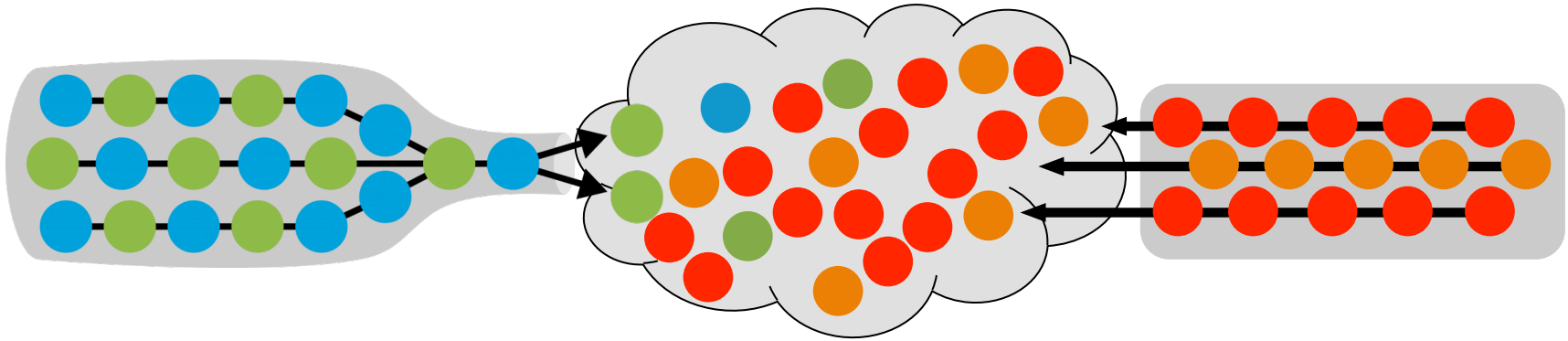


The Internet of Things

Cognition for Cost Savings and Efficiency Improvements

Josh Siegel, PhD

j_siegel@mit.edu

MIT AutoID and Field Intelligence Laboratories

Today, I represent two research groups

- **AutoID Lab**
  - RFID
  - TABS
  - Metamaterials

- **Field Intelligence Lab**
  - Pervasive Sensing
  - Vehicles
  - City Scanning
  - Drones

- Both run by Professor Sanjay Sarma, VP for Open Learning

Today’s presentation is an IoT primer

Topics for discussion

- **What is the Internet of Things (IoT)** and why should businesses care?
- How can we address **challenges to IoT’s deployment?**
- Can pervasive sensing and connectivity **improve system, process, and business performance?**
- Summary

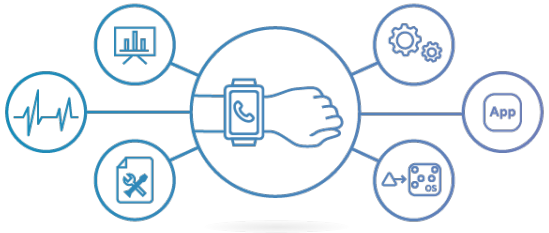
What is IoT, and why should businesses care?

Connectivity has great potential

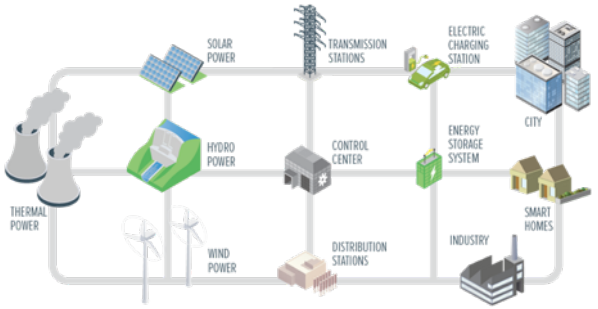
Cars

Home

Factories



Wearables



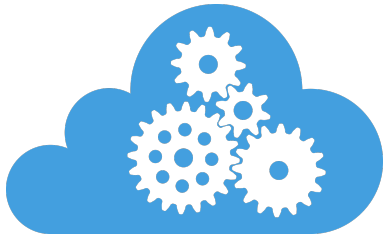
Infrastructure

Connectivity is necessary but not sufficient to transform industries

- It takes more to unlock new opportunities
  - **Sensing** to generate data
  - **Inference** to provide intelligence
  - **Action** to have meaningful output

- Key technologies allowing machines to act independently and at scale are newly pervasive

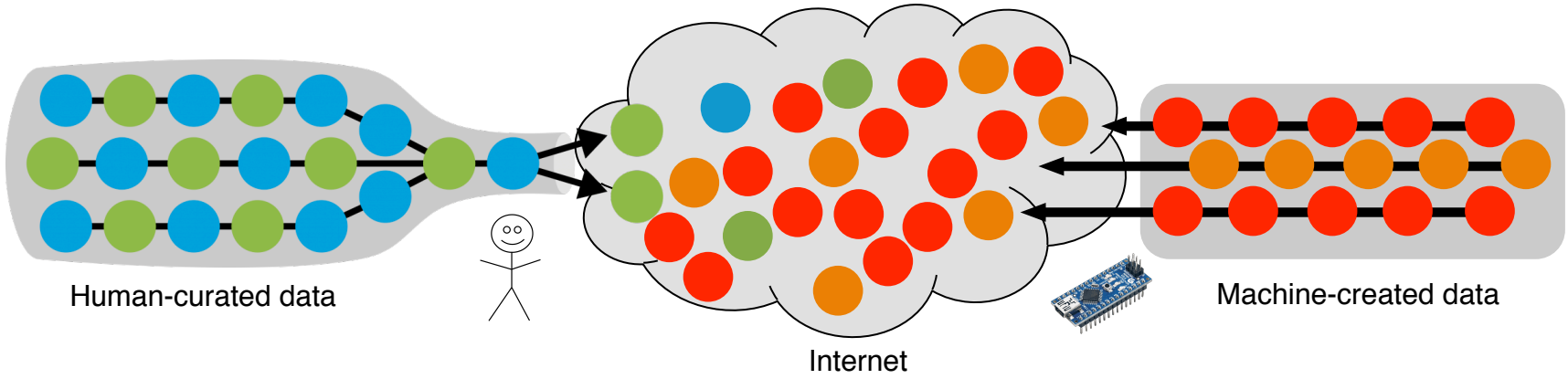
Sensing



Processing

Connectivity

Technology removes the human bottleneck, allowing for Big Data



- Today's devices and services **self-report**
  - 90% of the world's data has been created in the last two years
  - Devices now make data-informed inferences and apply machine intelligence

The IoT is an **intelligent networked system** taking advantage of these advances

1. Device and service intelligence and self-awareness
2. Local and global operation
3. Data inputs and actuator outputs
4. Historic, realtime, and anticipated data
5. Machine learned, rule based, and human in the loop

As our group defines it:

If devices and services connect to one another intelligently, and can sense, infer, and act, those devices and services are part of the Internet of Things

IoT's financial implications are massive

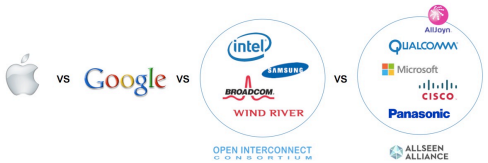
- **2015**
  - 16 billion connected things
  - $1.9 billion from IoT services
- **2020**
  - ABI: 250,000 connected cars, 40 billion devices
  - Gartner: $300 billion from IoT products
  - IDC: $7.1 trillion global market
- **2035**
  - GE: $10-15 trillion added to GDP
  - Cisco: $19 trillion
  - ABI: 450 million IoT cars

All estimates in USD

If the technology and markets are ready, why is IoT not everywhere?

