ENGR 100-430: Music Signal Processing

Prof. Jeff Fessler (he/him)

W24

1. Team / Course overview
2. Technical part: digital signal processing (DSP) introduction
3. Technical communications part: significance to engineers
   (More introduction to technical communications next lecture)
4. `Julia` introduction (your "lab" for this course) (if time permits)

Part 1: Team / Course overview

Team

Jeff Fessler	Professor; EECS Department, ECE Div.
Philip Derbesy	Lecturer; Program in Technical Comm.
Ella Alhudithi	Lecturer; Program in Technical Comm.
Debrini Sarkar	Instructional Assistant (IA); EE
Zak Kerhoulas	Instructional Assistant (IA); CS/Sound Engineering
Amaya Murguia	Graduate Student Instructor (GSI); ECE

Debrini:  Zak:  Amaya: 

Course information

- Course management tool: Canvas
- Labs, projects, homework, reading questions, schedule, syllabus, ...
- Many of these stored under Google Drive link on Canvas home page
- Submissions to Canvas or Gradescope
- DSP lectures available online in advance for printing / downloading.
  (Printing is optional but recommended unless you have a tablet.)
  In "dsp-lectures" folder on Google Drive
- See syllabus on Google Drive for contact information, office hours, etc.

Course overview

- 50% technical content (DSP)
- 50% technical communications
- Both are equally important to your *grade* and to your future *career* (more later)
- *cf.* old-school way

- 4 problem sets (homework) + HW0 (`Julia` tutorial)
- 3 labs, preparation for:
- 3 projects (2 small, 1 large final team project)
- Final musical signal processiong project (synthesizers / transcribers...)
- 1 midterm in class on Mar. 20; no final exam
- Technical comm.: memos, oral and written presentations, ...

Schedule overview

- Lab 1 begins this week (read ahead!)
- Full schedule on Google Drive
- `Julia` help sess. Tue. Jan 16, 5:30-6:30PM, 1311 EECS (*cf.* HW0, Lab1)
- Planning your week
  - 3 hours of work / week / credit
  - 4 credits $\Longrightarrow$ 12 hours / week
  - 6 contact hours: 3 lecture, 1 discussion, 2 lab
  - 6 hours of work / week outside class (on average)
    - review lecture notes
    - read lab materials *before* lab
    - answer lab / project "reading questions" before start of ***first*** (!) lab section using Canvas "Quizzes." (learning not assessment)
    - prepare lab reports, TC assignments, problem sets, project presentations ...

Schedule specifics: First half of semester

Schedule for Engineering 100-430 Winter 2024
Music Signal Processing

WEEK (Mon-Fri)	MONDAY CLASS*	WEDNESDAY CLASS*	LAB/ PROJ	LAB TOPIC	DISCUSS TOPIC	DUE**	To ***	Points Indiv	Points Team
Jan 8-12	N/A	Goals, Overview	Lab1	Julia &	Intro to Tech. Comm.				
(Wed start)		& Sampling		Sampling	Correspondance				
Jan. 15-19	MLK Day	Measure Freqs	Lab1	Sampling &	CRAP Visual Rhetoric	**Lab 1 reading q**	C	8	
		& Semilog Plots		Sinusoids		**Lab 1 results**	G	30	
	(Julia help Tue. 5:30-6:30PM 1311 EECS)					**Intro Email**	C	20	
Jan. 22-26	Genre Analysis	Project 1 Specs:	Lab2	Measuring	Genre Analysis	**Lab 2 reading q**	C	6	
	Problem Statements	Tone Synthesizer		Music Freqs		**HW0 (Julia tutor.)**	G	10	
		and Transcriber							
Jan 29-	Oral Presentations	FFT &	Proj1	Synthesizer	P1 Rhet Analysis	**Lab 2 results**	G	43	
Feb 2	Ethos+Slides	Spectogram I		Transcriber		**P1 reading q**	C	4	
						HW1 (5pm)	G	10	
						P3 PS Topic Idea	C	10	
Feb 5-9	Finding and using	FFT &	Lab3	Synthesizer	Project 1	**P1 oral**	D	50	
	Sources	Spectogram II		Transcriber	Oral Presentation	**HW2 (5pm)**	G	18	
	Libray Visit					**Lab 3 reading q**	C	4	
						P3 PS Sources	C	10	
Feb 12-16	Written Document	Spectrogram III	Lab3	Spectra and	Employing Evidence	PS Section	C	10	
	Organization (IMRD)			Spectrogram	(Section Peer Review)				
	Document Design								
Feb 19-23	Effective Visuals	Project 2 Specs:	Proj2	Touch-tone	Visuals Practice	**Lab 3 results**	G	50	
		Touch-tone Phone		Project Work		**HW3 (5pm)**	G	12	
						P2 reading q	C	2	
						P3 Problem Statement	C	75	

Second half of semester

Feb 26-	SPRING BREAK								
Mar 1									
Mar 4-8	Team Decision-	Project 3 Specs	Proj3	Feedback on P3	Team Planning	**P2 report/code**	C		50
	Making	git / collab. coding	ideas	project ideas	Documents	**HW4 (5pm)**	G	21	
	Team Writing			(JF and GSI/IA)					
Mar 11-15	PDR Work	Review	Proj3	PDR	PDR	**P3 PDR**	C		50
				(JF and TC and Lab Instr.)					
Mar 18-22	CSED Case Study	**Midterm**	Proj 3	P3 work	Midterm	**DSP Midterm**	prof	100	
		(also 104 EWRE)		subsystems	Reflection	**TC Midterm**	C	100	
						CSED Pre-work	C	5	
Mar 25-29	Memos	Synthesizer methods	CDR	P3/CDR work	Memo Frontmatter	**Practice Memo**	C	15	
	Progress Reports	P3 test/validate		alpha demo	Practice	**Frontmatter**			
Apr 1-5	Formal Reports	Transcriber methods	Proj3	P3 work	Organizing				
	Scoping	P3 help			Final Reports				
Apr 8-12	Exec Summaries	ABR	Proj 3	P3 work	Work	**CDR (Report)**	C		100
	Revising Organization	P3 help ???							
	Work time								
Apr 15-19	Revising for clarity	P3 help	None	Report Work	Th/Fri Disc. P3	**Presentation (Fri)**	C		100
	Work time				Presentations				
					(Rehearse/Record)				
Apr 22-26	Wrap-Up	(Study day)				**Final Report Due**	C		150
	Demos! (Mon)					**3:30 Mon Apr 29**			
	(classes end Tue Apr 23)								
						iClicker	class	37	
*** Topics for class and discussions subject to change.**						course evaluations	G	10	
**** Lab/project 'reading questions' are due 24 hours before each lab begins.**						In-Class TC	D	40	
***** C = Canvas, D = Discussion, G = Gradescope, T = Tandem**						Tandem	T	60	
****** See Canvas/Tandem for Tandem due dates (too many little things to list here)**						TOTAL		700	450

