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# Applying Game Theory in Libraries: Review and Preview

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## Introduction

Game theory is the study of how people behave in strategic situations. It is concerned with "how rational individuals make decisions when they are mutually interdependent" (Romp, 1997). "Game" in this context means "sport of any kind," and therefore implies two or more players and a set of rules. The outcome of a game depends on the player him or herself, as well as other players. The root of game theory can be traced to philosophical and political works such as Plato's Republic, in which Socrates worries that "a soldier is better off running away regardless of who is going to win the battle" and "if all of the soldiers reason this way -- then this will certainly bring about the outcome in which the battle is lost" (Ross, 2006).

The development of game theory is well summarized as "a conjunction of indirections: ideas, both in mathematics and in economics whose implications and fruitfulness were not understood, dramatizations of concepts for the wrong reasons, and fruits in applications not originally considered" (Arrow, 2003). Von Neumann is considered the founder of game theory (Von Neumann and Morgenstern 1944), including the "minimax" theorem, which is a way of " *mini*mizing the *max*imum possible loss" (Minimax 2008). It was John Nash's definition and proof of existence for the equilibrium point, however, that exerts the direct impact of game theory on economics.

Strategic games commonly involve three important aspects: players, strategies, and payoffs. The players are "the individuals who make the relevant decisions"; strategies refer to "a complete description of how a player could play a game"; and the pay-offs are "what a player will receive at the end of the game, contingent upon the actions of all the players in the game" (Romp, 1997). As a result, the player will choose a strategy that yields the maximum payoff. Several assumptions are required to understand game theory: individualism, rationality, and mutual interdependence.

The simplest form of game theory is a two-person game. Since each player can choose one of two strategies, the two players will reach four possible decisions as a joint effort. There are three prototypes of two-person game: Prisoner's dilemma, Chicken, and Assurance. Prisoner's dilemma is also known as a game of cooperation, because each player needs to cooperate with the other in order to yield the "dominant" strategy (i.e., the efficient outcome). The following is an explanation of prisoner's dilemma.

**Prisoner's dilemma**: Two suspects, say Bonnie and Clyde, are arrested for a crime. Lacking sufficient evidence to charge both, the police need at least one of the suspects to confess. To facilitate questioning and possibly get a confession, the police separate the suspects. Each of them is given two choices: confess or not confess. Both are made aware of the consequences of the two choices. Consequences for each prisoner depend on what the other does (confess or not). Consequences are displayed in Table 1.

**Table 1. Prisoner's Dilemma**

| | | Clyde | |
|---|---|---|---|
| | | Confess | Do Not Confess |
| Bonnie | Confess | (10 mo., 10 mo.) | (0 mo., 20 mo.) |
| | Do Not Confess | (20 mo., 0 mo.) | (1 mo., 1 mo.) |

If Bonnie and Clyde both confess, then each is sentenced to 10 months in prison (the first number in brackets is Bonnie's sentence while the second number is that of Clyde). If one confesses and the other does not, the confessor is released while the non-confessor receives the maximum sentence (20 months). If neither Bonnie nor Clyde confess, then they are held on a technicality for one month and later released. This cell (Do Not Confess, Do Not Confess) is an efficient outcome since it leads to a situation where the two suspects have the lowest combined sentence. If, however, Bonnie confesses and Clyde is made aware of it, then it is in Clyde's best interest also to confess, because he would only get 10 months instead of 20.

In fact, regardless of what Bonnie chooses to do, it is in Clyde's best interest to confess. "Confess" is a dominant strategy for Clyde. The same holds true for Bonnie. When all is said and done, i.e., in *equilibrium*, both suspects will choose to confess. *Nash equilibrium* is a weaker condition of a dominant strategy. John Nash is a mathematician who theorized that in non-cooperative finite games with multiple players, an equilibrium, later known as *Nash equilibrium*, does exist, such that given the other player's action, one player would not deviate from their strategy choice. Hence the outcome, with cooperation, that would benefit both agents (Do Not Confess, Do Not Confess) is dominated by the outcome (Confess, Confess).

