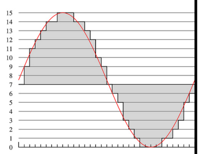
Penn Engineering

ESE

Finish preclass.
Submit Learning Style Form
Lecture starts 9:05am



Lecture #1 - Course Introduction / Intro to Digital Audio

ESE 150 – DIGITAL AUDIO BASICS

Based on slides © 2009-2021 DeHon
Additional Material © 2014-2017 Farmer

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
- Quick Week-by-week breakdown of class itself
- Summary

- History & Motivation
- Short Story / Overview
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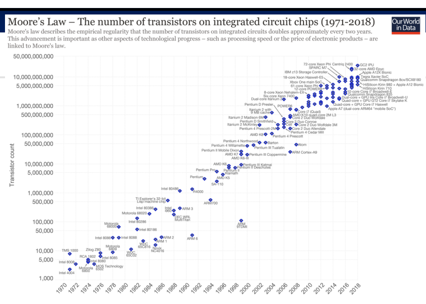
HISTORY & MOTIVATION

POLL

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

CHANGING WORLD

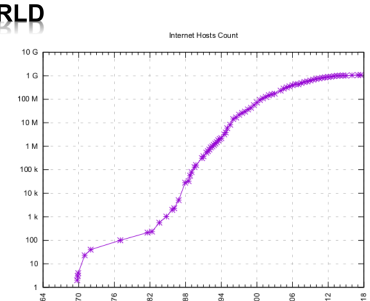


https://commons.wikimedia.org/wiki/File:Moore%27s_Law_Transistor_Count_1971-2018.png

- **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…

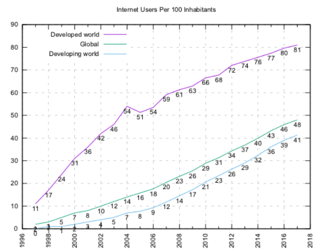
CHANING WORLD

- Moore's Law
- Internet Grew



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

Connecting the World



By Jeff Ogden (W163) and Jim Scarborough (Ke4roh) - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=18972898

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**
- **2012: Makerbot Replicator, Tinder launched**
- **2013: Google Glass**
- **2014: Amazon Alexa**
- **2015: iWatch**
- **2016: AirPods, Pokemon Go**
- **2017: Tik Tok**
- **2019: Disney+, Apple+**

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
- Integrated (e.g. iPhone, iPad)
- DVRs (e.g. TiVo)
- E-book readers (e.g. Kindle)
- 3D printers (e.g. Makerbot)
  - Circuit Scribe – draw actual circuits, electric ink!
  - Replicator…
- Augmented Reality (e.g. Jedi Challenge, Pokemon-Go)
  - Holodeck…

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

What do these things involve?

- **Computation**
- **Communications**
- **Hardware**
- **Substantial software**

- **➔ Products of Computer Engineers**

Changing World: Small World

- **Ubiquitous Internet**
  - This changed everything
  - Smartphone let us carry Internet with us
- **Facebook**
  - Allowed us instantly find anyone!
  - United the world in many ways

Changing World: Easy Sharing

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

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!

Changing World: New Wealth, New Players

- **Microsoft founded 1975**
  - World's richest man…for a while
- **Apple founded 1976**
  - Highest valued company
- **Oracle 1977**
- **CISCO 1984**
- **NVIDIA 1993**
- **Amazon.com 1994**
  - Just passed richest man…
- **E-Bay 1995**
- **Google, Netflix, PayPal 1998**
- **Tesla 2003**
  - New richest man
- **Facebook 2004**
- **Twitter 2006**
- **Bitcoin 2008**
- **Venmo 2009**

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 $$

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?**

Before going on…Callibration:

- **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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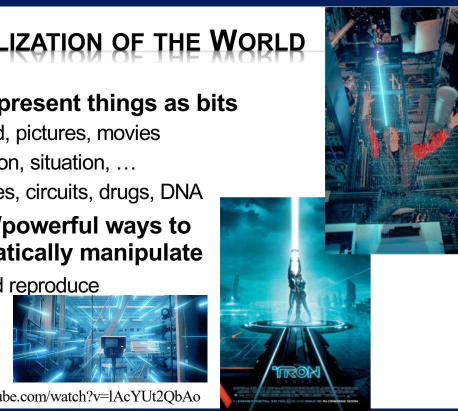
SHORT STORY

