Chapter 1

Introduction and Overview

In this chapter, we bring out the importance and current relevance of game theory and mechanism design. The modern era, marked by magnificent advances in information and communication technologies, has created possibilities for fascinating new applications. In many of these applications, the research challenges can be effectively addressed using game theory and mechanism design. In this chapter, we describe a few motivational examples and present several modern research trends that have brought game theory and mechanism design to the forefront.

Game theory and mechanism design deal with interactions among *strategic agents*. While game theory is concerned with *analysis of games*, mechanism design involves *designing games* with desirable outcomes. Currently these are lively and active areas of research for inter-disciplinary problem solving. The central objective of this book is to gain a sound understanding of the science behind the use of game theory and mechanism design in solving modern problems in the Internet era. This book deals with three broad areas: *non-cooperative game theory*, *cooperative game theory*, and *mechanism design*.

Disciplines where game theory and mechanism design have traditionally been used include economics, business science, sociology, political science, biology, philosophy, and engineering. In engineering, it has been most widely used in industrial engineering, inventory management, supply chain management, electronic commerce, and multiagent systems. More recently, game theory has been embraced by computer science and electrical engineering disciplines in the context of many emerging applications.

1.1 Game Theory: The Science of Strategic Interactions

The term *game* used in the phrase *game theory* corresponds to an interaction involving decision makers or players who are rational and intelligent. Informally, *rationality* of a player implies that the player chooses his strategies so as to maximize a well defined individualistic payoff while *intelligence* means that players are capable enough to compute their best strategies. Game theory is a tool for logical

1	2	
	IISc	MG Road
IISc	$100, 100$	$0, 0$
MG Road	$0, 0$	$10, 10$

Table 1.1: Payoffs for the students in different situations

and mathematical analysis that models conflict as well as cooperation between the decision makers and provides a principled way of predicting the result of the interactions among the players using equilibrium analysis. Traditional games such as chess and bridge represent games of a fairly straightforward nature. Games that game theory deals with are much more general and could be viewed as abstractions and extensions of the traditional games. The abstractions and extensions are powerful enough to include all complexities and characteristics of social interactions. For this reason, game theory has proved to be an extremely valuable tool in social sciences in general and economics in particular. While *game theory* focuses on analysis of games, *mechanism design* is concerned with design of games to obtain desirable outcomes - mechanism design could be described as reverse engineering of games. In the sequel, whenever there is no need for emphasis, we use the single phrase *game theory* instead of the phrases *game theory* and *mechanism design*.

Value of Game Theory and Mechanism Design

We provide four simple, stylized examples which bring out the value of game theory and mechanism design in modeling situations of conflict and cooperation among strategic agents. These examples are abstractions of representative real-world situations and applications.

Student Coordination Problem

Imagine two typical students (call them 1 and 2), say belonging to the Indian Institute of Science (IISc), Bangalore, who are close friends. The students derive utility by spending time together either studying (in IISc) or going to the MG Road (Mahatma Gandhi Road, a location in Bangalore, frequented by young students seeking entertainment). Thus to spend time together, they have two options (or strategies): IISc and MG Road. If both of them are in IISc, each one gets a payoff of 100. If both of them go to MG Road, each gets a payoff of only 10. If one of them remains in IISc and the other goes to MG Road, the payoff is 0 for each. The payoffs are shown in Table 1.1 and are self-explanatory. Suppose the two friends have to choose their strategies simultaneously and independently of each other. Being rational and intelligent, each one would like to select the best possible strategy. It is clear that both opting for IISc is the best possible outcome and both opting for MG Road is also fine though clearly worse than both opting for IISc. The worst happens when they choose different options since each ends up with zero utility.

Game theory helps us with a principled way of predicting the options that would be chosen by the two students. In this case, the outcome of both opting for IISc and the outcome of both opting for MG Road can be shown to be what are called *Nash equilibria* which are strategy profiles in which no player is better off by unilaterally deviating from her equilibrium strategy. Game theory also provides one more prediction for this game which on the face of it is counter-intuitive but represents an equilibrium outcome that the students will not be averse to playing. This outcome which is technically called a *mixed strategy Nash equilibrium* corresponds to the situation where each student chooses IISc with probability $\frac{1}{11}$ and MG Road with probability $\frac{10}{11}$. This perhaps explains why some students are found mostly in MG Road and rarely in IISc!

The above game which is often called the *coordination game* is an abstraction of many social and technical situations in the real world. We will not get into details here but only leave the comment that game theory enables a scientific way of predicting the outcome of such interactions among decision makers.

