university of groningen

faculty of science and engineering

Lecture 1A: Signals and Systems

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Signals and Systems
1B - 2024/2025

Preliminaries

- You can now enroll with a lab partner in groups for the assignments; and choose your preferred Tutorial schedule in the Tools/Groups tab. The enrollment deadline is Tuesday, November 19th at midnight.
- Please check you have access to Brightspace and Themis.
- The first lab assignment will be available during this week. And its deadline is on Friday, December 6, at 17:30.

Preliminaries

AI & CCS/CS Programme Committees event

On **November 20**, the programme committees of CS, AI, and CCS will hold an event where they will introduce themselves and explain their roles. You will have the opportunity to meet your representatives, ask questions, raise any issues you have encountered in your studies, and recommend outstanding lecturers for this year's Teacher of the Year Award.
The event will begin at 12:00 in **BB 5161.0116**, and you are welcome to stop by until 16:00. Free pizza and drinks will be provided.

Overview

1. Motivation
2. Signals
3. Systems
4. Closing Remarks

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Why does an AI professional study signal processing?

What is this course all about?

Experiencing an online class involves a lot of signal processing

- Visual information is captured by a camera
- The information is transferred across the internet
- The information is interpreted to produce monitor output
- The monitor output is captured by your retina
- This information is interpreted by your brain

What is this course all about?

Experiencing an online class involves a lot of signal processing

- Visual information is captured by a camera
  - Real-life continuous data is converted into discrete data
  - $640 \times 480 \times 30 \times 3 \times 4 \approx 110$ MB per second
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  - The discrete decompressed data approximates a real-life continuous datastream
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- The monitor output is captured by your retina
  - Continous data is interpreted by ~ 120 million rods and cones
- This information is interpreted by your brain

What is this course all about?

Experiencing an online class involves a lot of signal processing

- Audio information is captured by a microphone
- The information is transferred across the internet
- The information is interpreted to produce speaker output
- The speaker output is captured by your cochlea
- This information is interpreted by your brain

