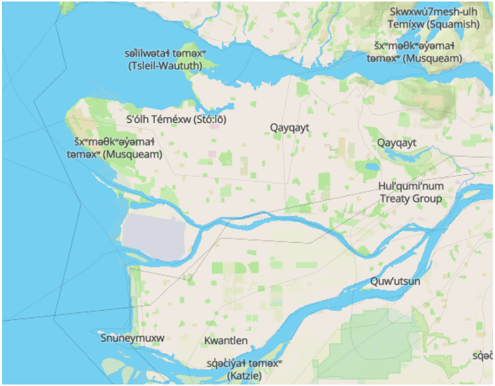
ELEC 221 Lecture 01
Overview and intro to signals and systems

Thursday 5 September 2024

Land acknowledgement

The land on which we gather today is the traditional, ancestral, and unceded territory of the Musqueam People.



Explore more:

- https://www.musqueam.bc.ca/
- https://native-land.ca/

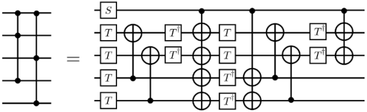
Olivia Di Matteo – KAIS 3043 – `olivia@ece.ubc.ca`

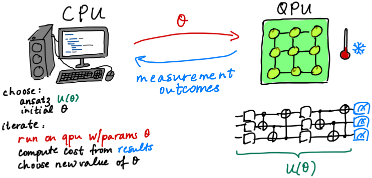
I have a physics background and I work on **quantum software and algorithms**.

```
import pennylane as qml

dev = qml.device("default.qubit", wires=3)

@qml.qnode(dev, diff_method="parameter-shift")
@qml.compile()
def circuit(data, params):
    qml.AngleEmbedding(data, wires=range(3))
    qml.RY(params[0], wires=0)
    qml.RX(params[1], wires=1)
    qml.RZ(params[2], wires=2)
    qml.CNOT(wires=[0, 1])
    qml.CNOT(wires=[1, 2])
    qml.CNOT(wires=[2, 0])
    return qml.expval(qml.PauliZ(0))
```





(Find me on GitHub as glassnotes.)

Signals and systems are EVERYWHERE: audio processing

- how do equalizers and effect pedals work?
- how do you synthesize digital sounds?
- how does active noise cancellation work?

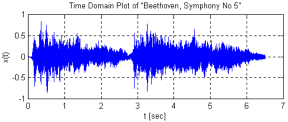
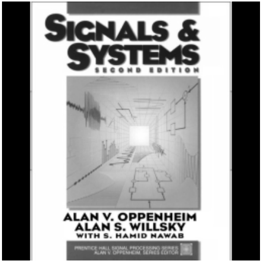
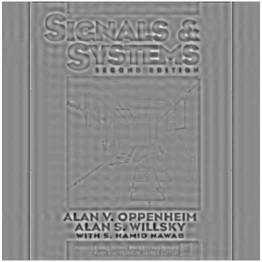


Image credits:
https://www.uberchord.com/blog/guitar-effects-pedalboard-order/
https://en.wikipedia.org/wiki/File:Karplus-strong-schematic.svg
https://stats.stackexchange.com/questions/72386/find-music-tempo-with-a-audio-signal

Signals and systems are everywhere: image/video processing

- why do wheels in old movies spin backwards?
- how do photo filters work?
- how can we improve the quality of blurry or noisy images?





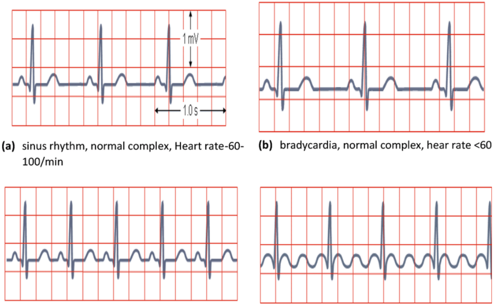
Signals and systems are everywhere: data processing and analysis

- how do we encode and transmit data correctly and efficiently?
- how do we identify trends and make predictions from data?
- how do we engineer systems that adapt based on input data?

Image credit: google.com market summary

Signals and systems are everywhere: life sciences

- how do we engineer better hearing aids?
- how does medical imaging work?
- how do we process and interpret the results of medical tests?



