Lecture 02
SmartPhone Sensing

Today's menu

- Recap/Finish KNN for localization
- Localization
  - Bayesian Inference (Bayesian Filters)
  - Particle Filters
- Parts of this lecture are based on content from
  - "Artificial Intelligence for Robotics"
    - https://www.udacity.com/course/cs373
    - This is an *excellent* course from Udacity.
  - "A Tutorial on Particle Filters for Online Nonlinear/Non-Gaussian Bayesian Tracking"
    - http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=00978374

but wait …

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

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

you can detect potholes and traffic conditions

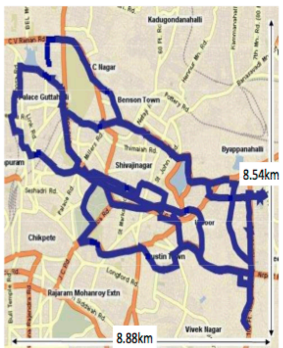


Figure 1: Map of Bangalore with drive routes highlighted

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

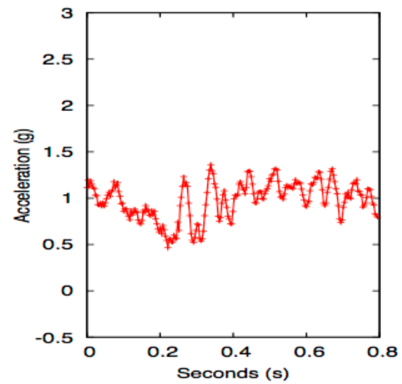


Figure 6: a_Z when traversing a bump at low speed

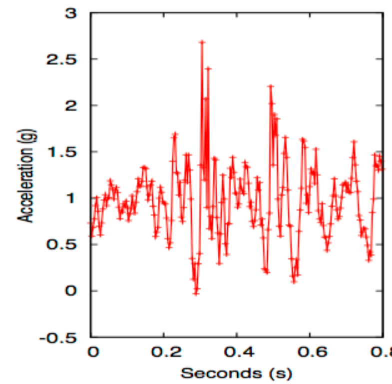
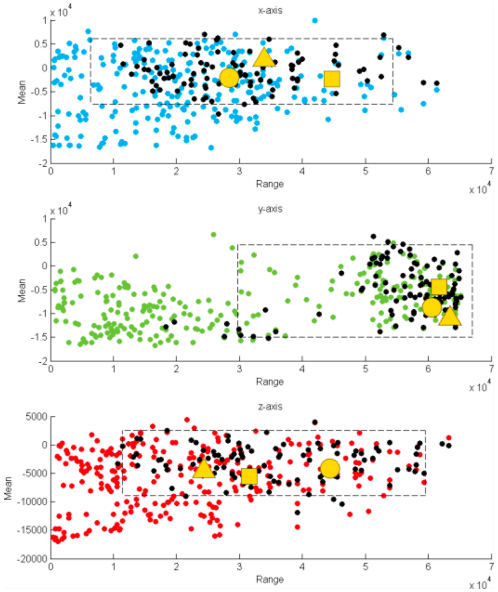


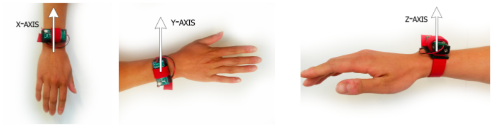
Figure 7: a_Z when traversing a bump at high speed

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





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

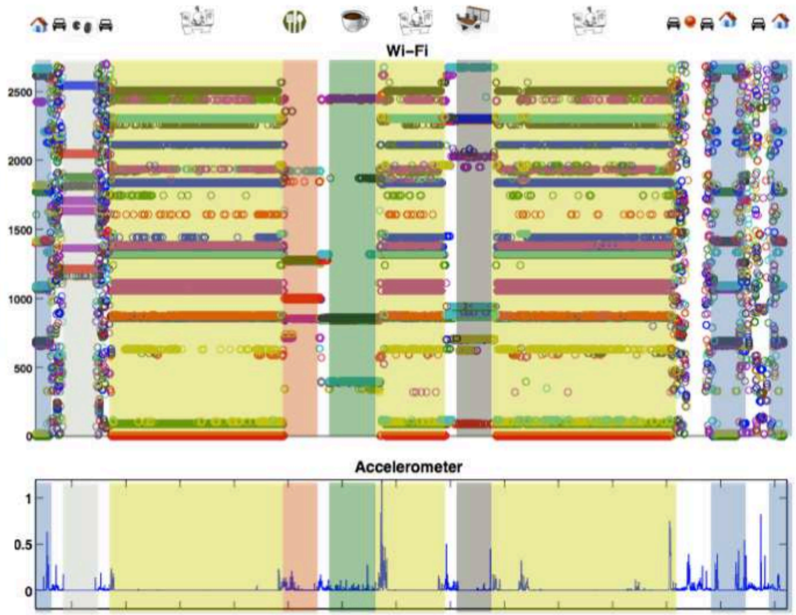
More theory of KNN: https://www.cs.rit.edu/~rlaz/PatternRecognition/slides/kNearestNeighbor.pdf

Now let's use k-NN for localization

activity

Unique
WiFi access
point (IDs)

accelerometer
variance (g)



time

WiFi ids

x={1011100}
y={0011000}

D(x,y) = 2

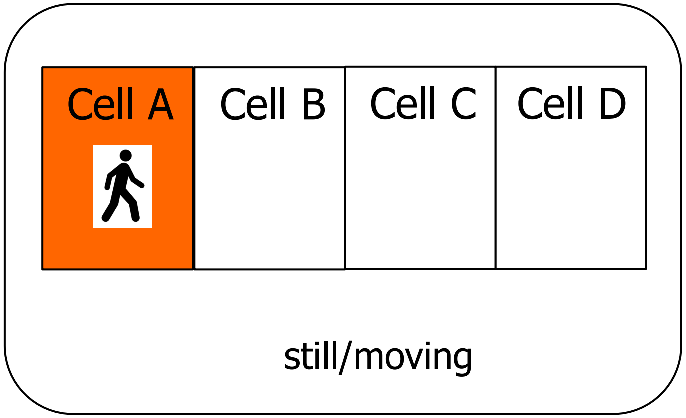
Step 1) raw data. Each scan gives you the id of the Access Point (SSID) and its rss
(time_stamp, $<id_1, rss_1>$ $<id_2, rss_2>$ … $<id_n,rss_n>$)
Step 2) What features would you use?
Step 3) How would you use k-NN to obtain location information?

