

Cambridge University Press
978-0-521-84868-8 - Channel Codes: Classical and Modern
William E. Ryan and Shu Lin
Frontmatter
[More information](#)

Channel Codes

Channel coding lies at the heart of digital communication and data storage, and this detailed introduction describes the core theory as well as decoding algorithms, implementation details, and performance analyses.

Professors Ryan and Lin, known for the clarity of their writing, provide the latest information on modern channel codes, including turbo and low-density parity-check (LDPC) codes. They also present detailed coverage of BCH codes, Reed–Solomon codes, convolutional codes, finite-geometry codes, and product codes, providing a one-stop resource for both classical and modern coding techniques.

The opening chapters begin with basic theory to introduce newcomers to the subject, assuming no prior knowledge in the field of channel coding. Subsequent chapters cover the encoding and decoding of the most widely used codes and extend to advanced topics such as code ensemble performance analyses and algebraic code design. Numerous varied and stimulating end-of-chapter problems, 250 in total, are also included to test and enhance learning, making this an essential resource for students and practitioners alike.

William E. Ryan is a Professor in the Department of Electrical and Computer Engineering at the University of Arizona, where he has been a faculty member since 1998. Before moving to academia, he held positions in industry for five years. He has published over 100 technical papers and his research interests include coding and signal processing with applications to data storage and data communications.

Shu Lin is an Adjunct Professor in the Department of Electrical and Computer Engineering, University of California, Davis. He has authored and co-authored numerous technical papers and several books, including the successful *Error Control Coding* (with Daniel J. Costello). He is an IEEE Life Fellow and has received several awards, including the Alexander von Humboldt Research Prize for US Senior Scientists (1996) and the IEEE Third-Millennium Medal (2000).

Cambridge University Press
978-0-521-84868-8 - Channel Codes: Classical and Modern
William E. Ryan and Shu Lin
Frontmatter
[More information](#)

Channel Codes

Classical and Modern

WILLIAM E. RYAN

University of Arizona

SHU LIN

University of California, Davis



CAMBRIDGE
UNIVERSITY PRESS

Cambridge University Press
978-0-521-84868-8 - Channel Codes: Classical and Modern
William E. Ryan and Shu Lin
Frontmatter
[More information](#)

CAMBRIDGE UNIVERSITY PRESS

Cambridge, New York, Melbourne, Madrid, Cape Town, Singapore, São Paulo, Delhi

Cambridge University Press

The Edinburgh Building, Cambridge CB2 8RU, UK

Published in the United States of America by Cambridge University Press, New York

www.cambridge.org

Information on this title: www.cambridge.org/9780521848688

© Cambridge University Press 2009

This publication is in copyright. Subject to statutory exception and to the provisions of relevant collective licensing agreements, no reproduction of any part may take place without the written permission of Cambridge University Press.

First published 2009

Printed in the United Kingdom at the University Press, Cambridge

A catalog record for this publication is available from the British Library

ISBN 978-0-521-84868-8 Hardback

Cambridge University Press has no responsibility for the persistence or accuracy of URLs for external or third-party internet websites referred to in this publication, and does not guarantee that any content on such websites is, or will remain, accurate or appropriate.

Contents

	<i>Preface</i>	<i>page</i> xiii
1	Coding and Capacity	1
	1.1 Digital Data Communication and Storage	1
	1.2 Channel-Coding Overview	3
	1.3 Channel-Code Archetype: The (7,4) Hamming Code	4
	1.4 Design Criteria and Performance Measures	7
	1.5 Channel-Capacity Formulas for Common Channel Models	10
	1.5.1 Capacity for Binary-Input Memoryless Channels	11
	1.5.2 Coding Limits for M -ary-Input Memoryless Channels	18
	1.5.3 Coding Limits for Channels with Memory	21
	Problems	24
	References	26
2	Finite Fields, Vector Spaces, Finite Geometries, and Graphs	28
	2.1 Sets and Binary Operations	28
	2.2 Groups	30
	2.2.1 Basic Concepts of Groups	30
	2.2.2 Finite Groups	32
	2.2.3 Subgroups and Cosets	35
	2.3 Fields	38
	2.3.1 Definitions and Basic Concepts	38
	2.3.2 Finite Fields	41
	2.4 Vector Spaces	45
	2.4.1 Basic Definitions and Properties	45
	2.4.2 Linear Independence and Dimension	46
	2.4.3 Finite Vector Spaces over Finite Fields	48
	2.4.4 Inner Products and Dual Spaces	50
	2.5 Polynomials over Finite Fields	51
	2.6 Construction and Properties of Galois Fields	56
	2.6.1 Construction of Galois Fields	56
	2.6.2 Some Fundamental Properties of Finite Fields	64
	2.6.3 Additive and Cyclic Subgroups	69

