Recap from last class

- Timers and counters
  - Watchdog timer
- Practical I/O interfaces
  - Parallel I/O vs. serial I/O
  - General mode: master/slave connections
  - Inter-integrated Circuit (I^2C or I2C)
  - Serial Peripheral Interface (SPI)
  - Universal Serial Bus (USB)
  - General-Purpose IO (GPIO)

ECE 1175
Embedded Systems Design

ARM Architecture

Wei Gao

ARM Architecture

- Dominant architecture for embedded systems

ARM Architecture

- Who is ARM?
  - Founded in November 1990
  - Designs the ARM range of RISC processor cores
  - Licenses ARM core designs to semiconductor partners who fabricate and sell to their customers
  - Software tools, boards, debug hardware, application software, bus architectures, peripherals etc

ARM Partnership

ARM Instruction Sets

- ARM instructions can be made to execute conditionally by postfixing them with the appropriate condition code field.
  - This improves code density *and* performance by reducing the number of forward branch instructions.

```
  CMP    r3,#0
   BEQ    skip
   ADD    r0,r1,r2
skip
```

```
CMP    r3,#0
 ADDNE r0,r1,r2
```

Condition Codes

- The possible condition codes are listed below:
  - Note AL is the default and does not need to be specified

Suffix	Description	Flags tested
`EQ`	Equal	**Z=1**
`NE`	Not equal	**Z=0**
`CS/HS`	Unsigned higher or same	**C=1**
`CC/LO`	Unsigned lower	**C=0**
`MI`	Minus	**N=1**
`PL`	Positive or Zero	**N=0**
`VS`	Overflow	**V=1**
`VC`	No overflow	**V=0**
`HI`	Unsigned higher	**C=1 & Z=0**
`LS`	Unsigned lower or same	**C=0 or Z=1**
`GE`	Greater or equal	**N=V**
`LT`	Less than	**N!=V**
`GT`	Greater than	**Z=0 & N=V**
`LE`	Less than or equal	**Z=1 or N=!V**
`AL`	Always	

Examples of conditional execution

- Use a sequence of several conditional instructions

```
if (a==0) func(1);
    CMP      r0,#0
    MOVEQ    r0,#1
    BLEQ     func
```

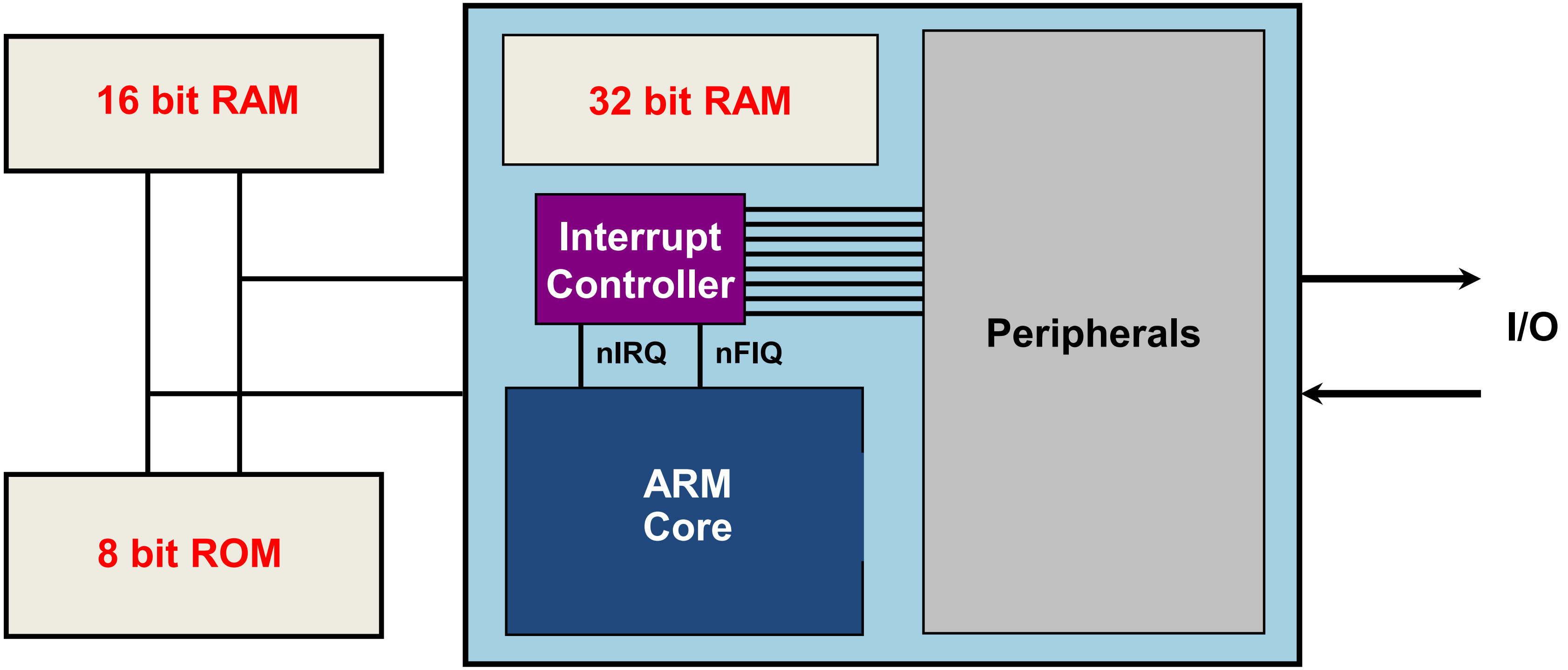
- Set the flags, then use various condition codes

```
if (a==0) x=0;
if (a>0)  x=1;
    CMP      r0,#0
    MOVEQ    r1,#0
    MOVGT    r1,#1
```

