Socrates

Nathan	EE	Freshman
Rohit	EE	Sophomore
Jason	EE	Freshman
Hooman	EE	Sophomore
Sauli	BioE	Sophomore

EE102

Lecture 1

Starts 5’ after the hour

Please show up @ ~4pm

EE102: Signals and Systems

PhD UCLA

Prof. Achuta Kadambi	TA: Pradyumna Chari	Reader: Krish Kabra
achuta@ee.ucla.edu	zhaoguangyuan@g.ucla.edu	safon007@g.ucla.edu

** This class is remote for Spring 2021!

Purpose of this Lecture

1. Discuss what this class is about, how it relates to EE/CS and also the class logistics and syllabus.
2. Though a required class, the topic is fun and used in industry on a daily basis.
3. ~~Please use remote office hours to ask questions, since lecture is video~~.

A note on slide credits: The instructor would like to acknowledge his colleagues for allowing them to adopt slides. The slide credits go to Prof. Kao (UCLA), Prof. Cabric (UCLA), Prof. Fragouli (UCLA), Prof. Pauly (Stanford), and Prof. Yu (CMU). The instructor thanks them all.

Slides will in many cases be directly adapted from Prof. Kao (UCLA)

“Signals and Systems” - what is this?

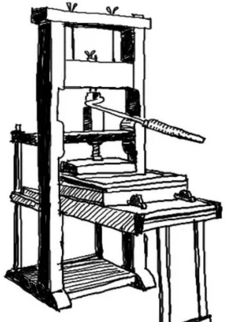
Our world and society relies on our ability to:

** **Capture** Information

** **Represent** Information

** **Act upon** Information

Cuneiform



Gutenberg's Press

“Signals and Systems” - what is this?

Our world and society relies on our ability to:

** **Capture** Information - includes “Scraping, Audio Capture, Video Capture, etc.

** **Represent** Information - includes “Storage, Compression, Hashing, etc”

** **Act upon** Information - includes ‘Share, Process, Operate, Display, Communicate”

“Signals and Systems” - what is this?

Our world and society relies on our ability to:

** **Capture** Information -> **Sensing**

** **Represent** Information -> **Signals**

** **Act upon** Information -> **Systems**

“Signals and Systems” - what is this?

Our world and society relies on our ability to:

EE

** ~~**Capture** Information -> **Sensing**~~ (learn more in the PWE and CES areas of our Department)

** **Represent** Information -> **Signals**

** **Act upon** Information -> **Systems**

ECE

Circuits and Embedded Systems

Signals / Systems

Physical Wave Electronics

“Signals and Systems” - what is this?

Our world and society relies on our ability to:

** **Represent** Information -> **Signals**

** **Act upon** Information -> **Systems**

Golden Rule: *Information is represented as a signal. Information changes or is processed through systems.*

Examples of Signals and Systems

What are examples of signals and systems?

- My voice is a **signal**, and my cell phone (**a system**) records it, transforms it into a transmittable form, communicates it to a cell phone tower(s), eventually reaching the person I'm speaking to who hears it... in almost real time.

- YouTube videos are a **signal**, and our computer or phone (**a system**) plays them, adjusting their resolution based on our WiFi speed, etc.

- Moving a computer mouse or typing on a keyboard is a **signal**, and our computer then uses circuits (**a system**) to translate this information to show you an updated computer screen.

Examples of Signals and Systems

But signals and systems **are not** limited to digital signals that we study in EECS.

** Any physical or abstract quantity that can be measured is a signal.

** Anything that changes a signal is a system.

** This is a general abstraction.

- The federal deficit is a **signal**, and policies passed by Congress, the interaction of national and global economies, etc. are **systems**.
- The concentration of a virus in the body is a **signal**, and the body's immune system is a **system**.
- Sensory and visual evidence is a **signal**, and our brain that interprets and processes this information is a **system**.

"Check Your Understanding" (CYU) → Identify examples of signals/systems

Signals and Systems Block Diagram

A block diagram is used to decompose a problem into components.

$x \longrightarrow \boxed{\text{System}} \longrightarrow y$

Blurry Image — "Unblur" the image — Sharp Image

EE 114, EE 211, CS 188

Input signal — Output signal

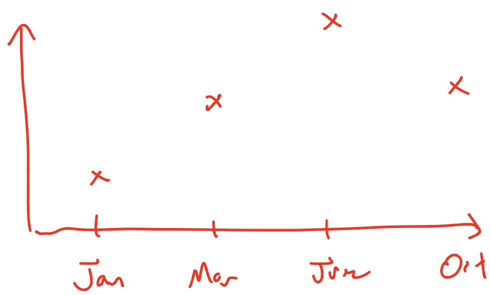
$$x(t) \longrightarrow \boxed{\text{System}} \longrightarrow y(t)$$

$x \to \boxed{S1} \to \boxed{S2} \to y$

Later on we will see how this abstraction enables us to chain systems together into **composite systems.**

** you will see this block diagram frequently in courses

Signal: Any fn. that varies in space, time, or another dimension



$x(t) \Rightarrow$ discrete time signal

Diversity of Signals and Systems

There are a wide variety of signals and systems (cell phones to viruses in the body)

How do we (rigorously) represent signals and systems?

The short answer: depending on the application, there can be several ways to represent signals; **how we represent signals, and what we aim to do with them, determines the types of tools we need to analyze them.**

Diversity of Signals and Systems..

Traditional signal processing (Fourier analysis):

Signals are 1-D, and do not have a noise model.

Examples: Radio, communications, control systems, circuit analysis.

Statistical signal processing:

Signals can be multi-dimensional, and incorporate noise models.

Examples: Communications over noisy channels, information theory, noisy control

Machine learning:

Signals can be multi-dimensional, and incorporate noise models.

Examples: Artificial intelligence, neural networks and deep learning, prediction systems, unsupervised learning.

Diversity of Signals and Systems

Traditional signal processing (Fourier analysis): **EE 102, 113, 142**

Signals are 1-D, and do not have a noise model.

Examples: Radio, communications, control systems, circuit analysis.

Statistical signal processing: **EE 131A, 133A, C143A**

Signals can be multi-dimensional, and incorporate noise models.

Examples: Communications over noisy channels, information theory, noisy control

Machine learning: **EE M146, CS188, + more**

Signals can be multi-dimensional, and incorporate noise models.

Examples: Artificial intelligence, neural networks and deep learning, prediction systems, unsupervised learning.

Diversity of Signals and Systems

Traditional signal processing (Fourier analysis): **EE 102, 113, 142**

Signals are 1-D, and do not have a noise model.

Examples: Radio, communications, control systems, circuit analysis.

Focus of EE102!

What is a signal?

Boston MA Logan Airport

A signal is a function of one or more variables

Discrete-time Signal

What is a function?

- We ought be familiar with functions from mathematics: denoted by $f(\cdot)$, it typically accepts some input, x and return some output, y. We write this as:

$$y = f(x)$$

- We usually denote this function as: $f : \mathbb{R} \to \mathbb{R}$, indicating that f is a function mapping a real number (the first $\mathbb{R}$) to another real number (the second $\mathbb{R}$).

$$f : \mathbb{R} \to \mathbb{R}$$

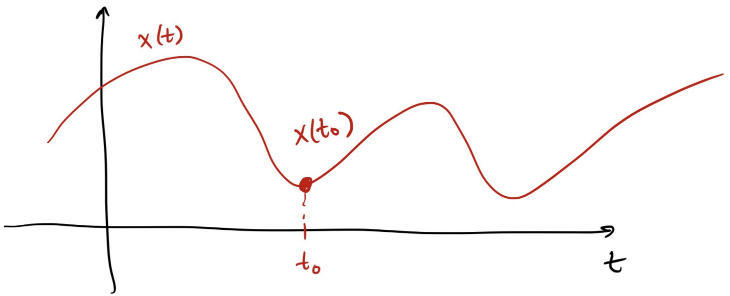
Signals..

The time domain → Focus of this class

Signals usually have to do with *time* domain representations.

