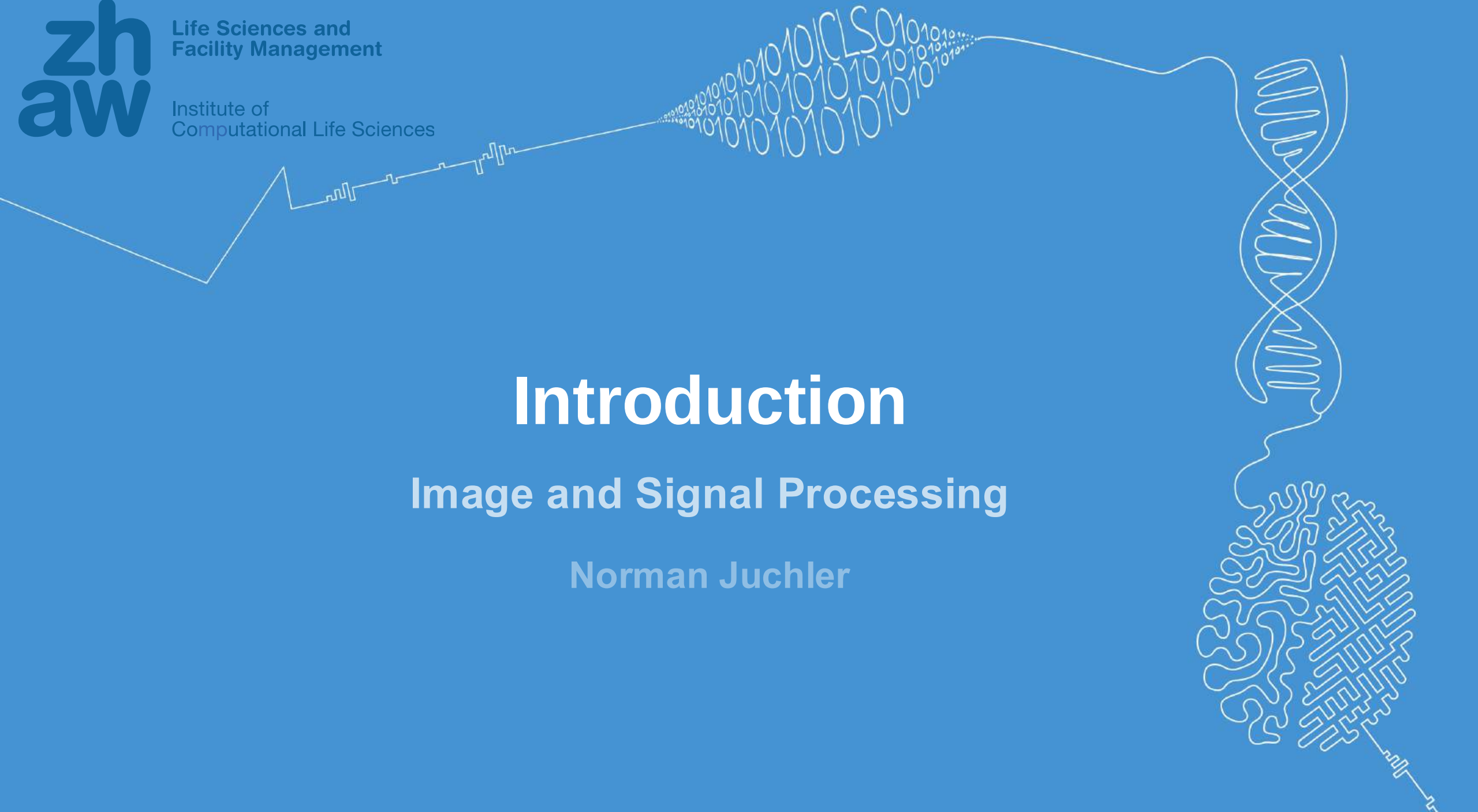
Life Sciences and
Facility Management

Institute of
Computational Life Sciences



Introduction

Image and Signal Processing

Norman Juchler

Overture

What is a signal?
What is signal processing?

Spot the signals!

The video shows the band Moin at a concert in Baden in 2024

Spot the signals!

Task 1: In teams of two, examine the various signals that you have just experienced. Where did they occur, what happened to the signals? Create a list of 10 observations. Be creative!

Task 2: Try to produce a concise definition for signals.

