FootPath

Accurate Map-based Indoor Navigation Using Smartphones

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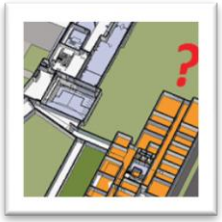
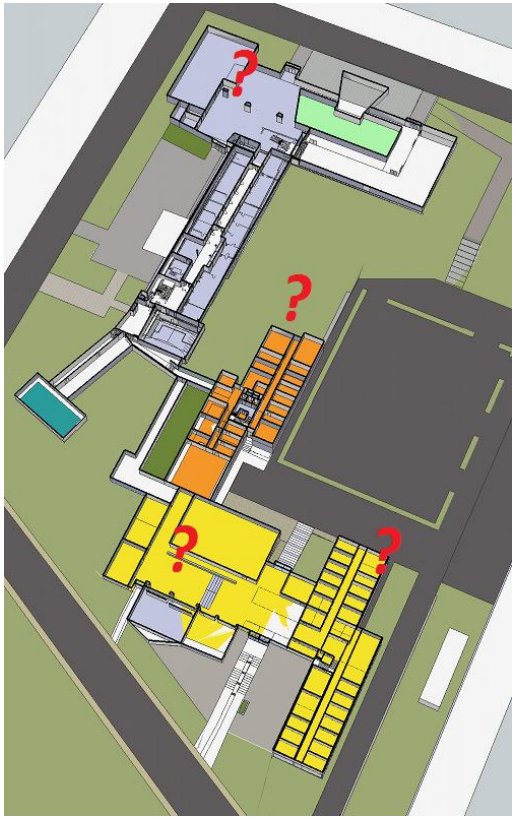
Motivation - Requirements



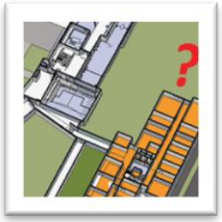
- **Smartphone based**
  - Widely distributed
  - Easy to program



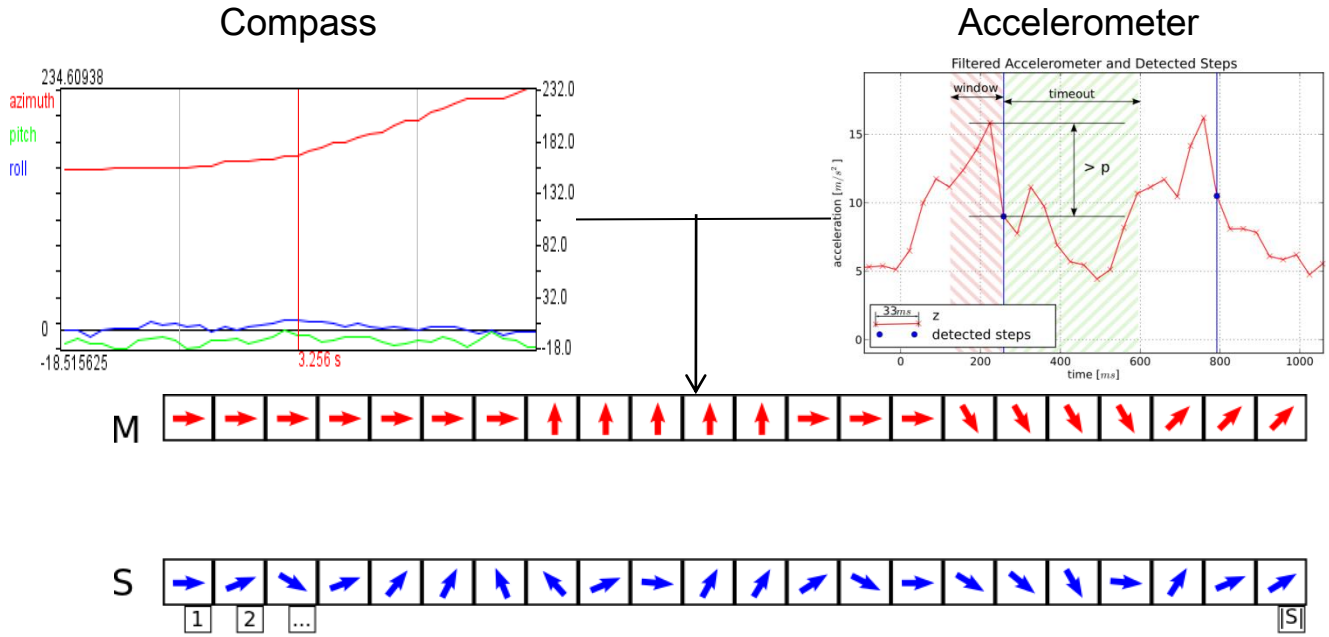
- **Infrastructureless:**
  - No GPS reception
  - Setting up infrastructure is costly and time consuming

- **Incremental deployment**

Core Idea

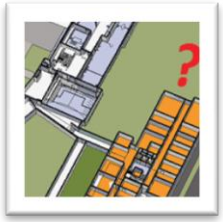


- **Simplify location estimation by restricting to a path**
- **Navigate along the path using sensors readily found in mobile phones**
- **Incremental deployment using OpenStreetMap**

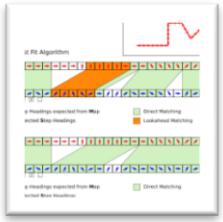


Structure

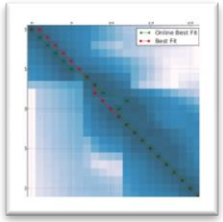
- **Motivation**



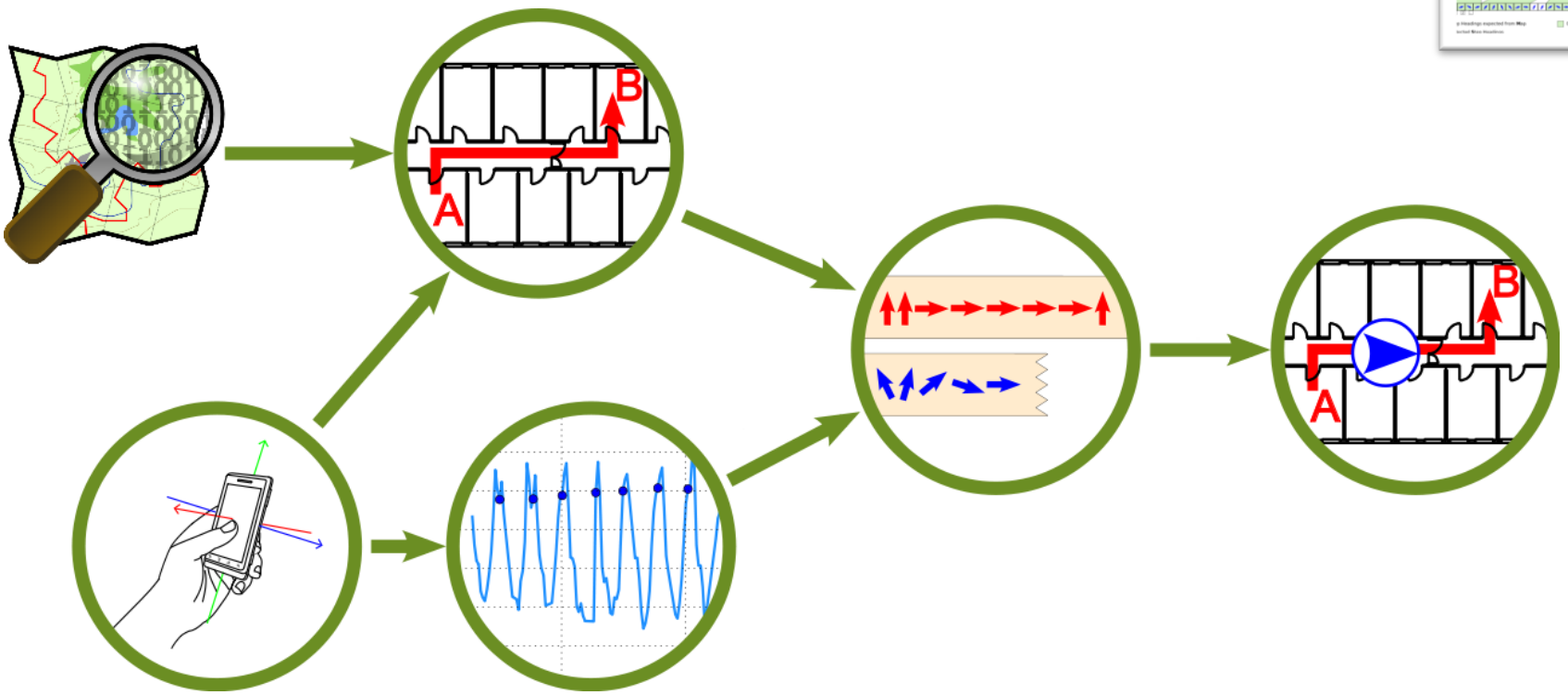
- **Design**
  - Map acquisition
  - Step detection
  - Path matching