Braess Paradox

We now illustrate the Braess paradox which is named after the German mathematician Dietrich Braess. This paradox is usually associated with transportation networks and brings out the counter-intuitive fact that a transportation network with extra capacity added may actually perform worse for commuters (in terms of time delays) than without the extra capacity. The game that we describe here is developed on the lines presented in the book by Easley and Kleinberg [1].

Figure 1.1 shows a network that consists of a source S and a destination T, and two intermediate hubs A and B. All vehicles traveling from S can go via hub A or hub B. Suppose, regardless of the number of vehicles on the route, it takes 25 minutes to travel from S to B or from A to T. On the other hand, the travel time from S to A is $\frac{m}{50}$ minutes where m is the number of vehicles traveling on that link. Similarly, the travel time from B to T is $\frac{m}{50}$ minutes where m is the number of vehicles on that link.

Suppose we now introduce an additional fast link from A to B to ease the congestion in the network (as a degenerate case, we will assume the travel time from A to B to be zero). Figure 1.2 depicts this new network with an extra link added from A to B. Now a vehicle can go from S to T in three different ways: (1) S to A to T; (2) S to B to T; and (3) S to A to B to T. The users of this network would be happier if the time to travel from S to T is lower. Intuition tells us that the second configuration where we have an additional link should make the users happier. However, game theoretic analysis proves, using equilibrium analysis, that the first configuration is in fact better for the users.

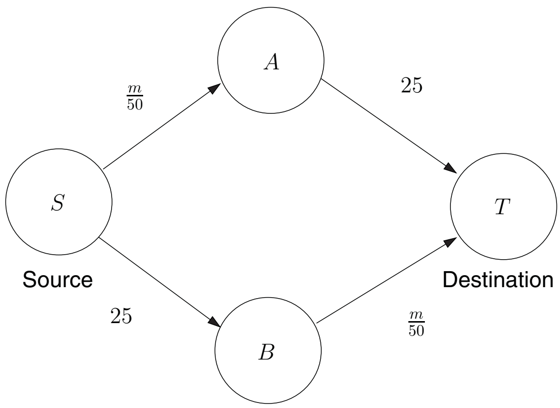

Fig. 1.1: A transportation network with four nodes

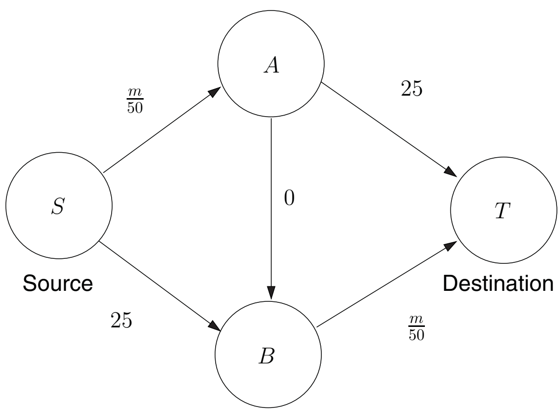

Fig. 1.2: Transportation network with an additional high speed link from A to B

There is considerable evidence for the Braess paradox. For example, in Seoul, South Korea, traffic congestion around the city dramatically reduced when a particular high speed arterial link was closed for traffic as a part of the Cheonggyecheon restoration project. In Stuttgart, Germany, a huge investment was made in decongesting the traffic on the roads by building additional roads but the traffic situation improved only when some of the newly-built roads were closed for traffic. Game theory could be used to obtain scientific predictions of what is likely to happen, by modeling the situation as a game involving the users of the transportation network and capturing their interactions. In chapters 4, 5, and 6, we study this example in some detail.

Vickrey Auction

Consider a seller who wishes to allocate an indivisible item to one of n prospective buyers in exchange for a payment. An example would be the sale of a spectrum license by the Government to one of several telecom service providers seeking to buy the license (See Figure 1.3). Each player has a certain valuation for the item on sale. For example, in the spectrum license case, imagine that there are four service providers 1, 2, 3, 4 who value the license at Rs. 400 million, Rs. 500 million, Rs. 700 million, and Rs. 1000 million. In a spectrum auction, the Government invites bids from prospective buyers and allocates the license based on an auction protocol. Two simple and common auction methods are *first price sealed bid auction* and *second price sealed bid auction*. In the first price auction, the one who bids highest will be allocated the item and the winning bidder will pay an amount equal to the bid. In the second price auction, the one who bids highest will be allocated the item but the winning bidder will pay an amount equal to the second highest bid.

