Inferring Maps from GPS Data

1. Why infer maps from GPS traces?
2. Biagioni/Eriksson algorithm
3. Evaluation metrics
4. Similar approaches: satellite images, map update
5. Lab 4

Map making

Uber is planning on investing $500 million to map the world's roads

This will reduce Uber's reliance on Google Maps

by Andrew Liptak | @AndrewLiptak | Jul 31, 2016, 5:54pm EDT

Will Your Next New Car Help Build Maps for Self-Driving?

Mobileye will use cameras on a growing list of automakers' cars to build maps for self-driving vehicles.

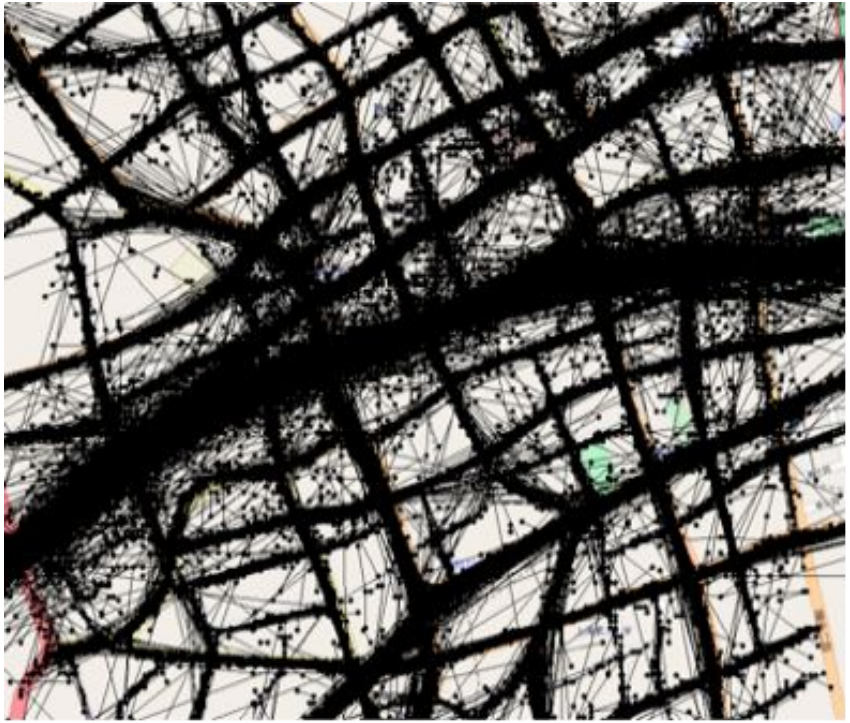
Why Ford Motor Is Investing in 3D Mapping Startup Civil Maps

Tencent, partners invest in HERE's digital maps to get a leg up on self-driving cars

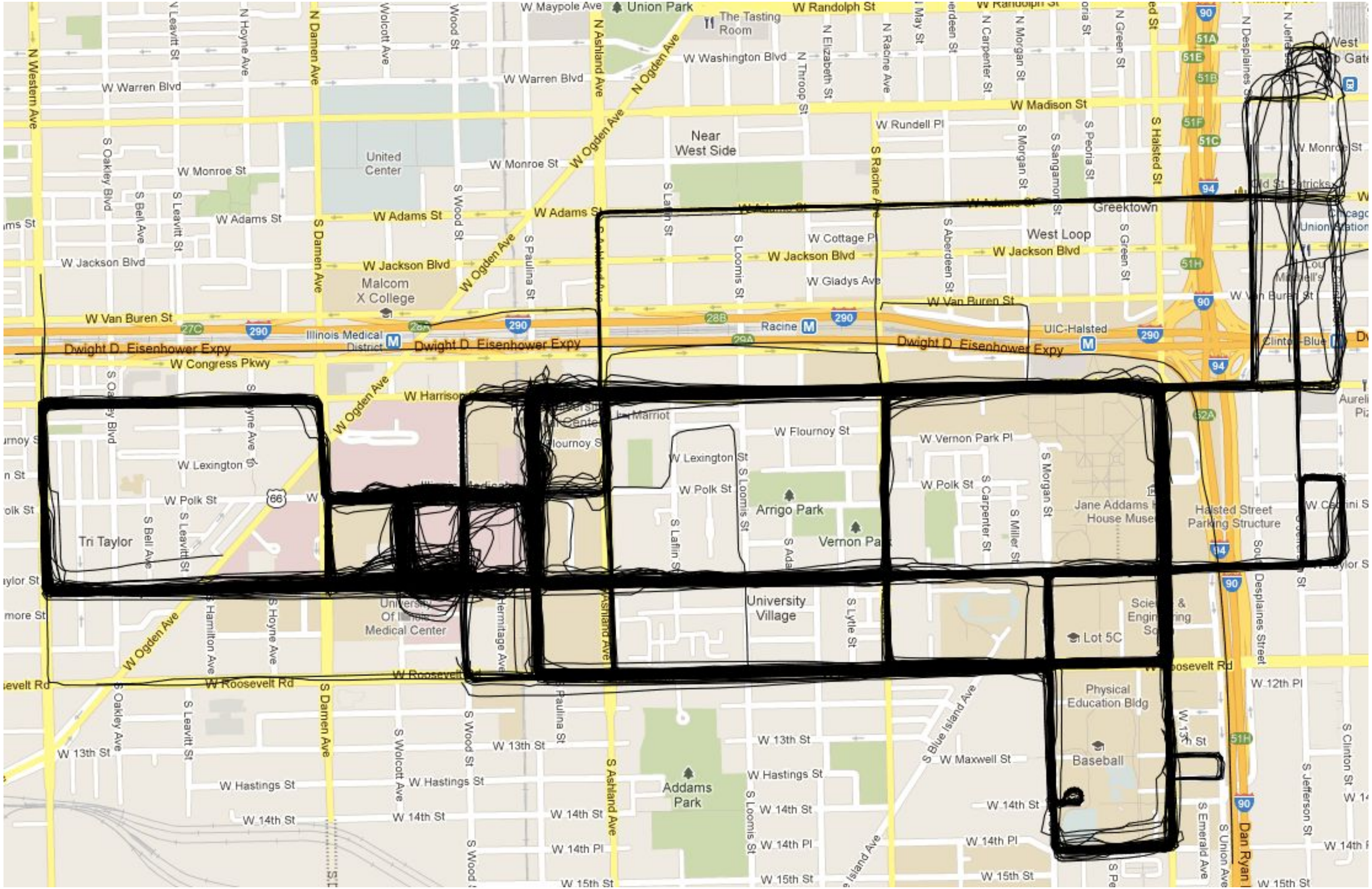
OpenStreetMap

- Licensed under Open Data Commons Open Database License
- Built using several data sources:
  - U.S. Census Bureau’s TIGER data
  - GPS traces
  - Aerial images
- Humans process traces and images to update the map
- Decent coverage in large cities where there are many contributors, but often inaccurate or incomplete elsewhere

Opportunistic data collection



GPS traces, e.g., from smartphone apps, taxis, etc



W Maypole Ave
Union Park
W Randolph St
The Tasting Room
W Washington Blvd
W Warren Blvd
W Madison St
W Rundell Pl
Near West Side
United Center
W Monroe St
W Adams St
Greektown
West Loop
W Cottage Pl
W Jackson Blvd
W Gladys Ave
W Van Buren St
Malcom X College
Illinois Medical District
Racine
UIC-Halsted
Dwight D. Eisenhower Expy
W Congress Pkwy
W Harrison St
W Flournoy St
W Vernon Park Pl
W Lexington St
W Polk St
Arrigo Park
Vernon Park
Tri Taylor
Jane Addams Hull-House Museum
Halsted Street Parking Structure
University Village
University Of Illinois Medical Center
Lot 5C
W Roosevelt Rd
Physical Education Bldg
Baseball
W 13th St
W Maxwell St
W Hastings St
Addams Park
W 14th St
W 14th Pl
W 15th St
N Western Ave
N Damen Ave
S Damen Ave
N Ashland Ave
S Ashland Ave
N Ogden Ave
W Ogden Ave
S Racine Ave
S Halsted St
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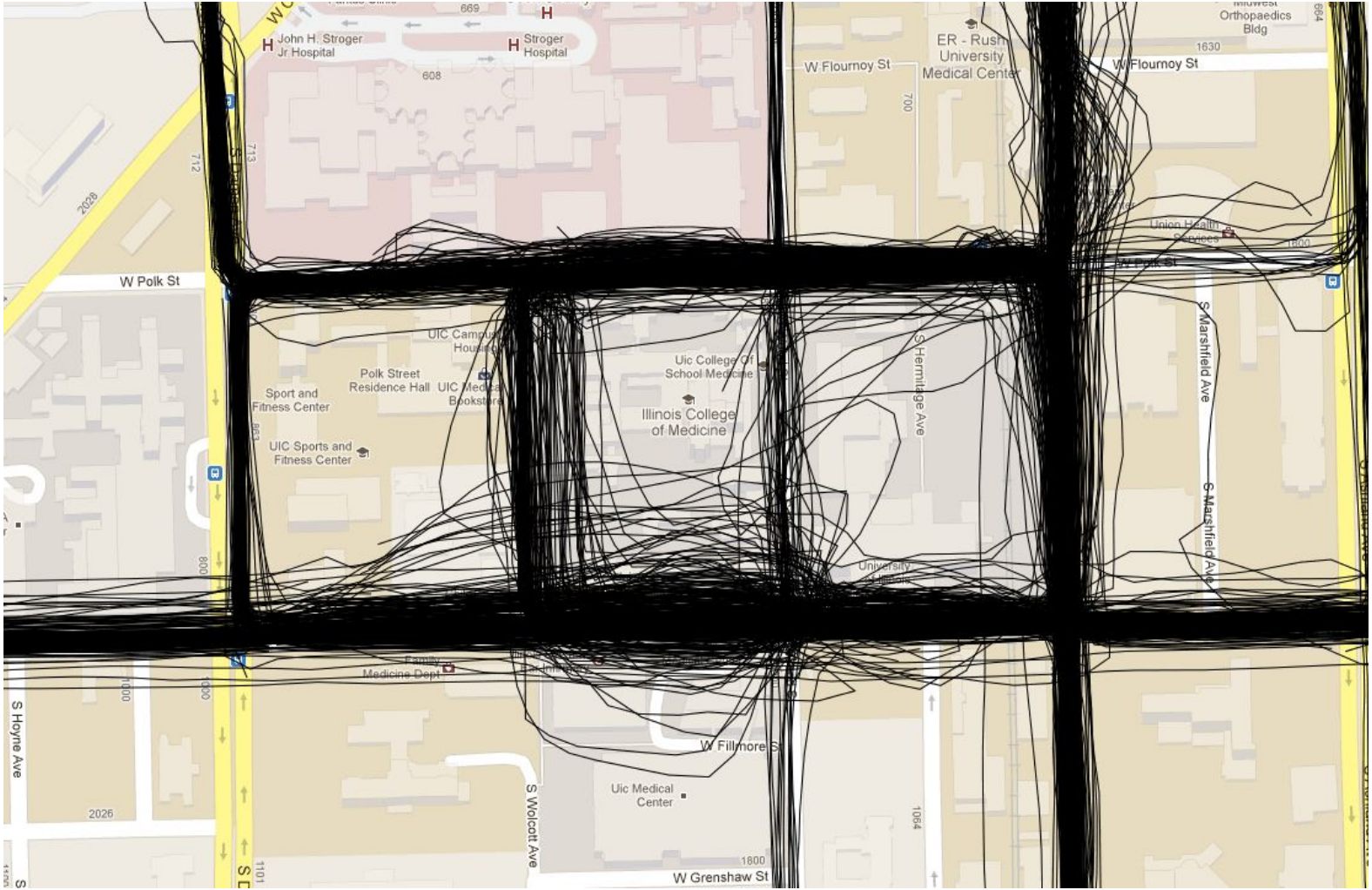
S Oakley Blvd
S Leavitt St
S Desplaines Street
S Blue Island Ave
Dan Ryan Expy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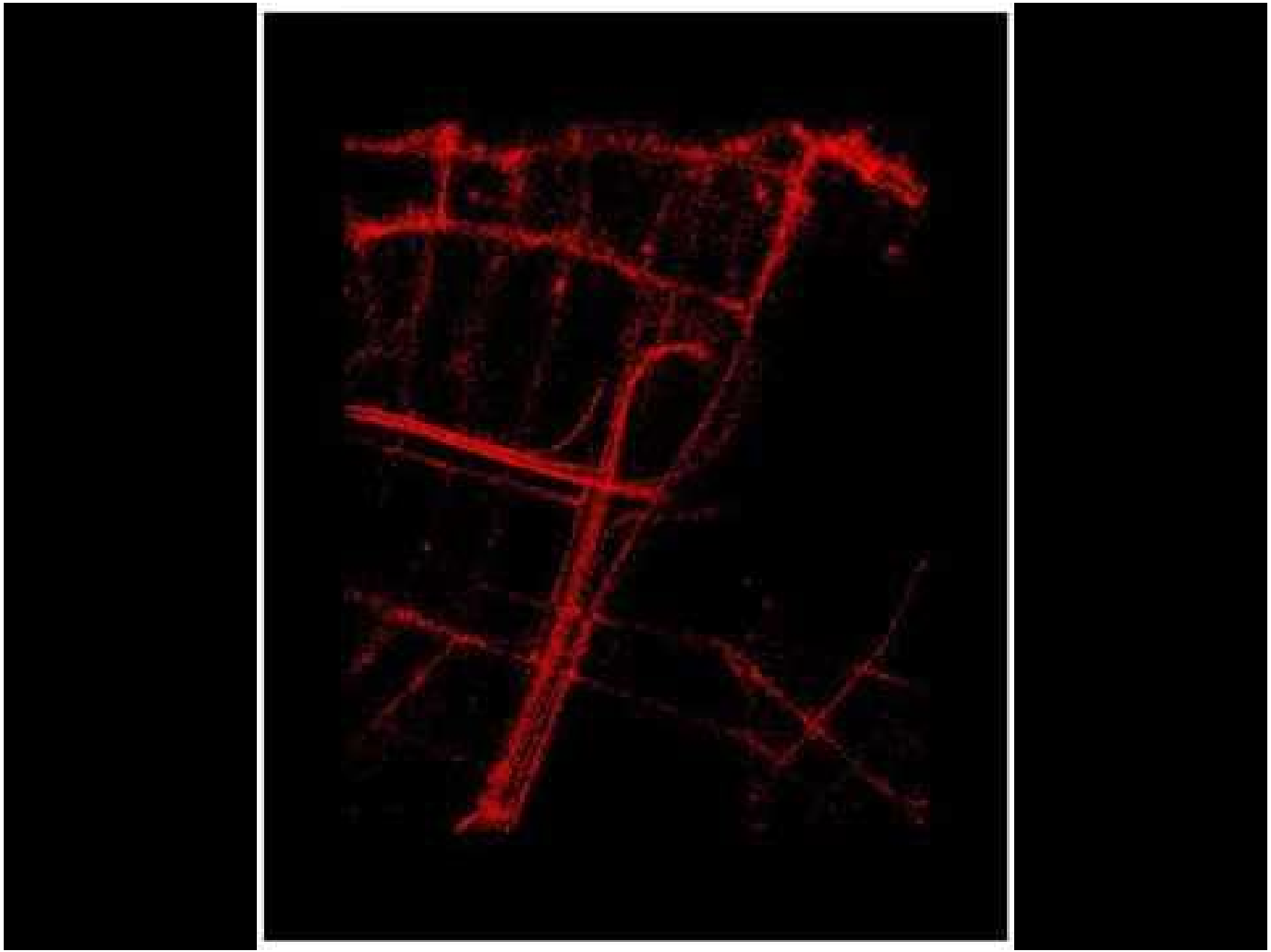
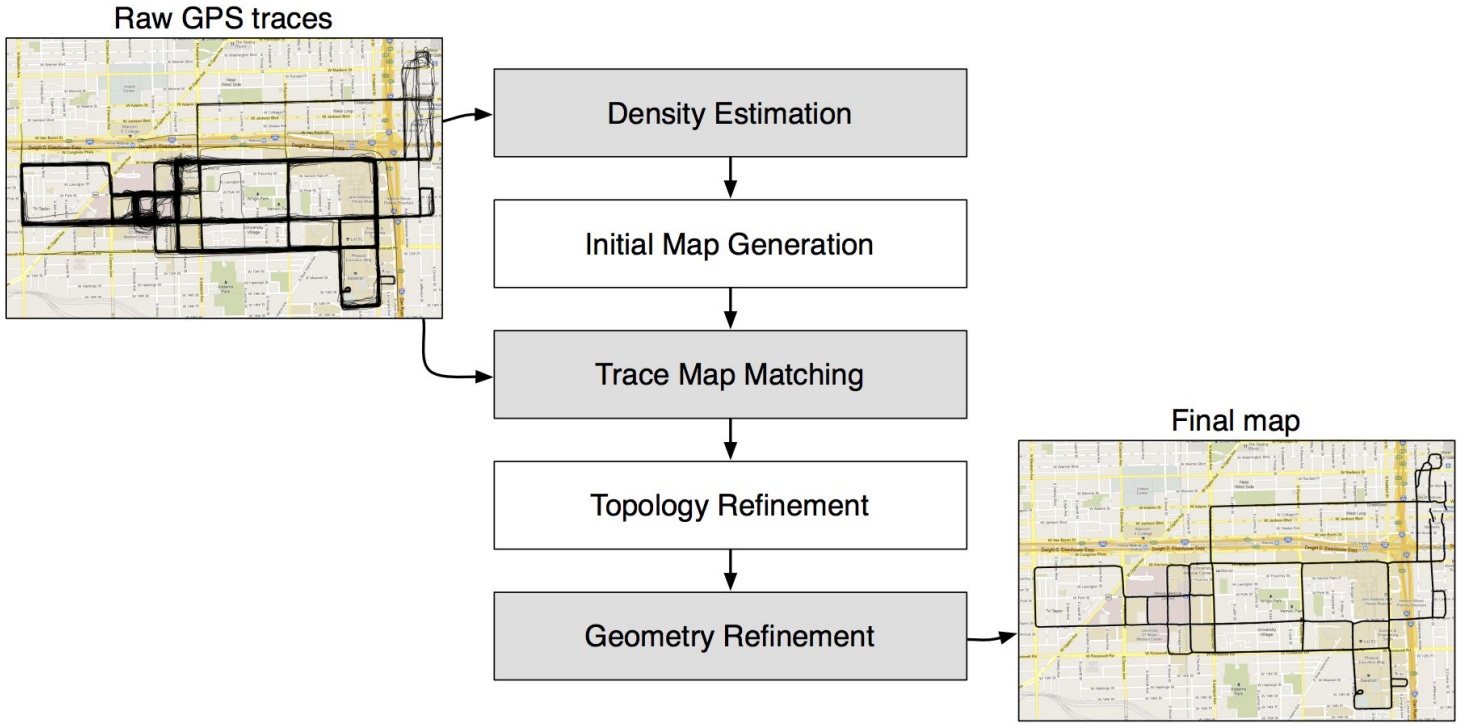
Stroger Hospital
ER - Rush University Medical Center
Midwest Orthopaedics Bldg
W Flournoy St
W Polk St
W Fillmore St
W Grenshaw St
Union Health Services
Polk Street Residence Hall
UIC Campus Housing
UIC Medical Bookstore
Sport and Fitness Center
UIC Sports and Fitness Center
Uic College Of School Medicine
Illinois College of Medicine
Family Medicine Dept
Uic Medical Center
S Hermitage Ave
S Marshfield Ave
S Hoyne Ave
S Wolcott Ave
University

Challenges

- GPS errors
- Sparsity of data
- Differential sampling rate (1s, 10s, 1m)
- Urban Canyons
- Complex intersections such as roundabouts, highway intersections



Map inference in the face of noise and disparity



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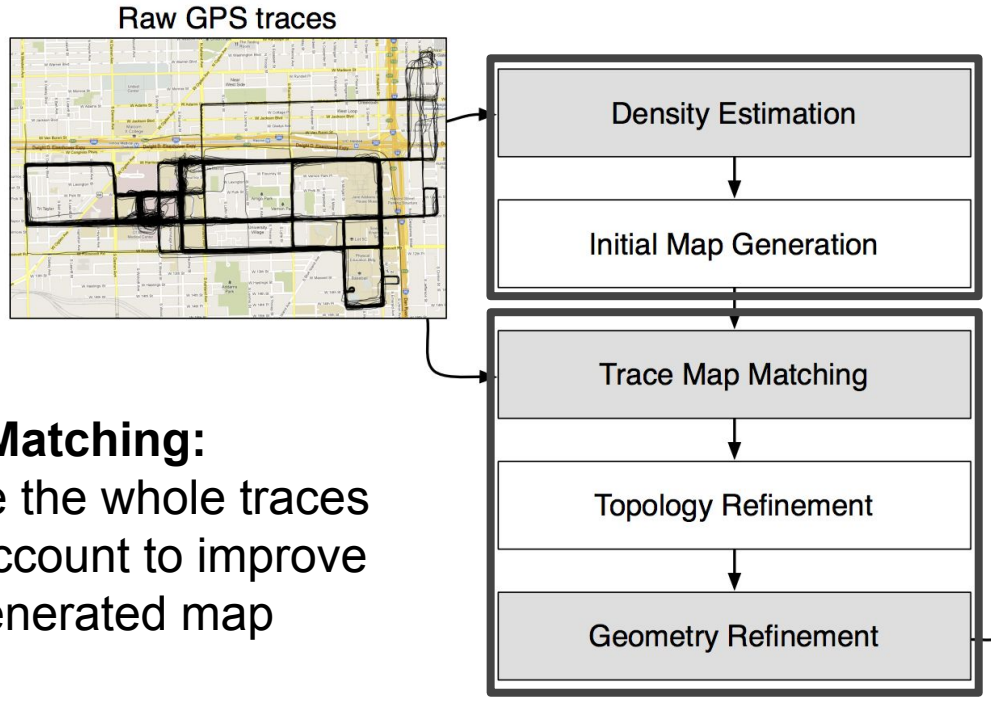
Map inference in the face of noise and disparity

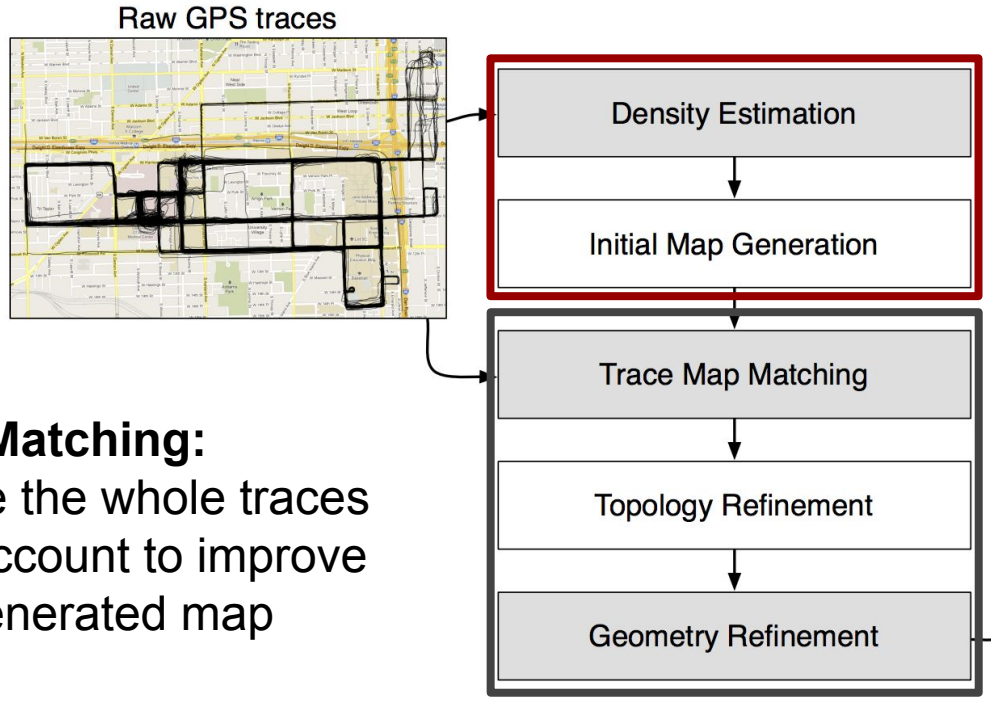


Gray-scale Skeletonization
- Cope with noise and disparity

Map Matching:
- Take the whole traces into account to improve the generated map

"*Map inference in the face of noise and disparity*." Biagioni, James, and Jakob Eriksson. *Proceedings of the 20th International Conference on Advances in Geographic Information Systems*. ACM, 2012.

