# Selected Topics Communications and Mobile Computing (Smart Health)

TU Graz

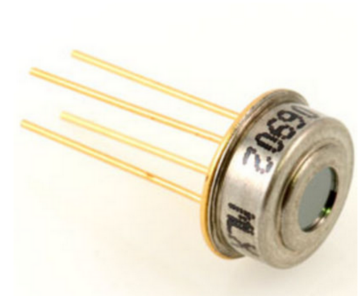
University of Notre Dame

# Sensors & Sensing

- A **sensor** is a converter that measures a physical quantity and converts it into a signal which can be read by an instrument

Visual Sensor

Ultrasound Sensor



Infrared Sensor

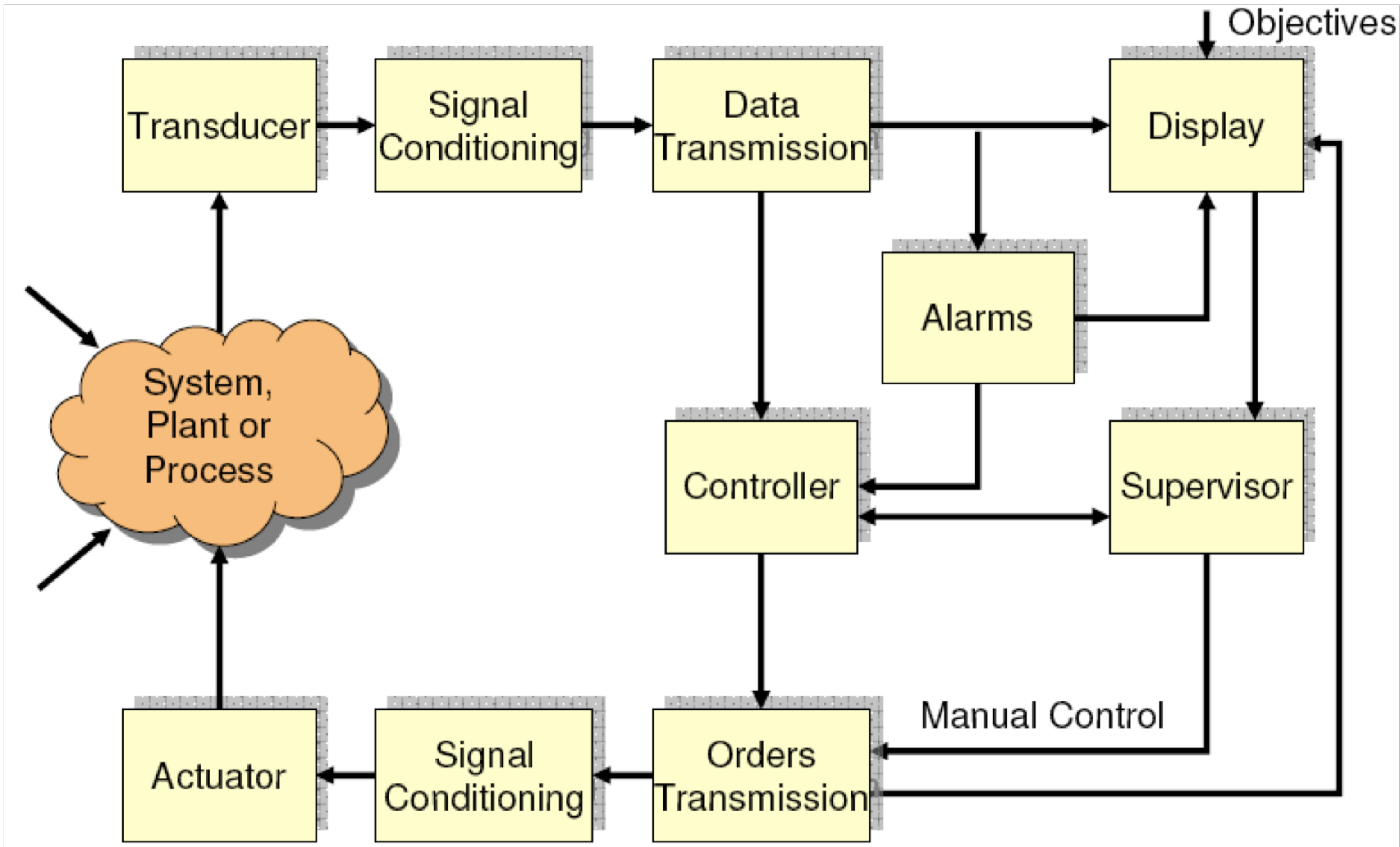
# Basic Terms

- **Transducer:** a device which converts one form of energy to another

- **Sensor:** a transducer that converts a physical phenomenon into an electric signal
  - Interface between the physical world and the computing world

- **Actuator:** a transducer that converts an electric signal to a physical phenomenon

# Sensor/Actuator System



# Sensor-to-Signal Interface

- Action of environment on a sensor causes it to **generate** an electrical signal directly
  - voltage source (V), current (I), or charge (Q) source

- Action of environment on sensor **changes** an electrical parameter that we can measure
  - Resistance changes: $V = I * R$ ($R$ = resistance)
  - Capacitance changes: $C = \varepsilon * A / d$ ($A$ = area, $d$ = distance, $\varepsilon$ = permittivity)
  - Inductance changes: $V \sim dI/dt$, $I \sim \int V\,dt$

# Signal Conditioning

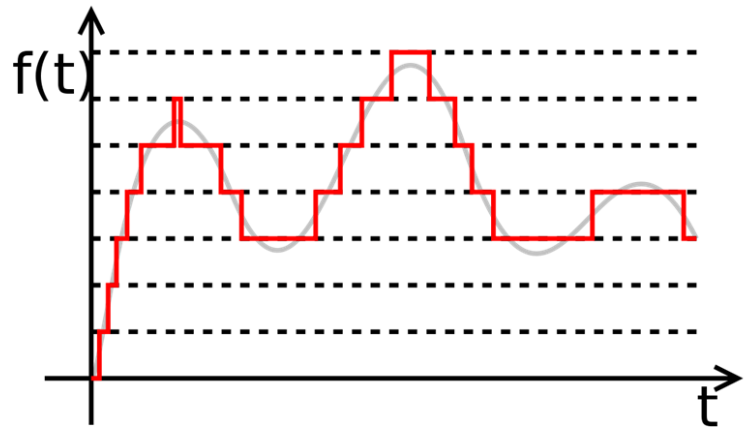
- Filter for expected frequency regime
- Subtract DC offset (“zeroing”)
- Amplify or attenuate signal (“scaling”)
- Linearize relationship between measured and observed electrical parameter
- ...

# Analog-to-Digital Converter (ADC)

- Many different principles
- All involve trade-offs of speed (conversion time), resolution (number of bits), and cost
- “Flash converter” is the fastest, has the lowest resolution, and the highest cost
- Successive approximation ADC: binary search through all possible quantization levels

# Example

$$Q = \frac{E_{FSR}}{2^M} = \frac{E_{FSR}}{N}$$




- Q = resolution in volts per step
- M = resolution in bits
- N = Number of intervals (steps)
- $E_{FSR}$ = Full scale voltage range

- Voltage range 0 – 10V; M = 12 bits
- N = 4096 intervals (steps)
- Q = 2.44 mV/code

# Sensor Types

| Criterion | Classes | Example |
|---|---|---|
| Power supply | Modulating | Thermistor* |
| | Generating | Thermocouple** |
| Output signal | Analog | Potentiometer |
| | Digital | Position encoder |
| Operating mode | Deflection | Deflection accelerometer |
| | Null | Servo-accelerometer |

* *Thermistor*: a resistor whose resistance changes with temperature.
** *Thermocouple*: a temperature-sensing element which converts thermal energy directly into electrical energy

# Sensor Types: Power Supply

- Modulating
  - Also known as Active Sensors
  - They need auxiliary power to perform functionality
- Self-Generating
  - Also known as Passive Sensors
  - They derive the power from the input

# Sensor Types: Operating Mode

- Deflection
  - The measured quantity produces a physical effect
  - Generates an apposing effect which can be measured
  - Faster

- Null
  - Applies the counter force
  - To balance the deflection from the null point (balance condition)
  - Can be more accurate but slow

# Sensor Types: Physical Property

- Temperature
- Pressure
- Humidity
- Light
- Microphone (sound)
- Motion detector
- Chemical detector
- Image Sensor
- Flow and level sensor
- …

# Sensor Types: HW & SW

- **Hardware**-based sensors
  - Physical components built into a device
  - They derive their data by directly measuring specific environmental properties
- **Software**-based sensors
  - Not physical devices, although they mimic hardware-based sensors
  - They derive their data from one or more hardware-based sensors

# Sensor Types: Function Type

- Motion sensors
  - Measure acceleration forces and rotational forces along three axes, e.g., accelerometer, gyroscope, etc.
- Position sensors
  - Measure the physical position of a device, e.g., GPS, proximity sensor, etc.
- Environmental sensors
  - Measure various environmental parameters, e.g., light sensor, thermometer, etc.

# Sensor List

| Sensor | Function Type | Software-based or Hardware-based |
|---|---|---|
| Accelerometer | Motion Sensor | Hardware-based |
| Gyroscope | Motion Sensor | Hardware-based |
| Gravity | Motion Sensor | Software-based |
| Rotation Vector | Motion Sensor | Software-based |
| Magnetic Field | Position Sensor | Hardware-based |
| Proximity | Position Sensor | Hardware-based |
| GPS | Position Sensor | Hardware-based |
| Orientation | Position Sensor | Software-based |
| Light | Environmental Sensor | Hardware-based |
| Thermometer | Environmental Sensor | Hardware-based |
| Barometer | Environmental Sensor | Hardware-based |
| Humidity | Environmental Sensor | Hardware-based |

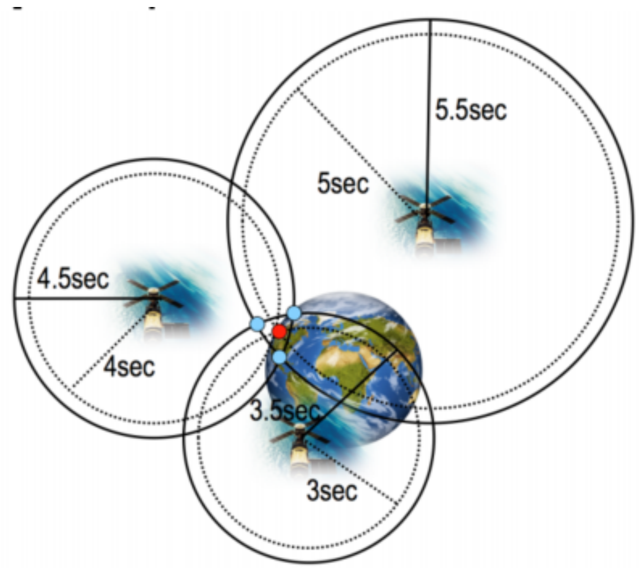
# Smartphone and Wearable Sensing

- Light
- Proximity
- Cameras (multiple)
- Microphones (multiple)
- Touch
- Position
  - GPS, Wi-Fi, cell, NFC, Bluetooth
- Accelerometer
- Gyroscope
- Magnetometer
- Pressure
- Temperature
- Humidity
- Fingerprint sensor


- Accelerometer
- Gyroscope
- Microphone
- Position
- Infrared thermopile
- Photoplethysmography (PPG)
- Electrodermal activity (EDA)
- Electrocardiogram (ECG)

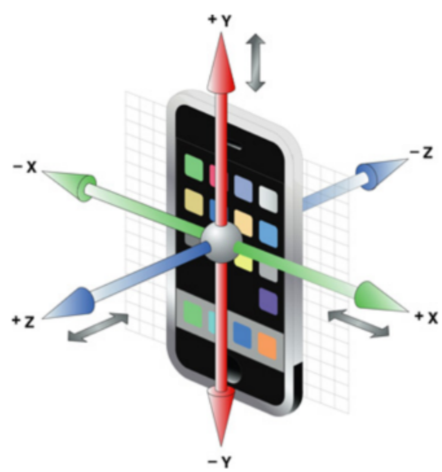
# Sensor: GPS

- Need connection to 3 satellites for 2D positioning, 4 satellites for 3D positioning (theoretically)
- More visible satellites increase precision
- Based on concept of trilateration



# Sensor: Motion and Orientation

- Most of the sensors use the same **coordinate system**
- When a device's screen is facing the user
  - The X axis is horizontal and points to the right
  - The Y axis is vertical and points up
  - The Z axis pints toward outside of the screen face



# Sensor: Accelerometer

- Measure proper acceleration (acceleration it experiences relative to freefall)
- Units: g

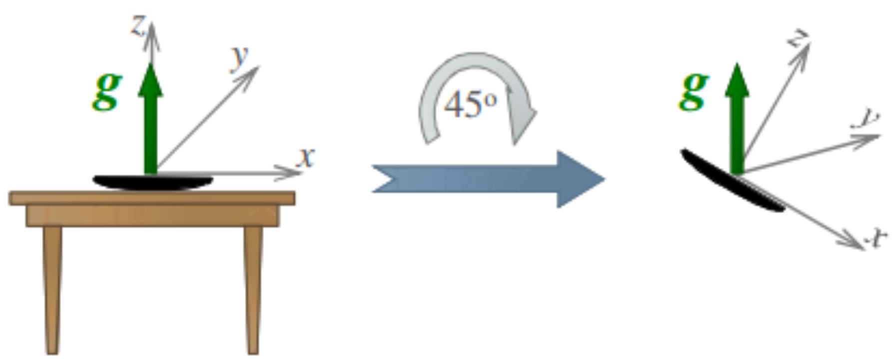
| Example | G Force |
|---|---|
| Standing on earth at sea level | 1g |
| Bugatti Veyron from 0 to 100 km/h (2.4s) | 1.55g |
| Space Shuttle, maximum during launch and reentry | 3g |
| Formula 1 car, peak lateral in turns | 5-6g |
| Death or serious injury | 50g |
| Shock capability of mechanical Omega watches | 5000g |

# Sensor: Accelerometer

- Acceleration is measured on 3 axes
- Note that the force of gravity is always included in the measured acceleration
  - When the device is sitting on the table stationary, the accelerometer reads a magnitude of 1g
  - When the device is in free fall, the accelerometer reads a magnitude of 0g
- To measure the real acceleration of the device, the contribution of the force of gravity must be removed from the reading, for example, by calibration

# Sensor: Accelerometer

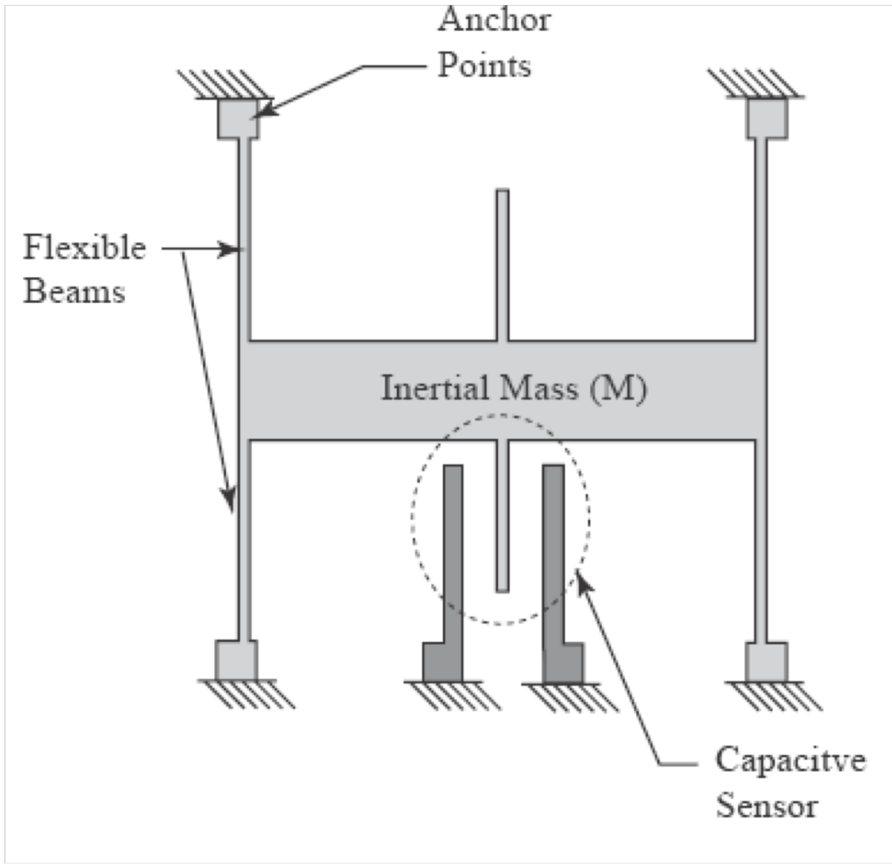
- When the device is lying flat
  - gives +1g (gravitational force) reading on Z axis
- Stationary device, after 45 degree rotation
  - Same magnitude, but rotated




$$a_x = a_y = 0$$
$$a_z = g$$

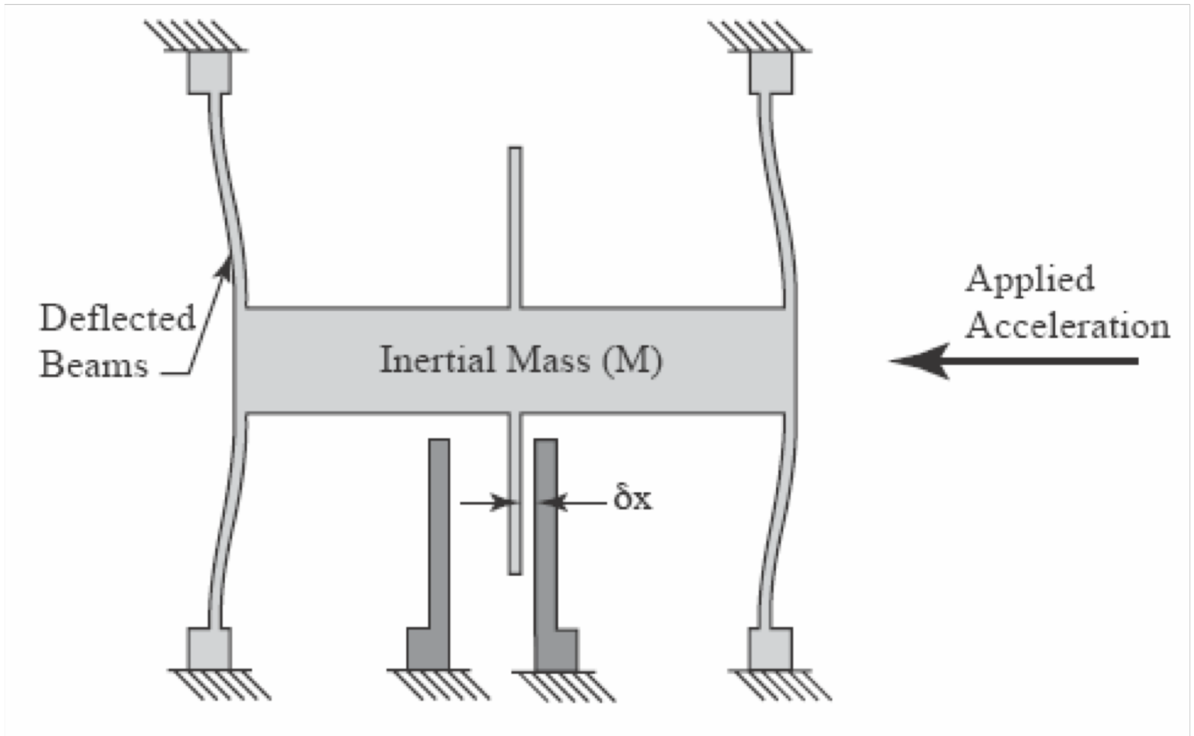
$$a_y = 0$$
$$a_z = -a_x = g/\sqrt{2}$$

# Accelerometer: Inner Working (1 of 2)




It consists of beams and a capacitive sensor with some anchor points

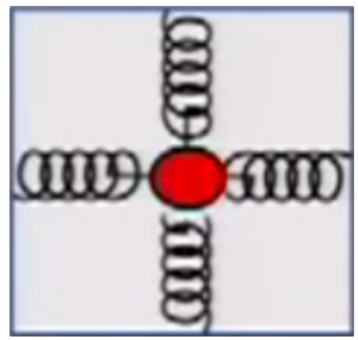
# Accelerometer: Inner Working (2 of 2)

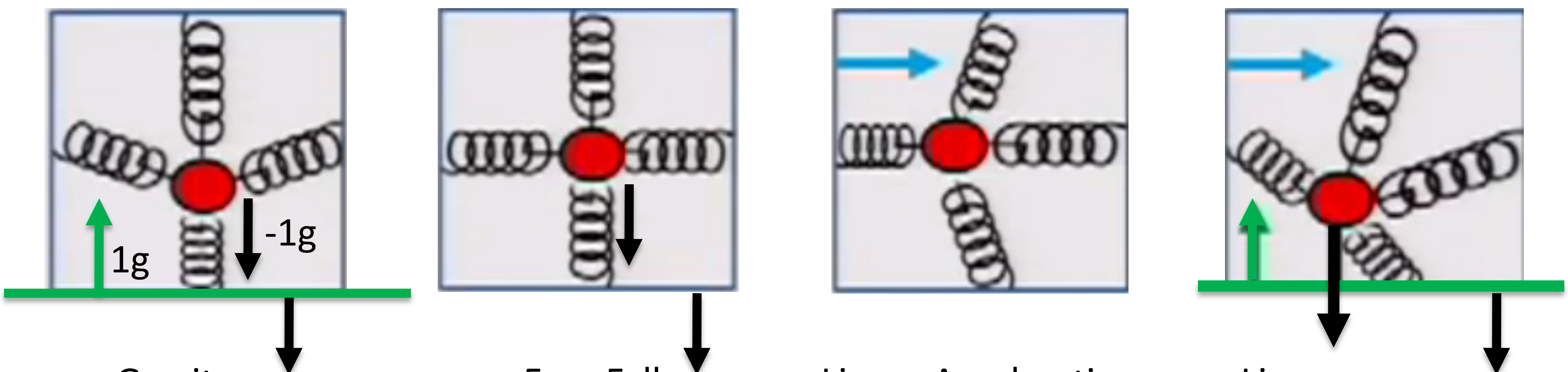



On applying the acceleration, the beams deflect and cause the change in capacitance.

