CS 525M Mobile and Ubiquitous Computing

Emmanuel Agu

A Little about me

- Faculty in WPI Computer Science
- Research interests:
  - graphics, mobile computing/wireless and mobile graphics
- How did I get into mobile and ubiquitous computing
  - 3 years in wireless LAN lab (*pre 802.11*)
  - Designed, simulated, implemented wireless protocols
  - Group built working wireless LAN prototype (*pre 802.11*)
- Computer Systems/Electrical/Computer Science background
  - Hardware + software

About this class (Administrivia)

- Class goal: give overview, insight into hot topics, ideas and issues in mobile and ubiquitous computing
- Focus: ideas implemented using smartphone
- Meet for 14 weeks, break on March 5 (term break)
- Seminar style: I will present, YOU will present papers
- See big picture through focussed discussions
- Course website: http://web.cs.wpi.edu/~emmanuel/courses/cs525m/S13/
- Projects: 1 or 2 assigned, 1 big final project
- This area combines lots of other areas: (networking, OS, software, machine learning, programming, etc)
  - Most people don't have all the background!!
  - Independent learning is crucial
  - Projects: Make sure your team has requisite skills

Administrivia: Papers

- *Week 1:* I will present (today)
- *Weeks 2 – 13: You* will present
  - I will present background material on the week's topic, other stuff
  - 4 student presentations from Required Papers for the week
  - Discussions
- Student presentations: ~25 mins + ~10 mins discussion
- 15-min break halfway

Formal Requirements

- *What do you have to do to get a grade?*
- Seminar: Come to class + Discuss!! Discuss!! Discuss!!
- Present 1 or 2 papers
- Email me 1-page summaries (in ASCII text) for weekly papers
- Do assigned project(s)
- Do term project: 5-phases
  - Pick partner + decide project area
  - Submit intro + related work
  - Propose project plan
  - Build, evaluate, experiment, analyze results
  - Present results + submit final paper (in week 14)
- Grading policy: Presentation(s) 20%, Class participation 10%, Assigned Projects 20%, Final project: 40%, Summaries: 10%

Written Summaries

- Email to me *before class* in ASCII text. No Word, Latex, etc
- Summarize key points of all 4 papers for week
  - Main contributions
  - Limitations of the work
  - What you like/not like about paper
  - Any project ideas?
- Half a page max per paper
- Summary should quickly refresh memory in even 1 year's time
  - Include main ideas/algorithms, results, etc.
- See handout for more details

Students: Please Introduce Yourselves!

- Name
- Status: grad/undergrad, year
- Relevant background: e.g. coal miner ☺
- Relevant courses taken:
  - *Systems:* Networks, OS,
  - *Advanced:* machine learning, advanced networks, etc
- What you would like to get out of this class?
  - Understanding a hot field
  - Just a class for masters degree/PhD
  - Looking for research area, masters thesis, PhD thesis
  - Compliments your current research interests/publications
  - My spouse told me to ☺

Next… Overview

- Brief overview of area topics/issues
- Define/motivate area, excite (or discourage) you
- Provoke thinking:
  - More questions, problems than solutions
- Sample of topics to be covered in class
- Topics covered in more detail later
- Students may only understand some topics in today's overview

Mobile computing

- Mark Weiser, Xerox PARC CTO
- 1991, articulated vision (and issues) for ubiquitous and mobile computing
- *Weiser's Vision:*

  "Environment saturated with computing and communication capabilities, with humans gracefully integrated"

- Core idea: Invisible hardware/software that assist human
  - *Hardware:* smart phones, sensors, tablets, wearable devices, etc
  - *Software:* Voice recognition, Mobile OS, Networking/communication software, protocols, etc
- Weiser's vision ahead of its time, available hardware and software
- Example: voice recognition was not available then
- Today, envisioned hardware and software is available

Mobile vs Ubiquitous Computing

- Mobile computing
  - deals mostly with *passive* network components
  - Human computes seamlessly while moving, continuous network connectivity
  - Human initiates all activity, clicks on apps!!
  - Example: Using *foursquare.com* on smart phone
- Ubiquitous computing
  - introduces collection of specialized assistants to assist human in tasks (reminders, personal assistant, staying healthy, school, etc)
  - Networked array of *active* elements, sensors, software agents, artificial intelligence
  - Builds on *mobile computing* and *distributed systems* (more later)

Ubicomp Sensing

- Sense what?
  - *Human:* motion, mood, identity, gesture
  - *Environment:* temperature, sound, humidity, location
  - *Computing Resources:* Hard disk space, memory, bandwidth
  - *Ubicomp example:*
    - *Assistant senses:* Temperature outside is 10F (environment sensing) + Human plans to go work (schedule)
    - *Ubicomp assistant advise:* Dress warm!
- Sensed environment + Human + Computer resources = *Context*
- *Context-Aware* applications adapt their behavior to context

Sensing the Human

- Environmental sensing is relatively straight-forward
  - Use specialized sensors for temperature, humidity, pressure, etc
- Human sensing is a little harder (ranked easy to hard)
  - **When:** time (Easiest)
  - **Where:** location
  - **Who:** Identification
  - **How:** (Mood) happy, sad, bored (gesture recognition)
  - **What:** eating, cooking (meta task)
  - **Why:** reason for actions (extremely hard!)
- Human sensing (gesture, mood, etc) easier with cameras than sensors
- Research in ubiquitous computing integrates location sensing, user identification, emotion sensing, gesture recognition, activity sensing, user intent

Using context

- Accurately determining context = timely feedback
- Inaccurately inferred context = distraction
- Example:
  - If user is driving and systems thinks they are relaxing on their couch, system may send pop-up messages about doing housework (distracting)

Mobile Devices

- Smart phones (Blackberry, iPhone, Android, etc)
- Tablets (iPad, etc)
- Laptops







SmartPhone Hardware

- Quad core CPUs, Powerful GPUs
- Mobile GPUs support OpenGL ES
- **OpenGL ES** for graphics, OpenCL for GPGPU

