Mobile Software Technologies (SW8/CS-iT8)

2. Location Based Services (LBS)

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Agenda

- LBS in General
- Positioning and Tracking
- Map Matching

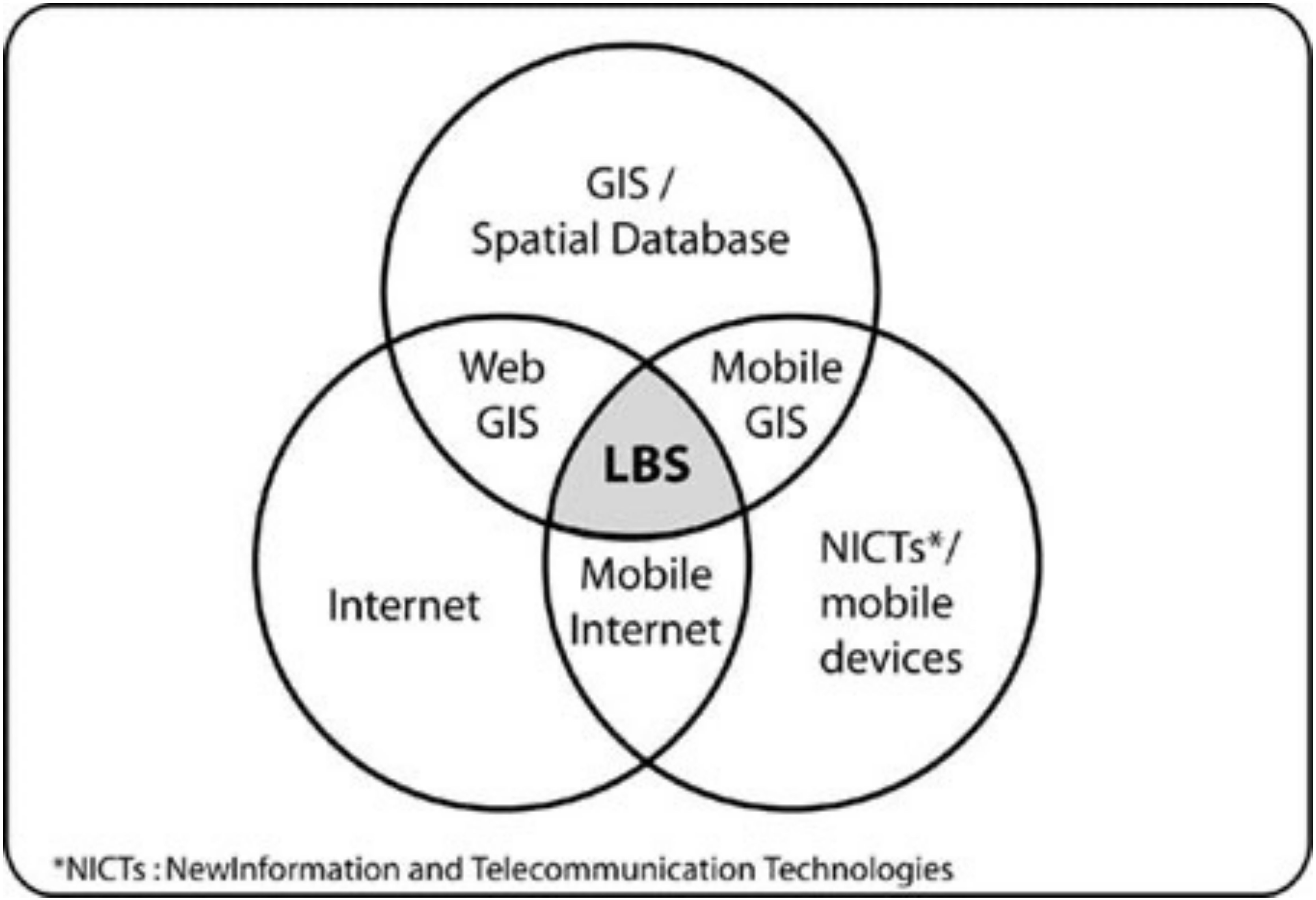
Definitions

- **Definition 1**
  - LBS's are information services accessible with mobile devices through the mobile network and utilizing the ability to make use of the location of the mobile device. (Virrantaus et al. 2001)

- **Definition 2**
  - A wireless-IP service that uses geographic information to serve a mobile user. Any application service that exploits the position of a mobile terminal. (Open Geospatial Consortium 2005)

•**VIRRANTAUS, K., MARKKULA, J., GARMASH, A., TERZIYAN, Y.V.**, 2001. Developing GIS-Supported Location-Based Services. *In: Proc. of WGIS'2001 – First International Workshop on Web Geographical Information Systems., Kyoto, Japan*. 423–432.
•OPEN GEOSPATIAL CONSORTIUM, 2005. Open Location Services 1.1.

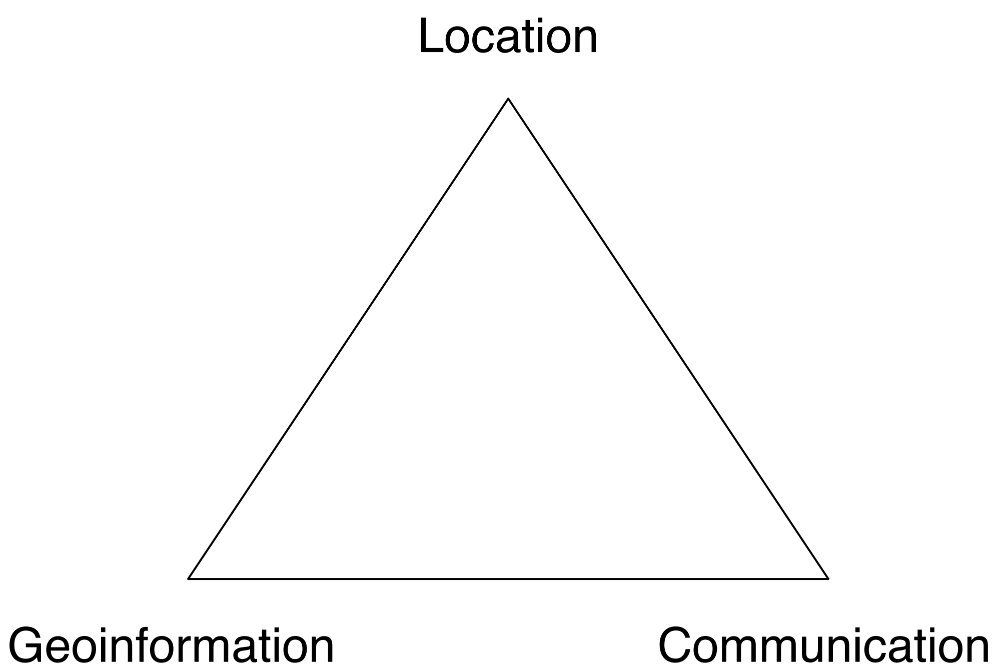
Intersection of Technologies



LBS as an intersection of technologies (Brimicombe 2002)
BRIMICOMBE, A. J., 2002. GIS - Where are the frontiers now?. *In: Proceedings GIS 2002., Bahrain*. 33-45.

LBS Triangle

- Geoinformation -> contents
- Location -> location-dependent contents/service
- Communication -> service delivery

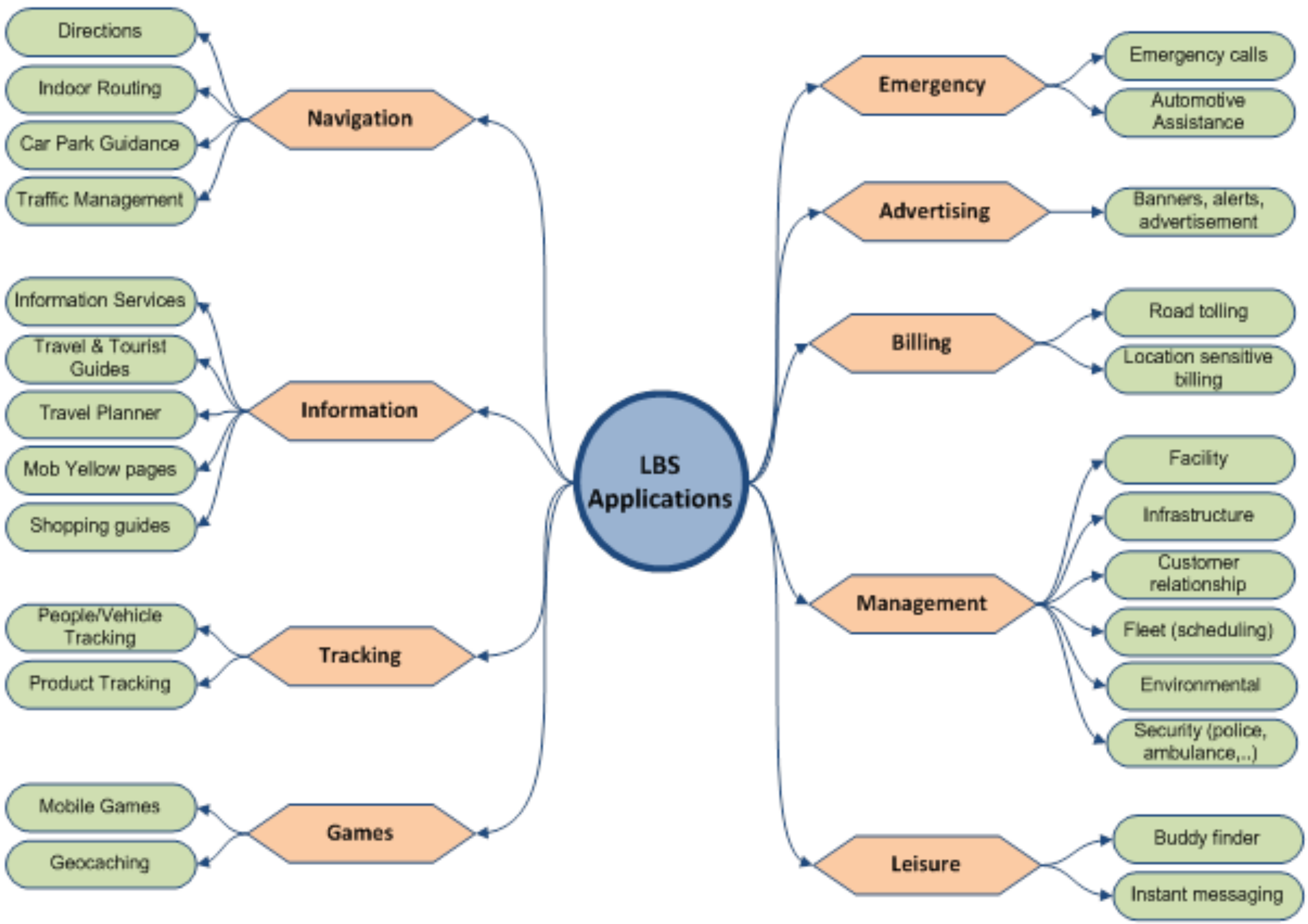


Martin Werne: Indoor Location-Based Services Prerequisites and Foundations. Springer. 2014

Components in LBSs

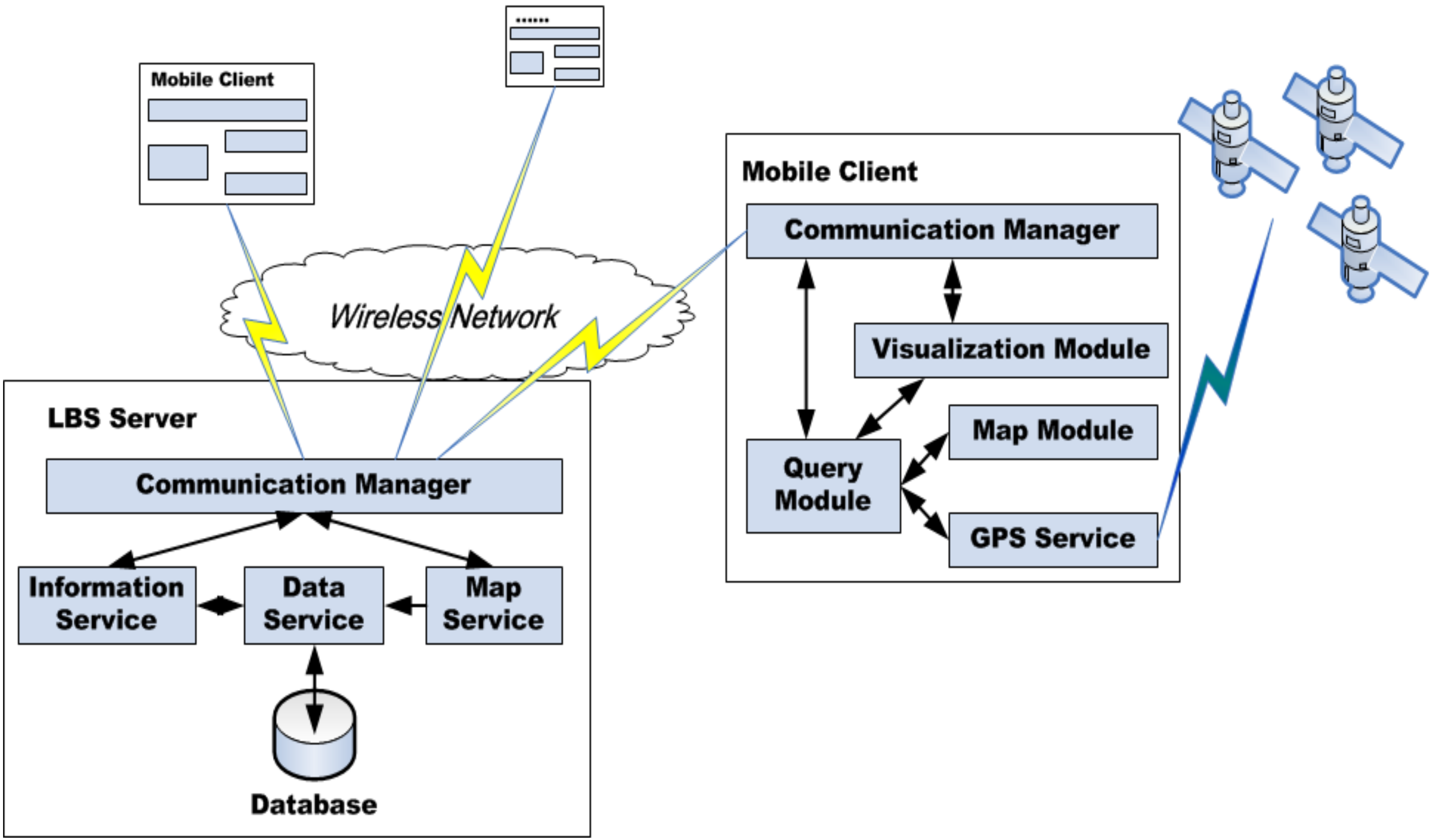
- Localization (Positioning)
  - Outdoor: GPS, cellular, WiFi
  - Indoor: WiFi, Bluetooth, RFID
- Service component
  - Request parsing
  - Location-dependent query processing
  - Result delivery
- Information rendering
  - Display to the user
  - Coordination (e.g., on caching) with the service component

LBS Application Categories



http://www.e-zest.net/insights/whitepapers/location-based-services

GPS-based LBS Architecture



Important Issues in LBSs

- Positioning (Localization technologies)
- Location data management
- Location-dependent query processing
- Location privacy

- Each issue has the indoor and outdoor aspects
  - As well as a mix of both

- Today we take a brief look at outdoor positioning and track, and leave others for future lectures

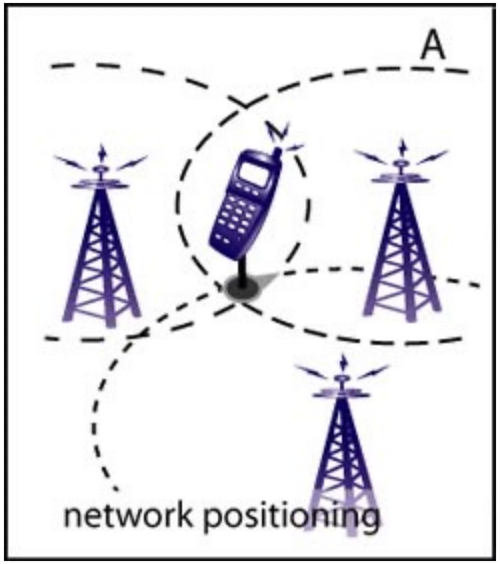
Positioning

- “If you don’t know where you are, you can’t know where you’re going.”

