Indoor Localization using Place and Motion Signatures

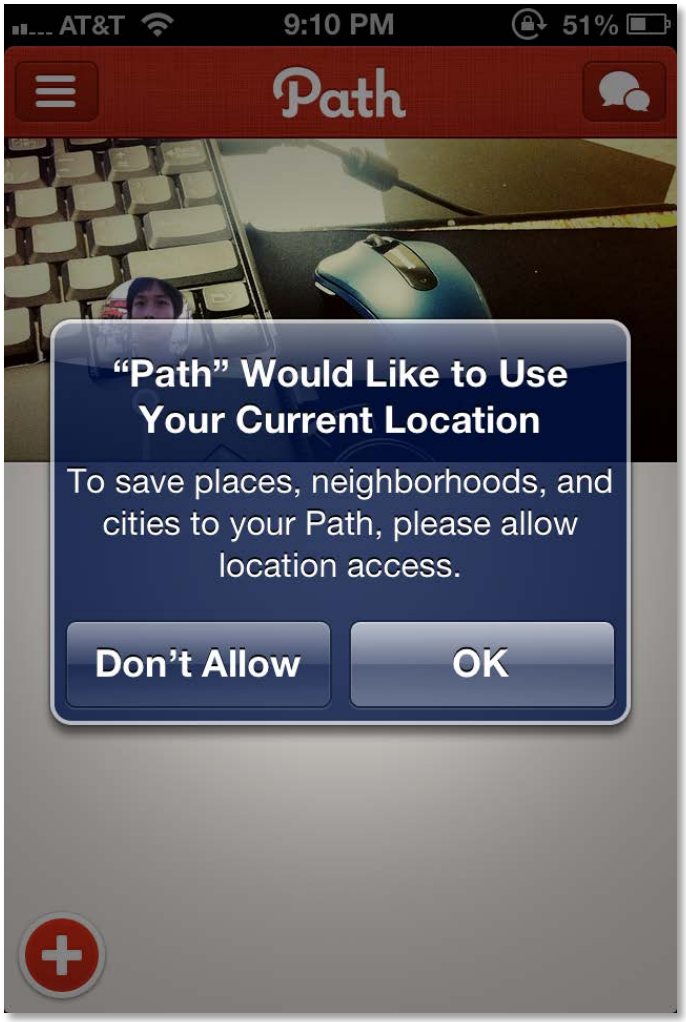
Jun-geun Park

Thesis Committee:
Prof. Seth Teller (Advisor)
Prof. Nick Roy
Prof. Tommi Jaakkola

Outline

- Motivation & prior work
- Thesis contribution
- ~~Algorithms for organic indoor localization (part I)~~
- Motion compatibility-based indoor localization (part II)
  - Overview
  - Motion labeling
  - Route network generation
  - Trajectory matching

Location, Location, Location

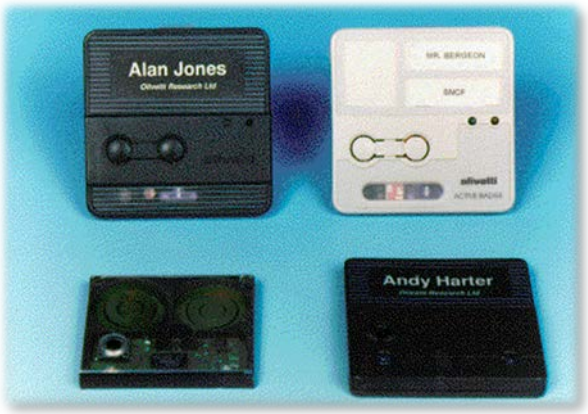


GPS does not work indoors…

- Ultra-high frequency (1.57 GHz) signals of GPS do not penetrate walls very well.
- GPS does not provide enough precision for room-grained location-based services.

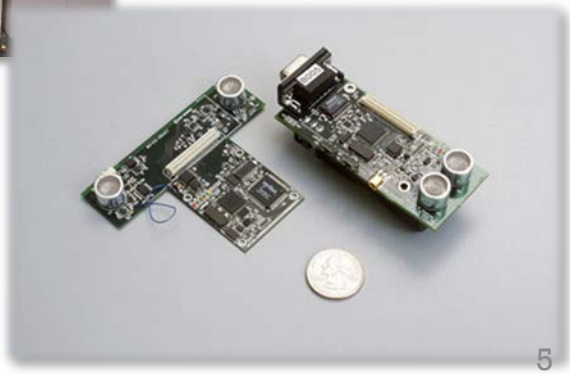
Early Approaches

Require instrumenting spaces with dedicated transceivers.



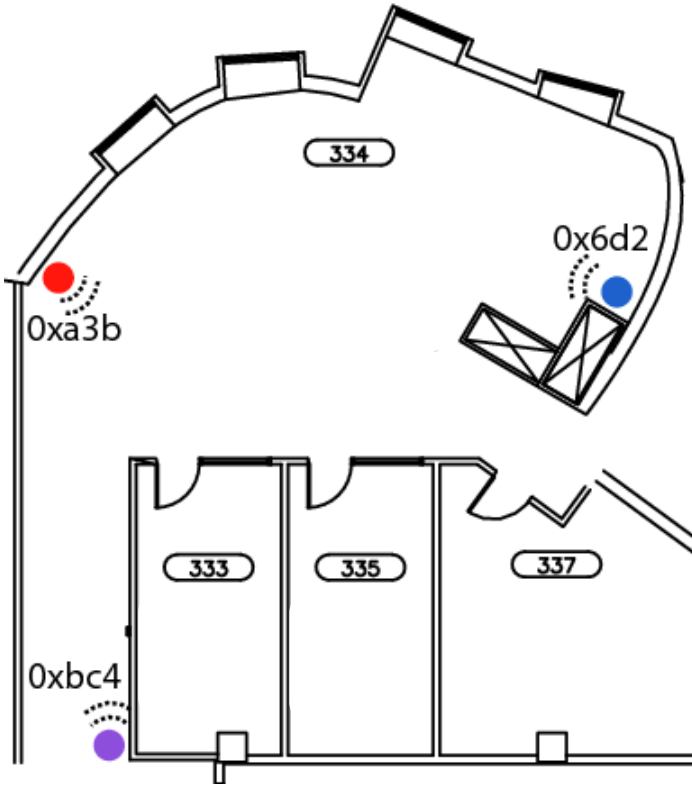
"Active Badge" (Infrared), 1992

MIT "Cricket" (RF+Ultrasound), 2000



WiFi Localization

Survey environment to build WiFi fingerprint database.



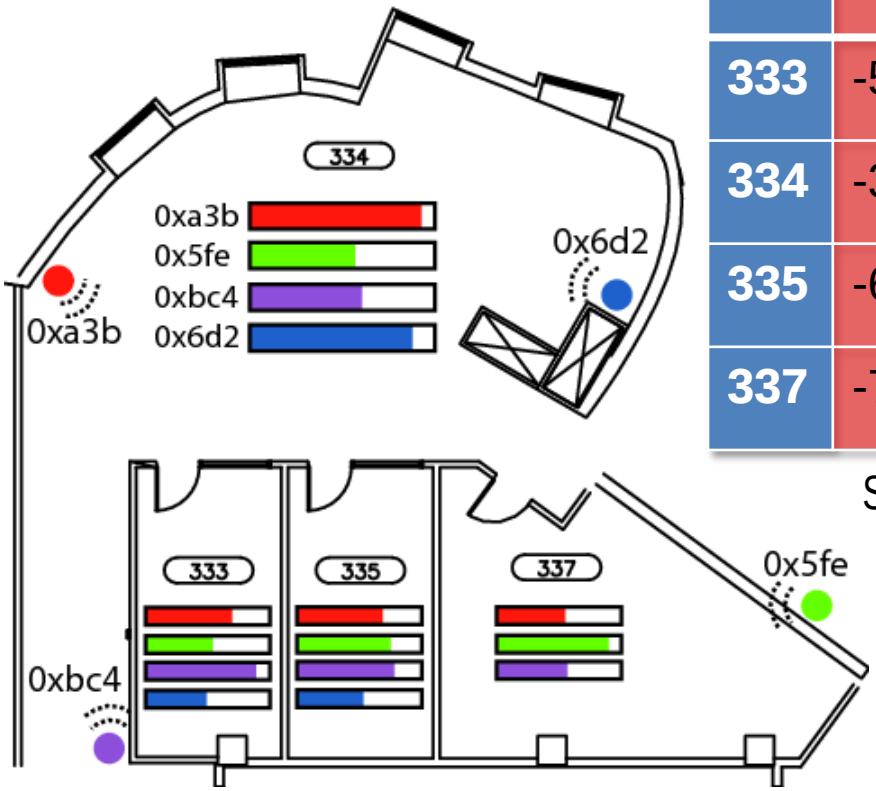
	0xa3b	0x5fe	0xbc4	0x6d2
333				
334				
335				
337				

Signal strength (dBm)

WiFi Localization

Survey environment to build WiFi fingerprint database.

Surveyor



	0xa3b	0x5fe	0xbc4	0x6d2
333	-55	-82	-39	-85
334	-30	-65	-63	-45
335	-60	-55	-50	-73
337	-72	-31	-73	N/A