vi	Contents	
	2.7 Finite Geometries	70
	2.7.1 Euclidean Geometries	70
	2.7.2 Projective Geometries	76
	2.8 Graphs	80
	2.8.1 Basic Concepts	80
	2.8.2 Paths and Cycles	84
	2.8.3 Bipartite Graphs	86
	Problems	88
	References	90
	Appendix A	92
3	Linear Block Codes	94
	3.1 Introduction to Linear Block Codes	94
	3.1.1 Generator and Parity-Check Matrices	95
	3.1.2 Error Detection with Linear Block Codes	98
	3.1.3 Weight Distribution and Minimum Hamming Distance of a Linear Block Code	99
	3.1.4 Decoding of Linear Block Codes	102
	3.2 Cyclic Codes	106
	3.3 BCH Codes	111
	3.3.1 Code Construction	111
	3.3.2 Decoding	114
	3.4 Nonbinary Linear Block Codes and Reed–Solomon Codes	121
	3.5 Product, Interleaved, and Concatenated Codes	129
	3.5.1 Product Codes	129
	3.5.2 Interleaved Codes	130
	3.5.3 Concatenated Codes	131
	3.6 Quasi-Cyclic Codes	133
	3.7 Repetition and Single-Parity-Check Codes	142
	Problems	143
	References	145
4	Convolutional Codes	147
	4.1 The Convolutional Code Archetype	147
	4.2 Algebraic Description of Convolutional Codes	149
	4.3 Encoder Realizations and Classifications	152
	4.3.1 Choice of Encoder Class	157
	4.3.2 Catastrophic Encoders	158
	4.3.3 Minimal Encoders	159
	4.3.4 Design of Convolutional Codes	163
	4.4 Alternative Convolutional Code Representations	163
	4.4.1 Convolutional Codes as Semi-Infinite Linear Codes	164
	4.4.2 Graphical Representations for Convolutional Code Encoders	170

4.5	Trellis-Based Decoders	171
4.5.1	MLSD and the Viterbi Algorithm	172
4.5.2	Differential Viterbi Decoding	177
4.5.3	Bit-wise MAP Decoding and the BCJR Algorithm	180
4.6	Performance Estimates for Trellis-Based Decoders	187
4.6.1	ML Decoder Performance for Block Codes	187
4.6.2	Weight Enumerators for Convolutional Codes	189
4.6.3	ML Decoder Performance for Convolutional Codes	193
	Problems	195
	References	200
5	Low-Density Parity-Check Codes	201
5.1	Representations of LDPC Codes	201
5.1.1	Matrix Representation	201
5.1.2	Graphical Representation	202
5.2	Classifications of LDPC Codes	205
5.2.1	Generalized LDPC Codes	207
5.3	Message Passing and the Turbo Principle	208
5.4	The Sum-Product Algorithm	213
5.4.1	Overview	213
5.4.2	Repetition Code MAP Decoder and APP Processor	216
5.4.3	Single-Parity-Check Code MAP Decoder and APP Processor	217
5.4.4	The Gallager SPA Decoder	218
5.4.5	The Box-Plus SPA Decoder	222
5.4.6	Comments on the Performance of the SPA Decoder	225
5.5	Reduced-Complexity SPA Approximations	226
5.5.1	The Min-Sum Decoder	226
5.5.2	The Attenuated and Offset Min-Sum Decoders	229
5.5.3	The Min-Sum-with-Correction Decoder	231
5.5.4	The Approximate Min* Decoder	233
5.5.5	The Richardson/Novichkov Decoder	234
5.5.6	The Reduced-Complexity Box-Plus Decoder	236
5.6	Iterative Decoders for Generalized LDPC Codes	241
5.7	Decoding Algorithms for the BEC and the BSC	243
5.7.1	Iterative Erasure Filling for the BEC	243
5.7.2	ML Decoder for the BEC	244
5.7.3	Gallager's Algorithm A and Algorithm B for the BSC	246
5.7.4	The Bit-Flipping Algorithm for the BSC	247
5.8	Concluding Remarks	248
	Problems	248
	References	254

