# Internet of Things (IoT)

see

CSE237a

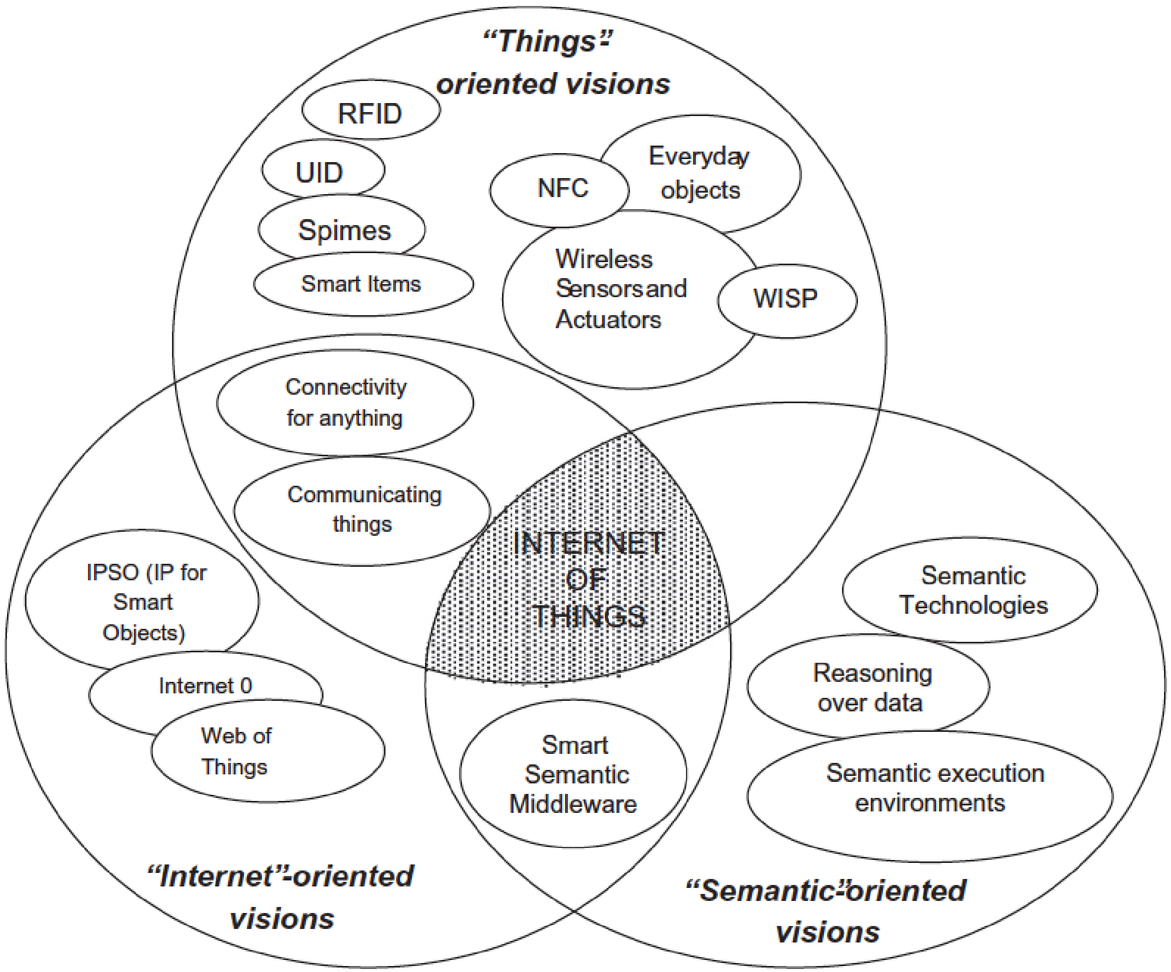
# Class Overview

- What've covered until now in SW:
  - Everything!!!!!
- Where we are going today:
  - IoT
- Due today:
  - Articles on IoT
- Upcoming:
  - HW3 assigned
  - Final project due Thursday
  - Exam the last day of class; no book/notes
    - Bring one 8 ½ x 11" sheet of paper with handwritten notes
  - Course evaluations are out!!!!
    - Please provide your feedback re. course – we take your feedback very seriously and look forward to hearing from you!

# What is IoT?


- A phenomenon which connects a variety of ***things***
  – Everything that has the ability to communicate

# Connection of Multiple Visions




Source: Atzori et al. 2010

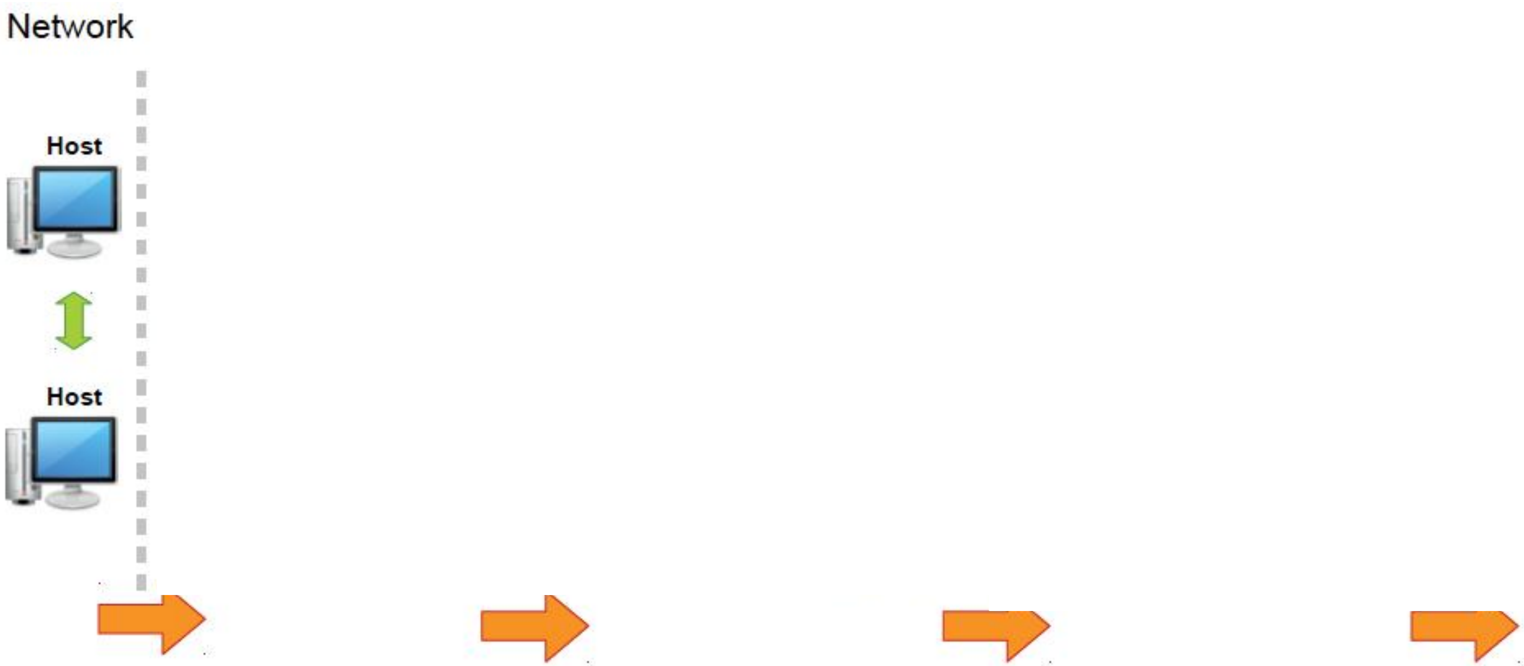
# IoT Definitions

- The Internet of Things, also called The Internet of Objects, refers to a wireless network between objects, usually the network will be wireless and self-configuring, such as household appliances. **(Wikipedia)**

- The term "Internet of Things" has come to describe a number of technologies and research disciplines that enable the Internet to reach out into the real world of physical objects. **(IoT 2008)**

- “Things having identities and virtual personalities operating in smart spaces using intelligent interfaces to connect and communicate within social, environmental, and user contexts”. **(IoT in 2020)**

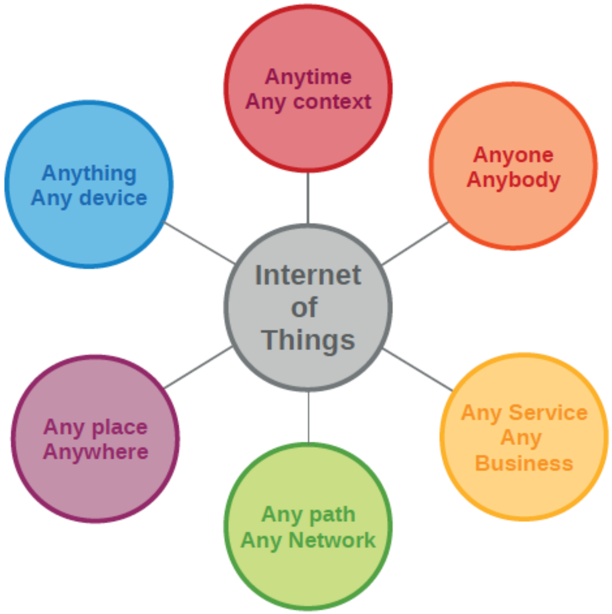
# IoT Evolution




- Starts with only network and evolves into everything that can be connected with *a network*

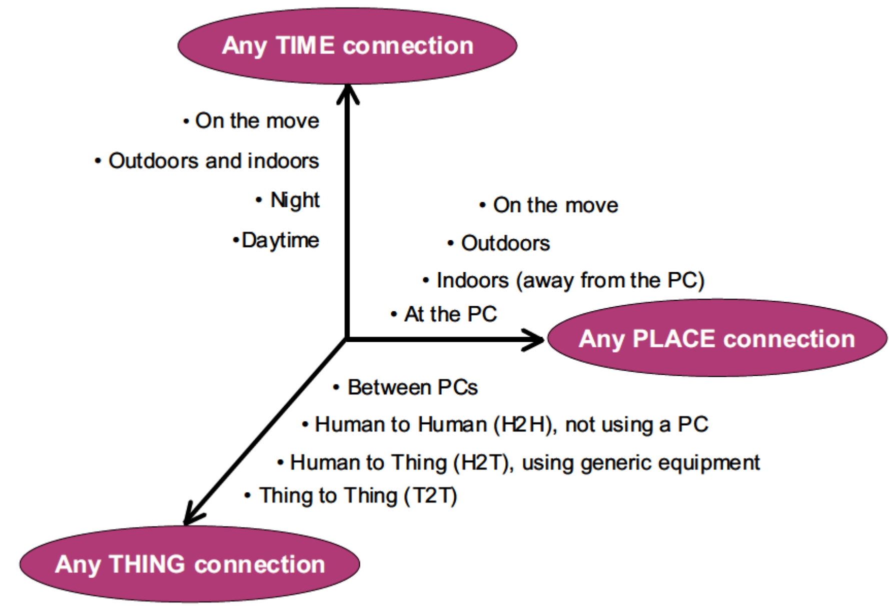
Source: Perera et al. 2014

# Any-X Point of View




Source: Perera et al. 2014

**Figure 1 – A new dimension**



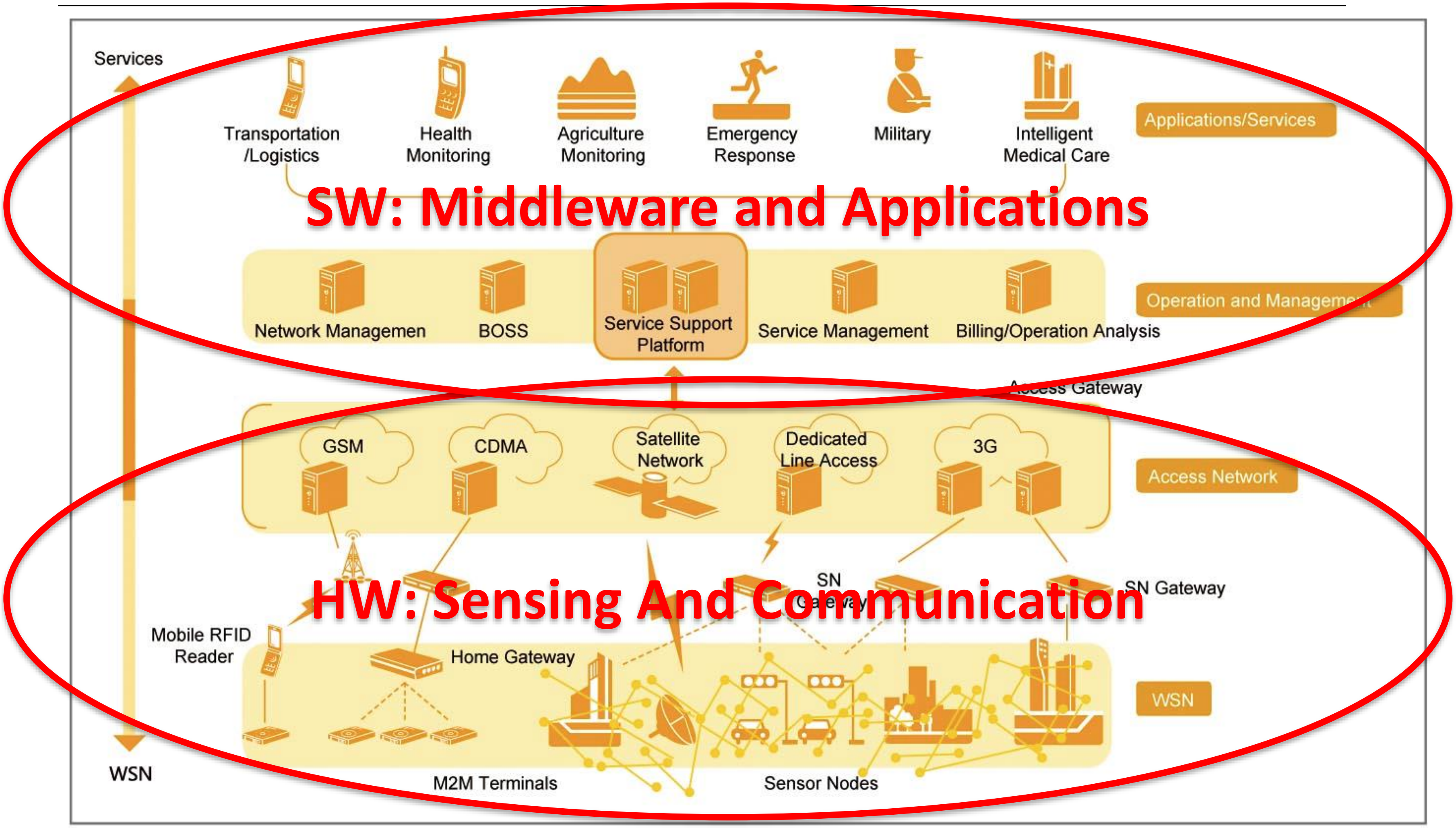

*Source*: ITU adapted from Nomura Research Institute

- The Internet of Things allows people and things to be connected Anytime, Anyplace, with Anything and Anyone, ideally using Any path/network and Any service.

# Characteristics of IoT

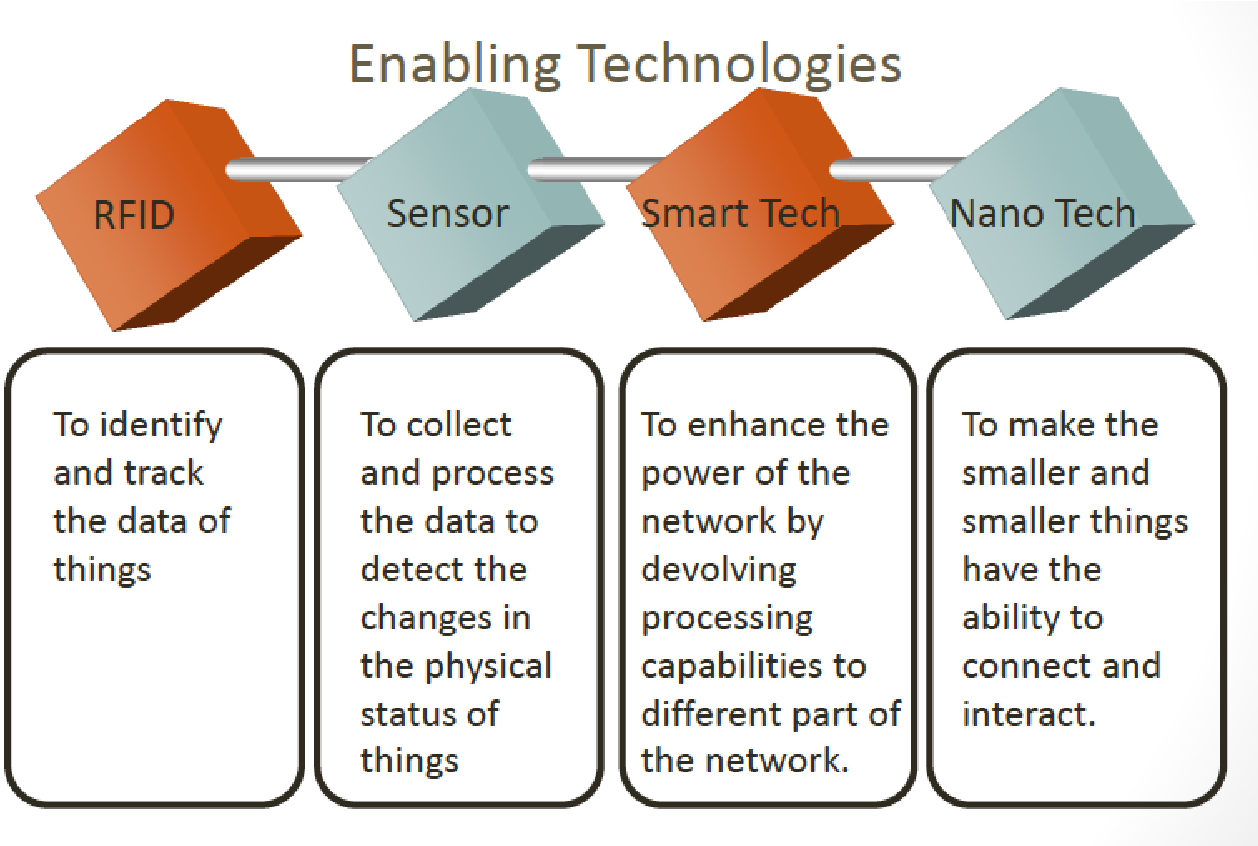
1. Intelligence
   - Knowledge extraction from the generated data
2. Architecture
   - A hybrid architecture supporting many others
3. Complex system
   - A diverse set of dynamically changing objects
4. Size considerations
   - Scalability
5. Time considerations
   - Billions of parallel and simultaneous events
6. Space considerations
   - Localization
7. Everything-as-a-service
   - Consuming resources as a service

# IoT Layered Architecture




Source: ZTE

# Networking and Communication




- RFID to smallest enabling technologies, such as chips, etc.
- Mobile platforms, such as sensors, phones, etc.