Map inference in the face of noise and disparity



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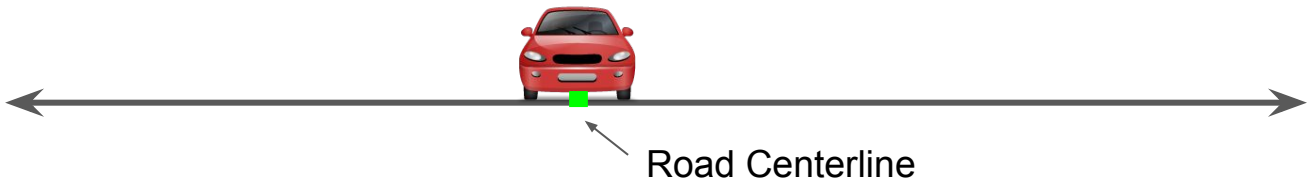
Density Estimation

- 1D Example
  - What does a density estimation based map-inference algorithm look like?
  - What is the problem with it?

Density Estimation

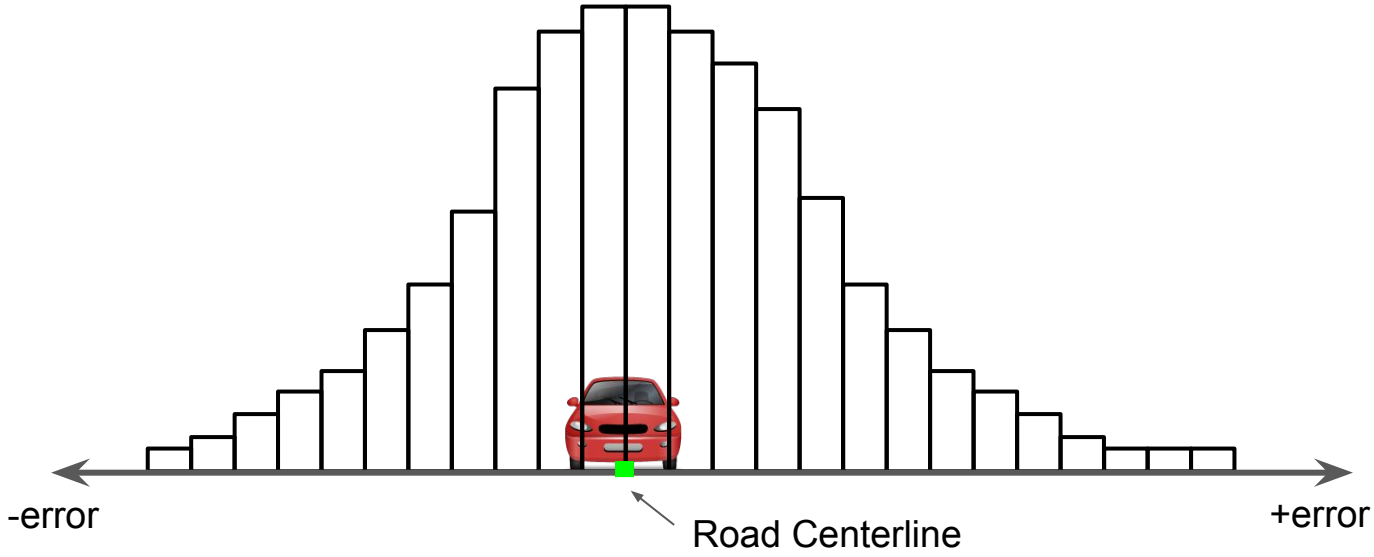
- 1D Example



Density Estimation

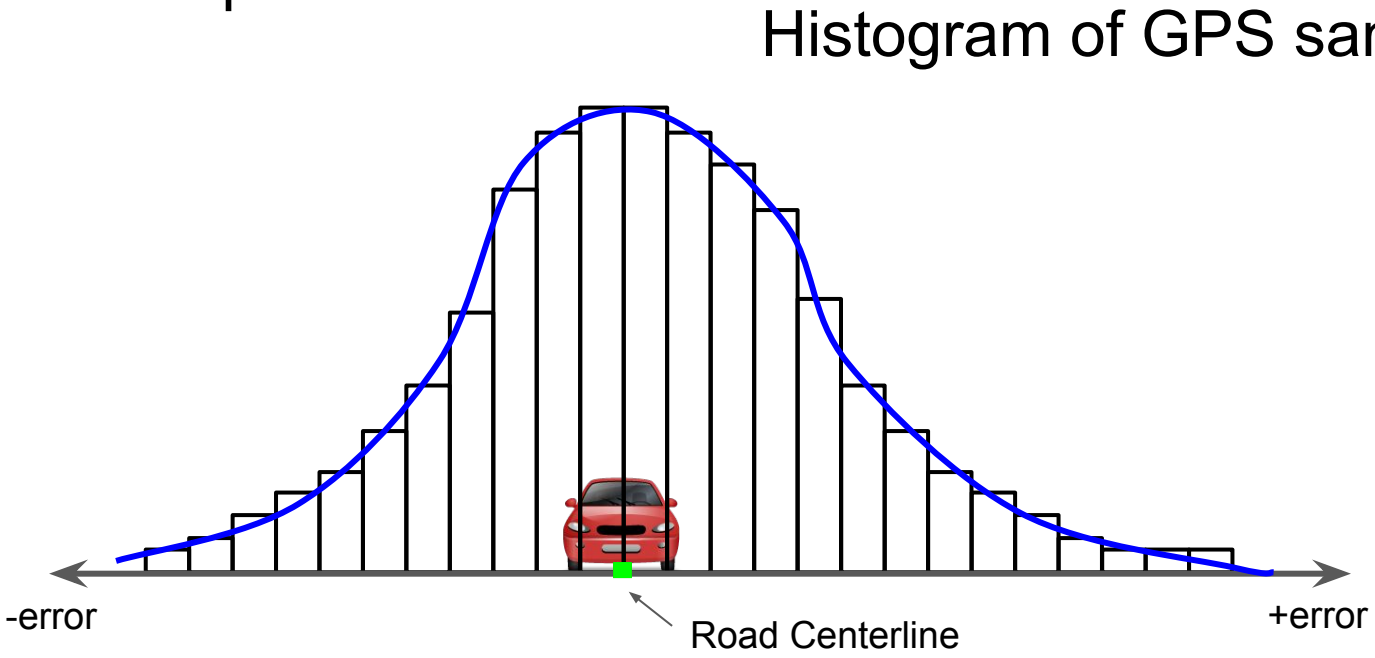
- 1D Example

Histogram of GPS samples



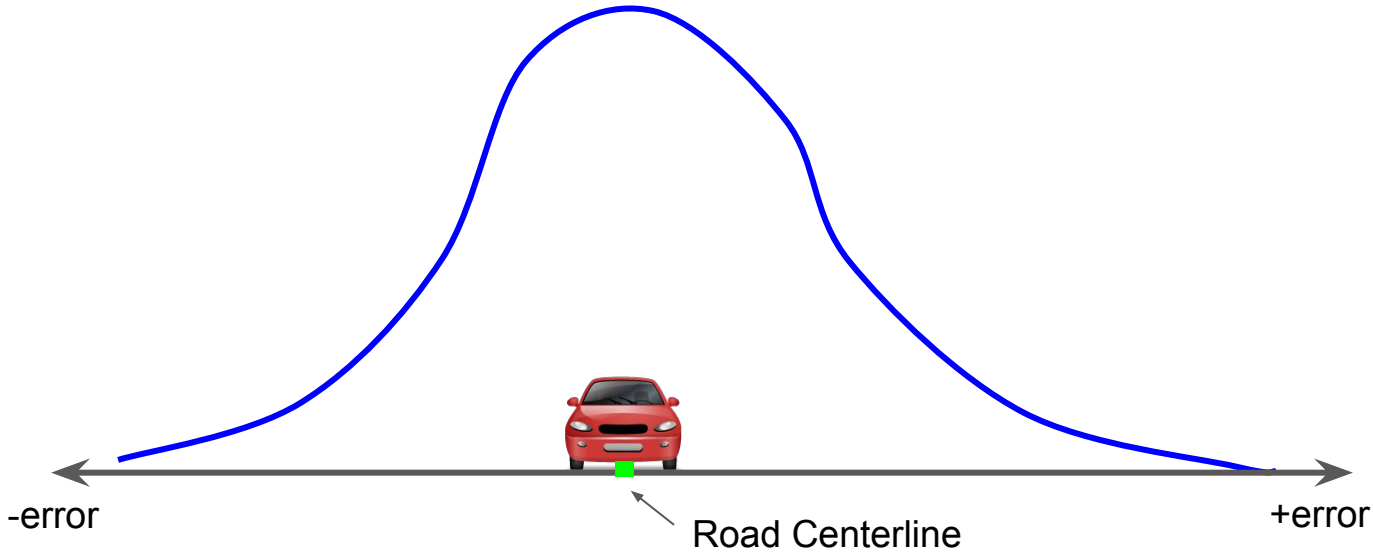
Density Estimation

- 1D Example



Density Estimation

- 1D Example



Density Estimation

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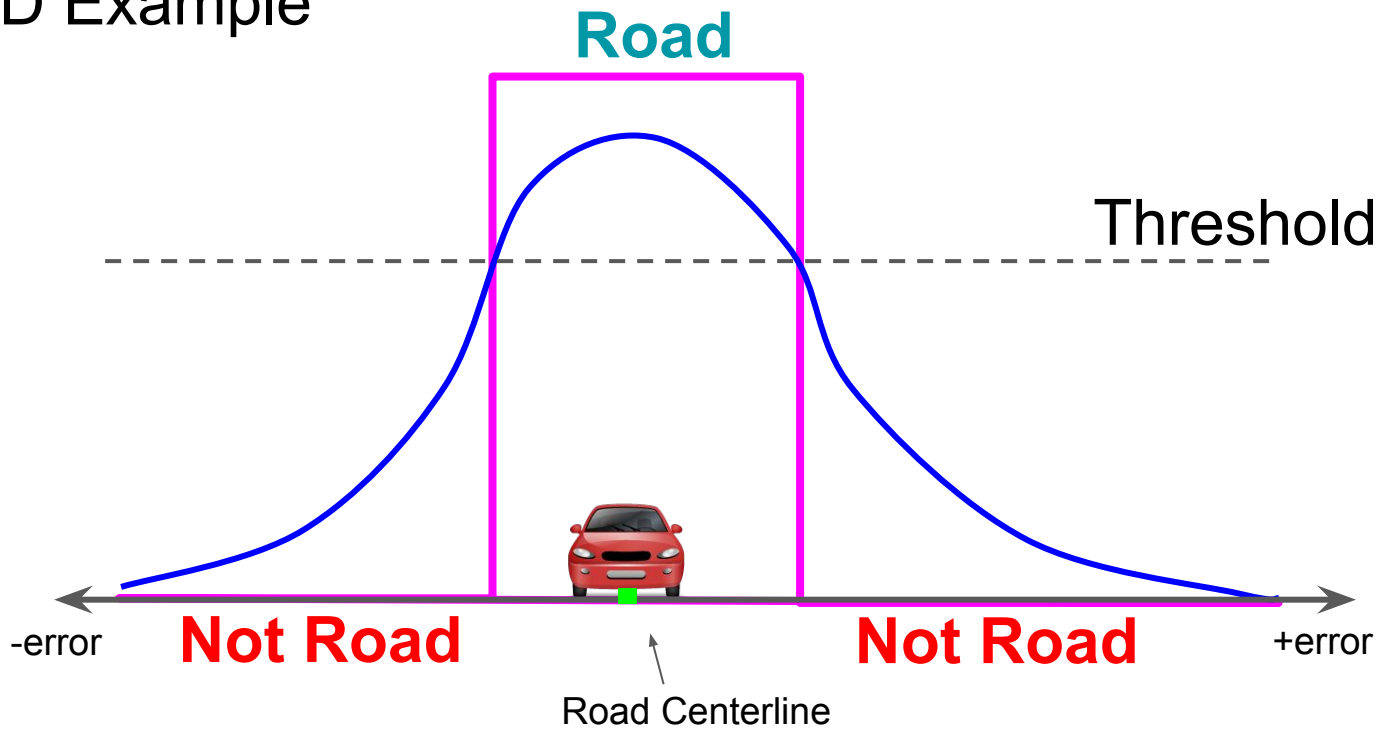
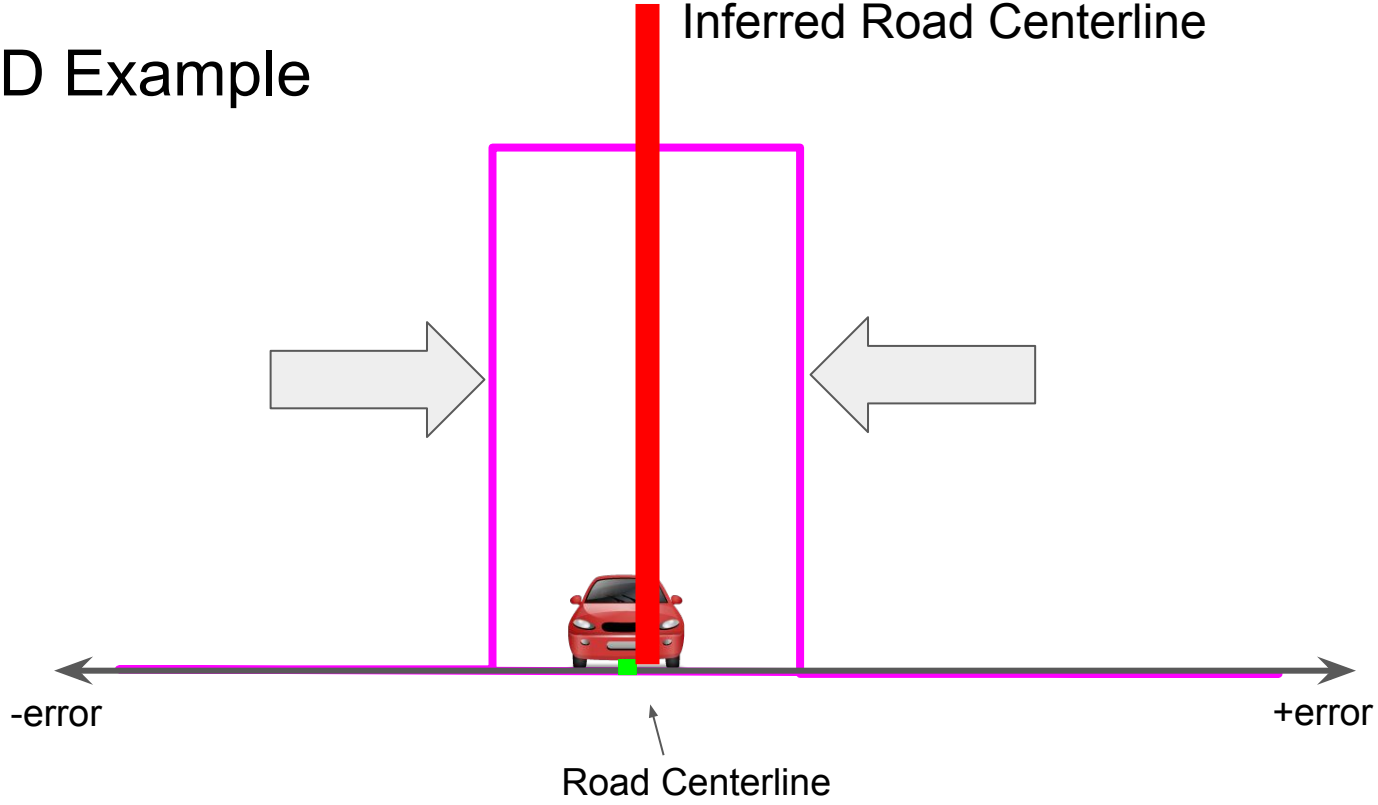


Density Estimation

- 1D Example

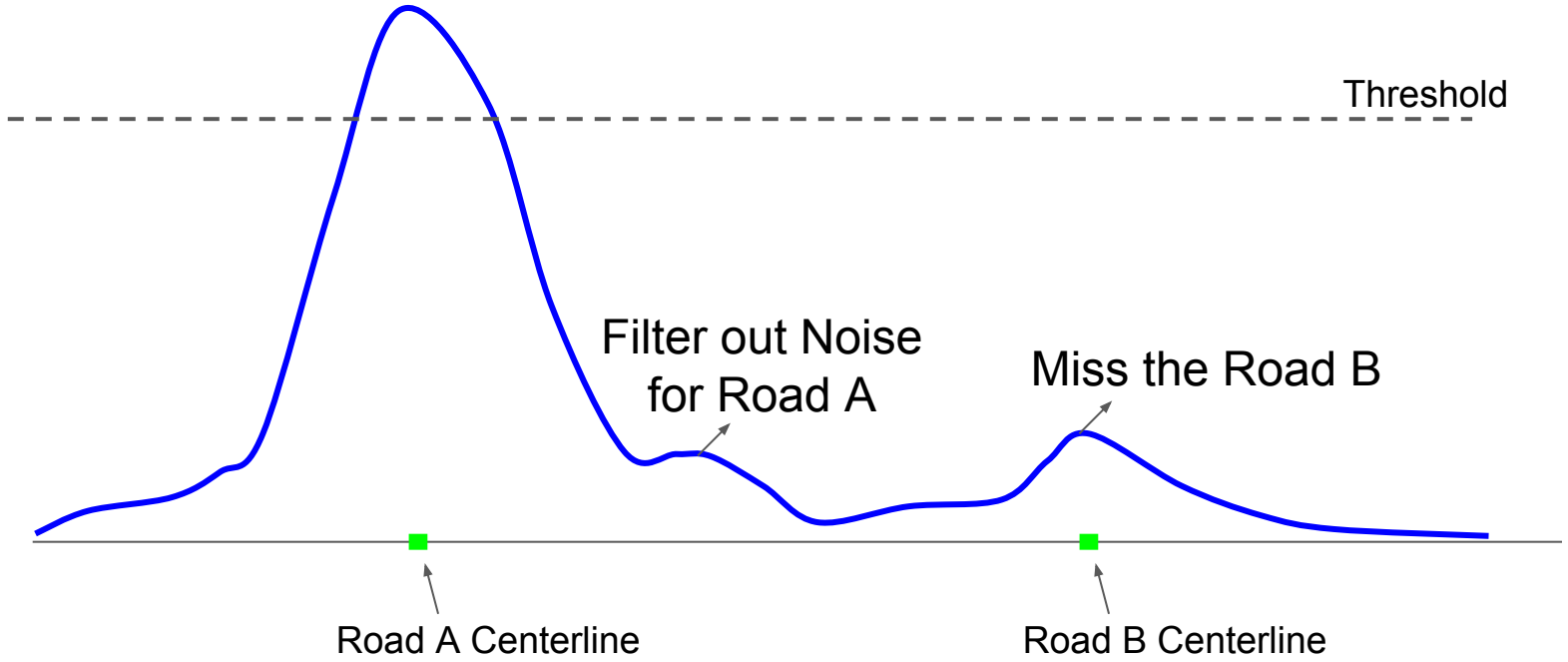


Density Estimation

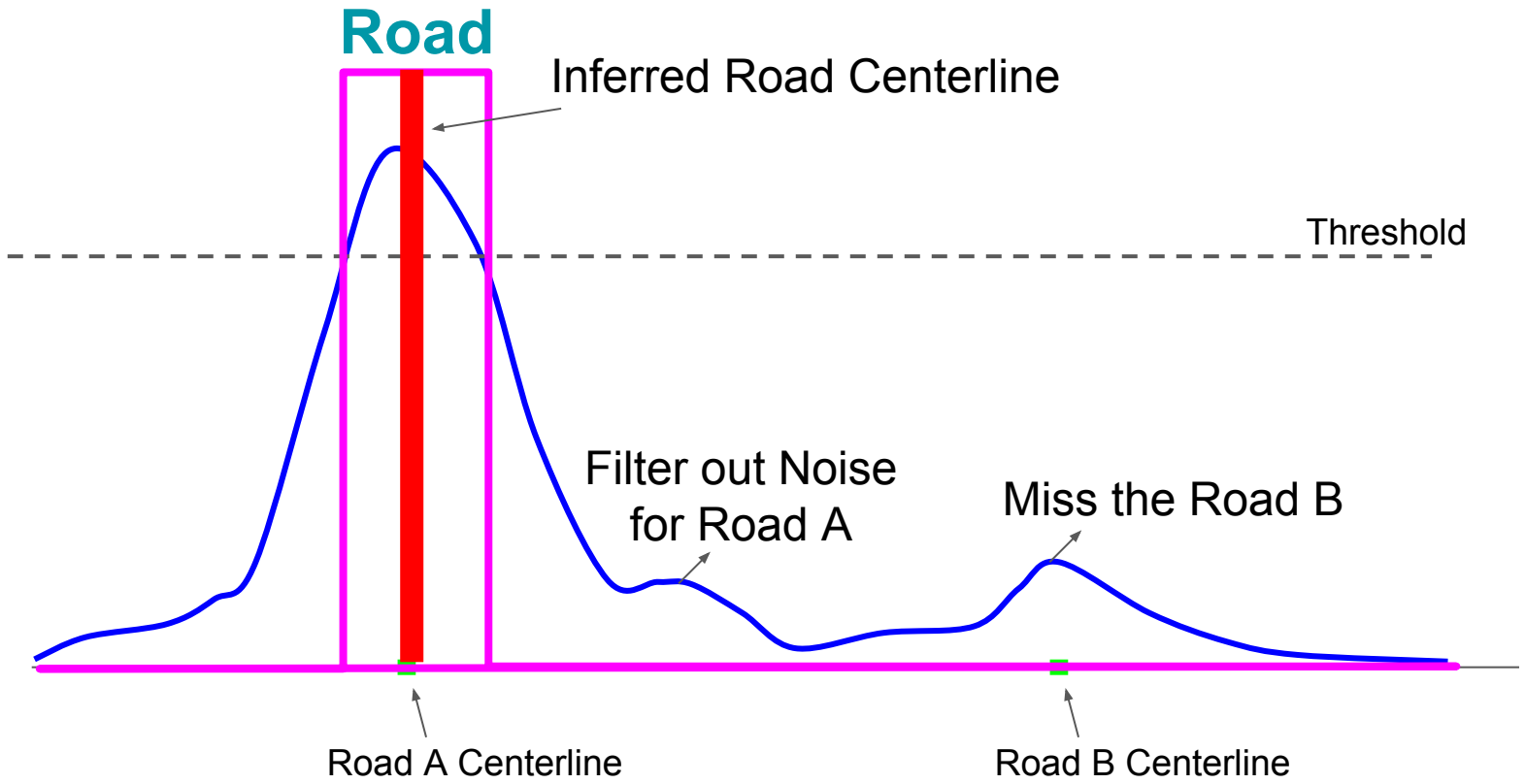
- 1D Example
  - What’s the problem with this algorithm?

