
Information Theory: Principles and Applications

MAP-I Curricular Unit in Theory and Fundaments

Summary

This document describes a Ph.D. level course intended as a Curricular Unit in Theory and Fundaments for the MAP-I Doctoral Programme in Informatics. It is offered jointly by (i) Departamento de Ciência de Computadores, Universidade do Porto and (ii) Departamento de Electrónica, Telecomunicações e Informática, Universidade de Aveiro. The objective is to expose students to the principles and practice of information theory, covering various topics in data/information compression, transmission, storage and processing, as well as cutting edge applications in the analysis, design and optimization of wireless systems and networks, sensor networks and network information flow. It is the intention to accredit the Curricular Unit in the Doctoral Programme of Carnegie Mellon University (CMU).

Instructors

Miguel Rodrigues (Coordinator)	DCC, FCUP	mrodrigues@dcc.fc.up.pt
José Vieira	DETI, UA	vieira@ua.pt

Course Objectives

The objective of the course is to expose students to the principles and practice of information theory, covering both theoretical and applied issues of recognized importance in data/information compression, transmission, storage and processing. The first part of the course covers the basic principles of information theory, including the basic theory and algorithms behind source and channel coding for single-user (point-to-point) and multi-user systems. The second part of the course covers advanced applications of information theory, including the analysis, design and optimization of wireless communications systems and networks, sensor networks, and network information flow.

This course covers material typical of various advanced modules at leading academic institutions in the field, namely:

- Information Theory, Thomas Cover, Stanford University
- Information Theory, Sergio Verdú, Princeton University
- Transmission of Information, Lizhong Zheng, MIT
- Information Theory, Michael Mecking, Technische Universität München
- Information Theory, Pierre Moulin, University of Illinois at Urbana-Champaign

Learning Outcomes

- Familiarity with the principles and applications of information theory in data compression, transmission, storage and processing, as well as in the analysis, design and optimization tool for wireless systems and networks, sensor networks, network information flow.
- Exposure to cutting-edge research topics in information theory and its applications.
- Ability to extract information from scientific papers in the field, and acquisition of technical writing and presentation skills.

Teaching Methods and Assessment

The course is composed by a series of lectures, discussions, and student assignments and presentations. In accordance with the philosophy of the course, the theoretical material will be complemented with specific application examples and case-studies. The student assessment is based on the following key components:

- 50% Final Exam
- 40% Assignments and Presentations
- 10% Class Participation

Course Content

The course consists of two parts: (i) principles and (ii) applications.

- **Part I: Principles**
 1. **Information Measures:** entropy; relative entropy; mutual information; Jensen's inequality; Fano's inequality; data processing inequality.
 2. **Source Coding:** asymptotic equipartition property; source coding theorem – achievability and converse; source coding algorithms – Huffman coding, Shannon-Fano-Elias coding, arithmetic coding, Lempel-Ziv coding.
 3. **Channel Coding:** joint asymptotic equipartition property; channel coding theorem – achievability and converse; channel coding and decoding algorithms – block codes, convolutional codes, Viterbi decoding, sequential decoding, belief propagation; joint source channel coding theorem; channel capacity with and without feedback.

4. **Rate Distortion Theory:** rate distortion function; rate distortion theorem – achievability and converse; channel capacity and rate distortion function computation algorithms.
5. **Multuser Information Theory:** multiple-access channel; broadcast channel; relay channel; Slepian-Wolf coding; source coding with side information; rate distortion with side information.

• **Part II: Applications**

1. **Wireless Systems and Networks:** fading channels capacity – the ergodic, block, and quasi-static fading channels; space-time coding; space-time multiplexing; diversity-multiplexing tradeoff.
2. **Sensor Networks:** sensing capacity; compressed sensing; distributed source coding; distributed inference.
3. **Network Information Flow:** routing versus network coding; network code construction; randomized network coding; network coding protocols.
4. **Advanced Coding Applications:** Coding in the real and complex number field; random codes; digital fountains; explicit and implicit graph (rateless) codes; LT and Raptor codes; joint source-channel coding; efficient and reliable downloads from multiple sources, distributed storage, multimedia broadcast.