Source: Qian Zhang. Lecture notes. 2013

# Wireless Technologies

- Telecommunication systems
  - Initial/primary service: mobile voice telephony
  - Large coverage per access point (100s of meters – 10s of kilometers)
  - Low/moderate data rate (10s of kbit/s – 10s of Mbits/s)
  - Examples: GSM, UMTS, LTE
- WLAN
  - Initial service: Wireless Ethernet extension
  - Moderate coverage per access point (10s – 100s meters)
  - Moderate/high data rate (Mbits/s – 100s)
  - Examples: IEEE 802.11(a-g), Wimax

Source: Geert Heijenk. Mobile and Wireless Networking. Lecture Notes. 2014

# Wireless Technologies

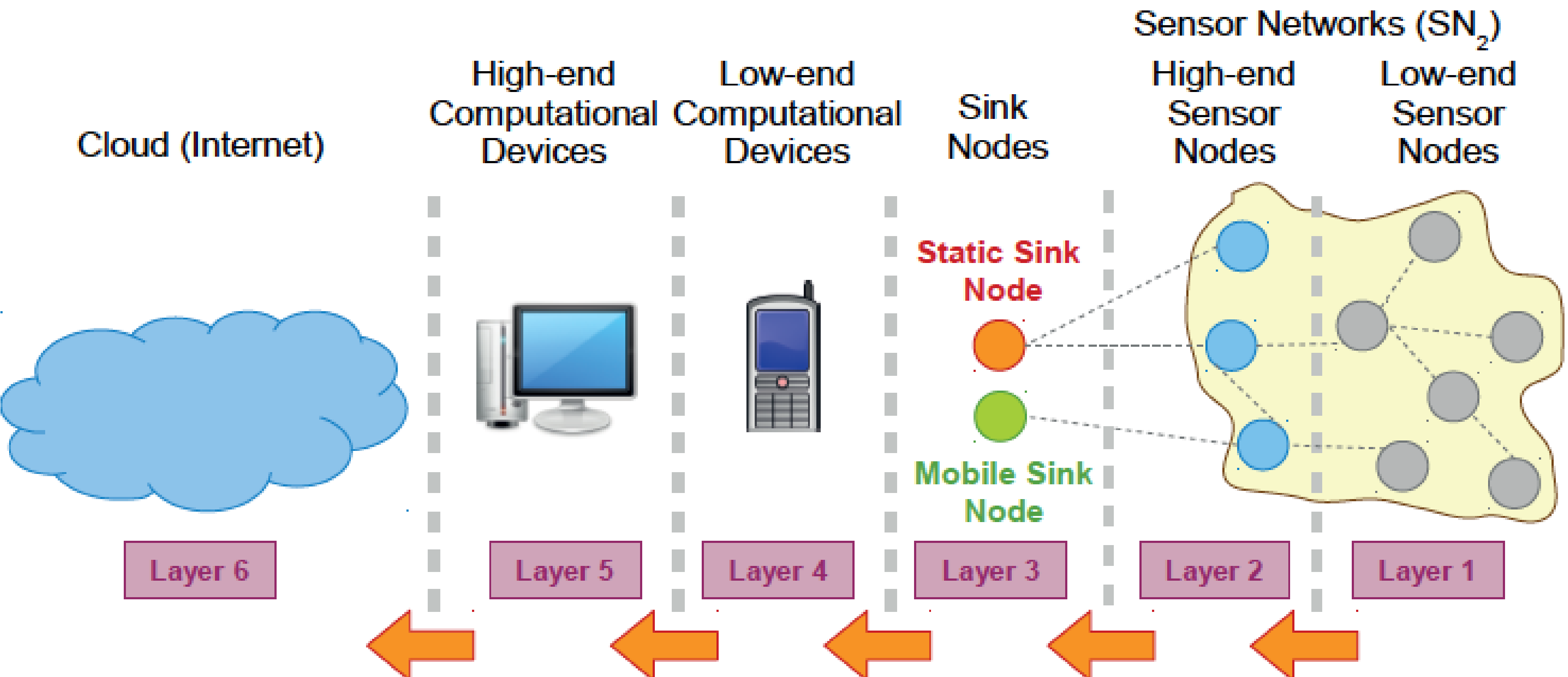
- Short range:
  - Direct connection between devices – sensor networks
  - Typical low power usage
  - Examples: Bluetooth, Zigbee, Z-wave (house products)
- Other examples:
  - Satellite systems
    - Global coverage
    - Applications: audio/TV broadcast, positioning, personal communications
  - Broadcast systems
    - Satellite/terrestrial
    - Support for high speed mobiles
  - Fixed wireless access
    - Several technologies including DECT, WLAN, IEEE802.16, etc.



Source: Geert Heijenk. Mobile and Wireless Networking. Lecture Notes. 2014

# Sensor Networks (SNs)

- Consist of a certain number (which can be very high) of sensing nodes (generally wireless) communicating in a wireless multi-hop fashion




Source: Perera et al. 2014

# Sensor Networks (SNs)

- SNs generally exist without IoT but IoT cannot exist without SNs
- SNs have been designed, developed, and used for specific application purposes
  - Environmental monitoring, agriculture, medical care, event detection etc.
- For IoT purposes, SNs need to have a middleware addressing these issues:
  - Abstraction support, data fusion, resource constraints, dynamic topology, application knowledge, programming paradigm, adaptability, scalability, security, and QoS support

# Example: Indoor Localization

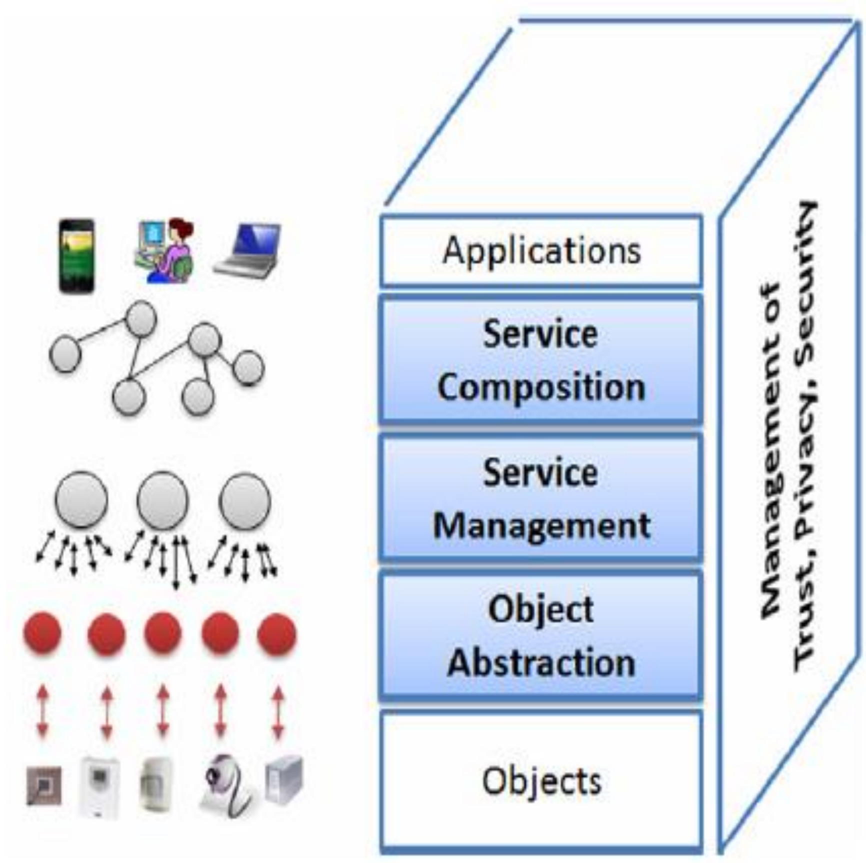
- An indoor positioning system (IPS) is a solution to locate objects or people inside a building using radio waves, magnetic fields, acoustic signals, or other sensory information collected by mobile devices.
- For indoor localization:
  - Any wireless technology can be used for locating
  - GPS, WiFi, Bluetooth, RFID, Ultrawide band, Infrared, Visible light communication, Ultrasound

# Middleware

- *Middleware is a software layer that stands between the networked operating system and the application and provides well known reusable solutions to frequently encountered problems like heterogeneity, interoperability, security, dependability [Issarny, 2008]*

- IoT requires stable and scalable middleware solutions to process the data coming from the networking layers

# Service Oriented Architecture (SOA)




Source: Atzori et al. 2010

- Middleware solutions for IoT usually follow SOA approaches
- Allows SW/HW reuse
  - Doesn't impose specific technology
- A layered system model addressing previous issues
  - Abstraction, common services, composition

# Other Middleware Examples

- Fosstrak Project
  - Data dissemination/aggregation/filtering/interpretation
  - Fault and configuration management, lookup and directory service, tag ID management, privacy
- Welbourne et al.
  - Tag an object/create-edit location info/combine events collected by antennas
- e-Sense Project
  - Middleware only collects data in a distributed fashion and transmits to actuators
- UbiSec&Sens Project
  - Focuses on security → secure data collection, data store in memory, etc.

# Open Problems and Challenges

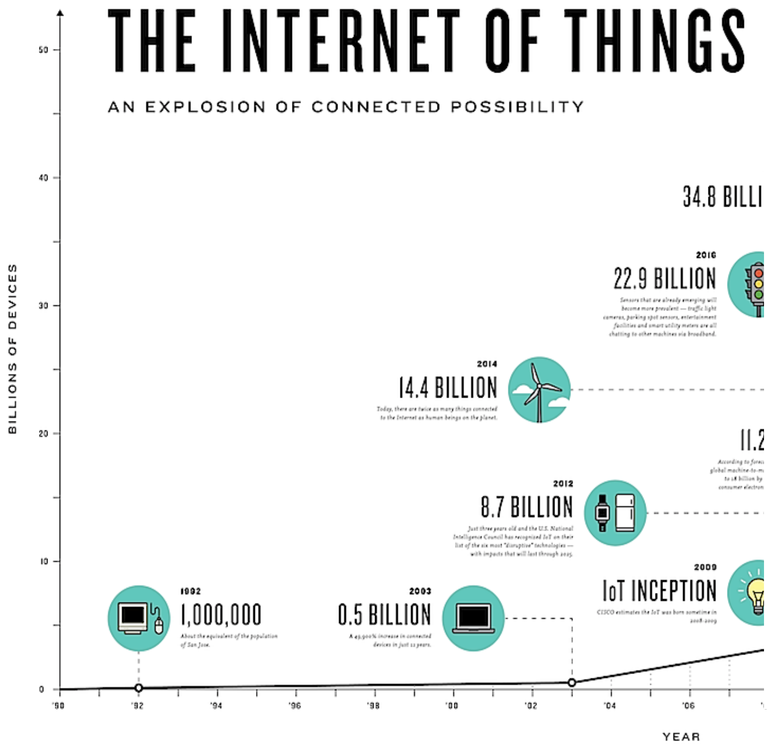
- Lack of standardization
- Scalability
  - Addressing issues
  - Understanding the big data
- Support for mobility
- Address acquisition
- New network traffic patterns to handle
- Security/Privacy issues

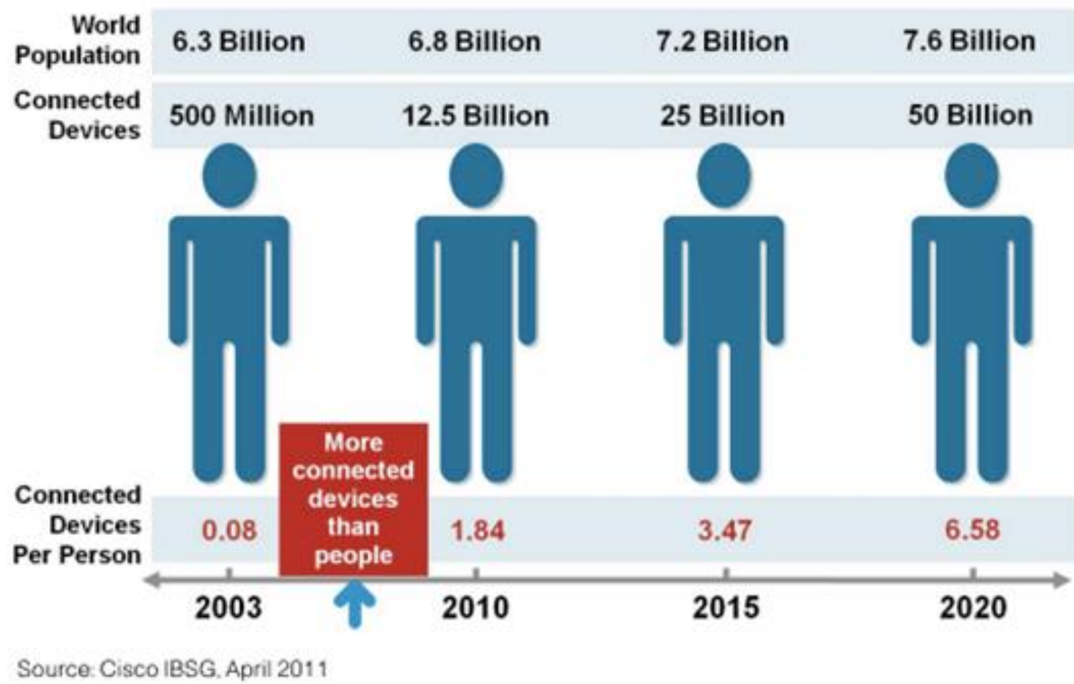
# Standardization

- Several standardization efforts but not integrated in a comprehensive framework
- Open Interconnect Consortium: Atmell, Dell, Intel, Samsung and Wind River
- Industrial Internet Consortium: Intel, Cisco, GE, IBM
- AllSeen Alliance: Led by Qualcomm, many others

| Standard | Objective | Status | Comm. range (m) | Data rate (kbps) | Unitary cost ($) |
|---|---|---|---|---|---|
| *Standardization activities discussed in this section* | | | | | |
| EPCglobal | Integration of RFID technology into the electronic product code (EPC) framework, which allows for sharing of information related to products | Advanced | ~1 | $\sim 10^2$ | ~0.01 |
| GRIFS | European Coordinated Action aimed at defining RFID standards supporting the transition from localized RFID applications to the *Internet of Things* | Ongoing | ~1 | $\sim 10^2$ | ~0.01 |
| M2M | Definition of cost-effective solutions for machine-to-machine (M2M) communications, which should allow the related market to take off | Ongoing | N.S. | N.S. | N.S. |
| 6LoWPAN | Integration of low-power IEEE 802.15.4 devices into IPv6 networks | Ongoing | 10–100 | $\sim 10^2$ | ~1 |
| ROLL | Definition of routing protocols for heterogeneous low-power and lossy networks | Ongoing | N.S. | N.S. | N.S. |
| *Other relevant standardization activities* | | | | | |
| NFC | Definition of a set of protocols for low range and bidirectional communications | Advanced | $\sim 10^{-2}$ | Up to 424 | ~0.1 |
| Wireless Hart | Definition of protocols for self-organizing, self-healing and mesh architectures over IEEE 802.15.4 devices | Advanced | 10–100 | $\sim 10^2$ | ~1 |
| ZigBee | Enabling reliable, cost-effective, low-power, wirelessly networked, monitoring and control products | Advanced | 10–100 | $\sim 10^2$ | ~1 |

# Scalability

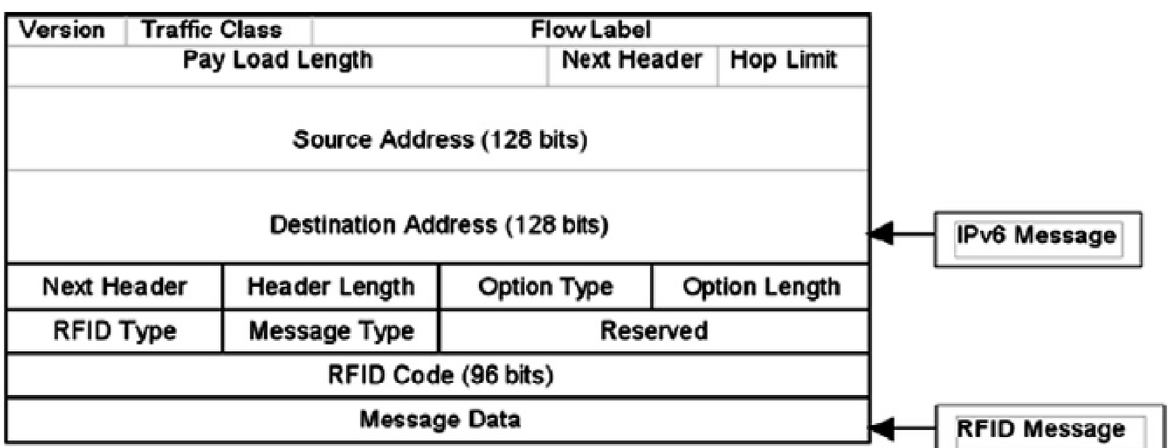



- Number of devices increasing exponentially
  - How can they uniquely be tagged/named?
  - How can the data generated by these devices be managed?

