



Walkway Discovery from Large Scale Crowdsensing

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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

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

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

...

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

Acceleration

Locations

Step count

Travel mode

...

2 Motivation

- ❖ Walkways are important for pedestrians



Recommended route of Google Maps from NTU to BLK 941

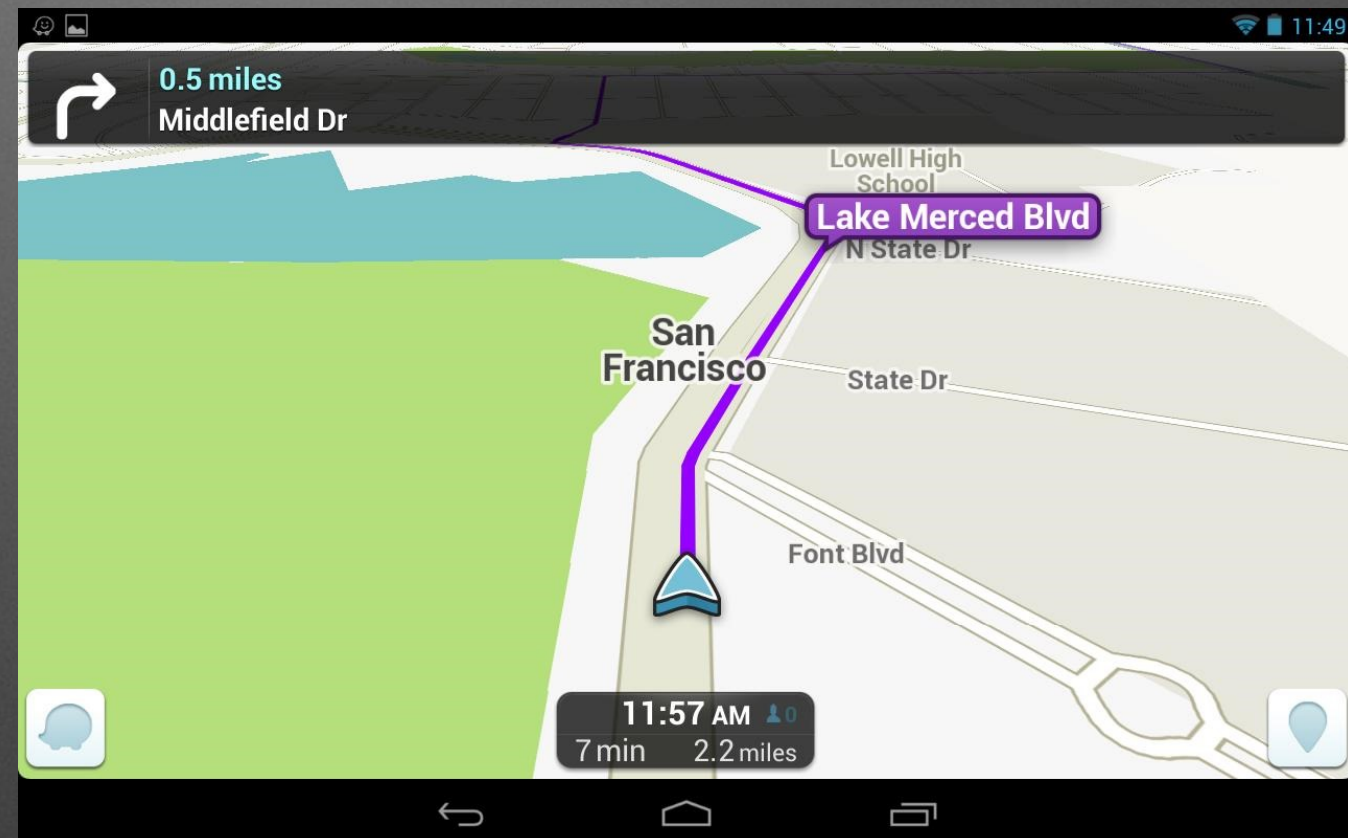
2 Motivation

❖ 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

CrowdAtlas
MobiSys
2013

COBWEB
UbiComp
2015

- 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
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Walkways
Unstructured

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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.

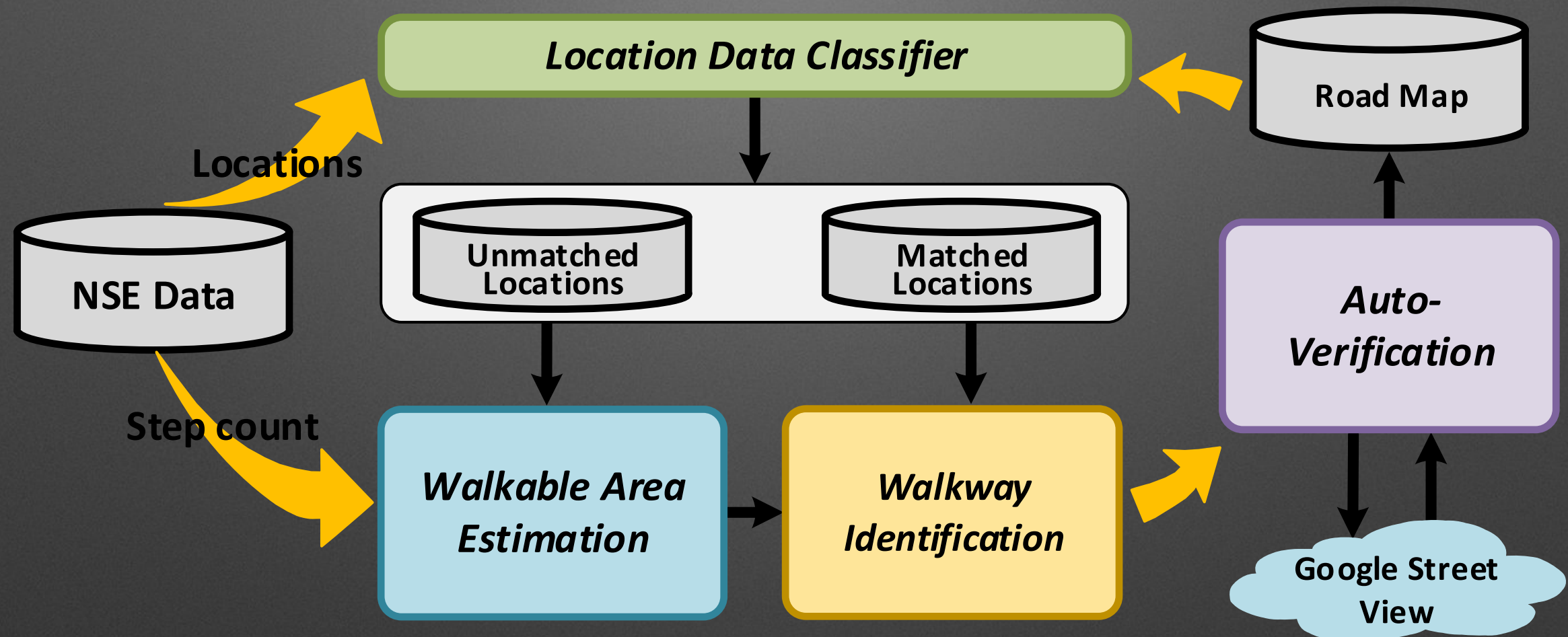
● Ours

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.

