ENGINEERING FOR impact

mit 6.900

Lecture 1

February 7, 2023

TODAY

- What is this class about?
- What will I learn?
- Some logistics
- A taste for what we'll learn

6.900 staff

Instructors

Joel Voldman

Joe Steinmeyer

TAs

Daniel Klahn

Fischer Moseley

Special guests

Abby Berenson

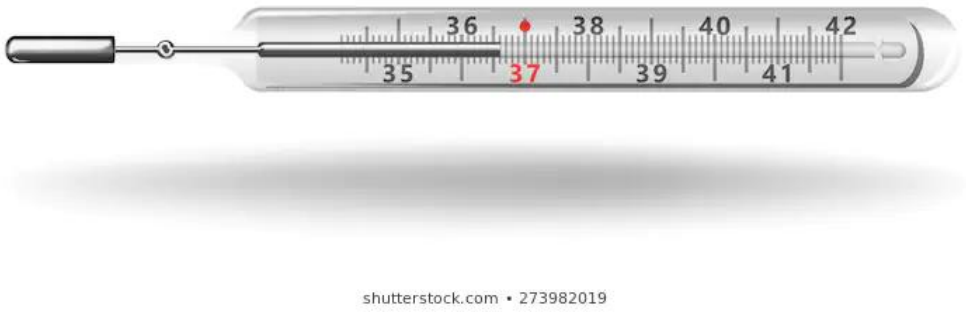
Katrina Lacurts

Consider the medical thermometer

Why do we use medical thermometers?

What features do we want?

mercury thermometer



alcohol thermometer

Consider the medical thermometer

ear thermometer

Range: 34-42.2 °C
Accuracy: ±0.2 °C
Time: ~3 sec
Price: $55

oral thermometer

Range: 32-42.9 °C
Accuracy: ±0.1 °C
Time: ~10 sec
Price: $7

Today's thermometers

Consider the medical thermometer

ear thermometer

Range: 34-42.2 °C
Accuracy: ±0.2 °C
Time: ~3 sec
Price: $55

oral thermometer

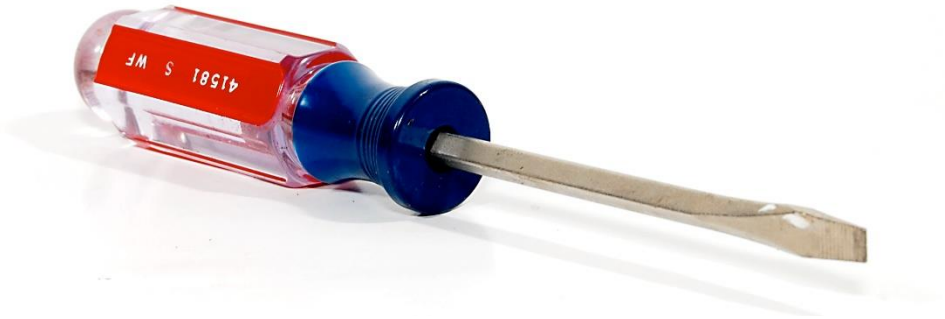
Sensing, electronics, computation, actuation (display)
[some even have Bluetooth communications]

Consider the drill/driver

Why do we use drill/drivers?

What features do we want?

handheld screwdriver



handheld drill

Consider the drill/driver

manual

corded drill/driver
~1900s

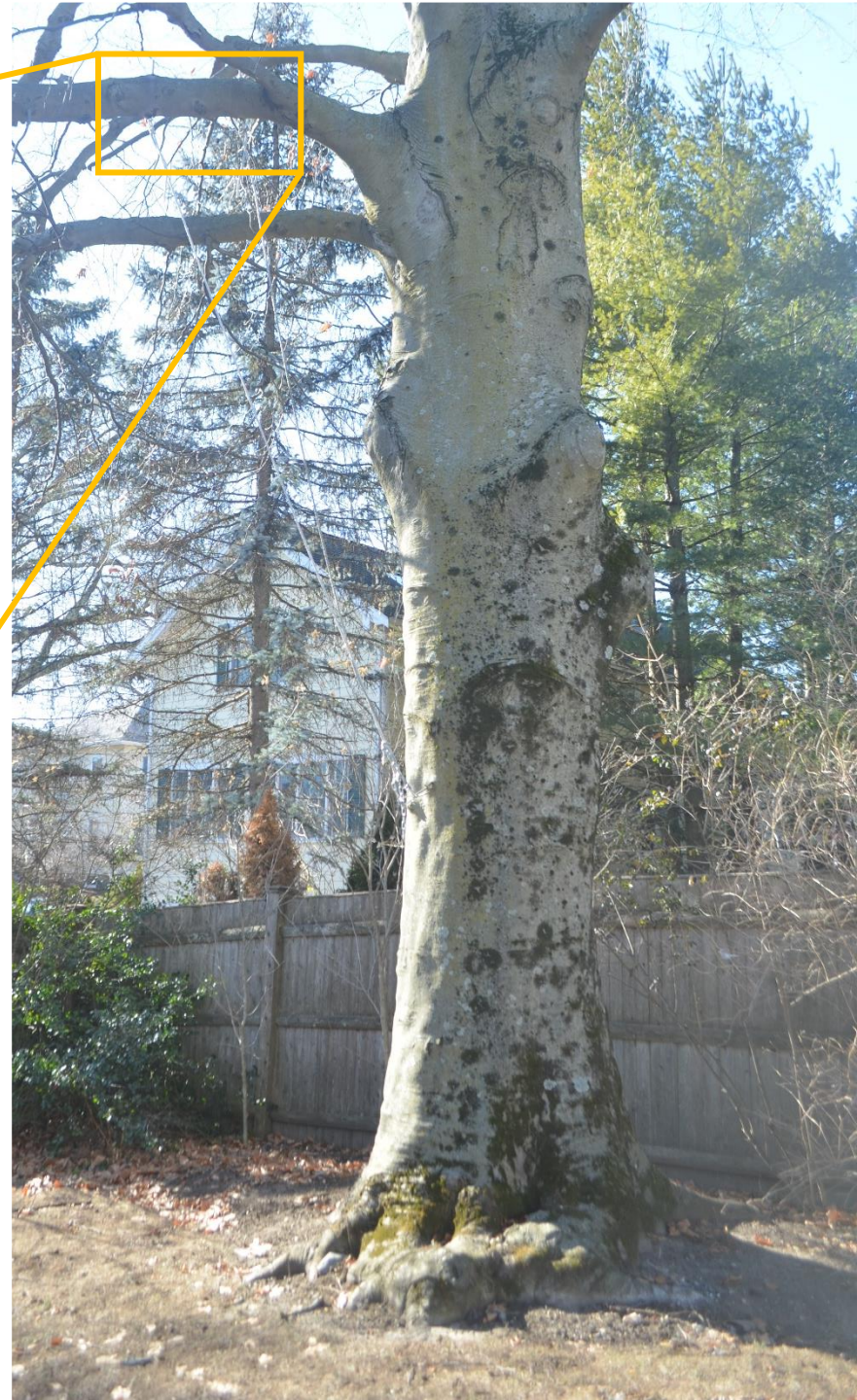
cordless drill/driver
1978

cordless drill/driver with brushless motor, tool tracking, etc.
today

circuits, actuation

sensing, electronics, computation, comms, actuation

Consider the drill/driver



Isolated cases?

These are hardware/software EECS systems

Our definition: A system that has most of:

- Sensing
- Electronics
- Computation
- Software
- Communications
- Control
- Actuation

Though not a formal law, products ➔ HW/SW over time

To create these systems

We need expertise in

- Sensing
- Electronics
- Computation
- Software
- Communications
- Control
- Actuation

} **our focus**

And yes,

- Mechanical, thermal, manufacturing, medical, UI/UX, economics, marketing, etc.