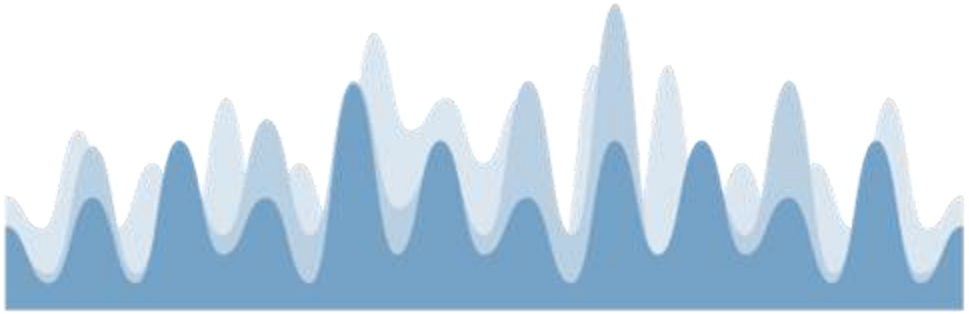


Illustration based on Adobe Stock / 354425450

Some observations involving signals...

- The drummer sets the beat
- The guitarist's effects unit distorts the sound
- Various microphones or pickup systems record the instruments
- A sound reinforcement system amplifies and mixes the sound
- The bassist recognizes the change in harmony in time
- Spotlights swirl around and generate a programmed lighting effect
- A spectator’s body signals a critical level of intoxication through slight nausea
- The DJ plays samples that were previously processed in an audio editing tool
- A red LED signals the status of the guitarist’s monitor speaker
- ...

Some observations involving signals...

- ...
- The video and audio are recorded using a smartphone camera
- The video was edited and converted into a compatible format
- The beamer produces the video on the canvas
- The computer streams the data from a file
- The image reaches the students' attention via their retinas
- ...while at the same time a specific pattern of neural activity signals:

The concept of signal is omnipresent!

What is a signal?

Definition: A detectable physical quantity or impulse (such as a voltage, current, or magnetic field strength) by which messages or information can be transmitted

Based on Merriam-Webster

Definition: Signal refers to both the process and the result of transmitting data, typically accomplished by varying a physical quantity over time or space.

Based on Wikipedia

Definition: Carrier of information (e.g., an electromagnetic wave), which is modulated/modified according to the content of the information to be transmitted.

Based on Duden

Illustration based on Adobe Stock / 354425450

Properties of signals

Task 3: From a previous course, we recall the smartphone app **Phyphox**, which allows users to explore and visualize signals obtained from the sensors of their smartphones.

In teams of two, investigate the properties of different signals.

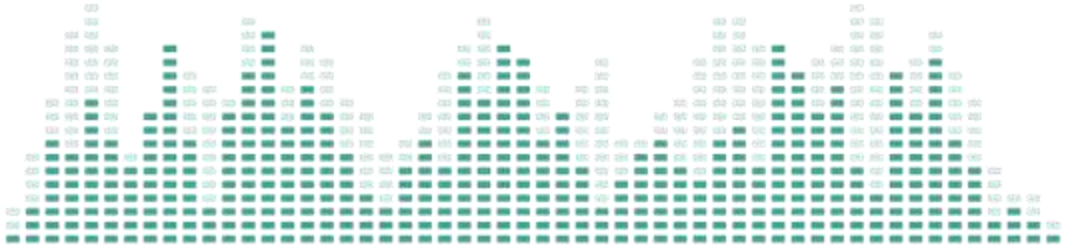
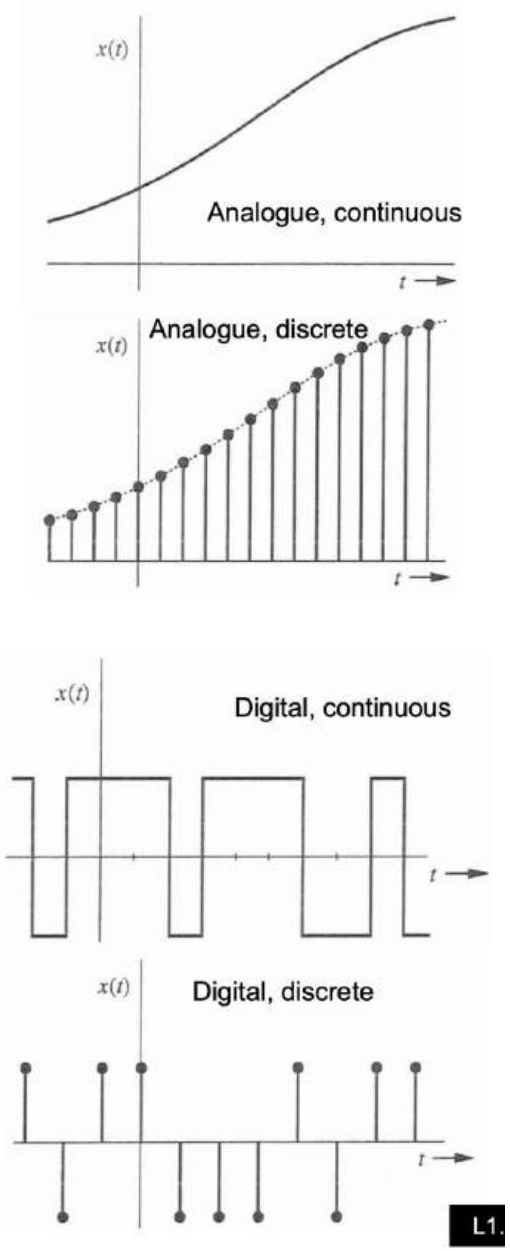