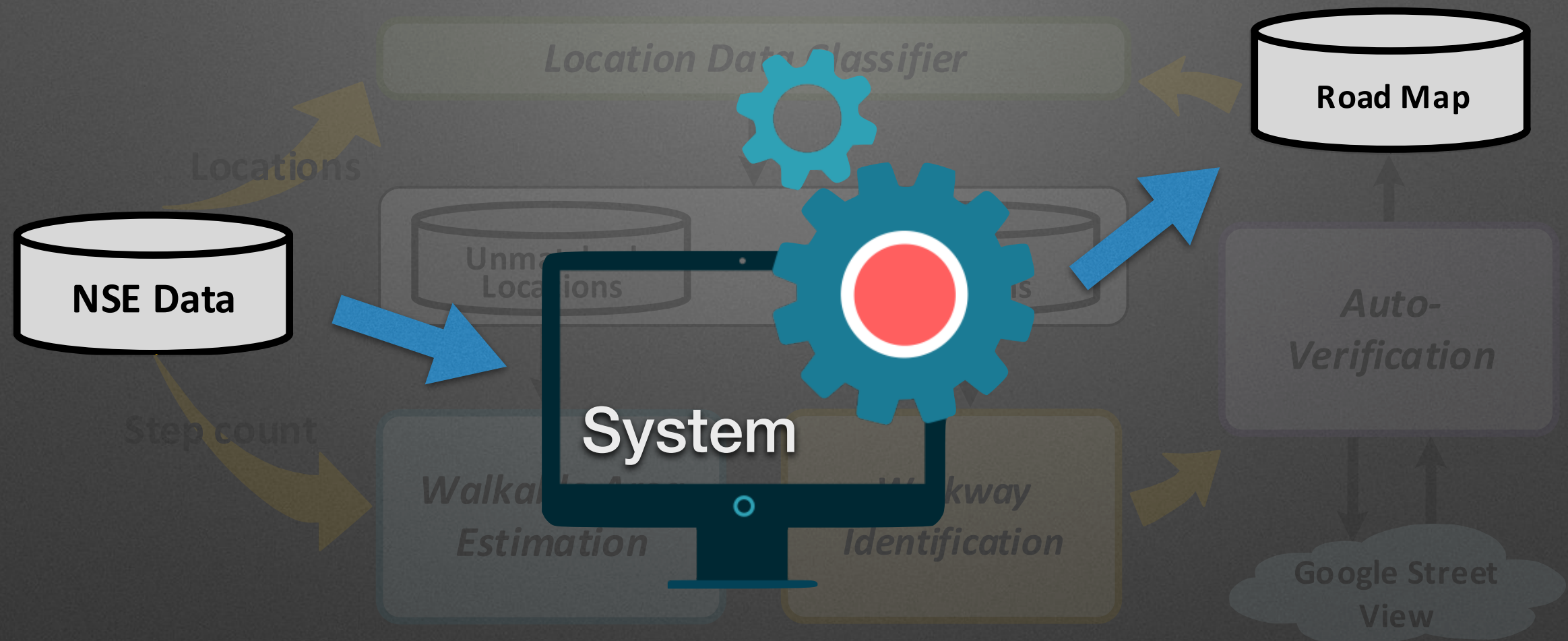
5 System Design

❖ System architecture



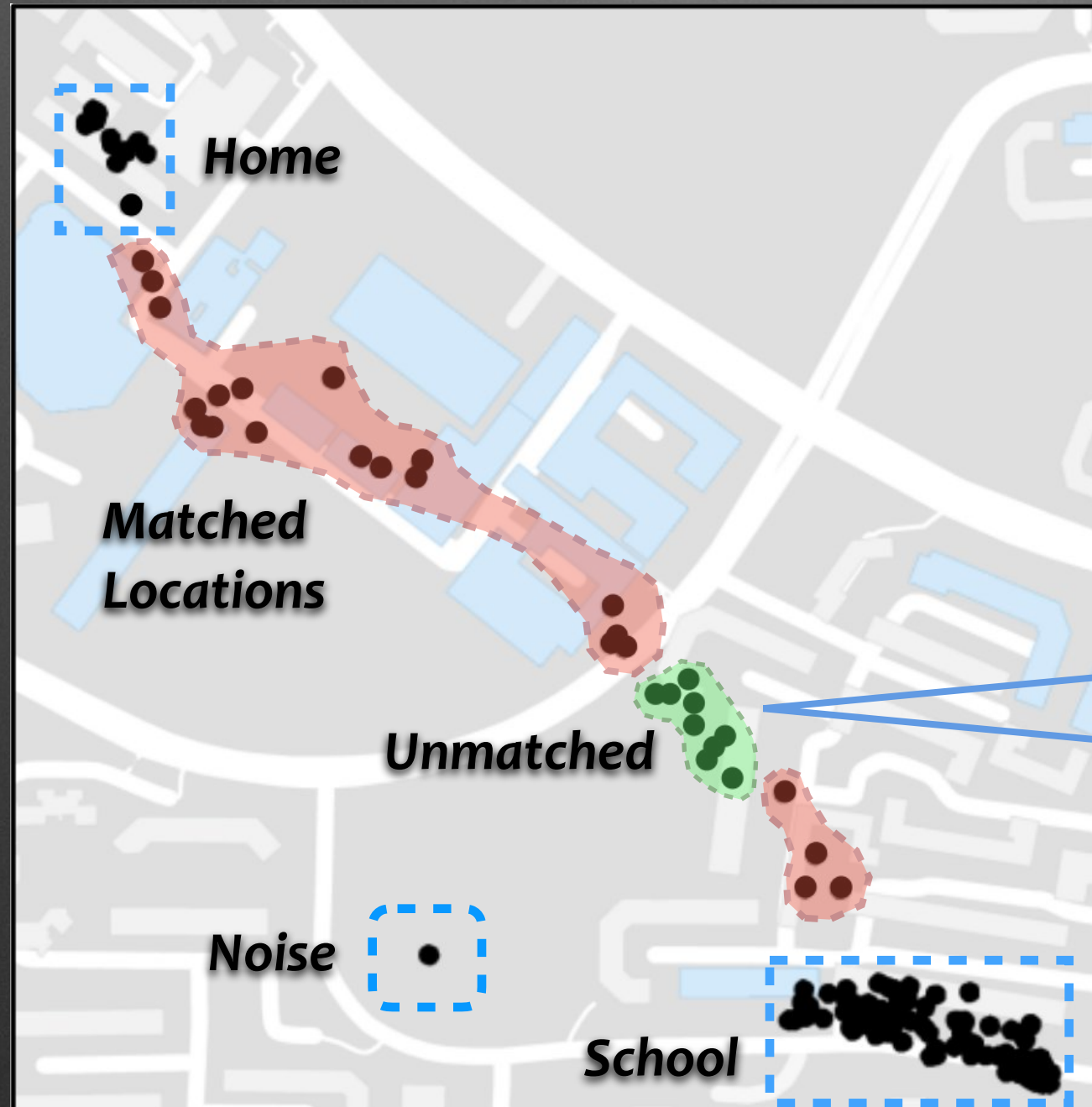
5 System Design

❖ System architecture



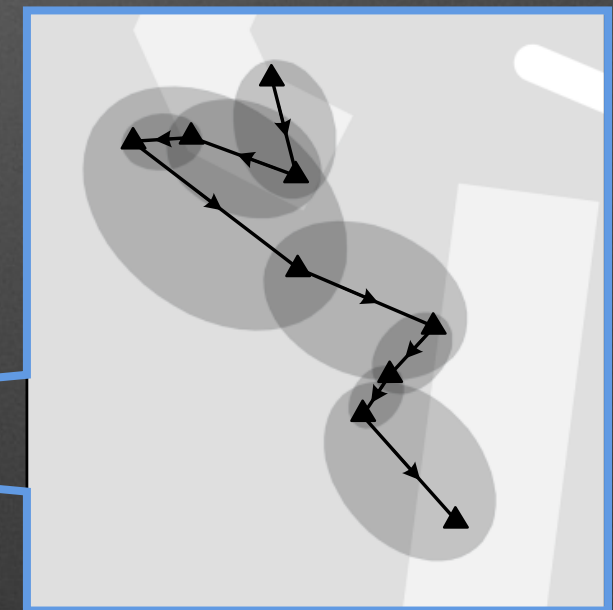
5 System Design

❖ Data classification



HDBSCAN

Map Matching

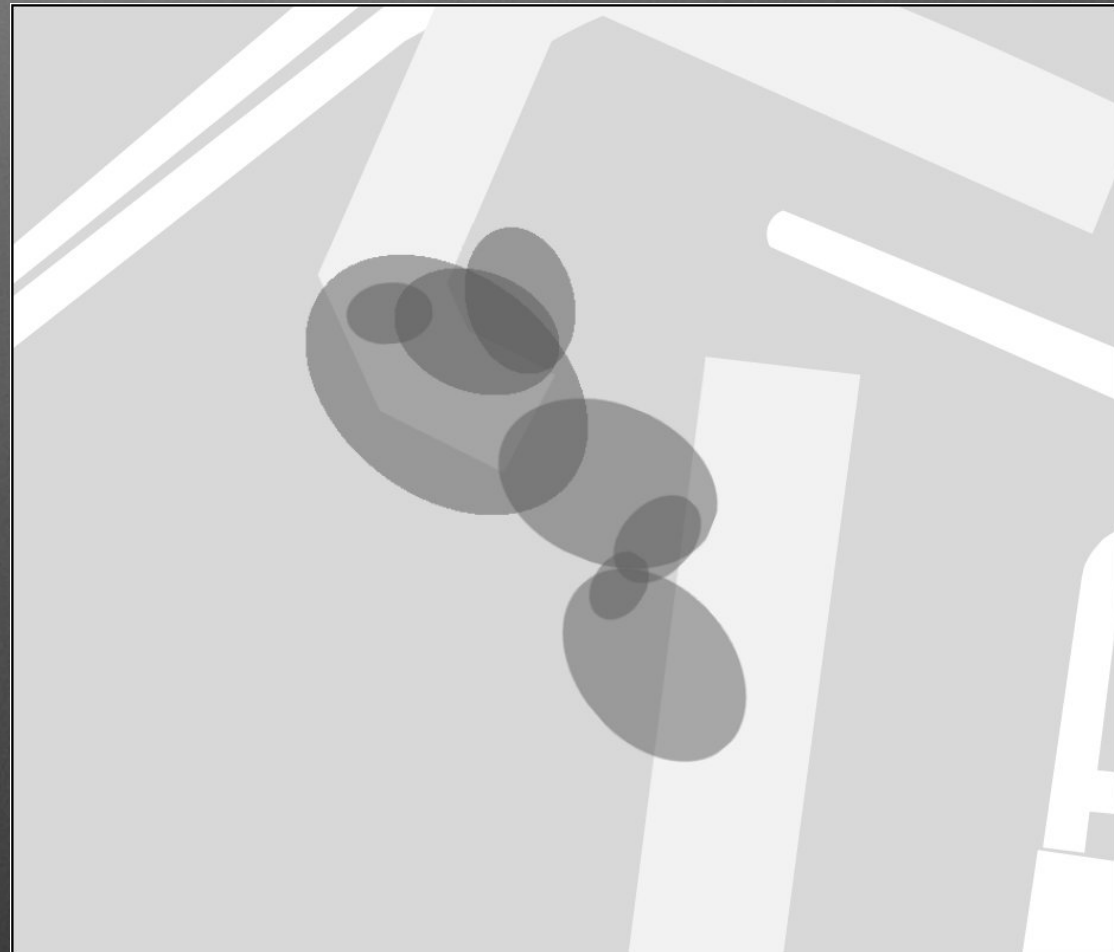


5 System Design