Chicken is a game where "each player prefers not to yield to the other," but "the outcome where neither player yields is the worst possible one for both players" (Chicken [game] 2008). The name refers to the use of "chicken" to mean "cowardly." It is a game of differentiation, since both players must choose a different strategy to maximize pay-off. An assurance game, on the other hand, requires players to choose the same strategy to maximize payoff. The assurance game is also known as the game of coordination or "Battle of the Sexes."

A more complicated form of game theory involves more than two persons. In a multi-person game or n-person game, the number of players choosing a certain strategy will influence the payoff for each player. As a result, more than one solution should be adopted to address individual cases. Another method of categorizing game theory is whether game players will “collude” or “cooperate”. In a "non-cooperative" game, each person maximizes his or her own rewards regardless of the results for others. In a "cooperative" game, the strategies of the participants coordinate to attain the best result for the whole group.

**Field of Study**

This article reviews the literature of applying game theory in a multidisciplinary setting, and provides suggestions for library administration and management. The published literatures across several databases was searched, including *Business Source Premier* and *ABI/INFORM* as sources of literature in

economics, business, and management. *Library and Information Science Abstracts* and *Library Literature* were searched to cover the literature of information science, information economics, and information technology. Finally, *Engineering Index* was searched to capture literature on game theory application in information technology.

Although a remarkable number of articles have contributed to applying game theory to intelligent agents, information service, information technology, information systems, and information economics, a small number were focused on applying game theory in library networking and cooperation.

**Literature Review**

Gintis (2000) says that, "game theory is a universal language for the unification of the behavioral sciences." Aumann and Maschler (1995) describe the potential application of game theory as, “the analysis of such a highly simplified abstraction can very seldom lead to any specific recommendations in a specific situation. But it can lead to insights of a general nature. These insights can then be used by policy makers in making specific decisions or in formulating general policies”. Recent years have seen game theory applied in new disciplines including information technology, management, and economics in a society that is increasingly reliant on information.

**General Applications in Information Society**

**Service outsourcing**

The rise of information technology brings about higher efficiency and flexibility, since resources can now be allocated to the sectors that will produce more efficiently and cheaply. The quality of service providers or vendors is often uncertain, however. Elitzur and Wensley (1997) propose game theory as a tool for understanding information services outsourcing. By focusing on two-person non-cooperative games, seven lessons are drawn to apply game theory to a specific situation. Issues discussed include the transfer of information systems assets, risk sharing, technology upgrading, contract duration, relationship management, and fee determination. Although the study explores only the qualitative aspects of game-theoretic analysis, it is of high value for three reasons: it points out the relationships between features of outsourcing management and game theory, provides recommendations to contract makers for higher efficiency, and it provides directions for future research.

Snir and Hitt (2004) also focus their lens on increasing outsourcing in the information technology services in the past decade. They state that “estimates place the US IT outsourcing market at $160 billion in 2005, up from $101 billion in 2000,” since many IT companies found that “purchasing IT components or services from external contractors allows them to enjoy the benefits of specialization and lower costs, and to redeploy internal staff on projects that must be developed in house.” The classic “lemons problem” often arises during the vendor selection process, when “only low-quality firms aggressively (bid) and win contracts.” This study proposes an alternative two-stage screening mechanism for selecting high-quality vendors. In the first stage, a vendor is assigned a pilot project and the outcome is observed by the client. The client then decides whether to terminate or to continue. The study suggests that this game theoretical approach provides more efficient vendor selection, especially because of the diverse nature of outsourcing projects and the uncertainty of vendor quality.

**Bargaining and negotiation**

The issues of bargaining and agent negotiation have attracted much attention from researchers and practitioners in artificial intelligence, social psychology, and economics (Raiffa, 1982; Pruitt, 1981; Mueller, 1996). Many studies have also been conducted using game theoretic analysis. Various approaches and models are made available to address this issue (Binmore, 1992; Kraus, 1997), among which the study by Fatima, Wooldridge, and Jennings (2004) is worth noticing. In this study, a new model

for “multi-issue negotiation under time constraints in an incomplete information setting” is presented. In this agenda-based model, agents who have conflicting or similar preferences over the agenda may not be aware of it. The model can be applied to bargaining over both a single good/service and multiple goods/services and therefore enjoys more popularity.