Office hours (from syllabus on gdrive)

Jeff Fessler	Professor; EECS	fessler@umich.edu	4431 EECS	Wed 10:30-11:30AM or appt.
Philip Derbesy	Lecturer; Tech Comm	philipcd@umich.edu	312 GFL	Tues 3:00-5:00 via Zoom (link); Weds 11:00-12:00 GFL 312; or appt
Ella Alhudithi	Lecturer; Tech Comm	alella@umich.edu	324 GFL	Tue 9-10 am & by appt via Zoom (link), Wed 10:40-11:40 am in 324 GFL
Amaya Murguia	GSI; ECE	amurguia@umich.edu		Mon 4-5PM 3312 EECS
Zak Kerhoulas	Instr. Asst.	zkerhoul@umich.edu		Thu 5-6PM 3312 EECS
Debrini Sarkar	Instr. Asst.	debrini@umich.edu		Tue 2:30-3:30 UGLI Maker Sp.

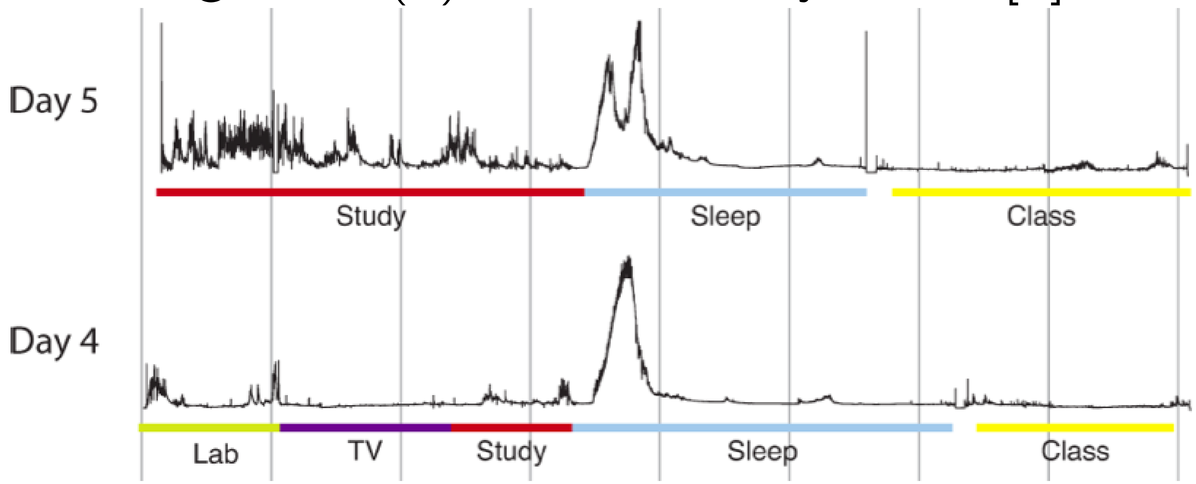
Room Key: EECS = Electrical Engineering and Computer Science Bldg.; GFL= Gorguze Family Laboratory; BEYST=Bob and Betty Beyster Building; FXB=François-Xavier Bagnoud Building; CSRB=Climate and Space Research Building; NAME=Naval Architecture and Marine Engineering; GGBL=G.G. Brown Laboratory

Lectures: Mon & Wed, 9-10:20AM, 1200 EECS

Day	**Lab Sec.**	**Lab Time**	**Lab Instr.**	**Lab Room**	**Disc. Sect.**	**Disc. Time**	**Disc. Instr.**	**Disc. Room**
Thu	431	10:30-12:30	DS	2230 CSRB	432	9:30-10:30	Derbesy	2147 GGBL
Thu	433	1:30-3:30	AM	2230 CSRB	434	12:30-1:30	Derbesy	1690 BEYS
Fri	435	10:30-12:30	ZK	2517 GGBL	436	9:30-10:30	Alhudithi	1025 GGBL
Fri	437	1:30-3:30	AM	134 NAME	438	12:30-1:30	Alhudithi	1045 GGBL

iClickers

- Register and get free iClicker App from https://iclicker.com
- Bring a device (phone, tablet, laptop) with iClicker App to every class.
- Clicker question scoring: 2 points for answering, 3 points for correct answer. (Learning, not assessment.)
  Clicker scores in the 1st week of class do not count towards grade.
  Prorated to about 3% of total score at end of term (≈1/3 letter grade)
- Why? From M Poh, M Swenson, R Picard: "A wearable sensor for unobtrusive, long-term assessment of electrodermal activity." IEEE Tr. on Biomed. Engin., 57(5):1243-52, May 2010. [1]



Research shows that active learning is more effective (than conventional lecturing) even though students may not realize it. Students sometimes feel like they are learning *less* with active learning because when a Professor simply lectures in class it can "sound easy" and students can think they understand; in contrast, when students must answer questions related to the material, they become more aware that they still do not fully understand.