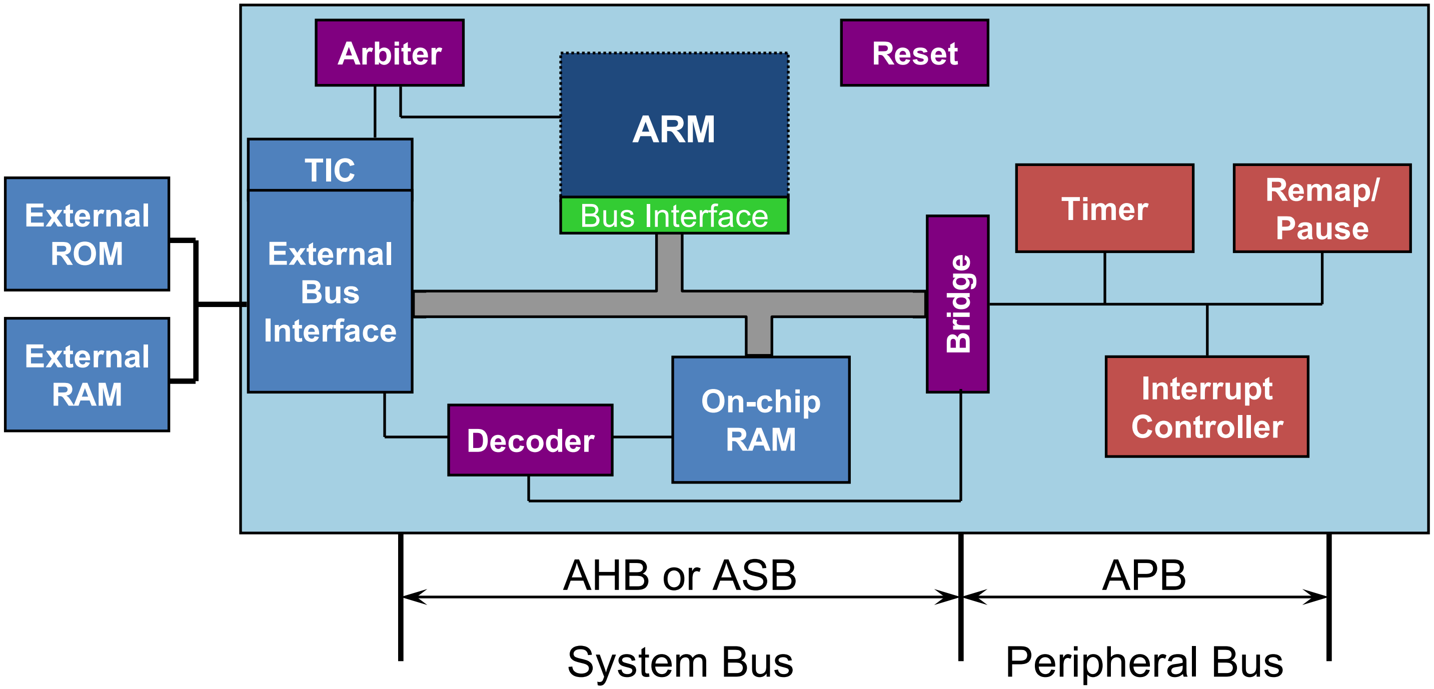
- Use conditional compare instructions

```
if (a==4 || a==10) x=0;
    CMP      r0,#4
    CMPNE    r0,#10
    MOVEQ    r1,#0
```

ARM System Design

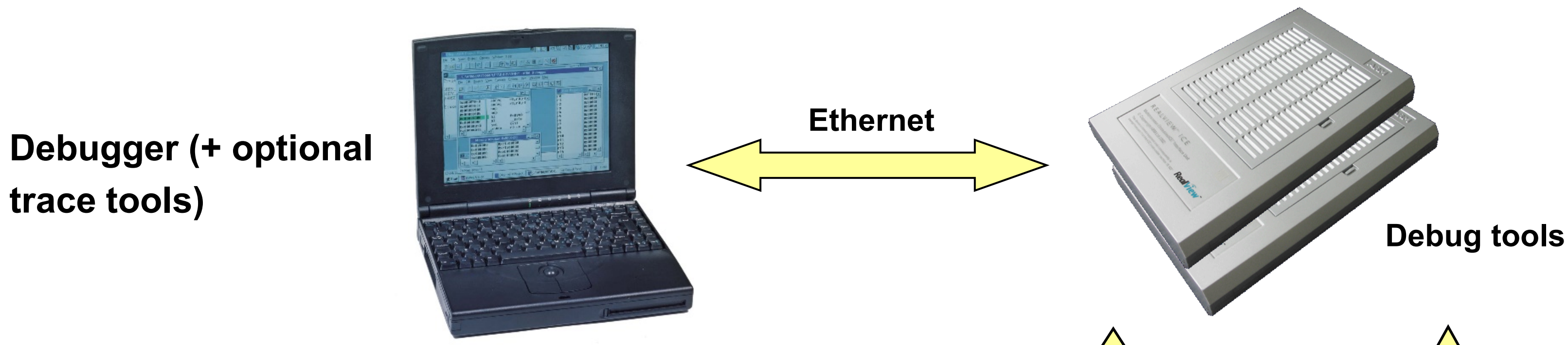


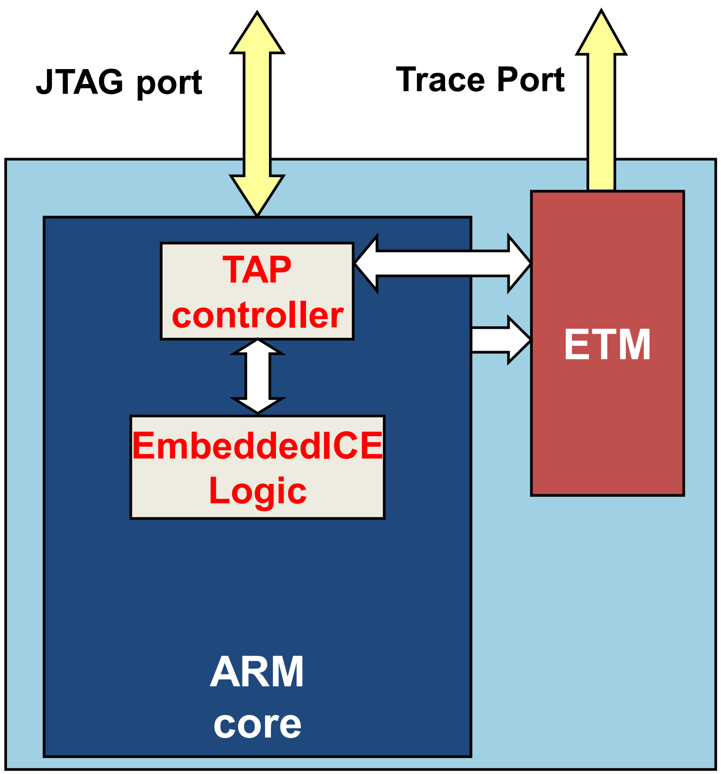
ARM Bus System



- **AMBA**
  - Advanced Microcontroller Bus Architecture
- **ADK**
  - Complete AMBA Design Kit
- **ACT**
  - AMBA Compliance Testbench
- **PrimeCell**
  - ARM's AMBA compliant peripherals

