Contents

			st Edition	page xv
Preje	ace to t	ine Seco	ond Edition	xix
1	Intr	oducti	on to Probabilities, Graphs, and Causal Models	1
	1.1	Introd	luction 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	Graph	as and Probabilities	12
		1.2.1	Graphical Notation and Terminology	12
		1.2.2	Bayesian Networks	13
		1.2.3	The d-Separation Criterion	16
		1.2.4	Inference with Bayesian Networks	20
	1.3	Causa	l Bayesian Networks	21
		1.3.1	Causal Networks as Oracles for Interventions	22
		1.3.2	Causal Relationships and Their Stability	24
	1.4	Functi	ional Causal Models	26
		1.4.1	Structural Equations	27
		1.4.2	Probabilistic Predictions 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	Causa	l versus Statistical Terminology	38
2	AT	heory (of Inferred Causation	41
	2.1	Introd	luction – The Basic Intuitions	42
	2.2	The C	Causal Discovery Framework	43
	2.3	Mode	l Preference (Occam's Razor)	45
	2.4	Stable	e Distributions	48
	2.5	Recov	vering DAG Structures	49
	2.6	Recov	vering Latent Structures	51

Contents

	2.7	Local	Criteria for Inferring Causal Relations	54
			emporal Causation and Statistical Time	57
		Concl		59
		2.9.1	On Minimality, Markov, and Stability	61
3	Cau	ısal Di	agrams and the Identification of Causal Effects	65
	3.1	Introd	luction	66
	3.2	Interv	rention in Markovian Models	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	Contr	olling Confounding Bias	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 Cal	culus 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	Graph	nical Tests of Identifiability	89
		3.5.1	Identifying Models	91
		3.5.2	Nonidentifying Models	93
	3.6	Discu	ssion	94
		3.6.1	Qualifications and Extensions	94
		3.6.2	Diagrams as a Mathematical Language	96
		3.6.3		98
		3.6.4	Relations to Robins's G-Estimation	102
4	Act	ions, P	lans, and Direct Effects	107
	4.1	Introd	luction	108
		4.1.1	Actions, Acts, and Probabilities	108
		4.1.2	Actions in Decision Analysis	110
		4.1.3	Actions and Counterfactuals	112
	4.2	Condi	itional Actions and Stochastic Policies	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 Id	dentification of Dynamic Plans	118
		4.4.1		118
		4.4.2	Plan Identification: Notation and Assumptions	120

Contents

		4.4.3	Plan Identification: The Sequential Back-Door Criterion	121			
		4.4.4	Plan Identification: A Procedure	124			
	4.5	Direct	and Indirect Effects	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	Natural Direct Effects	130			
		4.5.5	Indirect Effects and the Mediation Formula	132			
5	Cau	isality a	and Structural Models in Social Science and Economics	133			
	5.1	Introd	uction	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	Graph	s 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	Graph	s 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	Concl	usion	170			
	5.6	Postsc	cript for the Second Edition	171			
		5.6.1	8	171			
		5.6.2		171			
		5.6.3	Robustness of Causal Claims	172			
6	Sim	Simpson's Paradox, Confounding, and Collapsibility					
	6.1	Simps	son'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 7	There Is No Statistical Test for Confounding, Why Many				
		Think	There Is, and Why They Are Almost Right	182			
		6.2.1	Introduction	182			
			Causal and Associational Definitions	184			
	6.3		the Associational Criterion Fails	185			
			Failing Sufficiency via Marginality	185			
		632	Failing Sufficiency via Closed-World Assumptions	186			

Contents

		6.3.3	Failing Necessity via Barren Proxies	186
		6.3.4	Failing Necessity via Incidental Cancellations	188
	6.4		e 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	Confo	ounding, Collapsibility, and Exchangeability	193
		6.5.1	Confounding and Collapsibility	193
		6.5.2	Confounding versus Confounders	194
		6.5.3	Exchangeability versus Structural Analysis of Confounding	196
	6.6	Concl	usions	199
7	The	Logic	of Structure-Based Counterfactuals	201
	7.1	Struct	tural Model Semantics	202
		7.1.1	Definitions: Causal Models, Actions, and Counterfactuals	202
		7.1.2	Evaluating Counterfactuals: Deterministic Analysis	207
		7.1.3	8	212
			The Twin Network Method	213
	7.2	Appli	cations and Interpretation of Structural Models	215
		7.2.1	, , , , , , , , , , , , , , , , , , , ,	
			An Example	215
		7.2.2	The same of the sa	217
		7.2.3	The second section of the second seco	221
		7.2.4		223
			Simon's Causal Ordering	226
	7.3		matic Characterization	228
		7.3.1	The Axioms of Structural Counterfactuals	228
		7.3.2	-8	231
	7.4	7.3.3	Axioms of Causal Relevance	234
	7.4		tural and Similarity-Based Counterfactuals	238
		7.4.1	Relations to Lewis's Counterfactuals	238
		7.4.2		240
		7.4.3	2 2	242
		7.4.4	•	243
		7.4.5		245
	75	Ctmat	Graphical Definitions	245
	1.3	7.5.1	tural versus Probabilistic Causality	249
		7.5.2	The Reliance on Temporal Ordering	249
		7.5.2	•	250 252
		7.5.4	8 8	253
		7.5.5	Summary	256
0	T		•	
8	_		Experiments: Bounding Effects and Counterfactuals	259
	8.1	Introd		259
		8.1.1	Imperfect and Indirect Experiments Noncompliance and Intent to Treat	259
		0.1.2	ryoncomphance and intent to freat	261

