Introduction
Overview

• A bit of motivation
  • Why audio computing, what is it?

• Class logistics and administrivia

• Overview of class syllabus
  • And short discussion on extra material to cover
A little quiz

• What do these companies have in common?
One more ...

- What do these commonplace technologies have in common?

- Digital Signal Processing
- Perceptual Coding
- Pattern Recognition
- p2p networking
- Collaborative filtering
The point is

• Audio is a major part of our life!
  • Music, telephones, radio, ultrasound, ...
  • It has changed the way we live

• It helps shape our society
  • Research innovations
  • Economic impact
    • Telecoms = $4.7T, Music = $70B, ...
How big is audio?

Top 40 videos, yellow entries are non-music

<table>
<thead>
<tr>
<th>Rank</th>
<th>Video name</th>
<th>Uploader/artist</th>
<th>Views (million)</th>
<th>Upload date</th>
<th>Notes</th>
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<tbody>
<tr>
<td>1.</td>
<td><em>Despacito</em>&lt;sup&gt;[X]&lt;/sup&gt;</td>
<td>Luis Fonsi featuring Daddy Yankee</td>
<td>4.69</td>
<td>January 12, 2017</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td><em>Shape of You</em>&lt;sup&gt;[X]&lt;/sup&gt;</td>
<td>Ed Sheeran</td>
<td>3.94</td>
<td>April 6, 2017</td>
<td></td>
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<td>4.</td>
<td><em>Put It Freestyle</em>&lt;sup&gt;[X]&lt;/sup&gt;</td>
<td>Mark Ronson featuring Bruno Mars</td>
<td>2.88</td>
<td>November 14, 2014</td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td><em>Sorry</em>&lt;sup&gt;[X]&lt;/sup&gt;</td>
<td>Justin Bieber</td>
<td>2.87</td>
<td>October 25, 2014</td>
<td></td>
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<tr>
<td>7.</td>
<td><em>Sugar</em>&lt;sup&gt;[X]&lt;/sup&gt;</td>
<td>Maroon 5</td>
<td>2.30</td>
<td>January 14, 2015</td>
<td></td>
</tr>
<tr>
<td>8.</td>
<td><em>Worth It</em>&lt;sup&gt;[X]&lt;/sup&gt;</td>
<td>Taylor Swift</td>
<td>2.48</td>
<td>August 16, 2014</td>
<td></td>
</tr>
<tr>
<td>12.</td>
<td><em>Blank Space</em>&lt;sup&gt;[X]&lt;/sup&gt;</td>
<td>Taylor Swift</td>
<td>2.17</td>
<td>November 14, 2014</td>
<td></td>
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<tr>
<td>13.</td>
<td><em>Dark Horse</em>&lt;sup&gt;[X]&lt;/sup&gt;</td>
<td>Katy Perry featuring Juicy J</td>
<td>2.21</td>
<td>February 14, 2014</td>
<td></td>
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<td>14.</td>
<td><em>Happy</em>&lt;sup&gt;[X]&lt;/sup&gt;</td>
<td>Pharrell Williams</td>
<td>2.15</td>
<td>October 23, 2013</td>
<td></td>
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<tr>
<td>15.</td>
<td><em>All About That Base</em>&lt;sup&gt;[X]&lt;/sup&gt;</td>
<td>Meghan Trainor</td>
<td>2.17</td>
<td>June 11, 2015</td>
<td></td>
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<tr>
<td>17.</td>
<td><em>Cheerleader</em>&lt;sup&gt;[X]&lt;/sup&gt;</td>
<td>Collapse feat. Sabrina Claudio</td>
<td>2.07</td>
<td>October 7, 2014</td>
<td></td>
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<tr>
<td>18.</td>
<td><em>Waves</em>&lt;sup&gt;[X]&lt;/sup&gt;</td>
<td>Get Motivated</td>
<td>2.06</td>
<td>November 14, 2014</td>
<td></td>
</tr>
<tr>
<td>19.</td>
<td><em>Waves on the Buoy</em>&lt;sup&gt;[X]&lt;/sup&gt;</td>
<td>Mtttk &amp; Blly flute</td>
<td>2.06</td>
<td>August 6, 2014</td>
<td></td>
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<tr>
<td>21.</td>
<td><em>This Is What You Came For</em>&lt;sup&gt;[X]&lt;/sup&gt;</td>
<td>Calvin Harris featuring Rihanna</td>
<td>1.88</td>
<td>June 16, 2016</td>
<td></td>
</tr>
<tr>
<td>24.</td>
<td><em>Charlie</em>&lt;sup&gt;[X]&lt;/sup&gt;</td>
<td>5SOS</td>
<td>1.78</td>
<td>May 6, 2014</td>
<td></td>
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<tr>
<td>28.</td>
<td><em>No I'm Not Sorry</em>&lt;sup&gt;[X]&lt;/sup&gt;</td>
<td>Ellie Goulding</td>
<td>1.65</td>
<td>January 28, 2015</td>
<td></td>
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<tr>
<td>29.</td>
<td><em>We Came To Party</em>&lt;sup&gt;[X]&lt;/sup&gt;</td>
<td>J Balvin &amp; Willy William</td>
<td>1.66</td>
<td>June 30, 2017</td>
<td></td>
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<td>30.</td>
<td><em>What Do You Mean</em>&lt;sup&gt;[X]&lt;/sup&gt;</td>
<td>F Fitz Harmony featuring Ryn Stock</td>
<td>1.52</td>
<td>March 26, 2015</td>
<td></td>
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<tr>
<td>31.</td>
<td><em>Faded</em>&lt;sup&gt;[X]&lt;/sup&gt;</td>
<td>Alan Walker</td>
<td>1.50</td>
<td>December 28, 2015</td>
<td></td>
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<td>32.</td>
<td><em>Cold</em>&lt;sup&gt;[X]&lt;/sup&gt;</td>
<td>Shaem</td>
<td>1.49</td>
<td>July 16, 2015</td>
<td></td>
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<tr>
<td>33.</td>
<td><em>Lose The Way You Lie</em>&lt;sup&gt;[X]&lt;/sup&gt;</td>
<td>Eminem featuring Rihanna</td>
<td>1.46</td>
<td>August 26, 2010</td>
<td></td>
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<tr>
<td>34.</td>
<td><em>Watch Me (Whip/Nae Nae)</em>&lt;sup&gt;[X]&lt;/sup&gt;</td>
<td>Silento</td>
<td>1.45</td>
<td>June 20, 2015</td>
<td></td>
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<td>35.</td>
<td><em>Faded</em>&lt;sup&gt;[X]&lt;/sup&gt;</td>
<td>Alan Walker</td>
<td>1.45</td>
<td>December 3, 2015</td>
<td></td>
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<td>36.</td>
<td><em>We Made It</em>&lt;sup&gt;[X]&lt;/sup&gt;</td>
<td>J Balvin</td>
<td>1.44</td>
<td>August 29, 2014</td>
<td></td>
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<tr>
<td>37.</td>
<td><em>We Made It</em>&lt;sup&gt;[X]&lt;/sup&gt;</td>
<td>J Balvin</td>
<td>1.43</td>
<td>July 29, 2013</td>
<td></td>
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</table>
Why should you care?