To create these systems

In industry, you'll probably be on a team that does ~1 of these functions

But you'll be a better engineer if you can understand the rest to some extent

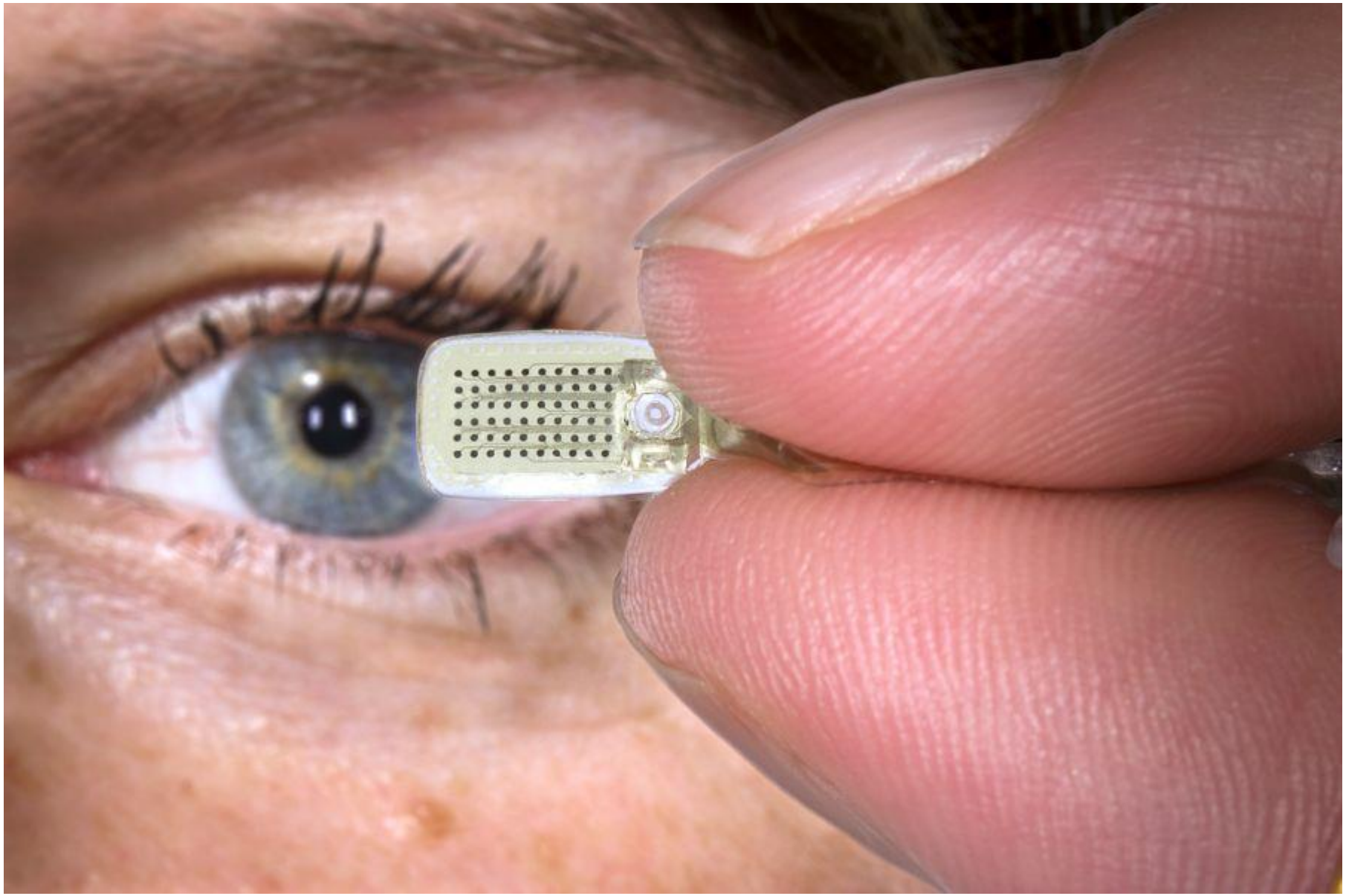
In this class, we'll undertake this *full stack* design

So we'll need to synthesize material *across* classes

Our EECS *responsibility*

Markus Möllmann-Bohle has been left to manage his implanted electronic device alone. Credit: Nyani Quarmyne/Panos Pictures for *Nature*

Our EECS *responsibility*



Our EECS *responsibility*

Our EECS *responsibility*

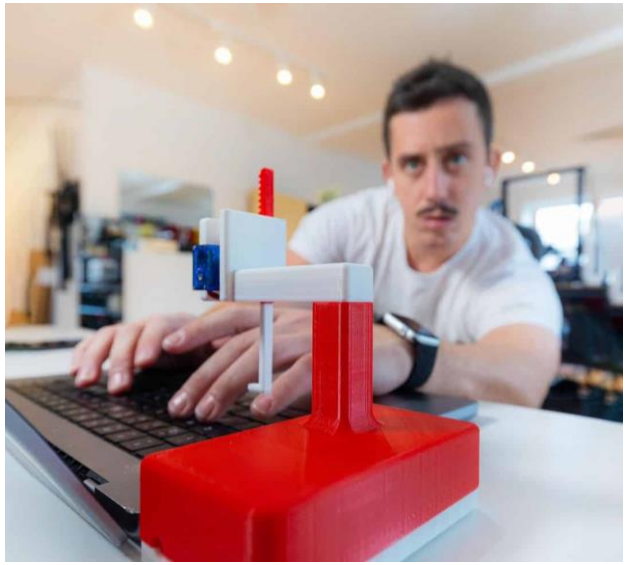
Our EECS *responsibility*

as designers with access to extremely powerful technologies,

we must be mindful of the *implications* of the choices we make in those designs

Let’s talk about *impact*

- There are many reasons to create new HW/SW systems
- Arguably, every HW/SW system has impact…



tHe tEeN TyPEr™, Matt Benedetto [Unnecessary Inventions]

Our reason: to improve the world around us…to use our superpowers to help those who can’t do what we can do

Let's talk about *impact*

- There are many reasons to create new HW/SW systems
- Arguably, every HW/SW system has impact…

BigBelly's Solar trash compactor and recycling cans

Juicero

More here… than here

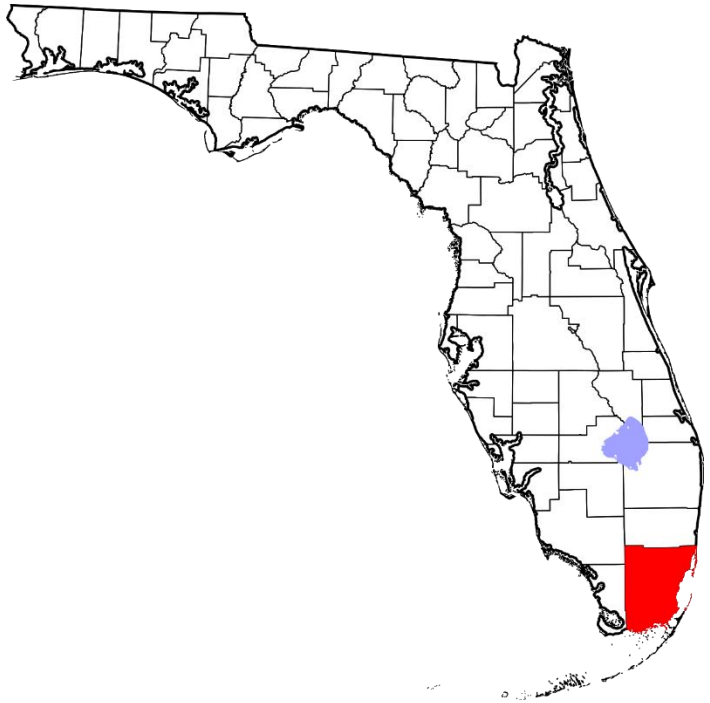
Our reason: to improve the world around us…to use our superpowers to help those who can't do what we can do