# Addressing Issues

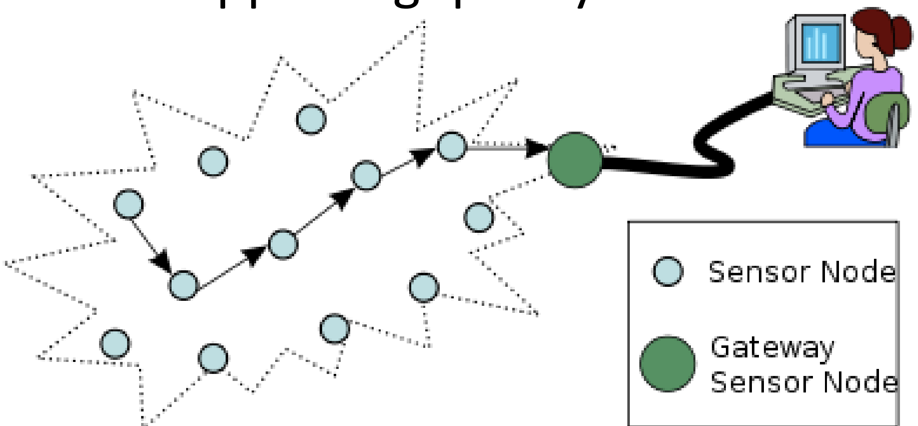
- Incredibly high number of nodes, each of which will produce content that should be retrievable by any authorized user
  - This requires effective addressing policies
  - IPv4 protocol may already reached its limit. Alternatives?
  - IPv6 addressing has been proposed for low-power wireless communication nodes within the 6LoWPAN context
- IPv6 addresses are expressed by means of 128 bits →1038 addresses, enough to identify objects that need to be addressed
- RFID tags use 64–96 bit identifiers, as standardized by EPCglobal, solutions to enable the addressing of RFID tags into IPv6 networks




Encapsulation of RFID message into an IPv6 packet.
Source: Atzori et al. (2010)

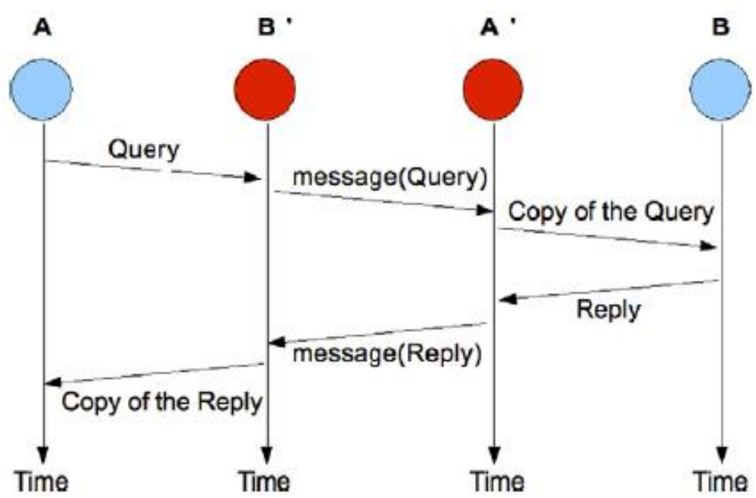
# New Traffic to Handle

- The characteristics of the smart objects traffic in the IoT is still not known
  - Important → basis for the design of the network infrastructures and protocols
- Wireless sensor networks (WSNs) traffic characterization
  - Strongly depend on the application scenario
  - Problems arise when WSNs become part of the overall Internet
  - The Internet will be traversed by a large amount of data generated by sensor networks deployed for heterogeneous purposes → extremely different traffic characteristics
  - Required to devise good solutions for supporting quality of service



# Security

- The components spend most of the time unattended
  - It is easy to physically attack them
- IoT components are characterized by low capabilities in terms of both energy and computing resources
  - They can't implement complex schemes supporting security
- Authentication problem
  - Proxy attack, a.k.a. man in the middle attack problem

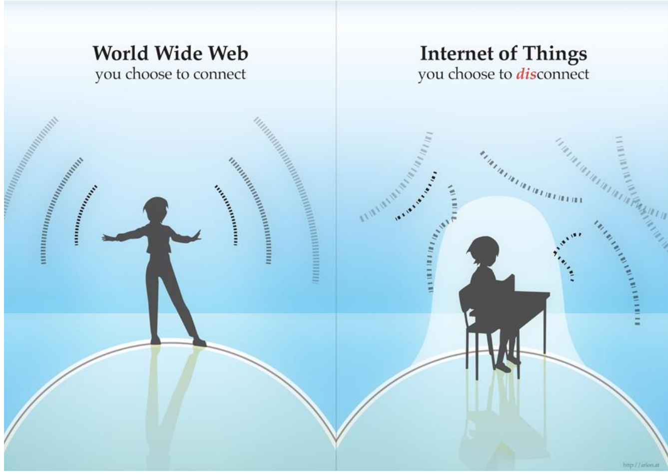



- Data integrity
  - Data should not be modified without the system detecting it
  - Attacks on the node
    - Memory protection
  - Attacks over the network
    - Keyed-Hash Message Auth. Code

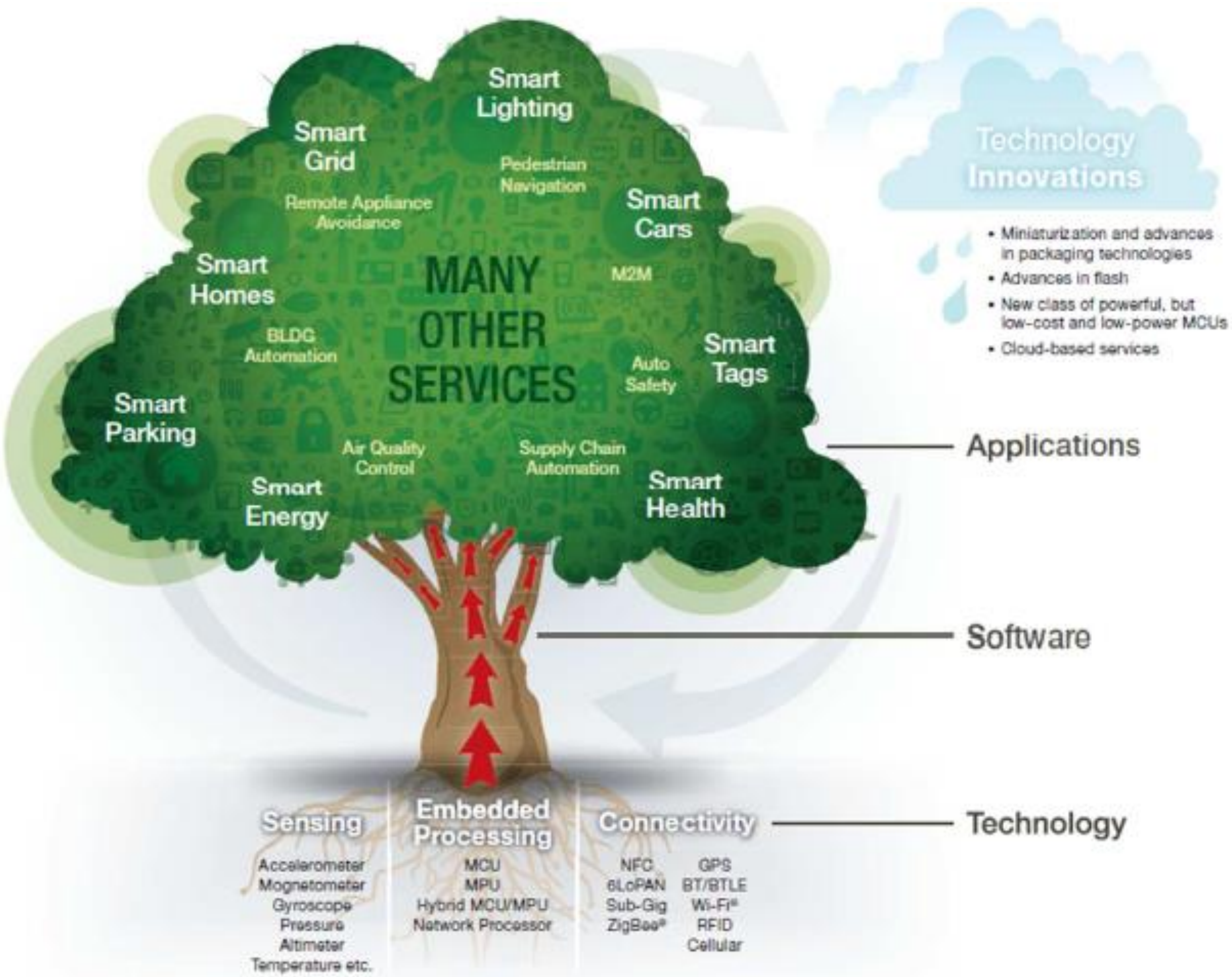
Man in the middle attack Source: Atzori et al. (2010)

# Privacy

- How is it different than traditional privacy?
  - Legislative issues
  - Ethics issues
- Easy for a person to get involved in IoT without knowing
- Data can be stored indefinitely
- Current solutions are not enough
  - Encryption, pseudo-noise signal, privacy broker

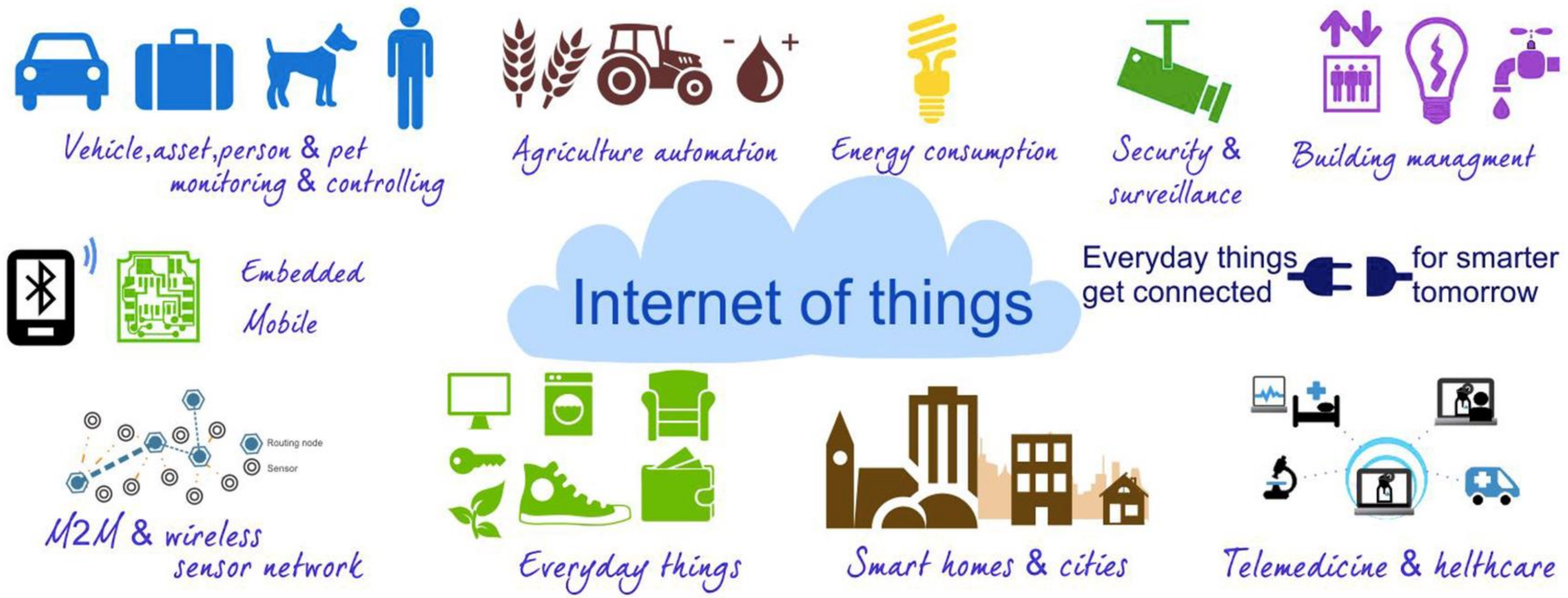


# Putting it all together



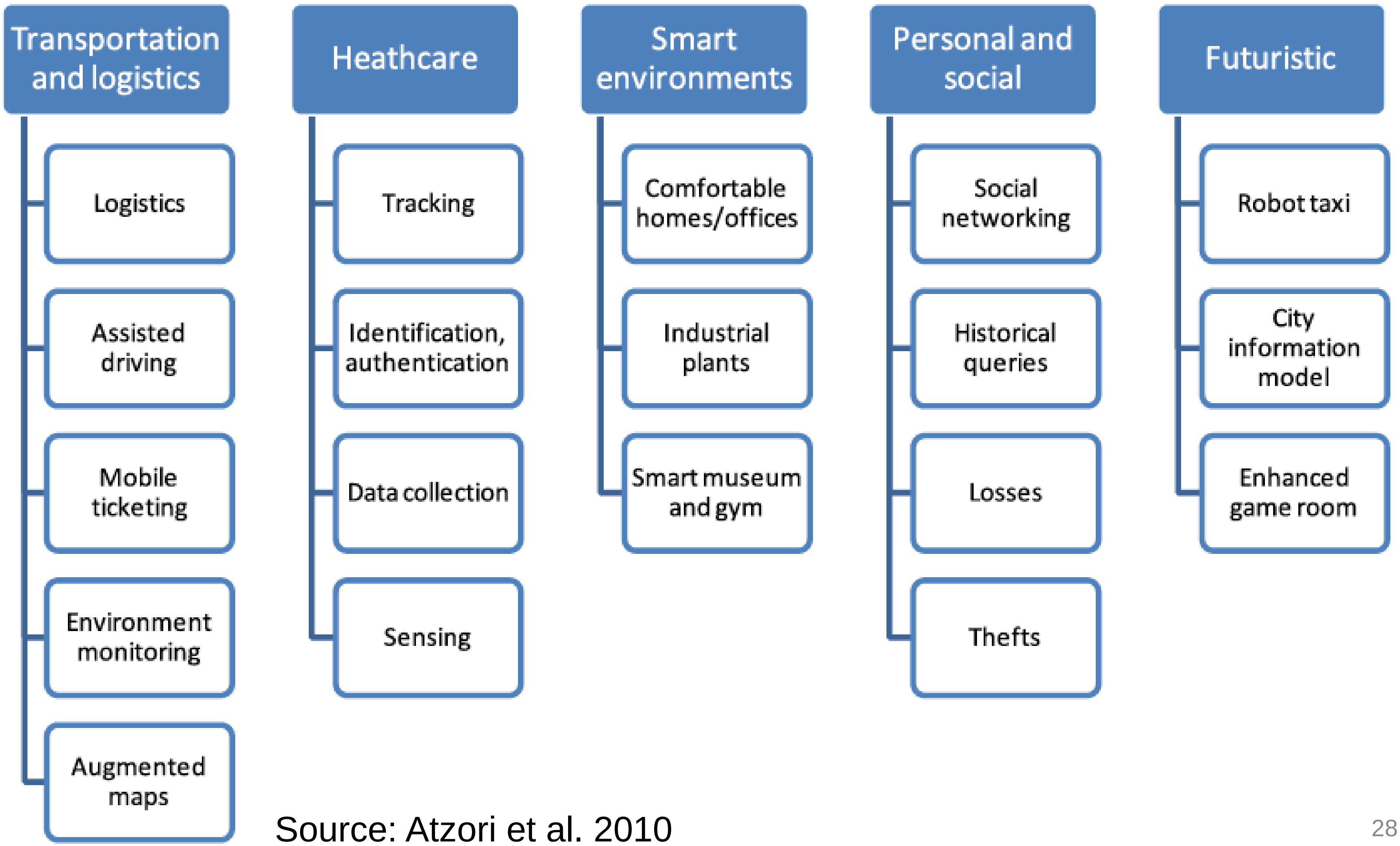

Source: “What the Internet of Things (IoT) Needs to Become a Reality,” White Paper, by K. Karimi and G. Atkinson

# Applications




- Several different domains
  - Transportation and logistics
  - Healthcare
  - Smart environment (home, office)
  - Personal and social domain
- Implications
  - Industry practices
  - IoT economics
  - Human behavior/habits

# Application Domains and Scenarios




Source: Atzori et al. 2010

# Healthcare Applications

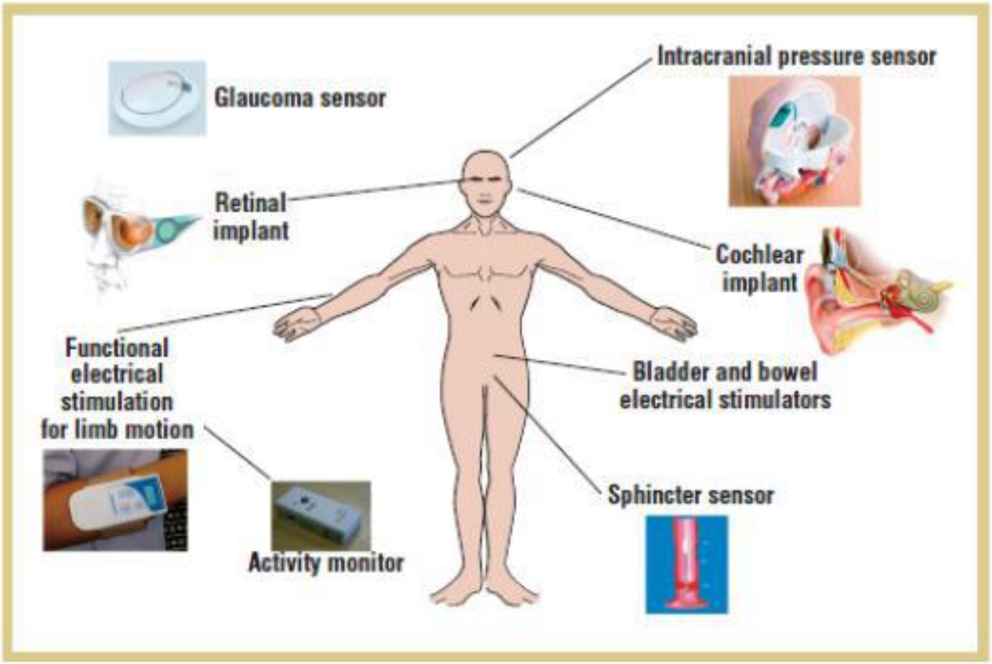


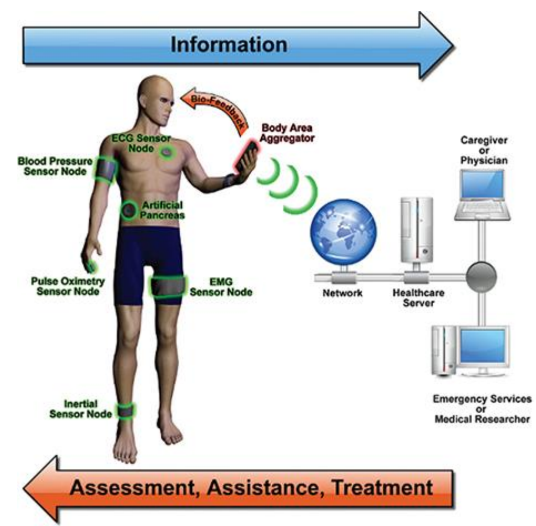

Figure 6. Fully implantable wireless sensor for the intracranial pressure monitoring system.

Source: Qian Zhang. Lecture notes. 2013

- Various sensors for various conditions
- Example ICP sensor: Short or long term monitoring of pressure in the brain cavity
- Implanted in the brain cavity and senses the increase of pressure
- Sensor and associated electronics encapsulated in safe and biodegradable material
- External RF reader powers the unit and receives the signal
- Stability over 30 days so far

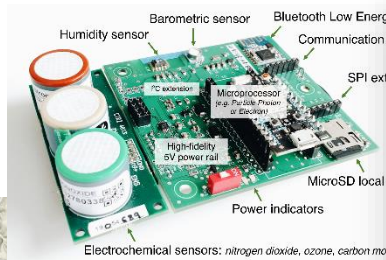
# Healthcare Applications

- Other applications:
  - National Health Information Network
  - Electronic Patient Record
  - Home monitoring and control
    - Pulse oximeters, blood glucose monitors, infusion pumps, accelerometers
  - Bioinformatics
    - Gene/protein expression
    - Systems biology
    - Disease dynamics




Source: Qian Zhang. Lecture notes. 2013

# CitiSense Deployment: Wearables and Environmental Sensors

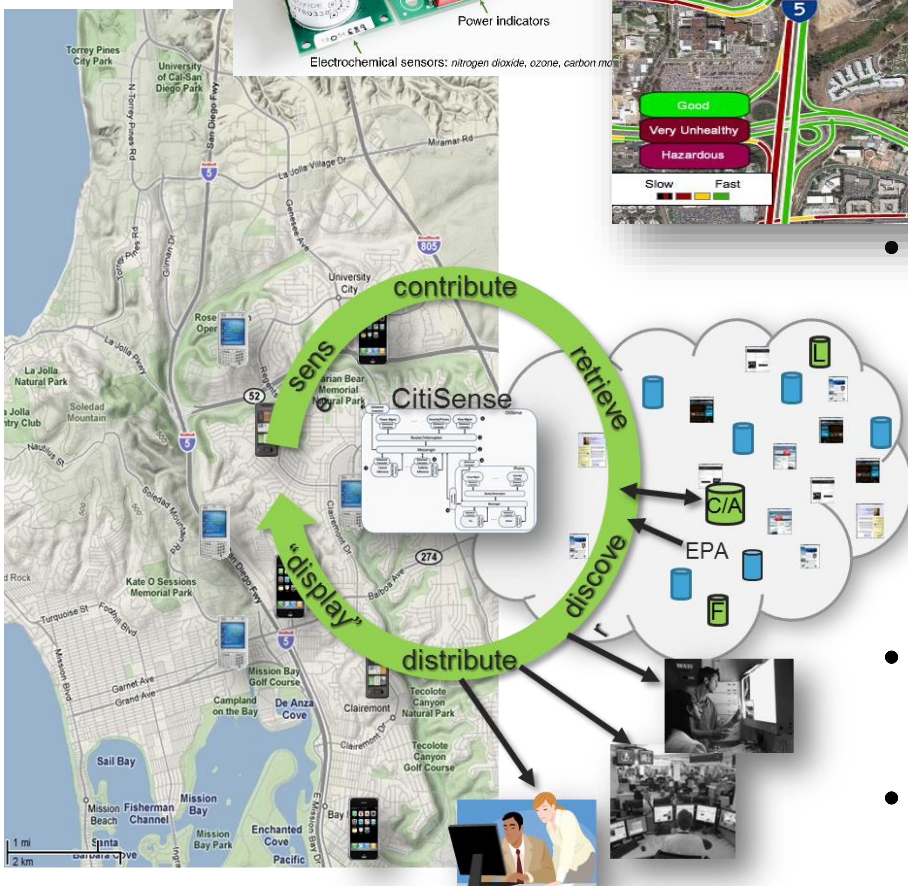




THE WALL STREET JOURNAL.

