Mobile Sensing

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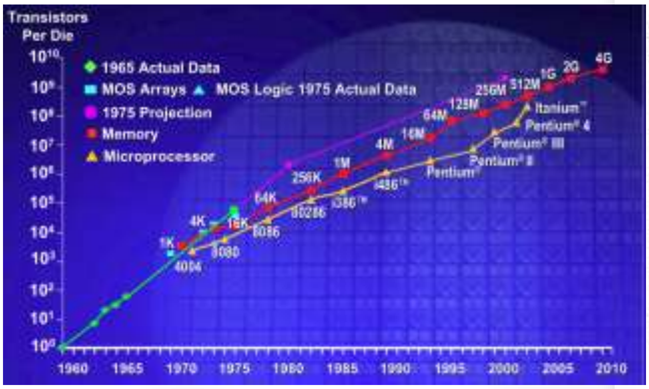
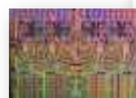
Outline

- Sensornet major developments in the past decade
  - Smart dust vision
  - HW, networking and SW, tasking, big data
- Ubiquity of mobile sensors
  - Sense proximity, location, and context
  - Enable new user apps and experiences

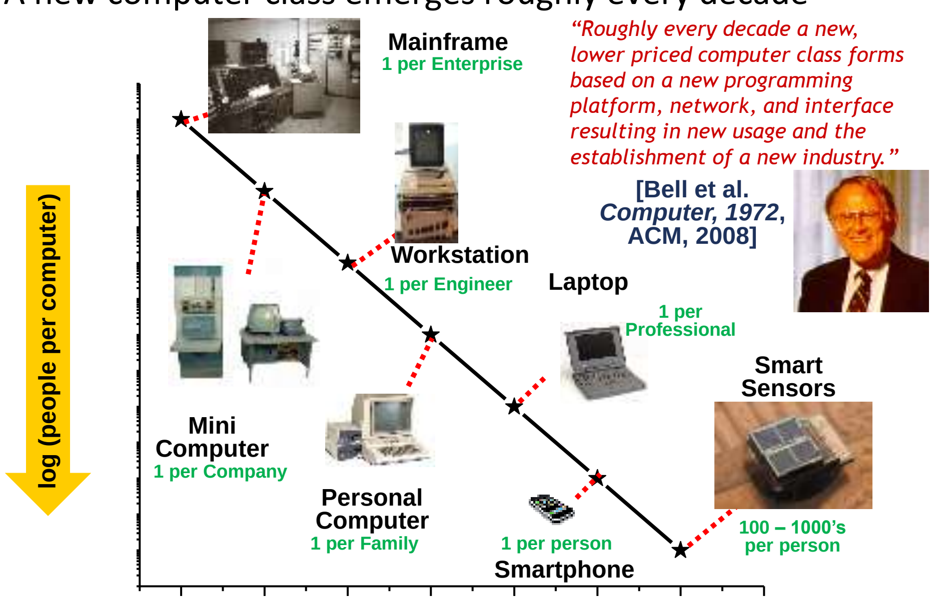
Moore’s Law:
IC transistor count doubles roughly every two years




Intel 4004


Intel Core i7

Bell’s Law of Computer Classes:
A new computer class emerges roughly every decade

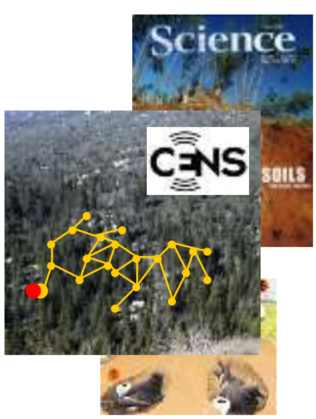


Credit: Dutta

A Brief History of Sensornet

- 1980: DARPA DSN (PM: Bob Kahn) – sensors are truck-sized, connected via Ethernet using microwave radios
- 1994: Smart dust (Kris Pister)
- 1994-98: *UCLA* WINS, *Xerox PARC* Smart Matter
- 2000: *Berkeley* motes; Intel Berkeley Lab
- 1999-: Gov't funding
  - DARPA SensIT (USC/ISI, Cornell, Xerox PARC, BBN, BAE, UCLA, Penn State, Wisconsin, UIUC, MIT, Berkeley, LSU/Tennessee)
  - DARPA NEST (Berkeley TinyOS, Ohio State, UVA, …)
  - NSF NETS/NOSS/CPS
  - China 973, Korea, Japan, EU, IoT, …
- 2000-: Industry:
  - Startups: Crossbow, Ember, Dust, Sensicast …
  - Industrial R&D: Agilent, Cisco, Hitachi, HP, Intel, IBM, Microsoft, Motorola, Nokia, Sun, Xerox PARC, …

