

# Pajek

Sociology



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This page intentionally left blank Exploratory Network Analysis with Pajek

This is the first textbook on social network analysis integrating theory, applications, and professional software for performing network analysis (Pajek). Step by step, the book introduces the main structural concepts and their applications in social research with exercises to test the understanding. In each chapter, each theoretical section is followed by an application section explaining how to perform the network analyses with Pajek software. Pajek software and data sets for all examples are freely available, so the reader can learn network analysis by doing it. In addition, each chapter offers case studies for practicing network analysis. In the end, the reader has the knowledge, skills, and tools to apply social network analysis in all social sciences, ranging from anthropology and sociology to business administration and history. Wouter de Nooy specializes in social network analysis and applications of network analysis to the fields of literature, the visual arts, music, and arts policy. His international publications have appeared in *Poetics and Social Networks*. He is Lecturer in methodology and sociology of the arts, Department of History and Arts Studies, Erasmus University, Rotterdam. Andrej Mrvar is assistant Professor of Social Science Informatics at the University of Ljubljana, Slovenia. He has won several awards for graph drawings at competitions between 1995 and 2000. He has edited *Metodoloski zvezki* since 2000. Vladimir Batagelj is Professor of Discrete and Computational Mathematics at the University of Ljubljana, Slovenia and is a member of the editorial boards of *Informatica* and *Journal of Social Structure*. He has authored several articles in *Communications of ACM*, *Psychometrika*, *Journal of Classification*, *Social Networks*, *Discrete Mathematics*, *Algorithmica*, *Journal of Mathematical Sociology*, *Quality and*

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Quantity, Informatica, Lecture Notes in Computer Science, Studies in Classification, Data Analysis, and Knowledge Organization. Structural Analysis in the Social Sciences Mark Granovetter, editor The series Structural Analysis in the Social Sciences presents approaches that explain social behavior and institutions by reference to relations among such concrete entities as persons and organizations. This contrasts with at least four other popular strategies: (a) reductionist attempts to explain by a focus on individuals alone; (b) explanations stressing the casual primacy of such abstract concepts as ideas, values, mental harmonies, and cognitive maps (thus, "structuralism" on the Continent should be distinguished from structural analysis in the present sense); (c) technological and material determination; (d) explanation using "variables" as the main analytic concepts (as in the "structural equation" models that dominated much of the sociology of the 1970s), where structure is that connecting variables rather than actual social entities. The social network approach is an important example of the strategy of structural analysis; the series also draws on social science theory and research that is not framed explicitly in network terms, but stresses the importance of relations rather than the atomization of reduction or the determination of ideas, technology, or material conditions. Though the structural perspective has become extremely popular and influential in all the social sciences, it does not have a coherent identity, and no series yet pulls together such work under a single rubric. By bringing the achievements of structurally oriented scholars to a wider public, the Structural Analysis series hopes to encourage the use of this very fruitful approach. Mark Granovetter Other Books in the Series 1. Mark S. Mizruchi and Michael Schwartz, eds., Intercorporate Relations: The <https://assignbuster.com/pajek/>

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networks/book/) dedicated to this book. All the commands that are needed to produce the graphical and numerical results presented in this book are extensively discussed and illustrated. Step by step, the reader can perform the analyses presented in the book. Note, however, that the graphical display on a computer screen will never exactly match the printed figures in this book. After all, a book is not a computer screen. Furthermore, newer versions of the software will appear, with features that may differ from the descriptions presented in this book. We strongly advise using the version of Pajek software supplied on the book's Web site (<http://vlado.fmf.uni-lj.si/pub/networks/book/>) while studying this book and then updating to a newer version of Pajek afterwards, which can be downloaded from <http://vlado.fmf.unilj.si/pub/networks/pajek/default.htm>. Overview This book contains five sections. The first section (Part I) presents the basic concepts of social network analysis. The next three sections present the three major research topics in social network analysis: cohesion xxiii xxiv Preface (Part II), brokerage (Part III), and ranking (Part IV). We claim that all major applications of social network analysis in the social sciences relate to one or more of these three topics. The final section discusses an advanced technique (viz., blockmodeling), which integrates the three research topics (Part V). The first section, titled Fundamentals, introduces the concept of a network, which is obviously the basic object of network analysis, and the concepts of a partition and a vector, which contain additional information on the network or store the results of analyses. In addition, this section helps the reader get started with Pajek software. Part II on cohesion consists of three chapters, each of which presents measures of cohesion in a particular type of network: ordinary networks (Chapter 3), <https://assignbuster.com/pajek/>

