Lecture 01

Smart Phone Sensing

- Instructor
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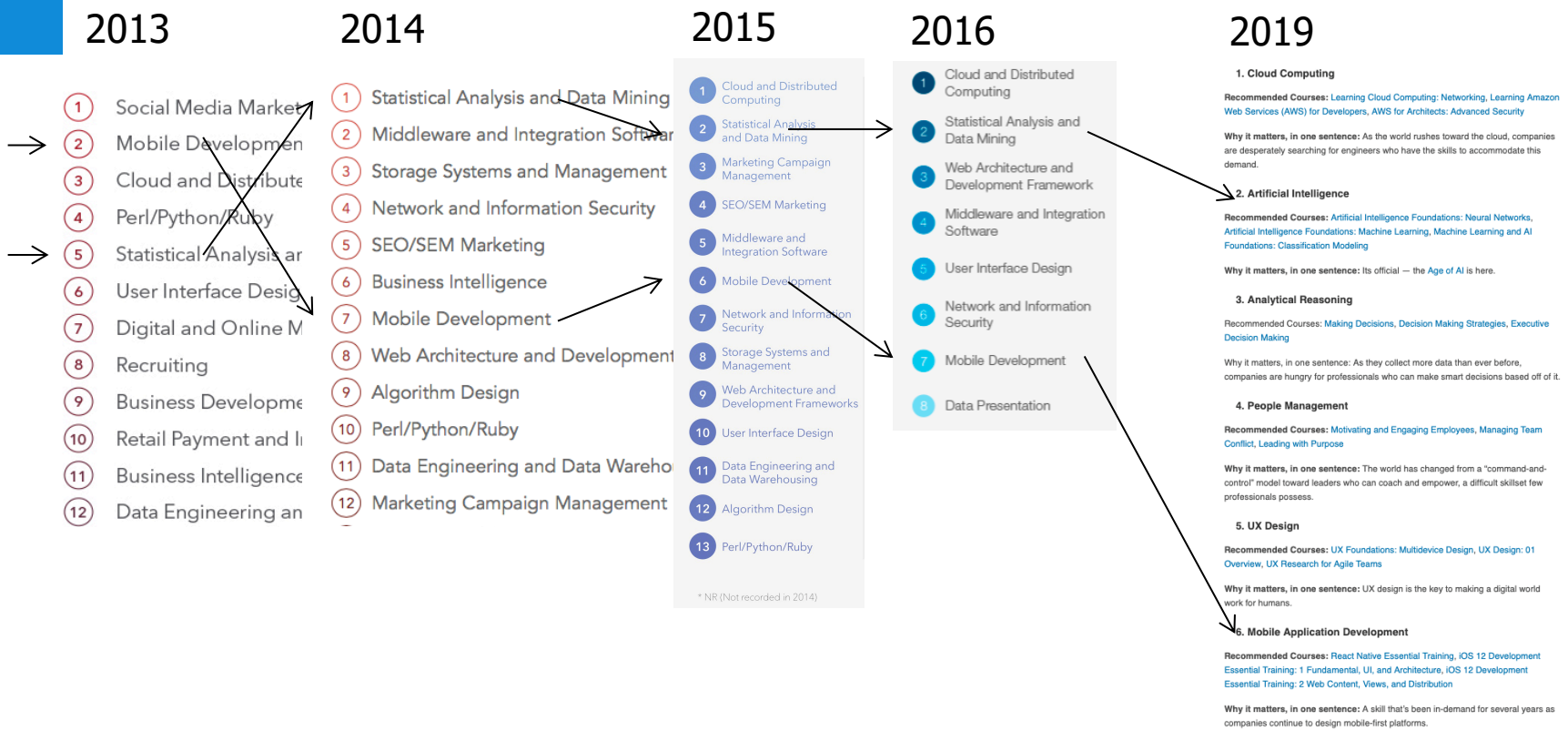
- Lectures
  - Monday: 08:30 – 10:30
  - Wednesday: 15:30 – 17:30
- Lab (not mandatory, mainly for advise and Q&A)
  - Wednesday: 13:30 – 17:30 [Starting May 15th]

WHY CARE?

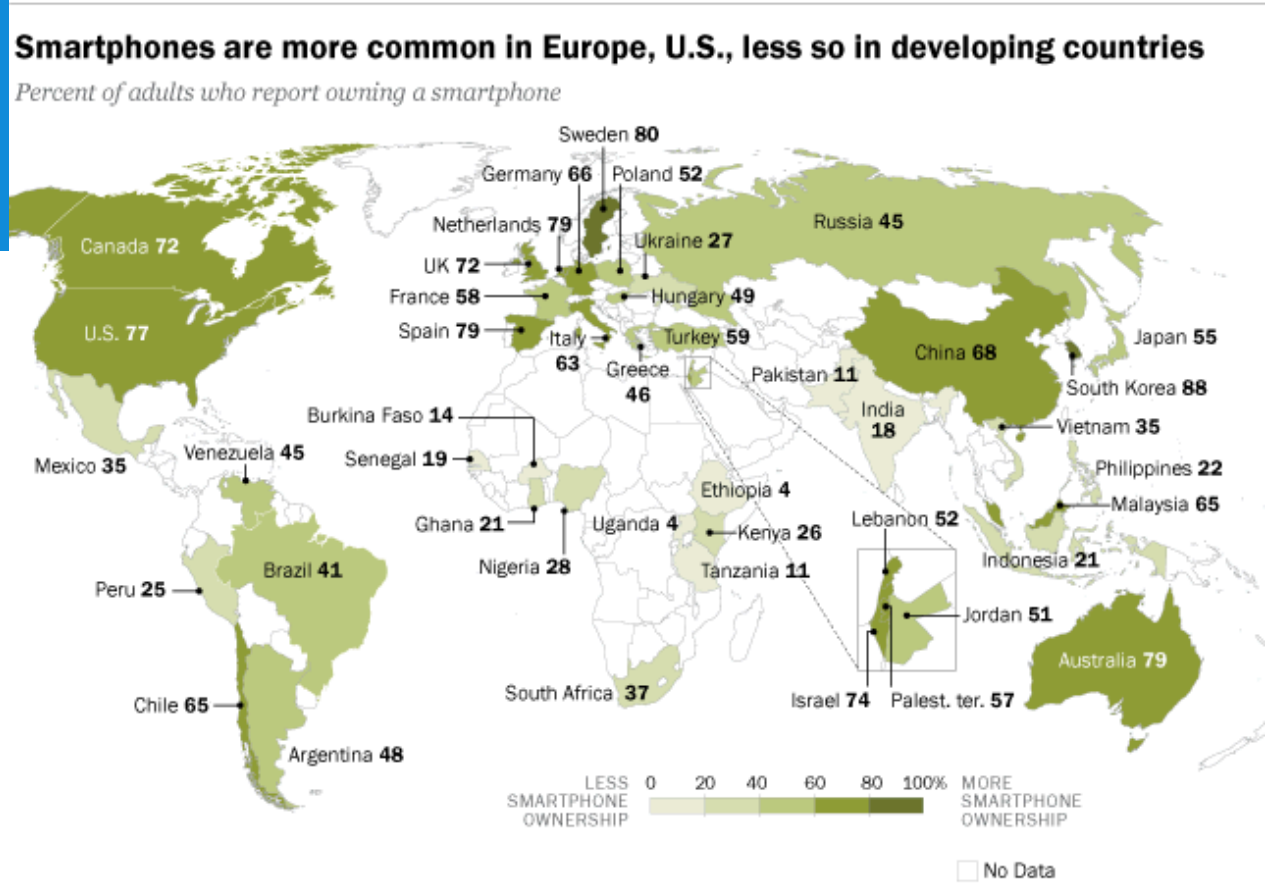
Why care?