Diversity of sensornet applications



Environmental
- Monitoring space
- E.g., habitat, birds

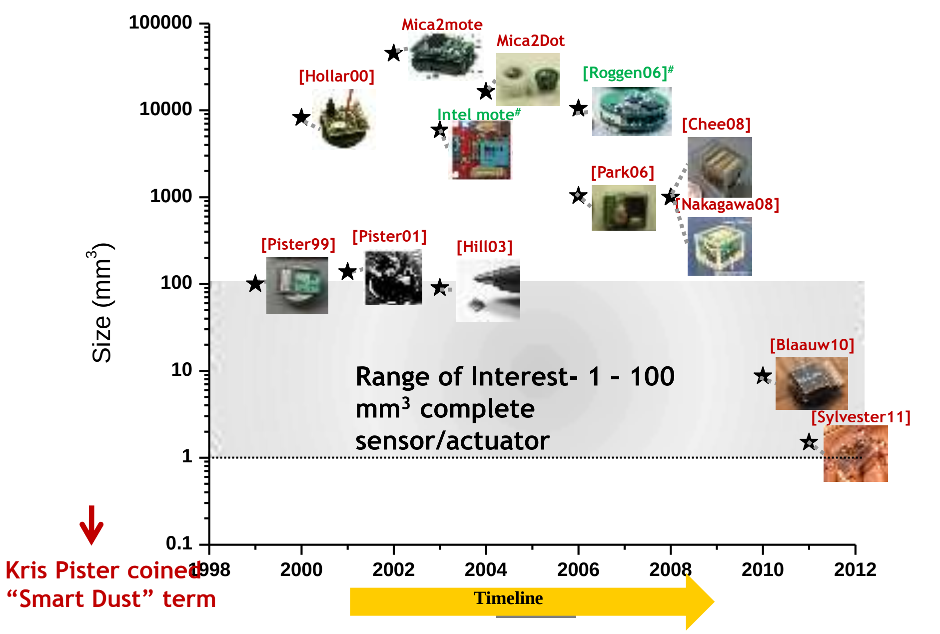
Industrial:
- Monitoring objects
- E.g. machines, inventories

People and community:
- Monitoring activities
- E.g. heath, play, connect

Major advances in sensornet

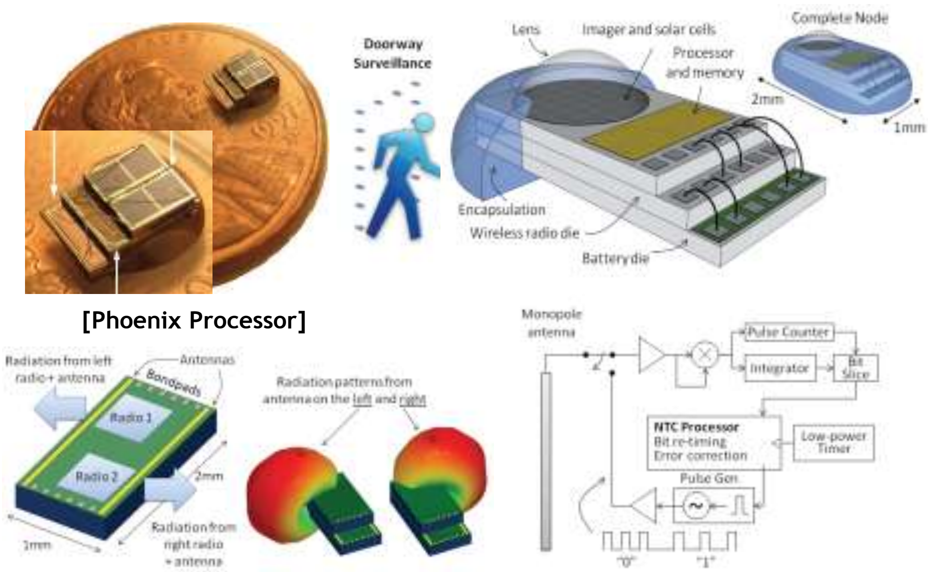
- Hardware miniaturization and lowering cost
- Network standardization and modular software
- Sensor tasking
- Big (sensor) data