Illustration based on Adobe Stock / 354425450

Properties of signals

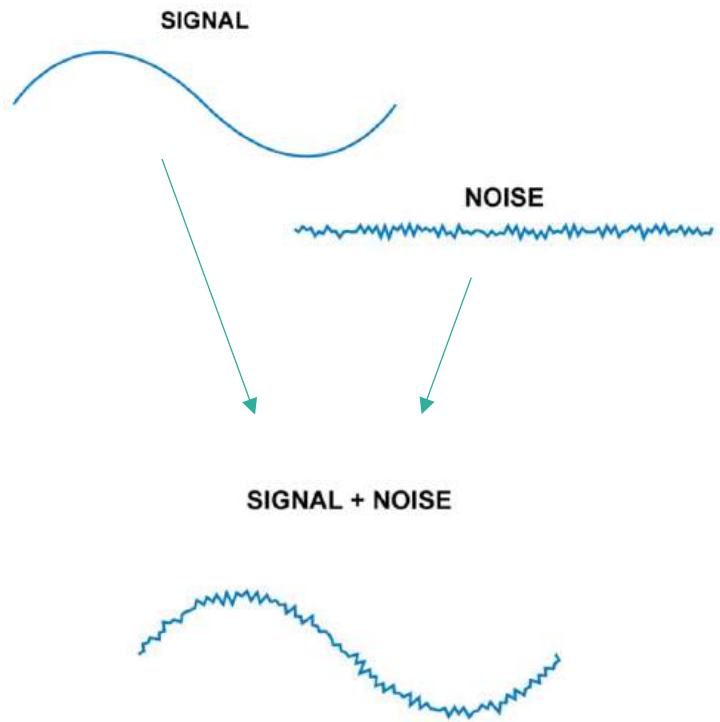
- Signals can be transmitted and received
- Signals can be processed and stored
- Signals carry information
- Signals can be classified by mathematical properties*
  - Continuous-time vs. discrete-time signals
  - Analog vs. digital signals
  - Periodic vs. aperiodic signals
  - Even vs. odd signals
  - Deterministic vs. random signals



*More of this in the next lecture

Properties of signals

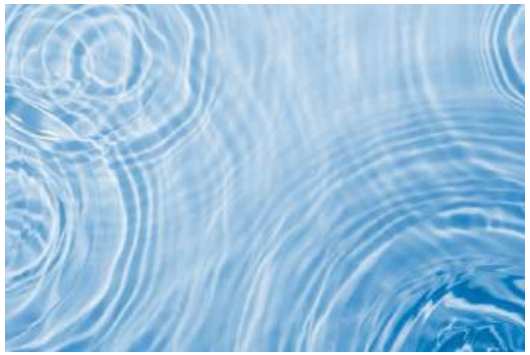
- Signals can be transmitted and received
- Signals can be processed and stored
- Signals carry information
- Signals can be classified by mathematical properties*
- Signals can be modelled mathematically*, by means of
  - Amplitude
  - Characteristic frequencies
  - Latency (time delay between signal initiation and reception)
  - Period (for periodic signals)
  - Amount of energy or power carried by a signal
- Signals can suffer from noise or distortions