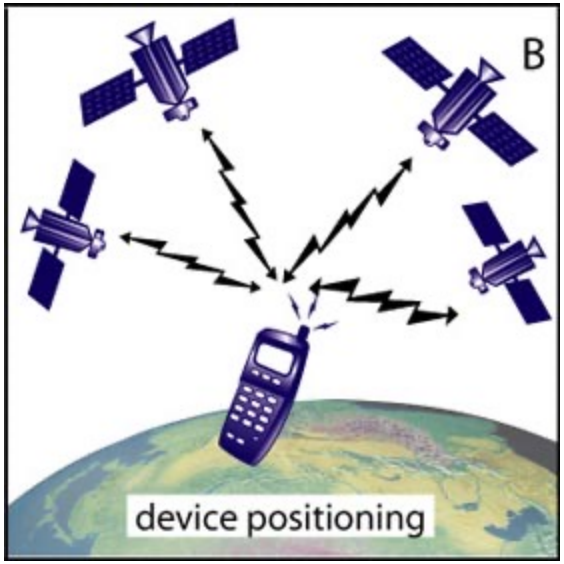
  --Terry Pratchett

Location Technologies

- Network-based
  - Technologies that exploit the infrastructure (base station, BS) to obtain geo-location information.
  - The mobile device sends either a signal or is sensed by the network.

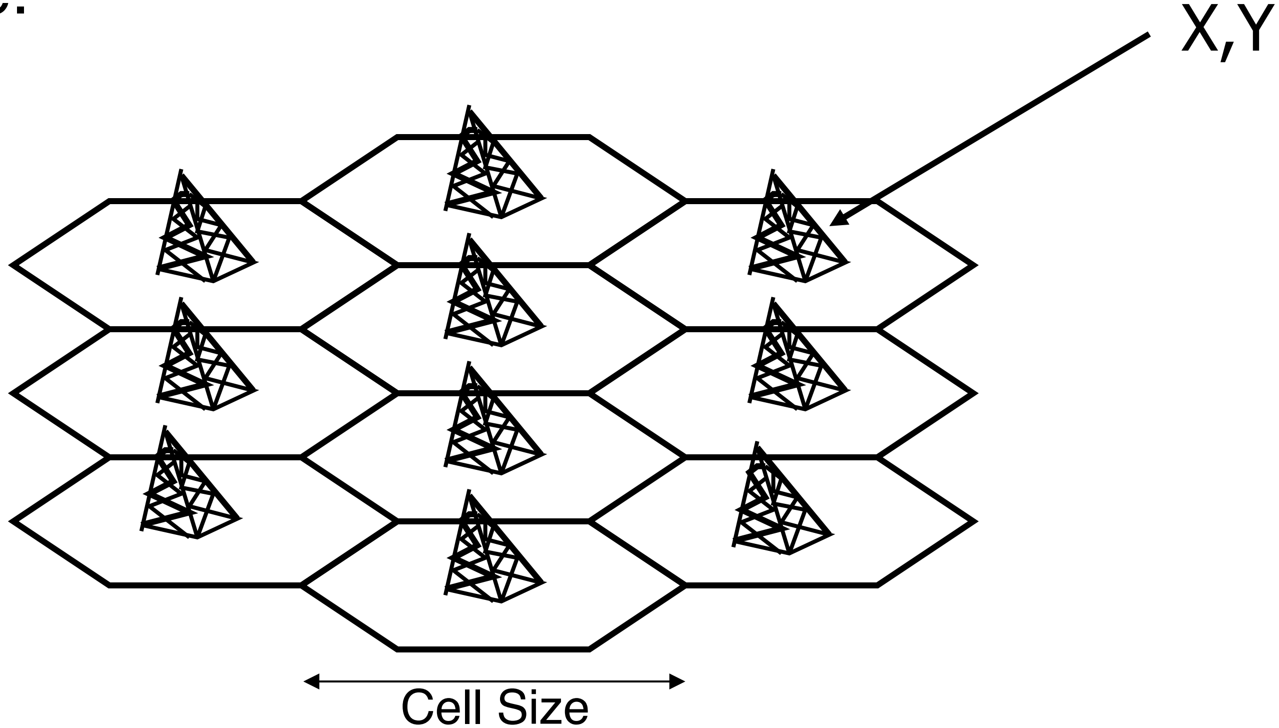


- Terminal-based
  - Location intelligence is stored within terminal.
  - The location is calculated by the user device itself from signals received from base stations.
  - E.g., GPS receiver and GPS satellites.



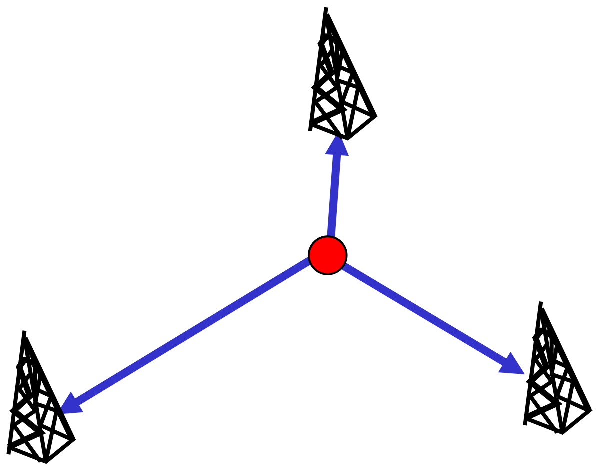
Cell Global Identity (CGI)

- Cell of origin (COO), Cell-ID, location signature, location beacons
- If a cell phone is connected to a cellular network, the phone's position can be determined using the ID (or even its geo-location) of the cell that is currently covering the phone.



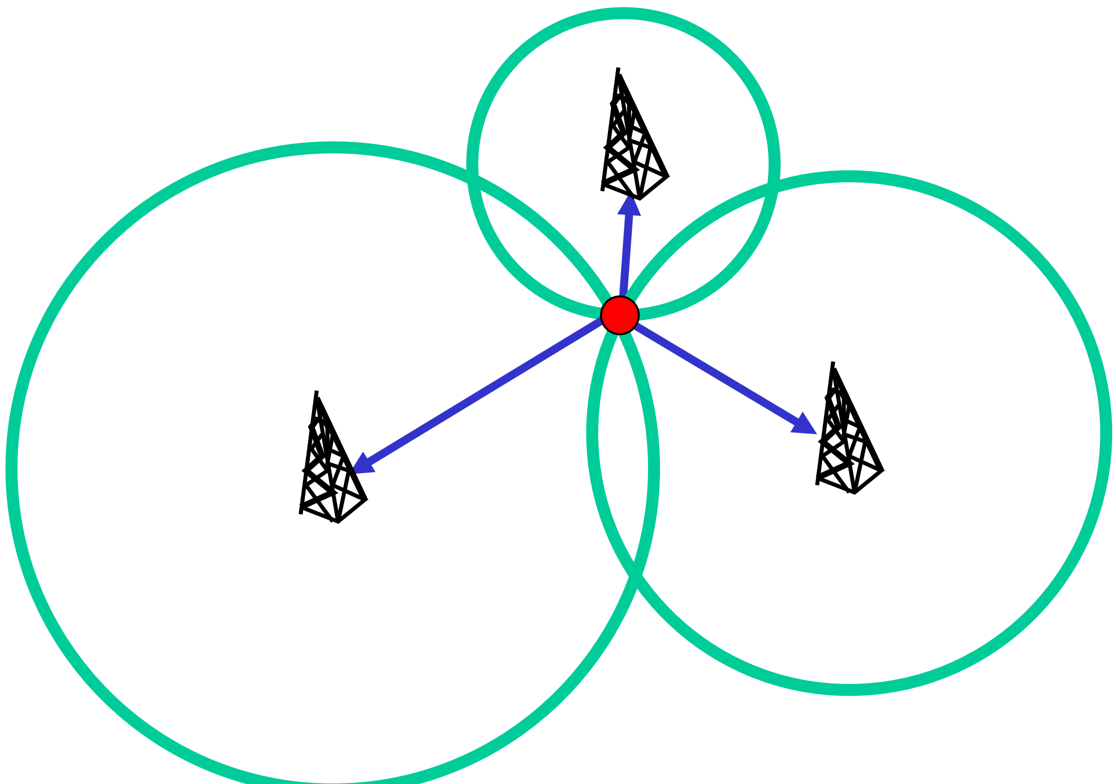
Time of Arrival (TOA)

- UL-TOA (Uplink Time of Arrival)
- Knowing the speed and the time difference between sending and receiving a signal (time of arrival), the terminal-BS distances can be computed.



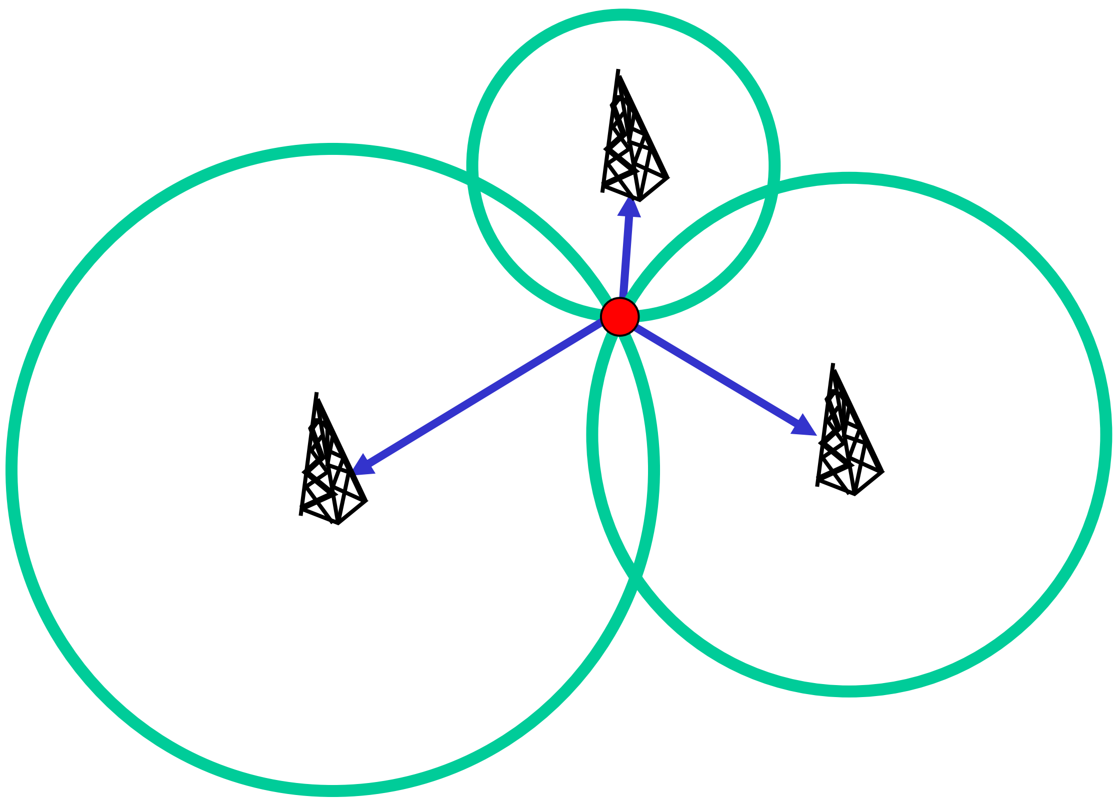
Time of Arrival (TOA)

- UL-TOA (Uplink Time of Arrival)
- Knowing the speed and the time difference between sending and receiving a signal (time of arrival), the terminal-BS distances can be computed.
  - Time indicates the distance, and then the position



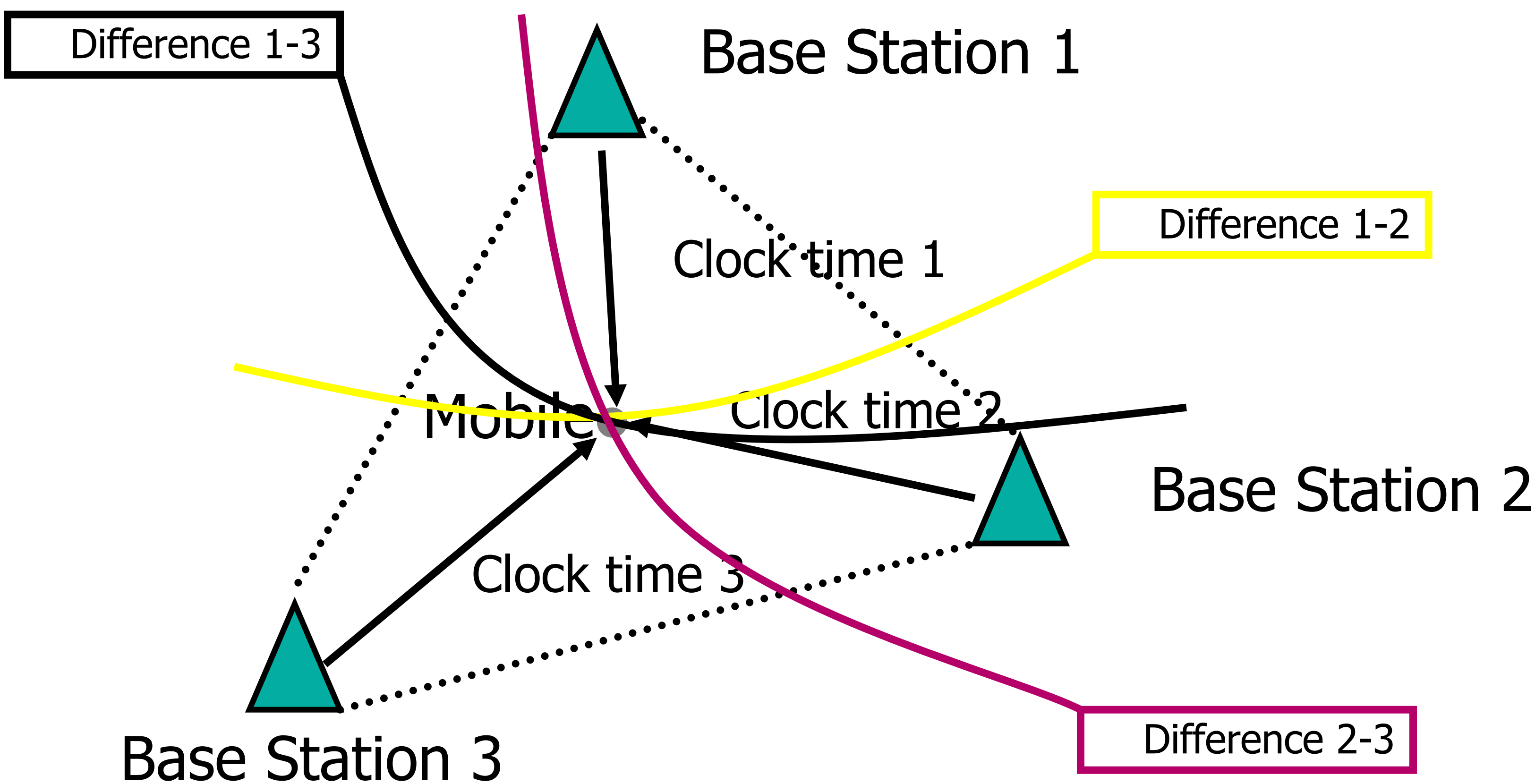
Time of Arrival (TOA)

