Lecture 01
Introduction

CE346 – Microprocessor System Design

Branden Ghena – Fall 2022

Some slides borrowed from:
Josiah Hester (Northwestern), Prabal Dutta (UC Berkeley)

Welcome to CE346!

- Focus on hardware/software systems and their design
    - Hardware/Software co-design
        - How do you write software that interacts with hardware?
        - How do you choose hardware to support software needs?
    - Sensors and Sensing
        - What can sensors do and how do they work?
        - How do you write applications that sense the world?

Asking questions, four ways

1. You can always ask questions during lecture!
    - I'll let you know if I need to move on for now and answer you after class

2. We'll take breaks during lecture
    - I'll pause after each break to see if any questions came up

3. I will hang out after class for questions
    - Plenty of time to answer everyone

4. You can always ask questions on Campuswire too

    The class message board app

Today’s Goals

- What are the goals of this course?

- Why do I think embedded systems are so important?

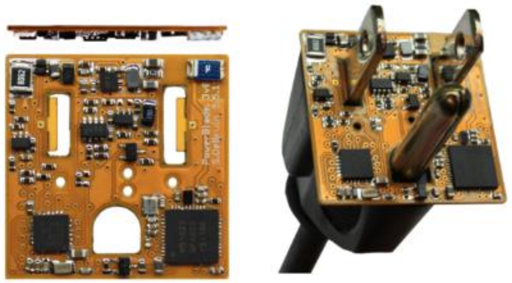
- How is the course going to operate?

Outline

- **Who and Why**
- Embedded Systems
- Course Overview

Branden Ghena (he/him)

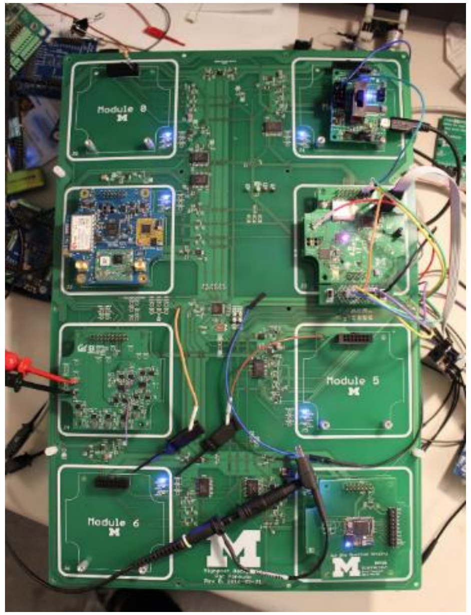
- Assistant Faculty of Instruction
- Education
  - Undergrad: Michigan Tech
  - Master's: University of Michigan
  - PhD: University of California, Berkeley
- Research
  - Resource-constrained sensing systems
  - Low-energy wireless networks
  - Embedded operating systems
- Teaching
  - Computer Systems
    - CS211: Fundamentals of Programming II
    - CS213: Intro to Computer Systems
    - CS343: Operating Systems
    - CE346: Microprocessor System Design
    - CS397: Wireless Protocols for the IoT



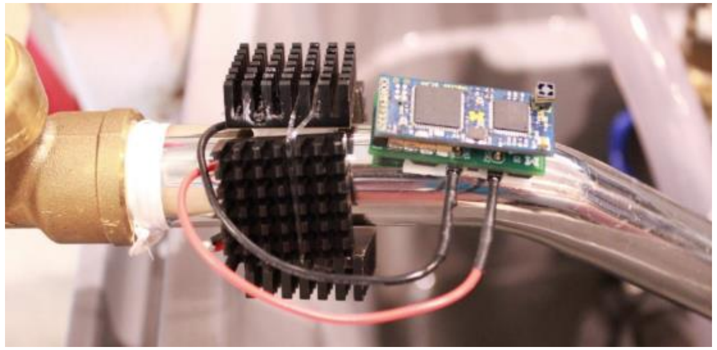
Tock

Things I love

Research area: resource-constrained embedded systems



- Most interesting to me: the interfaces
  - Hardware and software
  - Applications and OS
  - Communication



Faculty: now I can choose what to teach!

- Goal: provide classes that teach more advanced embedded systems topics
    - Hopefully, generally useful to other nearby domains of CS and ECE too!

- Result: this course!
    - Course goal: introduce students to hardware-software interactions
        - Practical hands-on experience with microcontrollers and sensors
        - Open-ended project where students can choose their specific focus

Outline

- Who and Why
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What is an embedded system?

- A computer built into a device
  such that the device is interacted with, **not** the computer
    - Not a desktop, laptop, server, smartphone, smartwatch
    - (although many of those deal with overlapping hardware/software issues)

- Many domains
    - Robotics
    - Industrial processes
    - Smart home
    - Smart city
    - Wearables and health sensing
    - Generally: Internet of Things

Discussion: identify some embedded systems

- What devices that you might not usually consider as computers actually have embedded computers in them?
  - Talk with the others around you
  - Goal: come up some unique ideas
  - We’ll share ideas with the class afterwards

Trend: embedded computers instead of custom hardware

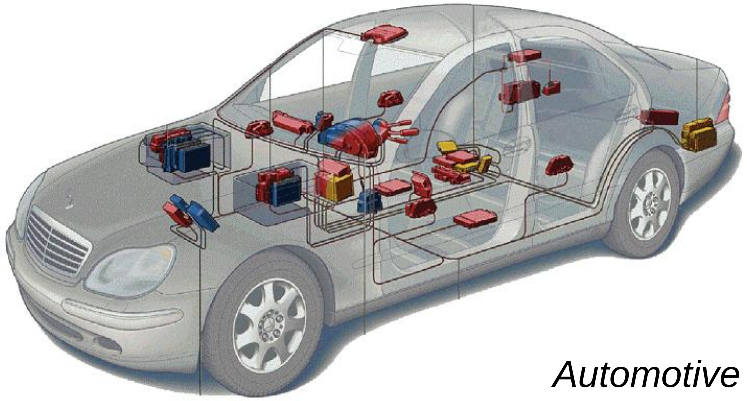
- Some embedded devices could be a state machine in custom hardware instead

- However, computers are increasingly common in those cases
    1. Embedded computers are increasingly cheap
    2. More software developers than hardware developers

Related area: Cyber-Physical Systems

- Systems that are part computational and part real-world
  - Example: autonomous vehicles

- Combines multiple fields to handle this problem
  - Embedded Systems
  - Electronics
  - Controls
  - Software Engineering
  - Computer Theory