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

Step by Step guidelines for first report

- Step 1) Get rss and acc data
  - Use Android sample code
- Step 2) Identify features to train your data.
  - Divide the raw data in windows
  - For each window identify features
  - Label training data and save it in the phone
- Step 3) test your data
  - Get raw data, divide it windows, get features
  - Apply KNN to classify your data
  - Show the classified label in the phone

Guidelines for App



(1) Determine where you are among four zones and
(2) Determine if you are still or walking

Code & load sharing

"Software engineers do not like to write code, they like to copy/paste it", anonymous

- Build on top of what it is there, but cite it in your report.
- By all means share knowledge and pointers amongst yourselves but give credit to your (peer) source in your report.
- Balance the work. Else one passes and the other doesn't.

LET'S HAVE A BIRD'S EYEVIEW OF THE TECHNIQUES

The core of the course

App option 1: Localization

Basic localization & Activity monitoring

- kNN

Advanced localization

- **Bayesian filters**
- **Particle filters**
- Log normal shadowing
- Visible Light Communication

CONDITIONAL PROBABILITIES

Quick test on conditional probabilities

- P (A/B) = P (A and B) / P(B)

  = P(B/A) P(A)/P(B)

- The probability a person is 1.90 m tall is 0.05, the probability a person is Dutch and is 1.90 m tall is 0.01. What is the probability that a person is Dutch given that the person is 1.90 m tall?

Solution

A = person is Dutch
B = person is 1.9m tall

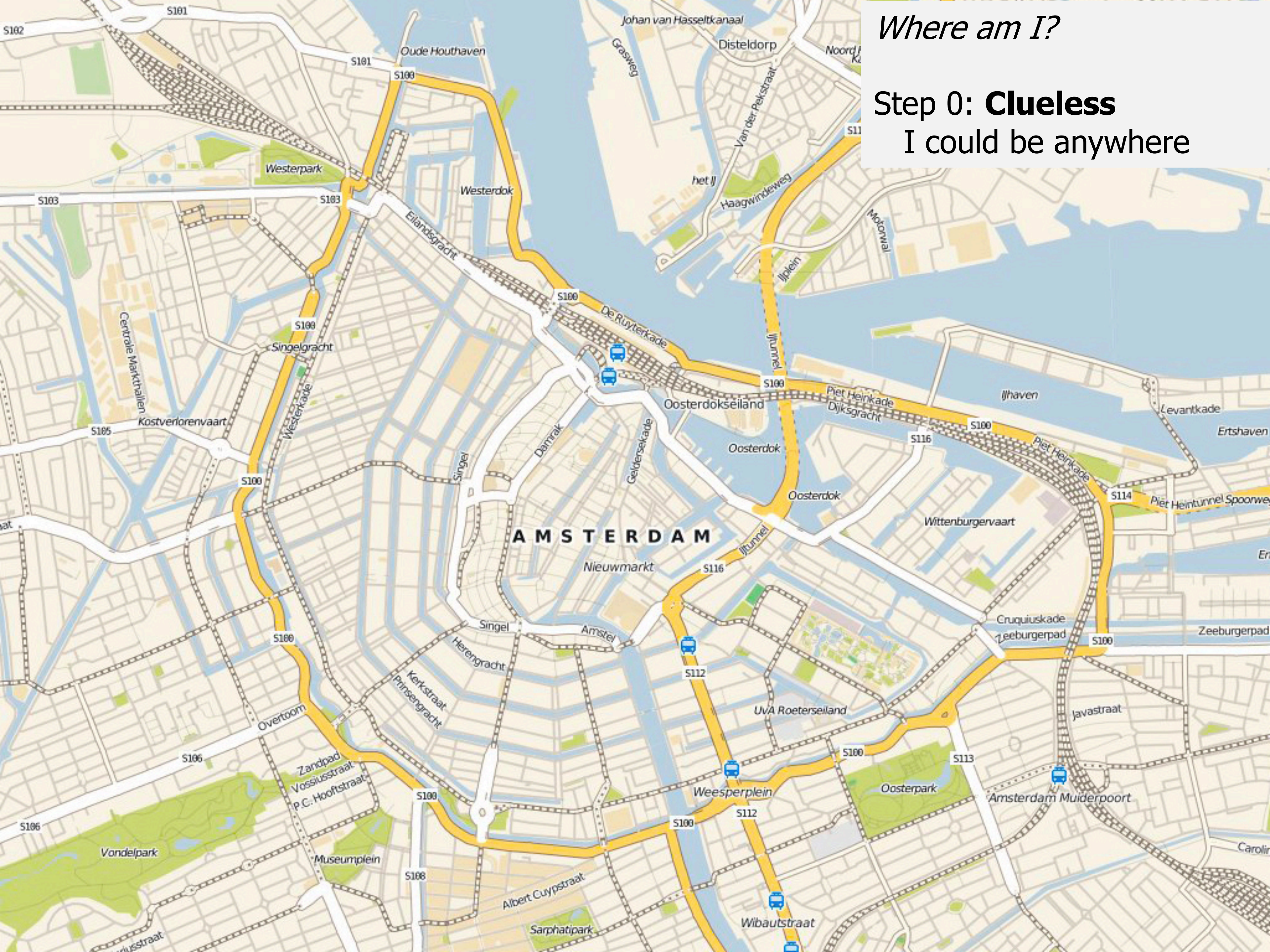
$P(A \text{ and } B) = 0.01$
$P(B) = 0.05$

$$P(A/B) = P(A \text{ and } B)/P(B) = 0.01/0.05 = 20\%$$

LOCALIZATION BASICS

Where am I?