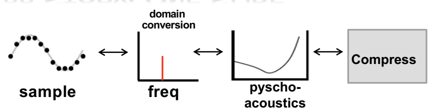
VIRTUALIZATION OF THE WORLD

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



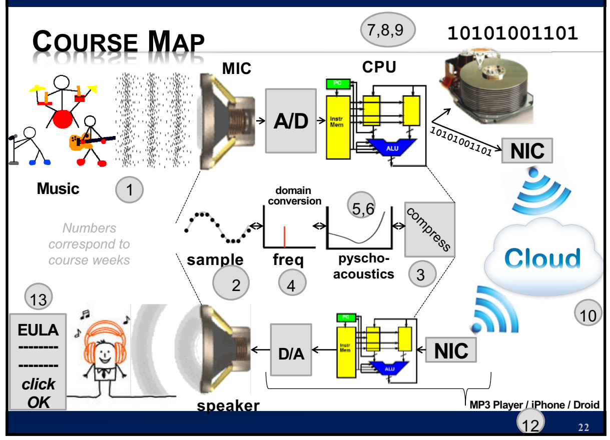
https://www.youtube.com/watch?v=lAcYUt2QbAo

CLASS STORY: ONE SLIDE



- 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

COURSE MAP



- History & Motivation
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COURSE INTRODUCTION

ABOUT THE COURSE

ESE150
Compression, MP3s, Psychoacoustics, and Everything

- ESE 150: 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*

Mechanics of the Class

- **Wednesday, Friday: 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
- **Friday: Lab Report due**
  - (except formal one – Sunday, and final one…)

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Lecture Timeline

- **Put preclass out previous day**
- **9:05am – actual start lecture**
- **9:55am – target end lecture**
- **Recommend attend synchronous lecture recording**
  - If not, complete lecture quiz before next 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; post piazza
- **Big Idea – 1p'er for every week**
- **Reading**
- **Preclass – available day before class**
  - 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 during synchronous recording**
  - 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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ESE150

Compression,
MP3s,
Psychoacoustics, and
Everything

End Part 1

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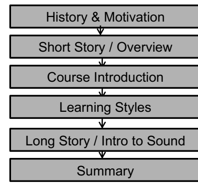

Learning Styles

(Interlude)

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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.

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

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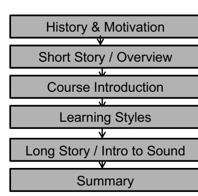
Aware of Differences

- **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

Part 2



Long Story

Week 1 & Week to Week

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Week 1: Introduction to Sound

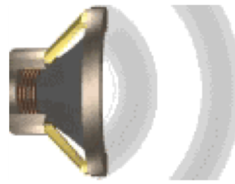
- **Sound is a pressure wave**

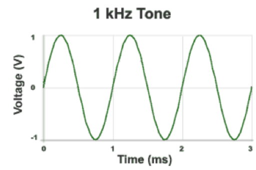
http://www.archive.org/details/SoundWavesAn

Week 1: Introduction to Sound Waves

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

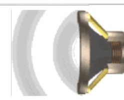
1kHz = 1000 cycles/s





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

Week 1: Pressure to Voltage

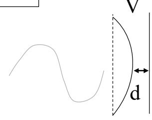


- Microphones convert pressure to voltage
  - (speakers/headphones voltage to pressure)
  - Physical position to voltage

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

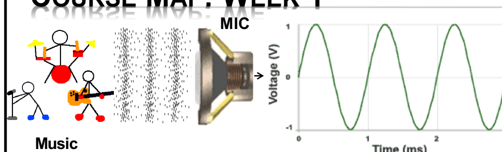
- Reason as parallel plate capacitor
  - ESE 112 or PHYS 151

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

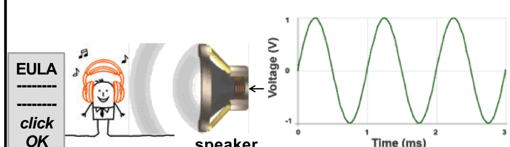


$$Q = CV \qquad V = \frac{Q}{C}$$

Course Map: Week 1



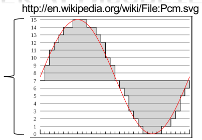
you will do this in first lab!



