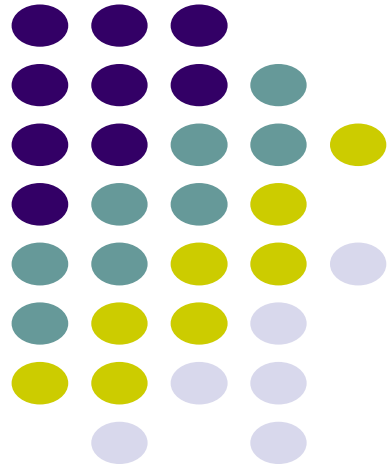
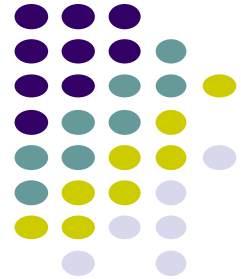
Mobile and Ubiquitous Computing on Smartphones

Chapter 9b: Wearables, Quantified Self & Physiological Sensing

Emmanuel Agu





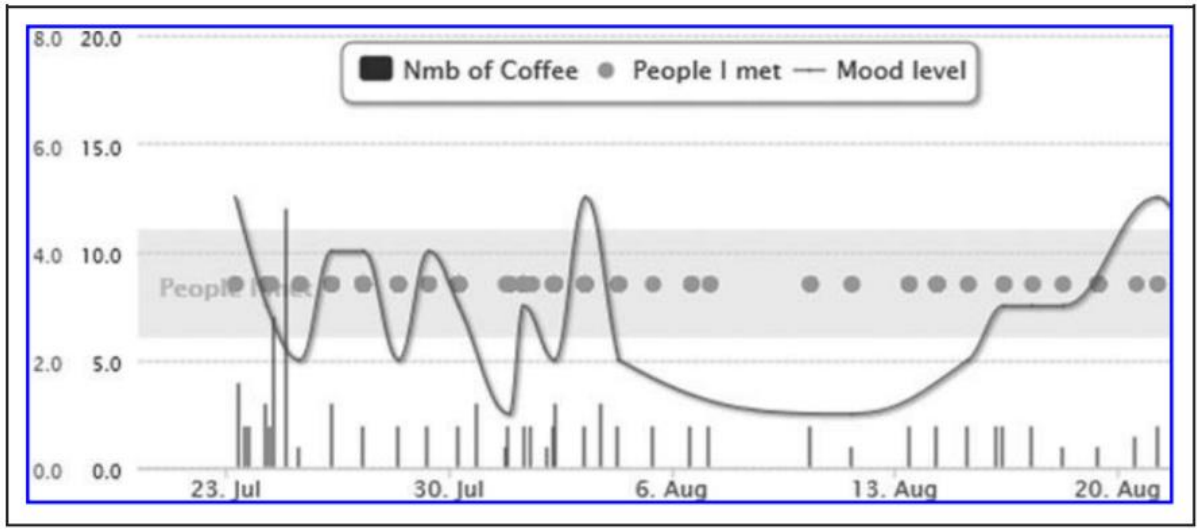
Tracking Health, Wellness & Quantified Self

Quantified Self (QS)

- QS: Community of People who want to measure, log, share metrics about various aspects of their lives. E.g.
- **Defn:** Obtaining self-knowledge through self-tracking
- Also known as personal informatics or lifelogging
  - Sleep, daily step count, food consumed, air quality, mood, etc.
- Measurements typically done using wearables/technology
  - Activity trackers, steps, sleep tracker, calories burned, etc
  - Now more available, cheaper

QS: Why Track?

- Why track? To figure out causes of certain behaviors, improve health/wellness
  - E.g. Why do I feel tired on Friday afternoons?
- Data to back up your choices/decisions
  - Did that cup of coffee make you more productive?
- Discover new patterns that are fixable
  - Whenever I go to my mother's house, I add at least 5 pounds on Monday morning
  - Am I happier when I meet more people or when I drink more coffee?



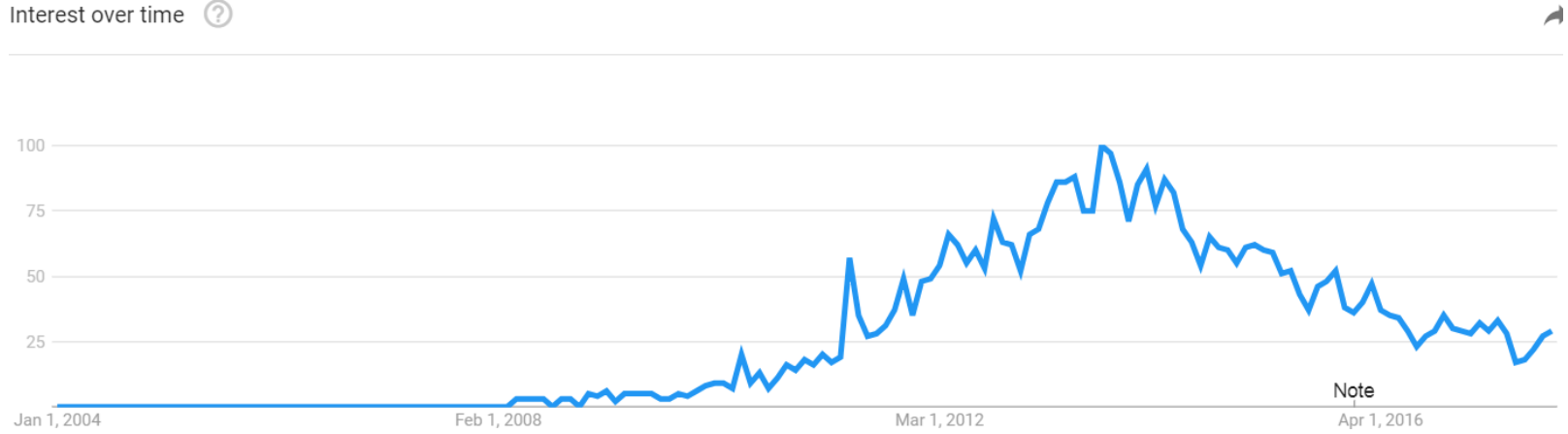
Courtesy
Melanie Swan

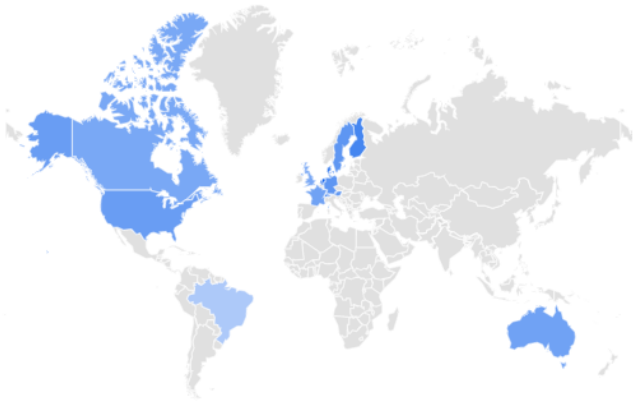
QS: How Popular?

