

# INFORMATION THEORY AND RELIABLE COMMUNICATION

*Robert G. Gallager*

Massachusetts Institute of Technology

Technische Hochschule Darmstadt	
FACHBEREICH INFORMATIK	
B I B L I O T H E K	
Inventar-Nr.:	<u>3239</u>
Sachgebiete:	_____
Standort:	_____

JOHN WILEY AND SONS, INC.

*New York · London · Sydney · Toronto*

# CONTENTS

<b>1</b>	<b>Communication Systems and Information Theory</b>	<b>1</b>
1.1	Introduction	1
1.2	Source Models and Source Coding	4
1.3	Channel Models and Channel Coding	6
	Historical Notes and References	12
<b>2</b>	<b>A Measure of Information</b>	<b>13</b>
2.1	Discrete Probability: Review and Notation	13
2.2	Definition of Mutual Information	16
2.3	Average Mutual Information and Entropy	23
2.4	Probability and Mutual Information for Continuous Ensembles	27
2.5	Mutual Information for Arbitrary Ensembles	33
	Summary and Conclusions	37
	Historical Notes and References	37
<b>3</b>	<b>Coding for Discrete Sources</b>	<b>38</b>
3.1	Fixed-Length Codes	39
3.2	Variable-Length Code Words	43
3.3	A Source Coding Theorem	50
3.4	An Optimum Variable-Length Encoding Procedure	52
3.5	Discrete Stationary Sources	56
3.6	Markov Sources	63
	Summary and Conclusions	69
	Historical Notes and References	70
<b>4</b>	<b>Discrete Memoryless Channels and Capacity</b>	<b>71</b>
4.1	Classification of Channels	71
4.2	Discrete Memoryless Channels	73
		<b>xi</b>

4.3	The Converse to the Coding Theorem	76
4.4	Convex Functions	82
4.5	Finding Channel Capacity for a Discrete Memoryless Channel	91
4.6	Discrete Channels with Memory	97
	Indecomposable Channels	105
	Summary and Conclusions	111
	Historical Notes and References	111
	Appendix 4A	112
<b>5</b>	<b>The Noisy-Channel Coding Theorem</b>	<b>116</b>
5.1	Block Codes	116
5.2	Decoding Block Codes	120
5.3	Error Probability for Two Code Words	122
5.4	The Generalized Chebyshev Inequality and the Chernoff Bound	126
5.5	Randomly Chosen Code Words	131
5.6	Many Code Words—The Coding Theorem	135
	Properties of the Random Coding Exponent	141
5.7	Error Probability for an Expurgated Ensemble of Codes	150
5.8	Lower Bounds to Error Probability	157
	Block Error Probability at Rates above Capacity	173
5.9	The Coding Theorem for Finite-State Channels	176
	State Known at Receiver	182
	Summary and Conclusions	187
	Historical Notes and References	188
	Appendix 5A	188
	Appendix 5B	193
<b>6</b>	<b>Techniques for Coding and Decoding</b>	<b>196</b>
6.1	Parity-Check Codes	196
	Generator Matrices	199
	Parity-Check Matrices for Systematic Parity-Check Codes	200
	Decoding Tables	202
	Hamming Codes	203
6.2	The Coding Theorem for Parity-Check Codes	206

6.3	Group Theory	209
	Subgroups	210
	Cyclic Subgroups	211
6.4	Fields and Polynomials	213
	Polynomials	214
6.5	Cyclic Codes	219
6.6	Galois Fields	225
	Maximal Length Codes and Hamming Codes	230
	Existence of Galois Fields	235
6.7	BCH Codes	238
	Iterative Algorithm for Finding $\sigma(D)$	245
6.8	Convolutional Codes and Threshold Decoding	258
6.9	Sequential Decoding	263
	Computation for Sequential Decoding	273
	Error Probability for Sequential Decoding	280
6.10	Coding for Burst Noise Channels	286
	Cyclic Codes	291
	Convolutional Codes	297
	Summary and Conclusions	305
	Historical Notes and References	305
	Appendix 6A	306
	Appendix 6B	309
<b>7</b>	<b>Memoryless Channels with Discrete Time</b>	<b>316</b>
7.1	Introduction	316
7.2	Unconstrained Inputs	318
7.3	Constrained Inputs	323
7.4	Additive Noise and Additive Gaussian Noise	333
	Additive Gaussian Noise with an Energy Constrained Input	335
7.5	Parallel Additive Gaussian Noise Channels	343
	Summary and Conclusions	354
	Historical Notes and References	354
<b>8</b>	<b>Waveform Channels</b>	<b>355</b>
8.1	Orthonormal Expansions of Signals and White Gaussian Noise	355
	Gaussian Random Processes	362
	Mutual Information for Continuous-Time Channels	369

8.2	White Gaussian Noise and Orthogonal Signals	371
	Error Probability for Two Code Words	374
	Error Probability for Orthogonal Code Words	379
8.3	Heuristic Treatment of Capacity for Channels with Additive Gaussian Noise and Bandwidth Constraints	383
8.4	Representation of Linear Filters and Nonwhite Noise	390
	Filtered Noise and the Karhunen-Loeve Expansion	398
	Low-Pass Ideal Filters	402
8.5	Additive Gaussian Noise Channels with an Input Constrained in Power and Frequency	407
8.6	Fading Dispersive Channels	431
	Summary and Conclusions	439
	Historical Notes and References	440
<b>9</b>	<b>Source Coding with a Fidelity Criterion</b>	<b>442</b>
9.1	Introduction	442
9.2	Discrete Memoryless Sources and Single-Letter Distortion Measures	443
9.3	The Coding Theorem for Sources with a Fidelity Criterion	451
9.4	Calculation of $R(d^*)$	457
9.5	The Converse to the Noisy-Channel Coding Theorem Revisited	465
9.6	Discrete-Time Sources with Continuous Amplitudes	470
9.7	Gaussian Sources with Square Difference Distortion	475
	Gaussian Random-Process Sources	482
9.8	Discrete Ergodic Sources	490
	Summary and Conclusions	500
	Historical Notes and References	501
	Exercises and Problems	503
	References and Selected Reading	569
	Glossary of Symbols	578
	<b>Index</b>	<b>581</b>