It is a good skill to have (LinkedIn)



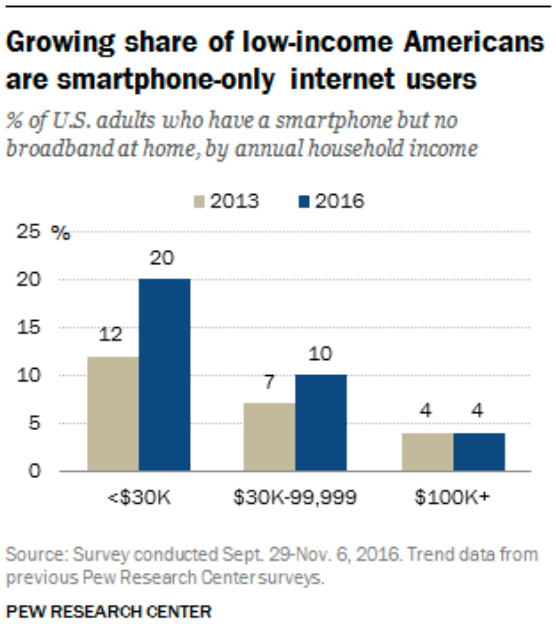
Source:LinkedIn

Why is it a good skill? Planet of the phones



6 Billions smartphones by 2020

Smartphones are far more popular than tablets and PCs

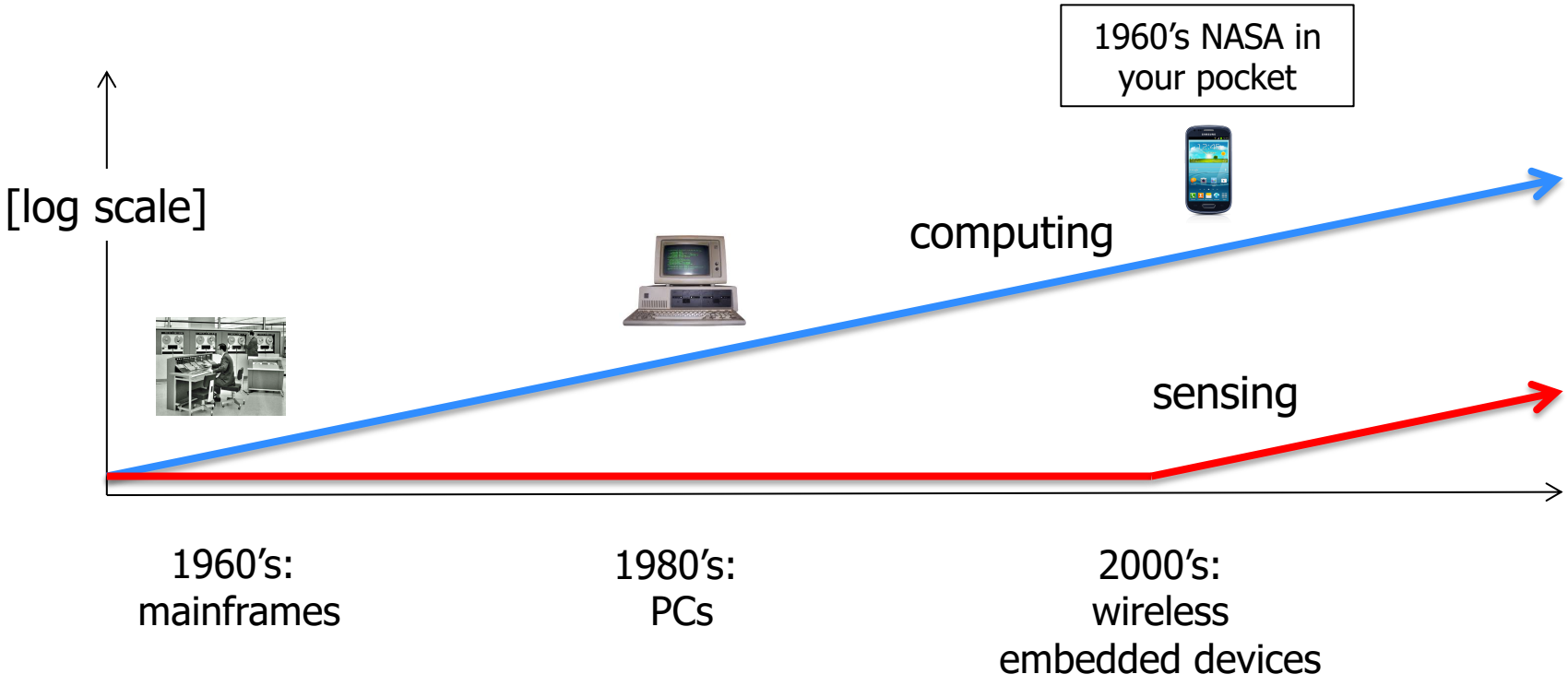


TECHNICALLY, WHY ARE SMARTPHONES CREATING SUCH A REVOLUTION?

LISTEN TO THIS!

Why is it a good skill?

