

Contents

Preface

page xiii

1	Introduction to Probabilities, Graphs, and Causal Models	1
1.1	Introduction to Probability Theory	1
1.1.1	Why Probabilities?	1
1.1.2	Basic Concepts in Probability Theory	2
1.1.3	Combining Predictive and Diagnostic Supports	6
1.1.4	Random Variables and Expectations	8
1.1.5	Conditional Independence and Graphoids	11
1.2	Graphs and Probabilities	12
1.2.1	Graphical Notation and Terminology	12
1.2.2	<u>Bayesian Networks</u>	13
1.2.3	The d -Separation Criterion	16
1.2.4	Inference with Bayesian Networks	20
1.3	Causal Bayesian Networks	21
1.3.1	Causal Networks as Oracles for Interventions	22
1.3.2	Causal Relationships and Their Stability	24
1.4	Functional Causal Models	26
1.4.1	<u>Structural Equations</u>	27
1.4.2	<u>Probabilistic Predictions</u> in Causal Models	30
1.4.3	Interventions and Causal Effects in Functional Models	32
1.4.4	Counterfactuals in Functional Models	33
1.5	Causal versus Statistical Terminology	38
2	A Theory of Inferred Causation	41
2.1	Introduction	42
2.2	The Causal Modeling Framework	43
2.3	<u>Model Preference (Occam's Razor)</u>	45
2.4	Stable Distributions	48
2.5	Recovering DAG Structures	49
2.6	Recovering Latent Structures	51
2.7	Local Criteria for Causal Relations	54

2.8	Nontemporal Causation and Statistical Time	57
2.9	Conclusions	59
2.9.1	On Minimality, Markov, and Stability	61
3	Causal Diagrams and the Identification of Causal Effects	65
3.1	Introduction	66
3.2	Intervention in <u>Markovian Models</u>	68
3.2.1	Graphs as Models of Interventions	68
3.2.2	Interventions as Variables	70
3.2.3	Computing the Effect of Interventions	72
3.2.4	Identification of Causal Quantities	77
3.3	Controlling <u>Confounding Bias</u>	78
3.3.1	The Back-Door Criterion	79
3.3.2	The Front-Door Criterion	81
3.3.3	Example: Smoking and the Genotype Theory	83
3.4	A Calculus of Intervention	85
3.4.1	Preliminary Notation	85
3.4.2	Inference Rules	85
3.4.3	Symbolic Derivation of Causal Effects: An Example	86
3.4.4	Causal Inference by Surrogate Experiments	88
3.5	Graphical <u>Tests of Identifiability</u>	89
3.5.1	Identifying Models	91
3.5.2	Nonidentifying Models	93
3.6	Discussion	94
3.6.1	Qualifications and Extensions	94
3.6.2	Diagrams as a Mathematical Language	96
3.6.3	Translation from Graphs to Potential Outcomes	98
3.6.4	Relations to Robins's <i>G</i> -Estimation	102
4	Actions, Plans, and Direct Effects	107
4.1	Introduction	108
4.1.1	Actions, Acts, and Probabilities	108
4.1.2	Actions in <u>Decision Analysis</u>	110
4.1.3	Actions and Counterfactuals	112
4.2	Conditional Actions and <u>Stochastic Policies</u>	113
4.3	When Is the Effect of an Action Identifiable?	114
4.3.1	Graphical Conditions for Identification	114
4.3.2	Remarks on Efficiency	116
4.3.3	Deriving a Closed-Form Expression for Control Queries	117
4.3.4	Summary	118
4.4	The Identification of Plans	118
4.4.1	Motivation	118
4.4.2	Plan Identification: Notation and Assumptions	120
4.4.3	Plan Identification: A General Criterion	121
4.4.4	Plan Identification: A Procedure	124

4.5	Direct Effects and Their Identification	126
4.5.1	Direct versus Total Effects	126
4.5.2	Direct Effects, Definition, and Identification	127
4.5.3	Example: Sex Discrimination in College Admission	128
4.5.4	Average Direct Effects	130
5	Causality and Structural Models in Social Science and Economics	133
5.1	Introduction	134
5.1.1	Causality in Search of a Language	134
5.1.2	SEM: How its Meaning Became Obscured	135
5.1.3	Graphs as a Mathematical Language	138
5.2	Graphs and Model Testing	140
5.2.1	The Testable Implications of Structural Models	140
5.2.2	Testing the Testable	144
5.2.3	Model Equivalence	145
5.3	Graphs and Identifiability	149
5.3.1	Parameter Identification in Linear Models	149
5.3.2	Comparison to Nonparametric Identification	154
5.3.3	Causal Effects: The Interventional Interpretation of Structural Equation Models	157
5.4	Some Conceptual Underpinnings	159
5.4.1	What Do Structural Parameters Really Mean?	159
5.4.2	Interpretation of Effect Decomposition	163
5.4.3	Exogeneity, Superexogeneity, and Other Frills	165
5.5	Conclusion	170
6	Simpson's Paradox, Confounding, and Collapsibility	173
6.1	Simpson's Paradox: An Anatomy	174
6.1.1	A Tale of a Non-Paradox	174
6.1.2	A Tale of Statistical Agony	175
6.1.3	Causality versus Exchangeability	177
6.1.4	A Paradox Resolved (Or: What Kind of Machine Is Man?)	180
6.2	Why There Is No Statistical Test for Confounding, Why Many Think There Is, and Why They Are Almost Right	182
6.2.1	Introduction	182
6.2.2	Causal and Associational Definitions	184
6.3	How the Associational Criterion Fails	185
6.3.1	Failing Sufficiency via Marginality	185
6.3.2	Failing Sufficiency via Closed-World Assumptions	186
6.3.3	Failing Necessity via Barren Proxies	186
6.3.4	Failing Necessity via Incidental Cancellations	188
6.4	Stable versus Incidental Unbiasedness	189
6.4.1	Motivation	189
6.4.2	Formal Definitions	191
6.4.3	Operational Test for Stable No-Confounding	192