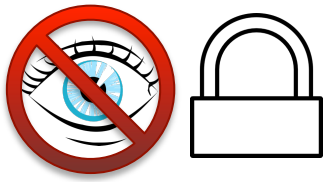
Key challenges threaten IoT's deployment

1. Fragmentation, openness and interoperability

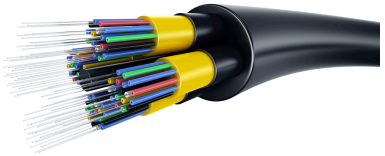


2. Data ownership

3. Privacy and security



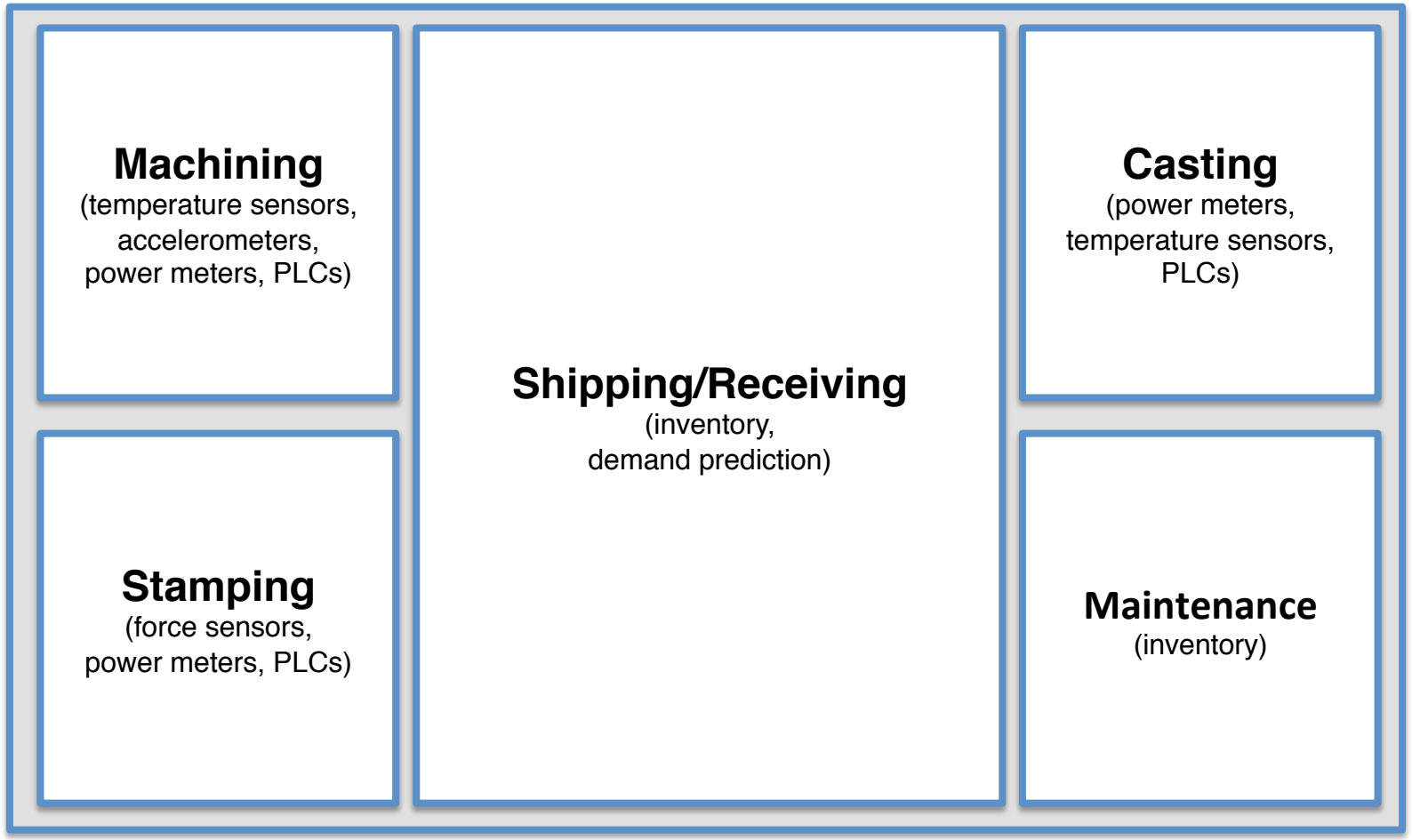
4. Resource use



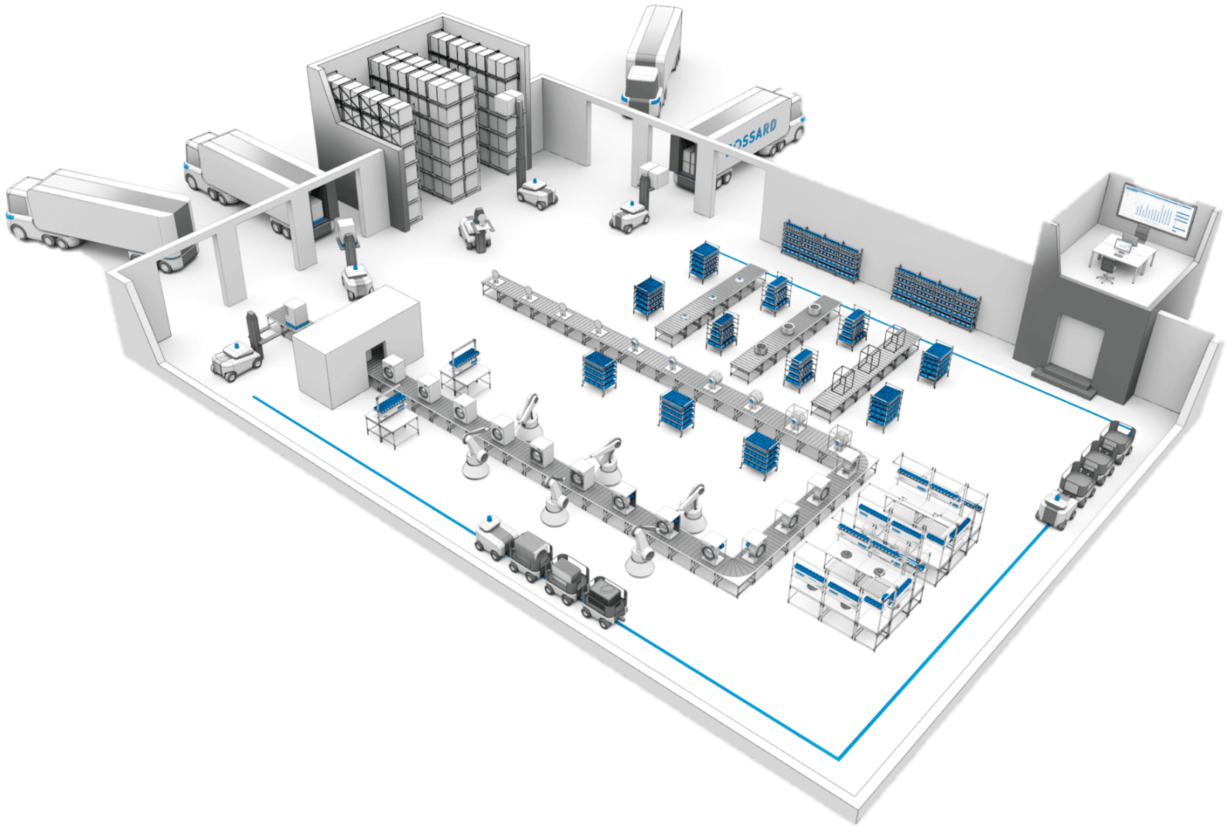
Policy Decisions

Technical Capabilities

Consider the case of a Smart Factory

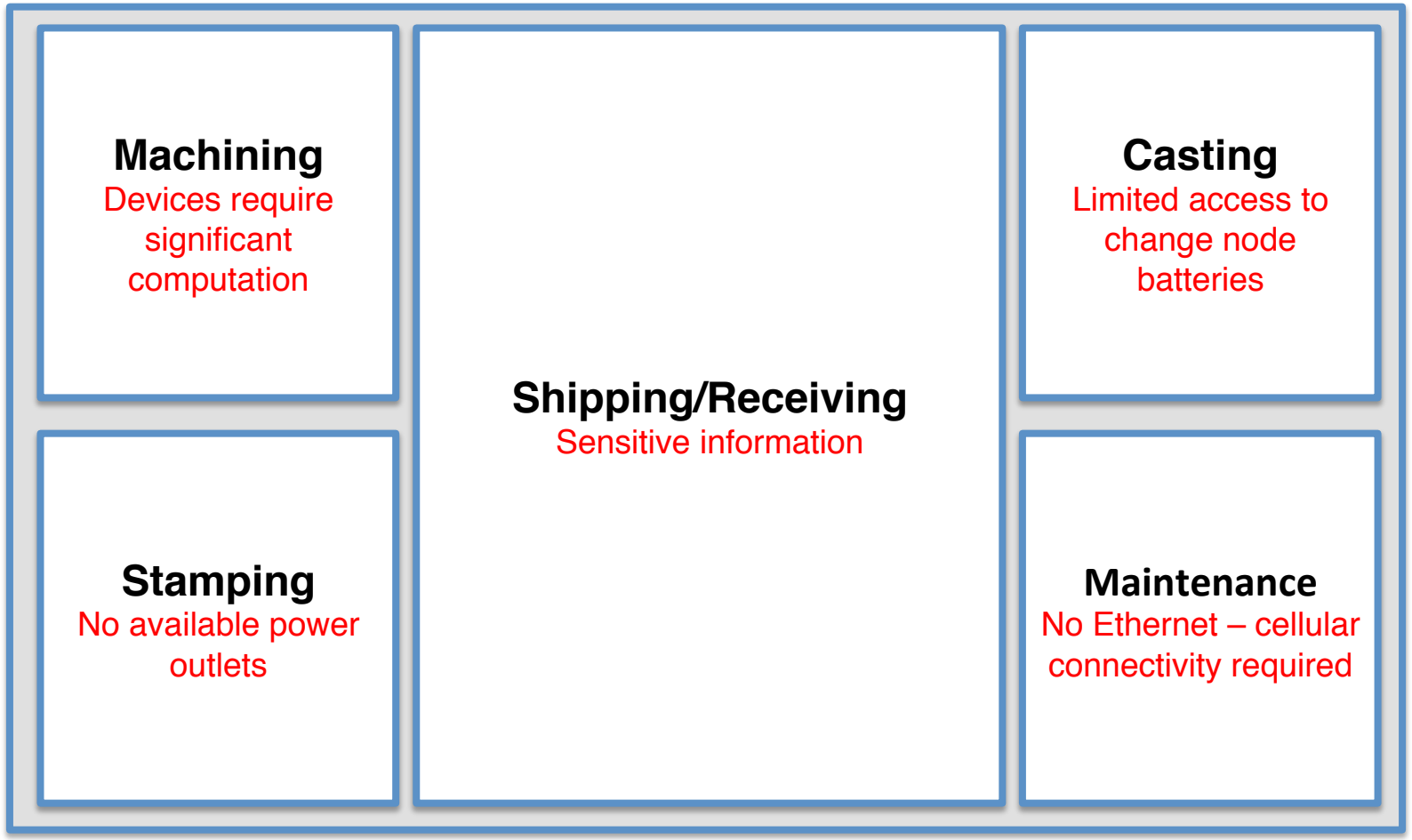


Sensing and actuation improve production



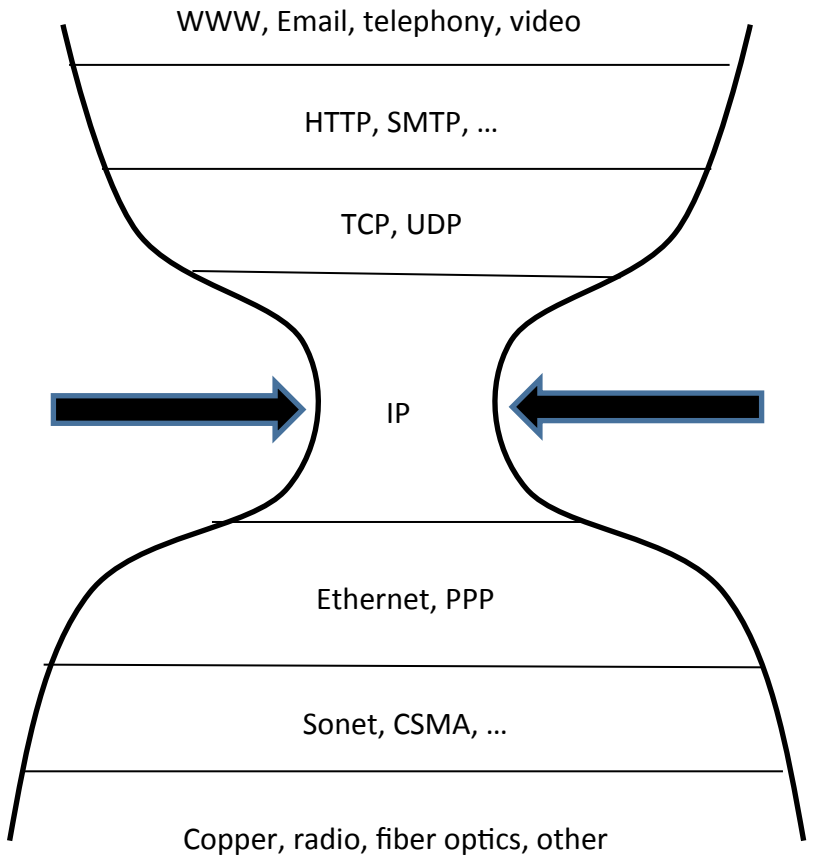
Improved Quality **Reduced Cost** **Enhanced Efficiency**

