

Activity Sensing

CS 347

Andrew Head & **Danaé Metaxa**

Danaé Metaxa

Assistant Professor

Penn HCI

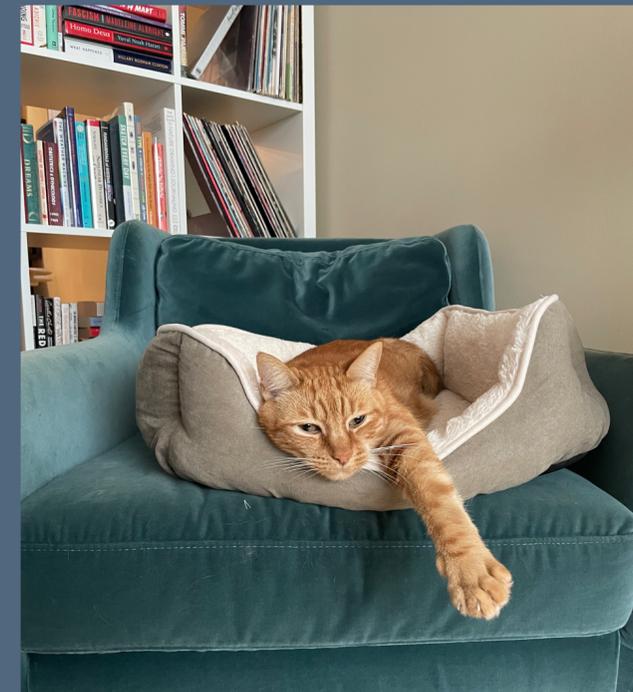
Office hours: on request



Carl P. Metaxa

Penn HCI Mascot

Office hours: none



Announcements

We expect class permissions to be finalized by EOD Friday.

Only one reading for Tuesday — *long but crucial!*

First quiz is also Tuesday

Very beginning of lecture — come **on time**, bring a **pencil/pen**

Covers material in lectures and readings through today

Example quiz will be sent out on Canvas

Message us on Ed with questions or requests

Don't email just me!

(Corollary: Apologies if you've gotten lost in my inbox!)

Feedback from your TA

The main issue I'm seeing in today's reading responses is a lack of examples to support claims. If a specific point, claim, or critique is mentioned about a text and it's not immediately apparent how it connects to the text, follow it up with an example.

For example, for the claim, “[something] can introduce privacy risks if personal health information that was meant to be private is exposed...”, leaves me wondering what kind of privacy risks?

A follow-up example could be: "For example, after the 2022 decision on federal abortion rights, law enforcement proposed subpoenaing period tracking app companies for private reproductive health data to use as evidence in criminal cases."

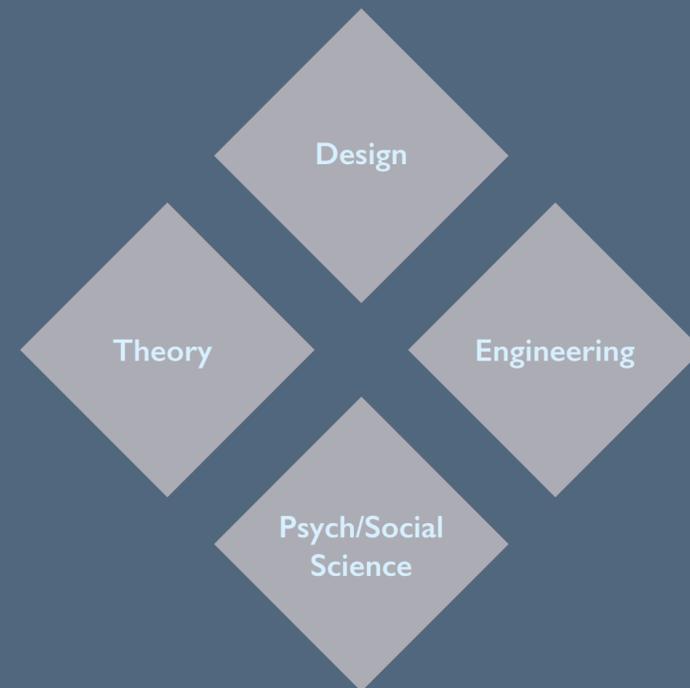
Last time

Ubiquitous computing input and output

The typical ubicomp sensing and recognition pipeline

Nontraditional display technologies, augmented reality, virtual reality

HCI interdisciplinarity



Today

Ubicomp envisioning technology in support of our long-term goals

- via commodity sensing

- via infrastructure-mediated sensing

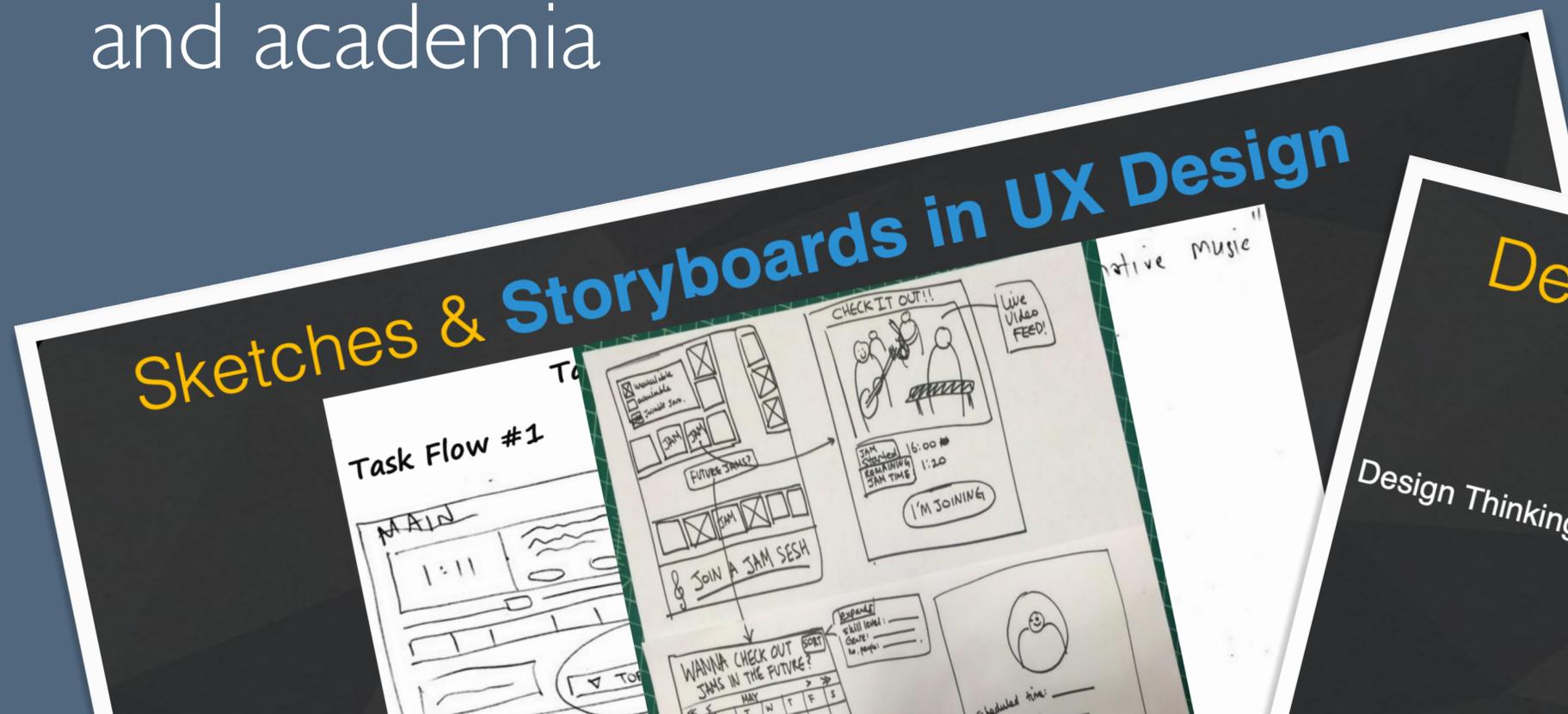
But what do we do about privacy?