Types of Signals

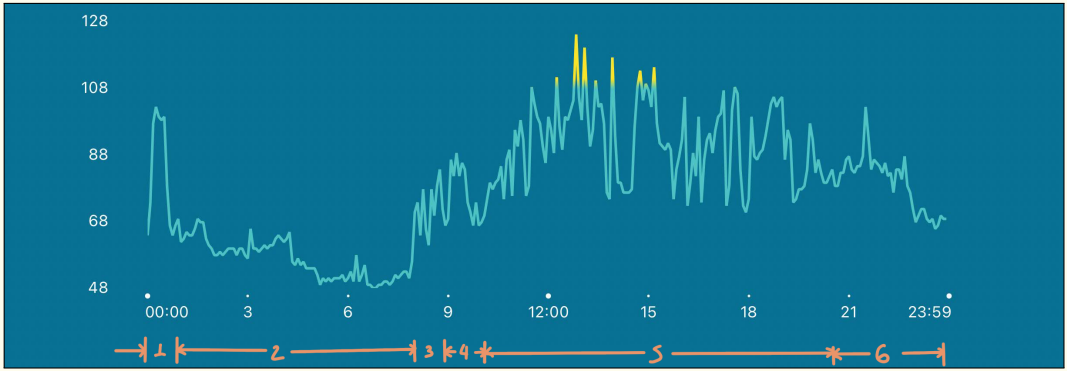

Figure: Beats per minute during a bike trip day. Image taken from the Fitbit app

Types of Signals

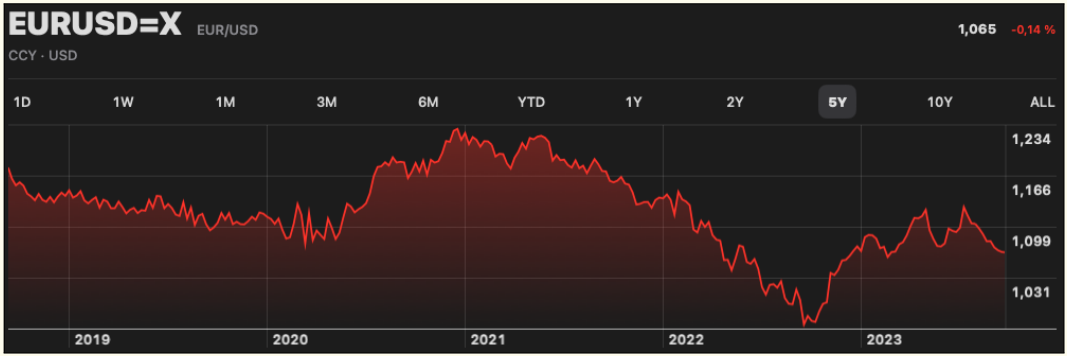

Figure: Exchange rate Euro-USD dollar between 2018 and 2023. Image taken from Apple stocks app

Types of Signals

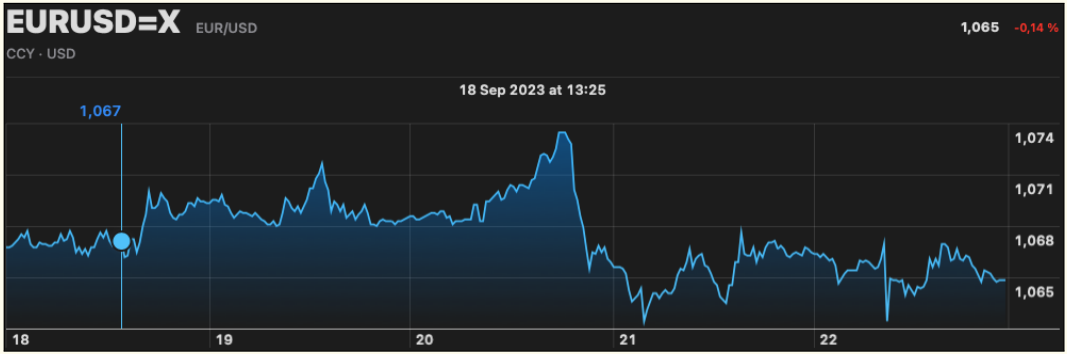

Figure: Exchange rate Euro-USD dollar during week 38, 2023. Image taken from Apple stocks app

Types of Signals

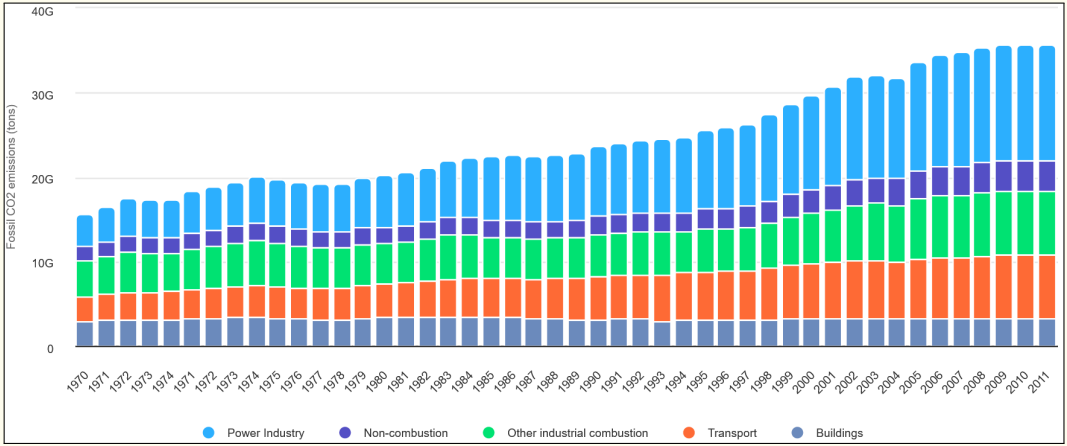

Figure: Global CO_2 emissions by year (1971 - 2011). Image taken from worldometers.com