Cost, serviceability and security limit connectivity

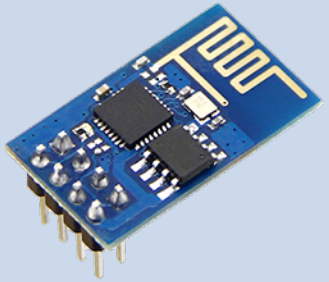


A new architecture can solve problems across the stack

- Architectures offer a **design language** providing **standardized interfaces** for reuse and reconfiguration
- **Abstraction** and **modularity enhance security** and **simplify maintenance**
- **Hourglass architectures**, like IP, **simplify and tame** emerging technological frontiers



Can we make an architecture for secure, efficient IoT on this



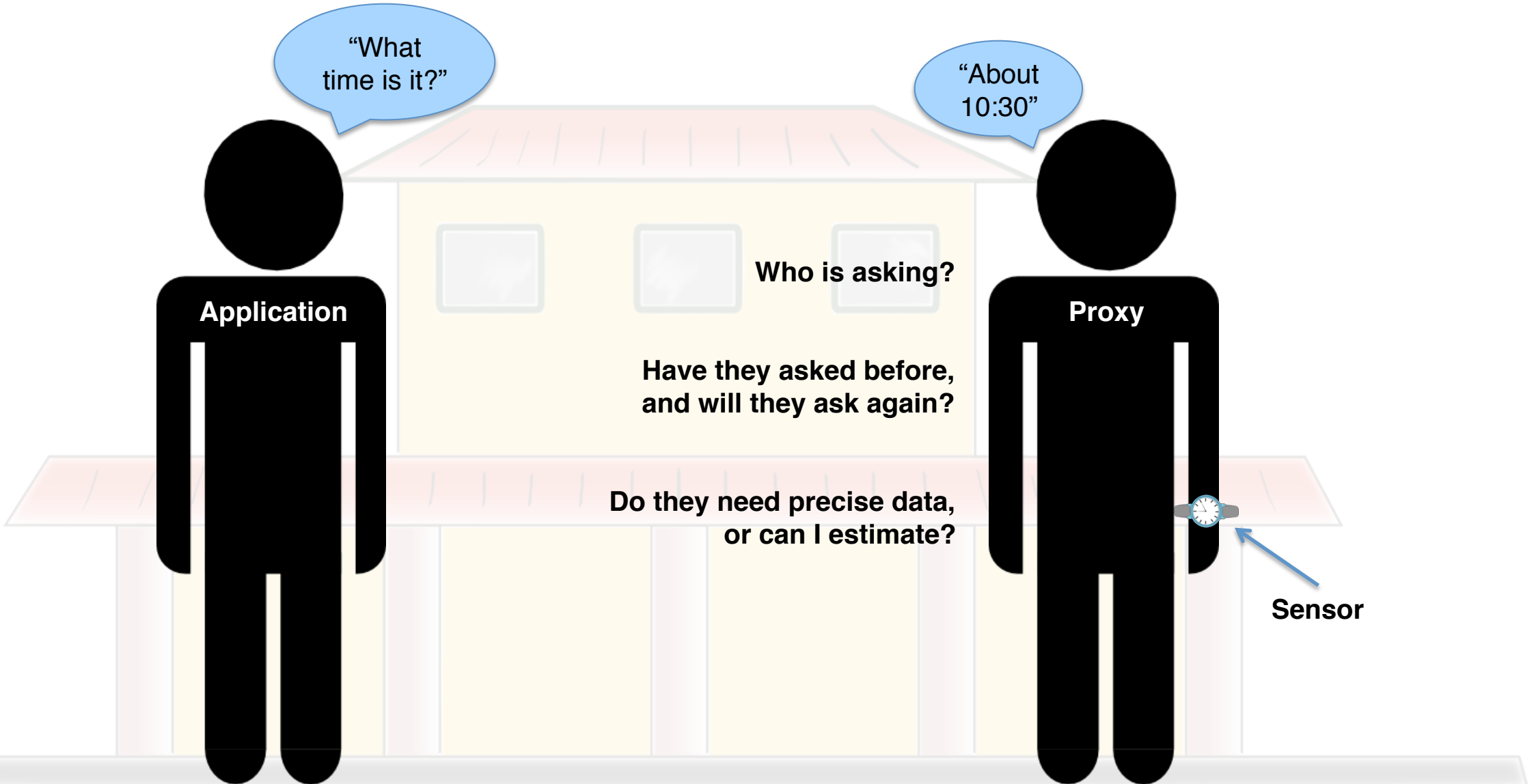
by taking advantage of this?

