CS 528 Mobile and Ubiquitous Computing
Lecture 1a: Introduction

Emmanuel Agu

About Me

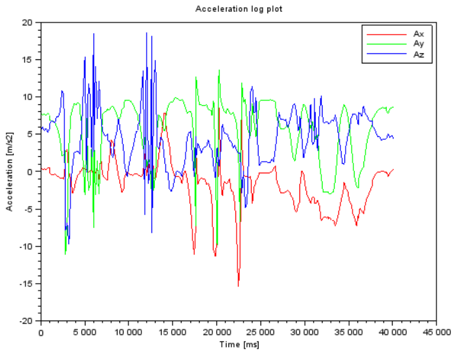
A Little about me

- WPI Computer Science Professor
- Current research interests:
  - Mobile computing especially intelligent mobile health apps that use machine learning
  - Computer graphics
- Started working in mobile computing, wireless in grad school
- Background in:
  - Computer Science (software) +
  - Electrical and Computer Engineering (Hardware)

Example Research: Intelligent health applications that use ML/DL

- **Gait:** Way a person walks, impaired by alcohol
- AlcoGait app to detect drunk smartphone owner, prevent DUI
  - Continuously gathers smartphone sensor data **accelerometer, gyroscope**
  - Analyze sensor data, quantify swaying, impairment using machine learning
  - Detect Blood Alcohol Content (BAC) with 89% accuracy
  - Notify user when over the limit

- Old Alcogait news clip
  - https://www.youtube.com/watch?v=pwZaoKmfq8c



Administrivia

Administrivia: Schedule

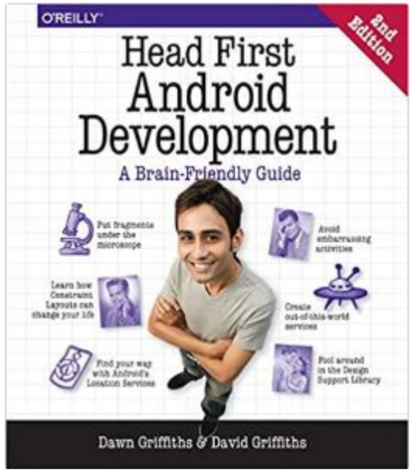
- ***Week 1-8, 10 and 13:*** I will present, introduce class, concepts, Android (Students: Android programming, assigned projects)
  - **Goal:** Students acquire basic Android programming skills for excellent final projects
  - To program apps that utilize mobile & ubicomp components
- ***Week 9:*** Students will present final project proposal
- ***Week 9-14:*** Students work on final project
- ***Week 11 - 12:*** Students present papers on cutting edge mobile and ubicomp research topics
- ***Week 14:*** Students present + submit final projects
- Quizzes (5) throughout

Requirements to get a Grade

- **Grading policy:**
  - Paper presentation 14%, Assigned Projects 36%, Final project: 30%, Quizzes: 20%
- **Final project phases:** (See class website for deadlines)
  1. Pick partners, form project groups of 5 members
  2. Submit 1-slide summarizing proposed idea (problem + envisioned solution)
  3. Present project proposal
  4. Program app, evaluate, experiment, analyze results
  5. Present results + submit final paper (in week 14)
- **Degree of difficulty of project taken into account in grading rubric (more later)**

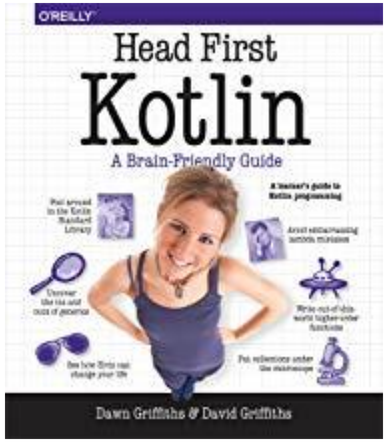
Course Texts

- **Android Texts:**
  - *Head First Android Development,* Dawn Griffiths and David Griffiths (3rd Edition), O'Reilly Books, 2021
  - *Android Programming: The Big Nerd Ranch (Fifth edition)*, by Bryan Sills, Brian Gardner et al., The Big Nerd Ranch, 2022



Gentler, visual intro

Bootcamp Tutorial



Visual kotlin intro (optional)

- Will also use official Google Android documentation
- Learn from research papers: Why not text?

Grader & Class Structure: 2 Halves

- Grader: Akanksha Pawar, adpawar@wpi.edu
  - Took class last semester. Can help you!!

- Class structure: 2 Halves
  - First half: 1 hour 15 mins
  - Break: 20 mins
  - Second half: 1 hour 15 mins

- Talk to me **at the end of class NOT during break**
  - I need a break too

Poll Question

- How many students:
  1. **Own** recent Android phones (running Android 4.4, 5, 6 , 7, 8 …. 12?)
  2. **Can borrow** Android phones for projects (e.g. from friend/spouse)?
  3. **Do not own and cannot borrow** Android phones for projects?

Mobile Devices

Mobile Devices

- Wide range of hardware specs
  - Smartphones (iPhone, Android, etc.)
  - Tablets (Google Pixel tablet, etc.)
  - Laptops
  - Smartwatches

SmartPhone Hardware

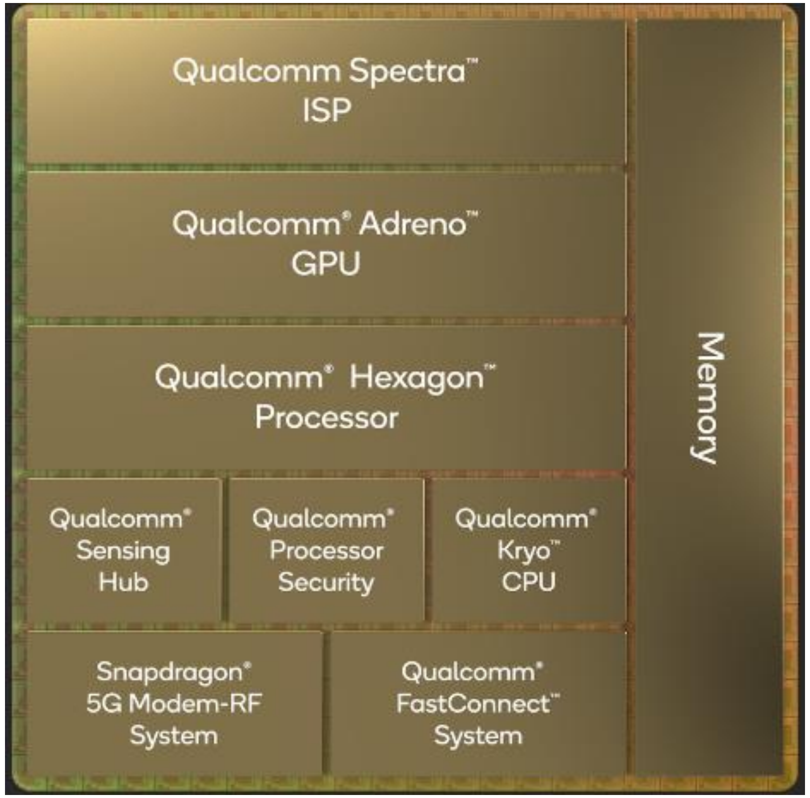
- Smartphones have capabilities beyond calling and texting (or feature phones)

Smart = Communication **+** Computing **+** Sensors

  - **Communication:** Talk, SMS, chat, Whatsapp, Internet access
  - **Computing:** Powerful CPUs, GPUs, programmable OS, Java/kotlin apps, JVM, apps
  - **Sensors:** Camera, video, GPS, accelerometer, temperature, heart rate sensor, etc
- Example: Google Pixel XL 5 phone: 8 core CPU (2x2.85 GHz Cortex-X1 & 2x2.35 GHz Cortex-A78 & 4x1.80 GHz Cortex-A55), Mali-G710 MP7 GPU, 128GB RAM
  - A PC (~specs from 3 years ago) in your pocket!!
  - Sensors: Fingerprint (under display, optical), accelerometer, gyro, proximity, compass, barometer
  - 3 cameras: 50 MP (wide), 48MP (telephoto), 12MP (ultrawide)
  - Linux OS, JVM, runs OpenGL ES, OpenCL and now Deep learning (Tensorflow)

Qualcomm SnapDragon 8 Gen 1 Mobile Processor

- Hardware Core of most high end smartphones shipped in 2022
- SnapDragon is a System on a Chip (SoC)
- **SoC:** Chip that integrates most computer hardware components: CPU, GPU, memory, I/O, storage



Ref: https://www.notebookcheck.net/Qualcomm-Snapdragon-8-Gen-1-Processor-Benchmarks-and-Specs.633861.0.html

Smartphone Sensors

- Typical smartphone sensors today
  - accelerometer, compass, GPS, microphone, camera, proximity
- Can sense physical world, inputs to intelligent sensing apps
  - E.g. Automatically sense when user walks into a class, turn off smartphone ringer

Growth of Smartphone Sensors

- Smartphone generations have more and more sensors!!