signed networks (Chapter 4), and valued networks (Chapter 5). Networks may contain different types of relations. The ordinary network just shows whether there is a tie between people, organizations, or countries. In contrast, signed networks are primarily used for storing relations that are either positive or negative such as affective relations: liking and disliking. Valued networks take into account the strength of ties, for example, the total value of the trade from one country to another or the number of directors shared by two companies. Part III on brokerage focuses on social relations as channels of exchange. Certain positions within the network are heavily involved in the exchange and flow of information, goods, or services, whereas others are not. This is connected to the concepts of centrality and centralization (Chapter 6) or brokers and bridges (Chapter 7). Chapter 8 discusses an important application of these ideas, namely the analysis of diffusion processes. The direction of ties (e. g., who initiates the tie) is not very important in the section on brokerage, but it is central to ranking, presented in Part IV. Social ranking, it is assumed, is connected to asymmetric relations. In the case of positive relations, such as friendship nominations or advice seeking, people who receive many choices and reciprocate few choices are deemed as enjoying more prestige (Chapter 9). Patterns of asymmetric choices may reveal the stratification of a group or society into a hierarchy of layers (Chapter 10). Chapter 11 presents a particular type of asymmetry, namely the asymmetry in social relations caused by time: genealogical descent and citation. The final section, Part V, on roles, concentrates on rather dense and small networks. This type of network can be visualized and stored efficiently by means of matrices. Blockmodeling is a suitable technique for analyzing cohesion, brokerage, and

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ranking in dense, small networks. It focuses on positions and social roles (Chapter 12). The book is intended for researchers and managers who want to apply social network analysis and for courses on social network analysis in all social sciences as well as other disciplines using social methodology (e.g., history and business administration). Regardless of the context in which the book is used, Chapters 1, 2, and 3 must be studied to understand the topics of subsequent chapters and the logic of Pajek. Chapters 4 and 5 may be skipped if the researcher or student is not interested in networks

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 Ch. 5 - Affiliations  
 Ch. 11 - Genealogies and citations  
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 Ch. 2 - Attributes and relations  
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Figure 1. Dependencies between the chapters. with signed or valued relations, but we strongly advise including them to be familiar with these types of networks. In Parts III (Brokerage) and IV (Ranking), the first two chapters present basic concepts and the third chapter focuses on particular applications. Figure 1 shows the dependencies among the chapters of this book. To study a particular chapter, all preceding chapters in this flow chart must have been studied before. Chapter 10, for instance, requires understanding of Chapters 1 through 4 and 9. Within the chapters, there are not sections that can be skipped. In an undergraduate course, Part I and II should be included. A choice can be made between Part III and Part IV or, alternatively, just the first chapter from each section may be selected. Part V on social roles and blockmodeling is quite advanced and more appropriate for a postgraduate course. For managerial purposes, Part III is probably more interesting than Part IV. Justification This book offers an

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introduction to social network analysis, which implies that it covers a limited set of topics and techniques, which we feel a beginner must master to be able to find his or her way in the field of social network analysis. We have made many decisions about what to include and what to exclude and we want to justify our choices now. As reflected in the title of this book, we restrict ourselves to exploratory social network analysis. The testing of hypotheses by means of statistical models or Monte Carlo simulations falls outside the scope of this book. In social network analysis, hypothesis testing is important but complicated; it deserves a book on its own. Aiming our book at people who are new to social network analysis, our first priority is to have them explore the structure of social networks to give them a feel for the concepts and applications of network analysis. Exploration involves visualization and manipulation of concrete networks, whereas hypothesis testing boils down to numbers representing abstract parameters and probabilities. In xxvi Preface our view, exploration yields the intuitive understanding of networks and basic network concepts that are a prerequisite for well-considered hypothesis testing. From the vast array of network analytic techniques and indices we discuss only a few. We have no intention of presenting a survey of all structural techniques and indices because we fear that the readers will not be able to see the forest for the trees. We focus on as few techniques and indices as are needed to present and measure the underlying concept. With respect to the concept of cohesion, for instance, many structural indices have been proposed for identifying cohesive groups:  $n$ -cliques,  $n$ -clans,  $n$ -clubs,  $m$ -cores,  $k$ -cores,  $k$ -plexes, lambda sets, and so on. We discuss only components,  $k$ -cores, 3-cliques, and  $m$ -slices ( $m$ -cores) because they suffice to explain the basic