- That is, signals are usually functions that accept an input time, t, and return the value of the signal at that time. For example, a signal could be represented $x(t)$, which denotes the value of the signal at time t.

x(t)



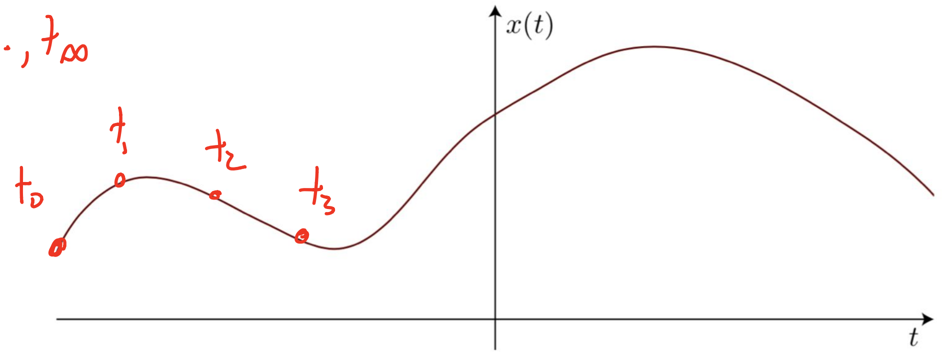
Signals..

The time domain

Signals usually have to do with *time* domain representations.

- That is, signals are usually functions that accept an input time, t, and return the value of the signal at that time. For example, a signal could be represented $x(t)$, which denotes the value of the signal at time t.
- We think of this as a time series, or a sequence of values through time.

$t_0, t_1, \ldots, t_\infty$



Signals - key concepts

** What kind of structure should we look for in signals

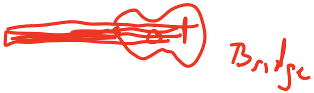
** Is this structure useful in general settings?

** What kind of systems can we design when we find this structure?

This lecture provides an **overview** of these key concepts - it is okay not to grasp all of it in lecture 1!