Q0.1 Have you use something like clickers in a class before?

A: Never B: A bit C: A lot

Grading

See schedule/syllabus for details.

- Your total score is sum of your scores on each assignment. (See points listed on the schedule.)
- Final grades are based on your total score / $\approx$ 1150 points.
- Grade cutoff between A-/B+ will be $\leq$90%, for B-/C+ will be $\leq$80% (or lower), etc.
- For reference, the table below lists the score ranges from F10 in the ENGR 100 section taught by Prof. Fessler/Zahn.

GRADE	A+	A	A-	B+	B	B-	C+	F
# getting	1	15	9	6	7	2	1	1
maximum	97.6	93.7	89.4	87.9	85.7	82.2	78.6	25.5
minimum	97.6	89.6	88.3	86.6	83.7	80.9	78.6	25.5

- Grade history for ENGR 100 at Atlas
- See syllabus for collaboration and honor code policies.

Labs

Goals:

- Learn technical skills useful in projects
- Learn fundamentals of music signals and DSP

Lab synopsis

- Lab 1: Introduction to `Julia` and sinusoids
- Lab 2: Measure frequencies of music tones with DSP, and visualize graphically
- Lab 3: Compute spectra of signals, filter noisy signals, visualize using spectrogram

Projects

Goals:

- To work as a team to design, build, test, and refine simple music signal processing systems
- To apply tech. comm. skills to present your design and results

- Project 1: Build a music tone synthesizer and transcriber
- Project 2: Reverse-engineer touch-tone phone signals:
  - Determine frequencies
  - Build touch-tone synthesizer and transcriber
  - Investigate transcriber behavior in noise.
- Project 3: (open ended)
  Example: Build simple music synthesizer and transcriber
  - Multiple-instrument synthesizer with GUI keys
  - Generate musical staff-like notation from signals
  - Report results using tech. comm. principles.

Project 1: Synthesizer GUI

Mimics piano keyboard: mouse click on key plays note.
Much room for customization!

Project 1: Tone Transcriber

Transcriber (reverse musician):

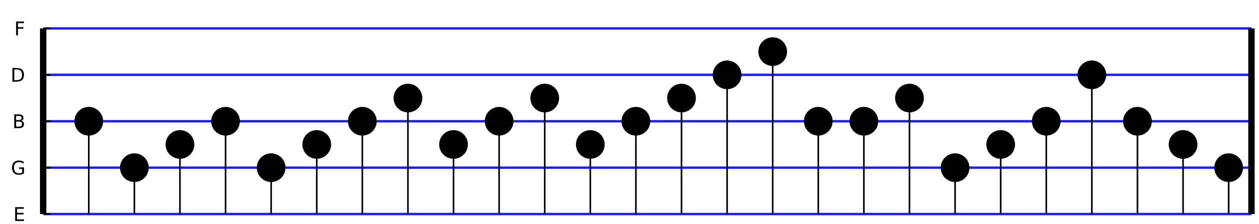
play   music signal → transcriber → music notation

Computer-based transcription of polyphonic music with arbitrary instruments is an unsolved problem!

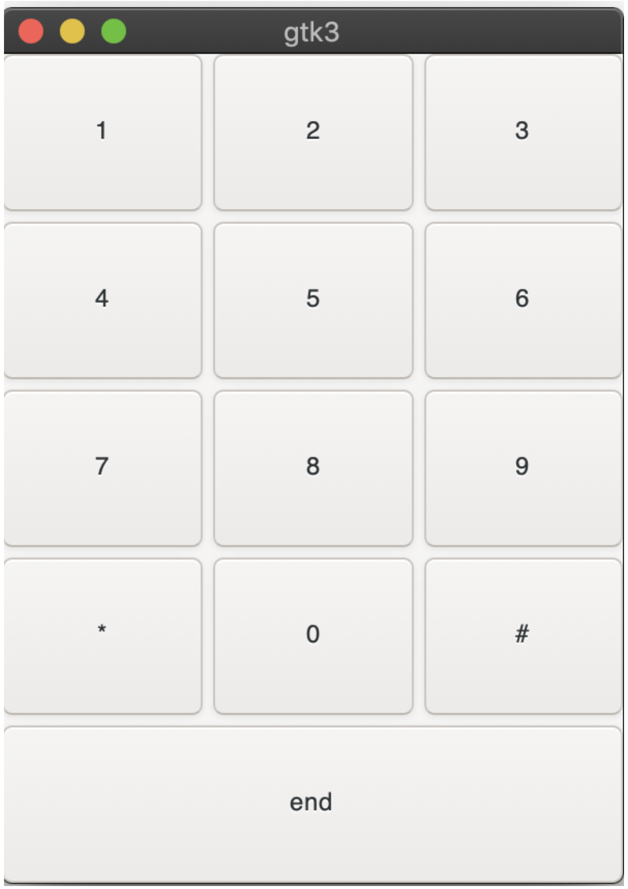
P1 simplifications:

- all notes have same duration
- simple stem plot instead of notes, but correct heights

