

Contents

Preface	xvii
1 Introduction	1
1.1 Compression Techniques	3
1.1.1 Lossless Compression	4
1.1.2 Lossy Compression	5
1.1.3 Measures of Performance	5
1.2 Modeling and Coding	6
1.3 Summary	10
1.4 Projects and Problems	11
2 Mathematical Preliminaries for Lossless Compression	13
2.1 Overview	13
2.2 A Brief Introduction to Information Theory	13
2.2.1 Derivation of Average Information ★	18
2.3 Models	23
2.3.1 Physical Models	23
2.3.2 Probability Models	23
2.3.3 Markov Models	24
2.3.4 Composite Source Model	27
2.4 Coding	27
2.4.1 Uniquely Decodable Codes	28
2.4.2 Prefix Codes	31
2.4.3 The Kraft-McMillan Inequality ★	32
2.5 Algorithmic Information Theory	35
2.6 Minimum Description Length Principle	36
2.7 Summary	37
2.8 Projects and Problems	38
3 Huffman Coding	41
3.1 Overview	41
3.2 The Huffman Coding Algorithm	41
3.2.1 Minimum Variance Huffman Codes	46
3.2.2 Optimality of Huffman Codes ★	48
3.2.3 Length of Huffman Codes ★	49
3.2.4 Extended Huffman Codes ★	51

3.3	Nonbinary Huffman Codes ★	55
3.4	Adaptive Huffman Coding	58
3.4.1	Update Procedure	59
3.4.2	Encoding Procedure	62
3.4.3	Decoding Procedure	63
3.5	Golomb Codes	65
3.6	Rice Codes	67
3.6.1	CCSDS Recommendation for Lossless Compression	67
3.7	Tunstall Codes	69
3.8	Applications of Huffman Coding	72
3.8.1	Lossless Image Compression	72
3.8.2	Text Compression	74
3.8.3	Audio Compression	75
3.9	Summary	77
3.10	Projects and Problems	77
4	Arithmetic Coding	81
4.1	Overview	81
4.2	Introduction	81
4.3	Coding a Sequence	83
4.3.1	Generating a Tag	84
4.3.2	Deciphering the Tag	91
4.4	Generating a Binary Code	92
4.4.1	Uniqueness and Efficiency of the Arithmetic Code	93
4.4.2	Algorithm Implementation	96
4.4.3	Integer Implementation	102
4.5	Comparison of Huffman and Arithmetic Coding	109
4.6	Adaptive Arithmetic Coding	112
4.7	Applications	112
4.8	Summary	113
4.9	Projects and Problems	114
5	Dictionary Techniques	117
5.1	Overview	117
5.2	Introduction	117
5.3	Static Dictionary	118
5.3.1	Digram Coding	119
5.4	Adaptive Dictionary	121
5.4.1	The LZ77 Approach	121
5.4.2	The LZ78 Approach	125
5.5	Applications	133
5.5.1	File Compression—UNIX <code>compress</code>	133
5.5.2	Image Compression—The Graphics Interchange Format (GIF)	133
5.5.3	Image Compression—Portable Network Graphics (PNG)	134
5.5.4	Compression over Modems—V.42 bis	136

