# ECE 1175
# Embedded Systems Design

## Introduction

Wei Gao

# Course Information

- Class time: 2:30pm – 3:45pm TuTh
  - Lectures will be online in the first two weeks
  - Zoom link for lectures: https://pitt.zoom.us/j/96782480025
    - Password: 191903
- Instructor: Wei Gao, weigao@pitt.edu
  - Office hour: 1:30pm – 2:30pm TuTh
  - Zoom link for office hours: https://pitt.zoom.us/j/91955368165
- TA: Xiangyu Yin, eric.yin@pitt.edu
  - TA Office hour: TBD
- Schedule and lecture notes posted at instructor website
  - http://www.pitt.edu/~weigao/ece1175/fall2021/ece1175-fa21.html
  - Each lecture note will be posted before class
  - For online lectures, lectures will be recorded and video recordings will also be available online
- Canvas will be used for posting announcements and grades

# Lab Information

- Lab hours: Friday 12:00pm – 2:50pm
  - 1211A/B
  - Pitt policy: any lab should only accommodate <25 students
- No labs in the first weeks of the semester
  - Labs will be open after we have covered the basics of course contents
  - Roughly in mid September
  - Notifications will follow.

# Definition

- Embedded system: any device that includes a computer but is not itself a general-purpose computer.

- Application specific
  - The design is specialized and optimized for specific application
  - Don’t need all the general-purpose bells and whistles.

