Abstract In the emerging crowd cyber-eco systems, millions of deeply connected individuals, smart devices, government agencies, and enterprises actively interact with each other and influence each other’s decisions. It is crucial to understand such intelligent entities’ behaviors and to study their strategic interactions, which provides important guidelines on the design of reliable networks capable of predicting and preventing detrimental events with negative impacts on our society and economy. This chapter introduces basic concepts in behavior and evolutionary dynamics in crowd networks. Using information diffusion over social networks as an example, we discuss challenges in the modeling and analysis of user behavior and their interactions in large-scale, decentralized and heterogeneous networks, and introduce an evolutionary game theoretic framework to study behavior dynamics in crowd networks.

Keywords Crowd networks · Behavior dynamics · Information diffusion · Social networks · Evolutionary game theory

1.1 Crowd Networks

With the recent development of social media, Internet of things, big data, cloud computing, and many other new technologies, we witness new industrial and social management patterns, and the emergence of crowd cyber eco-systems consisting of smart and deeply connected entities such as individuals, enterprises and government agencies. Examples of such crowd networks include online e-commerce platforms such as Amazon and Tmall that connect customers, small businesses, and large enterprises, online communities such as Reddit and Quora that connect users worldwide with a common interest, globally connected supply chains, etc.

In these networks, smart entities regularly interact with each other, influence each other’s decisions, and have a significant impact on our society and economy. Due to the complex structures of these networks and the dynamic interactions among users, we often observe dangerous and damaging events that spread rapidly and
globally in these networks [1]. One example is the “salt panic” in China after the 2011 Tohoku Tsunami, where the news of nuclear leakage greatly stimulated the rumors like “iodized salt can help ward off radiation poisoning”, which lead to the “long lines and mob scenes at stores” and “10-fold jump of salt price” throughout China [2]. Another example is the COVID-19 crisis, where the highly contagious novel coronavirus spreads quickly all over the world and has severe impacts on our health, social lives, and economics [3]. Thus, to better understand the behavior of these complex crowd networks and to avoid such detrimental events, it is of crucial importance to study how such smart entities interact with each other, to understand their decision-making process, to analyze how they influence each other and the impact of such interactions on the entire crowd intelligence networks. Such investigation provides important guidelines on the design of efficient and effective mechanisms to manage such crowd intelligence networks.

1.2 Information Diffusion

In this book, we use information propagation over social networks as an example and study the impact of user behavior on network evolution. The social network, a social structure made up of social actors (such as individuals or organizations), sets of dyadic ties, and other social interactions between actors, is a prominent tool for the diffusion of information in society [4]. For example, by posting some videos and pictures related to personal preferences on Facebook, or declaring some political opinions on Twitter, or releasing promotional advertisements in Wechat Moments, people interact with each other for their own purposes. Once a piece of information is published on the network, it may vanish quickly after its appearance, or it may last for a long time and inspire a heated discussion. Thus, the prediction of its propagation process and the final destiny of information spread is vital in many applications, including advertising and political campaigns. Information diffusion over social networks may also have significant impacts on our society. As an example, according to MIT Technology Review, in the COVID-19 crisis, “social media has zipped information and disinformation around the world at unprecedented speeds, fueling panic, racism, ... and hope” [5]. Therefore, modeling and predicting information diffusion over social networks has been a hot research topic in recent years.

The research on information diffusion is critical. On the one hand, from the perspective of profits, the study of information diffusion can help the enterprises or politicians to identify influential users and links and then make advertisements or advocation more effective. On the other hand, from a security perspective, this study can help prevent the spread of detrimental information such as rumors and computer viruses, which would reduce unnecessary losses significantly. The recent developments of information and communication technologies enable us to collect, store, and access big data, making the research of information dissemination versatile and meaningful, but also more challenging.
The study on information diffusion originates from the research of computer virus/epidemic spreading over networks [6]. One of the earliest and prominent works about information diffusion is [7], which focused on the dynamics of information propagation through blog space from both macroscopic and microscopic points of views. Subsequently, there are a large number of works on information diffusion. The researchers explore the problem from different angles and adopt a variety of methods to resolve the problem. From the research object, existing works can be divided into three categories: (1) diffusion characteristics analysis; (2) diffusion dynamics analysis; (3) diffusion stability analysis. Based on the adopted method, works could also be divided into two categories. The first category models the information diffusion from the macroscopic aspect, usually adopting machine learning or data mining techniques to predict the dynamics or properties of networks. The methods based on machine learning or data mining have a common drawback—a lack of understanding of the underlying microscopic mechanisms of individual decision-making during the diffusion process, which is the focus of the second category. The second category stressed on micro exploration, paying more attention to the decisions and motivations of individuals.