Step 0: **Clueless**
I could be anywhere



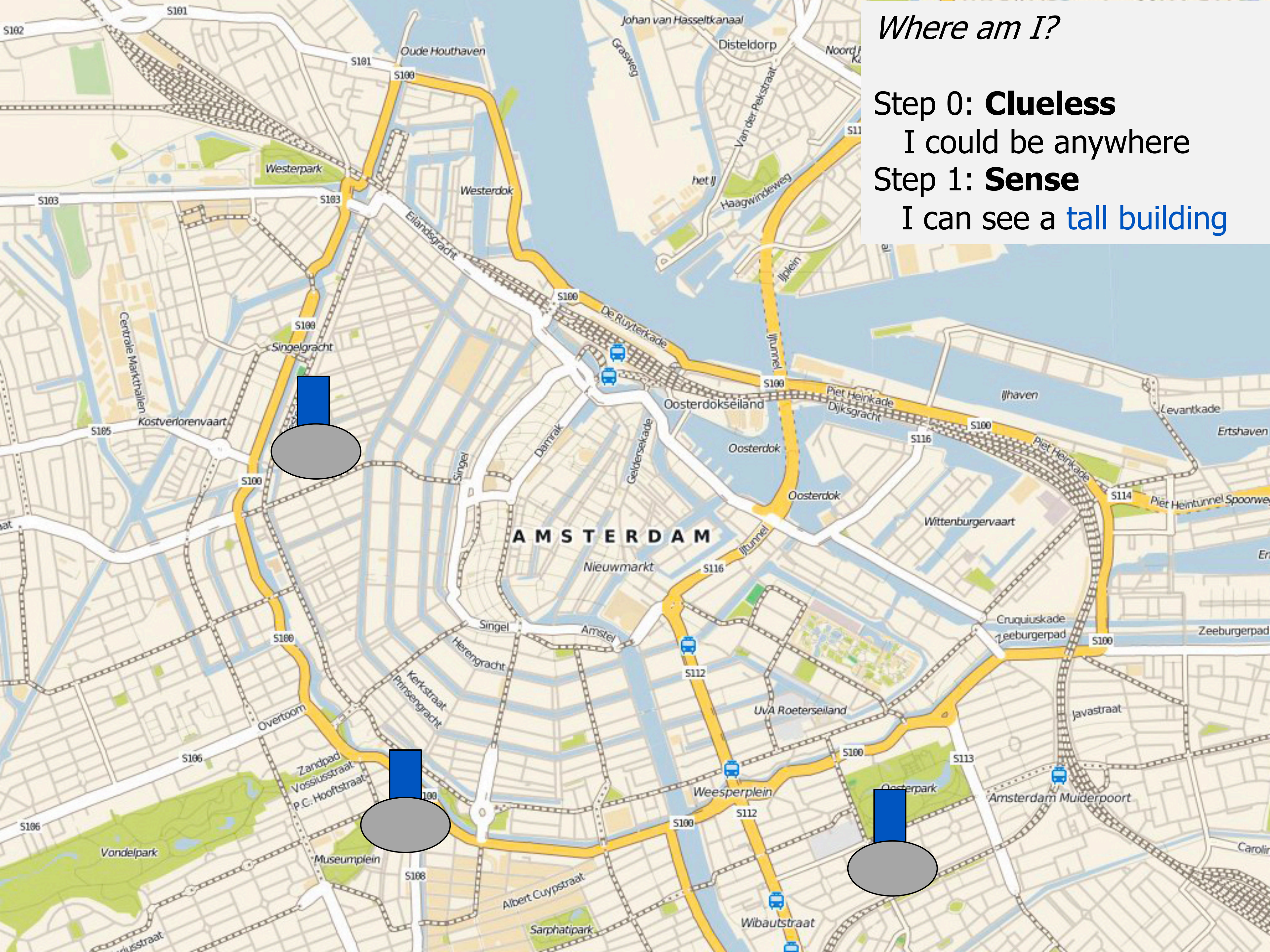
Where am I?