5.6	Summary	138
5.7	Projects and Problems	139
6	Context-Based Compression	141
6.1	Overview	141
6.2	Introduction	141
6.3	Prediction with Partial Match (<i>ppm</i>)	143
6.3.1	The Basic Algorithm	143
6.3.2	The Escape Symbol	149
6.3.3	Length of Context	150
6.3.4	The Exclusion Principle	151
6.4	The Burrows-Wheeler Transform	152
6.4.1	Move-to-Front Coding	156
6.5	Associative Coder of Buyanovsky (ACB)	157
6.6	Dynamic Markov Compression	158
6.7	Summary	160
6.8	Projects and Problems	161
7	Lossless Image Compression	163
7.1	Overview	163
7.2	Introduction	163
7.2.1	The Old JPEG Standard	164
7.3	CALIC	166
7.4	JPEG-LS	170
7.5	Multiresolution Approaches	172
7.5.1	Progressive Image Transmission	173
7.6	Facsimile Encoding	178
7.6.1	Run-Length Coding	179
7.6.2	CCITT Group 3 and 4—Recommendations T.4 and T.6	180
7.6.3	JBIG	183
7.6.4	JBIG2—T.88	189
7.7	MRC—T.44	190
7.8	Summary	193
7.9	Projects and Problems	193
8	Mathematical Preliminaries for Lossy Coding	195
8.1	Overview	195
8.2	Introduction	195
8.3	Distortion Criteria	197
8.3.1	The Human Visual System	199
8.3.2	Auditory Perception	200
8.4	Information Theory Revisited ★	201
8.4.1	Conditional Entropy	202
8.4.2	Average Mutual Information	204
8.4.3	Differential Entropy	205

8.5	Rate Distortion Theory ★	208
8.6	Models	215
8.6.1	Probability Models	216
8.6.2	Linear System Models	218
8.6.3	Physical Models	223
8.7	Summary	224
8.8	Projects and Problems	224
9	Scalar Quantization	227
9.1	Overview	227
9.2	Introduction	227
9.3	The Quantization Problem	228
9.4	Uniform Quantizer	233
9.5	Adaptive Quantization	244
9.5.1	Forward Adaptive Quantization	244
9.5.2	Backward Adaptive Quantization	246
9.6	Nonuniform Quantization	253
9.6.1	<i>pdf</i> -Optimized Quantization	253
9.6.2	Companded Quantization	257
9.7	Entropy-Coded Quantization	264
9.7.1	Entropy Coding of Lloyd-Max Quantizer Outputs	265
9.7.2	Entropy-Constrained Quantization ★	265
9.7.3	High-Rate Optimum Quantization ★	266
9.8	Summary	269
9.9	Projects and Problems	270
10	Vector Quantization	273
10.1	Overview	273
10.2	Introduction	273
10.3	Advantages of Vector Quantization over Scalar Quantization	276
10.4	The Linde-Buzo-Gray Algorithm	282
10.4.1	Initializing the LBG Algorithm	287
10.4.2	The Empty Cell Problem	294
10.4.3	Use of LBG for Image Compression	294
10.5	Tree-Structured Vector Quantizers	299
10.5.1	Design of Tree-Structured Vector Quantizers	302
10.5.2	Pruned Tree-Structured Vector Quantizers	303
10.6	Structured Vector Quantizers	303
10.6.1	Pyramid Vector Quantization	305
10.6.2	Polar and Spherical Vector Quantizers	306
10.6.3	Lattice Vector Quantizers	307
10.7	Variations on the Theme	311
10.7.1	Gain-Shape Vector Quantization	311
10.7.2	Mean-Removed Vector Quantization	312

10.7.3	Classified Vector Quantization	313
10.7.4	Multistage Vector Quantization	313
10.7.5	Adaptive Vector Quantization	315
10.8	Trellis-Coded Quantization	316
10.9	Summary	321
10.10	Projects and Problems	322
11	Differential Encoding	325
11.1	Overview	325
11.2	Introduction	325
11.3	The Basic Algorithm	328
11.4	Prediction in DPCM	332
11.5	Adaptive DPCM	337
11.5.1	Adaptive Quantization in DPCM	338
11.5.2	Adaptive Prediction in DPCM	339
11.6	Delta Modulation	342
11.6.1	Constant Factor Adaptive Delta Modulation (CFDM)	343
11.6.2	Continuously Variable Slope Delta Modulation	345
11.7	Speech Coding	345
11.7.1	G.726	347
11.8	Image Coding	349
11.9	Summary	351
11.10	Projects and Problems	352
12	Mathematical Preliminaries for Transforms, Subbands, and Wavelets	355
12.1	Overview	355
12.2	Introduction	355
12.3	Vector Spaces	356
12.3.1	Dot or Inner Product	357
12.3.2	Vector Space	357
12.3.3	Subspace	359
12.3.4	Basis	360
12.3.5	Inner Product—Formal Definition	361
12.3.6	Orthogonal and Orthonormal Sets	361
12.4	Fourier Series	362
12.5	Fourier Transform	365
12.5.1	Parseval's Theorem	366
12.5.2	Modulation Property	366
12.5.3	Convolution Theorem	367
12.6	Linear Systems	368
12.6.1	Time Invariance	368
12.6.2	Transfer Function	368
12.6.3	Impulse Response	369
12.6.4	Filter	371