Debugging ARM

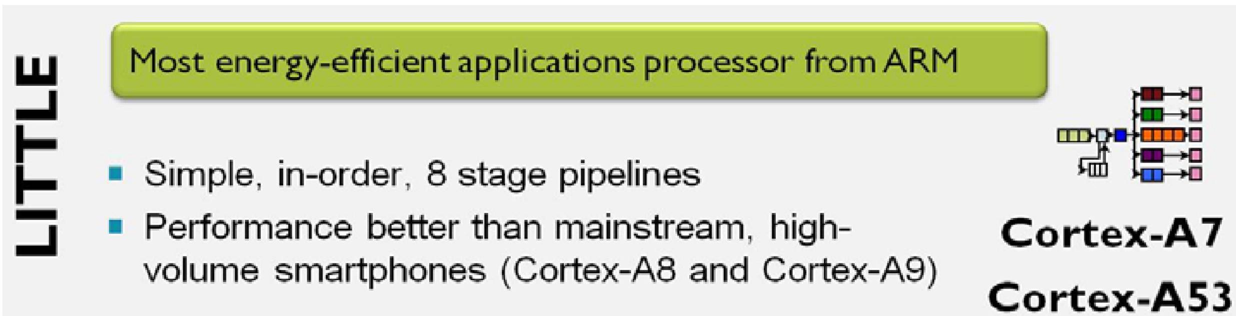




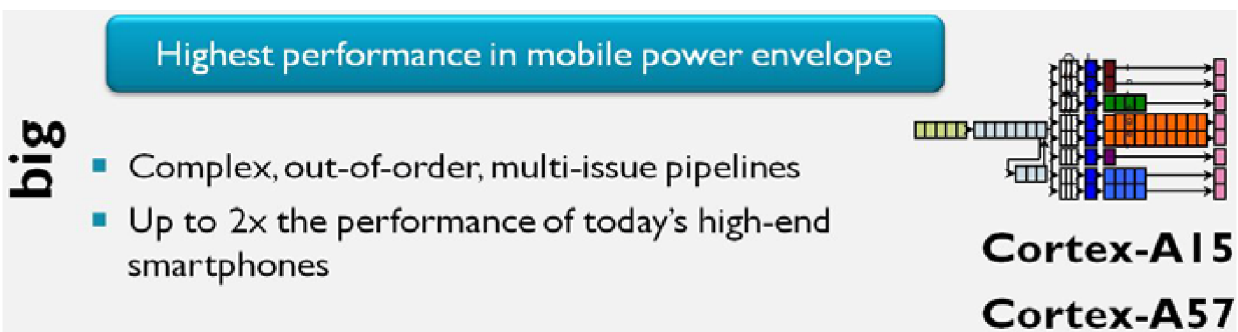
- EmbeddedICE Logic
  - Provides breakpoints and processor/system access
- JTAG interface (ICE)
  - Converts debugger commands to JTAG signals
- Embedded trace Macrocell (ETM)
  - Compresses real-time instruction and data access trace
  - Contains ICE features (trigger & filter logic)
- Trace port analyzer (TPA)
  - Captures trace in a deep buffer

Big.LITTLE architecture

- ARM: Same architecture, different micro-architecture
  - Cortex A7:

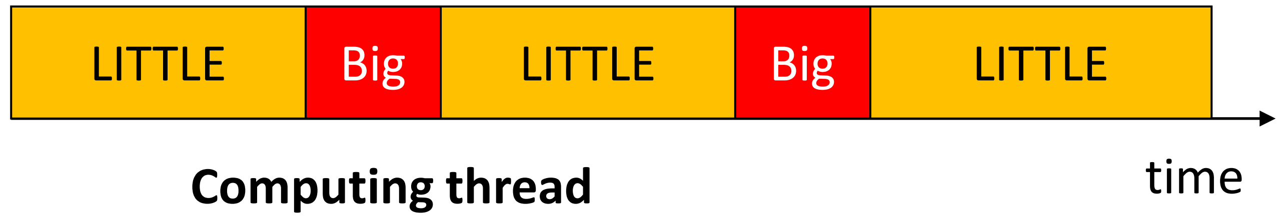


  - Cortex A15:



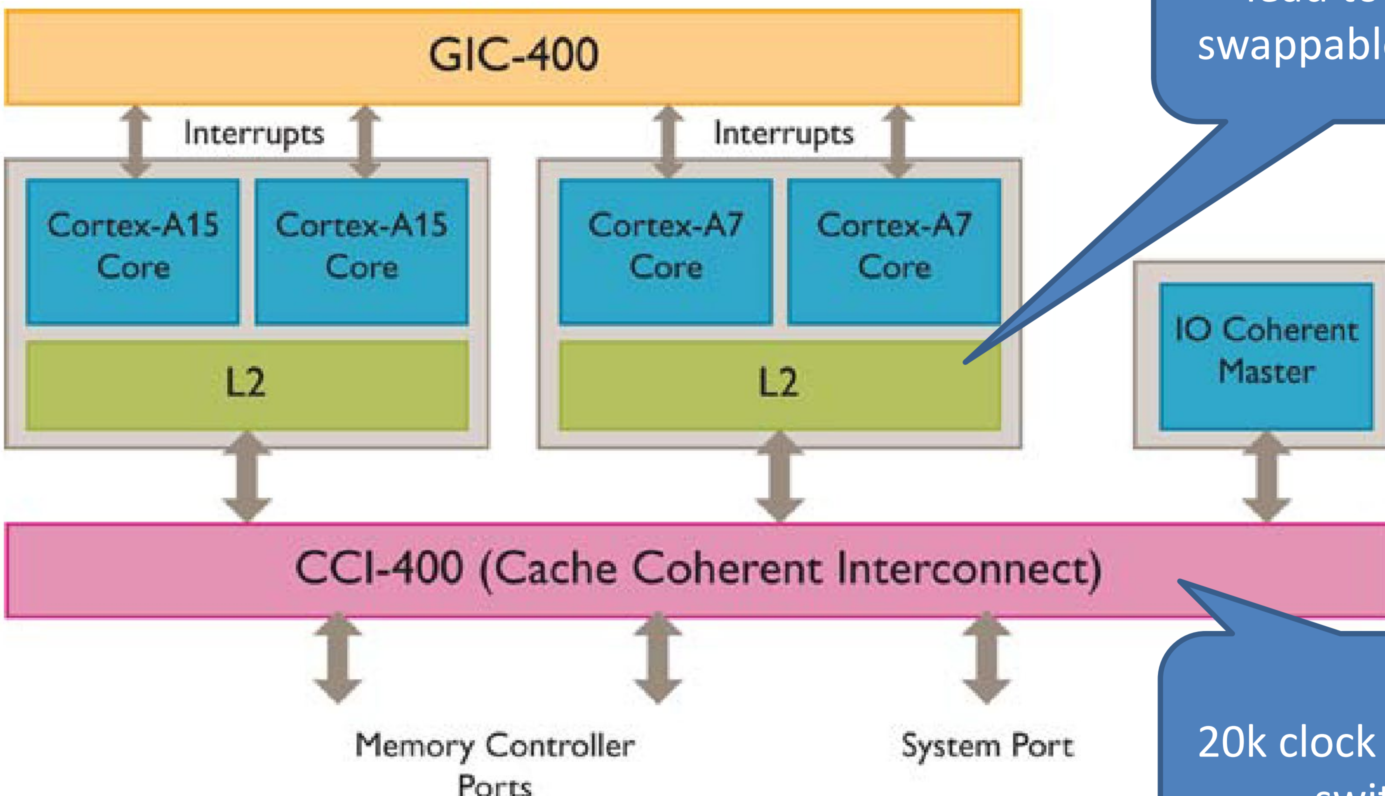
Big.LITTLE architecture

- ARM: Same architecture, different micro-architecture
- Design principle
  - Prompt switch between the big and little cores
  - Only computation intensive tasks on the big cores
  - Little cores for I/O-expensive tasks



Big.LITTLE architecture

- Hardware Design



Separate caches lead to “hot-swappable” cores

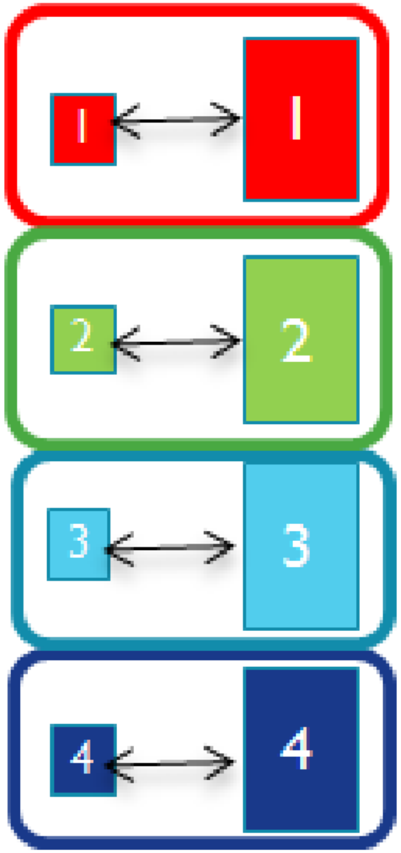
20k clock cycles to switch

Big.LITTLE architecture

- Software Design: How to switch between cores
  - Clustered switching via CPU migration
  - Pairing the big and little cores
  - Only one core in each pair can be active