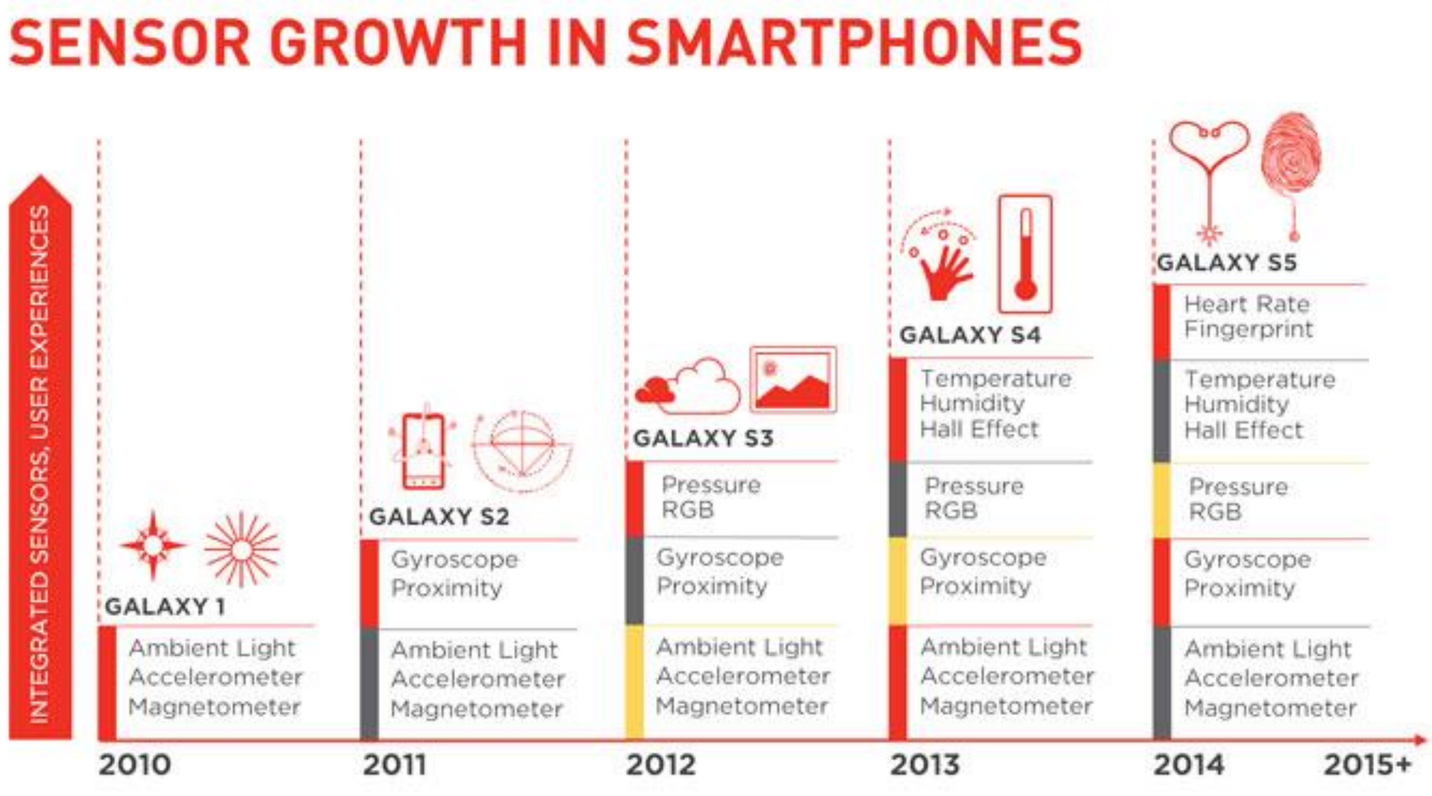
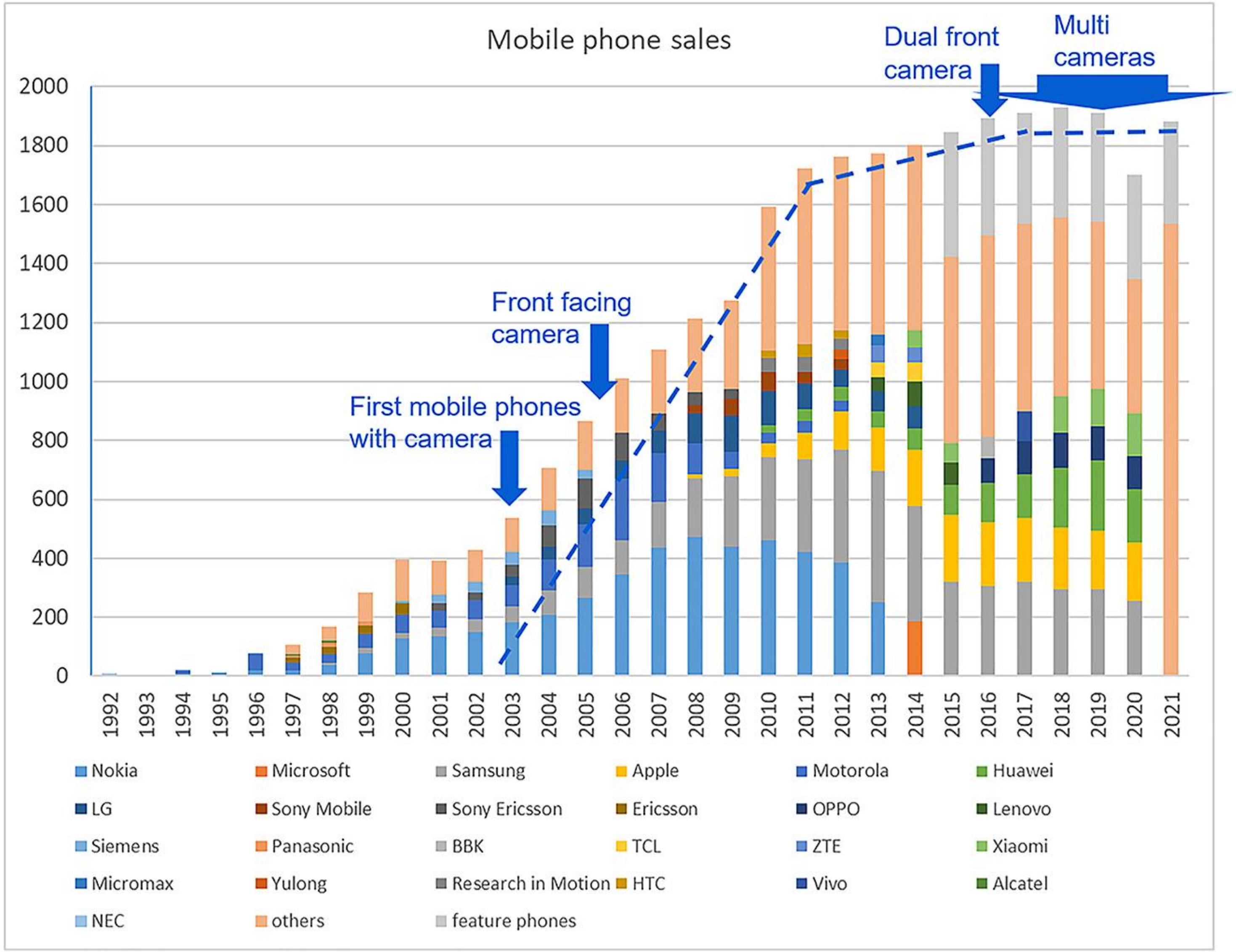


Image Credit: Qualcomm https://www.qualcomm.com/news/onq/2014/04/behind-sixth-sense-smartphones-snapdragon-processor-sensor-engine

Future sensors?

