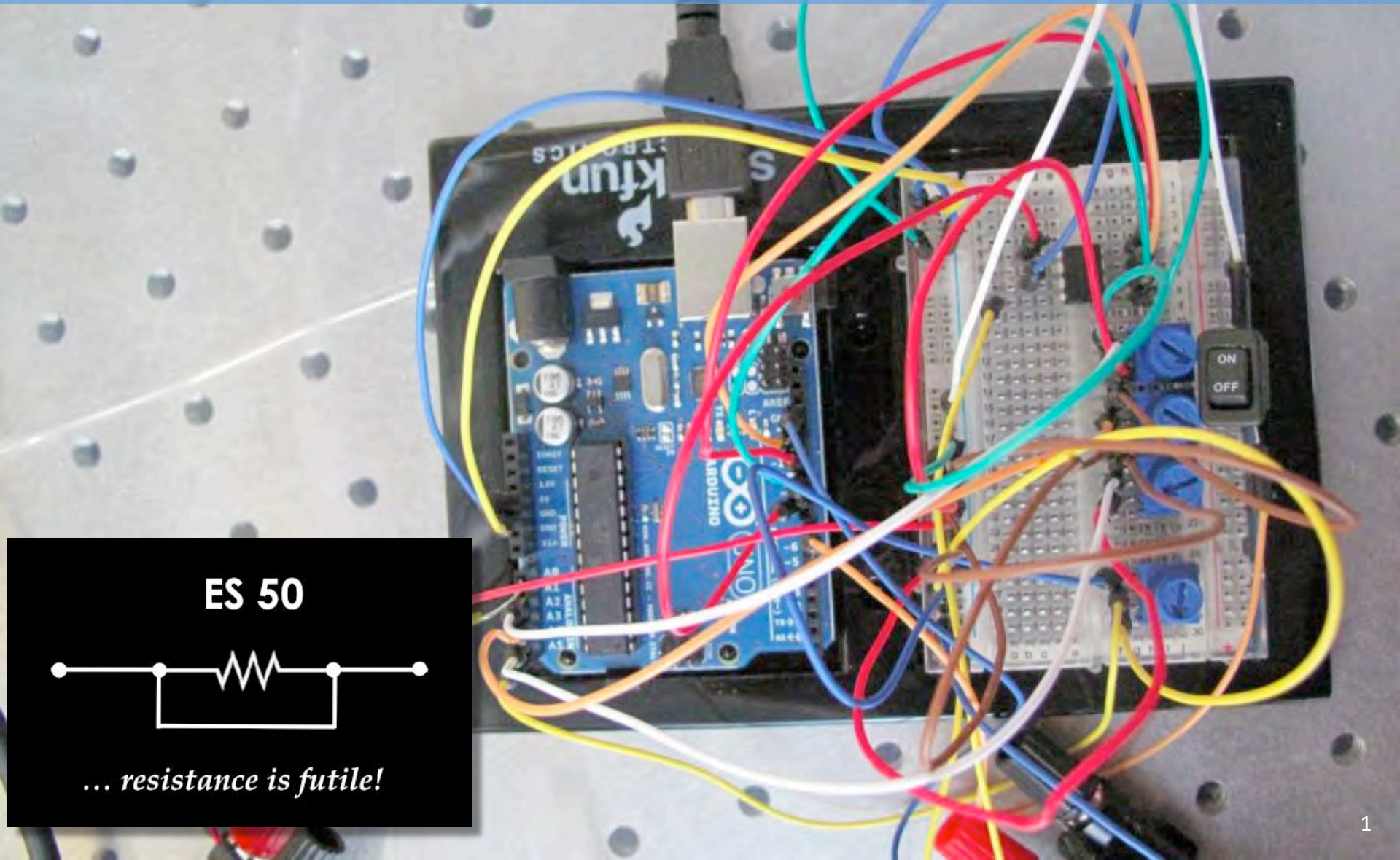
ES 50: Introduction to Electrical Eng.

Explore EE, satisfy a Gen Ed requirement & have fun



ES 50

… resistance is futile!

ES 50 Teaching Staff

Prof. Gu-Yeon Wei

Dr. Chris Lombardo

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ES 50 Teaching Staff

Jessica Lam

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ES 50: Introduction to Electrical Engineering

Lectures: MW 2-3.30pm, Northwest Building - B103

Instructors: Gu-Yeon Wei guyeon@seas.harvard.edu, (617) 384-8131; Office: MD 333
Chris Lombardo lombardo@seas.harvard.edu, (617) 496-5185; Office: Pierce 287

Lab Head: Xuan Liang xuan@seas.harvard.edu, (617) 495-2870; Office: Pierce G11A

TAs: 10-ish TAs, many more proctors, and other CAs;

Office hours: TBD - please check the course web site;
Please do take advantage of office hours – they are an ***excellent*** way to review the material and learn in small group settings
Cannot make the office hours? No Problem!
Please e-mail us and schedule separate meetings whenever needed!

Course website:

The website will have A LOT of information. Please visit it frequently and stay up to date with the course. You can also check out photos and videos of last year's final projects and labs, Q guide scores (2011, 2012, 2013, 2014), etc.

Main Course Objectives

- To introduce you to the exciting and useful world of electrical engineering
- To explain how many of the gadgets that you use every day actually work
- To empower you with the ability to build and program gizmos that sense and actuate the physical world around you!
- To encourage you (some of you at least ☺) to pursue carriers in EE and/or motivate others to leverage your newly acquired understanding of EE concepts across a wide range of disciplines, e.g., designing products, doing brain surgeries, making beautiful art, etc.

Course Outcomes

After taking ES 50:

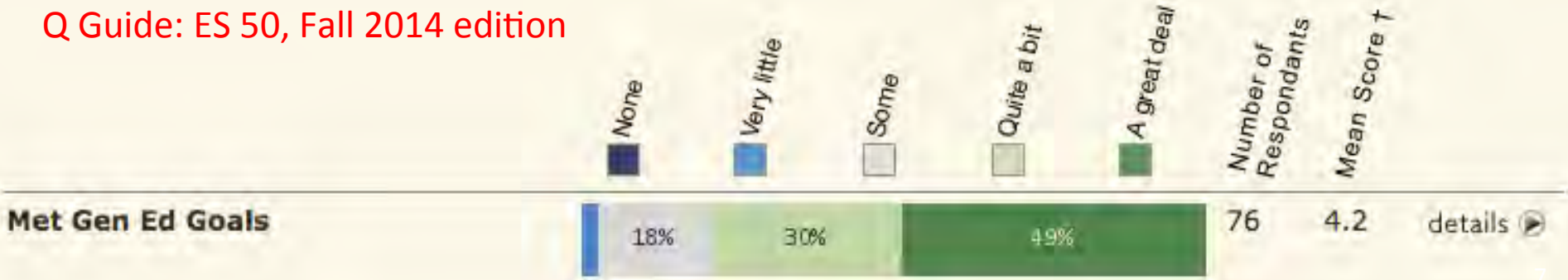
- You will be able to leverage the power of electronics to build intelligent & autonomous systems (robots), audio amplifiers (e.g., guitar amp), interactive art installations, light shows, mind-controlled machines, & much more…
- Your friends will be really impressed*
- Your roommates will think that you are super cool*
- You will get invited to many parties*
- You may even decide to start a company*

* Individual results may vary

You should take this class if…

- You want to sense the physical world around you build gizmos that do cool things! Think IoT.
- You've always wondered what EE is
- You want to learn cool stuff & you are curious about technology
- You want to have fun
- You have not taken any higher-level EE (and some CS) classes (it is okay to take them concurrently with ES 50, though)
- You need/want Gen Ed credit (Science of the Physical Universe or Empirical and Mathematical Reasoning)

Q Guide: ES 50, Fall 2014 edition



Prerequisites

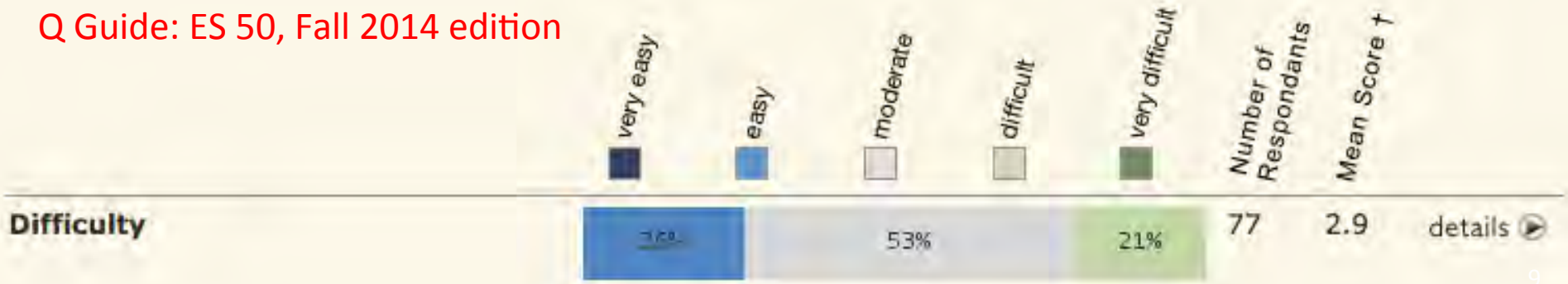
- Enthusiasm, curiosity, and desire to build things!
- Previous engineering or programming experience is NOT needed
  - The amount of high school physics required is minimal, and is limited to basic concepts only
- *You should be comfortable with algebra*

If you find yourself struggling with any of these concepts contact an instructor or TF right away – no need to waste time on this since it is more fun to build robots ☺.

Words of wisdom….

- This is not a difficult course, BUT you will definitely be challenged and work pretty hard during some weeks.
- There is a little bit for everyone in ES 50:
  - Some may find hw and quizzes difficult, but thrive in the labs
  - Others may excel on the hw and quizzes, but find hands-on lab activities more challenging
- But (I guarantee you ☺) most of you will really enjoy working hard on your final projects! And you will be very proud of them!

Q Guide: ES 50, Fall 2014 edition



Course Logistics

Grade

- Homework assignments (25%)
- Labs and lab reports (25%)
- Quizzes (25%)
- Final Project (25%)

Collaboration on homework and labs is allowed and encouraged!

- However, obvious copying of someone else's solutions or using any other unfair advantage (e.g., previous year's solutions) can result in disciplinary action.

Course Logistics

Lectures MW 2:30-4PM

- Will be recorded and posted on the course web site
- Lecture slides/notes will be available for download before lecture

Homework

- 10 assignments, first going out end of next week
- Will ordinarily be posted on the website on Saturday and due the following Saturday in a drop-box in Maxwell-Dworkin basement
- Problem-solving sessions will be offered by TAs
- TAs and the instructors will have weekly office hours where you can get help with specific homework problems

Labs

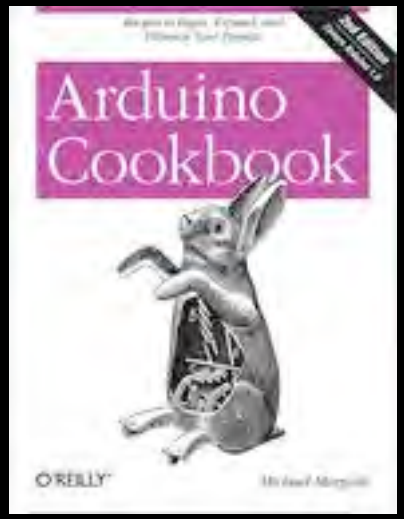
- 9 labs, starting the week of Sept 14, scheduled for 3-hour periods
- All labs will meet in the basement of Maxwell-Dworkin, B-112

Final Projects

- In addition to labs, perhaps the most exciting part of the course!!!
- You will have four weeks, and a budget of <$100, to propose, design, build, and program complex systems using the skills that you acquired in ES 50.
- The final projects will be done in teams of three, but larger or smaller teams are also possible with permission.
- During reading week (Wed., Dec 9) you will feature your projects in a design and engineering fair, open to the public. This should be A LOT OF FUN!

FREE e-books and other resources…

- Check the course web site regularly for additional resources.



Safari books on-line e-books, available through Harvard's library system, are great resource of information!

Safari Books Online

What will you learn in ES50?