Our project this term

- More details on Thursday, but…
- We're partnering with MIT's PKG Center
- And Miami-Dade County

PKG

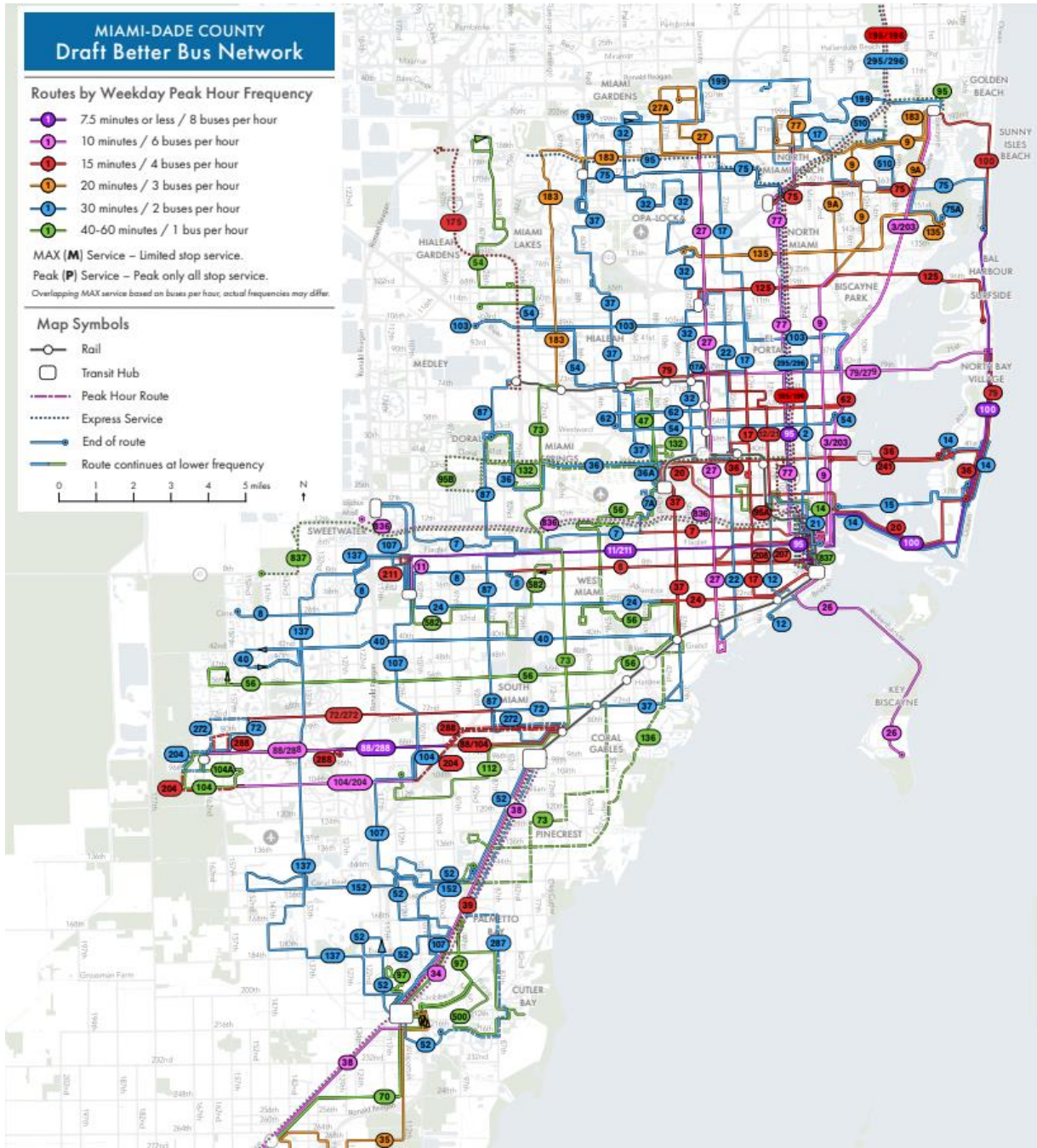
PRISCILLA KING GRAY
PUBLIC SERVICE CENTER



MIAMI-DADE
COUNTY

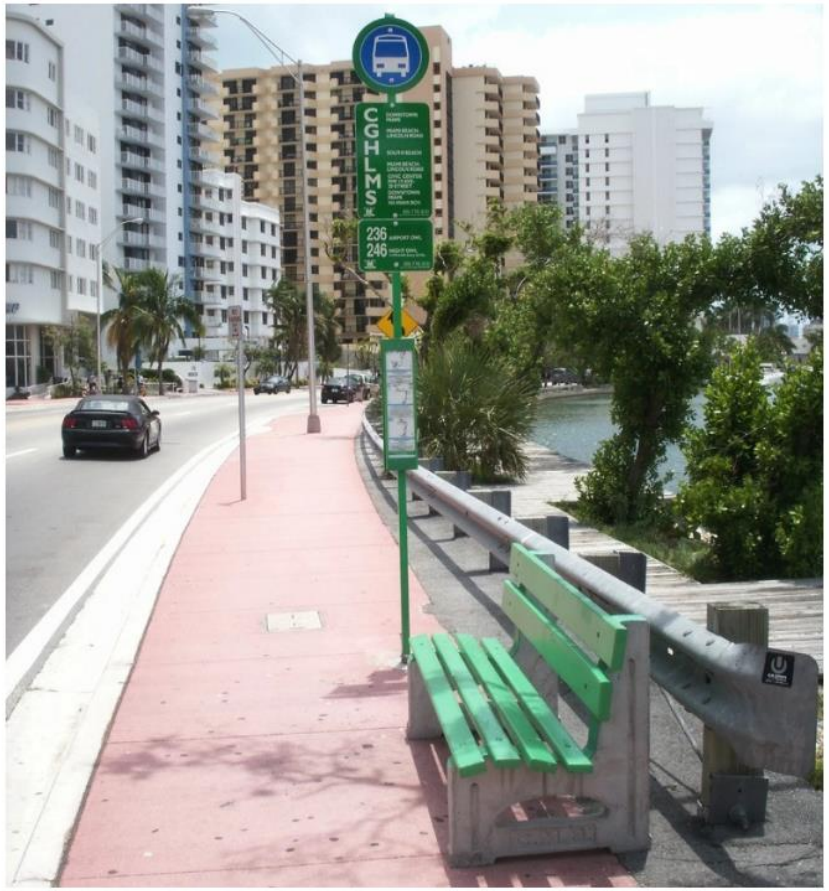
Our project this term

- Miami-Dade County has an extensive bus transit network (>7k stops)
- They want to increase use of public transit ➔ serve community, help get to net-zero emissions
- But riders will only use system if it is convenient and comfortable
- They know who is taking the bus, where they get on and get off, where their buses are, etc.



Our project this term

- But they don't know who **isn't** taking the bus
- Who comes to the bus stop but leaves because it is too hot



An uncovered bus stop on South Beach

Credit Vera Arias /

Bus stops like this one can get very hot in the summer.

https://www.wlrn.org/news/2014-06-19/we-asked-miami-dade-transit-why-not-every-bus-stop-has-a-shelter

Our project this term

- They want to deploy resources to make the bus stops more comfortable…here is the current metric

> Albert Hernandez is assistant director for the Division of Engineering, Planning and Development at Miami-Dade Transit.
>
> He says the lack of shelters is apparently not due to money.
>
> **Walk me though what the process is for getting a bus shelter in Miami-Dade County.** Bus shelters are placed at bus stops with the greatest amount of patrons. ... We require at least 100 boardings per day at the location. ... We place bus benches at all locations that do not have shelters.

- What's incomplete about this metric?

