Slide 1

ESE

Finish preclass.
Submit Learning Style Form
Lecture starts 12:05pm

Lecture #1 - Course Introduction / Intro to Digital Audio

ESE 1500 –
DIGITAL AUDIO BASICS

Based on slides © 2009-2023 DeHon
Additional Material © 2014-2017 Farmer

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Slide 2

LECTURE TOPICS

- **History & Motivation**
  - Computing and Digital Audio
- **Overview of Class Schedule**
  - Big picture of our class goals
- **Course Introduction / Goals of Class**
  - Syllabus; Laboratory; Grading
- **Course Content Overview**
- **PART 2 (as time permits)**
- **Quick Week-by-week breakdown of class itself**
- **Summary**

2

Slide 3

History & Motivation
Short Story / Overview
Course Introduction
Learning Styles
Long Story / Intro to Sound
Summary

HISTORY & MOTIVATION

3

Slide 4

POLL

- **Believe I can assume you use a cell phone and GPS**
- **How do you obtain music?**
- **Communicate with friends outside of school?**
  - Voice phone, e-mail, text message, facebook, skype?
- **Where do you go to find answers?**
  - Google, wikipedia

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Slide 5

CHANGING WORLD

Moore's Law: The number of transistors on microchips doubles every two years
Moore's law describes the empirical regularity that the number of transistors on integrated circuits doubles approximately every two years. This advancement is important for other aspects of technological progress in computing – such as processing speed or the price of computers.

Transistor count

By Max Roser, Hannah Ritchie - https://ourworldindata.org/upload s/2020/11/Transistor-Count-over-time.png, CC BY 4.0, https://commons.wikimedia.org/w/index.php?curid=98219918

- **Moore's Law:** Every 18 months, size of transistor halved
  - Who cares?
    - In same area, can fit twice as many transistors, twice the computing power!
    - Also, generally: if you make a transistor smaller, it gets a bit faster
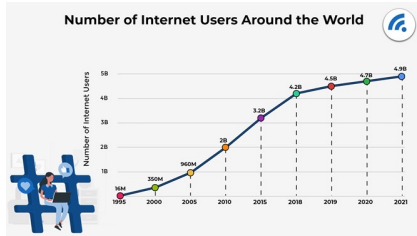   - …up to a point…

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Slide 6

CHANGING WORLD

- **Moore's Law**
- **Internet Grew**

Internet Hosts Count

By Kopiersperre , Ke4roh - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=36391402

6

CONNECTING THE WORLD

Number of Internet Users Around the World

Source: https://www.broadbandsearch.net/blog/how-people-use-the-internet
How People use the Internet

7

IN YOUR LIFETIME…

- 1998: Google, PayPal, First commercial MP3 player
- 2001: iPod, Wikipedia launched
- 2002: Go Pro launched
- 2003: iTunes launched, Skype released, Tesla launched
- **2004: Facebook launched**
- **2005: YouTube launched**
- **2006: Twitter launched, DJI launched**
- **2007: iPhone introduced, Hulu launched, Netflix add video streaming**
- **2008: Bitcoin, Spotify**
- **2009: Venmo**
- **2010: Instagram**
- **2011: Siri, Snapchat, Google driverless cars, Uber, Zoom**
- **2012: Makerbot Replicator, Tinder launched**
- **2013: Google Glass**
- **2014: Amazon Alexa**
- **2015: iWatch**
- **2016: AirPods, Pokemon Go, Oculus Rift**
- **2017: Tik Tok**
- **2019: Disney+, Apple+**

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COOL STUFF OF TODAY…

- Today's "must have" technology is:
  - computerized, networked, and based on digital media
- Cell phones
- MP3 players (Digital Audio Players)
  - Internet enabled
- Digital cameras and video recorders (part of phones!)
- Realistic Video Games
- DVRs (e.g. TiVo), Streaming (Netflix, Disney+)
- E-book readers (e.g. Kindle)
- Integrated (e.g. iPhone, iPad)
- 3D printers (e.g. Makerbot)
  - Circuit Scribe – draw actual circuits, electric ink!
  - Replicator…
- Augmented Reality (e.g. Jedi Challenge, Pokemon-Go, Oculus)
  - Holodeck…

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WHAT MAKES US SAFER, LIVE LONGER?

