Welcome!

CIS 3990

Mobile and IoT Computing

https://penn-waves-lab.github.io/cis3990-24spring

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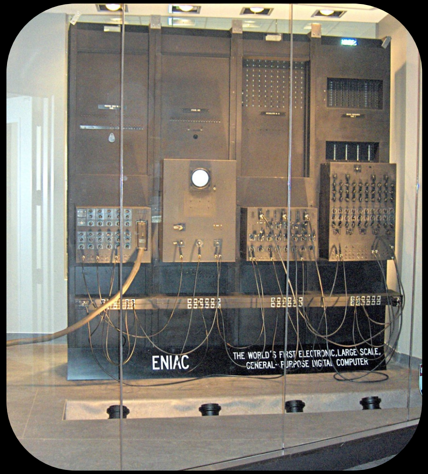
Computing Paradigms

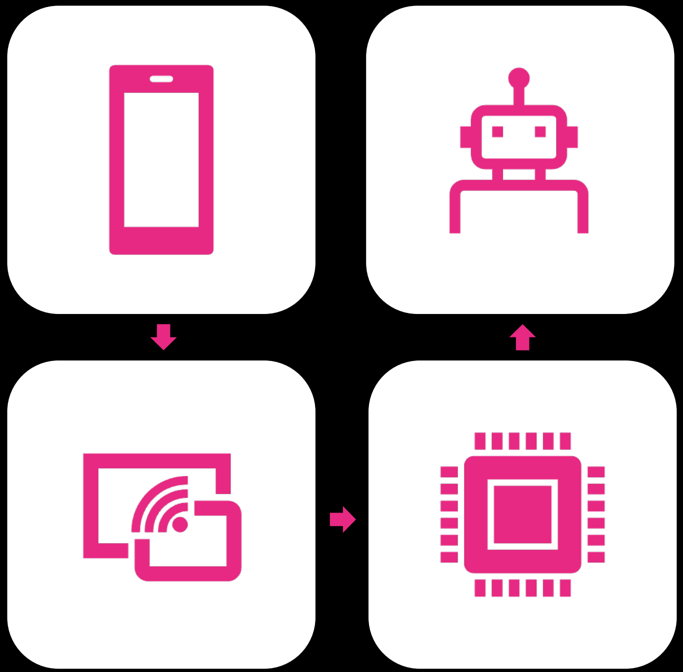


Mainframe 1950s	PC 1990s	Mobile 2010s	IoT 2020s
Automation Aggregation	Customization Productivity	Personalization Mobility & Connectivity	Ubiquity Intelligence

Mobile and IoT Computing

The convergence of sensing, communication, and computation that allows us to:

Acquire data from the environment



Act based on the data

Aggregate data from multiple sources

Analyze data (cloud/edge) and provide insights about the world

Mobile and IoT Computing

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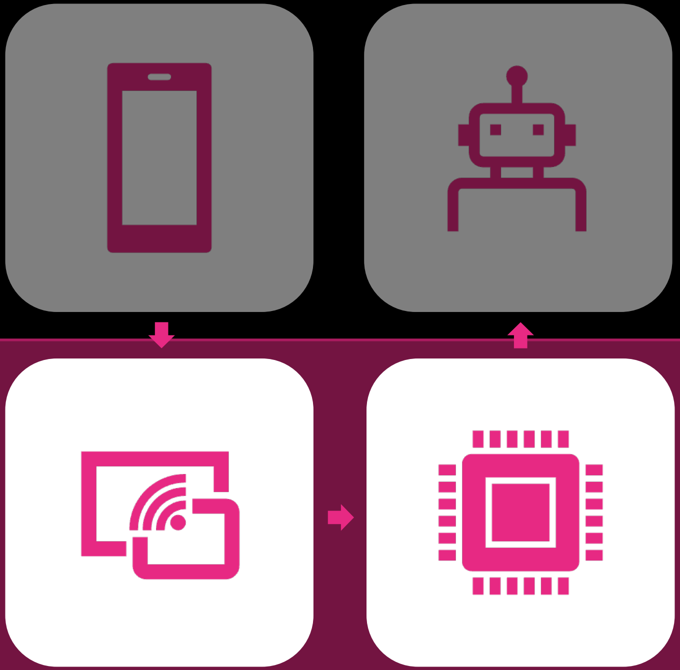


Aggregate data from multiple sources

Analyze data (cloud/edge) and provide insights about the world

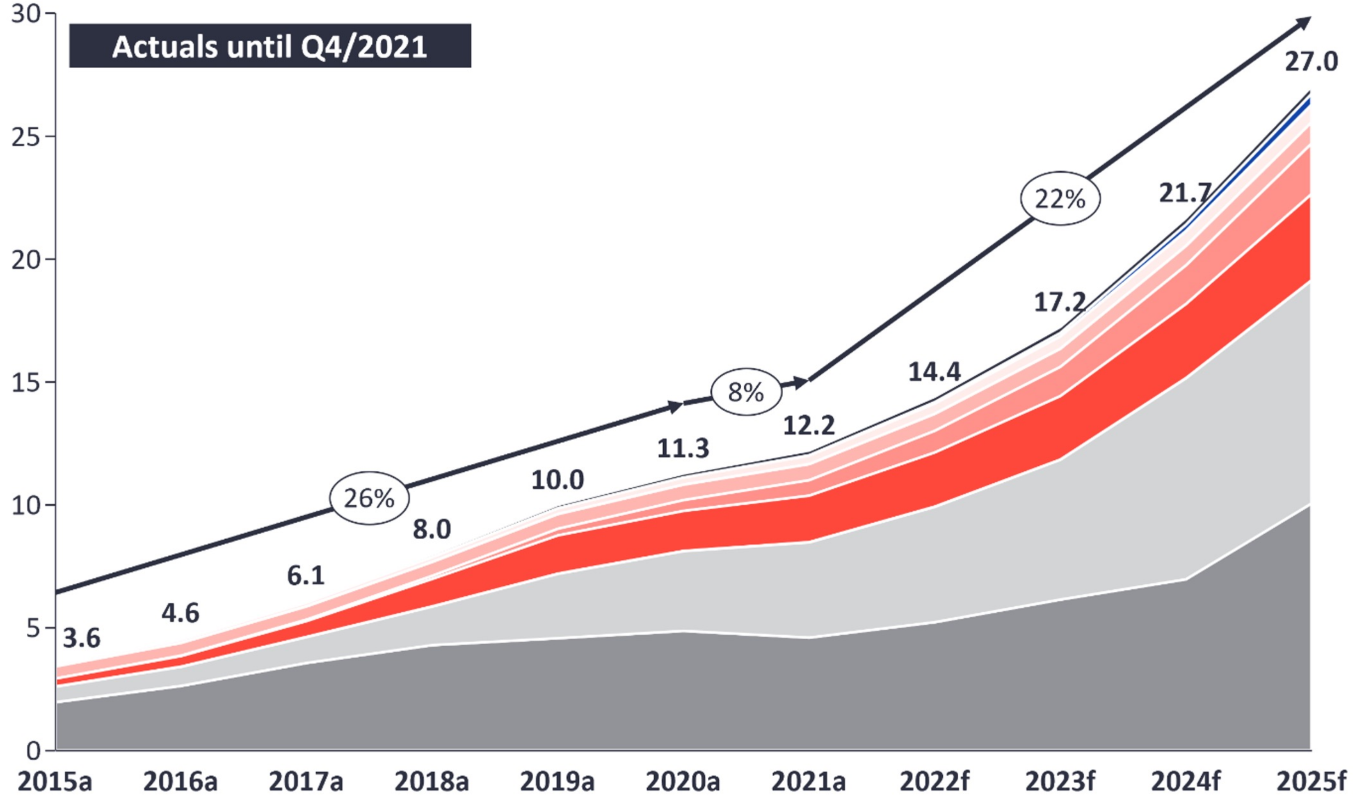
This course

IOT ANALYTICS

Your Global IoT Market Research Partner

Global IoT Market Forecast [in billion connected IoT devices]