*Bad Air at State and Main*

Need advance warning of ozone at the n
air-quality sensors that feed data to sma
and others to avoid the heaviest concen

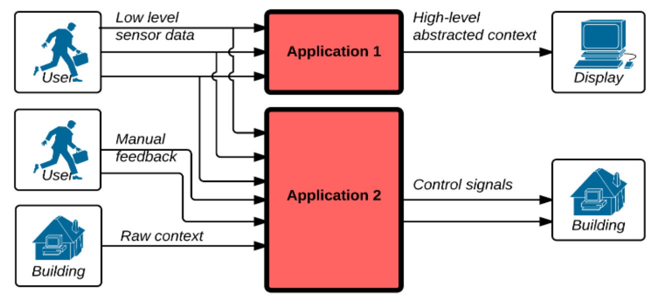



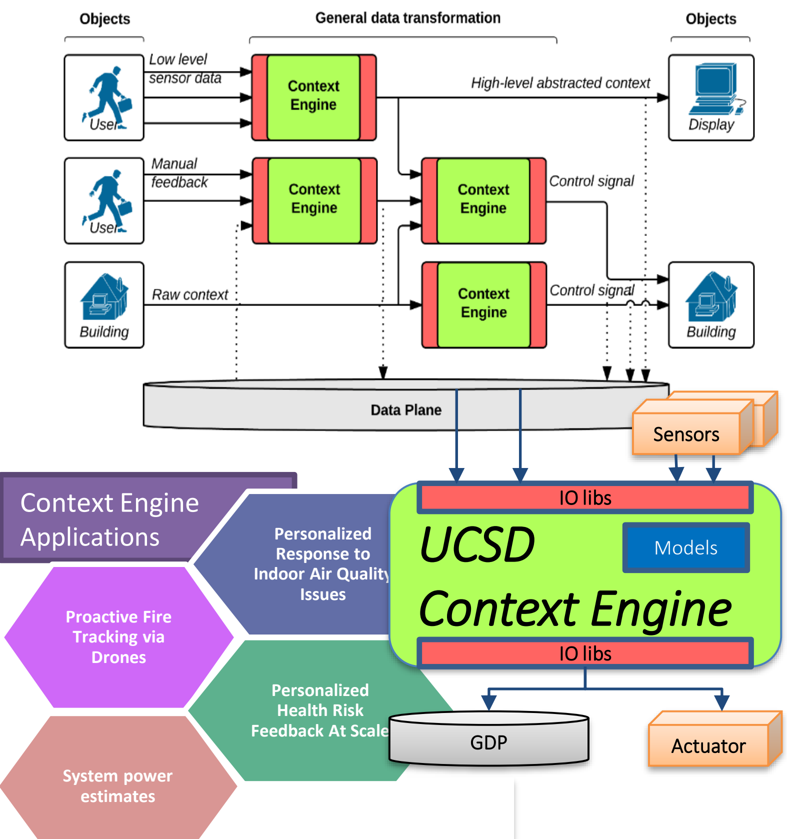

- Sensors and phones given to commuters using various transportation means throughout the greater San Diego area

  Results found "urban valleys" where buildings trapped pollution
- Major routes reported contrastingly high/low AQI for the same location
- Ease of deployment and in-network adaptation is key: learn from context!

# Context Engine & Applications

- **Goal: seamless analysis and reuse of context**
- Applications process raw input data → output actions
  - Avoids processing redundancy & monolithic applications
- Provide ontological information
  - Ontology provides range, discretization, type of input data



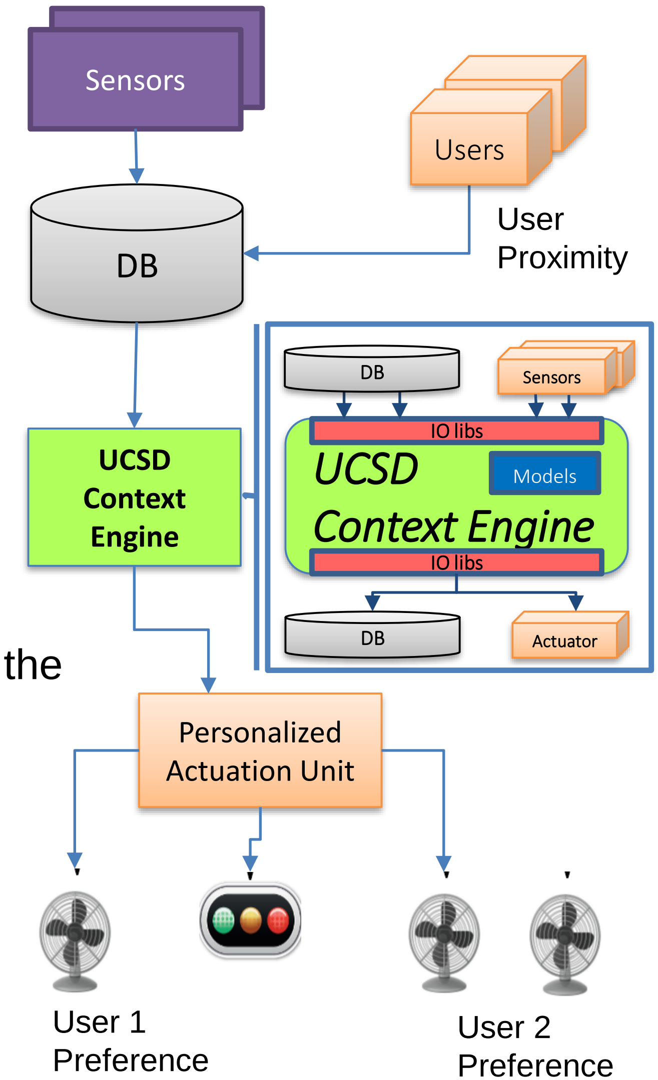



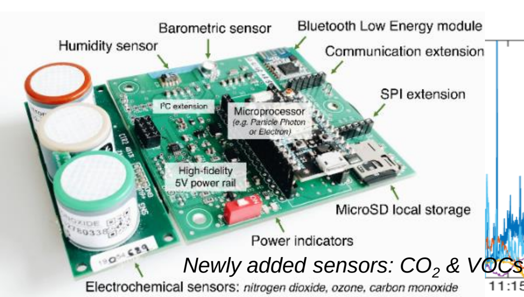

**Our approach:** Replace black-box applications with multi-input single-output functional units – ***context engines***

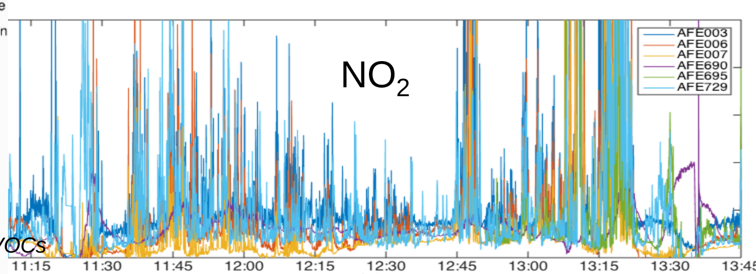
- Composable units allow data reuse & parallelization
- General purpose statistical learning to generate output based on ontological metadata:
  - Classification: Decision Trees, SVM
  - Regression: KNN, SVR, Linear Regression, TESLA
  - Clustering: K-means, D-Stream II
  - Anomaly Detection
- Simple API facilitates development; includes full RSA
- Runs on small devices (Arduino, RPi3), and on larger systems (laptops, servers)
- Easily scalable and capable of adapting to change

# Context for Proactive Indoor Air Quality Monitoring & Personalized Response

- **Goal:** Ensure a healthy environment while detecting & respecting personal preferences via flexible infrastructure
- Database interfaces with the UCSD context engine to store relevant data and interesting context needed to act on in a sensitive and personalized way
  - Complete reuse of the same SW infrastructure as for the drone firefighter app, with a different user facing interface
- Calibration of indoor air quality sensors is performed across contextual elements
  - Same SW infrastructure now detects context of power circuitry, environmental conditions, and sensor cross sensitivities
- We remotely control plug loads based on the **specific user's proximity & individual preferences** detected and derived by the **context engine** in the response to deteriorating air quality



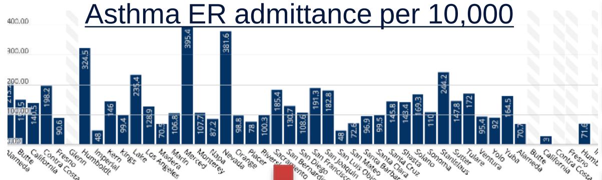
# Proactive Health at Scale: Population & Individual Context for Personal Feedback re. Health Risks

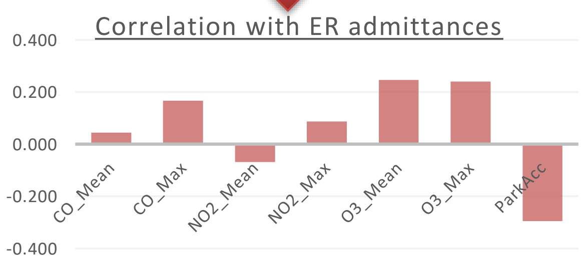
Goal: Enable citizens to take *personal* sensor readings and view it in the larger context of *population-level knowledge* to gain a more meaningful understanding of their health implications

## Population Level Analysis

- Per-county demographics, habits and environmental data -> context engine models
  - e.g. ER admittance & hospitalization to model asthma complications risk

"Let's Get Healthy California" Task Force: Asthma ER admittance per 10,000

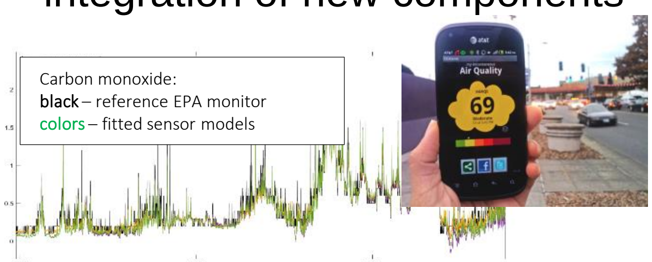





## Personal Sensing

Collect individual context

- Current environmental exposure *(e.g. exercise, daily pollutant exposure & movement etc.).*
- Ensures seamless and adaptive integration of new components

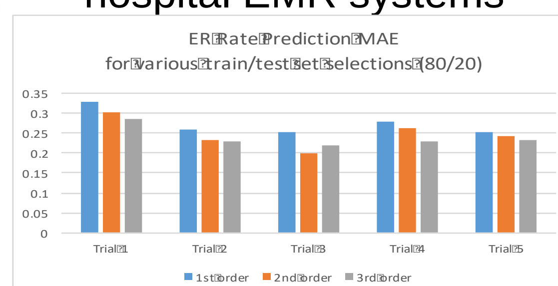



Provide actionable feedback based on personal readings, aggregated local data for multiple individuals and population level models that are all combined via context engine

## Proactive Feedback

Estimate risk

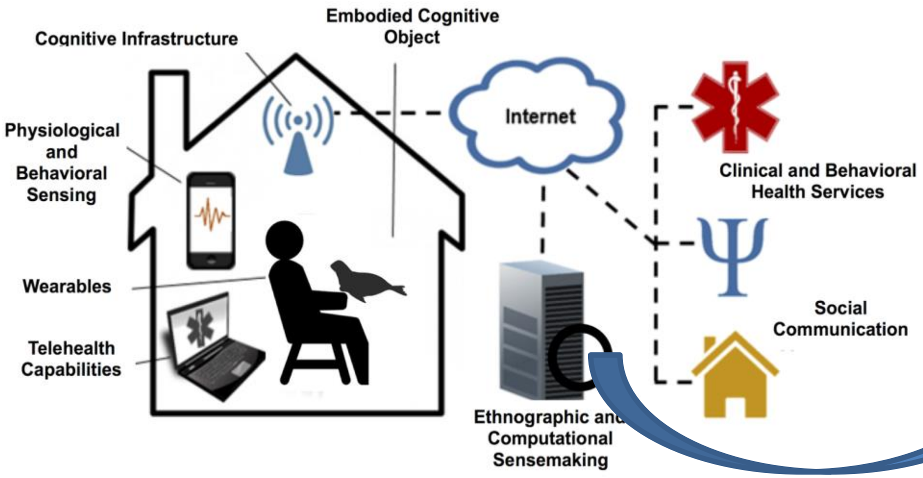
- As a function of models developed & insights gained from while monitoring daily habits
- *Context engine* active across scale: e.g. UCSD air quality sensor, patient's mobile phones, local data aggregators, hospital EMR systems




In collaboration with UCSD School of Medicine

# Healthy Aging in Place

- Longitudinal Community Research
- Ethnographic Studies
- Reading Humans
- Embodied Cognitive Objects
- Cognitive Infrastructure

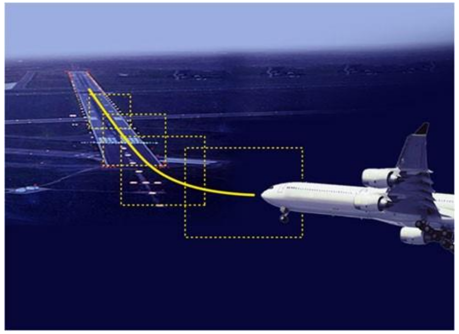


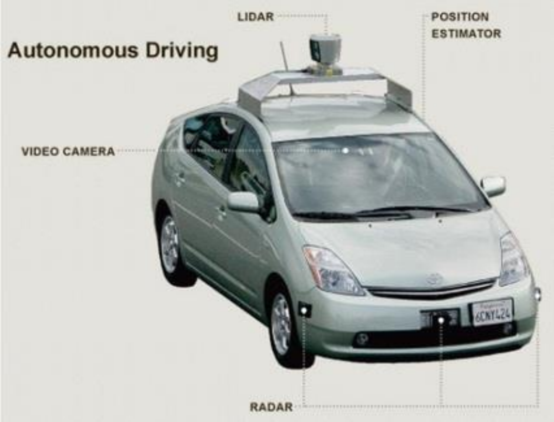

Based on image from Luxton and Riek, 2017

- HOMeAGE-Net
  - Five years of neuropsychological, ethnographic, microbiome & sensor data tied to psychosocial predictors of healthy aging
- Distributed embodied cognitive objects & infrastructure integrated with the cloud
- Suite of models and algorithms
  - Model of daily living
  - Behavioral categorization metrics
  - Personalized prediction of cognitive changes in aging
  - Personalized interventions via multiple cognitive objects

# Vehicles

- **Vehicle control:** Airplanes, automobiles, autonomous vehicles
  - All kinds of sensors to provide accurate, redundant view of the world
  - Several processors in cars (Engine control, break system, airbag deployment system, windshield wiper, door locks, entertainment system, etc.)
  - Actuation is maintaining control of the vehicle
  - Very tight timing constraints and requirements enforced by the platforms





# Example Transportation Scenarios

1. A network of sensors in a vehicle can interact with its surroundings to provide information
   - Local roads, weather and traffic conditions to the car driver
   - Adaptive drive systems to respond accordingly
2. Automatic activation of braking systems or speed control via fuel management systems.
   - Condition and event detection sensors can activate systems to maintain driver and passenger comfort and safety through the use of airbags and seatbelt pre-tensioning
3. Sensors for fatigue and mood monitoring based on driving conditions, driver behavior and facial indicators
   - Ensuring safe driving by activating warning systems or directly controlling the vehicle

Source: Qian Zhang. Lecture notes. 2013

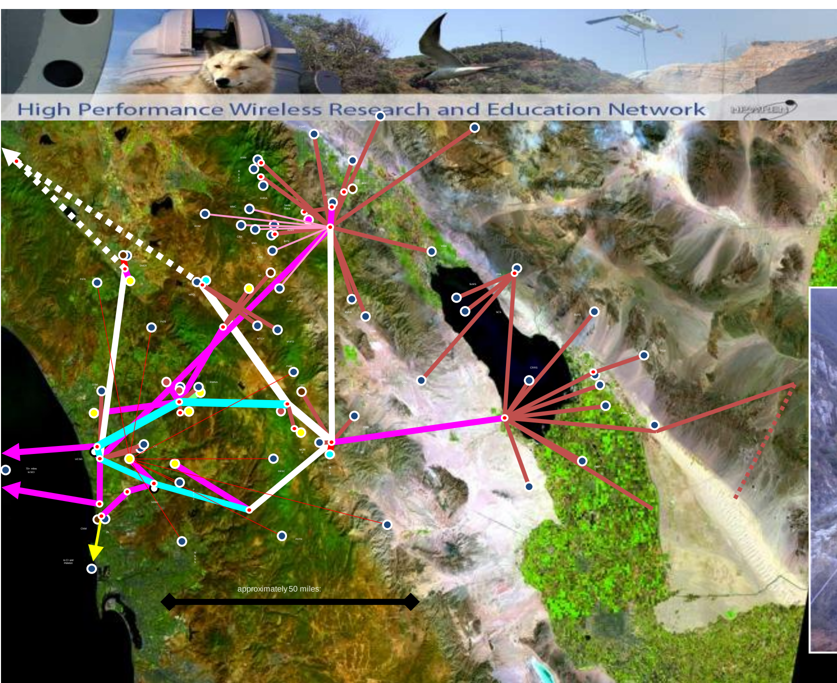
# High Performance Wireless Research and Educational Network – HPWREN 1999-pres.

HPWREN wireless connectivity covers 20k sq. mile area with numerous sensors

Motion detect cameras

Wildfire tracking cams

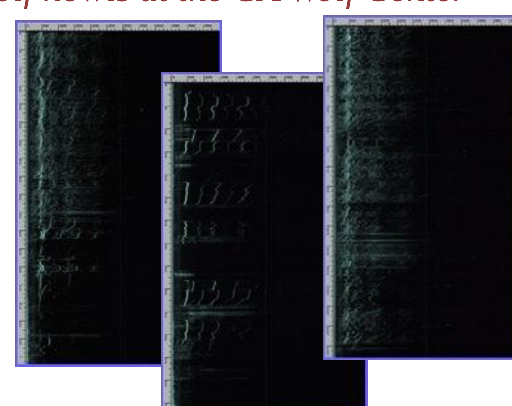
*Cal Fire Dept.*




Environmental sensors & cams

Acoustic sensors

*Wolf howls at the CA Wolf Center*



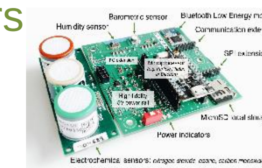
HW Braun, F. Vernon, T. S. Rosing, UCSD

# Proactive Fire Tracking in San Diego County

*Current state of the art:* Stationary sensors & cameras are placed in high risk areas. In 2003 & 2007 San Diego fires, the flames already spread beyond our ability to control them as they started away from the sensors.