# Accelerometer

Mass on spring






Gravity

1g = 9.8m/s²

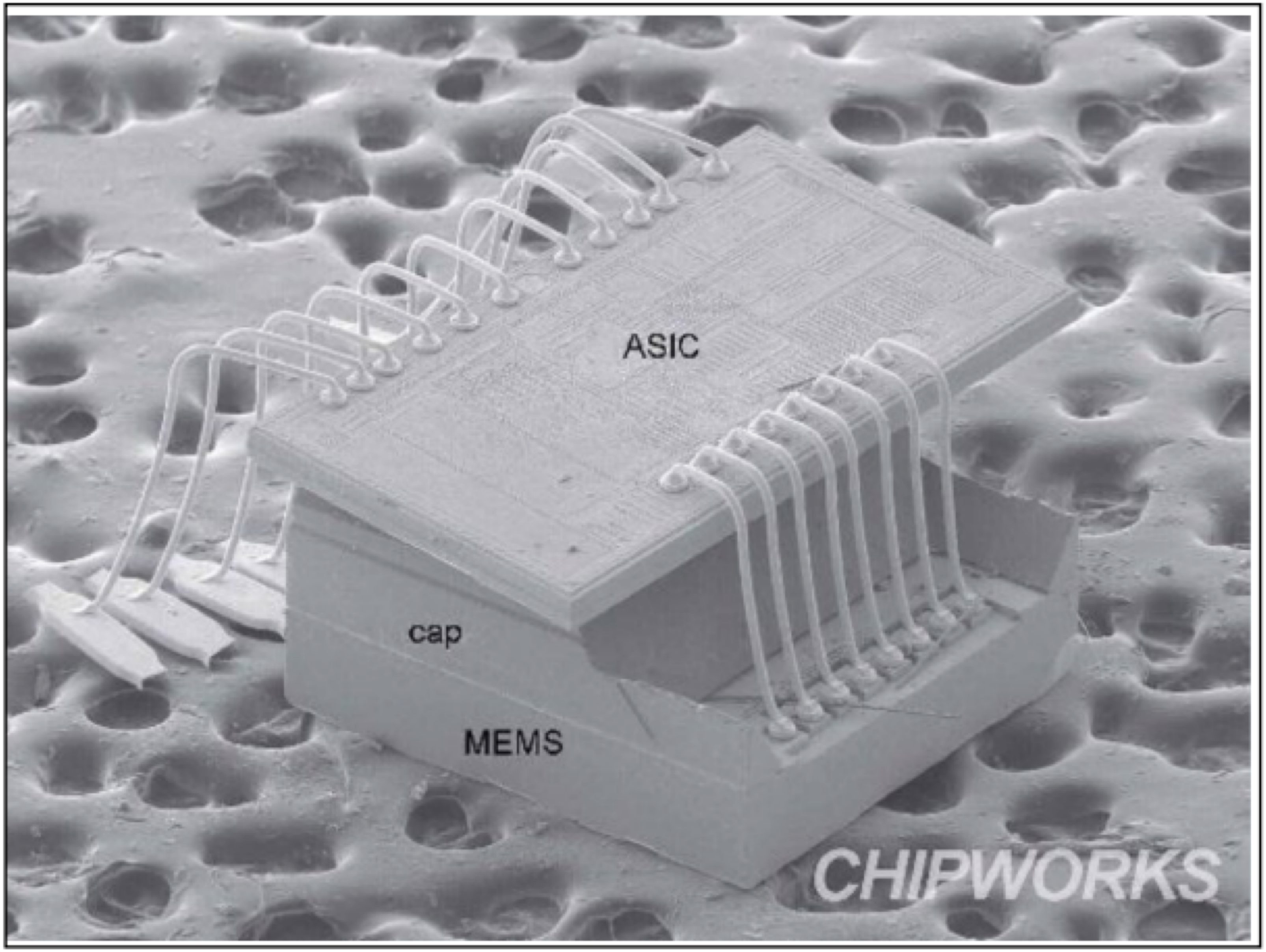
Free Fall

Linear Acceleration

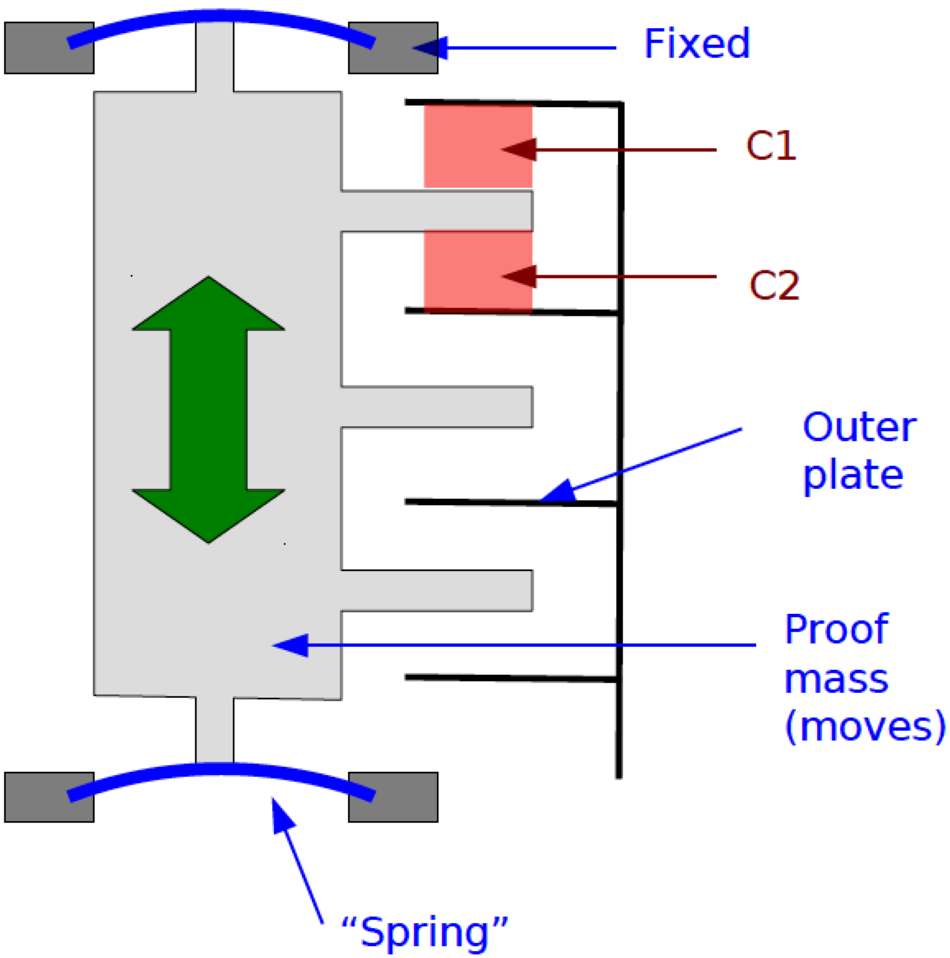
Linear Acceleration plus gravity

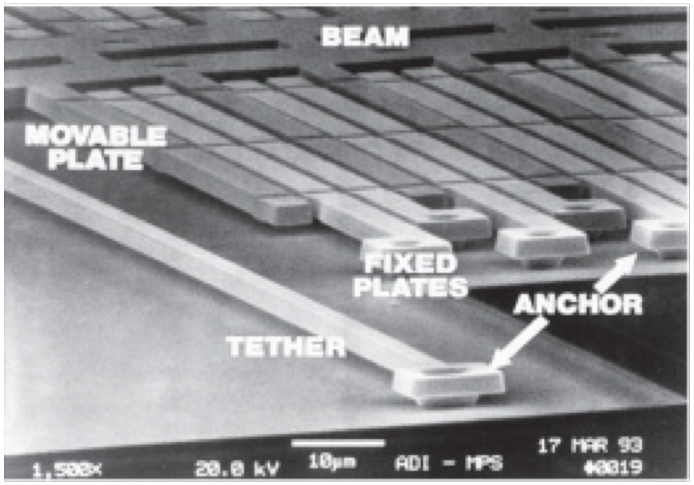
# Smartphones: MEMS Sensors

- Micro Electro-Mechanical Systems
- Term coined in 1989
- Describes creation of mechanical elements at a scale more usually reserved for microelectronics
- MEMS use cavities, channels, cantilevers, membranes, etc. to imitate traditional mechanical systems
- Small enough to be integrated with the electronics


ASIC
cap
MEMS
CHIPWORKS

# MEMS Accelerometer




- Have a proof mass between springs and a series of ‘plates’
- Measure deflection via capacitance changes
- 1-D only

# Sensor: Gravity

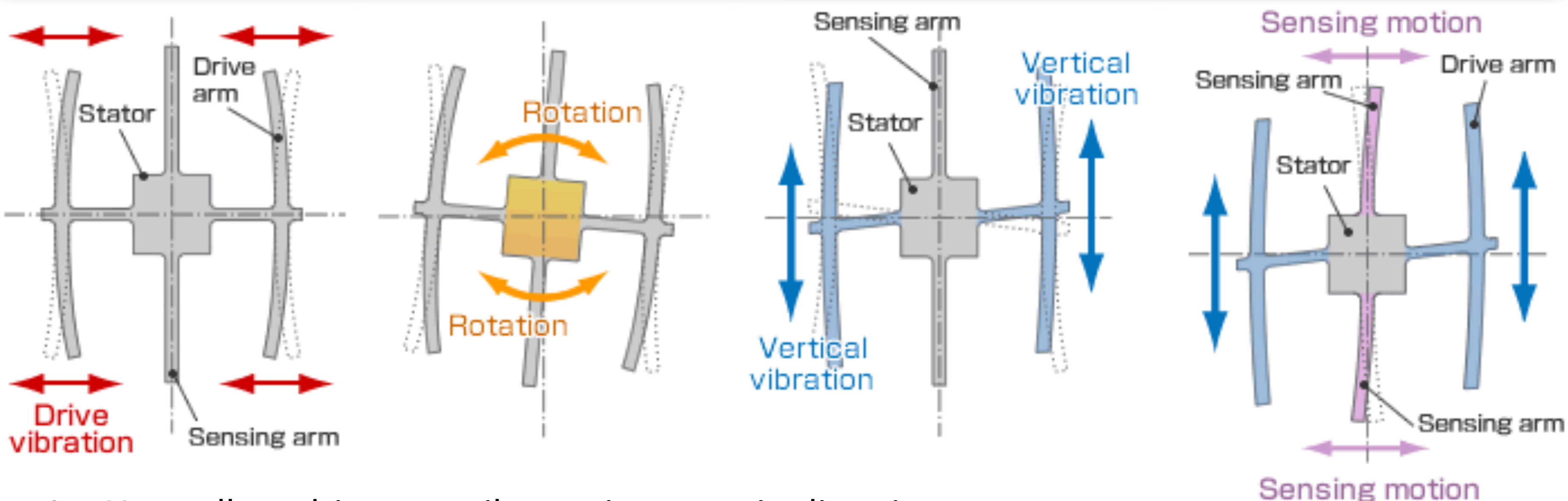
- Gravity sensor is not a separate hardware
- It is a virtual sensor based on the accelerometer
- It is the result when real acceleration component is removed from the reading

# Sensor: Gyroscope

- Measures the rate of rotation (angular speed) around an axis
- Speed is expressed in rad/s on 3 axis
- When the device is not rotating, the sensor values will be zeros
- It gives us 3 values
  - Pitch value (rotation around X axis)
  - Roll value (rotation around Y axis)
  - Yaw value (rotation around Z axis)

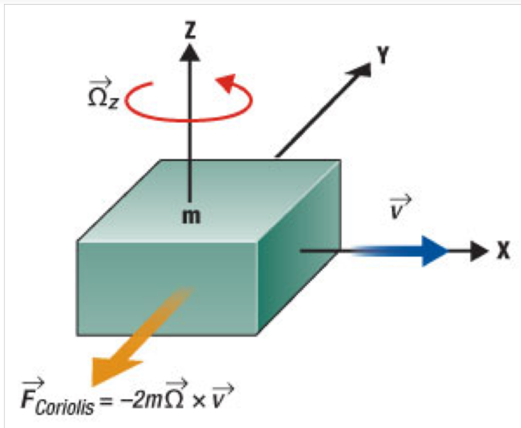

- Unfortunately, gyroscope is error prone over time.
- As time goes, gyroscope introduces drift in result
- By sensor fusion (combining accelerometer and gyroscope), results can be corrected and path of movement of device can be obtained correctly

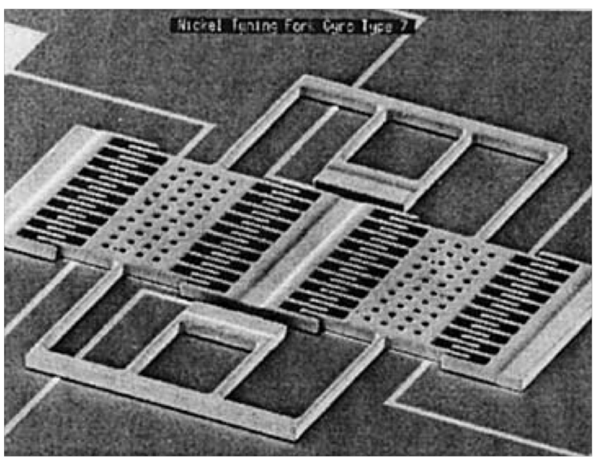
# Gyroscope

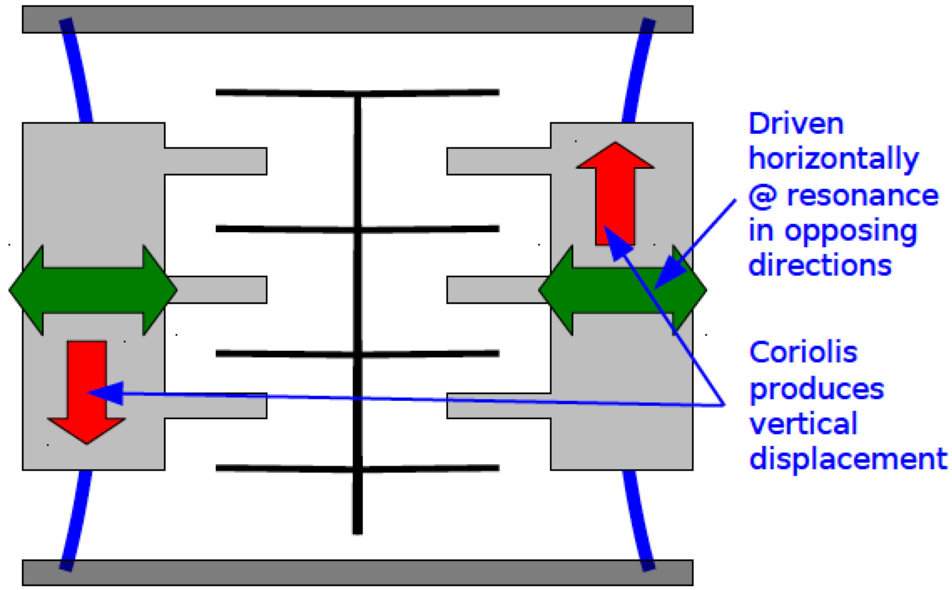



1. Normally, a drive arm vibrates in a certain direction.
2. Direction of rotation
3. When the gyro is rotated, the Coriolis force acts on the drive arms, producing vertical vibration.
4. The stationary part bends due to vertical drive arm vibration, producing a sensing motion in the sensing arms.
5. The motion of a pair of sensing arms produces a potential difference from which angular velocity is sensed. The angular velocity is converted to, and output as, an electrical signal.