Number of global active IoT Connections (installed base) in Bn



CONNECTIVITY TYPE	CAGR 20-21	CAGR 21-25
Wireless Neighborhood Area Networks (WNAN)	17%	11%
5G IoT	-	159%
Other	22%	20%
Wired IoT	4%	7%
LPWA	42%	34%
Legacy Cellular (2G/3G/4G)	16%	17%
Wireless Local Area Networks (WLAN)	19%	24%
Wireless Personal Area Networks (WPAN)	-6%	22%

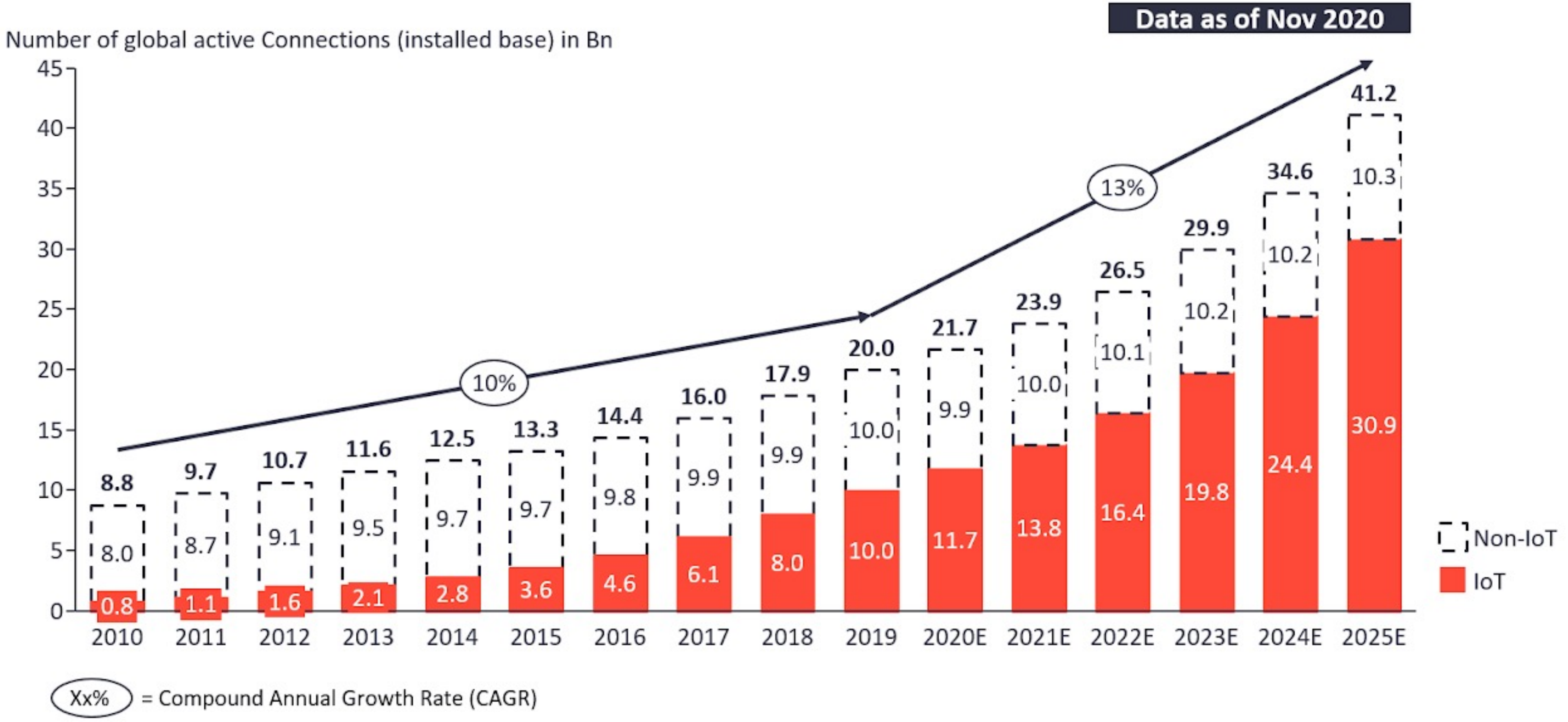
XX% = CAGR

Note: IoT Connections do not include any computers, laptops, fixed phones, cellphones or tablets. Counted are active nodes/devices or gateways that concentrate the end-sensors, not every sensor/actuator. Simple one-directional communications technology not considered (e.g., RFID, NFC). Wired includes Ethernet and Fieldbuses (e.g., connected industrial PLCs or I/O modules); Cellular includes 2G, 3G, 4G; LPWAN includes unlicensed and licensed low-power networks; WPAN includes Bluetooth, Zigbee, Z-Wave or similar; WLAN includes Wi-fi and related protocols; WNAN includes non-short range mesh, such as Wi-SUN; Other includes satellite and unclassified proprietary networks with any range.

Source: IoT Analytics Research 2022. We welcome republishing of images but ask for source citation with a link to the original post and company website.

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

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



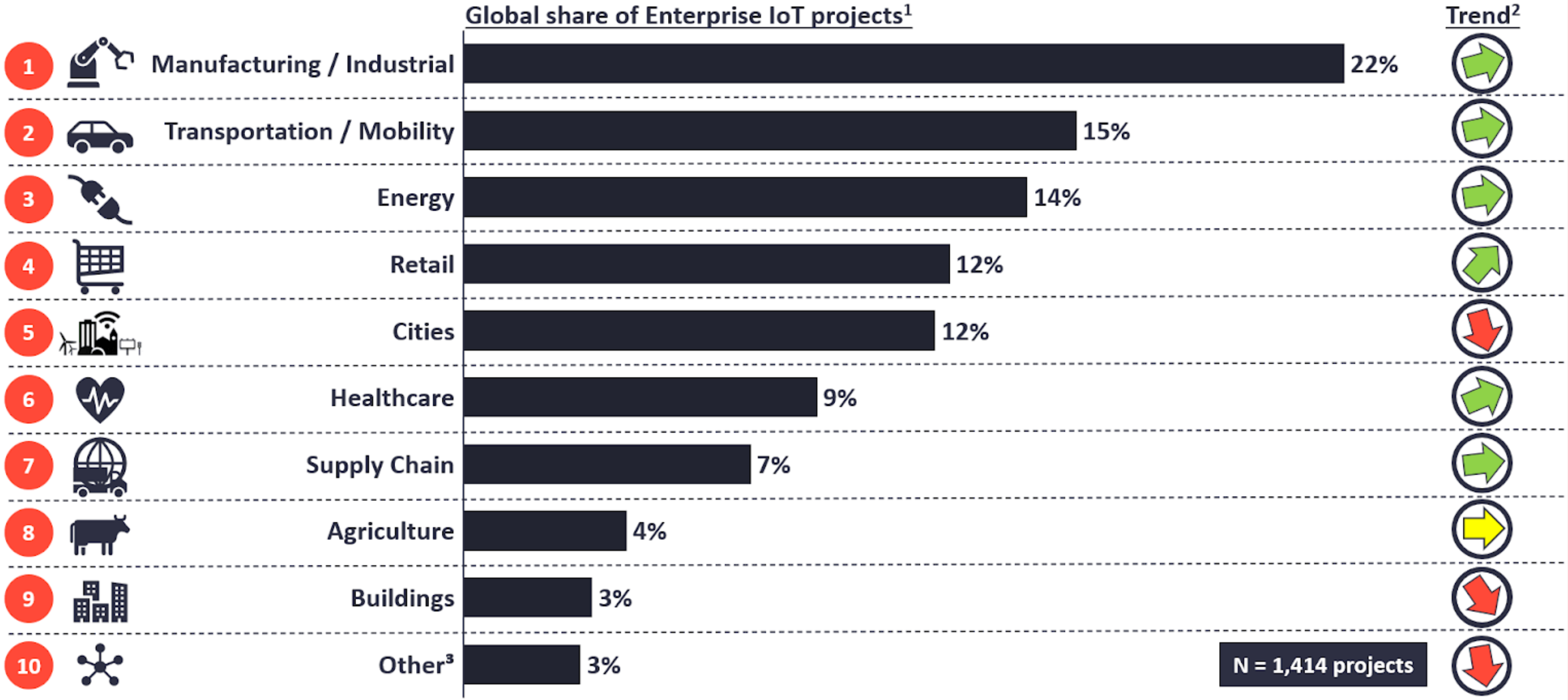
Note: Non-IoT includes all mobile phones, tablets, PCs, laptops, and fixed line phones. IoT includes all consumer and B2B devices connected – see IoT break-down for further details