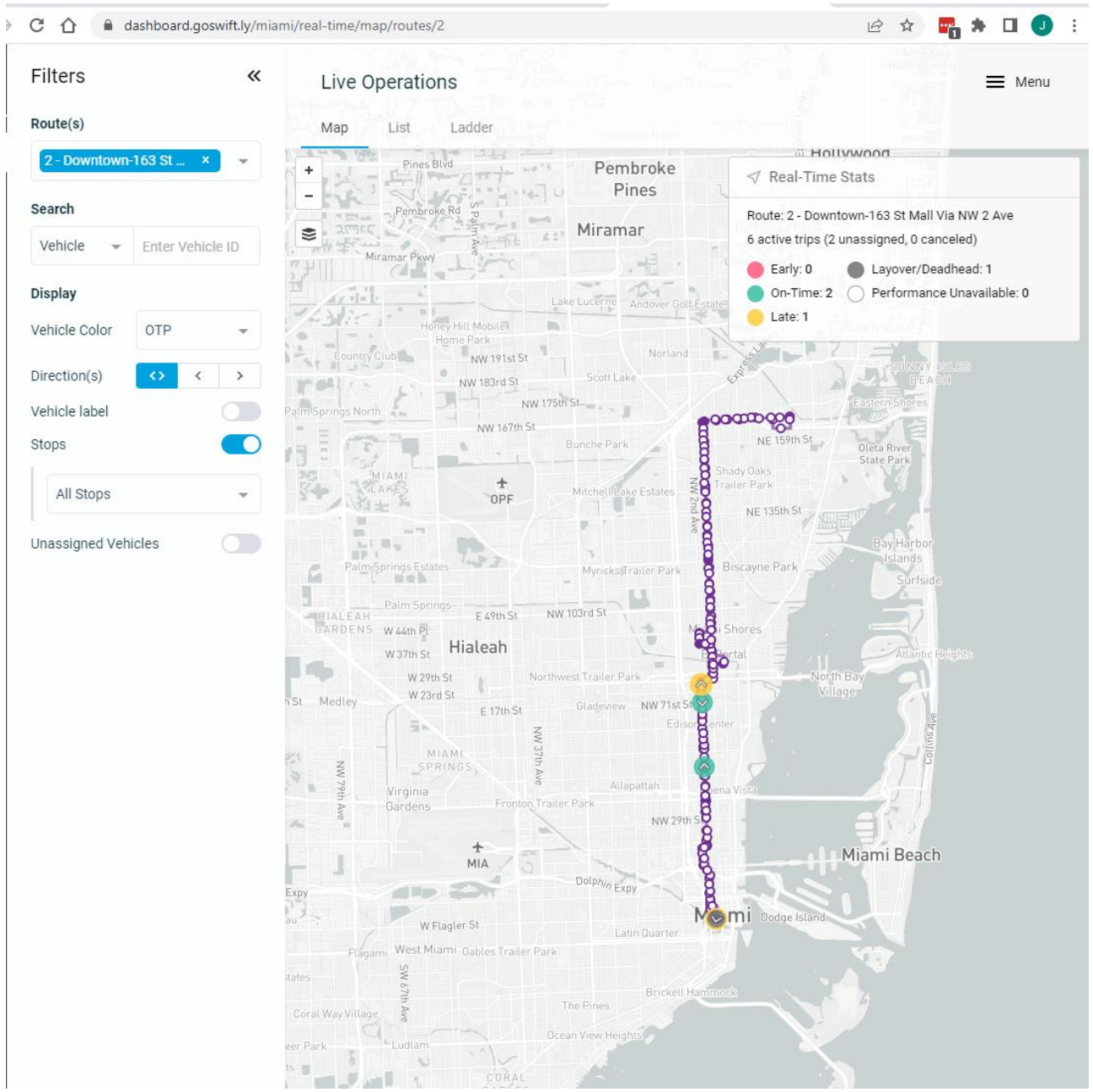
https://www.wlrn.org/news/2014-06-19/we-asked-miami-dade-transit-why-not-every-bus-stop-has-a-shelter

Our project this term

- We’re going to create a system with a HW sensor node that can be deployed at bus stops around the city to monitor local weather conditions (how [un]comfortable is it) **and** occupancy (who comes to the bus stop, how long they wait, whether they get on the bus [or not])

Our project this term

- We'll combine this data with data from an existing provider (Swift.ly)
  - Static info: routes, schedules, etc.
  - Real-time: Bus GPS, etc.
- Teams will have keys to access their API



Our project this term

If we're successful, we can help Miami-Dade understand where to plant new trees, add bus shelters, etc.

so that ridership can improve

and the community can be better served

and emissions can decrease

and maybe we can even apply similar systems in other communities

What will I learn?

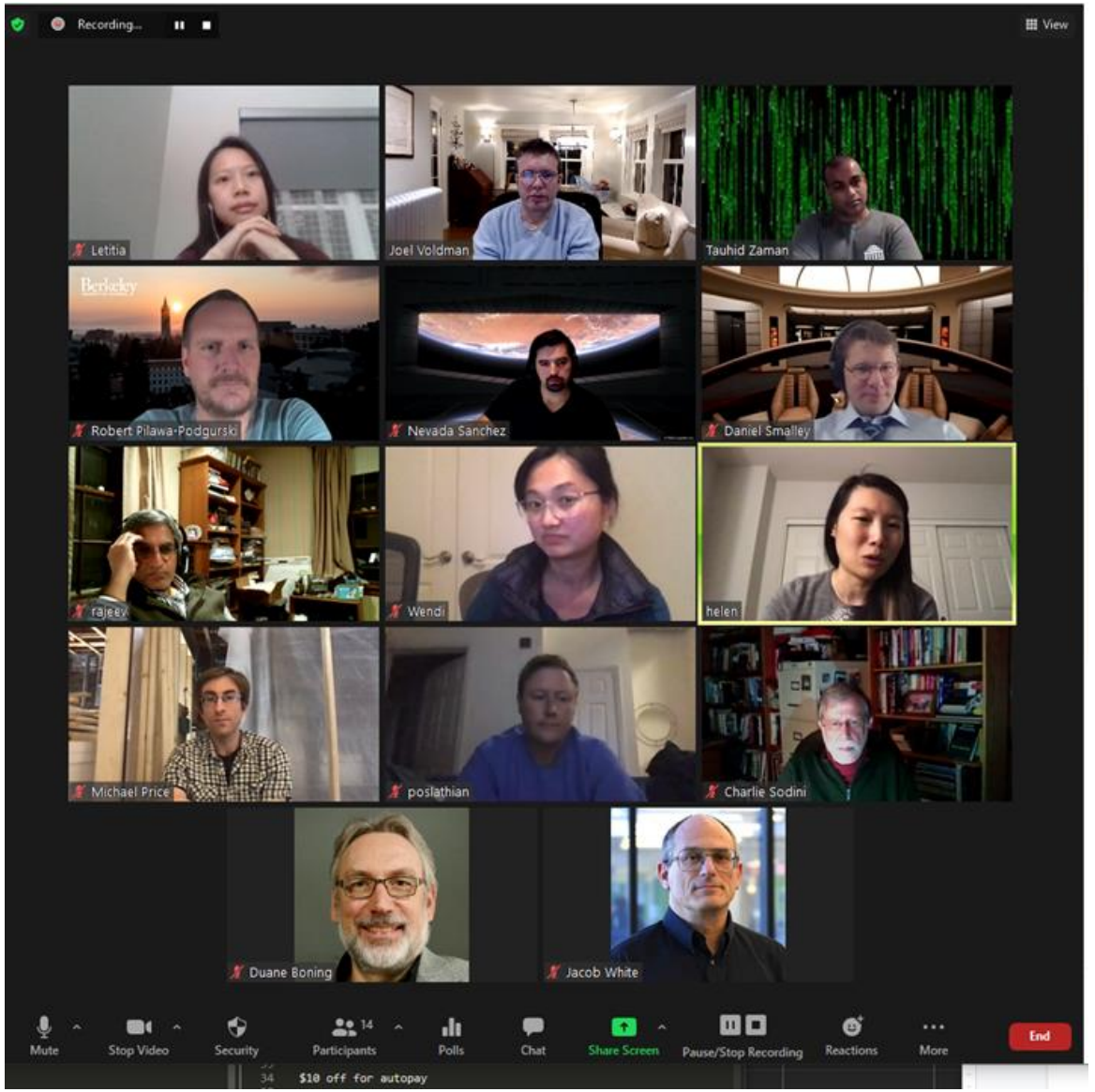
- Principled ways to design HW/SW systems
- How to go from requirements ➔ specifications ➔ system design ➔ detailed design ➔ prototyping ➔ testing & verification
- How different system design choices and partitions affect tradeoffs in meeting our specifications
- Evaluate the size, weight, power, cost, lifetime, etc. tradeoffs of various designs

Mostly, how to **synthesize and apply** your knowledge from other EECS classes

Yes, you'll build stuff

How will we do it?