*More of this in the next lecture

Signals and transmission media

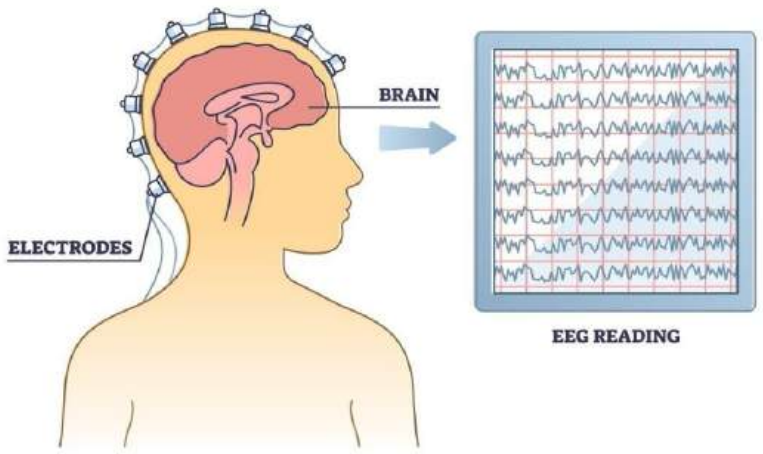
- Some forms of signals require a medium for signal transmission, that is, a material or substance capable of propagating waves or energy. Examples:
  - Sound waves require a fluid or solid medium
  - Electrical signals (that involve the movement of charge carriers, like electrons) can travel through conductive materials such as wires
  - Biochemical signals in an organism (like hormones, neurotransmitters or cytokines) usually require a bodily fluid as a medium (like cytosol, interstitial fluid, blood)

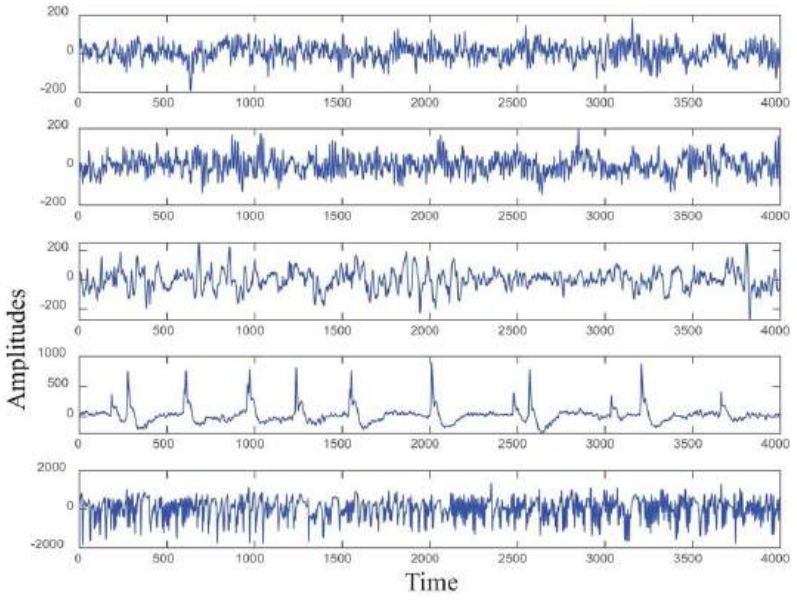


- Other forms of signals do not require a transmission medium. Examples:
  - Electromagnetic waves (light, radio waves, microwaves)
  - Gravitational waves

Example: Electroencephalography (EEG)

- EEGs measure the electrical activity of the brain
- Records the electrical signals produced by millions of neurons firing synchronously
- Different types of brain waves are characteristic for different states of consciousness