Types of Signals

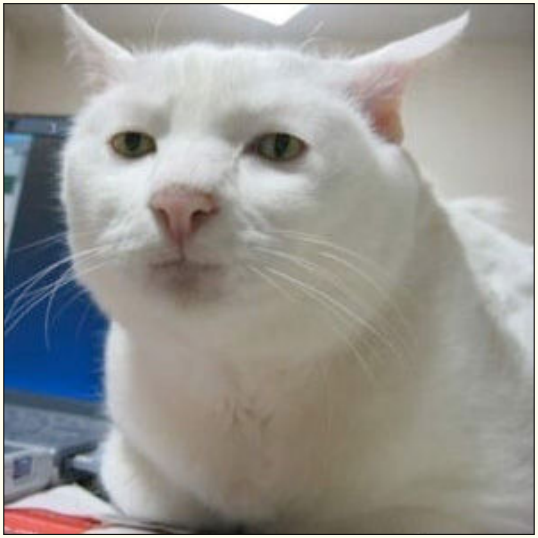

Figure: Serious Cat meme. Image taken from knowyourmeme.com

Types of Signals

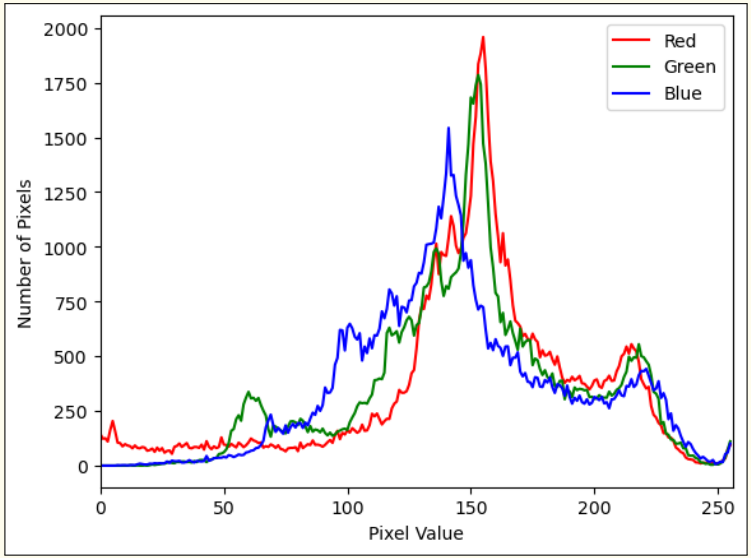

Figure: Histogram for RGB channels in serious Cat meme.

Types of Signals

Once upon a midnight dreary, while I pondered, weak and weary, Over many a quaint and curious volume of forgotten lore, While I nodded, nearly napping, suddenly there came a tapping, As of someone gently rapping, rapping at my chamber door. "'Tis some visitor," I muttered, "tapping at my chamber door, Only this, and nothing more."

