# Contents

Foreword xi

Preface to the second edition xvii

Preface to the first edition xxi

1 The logic of decision 1

1.1 Uncertainty and probability 1

1.1.1 Probability is not about numbers, it is about coherent reasoning under uncertainty 1

1.1.2 The first two laws of probability 2

1.1.3 Relevance and independence 3

1.1.4 The third law of probability 5

1.1.5 Extension of the conversation 6

1.1.6 Bayes’ theorem 6

1.1.7 Probability trees 7

1.1.8 Likelihood and probability 9

1.1.9 The calculus of (probable) truths 10

1.2 Reasoning under uncertainty 12

1.2.1 The Hound of the Baskervilles 12

1.2.2 Combination of background information and evidence 13

1.2.3 The odds form of Bayes’ theorem 15

1.2.4 Combination of evidence 16

1.2.5 Reasoning with total evidence 16

1.2.6 Reasoning with uncertain evidence 18

1.3 Population proportions, probabilities and induction 19

1.3.1 The statistical syllogism 19

1.3.2 Expectations and population proportions 21

1.3.3 Probabilistic explanations 22

1.3.4 Abduction and inference to the best explanation 25

1.3.5 Induction the Bayesian way 26
### CONTENTS

1.4 Decision making under uncertainty  
1.4.1 Bookmakers in the Courtrooms? 28  
1.4.2 Utility theory 29  
1.4.3 The rule of maximizing expected utility 33  
1.4.4 The loss function 34  
1.4.5 Decision trees 35  
1.4.6 The expected value of information 38  
1.5 Further readings 42  

2 The logic of Bayesian networks and influence diagrams 45  
2.1 Reasoning with graphical models 45  
2.1.1 Beyond detective stories 45  
2.1.2 Bayesian networks 46  
2.1.3 A graphical model for relevance 48  
2.1.4 Conditional independence 50  
2.1.5 Graphical models for conditional independence: $d$-separation 51  
2.1.6 A decision rule for conditional independence 53  
2.1.7 Networks for evidential reasoning 53  
2.1.8 The Markov property 56  
2.1.9 Influence diagrams 58  
2.1.10 Conditional independence in influence diagrams 60  
2.1.11 Relevance and causality 61  
2.1.12 *The Hound of the Baskervilles* revisited 63  
2.2 Reasoning with Bayesian networks and influence diagrams 65  
2.2.1 Divide and conquer 66  
2.2.2 From directed to triangulated graphs 67  
2.2.3 From triangulated graphs to junction trees 69  
2.2.4 Solving influence diagrams 71  
2.2.5 Object-oriented Bayesian networks 74  
2.2.6 Solving object-oriented Bayesian networks 79  
2.3 Further readings 82  
2.3.1 General 82  
2.3.2 Bayesian networks and their predecessors in judicial contexts 83  

3 Evaluation of scientific findings in forensic science 85  
3.1 Introduction 85  
3.2 The value of scientific findings 86  
3.3 Principles of forensic evaluation and relevant propositions 90  
3.3.1 Source level propositions 92  
3.3.2 Activity level propositions 94  
3.3.3 Crime level propositions 97  
3.4 Pre-assessment of the case 100  
3.5 Evaluation using graphical models 103  
3.5.1 Introduction 103  
3.5.2 General aspects of the construction of Bayesian networks 103  
3.5.3 Eliciting structural relationships 105  
3.5.4 Level of detail of variables and quantification of influences 106  
3.5.5 Deriving an alternative network structure 108
CONTENTS ix

4 Evaluation given source level propositions 113
  4.1 General considerations 113
  4.2 Standard statistical distributions 115
  4.3 Two stains, no putative source 117
    4.3.1 Likelihood ratio for source inference when no putative source is available 117
    4.3.2 Bayesian network for a two-trace case with no putative source 119
    4.3.3 An alternative network structure for a two trace no putative source case 121
  4.4 Multiple propositions 122
    4.4.1 Form of the likelihood ratio 122
    4.4.2 Bayesian networks for evaluation given multiple propositions 123

5 Evaluation given activity level propositions 129
  5.1 Evaluation of transfer material given activity level propositions assuming a direct source relationship 130
    5.1.1 Preliminaries 130
    5.1.2 Derivation of a basic structure for a Bayesian network 131
    5.1.3 Modifying the basic network 134
    5.1.4 Further considerations about background presence 137
    5.1.5 Background from different sources 139
    5.1.6 An alternative description of the findings 142
    5.1.7 Bayesian network for an alternative description of findings 145
    5.1.8 Increasing the level of detail of selected propositions 147
    5.1.9 Evaluation of the proposed model 149
  5.2 Cross- or two-way transfer of trace material 150
  5.3 Evaluation of transfer material given activity level propositions with uncertainty about the true source 154
    5.3.1 Network structure 154
    5.3.2 Evaluation of the network 154
    5.3.3 Effect of varying assumptions about key factors 157

6 Evaluation given crime level propositions 159
  6.1 Material found on a crime scene: A general approach 159
    6.1.1 Generic network construction for single offender 159
    6.1.2 Evaluation of the network 161
    6.1.3 Extending the single-offender scenario 163
    6.1.4 Multiple offenders 166
    6.1.5 The role of the relevant population 168
  6.2 Findings with more than one component: The example of marks 168
    6.2.1 General considerations 168
    6.2.2 Adding further propositions 169
    6.2.3 Derivation of the likelihood ratio 170
    6.2.4 Consideration of distinct components 172
    6.2.5 An extension to firearm examinations 177
    6.2.6 A note on the likelihood ratio 181
  6.3 Scenarios with more than one trace: ‘Two stain-one offender’ cases 182
  6.4 Material found on a person of interest 185
CONTENTS