- **Transportation**
  - Anti-lock brakes
  - Traction control
  - Blind-side assist
- **Watch over**
  - Security cameras
  - Baby monitors
- **Medical Devices**
  - Ultrasound
  - MRI
  - DNA sequencing
  - Pacemakers

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WHAT DO THESE THINGS INVOLVE?

- **Computation**
- **Communications**
- **Hardware**
- **Substantial Software**

- **➔ Products of Computer Engineers**

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CHANGING WORLD: SMALL WORLD

- **Ubiquitous Internet**
  - This changed everything
  - Smartphone always connected
- **Facebook**
  - Allowed us instantly find (stay in touch with) anyone!
  - United the world in many ways
- **Zoom**
  - Hold classes remotely in pandemic
    - With students on all continents!

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2

CHANGING WORLD: EASY SHARING

- Easy Instant sharing and storage
- Photos, videos, writing
- Web, Facebook, Youtube, Blogs, Twitter, Tik Tok
- Backed up, Cloud
- Accessible anywhere in the world
- Indexed and searchable
- Can carry it with you

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CHANGING WORLD: INSTANT GRATIFICATION

- **Search engines**
  - Instant access to knowledge
- **iTunes/Spotify**
  - Instant access to music/casts/apps/video too
- **Streaming video**
  - Instant access to video/news/visual information
  - Internet services/Netflix/Hulu/YouTube/On-Demand/etc.
- **Amazon.com**
  - Instant access to nearly any product, ~drone delivery!

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CHANGING WORLD: NEW WEALTH, NEW PLAYERS

- **Microsoft founded 1975**
  - World's richest man…for a while (currently 5)
- **Apple founded 1976**
  - Highest valued company
- **Oracle 1977**
- **CISCO 1984**
- **TSMC 1987**
- **NVIDIA 1993**
- **Amazon.com 1994**
  - Rrichest man (currently 4)
- **E-Bay 1995**
- **Google, Netflix, PayPal 1998**
- **Tesla 2003**
  - Was richest man for a while… (some still list as 1 or 2)
- **Facebook (Meta) 2004**
- **Twitter 2006**
- **Bitcoin 2008**
- **Venmo 2009**

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CONVERGENCE

- **Big Ideas and Advanced Technology**
  - Digitize Everything
  - Cheap Digital Processing
  - Cheap Storage
  - Cheap Digital Bandwidth
- **Driven by Moore's Law**
  - Store and compute more bits per $$

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ENABLED BY VISIONARY ENGINEERS

- **Hard work, inspiration, and competition**
  - …would not have just happened
  - Certain applications/products tie many things together
    - No one realized facebook/music would be "killer app" for smartphone revolution
- **Most inconceivable just prior**
  - Compare how archaic the "future" looks in most movies just 20 years old
- **What's next?**
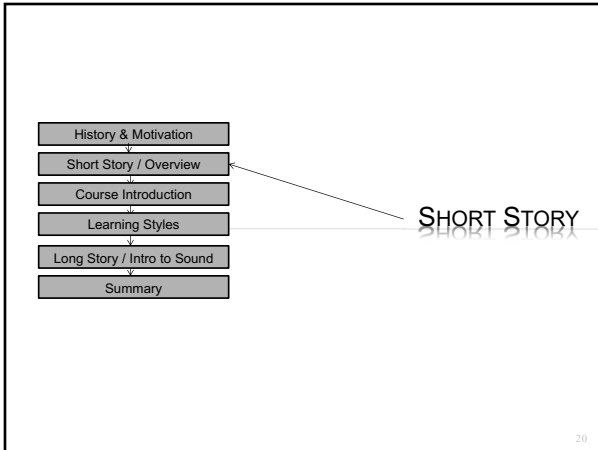- **How can we harness to make the world better?**