Course Schedule

The course will be covered by Miguel Rodrigues (MR), José Vieira (JV), and invited lecturers (IL) with research contributions in selected topics.

Topic	I.1	I.2	I.3	I.4	I.5	II.1	II.2	II.3	II.4
No. of lectures	1	2	2	1	2	2	1	1	2
Instructor	MR	MR	MR	MR	MR	MR	IL	IL	JV

Bibliography

- T. M. Cover and J. A. Thomas. Elements of Information Theory, 2nd Edition. John Wiley & Sons, New York, 2006.
- R. G. Gallager. Information Theory and Reliable Communication. John Wiley & Sons, New York, 1968.
- R. W. Yeung. A First Course in Information Theory. Springer, New York, 2002.
- D. J. C. MacKay. Information Theory, Inference and Learning Algorithms. Cambridge University Press, Cambridge, 2003.

Instructor Team

The team of instructors is actively involved in research in the field of information theory, addressing both theoretical issues as well as cutting-edge applications of recognized importance, as evidenced by an extensive publication list with articles in various relevant IEEE Transactions and IEEE Conference Proceedings. A brief biography of the instructors is provided below:

Miguel Rodrigues: Miguel Rodrigues was born in Porto, Portugal on May 30, 1975. He received the Licenciatura degree in Electrical Engineering from the Faculty of Engineering of the University of Porto, Portugal in 1998 and the Ph.D. degree in Electronic and Electrical Engineering from University College London, U.K. in 2002.

From January 2003 to September 2006, he has held postdoctoral research appointments at Cambridge University, U.K., both as a Research Associate and later as a Senior Research Associate. From September 2006 to March 2007, he was a Visiting Researcher at Princeton University, U.S.A. He joined the faculty of the Department of Computer Science, Faculty of Sciences of the University of Porto as an Assistant Professor in March 2007. He is an Honorary Senior Researcher at University College London, U.K. He has also been a Visiting Researcher at Princeton University, U.S.A. in the summer of 2007.

His research interests include the general areas of information theory, communications theory, signal processing and optimization, and their applications to wireless and optical systems and networks. He has over 70 publications in international journals and conference proceedings in these areas. He has also been lecturing frequently abroad and has also served as a technical consultant to major international telecommunication companies.

Dr. Rodrigues has served on the technical programme committee of various international conferences. He has been the recipient of the the Prize Engenheiro António de Almeida, the Prize Engenheiro Cristiano Spratley, and the Merit Scholarship from the University of Porto, and the best student poster prize at the 2nd IMA Conference on Mathematics in Communications. He has also been the recipient of doctoral and postdoctoral fellowships from the Portuguese Foundation for Science and Technology, and a postdoctoral fellowship from Foundation Calouste Gulbenkian.

José Vieira: José Vieira was born in Aveiro, Portugal on September 4, 1963. He received the Licenciatura degree in Electrical Engineering from University of Coimbra, Portugal in 1988, the Master degree in Electrical Engineering from the same university in 1993 and the Ph.D. degree in Electrical Engineering from University of Aveiro, Portugal in 2000.

From 1989 to 1991, he was a research assistant at the University of Coimbra working on the development of a digital seismograph. In 1991 he joined the Electronics and Telecommunications Department at the University of Aveiro where he is an Assistant Professor.

His main research interest is the general area of digital signal processing with applications to audio and communications. The main topic of its Ph.D thesis was signal reconstruction and its relations with coding theory. He has been working on real number coding, compressed sensing and digital fountains. He is one of the founders of the Portuguese section of the Audio Engineering Society. He is also an active reviewer of several journals on the area of digital signal processing.