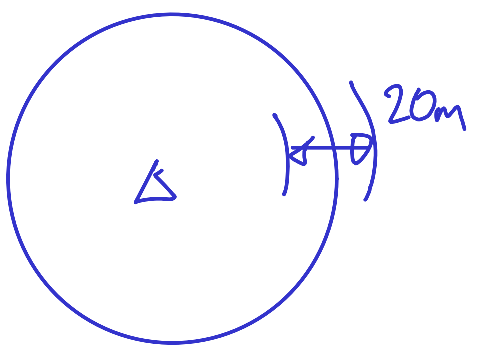
ToA: Requirements

- We aim to time how long a signal takes to travel from transmitter to receiver
- We need to start and stop a virtual stopwatch
  - **Start**: sync the clocks
  - **Stop**: cross-correlate the signal with what we believe was sent

ToA: Timing Accuracies

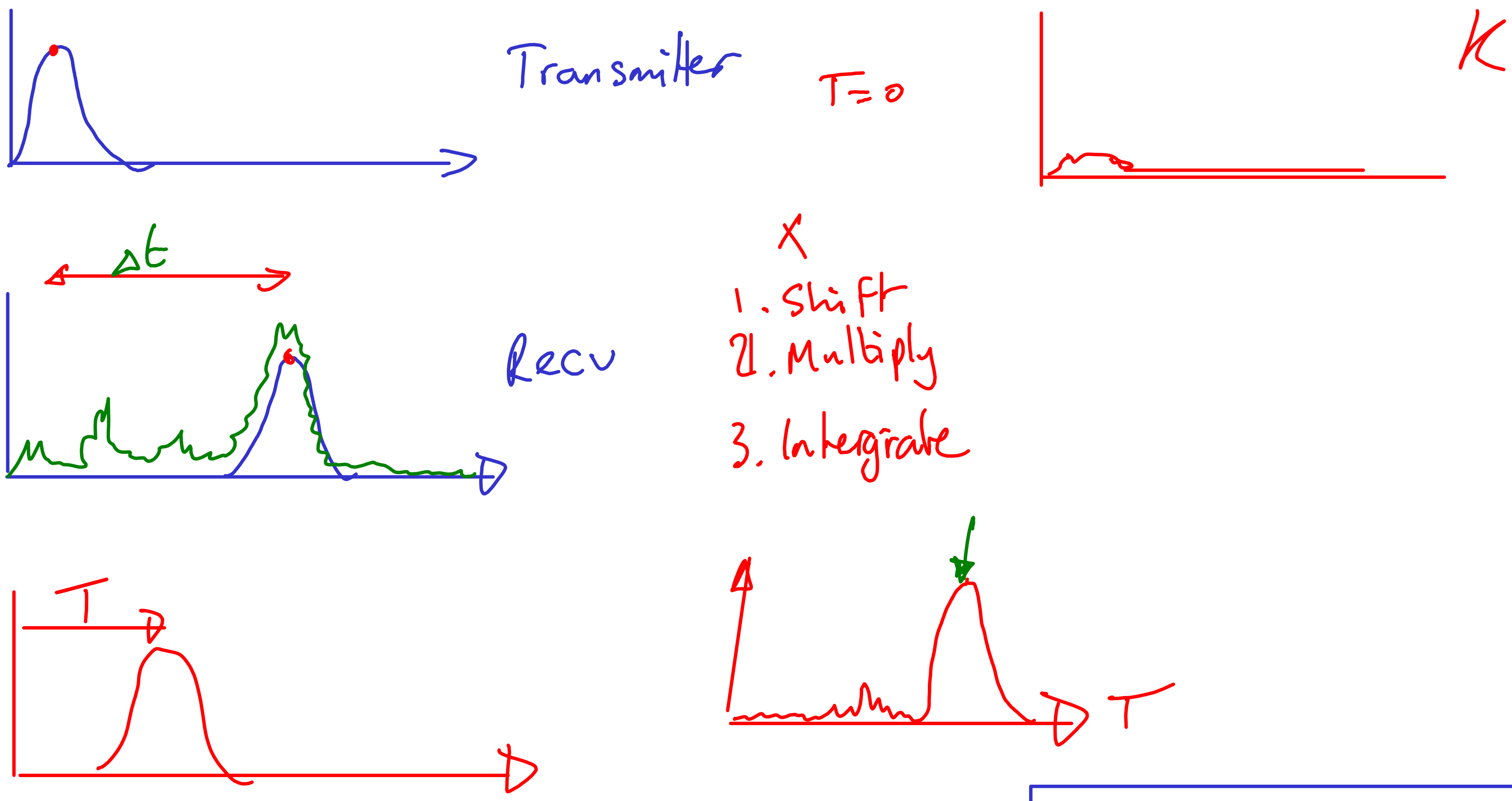


Signal speed c

$$\delta t = \frac{10}{c}$$

$$= \frac{10}{3 \times 10^8} = 30ns$$