Inspired by humans:
Architecting context and cognition in the Cloud

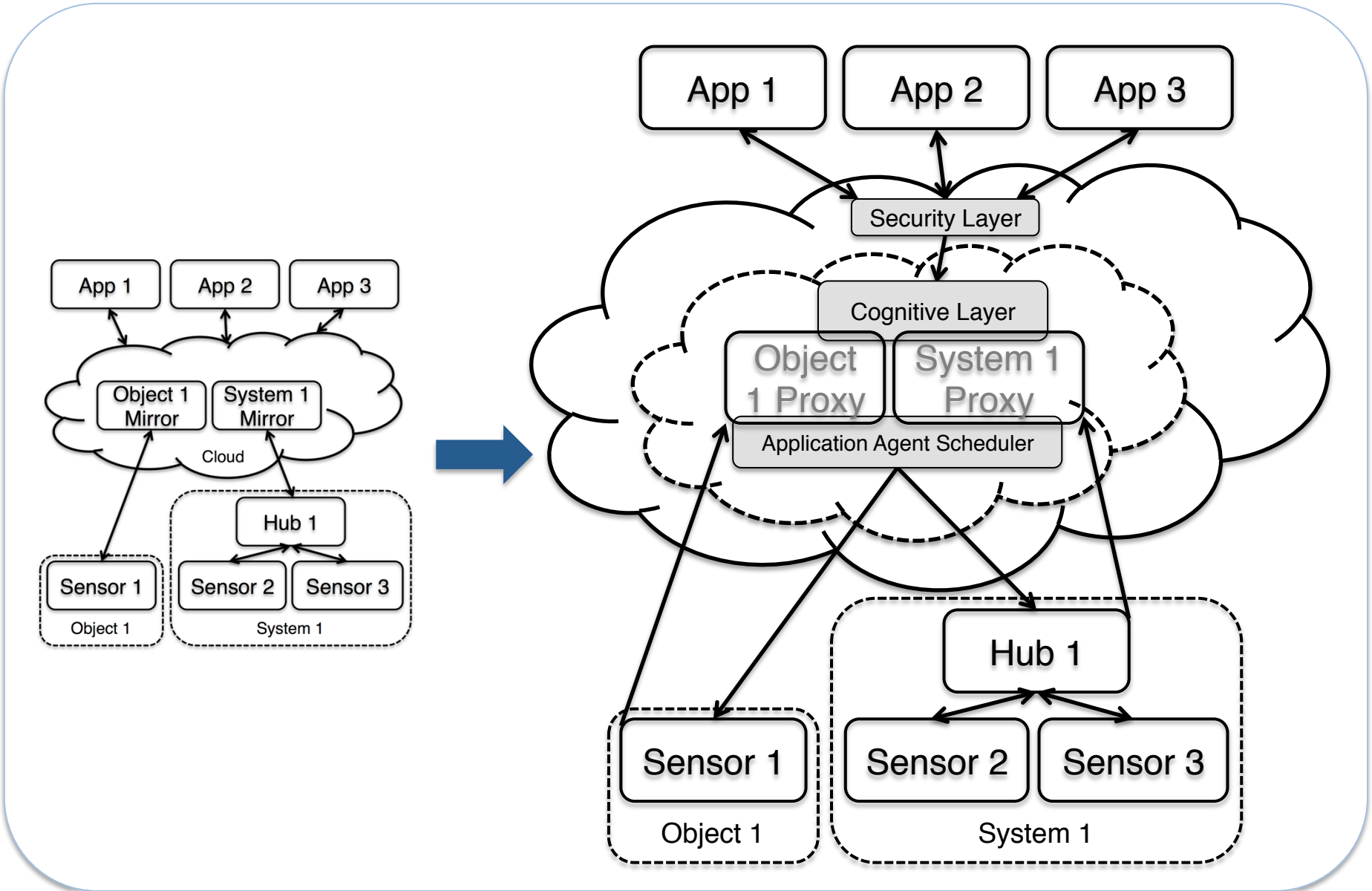
Consider how humans share, synthesize, and act upon data

- We **apply context** to distribute information
- We **synthesize** multiple sources
- We **minimize effort** with appropriate **estimation**
- We **protect** ourselves and our resources by **abstraction**

EXAMPLE: How people act as “applications” and “proxies” in real life

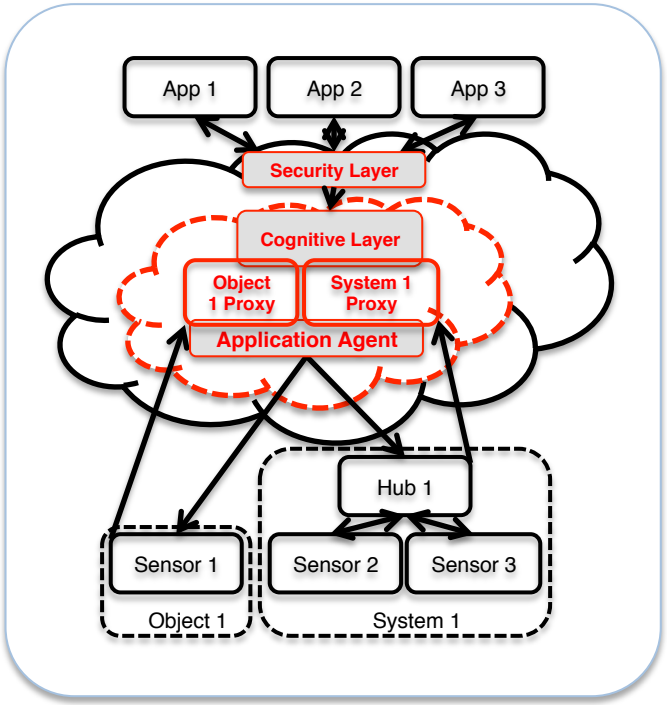


Our architecture extends the Cloud with “human” cognition



We developed five new elements

- **Quality of Data (QoD)** in client requests
- **Security Layer** moderates connections
- **Cognitive Layer** observes the system
- **Data Proxies** estimate state
- **Application Agent** schedules sampling



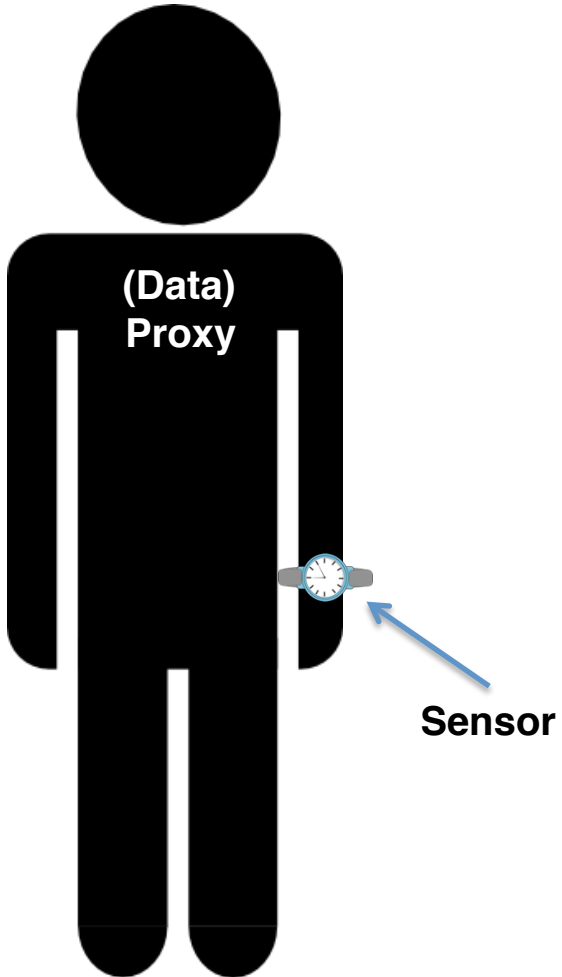
These elements enhance security and efficiency