- Complex activity sensor,
- Pollution sensor,
- etc

Growth in Smartphone Imaging Technology

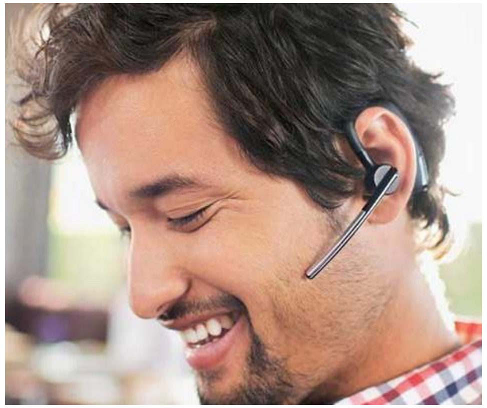


Wireless Networks

Wireless Network Types

- **Wi-Fi (802.11):** (e.g., Starbucks Wi-Fi)
- **Cellular networks:** (e.g., T-Mobile network)
- **Bluetooth:** (e.g., headset)
- **Near Field Communications (NFC)**

  e.g., Mobile pay: swipe phone at dunkin donuts



Bluetooth

Wi-Fi

NFC

Wireless Networks Comparison

Network Type	Speed	Range	Power	Common Use
WLAN (IEEE Wi-Fi 6)	9608 Mbps	45 m – 90 m	100 mW	Internet.
LTE (4G)	5-12 Mbps	35km	120 – 300 mW	Mobile Internet
5G	20 GBps	1-3 miles	30 kW	Mobile Internet
Bluetooth	1 – 3 Mbps	100 m	1 W	Headsets, audio streaming.
Bluetooth LE	1 Mbps	100+ m	.01–.5 W	Wearables, fitness.
NFC	400 kbps	20 cm	200 mW	Mobile Payments

Table credit: Nirjoin, UNC

Different speeds, range, power, uses, usage

Mobile Computing

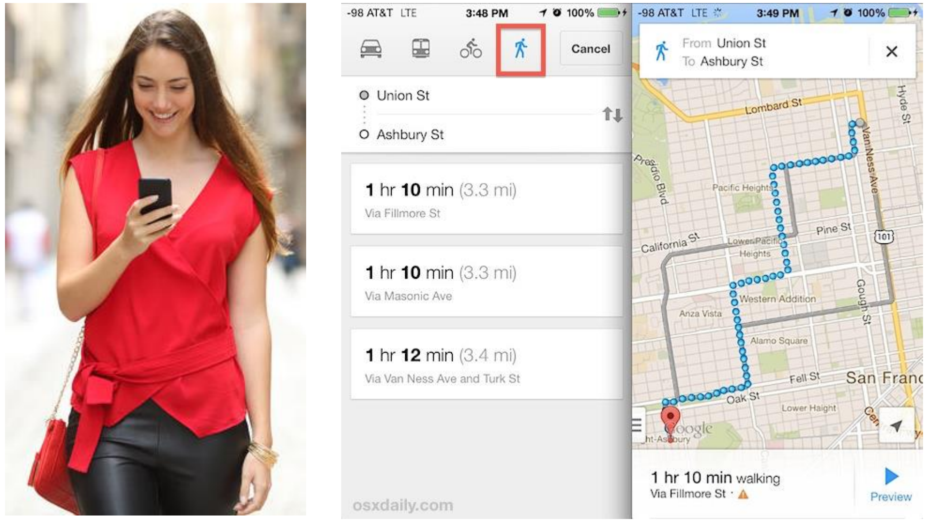
mo·bile

adjective
/ˈmōbəl,ˈmōˌbīl/

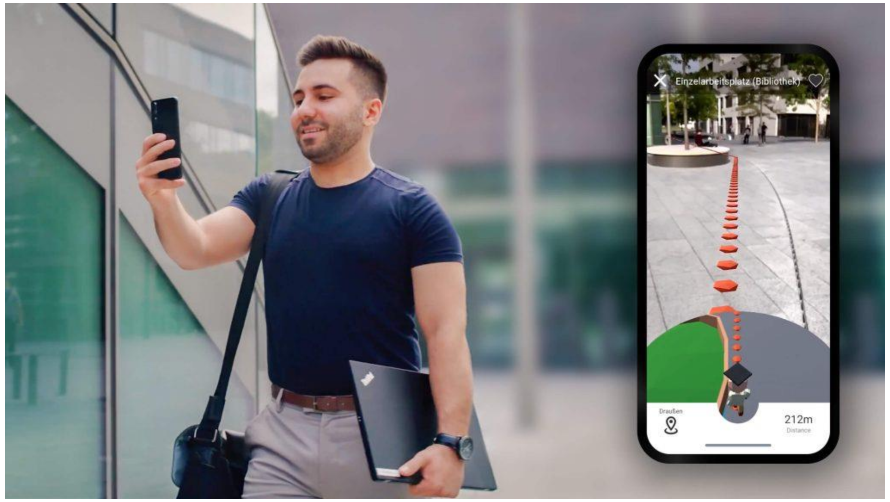
1. able to move or be moved freely or easily.

Mobile Computing

- Human computes while moving
  - Continuous network connectivity,
  - Points of connection (e.g., cell towers, Wi-Fi access point) might change
- **Note: Human initiates all activity**, (e.g launches apps)
- Wireless Network is *passive*
- **Examples:** Using *Google Maps* (Walking directions) or Augmented Reality (AR) while walking

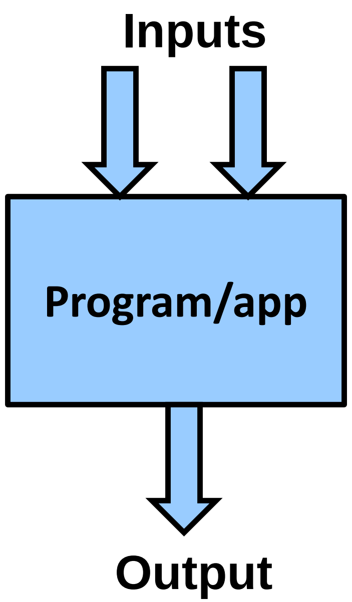


Google Maps

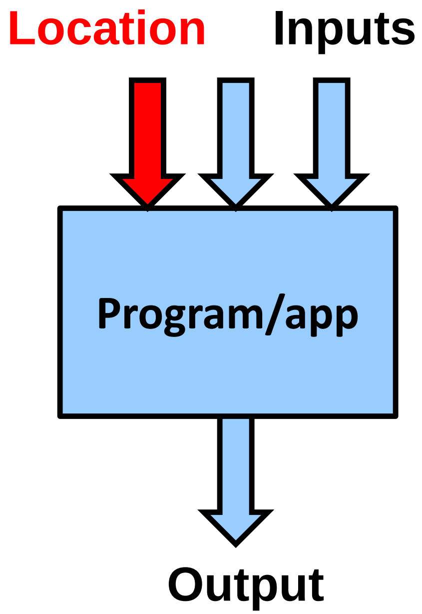


Augmented Reality

Related Concept: Location-Awareness



Non-mobile app



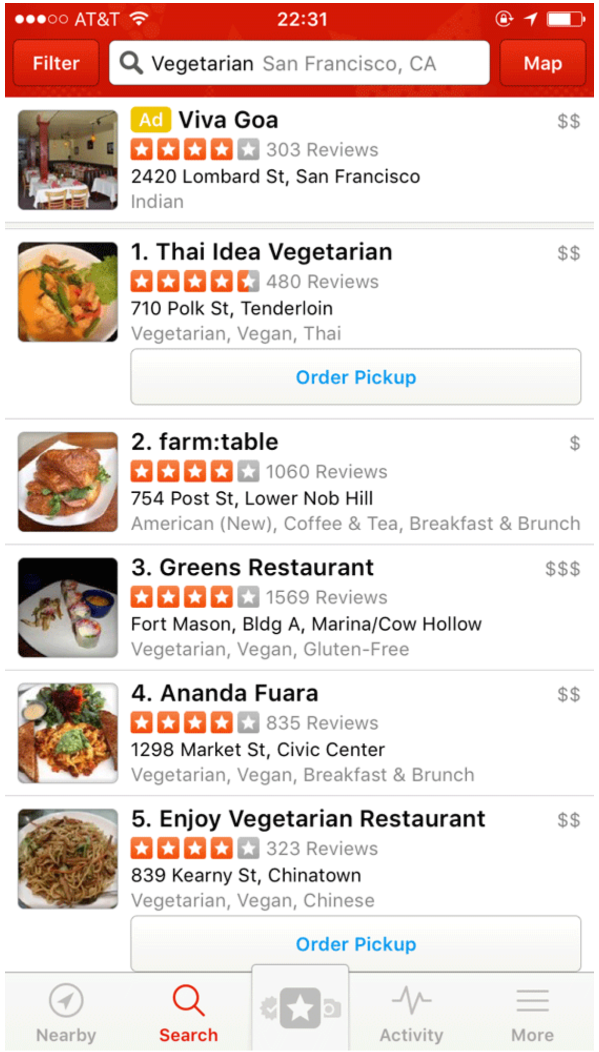
Mobile app

- Mobile computing = computing while location changes
- **Location-aware:** Location must be one of app/program’s inputs, changes output
  - Different user location = different output (e.g., maps)
- **E.g.,** User in California gets different map from user in Boston, same software