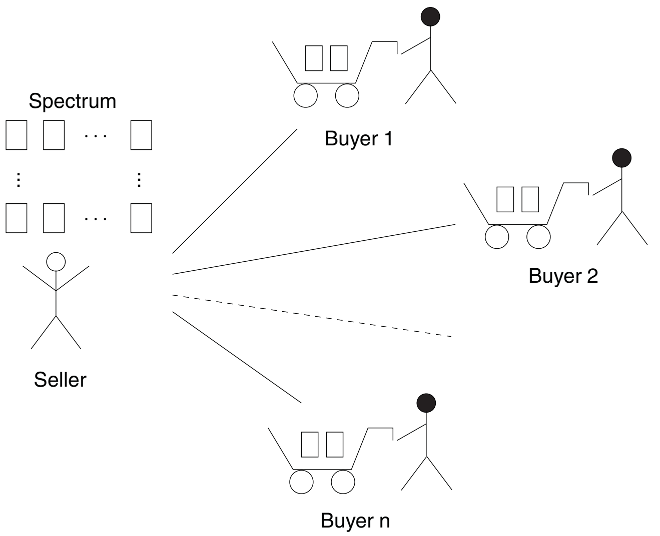

Fig. 1.3: A spectrum auction

Each auction above can be modeled as a game involving the seller and the buyers. In the first price auction, the bidders will bid amounts which are less than their valuations. In the second price auction, the bidding will be more aggressive since the bidders know that they would be paying less than what they bid in case they win. William Vickrey, in his Nobel prize winning work, proved the remarkable result that the bids in the second price auction will be exactly equal to the respective valuations. In fact, Vickrey showed that it is best for every bidder to bid her true valuation irrespective of whatever is bid by the other players. In the example above, if second price auction is employed, then the players will bid their valuations and the license will be awarded to player 4. This player will pay an amount equal to Rs. 700 million which is the second highest bid. Thus the seller who does not know the valuations of the bidders is able to extract these valuations in the form of their bids. Game theory and mechanism design constitute the science behind the design of a whole gamut of auction protocols which are ubiquitous and extensively used these days.

Divide the Dollar Game

Suppose there are three individuals who wish to divide a total wealth of 300 among themselves. Each player can propose an allocation such that no player's payoff is negative and the sum of all the payoffs does not exceed 300. Assume that if two or more players propose the same allocation, then that allocation will be implemented. For example, if players 1 and 2 propose an allocation $(150, 150, 0)$ and player 3 proposes $(100, 100, 100)$, the allocation $(150, 150, 0)$ will be implemented. However, player 3 may tempt player 2 with the allocation $(0, 225, 75)$ and if players 2 and 3 propose this, the original allocation $(150, 150, 0)$ gets overturned. Note that this allocation is strictly better for both 2 and 3. Player 1 may now entice player 3 and jointly propose with player 3 an allocation $(200, 0, 100)$ which is better for both 1 and 3. Bargaining of this kind can be never ending leading to the perpetual breaking and making of coalitions. This is a situation that is common in the real world (for example in politics and business).

Predicting the final outcome in such situations is hard using conventional techniques. Cooperative game theory helps us analyze such situations in a systematic and scientific way. For example, by modeling the above as a cooperative game, one can show that the *core* of this game is empty implying that none of the allocations is stable and can always by derailed by a pair of players coming together. One can also show that the *Shapley value* of this game is $(100, 100, 100)$ which provides a fair way of allocating the wealth among the three players in this case.

Game Theory: A Rich History

Game theory, as a mathematical discipline and modeling tool, has a rich history and its foundations and advances have been the contributions of some of the most brilliant minds of the twentieth century. Figure 1.4 shows the legends who have made path breaking contributions to game theory and mechanism design. John von Neumann and Oskar Morgenstern were the principal architects of game theory in the late 1920s, 1930s, and early 1940s. Their marvelous collaboration built the foundations of game theory and yielded a monumental book entitled *The Theory of Games and Economic Behavior* [2]. This book continues to be an authentic source of early pioneering results in game theory. Following their work, several celebrated game theorists have contributed to developing game theory as the science of economics. The importance of the discipline of game theory and their contributions have been recognized through a number of Sveriges Riksbank prizes (Nobel Prize in Economic Sciences) being awarded to game theorists, including the 1994, 1996, 2005, 2007, and 2012 prizes. In fact, between 1994 and 2012, as many as 11 game theorists have been awarded the prize.