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parameters involved: density, connectivity, and strength of relations within cohesive subgroups. Our choice is influenced by the software that we use because we have decided to restrict our discussion to indices and techniques that are incorporated in this software. Pajek software is designed to handle very large networks (up to millions of vertices). Therefore, this software package concentrates on efficient routines, which are capable of dealing with large networks. Some analytical techniques and structural indices are known to be inefficient (e. g., the detection of  $n$ -cliques), and for others no efficient algorithm has yet been found or implemented. This limits our options: we present only the detection of small cliques (of size 3) and we cannot extensively discuss an important concept such as  $k$ -connectivity. In summary, this book is neither a complete catalogue of network analytic concepts and techniques nor an exhaustive manual to all commands of Pajek. It offers just enough concepts, techniques, and skills to understand and perform all major types of social network analysis. In contrast to some other handbooks on social network analysis, we minimize mathematical notation and present all definitions verbatim. There are no mathematical formulae in the book. We assume that many students and researchers are interested in the application of social network analysis rather than in its mathematical properties. As a consequence, and this may be very surprising to seasoned network analysts, we do not introduce the matrix as a data format and display format for social networks until the end of the book. Finally, there is a remark on the terminology used in the book. Social network analysis derives its basic concepts from mathematical graph theory. Unfortunately, different "vocabularies" exist within graph theory, using different concepts to refer to the same phenomena. Traditionally, social

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network analysts have used the terminology employed by Frank Harary, for example, in his book *Graph Theory* (Reading, Addison-Wesley, 1969). We choose, however, to follow the terminology that prevails in current textbooks on graph theory, for example, R. J. Wilson's *Introduction to Graph Theory* (Edinburgh, Oliver and Boyd, 1972; published later by Wiley, New York). Thus, we hope to narrow the terminological gap between social network analysis and graph theory. As a result, we speak of a vertex instead of a node or a point and some of our definitions and concepts differ from those proposed by Frank Harary.

Preface xxvii Acknowledgments The text of this book has benefited from the comments and suggestions from our students at the University of Ljubljana and the Erasmus University Rotterdam, who were the first to use it. In addition, Michael Frishkopf and his students of musicology at the University of Alberta gave us helpful comments. Mark Granovetter, who welcomed this book to his series, and his colleague Sean Farley Everton have carefully read and commented on the chapters. In many ways, they have helped us make the book more coherent and understandable to the reader. We are also very grateful to an anonymous reviewer, who carefully scrutinized the book and made many valuable suggestions for improvements. Ed Parsons (Cambridge University Press) and Nancy Hulan (TechBooks) helped us through the production process. Finally, we thank the participants of the workshops we conducted at the XXII<sup>nd</sup> and XXIII<sup>rd</sup> Sunbelt International Conference on Social Network Analysis in New Orleans and Cancun for their encouraging reactions to our manuscript. Most data sets that are used in this book have been created from sociograms or listings printed in scientific articles and books. Notwithstanding our conviction that reported scientific results should be

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used and distributed freely, we have tried to trace the authors of these articles and books and ask for their approval. We are grateful to have obtained explicit permission for using and distributing the data sets from them. Authors or their representatives whom we have not reached are invited to contact us.

Part I Fundamentals Social network analysis focuses on ties among, for example, people, groups of people, organizations, and countries. These ties combine to form networks, which we will learn to analyze. The first part of the book introduces the concept of a social network. We discuss several types of networks and the ways in which we can analyze them numerically and visually with the computer software program Pajek, which is used throughout this book. After studying Chapters 1 and 2, you should understand the concept of a social network and you should be able to create, manipulate, and visualize a social network with the software presented in this book.