Music

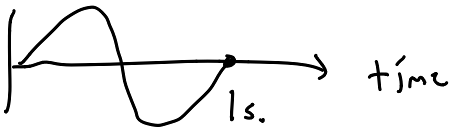
Musical Notes are Sine Waves



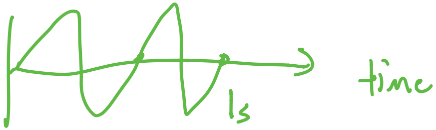
Think of this a string

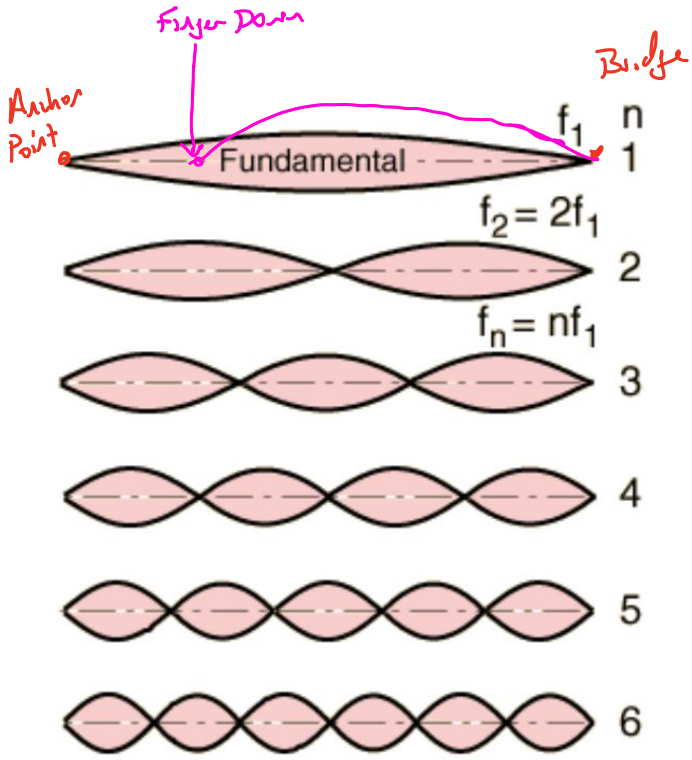
$\sin(2\pi f t)$

Suppose $f = 1$ Hz

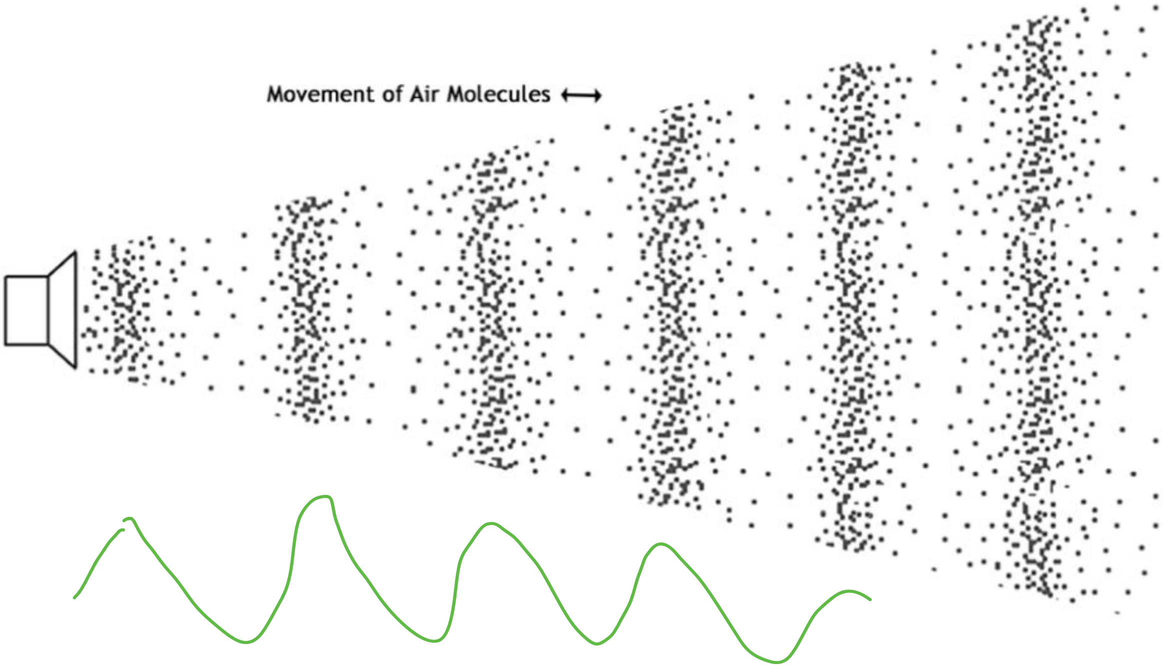


Suppose $f = 2$ Hz

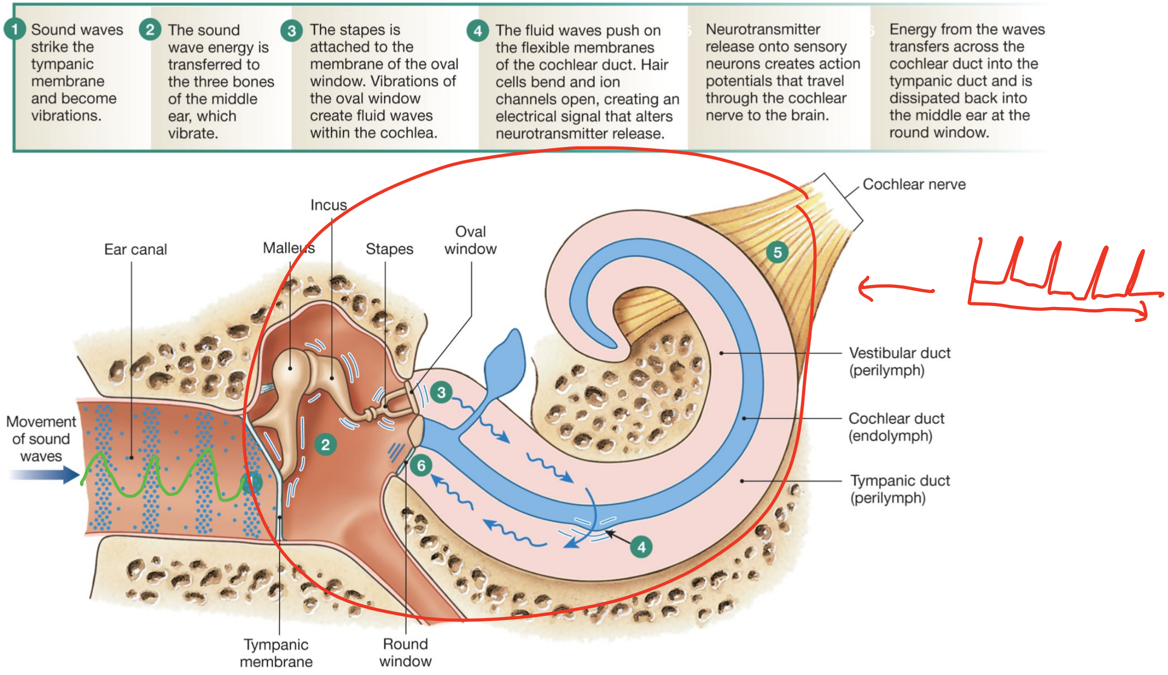




Sound Propagation

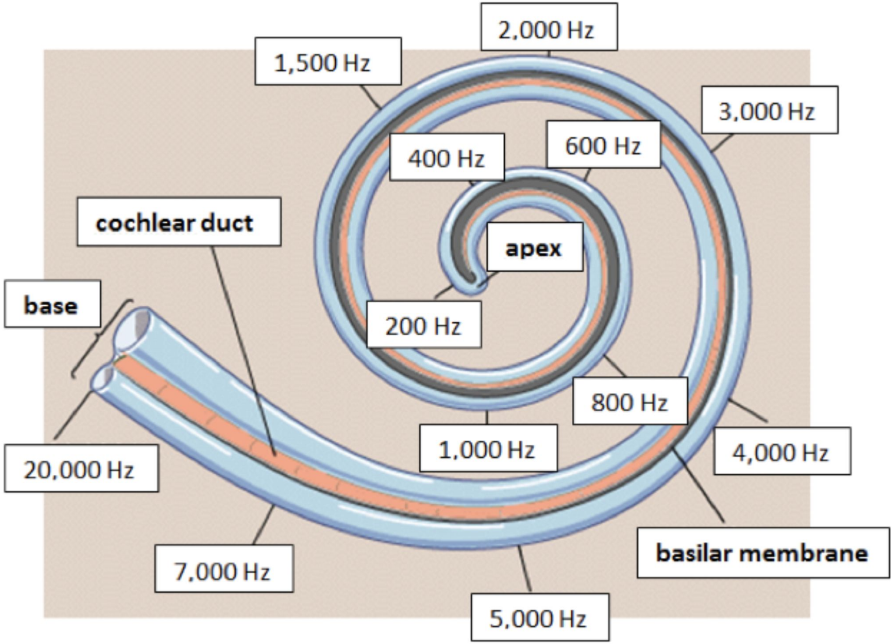


Music



https://content.openclass.com/eps/pearson-reader/api/item/ab914c98-1923-486b-bdb4-b9187be18b9e/1/file/silverthornHP7-071415-MJ-BO/OPS/img/9812210017.png

Music


2,000 Hz
1,500 Hz
3,000 Hz
400 Hz
600 Hz
cochlear duct
apex
base
200 Hz
800 Hz
1,000 Hz
4,000 Hz
20,000 Hz
basilar membrane
7,000 Hz
5,000 Hz

Music

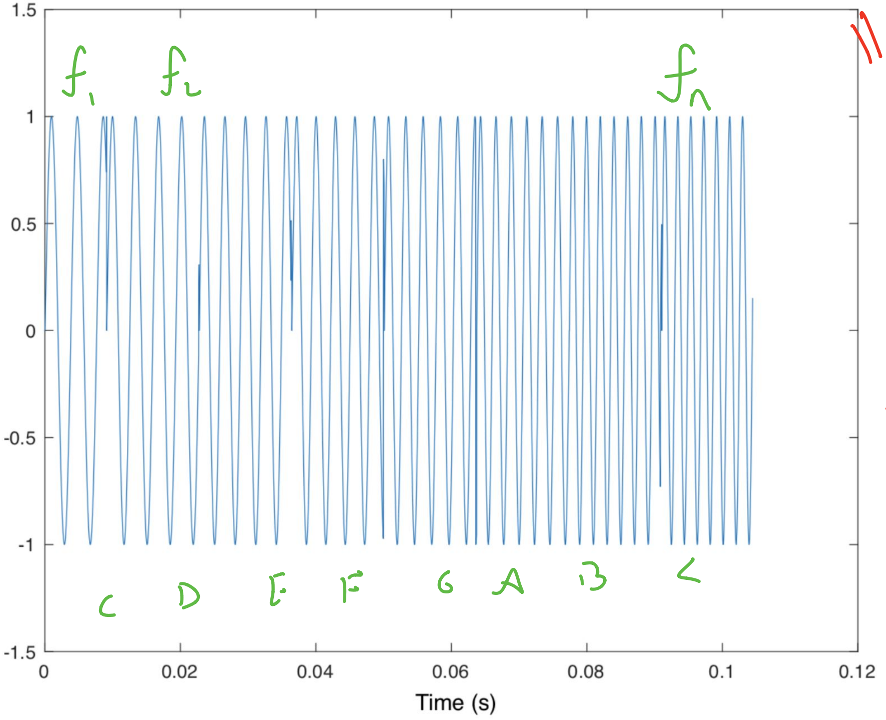
How music works

- Music is something most of us are familiar with.
- Music is fundamentally sine wave signal, $x(t) = \sin(2\pi ft)$. The tone of the note is determined by its *frequency*, denoted f in the equation.
- Every note (or tone) has a unique frequency associated with it. As the notes go higher, the frequencies also go higher. E.g.,
  - C: 261.6 Hz
  - D: 293.7 Hz
  - E: 329.6 Hz
  - F: 349.2 Hz
  - G: 392 Hz
  - A: 440 Hz
  - B: 493.9 Hz
  - C: 523.2 Hz

What is this signal?

cyu: what signal is this?

Answer: A "chirp" signal.



$f_1 = 261.6$ Hz

$f_2 = 293.7$ Hz

cyu @ home: How would you determine value of f_1

Take-home Message of this Class

One of the great secrets of the Universe

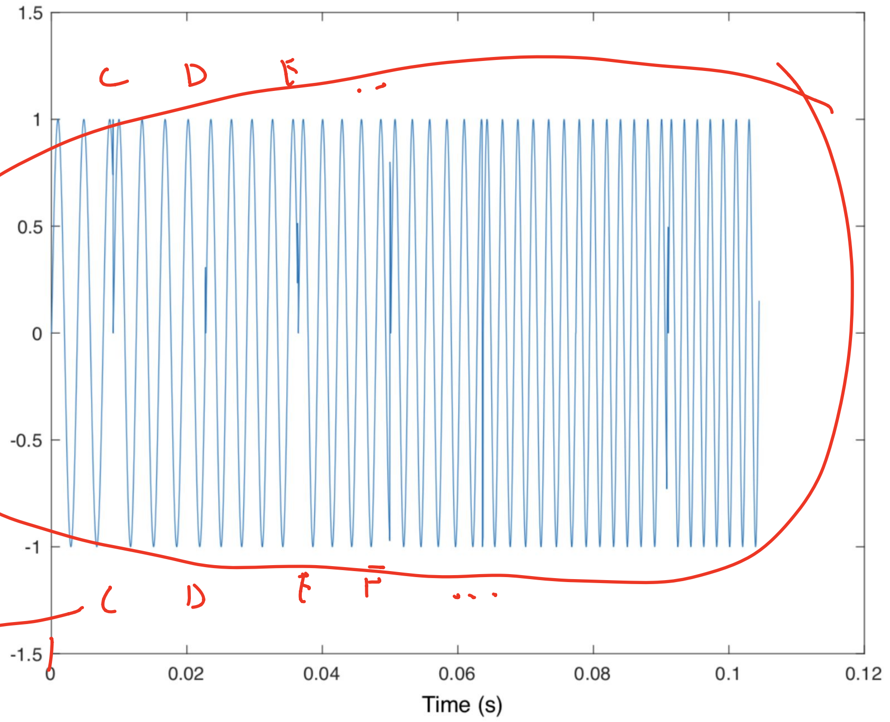
Every signal has a spectrum and is determined by its spectrum. You can analyze the signal either in the time (or spatial) domain or in the frequency domain. I think this qualifies as a Major Secret of the Universe.

- Prof. Brad Osgood, Stanford University

What is this signal?