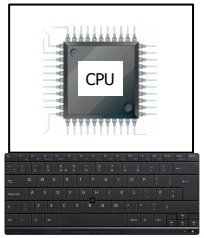
Tackles a major technological change



For the first time in history we have plenty of computing and sensing capabilities

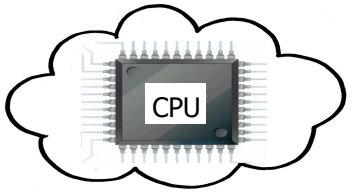
Computation & Sensing

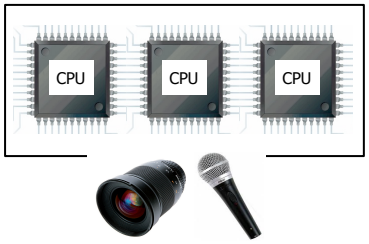
~until 2000



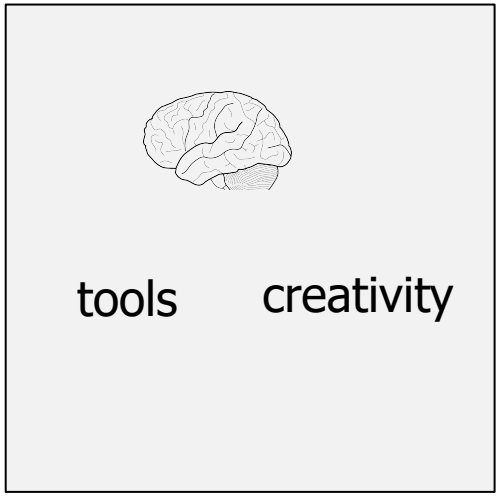
data

now





still missing

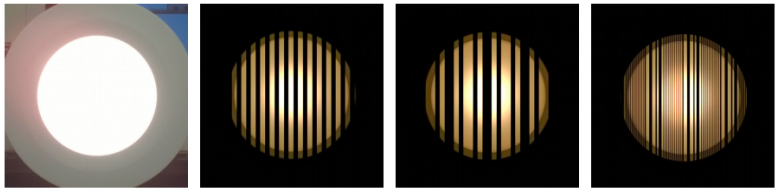


sensing	implies we can now gather tons of DATA
computing	implies we can process these tons of DATA

Research example 1: Indoor localization

Problem
- GPS does not work inside
- We spend almost 90% of our time indoors

Solutions
- sensor: many, but let's look at a very recent one based on LEDs
- tool: Visible Light Communication
- output: information



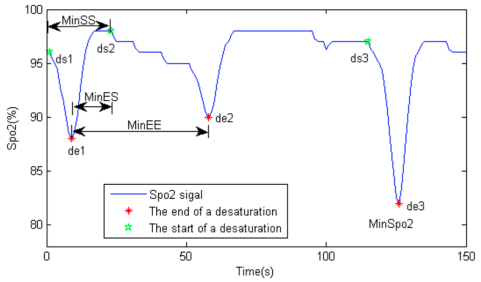
Paper: "Luxapose: Indoor Positioning with Mobile Phones and Visible Light", ACM Mobicom 2014

Research example 2: Sleep Apnea

Problem
- treat sleep apnea at home

Solution
- sensor: pulsoximeter
- tools: machine learning
- actuation: adjustable pillow

photo courtesy of http://sleepapneadisorder.info



Paper:
"A real-time auto-adjustable smart pillow system for sleep apnea detection and treatment",
IEEE/ACM IPSN 2013
http://dl.acm.org/citation.cfm?id=2461405

Reason to care

There are lots of *smartphones* out there …

… collecting lots of **data**

… and enabling lots of *applications*

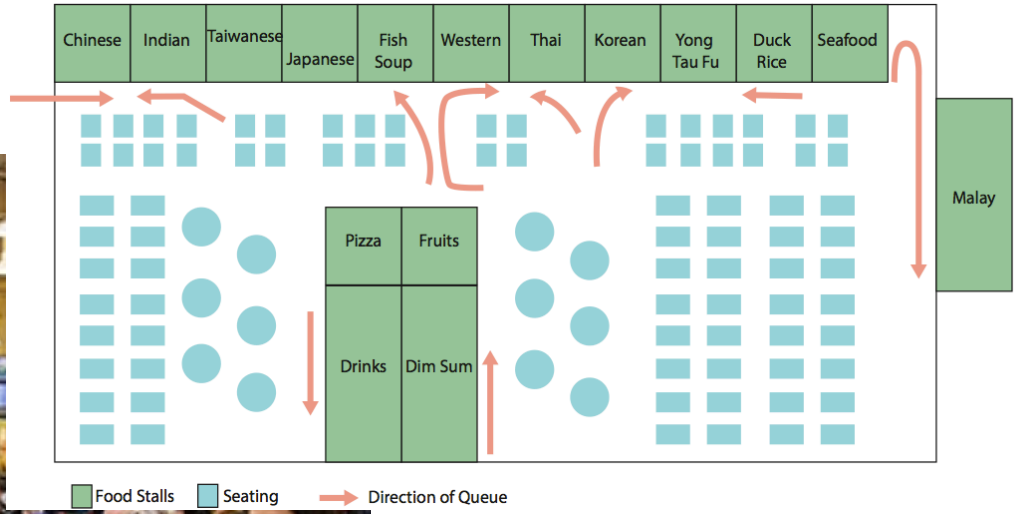
It is a good idea to know about them

Now some information from you!

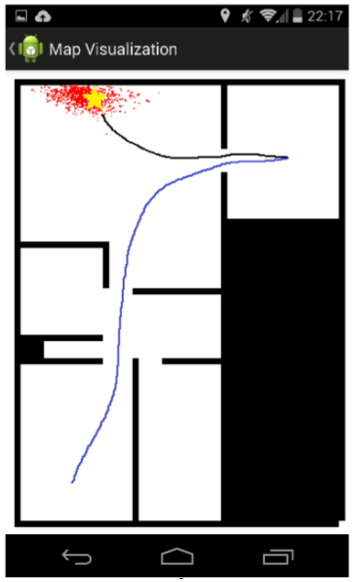
- We will be using feedback fruits and github
- We will learn it as we go
- For now three questions on your background
  Please be accurate don't overestimate or underestimate your skills.
  - EE/CS
  - Programming Background
  - Probability Background

WHAT APP WILL YOU DEVELOP?