- **Abstracts** digital from physical
- **Applies context** to supervise and protect
- **Estimates** states to minimize sampling
- **Fuses data** to obtain results
- **… just as people do!**

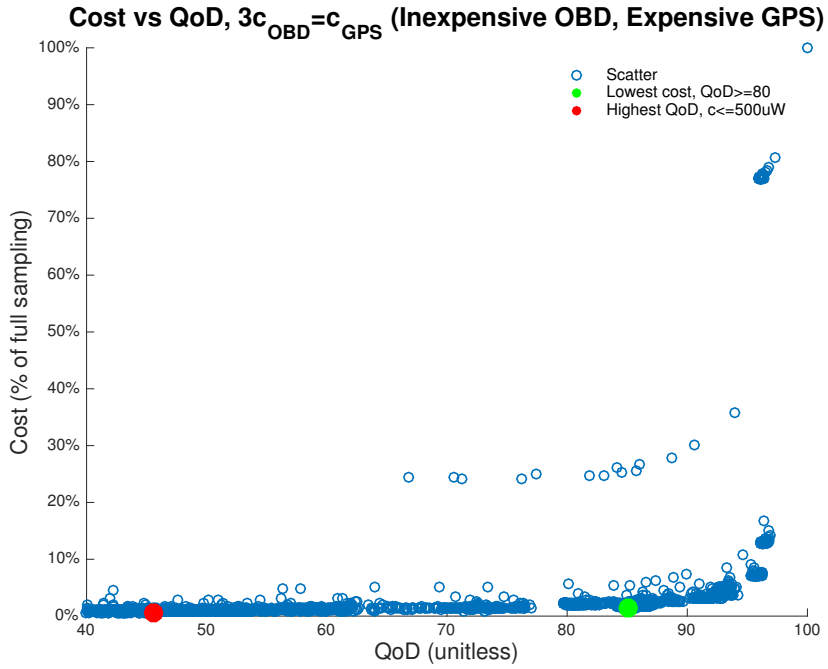
Who is asking?
(Security Layer/ QoD)

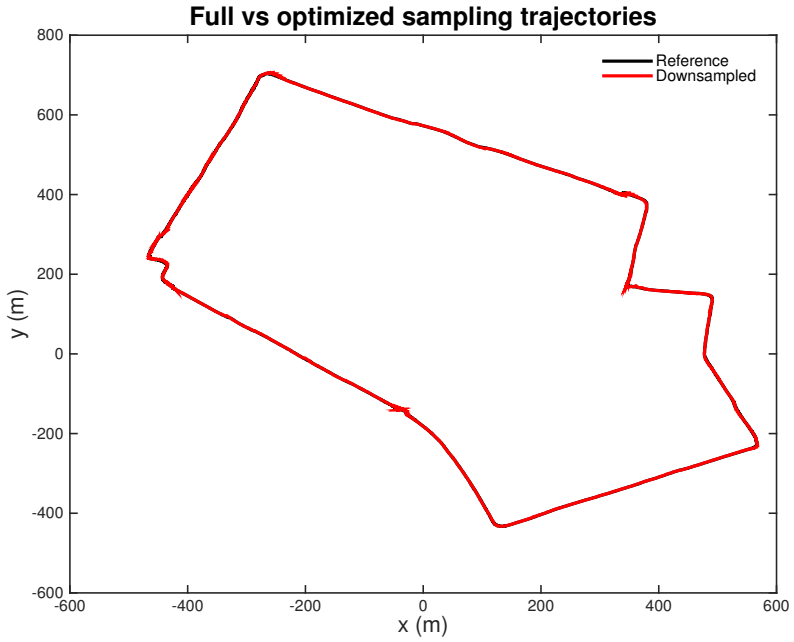
Have they asked before,
and will they ask again?
Is this something I can do?
(Security and Cognitive Layers)

Do they need precise data,
or can I estimate?
(QoD / Application Agent)



In testing, our architecture significantly reduces cost without increasing error





95% the data quality for 5% the cost

This makes connectivity tenable in more places

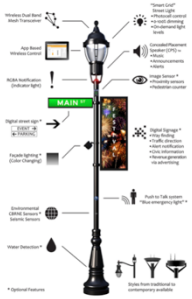
1. J. Siegel. “Data Proxies, the Cognitive Layer, and Application Locality: Enablers of Cloud-Connected Vehicles and Next-Generation Internet of Things” PhD Dissertation. Massachusetts Institute of Technology, 2016
2. J. Siegel, S. Kumar, S. Sarma, “The Future Internet of Things: Secure, Efficient, and Model-Based.” Submitted to JNCA Special Issue on IoT.
3. J. Siegel, S. Kumar, “Cloud, Context, and Cognition: Paving the Way for Efficient and Secure IoT Implementations.” Submitted to “Integration of Cloud Computing, Cyber Physical Systems and Internet of Things.”

This more secure and efficient IoT facilitates broader connectivity

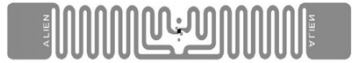
Smart Factories
Lower instrumentation cost
Cognitive Firewall security

Wearables
Increased battery life
Protected privacy
Supervisor for health tracking

Connected Homes
Improved privacy and security
Reduced wiring



Intelligent Infrastructure
Reduced connectivity cost



Pervasive sensing
Longer sensor life

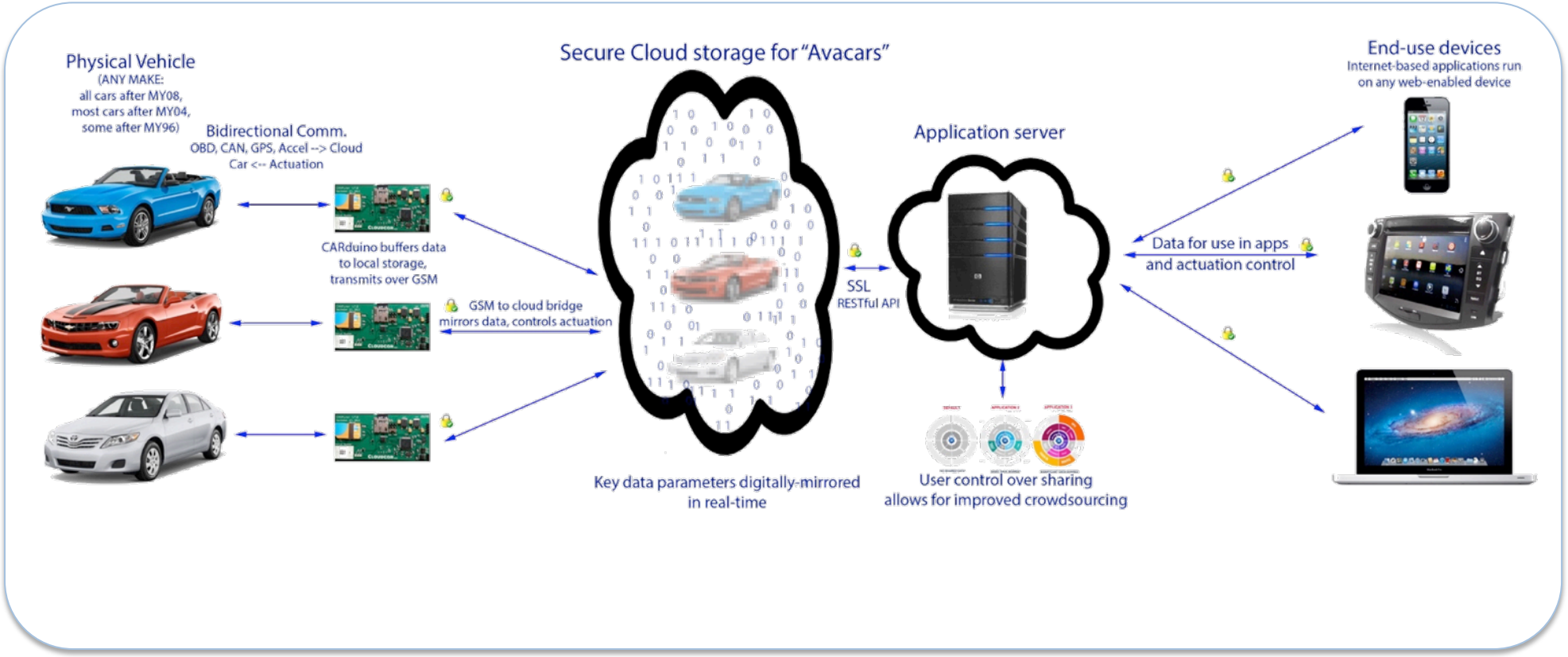
IoT and Connected Pervasive Sensing Applications