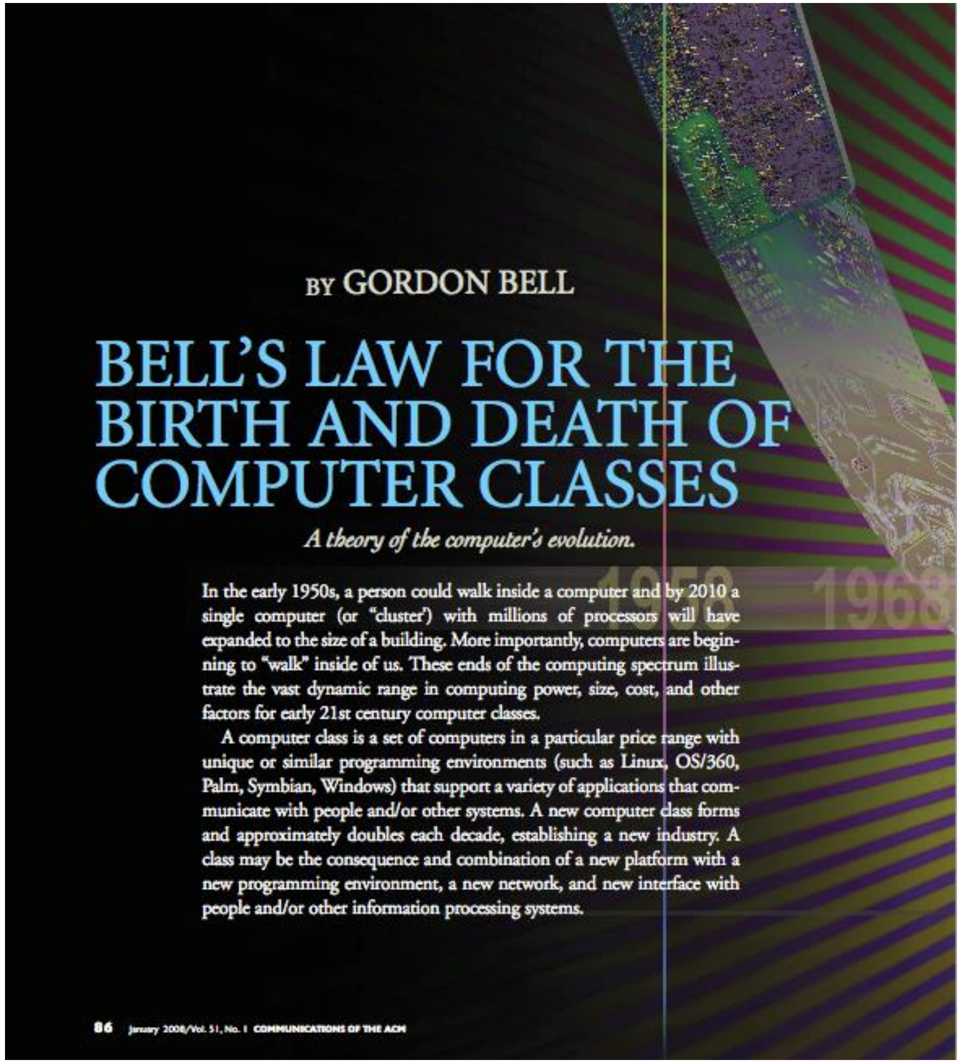


Automotive

Bell’s Law: A new computer class every decade

“Roughly every decade a new, lower priced computer class forms based on a new programming platform, network, and interface resulting in new usage and the establishment of a new industry.”

- Gordon Bell [1972,2008]



BY GORDON BELL

BELL’S LAW FOR THE BIRTH AND DEATH OF COMPUTER CLASSES

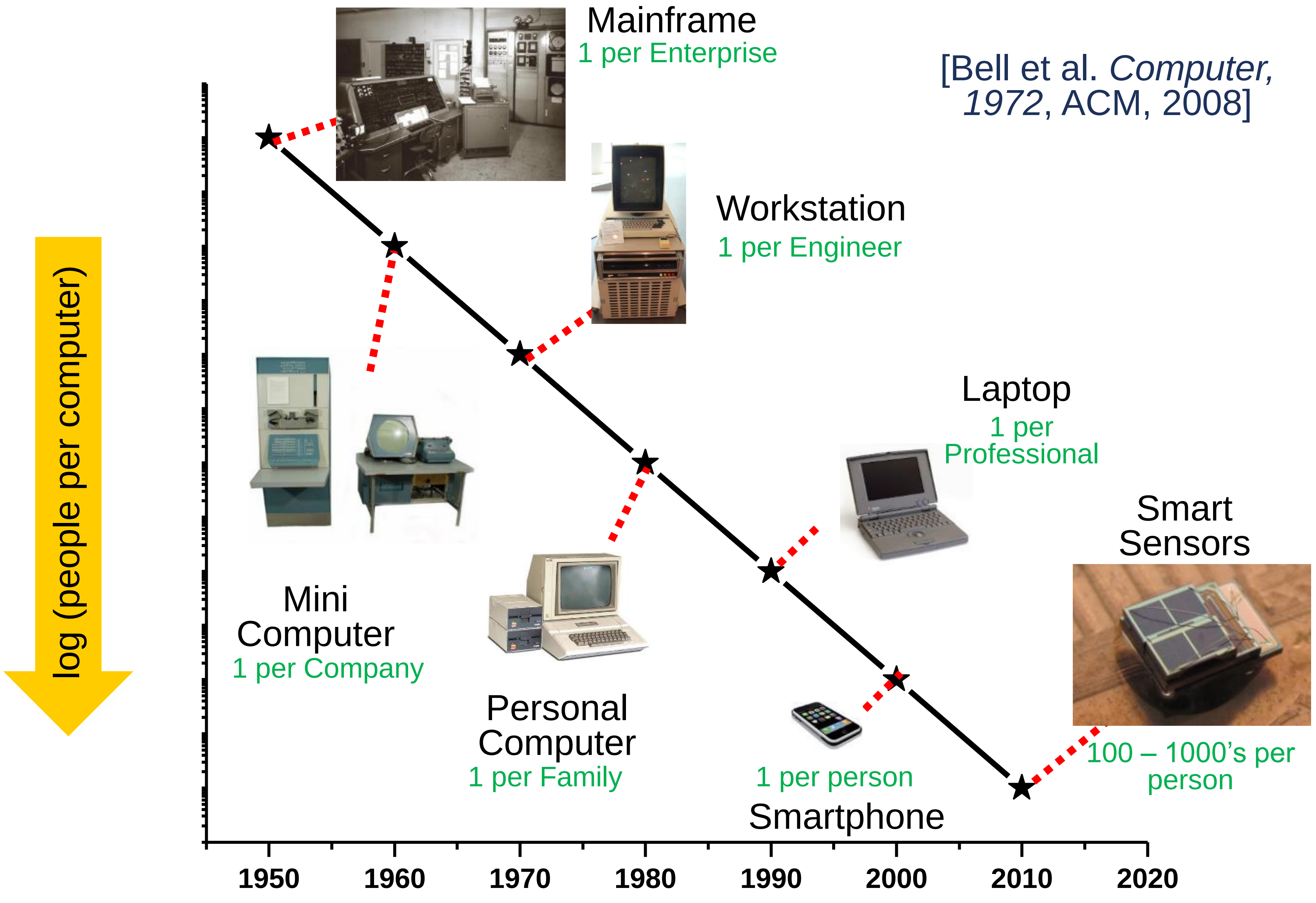
A theory of the computer’s evolution.