- We'll work in teams…**BIG*** teams
- Why?
  - IRL, this is the way
  - Feedback from alumni
  - You can do more…together



*for EECS

How will we do it?

- We'll work in teams…**BIG*** teams
- Why?
  - IRL, this is the way
  - Feedback from alumni
  - You can do more…together
- Don't worry…we're partnering with folks from Sloan to provide guidance on managing these teams

Abby Berenson (MIT Sloan)

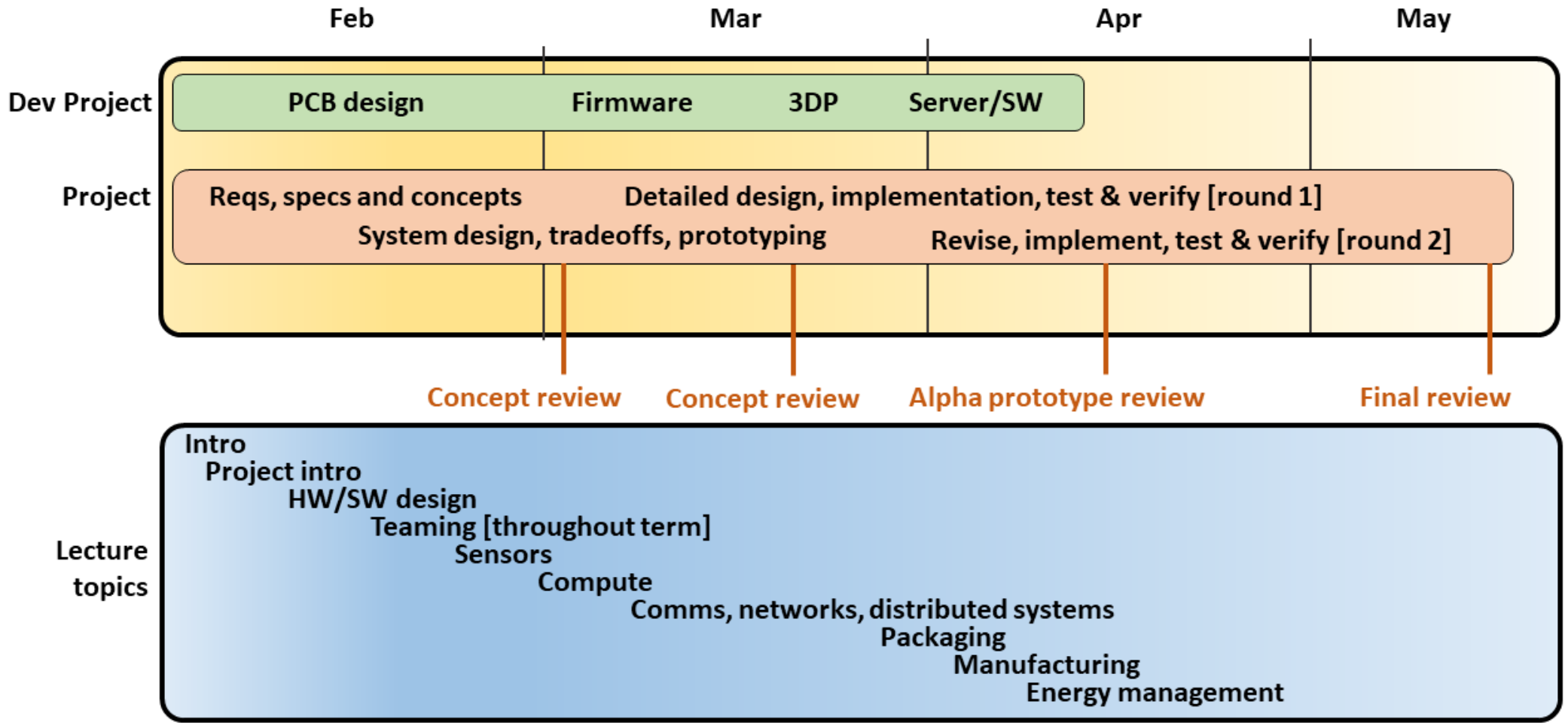
*for EECS

How will we do it?

- You'll work in teams with our partner to set specifications
- You'll develop concepts, then analyze them, refine them
- Ultimately develop a single design
- Then go and implement
- Two rounds of prototyping: alpha (function) and beta (form + function)

Along the way, there will be plenty of feedback from staff, partner, teammates, other teams

How will we do it?



How will we do it?

- During the first half of the term, we'll design and prototype **MILO**
  - **M**it a**I**r qua**L**ity m**O**nitor
- A "development system" that incorporates sensing, compute, communications, server, db, in a guided experience
- Some parts individual, some parts as a team
- You'll learn electronics design, PCB layout & prototyping, firmware, 3DP enclosures, back-end server w/ database
- This will give you some of the tools needed to undertake the project

Full disclosure

- This is our first offering of this class
- We've never done anything like this in EECS before

We're not going to get it perfect!

Full disclosure

- This is our first offering of this class
- We've never done anything like this in EECS before

We're not going to get it perfect!

But…

- You get to help shape the class, not just the system
- You are the pioneers, the trailblazers, the early adopters
- We will be suitably lenient in grading
- You will learn how to be real engineers
- You will gain confidence in your skills
- You will have an experience & a system to talk about with employers
- ~~You~~we will have fun

Do I have the background?

- In steady state, this class will require 6.200[6.002], 6.191[6.004], 6.310[6.302]
- For this first offering, we are going to be lax

If you're worried about your background, come talk with us…

Some logistics

- This afternoon: team formation survey in EX00 – **due end of Saturday!!**
- Teams will go out on Sun or Mon, based on background

- Labs are on Friday 11-2p – starting this Friday!
- Psets every week or so – EX01 comes out on Friday
- No exams
- Piazza and slack ← sign up!
- There will be presentations, but this is not a CI-M class…
- Late policy, etc. on catsoop site

efi.mit.edu

Let’s get a taste for tradeoffs

Let’s say we want to make a system to monitor “health”

That often translates to: monitor activity

Which means: monitor motion

This is the world of so-called “fitness trackers”

Activity monitors are not new

- 1965: Mampo-kei pedometer (mechanical)
  - Purely mechanical
  - Origin of 10k steps/day
- 1982: Polar PE2000
  - Wireless heart-rate monitor (not steps)

More-modern history

- Fitbit: established ~2007
- Fitbit Tracker 2009
  - 3-axis accelerometer + base station
- Then add more sensors, comms
- Smartwatches: Pebble (2013), Apple (2015), etc.