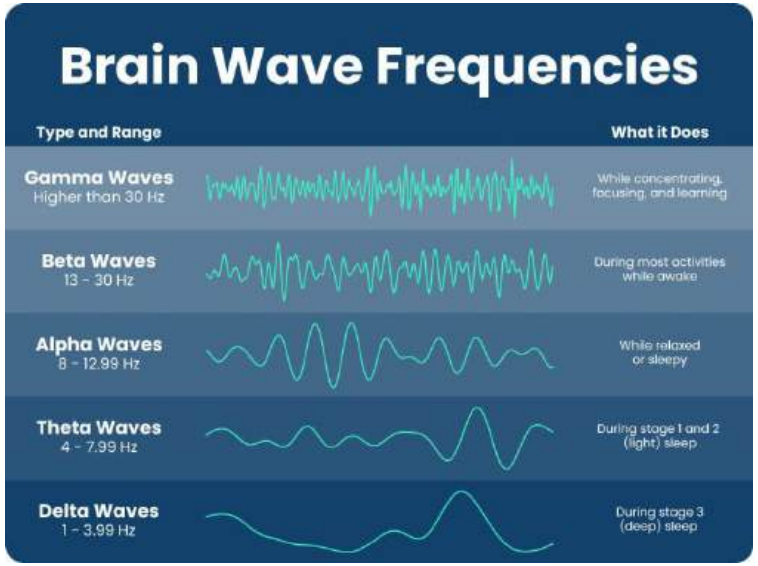


Image sources: Link 1,, Link 2, Link 3

Distinction of subdisciplines

- Analog signal processing (ASP)
  - Operates on continuous signals
  - Modify signals using physical principles
  - Example: amplify or filter an electric signal with analog circuits
  - Applications: radio frequency communication, audio processing, optical filters / classical optics
  - Historical significance in early electronic devices before the advent of digital signal processing

This course:
digital signal and image processing

- Digital signal processing (DSP)
  - Operates on digital representations of signals (discrete-time, discrete-amplitude): often as sequences of numbers sampled at regular intervals
  - DSP employs various algorithms and techniques to transform, filter, or enhance signals
  - DSP algorithms are typically implemented using software on computers or specialized hardware
  - DSP has a wide range of applications, from telecommunications, audio and speech processing, image and video processing, and more
  - Predominant form of signal processing, DSP has revolutionized various industries

Distinction of subdisciplines

- Common specialties
  - Audio and speech processing
  - Telecommunication
  - Image processing
  - Video processing
  - Biomedical image processing
  - Radar and sonar signal processing
  - Metrology / sensor signal processing
- Related domains:
  - Machine learning: Enhances signal processing workflows by employing algorithms that learn patterns from data.
  - Mathematics, statistics, stochastics: Used to model and describe signals and data generating processes.
  - Information theory: Studies the processing, extraction, storage, transmission and quantification of information
  - System theory: Studies dynamic systems, the inner states of systems, and their in- and output behavior. Used for, instance to, model signal generating processes.
  - Control systems: Studies how to control the states of dynamic systems. Involves measurement and control signals

Structure of the course

Overview: Content of the course

- Analog and digital signals
- Sampling, sampling theorem
- Fourier transform and spectra
- Noise and other sources of error
- Important filter operations and transformations
- Process and visualize time series and image data in Python
- Applications of image and signal processing

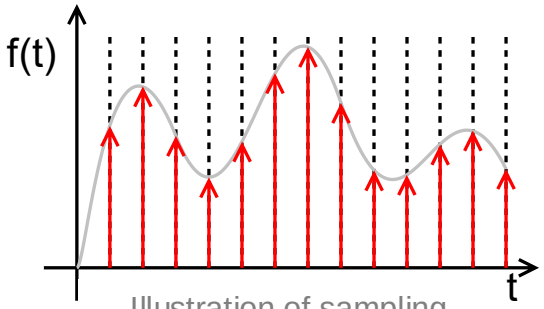
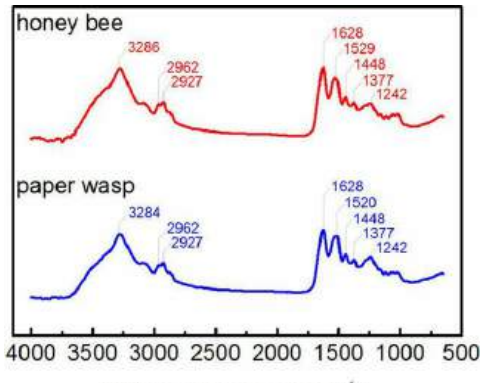


Illustration of sampling



Spectra of two insects

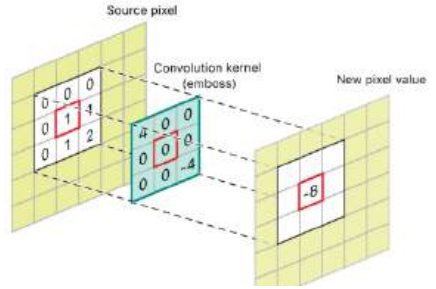


Illustration of 2D convolution

Semester plan

- Course is organized in three blocks:
  - Time signal processing
  - Image processing
  - Applications
- The two first parts are completed with a graded written **examination**
- In the second half, students work on a **project**