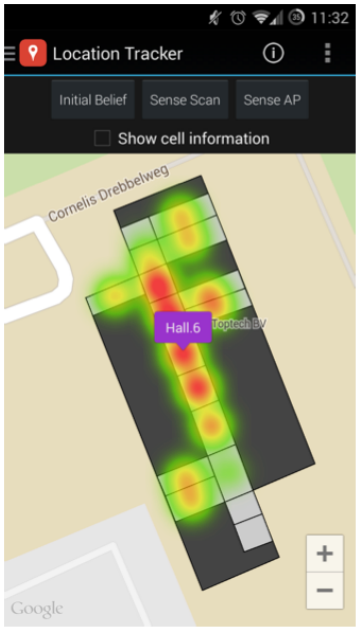
Your App (option 1): indoor localization



Last years



TrackMe@Home:
a student tracking his location at his place



TrackMe@Work:
a student tracking his location at EWI, 9th floor

Shazam:
a scaled-down version

What this course is about (1)

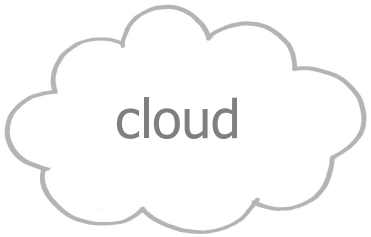
- Smartphone + data + math = Awesome Apps

- You need to be familiar with
  - (1) the signals smartphones can gather,
  - (2) the math tools to process those signals

- We use techniques from algorithms, signal processing and machine learning to develop some exciting apps!

$$p(X_k \mid Z_{1:k-1}) = \int p(X_k \mid X_{k-1})\, p(X_{k-1} \mid Z_{1:k-1})\, dX_{k-1}$$

What this course is about (2)



(4)

(2)

(3)

(1)

Theory

- (2) tools: math & algorithms

Practice (pointers)

- (1) Sensors: data acquisition
- (4) Cloud: communication

Practice (pointers)

- (3) GUI & Actuation

LOGISTICS

Got a smartphone?

- If yes, please use your own
- If no, we have some smartphones available but we need to time-share them.
- If you need a smartphone (or laptop), send an email to the TA.
- We moved to a new building.
- This year you will evaluate your App in two phones

Project based (groups of 2)

Per group: send names and ids to TA by the end of the week
No partner? post message in FF

Option 1: Indoor Localization

1) Localization:
   - RSS + KNN
   - RSS + Filters
   - IMU + Sensors
2) Innovation (beyond class):
   - Light Sensors
   - Your own ideas
3) GUI

Option 2: Your own

Your own project
- Requires prior approval

Evaluation criteria
- Technical depth & creativity

Other Options:
- Escort Services
- Visible Light Communication

All code must be on the phone itselft!

If you want to go for option 2, please contact me after the lecture.

Grading

- Option 1
  - First Report (max 1 page text + figures) 5% week 3
  - Second Report (max 1 page text + figures) 5% week 6
  - Final Report (max 4 pages) 10% week 8
  - App evaluation 60% weeks 9-10
  - Novel Twists 20%

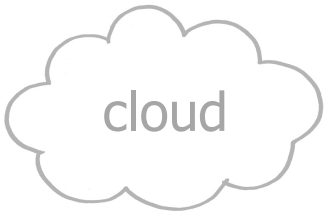
- Option 2 (weekly mentoring)
  - Pitch report (2 pages) 5% week 2
  - Final Report (5 pages), 15% week 8 (or week 10)
  - App Evaluation 80% week 12 (or week 10)

- There is NO resit

More background information

1) KNN: K nearest neighbors
2) Bayesian Filters
3) Particle Filters
4) Visible Light Communication

ACTIVITY MONITORING & LOCALIZATION



(4)

(2)

(3)

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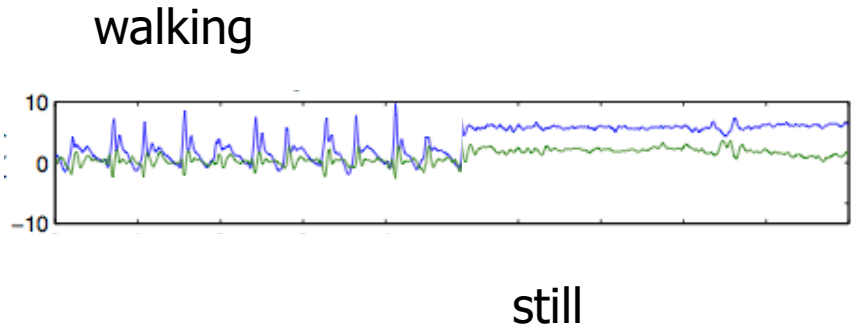
Option 1

Indoor Localization

1) Localization
   - RSS + KNN
   - RSS + Filters
   - IMU + Filters

Problem

- What am I doing?



Steps for classification: get raw signal

(1) Raw signal (sensor information)

(2) Feature extraction (art and science)

(3) Classification method (art and science)

Key sensors for our app…

… and many many other applications

- Accelerometers convert acceleration into an electrical signal.
- Gyroscopes measure angular rate (how quickly an object turns).
- Magnetometer sensor detect the magnetic field of the Earth.
- Radio transceivers detect surrounding access points and their signal strength (RSS)

Energy matters!