# MEMS Gyroscope






- Based on measuring Coriolis force as experienced by a moving object in a rotating frame of reference
- Many implementations, but the “tuning fork” method is most common

# Accelerometer vs. Gyroscope

- Accelerometer
  - Senses linear movement: not good for rotations, good for tilt detection
  - Does not know difference between gravity and linear movement
- Gyroscope
  - Measures all types of rotations
  - Not movement
- A+G = both rotation and movement tracking possible

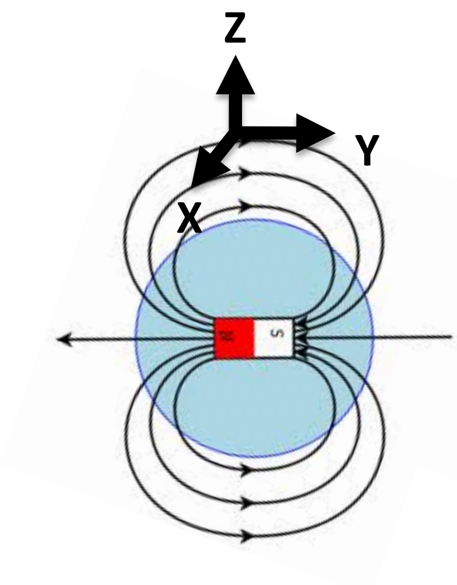
# Sensor: Magnetic Field

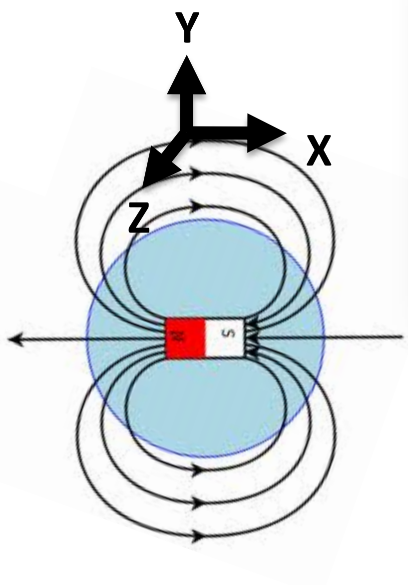
- Measures direction and strength of earth's magnetic field
- Strength is expressed in tesla (T)

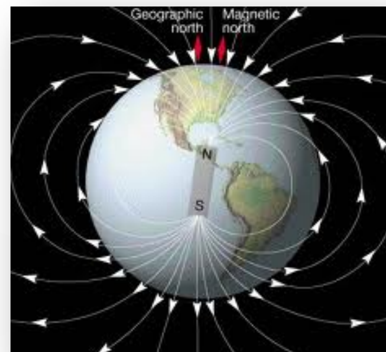
| Example | Field strength |
| --- | --- |
| Earth's magnetic field on the equator (0° latitude) | 31μT (0.00031T) |
| Typical fridge magnet | 5mT (0.005T) |
| Strong neodymium magnet | 1.25T |
| MRI system | 1.5T – 3T |

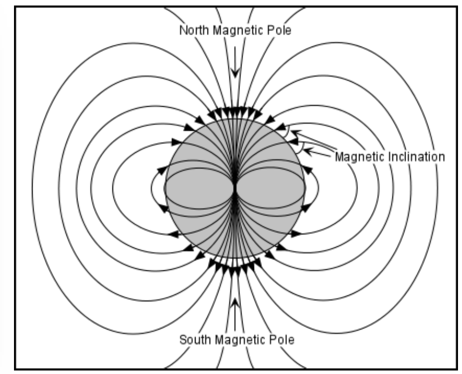
# Compass

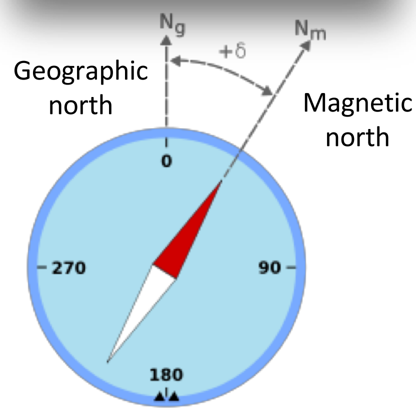
- Magnetic field sensor (magnetometer)



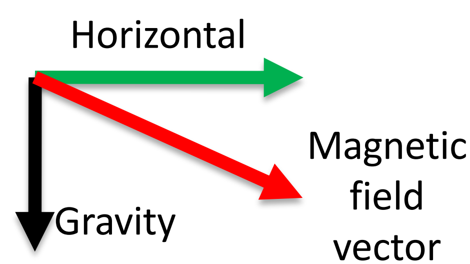



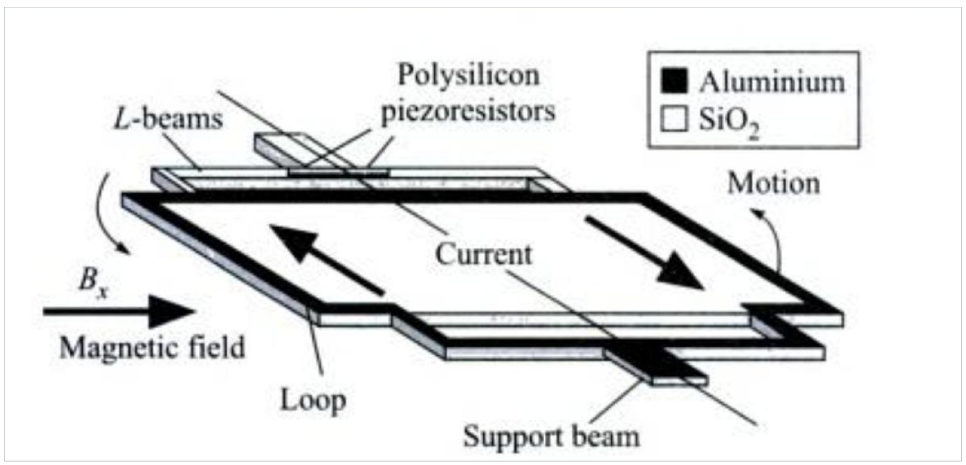

Magnetic declination

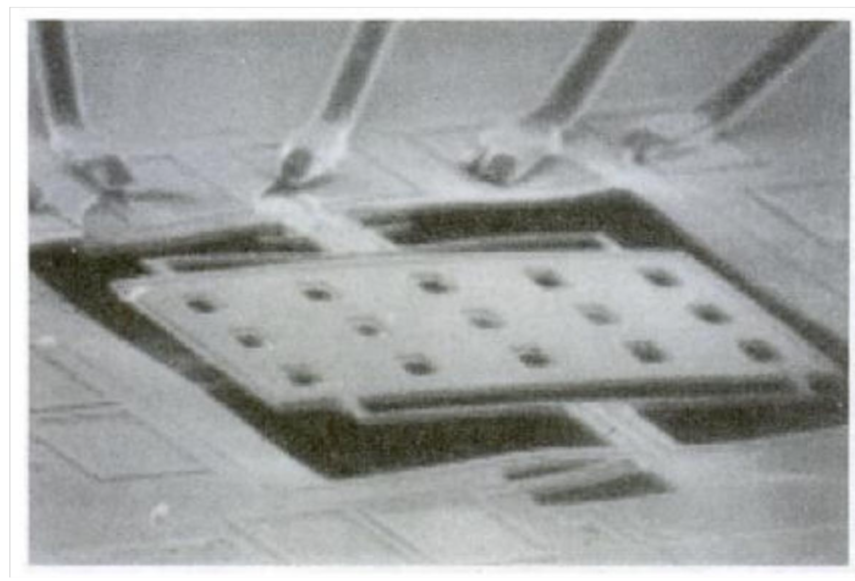



Magnetic inclination

# MEMS Compass

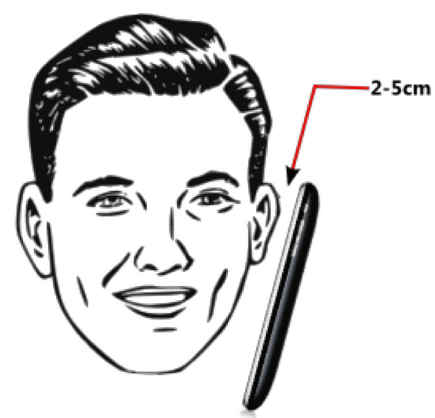
- Most use Lorentz Force
- A current-carrying wire in a magnetic field experiences a perpendicular force



# Sensor: Proximity

- A proximity sensor can detect the presence of nearby objects without physical contact
- It often emits an electromagnetic field (e.g., infrared) and looks for changes in the field or return signal
- It is usually used by mobile device to determine how far a person's head is from the face of a handset
  - E.g., a user is making a phone call




- The measured results could be different based on different devices
  - Most proximity sensors return the absolute distance in centimeters (cm)
  - Some return only a flag that represents near or far
  - Some return either 0.0 or the maximum value only

# Sensor: Light

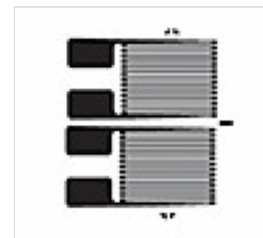
- It gives a reading of the light level detected by the light sensor of the device
- Located at front of mobile device near to front facing camera
- The units are in SI lux units
- The device uses the data to adjust the display's brightness automatically
  - When ambient light is plentiful, the screen's brightness is pumped up and when it is dark, the display is dimmed down
  - High-end Samsung galaxy phones use an advanced light sensor that can measure white, red, green, and blue light independently to fine tune image representation

# Sensor: Thermometer

- Ambient temperature outside of the device
- In fact, there's a thermometer in almost every mobile device and some handsets might have more than one of them; however, they are used to monitor the temperature inside the device and its battery to detect overheating
- A temperature sensor detects a change in a physical parameter such as resistance or output voltage that corresponds to a temperature change
- Contact (direct physical contact) vs. non-contact (radiant energy of a heat source)

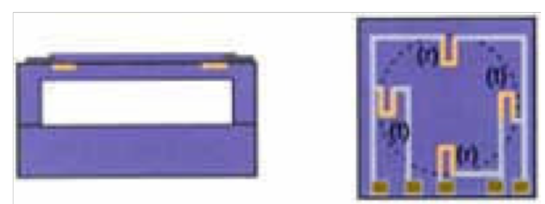
# Sensor: Pressure

- Transduces pressure into electrical quantity
- Pressure exerts force which can be converted to electrical voltage using various methods
- **Strain Gauges**
  - Based on the variation of resistance of a conductor or semiconductor when applied to mechanical stress



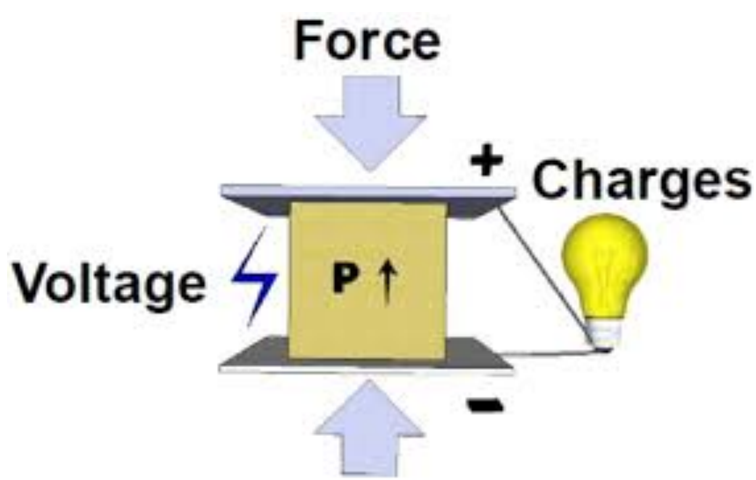
- **Capacitive diaphragms**
  - Diaphragm acts as one plate of capacitor
  - The stress changes the space between capacitor plates

- **Piezo-resistive**
  - Micro-machined silicon diaphragms
  - Piezo-resistive strain gauges diffused into it
  - Very sensitive to pressure



# Piezoelectric Sensors

- Device that measures changes in pressure, strain, force, etc. by converting them to an electrical charge
- Typically crystals or ceramics



# Sensor: Sound

- A **microphone** is an acoustic to electric transducer that converts sound into an electrical signal

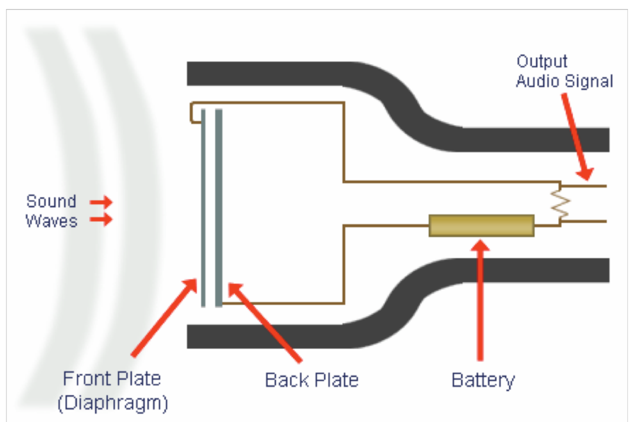
- Microphones **capture sound waves with a thin, flexible diaphragm**; the vibrations of this element are then converted by various methods into an electrical signal that is an analog of the original sound.

- Most microphones in use today use electromagnetic generation (**dynamic microphones**), capacitance change (**condenser microphones**) or **piezo-electric generation** to produce the signal from mechanical vibration.

# Condenser (or Capacitor) Microphones

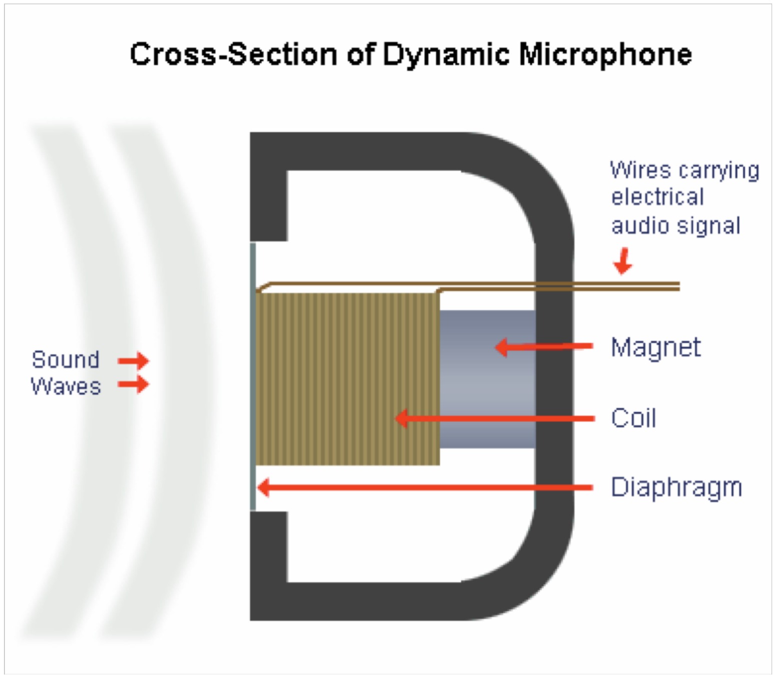
- In a condenser microphone, the diaphragm acts as one plate of a capacitor, and the vibrations produce changes in the distance between the plates.

- Since the plates are biased with a fixed charge (Q), the voltage maintained across the capacitor plates changes with the vibrations in the air.



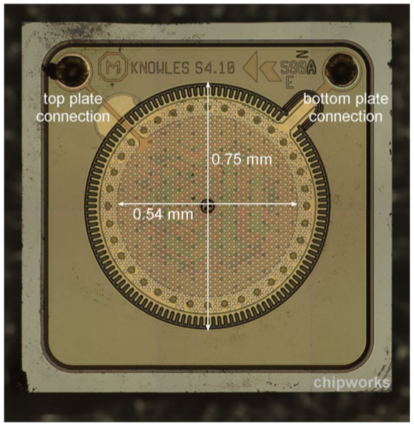
# Dynamic Microphones

- In a dynamic microphone, a small **movable induction coil**, **positioned in the magnetic field of a permanent magnet**, is attached to the diaphragm.
- When sound enters through the windscreen of the microphone, the sound wave vibrations move the diaphragm.
- When the diaphragm vibrates, the coil moves in the magnetic field, producing a varying current in the coil through **electromagnetic induction**.



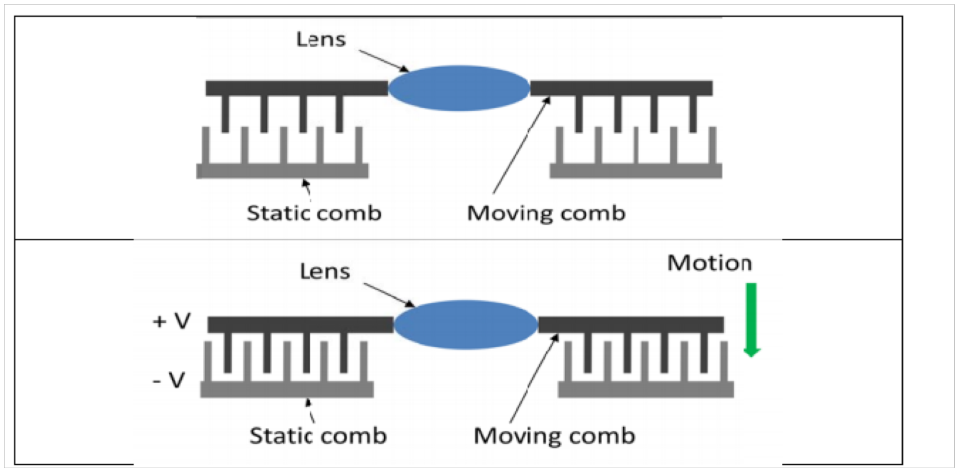
# Microphones in Smartphones

- Almost all new handsets use MEMS microphones (often plural!)
- Two conducting membranes, one on top of the other, acting as a capacitor
- Vibrations cause the capacitance to change



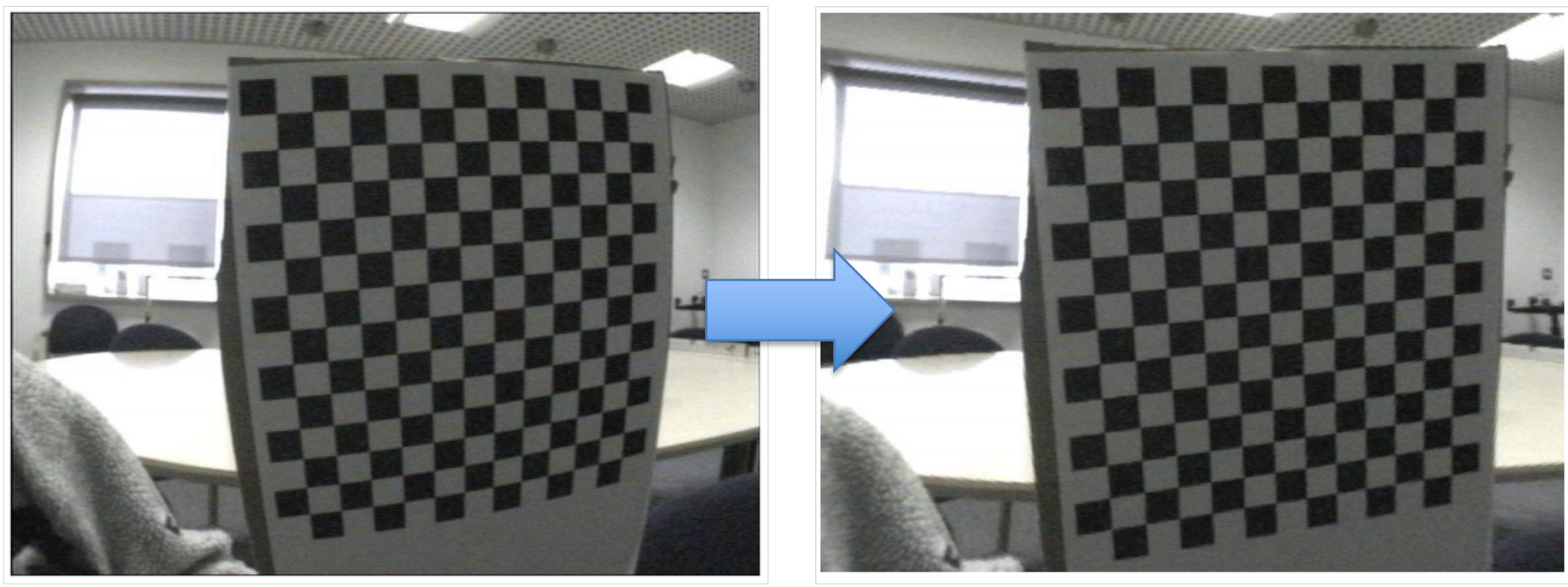
# Sensor: Cameras

- These vary, but more and more make use of MEMS for (auto)focus
- The underlying light sensor is no different from 'normal' cameras
- However the small, cheap lenses inevitably suffer from distortion



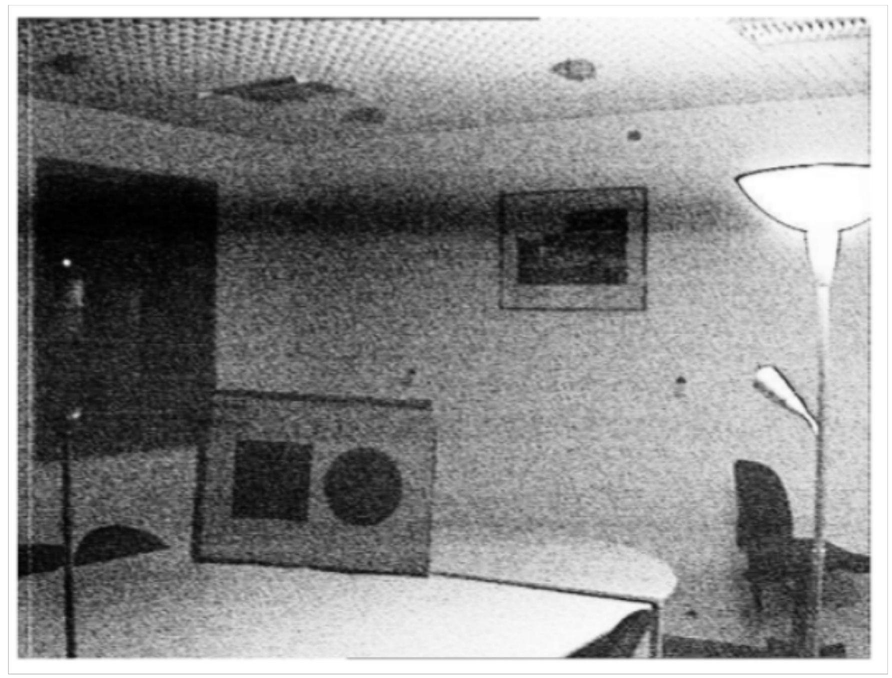
# Distortion Correction

- Calibrate lens -> Remove distortion
- But this is a costly process



# Camera Sensor

- With such small apertures, longer exposures are needed to get good output
- Hence phone cameras suffer from extensive noise in low light levels
  - Photon shot noise



# Continuous Sensing

- Most of the smartphone OSes assume you don’t want to register for 24/7 sensing events
- If you do, watch out that the OS doesn't require some extra action on your part
  - e.g., some versions of Android put the CPU into a low power state after a certain time of screen inactivity. The lowest power states preclude polling the sensor data...!
- You might have to hold a wake lock on the CPU if you want to do this (which means the battery will deplete faster!)