CW	SW	Date	What	Topics
8	1	17.02.25	Practice	**Introduction:** Motivation, general information and setup
		21.02.25	Lecture	**Time signal processing:** Continuous and discrete signals, sampling
9	2	24.02.25	Practice	**Time signal processing:** Audio signals, superposition, sampling, autocorrelation
		28.02.25	Lecture	**Fourier:** Types of Fourier transforms, time-frequency duality, spectra
10	3	03.03.25	Practice	**Fourier:** FT for own signal, spectra and visualizations
		07.03.25	Lecture	**Filtering:** Convolution, signal characteristics and noise, purpose
11	4	10.03.25	Practice	**Filtering:** Time-domain behavior of different filters
		14.03.25	Lecture	**Filtering:** Common filters for (discrete) time signals
12	5	17.03.25	Practice	**Filtering:** Frequency domain behavior of filters
		21.03.25	Lecture	**Images:** Sampling, formats, spatial and color space transformations
13	6	24.03.25	Practice	**Examination 1: Signal processing** / Basics about image processing
		28.03.25	Lecture	**Fourier in 2D:** Amplitude (and phase) images, spectrogram
14	7	31.03.25	Practice	**Fourier in 2D:** Spectral images, DIY kernels / **Group projects: Topic fair**
		04.04.25	Lecture	**Image processing:** Gradients, noise removal, detection
15	8	07.04.25	Practice	**Image processing:** Noise removal, detection
		11.04.25	Lecture	**Image processing:** Masks, morphological operations, contours, segmentation
16	9	14.04.25	Practice	**Image processing:** Masks, ... / **Group projects: Problem statement**
		18.04.25		Karfreitag / Good Friday
17	10	21.04.25		Easter Monday
		25.04.25	Lecture	**Image processing:** Feature extraction
18	11	28.04.25		Industry visits / Brücke
		02.05.25		
19	12	05.05.25	Practice	**Examination 2: Image processing**
		09.05.25	Lecture	**Applications:** Matching / registration, stereo vision, demos
20	13	12.05.25	Practice	**Group projects: Q&A**
		16.05.25	Lecture	**Applications:** Compression (JPEG / MPEG), demos
21	14	19.05.25	Practice	**Applications:** From Bar- to QR-Codes
		23.05.25	Lecture	**Summary / Buffer**
22	15	26.05.25	Practice	**Group projects: Q&A**
		30.05.25		Auffahrt / Brücke
23	16	02.06.25		Semester break
		06.06.25		**Group projects: Submission of notebooks – Fr 06.06.25, 23:59**
24	17	09.06.25		Semester break
		13.06.25		**Group projects: Submission peer feedback – Fr 13.06.25, 23:59**

Course assessment

Assessment	Weight
Experience grade	30%
Grade of intermediate exam I	5%
Grade of intermediate exam II	5%
Grade of course project (teams of 2-3)	20%
Final written module examination	70%

Intermediate exams

- Duration: 30min
- (Pen and paper or Moodle)
- Permitted aids:
  - Summary: max. 2 A4 pages
  - Calculator
  - Dictionary
- In presence (on Monday morning)
- Topics: Consult the learning objectives!
- In the event of illness (medical certificate required):
  Oral exam on a separate date

Date	Time	Exams	Topics
Monday, 24.03.2025	08:15	Intermediate 1	Signals
Monday, 05.05.2025,	08:15	Intermediate 2	Images

Group projects

- In group of 2-3 students
- Goal: Realize a filter project
- Possible topics:
  - Own or prepared ones
  - During the **topic fair**, we form groups and discuss possible topics
- Submission:
  - A documented Jupyter notebook (A template will be provided)
  - All relevant datafiles

Date	Event
Mo, 31.03.2025	Topic fair for group projects
Mo, 14.04.2025	Start group projects
Fr, 06.06.2025	Submission project notebooks