The Victors as a stem plot



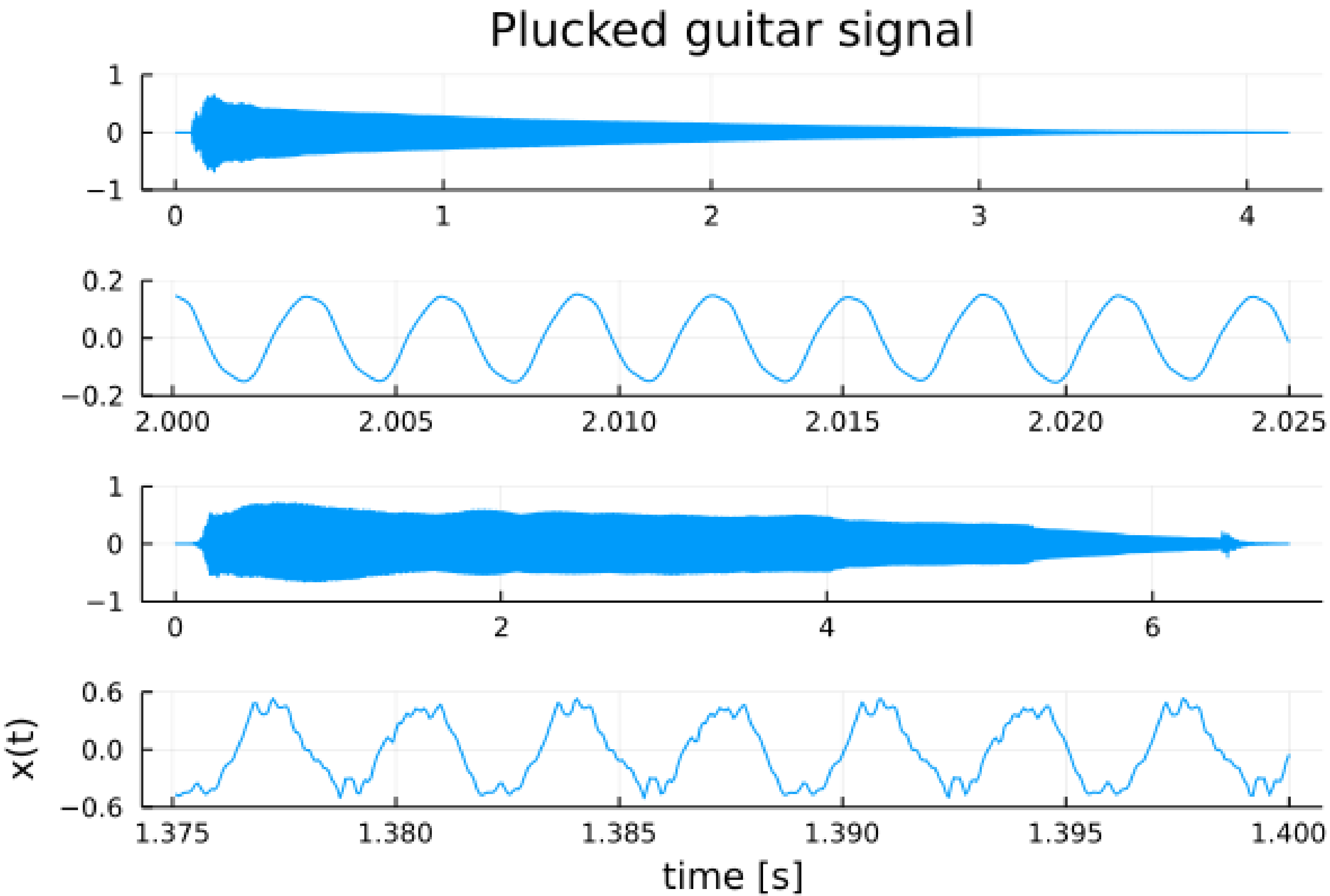
Project 2: Touch-Tone Synthesizer



- Used to generate sequence of tones play
- Transcriber must produce correct sequence, *i.e.*, 7631434
- Investigate how transcription accuracy degrades with noise

Part 2: DSP Overview

Plucked guitar demo



play

play

Plucked guitar demo: details

Basic audio recording with `Julia`:

```
using Sound # record
using Plots # plot
x, S = record(5)
plot((1:length(x))/S, x, xlabel="t [s]", ylabel="x(t)")
```

This records `5` seconds of monaural audio sampled at `S = 44100` $\frac{\text{Sample}}{\text{Second}}$ and stores the results in vector `x` that is plotted.

(Requires a microphone.)

Plucked guitar frequency

frequency = 1 / period

For plucked guitar on previous page:
period = (2.015 - 2) / 5 = 0.003 seconds

frequency = 1 / period = 1 / 0.003 = 333 Hz

What note is that? [wiki]

E4 ("high E" on guitar) is 329.628 Hz

We just did some (manual) music signal processing.

ECE overview

Electrical and Computer Engineering: (UM / CoE / EECS)

1. power/energy
2. information
   - control (*e.g.*, anti-lock brake systems, autonomous vehicles...)
   - communications and signal processing
     - telephones, radios, stereos, televisions
     - digital audio and video
     - science, medicine (*e.g.*, MRI scans), ...

Major areas of ECE

- Physical devices / hardware (Phys. 240):
  electricity, electromagnetics, optics, semiconductors, ...
- Computers and computing (Eng. 101, EECS 270, 280, ...)
- Systems (signals / algorithms): EECS 216, 351, 452, 455, 460

DSP is everywhere

Signals: create, record, store, transmit, receive, process
Each can be done by analog or digital means
Digital usually provides numerous advantages
(cost, reliability, programmability, fidelity, ...)

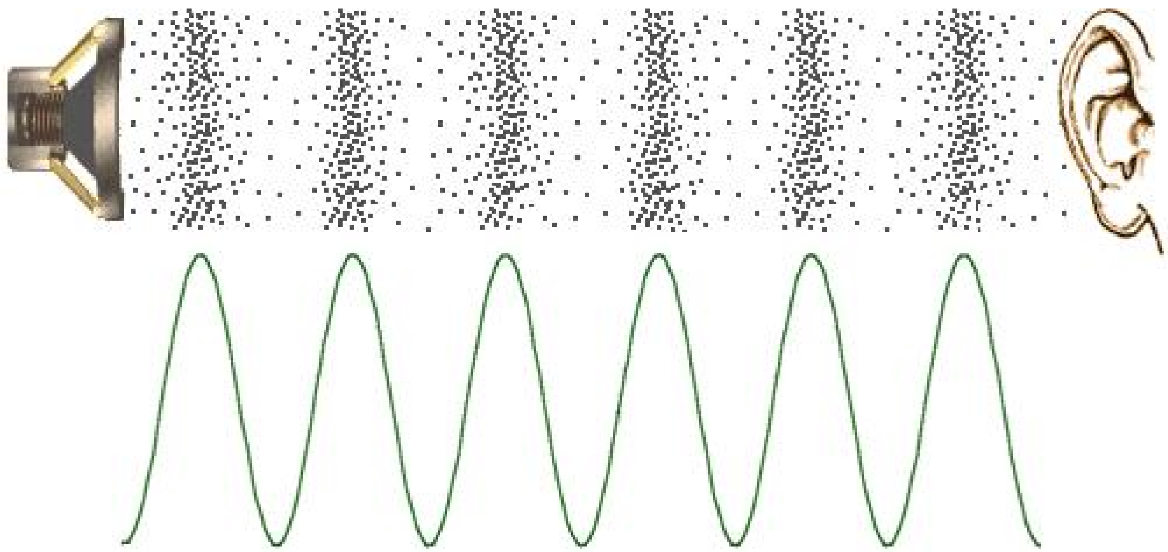
Storing audio signals (*e.g.*)