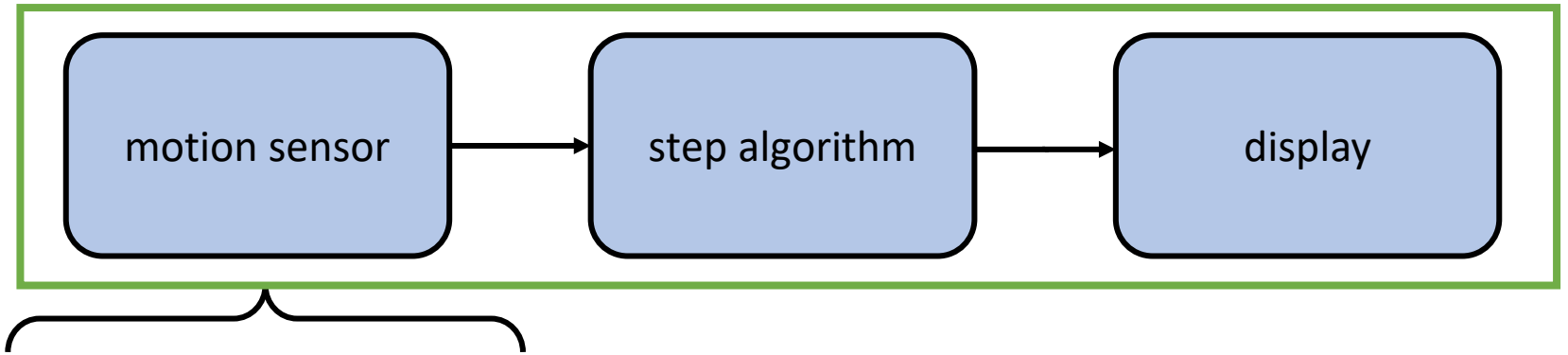
A wearable step tracker

- We want a fitness tracker *aka* step counter
- What do we need? What are our requirements?
  - A way to sense motion
  - A way to turn motion into steps
  - A way to present that information to the user
- We can imagine many other requirements
  - Portable, long battery lifetime, accurate, inexpensive, stylish, durable, etc.

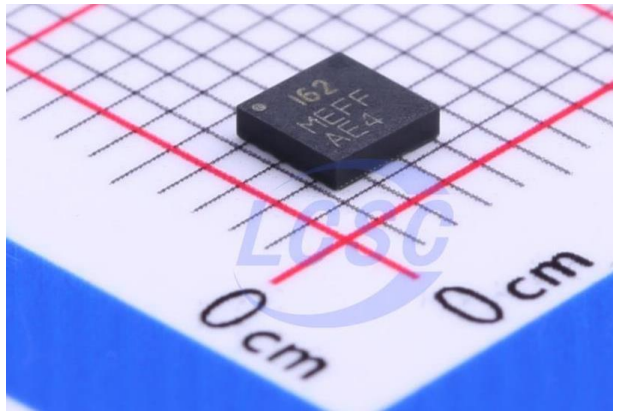
A wearable step tracker

- A minimal system

QTY	UNIT PRICE
1	$5.63000
5	$4.96800
10	$4.38800
25	$3.56040
50	$3.14640
100	$3.06360
500	$2.56680
1,000	$2.40120

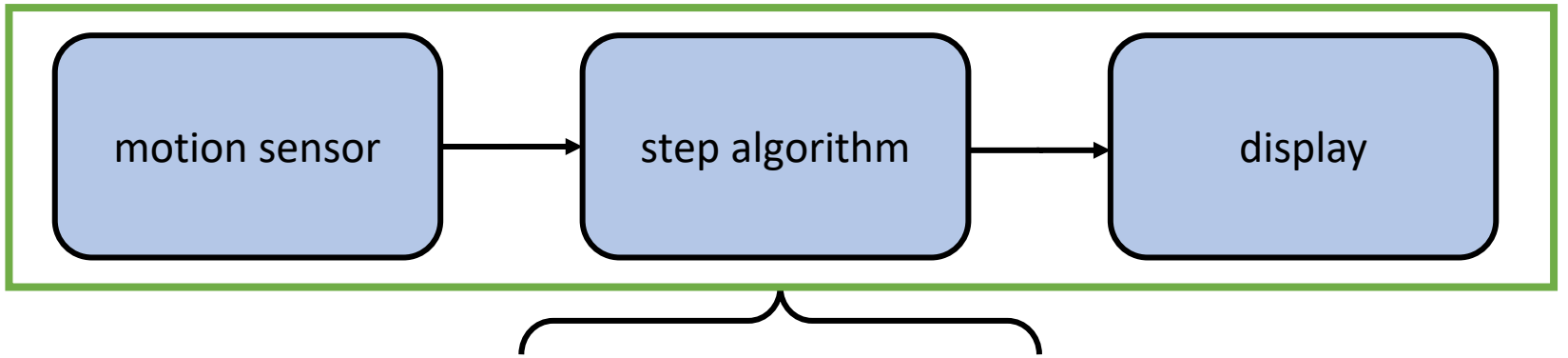


6-axis IMU
Invensense ICM-20602
$2.40 @ 1k
digital output (I2C), etc.



A wearable step tracker

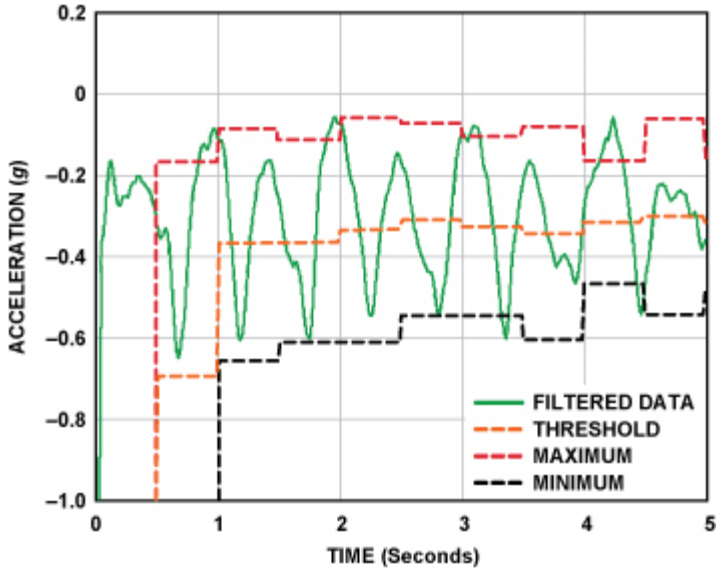
- A minimal system



many step-counting algorithms

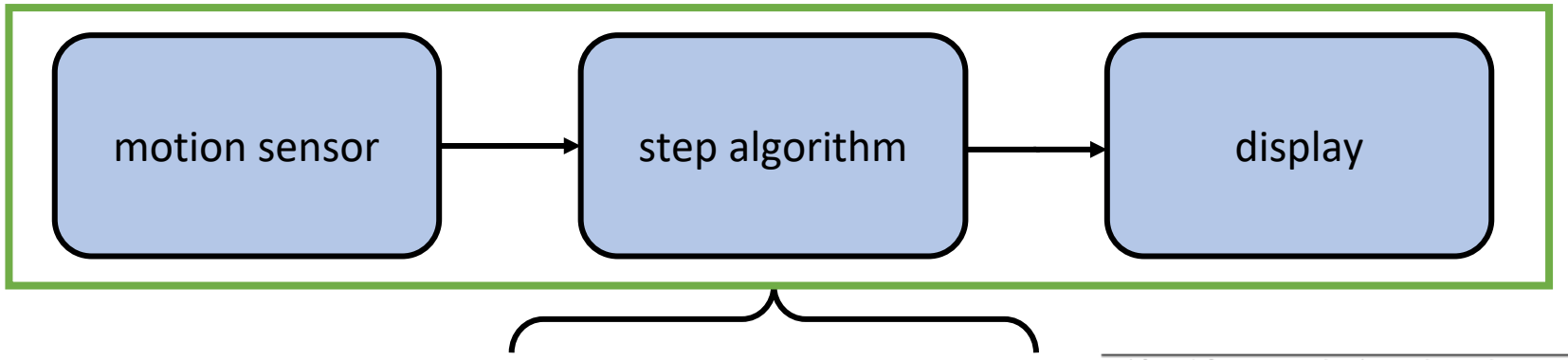
wide variations in time- and space-complexity

- peak detection w/ or w/o adaptation
- correlation w/ templates
- fourier transform-based frequency analysis
- deep learning



A wearable step tracker

- A simplest system



many step-counting algorithms

wide variations in time- and space-complexity

- **peak detection** w/ or w/o adaptation
- correlation w/ templates
- fourier transform-based frequency analysis
- deep learning

1's of parameters
simple math
less accurate, adaptive, etc.