viii	Contents	
6	Computer-Based Design of LDPC Codes	257
6.1	The Original LDPC Codes	257
6.1.1	Gallager Codes	257
6.1.2	MacKay Codes	258
6.2	The PEG and ACE Code-Design Algorithms	259
6.2.1	The PEG Algorithm	259
6.2.2	The ACE Algorithm	260
6.3	Protograph LDPC Codes	261
6.3.1	Decoding Architectures for Protograph Codes	264
6.4	Multi-Edge-Type LDPC Codes	265
6.5	Single-Accumulator-Based LDPC Codes	266
6.5.1	Repeat–Accumulate Codes	267
6.5.2	Irregular Repeat–Accumulate Codes	267
6.5.3	Generalized Accumulator LDPC Codes	277
6.6	Double-Accumulator-Based LDPC Codes	277
6.6.1	Irregular Repeat–Accumulate–Accumulate Codes	278
6.6.2	Accumulate–Repeat–Accumulate Codes	279
6.7	Accumulator-Based Codes in Standards	285
6.8	Generalized LDPC Codes	287
6.8.1	A Rate-1/2 G-LDPC Code	290
	Problems	292
	References	295
7	Turbo Codes	298
7.1	Parallel-Concatenated Convolutional Codes	298
7.1.1	Critical Properties of RSC Codes	299
7.1.2	Critical Properties of the Interleaver	300
7.1.3	The Puncturer	301
7.1.4	Performance Estimate on the BI-AWGNC	301
7.2	The PCCC Iterative Decoder	306
7.2.1	Overview of the Iterative Decoder	308
7.2.2	Decoder Details	309
7.2.3	Summary of the PCCC Iterative Decoder	313
7.2.4	Lower-Complexity Approximations	316
7.3	Serial-Concatenated Convolutional Codes	320
7.3.1	Performance Estimate on the BI-AWGNC	320
7.3.2	The SCCC Iterative Decoder	323
7.3.3	Summary of the SCCC Iterative Decoder	325
7.4	Turbo Product Codes	328
7.4.1	Turbo Decoding of Product Codes	330
	Problems	335
	References	337

8	Ensemble Enumerators for Turbo and LDPC Codes	339
	8.1 Notation	340
	8.2 Ensemble Enumerators for Parallel-Concatenated Codes	343
	8.2.1 Preliminaries	343
	8.2.2 PCCC Ensemble Enumerators	345
	8.3 Ensemble Enumerators for Serial-Concatenated Codes	356
	8.3.1 Preliminaries	356
	8.3.2 SCCC Ensemble Enumerators	358
	8.4 Enumerators for Selected Accumulator-Based Codes	362
	8.4.1 Enumerators for Repeat–Accumulate Codes	362
	8.4.2 Enumerators for Irregular Repeat–Accumulate Codes	364
	8.5 Enumerators for Protograph-Based LDPC Codes	367
	8.5.1 Finite-Length Ensemble Weight Enumerators	368
	8.5.2 Asymptotic Ensemble Weight Enumerators	371
	8.5.3 On the Complexity of Computing Asymptotic Ensemble Enumerators	376
	8.5.4 Ensemble Trapping-Set Enumerators	379
	Problems	383
	References	386
9	Ensemble Decoding Thresholds for LDPC and Turbo Codes	388
	9.1 Density Evolution for Regular LDPC Codes	388
	9.2 Density Evolution for Irregular LDPC Codes	394
	9.3 Quantized Density Evolution	399
	9.4 The Gaussian Approximation	402
	9.4.1 GA for Regular LDPC Codes	403
	9.4.2 GA for Irregular LDPC Codes	404
	9.5 On the Universality of LDPC Codes	407
	9.6 EXIT Charts for LDPC Codes	412
	9.6.1 EXIT Charts for Regular LDPC Codes	414
	9.6.2 EXIT Charts for Irregular LDPC Codes	416
	9.6.3 EXIT Technique for Protograph-Based Codes	417
	9.7 EXIT Charts for Turbo Codes	420
	9.8 The Area Property for EXIT Charts	424
	9.8.1 Serial-Concatenated Codes	424
	9.8.2 LDPC Codes	425
	Problems	426
	References	428
10	Finite-Geometry LDPC Codes	430
	10.1 Construction of LDPC Codes Based on Lines of Euclidean Geometries	430
	10.1.1 A Class of Cyclic EG-LDPC Codes	432
	10.1.2 A Class of Quasi-Cyclic EG-LDPC Codes	434

