

EE102

Lecture 1

Starts 5' after the hour

EE102: Signals and Systems

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** 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)

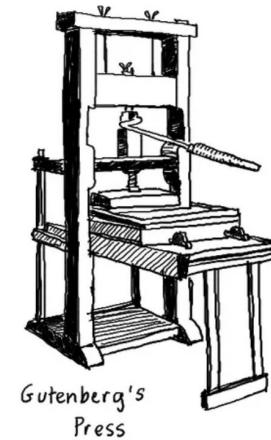
“Signals and Systems” - what is this?

Our world and society relies on our ability to:

**** Capture** Information

**** Represent** Information

**** Act upon** Information



“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:

- ** ~~Capture~~ Information → **Sensing** (learn more in the PWE and CES areas of our Department)
- ** **Represent** Information -> **Signals**
- ** **Act upon** Information -> **Systems**

“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.

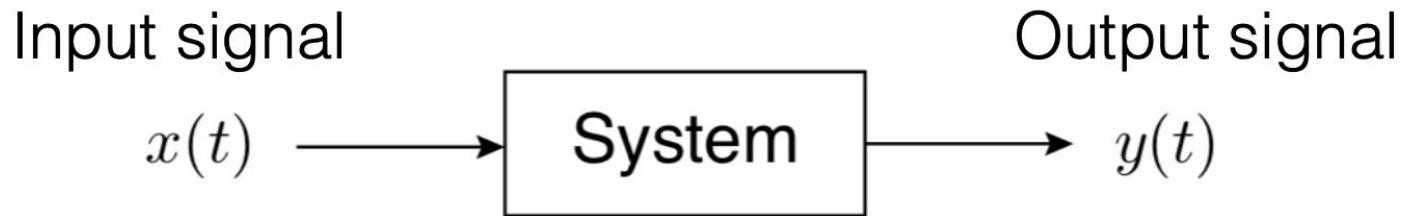
** Anything that changes a signal is a system.

** 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**.

Signals and Systems Block Diagram

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



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

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?

A signal is a function of one or more variables

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:

$$y = f(x)$$

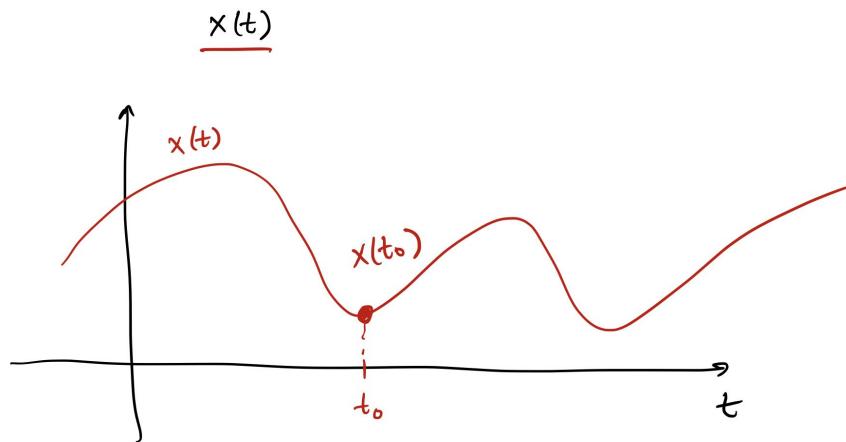
- We usually denote this function as: $f : \mathbb{R} \rightarrow \mathbb{R}$, indicating that f is a function mapping a real number (the first \mathbb{R}) to another real number (the second \mathbb{R}).

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 .

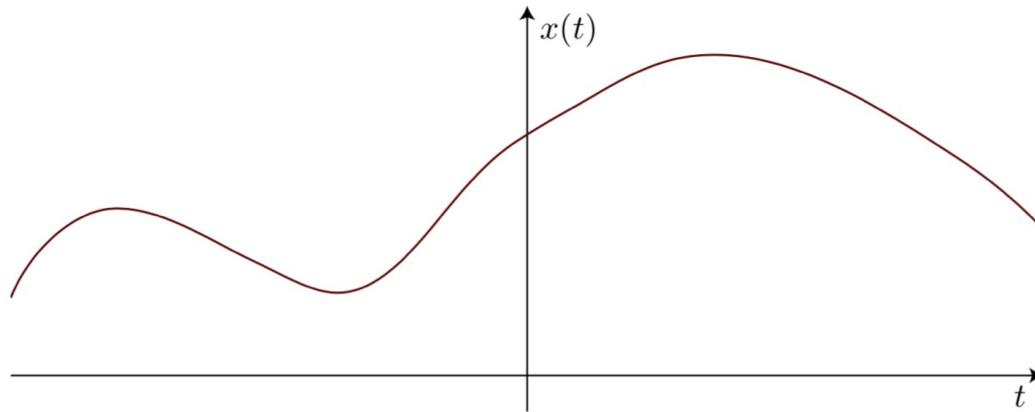


Signals..

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.



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?

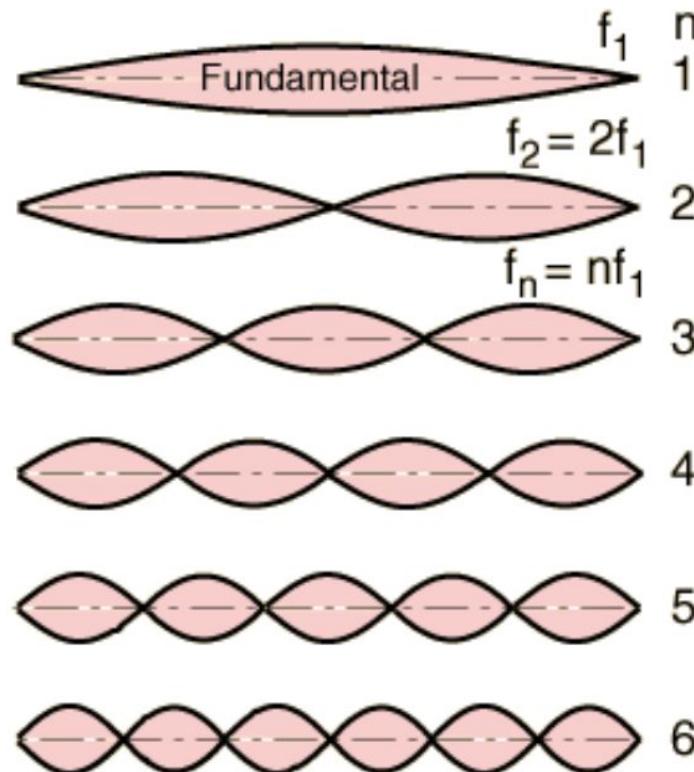
This lecture provides an **overview** of these key concepts - it is okay not to grasp all of it in lecture 1!