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

IOT ANALYTICS

Insights that empower you to understand IoT markets

Top 10 IoT Application areas 2020

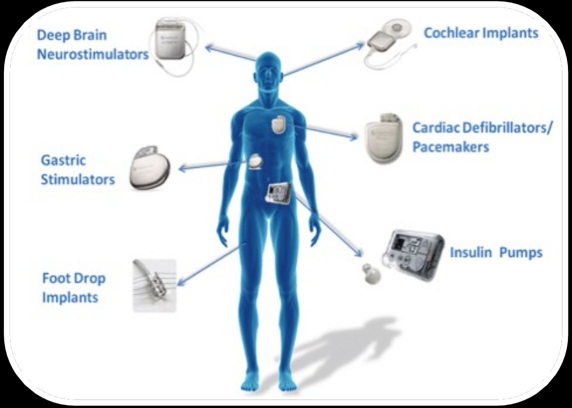


Note: 1. Based on 1,414 publically known IoT projects (not including consumer IoT projects eg smart home, wearables, etc.) 2. Trend based on relative comparison with % of projects in the 2018 IoT Analytics IoT project list e.g., a downward arrow means the relative share of all projects has declined, not the overall number of projects. 3. Other includes IoT projects from Enterprise & Finance sectors. **Source**: IoT Analytics Research - July 2020