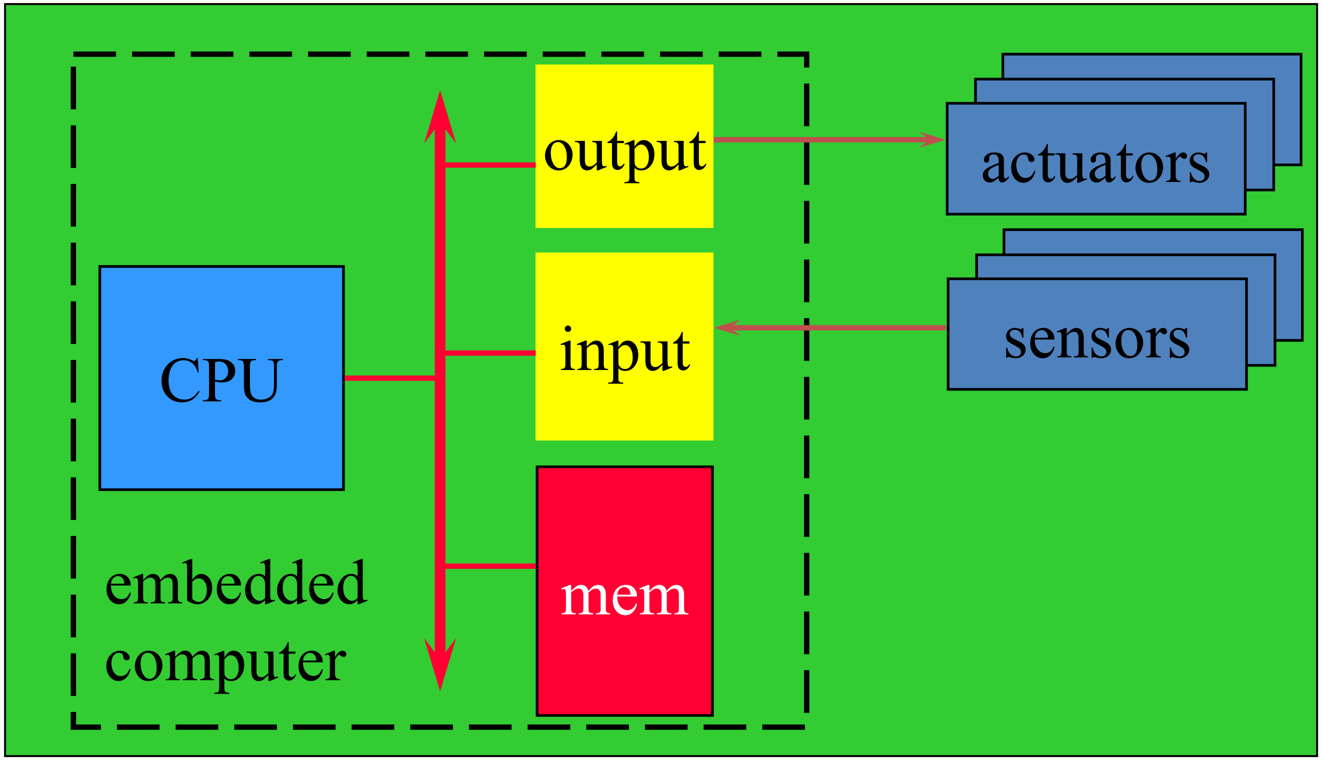
# Examples of Embedded Systems

- Cellphone, Personal Digital Assistant (PDA)
- Printer.
- GPS.
- Automobile: engine, brakes, dash, etc.
- Digital camera.
- Household appliances: microwave, air conditioning
- Wrist watch.
- Implanted medical devices.
- and a lot more …

- Fact: > 95% of all microprocessors are used for embedded systems.

# Embedding a Computer

- A computer-on-a-chip
  - a type of microprocessor emphasizing self-sufficiency and cost-effectiveness
  - has CPU, input/output, RAM, ROM, clock and etc on a single chip



# Embedding a Computer

- More than simply a computer
- Functionality
  - Sensing
  - Communication
  - Control & actuation
- The appropriate I/O is important!

# Early history

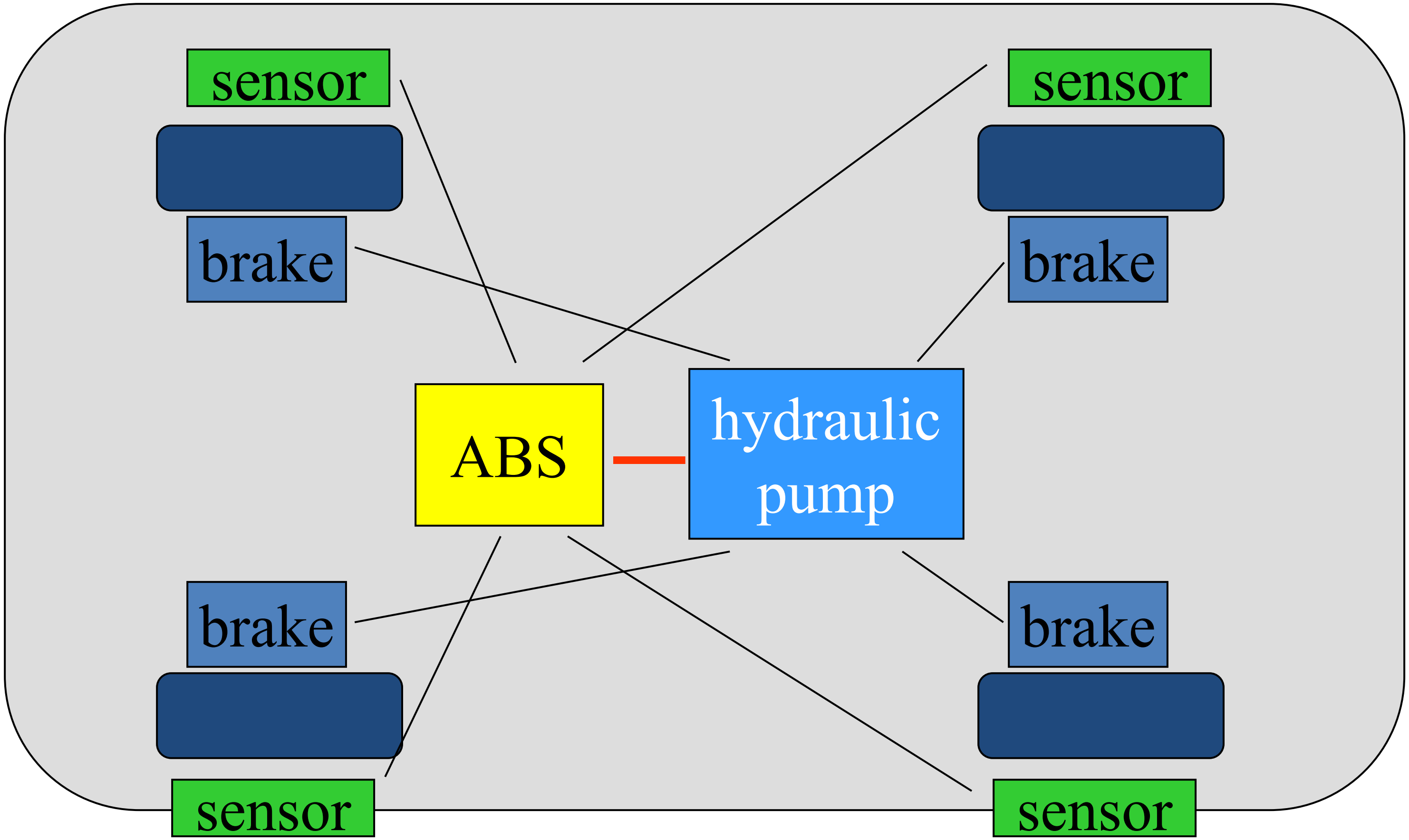
- Late 1940’s: MIT Whirlwind computer was designed for real-time operations.
  - Originally designed to control an aircraft simulator.
- First microprocessor was Intel 4004 in early 1970’s.
  - Predecessor of the famous Intel 8086
- HP-35 calculator used several chips to implement a microprocessor in 1972.