In the early 1950s, a person could walk inside a computer and by 2010 a single computer (or “cluster”) with millions of processors will have expanded to the size of a building. More importantly, computers are beginning to “walk” inside of us. These ends of the computing spectrum illustrate the vast dynamic range in computing power, size, cost, and other factors for early 21st century computer classes.

A computer class is a set of computers in a particular price range with unique or similar programming environments (such as Linux, OS/360, Palm, Symbian, Windows) that support a variety of applications that communicate with people and/or other systems. A new computer class forms and approximately doubles each decade, establishing a new industry. A class may be the consequence and combination of a new platform with a new programming environment, a new network, and new interface with people and/or other information processing systems.

86 January 2008/Vol. 51, No. 1 COMMUNICATIONS OF THE ACM

Number of computers per person grows over time



Mainframe
1 per Enterprise

Mini
Computer
1 per Company

Workstation
1 per Engineer

Personal
Computer
1 per Family

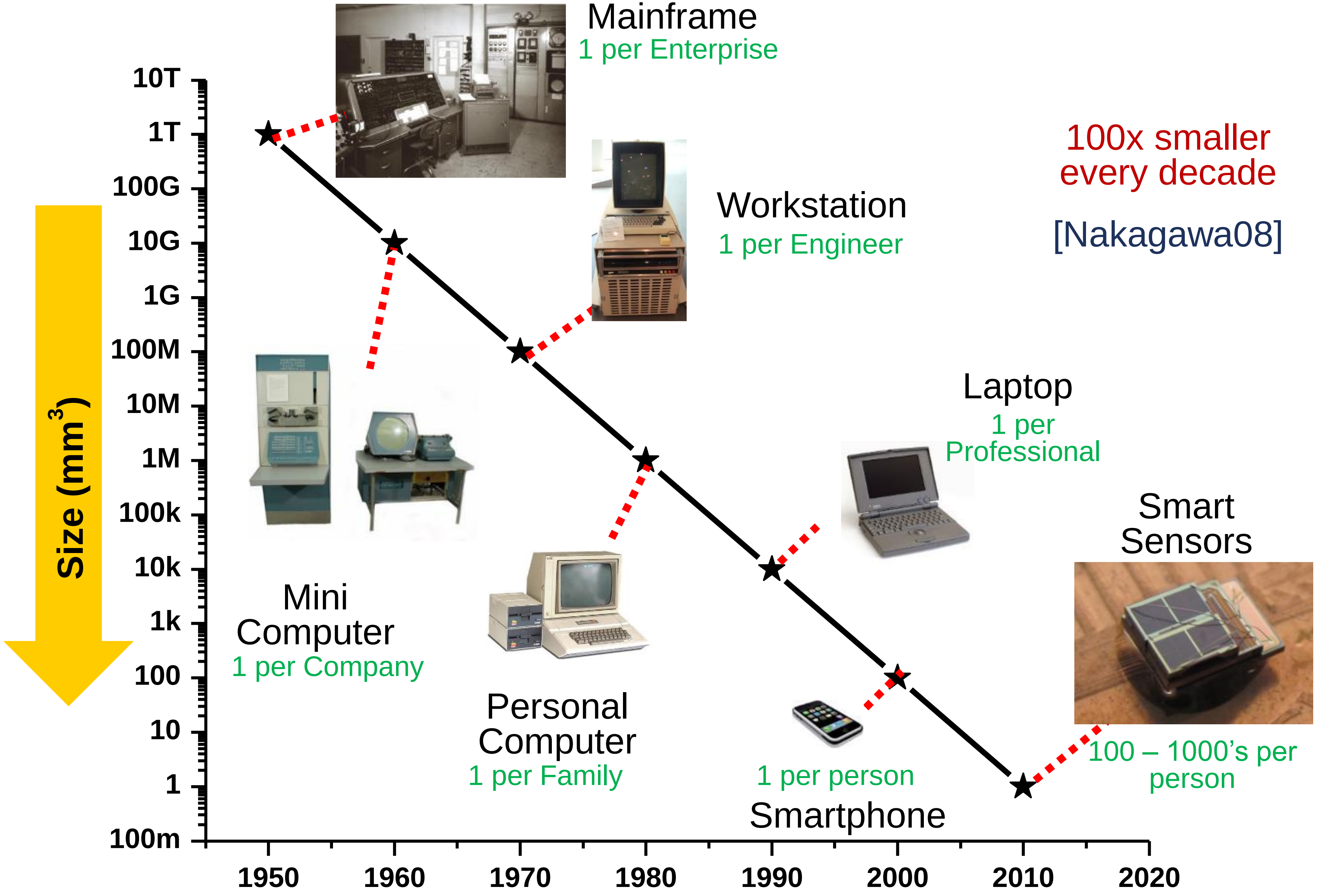
Laptop
1 per
Professional

1 per person
Smartphone

Smart
Sensors
100 – 1000's per
person

[Bell et al. *Computer, 1972*, ACM, 2008]

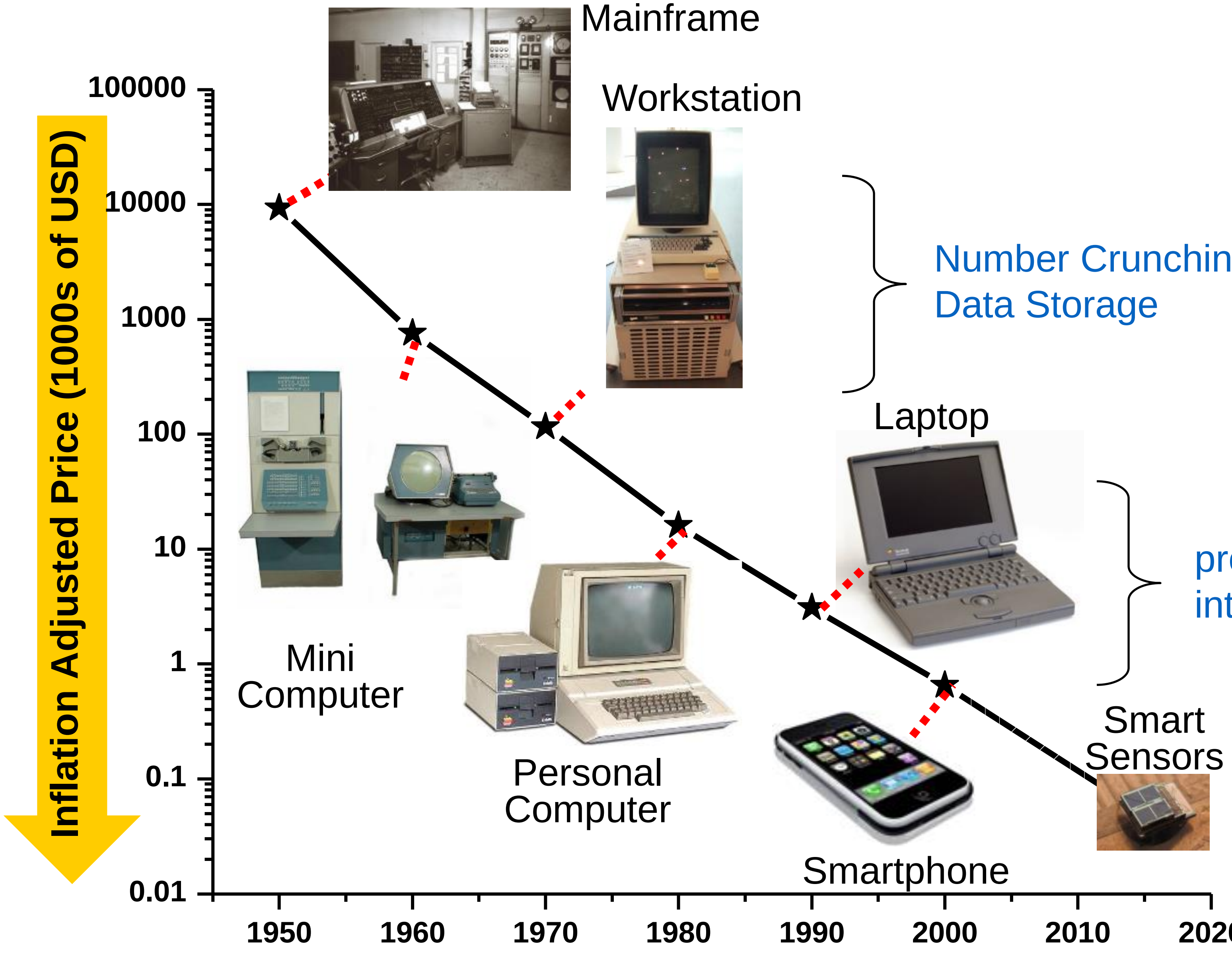
Computer volume shrinks by 100x every decade