- **Evaluation**
- **Conclusion & Future Work**

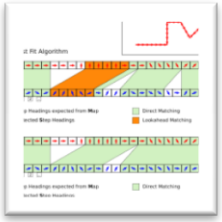


Design: FootPath Data Flow



Map Acquisition

- **Map Source: OpenStreetMap**
  - Community based effort to distribute free geographic data

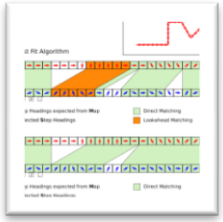


- **Data**
  - XML File consisting of
    - Nodes
    - Ways

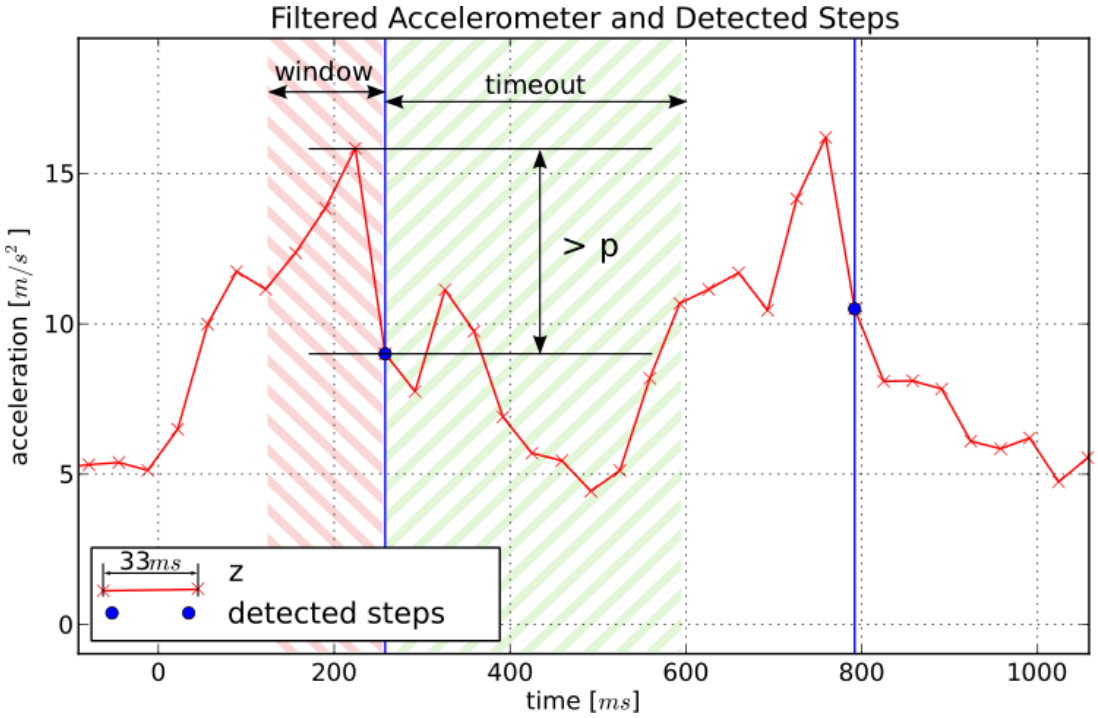
- **Provisional indoor support:**
  - Indoor - Attributes:
    - indoor = yes
    - level = …, -2, -1, 0, 1, 2, …
    - wheelchair = yes
    - highway = steps, elevator, door
    - stepcount = *
    - name = *

- **Java OpenStreetMap Editor (JOSM)**

Step Detection

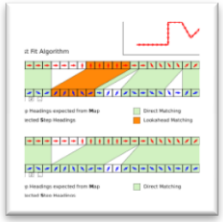


- **Use low pass filtered z-axis from accelerometer**
- **Poll values at 30Hz**
- **Step detected, if**
  - drop larger than p = 2.0 m/s² is registered within 165ms (5 samples)
  - and outside of timeout

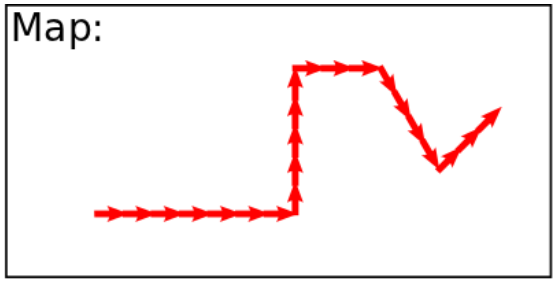


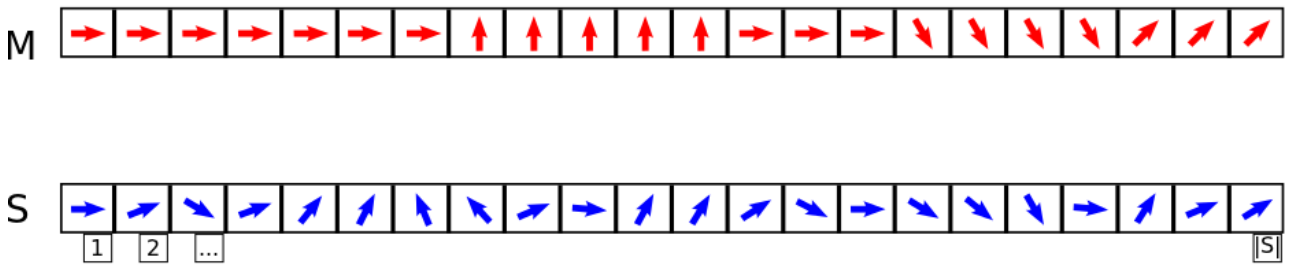
Step Matching

- **Establish position by matching detected steps to the path**



- **With each step, progress along path using step length estimation**
  - Step length ≈ height * 0.415 [m]

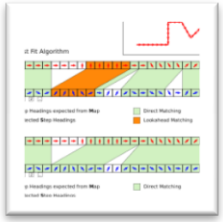




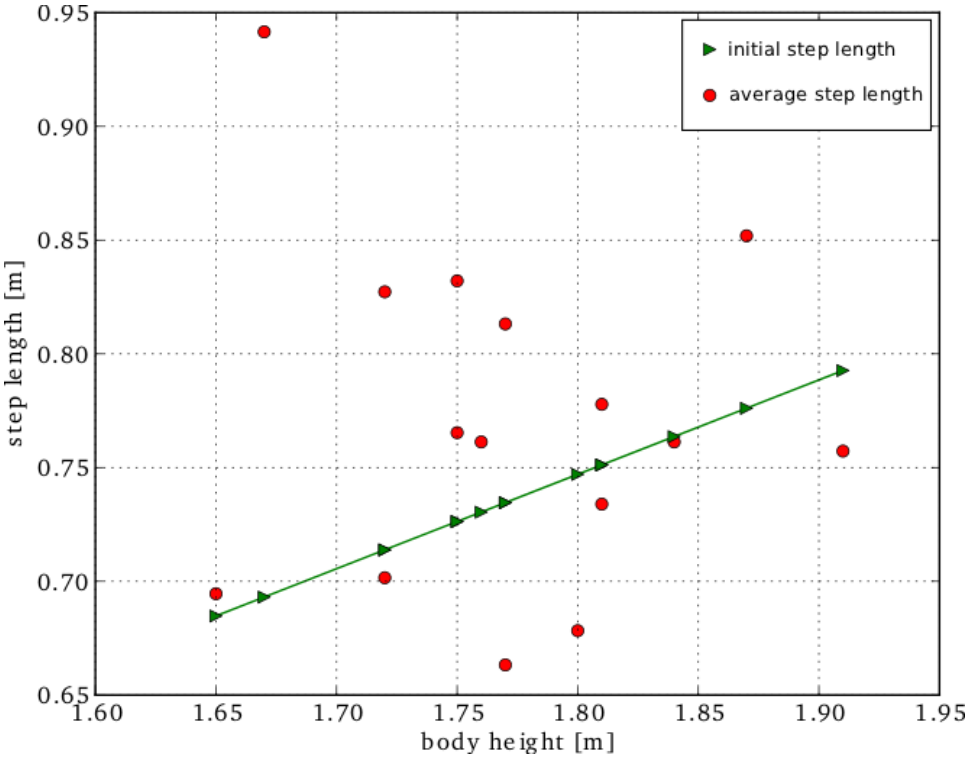
M Step Headings expected from **M**ap

S Detected **S**tep Headings

Step Matching



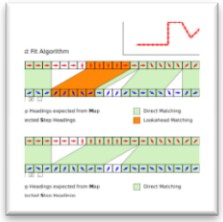
- **Deal with noisy data, i.e.:**
  - Varying step length
  - errors in compass readings
    - metal objects: radiators, elevators
    - doors
    - evading other persons
    - ...