TIME

"Chirp Signal"



261.6 Hz

x(t) : time domain

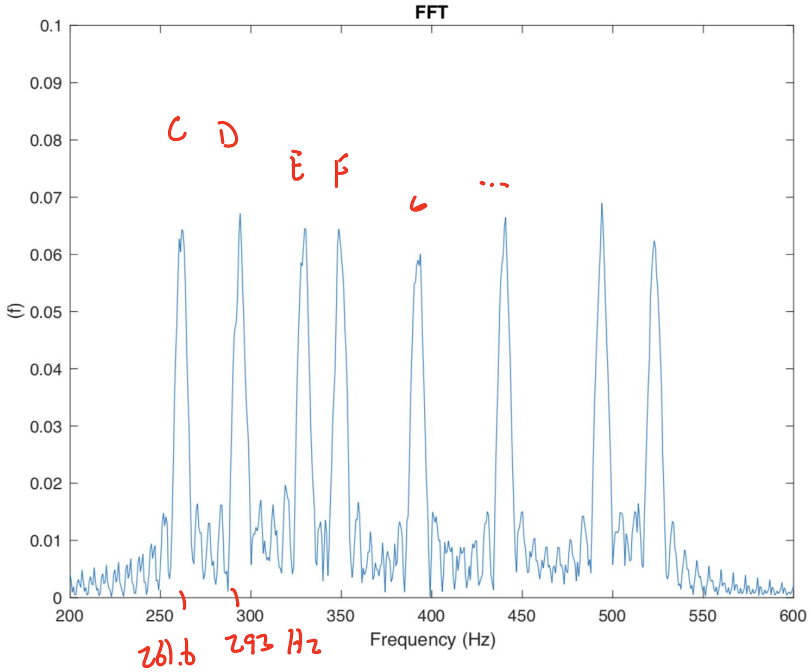
FFT

X(f) : frequency domain

Spectral Representation of Signal

FREKUENCI

The "Fourier Transform" of this signal.

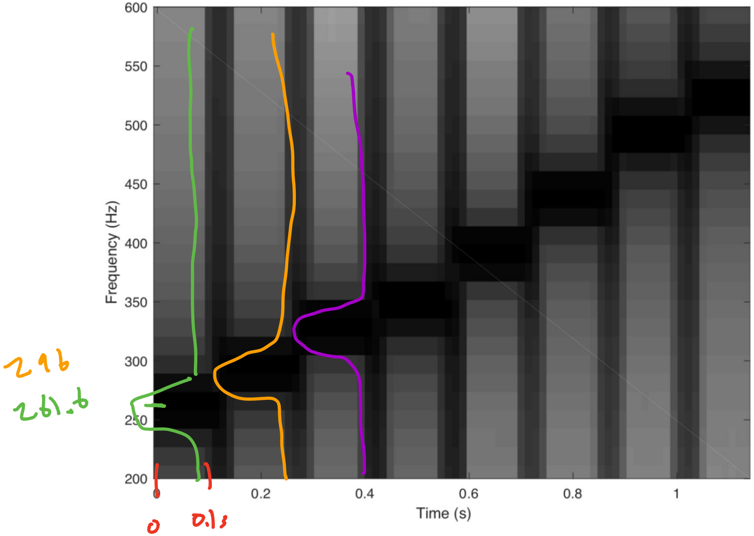


Spectral Representation

Plotting the spectrum through time

Spectogram

- If we plot a heatmap (where black is the largest amplitude) of the frequency power through time, we see that the frequency increases at discrete jumps, as in a scale.



$x(t) \rightarrow \boxed{\mathcal{F}} \rightarrow X(f)$

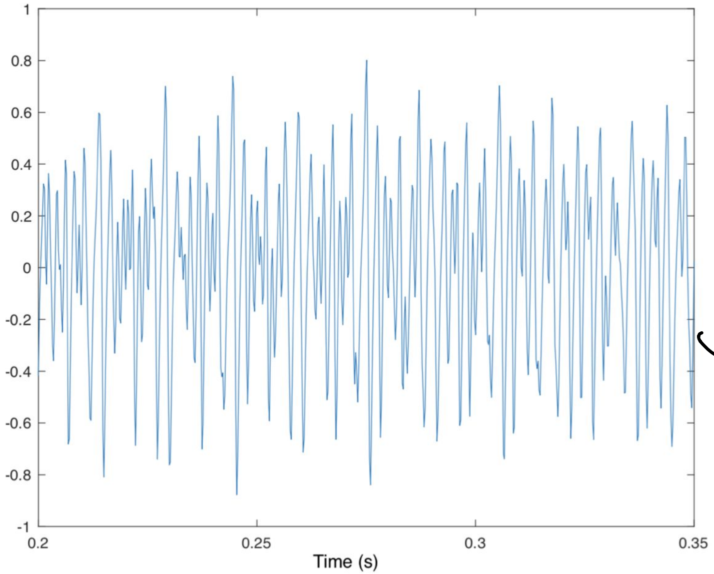
More complicated signals?

A more complicated signal

- In our prior example, it was easy to see clear sine waves.
- What about when it's not as clear?

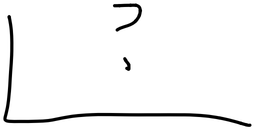
Qu: what frequency building blocks make up this signal?

Amplitude



Answer: I don't know!

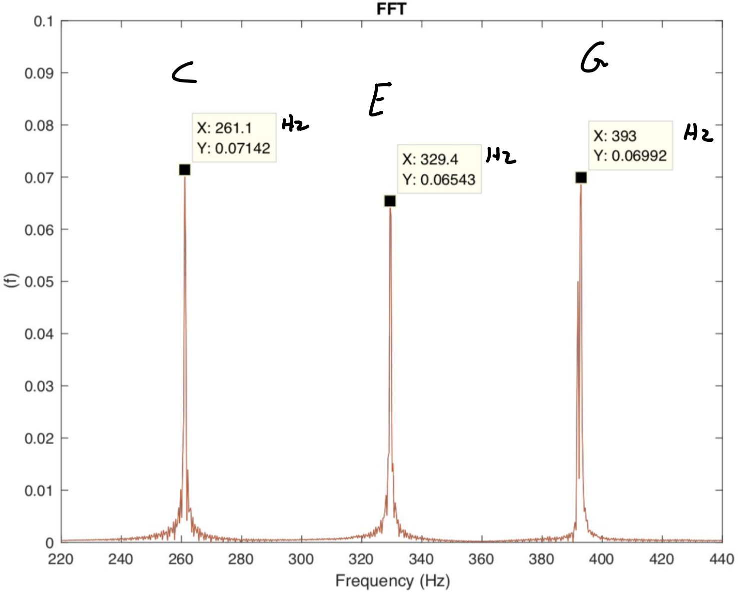
Take FFT



Frequency Domain can Simplify Analysis of Many Signals

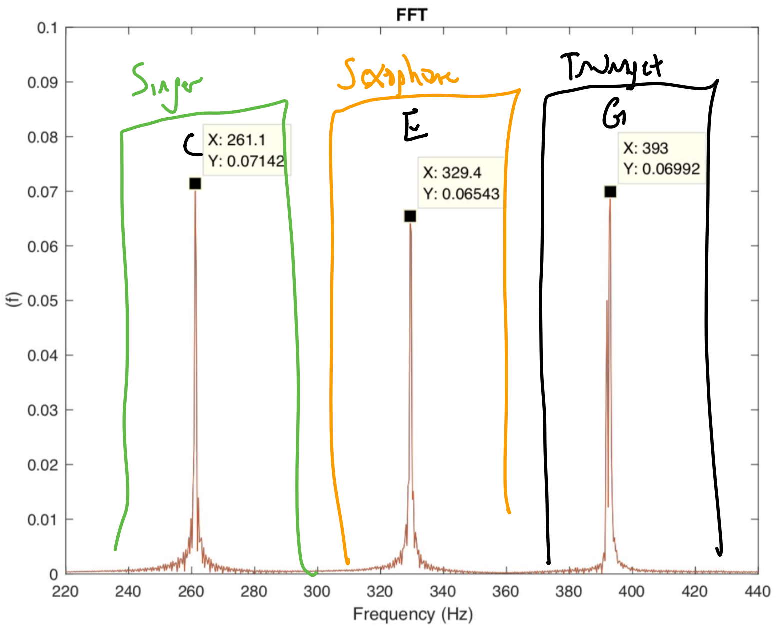
A more complex signal

- Sometimes the frequency domain reveals clear structure not apparent in the time domain.



