# ECE 101: Linear Systems Fundamentals

Spring 2025 - Lecture 1

Paul Siegel

University of California, San Diego

# Today's topics

- Introduction to the course
- Signals
- Basic operations on signals

Signals and Systems (2nd Edition): sections 1.1.1 and 1.2.1

# Introduction to the course

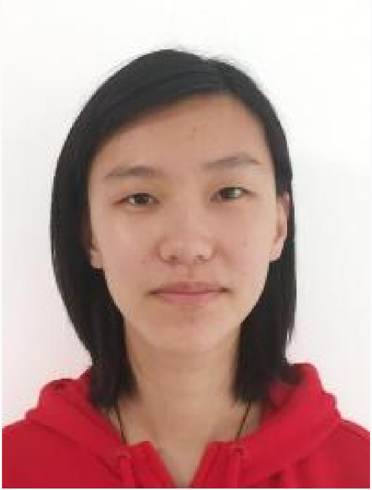
# Introduction to the course: Instructor

- Instructor: Paul Siegel
    - Email: psiegel@ucsd.edu
    - Zoom office hours: Wednesdays, 1 pm - 2 pm and by appointment at other times

# Introduction to the course: TAs

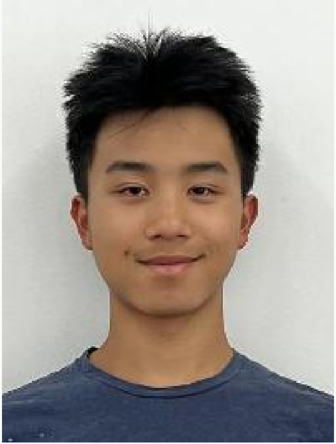
- TA: Deepak Sridhar
  - Email: desridha@ucsd.edu
  - Office hours:

# Introduction to the course: TAs (cont.)



- TA: Qianyi Wu
  - Email: qiw010@ucsd.edu
  - Office hours:

## Introduction to the course: Tutors/Readers



- Tutor/Reader: Kyle Lou
  - Email: kylou@ucsd.edu
  - Office hours:

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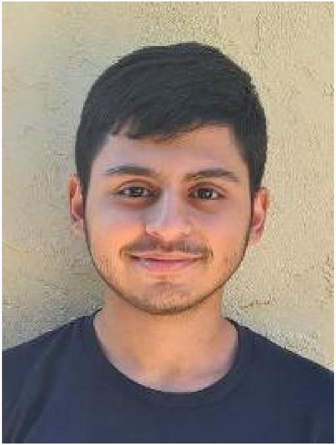

- Tutor/Reader: Alex Simonyan
  - Email: asimonya@ucsd.edu
  - Office hours:

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- You are asked to watch these videos **before** attending each lecture.

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- Lectures will address your questions and provide many problem solving examples.
- You will have opportunities to work on sample problems during the in-class activities.
- In-class "clicker questions" (using iClicker Cloud on your smartphones) will provide real-time feedback on your understanding of the material.

# Introduction to the course: course structure

- Your assignments include 5 Problem Sets and 5 MATLAB labs.
- You may use MATLAB Online or MATLAB on your computer to complete the labs.
- Complete the MATLAB Onramp tutorial ASAP.
- We will demonstrate many concepts using in-class MATLAB demos throughout the course.
- MATLAB brings the course material to life!

# Introduction to the course: course websites

- In this course, we will use Canvas, Gradescope and Piazza for delivering the course content, submitting/grading the assignments and discussions.
- Be sure you are enrolled at all websites - contact me with any problems.

# Introduction to the course: textbooks and reference notes

- Textbook

  Signals and Systems, 2nd Edition by A.V. Oppenheim and A.S. Willsky (with S.H. Nawab) Prentice Hall, 1997.

- Lab textbook

  Computer Explorations in Signals and Systems (Using MATLAB), 2nd Edition, by J.R. Buck, M.M. Daniel, and A.C. Singer, Prentice Hall, 2002.

- Reference Notes for Signals and Systems (available on Canvas)

# Introduction to the course: resources

- Resources (lecture videos, lecture notes, reading quizzes, assignments, etc.) are available on Canvas
- Submit assignments using Gradescope: Entry Code 42JVN7
- Piazza page:

  https://piazza.com/ucsd/spring2025/ece101_sp25_a00

## Introduction to the course: grade breakdown

- 10% Reading quizzes and clicker questions
- 10% Problem Sets
- 15% MATLAB Assignments
- 30% Midterm exam
- 35% Final exam