100x smaller every decade

[Nakagawa08]

Price falls dramatically, enabling new applications



Number Crunching
Data Storage

productivity
interactive

streaming
information
to/from the
physical
world

The Internet of Things (IoT)

REALTOR
REAL ESTATE AND THE INTERNET OF THINGS
HOW WILL SUPER CONNECTIVITY CHANGE REAL ESTATE
challenge
Say Hello to the INTERNET of THINGS
A FULL GUIDE FOR INTERNET OF THINGS! GET ONE FOR A REVIEW
DIGITAL REVIEW
INTERNET OF THINGS
What it means for the future?
The Big Data Barn
A Spectrum of Smart Stuff
We Robots
DIGITAL LOCKS & SMART BUILDINGS
EXCLUSIVE!
CAN'T ALL OUR THINGS JUST GET ALONG?
40.02 Percent
Business and marketing
30.3 Health Care
8.3 Retail
7.7 Security
Terror Central / The Antisocial Network / Summer Books
TIME
THE SMARTER HOME
Forbes INSIGHTS
HARNESSING THE INTERNET OF THINGS
HOW TO DERIVE BIG BUSINESS BENEFITS FROM THE CONNECTED WORLD
pitney bowes
Volume
INTERNET OF THINGS
With Trust Design #2 and Tracing Concepts
The Price of Ubiquity 18 • Strategic Technology 27 • Hungry for Business 38
SIGNAL
Small Business Leads The Way in Innovation
AFCEA'S INTERNATIONAL JOURNAL • JANUARY 2015
THE INTERNET of THINGS
Disparate Elements, Unknown Outcomes
HBR.ORG
Harvard Business Review
NOVEMBER 2014
The HBR List of Best-Performing CEOs
The New Deal on Data
Do Business and Politics Mix?
THE INTERNET OF EVERYTHING
Smart, connected products will transform your business PAGE 64

Discussion: what is the Internet of Things?

1. Name a few Internet of Things devices

2. What are the **qualities** that designate those devices at “IoT”?

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Thought experiment on capabilities

- What if the Nest thermostat was powered by an entire desktop?
  - 8-core x86-64 processor, 32 GB RAM, 1 TB SSD
- Would that still count as IoT?
- Could that still be an embedded system?
- Why don’t we see that in practice?

Thought experiment on capabilities

- What if the Nest thermostat was powered by an entire desktop?
  - 8-core x86-64 processor, 32 GB RAM, 1 TB SSD

- Would that still count as IoT?
  - **Doesn’t really feel right. Built in assumption of limitations.**

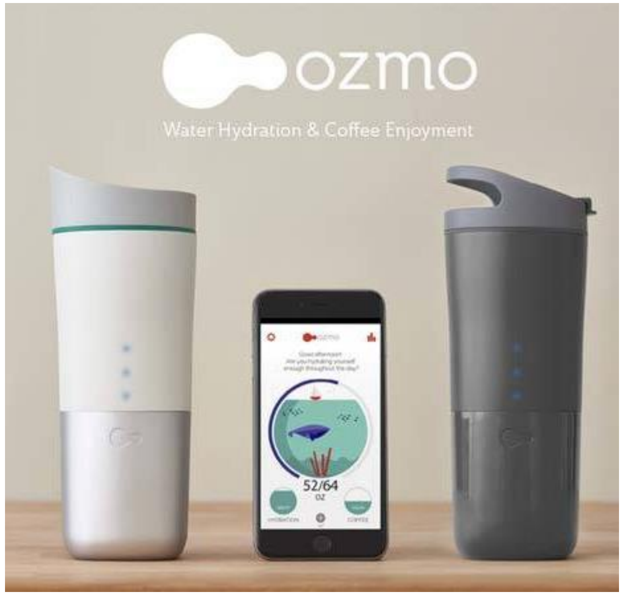
- Could that still be an embedded system?
  - **Yes**

- Why don’t we see that in practice?
  - **Cost**

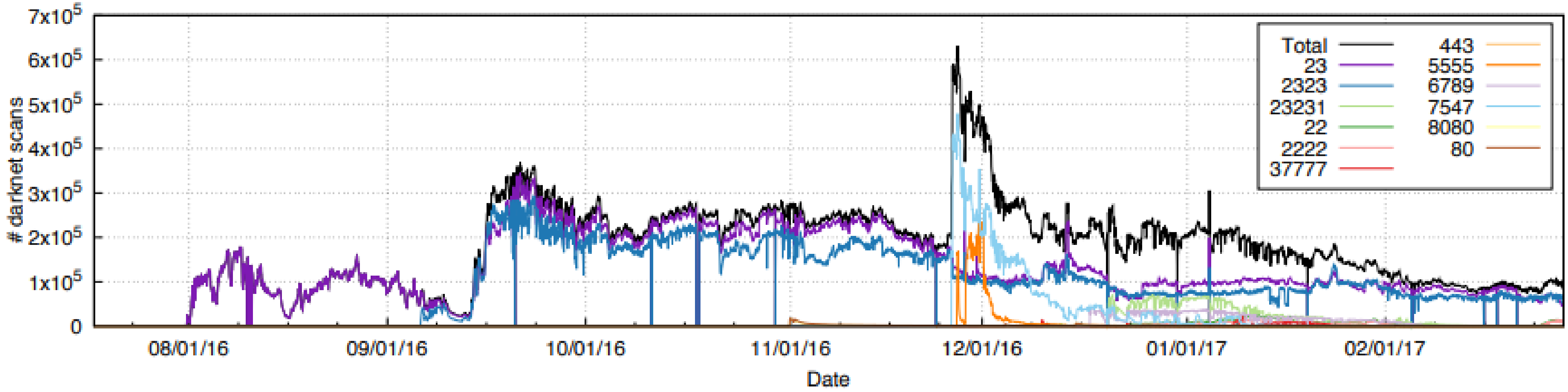
Branden’s take on the Internet of Things

