NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

Walkway Discovery from Large Scale Crowdsensing

Chu Cao [1], Zhidan Liu [2], Mo Li [1], Wenqiang Wang [3], Zheng Qin [3]

Nanyang Technological University[1], Singapore
Shenzhen University[2], Shenzhen, China
Institute of High Performance Computing[3], Singapore

11 Apr. 2018

IPSN'18, Porto, Portugal

1 National Science Experiment

- An island-wide outdoor science experiment carried by Singapore students.
- Organised by National Research Foundation and Ministry of Education in Singapore.
- Crowdsensing platform.

Students with SENSg

Portal for students

NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

1 National Science Experiment

- Coverage of NSE project

450,000 students

122 schools in 2015

85 schools in 2016

IMU

WiFi

Microphone

Light sensor

Infrared sensor

Pressure sensor

Humidity sensor

Temperature sensor

NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

1 National Science Experiment

- Coverage of NSE project

450,000 students

122 schools in 2015

85 schools in 2016

Atmospheric pressure
Relative humidity
Temperature
Sound pressure level
Light intensity
Inertial measurement
Locations
Step count
Travel mode
…

NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

1 National Science Experiment

- Coverage of NSE project

450,000 students

122 s
in 20

85 schools in 2016

Walkway Discovery

Atmospheric pressure
Relative humidity
Temperature
Sound pressure level
ement
Locations
Step count
Travel mode
…

NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

2 Motivation

- Walkways are important for pedestrians

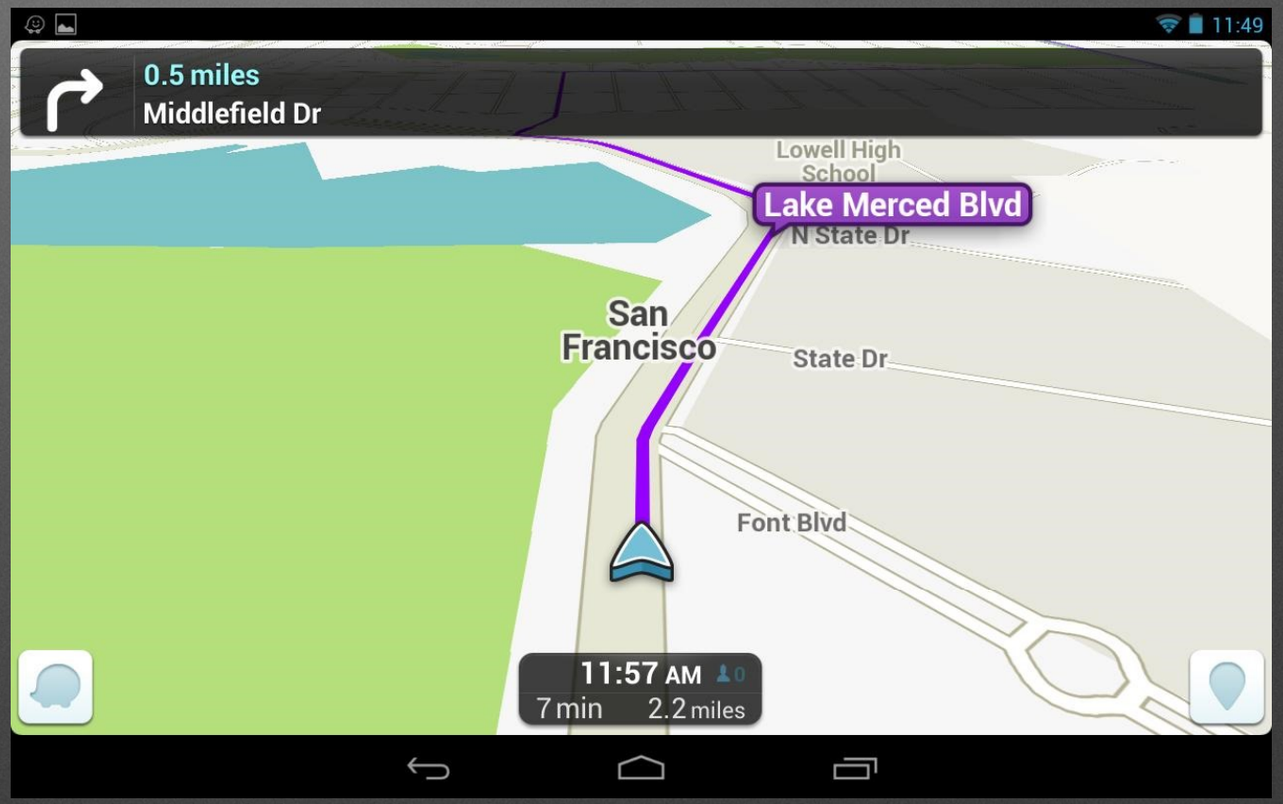
Recommended route of Google Maps from NTU to BLK 941

2 Motivation

- Samples of uncharted walkways

3 Related Work

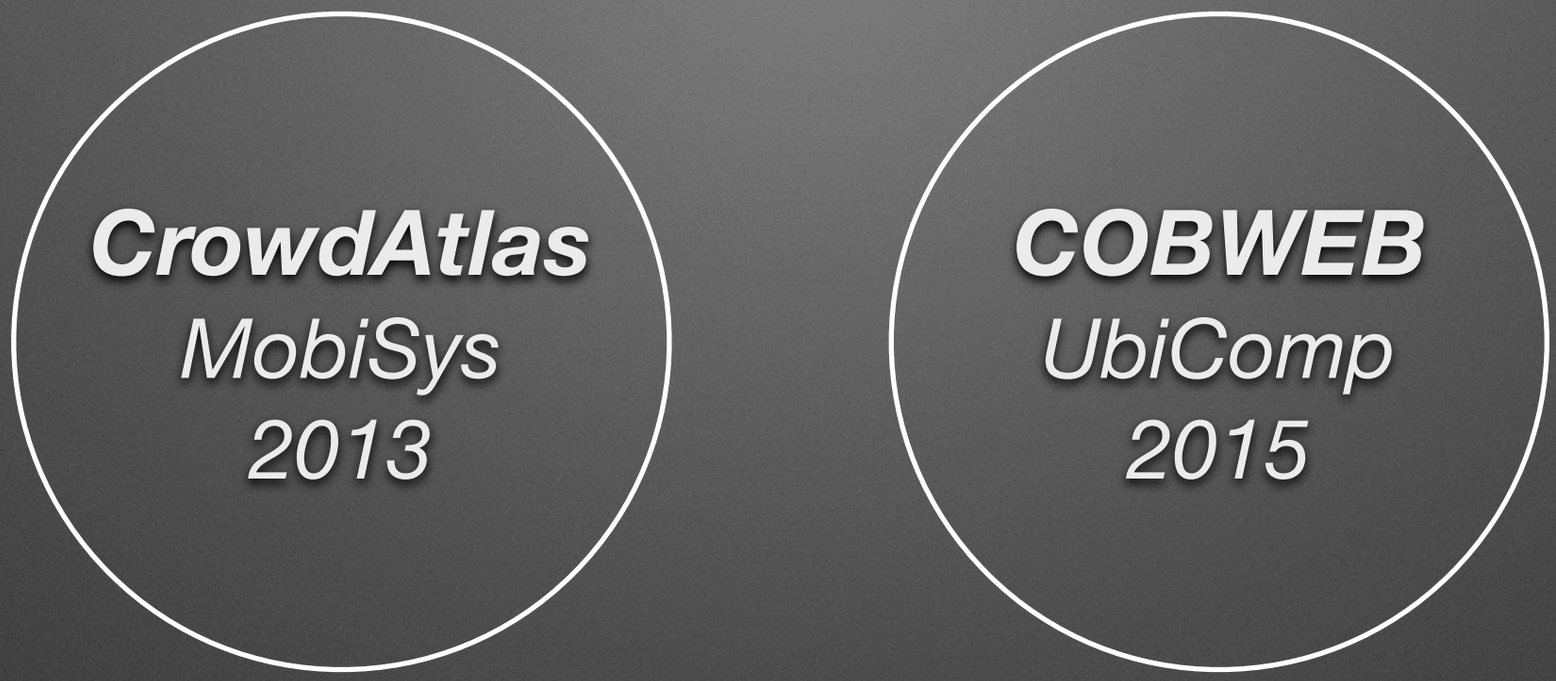
- Map completion: automatic map updating



- Frequently used uncharted route will be added to existing map.

3 Related Work

- Map completion: automatic map updating



- Both of them focus on **motorways** using GPS data
- Potential assumption: **structured** motorways

Wang Y, Liu X, Wei H, et al. CrowdAtlas: Self-updating maps for cloud and personal use
Shan Z, Wu H, Sun W, et al. COBWEB: a robust map update system using GPS trajectories

3 Related Work

- Map completion: automatic map updating

CrowdAtlas
MobiSys
2013

COBWEB
UbiComp
2015

Walkways
Unstructured

Wang Y, Liu X, Wei H, et al. CrowdAtlas: Self-updating maps for cloud and personal use

Shan Z, Wu H, Sun W, et al. COBWEB: a robust map update system using GPS trajectories

4 Problem Definition

- A road network is a directional graph G(V,E)

  - **Previous work**

    Given structured location data, discover road segments.

    A road segment is a directed edge in graph G, associated with a deterministic travelling direction and two terminal points.