# Introduction to the course: topics covered in this course

- Discrete-time (DT) and continuous-time (CT) signal properties
- DT and CT system properties
- Linear Time Invariant (LTI) systems and their properties
- Fourier Series and Fourier Transform of DT and CT signals
- Frequency analysis of DT and CT systems
- Amplitude Modulation (AM) for communication systems
- Sampling Theory, DT processing of CT signals
- Laplace transform of CT signals, Feedback control

# Today's topics

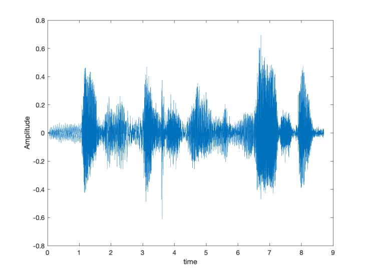
- Signals
- Basic operations on the signals

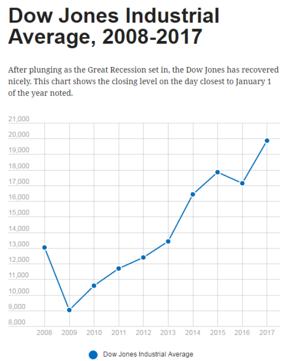
# Signals

# What is a signal?

- A signal is a quantitative description of a physical phenomenon, event or process that often has *time-dependency*.

- Examples:



# What is a signal?

- Signals:
  - Continuous-time (CT)
  - Discrete-time (DT)

# Continuous-time Signals

- **Continuous-time Signals**: Signals that are functions of real-valued independent variables (time variable $t$).
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  - reserve time variable $t$ for continuous-time signals' independent variable
  - use parenthesis $(\cdot)$

# Discrete-time Signals

- **Discrete-time Signals**: Signals that are defined only at discrete times (time variable $n$).
- For these signals, the independent variable takes on only a discrete set of values.
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# Complex signals

# Complex Signals - Notation

- A complex CT signal $x(t)$ is formed by the signal pair $\{x_r(t), x_j(t)\}$, where both $x_r(t)$ and $x_j(t)$ are real-valued signals.

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- The relationship between these signals is given by:

  $$x(t) = x_r(t) + j\, x_j(t)$$

  where $j = \sqrt{-1}$

# Complex Signals - Notation

- Similarly, a complex DT signal $x[n]$ can be represented as

  $$x[n] = x_r[n] + j\ x_j[n]$$

  where both $x_r[n]$ and $x_j[n]$ are real-valued DT signals.

# Basic Notations

- $\mathbb{Z}$ : the set of integers $\ldots, -2, -1, 0, 1, 2, \ldots$
- $\mathbb{R}$ : the set of real numbers
- $\mathbb{C} := \{(a + bj) \mid a, b \in \mathbb{R}\}$ the set of complex numbers

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- $\mathbb{R}$ : the set of real numbers
- $\mathbb{C} := \{(a + bj) \mid a, b \in \mathbb{R}\}$ the set of complex numbers
  - $x = a + bj$ is Cartesian coordinate representation
  - $x = re^{j\theta}$, where $r = \sqrt{a^2 + b^2}$ and $\theta = \tan^{-1}(\frac{b}{a})$ is the polar coordinate representation
  - Euler's Formula:

$$e^{j\theta} = \cos(\theta) + j\sin(\theta)$$

# Euler's Formula and Coordinate Transformation

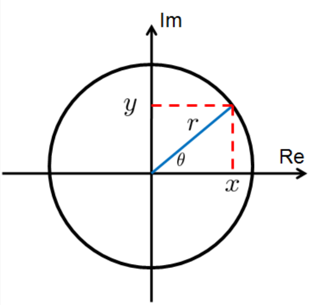
- Euler's Formula:

$$e^{j\theta} = \cos(\theta) + j\sin(\theta)$$

- Cartesian/polar coordinates:

$$z = x + j\,y$$

$$re^{j\theta} = r\cos(\theta) + j\,r\sin(\theta)$$



# Basic Operations on Signals

# Time Shift

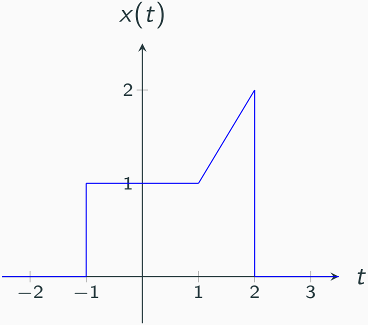
- For any $t_0 \in \mathbb{R}$ and $n_0 \in \mathbb{Z}$, **time shift** is defined as

$$\begin{aligned} x(t) &\longrightarrow x(t - t_0) \qquad \text{CT} \\ x[n] &\longrightarrow x[n - n_0] \qquad \text{DT} \end{aligned}$$

- For $t_0 > 0$ ($n_0 > 0$), it is called **delay** and for $t_0 < 0$ ($n_0 < 0$) it is called **advance**.