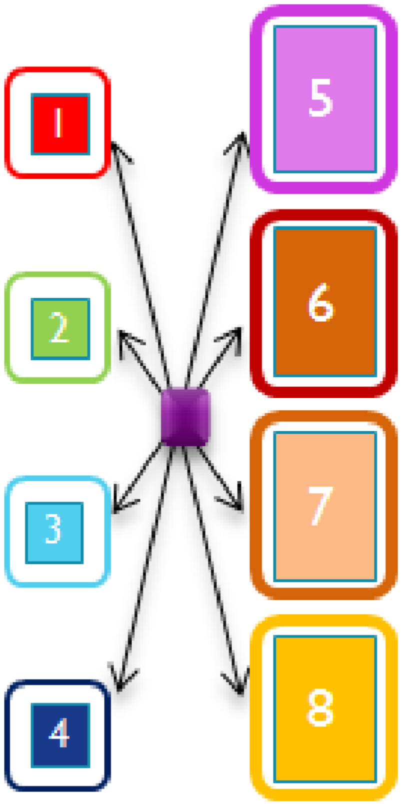
    at one time

  - Various implementations
    - Example: In-kernel switcher from Linaro



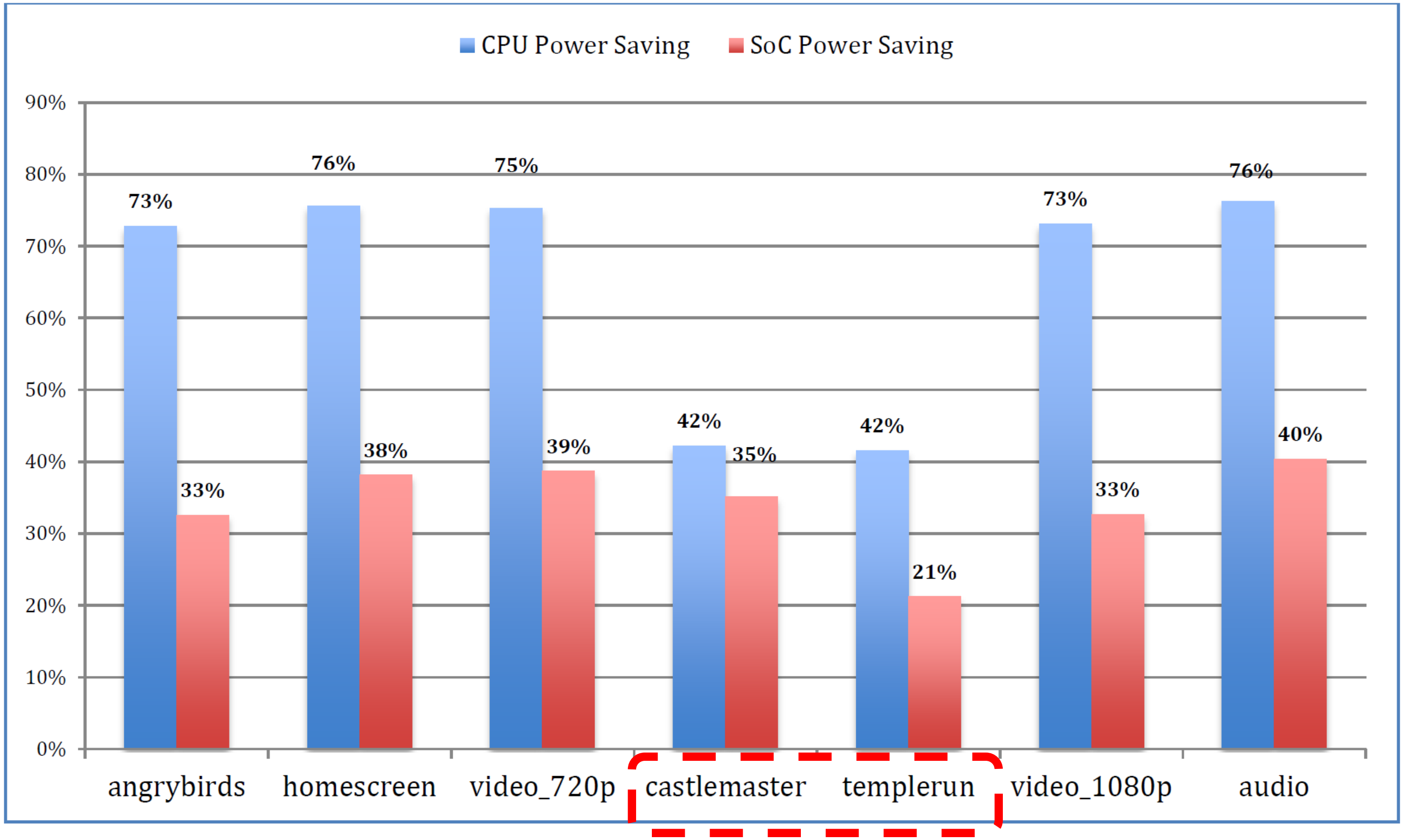
Big.LITTLE architecture

- Software Design: When to switch between cores
  - Global task scheduling
  - Based on the difference of computing capability
  - Thread-level scheduling based on their computing needs
    - RMS/EDF scheduling policy is then applied
  - Unused processors can be powered off



Big.LITTLE architecture

- Power saving



ECE 1175
Embedded Systems Design

Embedded Sensor Designs

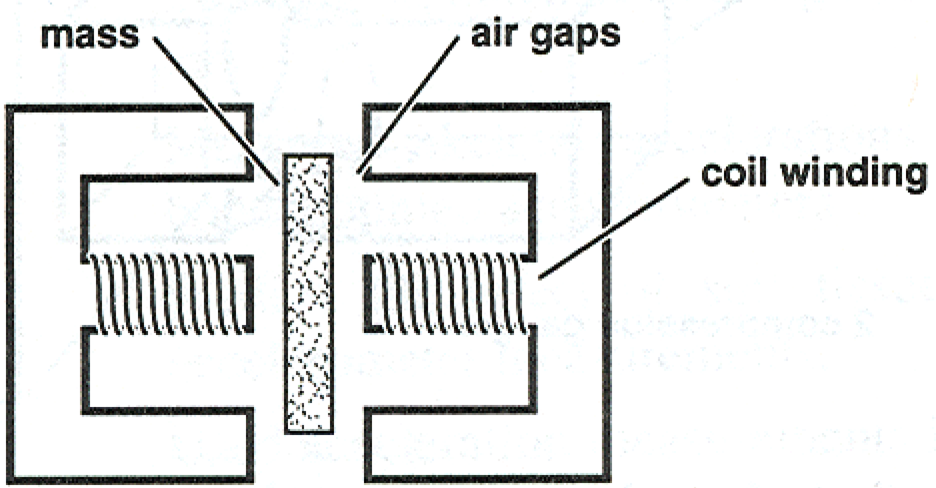
Wei Gao

Great variety of on-board sensors

- Accelerometer and gyroscope
- Ambient light
- Heart beat sensor
- Human physiological sensors

Accelerometer

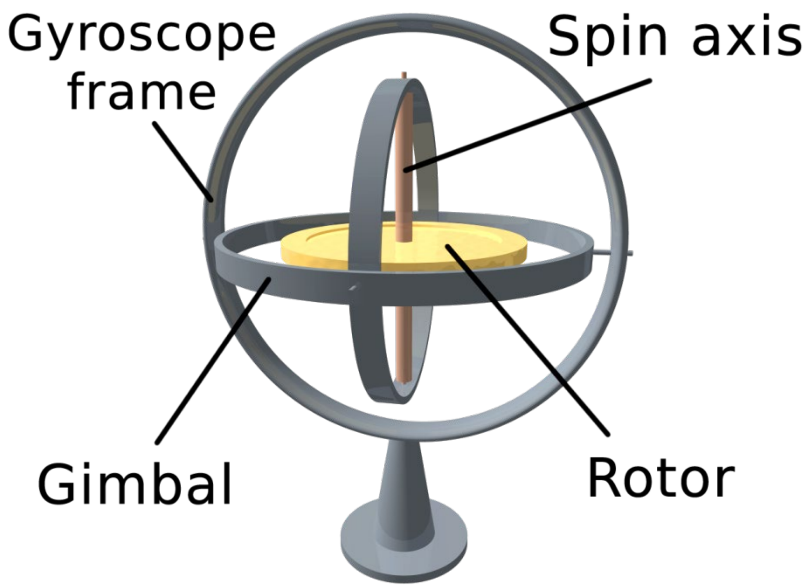
- Inductive-based sensing



Schematic illustration of the construction of an inductive accelerometer.