IoT creates opportunities for data-informed products and services

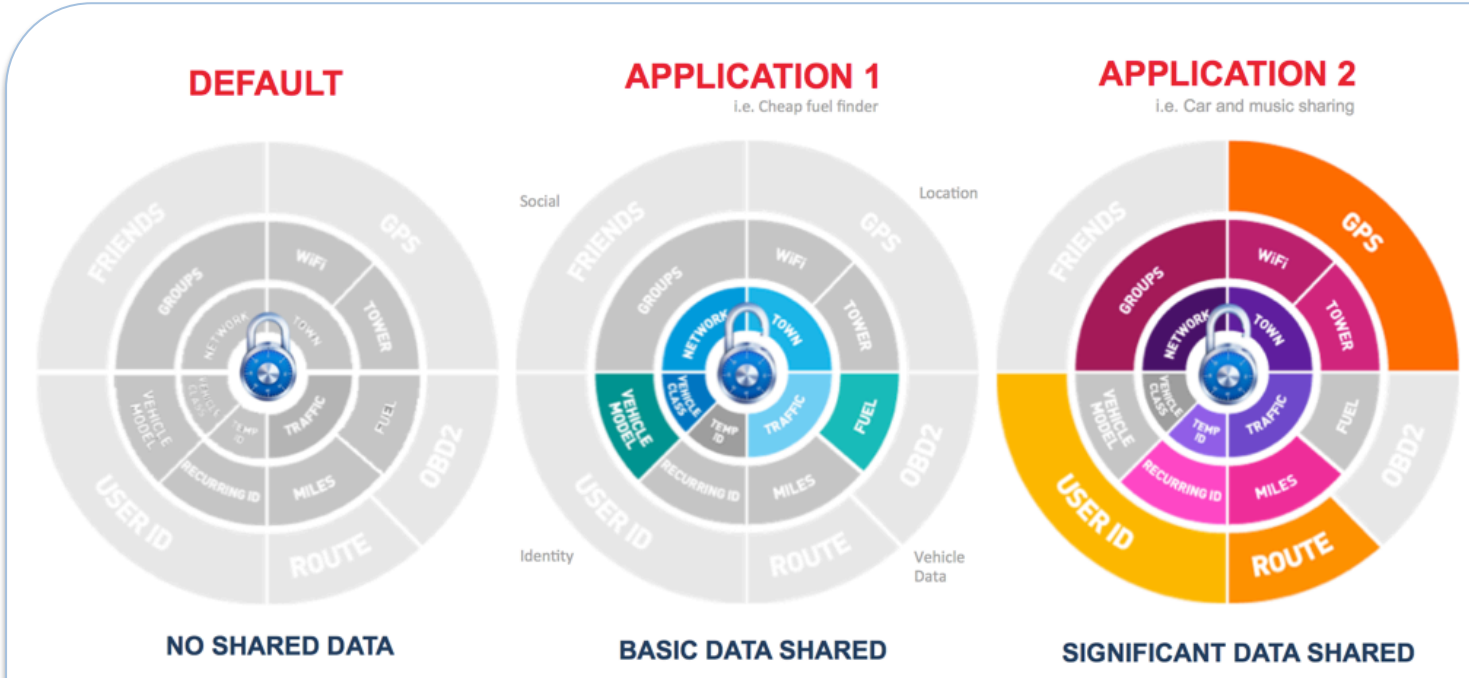
- **Improved instrumentation** and **analytics in product design, manufacturing, and use**
- **New applications** based on sensing, inference, and action
- Ongoing **customer engagement**

IoT and Transportation

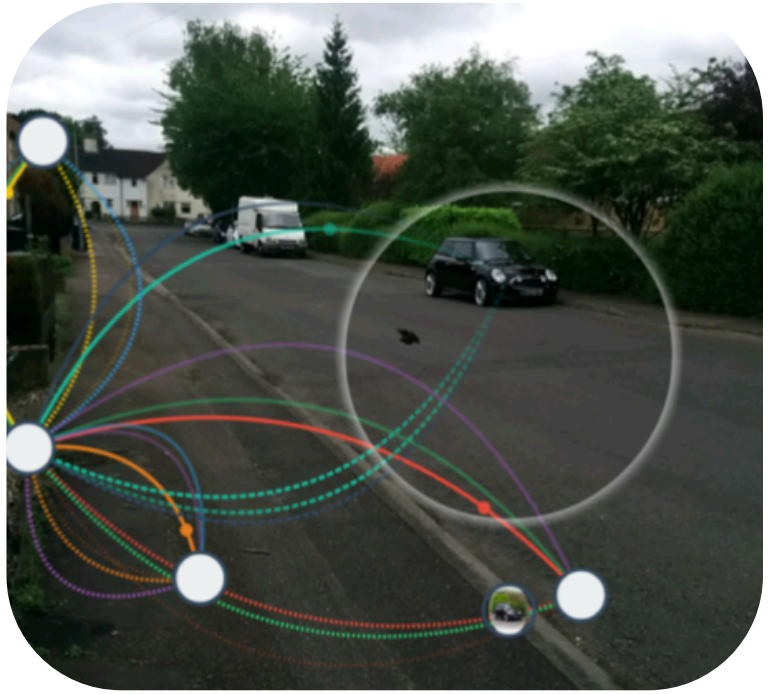
In our work with cars, Proxies allow us to build "Avacar" mirrors useful for application development



Beyond using a secure architecture, we built privacy tools to moderate data sharing



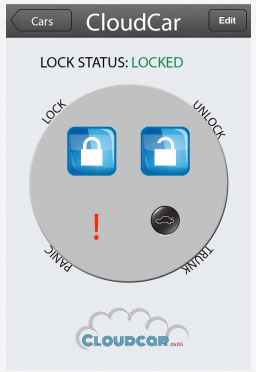
Privacy Radar for permission visualization



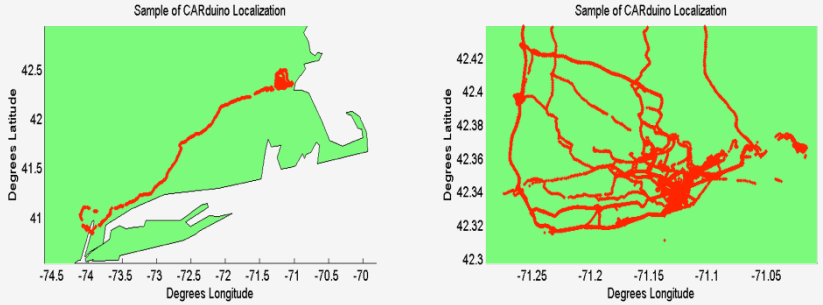
Magic Lens
Augmented Reality data interaction display

E. Wilhelm, J. Siegel et al. "Cloudthink: a scalable secure platform for mirroring transportation systems in the cloud." Transport, Volume 30, 2015.
S. Mayer, J. Siegel. “Conversations with Connected Vehicles.” IoT 2015.

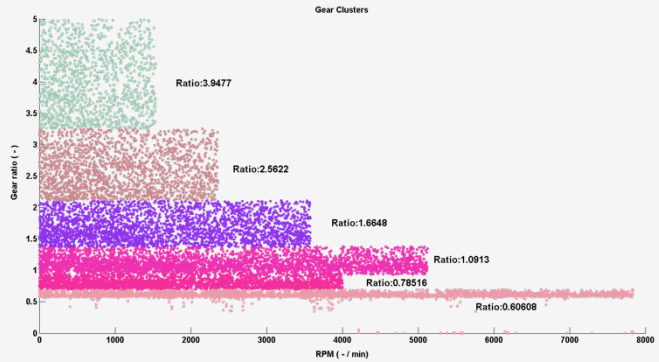
This architecture and Cloud platform allowed us to build new applications



