Application of Game Theory in Computer Security

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ABSTRACT

Due to the capability of game theory to solve the situations of conflict and competition, Game Theory has been used as a mathematical tool in economics, politics, biology and human psychology. Nash Equilibrium, being the solution of a non-cooperative game, gives a stable state in a sense that no agent/player has any positive incentive to deviate from its current adopted strategy, when all other players of the game stick to their current moves. In Computer security, the cooperation to follow a certain protocol cannot be taken as for granted, keeping in view the selfish nature of now a day's network entities. To cope with the selfish and competitive behavior of the network entities, Game Theory provides a feasible solution for resource utilization and service provisioning, Detection and defense against some forms of attack that threatens the optimal performance of computer networks. This paper presents the detailed overview of the Game Theory concepts and its applications in the Computer security, both from cooperative and non-cooperative perspectives.

Keywords: Game Theory, Nash Equilibrium, Computer security, SYN-flooding Attacks, TCP, DoS attacks,

1.0 INTRODUCTION

What is game theory? Game theory is the formal study of conflict and cooperation. Game theoretic concepts apply whenever the actions of several agents are interdependent. These agents may be individuals, groups, firms, or any combination of these (Theodore L. Turocy and Bernhard von Stengel, . The concepts of game theory provide a language to formulate structure, analyze, and understand strategic scenarios.

1.1 History and impact of game theory

The earliest example of a formal game-theoretic analysis is the study of a duopoly by Antoine Cournot in 1838. The mathematician Emile Borel suggested a formal theory of games in 1921, which was furthered by the mathematician John von Neumann in 1928 in a "theory of parlor games." Game theory was established as a field in its own right after the 1944 publication of the monumental volume

Theory of Games and Economic Behavior by von Neumann and the economist Oskar Morgenstern. This book provided much of the basic terminology and problem setup that is still in use today. In 1950, John Nash demonstrated that finite games have always have an equilibrium point, at which all players choose actions which are best for them given their opponents' choices. This central concept of noncooperative game theory has been a focal point of analysis since then. In the 1950s and 1960s, game theory was broadened theoretically and applied to problems of war and politics. Since the 1970s, it has driven a revolution in economic theory. Additionally, it has found applications in sociology and psychology, and established links with evolution and biology. Game theory received special attention in 1994 with the awarding of the Nobel prize in economics to Nash, John Harsanyi, and Reinhard Selten. At the end of the 1990s, a high-profile application of game theory has been the design of auctions. Prominent game theorists have been involved in the design of auctions for allocating rights to the use of bands of the electromagnetic spectrum to the mobile telecommunications industry. Most of these auctions were designed with the goal of allocating these resources more efficiently than traditional governmental practices, and additionally raised billions of dollars in the United States and Europe (Theodore L. Turocy and Bernhard von Stengel, 2001).

1.2 Game theory and information systems

The internal consistency and mathematical foundations of game theory make it a prime tool for modeling and designing automated decision-making processes in interactive environments.

For example, one might like to have efficient bidding rules for an auction website, or tamper-proof automated negotiations for purchasing communication bandwidth.

Research in these applications of game theory is the topic of recent conference and journal papers (see, for example, Binmore and Vulkan, "Applying game theory to automated negotiation," *Netnomics* Vol. 1, 1999, pages 1–9) but is still in a nascent stage. The automation of strategic choices enhances the need for these choices to be made efficiently, and to be robust against abuse. Game theory addresses these requirements.

As a mathematical tool for the decision-maker the strength of game theory is the methodology it provides for structuring and analyzing problems of strategic choice. The process of formally modeling a situation as a game requires the decision-maker to enumerate explicitly the players and their strategic options, and to consider their preferences and reactions. The discipline involved in constructing such a model already has the potential of providing the decision-maker with a clearer and broader view of the situation. This is a "prescriptive" application of game theory, with the goal of improved strategic decision making. With this perspective in mind, this article explains basic principles of game theory, as an introduction to an interested reader without a background in economics.

p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 03 Issue 12
August 2016

2.0 Definitions of games

The object of study in game theory is the *game*, which is a formal model of an interactive situation. It typically involves several *players*; a game with only one player is usually called a *decision problem*. The formal definition lays out the players, their preferences, their information, and the strategic actions available to them, and how these influence the outcome.