6.5	Confounding, Collapsibility, and Exchangeability	193
6.5.1	Confounding and Collapsibility	193
6.5.2	Counfounding versus Confounders	194
6.5.3	Exchangeability versus Structural Analysis of Confounding	196
6.6	Conclusions	199
7	The Logic of Structure-Based Counterfactuals	201
7.1	Structural Model/Semantics	202
7.1.1	Definitions: Causal Models, Actions, and Counterfactuals	202
7.1.2	Evaluating Counterfactuals: Deterministic Analysis	207
7.1.3	Evaluating Counterfactuals: Probabilistic Analysis	212
7.1.4	The Twin Network Method	213
7.2	Applications and Interpretation of Structural Models	215
7.2.1	Policy Analysis in Linear Econometric Models: An Example	215
7.2.2	The Empirical Content of Counterfactuals	217
7.2.3	Causal Explanations, Utterances, and Their Interpretation	221
7.2.4	From Mechanisms to Actions to Causation	223
7.2.5	Simon's Causal Ordering	226
7.3	Axiomatic Characterization	228
7.3.1	The Axioms of Structural Counterfactuals	228
7.3.2	Causal Effects from Counterfactual Logic: An Example	231
7.3.3	Axioms of Causal Relevance	234
7.4	Structural and Similarity-Based Counterfactuals	238
7.4.1	Relations to Lewis's Counterfactuals	238
7.4.2	Axiomatic Comparison	240
7.4.3	Imaging versus Conditioning	242
7.4.4	Relations to the Neyman–Rubin Framework	243
7.4.5	Exogeneity Revisited: Counterfactual and Graphical Definitions	245
7.5	Structural versus Probabilistic Causality	249
7.5.1	The Reliance on Temporal Ordering	249
7.5.2	The Perils of Circularity	250
7.5.3	The Closed-World Assumption	252
7.5.4	Singular versus General Causes	253
7.5.5	Summary	256
8	Imperfect Experiments: Bounding Effects and Counterfactuals	259
8.1	Introduction	259
8.1.1	Imperfect and Indirect Experiments	259
8.1.2	Noncompliance and Intent to Treat	261
8.2	Bounding Causal Effects	262
8.2.1	Problem Formulation	262
8.2.2	The Evolution of Potential-Response Variables	263
8.2.3	Linear Programming Formulation	266

8.2.4	The Natural Bounds	268
8.2.5	Effect of Treatment on the Treated	269
8.2.6	Example: The Effect of Cholestyramine	270
8.3	Counterfactuals and <u>Legal Responsibility</u>	271
8.4	A Test for Instruments	274
8.5	Causal Inference from Finite Samples	275
8.5.1	<u>Gibbs Sampling</u>	275
8.5.2	The Effects of Sample Size and Prior Distribution	277
8.5.3	Causal Effects from <u>Clinical Data with Imperfect Compliance</u>	277
8.5.4	Bayesian Estimate of Single-Event Causation	280
8.6	Conclusion	281
9	Probability of Causation: Interpretation and Identification	283
9.1	Introduction	283
9.2	Necessary and Sufficient Causes: Conditions of Identification	286
9.2.1	Definitions, Notation, and Basic Relationships	286
9.2.2	Bounds and Basic Relationships under Exogeneity	289
9.2.3	Identifiability under <u>Monotonicity and Exogeneity</u>	291
9.2.4	Identifiability under Monotonicity and Nonexogeneity	293
9.3	Examples and Applications	296
9.3.1	Example 1: <u>Betting against a Fair Coin</u>	297
9.3.2	Example 2: <u>The Firing Squad</u>	297
9.3.3	Example 3: <u>The Effect of Radiation on Leukemia</u>	299
9.3.4	Example 4: Legal Responsibility from Experimental and Nonexperimental Data	302
9.3.5	Summary of Results	303
9.4	Identification in Nonmonotonic Models	304
9.5	Conclusions	307
10	The Actual Cause	309
10.1	Introduction: The Insufficiency of Necessary Causation	309
10.1.1	Singular Causes Revisited	309
10.1.2	Preemption and the Role of Structural Information	311
10.1.3	Overdetermination and Quasi-Dependence	313
10.1.4	Mackie's INUS Condition	313
10.2	Production, Dependence, and <u>Sustenance</u>	316
10.3	Causal Beams and Sustenance-Based Causation	318
10.3.1	Causal Beams: Definitions and Implications	318
10.3.2	Examples: From Disjunction to General Formulas	320
10.3.3	Beams, Preemption, and the Probability of Single-Event Causation	322
10.3.4	Path-Switching Causation	324
10.3.5	Temporal Preemption	325
10.4	Conclusions	327

Epilogue The Art and Science of Cause and Effect

A public lecture delivered November 1996 as part of the UCLA Faculty Research Lectureship Program	331
<i>Bibliography</i>	359
<i>Name Index</i>	375
<i>Subject Index</i>	379