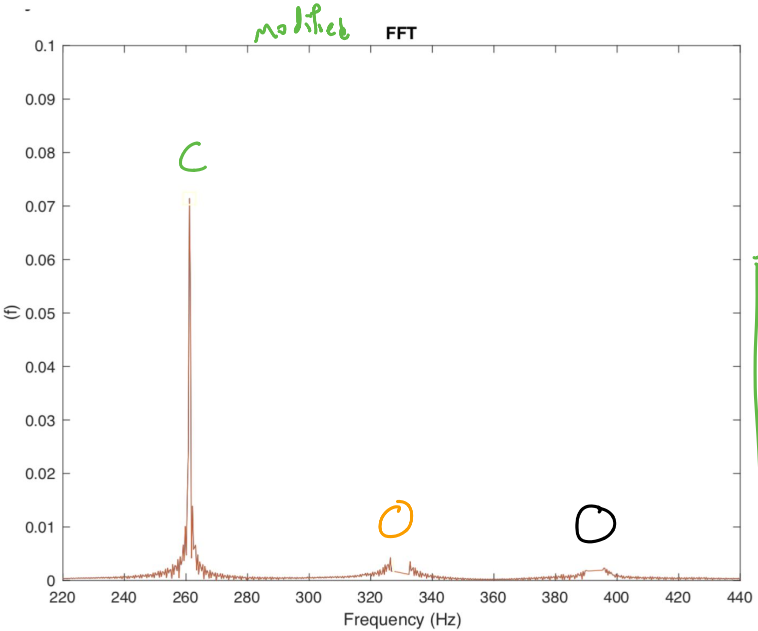
An example of a system

If I could now do operations on this signal representation (i.e., **a system**), I can now do some cool things.



Example of a System

If I could now do operations on this signal representation (i.e., **a system**), I can now do some cool things.



Take an inverse F.T.

$\downarrow$

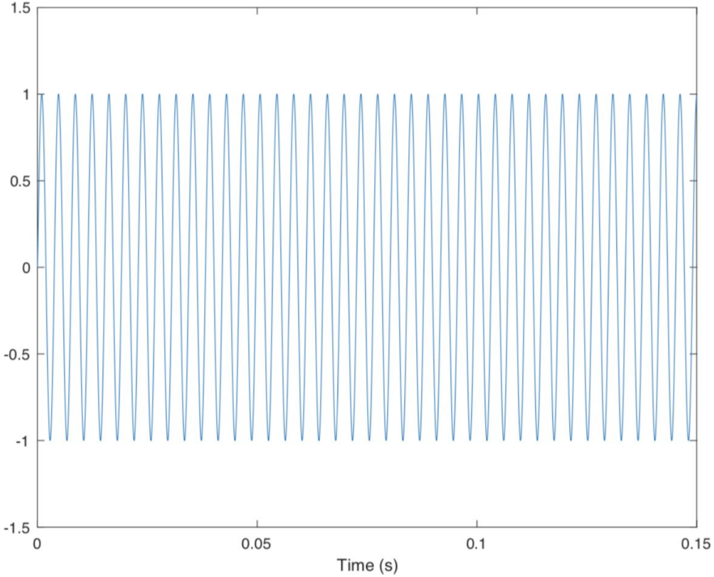
Isolated version of the star singer

$$x(t) \xrightarrow{\mathcal{F}} X(f) \xrightarrow{\text{thresh.}} \tilde{X}(f)$$

$$\downarrow \text{IFT}$$

$$\tilde{x}(t)$$

If I could now do operations on this signal representation (i.e., **a system**), I can now do some cool things.

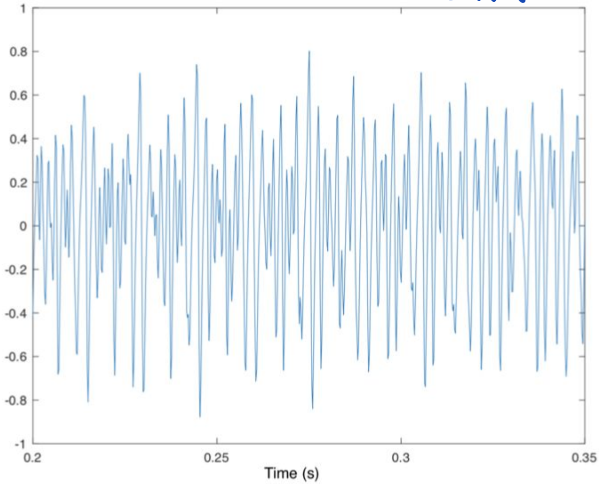


Isolated C note

What we did to the complex signal

Filtering

Impossible to isolate C contribution.

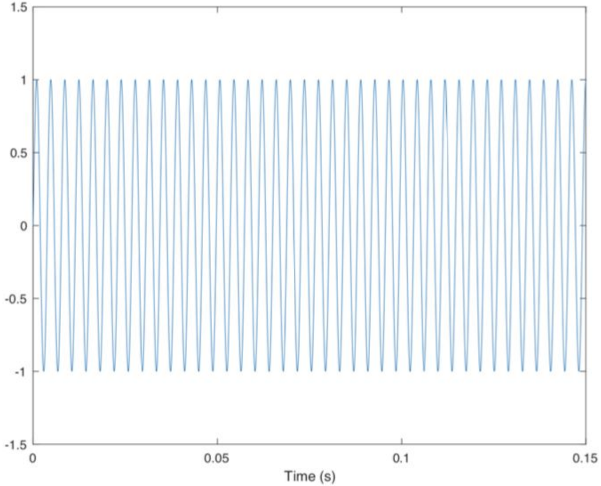


C + E + G + Noise

System

"Filtering out E and G" in the freq domain

Isolated Signal



C

we talk about music, we talk about sine waves with frequencies of **Hertz**.

ave all heard "Hertz" before.

adio: Radio stations are frequencies (like 800 kHz).
adio: Radio stations are frequencies (like 106.1 MHz).

FCC

ATT: 900 MHz

WiFi: 2.4 GHz
5 GHz

4G LTE: 1.9 GHz

Wireless Technologies

- Several technologies that rely on **wireless communication** have become a part of everyday life.

Wireless Technologies and EE 102

It would not be an exaggeration to say that wireless communications could not exist without the material we will learn in EE102.

Do sine waves generalize?

Where are sine waves outside of music?

** The sine example is clear for music

** But a lot of signals in real life don't look like sine waves.

** So how is this relevant?

Take-home Message of this Class

One of the great secrets of the Universe

Every signal has a spectrum and is determined by its spectrum. You can analyze the signal either in the time (or spatial) domain or in the frequency domain. I think this qualifies as a Major Secret of the Universe.

- Prof. Brad Osgood, Stanford University

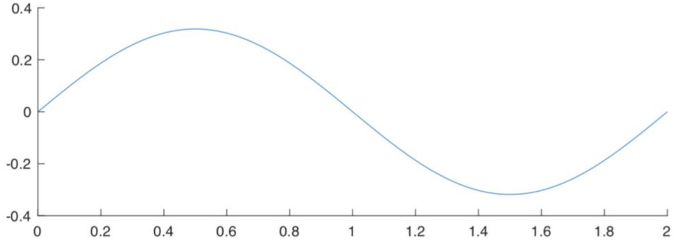
Sine waves apply to diversity of signals!

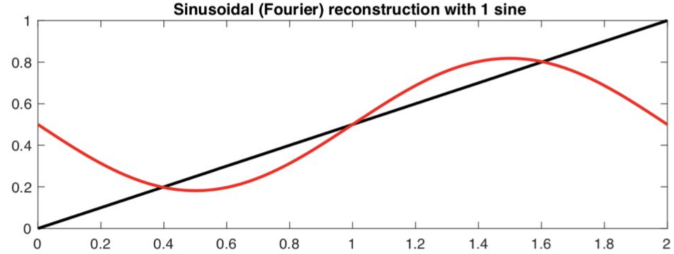
$\| \cdot \|_2^2$

An illustration of where sine waves fit in

- One thing we do constantly run into are straight lines.
- Can we make a straight line out of sines?
- Let's try below. If we get one sine wave (red) to reconstruct the straight line (black), we obviously don't do a good job.

Approximation Error: $\| x(t) - \hat{x}(t) \|_2^2$





$x(t)$

$\hat{x}(t)$

Sine waves apply to diversity of signals!

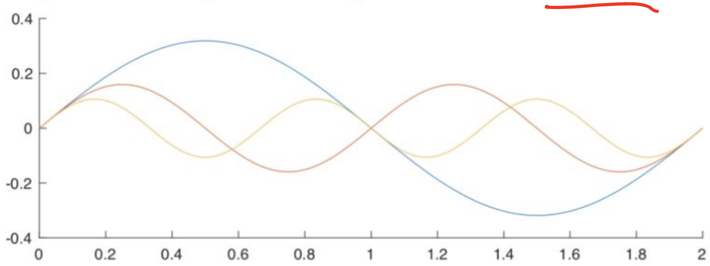
An illustration of where sine waves fit in

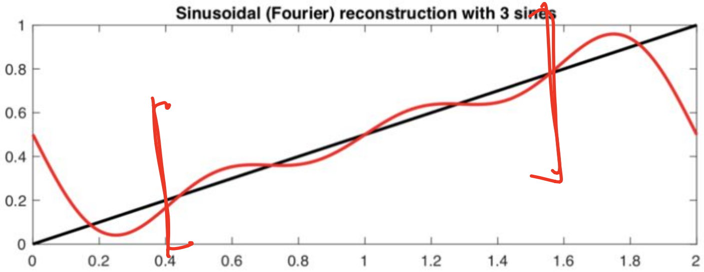
- What if we get to add together multiple sine waves? Say 3?