L1 – L8: Analog world

Use electronics to sense the environment, amplify and communicate the obtained information, and respond to it (e.g., move something);

#	Date	Lecture Subject	Homework	Lab
L1	09/02	***Introduction to ES50 - Guide To Programming the Physical World*** *Course overview;* demos of prior years' final projects		
	09/07	*Labor Day*		
L2	09/9	***Analog Electronics: Electrical Circuits & their Elements*** Signals as electrical currents and voltages; voltage and current sources; resistors; Ohm's Law; electric power	**HW1** (due 09/12)	
L3	09/14	***Analog Electronics: Circuit Analysis***: Kirchoff's laws	**HW2** (due 09/19)	**Lab 1:** Arduino µ-controller; generating & observing electrical signals;
L4	09/16	***Analog Electronics: Amplifiers***		
L5	09/21	***Analog Electronics: Circuits with Amplifiers*** Design and Analysis	**HW3** (due 09/26)	**Lab 2:** Testing simple circuits; soldering 101
L6	09/23	***Analog Electronics***: *More examples & catch-up*		
L7	09/28	***Control Theory: Feedback vs Open-Loop Control*** *PID controller*	**HW4** (due 10/03)	**Lab 3:** Audio Amplifier
L8	09/30	***Analog Electronics: Inductors, Capacitors & Applications*** Filtering, sensing, actuation (motors); generation, transmission and storage of electrical energy		

What will you learn in ES50?

L9 – L17: **Digital world & digital signal processing**

Why going digital? How do we obtain digital information and how do we manipulate, communicate, and respond to it? Examples: digital music, images, movies. How do computers work?

L9	10/14	***Signals:* Analog-to-Digital Conversion (ADC)** Sampling and quantization; Nyquist theorem	(due 10/17)	**Lab 5:** AD/DA conversion
L10	10/19	***Digital Electronics:* Logic Gates & Combinatory Circuits** How a computer adds, makes decisions, processes information, etc.	**HW7** (due 10/24)	**Lab 6:** Digital electronics: (shift registers, multiplexers, counters, etc.)
L11	10/21	***Digital Electronics:* Flip-Flops & Sequential Circuits** How does computer memory work?		
L12	10/26	***Digital Electronics:* Finite-State Machines; Timers**; Now you too can build vending & ATM machines, elevator brain, etc.	**Final project proposal** (due 10/31)	**Lab 7:** Final project: Brainstorming & proposal writing
L13	10/28	***Signals:* Images as 2-D Digital Signals** Color, gray scale and bit-map images		
L14	11/02	***Signals:* Image Processing and Machine Vision**	**HW8 & Final project part list** (due 11/07)	**Lab 8:** Arduino smart car (BoeBot)
	11/04	**Final Project Workshop:** 1 min & 1 slide presentation by each team		
L15	11/09	***Signals:* Lossless vs. Lossy Compression** Huffman code, JPEG and MPEG	**HW9** (due 11/14)	**Lab 9:** Machine vision
L16	11/11	***Communications:* Analog Information Transmission** How do we transmit information? Why modulate? AM & FM radio		
L17	11/16	***Communications:* Digital information Transmission** Shift keying (FSK, ASK, PSK); noise and codes to overcome it	**HW10**	**Work on Final Project**

What will you learn in ES50?

L18 – L19: **Electronic Devices & Modern Technology**
How do microprocessors **actually** work, and what inside the black box?

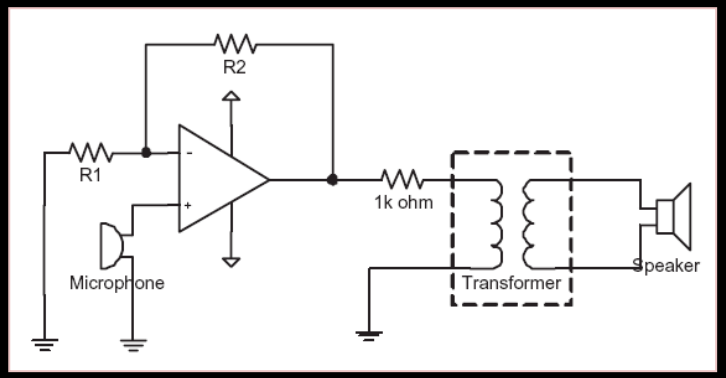
L18	11/30	***Semiconductor Devices and Integrated Circuits:*** PN junctions, MOSFETs, RAMs, NVM, CPUs, SoCs, etc.	**Work on Final Project**
L19	12/02	***Beyond CMOS & Concluding remarks*** Summary & what's next?	
	TBD	***Final Project Fair – during reading period***	

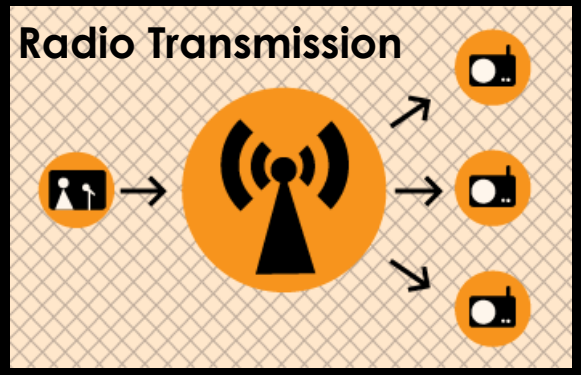
You will learn A LOT but you will not learn everything!
This course is designed to expose you to the broad world of EE and get you excited about the field. The course covers many **different** topics which means we cannot go into much detail for any one topic.

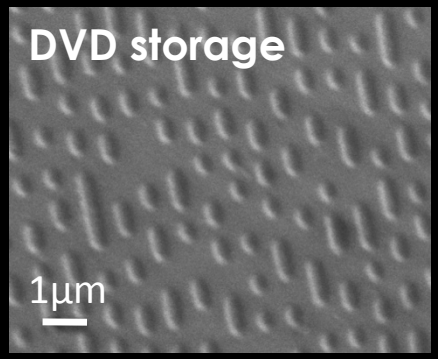
For every topic covered in ES 50 there is one (or many) courses at Harvard that you could/should take to become an Electrical Engineer.
Hopefully for some of you the journey starts today ☺!

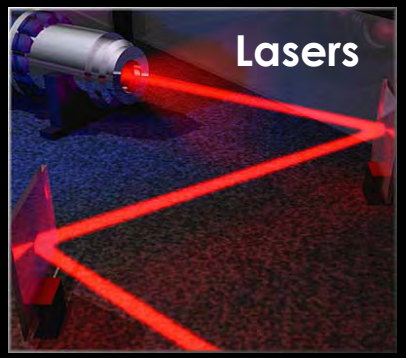
ES 50: Introduction to Electrical Eng.

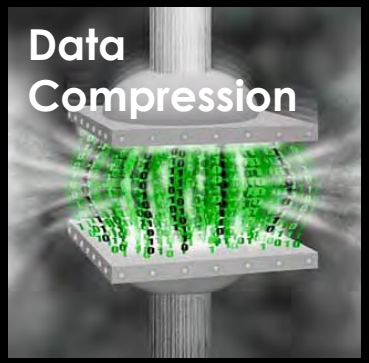
Emphasis on breadth & hands on experience

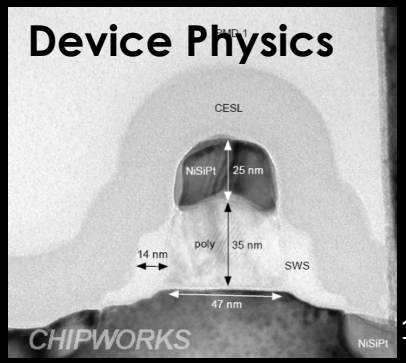










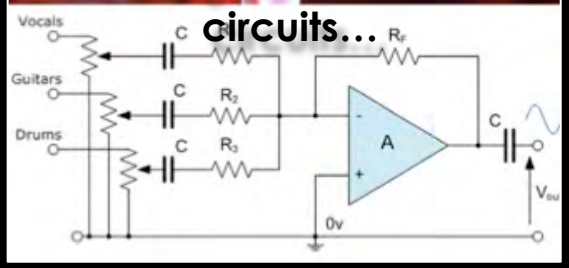


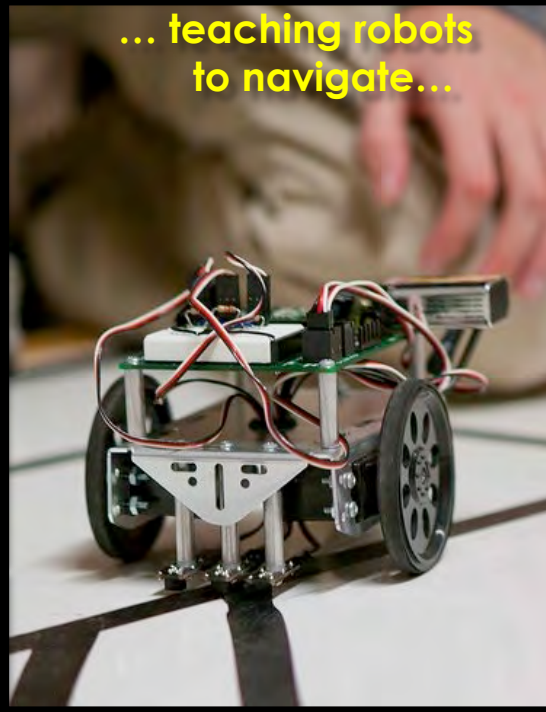
Weekly labs are essential component of the course!!!

…controlling the world with Arduino…

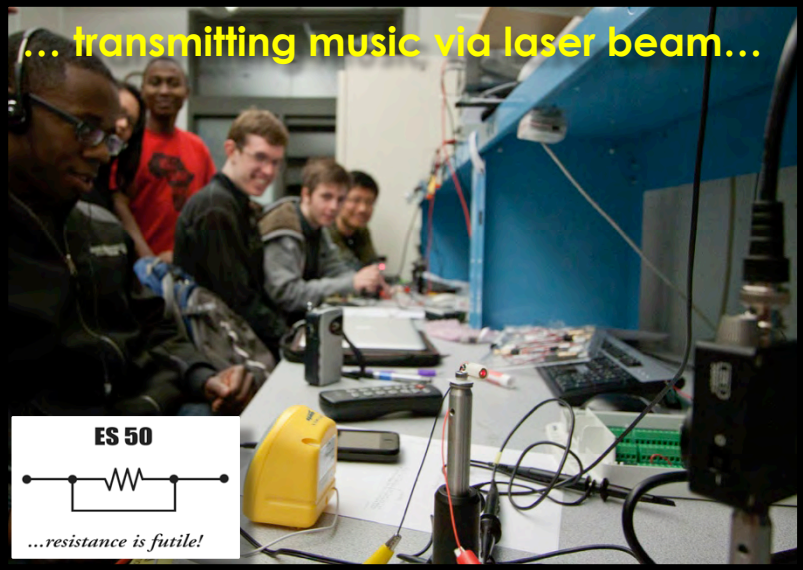
… teaching machines to see & count money…