ToA: Cross Correlation



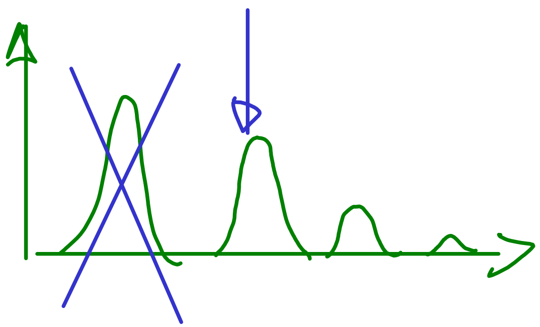
$$[f \star g]_i = \int_{j=-\infty}^{\infty} f_j g_{i+j}$$

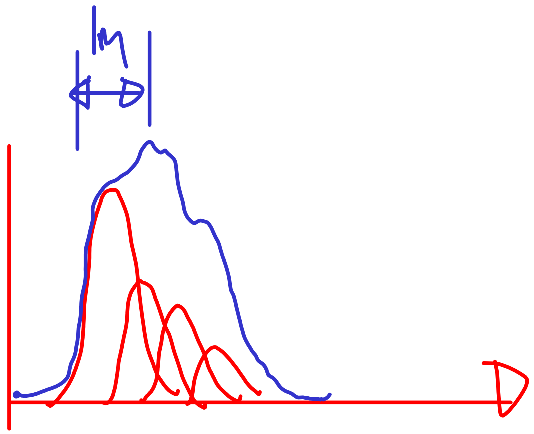
Multipath

- Multipath (signals bouncing around) can get us in two ways:

1) If we **don't** get the direct signal, we will mistakenly use the first bounce

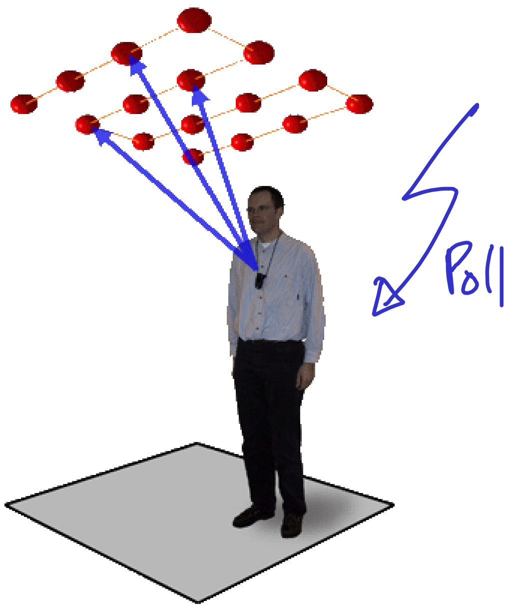
2) If we **do** get the direct signal, we might lose it in the reflections





