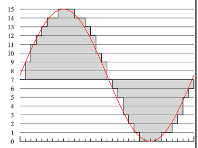
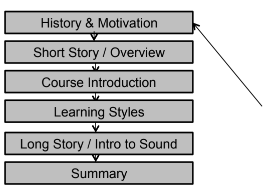


Lecture #1 - Course Introduction / Intro to Digital Audio

ESE 150 – DIGITAL AUDIO BASICS

LECTURE TOPICS

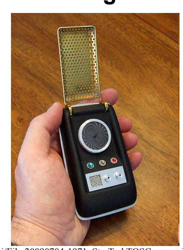
- **Course Introduction / Goals of Class**
  - Syllabus; Laboratory; Grading
- **History & Motivation**
  - Computing and Digital Audio
- **Overview of Class Schedule**
  - Big picture of our class goals
- **Week 1: Intro to Sound Waves**
  - Week by week breakdown of class itself
- **Summary**



HISTORY & MOTIVATION

STAR TREK TECHNOLOGY

- **Forward looking Science Fiction**
- **Envisioned many wonderful things**
  - Warp Drive
  - Transporter
  - Phasor
  - …and a hand-held communicator



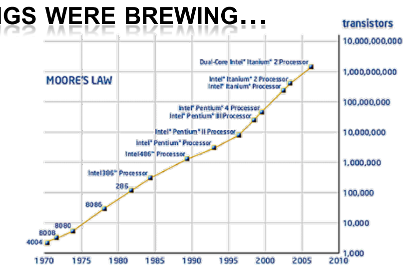
http://en.wikipedia.org/wiki/File:20090704-1971_StarTrekTOSCommunicatorReplica.jpg

HISTORICAL CONTEXT: 1966

- **Star Trek debut**
- **20lb. in-car phone: 1965**
  - 2.5lb. cell phone: Motorola 1973
  - Martin Cooper beats AT&T ☺
- **Long distance was expensive**
- **Computers owned by companies and universities**
  - 20 years after ENIAC, 10 years before Apple
- **Internet was conceived (but 3 yrs to first node)**
- **Cameras used film**
- **Beatles release "Yesterday and Today" on LP**
  - And you had to go to a record store to buy it
- **One year after Gordon Moore hypothesized his famous "Law"**

http://en.wikipedia.org/wiki/File:2007Computex_e21Forum-MartinCooper.jpg

THINGS WERE BREWING…



- **Moore's Law: Every 18 months, size of transistor will be 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

THINGS WERE BREWING…

- Moore's Law
- Internet Grew

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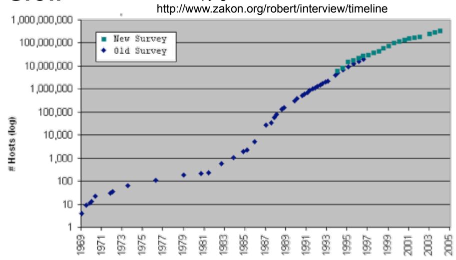
http://www.zakon.org/robert/interview/timeline



THINGS WERE BREWING…

- Moore's Law
- Internet Grew
- Personal Stereo
  - Sony Walkman 1979
  - AT&T licenses transistor to Sony in 1955

http://en.wikipedia.org/wiki/File:Sony_Walkman_WM-2.jpg

THINGS WERE BREWING…

- Moore's Law
- Internet Grew
- Personal Stereo
  - Sony Walkman 1979
- Compact Discs 1982
  - 700MB, 80 minutes music

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

THINGS WERE BREWING…

- Moore's Law
- Internet Grew
- Personal Stereo
  - Sony Walkman 1979
- Compact Discs 1982
  - 700MB, 80 minutes music
- IBM PC/XT 1983
  - 10MB Hard Disk

http://en.wikipedia.org/wiki/File:Ibm_px_xt_color.jpg

POLL

- How many of you have:
  - Cell phone ?
  - Digital Music Player (separate from phone?)
  - Digital camera (separate from phone?)
- Use 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

IN YOUR LIFETIME…

- 1998: Google, First commercial MP3 player
- 2001: iPod, Wikipedia launched
- 2003: iTunes launched, Skype released
- 2004: Facebook launched
- 2005: YouTube launched
- 2006: Twitter launched
- 2010: Instagram
- 2011: Siri, Snapchat, Google driverless cars, Uber
- 2012: Makerbot Replicator
- 2013: Google Glass
- 2015: iWatch

Cool Stuff of Today…

- Today's "must have" technology is:
  - computerized, networked, and based on digital media
- Cell phones - *smaller than ST Communicator*
- MP3 players (Digital Audio Players) - *make walkman bulky*
  - 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!
- Augmented Reality (e.g. Jedi Challenge,Pokemon-Go)

What else add to this list?