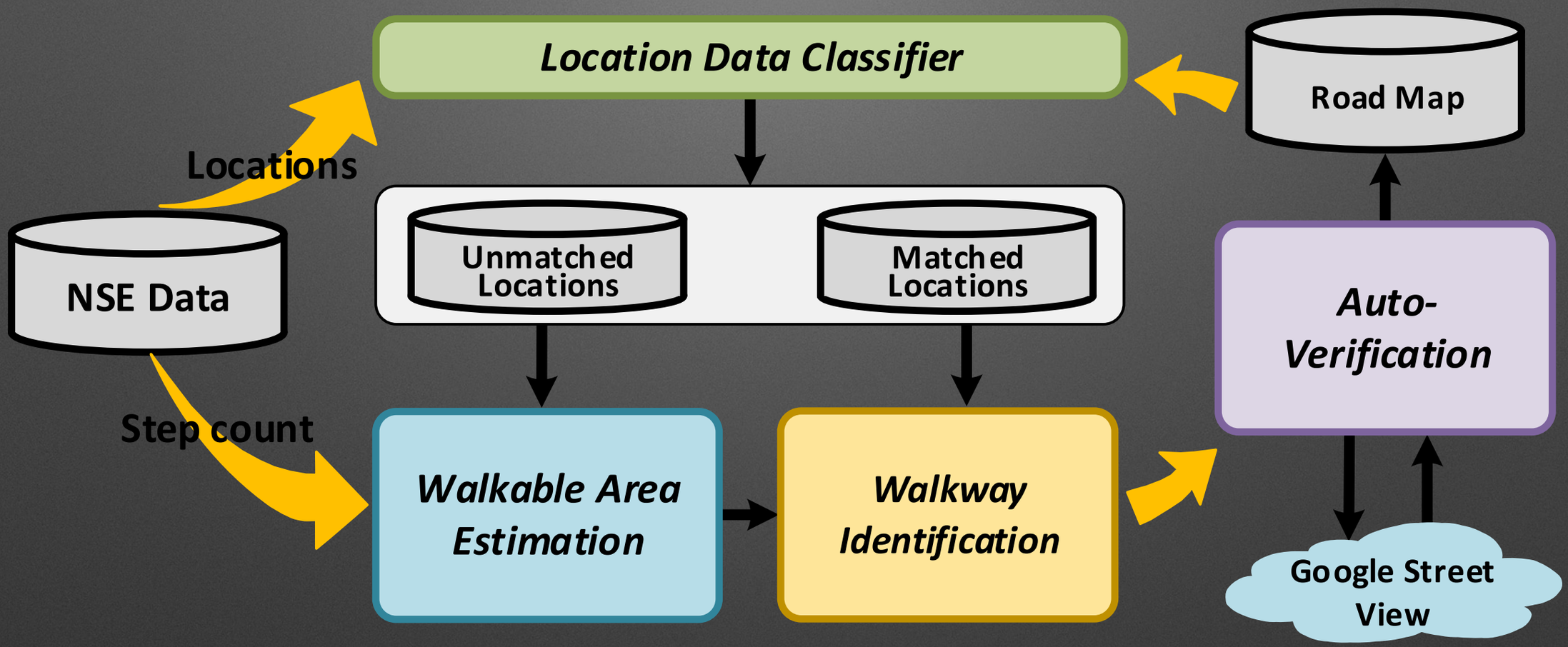
  - **Ours**

    Given unstructured location data, discover walkable areas.

    A walkable area is an area bounded by nearby road segments or points of interest. Unconstrained movements of people are allowed within the area.