- What is the drawback of this method?
  - Need the time that the signal was sent from the target



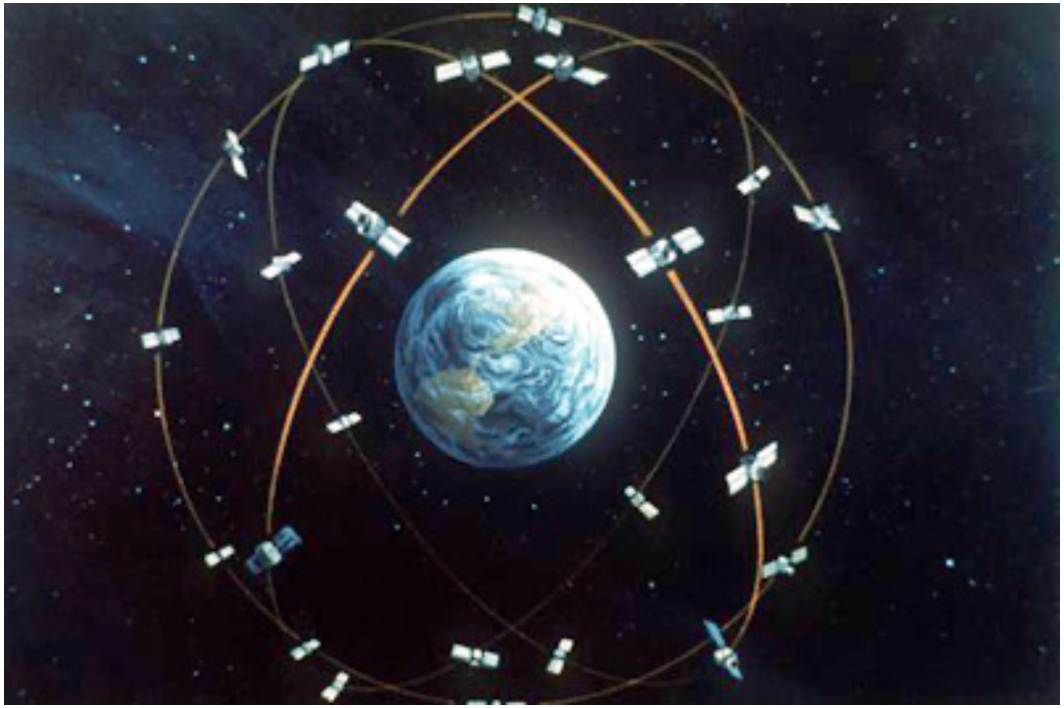
Time Difference of Arrival (TDOA)

- Measure the time difference between two BSs, and get the distance difference between terminal-BS1 and terminal-BS2
  - The terminal's position is determined on a curve
  - More BS pairs are used to get more curves to 'fix' the terminal's position

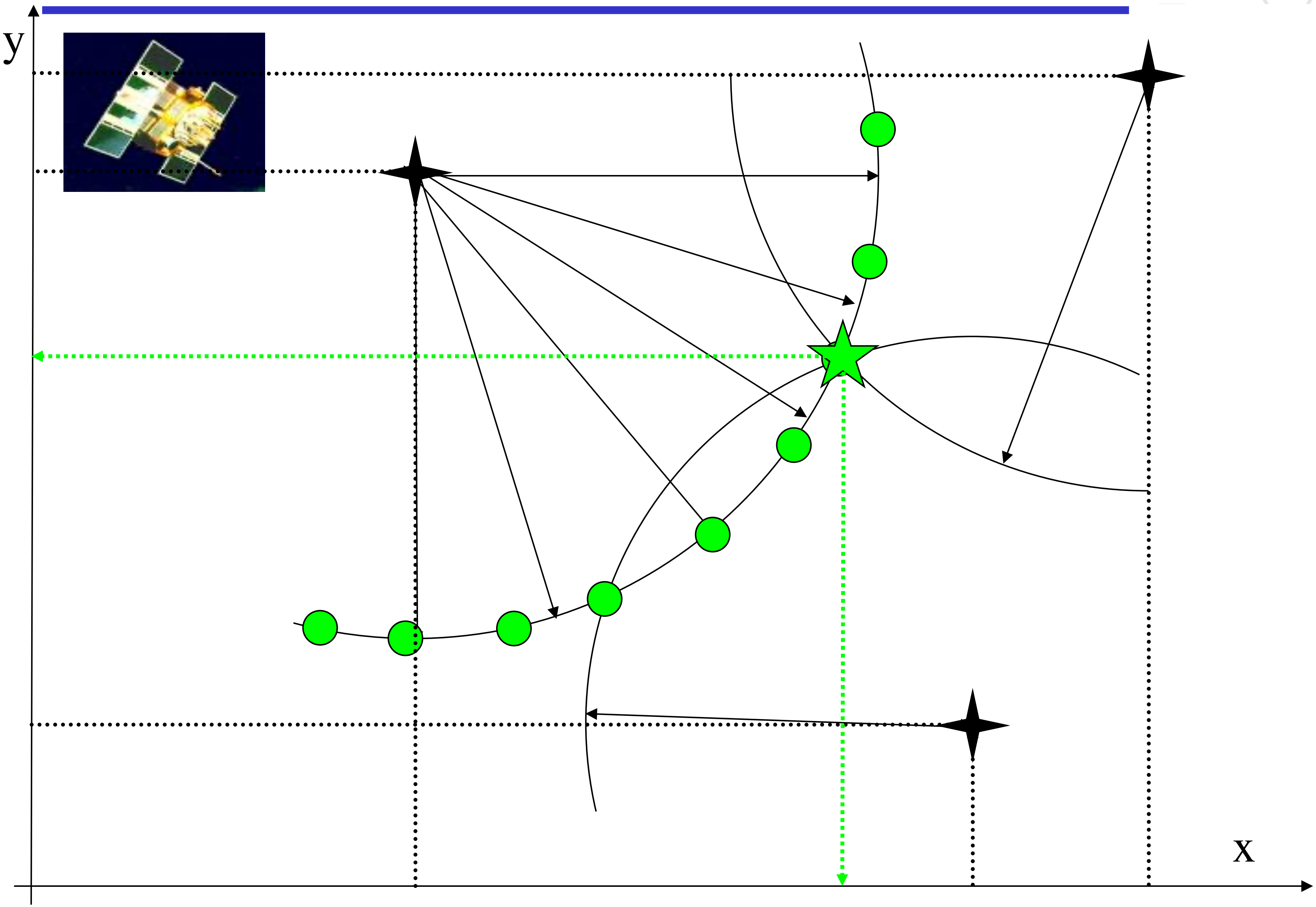


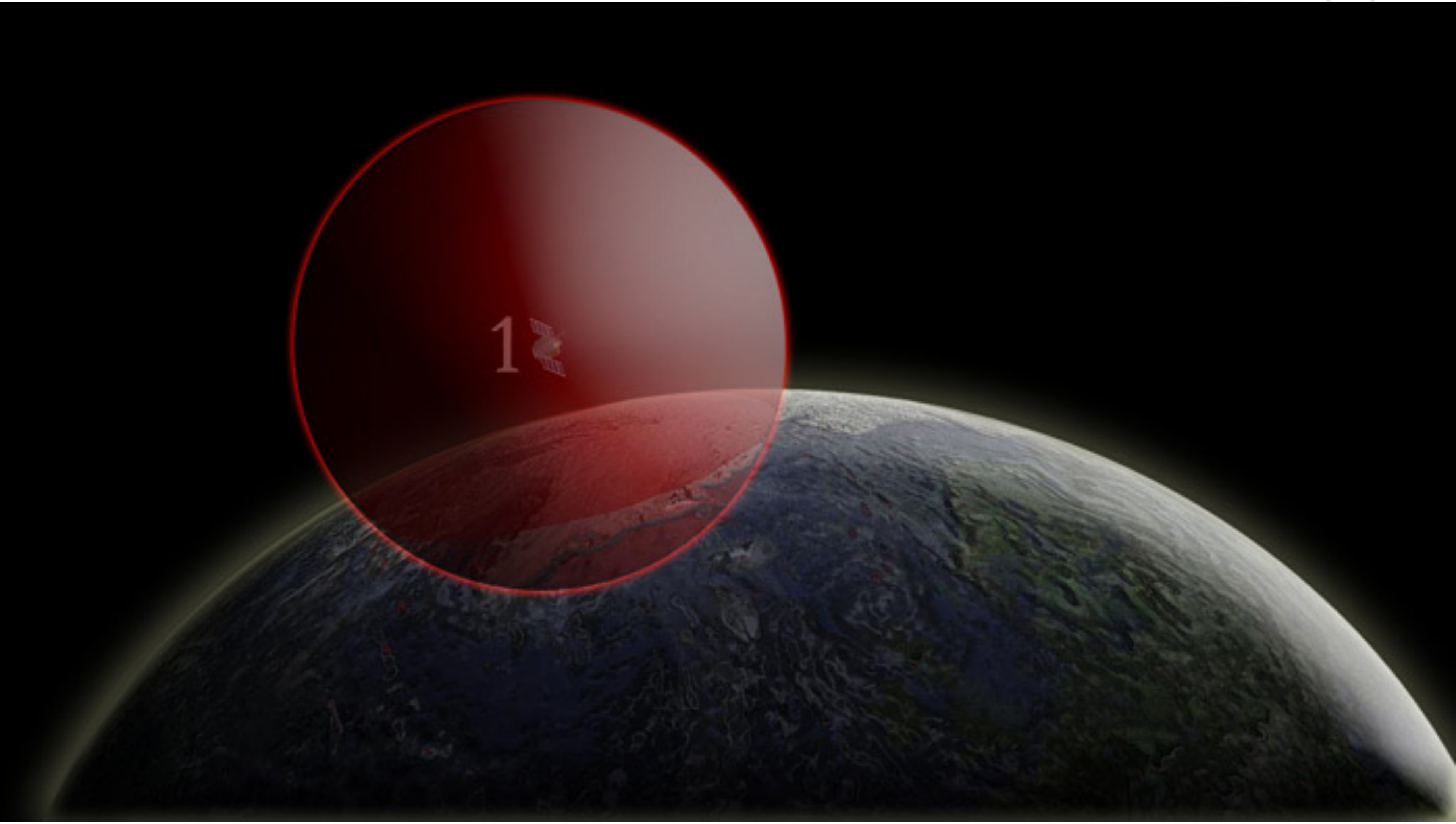
Global Positioning System (GPS)

- GPS works on the same principle of speed, time, and distance (TOA, TDOA).
- However, the base stations are satellites in the space!
  - As of October 2014, 68 GPS satellites have been launched.
  - Currently 30 are orbiting the earth a height of almost 21,000 km above the earth's surface.
  - At least 24 GPS satellites, 95% of the time available