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**
  - Instant access to music/casts/apps/video too
- **Streaming video**
  - Instant access to video/news/visual information
  - Internet services/Netflix/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**
  - New world's richest man…
- **E-Bay 1995**
- **Google 1998**
- **Facebook 2004**
- **Twitter 2006**
- **Bitcoin 2009**

Convergence

- **Big Ideas and Advanced Technology**
  - Digitize Everything
  - Cheap Digital Processing
  - Cheap Storage
  - Cheap Digital Bandwidth

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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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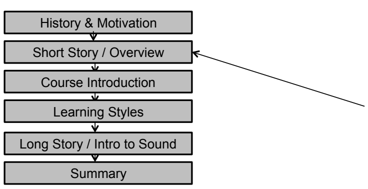

Short Story

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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

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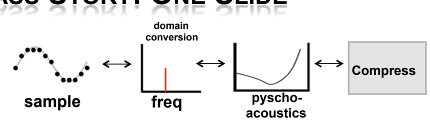
Class Story: One Slide



- **Sound can be converted to/from bits**
  - and compressed, <u>without</u> 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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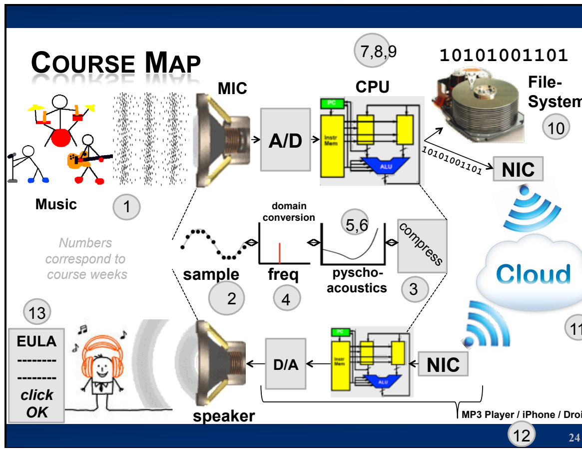
Course Map



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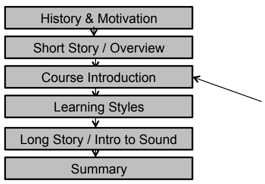


COURSE INTRODUCTION

ABOUT THE COURSE

- **ESE 150: Digital Audio Basics**
  - But really: "Introduction to Computer Engineering"
- **Our Goals:**
  - Deliver 13 lectures on 13 topics in Comp. Eng.
    - *Each lecture…maps to nearly 13 different courses!*
  - Expose you to the *big* topics in Comp. Eng.
    - *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*
    - *Labs are not perfect, connections sometimes not obvious at first*
      - You might think lab is "stand-alone"…not really true!

THE BIG PICTURE…

- Computer Engineering
  - *very large field of engineering*
- Seeing the top 13 ideas…through the guise of digital audio
  - *helps you see the big picture of comp. eng.*
- We want you to see the "big picture" of comp eng.
  - *before taking a lot of unnecessary courses*
- Miss one lecture…miss a lot!
  - *Common complaint…I don't need lecture to succeed in lab*
    - You might be right! … but it should make it more meaningful.
- Help us help you…
  - *If you don't see how lecture/lab fit together, tell us!! Help us improve course*

MECHANICS OF THE CLASS

- **Wednesday: Lecture**
  - Introduce 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)

GRADING

- **10% - Class Participation and Quizzes (if necessary)**
  - Based on assigned reading material
- **50% - Weekly Lab Report Writeup**
  - Work in groups of 2 (we assign and mix up week-to-week)
  - Some labs may have "prelab" work to do – counted as part of lab writeup
  - Drop lowest score on <u>attempted labs</u>
- **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

COMPONENTS

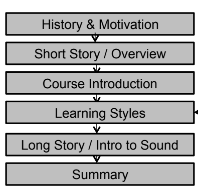
- **Lecture slides online morning of lecture**
- **Preclass – available beginning (ideally 4:25pm)**
  - Work through to get you thinking about the topic
  - …and gives you some of the questions will ask in lecture
- **"Warm" Calls**
  - Promote interaction/engagement
- **Feedback sheets**
  - Turn in at end of lecture
  - Help me tune lecture for class

Class Goals

- **Provide digital audio background for ESE350**
  - …build an actual digital audio platform
- **Context and motivation for CMPE major**
- **Appreciate how CMPE, EE, CIS:**
  - Work together
  - How they impact today's world
- **Start thinking like an engineer!**

Outcomes

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



Learning Styles

(Interlude)

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

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

http://www4.ncsu.edu/unity/lockers/users/f/felder/public/ILSdir/styles.htm

Active vs. Reflective

- **Active learners tend to retain and understand information best by doing something active with it**
  - "Let's try it out and see how it works" is an active learner's phrase
- **Reflective learners prefer to think about it quietly first.**
  - "Let's think it through first" is the reflective learner's response.
- **Active learners tend to like group work more than reflective learners, who prefer working alone.**
- **Sitting through lectures without getting to do anything physical but take notes is hard for both learning types, but particularly hard for active learners.**

http://www4.ncsu.edu/unity/lockers/users/f/felder/public/ILSdir/styles.htm

Sensing vs. Intuitive (1 of 2)