❖ Walkable area estimation



Unmatched locations

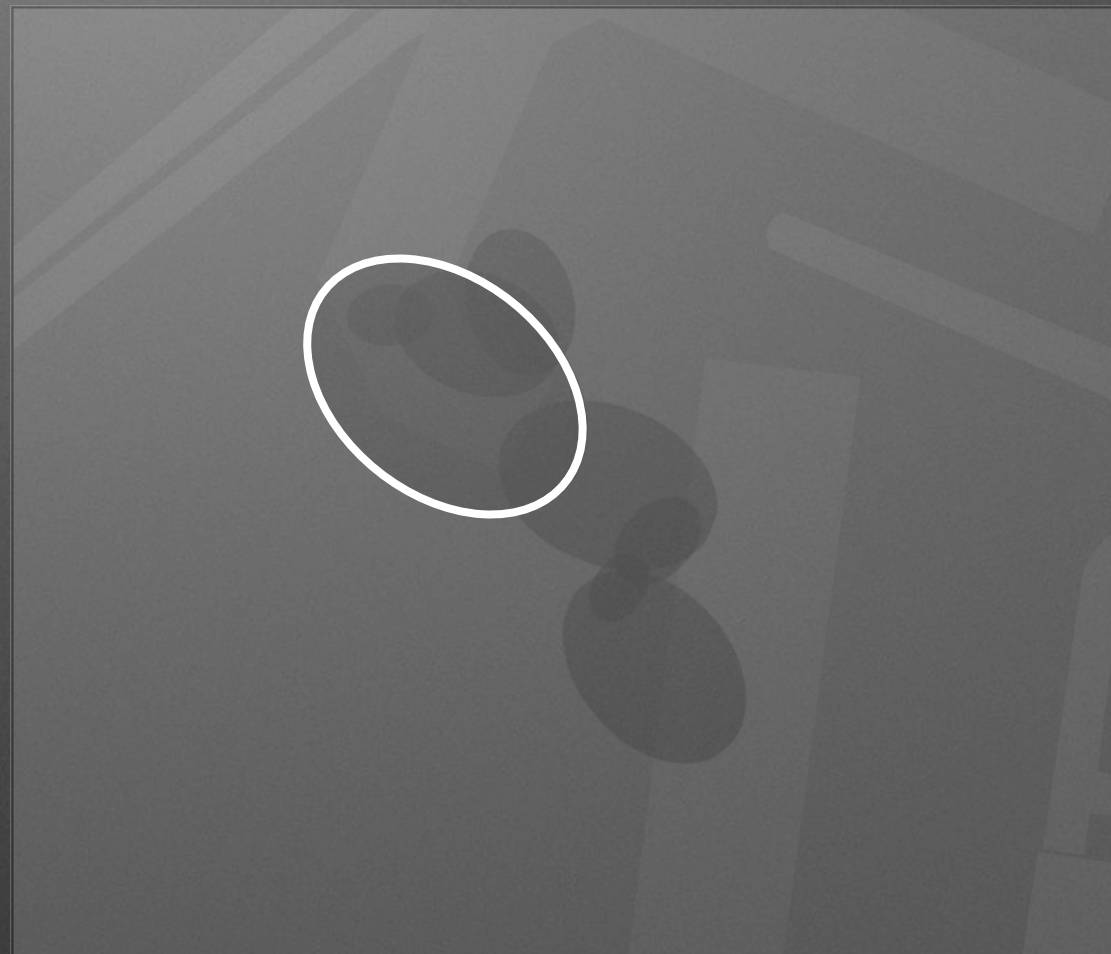


5 System Design

❖ Walkable area estimation



Unmatched locations



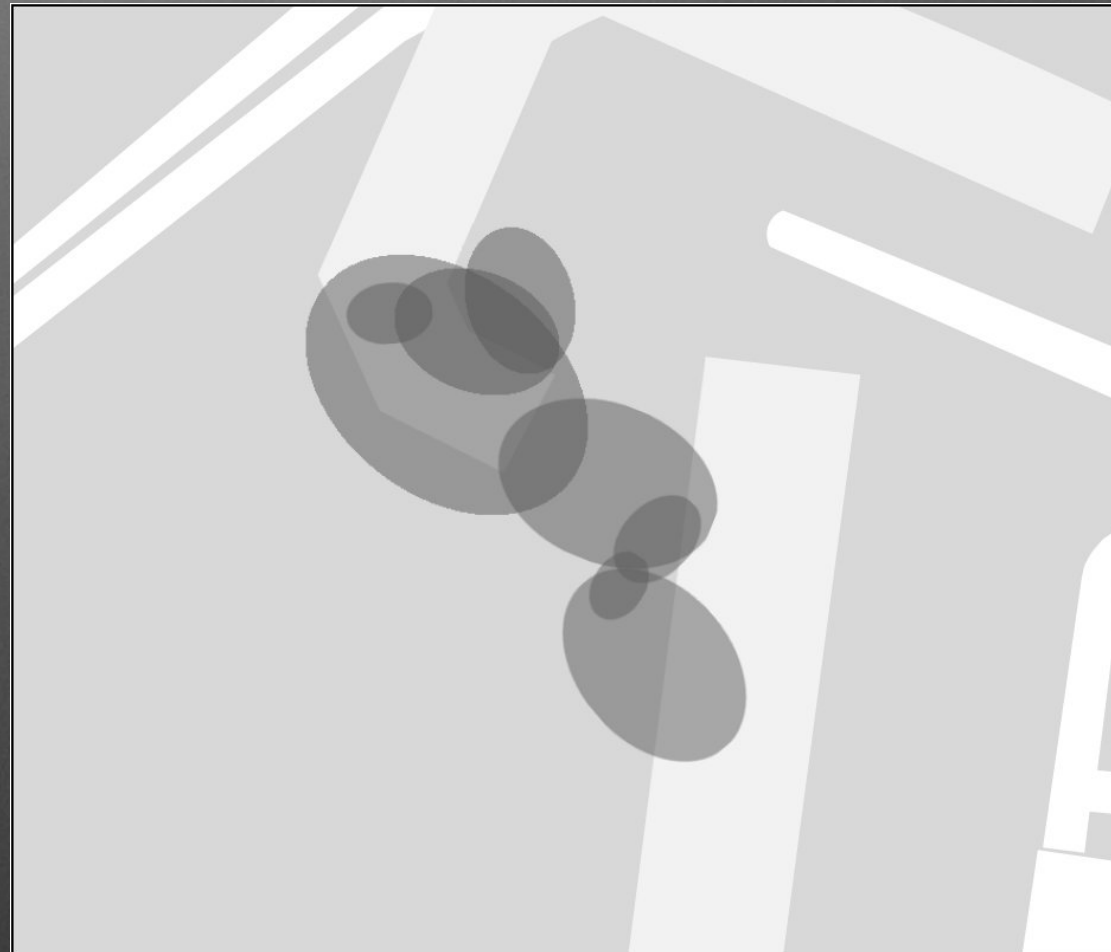
- ◉ Position: focal points determined by consecutive locations
- ◉ Shape: $\text{length sum} = \text{step_count} \times \text{stride_length}$