- 69% of US adults already track at least 1 health metric (Pew Research)
- Local meetings, conferences, website
  - quantifiedself.com/

QS: Google Search Trends

- Google Trends displays how often a term is searched
- “Quantified Self” Searches peaked ~ 2014
- Now more popular in Europe (Netherlands = 1, USA = 8)





6	Germany	47
7	Austria	43
8	United States	41
9	Australia	37
10	France	37

QS Wellness Tracking Devices

Smart fork: eating/calories

Sleep manager

Bluetooth scale

Body worn activity trackers
(steps, activities, calories)

Quantified Self Big Picture

1. Track

Physiological

Eating

Exercise

Sleep

Weight

Blood pressure

Heart rate

Stress

+ Other Context

Location

Travel

Calendar

Email

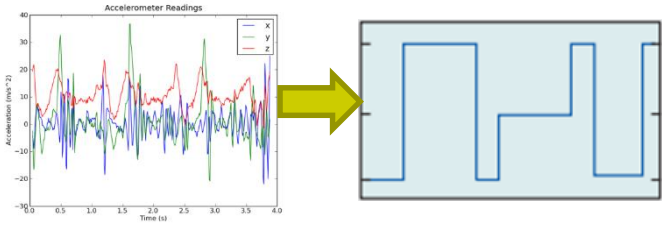
Lab results

2. Analyze

Analytics websites

Bodytrack.org

Machine Learning



Regression, classification, etc

3. Inform

Mobile App

Hire Coach/Dr

Mymee.com
(data-driven
coaching)

Bodytrack Project

http://www.cmucreatelab.org/projects/BodyTrack

ICAN-QU Visualization Dashboard

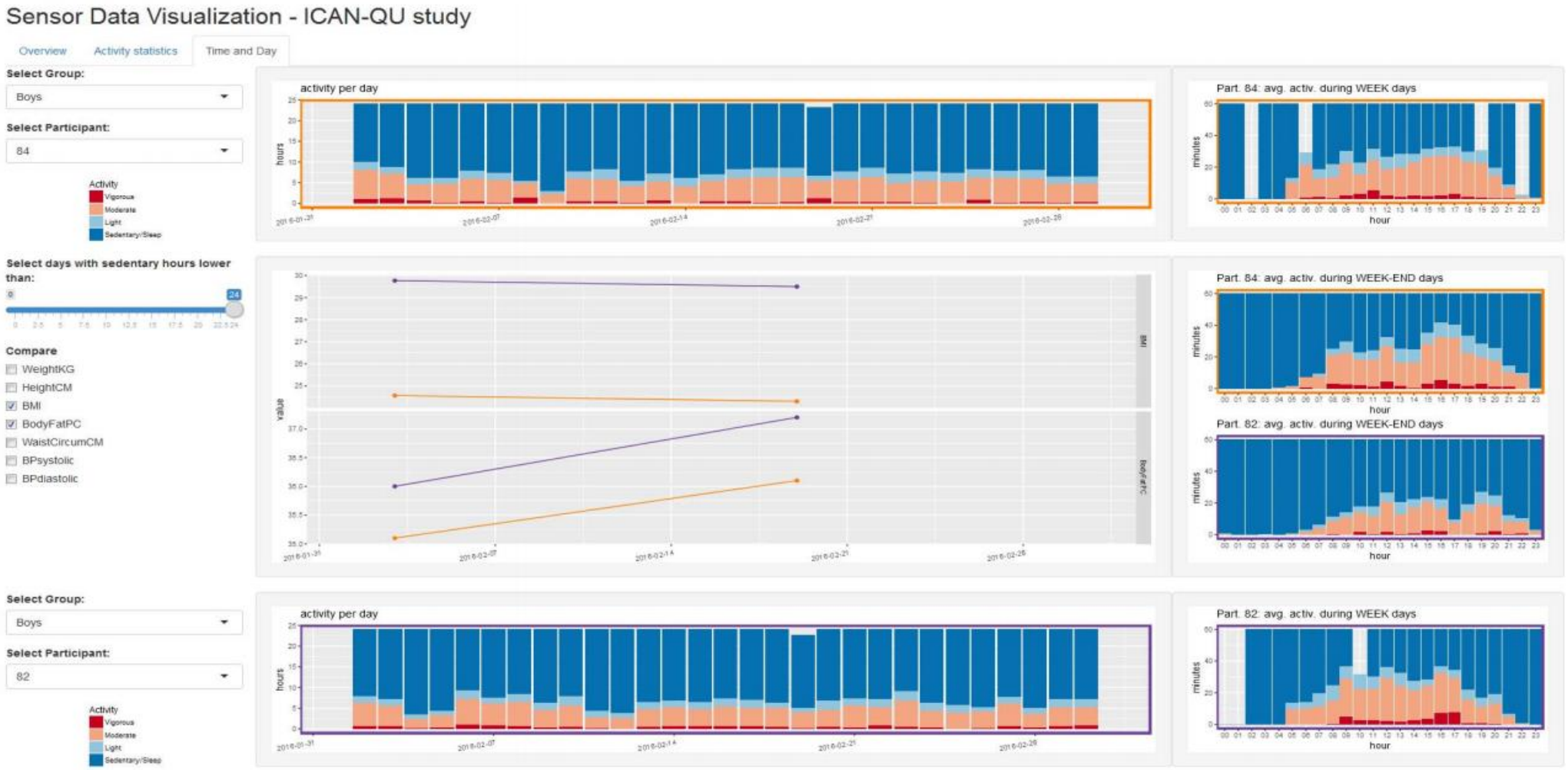
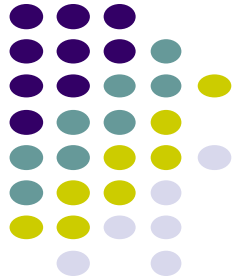


Figure 1. The visualization dashboard for actigraphy data and biometrics analysis.

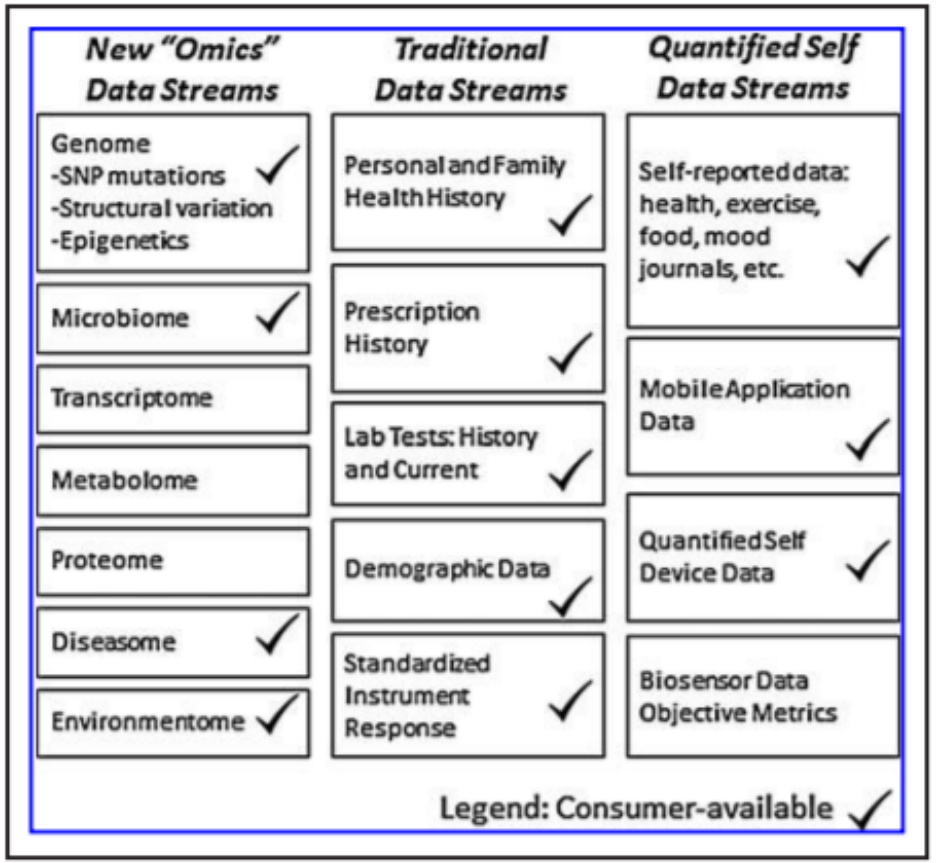
QS: Other Personal Data Sources

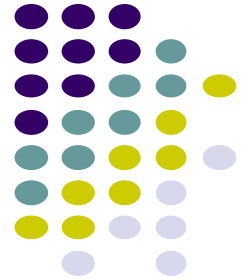


- Social media: Facebook, Twitter, Foursquare
- Search engines: Google, Bing
- E-commerce sites: Amazon, Airline sites
- Entertainment/game sites: Netflix
- Email: Outlook, gmail, etc