12.7	Sampling	372
	12.7.1 Ideal Sampling—Frequency Domain View	373
	12.7.2 Ideal Sampling—Time Domain View	375
12.8	Discrete Fourier Transform	376
12.9	Z-Transform	378
	12.9.1 Tabular Method	381
	12.9.2 Partial Fraction Expansion	382
	12.9.3 Long Division	386
	12.9.4 Z-Transform Properties	387
	12.9.5 Discrete Convolution	387
12.10	Summary	389
12.11	Projects and Problems	390
13	Transform Coding	391
13.1	Overview	391
13.2	Introduction	391
13.3	The Transform	396
13.4	Transforms of Interest	400
	13.4.1 Karhunen-Loève Transform	401
	13.4.2 Discrete Cosine Transform	402
	13.4.3 Discrete Sine Transform	404
	13.4.4 Discrete Walsh-Hadamard Transform	404
13.5	Quantization and Coding of Transform Coefficients	407
13.6	Application to Image Compression—JPEG	410
	13.6.1 The Transform	410
	13.6.2 Quantization	411
	13.6.3 Coding	413
13.7	Application to Audio Compression—the MDCT	416
13.8	Summary	419
13.9	Projects and Problems	421
14	Subband Coding	423
14.1	Overview	423
14.2	Introduction	423
14.3	Filters	428
	14.3.1 Some Filters Used in Subband Coding	432
14.4	The Basic Subband Coding Algorithm	436
	14.4.1 Analysis	436
	14.4.2 Quantization and Coding	437
	14.4.3 Synthesis	437
14.5	Design of Filter Banks ★	438
	14.5.1 Downsampling ★	440
	14.5.2 Upsampling ★	443
14.6	Perfect Reconstruction Using Two-Channel Filter Banks ★	444
	14.6.1 Two-Channel PR Quadrature Mirror Filters ★	447
	14.6.2 Power Symmetric FIR Filters ★	449

14.7	<i>M</i> -Band QMF Filter Banks ★	451
14.8	The Polyphase Decomposition ★	454
14.9	Bit Allocation	459
14.10	Application to Speech Coding—G.722	461
14.11	Application to Audio Coding—MPEG Audio	462
14.12	Application to Image Compression	463
	14.12.1 Decomposing an Image	465
	14.12.2 Coding the Subbands	467
14.13	Summary	470
14.14	Projects and Problems	471
15	Wavelet-Based Compression	473
15.1	Overview	473
15.2	Introduction	473
15.3	Wavelets	476
15.4	Multiresolution Analysis and the Scaling Function	480
15.5	Implementation Using Filters	486
	15.5.1 Scaling and Wavelet Coefficients	488
	15.5.2 Families of Wavelets	491
15.6	Image Compression	494
15.7	Embedded Zerotree Coder	497
15.8	Set Partitioning in Hierarchical Trees	505
15.9	JPEG 2000	512
15.10	Summary	513
15.11	Projects and Problems	513
16	Audio Coding	515
16.1	Overview	515
16.2	Introduction	515
	16.2.1 Spectral Masking	517
	16.2.2 Temporal Masking	517
	16.2.3 Psychoacoustic Model	518
16.3	MPEG Audio Coding	519
	16.3.1 Layer I Coding	520
	16.3.2 Layer II Coding	521
	16.3.3 Layer III Coding— <i>mp3</i>	522
16.4	MPEG Advanced Audio Coding	527
	16.4.1 MPEG-2 AAC	527
	16.4.2 MPEG-4 AAC	532
16.5	Dolby AC3 (Dolby Digital)	533
	16.5.1 Bit Allocation	534
16.6	Other Standards	535
16.7	Summary	536