Fig. 1.4: Legends of game theory and mechanism design

John Nash, John Harsanyi, and Reinhard Selten received the prize in 1994 for their path breaking work in equilibrium analysis of games. William Vickrey won the prize in 1996 for his influential work in auction theory. In 2005, Robert Aumann and Thomas Schelling received the prize for having enhanced the understanding of conflict and cooperation through game theory analysis. In 2007, the prize was awarded to Leonid Hurwicz, Eric Maskin, and Roger Myerson for their fundamental contributions to mechanism design theory. More recently, in 2012, Lloyd Shapley and Alvin Roth have been awarded the prize for advancing the theory of stable allocations and the practice of market design. Before all these contributions, Kenneth Arrow had been awarded the prize in 1972 for his masterly work on social choice theory which had been carried out as early as 1950s. Clearly, game theory and mechanism design have held the center-stage for several decades now in the area of social sciences. The development of game theory can be truly described as one of the most significant achievements of the twentieth century since it has shown that mathematical reasoning can be applied to studying complex human interactions.

1.2 Current Trends and Modern Applications

Since the 1990s, two related threads have catapulted game theory to the centerstage of problem solving in modern times. The first thread is the emergence of theoretical research areas at the interface of game theory and varied subjects like computer science, network science, and other engineering sciences. The second thread is the natural and often compelling use of game theory in breathtaking new applications in the Internet era. In the modern era, game theory has become a key ingredient for solving problems in areas as diverse as electronic commerce and business, Internet advertising, social network analysis and monetization, wireless networks, intelligent transportation, smart grids, and carbon footprint optimization. We touch upon a few relevant current trends and modern applications.

Current Trends

To illustrate the first thread above, we allude to a lively new theoretical research area, algorithmic game theory, at the interface of game theory and computer science. The importance and limelight can be appreciated by the fact that the 2012 Gödel Prize which recognizes outstanding papers in theoretical computer science has been awarded to six researchers (Elias Koutsoupias, Christos Papadimitriou, Tim Roughgarden, Eva Tardos, Noam Nisan, and Amir Ronen) in algorithmic game theory. The award has cited three papers [3, 4, 5] which have laid the foundations in this area. Here is a brief overview of the three papers to get a quick idea of the central themes in this area.

Koutsoupias and Papadimitriou [3] introduced the key notion of *price of anarchy* in their paper entitled *Worst-case Equilibria*. The price of anarchy measures the extent to which selfish behavior by decentralized agents affects the achievement of a social optimum. In particular, the paper quantifies how much efficiency is lost due to selfish behavior on the Internet which does not have a central monitor or authority to coordinate or control the actions of its users. Their study is based on a game theoretic model of the Internet and they use the notion of Nash equilibrium to formalize the concept of price of anarchy.

The concept of price of anarchy is used by Roughgarden and Tardos [4] to study the specific problem of routing traffic in large scale transportation networks or communication networks. Their beautiful analysis explains the well known Braess's paradox (see Chapters 4 and 5) in transportation science using a game theoretic model and establishes the relationship between centrally optimized routing and selfish routing in congested networks. Through such studies, game theory becomes a valuable tool for design of routing policies and traffic networks.

The third Gödel prize winning paper by Nisan and Ronen [5] proposes a fascinating new problem domain which they call *algorithmic mechanism design*. In this paper, the authors show how game theory and mechanism design could be used to solve algorithmic problems where the inputs to the problem constitute the private information of rational and intelligent agents. Traditional computer science assumes that algorithms once designed will work as per design when executed. The computing systems that execute the algorithms will follow the rules written for them faithfully. However if self-interested participants are required to provide inputs to the computing system during the execution of the algorithm, the inputs provided to the algorithm may or may not be truthful. Making algorithms robust to manipulation by strategic agents is the central theme of algorithmic mechanism design. Algorithmic game theory is now an active research area in many leading computer science departments in the world. It represents one of many such recent research trends in which game theory is a key ingredient.

We now take a look at the second thread which has pushed game theory to the forefront of problem solving. This thread is inspired by a natural relevance of game theory to many emerging applications in the Internet era.

Some Modern Applications

Modern applications often involve the Internet which often encourages strategic behavior by the users due to its decentralized nature. Also, modern applications in the social, economic, or business domain invariably involve individuals and organizations which have their own self-interests and act strategically. To make these modern applications perform as intended in spite of the presence of strategic users in the system, one could use creative techniques offered by game theory and mechanism design as a part of system design. This explains the second trend that has pushed game theory and mechanism design to the forefront. To drive home the point that game theory has proved crucial for advancing the current art in modern day problem solving, we provide four examples below.

