Kenneth P. Burnham David R. Anderson

Model Selection and Multimodel Inference

A Practical Information-Theoretic Approach Second Edition

With 31 Illustrations





Contents

Pı	eface			vii	
A I	bout th	e Autho	ors	xxi	
G	Glossary				
1	Intro	duction		1	
	1.1	Object	ives of the Book	1	
	1.2		round Material	5	
		1.2.1		. 5	
		1.2.2	Likelihood and Least Squares Theory	6	
		1.2.3	The Critical Issue: "What Is the Best Model		
			to Use?"	13	
		1.2.4	Science Inputs: Formulation of the Set of		
			Candidate Models	15	
		1.2.5	Models Versus Full Reality	20	
		1.2.6	An Ideal Approximating Model	22	
	1.3	Model	Fundamentals and Notation	23	
		1.3.1	Truth or Full Reality f	23	
		1.3.2	Approximating Models $g_i(x \theta)$	23	
		1.3.3	The Kullback–Leibler Best Model $g_i(x \theta_0)$	25	
		1.3.4	Estimated Models $g_i(x \hat{\theta})$	25	
		1.3.5	Generating Models	26	
		1.3.5			
		1.5.0	Global Model	26	

		1.3.7 Overview of Stochastic Models in the	
		Biological Sciences	1
	1.4	Inference and the Principle of Parsimony)
		1.4.1 Avoid Overfitting to Achieve a Good Model Fit 29)
		1.4.2 The Principle of Parsimony	Ĺ
		1.4.3 Model Selection Methods	5
	1.5	Data Dredging, Overanalysis of Data, and	
		Spurious Effects	7
		1.5.1 Overanalysis of Data	3
	•	1.5.2 Some Trends)
	1.6	Model Selection Bias	3
	1.7	Model Selection Uncertainty 45	5
	1.8	Summary	7
2	Infor	mation and Likelihood Theory: A Basis for Model	
_		tion and Inference)
	2.1	Kullback-Leibler Information or Distance Between	
		Two Models)
		2.1.1 Examples of Kullback-Leibler Distance 54	4
		2.1.2 Truth, f , Drops Out as a Constant	3
	2.2	Akaike's Information Criterion: 1973 60)
	2.3	Takeuchi's Information Criterion: 1976 65	5
	2.4	Second-Order Information Criterion: 1978 66	5
	2.5	Modification of Information Criterion for Overdispersed	
		Count Data	7
	2.6	AIC Differences, Δ_i	0
	2.7	A Useful Analogy	2
	2.8	Likelihood of a Model, $\mathcal{L}(g_i data)$	4
	2.9	Akaike Weights, w_i	5
		2.9.1 Basic Formula	5
		2.9.2 An Extension	5
	2.10	Evidence Ratios	7
	2.11	Important Analysis Details	0
		2.11.1 AIC Cannot Be Used to Compare Models of	
		Different Data Sets	0
		2.11.2 Order Not Important in Computing AIC Values 8:	1
		2.11.3 Transformations of the Response Variable 8	1
	•	2.11.4 Regression Models with Differing	
		Error Structures	2
		2.11.5 Do Not Mix Null Hypothesis Testing with	
		Information-Theoretic Criteria 8	3
		2.11.6 Null Hypothesis Testing Is Still Important in	
		Strict Experiments	3
		2.11.7 Information-Theoretic Criteria Are Not a "Test" 8	
		2.11.8 Exploratory Data Analysis 8	4

			Contents	s xv
	2.12	Some 1	History and Further Insights	85
			Entropy	
			A Heuristic Interpretation	
			More on Interpreting Information-	
		2.12.5	Theoretic Criteria	. 87
		2.12.4	Nonnested Models	
			Further Insights	-
	2.13		rap Methods and Model Selection Frequencies π_i	
	2.13	2.13.1	-	
		2.13.2		, , ,
		2.13.2	The Basic Idea	93
	2.14	Return	to Flather's Models	
	2.15		ary	
	2.13	Summ	ary	. 90
2	D!-	TiP	the Information Theorytic Assumption	98
3			the Information-Theoretic Approach	
	3.1 3.2		action	
	3.2	_	ble 1: Cement Hardening Data	
		3.2.1		
		3.2.2	<u>.</u>	
	2.2	3.2.3	A Summary	
	3.3		ble 2: Time Distribution of an Insecticide Added to a	
			ated Ecosystem	
		3.3.1	Set of Candidate Models	
		3.3.2	Some Results	
	3.4		ble 3: Nestling Starlings	
		3.4.1	Experimental Scenario	
		3.4.2	Monte Carlo Data	
		3.4.3	Set of Candidate Models	
		3.4.4	Data Analysis Results	. 117
		3.4.5	Further Insights into the First Fourteen	
			Nested Models	. 120
		3.4.6	Hypothesis Testing and Information-Theoretic	
			Approaches Have Different	
			Selection Frequencies	. 121
		3.4.7	Further Insights Following Final	
			Model Selection	. 124
		3.4.8	Why Not Always Use the Global Model	
		_	for Inference?	
	3.5		ple 4: Sage Grouse Survival	
		3.5.1	Introduction	
		3.5.2	Set of Candidate Models	
		3.5.3	Model Selection	. 129
		3.5.4	Hypothesis Tests for Year-Dependent	
			Survival Probabilities	. 131