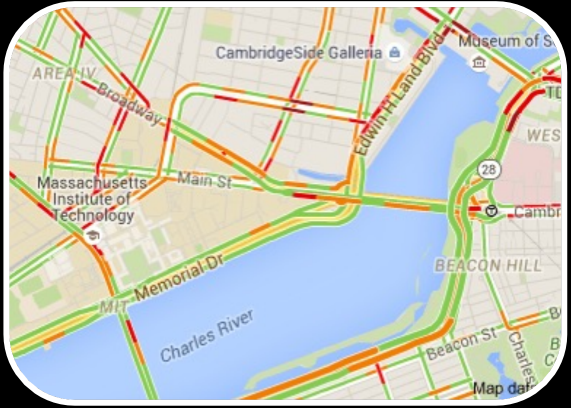
Areas Will Be Covered in This Course

Smart Homes

Health & Wellness

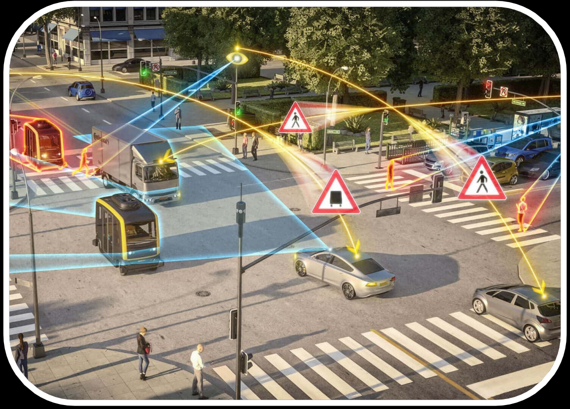


Transportation



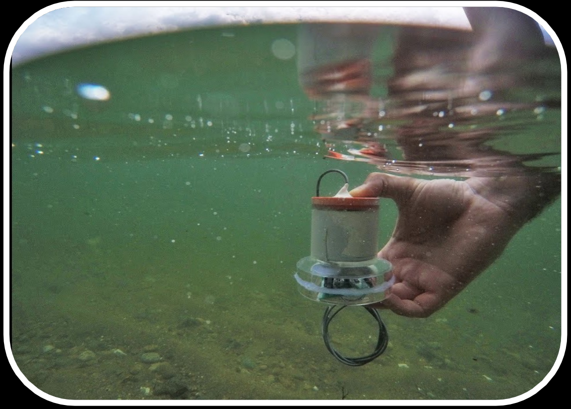
Wearables

Connected Vehicles



Digital Agriculture

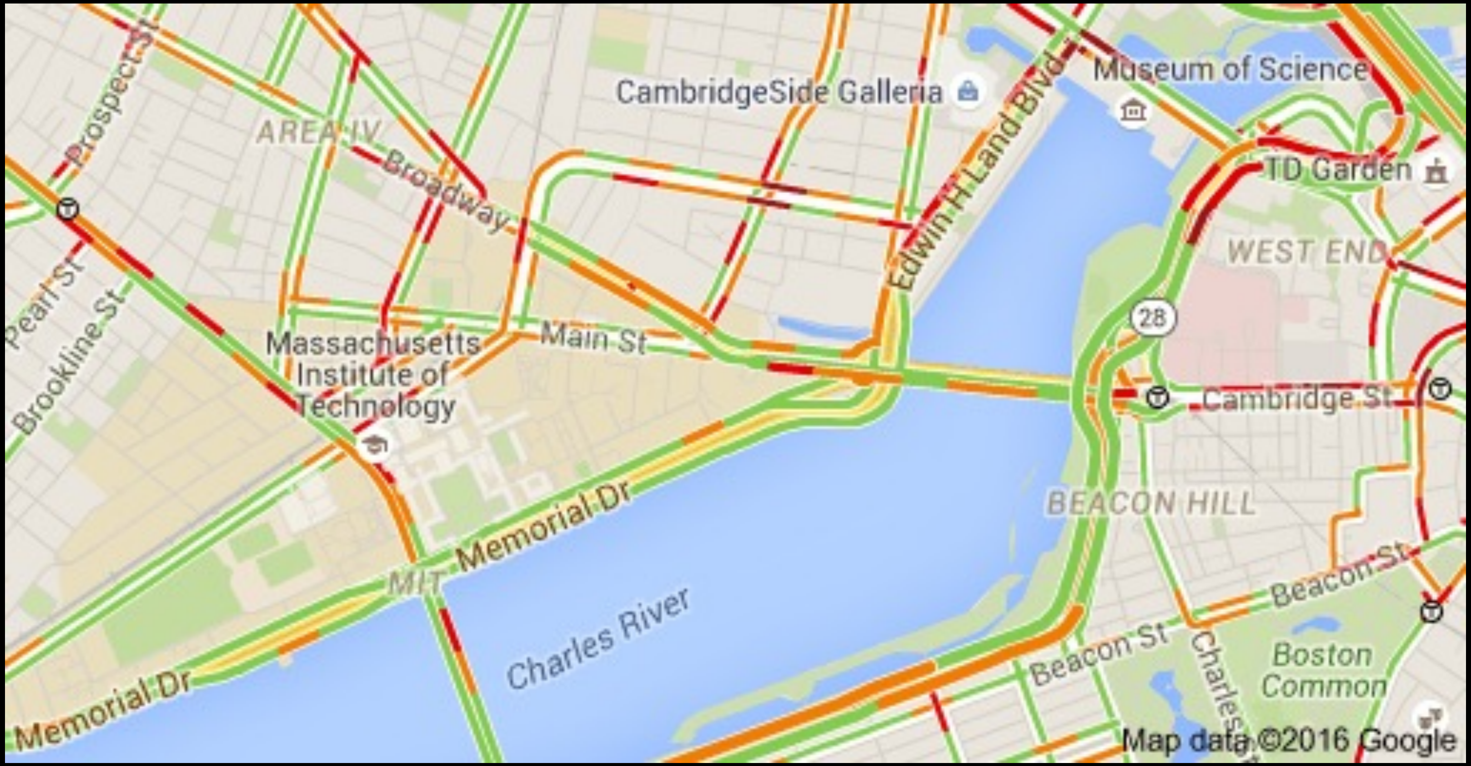
Ocean IoT



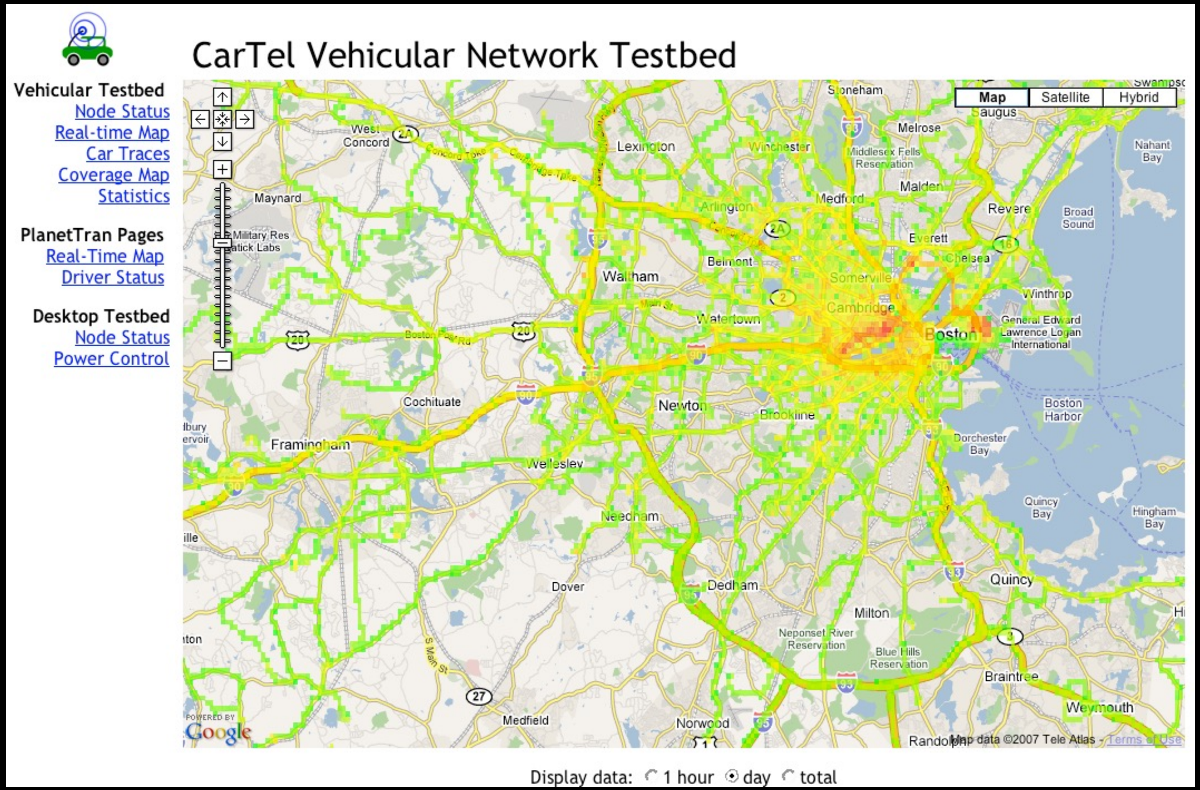
Space

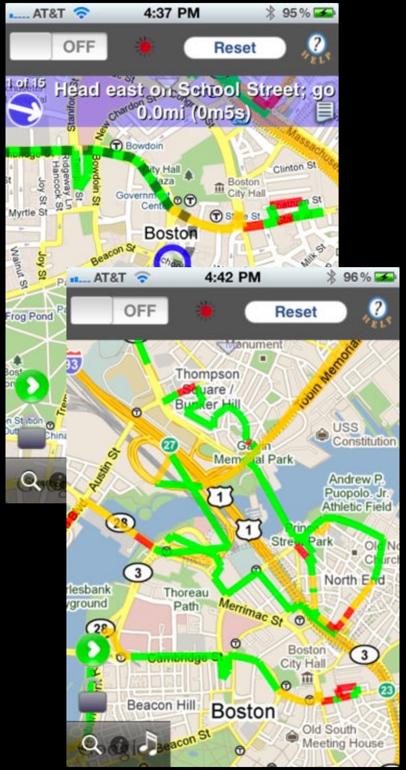
Example System

Transportation & Smart Cities

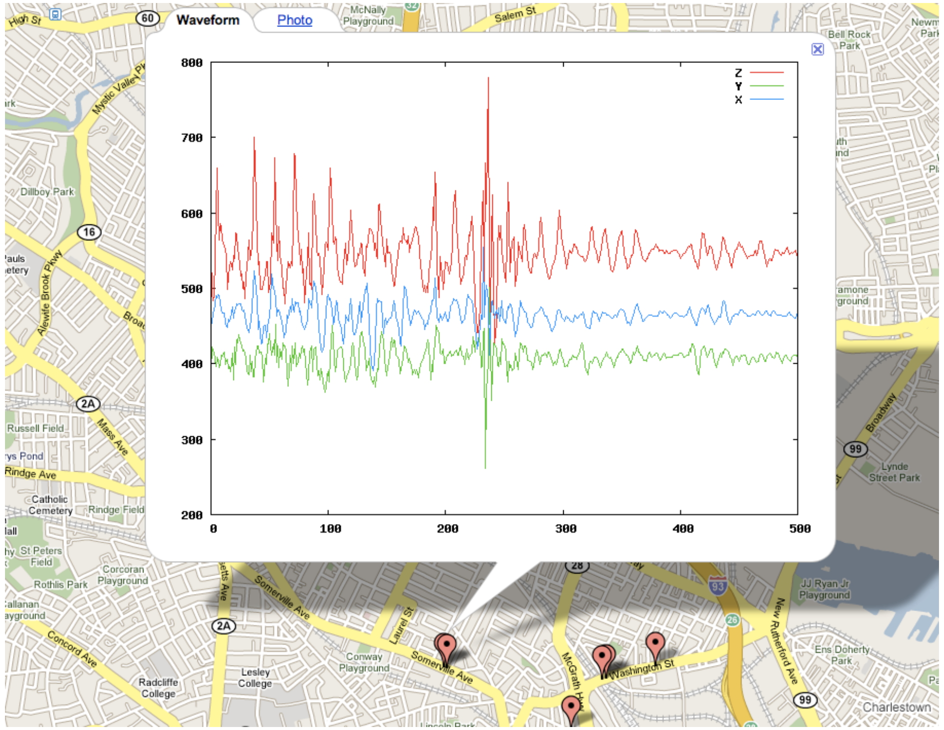


* Slides Courtesy of Fadel Adib and Hari Balakrishnan at MIT





CarTel Project at MIT (2005-2011)



Pothole Patrol (MobiSys 2008)