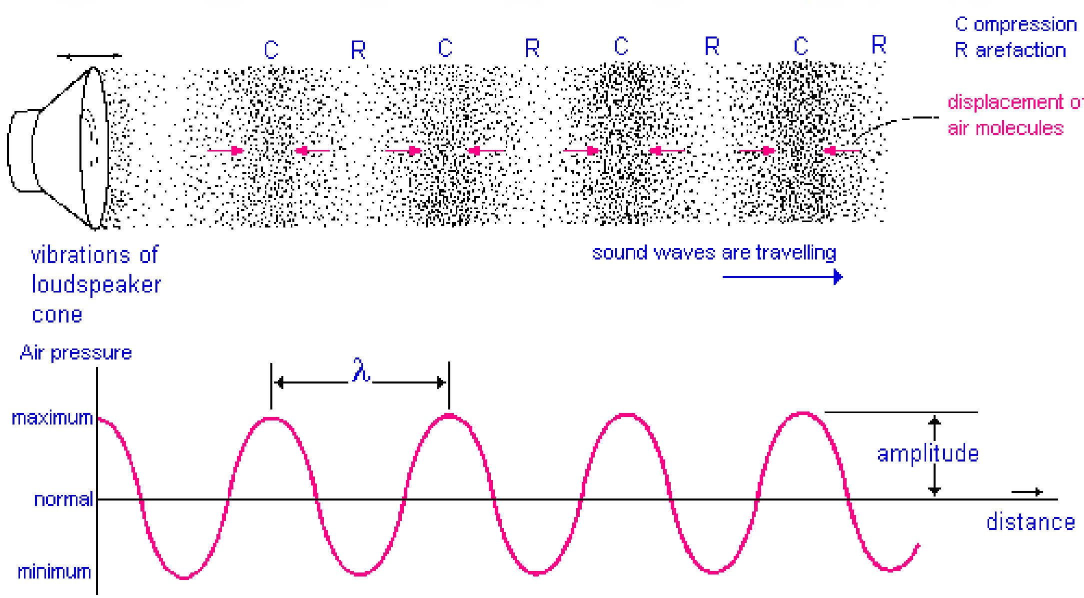
- Analog storage: wax, wires, vinyl records, cassette tapes, ...
- Digital storage: magnetic (floppy disks, hard drive), optical (CD, DVD), semiconductor (flash, etc.), ...
  Allows compression and lossless storage / transmission

Some audio applications of Digital Signal Processing (DSP)

- Analysis of signals: What is frequency or pitch of a note?
  What is its spectrum? What type of instrument? Speech recognition.
- Filtering of signals: Removing noise; removing interference
- Enhancing signals: bass boost, reverb, auto-tune...

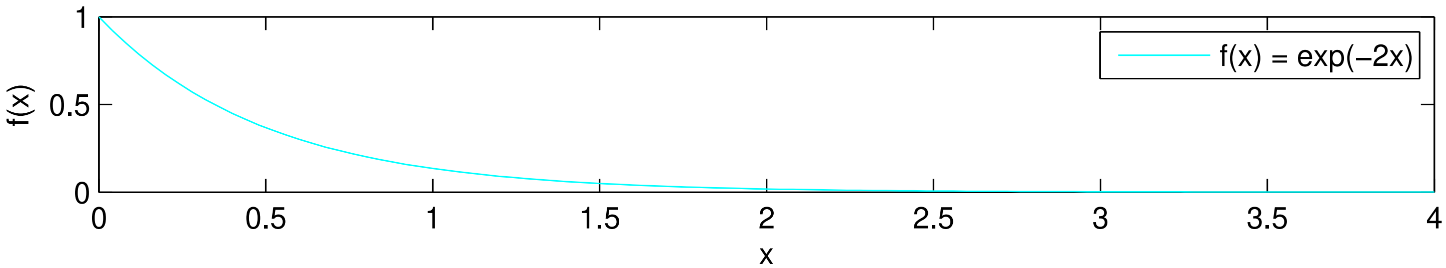
Sound waves



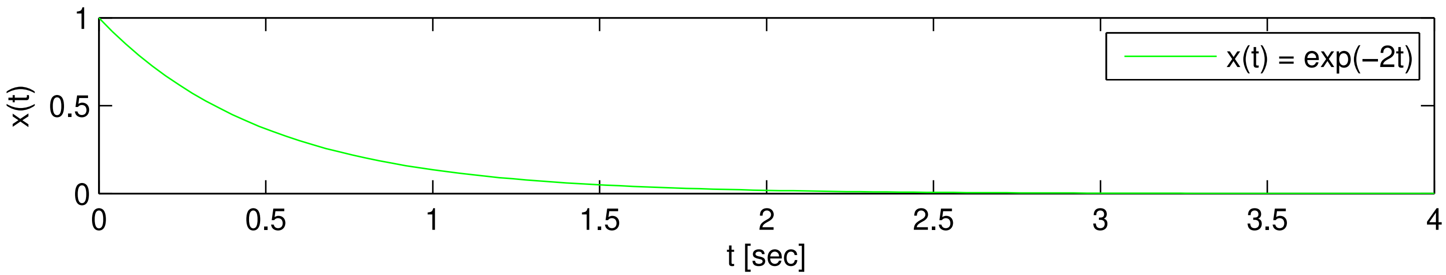

C R C R C R C R
C ompression
R arefaction
displacement of
air molecules
vibrations of
loudspeaker
cone
sound waves are travelling
Air pressure
λ
maximum
normal
minimum
amplitude
distance

DSP basics: Notation

In calculus: $f(x) = \mathrm{e}^{-ax}$
Here: x is a *variable* and a is a parameter that defines the shape of the function $f(x)$ when graphed versus x.