Location-Aware App Example

- Location-aware app must have different output/behavior at different locations
- Example: Mobile yelp

- **Example search:** Find "vegetarian restaurant nearby"
  1. App checks user's location
  2. Vegetarian restaurants **close to user's location** are returned

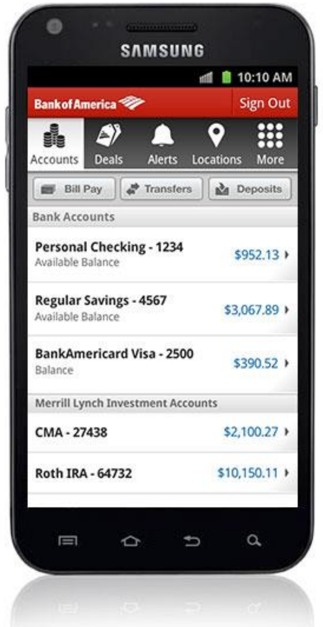


Example of Truly Mobile App: Word Lens

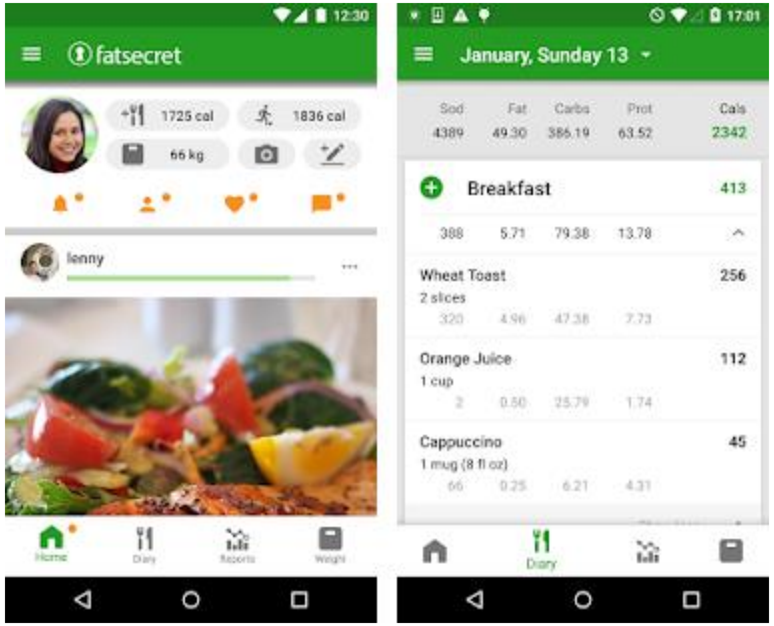
- Translates signs in foreign Language
- Location-dependent because location of sign, language varies with location
- Acquired by Google in 2015, now part of Google Translate

Some Smartphone apps are not Location-Aware

- If app's output/behavior do not change as location changes, not location-aware
- Such apps run on mobile phone **just for convenience**
- **Examples:**



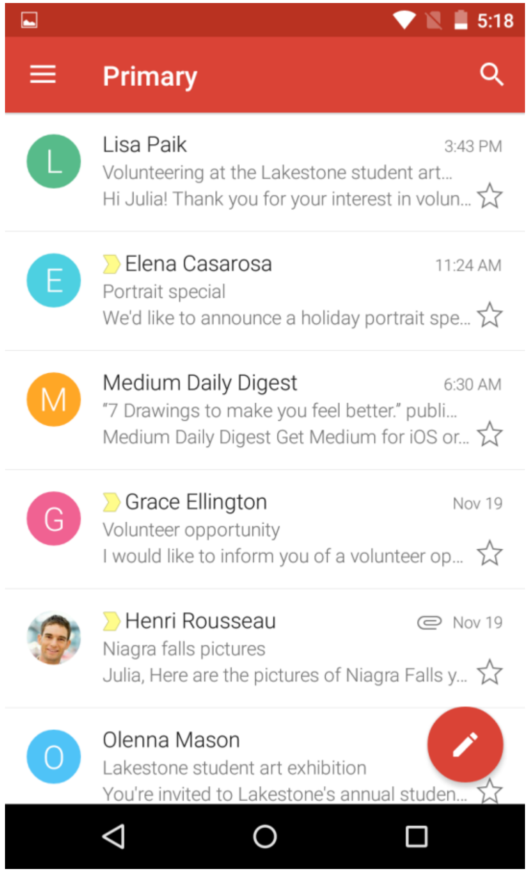
Mobile banking app



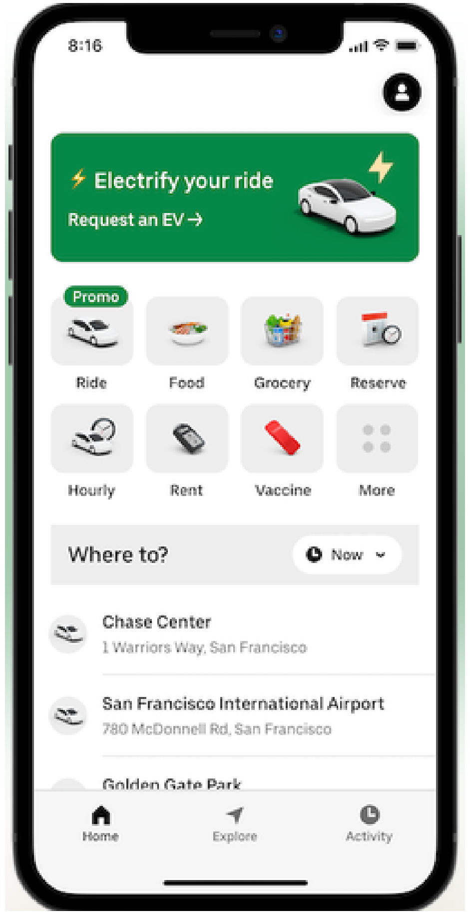
Diet recording app

- Distinction can be fuzzy. E.g. Banking app may have location-aware components (e.g. display nearest bank locations)

Which of these apps are Location-Aware?



a. Gmail smartphone app



b. Uber app

Notable: Sharing Economy Apps

- **Idea:** Share resource (e.g. car, house), maximize utilization
- **E.g.,** Uber: share car, Airbnb: Share house
- **Question:** How is mobile/ubicomp used in sharing apps?