- Sensing learners tend to like learning facts
- Intuitive learners often prefer discovering possibilities and relationships.
- Sensors often like solving problems by well-established methods and dislike complications and surprises;
- Intuitors like innovation and dislike repetition.
- Sensors are more likely than intuitors to resent being tested on material that has not been explicitly covered in class.

http://www4.ncsu.edu/unity/lockers/users/f/felder/public/ILSdir/styles.htm

Sensing vs. Intuitive (2 of 2)

- Sensors tend to be patient with details and good at memorizing facts and doing hands-on (laboratory) work
- Intuitors may be better at grasping new concepts and are often more comfortable than sensors with abstractions and mathematical formulations.
- Sensors tend to be more practical and careful than intuitors;
- Intuitors tend to work faster and to be more innovative than sensors.
- Sensors don't like courses that have no apparent connection to the real world;
- Intuitors don't like "plug-and-chug" courses that involve a lot of memorization and routine calculations.

http://www4.ncsu.edu/unity/lockers/users/f/felder/public/ILSdir/styles.h

Visual vs. Verbal

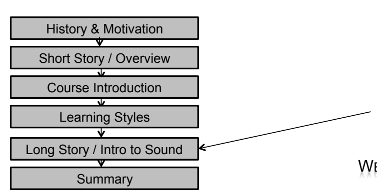
- Visual learners remember best what they see
  - pictures, diagrams, flow charts, time lines, films, and demonstrations.
- Verbal learners get more out of words--written and spoken explanations.

Sequential vs. Global

- Sequential learners tend to gain understanding in linear steps, with each step following logically from the previous one.
- Global learners tend to learn in large jumps, absorbing material almost randomly without seeing connections, and then suddenly "getting it."
- Sequential learners tend to follow logical stepwise paths in finding solutions;
- Global learners may be able to solve complex problems quickly or put things together in novel ways once they have grasped the big picture, but they may have difficulty explaining how they did it.

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



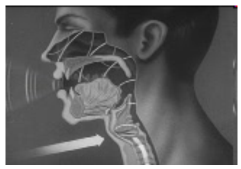
Long Story

Week 1 & Week to Week

42

Week 1: Introduction to Sound

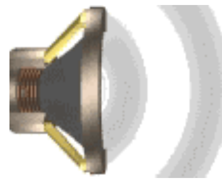
- Sound is a pressure wave

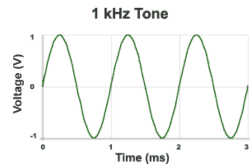


http://www.archive.org/details/SoundWavesAn

Week 1: Introduction to Sound Waves

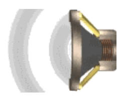
Recall from Math: Hertz (Hz) = 1 cycle per second
1kHz = 1000 cycles/s





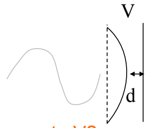
Source: http://www.mediacollege.com/audio/01/sound-waves.html

Week 1: Pressure to Voltage



- Microphones convert pressure to voltage
  - (speakers/headphones voltage to pressure)
- Parallel plate capacitor with pressure activated plate
  - over short time scale:
    - charge (Q) is conserved (not changing)
    - if *d* changes, what happens to C?

$$C \propto \frac{A}{d}$$

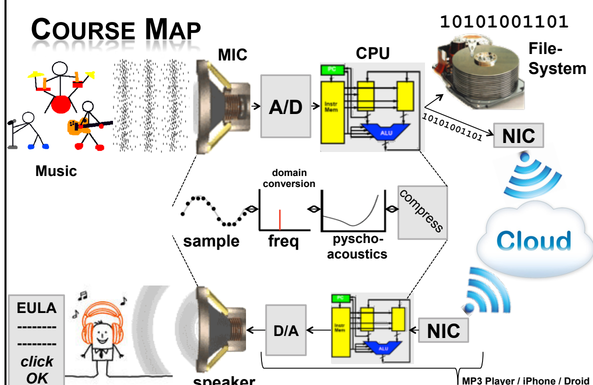


- and when C changes, Q holds, what happens to V?

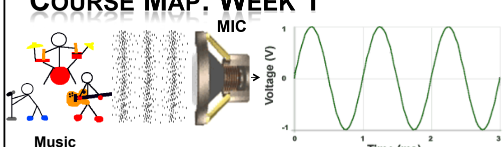
$$Q = CV \qquad V = \frac{Q}{C}$$

Δd → ΔC → ΔV

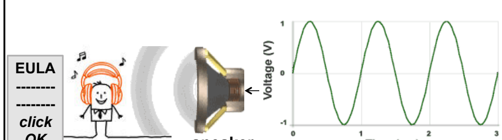
Course Map



Course Map: Week 1



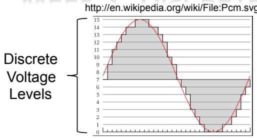
This week: you will do this in the lab!



Before next slide…Mini-Quiz:

- What is a bit (a Binary Digit)?
  - Smallest piece of information we can store (on/off)
- 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 bits to store a typical song?