Fragment of "The Raven", by Edgar Allan Poe

Types of Signals

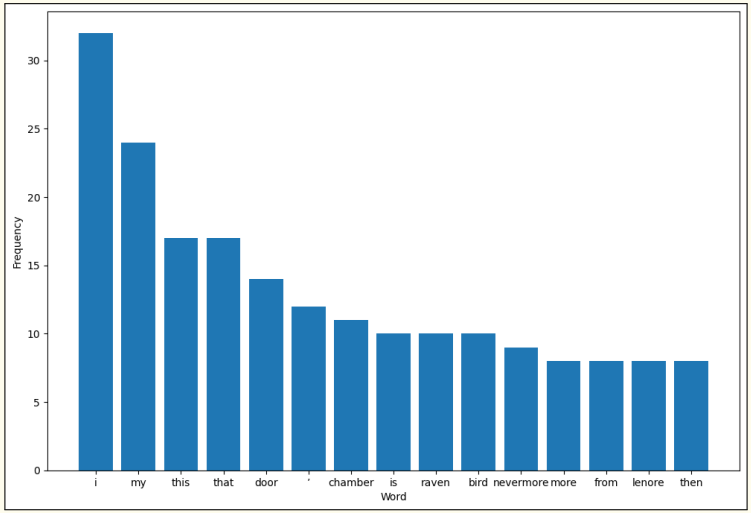

Figure: Histogram for 15 most used words in the “The Raven” poem.

Types of Signals

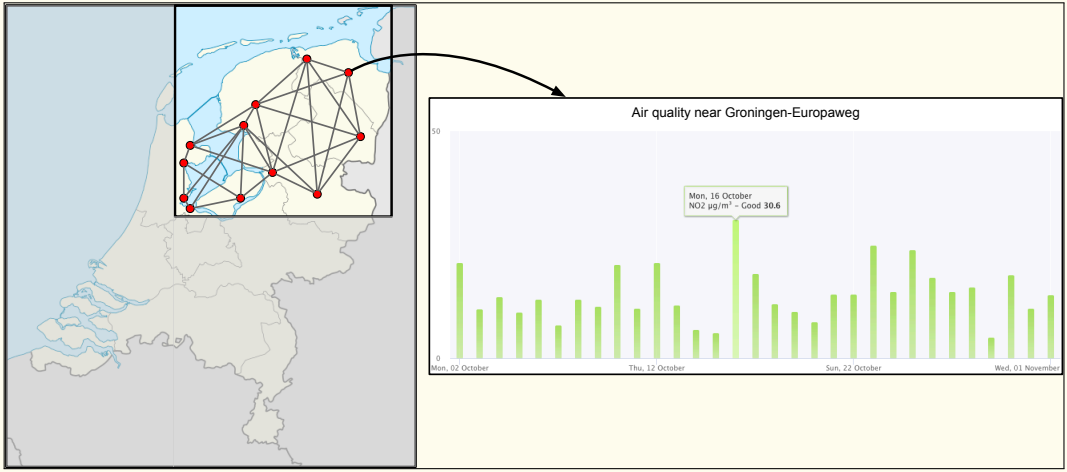

Figure: Illustrative graph structure for air quality sensors in the north of The Netherlands - Measure: NO_2 in $\mu g/m^3$. Images modified from commons.wikimedia.org and iqair.com

Signals

Question

Can you think of another example of a signal whose independent variables are position and time?

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Signals

Definition

A signal is a pattern of variation that represents or encodes information.

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A signal is a pattern of variation that represents or encodes information.

- Signals have the information we may use to make decisions, infer more information, forecast possible future events, and detect anomalies, among other **tasks in AI**.
- However, **extracting information** from a signal is not always straightforward. Due to noise, missing or inaccurate information. Or the shape is too complex to interpret by visual inspection.

Signals

- A **continuous-time signal** is a function $x(t)$ over time, $t \in \mathbb{R}$. E.g., human speech

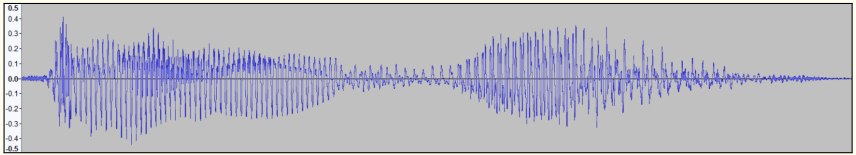

Figure: Harmen de Weerd, Hello world in Audacity, 2021

- A **discrete signal** is a function $x[n]$ that is only defined $n \in \mathbb{Z}$. E.g., a digital recording of human speech