Week 2: Discrete Sampling

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

Discrete Voltage Levels



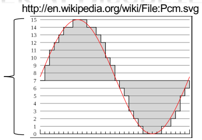
http://en.wikipedia.org/wiki/File:Compact_disc.svg

- **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?**

Week 2: Discrete Sampling

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

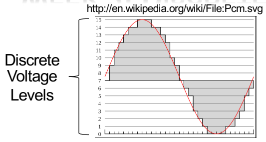
Discrete Voltage Levels



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?**
- **$N=2^B$** **$B=\lceil \log_2(N) \rceil$**

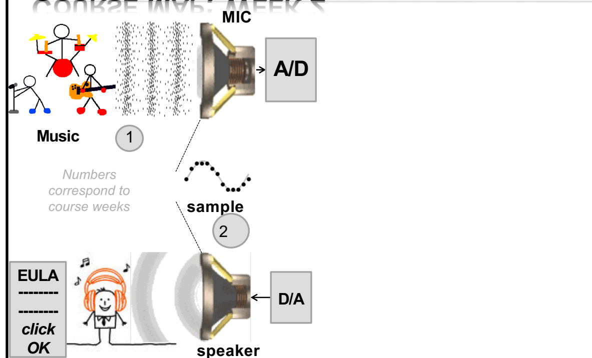
Week 2: Discrete Sampling



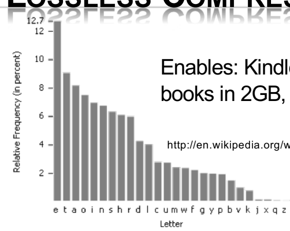
- Voltages can be sampled discretely
  - Both in time and amplitude
- Can turn sound wave into sequence of bits
  - 0111 1001 1011 1100 1101 1110 1110 1111 1111 ….
- What precision do we need?
  - Compact Disks: 16bits at 44KHz
    - How many bits is a typical 3-minute song?

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

Course Map: Week 2



Week 3: Lossless Compression

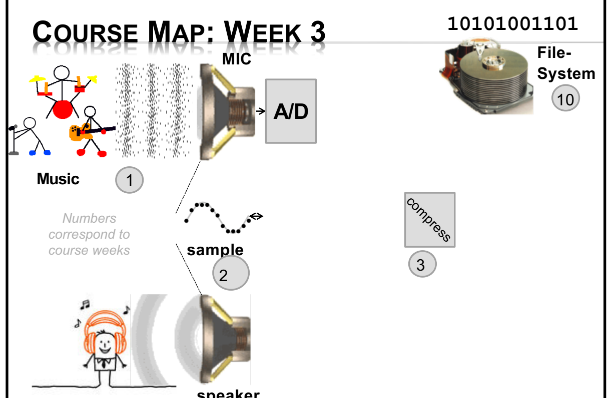


Enables: Kindle to store 1500 books in 2GB, SMS text

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)

Course Map: Week 3



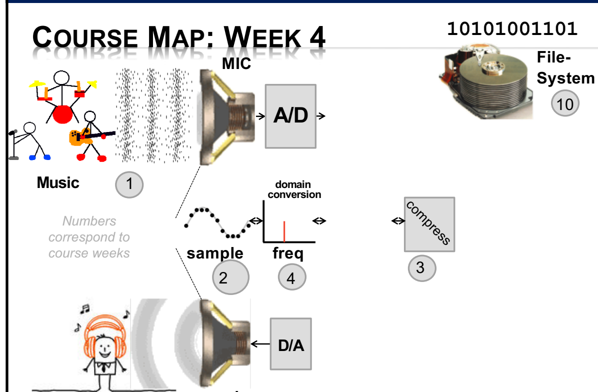
Week 4: Time-Frequency Conversion

- There are other ways to represent
  - Frequency representation particularly efficient

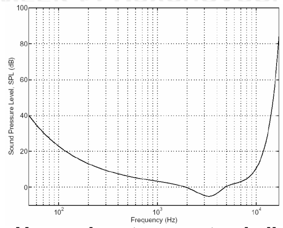
392 311 348 294

Frequencies in Hertz

Course Map: Week 4

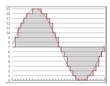


Week 5: Psychoacoustics



The Theory behind MP3

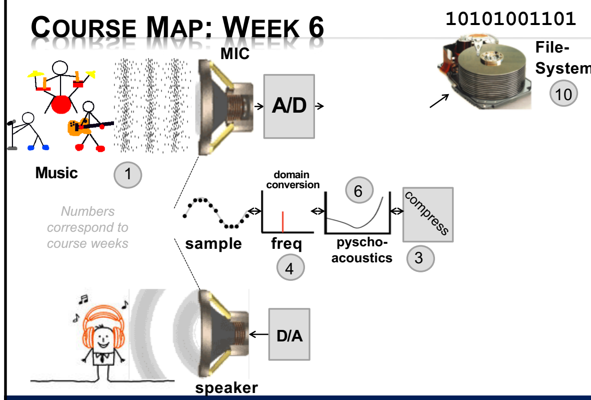
http://www.mp3-tech.org/programmer/docs/mp3_theory.pdf