Smart dust



Credit: Dutta

Michigan Micro Mote (M3): cubic-mm, nW



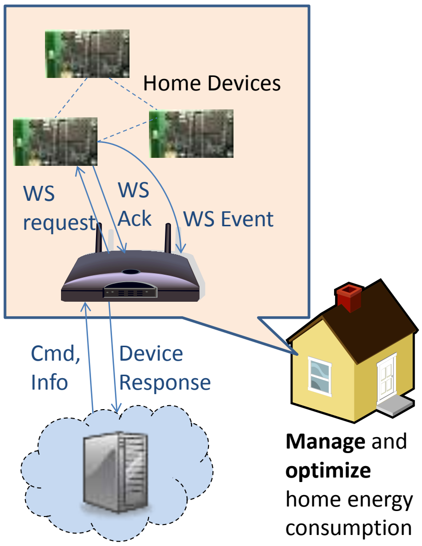
Dutta, Wentzloff, Blaauw, Schmid, Sylvester, 2012, in progress

A Low-Power Standard Link

	802.15.4	802.15.1	802.15.3	802.11	802.3
Class	WPAN	WPAN	WPAN	WLAN	LAN
Lifetime (days)	100-1000+	1-7	Powered	0.1-5	Powered
Net Size	65535	7	243	30	1024
BW (kbps)	20-250	720	11,000+	11,000+	100,000+
Range (m)	1-75+	1-10+	10	1-100	185 (wired)
Goals	Low Power, Large Scale, Low Cost	Cable Replacement	Cable Replacement	Throughput	Throughput

- Low transmit power, Low signal-to-noise ratio (SNR), modest BW, Little frames

Tiny Web Services



Why is Web Service Hard?

Web Server:
MSP430 processor
and 802.15.4 radio

Because Server is Low Power, Low Cost:

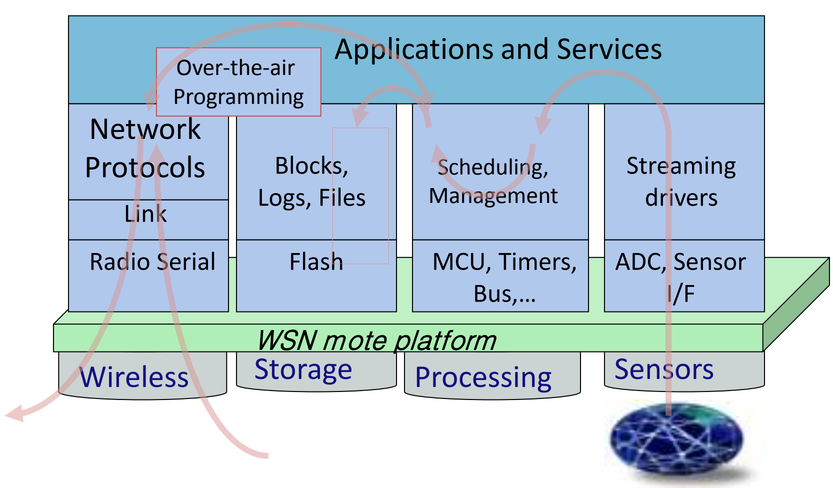
- 48k code space, 10k RAM
- 250kbps radio
- Server MUST sleep: 4 years on AA battery

Our approach:

- Server sleeps: using WS Eventing
- Reduce msg size via HTTP binding
- Simplify XML processing by constraining WSDL

Bodhi Priyantha, Aman Kansal, Michel Goraczko, and Feng Zhao, "*Tiny Web Services for Sensor Device Interoperability*." Demo abstract, IPSN'08.