5 System Design

❖ Walkable area estimation



Unmatched locations



5 System Design

❖ Walkable area estimation



Unmatched locations

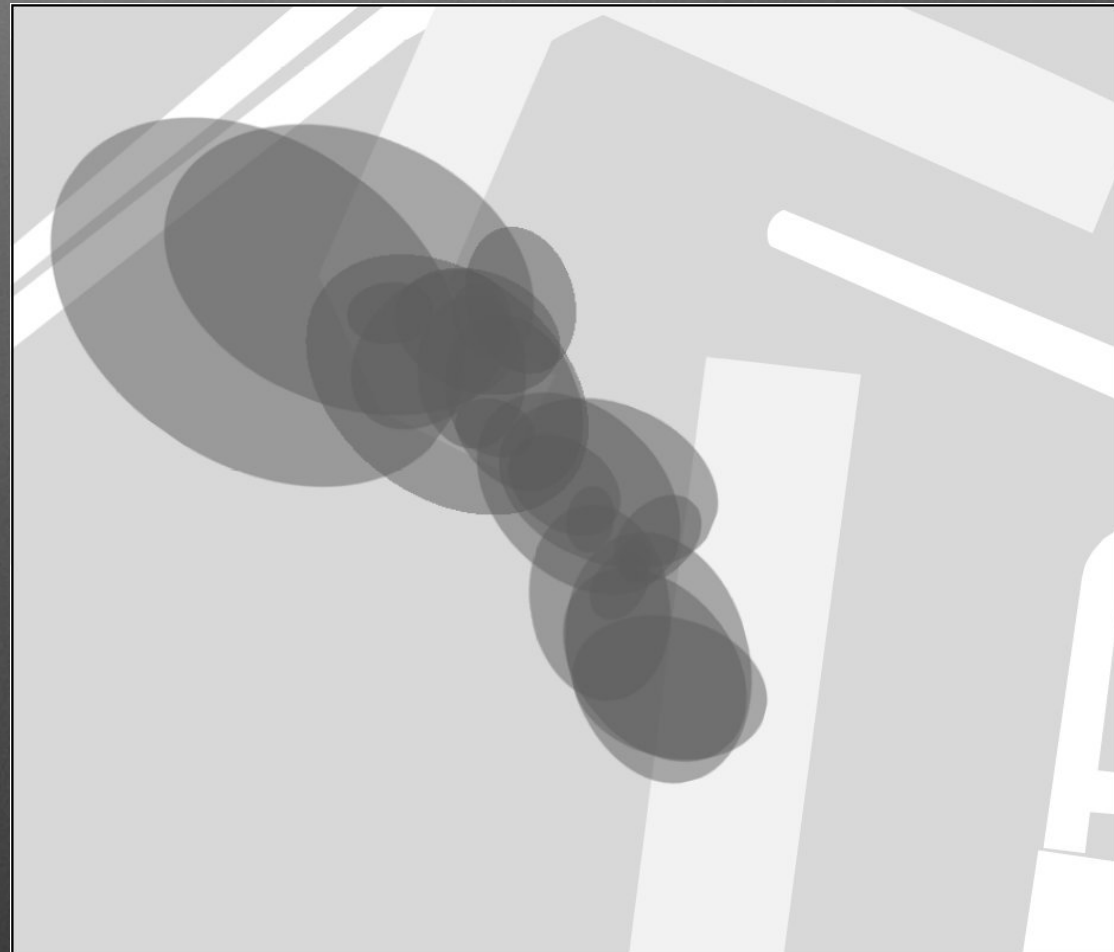


5 System Design

❖ Walkable area estimation

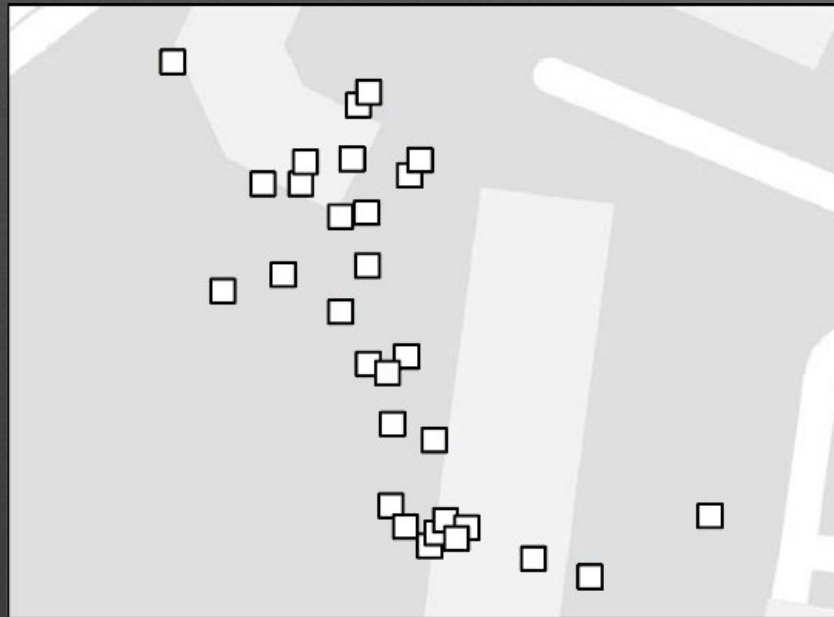


Unmatched locations

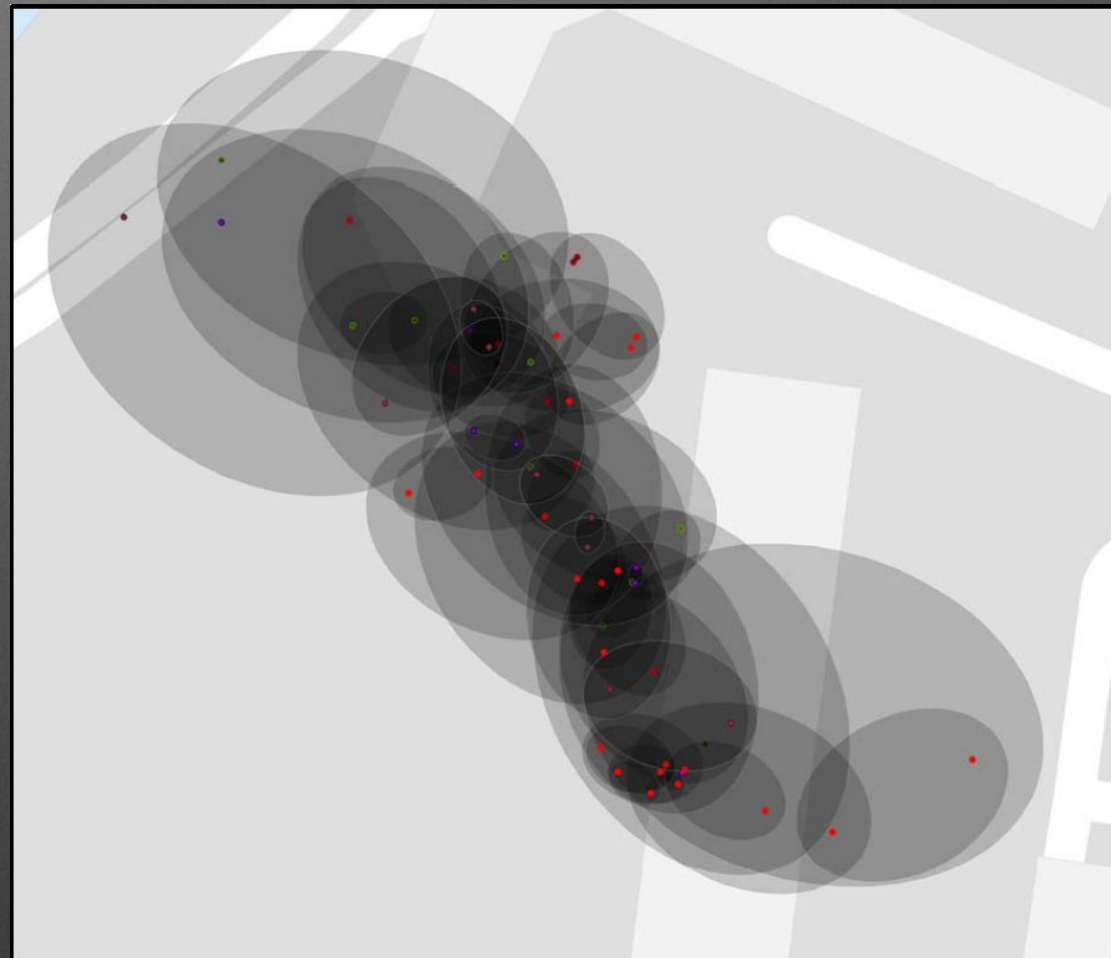


5 System Design

❖ Walkable area estimation



Unmatched locations



5 System Design

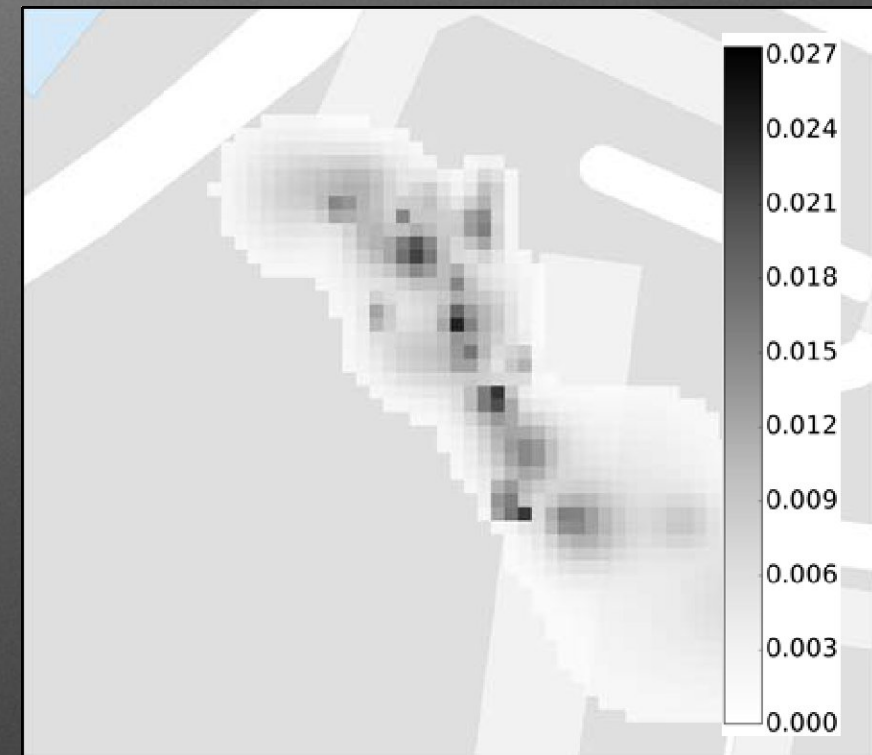
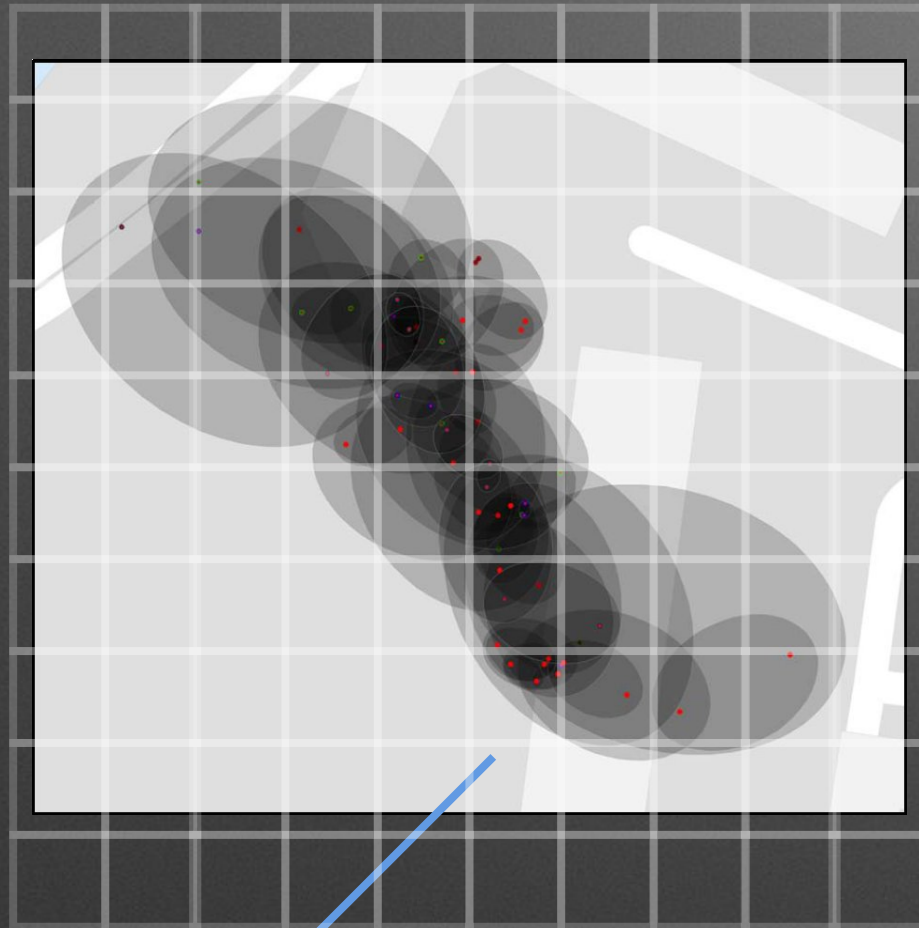
❖ Representative walkway