# Early history

- Automobiles used microprocessor-based engine controllers starting in 1970’s.
  - Control fuel/air mixture, engine timing, etc.
  - Multiple modes of operation: warm-up, cruise, hill climbing, etc.
  - Provides lower emissions, better fuel efficiency, and better safety

# Anti-Lock Brake System

- Pumps brakes to reduce skidding.
  - Real-time and safety



# Automotive Systems

- A high-end car may have **100** microprocessors:
  - 4-bit microcontroller checks seat belt;
  - microcontrollers run dashboard devices;
  - 16/32-bit microprocessor controls engine;
  - Navigation;
  - Entertainment: DVD, audio, satellite radio…

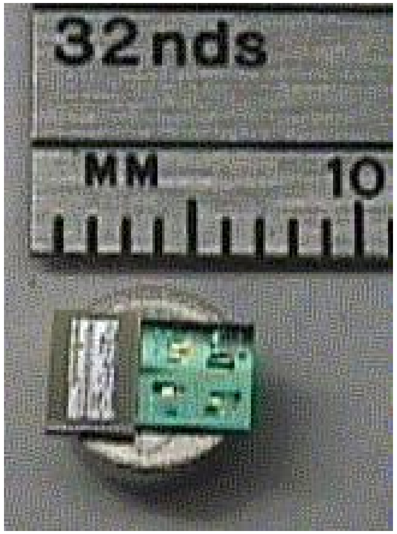
# Other examples

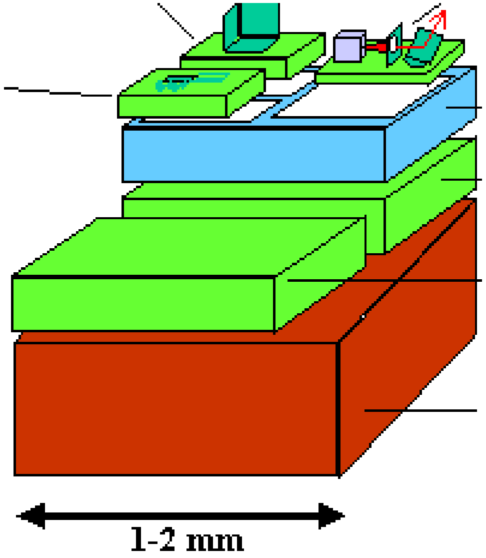
- Simple control
  - Front panel of microwave oven
  - Digital control of air conditioning
- Canon EOS 3 has three microprocessors.
  - 32-bit RISC CPU runs autofocus and eye control systems.

- Sony BRAVIA LCD TV has a standalone microprocessor for image processing
  - BRAVIA Engine
  - HD video streaming: high throughput required
  - AI embedding