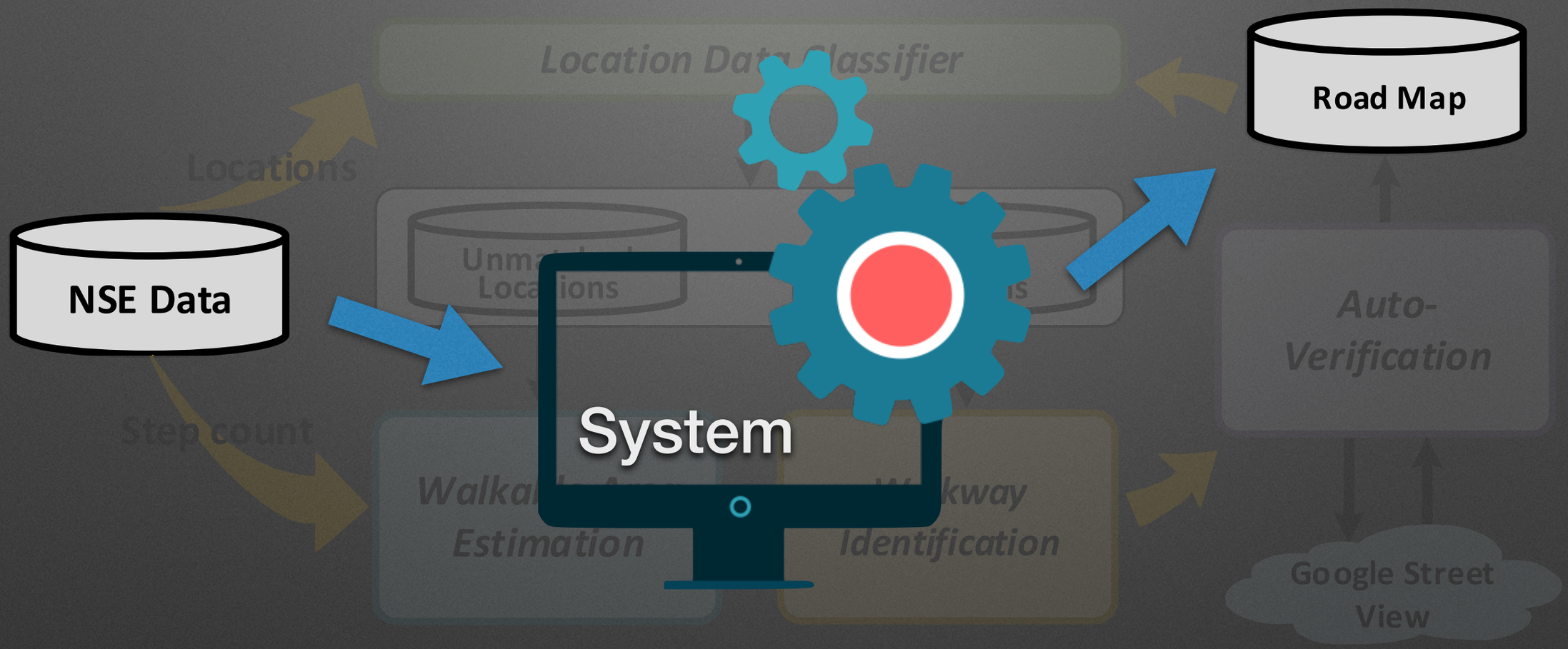
5 System Design

- System architecture



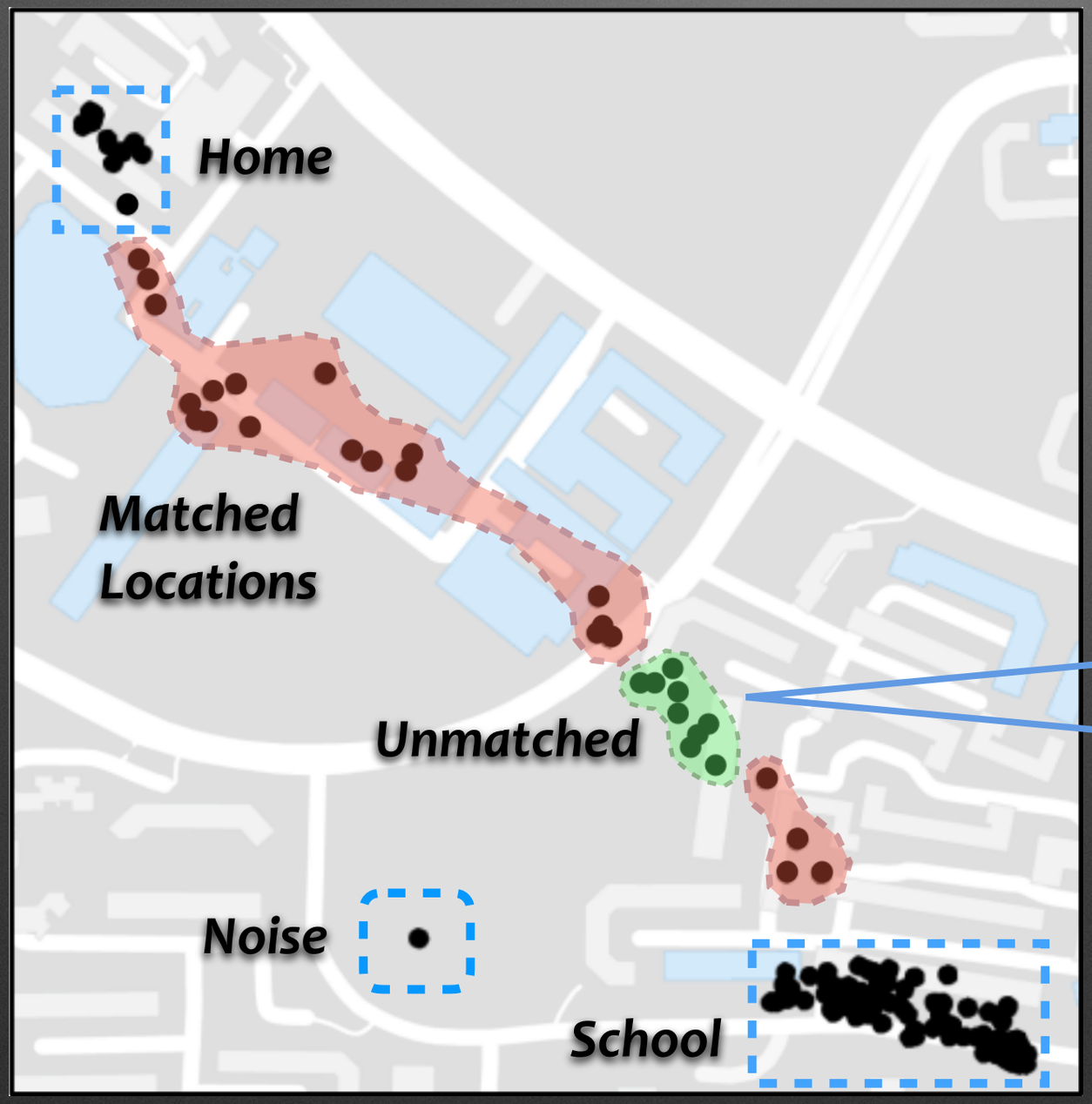
5 System Design

- System architecture



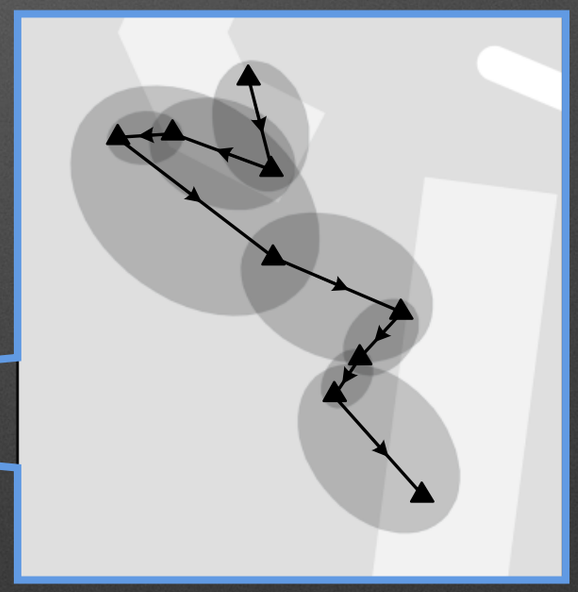
5 System Design

- Data classification



HDBSCAN

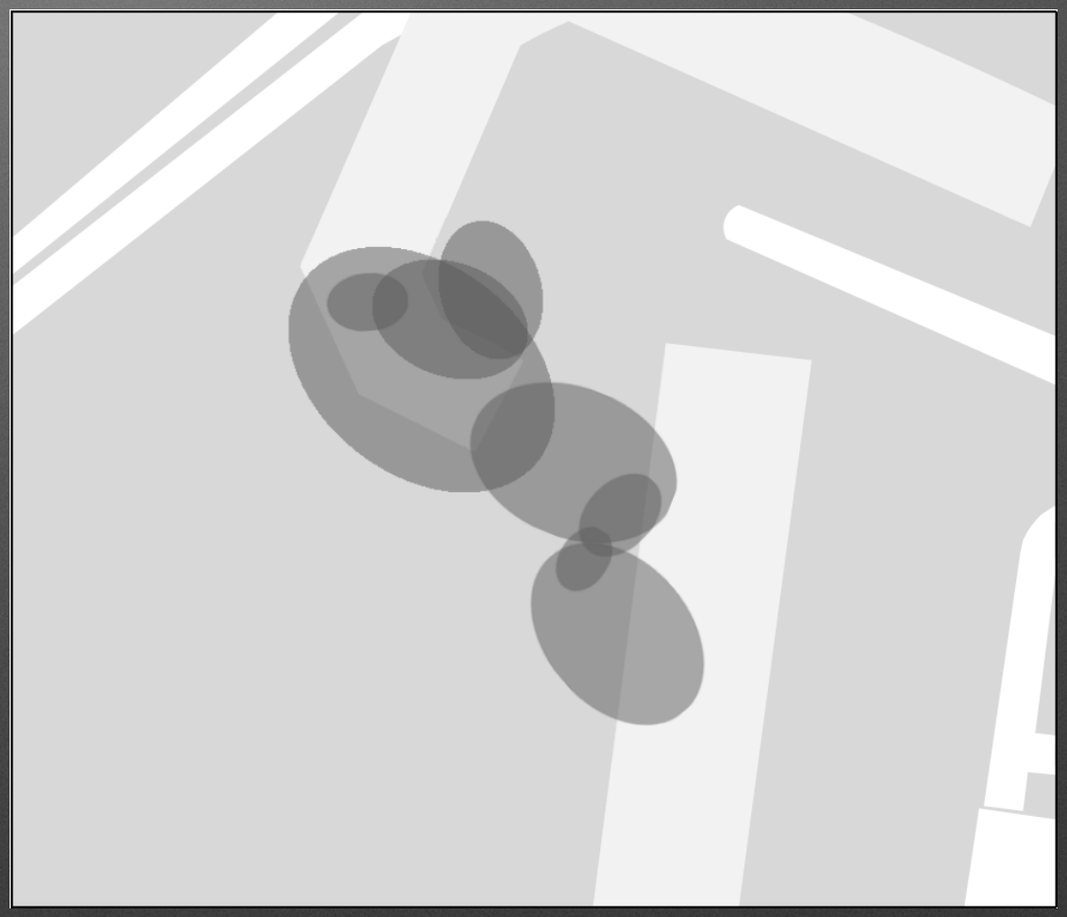
Map Matching



5 System Design

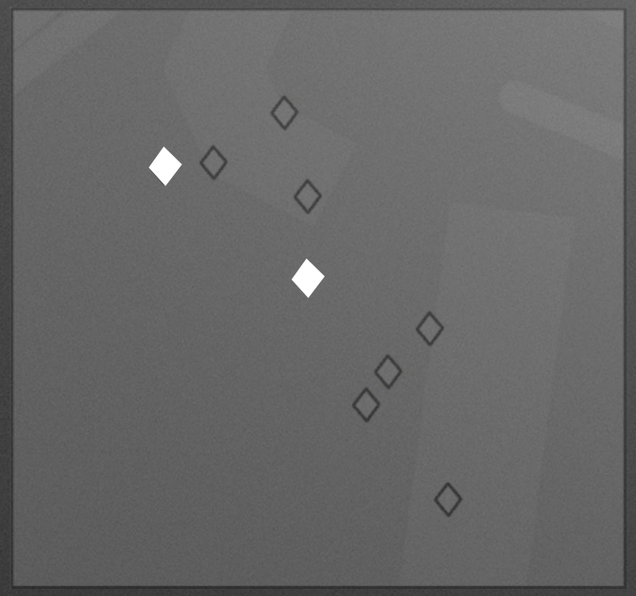
- Walkable area estimation

Unmatched locations



5 System Design

- Walkable area estimation



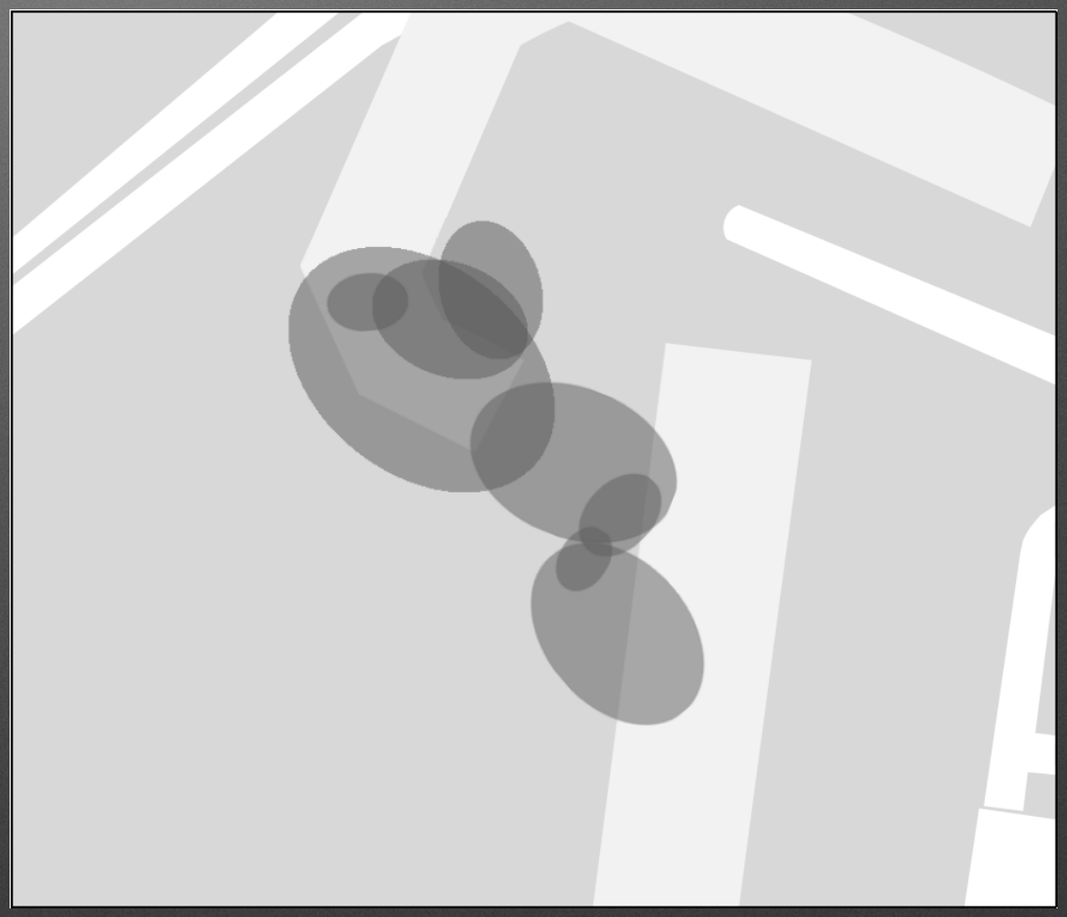
Unmatched locations

- Position: focal pints determined by consecutive locations
- Shape: length sum = step_count x stride_length