- Contextual integrity

HCI 101: tasks and usability

The traditional frame of human-centered design has focused on improving **usability** for well-defined **tasks**, especially tasks of short duration and focused attention

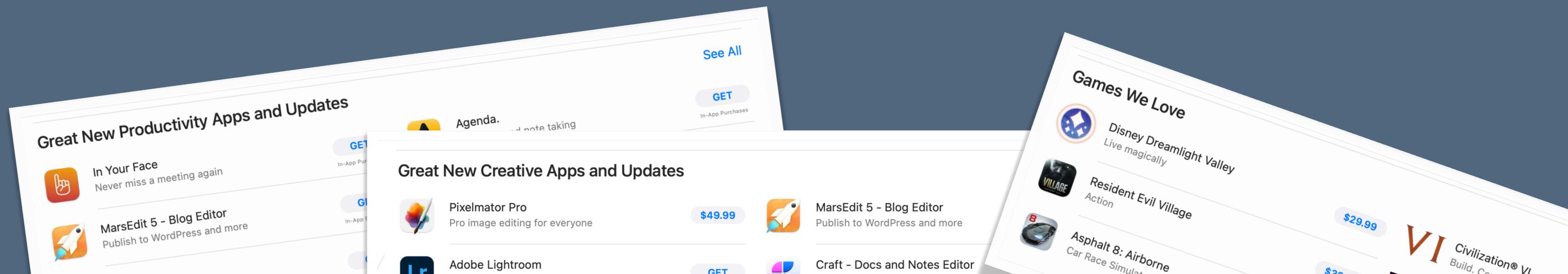
Result: HCI, UI design, usability are now commonplace in industry and academia



HCI 101: tasks and usability

But, this success has come **at a cost**: a focus on interaction design and usability that is not backgrounded as per ubiquitous computing, but **apps at the forefront** of our attention

This is a **legitimacy trap**: what we used to argue for the importance and legitimacy of HCI—task-based usability—is now holding us back [Dourish 2019]



Ubiquitous computing's response: “Nah”

This reductive view of interaction as app-ification is limiting

As technology diffuses into all aspects of our lives, its biggest impact may be not on short-lived tasks on screens, but in **issues of much greater societal importance**—education, health, sustainability—
and **issues facing a wider cross-section of the population**

This position entails a lens on what a design might encompass—
what is/isn't in scope—far beyond typical app bounds

Beyond apps

Once we expand the design lens, bigger social challenges come into scope:

- Health
- Sustainability
- Education

Behavior change and HCI

Many of the goals in today's lecture fit under the heading of **behavior change**: designs that shape what we do and when

Change in behavior usually requires new interface design:

“If I only knew how much I was doing, I'd stop.”

“If only I got a reminder at the right time...”

“If only I could know if my health were at risk...”



Where to focus?

Identify a long-lived activity or **resilient societal challenge**

Ask whether computing can help produce the data or intervention necessary to move the needle in a meaningful way

The answer may be “no”!

But sometimes it's



“Yes!”

Commodity sensing:
repurposing existing
hardware

Typical recipe: unobtrusive and commodity

“Can we **unobtrusively detect** _____ using **commodity smartphones**?”

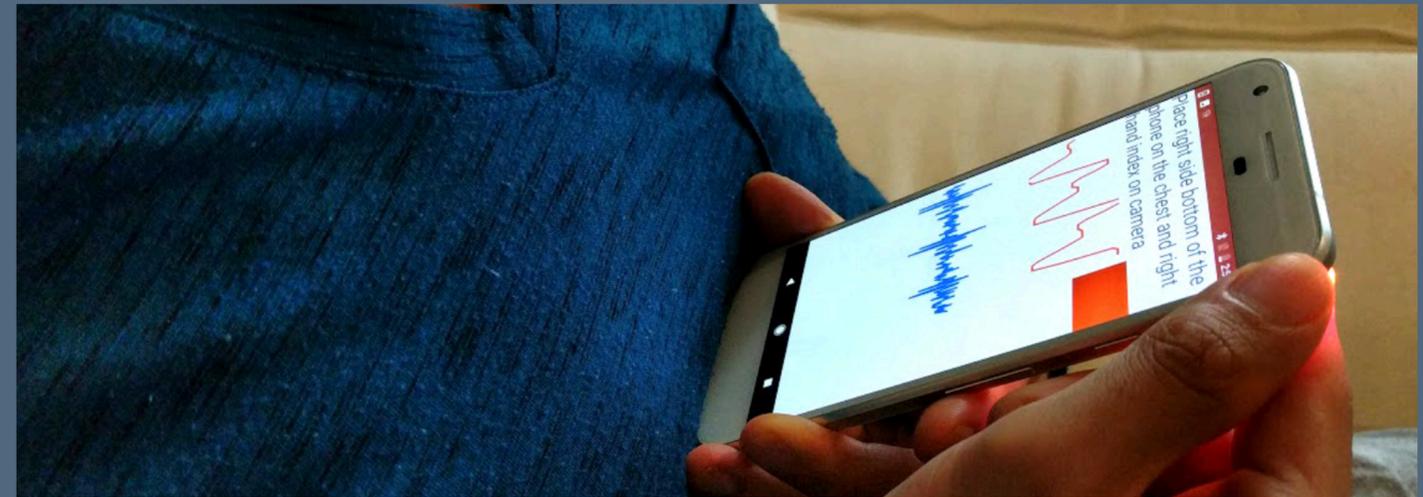
Unobtrusive: without much active user participation

Commodity: widely available and mass produced

Using a similar recognition pipeline as the previous input lecture

...and potentially using novel sensors that could feasibly be integrated into a smartphone or smartwatch in the future

Physical health



Can we monitor blood pressure using commodity smartphones? [Wang et al. 2018a]

Yes: measure the time between the heart pumping (via phone accelerometer) and the blood moving in an artery in your finger (via phone camera with flashlight on)

Can we detect opioid overdose with commodity smartphones? [Nandakumar, Goldakota, Sunshine 2019]

Yes: emit an inaudible frequency sweep (FMCW) to detect breathing cessation. It bounces off the person and returns to the phone's mic. The chest movement modulates the time to return, derive a breathing rate

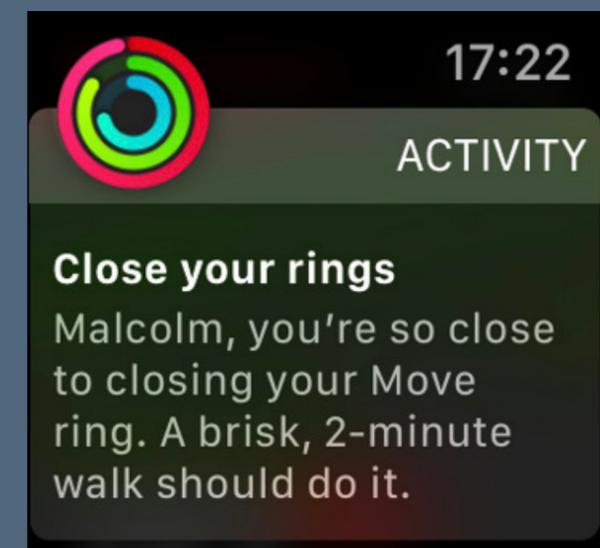
Physical health

Ubifit [Consolvo et al. 2008]: the first system to show that exercise interventions could work with commodity sensors and readily-available glanceable interfaces over long periods

Possible frontiers (not yet deployed):

Detect when someone is eating, using inertial measurements on a smartwatch [Thomaz, Essa, Abowd 2015]

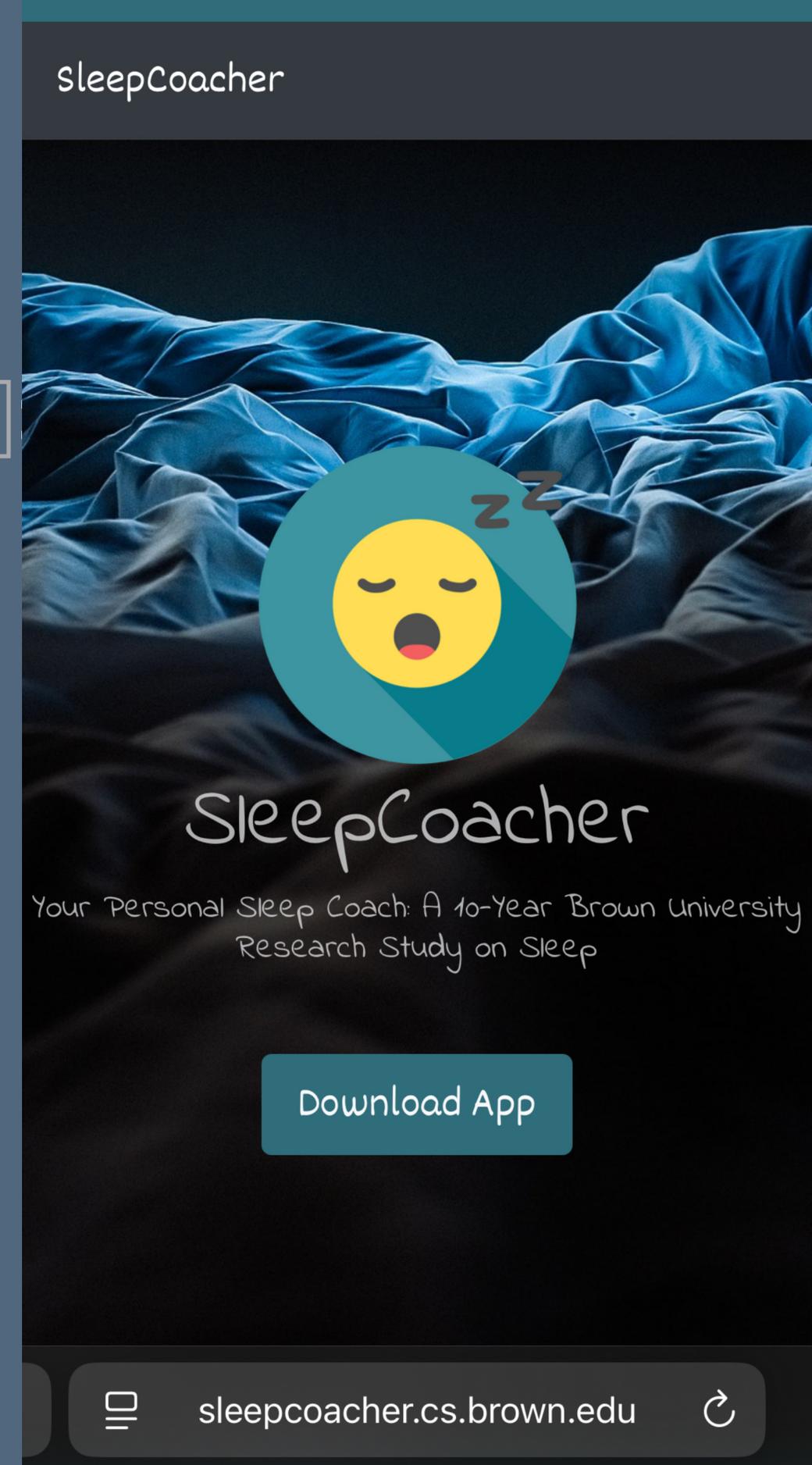
Data-driven answers to: Do I gain/lose weight when I have busy days? Do I walk less when I work from home? Do I sleep better after I work out? [Bentley et al. 2013]