Games can be described formally at various levels of detail. A *coalitional* (or *cooperative*) game is a high-level description, specifying only what payoffs each potential group, or coalition, can obtain by the cooperation of its members. What is not made explicit is the process by which the coalition forms. As an example, the players may be several parties in parliament. Each party has a different strength, based upon the number of seats occupied by party members. The game describes which coalitions of parties can form a majority, but does not delineate, for example, the negotiation process through which an agreement to vote en bloc is achieved.

Cooperative game theory investigates such coalitional games with respect to the relative amounts of power held by various players, or how a successful coalition should divide its proceeds. This is most naturally applied to situations arising in political science or international relations, where concepts like power are most important. For example, Nash proposed a solution for the division of gains from agreement in a bargaining problem which depends solely on the relative strengths of the two parties' bargaining position. The amount of power a side has is determined by the usually inefficient outcome that results when negotiations break down. Nash's model fits within the cooperative framework in that it does not delineate a specific timeline of offers and counteroffers, but rather focuses solely on the outcome of the bargaining process.

In contrast, *noncooperative game theory* is concerned with the analysis of strategic choices. The paradigm of noncooperative game theory is that the details of the ordering and timing of players' choices are crucial to determining the outcome of a game. In contrast to Nash's cooperative model, a noncooperative model of bargaining would post a specific process in which it is specified who gets to make an offer at a given time. The term "noncooperative" means this branch of game theory explicitly models the process of players making choices out of their own interest. Cooperation can, and often does, arise in noncooperative models of games, when players find it in their own best interests.

Branches of game theory also differ in their assumptions. A central assumption in many variants of game theory is that the players are *rational*. A rational player is one who always chooses an action which gives the outcome he most prefers, given what he expects his opponents to do. The goal of game-theoretic analysis in these branches, then, is to predict how the game will be played by rational players, or, to give advice on how best to play the game against opponents who are rational. This rationality assumption can be relaxed, and the resulting models have been more recently applied to the analysis of observed behavior (Kagel and Roth, eds., *Handbook of Experimental Economics*, Princeton Univ. Press, 1997). This kind of game theory can be viewed as more "descriptive" than the prescriptive approach taken here.

This article focuses principally on noncooperative game theory with rational players.
In addition to providing an important baseline case in economic theory, this case is designed so that it gives good advice to the decision-maker, even when – or perhaps especially when – one's opponents also employ it.

2.1 Strategic and extensive form games
The *strategic form* (also called *normal form*) is the basic type of game studied in noncooperative game theory. A game in strategic form lists each player's strategies, and the outcomes that result from each possible combination of choices. An outcome is represented by a separate *payoff* for each player, which is a number (also called *utility*) that measures how much the player likes the outcome.

The *extensive form*, also called a *game tree*, is more detailed than the strategic form of a game. It is a complete description of how the game is played over time. This includes the order in which players take actions, the information that players have at the time they must take those actions, and the times at which any uncertainty in the situation is resolved.
A game in extensive form may be analyzed directly, or can be converted into an equivalent strategic form. Examples in the following sections will illustrate in detail the interpretation and analysis of games in strategic and extensive form.

2.2 Dominance in Games
Since all players are assumed to be rational, they make choices which result in the outcome they prefer most, given what their opponents do. In the extreme case, a player may have two strategies *A* and *B* so that, given any combination of strategies of the other players, the outcome resulting from *A* is better than the outcome resulting from *B*. Then strategy *A* is said to *dominate* strategy *B*. A rational player will never choose to play a dominated strategy. In some games, examination of which strategies are dominated results in the conclusion that rational players could only ever choose one of their strategies.

The following examples illustrate this idea.

2.2.1 Example: Prisoner's Dilemma
The Prisoner's Dilemma is a game in strategic form between two players. Each player has two strategies, called "cooperate" and "defect," which are labeled *C* and *D* for player I and *c* and *d* for player II, respectively. (For simpler identification, upper case letters are used for strategies of player I and lower case letters for player II.)

International Journal of Research
Available at https://edupediapublications.org/journals
p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 03 Issue 12
August 2016

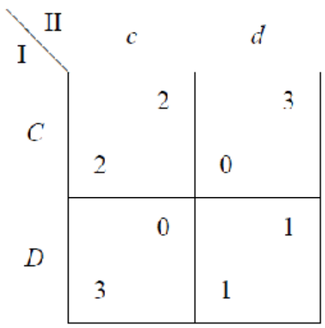

Figure 1. The Prisoner's Dilemma game.

