Contents

Preface **vii**

1 Channels and Constraints **1**

1.1 Magnetic Recording 1

1.2 Classical runlength constraints 3

1.3 Coding for Channels 5

1.4 Encoding and decoding for constrained systems 6

1.5 Examples of constraints 11

1.5.1 Anti-whistle constraints 11

1.5.2 Synchronization constraints 12

1.5.3 Multiple-spaced runlength constraints 13

1.5.4 Spectral-null constraints 15

1.5.5 Combined charge–runlength constraints 17

1.5.6 Constraints for PRML 18

1.6 Background on magnetic recording 20

1.6.1 Peak detection 20

1.6.2 PRML detection 22

1.7 Coding in optical recording 25

1.7.1 The compact disk 25

1.7.2 EFM code at rate 8 : 16 26

1.7.3 Dc control 28

1.8 Two-dimensional constraints 31
Problems 33

2 Constrained Systems **37**

2.1 Labeled graphs and constraints 37
2.2 Properties of labelings 40
2.2.1 Deterministic presentation 40
2.2.2 Finite anticipation 41
2.2.3 Finite memory 42
2.2.4 Definite graphs 42
2.2.5 Lossless graphs 43
2.2.6 Summary of terms 43
2.2.7 State labeling 44
2.3 Finite-type constraints 45
2.4 Some operations on graphs 48
2.4.1 Power of a graph 48
2.4.2 Higher edge graph 49
2.4.3 Fiber product of graphs 50
2.5 Irreducibility 50
2.5.1 Irreducible graphs 50
2.5.2 Irreducible constrained systems 52
2.6 Minimal presentations 53
2.6.1 Follower sets and reduced labeled graphs 54
2.6.2 The Moore algorithm 54
2.6.3 Homing words 56
2.6.4 Shannon cover of irreducible constrained systems 57
2.6.5 Shannon cover of finite-type constrained systems 58
2.7 Testing algorithms 60

2.7.1 Testing for losslessness 60
2.7.2 Testing for finite anticipation 61
2.7.3 Testing for finite memory 61
2.7.4 Testing for definiteness 62
Problems 62

3 Capacity **69**
3.1 Combinatorial characterization of capacity 69
3.2 Algebraic characterization of capacity 72
3.3 Perron-Frobenius theory 76
3.3.1 Irreducible matrices 76
3.3.2 Primitivity and periodicity 77
3.3.3 Perron-Frobenius Theorem 81
3.3.4 Stronger properties in the primitive case 85
3.4 Markov chains 88
3.5 Probabilistic characterization of capacity 91
3.6 Approaching capacity by finite-type constraints 94
Problems 95

4 Finite-State Encoders **108**
4.1 Definition of finite-state encoders 108
4.2 Block encoders 112
4.3 Sliding-block decodable encoders 116
4.4 Block decodable encoders 121
4.5 Non-catastrophic encoders 123
4.6 Relationships among decodability properties 125
4.7 Markov chains on encoders 125
4.8 Spectral analysis of encoders 126

Problems . . . 129

5 The State-Splitting Algorithm 134

5.1 State splitting . . . 135

5.2 Approximate eigenvectors and consistent splitting . . . 138

5.2.1 Approximate eigenvectors . . . 139

5.2.2 Computing approximate eigenvectors . . . 141

5.2.3 $\mathbf{x}$-consistent splitting . . . 143

5.3 Constructing the encoder . . . 146

5.4 Strong decoders . . . 151

5.5 Simplifications . . . 155

5.5.1 State merging . . . 155

5.5.2 Sliding-block decoder window . . . 161

5.6 Universality of the state-splitting algorithm . . . 164

5.6.1 Universality for sliding-block decodable encoders . . . 164

5.6.2 Universality for encoders with finite anticipation . . . 165

Problems . . . 166

6 Other Code Construction Methods 173

6.1 IP encoders . . . 173

6.2 Stethering encoders . . . 174

6.3 Generalized tagged (S, n)-encoders . . . 176

6.4 Encoders through variable-length graphs . . . 177

6.4.1 Variable-length graphs and n-codability . . . 177

6.4.2 Variable-length state splitting . . . 178

6.4.3 Method of poles . . . 179

6.5 Look-ahead encoders . . . 180

6.6 Bounded-delay encoders . . . 182

6.7 Transforming a generalized encoder to an ordinary encoder 183
Problems 184

7 Complexity of Encoders 186

7.1 Complexity criteria 186
7.2 Number of states in the encoder 187
7.3 Values of p and q 191
7.4 Encoder anticipation 193
7.4.1 Deciding upon existence of encoders with a given anticipation 193
7.4.2 Upper bounds on the anticipation 195
7.4.3 Lower bounds on the anticipation 198
7.5 Sliding-block decodability 201
7.6 Gate complexity and time–space complexity 203
Problems 205

8 Error Correction and Concatenation 207

8.1 Error-Correction Coding 208
8.2 Linear Codes 209
8.2.1 Definition 209
8.2.2 Generator Matrix 210
8.2.3 Parity-check matrix 212
8.3 Introduction to Finite Fields 213
8.4 The Singleton bound and Reed-Solomon codes 216
8.5 Concatenation of ECC and constrained codes 217
8.6 Block and sliding-block compressible codes 220
8.7 Application to burst correction 223
8.8 Constructing sliding-block compressible excoders 226
8.8.1 Super-vectors 226

8.8.2 Consistent splittings 229
8.8.3 Reduction of edge effect in error propagation 234
Problems 235

9 Error-Correcting Constrained Coding **239**
9.1 Error-mechanisms in recording channels 239
9.2 Gilbert-Varshamov-type lower bounds 240
9.2.1 Classical bound for the Hamming metric 240
9.2.2 Hamming-metric bound for constrained systems 241
9.2.3 Improved Hamming-metric bounds 243
9.3 Towards sphere-packing upper bounds 247
9.4 Distance properties of spectral-null codes 250
9.5 Synchronization/bitshift error correction 250
9.6 Soft-decision decoding through Euclidean metric 256
9.7 Forbidden list codes for targeted error events 260
Problems 260

Bibliography **263**