ToA: The Bat System

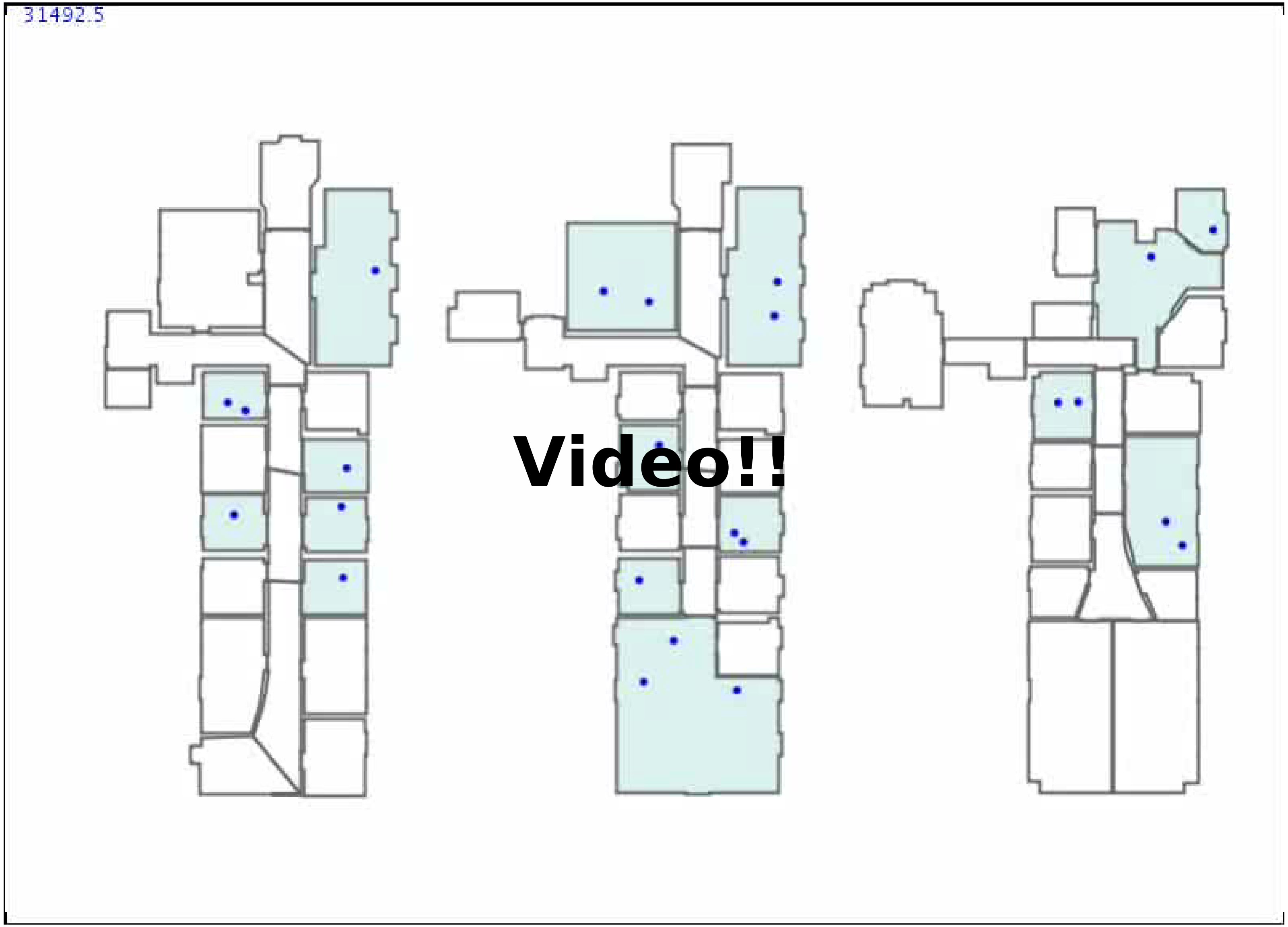
- Put lots of ultrasonic receivers in the ceiling (avoid multipath)
- Add a radio channel
- Radio polls each Bat, causing it to emit ultrasound



ToA: The Bat System

- Key Points
  - Got around the sync problem by using ultrasound, which moves so much slower that relatively big timing errors correspond to quite small distances
  - Needs to see at least 3 receivers to get a position
    - WGB deployment uses over 400 for one corridor!!
    - Each one has to be carefully surveyed...
  - 3cm accuracy 95% of the time (in 3D!)