Figure 1 shows the resulting payoffs in this game. Player I chose a row, either *C* or *D*, and simultaneously player II chooses one of the columns *c* or *d*. The strategy combination (*C; c*) has payoff 2 for each player, and the combination (*D; d*) gives each player payoff 1. The combination (*C; d*) results in payoff 0 for player I and 3 for player II, and when (*D; c*) is played, player I gets 3 and player II gets 0. II since they act simultaneously (that is, without knowing the other's action), which makes the symmetry possible.

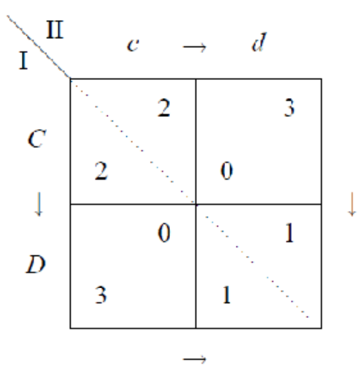

Figure 2. (Adopted from CDAM Research Report LSE-CDAM-2001-09, October 8, 2001)

The game of Figure 1 with annotations, implied by the payoff structure. The dotted line shows the symmetry of the game (Binmore, Ken, 1991),. The arrows at the left and right point to the preferred strategy of player I when player II plays the left or right column, respectively. Similarly, the arrows at the top and bottom point to the preferred strategy of player II when player I plays top or bottom.

In the Prisoner's Dilemma game, "defect" is a strategy that dominates "cooperate." Strategy *D* of player I dominates *C* since if player II chooses *c*, then player I's payoff is 3when choosing *D* and 2 when choosing *C*; if player II chooses *d*, then player I receives 1 for *D* as opposed to 0 for *C*. These preferences of player I are indicated by the downward pointing arrows in Figure 2. Hence, *D* is indeed always better and dominates *C*. In the same way, strategy *d* dominates *c* for player II.

No rational player will choose a dominated strategy since the player will always be better off when changing to the strategy that dominates it. The unique outcome in this game, as recommended to utility-maximizing players, is therefore (*D; d*) with payoffs (1*;* 1). Somewhat paradoxically, this is less than the payoff (2*;* 2) that would be achieved when the players chose (*C; c*).

The story behind the name "Prisoner's Dilemma" is that of two prisoners held suspect of a serious crime. There is no judicial evidence for this crime except if one of the prisoners testifies against the other. If one of them testifies, he will be rewarded with immunity from prosecution (payoff 3), whereas the other will serve a long prison sentence (payoff 0). If both testify, their punishment will be less severe (payoff 1 for each). However, if they both "cooperate" with each other by not testifying at all, they will only be imprisoned briefly, for example for illegal weapons possession (payoff 2 for each). The "defection" from that mutually beneficial outcome is to testify, which gives a higher payoff no matter what the other prisoner does, with a resulting lower payoff to both. This constitutes their "dilemma."

Prisoner's Dilemma games arise in various contexts where individual "defections" at the expense of others lead to overall less desirable outcomes. Examples include arms races, litigation instead of settlement, environmental pollution, or cut-price marketing, where the resulting outcome is detrimental for the players. Its game-theoretic justification on individual grounds is sometimes taken as a case for treaties and laws, which enforce cooperation.

Game theorists have tried to tackle the obvious "inefficiency" of the outcome of the Prisoner's Dilemma game. For example, the game is fundamentally changed by playing it more than once. In such a *repeated game*, patterns of cooperation can be established as rational behavior when players' fear of punishment in the future outweighs their gain from defecting today.

2.2.2 Nash equilibrium

In the previous examples, consideration of dominating strategies alone yielded precise advice to the players on how to play the game. In many games, however, there are no dominated strategies, and so these considerations are not enough to rule out any outcomes or to provide more specific advice on how to play the game.

The central concept of *Nash equilibrium* is much more general. A Nash equilibrium recommends a strategy to each player that the player cannot improve upon *unilaterally*, that is, given that the other players follow the recommendation. Since the other players are also rational, it is reasonable for each player to expect his opponents to follow the recommendation as well.