# Nominal Rates

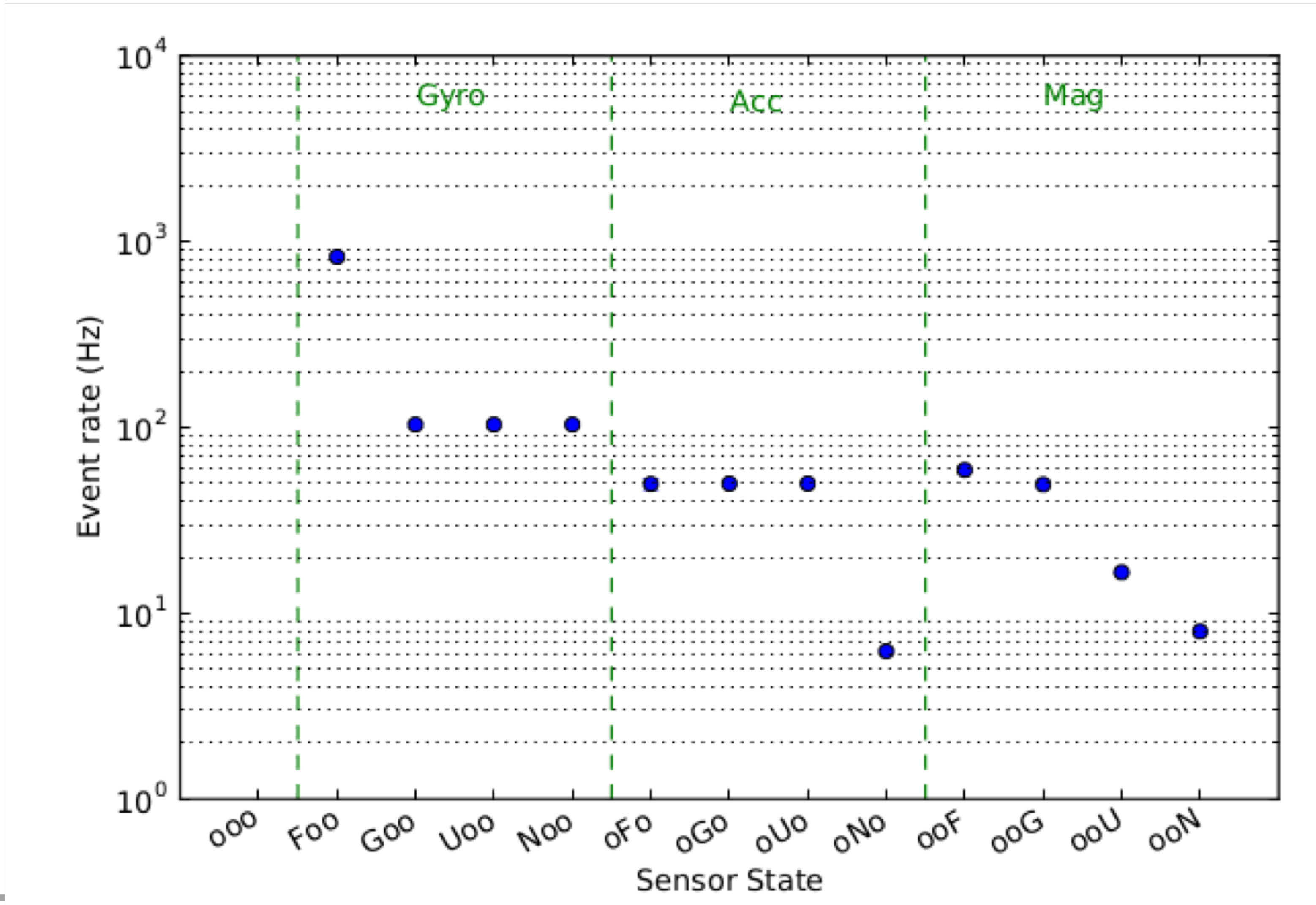
- The sensor hardware samples at a constant ('nominal') rate but timestamping is error-prone
- Hence most smartphone APIs shy away from numerical rates. Android uses:

```
case SENSOR_DELAY_FASTEST:
    delay = 0;
    break;
case SENSOR_DELAY_GAME:
    delay = 20000;
    break;
case SENSOR_DELAY_UI:
    delay = 66667;
    break;
case SENSOR_DELAY_NORMAL:
    delay = 200000;
```

# Sampling

- Smartphone OSes are not real-time. Most sensors regularly update a register with values. The updates produce interrupts and eventually the OS gets around to collecting the value.
- If the OS is busy already, a new value could come in before we've read the last!
- Dropped readings...
- More recent sensors use a ring buffer so we don't drop any, but...
- The timestamps are currently of the time the datum was collected and not the instant it was created...

# Nominal Rate Example (Nexus S)



# Sensor Filtering

- Warning: sometimes getting a higher sampling rate is pointless
- More and more sensors now have built-in low-pass filtering, which limits the max. frequency present. So high sampling rates might just result in oversampling!
- Normally not an issue (in fact a good thing) but wastes power and performance

# Process Interference

- Sampling consistency can also be affected by high priority resource-intensive processes. In Android 2.3, the garbage collector ran with a higher priority than sensing...
- And other processes may request a higher rate for the same sensor at the same time! The logical thing is to run at the highest requested rate, but this might mean your app sees significant jumps in the rate of events.

# Derived Sensors

- Initially the sensor access was raw, but now we have derived sensor types that fuse raw data to estimate other quantities. E.g., in Android:
  - **TYPE_GRAVITY** – Estimates the gravity vector by low pass filtering the accelerometers
  - **TYPE_LINEAR_ACCELERATION** – Estimates the acceleration having subtracted gravity
  - **TYPE_ROTATION_VECTOR** – Estimates the full rotational pose of the sensor in a world frame
- Specific implementation details vary (e.g. software/hardware, gyroscope for rotation or not)
- Can ignore and fuse ourselves of course...

# Inertial Tracking

- It is very tempting to fuse the sensors together to track the phone’s trajectory → Inertial Measurement Unit
- Such tracking is relative; errors accrue over time (drift)

# Example: Linear Acceleration

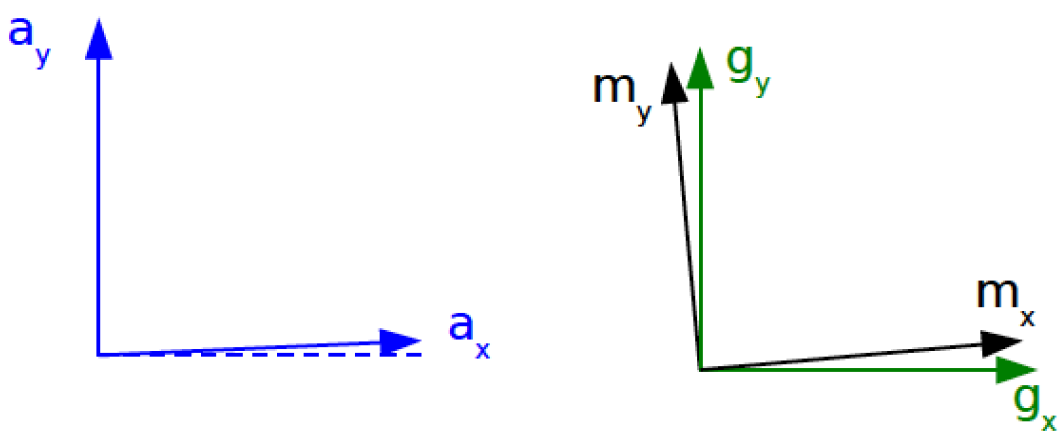
- If the pose of the device is constant, double integrating the accelerometers after removing gravity should give displacement

$$s = \iint (a - g)\,dt$$

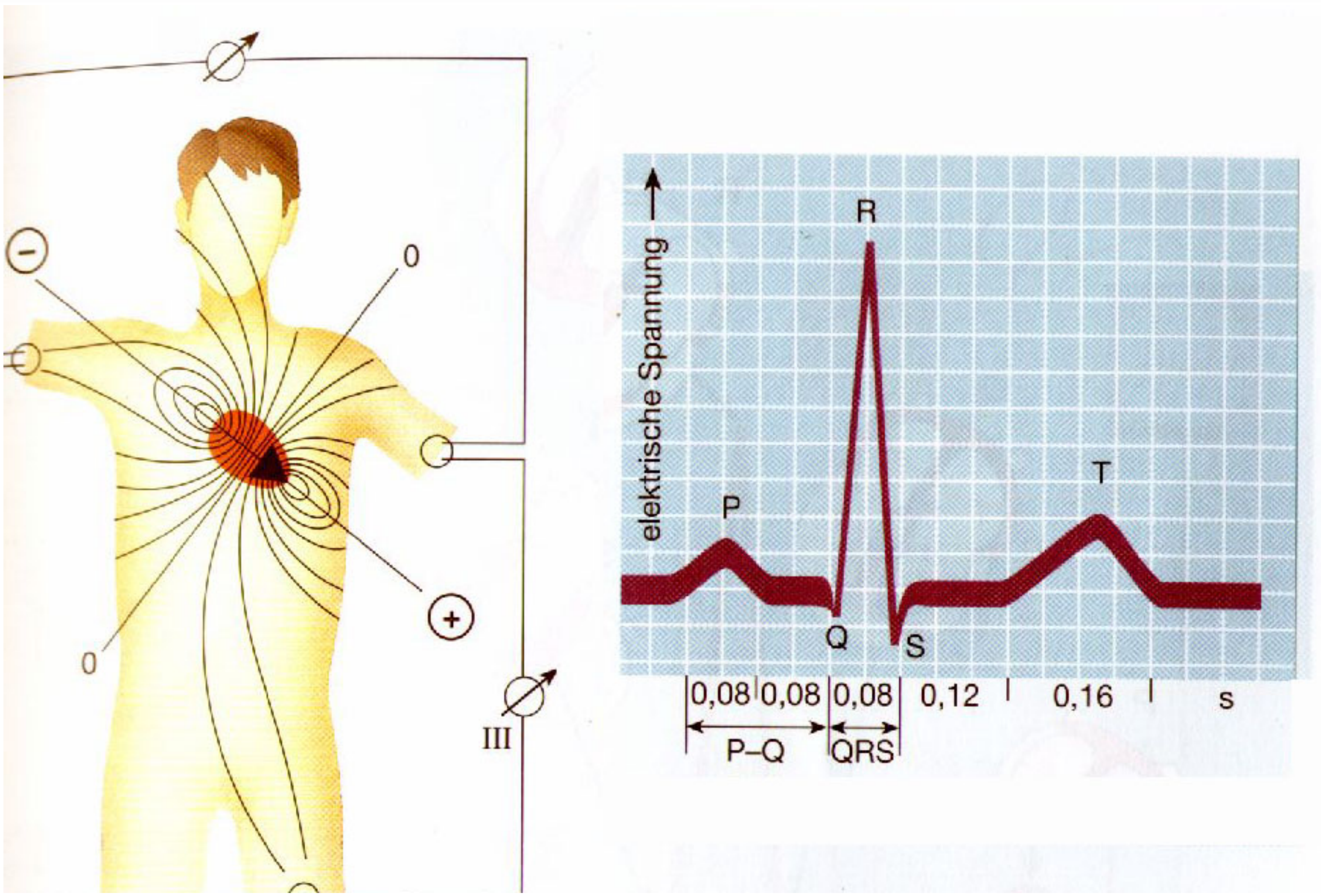
- Error grows quadratically over time
- End result is a fast (and unlimited) accrual of error

# Sensor Alignment

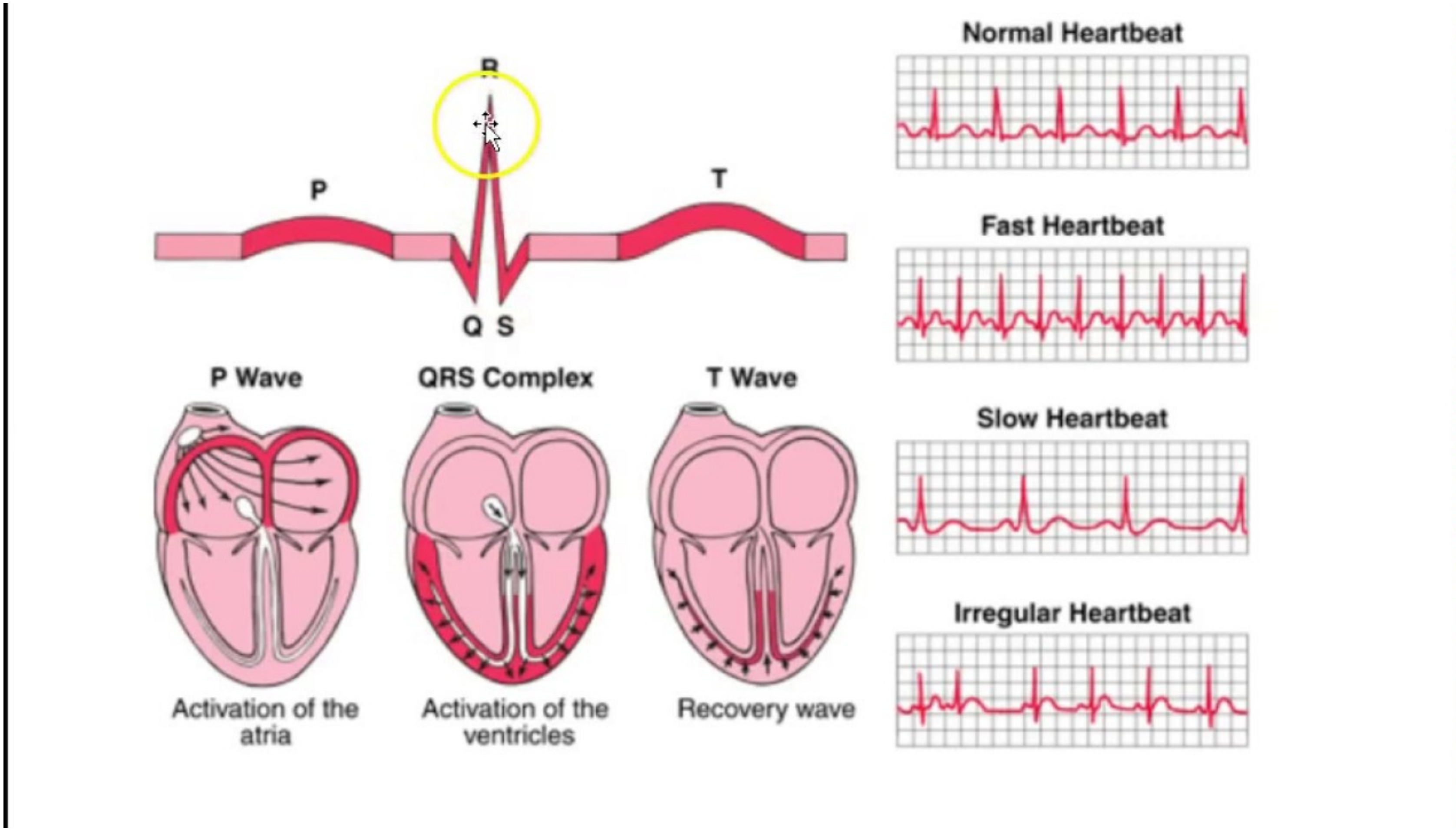
- It can be dangerous to assume the three sensors in a 3-D sensor are:
  - Perfectly orthogonal
  - Perfectly parallel to those of other sensors



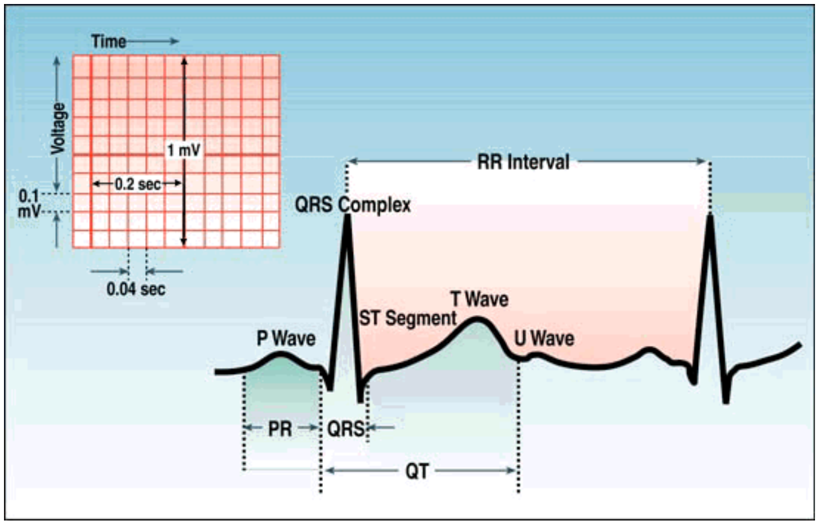
# Electrocardiogram (Heart Activity)

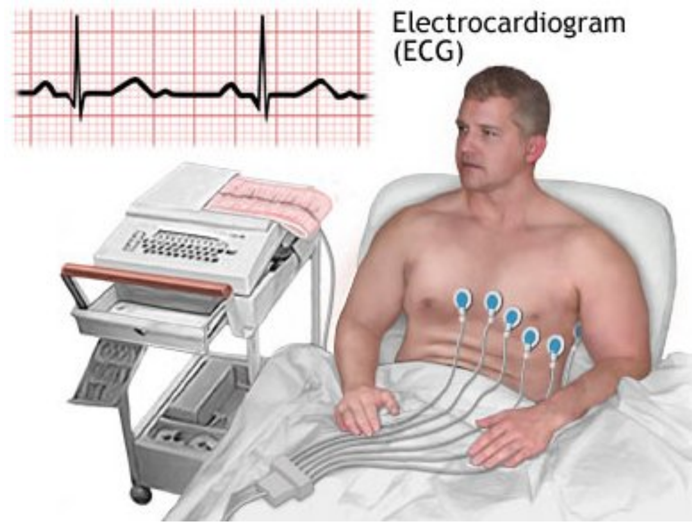


# Electrocardiogram (Heart Activity)



# Electrocardiogram (Heart Activity)




The P wave is associated with the contractions of the atria (the two chambers in the heart that receive blood from outside)

