Welcome!

CIS 7000: Special Topics on Mobile and IoT Sensing

Mingmin Zhao

cis.upenn.edu/~mingminz/courses/cis7000-23f

Lecture 1

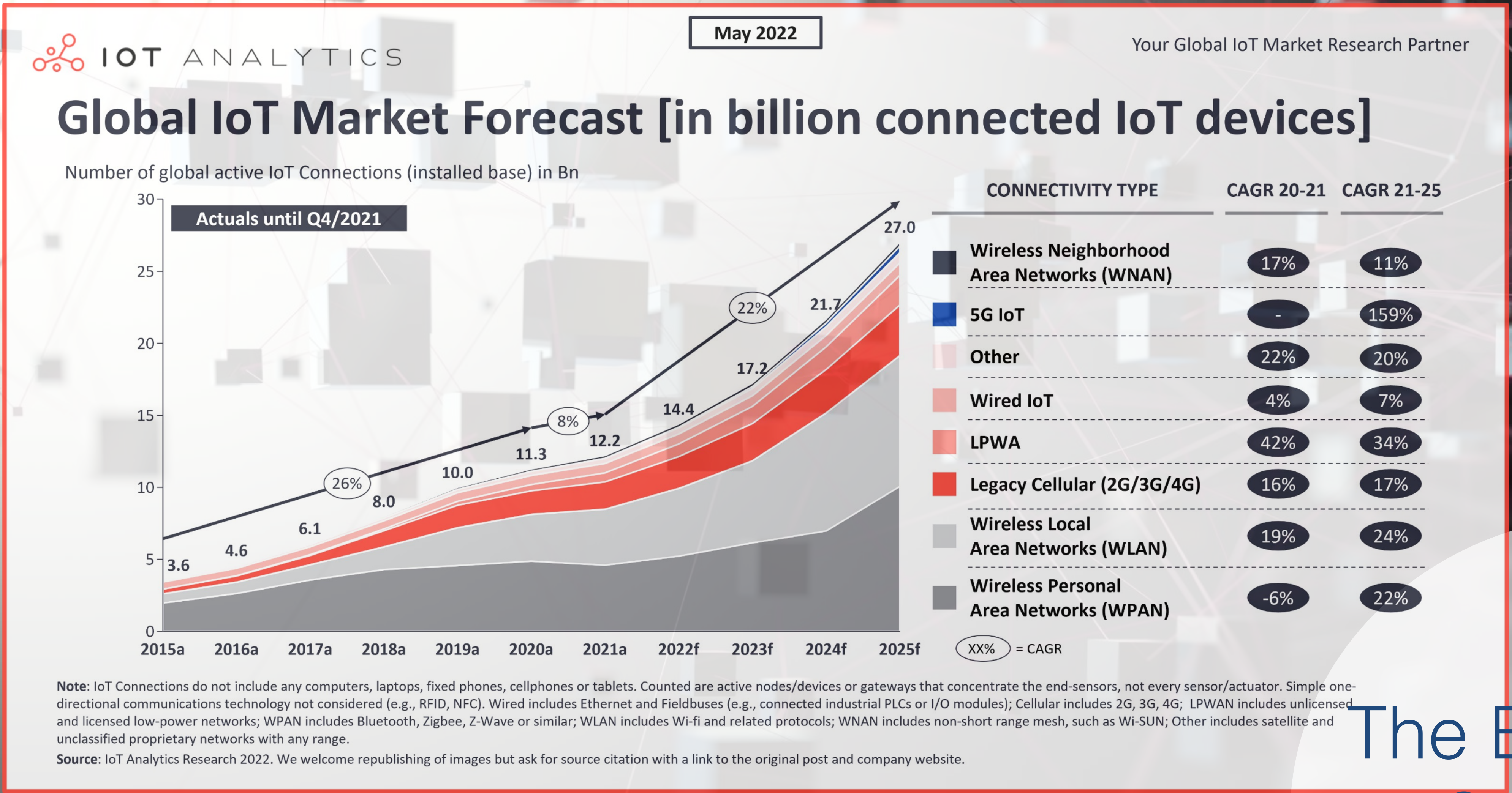
Penn
University of Pennsylvania

Internet of Things

Convergence of micro-sensing, computation, and communication that allows us to:

- *Acquire* (*sense*) data from the environment
- *Pre-process* data locally (on-device / “edge”)
- *Deliver* data to servers (“cloud”)
- *Draw inferences* and *provide insights* about the world from the data:
    - Sensor fusion, data integration
    - Signal processing
    - Machine learning
- *Control* actions in the environment

Focus of this course: how we got to now and how could it transform the future



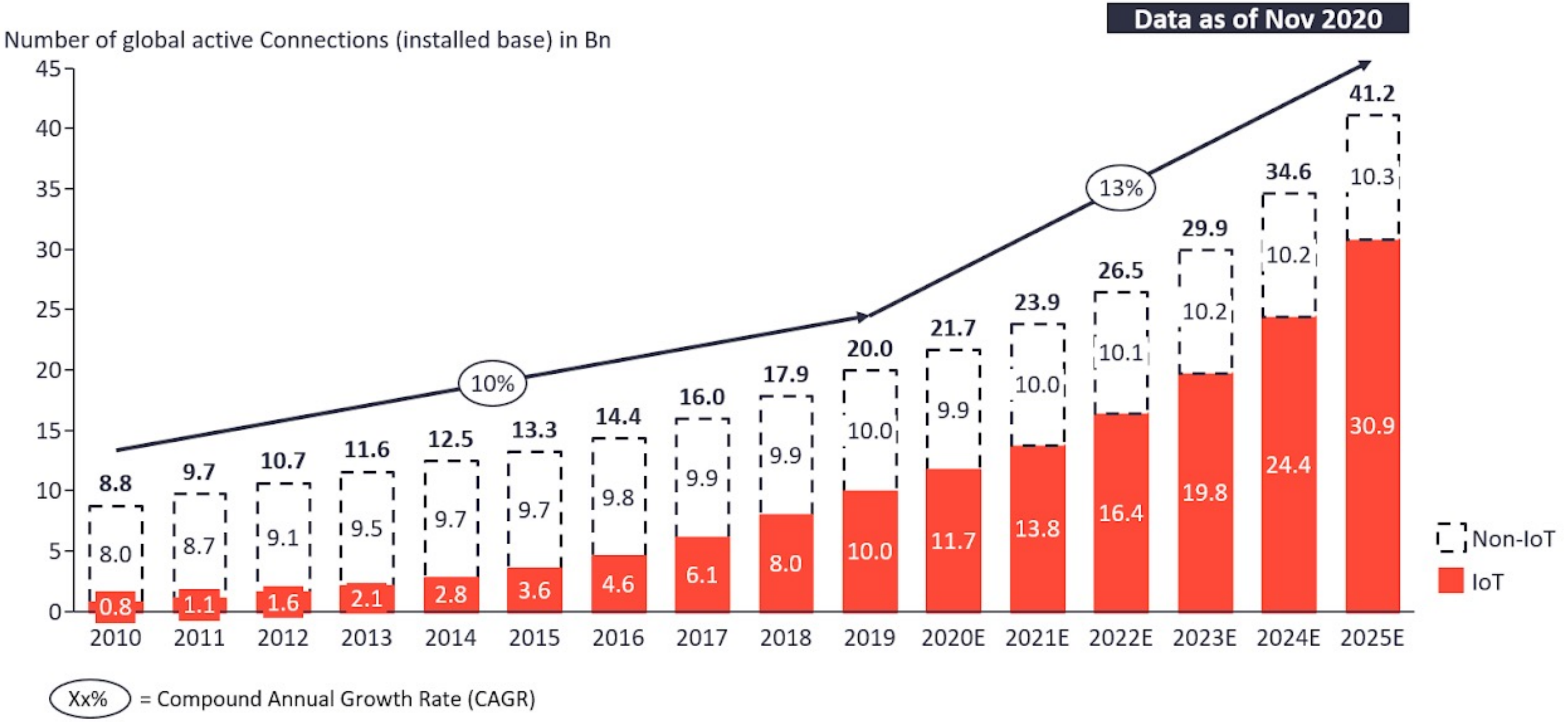
The Explosion of Connected Devices

IOT ANALYTICS

Insights that empower you to understand IoT markets

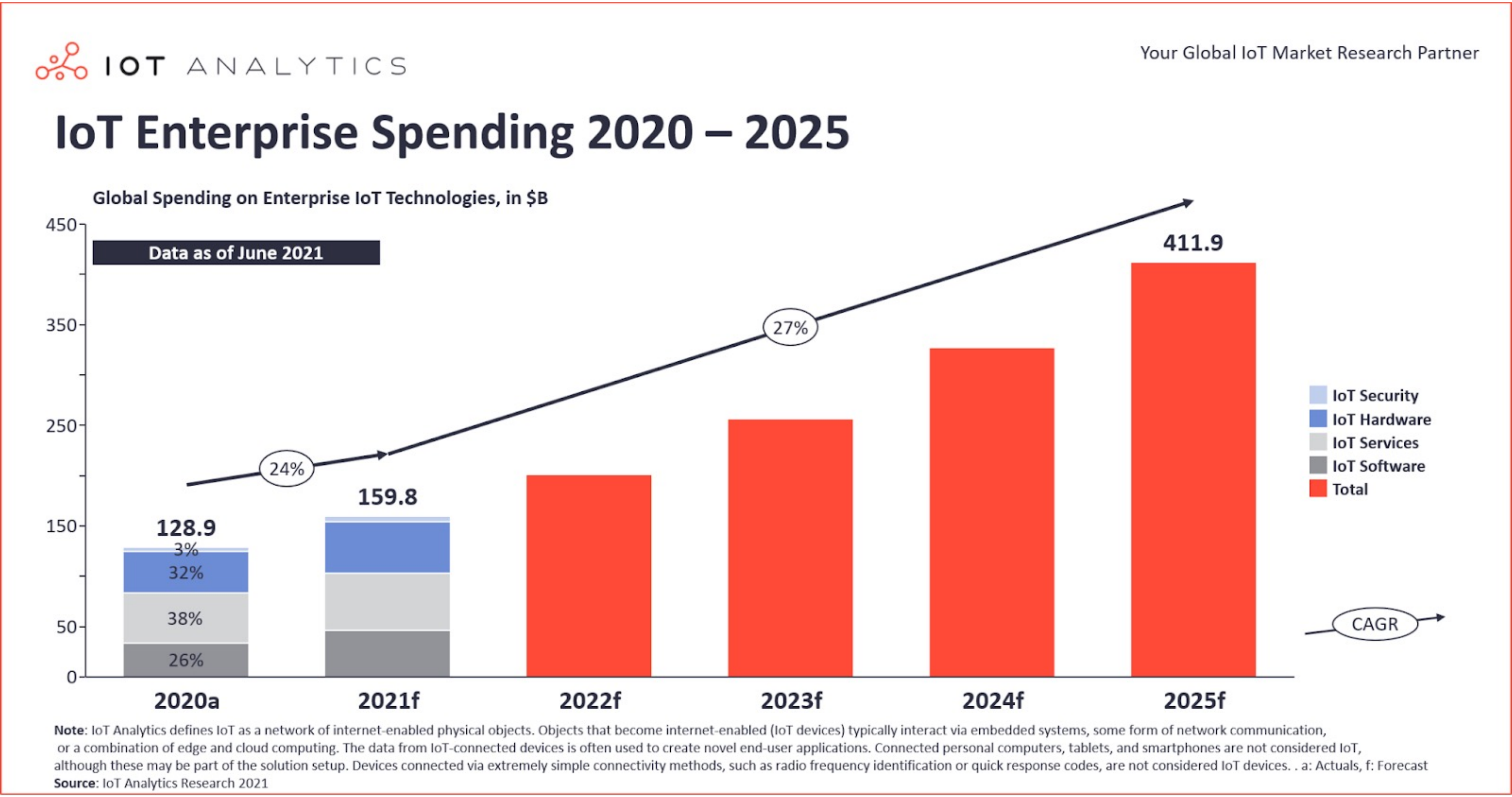
Total number of device connections (incl. Non-IoT)

