6.S062: Mobile and Sensor Computing

aka IoT Systems

http://6s062.github.io/6MOB

Lecturers

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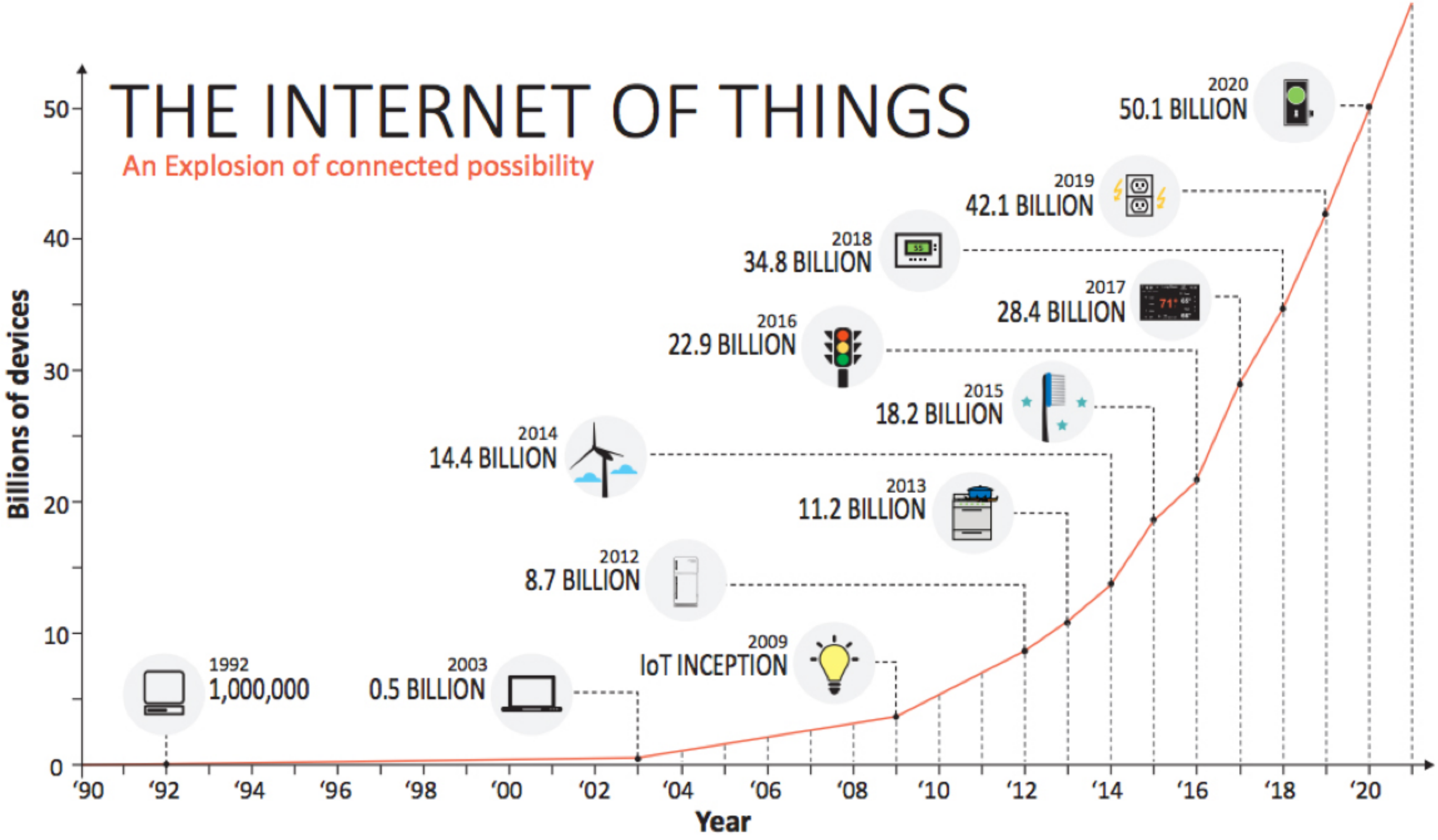
Sign up on Piazza for announcements

Internet-of-Things

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

- *Acquire* (*sense*) data from the environment
- *Pre-process* data locally
- *Deliver* data to servers
- *Draw inferences* and *provide insights* about the world from the data using computational techniques
    - Sensor fusion, data integration
    - Signal processing
    - Machine learning
- *Control* actions in the environment


THE INTERNET OF THINGS
An Explosion of connected possibility
Billions of devices
50
40
30
20
10
0
1992
1,000,000
2003
0.5 BILLION
2009
IoT INCEPTION
2012
8.7 BILLION
2013
11.2 BILLION
2014
14.4 BILLION
2015
18.2 BILLION
2016
22.9 BILLION
2017
28.4 BILLION
2018
34.8 BILLION
2019
42.1 BILLION
2020
50.1 BILLION
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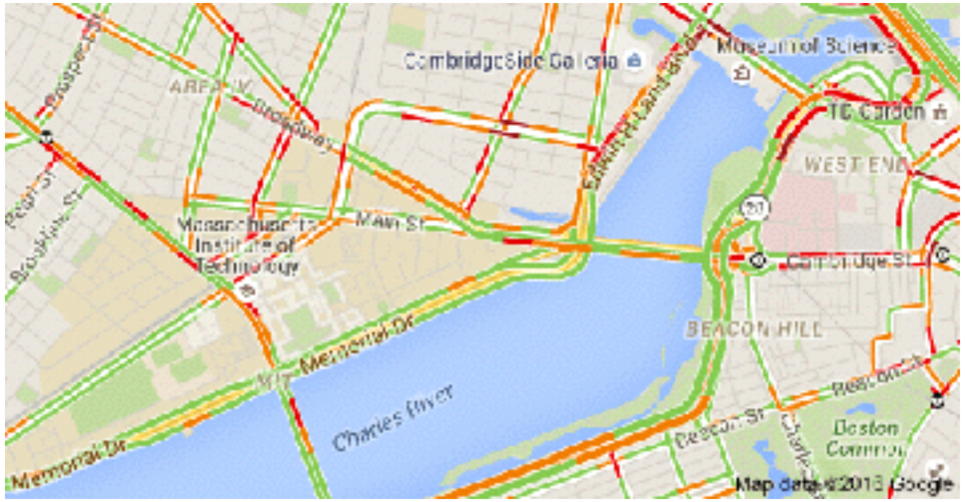
Year

