ELEN 4810
Digital Signal Processing

Introduction

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Welcome to 4810, Digital Signal Processing

**Signal**: loosely, any information bearing function:

**Processing:**

Sampling  
Denoising / superresolving  
Analyzing / interpreting / classifying

**Digital Signal Processing:**

Acquiring, enhancing, analyzing, and synthesizing signals using a computer, or any other platform that works with

Finitely many samples  
Finite precision arithmetic

EKG signal from [Serra et. al., ‘07]
Why work in the digital domain?

Classical arguments

Flexibility
Programming is usually easier than implementing new hardware

Advances in computing power

Reproducibility:
Same data, same result

Power / precision
Attractive tradeoffs vis. analog implementations

Plus a few recent developments:

New computing platforms
Your phone is a camera, microphone and powerful digital computer!

Data as a resource
The most effective algorithms for signal classification, denoising, superresolution, etc., use massive amounts of training data
What is this class really about?

A few core mathematical tools for thinking about discrete time signals and systems.

Introduction: Applications, review of complex math, basic sequences
Time Domain: LTI systems, convolution, impulse response
Frequency Domain: Discrete Time Fourier Transform (DTFT), DFT
Sampling: Shannon-Nyquist, Analog-Digital conversion

Midterm exam

Z-transform: Definition, poles, zeros, application in system analysis
Filters: Magnitude, phase response, linear/generalized linear phase
Filter design: FIR design tools, IIR design tools

Algorithms: Fast Fourier Transform, fast convolution
Special topics: Recent developments, examples, applications

Final exam, course project
Motivation (1): Camera Shake Removal

The picture I want:

The picture actually get:

Example from [Wipf + Zhang, Revising Bayesian Blind Deconvolution, 2013]
Motivation (1): Camera Shake Removal

The picture I want:

The picture actually get:

\[ f(t) = \sum_{\text{translations } \tau} \kappa(\tau) f(t - \tau) \]

Example from [Wipf + Zhang, Revising Bayesian Blind Deconvolution, 2013]
Motivation (1): Camera Shake Removal

The picture I want:

The picture actually get:

Example from [Wipf + Zhang, Revising Bayesian Blind Deconvolution, 2013]
Motivation (1.5): Scanning Tunneling Spectroscopy

The electron microscope gives:

Want to determine where the material defects are located, and what the basic defect “signature” is...

Joint work with J. Sun, S. Cheung, A. Pasuapathy
Motivation (1.5): Scanning Tunneling Spectroscopy

The electron microscope gives:

\[ Y \in \mathbb{R}^{m \times n \times p} \]
Observation

\[ A \in \mathbb{R}^{m' \times n' \times p} \]
Defect signature (spatial domain)

\[ X \in \mathbb{R}^{m \times n} \]
Activation map

\[ Z \in \mathbb{R}^{m \times n \times p} \]
Noise

Want to determine where the material defects are located, and what the basic defect “signature” is...

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Motivation (1.5): Scanning Tunneling Spectroscopy

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Want to determine where the material defects are located, and what the basic defect “signature” is...

Joint work with Y. Lau, S. Cheung, A. Pasuapathy
Motivation (2): Spectrum Sensing

New communications technology is spectrum-hungry...

... and available RF spectrum is increasingly scarce.
Motivation (3): Dynamic MRI

... and for other completely different signal modalities, e.g., magnetic resonance imaging:

Example from [Otazo+Candes+Sodickson, Low-Rank and Sparse Matrix Decomposition for Accelerated MRI, 2014]
Syllabus

Introduction: Applications, review of complex math, basic sequences
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Final exam, course project
Course Organization

_Discrete-Time Signal Processing_
Oppenheim + Schafer, 3rd Ed.
[Yes, digital/pdf version is fine.]

**Instructor:**  John Wright  
johnwright@ee.columbia.edu  
Office hours: 3:30-5, Friday, 716 CEPSR.  
[For course related email, please start the subject with “4810:”]

**TA:**  Yenson Lau  
yl3027@columbia.edu  
Office hours: Tuesdays and Fridays, 10-11 AM, Place TBA

**Website:**  http://www.columbia.edu/~jw2966/4810_Fa2015/4810_Fa2015.html
Grades

<table>
<thead>
<tr>
<th>Course</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Homework</td>
<td>10%</td>
</tr>
<tr>
<td>Midterm</td>
<td>30%</td>
</tr>
<tr>
<td>Final</td>
<td>30%</td>
</tr>
<tr>
<td>Course Project</td>
<td>30%</td>
</tr>
</tbody>
</table>

**Exams** are closed-book. No phones, calculators, or other computing devices.

One sheet of handwritten notes is allowed for the midterm.

Two sheets of handwritten notes are allowed for the final.
Homework

Analytical problems (Oppenheim-Schafer) + Matlab exercises, due every Wednesday at the start of class.

Homework will start heavy and then get much lighter at the end of the semester.

You can get Matlab for free through SEAS:  
https://portal.seas.columbia.edu/matlab/

If you don’t know Matlab, a good resource for getting started is:  
http://www.ee.columbia.edu/ee-matlab

Feel free to discuss with peers, but you must write up your solutions independently. Please don’t cheat yourself out of learning the material!

Late homework will not be accepted. We will drop your lowest homework score, as a buffer against illness, travel, hungry pets, meteor strike, ect.

First homework (really easy!) is out, due next Wed.
Course Project

Process some kind of real signal.

Teams:

3-4 students. You can self-organize around common interests via the course forum on CourseWorks.

Students who cannot find teammates will be randomly grouped.

1-2 student teams are also acceptable, with instructor approval.

Programming language:

Any programming language/platform is ok. We recommend Matlab.

Deliverables:

Proposal in writing, by Oct. 20. Details in the syllabus.

Code

Project report (~4 pages)
Course Project

Process some kind of real signal.

Project ideas (more online):

**Audio**: speech classification, pitch detection, guitar effects  
**Images**: superresolution (“magic” zoom), categorization, camera shake removal  
**Videos**: transform coding / compression  
**Depth data**: denoising / interpolation  
Other types of data are great:  
- Bioinformatic data, financial time series, seismic surveys

Good projects are often **fun and relevant** to your everyday life.

**Advanced tools** are also great …

- Machine learning techniques, deep learning  
- Nonlinear features,  
- Compressed sensing, sparse approximation,  
- Source separation techniques

… as long as you’re applying them to some type of real data.

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