Road Safety

50 MILLION

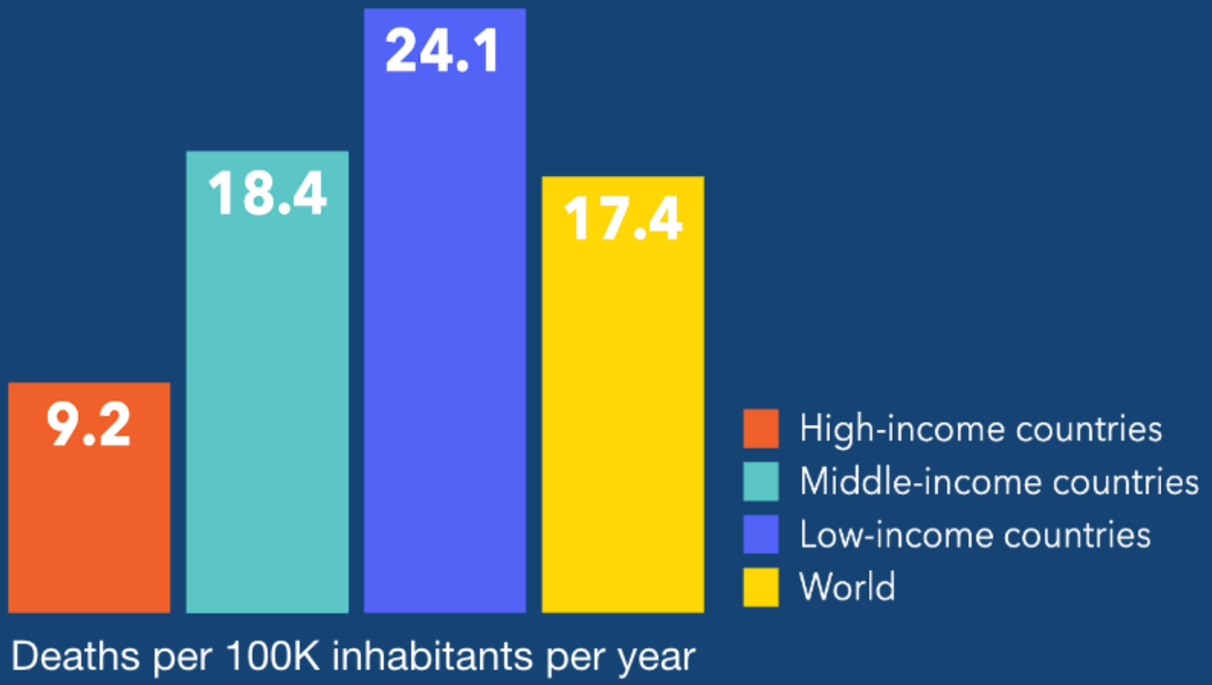
Road injuries per year

$1.8 TRILLION

Loss costs per year

1.35 MILLION

Road deaths per year
(50% of COVID)



Collect raw sensor data

IoT sensors

Phone sensors

Connected car sensors

Video

Fleet devices

CAMBRIDGE MOBILE TELEMATICS

Transform in DriveWell™ IoT SaaS platform

Deliver insights to your systems & processes

Risk

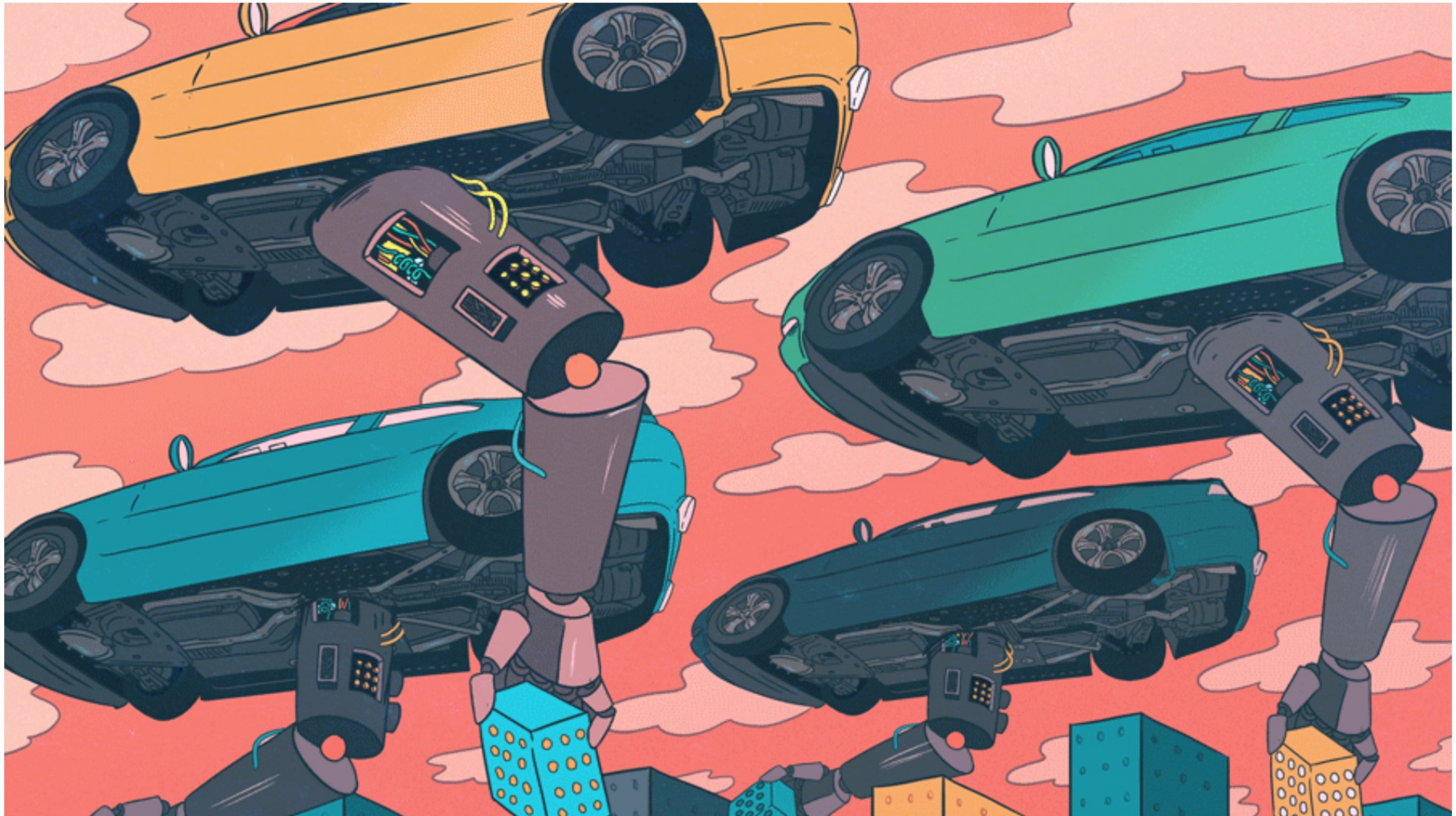
Crash assistance

Claims

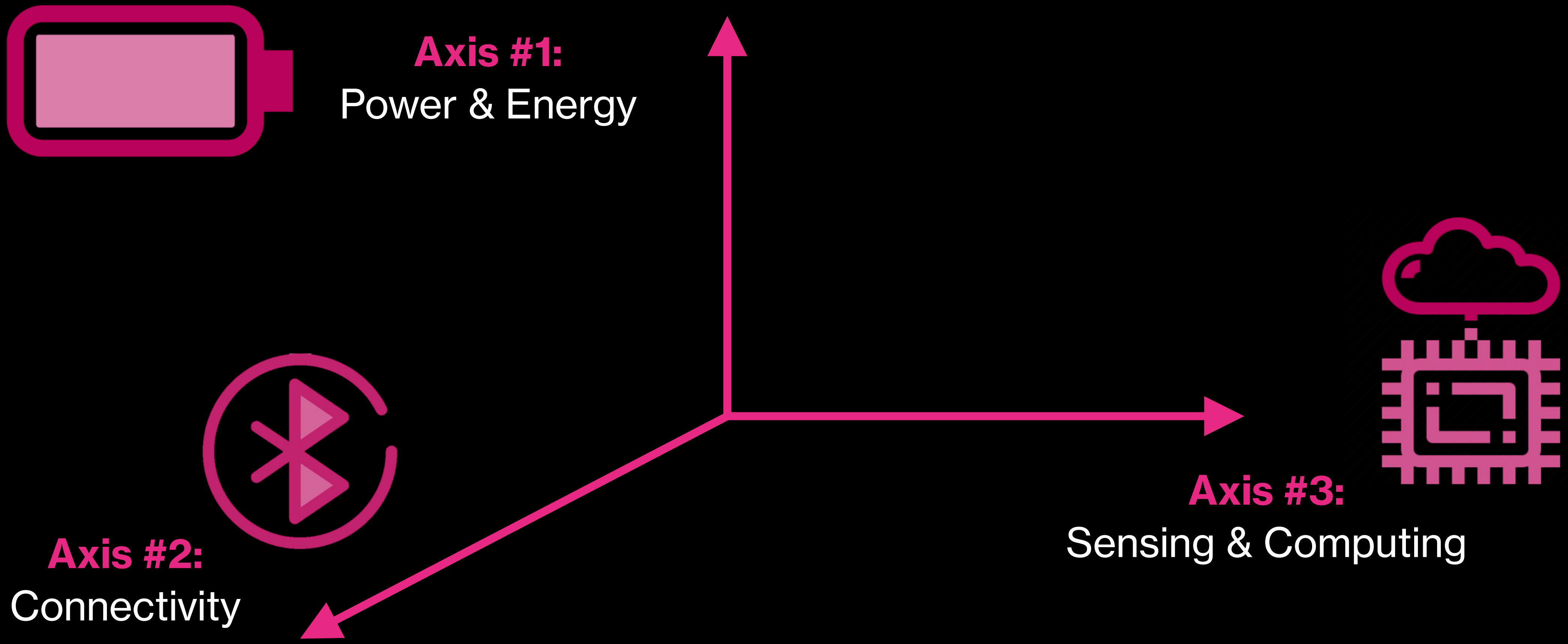
Behavior change

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

Jason D. Rowley December 19, 2018



Main Component of IoT Systems



Axis #3: Sensing & Computing

WHAT?