**Internal cooperation**

The structure of cooperation is another important area to which game theory is applied. Cooperation, strategic alliances, networks, coalitions, partnerships, and consortia are buzzwords in the information era. Based on voluntary agreement, such relationships often lack stability due to the uncertainty of a partner's future behavior. Parkhe (1993) argues that “the self-interest orientation of each party can lead to actions that are individually rational yet produce a collectively suboptimal outcome.” Parkhe constructs a general model of alliance structuring that is grounded theoretically in game theory and has a paradigm of transaction cost. Parkhe further suggests that although interfirm cooperation is complex, there is a distinction between “stable, high-performing alliances” and “unstable, low performers.” This research has made two primary contributions: an important theoretical model describing the complexity of cooperation structure, and the first large-scale empirical study on this issue.

**Understanding information needs**

An information society witnesses information exchange and information sharing growing exponentially. Information can be viewed as a good traded on the “knowledge market” (Davenport and Prusak, 1999), among information buyers, sellers, and brokers. Another notion suggests that information is shared in a “knowledge community” (Constant, et al *.,* 1994). A lot of attention has been focused on the factors that influence knowledge sharing. Chua (2003) uses a multi-person game-theoretic framework to explain why an individual chooses to share knowledge even though he/she belongs to an organization whose culture discourages knowledge sharing. Findings suggest that “an individual's knowledge sharing tendency is driven by a set of contextualised concerns and interests not unlike the notion of payoff in game theory” (Chua, 2003). Recommendations are also provided to managers who aim to promote knowledge sharing among employees. This study shed insight on applying game theoretical analysis to disciplines in knowledge management and information science. The findings can also help information professionals better understand the information needs and behaviors of information consumers.

**Applications in Library Settings**

In a competitive knowledge market, libraries are market players who must work cooperatively with other institutions. Cohen and Vijverberg (1980) and Hayes (2003) look at game theory as applied to library networks. The former study tries to answer the practical questions that every library faces when joining a cooperative venture. By using game theoretical analysis, Cohen and Vijverberg further explore the four base subjects embedded in the integration of game theory and library networks. These include “the development of a systematic way to study individual coalitions, the calculations of the costs of a network, the calculations of the gross benefits for the whole network, the distribution of the net benefits among the member of the network,” among which the first and the last receive most discussion. This empirical study concludes that libraries choose to join networks if “it pays for them to do so.” A network is stable when “members of the coalitions in the division have more to distribute among themselves than they would in any other division” and “any variation in the coalition structure will reduce total net benefits to coalition members.”

Hayes (2003) uses cooperative game theory to explain decision-making behaviors using cooperative acquisitions and cooperation in automation as examples. This article provides a good review on economic game theory, which fills a knowledge gap for librarians who may not have had been exposed to this subject. It also points out that cooperative game theory could potentially benefit decision-making in library cooperation since “negotiation and cooperation among libraries is of special economic

importance." More specifically, the possible application areas could be resources sharing, cooperative acquisitions, cooperative automation, shared cataloging, shared storage, and preservation and access. Hayes provides libraries with a powerful tool to use when dealing with cooperative issues.

Bridges (2004) proposes the application of game theory to decision-making. He proposes a non-cooperative two-person model in which the librarian and patron are "adversaries." Librarians are advised to use the Observation-Orientation-Decision-Action (OODA) loop to learn as much as possible about users and their needs and behavior.

**Competition Analysis**

Whether information should be seen as a social good or as an economic commodity is still under debate (Detlefsen, 1984), and the existence of an information market is well-recognized. Libraries face competition from other providers such as bookstores, TV, and, more significantly, the Internet. In this rapidly changing market, each player must decide how to direct its efforts in developing and marketing its products or services, and the best plan for one to follow is dependent on the plans adopted by the others. A market player should choose the most suitable size and the right strategy so as to stay competitive. In this context, adopting a non-cooperative game approach might help libraries evaluate the situation. A library might need to focus on a specific sub-market and keep up to retain greater market power and survive.