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BEFORE GOING ON…CALIBRATION:

- **What is a bit (a Binary Digit)?**
  - Smallest piece of information we can store (on/off)
  - Indicates true or false
- **How many bits in a byte?**
  - 8
- **Bytes in a Kilobyte?**
  - 2^{10} x 1 byte = 1024 bytes
- **Bytes in a Megabyte?**
  - 2^{10} x 1KB = 1,048,576 bytes
- **Bytes in a Gigabyte?**
  - 2^{10} x 1MB = 1,073,741,824 bytes
- **How many Bytes to store a typical song?**

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3

Slide 20

History & Motivation
Short Story / Overview
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SHORT STORY

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Slide 21

VIRTUALIZATION OF THE WORLD

- **Can represent things as bits**
  - sound, pictures, movies
  - location, situation, …
  - shapes, circuits, drugs, DNA
- **Cheap/powerful ways to automatically manipulate**
  - …and reproduce

https://www.youtube.com/watch?v=lAcYUt2QbAo

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Slide 22

CLASS STORY: ONE SLIDE

sample — freq — pyscho-acoustics — Compress

domain conversion

- **Sound can be converted to/from bits**
  - and compressed, without loss of information
- **More information can be discarded without humans noticing → fewer bits**
- **Process this information with inexpensive machines**
  - Store it for retrieval
- **Send it between machines**
  - Even if not directly connected

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Slide 23

COURSE MAP

7,8,9   10101001101

MIC   CPU   A/D

Music   1

Numbers correspond to course weeks

sample 2   freq 4   pyscho-acoustics 3   compress 5,6

1010100110   NIC

Cloud

13   EULA --------- --------- *click OK*

D/A   NIC   10

speaker   12

MP3 Player / iPhone / Droid

domain conversion

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Slide 24

History & Motivation
Short Story / Overview
Course Introduction
Learning Styles
Long Story / Intro to Sound
Summary

COURSE INTRODUCTION

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Slide 25
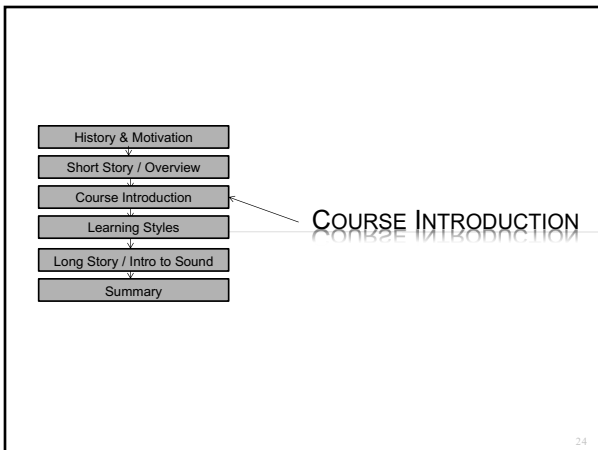
ABOUT THE COURSE   ESE150

Compression, MP3s, Psychoacoustics, and Everything

- **ESE 1500: Digital Audio Basics**
  - But really: "Introduction to Computer Engineering"
- **Our Goals:**
  - Give you broad context for Computer Engineering
    - Each week full course on later; 13 different courses!
  - Expose you to the *big* topics in Computer Engineering
    - You won't like them all…but you will probably love 1 or 2!
    - Help you figure out which path in Comp. Eng. to take
  - Use digital audio as common theme between lectures
    - This information goes way beyond digital audio
  - Tie theory to practice ("feel-the-bits") through a weekly lab
    - To see concepts discussed in lecture in a lab environment

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MECHANICS OF THE CLASS

- **Monday, Wednesday: Lecture**
  - Introduce concepts (theory)
  - Help paint the big picture
- **Monday: Lab**
  - Put theory into practice
  - Apply 1 big concept in real world
    - Many concepts may appear in lecture…
    - One will be put to use in guise of digital audio in the lab
  - Work in teams of 2
  - Individual lab report write-ups
- **Monday: Lab Report due**