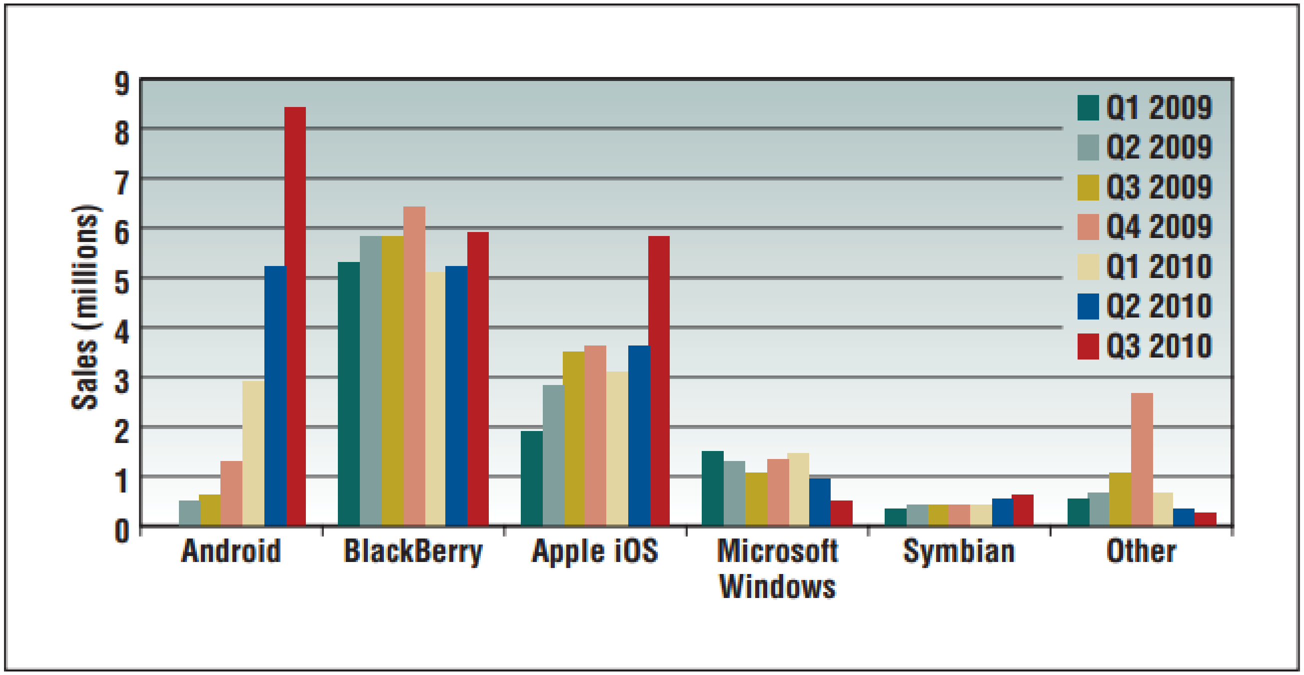
	Nexus 4	Galaxy S III	iPhone 5	Moto Droid
CPU	APQ8064	MSM8960	Apple A6	OMAP 3430
	1.7 GHz **Quad**-core	1.7 GHz **Dual**-core	1.3 GHz **Dual**-core	600 MHz
GPU	Adreno 320	Adreno 225	PowerVR SGX543MP3	PowerVR SGX 530
	OpenGL ES 3.0 **OpenCL 1.2** OpenVG 1.1	OpenGL ES 2.0 OpenVG 1.1	OpenGL ES 2.0 Shader Model 4.1	OpenGL ES 2.0 Shader Model 4.1
	NA **40-45 GFLOPS**	400 MHz **19.2 GFLOPS**	266 MHz (**Tri**-core) **25.5 GFLOPS**	200 MHz (1.6 GFLOPS)

GLOPS: floating-point operations per second

Comparison courtesy of Qian He (Steve)

SmartPhone OS

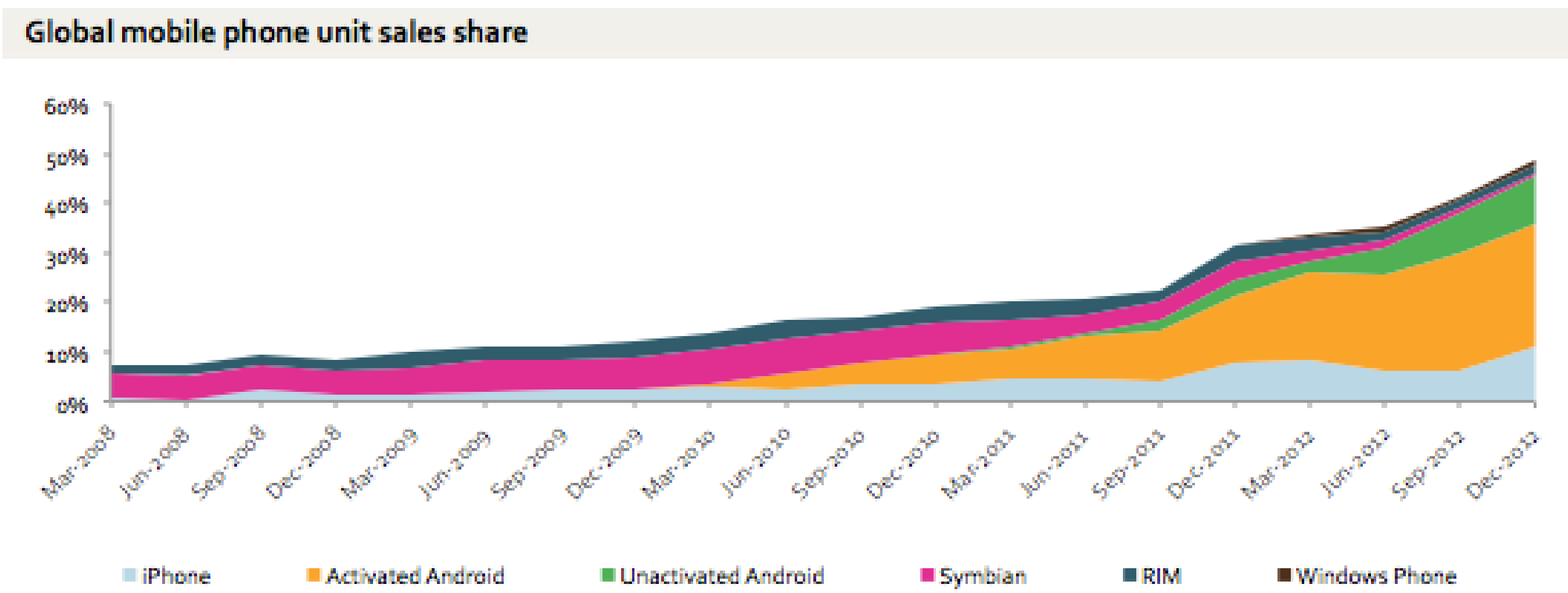
- Android leader in SmartPhone OS since Q4 2010