- Key features
  - Computation
    - Local to the device
    - With some capability for arbitrary compute and storage
  - Connectivity
    - Almost certainly wireless
    - Likely Internet, possibly local
  - Interaction
    - Sensing or Actuation
- Secondary features
  - Low energy
  - (Relatively) Low cost

Warning: Internet of Crap



Internet of Insecure Crap



- Mirai botnet (2016)
- Takes control of up to 600,000 insecure connected devices
  - IP-attached cameras, DVRs, routers, printers
- Used to DoS websites

What makes resource-constrained embedded systems interesting?

- Focus on the real world
  - You can actually see the purpose and effects of your applications
  - Easily explainable to non-engineer humans

- Challenging limitations
  - Limited memory and processing
  - Energy concerns

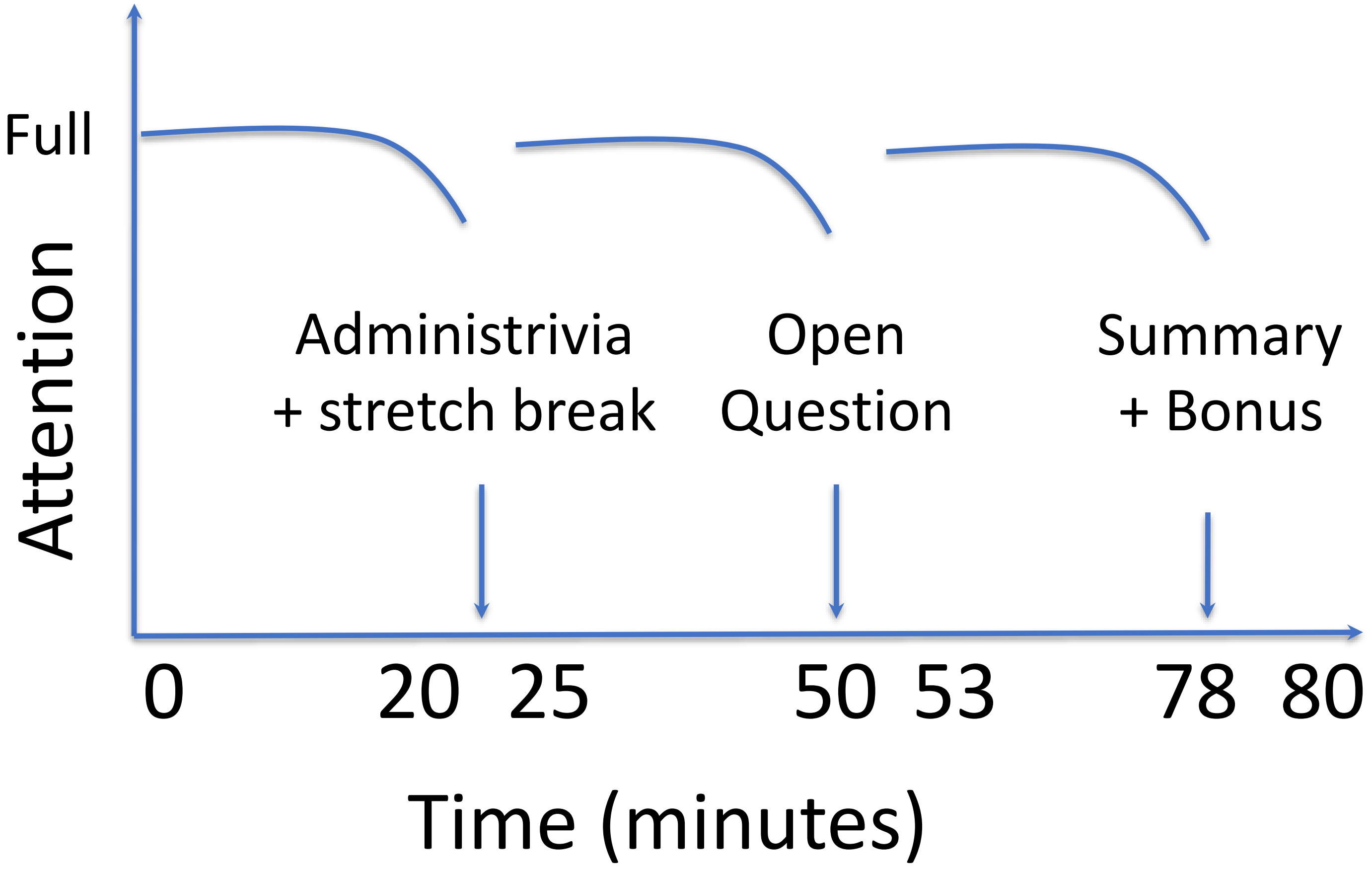
What makes resource-constrained embedded systems frustrating?

- Challenging limitations
  - Limited memory and processing
  - Energy concerns

- Full-stack development means problems could be *anywhere*
  - Hardware problems
  - Firmware problems
  - Software problems

  - Example: my first grad project eye-tracking glasses
    - Camera -> ADC -> FPGA -> Linux driver -> Linux app -> Network -> Visualizer app

Architecture of a lecture



Outline

- Who and Why
- Embedded Systems
- **Course Overview**

Course Staff and Office Hours

- Four PMs who previously took the class
  - Kevin Zhu
  - Will Phillips
  - Tee Amornkasemwong
  - Huaxuan Chen

  - They will help out during labs and also provide lab office hours

- Office Hours: TBD
  - We’ll post a schedule soon. PM office hours will be in the labs.
  - Also by request! (especially during projects)

Course lectures

- Lecture: Tuesdays and Thursdays 3:30-4:50pm, 555 Clark room B03
  - I’m considering if I need to start a few minutes late

- Provides background on everything we’ll be doing in labs
  - Lectures are automatically recorded so you can review them

- No textbook for this class
  - Nobody seems to write a good one
  - The datasheet for our microcontroller (nRF52833) will be important though!