… learning about devices & circuits…

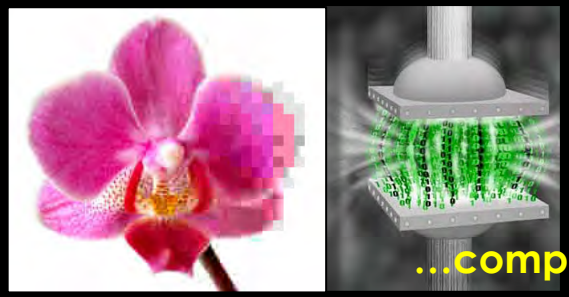




… teaching robots to navigate…

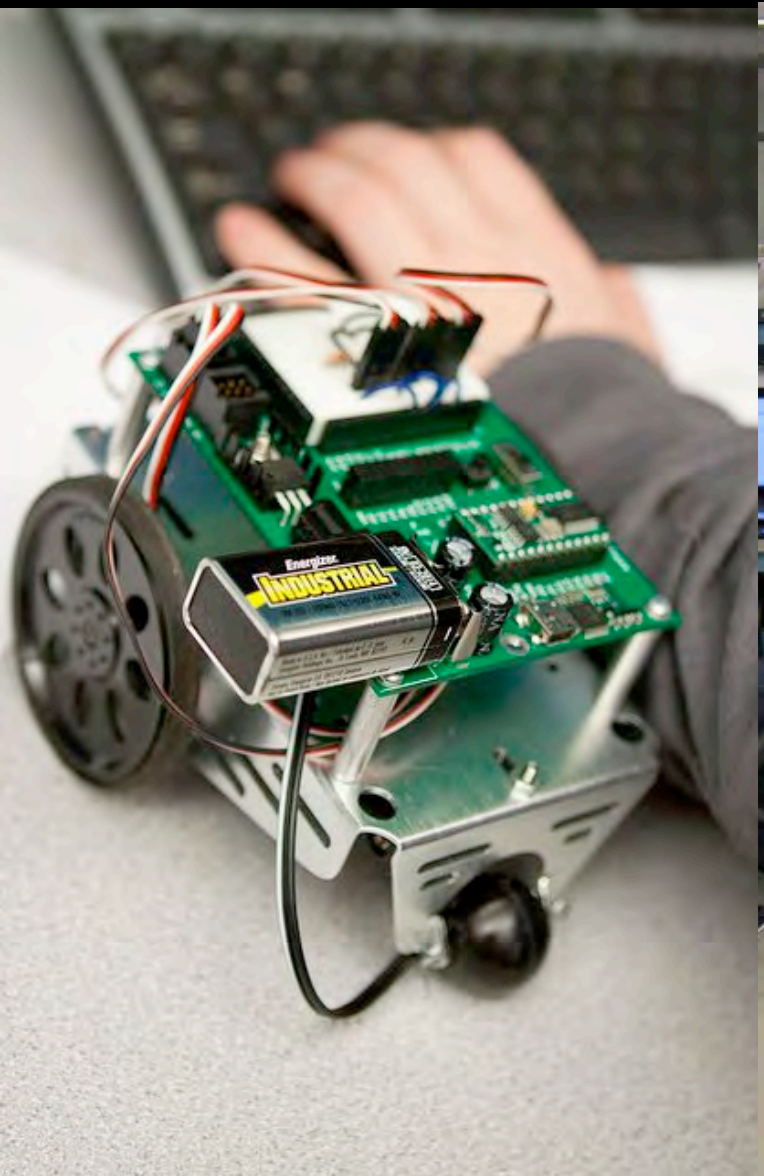


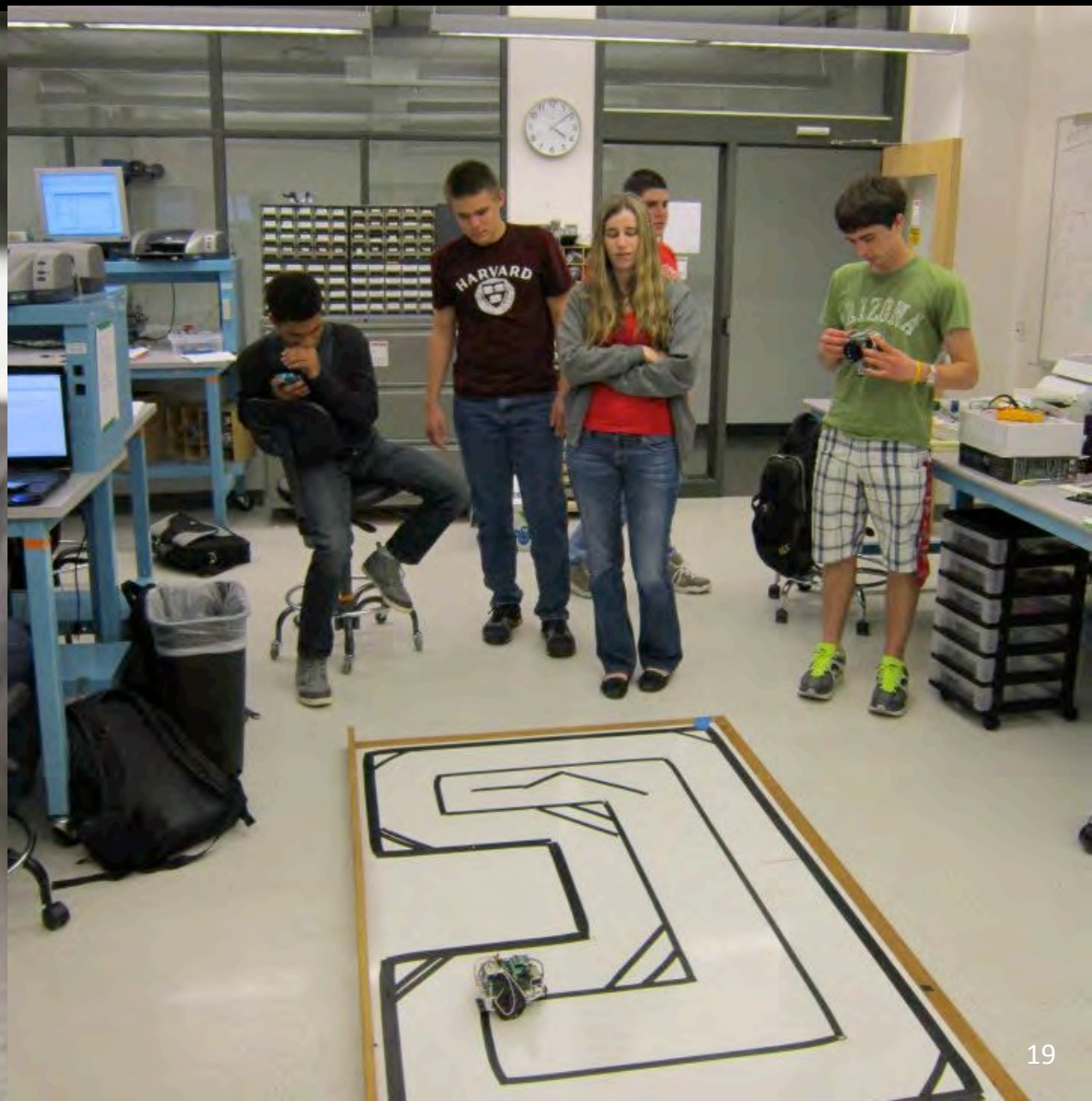
… transmitting music via laser beam…

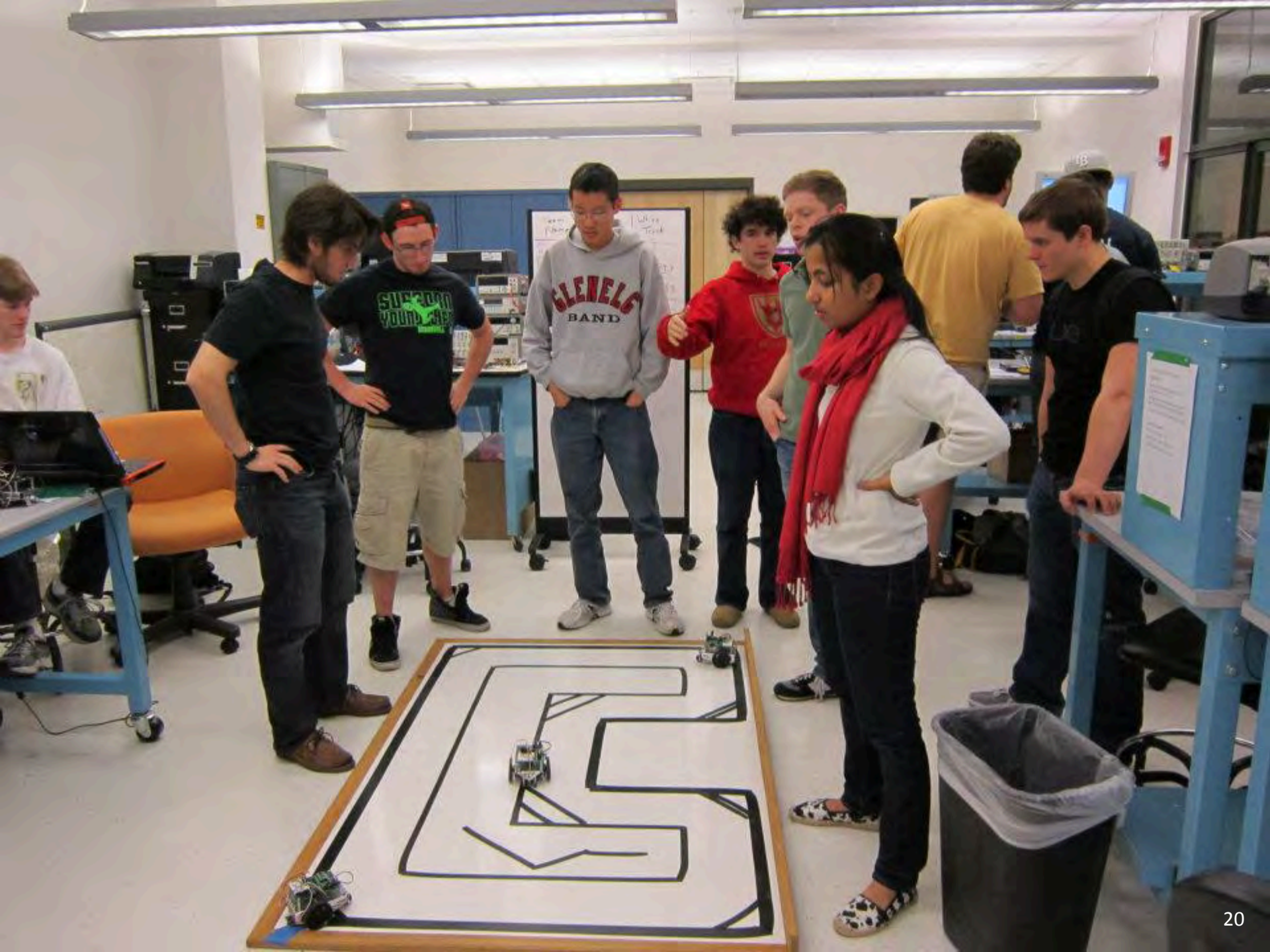


…compressing images…

the robot Lab

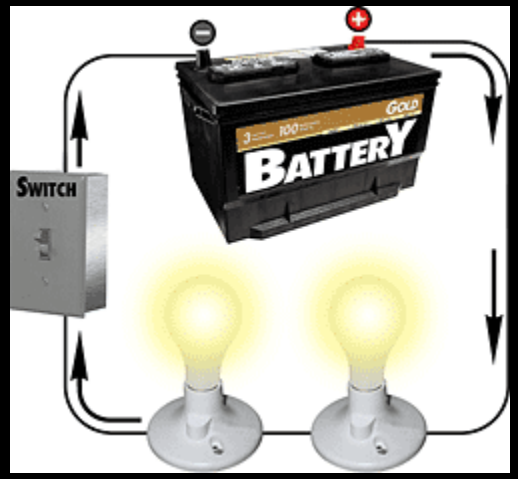


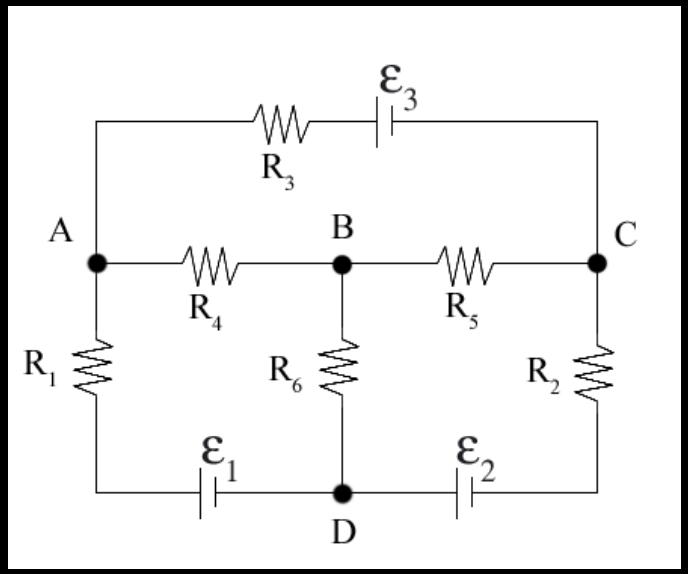


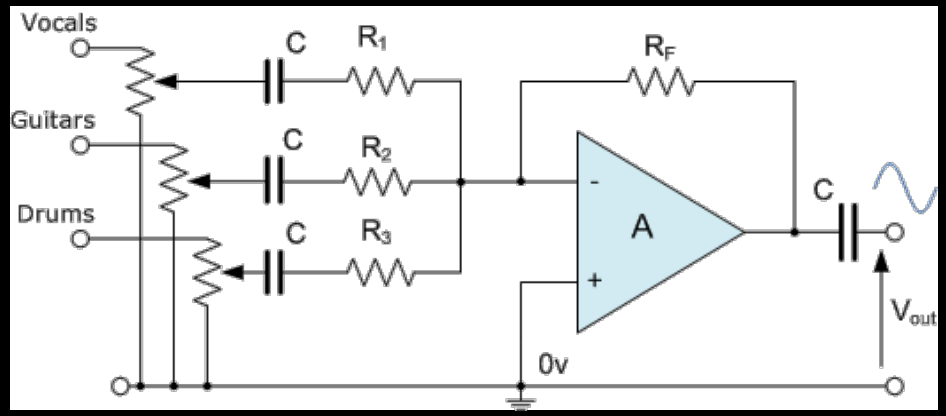

BAND

Black Track
White Track
Team Walk

Analog Circuits; Amplifiers & Sound Mixers







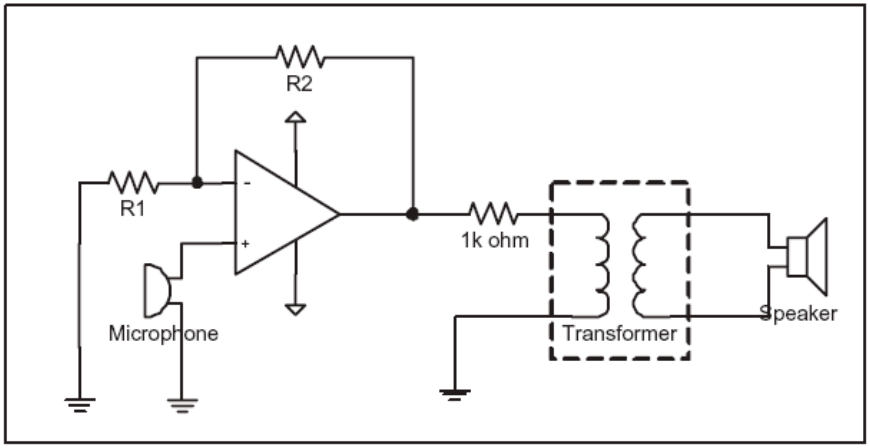