Courtesy Margaret Butler

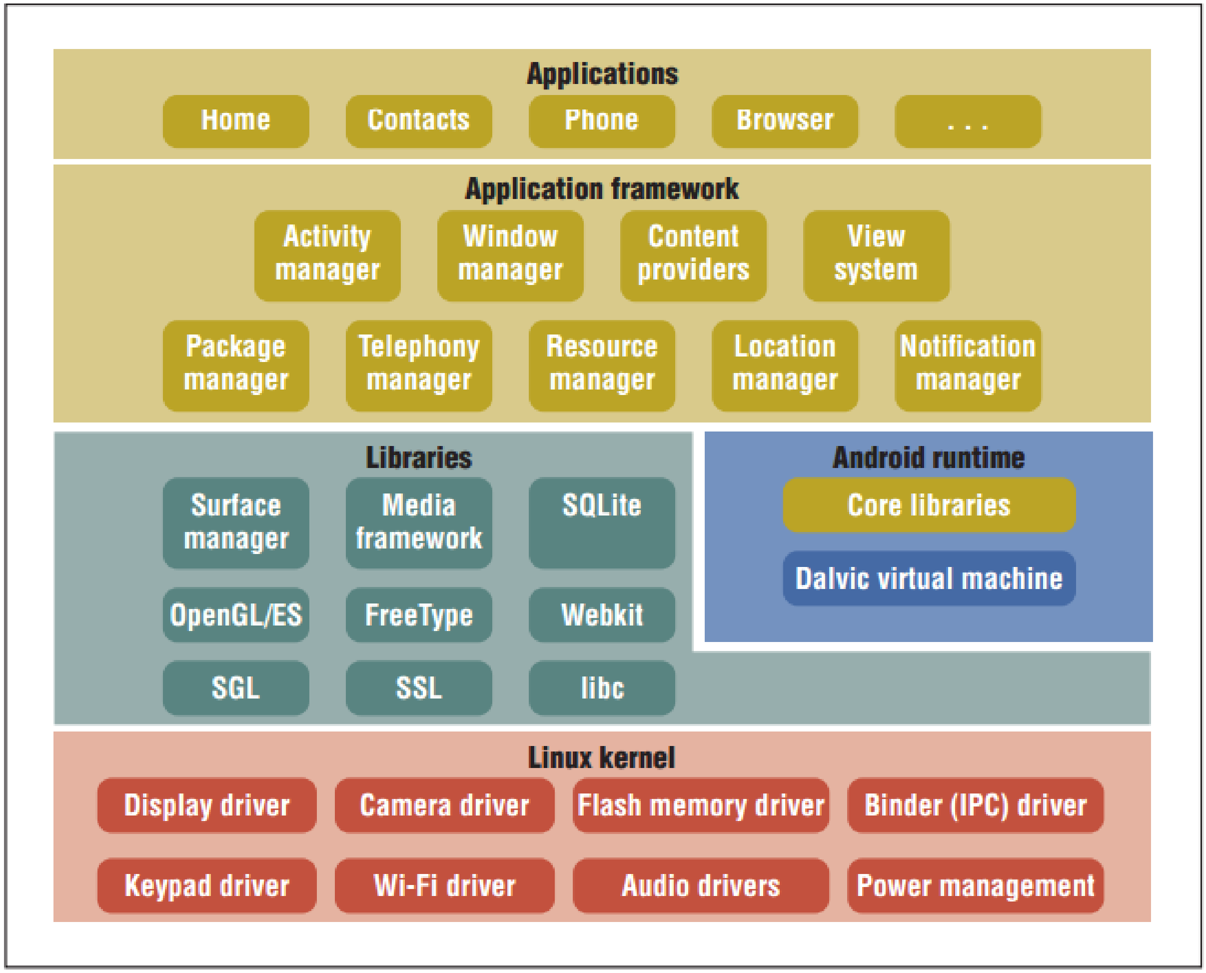
SmartPhone OS

- Now?
  - Over 80% of all phones sold are smartphones
  - Android share 75% worldwide in Q4 2012



[Source: Enders Analysis]

Android System Architecture



Courtesy Margaret Butler

Mobile Devices: Droid

- This class: Google Droid as main mobile device
- Google donated Motorola Droid smart phones
- One assigned project and final project based on Droid
  - Connects to Verizon network, WLAN or Bluetooth
  - Google Android OS (updated 4.0.4, ice cream sandwich)
  - 5 MegaPixel camera
  - Streaming video: mpeg, H.264
  - GPS, google maps, etc
  - Sensors: accelerometer, proximity
    eCompass, ambient light

Sensor Node

- Sensor? Think of automatic doors
- Automatic door sensor has single purpose: detect human
- New multi-functional sensors, programmable for various tasks (intrusion detection, temperature, humidity, pressure, etc)
- Low cost ($1 per sensor), 1000's per room, attach to objects
- Capabilities: Sense, process data, communicate with sink node
- Constraints: Small CPU, OS, programmable

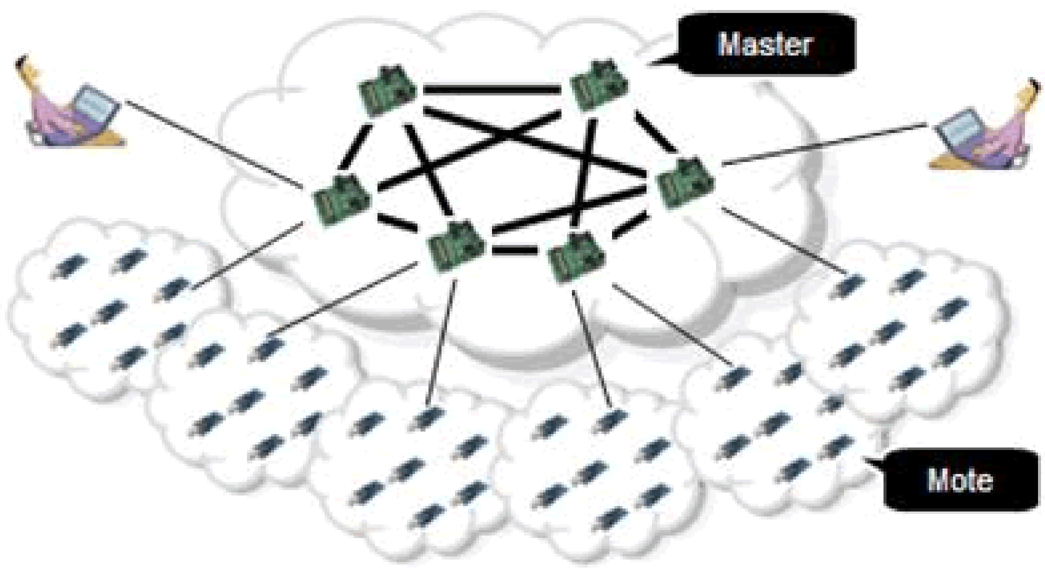
(courtesy of MANTIS project, U. of Colorado)

RFID tags

Tiny Mote Sensor, UC Berkeley

Wireless Sensors for Environment Monitoring

- Embedded in room/environment
- Many sensors cooperate/communicate to perform task
- Monitors conditions (temperature, humidity, etc)
- User can query sensor (What is temp at sensor location?)

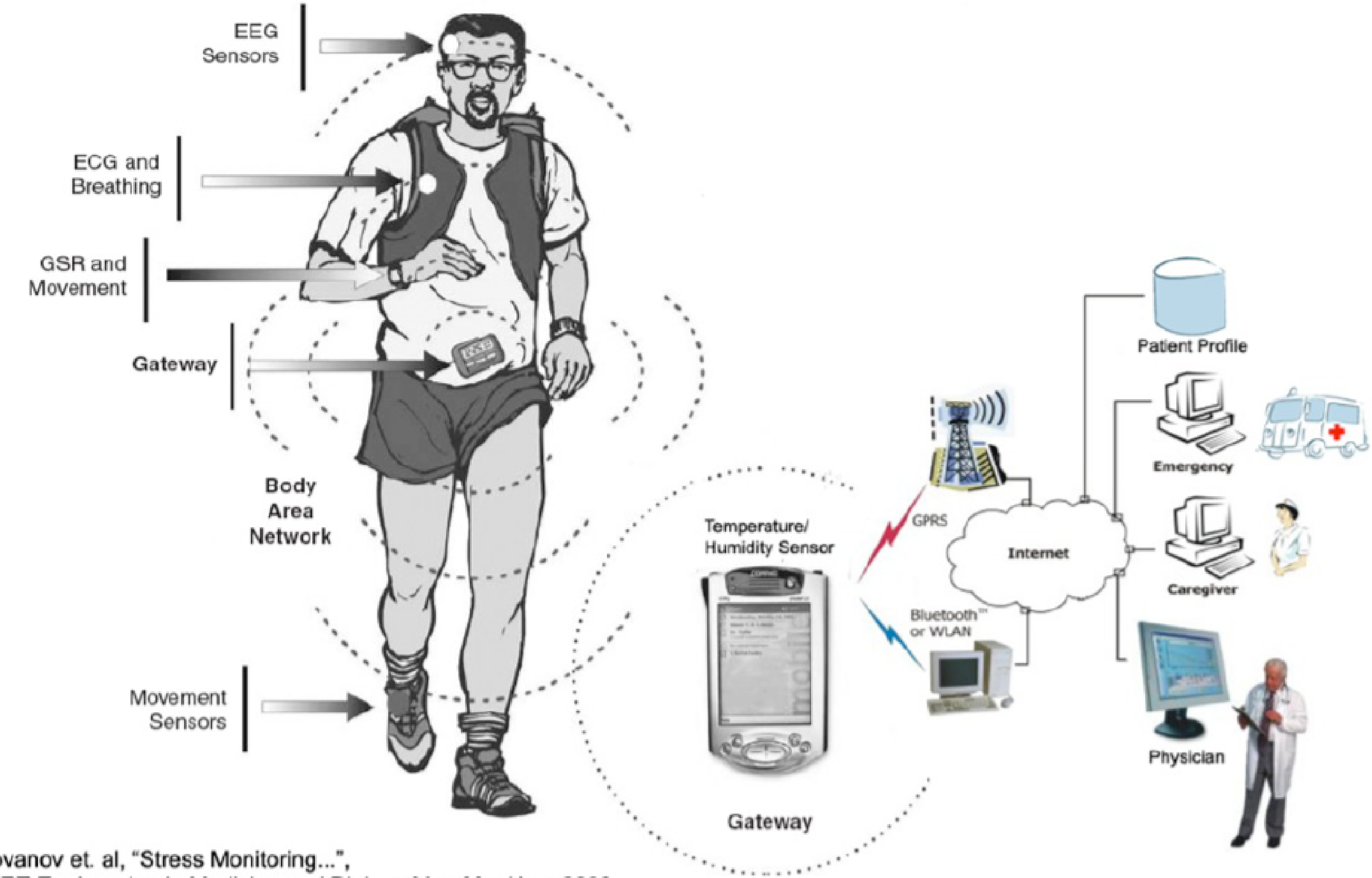


Classic Wireless Sensor Network

- **ZebraNet:** Novel studies of zebra migration and inter-specie interactions
- **Basic idea:** Put sensors on zebras, study them