• This class is about preparing you for all that
  • How do you handle/analyze/process/synthesize sound
  • How to innovate using sound technologies

• Skills we will cover:
  • Technical background for audio technologies
  • How to implement many commonplace technologies
  • How to perform a little bit of research on audio
So what do we do in audio?

• Very broad subject!
  • Physical audio technologies
    • Design of microphones, speakers, symphony halls!
  • Electrical audio technologies
    • Analog transmission and storage, analog manipulation
  • Digital audio technologies
    • Synthesis, analysis, compression, streaming

• Audio/Acoustic engineers make audio technologies that we all use everyday
A brief tour of audio history

- Long time ago ...
  - Pythagoras (music), Vitruvius (architectural acoustics)

- Some time ago ...
  - Gallileo (vibrating strings), Mersenne (speed of sound)

- A little later ...
  - Helmholtz (physiology), Raleigh (theory of sound)
A brief tour of acoustic history

• The electrical age
  • Ohm, Henry, Wheatstone (electricity / acoustics connection)

• The phone and radio age!
  • Bell, Marconi

• Recording
  • Edison (phonograph), Berliner (gramophone)
Modern audio technologies

• Tape machines, audio studios
  • The Walkman, multi-track tape recording

• Digital audio devices
  • iPods, MP3 players, audio recorders, hearing aids

• Telephone and speech technology
  • Cell phones, speech recognition, speech synthesis
Use of audio technologies today

- **Entertainment**
  - Radio, TV, music playback, music synthesis

- **Medicine and biology**
  - Ultrasound, hearing aids, bioacoustics

- **Monitoring**
  - Ocean mapping, noise measuring, surveillance

- **Acoustic optimization**
  - Making quieter cars, planes, boats, better rooms
More than meets the eye!
Who’s teaching?

