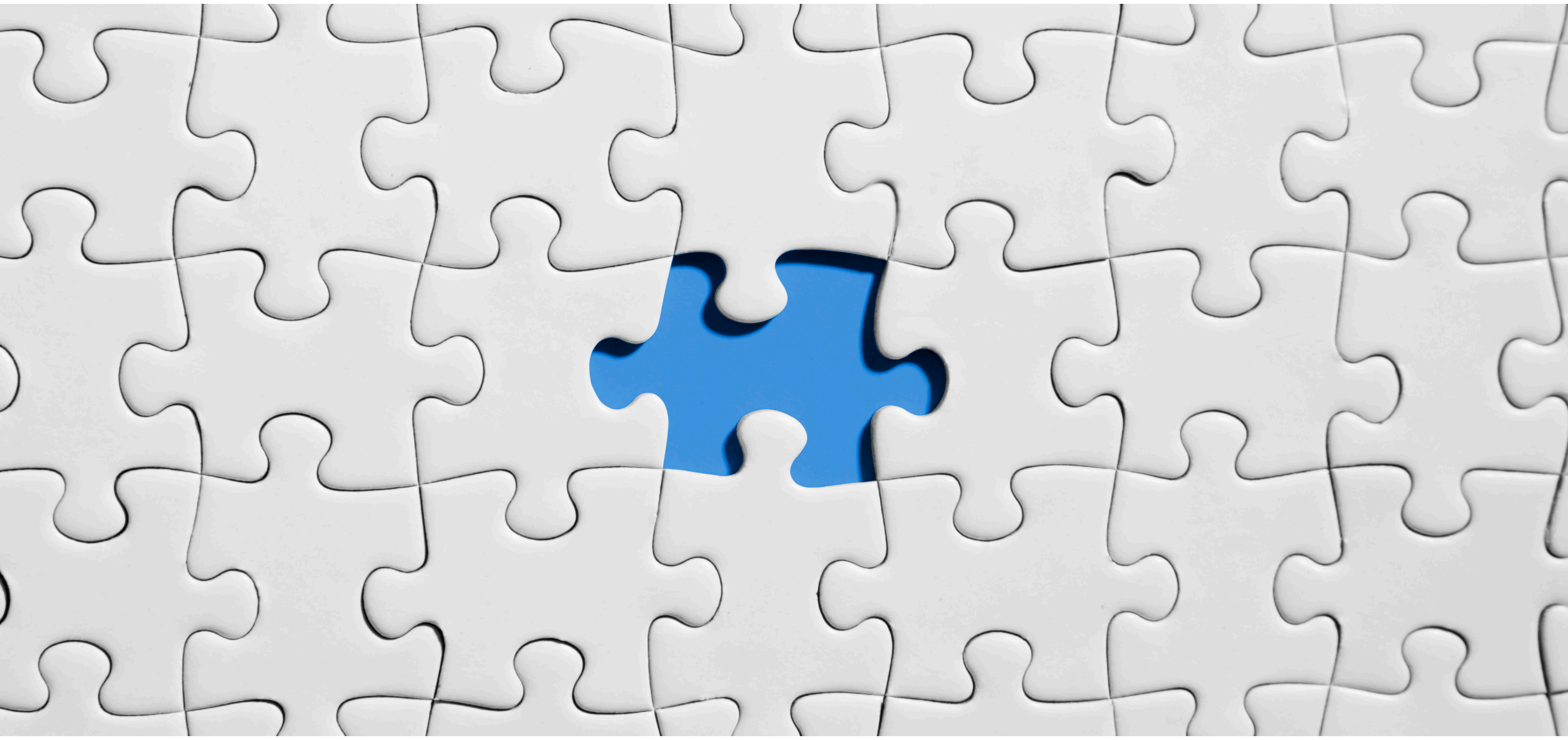
GAME THEORY IN STORAGE SYSTEMS



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Glossary

D@RE	Data at Rest Encryption
FAST	Fully Automated Storage Tiering
FAST VP	Fully Automated Storage Tiering for Virtual Pools
FEC	Forward Error Correction
IOPS	Input/Output Operations Per Second
I/O	Input/Output
P2P	Peer-To-Peer
RAID	Redundant Array of Independent Disks
SSD	Solid State Disk

Abstract

In storage systems, there are a number of intelligent components and features interacting with each other which consitutes a game. Game theory is a mathematical model to understand, design and predict the outcomes. Those outcomes leverage decision making processes. A utility function is defined for each component and features those represent the storage administrator’s selection with respect to a company’s storage priorities and strategies. There exists an ideal working point – “Nash equilibrium” – that is exceptional for a proper utility function. This article briefly explores game theory and its theoretical applications to storage systems.

1. Introduction

Game theory is a broad research area of which many books and articles have been written. A considerable number of them embrace a financial or mathematical point of view. Game theory has been utilized in financial aspects, so as to model rivalry between companies and countries. Over the most past three decades, game theory has been connected to not only financial aspects but also applied in political science, biology, sociology, computer science, etc. as shown in Figure 1. Recently, game theory has been connected to a few systems administration issues, for example, control of power, spectrum allocation, medium access control and routing in a heavy traffic environment within computer science [1]. Other application fields within computer science are distributed computers, algorithms, internet, networking (including P2P, Ad-hoc, mesh, cellular), cognitive radio, sensor networks, etc.