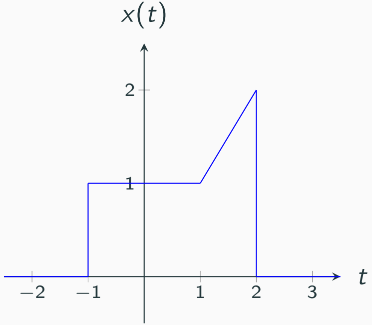
# Time Shift: example

- Example: Suppose $x(t)$ is as shown below. Sketch $x(t-1)$.



# Time Reversal: example

- Example: Suppose $x(t)$ is as shown below. Sketch $x(-t)$.

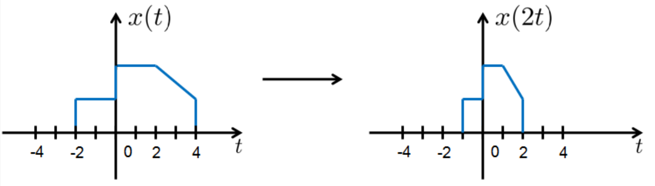


# Time Scaling: Continuous Time

- For CT Signals, time-scaling by a factor $a > 0$ is defined as

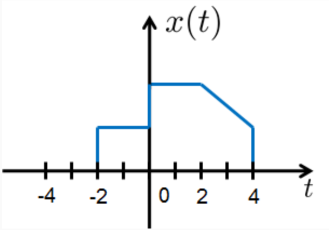
$$x(t) \quad \longrightarrow x(at), \quad a > 0.$$

- If $a > 1$, it is called **Decimation** (squeezing)
- If $0 < a < 1$, it is called **Expansion** (enlarging)



# Class activity:

- Sketch $x(\frac{t}{2})$ for the below signal.

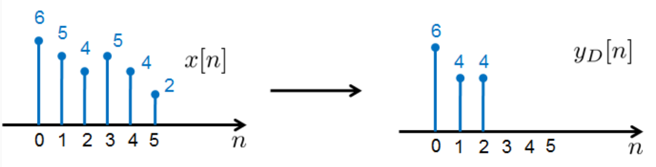


# Time Scaling: Discrete Time

- **Decimation**: For a DT Signal, and an **integer** factor $M \geq 1$, the decimated signal is defined by:

$$y_D[n] = x[Mn].$$

- An example of decimation for M = 2:

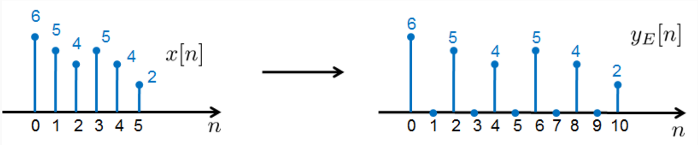


# Time Scaling: Discrete Time

- **Expansion**: For an integer $L \geq 1$, the discrete-time expanded signal (by a factor $L$) is:

$$y_E[n] = \begin{cases} x\left[\frac{n}{L}\right], & n = \text{integer multiple of } L \\ 0, & \text{otherwise.} \end{cases}$$

- An example of expansion for L = 2:



# Combination of Operations

- Often we are interested in the transformation $x(t) \to x(at - b)$
- A combination of time shift and time scaling is needed (order matters):
- The recommended method is
    1. Define $v(t) = x(t - b)$,
    2. Define $y(t) = v(at) = x(at - b)$.
- So $x(t) \to x(at - b)$ is equivalent to time delay then scale!

# Combination of Operations

- The second method is

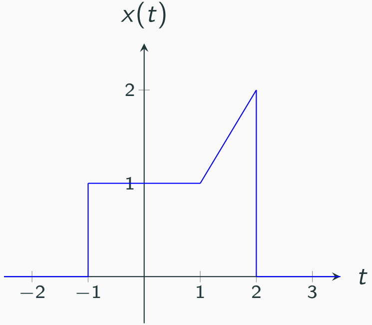
  1. Define $v(t) = x(at)$,

  2. Define $y(t) = v(t - b/a) = x(at - b)$.

- This method will not always result in a correct answer for the discrete-time signals.