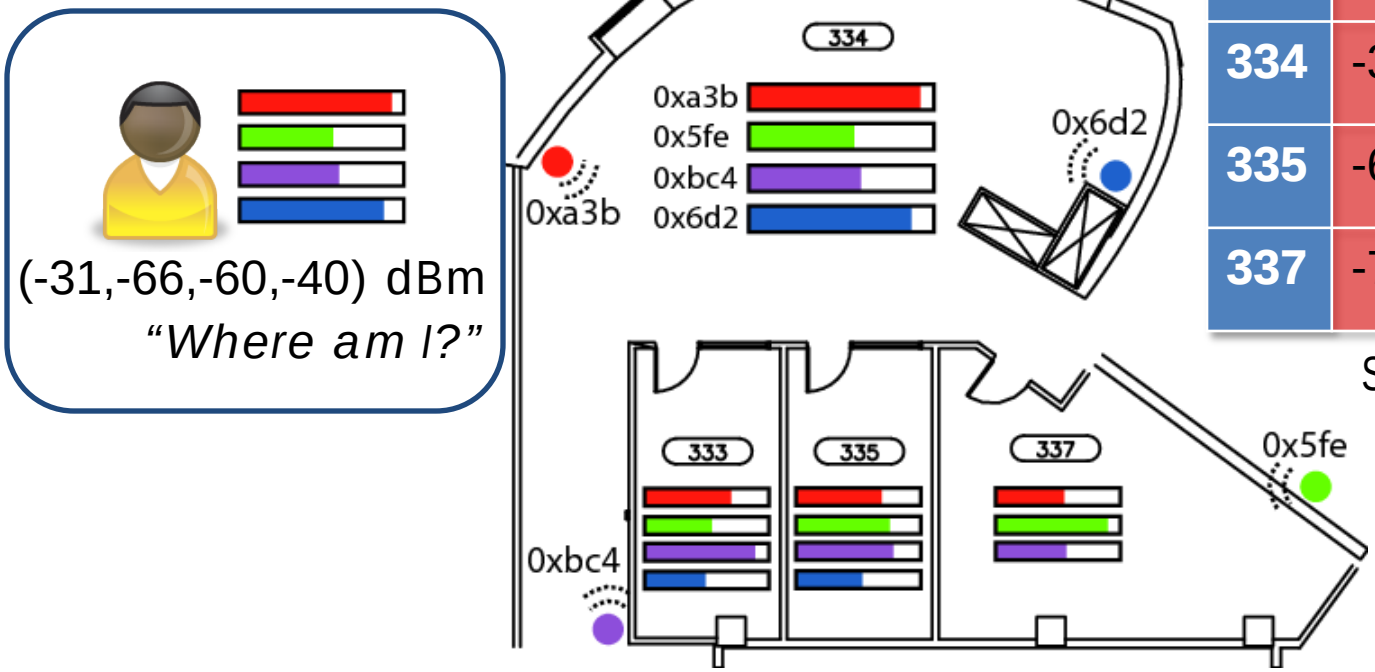
Signal strength (dBm)

WiFi Localization

Survey environment to build WiFi fingerprint database.

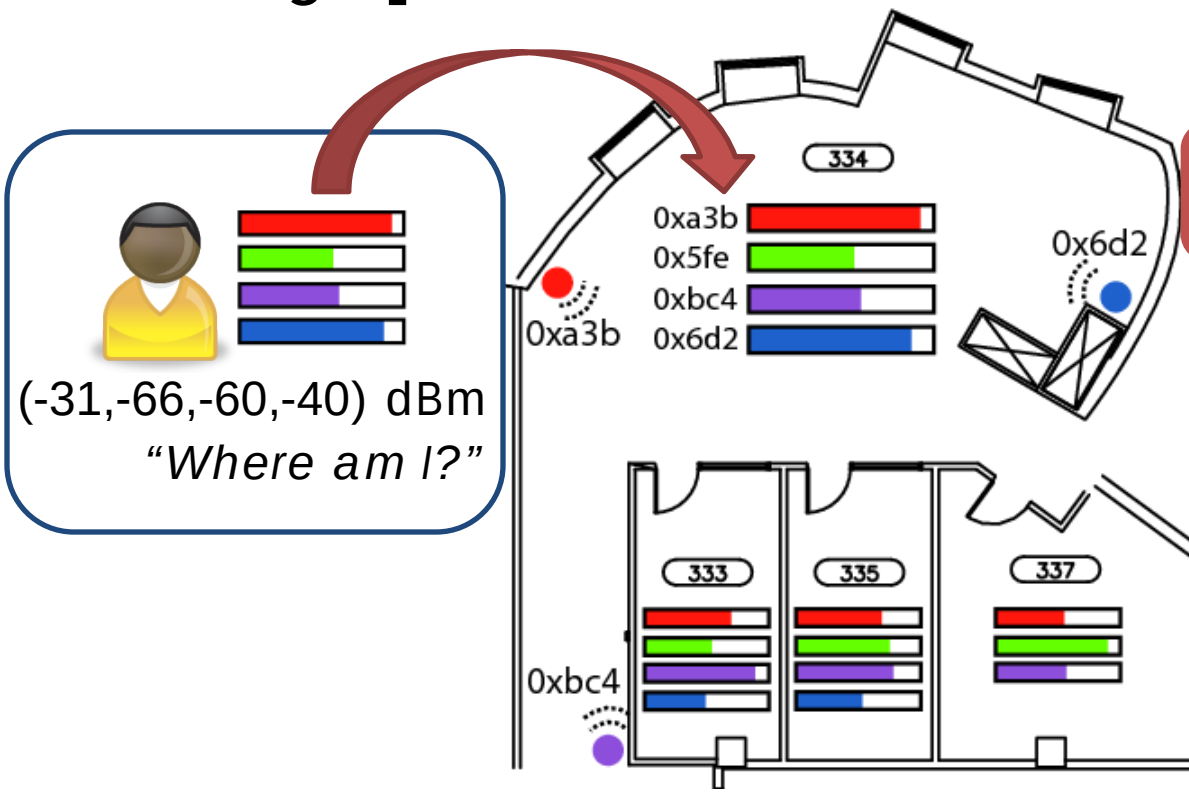
	0xa3b	0x5fe	0xbc4	0x6d2
333	-55	-82	-39	-85
334	-30	-65	-63	-45
335	-60	-55	-50	-73
337	-72	-31	-73	N/A

Signal strength (dBm)



WiFi Localization

Survey environment to build WiFi fingerprint database.



	0xa3b	0x5fe	0xbc4	0x6d2
333	-55	-82	-39	-85
334	-30	-65	-63	-45
335	-60	-55	-50	-73
337	-72	-31	-73	N/A

Signal strength (dBm)

WiFi Localization

- Fingerprinting-based methods require extensive, costly survey.

- Not suitable for large-scale, long-term location services.

Extending the Horizon

Users

"Organic" place signatures collected by end-users.

Motion signatures

The shape and the type of a space define motions.

Thesis Contributions

- Part I: Algorithms for Organic Localization
  - User prompting
  - Erroneous user input filtering
  - Device heterogeneity

"Users"

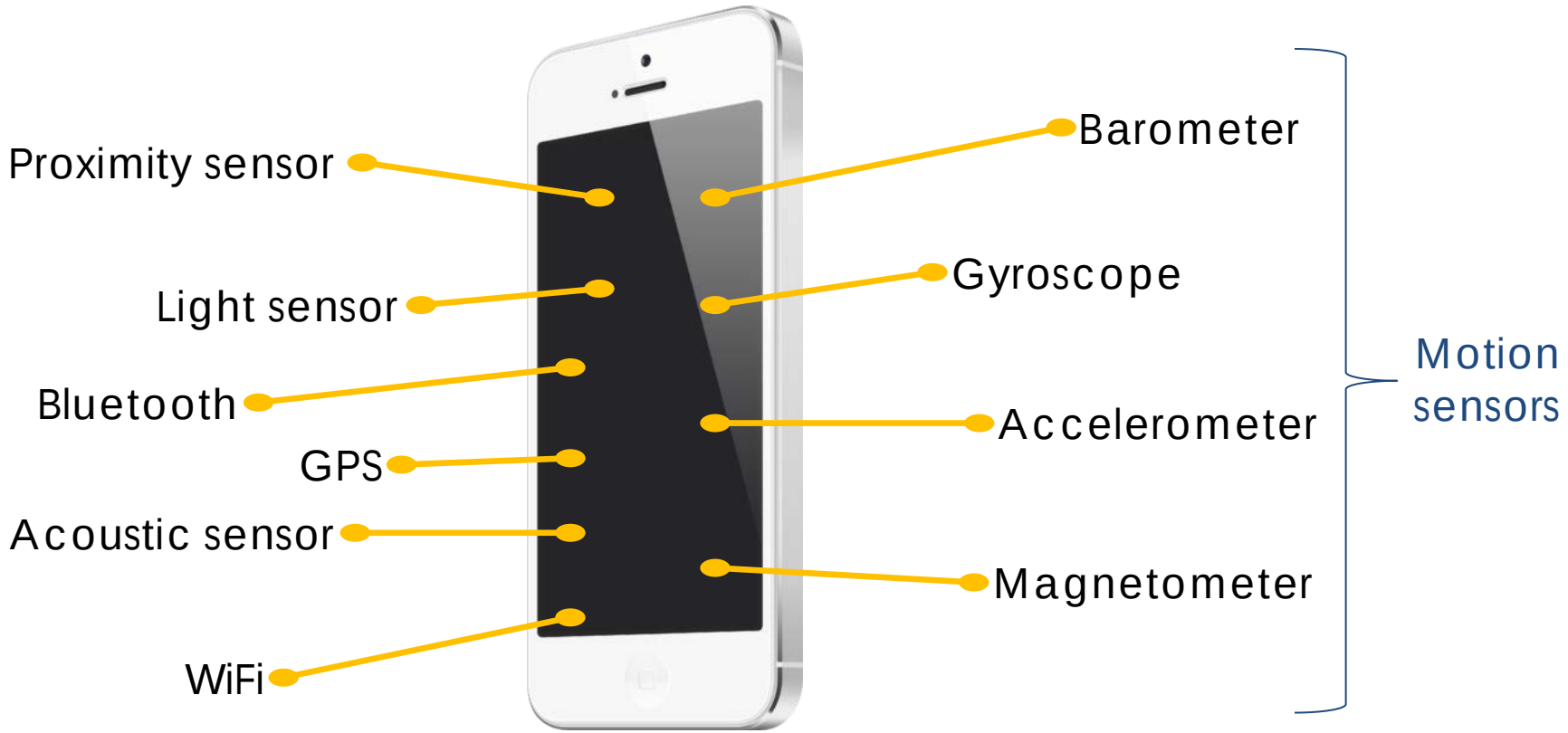
TODAY

- Part II: Motion Compatibility-Based Localization
  - Motion labeling
  - Route network generation
  - Trajectory matching

"Motion signatures"

II. Motion Compatibility-Based Indoor Localization

Modern smartphones are equipped with a variety of sensors.



Previous Work

"Indoor Pedestrian Navigation"

Step 1: Sensors at a fixed, known position

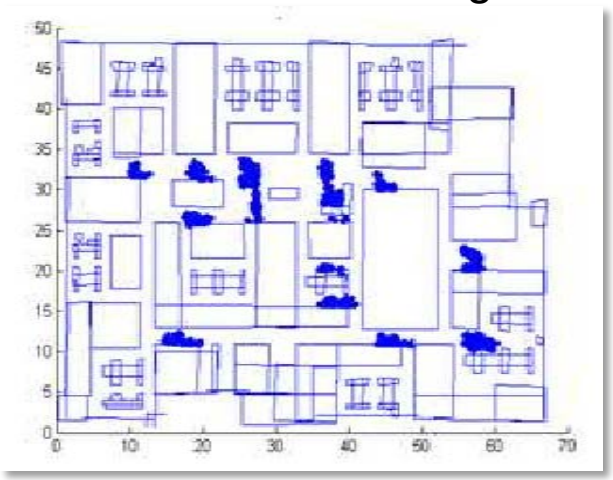
Step 2: Step-counting & heading estimation

Step 3: Kalman filters / particle filters

Foot-mounted IMU for "zero velocity update"

Ascher et al., "Dual IMU Indoor Navigation with Particle Filter based Map-Matching on a Smartphone", IPIN, 2010.