5 System Design

- Walkable area estimation

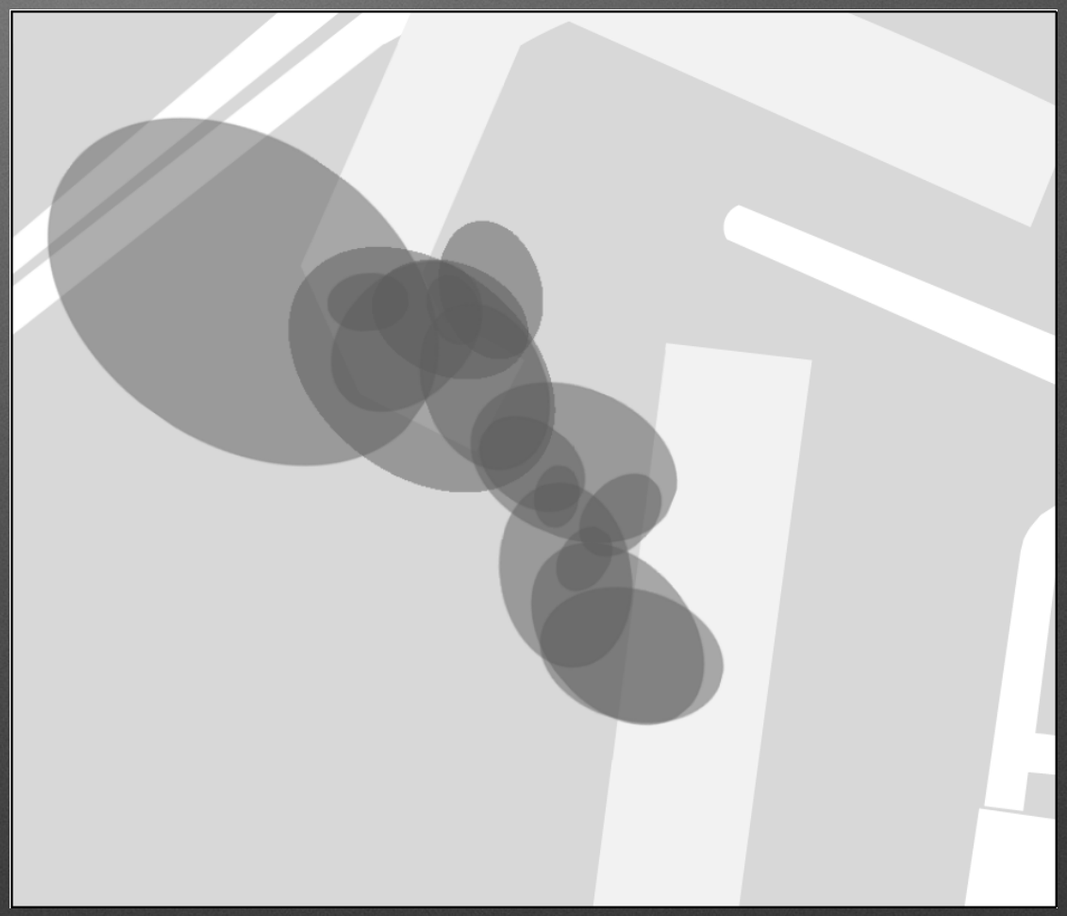
Unmatched locations



5 System Design

- Walkable area estimation

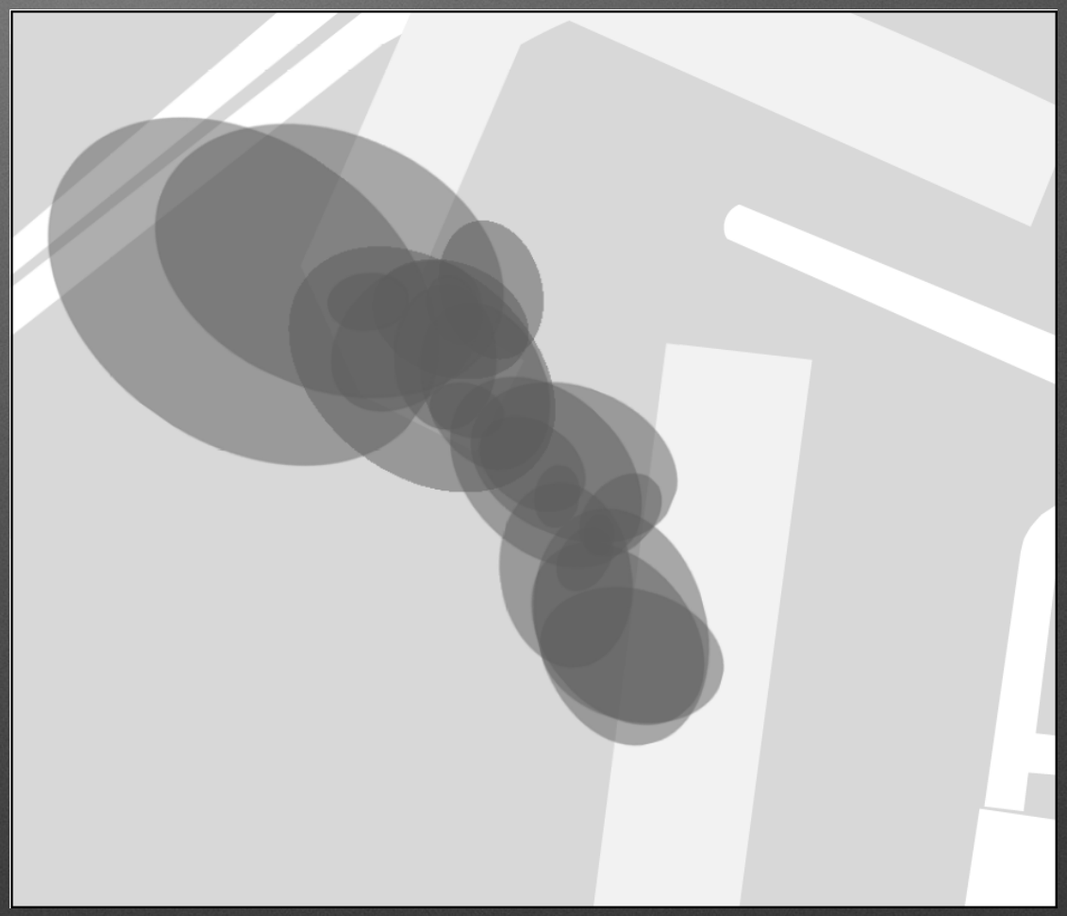
Unmatched locations



5 System Design

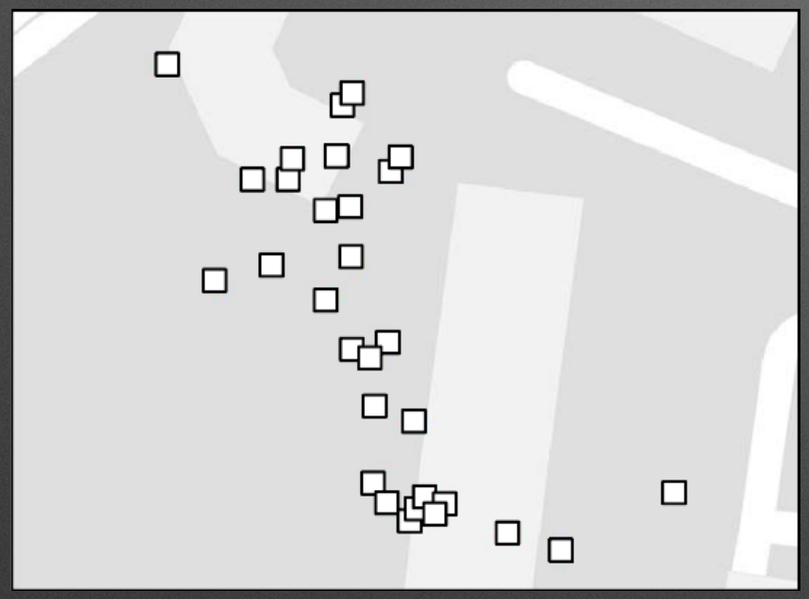
- Walkable area estimation

Unmatched locations

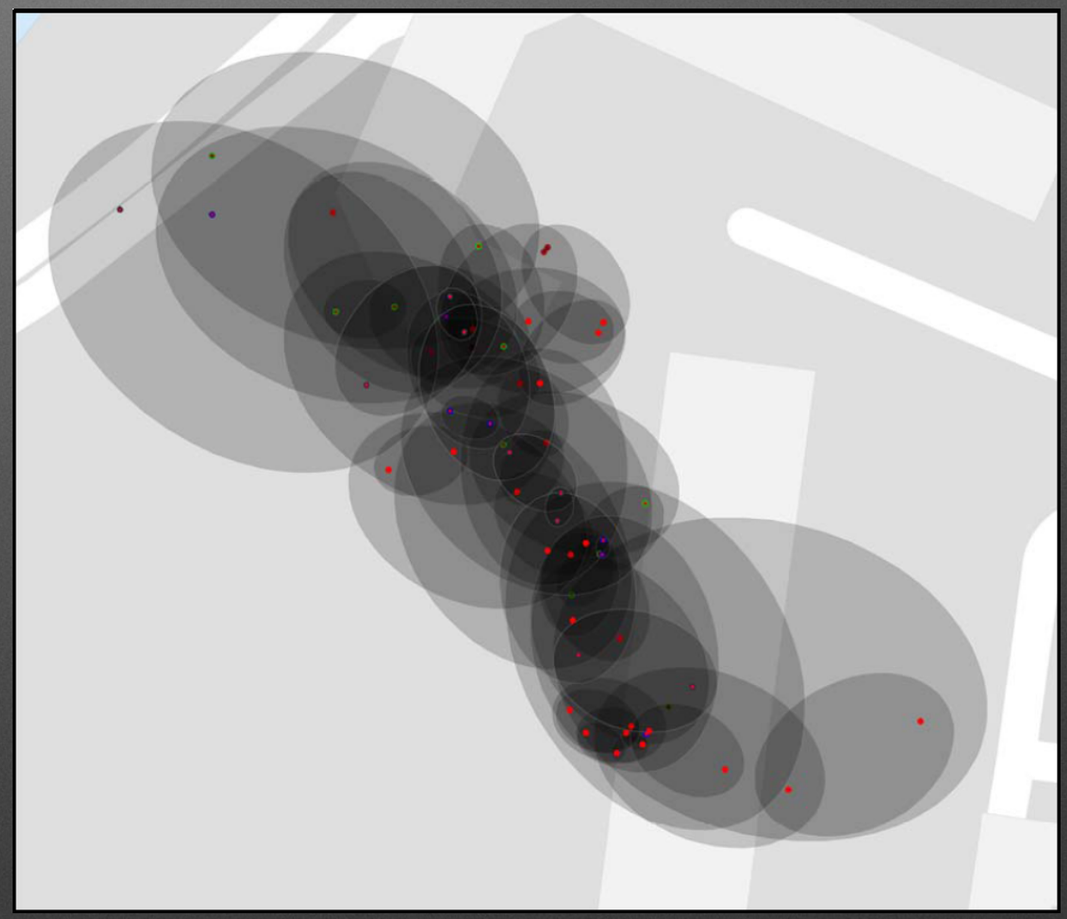


5 System Design

- Walkable area estimation



Unmatched locations



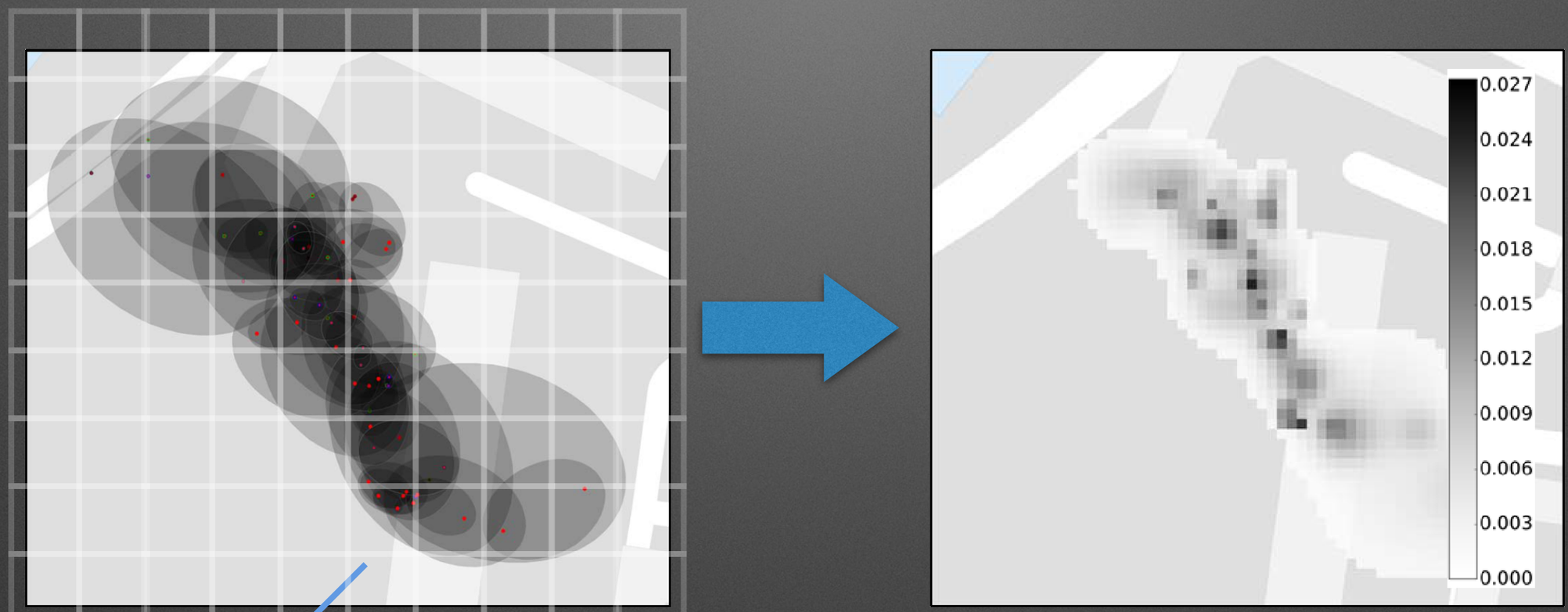
5 System Design

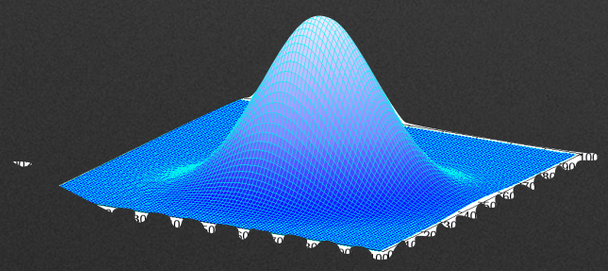
- Representative walkway
  - Insufficient sampling data
  - Better compatible with current map

A representative walkway represents the connectivity a walkway area serves between two known road segments. If we specify the intersection points between the road segments and the walkable area, the representative walkway can be denoted as a polyline connecting the two intersection points and integrated into the road graph G as an edge. There may be multiple representative walkways connecting different road segments adjacent to the same walkable area.