x	Contents	
	10.2 Construction of LDPC Codes Based on the Parallel Bundles of Lines in Euclidean Geometries	436
	10.3 Construction of LDPC Codes Based on Decomposition of Euclidean Geometries	439
	10.4 Construction of EG-LDPC Codes by Masking	444
	10.4.1 Masking	445
	10.4.2 Regular Masking	446
	10.4.3 Irregular Masking	447
	10.5 Construction of QC-EG-LDPC Codes by Circulant Decomposition	450
	10.6 Construction of Cyclic and QC-LDPC Codes Based on Projective Geometries	455
	10.6.1 Cyclic PG-LDPC Codes	455
	10.6.2 Quasi-Cyclic PG-LDPC Codes	458
	10.7 One-Step Majority-Logic and Bit-Flipping Decoding Algorithms for FG-LDPC Codes	460
	10.7.1 The OSMLG Decoding Algorithm for LDPC Codes over the BSC	461
	10.7.2 The BF Algorithm for Decoding LDPC Codes over the BSC	468
	10.8 Weighted BF Decoding: Algorithm 1	469
	10.9 Weighted BF Decoding: Algorithms 2 and 3	472
	10.10 Concluding Remarks	477
	Problems	477
	References	481
11	Constructions of LDPC Codes Based on Finite Fields	484
	11.1 Matrix Dispersions of Elements of a Finite Field	484
	11.2 A General Construction of QC-LDPC Codes Based on Finite Fields	485
	11.3 Construction of QC-LDPC Codes Based on the Minimum-Weight Codewords of an RS Code with Two Information Symbols	487
	11.4 Construction of QC-LDPC Codes Based on the Universal Parity-Check Matrices of a Special Subclass of RS Codes	495
	11.5 Construction of QC-LDPC Codes Based on Subgroups of a Finite Field	501
	11.5.1 Construction of QC-LDPC Codes Based on Subgroups of the Additive Group of a Finite Field	501
	11.5.2 Construction of QC-LDPC Codes Based on Subgroups of the Multiplicative Group of a Finite Field	503
	11.6 Construction of QC-LDPC Code Based on the Additive Group of a Prime Field	506
	11.7 Construction of QC-LDPC Codes Based on Primitive Elements of a Field	510
	11.8 Construction of QC-LDPC Codes Based on the Intersecting Bundles of Lines of Euclidean Geometries	512
	11.9 A Class of Structured RS-Based LDPC Codes	516
	Problems	520
	References	522