3

Sine

waves



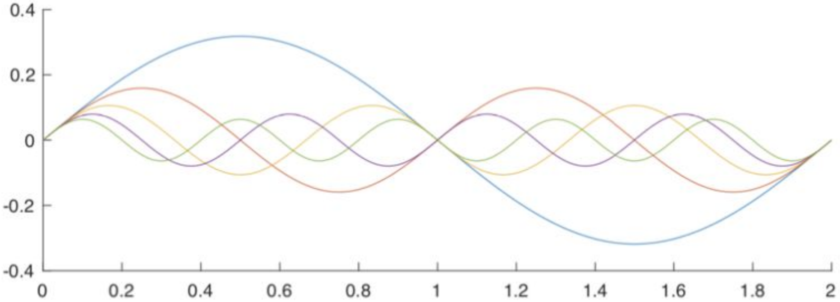


- We can see we're already starting to do better.

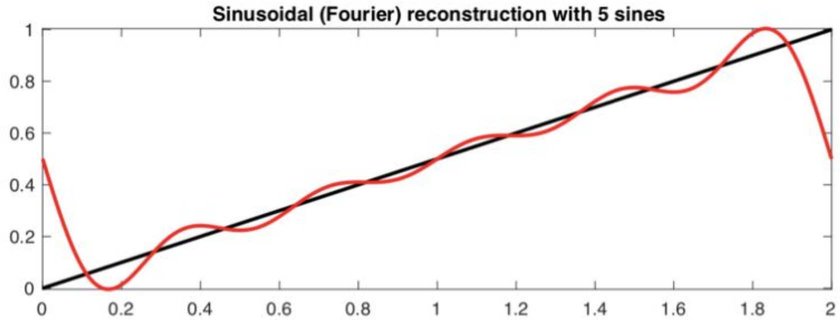
Sine waves apply to diversity of signals!

- Reconstruction with 5 sine waves.

5 sine wave



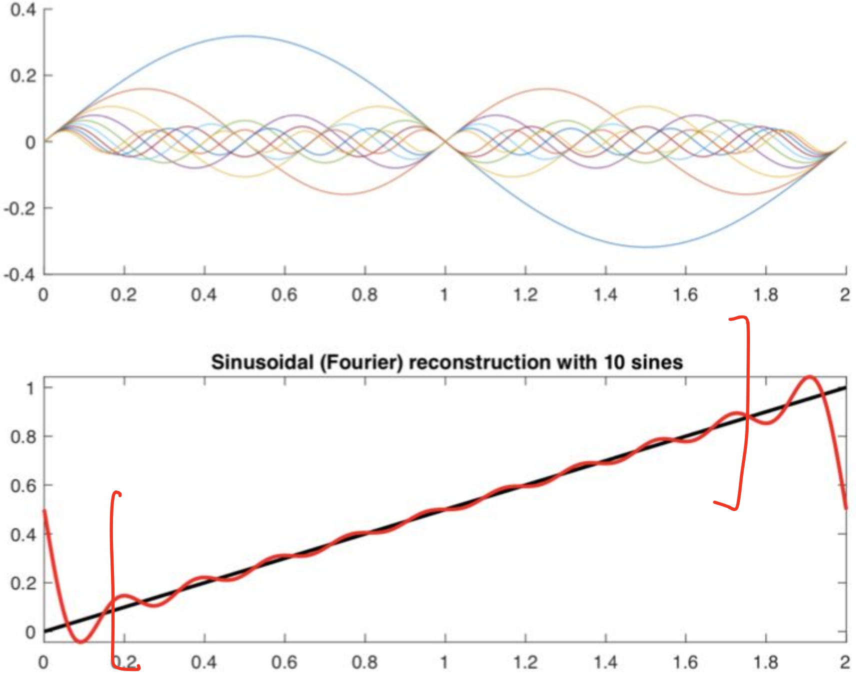
Even Better



Sine waves apply to diversity of signals!

- Reconstruction with 10 sine waves.

10

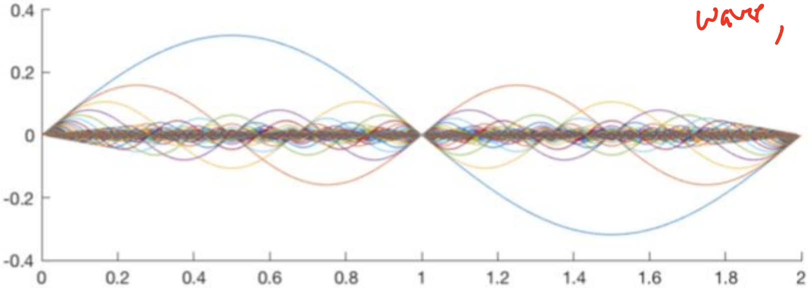


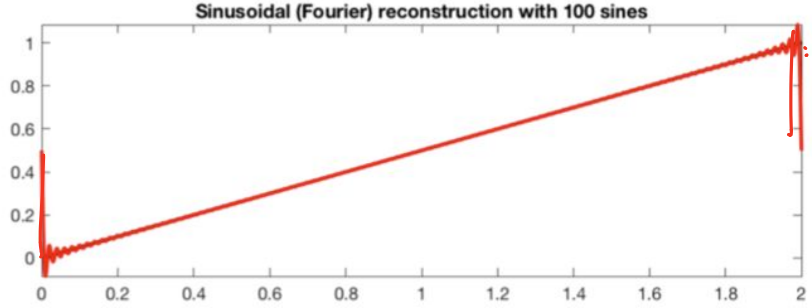
Sine waves apply to diversity of signals!

- Reconstruction with 100 sine waves.

Take-home: With enough sine waves, we can reconstruct any signal.

100 sine waves





But what about other signals?