Sensing Objectives

Locations

Health

Motion & Activity

Environment

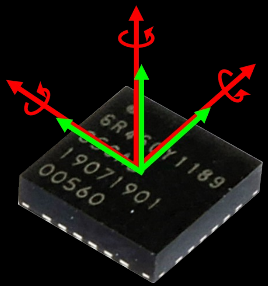
HOW?

Sensing Modalities

Radio

Acoustic

Inertial

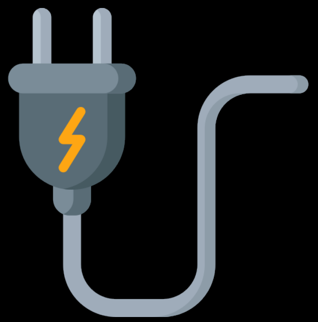


Visual

Axis #2: Power & Energy

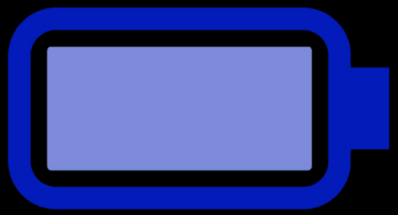
Power source

Infrastructure



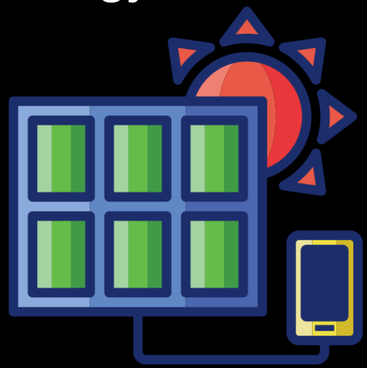
- Electricity, Network

Battery



- Rechargeable?

Energy Harvest



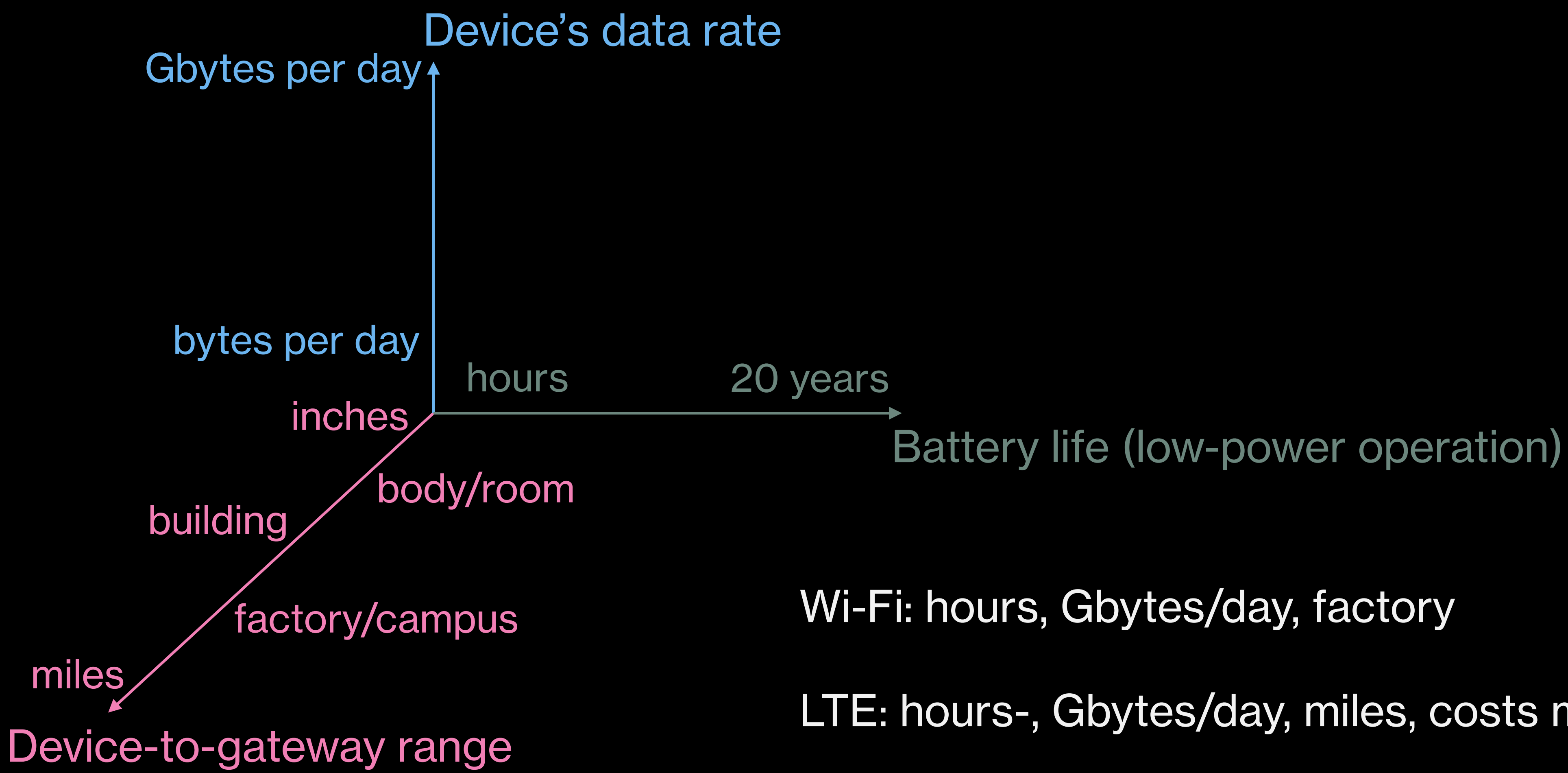
- Ambient, wireless power
- Solar, waves, human motion

Efficient Computing

- Edge vs cloud processing
- Efficient ML/processing with resource constraints

Axis #1: Connectivity

What are the metrics that we care about?