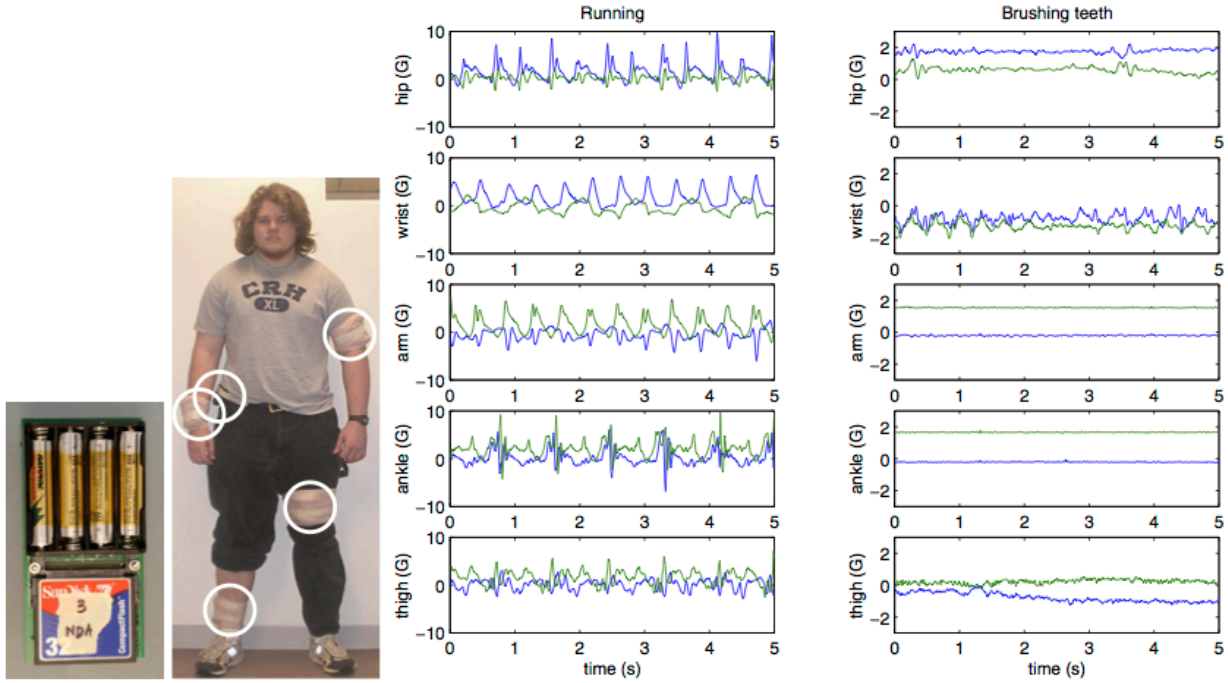
Energy consumption for Ipaq hw 6965

- GPS 620 mW
- Microphone 225 mW
- Accelerometer 2 mW

In general, always solve the problem using as little energy as possible

Activity recognition

- Most smartphones have 3-axis accelerometers.
- Accelerometers can provide a lot of information.



Paper: "Activity Recognition from User-Annotated Acceleration Data", Pervasive 2004

Steps for classification: train your system

(1) Raw signal

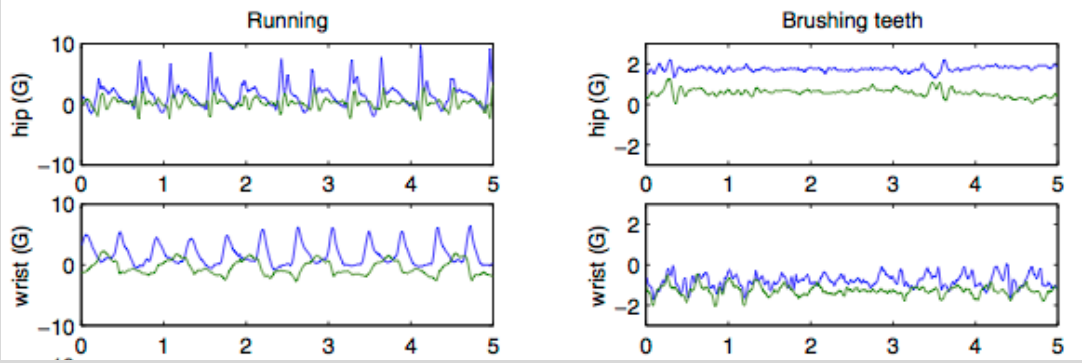
(2) Feature extraction (art and science)

Training

(3) Classification method (science)

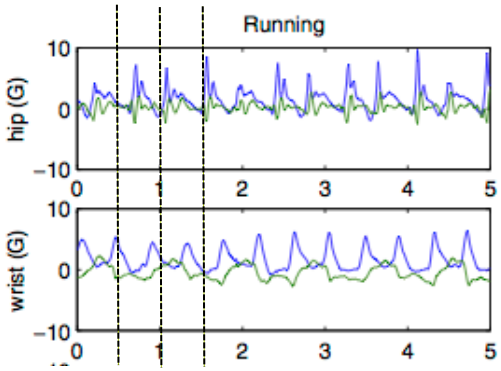
Identifying Features

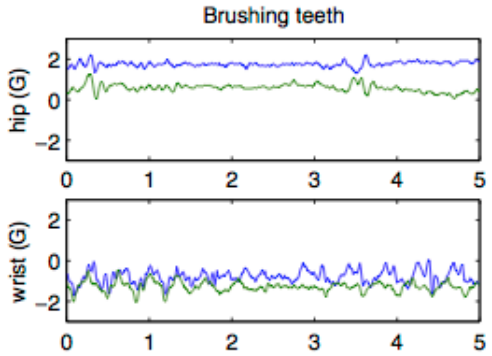
- How would you describe a signal statistically?



Features: Training Data

- Choose a window size
  - 20 samples
  - 500 ms
- Then select features
  - Mean
  - Max Min
  - Variance
  - Fourier Transforms
  - Autocorrelation





Steps for classification: test your system

(1) Raw signal

(2) Feature extraction (art and science)

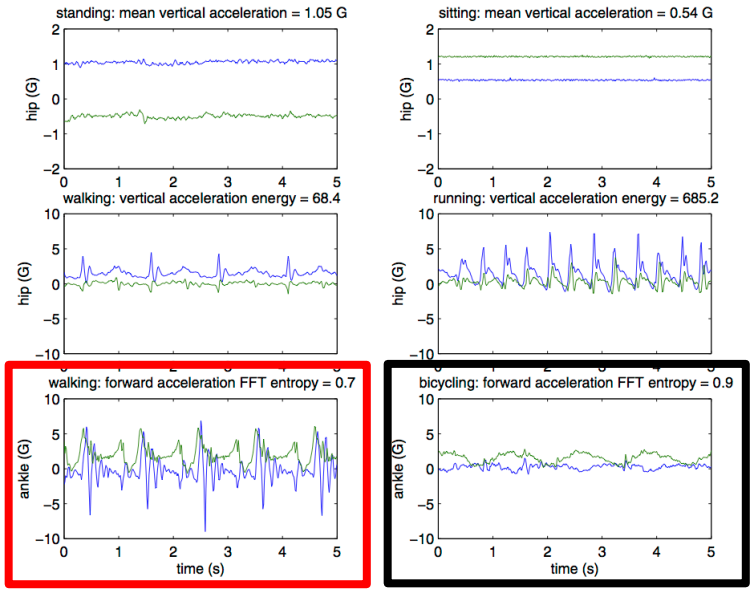
Training Phase

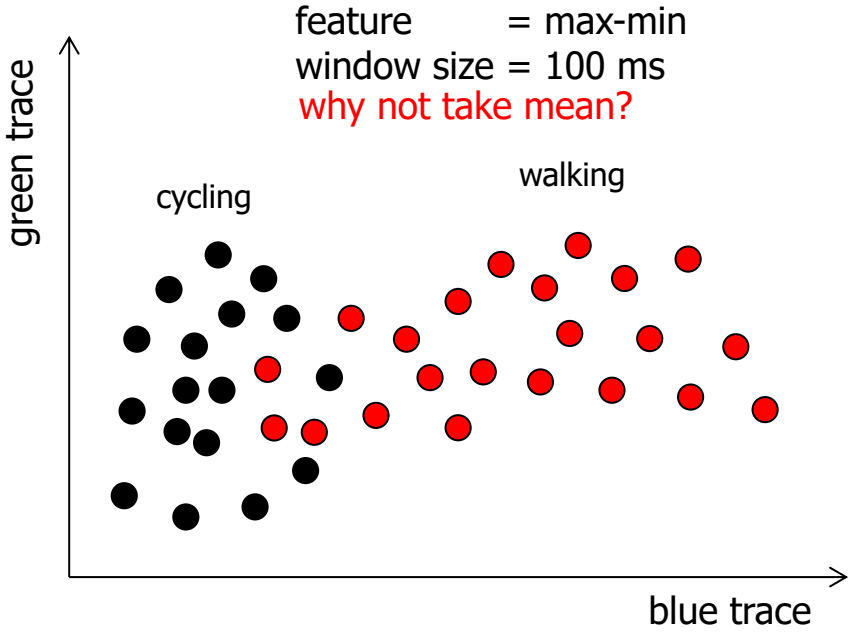
(3) Classification method (art and science)