Simplified Illustration in 2 Dimensions

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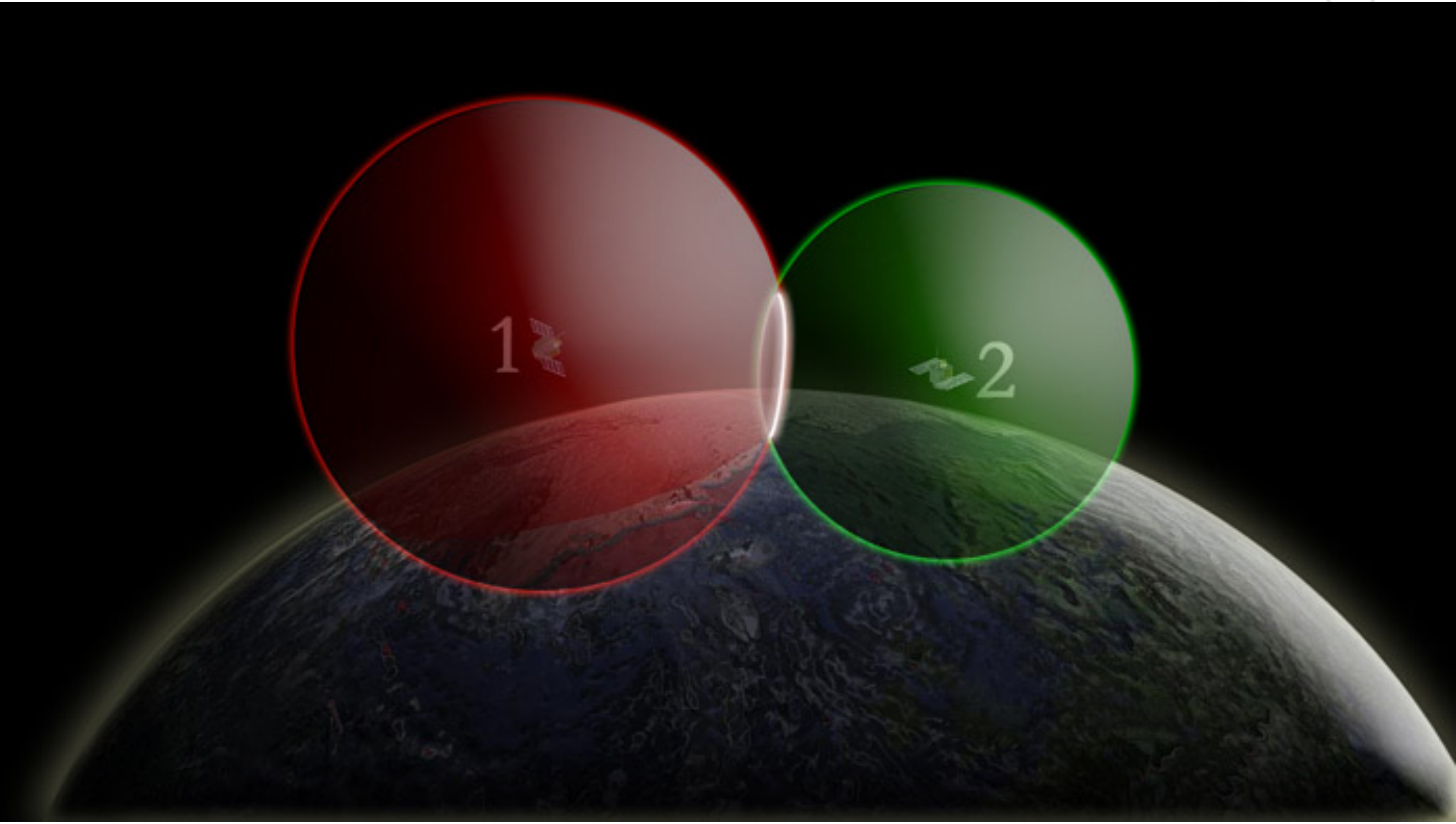
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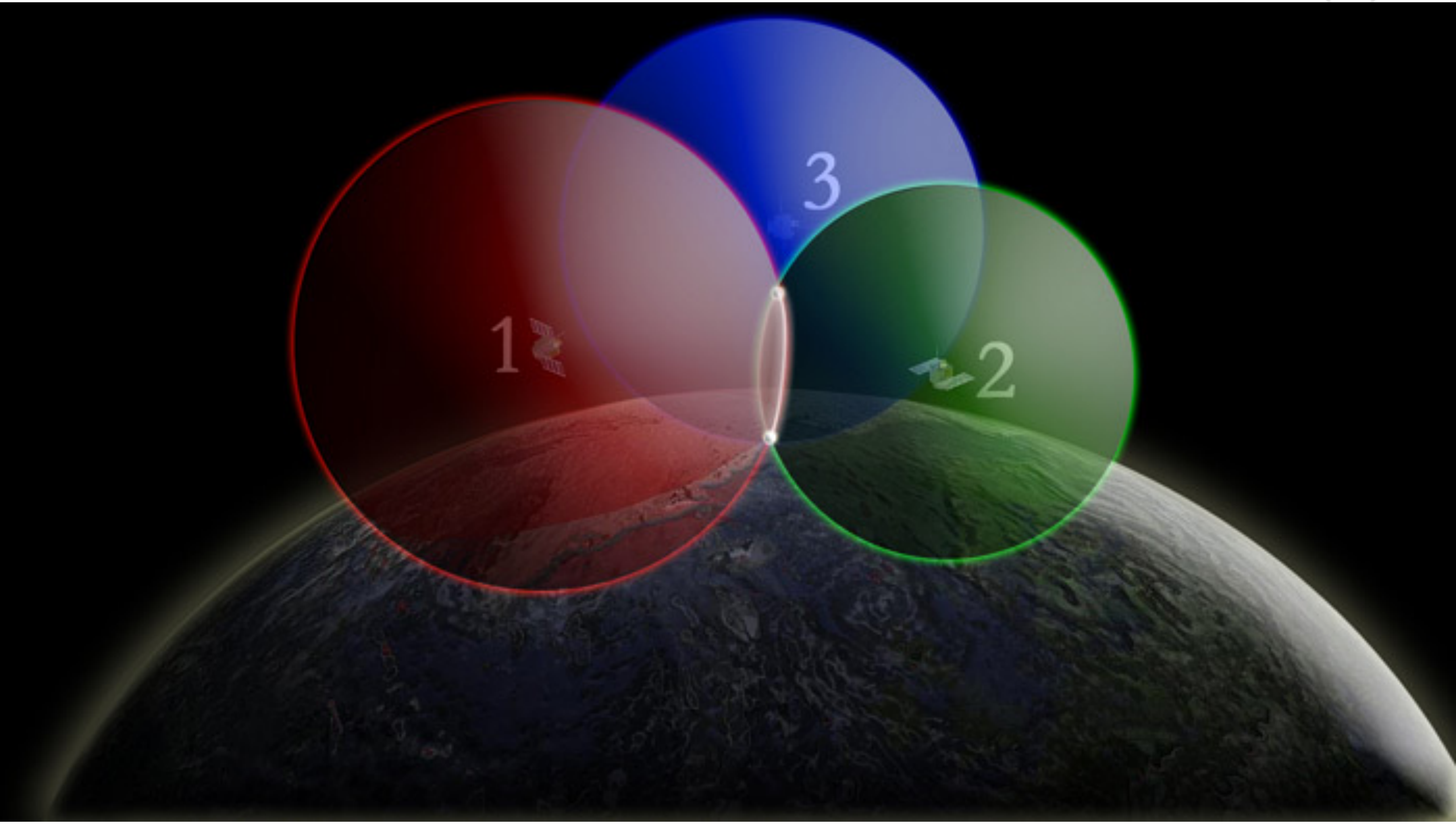
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1
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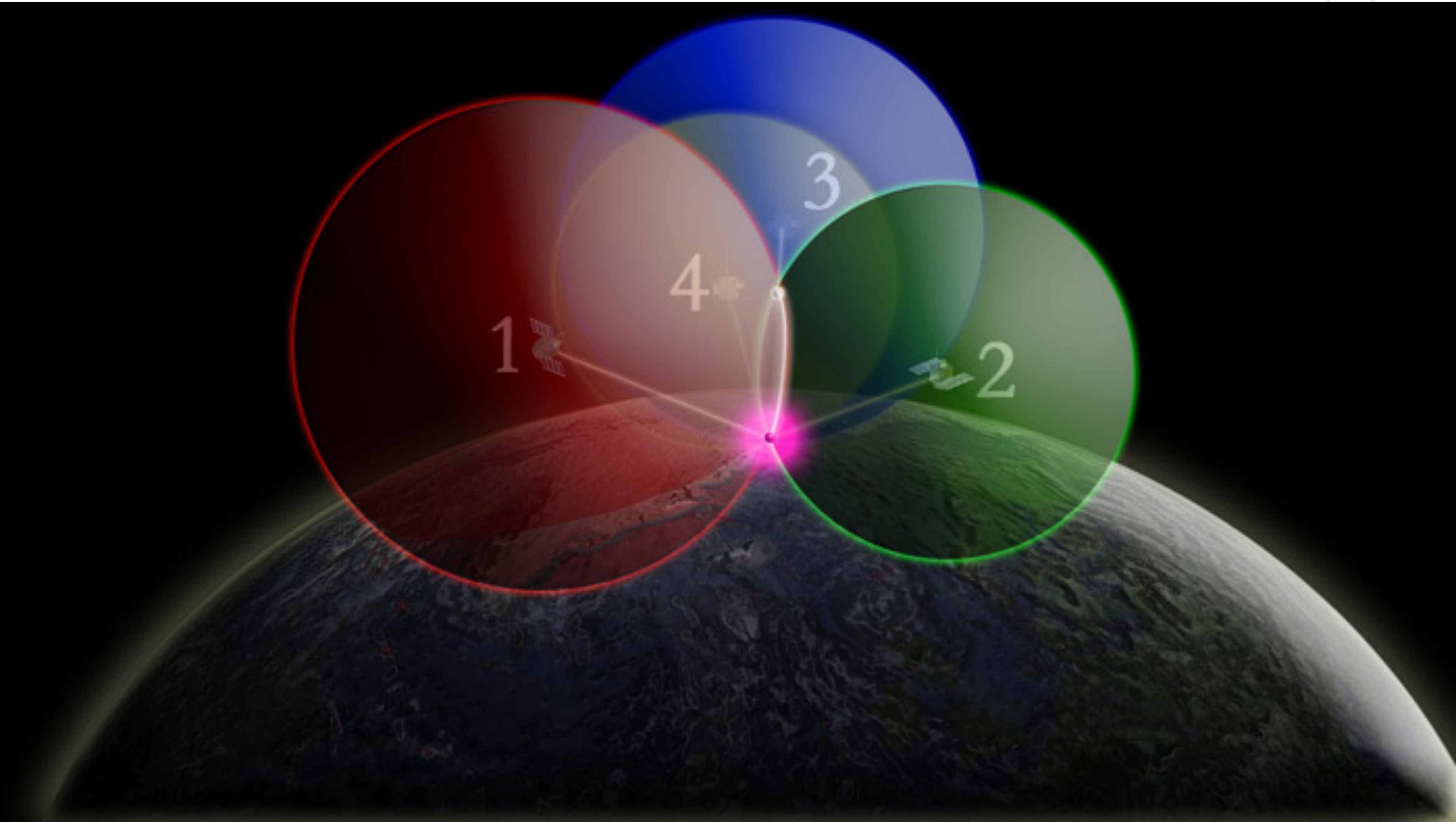
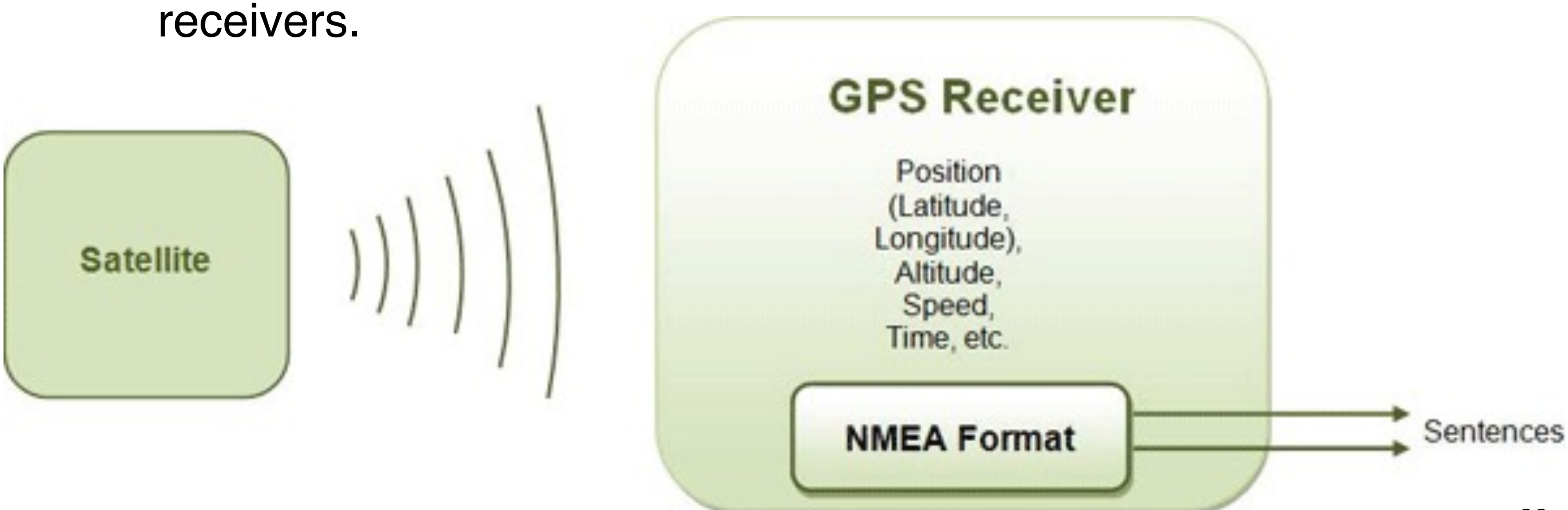


1
2
3
4

NMEA Standards

- The National Marine Electronics Association (NMEA)
  - Standard related to data communication between marine electronics devices.
  - Transmission of GPS data from GPS receiver to other devices (e.g. GPS receiver to mobile phone) for real time positioning
- In its standards, NMEA has specified to send a message (a series of data) in a *sentence*.
  - You need to deal with such sentences when you program for GPS receivers.



NMEA Message Format

- $aaaaa,df1,df2……… [Carriage Return][Line Feed]
  - Each message starts with $
  - The first two letters after $ form a prefix that defines the device for which it is being used.
    - E.g., for GPS receivers the prefix is GP.
  - The following three letters represent the content of the sentence.
  - Multiple data fields delimited by commas
  - Up to 82 characters per each sentence

- The most important sentences for $GP
  - GGA provides the current fix data (3D location and accuracy data)
  - RMC provides the minimum GPS sentences information
  - GSA provides the satellite status data

$GPGGA Sentence Example

```
$GPGGA,123519,4807.038,N,01131.000,E,1,08,0.9,545.4,M,46.9,M,,*47

Where:
     GGA          Global Positioning System Fix Data
     123519       Fix taken at 12:35:19 UTC
     4807.038,N   Latitude 48 deg 07.038' N
     01131.000,E  Longitude 11 deg 31.000' E
     1            Fix quality: 0 = invalid
                               1 = GPS fix (SPS)
                               2 = DGPS fix
                               3 = PPS fix
                               4 = Real Time Kinematic
                               5 = Float RTK
                               6 = estimated (dead reckoning) (2.3 feature)
                               7 = Manual input mode
                               8 = Simulation mode
     08           Number of satellites being tracked
     0.9          Horizontal dilution of position
     545.4,M      Altitude, Meters, above mean sea level
     46.9,M       Height of geoid (mean sea level) above WGS84
                      ellipsoid
     (empty field) time in seconds since last DGPS update
     (empty field) DGPS station ID number
     *47          the checksum data, always begins with *
```

$GPRMC Sentence Example

```
$GPRMC,123519,A,4807.038,N,01131.000,E,022.4,084.4,230394,003.1,W*6A

Where:
     RMC            Recommended Minimum sentence C
     123519         Fix taken at 12:35:19 UTC
     A              Status A=active or V=Void.
     4807.038,N     Latitude 48 deg 07.038' N
     01131.000,E    Longitude 11 deg 31.000' E
     022.4          Speed over the ground in knots
     084.4          Track angle in degrees True
     230394         Date - 23rd of March 1994
     003.1,W        Magnetic Variation
     *6A            The checksum data, always begins with *
```

$GPGSA Sentence Example

```
  $GPGSA,A,3,04,05,,09,12,,,24,,,,,2.5,1.3,2.1*39

Where:
     GSA       Satellite status
     A         Auto selection of 2D or 3D fix (M = manual)
     3         3D fix - values include: 1 = no fix
                                        2 = 2D fix
                                        3 = 3D fix
     04,05...  PRNs of satellites used for fix (space for 12)
     2.5       PDOP (dilution of precision)
     1.3       Horizontal dilution of precision (HDOP)
     2.1       Vertical dilution of precision (VDOP)
     *39       the checksum data, always begins with *
```

Other Positioning Systems

- Global navigation satellite system (GNSS)
  - GPS (US)
  - GLONASS (Russia)
  - Galileo (EU)
  - Beidou (CN)
- Automatic identification System (AIS)
  - Used for ships
  - Combination of radar, satellites and communications
- Other vertical, specialized systems
- You may need to program for systems other than GPS…

Agenda

- LBS in General
- Positioning and Tracking
- Map Matching

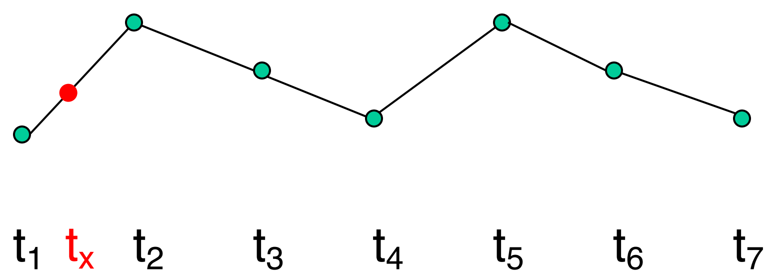
Positioning and Tracking

- A **positioning system** emits (id, position) records, where position is some subset of space, i.e. a "generalized" position with error bound(s).
  - The maintenance of positioning is based on sampling.
    - A sample contains the time and a possibly inaccurate position.
  - E.g., GPS and GPS signals outdoors
  - E.g., Wi-Fi or Bluetooth indoors

- A **tracking system** uses information from a positioning system to approximate the (true) trajectory of a moving/mobile object
  - Offline tracking: to approximate the historical trajectory
  - Online tracking: to maintain the current position and predict future
  - E.g., a GPS based navigation system
  - Approximation depends on multiple factors including *positioning sampling frequency* and *tracking method*