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LECTURE TIMELINE

- **Preclass available beginning of lecture**
  - Generally before 11:55
- **12:05pm – actual start lecture**
- **12:55pm – target end lecture**
- **Complete lecture quiz within 48 hours**
  - Wednesday lecture → by Friday
  - Monday lecture → before Wednesday lecture

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GRADING

- **10% - Class Participation and Quizzes**
  - Per lecture quiz: Based on lecture content
- **50% - Weekly Lab Report Writeup**
  - Work in groups of 2 (we assign and mix up week-to-week)
  - Labs have "prelab" work to do – counted as part of lab writeup
  - Drop lowest score on attempted labs
- **20% - Formal Lab Report**
- **5% - Midterm Exam**
  - Warmup for final
- **15% - Final Exam**
  - Based on reading material, lecture material, lab work
- **Read web page for policies**
  - Not hard, but must show up, engage, do the work

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COMPONENTS

- **Lecture slides online morning of lecture**
  - Probably night before
- **Big Idea – 1p'er for every week**
- **Reading**
- **Preclass – available at beginning of lecture**
  - Work through to get you thinking about the topic
  - …and gives you some of the questions will ask in lecture
  - Won't be available later; stay up with class
- **"Warm" Calls**
  - Promote interaction/engagement
- **Feedback forms**
  - Complete at end of lecture (or after watch)
  - Help me tune lecture for class

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CLASS GOALS

- **Context and motivation for CMPE major**
- **Appreciate how CMPE, EE, CSCI, SSE:**
  - Work together
  - How they impact today's world
- **Start thinking like an engineer!**

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OUTCOMES

- **Able to conduct experiments**
  - Psychoacoustic, network, hardware
- **Able to optimize information encoding**
- **Able to quantify quality vs. size tradeoffs in audio**
- **Able to use oscilloscope, matlab, Arduino, FPGA**
- **Able to write formal lab report**
- **Understand role of Intellectual Property**
- **Appreciate User Interface design**
- **Understand technology enables new capabilities**

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Slide 32

ESE150

Compression,
MP3s,
Psychoacoustics, and
Everything

END PART 1

Slide 33

- History & Motivation
- Short Story / Overview
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LEARNING STYLES

(INTERLUDE)

Slide 34

DIMENSIONS

- **Active (ACT) vs. Reflective (REF)**
  - Doing vs. thinking
- **Sensing (SEN) vs. Intuitive (INT)**
  - Facts and methods vs. abstractions and innovation
- **Visual (VIS) vs. Verbal (VRB)**
  - Pictures, diagrams vs. descriptions
- **Sequential (SEQ) vs. Global (GLO)**
  - Linear steps vs. context and connections

See reading link on syllabus.

Slide 35

HOW DO PEOPLE COME OUT?

- **Create Histogram**
- **How I came out…**
- **Count numbers by students:**
  - Bin: 9+, 8-4, 3-1, 0, 1-3, 4-8, 9+
- **Histograms:**
  - Active/Reflective
  - Sensing/Intuitive
  - Visual/Verbal
  - Sequential/Global

Slide 41

AWARE OF DIFFERENCES

- **Differences among people**
- **Differences between faculty and students?**
  - Claim college courses are biased toward:
    - Reflective, intuitive, verbal, sequential
- **This course:**
  - Active, sensing?, visual, global
- **Read explanation**
  - Being aware and how to cope useful for navigating all your courses at Penn

Slide 42

Part 2

- History & Motivation
- Short Story / Overview
- Course Introduction
- Learning Styles
- Long Story / Intro to Sound
- Summary

LONG STORY

WEEK 1 & WEEK TO WEEK

Skip to wrapup

WEEK 1: INTRODUCTION TO SOUND

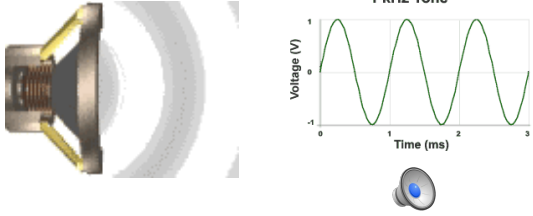× **Sound is a pressure wave**

http://www.archive.org/details/SoundWavesAn

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WEEK 1: INTRODUCTION TO SOUND WAVES