Libraries are one player while a composite of other information providers are the other in a two-player game. In order to understand such a game, it is easier to focus on particular aspects of information provision, such as free content. Competing agents for libraries in that domain include the broad category of the "Internet," but specifically, sites such as Wikipedia. This category would also include bookstores. The level of differentiation would depend on whether or not "payment" is required for content provision. The game can be sorted into libraries that require "membership" to provide content outside the library (online). Similarly, bookstores require consumers to purchase in order to acquire content remotely. Certain websites may require subscription for detailed content.

**Vendor Negotiation and Bargaining**

The information technology services market provides libraries with new opportunities and challenges. Library administrators and librarians will find themselves in the position of negotiator and bargainers dealing with buying a service or resource from vendors. Fatima, Wooldridge, and Jennings (2003) observe that, "negotiation is a means for agents to communicate and compromise to reach mutually beneficial agreements." How to negotiate with vendors to achieve a win-win situation is an important question. A two-person non-cooperative game could be the right approach, especially in settings where vendor credibility is uncertain, which is normal in a booming market.

The two players in such a game are library consortia and vendors of library materials. Consortia can act as cartels (groups of individuals colluding to act as a unit) in their strategic moves against vendors. By doing so, consortium members gain greater negotiating power and enjoy better. Cartel members may also have incentive to deviate from the agreed upon decision if doing so benefits them, especially if such deviations can be accomplished without other members being aware. Hence, most cartels eventually break down. There is also the issue of member libraries negotiating separate contracts with vendors. Since this is a repeated game, however, penalties may be high enough to discourage this type of behavior.

**Library Cooperation**

Hayes (2003) states that, while "libraries have a long history of cooperation," currently "there is an expansion of that tradition into a variety of contexts and purposes and into formalized structures." A two-

person or n-person cooperative game could provide insight into establishing and maintaining robust. The essential feature of such games is the players' ability to enter into legally binding contracts with one another. More specifically, the outcome of the game is a contract if the players agree or a breakdown if they do not. Libraries who belong to the same coalition or consortium will agree to an outcome giving each library at least a payoff at some point that could not be jointly improved upon.

As we get more specific, we can also apply game theory to the idea of libraries competing/cooperating with each other's acquisitions and collections. The ultimate goal of a library is assumed to be maximizing the number of users, whether measured as number of patrons or as the number of people using the resources. Another measure could be the maximization of collections. The two measures would require slightly different strategies. The number of library users may be maximized by increasing the size of collections or through inter-library loan.

To maximize the number of users, a library may apply game theory in determining which serials to continue and which to discontinue. This type of operations-specific situation may be addressed more efficiently as an optimization problem. Optimization is the process of evaluating any mathematical condition in an effort to find a maximum or minimum, given a set of limiting conditions. It can also be used in game theory as part of the decision making process. An example of an optimization problem would be an individual library attempting to find the optimal (minimum) number of serials it can carry under specific budget, constrained by maintaining a minimum number of patrons/users.

**Understanding Users Information Behavior**

The mission of libraries is to provide high quality service to all library users, which requires an understanding of user information-seeking behavior. It is beneficial for libraries to understand why people choose to use libraries and what factors contribute to the knowledge distribution and knowledge sharing. A *multi-person game-theoretic approach* will promote such understanding, since information behavior could be also regarded as strategic games played between two or more players. An information user makes decisions on whether to access certain information, to share with others, or to withhold the information based on the payoff such actions would yield.

**Conclusion**

Hayes (2003) observes that “cooperation is a part of the ethos of the (librarian) profession.” An information society inevitably brings about more uncertainty, so libraries working cooperatively as important players in an information market should have a better understanding of their dynamic relationships with competitors, cooperators, and users. How to establish and maintain such relationships must be examined by library administrations and managers. Game theory may serve as a useful tool to help make more rational decisions when facing uncertainties.