Demo

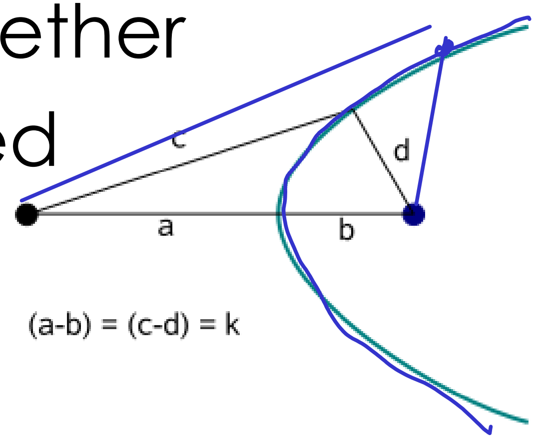


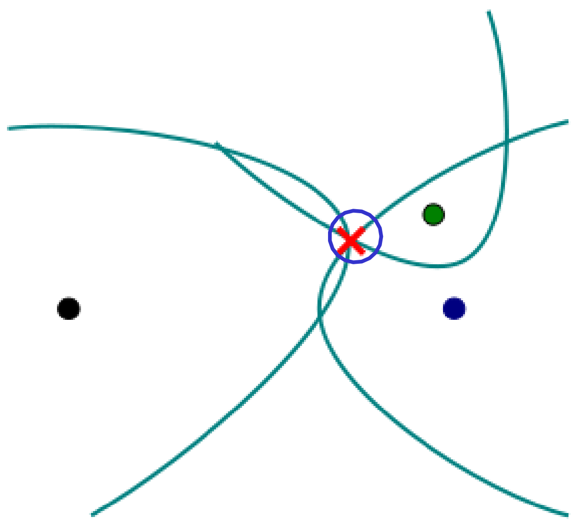
ToA: Realities

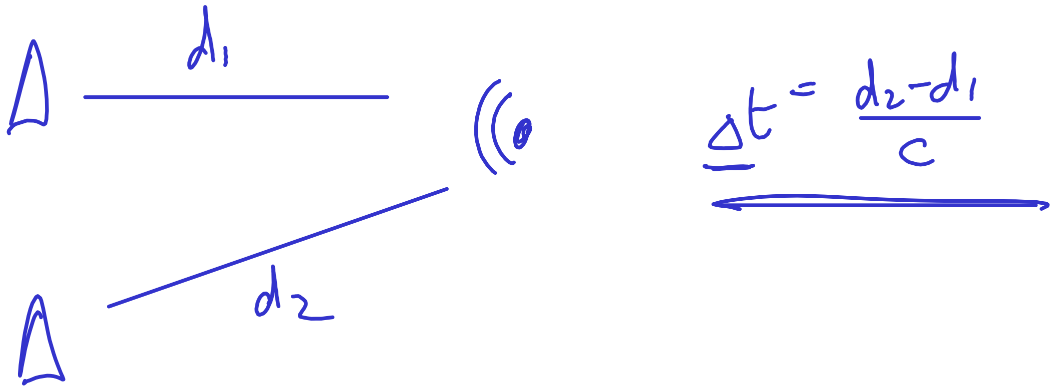
- To be commercially realistic, we usually need radio so we don't need lots of receivers in each room
- In practice, the <u>**sync**</u> is then a real problem
  - Wireless sync to nanoseconds is **hard** and **expensive**
- And <u>**multipath**</u> is a major issue too as we saw

TDoA Systems

- Time Difference of Arrival
  - Base stations synced together
  - But mobile unit **not** synced