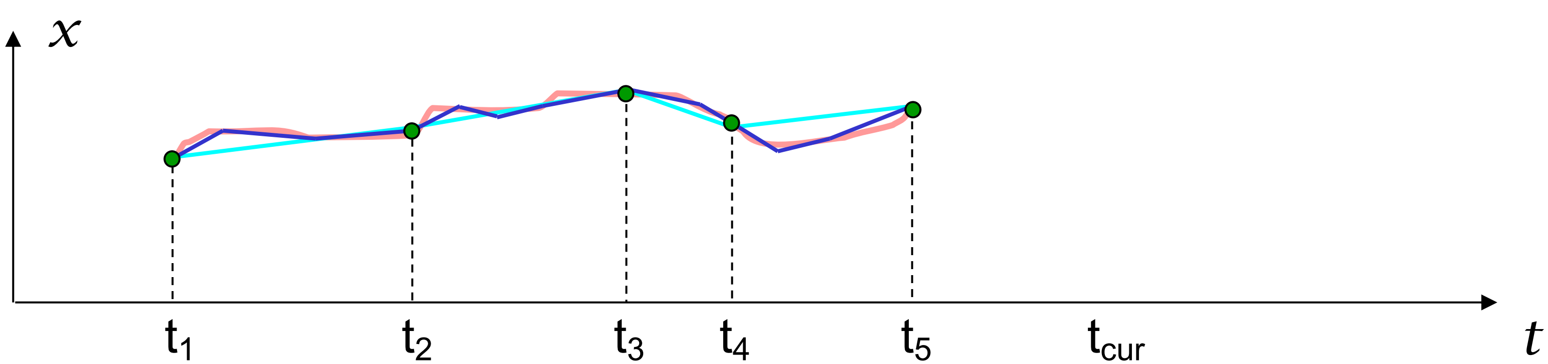
Trajectories

- Moving objects yield trajectories
- Usually we can sample the positions of the objects at periodic time intervals Δt
  - E.g., GPS reports (x1, y1, t1), (x2, y2, t2), …
- Trajectory: a sequence of 2 or 3-dim locations
- What is the object at time t_x that is in $[t_1,t_2]$?
  - Linear Interpolation: easy and accurate enough if sampling frequency is sufficiently high



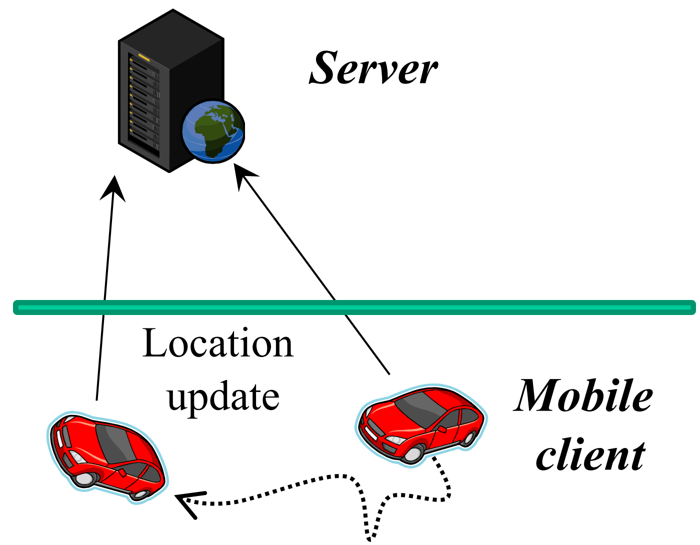
Three Cases of Tracking

- Off-line
  - Given a set of samples, derive trajectory up until the time of the last sample.
- On-line
  - Maintain a representation of the current (and near-future) location.
- Prediction
  - Infer the future movement of an object using information such as
    - Historical positions
    - Movement velocity



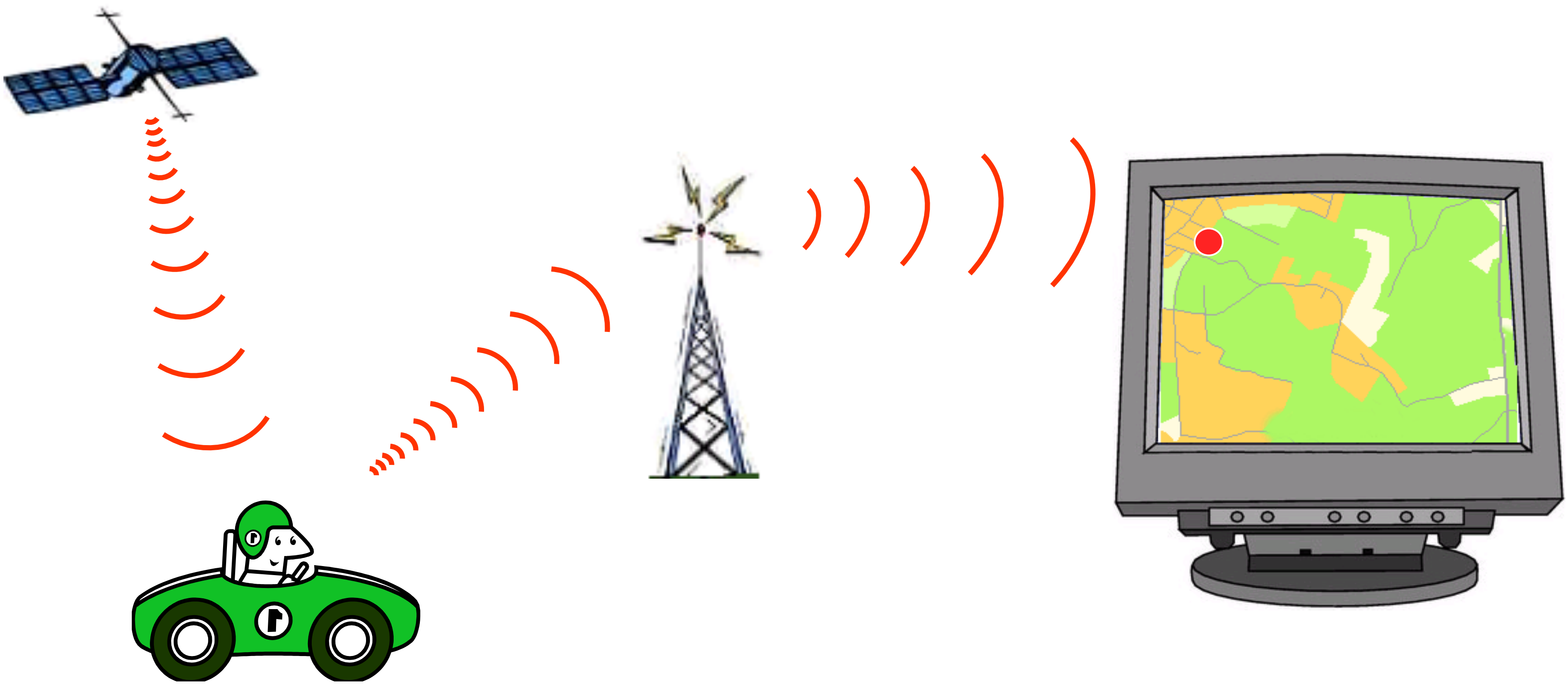
Online Location Tracking

- Applications of tracking
  - Traffic jam detection
  - Alert-ahead service
  - Fleet management
- Mobile clients (e.g., vehicles)
  - Continuously moving objects
    - Its velocity could change over time (e.g., due to traffic)
  - Use a positioning technology to measure its location
    - E.g., GPS, radio signal triangulation, Wi-Fi fingerprint
- Centralized server
  - Maintains accurate location for each client
- Client sends a location update to the server
  - When and How?



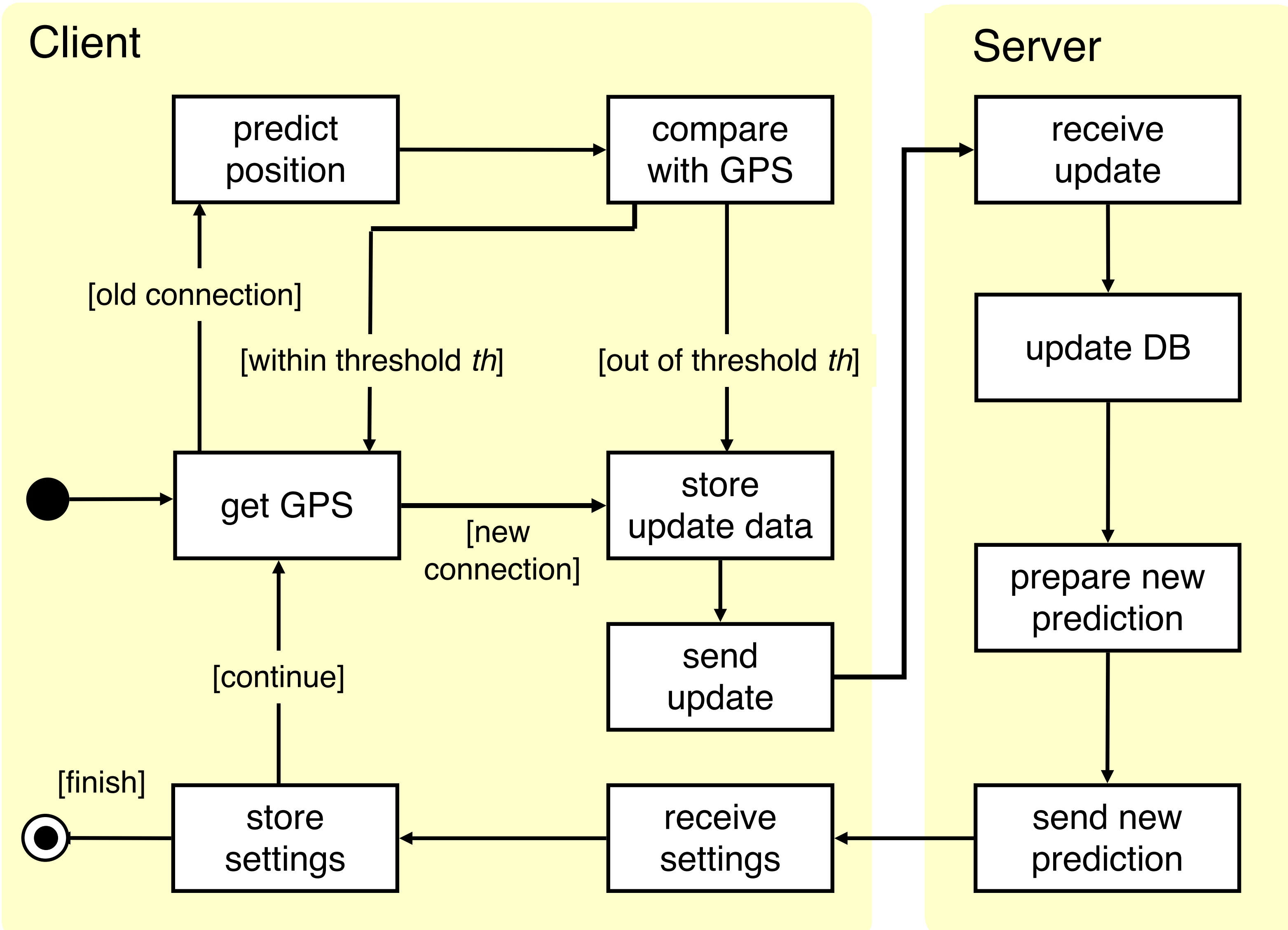
GPS-Based Outdoor Tracking

Aim: To track moving objects (e.g., buses) with accuracy guarantees



Objective: To reduce communication cost between moving client and server while maintaining the tracking accuracy

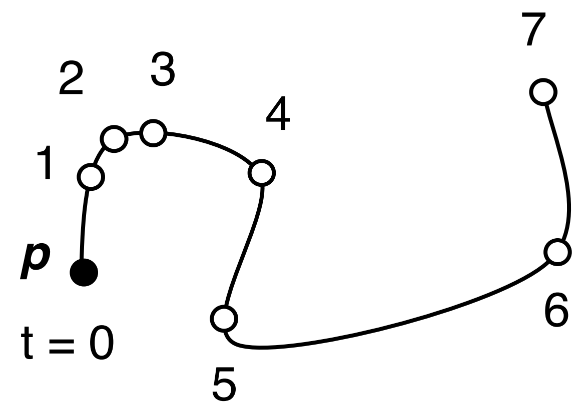
Tracking Approach



Client Side Update Policies

- Let *p* be the location of the mobile client
- Let *t* be the current time

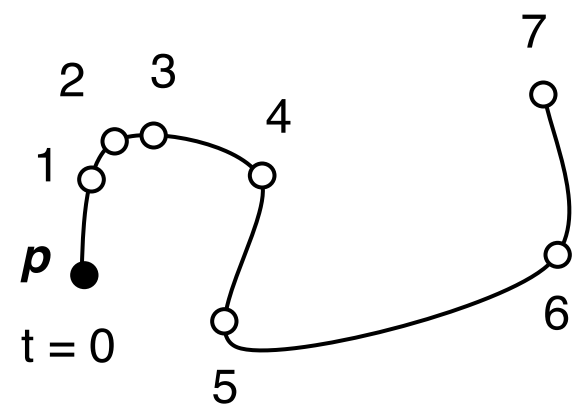
- Client side Update policies
  - Periodic update
  - Region based update
  - Point based update
  - Vector based update
  - Segment based update



Period Update

- Overview
  - Given a time period ΔT (e.g., 1 minute)
  - Every ΔT time units, the **client** reports its location *p* to the **server**
  - The server only stores the last reported location

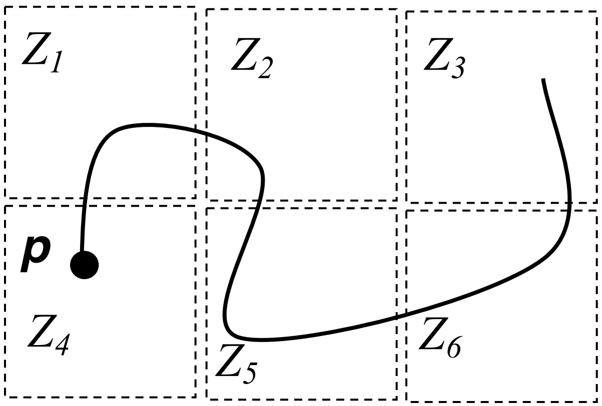
- Drawbacks
  - Small ΔT ➔ high communication cost
  - Large ΔT ➔ inaccurate location
  - Accuracy guarantee depends on the maximum speed of the client.



Server: where is the client location at t=5.5 ?