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

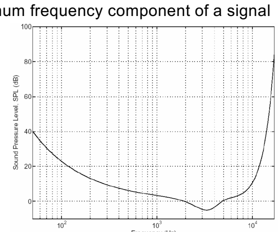
- Human input apparatus is limited
- If we only care about human perception
  - …that reduces the information needed (reduces samples/sec)
- Limited maximum frequency

Course Map: Week 6



Week 2: Nyquist-Shannon

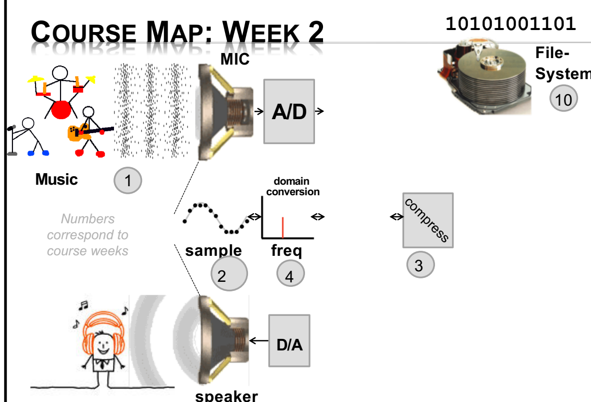
- Sampling Theorem:
  - Only need to sample 2 x maximum frequency component of a signal
- Range of human hearing?
  - 20 Hz → 20 kHz
- How many samples?
  - 2 x 20 kHz = 40 kHz
- CD samples /sec:
  - 44,000 Samples / sec



The Theory behind MP3

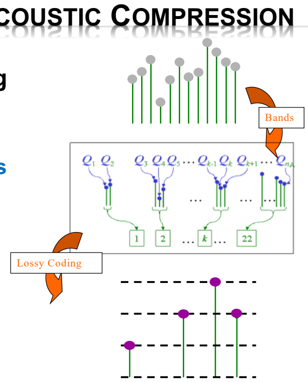
http://www.mp3-tech.org/programmer/docs/mp3_theory.pdf

Course Map: Week 2

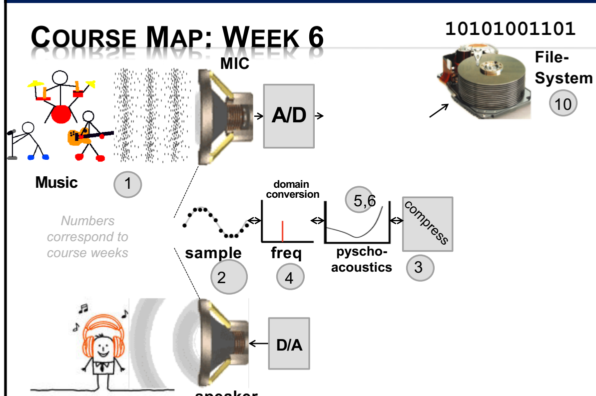


Week 6: Psychoacoustic Compression

- 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

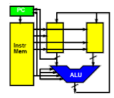


Course Map: Week 6



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

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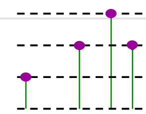
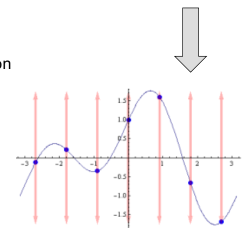
Week 8: Hardware



- 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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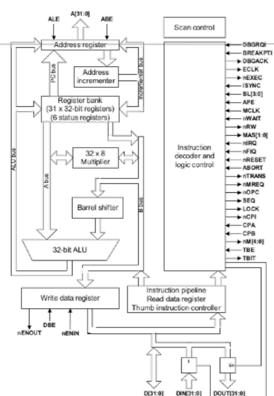
Week 8: iPod Processor