Step 0: **Clueless**

I could be anywhere

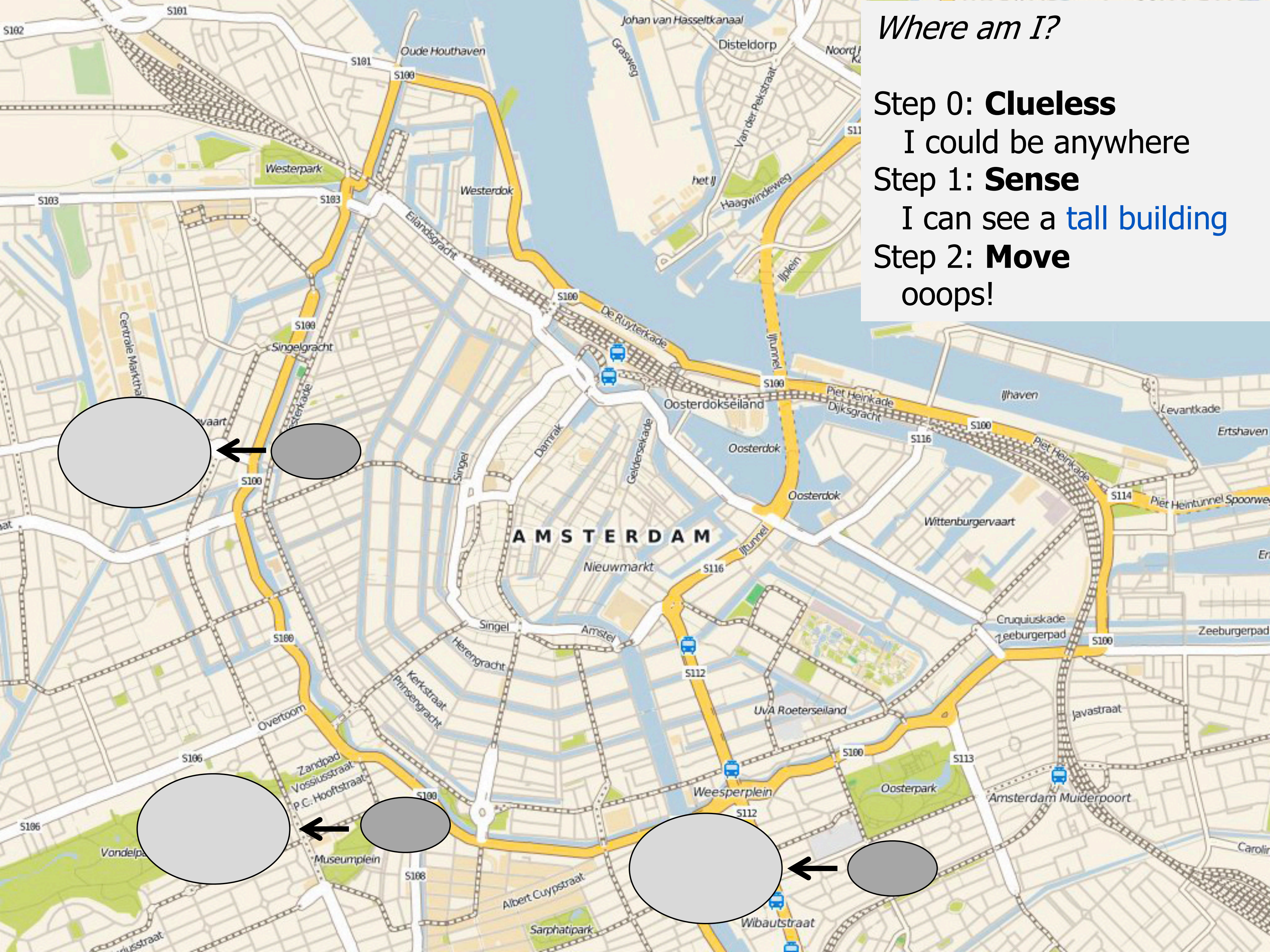
Step 1: **Sense**

I can see a tall building



Where am I?

Step 0: **Clueless**
I could be anywhere
Step 1: **Sense**
I can see a tall building
Step 2: **Move**
ooops!



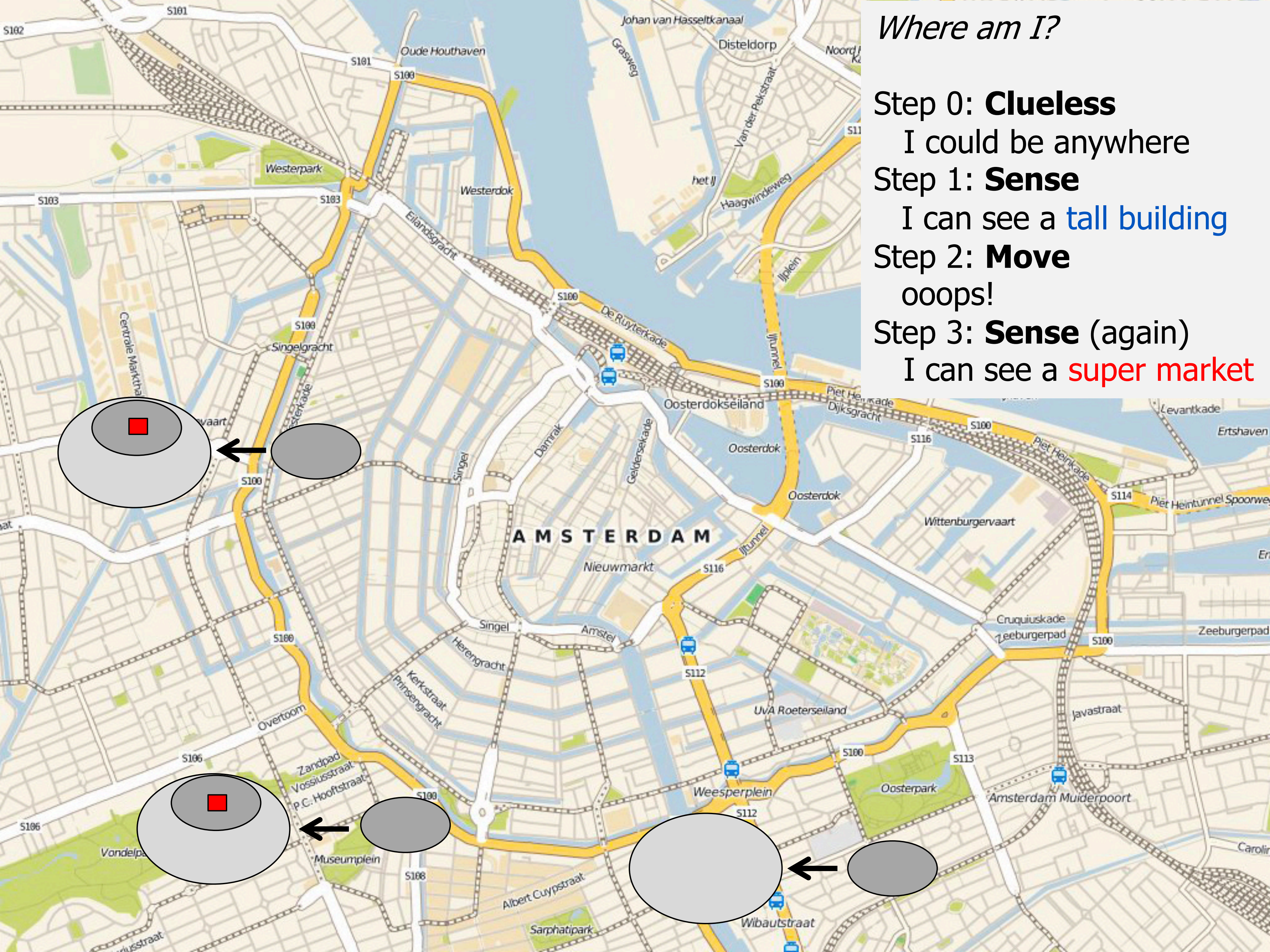
Where am I?