- Paris Smaragdis (me)
  - paris@illinois.edu
  - CS & ECE depts.
  - Office: Siebel 3231
    - Send me email to meet

- Have been doing research on audio since tapes were around!
Who else will you see here?

- Cem Subakan
  - subakan2@illinois.edu
  - CS dept. Ph.D. student

- Shrikant Venkataramani
  - svnktrm2@illinois.edu
  - ECE dept. Ph.D. student

- Both will help in Thursday sessions
  - They are not TAs!
Workload

- Tuesdays will be lecture days
  - Each week will have a different theme
  - I’ll provide all the reading material and lecture on the theory

- Thursdays will be lab(ish) days
  - Bring your laptop in, have iPython/Jupyter installed on it
  - We will learn how to code Tuesday’s material
  - By the end of this class you will be able to code most common audio processing operations
Grading

- Lab assignments: 80%
  - We will have about 10 labs
  - We will not count your two worst performances
    - More on the grading process later

- Attendance/involvement: 20%
  - It helps if we know who you are!
    - Be active in class, ask questions, bring fun problems!
Class web page

- Available at:
  - https://courses.engr.illinois.edu/cs498ps3/

- Will upload slides/reading material/labs
  - Usually right after class

- Will also setup piazza (offline help)
  - And Slack (for online help during Thursdays)
What should you (sort of) know?

- Basic high school acoustics
  - Waves, frequencies, properties, etc.
    - We’ll review most of these

- Some calculus, trig, and linear algebra
  - We’ll review as needed

- Some programming
  - Use whatever language you want (Python is best)
    - We will have a short review on Thursday
Getting some class stats

- Any non-CS students?

- Taken any relevant classes?
  - ECE310/402?

- What do you want to learn from this class?
  - How do you use sound/acoustics in life/research?
  - What material would you like to cover?
    - Topic likes/dislikes?
Class syllabus

• This is a new class!
  • We are going for breadth, not depth
    • If you really like audio you should also take: ECE310 & ECE402

• The syllabus is still flexible
  • Please let me know what you would like to see in lecture
Overall syllabus structure

- Introduction material – 2-3 weeks
- Themed lectures – ~10 weeks
  - Room and spatial acoustics, 3D audio, noise/denoising, musical acoustics, MIR, pitch detection and correction, music transcription, speech acoustics and recognition, psychoacoustics and audio coding
- Custom lectures – about 2 weeks
  - What audio technology do you want to learn how to do?
Week 2 – Basic digital signal processing

- Why? Cause everything is digital nowadays
- Material to cover:
  - Discrete signals
    - Sample rates and resampling
  - Representations of discrete signals
    - Waveforms, DFTs, spectrograms
  - Analog to digital to analog conversions
  - Audio processing chains
    - Linear, shift-invariant systems
Week 2 – Lab objectives

- Read/write audio on disk and from ADC/DAC
- Implement a real-time audio loop
- Implement a spectrogram
- Visually represent and examine sounds
Week 3 – Filters, design and usage

• Why? Most audio processing is filtering

• Topics to cover:
  • From resonance to filtering
    • What is linear filtering?
  • How do we design a filter?
    • Various types of filters
  • When do we use filters?
    • Some real-life examples
  • Equalization
Week 3 – Lab objectives

• Design of basic filter types
  • Lowpass, highpass, bandpass, bandreject

• Design of custom response filters

• Design an audio equalizer

• Design a simple denoiser using filters
Week 4 – Mics and Mic Arrays

• Why? Commonplace devices and really cool!

• Topics to cover:
  • Basic array theory
    • ULAs
  • Localization
    • Single-source
  • Beamforming
    • Multi-source localization
Week 4 – Lab objectives

- Design a simple microphone array
- Find where a sound is coming from
  - e.g. localize gunshots
- Enhance a sound coming from a specific direction
  - e.g. for speech denoising from a cell phone
Week 5 – Rooms and reverberation

• Why? It is in every music recording you have!