The QRS is a series of waves associated with ventricular contractions (the ventricles are the two major pumping chambers in the heart)

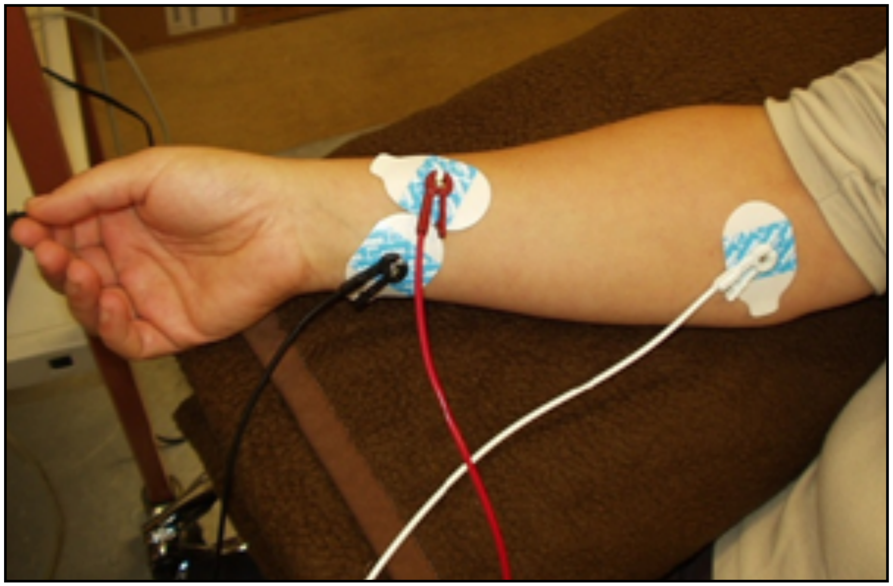
The T and U waves follow the ventricular contractions

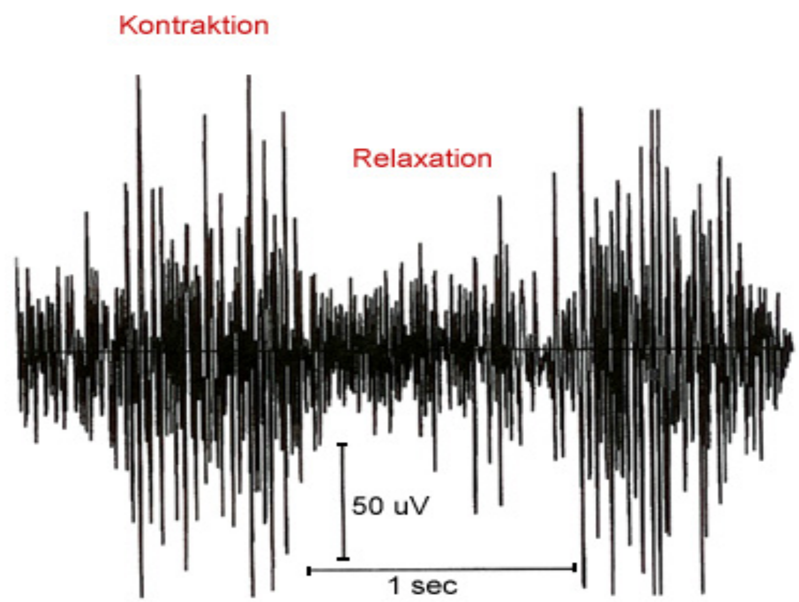
https://www.youtube.com/watch?v=gWakpOAxWAU

# ECG Applications

- Diagnostics
- Functional analysis
- Implants (pace maker)
- Biofeedback (neartrate variability, HRV)
- Peak performance training, monitoring

# Electromyogram (Muscle Movement)

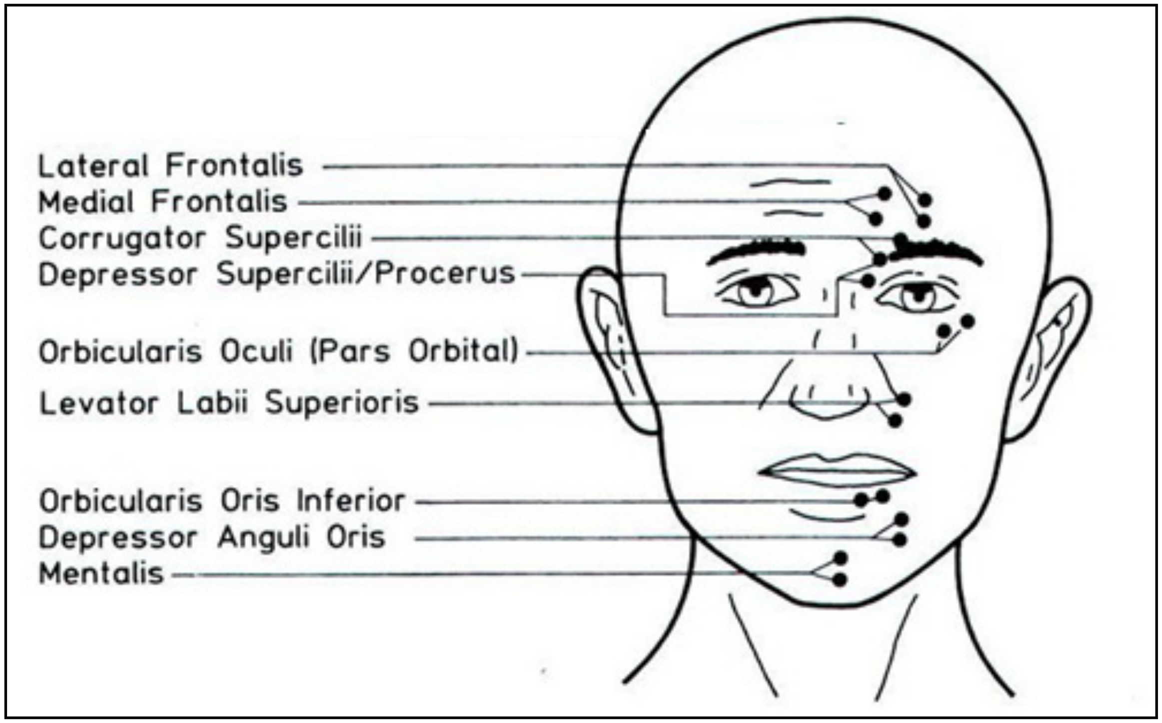





**EMG surface (glue-)electrodes**

**EMG - signal (up to 3mV, 1kHz)**

# Electromyogram (Muscle Movement)

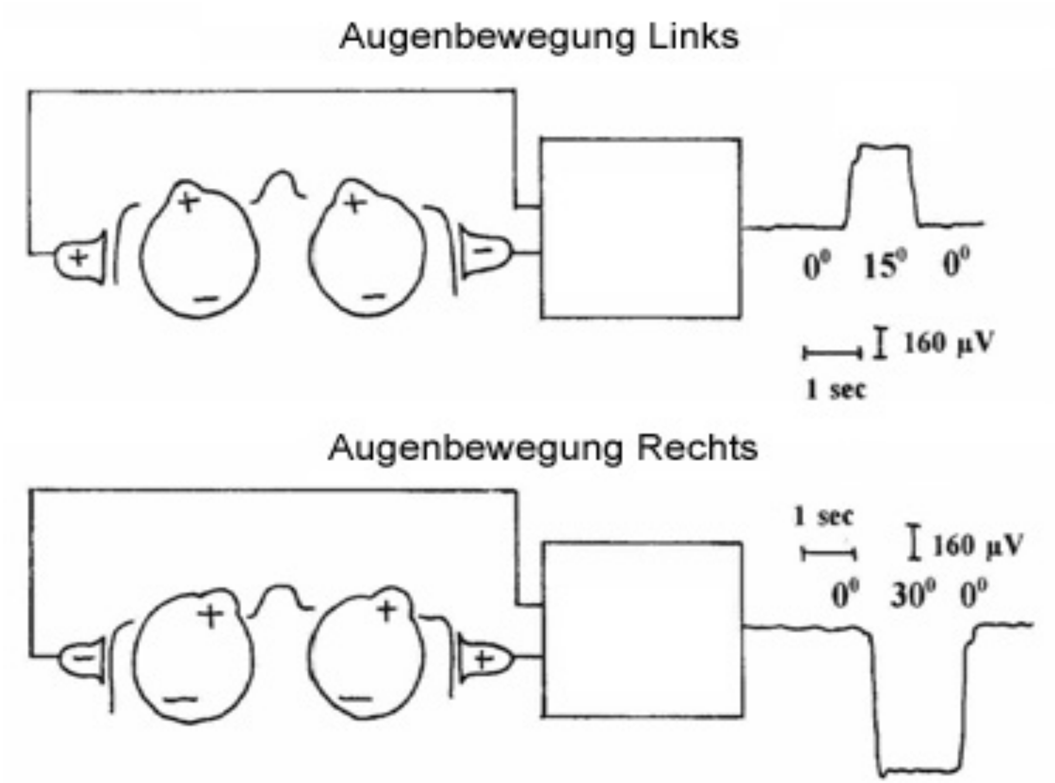



**Recording locations for facial EMG**

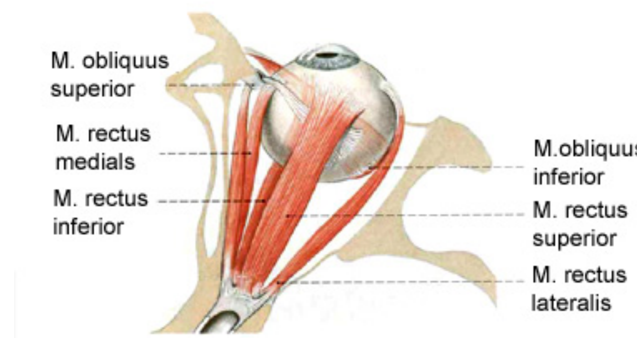
# EMG Applications

- Rehabilitation
- Functional analysis
- Active prosthetics
- Biomechanics, sports medicine

# Electrooculogram (Eye Movement)




**Electrooculogram (EOG)**

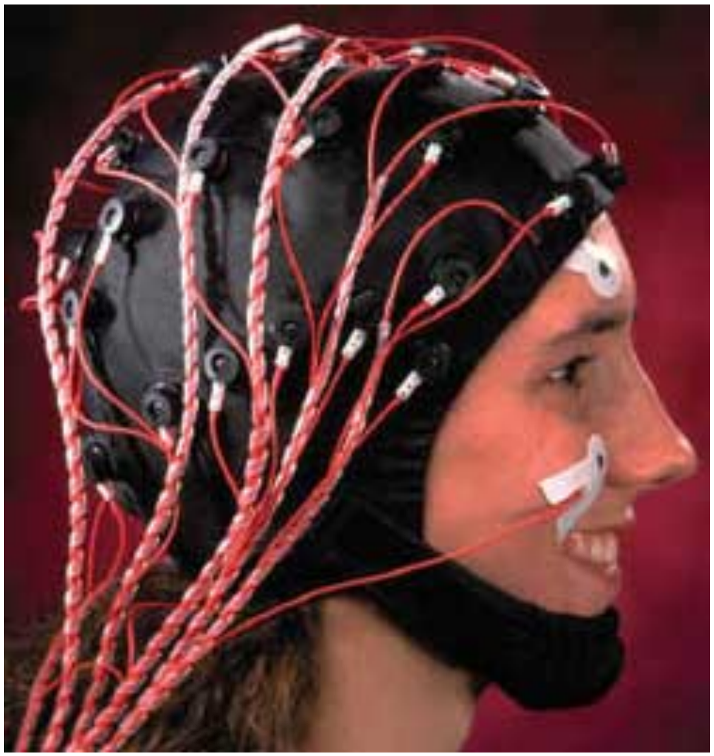



**Eye Dipole**

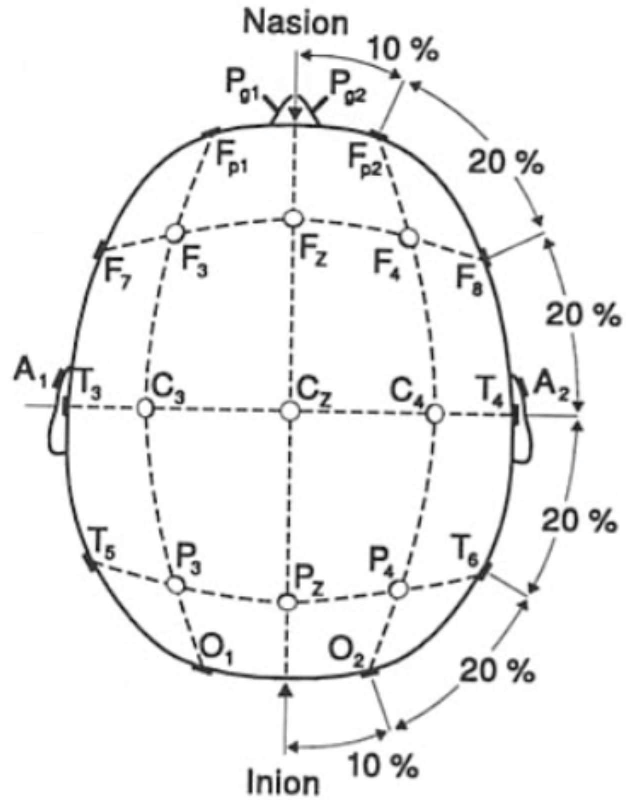
# EOG Applications

- Diagnostics
- Functional analysis
- Human-computer interfaces

# Electroencephalogram (Brain Activity)

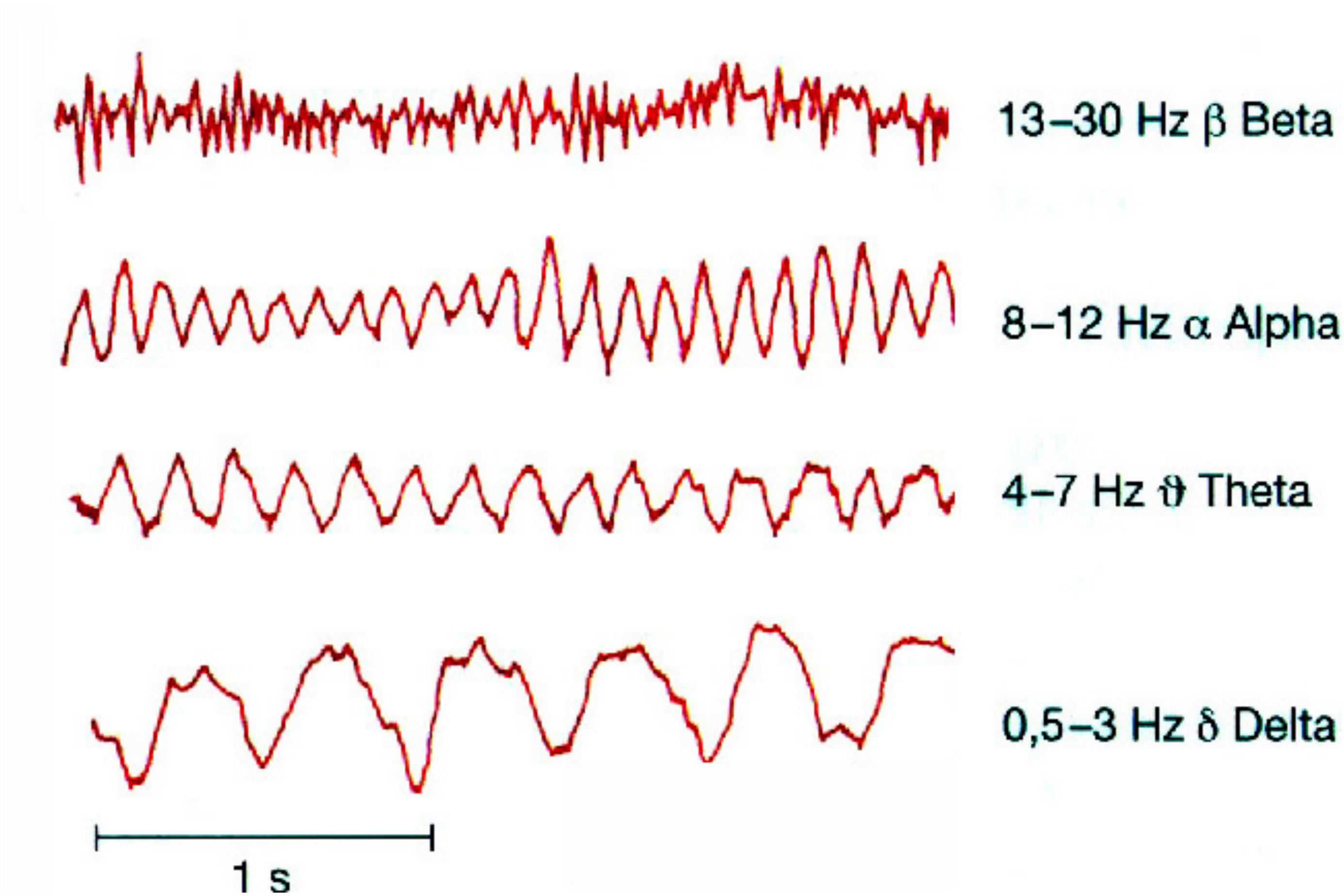


EEG electrode cap




Locations of 10/20 system

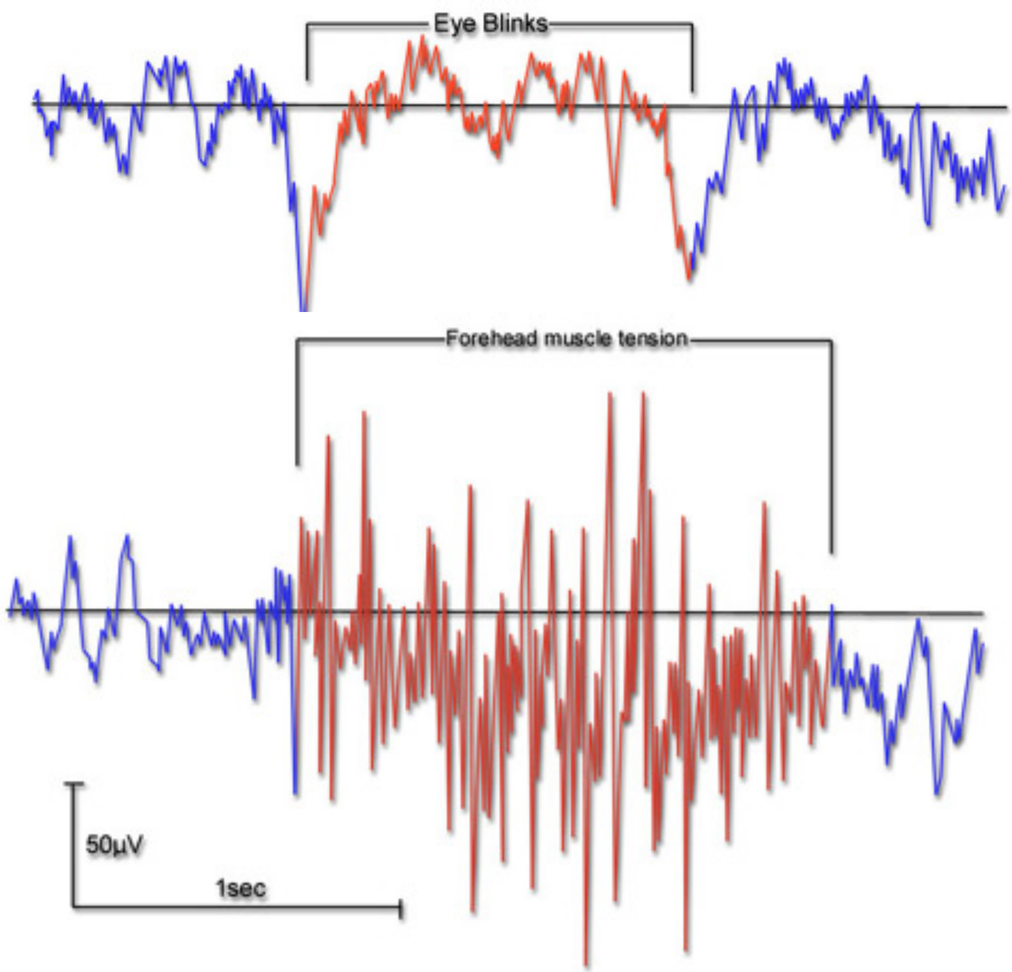
# Electroencephalogram (Brain Activity)