Game theory has not yet been widely adopted in the library setting. This could be because the idea that a library should act as a market player and operate like a business is not widely accepted. Library administrations and librarians may still not be familiar with game theory and are therefore not aware of its relevance to library management. Using game theory requires a basic understanding of economic theory, and librarians may need training from other disciplines to use it.

By reviewing selected literature on the application of game theory to information- related fields, this article demonstrates the role of game theory in helping libraries deal with economic, administrative, and management issues in an uncertain environment.

**References**


Arrow, K. (2003). Introductory remarks on the history of game theory. *Games and Economic Behavior 45*, 15-18.

Aumann, R. J., & Maschler, M. B. (1995). *Repeated games with incomplete information*. Cambridge, Mass.: MIT Press.

Binmore, K. (1992). *Fun and games: A text on game theory*. Lexington, Mass.: D.C. Heath.

Bridges, K. (2004). Boyd Cycle Theory in the context of non-cooperative games: Implications for libraries. *Library Philosophy and Practice 6*(2). Available: http://libr.unl.edu:2000/LPP/bridges2.htm

Chicken (game) (2008). In *Wikipedia, The Free Encyclopedia*. Available: http://en.wikipedia.org/w/index.php?title=Chicken_(game)&oldid=234010782

Chua, A. (2003). Knowledge sharing: A game people play. *Aslib Proceedings 55*(3), 117-29.

Cohen, J., & Vijverberg, W. (1980). Applying game theory to library networks. *Journal of the American Society for Information Science 31*(5), 369-374.

Constant, D., Kiesler, S., & Sproull, L. (1994). What's mine is ours, or is it? A study of attitudes about information sharing. *Information Systems Research 5*(4), 400-421.

Davenport, T., & Prusak, L. (1999). *Working knowledge*. Boston: MA: Harvard Business School Press.

Detlefsen, E. (1984). User costs: information as a social good vs. information as a commodity. *Government Publications Review 11*, 385-394.

Elitzur, R., & Wensley, A. (1997). Game theory as a tool for understanding information services outsourcing. *Journal of Information Technology 12*, 45-60.

Fatima, S., Wooldridge, M., & Jennings, N. (2004). An agenda-based framework for multi-issue negotiation. *Artificial Intelligence 152*, 1-45.

Gibbons, R. (1992). *Game theory for applied economists*. Princeton, NJ: Princeton University Press

Gintis, H. (2000). *Game theory evolving a problem-centered introduction to modeling strategic behavior*. Princeton, N.J.: Princeton University Press.

Hayes, R. (2003). Cooperative game theoretical models for decision-making in contexts of library cooperation. *Library Trends 51*(3), 441-461.

Kraus, S. (1997). Negotiation and cooperation in multi-agent environments. *Artificial Intelligence 94*, 79-97.

Minimax (2008, August 22). In *Wikipedia, The Free Encyclopedia*. Available: http://en.wikipedia.org/w/index.php?title=Minimax&oldid=233608240

Mueller, H. J. (1996). Negotiation principles. In O'Hare, G.M.P., & Jennings, N.R. (Eds.), *Foundations of distributed artificial intelligence* (pp. 211-229). New York: J. Wiley.

Parkhe, A. (1993). Strategic alliance structuring: a game theoretic and transaction cost examination of interfirm cooperation. *Academy of Management Journal 36*(4), 794-829.

Pruitt, D. G. (1981). *Negotiation behavior*. New York: Academic Press.

Raiffa, H. (1982). *The art and science of negotiation*. Cambridge, Mass.: Belknap Press of Harvard University Press.

Romp, G. (1997). *Game theory: Introduction and applications*. New York: Oxford University Press.

Ross, D. (2006). Game theory. In *The Stanford Encyclopedia of Philosophy*. (Spring 2006 Edition), Edward N. Zalta (ed.). Available: http://plato.stanford.edu/archives/spr2006/entries/game-theory/

Snir, E. M., & Hitt, L. M. (2004). Vendor screening in information technology contracting with a pilot project. *Journal of Organizational Computing and Electronic Commerce 14* (1), 61-88.

von Neumann, J., & Morgenstern, O. (1944). *Theory of games and economic behavior*. Princeton: Princeton Univ. Press.