- ◉ 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.

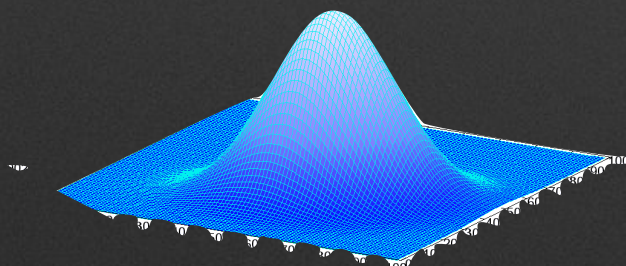
5 System Design

❖ Walkway identification



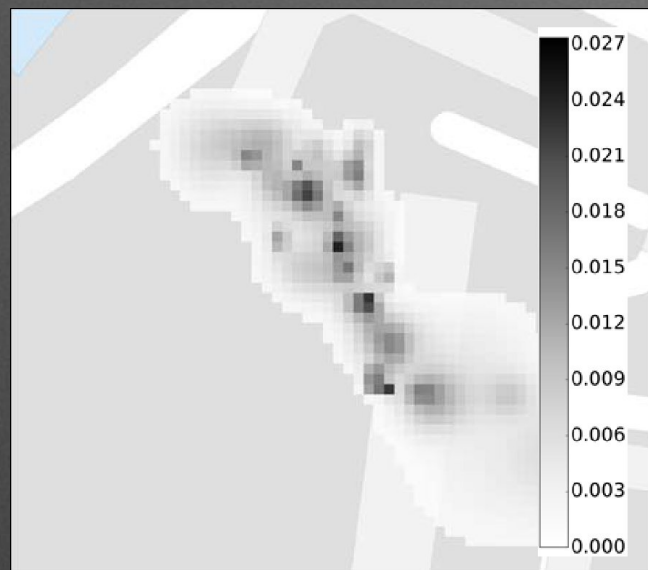
Probability density $f(X) = \frac{1}{2\pi\sqrt{|\Sigma|}} \exp\left(-\frac{1}{2}X^T \Sigma^{-1} X\right)$