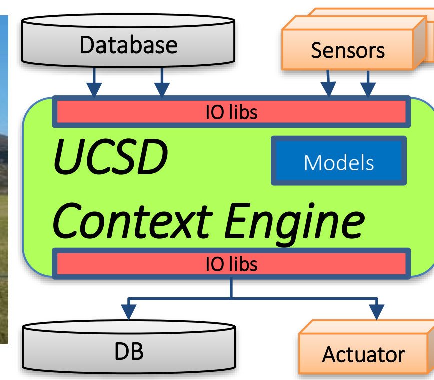
***Our goal:*** Develop a proactive infrastructure that leverages both stationary & drone based sensors to **sniff out fires & provide adaptive wireless connectivity to the troops on the ground**

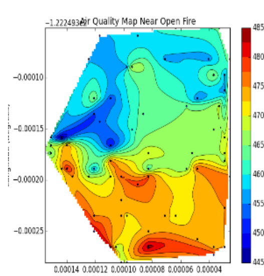
Fire tracking cameras and weather sensors
*Cal Fire Dept.*

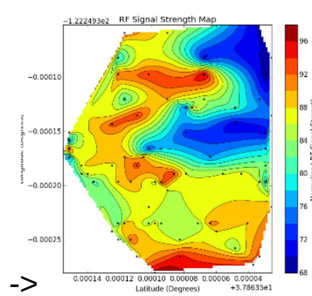



Wireless connectivity covers 20,000mile$^2$

Small fire detected

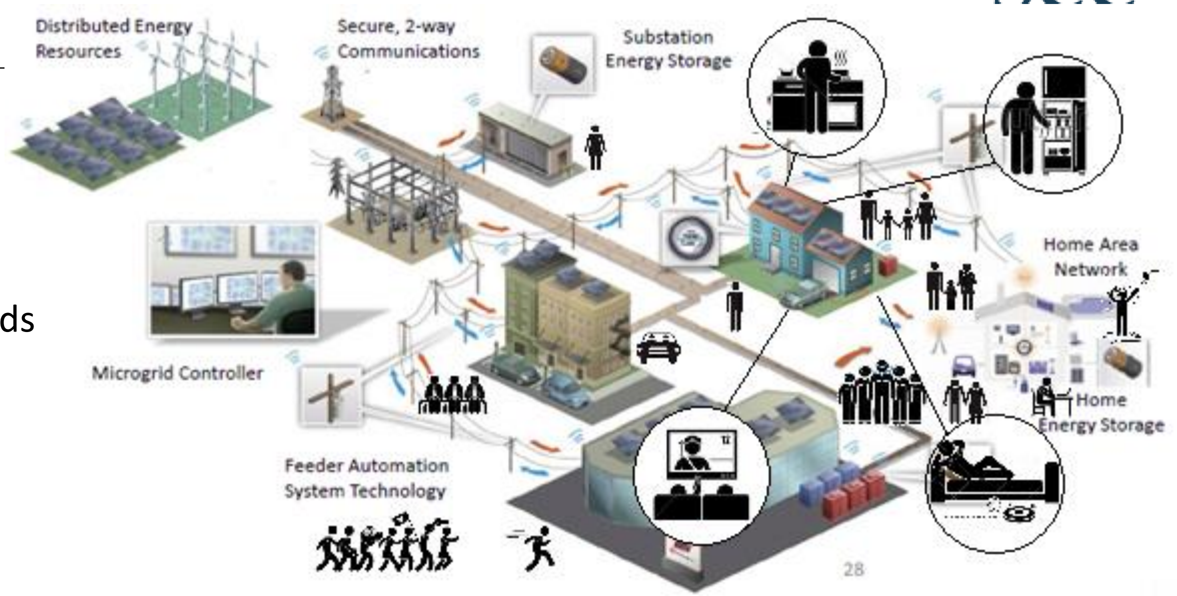


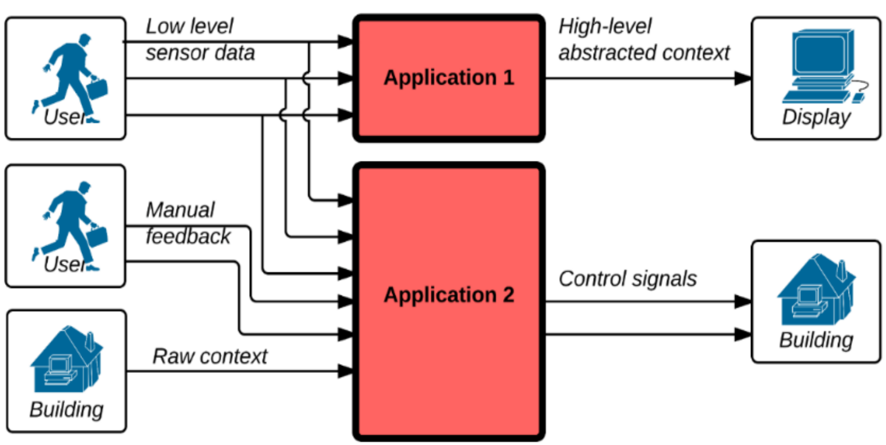




<- Air quality & RF spectrum ->

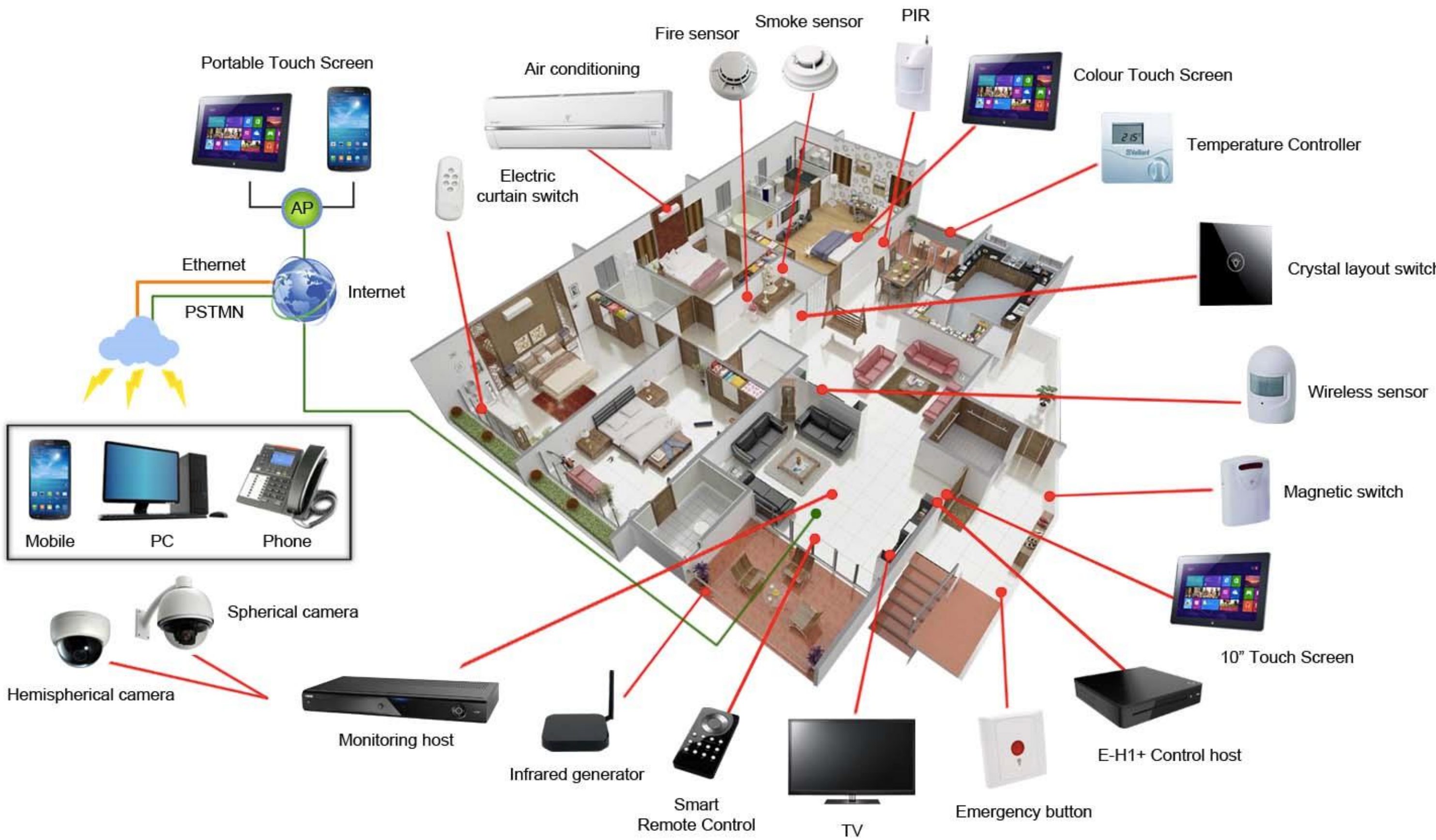
# User Context in the Smart Grid




- Context is inherent in the grid
  - Heterogeneous nodes
    - Renewable availability
    - Heterogeneous load demands
    - Energy storage
      - Stationary and EVs
  - User's habits
  - Pricing etc.
- Growing number of connected devices and associated human users provide additional grid-related ***context***:
  - Smart appliances, storage elements
  - User behavior trackers
  - To date context has been use in static manner, with monolithic applications



# Smart Home Applications



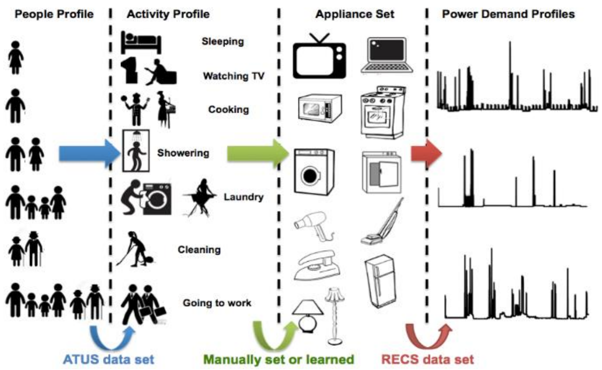

- Smart meters, heating/cooling, motion/temperature/lighting sensors, smart appliances, security, etc.

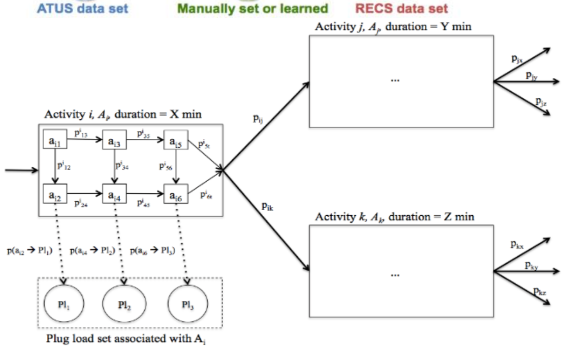
# Modeling User Behavior for Smart Grid Control at Large Scale

We are developing an automated framework to model human behavior relevant for design of context-aware distributed control in Smart Grid applications across various geographies and for all key demographics of interest

## Workload modeling

Create footprint profiles based on human activities

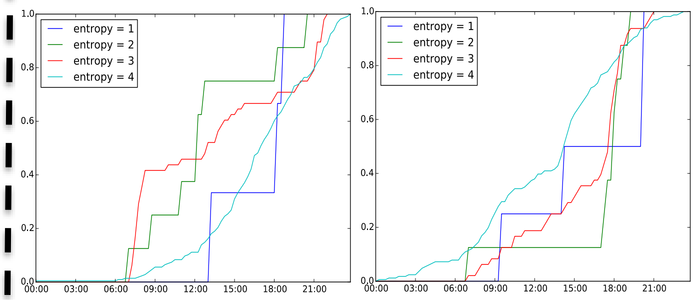


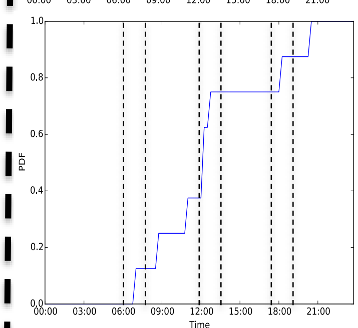




## Quality of service modeling

Find user flexibility regions

- E.g. CDFs for dishwasher and oven



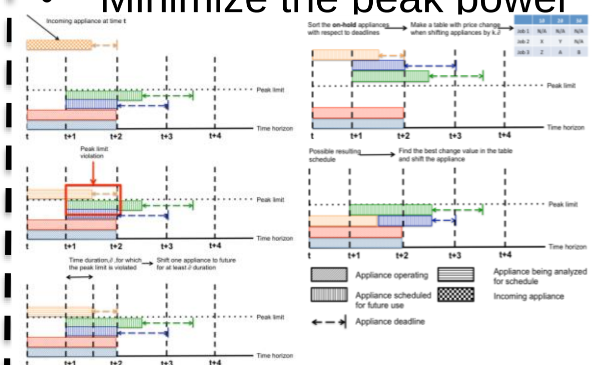

Classify the CDFs wrt entropy

Place flexibility ranges based on timing

## Scheduling

Application to neighborhood:

- Consider user flexibility
- Reduce overall cost
- Minimize the peak power



Tradeoffs: cost vs. peak power:

- 16% cost ↓--22% peak power↑
- 12% cost ↓--11% peak power↓
- 1% cost ↑-- 5% peak power↓

Funded in part by IBM

# Timely Context-Awareness

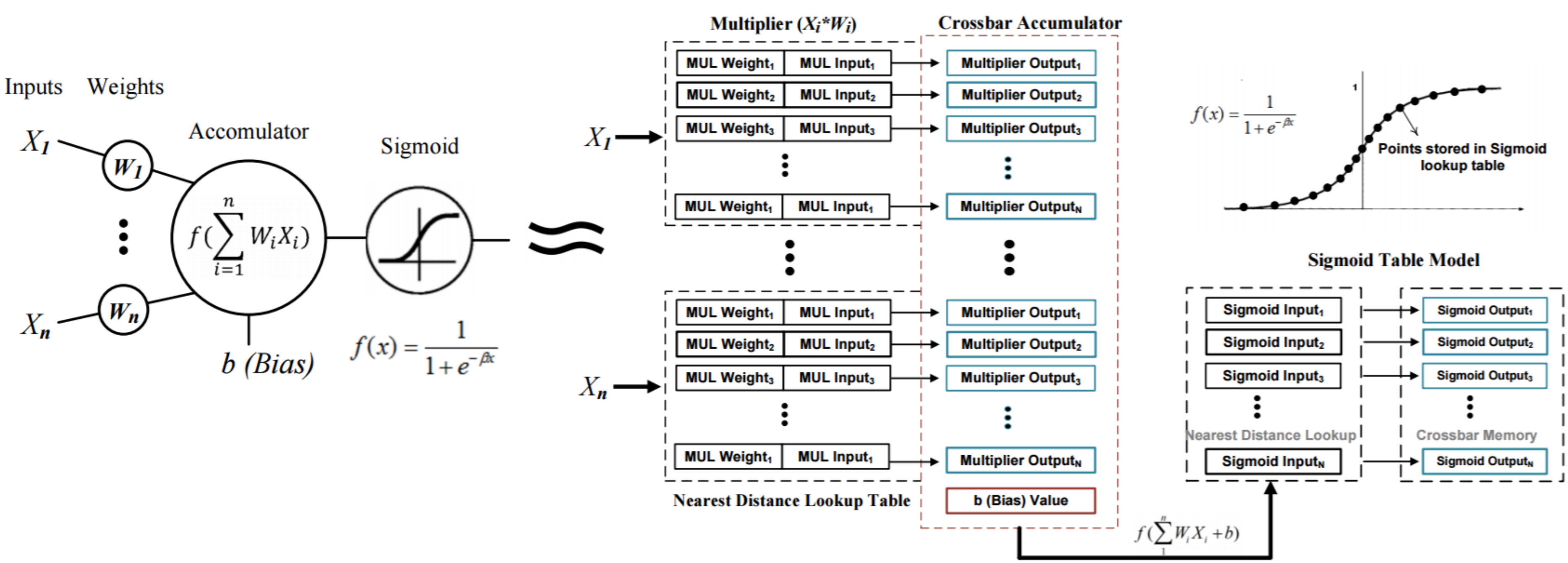
- Context should be detected at location where data is generated
  - Dramatic reductions in the total data communicated
  - Timeliness of response to relevant events
  - Easier to ensure privacy and security
- Modular context detection requires hierarchical machine learning algorithms with bounded errors
  - Sensors to servers
- We need energy-efficient and scalable implementations of machine learning algorithms on a hierarchy of IoT devices
  - ML algorithms are data intensive
    - Traditional architectures are inefficient
    - Design novel, efficient in-memory processing architectures

# In-Memory Acceleration

- **Machine learning memory-based accelerators:**
  - Classification algorithms such has K-nearest neighbor
  - Clustering algorithms such as K-means, Hierarchical Clustering, etc.
  - Neural networks:
    - convolutional neural network (CNN)
    - deep neural network (DNN)
  - Decision trees
  - AdaBoost
  - Hyperdimensional computing
- **Others algorithms:**
  - Query processing (databases)
  - Multioperand bitwise computation (for graph processing)
  - General parallelizable algorithms using only multiplications and additions, such as several image processing apps

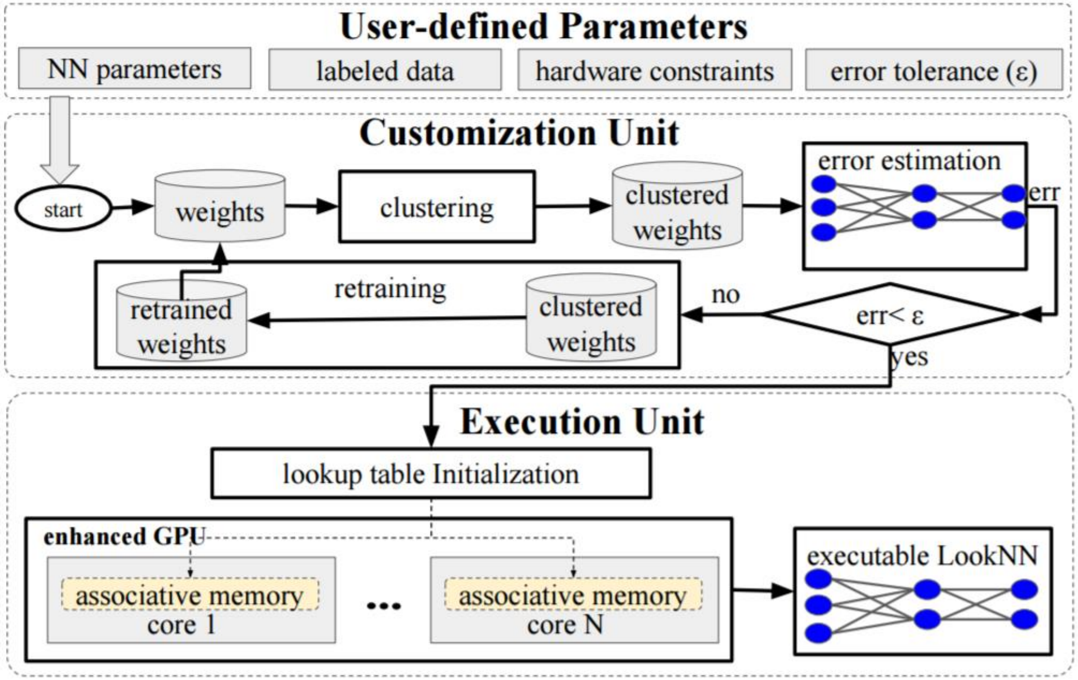
# In-Memory Neural Network Accelerator

- Neural network has convolutional, pooling & fully connected layers
- Model each neuron in memory:
  - Multiplication: lookup table
  - Accumulation: in-memory computing
  - Sigmoid and max pooling: approximate lookup table with nearest distance search capability