Density Estimation

Single threshold doesn’t work well



Density Estimation



Density Estimation

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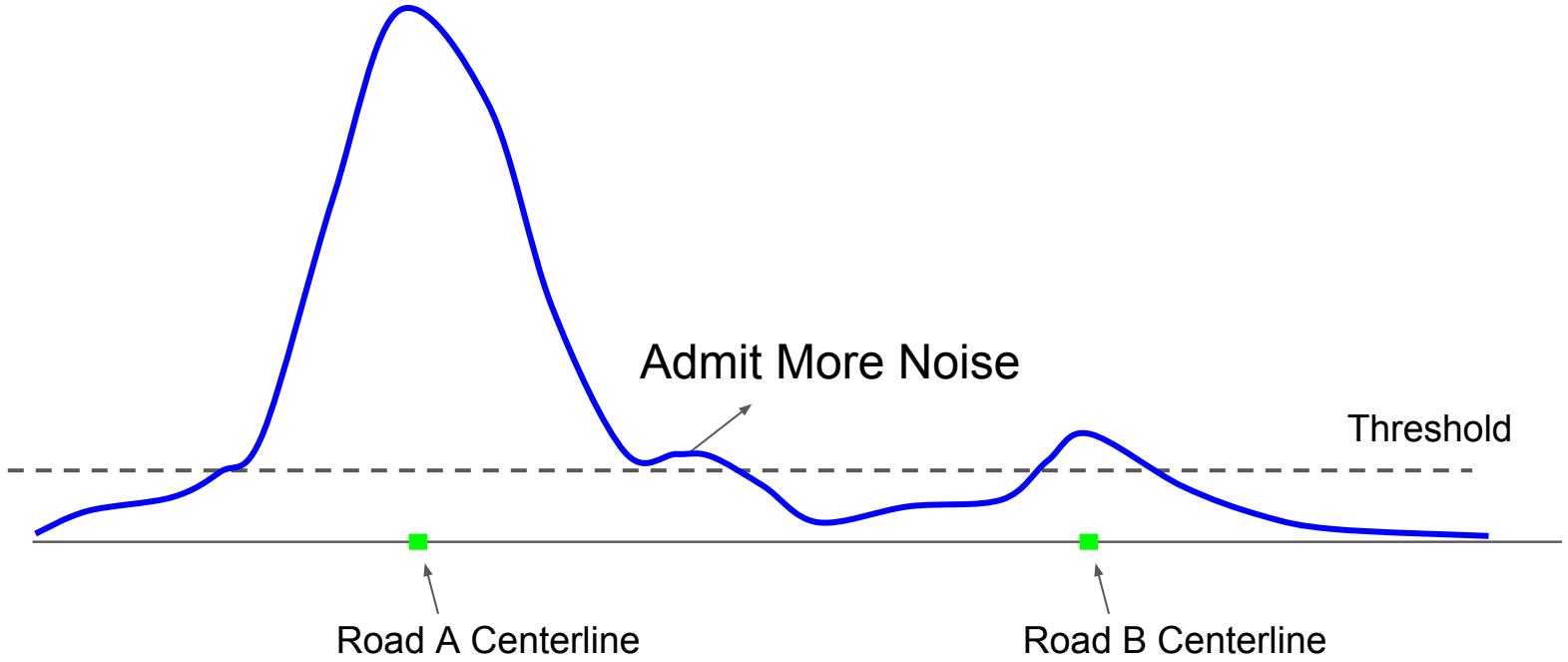

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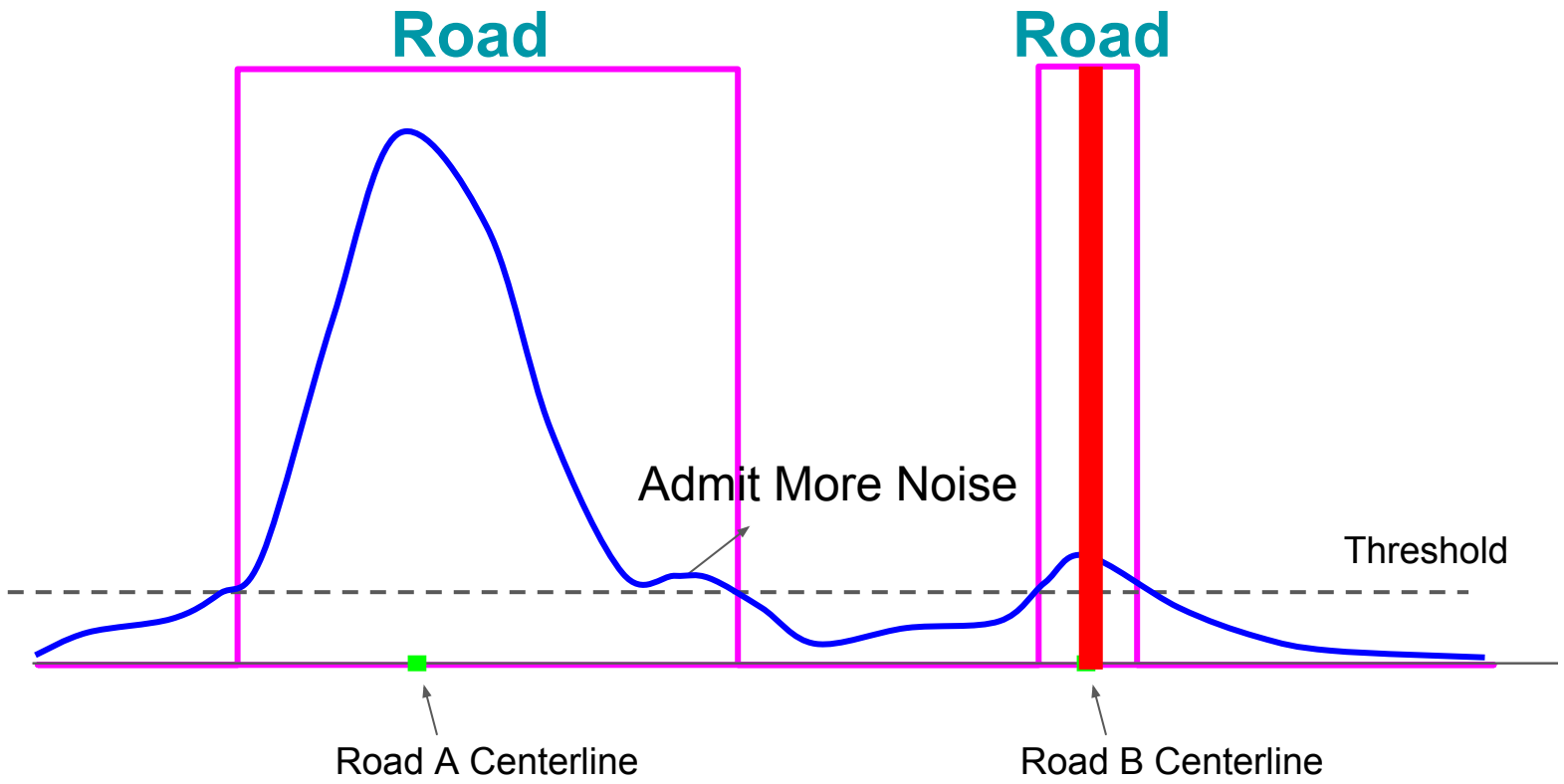

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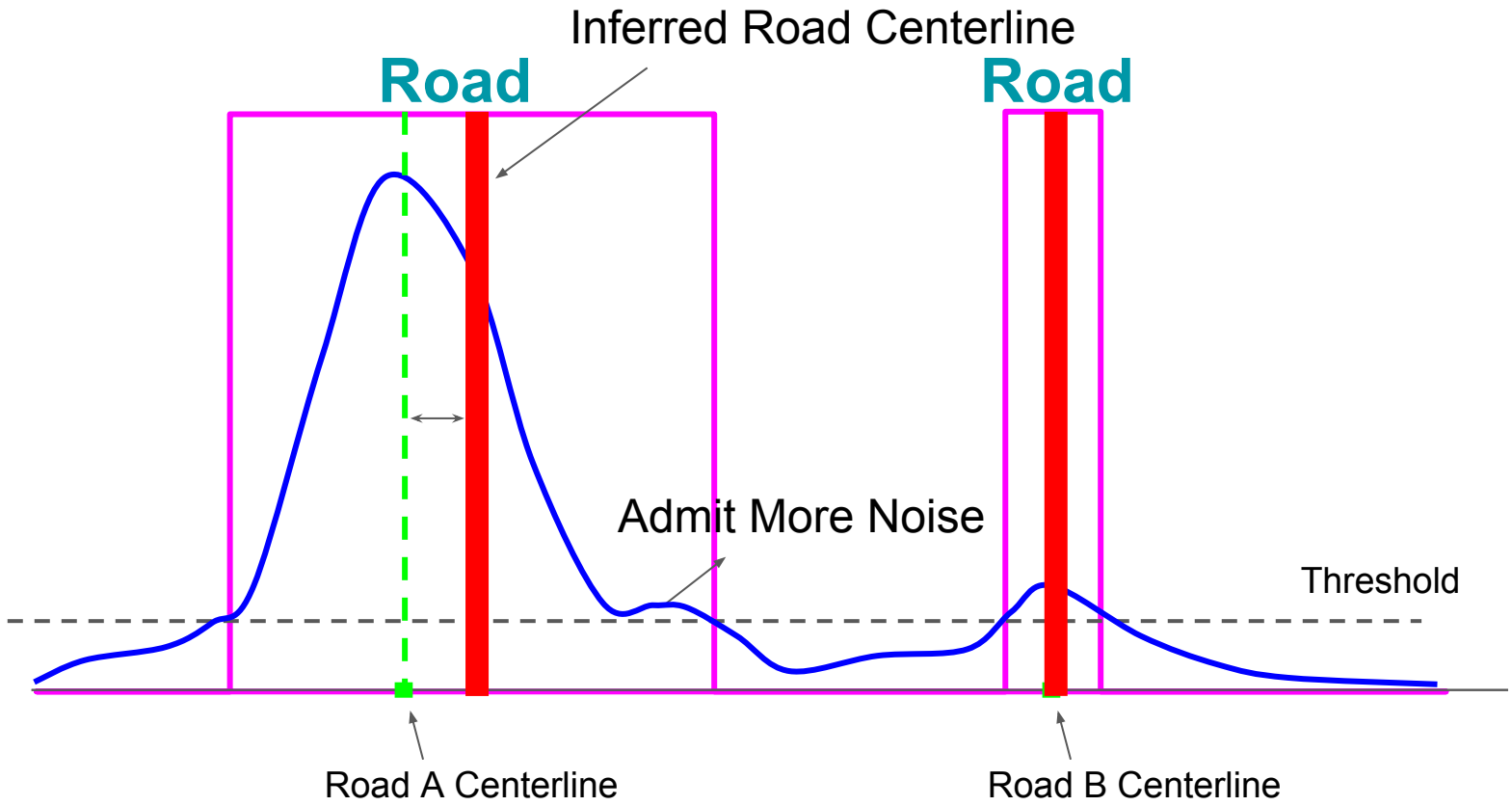

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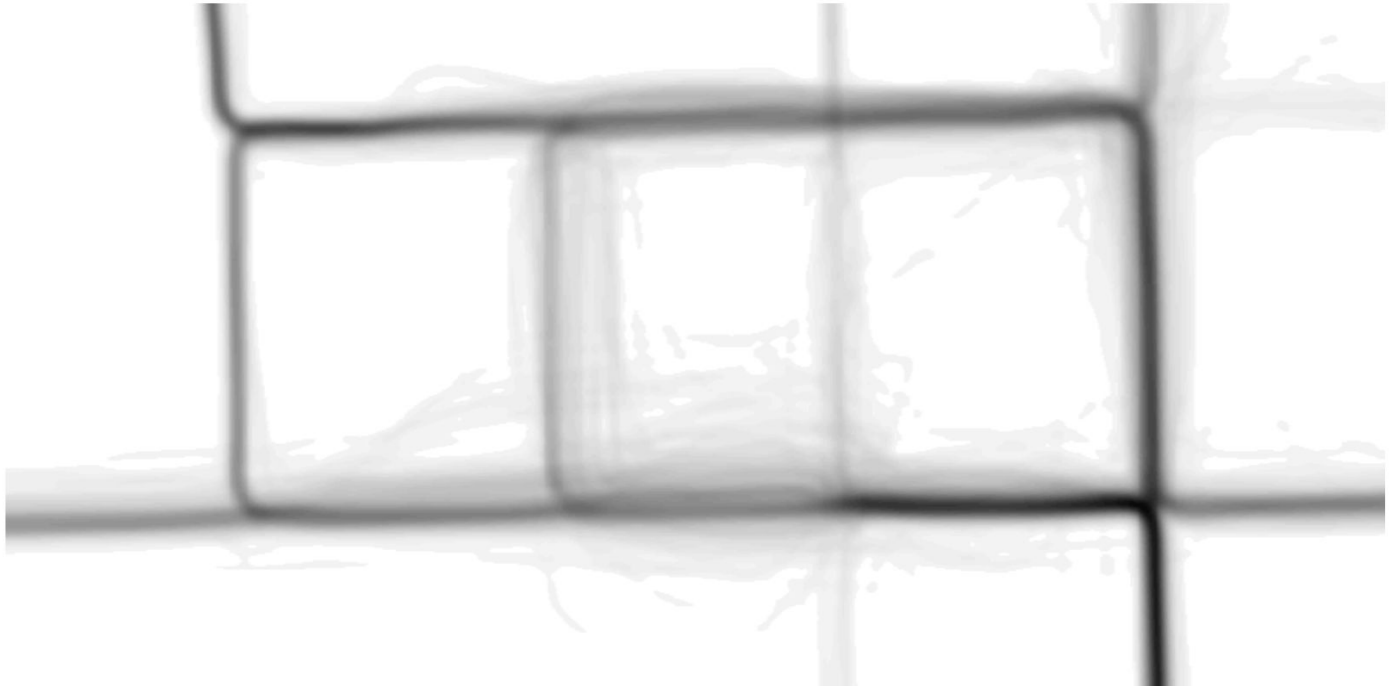
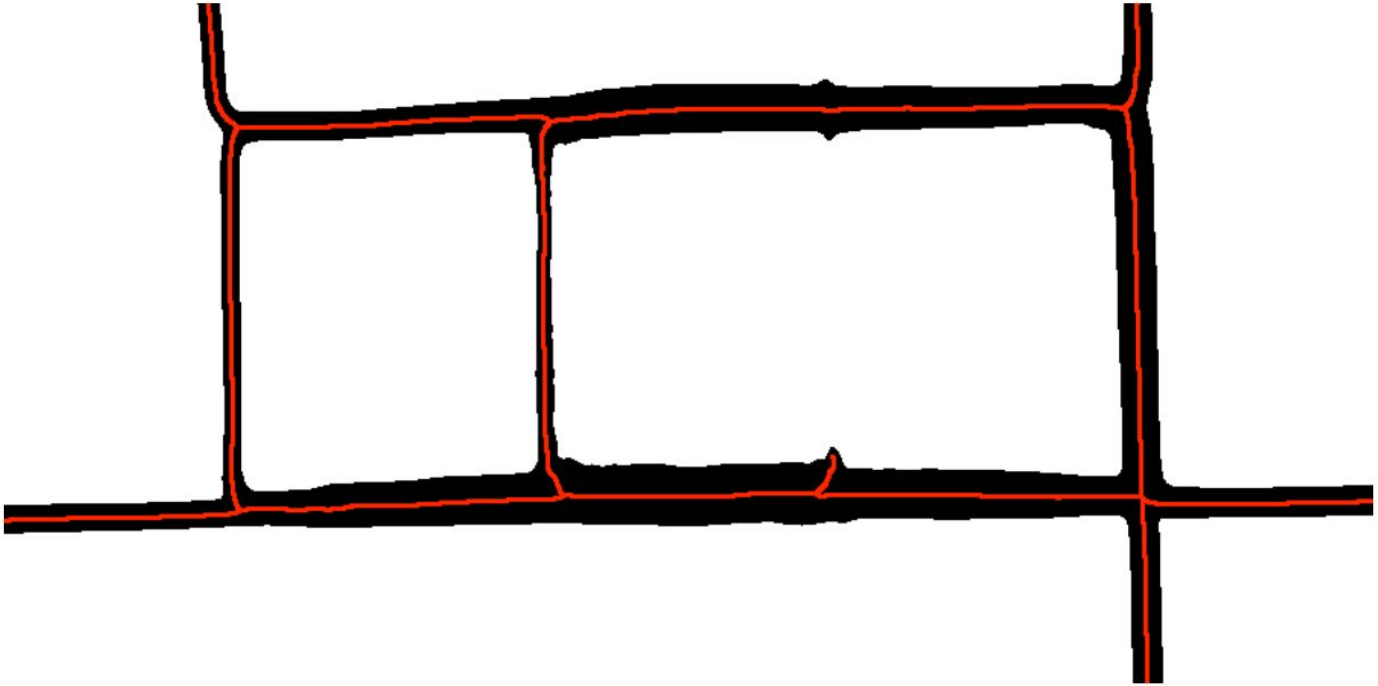


Density Estimation

High Threshold



Density Estimation

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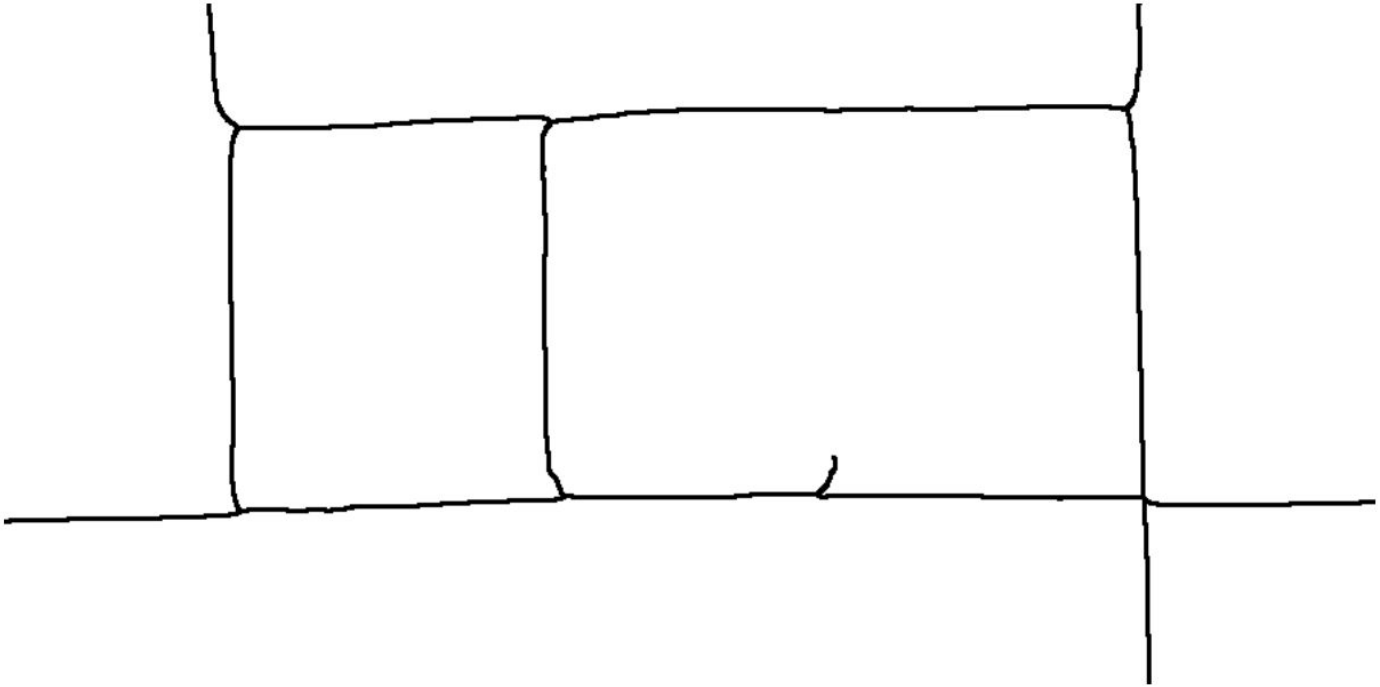