Week 2: Discrete Sampling

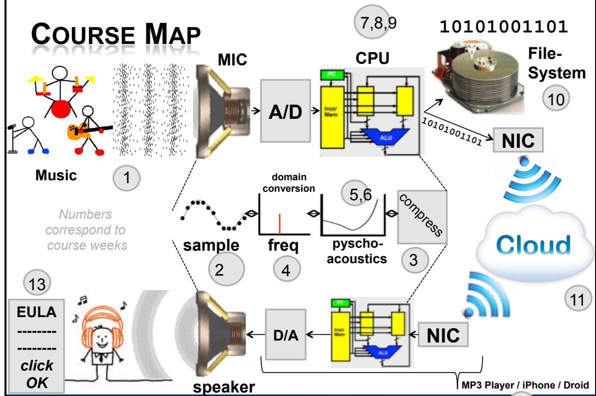


- Voltages can be sampled discretely
  - Both in time and amplitude
- Can turn sound wave into sequence of bits
  - 0111 1001 1011 1100 1101 1110 1110 1111 1111 ….
- What precision do we need?
  - Compact Disks: 16bits at 44KHz
    - How many bits is a typical 3-minute song?

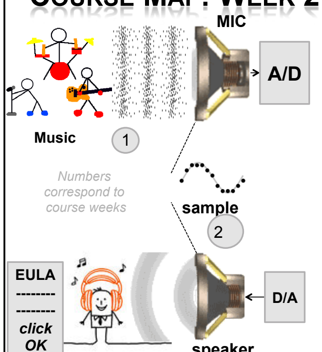
$$\left(44{,}000\,\frac{samples}{1\,sec}\right)\left(16\,\frac{bits}{sample}\right)\left(60\,\frac{sec}{1\,min}\right)\left(3\,\frac{min}{song}\right) = 15{,}840{,}000\,\frac{bytes}{song} = 15.1\,\frac{MB}{song}$$

$$= 126{,}720{,}000\,\frac{bits}{song}$$

Course Map

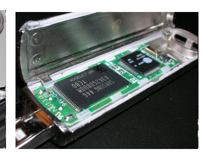


Course Map: Week 2



Digital Storage (Week 10)

- Record bits to non-volatile memory
  - Store and reproduce sound
- Media: CD, Hard Disk, Flash

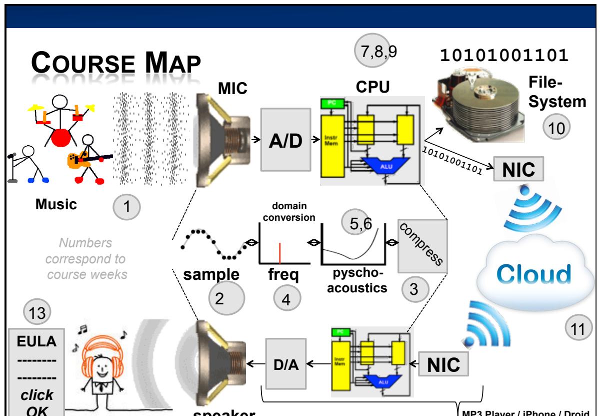


http://en.wikipedia.org/wiki/File:Compact_disc.svg
http://en.wikipedia.org/wiki/File:DSCN0411.JPG
http://en.wikipedia.org/wiki/File:Hard_disk_platters_and_head.jpg

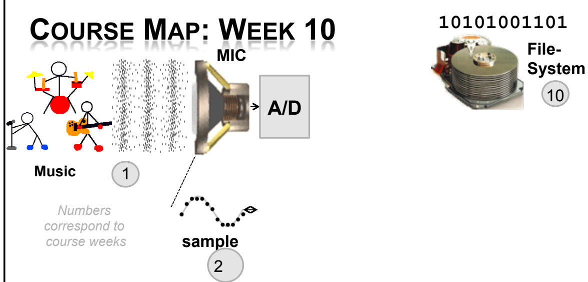
Calculating Capacity

- How many songs can we fit on a CD?
  - How many MB can a CD hold?
    - 650 MB (for Data)
    - About 780 MB (for Audio)
  - If 3 minute song = 15.1 MB…
    - 1 minute audio ~ 5.04MB
    - But, we record in stereo: (R/L)
      - 5.04 MB x 2 = 10.07 MB per minute
    - 780 MB / 10.0 MB per minute ~ 78 minutes
- How much memory does your MP3 player have?
  - Given unit of information to store, we can architecture storage!