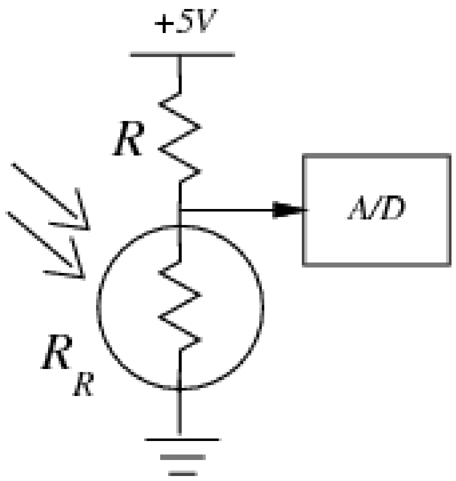
Gyroscope

- Measure or maintain orientation
- Working based on angular momentum
- Consisting of a spinning mass on an axel



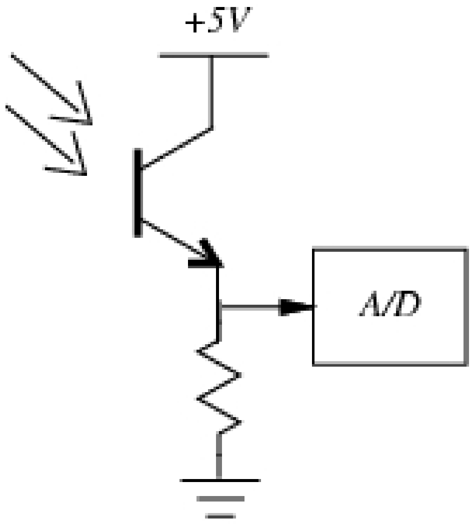
Ambient Light Sensor

- Photo-resistor based
  - voltage divider V_{signal} = (5V) $R_R/(R + R_R)$
    - Choose $R=R_R$ when ambient light is midrange
    - Cheap



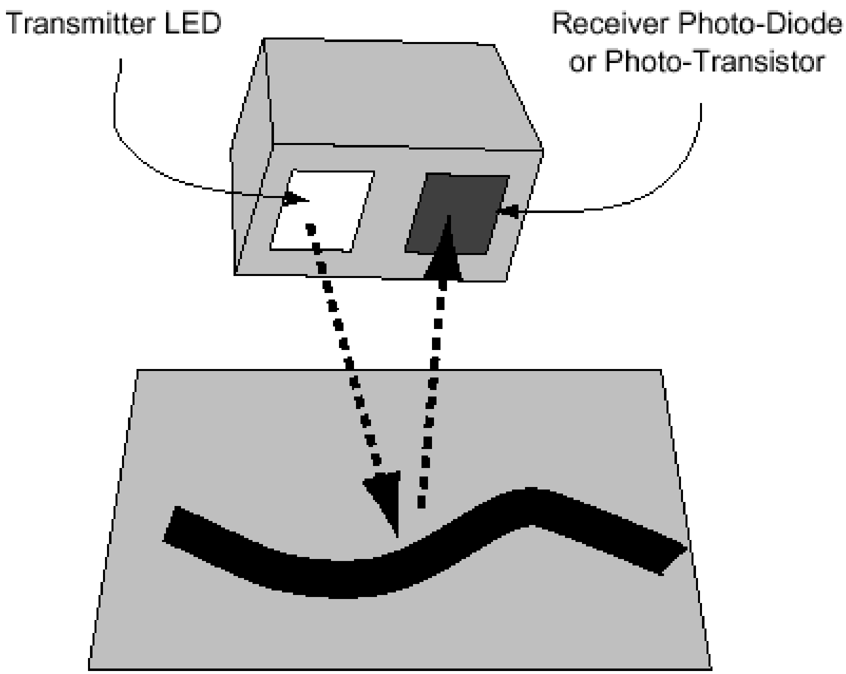
Ambient Light Sensor

- Photo-transistor based
  - Greater sensitivity



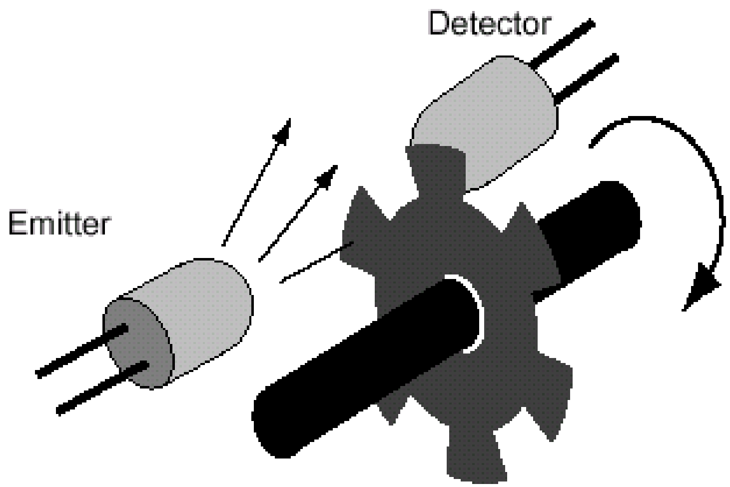
Proximity Sensor

- An application of reflective opto-sensors
  - Using invisible beams: IR or ultrasonic



Proximity Sensor

- Extension: break beam sensors
  - The emitter and detector are facing each other



Tachometer: RPM measurement

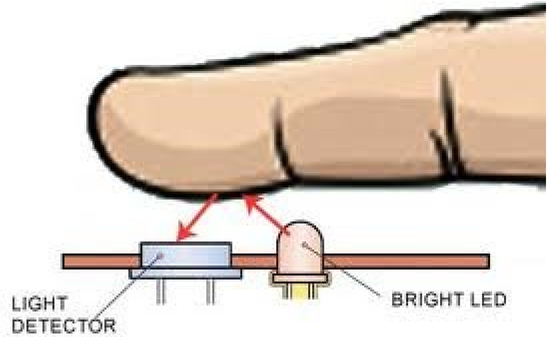
Heart Beat Sensor

- Widely provided at wearables

- Difficulty: what’s happening inside the body?