Region-based Update

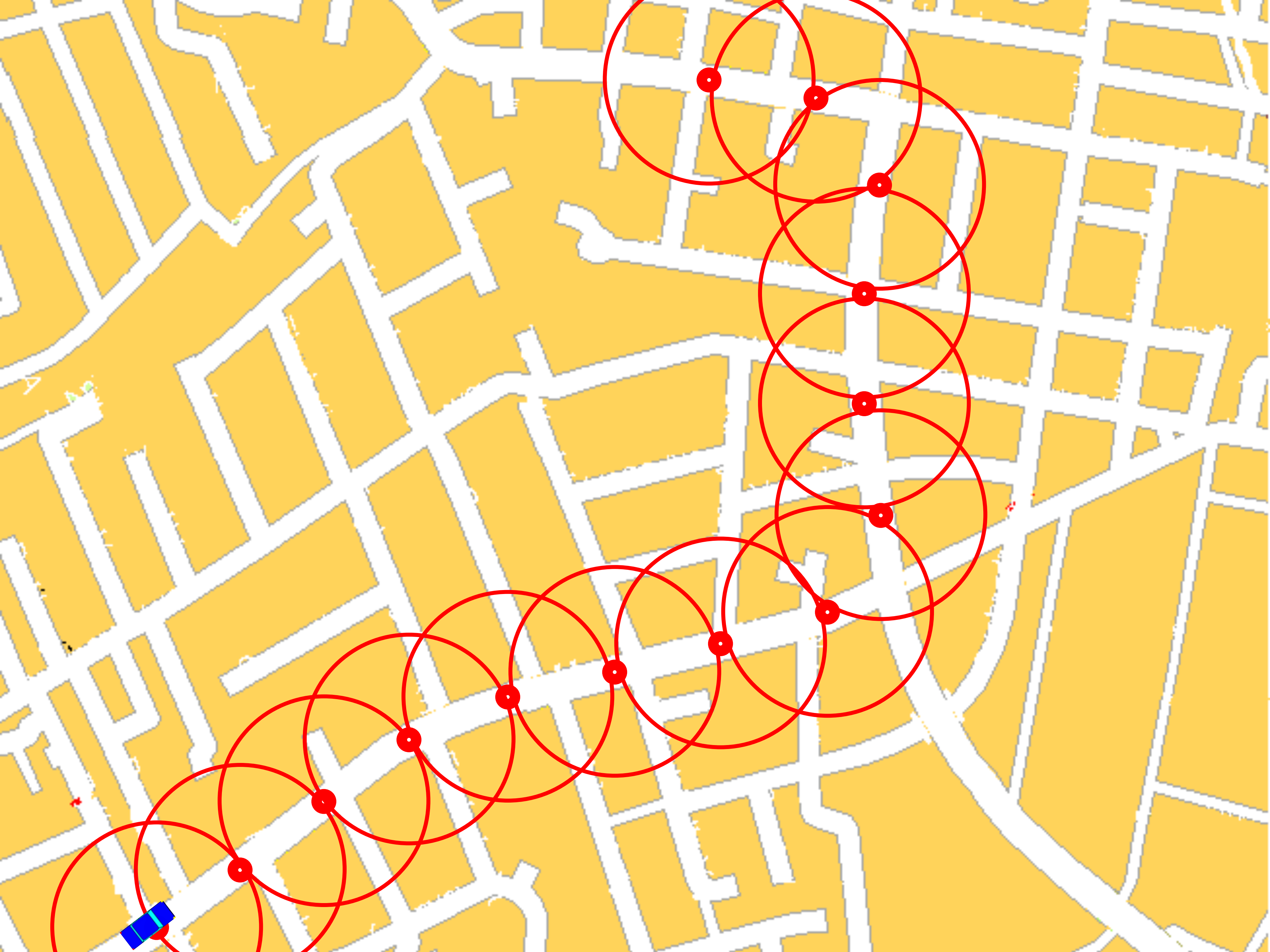
- Overview
  - Decompose the domain into regions
  - A client reports to the server that the region she/he stays in
    - The server keeps the last reported region
  - Event: the client moves to a new region
    - The client reports the new region to the server
  - Example: the client reports the regions Z_4, Z_1, Z_2, Z_5, Z_6, Z_3



- Notes
  - Update frequency is controlled by the area of regions
  - Region-based guarantee: an object is located within its region
    - Finer regions mean higher accuracy but also higher communication cost
    - Coarser regions mean lower communication cost but also lower accuracy

Other Client Side Update Policies

- Point based
  - As long as the client is within the circle centered at a known point, no updates sent to the server
    - The radius of the circle is the threshold
- Vector based
  - As long as the client's current position is still close enough to the vector, no updates sent to the server
- Segment based
  - Applicable to road network based moving client
  - As long as the client is still close enough to the identified road segment (a polyline), no update



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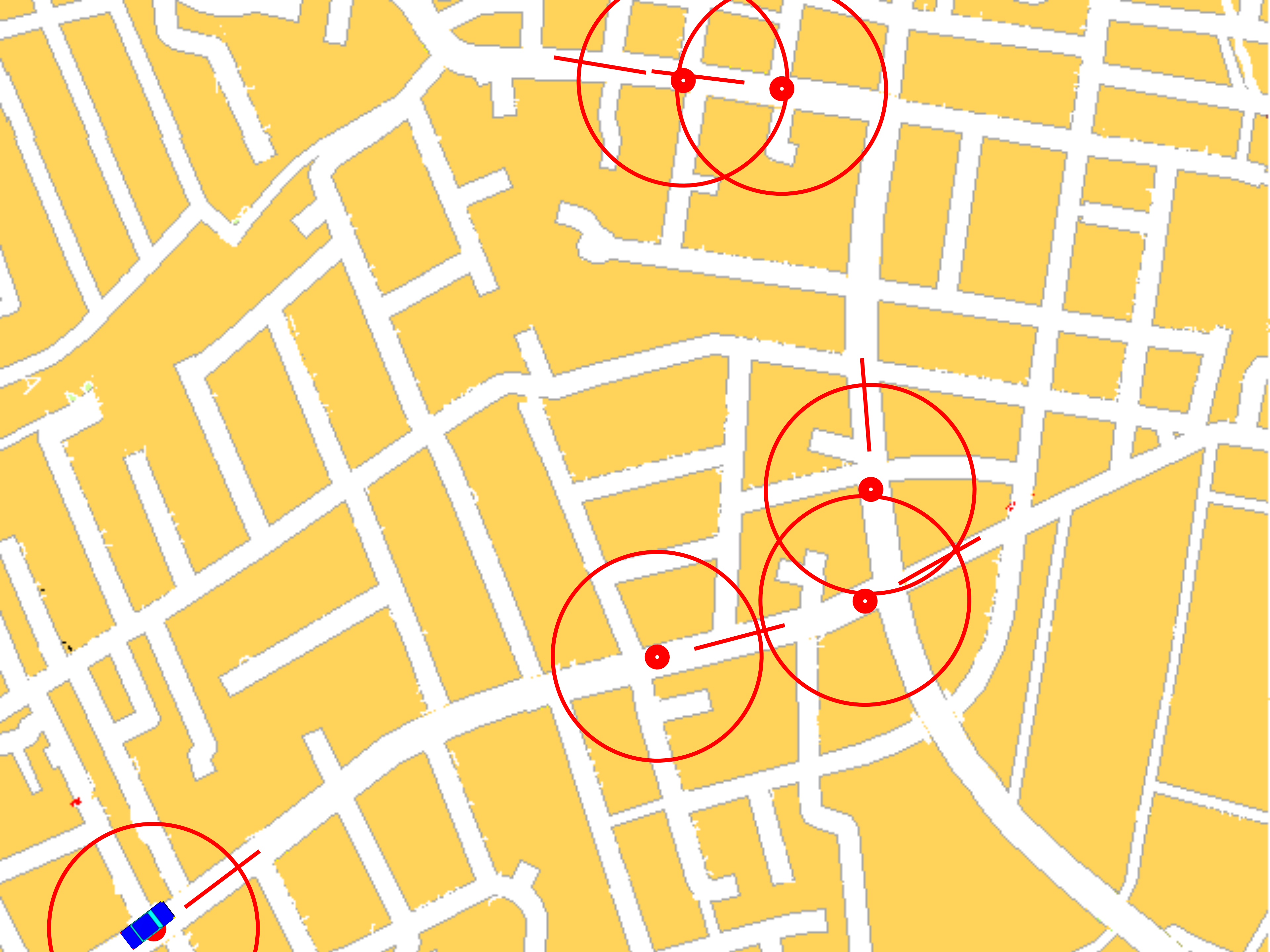

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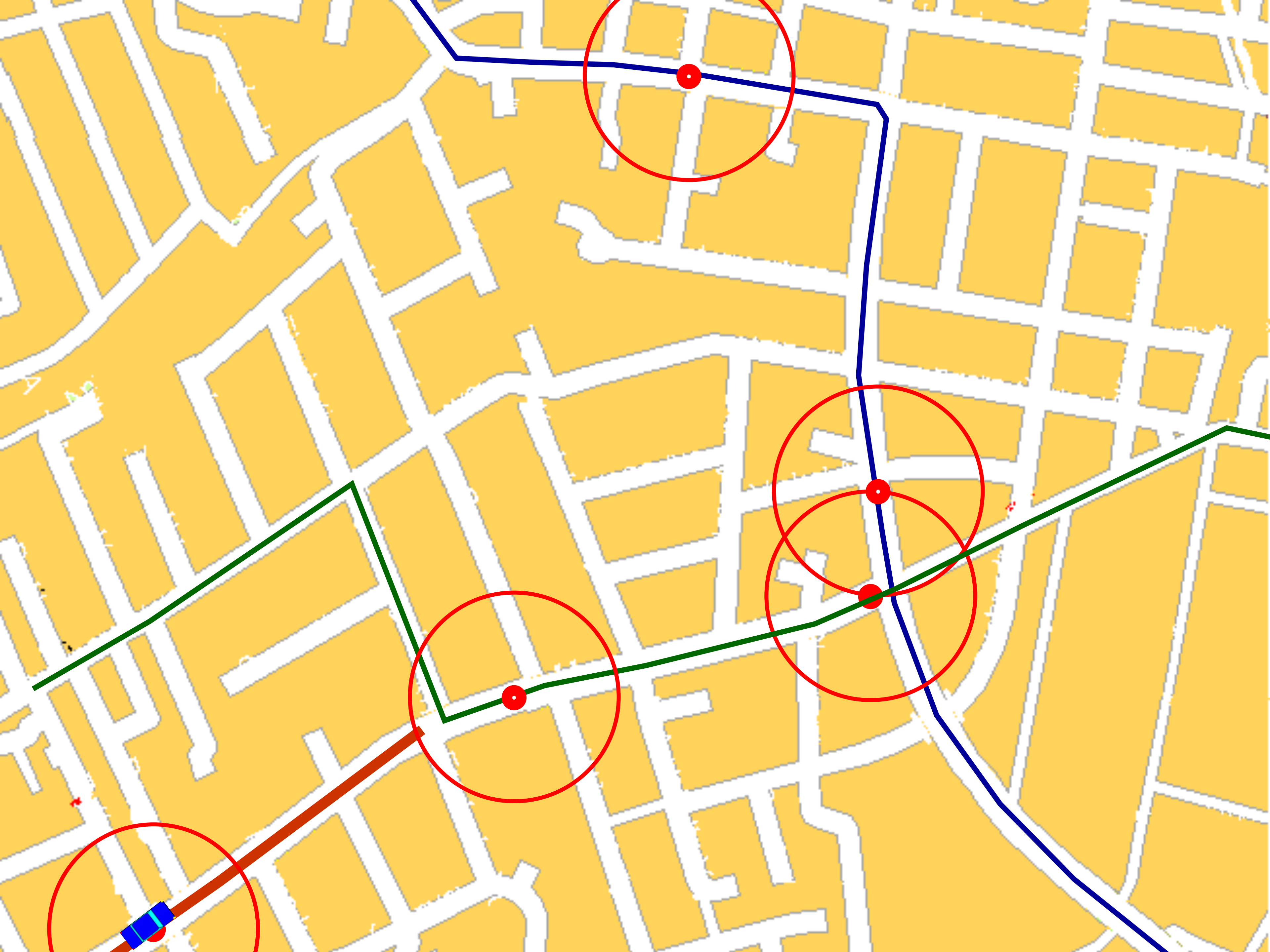


Comparison

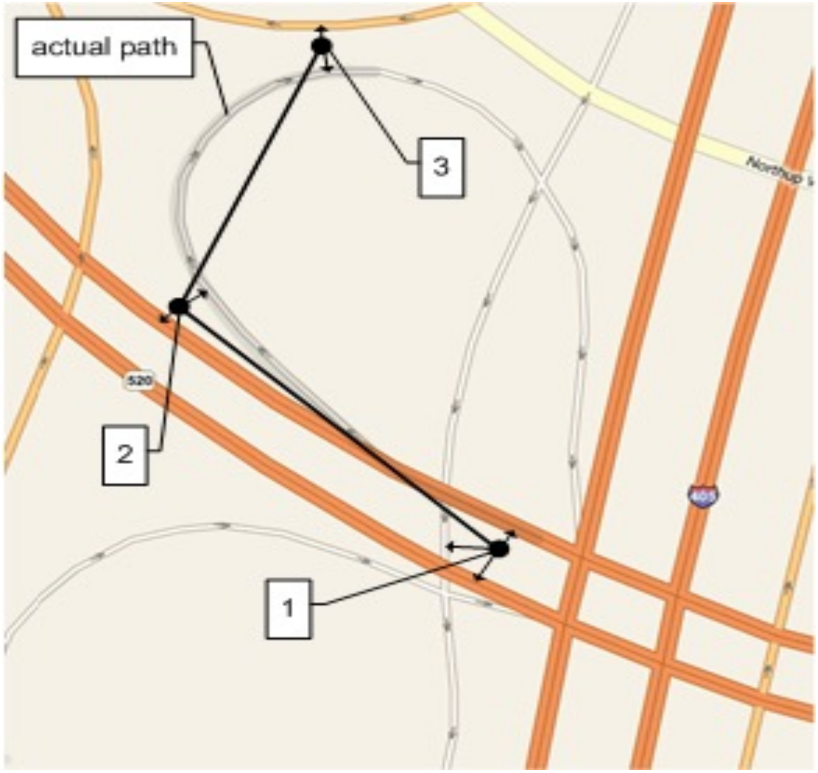
Method	Notes
Periodic	• Accuracy and communication cost depend on the updating period • Usually high accuracy and high communication cost • Applicable to road network and free moving space
Region based	• Accuracy and communication cost depend on the region configuration • Applicable to free moving space
Point based	• Accuracy and communication cost depend on the threshold (radius) • Applicable to road network and free moving space
Vector based	• Medium accuracy and medium communication cost • Applicable to road network and free moving space
Segment based	• Relatively low accuracy and low communication cost • Applicable to road network only • May need other information to determine segments

Agenda

- LBS in General
- Positioning and Tracking
- Map Matching

Why Map Matching?

- Sometimes, GPS reports may be of low precision. When a road network is involved, such a GPS report (incorrectly) means an object moves out of any road
- Given noisy reports 1, 2, and 3, which roads were actually driven on?
- Map Matching is to find roads corresponding to a GPS trajectory.
  - Online
  - Offline



Online vs. Offline

- On-line map matching relates the reported GPS positions to the road network while (immediately after) such positions are being reported.
  - E.g., GPS navigation for driving
  - Real time map matching can only rely on so far recorded points. This brings a compromise of performance over accuracy.
- Off-line map matching is conducted after the data (complete trajectory) is collected.
  - E.g., analyze a car's driving history
  - Off-line map matching can consider all GPS positions reported and allow for slower performances in favor of accuracy.

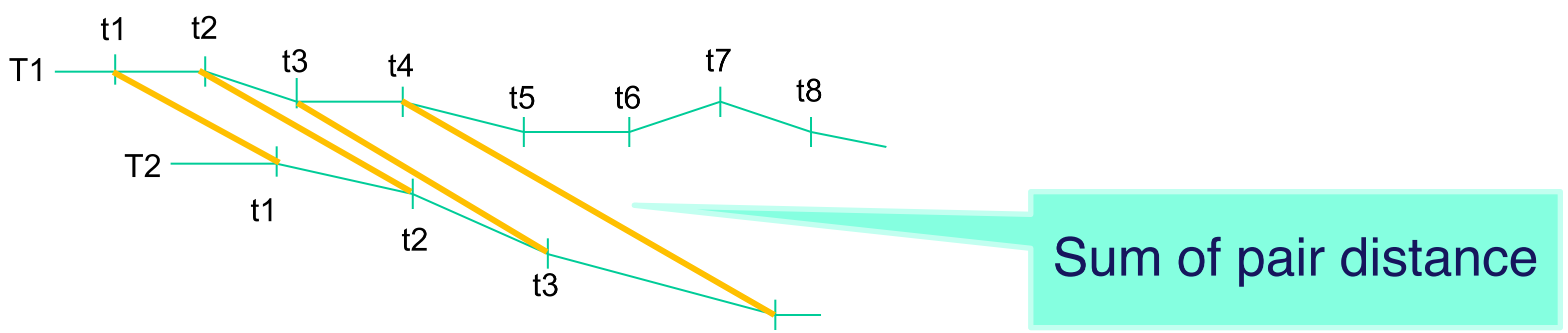
Main Steps in Offline Map Matching

- Data preprocessing
  - To identify and remove outliers, as they can affect the matching accuracy very negatively
  - E.g., DBSCAN clustering of GPS positions can be used
- Matching
  - Use an offline method
- Post processing
  - Evaluate the results
    - We need to know the ground truth for evaluation
      - We can measure the distance between the trajectory after map matching and the ground truth trajectory
      - We can count how many errors the matched trajectory still have, or calculate the error reduction rate the matching achieves.
  - Sometimes manual adjustment may be needed

Distance between Trajectories

- There are many distance metrics for this purpose
  - Trajectory similarity measurement
  - Geometric based
  - Semantic based
  - Hybrid
  - We don’t cover them in this course

- A very simple example



Inputs to Map Matching

- Basic inputs
  - GPS trajectory (online or offline)
  - Road network
- Other information that can be used
  - Vehicle speed
  - Properties of the road network
    - Topology
    - Speed limit
    - Etc.
- Some map matching methods only use the basic inputs while others also make use of the other information to improve the accuracy.