Contents xi

	8.2	Bound	ing Causal Effects with Instrumental Variables	262
		8.2.1	Problem Formulation: Constrained Optimization	262
		8.2.2	Canonical Partitions: The Evolution of	
			Finite-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 (ETT)	269
		8.2.6	Example: The Effect of Cholestyramine	270
	8.3	Counte	rfactuals and Legal Responsibility	271
	8.4		for Instruments	274
	8.5	A Baye	esian Approach to Noncompliance	275
		8.5.1	Bayesian Methods and Gibbs Sampling	275
		8.5.2	The Effects of Sample Size and Prior Distribution	277
		8.5.3	Causal Effects from Clinical Data with Imperfect	
			Compliance	277
		8.5.4	Bayesian Estimate of Single-Event Causation	280
	8.6	Conclu	sion	281
9	Prob	ability o	of Causation: Interpretation and Identification	283
	9.1	Introdu	ection	283
	9.2	Necess	ary 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 Monotonicity and Exogeneity	291
		9.2.4	Identifiability under Monotonicity and Nonexogeneity	293
	9.3	Examp	les and Applications	296
		9.3.1	Example 1: Betting against a Fair Coin	296
		9.3.2	Example 2: The Firing Squad	297
		9.3.3	Example 3: The Effect of Radiation on Leukemia	299
		9.3.4	Example 4: Legal Responsibility from Experimental and	
			Nonexperimental Data	302
		9.3.5	Summary of Results	303
	9.4	Identifi	cation in Nonmonotonic Models	304
	9.5	Conclu	sions	307
10	The	Actual (Cause	309
	10.1	Introdu	action: 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
			Mackie's INUS Condition	313
	10.2	Produc	tion, Dependence, and Sustenance	316
	10.3		Beams and Sustenance-Based Causation	318
			Causal Beams: Definitions and Implications	318
			Examples: From Disjunction to General Formulas	320
			Beams, Preemption, and the Probability of	
			Single-Event Causation	322

xii Contents

		10.3.4	Path-Switching Causation	324
		10.3.5	Temporal Preemption	325
	10.4	Conclusi	ions	327
11	Refle	ections, El	laborations, and Discussions with Readers	331
	11.1	Causal,	, Statistical, and Graphical Vocabulary	331
		11.1.1	Is the Causal-Statistical Dichotomy Necessary?	331
		11.1.2	d-Separation without Tears (Chapter 1, pp. 16–18)	335
	11.2	Reversi	ing Statistical Time (Chapter 2, p. 58-59)	337
	11.3	Estima	ting Causal Effects	338
		11.3.1	The Intuition behind the Back-Door Criterion	
			(Chapter 3, p. 79)	338
		11.3.2	Demystifying "Strong Ignorability"	341
		11.3.3	Alternative Proof of the Back-Door Criterion	344
		11.3.4	Data vs. Knowledge in Covariate Selection	346
		11.3.5	Understanding Propensity Scores	348
		11.3.6	The Intuition behind do-Calculus	352
		11.3.7	The Validity of G-Estimation	352
	11.4	Policy ?	Evaluation and the do-Operator	354
		11.4.1	Identifying Conditional Plans (Section 4.2, p. 113)	354
		11.4.2	The Meaning of Indirect Effects	355
		11.4.3	Can $do(x)$ Represent Practical Experiments?	358
		11.4.4	Is the $do(x)$ Operator Universal?	359
		11.4.5	Causation without Manipulation!!!	361
		11.4.6	Hunting Causes with Cartwright	362
		11.4.7	The Illusion of Nonmodularity	364
	11.5	Causal	Analysis in Linear Structural Models	366
		11.5.1	General Criterion for Parameter Identification	
			(Chapter 5, pp. 149–54)	366
		11.5.2	The Causal Interpretation of Structural Coefficients	366
		11.5.3	Defending the Causal Interpretation of SEM (or, SEM	
			Survival Kit)	368
		11.5.4	Where Is Economic Modeling Today? – Courting	
			Causes with Heckman	374
		11.5.5	External Variation versus Surgery	376
	11.6	Decisio	ons and Confounding (Chapter 6)	380
		11.6.1	Simpson's Paradox and Decision Trees	380
		11.6.2	Is Chronological Information Sufficient for	
			Decision Trees?	382
		11.6.3	Lindley on Causality, Decision Trees, and Bayesianism	384
		11.6.4	Why Isn't Confounding a Statistical Concept?	387
	11.7		lculus of Counterfactuals	389
		11.7.1	Counterfactuals in Linear Systems	389
		11.7.2	The Meaning of Counterfactuals	391
		11.7.3	d-Separation of Counterfactuals	393

	xiii		
mental Variables and Noncompliance	395		
1 Tight Bounds under Noncompliance	395		
on Probabilities of Causation	396		
1 Is "Guilty with Probability One" Ever Possible?	396		
2 Tightening the Bounds on Probabilities of Causation	398		
Epilogue The Art and Science of Cause and Effect			
ure delivered in November 1996 as part of			
aculty Research Lectureship Program	401		
	429		
	454		
	460		
t	e on Probabilities of Causation 1 Is "Guilty with Probability One" Ever Possible? 2 Tightening the Bounds on Probabilities of Causation		