The Future: Precision Medicine

- In future combine data from quantified self + medical data + genomics data = Precision medicine





Smartwatches + Wearables

Main Types of Wearables

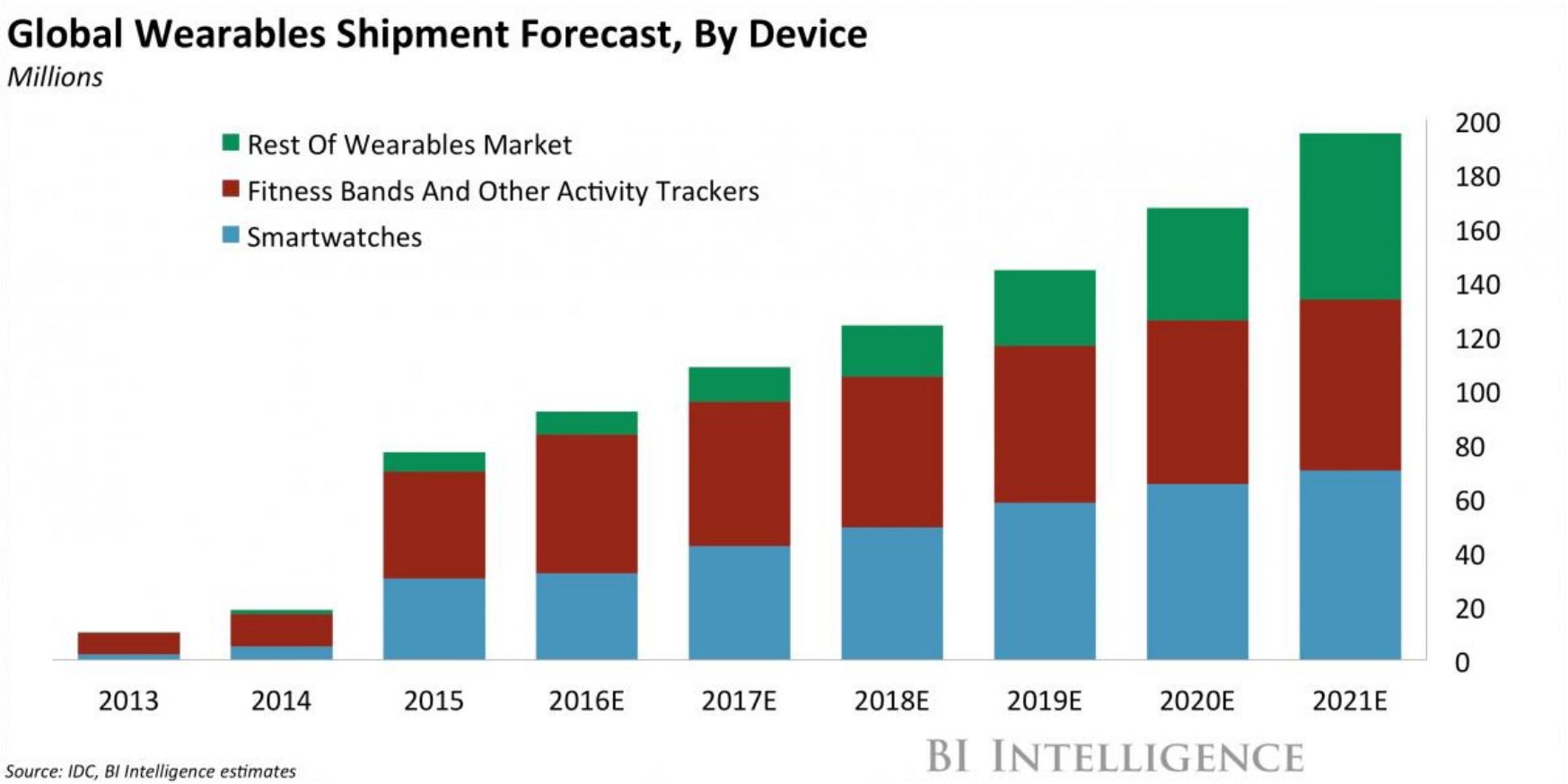
- **Activity/Fitness Trackers:**
  - physiological sensing (activity, step count, sleep duration and quality, heart rate, heart rate variability, blood pressure, etc)
  - E.g. Fitbit Charge 2
- **Smartwatches**
  - Some activity/fitness tracking
  - Also programmable: notifications, receive calls, interact/control smartphone
  - E.g. Apple watch, Samsung Gear

Fitbit Charge 2

Apple Watch 5

Samsung Gear 3 SmartWatch

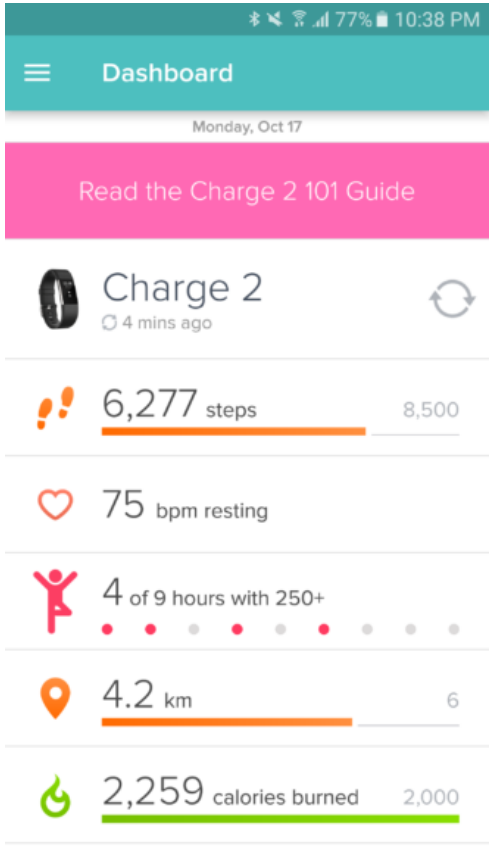
How Popular are Smartwatches/Wearables?