Sleep

SleepCoacher [Daskalova, (Metaxa), et al. 1016] system for users to conduct self-experiments

- User keeps sleep diary, device senses sleep quality
- ML predicts interventions, clinicians review
- User decides what experiment to run on themselves, system detects efficacy over time



Mental health

Stress: can we detect stress levels by listening to your voice [Lu et al. 2012], or by how tightly you're gripping the mouse+keyboard at a computer [Hernandez et al. 2014] or your steering wheel in your car? [Paredes et al. 2018]

Depression: Can we detect depression symptoms using commodity smartphones? [Wang et al. 2018b, Xu et al. 2019] Loneliness and social isolation? [Doryab et al. 2019]

Mental changes: Can we detect mental health changes such as psychotic relapse before they're typically diagnosed? [Ben-Zeev 2017; Wang et al. 2016]

Elder care

How might we design technologies to support successful aging in place? [Kidd et al. 1999]

Can we detect...

Falls, without smartwatches? [Palipana et al. 2018]

Levels of movement and activity in the home? [Deen 2015]

The answer to all of these questions is now a (qualified) yes.

**Infrastructure-mediated
sensing: add purpose-built
sensors to the environment**

Typical recipe, part deux

“Can we **unobtrusively detect** _____ using **a sensor in the environment?**”

Goal: avoid needing to instrument *people* in any way (unobtrusive)

Again using a machine learning classification pipeline

Typically, we achieve this by leveraging infrastructure *already available* in the environment. This is referred to as **infrastructure-mediated sensing** [Patel et al. 2008].

Sustainability

One major challenge is knowing where my energy and power is going: **which appliances and activities are driving most of my consumption?**

If we knew that, we could identify ways to reduce our energy or water use.

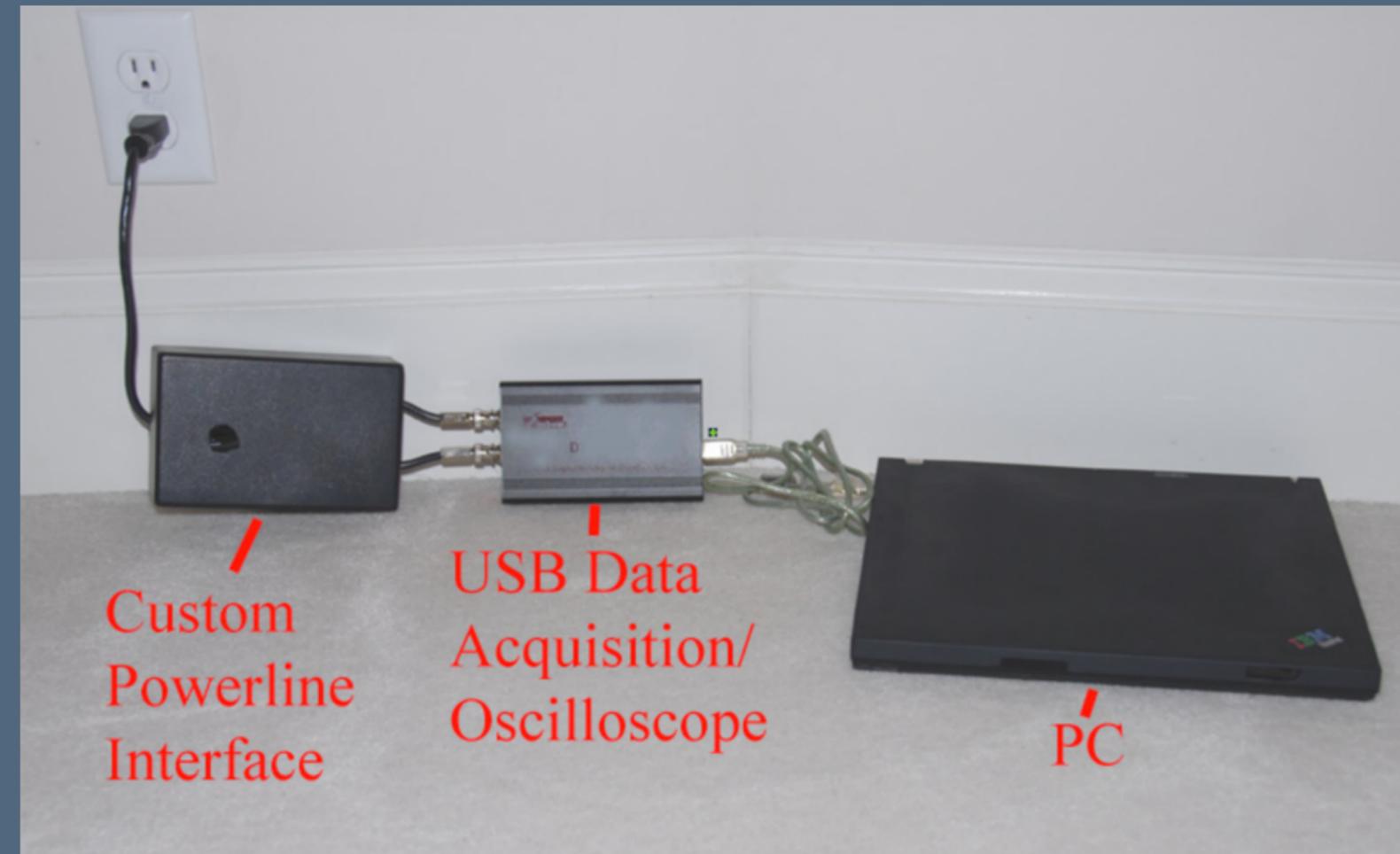
But we can't go around fitting every socket with a sensor...

Disaggregating electrical use

[Patel et al. 2007]

Can we track appliance usage without complex installation or many invasive sensors?

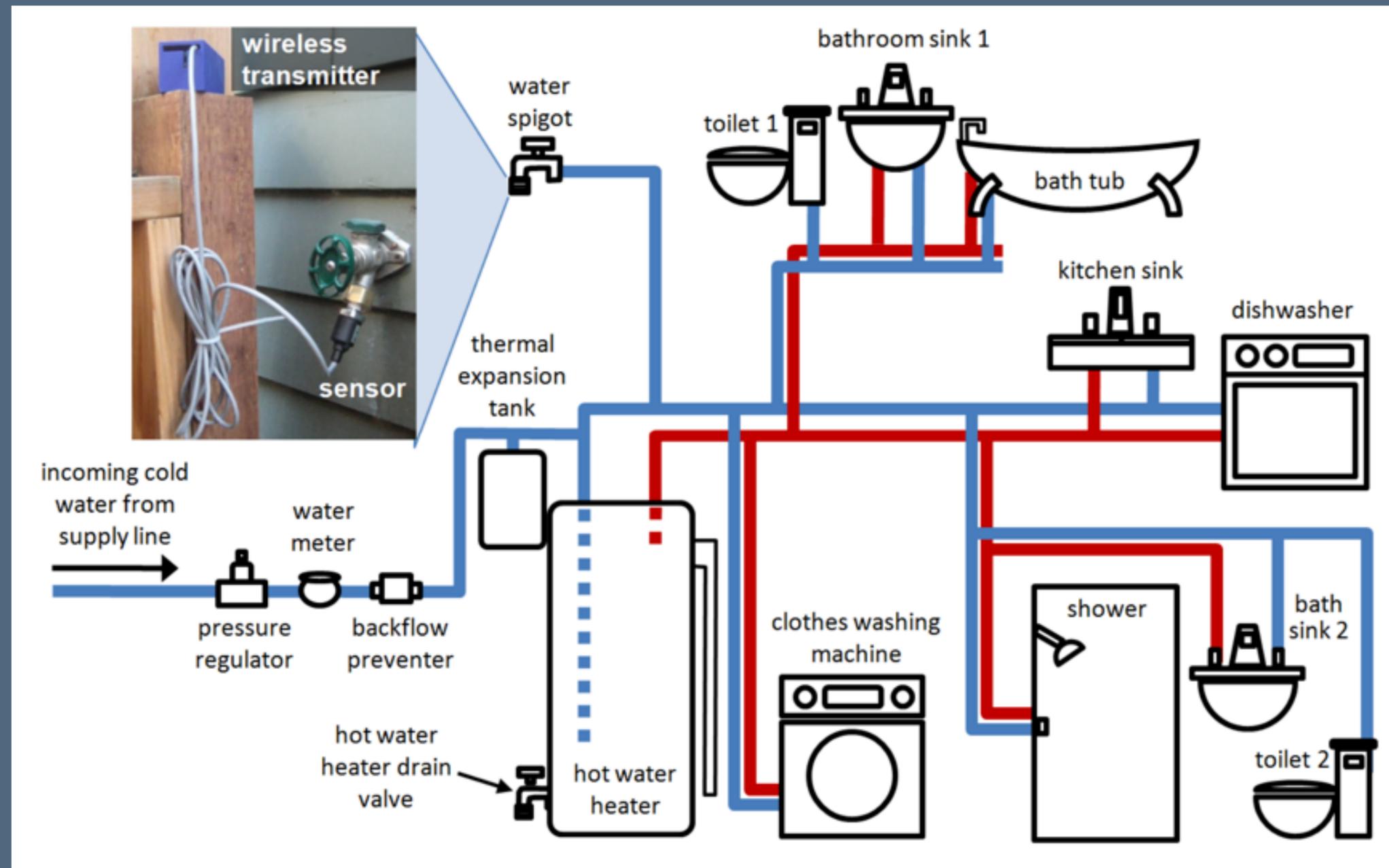
Plug a sensor into a single plug in your home and listen to electrical noise on the power line when switched or in operation