### 1.1 Looking for Social Structure

#### 1.1.1 Introduction

The social sciences focus on structure: the structure of human groups, communities, organizations, markets, society, or the world system. In this book, we conceptualize social structure as a network of social ties. Social network analysts assume that interpersonal ties matter, as do ties among organizations or countries, because they transmit behavior, attitudes, information, or goods. Social network analysis offers the methodology to analyze social relations; it tells us how to conceptualize social networks and how to analyze them. In this book, we present the most important methods of exploring social networks, emphasizing visual exploration. Network visualization has been an important tool for researchers from the very beginning of social network analysis. This chapter introduces the basic elements of a social network and shows how to construct and draw a social

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network. 1. 2 Sociometry and Sociogram The basis of social network visualization was laid by researchers who called themselves sociometrists. Their leader, J. L. Moreno, founded a social science called sociometry, which studies interpersonal relations. Society, they argued, is not an aggregate of individuals and their characteristics, as statisticians assume, but a structure of interpersonal ties. Therefore, the individual is not the basic social unit. The social atom consists of an individual and his or her social, economic, or cultural ties. Social atoms are linked into groups, and, ultimately, society consists of interrelated groups. From their point of view, it is understandable that sociometrists studied the structure of small groups rather than the structure of society at large. In particular, they investigated social choices within a small group. They asked people questions such as, " Whom would you choose as a friend [colleague, advisor, etc.]? " This type of data has since been known as sociometric choice. In sociometry, social choices are considered the most important expression of social relations. 3 4 Exploratory

Network Analysis with Pajek Louise 2 2 1 2 1 2 1 Ada 1 Lena Adele 1 Marion 2 1 2 2 1 1 2 2 Jane Cora 2 2 2 1 Frances 1 Maxine 2 1 1 2 1 1 Mary 1 Eva 1 2 Edna Anna Ruth 1 Martha 1 2 2 1 2 Betty 2 2 Jean 1 1 Robin 2 Alice Helen Laura 1 2 2 1 Hazel 1 2 Ellen 2 1 Hilda Ella 2 1 Irene

Figure 2. Sociogram of dining-table partners. Figure 2 presents an example of sociometric research. It depicts the choices of twenty-six girls living in one " cottage" (dormitory) at a New York state training school. The girls were asked to choose the girls they liked best as their dining-table partners. First and second choices are selected only. (Here and elsewhere, a reference on the source of the data can be found under Further Reading, which is at the end of each chapter.)

Figure 2 is an example of a sociogram, which is a graphical representation of <https://assignbuster.com/pajek/>

group structure. The sociogram is among the most important instruments originated in sociometry, and it is the basis for the visualization of social networks. You have most likely already "read" and understood the figure without needing the following explanation, which illustrates its visual appeal and conceptual clarity. In this sociogram, each girl in the dormitory is represented by a circle. For the sake of identification, the girls' names are written next to the circles. Each arc (arrow) represents a choice. The girl who chooses a peer as a dining-table companion sends an arc toward her. Irene (in the bottom right of the figure), for instance, chose Hilda as her favorite dining-table partner and Ellen as her second choice, as indicated by the numbers labeling each arrow. A sociogram depicts the structure of ties within a group. This example shows not only which girls are popular, as indicated by the number of choices they receive, but also whether the choices come from popular or unpopular girls. For example, Hilda receives four choices from Irene, Ruth, Hazel, and Betty, and she reciprocates the last two choices. But none of these four girls is chosen by any of the other girls. Therefore, Hilda is located at the margin of the sociogram, whereas Frances, who is chosen only twice, is more central because she is chosen by "popular" girls such as Adele and Marion. A simple count of choices does not reveal this, whereas a sociogram does.

Looking for Social Structure The sociogram has proved to be an important analytical tool that helped to reveal several structural features of social groups. In this book, we make ample use of it.

### 5.1.3 Exploratory Social Network Analysis

Sociometry is not the only tradition in the social sciences that focuses on social ties. Without going into historical detail (see Further Reading for references on the history of social network analysis), we may note that scientists from several social

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sciences have applied network analysis to different kinds of social relations and social units. Anthropologists study kinship relations, friendship, and gift giving among people rather than sociometric choice; social psychologists focus on affections; political scientists study power relations among people, organizations, or nations; economists investigate trade and organizational ties among firms. In this book, the word actor refers to a person, organization, or nation that is involved in a social relation. We may say that social network analysis studies the social ties among actors. The main goal of social network analysis is detecting and interpreting patterns of social ties among actors. This book deals with exploratory social network analysis only. This means that we have no specific hypotheses about the structure of a network beforehand that we can test. For example, a hypothesis on the diningtable partners network could predict a particular rate of mutual choices (e. g., one of five choices will be reciprocated). This hypothesis must be grounded in social theory and prior research experience. The hypothesis can be tested provided that an adequate statistical model is available. We use no hypothesis testing here, because we cannot assume prior research experience in an introductory course book and because the statistical models involved are complicated. Therefore, we adopt an exploratory approach, which assumes that the structure or pattern of ties in a social network is meaningful to the members of the network and, hence, to the researcher. Instead of testing prespecified structural hypotheses, we explore social networks for meaningful patterns. For similar reasons, we pay no attention to the estimation of network features from samples. In network analysis, estimation techniques are even more complicated than estimation in statistics, because the structure of a random sample seldom matches the