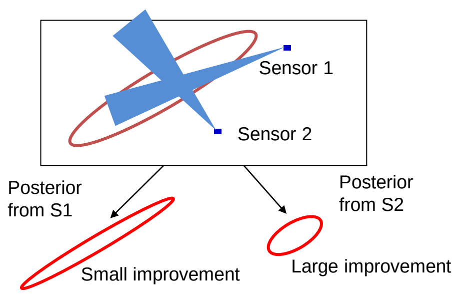
TinyOS – Communication centric, resource-constrained, event-driven



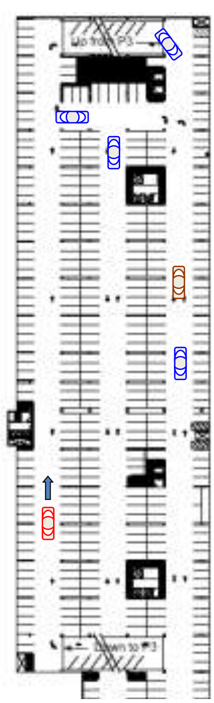
Credit: Culler

IDSQ: Information-Directed Sensor Tasking

- **Idea**: maximize the *predicted* information that a sensor's measurement will bring, given the current estimation
- Information is measured using mutual information; Choose the sensor which will give the greatest change to the current belief



Zhao, Shin, & Reich, 2001



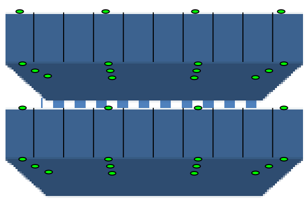
Parking garage application

- Application scenarios
  - Parking space finder
    - Each spot costs $1000s / year to maintain
  - Other apps include security and air quality monitoring
- Sensors may be used to monitor vehicle traffic
  - To improve space usage
  - But wiring is expensive, sensor may fail
- Re-taskable wireless sensor net testbed
  - Multi-sensing modality
  - Support cross-node coordination
  - Answer independent queries from concurrent users

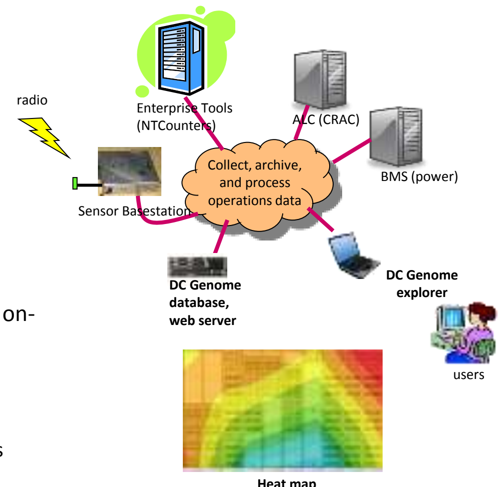
Circa summer 2004, B112 garage, MS campus

Data center sensing: DC Genome

Instrumentation, data collection, and evaluation tools for *capacity planning*, *power management*, and *diagnostics*



Wireless sensors placed around equipment

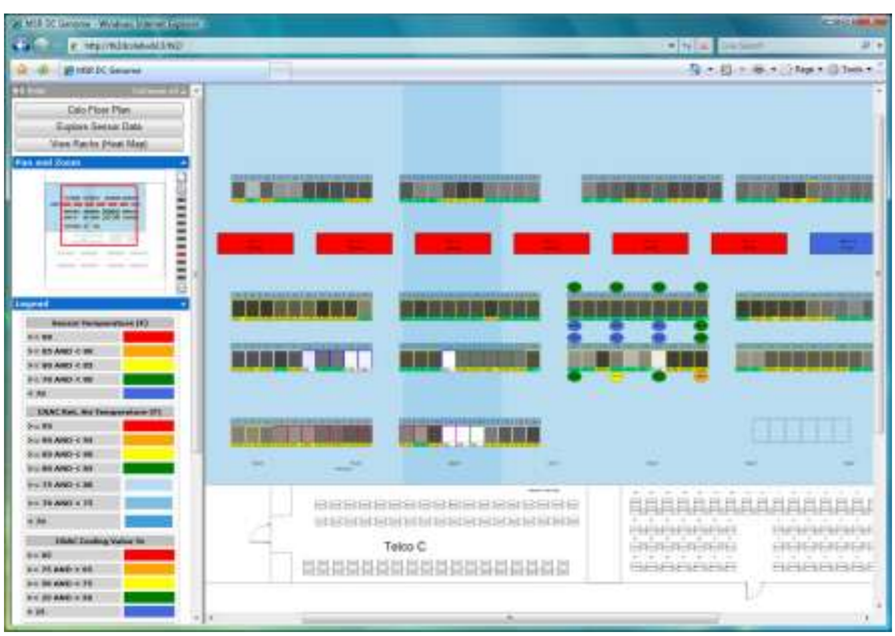


A toolkit for rapid instrumentation, on-the-fly data analysis, and timely decision support