Step 0: **Clueless**
I could be anywhere

Step 1: **Sense**
I can see a tall building

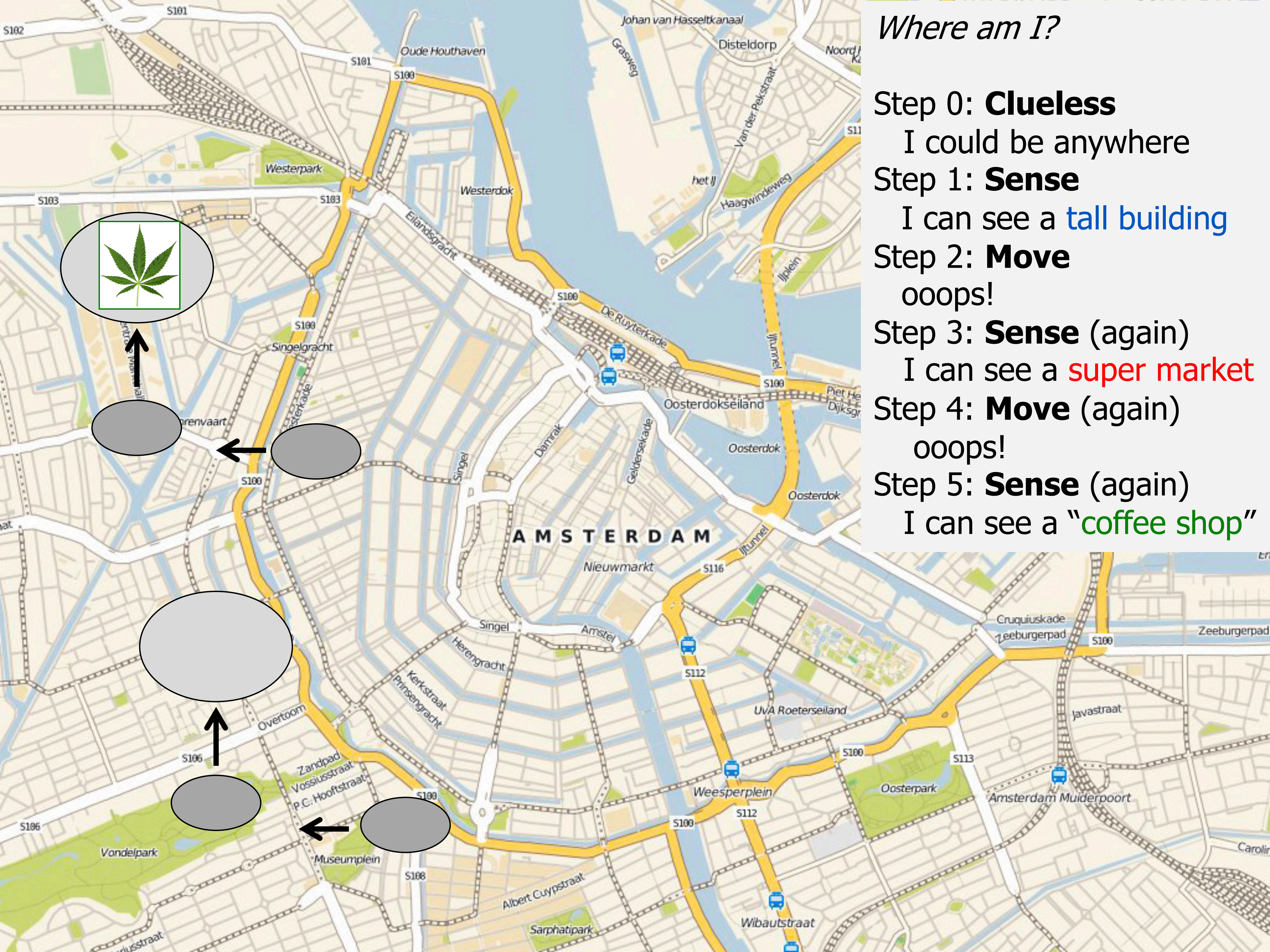
Step 2: **Move**
ooops!

Step 3: **Sense** (again)
I can see a super market



Where am I?

Step 0: **Clueless**
I could be anywhere
Step 1: **Sense**
I can see a tall building
Step 2: **Move**
ooops!
Step 3: **Sense** (again)
I can see a super market
Step 4: **Move** (again)
ooops!
Step 5: **Sense** (again)
I can see a “coffee shop”



Where am I?

Step 0: **Clueless**
I could be anywhere

Step 1: **Sense**
I can see a tall building

Step 2: **Move**
ooops!