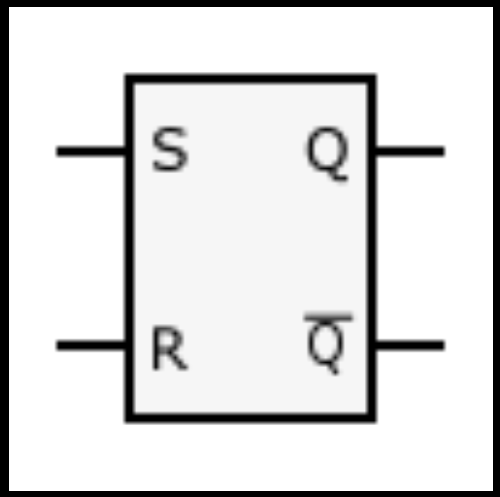
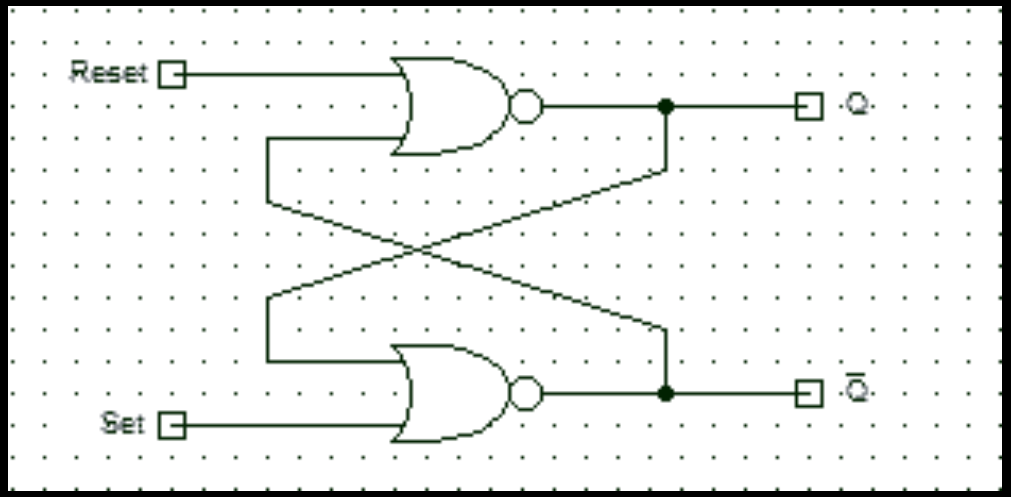
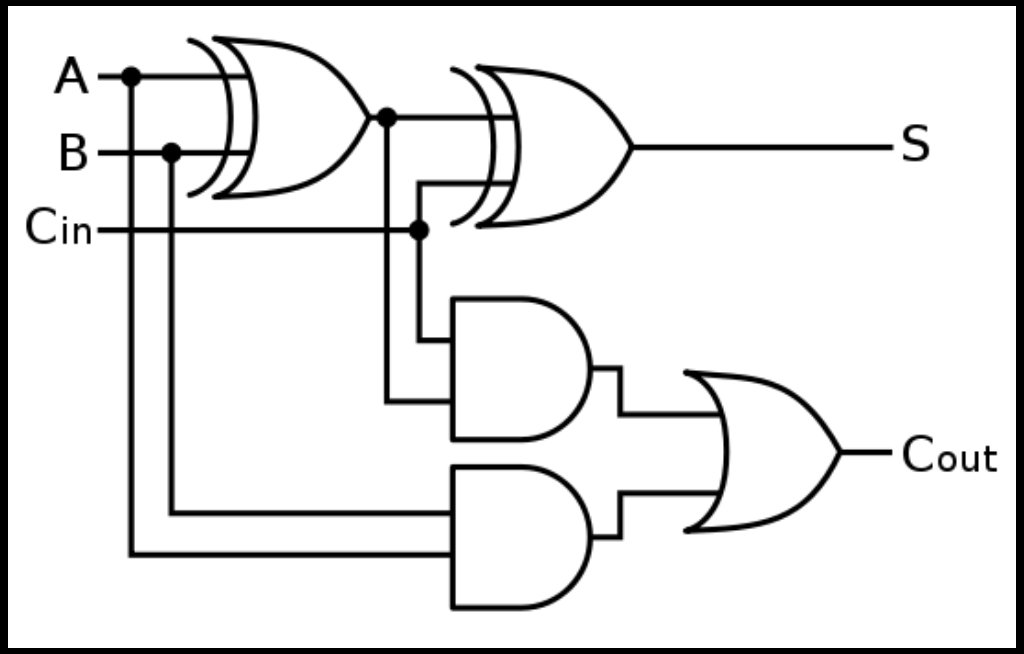


Figure 3: Schematic of an amplifier circuit with transformer.

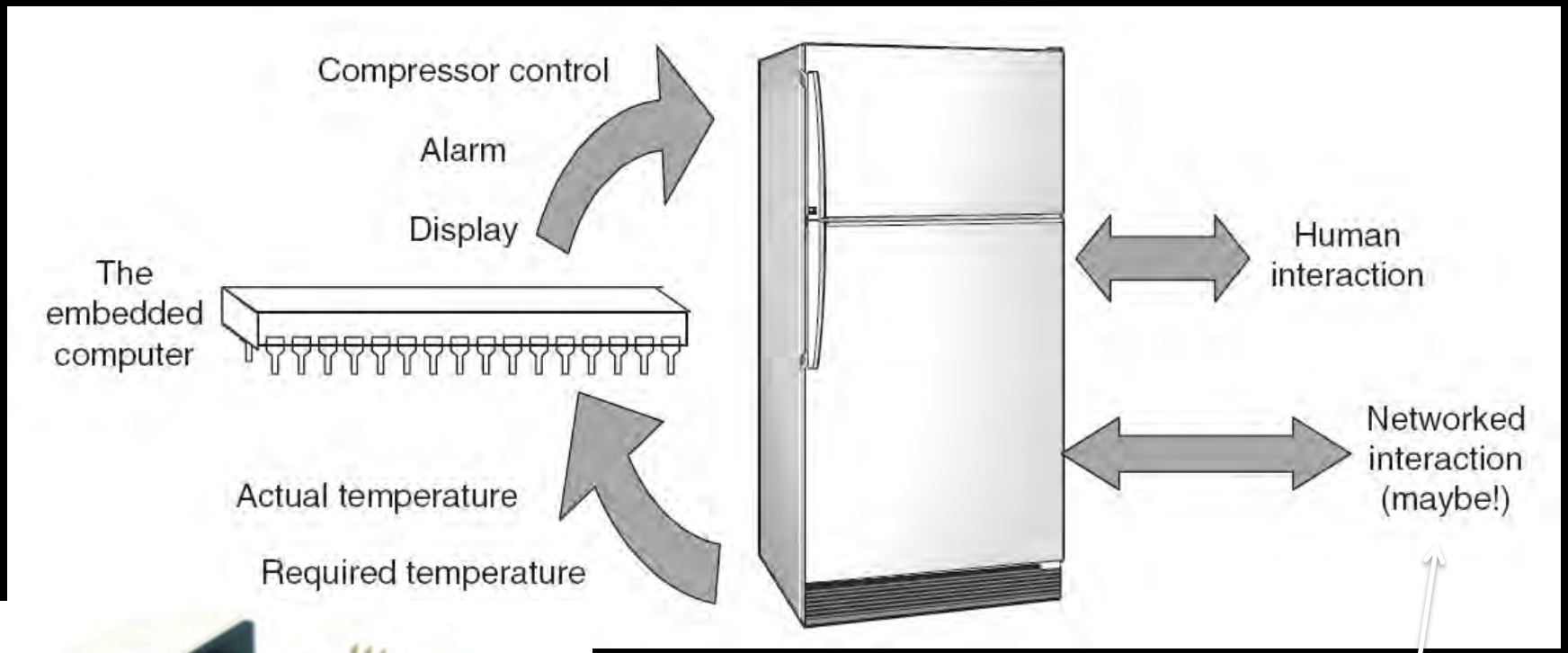
Digital Circuits & Systems







Embedded Systems
Example: Smart Refrigerator

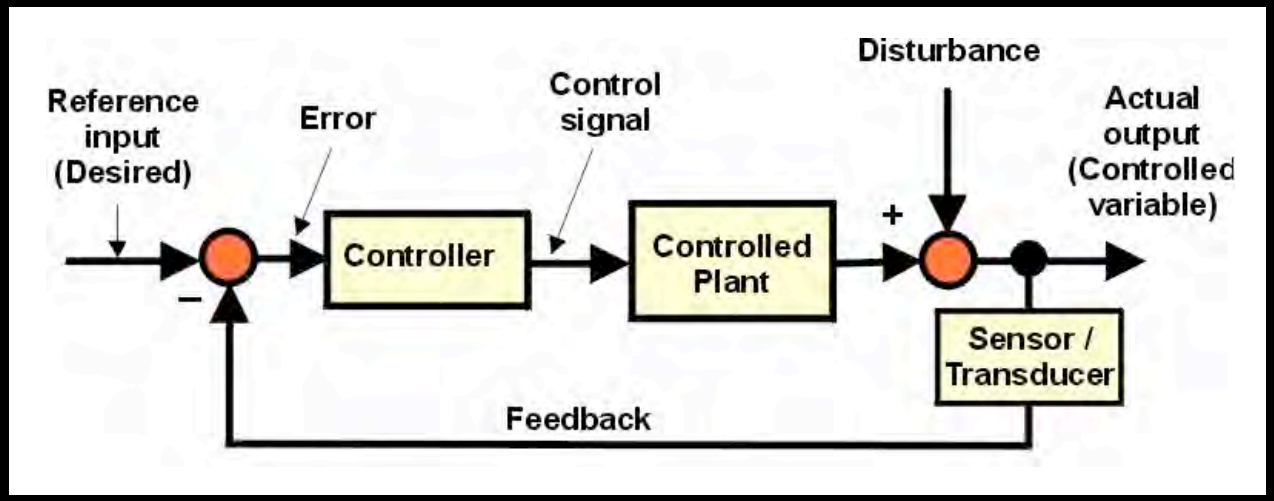


Arduino Microcontroller

Wouldn't it be cool if your fridge could send you a text message, tweet, or change your facebook status when you are running low on milk (or some other beverages)?