Ubiquitous Computing: Wearable sensors for Health

remote patient monitoring

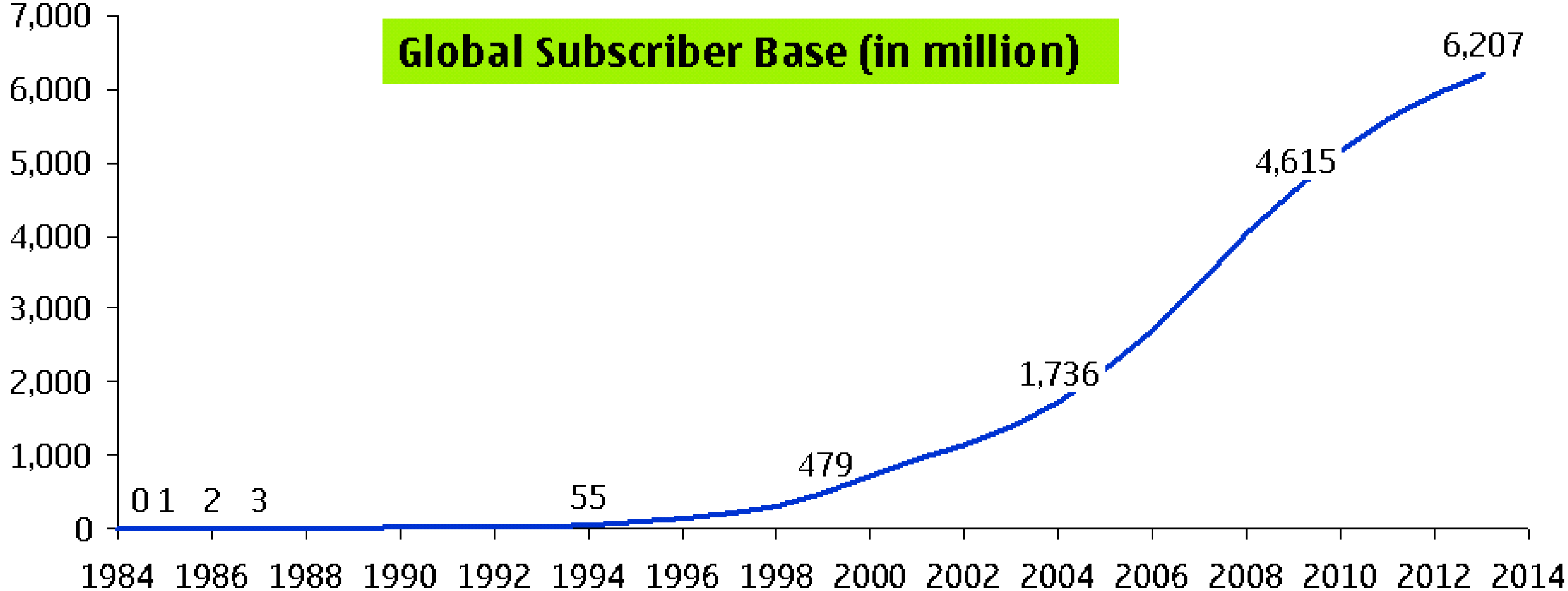


Jovanov et. al, "Stress Monitoring...",
IEEE Engineering in Medicine and Biology Mag.May/June2003

Body Worn Activity Trackers

Wellness Smart (Bluetooth) Devices

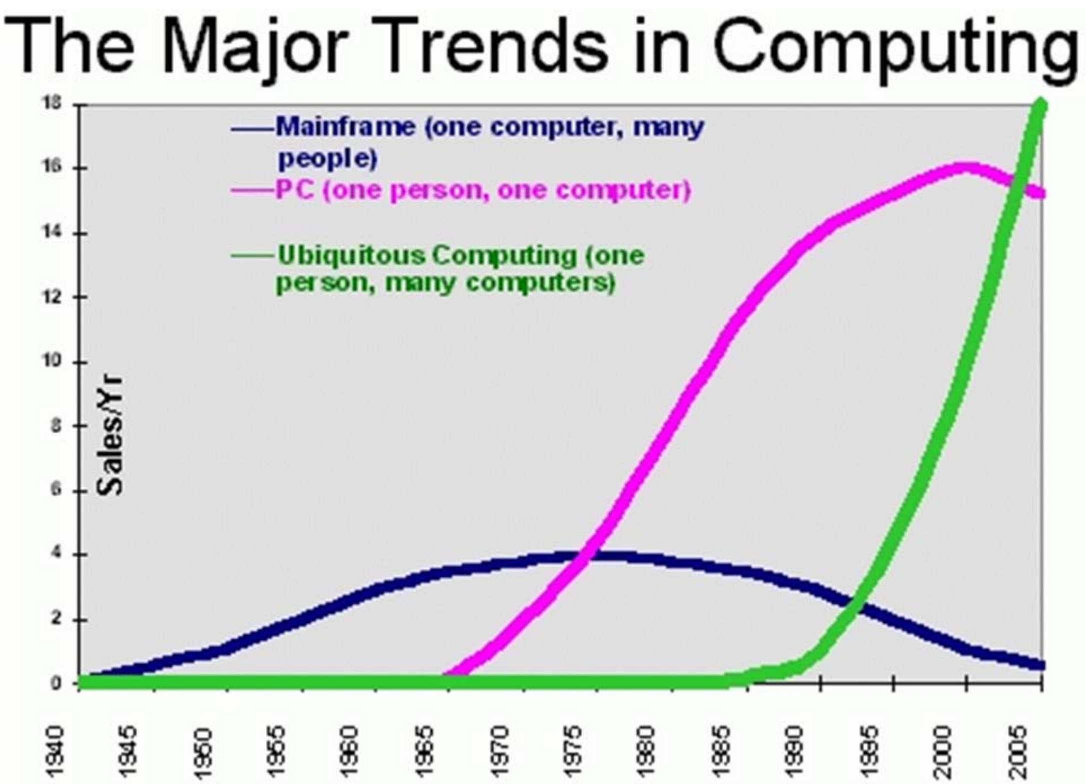
Worldwide cellular subscriber growth



Source: Informa

Explosion of Devices

- *Recent Nokia quote:* More cell phones than tooth brushes
- Many more sensors envisaged
- ***Ubiquitous computing:*** Many computers per person



Definitions: Portable, mobile & ubiquitous computing

- ***Distributed computing:*** system is physically distributed. User can access system/network from various points. E.g. Unix, WWW. (huge 70's revolution)

- ***Portable (nomadic) computing:*** user intermittently changes point of attachment, disrupts or shuts down network activities