# Electroencephalogram (Brain Activity)

- Delta (up to 4Hz)
  - Front in adults, back in children
  - Sleep, babies, during some continuous attention tasks
  - (subcortical lesions, diffuse lesions, …)
- Theta (4-8Hz)
  - Locations not related to task at hand
  - Young children, drowsiness or arousal, idling
  - (focal subcortical lesions, deep midline disorders, …)
- Alpha (8-13Hz)
  - Posterior regions, both sides
  - Relaxed, reflecting, closing eyes, inhibition control
  - (coma)
- Beta (13-30Hz)
  - Both sides, symmetrical distribution
  - Alert/working; active, busy or anxious thinking, active concentration
  - (benzodiazepines)

# Electroencephalogram (Brain Activity)

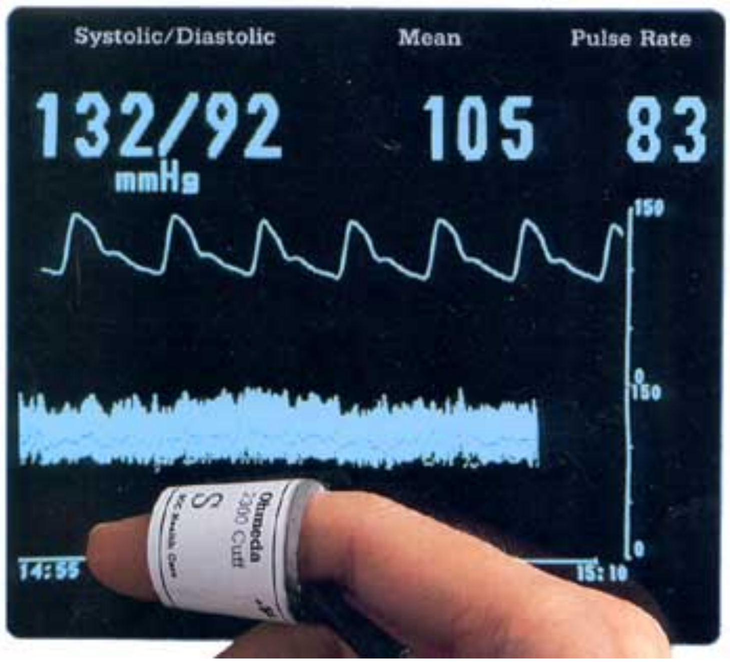


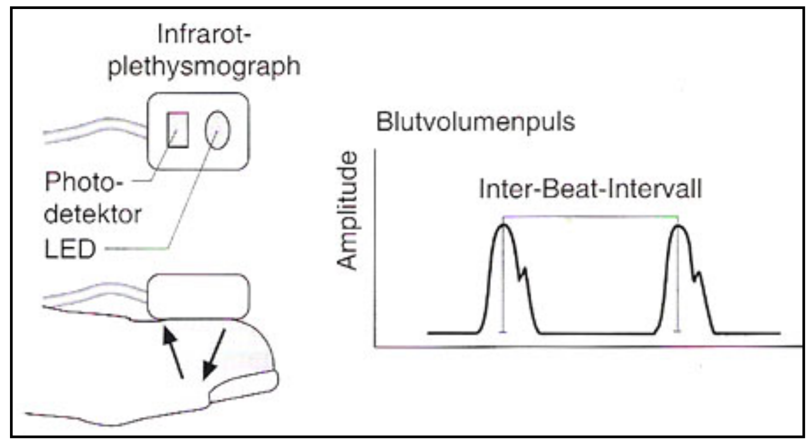

EEG artifacts: Eye blinks, muscle tension

# EEG Applications

- Diagnostics (epilepsy, oncology, ..)
- Cognitive sciences
- Sleep analysis
- Human computer interfaces (BCIs)
- Pharmacology
- Intensive care, monitoring

# Other Biosignals




Blood volume

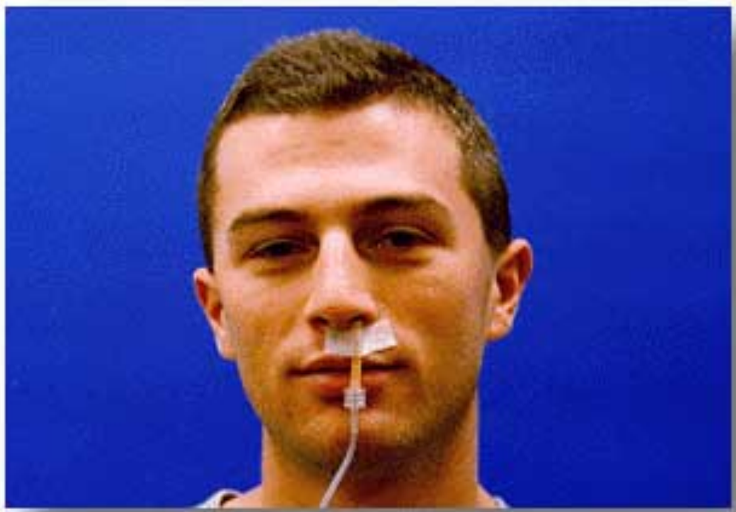
Infrared plethysmography

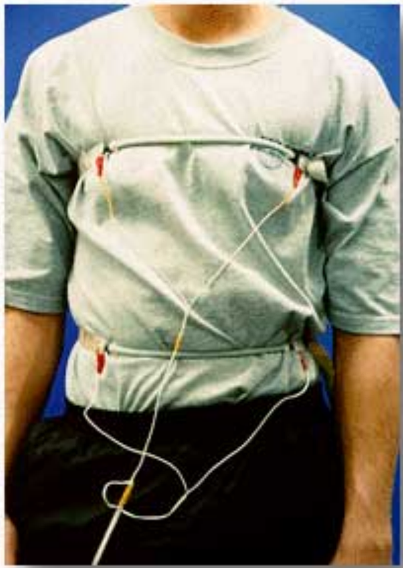
# Other Biosignals

- Pulse oximeter
- Non-invasive technology used to measure the **heart rate (HR)** and **blood oxygen saturation ($SpO_2$)**
- Project infrared and near-infrared light through blood vessels near the skin
- Detect the amount of light absorbed by hemoglobin in the blood at two different wavelengths to help determine level of oxygen
- Blood vessels contract and expand with the patient's pulse which affects the pattern of light absorbed over time
- Computation of HR and $SpO_2$ from the light transmission waveforms can be performed using standard DSP algorithms

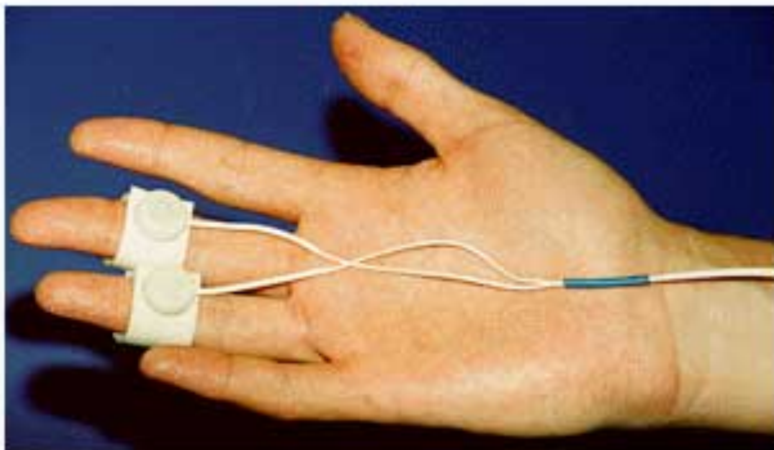
# Other Biosignals

Breathing sensors (thermal/optical/mechanoresistive)





# Other Biosignals



**Galvanic skin response (GSR)**
**Electrodermal activity (EDA)**
**Skin conductance level (SCL)**

**Peripheral body temperature**

# Biomedical Measurements

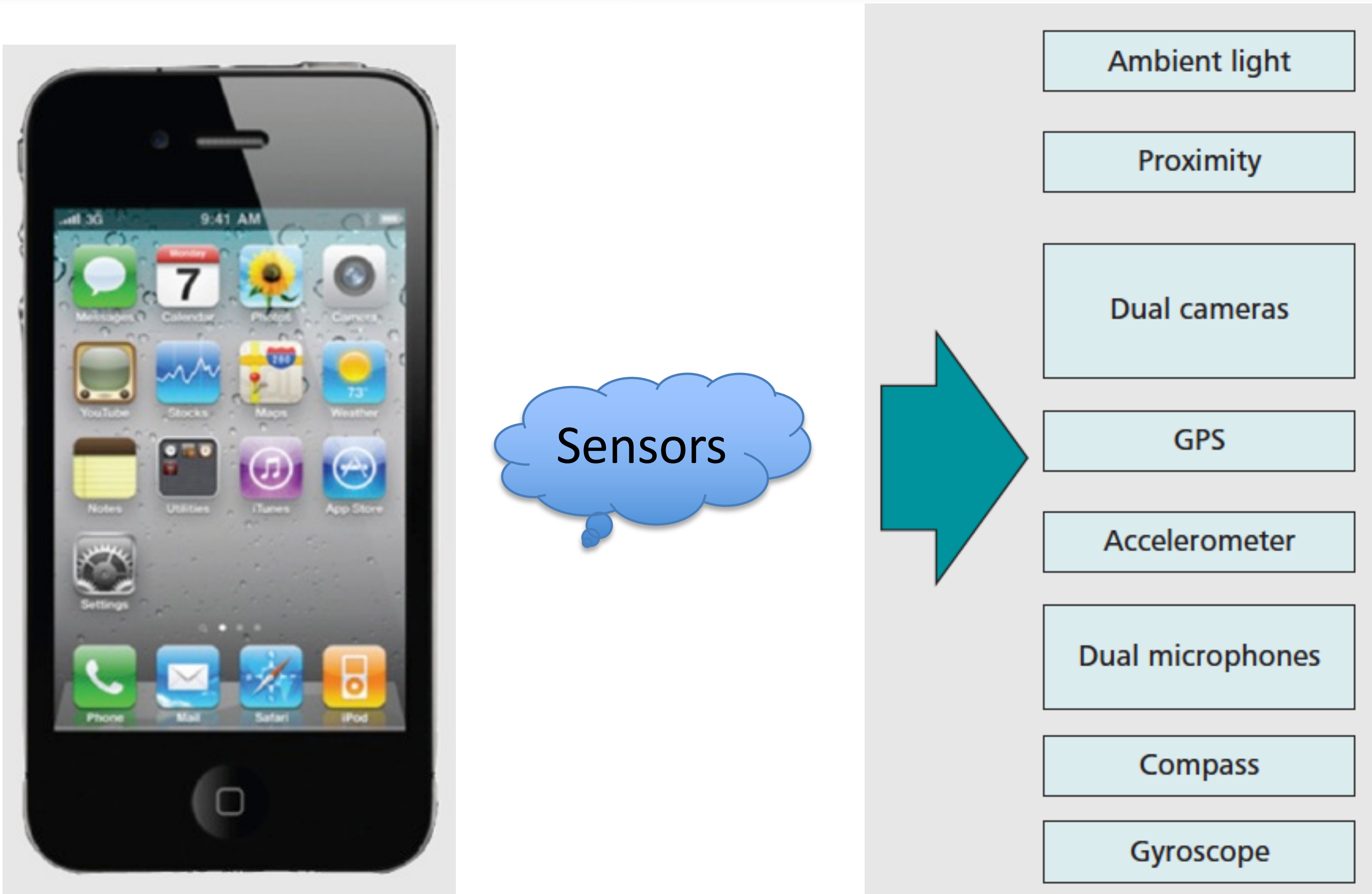
| Biomedical measurements | Voltage range (V) | Number of users = $K$ (sensors) | Bandwidth (Hz) | Sample rate (samples/s) = (Hz) | Resolution [b/sample] | Information rate [b/s] |
|---|---|---|---|---|---|---|
| ECG | 0.5–4 m | 5–9 | 0.01–250 | 1250 | 12 | 15,000 |
| Heart sound | Extremely small | 2–4 | 5–2000 | 10,000 | 12 | 120,000 |
| Heart rate | 0.5–4 m | 2 | 0.4–5 | 25 | 24 | 600 |
| EEG | 2–200 μ | 20 | 0.5–70 | 350 | 12 | 4200 |
| EMG | 0.1–5 m | 2+ | 0–10,000 | 50,000 | 12 | 600,000 |
| Respiratory rate | Small | 1 | 0.1–10 | 50 | 16 | 800 |
| Temperature of body | 0–100 m | 1+ | 0–1 | 5 | 16 | 80 |

Bandwidth = $f_{max} - f_{min}$
Sample rate = 5_$f_{max}$
Information rate = $R_b$ = Resolution_Sample rate

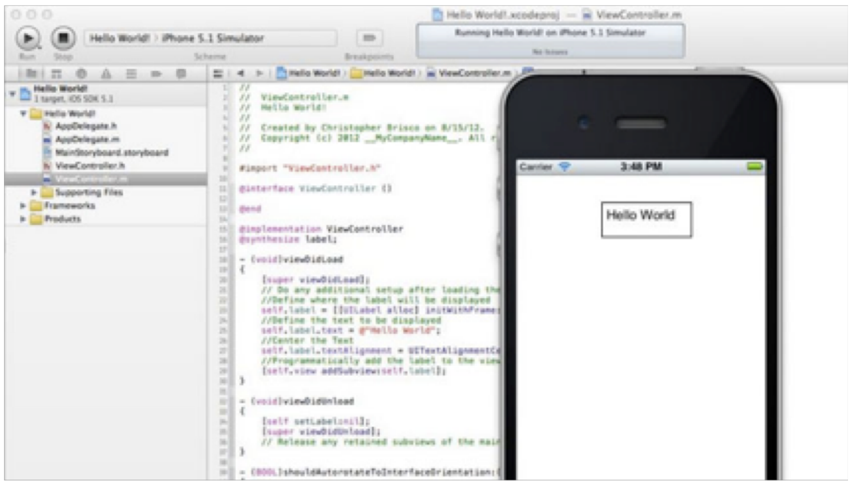
S. Arnon, et al., "A Comparative Study of Wireless Communication Network Configurations for Medical Applications," IEEE Wireless Communications, pp. 56-61, February 2003

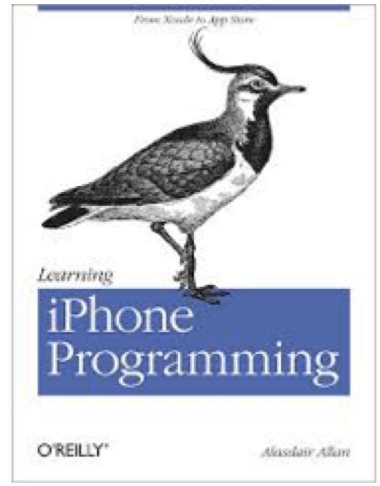
# From Smart Devices to Crowdsensing

# Technical Enabler 1: Powerful Embedded Sensors in Smartphones



# Technical Enabler 2: Open and Programmable



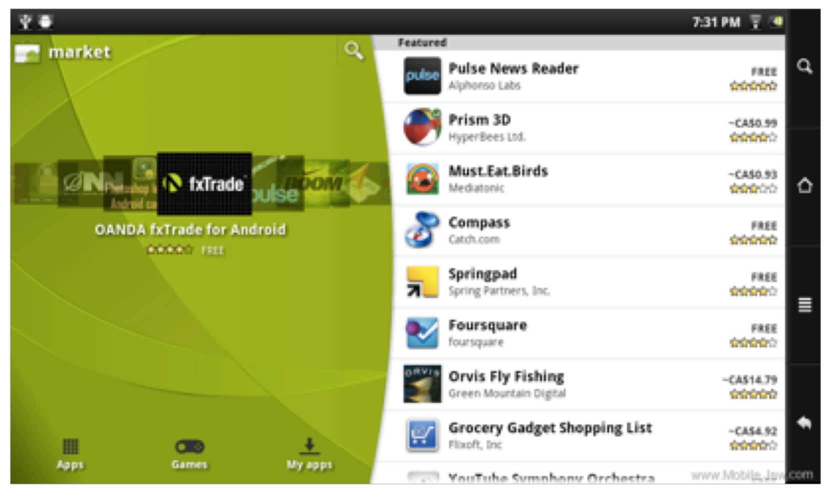





# Technical Enabler 3: App Store

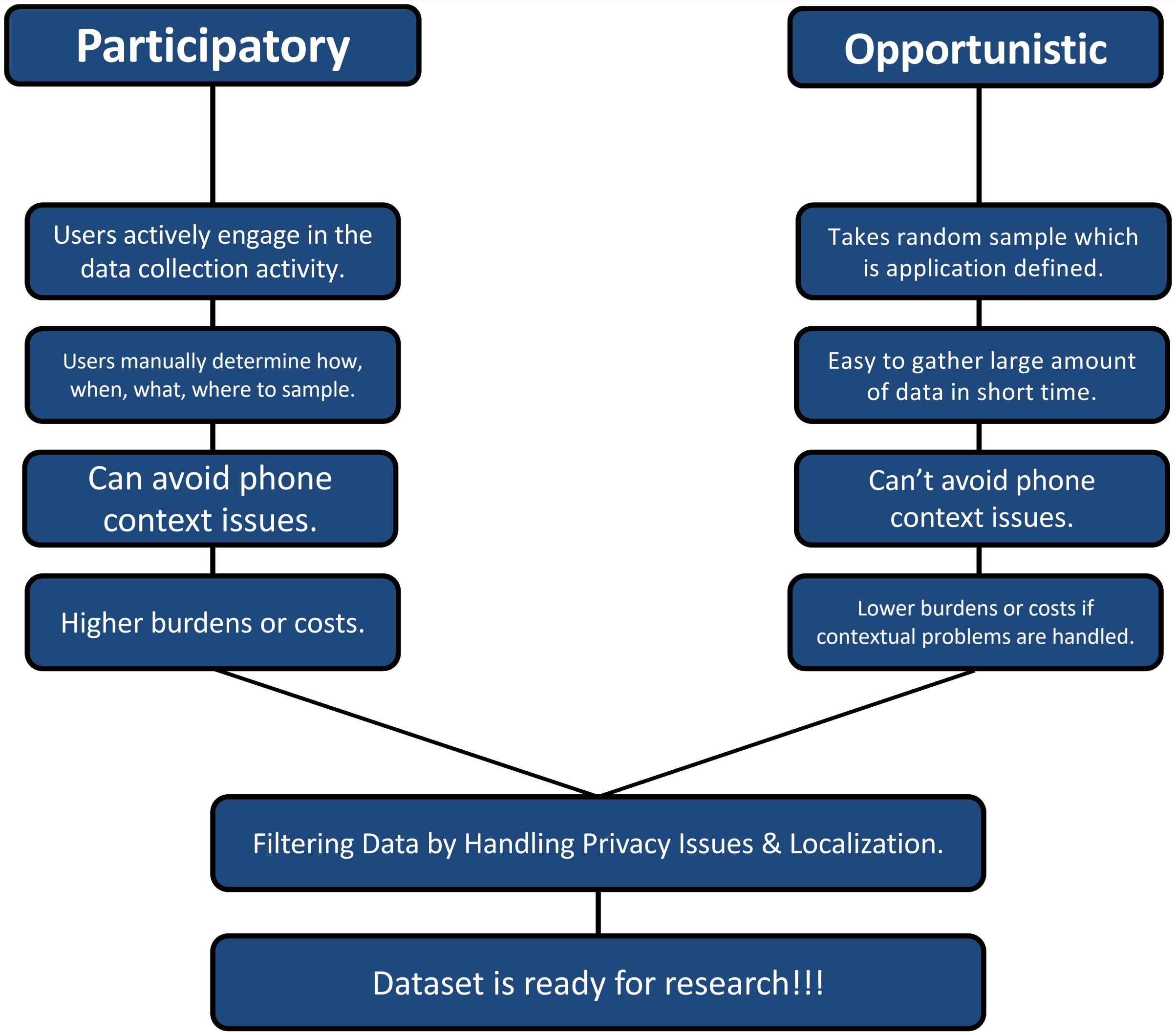
Apple Store

ANDROID APP ON Google play

# Technical Enabler 4: Mobile Computing Cloud

# MCS Paradigm



# Sensing Paradigms

- Participatory Sensing
  - Users actively engage in the “sensing process”
  - Human intelligence can be leveraged for complex tasks
  - More costs or incentives are needed to keep humans involved
  - Privacy issues
- Opportunistic Sensing
  - Fully automated and no user involvement
  - Less burden and costs on the user
  - Detect the phone context
  - Humans are underutilized
  - Privacy and energy issues

