ELEN E4896 MUSIC SIGNAL PROCESSING

Lecture I: Course Introduction

Course Structure DSP: The Short-Time Fourier Transform

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- Music is a very rich signal
- Signal Processing can expose some of it
- We want to get inside it

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I. Course Goals

- Survey of applications

 of signal processing to music audio
 music synthesis
 music/audio processing (modification)
 music audio analysis
- Connect basic DSP theory to sound phenomena and effects
- Hands-on, live investigations of audio processing algorithms
 using Matlab, Pd, ...

Course Structure

Two weekly sessions

• Monday:

presentations, practical exposition, discussion

• Wednesday:

presentations, practical, sharing

• Grade structure

- 20% practicals participation
- 10% one presentation
- 30% three mini-project assignments
- 40% one final project

Flipped Classroom

 Video Lectures are required viewing before Monday session

• 30-50 mins each

• recorded in 2013

• bring one question (at least) to class

• pop quizzes



Hands-on Practicals

- Music Signal Processing involves connecting algorithms with perceptions
- Our goal is to be able to 'play' with algorithms to feel how they work
 In class, on laptops, in small groups
- We will use several platforms:



Python

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Projects

There will be 3 "mini projects" assigned approx. week 3, week 5, week 7

• provide basic pieces, but open-ended

• involve implementation & experimentation

• Also, Final project

on a topic of your choice
implement some kind of music signal processing
due at end of semester

• Good projects ...

• ... start with clear goals

- ... apply ideas from class
- ... evaluate performance & modify accordingly

• Could continue into summer...

Project Examples



• Beat Tracking

Mood
 Classification







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Presentations

- Everyone will make at least one in-class presentation
 - e.g. presentation of a relevant paper
 - ... or your latest mini-project
 - ... or just something you're curious about
- We will assign time slots first-come-first served
 - slots each class
 - check course calendar to choose a time
 email TA
- Encourage discussion

• informal presentations of practical findings





 Information distributed via: <u>http://www.ee.columbia.edu/~dpwe/e4896/</u>

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Department of Electrical Engineering - Columbia University ELEN E4896 - Spring 2016 MUSIC SIGNAL PROCESSING				
Home page	Announcements			
Course outline Code Practicals	2016-01-19 First lecture is tomorrow, Wednesday Jan 20th. Our classroom is 545 Mudd. The calendar within the <u>E4896 Courseworks page</u> shows the slots available to sign up for presentation. Please email the course assistant, Zhuo Chen, to reserve a slot as soon as possible.			
Assignments	General Information			
<u>Columbia</u> <u>Courseworks</u> <u>E4896</u>	Instructor:	Dan Ellis <dpwe@ee.columbia.edu> Schapiro CEPSR room 718</dpwe@ee.columbia.edu>		
	Instructor office hours:	Mondays 10:00-12:00		
	Course assistant:	Zhuo Chen <zc2204@columbia.edu></zc2204@columbia.edu>		
	CA office hours:	By appointment/TBA		
	Text:	We won't have a single text, but we will be using parts of: <u>DAFX: Digital Audio Effects (2nd ed.)</u> Edited by Udo Zölzer (ISBN: 978-0470665992, John Wiley & Sons, 2011)		

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Course Outline

Jan 20: Intro	Mar 07: Pitch tracking
Jan 25: Acoustics	Mar 21:Time & pitch scaling
Feb 01: Perception	Mar 28: Beat tracking
Feb 08: Analog synthesis	Apr 04: Chroma & Chords
Feb 15: Sinusoidal models	Apr II: Audio alignment
Feb 22: LPC models	Apr 18: Music fingerprinting
Feb 29: Filtering & Reverb	Apr 25: Source separation

• Anything missing?