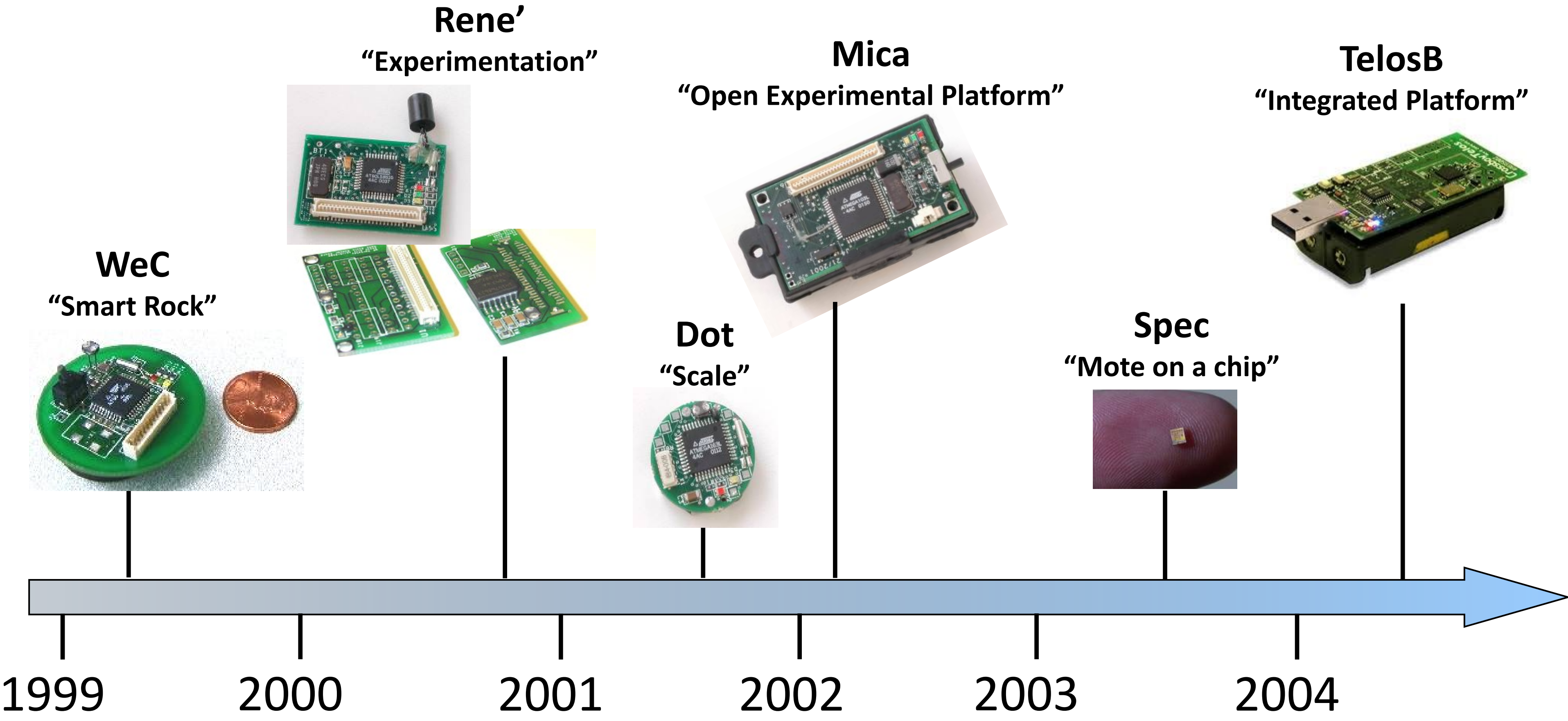
# Typical Application: Wireless Sensor Motes

- sensors + microcontroller + radio
  - All feasible at very small scale
  - e.g., Berkeley Smart Dust