➔ **Algorithm:**

- Best Fit compensates errors

Matching - Best Fit



- **Calculating best match of steps to path:**
  - String S: detected steps
  - String M: expected steps from path
  - Iteratively calculate matrix D:

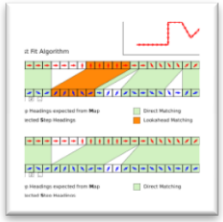
$$D(i,j) = \min\{D(i-1,j-1) + \texttt{score}(M(i), S(j)),$$
$$D(i-1,j) + \texttt{score}(M(i), S(j-1)) + 1.5,$$
$$D(i,j-1) + \texttt{score}(M(i-1), S(j)) + 1.5\}$$

  - Scoring function:

$$\texttt{score}(\alpha,\beta) = \begin{cases} 0.0 & \text{if } \sphericalangle(\alpha,\beta) \leq 45° \\ 1.0 & \text{if } 45° < \sphericalangle(\alpha,\beta) \leq 90° \\ 2.0 & \text{if } 90° < \sphericalangle(\alpha,\beta) \leq 120° \\ 10.0 & \text{else} \end{cases}$$

Matching - Best Fit

- **Calculating best match of steps to path:**

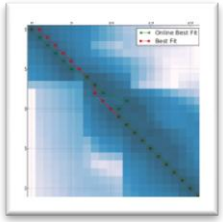


$$D_0 = \begin{pmatrix} 0.0 & \infty & \infty & \infty & \infty & \cdots \\ \infty & & & & & \\ \infty & & & & & \\ \infty & & & & & \\ \infty & & & & & \\ \vdots & & & & & \end{pmatrix} \rightsquigarrow D_1 = \begin{pmatrix} 0.0 & \infty & \infty & \infty & \infty & \cdots \\ \infty & \mathbf{0.0} & & & & \\ \infty & 1.5 & & & & \\ \infty & 3.0 & & & & \\ \infty & 4.5 & & & & \\ \vdots & \vdots & & & & \end{pmatrix}$$

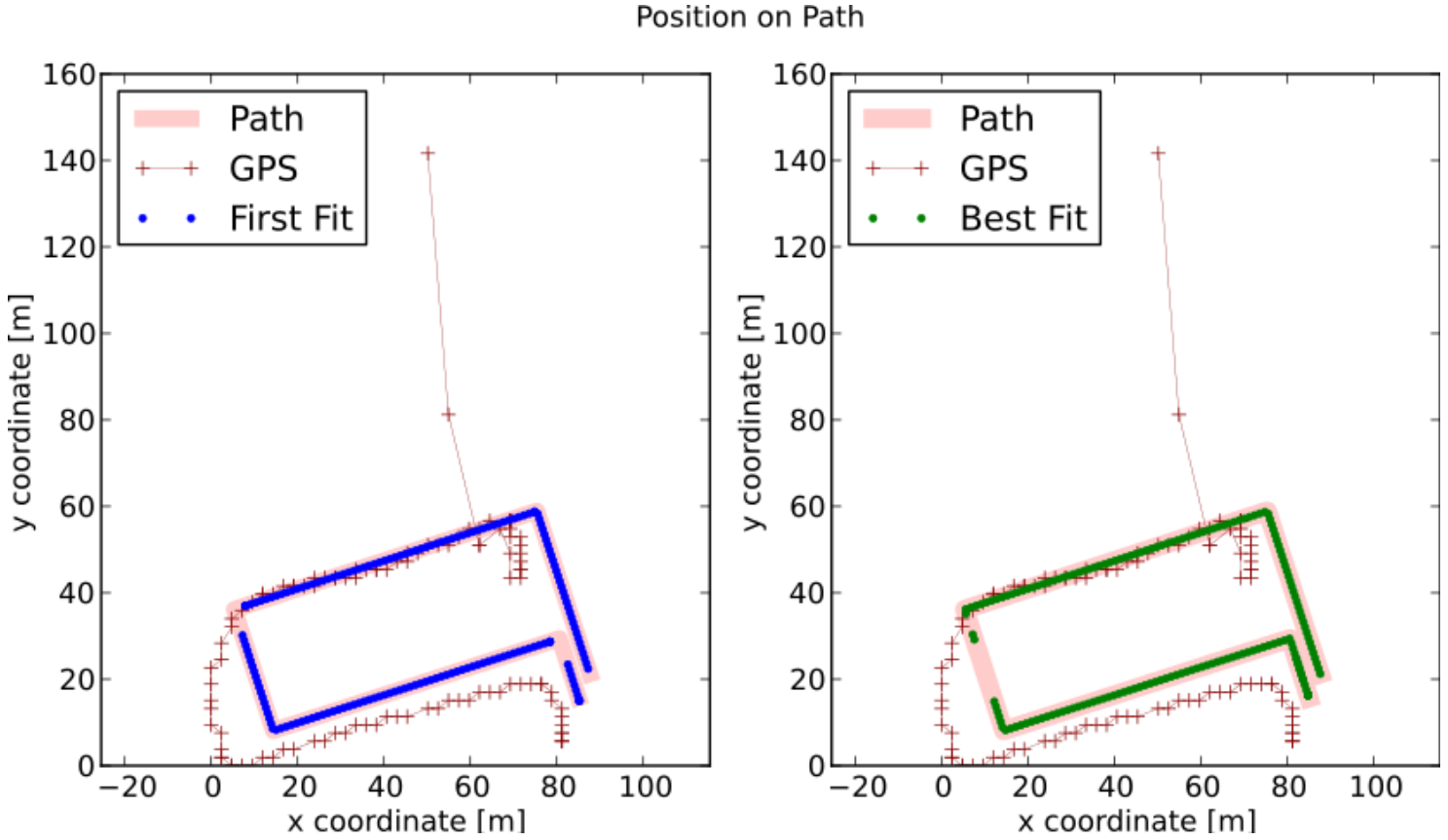
$$\rightsquigarrow D_2 = \begin{pmatrix} 0.0 & \infty & \infty & \infty & \infty & \cdots \\ \infty & \mathbf{0.0} & 1.5 & & & \\ \infty & 1.5 & \mathbf{0.0} & & & \\ \infty & 3.0 & 1.5 & & & \\ \infty & 4.5 & 3.0 & & & \\ \vdots & \vdots & \vdots & & & \end{pmatrix} \rightsquigarrow D_3 \rightsquigarrow \ldots \rightsquigarrow D$$

➔ **Current location is the position with the least penalty for each step**

Evaluation – Comparison with GPS

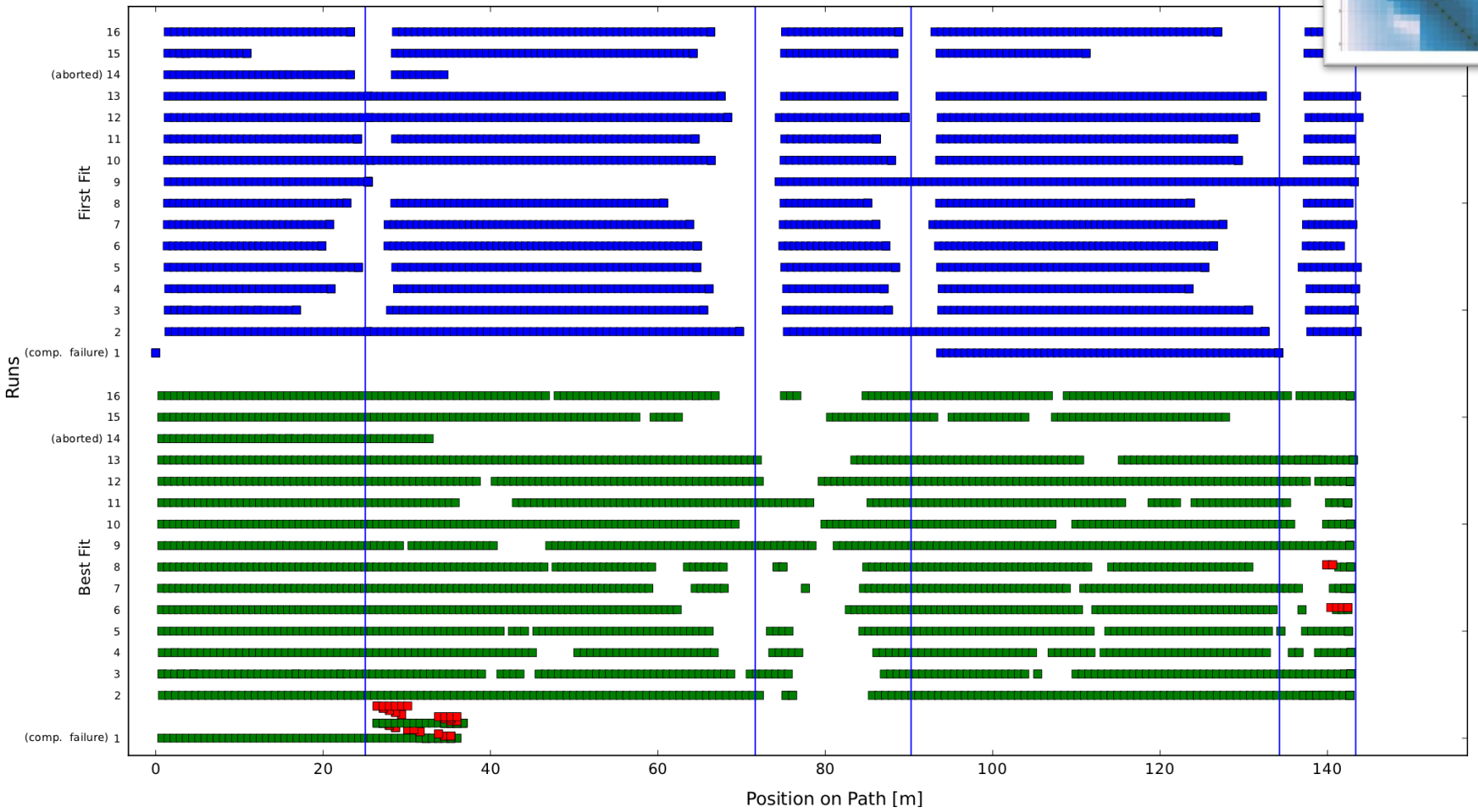


- **Outdoor experiment**
  - 16 runs across parking lot
  - Traces include GPS, sensors, detected steps