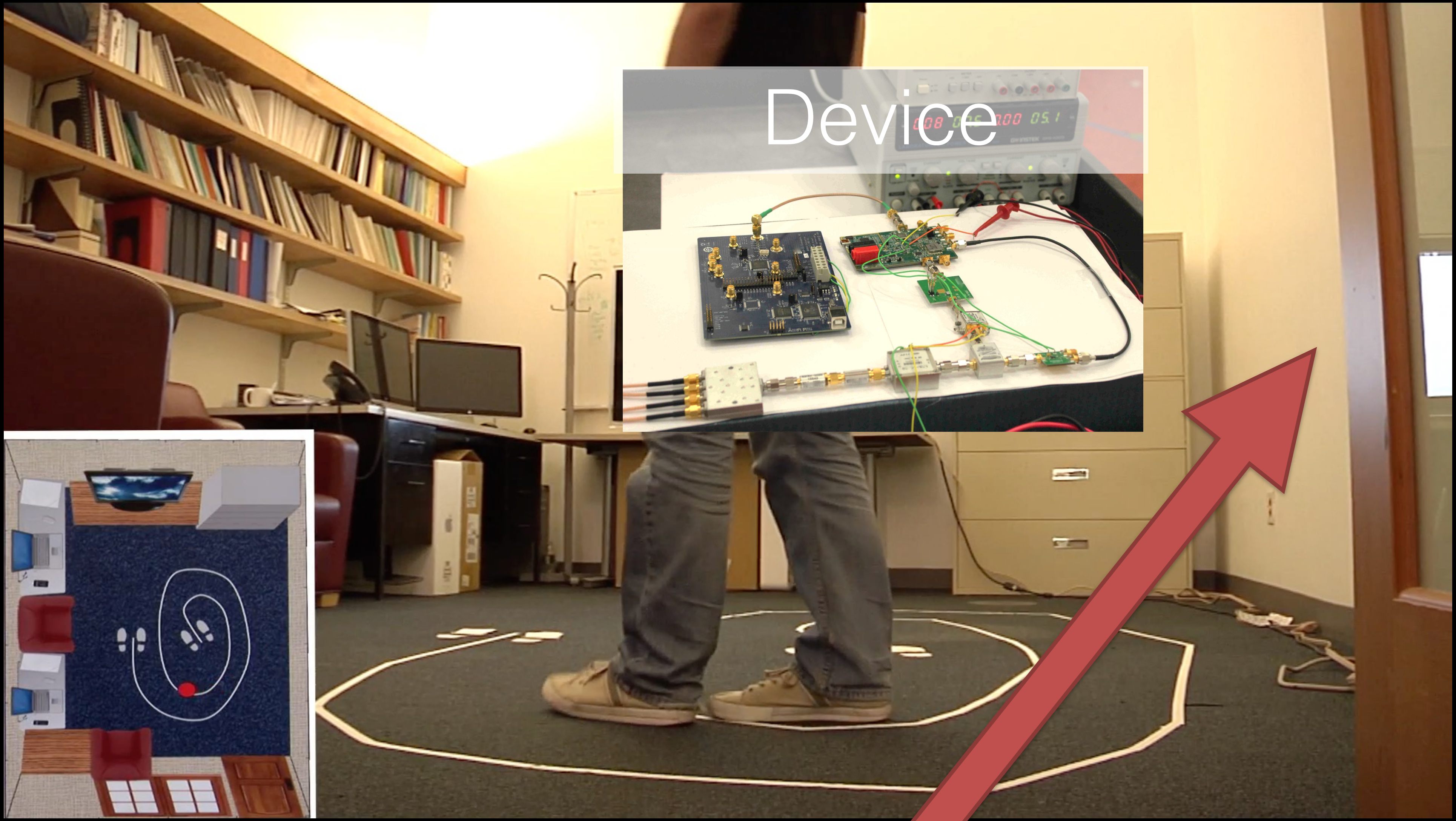


Wi-Fi: hours, Gbytes/day, factory

LTE: hours-, Gbytes/day, miles, costs more

Example Mobile and IoT Systems

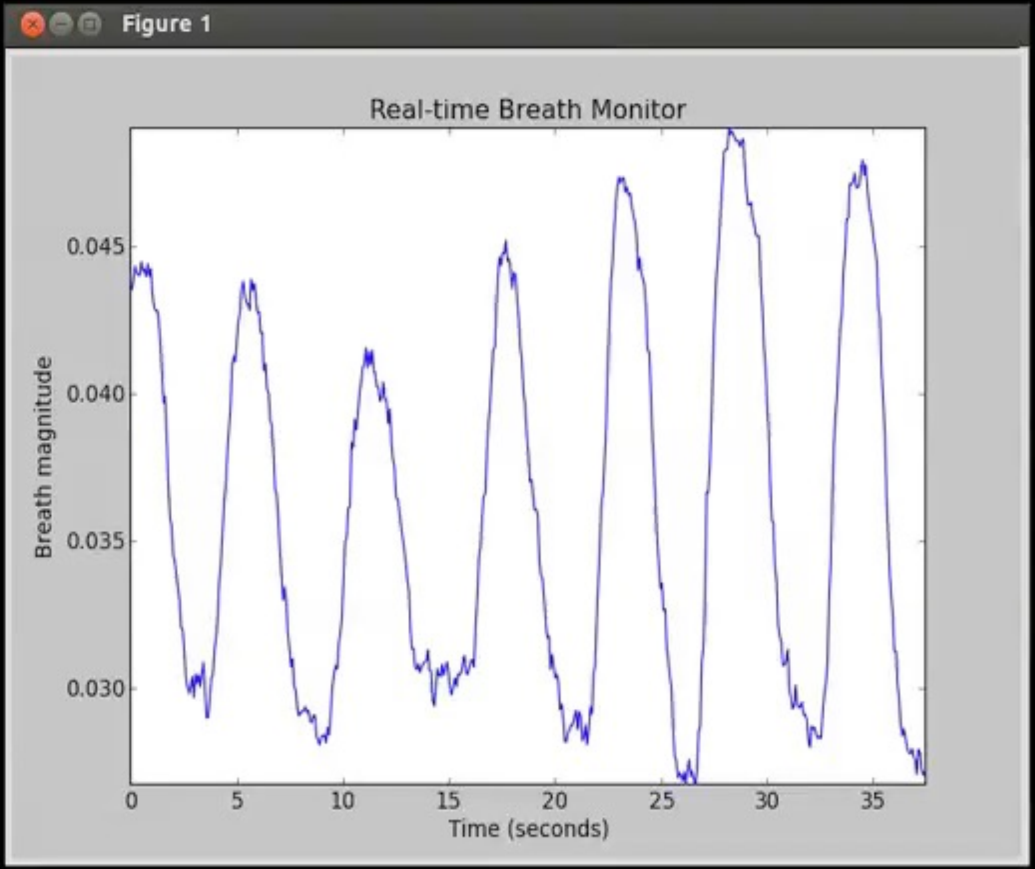
Device-Free Localization (WiTrack, 2014)