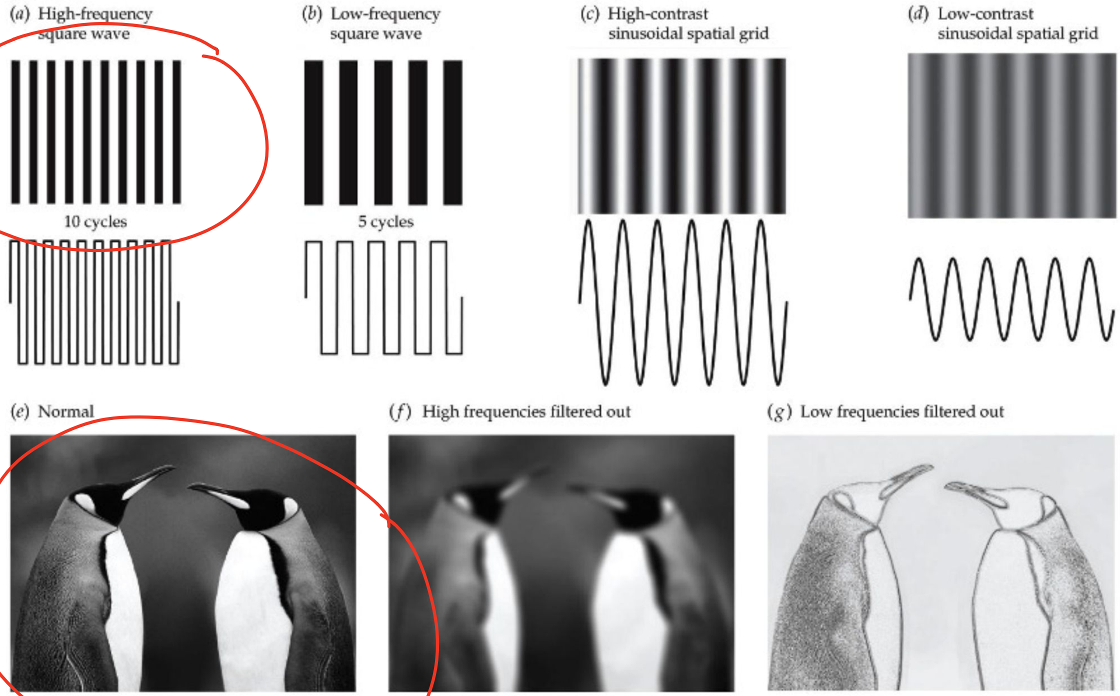


Figure 1 Spatial Frequencies

Figure from Watson and Breedlove Mind's Machine 2nd edition

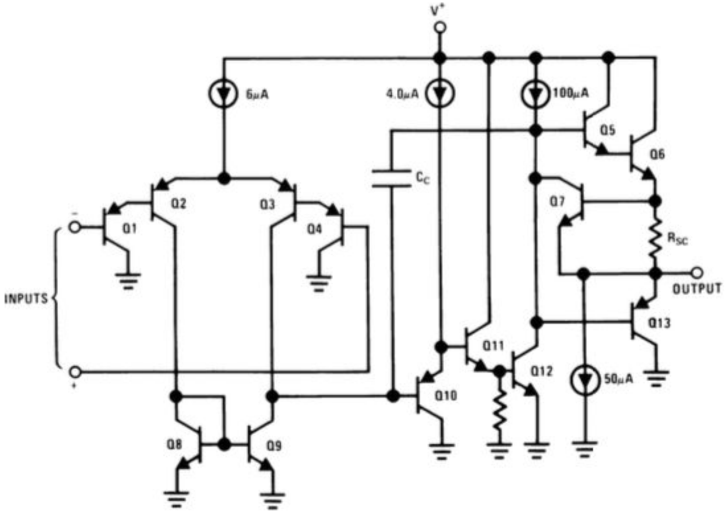
But what about other signals?

Bottom line

- Once we understand the mathematics of how to create things with sine waves (frequency domain or spectrum), we can do very powerful operations. This is the basis for many technologies that we may (sometimes) take for granted.

Applications of Signals

The design of analog circuits



Magnetic resonance imaging

Nobel Prize Jerome Singer

Applications of Signals (Cont’d)

Traditional control systems

Mixing music

Applications of Signals (Cont'd)

My research

Virtual Reality and Augmented Reality (VR/AR/MR)

Display: Signal

Brain: System

Computational Photography

Punchline: Signal Processing (SP) is Ubiquitous

- We interact with systems that use this kind of math every day.

- SP is an area of math that is well-developed, and has precise analytical solutions for many problems.

- SP provides a way of thinking about how to:

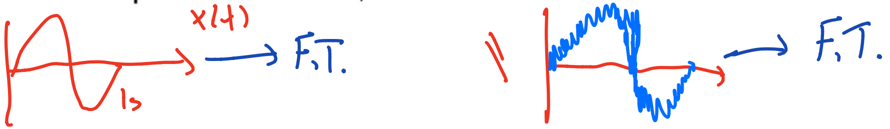
    Interpret and find structure in signals.
    Encode and decode information.
    Manipulate information (e.g., transmit them over WiFI)

- SP will lay the foundation for many future endeavors in EE and other applications. e.g., I know many biologists, doctors, engineers, mathematicians who must learn this stuff for their job.

Ripe opportunity for further study

Signals can get more complicated

The following topics are beyond the scope of this class, but these are still worth mentioning.



Noisy signals:

- In this class, we will work with *deterministic* signals, which means that at every point in time, we know the *exact* value of the signal.
- But in real life, signals have noise. Thus, they have a *random* component, and their values at a given time cannot be exactly known. This is described by probability theory, e.g., ECE 131A.

Multivariate signals: $x(x_1, x_2, x_3 \ldots)$

- In this class, we will work with signals that are *univariate*, which means the value of the signal at every point in time is a scalar (or real value). $x(t)$
- In real life, signals are sometimes *vectors*, meaning that the signal is multi-dimensional. This is described by linear algebra.

My own research

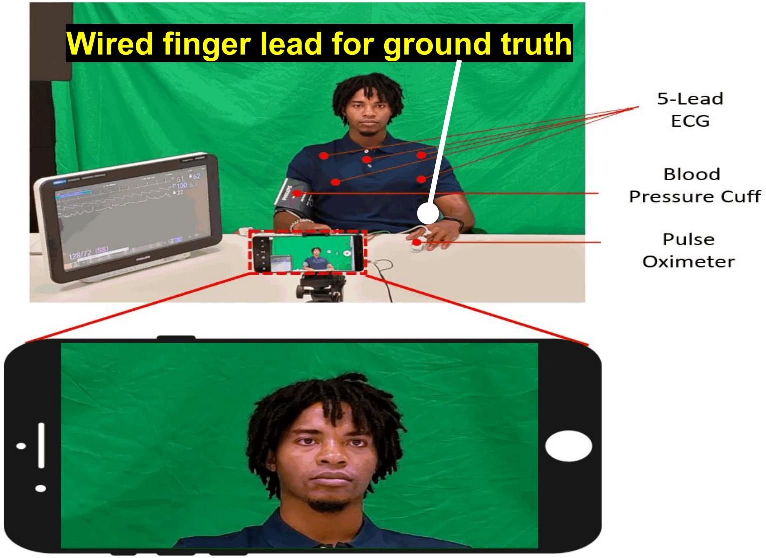
I use signals and systems nearly every day in my research

$$
\begin{aligned}
c_{r,i*\varphi*\xi}[\tau] &= (r \otimes (i * \varphi * \xi))[\tau] \\
&= \underbrace{(r \otimes i)}_{\zeta[t]} * \varphi * \underbrace{\sum_{k=0}^{K-1} \alpha_k \delta[\cdot - t_k]}_{\text{Sparse Environment Response}} \\
&= \zeta * \varphi * \sum_{k=0}^{K-1} \alpha_k \delta[\cdot - t_k].
\end{aligned}
$$

Signal processing on light

Wireless HR through Cell Phone Video on Dark Skin

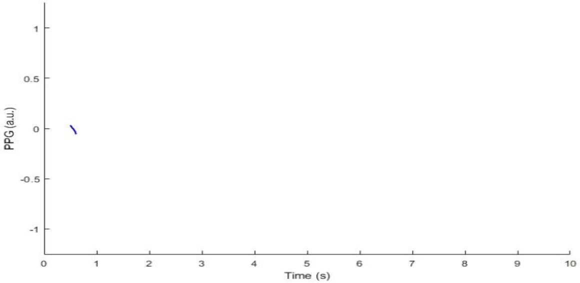
Traditional setup requires <u>multiple wearable devices</u>



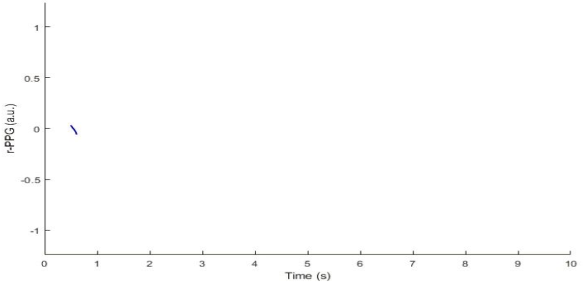
Proposed method requires <u>only a smartphone camera</u>

Video from Consumer Device: Samsung S10

Ground Truth HR: 55 bpm



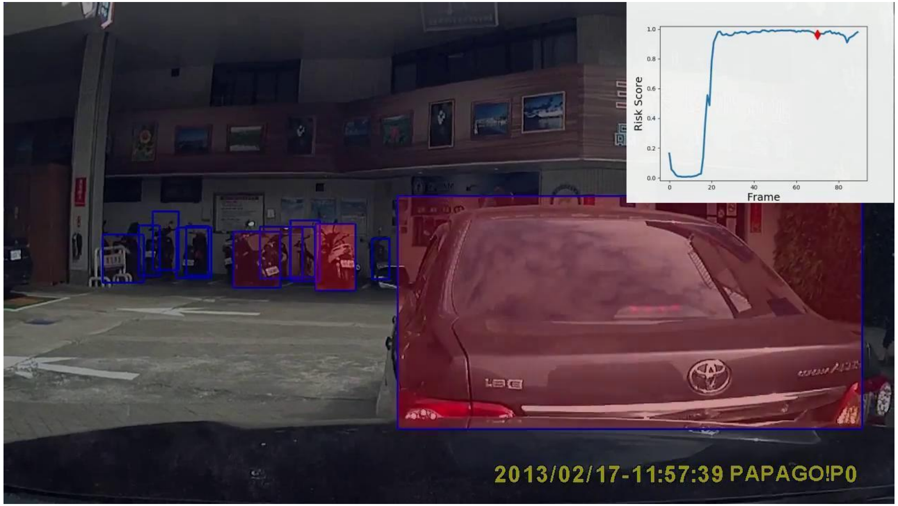
Predicted HR: 57 bpm



My own research

I use signals and systems nearly every day in my research

Example: Predicting Car Accidents Before they Happen



My own research

I use signals and systems nearly every day in my research

Example: Predicting Car Accidents Before they Happen

Class Administration

Lectures with New Material

There are 17 “new concept” lectures for the course.

