Reciprocity, Evolution, and Decision Games in Network and Data Science

Learn how to analyze and manage evolutionary and sequential user behaviors in modern networks, and how to optimize network performance by using indirect reciprocity, evolutionary games, and sequential decision-making. Understand the latest theory without the need to go through the details of traditional game theory. With practical management tools to regulate user behavior and simulations and experiments with real data sets, this is an ideal tool for graduate students and researchers working in networking, communications, and signal processing.

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Reciprocity, Evolution, and
Decision Games in Network
and Data Science

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Preface

Human-like behaviors commonly exist in various networks, such as wireless and social networks. Smartphones compete with each other to access wireless networks. Social agents cooperate with each other to provide discount deals on social media, and collaborate with each other to provide answers to various questions on social computing networks. These behaviors could be analyzed using traditional game theory, which has been proven to be a great success over the decades. Nevertheless, existing studies based on traditional game theory have reached their limit when it comes to more realistic settings in modern networks, including repetitive interactions, indirect relationships, information asymmetry, network externality, and so on.

These challenges call for modern game theory, which extends traditional game theory and is inspired by the study of human social behaviors in the social sciences and biological evolution in nature. To resolve the indirect relationship challenge, indirect reciprocity with the key concept “I help you not because you have helped me, but because you have helped others” could be borrowed from the social sciences in order to build up a reputation and social judgment system, while in order to model the evolution of repetitive interactions, we could bring in evolutionary games from evolutionary biology to capture the idea of “survival of the fittest.” In this book we discuss how to utilize modern game theory to study behaviors in network and data science, particularly addressing the analysis and prediction of the competitive and/or cooperative behaviors of agents in a complex social and information-related network.

In the wireless networks access problem, for instance, mobile users may access a network at different times with different requirements. Rational users tend to select the best wireless network with the greatest transmission quality. The information regarding the wireless network could be more accurate when these users share their collected information with each other. This advantage potentially leads to cooperative behaviors. However, due to network externality, the more users select the same network, the less access time each user may receive. This suggests that competitive behaviors among users also exist. In addition, each user may be facing different network statuses, since some users may have selected certain networks and some may become inactive and leave the networks – this is known as information asymmetry.

Another example is the information diffusion problem, where users repeatedly decide whether to post information or not on social networks. This information forwarding is often not unconditional. One has to make a decision as to whether or not to share this information based on many factors, such as whether the information is
exciting or whether one’s friends are interested in it. Moreover, due to their selfish nature, users will act to pursue their own interests, which often conflicts with the system designers’ goal. How can system designers create incentives to steer users toward behaving in the way that the system designers desire, especially when the relationship among users is indirect?

These critical characteristics should be addressed as a whole when studying networks. Nevertheless, they are only partly addressed, if not ignored entirely, in the existing studies based on traditional game theory. A full understanding of the process of rational, repetitive, sequential, indirect, information-asymmetric, and dynamic-aware decision-making based on modern game theory is necessary to investigate the potential influence of these networks on the overall system, and proper regulation and management solutions can then be proposed to improve the overall network performance.

The main goal of this book is to summarize the recent progress in both the theoretical analysis and the applications of modern game theory. Three branches of modern game theory – indirect reciprocity, evolutionary games, and sequential decision-making – are presented and studied in this volume. For each branch, a series of game-theoretic frameworks will be introduced, and through the evolution of the frameworks, the critical characteristics of each branch will be captured. Given the foundations in theoretical analysis, practical management tools for regulating the behaviors of users will be discussed. In summary, both in-depth theoretical analysis and data-driven experimental results on various applications will be presented.

In Chapter 1, the fundamental concepts of game theory, which include the basic settings, game models, and corresponding solution concepts and their applications, are introduced. Then, the three main parts of this book (i.e., indirect reciprocity, evolutionary games, and sequential decision-making) are discussed.

In the first part of this book, the first branch of modern game theory – indirect reciprocity – is studied. Chapter 2 introduces the basic model to illustrate the concepts and characteristics of indirect reciprocity. The application to cognitive networks is also highlighted. Chapter 3 studies the application of indirect reciprocity to dynamic channel access with a theoretical analysis of reputation updating policy and stationary reputation distribution. In Chapter 4 an indirect reciprocity game for cooperative wireless communication is presented. Stability analysis based on Markov decision processes is provided in this chapter. Finally, Chapter 5 introduces a new form of indirect reciprocity game for general data fusion problems. Its application for improving the accuracy of dynamic channel access is presented.

In the second part of this book, the second branch of modern game theory – evolutionary games – is studied. In Chapter 6 the basic evolutionary game model for peer-to-peer streaming is presented for studying cooperative behavior. The basic approach for analyzing the evolutionarily stable strategy in this evolutionary game is discussed. In Chapter 7 we extend the evolutionary game to solve the problems of spectrum sensing and access in cognitive radio networks. Chapter 8 introduces an advanced graphical evolutionary game for distributed adaptive networks in signal processing. Chapter 9 introduces the graphical evolutionary game formulation for information diffusion in
social networks. The characteristics of information diffusion in different types of networks are studied. The results are also verified with experiments based on real social network data. Finally, in Chapter 10, an extended graphical evolutionary game for information diffusion in heterogeneous social networks is presented. The influence of heterogeneous user types, either known or unknown, is studied theoretically.

In the third part of this book, the third branch of modern game theory – sequential decision-making – is presented. In Chapter 11 the motivation of sequential decision-making is presented using several examples from real-world systems. The important components in sequential decision-making, such as network externality, information asymmetry, and user rationality, are presented and defined. The limitations of the existing approaches, such as social learning, multiarmed bandit problems, and reinforcement learning, are also presented. In Chapter 12 the sequential decision-making problem is analyzed in a static system. Network externality and the Bayesian learning model are presented to formulate how rational users learn about the uncertain system state through the observed signals shared by others. Chapter 13 analyzes the sequential decision-making problem in a dynamic system. A stochastic game-theoretic model called the Dynamic Chinese Restaurant Game is introduced to consider the uncertainty in both the network externality and the system state. Chapter 14 presents the first extension of the Chinese Restaurant Game, which considers the case in which one agent may make multiple decisions simultaneously in sequential order. The non-Bayesian learning approach is also considered in this extension. In Chapter 15 the signal-based information space is extended to an action-based information space in the Hidden Chinese Restaurant Game to show that actions are as informative as signals in the learning process. This extension prevents extra overheads in signal exchanges and gets rid of the assumption of reliable signal exchange protocols. Chapter 16 presents the wireless access point selection problem as the first application of the Chinese Restaurant Game framework. A mechanism design is presented to regulate the access decisions of rational users in order to improve the overall system performance within the sequential decision-making scenario. In Chapter 17, the second application – the deal selection problem and cross-media learning behavior in social media – is presented. The experimental results in real social media networks verify the rationality assumption of the model. Finally, Chapter 18 presents the third application: rationality analysis of the heterogeneous actions (answer vs. vote) of users in social computing systems. The experimental results based on user behavior data collected from Stack Overflow confirm the correctness of the model.

This book is aimed at graduate students and researchers who work/study electrical engineering or computer science, especially in the area of network and data science. This book can be used as a graduate-level course textbook in courses focused on modern game theory in network and data science. Readers should have prior knowledge of probability and wireless communications.

This book would not have been possible without the contributions of the following people: Biling Zhang, Yang Gao, Yu-Han Yang, and Xuanyu Cao. We also would like to thank them for their technical assistance during the preparation of this book.