TDoA: Mobile Phones

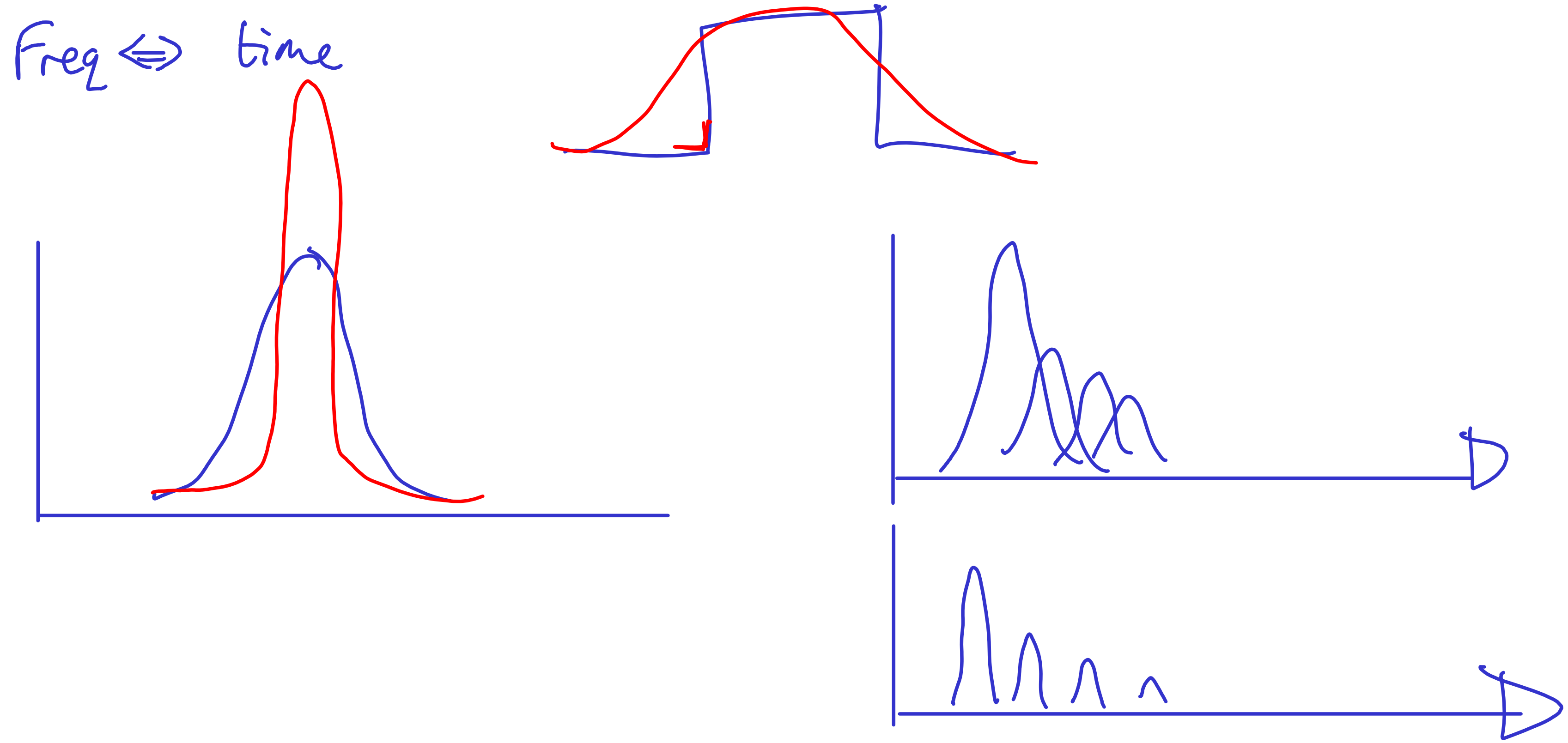
- U-TDoA
  - Modify BTSs to listen for phones that they aren't the serving cell for
  - Capture the same signal at multiple BTSs and apply standard TDoA
  - Not bad for outdoors: 150m 95%
  - Not good enough indoors

TDoA: Ubisense

- The guys who made the Bat system (here!) went on to found Ubisense
  - Same basic system but dispensing with the ultrasound and using ultra wideband radio (UWB)
    - This is radio with a really big range of frequencies
    - 1GHz-10GHz (all of it!)
    - Huge data bandwidth (obviously) so it's being pushed as a way to wirelessly connect monitors etc.
    - But it has another advantage for location...

Ubisense: UWB

- The key is that wide ranges in the frequency domain mean narrow ranges in the time domain (remember Fourier Transforms?)...



Ubisense: UWB

- ...and this is better for indoor multipath!