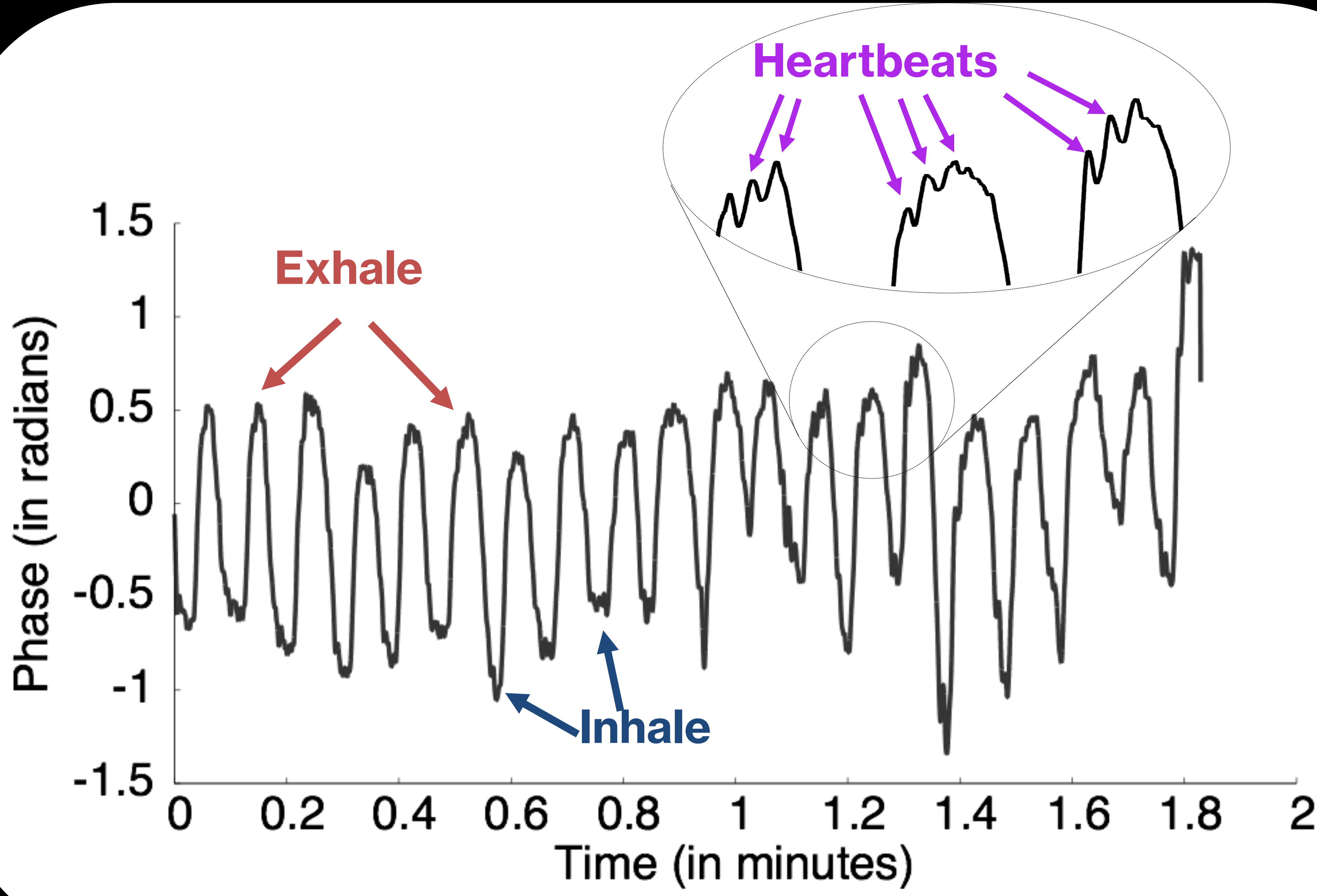


Device in another room

Through-Wall Vision (RF-Pose, 2018)

Breath Monitoring (Vital-Radio, 2015)





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

Mobile Security
Case Study: Inaudible Voice Commands

Can hack Android/Alexa using inaudible voice commands

Tiny Deep Learning on IoT Devices

1. Person Detection
2. Visual Wake Words
3. Face & Mask Detection

End-to-end IoT System
Case Study: Precision Agriculture

Course Organization

Module 1: Localization and Motion Tracking

Contextual information: location impacts how data is interpreted

Location-based services: ride-sharing, retail in-store promotion

Spatial computing: motion tracking for immersive interactions

Spatial intelligence: combine sensor readings across buildings/cities

We will cover:

- Fundamental principles for localization and tracking
- Different sensing modalities for localization: radio, ultrasound, inertial, and cameras.

Course Organization

Module 1: Localization and Motion Tracking

Module 2: Sensing

Module 3: Connectivity

Module 4: Low-power IoT & Efficient Computing

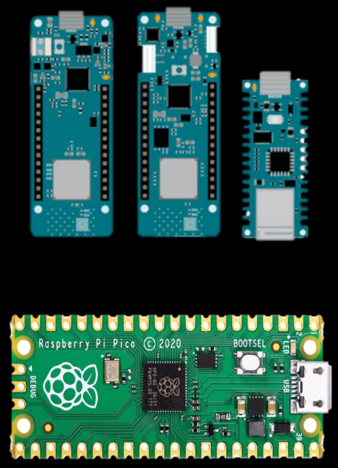
Module 5: Emerging Topics

Our lecture = Fundamentals + State-of-the-art systems

iOS Labs

Phone loaded with sensors

MCU



Sensors

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?

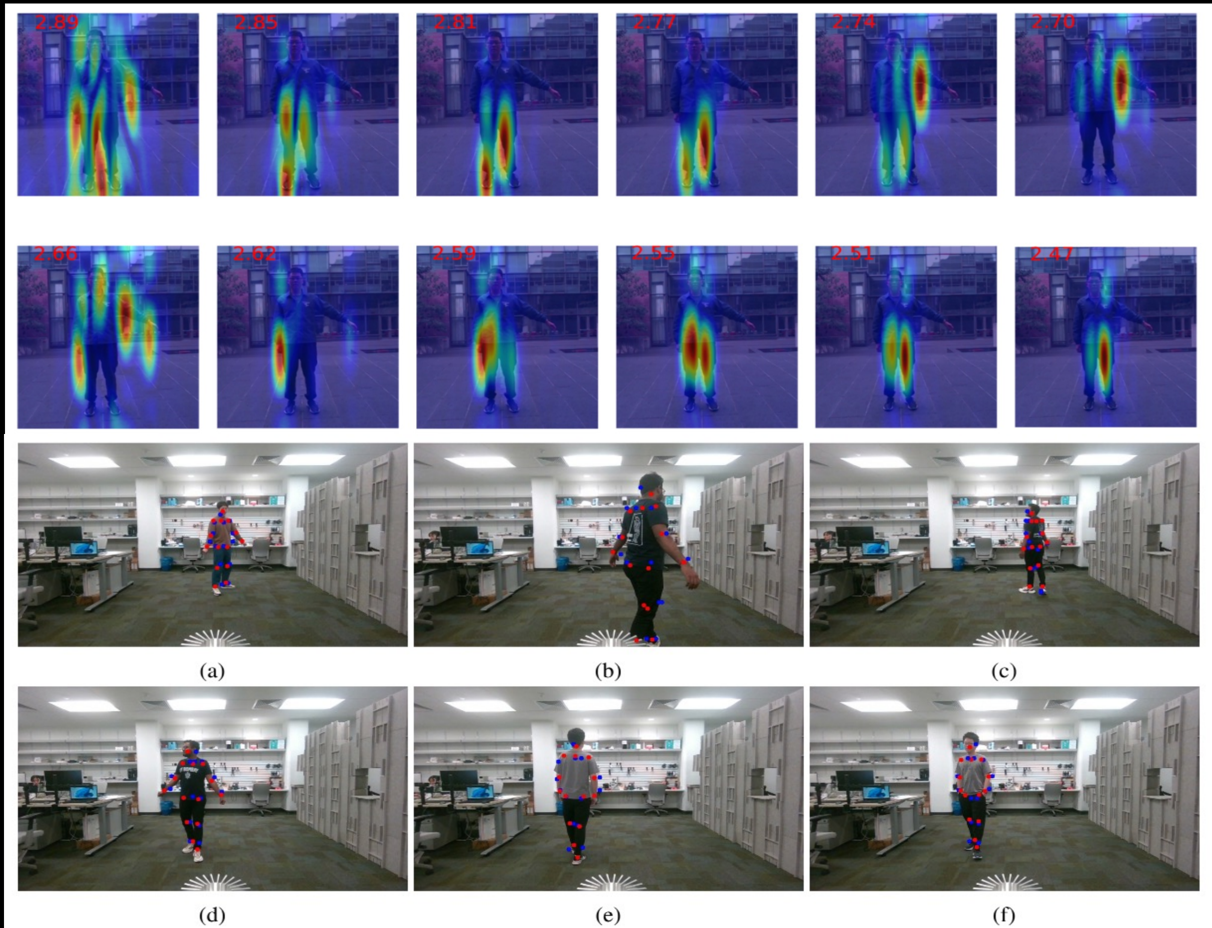
Timeline:

- Proposal (2 pages): March 15th
- Weekly project meetup: starting from March 15th
- Final presentation: April 29th
- Final report: May 5th

Past Course Projects

Localization in Penn Engineering

Pose Estimation with mmWave Radar



What you are expected to learn from this class

Lectures:

- Fundamentals of Mobile and IoT Computing
- How are they applied across various industries?
- What are emerging IoT domains and what does the future of IoT look like?

Labs:

- iOS APIs, including Bluetooth, inertial, basic UI programming

Project:

- Build a physical IoT project using material learnt from class
- Collaboration

Logistics

Grading:

- Reading assignment (20%)
- Module reviews (20%)
- iOS labs (20%)
- Course project (30%)
- Class participation (10%)

Staff:

- Lecturer: Mingmin Zhao (mingminz@cis.upenn.edu)
- TA: Haowen Lai (hwlai@cis.upenn.edu)

Haowen Lai (hwlai@cis.upenn.edu)

Next Lecture

- Time: Wed Jan 24^{th}
- Topic: Fundamentals of Localization
- Readings: **Chapter on Localization**