Music

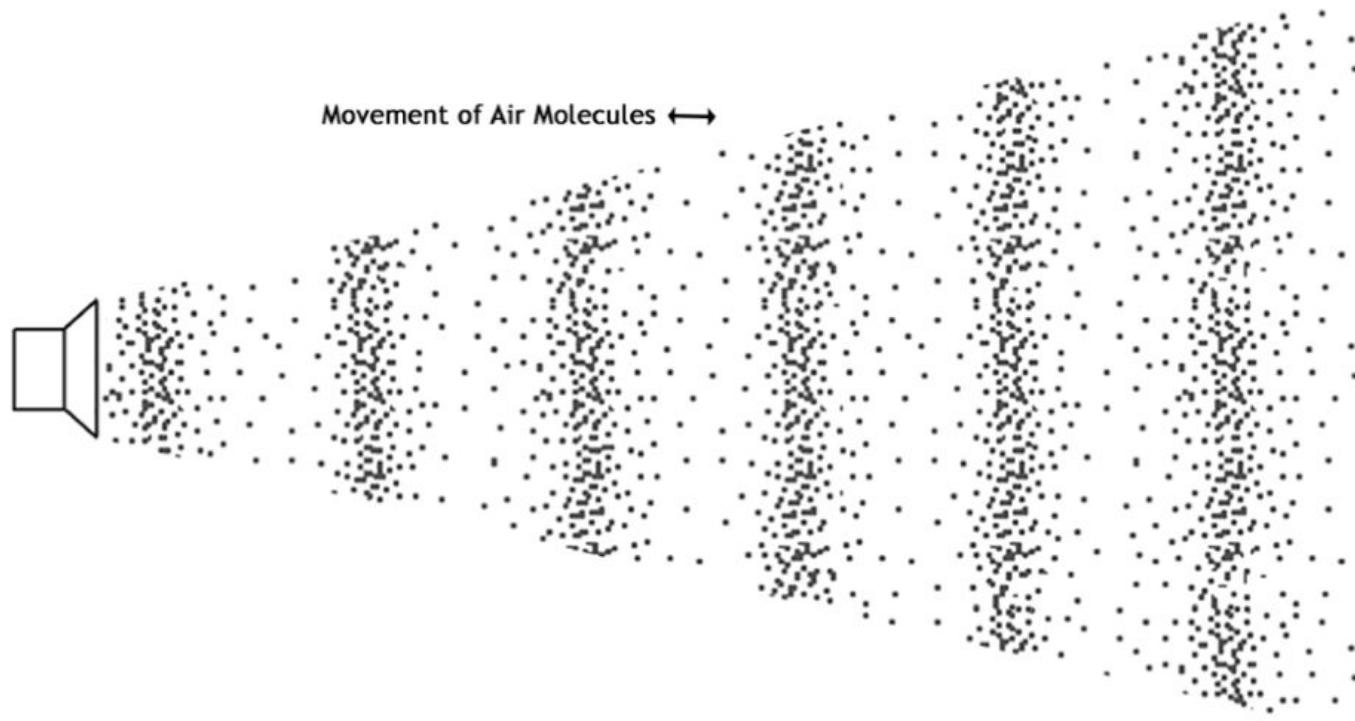


Musical Notes are Sine Waves

Think of this a string

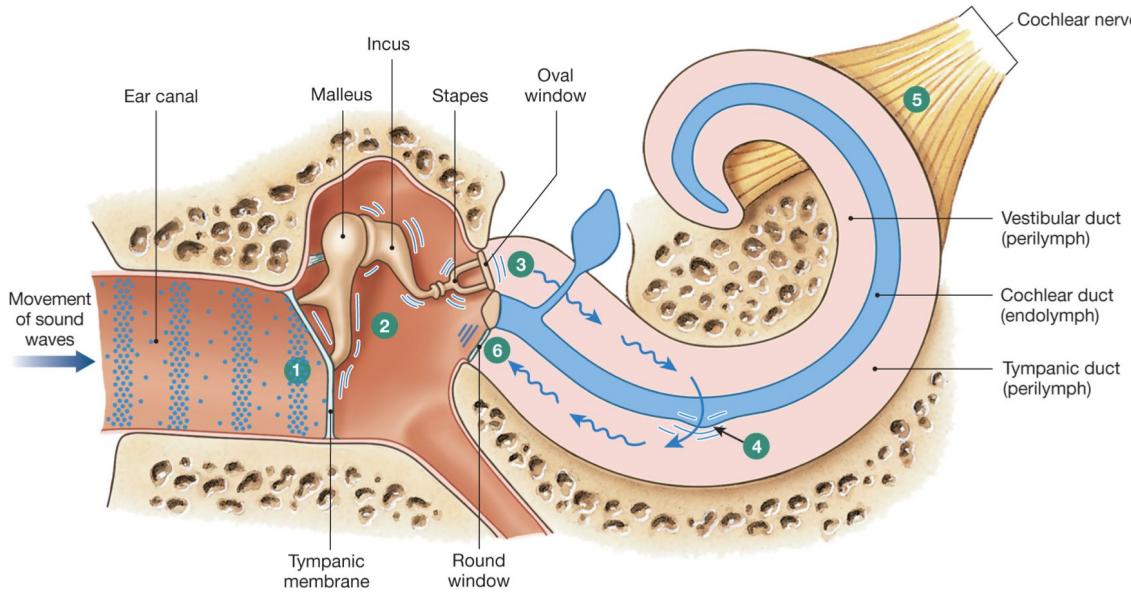


Sound Propagation

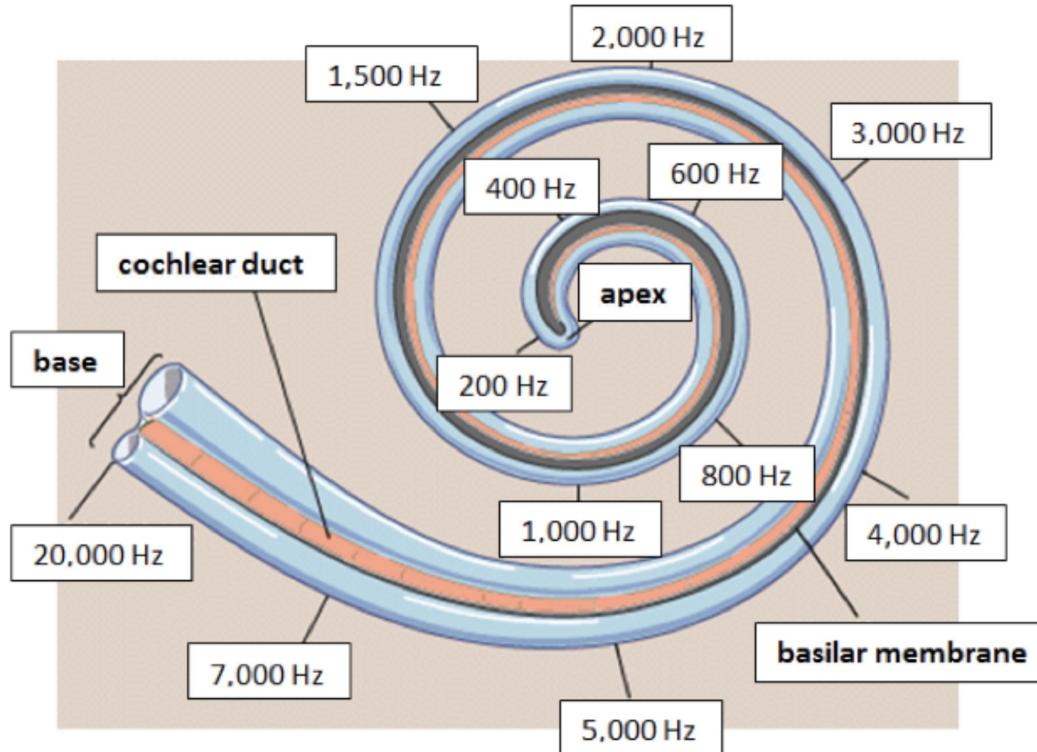


Music

- 1 Sound waves strike the tympanic membrane and become vibrations.
- 2 The sound wave energy is transferred to the three bones of the middle ear, which vibrate.
- 3 The stapes is attached to the membrane of the oval window. Vibrations of the oval window create fluid waves within the cochlea.
- 4 The fluid waves push on the flexible membranes of the cochlear duct. Hair cells bend and ion channels open, creating an electrical signal that alters neurotransmitter release.
- 5 Neurotransmitter release onto sensory neurons creates action potentials that travel through the cochlear nerve to the brain.
- 6 Energy from the waves transfers across the cochlear duct into the tympanic duct and is dissipated back into the middle ear at the round window.