Wearables Example: Fitbit Charge 2

Fitbit Charge 2

synchronize

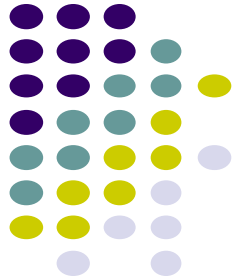


Smartphone companion app
(displays all variables tracked)

Example: Samsung Gear SmartWatch Uses

Image credits: Samsung

SmartPhone Vs Smartwatch



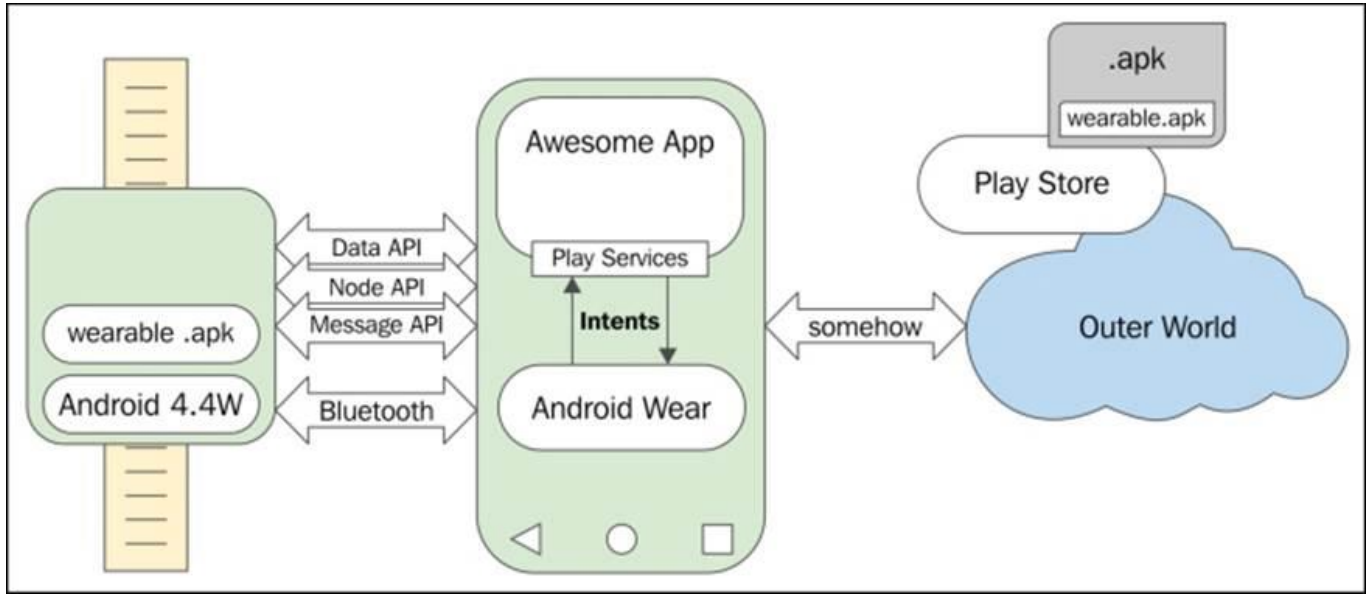
- Smartphone:
  - More processing power, memory, sensors
  - More programming APIs

- Smartphone Cons:
  - Sometimes not carried (Left on table, in pocket, bag, briefcase, gym locker)
    - Smartphone within arms reach, on person ~50% of the time (Anind Dey *et al*, Ubicomp 2011)
  - Why? Sometimes inconvenient, impossible (e.g when swimming)
  - Consequence: Missed activity (steps, activity, etc), incomplete activity picture

- Smartwatch:
  - Lower processing power, memory, sensors, but
  - Always carried/worn
  - Can sense physiological variables continuously, or require contact (e.g. skin temperature)

Programming Android Wearables

- Programmable using Android Wear (latest version is 2.0)
- Supported by Android Studio
- Needs to be connected to a smartphone (via Bluetooth)
- Architecture:
  - **Node API:** tracks all connected/disconnected nodes (E.g. wearables, smartwatches)
  - **Message API:** Used to send **messages** between wearable and smartphone
  - **Data API:** Used to synch **data** between app and smartwatch



A bit outdated, but nice overview for Android Wear for kitkat Android 4.4W

Android Wear Evolution

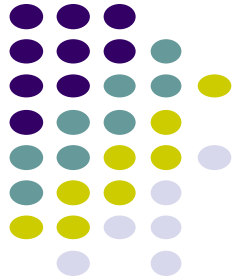
https://en.wikipedia.org/wiki/Android_Wear

Android Wear Version	Android Smartphone Version	Release Date	Major New Features
4.4W1	4.4	June 2014	Initial release at Google I/O 2014
4.4W2	4.4	Oct 2014	GPS support, music playback
1.0	5.0.1	Dec 2014	Watch face API (face design) Sunlight & theater modes, battery stats
1.1	5.1.1	May 2015	WiFi, Drawable Emojis, Pattern Lock, swipe left, wrist gestures
1.3	5.1.1	Aug 2015	Interactive Watch Face, Google Translate
1.4	6.0.1	Feb 2016	Speaker support, send voice messages
1.5	6.0.1	June 2016	Restart watch, Android security patch
2.0	7.1.1	Feb 2017	UI (material design, circular faces), watch keyboard, handwriting recognition, cell supp.

Evolved into Google Wear OS in June 2018!!

Wear OS Evolution

Wear OS version	System versions	Release date	New features	Notes
1.0[51]	Android 8 Oreo	March 2018	• Rebranding to Wear OS[52] • Expand Google Pay Support in more countries	Version number reset to "1.0". Wear OS App version: 2.10[53]
1.4	Android 8 Oreo	July 2018	• Faster Google Pay startup • More glanceable design for events and appointments • Time zone sync bug fix[54]	Wear OS App version: 2.14[55]
2.0	Android 8 Oreo	September 2018	• Swipe actions for faster access to Google Assistant and Google Fit[56] • Google Assistant feed with proactive personalized information • New design for quick toggles and notifications stream • New music controls with physical button support • Bolder font in the app launcher	Wear OS App version: 2.18
2.2	Android 9 H MR1	November 2018	New features for System version H MR1: • Brings Android 9.0 Pie features to smartwatches • Enables Battery Saver mode to only display the time once the battery falls below 10% • Improves restoring the state of previously used apps • Watches now enter a deep sleep mode after 30 minutes of inactivity • Holding down the power button now provides options for shutting down or restarting the watch	Wear OS App version: 2.20
2.6	Android 9 H MR1	May 2019	• *Tiles* functionality when swiping left, providing access to next calendar events, weather forecast, heart rate, news headlines and timer functionality.[57]	Wear OS App version: 2.24
2.7	Android 9 H MR1	June 2019	• Bugfixes	Wear OS App version: 2.25
2.9	Android 9 H MR1	July 2019	• Notifications	Wear OS App version: 2.26
2.17	Android 9 H MR1	April 2020	• New 'Wash hands' timer regarding coronavirus. • New UI and Tiles for Google Fit	Wear OS App Version: 2.35
2.19	Android 9 H MR2	September 2020	Changes in System H MR2:[*citation needed*] • CPU core improvements: app launch and boot time up to 20% faster • SysUI improvements: more intuitive controls for managing different watch modes and workouts • Increased performance with the Qualcomm Snapdragon Wear 4100 and 4100+ platforms • Improved LTE support • Simplified pairing process • Better battery life • Support for an increased numbers of Tiles • New Weather Tile design • Upcoming changes to Music	Wear OS App version: 2.40
Upcoming	Android 11	2021	Brings Android 11 features to smartwatches • New features	Wear OS App version:

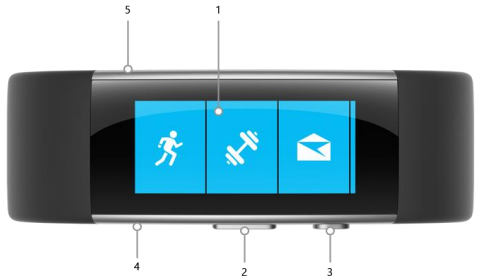


Physiological Sensing

Wearables for Physiological Sensing

- Some wearables measure more physiological signals
  - Cardiac rhythms (heartbeat), breathing, sweating, brain waves, gestures, muscular contractions, eye movements, etc
- Basis Health tracker: heart rate, skin temperature, sleep
- Microsoft Band 2: Heart rate, UltraViolet radiation, Skin conductance

