Eng. 100-300: Music Signal Processing

Prof. Jeff Fessler

Fall 2015

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. Matlab introduction (your “lab” for this course)
Part 1: Team / Course overview
## Team

<table>
<thead>
<tr>
<th>Name</th>
<th>Title and Department</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jeff Fessler</td>
<td>Professor; EECS Department</td>
</tr>
<tr>
<td>Paul Kominsky</td>
<td>Lecturer; Program in Technical Comm.</td>
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<tr>
<td>Thomas Bowden</td>
<td>Lecturer; Program in Technical Comm.</td>
</tr>
<tr>
<td>Izzy Salley</td>
<td>Instructional Assistant (IA); EE</td>
</tr>
<tr>
<td>Sydney Williams</td>
<td>Graduate Student Instructor (GSI); BME</td>
</tr>
</tbody>
</table>

Izzy:  
Sydney:
Course information

- Course management tool: Canvas
- Login with UM ID and your password
- Select “ENGR 100 300”
- Labs, projects, homework, reading questions, schedule, syllabus, ...
- DSP lectures available online in advance for printing / downloading. (Printing is optional but recommended unless you have a tablet.) Under “Files/lectures-dsp-fessler” link
- See syllabus for contact information, book, office hours, etc.

On Canvas or https://goo.gl/wnlVlP
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)
- 3 labs, preparation for:
  - 3 projects (2 small, 1 large final team project)
  - Final project: music synthesizer and transcriber (*e.g.*)
- 2 exams (one midterm in class, one final)
- Technical comm.: memos, oral and written presentations, ...
Schedule overview

- Tuesday-Monday week!
- Lab 1 begins this week (read ahead!): Thu/Fri/Mon
- Full schedule on Canvas
- No slack in schedule
- Planning your week
  - 3 hours of work / week / credit
  - 4 credits $\rightarrow$ 12 hours / week
  - 6 contact hours: 3 lecture, 1 discussion, 2 lab
  - 6 hours of work / week outside class (on average)
    - review lecture notes / textbook sections
    - read lab materials before lab
    - answer lab / project “reading questions” due 24 hours before lab starts using Canvas “Quizzes.” (learning not assessment)
    - prepare lab reports, TC assignments, problem sets, project presentations ...
### Schedule for Engineering 100-300 Fall 2015

**Music Signal Processing**

<table>
<thead>
<tr>
<th>WEEK (Tue-Mon)</th>
<th>TUESDAY</th>
<th>THURSDAY</th>
<th>REF</th>
<th>LAB/</th>
<th>LAB</th>
<th>DISCUSS</th>
<th>DUE**</th>
<th>Points</th>
<th>To:</th>
<th>Who</th>
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<tbody>
<tr>
<td>Sep 8-14</td>
<td>Goals, Overview &amp; Sampling</td>
<td>Intro to Tech. Comm. and Memo Writing</td>
<td>Ch. 1</td>
<td>Lab 1</td>
<td>Matlab and Sampling</td>
<td>Teamwork</td>
<td>Lab 1 reading q</td>
<td>8</td>
<td>lab</td>
<td>indiv</td>
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<td>Sep 15-21</td>
<td>Measure Freqs &amp; Semilog Plots</td>
<td>Memos</td>
<td>Ch. 2</td>
<td>Lab 2</td>
<td>Measuring and Summaries</td>
<td>Memos: Forewords</td>
<td>(lab 1 results at latest)</td>
<td>30</td>
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<td>Sep 22-28</td>
<td>Project 1 Specs: Tone Synthesizer and Transcriber</td>
<td>Oral Presentations &amp; Writing Strategies</td>
<td>Ch. 8</td>
<td>Proj 1</td>
<td>Synthesizer and Transcriber</td>
<td>Memos: Practice</td>
<td>Lab 2 results</td>
<td>40</td>
<td>lab</td>
<td>indiv</td>
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<td>Sep 29 - Oct 5</td>
<td>Content Developm. Research Reviews</td>
<td>Matlab's fft and Spectrogram I</td>
<td>Ch. 7</td>
<td>None</td>
<td>None</td>
<td>Project 1: Oral Presentation</td>
<td>P1 oral</td>
<td>50</td>
<td>disc</td>
<td>team</td>
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<tr>
<td>Oct 6-12</td>
<td>Matlab's fft and Spectrogram II</td>
<td>Spectrogram III</td>
<td>Lab 3</td>
<td>Spectra and Memo quiz</td>
<td>Spectrogram</td>
<td>HW2 (Thu)</td>
<td>25</td>
<td>disc</td>
<td>indiv</td>
<td></td>
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<tr>
<td>Oct 13-19</td>
<td>Ethics/Teamwork Review</td>
<td>Lab3</td>
<td>Spectra and Engin. Ethics</td>
<td>Spectrogram</td>
<td>Memo 2: research</td>
<td>HW3 (Thu)</td>
<td>30</td>
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<td>Oct 20-26</td>
<td>(Fall break) EXAM 1</td>
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<td>None***</td>
<td>None***</td>
<td>Exam 1</td>
<td>100</td>
<td>prof</td>
<td>indiv</td>
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*See Canvas or http://goo.gl/MJXQh1*
# Second half of semester