You can do this with an Arduino!!!

How does it work?



Embedded systems are reactive systems: they operate in continuous interaction with the environment. Embedded systems include sensors, controllers, & plants/actuators.

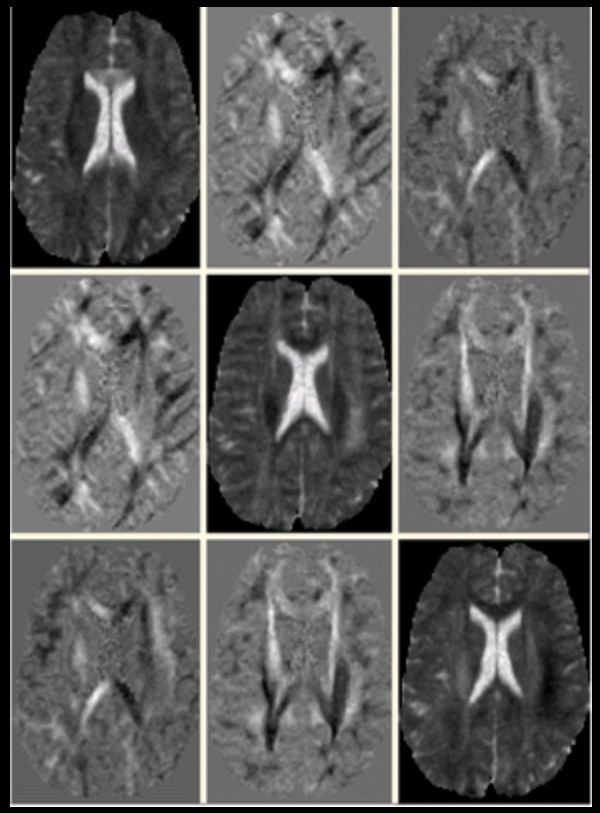
- Sensors: measure conditions within a physical environment, such as distance, acceleration, light, pressure, reflection of a surface, motion, etc.
- The "controller" is the brain of an embedded system. It's can be a tiny computer, with a processor and memory, which means you can run your own programs on it. In ES 50 we will use the Arduino microcontroller!
- Plant/Actuators: Affect the physical environment

Why should you study embedded systems?

They are everywhere! And YOU can learn how to build one yourself.

- Automate your home
- Control appliances from your computer or cell phone
- Build a remote-controlled surveillance camera
- Create interactive artwork
- Integrate sensors into a game that you can control without touching anything
- And so much more…

Image Processing: Medical Analysis



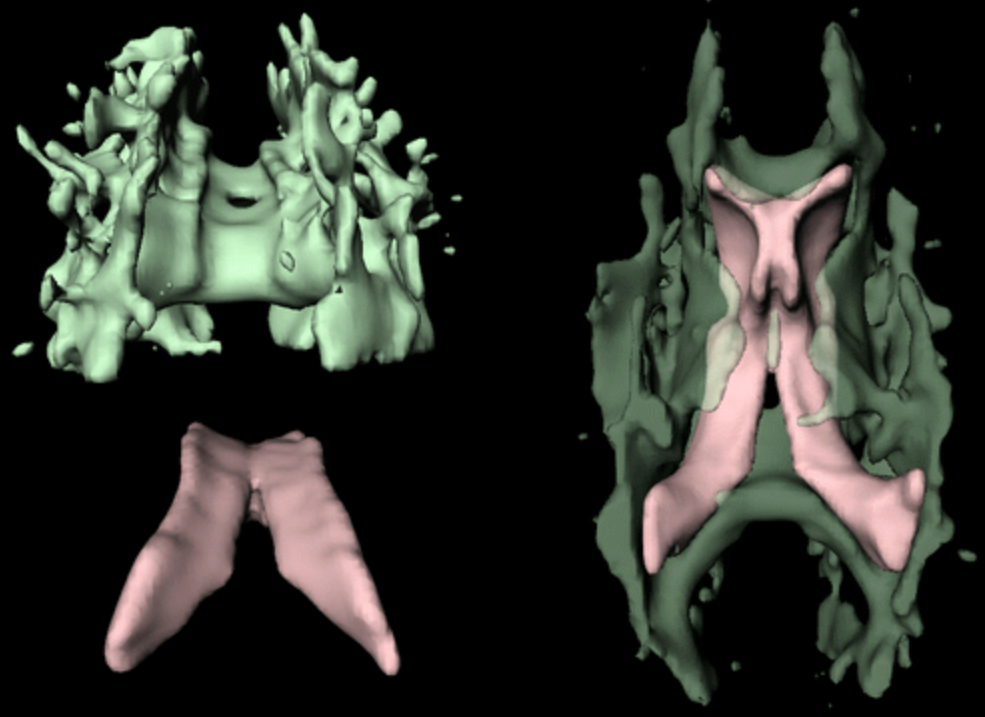


Image Processing: Object recognition

Image Compression

512×512 = 262,144 bytes

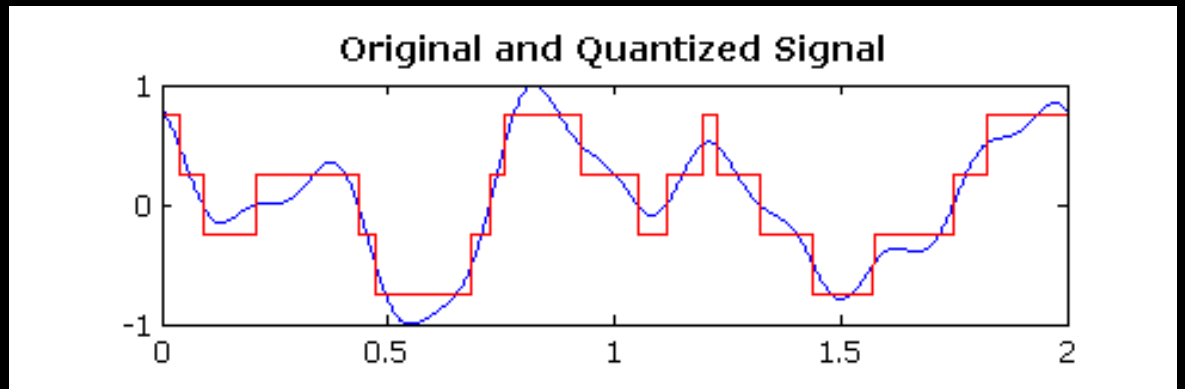
8-bit (264 kB)

4-bit (65 kB)

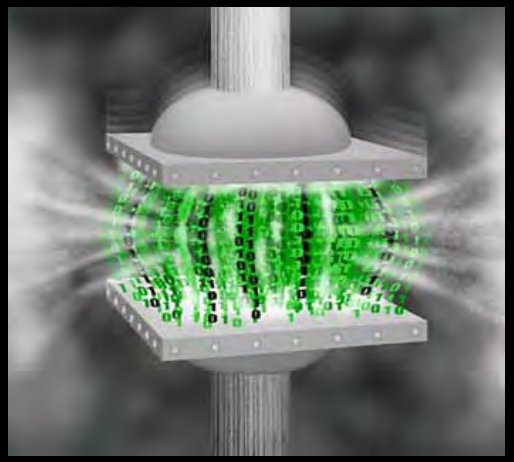
2-bit (21 kB)

1-bit (10 kB)

Analog-to-Digital Conversion

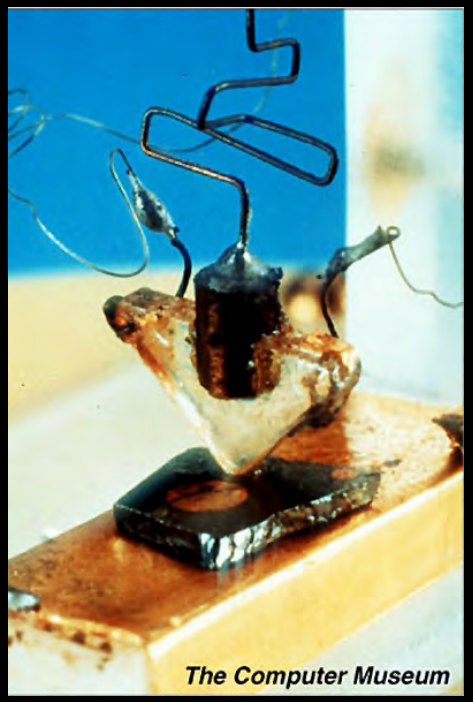


Data Compression

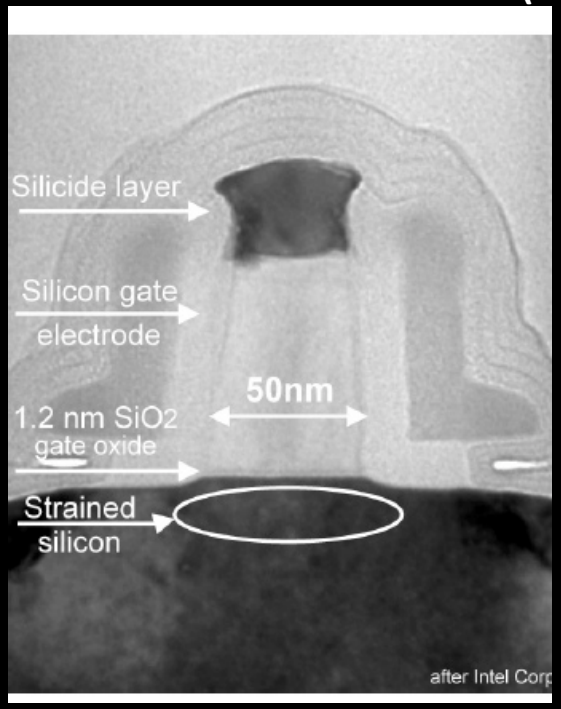


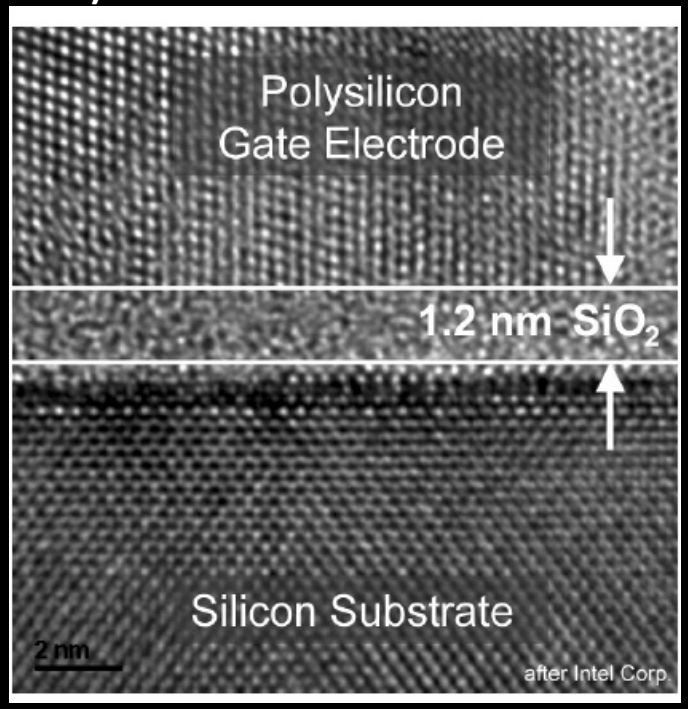
Modern Transistors

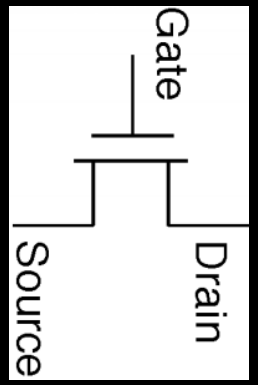
The First Transistor
Bell Labs, 1947

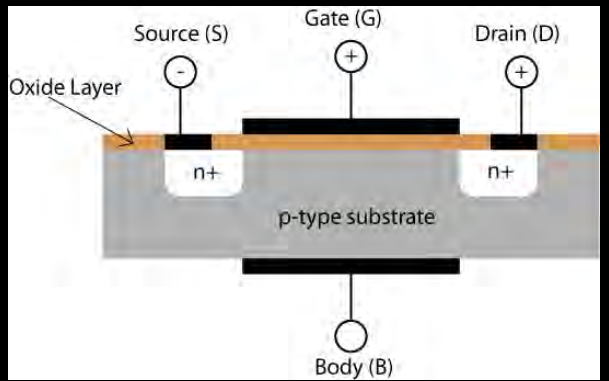


Today's Transistor (MOSFET)