Mobile Device Issue: Energy is most Scarce Resource

- Most resources increasing exponentially *except* battery energy
- As resource capacity increased, many mobile systems resources (e.g. CPU, disk space, wireless capacity) in mobile devices stopped being issue

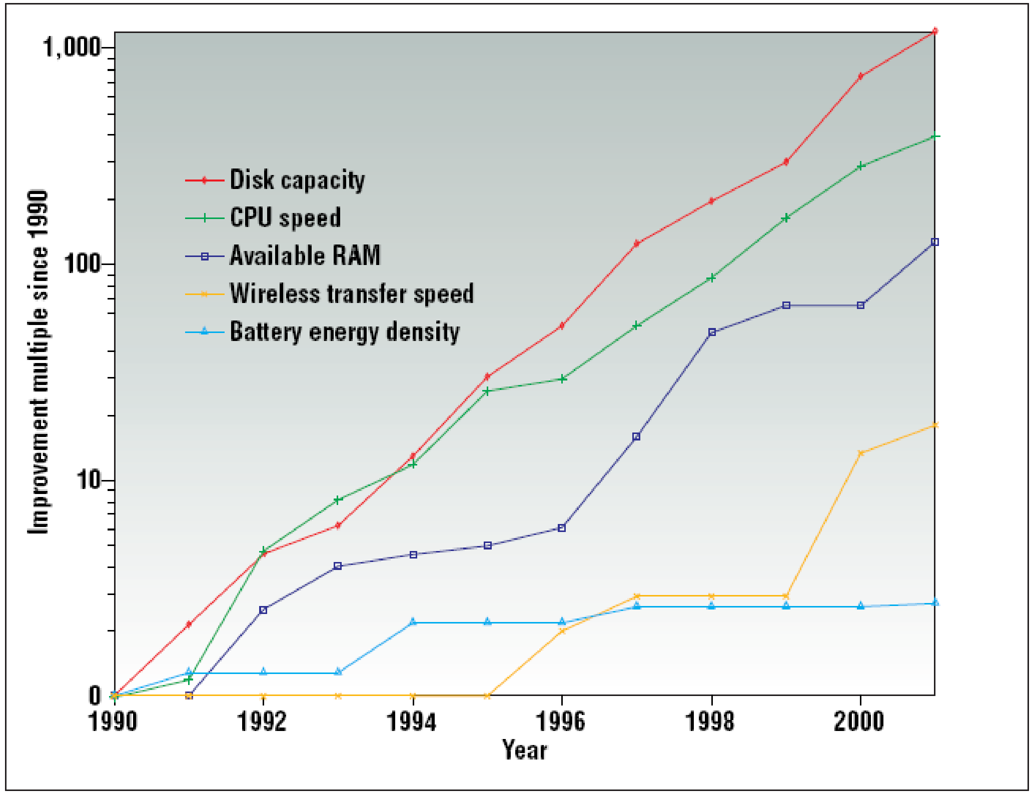


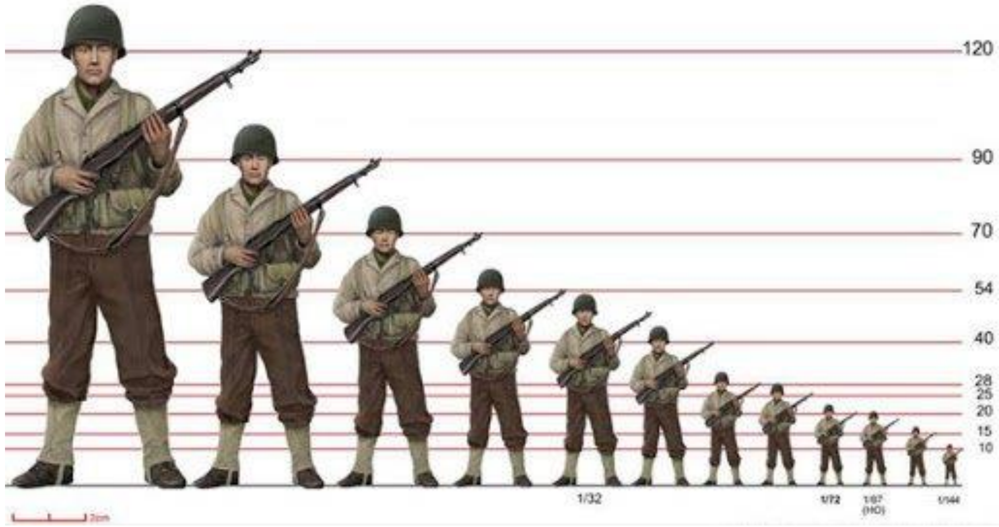
Figure 1. Improvements in laptop technology from 1990–2001.

(ref. Starner, IEEE Pervasive Computing, Dec 2003)

Mobile Device Energy Efficiency Strategies

- **Energy harvesting:** Energy from vibrations, charging mats, moving humans
- **Scale content:** Reduce image, video resolutions to save energy
- **Auto-dimming:** Dim screen whenever user not using it. E.g. talking on phone
- **Better user interface:** Estimate and inform user how long each task will take
  - E.g: At current battery level, you can either:
    - Type a paper for 45 mins
    - Watch video for 20 mins, etc

Dim screen while talking



Scale images to save energy

Ubiquitous Computing

u·biq·ui·tous

/yo͞oˈbikwədəs/

adjective

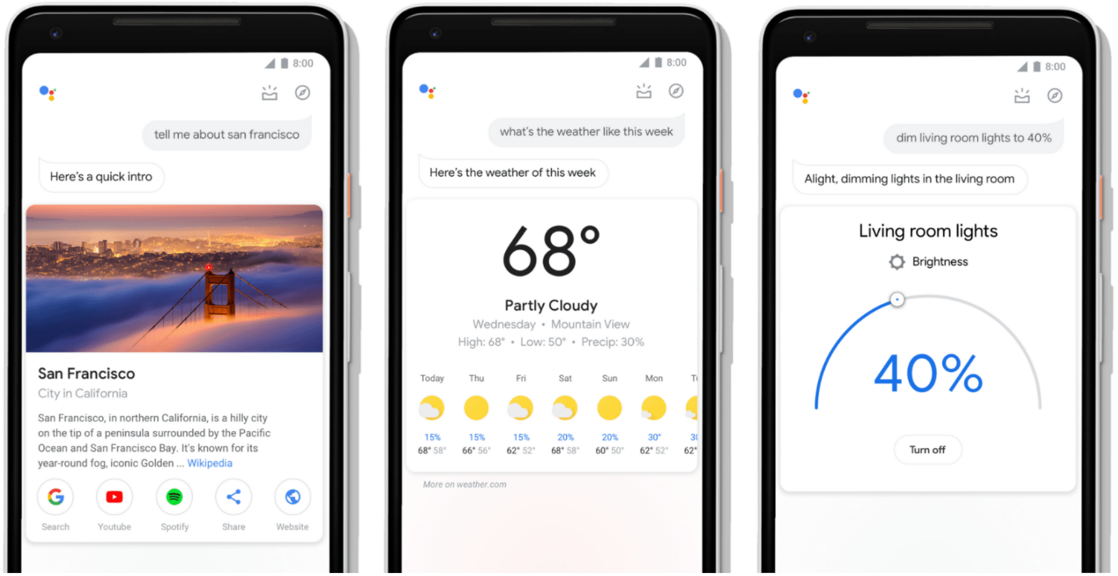
present, appearing, or found everywhere.
"his ubiquitous influence was felt by all the family"
synonyms: omnipresent, ever-present, everywhere, all over the place, pervasive,

Ubiquitous Computing

- Collection of *active* specialized assistants to assist human in tasks (reminders, personal assistant, staying healthy, school, etc)
- App figures out user's current situation, intent, then assists them
- **How?** array of *active* elements, sensors, software, data analyzed using Artificial intelligence
- Extends *mobile computing* and *distributed systems* (more later)
- **Note:** Ubicomp system/app initiates activities, has intelligence

Ubiquitous Computing Example: Google Assistant

- Google Assistant, assists user across multiple (e.g., Google Home, smartphone), update feed informs user of
  - Driving time to work, home
  - News articles user will like
  - Weather
  - Favorite sports team scores, etc
- Also supports 2-way conversations



User Context

- Imagine a genie/personal assistant who wants to give you the “right information” at the “right time”
  - Without asking you any questions
- Genie/personal assistant needs to passively detect user’s:
  - Current situation (Context)
  - Intention/plan
- Examples: Genie detects => suggested action
  - Traffic ahead => suggest alternate route
  - Bored user => suggest exciting video, etc.

