Guest Editorial

INFORMATION Theory is one of the few scientific disciplines fortunate enough to have a precise date of birth. This special commemorative issue of the IEEE TRANSACTIONS ON INFORMATION THEORY celebrates the 50th anniversary of Claude E. Shannon's "A Mathematical Theory of Communication," published in July and October 1948.

With communication engineering at the epicenter of the bombshell, the sensational aftermath of Shannon's paper soon reached Mathematics, Physics, Statistics, Computing, and Cryptology. Even Economics, Biology, Linguistics, and other fields in the natural and social sciences felt the ripples of Shannon's new theory. Although Information Theory eventually failed to become the ''theory of everything'' that a few had envisioned, it thrived in its natural habitat of information compression, transmission, and processing.

Claude Shannon became an instant celebrity of the postwar industrial age with articles in the popular press that had the foresight to proclaim the far-reaching importance of Information Theory, e.g.:[1]

> Great scientific theories, like great symphonies and great novels, are among man's proudest—and rarest—creations. What sets the scientific theory apart from and, in a sense, above the other creations is that it may profoundly and rapidly alter man's view of his world... Within the last five years a new theory has appeared that seems to bear some of the same hallmarks of greatness... It may be no exaggeration to say that man's progress in peace, and security in war, depend more on fruitful applications of information theory than on physical demonstrations, either in bombs or power plants, that Einstein's famous equation works.

Today, in addition to Shannon's theory of fundamental limits of information transmission and compression, Information Theory encompasses the design of compression, coding, signaling, detection, and classification techniques that underlie contemporary information transmission, storage and processing technologies. With the inexorable advance of technology, Shannon's fundamental limits become increasingly relevant to the design of systems in which resources such as bandwidth, energy, time, and space are at a premium.

This issue contains 25 papers written by a total of 57 authors, who were invited to offer tutorial perspectives on the development and state-of-the-art of the major fields under the purview of the IEEE TRANSACTIONS ON INFORMATION THEORY. Targeted to a wide audience and destined to become classic references, the articles in this issue are invaluable sources for specialists and novices alike.

Without aiming to be exhaustive, the topics selected for this issue provide a snapshot of some of the most dynamic research fields in Information Theory today. The interdisciplinary nature of Information Theory is evident from the list of invited authors, in which we find engineers, mathematicians, computer scientists, probabilists, statisticians, and physicists.

Calderbank's personal perspective on the past, present, and future of coding theory covers the major trends in Hamming and Euclidean spaces as well as the impact of coding beyond reliable communication through noisy channels. The overview by Costello, Hagenauer, Imai, and Wicker illustrates the rich variety of practical applications of error control codes in space communication, voiceband modems, data storage, broadcasting, mobile communication, and network protocols. Forney and Ungerboeck give an account of the basic principles and techniques responsible for the greatest technological success story of coding theory: the pursuit of the capacity of the linear Gaussian channel. Blake, Heegard, Hoeholdt, and Wei offer a self-contained introduction to the theory of algebraic-geometry codes—a class of codes with great, but yet unrealized, practical potential, which has been championed by a number of algebraic coding theorists over the last two decades. As surveyed in the paper by Delsarte and Levenshtein, the unifying tools provided by the combinatorial theory of association schemes have led to important advances in algebraic coding theory over the last 25 years.

The survey by the Guest Editor spans the three major fields founded by Shannon in 1948, namely, lossless data compression algorithms and their fundamental limits, the capacity of noisy channels, and the asymptotic theory of lossy data compression.

Over the last decade, the theory of pattern recurrence times (pioneered by Kac in 1947) has emerged as a powerful tool in the analysis and design of universal lossless data compression algorithms. Wyner, Ziv, and Wyner present a general approach to pattern matching in problems of classification, distribution estimation, entropy estimation, lossless compression, and prediction. In fact, the strong link between compression and prediction of finite-alphabet time series was recognized by Shannon in the early days of Information Theory. Merhav and Feder give a survey of universal prediction of both probabilistically modeled sources and individual deterministic sequences.

Shannon foresaw in 1948 that some communication channels would require the addition of redundancy to the data, not (only) to combat channel noise, but to avoid transmitting certain forbidden sequences. Data-recording systems are prime examples of such channels. Immink, Siegel, and Wolf give

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[1] "The Information Theory," *Fortune*, pp. 136–158, Dec. 1953.

a comprehensive account of the fundamental limits on the redundancy of constrained sequences, and the progress in constructing algorithms that approach those limits.

In 1956 a new branch of combinatorics sprang up from Shannon's definition of the capacity of a graph. Körner and Orlitsky survey the major results on zero-error capacity, zero-error source coding, interactive communication, and protocol complexity. At the intersection of large deviations and combinatorics, the information-theoretic method of types enjoys much popularity in dealing with discrete memoryless sources, channels and hypothesis testing problems. Csiszár gives an overview of the basic tools and achievements of this method. Determining the fundamental limits of sources and channels with memory often calls for ergodic-theoretic tools. Conversely, Information Theory has proved to be instrumental in the proof of key results in ergodic theory. The many facets of the interplay between Information Theory and ergodic theory are discussed in the tutorial paper by Shields.