(a) sinus rhythm, normal complex, Heart rate-60-100/min

(b) bradycardia, normal complex, hear rate <60

(c) tachycardia, normal complex, heart rate >100/minute

(d) Atrial flutter, the irregular response of ventricular, rapid flutter waves

Image credit: Thirugnanam, Mythili & Pasupuleti, Megana. (2021). Cardiomyopathy-induced arrhythmia classification and pre-fall alert generation using Convolutional Neural Network and Long Short-Term Memory model. Evolutionary Intelligence. 14. 10.1007/s12065-020-00454-0.

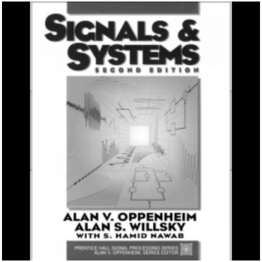
Course learning outcomes

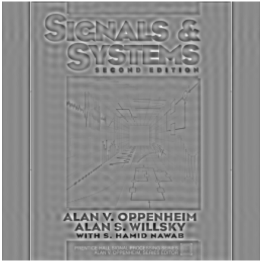
A broad overview of the processing and analysis of signals and systems, grounded in *real-world examples*.

- Express continuous- and discrete-time signals as functions, and characterize how linear, time-invariant systems respond to them
- Apply Fourier analysis (and generalized transforms) to determine key properties of signals and systems in the time and frequency domain
- Design systems that modify signals using filters, sampling, modulation, and feedback

By the end of the course you'll be able to do the above both **mathematically** and **computationally**.

Recommended text: *Signals & Systems* 2e, Oppenheim & Willsky.





All lecture slides/demos will be posted on the course GitHub:

`https://github.com/glassnotes/ELEC-221`

Course overview: questions

My office hours (KAIS 3043):

- Friday 14:30-15:30
- open-door after 1pm on weekdays
- by appointment

TA office hours (KAIS 3047):

- Tuesdays 12:30-13:30
- Thursdays 17:00-18:00

Four TAs: Rouzbeh Ghaderi, Mohammadreza Hallajiyan, Ailar Mahdizadeh, Tate McCartney (contact details in syllabus)

TAs will facilitate Monday tutorials.

Survey

Go to `menti.com` and enter the code on the screen.

Course overview: assignments and grading

- 20% Assignments (5)
- 10% Tutorial assignments (5)
- 10% In-class quizzes (10)
- 15% Midterm 1
- 15% Midterm 2
- 30% Final exam

Course overview: assignments and grading

(20%) Assignments (5)

- Distributed and submitted on PrairieLearn
- Mix of numerical input and pen-and-paper
- You may consult with your classmates, however:
  - What you submit must be your own work, that you wrote
  - You **must** include a statement of contributions (template will be provided)

No late submission. Lowest assignment grade automatically dropped.

Usage of generative AI tools is not permitted on any assessed course material, unless explicitly stated (please see syllabus for formal statements re. misconduct and AI usage).

Course overview: assignments and grading

Half of tutorial sessions are problem-solving, others are interactive.

(10%) Tutorial assignments (5)[1]

- Distributed and submitted on PrairieLearn
- Done in groups of up to 4; start in tutorial, due later
- Hands-on signal processing with Python

Calendar in syllabus. First one **Monday** about Python basics.

No late submission. Graded for reasonable effort and completion.

Note: distributing code / solutions to others is misconduct.

[1] Developed by ENPH students, funded by UBC Open Educational Resources Implementation Grant!

(10%) In-class quizzes (10)

- Done in PrairieLearn during first 10 minutes of most Tuesday classes (calendar in syllabus)
- 1-3 auto-graded multiple choice questions based on material from previous week
- Open-book, but individual

Quiz 1 this Tuesday.

No deferred quizzes. Lowest quiz grade automatically dropped.