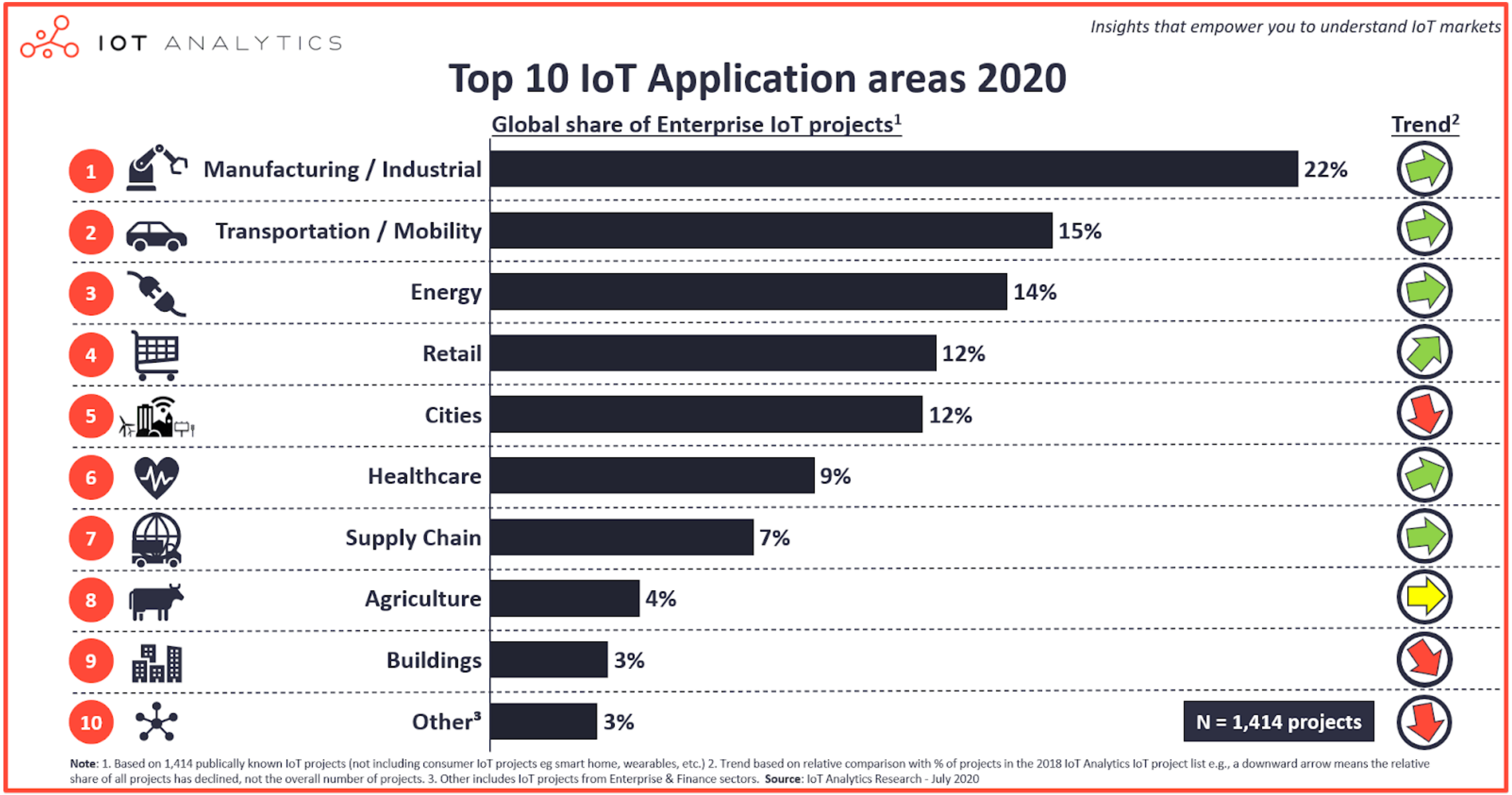
20.0Bn in 2019– expected to grow 13% to 41.2Bn in 2025



Note: Non-IoT includes all mobile phones, tablets, PCs, laptops, and fixed line phones. IoT includes all consumer and B2B devices connected – see IoT break-down for further details

Source(s): IoT Analytics - Cellular IoT & LPWA Connectivity Market Tracker 2010-25


IOT ANALYTICS
Your Global IoT Market Research Partner
IoT Enterprise Spending 2020 – 2025
Global Spending on Enterprise IoT Technologies, in $B
Data as of June 2021
450
350
250
150
50
0
128.9
3%
32%
38%
26%
159.8
411.9
24%
27%
2020a
2021f
2022f
2023f
2024f
2025f
IoT Security
IoT Hardware
IoT Services
IoT Software
Total
CAGR
Note: IoT Analytics defines IoT as a network of internet-enabled physical objects. Objects that become internet-enabled (IoT devices) typically interact via embedded systems, some form of network communication, or a combination of edge and cloud computing. The data from IoT-connected devices is often used to create novel end-user applications. Connected personal computers, tablets, and smartphones are not considered IoT, although these may be part of the solution setup. Devices connected via extremely simple connectivity methods, such as radio frequency identification or quick response codes, are not considered IoT devices. . a: Actuals, f: Forecast
Source: IoT Analytics Research 2021

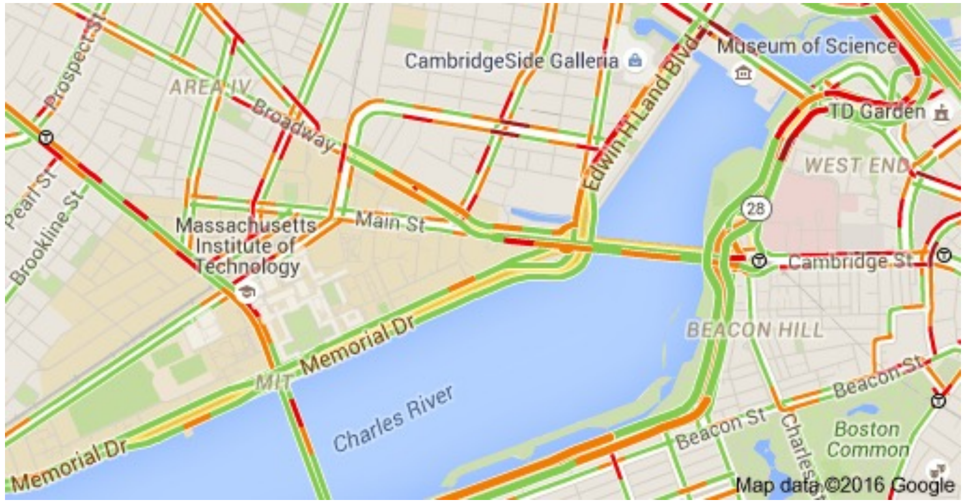


Connected solutions bring increased vehicle uptime for our customers, better safety for drivers, operators and other road users

– *Martin Lundstedt, CEO of the Volvo Group, Oct 2019*

IoT is Transforming Industries

Transportation & Smart Cities



Medicine

Smart Homes

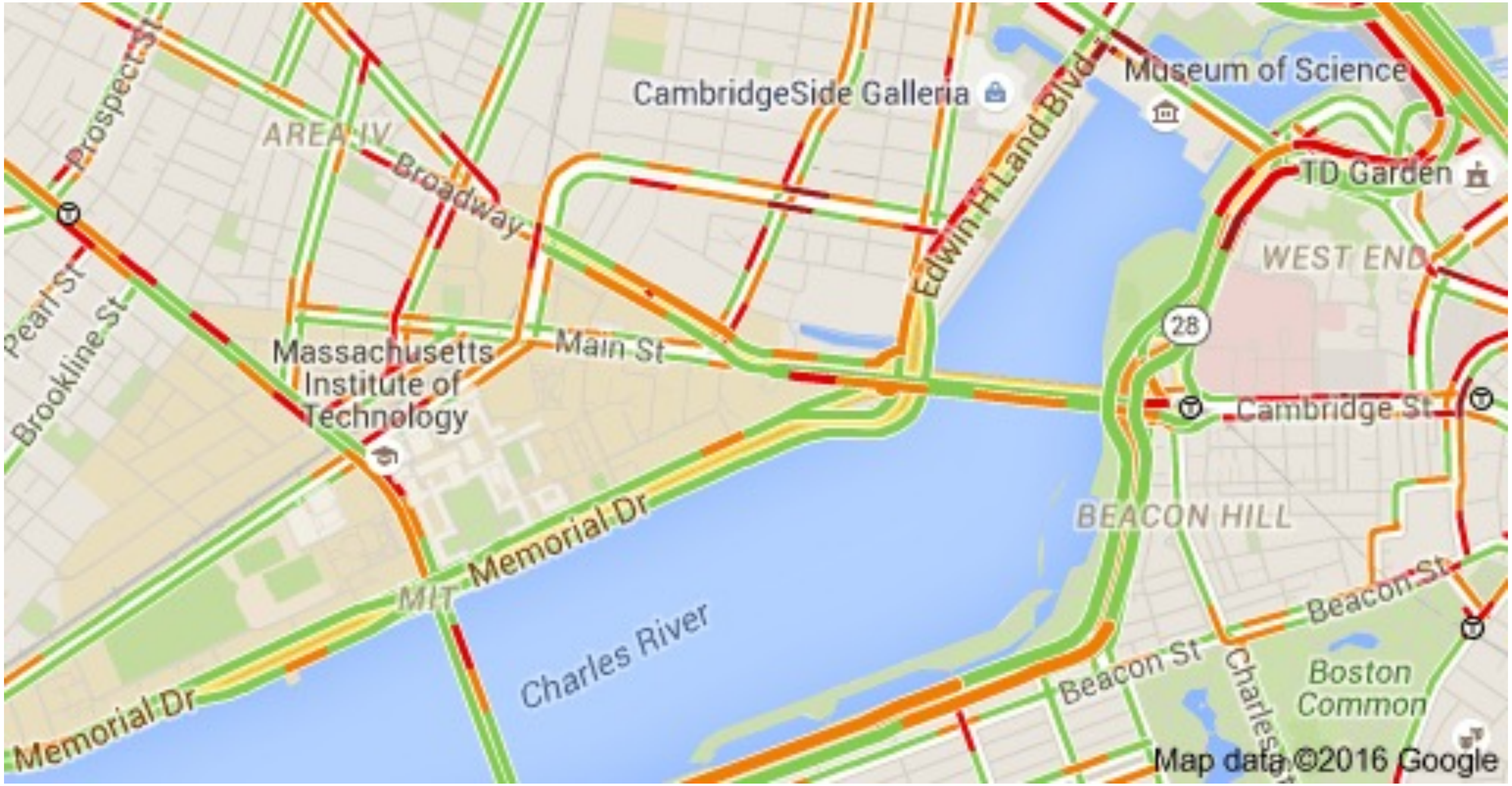
Health & Wellness

Connected Vehicles

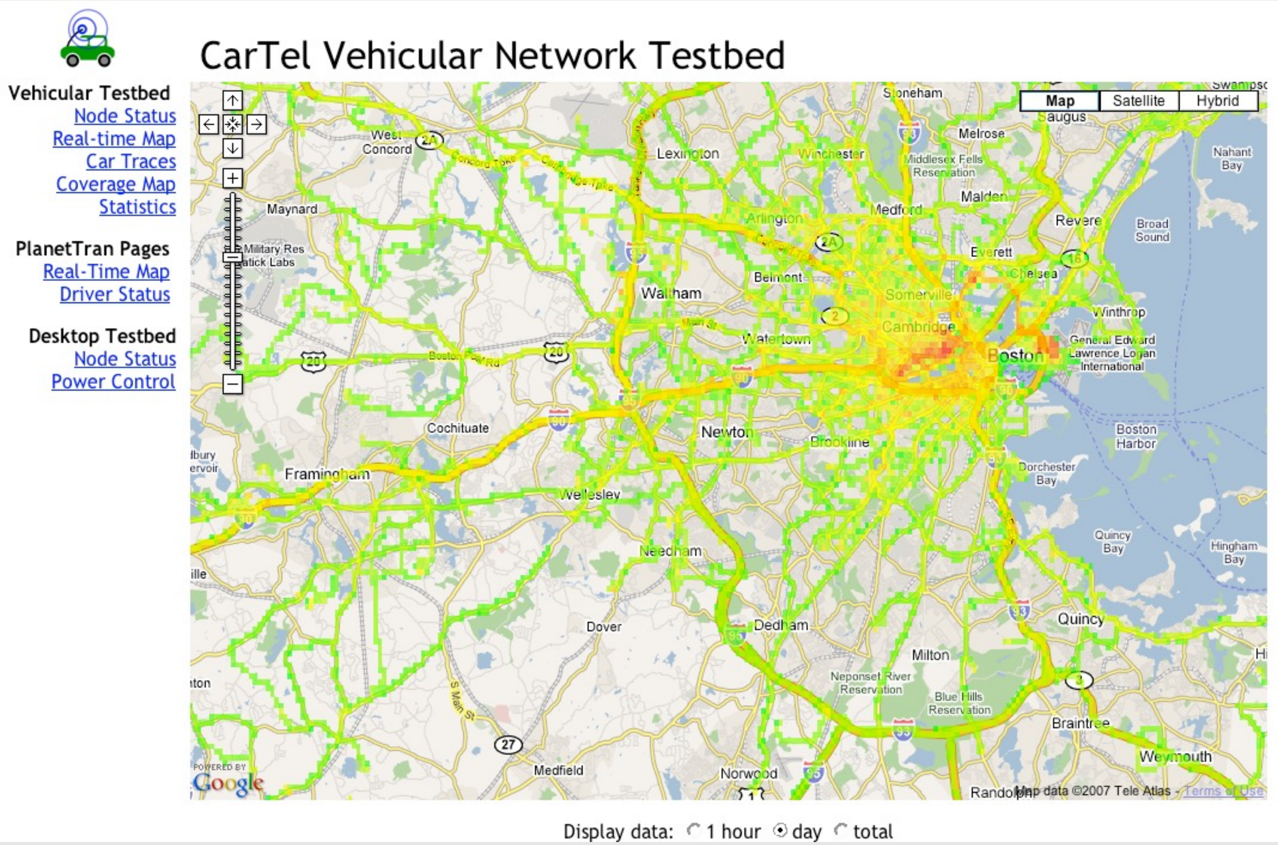
Precision Agriculture

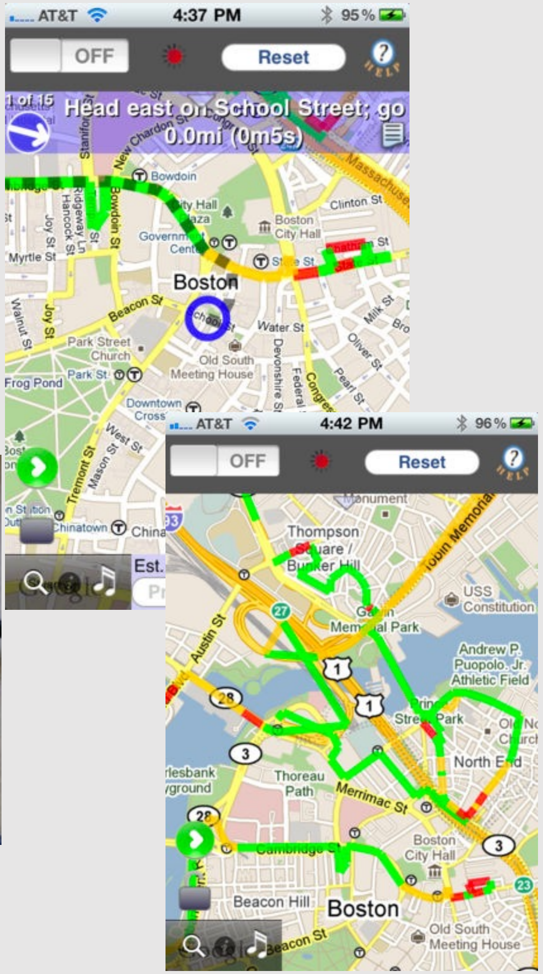
Example systems we will cover

Transportation & Smart Cities



CarTel Project at MIT (2005-2011)





