WAVE THEORY OF INFORMATION

By Massimo Franceschetti,
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Reviewer: Pulkit Grover

Information theory textbooks and courses largely limit themselves to a purely mathematical treatment of the subject. However, the real world is not just limited by laws of mathematics, but also by laws of physics. This is the gap that "Wave Theory of Information" attempts to fill, at least in the context of wave theory. The book weaves beautiful concepts in physics and information theory in a manner that is equally engaging to a student and an expert in information theory. The author, Massimo Franceschetti, is a renowned researcher from UC San Diego, who is responsible for one of the central results characterizing the degrees of freedom of electromagnetic (EM) waves in a scattering environment.

Indeed, central to the book is the concept — and the quantification — of the number of degrees of freedom of spatio-temporal signals. A rigorous treatment of degrees of freedom of bandlimited signals is provided in Chapters 2 and 3. Chapters 4 and 5 provide the background on EM waves and their propagation. Fundamental results from information theory are discussed on the way, including those on representation, communication and sensing of signals in space and time. Chapter 7 discusses fundamentals of wireless communication, including an overview of current technologies and strategies for point-to-point and network communication, with an emphasis on attainable degrees of freedom. This builds up to Chapters 8 and 9, where it is shown how, in an arbitrary scattering environment, the radiated field filtered by the Green's operator becomes spatially bandlimited. Finally, the number of degrees of freedom of bandlimited waves propagating in physical media is characterized through the concept of surface cut-set integral. This establishes limits on amount of information that can radiate from a scattering system, an aspect of communication theory that has been of interest for several decades before significant advances in the 2000s.

Ensuing chapters discuss additional in-depth results, e.g., how quantifying the number of degrees of freedom can be used for a rigorous treatment of communication over noisy channels. Specifically, the difficulty of considering communication using a bandlimited signal over a finite time-window is resolved (Chapter 12) by taking the rigorous degrees of freedom approach adopted in the book.

At the end of every chapter there is a brief history of how the concepts presented in that chapter developed. Such an approach can aid with further reading, and is followed by exercises, with hints when needed, that delve deeper and improve intuitive understanding of the material.

As in many conceptually beautiful expositions, the journey in this book is as important as, if not more than, the destination. In arriving at these results, many interesting and deep aspects relating information and physics arise naturally, and are discussed in a manner that is rigorous and yet accessible to students with background in probability and physics. My personal favorites are connections of degrees of freedom with Heisenberg's uncertainty principle, entropy of black holes, gravitational limits, relationships between statistical and thermodynamic entropy, and high energy limits of information. The reader is likely to find other connections intriguing. Beyond the core results and derivations, I believe that this book is a great success for the following reason: it enables information theorists with interests in physics to understand and contribute to the solution of informational puzzles and paradoxes in physics, which can (and will) enrich both areas. For example, the information paradoxes in black holes, information dissipation in closed systems, informational degrees of freedom, etc., are of central interest to any information theorist, and rigorous treatments of these topics has not, until now, been easily accessible to a student, or even an expert, in information theory.

The book can also serve, in my view, as a textbook for a semester long advanced course on information theory. In due time, as this theory percolates within the scientific community, it can be broadened into a two-semester course that discusses techniques and concepts in network information theory in parallel with related concepts from wave theory of information. The book is timely: information theory is expanding its horizons and now, more than ever, there is a need to closely tie the information-theoretic understanding with fundamental physics. The book is also timeless: it serves as a great illustration of how, in our attempt to expand these horizons, we still need to embed our understanding in intellectual depth and mathematical rigor and avoid the "scientific bandwagon" that Shannon warned us of in his 1956 article.

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Workshop for Machine Learning For Optical Communication Systems

NIST will hold a workshop at the Boulder Colorado Laboratories to discuss the role of machine learning (ML) in optical communication systems. Optical communication systems are increasingly used closer to the network edge and are expected to find use in new applications that require more intelligent functionality. Optical networks are needed to address the high speeds and low latency of 5G wireless networks. The analog nature of optical transmission and the complexity of operation and management remain an impediment to greater use of software controls. Furthermore, optical systems are running up against spectral density limits that threaten traditional capacity-based scaling. New efficiency-based scaling methods are needed to further improve the cost/bit/s without relying on capacity improvements alone. Artificial intelligence (AI) and machine learning provide a new direction with the potential to both enable wider use of software controls and to further optimize the efficiency of optical systems across multiple dimensions. Reference data sets for ML would improve functionality and operability across industry further enabling scaling and efficiency. This workshop seeks to identify and develop applications of AI, and ML in the context of accelerating the use of software-based networking in optical systems for improved performance and scalability. Paths to realizing reference training data sets for ML in optical communications systems including needs for new or different metrology will be examined.

Workshop Registration Website: **https://www.nist.gov/news-events/events/2019/08/machine-learning-optical-communication-systems**