- ***Mobile computing:*** continuous access, automatic reconnection

- ***Ubiquitous (or pervasive) computing:*** computing environment including sensors, cameras and integrated active elements that cooperate to help user

- Class concerned mostly with mobile and ubiquitous computing

Distributed Computing

- ***Distributed computing example:*** You, logging in and web surfing from different terminals on campus. Each web page consists of hypertext, pictures, movies and elements anywhere on the internet.
- Note: network is fixed, Human moves
- Issues:
  - Remote communication (RPC),
  - Fault tolerance,
  - Availability (mirrored servers, etc)
  - Caching (for performance)
  - Distributed file systems (e.g. Network File System (NFS)
  - Security (Password control, authentication, encryption)

Nomadic computing

Nomadic Computing

- ***Portable (nomadic) computing example:*** I own a laptop. Plugs into my home network, sit on couch, surf web while watching TV. In the morning, wake up, un-plug, shut down, bring laptop to school, plug into WPI network, start up!
- Note: Network is fixed, device moves and changes point of attachment.
- Issues:
  - File/data pre-fetching
  - Caching (to simulate availability)
  - Update policies
  - Re-integration and consistency models
  - Operation queuing (e.g. emails while disconnected)
  - Resource discovery (closest printer while at home is not closest printer while at WPI)
- Note: much of the adaptation in “middleware” layer

Mobile Computing Example

- ***Mobile computing:*** Sarah owns SPRINT PCS phone with web access, voice, SMS messaging and can run apps like facebook and foursquare . She remains connected while she drives from Worcester, Massachusetts to Compton, California
- Note: Network topology changes, because sarah and mobile users move. Network deals with changing node location
- Issues
  - Mobile networking (mobile IP, TCP performance)
  - Mobile information access (bandwidth adaptive)
  - System-level energy savings (variable CPU speed, hard disk spin-down, voltage scaling)
  - Adaptive applications: (transcoding proxies, adaptive resource management)
  - Location sensing
  - Resource discovery (e.g. print to closest printer)

Ubiquitous Computing Example

- ***Ubiquitous computing:*** John is leaving home to go and meet his friends. While passing the fridge, the fridge sends a message to his shoe that milk is almost finished. When John is passing grocery store, shoe sends message to glasses which displays "BUY milk" message. John buys milk, goes home.
- **Core idea:** ubiquitous computing assistants **actively** help John
- Issues:
  - Sensor design (miniaturization, low cost)
  - Smart spaces
  - Invisibility (room million sensors, minimal user distraction)
  - Localized scalability (more distant, less communication)
  - Uneven conditioning
  - Context-awareness (assist user based on her current situation)
  - Cyber-foraging (servers augment mobile device)
  - Self-configuring networks

Smartphone Sensors

- Typical smartphone sensors today
  - accelerometer, compass, GPS, microphone, camera, proximity

Future sensors?
- Heart rate monitor,
- Activity sensor,
- Pollution sensor,
- etc

Mobile CrowdSensing

- **Internet of things:** Sensing data from consumer-centric devices including
  - Smartphones (iPhone, Google Nexus,)
  - Music players (iPods)
  - Sensor embedded gaming systems (Wii, Xbox, kinect)
  - In-vehicle sensors (GPS)
  - Body-worn sensors (e.g. fitbit, Nike+)
- **Mobile crowdsensing:** sense these devices
  - personal, community- and Internet-wide
- Sensing applications at community scale possible

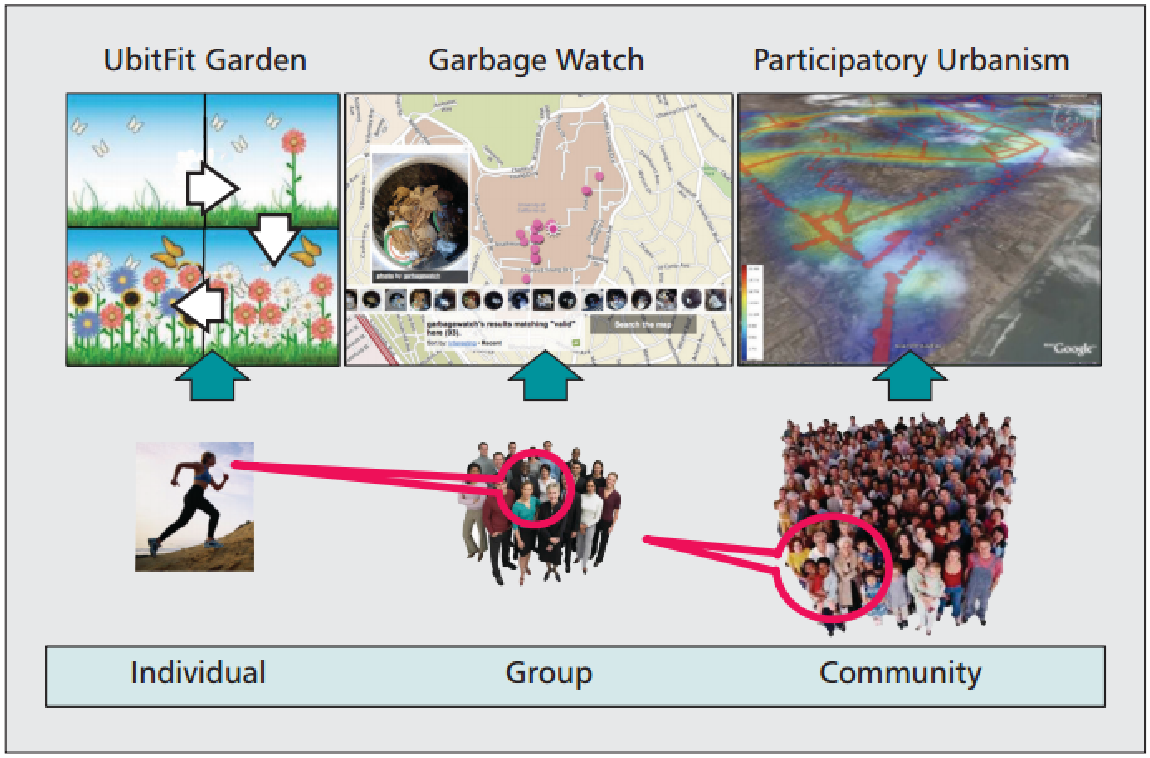
Mobile CrowdSensing

- **Personal sensing:** phenomena pertain to individual
  - E.g: activity detection and logging for health monitoring
- **Group:** friends, co-workers, neighborhood
  - GarbageWatch to improve recycling, neighborhood surveillance
- **Community sensing (mobile crowdsensing):**
  - Large-scale phenomena monitoring
  - Many people contribute their individual readings
  - **Examples:** Traffic congestion, air pollution, spread of disease, migration pattern of birds, city noise maps

Mobile CrowdSensing Types

- **Participatory sensing: active** involvement of individuals (e.g taking a picture, reporting potholes)
- **Opportunistic sensing: passive** user involvement

  (continuous location sampling without explicit user action)



Mobile Crowdsensing Enablers

- **Cheap phone sensors:** are now available
- **Easily programmable:** Smartphones are easily programmable (Android SDK, PhoneGap, AppInventor)
- **Easy deployment:** App stores make deployment easy
- **Cloud resources:** Compute- intensive or storage-hungry applications can be offloaded

Sense What?