Matching Markets

This is a traditional problem setting that continues to throw up exciting new applications in modern times as well. Matching is the process of allocating one set of resources or individuals to another set of resources or individuals. Examples include matching buyers to sellers in a market; matching resources to tasks; matching new doctors to hospitals; matching job-seeking engineers to companies; and matching students to schools (see Figure 1.5). There are also examples with deep societal impact such as matching kidneys to patients (or in general organ donors to organ recipients). Such matching problems are broadly categorized into marriage problems and house allocation problems. In a marriage problem, the resources on each side of the market have preferences over the resources on the other side. In house allocation, only resources on one of the sides have preferences over the resources on the other side. In either case, the matching has to be accomplished so that the individual preferences are honored and performance is optimized.

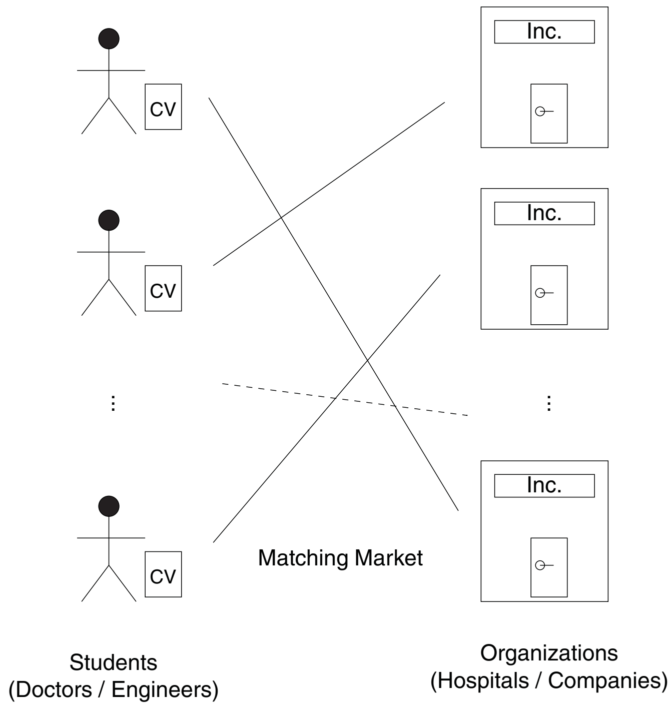

Fig. 1.5: A matching market

Two key requirements of any solution to the matching problem are *stability* and *incentive compatibility*. Informally, a solution is said to be stable if the solution cannot become strictly better through a reallocation. A solution is called incentive compatible if the preferences are reported truthfully by all the agents. Game theory has been used to analyze in a rigorous manner both stability and incentive compatibility. Since the 1960s, game theory and game theorists have contributed immensely to the development of a comprehensive theory of matching markets. The existence of a large number of successful matching markets in real world applications is one of the significant successes of game theory. In fact, the Nobel Prize in Economic Sciences for the year 2012 has been awarded to Lloyd Shapley and Alvin Roth for their pioneering work on matching theory and matching markets [6].

Matching markets have many socially important applications such as competitive matching of colleges with students and hospitals with interns, leading to maximization of social welfare. They have also saved precious human lives through better and faster matching of kidneys and human organs. Game theory and mechanism design have played a significant role in ensuring the success of these markets.

Sponsored Search Auctions

Sponsored search is by now a well known example of an extremely successful business model in Internet advertising. When a user searches a keyword, the search engine delivers a page with numerous results containing the links that are relevant to the keyword and also sponsored links that correspond to advertisements of selected advertisers. Figure 1.6 depicts a typical scenario.

