

Lecture #25 – Wrap Up! (final lecture)

ESE 1500 – DIGITAL AUDIO BASICS

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LECTURE TOPICS

- × Review
- × Generalize
- × Final
- × Engineering Disciplines
- × What's Next?

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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

Compress

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IN THE PROCESS

- × Sampling
- × Signal Processing
- × Frequency Domain
- × Compression
- × Human Hearing
- × Optimization
- × Processing Requirements
- × Hardware (gates)
- × Sharing hardware (OS)
- × Networking
- × Sensing and Actuation
- × User Interfaces
- × Intellectual Property

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COURSE MAP

Music (1) → sample (2.5) → freq (4) → psycho-acoustics (3) → compress → CPU (7,8,9) → A/D → D/A → speaker

10101001101 → NIC → Cloud → MP3 Player / iPhone / Droid (12)

EULA (13) → click OK

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ESE1500


Compression, MP3s, Psychoacoustics, and Everything

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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



TRON 1982

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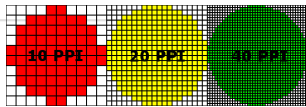
AUDIO

- × Told detail story in terms of Audio
- × 1D signal
- × Sample in time
- × Quantize amplitude
- × Quantize fine enough
 - + Lose no information that humans can perceive

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IMAGES



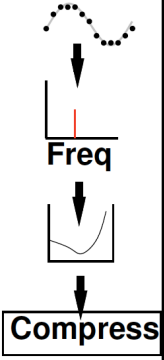
- × 2D signal
- × Quantize in space into pixels
- × Quantize amplitude of pixels
- × Quantize fine enough
 - + Lose no information human can perceive
 - + 0.1 mm at 30cm (50 cycles per degree)
 - + "Retina" Display 57 pixels per degree
 - × 128 pixels/cm

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IMAGE PROCESSING ONE SLIDE

- × Images 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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COMPRESS IMAGES

- × How do we compress images?
 - + Lossy?
 - + Lossless?

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MOTION PICTURES

- × 3D signal
- × Sample in time
- × Quantize in space into pixels
- × Quantize amplitude of pixels
- × Sample fine enough
 - + Lose no information human can perceive
 - + 30 frames per second

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VIDEO PROCESSING ONE SLIDE

- × **Motion 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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COMPRESS VIDEOS

- × **How do we compress videos?**
 - + Lossy?
 - + Lossless?

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3D OBJECT CAPTURE AND REPRODUCTION

makerbot.com

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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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WORLD OF BITS

- × **What else can we capture as bits?**
- × **Reproduce from bits?**

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- × http://news.cnet.com/8301-27083_3-20079504-247/prosthetic-dentistry-print-your-own-teeth/
- × <http://phys.org/news/2011-02-3d-bio-printers-skin-body.html>
- × <https://www.nbcnews.com/mach/science/digital-smell-technology-could-let-us-transmit-odors-online-chats-cnca940121>
- × <https://www.makepartsfast.com/3d-printed-circuit-boards-how-theyre-made-and-why-they-matter/>
- × <https://time.com/6162775/tiktok-3d-printed-houses/>
- × <https://cen.acs.org/food/food-science/3D-printed-foods-enter-kitchen/100/i5>
- × <https://www.3dnatives.com/en/3d-printed-drugs-personalized-medicine-140520204/>


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DNA

- × Nature's bitstream
- × Can read into bits
- × Can reproduce from bits
- × Digitize organisms....
- × Those bits control behavior
- × Control function of cells
 - + Even what the cells manufacture and produce



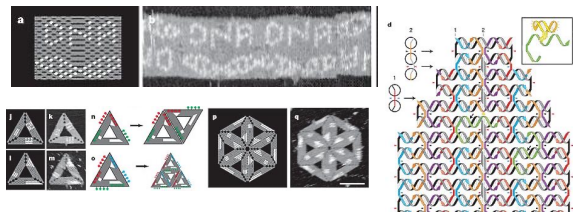
http://www.astrochem.org/sci_img/dna.jpg

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PROGRAMMING THE PHYSICAL WORLD (DNA)



- × How do we program DNA?
 - + Self-assemble into arbitrary useful structures?
 - + Perform specific functions in cells?
 - + ...becoming a problem of information and computation

[Winfree & Rothemund, CALTECH]

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LIMITS?

- × What can't we capture and reproduce from bits?

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CLARKE'S LAWS

1. When a distinguished but elderly scientist states that something is possible, he is almost certainly right.
2. When he states that something is impossible, he is very probably wrong. The only way of discovering the limits of the possible is to venture a little way past them into the impossible.
3. Any sufficiently advanced technology is indistinguishable from magic.