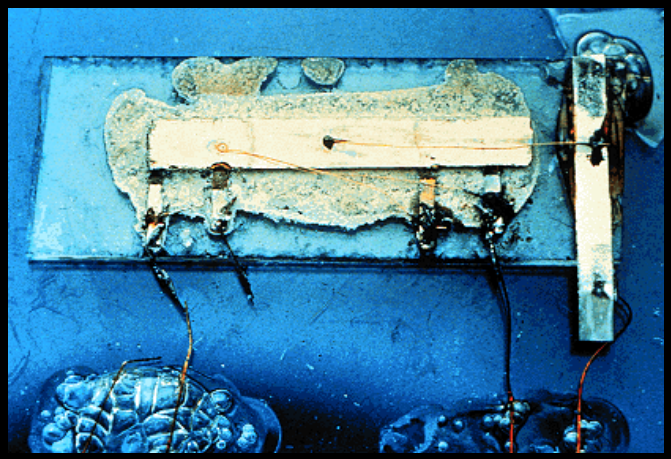


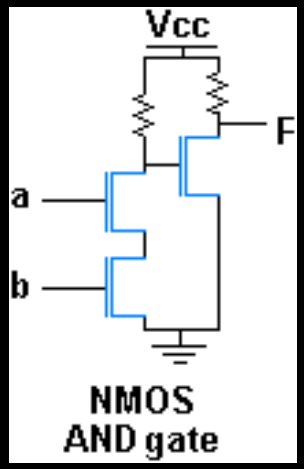
Integrated Circuits

The first electronic circuit

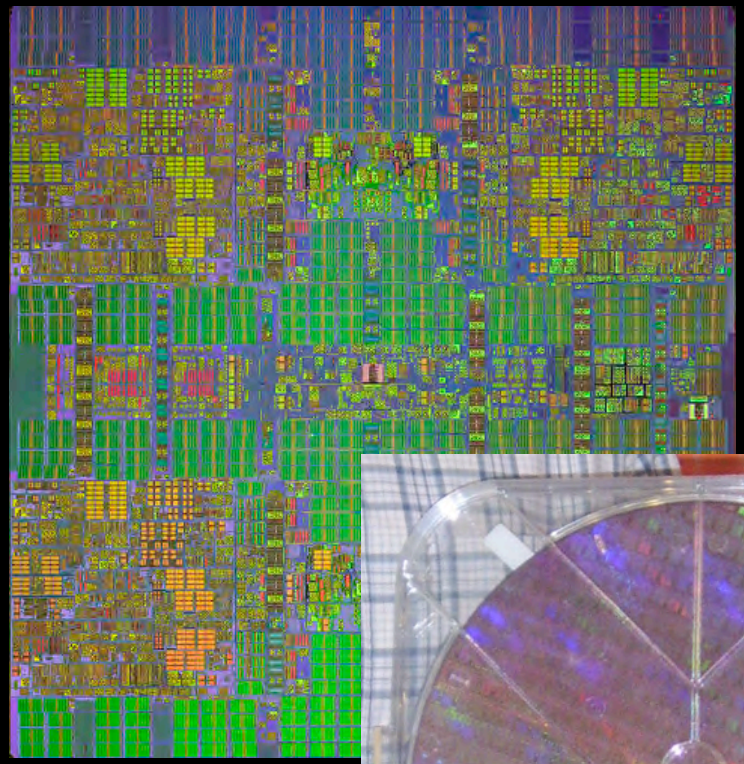
Texas Instruments (1958)

About a half inch wide, consists of two transistors mounted on a bar of germanium

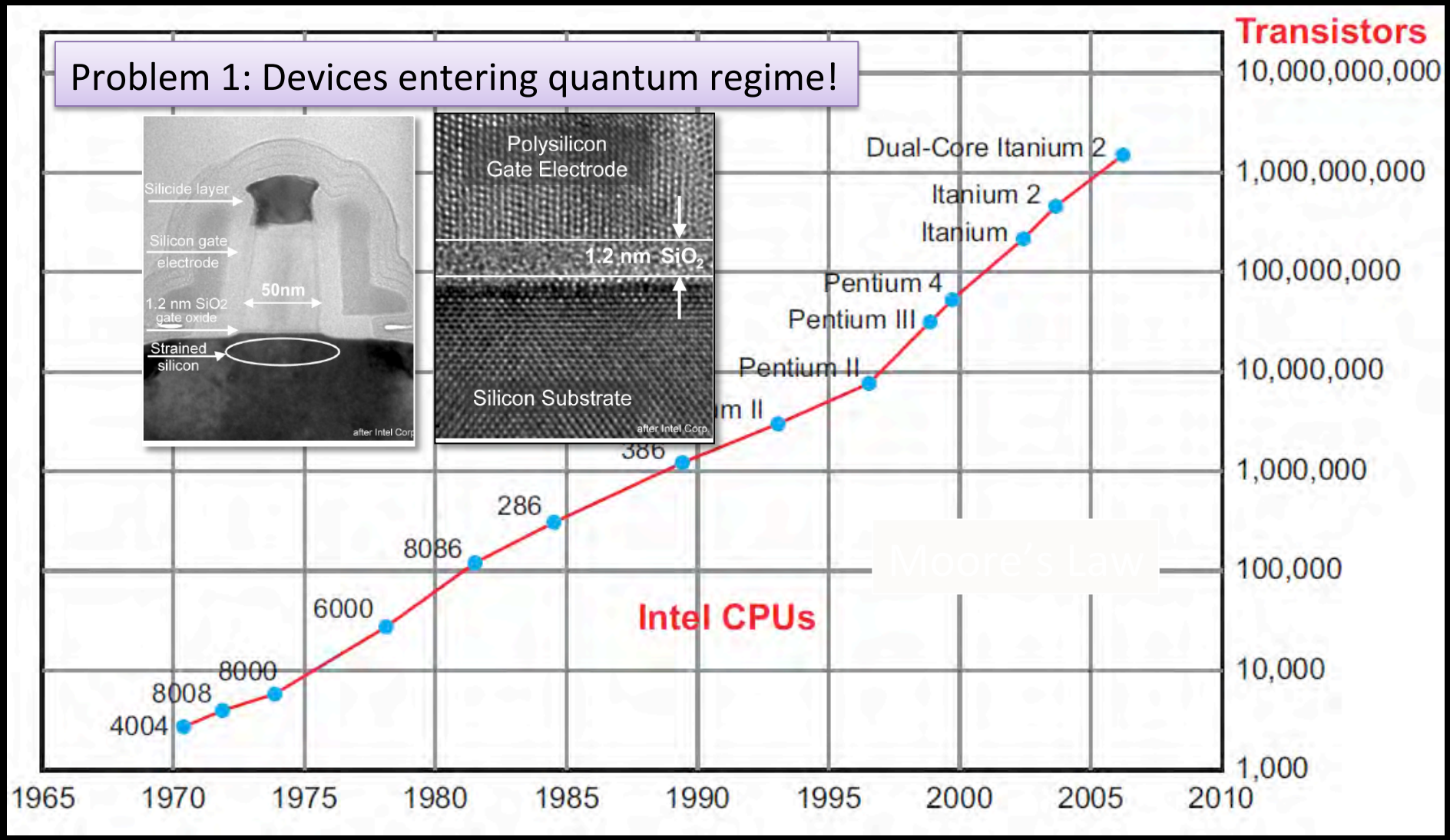




Today's Integrated Circuits

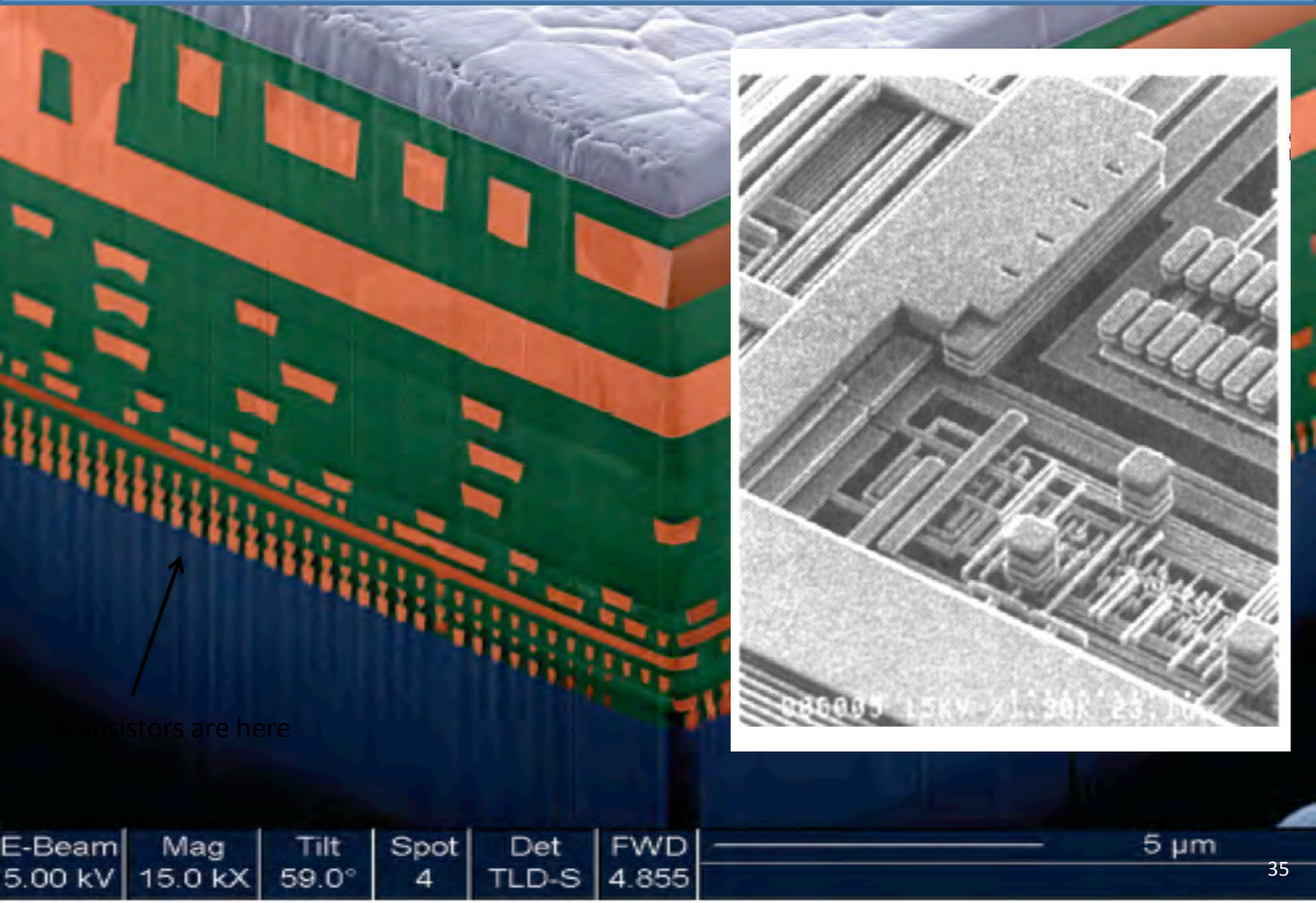


Electrical Engineering in Action



Problem 2: How do we connect all these switches (transistors)?

A LOT of wires to connect all those switches!



…. And a lot of wires make a lot of HEAT!

Electrical wires:

large power dissipation due to Ohmic losses

a major contributor to large CPU power consumption: between 50%-80%

What can we do about this?

Ability to build things is important!!!