5 System Design

- Walkway identification



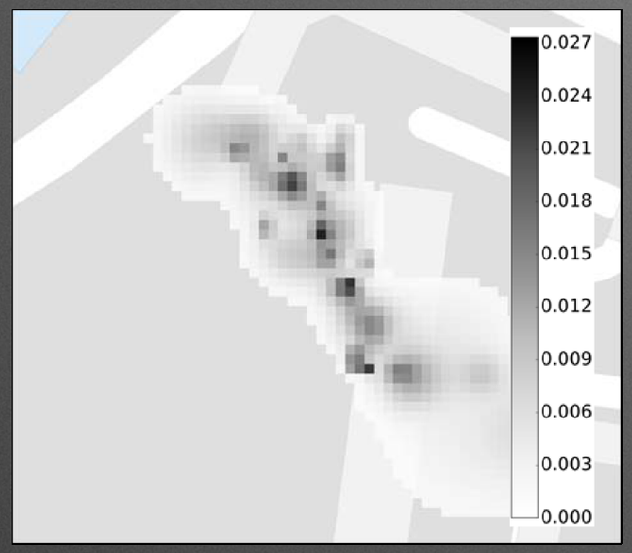


Probability density $f(X) = \frac{1}{2\pi\sqrt{|\Sigma|}} exp(-\frac{1}{2} X^T \Sigma^{-1} X)$

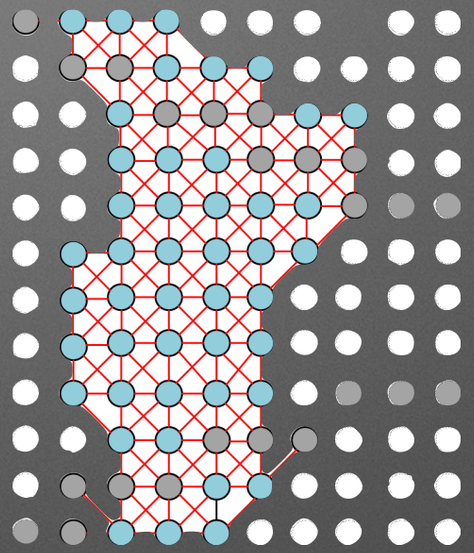
Probability: integral of f(X)