# Sensor Motes Timeline



**WeC**
"Smart Rock"

**Rene'**
"Experimentation"

**Dot**
"Scale"

**Mica**
"Open Experimental Platform"

**Spec**
"Mote on a chip"

**TelosB**
"Integrated Platform"

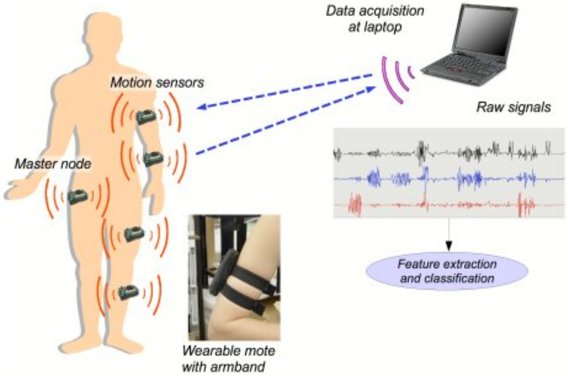
1999 2000 2001 2002 2003 2004

# Typical Applications of Sensor Networks

Structural Health Monitoring

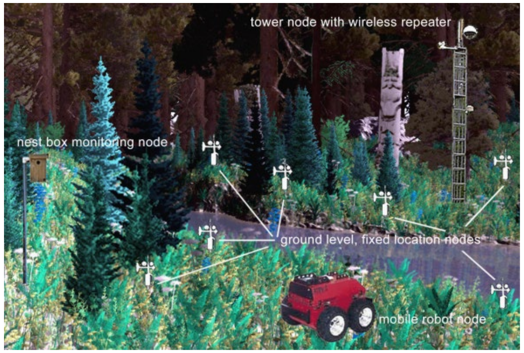
Fire Monitoring

1. Smart sensors massively distributed and embedded in environments
2. Self-organized wireless network by communicating with each other
3. Real-time environment monitoring and control

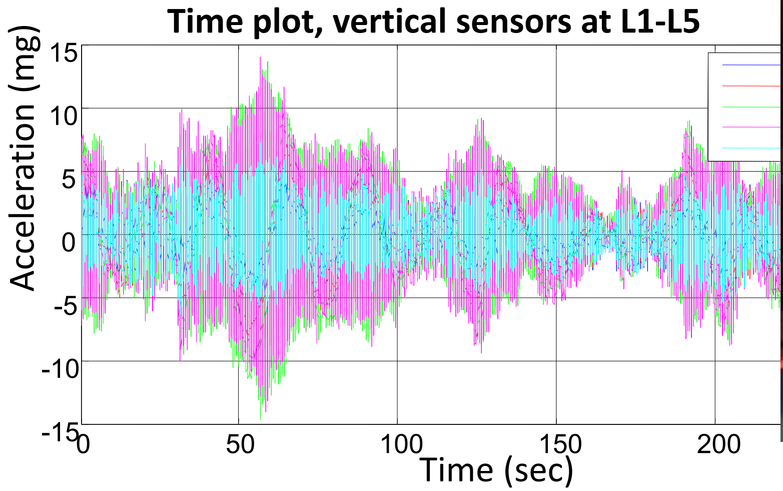

Data acquisition at laptop
Motion sensors
Raw signals
Master node
Feature extraction and classification
Wearable mote with armband

Health Care

Habitat Monitoring


tower node with wireless repeater
nest box monitoring node
ground level, fixed location nodes
mobile robot node

