Information Theory (5XSE0)
Syllabus

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1 Introduction

Information theory was invented by Claude E. Shannon in 1948 as a mathematical theory for data communication. It has since become a well-established discipline with a wide range of applications, including: data compression and storage, wired and wireless communications, statistical inference and machine learning, to name a few. In this course, you will learn the basic concepts of information theory and some of their primary applications.

The first part focuses on information measures, including entropy and mutual information, and their basic properties. Consequent parts focus on two fundamental questions in information theory:

- What is the least number of bits required to represent a data-set? (data compression)
- What is the most number of bits that can be transferred over a noisy channel? (data communication)

We will see how entropy and mutual information emerge as fundamental answers to the above questions.

2 Course Information

Staff: (all staff are with the ICT Lab, SPS Group, EE Department)
- Dr. Hamdi Joudeh (h.joudeh[at]tue.nl), Lecturer
- Ms. Mehrangiz Ensan (m.ensan[at]tue.nl), Teaching Assistant
- Mr. Sebastiaan Goossens (s.a.r.goossens[at]tue.nl), Teaching Assistant
- Mr. Han Wu (h.wu1[at]tue.nl), Teaching Assistant

Lectures and Instructions:

Monday (place: MS Teams)
- 08.45-09.30: **Quiz + Quiz Discussion** (TAs, H.J)
- 09.45-11.30: **Lecture** (H.J)
- 11.45-12.30: **Instruction** (TAs, H.J)

Thursday (place: MS Teams or AUDITORIUM 11 – TBD)
- 13.30-15.15: **Lecture** (H.J)
- 15.30-17.15: **Instruction** (TAs, H.J)

Grading:
- 10% Quizzes, 30% Assignments, 60% Exam.

Assumed Previous Knowledge:
- Basic analysis (limits, convergence); basic probability (discrete random variables, conditioning, expected value, variance, Gaussian random variables); basic linear algebra (vectors, matrices).
- Mathematics II (5EMA0); Communication theory (5ETB0).
- Mathematical preliminaries will be reviewed in the first week.

3 Outline and Tentative Schedule

Part I: Basics

- Ch.0: Mathematical Preliminaries ($\sim$ week 1)
- Ch.1: Information Measures ($\sim$ week 2-3)

Part II: Data Compression

- Ch.2: Data Compression ($\sim$ week 3-4)
- Ch.3: Asymptotic Equipartition Property ($\sim$ week 5)

Part III: Data Communication

- Ch.4: Channel Capacity ($\sim$ week 5-7)
- Ch.5: Gaussian Channels ($\sim$ week 7-8)

4 Learning Outcomes

After completion of this course, you should be able to:

Part I: Basics

- Define basic information measures: entropy, mutual information, and relative entropy.
- Derive basic properties of information measures, including chain rules and inequalities.
- Prove the data processing inequality and Fano's inequality.

Part II: Data Compression

- Explain basic concepts related to lossless coding for discrete memoryless sources.
- Prove the Kraft inequality for prefix and uniquely decodable codes.
- Design optimal prefix codes using Huffman coding.
- Explain the asymptotic equipartition property.
- Describe the basic concept of typicality and properties of typical sets.

Part III: Data Communication

- Explain basic concepts related to channel coding for discrete memoryless channels.
- Compute the channel capacity for elemental discrete memoryless channels.
- Explain the main steps involved in the achievability proof of the channel coding theorem.
- Prove the converse to the channel coding theorem.
- Define differential entropy and explain features that distinguish it from the entropy.
- Explain basic concepts related to the Gaussian channel capacity.

5 Course material

Primary material:

- **Lecture Notes:** Chapters in the course outline.
- **Exercise Sheets:** Will be discussed during instruction sessions.

All primary material will be made available through CANVAS.

Textbooks: For those who wish to go deeper into some topics, the following textbooks are recommended. Parts to read from each textbook are indicated in the lecture notes.

- T. Cover and J. Thomas, "Elements of Information Theory", Wiley, 2nd Ed., 2006. **(main textbook)**
- R.G. Gallager, "Information Theory and Reliable Communication", Wiley, 1968.
- D. MacKay, "Information Theory, Inference and Learning Algorithms", Cambridge Uni. Press, 2003.

6 Assignments

There will be 3 assignments, one for each part of the course. Assignments will be released two weeks before the deadline. Deadlines are always on **Sunday (23:59)**. Late submissions will not be accepted.

Assignment I

- Deadline: ~~Sunday, 28 Feb. (end of week 4)~~. **Sunday, 7 Mar.**

Assignment II

- Deadline: ~~Sunday, 14 Mar. (end of week 6)~~. **Sunday, 21 Mar.**

Assignment III

- Deadline: ~~Sunday, 28 Mar. (end of week 8)~~. **Sunday, 4 Apr.**

All assignments have equal weights, and together they contribute 30% of the total grade.

7 Quizzes

There will be 6 quizzes, starting week 3 and ending week 8. Quizzes will be held on CANVAS. They will be available from **08:45 AM** until the end of the Quiz. Typically, each Quiz will have a duration of 15 minutes. To take a Quiz, you will need to log in to CANVAS on time and go to the "Quizzes" section.

Grades of the best 5 quizzes will be considered (you can miss at most 1 quiz without affecting your total grade). All quizzes have equal weights, and together they contribute 10% of the total grade.

8 Exam and Total Grade

The course will end with a final exam, which counts for 60% of your total grade. Your total grade T will be calculated as follows:

$$T = 0.1Q + 0.3A + 0.6E$$

where Q is your average Quizzes grade, A is your average Assignments grade, and E is your Exam grade. To pass the course you will need: at least a 5.0 in the exam (i.e. $E \geq 5.0$); and at least a 5.5 for the total grade (i.e. $T \geq 5.5$). Both conditions have to be satisfied!