Particle filtering



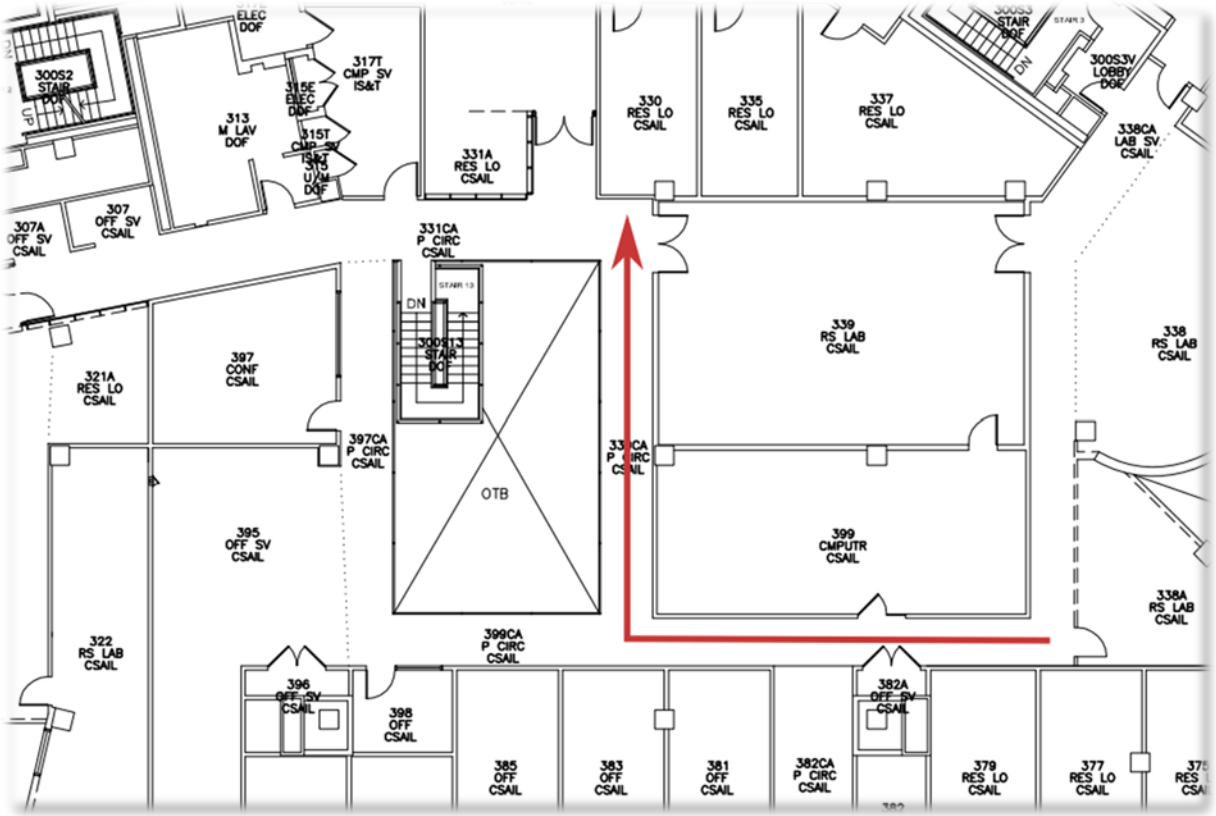
Rai et al., "Zee: Zero-Effort Crowdsourcing for Indoor Localization", MobiCom, 2012

Motion Compatibility-Based Indoor Localization

- Human motions in indoor environments are highly structured.
- The shape and the type of a space imply a motion signature.
- Observed motions → originating path