- Wireless sensors
- Database and interfaces
- Data analytics: explore and turn bits into meaningful information

Circa 2007, MS datacenters

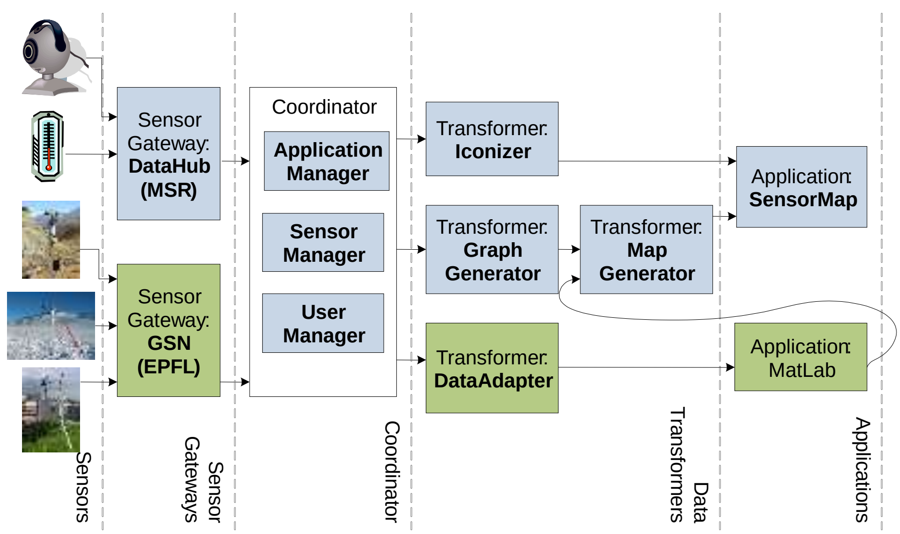
DC Genome Explorer Demo



Swiss Experiment

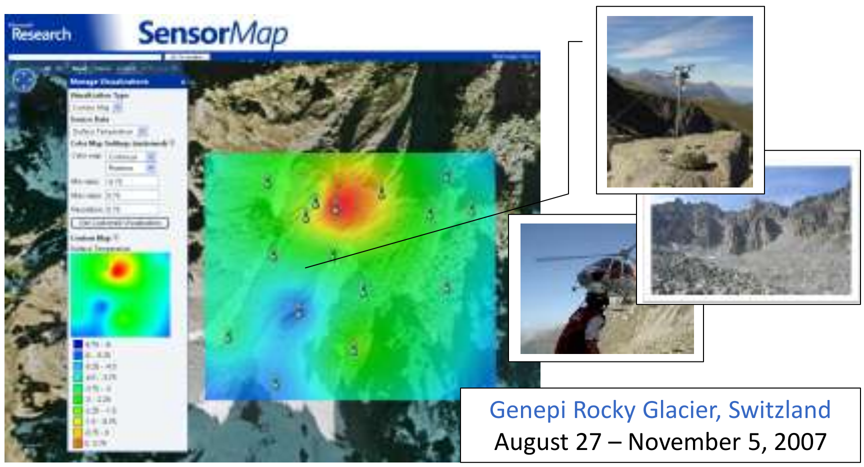
Karl Aberer, Marc Parlange, et al., EPFL, in collaboration with MSR, 2007-2009

SenseWeb Architecture



In-Situ Data Visualization (space + time)

Generate real-time spatial visualizations overlaid on maps, and also over time



Genepi Rocky Glacier, Switzerland
August 27 – November 5, 2007

Major advances in sensornet

- Hardware miniaturization and lowering cost
- Network standardization and modular software
- Sensor tasking
- Big (sensor) data

GPS

WiFi

Accelerometer

Compass

Bluetooth

Light

Barometer

Gyroscope

Camera

Microphone

Anoop Gupta: why not have FitBit on phone?