5 System Design

- Walkway identification



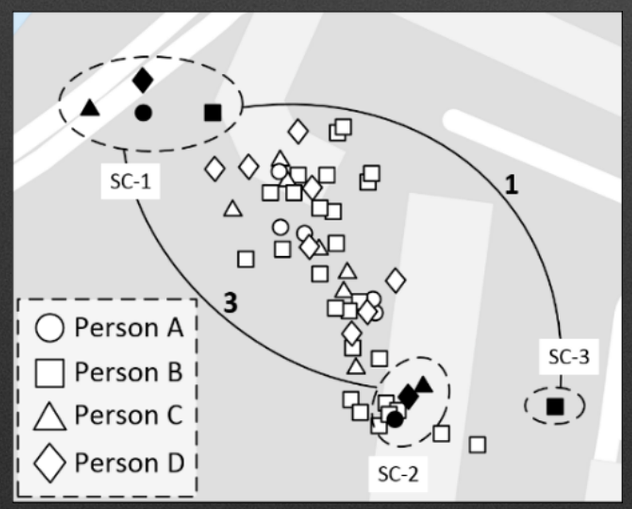
Score map



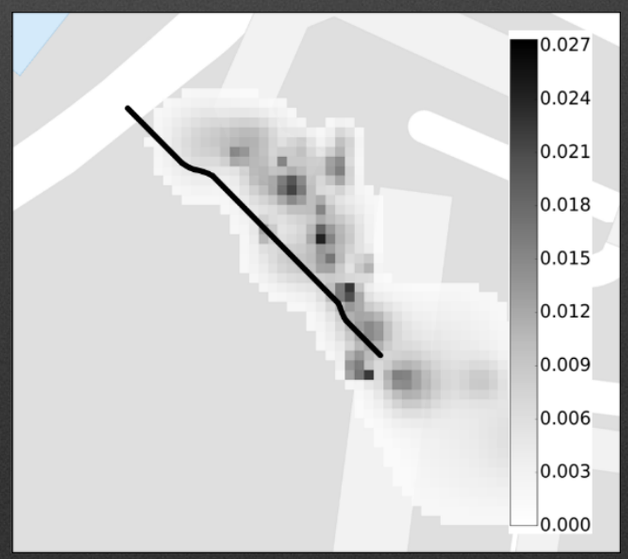
node
weight
edge

$$\sum_{i=1}^{n} f(v_i)$$

Weighted graph

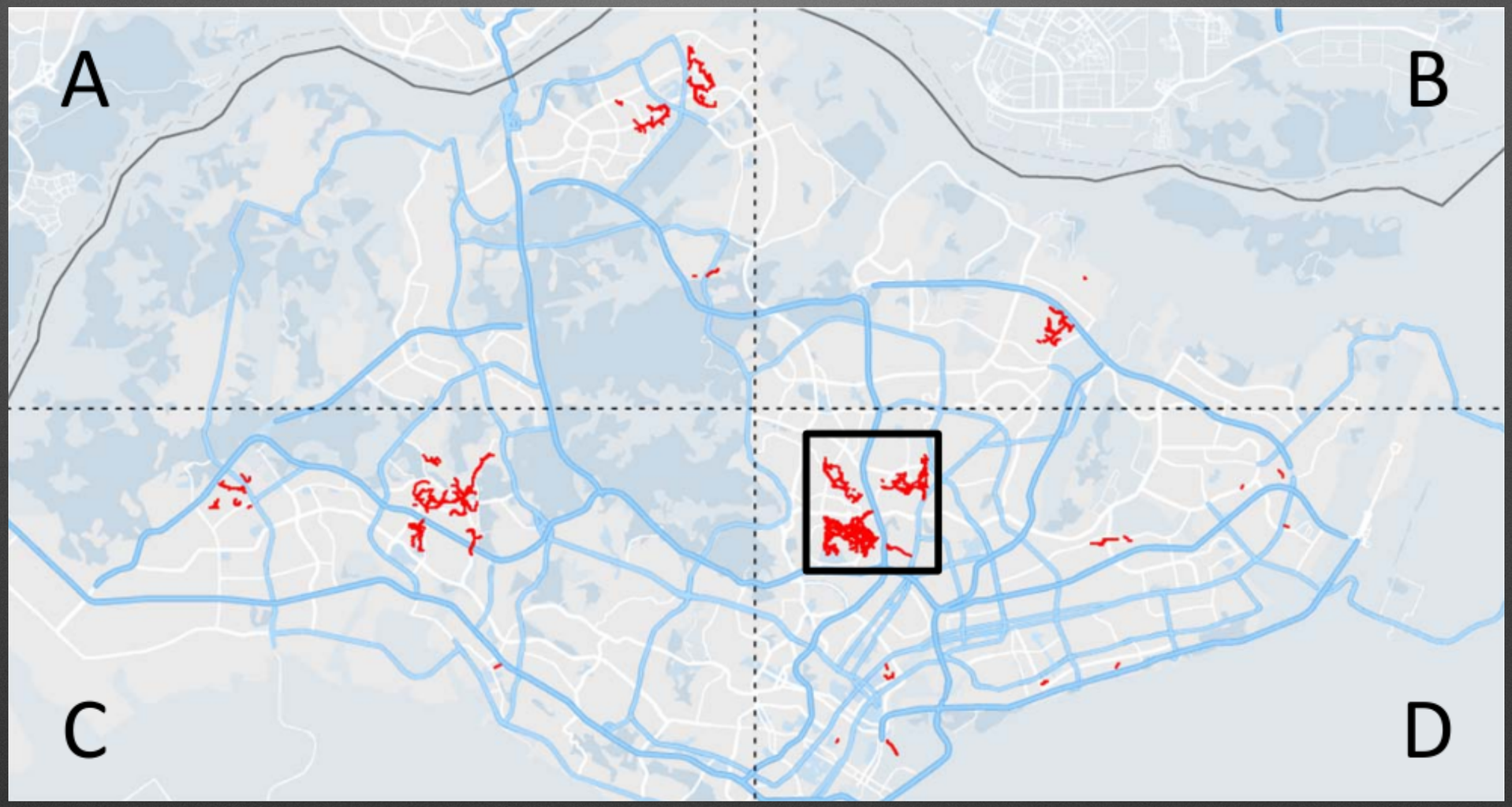


Two-phase clustering



6 Evaluation

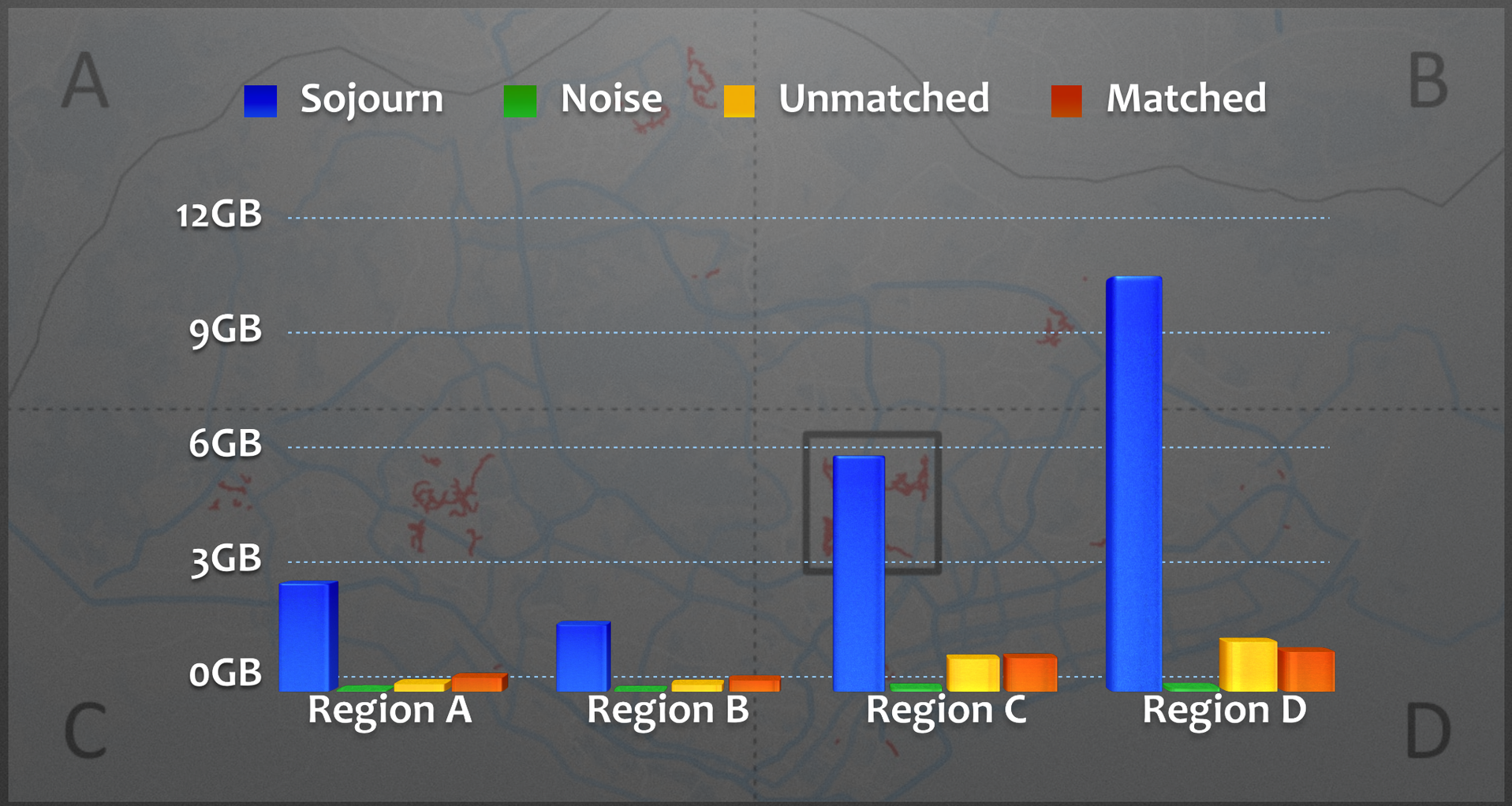
- Walkway discovery



- 736 walkways discovered with data from about 13,000 students in 1 week

6 Evaluation

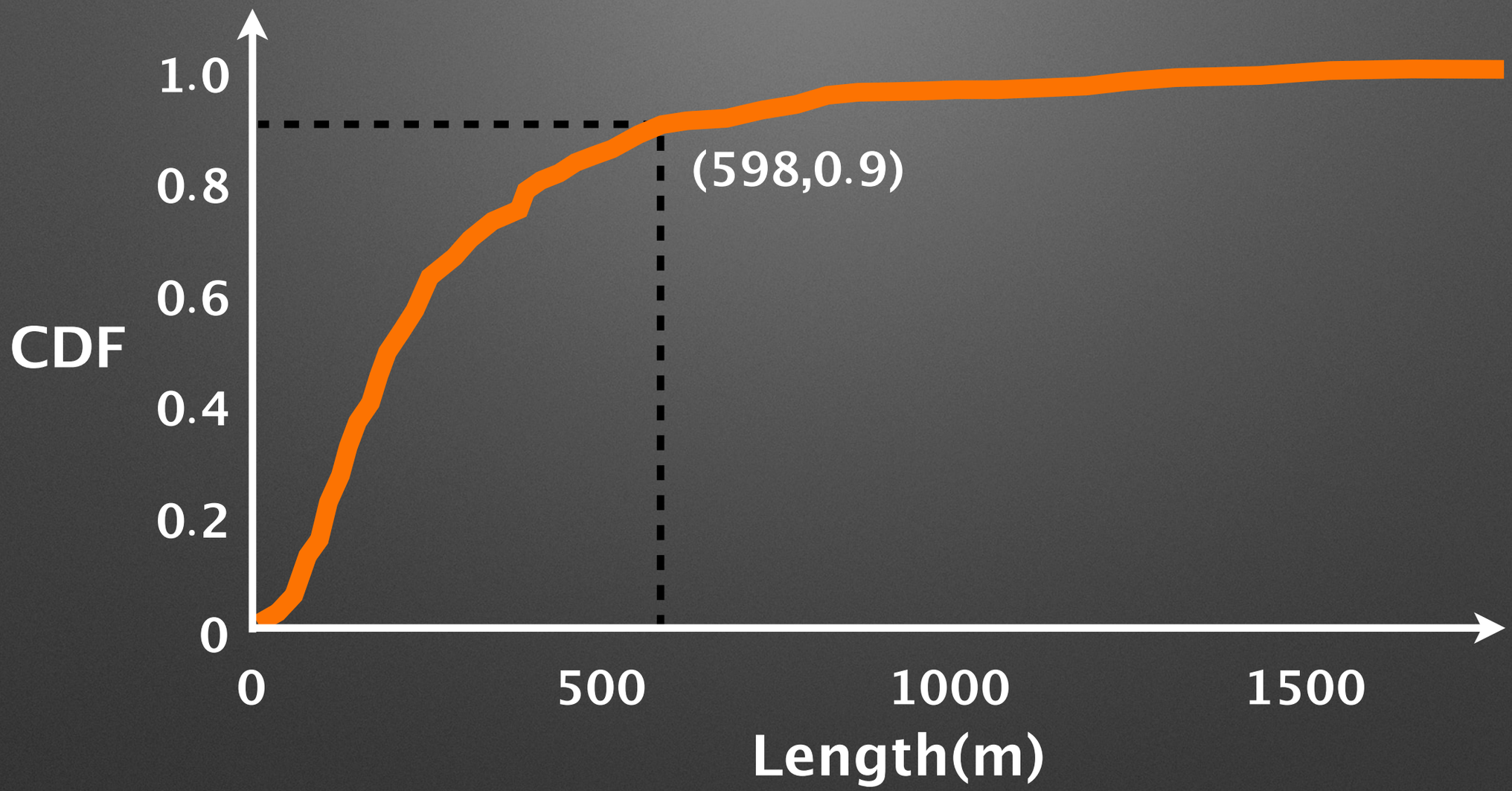
- Walkway discovery



- Region D contains most data more than 10G

6 Evaluation

- Walkway discovery

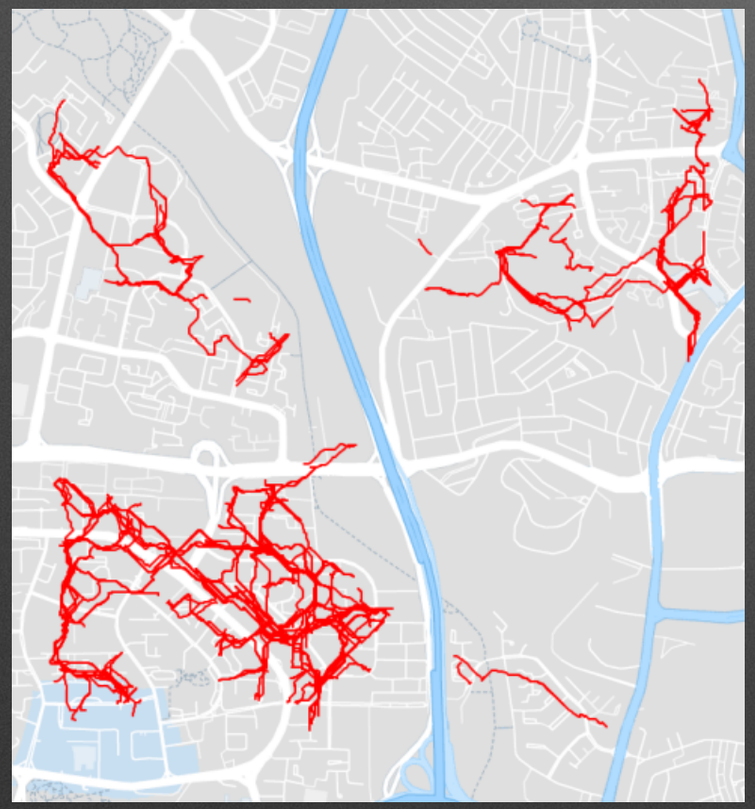