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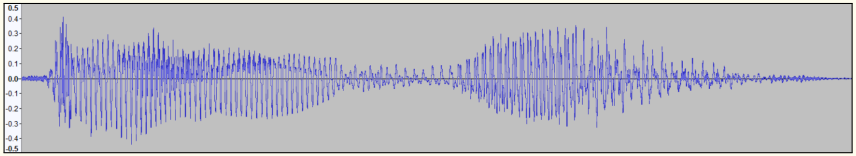

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- A **discrete signal** is a function $x[n]$ that is only defined $n \in \mathbb{Z}$. E.g., a digital recording of human speech

Comment

Note the convention for discrete-time $x[n]$ and continuous time $x(t)$.

Signals

In general, signals may be **multi-dimensional**

- E.g., pictures made by an analog camera $x(s, t)$
- E.g., pictures made by a digital camera $x[n, m]$

Figure: Mali Maeder, Silver and Black Point-and-shoot Camera, 2016

Signals

Weekend Miljonairs - SaS Edition

Which of the following signals is discrete?

(a) The temperature

(b) An electroencephalogram (EEG)

(c) An electrocardiogram (ECG)

(d) A digital video

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Systems

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- A **continuous-time system** transforms continuous-time signals
  - $y(t) = \mathcal{T}\{x(t)\}$
  - E.g., an analog amplifier
- A **discrete-time system** transforms discrete-time signals
  - $y[n] = \mathcal{T}\{x[n]\}$
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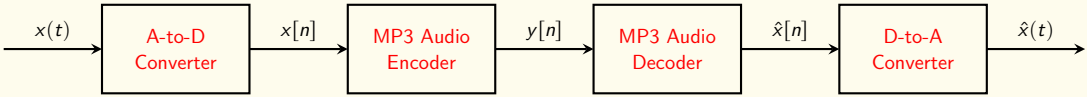
- A **discrete-time system** transforms discrete-time signals
  - $y[n] = \mathcal{T}\{x[n]\}$
  - E.g., a digital amplifier
- A **sampler** converts continuous signals to digital signals
  - $x[n] = x(nT_s)$, where T_s is the **sampling period**
  - Also known as **ideal C-to-D converter**

Complex systems

Complex systems consist of a sequence of operations. Example: Suppose $x(t)$ is an analog audio signal and consider the following **block diagram**:



The system above shows a common (and simplified) system and subsystems that represent the workflow for recording audio in a **digital** format, compressing the information in MP3 format, decompressing the information, and reconstructing the **analog** audio signal.

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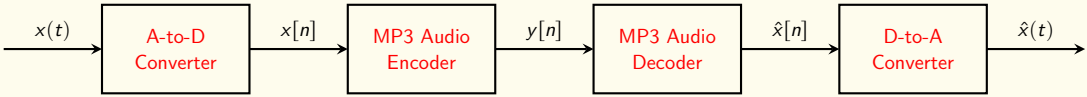

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Comment

Note that $x \neq \hat{x}$ due to potential information loss in the MP3 encoder/decoder and the finite sampling rate in the A-to-D converter.

Complex systems

Question

- How would you build a similar system for images? (Hint: PNG is a lossless image compression format)
- Will the image lose information in the proposed system?