Basis Health tracker



Microsoft Band 2

Empatica E4 WristBand

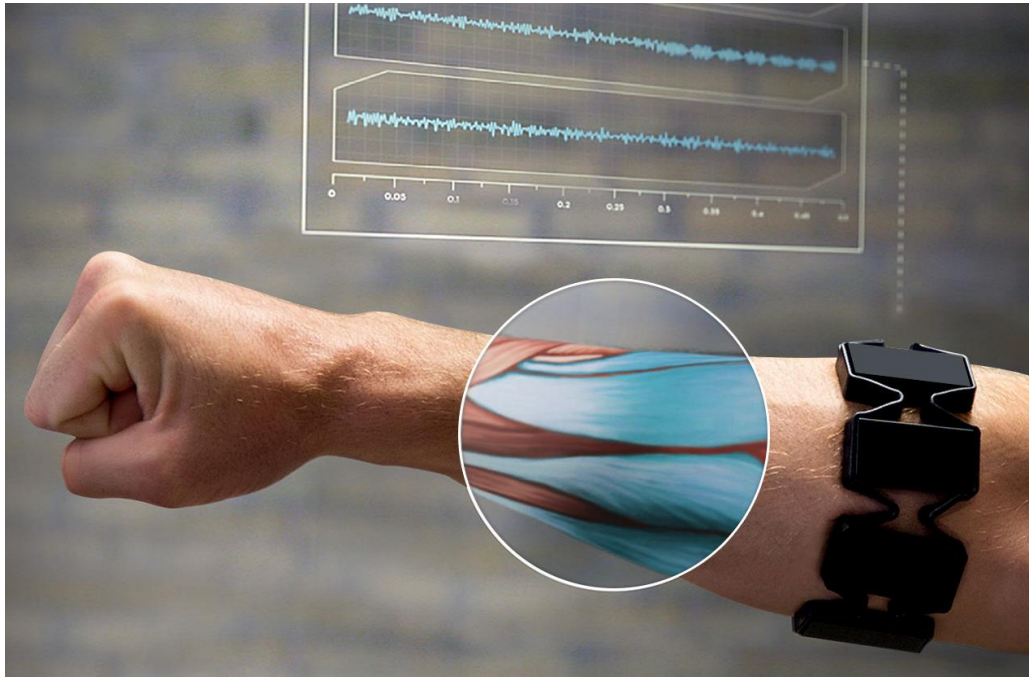
- Wristband measures physiological signals real time (PPG, EDA, accelerometer, infra-red temperature reader)

E4 wristband

Companion app

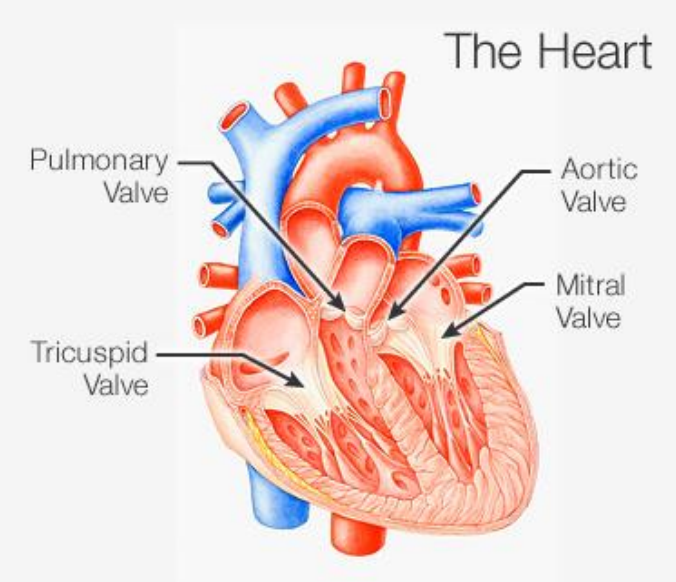
Myo Armband

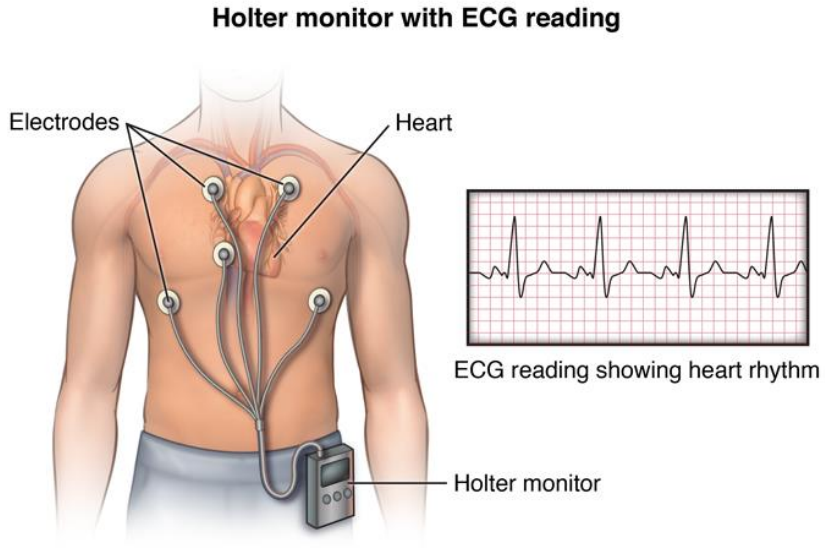
- Measures muscle contraction (electromyography or EMG), to detect gestures
- EMG measures electrical activity, used to assess health of muscles



Electrocardiogram (ECG)

- ECG (or EKG): recording of electrical activity of the heart
- Each heartbeat causes electrical signal to spread from top to bottom of heart
- Electric Signal
  - is rhythmic, causes heart to contract and pump blood
  - Can be measured electric activity between 2 electrodes placed on chest

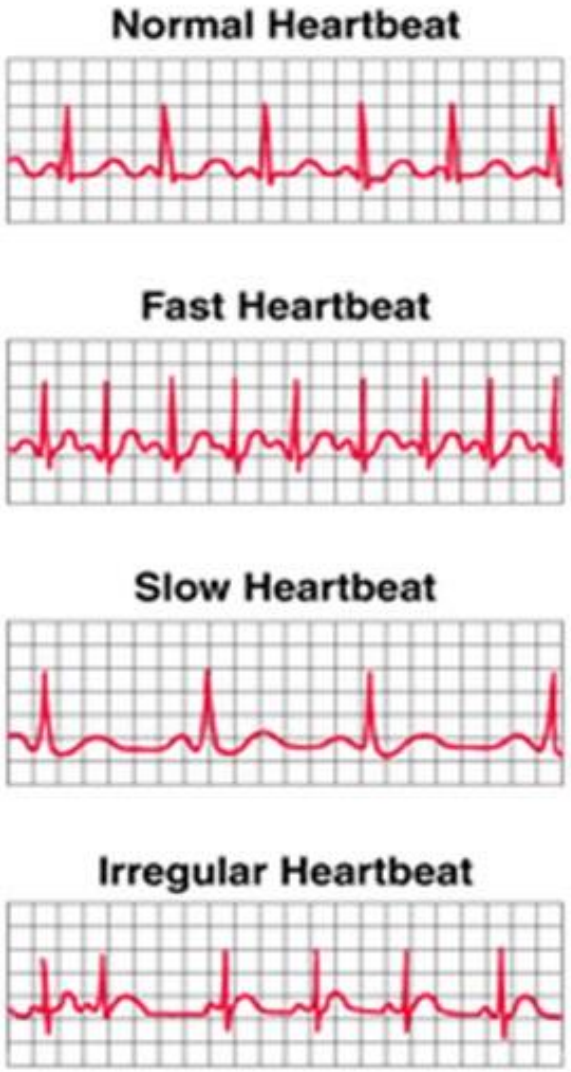




Electrocardiogram (ECG)