Music

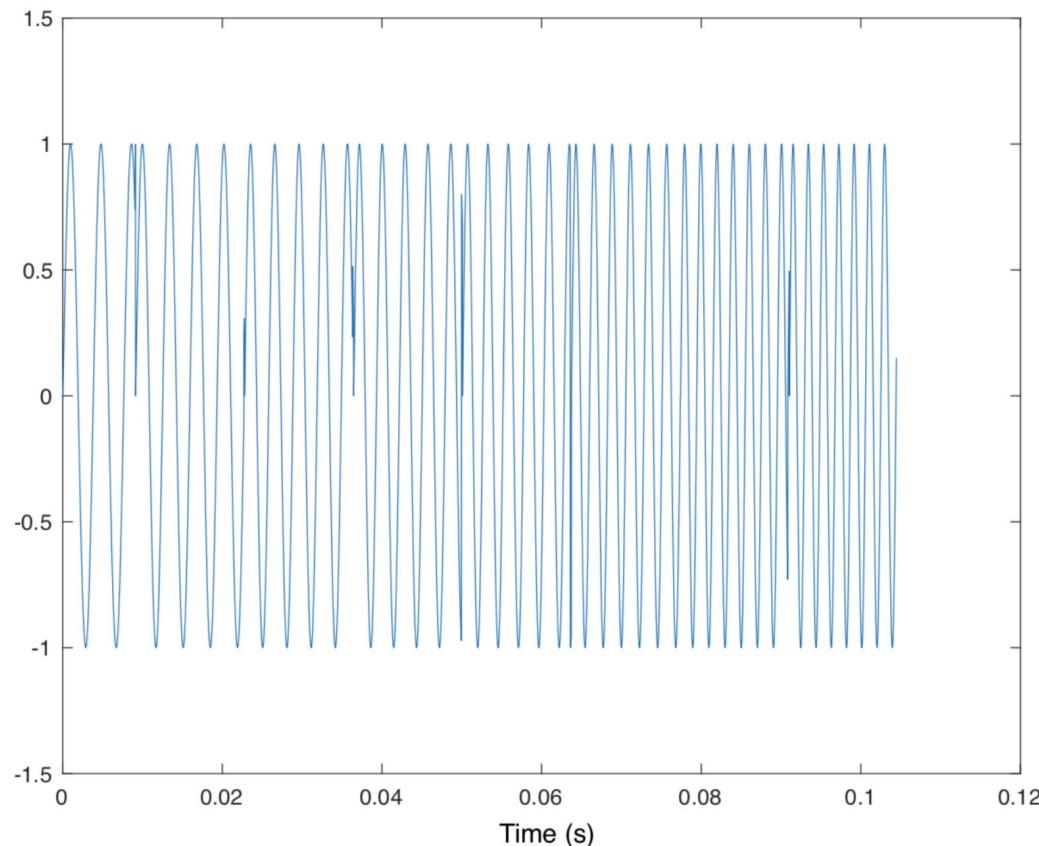


Music

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?



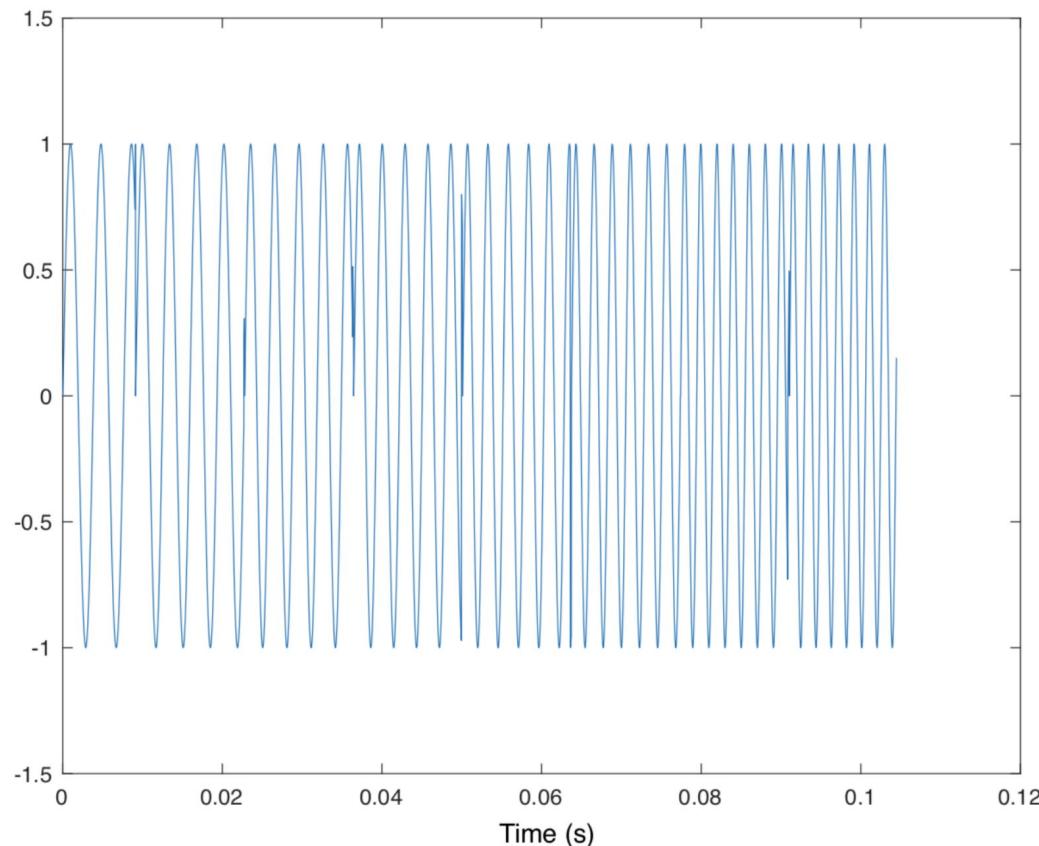
Take-home Message of this Class

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.

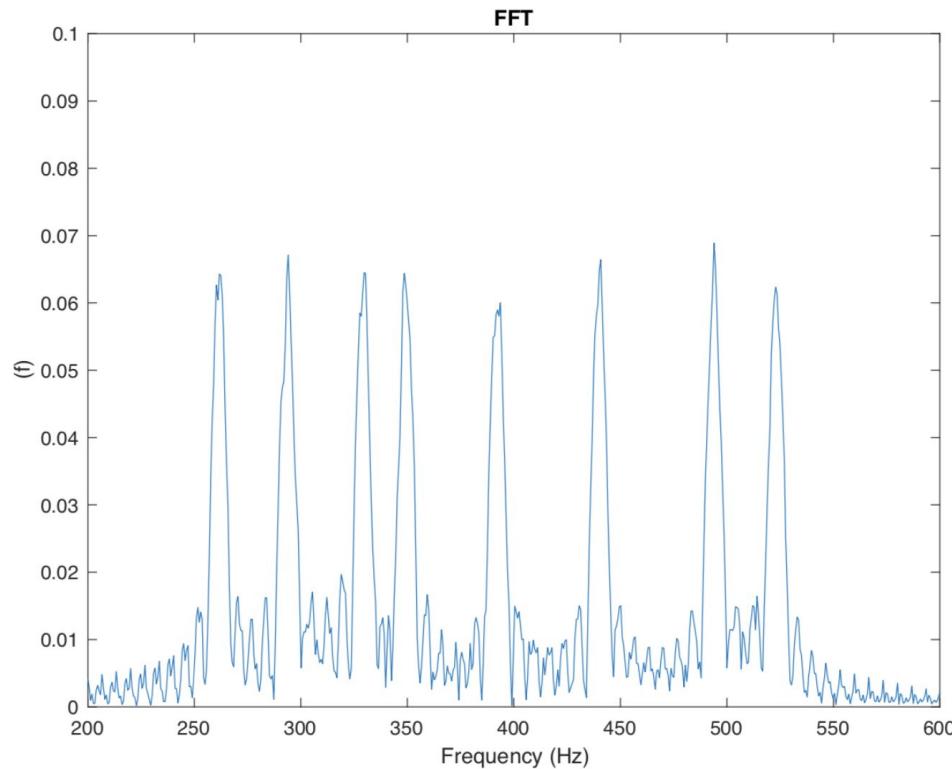
- Prof. Brad Osgood, Stanford University

What is this signal?