Pulses thinner ~ns

Discard reflection

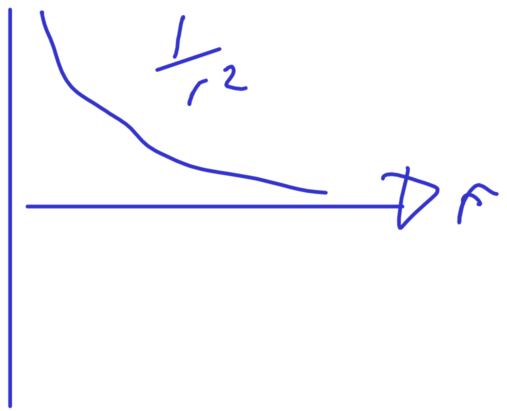
Ubisense

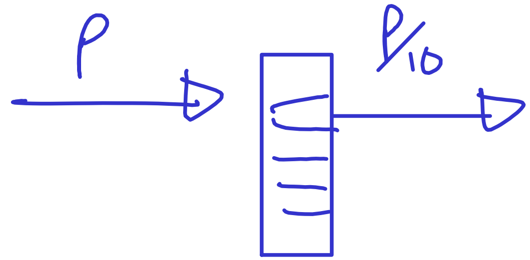
- So now we can discard multipathed signals and apply TDoA to get positions using a radio system (note that we can't do ToA because everything's at light speed).
  - Average of 1 sensor per room
  - Accuracy around 15cm 95% (3D)
  - Commercially viable! But bloody expensive just now! ;-)

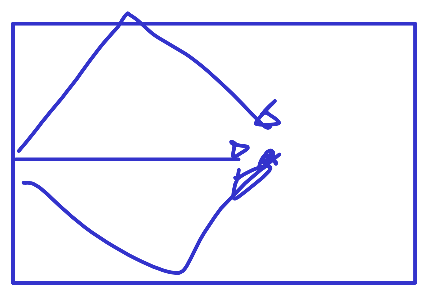
Fingerprinting

- UWB is rather too pricey for most just now, so can we get sub-metre accuracies using 'normal' radio? Perhaps...