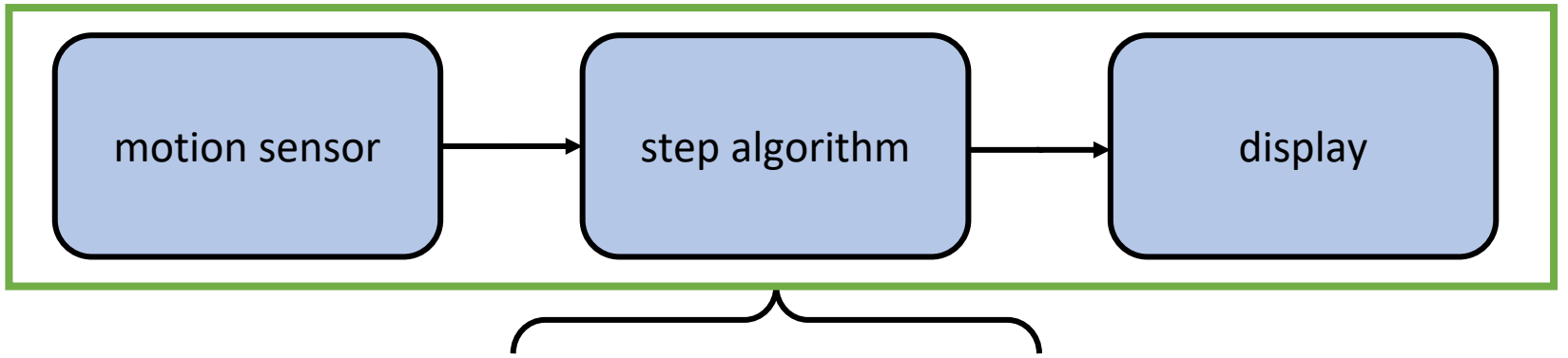
Algorithm 2: Multiple Peak Finding

```
Input: signal
Output: indices
peakIndices := [];
peakIndex := null;
peakValue := null;
baseline := average(signal);
for index, value in signal do
    if value > baseline then
        if peakValue == null or value > peakValue then
            peakIndex := index;
            peakValue := value;
        end
    else if value < baseline and peakIndex != null then
        peakIndices.push(peakIndex);
        peakIndex := null;
        peakValue := null;
    end
end
if peakIndex != null then
    peakIndices.push(peakIndex);
end
return peakIndices;
```

https://www.baeldung.com/cs/signal-peak-detection

A wearable step tracker

- A simplest system



many step-counting algorithms

wide variations in time- and space-complexity

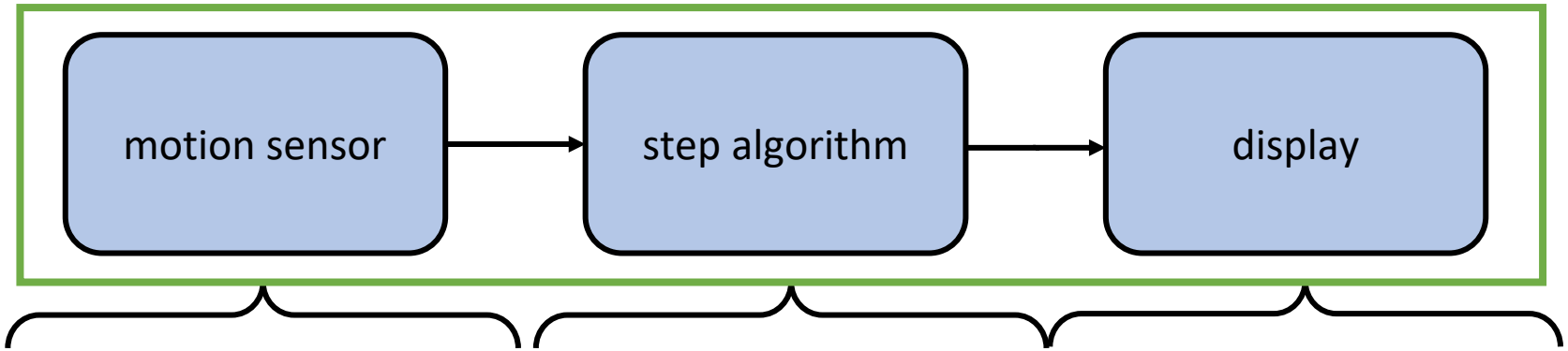
- peak detection w/ or w/o adaptation
- correlation w/ templates
- fourier transform-based frequency analysis
- **deep learning**

1,000s of parameters or more
may require storage of longer time series
more accurate, adaptive, etc.

https://www.baeldung.com/cs/signal-peak-detection

A wearable step tracker

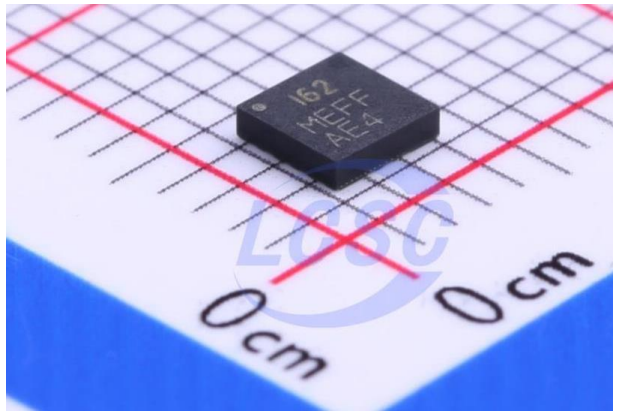
- One design



6-axis IMU
Invensense ICM-20602
$2.40 @ 1k
digital output, etc.

peak detection w/ adaptation
STM32C011J4M8 MCU
$0.65 @ 1k
16k Flash, 6kB SRAM

3-digit LCD display
<$0.50 @ 1k

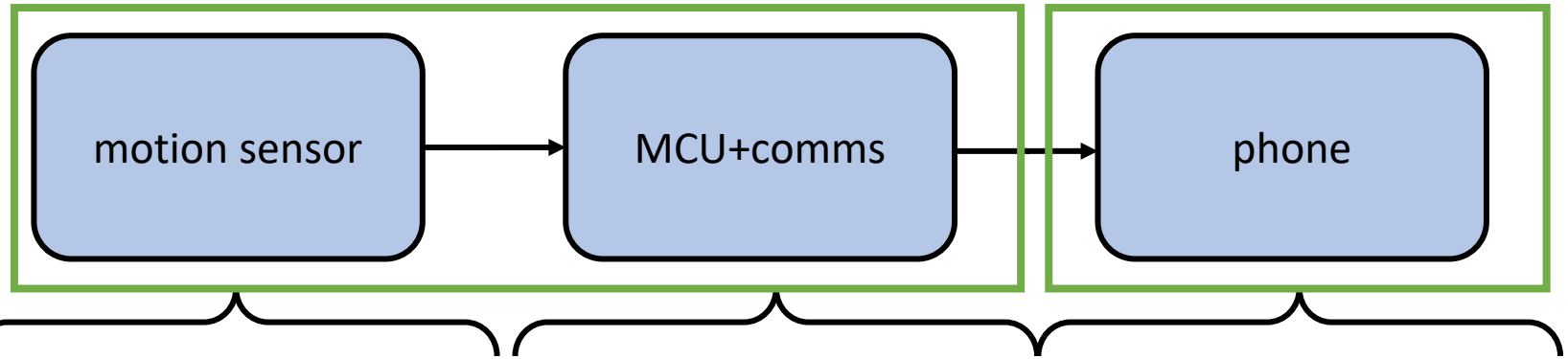


SO8N
4.9 × 6 mm

Note that we haven't considered many specs: size, power, etc.