Remote locking



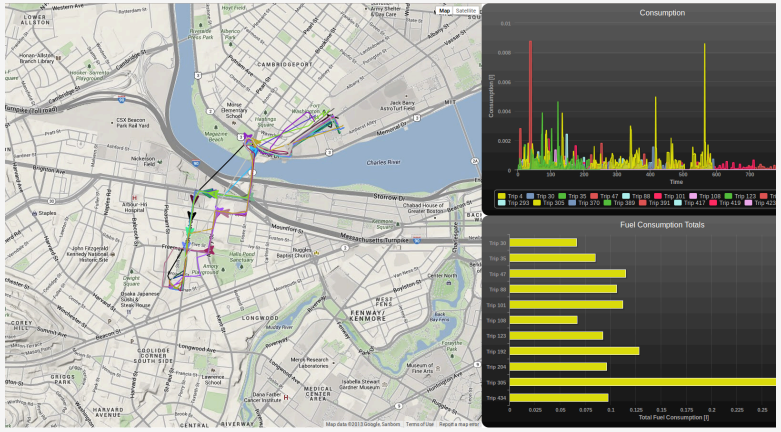
Route histories



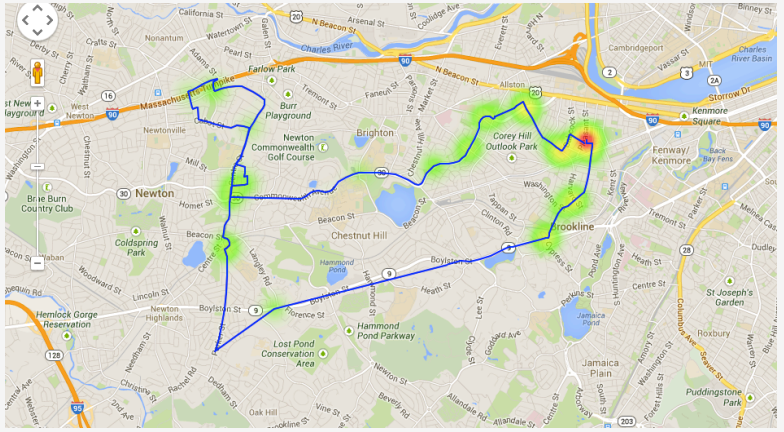
Vehicle health monitoring

Driver tracking

Fuel economy over time



Idling & Emissions mapping

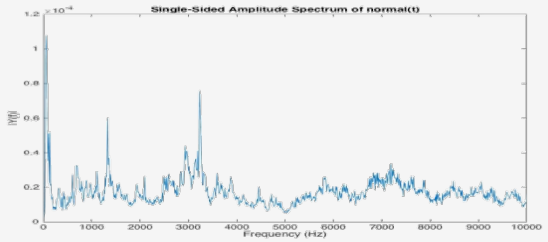


On the road, other connected systems can help to maintain vehicles

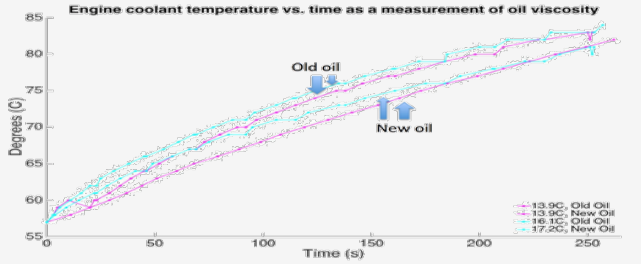
Smartphones
passively monitor
vehicle health

(like *Shazam* for automotive faults)

Machine-learning detects common vehicle faults early

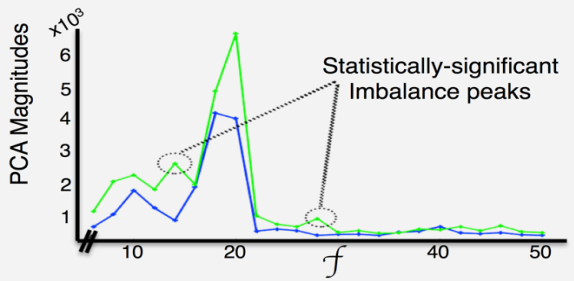


Misfire detection

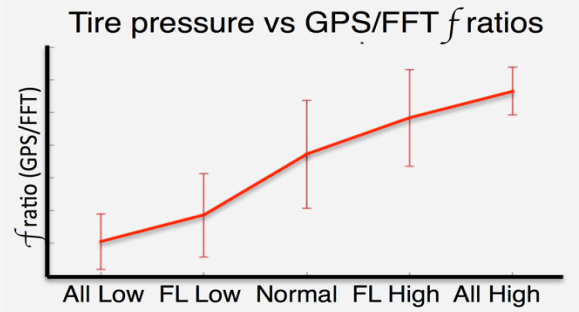


Oil monitoring

Baseline vs Imbalanced PCA(FFT)



Wheel imbalance identification



Tire pressure and tread depth supervision

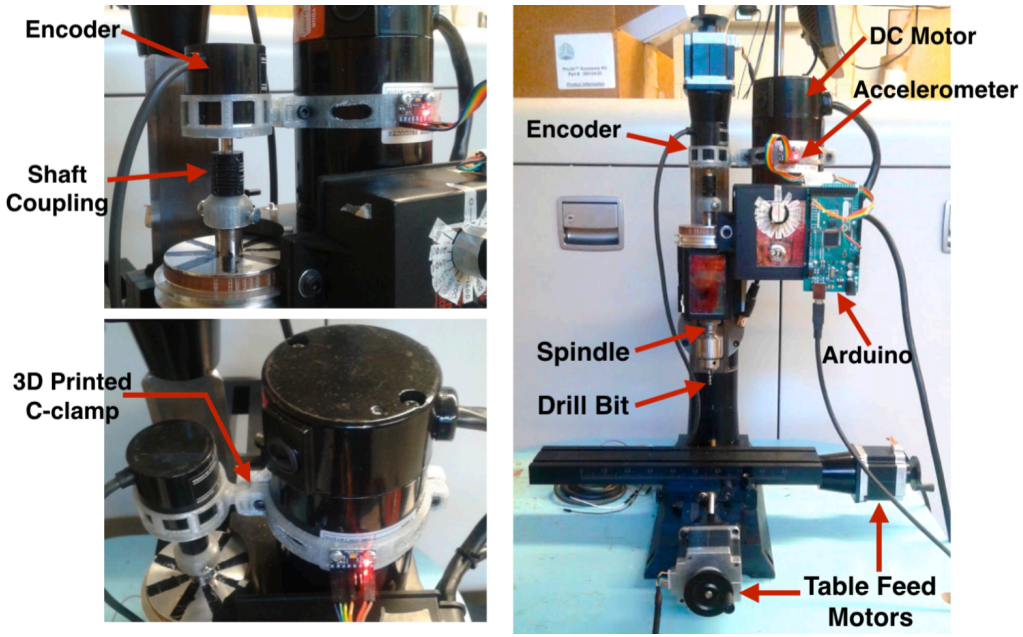
1. J. Siegel, S. Kumar, I. Ehrenberg, S. Sarma, “Engine Misfire Detection With Pervasive Mobile Audio,” ECML KDD 2016.
2. J. Siegel, R. Bhattacharyya, A. Deshpande, S. Sarma. “Smartphone-Based Vehicular Tire Pressure and Condition Monitoring.” SAI Intelligent Systems 2016.
3. J. Siegel, R. Bhattacharyya, A. Deshpande, S. Sarma. “Smartphone-Based Wheel Imbalance Detection.” Dynamic Systems and Controls Conference 2015.
4. J. Siegel, R. Bhattacharyya, A. Deshpande, S. Sarma. “Vehicular Engine Oil Service Life Characterization Using On-Board Diagnostic Sensor Data.” IEEE Sensors 2014

IoT in manufacturing

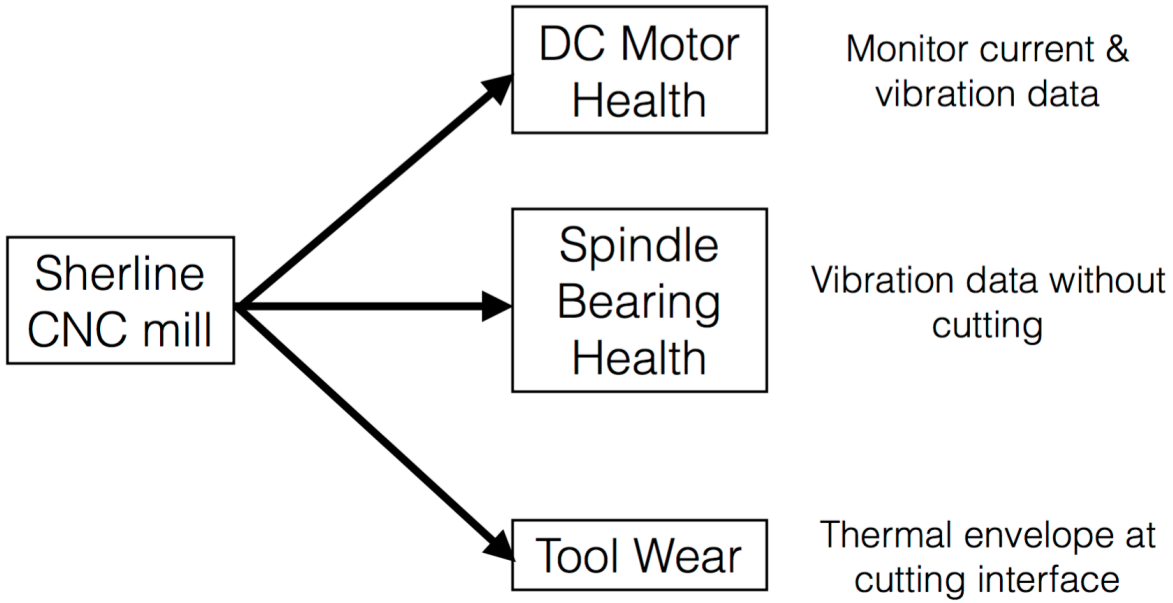
Low-cost sensing can be used to instrument manufacturing equipment