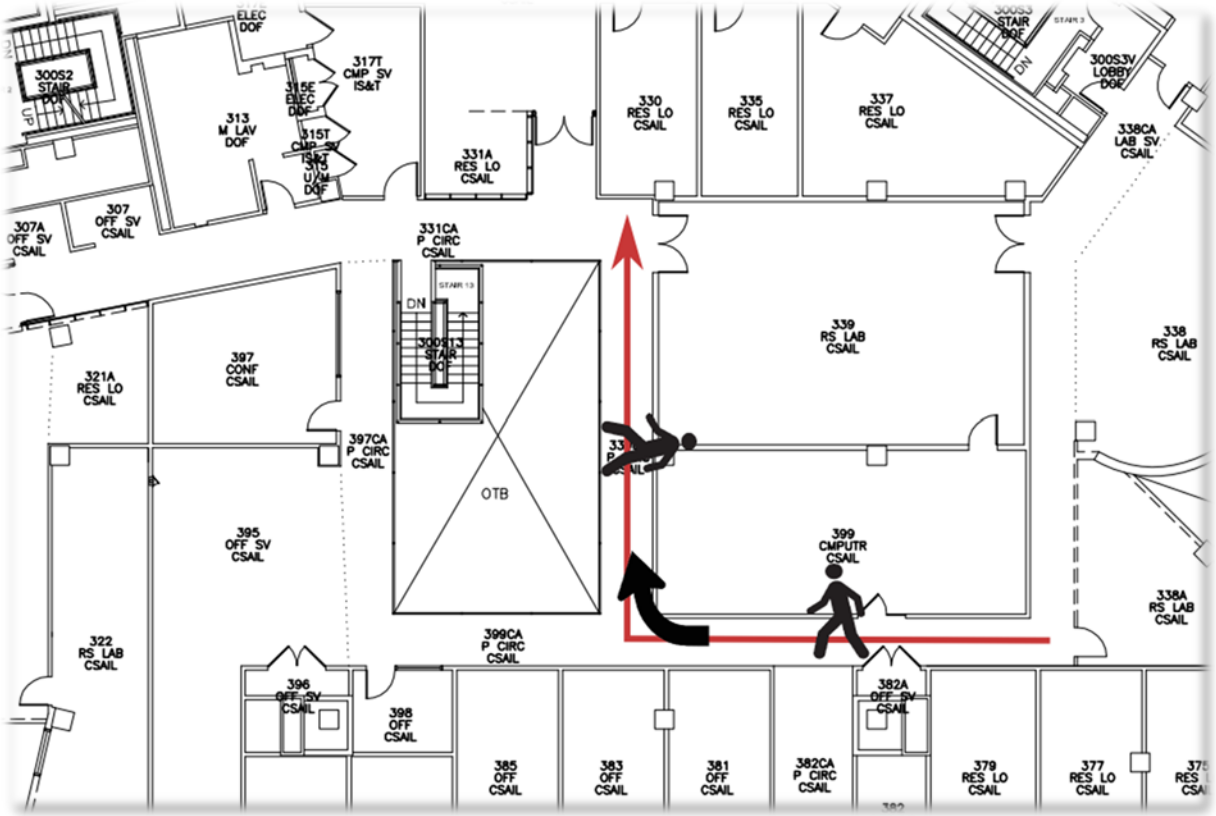
Recovering Paths from Motions

Original path →



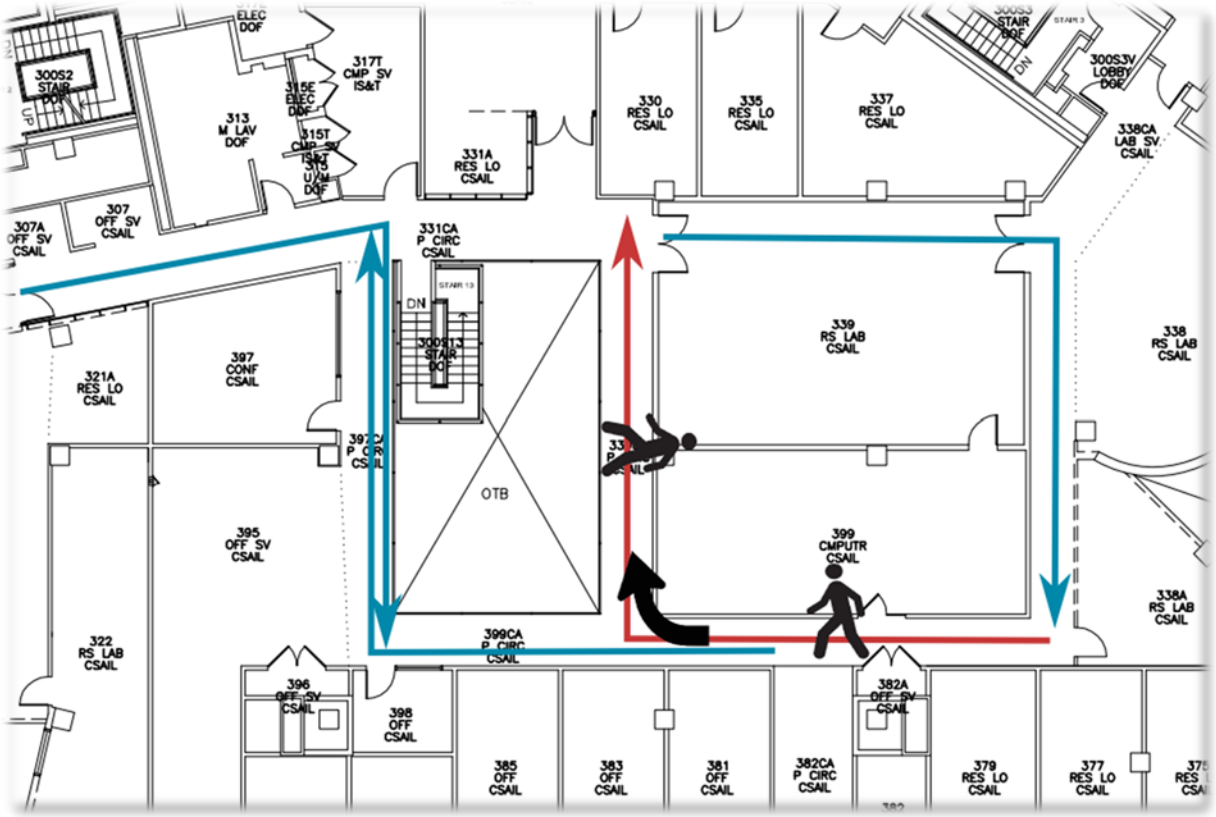
Recovering Paths from Motions

Original path → 3-motion sequence →



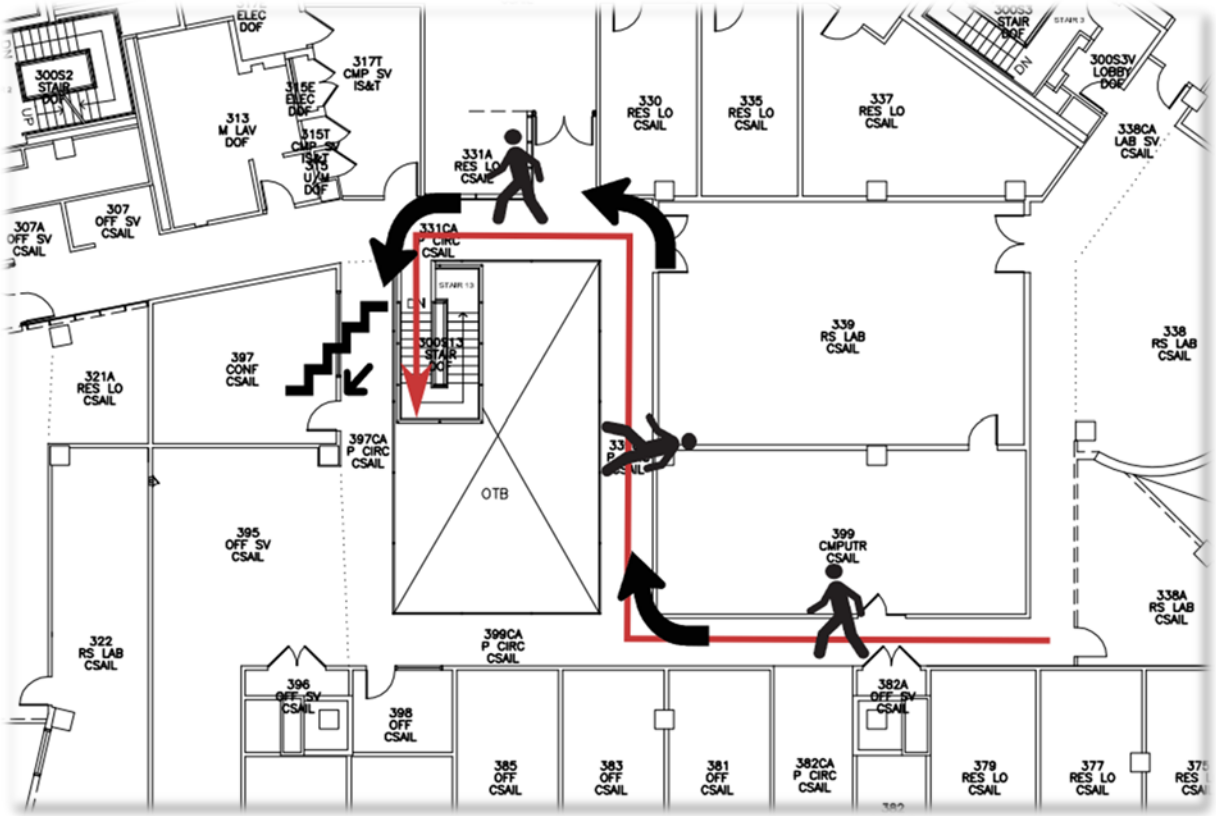
Recovering Paths from Motions

Original path → 3-motion sequence → Many plausible paths



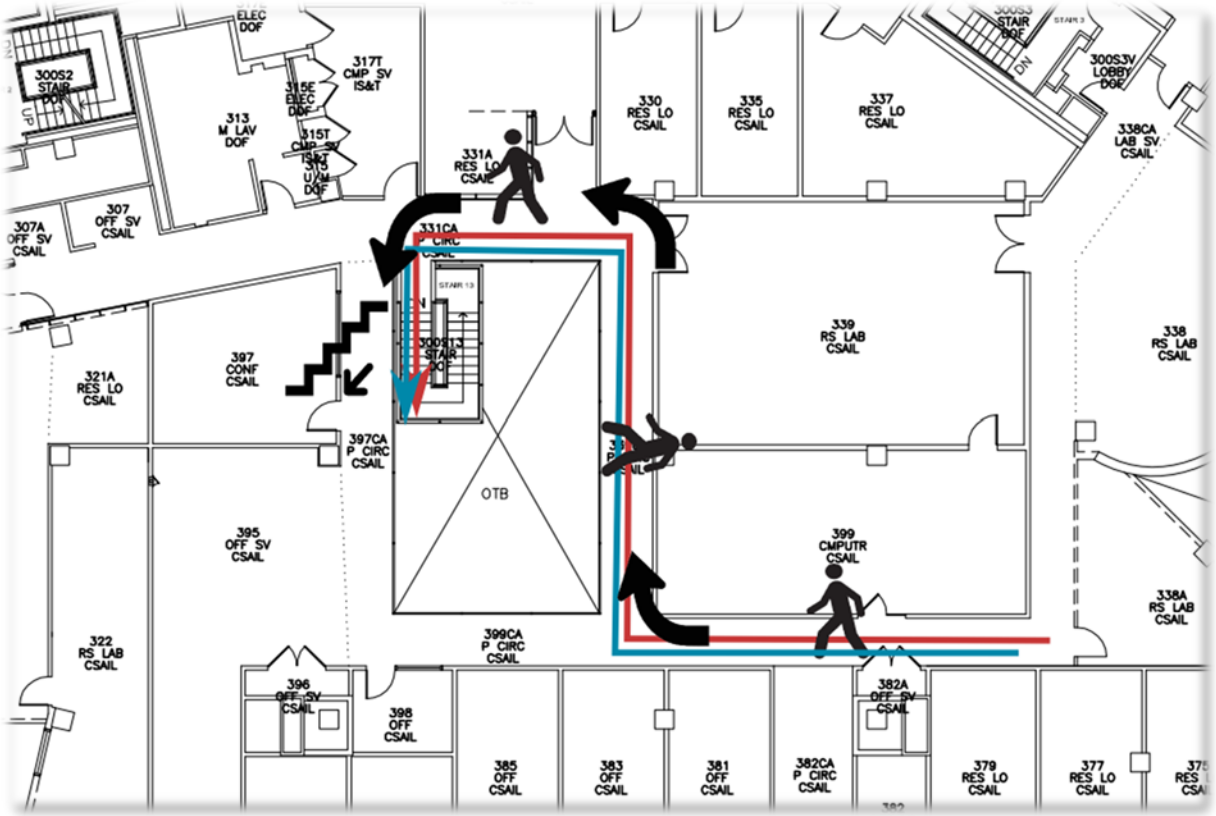
Recovering Paths from Motions

Original path → 7-motion sequence →



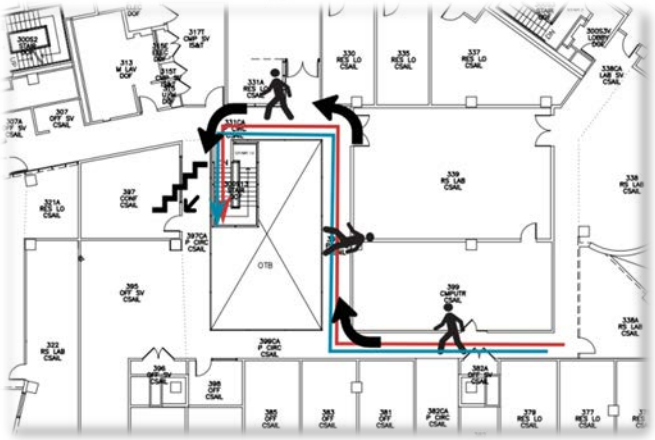
Recovering Paths from Motions

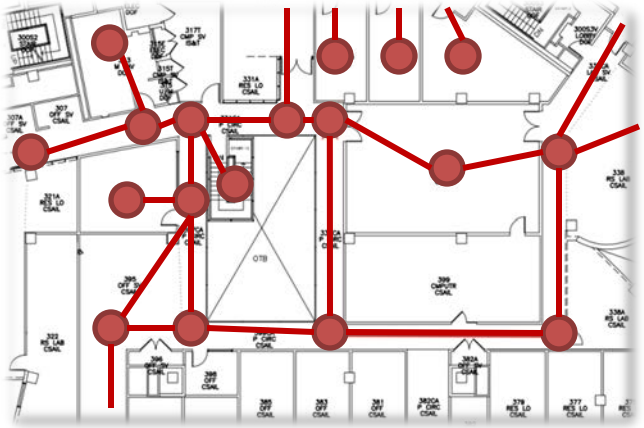
Original path → 7-motion sequence → One matching path



Recovering Paths from Motions

1. "Path-compatibility": Metric/topological/semantic constraints over paths.
    1. Less constraints → higher ambiguity.
    2. More constraints → Lower ambiguity.
2. (Accurate) motion labeling
3. (Automatic) map generation.
4. Uncertainty & noise in inputs.
5. Salient features: vertical motions, "opening a door"…





Recovering Paths from Motions

Motion labeling

Sensor data stream → Motion sequence

Route network generation

Floorplan → Route network

Trajectory matching

Motion + map → User path

Motion Models

- Rest (Sitting)
- Standing
- Straight Walk
- Turn
- Walking Ascent / Descent (on stairs)
- Elevator Up / Down
- Access ("Opening a door",
  "Pressing a button")