2.2.3 Equilibrium selection

If a game has more than one Nash equilibrium, a theory of strategic interaction should
guide players towards the "most reasonable" equilibrium upon which they should focus(Fudenberg et al, 1991).

Indeed, a large number of papers in game theory have been concerned with "equilibrium refinements" that attempt to derive conditions that make one equilibrium more plausible or convincing than another. For example, it could be argued that an equilibrium that is better for both players, like (*High*, *buy*) in Figure 4, should be the one that is played.

However, the abstract theoretical considerations for equilibrium selection are often more sophisticated than the simple game-theoretical models they are applied to. It may be more illuminating to observe that a game has more than one equilibrium, and that this is a reason that players are sometimes stuck at an inferior outcome.

One and the same game may also have a different interpretation where a previously undesirable equilibrium becomes rather plausible. As an example, consider an alternative scenario for the game in Figure 4. Unlike the previous situation, it will have a symmetric description of the players, in line with the symmetry of the payoff structure.

Two firms want to invest in communication infrastructure. They intend to communicate frequently with each other using that infrastructure, but they decide independently on what to buy. Each firm can decide between *High* or *Low* bandwidth equipment (this time, the same strategy names will be used for both players). For player II, *High* and *Low* replace *buy* and *don't buy* in Figure 4. The rest of the game stays as it is.
The (unchanged) payoffs have the following interpretation for player I (which applies in the same way to player II by symmetry): A *Low* bandwidth connection works equally well (payoff 1) regardless of whether the other side has high or low bandwidth. However, switching from *Low* to *High* is preferable only if the other side has high bandwidth (payoff 2), otherwise it incurs unnecessary cost (payoff 0).

As in the quality game, the equilibrium (*Low, Low*) (the bottom right cell) is inferior to the other equilibrium, although in this interpretation it does not look quite as bad.
Moreover, the strategy *Low* has obviously the better *worst-case* payoff, as considered for all possible strategies of the other player, no matter if these strategies are rational choices or not. The strategy *Low* is therefore also called a *max-min* strategy since it maximizes the minimum payoff the player can get in each case. In a sense, investing only in low bandwidth equipment is a safe choice. Moreover, this strategy is part of equilibrium, and entirely justified if the player expects the other player to do the same.

3.0 Game Types

3.1 Cooperative / Non-cooperative

A game is cooperative if the players are able to form binding commitments. For instance, the legal system requires them to adhere to their promises. In non-cooperative games, this is not possible.

Often it is assumed that communication among players is allowed in cooperative games, but not in non-cooperative ones. However, this classification on two binary criteria has been questioned, and sometimes rejected.

Of the two types of games, non-cooperative games are able to model situations to the finest details, producing accurate results. Cooperative games focus on the game at large. Considerable efforts have been made to link the two approaches. The so-called Nash-programme (Nash program is the research agenda for investigating on the one hand axiomatic bargaining solutions and on the other hand the equilibrium outcomes of strategic bargaining procedures) has already established many of the cooperative solutions as non-cooperative equilibria.

Hybrid games contain cooperative and non-cooperative elements. For instance, coalitions of players are formed in a cooperative game, but these play in a non-cooperative fashion.

p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 03 Issue 12
August 2016

3.2 Symmetric / Asymmetric

A symmetric game is a game where the payoffs for playing a particular strategy depend only on the other strategies employed, not on who is playing them. If the identities of the players can be changed without changing the payoff to the strategies, then a game is symmetric. Many of the commonly studied 2×2 games are symmetric. The standard representations of chicken, the prisoner's dilemma, and the stag hunt are all symmetric games. Some scholars would consider certain asymmetric games as examples of these games as well. However, the most common payoffs for each of these games are symmetric.

Most commonly studied asymmetric games are games where there are not identical strategy sets for both players. For instance, the ultimatum game and similarly the dictator game have different strategies for each player. It is possible, however, for a game to have identical strategies for both players, yet be asymmetric. For example, the game pictured to the right is asymmetric despite having identical strategy sets for both players.

3.3 Zero-sum / Non-zero-sum

Zero-sum games are a special case of constant-sum games, in which choices by players can neither increase nor decrease the available resources. In zero-sum games the total benefit to all players in the game, for every combination of strategies, always adds to zero (more informally, a player benefits only at the equal expense of others). Poker exemplifies a zero-sum game (ignoring the possibility of the house's cut), because one wins exactly the amount one's opponents lose. Other zero-sum games include matching pennies and most classical board games including Go and chess.