		3.5.5 Hypothesis Testing Versus AIC in	
			32
			134
	3.6		137
		3.6.1 Set of Candidate Models	138
		3.6.2 Comments on Analytic Method	138
			139
	3.7		[4]
	3.8		142
	3.9		143
4		al Inference From More Than One Model:	
			149
	4.1		149
	4.2		150
			150
		<i>U U</i>	151
	4.3	Model Selection Uncertainty	153
		4.3.1 Concepts of Parameter Estimation and	
			155
		4.3.2 Including Model Selection Uncertainty in	
			158
			164
	4.4		16
	4.5		169
			169
		4.5.2 Δ_i , Model Selection Probabilities,	
		- · · · · · · · · · · · · · · · · · · ·	17
	4.6	T T T T T T T T T T T T T T T T T T T	173
	4.7	•	170
	4.8		17'
	4.9		18:
	4.10		18'
	4.10		18
			190
		4.10.3 Confidence Intervals on Predicted	
		· · · · · · · · · · · · · · · · · · ·	19
		•	19:
	4.11		19
	4.12	Publication of Research Results	20
	4.13	Summary	20
5	Man	to Carlo Incights and Extended Examples	20
3			20 20
	5.1 5.2		20' 20'

			Contents	XVII
		5.2.1	A Chain Binomial Survival Model	207
		5.2.2	An Example	210
		5.2.3	An Extended Survival Model	
		5.2.4	Model Selection if Sample Size Is Huge,	
			or Truth Known	219
		5.2.5	A Further Chain Binomial Model	
	5.3		oles and Ideas Illustrated with Linear Regression	
		5.3.1	All-Subsets Selection: A GPA Example	
		5.3.2	A Monte Carlo Extension of the GPA Example	
		5.3.3	An Improved Set of GPA Prediction Models	
		5.3.4	More Monte Carlo Results	
		5.3.5	Linear Regression and Variable Selection	244
		5.3.6	Discussion	
	5.4	Estima	ation of Density from Line Transect Sampling	
		5.4.1	Density Estimation Background	
		5.4.2	Line Transect Sampling of Kangaroos at	
			Wallaby Creek	256
		5.4.3	Analysis of Wallaby Creek Data	256
		5.4.4	Bootstrap Analysis	
		5.4.5	Confidence Interval on D	258
		5.4.6	Bootstrap Samples: 1,000 Versus 10,000	260
		5.4.7	Bootstrap Versus Akaike Weights: A Lesson	
			on $QAI\hat{C}_c$	261
	5.5	Summ	ary	
_	A .J.,,		arrag and Dagman Insights	267
6	6.1		sues and Deeper Insights uction	
	6.2		uction	. 207
	0.2		Models	269
		6.2.1	Body Fat Data	
		6.2.2	· · · · · · · · · · · · · · · · · · ·	
		6.2.3		_
		6.2.4		
		6.2.5	An A Priori Approach	
		6.2.6	* *	
		6.2.7	Monte Carlo Simulations	
		6.2.8	Summary Messages	
	6.3		iew of Model Selection Criteria	. 207 . 210 . 215 . 219 . 221 . 224 . 225 . 238 . 244 . 248 . 255 . 256 . 256 . 256 . 258 . 260 . 261 . 264 . 267 . 267 . 268 . 269 . 271 . 274 . 276 . 279 . 281 . 284 . 284 . 288 . 289 . 293
	0.5	6.3.1	Criteria That Are Estimates of K-L Information	
		6.3.2	Criteria That Are Consistent for K	
		6.3.3	Contrasts	
		6.3.4	Consistent Selection in Practice:	. 200
		0.5.4	Quasi-true Models	280
	6.4	Contra	asting AIC and BIC	
	٠. ٠	6.4.1		