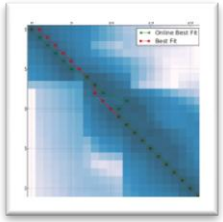
Evaluation – Outdoor

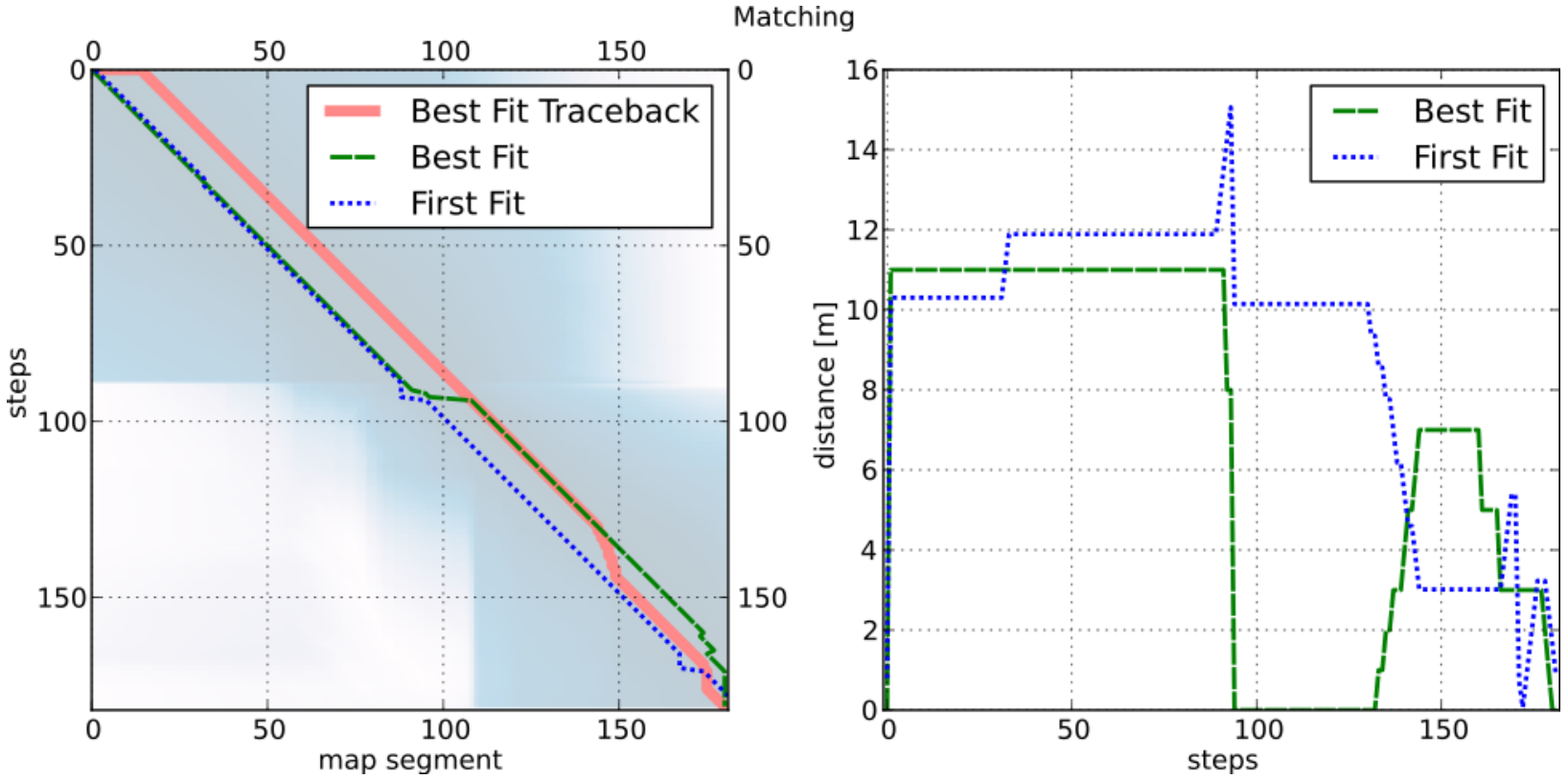
- **Positions on path**



Evaluation – Outdoor

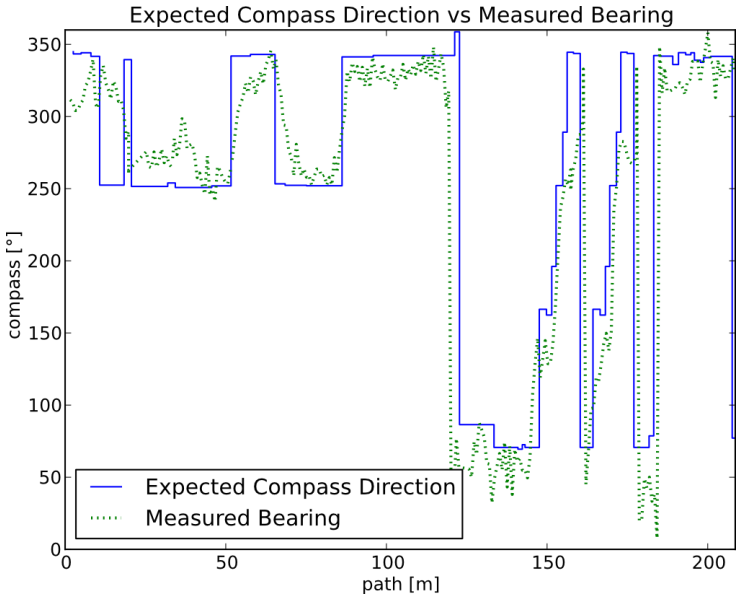
- **Location error:**
  - Distance to Best Fit Traceback

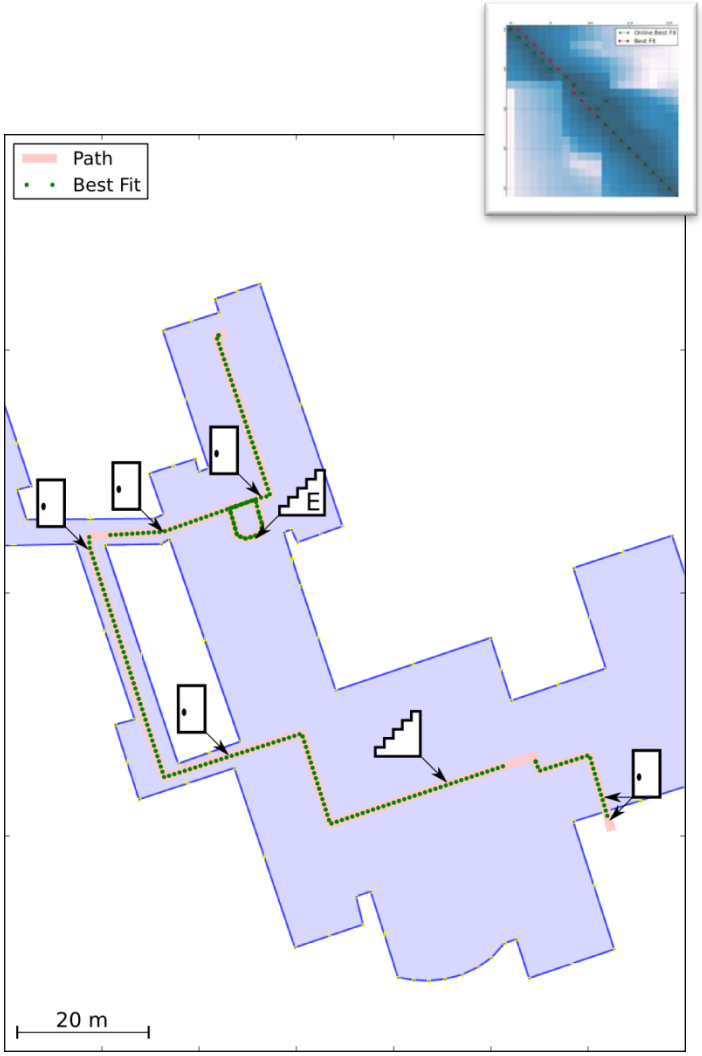




Evaluation – Indoor Path

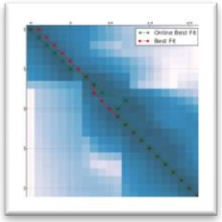
- Path through university
- Robust against magnetic disturbance
- Corners actually help us!