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structure of the overall network. It is easy to demonstrate this. For example, select five girls from the diningtable partners network at random and focus on the choices among them. You will find fewer choices per person than the two choices in the overall network for the simple reason that choices to girls outside the sample are neglected. Even in this simple respect, a sample is not representative of a network.

### 6 Exploratory Network Analysis with Pajek

We analyze entire networks rather than samples. However, what is the entire network? Sociometry assumes that society consists of interrelated groups, so a network encompasses society at large. Research on the so-called Small World problem suggested that ties of acquaintanceship connect us to almost every human being on the earth in six or seven steps, (i. e., with five or six intermediaries), so our network eventually covers the entire world population, which is clearly too large a network to be studied. Therefore, we must use an artificial criterion to delimit the network we are studying. For example, we may study the girls of one dormitory only. We do not know their preferences for table partners in other dormitories. Perhaps Hilda is the only vegetarian in a group of carnivores and she prefers to eat with girls of other dormitories. If so, including choices between members of different dormitories will alter Hilda's position in the network tremendously. Because boundary specification may seriously affect the structure of a network, it is important to consider it carefully. Use substantive arguments to support your decision of whom to include in the network and whom to exclude. Exploratory social network analysis consists of four parts: the definition of a network, network manipulation, determination of structural features, and visual inspection. In the following subsections we present an overview of these techniques. This

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overview serves to introduce basic concepts in network analysis and to help you get started with the software used in this book.

1. 3. 1 Network  
Definition To analyze a network, we must first have one. What is a network? Here, and elsewhere, we use a branch of mathematics called graph theory to define concepts. Most characteristics of networks that we introduce in this book originate from graph theory. Although this is not a course in graph theory, you should study the definitions carefully to understand what you are doing when you apply network analysis.

Throughout this book, we present definitions in text boxes to highlight them. A graph is a set of vertices and a set of lines between pairs of vertices. What is a graph? A graph represents the structure of a network; all it needs for this is a set of vertices (which are also called points or nodes) and a set of lines where each line connects two vertices. A vertex (singular of vertices) is the smallest unit in a network. In social network analysis, it represents an actor (e. g., a girl in a dormitory, an organization, or a country). A vertex is usually identified by a number. A line is a tie between two vertices in a network. In social network analysis it can be any social relation. A line is defined by its two endpoints, which are the two vertices that are incident with the line. A loop is a special kind of line, namely, a line that connects a vertex to itself. In the dining-table partners network, loops do not occur Looking for Social Structure because girls are not allowed to choose themselves as a dinner-table partner. However, loops are meaningful in some kinds of networks. A line is directed or undirected. A directed line is called an arc, whereas an undirected line is an edge. Sociometric choice is best represented by arcs, because one girl chooses another and choices need not be reciprocated (e. g., Ella and Ellen in Figure 2). A directed graph

or digraph contains one or more arcs. A social relation that is undirected (e.g., is family of) is represented by an edge because both individuals are equally involved in the relation. An undirected graph contains no arcs: all of its lines are edges. Formally, an arc is an ordered pair of vertices in which the first vertex is the sender (the tail of the arc) and the second the receiver of the tie (the head of the arc). An arc points from a sender to a receiver. In contrast, an edge, which has no direction, is represented by an unordered pair. It does not matter which vertex is first or second in the pair. We should note, however, that an edge is usually equivalent to a bidirectional arc: if Ella and Ellen are sisters (undirected), we may say that Ella is the sister of Ellen and Ellen is the sister of Ella (directed). It is important to note this, as we will see in later chapters. The dining-table partners network has no multiple lines because no girl was allowed to nominate the same girl as first and second choice. Without this restriction, which was imposed by the researcher, multiple arcs could have occurred, and they actually do occur in other social networks. In a graph, multiple lines are allowed, but when we say that a graph is simple, we indicate that it has no multiple lines. In addition, a simple undirected graph contains no loops, whereas loops are allowed in a simple directed graph. It is important to remember this. A simple undirected graph contains neither multiple edges nor loops. A simple directed graph contains no multiple arcs. Now that we have discussed the concept of a graph at some length, it is very easy to define a network. A network consists of a graph and additional information on the vertices or lines of the graph. We should note that the additional information is irrelevant to the structure of the network because the structure depends on the pattern of ties. A network consists of a graph