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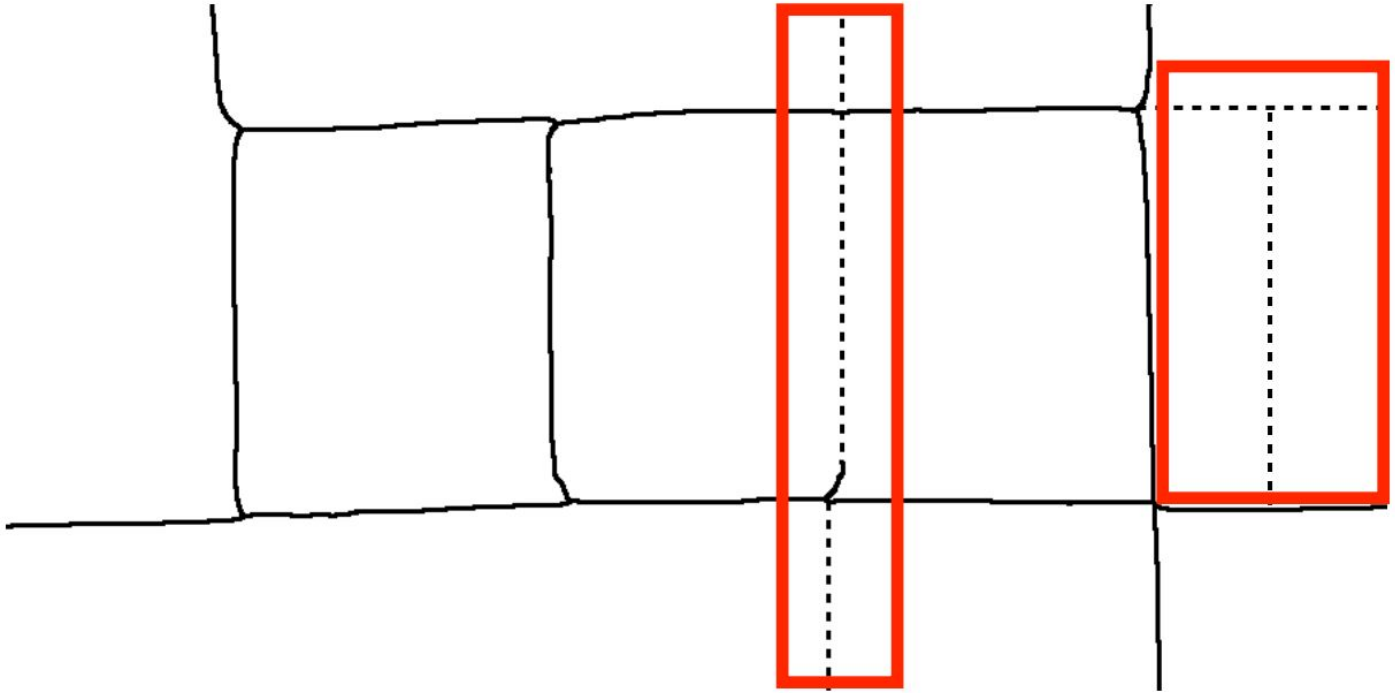
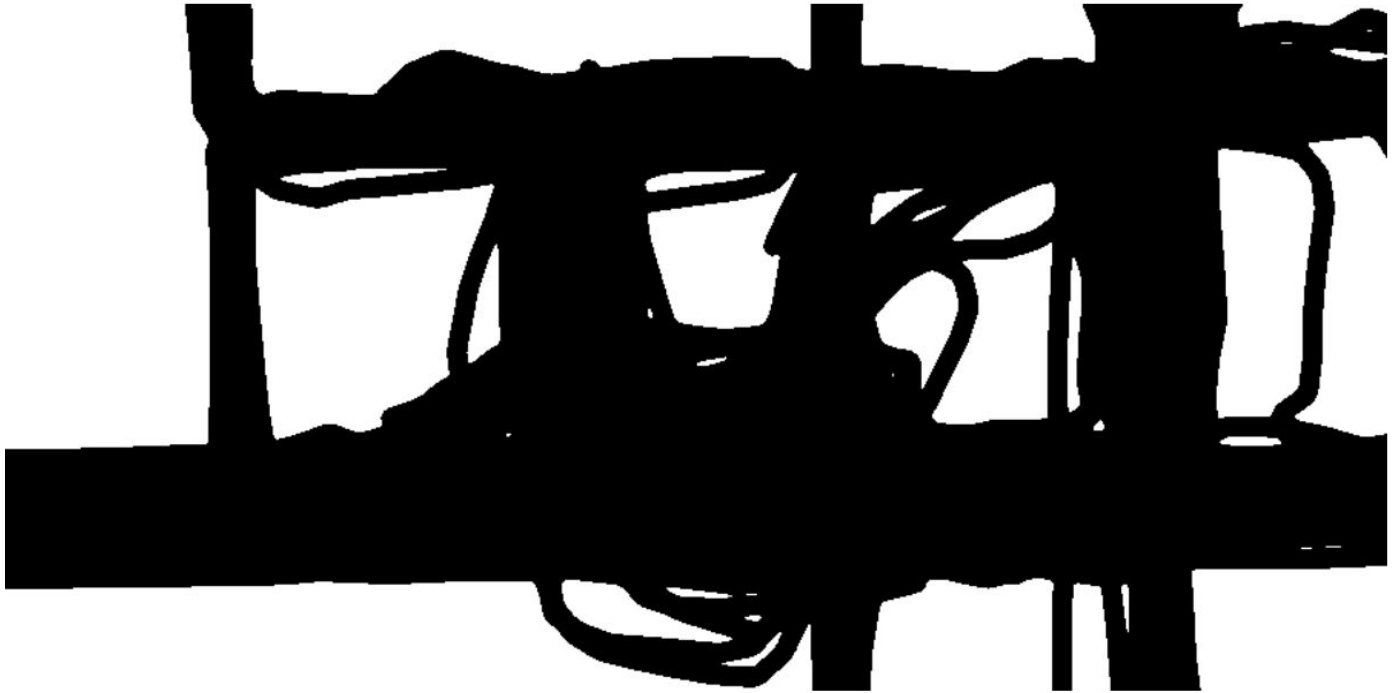
High Threshold



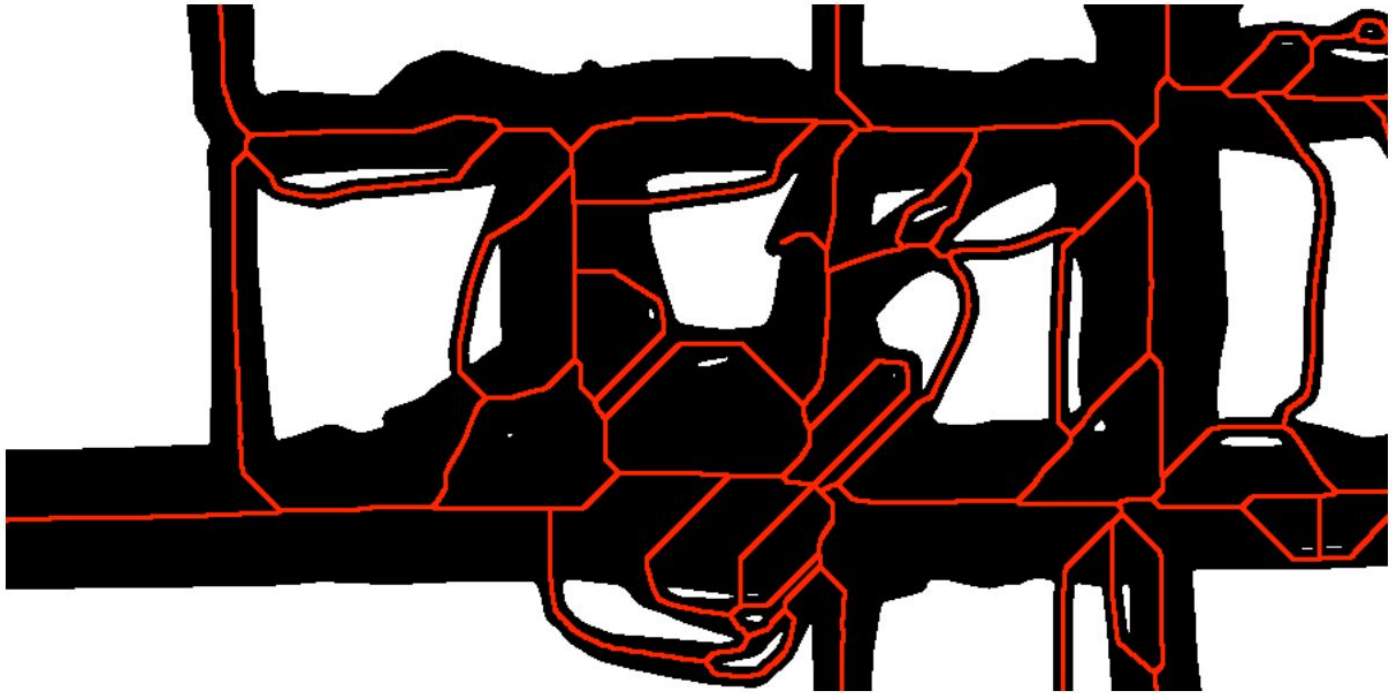
Density Estimation

Low Threshold



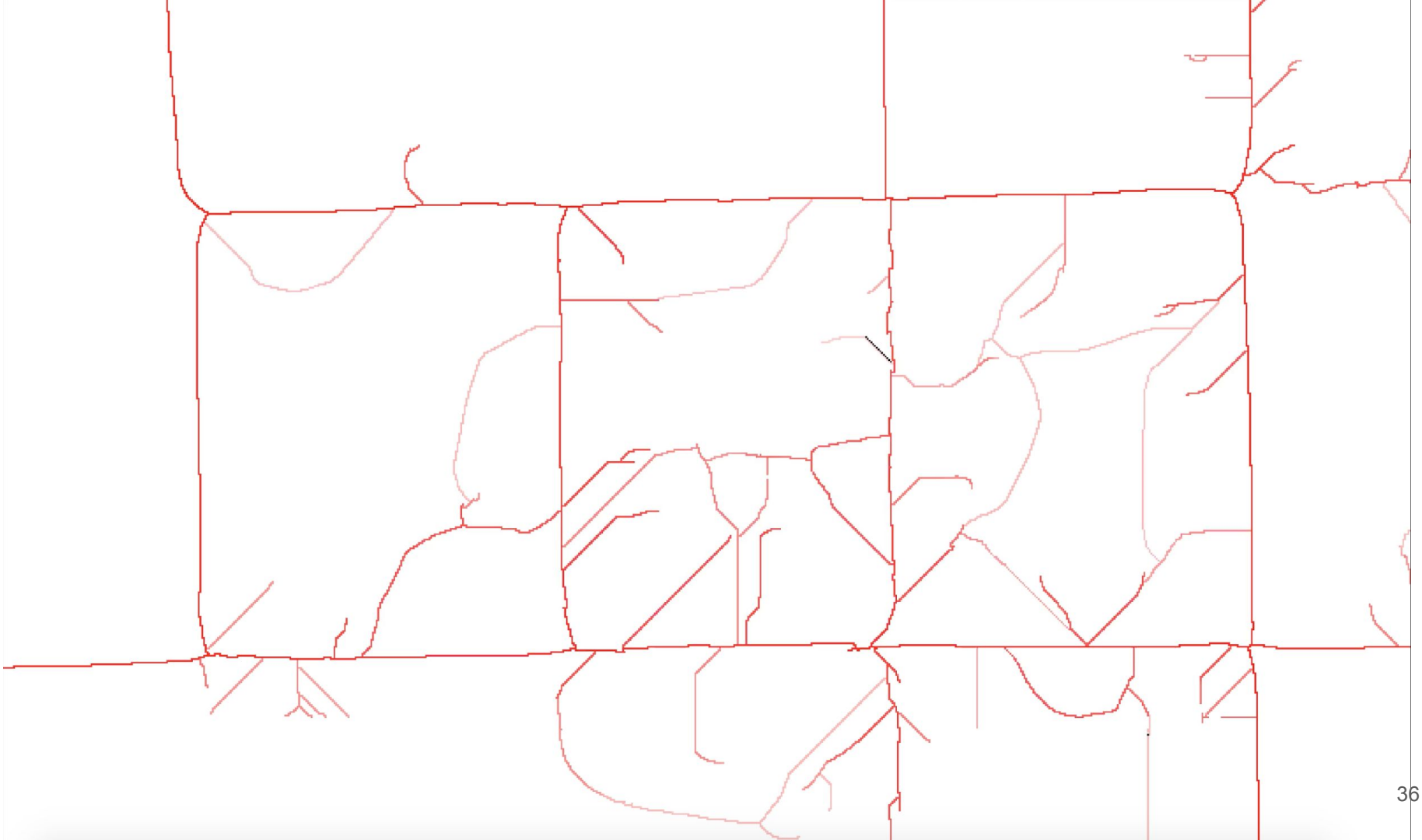
Density Estimation

Low Threshold

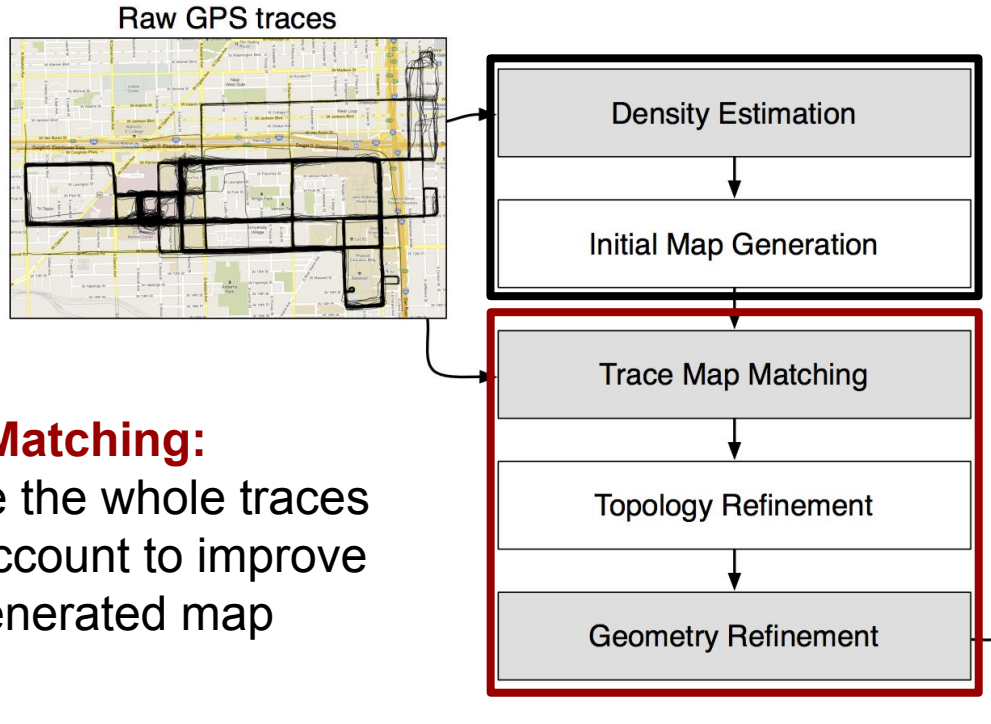


Density Estimation - Gray-scale Skeletonization

- Skeletonization with different thresholds, from high to low
- Remain the results from high thresholds
- Assign weights to each pixel



Map inference in the face of noise and disparity



Gray-scale Skeletonization
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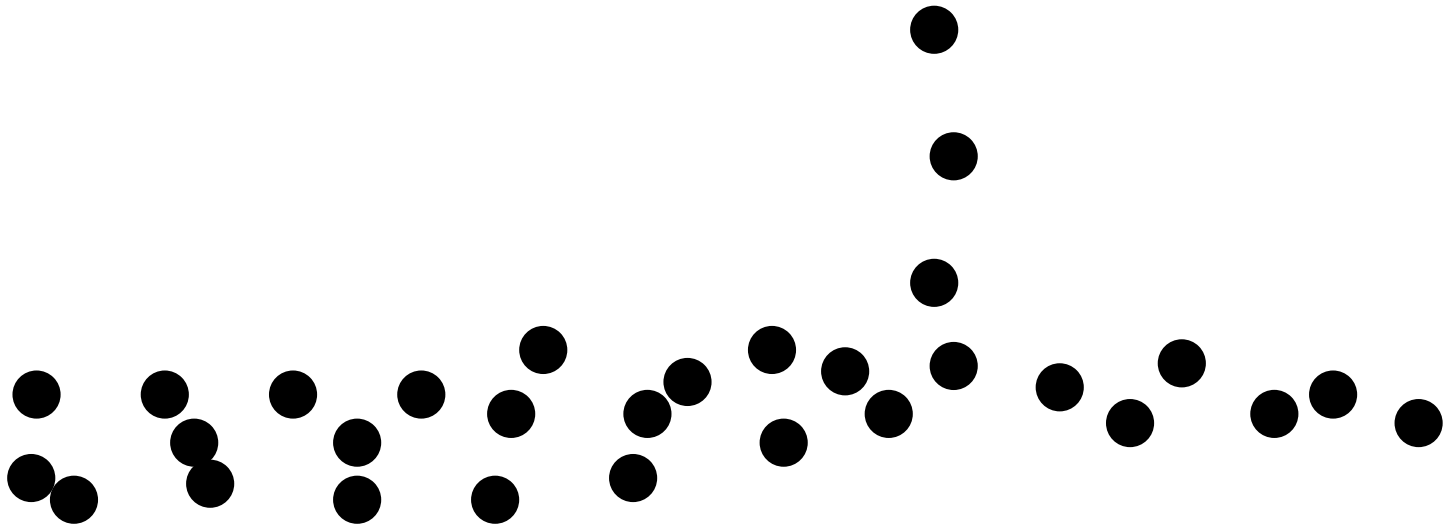
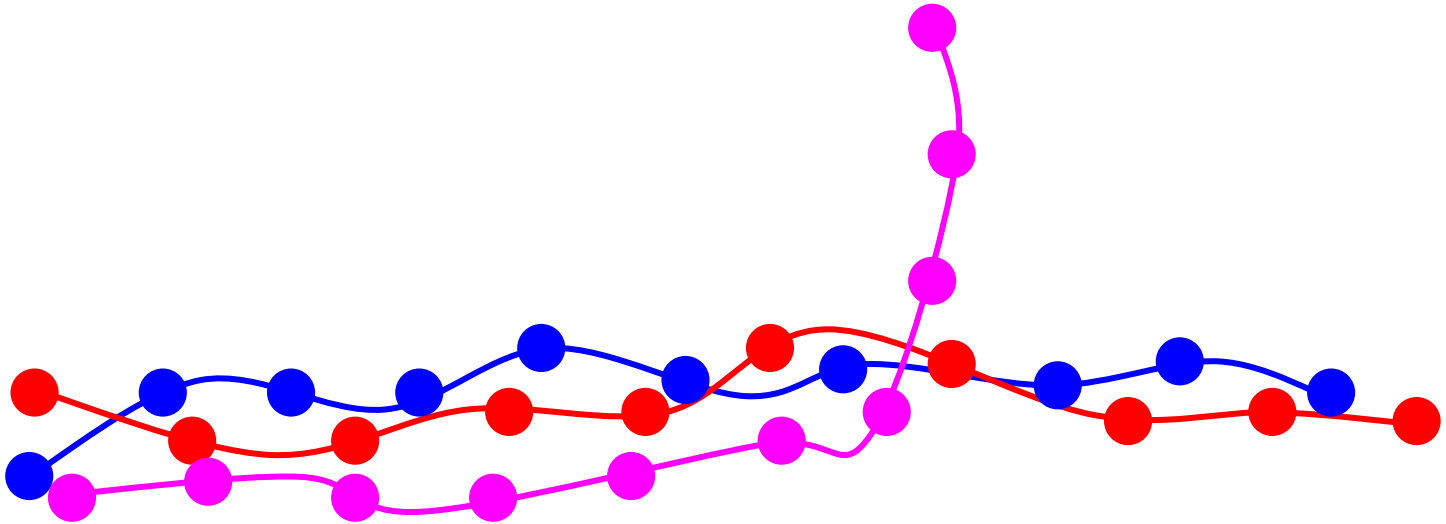
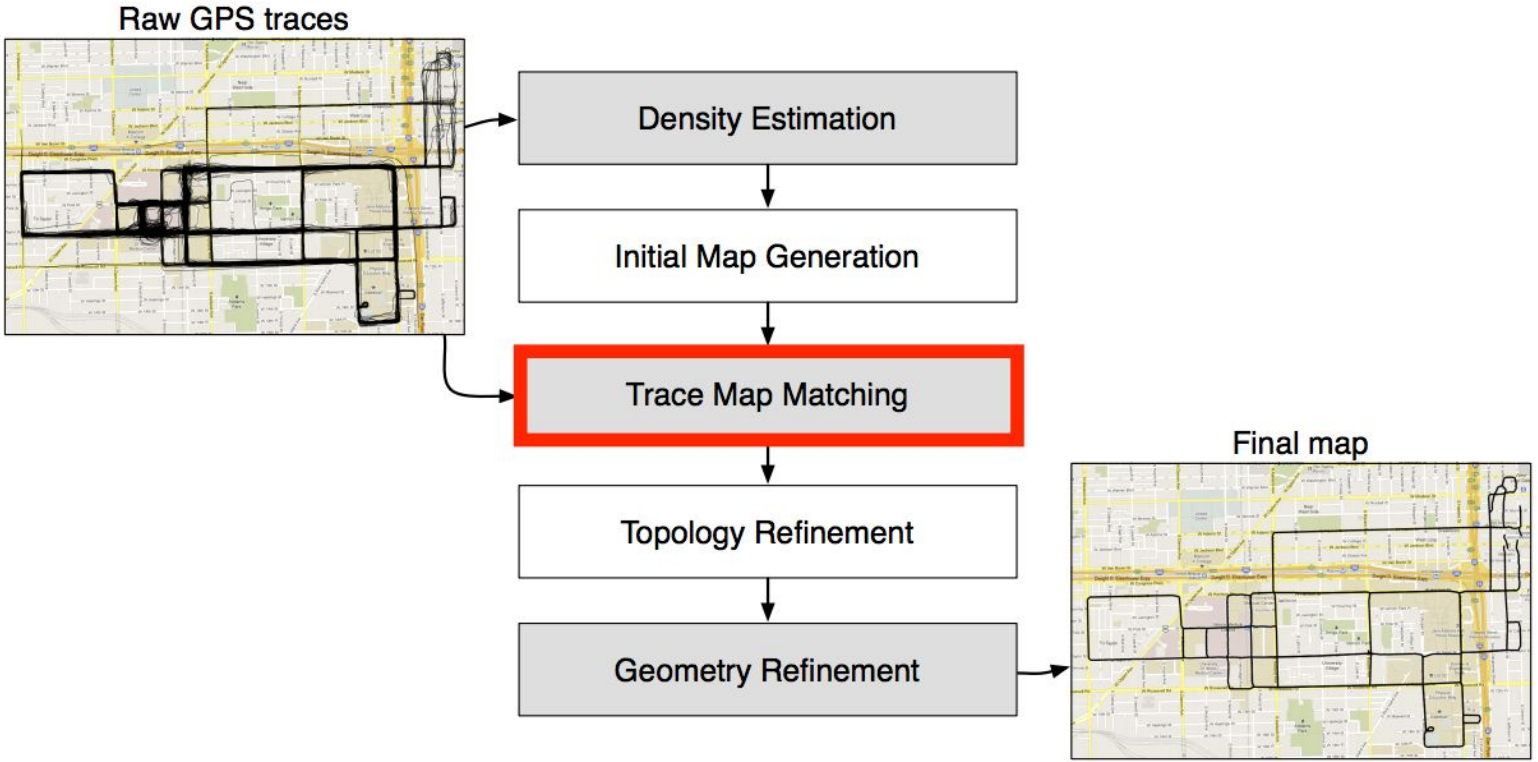
The View of Traces from Density Estimation