Jamming and fading are some of the impairments under which the statistical description of the channel available to encoder and/or decoder may be incomplete. Lapidoth and Narayan give a systematic exposition of the existing coding theorems for compound and arbitrarily varying channels. Much has been done and much remains to be done in the field of reliable and efficient communication through time-varying channels. Coding, equalization, and capacity of fading channels are reviewed by Biglieri, Proakis, and Shamai.

Multiuser information theory, founded by Shannon in 1960, has seen a number of fundamental contributions over the last three decades. However, several key canonical problems have defied many efforts. Cover summarizes the progress achieved in the partial solution of the broadcast channel he introduced in 1972. Since the 1970's, information theorists have been responsible for key advances in data networking. However, the information theory of communication networks remains at an embryonic stage. Ephremides and Hajek offer a broad view of networking from an information-theoretic perspective.

The timely tutorial survey of quantum information theory by Bennett and Shor gives an accessible introduction to compression, transmission and cryptography for quantum-mechanical models.

Gray and Neuhoff give a definitive exposition of the historical development of the principles and practice of quantization. The asymptotic theory of analog-to-digital conversion, known as rate-distortion theory, was pioneered by Shannon in 1948 and 1959. Its development is surveyed by Berger and Gibson with emphasis on its first three decades and on the subsequent impact that Information Theory has had on the state-of-the-art in audio, image, and video compression. Many of those algorithms are based on modern harmonic analysis and, in particular, the theory of wavelets. The team of Donoho, Daubechies, DeVore, and Vetterli assembles a broad array of expertise in a forward-looking paper on the use of wavelets and other transform techniques in lossy source coding.

Statistical inference methods in imaging are surveyed by O'Sullivan, Blahut, and Snyder highlighting the important role that Information Theory has played and is expected to play in the development of modeling and estimation techniques. Systems with several sensors connected to a central controller through a capacity-constrained channel give rise to decentralized statistical inference problems with a distinct Shannon-theoretic flavor. Although key open problems remain, the considerable progress in this two-decade-old field is synthesized by Han and Amari.

Information Theory is having a major impact on the field of Statistics thanks to the minimum description length principle put forth around 1980 by Rissanen. Barron, Rissanen, and Yu give an introduction to the subject and to its applications in data compression and statistical inference. Focussing on the two-class classification paradigm, the tutorial survey by Kulkarni, Lugosi, and Venkatesh serves as an introduction to statistical pattern recognition and learning theory—a field with a distinguished tradition in this journal. The detection of signals embedded in noise is another field that has supplied major contributions to the TRANSACTIONS ON INFORMATION THEORY. Kailath and Poor concentrate on two major subfields of interest in communication theory: the structure of the likelihood ratio, and sequence detection.

It is a pleasure to acknowledge those people who, in addition to the authors, have been instrumental in making this publication possible. The initiative to publish a Golden Jubilee Special Issue is due to Robert Calderbank, past Editor-in-Chief, who appointed the Guest Editor and offered valuable advice in the selection of topics and authors. The flawless production of the issue is the result of the generous efforts of our Publications Editor, Steve McLaughlin. Nela Rybowicz, Senior Associate Editor at IEEE Periodicals, has added one more item to her long list of services to the IEEE TRANSACTIONS ON INFORMATION THEORY. Under severe time constraints, the referees provided unusually insightful and thorough reviews. Aaron Wyner's enthusiasm for this project meant a lot to us. His posthumous article leads this issue.

United in the spirit of Claude Shannon's legacy, we celebrate one of the towering scientific achievements of the twentieth century. This commemorative issue is a proud testimony of the great accomplishments of five fascinating decades and of the vibrancy of our field today. Let the second 50 years of Information Theory begin.

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Guest Editor

Sergio Verdú (S'80–M'84–SM'88–F'93) was born in Barcelona, Spain, on August 15, 1958. He received the Telecommunications Engineering degree from the Polytechnic University of Barcelona, in 1980 and the Ph.D. degree in electrical engineering from the University of Illinois at Urbana-Champaign, in 1984.

In 1984 he joined the Faculty of Princeton University, Princeton, NJ, where he is a Professor of Electrical Engineering. His research interests are in information theory and multiuser communication. He has authored *Multiuser Detection* (Cambridge University Press, 1998). He has held visiting appointments at the Australian National University, the Technion–Israel Institute of Technology, the University of Tokyo, and the University of California, Berkeley.

Dr. Verdú served as Associate Editor for Shannon Theory of the IEEE TRANSACTIONS ON INFORMATION THEORY. He has served on the Board of Governors of the Information Theory Society since 1989, and was President of the Society in 1997. He was Cochairman of the Program Committee of the 1998 IEEE International Symposium on Information Theory, and is serving as Cochairman of the 2000 IEEE International Symposium on Information Theory. He is a recipient of the NSF Presidential Young Investigator Award, the IEEE Donald Fink Paper Award, and a Golden Jubilee Paper Award from the Information Theory Society. He is also the corecipient (with V. Anantharam) of the 1998 Information Theory Society Paper Award.