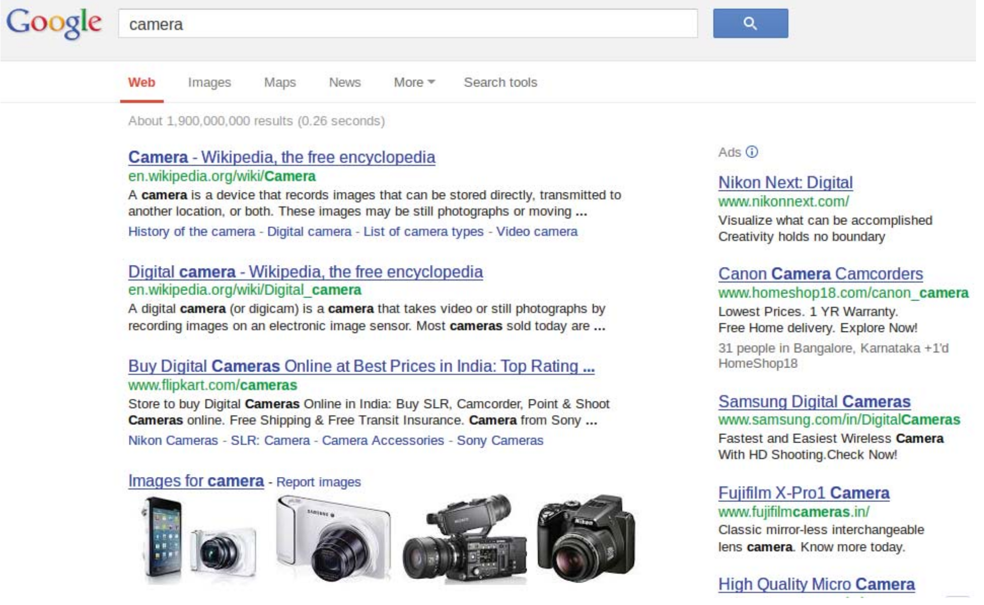

Fig. 1.6: Keyword auction on a search engine

When a sponsored link is clicked, the user is directed to the corresponding advertiser's web page. In the commonly used pay-per-click model, the advertiser makes a certain payment to the search engine for directing the user to its web page. Against every search performed by any user on any keyword, the search engine faces the problem of matching a set of advertisers to the (limited number of) sponsored slots. In addition, the search engine also needs to decide on a payment to be made by the advertiser against each click. Most search engines currently use an auction mechanism for this purpose, known as sponsored search auction. A significant percentage of the revenue of Internet giants such as Google, Microsoft, Yahoo!, etc., accrues from sponsored search auctions. In a typical sponsored search auction, advertisers are invited to specify their willingness to pay for their preferred keywords, that is, the maximum amount they would be willing to pay when an Internet user clicks on the respective sponsored slots. This willingness to pay is typically referred to as *cost-per-click*. Based on the bids submitted by the advertisers for a particular keyword, the search engine determines (1) a subset of advertisements to display; (2) the order in which the selected advertisements are displayed; and (3) the payments to be made by the selected advertisers when their respective slots are clicked by a user. The actual payment to be made depends on the bids submitted by the advertisers. The decisions (1), (2), and (3) constitute the sponsored search auction mechanism.

The search engine would typically like to maximize its revenue whereas the advertisers would wish to achieve maximum payoffs within a given budget. This leads to a classic game situation where the search engine and the advertisers are the players. The players are rational in the sense of trying to maximize their payoffs and this induces the advertisers to bid strategically after computing their best possible bids. The problem of designing a sponsored search auction mechanism becomes a problem of designing a game involving the search engine and the advertisers. The rules of the game have to be designed in a way that a well defined set of criteria would be realized by an equilibrium solution for the game.

Crowdsourcing Mechanisms

In the recent years, crowdsourcing has emerged as a major paradigm for getting work done through a large group of human resources. It can be described as distribution of work to a possibly unknown group of human resources in the form of an open call. There is a proliferation of crowdsourcing platforms in the past few years. Some of the prominent ones are Amazon Mechanical Turk, CrowdCloud, CrowdFlower, Elance, Innocentive, Taskcn, Topcoder, etc. Examples of tasks typically performed using crowdsourcing include: labeling of images, graphical design of logos, preparation of marketing plans, design of websites, developing efficient code for algorithmic business problems, classification of documents (legal documents, patents, etc.), translation services from one language to another, eliciting answers for questions, search and rescue missions in a wide geographical area, etc.

A well known crowdsourcing experiment in the recent times is the DARPA red balloon challenge which involved discovering, in as short a time as possible, 10 red balloons that were launched at ten undisclosed locations in the United States (locations shown in Figure 1.7). The total prize money was US$ 40000. The winning team from the Massachusetts Institute of Technology (MIT) employed the following mechanism. First a team of volunteers was recruited (first level volunteers) and each member of this team recruited second level volunteers. The second level volunteers recruited third level volunteers, and so on. The volunteer (say X) who first discovers a red balloon and reports it will get an incentive of US$ 2000 while the volunteer (say Y) who recruited X will get an incentive of US$ 1000, the volunteer who recruited Y will get US$ 500, and so on. The above mechanism proved highly successful and the MIT team was able to discover all ten red balloons in less than 10 hours time. The winning mechanism is an excellent example of application of game theory and mechanism design to this fascinating challenge.

