

---

# Contents

---

List of models	xi
List of examples	xiii
Preface	xv
<b>Part I: Fundamentals of Bayesian Inference</b>	<b>1</b>
<b>1 Background</b>	<b>3</b>
1.1 Overview	3
1.2 General notation for statistical inference	4
1.3 Bayesian inference	7
1.4 Example: inference about a genetic probability	10
1.5 Probability as a measure of uncertainty	12
1.6 Example of probability assignment: football point spreads	15
1.7 Some useful results from probability theory	18
1.8 Summarizing inferences by simulation	21
1.9 Bibliographic note	24
1.10 Exercises	25
<b>2 Single-parameter models</b>	<b>28</b>
2.1 Estimating a probability from binomial data	28
2.2 Posterior distribution as compromise between data and prior information	32
2.3 Summarizing posterior inference	33
2.4 Informative prior distributions	34
2.5 Example: estimating the probability of a female birth given placenta previa	39
2.6 Estimating the mean of a normal distribution with known variance	42
2.7 Other standard single-parameter models	45
2.8 Noninformative prior distributions	52

2.9	Bibliographic note	57
2.10	Exercises	58
<b>3</b>	<b>Introduction to multiparameter models</b>	<b>65</b>
3.1	Averaging over ‘nuisance parameters’	65
3.2	Normal data with a noninformative prior distribution	66
3.3	Normal data with a conjugate prior distribution	71
3.4	Normal data with a semi-conjugate prior distribution	73
3.5	The multinomial model	76
3.6	The multivariate normal model	78
3.7	Example: analysis of a bioassay experiment	82
3.8	Summary of elementary multiparameter modeling and computation	86
3.9	Bibliographic note	87
3.10	Exercises	88
<b>4</b>	<b>Large-sample inference and connections to standard statistical methods</b>	<b>94</b>
4.1	Normal approximations to the posterior distribution	94
4.2	Large-sample theory	100
4.3	Counterexamples to the theorems	101
4.4	Frequency evaluations of Bayesian inferences	104
4.5	Bayesian interpretations of other statistical methods	106
4.6	Bibliographic note	111
4.7	Exercises	112
<b>Part II: Fundamentals of Bayesian Data Analysis</b>		<b>117</b>
<b>5</b>	<b>Hierarchical models</b>	<b>119</b>
5.1	Constructing a parameterized prior distribution	120
5.2	Exchangeability and setting up hierarchical models	123
5.3	Computation with hierarchical models	128
5.4	Estimating an exchangeable set of parameters from a normal model	134
5.5	Example: combining information from educational testing experiments in eight schools	141
5.6	Hierarchical modeling applied to a meta-analysis	148
5.7	Bibliographic note	154
5.8	Exercises	156
<b>6</b>	<b>Model checking and sensitivity analysis</b>	<b>161</b>
6.1	The place of model checking and sensitivity analysis in applied Bayesian statistics	161
6.2	Principles and methods of model checking	162

6.3	Checking a model by comparing data to the posterior predictive distribution	167
6.4	Sensitivity analysis	174
6.5	Comparing a discrete set of models using Bayes factors	175
6.6	Model expansion	177
6.7	Practical advice	179
6.8	Model checking for the educational testing example	179
6.9	Bibliographic note	183
6.10	Exercises	185
<b>7</b>	<b>Study design in Bayesian analysis</b>	<b>190</b>
7.1	Introduction	190
7.2	Relevance of design or data collection: simple examples	192
7.3	Formal models for data collection	194
7.4	Ignorability	199
7.5	Designs that are ignorable and known with no covariates, including simple random sampling and completely randomized experiments	200
7.6	Designs that are ignorable and known given covariates, including stratified sampling and randomized block experiments	205
7.7	Designs that are ignorable and unknown, such as experiments with nonrandom treatment assignments based on fully observed covariates	213
7.8	Designs that are nonignorable and known, such as censoring	215
7.9	Designs that are nonignorable and unknown, including observational studies and unintentional missing data	219
7.10	Sensitivity and the role of randomization	221
7.11	Discussion	224
7.12	Bibliographic note	224
7.13	Exercises	225
<b>8</b>	<b>Introduction to regression models</b>	<b>233</b>
8.1	Introduction and notation	233
8.2	Bayesian justification of conditional modeling	235
8.3	Bayesian analysis of the classical regression model	235
8.4	Example: estimating the advantage of incumbency in U.S. Congressional elections	240
8.5	Goals of regression analysis	248
8.6	Assembling the matrix of explanatory variables	250
8.7	Unequal variances and correlations	253
8.8	Models for unequal variances (heteroscedasticity)	257
8.9	Including prior information	259
8.10	Hierarchical linear models	262