Recovering Paths from Motions

Motion labeling

Sensor data stream → Motion sequence

Route network generation

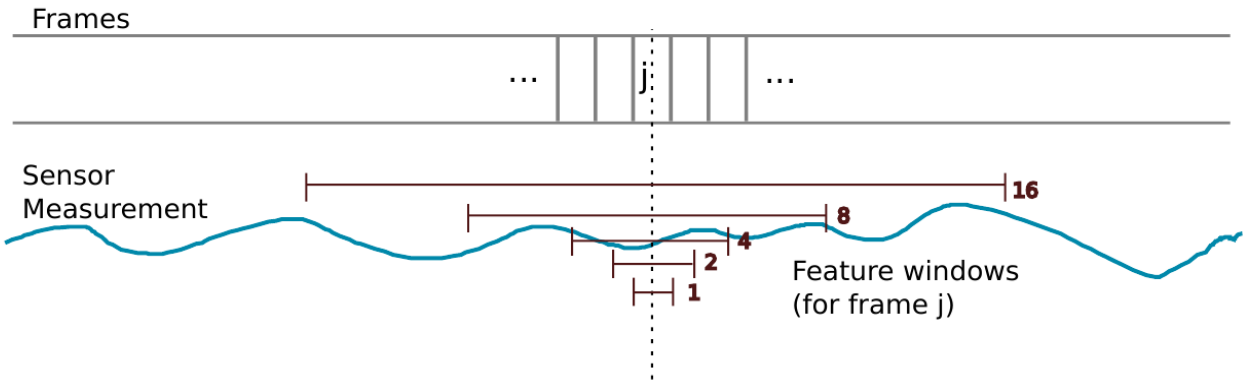
Floorplan → Route network

Trajectory matching

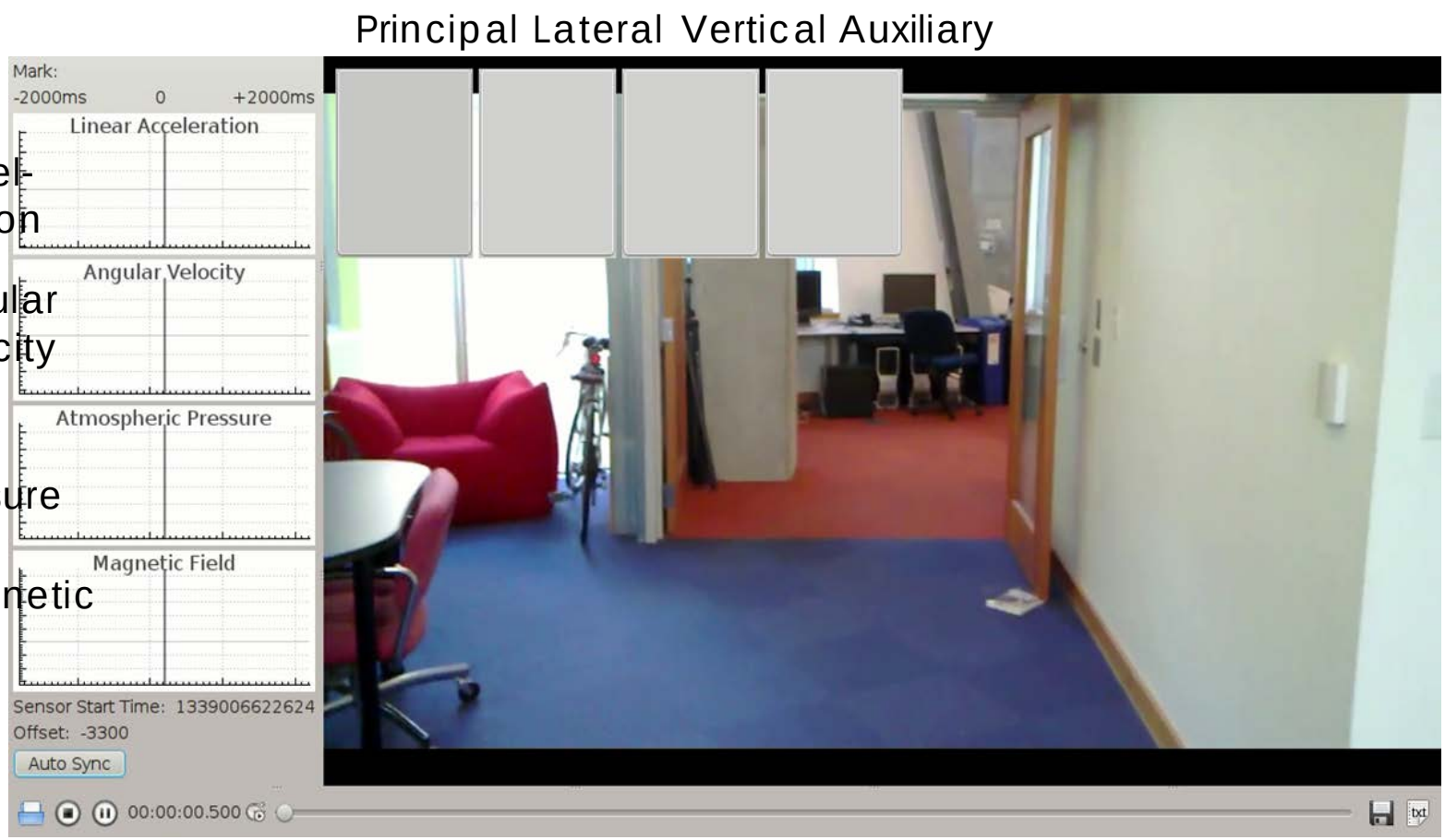
Motion + map → User path

Motion Labeling

- CRF (Conditional Random Field) based sequence classifier, labeling motions at 3Hz.
- Accelerometer/gyroscope/barometer/magnetometer
- Challenge: Different motion durations.
- Solution:
  - Multiple feature windows with varying widths for each feature.
  - CRF learns an "optimal" weight for each window.
  - +10~15% improvement over single-window cases.



Motion Labeling Demo



Motion Labeling Performance

- 94% per-frame overall "accuracy" (F-measure)
- Confusions between

  "Door Open" ←→ "Button Press"

  "Sitting" ←→ "Standing"

Recovering Paths from Motions

Motion labeling

Sensor data stream → Motion sequence

Route network generation

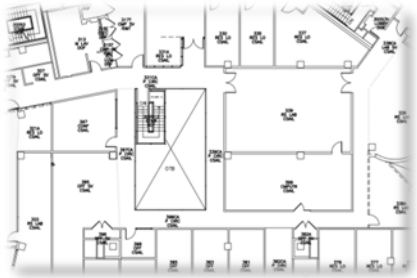
Floorplan → Route network

Trajectory matching

Motion + map → User path

Route Network Generation

CAD drawings (AutoCAD DXF)



By BMG (building model generation) group

Floor plan XML documents

```
<contour>
  <centroid x="710448.767146" y="496440.14
  <extent maxy="496449.009485" miny="49643
          maxx="710455.963341" minx="71044
  <point x="710441.497540" y="496446.04907
  <point x="710444.834064" y="496447.56961
  ...
  <point x="710441.497540" y="496446.04907
</contour>
<portal type="stair" class="vertical" targ
<portal type="implicit" class="horizontal"
  <edge maxparam="1.000000" minparam="0.00
</portal>
```

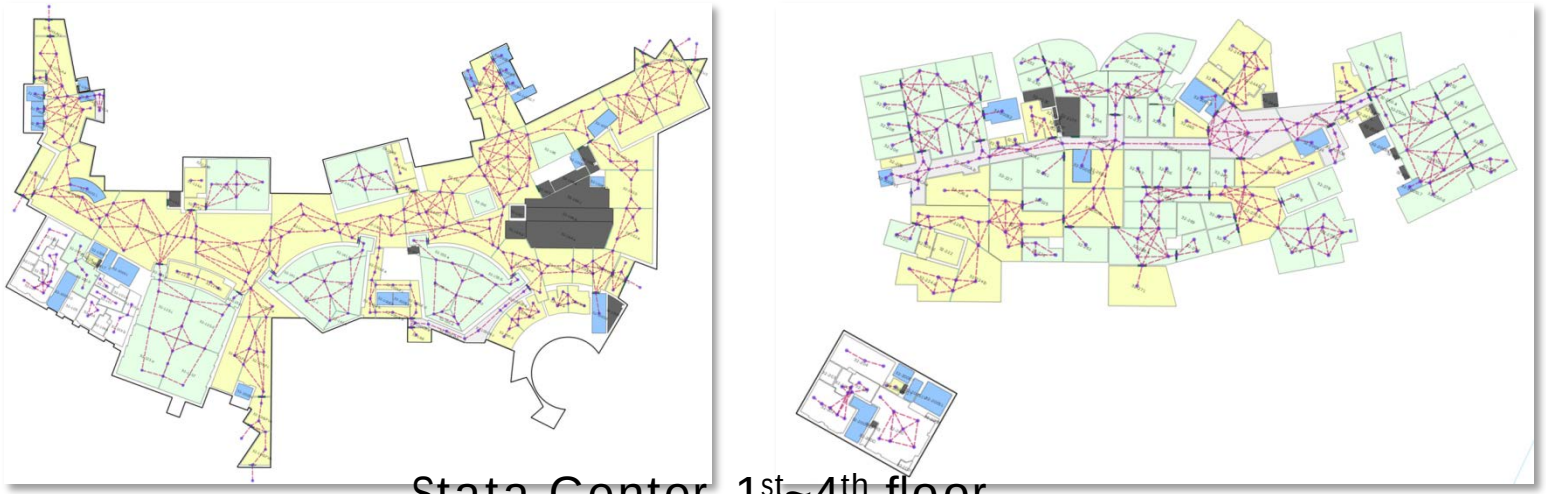
Medial axis approximation

(using constrained Delaunay triangulations)

Route networks

Linked through horizontal & vertical adjacencies

Route Network Generation



Stata Center, 1st~4th floor

Recovering Paths from Motions

Motion labeling

Sensor data stream → Motion sequence

Route network generation

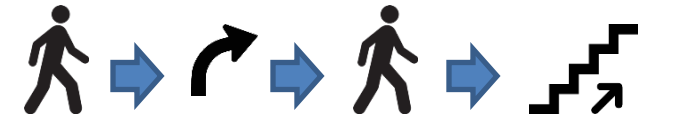
Floorplan → Route network

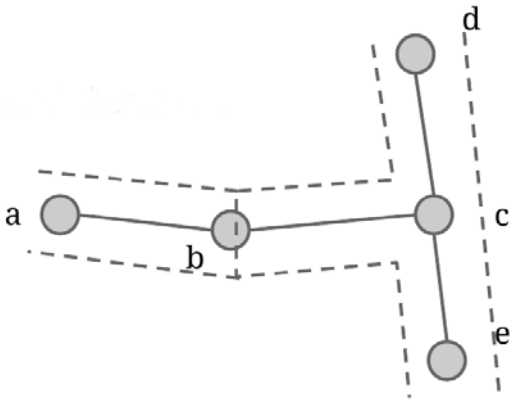
Trajectory matching

Motion + map → User path

Trajectory Matching

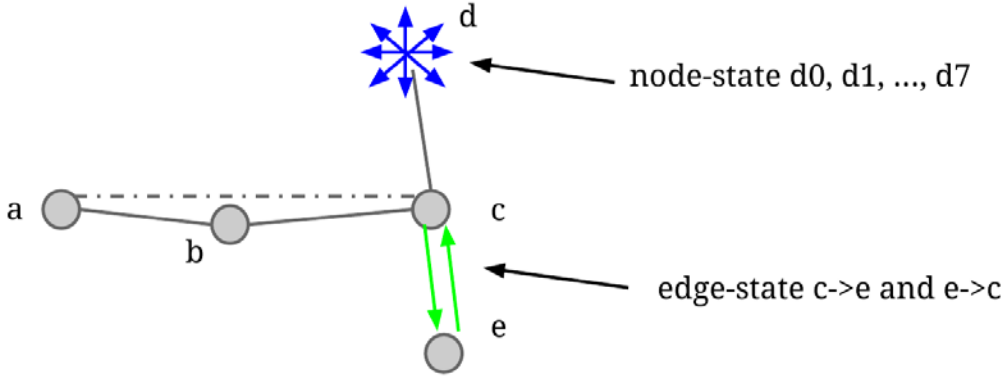
- Inputs

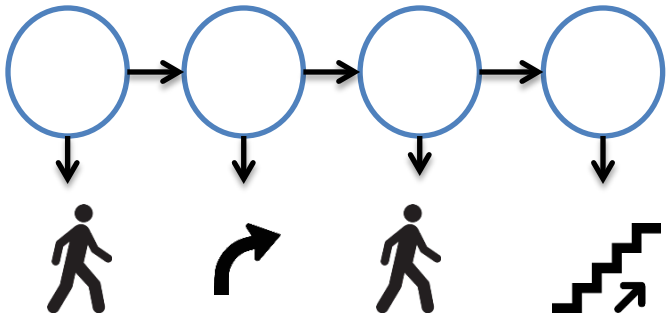




- Sequence labeling with HMM.