IoT is Transforming Industries

Transportation & Smart Cities



Medicine

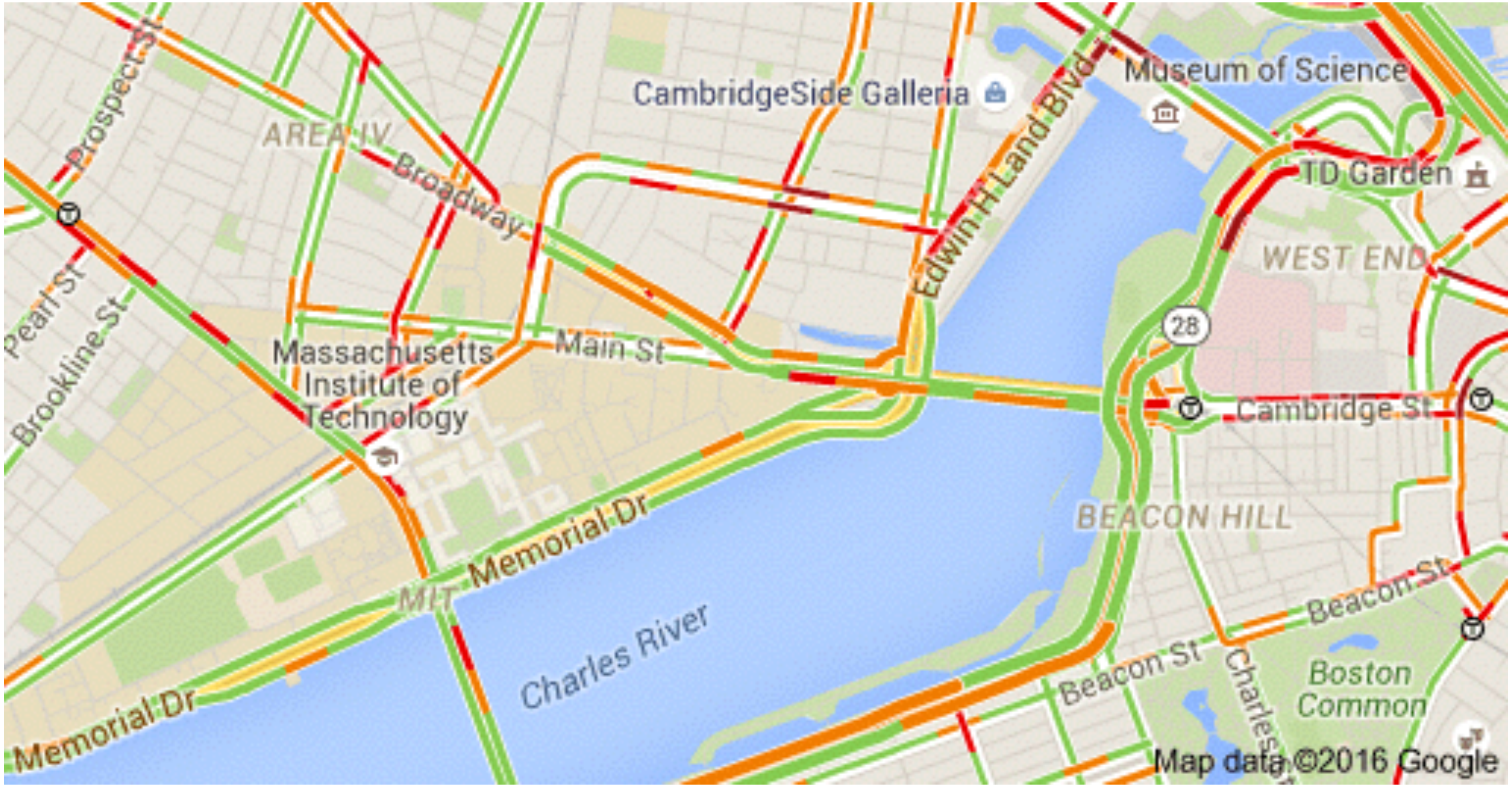
Smart Homes

Health & Wellness

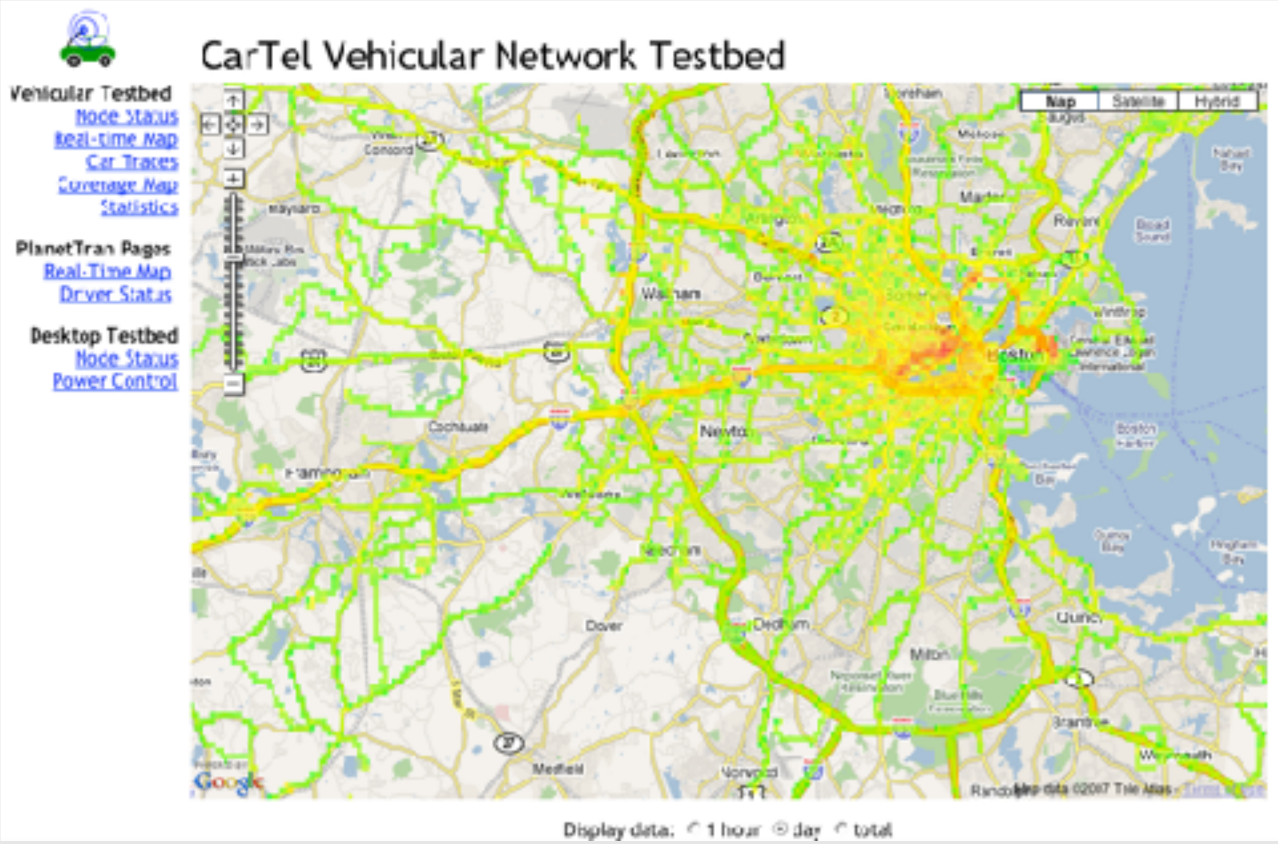
Connected vehicles

Precision Agriculture

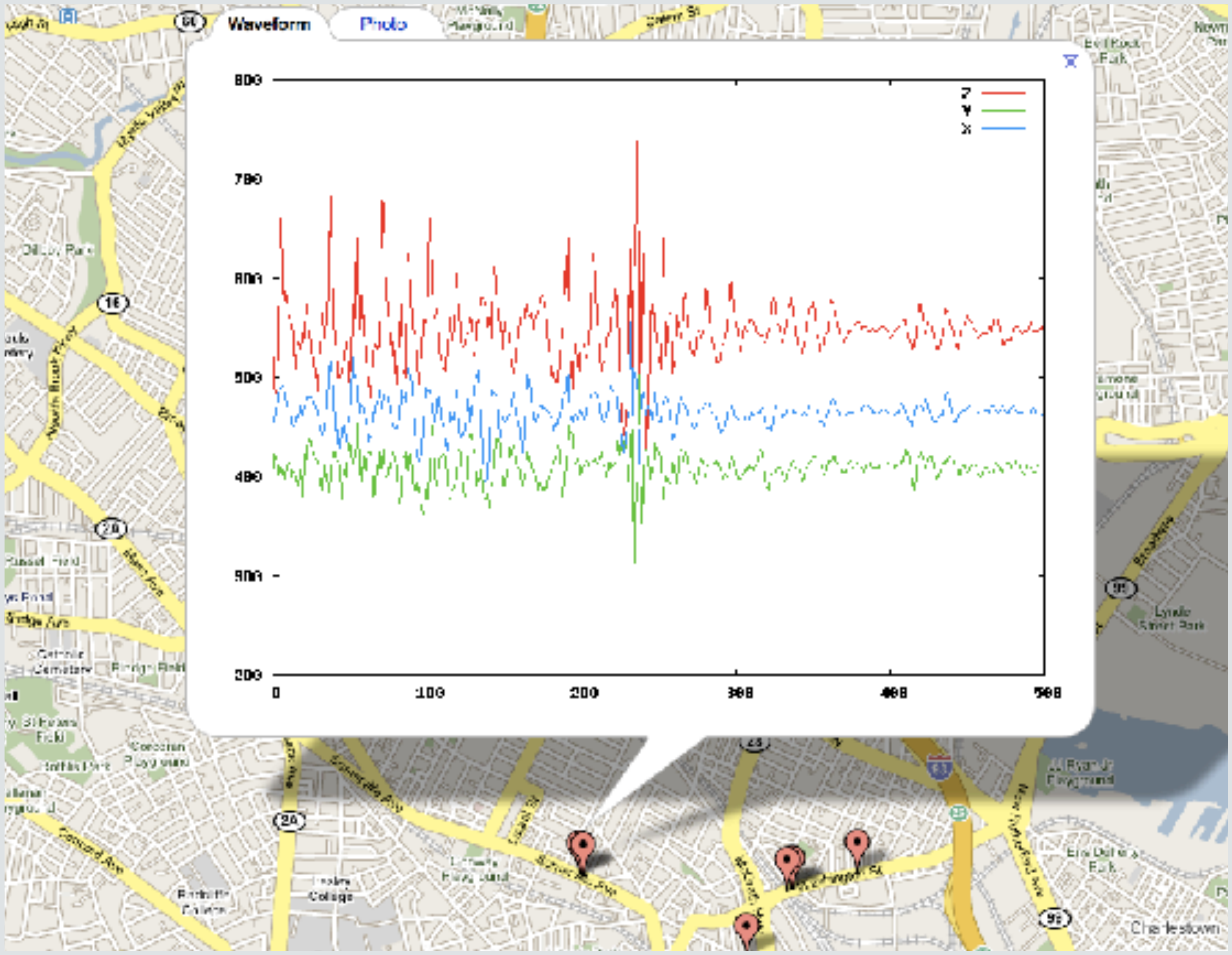
Transportation & Smart Cities



CarTel Project at MIT (2005-2011)