Cycle = 1 iteration of sine wave
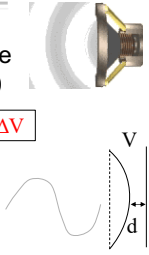Hertz (Hz) = 1 cycle per second

1kHz = 1000 cycles/s

1 kHz Tone

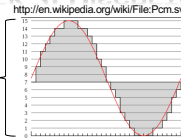Source: http://www.mediacollege.com/audio/01/sound-waves.html

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WEEK 1: PRESSURE TO VOLTAGE

× Microphones convert pressure to voltage
  + (speakers/headphones voltage to pressure)
  + Physical position to voltage

$\Delta d \rightarrow \Delta C \rightarrow \Delta V$

× Reason as parallel plate capacitor
  + ESE 112 or PHYS 151

$$C = \frac{\varepsilon A}{d}$$

$$Q = CV \qquad V = \frac{Q}{C}$$

45

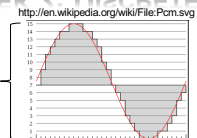## WEEK 2: DISCRETE SAMPLING

http://en.wikipedia.org/wiki/File:Pcm.svg

Discrete Voltage Levels

http://en.wikipedia.org/wiki/File:Compact_disc.svg

× **Voltages can be sampled discretely**
  + Both in time and amplitude
× **How many bits to represent one of 16 discrete values?**
× **In general: 1 of N discrete values?**
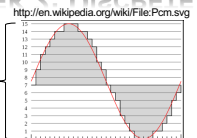× **Alternately: B bit number can represent how many things?**

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WEEK 2: DISCRETE SAMPLING

http://en.wikipedia.org/wiki/File:Pcm.svg

Discrete Voltage Levels

http://en.wikipedia.org/wiki/File:Compact_disc.svg

× **Voltages can be sampled discretely**
  + Both in time and amplitude
× **In general: 1 of N discrete values?**
× **Alternately: B bit number can represent how many things?**
× **N=2^B**   **B=$\lceil$log$_2$(N)$\rceil$**

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WEEK 2: DISCRETE SAMPLING

http://en.wikipedia.org/wiki/File:Pcm.svg

Discrete Voltage Levels

http://en.wikipedia.org/wiki/File:Compact_disc.svg

× **Voltages can be sampled discretely**
  + Both in time and amplitude
× **Can turn sound wave into sequence of bits**
  + 0111 1001 1011 1100 1101 1110 1110 1111 1111 ….
× **What precision do we need?**
  + Compact Disks: 16bits at 44KHz
    × How many bits is a typical 3-minute song?

$$\left(44{,}000 \; \frac{samples}{1\,sec}\right)\left(16 \; \frac{bits}{sample}\right)\left(60 \; \frac{sec}{1\,min}\right)\left(3 \; \frac{min}{song}\right) = 126{,}720{,}000 \; \frac{bits}{song} = 15{,}840{,}000 \; \frac{bytes}{song} = 15.1 \; \frac{MB}{song}$$

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WEEK 3: LOSSLESS COMPRESSION

Enables: Kindle to store 1500 books in 2GB, SMS text

http://en.wikipedia.org/wiki/File:English-slf2.PNG

- × **Statistics of data allow compression**
- × **If all symbols (characters, voltages) aren't equally likely,**
  - + Can assign shorter bit sequences to most common cases
  - + and reduce bits required to store or transmit!
- × **Famous Example of statistical storage: Morse Code:**
- × **THE = — • • • •   •   = 6 symbols   (not 18 as you might expect)**

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WEEK 4: TIME-FREQUENCY CONVERSION

- × **There are other ways to represent**
  - + Frequency representation particularly efficient