- Computers are everywhere, but being able to use computers, code, and press keys is not enough any more!
- **In today's globalized economy, maintaining a technological edge requires *dealing with the physical (hardware) world.***
- ***YOU can make an impact with hardware!***

If you don't believe me, would you believe Bill Gates?

In a 2006 *Scientific American article,* Bill Gates predicted that robotics would be the next revolution, and that robots will soon become a natural part of a home, taking care of simple tasks such as vacuum cleaning, lawn mowing, surveillance, and food service. He also compared the current state of the robotics industry to the computing industry in the 1970s (we'll look back at early days of computing later…)

Google Jobs

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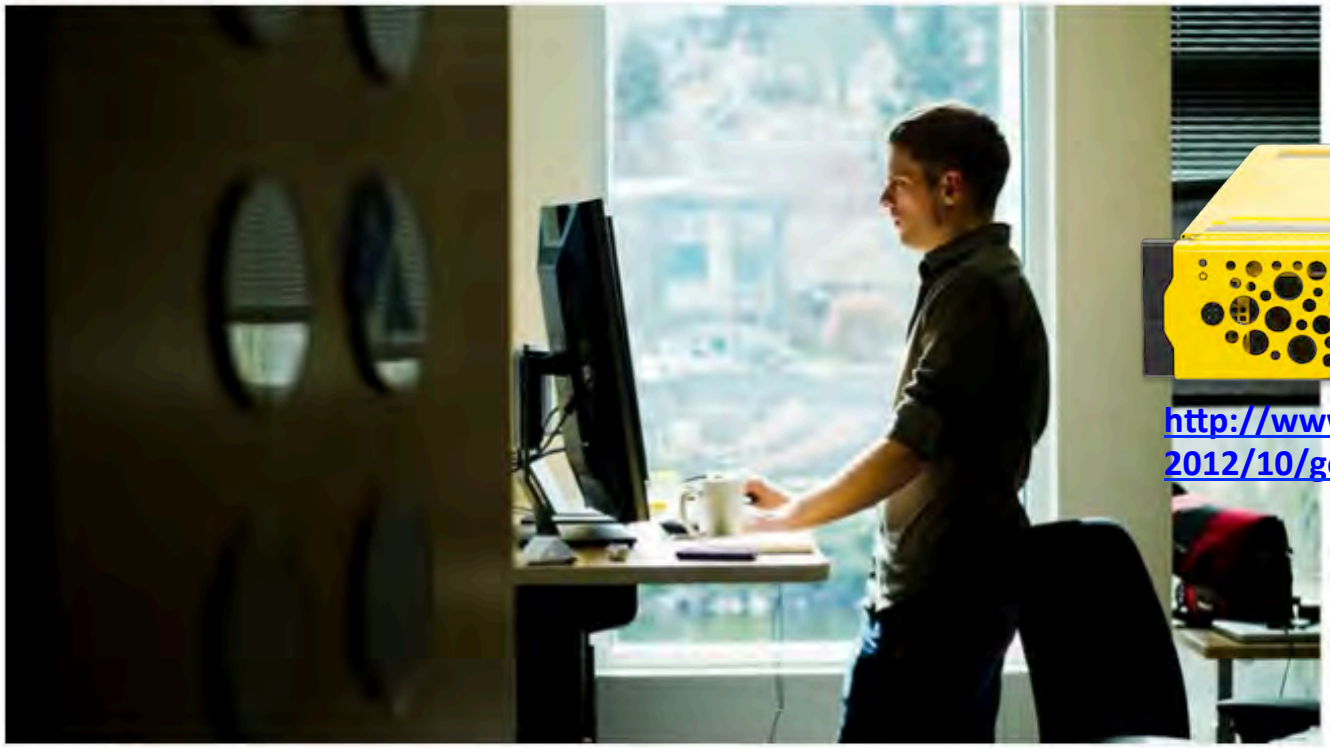
About Google Jobs Teams and Roles Engineering & Design Hardware

Hardware

12

Design and build the systems at the heart of one of the world's largest computing infrastructures.



http://www.wired.com/wiredenterprise/2012/10/google-search-appliance/

Keeping up with the growth of the Internet is just the starting requirement for infrastructure engineering. Our computational challenges are so big, complex and unique we can't just purchase off-the-shelf hardware, we've got to make it ourselves. Our Platforms Team designs and builds the hardware, software and networking technologies that power all of Google's services.

As a Hardware Engineer, you design and build the systems that are the heart of one of the world's largest and most powerful computing infrastructures. You develop from the lowest levels of circuit design to large system design and see those systems all the way through to high volume manufacturing. Your work has the potential to shape the machinery that goes into our cutting-edge data centers, affecting millions of Google users.

Still not sure if ES 50 is for you?

After taking ES 50, you will be able to leverage the power of electronics to build:

- intelligent and autonomous systems (robots),
- audio amplifiers (e.g. guitar amp),
- interactive art installations,
- light-shows,
- mind-controlled machines,
- pull sophisticated pranks on others ☺

Your friends will be really impressed. Your roommates will think that you are super cool. You will get invited to many parties.

- You may even decide to start a company?

You still don't believe?

Okay, let's see what last year students accomplished…

Use your **brain (literally!)** to build gizmos that control the physical

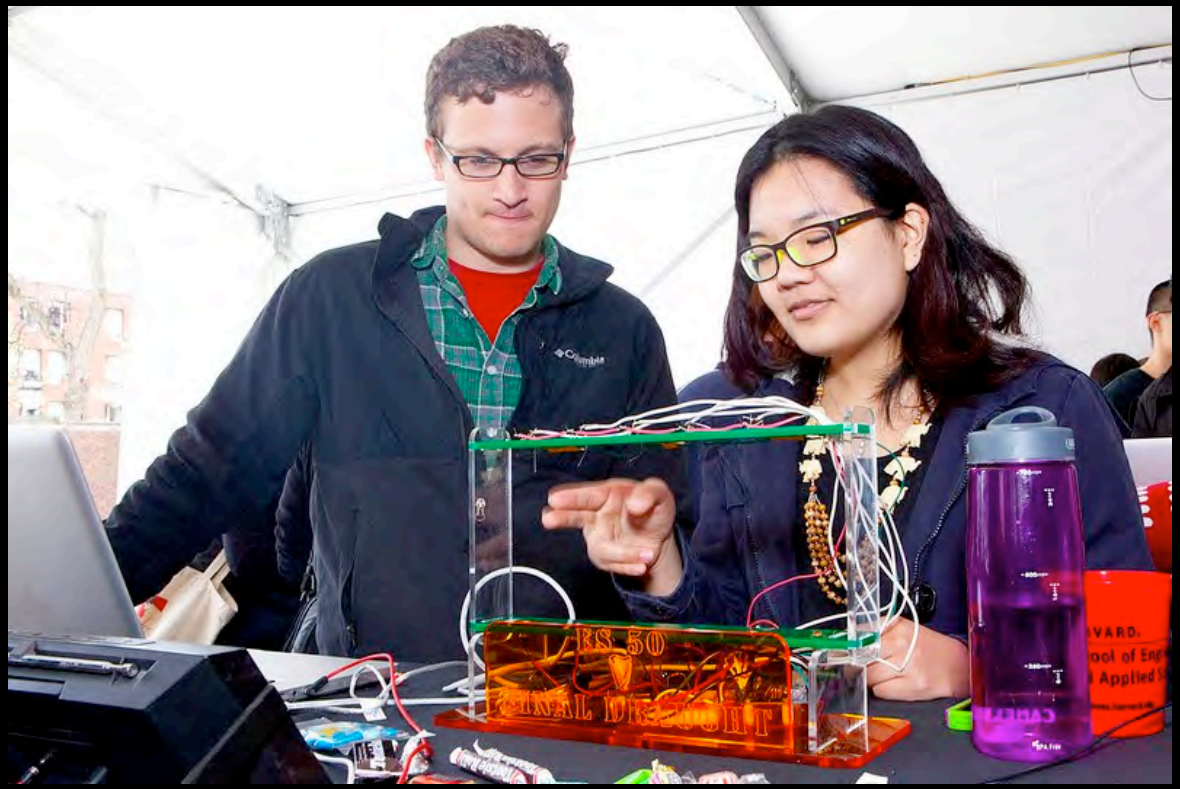
Charles Zhang, Douglas Muhlestein, Sean Bennet

