

COMP2610 / COMP6261 Information Theory

Lecture 1: Introduction

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July 23, 2018

What is the world made of?

- Ancient times: **Matter** — atoms

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What is the world made of?

- Ancient times: **Matter** — atoms
- 20th Century: **Energy** — mass=energy

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What is the world made of?

- Ancient times: **Matter** — atoms
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Information underpins

- **Ph**
info

asing

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Information underpins

- **Physics** (relativity, quantum mechanics)
- **Chemistry** (molecular structure)
- **Biology** (genetic code)

using

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What is the world made of?

- Ancient times: **Matter** — atoms
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- 21st Century: **Information** — ????

Information underpins

- **Physics** (classical *physics* and *quantum physics*)
- **Chemistry** (classical *chemistry* and *quantum chemistry*)
- **Biology** (genetic code)
- **Immunology** (pattern recognition of self from non-self)

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What is the world made of?

- Ancient times: **Matter** — atoms
- 20th Century: **Energy** — mass=energy
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Information underpins

- **Physics** (classical, quantum, relativity, *string* theory, cosmology)
- **Chemistry** (atoms, molecules, quantum chemistry)
- **Biology** (genetic code)
- **Immunology** (pattern recognition of self from non-self)
- **Economics** (price, markets, the economy)

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What is the world made of?

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Information underpins

- **Physics** (physics, *using* info)
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- **Biology** (genetic code)
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- **Economics** (price, markets, the economic system)
- **Sociology** (media, social networks)
- **Philosophy** (ontology, epistemology, morality)

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- **Engineering** (your telephone for example)

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- Ancient times: **Matter** — atoms
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Information underpins

- **Physics** (physics of the universe, *using* info)
- **Chemistry** (chemistry of the universe)
- **Biology** (genetic code)
- **Immunology** (pattern recognition of self from others)
- **Economics** (price, markets, the economy)
- **Sociology** (media, social networks)
- **Philosophy** (ontology, epistemology, morality)
- **Engineering** (your telephone for example)
- **Computing** (What is that computers do? *They process information*)

References for the curious ... for interest only!

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What Is Information? (1)

According to a dictionary definition, **information** can mean

1 Facts provided or learned about something or someone:
a vital piece of information.

2 When
sequentially
genetically transmitted information.

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What Is Information? (1)

According to a dictionary definition, **information** can mean

1 Facts provided or learned about something or someone:
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Important!

- Usually unhelpful to ask “What is?” questions

What Is Information? (1)

According to a dictionary definition, **information** can mean

1 Facts provided or learned about something or someone:
a vital piece of information.

2 Wh
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genetically transmitted information.

Important!

- Usually unhelpful to ask “What is?” questions
- Better to ask what happens to it? “Grothendieck’s Relative method”

What is Information? (2)

In this course: information in the context of *communication* (includes information storage).

- Exp
info
deri

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- Claude Shannon (1948): "Amount of unexp
contains"

- ▶ A theory of information **transmission**

What is Information? (3)

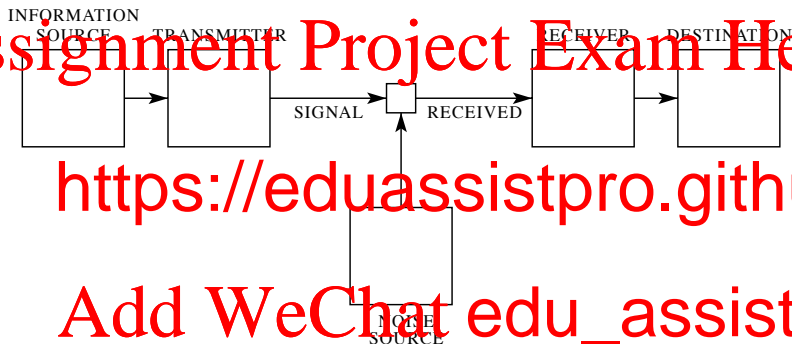


Fig. 1 — Schematic diagram of a general communication system.

From Claude Shannon, A Mathematical Theory of **Communication**, *Bell System Technical Journal* (1948).

What Is Information? (4)

Information is a message that is *uncertain* to receivers:

- If we receive something that we already knew with absolute certainty, then it is non-informative

- Unc
- We will deal with uncertainty using probability

What Is Information? (4)

Information is a message that is *uncertain* to receivers:

- If we receive something that we already knew with absolute certainty, then it is non-informative

- Uncertainty
- We will deal with uncertainty using probability

Information Theory

Information theory is the study of the fundamental *limits* and *potential* of the **representation** and **transmission** of information.

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Example 1: What Number Am I Thinking of?

- I have in mind a number that is between 1 and 20

- You are allowed to ask me one question at a time

- I can only answer yes/no

- Yo

- ^{Wh}<https://eduassistpro.github.io>

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Example 1: What Number Am I Thinking of?

- I have in mind a number that is between 1 and 20
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- Yo

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Your strategy + my answers = a code for e

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Some variants:

- What if you knew I never chose prime numbers?
- What if you knew I was twice as likely to pick numbers more than 10?
- What if you knew I only ever chose one of 7 or 13?

Example 2: How Much Is Information Worth?

Simplified Version of "Deal or No Deal"

\$1000 Hidden in one of 16 cases.

- All equally likely to contain the prize

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Example 2: How Much Is Information Worth?

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How much would you pay to know:

- 1 Exa
- 2 Wh
- 3 ... is less than 12?
- 4 Which range out of 0–3, 4–7, 8–11, or 12–15 the

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Key Question:

- Can we use these ideas to *quantify* information?