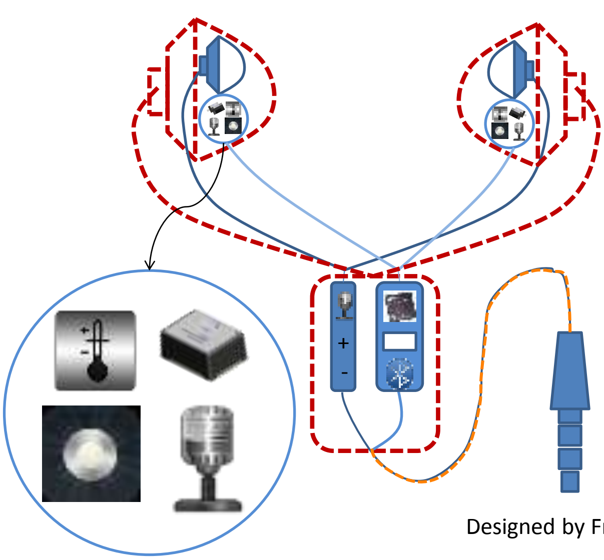
Gordon Bell's Life Logging

Phone as the life logger?

Storage

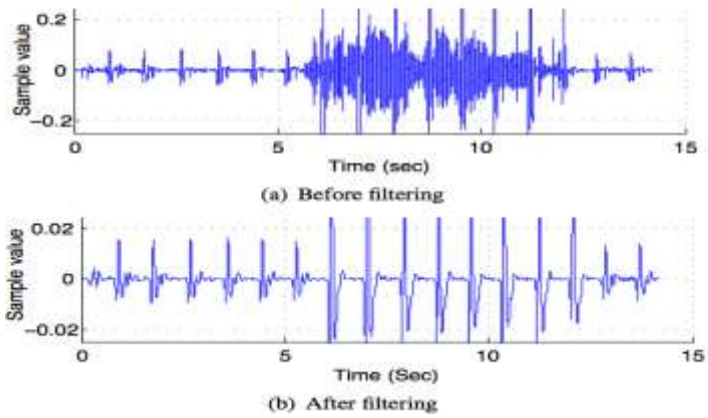
- How much data in one's life
  - (8hr audio + picture@30sec)/day, for 60yrs
    - ⇒ ~10TB
    - ⇒ If continuous video => ~10PB
- Disk storage
  - $44/GB in 2000 => $0.07/GB in 2010
  - A x600 reduction!

SEPTIMU: add sensors to earbud



Designed by Fred Jiang and Jacky Shen, MSR-A

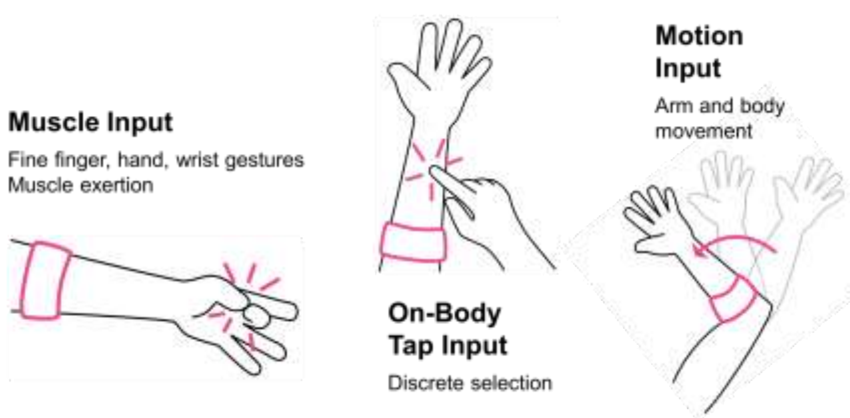
Heart-rate, activity level detection



Heart rate detection

In collaboration with Stankovic/UVA, "MusicalHeart: A Hearty Way of Listening to Music."

Physiological signal as input

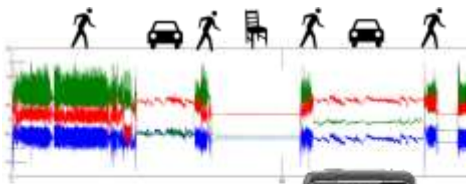


Credit: Desney Tan

Activity Recognition

- Diverse, noisy signals
- Important for context awareness

Mobile Sensor Data Classification



GPS
Microphone
Accelerometer
Gyroscope
…

Human Activities:
- walk, run, sit
- conversation
- car, bus, bike…

Contextual Information
- recognize place/face
- ambient sound

Apps: Health & Wellbeing, Games, Automated Diaries, Local Search, Social Networking