• Topics to cover:
  • How do we make reverberation
    • Simple filter structures, long convolutions
  • How do we emulate a room?
    • Source-image models
  • How do we remove reverb from recordings?
Week 5 – Lab objectives

• Learn how to simulate a reverb
  • Using simple filters
  • Using measured impulse responses

• Measure the impulse response of a room

• Create a virtual room recording
Week 6 – Spatial (3D) Audio

- Why? Cause 3D audio is useful for AR/VR (and cool!)
- Topics to cover:
  - Designing a simple 3D audio system
    - Making use of ITDs and ILDs
  - Measuring and using HRTFs for 3D audio
  - Why your laptop’s 3D audio sucks
    - And how you can try to make it better
Week 6 – Lab objectives

- Spatialize sounds
  - i.e. make 3D audio files with sounds moving around your head

- Measure Head-Related Transfer Functions
  - Make custom filters to make 3D audio for a specific person
Week 7 – Noise measurement & removal

• Why? Because nobody likes noise

• Topics to cover:
  • Single-channel noise reduction systems
    • Wiener filters, Spectral subtraction
  • Multi-channel systems
    • Simple two-channel denoising
  • Microphone array methods
Week 7 – Lab objectives

- Remove noise from monophonic recordings
  - Spectral subtraction

- Remove noise from multichannel recordings
  - Steer an array to a target signal in space
  - Use of a secondary mic in cell phones
Week 8 – Pitch

• Why? Pitch is a dominant feature of sound

• Topics to cover:
  • Pitch tracking
    • Monophonic and polyphonic

  • Pitch modifications
    • Pitch-shifting
    • Autotuning
Week 8 – Lab objectives

- Design a pitch tracker to transcribe monophonic music
- Design an real-time auto-tuner to fix bad singing!
Week 9 – Classification and MIR

- Why? Cause understanding audio is big business
- Topics to cover:
  - Basic features and tools for classification
    - Basic machine learning tools
  - Genre/artist identification
  - Audio fingerprinting
  - Simple music recommender systems
Week 9 – Lab objectives

• Learn how to detect certain types of sounds

• Learn how to recognize the style of music of a file
  • And potentially the artist too

• Implement a Shazam-type system
Week 10 – Speech & speech recognition

- Why? Important function for many devices
- Topics to cover:
  - How do we synthesize speech?
  - Basic machine learning tools for speech
  - How do we model a speech sound
  - Basic DTW methods
    - Keyword recognition
  - Principles of speech recognition systems
Week 10 – Lab objectives

• Make a speech detector
• Design a simple speech recognizer
• Design a male/female speech classifier
Week 11 – Audio Restoration

• Why? Because we have lots of bad recordings!

• Topics to cover:
  • How to CD’s deal with scratches?
  • How do we remove artifacts from ancient archived recordings?
  • How do we make up data when the internet radio stream drops?
Week 11 – Lab objectives

• Remove clicks from a poor-quality recording

• Make up missing data from a bad real-time stream
  • e.g. missing a second of sound from an internet radio
Week 12 – Spectral Factorization methods

• Why? They are very useful tools for many tasks
• Topics to cover:
  • Simple polyphonic transcription
  • Basic models for source separation
  • Resampling by example
  • Novel audio interfaces
Week 12 – Lab objectives

• Perform source separation on a recording of two simultaneous speakers

• Simple polyphonic transcription
Week 13 – Audio Compression

• Why? Because sound is mostly redundant

• Topics to cover:
  • Lossless compression of sound
  • How do we game hearing to compress sound
    • What can we throw away?
  • How does lossy compression of sound work
  • How do MP3’s work?
Open subjects

• We have about 2-3 weeks for any subject you like
  • Will look at popular audio editors and implement what we skipped

• What else would you like to see?
  • Some options:
    • Machine learning for audio processing and analysis
    • Music synthesis
    • Real-time audio processing
      • e.g. effects for audio
    • ...?
Next class

• Python refresher and audio basics lab
  • Basic Python processing
  • Basic audio I/O using Python
    • And some fun experiments with sound

• Bring your laptop and a pair of headphones!
An (ungraded) assignment

• Send me email on what you think is important
  • paris@illinois.edu

• What audio technology do you find exciting?

• What do you want to learn how to do?