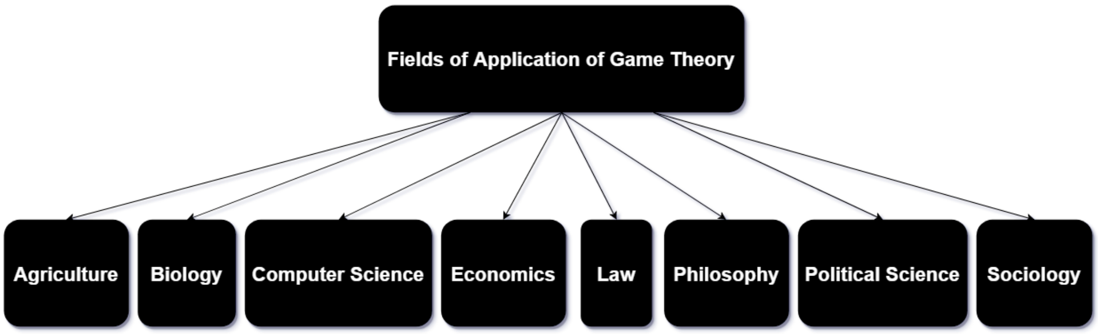

Figure 1 : Fields of Application of Game Theory

Game theory investigates the interaction of independent operators with interests that are conflicting within. Intelligent storage systems are running distributed protocols depending information from other controllers and nodes. Hence, those controllers and nodes are independent operators that make decisions about tiering, QoS, cache usage, hit/miss operation, packet forwarding, encryption etc. [2]. In an independent environment, controllers and nodes may look out for only their own connected host's interests by using more system resources than others selfishly. To extend the issue further, they could rapidly reduce the overall IOPS and network performance for other hosts and end-users. Thus, utilization of game theory could be very handy as a tool to analyze the interaction of storage processors as decision makers or players in a limited resource environment. The concept of equilibrium is vital for players to find a robust solution via game theory formulations [3].

2. Game Theory in Storage Systems

Game theory is a mathematical formulation for modeling and predicting the outcomes of games, where a game is characterized by the number of intelligent players interacting with each other [4]. To continue further, the game should be defined clearly. A game is described by at least two or more players and they must be intelligent and rational. In a game, each player interacts with the other player/s by selecting various actions, based on their assigned preferences. A game should have the following crucial elements: players, actions and preferences.

Nash equilibrium is widely used in game theory. It only occurs when best responses are achieved from the strategies of players. Nash equilibrium is a joint strategy where no player can increase the utility by unilaterally deviating [2]. Formally, according to strategies of players, the action profile a^* is Nash equilibrium if, for every player i and every action a_i of player i, a^* is at least as good according to player i's preferences as the action profile (a_i, a_{-i}^*) in which player i chooses a_i while every other player j chooses a_j^* (a_{-i} be a strategy profile of all players except for player i). Equivalently, for every player

$$u_i(a_i^*, a_{-i}^*) \geq u_i(a_i, a_{-i}^*) \quad \textbf{(1.1)}$$

for every action a_i of player i, where u_i is a payoff function that represents player i's preferences.

According to the player's strategies, an action profile is Pareto optimal if some players must be hurt in order to improve the payoff of other players.

Formally, an action profile a^* is said to be Pareto optimal if and only if there exists no other action profile a', such that if for some i,

$$u_i(a_i', a_{-i}^*) \geq u_i(a_i^*, a_{-i}^*) \quad \textbf{(1.2)}$$

Games are divided into two groups; cooperative and non-cooperative games. In non-cooperative games, the autonomous players make their decisions independently and rival each other. Contrarily, players can interact and apply joint strategies in cooperative games [4]. So it can be easily assumed that there is a communication in cooperative games. As a result of that, they enable more intelligent outcomes. That is why communication between controllers and nodes is becoming more important in storage systems today.

Players are a finite set of decision makers. In storage systems, most of them are called storage processors, controllers, core processors, nodes, appliances, etc. Actions can be defined as the default and licensed options available to each player such as RAID (mirroring, striping and/or both), FEC, D@RE, QoS, Compression, Tiering, Caching and so on. Storage systems administrators would prefer more storage, higher RAID or FEC levels, more IOPS, fewer fiber cables, more redundancy, fewer hardware components, more cache, more SSDs, and more storage space, although these aims obviously conflict in the storage system realm. After each game ends, players have a numerical payoff depending on their actions. A preference relationship per player shows its assessment of all possible outcomes. Preferences can be shown in a tradeoff function or a utility function. A numerical value is assigned to each outcome by the utility function. A desirable outcome has become more obvious with higher utility values [5].

3. Conclusion

Increased interest in storage resulted in intelligent storage systems with more features. This article shows how basic administrator needs create conflicts in designing, implementation and product support. Storage systems as a whole constitute a game which definitely has more games within. There are numerous ways to select the optimal choice and utilizing game theory is one of them is. Game theory sees most of the options of basic and advanced adjustment elements as conflicting interest and provides optimal equilibrium.

Clearly, game theory is an interesting field of study with great potential to improve future storage systems and make a storage administrator's job easier.

References

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