2. Digital Signals



- $\bullet \ {\rm Sampling\ interval}\ T$
- Sampling frequency $\Omega_0=2\pi/T$
- Quantizer $Q(x) = \epsilon \cdot \operatorname{round}(x/\epsilon)$

Fourier Series

Observation: Any periodic signal can be constructed from sinusoids at integer multiples of the fundamental frequency $x(t) = x(t+T) \quad \Leftrightarrow \quad x(t) \quad \approx \sum_{k=1}^{\infty} a_k \cos(\frac{2\pi k}{T}t + \phi_k)$ k=0• E.g., square wave $\phi_k = 0; a_k = \begin{cases} (-1)^{\frac{k-1}{2}} \frac{1}{k} & k = 1, 3, 5, \dots \\ 0 & \text{otherwise} \end{cases}$



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Fourier Transform

• Complex form of Fourier Series + analysis

$$x(t) \approx \sum_{k=-M}^{M} c_k e^{j\frac{2\pi k}{T}t} \qquad c_k = \frac{1}{T} \int_{-T/2}^{T/2} x(t) e^{-j\frac{2\pi k}{T}t} dt$$

• Let $T \to \infty$

Harmonics become infinitely close:

$$x(t) = \frac{1}{2\pi} \int_{\infty}^{\infty} X(j\Omega) e^{j\Omega t} d\Omega$$
$$X(j\Omega) = \int_{\infty}^{\infty} x(t) e^{-j\Omega t} dt$$



• $x(t), X(j\Omega)$ are equivalent, dual descriptions

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Spectrum of Periodic Sounds

If sound is (nearly) periodic (i.e., pitched),
 Fourier Transform approaches Fourier Series

$$x(t) \approx \qquad x(t+T)$$
$$X(j\Omega) \approx \qquad \sum_{k} c_k \delta(\Omega - k \frac{2\pi}{T})$$



• n.b.: $|X(j\Omega)|$ plotted in log units: $dB(x) = 20 \log_{10}(x)$ Discrete-Time Fourier Transf. (DTFT)

• Sampled x[n] = x(nT) has same FT form

$$x[n] = \frac{1}{2\pi} \int_{-\pi}^{\pi} X(e^{j\omega}) e^{j\omega n} d\omega$$
$$X(e^{j\omega}) = \sum_{n=-\infty}^{\infty} x[n] e^{-j\omega n}$$

• ... but results in spectrum with period 2π :



Discrete Fourier Transform (DFT)

N-point finite-length sampled signal
 the kind you can have on a computer!

$$x[n] = \frac{1}{N} \sum_{k=0}^{N-1} X[k] W_N^{nk}$$
$$W_N = e^{-j\frac{2\pi}{N}}$$
$$X[k] = \sum_{n=0}^{N-1} x[n] W_N^{-nk}$$

• Just a matrix-multiply between vectors

$$\begin{bmatrix} X[0] \\ X[1] \\ X[2] \\ \vdots \\ X[N-1] \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & \cdots & 1 \\ 1 & W_N^1 & W_N^2 & \cdots & W_N^{(N-1)} \\ 1 & W_N^2 & W_N^4 & \cdots & W_N^{2(N-1)} \\ \vdots & \vdots & \ddots & \vdots \\ 1 & W_N^{(N-1)} & W_N^{2(N-1)} & \cdots & W_N^{(N-1)^2} \end{bmatrix} \begin{bmatrix} x[0] \\ x[1] \\ x[2] \\ \vdots \\ x[N-1] \end{bmatrix}$$

Short-Time Fourier Transform

To localize energy in time and frequency...
 chop signal into N-point windows every L points
 take DFT of each one



The Spectrogram

• Plot STFT |X[k, m]| as a grayscale image



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Time-Frequency Tradeoff

• Shorter window

 \rightarrow better resolution of time detail

→ worse resolution of frequency detail



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Spectrogram in Matlab



https://www.ee.columbia.edu/~dpwe/e4810/matlab/M14-fft.diary

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Live Matlab Spectrogram



http://www.wakayama-u.ac.jp/~kawahara/MatlabRealtimeSpeechTools/

2016-01-20 - 22/23

Summary + Assignment

Music Signal Processing

synthesis, modification, analysishands-on investigation

Course

• participation, practicals, projects, presentations

Digital Signal Processing

• signals on computers

• Fourier analysis & spectrogram

• Assignment

• Watch Acoustics video & prepare question

• Do Pd tutorial <u>http://en.flossmanuals.net/pure-data/</u> through to ''Amplitude Modulation''