6.4.1 General form 185
6.4.2 Extending the numerator 187
6.4.3 Extending the denominator 189
6.4.4 Extended form of the likelihood ratio 190
6.4.5 Network construction and examples 190

7 Evaluation of DNA profiling results 196
7.1 DNA likelihood ratio 196
7.2 Network approaches to the DNA likelihood ratio 198
7.2.1 The ‘match’ approach 198
7.2.2 Representation of individual alleles 198
7.2.3 Alternative representation of a genotype 202
7.3 Missing suspect 203
7.4 Analysis when the alternative proposition is that a brother of the suspect left the crime stain 206
7.4.1 Revision of probabilities and networks 206
7.4.2 Further considerations on conditional genotype probabilities 212
7.5 Interpretation with more than two propositions 214
7.6 Evaluation with more than two propositions 217
7.7 Partially corresponding profiles 220
7.8 Mixtures 223
7.8.1 Considering multiple crime stain contributors 223
7.8.2 Bayesian network for a three-allele mixture scenario 225
7.9 Kinship analyses 227
7.9.1 A disputed paternity 227
7.9.2 An extended paternity scenario 230
7.9.3 A case of questioned maternity 232
7.10 Database search 234
7.10.1 Likelihood ratio after database searching 234
7.10.2 An analysis focussing on posterior probabilities 237
7.11 Probabilistic approaches to laboratory error 241
7.11.1 Implicit approach to typing error 241
7.11.2 Explicit approach to typing error 243
7.12 Further reading 246
7.12.1 A note on object-oriented Bayesian networks 246
7.12.2 Additional topics 246

8 Aspects of combining evidence 249
8.1 Introduction 249
8.2 A difficulty in combining evidence: The ‘problem of conjunction’ 250
8.3 Generic patterns of inference in combining evidence 252
8.3.1 Preliminaries 252
8.3.2 Dissonant evidence: Contradiction and conflict 252
8.3.3 Harmonious evidence: Corroboration and convergence 256
8.3.4 Drag coefficient 261
8.4 Examples of the combination of distinct items of evidence
8.4.1 Handwriting and fingermarks
8.4.2 Issues in DNA analyses
8.4.3 One offender and two corresponding traces
8.4.4 Firearms and gunshot residues
8.4.5 Comments

9 Networks for continuous models
9.1 Random variables and distribution functions
9.1.1 Normal distribution
9.1.2 Bivariate Normal distribution
9.1.3 Conditional expectation and variance
9.2 Samples and estimates
9.2.1 Summary statistics
9.2.2 The Bayesian paradigm
9.3 Continuous Bayesian networks
9.3.1 Propagation in a continuous Bayesian network
9.3.2 Background data
9.3.3 Intervals for a continuous entity
9.4 Mixed networks
9.4.1 Bayesian network for a continuous variable with a discrete parent
9.4.2 Bayesian network for a continuous variable with a continuous parent and a binary parent, unmarried

10 Pre-assessment
10.1 Introduction
10.2 General elements of pre-assessment
10.3 Pre-assessment in a fibre case: A worked through example
10.3.1 Preliminaries
10.3.2 Propositions and relevant events
10.3.3 Expected likelihood ratios
10.3.4 Construction of a Bayesian network
10.4 Pre-assessment in a cross-transfer scenario
10.4.1 Bidirectional transfer
10.4.2 A Bayesian network for a pre-assessment of a cross-transfer scenario
10.4.3 The value of the findings
10.5 Pre-assessment for consignment inspection
10.5.1 Inspecting small consignments
10.5.2 Bayesian network for inference about small consignments
10.5.3 Pre-assessment for inspection of small consignments
10.6 Pre-assessment for gunshot residue particles
10.6.1 Formation and deposition of gunshot residue particles
10.6.2 Bayesian network for grouped expected findings (GSR counts)
10.6.3 Examples for GSR count pre-assessment using a Bayesian network
CONTENTS

11 Bayesian decision networks 343
   11.1 Decision making in forensic science 343
   11.2 Examples of forensic decision analyses 344
      11.2.1 Deciding about whether or not to perform a DNA analysis 344
      11.2.2 Probability assignment as a question of decision making 352
      11.2.3 Decision analysis for consignment inspection 357
      11.2.4 Decision after database searching 366
   11.3 Further readings 368

12 Object-oriented networks 370
   12.1 Object orientation 370
   12.2 General elements of object-oriented networks 371
      12.2.1 Static versus dynamic networks 371
      12.2.2 Dynamic Bayesian networks as object-oriented networks 373
      12.2.3 Refining internal class descriptions 374
   12.3 Object-oriented networks for evaluating DNA profiling results 378
      12.3.1 Basic disputed paternity case 378
      12.3.2 Useful class networks for modelling kinship analyses 379
      12.3.3 Object-oriented networks for kinship analyses 381
      12.3.4 Object-oriented networks for inference of source 383
      12.3.5 Refining internal class descriptions and further considerations 385

13 Qualitative, sensitivity and conflict analyses 388
   13.1 Qualitative probability models 389
      13.1.1 Qualitative influence 389
      13.1.2 Additive synergy 392
      13.1.3 Product synergy 394
      13.1.4 Properties of qualitative relationships 396
      13.1.5 Implications of qualitative graphical models 401
   13.2 Sensitivity analyses 402
      13.2.1 Preliminaries 402
      13.2.2 Sensitivity to a single probability assignment 403
      13.2.3 Sensitivity to two probability assignments 405
      13.2.4 Sensitivity to prior distribution 408
   13.3 Conflict analysis 410
      13.3.1 Conflict detection 411
      13.3.2 Tracing a conflict 414
      13.3.3 Conflict resolution 415

References 419

Author index 433

Subject index 438