More Information if You Consider the Whole Trace



Map Matching



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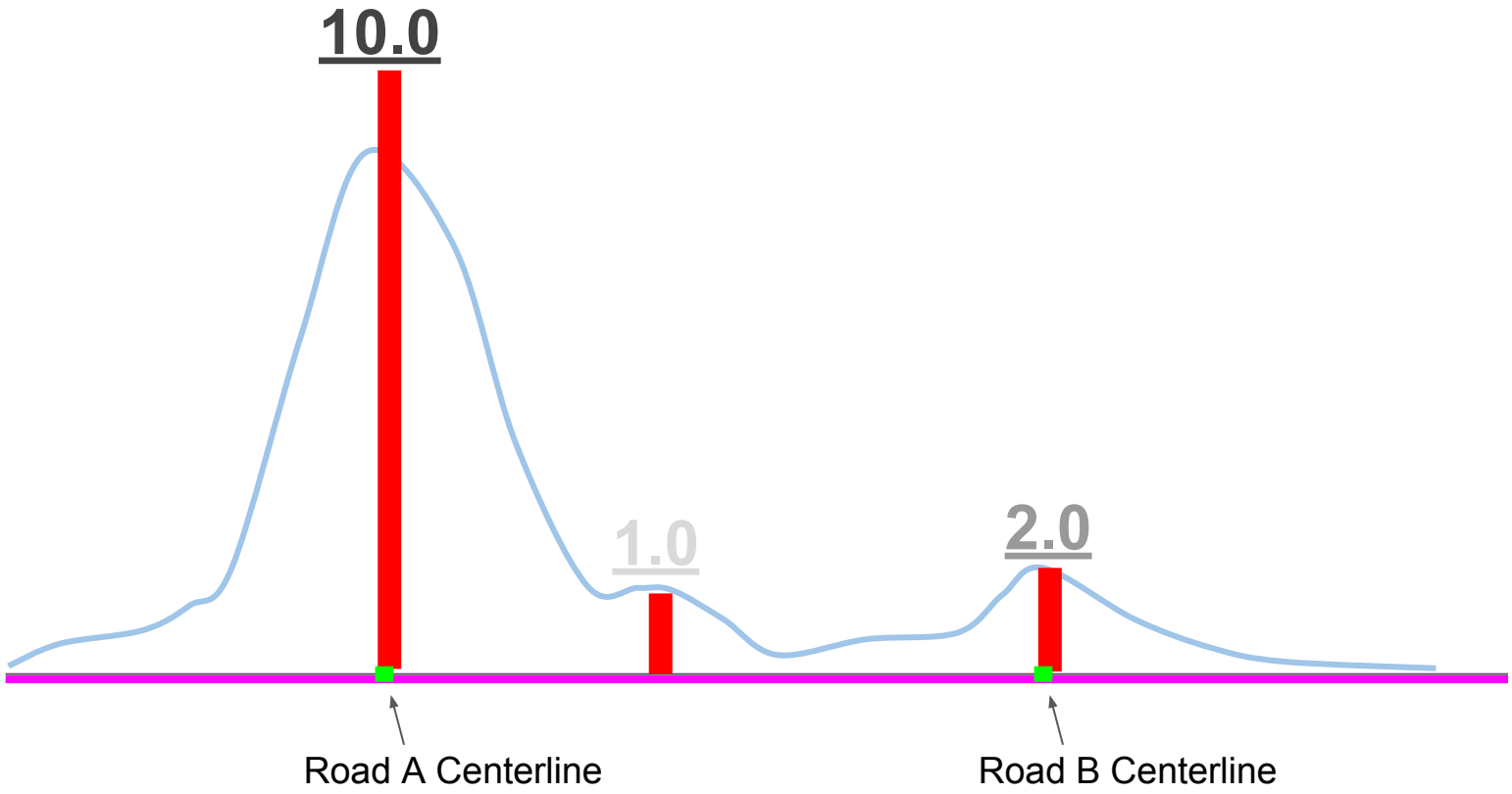

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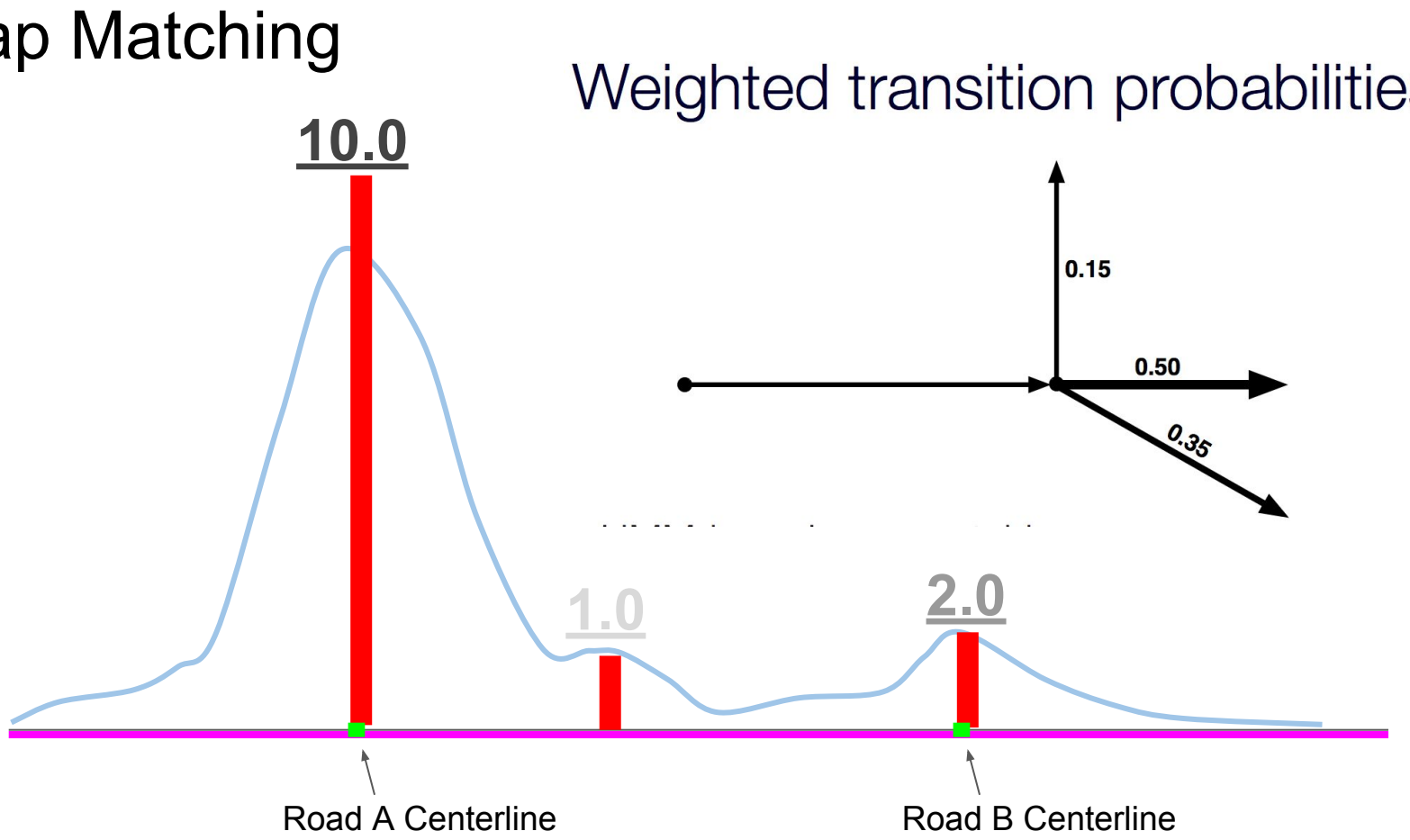

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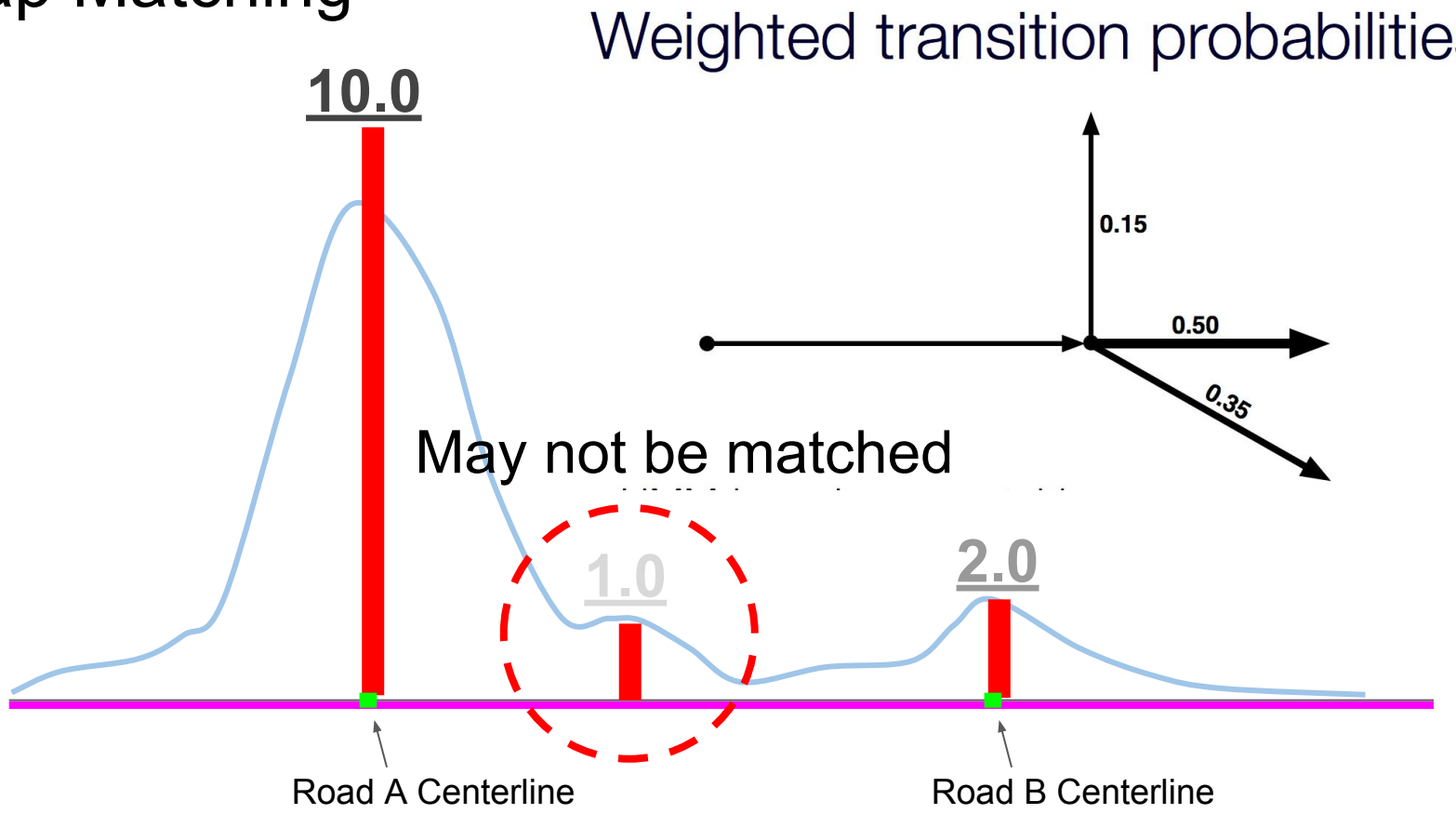
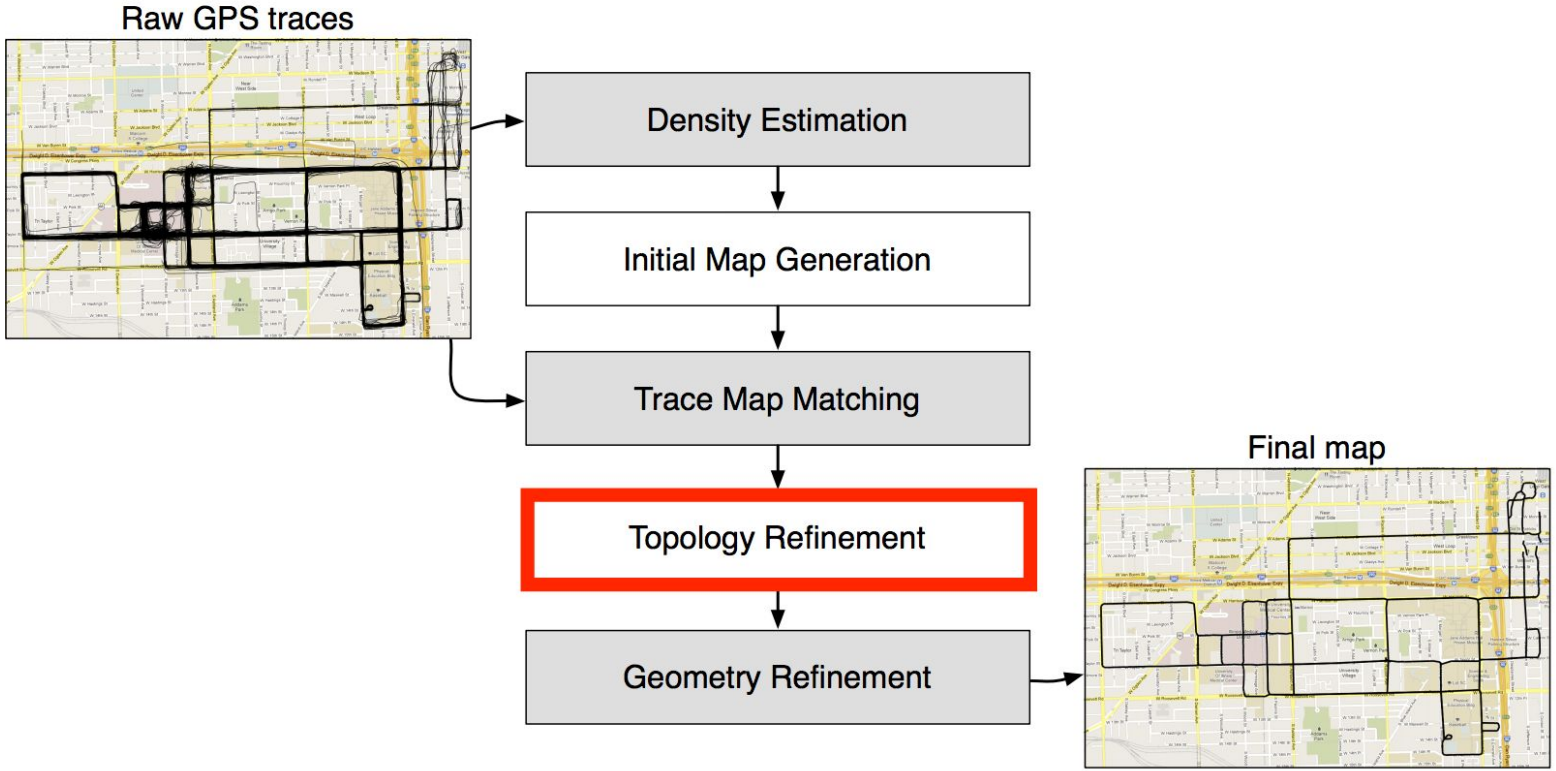


Topology Refinement



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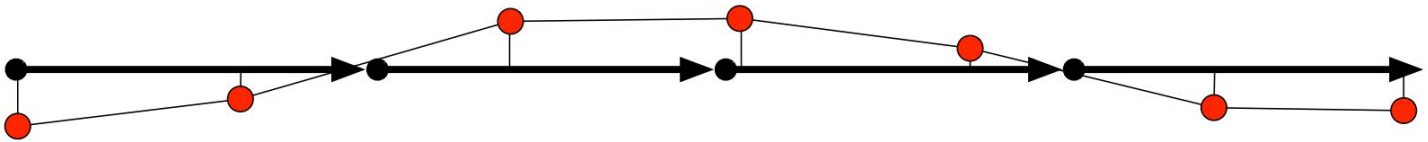
Topology Refinement

Well-matched Traversal

Goodness of fit

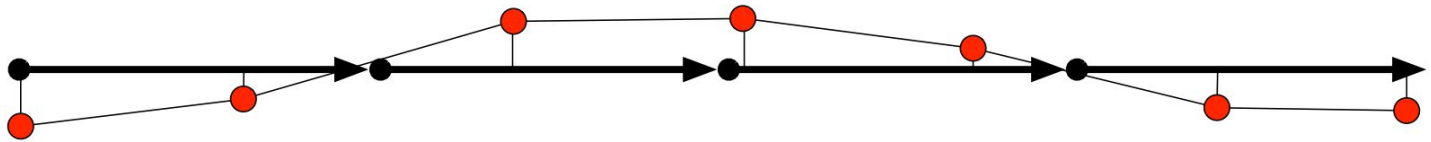


$$RMSD(\tau, e) = \sqrt{\frac{1}{|\tau|} \sum_{p \in \tau} dist(p, e)^2}$$

$$RMSD(\tau, e) < RMSD_{max}$$

Topology Refinement

Remove edges with less than two well-matched traversals



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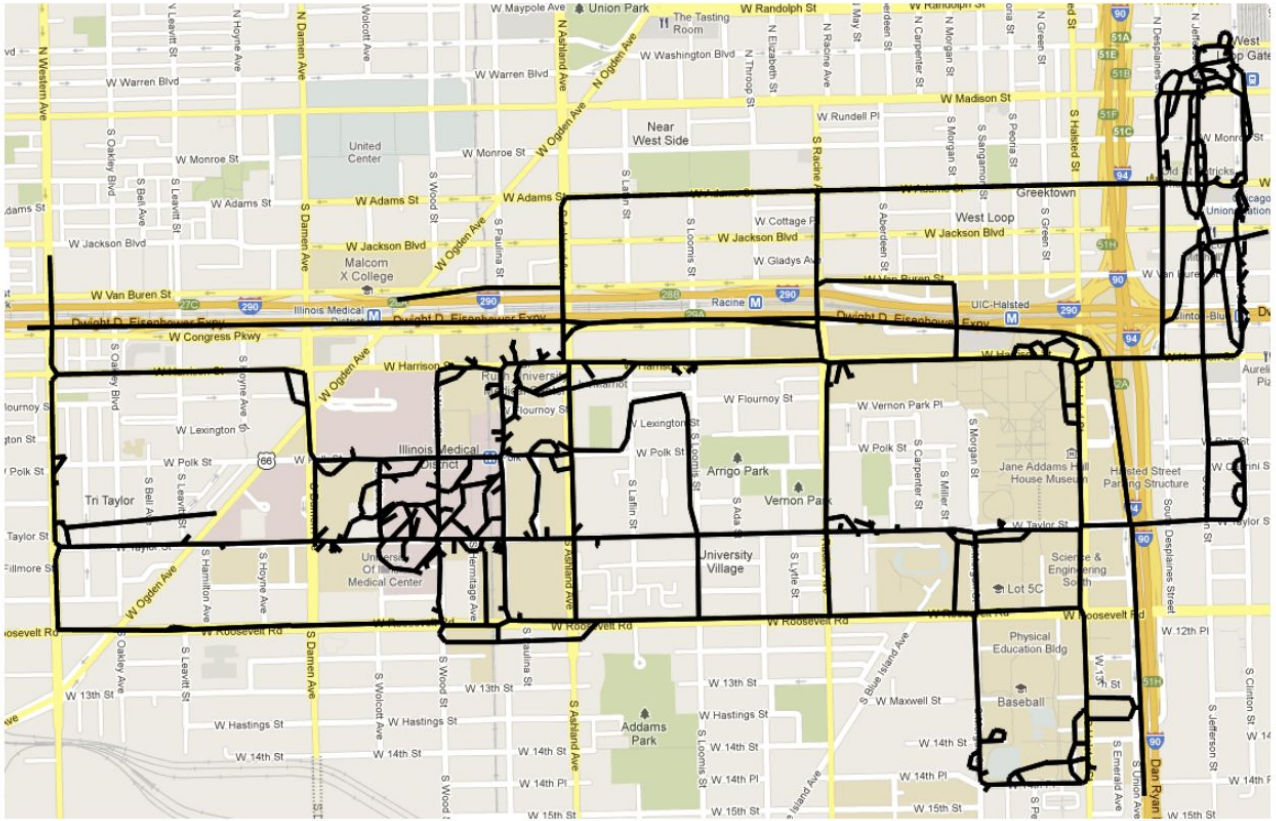
Topology Refinement - Before Pruning



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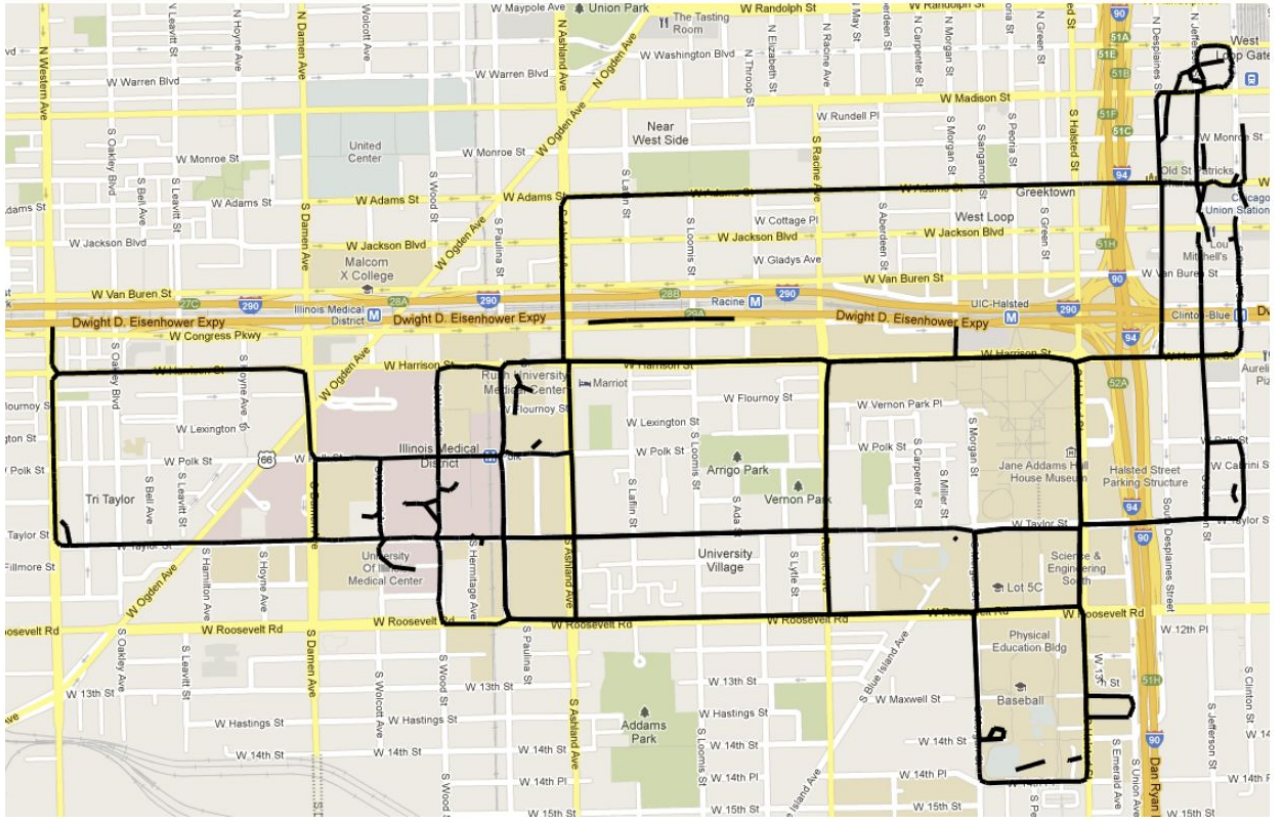
Topology Refinement - After Pruning