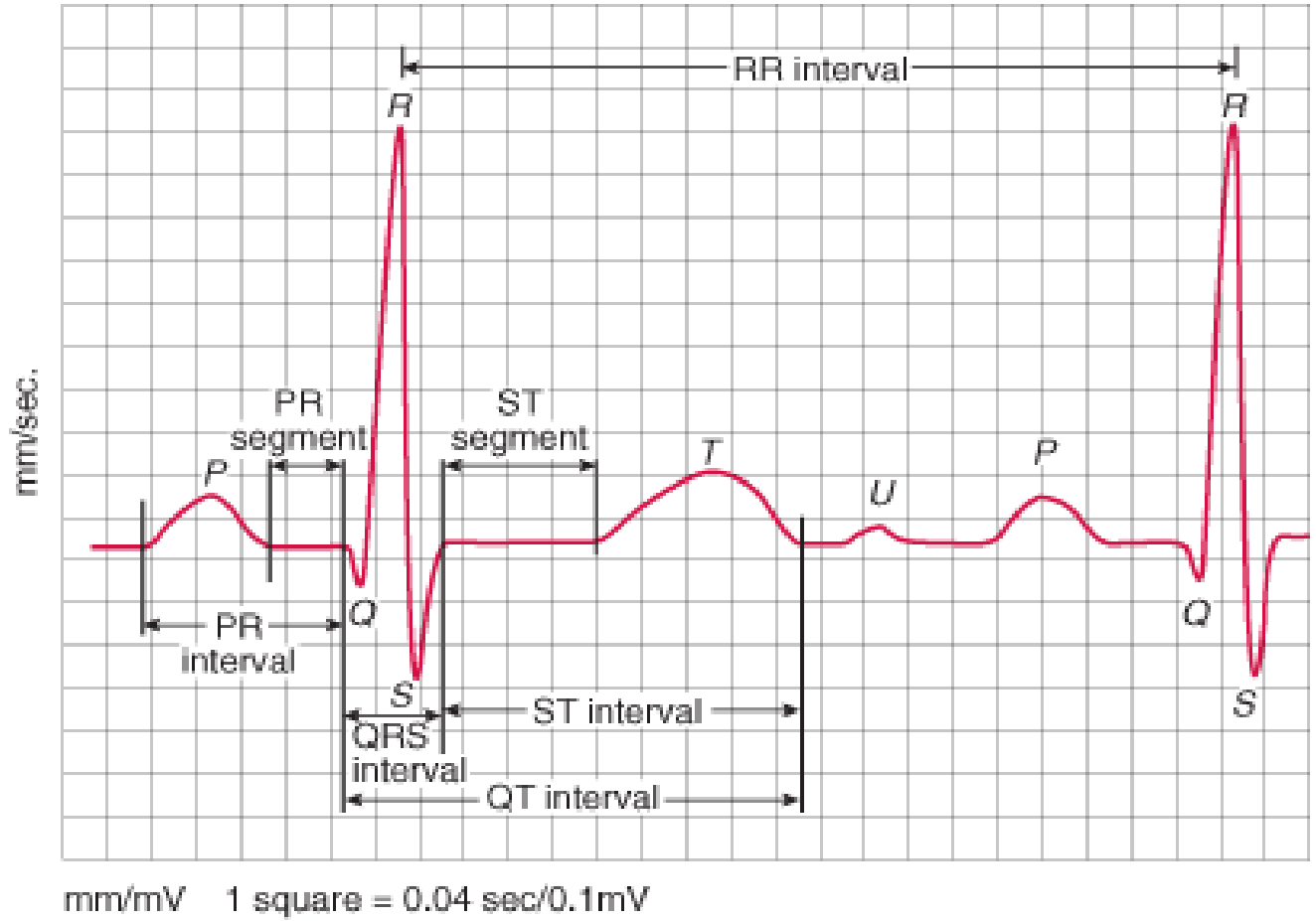
- ECG shows:
  - How fast the heart is beating
  - Rhythm of heartbeat (steady vs irregular)
  - Strength and timing of electrical signals

- **Arryhthmia:** fast or irregular heartbeat, can cause stroke or heart failure



Electrocardiogram (ECG)

- ECG waveform comprises sequence of peaks and trough (P,Q,R,S,T), which repeats
  - Occasionally a U wave after T

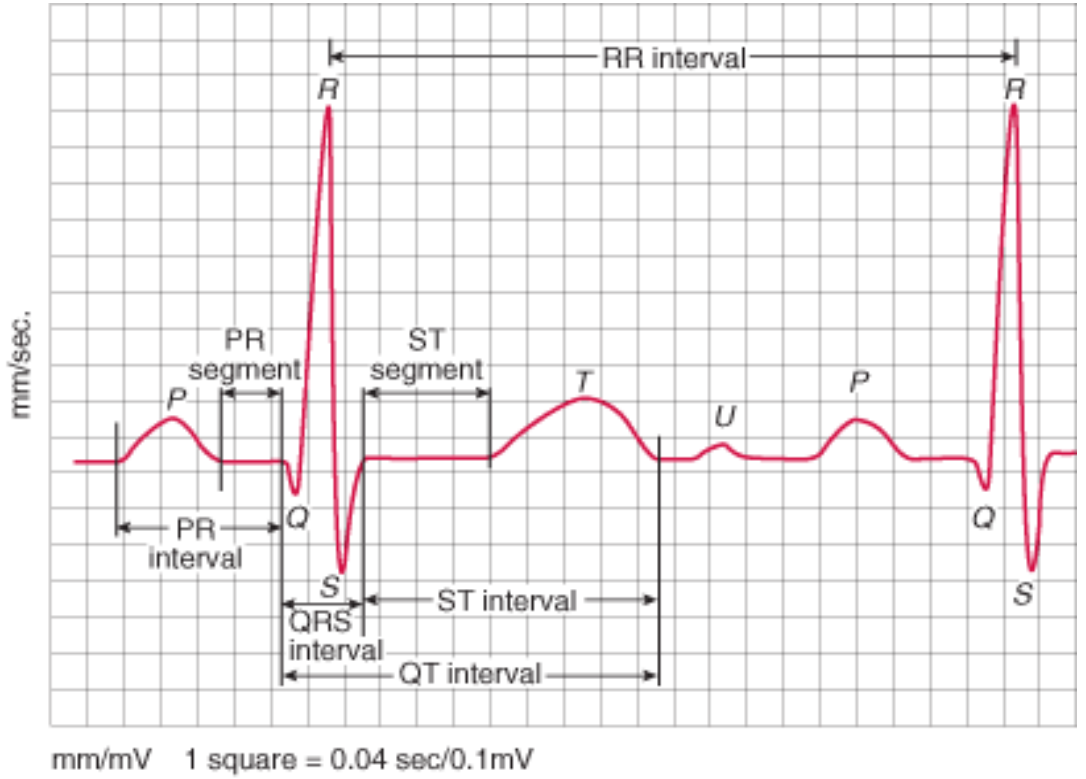


ECG Features for Classification

- From a waveform with at least 5 peaks, can extract as features for classification, the following timing intervals
  - RR interval
  - PR interval
  - QRS interval
  - QT interval, etc