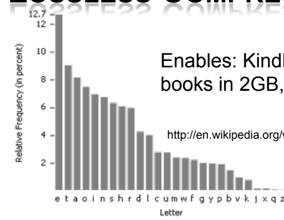
Course Map



Course Map: Week 10



Week 3: Lossless Compression

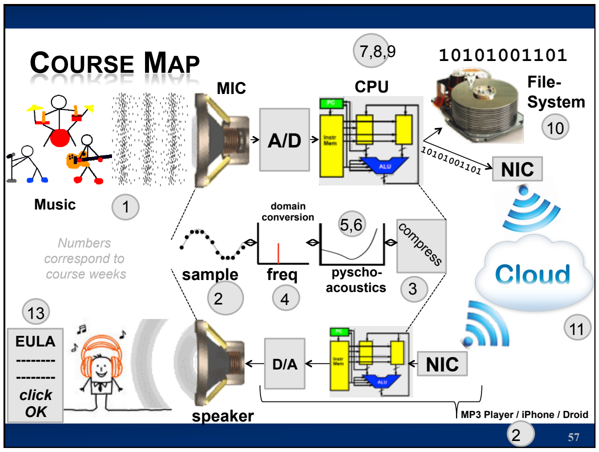


Enables: Kindle to store 1500 books in 2GB, SMS text

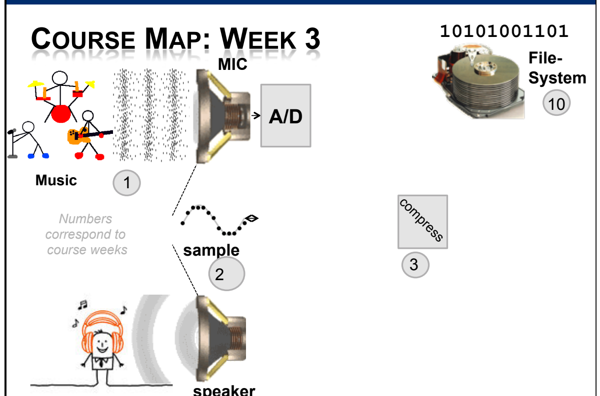
http://en.wikipedia.org/wiki/File:English-slf2.PNG

- **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

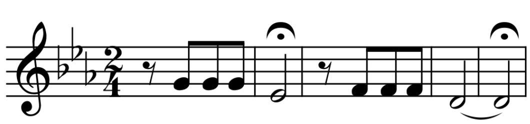


Course Map: Week 3

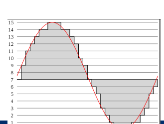


Time-Frequency Conversion

- **There are other ways to represent**

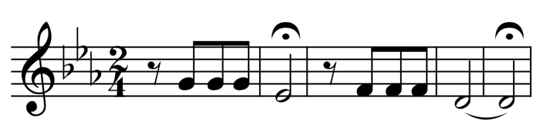


How does the musical staff representation of sound differ from time samples?



Week 4: Time-Frequency Conversion

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

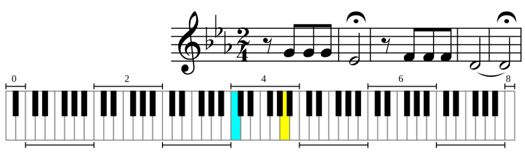


392 311 348 294

Frequencies in Hertz

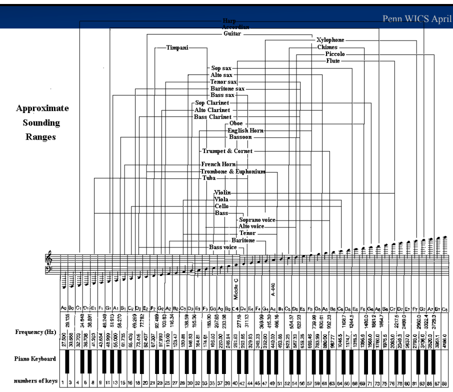
Time-Frequency Conversion

- **1s / quarter note ➔ 10s of sound**
  - 44K Hz x 16b/sample x 10s = 7040K =7Mbits
- **How many keys on piano?**
  - (7b/note+8b/duration) x 7 note = 105 bits?



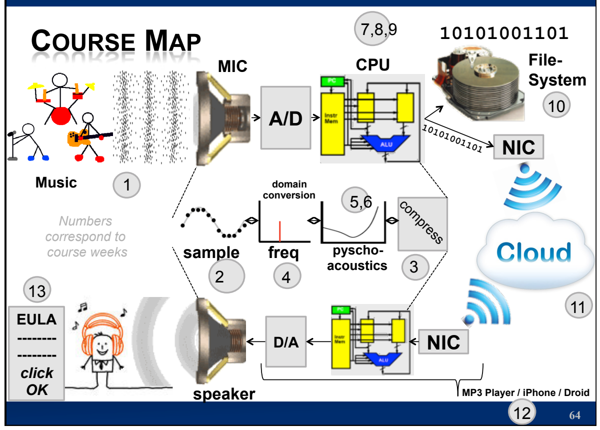
AlwaysAngry: https://commons.wikimedia.org/wiki/File%3APiano_Frequencies.svg

Hamburg Steinway D-274 Piano photo by Karl Kunde
https://commons.wikimedia.org/wiki/File:D274.jpg