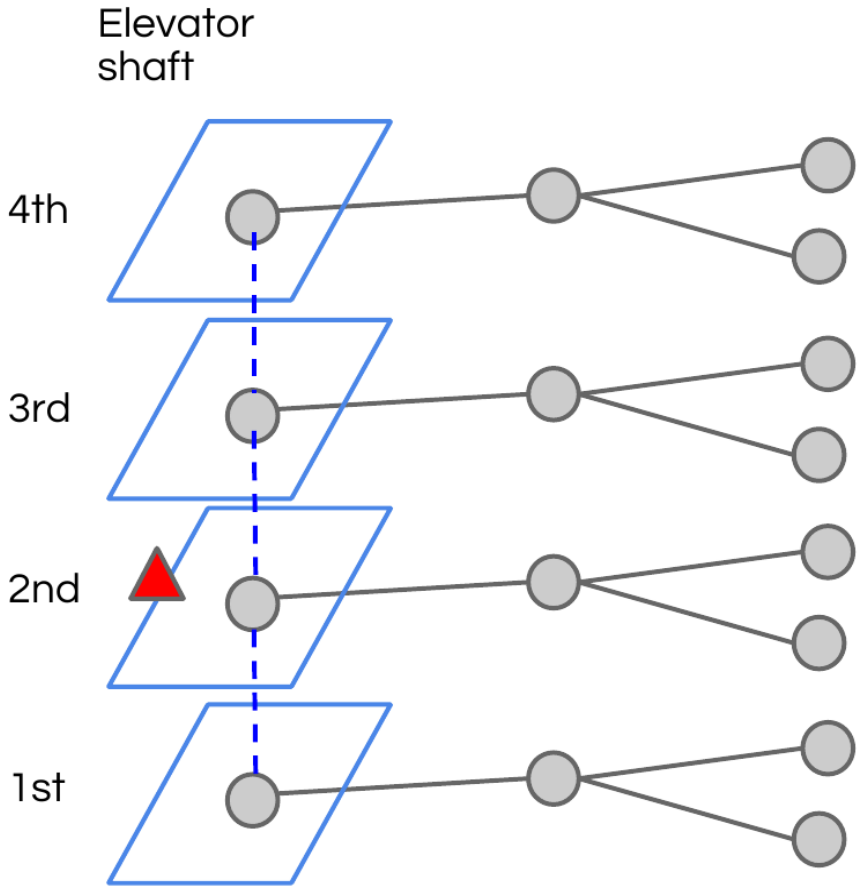
States: Nodes/edges in the route network, parameterized with directions.





Trajectory Matching: Models

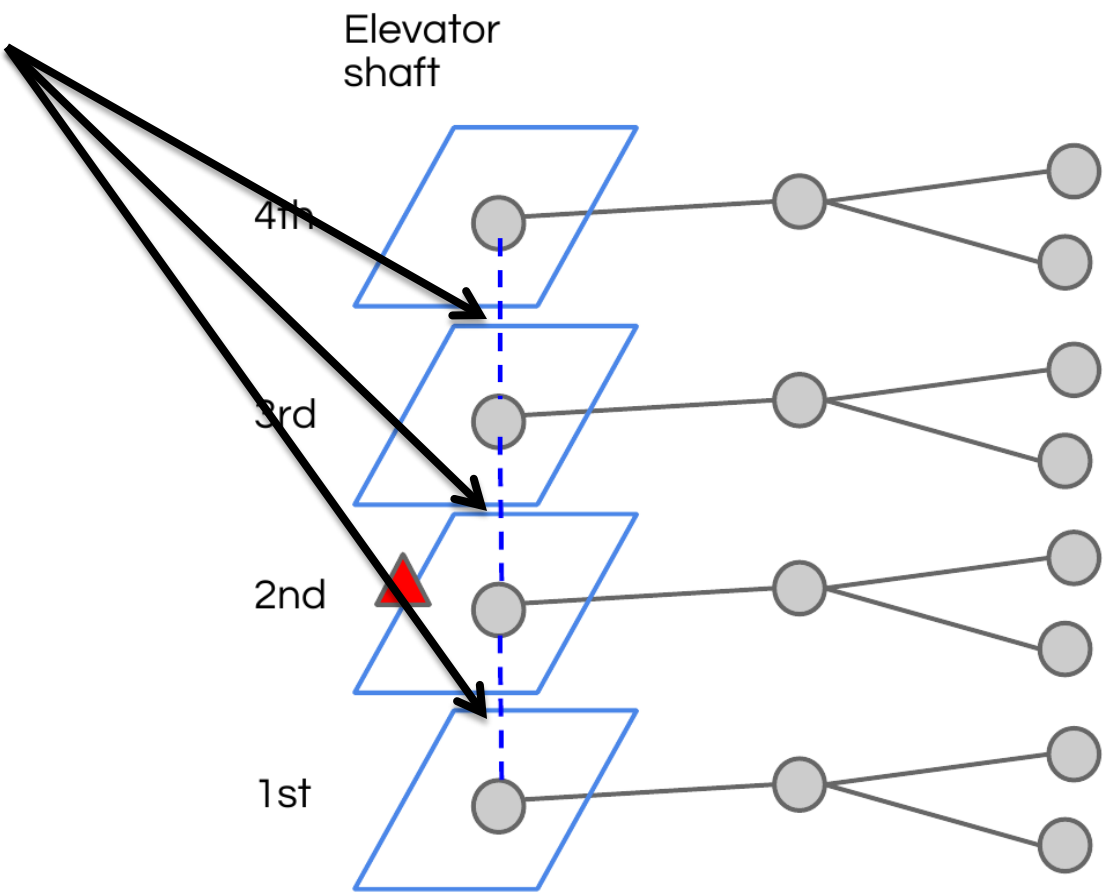
Example: **Elevator Up (11 sec.)**



Trajectory Matching: Models

Example: **Elevator Up (11 sec.)**

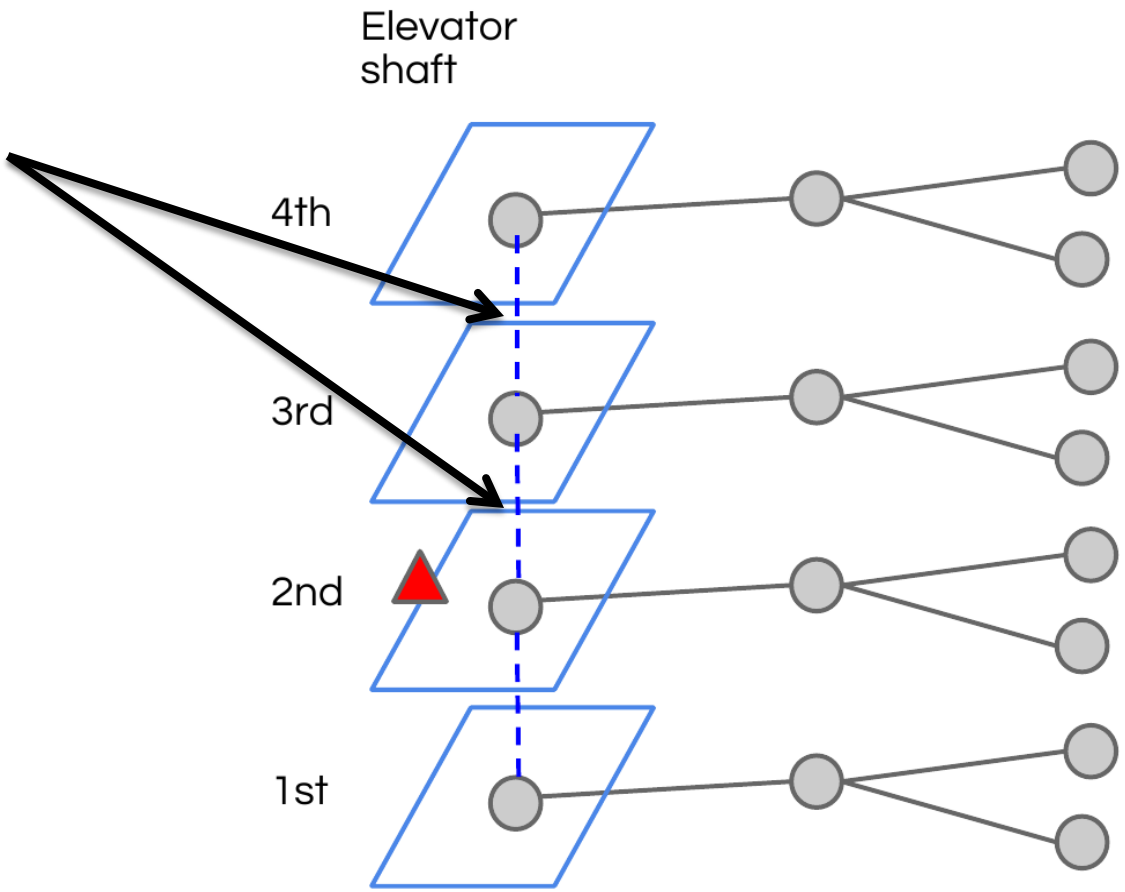
1. Elevator
   (2→1,
   2→3,
   2→4)