Map Matching Methods

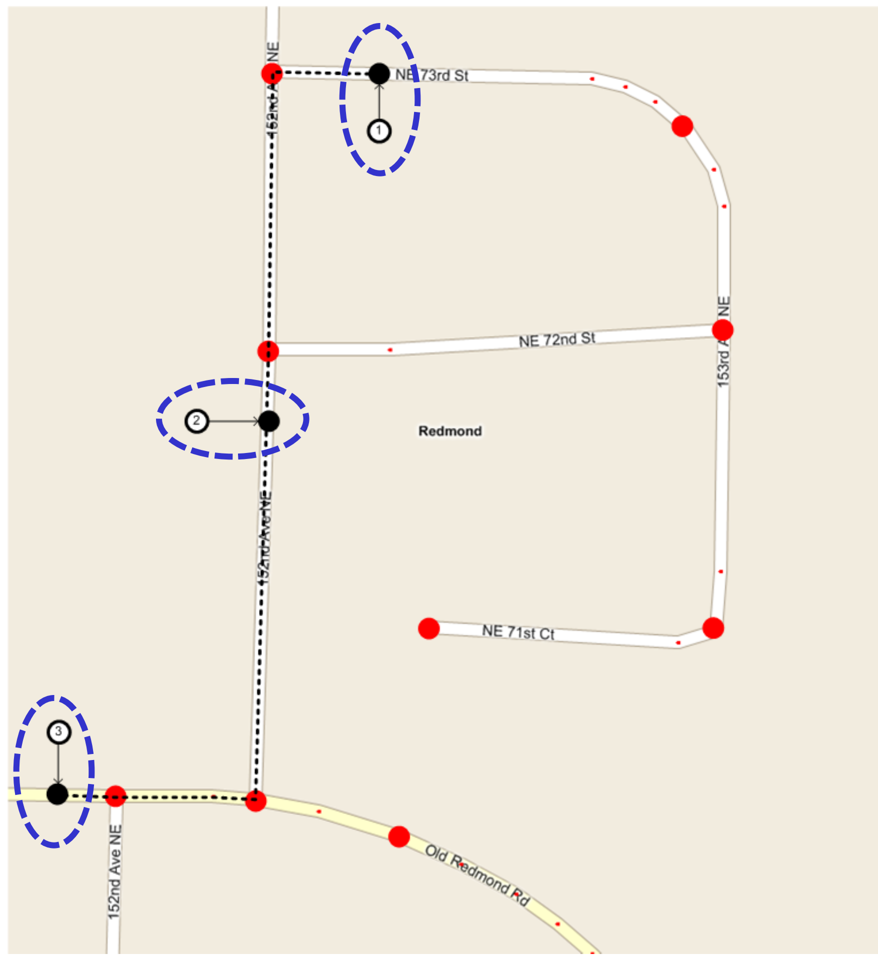
- Local/incremental methods
  - For each point in the given trajectory, find the *local* match (point or road segment) from the road network.
- Global methods
  - Match the *entire trajectory* with the road network.
- Statistical methods
  - Use probability related tools such as Bayesian classifier, Hidden Markov Model, Kalman filter

	Local	**Global**	**Statistical**
Online	✓		✓
Offline	✓	✓	✓

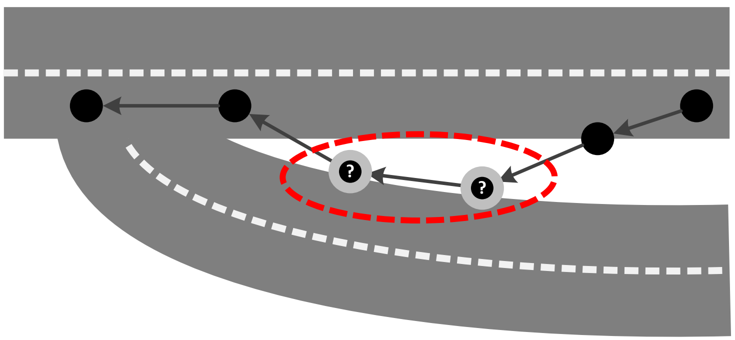
- All categories may opt to use basic and/or more inputs.

Naïve Map Matching

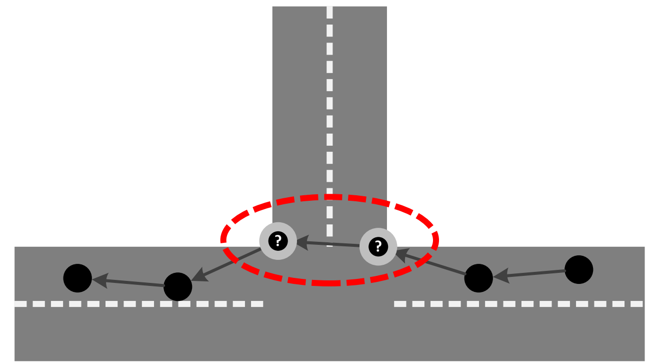
- Snap each reported point to its nearest road segment
- Easy to implement but not always work
- A local method



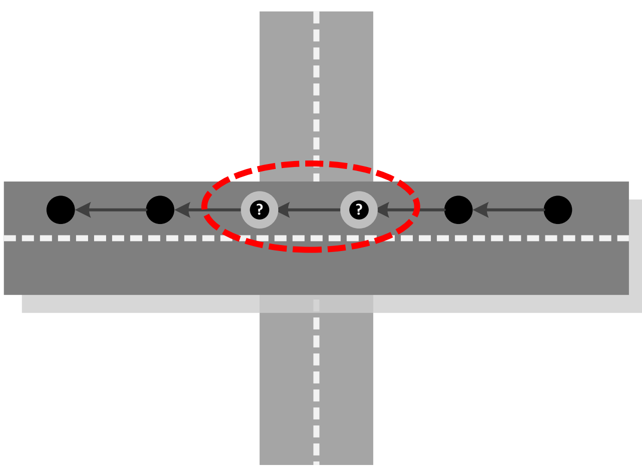
Failures of Naïve Map Matching



Parallel road



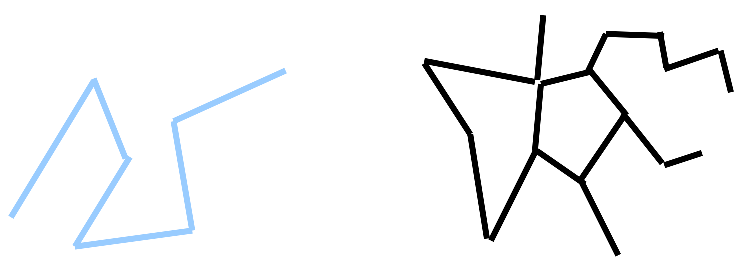
Spur road



Overpass

Global Method

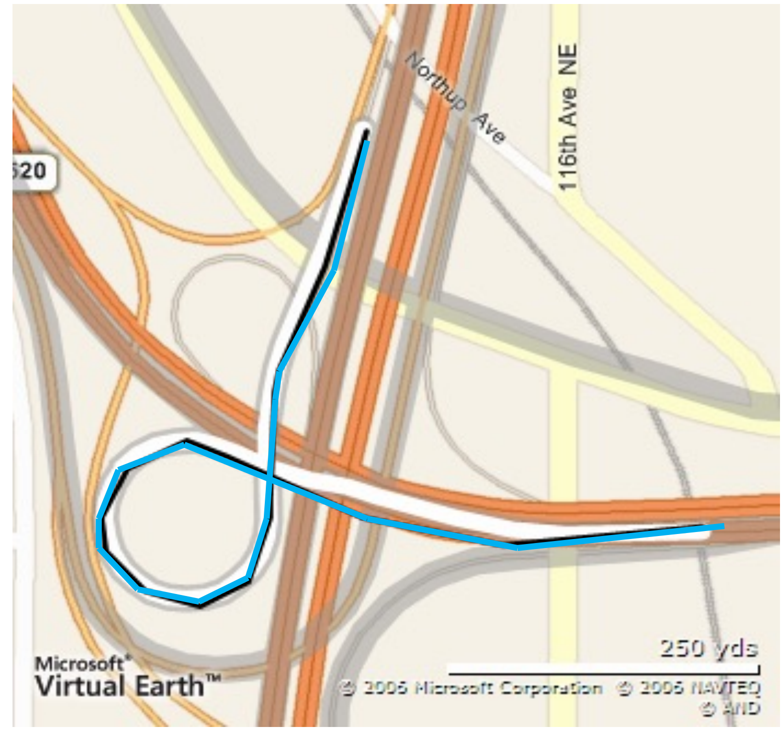
- Try to find a curve in the road network that is *as close as possible* to the given trajectory.
  - The road network is modeled as a graph embedded in the plane with straight-line edges.
- There are different distance measures
  - Fréchet distance is often used
- Aka geometric map matching



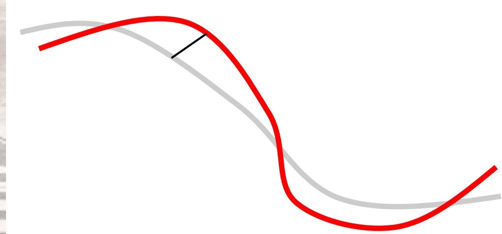
Geometric Map Matching Example

- A global method

Where does this curve match?

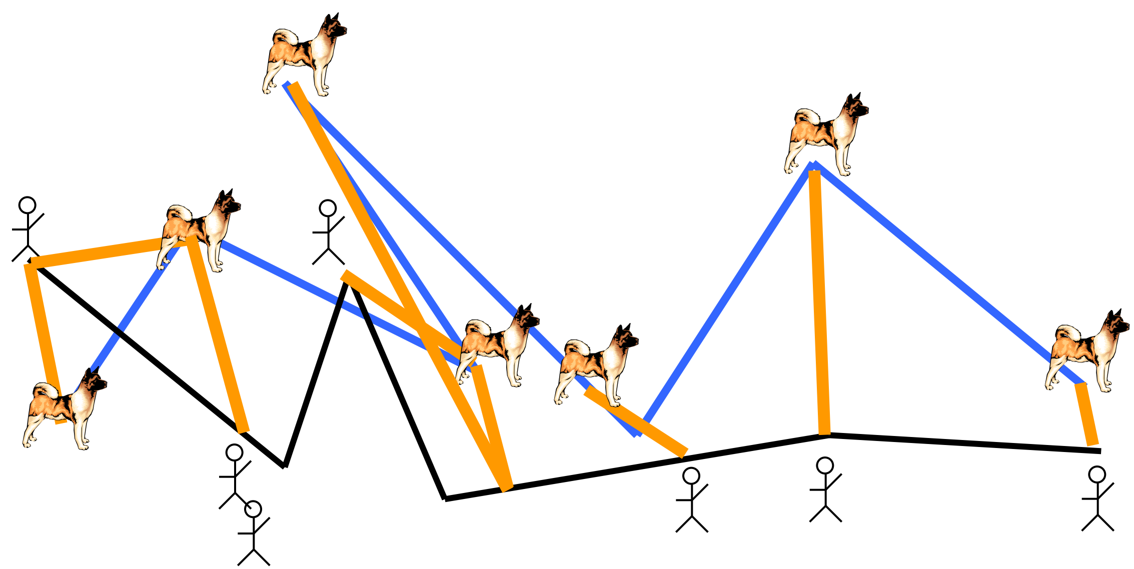


- Fréchet distance
  - the minimum length of a leash required to connect a dog and its owner



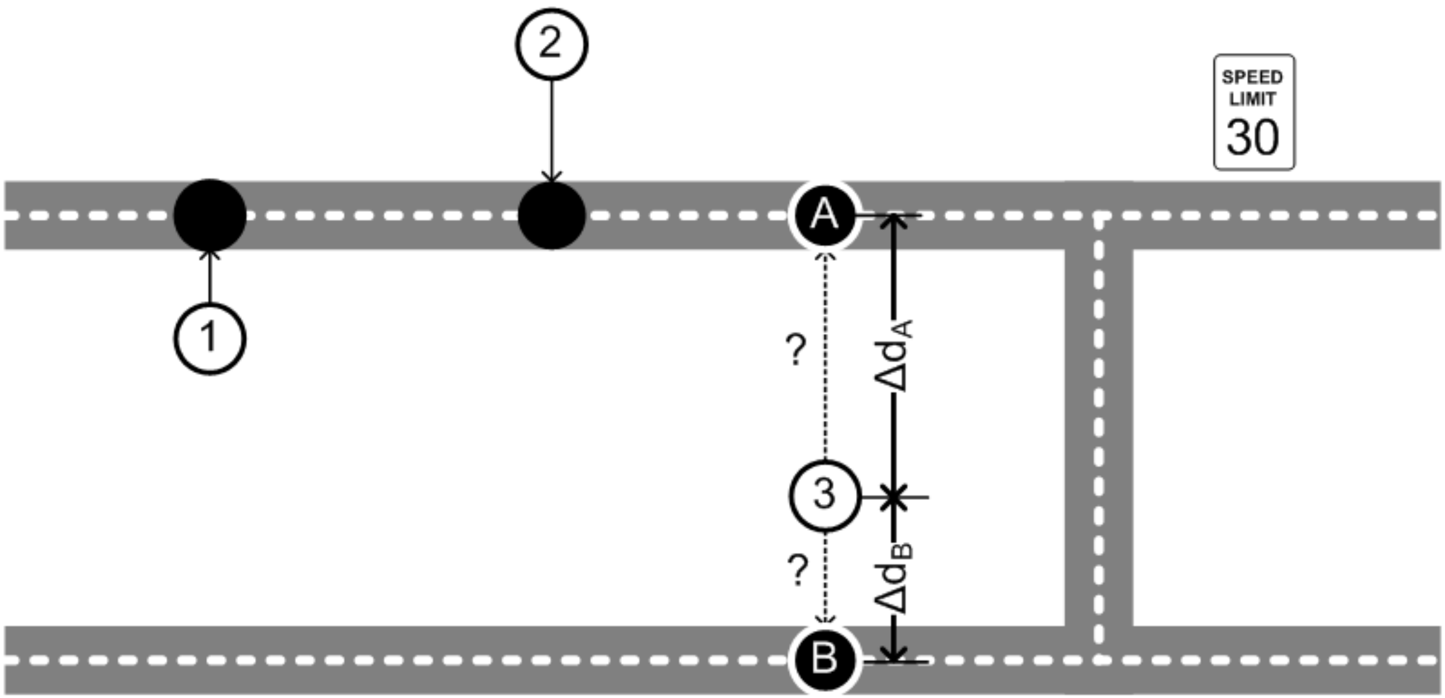
Fréchet Distance Example

- Dog walking example
  - Person is walking his dog (person on one curve and the dog on other)
  - Allowed to control their speeds but not allowed to go backwards!
  - Fréchet distance of the curves: ***minimal leash length*** necessary for both to walk the curves from beginning to end