Vision

Current “personal assistant”

Smart Assistant/speaker

- User asks questions
- Answer questions, user requests
- Stream music, order a pizza,
- Weather, news, control smart home

Ubicomp Senses User's Context

- Context?
  - *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 advises:* Dress warm!
- Sensed **environment + Human + Computer resources** = ***Context***
- *Context-Aware* applications adapt their behavior to context

Sensing the Human

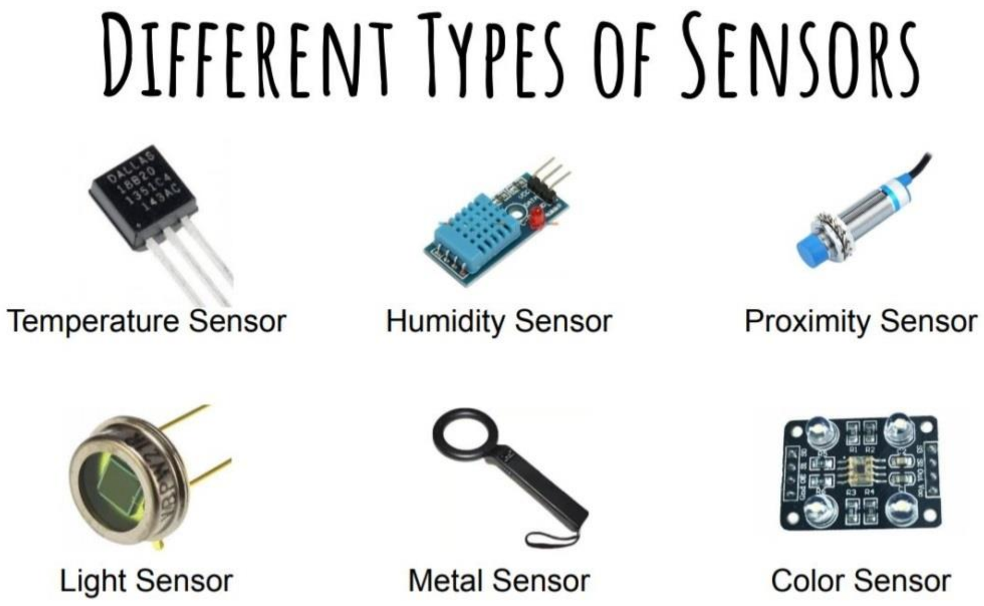
- Environmental sensing is relatively straight-forward
  - Use specialized sensors for temperature, humidity, pressure, etc
- Human sensing is a little harder (ranked easy to hard)
  - **When:** time (Easiest)
  - **Where:** location
  - **Who:** Identification
  - **How:** (Mood) happy, sad, bored (gesture recognition)
  - **What:** eating, cooking (meta task)
  - **Why:** reason for actions (extremely hard!)

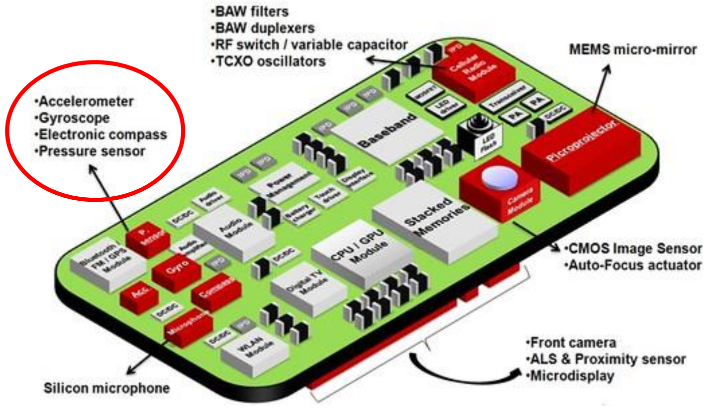
5 W's + 1 H

- Human sensing (gesture, mood, etc) often easiest using cameras
- Research in ubiquitous computing integrates multiple sensed modalities
  - location sensing, user identification, emotion sensing, gesture recognition, activity sensing, user intent

Sensor

- **Example:** E.g. door senses only human motion, opens
- **Sensor:** device that can sense physical world, programmable, multi-functional for various tasks (movement, temperature, humidity, pressure, etc)
  - Includes camera, microphone, etc
- Ubicomp uses/analyzes data from sensors in phone, wearables (e.g. clothes), appliances, etc.
- Smartphones have many sensors already built in





Smartphone sensors integrated into a chip

Ubiquitous Computing: Wearables

UbiComp: Wearables, Bluetooth Devices

Running Tracker

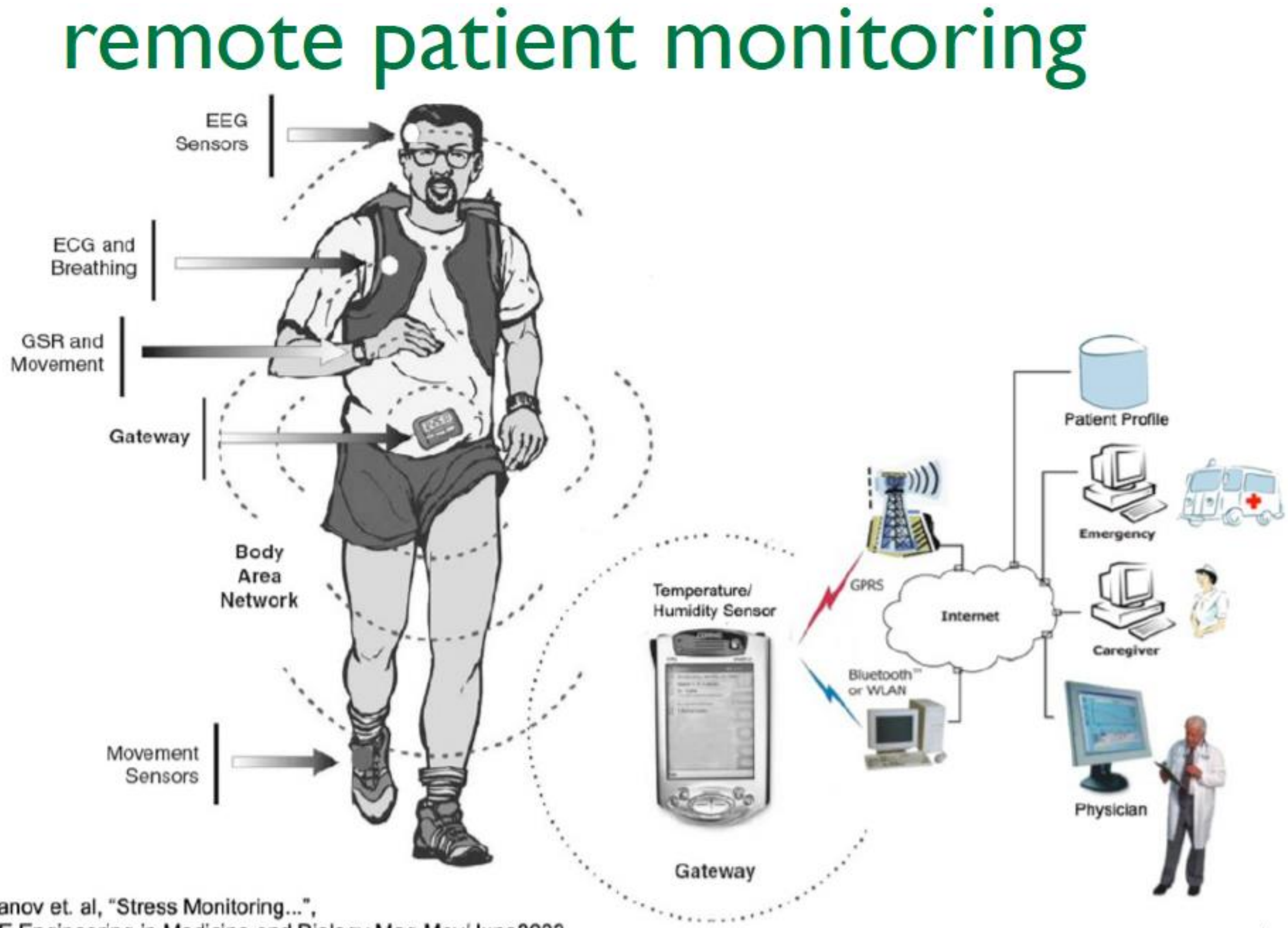
Body Worn Activity, Sleep Trackers

Calorie counting fork

Bluetooth Health & Wellness Devices

External sources of data for smartphone

Ubiquitous Computing:
Wearable Sensors for Health: Early Vision



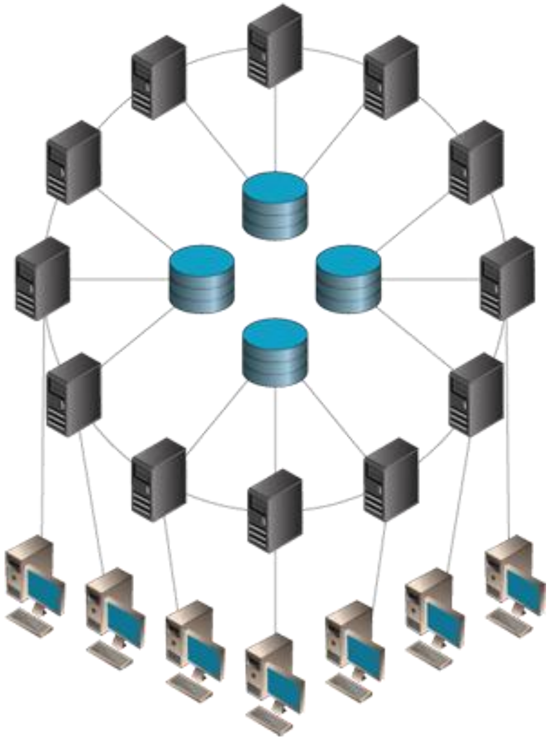
Jovanov et. al, "Stress Monitoring...",
IEEE Engineering in Medicine and Biology Mag.May/June2003

Definitions: Portable, mobile & ubiquitous computing

Distributed Computing

- Computer system is physically distributed
- User can access system/network from various points.
- E.g. Unix cluster, WWW
- Huge 70’s revolution

- ***Distributed computing example:***
  - WPI students have a CCC account
  - Log into CCC machines,
  - Web surfing from different terminals on campus. Physically go to different terminals (library, dorm room, zoolab, etc).