61 The Hu
Eric Rodrigo, Ian Meyer, Mark
Steinbrick, Neal Champagne
www.avery.com

I took CS5

Laser Harp

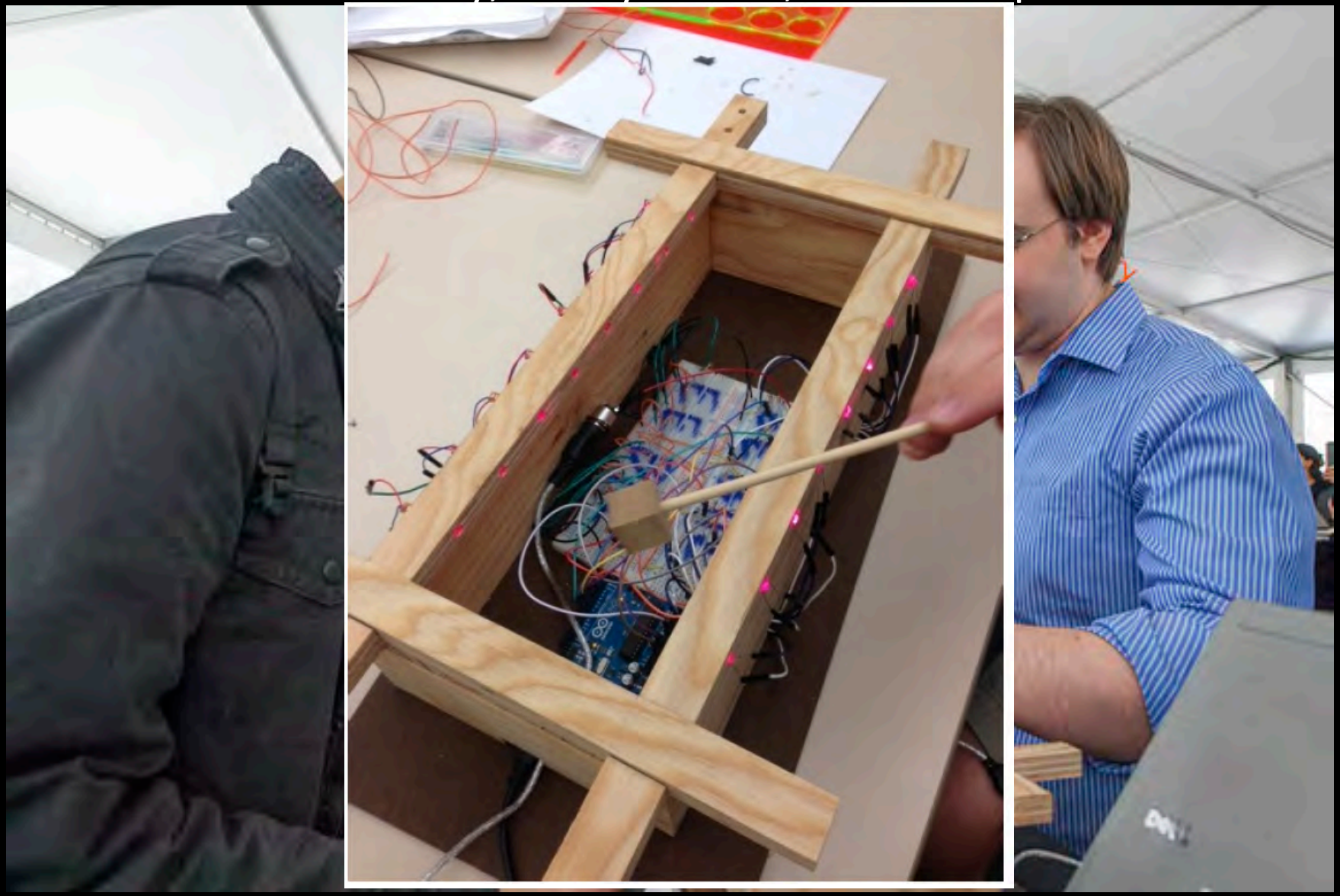
Doug Bright, Thomas Esch, Jamie Song



http://vimeo.com/65517241

Lazyr

Thomas Esty, Danny Bredar, Andrei Ciupan



The Pianist
Ha Le, Eric Hendey, Janice Zhang

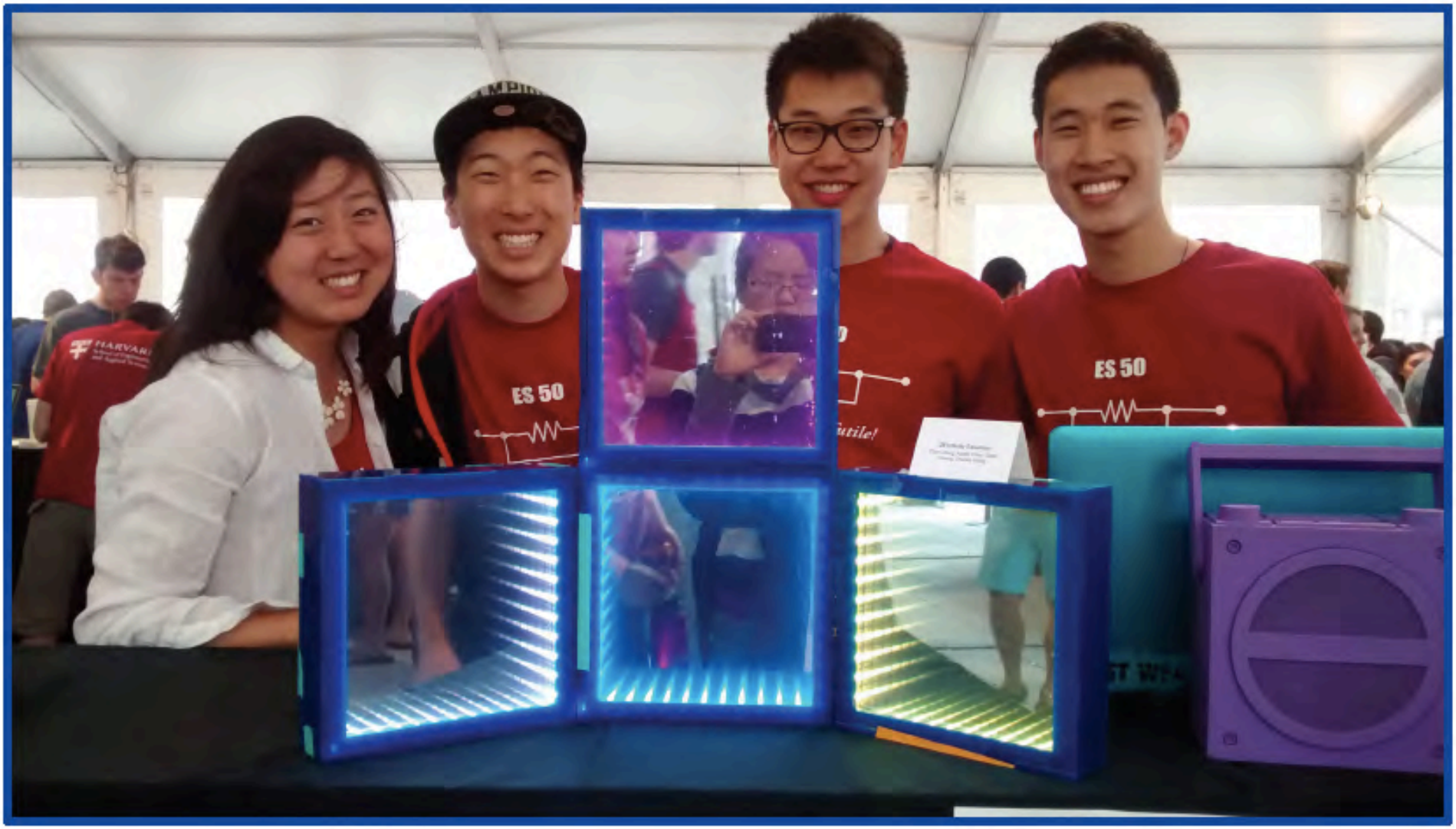
https://www.youtube.com/watch?v=Pz11H8UQ0xI

Dan Lobo, Angie Peng, Amy Robinson, Theresa Tharakan
(AKA The WolfPack)

Lil' Thermin
Theo Breen, Max Seiss

https://www.youtube.com/watch?v=neDpK2fHMVI&feature=youtu.be

eliza chang, austin chen, dabin hwang, charles wong



https://www.youtube.com/watch?v=XZ92eJUd2JQ

Super SMASH Bros

Jason SMith, Trevor nASH

RetroBlue:
Bluetooth Rotary Phone

https://www.youtube.com/watch?v=ulu5tc6mviA&feature=youtu.be

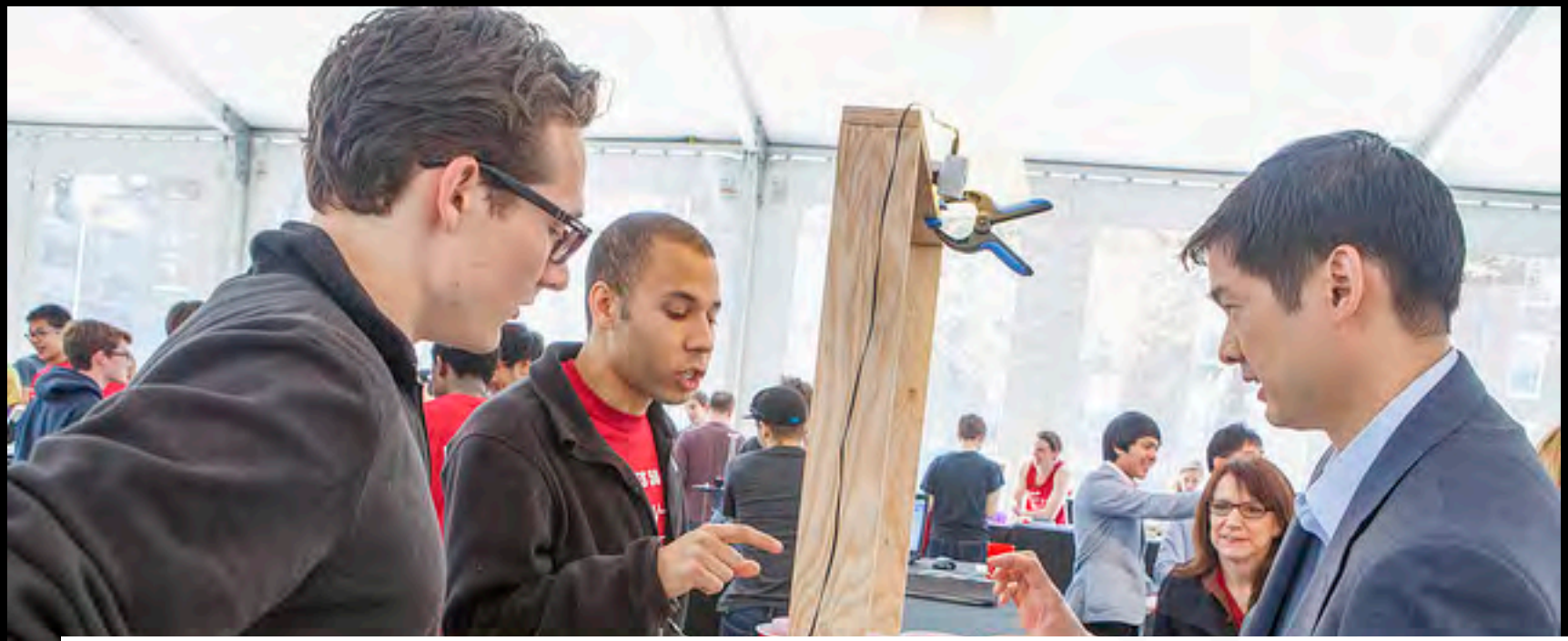
Michelle Luo, Karen Xiao, & Kenny Yu

http://www.karenxiao.com/tinibot/

https://www.youtube.com/watch?v=L5XI8LAHq6I

Beer Pong Revolution

Tiana Abdulmassih, Nathan Bruns, Karwehn Kata



MATLAB Generated Images Using Background Subtraction

3 Colors!
Angela Li, Violet Li, Shirley Ai, Lucas Freitas

COLOR!

1d Pong

Perry Green, Matthew Warshauer, and Julia Carvalho

https://www.youtube.com/watch?v=YpqpQz4mYZk&feature=youtu.be

wayfair

34 HandiCab
Gunsager Gulati, Harnek Gulati, Justin
Mathew, Nicholas Mahlangu

ES 50

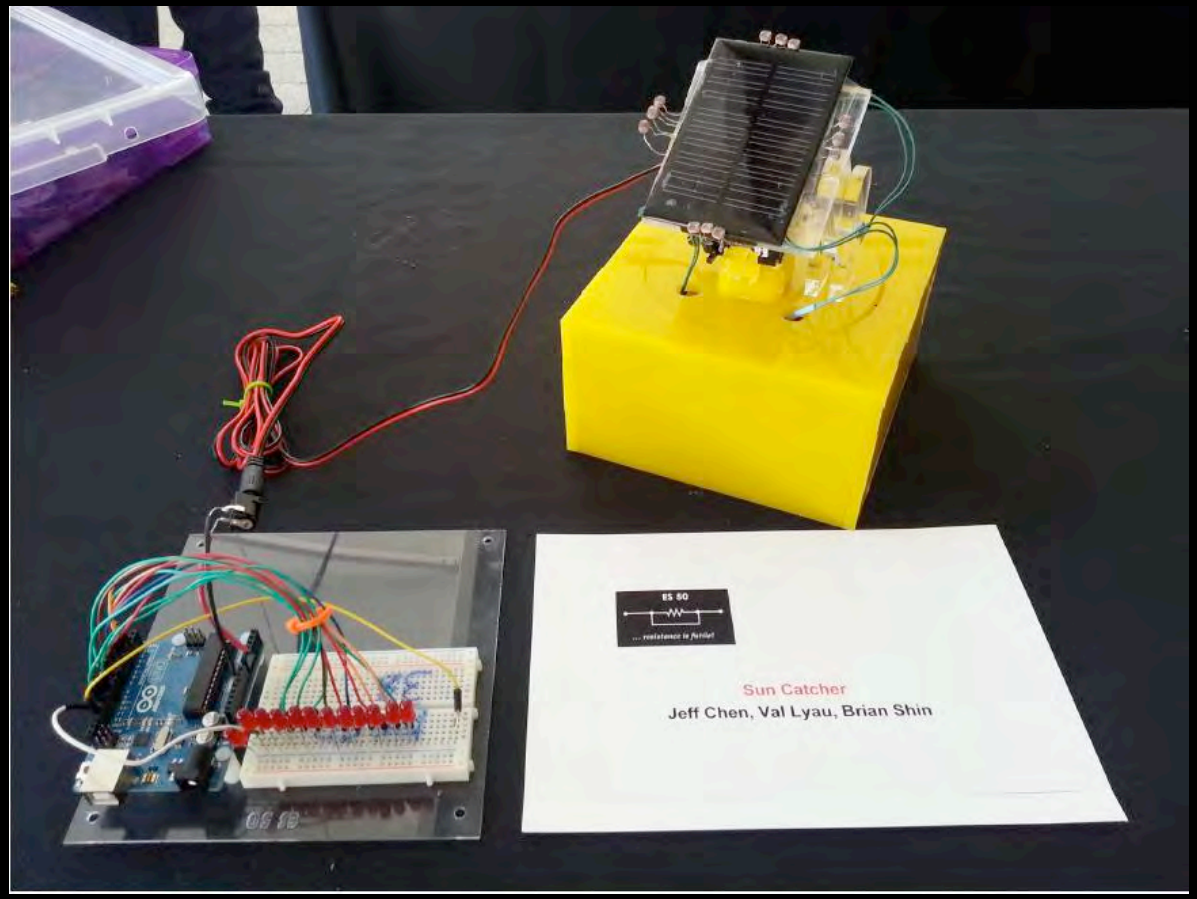
Stayin' Alive

Samuel Becker, Bryan Bu, and Brian Krentz

A compact medical Tricorder device used to measure major body vital signs

SunCatcher

Jeffrey Chen, Valentina Lyau, and Brian Shin



http://www.youtube.com/watch?v=Y4WeacRmN2s&feature=youtu.be

Wireless Fencing

Ping Pong Assassins

ES50:
Resistance is Futile