Probability: integral of $f(X)$

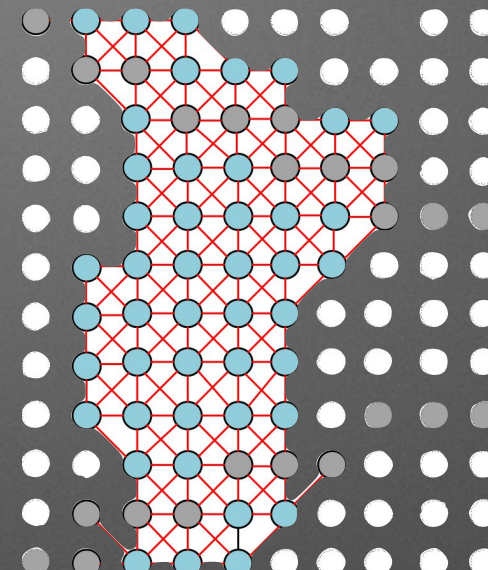


5 System Design

❖ Walkway identification



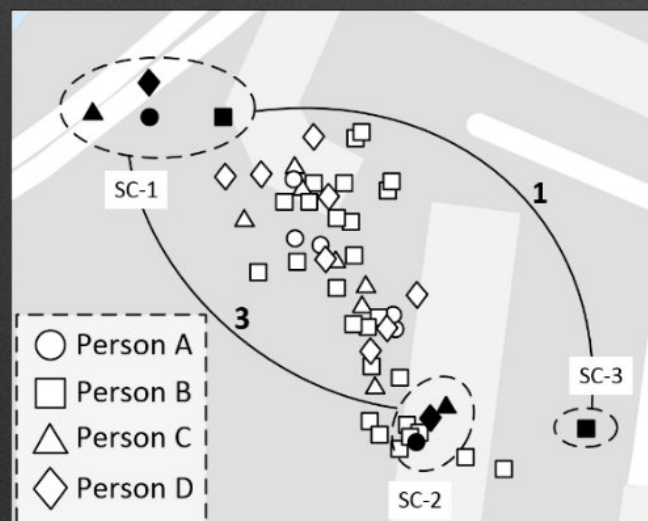
Score map



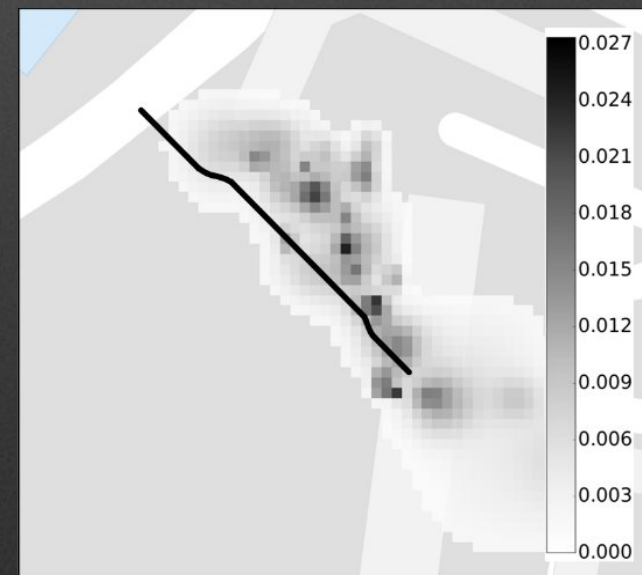
Weighted graph

node
weight
edge

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



Two-phase clustering



6 Evaluation

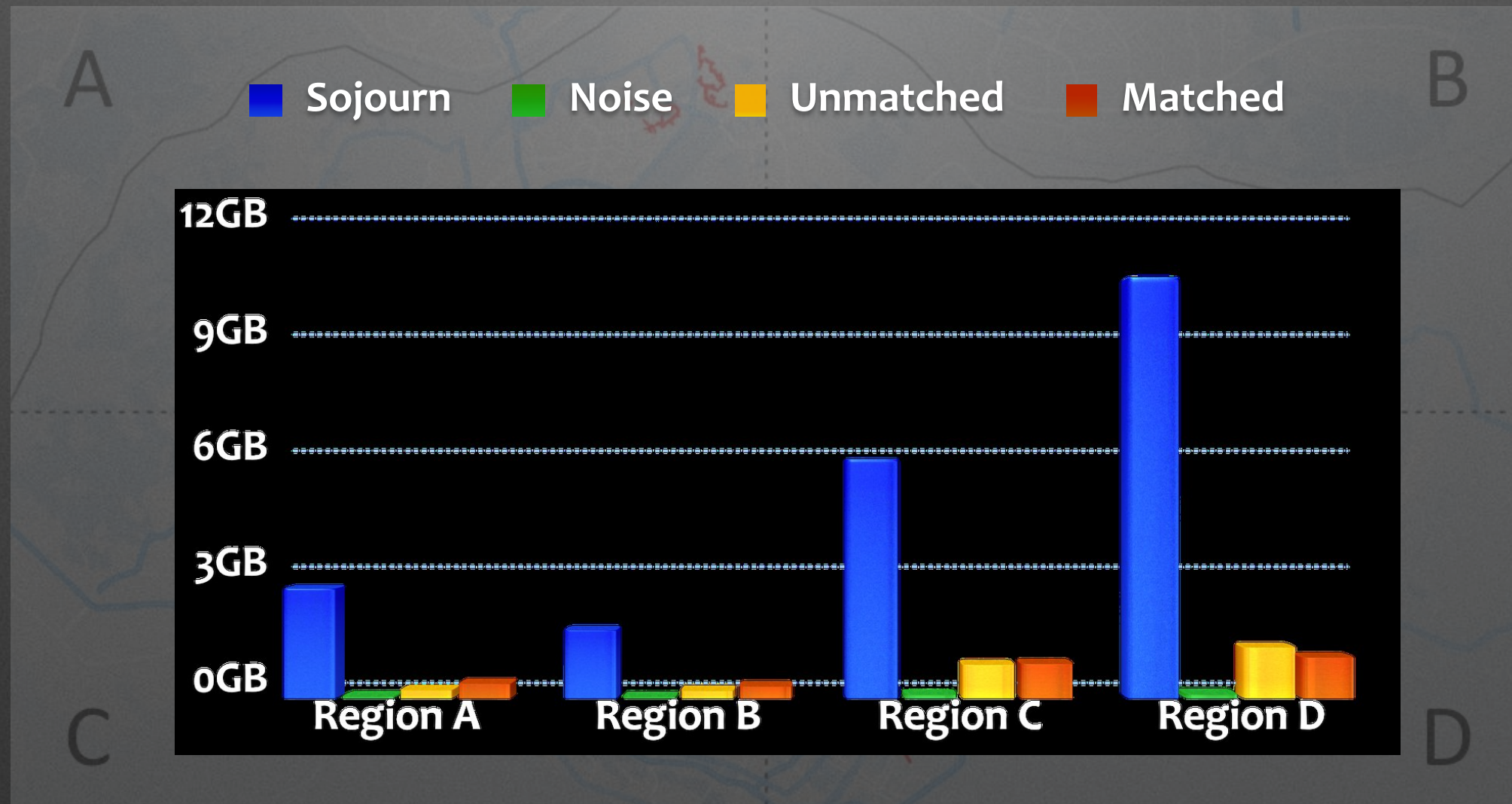
❖ Walkway discovery



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

6 Evaluation

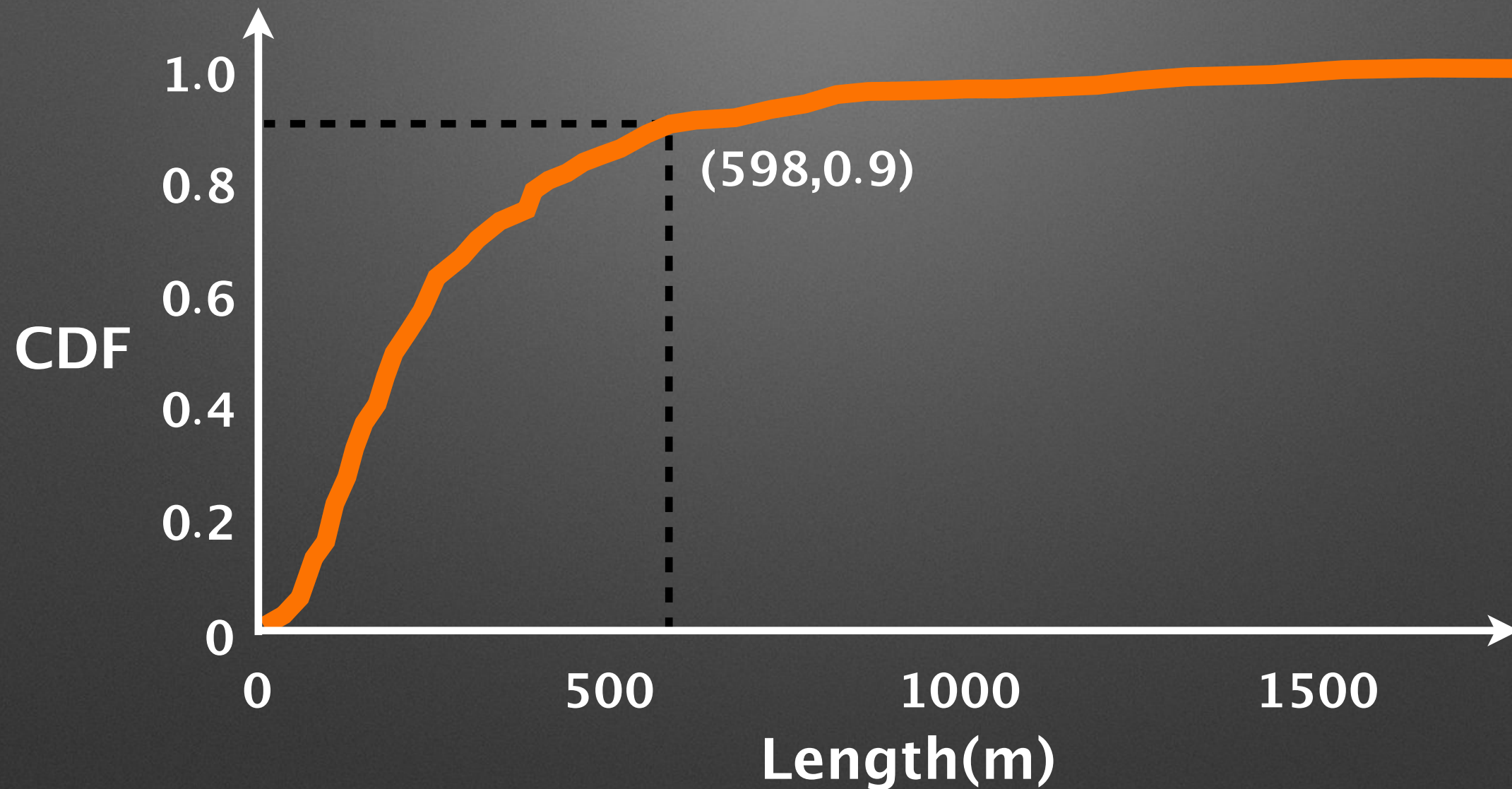
❖ Walkway discovery



- ◉ Region D contains most data more than 10G

6 Evaluation

❖ Walkway discovery

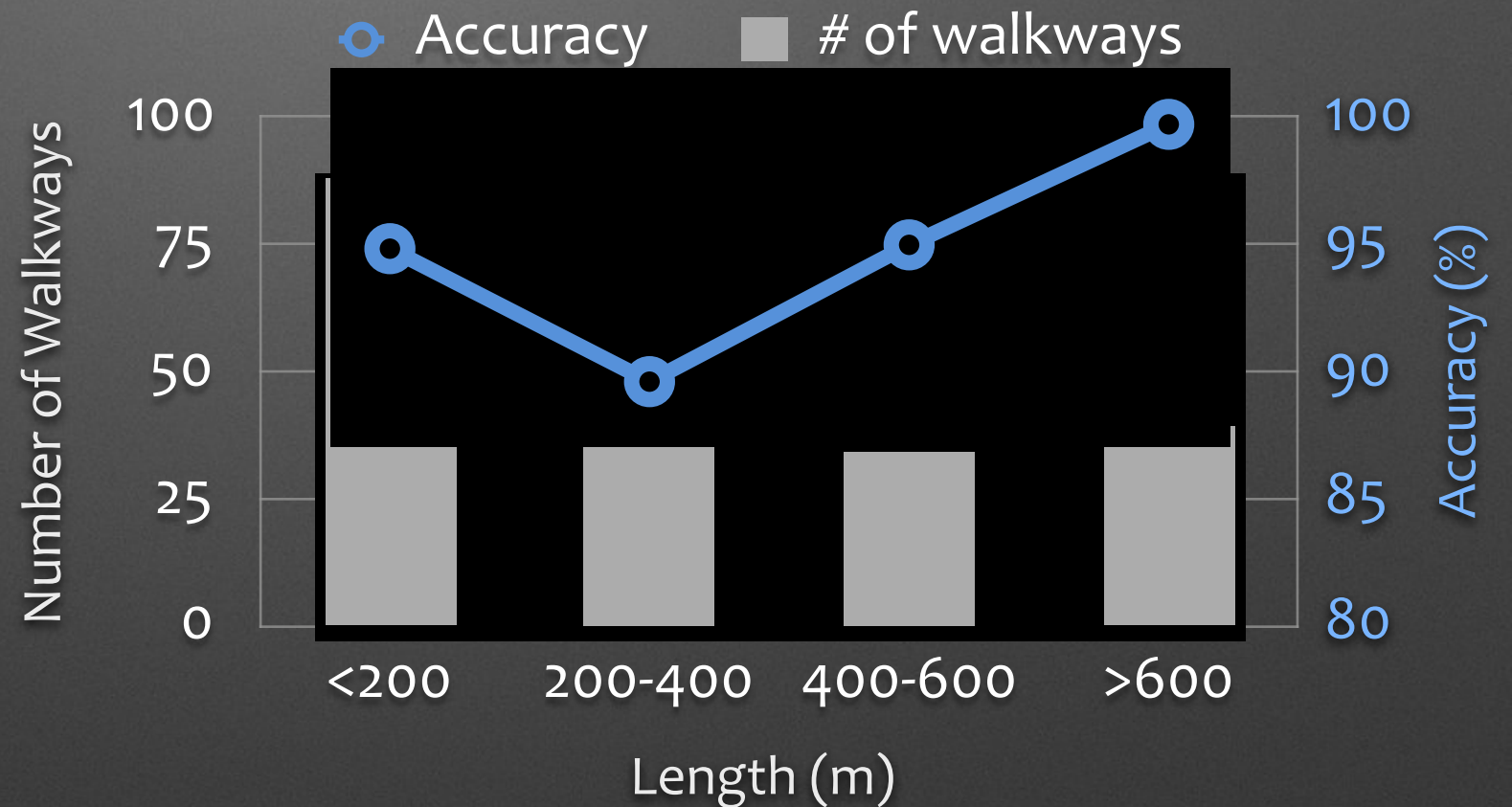
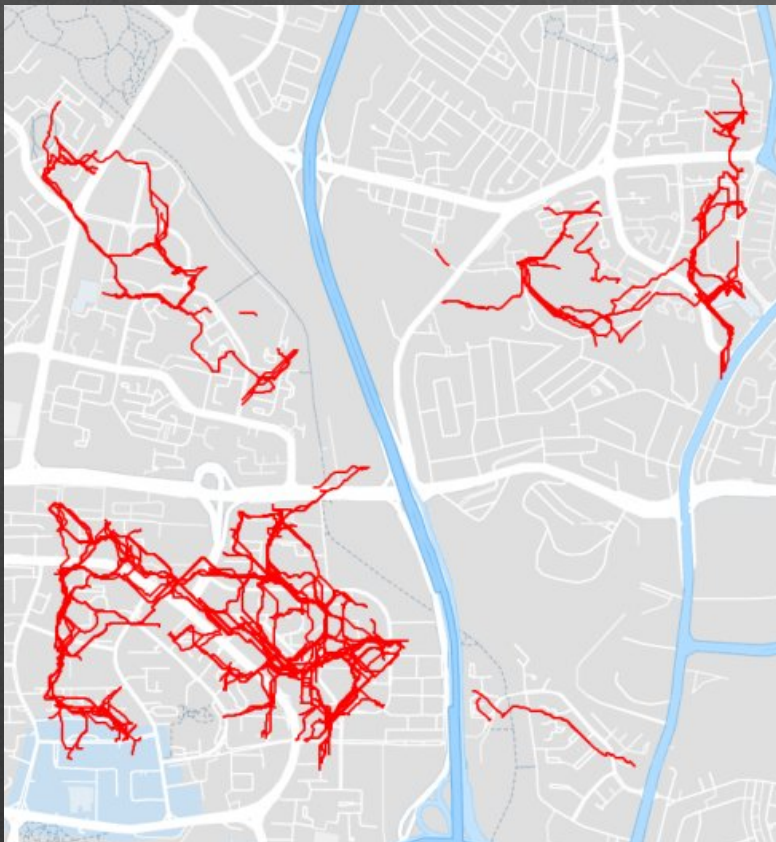