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Penn Engineering

ESE

Part 2

ADMINISTRATIVE INTERLUDE: FINAL

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FINAL

- × Final Office Hours: (see Ed Discuss)
 - + Wednesday (5/3) review, Thursday (5/4)
- × Final: Friday (5/5)
 - + Like Midterm (but 2 hours, so longer)
 - × Closed book; bring calculator
 - + 15% of grade
 - + Comprehensive (intent...does tend to weight 2nd half)
 - × Probably mix ideas from first and second half
 - + Last few years final and answers linked to syllabus
 - × 2020, 2021 were online/open-book (so less representative)

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FINAL TOPICS

Pre Midterm	Post midterm
× Data representation in bits	× Combinational Logic
× Sounds waves	× Finite-State Machines
× Sampling	× Stored-Program Processors
× Quantization	× Processing Requirements
× Nyquist	× Process Virtualization
× Lossy/lossless compression	× Networking
× Common case	× Sensing, Actuation, Control
× Frequency domain	× User Interface
× Psychoacoustics	× Intellectual Property
× Perceptual coding	

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ENGINEERING DISCIPLINES

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UNDERSTANDING

- × **Computer Engineering**
- × **Electrical Engineering**
- × **Computer Science**
- × **Systems Science and Engineering**

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INFORMATION AS UNIFIER

- × **EE**
 - + Signal processing, control
 - + Electrical systems to process; electrical and optical to communicate
- × **CIS**
 - + Algorithms, software, strategy
- × **MEAM**
 - + Capture, reproduce, control
- × **BE**
 - + Cellular behavior, synthetic Biology
- × **SSE**
 - + Resuable math and information processing

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DATA SCIENCE AND MACHINE LEARNING

- × **How do we make sense of raw data?**
- × **Turn it into useful information?**
- × **Use it to control things?**
- × **Automate the processing and adaptation (learning)**
- × **Mathematics developed in**
 - + EE, Systems, Statistics, Operations Management, ...
- × **Implemented in**
 - + Programming languages and algorithms – CSCI, CMPE
- × **Implemented on and enabled by**
 - + Computer hardware and systems designed and optimized by CMPEs
- × **Enables**
 - + Autonomous Vehicles, Robots, Assistance, Business, Science, Engineering,

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PROCESSING FOR MACHINE LEARNING

- × **At core Linear Algebra**
 - + Dot Products
 - + Matrix Operations
 - × matrix-vector multiplication, matrix-matrix multiplication
- × **Same computation we have been using for Audio processing**
 - + Dot Products, Fourier Transforms
- × **Learn more: ESE5390**

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Topic	CSCI	CMPE	EE	ESE
Analog Circuits		ESE2150	ESE2150	
Compress	CIS1210	CIS1210		
Nyquist, Fourier			ESE2240, ESE3250	ESE2240, ESE3250
Optimization	CIS3200	(many)		ESE2040
Digital Logic	CIS2400	CIS2400, ESE3700, ESE5320		
Processor	CIS4710	CIS4710		
OS	CIS3800	CIS3800		
Embedded, Actuation	ESE3500	ESE3500, ESE4210, CIS4410	ESE3500, ESE4210	ESE3500, ESE4210
IP		EAS5450	ESE5450	ESE5450
Networking	CIS5530	ESE4070 or CIS5530	ESE4070	ESE4070
UI				ESE5430

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(NOTES FOR PREVIOUS SLIDE)

- × **Bold – required**
- × Not bold – restricted elective
- × Simplified to fit on one slide
 - + (e.g. should show many more analog circuits courses as restricted-electives for EE)

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HOLISTIC/UNIFIED ENGINEERING

- × Today's devices and products crosscutting
- × Fewer that fit in one silo
- × Harder to draw boundary

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NO BOUNDARIES: HW/SW

- × Hardware/software divide is artificial, antiquated, and harmful
- × **Computer engineers understand computation**
 - + hardware and software are just tools and design options
- × **Computational system design (co-design)**
 - + Decide what goes in hardware, software
 - + With FPGAs, hardware is programmable, too
 - + Can describe both HW and SW in C

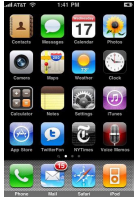
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NO BOUNDARIES: PRODUCT

- × **Who owns a product like a smart phone or tablet?**
 - + Hardware platform
 - + Energy budget, heat budget
 - + Substantial software
 - + Plays with world-wide communication infrastructure
- × **Seen how this comes together in this course**



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NO BOUNDARIES: CHIPS/SYSTEMS

- × **Computer engineering is about the computing system**
 - + Can be a single chip
 - + Can be a board or box with 10s to 100s of chips
 - + Can be an autonomous car with 100s of processing chips
 - + Can be datacenter with 10,000 processors, Petabits of network bandwidth, and zettabytes of storage
 - + Can be the global Internet

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WHAT'S NEXT?

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"MOORE'S LAW" TODAY

Moore's Law: The number of transistors on microchips doubles every two years

Our World in Data

Transistor count

- × Exponential growth in Integrated Circuit (IC) capacity
- × Driven by a geometric shrink in transistor feature size

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MOORE'S LAW ENABLED

- × MP3 players
- × Smart phones and tablets
- × Digital cameras
- × Digital video recorders and players
- × Realistic Games
- × Skype, Zoom
- × DNA sequencing
- × Autonomous Vehicles, Drones
- × Alexa, Siri
- × Ubiquitous Machine Learning, Data Analytics

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CONTINUED SCALING

- × What will continued Moore's Law Scaling enable next?

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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?

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REMEMBER

- × Lecture and Lab feedback form
- × This is last lecture
- × Last day of term
 - + Lab 12 and DQ25 due today
- × Final Friday (5/5) 3pm – Towne 305

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