Live Tues/Thurs of Each Week and uploaded shortly after

Except for 4/29, ~~5/25~~, 6/3

E2

E1

Two Review Lectures

There are two short pre-recorded synthesis lectures on exam weeks.

Grades

Grade Structure: Letter grades assigned based on:

Exam 1	30%
Exam 2	40%
Homework	20%
Participation	10%
80% Evaluations	0.5 Bonus Point (Off-Scale)

Weekly Mindset to our Grade Structure

Schedule of Graded Assessments: A quarter has ten weeks. Setting aside the first week, each of the remaining nine weeks has a milestone that contributes to your grade. Exams occur in weeks 5 and 10; problem sets are due in weeks 2,3,4,6,7,8,9.

Exams

There are two exams

- **Exam 1 4/29**
- **Exam 2 6/3**

Exams are 24 hour take-home and released at 8am PT on the day of the exam, and due at 8am PT the following day. Exams are cumulative

Problem Sets

7 problem sets

Psets are more difficult than lectures. Please balance your time accordingly.

Pset 1: OUT: Friday 4/2	DUE: Friday, 4/9
Pset 2: OUT: Friday 4/9	DUE: Friday, 4/16
Pset 3: OUT: Friday 4/16	DUE: Friday, 4/23
Exam 1 on 4/29	
Pset 4: OUT: Friday 4/30	DUE: Friday, 5/7
Pset 5: OUT: Friday 5/7	DUE: Friday, 5/14
Pset 6: OUT: Friday 5/14	DUE: Friday, 5/21
Pset 7: OUT: Friday 5/21	DUE: Friday, 5/28
Exam 2 on 6/3	

Participation

Due to the pandemic, participation forms 10% of the grade. Participation will be based on:

- **Socrates Lecture**
    - **3-5 students turn on their cameras and mics for lecture and engague in a dialogue about the material. Their questions and answers to the CYU help adjust the cadence of the lecture for the majority.**
    - **Honor system**
        - **Near the end of the class, there is a google form that you will fill if you participated. Honor code applies.**
        - **If you cannot for personal reasons, attend even 1 lecture of this class live (or use your camera for 1 lecture), we will provide full credit for the Socrates lecture. We will trust that this clause is invoked in good judgment and we will not ask for any documentation.**

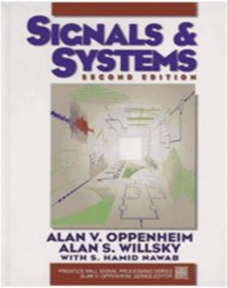
Class Administration

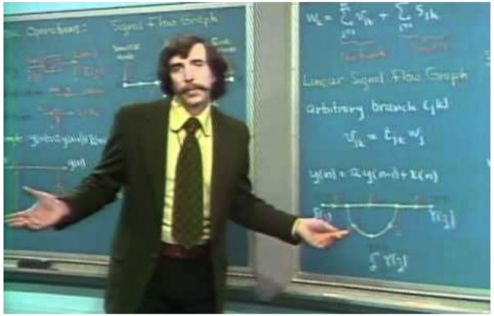
- **Please use Piazza for class discussion.**
  - Speak to the TAs if you are unable to join the Piazza
  - Piazza will be student-driven. Answers will be provided by other students. At the end of term, instructors will assign bonus points to students who provide answers to questions.
  - We cannot always answer emails immediately. For example, if a HW is due in less than 24 hours and you email us, we may be unable to respond.
- **For questions about personal matters (e.g. beyond the 3 late days)**
  - Feel free to email the grader directly.

Class Administration

- **Lecture Slides and Homework are your Main Exam Study Guides**
- **Optional Textbook**
    - Optional for students who would benefit from additional practice.
    - The textbook appears to be available on Amazon Kindle, so take advantage.
- **Optional Videos**
    - youtube.com/watch?v=rkvEM5Y3N60&list=PL8157CA8884571BA2

Signals and Systems
by Oppenheim & Willsky





1975

Class Administration

Rough sketch of topics

Lecture	Topic
1	Class Overview + Signals
2	Signal Operations + Properties
3	Elementary Signals
4	Systems and Their Properties
5	Impulse Response
6	Convolution
7	Fourier Series I
8	Fourier Series II

Lecture	Topic
9	Fourier Transform
10	Fourier Transform II
11	Fourier Transform III
12	Frequency Response
13	Sampling Theorem + Impulse Trains
14	Laplace Transform
15	Laplace Transform II
16	Laplace Transform III
17	[advanced] Multi-dimensional Signals

About your Instructor

- PhD MIT 2018 -> Asst Prof UCLA EE and CS Departments
- Research goal: “teach machines how to see”.
  - Next-gen factory robots
  - Self-driving cars
  - VR/AR/mobile cameras
- My experience is both academic and industrial
- I also teach
  - CS.188 “Intro to Computer Vision”
  - EE.211 “Digital Signal Processing”
  - EE.239 “Computational Imaging”

Lab Webpage: http://visual.ee.ucla.edu

Teaching Philosophy

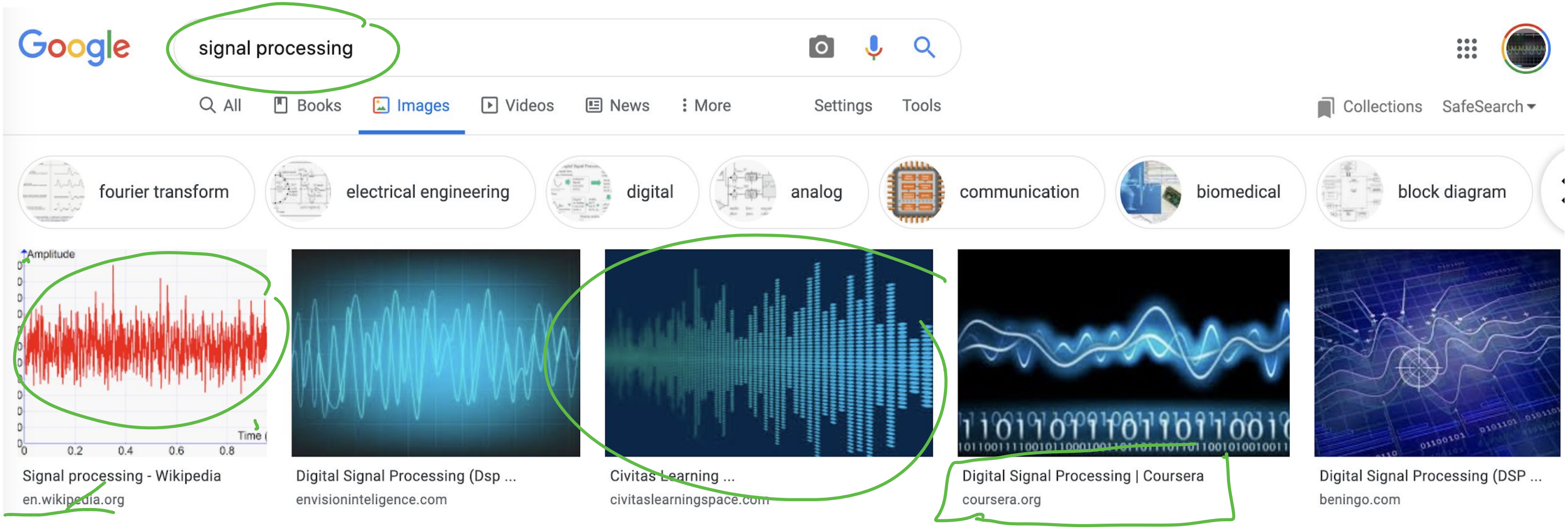
To me, I prefer a *bottom-up* approach: basics before advanced concepts. This class is structured following Prof. Kao's outline. If you take it with Prof. Cabric, she will cover Laplace Transforms earlier, while we cover it in Lecture 14.

I believe lectures and homeworks, if well-designed, are more effective than textbooks. Exam questions are drawn from lectures and homeworks.

Keep an eye out for Check your Understanding (CYU) questions.

Teaching Philosophy

In somewhat of an unusual style, for in-person classes in ECE, I encourage students to *use* phones/computers to scan online resources while in lecture. This should work out better for a remote format where you can pause the video.



Feedback Form

80% feedback for each lecture

Starting Next Lecture