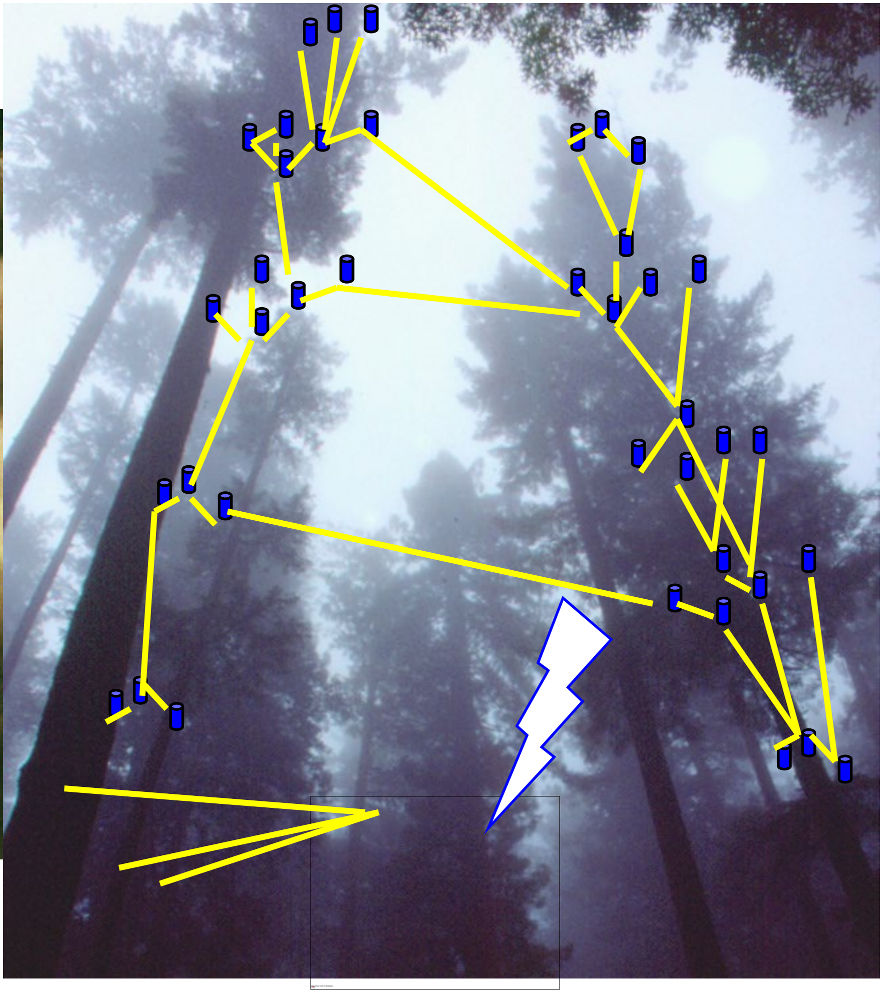
# Structural Health Monitoring


Time plot, vertical sensors at L1-L5

Source: David Culler’s MobiHoc’05 Keynote

# Habitat Monitoring – Redwood Trees

- To understand complex interactions of tree growth and environment



Source: David Culler’s MobiHoc’05 Keynote

# Smartphones – Blurring Boundary

- Specialized microprocessor
  - Somehow much more powerful

Samsung Galaxy S8

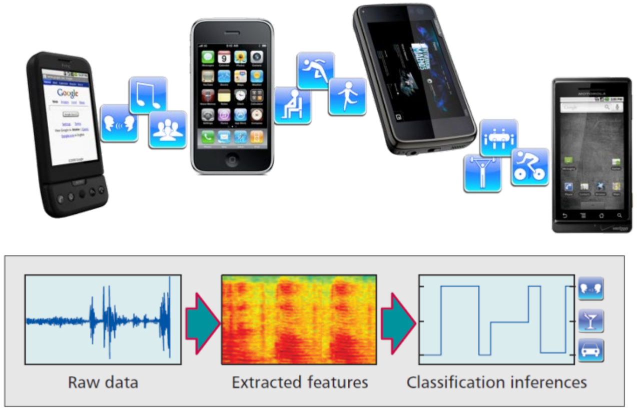
2.3 GHz w/ 8 cores

iPhone X

2.4 GHz w/ 6 cores

- Controls radio, sensors, display, speaker, …
- Multimedia contents and applications

# Typical Applications using Smartphones



Sensing human behaviors

Demo from Dartmouth

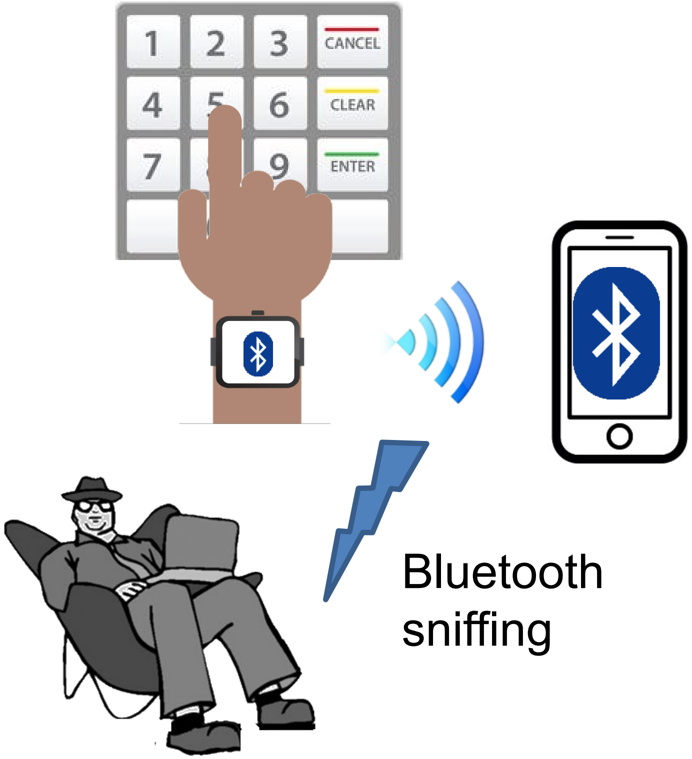
1. Sensing capabilities of smartphones
   - Mobile sensing
2. Mobile Internet access and user interaction
   - Mobile social media
3. Location-based services

