Contents

1 Introduction 1
Thomas Hermann, Andy Hunt, John G. Neuhoff
1.1 Auditory Display and Sonification 1
1.2 The Potential of Sonification and Auditory Display 3
1.3 Structure of the book 4
1.4 How to Read 6

I Fundamentals of Sonification, Sound and Perception 7

2 Theory of Sonification 9
Bruce N. Walker and Michael A. Nees
2.1 Chapter Overview 9
2.2 Sonification and Auditory Displays 10
2.3 Towards a Taxonomy of Auditory Display & Sonification 11
2.4 Data Properties and Task Dependency 17
2.5 Representation and Mappings 22
2.6 Limiting Factors for Sonification: Aesthetics, Individual Differences, and Training 27
2.7 Conclusions: Toward a Cohesive Theoretical Account of Sonification . . . 31

3 Psychoacoustics 41
Simon Carlile
3.1 Introduction 41
3.2 The transduction of mechanical sound energy into biological signals in the auditory nervous system 42
3.3 The perception of loudness 46
3.4 The perception of pitch 48
3.5 The perception of temporal variation 49
3.6 Grouping spectral components into auditory objects and streams 51
3.7 The perception of space 52
3.8 Summary 59
3.9 Further reading 59

4 Perception, Cognition and Action in Auditory Displays 63
John G. Neuhoff
4.1 Introduction 63
4.2 Perceiving Auditory Dimensions 64
4.3 Auditory-Visual Interaction 71
4.4 Auditory Space and Virtual Environments 71
4.5 Space as a Dimension for Data Representation 73

4.6 Rhythm and Time as Dimensions for Auditory Display 73
4.7 Auditory Scene Analysis 75
4.8 Auditory Cognition 77
4.9 Summary 81

5 Sonic Interaction Design **87**
Stefania Serafin, Karmen Franinović, Thomas Hermann, Guillaume Lemaitre, Michal Rinott, Davide Rocchesso
5.1 Introduction 87
5.2 A psychological perspective on sonic interaction 88
5.3 Product sound design 94
5.4 Interactive art and music 99
5.5 Sonification and Sonic Interaction Design 103
5.6 Open challenges in SID 106

6 Evaluation of Auditory Display **111**
Terri L. Bonebright and John H. Flowers
6.1 Chapter Overview 111
6.2 General Experimental Procedures 112
6.3 Data Collection Methods for Evaluating Perceptual Qualities and Relationships among Auditory Stimuli 120
6.4 Analysis of Data Obtained from Identification, Attribute Rating, Discrimination, and Dissimilarity Rating Tasks 126
6.5 Using "Distance" Data Obtained by Dissimilarity Ratings, Sorting, and Other Tasks 130
6.6 Usability Testing Issues and Active Use Experimental Procedures 137
6.7 Conclusion 141

7 Sonification Design and Aesthetics **145**
Stephen Barrass and Paul Vickers
7.1 Background 146
7.2 Design 148
7.3 Aesthetics: sensuous perception 154
7.4 Towards an aesthetic of sonification 161
7.5 Where do we go from here? 164

II Sonification Technology **173**

8 Statistical Sonification for Exploratory Data Analysis **175**
Sam Ferguson, William Martens and Densil Cabrera
8.1 Introduction 175
8.2 Datasets and Data Analysis Methods 178
8.3 Sonifications of Iris Dataset 186
8.4 Discussion 192
8.5 Conclusion and Caveat 193

9 Sound Synthesis for Auditory Display **197**
Perry R. Cook
9.1 Introduction and Chapter Overview 197
9.2 Parametric vs. Non-Parametric Models 197
9.3 Digital Audio: The Basics of PCM 198
9.4 Fourier (Sinusoidal) "Synthesis" 204
9.5 Modal (Damped Sinusoidal) Synthesis 209
9.6 Subtractive (Source-Filter) synthesis 213
9.7 Time Domain Formant Synthesis 218
9.8 Waveshaping and FM Synthesis 219
9.9 Granular and PhISEM Synthesis 221
9.10 Physical Modeling Synthesis 223
9.11 Non-Linear Physical Models 229
9.12 Synthesis for Auditory Display, Conclusion 232

10 Laboratory Methods for Experimental Sonification **237**
Till Bovermann, Julian Rohrhuber and Alberto de Campo
10.1 Programming as an interface between theory and laboratory practice 238
10.2 Overview of languages and systems 240
10.3 SuperCollider: Building blocks for a sonification laboratory 243
10.4 Example laboratory workflows and guidelines for working on sonification designs 251
10.5 Coda: back to the drawing board 270