- **Environmental:** pollution, water levels in a creek
- **Transportation:** traffic conditions, road conditions, available parking
- **City infrastructure:** malfunctioning hydrants and traffic signs
- **Social:** photoblogging, share bike route quality, petrol price watch
- **Health and well-being:**
  - Share exercise data (amount, frequency, schedule),
  - share eating habits and pictures of food

Sensing with Smartphones vs Motes

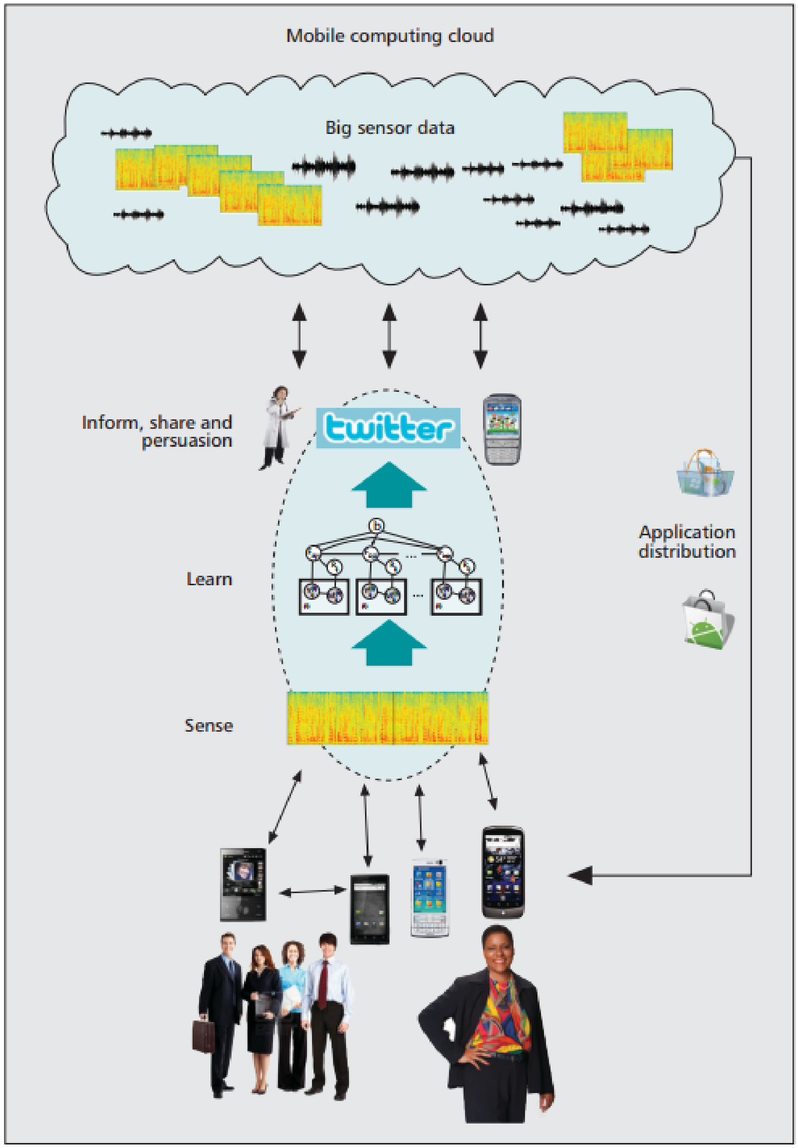
- **More resources:** Smartphones have much more processing and communication power
- **Easy deployment:** Millions of smartphones already owned by people
  - Instead of installing sensors in road, we detect traffic congestion using smartphones carried by drivers
- **Time-varying data:** population of mobile devices, type of sensor data, accuracy changes often due to user mobility and differences between smartphones

Sensing with Smartphones vs Motes

- **Reuse of few general-purpose sensors:** While sensor networks use dedicated sensors, smartphones reuse relatively few sensors for wide-range of applications
  - E.g. Accelerometers used in transportation mode identification, pothole detection, human activity pattern recognition, etc
- **Human involvement:** humans who carry smartphones can be involved in data collection (e.g. taking pictures)
  - Human in the loop can collect complex data
  - Incentives must be given to humans

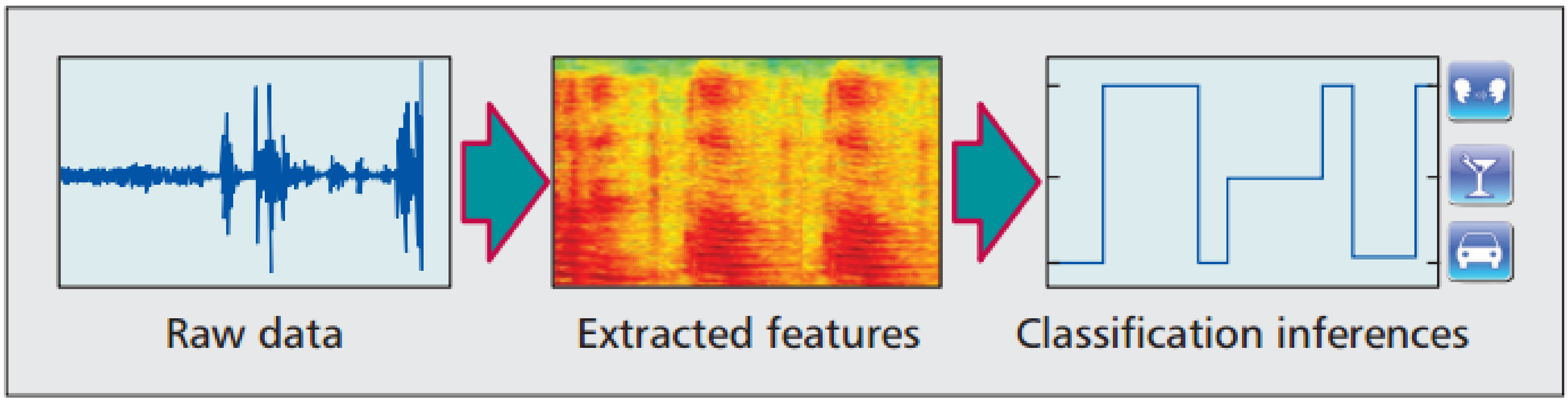
Mobile Phone Sensing Architecture

- **Sense:** Phones collect sensor data
- **Learn:** Information is extracted from sensor data by applying machine learning and data mining techniques
- **Inform, share and persuasion:** inform user of results, share with group/community or persuade them to change their behavior