12	LDPC Codes Based on Combinatorial Designs, Graphs, and Superposition	523
	12.1 Balanced Incomplete Block Designs and LDPC Codes	523
	12.2 Class-I Bose BIBDs and QC-LDPC Codes	524
	12.2.1 Class-I Bose BIBDs	525
	12.2.2 Type-I Class-I Bose BIBD-LDPC Codes	525
	12.2.3 Type-II Class-I Bose BIBD-LDPC Codes	527
	12.3 Class-II Bose BIBDs and QC-LDPC Codes	530
	12.3.1 Class-II Bose BIBDs	531
	12.3.2 Type-I Class-II Bose BIBD-LDPC Codes	531
	12.3.3 Type-II Class-II QC-BIBD-LDPC Codes	533
	12.4 Construction of Type-II Bose BIBD-LDPC Codes by Dispersion	536
	12.5 A Trellis-Based Construction of LDPC Codes	537
	12.5.1 A Trellis-Based Method for Removing Short Cycles from a Bipartite Graph	538
	12.5.2 Code Construction	540
	12.6 Construction of LDPC Codes Based on Progressive Edge-Growth Tanner Graphs	542
	12.7 Construction of LDPC Codes by Superposition	546
	12.7.1 A General Superposition Construction of LDPC Codes	546
	12.7.2 Construction of Base and Constituent Matrices	548
	12.7.3 Superposition Construction of Product LDPC Codes	552
	12.8 Two Classes of LDPC Codes with Girth 8	554
	Problems	557
	References	559
13	LDPC Codes for Binary Erasure Channels	561
	13.1 Iterative Decoding of LDPC Codes for the BEC	561
	13.2 Random-Erasure-Correction Capability	563
	13.3 Good LDPC Codes for the BEC	565
	13.4 Correction of Erasure-Bursts	570
	13.5 Erasure-Burst-Correction Capabilities of Cyclic Finite-Geometry and Superposition LDPC Codes	573
	13.5.1 Erasure-Burst-Correction with Cyclic Finite-Geometry LDPC Codes	573
	13.5.2 Erasure-Burst-Correction with Superposition LDPC Codes	574
	13.6 Asymptotically Optimal Erasure-Burst-Correction QC-LDPC Codes	575
	13.7 Construction of QC-LDPC Codes by Array Dispersion	580
	13.8 Cyclic Codes for Correcting Bursts of Erasures	586
	Problems	589
	References	590
14	Nonbinary LDPC Codes	592
	14.1 Definitions	592
	14.2 Decoding of Nonbinary LDPC Codes	593
	14.2.1 The QSPA	593
	14.2.2 The FFT-QSPA	598

xii	Contents	
	14.3 Construction of Nonbinary LDPC Codes Based on Finite Geometries	600
	14.3.1 A Class of q^m -ary Cyclic EG-LDPC Codes	601
	14.3.2 A Class of Nonbinary Quasi-Cyclic EG-LDPC Codes	607
	14.3.3 A Class of Nonbinary Regular EG-LDPC Codes	610
	14.3.4 Nonbinary LDPC Code Constructions Based on Projective Geometries	611
	14.4 Constructions of Nonbinary QC-LDPC Codes Based on Finite Fields	614
	14.4.1 Dispersion of Field Elements into Nonbinary Circulant Permutation Matrices	615
	14.4.2 Construction of Nonbinary QC-LDPC Codes Based on Finite Fields	615
	14.4.3 Construction of Nonbinary QC-LDPC Codes by Masking	617
	14.4.4 Construction of Nonbinary QC-LDPC Codes by Array Dispersion	618
	14.5 Construction of QC-EG-LDPC Codes Based on Parallel Flats in Euclidean Geometries and Matrix Dispersion	620
	14.6 Construction of Nonbinary QC-EG-LDPC Codes Based on Intersecting Flats in Euclidean Geometries and Matrix Dispersion	624
	14.7 Superposition–Dispersion Construction of Nonbinary QC-LDPC Codes	628
	Problems	631
	References	633
15	LDPC Code Applications and Advanced Topics	636
	15.1 LDPC-Coded Modulation	636
	15.1.1 Design Based on EXIT Charts	638
	15.2 Turbo Equalization and LDPC Code Design for ISI Channels	644
	15.2.1 Turbo Equalization	644
	15.2.2 LDPC Code Design for ISI Channels	648
	15.3 Estimation of LDPC Error Floors	651
	15.3.1 The Error-Floor Phenomenon and Trapping Sets	651
	15.3.2 Error-Floor Estimation	654
	15.4 LDPC Decoder Design for Low Error Floors	657
	15.4.1 Codes Under Study	659
	15.4.2 The Bi-Mode Decoder	661
	15.4.3 Concatenation and Bit-Pinning	666
	15.4.4 Generalized-LDPC Decoder	668
	15.4.5 Remarks	670
	15.5 LDPC Convolutional Codes	670
	15.6 Fountain Codes	672
	15.6.1 Tornado Codes	673
	15.6.2 Luby Transform Codes	674
	15.6.3 Raptor Codes	675
	Problems	676
	References	677
	<i>Index</i>	681