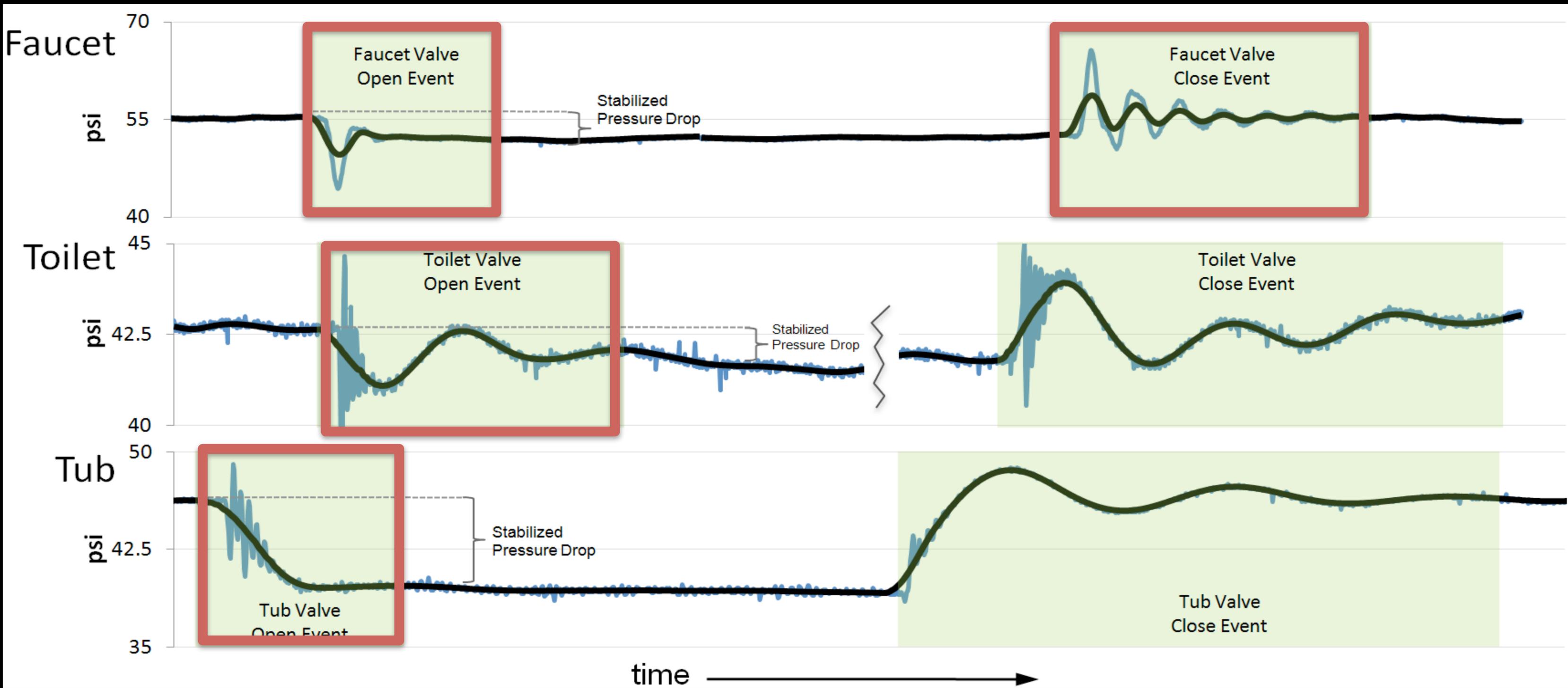


Disaggregating water use

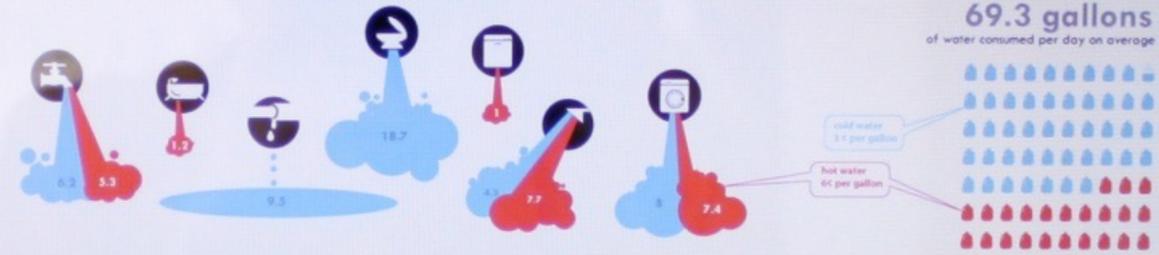
[Froehlich et al. 2009]

A single pressure sensor attached to a hose outdoor faucet
Since your water pipes are typically all connected, that one sensor can see a lot...





Daily average consumption by fixture for the month of May



Weekly consumption pattern for the month of May

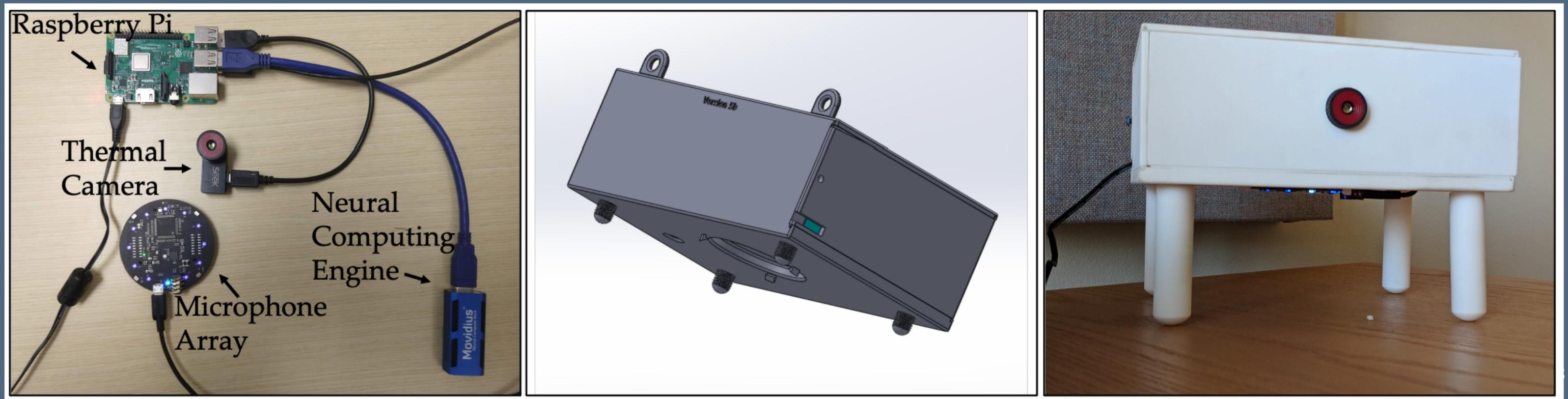


Public health (local flu sensing)

Can ubiquitous computing technologies help us track group or population-level health?