Didactic concept

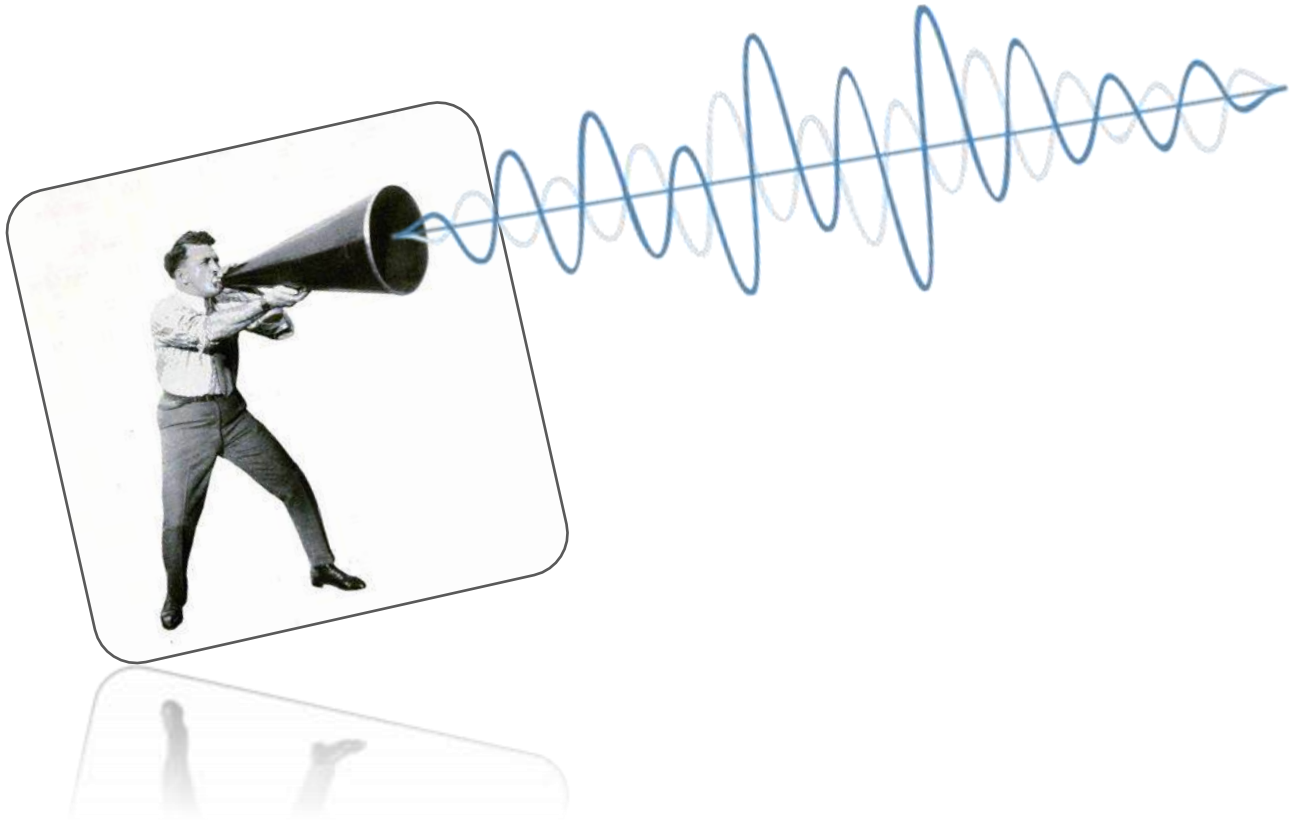
- Didactic challenges:
  - The range of topics is rather large
  - The concepts are abstract
  - At the same time, the course should serve joy and curiosity
- Advantages:
  - The topics are relevant to daily life and other subjects taught in the ADLS
  - Results appeal to the senses (hearing, seeing) and are therefore fun.

This course

- ...offers a blend of theory and practice
- ...promotes active participation for better learning effects
- ...requires the students to actively digest the provided materials
- ...relies on learning objectives to provide guidance (for the students and the tutor)
- (...favors Git/GitHub over Moodle)

Communication channels

- For personal messages:
  - norman.juchler@zhaw.ch
  - Monday morning in person
- From tutor to students:
  - Moodle announcements
- From everyone to everyone:
  - GitHub Discussions
- Learning resources:
  - GitHub project
  - Pull recent changes!
  - Enable “Watch” for notifications!



Illustrations based on Adobe Stock / 354425450 and Wikimedia: Thomas H. Ince – Megaphone 1922 (Link)