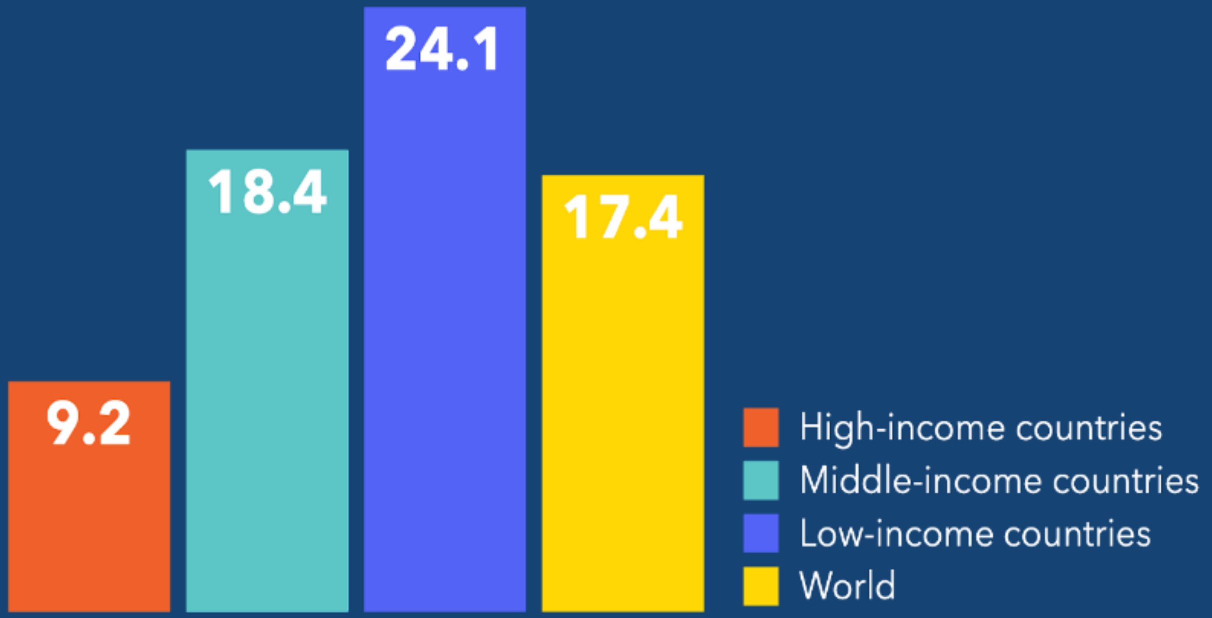
Pothole Patrol

Road Safety

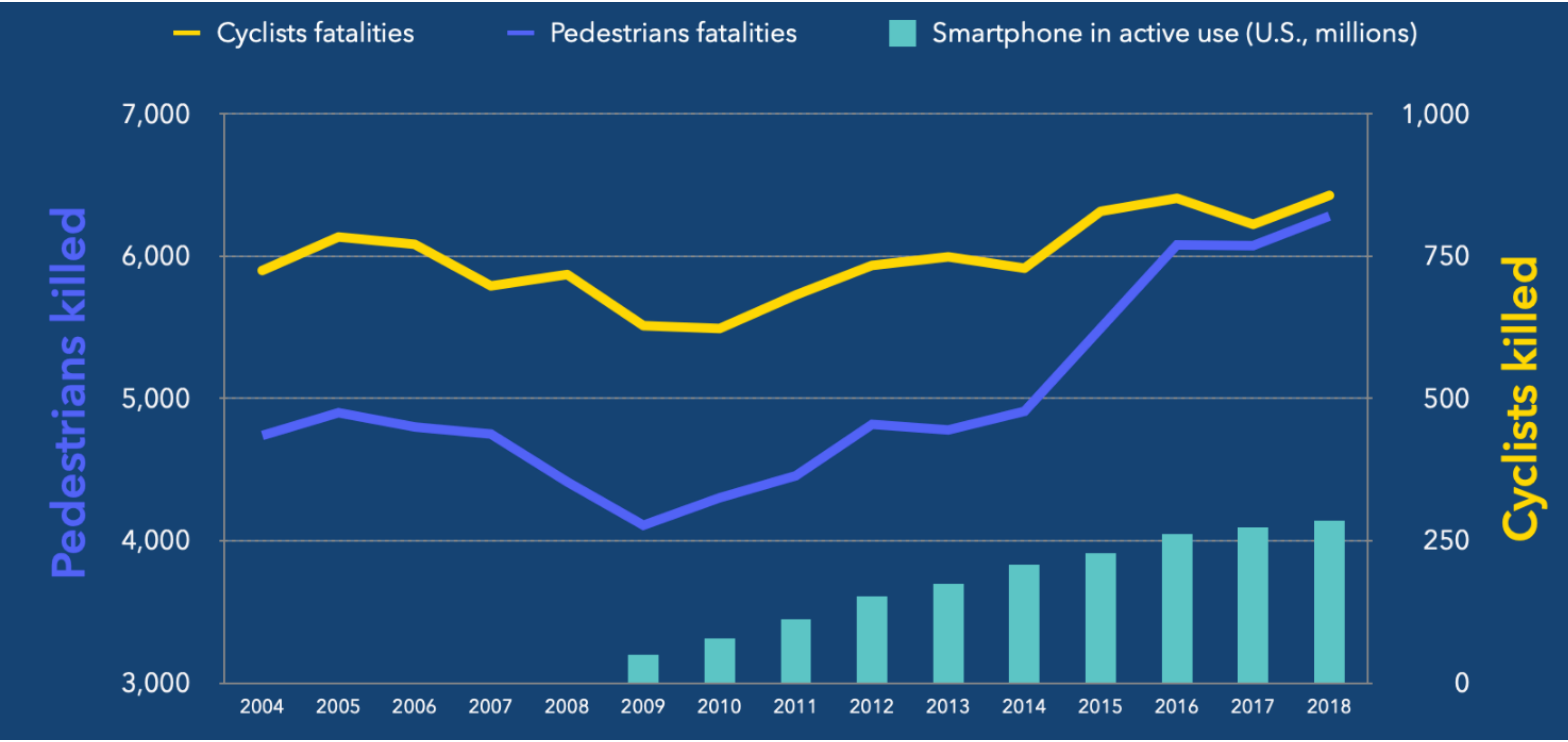
50 MILLION
Road injuries per year

$1.8 TRILLION
Loss costs per year

1.35 MILLION
Road deaths per year
(50% of COVID)



Deaths per 100K inhabitants per year



Cyclists fatalities
Pedestrians fatalities
Smartphone in active use (U.S., millions)
Pedestrians killed
Cyclists killed
7,000
6,000
5,000
4,000
3,000
1,000
750
500
250
0
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018

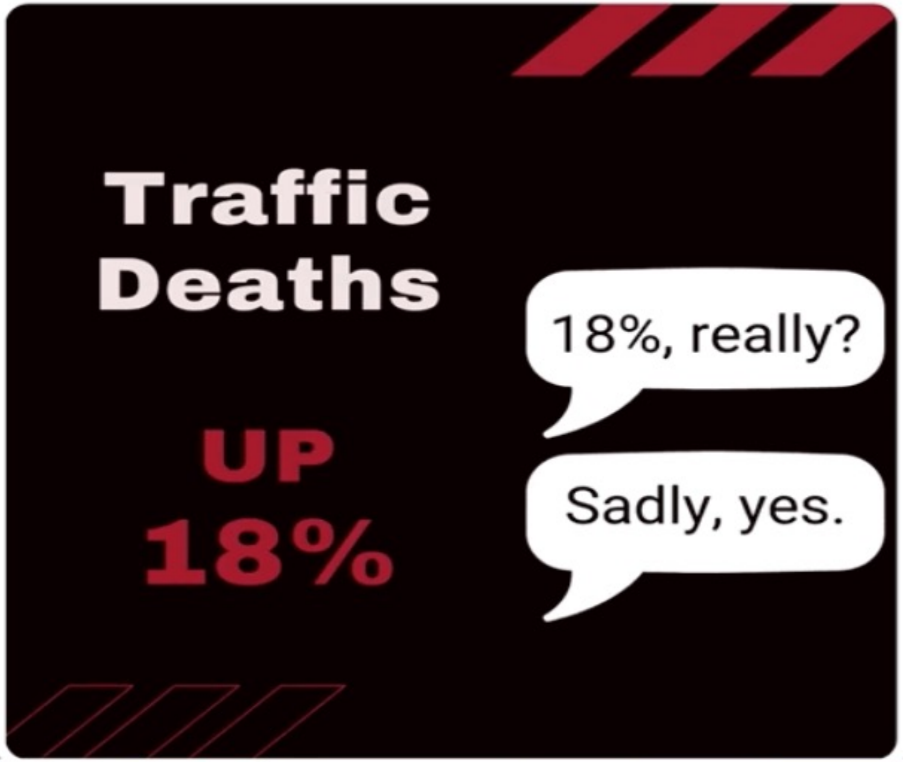
Traffic Fatalities Up 18% in H1 2021

20,160 U.S. Traffic Fatalities

Largest 6-Month Increase Ever Recorded

nhtsagov
@NHTSAgov

Really? Yes, really.



← NEWS

2020 Fatality Data Show Increased Traffic Fatalities During Pandemic

Collect raw sensor data

IoT sensors

Phone sensors

Connected car sensors

Video

Fleet devices

Deliver insights to your systems & processes

Risk

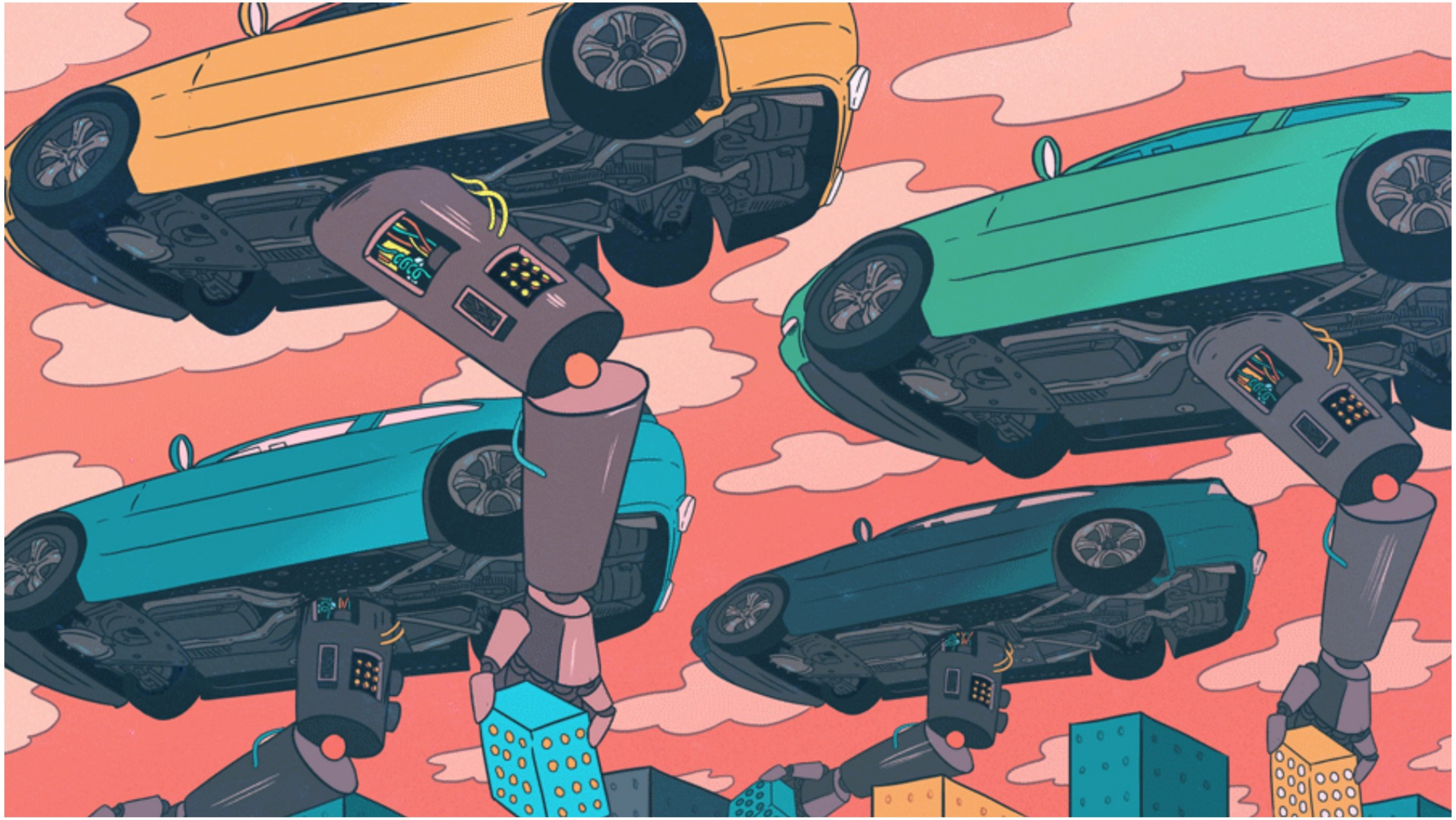
Crash assistance

Claims

Behavior change

SoftBank's Vision Fund Bets $500M On Driving Analytics Company CMT

Jason D. Rowley December 19, 2018



France
3 customers
Germany
3 customers
Russia
1 customer
Saudi Arabia
1 customer
Japan
1 customer
Thailand
1 customer
United States
54 customers
21 of top 25 insurers
Canada
3 customers
Top 2 insurers
Belgium
3 customers
Denmark
3 customers
Iceland
1 customer
Sweden
1 customer
Brazil
1 customer
Mexico
1 customer
United Kingdom
4 customers
2 of top 4 insurers
Italy
1 customer
South Africa
1 customer
Mauritius
1 customer
Australia
2 customers
Top 2 insurers
80
programs
20
countries
22M
IoT devices shipped
CAMBRIDGE
MOBILE TELEMATICS

Vehicle dynamics

Distraction

Mileage & speed

Map-matching

Transport mode & driver/ passenger

Real-time crash detection

Automatic recording

Low battery drain

Sensor data → Trip details

The Miracle of Technology: Apple Watch Saves the Lives of 3 People Involved in Major Crash

Published: 15 Feb 2023, 19:07 UTC • By: Bogdan Popa

The Crash Detection feature bundled with the Apple Watch Series 8 has manage
three passengers that were involved in a major car accident in Germany.