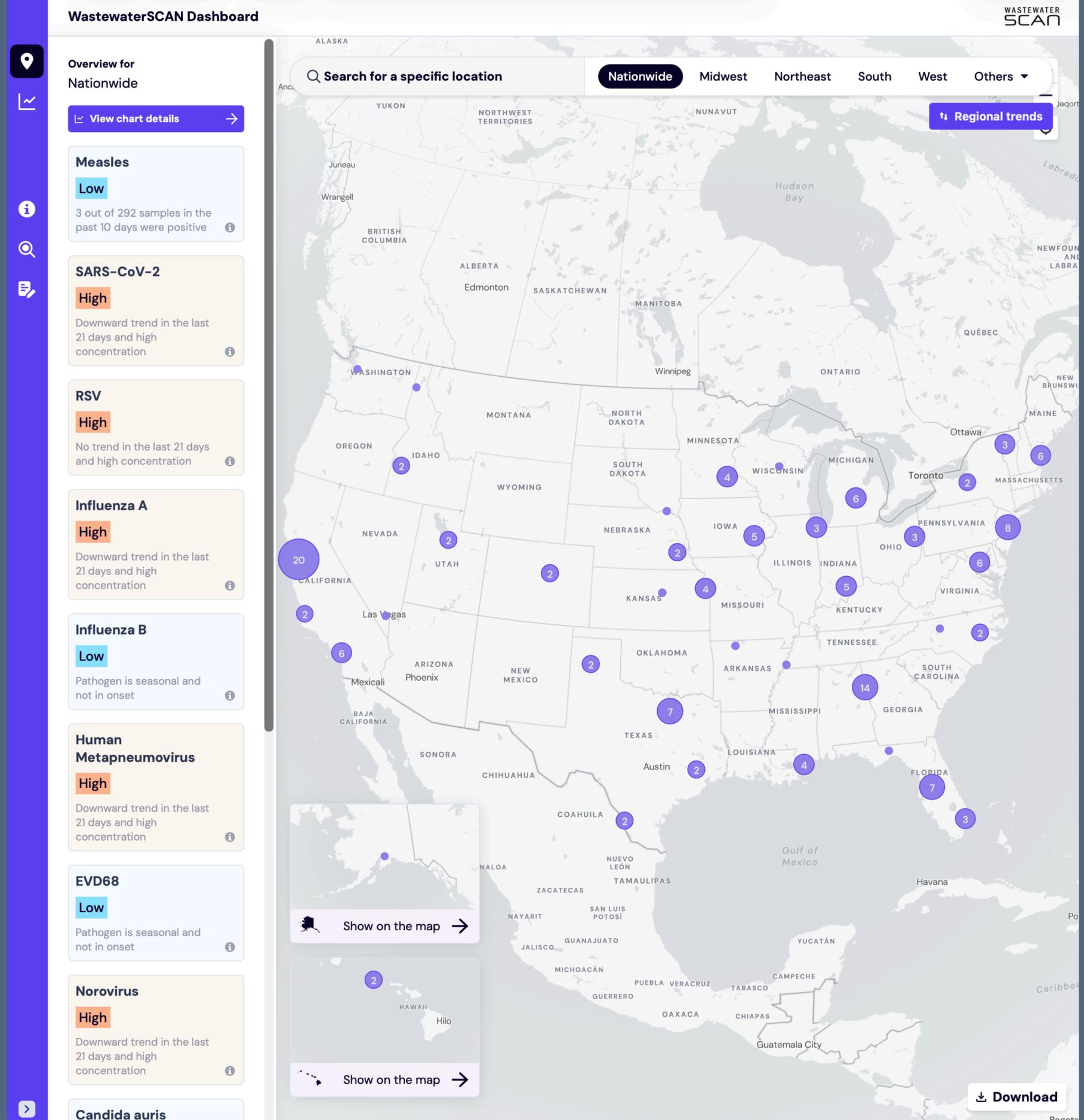
e.g., deploy a passive sensing box in clinic waiting areas

[Al Hossain et al. 2020]



Public health (population-scale illness)

WastewaterSCAN: test
samples from treatment
facilities around the country
to estimate population-level
rates of illness in real time
[Boehm et al. 2024]



WastewaterSCAN Regional Overview

Data for last 12 months 01/21/2025 - 01/21/2026 (365 days)

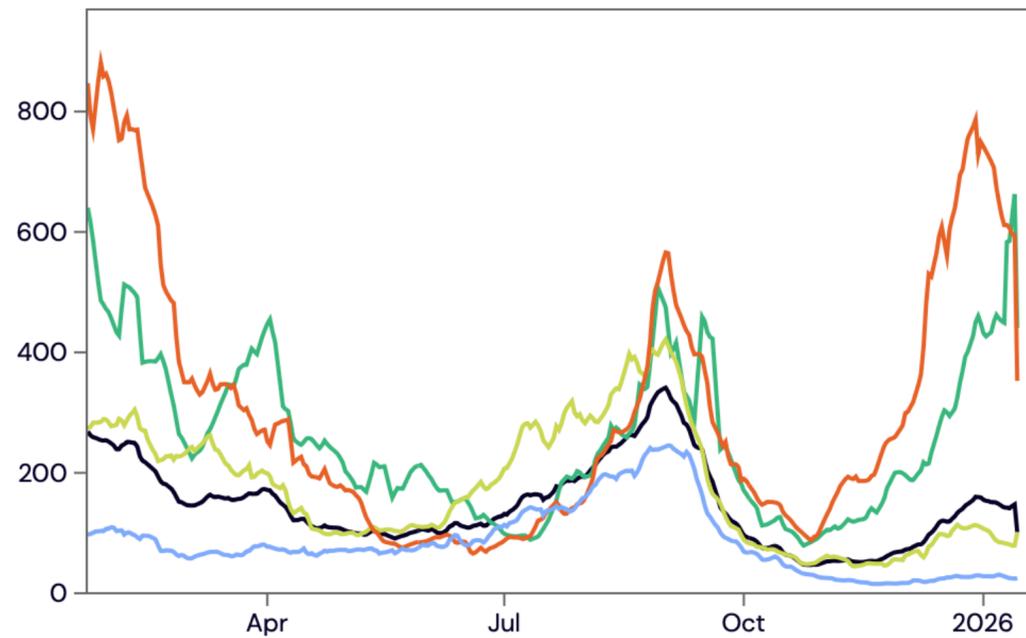
Last 12 months ▼

● National ● Northeast ● South ● Midwest ● West

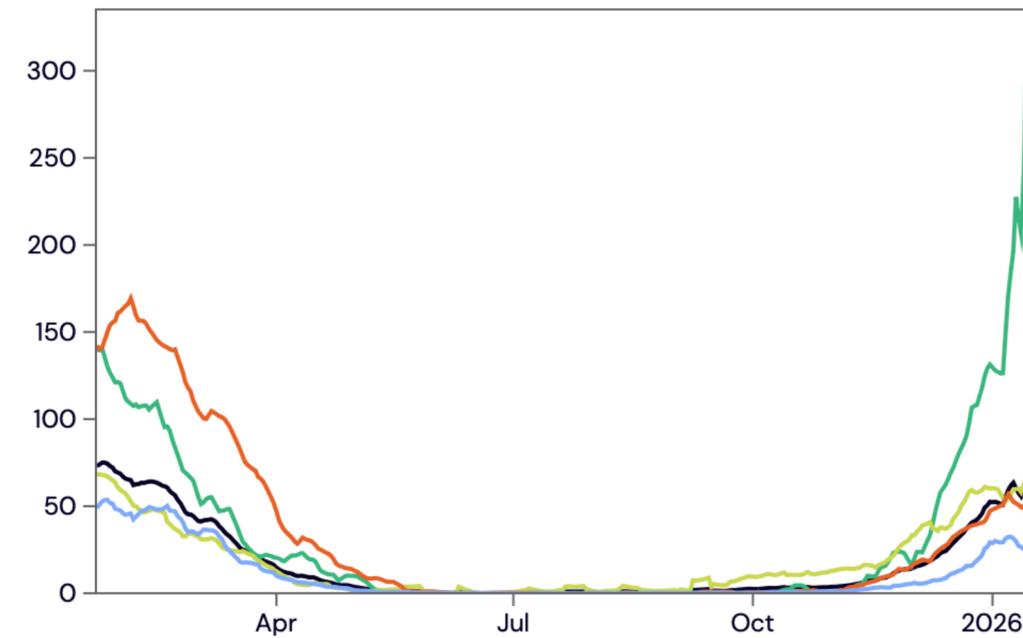
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All charts show quantity of nucleic-acids, PMMoV Normalized (x1 million)