- Option 1: Radio Propagation Models

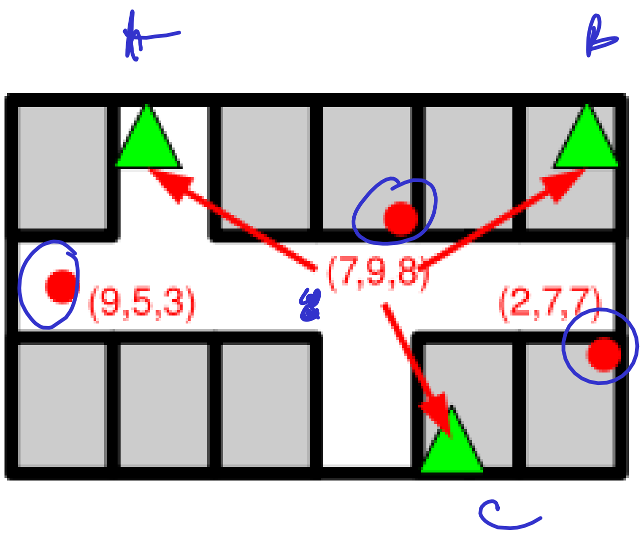


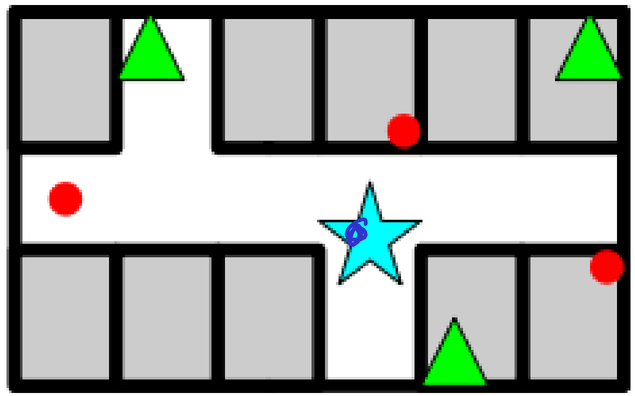




Fingerprinting

- Option 2: Fingerprinting
  - Positioning becomes pattern matching

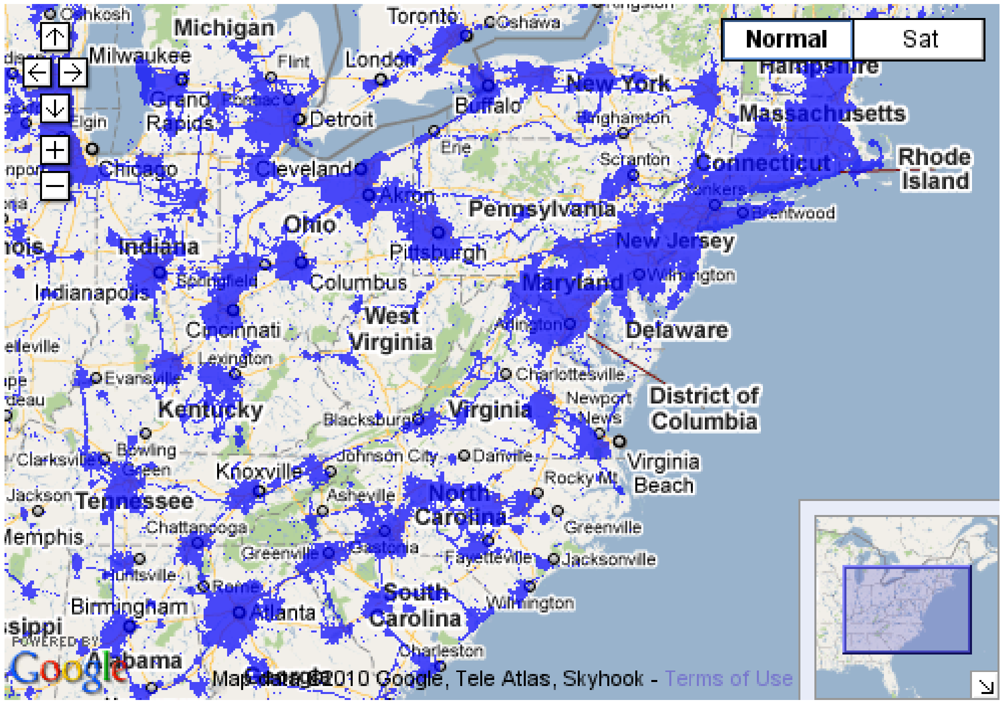




(8,8,7)

Fingerprinting: Does it work?

- Outdoors/large scale
  - Definitely: Skyhook, iPhone, Google (?)

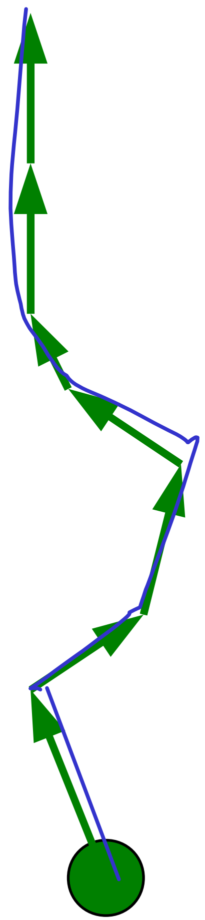


Fingerprinting: Does it work?

- Indoors/small scale
  - Possibly: Lots of research reports accuracies of a few metres
    - But some suspect methodologies
  - And you do need to increase the density of wifi points (not so free!)
  - No long term studies

Inertial (Dead Reckoning)

- *Relative* positioning rather than *absolute*
- Any sensor that can be used to give us *changes* in position
- E.g. Accelerometers