Class lab sessions

- Lab: Fridays 10:00-11:50am OR 1:00-2:50pm, Tech CG50

- Labs start next week Friday and are weekly from there
  - No lab this week!
  - Six labs total
  - When labs run out, I’ll use the time for project meetings with groups

Course grade components

- 42% Labs
  - 6 labs at 7% each
  - Guided exploration of course concepts
  - Staff gives checkoffs as you complete parts

- 20% Quizzes
  - Four timed quizzes at 5% each
  - Covers lecture material from last two weeks
  - Probably in-class at the end of class, I'll update you in advance

- 38% Final Project
  - Open-ended group project (will explain in a minute)

Labs

1. MMIO and Interrupts
2. Virtual Timers
3. LED Matrix
4. Breadboarding
5. Audio Input/Output
6. I2C Accelerometer/Magnetometer

- Labs will be partner work
    - You choose, but different partner each week

- Due one week from start of lab
    - Complete **Checkoffs** plus some **Post-lab Questions** due online

Quizzes

- In-class, on-paper, closed notes quizzes
  - Usually about 15 minutes and held at the end of lecture

- Cover the last two weeks worth of material
  - So make sure you’re up-to-date on what we’re talking about

- First quiz is Tuesday, October 4th (third week of classes)

Final projects

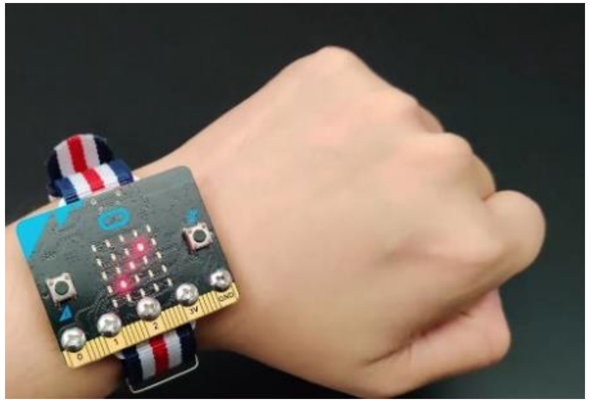
- Opportunity for you to apply your interests to this course
  - In groups of 2-3 students (maybe 4 for a really big idea)

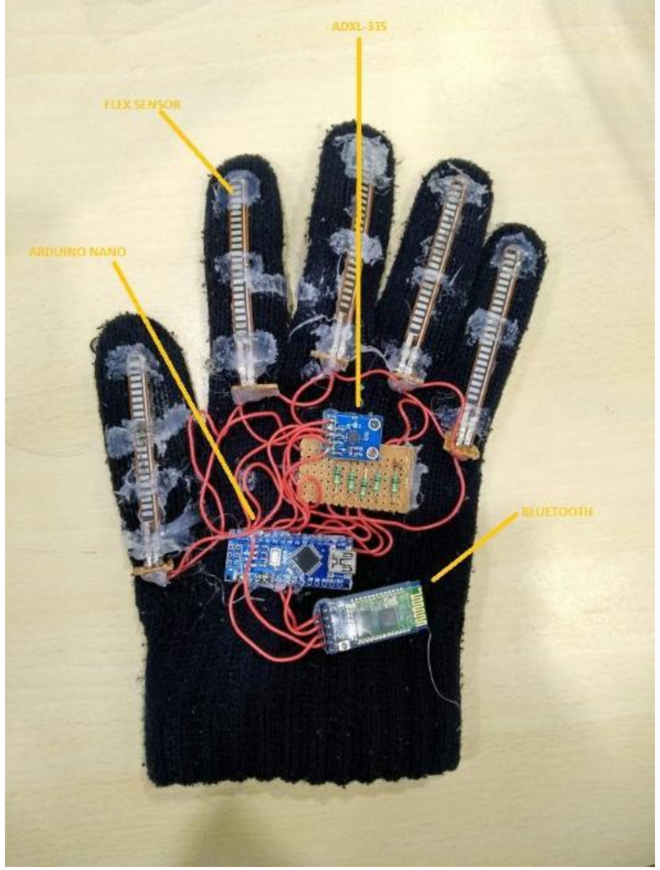
- Demonstrate course knowledge through any application
  - Microbit (99% required)
  - Various hardware I’ll have on hand
  - Small budget for purchasing additional stuff

Project Ideas

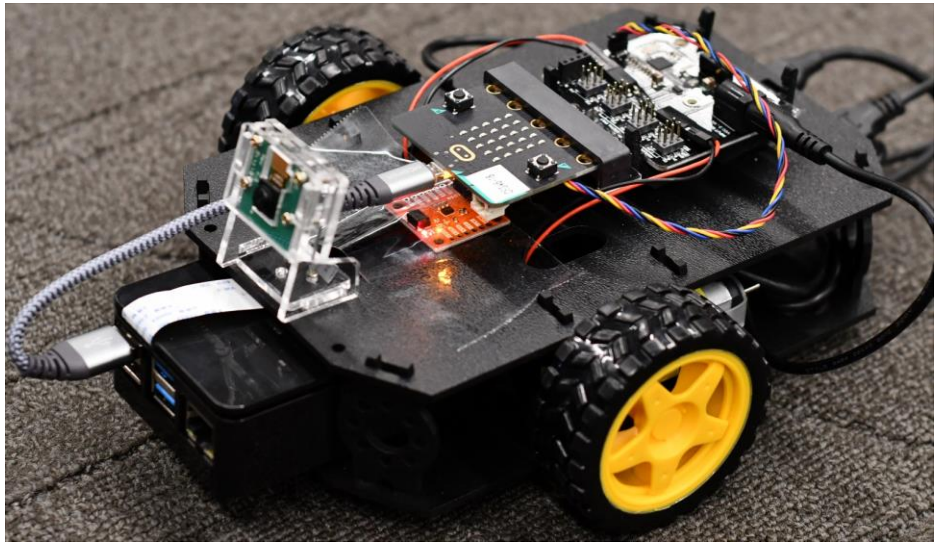
- Some ideas to get you thinking
  - Game with interesting control mechanism
  - Smart gloves
  - Smartwatch
  - Simple robotic systems

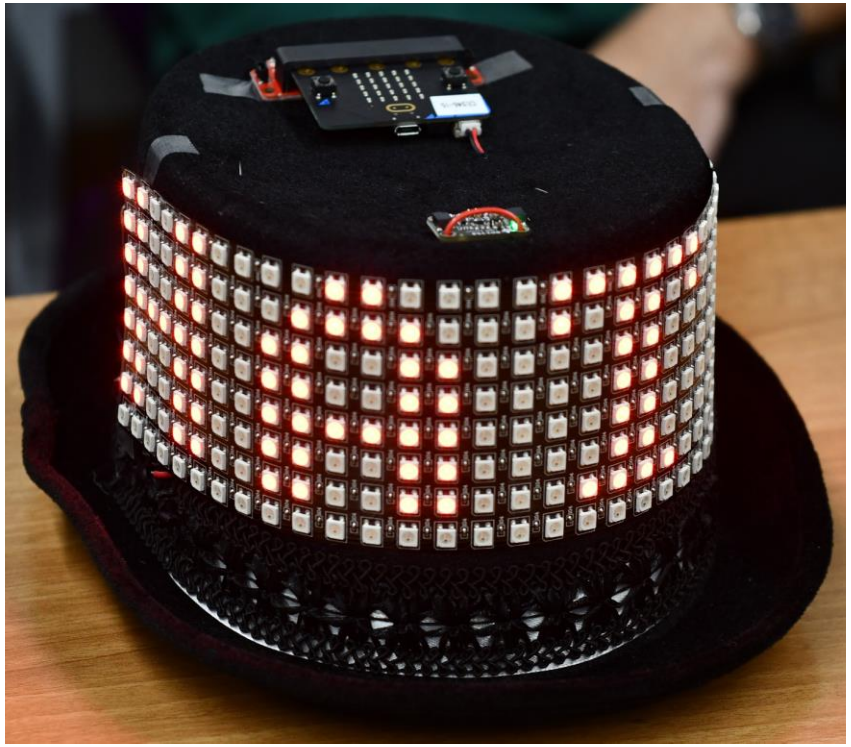
- Projects can use
  - Multiple Microbits
  - A personal computer for some amount of coordination
  - Lots of different sensors or actuators
    - Go explore sparkfun.com