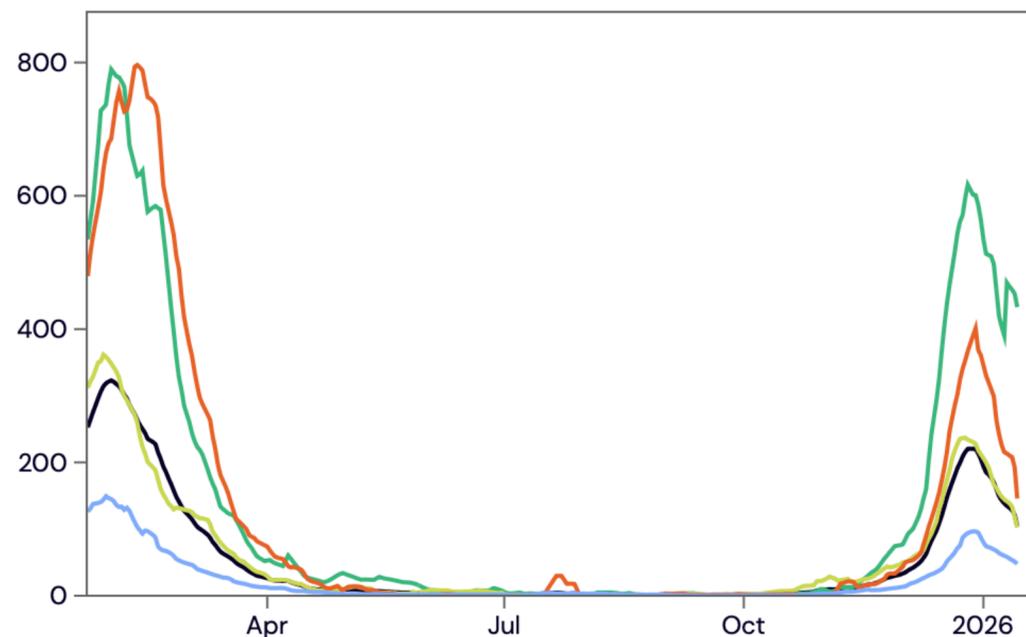
SARS-CoV-2



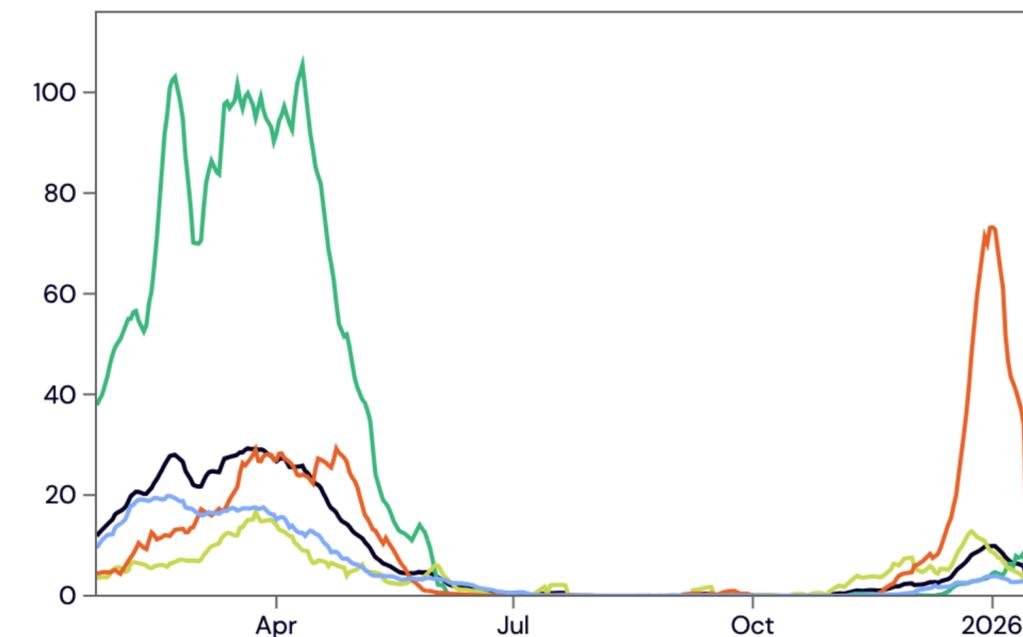
RSV



Influenza A



Influenza B



Human Metapneumovirus



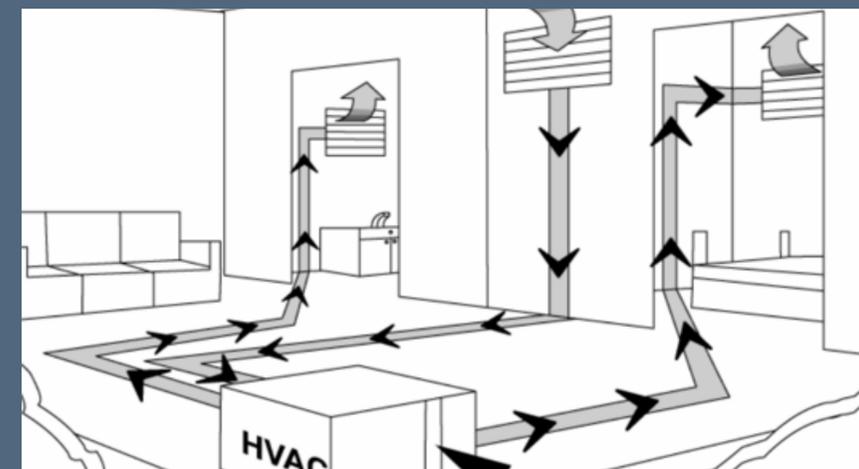
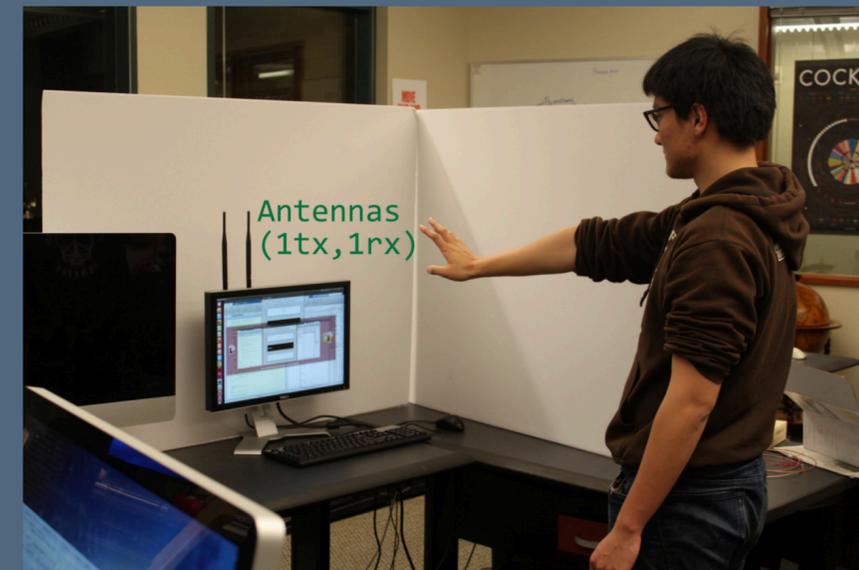
EVD68



Infrastructure-mediated sensing as input source

Your house is already blanketed in wifi: we can detect tiny Doppler shifts and multi-path distortions in wifi reflectance as you move [Pu et al. 2013]

As you walk through doorways in your house, you cause momentary pressure changes in your HVAC system, enabling a recognition of where you likely are [Patel, Reynolds, and Aboud 2008]



**Privacy and contextual
integrity**

Let's unpack this response to a ubicomp deployment

MIT Technology Review

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SMART CITIES

Computer scientists designing the future can't agree on what privacy means

Researchers at Carnegie Mellon University wanted to create a privacy-preserving smart sensor. Then, they were accused of violating their colleagues' privacy.

By Eileen Guo & Tate Ryan-Mosley



<https://www.technologyreview.com/2023/04/03/1070665/cmu-university-privacy-battle-smart-building-sensors-mites/>

“The overall goal of this project,” Agarwal explained at an April 2021 town hall meeting, is to “build a safe, secure, and easy-to-use IoT [Internet of Things] infrastructure,” referring to a network of sensor-equipped physical objects like smart light bulbs, thermostats, and TVs that can connect to the internet and share information wirelessly.

The researchers also believe that in the long term, Mites—and building sensors more generally—are key to environmental sustainability. They see other, more ambitious use cases too. A university write-up describes this scenario: In 2050, a woman starts experiencing memory loss. Her doctor suggests installing Mites around her home to “connect to ... smart speakers and tell her when her laundry is done and when she’s left the oven on” or to evaluate her sleep by noting the sound of sheets ruffling or nighttime trips to the bathroom. “They are helpful to Emily, but even more helpful to her doctor,” the article claims.

Not everyone was pleased to find the building full of Mites. Some in the department felt that the project violated their privacy rather than protected it. In particular, students and faculty whose research focused more on the social impacts of technology felt that the device’s microphone, infrared sensor, thermometer, and six other sensors, which together could at least sense when a space was occupied, would subject them to experimental surveillance without their consent.

But the Mites weren’t actually recording any video. And any audio captured by the microphones was scrambled so that it could not be reconstructed.

For some who were unhappy, exactly what data the sensors were *currently* capturing was beside the point. It didn’t matter that the project was not yet fully operational. Instead, the concern was that sensors more powerful than anything previously available had been installed in offices without consent. Sure, the Mites were not collecting data at that moment. But at some date still unspecified by the researchers, they could be. And those affected might not get a say.

Are these tools ethical to deploy?