Spectral Representation of Signal

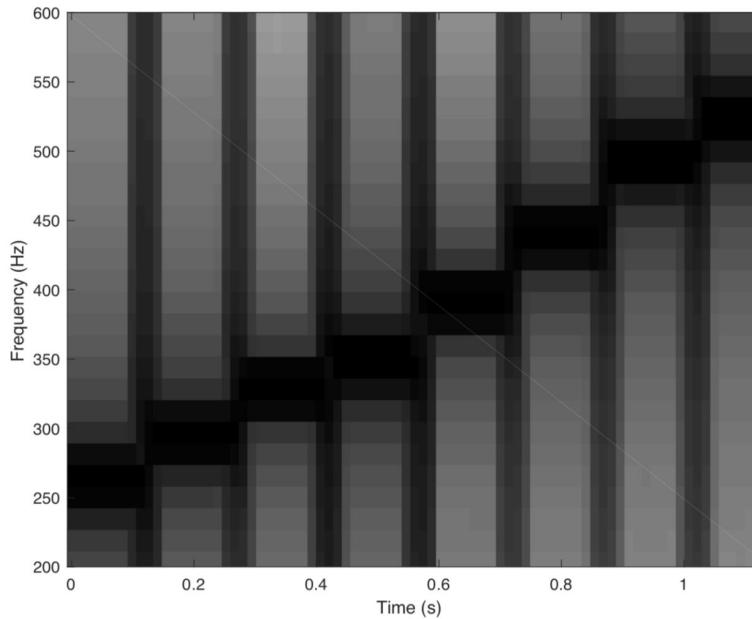
The “Fourier Transform” of this signal.



Spectral Representation

Plotting the spectrum through time

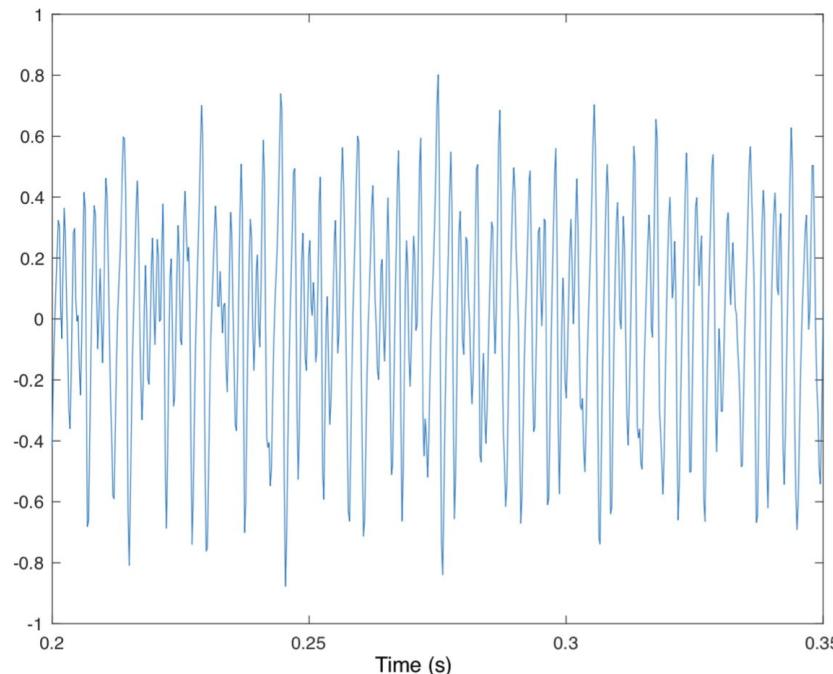
- If we plot a heatmap (where black is the largest amplitude) of the frequency power through time, we see that the frequency increases at discrete jumps, as in a scale.



More complicated signals?

A more complicated signal

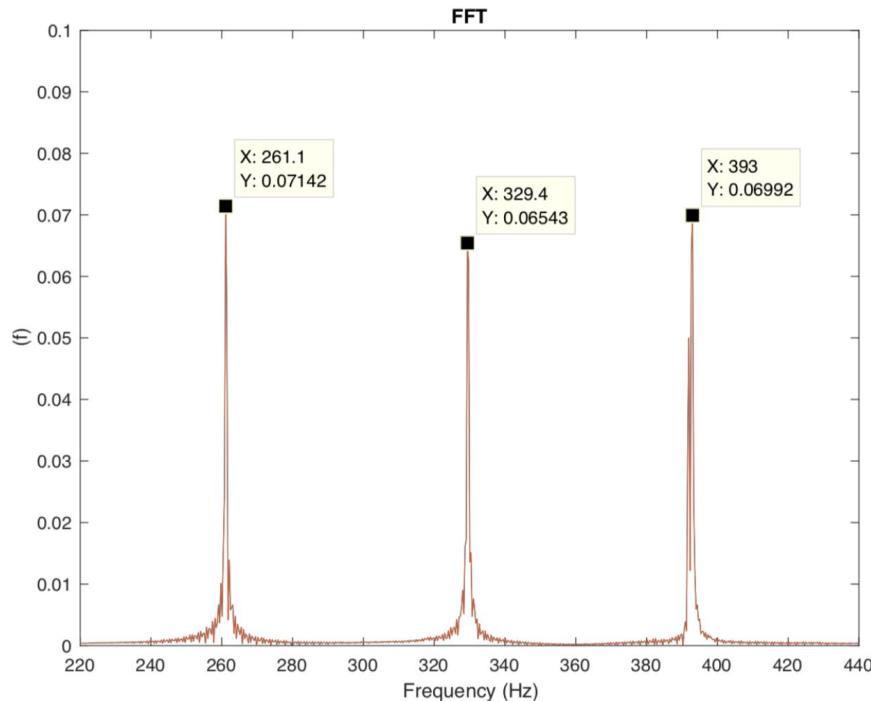
- In our prior example, it was easy to see clear sine waves.
- What about when it's not as clear?