Testing Phase

Classification

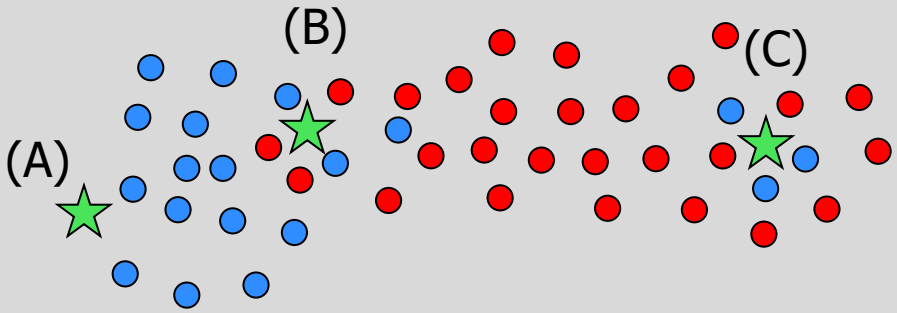
- Let's get some features and plot them
- There is going to be an overlap depending on the window's size





Paper: "Activity Recognition from User-Annotated Acceleration Data", Pervasive 2004

Classify points: Testing Data



k-NN in one slide

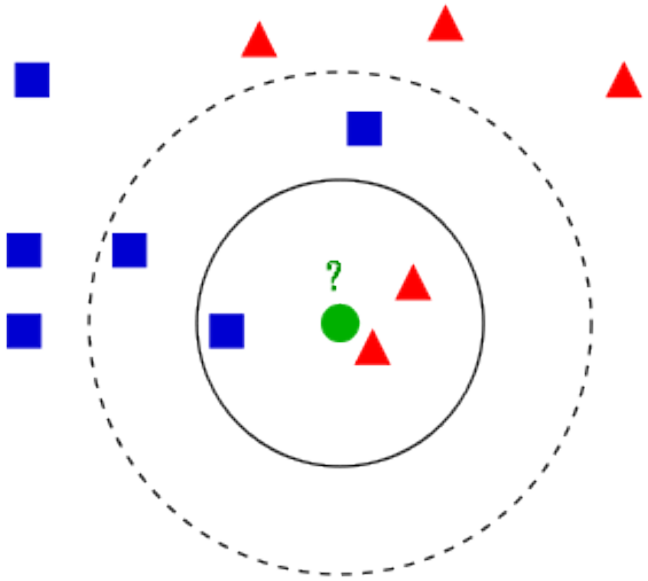
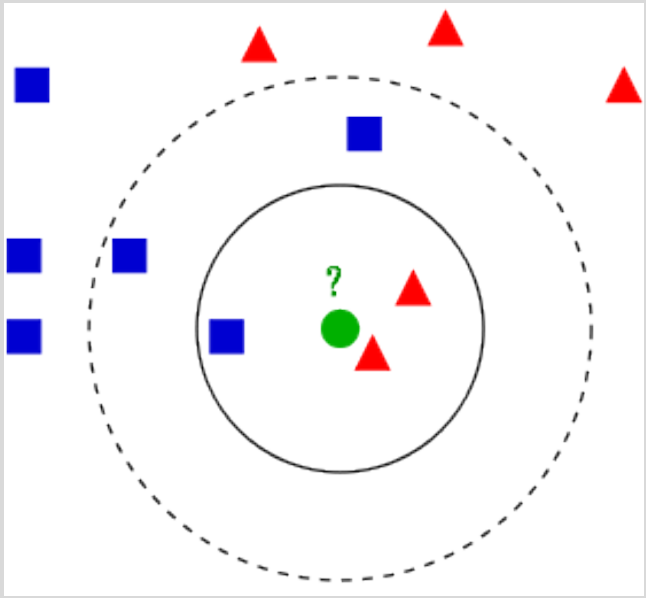


image from wikipedia: http://en.wikipedia.org/wiki/K-nearest_neighbor_algorithm

What is the best value for k?

What happens if k=1?
What happens if k =n?
    n is the total number of training points
What is the best value of k?



What K? What distance?

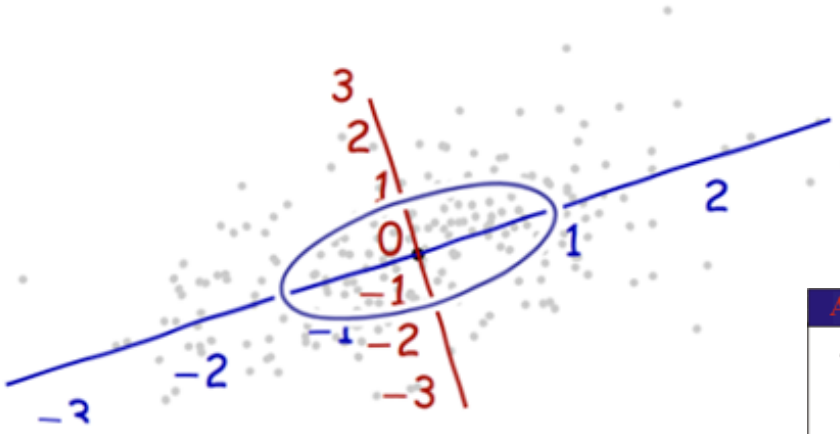
- Value of K:
  - Odd number
  - $\sqrt{n}$
- Distance:
  - Euclidean: $D(\mathbf{w}_i,\mathbf{v}_i) = \sqrt{\Sigma\ (\mathbf{w}_i-\mathbf{v}_i)^2}$
  - Manhattan: $D(\mathbf{w}_i,\mathbf{v}_i) = \Sigma\ |\mathbf{w}_i-\mathbf{v}_i|$
  - Hamming: $D(\mathbf{w}_i,\mathbf{v}_i) = \Sigma\ I(\mathbf{w}_i,\mathbf{v}_i)$
  - Mahalanobis: $D(\mathbf{w}_i,\mathbf{v}_i) = \sqrt{(\mathbf{w}-\mathbf{v})^T S^{-1}(\mathbf{w}-\mathbf{v})}$