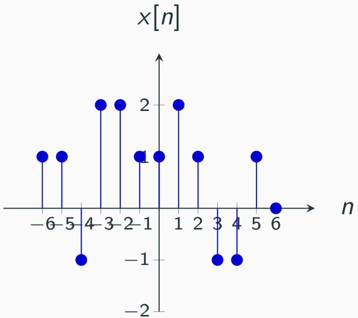
# Combination of Operations: example

- Example: Plot the signal $x(-t+2)$ for the signal $x(t)$ as bellow,

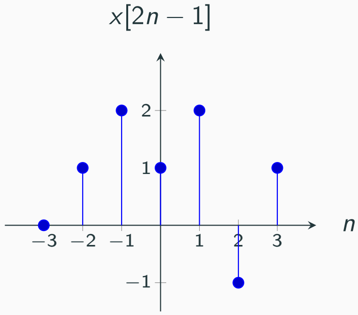


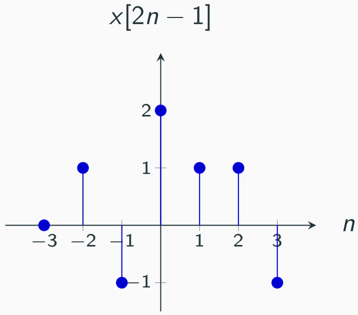
# Lecture 1 reading quiz

- A discrete-time signal $x[n]$ is shown below. Which option correctly represents $x[2n-1]$?

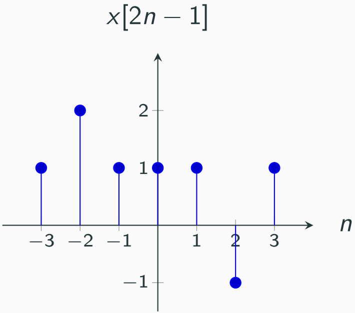


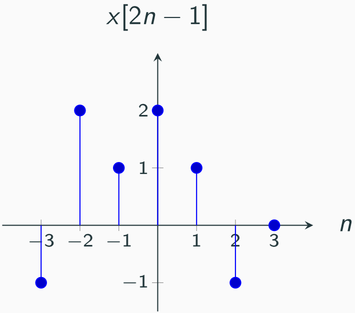
# Options for Quiz 1



# More options for Quiz 1



# Clicker question 1

- If $f(t) = x(t-1)$ and $g(t) = f(-2t)$, which option correctly represents $g(t)$?

  A. $g(t) = x(-2t + 2)$

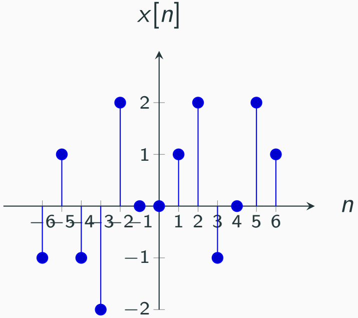
  B. $g(t) = x(-2t - 2)$

  C. $g(t) = x(-2t - 1)$

  D. $g(t) = x(-2t + \frac{1}{2})$

# Class activity 1

- A discrete-time signal, $x[n]$, is shown below. Sketch and label $y[n] = x[2n] + x[-n]$.



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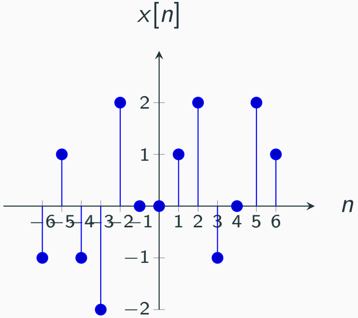
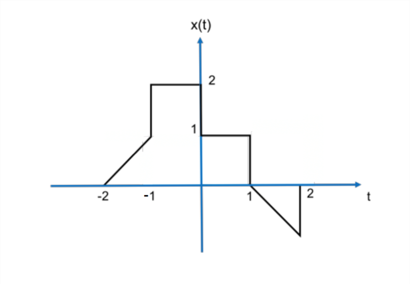


# Class activity 2

- A continuous-time signal, $x(t)$, is shown below. Sketch and label $x(-\frac{1}{4}t - 1)$.



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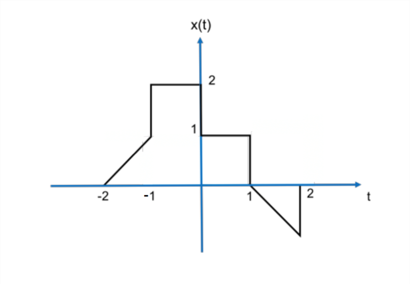

# Clicker question 2

- Consider the continuous-time signal, $x(t) = t - 1$.

  If $y(t) = x(-3t + 5)$, the time for which $y(t_0) = 0$ is given by:

  A. $t_0 = 0$

  B. $t_0 = -\frac{4}{3}$

  C. $t_0 = \frac{4}{3}$

  D. $t_0 = \frac{5}{3}$

# MATLAB Demo

- Lecture 1 Demo
  - Audio signals: loading, playing, plotting
  - Complex arithmetic
  - Complex signals: defining, plotting in 2D and 3D
- You will be able to download the MATLAB demo and its solution from the Canvas website.