Pothole Patrol



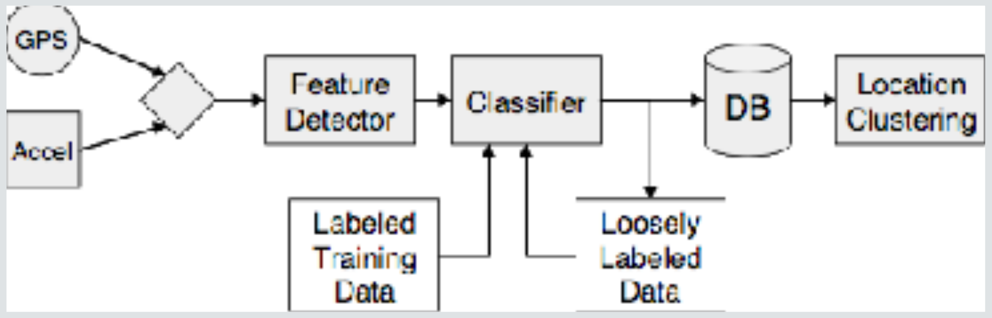
Classification-based Approach

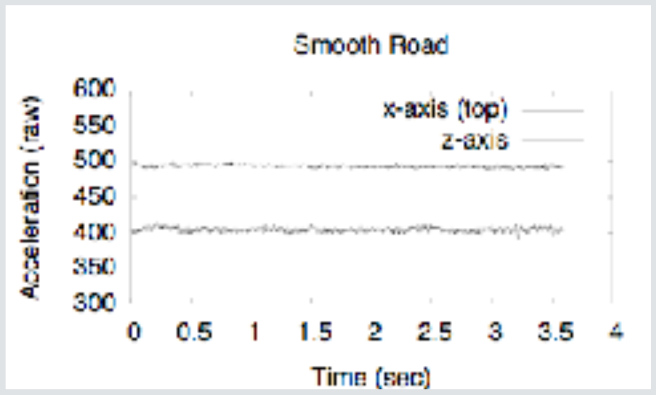
Classifier differentiates between several types of anomalies

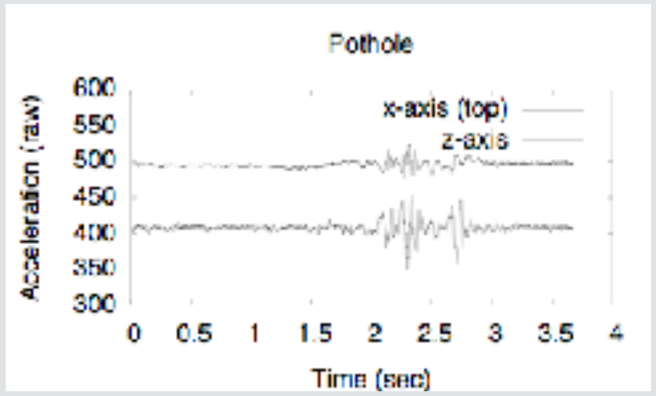
Window data, compute features per window

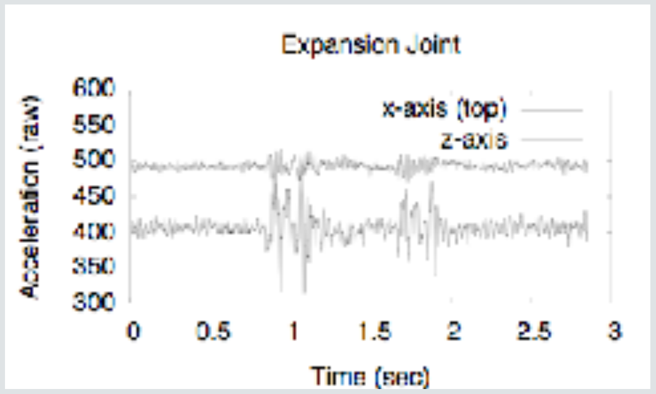
Variety of features:

- Range of X,Y,Z accel
- Energy in certain frequency bands
- Car speed
- …









DriveWell: Safe Driving

Make roads safer by making drivers better

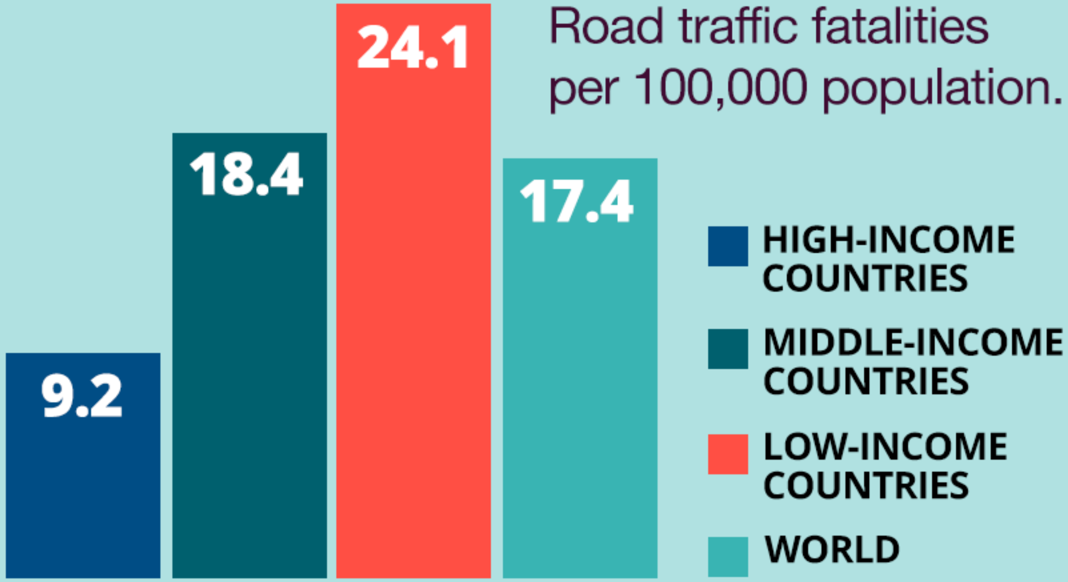
50 MILLION
ROAD INJURIES PER YEAR

1.25 MILLION
ROAD TRAFFIC DEATHS OCCUR EVERY YEAR

14%
INCREASE IN U.S. ROAD FATALITIES BETWEEN 2014 AND 2016

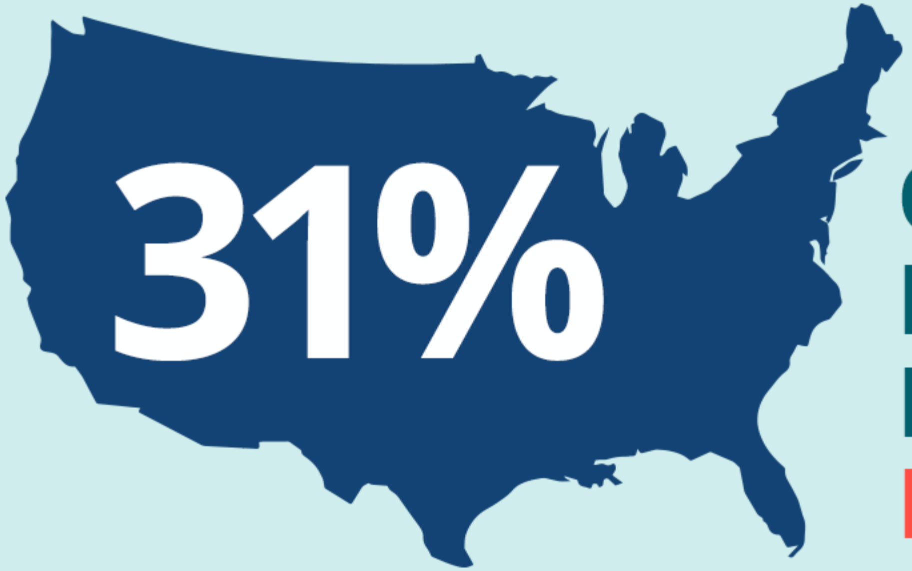
A GLOBAL PROBLEM.

Road traffic fatalities per 100,000 population.



Data Source: World Health Organization, Global Status Report on Road Safety, 2015, Distraction.gov & Cambridge Mobile Telematics

IN 2014, **431,000** WERE INJURED IN CRASHES INVOLVING DISTRACTED DRIVERS

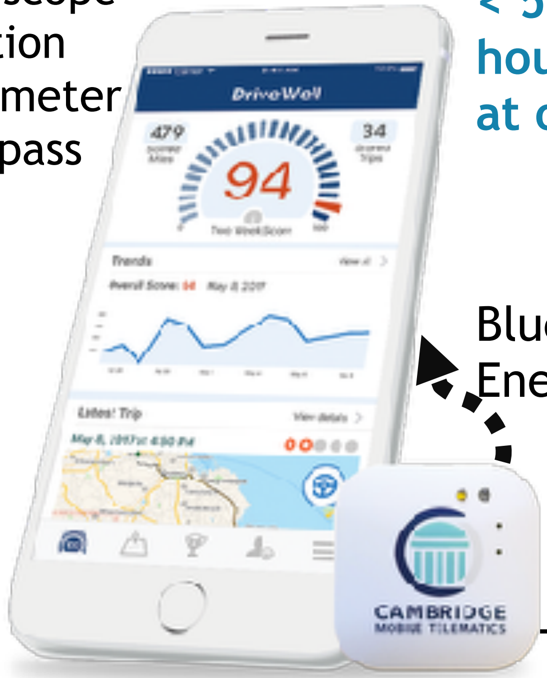


31% OF DRIVES IN THE U.S. HAVE **SIGNIFICANT DISTRACTION** (CMT DATA)

Example: Safe Driving (Drivewell)

Key capabilities: "safety score", incentives, end-to-end impact alerts

Smartphone sensors:
Acceleration
Gyroscope
Position
Barometer
Compass



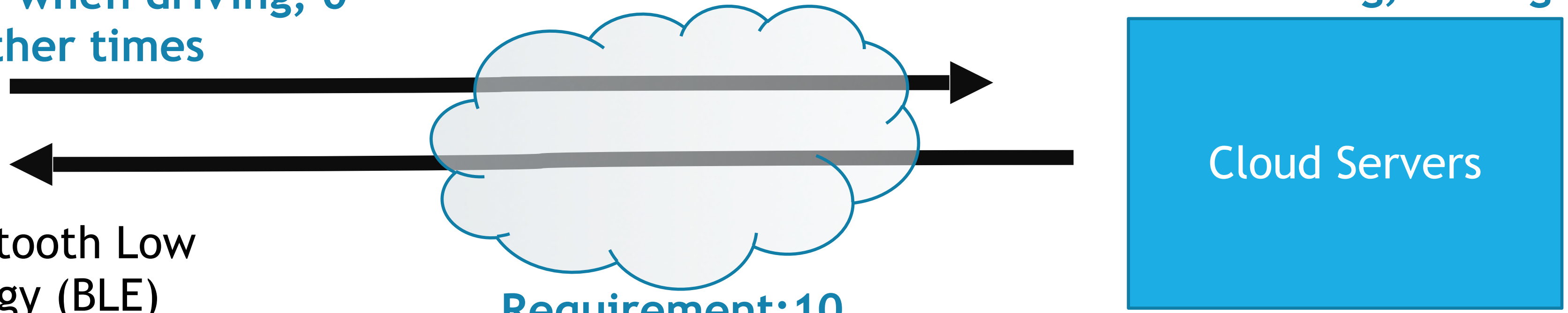
Requirement:
< 5% battery drain / hour when driving, 0 at other times

Bluetooth Low Energy (BLE)

Requirement:
4+ years battery life

Tag

Sense: Acceleration
Infer: Events, Impacts, trips start/end, mileage, duration



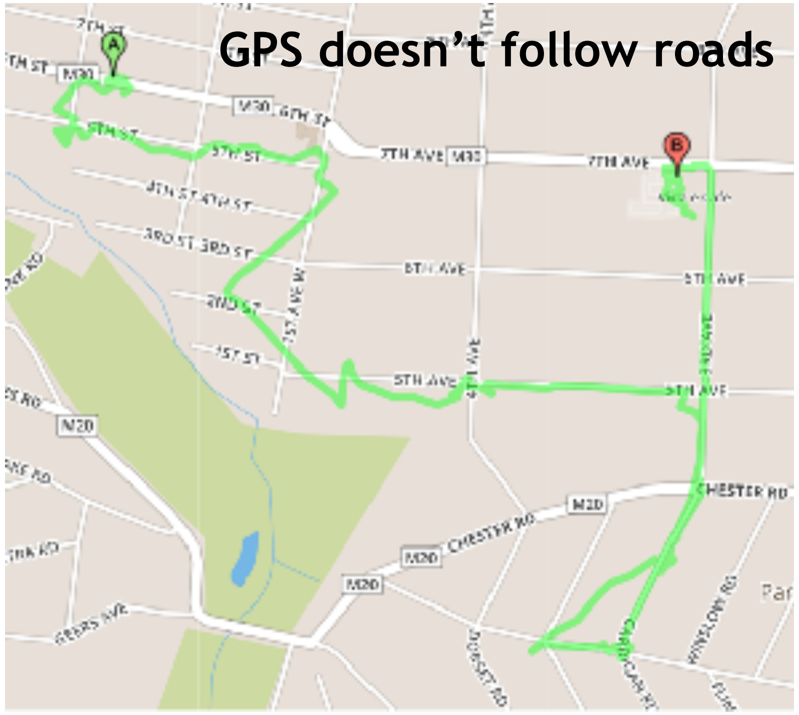
Requirement: 10 second end-to-end notification of accidents

Requirement: Accurately measure distracted driving, unsafe speeding, hard braking, mileage etc.