# MCS: Unique Characteristics

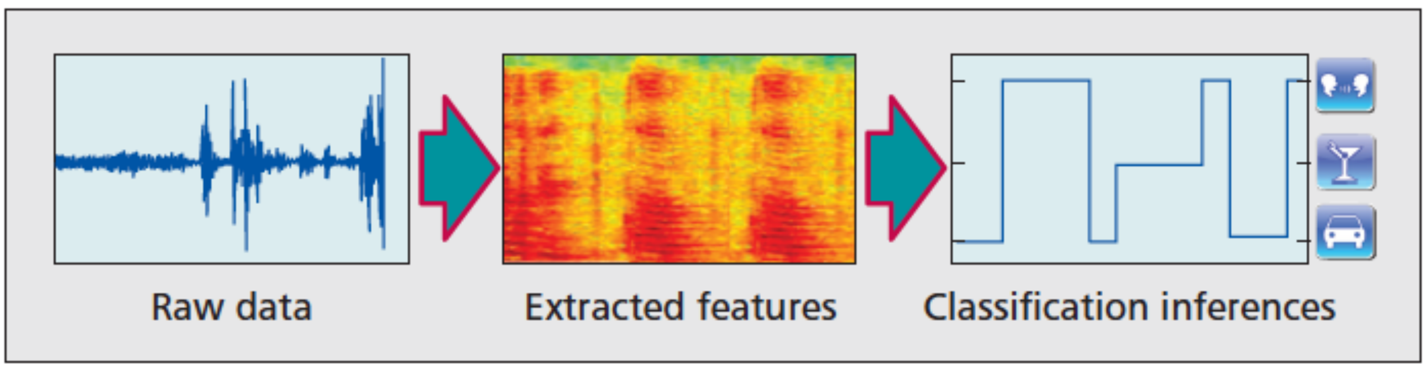
- Multi-modal sensing capabilities
- Deployed in the field (remote sensing/management)
- Device diversity; resource limitations
- Dynamic conditions
- Privacy concerns
- Energy consumption
- Amounts of data
- Effort/cost vs. incentives; compliance
- False data
- Labeling/annotations
- Localized/aggregate analytics

# Sensing

- Programmability:
  - Lack of low level sensor control
  - Different vendors offer different APIs
- Continuous sensing:
  - Need to support multitasking and background processing
  - Limited battery power on mobile phones
- Phone context:
  - Phones are used on the go and in different contexts (e.g., in vs. out of pocket)
  - Anticipating all possible different phone usage scenarios is very difficult

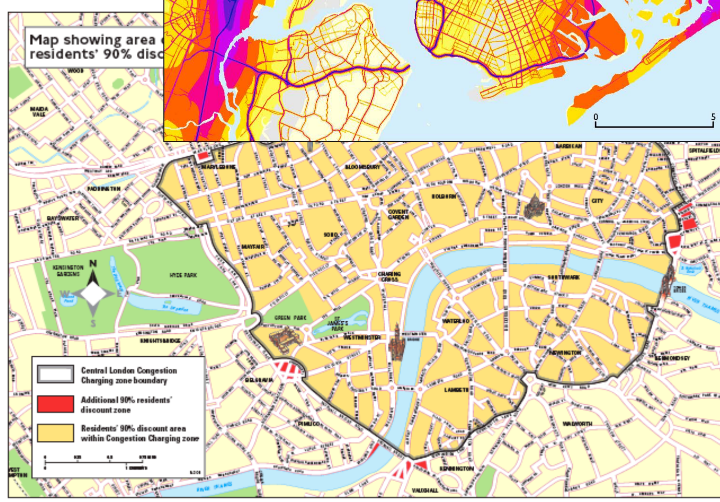
# Learning

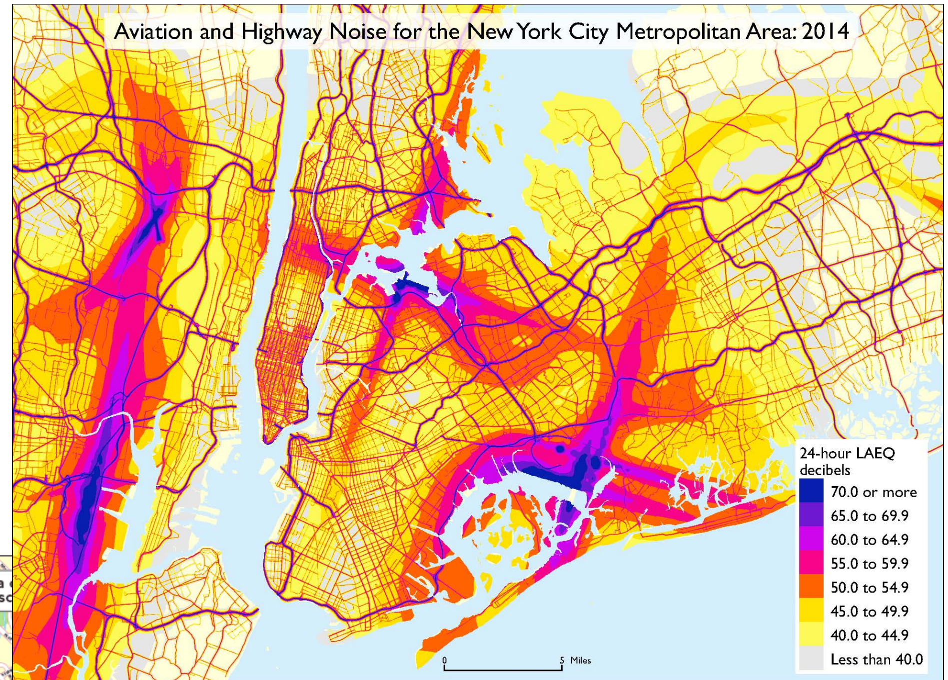
- Human behavior and context modeling
  - Supervised learning (small scale)
  - Semi-supervised/Unsupervised (medium to large scale)
  - Learn activities (e.g., brushing teeth, driving, running)
  - Learn places (e.g., work, home, coffee shop )



# Urban Sensing Apps

- Noise mapping
- Emotion mapping
- Congestion charging



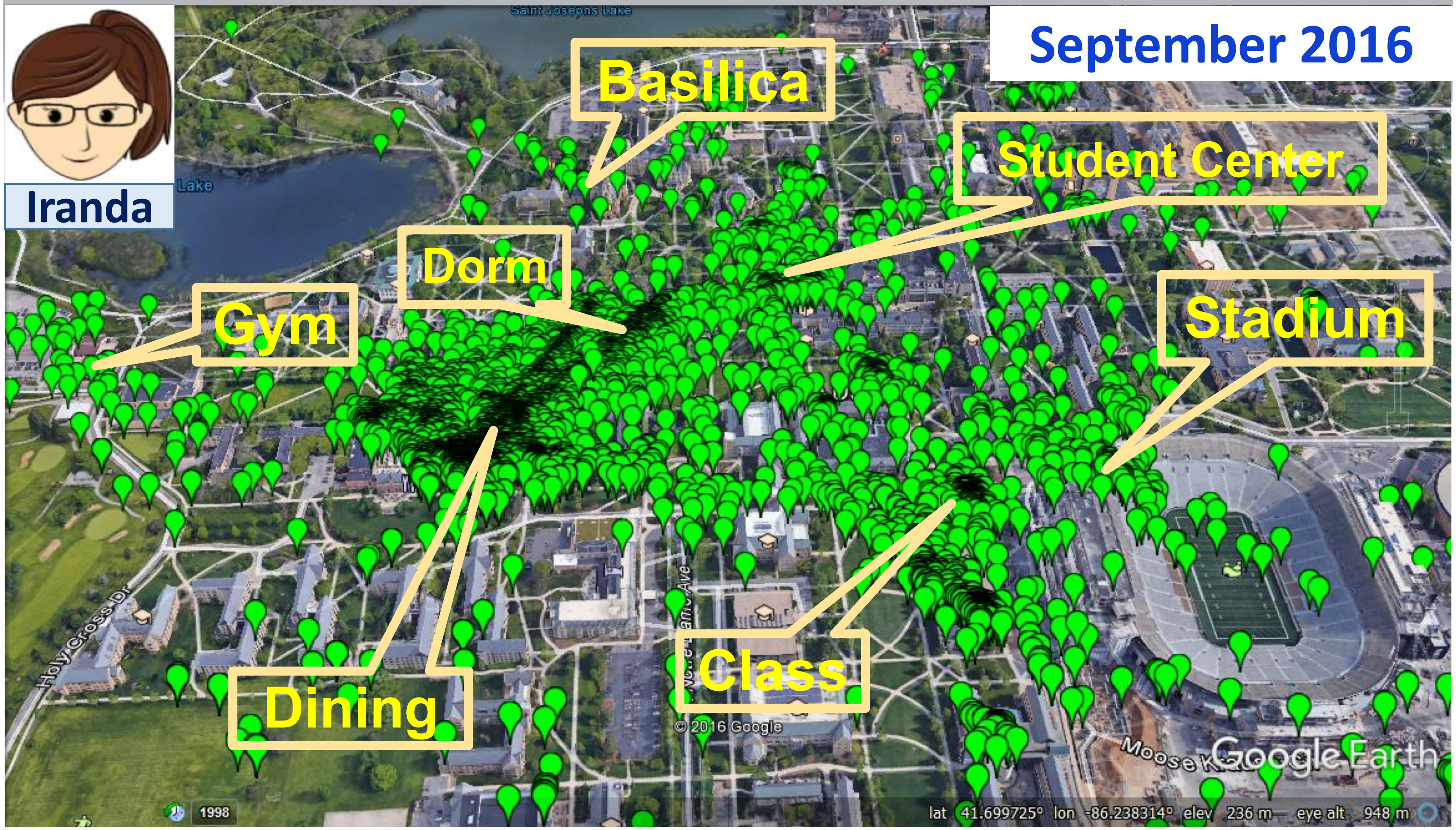


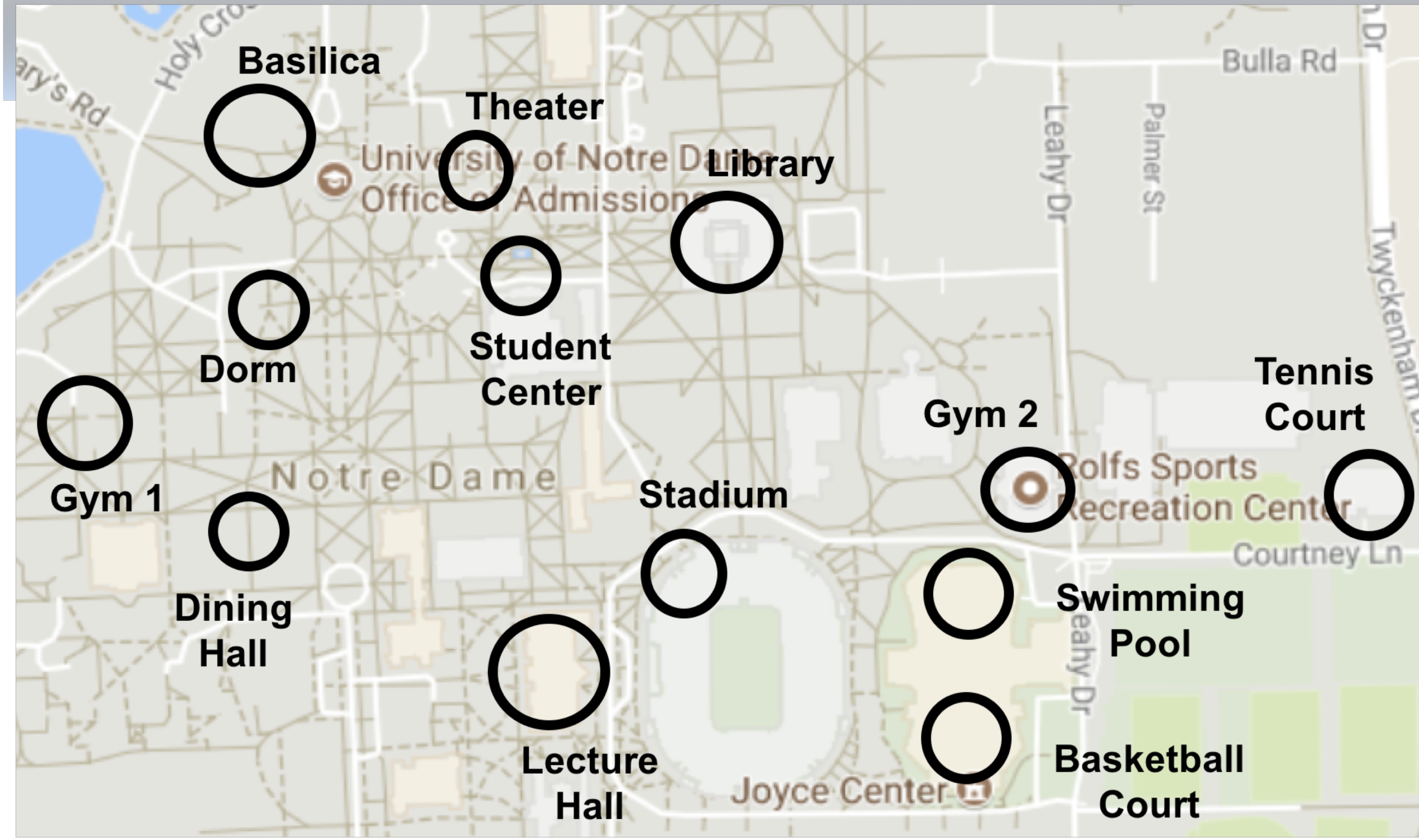
# NetHealth Study

- Smartphone Sensor Data

| Device | Data Type | Sampling Period (Min.) |
|---|---|---|
| iPhone | Location (Latitude, Longitude, Accuracy) | 2.75 |
| Fitbit | Step Counts, activity levels (sedentary, light, fair, high), Calorie burn, Heart rate | 1 |

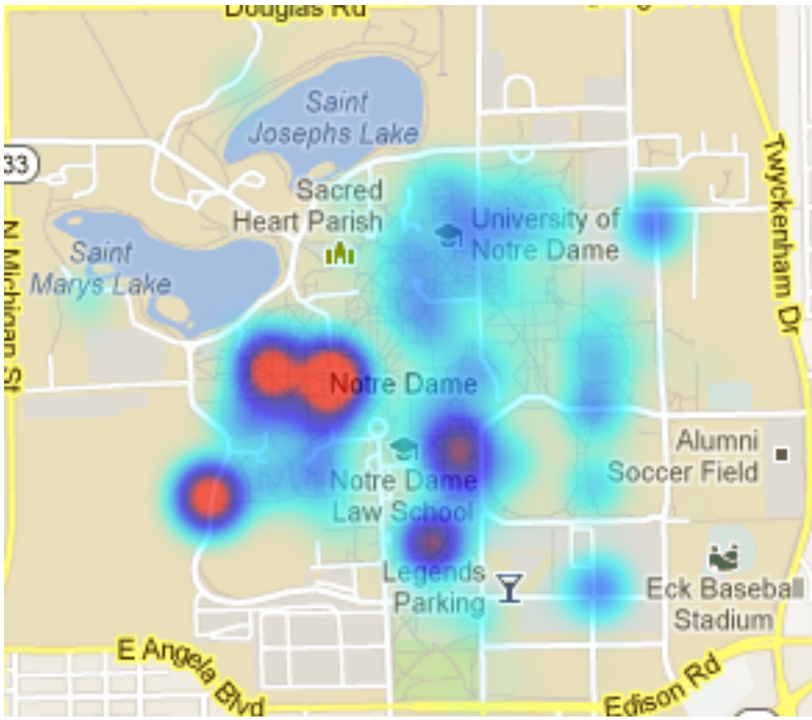
- Subjects
  - 467 iPhone users (on-campus freshmen)
  - Avg. age ~17y 11m (SD = 11m)
  - Fall 2015 – Fall 2016


Iranda
September 2016
Basilica
Student Center
Dorm
Gym
Stadium
Class
Dining
© 2016 Google
Google Earth
1998
lat 41.699725° lon -86.238314° elev 236 m eye alt 948 m

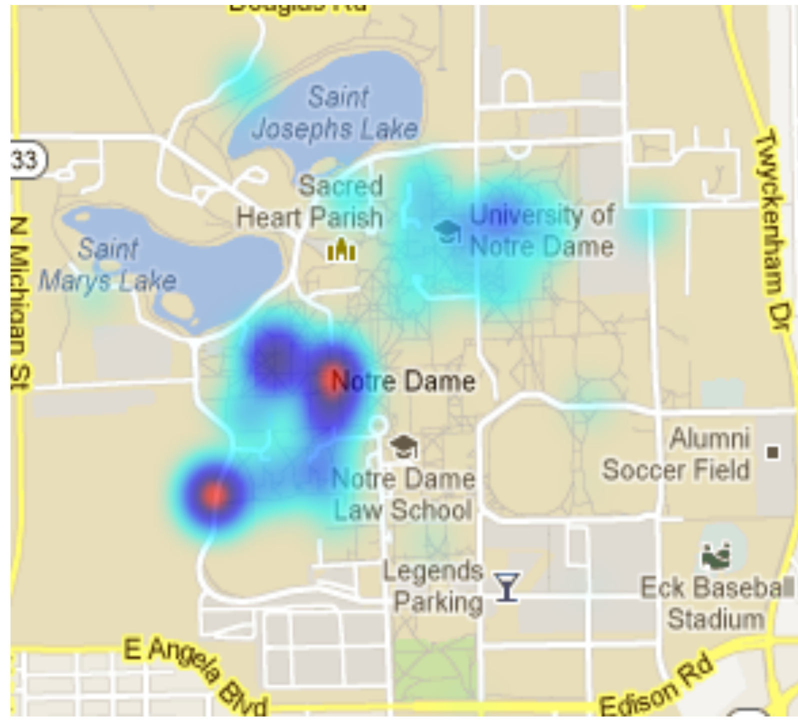


Basilica
Theater
University of Notre Dame
Office of Admissions
Library
Student Center
Dorm
Gym 1
Dining Hall
Notre Dame
Stadium
Lecture Hall
Joyce Center
Gym 2
Rolfs Sports Recreation Center
Tennis Court
Swimming Pool
Basketball Court
Bulla Rd
Leahy Dr
Palmer St
Twyckenham Dr
Courtney Ln
Holy Cross