392   311   348   294

Frequencies in Hertz

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WEEK 5: PSYCHOACOUSTICS

The Theory behind MP3

http://www.mp3-tech.org/programmer/docs/mp3_theory.pdf

http://en.wikipedia.org/wiki/File:Pcm.svg

- × **Human input apparatus is limited**
- × **If we only care about human perception**
  - + …that reduces the information needed (reduces samples/sec)
- × **Limited maximum frequency**

55

WEEK 2: NYQUIST-SHANNON

- × **Sampling Theorem:**
  - + Only need to sample 2 x maximum frequency component of a signal
- × **Range of human hearing?**
  - + 20 Hz → 20 kHz
- × **How many samples?**
  - + 2 x 20 kHz = 40 kHz
- × **CD samples /sec:**
  - + 44,000 Samples / sec

The Theory behind MP3

http://www.mp3-tech.org/programmer/docs/mp3_theory.pdf

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WEEK 6: PSYCHOACOUSTIC COMPRESSION

- × **MP3 based on putting these together**
  - + Convert to frequencies
  - + **Determine frequencies that don't matter**
  - + Quantize (fewer than 16b) for less important
- × **Significantly smaller size than raw, sampled bits**

Bands

Q_1 Q_2 Q_3 Q_4 Q_5 … Q_{k-1} Q_k Q_{k+1} … $Q_{n/k}$

1   2   …   k   …   22

Lossy Coding

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COURSE MAP: WEEK 6

MIC

A/D

Music

①

Numbers correspond to course weeks

domain conversion

sample   **freq**   **pyscho-acoustics**

②   ④   ③

5,6

compress

D/A

speaker

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WEEK 7: HARDWARE

- CPUs: We'll look at their operation and architecture

- **How fast does your laptop or cell phone run?**

- Modern chips run 100MHz to 4 GHz
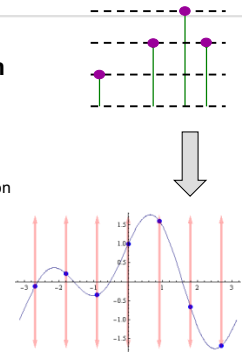 - → only need one multiplier, adder
  - Reuse hardware it in time
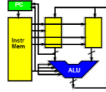
61

61

WEEK 8: HARDWARE

- **To perform decompression**
  - For audio playback
- **Need to perform**
  - a few million operations
    - Operations addition, multiplication
      - Calculate cosines
      - Scale values
      - Add waveforms
  - per second of audio
- How fast does CPU need to be to work with audio?

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WEEK 8: IPOD PROCESSOR

- **Early based on PortalPlayer series**
  - Two ARM7TDMI cores
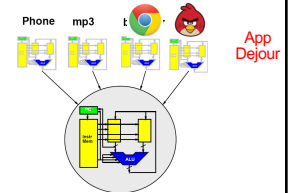 - 80MHz each
- **Current use ARM7 or ARM8**
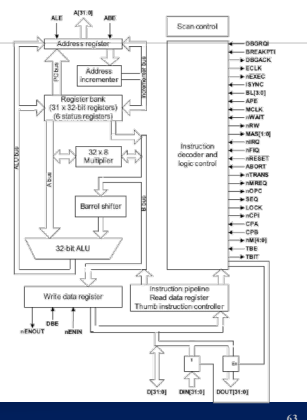
63

63

WEEK 9: OPERATING SYSTEM

- This hardware can be virtualized and shared among tasks
  - How does OS control hardware?
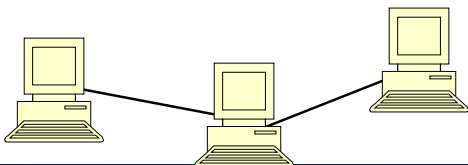 - Do we need giant OS or small portion for mp3?