- **Finer points:** network is fixed, Human moves

Satyanarayanan, M., 2001. Pervasive computing: Vision and challenges. *IEEE Personal communications*, *8*(4), pp.10-17.

Portable (Nomadic) Computing

- **Basic idea:**
  - Network is fixed
  - device moves and changes point of attachment
  - No computing while moving

- ***Portable (nomadic) computing example:***
  - Mary owns a laptop
  - Plugs into her home network,
  - **At home:** surfs web while watching TV.
  - Every morning, turns off laptop, brings laptop to school, plug into WPI network, boot up!
  - **No computing while traveling to school**
    - **Computing at either home or at WPI.**

Satyanarayanan, M., 2001. Pervasive computing: Vision and challenges. *IEEE Personal communications*, *8*(4), pp.10-17.

Mobile Computing Example

- Continuous computing/network access while moving, automatic network disconnection/reconnection

- ***Mobile computing example:***
  - John has SPRINT PCS phone with web access, voice, SMS messaging.
  - He runs apps like facebook, yelp, uber continuously connected while walking around Boston

- **Finer points:**
  - John, mobile users move
  - Network deals with changing node location, disconnection/reconnection to different cell towers

Satyanarayanan, M., 2001. Pervasive computing: Vision and challenges. *IEEE Personal communications*, *8*(4), pp.10-17.

Ubiquitous Computing Example

- ***Ubiquitous computing:*** John is leaving home to go and meet his friends. While passing the fridge, the fridge senses milk is almost finished, sends a message to John's 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, collaborate

Satyanarayanan, M., 2001. Pervasive computing: Vision and challenges. *IEEE Personal communications*, *8*(4), pp.10-17.

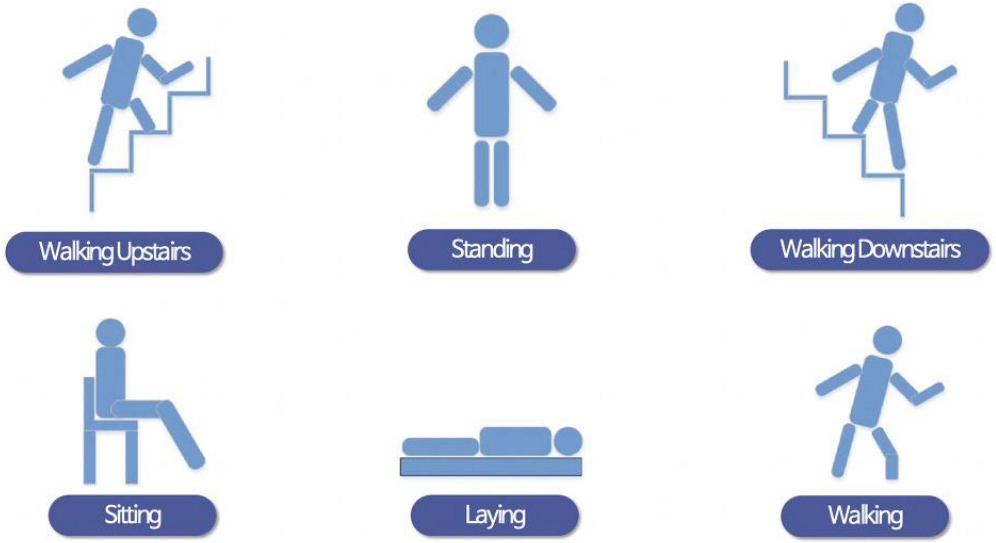
SmartPhone Sensing

Smartphone Sensing

- Smartphone used to sense human, environment (Analyze sensor data)

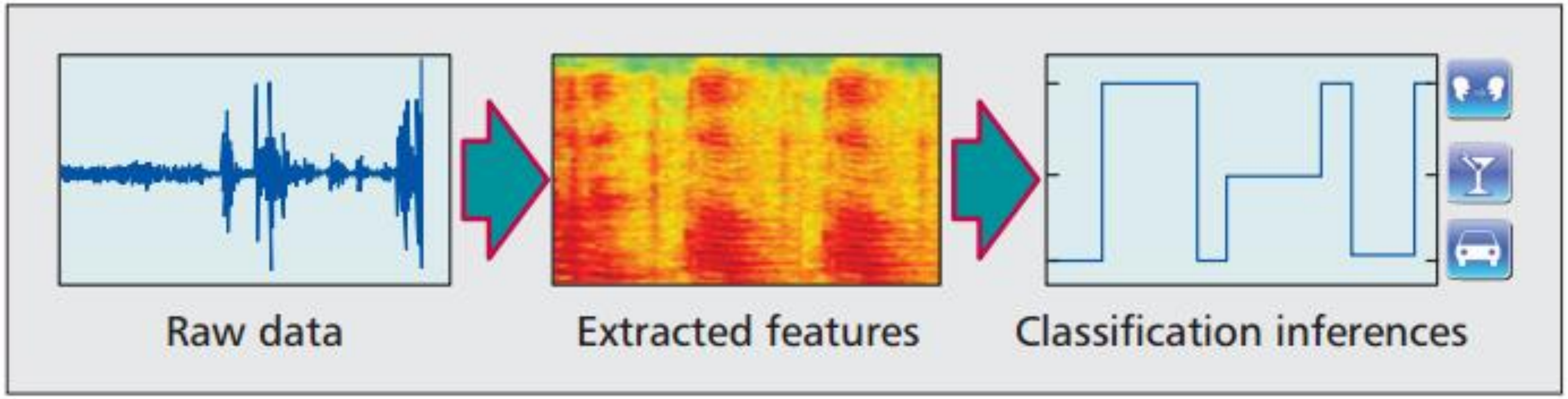
- *Example:* Human activity sensing (e.g., walking, driving, climbing stairs, sitting, lying down)

- *Example 2:* Covid Contact Tracing



Sensor Processing

- Machine learning commonly used to process sensor data
  - Action to be inferred is hand-labelled to generate training data
  - Sensor data is mined for combinations of sensor readings corresponding to action
- Example: Smartphone detects user’s activity (e.g., walking, running , sitting,) by classifying accelerometer sensor data