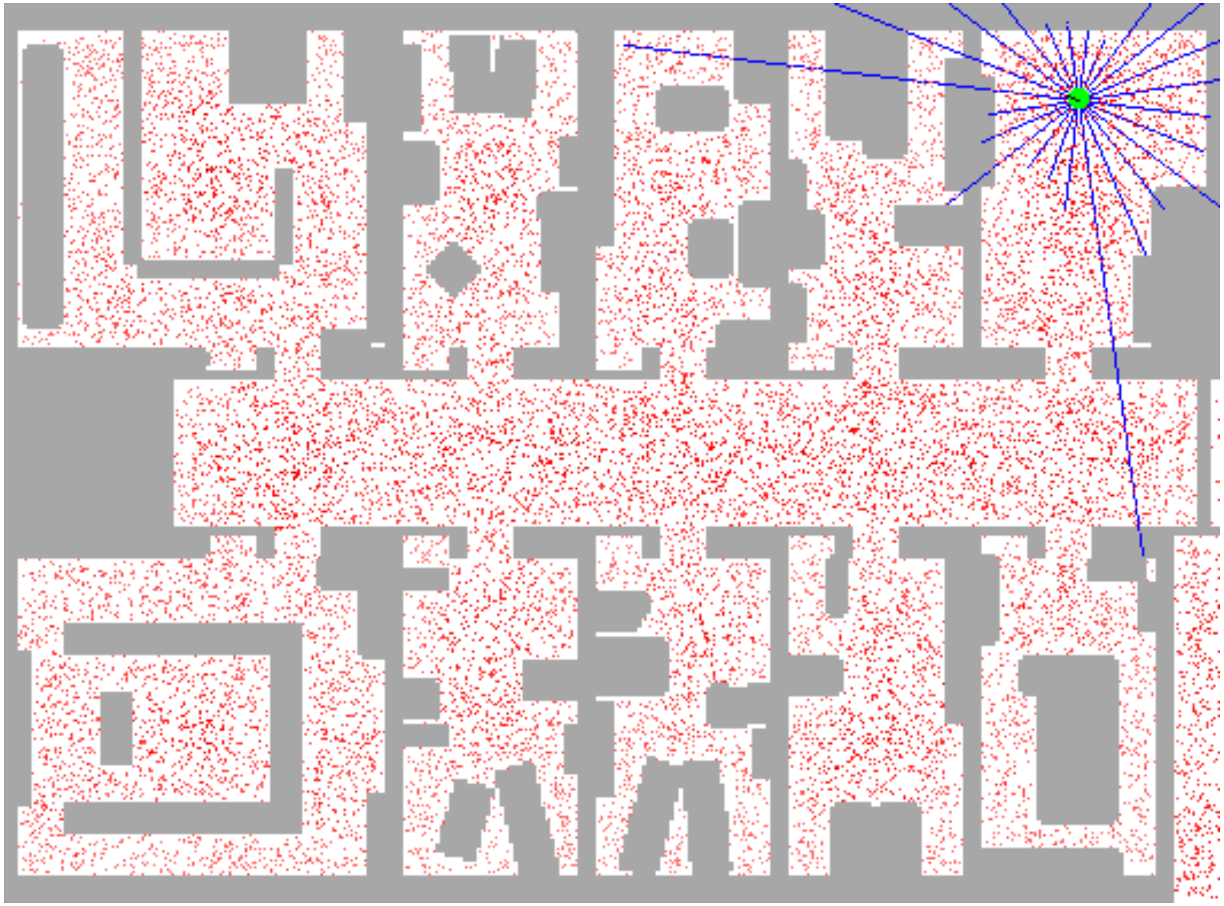
Step 3: **Sense** (again)
I can see a super market

Step 4: **Move** (again)
ooops!

Step 5: **Sense** (again)
I can see a “coffee shop”

I know where I am!

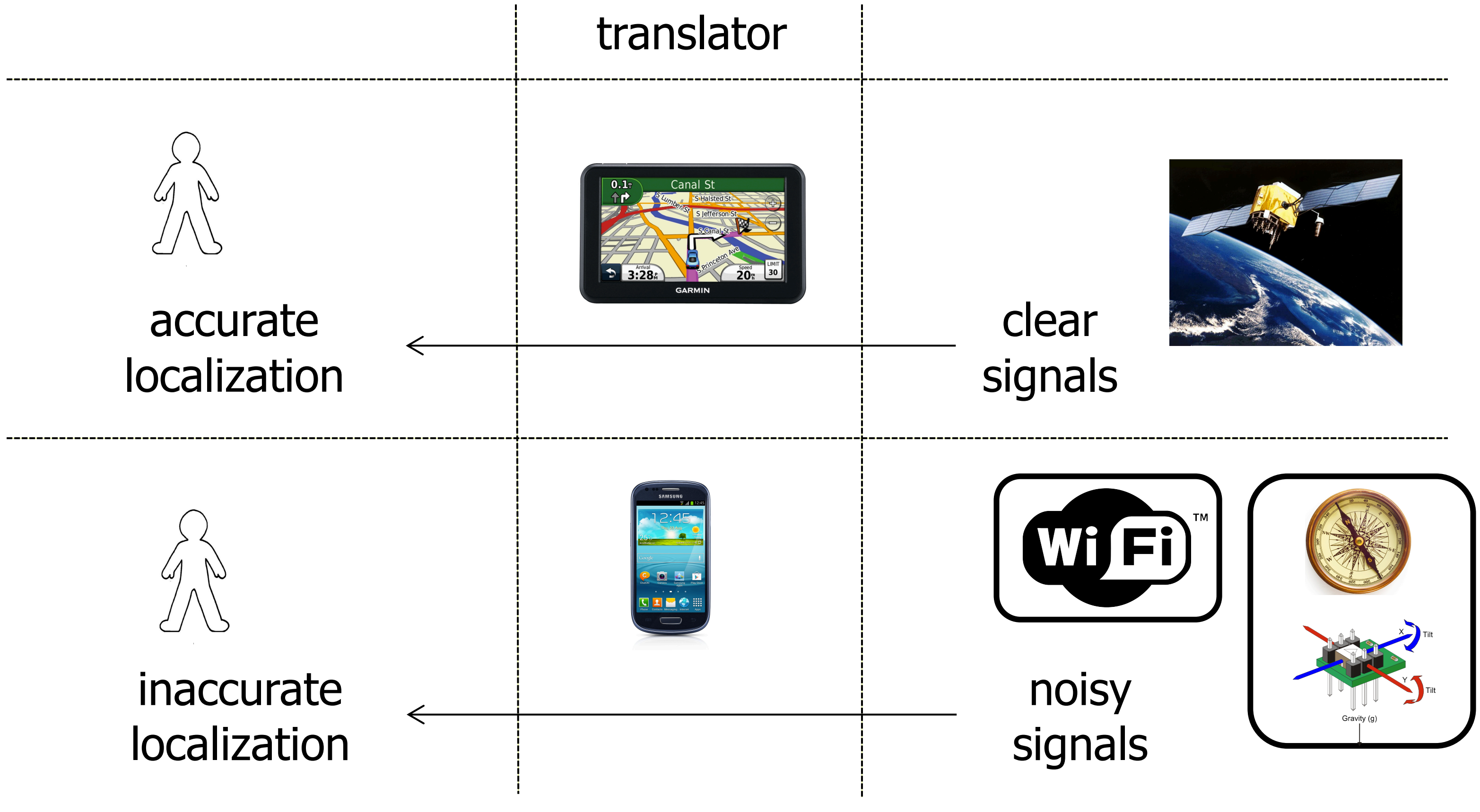
Now, a real evaluation of particle filters