Preface

The title of this book, *Channel Codes: Classical and Modern*, was selected to reflect the fact that this book does indeed cover both classical and modern channel codes. It includes BCH codes, Reed–Solomon codes, convolutional codes, finite-geometry codes, turbo codes, low-density parity-check (LDPC) codes, and product codes. However, the title has a second interpretation. While the majority of this book is on LDPC codes, these can rightly be considered to be both classical (having been first discovered in 1961) and modern (having been rediscovered circa 1996). This is exemplified by David Forney’s statement at his August 1999 IMA talk on codes on graphs, “It feels like the early days.” As another example of the classical/modern duality, finite-geometry codes were studied in the 1960s and thus are classical codes. However, they were rediscovered by Shu Lin *et al.* circa 2000 as a class of LDPC codes with very appealing features and are thus modern codes as well. The classical and modern incarnations of finite-geometry codes are distinguished by their decoders: one-step hard-decision decoding (classical) versus iterative soft-decision decoding (modern).

It has been 60 years since the publication in 1948 of Claude Shannon’s celebrated *A Mathematical Theory of Communication*, which founded the fields of channel coding, source coding, and information theory. Shannon proved the existence of channel codes which ensure reliable communication provided that the information rate for a given code did not exceed the so-called capacity of the channel. In the first 45 years that followed Shannon’s publication, a large number of very clever and very effective coding systems had been devised. However, none of these had been demonstrated, in a practical setting, to closely approach Shannon’s theoretical limit. The first breakthrough came in 1993 with the discovery of turbo codes, the first class of codes shown to operate near Shannon’s capacity limit. A second breakthrough came circa 1996 with the rediscovery of LDPC codes, which were also shown to have near-capacity performance. (These codes were first invented in 1961 and mostly ignored thereafter. The state of the technology at that time made them impractical.) Because it has been over a decade since the discovery of turbo and LDPC codes, the knowledge base for these codes is now quite mature and the time is ripe for a new book on channel codes.

This book was written for graduate students in engineering and computer science as well as research and development engineers in industry and academia. We felt compelled to collect all of this information in one source because it has

been scattered across many journal and conference papers. With this book, those entering the field of channel coding, and those wishing to advance their knowledge, conveniently have a single resource for learning about both classical and modern channel codes. Further, whereas the archival literature is written for experts, this textbook is appropriate for both the novice (earlier chapters) and the expert (later chapters). The book begins slowly and does not presuppose prior knowledge in the field of channel coding. It then extends to frontiers of the field, as is evident from the table of contents.

The topics selected for this book, of course, reflect the experiences and interests of the authors, but they were also selected for their importance in the study of channel codes – not to mention the fact that additional chapters would make the book physically unwieldy. Thus, the emphasis of this book is on codes for binary-input channels, including the binary-input additive white-Gaussian-noise channel, the binary symmetric channel, and the binary erasure channel. One notable area of omission is coding for wireless channels, such as MIMO channels. However, this book is useful for students and researchers in that area as well because many of the techniques applied to the additive white-Gaussian-noise channel, our main emphasis, can be extended to wireless channels. Another notable omission is soft-decision decoding of Reed–Solomon codes. While extremely important, this topic is not as mature as those in this book.

Several different course outlines are possible with this book. The most obvious for a first graduate course on channel codes includes selected topics from Chapters 1, 2, 3, 4, 5, and 7. Such a course introduces the student to capacity limits for several common channels (Chapter 1). It then provides the student with an introduction to just enough algebra (Chapter 2) to understand BCH and Reed–Solomon codes and their decoders (Chapter 3). Next, this course introduces the student to convolutional codes and their decoders (Chapter 4). This course next provides the student with an introduction to LDPC codes and iterative decoding (Chapter 5). Finally, with the knowledge gained from Chapters 4 and 5 in place, the student is ready to tackle turbo codes and turbo decoding (Chapter 7). The material contained in Chapters 1, 2, 3, 4, 5, and 7 is too much for a single-semester course and the instructor will have to select a preferred subset of that material.