# In-Memory Neural Network Accelerator

- Software reduces the dataset size and enables weight sharing in memory
- An automated framework to tune neural network accuracy at runtime
- Results: 100x-1000x EDP improvement over state-of-the-art DNNs on GPU



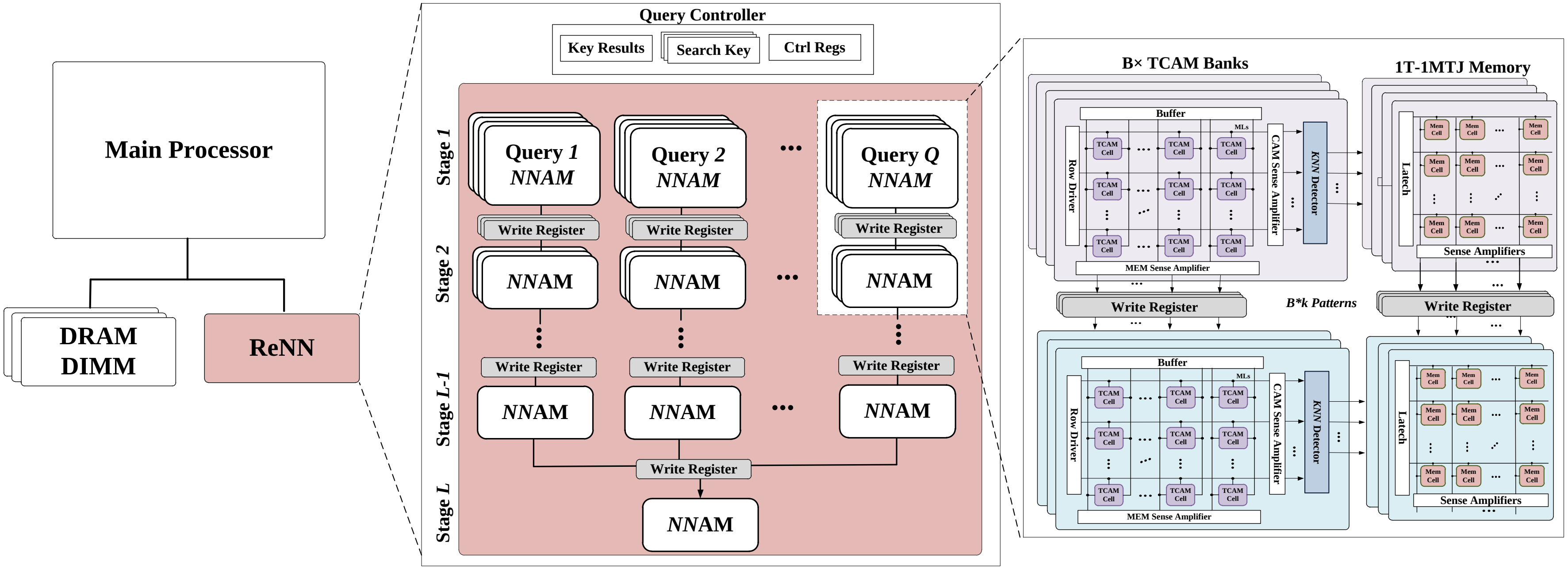


**[DATE'17]** M. Samragh, M. Imani, F. Koushanfar and T. Rosing, "LookNN: Neural Network with No Multiplication," IEEE/ACM Design Automation and Test in Europe Conference (DATE), 2017.

**[DATE'17]** M. Imani, D. Peroni, Y. Kim, A. Rahimi and T. Rosing, "Efficient Neural Network Acceleration on GPGPU using Content Addressable Memory," IEEE/ACM Design Automation and Test in Europe Conference (DATE), 2017.

# NN*gine:* KNN Accelerator

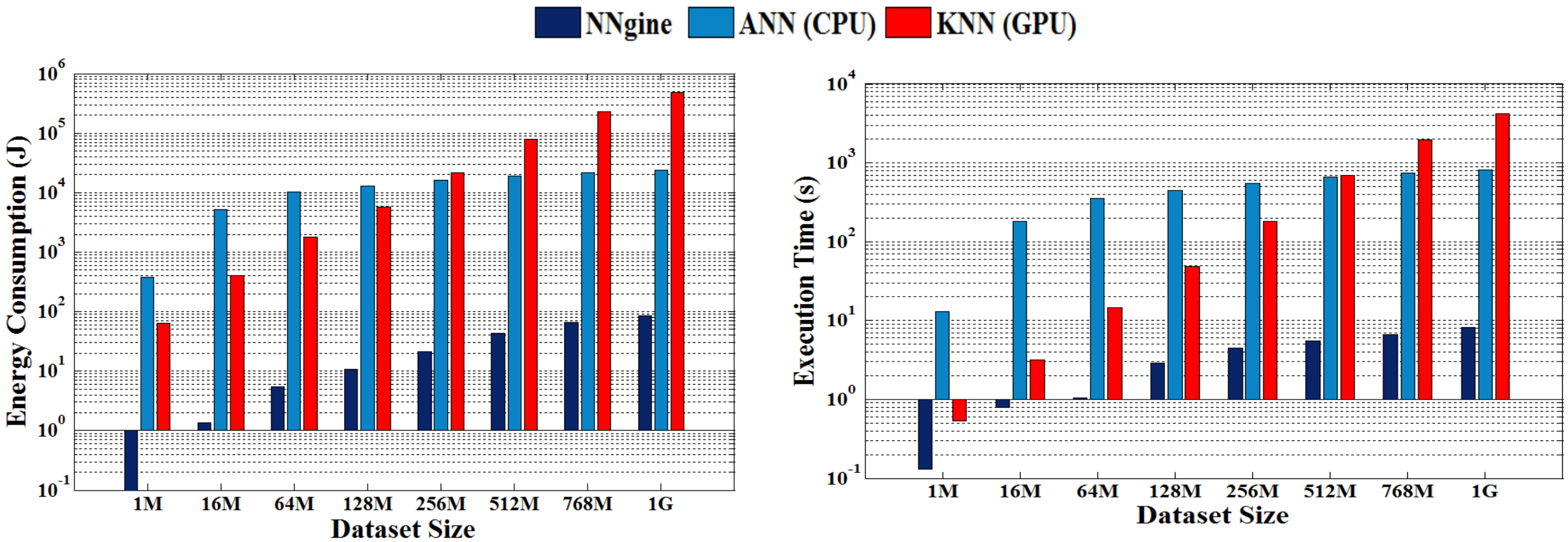
- **NN*gine*:** Nearest neighbor search accelerator
- **Applications:** pattern recognition, statistical classification, biology, computer vision, databases, coding theory, computational geometry
- Performing the search operation inside the magnetic memory next to DRAM
- ReNN can be used as memory and search engine




*NNAM: Associative memory with capability of finding k-nearest neighbor

# NN*gine* Results

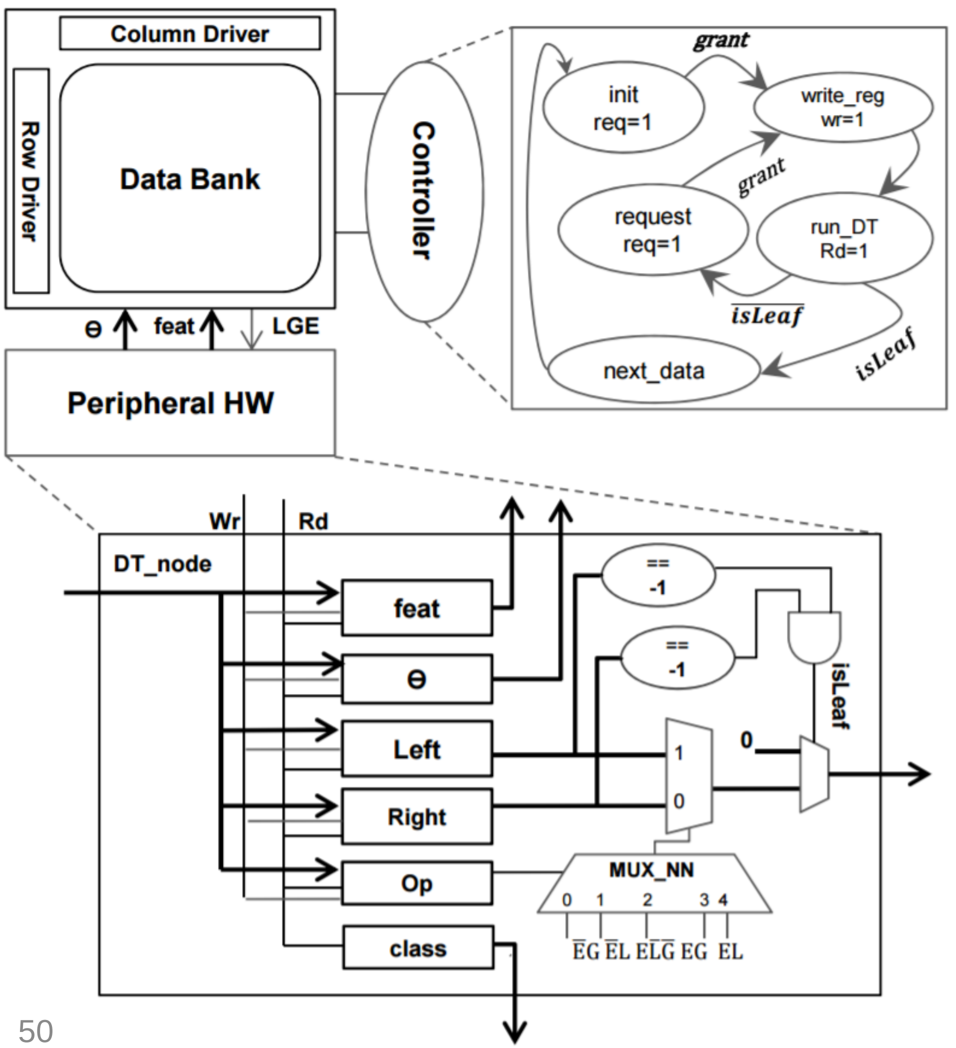
- Less than 0.5% QoS loss
- Not sensitive to dataset and query sizes




| | |
|---|---|
| **NN*gine* Energy Improvement** | 5590x |
| **NN*gine* Speed up** | 510x |

# ReDT: Decision Tree

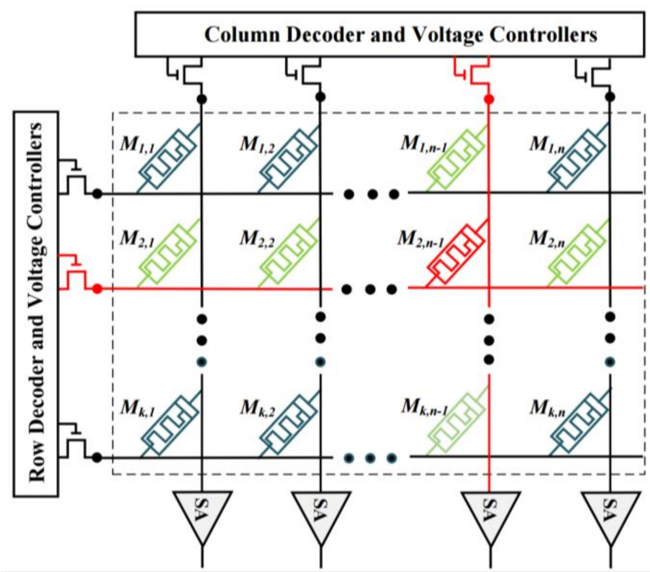
- **ReDT**: a specialized memory for Decision Tree classification
  - memory-intensive learning algorithm used in data analysis
  - Supports all kinds of equality and non-equality comparisons in memory
  - Placed closer to DRAM
- **Results:** 602X speedup and 16.5X energy savings compared to the GPU-based approach



# In-Memory Addition/ Multiplication

- Crossbar memristive memory which supports:
  - **Addition** for multiple in-memory inputs in exact & approximate modes
  - **Parallel multiplications** in a pipeline stage
- Application: at the compiler level map all instructions to addition and multiplication (e.g. via Taylor expansion) then run application in-memory

- **Applications:** data-intensive workloads such as machine learning, security, video/image processing, etc.
- **Results**: **20×** performance improvement and **480×** improvement in energy-delay product over GPU running six



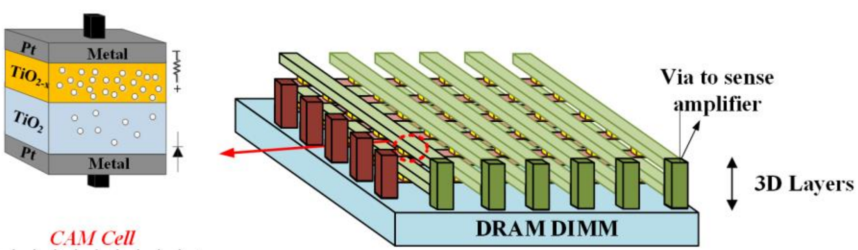


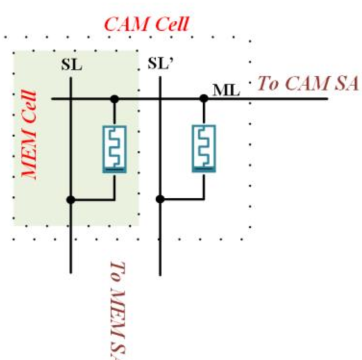
**[DAC'17]** M. Imani, S. Gupta, T. Rosing “Ultra-Efficient Processing In-Memory for Data Intensive Applications”, IEEE/ACM Design Automation Conference (DAC), 2017.

**[ISQED'17]** M. Imani, T. Rosing, "CAP: Configurable Resistive Associative Processor for Near-Data Computing," IEEE International Symposium on Quality Electronic Design (ISQED), 2017.

# MPIM: Bitwise/Search-based accelerator

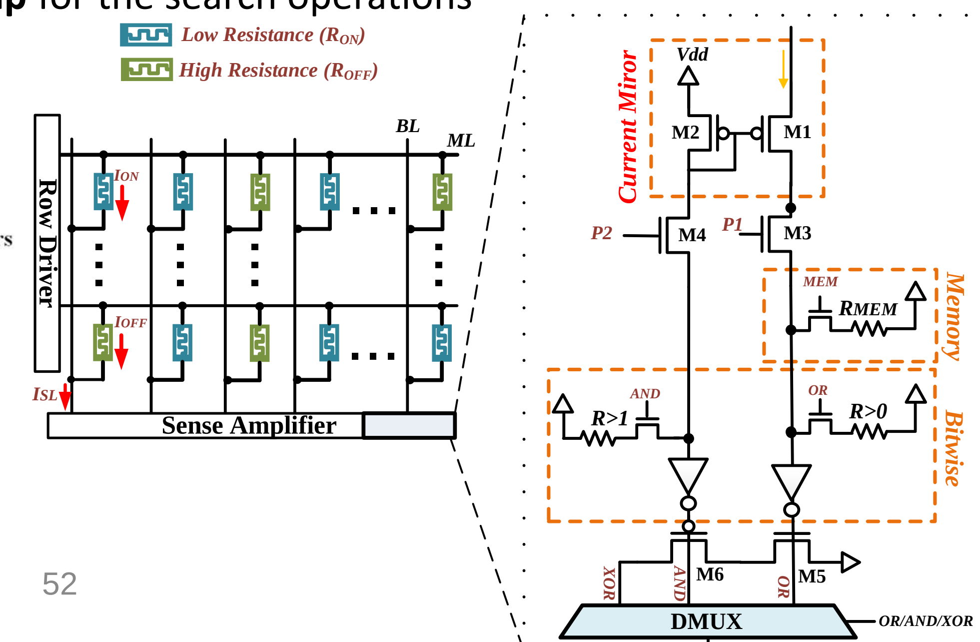
- Multi-purpose in-memory processing (MPIM) supports the following in addition to memory functionality:
  - **AND, OR, XOR computations**
    - Capable of processing bitwise operation on **up to 256 rows** at the same time.
    - **11000x** energy improvements with **62x** speedup over the SIMD-based computation
- **Search-based operations**
    - configure use as traditional resistive memory
    - **5.5x energy savings** and **19x speedup** for the search operations




Read/write/search operations

| | Data | ML | SL/BL | SL' |
|---|---|---|---|---|
| Write | 0 | VDD | 0 | Vdd |
| | 1 | 0 | Vdd | 0 |
| Search | 0 | Pre-Vdd | 0 | Vdd |
| | 1 | Pre-Vdd | Vdd | 0 |
| Read | | Pre-Vdd | - | Vdd |



# Brain-inspired Hyperdimensional Computing

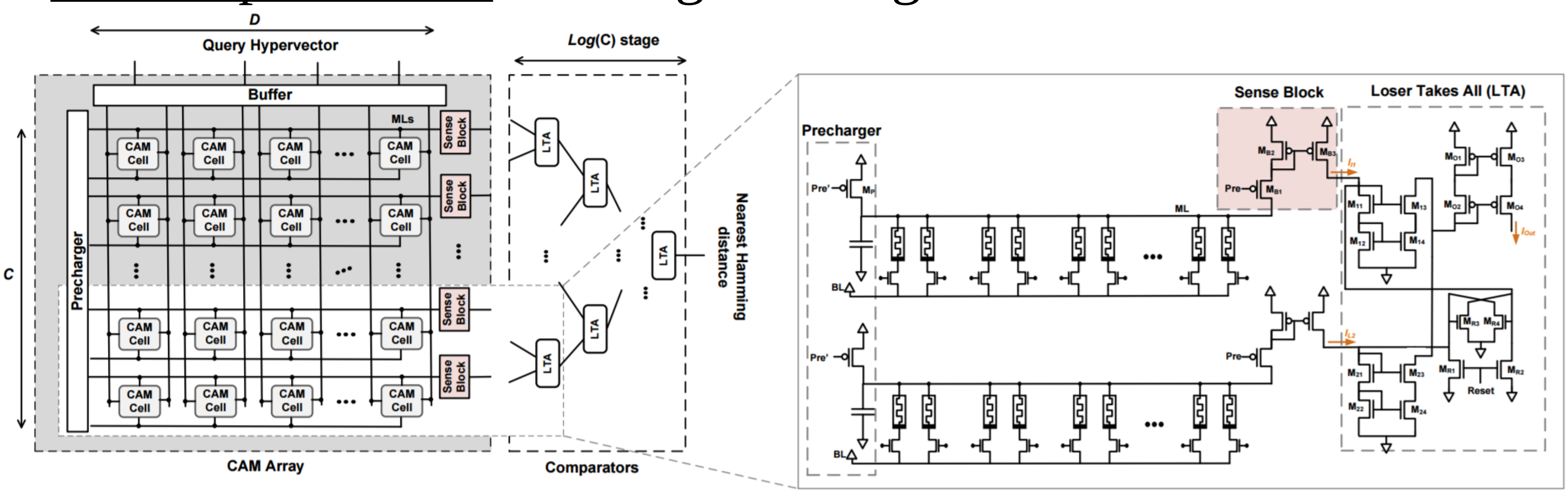
- Hyperdimensional (HD) computing:
  - Emulation of cognition by computing with **high-dimensional** vectors as opposed to computing with numbers
  - Information distributed in **high-dimensional space**
  - Supports **full algebra**
- Superb properties:
  - General and scalable model of computing
  - **Well-defined** set of arithmetic operations
  - **Fast and one-shot** learning (no need of back-prop)
  - Memory-centric with significantly **parallelizable** operations
  - **Extremely robust** against most failure mechanisms and noise

Manipulating and comparing large patterns: an efficient **associative memory for reasoning and classification**

# Brain-inspired Hyperdimensional Computing

Facilitate energy-efficient, fast, and scalable hyperdimensional associative memory (HAM):

- **Resistive HAM** (R-HAM): Timing discharge for approximate distance computing, 9.6x EDP improvement over digital
- **Analog HAM** (A-HAM): Faster and denser alternative, 1347x EDP improvement over digital design





**[HPCA'17]** M. Imani, A. Rahimi, D. Kong, T. Rosing, J. M. Rabaey "Exploring Hyperdimensional Associative Memory", IEEE International Symposium on High-Performance Computer Architecture (HPCA), 2017.