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and additional information on the vertices or the lines of the graph. In the dining-table partners network, the names of the girls represent additional information on the vertices that turns the graph into a network. Because of this information, we can see which vertex identifies Ella in the sociogram. The numbers printed near the arcs and edges offer additional information on the links between the girls: a 1 indicates a first choice and a 2 represents a second choice. They are called line values, and they usually indicate the strength of a relation. 7 8 Exploratory Network Analysis with Pajek The dining-table partners network is clearly a network and not a graph. It is a directed simple network because it contains arcs (directed) but not multiple arcs (simple). In addition, we know that it contains no loops. Several analytical techniques we discuss assume that loops and multiple lines are absent from a network. However, we do not always spell out these properties of the network but rather indicate whether it is simple. Take care!

Application In this book, we learn social network analysis by doing it. We use the computer program Pajek — Slovenian for spider — to analyze and draw social networks. The Web site dedicated to this book (<http://vlado.fmf.unilj.si/pub/networks/book/>) contains the software. We advise you to download and install Pajek on your computer (see Appendix 1 for more details) and all example data sets from this Web site. Store the software and data sets on the hard disk of your computer following the guidelines provided on the Web site. When you have done so, carry out the commands that we discuss under “ Application” in each chapter. This will familiarize you with the structural concepts and with Pajek. By following the instructions under “ Application” step by step, you will be able to produce the figures and results presented in the theoretical sections unless stated differently. Sometimes, the <https://assignbuster.com/pajek/>

visualizations on your computer screen will be slightly different from the figures in the book. If the general patterns match, however, you know that you are on the right track. Some concepts from graph theory are the building blocks or data objects of Pajek. Of course, a network is the most important data object in Pajek, so let us describe it first. In Pajek, a network is defined in accordance with graph theory: a list of vertices and lists of arcs and edges, where each arc or edge has a value. Take a look at the partial listing of the data file for the dining-table partners network (Figure 3, note that part of the vertices and arcs are replaced by [ . . . ]).

Open the file Dining-table\_partners.net, which you have downloaded from the Web site, in a word processor program to see the entire data file.

```
*Vertices 26 1 " Ada" 2 " Cora" 3 " Louise" 4 " Jean" [...] 25 " Laura" 26 "
Irene" *Arcs 1 3 2 1 2 1 2 1 1 2 4 2 3 9 1 3 11 2 [...] 1 25 15 25 17 2 26 13 1
26 24 2 *Edges Network data file 0. 1646 0. 0481 0. 3472 0. 1063 0. 1077
0. 3446 0. 0759 0. 6284 0. 5000 0. 5000 0. 5000 0. 5000 0. 5101 0. 6557 0.
5000 0. 7478 0. 9241 0. 5000
```

Figure 3. Partial listing of a network data file for Pajek. Looking for Social Structure First, the data file specifies the number of vertices. Then, each vertex is identified on a separate line by a serial number, a textual label [enclosed in quotation marks (" ")] and three real numbers between 0 and 1, which indicate the position of the vertex in three-dimensional space if the network is drawn. We pay more attention to these coordinates in Chapter 2. For now, it suffices to know that the first number specifies the horizontal position of a vertex (0 is at the left of the screen and 1 at the right) and the second number gives the vertical position of a vertex (0 is the top of the screen and 1 is the bottom). The text label is crucial for identification of vertices, the

more so because serial numbers of vertices may change during the analysis. The list of vertices is followed by a list of arcs. Each line identifies an arc by the serial number of the sending vertex, followed by the number of the receiving vertex and the value of the arc. Just as in graph theory, Pajek defines a line as a pair of vertices. In Figure 3, the first arc represents Ada's choice (vertex 1) of Louise (vertex 3) as a dining-table partner. Louise is Ada's second choice; Cora is her first choice, which is indicated by the second arc. A list of edges is similar to a list of arcs with the exception that the order of the two vertices that identify an edge is disregarded in computations. In this data file, no edges are listed. It is interesting to note that we can distinguish between the structural data or graph and the additional information on vertices and lines in the network data file. The graph is fully defined by the list of vertex numbers and the list of pairs of vertices, which defines its arcs and edges. This part of the data, which is printed in regular typeface in Figure 3, represents the structure of the network. The vertex labels, coordinates, and line values (in italics) specify the additional properties of vertices and lines that make these data a network. Although this information is extremely useful, it is not required: Pajek will use vertex numbers as default labels and set line values to 1 if they are not specified in the data file. In addition, Pajek can use several other data formats (e. g., the matrix format), which we do not discuss here. They are briefly described in Appendix 1. It is possible to generate ready-to-use network files from spreadsheets and databases by exporting the relevant data in plain text format. For medium or large networks, processing the data as a relational database helps data cleaning and coding. See Appendix 1 for details. We explain how to create a new