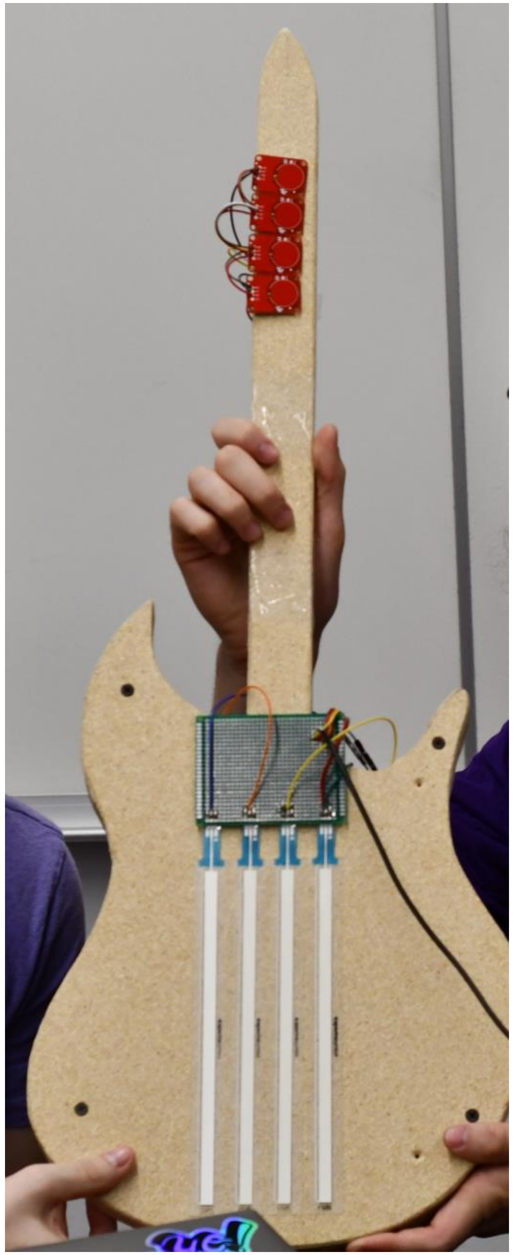


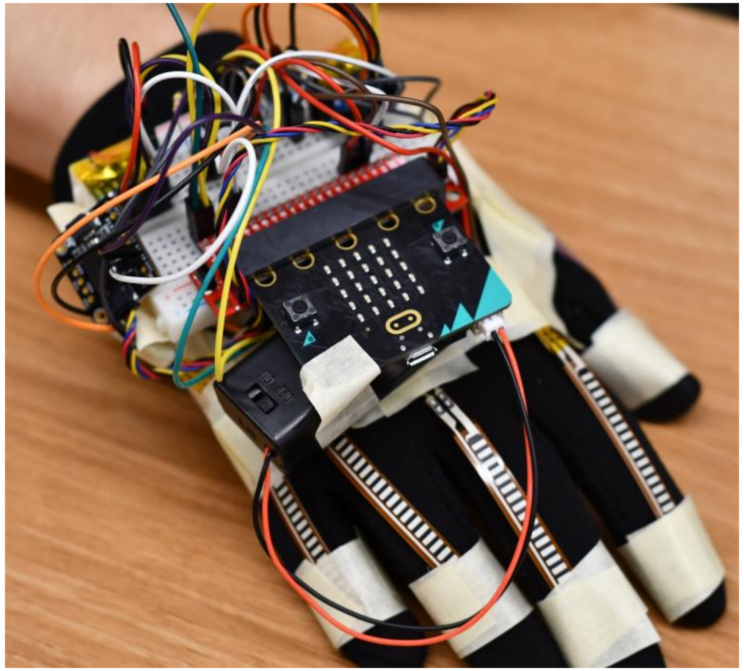


Some awesome Fall 2021 projects









Project Logistics

- Week 4: Proposals due
  - I'll get you feedback in a week

- Week 6: Project Design Presentations
  - Short presentations in class about your proposed project and design
  - Chance to give each other useful feedback about how to proceed

- Week 8-9: Labs are done and Fridays are used for update meetings

- Week 11: Live project demos!!
  - Public demo session
  - Almost certainly: Tuesday, December 6th (Tuesday of exam week)

Course Communication

- Campuswire
  - You should all already be registered on it
  - If you aren’t, let me know! (or if you want to change emails)

- All course communication goes through Campuswire, not email
  - Multiple people can respond to you
  - Messages are kept in one place and stay “unanswered”

  - You can post directly to “Instructors & TAs” if it is private
    - Use that feature to request office hour appointments if desired

Flexibility

- Sometimes stuff just doesn’t work
  - Especially when we’re working with hardware

- We can be flexible about those deadlines
  - If you’re having problems and **tell us**
  - Less flexible if you don’t communicate or if you started late