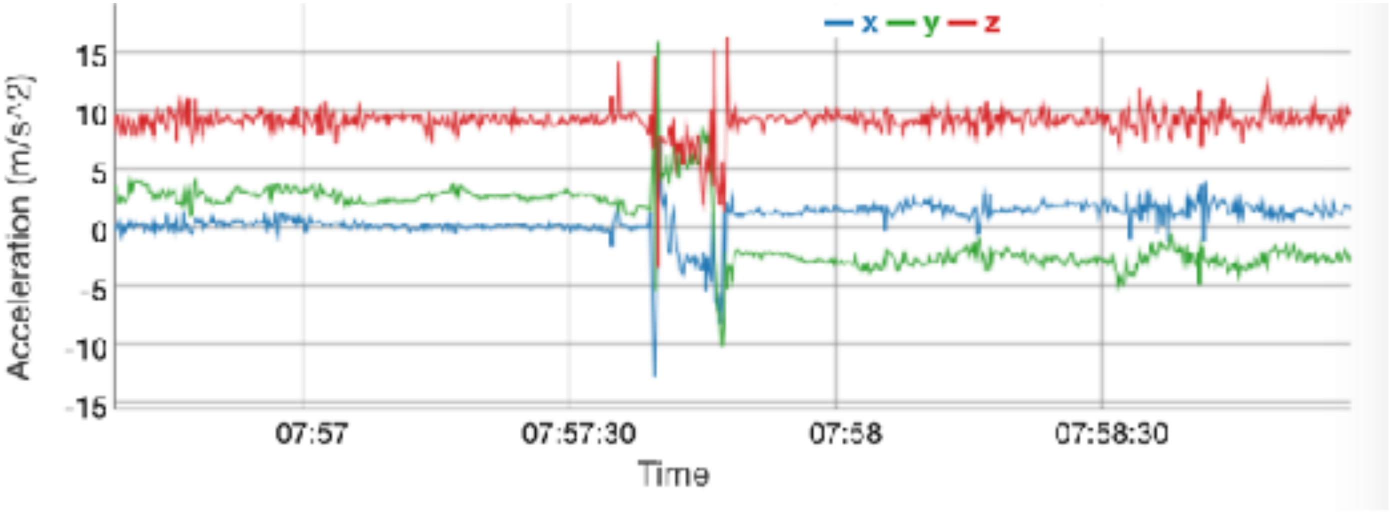
Requirement:
Prompt trip feedback within seconds-minutes

Drivewell Data Challenges

GPS doesn't follow roads



Users move phone while driving



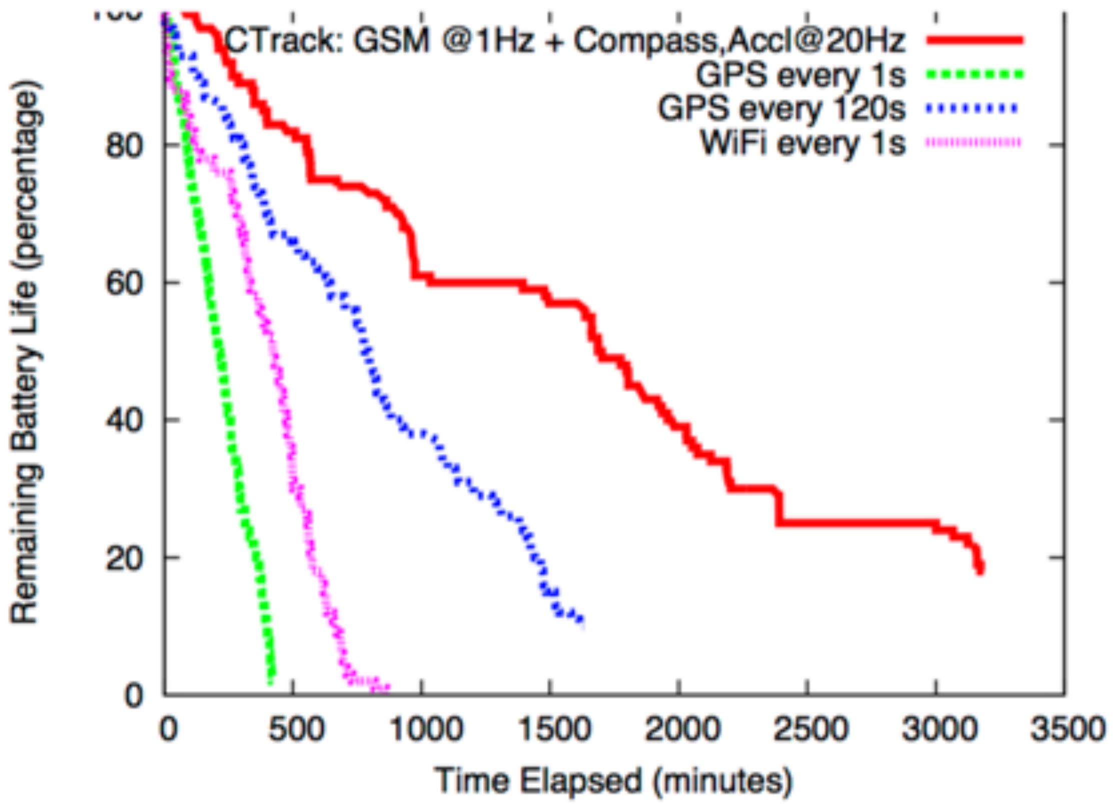
Certain classes of devices experience failures