- Heartrate is number of RR intervals/min
  = 60 / RR

- Note: RR is in seconds



Trends: Mobile ECG

- E.g. AliveCor kardia ECG
  - Hold 2 fingers on metal plates (ECG recorder) for at least 30 seconds

Photoplethysmography (PPG)

- **PPG:** Non-invasive technique for measuring blood volumes in blood vessels close to skin
- Now popular non-invasive method of extracting physiological measurements e.g. heart rate or oxygen saturation
- Traditional device for PPG is pulse oximeter
  - Measures concentration of oxygen in the blood
  - Low oxygen levels (< 80%) can compromise organs, lead to heart attack , etc

Pulse Oximeter

Pulse Oximeter PPG

- Amount of oxygen in the blood determines how much infared light absorbed, scattered, passes through (from LED to photodiode)

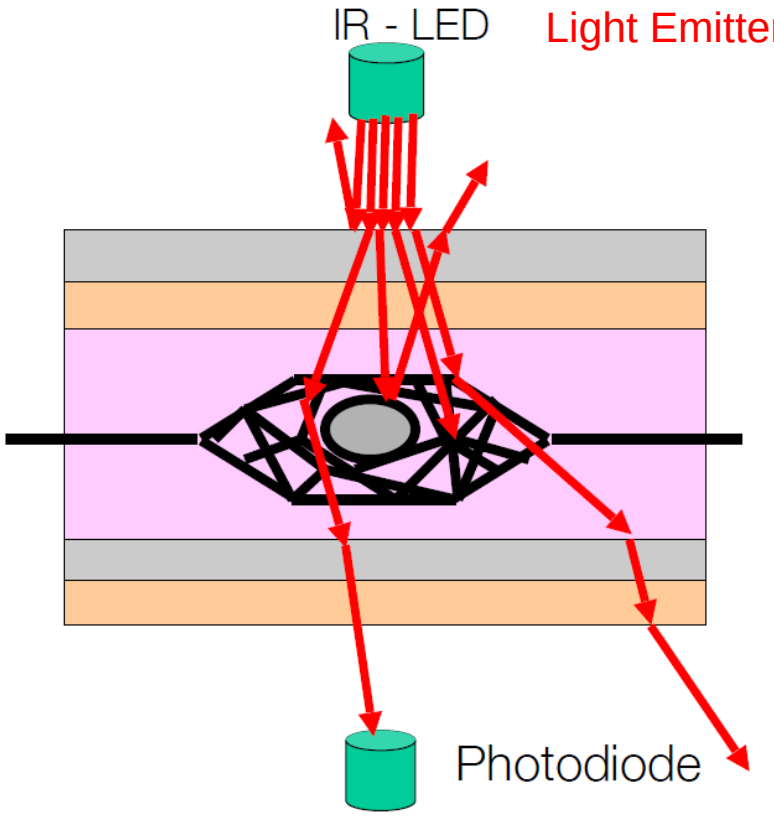
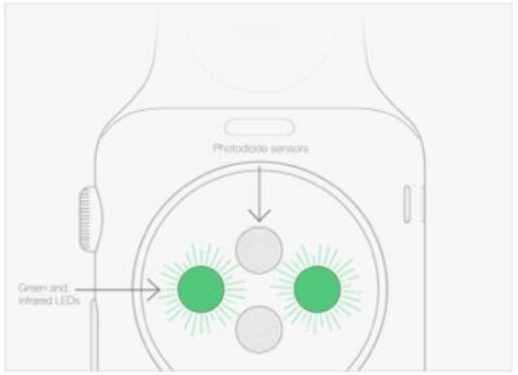
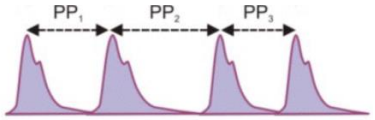


Image credit: Deepak Ganesan

Smartphone/Smartwatch PPG: Estimating HR

- **Principle:**
  - Blood absorbs green light
  - LED shines green light unto skin (back of wrist)
  - Blood pumping changes blood flow and hence absorption rhythmically
  - Photodiode measures rhythmic changes in green light absorption => HR





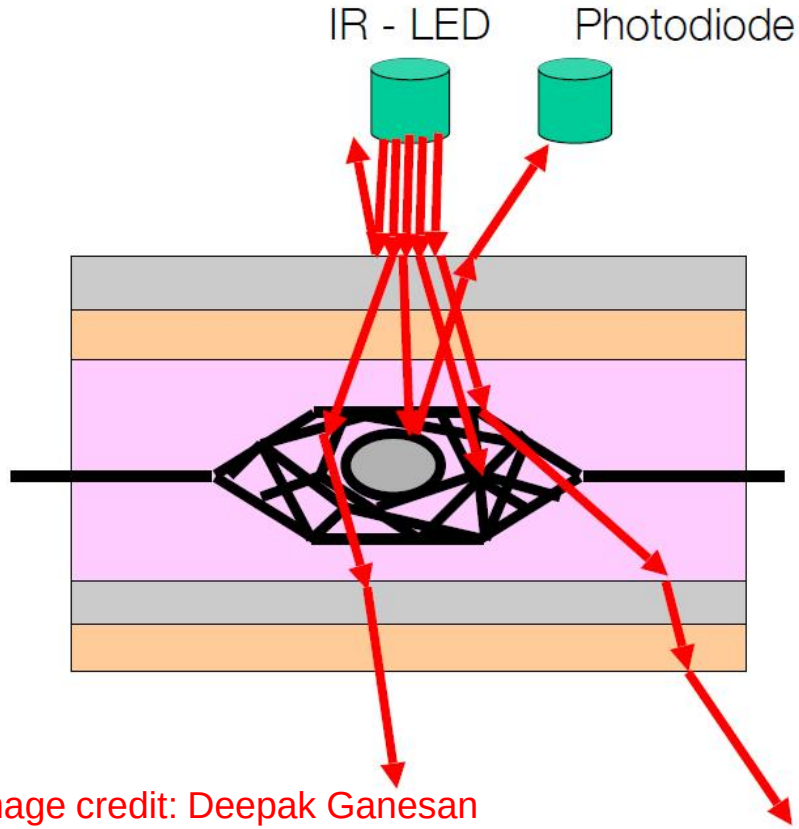


Image credit: Deepak Ganesan

Smartphone PPG: Heart Rate Detection

- Like smartwatch, use camera flash (emitter), camera as detector
- Place finger over smartphone's camera, shine light unto finger tip
- Heart pumps blood in and out of blood vessels on finger tip
  - Changes how much light is absorbed (especially green channel in RGB)
  - Causes rhythmic changes of reflected light
- **Ref:** Scully CG, Lee J et al."Physiological parameter monitoring from optical recordings with a mobile phone", IEEE Trans Biomed Eng, 2012 Feb;59(2):303-6