LOCAL NEWS

'It literally saved his life': Family credits Apple Watch alert with saving loved one after serious crash

911 was called immediately after the watch detected a crash and his daughter, who was his emergency contact, got an alert something was wrong.

iPhone 14 Crash Detection helps rescuers save man after 400-foot canyon drop: 'He probably would've bled out'

Chance Miller | Jul 24 2023 - 7:48 am PT 6 Comments

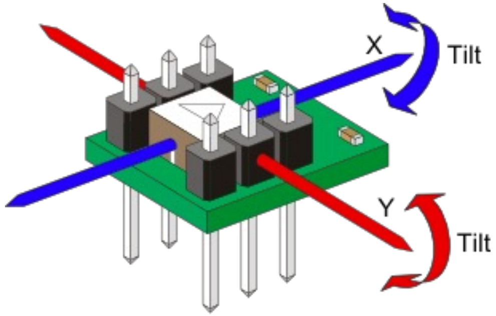
Two saved from burning car thanks to local bystander and Apple Watch

Jun 9, 2023, 4:43 PM | Updated: Jun 10, 2023, 2:18 pm

IoT Systems are designed along 4 quadrants

IoT Systems are designed along 4 quadrants

Sensing Tasks
& Modalities



Computation

Power/Energy

Connectivity

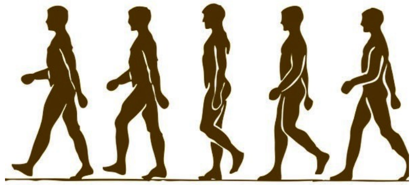
Sensing Tasks and Modalities

WHAT?

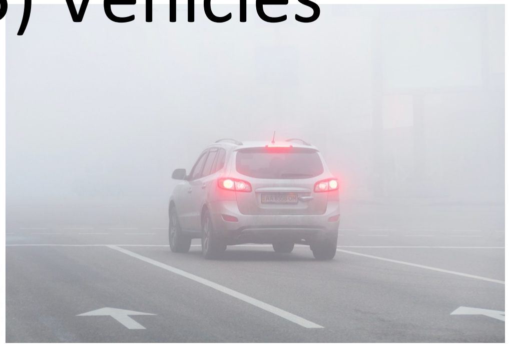
(1) Locations

(2) Health

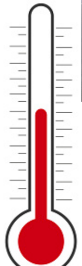
(3) Activity



(5) Vehicles



(4) Environment

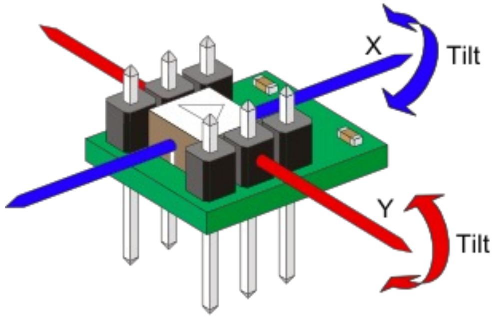


HOW?

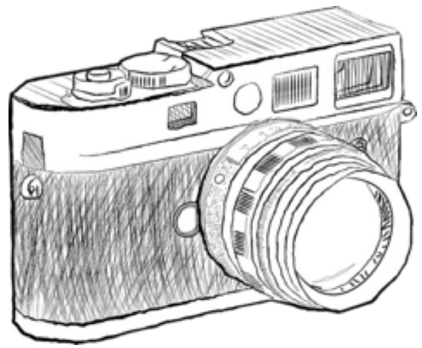
(1) Radio

(2) Acoustic/ Ultrasonic

(3) Inertial



(4) Visual



Computation

HOW can we use the sensing modalities to achieve the sensing task?

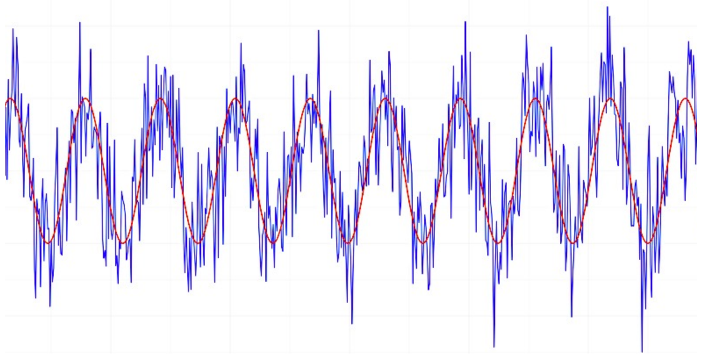
(1) Programming model

- Embedded
- Mobile
- Edge/Cloud

(2) Data Management

- Storage
- Queries

(3) Signal Processing & Inference



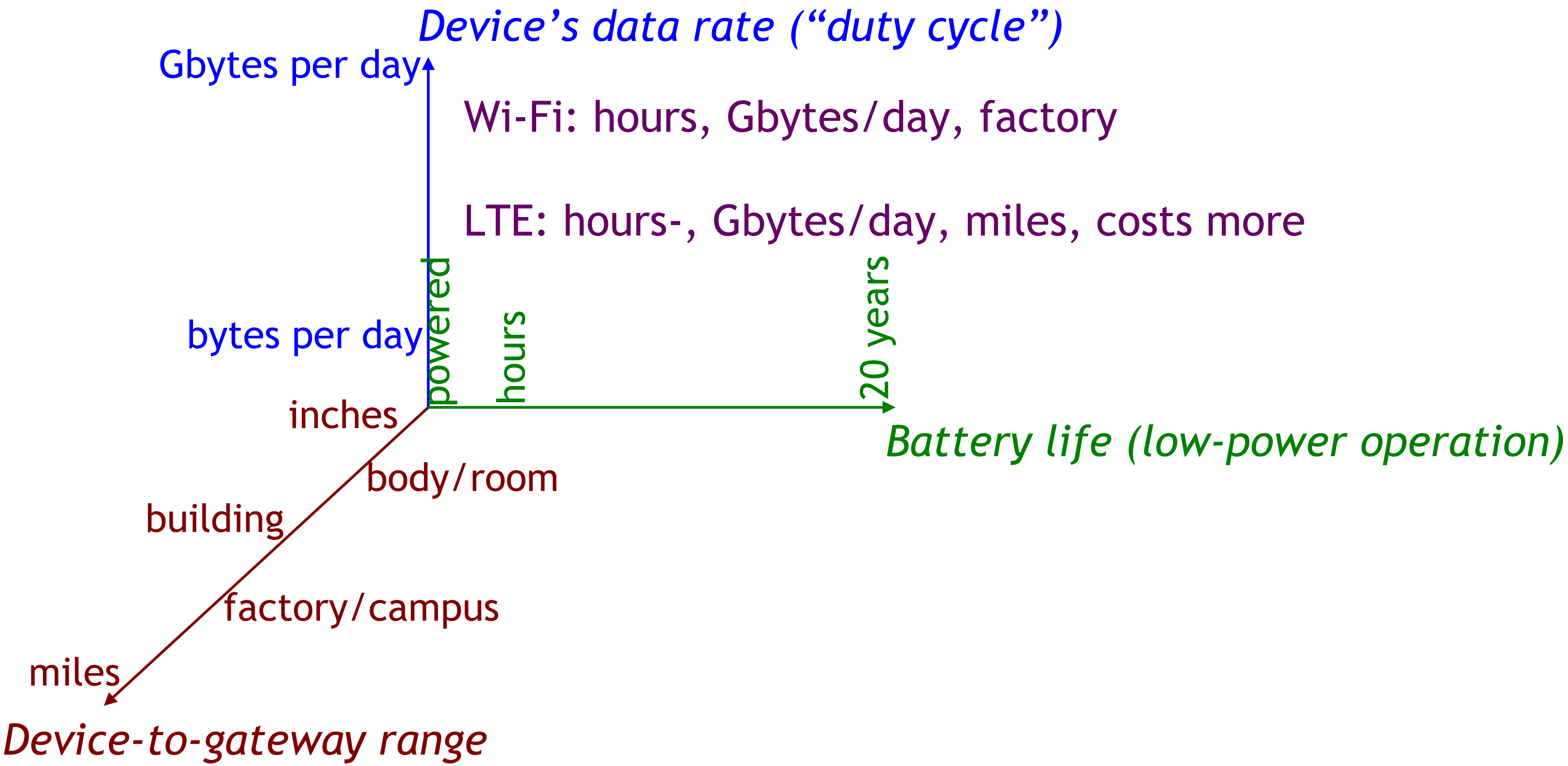
- Digitization
- Inference & Machine Learning

(4) Security

- Digital, Analog
- Trust, Privacy

Connectivity

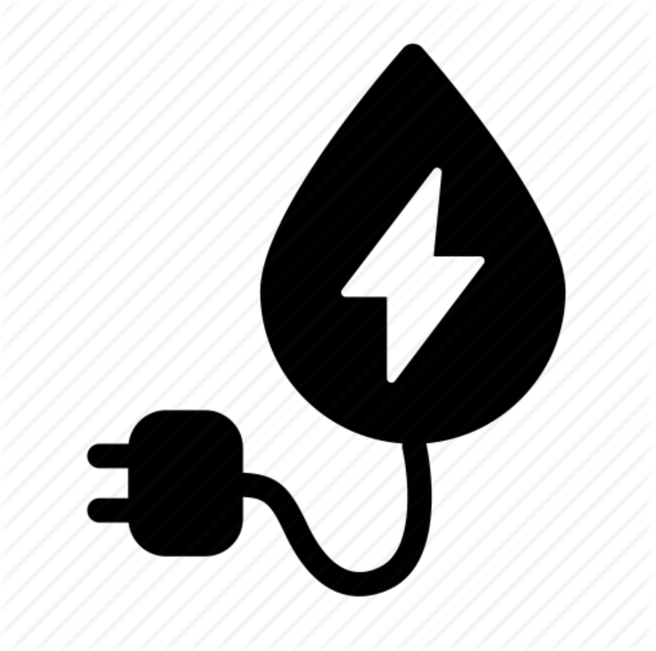
What are the metrics that we care about?



Power/Energy

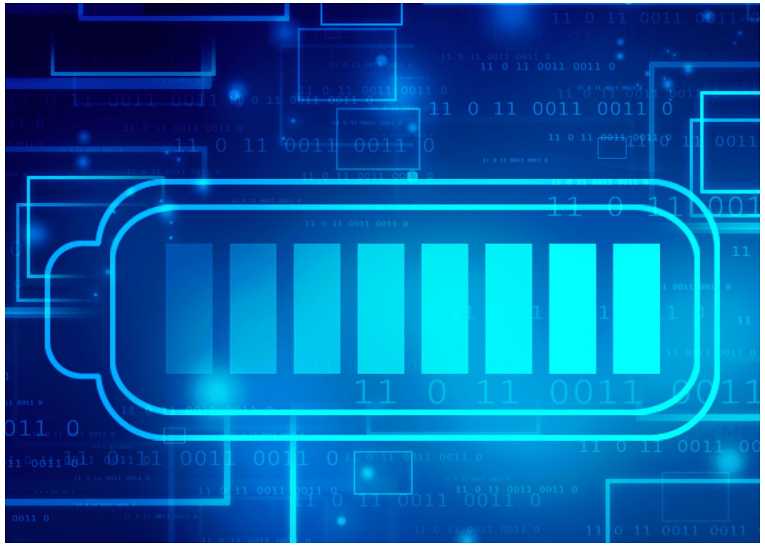
HOW will we power the nodes? And what are the energy constraints?