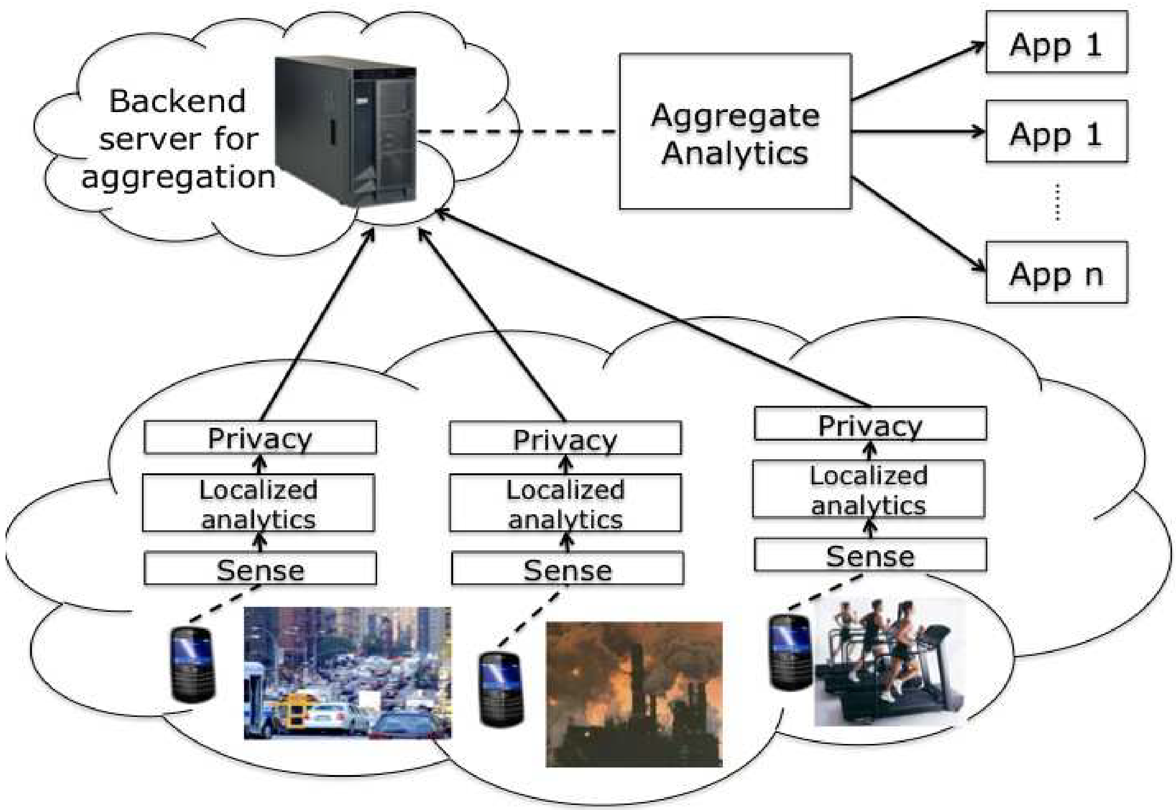
Sensor Processing

- Machine learning commonly used to process sensor data
  - Action to be inferred is hand-labelled to generate training data
  - Actual data is mined for combinations of sensor readings corresponding to action



LOCALIZED ANALYTICS

- Sensor data processed before sending to server
- Saves energy, time, and processing at backend
- **Examples:** filtering outliers, context inference (user state)

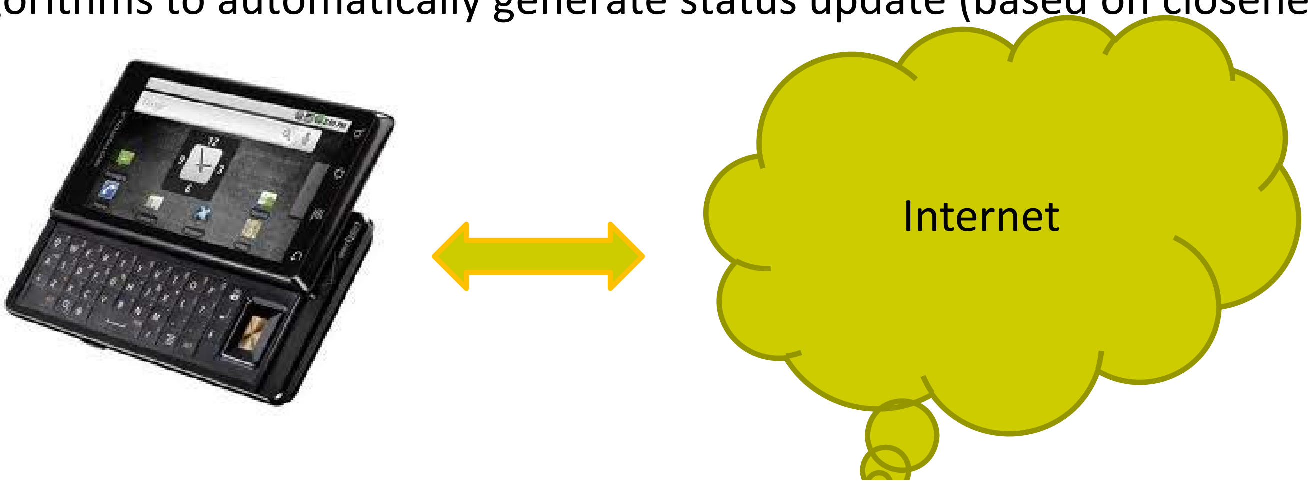


Other Issues

- Resources (Bandwidth, computational):
  - heterogeneous and time-varying
- Privacy, security and data integrity:
  - Contributing user’s information (e.g. location) becomes known (e.g criminals learn user’s path to work)
  - Criminals can contribute bad data to repository

Location-aware mobile computing apps

- Focus mostly on mobile and ubiquitous computing apps that use Smart Phone and Internet connectivity.
- Example: Location-aware mobile computing apps. Issues:
  - **Entropy:** Infering how close two facebook friends are based on locations mutually visited
  - **Anonymity:** May not want all facebook friends to know where I am
  - Automatically anonymize location information hierarchically
    - Fact: User is at Starbucks, 180 Main St, Worcester, MA
    - Status update to friend A: Emmanuel is at “coffee shop”
    - Status update friend B: Emmanuel is at “Starbucks, 180 Main St, Worcester”
    - Algorithms to automatically generate status update (based on closeness)



Internet as a data source for Location-aware apps

- *[Identifying the Activities Supported by Locations with Community-Authored Content ,* Dearman and Truong, Univ. of Toronto *]*

- User at location X would like to make location-based queries
  - What activities can I do here?
  - What's a good close place to do X activity (e.g. soccer)
- **Solution:** Yelp is a community-authored reviewer website for restaurants, activities, etc
- Yelp has: activities + location + goodness of venues
- Scrape + mine yelp: augment with location as searchable tag

Location-Aware Apps

- Easier location check-in
  - Ubicomp 2010 video p395

Context-Aware Search

- *[Hapori: Context-based Local Search for Mobile Phones using Community Behavioral Modeling and Similarity,* Nicholas D. Lane, Dartmouth College]

- Goal: Improves Internet search results using context, such as weather, age, profile of user, time, location and profile of other users to improve search.
- Example: a teenager gets a completely different set of recommendations from and elder.

Mobile Social Networking

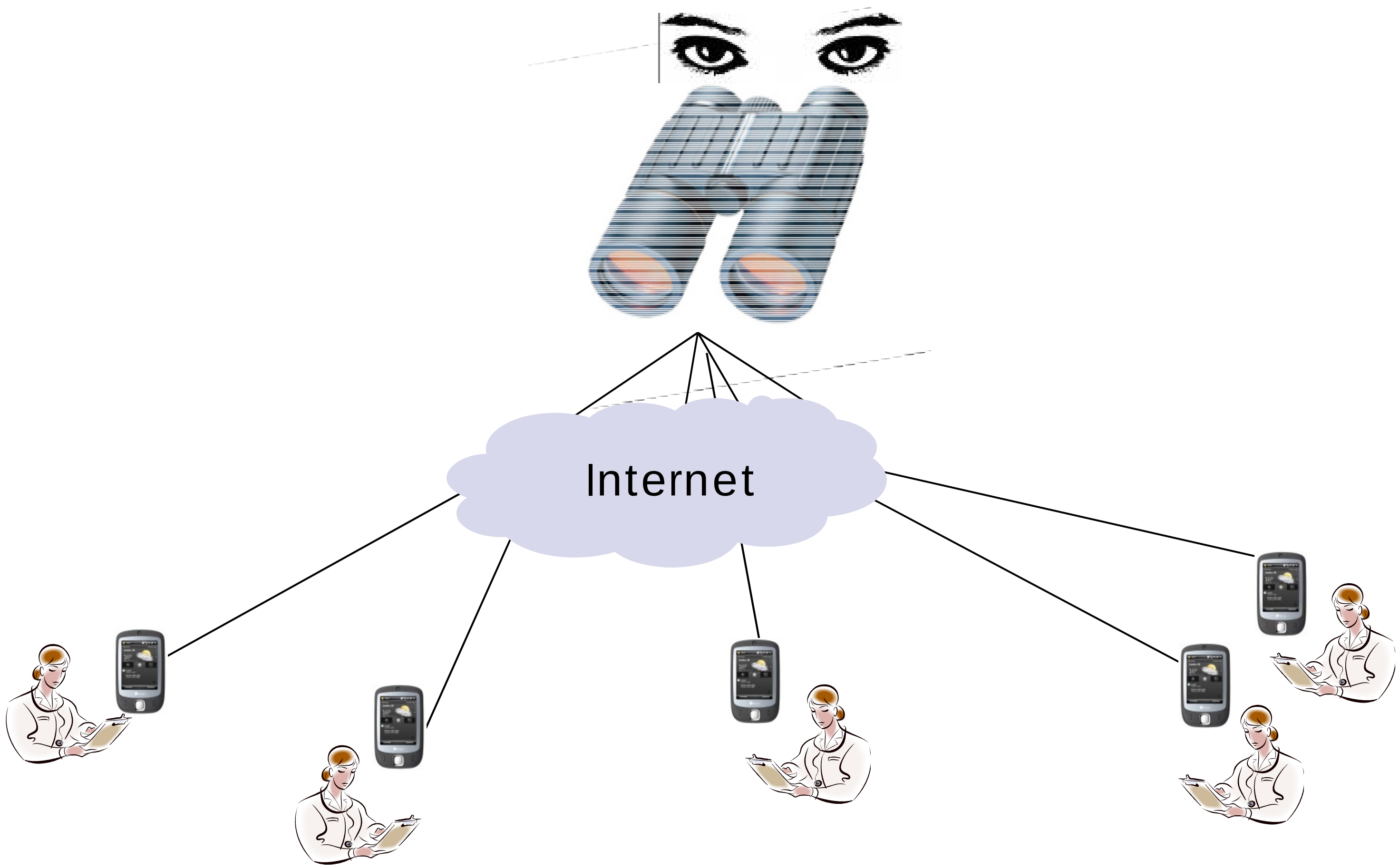
- Partipatory sensing: Many people cooperating on a task
- ***Classic example:*** Comparative shopping
- At CVS, ready to buy toothpaste. Is CVS price the best locally?
- Phone has software to query other members of my network
- People at other local stores (Walmart, Walgreens, etc) respond with prices