Course overview: assignments and grading

(15%) Midterm 1: Tuesday 8 Oct. (during class)

- Individual exam

(15%) Midterm 2: Monday 4 Nov. (during tutorial)

- Two-stage exam: do exam alone first, then do same exam again in small groups
- Weighted avg. of individual (85%) and group (15%) scores
- Not cumulative

(30%) Final exam (date TBD)

- Individual exam
- **Cumulative**, but more emphasis on later parts

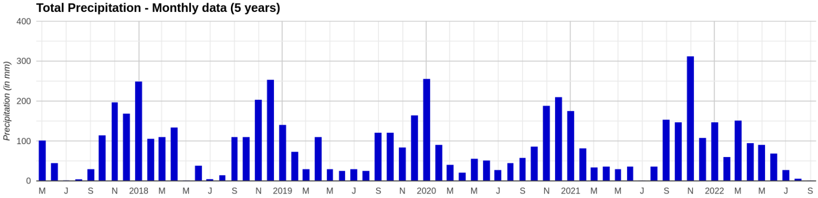
Today

Learning outcomes:

- Define signals and systems, and provide real-world examples of each
- Express continuous-time and discrete-time signals as functions
- Apply time shift, scaling, and reversal transforms to signals
- Identify if a system is causal, memoryless, stable, or invertible

Signals are "patterns of variations" that contain information about the behaviour of a phenomenon.

Example: total precipitation in Vancouver vs. time



Mathematically: functions of one or more independent variables (often, but not always, time).

Image generated from: `https://vancouver.weatherstats.ca/charts/precipitation-monthly.html`

Signals

In this class we will be

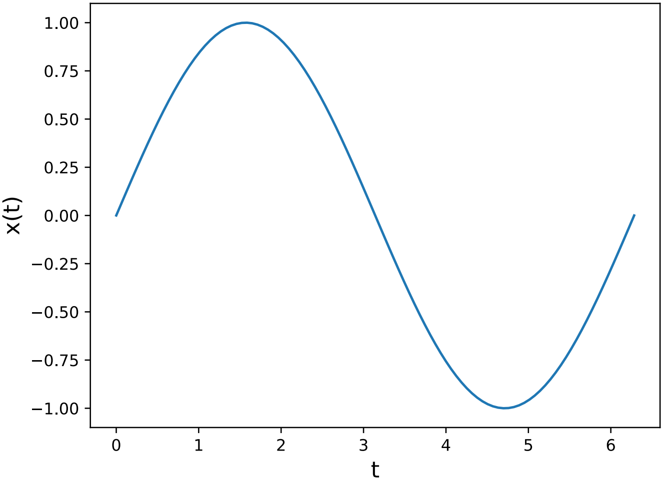
- Transforming signals
- Synthesizing and analyzing signals
- Determining how systems respond to them
- Designing systems to manipulate signals in specific ways

We consider two types of signals:

1. Continuous-time (CT)
2. Discrete-time (DT)

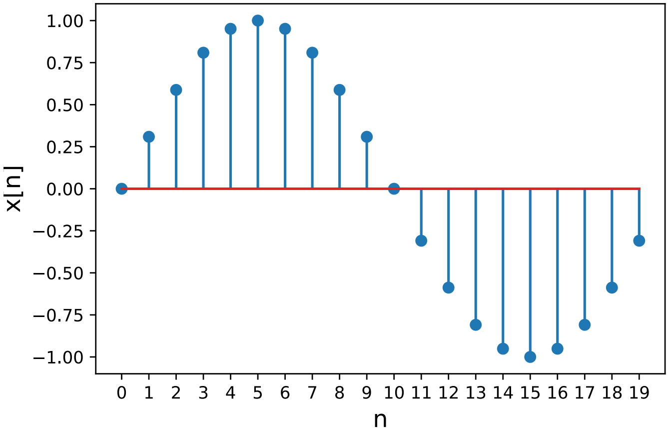
Continuous-time (CT) signals

Notation: $x(t)$, where t is any real number.



Discrete-time (DT) signals

Notation: $x[n]$, where n is strictly an integer (positive or negative).



Exercise: CT vs. DT signals

Are the following signals CT or DT?

Signal	Type
radio broadcast	CT or DT (internet radio)
seismogram	CT
daily temperature high	DT
speed of a car	CT
a movie	DT

Transformations of independent variables

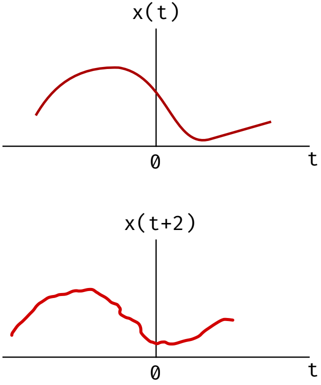
Most of what we do involves *transforming* signals.

Simplest example: transform the independent variable...