- ◉ The lengths of 90% of the walkways are shorter than 598m.

6 Evaluation

❖ Site-inspection

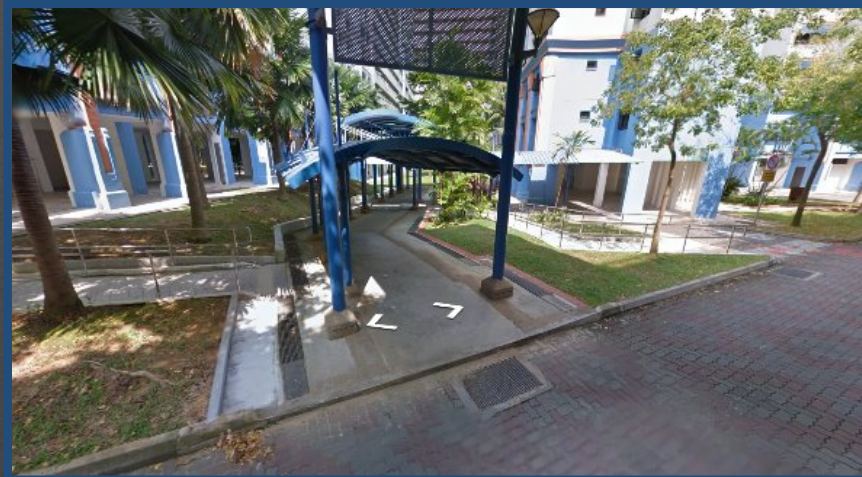
$$accuracy = \frac{N_{true \cap new}}{N_{new}}$$



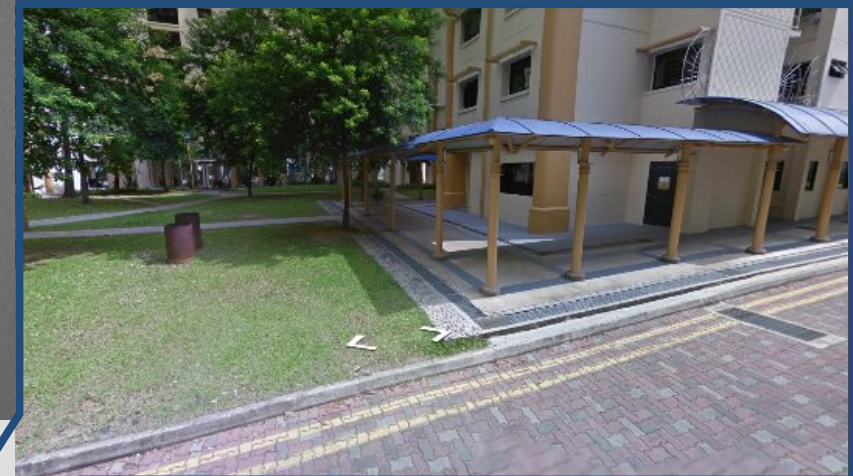
- ◉ 224 walkways are manually checked.
- ◉ The accuracy of 200–400 group is 89%.