Many games studied by game theorists (including the infamous prisoner's dilemma) are non-zero-sum games, because the outcome has net results greater or less than zero. Informally, in non-zero-sum games, a gain by one player does not necessarily correspond with a loss by another.

Constant-sum games correspond to activities like theft and gambling, but not to the fundamental economic situation in which there are potential gains from trade. It is possible to transform any game into a (possibly asymmetric) zero-sum game by adding a dummy player (often called "the board") whose losses compensate the players' net winnings.

3.4 Simultaneous / Sequential

Simultaneous games are games where both players move simultaneously, or if they do not move simultaneously, the later players are unaware of the earlier players' actions (making them effectively simultaneous). Sequential games (or dynamic games) are games where later players have some knowledge about earlier actions. This need not be perfect information about every action of earlier players; it might be very little knowledge. For instance, a player may know that an earlier player did not perform one particular action, while he does not know which of the other available actions the first player actually performed.

The difference between simultaneous and sequential games is captured in the different representations discussed above. Often, normal form is used to represent simultaneous games, while extensive form is used to represent sequential ones. The transformation of extensive to normal form is one way, meaning that multiple extensive form games correspond to the same normal form. Consequently, notions of equilibrium for simultaneous games are insufficient for reasoning about sequential games;

4.0 Applications of Game theory in computer security

The diversity of problem contexts in information security suggests a rich set of opportunities for game-theoretic studies. Indeed, research on game modeling of security has established a wide range of results on different problems and areas. A major game model used in these works is the attacker-defender game, which is played between some attacker(s) and defender(s) in a strict competition, i.e., they have opposite preferences over outcomes. Alternatively, many research also consider defenders-only games, in which the defenders try to collaborate (whilst being individually selfish) in mitigating a particular source of threat. As an illustration, we briefly review some of the most notable game-theoretic studies on computer network security - the areas that draw the most attention from intellectual fore

1. Applying Game Theory to Analyze Attacks and Defenses in Virtual Coordinate Systems.

(According to Sheila Beckery, University of Luxembourg, 6 rue Coudenhove-Kalergi, L-1359 Luxemburg, France Jeff Seibert ; David Zage ; Cristina Nita-Rotaru ; Radu Statey). Virtual coordinate systems provide an accurate and efficient service that allows hosts on the Internet to determine latency to arbitrary hosts based on information provided by a subset of participating nodes. Unfortunately, the accuracy of the service can be severely impacted by compromised nodes providing misleading information. We define and use a game theory framework in order to identify the best attack and defense strategies assuming that the attacker is aware of the defense mechanisms. Our approach leverages concepts derived from the Nash equilibrium to model more powerful adversaries. We consider attacks that target the latency estimation (inflation, deflation, oscillation) and defense mechanisms that combine outlier detection with control theory to deter adaptive adversaries. We apply the game theory framework to demonstrate the impact and efficiency of these attacks and defense strategies using a well-known virtual coordinate system and real-life Internet data sets(As published in 2011 IEEE/IFIP 41st International Conference on Dependable Systems & Networks (DSN).

2. Application of Game Theory in Wireless Sensor Networks Security

Wireless Sensor Networks (WSNs) are becoming an integral part of our lives. There are not widespread applications of WSNs without ensuring WSNs security (Ngai-Ming Kwok and Sheng-Yong Chen, 2012). Due to the limited capabilities of sensor nodes in terms of computation, communication, and energy, providing security to WSN has increasingly become one of the most interesting areas of research in recent years. WSN security is a primarily important and critical issue before WSN can be widely used. There usually exist two mechanisms of intrusion prevention and detection in WSN security. GT provides a mathematical method for analyzing and modeling WSN security problems for it considers scenarios where multiple players with contradictory objectives compete with each other.(Shen et al. 2011) had proposed a taxonomy which divides current existing typical game theory approaches for WSN security into four categories: preventing DoS attacks, intrusion detection, strengthening security, and coexistence with malicious sensor nodes. They pointed out some future research areas for ensuring WSN security based on game theory, including Base Station credibility, IDS efficiency, WSN mobility, WSN QoS, real-world applicability, energy consumption, sensor nodes learning, expanding game theory applications, and different games.