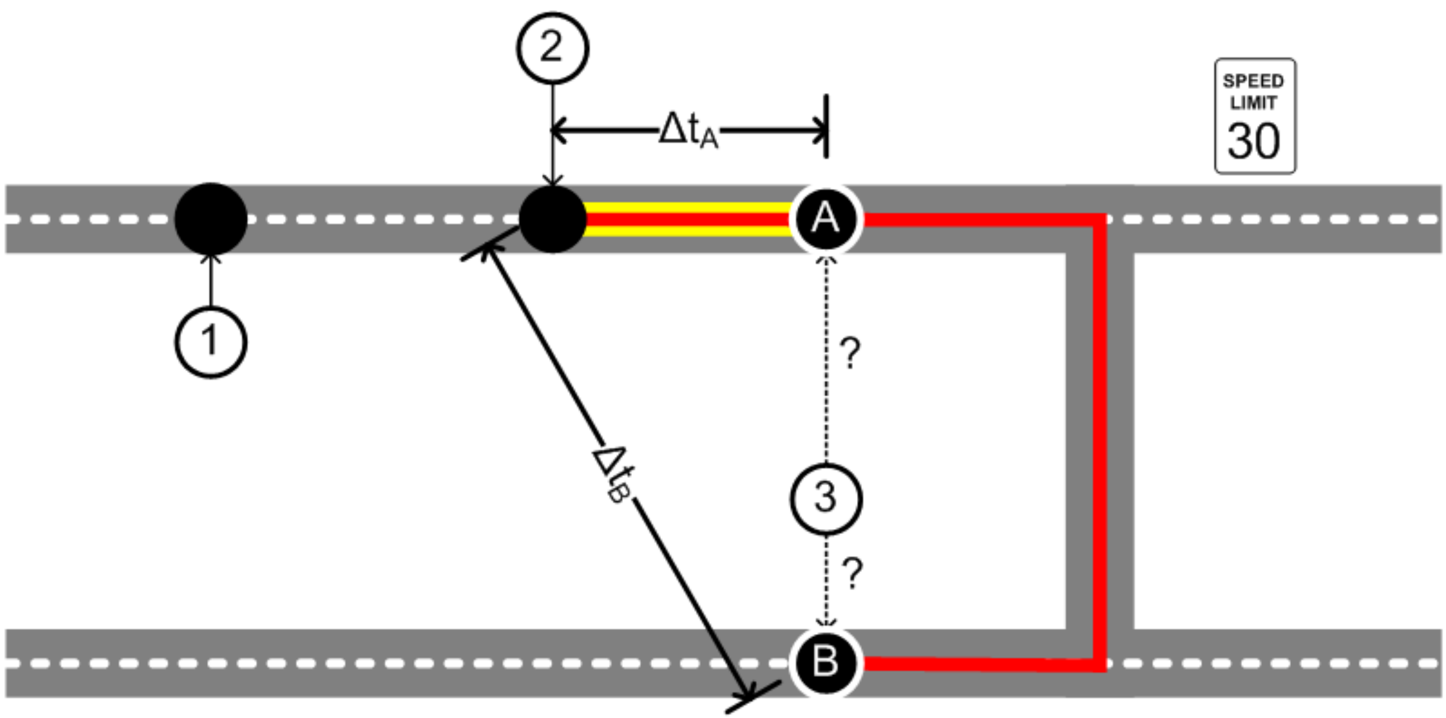
Probabilistic Map Matching

- Does GPS report 3 match position A or B?
  - We can look at a large pool of historical GPS trajectories. Find those ones with positions 1 and 2, and see the ratios of A or B that follows



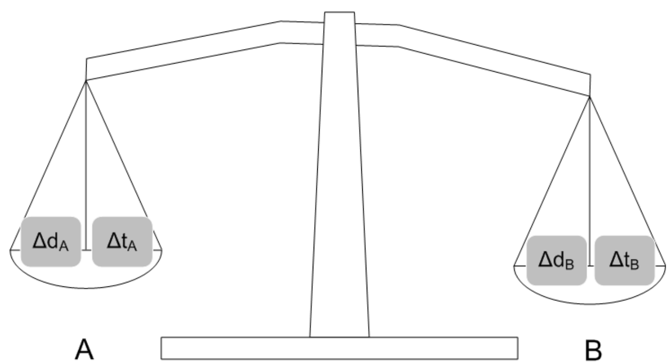
Time Based Map Matching

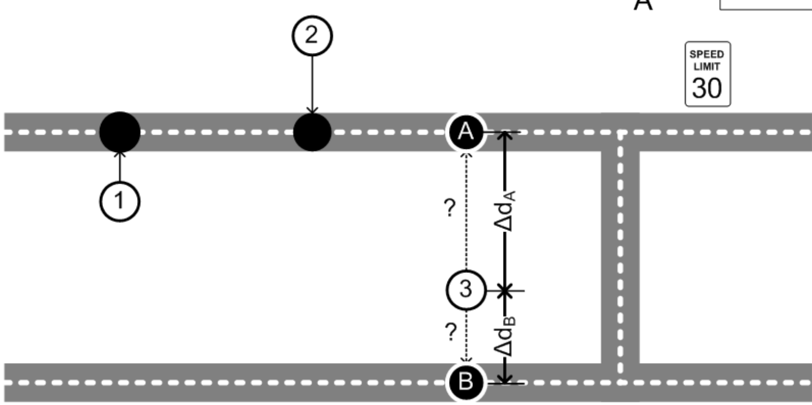
- Suppose 1 and 2 have been matched correctly.
- We also know the speed limit (assume the driver is reasonable) and the time difference between 2 and 3
  - This may help us rule out B

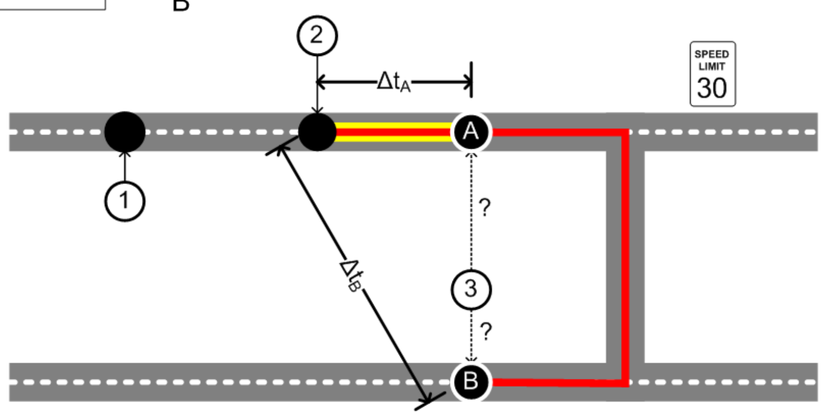


Tradeoff Distance and Time

- If A and B are still both possible, we can compare their corresponding distance/time deltas, and decide which one is more probable given the circumstance.
  - E.g., it may a bit too fast (although possible) to reach B
  - Or, it may a bit too slow (although possible) to just reach A

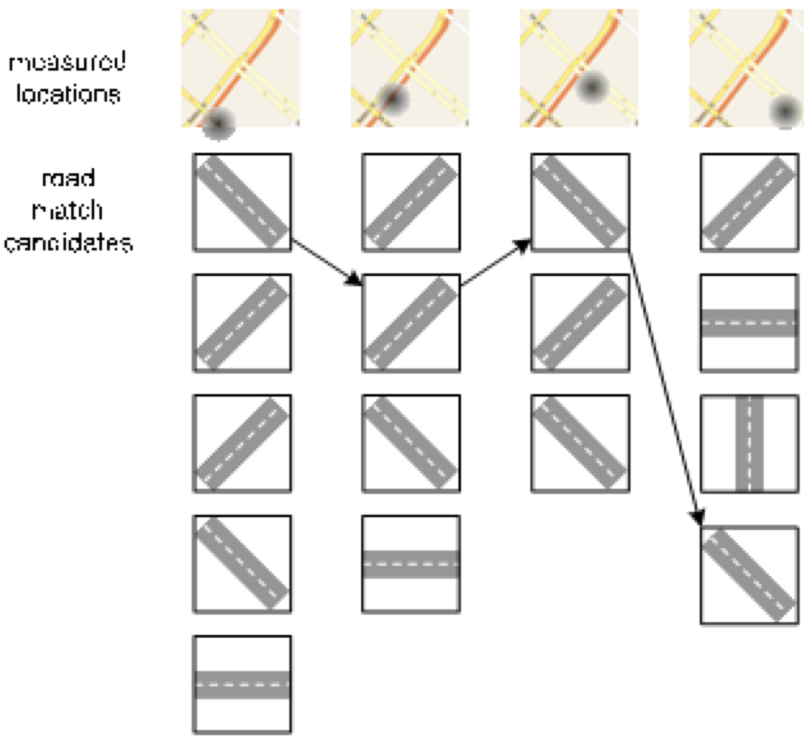


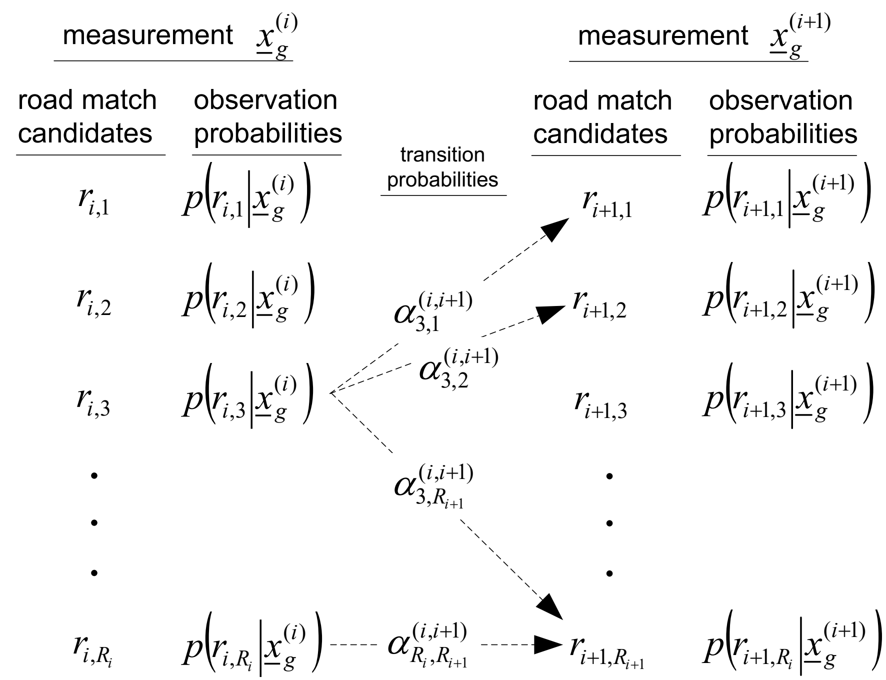




Hidden Markov Model

Optimize tradeoff between spatial and temporal errors

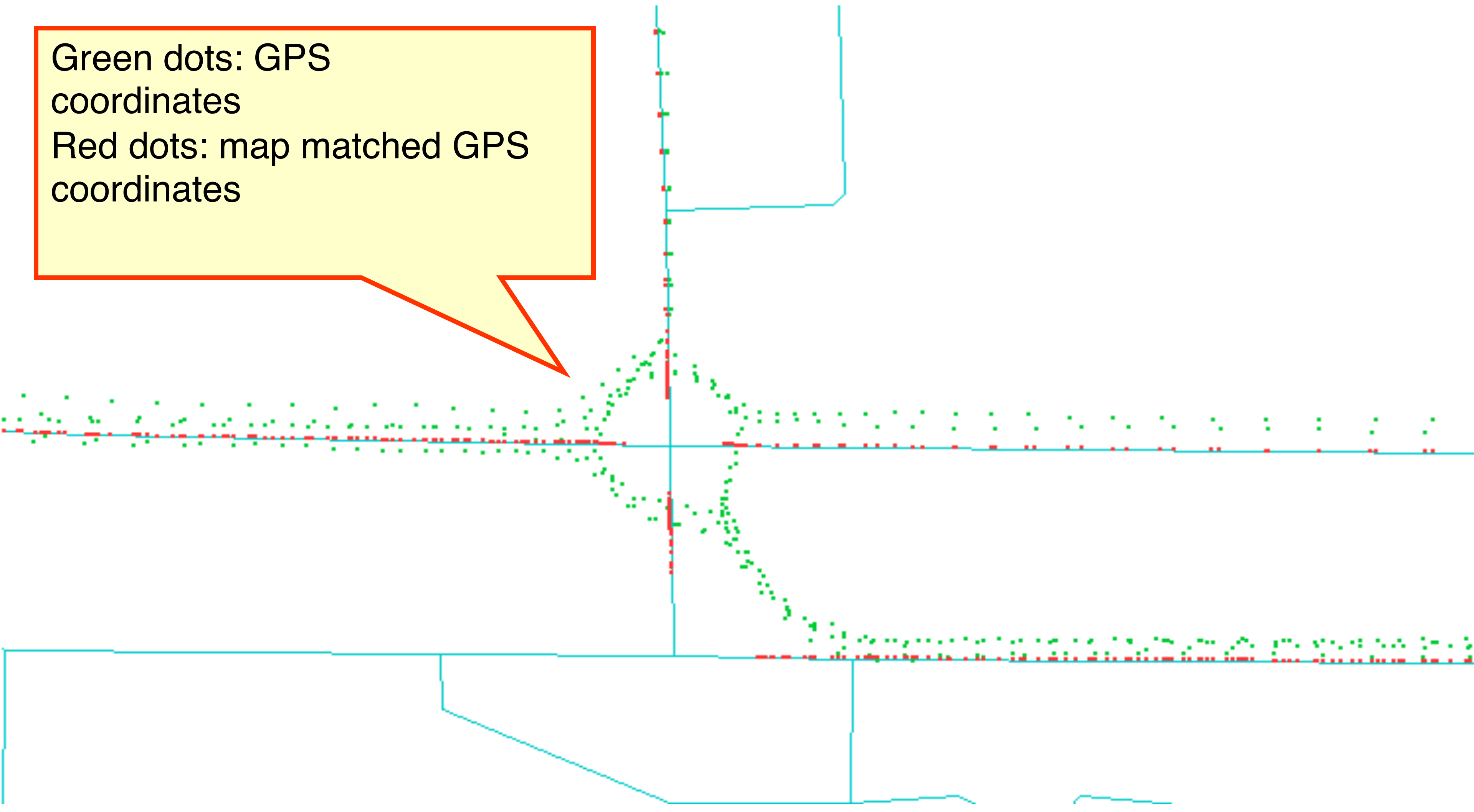




Spatial errors → observation probabilities
Temporal errors → transition probabilities

Map Matching and Inaccuracies

- Map matching is used in segment based tracking
- Non-trivial due to GPS and digital road network inaccuracies



Summary

- LBS in general
  - Components, categories, and architecture
  - Important issues
  - Outdoor positioning
- GPS based tracking of moving objects
  - Architecture
  - Client side update policies
- Map matching
  - Local methods
  - Global methods
  - Statistical methods

Readings

- In the ”Reading Material” Folder on Moodle

Acknowledgements

- Some slides and contents about LBS are from
  - Aloizio P. Silva, Federal University of Minas Gerais, Brazil
  - Casey Brennan, NOAA, USA
  - http://www.e-cartouche.ch
  - http://www.e-zest.net/
  - http://www.gpsinformation.org/dale/nmea.htm
  - http://www.e-cartouche.ch/content_reg/cartouche/LBSbasics/en/html/index.html
- Some slides about trajectories are adapted from the web site.
  - http://research.microsoft.com/en-us/projects/trajectorycomputing/default.aspx