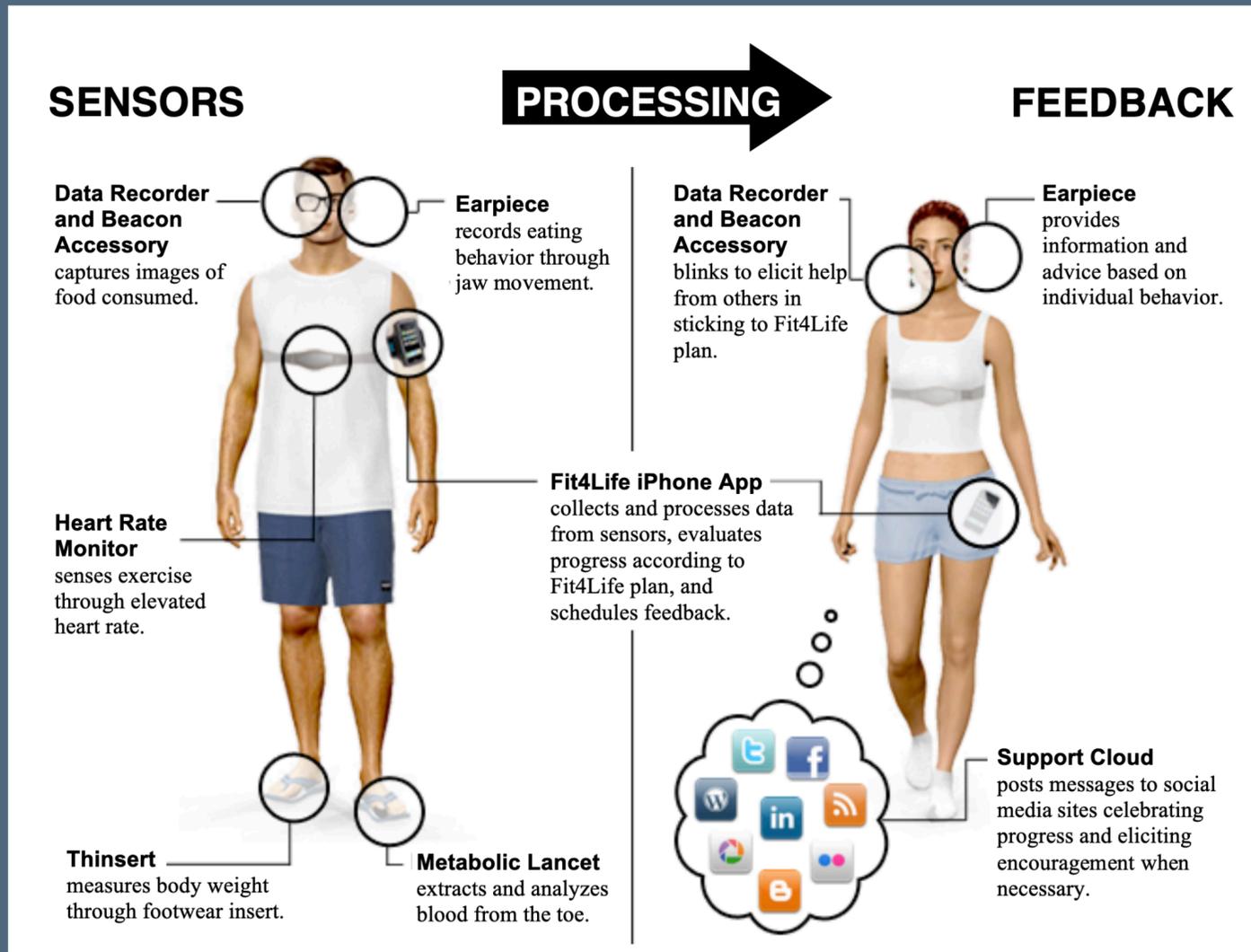
By whom?

With or without consent?

Tradeoff: privacy and autonomy,
vs. lack of access to mental
health services



Design fiction [Purpura 2011]



“Dave, the scone you are about to eat probably contains 400 calories. You’ve already consumed 300 calories today. There are 9 hours remaining in your wake period. After eating the scone, you will have consumed 45% of your total nutrition needs for today. You have free time today from Noon to 2 pm. Would you like me to schedule a long run?” [Reduction, Suggestion]

“Dave, you’ve eaten the scone and you didn’t run with me yesterday. I would like to go for a run soon.” [Personalization, Suggestion]

“I’m sorry, Dave, you shouldn’t eat that. Dave, you know I don’t like it when you eat donuts.” [Personalization, Suggestion]

Are these feedback strategies **persuasion** or **coercion**?

Whose idea of fitness is being enacted?

Privacy

Ubiquitous computing naturally raises many questions of how much privacy we are giving up in exchange for its benefits

Behavioral work has documented an empirical **privacy paradox**: people say they care strongly about privacy, but willingly give it up in their technology use in practice [Acquisti 2015]

Providing transparency and control are simply not enough

Traditional privacy notions

- 1) Limiting surveillance of citizens and use of sensitive information about them by government
- 2) Restricting access to private (sensitive, personal) information
- 3) Curtailing intrusions into places (physical spaces) deemed private or personal

Contextual integrity [Nissenbaum 2004]

These notions separate the **private** from the **public**.

My health data is private

My job is public (it's on my website)

My Penn ID card RFID usage (e.g., unlocking doors) is private

But, private vs. public is **not a very useful distinction** for ubicomp

Is it even possible for your Penn RFID card usage to be fully private?

What if my smart watch sells aggregated insights to advertisers?

Can public online art be used for training generative AI?

Contextual integrity [Nissenbaum 2004]

Instead, think of information as being shared within *contexts* that carry specific *norms*—

Norms of appropriateness: What is OK and not OK to reveal in a particular context

e.g., to a doctor, it's OK to reveal medical history, less so to a bank

Norms of distribution: what is OK and not OK to share beyond the original disclosure

e.g., secrets shared with a friend are not ok to pass further; companies use/sell the data you explicitly share with them & that they infer

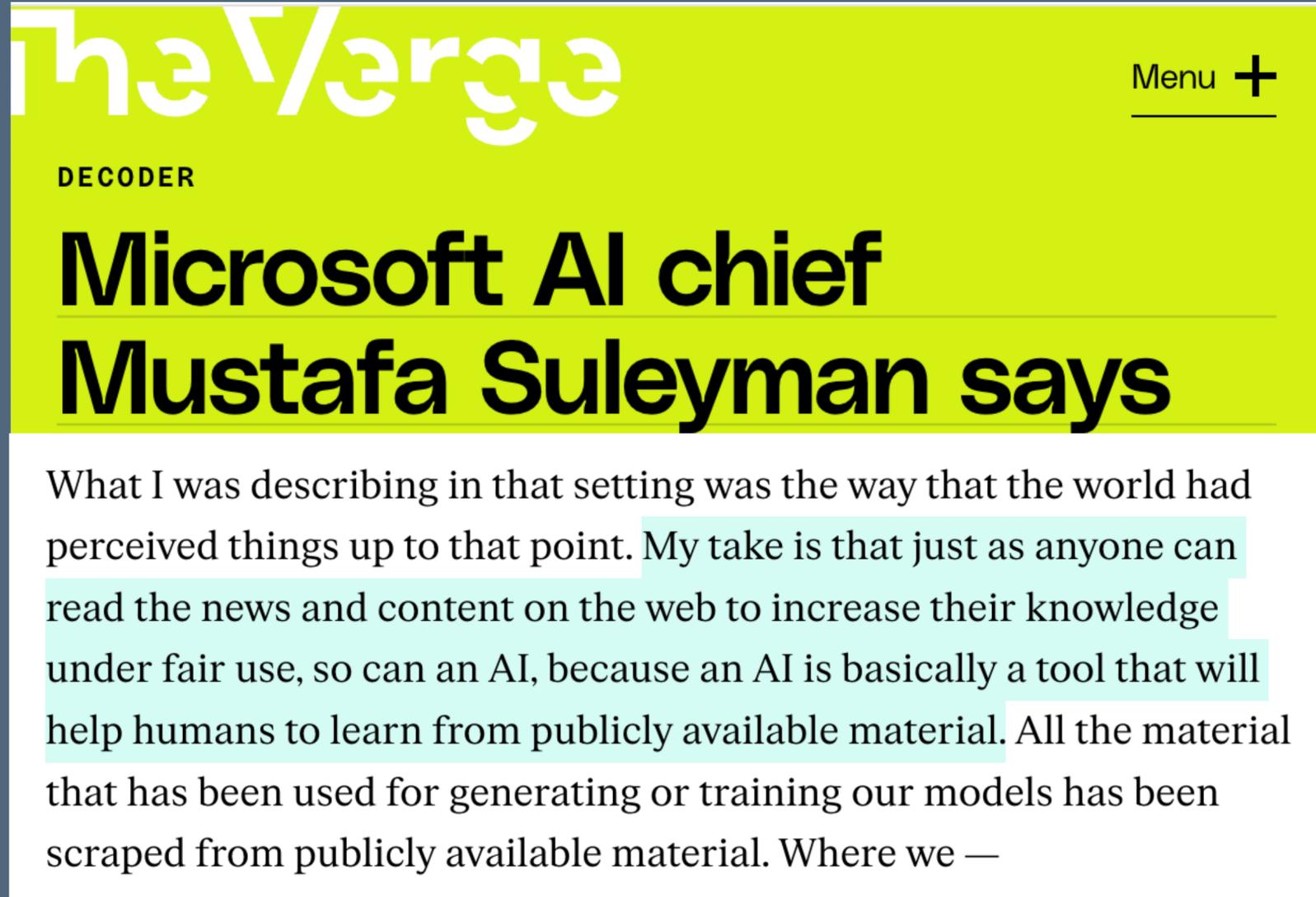
Contextual integrity [Nissenbaum 2004]