In recent years, evolutionary game theory (EGT) has attracted lots of attention. It is used to fully understand the details of information diffusion process and simulate the entire process, including diffusion dynamics as well as the final result. Initially, EGT derives from a biological problem of how to explain ritualized animal behavior in a conflict situation and then has become of interest to economists, sociologists, anthropologists, and philosophers [8]. It addresses the shortcomings of traditional game theory. In classical game theory, players are required to make rational choices, which means they need to carefully consider complicated reasonings, such as what they want, what their opponents want, what their opponents know, etc., and determine the best strategy in the competitions. At the same time, in EGT, there is no limitation for players’ actions and few assumptions about the reasoning processes of players, and the process of natural selection, i.e., evolution, is the focus.

1.3 Evolutionary Game Theory

EGT defines a framework of contests, strategies, and the measurable criteria that can be used to predict the performances of competing strategies. The results of a game include the dynamics of changes in the population, whether the strategy is successful, and any achievable equilibrium states. These basic elements in a game just correspond with the fundamental elements in information diffusion, so the whole information diffusion process could be regarded as a game: for users being players, their adopted strategies being the strategies in the game, the information spreading process being the evolution, and the consequence of information (survive or vanish, and if survive, how many users accept this piece of information) being the equilibrium states. Different from methods using lots of data, by applying EGT to information diffusion, we could predict every small change in the process, get the detailed dynamics, and
finally foretell the stable states. Meanwhile, we can interpret the mechanisms of how users interact with others from the individual’s view, rather than the whole network, which helps to understand the diffusion process more deeply.

In related research, the evolutionary game-theoretic models have been proven to achieve high accuracy, with less calculation than machine learning or data mining approaches. Based on the conclusions of the EGT framework, the dynamics and stable states in the process of information diffusion can be quickly predicted, which could be applied to plenty of areas such as online advertisements, rumor control, and network security. Therefore, in this book, we introduce several evolutionary game-theoretic models under different scenarios and illustrate how to apply EGT to the analysis of information diffusion. Evolutionary game theory has also been used to study user behavior in other applications, such as the natural biological world, the social world, and the virtual online world [9] as well as traffic flow analysis and epidemics [10].

1.4 About This Book

In this book, we aim to offer a holistic evolutionary game-theoretic framework to theoretically study behavior and evolutionary dynamics in large-scale, decentralized and heterogeneous crowd networks. We combine mathematical tools and engineering concepts with ideas from sociology, biology and game theory, and propose an interdisciplinary approach to model intelligent entities’ decision-making process and their interactions. In this book, we review the fundamental methodologies to study user interactions and evolutionary dynamics in crowd networks and discuss recent advances in this emerging inter-disciplinary research direction. Using information diffusion over social networks as an example, it provides a thorough investigation of the impact of user behavior on the network evolution process, and demonstrates how such understanding can help improve network performance.

Note that there are also other works on swarm intelligence and evolutionary algorithms that reviews recent research on complex networks, and analyze the relations between the dynamics of evolutionary algorithms, complex networks and coupled map lattices [11–13]. These works often consider homogeneous networks and assume that all agents/smart entities in the complex network have a common goal. Different from these works, we address new challenges in crowd intelligence networks, consider the existence of irrational and/or malicious behavior, study the impact of user heterogeneity on evolutionary dynamics, and analyze the evolution of correlated events.

This book targets graduate students and researchers from different disciplines, including but not limited to data science, networking, signal processing, complex systems, and economics. It aims to encourage researchers in related research fields to explore many untouched territories along this direction, and ultimately to design crowd networks with efficient, effective, and reliable services.
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