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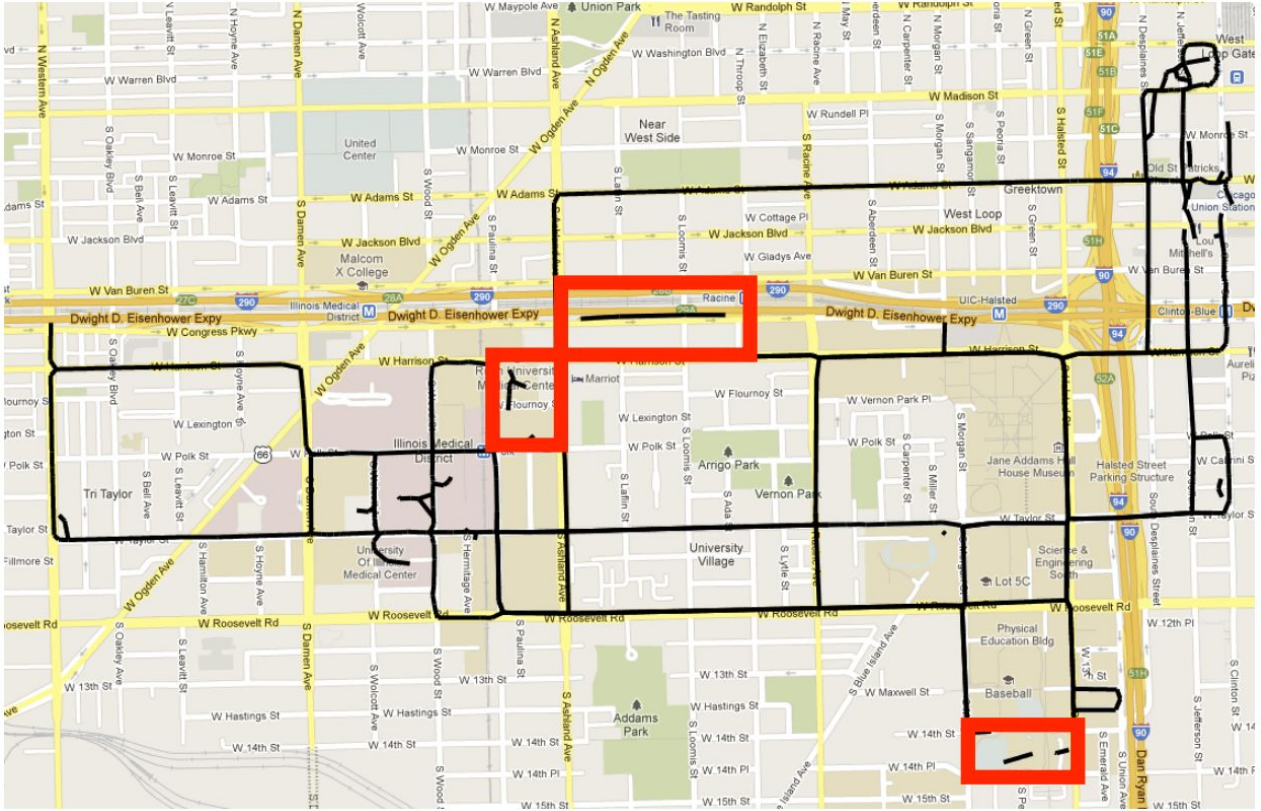

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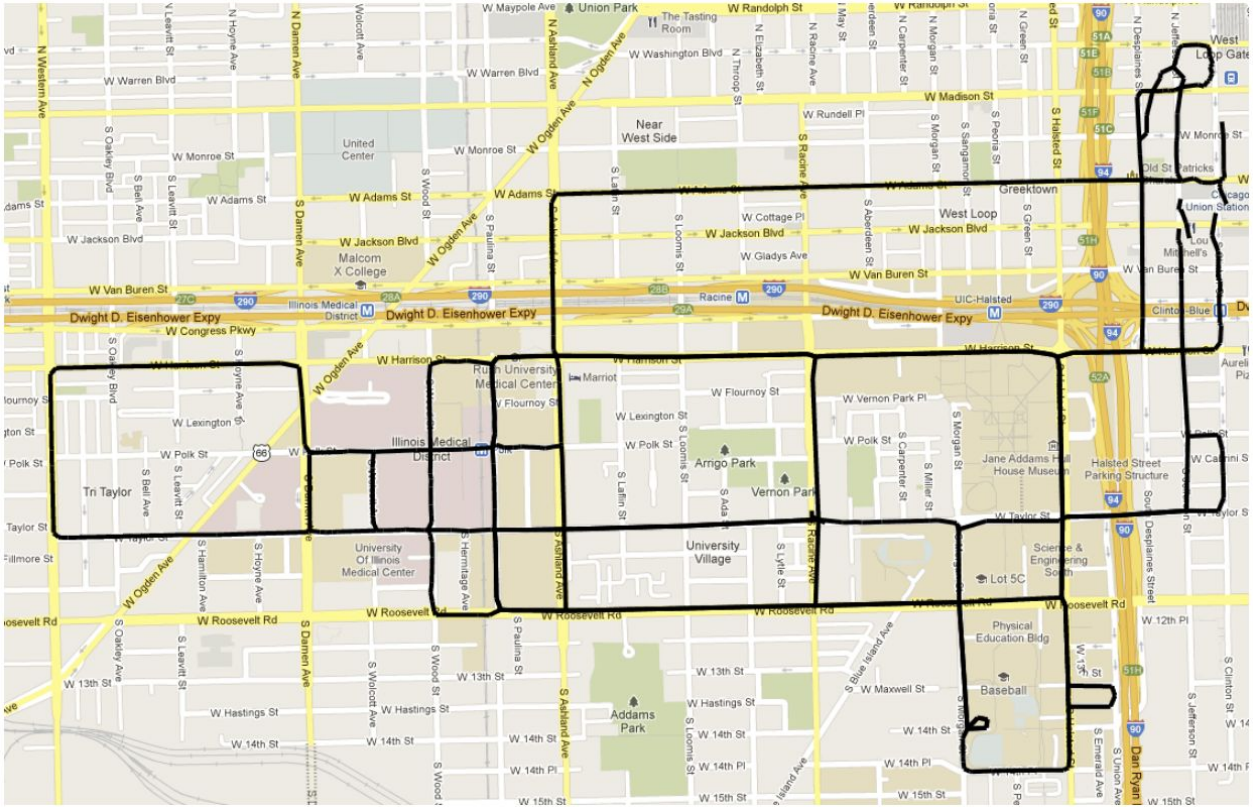
Topology Refinement - Pruning Again ...



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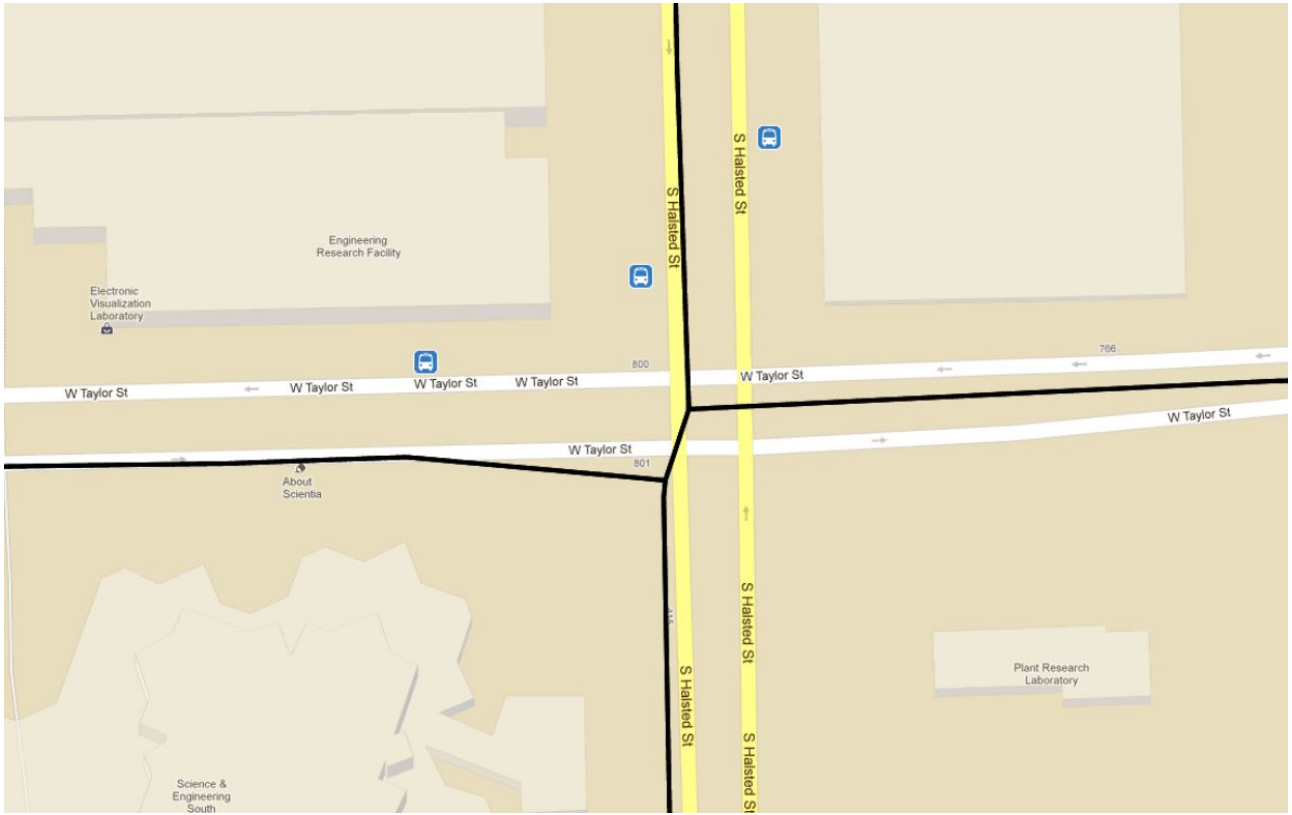
Topology Refinement - Incorrect Topology



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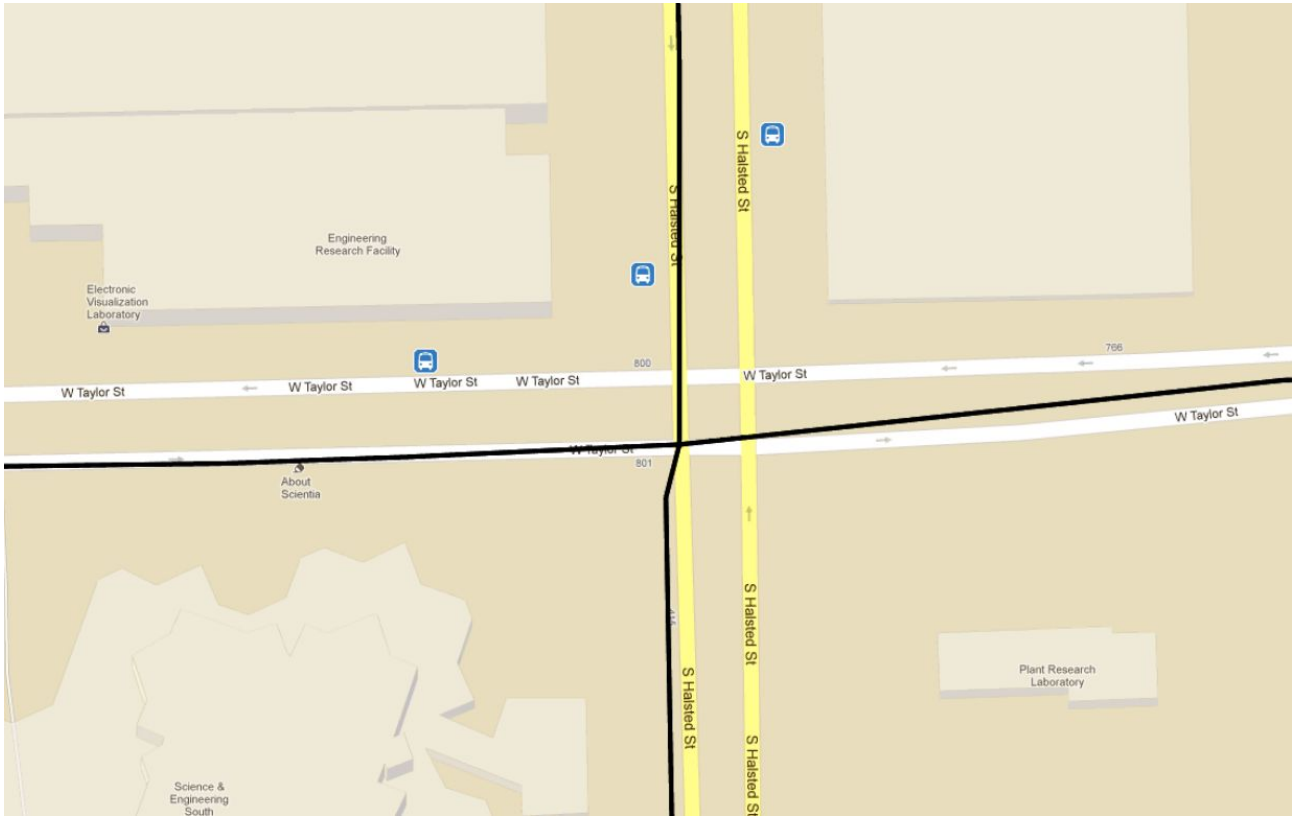
Topology Refinement - Collapsed Intersection



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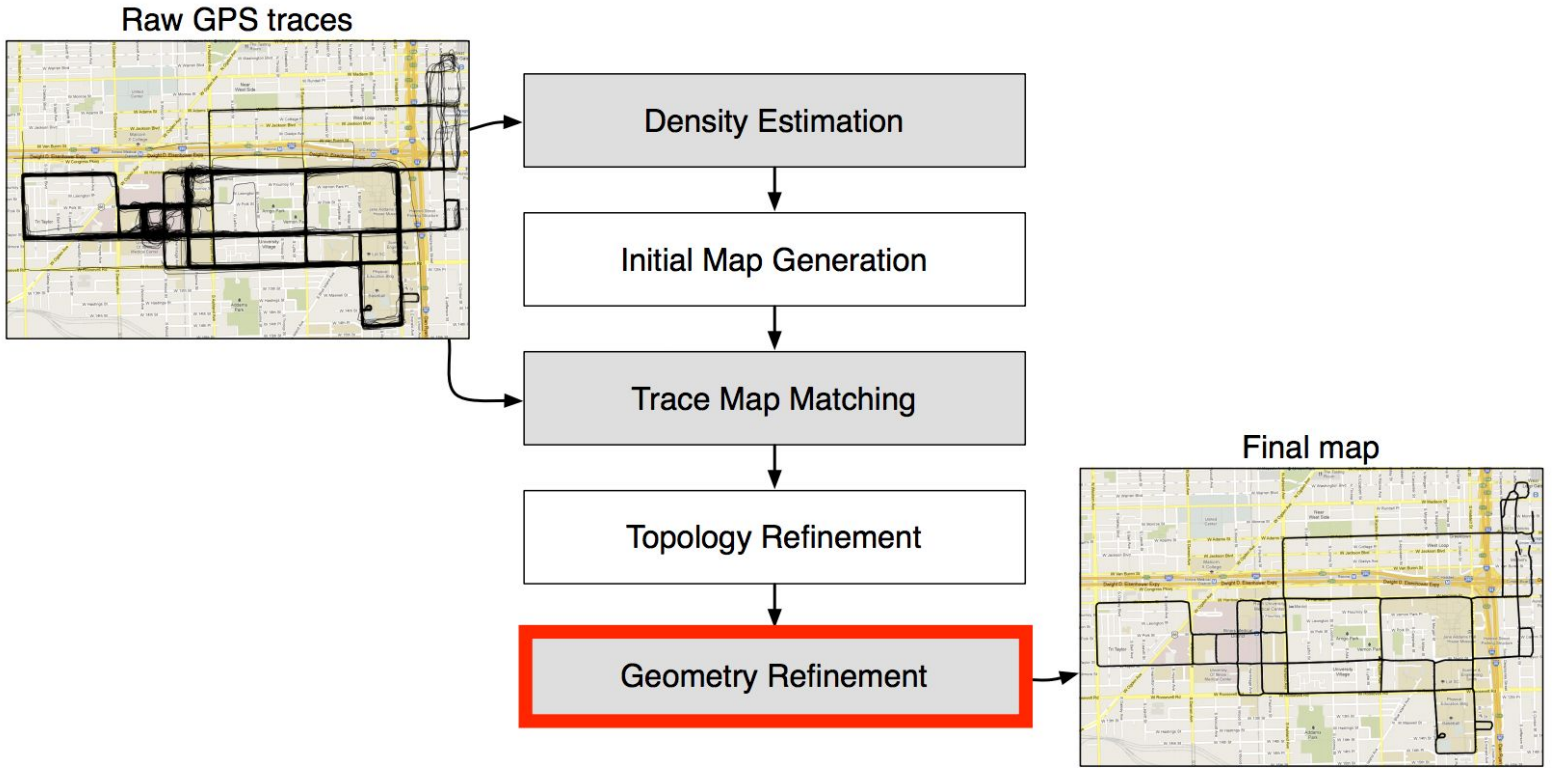
Geometry Refinement



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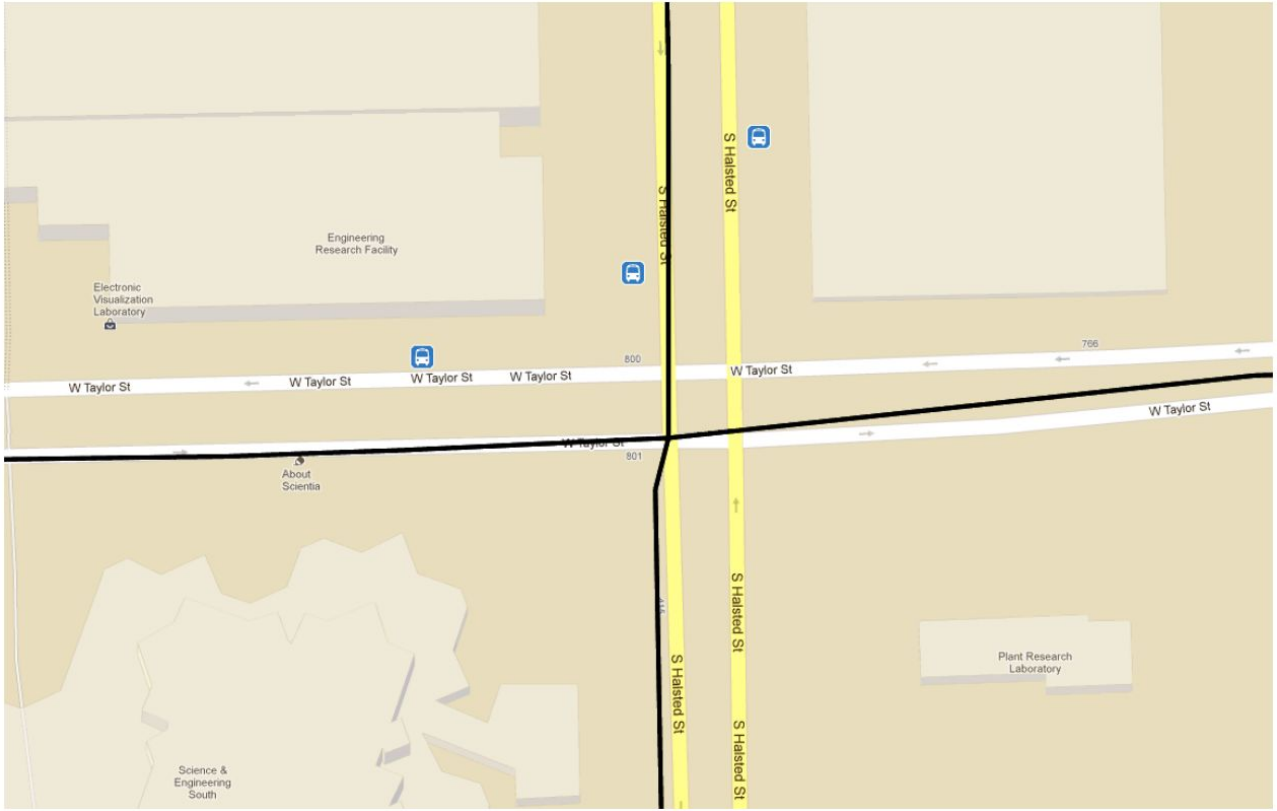
Geometry Refinement - Simple Geometry



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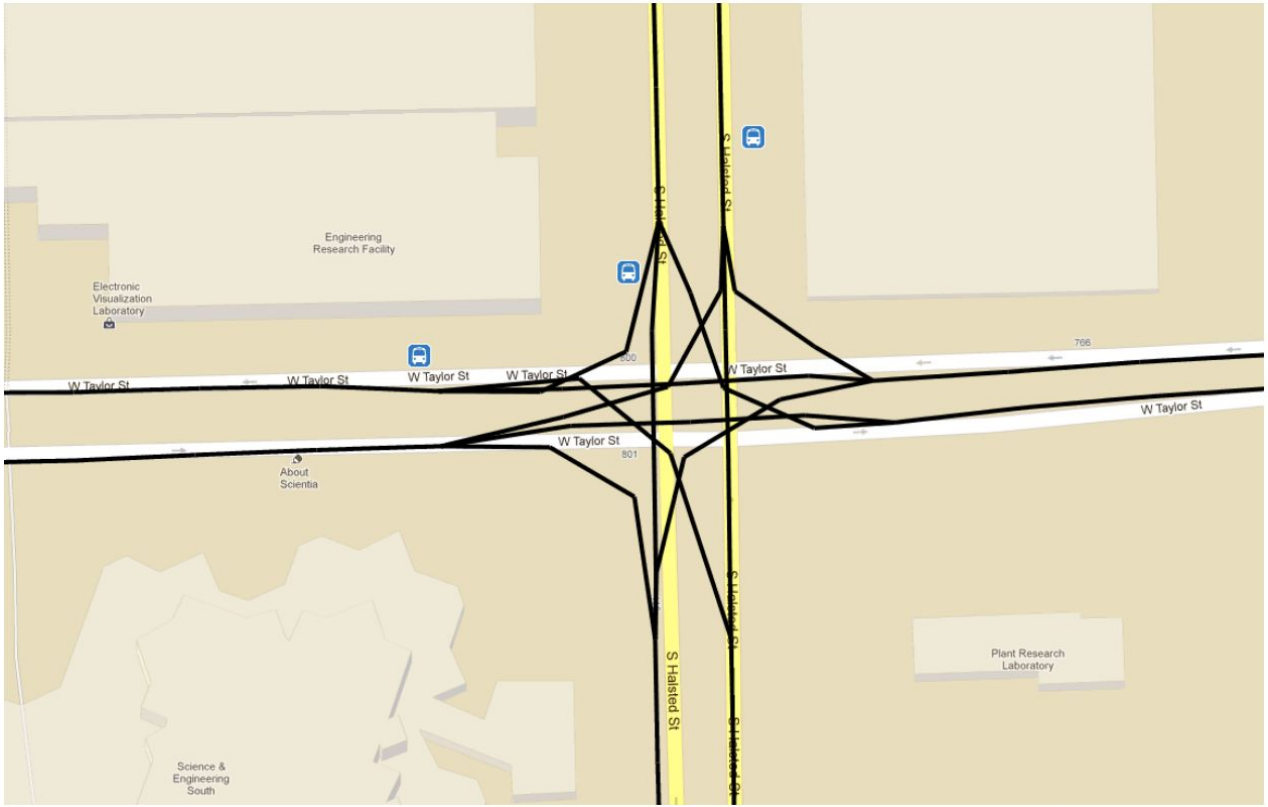
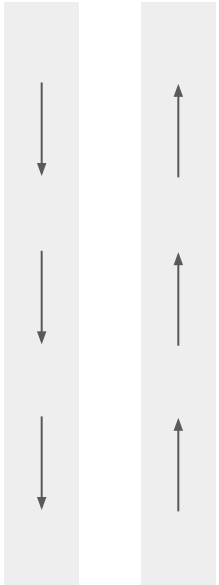
Geometry Refinement - Refined Geometry