11 Interactive Sonification **273**
Andy Hunt and Thomas Hermann
11.1 Chapter Overview 273
11.2 What is Interactive Sonification? 273
11.3 Principles of Human Interaction 276
11.4 Musical instruments – a 100,000 year case study 280
11.5 A brief History of Human Computer Interaction 283
11.6 Interacting with Sonification 286
11.7 Guidelines & Research Agenda for Interactive Sonification 293
11.8 Conclusions 296

III Sonification Techniques **299**

12 Audification **301**
Florian Dombois and Gerhard Eckel
12.1 Introduction 301
12.2 Brief Historical Overview (before ICAD, 1800-1991) 303
12.3 Methods of Audification 307
12.4 Audification now (1992-today) 316
12.5 Conclusion: What audification should be used for 319
12.6 Towards Better Audification Tools 320

13 Auditory Icons **325**
Eoin Brazil and Mikael Fernström
13.1 Auditory icons and the ecological approach . . . 325
13.2 Auditory icons and events . . . 326
13.3 Applications using auditory icons . . . 327
13.4 Designing auditory icons . . . 331
13.5 Conclusion . . . 335

14 Earcons **339**
David McGookin and Stephen Brewster
14.1 Introduction . . . 339
14.2 Initial Earcon Research . . . 340
14.3 Creating Earcons . . . 343
14.4 Earcons and Auditory Icons . . . 349
14.5 Using Earcons . . . 352
14.6 Future Directions . . . 357
14.7 Conclusions . . . 358

15 Parameter Mapping Sonification **363**
Florian Grond, Jonathan Berger
15.1 Introduction . . . 363
15.2 Data Features . . . 365
15.3 Connecting Data and Sound . . . 367
15.4 Mapping Topology . . . 369
15.5 Signal and Sound . . . 371
15.6 Listening, Thinking, Tuning . . . 373
15.7 Integrating Perception in PMSon . . . 374
15.8 Auditory graphs . . . 376
15.9 Vowel / Formant based PMSon . . . 378
15.10 Features of PMSon . . . 380
15.11 Design Challenges of PMSon . . . 385
15.12 Synthesis and signal processing methods used in PMSon . . . 388
15.13 Artistic applications of PMSon . . . 390
15.14 Conclusion . . . 392

16 Model-Based Sonification **399**
Thomas Hermann
16.1 Introduction . . . 399
16.2 Definition of Model-Based Sonification . . . 403
16.3 Sonification Models . . . 408
16.4 MBS Use and Design Guidelines . . . 415
16.5 Interaction in Model-Based Sonification . . . 418
16.6 Applications . . . 419
16.7 Discussion . . . 421
16.8 Conclusion . . . 425

IV Applications 429

17 Auditory Display in Assistive Technology 431
Alistair D. N. Edwards

17.1 Introduction 431
17.2 The Power of Sound 432
17.3 Visually Disabled People 433
17.4 Computer Access 434
17.5 Electronic Travel Aids 437
17.6 Other Systems 446
17.7 Discussion 449
17.8 Conclusion 450

18 Sonification for Process Monitoring 455
Paul Vickers

18.1 Types of monitoring — basic categories 455
18.2 Modes of Listening 457
18.3 Environmental awareness (workspaces and living spaces) 459
18.4 Monitoring program execution 462
18.5 Monitoring interface tasks 469
18.6 Potential pitfalls 473
18.7 The road ahead 479

19 Intelligent auditory alarms 493
Anne Guillaume

19.1 Introduction 493
19.2 The concept of auditory alarms 494
19.3 Problems linked to non-speech auditory alarm design 495
19.4 Acoustic properties of non-speech sound alarms 496
19.5 A cognitive approach to the problem 498
19.6 Spatialization of alarms 500
19.7 Contribution of learning 501
19.8 Ergonomic approach to the problem 503
19.9 Intelligent alarm systems 504
19.10 Conclusion 505

20 Navigation of Data 509
Eoin Brazil and Mikael Fernström

20.1 Navigation Control Loop 510
20.2 Wayfinding 510
20.3 Methods For Navigating Through Data 511
20.4 Using Auditory Displays For Navigation Of Data 515
20.5 Considerations for the Design of Auditory Displays for the Navigation of Data 521

21 Aiding Movement with Sonification in "Exercise, Play and Sport" 525
Edited by Oliver Höner

21.1 Multidisciplinary Applications of Sonification in the Field of "Exercise, Play and Sport" 525

21.2 Use of Sound for Physiotherapy Analysis and Feedback 528
21.3 Interaction with Sound in auditory computer games 532
21.4 Sonification-based Sport games and Performance Tests in Adapted Physical Activity 538
21.5 Enhancing Motor Control and Learning by Additional Movement Sonification 547
21.6 Concluding Remarks 551

Index **555**