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network in Section 1.4. Let us first look at the network of the dining-table partners. First, start Pajek by doubleclicking the file Pajek.exe on your hard disk. The computer will display the Main screen of Pajek (Figure 4). From this screen, you can open the dining-table partners network with the Read command in the File menu or by clicking the button with an icon of a folder under the word Network. In both cases, the usual Windows file dialog box appears in which you can search and select the file Dining-table\_partners.net on your hard disk, provided that you have downloaded the example data sets from the book's Web site. When Pajek reads a network, it displays its name in the Network dropdown menu. This menu is a list of the networks that are accessible to Pajek. You can open a drop-down menu by left-clicking on the button with the triangle at the right. The network that you select in the list is shown when you click File > Network > Read Network drop-down menu. Exploratory Network Analysis with Pajek Figure 4. Pajek Main screen. the list is closed (e.g., the network Dining-table\_partners.net in Figure 2). Notice that the number of vertices in the network is displayed in parentheses next to the name. The selected network is the active network, meaning that any operation you perform on a network will use this particular network. For example, if you use the Draw menu now, Pajek draws the dining-partners network for you. The Main screen displays five more drop-down menus beneath the Network drop-down menu. Each of these menus represents a data object in Pajek: partitions, permutations, clusters, hierarchies, and vectors. Later chapters will familiarize you with these data objects. Note that each object can be opened, saved, or edited from the File menu or by using the three icons to the left of a drop-down menu (see Section 1.4).

1.3.2 Manipulation In social network analysis, it is

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often useful to modify a network. For instance, large networks are too big to be drawn, so we extract a meaningful part of the network that we inspect first. Visualizations work much better for small (some dozens of vertices) to medium-sized (some hundreds of vertices) networks than for large networks with thousands of vertices. When social networks contain different kinds of relations, we may focus on one relation only; for instance, we may want to study first choices only in the dining-table partners network. Finally, some analytical procedures demand that complex networks with loops or multiple lines are reduced to simple graphs first. Application

Network manipulation is a very powerful tool in social network analysis. In this book, we encounter several techniques for modifying a network or selecting a subnetwork. Network manipulation always results in a new network. In general, many commands in Pajek produce new networks or other data objects, which are stored in the drop-down menus, rather than graphical or tabular output. Looking for Social Structure 11 Figure 5. Menu structure in Pajek. The commands for manipulating networks are accessible from menus in the Main screen. The Main screen menus have a clear logic. Manipulations that involve one type of data object are listed under a menu with the object's name; for example, the Net menu contains all commands that operate on one network and the Nets menu lists operations on two networks. Manipulations that need different kinds of objects are listed in the Operations menu. When you try to locate a command in Pajek, just consider which data objects you want to use. The following example highlights the use of menus in Pajek and their notation in this book. Suppose we want to change reciprocated choices in the dining-table partners network into edges. Because this operation concerns one network and no other data objects, we

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must look for it in the Net menu. If we left-click on the word Net in the upper left of the Main screen, a drop-down menu is displayed. Position the cursor on the word Transform in the drop-down menu and a new submenu is opened with a command to change arcs into edges (Arcs to Edges). Finally, we reach the command allowing us to change bidirectional arcs into edges and to assign a new line value to the new edge that will replace them (see Figure 5). We choose to sum the values of the arcs, knowing that two reciprocal first choices will yield an edge value of two, a first choice answered by a second choice will produce an edge value of three, and a line value of four will result from a reciprocal second choice. In this book, we abbreviate this sequence of commands as follows: [Main]Net> Transform> Arcs to Edges> Bidirected only> Sum Values

The screen or window that contains the menu is presented between square brackets and a transition to a submenu is indicated by the > symbol. The screen name is specified only if the context is ambiguous. The abbreviated command is also displayed in the margin (see above) for the purpose of quick reference. When the command to change arcs into edges is executed, an information box appears asking whether a new network must be made

Menu structure Net> Transform> Arcs to Edges> Bidirected only> Sum Values 12 Exploratory Network Analysis with Pajek Figure 6. An information box in Pajek. (Figure 6). If the answer is yes, which we advise, a new network named Bidirected Arcs to Edges (SUM) of N1 (26) is added to the Network drop-down menu with a serial number of 2. The original network is not changed. Conversely, answering no to the question in the information box causes Pajek to change the original network.