For a more advanced course centered on LDPC code design, the instructor could select topics from Chapters 10, 11, 12, 13, and 14. This course would first introduce the student to LDPC code design using Euclidean geometries and projective geometries (Chapter 10). Then the student would learn about LDPC code design using finite fields (Chapter 11) and combinatorics and graphs (Chapter 12). Next, the student would apply some of the techniques from these earlier chapters to design codes for the binary erasure channel (Chapter 13). Lastly, the student would learn design techniques for nonbinary LDPC codes (Chapter 14).

As a final example of a course outline, a course could be centered on computer-based design of LDPC codes. Such a course would include Chapters 5, 6, 8, and 9. This course would be for those who have had a course on classical channel

codes, but who are interested in LDPC codes. The course would begin with an introduction to LDPC codes and various LDPC decoders (Chapter 5). Then, the student would learn about various computer-based code-design approaches, including Gallager codes, MacKay codes, codes based on protographs, and codes based on accumulators (Chapter 6). Next, the student would learn about assessing the performance of LDPC code ensembles from a weight-distribution perspective (Chapter 8). Lastly, the student would learn about assessing the performance of (long) LDPC codes from a decoding-threshold perspective via the use of density evolution and EXIT charts (Chapter 9).

All of the chapters contain a good number of problems. The problems are of various types, including those that require routine calculations or derivations, those that require computer solution or computer simulation, and those that might be characterized as a semester project. The authors have selected the problems to strengthen the student's knowledge of the material in each chapter (e.g., by requiring a computer simulation of a decoder) and to extend that knowledge (e.g., by requiring the proof of a result not contained in the chapter).

We wish to thank, first of all, Professor Ian Blake, who read an early version of the entire manuscript and provided many important suggestions that led to a much improved book.

We also wish to thank the many graduate students who have been a tremendous help in the preparation of this book. They have helped with typesetting, computer simulations, proofreading, and figures, and many of their research results can be found in this book. The students (former and current) who have contributed to W. Ryan's portion of the book are Dr. Yang Han, Dr. Yifei Zhang, Dr. Michael (Sizhen) Yang, Dr. Yan Li, Dr. Gianluigi Liva, Dr. Fei Peng, Shadi Abu-Surra, Kristin Jagiello (who proofread eight chapters), and Matt Viens. Gratitude is also due to Li Zhang (S. Lin's student) who provided valuable feedback on Chapters 6 and 9. Finally, W. Ryan acknowledges Sara Sandberg of Luleå Institute of Technology for helpful feedback on an early version of Chapter 5. The students who have contributed to S. Lin's portion of the book are Dr. Bo Zhou, Qin Huang, Dr. Ying Y. Tai, Dr. Lan Lan, Dr. Lingqi Zeng, Jingyu Kang, and Li Zhang; Dr. Bo Zhou and Qin Huang deserve special appreciation for typing S. Lin's chapters and overseeing the preparation of the final version of his chapters.

We thank Professor Dan Costello, who sent us reference material for the convolutional LDPC code section in Chapter 15, Dr. Marc Fossorier, who provided comments on Chapter 14, and Professor Ali Ghayeb, who provided comments on Chapter 7.

We are grateful to the National Science Foundation, the National Aeronautics and Space Administration, and the Information Storage Industry Consortium for their many years of funding support in the area of channel coding. Without their support, many of the results in this book would not have been possible. We also thank the University of Arizona and the University of California, Davis for their support in the writing of this book.

Cambridge University Press
978-0-521-84868-8 - Channel Codes: Classical and Modern
William E. Ryan and Shu Lin
Frontmatter
[More information](#)

We also acknowledge the talented Mrs. Linda Wyrigatsch whose painting on the back cover was created specifically for this book. We note that the paintings on the front and back covers are classical and modern, respectively.

Finally, we would like to give special thanks to our wives (Stephanie and Ivy), children, and grandchildren for their continuing love and affection throughout this project.

William E. Ryan
University of Arizona

Shu Lin
University of California, Davis

Web sites for this book:

www.cambridge.org/9780521848688

<http://www.ece.arizona.edu/~ryan/ChannelCodesBook/>