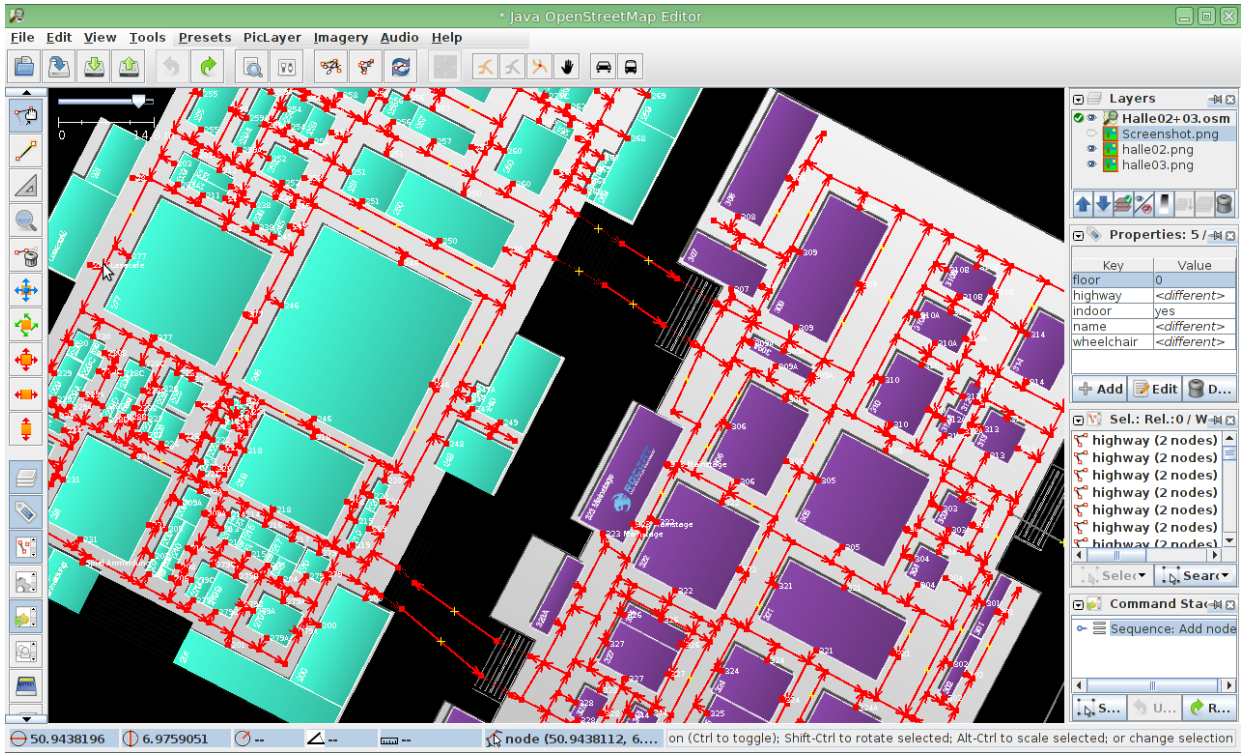




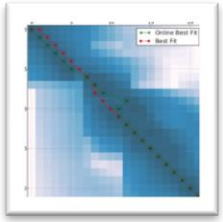
Evaluation – Map creation for Trade Fair

- Area: 20 000 m²
- Exhibitors: >100
- Time to integrate into OSM for a single mapper: ~ 2 hours





Other Approaches

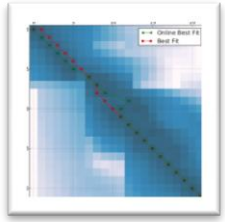


- **Infrastructure**
  - Pseudolites
  - RF – Fingerprinting
    - GSM/WiFi/Bluetooth/RFID
- **Infrastructureless**
  - CompAcc
    - Outdoor positioning via step matching
  - Pedestrian Dead Reckoning
    - Integration of sensor data using Kalman filter
  - Ambiance – Fingerprinting
    - Temperature, Colors, Lights, Acoustics

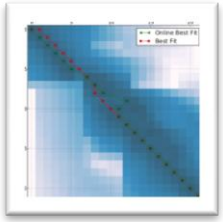
Comparison

Feature	FootPath	CompAcc	PDR	GPS
Indoor	+	-	+	-
Outdoor	+	+	○	+
No Infrastructure	+	-	○	-
No Initial Setup	+	+	+	-
No Maintenance	+	+	+	-
Error Resetting	+	○	○	-
Map basis	+	-	-	-

Feature	Pseudolites	WiFi F.pr.	Amb. F.pr.	Google Maps
Indoor	+	+	+	○
Outdoor	-	+	-	+
No Infrastructure	-	-	+	-
No Initial Setup	-	-	-	-
No Maintenance	-	-	-	-
Error Resetting	-	-	-	-
Map basis	-	-	-	-



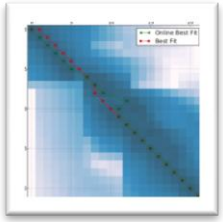
Future work



- **Multiple concurrent paths**
  - Currently: Undefined behavior when user leaves path
  - Evaluate several paths, opportunistically switch to best candidate
  - Approach: Multisequence alignment

- **Cooperative map creation**
  - Map places where no floor plan is available
  - Derive path segments from detected steps
  - Make use of points multiple times; sanitize using spring embedding