(1) Infrastructure



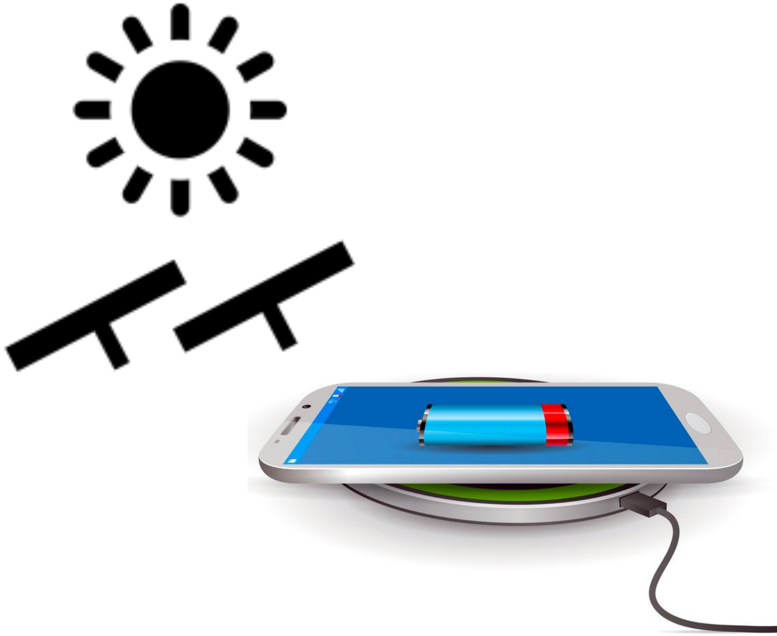
- Electricity, Network

(2) Battery



- Rechargeable/Non

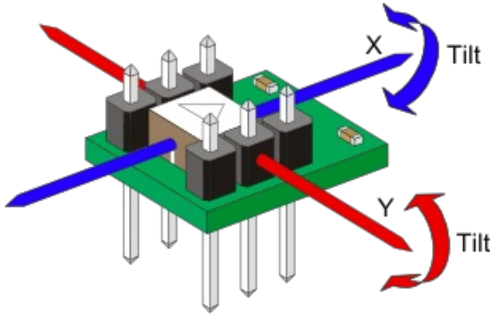
(3) Energy Harvesting



- Ambient, Wireless power
- Solar, Waves, Human Activity, RF

IoT Systems are designed along 4 quadrants

Sensing Tasks
& Modalities



Computation

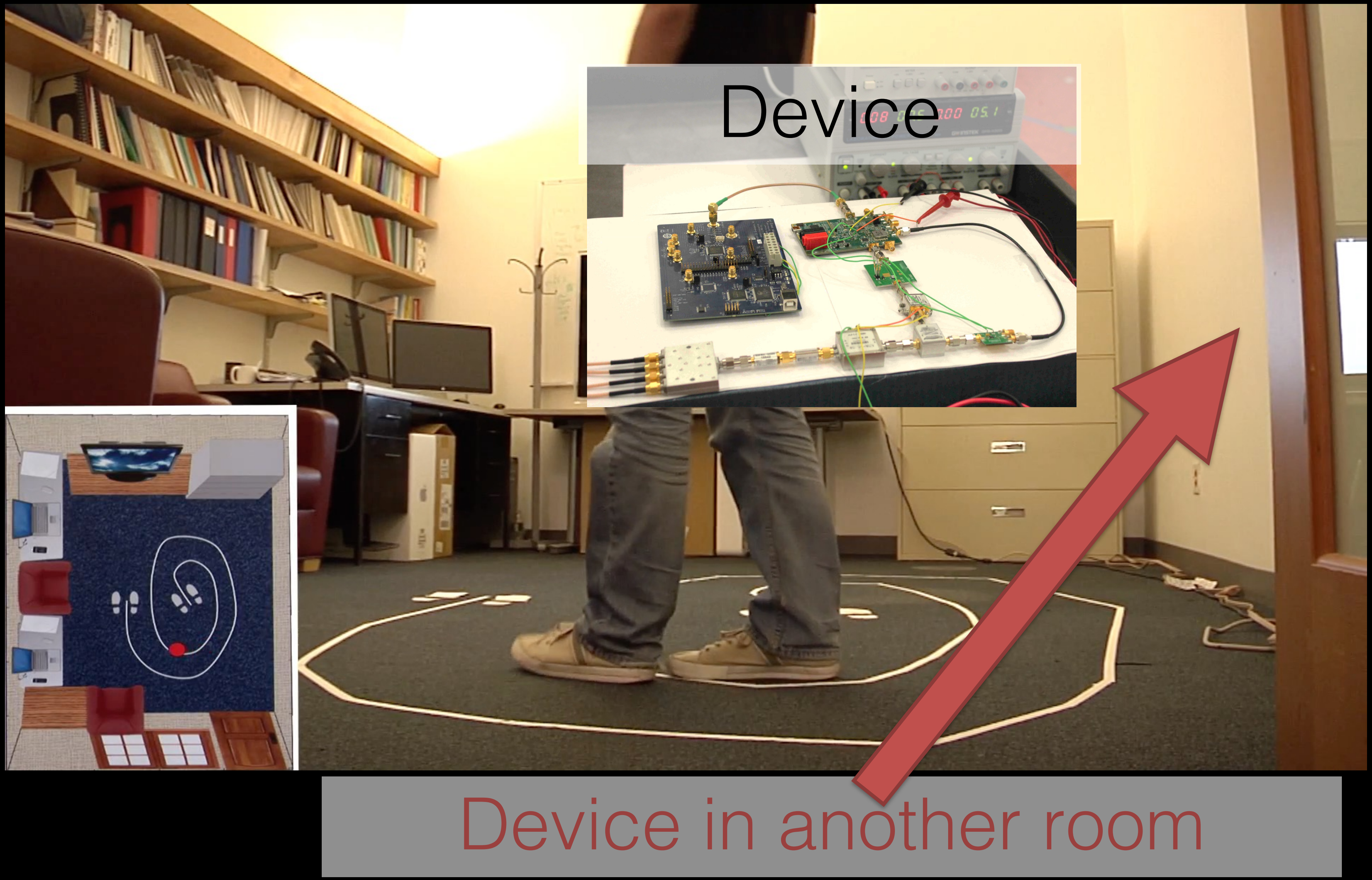
Power/Energy

Connectivity

Indoor Positioning (Cricket, 2001)

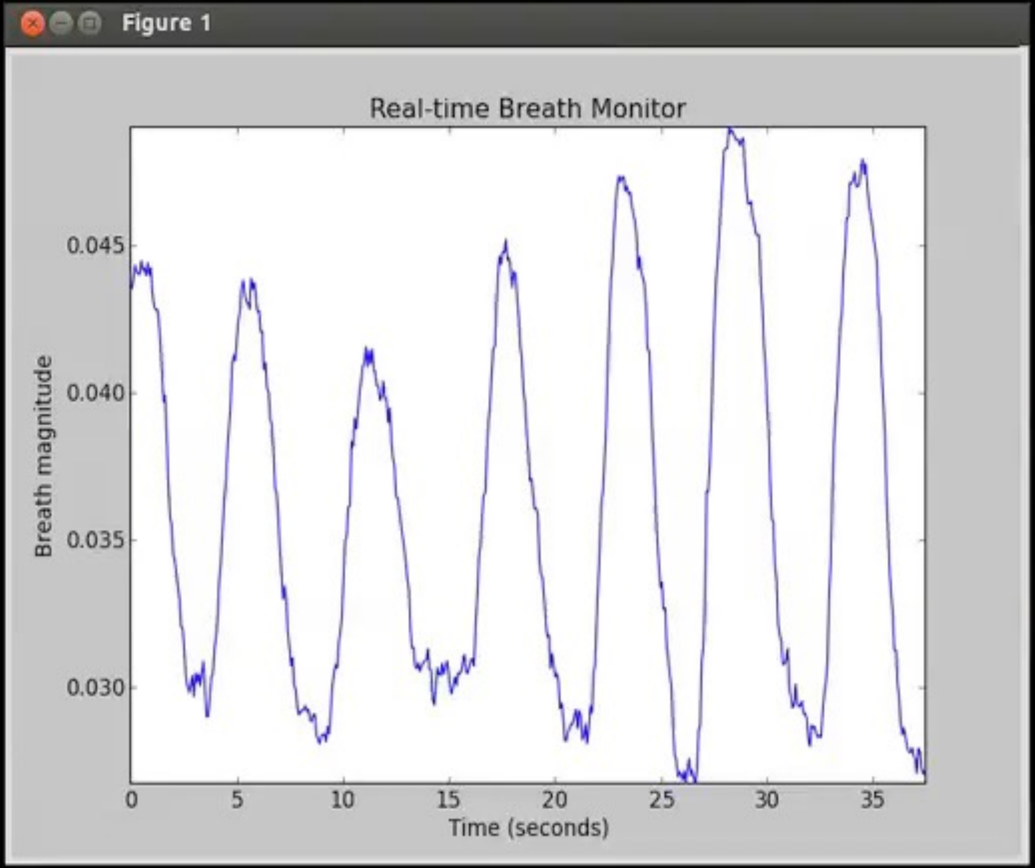
Accurate Localization (Cricket, 2003)

Device-Free Localization (WiTrack, 2014)




AI Senses People Through Walls

Breath Monitoring using Wireless (Vital-Radio, 2015)