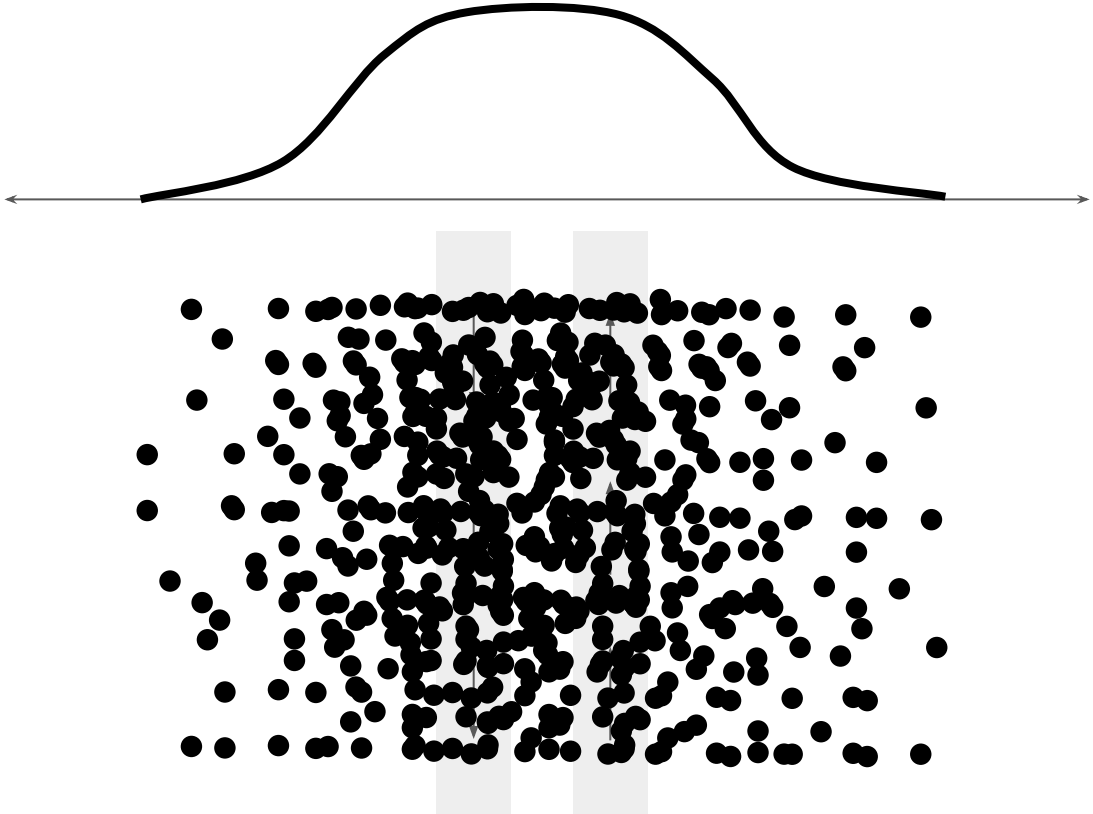


"*Map inference in the face of noise and disparity*." Biagioni, James, and Jakob Eriksson. *Proceedings of the 20th International Conference on Advances in Geographic Information Systems*. ACM, 2012.

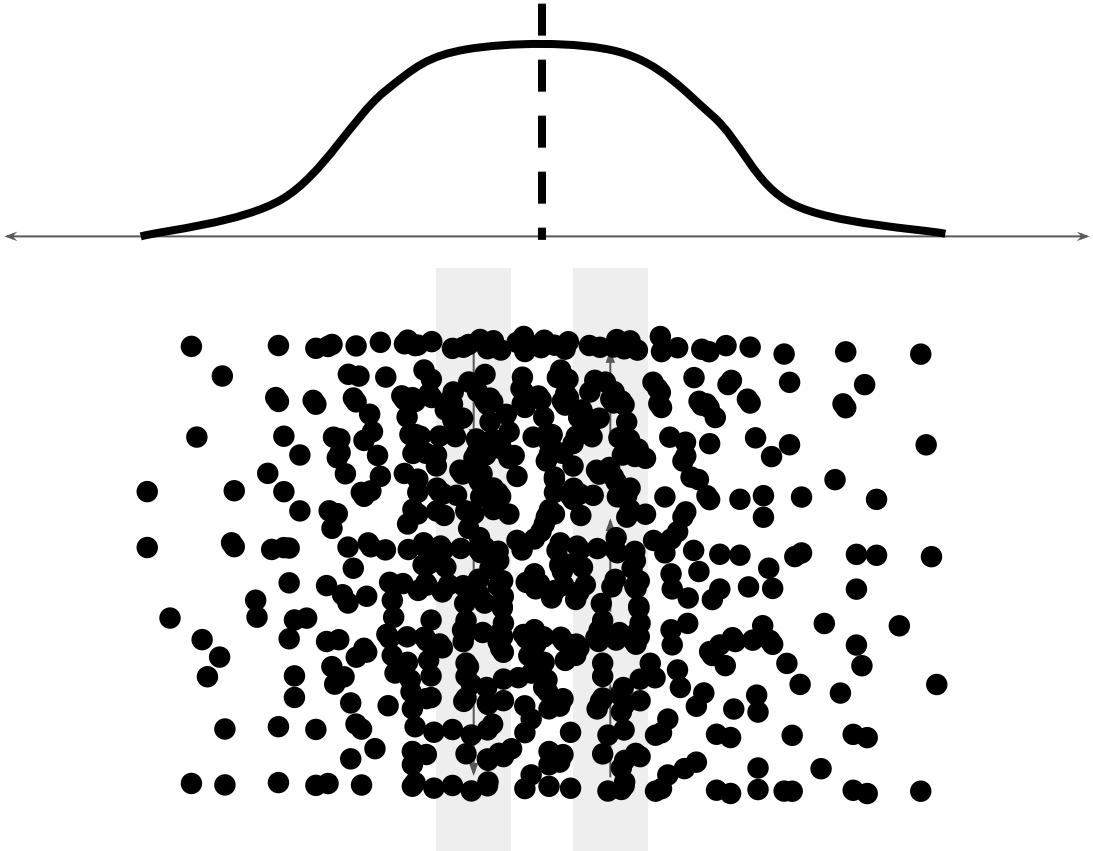
Geometry Refinement - Infer Parallel Road



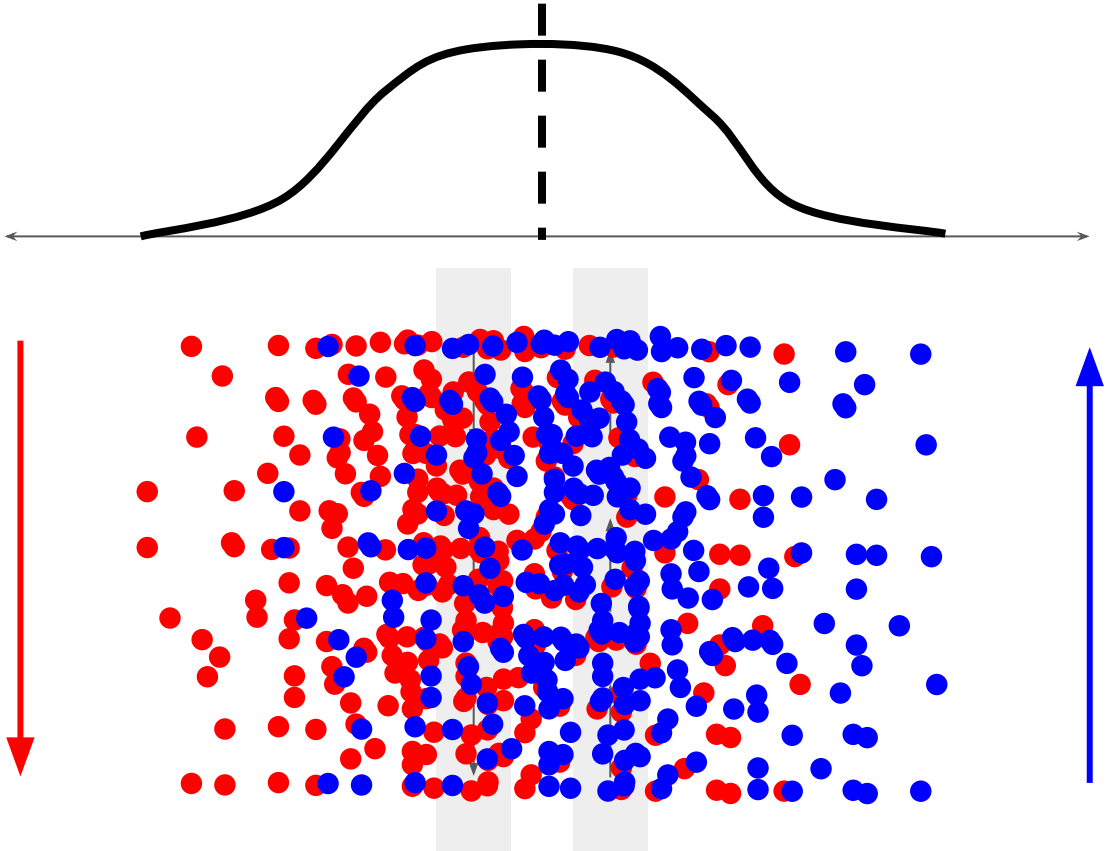
Geometry Refinement - Infer Parallel Road



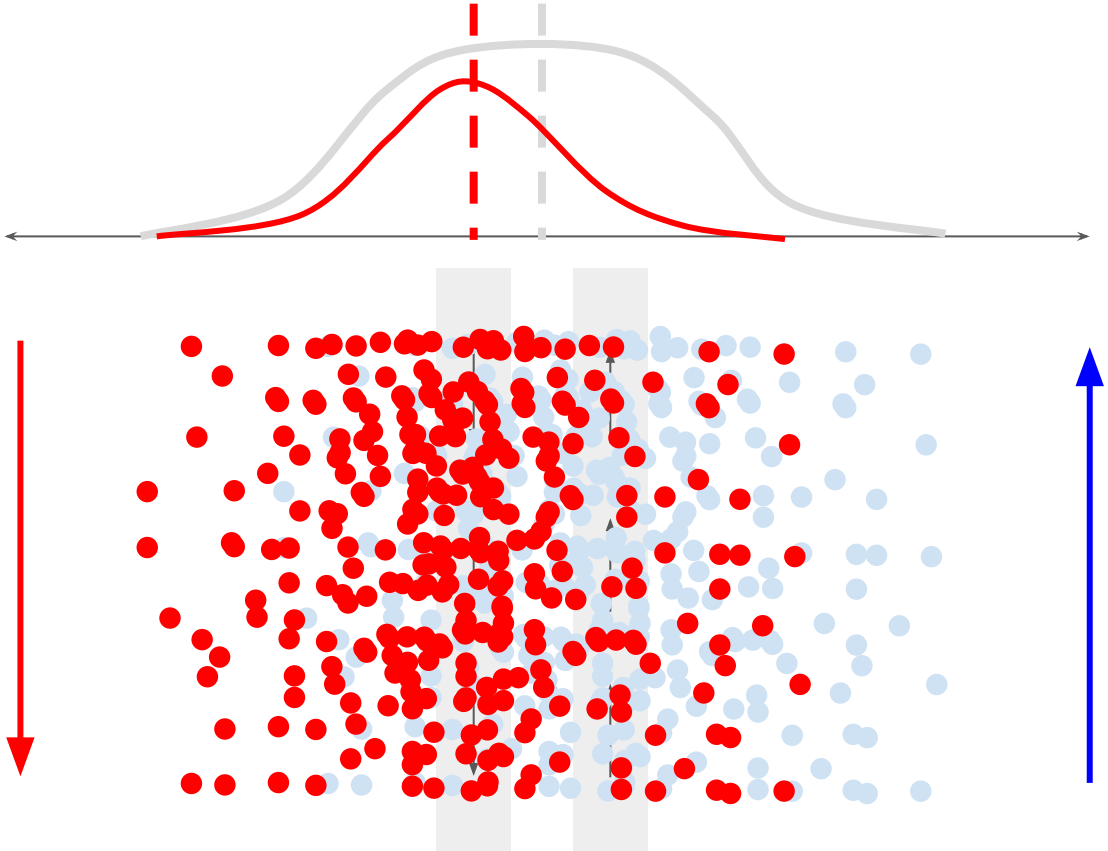
Geometry Refinement - Infer Parallel Road



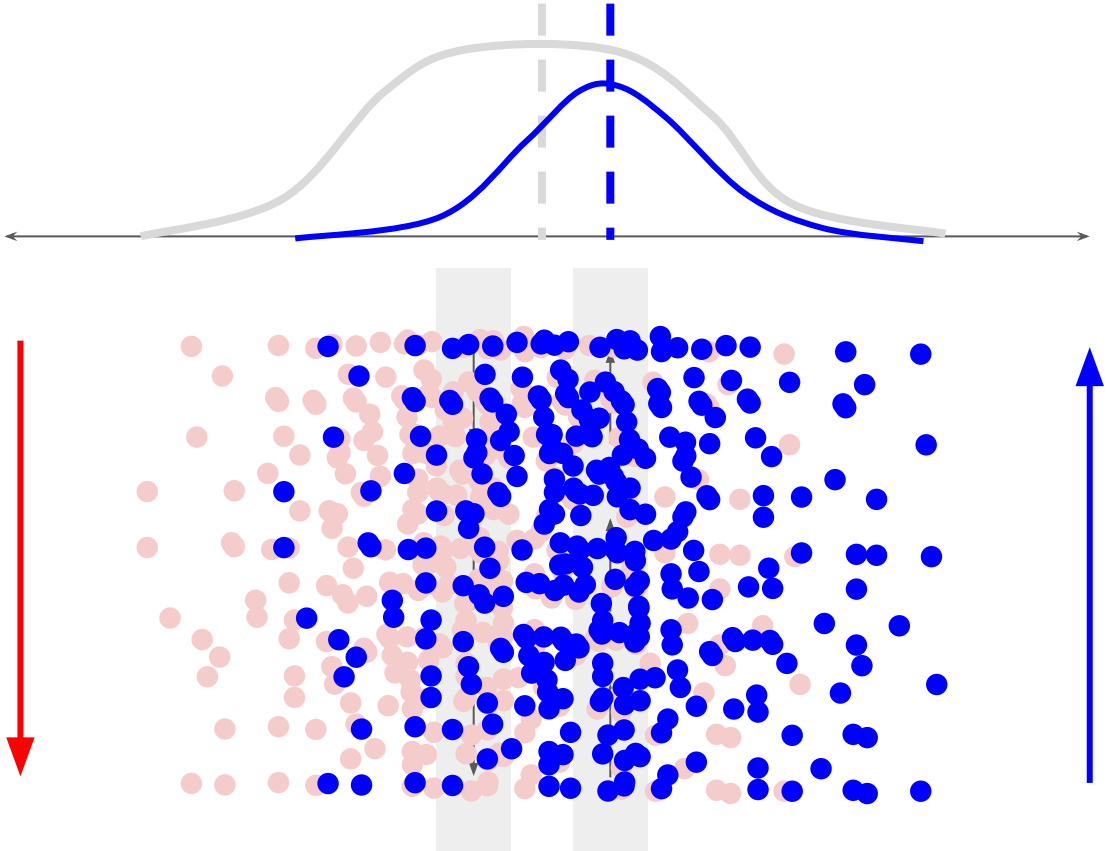
Geometry Refinement - Infer Parallel Road



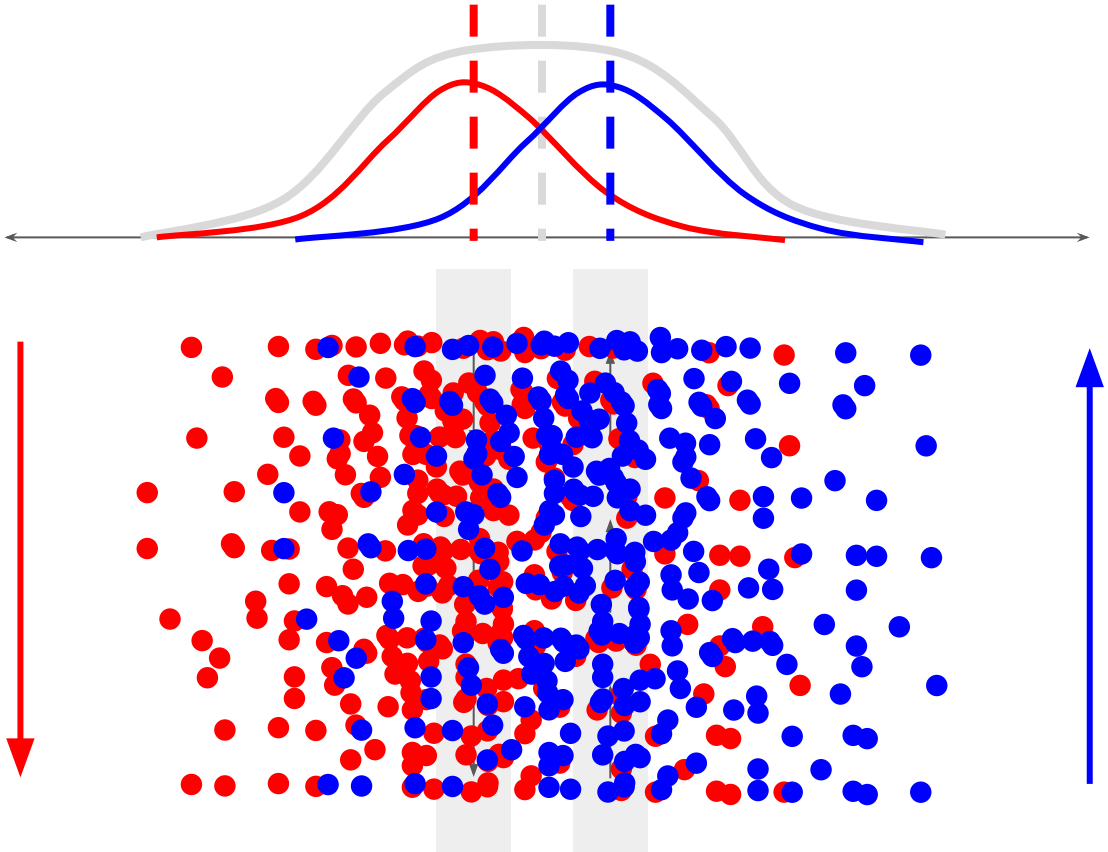
Geometry Refinement - Infer Parallel Road



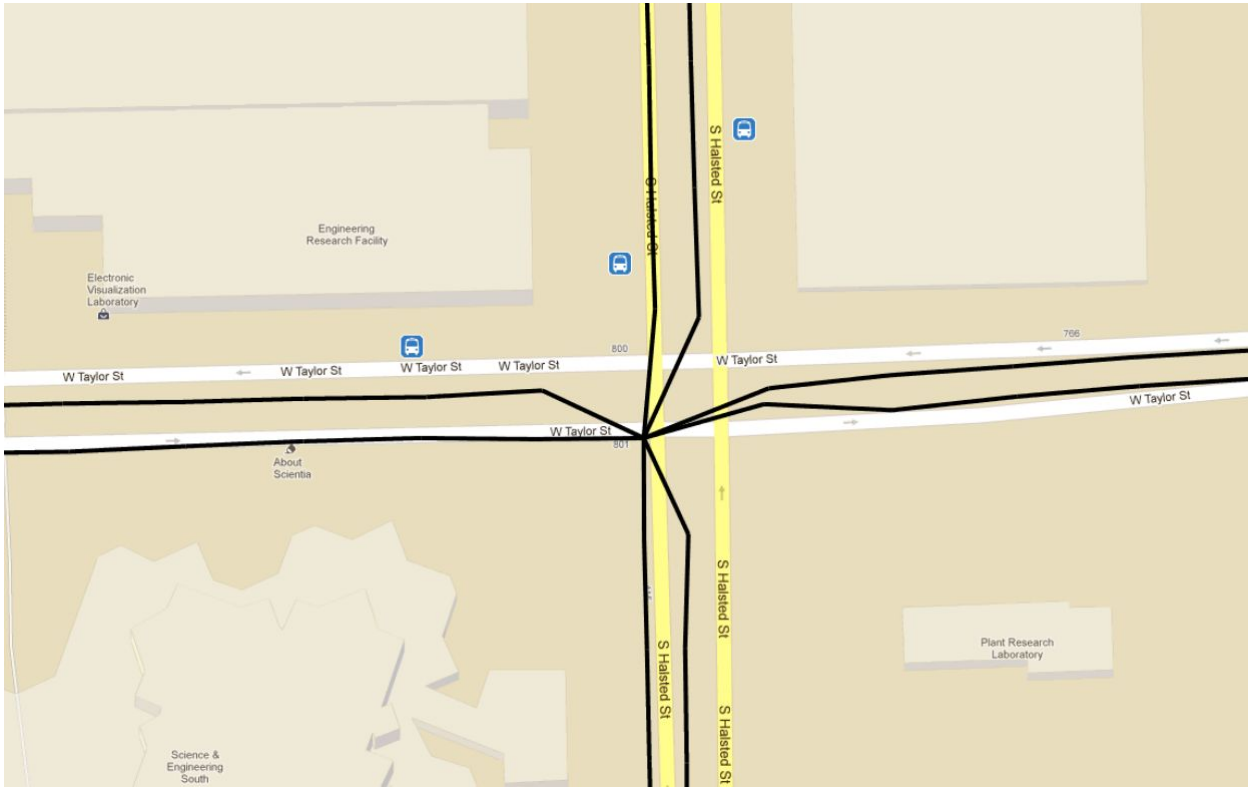
Geometry Refinement - Infer Parallel Road



Geometry Refinement - Infer Parallel Road

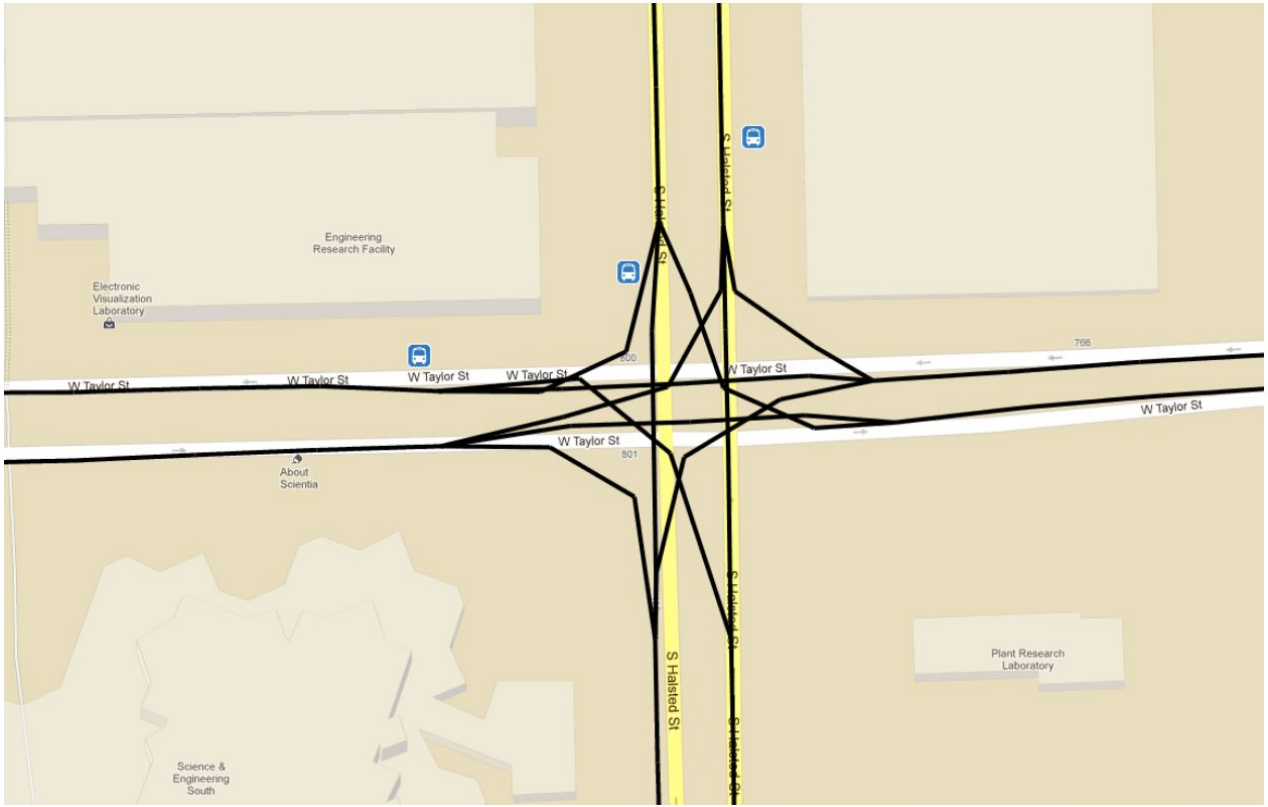


Geometry Refinement - Refined Parallel Road



"*Map inference in the face of noise and disparity*." Biagioni, James, and Jakob Eriksson. *Proceedings of the 20th International Conference on Advances in Geographic Information Systems*. ACM, 2012.