- IoT allows us to answer
  - **Can manufacturing be improved?**
  - **How can our clients better use our products?**

- We built a demo using a mill
  - Inexpensive, non-invasive sensors wirelessly monitor tool wear and consumable use



This inexpensive setup can save a lot of money



- Improved manufacturing gets **more devices** into the field **faster** and for **less money**
- These systems can provide **analytics to be sold to customers**

Published in: Balasaravanan, T K. “Development of a model system of internet of things enabled cnc milling machine.” IIT Madras BS Thesis, 2016.

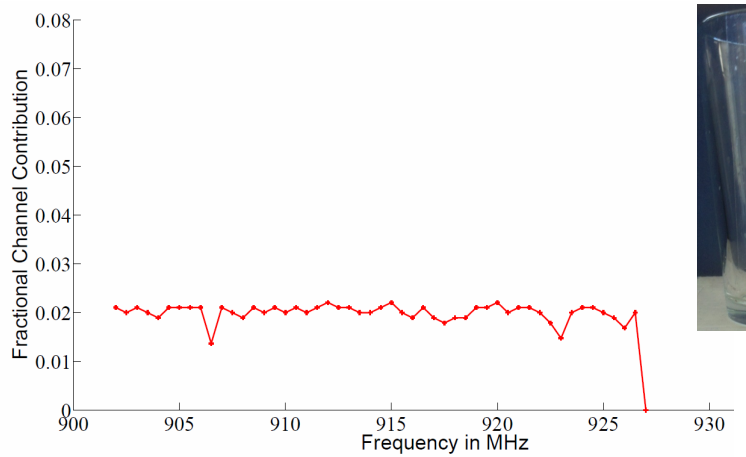
Where direct measurement is not possible, pervasive sensing is a low cost alternative

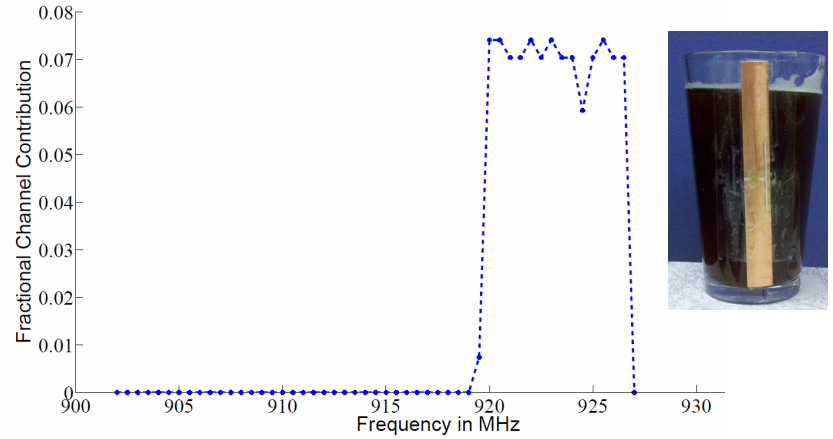
- Radio Frequency IDentification (RFID) is a low-cost digital identity tag used in inventory management and asset tracking
  - $100-$1000 reader
  - $0.03 tag

- Taking advantage of material properties turns RFID tags into sensors (we call these TABS, Tag Antenna Based Sensors)

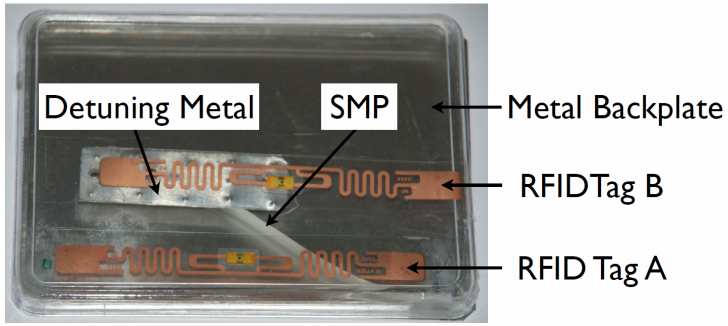
- With this, we can
  - Sense cracks (application to conduit)
  - Monitor fluid level (transformers)
  - Detect voltage (power lines)
  - Monitor temperature (freeze or burn detection)

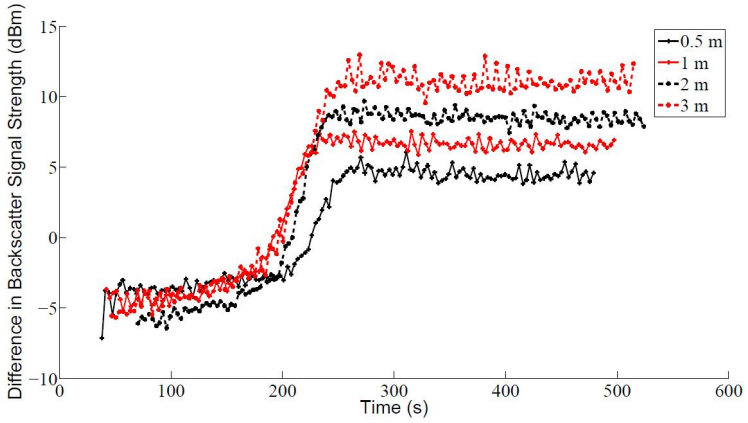
Fluid level changes detune tags

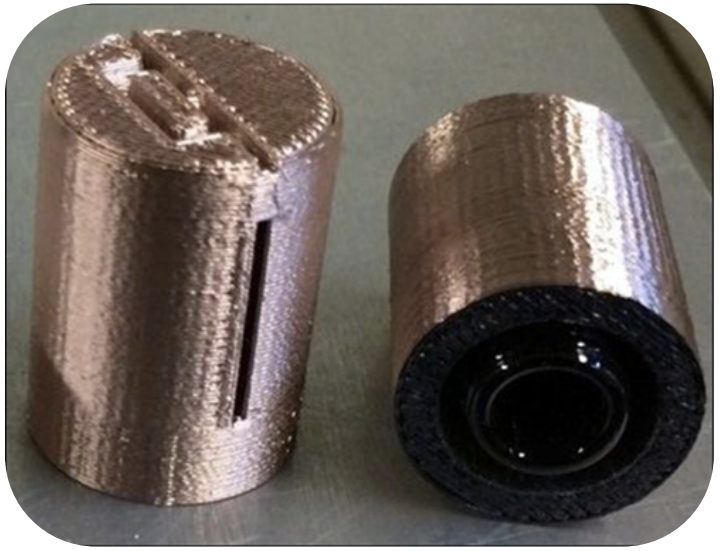




Shape memory polymers and freeze sensors measure temperature changes







Connectivity and Customer Experience

Today, connectivity offers opportunities for improved service

- QA validation
- **Predictive ordering**
- Regional and global **demand profiles**
- **Authenticity verification** and supply-chain tracability (RFID)

IoT will support novel applications at the intersection of existing devices and services, enhancing customer engagement

Conclusions

Conclusions

- We introduced IoT as an **intelligent network of people and self reporting devices and services** capable of **sensing, inference, and action**
- We identified the challenges and discussed how **a novel, cognitive architecture can improve efficiency and security**
- We showed **applications** enabled by lowering barriers to IoT's use
- We considered how **businesses may use IoT to monitor processes and equipment**

Thank You!

Want more IoT?

MIT will be hosting an “ IoT Bootcamp” in May 2017

The week-long course will offer a deep dive into IoT technologies and implementation through lectures, labs, and speaker visits

For more information, visit http://bootcamp.mit.edu