Claim: there is a **privacy violation if and only if there is a violation of the norms of appropriateness or norms of flow**

Consequence: “personal information revealed in a particular context is always tagged with that context and never ‘up for grabs’”

Data is never context-free

You (as a researcher) never have universal consent



The Verge

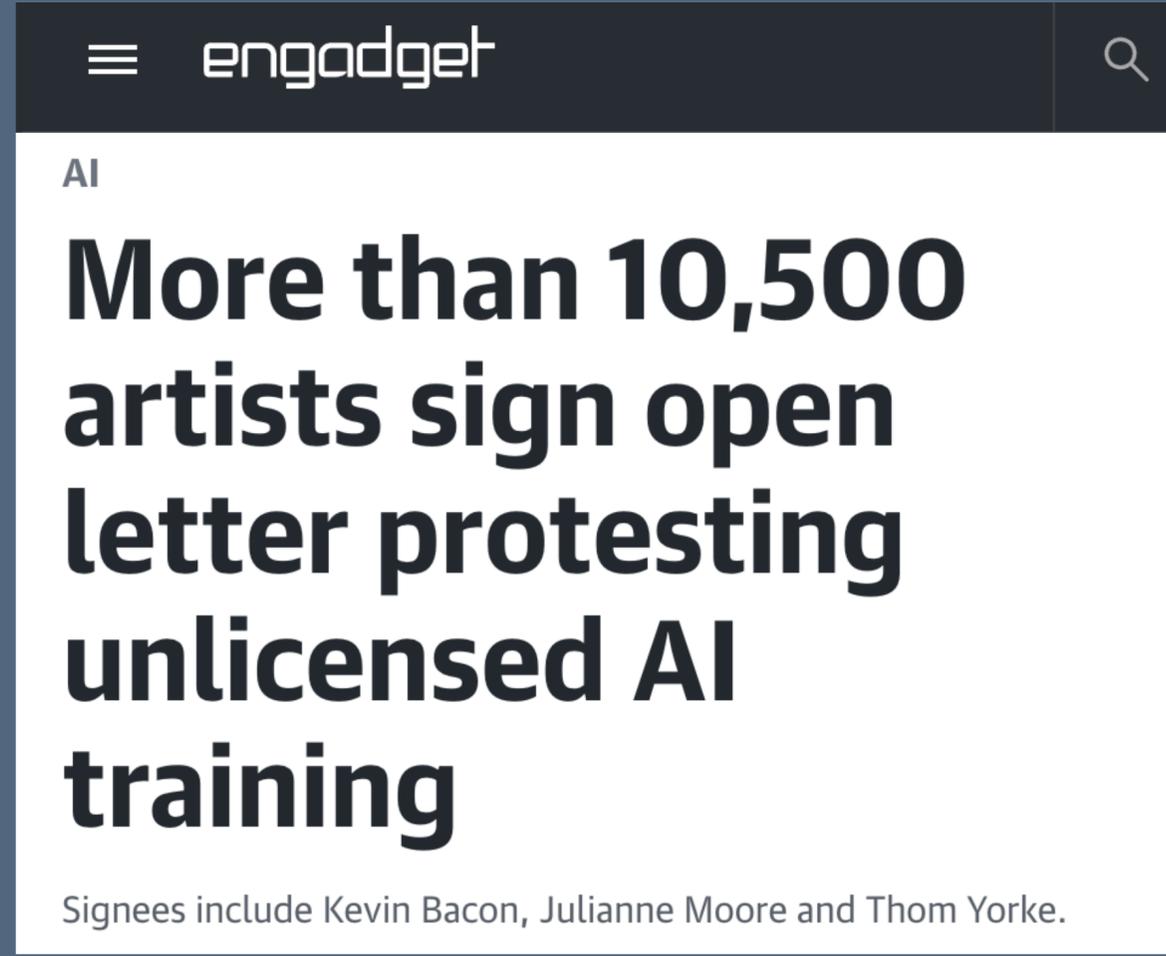
Menu +

DECODER

Microsoft AI chief Mustafa Suleyman says

What I was describing in that setting was the way that the world had perceived things up to that point. My take is that just as anyone can read the news and content on the web to increase their knowledge under fair use, so can an AI, because an AI is basically a tool that will help humans to learn from publicly available material. All the material that has been used for generating or training our models has been scraped from publicly available material. Where we —

VS.



engadget

AI

More than 10,500 artists sign open letter protesting unlicensed AI training

Signees include Kevin Bacon, Julianne Moore and Thom Yorke.

How would contextual integrity explain a source of friction here?

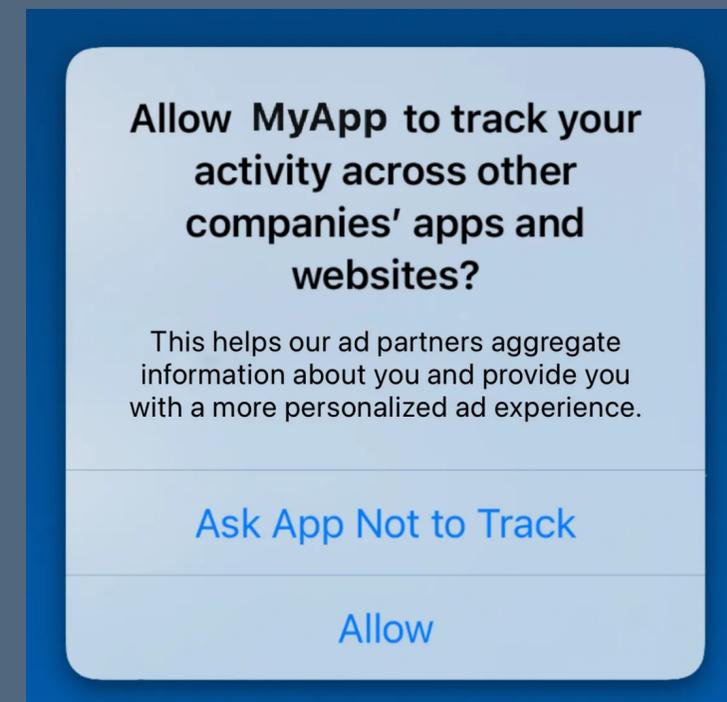
Translating contextual integrity into design

Contextual integrity diagnoses the issue, but doesn't offer many solutions that are readily amenable to design or engineering decisions

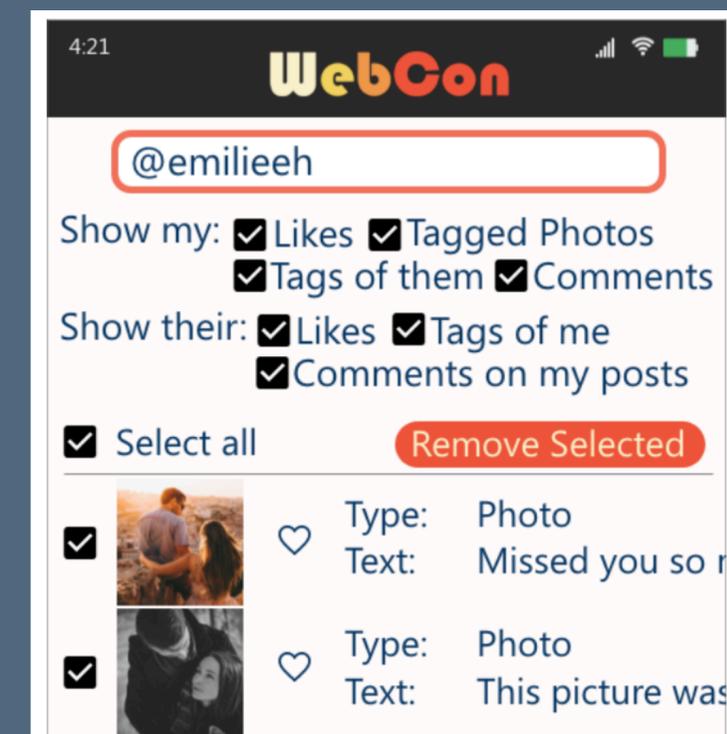
One design pattern is to require explicit opt-in 

Can LLMs become better “contextual integrity machines?” They understand more norms, but will still make mistakes (& are built on a violation!)

[9to5Mac]



[Im et al. 2021]



Summary

Ubicomp seeks to embed itself in **long-lived activities and goals**.

Across a number of domains, including: physical health, mental health and wellbeing, aging

To achieve these goals, it seeks **noninvasive sensing** approaches

Commodity sensing: hardware each person already has or could have

Infrastructure-mediated sensing: single-point sensors that connect to existing infrastructure

Contextual integrity adds insight to the privacy questions by asking what the *norms* of sharing are within the *sphere* the information was shared

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