In DSP: $x(t) = \mathrm{e}^{-at}$
Here: t is the *variable* (time) and a is a parameter that defines the shape of the function $x(t)$ *e.g.*, current through a resistor



Q0.2 What value of a was used to make these plots?

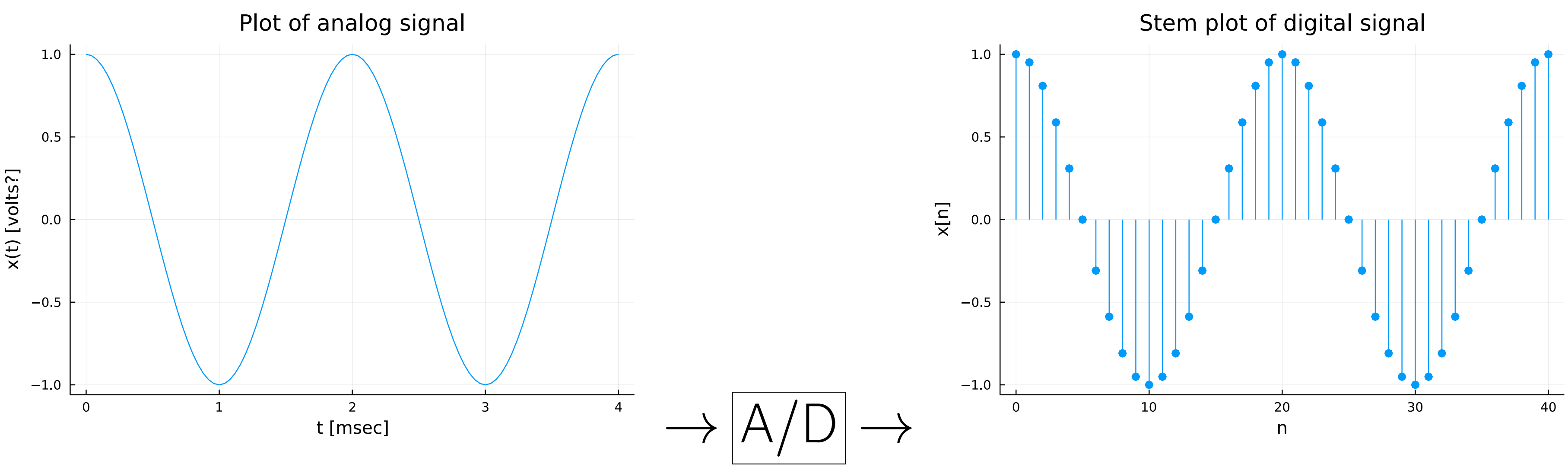
A: 1 B: 2 C: 3 D: 4 E: 5 ??

Note that x is on the vertical axis here.

We often use $v(t)$, $x(t)$, $y(t)$, $z(t)$ to denote signals.

DSP basics: Sampling

DSP systems start with a A/D converter (analog to digital)



Analog = continuous time $x(t)$

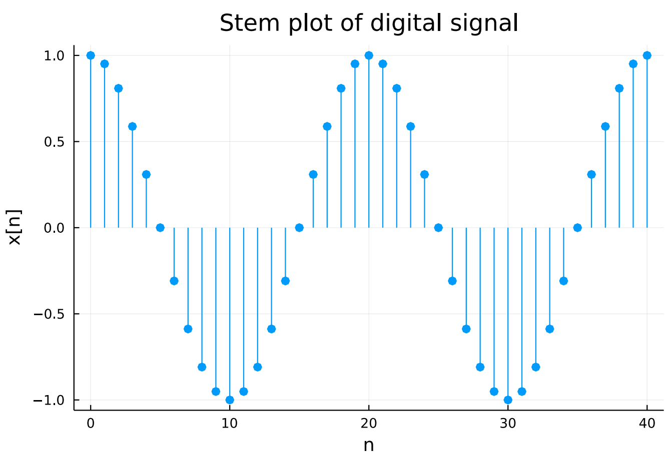
Digital = discrete time $x[n]$

The sampled signal $x[n]$ can be processed by digital computers.

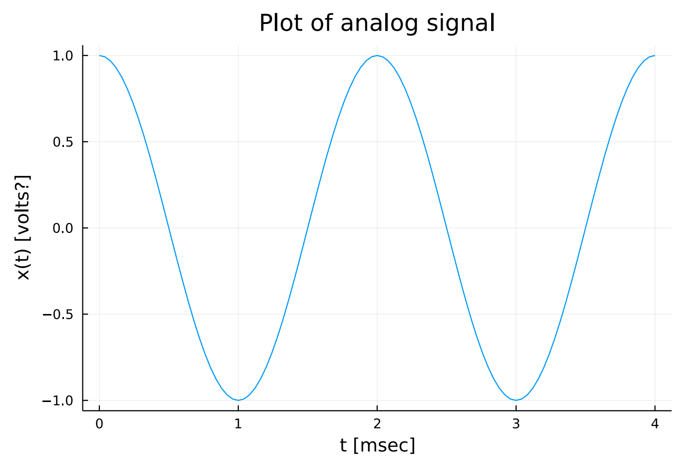
DSP basics: Interpolation

Does sampling an analog signal lose information?
Can we recover the original analog signal $x(t)$
from the sampled digital signal $x[n]$?