Discover CBCharacteristic for CBService misses a few characteristics

442 Views 15 Replies Latest reply: Sep 29, 2015 2:05 AM by masakazu

Map-matching

Tradeoff between accuracy and energy

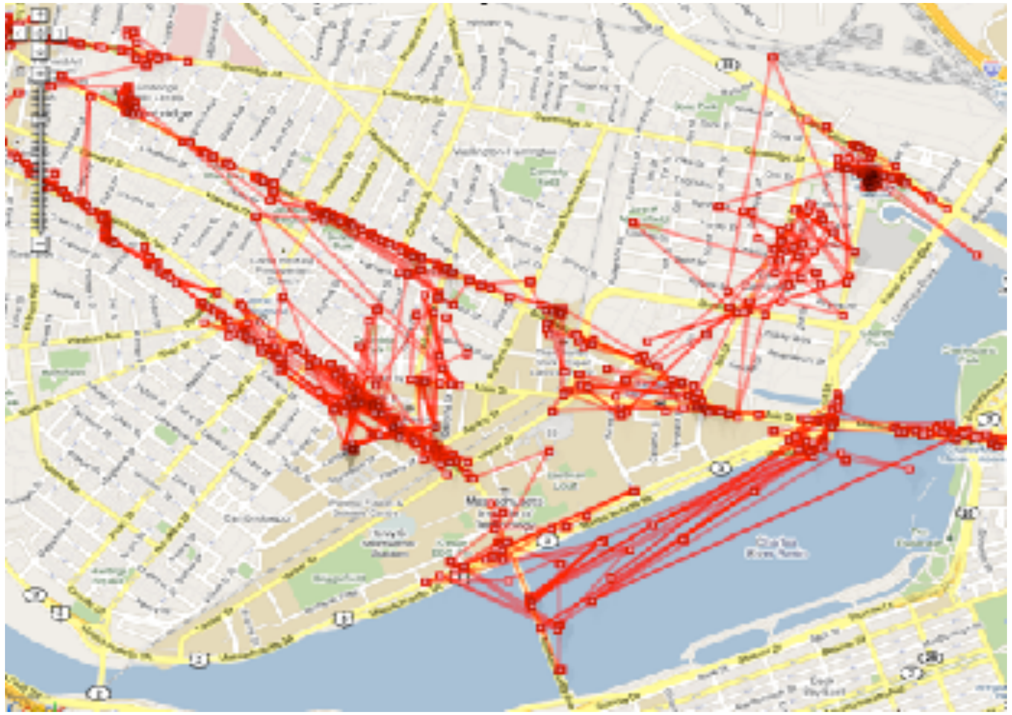


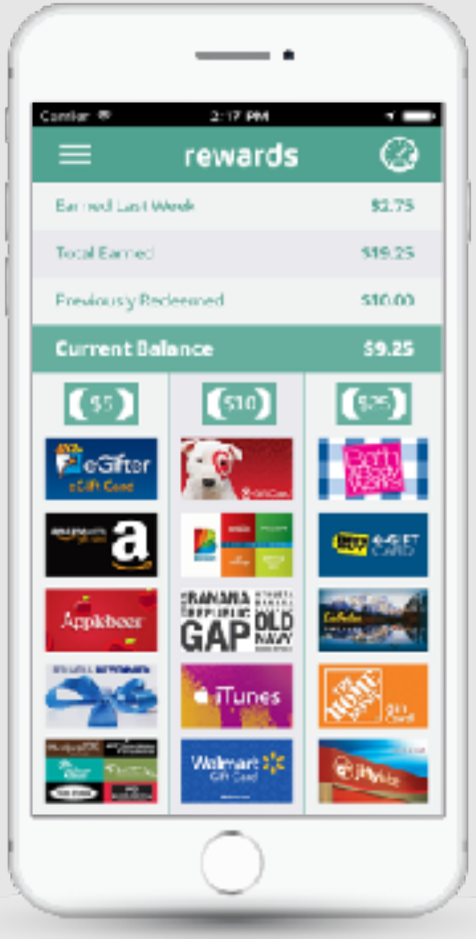
VTrack & CTrack Map-Matching Methods

Tradeoff between accuracy and cost

To this…

From this…

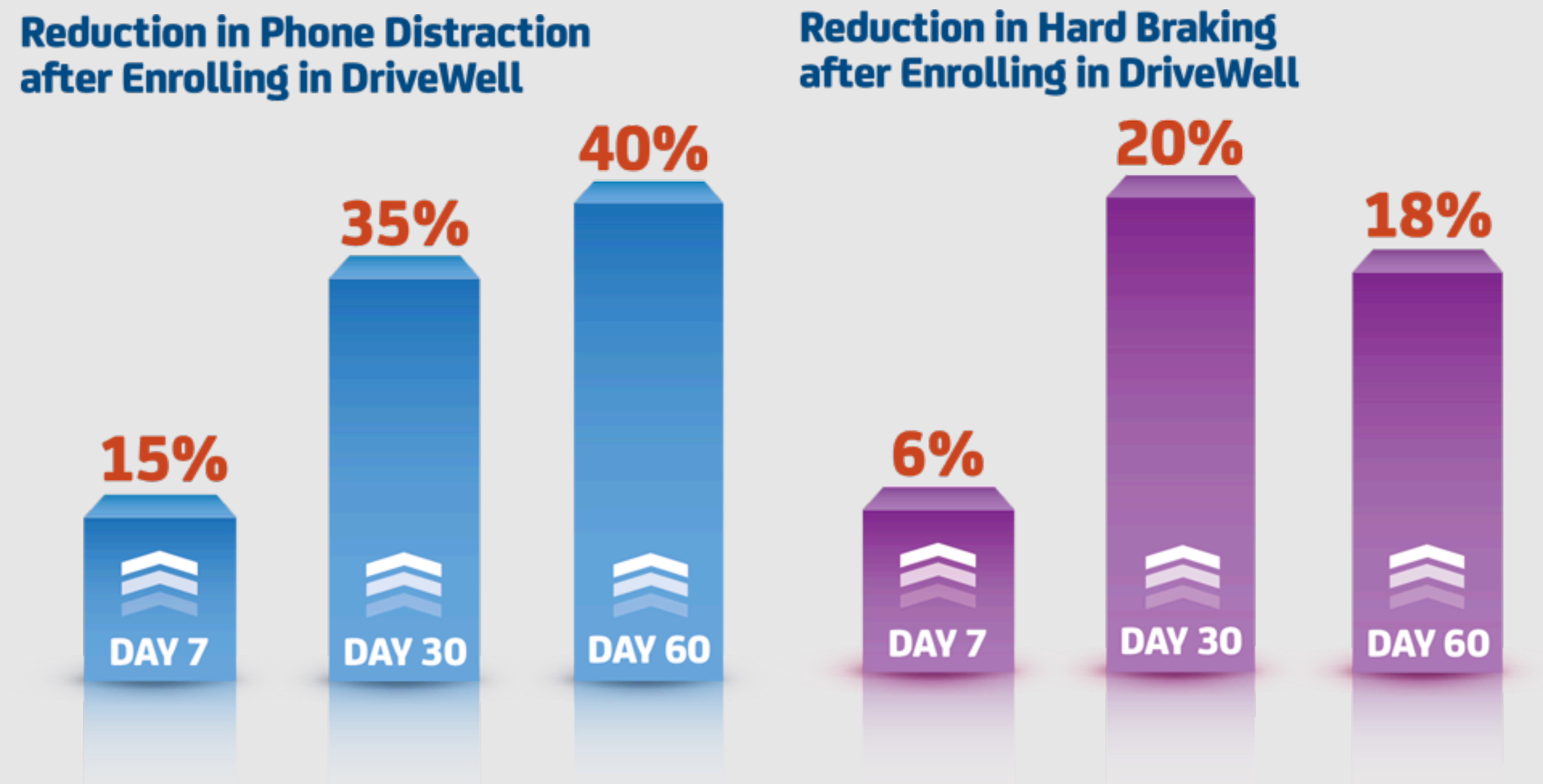




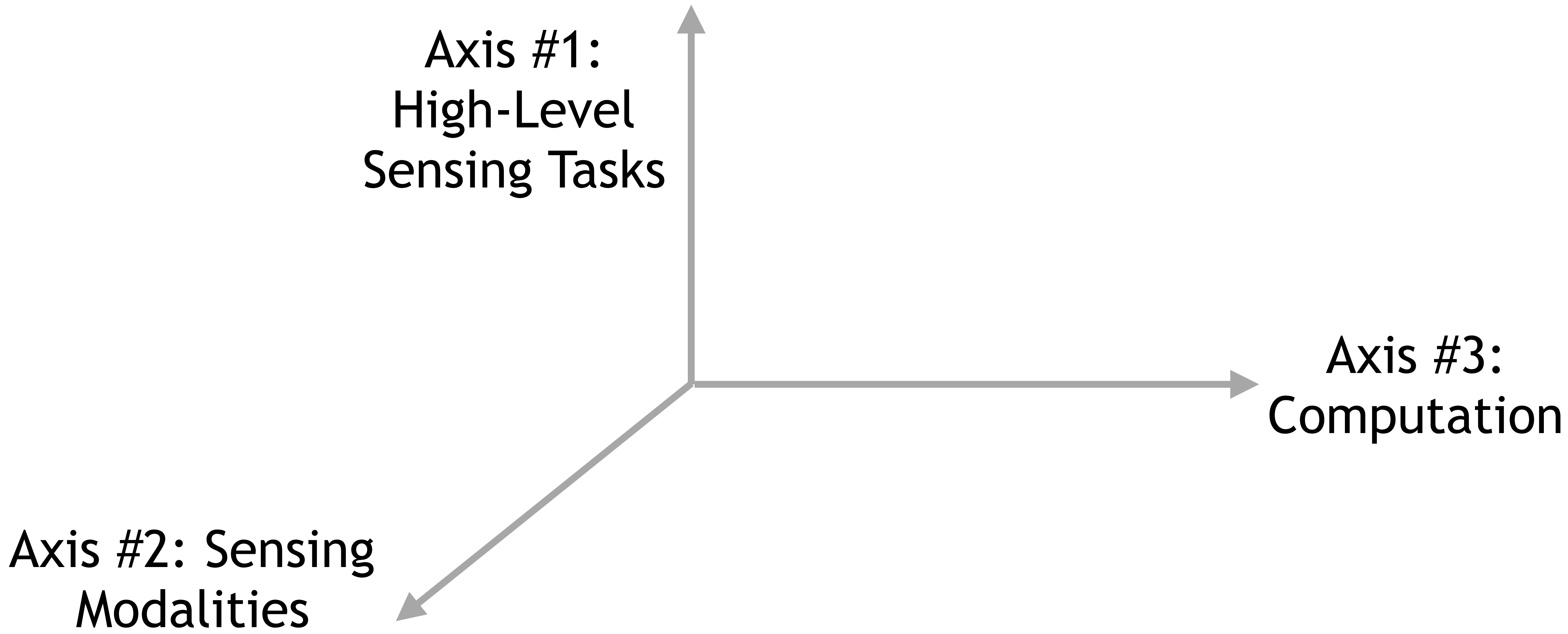
Rewards

Contests

Leaderboards & Social Features


Reduction in Phone Distraction
after Enrolling in DriveWell
15%
DAY 7
35%
DAY 30
40%
DAY 60
Reduction in Hard Braking
after Enrolling in DriveWell
6%
DAY 7
20%
DAY 30
18%
DAY 60

IoT Systems are designed along 3 main axes



Axis #1: High-Level Sensing Tasks

WHAT do we want to sense?

(1) Location

- Outdoors, indoors
- Humans, objects

(2) Dynamics

- Velocity, Acceleration
- Activities, Monitoring

(3) Properties

- Identify, Characterize
- Environment, Humans

Axis #2: Sensing Modalities

HOW will we perform this sensing?