# Sensing Example: Location Hotspots




Subjects' locations during daytime hours




Subjects' locations during nighttime hours

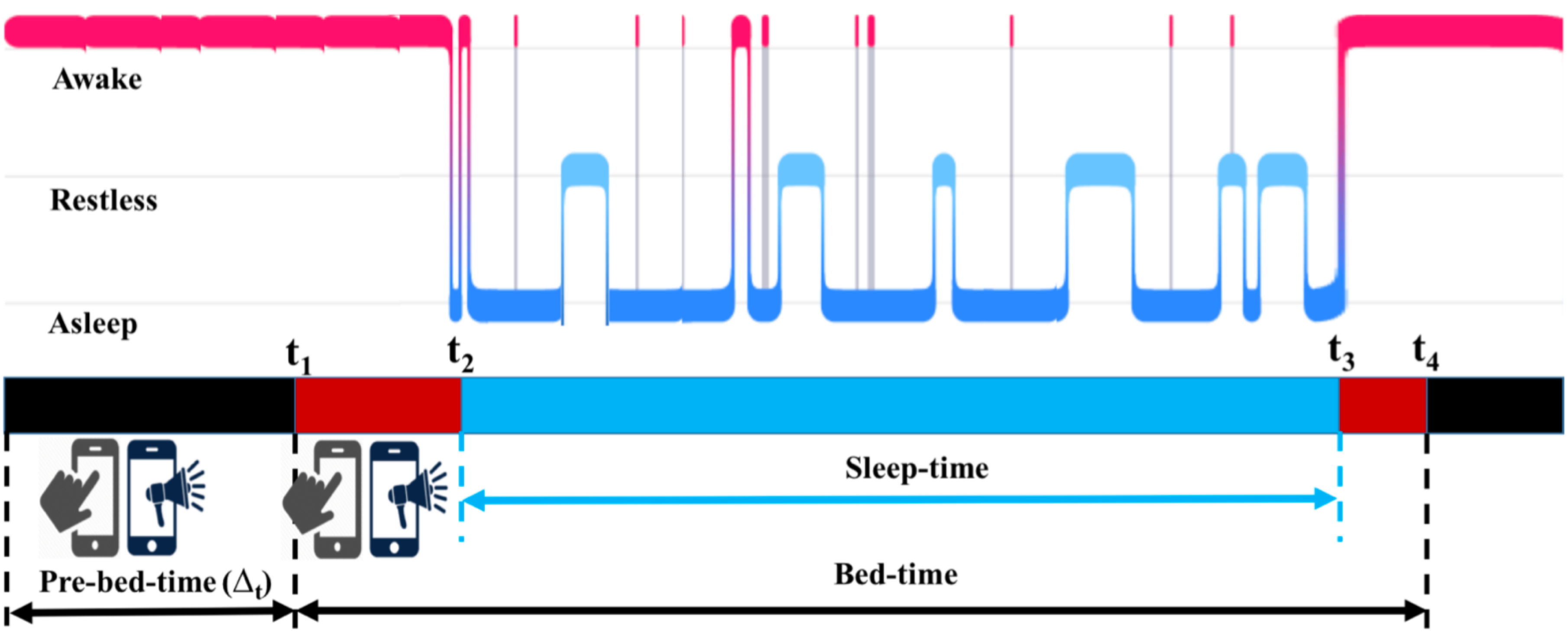
# Motivation

- Assess a user's **quality of life** through analysis of
  - Place visits and mobility patterns, social interactions, and levels of physical activity
- Researchers and healthcare providers can monitor **patient behavior** remotely
  - E.g., assess the effectiveness of stroke therapy
- Deliver place-specific mobile **health interventions**
  - E.g., encourage individuals to work out when near gyms or parks
- Deliver **customized surveys** to an individual's phone
  - E.g., social interaction surveys, or mood surveys

# Continuous Health Monitoring

- Opportunities of continuous monitoring:
  - Identify mobility patterns
    - Time spent indoors/outdoors; type of transportation; locations visited
  - Recognize social interactions
    - Electronic communications (email, phone, SMS, chat)
    - In-person meetings (individual/group, type of meeting, venue)
  - Identify activities
    - Healthy/unhealthy habits, routine household activities, physical activities
  - Other health-related information and events
    - Sleep times/quality, stress, moods, falls and other injuries

# Continuous Health Monitoring

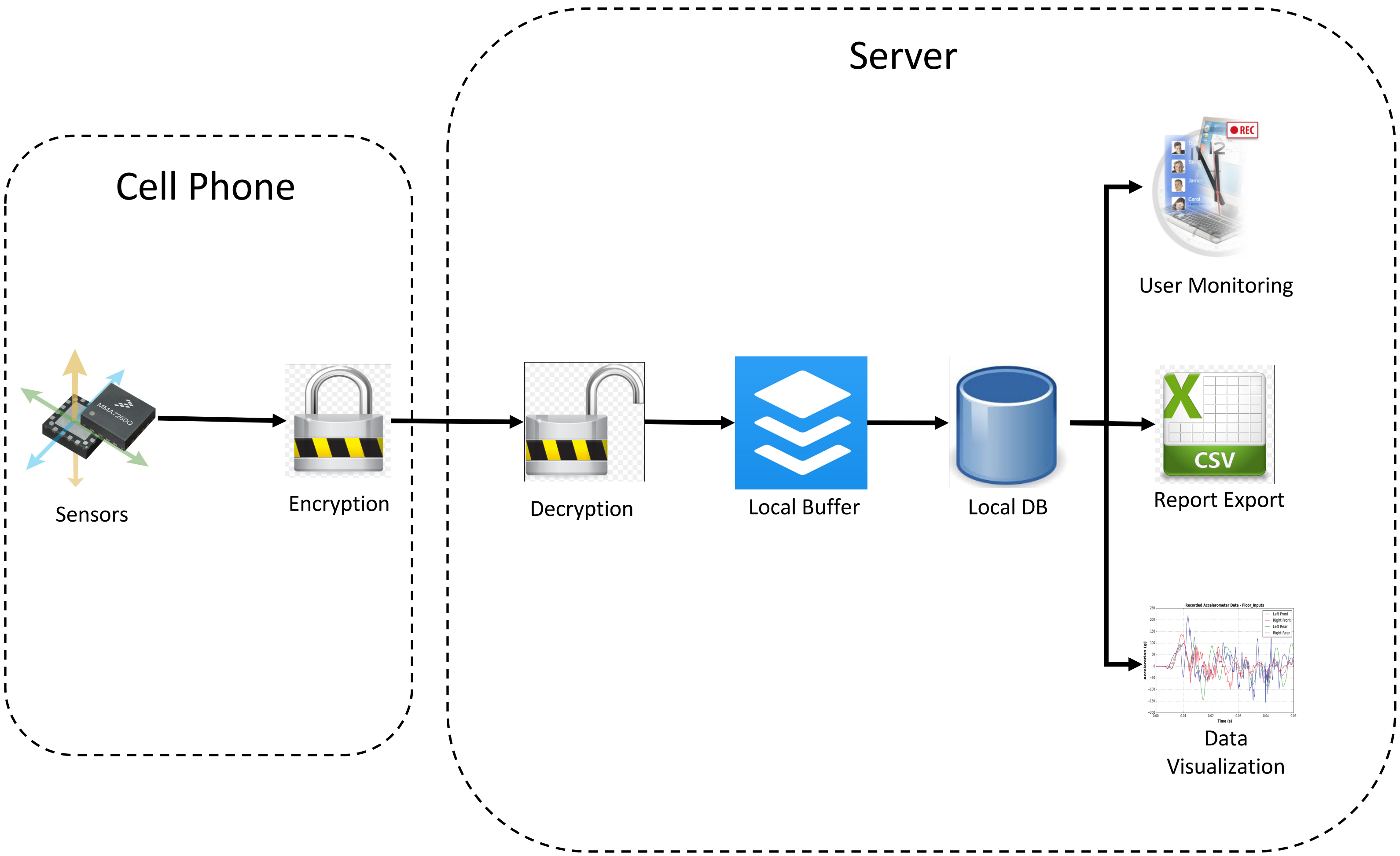


# The CIMON Monitoring Toolkit

- **C**onfigurable **I**ntegrated **MON**itoring Toolkit
- Powerful smartphone monitoring system for Android-based devices:
  - Monitor **sensor** activities (e.g., GPS, accelerometer, gyroscope, microphone, barometer, magnetometer, etc.)
  - Monitor **user** activities (e.g., communications, apps, music, browsing, etc.)
  - Monitor **system** activities (e.g., resource usage, network connections and traffic, etc.)
- Configurable to meet sensing needs of specific (health) situation

# Screenshots of Configuration Screens

# CIMON Framework



# Smartphone Sensors

| Sensor Name | Type | Status | Tested | Period |
|---|---|---|---|---|
| Memory | System | Integrated | Yes | 1s |
| CPU load | System | Integrated | Yes | 1s |
| CPU utilization | System | Integrated | Yes | 1s |
| Battery | System | Integrated | Yes | 1s |
| Network traffic | System | Integrated | Yes | 1s |
| Connectivity status | System | Integrated | Yes | 1s |
| Instruction count | System | Integrated | Yes | 1s |
| SDCard accesses | System | Integrated | Yes | 1s |
| Geo-location | Sensors | Integrated | Yes | 10s |
| Accelerometer | Sensors | Integrated | Yes | 100ms |
| Magnetometer | Sensors | Integrated | Yes | 100ms |
| Gyroscope | Sensors | Integrated | Yes | 100ms |
| Linear Acceleration | Sensors | Integrated | Yes | 100ms |
| Orientation | Sensors | Integrated | No | 100ms |
| Proximity sensor | Sensors | Integrated | No | 1s |
| Pressure | Sensors | Integrated | No | 1s |
| Light sensor | Sensors | Integrated | No | 1s |
| Humidity | Sensors | Not Integrated | Failed | 1s |
| Temperature | Sensors | Not Integrated | Failed | 1s |
| Screen state | User Activity | Integrated | No | 3min |

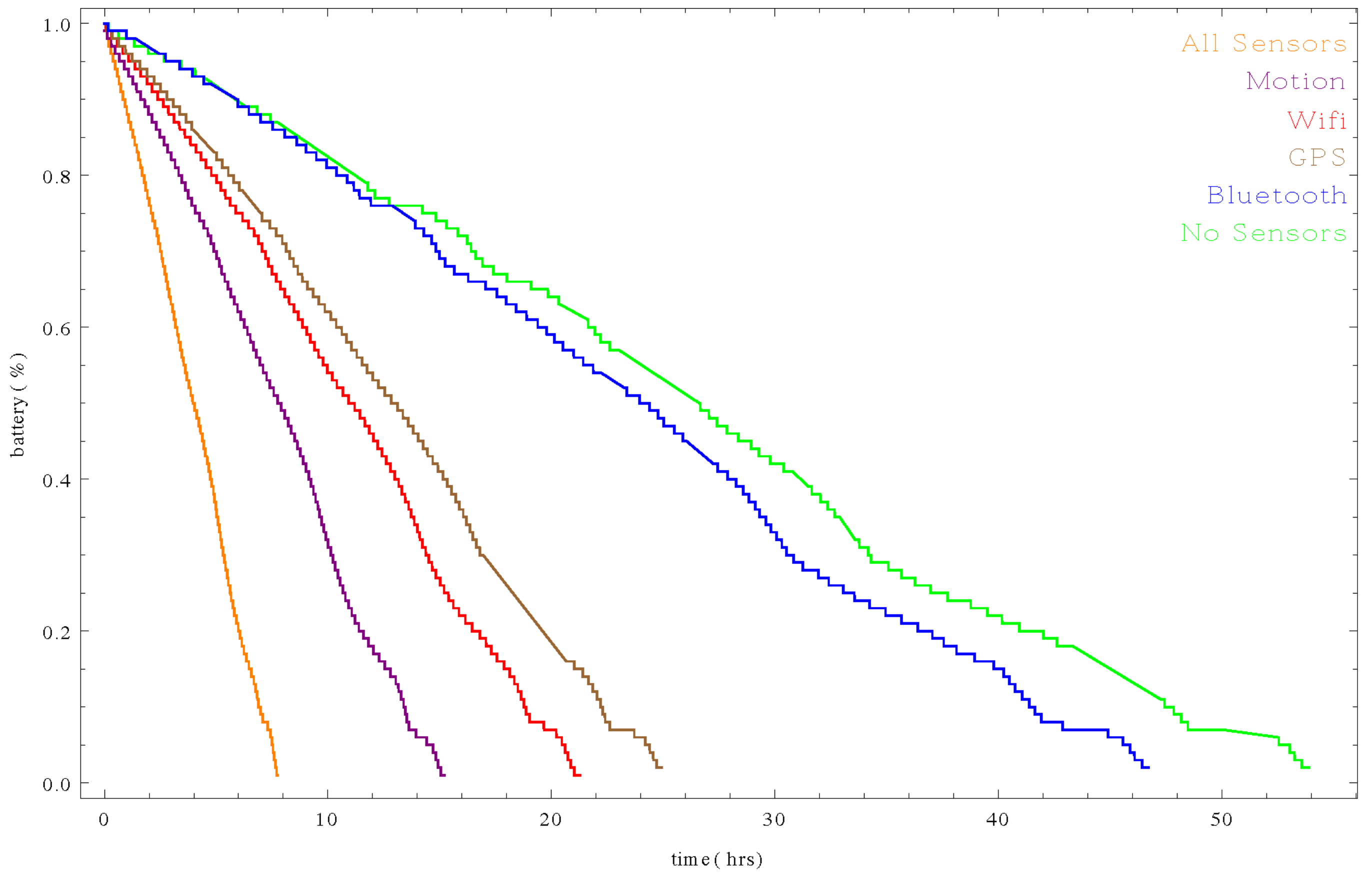
# Smartphone Sensors

| Sensor Name | Type | Status | Tested | Period |
|---|---|---|---|---|
| Phone Activity | User Activity | Integrated | No | 1s |
| SMS activity | User Activity | Integrated | No | 1s |
| MMS activity | User Activity | Integrated | No | 1s |
| Bluetooth activity | User Activity | Integrated | Yes | 3min |
| Wifi activity | User Activity | Integrated | Yes | 3min |
| Application | N/A | Implemented, Not Integrated | No | 1min |
| Audio | N/A | Implemented, Not Integrated | No | 10min |
| Browsing History | N/A | Implemented, Not Integrated | No | 1min |
| Call State | N/A | Implemented, Not Integrated | No | 1min |
| Cell Location | N/A | Implemented, Not Integrated | No | 10s |
| Media Store Image | N/A | Implemented, Not Integrated | No | 5min |
| Media Store Video | N/A | Not Implemented | No | 5min |
| MMS Information | N/A | Not Implemented | No | 1s |
| Phone Call Information | N/A | Not Implemented | No | 1s |
| Phone Identity | N/A | Not Implemented | No | 10min |
| SMS Information | N/A | Implemented, Not Integrated | Yes | 1s |

# Examples of Sensing Capabilities

| Sensor Type | Sensing Examples |
| --- | --- |
| GPS & Triangulation | Locations, routes, indoor/outdoor time |
| Accelerometer | Mode of transportation, activities, step counters |
| Gyroscope | Type of activities, unusual events (falls) |
| Wi-Fi Proximity | Locations, routes |
| Bluetooth Proximity | Proximity to friends, family, coworkers, etc. |
| Magnetometer | Type of activities |
| NFC/RFID | Locations (supermarket, library, etc.) |
| Barometer | Locations (floor of building) |
| Applications | Preferences, moods, interests/hobbies |
| Phone, EMail, SMS | Communication patterns, moods |
| Media (Music, Pictures, …) | Preferences, interests, moods |

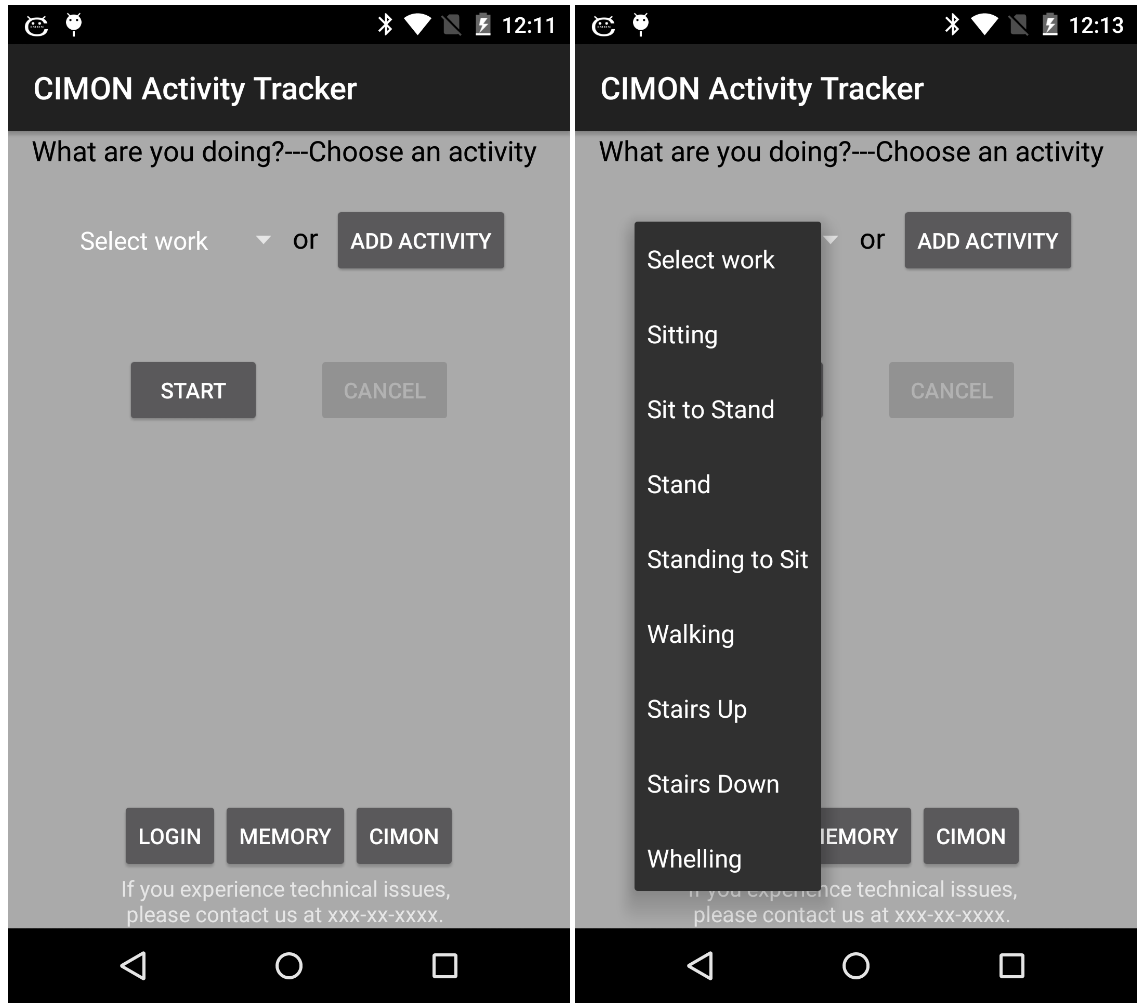
# Technical Challenge: Battery Life




Current research focus: *collect maximum amount of data at highest quality possible, while making sure that device will last 14-16 hours* (typical time between recharging)

# CIMON Sensing App: Labeling Interface

- Allows subjects to track common types of activities
- Used for development of activity detection algorithms
- In addition to pre-defined activities, subjects can add custom activities



# That's It For Today