In general, there are many research questions involved in deriving success out of

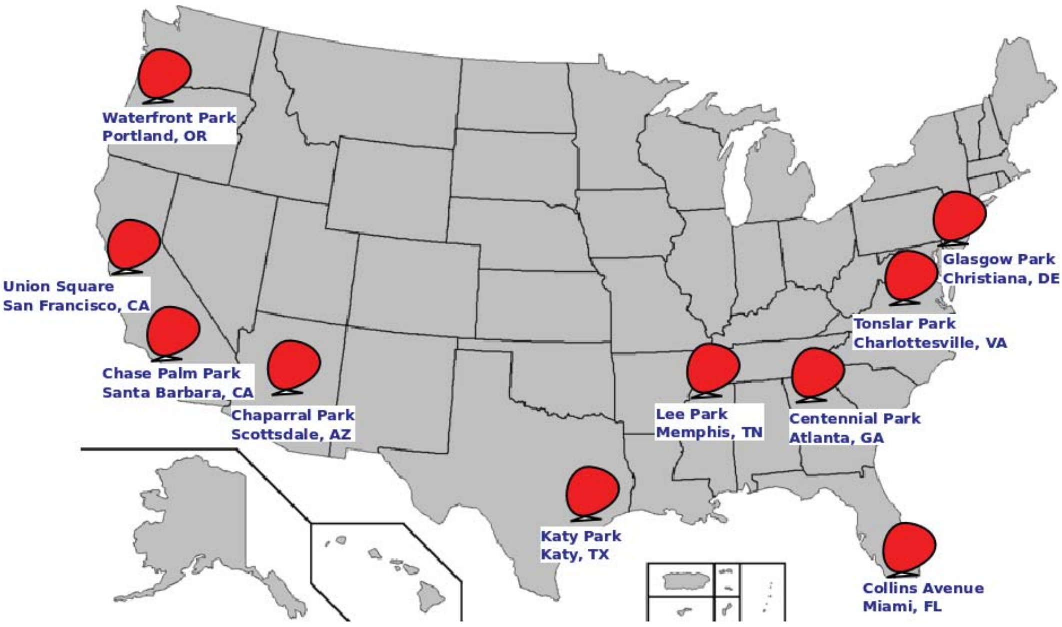

Fig. 1.7: Location of ten red balloons in the DARPA challenge

crowdsourcing. These issues include: attracting participation in required numbers, deciding on the nature and extent of incentives (cash or kind), eliciting truthful reports from the participants, and ensuring quality, timeliness, and cost-effectiveness of task execution. Game theory and mechanism design prove to be critical ingredients in designing such crowdsourcing campaigns.

Social Network Analysis

Social networks are now ubiquitous and are useful for many applications including information diffusion, electronic business, and search. Social network analysis is central to numerous Internet-based applications, for example, viral marketing, influence maximization, and influence limitation, that are based on social networks. Existing methods and tools for social network analysis have a lacuna: they do not capture the behavior (such as rationality and intelligence) of individual nodes nor do they model the strategic interactions that occur among these nodes. Game theory is a natural tool to overcome this inadequacy since it provides rigorous mathematical models of strategic interaction among autonomous, intelligent, and rational agents which form the nodes of a social network. The books by Jackson [7] and Easley and Kleinberg [1] emphasize the use of game theory in studying several social network analysis problems such as predicting topologies of social networks, modeling information diffusion, etc. For example, Figure 1.8 shows a social network in which the four most influential nodes have been identified using Shapley value, a solution concept in cooperative game theory [8]. Game theoretic approaches provide a suitable approach to designing scalable algorithms for social network analysis. Mechanism design has proved valuable in the area of social network monetization. Numerous applications using social networks have emerged in the recent times which have been enabled by the use of game theory and mechanism design.