movie link: http://robots.stanford.edu/movies/sca80a0.avi

The problem

You only get indirect noisy information of what you want

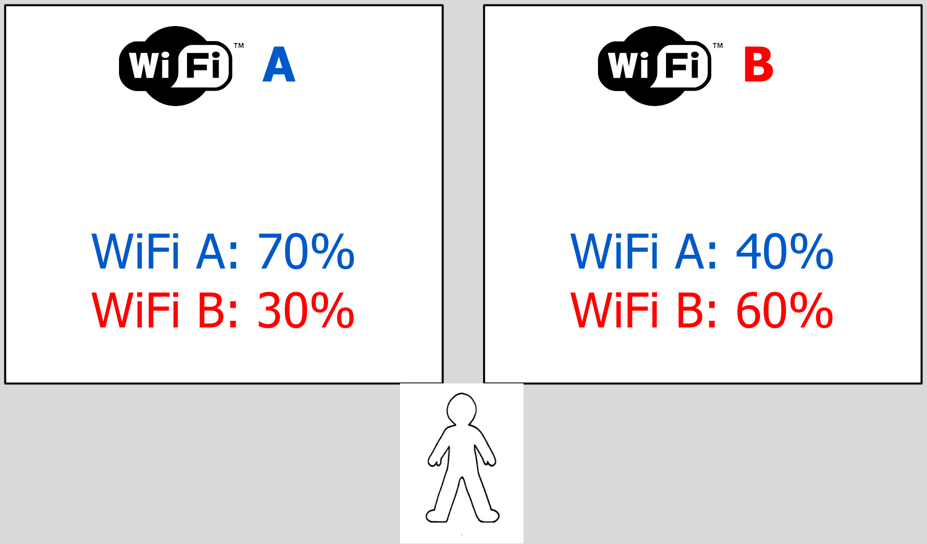


Teaser

$$P(A/B) = P(A \text{ and } B) / P(B)$$
$$= P(B/A)\,P(A)/P(B)$$

Room A

Room B



Initially the person can be anywhere. Either on cell A or cell B. What is the probability that the person is in cell A, given that it hears WiFi A?

Solution

A = person is in cell A

B = person is in cell B

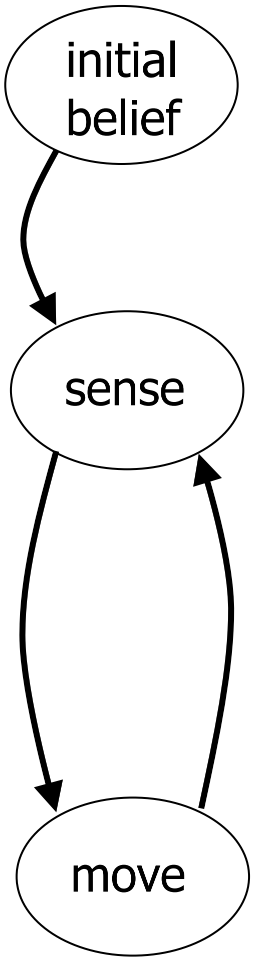
$Wifi\_A$ = person hears WiFi A

$$P(A/Wifi\_A) = P(Wifi\_A/A) * P(A) / P(Wifi\_A)$$
$$= 0.7 * 0.5 / P(Wifi\_A)$$

$$P(Wifi\_A) = P(Wifi\_A/A) * P(A) + P(Wifi\_A/B) * P(B)$$
$$= 0.7 * 0.5 + 0.4 * 0.5 = 0.55$$

$$P(A/Wifi\_A) = 0.35 / 0.55 = 7/11$$

You may have not realized it, but you already know the gist of Particle (and Bayesian) filters! Below, X represents location and Z measurements



current pdf (**posterior**) | perception model (sense) | pdf from last time step (prior)

$$p(X_k \mid Z_{1:k}) = \frac{p(Z_k \mid X_k) \quad p(X_k \mid Z_{1:k-1})}{p(Z_k \mid Z_{1:k-1})}$$

normalization

current pdf (**posterior**) | motion model (move) | pdf from last time step (prior)

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

Paper: "A Tutorial on Particle Filters for Online Nonlinear/Non-Gaussian Bayesian Tracking", IEEE Trans. Signal Processing, 2002.