Non-contact Respiration Monitoring

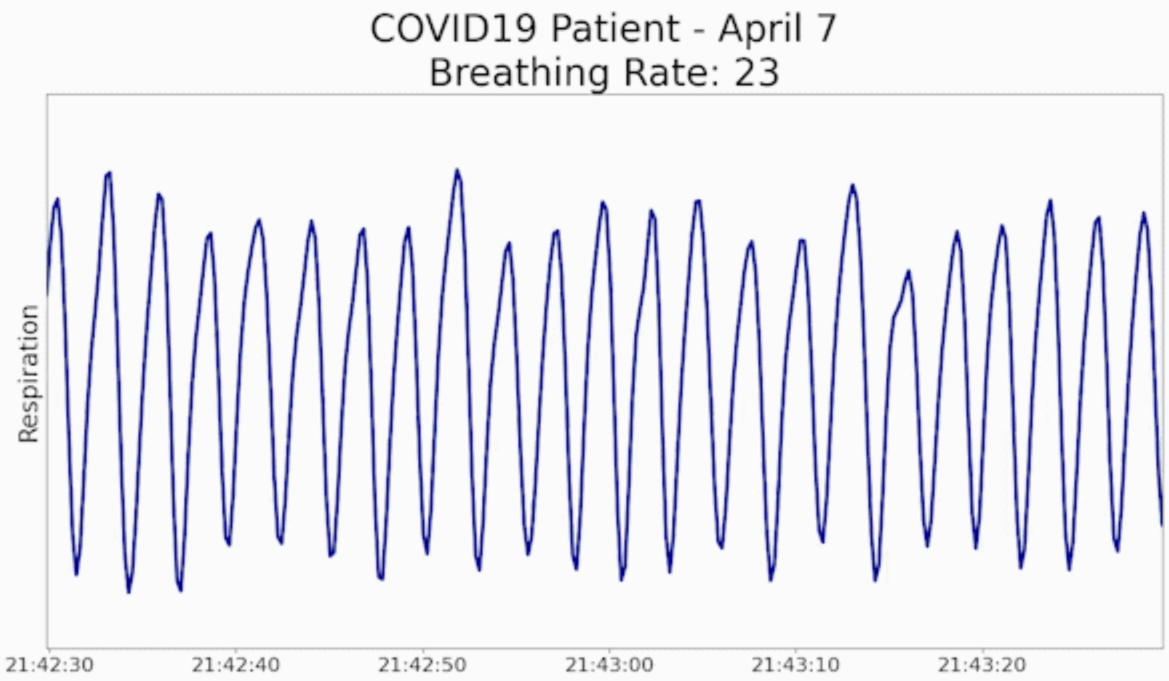
EMERALD

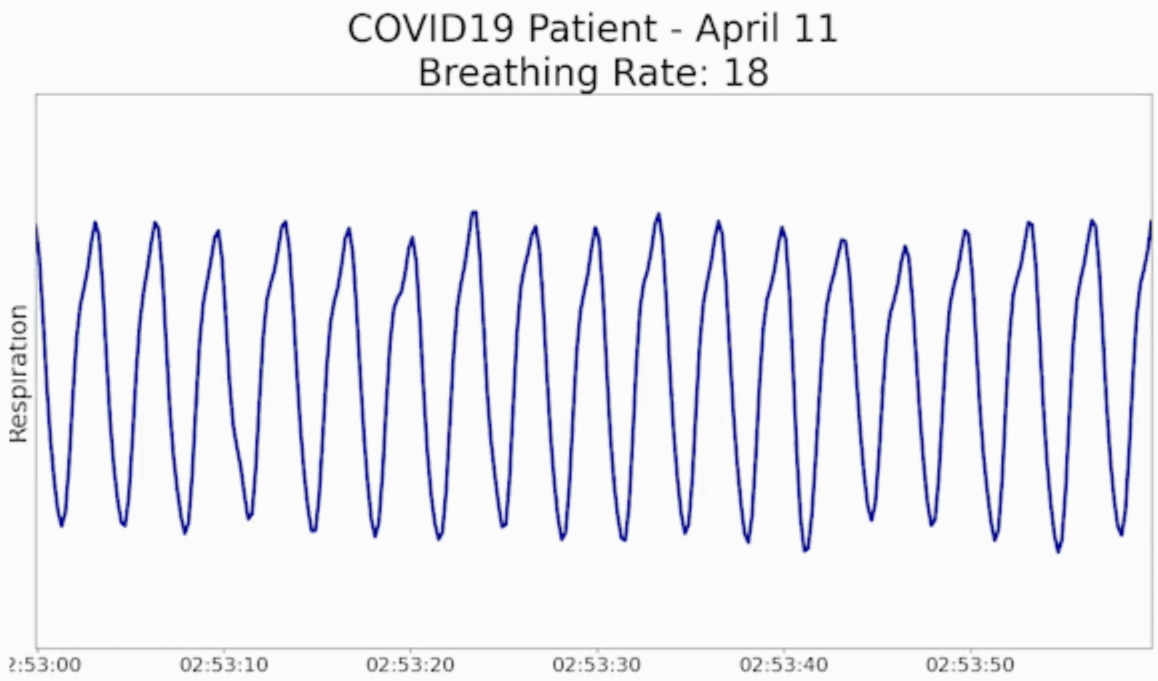
HERITAGE AT FRAMINGHAM

McLean HARVARD MEDICAL SCHOOL AFFILIATE

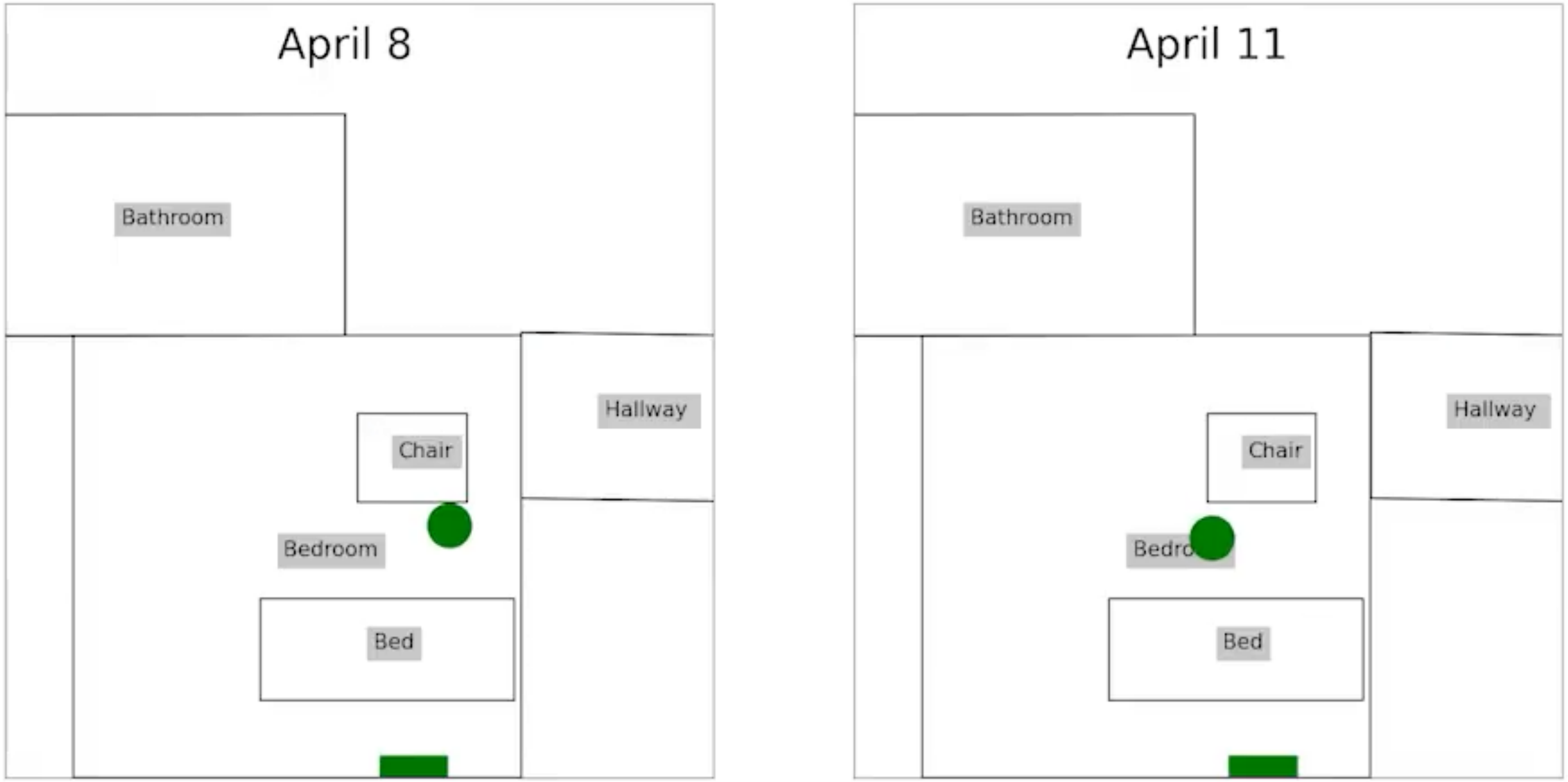
- Technology has been used in monitoring a COVID-19 Patient
- Deployed in ***Heritage Assisted Living*** in Boston suburb
- Medical doctors from Harvard Medical School analyzed remotely

Monitoring COVID-19 Patient



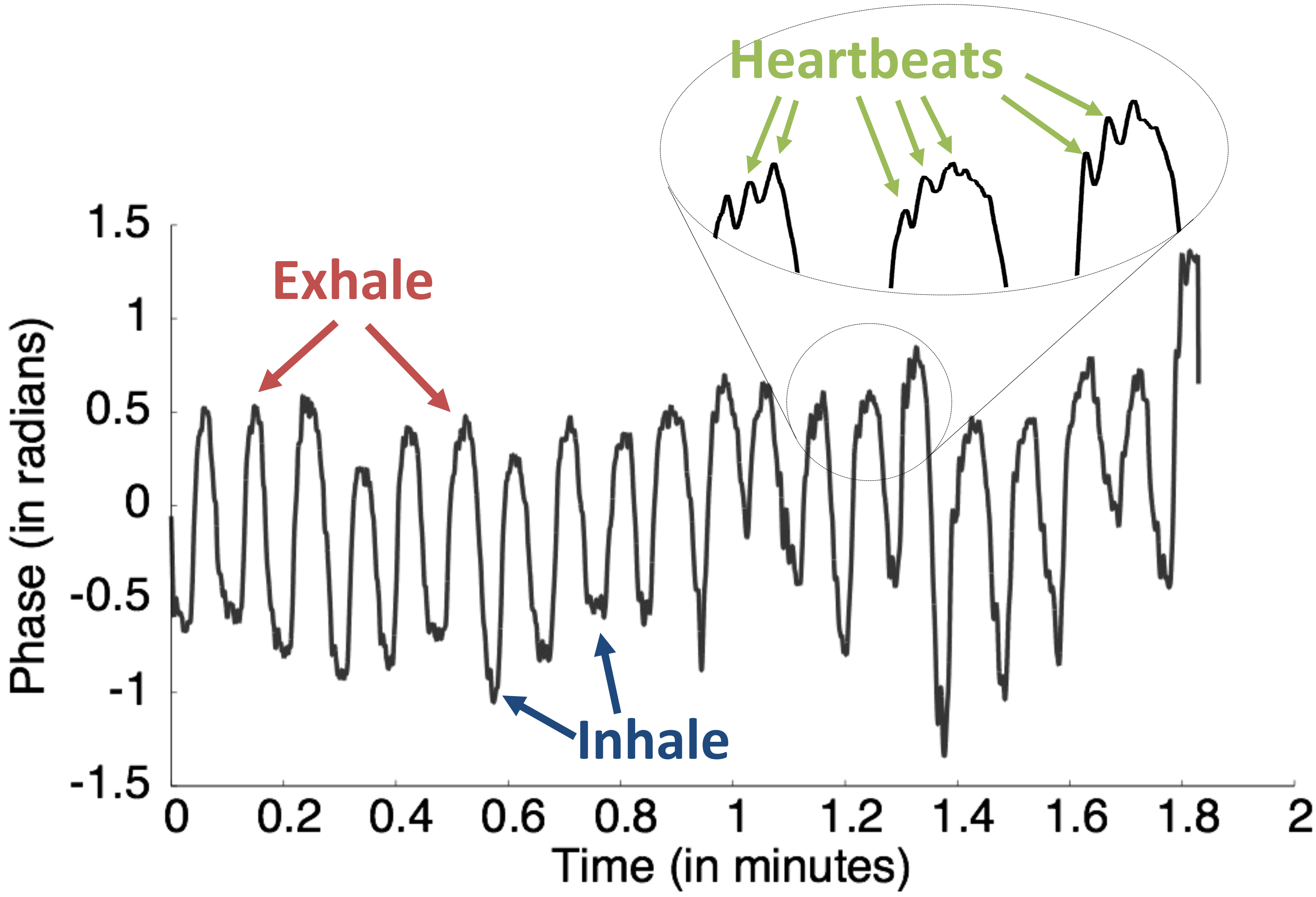


The patient's breathing decreased as it went back to normal



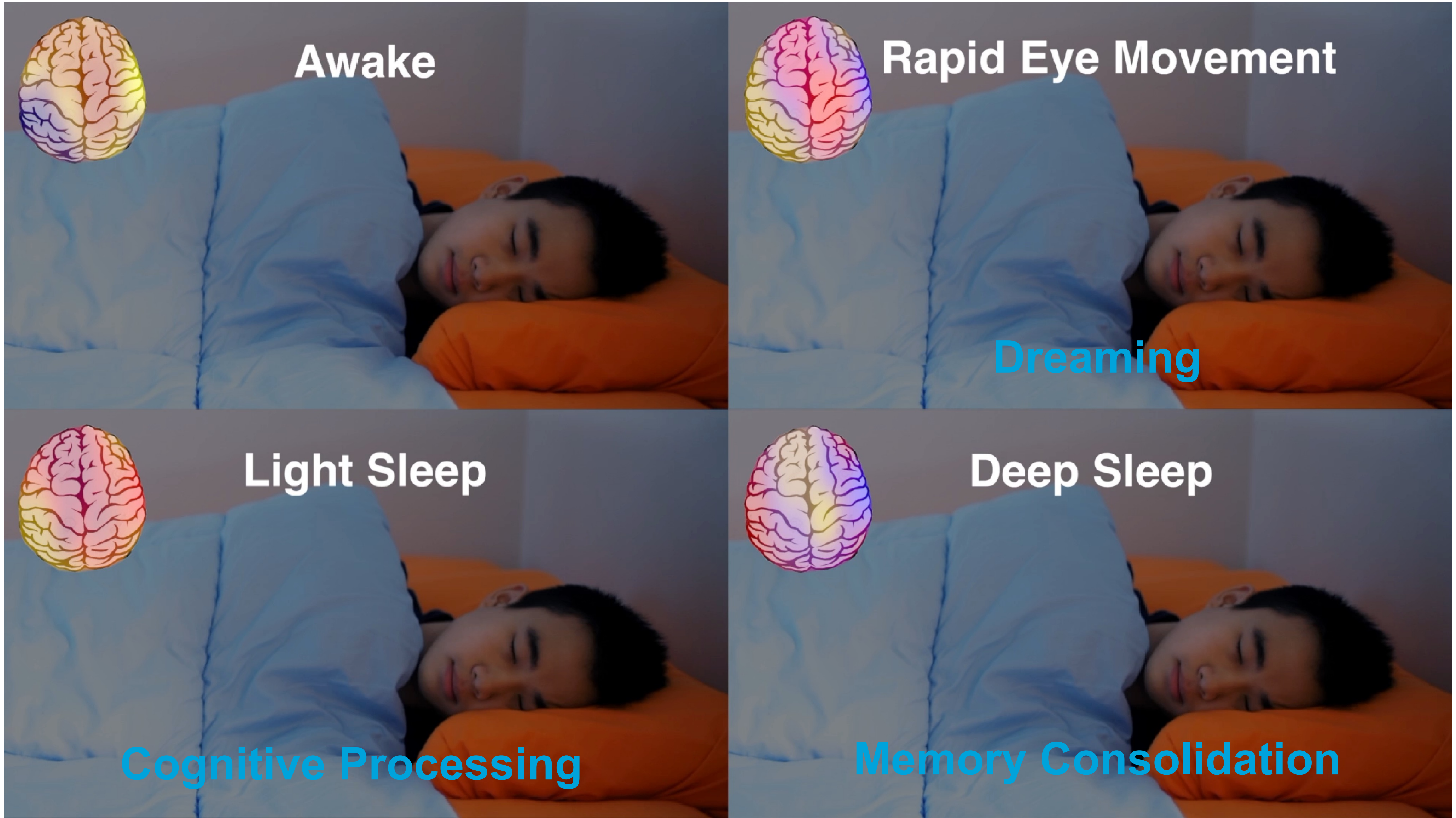
The patient's movements also demonstrate a marked improvement.

Let’s zoom in on respiration signals

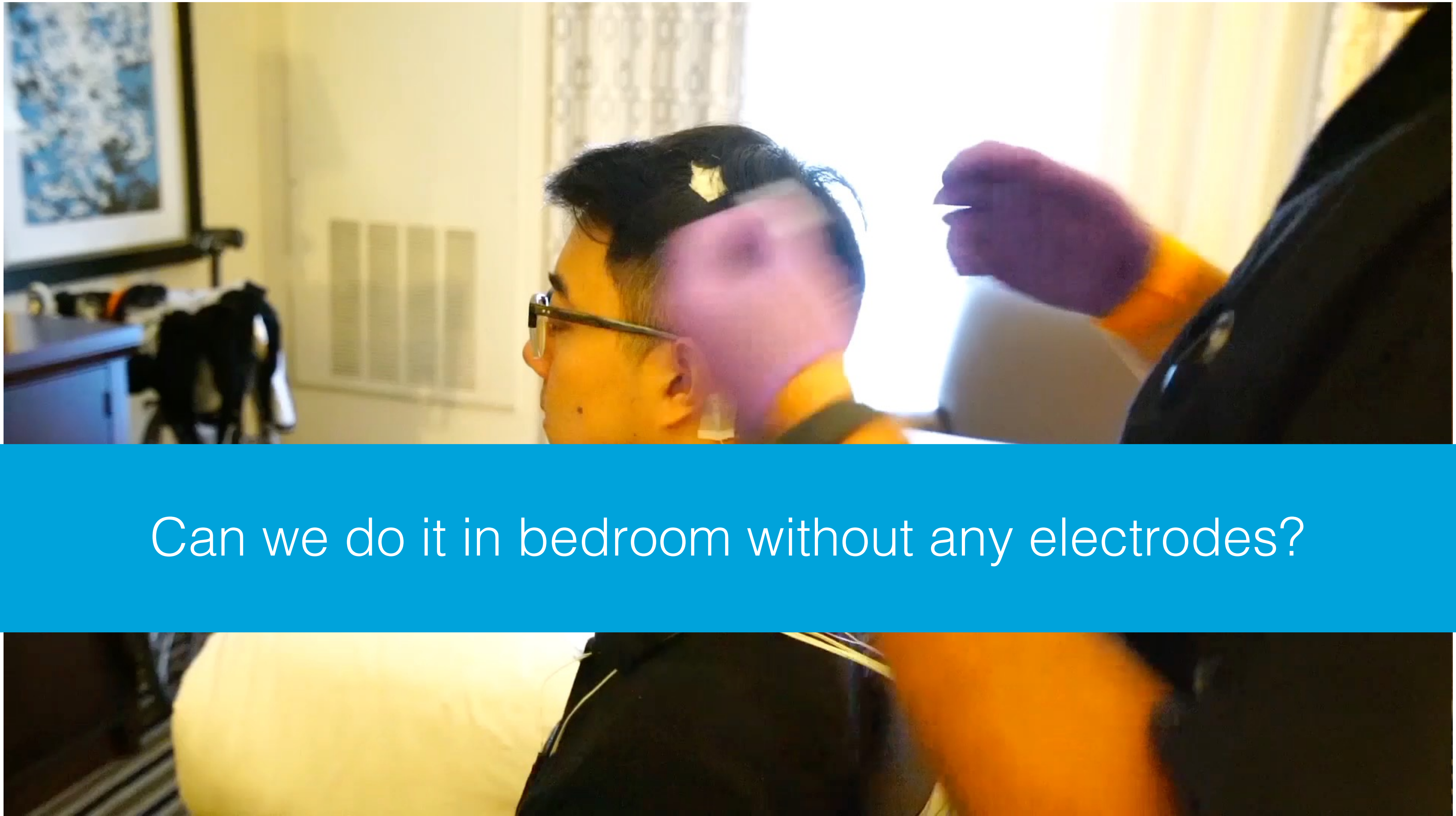


Heartbeats
Exhale
Inhale
Phase (in radians)
1.5
1
0.5
0
-0.5
-1
-1.5
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Time (in minutes)