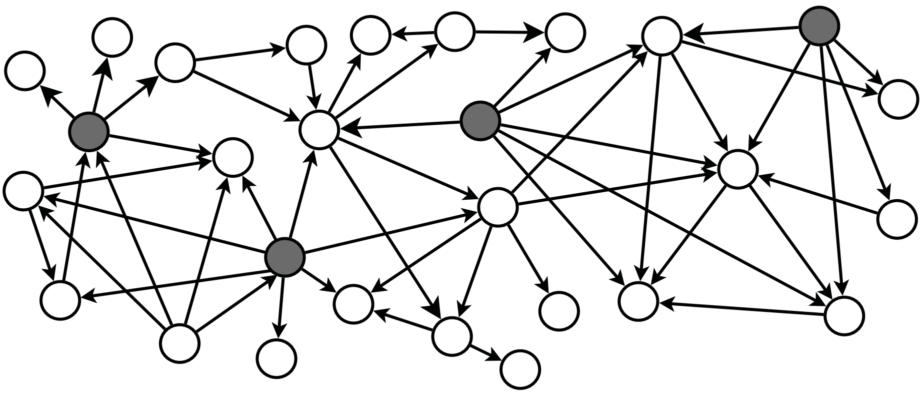

Fig. 1.8: Influential nodes in a social network

1.3 Outline of this Book

In the foregoing discussion, we have seen the increasingly influential and useful role game theory and mechanism design have come to play in inter-disciplinary research and modern applications. There is thus a heightened need to digest the foundations of game theory and mechanism design to gain a deeper understanding and appreciation of the value of game theory in the emerging applications. This textbook strives to fulfill this need.

After a thorough reading of the book, we expect that the reader will be able to use game theory and mechanism design to model, analyze, and solve centralized as well as decentralized design problems involving multiple autonomous agents that interact strategically in a rational and intelligent way. The book only assumes familiarity with an elementary course on calculus and probability. Familiarity with foundational aspects of linear algebra, real analysis, and optimization will be useful. The mathematical appendix included in Chapter 33 presents the key mathematical concepts and results that are used in the book.

There are numerous excellent textbooks and monographs available on game theory. Many of these textbooks are inspired by social sciences in general and microeconomics in particular. Our book has the primary objective of presenting the essentials of game theory and mechanism design to senior undergraduate students and above from various branches of engineering.

The book is structured into three parts:

(1) Non-cooperative game theory (Chapters 2 to 13)
(2) Mechanism design (Chapters 14 to 24)
(3) Cooperative game theory (Chapters 25 to 31)

In Part 1 (non-cooperative game theory), the chapters are devoted to key notions (such as utilities, rationality, intelligence, and common knowledge); extensive form games; strategic form games; dominant strategy equilibria; pure strategy Nash equilibria; mixed strategy Nash equilibria; utility theory; two person zero-sum games; existence theorems for Nash equilibrium (including the Nash theorem); computation of Nash equilibria; complexity of computing Nash equilibria; and Bayesian games,

Part 2 (mechanism design) is concerned with design of games. The chapters cover the following topics: building blocks of mechanisms; social choice functions and their implementation using mechanisms; notion of incentive compatibility and the equivalence of direct mechanisms and indirect mechanisms; the Gibbard-Satterthwaite theorem and the Arrow impossibility theorem; Vickrey-Clarke-Groves mechanisms; possibility and impossibility results in mechanism design; auctions and revenue equivalence theorem; optimal auctions; case study of sponsored search auctions; and mechanism implementation in ex-post Nash equilibrium.

Cooperative game theory is covered in Part 3. The chapters are devoted to correlated strategies and correlated equilibrium; Nash bargaining theory; coalitional games in characteristic form; the core of coalitional games; Shapley value; other solution concepts; and matching algorithms.

Chapter 32 (*Epilogue*) brings out the value game theory and mechanism design provide to a researcher in engineering sciences. Chapter 33 consists of a mathematical appendix that includes key concepts and results in probability, linear algebra, linear programming, mathematical analysis, and computational complexity which are often used in the textbook.

Each of the chapters commences with a motivating introduction to the chapter and concludes with a crisp summary of the chapter and a list of references to probe further. A set of problems is included in every chapter. Concepts and results are illustrated using a number of examples. These examples are carefully chosen from different domains including computer science, networks, and microeconomics; however they are fairly generic. The chapters also contain, at relevant places, informative biographical sketches of game theorists and mechanism designers who have made

We need to emphasize that our book is inspired by, and, indeed, has immensely benefited from the superb expositions available in the following books and monographs: Mas-Colell, Whinston, and Green [9]; Myerson [10]; Maschler, Solan, and Zamir [11]; Nisan, Roughgarden, Tardos, and Vazirani [12]; Shoham and Leyton-Brown [13]; Straffin [14]; and Osborne [15]. The monograph by Narahari, Garg, Narayanam, and Prakash [16] can be considered as a precursor to the current effort.

A superb collection of classic papers in game theory brought out in 1997 [17] is a must read for passionate students and researchers. We also refer the readers to a recent, very comprehensive book by Maschler, Solan, and Zamir [11].

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