6 Evaluation

❖ Example of new found walkways



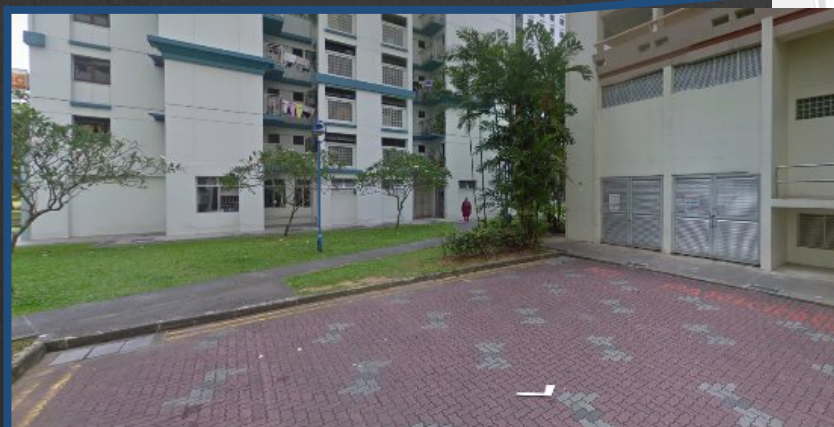
In residential area



Under HDB



Between buildings



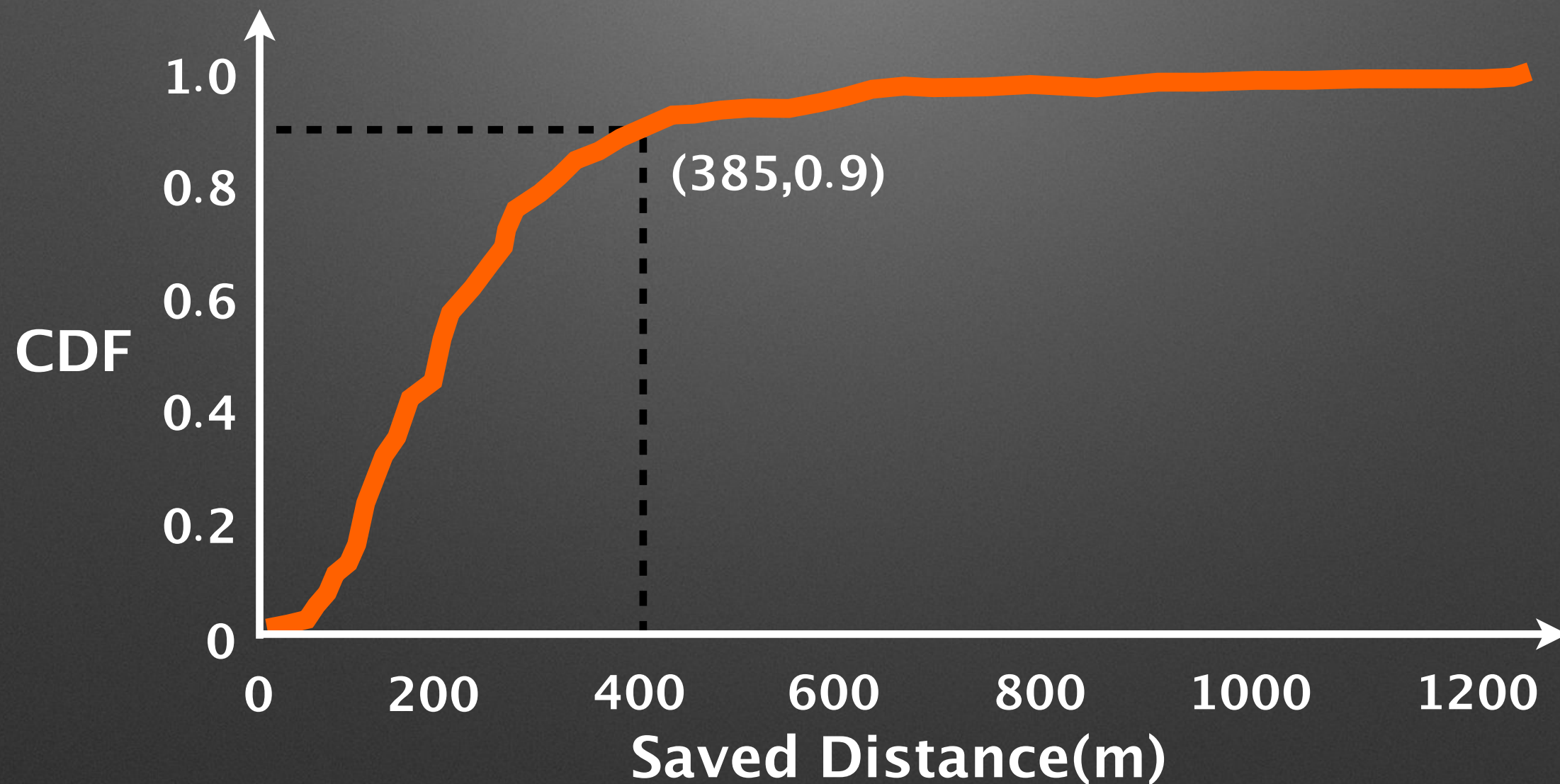
On grassland



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



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



One More Thing

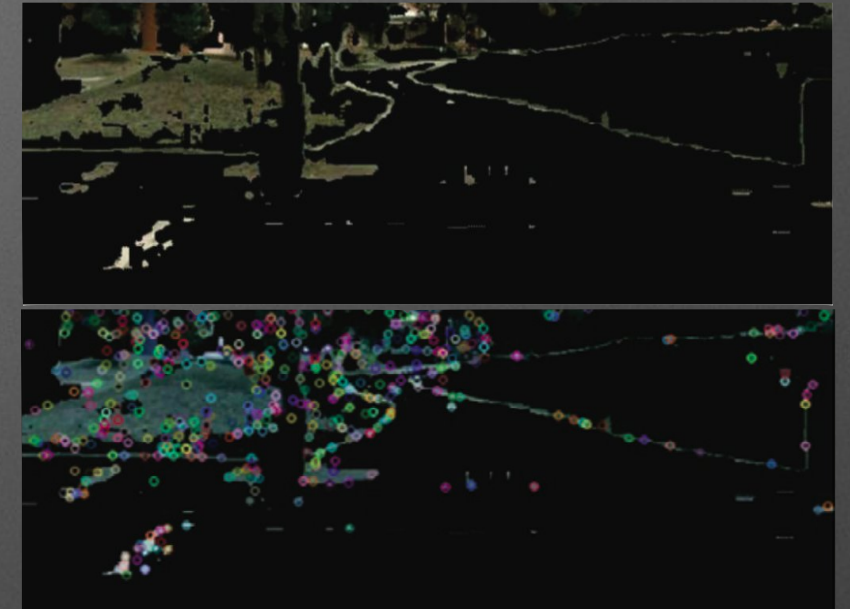
❖ Auto-Verification



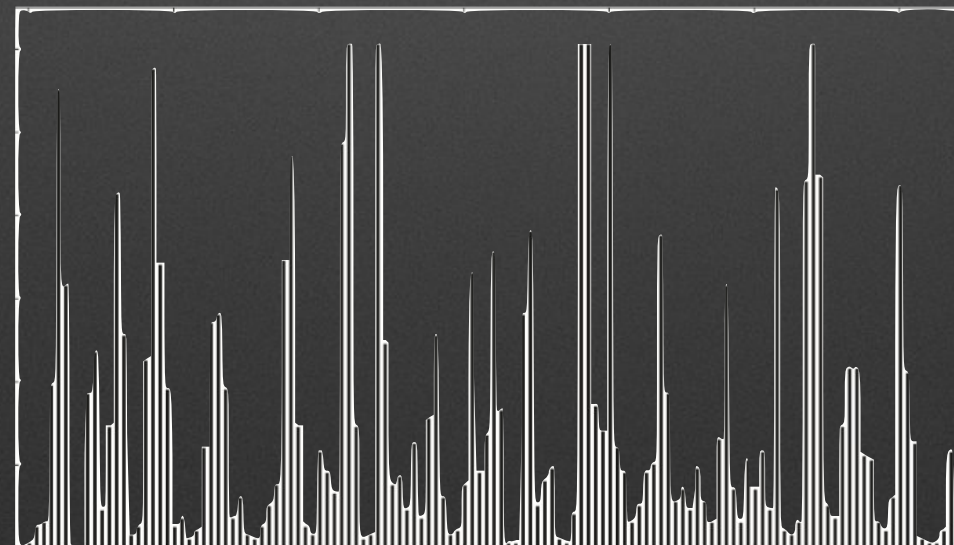
Walkway



Google Street View



Features



One More Thing

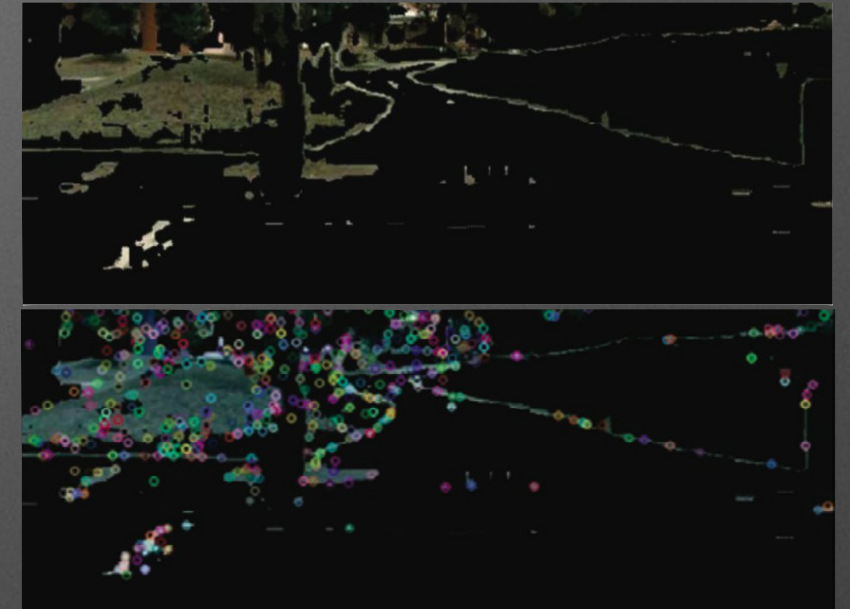
❖ Auto-Verification



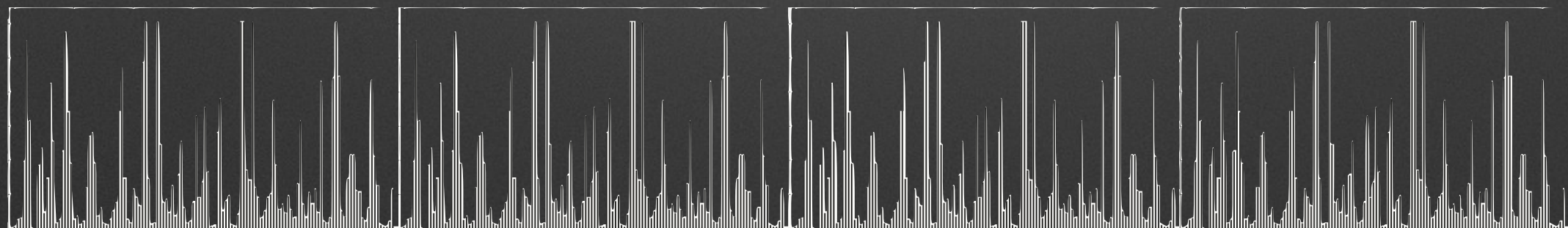
Walkway



Google Street View

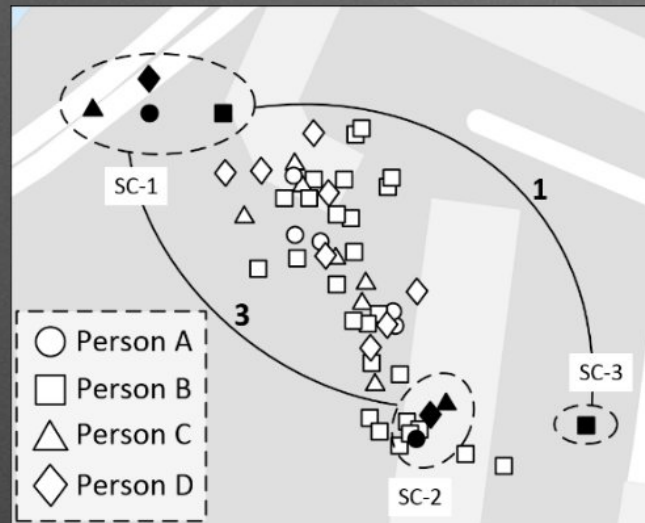


Features



One More Thing

❖ Effect of Auto-Verification on accuracy



Two-phase clustering

- support of $\langle \text{SC-1}, \text{SC-2} \rangle$ is **3**
- support of $\langle \text{SC-1}, \text{SC-3} \rangle$ 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.



Q & A

Thank you very much.

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