Digital-to-analog (D/A) converters use interpolation
(electrical version of "connect the dots")



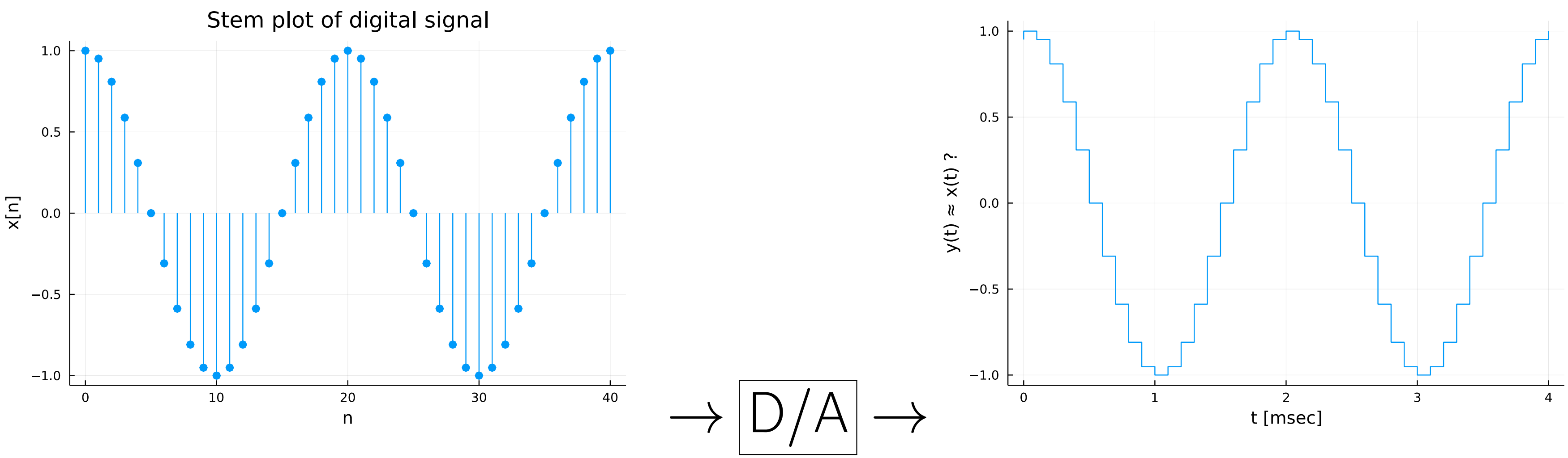
$\rightarrow$ D/A $\rightarrow$



In audio this conversion is essential for our analog ears.

Basic D/A conversion

0th-order sample-and-hold method:



Amazing Fact that is the foundation of our digital world:
we can reconstruct $x(t)$ from $x[n]$ perfectly if the sampling rate exceeds twice the maximum frequency of the original signal.

play “An analog girl in a digital world,” Judy Gorman, One Sky Music, 2000

Part 3: Technical Communications
Its engineering significance

Heads up...

- How you report results is as important as the technical results

- Technically good transcriber & poorly presented $\Longrightarrow$ poor grade.
- Technically so-so transcriber & well presented $\Longrightarrow$ good grade.
- Technically good transcriber & well presented $\Longrightarrow$ very good grade.

Why is presentation so important?

- This is absolutely how the real world works
- True in both industry and academia
- Replace *grades* in college with *salary, jobs and careers* in the real world
- Instead of taking our word for it, listen to UM engineering alumni:

UM EE alumni survey says:

Ranked most important in their professional experience:

1. Ability to function on a *team*
2. Oral *communication* skills
3. Written *communication* skills
4. Engineering problem-solving ability
5. Math, science, and engineering skills (yes, 5th)
6. Professional and *ethical* responsibility

Example: Amazon uses 6-page memos (not PowerPoint)
https://www.linkedin.com/pulse/beauty-amazons-6-pager-brad-porter

Example: before giving an elevator pitch, write a full thought-out plan.

Communication skills:

Poll: Few Firms Looking For Liberal Arts Grads, More Seeking Engineering, Business Majors.

The Los Angeles Times (2014-05-22, Hamilton) reports that according to a new survey by research and consulting firm Millennial Branding, only "2% of companies are actively recruiting college graduates with liberal-arts degrees," noting that "many more corporate hiring managers are on the lookout for engineering or business majors." The survey found that 27% of firms are seeking engineering and computer science grads, while 18% are seeking business majors. However, the survey found that over 80% of hiring managers "cited communication skills as a top trait they're looking for in job candidates, a skill typically in abundance among liberal-arts majors."

(http://www.latimes.com/business)

What UM EE alumni do:

- 62.5% Engineer
- 14.6% Manager
- 6.3% Marketing
- 16.7% Other

Source: UM College of Engineering Alumni Surveys
for graduating classes 00-01, 01-02, 02-03, 03-04

Conclusions

- Team and communication skills are more important on the job than technical competence.
- Hollywood has it all wrong. (*cf.* co-advising)

Part 4: `Julia` introduction / demo

Coding background?

Q0.3 Prior coding course? (choose highest)

A: ENGR 101 B: ENGR 183 C: ENGR 280

Q0.4 Prior `Julia` experience?

A: Never heard of it before ENGR 100-430

B: Heard of it but never used it

C: Tried it a couple times

D: Used it in a class (Rob 101?)