Frequency Domain can Simplify Analysis of Many Signals

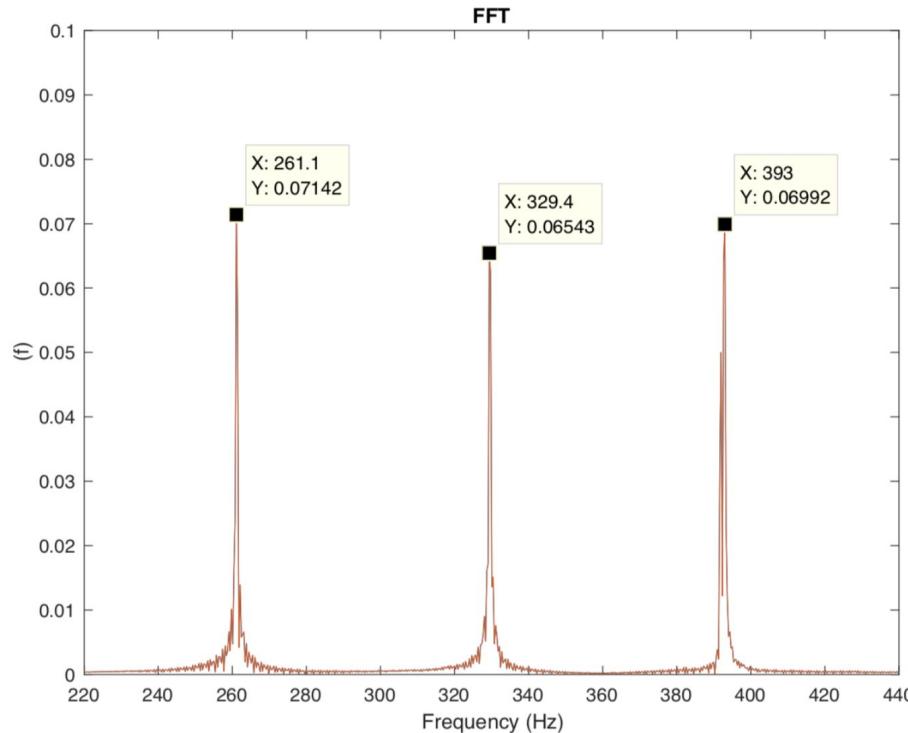
A more complex signal

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



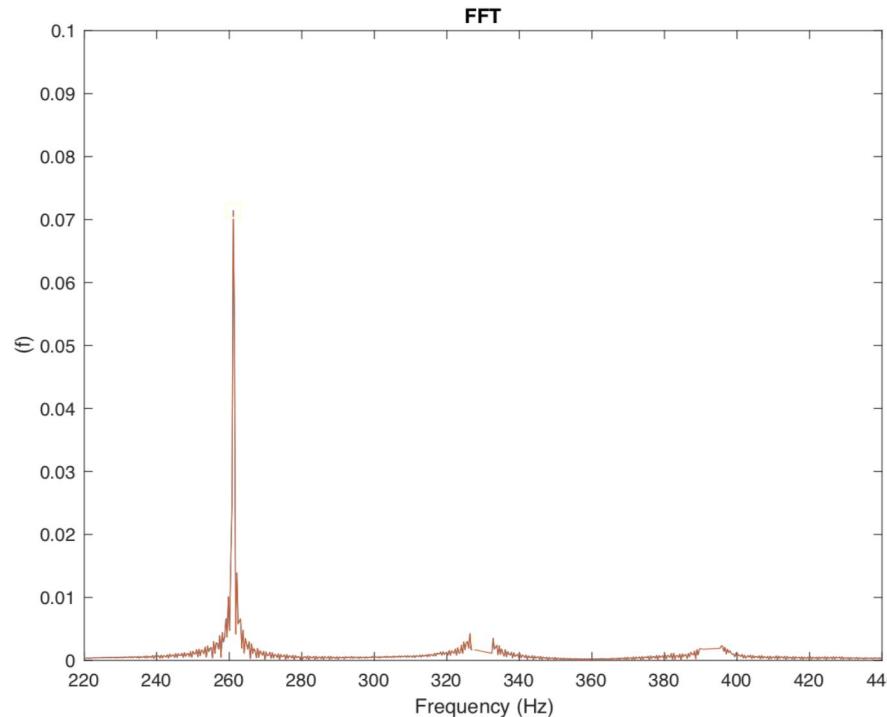
An example of a system

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

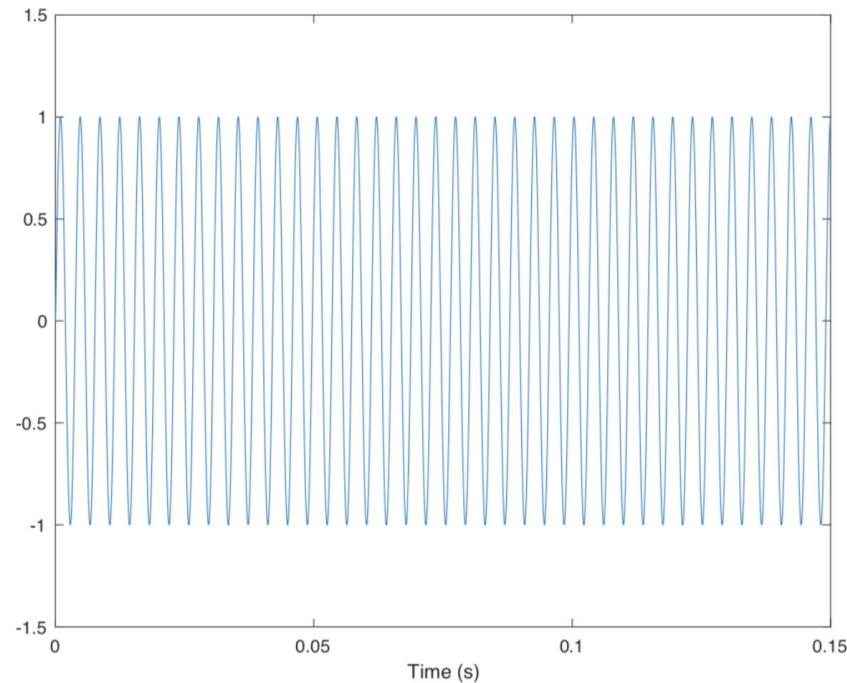


Example of a System

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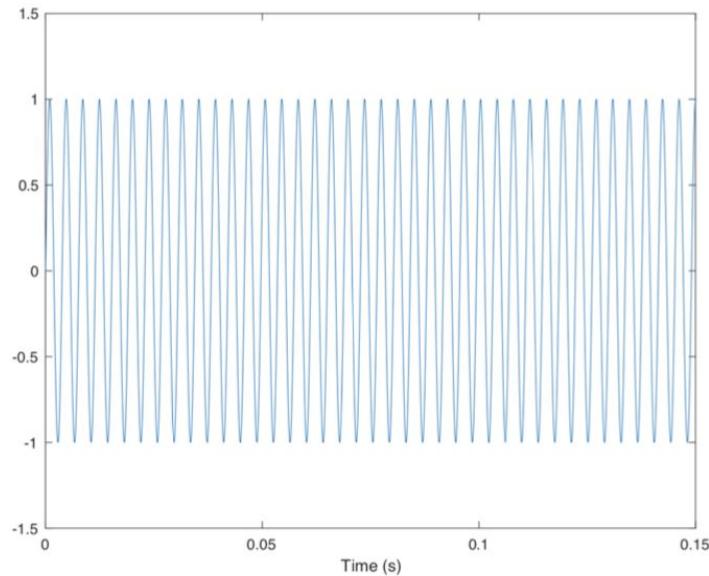
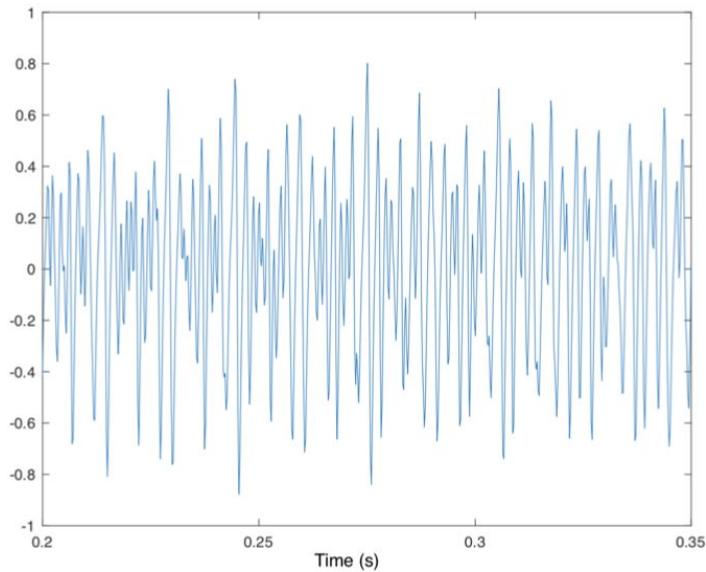


If I could now do operations on this signal representation (i.e., **a system**), I can now do some cool things.