	6.4.2	A K-L-Based Conceptual Comparison of	
		AIC and BIC	295
	6.4.3	Performance Comparison	298
	6.4.4	Exact Bayesian Model Selection Formulas	301
	6.4.5	Akaike Weights as Bayesian Posterior	
	-	Model Probabilities	302
6.5	Goodr	ness-of-Fit and Overdispersion Revisited	305
	6.5.1	Overdispersion \hat{c} and Goodness-of-Fit:	
		A General Strategy	305
	6.5.2	Overdispersion Modeling: More Than One \hat{c}	307
	6.5.3	Model Goodness-of-Fit After Selection	309
6.6	AIC a	nd Random Coefficient Models	310
	6.6.1	Basic Concepts and Marginal	
		Likelihood Approach	310
	6.6.2	A Shrinkage Approach to AIC and	
		Random Effects	313
	6.6.3	On Extensions	316
6.7	Select	ion When Probability Distributions Differ	
		odel	317
	6.7.1	Keep All the Parts	317
	6.7.2	A Normal Versus Log-Normal Example	318
	6.7.3	Comparing Across Several Distributions:	
		An Example	320
6.8	Lesso	ns from the Literature and Other Matters	323
	6.8.1	Use AIC _c , Not AIC, with Small Sample Sizes	323
·	6.8.2	Use AIC _c , Not AIC, When K Is Large	325
	6.8.3	When Is AIC _c Suitable: A Gamma	
		Distribution Example	326
	6.8.4	Inference from a Less Than Best Model	328
	6.8.5	Are Parameters Real?	330
	6.8.6	Sample Size Is Often Not a Simple Issue	332
	6.8.7	Judgment Has a Role	333
6.9	Tidbit	s About AIC	334
	6.9.1	Irrelevance of Between-Sample Variation	
		of AIC	334
	6.9.2	The G-Statistic and K-L Information	336
	6.9.3	AIC Versus Hypothesis Testing: Results Can Be	
		Very Different	331
	6.9.4	A Subtle Model Selection Bias Issue	339
	6.9.5	The Dimensional Unit of AIC	340
	6.9.6	AIC and Finite Mixture Models	342
	6.9.7	Unconditional Variance	344
	6.9.8	A Baseline for $w_+(i)$	34:
6.10		nary	34

			Contents	xix
7	Statis	stical Theory and Numerical Results		352
-	7.1	Useful Preliminaries		352
	7.2	A General Derivation of AIC		362
	7.3	General K-L-Based Model Selection: TIC		371
	7.5	7.3.1 Analytical Computation of TIC		371
		7.3.2 Bootstrap Estimation of TIC		372
	7.4	AIC _c : A Second-Order Improvement \dots		374
	7.4	7.4.1 Derivation of AIC $_c$		374
		7.4.1 Derivation of AiC_c		379
	75			319
	7.5	Derivation of AIC for the Exponential Family		200
	7.	of Distributions		380
	7.6	Evaluation of $\operatorname{tr}(J(\underline{\theta}_o)[I(\underline{\theta}_o)]^{-1})$ and Its Estimator	r	384
		7.6.1 Comparison of AIC Versus TIC in a		
		Very Simple Setting		385
		7.6.2 Evaluation Under Logistic Regression .		390
		7.6.3 Evaluation Under Multinomially Distribu	ıted	
		Count Data		397
		7.6.4 Evaluation Under Poisson-Distributed Da	ıta	405
		7.6.5 Evaluation for Fixed-Effects Normality-I	Based	
		Linear Models		406
	7.7	Additional Results and Considerations		412
		7.7.1 Selection Simulation for Nested Models		412
		7.7.2 Simulation of the Distribution of Δ_p		415
		7.7.3 Does AIC Overfit?		417
		7.7.4 Can Selection Be Improved Based on	, , , ,	
		All the Δ_i ?		419
		7.7.5 Linear Regression, AIC, and Mean Squar		421
		7.7.6 AIC _c and Models for Multivariate Data .		424
		7.7.7 There Is No True TIC_c		426
		7.7.8 Kullback–Leibler Information Relationsh		720
		Fisher Information Matrix		426
		7.7.9 Entropy and Jaynes Maxent Principle		427
		7.7.10 Akaike Weights w_i Versus Selection		421
				428
	7.8	Probabilities π_i		429
		Kullback-Leibler Information Is Always ≥ 0		434
	7.9	Summary	• • • • • •	434
o	G			425
8		mary		437
	8.1	The Scientific Question and the Collection of Da		439
	8.2	Actual Thinking and A Priori Modeling		440
	8.3	The Basis for Objective Model Selection		442
	8.4	The Principle of Parsimony		443
	8.5	Information Criteria as Estimates of Expected Re		
		Kullback-Leibler Information		444
	8.6	Ranking Alternative Models		446

	8.7	Scaling Alternative Models	447	
	8.8	MMI: Inference Based on Model Averaging	448	
	8.9	MMI: Model Selection Uncertainty	449	
	8.10	MMI: Relative Importance of Predictor Variables	451	
	8.11	More on Inferences	451	
	8.12	Final Thoughts	454	
References				
In	dex		485	

•