Trajectory Matching: Models

Example: **Elevator Up (11 sec.)**

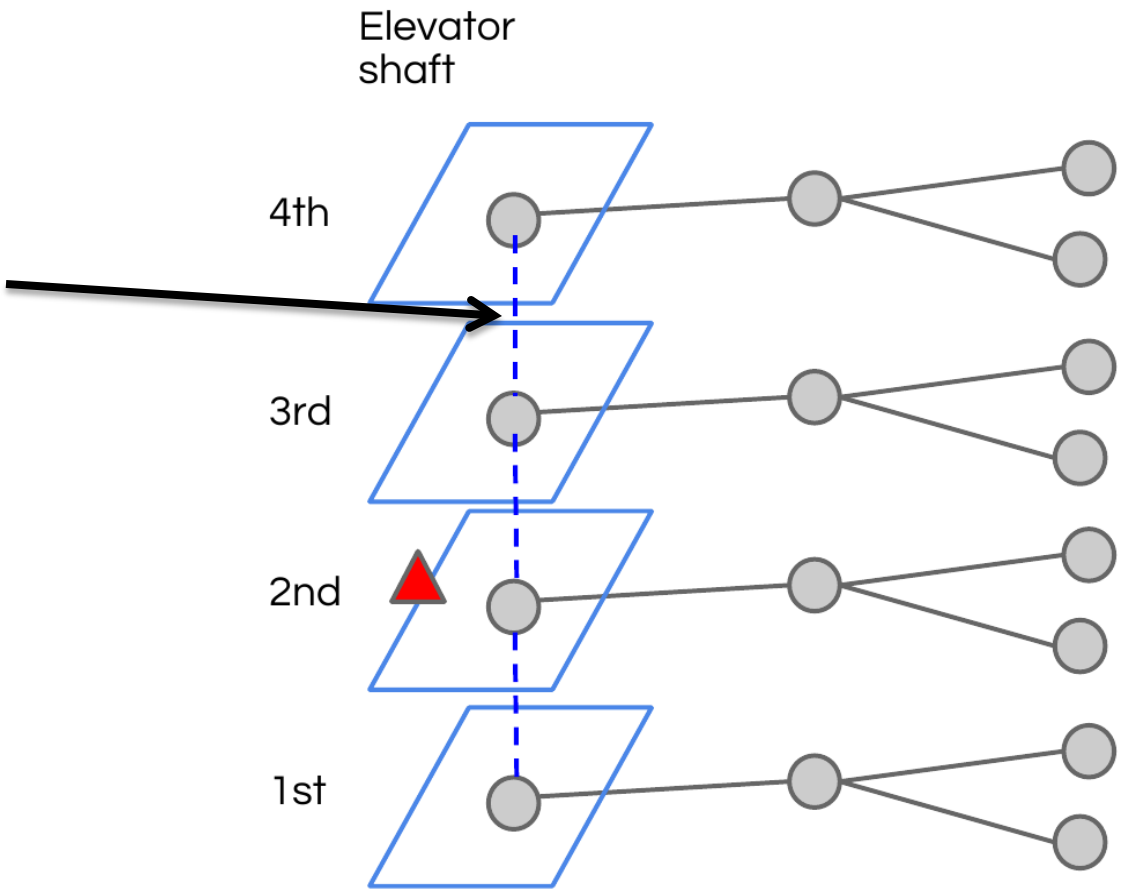
1. Elevator
2. Up
   (2→3,
   2→4)



Trajectory Matching: Models

Example: **Elevator Up (11 sec.)**

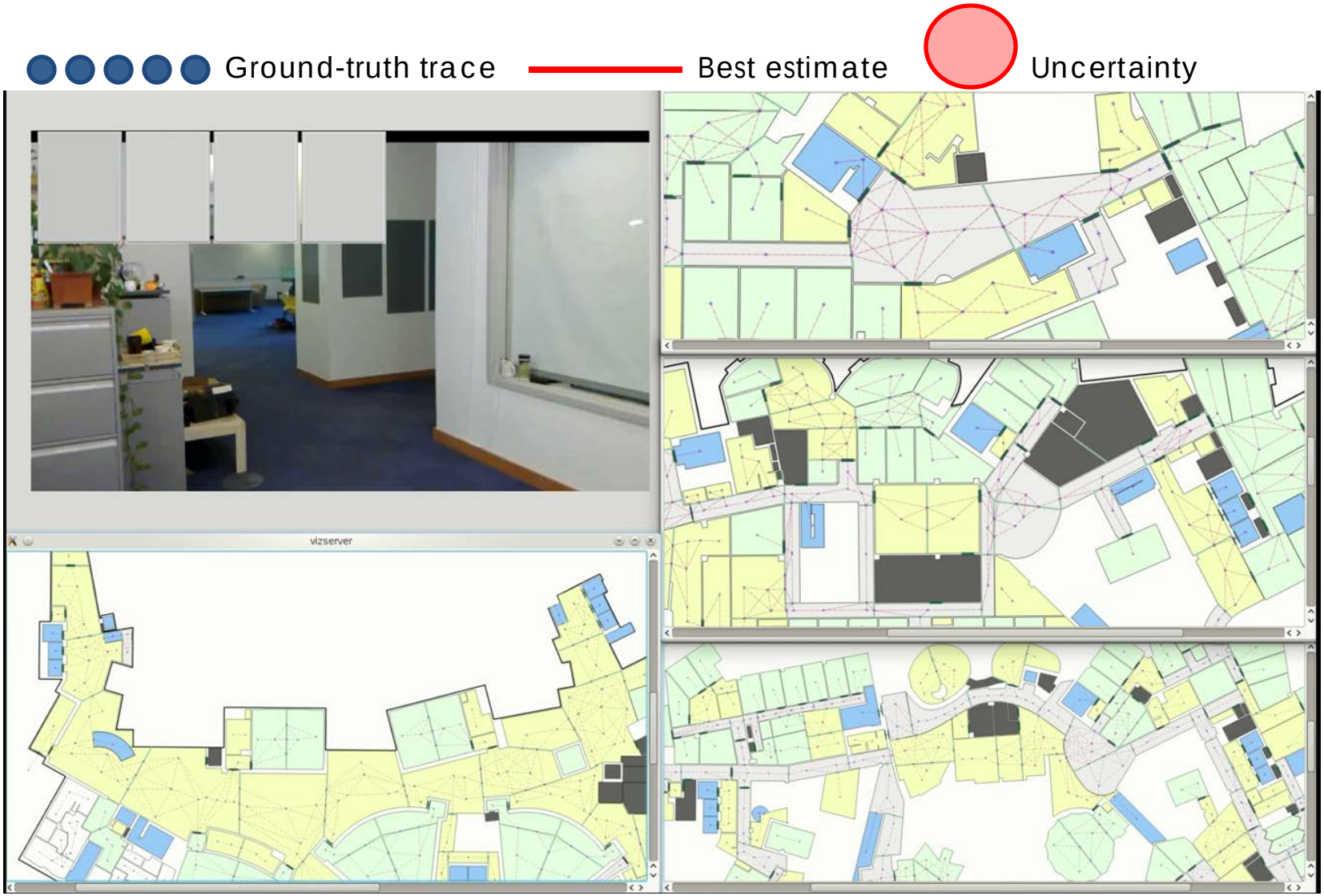
1. Elevator
2. Up
3. 11 sec
   (2→4)



Trajectory Matching: Algorithms

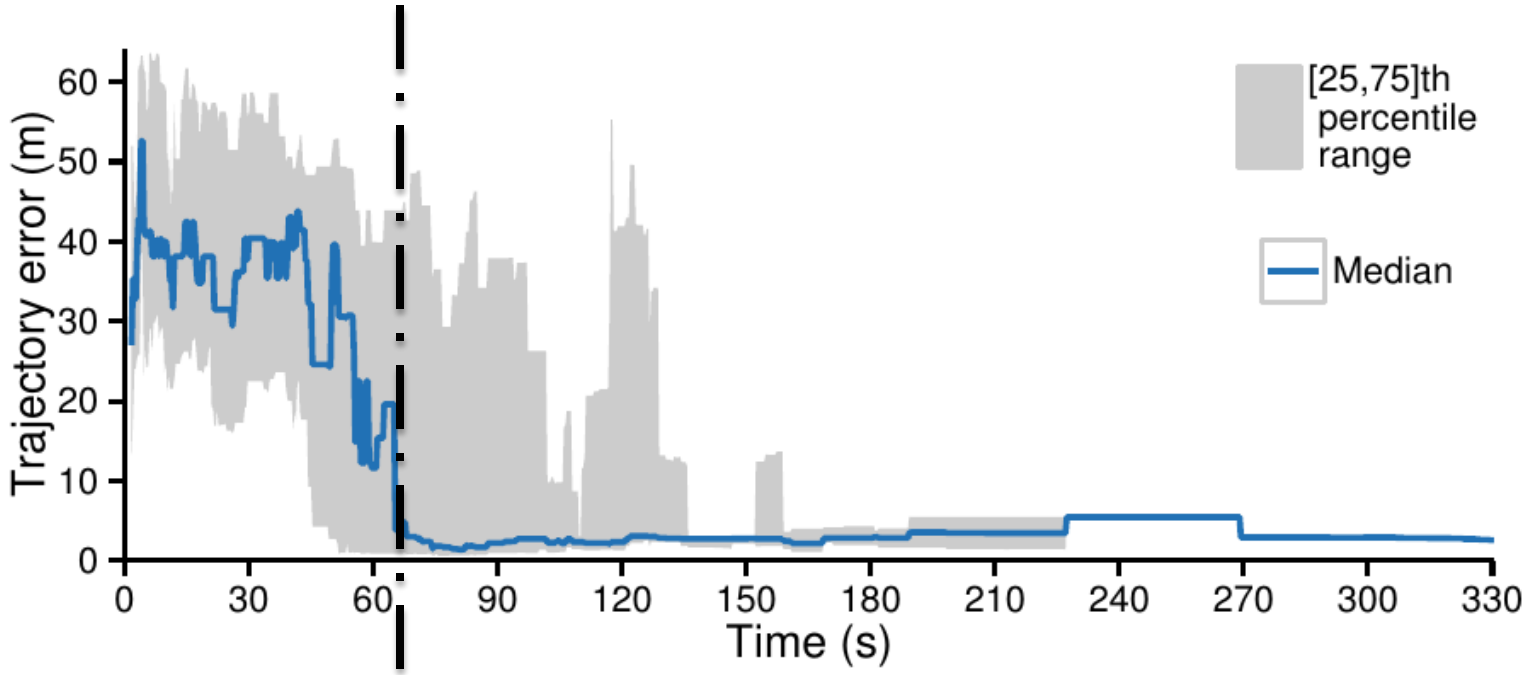
- Formulation as an HMM:
  - Inference ("decoding a trajectory") using standard algorithms (forward-backward, Viterbi…)
  - Parameter estimation (hard-EM)
    - Walking speed constant, matching flexibility parameters…