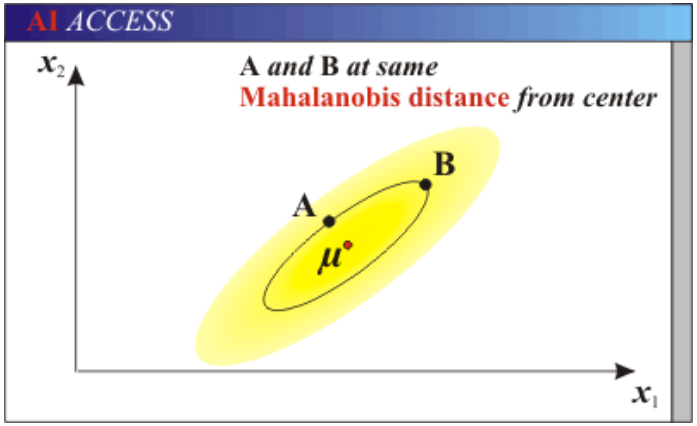
Mahalanobis distance: $D(\mathbf{w}_i,\mathbf{v}_j) = \sqrt{(\mathbf{w}-\mathbf{v})^T S^{-1}(\mathbf{w}-\mathbf{v})}$

S: covariance metric. $S_{wv} = E[(w-u_w)(v-u_v)]$

Intuition = $(\mathbf{x}-u)/\sigma$

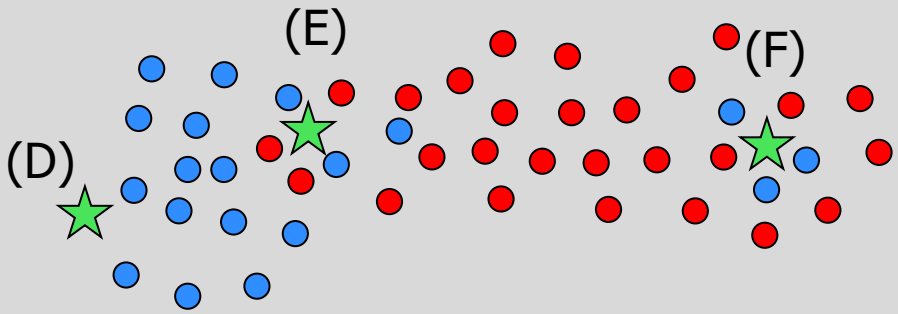
- unit-less measure
- If S=identity matrix, then mahalanobis = euclidean





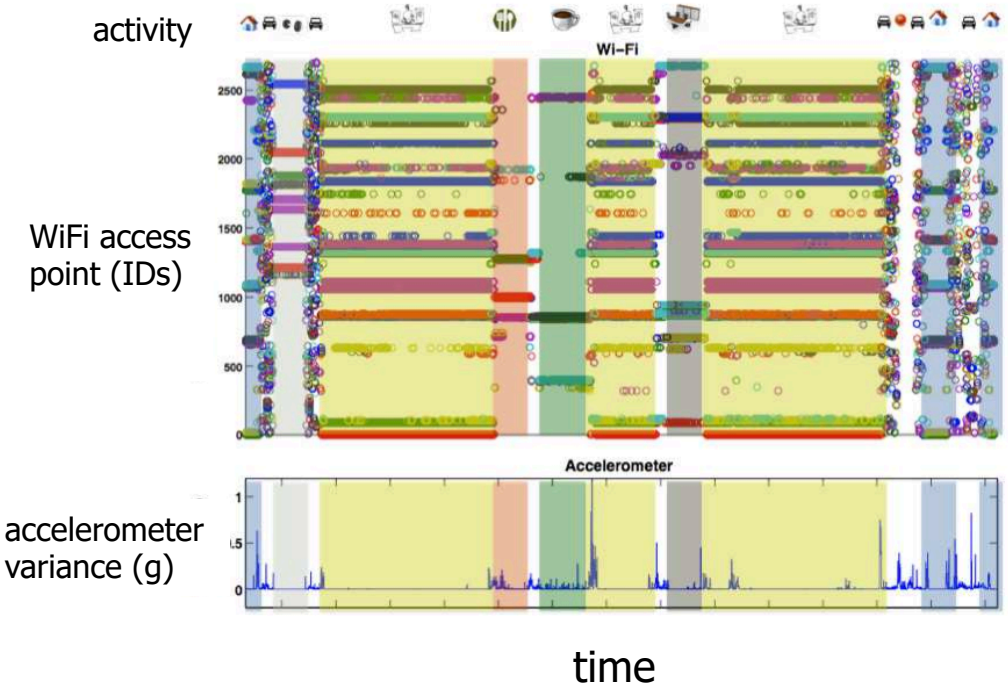
Images taken from:
http://stats.stackexchange.com/questions/62092/bottom-to-top-explanation-of-the-mahalanobis-distance
http://blog.csdn.net/lovelyloulou/article/details/6339976
Localization paper using mahalanobis distance:
"Paper Lightweight Map Matching for Indoor Localisation Using Conditional Random Fields", IEEE/ACM IPSN 2014.

Classify the points below
Assume k=5 and Euclidean distance



Hamming distance

: $D(\mathbf{w}_i,\mathbf{v}_i) = \Sigma\, I(\mathbf{w}_i,\mathbf{v}_i)$



WiFi ids

x={1011100}
y={0011000}

D(x,y) = 2

Image taken from "*SensLoc: Sensing Everyday Places and Paths using Less Energy*", ACM Sensys 2010

but wait …

you can also do a bunch of other useful stuff with accelerometers

you can detect potholes and traffic conditions

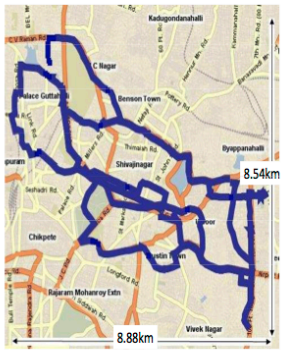


Figure 1: Map of Bangalore with drive routes highlighted

Figure 2: A typical chaotic road intersection with variety of vehicles at loggerheads