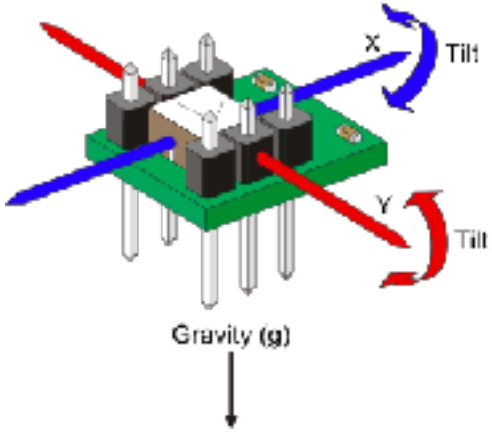
(1) Radio

- Wi-Fi
- Cellular
- Bluetooth

(2) Acoustic/ Ultrasonic

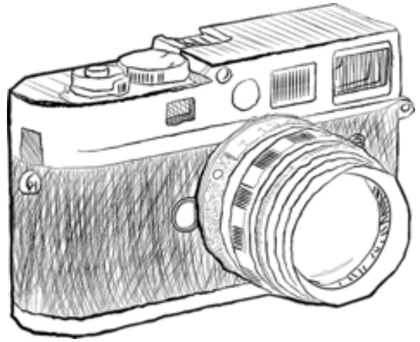
- Voices
- Engines
- Animals

(3) Inertial



- Gyroscope
- Accelerometer

(4) Visual



- Camera
- Infrared
- LIDAR

And many others: pressure, temperature, etc.

Axis #3: Computation

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

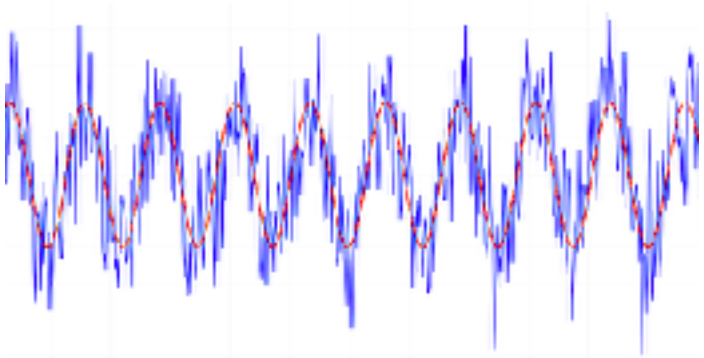
(1) Networking

- Connectivity
- Communication

(2) Data Management

- Storage
- Queries

(3) Signal Processing & Inference



- Digitization
- Inference & Machine Learning

(4) Security

- Digital, Analog
- Trust, Privacy

IoT System Architecture

Axis #1: Sensing Tasks	(1) Location	(2) Dynamics	(3) Properties	
Axis #3: Computation	(1) Networking	(2) Data Management	(3) Signal Processing & Inference	(4) Security
Axis #2: Sensing Modalities	(1) Radio	(2) Acoustic/ Ultrasonic	(3) Inertial	(4) Visual

Indoor Positioning (Cricket, 2001)

Accurate Localization (Cricket, 2003)

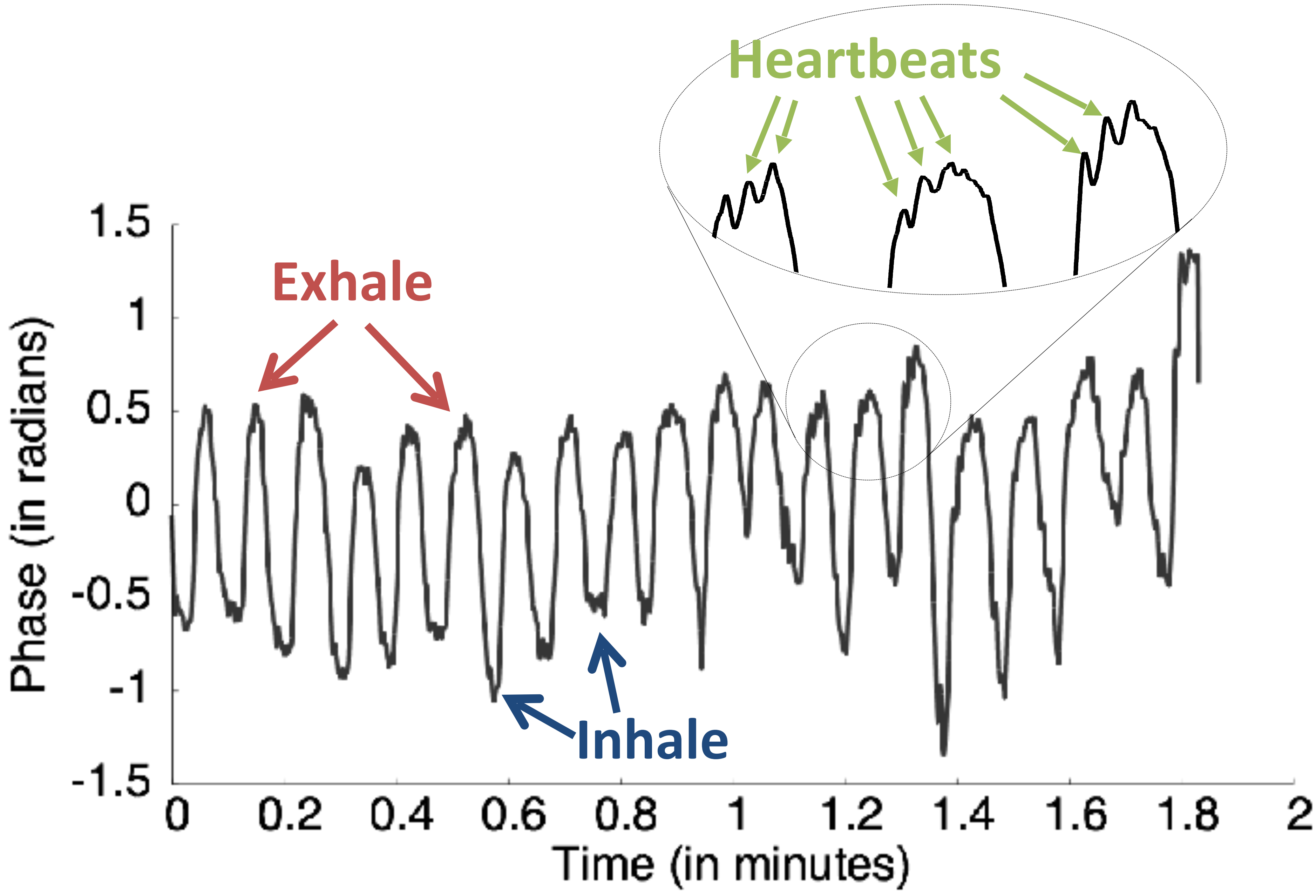
Device-Free Localization (WiTrack, 2014)

Device in another room

Seeing Through Walls (RF-Capture, 2015)

Breath Monitoring using Wireless (Vital-Radio, 2015)

Let’s zoom in on these signals



Heartbeats
Exhale
Inhale
1.5
1
0.5
0
-0.5
-1
-1.5
Phase (in radians)
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

Fundamental Constraints

- Noise
- Faults
- Energy (battery, power)
- Communication bandwidth
- Processing on “leaf” nodes (sensors)
- Security is harder than with datacenter servers
    - In uncontrolled areas, act as “servers” providing data, resource-constrained nodes, physical attacks, …