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



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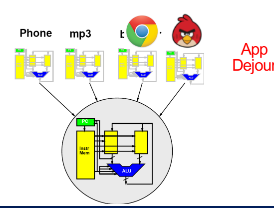
Week 9: Operating System

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



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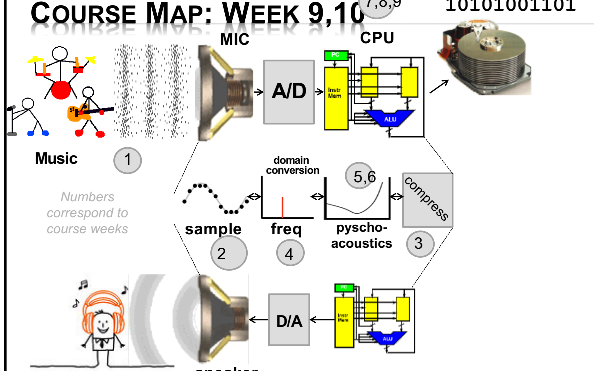
Course Map: Week 9,10



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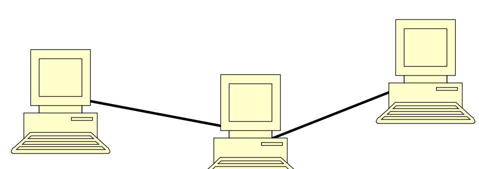
Week 10: Networking

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



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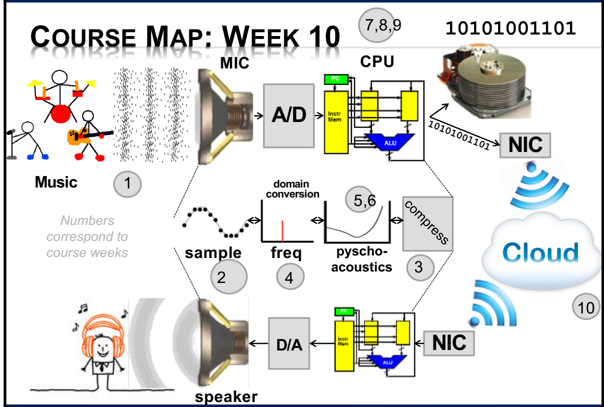
Course Map: Week 10



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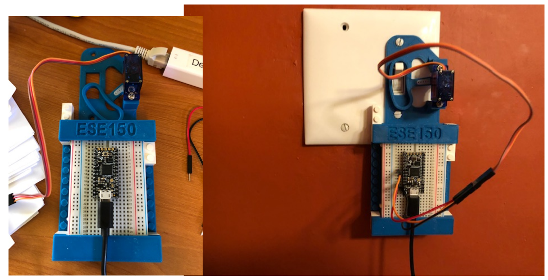
Week 11: Actuation

- How reach out and touch the world?



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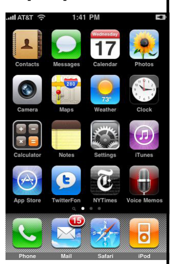
Week 12: User Interfaces

- 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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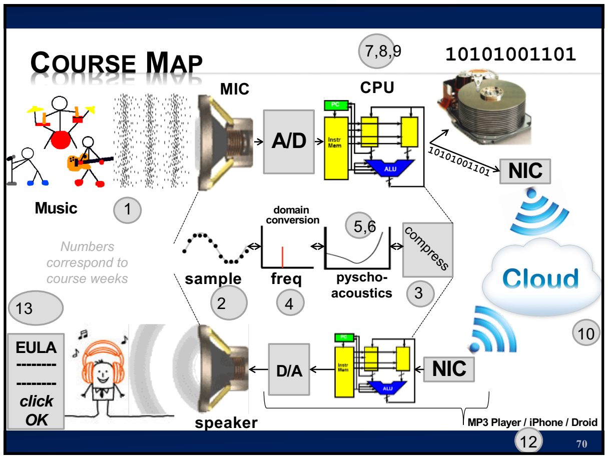
Course Map



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ESE150

Compression, MP3s, Psychoacoustics, and Everything

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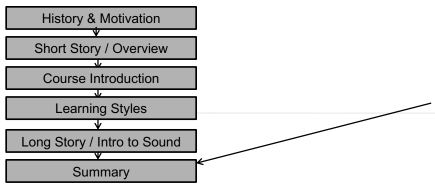

SUMMARY

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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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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?**

Complete: Lab Pickup Time Poll, Today's Feedback.

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