Exercise I Remove all second choices from the original network of dining-table partners with the command summarized in the left

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margin. Which number do you enter in the dialog box headed " Remove lines with high values" and why is this command part of the Net menu? (The answers to the exercises are listed in Section 1. 9.) Net> Transform> Remove> lines with value> higher than 1. 3. 3 Calculation In social network analysis, many structural features have been quantified (e. g., an index that measures the centrality of a vertex). Some measures pertain to the entire network, whereas others summarize the structural position of a subnetwork or a single vertex. Calculation outputs a single number in the case of a network characteristic and a series of numbers in the case of subnetworks and vertices. Exploring network structure by calculation is much more concise and precise than visual inspection. However, structural indices are sometimes abstract and difficult to interpret. Therefore, we use both visual inspection of a network and calculation of structural indices to analyze network structure. Application In Pajek, results of calculations and other kinds of feedback to the user are automatically reported in a separate window that we call the Report screen. If you closed the Report screen or if it is hidden behind other screens, you can show it again with the Show Report Window command in the File menu of Pajek's Main screen. The Report screen displays numeric results that summarize structural features as a single number, a frequency distribution, or a cross-tabulation. Calculations that assign a value to each vertex are not reported in this screen. They are stored as data objects in Pajek, notably as partitions and vectors (see Chapter 2). The Report screen displays text but no network Report screen File> Show Report Window Looking for Social Structure 13 Figure 7. Report screen in Pajek. drawings. The contents of the Report screen can be saved as a text file from its File menu. The Report screen depicted in Figure 7

shows the number of vertices, edges, and arcs in the original dining-table partners network. This is general information on the network that is provided by the command Info> Network> General (as you know now, this means the General command within the Network submenu of the Info menu). In addition to the number of vertices, edges, and arcs, the screen shows the number of multiple lines and loops and two indices of network density that are explained in Chapter 3. Also, this command displays the number of lines requested in the dialog box depicted in Figure 8. Info> Network> General

Figure 8. Dialog box of Info> Network> General command. 14 Exploratory Network Analysis with Pajek In this example, we typed a 5 in the dialog box, so the report screen shows the five lines with the highest line values that are second choices in the dining-table partners network. In the Report screen, each line is described by its rank according to its line value, a pair of vertex numbers, the line value, and a pair of vertex labels. Hence, the first line in Figure 7 represents the arc from Ada (vertex 1) to Louise (vertex 3), which is Ada's second choice. Exercise II Can you see the number of first choices from the listing in Figure 7 and does this number surprise you? Which number should you enter in the dialog box depicted in Figure 8 to get a list of all arcs representing first choices? 1. 3. 4 Visualization The human eye is trained in pattern recognition. Therefore, network visualizations help to trace and present patterns of ties. In Section 1. 2, we presented the sociogram as the first systematic visualization of a social network. It was the sociometrists' main tool to explore and understand the structure of ties in human groups. In books on graph theory, visualizations are used to illustrate concepts and proofs. Visualizations facilitate an intuitive understanding of network concepts, so we use them frequently. Our

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eyes are easily fooled, however. A network can be drawn in many ways, and each drawing stresses different structural features. Therefore, the analyst should rely on systematic rather than ad hoc principles for network drawing. In general, we should use automatic procedures, which generate an optimal layout of the network, when we want to explore network structure.

Subsequently, we may edit the automatically generated layout manually if we want to present it. Some basic principles of network drawing should be observed. The most important principle states that the distance between vertices should express the strength or number of their ties as closely as possible. In a map, the distance between cities matches their geographical distance. In psychological charts, spatial proximity of objects usually expresses perceived similarity. Because social network analysis focuses on relations, a drawing should position vertices according to their ties: vertices that are connected should be drawn closer together than vertice