Trajectory Matching Demo



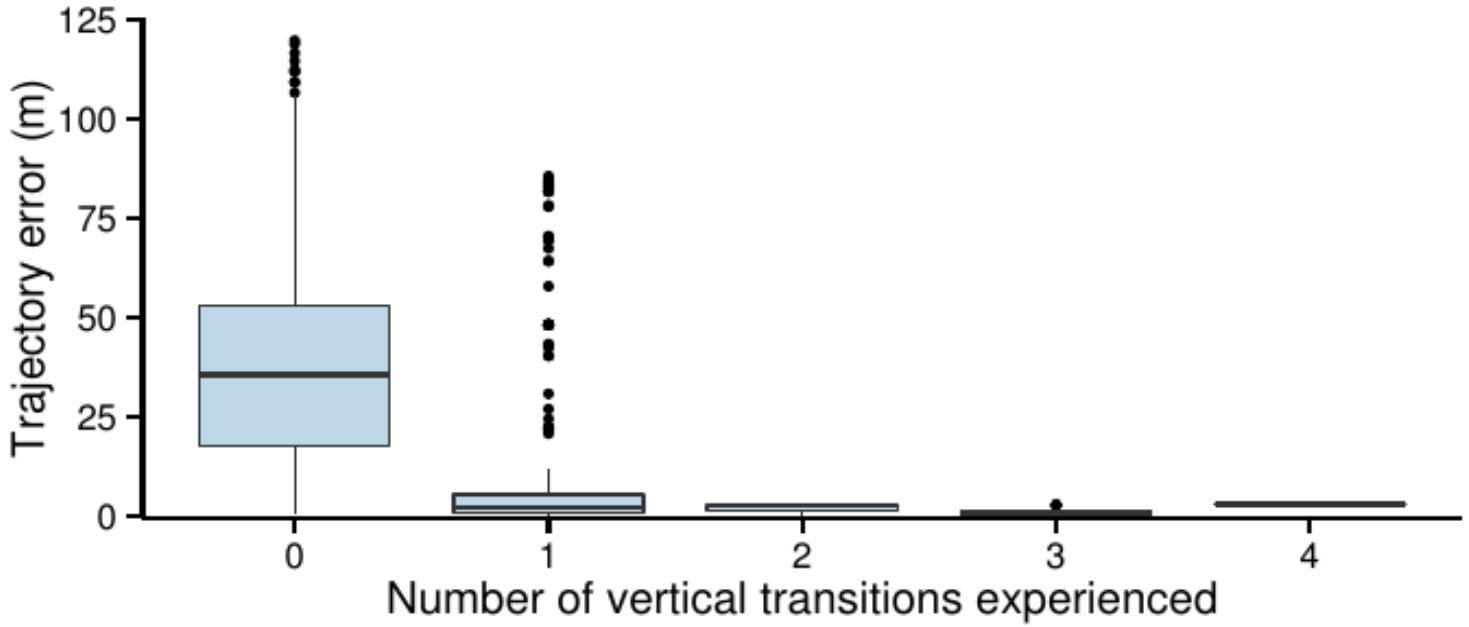
Trajectory Matching Evaluation (1/4)

Ensemble error: It takes 1+ min. of data after a "cold start." to achieve an accurate user path estimate.



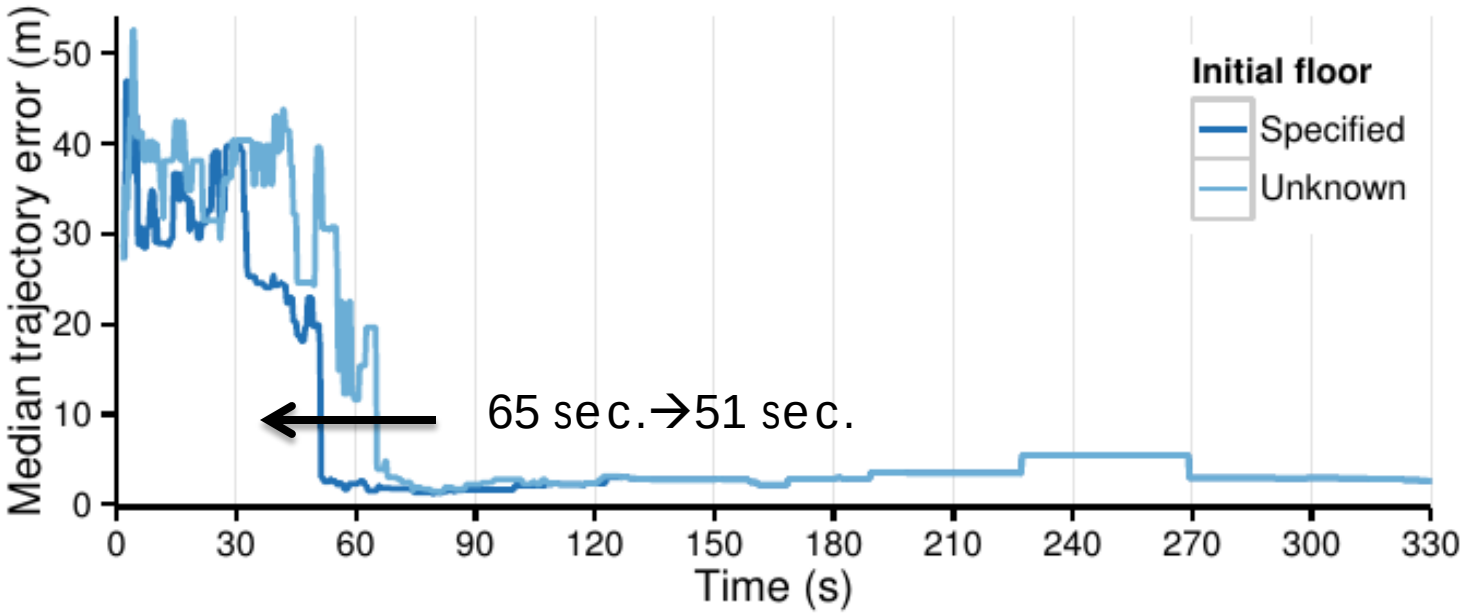
Trajectory Matching Evaluation (2/4)

Salient motions: **Distinctive motions** (vertical transitions, in particular) **facilitate matching.**



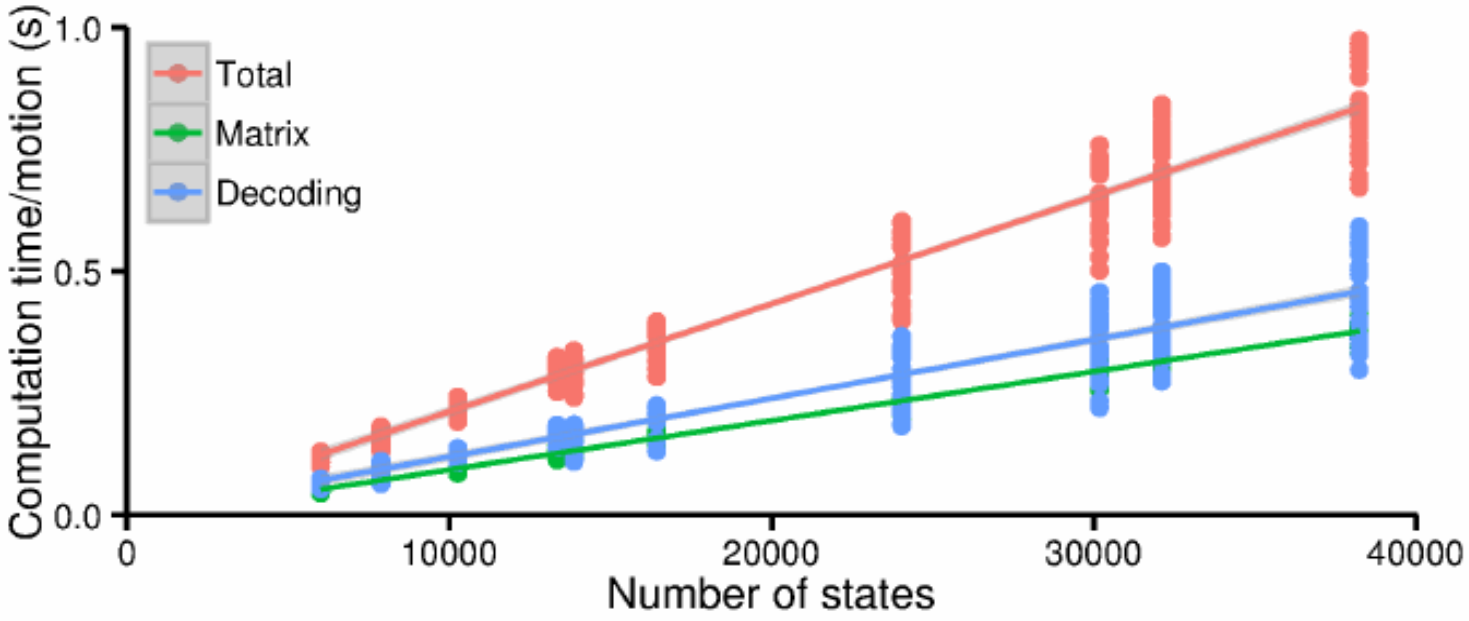
Trajectory Matching Evaluation (3/4)

Prior information: **Knowing the starting floor makes the matching faster.**



Trajectory Matching Evaluation (4/4)

Computation time: **Linear in the number of states** (map size) **& the length of the input** (input size).



Extending the Horizon, Further

- Any sensor data can form signatures.
- Multiple trips / multiple users
  - Inference on chains → on networks
- Bootstrapping signatures

Contributions

- Part I: Algorithms for Organic Localization
  - User prompting
  - Erroneous user input filtering
  - Device heterogeneity

- Park et al., "Growing an Organic Indoor Location System", MobiSys, 2010
- Park et al., "Implications of Device Diversity for Organic Localization", INFOCOM, 2011

- Part II: Motion Compatibility-Based Localization
  - Motion labeling
  - Route network generation
  - Trajectory matching

- Park et al., "Online Pose Classification and Walking Speed Estimation using Handheld Devices", UbiComp, 2012
- Park et al., "Motion Compatibility for Indoor Localization", submitted