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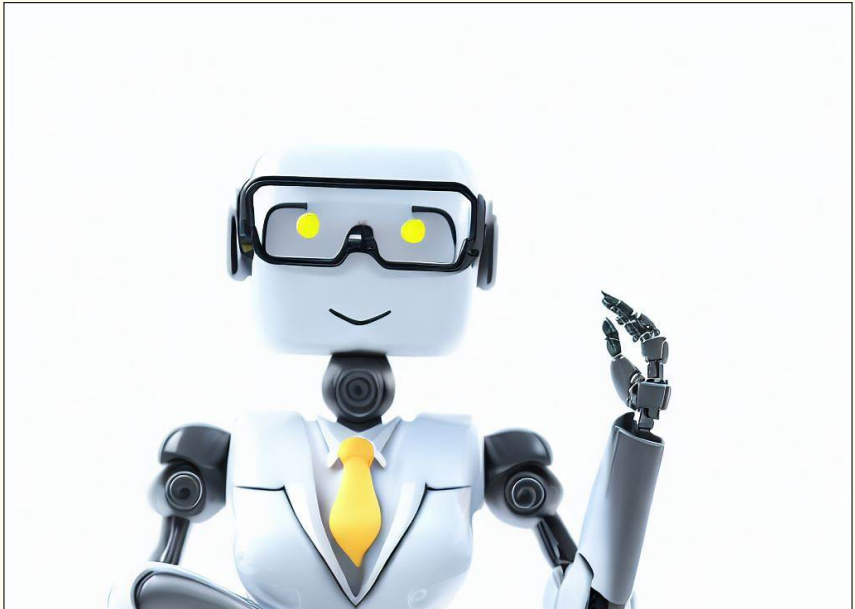
Let us wrap up the lecture!



Take-home Messages

- A signal is a pattern of variation that represents or encodes information.
- A system is an operator that transforms signals.
- Complex systems can be divided into smaller subsystems.
- We use block diagrams to represent the interaction between signals and systems.

Practice Questions

Similar questions might appear in the final exam:

- What is a signal?
- What is a system?
- Can you think of examples of systems closely related to AI?

Tutorial exercises

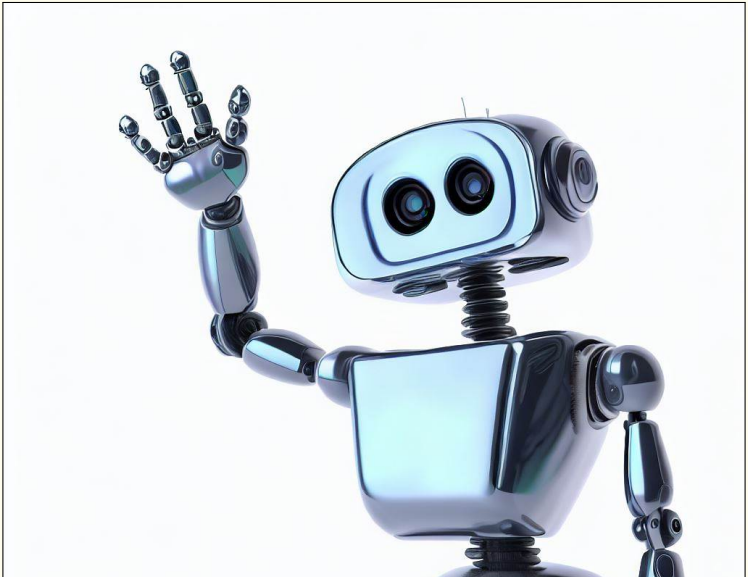
You will solve the following exercises in the tutorial session with the support of the TA.

SPF	DSPF
P 2.2 (p. 31)	P 2.2 (p. 60)
Ex 2.1 (p. 11)	Ex 2.1 (p. 34)
Ex 2.6 (p. 19)	Ex 2.6 (p. 44)
Ex 2.9 (p. 26)	Ex 2.8 (p. 54)
P 2.4 (p. 32)	P 2.4 (p. 61)
P 2.6 (p. 32)	P 2.6 (p. 61)
P 2.15 (p. 33)	P 2.15 (p. 63)
P 2.20 (p. 34)	P 2.24 (p. 65)

Let us use sine and cosine functions to represent signals.

Sinusoids

See you on Friday!



Acknowledgements

The material for this lecture series was developed by dr. Arnold Meijster and dr. Harmen de Weerd and modified by Juan Diego Cardenas-Cartagena.

Disclaimer

- Grammar was checked with Grammarly and Grammar checker GPT.
- Images without source were created with the assistance of DALL·E.