Mobile social networks

Yelp on smartphones

# Wearables

- Smartwatches & wristbands



Bluetooth sniffing

- New opportunities and challenges

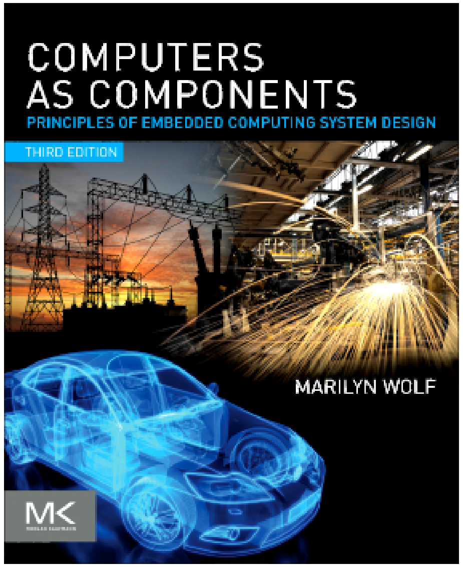
# Why are those systems special?

- Application specific
  - Specialize and optimize the design for specific application
  - *Not* a general-purpose computer.
    - Don’t need all the bells and whistles, e.g., hard drive, monitor, keyboard…
- Have to worry about both hardware and software
- Have to worry about non-functional constraints
  - Real-time
  - Memory footprint
  - Power
  - Reliability and safety
  - Cost

***Just functionally working is NOT enough!***

# Goal of This Course

- The common principles of embedded systems design
  - Instead of a specific type of microcontroller
  - Emphasize aspects that are distinct to embedded systems
- Recommended Textbook:
  - *Computers as Components: Principles of Embedded Computing System Design*, 3rd edition
  - Marilyn Wolf, Georgia Tech
  - Available online: [https://pitt.primo.exlibrisgroup.com/permalink/01PITT_INST/g3767l/alma9998575204906236](https://pitt.primo.exlibrisgroup.com/permalink/01PITT_INST/g3767l/alma9998575204906236)



- Experimentation platform
  - The up-to-date microcontroller platform with strong capabilities

# Goal of This Course

- References
  - Introduction to Embedded Systems: A Cyber-Physical System Approach
    - Ashford Lee and Sanjit Seshia
    - http://leeseshia.org/releases/LeeSeshia_DigitalV1_06.pdf
  - Embedded Systems: A Contemporary Design Tool
    - James Peckol
    - Wiley, 2011

# What will you learn from this course?

- Hardware/software co-design
  - Integrating individual component designs towards a **holistic system**
  - Systematic views and rationales
- Hardware
  - Embedded system components: microprocessors, I/O, caches, memory, bus
- Software
  - Programming and optimization for optimal performance and low power
  - Real-Time Scheduling Analysis
  - Operating System Basics
  - Real-Time Operating Systems (RTOS)
- Practical system programming
  - Embedded operating system: Raspberry Pi

# Skillsets & Prerequisites

- What skills do you need?
  - Basic understanding of analog and digital circuits
    - Logic gates, Boolean algebra, circuit building
  - Basic understanding about computers
    - Concept of processor, register, memory
  - Basic programming skills with sufficient proficiency with C and/or Python
- What skills will you get?
  - How to think and design systems as a whole piece
  - Hands-on system building skills
    - Operating digital I/O with heterogeneous data inputs and outputs
    - Practical programming over embedded platforms
    - Practicing buzz-word techniques over real system platforms

# What will you NOT learn from this course?

- Hardware chip design
  - ECE 1192/2192: Introduction to VLSI Design
  - ECE 2162: Computer Architecture
- Communication and Networking
  - ECE 1150: Introduction to Computer Networks
  - ECE 1472: Analog Communication Systems
- Mobile application development
  - Fancy UI, graphics optimization, user experience…

# Grading

- Homework assignments (4): 15%
  - HW1: 3%, HW2 – HW4: 4% each
  - One-week turnaround time
  - 2-4 short questions
- Lab assignments (5): 30% - 6% each
  - Two-week turnaround time
  - Each lab corresponds to a specific topic covered in lectures
  - Provide opportunities to practice hands-on skills
- Midterm exam: 25%
- Final exam: 25%
- Participation 5%

# Course policy

- Academic integrity
  - Must be your OWN work
  - No collaboration for homework/lab assignments
- Lab policy
  - Results must be checked by TA
- Exam policy
  - Closed-book, No discussion, No make-up exams
  - Online proctoring
- Class policy
  - Attend each lecture