- Time shift: $x(t) \longrightarrow x(t - t_0)$
- Time scaling: $x(t) \rightarrow x(at)$
- Time reversal: $x(t) \rightarrow x(-ta)$

Intuition: playing music slower/faster, or in reverse.

Exercise 1: Transformations of independent variables



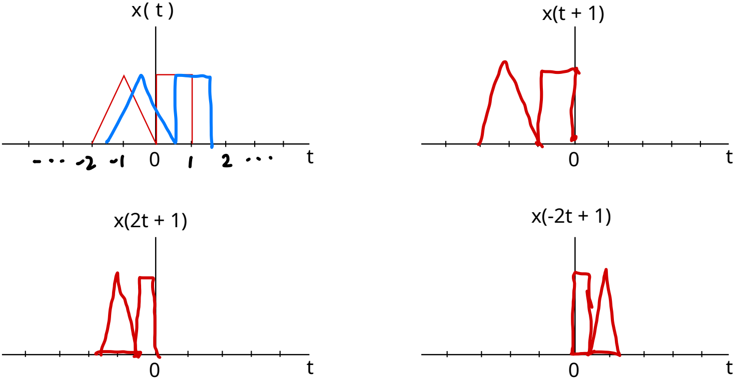
These transforms can also be *composed*:

$$x(t) \longrightarrow x(\alpha t + \beta)$$

Order matters!

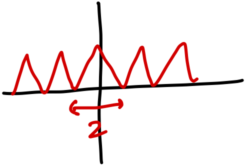
1. Shift by β
2. Scale by $|\alpha|$
3. Reverse if $\alpha < 0$

"shift, scale, reverse"



A CT signal is periodic with period T if for all t,

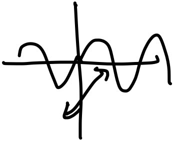
$$x(t+T) = x(t)$$



The smallest T for which this holds is the **fundamental period**.

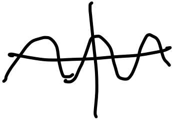
A CT signal is **odd** if for all t

$$x(-t) = -x(t)$$



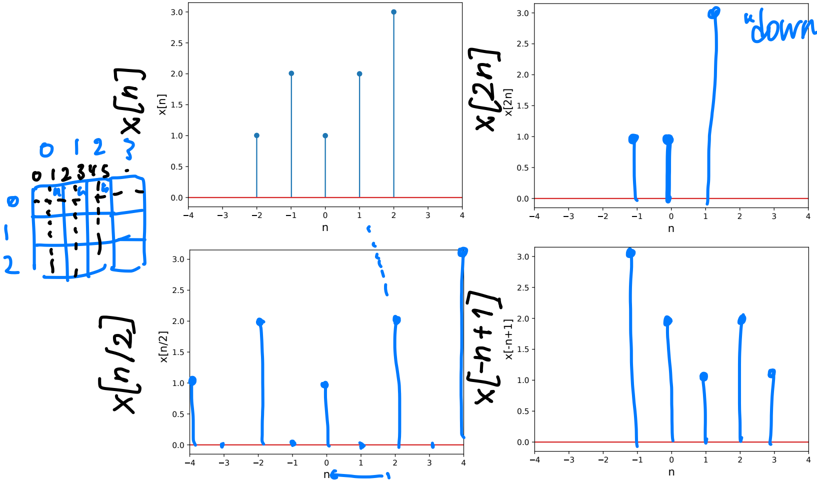
and **even** if

$$x(-t) = x(t)$$



- Time shift: $x[n] \to x[n-n_0]$
- Time scaling: $x[n] \to x[an]$
- Time reversal: $x[n] \to x[-n]$

decimation
"downsampling"



Consequences: periodicity

A DT signal is periodic with period N if for all n,

$$x[n+N] = x[n]$$

The smallest N for which this holds is the **fundamental period**.

A DT signal is **odd** if for all n

$$x[-n] = -x[n]$$

and **even** if

$$x[-n] = x[n]$$

Systems respond to signals and produce some desired behaviour, or other signals as outputs.

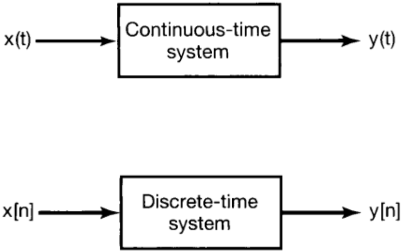


Image credits: Signals and Systems 2nd ed., Oppenheim

We can combine systems in series or parallel.