Audio Pipeline

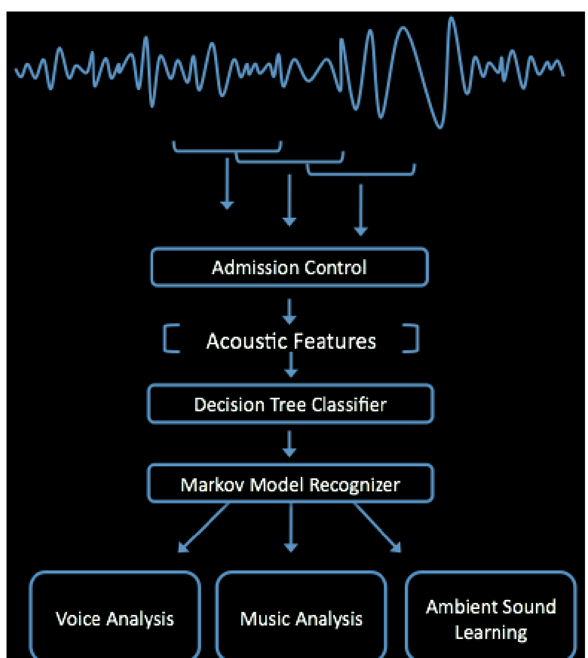
Sound Waveform

Framing

Feature Extraction

Coarse Category Classification

Intra-Category Classification



Credit: Nic Lane

Sensing Context is Expensive

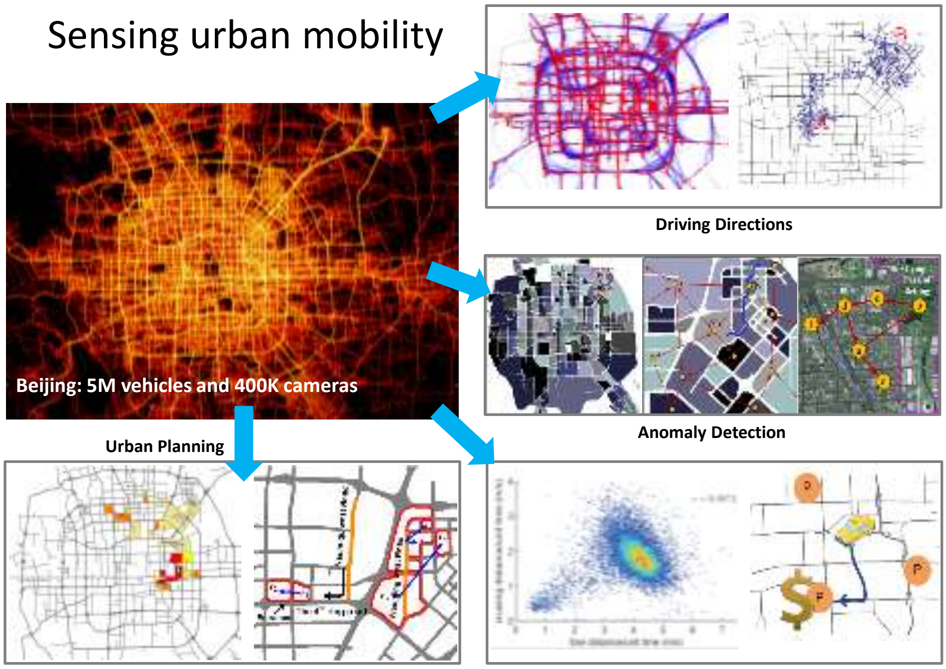
Context	Sensors	Sensing Energy (mJ)
IsWalking, IsDriving, IsJogging, IsSitting	Accelerometer (10 sec)	259
AtHome, AtOffice	WiFi	605
IsIndoor	GPS + WiFi	1985
IsAlone	Mic (10 sec)	2995
InMeeting, IsWorking	WiFi + Mic (10 sec)	3505

- Big difference in sensing energy
- Exploit correlation in context attributes
  - Inference caching
  - Speculative sensing
  - Automatically avoids un-needed sensing

ACE by Suman Nath

Sensors on wheels

Sensing urban mobility



Xing Xie and Yu Zheng, MSR-A

Take-Aways

- Sensornet has come a long way, finding apps from env, energy, to health
  - Advances in hardware, networking, software, big data
- Mobiles as the new ubiquitous platform for sensing
  - Enable new user apps and experiences built on proximity, location, and context