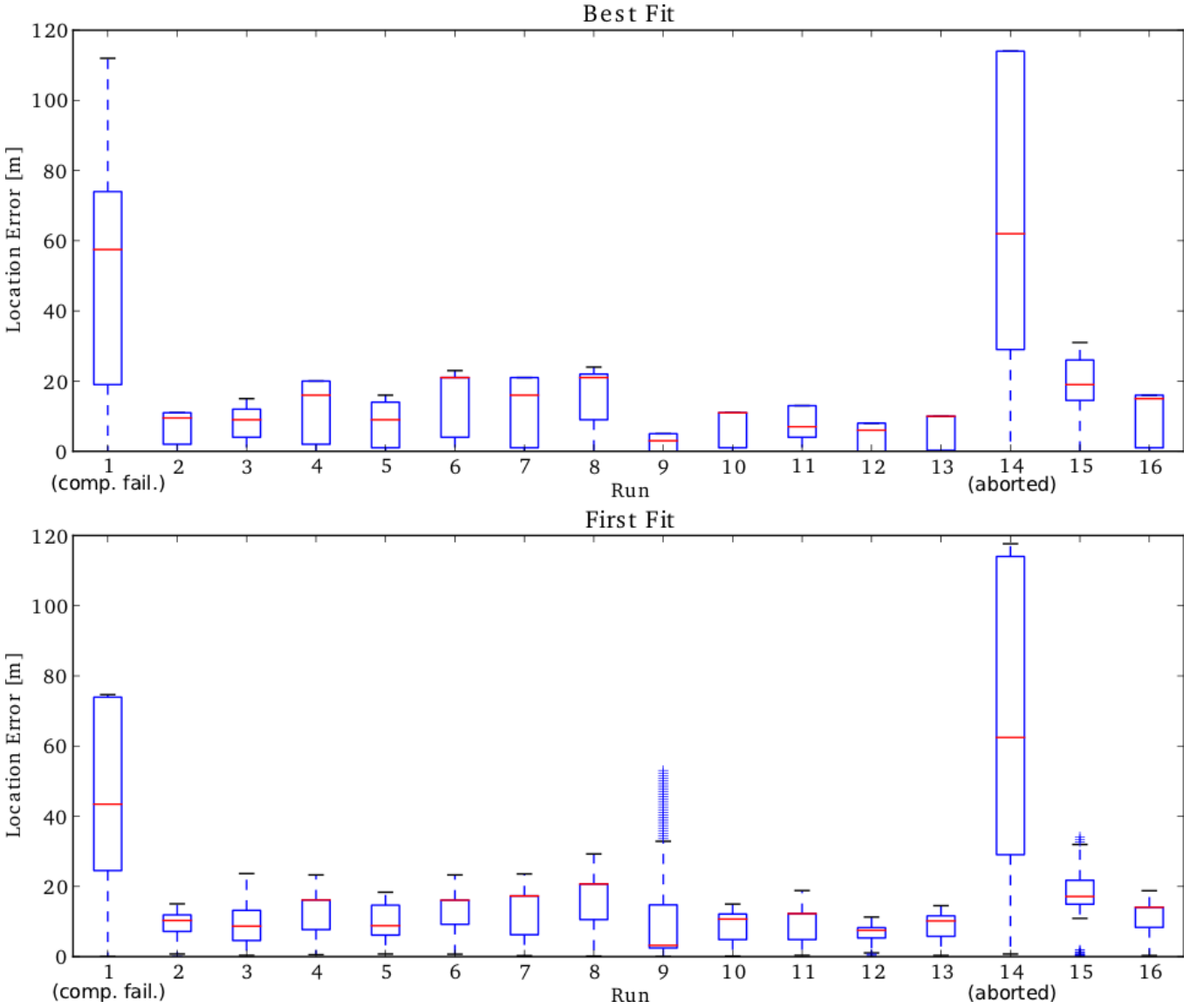
Conclusion



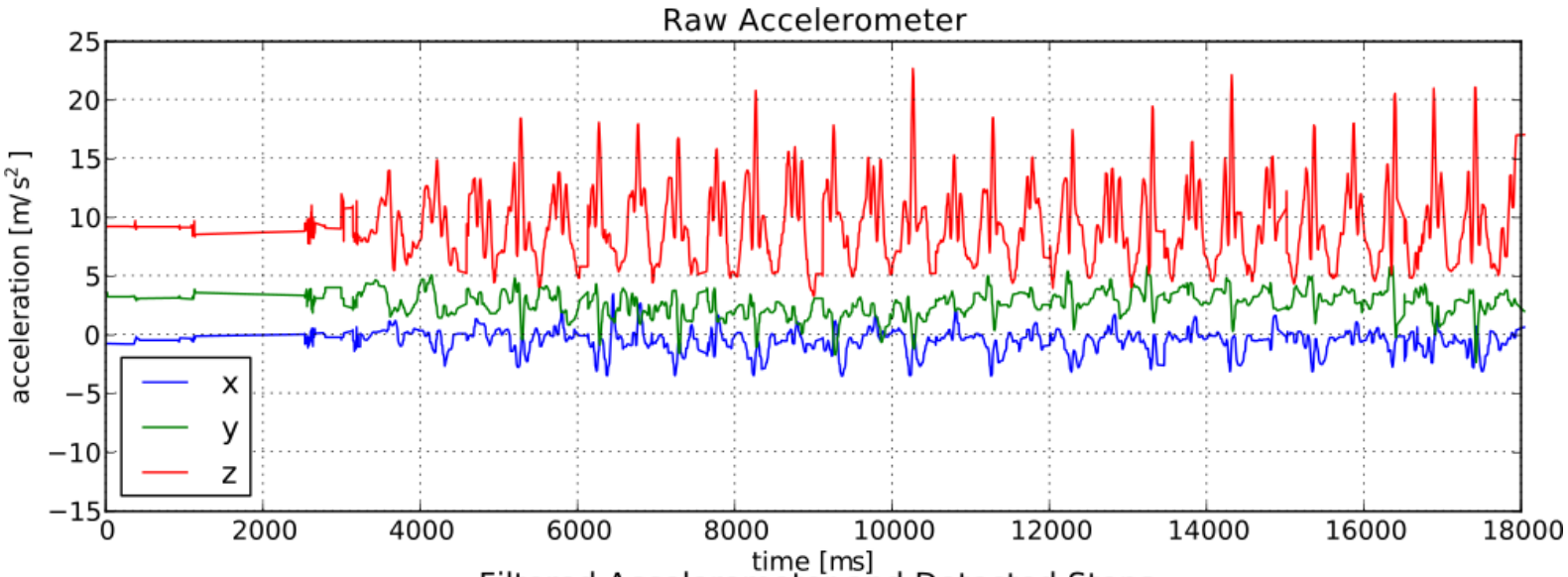
- Painless, cost-efficient indoor navigation using sensors available in mobile phones
- No war driving
- First Fit and Best Fit match steps on to the path, both reset accumulated errors at corners
- Editing and distribution of maps for public buildings using OpenStreetMap

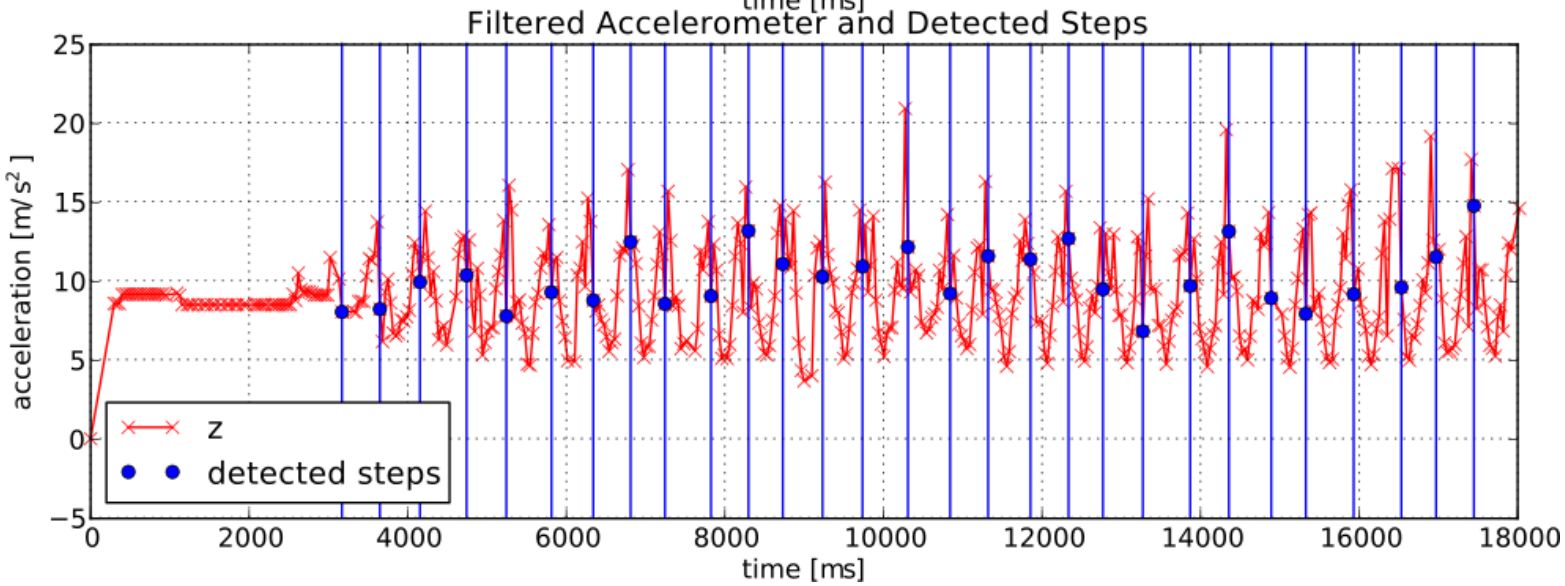
Thank you!

Location Error per Run



Sensor Data


Raw Accelerometer
acceleration [m/s^2]
time [ms]
x
y
z


Filtered Accelerometer and Detected Steps
acceleration [m/s^2]
time [ms]
z
detected steps

Experiment Data

User	h [m]	l [m]	$s_{\#}$	p	l_a [m]	e [m]	$e_{\%}$ [%]
1	1.77	0.7346	205	0.95	0.66	0.07	10.75
2	1.91	0.7927	189	1.00	0.75	0.03	4.67
3	1.84	0.7636	188	1.00	0.76	0.00	0.30
4	1.87	0.7761	168	1.00	0.85	-0.07	8.90
5	1.77	0.7346	176	1.00	0.81	-0.07	9.66
6	1.65	0.6848	204	0.99	0.69	-0.00	1.41
7	1.67	0.6931	152	1.00	0.94	-0.24	26.39
8	1.72	0.7138	173	1.00	0.82	-0.11	13.71
9	1.80	0.7470	211	1.00	0.68	0.06	10.12
10	1.72	0.7138	204	1.00	0.70	0.01	1.74
11	1.76	0.7304	188	1.00	0.76	-0.03	4.05
12	1.81	0.7512	195	1.00	0.73	0.01	2.34
13	1.75	0.7263	187	1.00	0.76	-0.03	5.10
14	1.75	0.7263	172	1.00	0.83	-0.10	12.72
15	1.81	0.7512	184	1.00	0.77	-0.02	3.42