Example 3: Redundancy and Compression

Cn y rd ths sntnc wtht ny vwls?

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Example 3: Redundancy and Compression

Cn y rd ths sntnc wtht ny vwls?

Can you read this sentence without any vowels?

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Written E

- App

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- Naïvely there should be almost 5 bits per letter

(For the moment think of “bit” as “number of yes/no qu

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Example 3: Redundancy and Compression

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Written E

- App

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(For the moment think of “bit” as “number of yes/no qu

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Key Question:

- How much redundancy can we *safely* remove?
(Note: “rd” could be “read”, “red”, “road”, etc.)

Example 4: Error Correction

Hmauns hvae the aitliby to cerroct for eorrrs in txet and iegmas.

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Key Question:

- How much noise is it possible to correct for and how?

1 Information and the Nature of the Universe

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2 A Brief History

3 Cour

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4 Logistics and Expectations

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5 What's Next

A Summary of the History of Information Theory

1920s : Nyquist & Hartley at Bell Labs

1940 : Turing and Goble at Bletchley Park (WWII)

1942 : Hedy Lamarr and George Anthell

1

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1951 : Huffman Coding

1958 : Peter Elias: "Two Famous Papers"

1970 : "Coding is Dead"

1970- : Revival with advent of digital computing

CDs, DVDs, MP3s, Digital TV, Mobiles, Internet, Deep-space
comms (Voyager), ...

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&

Information Theory and the Digital Age

by Aftab, Cheung, Kim, Thakkar, and Yeddapanudi.

<http://web.mit.edu/6.933/www/Fall2001/Shannon2.pdf>

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5 What's Next

Brief Overview of Course

- How can we quantify information?
 - ▶ Basic Definitions and Key Concepts
 - ▶ Probability, Entropy & Information

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- How

- ▶

- ▶ Source Coding Theorem, Kraft Inequality

- ▶ Block, Huffman, and Lempel-Ziv Coding

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- ▶ Noisy-Channel Coding
- ▶ Repetition Codes, Hamming Codes

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- What is randomness?

- ▶ Kolmogorov Complexity
- ▶ Algorithmic Information Theory

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- What is randomness? [Marcus Hutter]

- ▶ Kolmogorov Complexity
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We will study the fundamental limits and potential of the *representation* and *transmission* of information

- Mathematical Foundations

- Pro

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- Coding and Compression

- Communication

- Kolmogorov Complexity (Guest Lecture)

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Learning Outcomes

From <https://wattlecourses.anu.edu.au/course/view.php?id=25550>:

- 1 Understand and apply **fundamental concepts** in information theory such as probability, entropy, information content and their interrelationships

- 2 Un

- 3 Co

- 4 Imp

- 5 Understand the relationship of information t
Bayesian inference in data modelling and

- 6 Understand some key **theorems** and **inequalities** that quantify essential limitations on compression, communication and inference

- 7 Know the basic concepts regarding **communications over noisy channels**

What Tools Will We Use?

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- Elementary probability theory



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- Ele



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What Tools Will We Use?

Assignment Project Exam Help

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- Ele



- Basic programming skills



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Do you know your for loops from yo

What Tools Will We Use?

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- Ele



- ▶ <http://www.khanacademy.org/m>

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- ▶ "Do you know your for loops from yo

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Outline

- 1 Information and the Nature of the Universe

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- 2 A Brief

- 3 Cour

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- 4 Logistics and Expectations

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5 What's Next

Course Overview

See Wattle site (authoritative)

- Lectures: 23×1 hour (two lectures per week); one public holiday

- By me, except one guest lecture by Marcus Hutter (Aside: about me).

- Tut

- Ass
(below)

- Final Exam (60%) Hurdle assessment: You
pass the course. (New this year!)

- **Late Submission Policy: late submissions get zero marks — 100% penalty.**

Expectations

See the newly published expectations document:

<https://wattlecourses.anu.edu.au/pluginfile.php/1760092/course/section/423322/Learning%20expectations.pdf>

Key points:

- You are expected to have familiarity and ability with elementary probability theory. “Assignment 0” is designed to help you check wh

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- You are *not* obliged to attend any of the lectures. Not attending is a high-risk strategy

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- The course closely follows the text. In principle, you can do exercises, skip all lectures and tuts and get a HD.

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- If you do come to lectures, please come on time, pay attention, and put your telephone on silent. (Basic politeness)
- Learning mathematical material is hard and cannot be delegated or outsourced. “There is no royal road to geometry.” Don’t kid yourself!

Tutorials

- Problem sets of exercises will be provided for each tutorial
- These will review material covered in previous lectures

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and *then* seeing what you should have done

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Anders Ericsson and Robert Pool, *Peak: Secrets from the New
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- In a nutshell: The secret of success is *deliberate practice*.

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<http://www.inference.phy.cam.ac.uk>

- ▶ Note copyright rules: e.g. copying the whole book onto paper is not permitted.
- ▶ We will follow a different chapter order to that given in the book

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For an alternative take – David MacKay's Lectures:

http://www.inference.phy.cam.ac.uk/itprnn_lectures/

Consultation & Other Issues

Consultation:

- Best way to contact the course lecturers and tutors is via email
comp2610@anu.edu.au

- If yo

- Em

up to three days as a normal response time

- **Technical questions:** encouraged to pos

- Request for clarifying assignment: **must be** posted on Wattle

What's Next?

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- If you are not comfortable about your probability and algebra skills, start today on improving them

<https://eduassistpro.github.io>

- Get

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- Sign up to a tutorial (will open tomorrow, time an