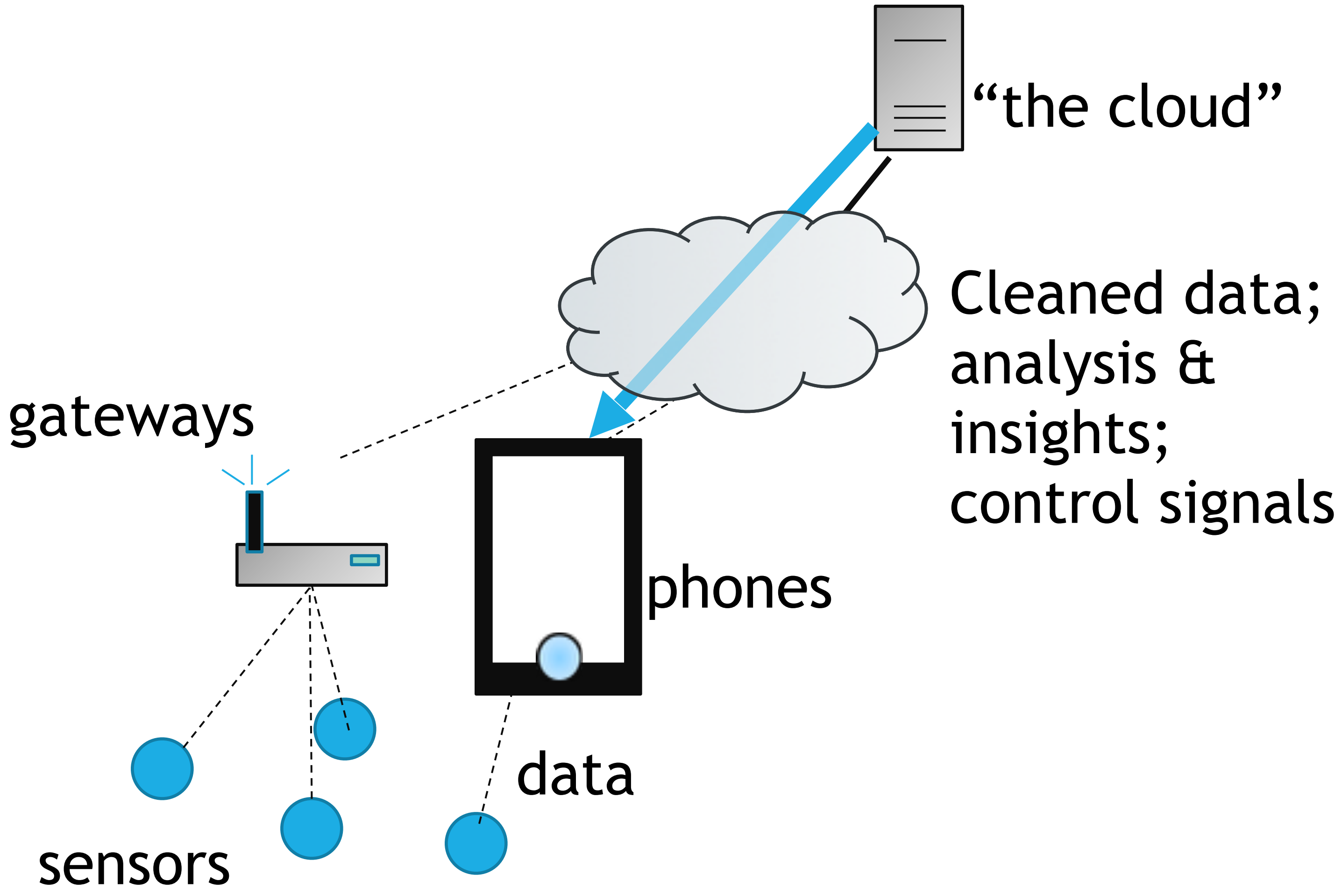
Canonical IoT System Architecture

Data path: sensors ➔ phones/ basestations ➔ cloud

Sensors use low-power (BLE, Zigbee) wireless

Phones and gateways use WiFi, cellular, or wired Internet links

Processing happens on sensors, basestations, phones, and cloud



Power used by some common components

Component	Approximate Power Consumption
LTE Radio (transmit @ 1 Mb/s)	1700 mW
3G Radio (transmit @ 1 Mb/s)	1700 mW
WiFi (transmit @ 1Mb / s)	400 mW
ARM+RAM uProc (100% cpu)	2000 mW
ARM+RAM uProc (idle)	70 mW
Smartphone Screen (full brightness)	850 mW
GPS (once lock is acquired)	100-150 mW
Accelerometer (@10 Hz)	75 uW
Image sensor (@1080p/30Hz)	270 mW (Sony IMX206CQC)

Split Processing

Case Study: Continuous Object Recognition

Continuous Object Recognition (Glimpse, 2015)

All processing done on server

With Glimpse with on-phone object tracking

End-to-end IoT System

Case Study: Precision Agriculture

Course Logistics

Grading:

- 1 Course Project (40%)
- 1 Quiz: April 24, during lecture (25%)
- 4+1 Labs (25%)
- Participation (10%)
    - Includes answering questions before every lecture

Website: https://6s062.github.io/6MOB/index.html

Piazza: Ask questions about lectures, labs, etc.

Late lab policy: 72 hours

This Friday: iOS Tutorial (2.30-4PM in 26-168)

Monday	Tuesday	Wednesday	Thursday	Friday
Feb 5 *Reg day*	Feb 6 **LEC 1:** Introduction and Course Overview *First day of classes*	Feb 7	Feb 8 **LEC 2:** Intro to Positioning and Indoor Location Systems **Preparation:** Read Cricket, Location-based Services, Chapter 6 **Assigned:** Lab 0	Feb 9
Feb 12	Feb 13 **LEC 3:** GPS: Outdoor Location **Preparation:** Read GPS **Assigned:** Lab 1 **DUE:** Lab 0	Feb 14	Feb 15 **LEC 4:** Indoor Location with RF **Preparation:** Read RADAR, WiTrack	Feb 16
Feb 19 President's day	Feb 20 *Monday schedule*	Feb 21	Feb 22 **LEC 5:** Connectivity Overview and BLE	Feb 23
Feb 26	Feb 27 **LEC 6:** Mesh and Multi-Hop Wireless Networks **Preparation:** Read ETX **Assigned:** Lab 2 **DUE:** Lab 1	Feb 28	Mar 1 **LEC 7:** Intro to Inertial Sensing and Activity Recognition **Preparation:** Read Developments of Inertial Sensing, Principles of Inertial Sensing, Activity Recognition	Mar 2
Mar 5	Mar 6 **LEC 8:** Pothole detection **Preparation:** Read Pothole Patrol	Mar 6	Mar 8 **LEC 9:** Wireless sensing **Preparation:** Read Vital-Radio	Mar 9
Mar 12	Mar 13 **LEC 10:** In-network Aggregation **Preparation:** Read TAG **DUE:** Project Proposals	Mar 14	Mar 15 **LEC 11:** Agriculture IoT **Preparation:** Read FarmBeats	Mar 16
Mar 19	Mar 20 *Project meetings* **Assigned:** Lab 3 **DUE:** Lab 2	Mar 21	Mar 22 **LEC 12:** Map-matching with cellular data **Preparation:** Read CTrack	Mar 23
Mar 26 Spring break	Mar 27 Spring break	Mar 28 Spring break	Mar 29 Spring break	Mar 30 Spring break
Apr 2	Apr 3 **LEC 13:** Map inference **Preparation:** Read Map Inference	Apr 4	Apr 5 **LEC 14:** Shooter localization **Preparation:** Read Sensor Network-Based Countersniper System **Assigned:** Lab 4 **DUE:** Lab 3	Apr 6
Apr 9	Apr 10 **LEC 15:** Attacks on acoustic sensing **Preparation:** Read BackDoor	Apr 11	Apr 12 **LEC 16:** Habitat monitoring with acoustic sensors **Preparation:** Read VoxNet	Apr 13
Apr 16 Patriots' day	Apr 17 Patriots' day	Apr 18	Apr 19 **LEC 17:** Continuous object recognition **Preparation:** Read Glimpse **DUE:** Lab 4	Apr 20
Apr 23	Apr 24 **Quiz during lecture time**	Apr 25	Apr 26 *Project meetings* ***DROP DATE***	Apr 27
Apr 30	May 1 *Project meetings*	May 2	May 3 *Project meetings*	May 4
May 7	May 8 *Project meetings*	May 9	May 10 *Project meetings* **DUE:** Project Titles and Abstracts	May 11
May 14	May 15 *Project meetings*	May 16	May 17 *Project presentations* **DUE:** Posters, Presentations, and Demos *Last day of classes*	May 18