What Can We Detect/Infer using Smartphone Sensors

<u>Smartphone Sensing!!</u>

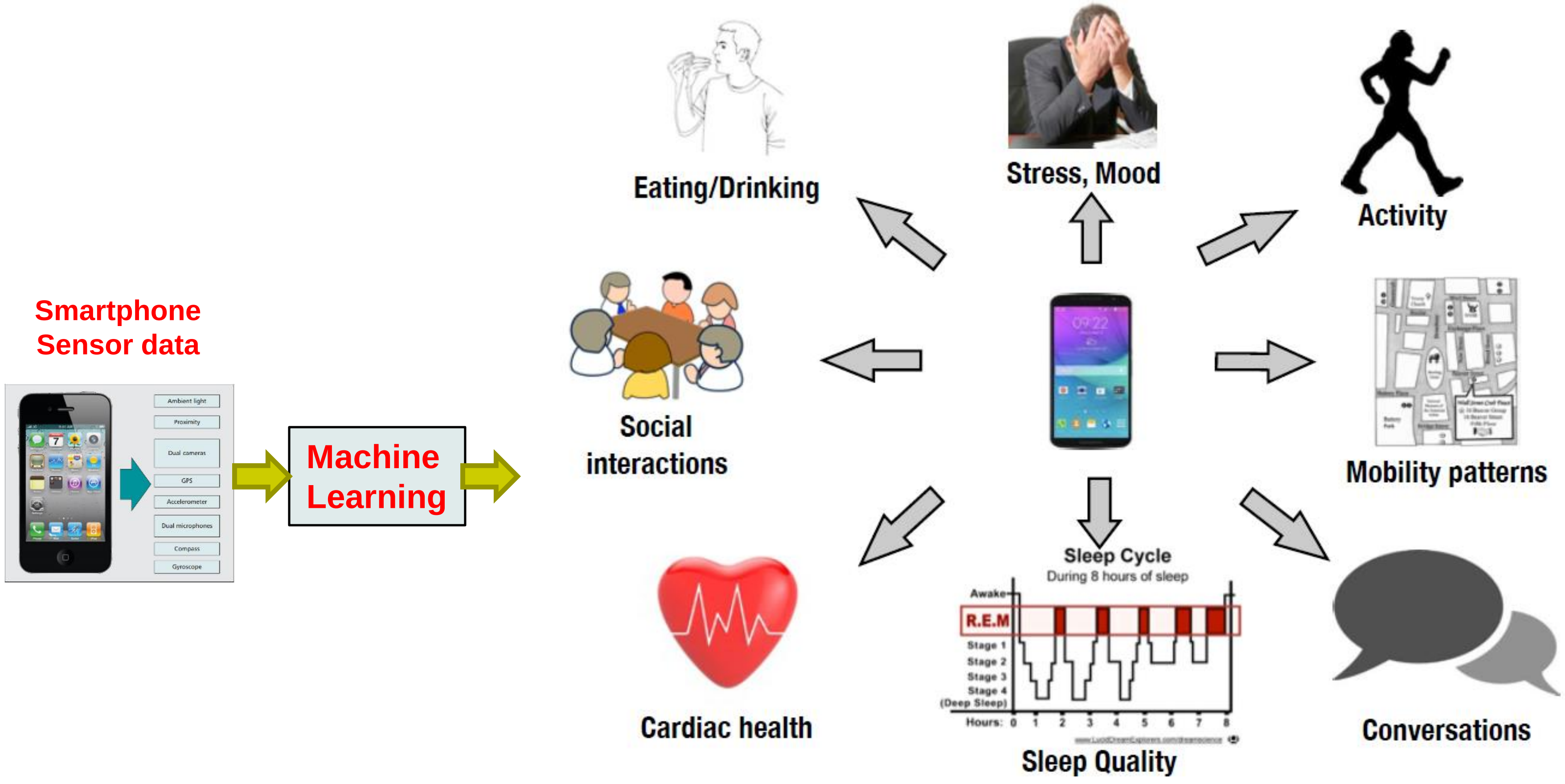


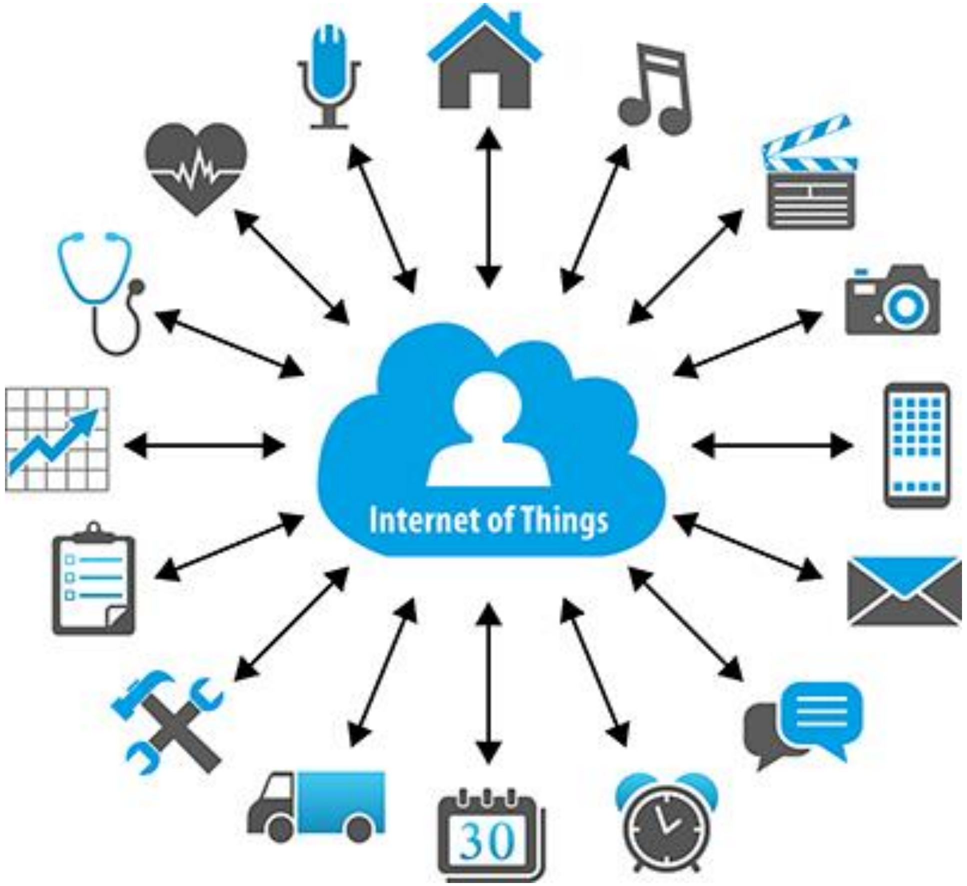
Image Credit: Deepak Ganesan, UMass

Internet of Things (IoT)

IoT: Definitions

- Internet extended to connect Devices
- New technology paradigm
- Internetworked smart machines and devices can
  - Interacting with each other
  - Exchanging information
  - Can be controlled over the Internet

Lee, I. and Lee, K., 2015. The Internet of Things (IoT): Applications, investments, and challenges for enterprises. Business Horizons, 58(4), pp.431-440.



IoT: Networked Smart Things (Devices)

- Smart things: Can be accessed, controlled over the network, auto-learns users patterns

Nest Smart thermostat

- Learns owners manual temp. settings
- Turns down heat when not around

Smart Fridge

- See groceries in fridge from anywhere on companion app

Other Ubicomp Systems

- **Smart Homes:** ambient intelligence, sensing, context-aware services, enable remote home control

  Alam, M.R., Reaz, M.B.I. and Ali, M.A.M., 2012. A review of smart homes—Past, present, and future. *IEEE trans sys. man, and cybernetics, 42*(6), pp.1190-1203.

  - Example: Falls kill many old people who live alone
  - Smartphone continuously monitors elders living in smart home, automatically dials 911 if elder falls or ill

- **Smart buildings:** intelligently improve comfort and energy efficiency

  Wang, Z., et al (2012a), "Integration of plug-in hybrid electric vehicles into energy and comfort management for smart building", Energy and Buildings, Vol. 47, pp. 260-266.

  - Senses presence of people, ambient temperature, people flow, dynamically adjusts heating/cooling
  - Up to 40% savings energy bill

Other Ubicomp Systems

- **Smart Cities:** intelligently improve citizens' quality of life, transport, traffic management, environment, economy and interaction with government

  Ismagilova, E., Hughes, L., Dwivedi, Y.K. and Raman, K.R., 2019. Smart cities: Advances in research—An information systems perspective. *International Journal of Information Management*, *47*, pp.88-100.

  - **Problem:** ~30% of traffic jam in large cities are caused by people hunting for parking
  - **Solution:** Real time data from Sensors embedded in street used to direct drivers to empty parking spots

Top 10 Smart Cities 2021

Rank	City	Change in rank from 2020
1	**Singapore**	-
2	Zurich, Switzerland	▲1
3	Oslo, Norway	▲2
4	Taipei, Taiwan	▲4
5	Lausanne, Switzerland	New entry
6	Helsinki, Finland	▼4
7	Copenhagen, Denmark	▼1
8	Geneva, Switzerland	▼1
9	Auckland, New Zealand	▼5
10	Bilbao, Spain	▲14

Sources: INSTITUTE FOR MANAGEMENT DEVELOPMENT, SINGAPORE UNIVERSITY OF TECHNOLOGY AND DESIGN
STRAITS TIMES GRAPHICS