E: Did something useful with it outside a class

Scalar variables and arithmetic

(*cf.* calculator)

```
diary file
```

```
2 + 3
```

```
x = 3
```

```
7 * x
```

```
y = 2 + x
```

```
x + y
```

```
x^2
```

Scalar variables and functions

```
cos(0), sin(pi/4)
```

```
x = pi/4; z = cos(x)
```

```
exp(-x)
```

```
10 * exp(-x)
```

```
z = 4; a = sin(z) * sin(z) + cos(z) * cos(z)
```

Variables and arrays

```
x = [2, 3, 4, 5]
```

or more concisely (this colon syntax is very convenient and frequent):

```
x = 2:5
```

skip by 3's:

```
x = 0:3:18
```

```
collect(x)
```

Arrays and arithmetic operations

In linear algebra, the only two vector operations are addition and scalar multiplication, and `Julia` supports those directly, working element-wise as expected:

```
x = 2:5
y = 10 * x
y + x
```

Other vector/scalar and vector/vector operations require **broadcast** using `.` to tell `Julia` to work element-wise:

```
x .+ 2
x .^ 2
y .* x
```

Trying it without the `.` produces an error.

Arrays and functions

Similarly, broadcast is needed for functions to act element-wise (key difference from `Matlab`):

```
x = 2:5
exp.(-x)
5 * sin.(x)
```

Many special functions have other purposes:

```
sum(x)
extrema(x)
```

To learn more about a function, *e.g.*, the `sum` function:

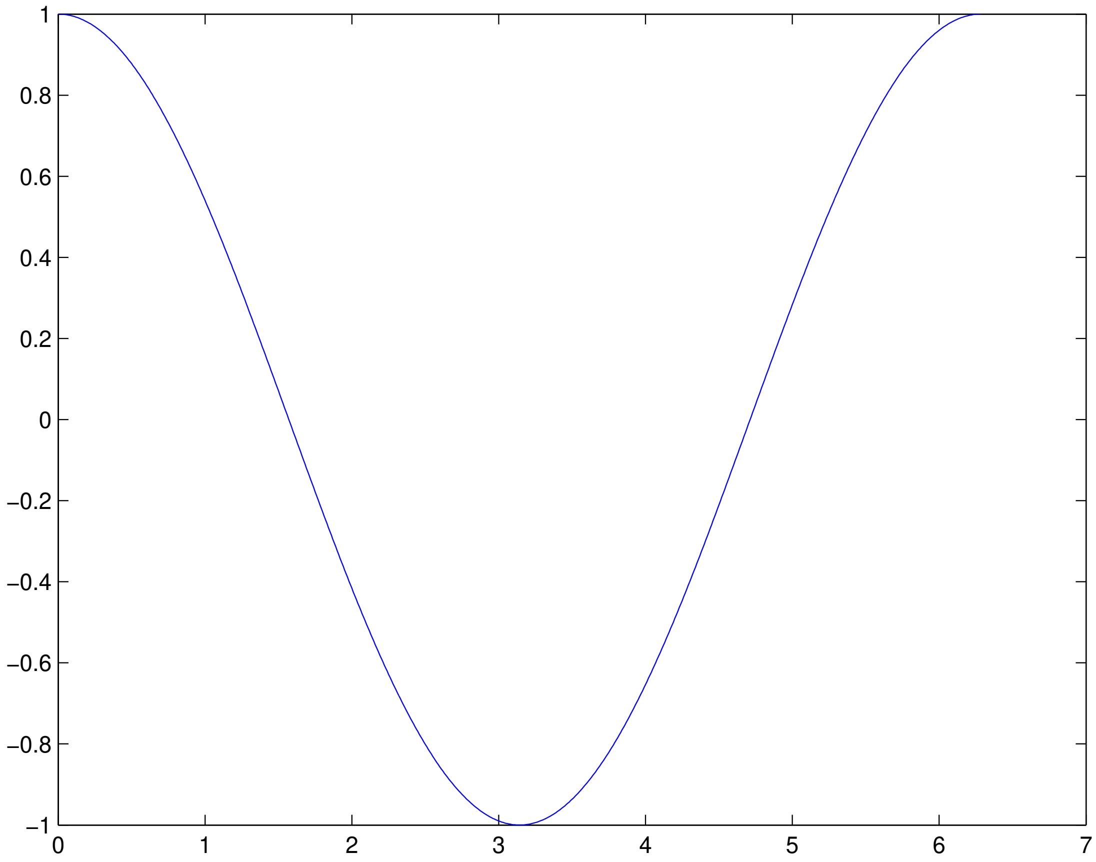
```
@doc sum
```

or:

```
? sum
```

Plotting

```
using Plots; x = 0:0.01:2pi; y = cos.(x); plot(x, y)
```



Sound

```
using Sound
S = 8192; t = 0:1/S:0.5
x = 0.9 * cos.(2pi*400*t)
plot(t,x)
sound(x, S)
```

play

Array manipulation

```
a = [10, 20]
b = 3:7
```

Vertical concatenation:

```
c = [a; b]
```

```
c = [a; b; (a .+ 1)]
```

Music?

```
S = 8192; t = 0:1/S:0.5
x = 0.9 * cos.(2pi*400*t)
y = 0.8 * cos.(2pi*300*t)
z = [x; y; 0.4*x]
sound(z, S)
```

play

```
w = [x; y; (x + y)]
soundsc(w, S)
```

play

Mini Laptop Concert

(need conductor)

Launch `Julia`

At `Julia` REPL (read-eval-print loop) prompt:

```
using Sound
S = 8192; t = 0:1/S:3
```

```
x = 0.9 * cos.(2pi*400*t)
x = 0.9 * cos.(2pi*600*t)
x = 0.9 * cos.(2pi*800*t)
```

```
sound(x, S)
```

Finale

Read Lab 1 before lab this week!
Lab reading questions due 24 hours before Lab section!

(Normally, but Lab 1 deadline is different in W22 due to Wed. start.)

It has more details about how to use `Julia`...

References

[1] M-Z. Poh, N. C. Swenson, and R. W. Picard. A wearable sensor for unobtrusive, long-term assessment of electrodermal activity. *IEEE Trans. Biomed. Engin.*, 57(5):1243–52, May 2010.