- Takeaway: let us know if you’re having problems

Class lab – Tech CG50

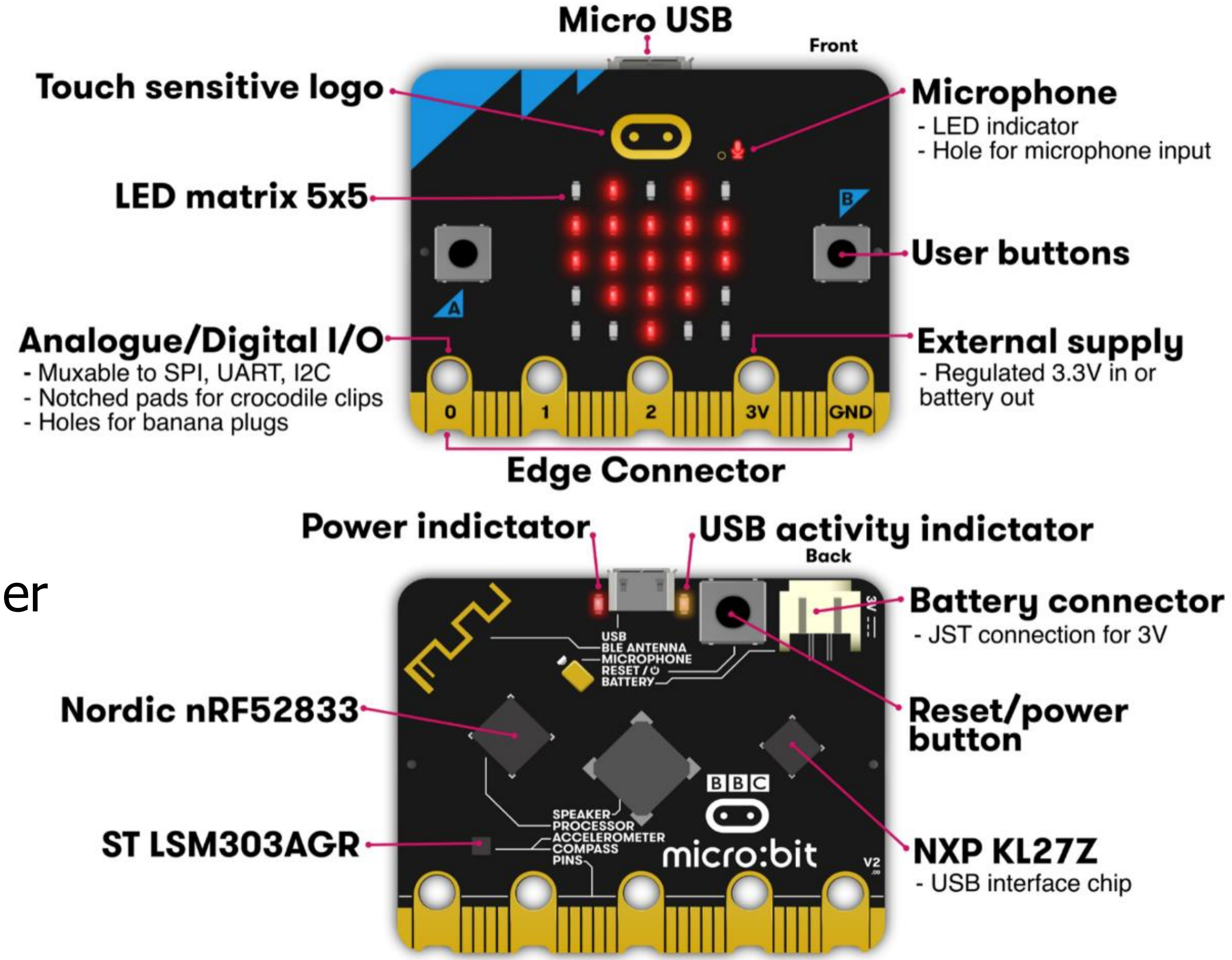
- Tech, Wing C, Ground Floor, Room 50

- You should have swipe access to get into lab 24/7
  - Work on labs or projects
  - We’ll keep class hardware down there so you can access it

- Important rules:
  1. No food or drink
  2. Clean up after yourself (tablespace, chairs, etc.)
  3. Class hardware does not leave the room

Micro:bit v2

- Legacy from 1980s "BBC Computer Literacy Project"
  - Reimagined today
- Under $20
  - Modern microcontroller AND sensors
- Plan for class:
  - Explore most of its functionality



Working on your own machine

- Generally, CG50 should have plenty of availability outside of lab sessions
    - Plus staff will hold office hours in there to provide checkoffs

- But it might be nice to have your own personal setup too
    - If you’ve already got a Linux install, you can just install the programs
    - Or you can set up a virtual machine
    - I’ll post instructions for this later this week

- You can buy your own Micro:bit v2
    - Chip shortage makes this difficult and/or expensive
    - Make sure you’re buying version 2 NOT version 1 (v2.2 should be fine)

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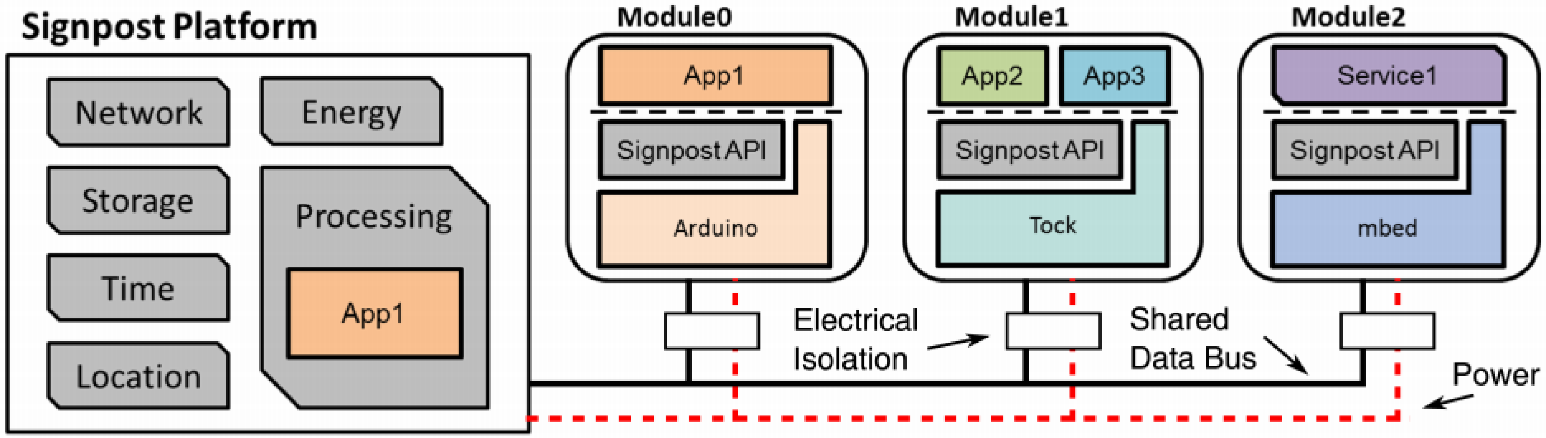
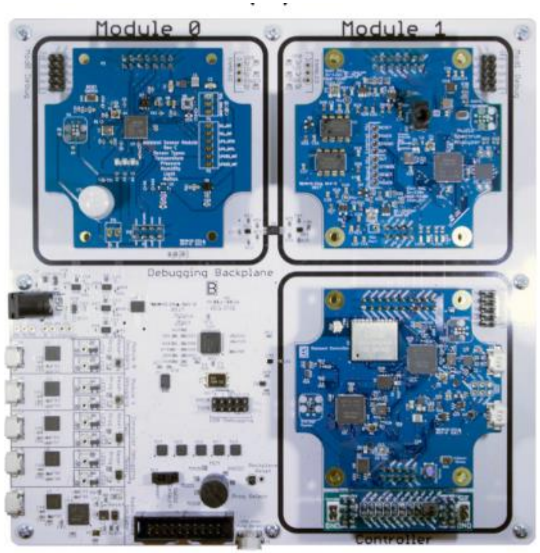
Signpost – City-Scale Sensing

- How do we reduce the burden of city-scale sensing experimentation?
- Platform provides resources
  - Modules provide sensor and application





PowerBlade – Smart Home

- Plug-load power meter
  - How do we measure *every* device in a home?

- Challenges
  - Deployability
  - Powering it
  - Sensing AC current and voltage
  - Reporting measurements

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