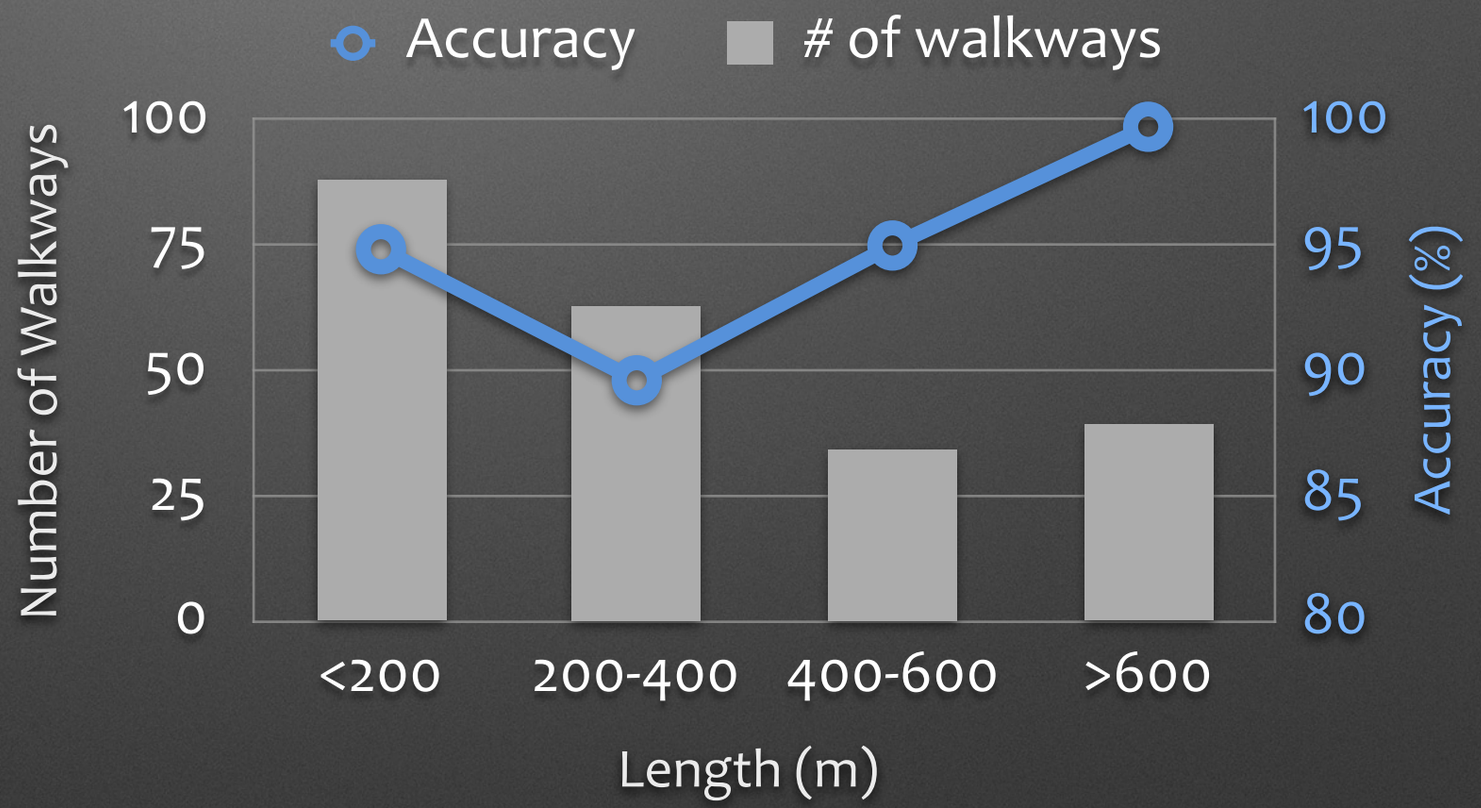
- The lengths of 90% of the walkways are shorter than 598m.

6 Evaluation

- Site-inspection

$$accuracy = \frac{N_{true \bigcap new}}{N_{new}}$$

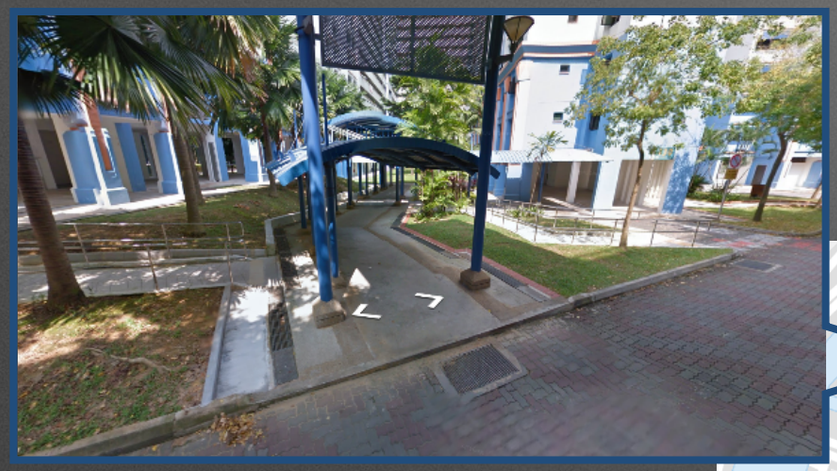




- 224 walkways are manually checked.
- The accuracy of 200–400 group is 89%.

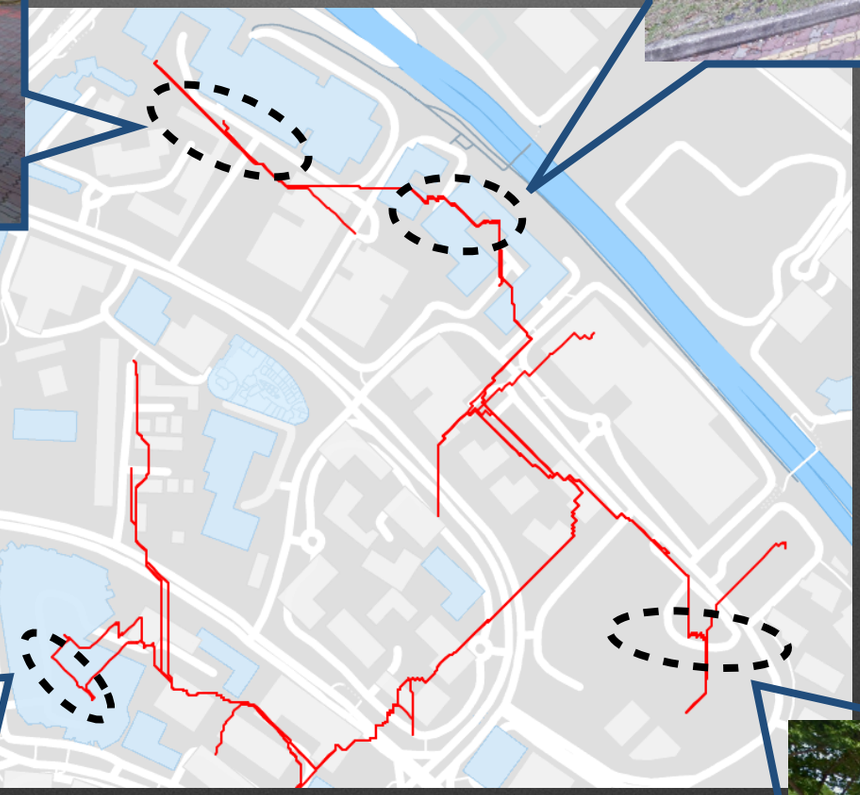
6 Evaluation

- Example of new found walkways



In residential area

Under HDB

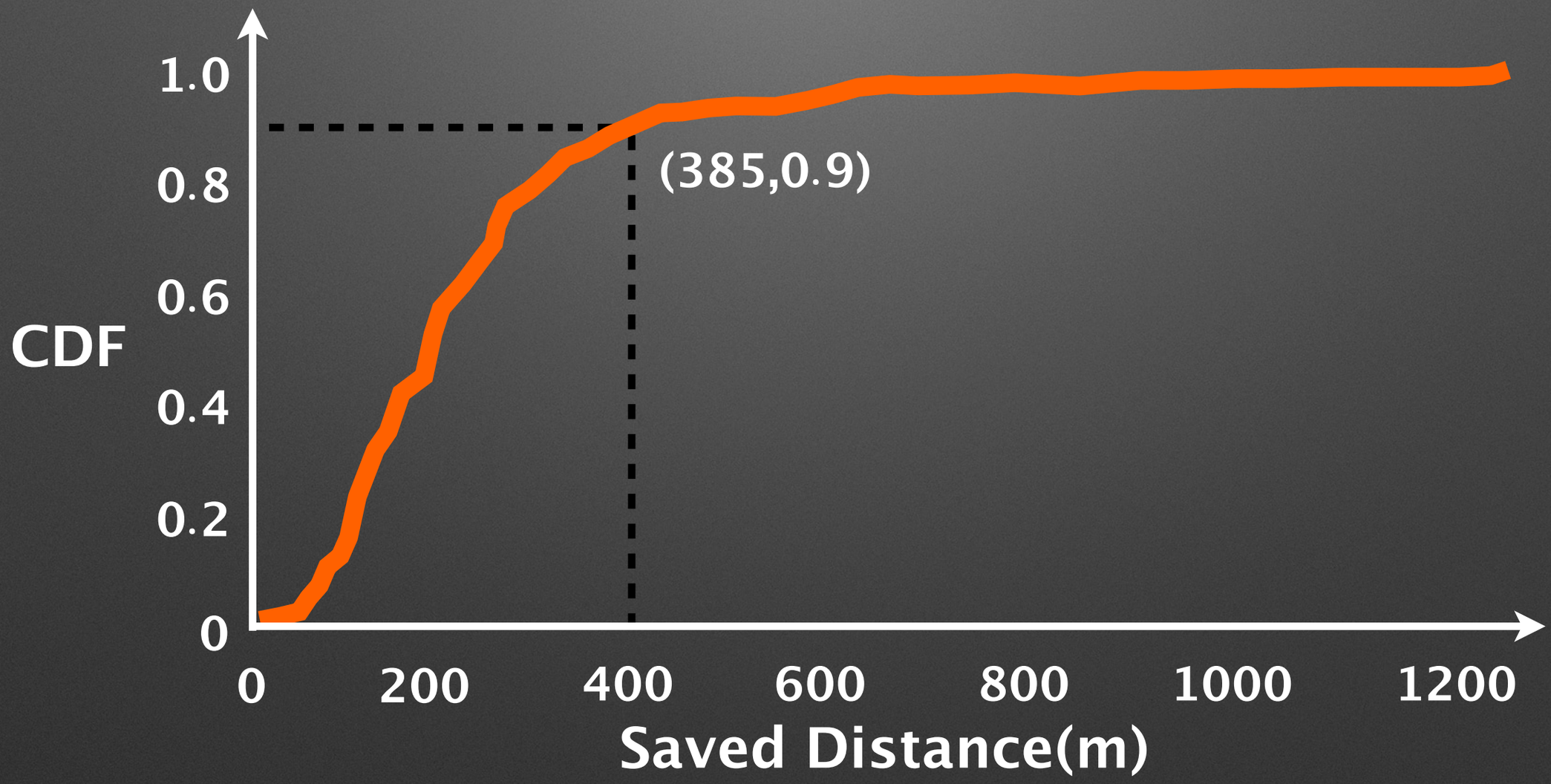


Between buildings

On grassland

6 Evaluation

- Utility study
  - Initiate 100 trips in this study.



  - Leveraging our new map can save travel distance.