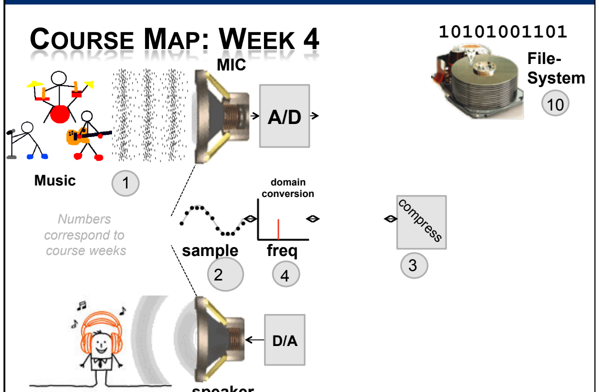


Larry Solomn: http://solomonsmusic.net/insrange.htm

Course Map

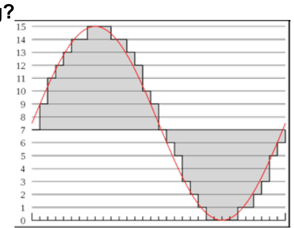


Course Map: Week 4

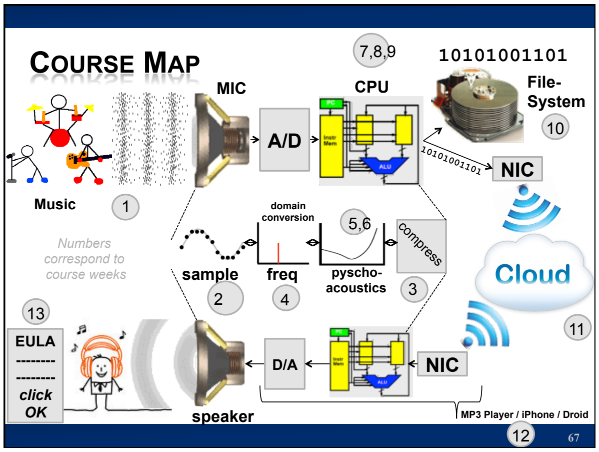


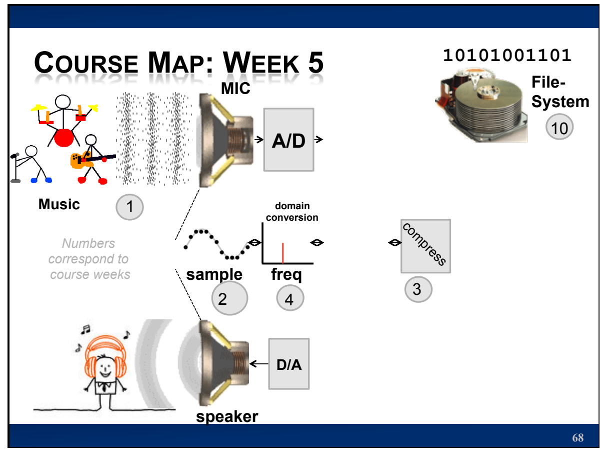
Week 2: Nyquist-Shannon

- **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

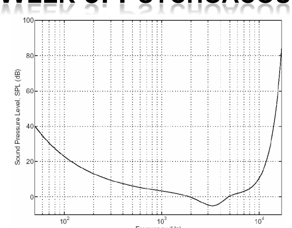


http://en.wikipedia.org/wiki/File:Pcm.svg



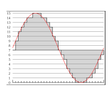


Week 5: Psychoacoustics



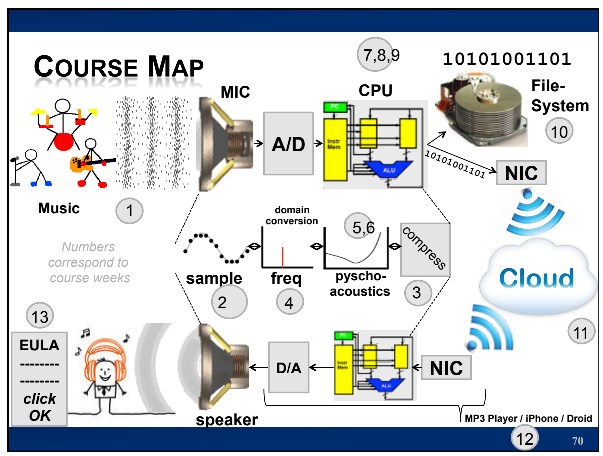
The Theory behind MP3

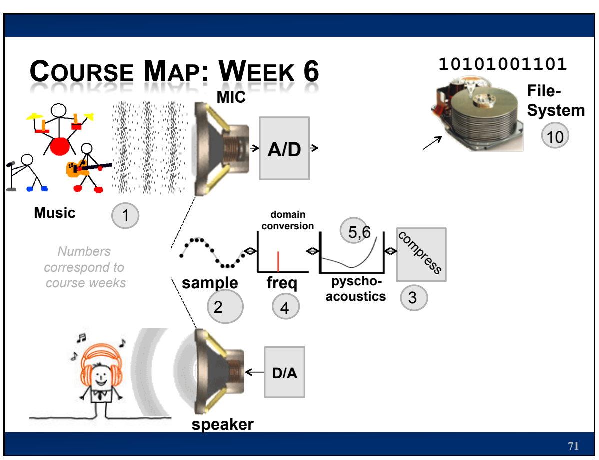
http://www.mp3-tech.org/programmer/docs/mp3_theory.pdf