Bayesian and particle filters are *very* popular and useful

- Job interviews at companies and universities

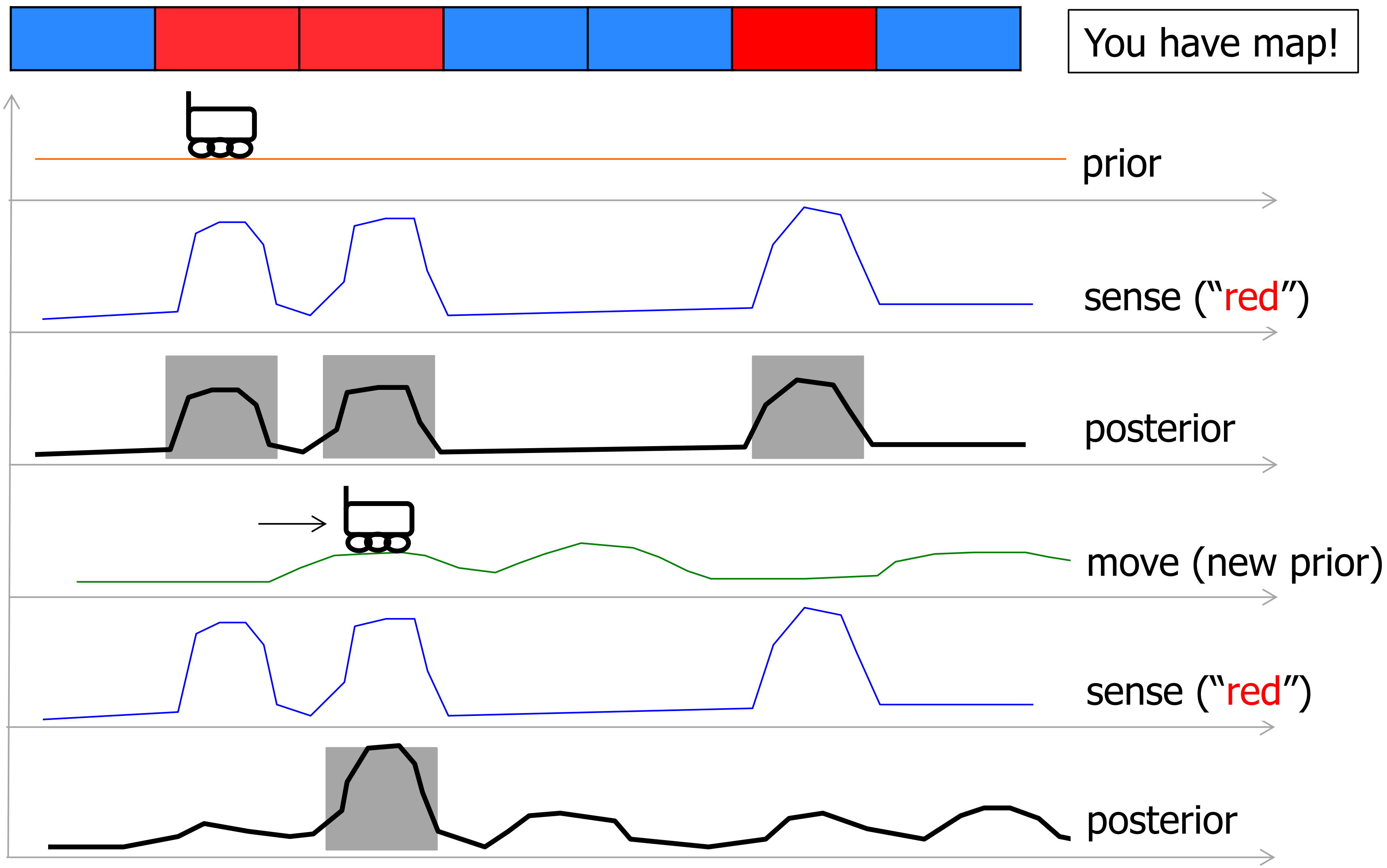
- Self driving cars
  - In deserts: DARPA challenge winner
  - In cities: GPS is not accurate enough

- Particle filters are a general tool (1990's)
  - The problem: Tracking the state of a system as it evolves over time
  - We have: Sequentially arriving (noisy or ambiguous) observations
  - We want to know: Best possible estimate of the hidden variables

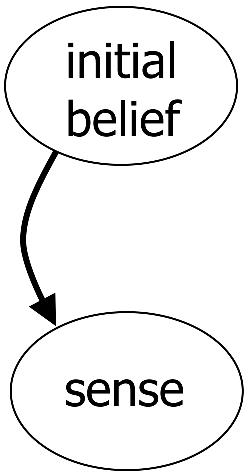
Localization, the discrete case

BAYESIAN INFERENCE

Bayesian Filter in one slide



First let's look at the sensing part

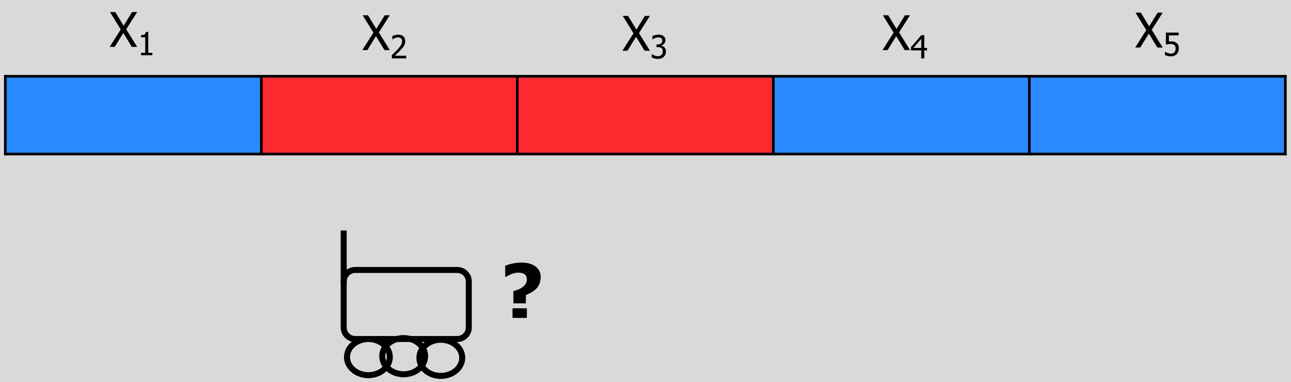


current pdf (**posterior**) = perception model (sense) × pdf from last time step (prior) / normalization

$$\underbrace{p(X_k \mid Z_{1:k})}_{\text{current pdf (posterior)}} = \frac{\underbrace{p(Z_k \mid X_k)}_{\text{perception model (sense)}} \; \underbrace{p(X_k \mid Z_{1:k-1})}_{\text{pdf from last time step (prior)}}}{\underbrace{p(Z_k \mid Z_{1:k-1})}_{\text{normalization}}}$$

Initial belief

a robot ***has a map*** of the grid below, but it doesn't know where it is, what is its initial belief?



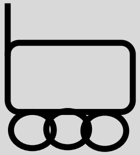
Sense

perception model

p(z="red" | Xi is "red") = 0.6 p(z="blue" | Xi is "blue") = 0.8

p(z="blue" | Xi is "red") = 0.4 p(z="red" | Xi is "blue") = 0.2

X_1	X_2	X_3	X_4	X_5
0.2	**0.2**	**0.2**	**0.2**	**0.2**



Exercise: 'Xi' represents cell i.
'z' is the sensing measurement

Question: the observation z is "red",
what is the new belief?