties in data collection. Game theory usually requires a large amount of data support to establish accurate models and predict results, such as obtaining data from attackers and defenders, or community users. However, collecting data is often very difficult. It not only consumes a lot of time, but also consumes a lot of money and manpower to collect data.

Game theory is often used in computer science to analyze complex problems, e.g., analyzing attackers' intentions, user data. These potentials often show that its future prospects are very large. The first is the automatic driving mentioned above, which requires the system to make correct judgments in a short time in a complex environment, and combines the concept of game theory to model all moving autonomous vehicle in a certain area, find their Nash equilibrium, and provide optimal strategies for each autonomous vehicle. With the continuous development of autonomous driving, game theory will also be more helpful to this technology. Secondly, game theory plays a significant role in preventing attackers in the network. As the interaction between attackers and defenders is constantly modeled, the experimenters' data will continue to increase. Thus, researchers can analyze more data to update the defense structure and improve the security and stability.

## 7. Conclusion

In conclusion, the ability of game theory to represent and evaluate the behavior of rational agents in both competitive and cooperative settings have made it an increasingly crucial tool in computer science. In machine learning, game theory is applied to studying the behavior of multiple agents in various environments, thereby analyzing and optimizing the behavior of agents, and ultimately designing more effective resource allocation mechanisms. In network security, game theory is applied to modeling and analyzing attackers and defenders, and to developing corresponding measures to protect the system. In social networks, it is used to model and analyze user information, and apply it to the improvement of the environment and mechanism of the community. Even though the application of game theory has limitations due to the incompleteness of human subjective thoughts or information up to now, with the continuous development of various fields of computer science, the application of game theory in computer science will continue to bring more benefits. The best proof is the update of defense measures for autonomous driving and unmanned aerial vehicles or various systems. Overall, these results offer a guideline for applications of game theory in computer science.

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