What we did to the complex signal

Filtering



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

have all heard “Hertz” before.

radio: Radio stations are frequencies (like 800 kHz).

radio: Radio stations are frequencies (like 106.1 MHz).



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

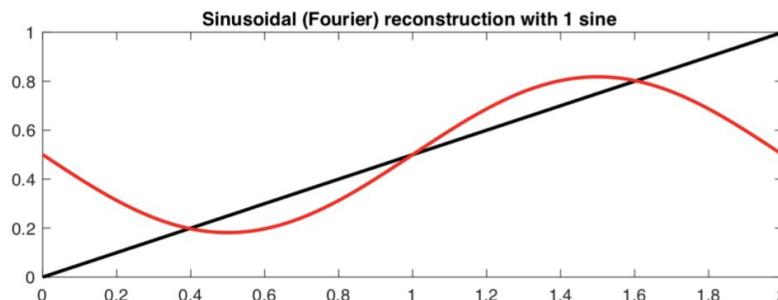
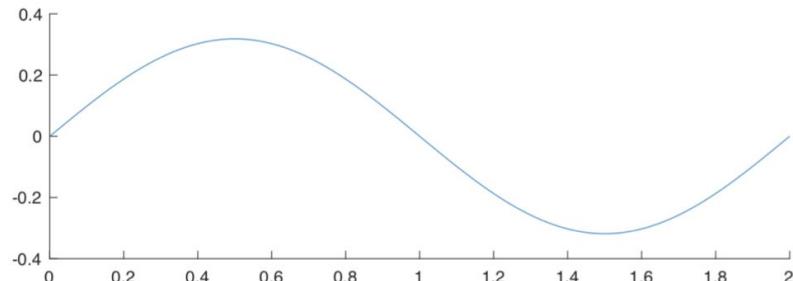
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Sine waves apply to diversity of signals!

An illustration of where sine waves fit in

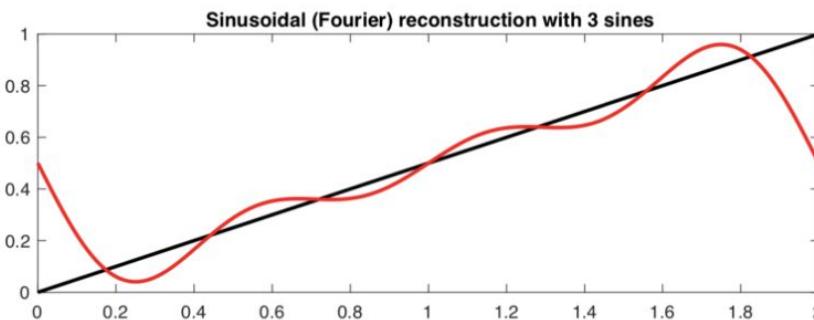
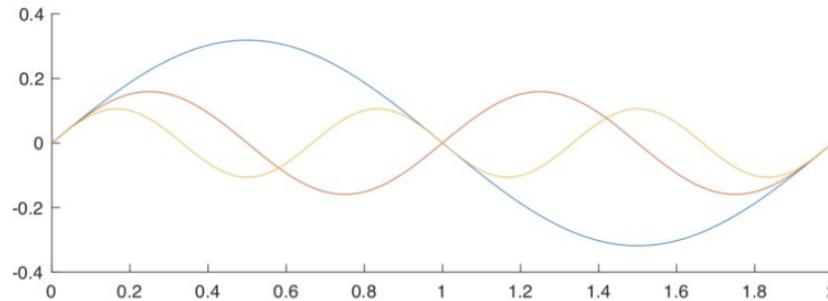
- One thing we do constantly run into are straight lines.
- Can we make a straight line out of sines?
- Let's try below. If we get one sine wave (red) to reconstruct the straight line (black), we obviously don't do a good job.



Sine waves apply to diversity of signals!

An illustration of where sine waves fit in

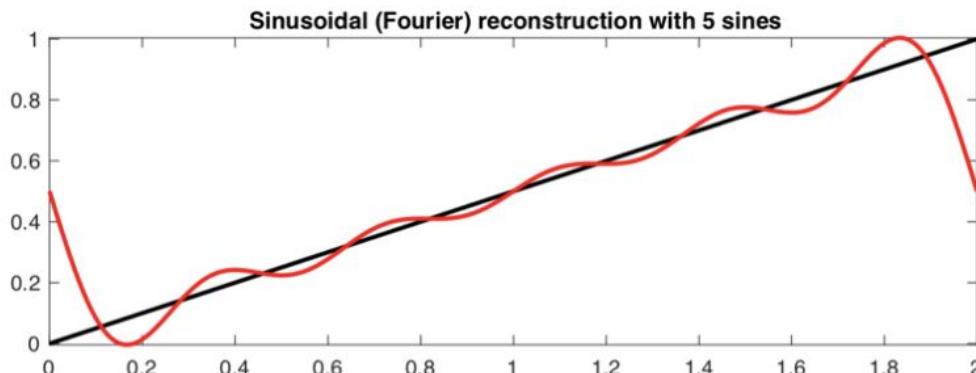
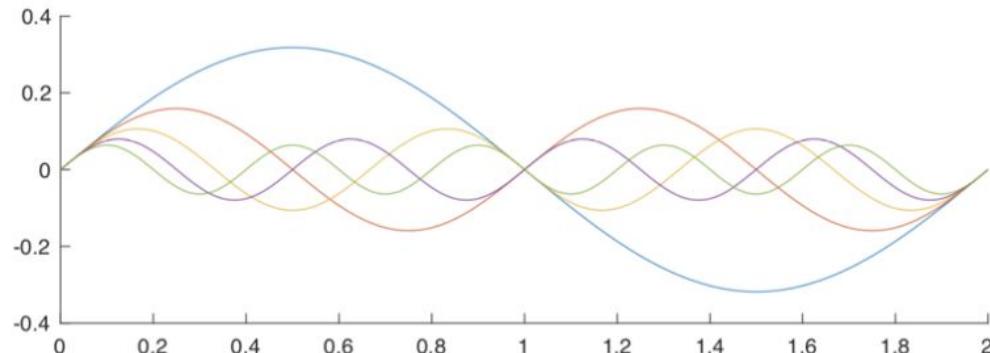
- What if we get to add together multiple sine waves? Say 3?