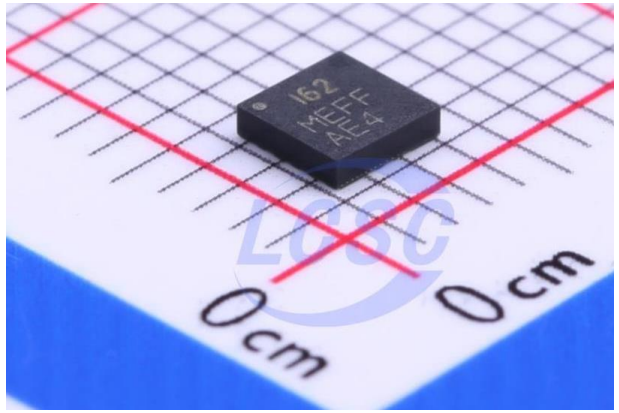
A wearable step tracker

- Move some function to phone



We have *<u>partitioned</u>* system differently!

6-axis IMU
Invensense ICM-20602
$2.40 @ 1k
digital output, etc.



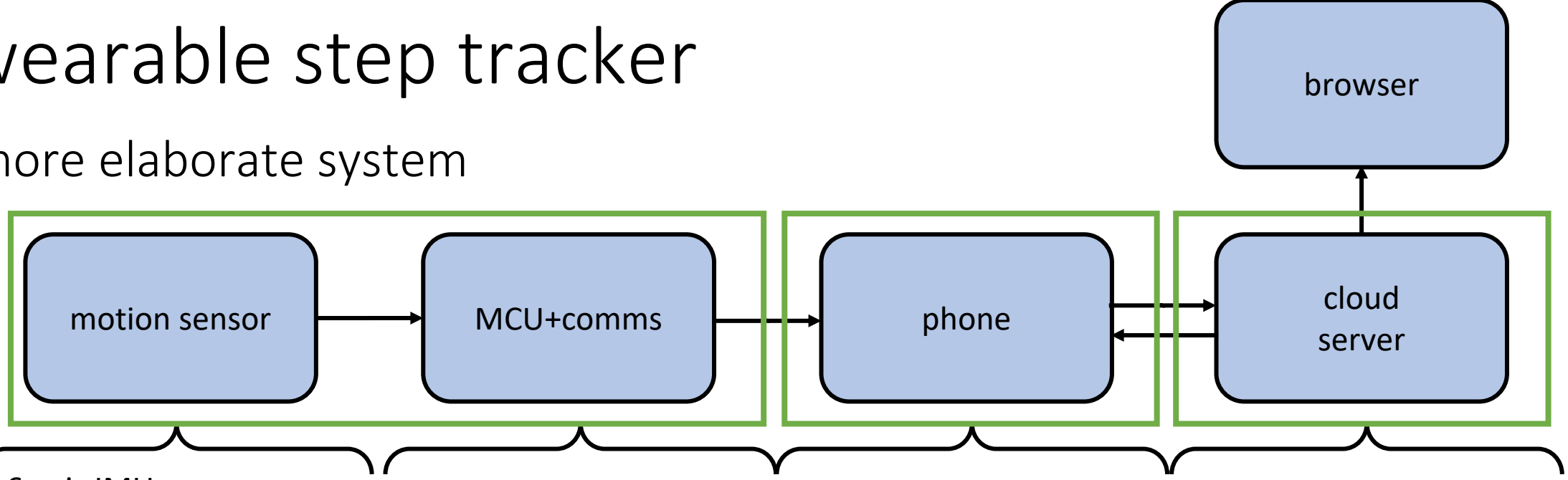
ESP32C3 w/ BLE module
$1.06 @ 1k

- DL algorithm run on phone
- phone of course has display
- can improve algorithms over time via phone connection to cloud server
- can potentially update firmware OTA

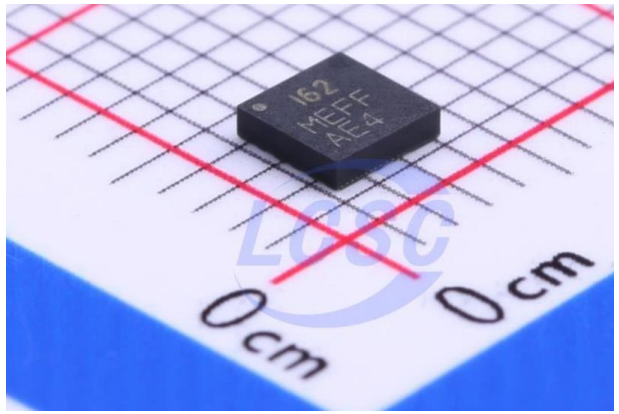
More functionality
Maybe more accuracy
Similar cost
Reduced privacy

A wearable step tracker

- A more elaborate system



6-axis IMU
Invensense ICM-20602
$2.40 @ 1k
digital output, etc.



ESP32C3 w/ BLE module
$1.06 @ 1k

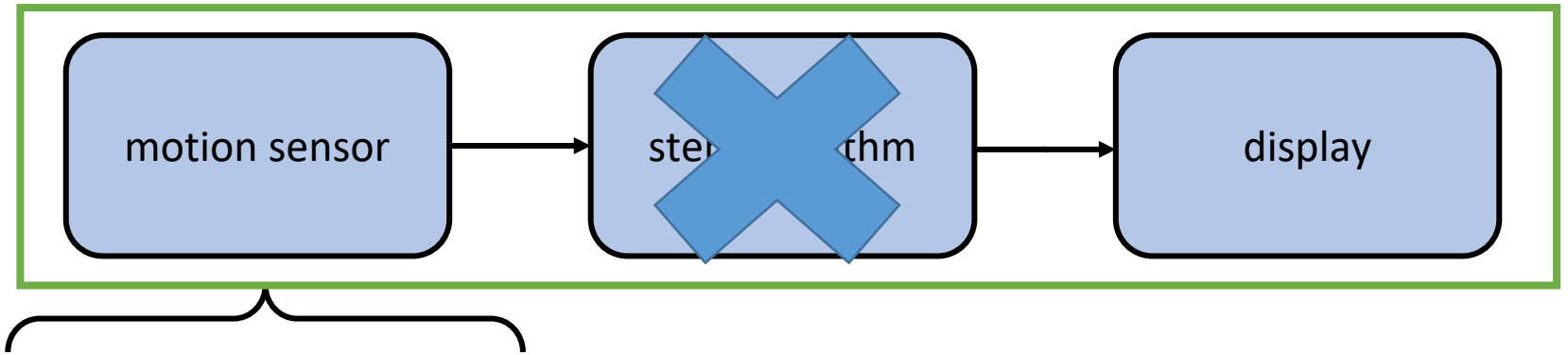
- phone as gateway
- step counter on phone
- phone has display

- can serve data to multiple devices
- can improve our company's algorithms

Even more functionality
Even more accuracy
Higher cost
Lowest privacy
Now need to develop FW, app, server

A wearable step tracker

- Other options exist…



6-axis IMU
STMicro LSM6DSO32TR
$3.44 @ 1k
integrated step counter

can even get fancier parts (more $) with ML algorithms, integrated MCU, etc.

Change in sensor (HW) ➔ can affect choice of compute (FW), communications, and so on

Closing thoughts

- Here we’re playing a bit, jumping in at the middle of the process
- Next week we’ll start more formally down the HW/SW design pathway
- Thursday we’ll talk in detail about the project
- Friday is our first lab!