Phone   mp3

App Dejour

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WEEK 10: NETWORKING

- **Bits can be transported between machines**
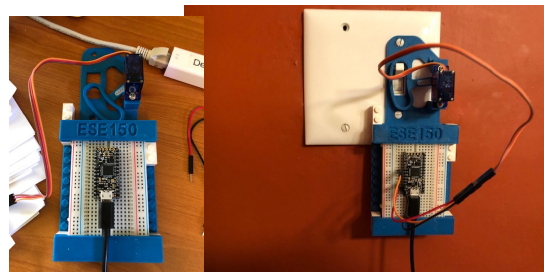 - How fast must network speed to be to stream audio?

66

66

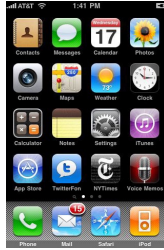## WEEK 11: ACTUATION

- How reach out and touch the world?

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68

9

WEEK 12: USER INTERFACES

- **These capabilities can be harnessed by all people**
  - Not just engineers
- **…but we must designed for people**
  - For the non-engineers
- **iPhone is a classic example:**
  - product that didn't do anything new
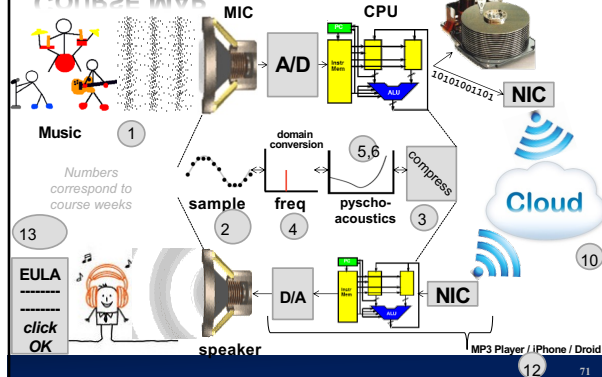 - BUT, it made everything simple
  - thanks to well designed UI

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WEEK 13: INTELLECTUAL PROPERTY

- **Who own's the bits?**
- **What is the law?**
- **Why is the law?**
- **Why should you care (as engineers)?**
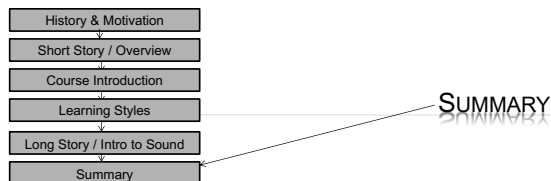- **How is the world changing?**

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COURSE MAP

7,8,9   10101001101

MIC   CPU
A/D
10101001101
NIC

Music   1
Numbers correspond to course weeks
domain conversion
5,6
compress
sample   freq   pyscho-acoustics
2   4   3
13
EULA

----
click OK
Cloud
10
D/A   NIC
speaker
MP3 Player / iPhone / Droid
12

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ESE150

Compression,
MP3s,
Psychoacoustics, and
Everything

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History & Motivation
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SUMMARY

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THIS COURSE

- **Always trying to improve:**
  - Attempts to explain a great deal of Computer Engineering
    - Without going to far in depth
  - Lecture/Lab
    - Intent is to tie them together well
    - Inevitably, the tie won't always be obvious
  - Help us, help you (and future students):
    - The more feedback you provide, the better we can make this course
    - If a tie isn't obvious, let us help make the connection stronger
    - We want you to love Comp Engineering as much as we do ☺
  - One form: daily feedback forms (link on syllabus)

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CHANGING WORLD

- **Automated computation changed world**
  + Faster than we imagined
- **World being digitized and refitted for computerized control and mediation**
  + People-to-people, people-to-machines
  + Infrastructure from bricks/concrete/steel to networking/computers/software
- **Enabling new engineering**
  + Computerization at center
- **Exciting and dangerous**
- **Computer Engineering at center**

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75

PARTING THOUGHT

- **From 1st computer to PCs in 30 years**
  + Eniac 1946→ Apple 1976
- **From first PCs to iPhone next 30 years**
  + Apple 1976→iPhone 2007
- **What will next 30 years hold?**
  + Beginning of your career
- **What will you imagine, create, enable?**

Monday MLK holiday – next lecture Wed. 1/18.

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