Legend:

h: body height

l: initial step length as $l = h \times 0.415$

$s_{\#}$: number of detected steps

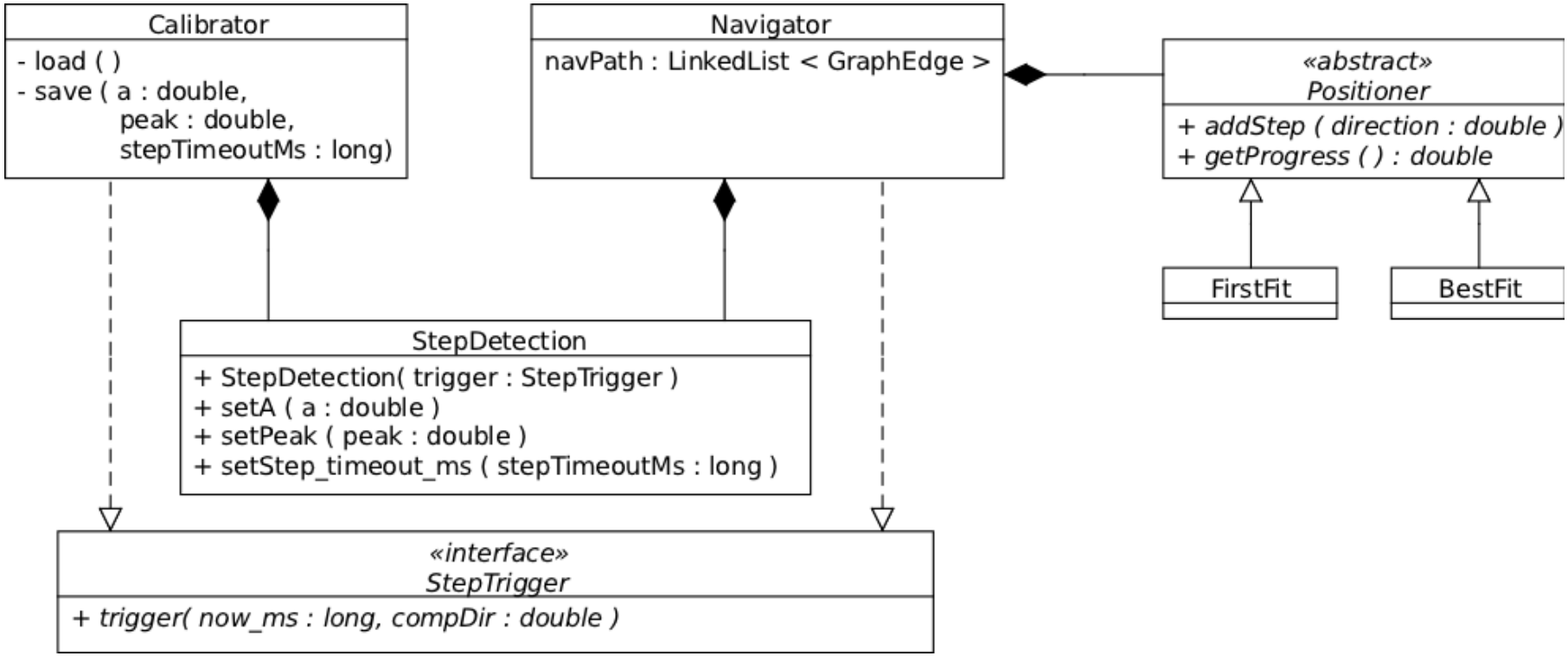
p: last position on the path using *First Fit* with $p \in [0, 1]$

l_a: average step length $l_1 = \frac{\text{distance walked}}{s_{\#}}$

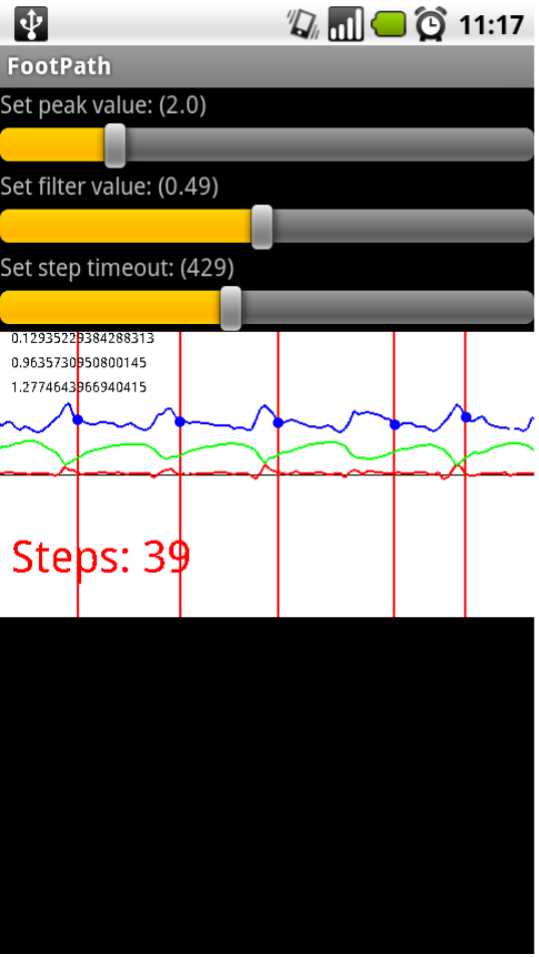
e: estimation error

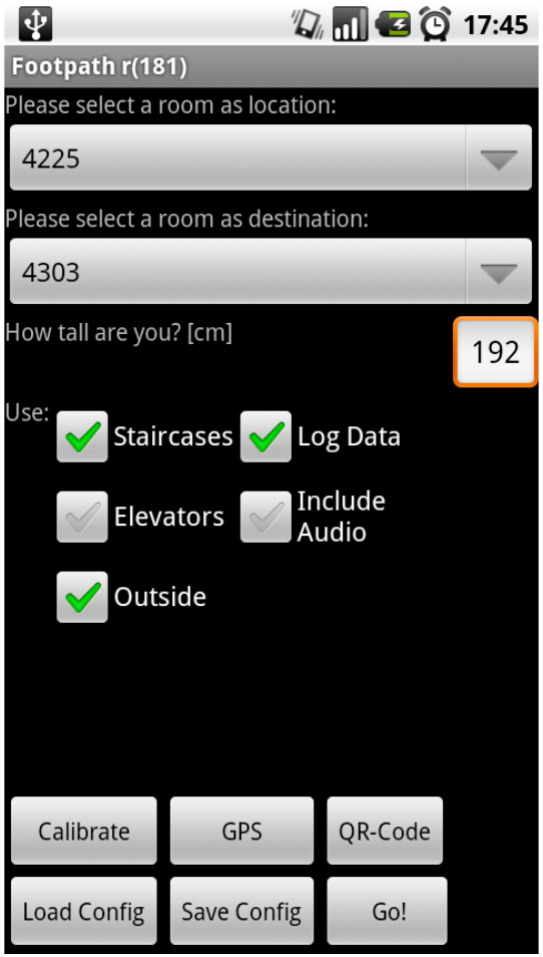
$e_{\%}$: absolute estimation error in percent