Baby Monitoring

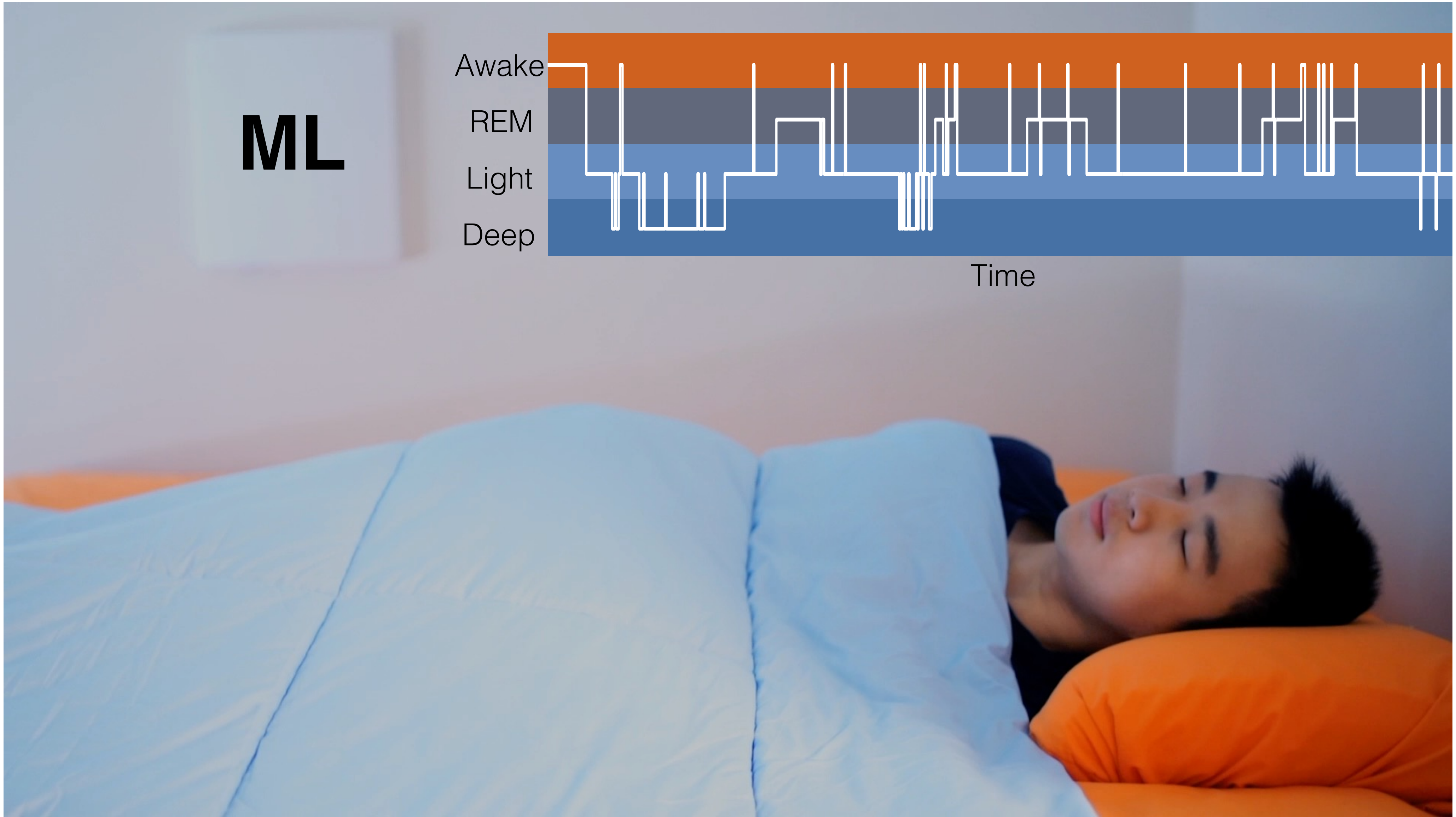

Awake
Rapid Eye Movement
Dreaming
Light Sleep
Deep Sleep
Cognitive Processing
Memory Consolidation

Monitoring Sleep Stages Is Difficult Today



Can we do it in bedroom without any electrodes?

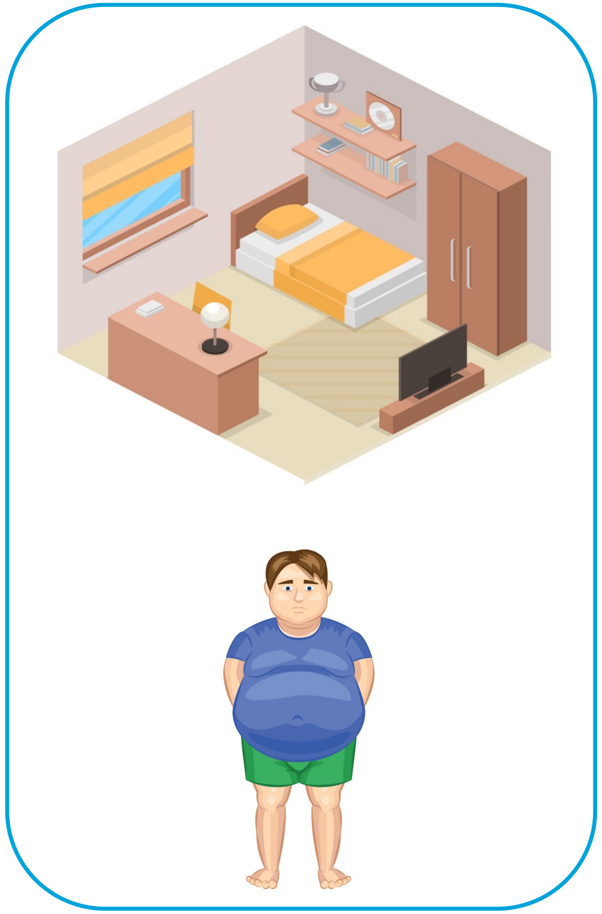
Contactless Sleep Monitoring



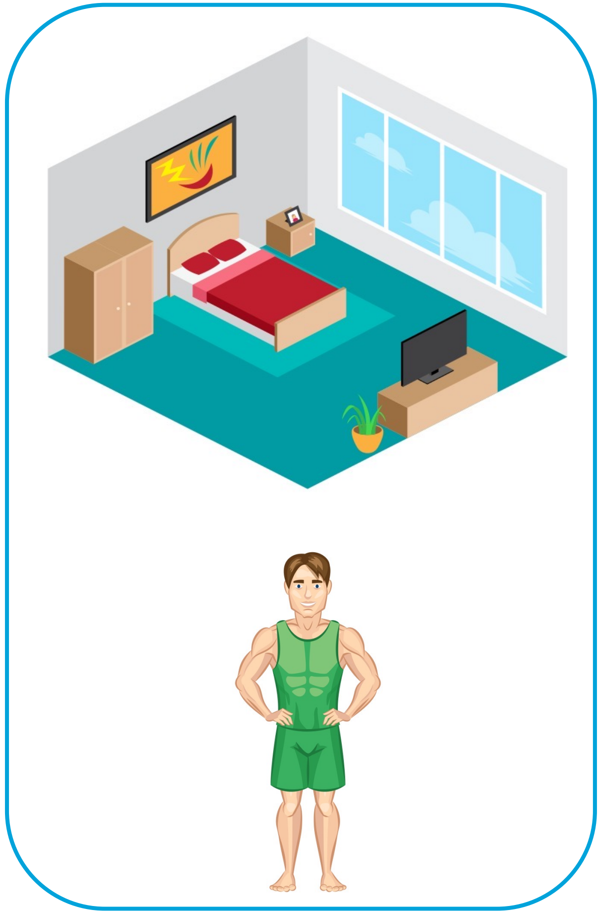
Multi-Source Domain Adaptation

domain = measurement condition + individual

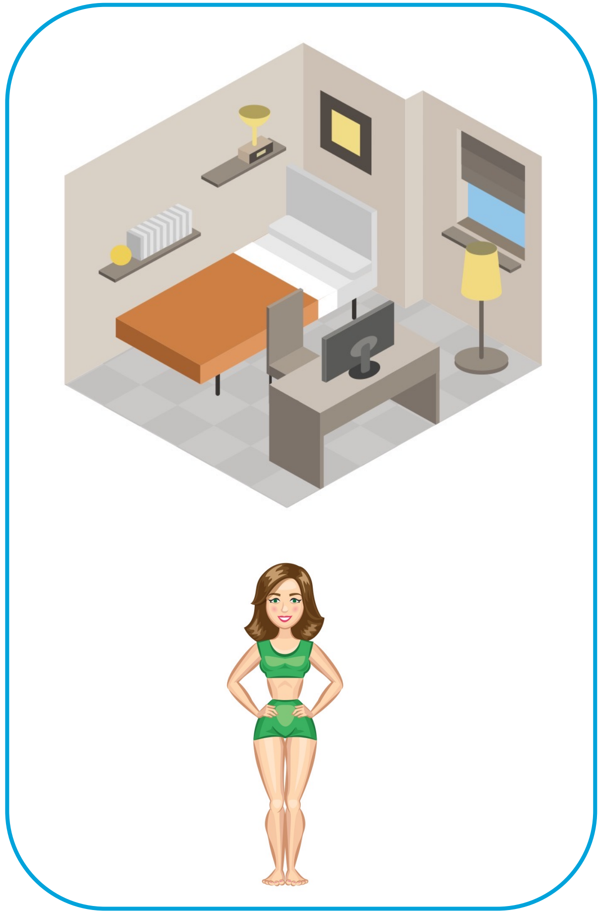
Source domain A



Source domain B



Target domain C



Mobile Security
Case Study: Inaudible Voice Commands

Can hack Android/Alexa using inaudible voice commands

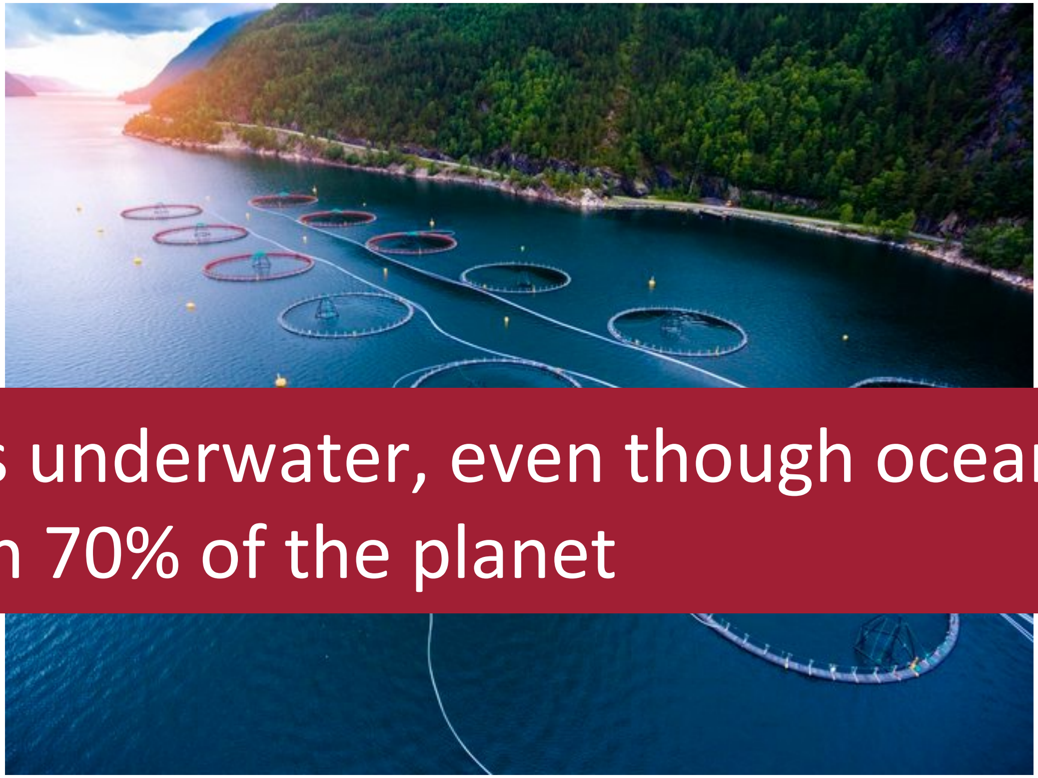
End-to-end IoT System

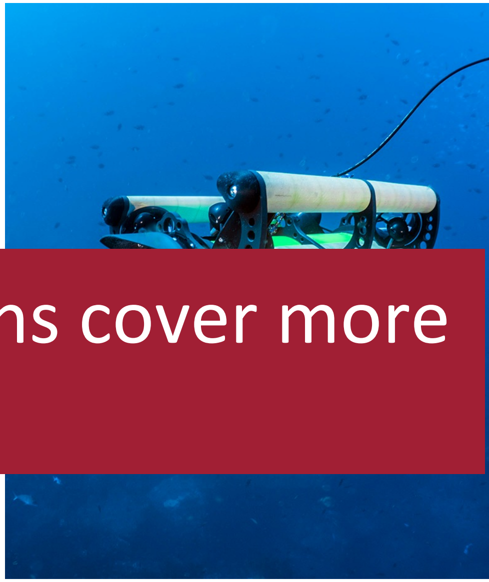
Case Study: Precision Agriculture

Taking the Internet of Things Underwater

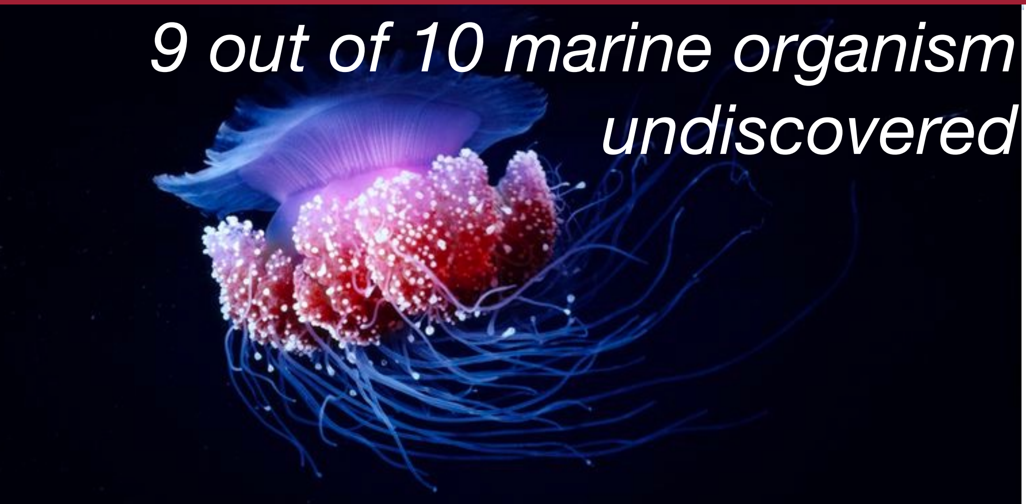
“More than 95% of ocean remains unobserved and unexplored.”