Heart Beat Sensor

- How does it work?
  - Optoelectronics-based solution

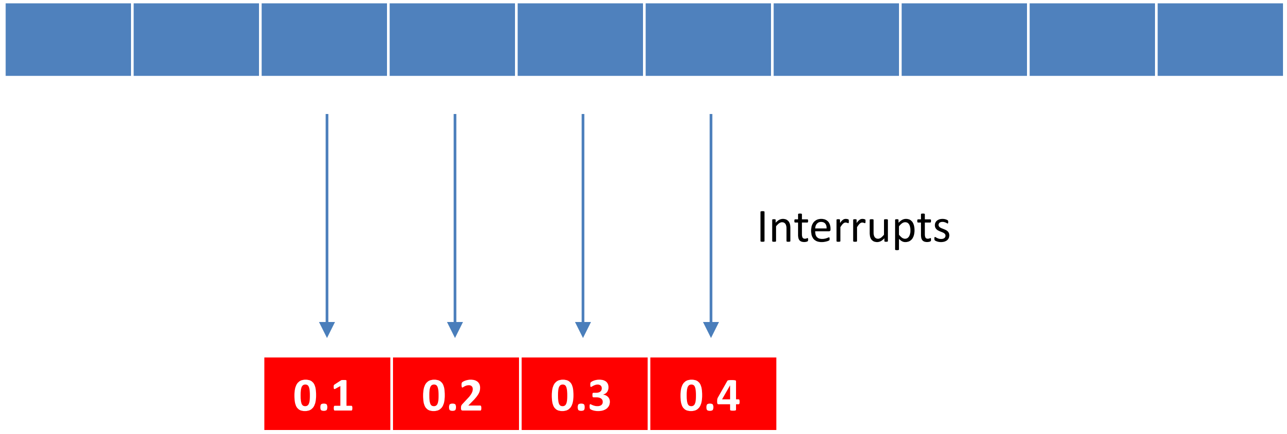


  - More blood pumping (heart squeezing) leads to more light absorption
  - Less blood pumping (heart relaxing) leads to less light absorption

  - Light detector: light-sensitive resistor -> voltage variation

Heart Beat Sensor

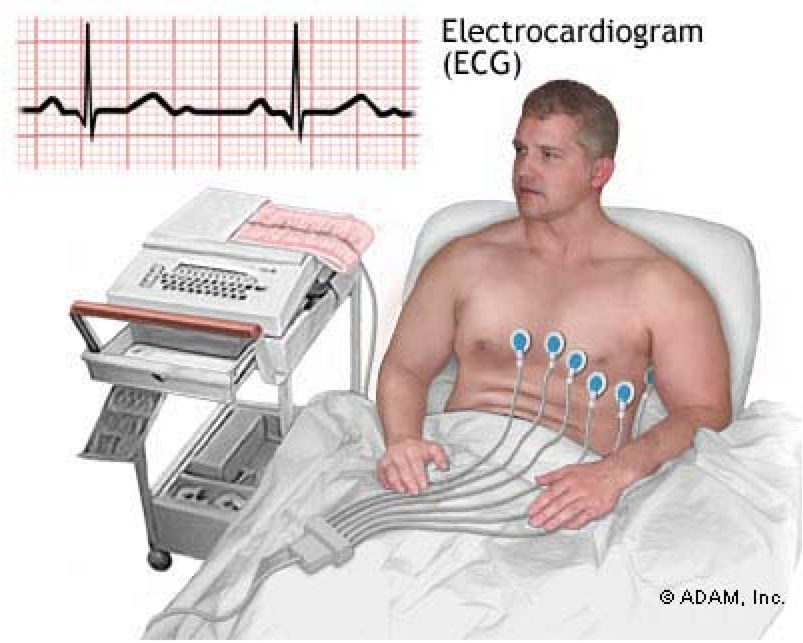
- Connecting the sensor to the system
  - Counting the heart beat: N per every 60 seconds
    - Weighted moving average