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

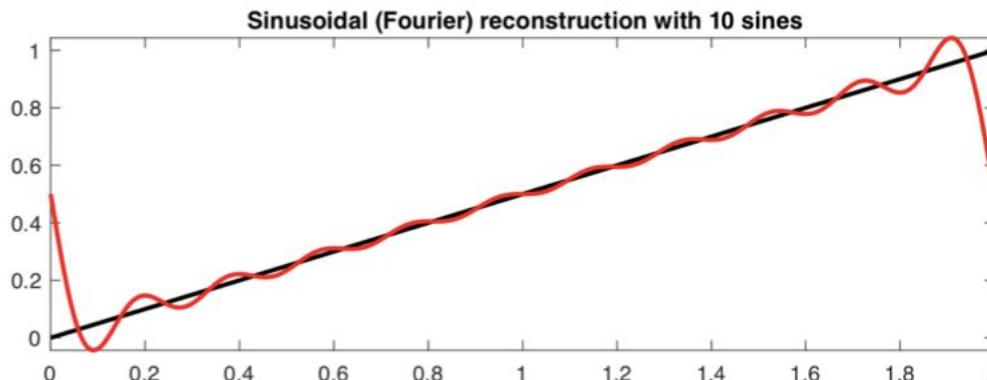
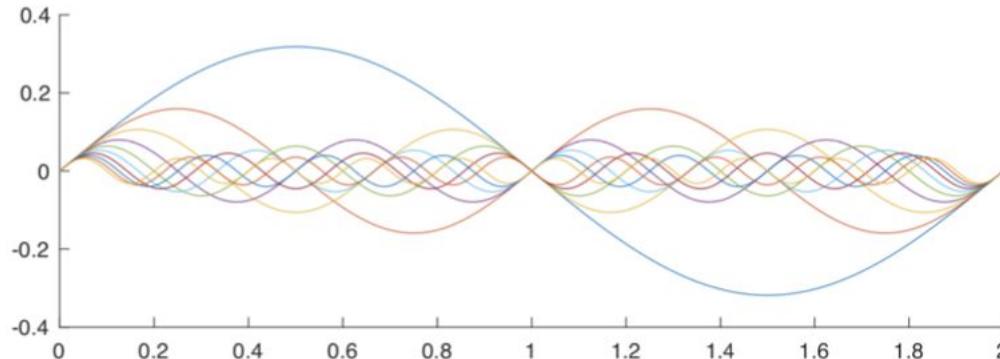
Sine waves apply to diversity of signals!

- Reconstruction with 5 sine waves.



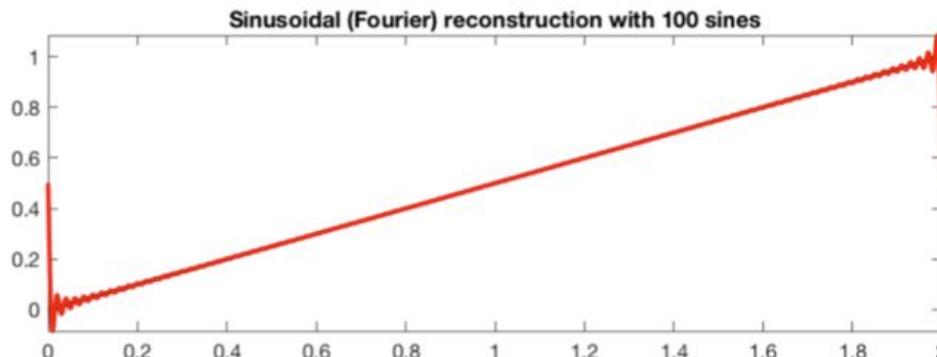
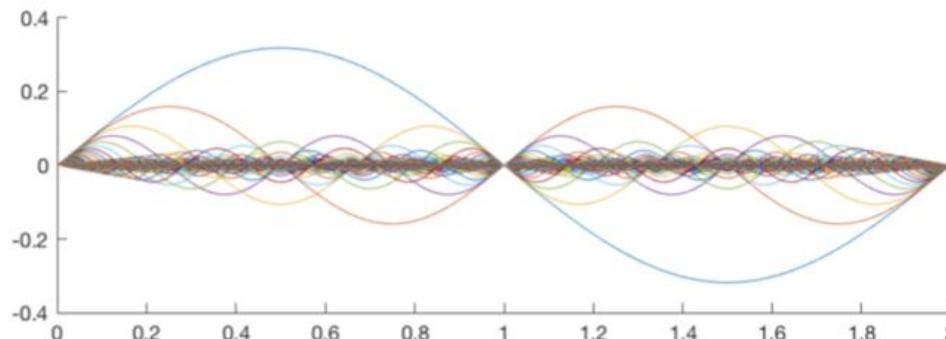
Sine waves apply to diversity of signals!

- Reconstruction with 10 sine waves.



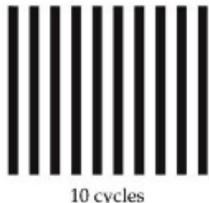
Sine waves apply to diversity of signals!

- Reconstruction with 100 sine waves.

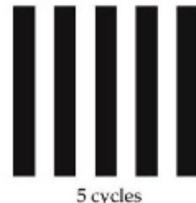


But what about other signals?

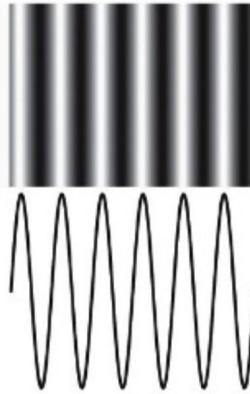
(a) High-frequency square wave



(b) Low-frequency square wave



(c) High-contrast sinusoidal spatial grid



(d) Low-contrast sinusoidal spatial grid



(e) Normal



(f) High frequencies filtered out



(g) Low frequencies filtered out

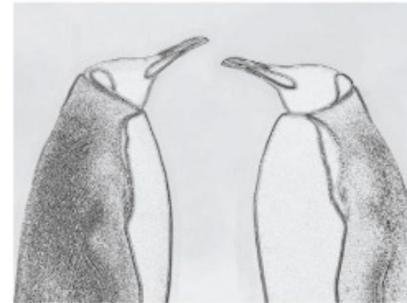


Figure 1 Spatial Frequencies

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

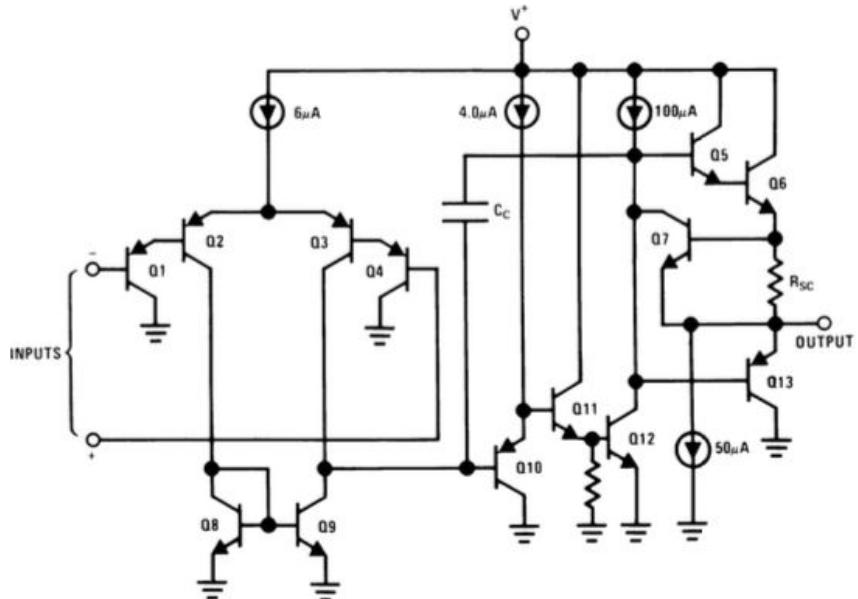
But what about other signals?