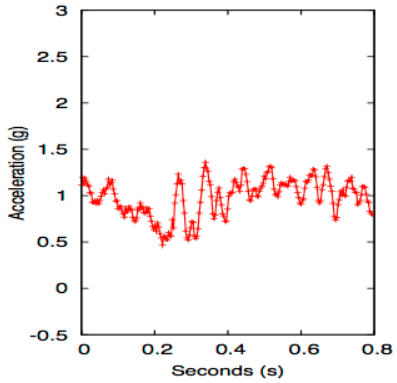


Figure 6: a_Z when traversing a bump at low speed

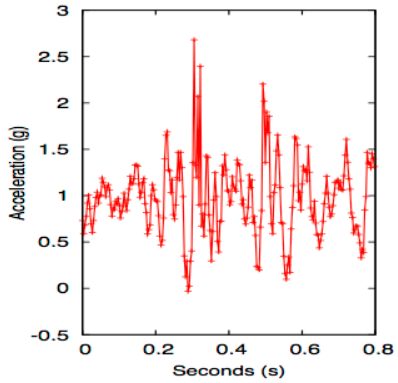
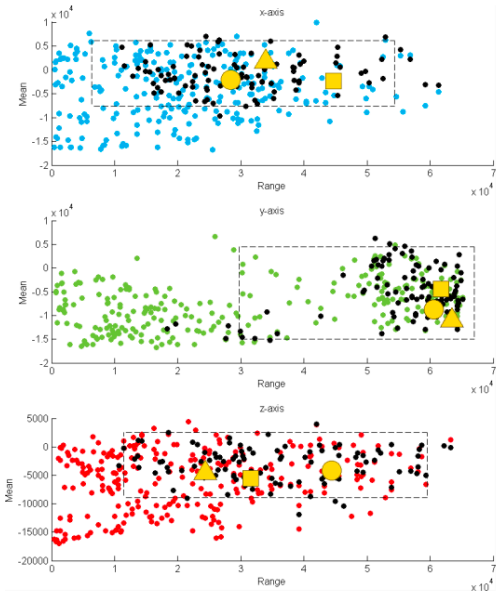


Figure 7: a_Z when traversing a bump at high speed

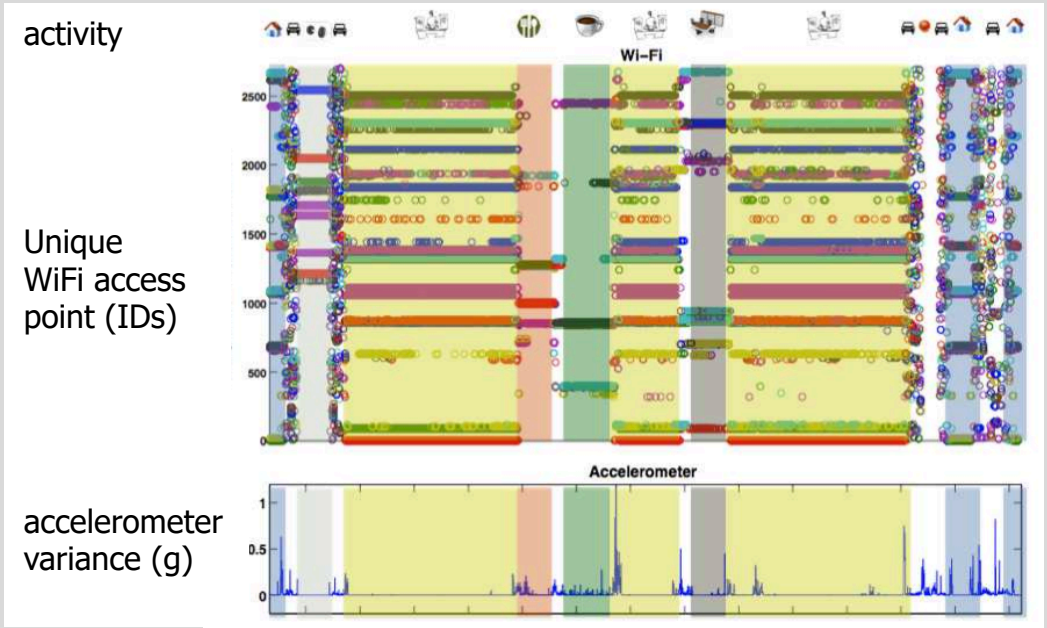
We can detect potholes using accelerometers

Paper: "*Nericell: Rich Monitoring of Road and Traffic Conditions using Mobile Smartphones",* ACM SenSys 2008

A nice example: Shake on



Now let's use k-NN for localization



WiFi ids

x={1011100}
y={0011000}

D(x,y) = 2

Step 1) raw data. Each scan gives you the id of the Access Point and its rss
(time_stamp, <id_1, rss_1> <id_2, rss_2> … <id_n,rss_n>)
Step 2) What features would you use?
Step 3) How would you use k-NN to obtain location information?

Image taken from "*SensLoc: Sensing Everyday Places and Paths using Less Energy*", ACM Sensys 2010

K-NN is a top-10 machine learning tool

- A formal definition:
  - A supervised method: training & testing.
  - **x** features, Y label: (xi, xj, …., Y)
- KNN is non parametric
  - does not make any assumption on underlying data distribution. This is very useful!
- Simple training, costly testing (in time and memory)
- Data (features) are in a metric space.
- Very good for being that simple:

  for K=1: $P^* \leq P \leq P^* (2 - c/(c-1) P^*$

  where "P" is the 1-NN error, "P*" is the Bayes error and c is the number of classes

More theory of KNN: https://www.cs.rit.edu/~rlaz/PatternRecognition/slides/kNearestNeighbor.pdf

POINTERS

Pointers: theory (1)

- K-NN:
  - http://en.wikipedia.org/wiki/K-nearest_neighbor_algorithm
  - http://ocw.mit.edu/courses/electrical-engineering-and-computer-science/6-034-artificial-intelligence-fall-2010/tutorials/MIT6_034F10_tutor03.pdf
  - http://saravananthirumuruganathan.wordpress.com/2010/05/17/a-detailed-introduction-to-k-nearest-neighbor-knn-algorithm/
- Mahalanobis distance:
  - http://en.wikipedia.org/wiki/Mahalanobis_distance
  - http://stats.stackexchange.com/questions/62092/bottom-to-top-explanation-of-the-mahalanobis-distance

Pointers theory (2)

- What's going on in other schools
  - UIUC: http://www.ece.illinois.edu/mediacenter/article.asp?id=1274
  - Darmouth: http://www.cs.dartmouth.edu/~campbell/smartphonesensing.html