

# Contents

<b>1</b>	<b>Introduction</b> .....	1
1.1	Why Networks? .....	1
1.2	Types of Network Analysis .....	3
1.2.1	Visualizing and Characterizing Networks .....	3
1.2.2	Network Modeling and Inference .....	5
1.2.3	Network Processes .....	7
1.3	Why Use R for Network Analysis? .....	8
1.4	About This Book .....	9
1.5	About the R code .....	10
<b>2</b>	<b>Manipulating Network Data</b> .....	13
2.1	Introduction .....	13
2.2	Creating Network Graphs .....	14
2.2.1	Undirected and Directed Graphs .....	14
2.2.2	Representations for Graphs .....	16
2.2.3	Operations on Graphs .....	17
2.3	Decorating Network Graphs .....	18
2.3.1	Vertex, Edge, and Graph Attributes .....	18
2.3.2	Using Data Frames .....	20
2.4	Talking About Graphs .....	21
2.4.1	Basic Graph Concepts .....	21
2.4.2	Special Types of Graphs .....	24
2.5	Additional Reading .....	28
<b>3</b>	<b>Visualizing Network Data</b> .....	29
3.1	Introduction .....	29
3.2	Elements of Graph Visualization .....	29
3.3	Graph Layouts .....	30
3.4	Decorating Graph Layouts .....	34
3.5	Visualizing Large Networks .....	36

3.6	Using Visualization Tools Outside of R .....	39
3.7	Additional Reading .....	41
<b>4</b>	<b>Descriptive Analysis of Network Graph Characteristics .....</b>	<b>43</b>
4.1	Introduction .....	43
4.2	Vertex and Edge Characteristics .....	44
4.2.1	Vertex Degree .....	44
4.2.2	Vertex Centrality .....	47
4.2.3	Characterizing Edges .....	50
4.3	Characterizing Network Cohesion .....	52
4.3.1	Subgraphs and Censuses .....	52
4.3.2	Density and Related Notions of Relative Frequency .....	55
4.3.3	Connectivity, Cuts, and Flows .....	57
4.4	Graph Partitioning .....	59
4.4.1	Hierarchical Clustering .....	60
4.4.2	Spectral Partitioning .....	62
4.4.3	Validation of Graph Partitioning .....	64
4.5	Assortativity and Mixing .....	66
4.6	Additional Reading .....	67
<b>5</b>	<b>Mathematical Models for Network Graphs .....</b>	<b>69</b>
5.1	Introduction .....	69
5.2	Classical Random Graph Models .....	70
5.3	Generalized Random Graph Models .....	72
5.4	Network Graph Models Based on Mechanisms .....	74
5.4.1	Small-World Models .....	74
5.4.2	Preferential Attachment Models .....	77
5.5	Assessing Significance of Network Graph Characteristics .....	79
5.5.1	Assessing the Number of Communities in a Network .....	79
5.5.2	Assessing Small World Properties .....	81
5.6	Additional Reading .....	83
<b>6</b>	<b>Statistical Models for Network Graphs .....</b>	<b>85</b>
6.1	Introduction .....	85
6.2	Exponential Random Graph Models .....	86
6.2.1	General Formulation .....	86
6.2.2	Specifying a Model .....	88
6.2.3	Model Fitting .....	92
6.2.4	Goodness-of-Fit .....	94
6.3	Network Block Models .....	95
6.3.1	Model Specification .....	96
6.3.2	Model Fitting .....	97
6.3.3	Goodness-of-Fit .....	100
6.4	Latent Network Models .....	102
6.4.1	General Formulation .....	102

6.4.2	Specifying the Latent Effects	103
6.4.3	Model Fitting	104
6.4.4	Goodness-of-Fit	107
6.5	Additional Reading	109
<b>7</b>	<b>Network Topology Inference</b>	<b>111</b>
7.1	Introduction	111
7.2	Link Prediction	112
7.3	Association Network Inference	116
7.3.1	Correlation Networks	118
7.3.2	Partial Correlation Networks	122
7.3.3	Gaussian Graphical Model Networks	126
7.4	Tomographic Network Topology Inference	129
7.4.1	Constraining the Problem: Tree Topologies	129
7.4.2	Tomographic Inference of Tree Topologies: An Illustration	132
7.5	Additional Reading	134
<b>8</b>	<b>Modeling and Prediction for Processes on Network Graphs</b>	<b>135</b>
8.1	Introduction	135
8.2	Nearest Neighbor Methods	136
8.3	Markov Random Fields	141
8.3.1	General Characterization	141
8.3.2	Auto-Logistic Models	142
8.3.3	Inference and Prediction for Auto-logistic Models	144
8.3.4	Goodness of Fit	147
8.4	Kernel Methods	148
8.4.1	Designing Kernels on Graphs	148
8.4.2	Kernel Regression on Graphs	152
8.5	Modeling and Prediction for Dynamic Processes	154
8.5.1	Epidemic Processes: An Illustration	154
8.6	Additional Reading	158
<b>9</b>	<b>Analysis of Network Flow Data</b>	<b>161</b>
9.1	Introduction	161
9.2	Modeling Network Flows: Gravity Models	162
9.2.1	Model Specification	162
9.2.2	Inference for Gravity Models	166
9.3	Predicting Network Flows: Traffic Matrix Estimation	170
9.3.1	An Ill-Posed Inverse Problem	171
9.3.2	The Tomogravity Method	175
9.4	Additional Reading	178

<b>10 Dynamic Networks</b> .....	179
10.1 Introduction .....	179
10.2 Representation and Manipulation of Dynamic Networks .....	180
10.3 Visualization of Dynamic Networks .....	186
10.4 Characterization of Dynamic Networks .....	191
10.5 Modeling Dynamic Networks .....	194
<b>References</b> .....	197
<b>Index</b> .....	205