- NOAA, 2018



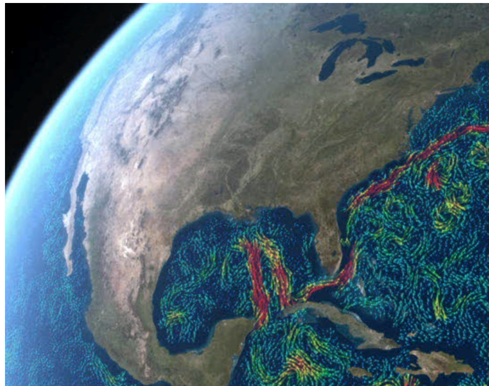


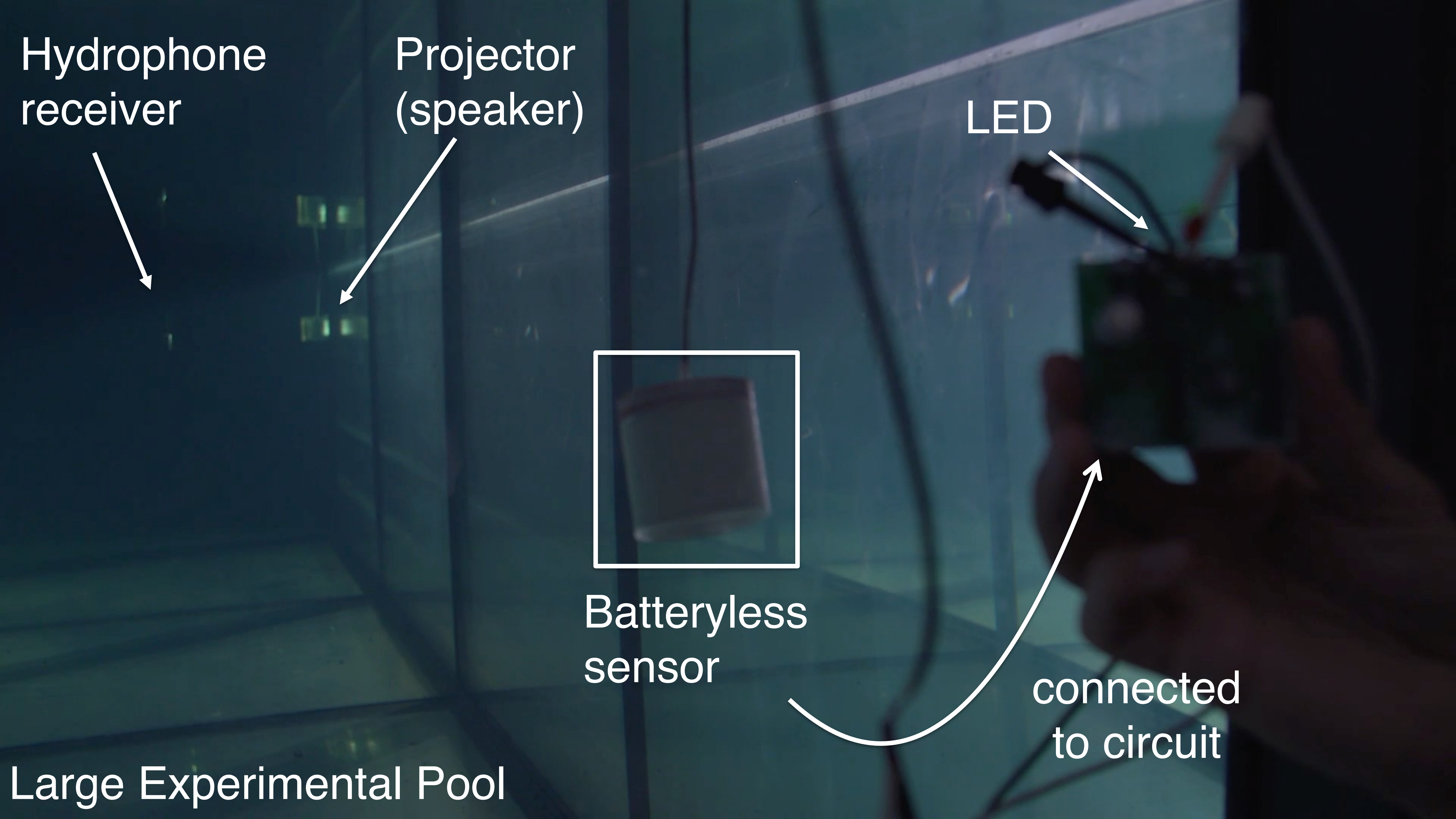
Less than 1 in a million of IoT is underwater, even though oceans cover more than 70% of the planet



Aquaculture is the “fastest growing food sector”

- UN Food & Ag org, 2022




Hydrophone
receiver
Projector
(speaker)
LED
Batteryless
sensor
connected
to circuit
Large Experimental Pool

Course Organization & Logistics

Website: https://www.cis.upenn.edu/~mingminz/courses/cis7000-23f/

Home | Course Information | Course Schedule | Labs

CIS 7000 (Fall 2023): Mobile and IoT Computing

Instructor: Mingmin Zhao
Lecture: Monday & Wednesday 1:45 - 3:15 PM @ Towne 303
Office Hour: Monday 3:15 - 4:15 PM @ Levine 503

Course Overview

The convergence of mobile computing, Internet of Things (IoT), and artificial intelligence (AI) is revolutionizing how we interact with the world increasingly driven by data. This course is designed to provide a deep understanding of the foundational principles of mobile computing and IoT, with a focus on acquiring, processing, and utilizing data to provide insights and control actions in the environment.

The course covers key topics such as sensor fusion, data integration, signal processing, machine learning, and on-device or "edge" computation, which are essential for developing intelligent systems that can sense, interpret, and respond to the world around us. It will also explore various applications of these principles across diverse domains such as digital health, human-machine interaction, virtual reality, autonomous vehicles, environmental science, and agriculture.

Throughout the course, students will engage in discussions on recent research articles that present innovative designs, algorithms, and applications for mobile and IoT computing. The course also includes a semester-long course project, where students will have the opportunity to design and build an intelligent system that leverages the principles of mobile computing and IoT to address a real-world problem.

Grading Policy

This class will be graded as follows:

- 1+4 iOS Labs (25%)
- Course Project (50%)
- Participation (25%)
  - Paper review before each lecture (may skip one without affecting grade)
  - Discussion during the lecture
  - Attendance is mandatory

Reading Questions

We will be reviewing and discussing research papers during each lecture. Please read the assigned papers (one for each lecture) before the class and answer the reading questions by the midnight the night before the class (i.e., Sunday 11:59 PM for a Monday lecture and Tuesday 11:59 PM for a Wednesday lecture). Please submit your answers here.

Course Schedule and Materials

Note: the schedule below is tentative and subject to change. Please check it regularly.

#	Date	Topic	Assigned Reading	Reading Questions	Notes
1	Wed, Aug 30	Course introduction & overview			
	Mon, Sep 4	No Class: Labor Day			
2	Wed, Sep 6	Fundamentals of Localization	Chap 6: Fundamentals of Positioning, Wikipedia: GPS.	Questions	
3	Mon, Sep 11	Device-based Localization (Indoor & Outdoor)			
4	Wed, Sep 13	Device-Free Localization & Seeing Through Walls			
	Sun, Sep 17	Lab 0 Due: 11:59 PM			
5	Mon, Sep 18	Network Connectivity			
6	Wed, Sep 20	Batteryless Connectivity & Smart Cities			
	Sun, Sep 24	Lab 1 Due: 11:59 PM			
7	Mon, Sep 25	Inertial Sensing & Activity Recognition			
8	Wed, Sep 27	Pothole detection			
	Sun, Oct 1	Lab 2 Due: 11:59 PM			
9	Mon, Oct 2	Crash Mapping			
10	Wed, Oct 4	Health & Vitals sensing			
	Sun, Oct 8	Lab 3 Due: 11:59 PM			
11	Mon, Oct 9	ML for Wireless Sensing & Through-Wall Vision			

Course Organization & Logistics

Grading:

- 1+4 iOS Labs (25%)
- Course Project (50%)
- Participation (25%)
  - Reading questions before each lecture (may skip one without affecting grade)
  - Discussion during the lecture
  - Attendance is mandatory

Each lecture = Fundamentals + State-of-the-art system(s)

Office hours

Reading Questions:

We will review and discuss 1 – 2 papers per class:

- Everyone is expected to read the papers before the class
- Submit your answers for the reading questions by the midnight the night before the class. (brief answer with 2-3 sentences)

2	Wed, Sep 6	Fundamentals of Localization	Chap 6: Fundamentals of Positioning, Wikipedia: GPS.	Questions (1) What is more privacy-preserving: network-based or terminal-based positioning (according to the taxonomy in Fig. 6-2)? Explain in 1 sentence. (2) Is GPS the former or the latter? (3) How does a GPS receiver distinguish between the signals received from different satellites?	

iOS Labs (need iPhone/iPad and Mac)

- 1+4 labs
- Work in groups of two
- Late policy: 5 days

- Lab 0: Get familiar with Xcode IDE and develop an OpenWeather API
- Lab 1: Develop Location API and explore the power drain vs accuracy trade-off
- Lab 2: Develop Anteater app to scan for a nearby Anthill, connect to it, and stream temperature and humidity readings from it
- Lab 3: Build a handwriting(2D) and gesture(3D) recognition system
- Lab 4: Detect distance through FMCW signal on laptop

Course Project

- Work in groups (ideal group size: 3)
- The projects involve system implementation
- Will suggest project ideas; students can choose their own projects
- What is expected?

Timeline:

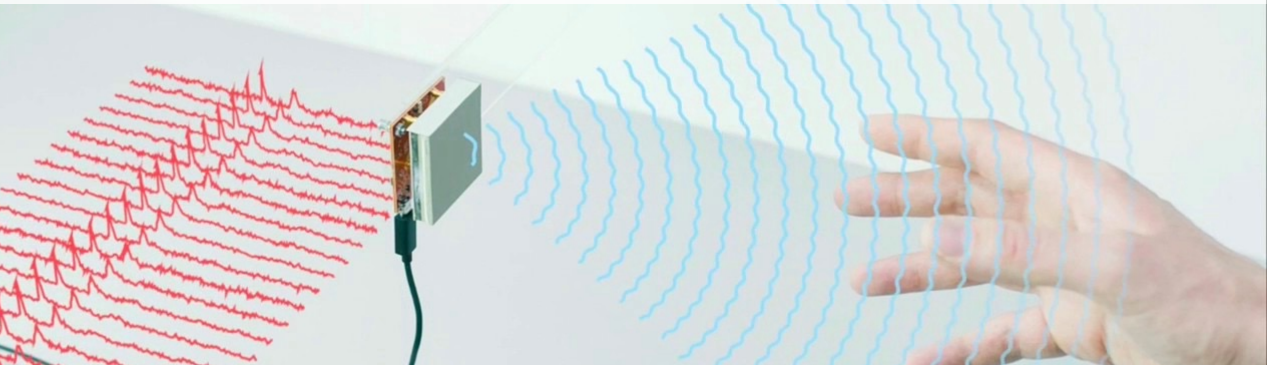
- Proposal (1-2 pages): Sunday Oct 22
- Project proposal discussion: Monday Oct 23
- Weekly discussion: Nov - Dec
- Final presentation: Dec 4 - 11
- Final report: Dec 17

COVID-19 Student Class Projects (in 2020)

Inform cleaning protocols in grocery stores

Track PPE shrinkage from warehouses & hospitals

Remote gesture recognition to minimize surface contact



Sensor fusion for social distancing & contact tracing

What you are Expected to Learn from This Class

Lectures & Papers:

- Fundamentals of mobile and IoT computing
- How is IoT applied across various industries?
- What are emerging IoT domains and what does the future of IoT look like?

Labs:

- iOS APIs, including Bluetooth, inertial, UI programming

Project:

- Build a Physical IoT project using material learnt from class
- Collaboration (groups of 3)

Next Class

- Time: Wed Sep 6th (no class on Monday 4th)
- Topic: Fundamentals of Localization
- Readings: **Chapter 6 on Localization + GPS**