Class Diagram

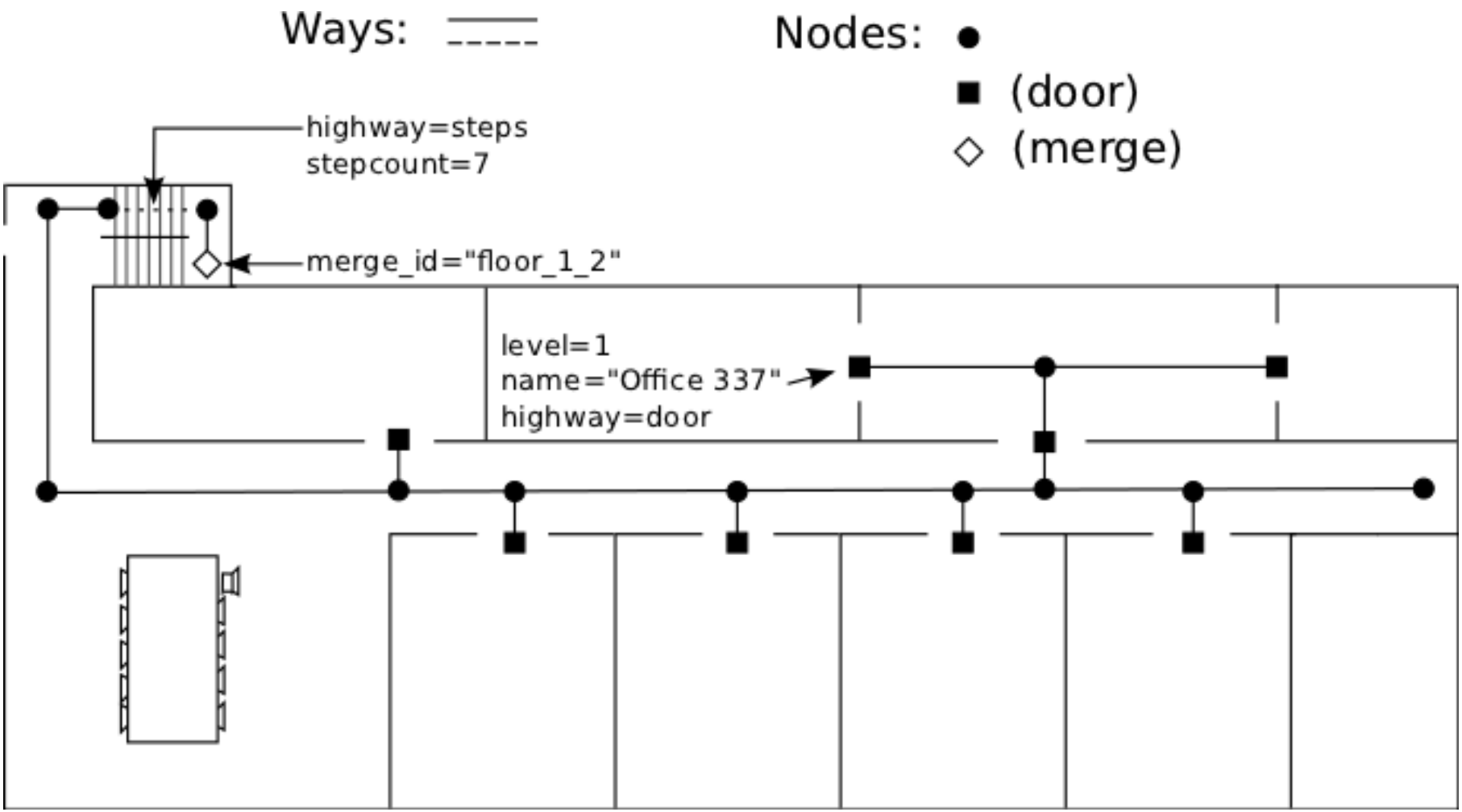


GUI: Calibration, Loader, Navigation

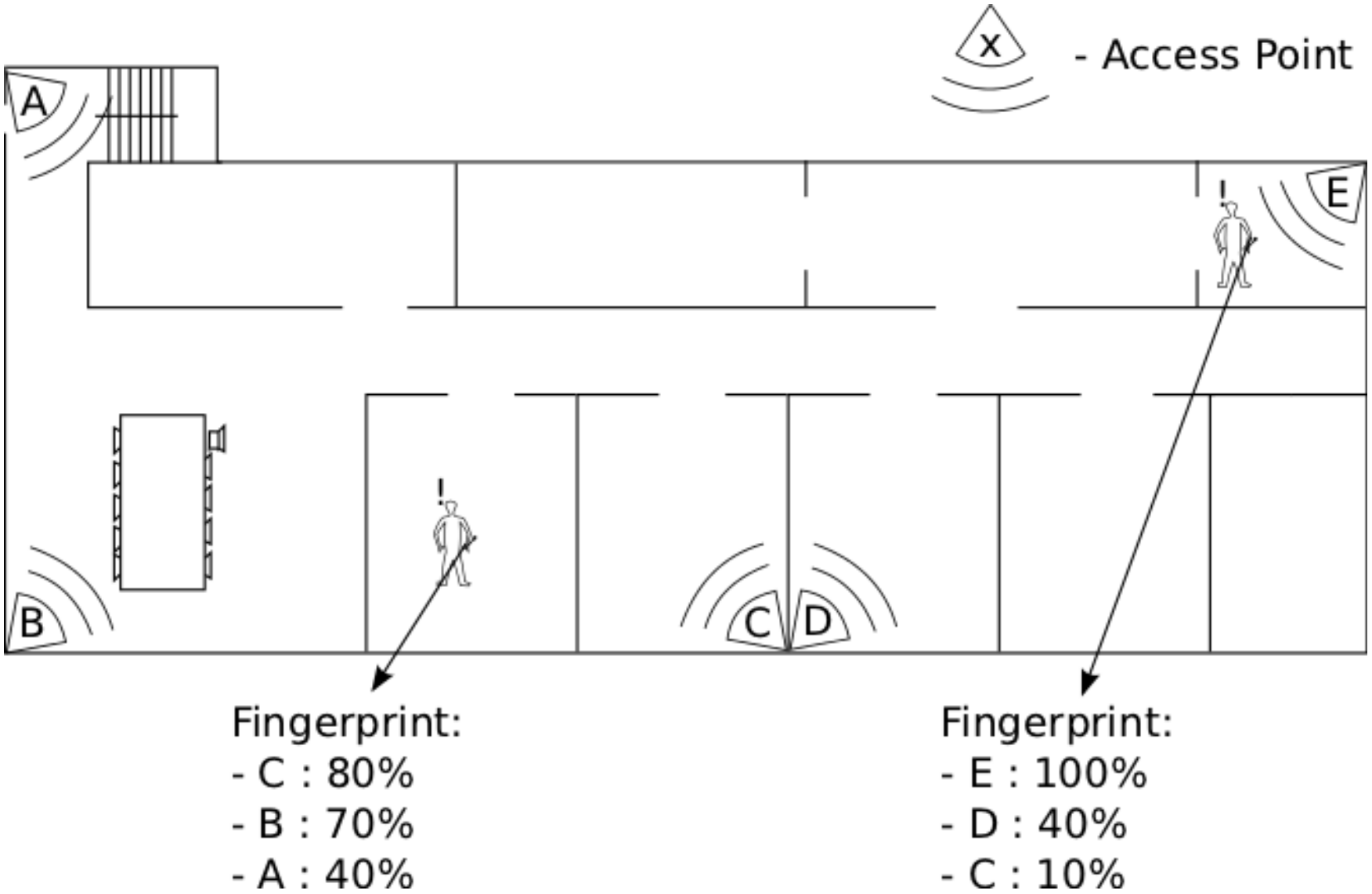




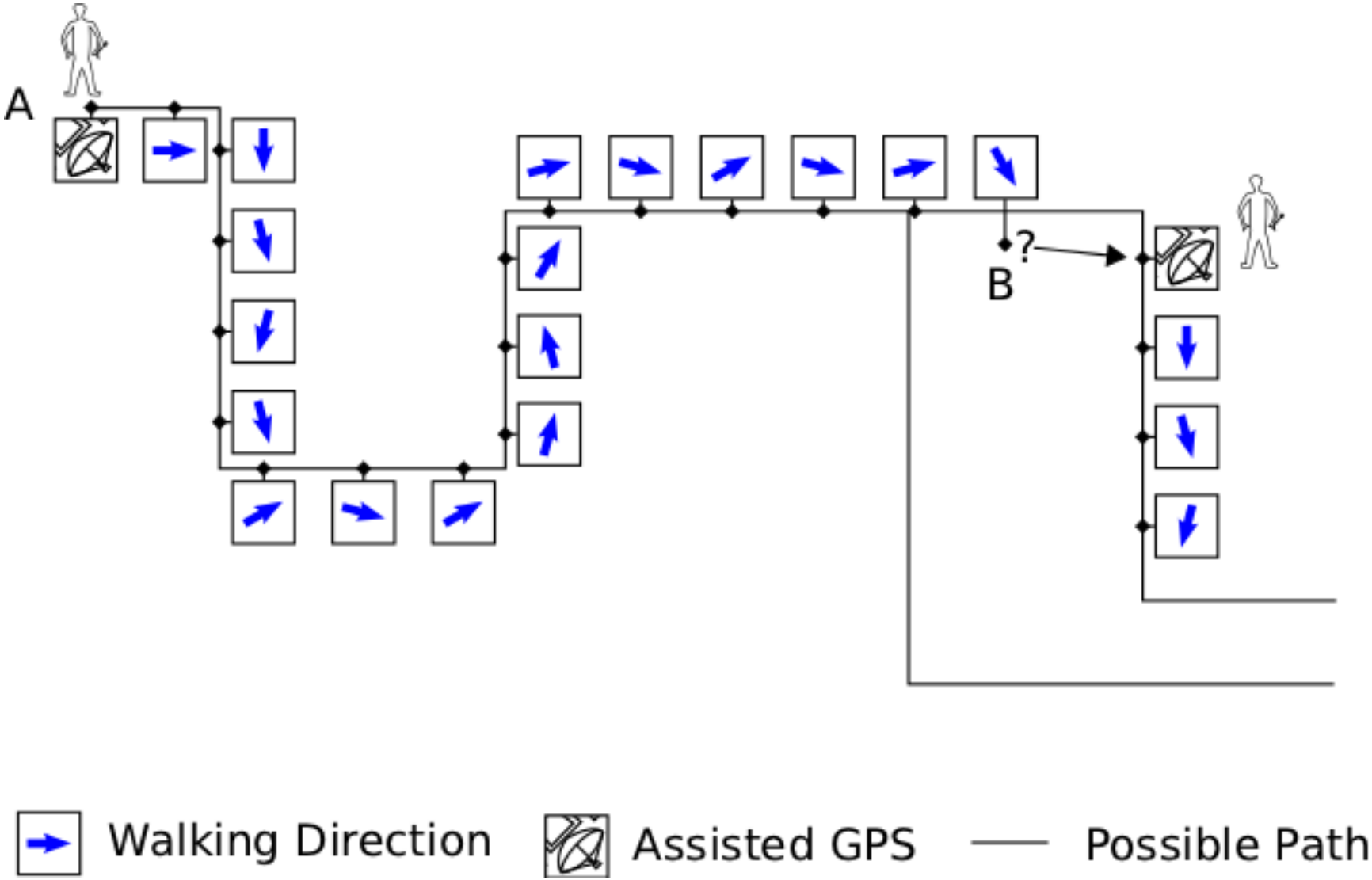
Map Structure



Wifi Fingerprinting



Wifi Fingerprinting



OSM Tiles

2x
2x
Seffenter Weg
Halifaxstraße
Ahornstraße
AH IV
AH I
5052
5054
RWTH
Allgemeines
Verfügungszentrum
Mensa
Ahorn 55
St. Sebastian
Pfarrbüro
St. Sebastian
Gymnastikraum
Ahornstraße
Sporthalle
Ahornstraße
5052 6019
Gemeinschaftslabor
für Elektronenmikroskop
5054
5055