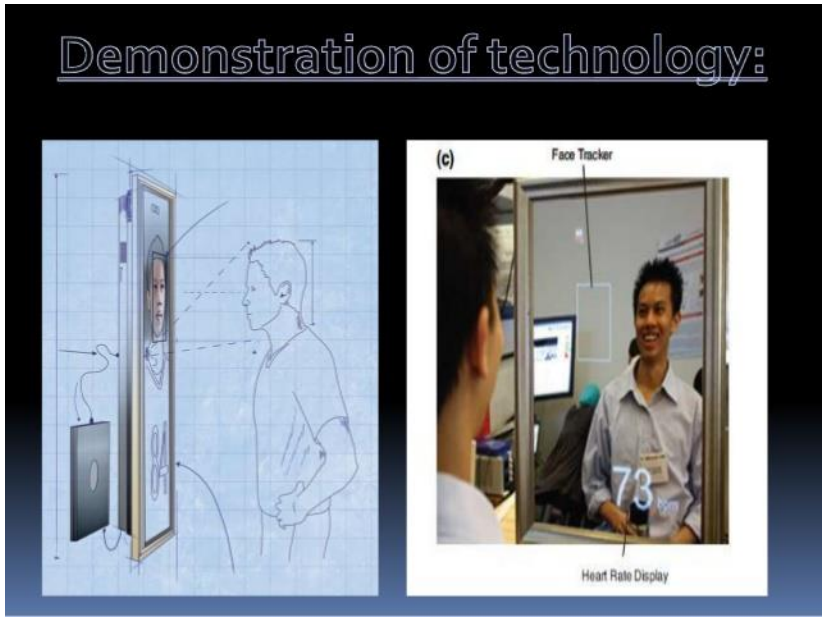
Smartphone PPG: Heart Rate Detection

- **Idea:**
  - Color expressed as (R G B)
  - Track intensity of Green channel of Camera response
  - Use peak finding algorithm (similar to step counter)
  - Time between peak is 1 cycle
  - Heart rate = cycles per minute = 60 / time for 1 cycles
- Can also extract breathing rate, heart rate variability

PPG: Final Words

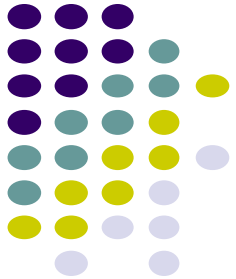
- PPG (or similar ideas) have been attempted:
  - on other body parts (ear lobes, face)
  - from video frames (detect, magnify small changes in facial color 100x)
  - Using other ubiquitous devices (e.g. Medical Mirror, Poh *et al*)

H.Y Wu, M. Rubinstein, E. Shih, J. Guttag, F. Durand, W.T. Freeman, Eulerian Video Magnification for Revealing Subtle Changes in the World. SIGGRAPH 2012



MZ **Poh**, D McDuff, R Picard A medical **mirror** for non-contact health monitoring, ACM SIGGRAPH 2011 Emergin

Electrodermal Activity (EDA)



- When people experience emotional arousal (e.g. danger), stress, cognitive load or physical exertion => increased sweating
- Increased sweating changes electrical conductance of skin
- Sometimes called Galvanic Skin Response (GSR)
- This response cannot be controlled by person
  - Hence, widely used in emotion/lie detection

EDA Features

- Features useful for classifying measured human EDA response
  - **Latency:** time between stimulus and response
  - **Rise time:** time for skin conductance to peak
  - **Amplitude:** Height of conductance signal
  - **Half recovery time:** Time for conductance signal to lose half of its peak value

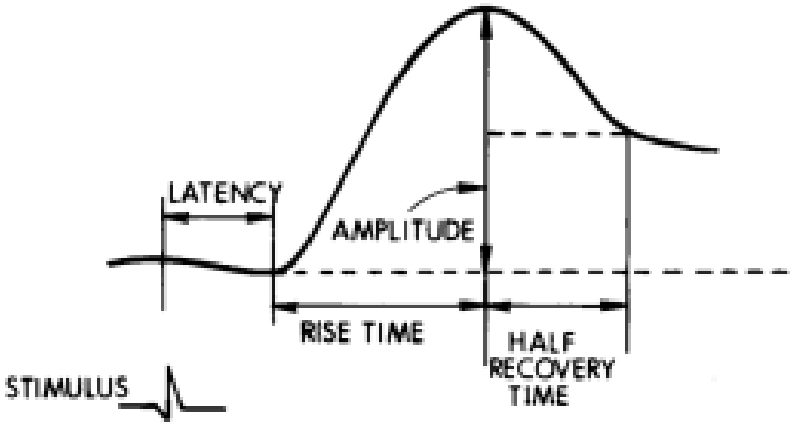
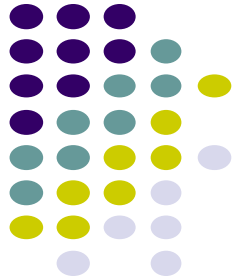


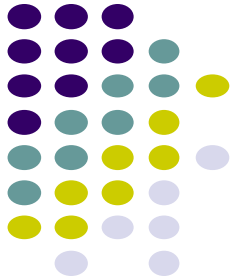
Figure 5. Graphical representation of principal EDA components.



Differentiating Productive Workers

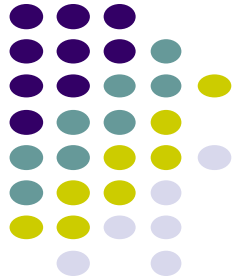
Differentiating Higher and Lower Job Performers in the Workplace Using Mobile Sensing

Mirjafari *et al*, IMWUT Journal 2019



- Workplace performance uses subjective evaluations which are manual, burdensome and potentially biased
  - E.g. peer ratings, supervisor ratings and self assessments
- Paper's goal: User smartphone sensor and wearable data to create an objective method to separate higher and lower workplace performers
  - Discover distinguishing behavioral patterns, in different types of companies
- Can provide objective criteria for promotions, firing?
- 1 year study of N=554 IT workers in mid-sized company, consultancy, Android and iOS
- Participated in study for between 2-8.5 months

Devices/Data Gathered



- Smartphone data gathering app:
  - Physical activity, location, phone usage (e.g., lock/unlock) and ambient light levels.
- Garmin Vivosmart wearable
  - heartrate, heartrate variability and stress, sleep quality and duration, light sleep, deep sleep, REM sleep and entire sleep time duration
- Gimbal Beacons
  - Workers presence in office

Features Extracted

- Subjects answered job performance (ITP, IRB, OCB, CWB) and health questionnaires (e.g., heart rate, sleep) at beginning, end of study at 3 times a week
- **Features extracted:** mobility, activity, phone usage, physiological signals and movement within the workplace features

Job Performance Questionnaires

Survey	Items	Answer Choices
ITP	Please indicate how often you carried out these three behaviors today 1. Carried out the core parts of your job well 2. Completed your core tasks well using the standard procedures 3. Ensured your tasks were completed properly	Response scale: 1 (Very little) 2 (Somewhat) 3 (Moderately) 4 (Considerably) 5 (A great deal)
IRB	Please indicate your level of agreement with whether you... 1. Adequately completed your assigned duties 2. Fulfilled responsibilities specified in your job description 3. Performed tasks that are expected of you 4. Met formal performance requirements of your job 5. Engaged in activities that will directly affect your performance evaluation 6. Neglected aspects of the job you are obligated to perform 7. Failed to perform essential duties	Response scale: 1 (Strongly disagree) 2 (Moderately disagree) 3 (Slightly disagree) 4 (Neutral) 5 (Slightly agree) 6 (Moderately agree) 7 (Strongly agree)
OCB	Today, I... 1. Went out of my way to be a good employee 2. Was respectful of other people's needs 3. Displayed loyalty to my organization 4. Praised or encouraged someone 5. Volunteered to do something that was not required 6. Showed genuine concern for others 7. Tried to uphold the values of my organization 8. Tried to be considerate to others	Response scale: Yes/No
CWB	Today, I... 1. Spent time on tasks unrelated to work 2. Gossiped about people at my organization 3. Did not work to the best of my ability 4. Said or did something that was unpleasant 5. Did not fully comply with a supervisor's instructions 6. Behaved in an unfriendly manner 7. Spoke poorly about my organization to others 8. Talked badly about people behind their backs	Response scale: Yes/No

References

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