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<tr>
<th>Oct 27-</th>
<th>Project 2 Specs: Proposals Ch. 4 Proj 2 Touch-tone Graphics &amp; Lab 3 results</th>
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<td>Nov 2</td>
<td>Touch-tone Phone Graphics App. C Proj 2 Project Work Presentations P2 reading q</td>
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<td>Nov 3-9</td>
<td>Project 3 Specs: Advanced Ch. 8 Proj 3 Pitch Writ. Strategies P2 report 50</td>
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<td>Music Synthesizer Oral Presentations project ideas Netiquette P2 peer eval 10</td>
<td>10</td>
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<td></td>
<td>and Transcriber</td>
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<td>Nov 10-16</td>
<td>Synthesizer methods Formal Reports Ch. 6 Proj 3 P3 work Writ. Strategies P3 proposal 40</td>
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<td>Nov 17-23</td>
<td>Transcriber methods Exec. Summary Exec. Summary Proj 3 P3 work Review: Draft</td>
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<td>P3 help Thanksgiving None None</td>
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<td>disc</td>
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<td>Dec 1-7</td>
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<td>disc</td>
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<td>Dec 15</td>
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<td>Dec 17</td>
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</table>

* Topics for class and discussions subject to change.

** Lab/project ‘reading questions’ are due 24 hours before each lab begins.

*** The Monday Oct. 19 lab & discussion will be held Oct. 26

course evaluations 10 online indiv

Lab participation 15 indiv

Disc. participation 20 indiv

Total points: 1302
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 / 1302 points.
- Grade cutoff between A-/B+ will be 90% (or lower), for B-/C+ will be 80% (or lower), etc.
- For reference, the table below lists the score ranges from F10 in the ENGN 100 section taught by Prof. Fessler/Zahn.

<table>
<thead>
<tr>
<th>GRADE</th>
<th>A+</th>
<th>A</th>
<th>A-</th>
<th>B+</th>
<th>B</th>
<th>B-</th>
<th>C</th>
<th>F</th>
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<td>1</td>
<td>15</td>
<td>9</td>
<td>6</td>
<td>7</td>
<td>2</td>
<td>1</td>
<td>1</td>
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<tr>
<td>maximum</td>
<td>97.6</td>
<td>93.7</td>
<td>89.4</td>
<td>87.9</td>
<td>85.7</td>
<td>82.2</td>
<td>78.6</td>
<td>25.5</td>
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<tr>
<td>minimum</td>
<td>97.6</td>
<td>89.6</td>
<td>88.3</td>
<td>86.6</td>
<td>83.7</td>
<td>80.9</td>
<td>78.6</td>
<td>25.5</td>
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</table>

- 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 Matlab 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
  - Build touch-tone 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 2: Tone Transcriber

Transcriber (reverse musician):

\[ \text{play} \quad \text{music signal} \rightarrow \text{transcriber} \rightarrow \text{music notation} \]

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

Simplifications:
- all notes have same duration
- simple stem plot instead of notes, but correct heights
Project 2: Touch-Tone Synthesizer

- Used to generate sequence of tones
- Transcriber must produce correct sequence, i.e., 7631434
- Investigate how transcription accuracy degrades with noise
Part 2: DSP Overview
Plucked guitar demo

Plucked guitar signal

play

x(t)