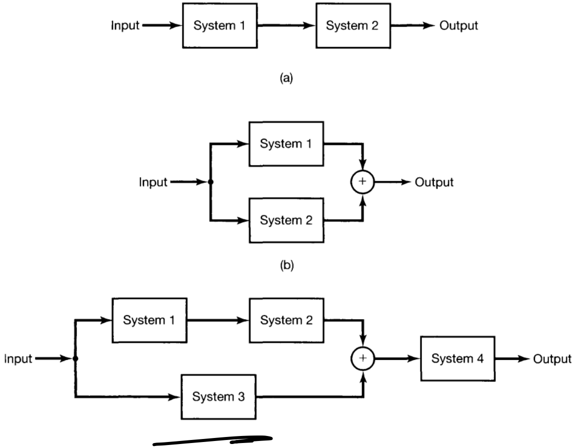


Image credits: Signals and Systems 2nd ed., Oppenheim

Properties of systems

1. Memory
2. Invertibility
3. Causality
4. Stability
5. Time invariance
6. Linearity

$\rightarrow$ Tuesday

Properties of systems: memory

A system is **memoryless** if the output at each time depends only on the input *at the same time*.

(✓) Output voltage after current goes through a resistor (R)

$$V(t) = R\,I(t)$$

(✗) Output voltage after current $I(t)$ goes through capacitor (C)

$$V(t) = \frac{1}{C}\int_{-\infty}^{t} I(\tau)\,d\tau$$

have memory

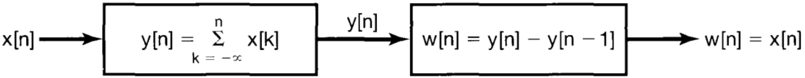
(✗) A delay system

$$y[n] = x[n-1]$$

$$x[n] \to \boxed{S} \to \boxed{S_{inv}} \to x[n]$$

A system is **invertible** if distinct inputs lead to distinct outputs.

(✓) Accumulator



(✗) The system

$$y(t) = x^2(t)$$

Image credits: Signals and Systems 2nd ed., Oppenheim

A system is **causal** if the output at *any* time depends only on the input at the present time or in the past.

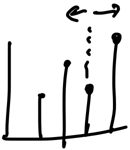
every

(✓) Output voltage after current $I(t)$ goes through capacitor (C)

Q from after class:
$y(t) = \sin(t+1)\, x(t)$
is causal because dependence of $x(t)$ is only from present/past

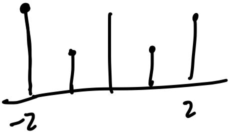
$$V(t) = \frac{1}{C}\int_{-\infty}^{t} I(\tau)\, d\tau$$

(✗) A moving average



$$y[n] = \frac{1}{2M+1}\sum_{k=-M}^{M} x[n-k]$$

(✗) Time reversal



$$y[n] = x[-n]$$

Properties of systems: stability

A system is **stable** if small changes in input do not cause the output to diverge (bounded inputs lead to bounded outputs).

(✓) Moving average of a bounded function, $x[n] \leq B$

$$y[n] = \frac{1}{2M+1} \sum_{k=-M}^{M} x[n-k]$$

(✗) Compound interest in a bank account

$$y[n] = 1.01\, y[n-1] + x[n]$$

Today's learning outcomes were:

- Define signals and systems, and provide real-world examples of each
- Express continuous-time and discrete-time signals as functions
- Apply time shift, scaling, and reversal transforms to signals
- Identify if a system is causal, memoryless, stable, or invertible

For next time

Content:

- Quiz #1 (transformations of variables, system properties)
- Linear time-invariant (LTI) systems, DT unit impulse, impulse response, and convolution sum

Action items:

1. Follow instructions on Canvas for PrairieLearn and Piazza
2. Prepare for tutorial assignment 1 on Monday

Recommended reading:

- from today's class: Oppenheim chapters 1.1-1.2, 1.5-1.6
- practice problems: 1.4, 1.5, 1.15, 1.21a-d, 1.22a-d, 1.30a-c,e-g,k-n
- for next class: Oppenheim 1.4, 2.1-2.3