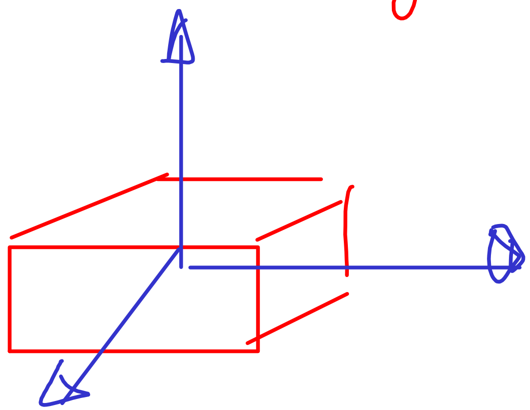


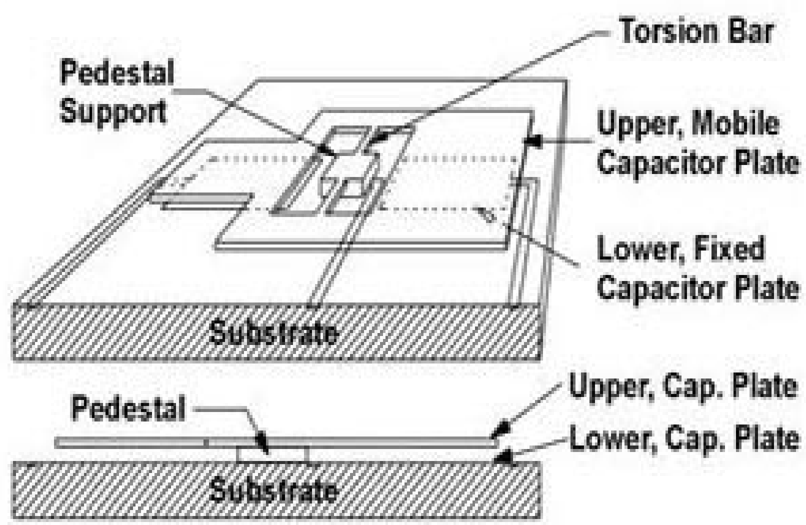
MEMS

- Micro Electro-Mechanical Systems

Xsens

Don't measure in global frame



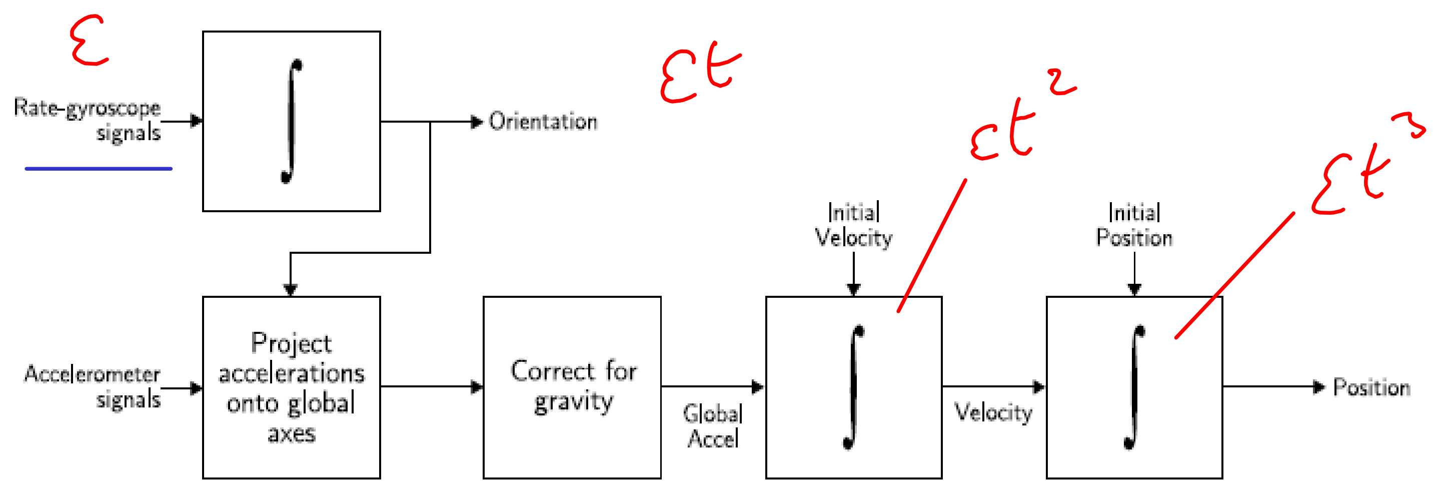


Common IMU sensors

- 3D Accelerometers (accelerations)
- Rate-gyros (angular velocity)
- Magnetometer (bearing)

Common IMU sensors

1) Resolve the accelerations into a global frame (magnetometer may help here)
2) Integrate angular vel. To get heading change.
3) Subtract gravity from a_z
4) Integrate accel. To get velocity
5) Integrate velocity to get change in position



More detail...

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UNIVERSITY OF CAMBRIDGE
Computer Laboratory

Overview

- Proximity
  - Bluetooth, WiFi, RFID
- Angle of Arrival
  - Pirate radio, seek and destroy
- Time of Arrival
  - Bat system
- Time Difference of Arrival
  - Mobile phones,
  - Ubisense
- Fingerprinting
  - WiFi, GSM
- Inertial