UCLA Partipatory Sensing Video

- Demo from UCLA

Mobile Social Networking

- Smart phones have many sensors, cameras, etc
- Imagine ability to access other people's phones: *Phone Sensing*
- Like a telescopic lens into different locations: *Microblogging*



Sensing Human Behavior

- *[Social Sensing for Epidimiological Behavior Change,* Anmol Madan et al, MIT Media Lab]

- **Goal:** infer how falling sick affects the [mobile/network] behaviors of human beings.
- **Examples:** Changes in call rates or visiting low entropy places more could mean person is sick
- Statistics of number of calls, co-location, proximity, WLAN and bluetooth entropy found to be good predictors of illness.
- Findings could be used as an early warning tool.
- If strong inference, then nurse could call the person

Energy Efficiency

- Most resources increasing exponentially *except* battery energy (ref. Starner, IEEE Pervasive Computing, Dec 2003)

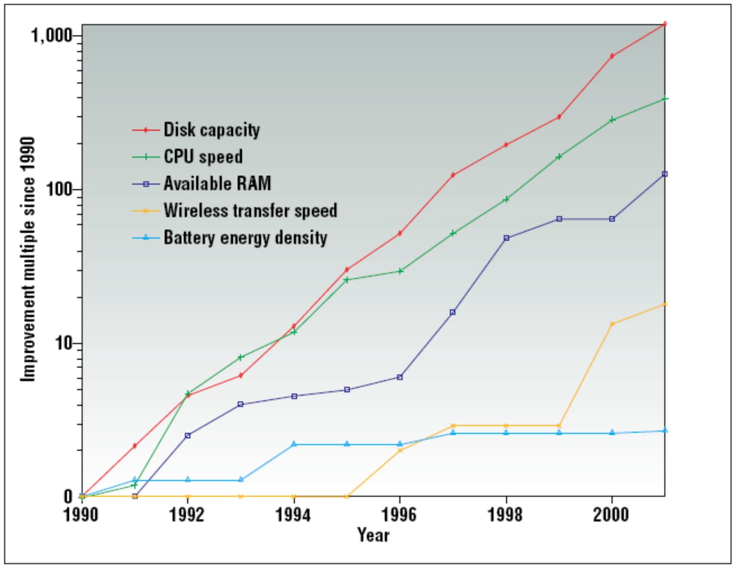


Figure 1. Improvements in laptop technology from 1990–2001.

- Strategies:
  - **Energy harvesting:** Energy from vibrations, moving humans
  - **Scale content:** Reduce image, video resolutions to save energy
  - **Better user interface:** Estimate and inform user how long each potential task will take
    - E.g: At current battery level, you can either type your paper for 45 mins, watch video for 20 mins, etc

Popular Wireless Networks Types

- ***Cellular Network:*** Wide area wireless network operated by Sprint, Verizon, AT&T, 3G/4G
- ***WLANs:***
  - ***Infrastructure networks:*** wired backbone (Internet), wireless last hop. E.g WPI wireless LAN, New: mesh networks
  - ***Ad hoc networks:*** all wireless, no backbone, no order known in advance. Few deployed examples.. .futuristic
- ***Bluetooth:*** Short range communications, printers, headsets, etc
- ***Sensor networks:*** self-organizing network of large numbers of cooperating sensors deployed inside phenomenon. E.g. even more futuristic. Many research projects

Mobile Measurement Studies

- Previous versions of class covered wireless protocols, standards
- This version: focus on measurement studies
  - How existing apps, mobile web, wireless networks are being used

Wireless Security

- Insecure wireless network
  - Wireless signals leak beyond building confines (less secure)
  - Security standards like Wireless Encryption Protocol (WEP) have significant demonstrated flaws
  - Mobility: tracking perpetuators is hard
- Mobile devices/OS almost now as complex as PCs
  - Subject to many of the same vulnerabilities as PCs?
- Mobile devices designed to be carried around=> more prone to theft or misplacement
- Mobile devices easily stolen, tampered with (drunk employees)
- Anderson: over 90% of security breaches caused by lapses in physical security:
- Example: drunk employee at bar with laptop

WLAN Vulnerabilities

- Protocol (e.g 802.11) vulnerabilities:
  - **Rogue APs:** Attacker inserts access point, hijacks mobile nodes
  - **Jamming:** ISM bands prone to that, microwaves, etc
  - **Induce congestions, collisions:** Induce collisions, congestion, disobey protocol. Delay bad for multimedia
  - **Exhaustion:** Keep sending packets to wireless node, prevent sleep modes, drain battery, DoS
  - **Packet header manipulation:** e.g sequence/ACK Nos.

Wi-Fi Privacy Ticker

- [Sunny Consolvo et al , Intel Labs Seattle , University of Washington]

- Many wireless security/privacy breeches occur
- Many open problems. Some too hard to solve for now
- Examples:
  - website A may send your information to website B without your knowledge
  - New google search sends typed characters BEFORE you hit enter
- Solution: Alert to user when info is being transmitted unsecurely
- Ticker streams violations of user's pre-defined breeches
- “Breeches“ identified and importance customizable
- Wi-Fi Ticker increased user awareness about security
- Even highly techno-savvy learned about breeches

Final Words

- This is a special topics graduate class
- **Special Topics:** I have picked selected topics that are hot.
- Coverage is not complete
- Graduate class so graduate level work/effort is expected
- **Seminar style classes:** You get out what you put into them

Homework

- **Today:** Sign up for papers to present
  - **Procedure:** Sign up sheet passed around, simply sign
- Summaries of week 2 papers (Healthcare and Personal assistants): due before next class
- **Two weeks:** decide project area and partners (if any)
  - Project? Never too early to start thinking about project, talking to me.