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

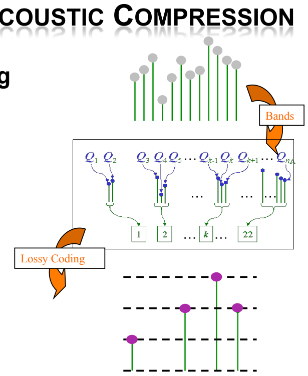
- **Human input apparatus is limited**
- **If we only care about human perception**
  - …that reduces the information needed (reduces samples/sec)
- **Limited maximum frequency**



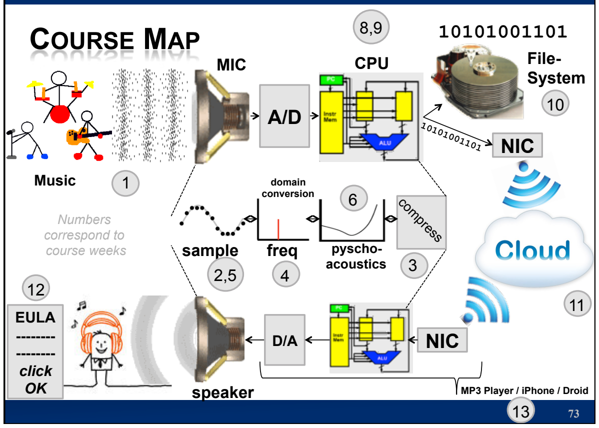


Week 6: Psychoacoustic Compression

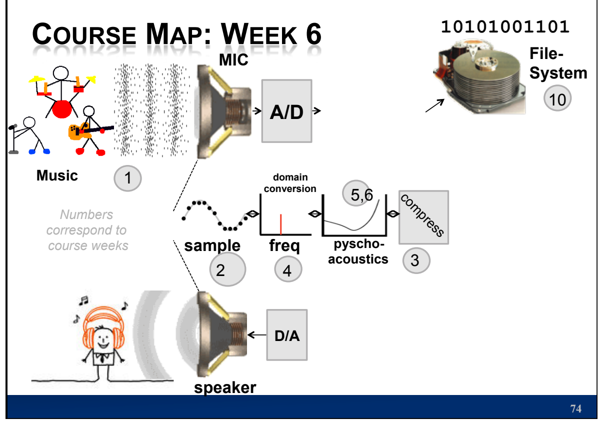
- **MP3 based on putting these together**
  - Convert to frequencies
  - Determine frequencies that don't matter
  - Quantize (fewer than 16b) for less important
- **Significantly smaller size than raw, sampled bits**



Course Map

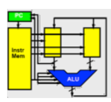


Course Map: Week 6



Week 7: Hardware

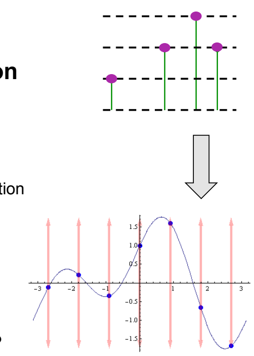
- **CPUs: We'll look at their operation and architecture**
- **How fast does your laptop or cell phone run?**



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

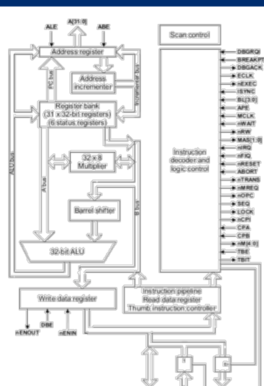
Week 8: Hardware

- **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?**



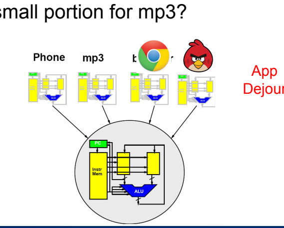
Week 8: iPod Processor

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

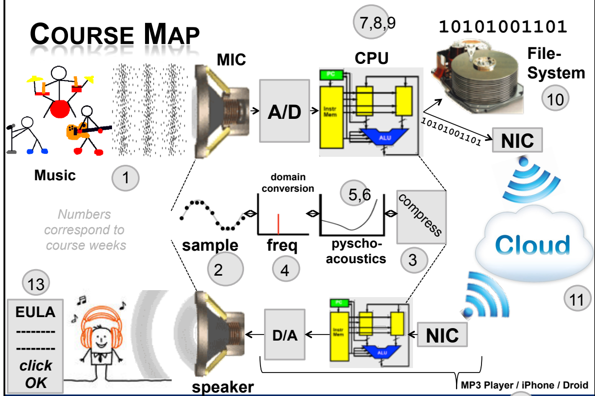


Week 9: Operating System

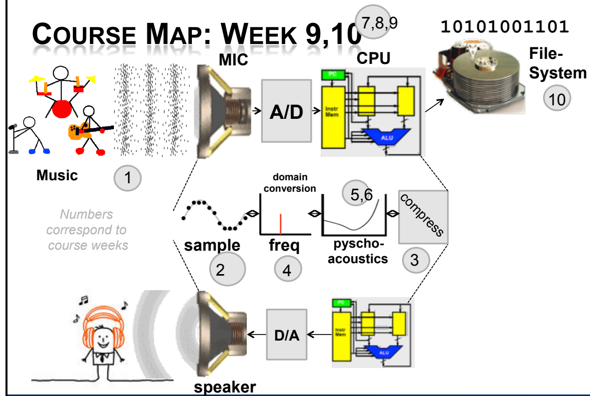
- **This hardware can be virtualized and shared among tasks**
  - How does OS control hardware?
  - Do we need giant OS or small portion for mp3?