8.11 Bibliographic note	262
8.12 Exercises	263
<b>Part III: Advanced Computation</b>	<b>267</b>
<b>9 Approximations based on posterior modes</b>	<b>269</b>
9.1 Introduction	269
9.2 Crude estimation by ignoring some information	270
9.3 Finding posterior modes	271
9.4 The normal and related mixture approximations	274
9.5 Finding marginal posterior modes using EM and related algorithms	276
9.6 Approximating the conditional posterior density, $p(\gamma \phi, y)$	283
9.7 Approximating $p(\phi y)$ using an analytic approximation to $p(\gamma \phi, y)$	283
9.8 Example: the hierarchical normal model	284
9.9 Example: a hierarchical logistic regression model for rat tumor rates	291
9.10 Bibliographic note	298
9.11 Exercises	298
<b>10 Posterior simulation and integration</b>	<b>300</b>
10.1 Posterior inference from simulation	300
10.2 Direct simulation	302
10.3 Numerical integration	305
10.4 Computing normalizing factors	308
10.5 Improving an approximation using importance resampling	312
10.6 Example: hierarchical logistic regression (continued)	313
10.7 Bibliographic note	316
10.8 Exercises	317
<b>11 Markov chain simulation</b>	<b>320</b>
11.1 Introduction	320
11.2 The Metropolis algorithm and its generalizations	322
11.3 The Gibbs sampler and related methods based on alternating conditional sampling	326
11.4 Inference and assessing convergence from iterative simulation	329
11.5 Constructing efficient simulation algorithms	333
11.6 Example: the hierarchical normal model (continued)	335
11.7 Example: linear regression with several unknown variance parameters	337
11.8 Bibliographic note	343
11.9 Exercises	344

<b>Part IV: Specific Models</b>	<b>345</b>
<b>12 Models for robust inference and sensitivity analysis</b>	<b>347</b>
12.1 Introduction	347
12.2 Overdispersed versions of standard probability models	349
12.3 Posterior inference and computation	352
12.4 Robust inference and sensitivity analysis for the educational testing example	354
12.5 Robust regression using Student- <i>t</i> errors	360
12.6 Bibliographic note	362
12.7 Exercises	363
<b>13 Hierarchical linear models</b>	<b>366</b>
13.1 Regression coefficients exchangeable in batches	367
13.2 Example: forecasting U.S. Presidential elections	369
13.3 General notation and computation for hierarchical linear models	376
13.4 Hierarchical modeling as an alternative to selecting explanatory variables	379
13.5 Bibliographic note	380
13.6 Exercises	381
<b>14 Generalized linear models</b>	<b>384</b>
14.1 Introduction	384
14.2 Standard generalized linear model likelihoods	386
14.3 Setting up and interpreting generalized linear models	387
14.4 Bayesian nonhierarchical and hierarchical generalized linear models	388
14.5 Computation	389
14.6 Models for multinomial responses	393
14.7 Loglinear models for multivariate discrete data	397
14.8 Bibliographic note	403
14.9 Exercises	404
<b>15 Multivariate models</b>	<b>407</b>
15.1 Introduction	407
15.2 Linear regression with multiple outcomes	407
15.3 Hierarchical multivariate models	410
15.4 Multivariate models for nonnormal data	412
15.5 Time series and spatial models	415
15.6 Bibliographic note	418
15.7 Exercises	419
<b>16 Mixture models</b>	<b>420</b>

16.1 Introduction	420
16.2 Setting up the model	421
16.3 Computation	424
16.4 Example: modeling reaction times of schizophrenics and nonschizophrenics	426
16.5 Bibliographic note	438
<b>17 Models for missing data</b>	<b>439</b>
17.1 Introduction	439
17.2 Notation for data collection in the context of missing data problems	439
17.3 Computation and multiple imputation	441
17.4 Missing data in the multivariate normal and $t$ models	443
17.5 Missing values with counted data	447
17.6 Example: an opinion poll in Slovenia	448
17.7 Inference using multiple imputation	453
17.8 Bibliographic note	454
17.9 Exercises	455
<b>18 Concluding advice</b>	<b>456</b>
18.1 Setting up probability models	456
18.2 Posterior inference	461
18.3 Model evaluation	462
18.4 Conclusion	468
18.5 Bibliographic note	469
<b>Appendixes</b>	<b>471</b>
<b>A Standard probability distributions</b>	<b>473</b>
A.1 Introduction	473
A.2 Continuous distributions	473
A.3 Discrete distributions	482
A.4 Bibliographic note	483
<b>B Outline of proofs of asymptotic theorems</b>	<b>484</b>
B.1 Bibliographic note	488
<b>References</b>	<b>489</b>
<b>Author Index</b>	<b>513</b>
<b>Subject Index</b>	<b>518</b>