17	Analysis/Synthesis and Analysis by Synthesis Schemes	537
17.1	Overview	537
17.2	Introduction	537
17.3	Speech Compression	539
17.3.1	The Channel Vocoder	539
17.3.2	The Linear Predictive Coder (Government Standard LPC-10)	542
17.3.3	Code Excited Linear Prediction (CELP)	549
17.3.4	Sinusoidal Coders	552
17.3.5	Mixed Excitation Linear Prediction (MELP)	555
17.4	Wideband Speech Compression—ITU-T G.722.2	558
17.5	Image Compression	559
17.5.1	Fractal Compression	560
17.6	Summary	568
17.7	Projects and Problems	569
18	Video Compression	571
18.1	Overview	571
18.2	Introduction	571
18.3	Motion Compensation	573
18.4	Video Signal Representation	576
18.5	ITU-T Recommendation H.261	582
18.5.1	Motion Compensation	583
18.5.2	The Loop Filter	584
18.5.3	The Transform	586
18.5.4	Quantization and Coding	586
18.5.5	Rate Control	588
18.6	Model-Based Coding	588
18.7	Asymmetric Applications	590
18.8	The MPEG-1 Video Standard	591
18.9	The MPEG-2 Video Standard—H.262	594
18.9.1	The Grand Alliance HDTV Proposal	597
18.10	ITU-T Recommendation H.263	598
18.10.1	Unrestricted Motion Vector Mode	600
18.10.2	Syntax-Based Arithmetic Coding Mode	600
18.10.3	Advanced Prediction Mode	600
18.10.4	PB-frames and Improved PB-frames Mode	600
18.10.5	Advanced Intra Coding Mode	600
18.10.6	Deblocking Filter Mode	601
18.10.7	Reference Picture Selection Mode	601
18.10.8	Temporal, SNR, and Spatial Scalability Mode	601
18.10.9	Reference Picture Resampling	601
18.10.10	Reduced-Resolution Update Mode	602
18.10.11	Alternative Inter VLC Mode	602
18.10.12	Modified Quantization Mode	602
18.10.13	Enhanced Reference Picture Selection Mode	603

18.11	ITU-T Recommendation H.264, MPEG-4 Part 10, Advanced Video Coding	603
18.11.1	Motion-Compensated Prediction	604
18.11.2	The Transform	605
18.11.3	Intra Prediction	605
18.11.4	Quantization	606
18.11.5	Coding	608
18.12	MPEG-4 Part 2	609
18.13	Packet Video	610
18.14	ATM Networks	610
18.14.1	Compression Issues in ATM Networks	611
18.14.2	Compression Algorithms for Packet Video	612
18.15	Summary	613
18.16	Projects and Problems	614
A	Probability and Random Processes	615
A.1	Probability	615
A.1.1	Frequency of Occurrence	615
A.1.2	A Measure of Belief	616
A.1.3	The Axiomatic Approach	618
A.2	Random Variables	620
A.3	Distribution Functions	621
A.4	Expectation	623
A.4.1	Mean	624
A.4.2	Second Moment	625
A.4.3	Variance	625
A.5	Types of Distribution	625
A.5.1	Uniform Distribution	625
A.5.2	Gaussian Distribution	626
A.5.3	Laplacian Distribution	626
A.5.4	Gamma Distribution	626
A.6	Stochastic Process	626
A.7	Projects and Problems	629
B	A Brief Review of Matrix Concepts	631
B.1	A Matrix	631
B.2	Matrix Operations	632
C	The Root Lattices	637
	Bibliography	639
	Index	655