# List of IoT companies

| Software vendors | Hardware vendors | End-to-end providers | Connectivity providers |
|---|---|---|---|
| AnyBridge | | ...rge Alliance | |
| Arayent | | ...rks | |
| Asy... | | | |
| A... | | | |
| Br... | | ...t | |
| Broad... | | | |
| Busiraks | | ...tions | |
| Carriots | | … | |
| Celizion Inc | EcoTelematics Group | … | |
| Cetec GmbH & Co KG | EELEO | ZTE Corp | |

What is the approach of large companies?

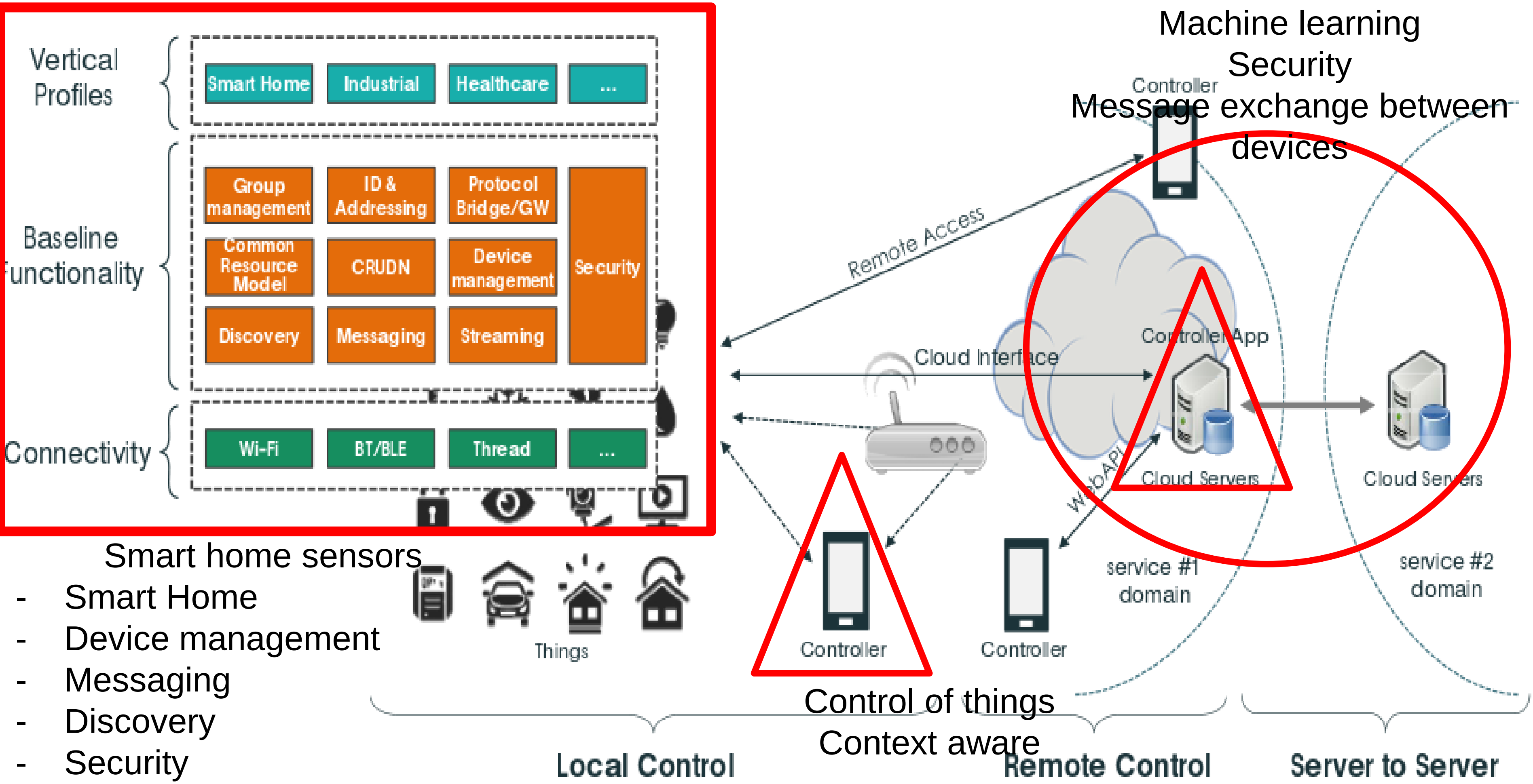
Intel, Samsung, Amazon, Google, Cisco, Microsoft, IBM, ARM, Qualcomm

www.iot-directory.com

# Big companies' approach

- IoT is big → one company cannot cover whole IoT
  - Interoperability is essential in IoT
- Open Connectivity Foundation (OCF)
  - Intel, Samsung, Microsoft, Electronux, Qualcomm, Cisco
  - Unify IoT standard and specify protocols and open source projects
  - Seeks to scale the emerging IoT ecosystem by including a broader array of companies
  - Range of customer, enterprise and embedded devices and sensors from a variety of manufactures to securely and seamlessly interact with one another
  - +100 companies, 11 academic/nonprofit centers

# OCF specification – IoT Scope




Machine learning
Security
Message exchange between devices

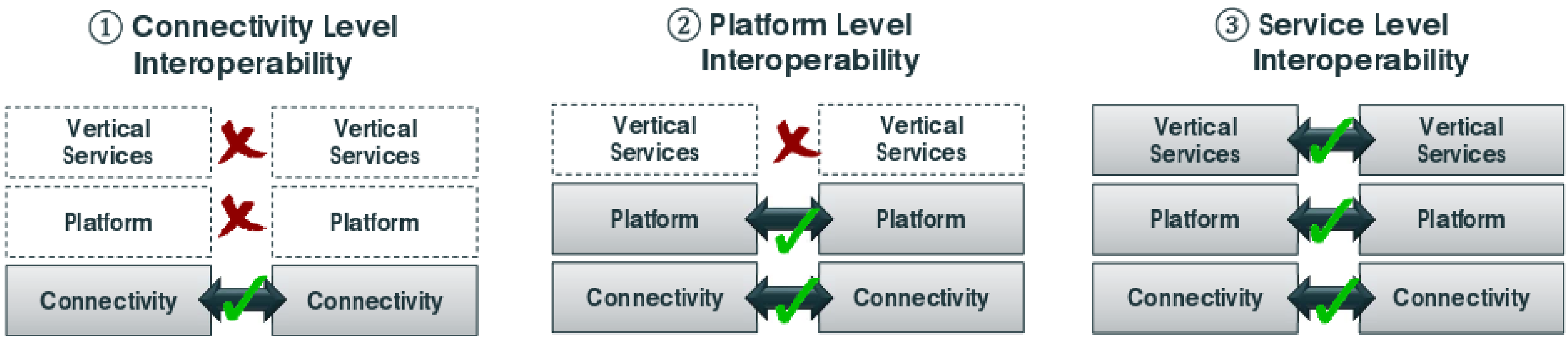
Control of things
Context aware

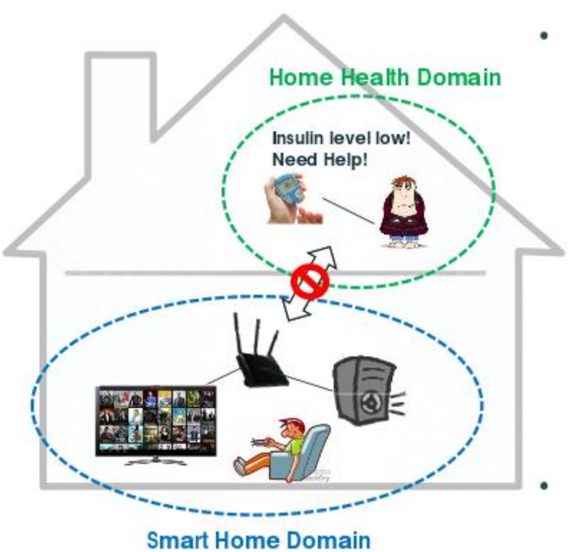
Smart home sensors

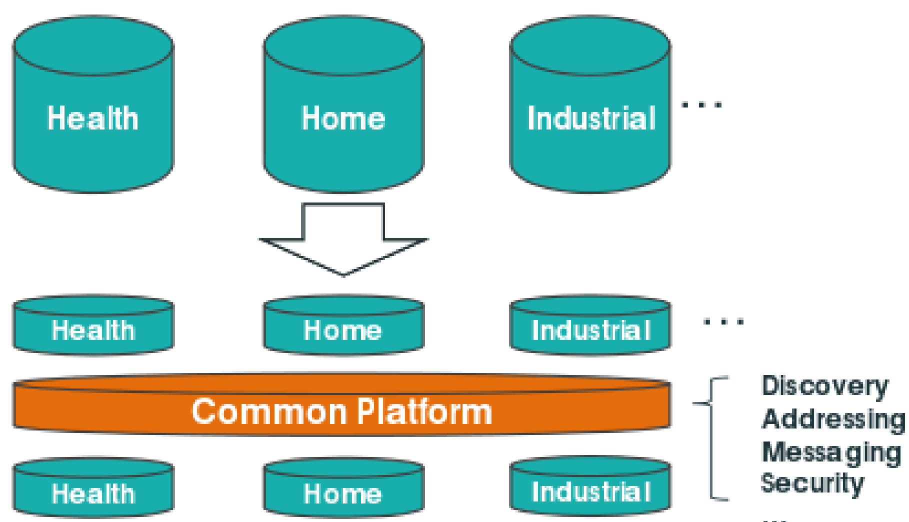
- Smart Home
- Device management
- Messaging
- Discovery
- Security
- WiFi/BL/Zigbee

# OCF specification - interoperability

- Heterogeneous things
  - Full interoperability from the connectivity layer up to the service layer

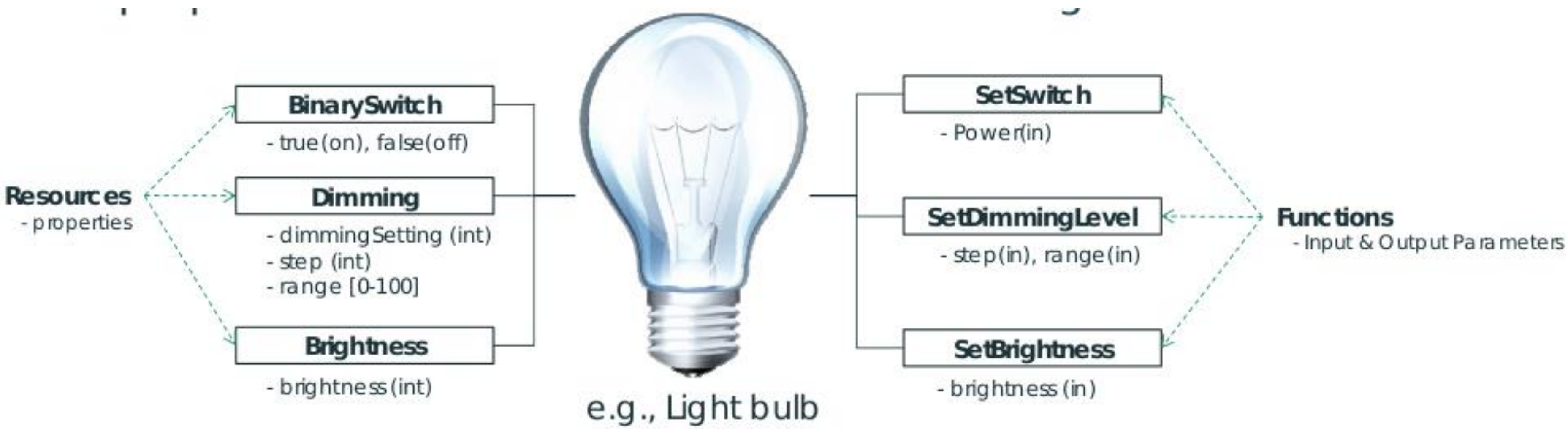


# OCT specification - definition

- Defining resources of things and its property
- Defining functions/operations of things
- Characteristics
  - Simple resource model
  - Minimize CPU load, memory impacts, traffic and bandwidth



# OCF specification - etc

- Free license which covers both code and standard
  - Standards and open source to allow flexibility creating solutions
- Certification and logo program
  - Guarantee all devices work together

# IoT industry segments

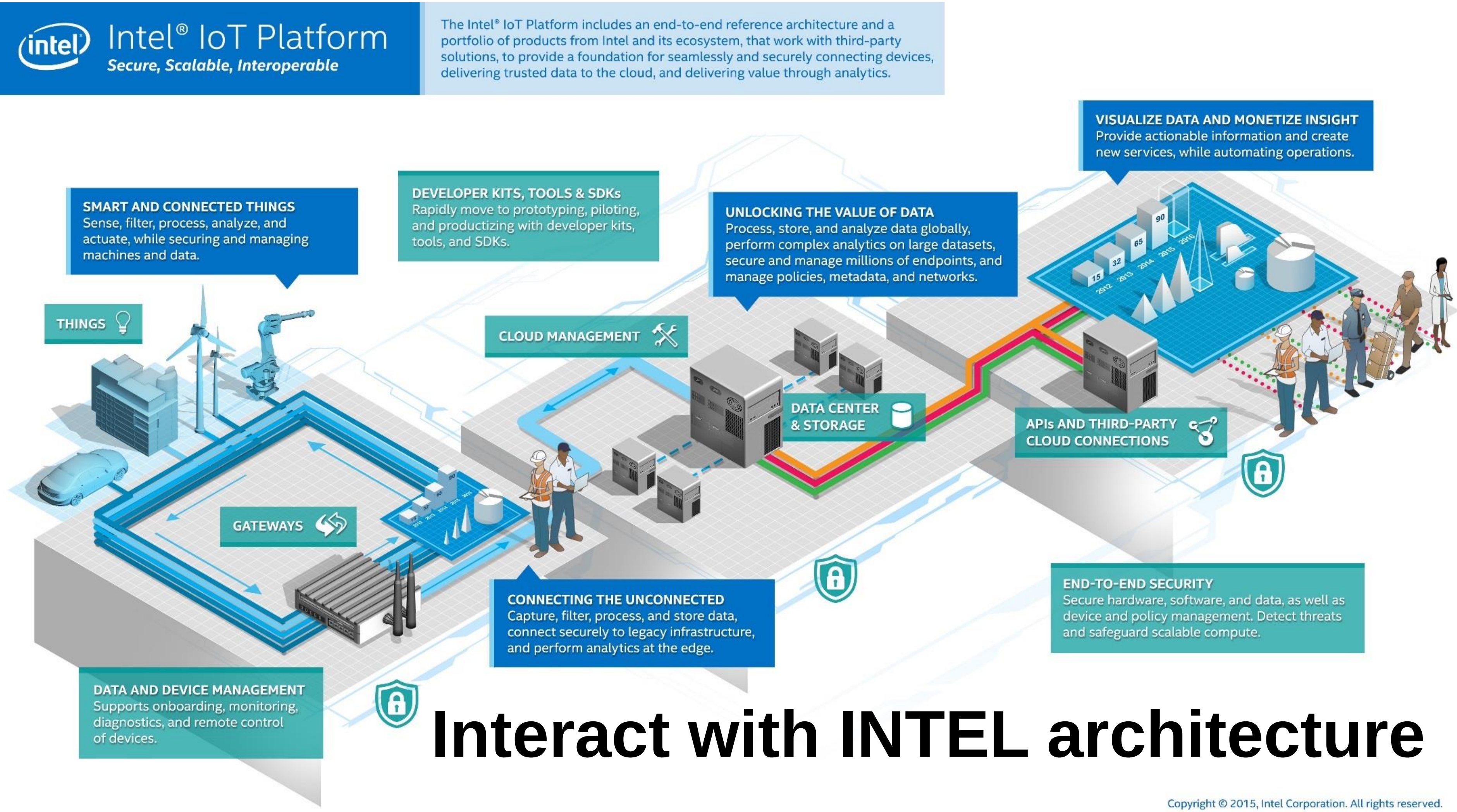
IoT Analytics – *Quantifying the connected world*

Q1/2015

| # | Company | Ranking vs. Q4/14 | Category | Overall rank[1] | Google searches[2] | Tweets[3] | News/blog mentions[4] | LinkedIn[5] |
|---|---|---|---|---|---|---|---|---|
| 1 | Intel | +5 | Semiconductor | 72% | 1k | 2.6k | 4k | 616 |
| 2 | Microsoft | +2 | Software | 69% | 480 | 1.6k | 26k | 545 |
| 3 | Cisco | +2 | Hardware | 66% | 1k | 1.4k | 5k | 719 |
| 4 | Google | -3 | Several | 59% | 390 | 3.1k | 21k | 99 |
| 5 | IBM | -3 | Software | 55% | 720 | 1.5k | 7k | 504 |
| 6 | Samsung | +3 | Consumer prod. | 34% | 590 | 1.6k | 5k | 29 |
| 7 | Apple | -4 | Consumer prod. | 31% | 170 | 1.3k | 15k | 37 |
| 8 | SAP | 0 | Software | 26% | 320 | 0.4k | 5k | 260 |
| 9 | Gartner | -2 | Market research | 24% | 390 | 1.2k | 3k | 40 |
| 10 | Oracle | 0 | Software | 22% | 170 | 0.3k | 6k | 277 |
| 11 | ARM | +3 | Semiconductor | 20% | 90 | 1.0k | 9k | 57 |
| 12 | GE | 0 | Ind. equipment | 19% | 70 | 0.4k | 3k | 319 |
| 13 | accenture | +11 | Consulting | 17% | 170 | 0.4k | <1k | 249 |
| 14 | amazon.com | -3 | Software | 15% | 110 | 0.4k | 7k | 67 |
| 15 | Hewlett Packard | +3 | Software | 15% | 90 | 0.1k | 7k | 151 |
| 16 | Arduino | -3 | Hardware | 15% | 390 | 0.5k | <1k | - |
| 17 | IDC | -2 | Market research | 15% | 210 | 0.4k | 5k | 30 |
| 18 | BlackBerry | new | Software | 13% | 210 | 0.3k | 4k | 25 |
| 19 | PTC | +10 | Software | 12% | 110 | 0.6k | <1k | 123 |
| 20 | verizon | -2 | M2M | 11% | 70 | 0.2k | 6k | 51 |