3. Preventing DoS attacks using Game theory

The game types for preventing DoS attacks include non-cooperative game, cooperative game, and repeated game. The jamming and anti-jamming issues are modeled as a zero-sum stochastic game in literature to defend DoS attack. In this game, the actions of the sensor and jammer are dependent on the current system state. A quadratic function is used as the payoff function, thus facilitating the LQG control of the power system. The NE of the game is analyzed, including the existence and the corresponding computation. Numerical simulations are carried out for a seven-dimensional linear system of power grid and demonstrate the increase of reward when proper anti-jamming actions are taken. (Dong et al. 2008) established an attacking-defending gaming model which can detect active DoS attacks effectively, where the strategy space and payoff matrix are given to both the IDS and the malicious nodes.

4. Defense against SYN-flooding Attacks by using Game Theory

Connection Management phase of TCP is susceptible to a classic attack that is called SYN-flooding. In this attack, source sends many SYN packets to the victim computer, but does not complete three-way handshaking algorithms (Sara Abbasvand et al,2014). This quickly consumes the resources allocated for communication in the under attack system and hence prevents it from serving other connection requests. This attack causes the victim host to populate its backlog queue with forged TCP connections. In other words it increases the number of legal connections rejected due to limited buffer space. In this paper, the under attack system are modeled by using queuing theory and then a game theoretic approach is employed to defend against SYN flooding attacks. The simulation results show that the proposed defense mechanism improves performance of the under attack system in terms of the ration of blocked connections and the buffer space occupied by attack requests.

5. Malware Detection in Delay-Tolerant Network Using Game Theory.

A delay-tolerant network (DTN) is a network designed to operate effectively over extreme distances where end-to-end data forwarding paths may not exist. Security and privacy are crucial to the wide deployments of DTN(B.Lakshmidevi, 2015). Proximity malware is a class of malware that exploits the opportunistic contacts and distributed nature of DTNs for propagation. In this paper, we propose Game theoretic method which is effective method in dealing with polymorphic or obfuscated malware. In this method there is high detection rate with less energy consumption. It is a powerful mathematical tool to handle large number of nodes. Furthermore, we propose homomorphic signature scheme to address the challenge of "malicious nodes sharing false evidence." Any malware-detection counter these attacks must be able to

4 Identify malicious code under the cover of obfuscation and

5 Provide some guarantee for the detection of future malware.

The cornerstone of this approach is a formalism called malspecs(i.e., specification of malicious behavior)that incorporates instruction semantics to gain resilience to common obfuscations (Chandramohan, M, et al. 2013). Experimental evaluation demonstrates that our behavior based malware detection algorithm can detect variants of malware due to their shared malicious behaviors, while maintaining arelatively low run-time overhead(A requirement for real-time protection). Additionally the malspec formalism enables reasoning about the resilience for proving the soundness and completeness of detection algorithms.

6. Cyber Insider Threats Situation Awareness Using Game Theory and Information Fusion-based User Behavior Predicting Algorithm

Cyber insider threat is a difficult problem because it is always covered by a legal identity. Researchers have proposed many methods to deal with this kind of problem which are model-based, graph-based and access control-based algorithms(Ke Tang, Mingyuan Zhao, Mingtian Zhou.2011). However, many of these methods are dependent upon traditional IDS which are impacted by false positive rate and not suitable for insider problem anymore. Some other game-based methods are dependent on assumption that insiders' decisions are optimal and rational. Nevertheless, this kind of algorithm cannot handle some irrational insider's behavior and determine when a round of interaction starts or ends for system defender. An algorithm for insider threat situation awareness has been proposed, which is based on game theory and information fusion. Using dynamic Bayesian network (DBN) structure and exact inference to acquire and fuse different type of insider information for behavior analysis and avoid traditional IDS shortcoming, finally we obtain situation awareness or prediction trend of insider's future actions by Quantal Response Equilibrium (QRE) calculation. Simulation experiment results indicate that our algorithm has better convergence and precision than other same algorithm even though we should pay additional but accepted computation cost.

5.0 Conclusion

This paper presents a detailed study of game theory and the associated concepts. The classification of games based on the information, rules, moves and rationality has been captured. Finally, the paper gives an insight to the use of game theory in the problems of Computer security both from cooperative and non-cooperative perspectives, perhaps illustrating the various applications in securing computers and associated networks.

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