Course Map

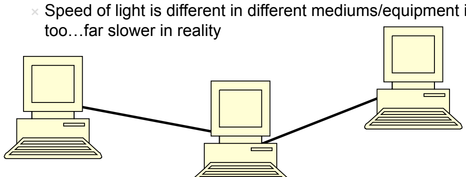


Course Map: Week 9,10

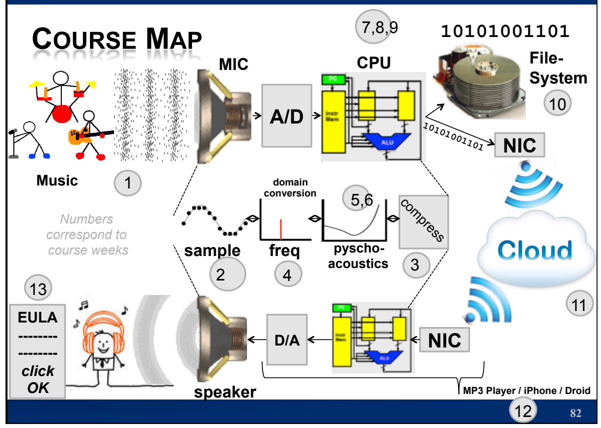


Week 11: Networking

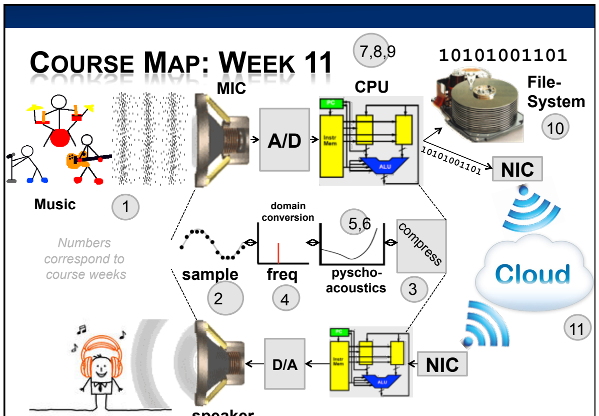
- **Bits can be transported between machines**
  - How fast must network speed to be to stream audio?
  - How fast can bits be sent ½ way around earth?
    - If c = 300,000 km/s and circumference of earth = 40,075 km
    - On an optical fiber, minimum time = 67 ms to go ½ way!
    - Speed of light is different in different mediums/equipment is slow too…far slower in reality



Course Map

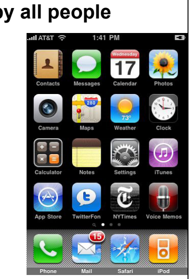


Course Map: Week 11



Week 12: User Interfaces

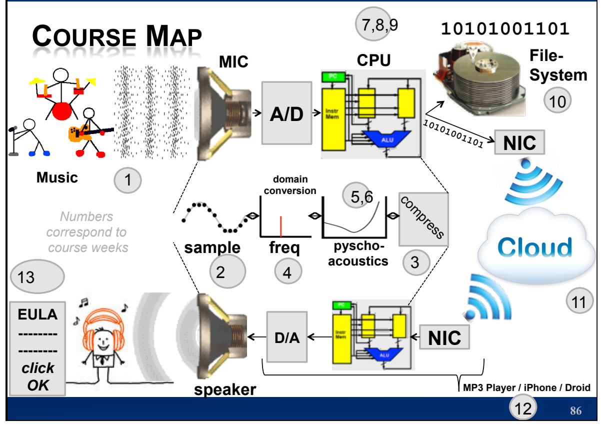
- **These capabilities can be harnessed by all people**
  - Not just engineers
- **…but we must designed for people**
  - For the non-engineers
- **iPhone is a classic example:**
  - product that didn't do anything new
  - BUT, it made everything simple
  - thanks to well designed UI

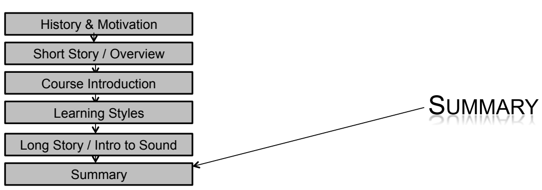


Week 13: Intellectual Property

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

Course Map





This course

- It is a work in progress:
  - Attempts to explain a great deal of Comp Eng
    - 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 yous):
    - 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 sheets

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**

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?**