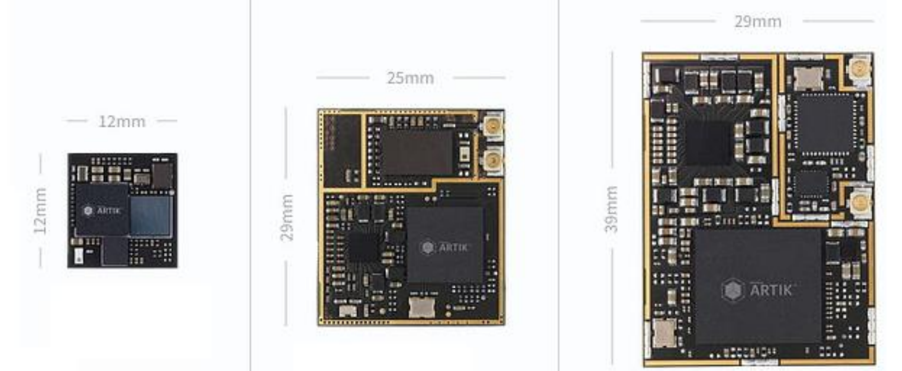
1. The highest ranking company in each aspect received a rating of 100%, with all other receiving a lower percentage in linear relation to the actual frequency. The overall result is the average of all four categories 2. Searches on Google in conjunction with IoT. 3. Tweets on Twitter in conjunction with IoT 4. Newspaper and blog mentions in conjunction with IoT 5. Number of employees that carry the tag "Internet of Things" on Linkedin. All numbers valid for Dec 2014 to Feb 2015. Sources: Google, Twitter, LinkedIn, Company websites, IoT Analytics

# Intel for IoT

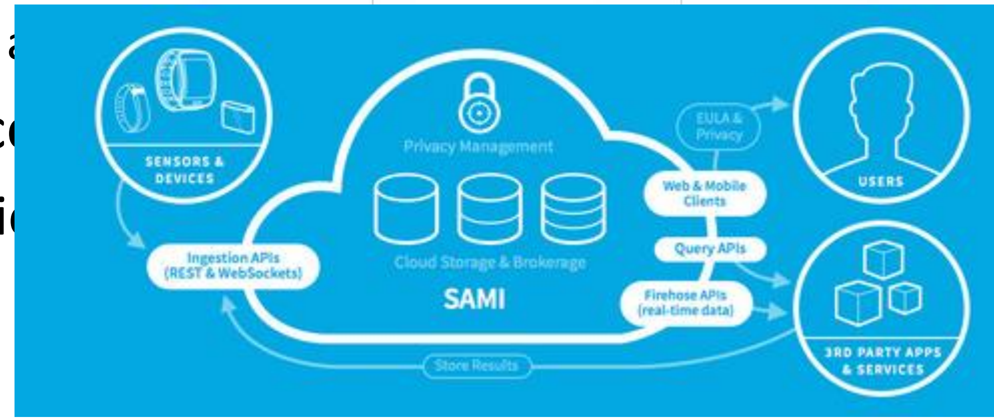


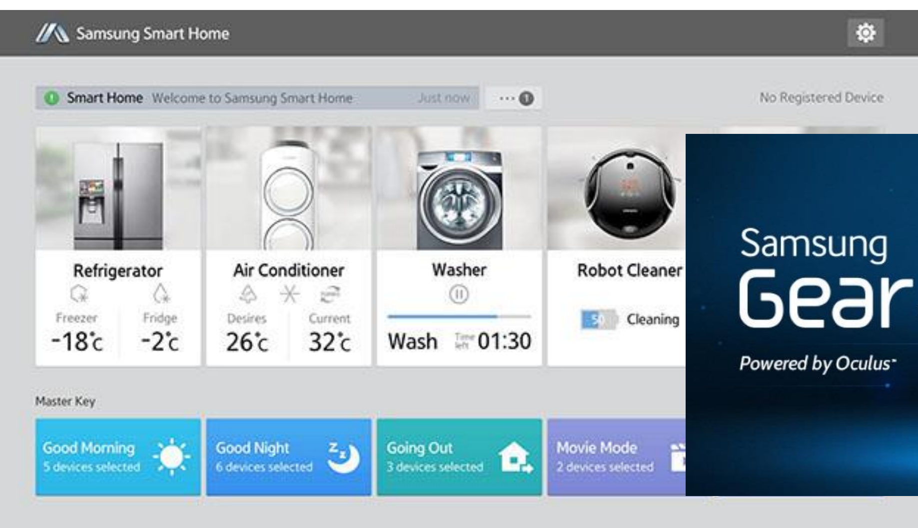

**Interact with INTEL architecture**

# Samsung




- What is Samsung products?
  - Smartphone, appliances, home a
- Connect 100% Samsung devic
  - Interoperability to other devi
- Spread power to things
  - Artik: programmable platform
  - Samsung open source tools for IoT (SAMI)





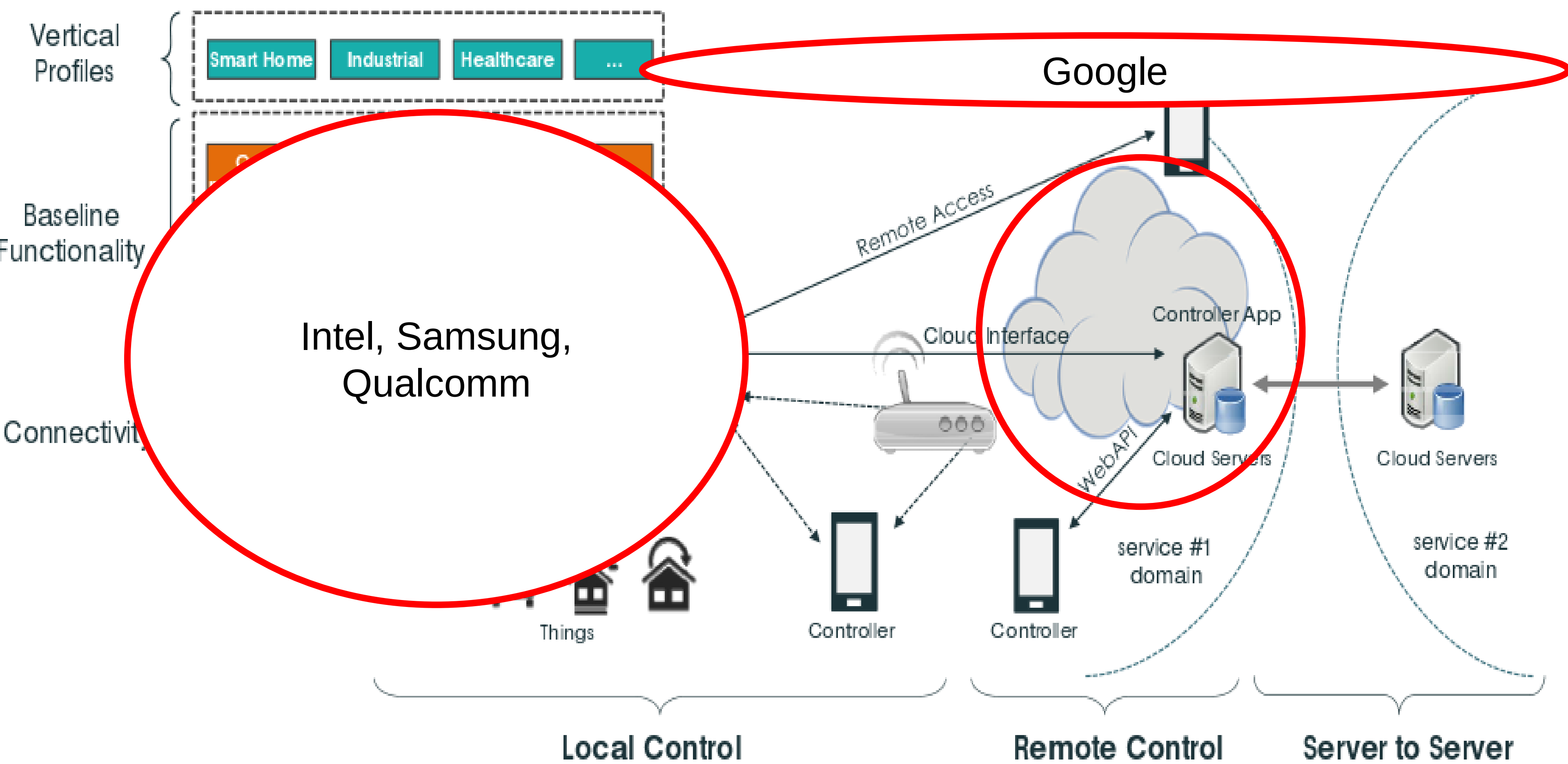
# Google f


- Google's focus
  - Machine learning, infrastructure, clou
    (Andriod)
- Brillo OS for IoT
  - The connected OS could be used on everything from major smart home appliances such as refrigerators, TV to smaller tech such as garden monitor, light bulb, door locks and sensors

AlphaGo

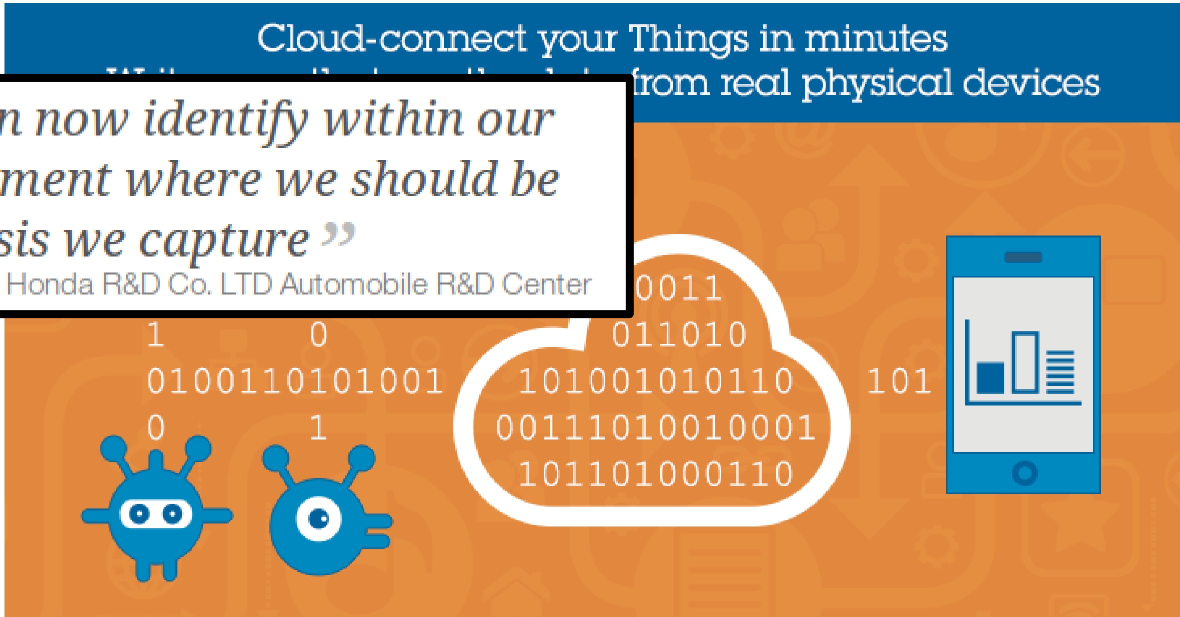
ANDROID

# OCF specification – IoT Scope



# IBM for IoT

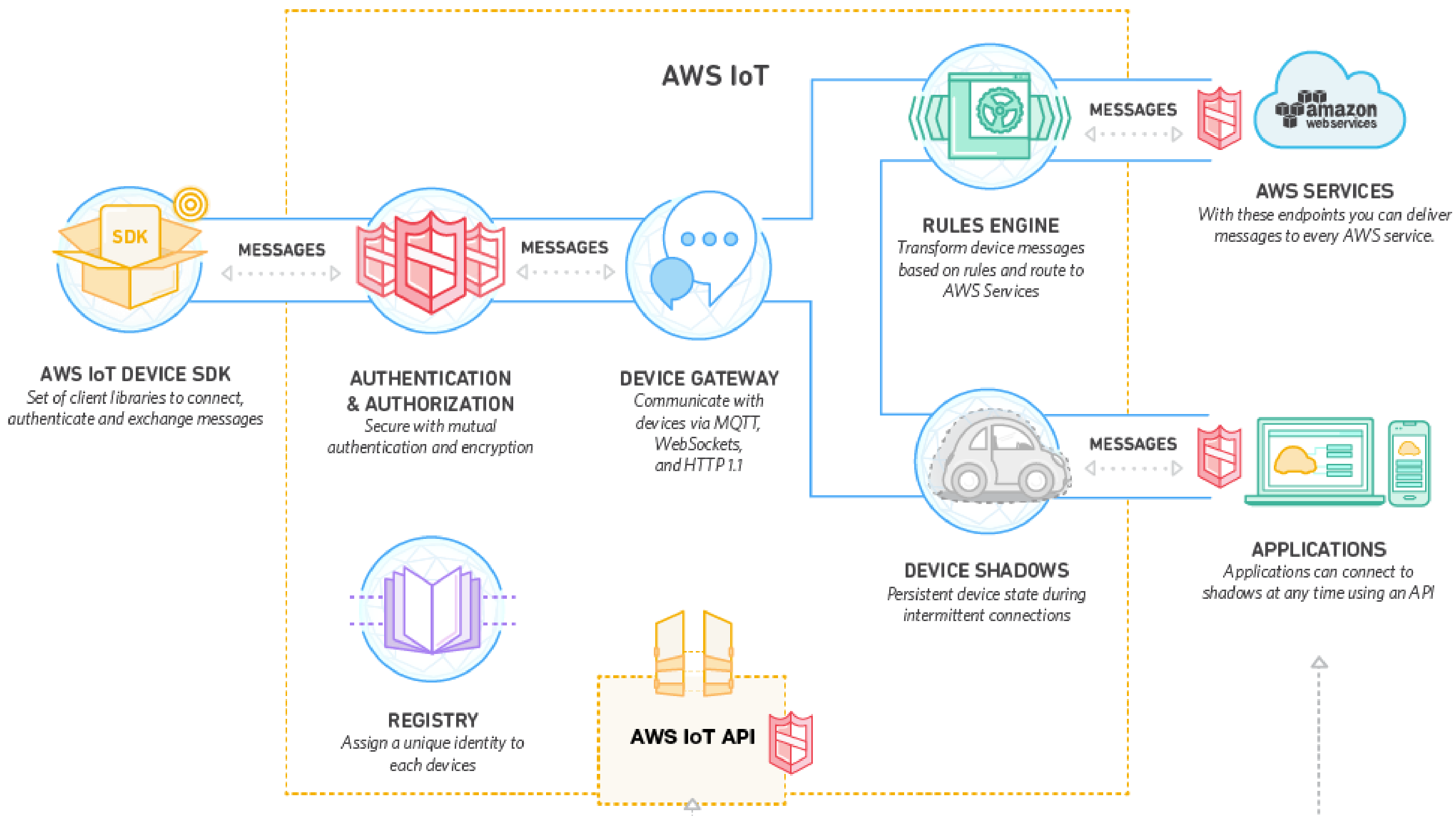
- Data analysis
  - Billions of devices, but 90% of generated data will go unused
- BlueMix
  - Provide API for App developments
  - Apps upload data to IBM cloud and analyze the data
  - Provide monitoring API




> *"With IBM Analytics we can now identify within our own research and development where we should be going from the data analysis we capture"*
>
> Kyoka Nakagawa, Research & Development, Honda R&D Co. LTD Automobile R&D Center

# Amazon for IoT

- Cloud computing: Amazon prime, music and shopping
- Shoppers: amazon prime members
  - Create Smart things: Echo, Fire TV, Dash
- Securely connect devices: AWS platform



# Company Summary

| Company | Specialty | Moto | Achievements |
| --- | --- | --- | --- |
| Intel | Chips | The IoT Engines | Intel IoT platform that helps companies to test, deploy and secure connected devices |
| Samsung | Chips/Appli ances | Internet Of Things is Internet of Everything | 90% devices IoT ready by 2017 and 100% by 2020 |
| Google | Software | IoT from A to Z | Creating a complete network of interoperable ioT devices and ensure security: Google cloud platform, Brillo IoT OS, Nest |
| IBM | Cloud | Big data analytics in IoT | Data analytics and cognitive computing |
| Amazon | Product | IoT starts with SmartHomes | Fire sticks, TV, Dash, Echo / real time data streaming analyzer Kinesis |

# Company Summary Cont.

| Company | Specialty | Moto | Achievements |
|---|---|---|---|
| Microsoft | Software | Windows 10 for IoT, | Convince retail, healthcare, manufacturing and automotive to embed Windows in their devices |
| ARM | Chips | All devices need to use ARM processors | ARM Cordio, ARM Cortex-M |
| CISCO | Network | There is No IoT without security | Nothing new here just that given Cisco's specific: exceptional reliability and security |
| Qualcomm | Chips | Connecting Internet of Everything | Qualcomm reaches $1 billion revenue in 2014 on IoT chipsets: SmartCities, Smarthones, wearable tech etc. |

# Example IoT Startups

| Company | What are they doing? |
|---|---|
| Adhere | Provide a connected pill bottle that ensures patients take their medications |
| Chui | Combine facial recognition with advanced computer vision and machine learning techniques to turn faces into “universal keys”. The world’s most intelligent doorbell |
| Enlighted | Provide smart lighting system on building, house and restaurants. Worker comfort and productivity |
| Heapsylon | Touch clothes into computers. Their socks are infused with textile pressure sensors and paired with proprietary electronics. Not only detect problems, but go well beyond that to track cadence, foot landing technique etc. |
| Humavox | Create technologies to wirelessly power IoT by using radio frequencies, thus eliminating the need for wired. |

www.cio.com – the top 10 hottest IoT startups

# Example IoT Startups

| Company | What are they doing? |
|---|---|
| Neura | Their goal is to become the glue connecting the IoT by developing an open platform that bridges objects, locations, people and the Web. |
| Revolv | Unified control of your smart home via a Smartphone or tablet app |
| TempoIQ | Provide a cloud-based sensor data analytics backend for IoT and M2M |
| Theatro | Provide small Wi-Fi based wearable devices intended for indoor communications within the enterprise |
| PubNub | Provide a global real-time network that solves the problems of large-scale IoT connectivity in the wild, enabling IoT providers to focus on their core business |

www.cio.com – the top 10 hottest IoT startups

# An exciting future!