One More Thing

- Google Street View

Google Street View

One More Thing

- Google Street View - easy to access
  - Help verify the ending points of new-found walkways

The image requirement is a HTTP URL formatted as below:

https://maps.googleapis.com/maps/api/streetview?parameters

- location

  either a text string (such as Chagrin Falls, OH) or a lat/lng value (40.457375,-80.009353)
- size

  specified as {width}x{height} - for example, size=600x400 (unit: pixel)
- heading

  compass heading of camera.from 0 to 360 (both values indicating North, with 90 indicating East, and 180 South)
- FOV

  horizontal field of view of the image.
- key

  a key of Google Service monitoring API usage

Google Street View

One More Thing

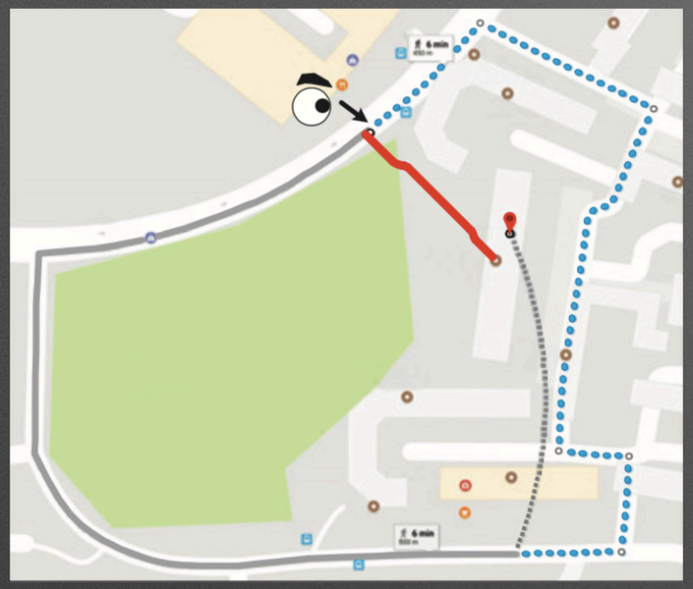
- Google Street View - easy to access

An example

https://maps.googleapis.com/maps/api/streetview?
size=640x320&
location=1.3633164,103.8502798&
heading=30&
fov=120&
key=AIzaSyDCdDvb_rHXOhM-O4rG-fNfxrgR-YrU6GU

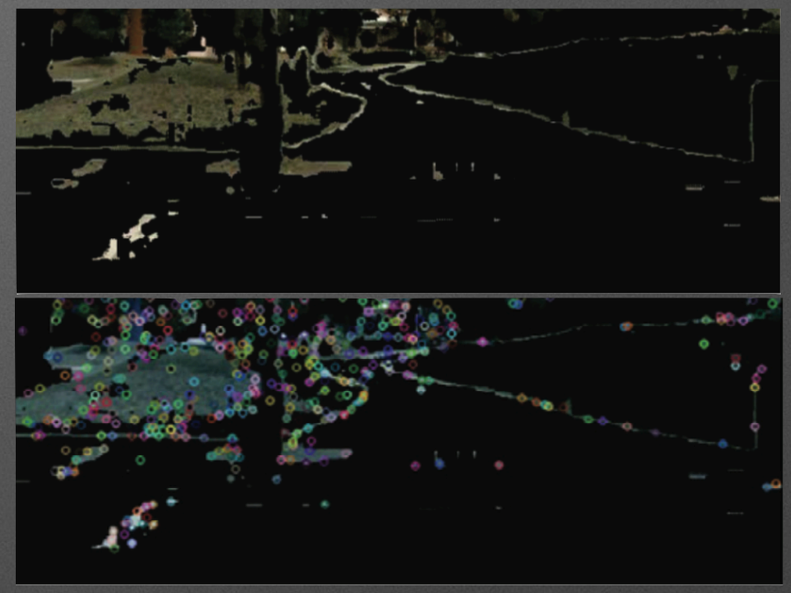
One More Thing

- Auto-Verification

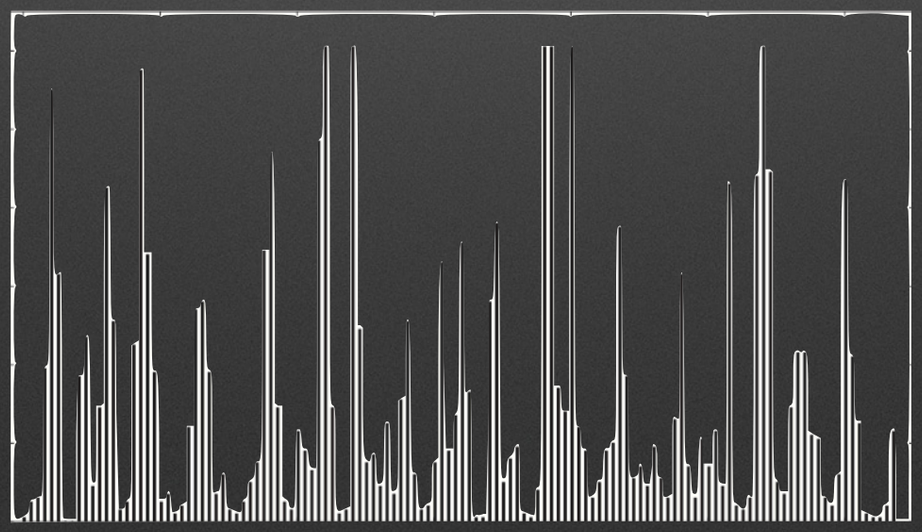


Walkway

Google Street View

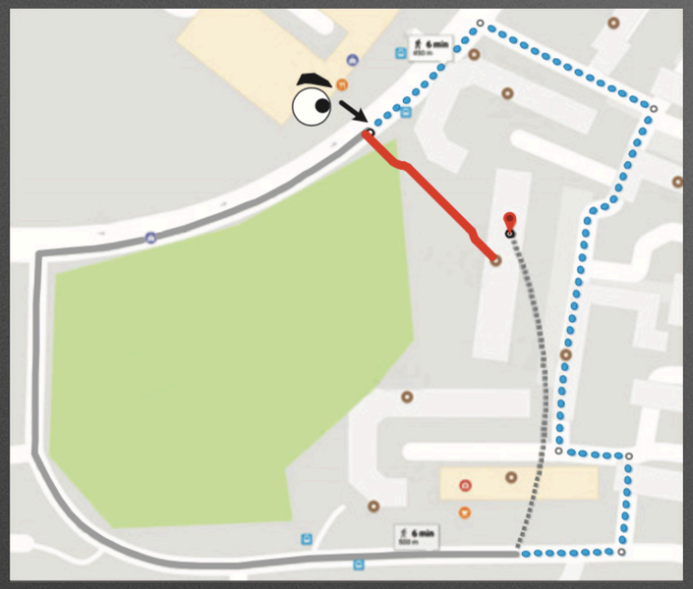


Features



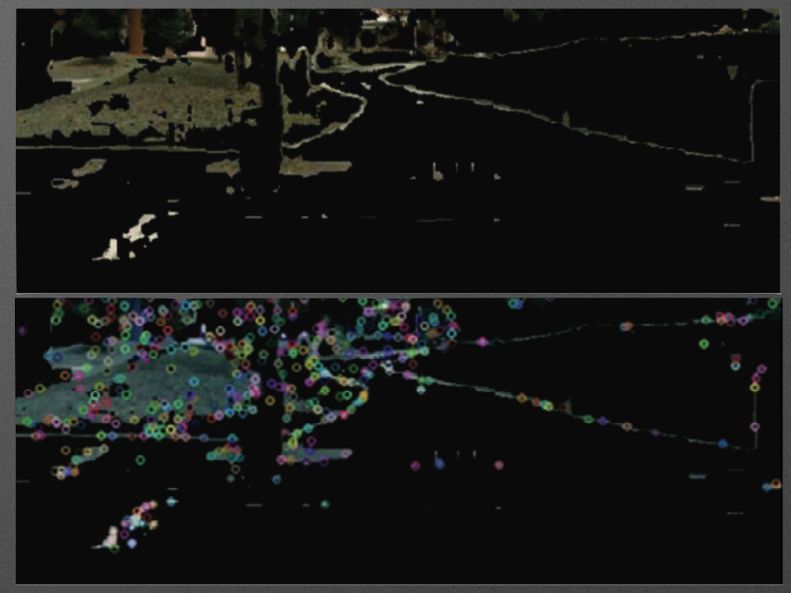
One More Thing

- Auto-Verification

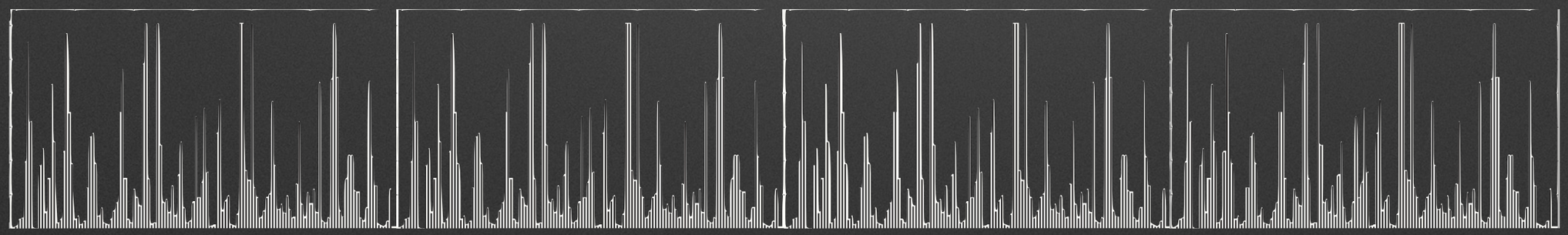


Walkway

Google Street View



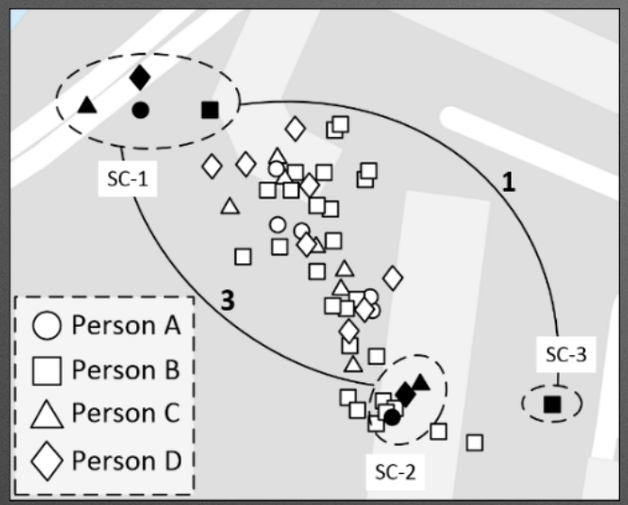
Features



...

One More Thing

- Effect of Auto-Verification on accuracy



Two-phase clustering

➡ support of <SC-1, SC-2> is *3*

➡ support of <SC-1, SC-3> is *1*

SUPPORT	2	4	6	8
w/ GSV	93.2%	94.8%	95.7%	96.0%
w/o GSV	80.9%	88.6%	93.5%	95.8%

Conclusion

- This is the first paper targeting at walkway discovery.
- Our work is a great application of the crowdsensing NSE project.
- Our proposed method is general enough to be fed with all kinds of geolocation data.

NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

Q & A

Thank you very much.

Source code: https://github.com/caochuntu/IPSN2018_guizu