Bottom line

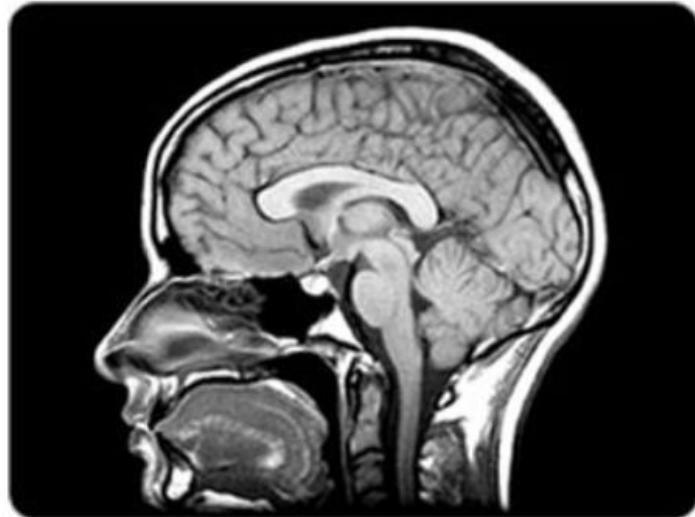
- Once we understand the mathematics of how to create things with sine waves (frequency domain or spectrum), we can do very powerful operations. This is the basis for many technologies that we may (sometimes) take for granted.

Applications of Signals

The design of analog circuits



Magnetic resonance imaging



Applications of Signals (Cont'd)

Traditional control systems



Mixing music



Applications of Signals (Cont'd)



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



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:

- 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).
- 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

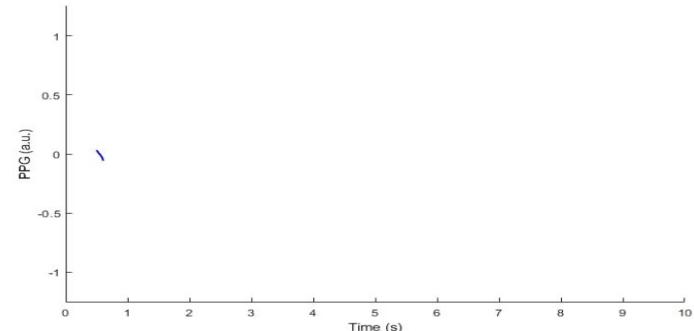
Wireless HR through Cell Phone Video on Dark Skin

Traditional setup requires multiple wearable devices



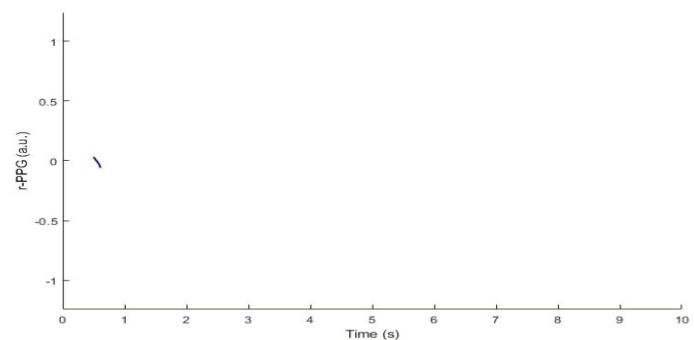
5-Lead ECG
Blood Pressure Cuff
Pulse Oximeter

Ground Truth HR: 55 bpm



Proposed method requires only a smartphone camera

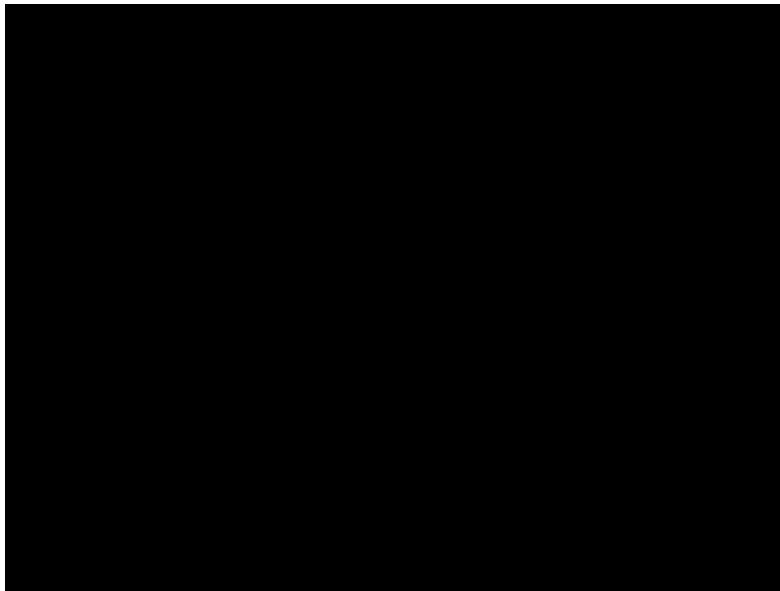
Video from Consumer Device: Samsung S10



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

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 engage 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.

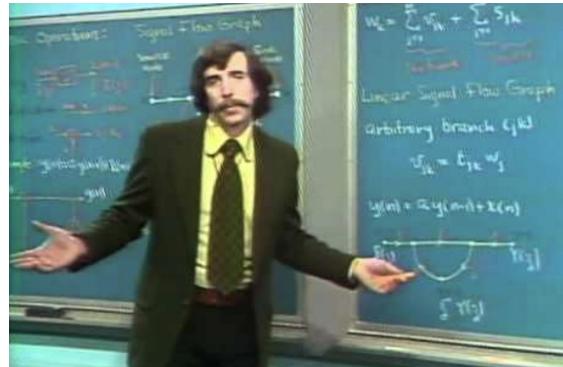
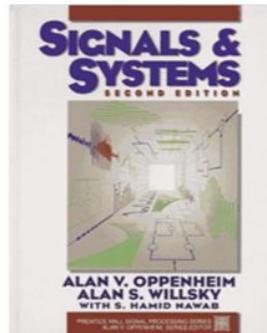
Class Administration

- ❑ **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](https://www.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.

A screenshot of a Google search results page for the query "signal processing". The search bar at the top contains "signal processing". Below the search bar are various navigation links: All, Books, Images (which is highlighted), Videos, News, More, Settings, Tools, Collections, and SafeSearch. The main content area displays a grid of image thumbnails and their corresponding links. The first row includes thumbnails for "fourier transform", "electrical engineering", "digital", "analog", "communication", "biomedical", and "block diagram". The second row includes thumbnails for "Signal processing - Wikipedia", "Digital Signal Processing (Dsp ...)", "Civitas Learning ...", "Digital Signal Processing | Coursera", and "Digital Signal Processing (DSP ...)". Each thumbnail is accompanied by its title and a small snippet of text or a URL.

Thumbnail	Title	Link
	fourier transform	fourier transform
	electrical engineering	electrical engineering
	digital	digital
	analog	analog
	communication	communication
	biomedical	biomedical
	block diagram	block diagram
	Signal processing - Wikipedia	Signal processing - Wikipedia
	Digital Signal Processing (Dsp ...)	Digital Signal Processing (Dsp ...)
	Civitas Learning ...	Civitas Learning ...
	Digital Signal Processing Coursera	Digital Signal Processing Coursera
	Digital Signal Processing (DSP ...)	Digital Signal Processing (DSP ...)

Feedback Form

80% feedback for each lecture