  - Reducing the latency
    - Sampling over 10 seconds instead of 60 seconds

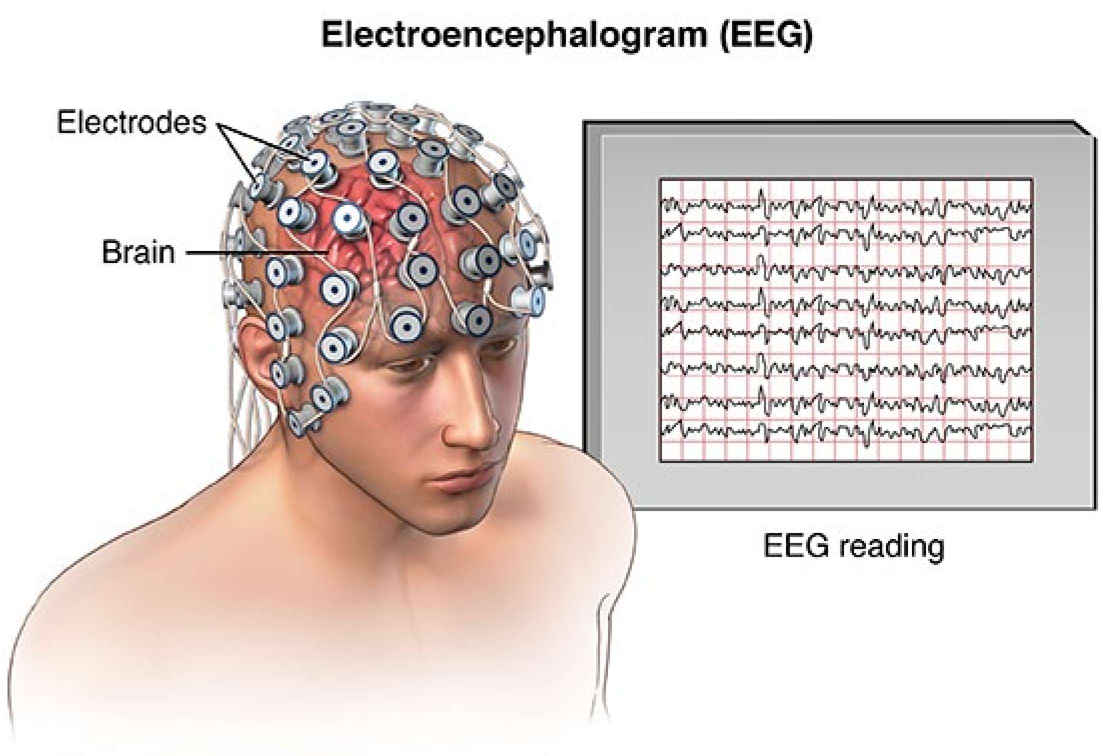
Human physiological sensors

- Electrocardiography (ECG)
  - Electrical patterns of heart beating



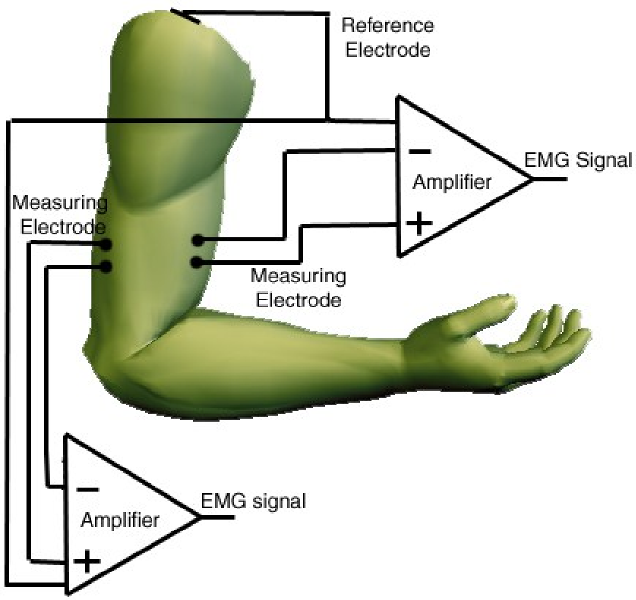
Human physiological sensors

- Electroencephalography (EEG)
  - Electrical response to brain activity



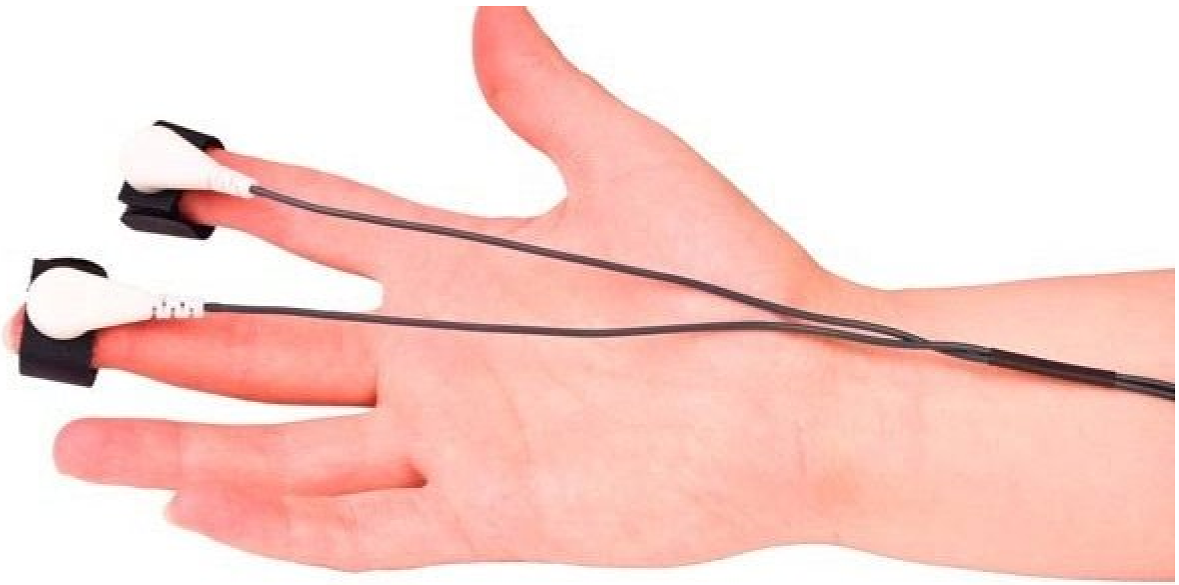
Human physiological sensors

- Electromyography (EMG)
  - Electric response to muscle movement

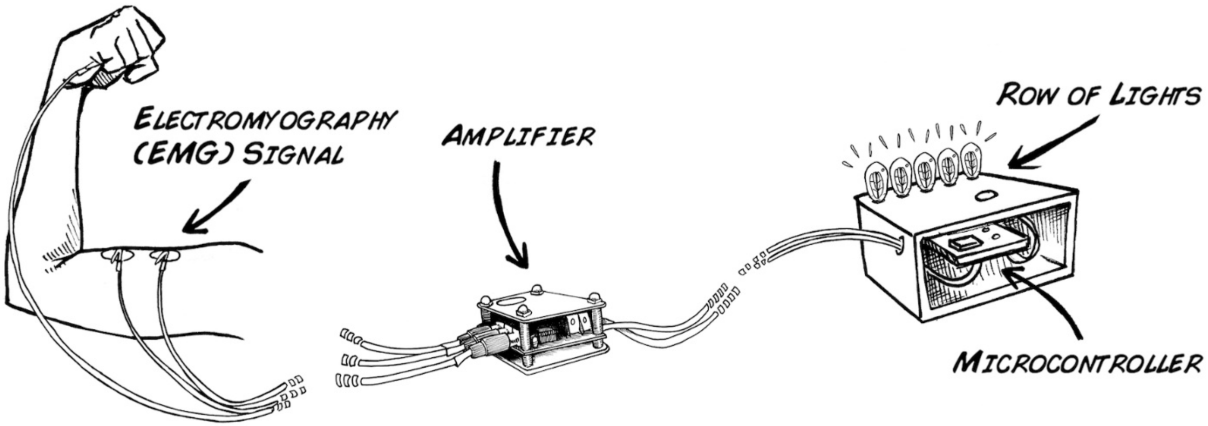


Human physiological sensors

- Galvanic Skin Response (GSR)



Actuation through your body



- Signal processing: denoising and smoothing
- Pattern recognition: classification & feature extraction
- I/O interfacing

Commonality

- A system that changes “physical” to “cyber”
  - Physical: a mechanical device that varies with the target being measured
  - Middleware: mechanical changes -> electrical changes
  - Cyber: digital interface that is readable by computer
  - New sensing modularities?