1.375 1.38 1.385 1.39 1.395 1.4

0 1

-1 0 1

Plucked guitar signal

0 0.5 1 1.5 2 2.5 3 3.5 4 4.5

−1 0 1

Plucked guitar signal

2 2.005 2.01 2.015 2.02 2.025

−0.2 0 0.2

Plucked guitar signal

0 1 2 3 4 5 6 7

−1 0 1

Plucked guitar signal

time [s]
Plucked guitar demo: details

Basic audio recording with Matlab:
obj = audiorecorder(8000, 8, 1);
recordblocking(obj, 5);
x = getaudiodata(obj);
plot([1:numel(x)]/8000,x)
xlabel 't [s]', ylabel 'x(t)'
grid; zoom xon

This records 5 seconds of monaural 8-bit audio sampled at 8000 Hz and stores the results in vector x.

(Requires a microphone.)
Plucked guitar frequency

\[
\text{frequency} = \frac{1}{\text{period}}
\]

For plucked guitar on previous page:
period = \(\frac{(2.015 - 2)}{5} = 0.003\) seconds

\[
\text{frequency} = \frac{1}{\text{period}} = \frac{1}{0.003} = 333\ \text{Hz}
\]

What note is that?

http://en.wikipedia.org/wiki/Piano_key_frequencies

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)
   - 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, 451, 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?
- Filtering of signals: Removing noise; removing interference
- Enhancing signals: bass boost, reverb, ...
DSP basics: Notation

In calculus: \( f(x) = e^{-ax} \)

Here: \( x \) is a \textit{variable} and \( a \) is a \textit{parameter} that defines the shape of the function \( f(x) \) when graphed versus \( x \).

What value of \( a \) was used to make this plot? ??

In DSP: \( x(t) = e^{-at} \)

Here: \( t \) is the \textit{variable} (time) and \( a \) is a \textit{parameter} that defines the shape of the function \( x(t) \) e.g., current through a resistor
DSP basics: Sampling

DSP systems start with an 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 sample digital signal $x[n]$?

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

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.

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 $\implies$ poor grade.

• Technically inferior transcriber & well presented $\implies$ good grade.

• Technically good transcriber & well presented $\implies$ 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
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.  
  (CT anecdote)
Part 4: Matlab introduction / demo
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

\[ \cos(0), \sin(\pi/4) \]

\[ x = \pi/4; \ z = \cos(x) \]

\[ \exp(-x) \]

\[ 10 \times \exp(-x) \]

\[ z = 4; \ a = \sin(z) \times \sin(z) + \cos(z) \times \cos(z) \]
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:

\[ x = [0:3:18] \]
Arrays and arithmetic operations

Act element-wise:

\[ x = 2:5 \]

\[ 10 \times x \]

\[ y = x + 2 \]

\[ y - x \]

\[ x \cdot^2 \]
Arrays and functions

Most familiar functions act element-wise (key feature!):

\[ x = 2:5 \]

\[ \exp(-x) \]

\[ 10 \times \exp(-x) \]

\[ \sin(x) \]

Many special functions have other purposes

\[ \text{sum}(x) \]

To learn more about a function, e.g., the \text{sum} function:

\[ \text{doc sum} \]
Plotting

\[ x = 0:0.01:2\pi; \ y = \cos(x); \ \text{plot}(x, y) \]
Sound

t = 0:1/8192:0.5;

plot(t,x)

x = 0.9 * cos(2*pi*400*t);

sound(x)

(The sound commands assumes a 8192 Hz sampling rate.)
Array manipulation

\[ a = [10 \ 20] \]
\[ b = 3:7 \]

Concatenation:

\[ c = [a, b] \]
\[ c = [a \ b \ (a+1)] \]
t = 0:1/8192:0.5;

x = 0.9 * cos(2*pi*400*t);

y = 0.8 * cos(2*pi*300*t);

z = [x y 0.4*x];

sound(z)

w = [x y (x + y)];

soundsc(w)

diary off
Mini Laptop Concert

(need conductor)

t = 0:1/8192:3;

x = 0.9 * cos(2*pi*400*t);

x = 0.9 * cos(2*pi*600*t);

x = 0.9 * cos(2*pi*800*t);

sound(x)
Finale

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

It has more details about how to use Matlab...
Library has Matlab books, but online help probably suffices.
See also matlab-overview.pdf document on Canvas.