Geometry Refinement - Refined Intersection



"*Map inference in the face of noise and disparity*." Biagioni, James, and Jakob Eriksson. *Proceedings of the 20th International Conference on Advances in Geographic Information Systems*. ACM, 2012.

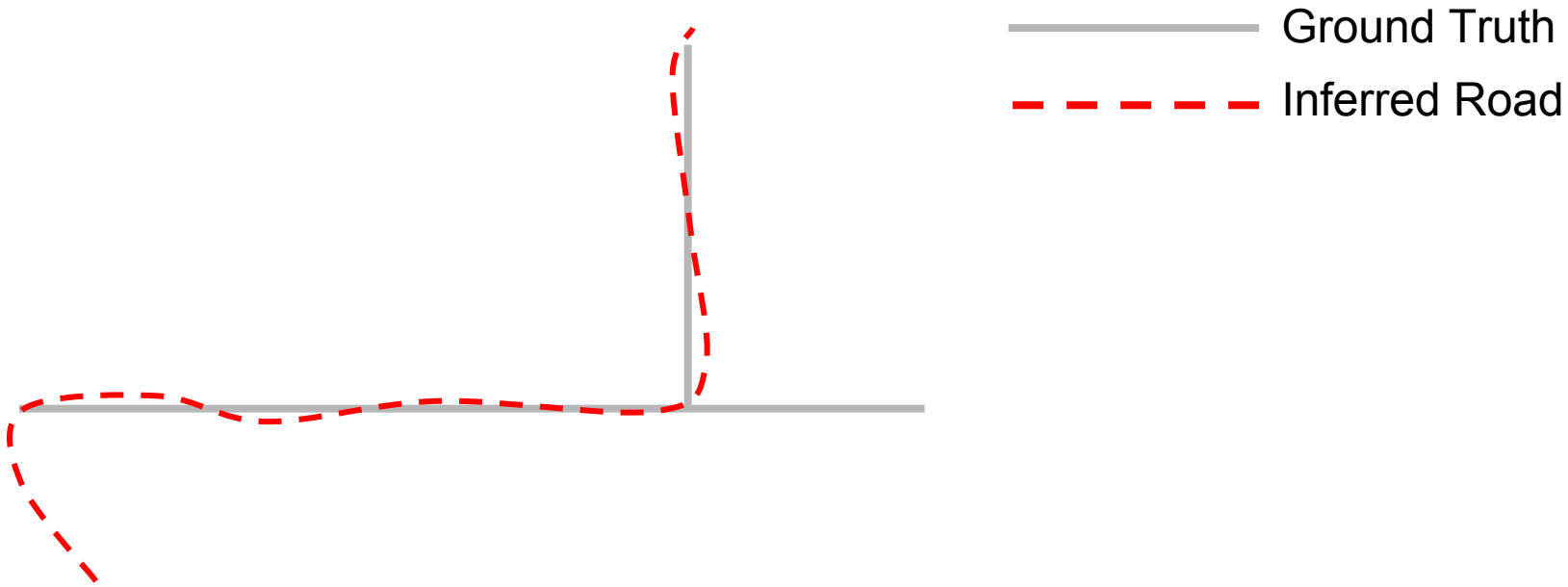
Evaluation Metrics

- Geometric evaluation (GEO)
- Graph-Sampling Based Distance (TOPO)
- Shortest Path Based Distance

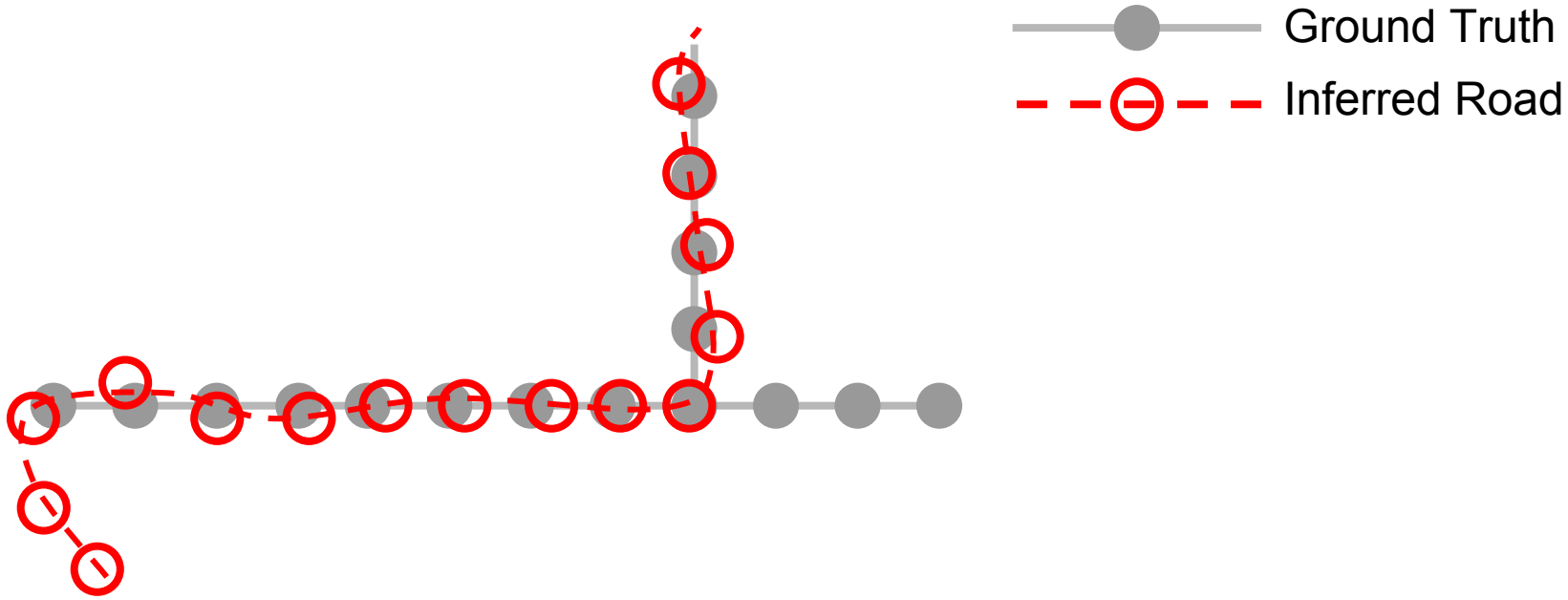
- Are those two maps the same?

- What’s the difference between those two maps?

Geometric evaluation (GEO)

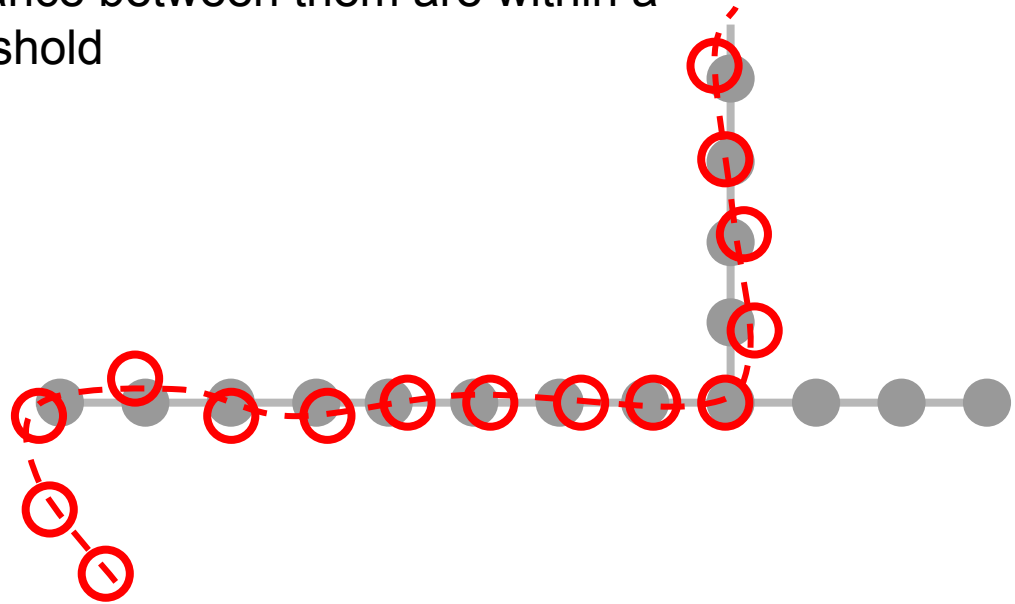


Geometric evaluation (GEO)



Geometric evaluation (GEO)

and could be matched if the distance between them are within a threshold

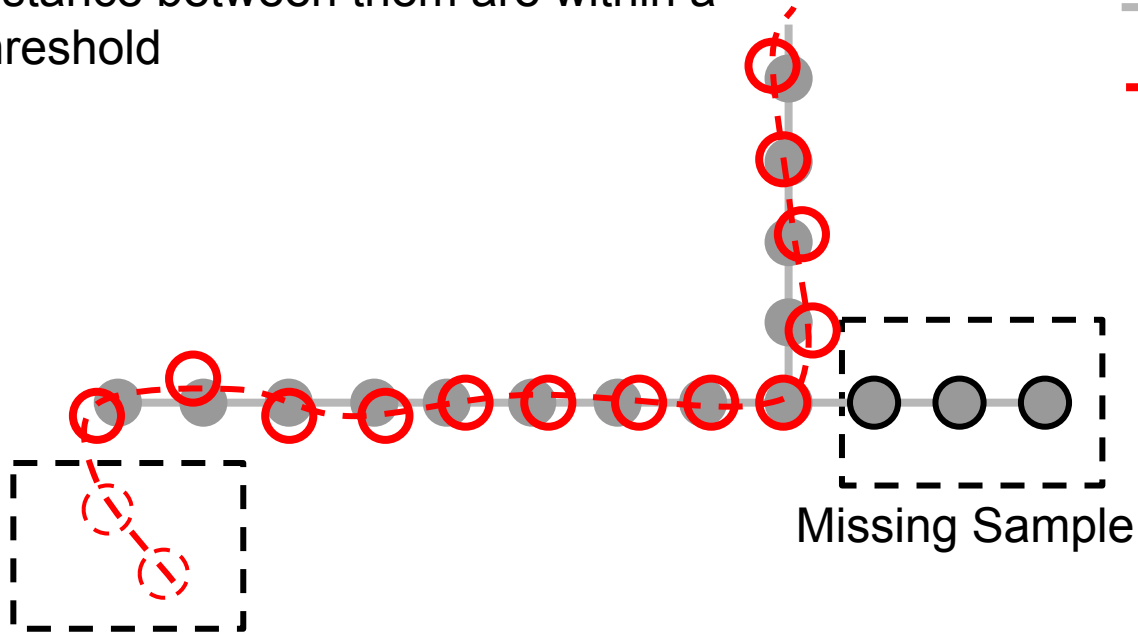


Ground Truth

Inferred Road

Geometric evaluation (GEO)

and could be matched if the distance between them are within a threshold



Ground Truth

Inferred Road

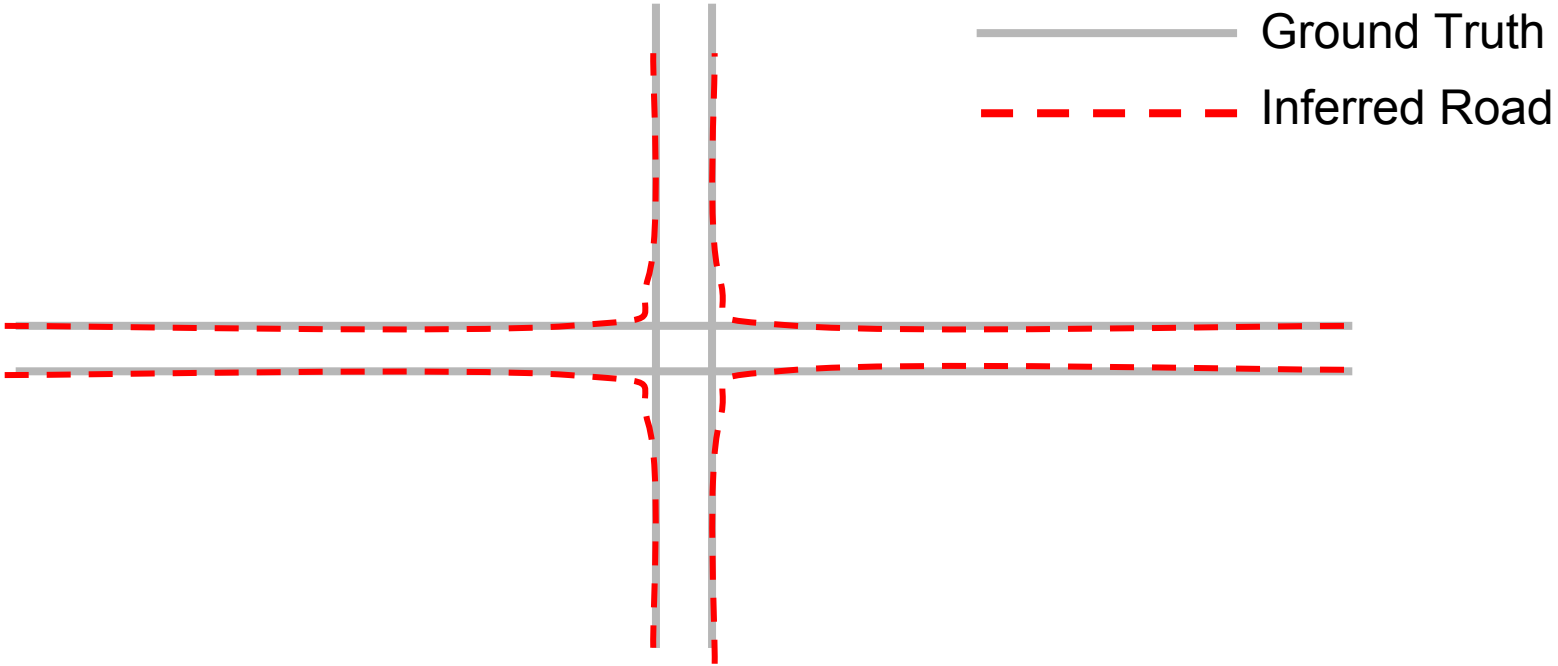
Overall performance

$$F = 2 \cdot \frac{precision \cdot recall}{precision + recall}$$

$$precision = 1 - \frac{|spurious\ samples|}{|inferred\ samples|}$$

$$recall = 1 - \frac{|missing\ samples|}{|ground\ truth\ samples|}$$

Geometric evaluation (GEO) Limitation



Graph-Sampling Based Distance (TOPO)

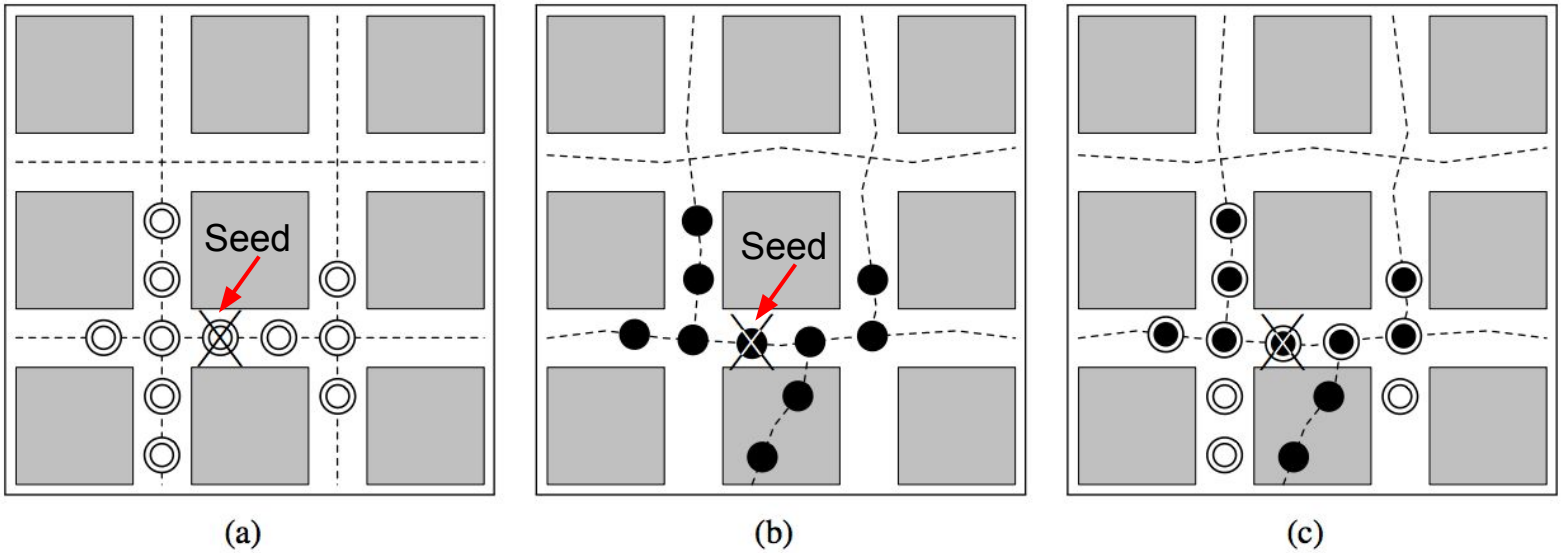
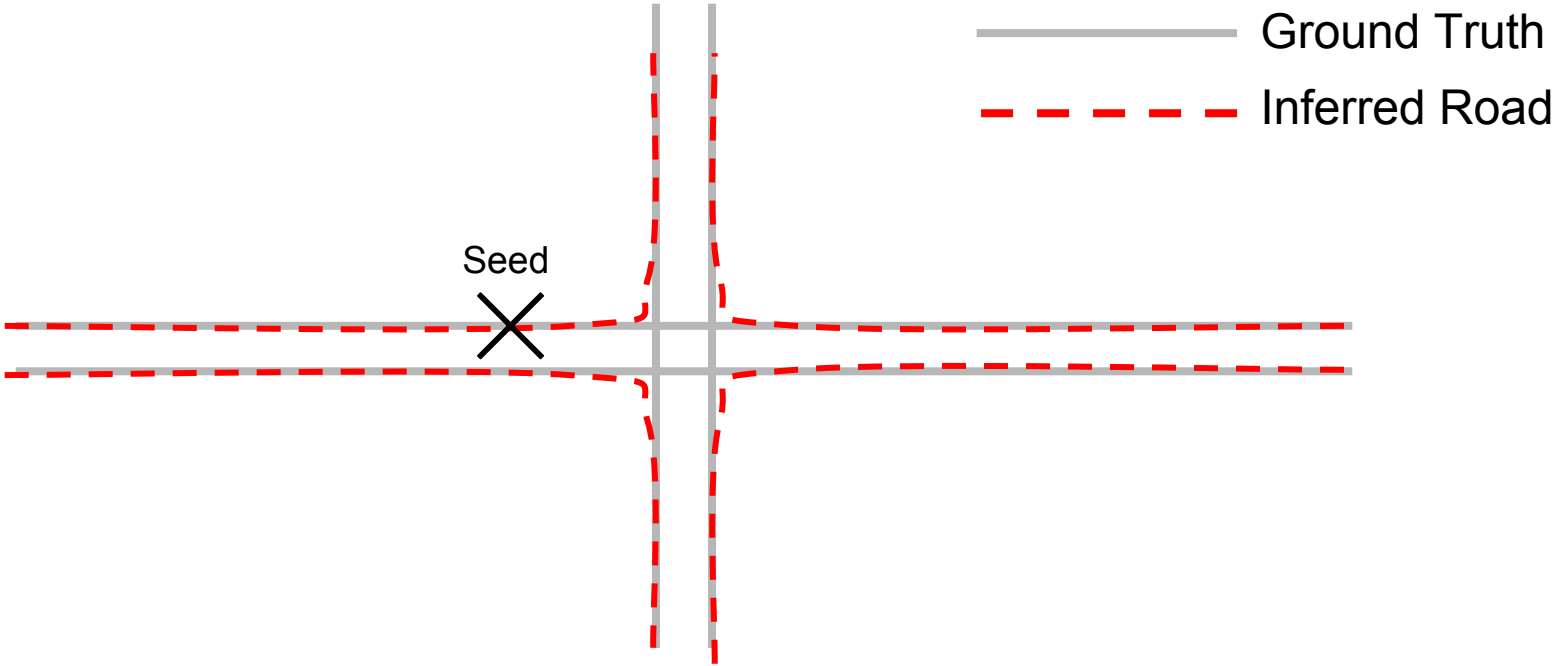


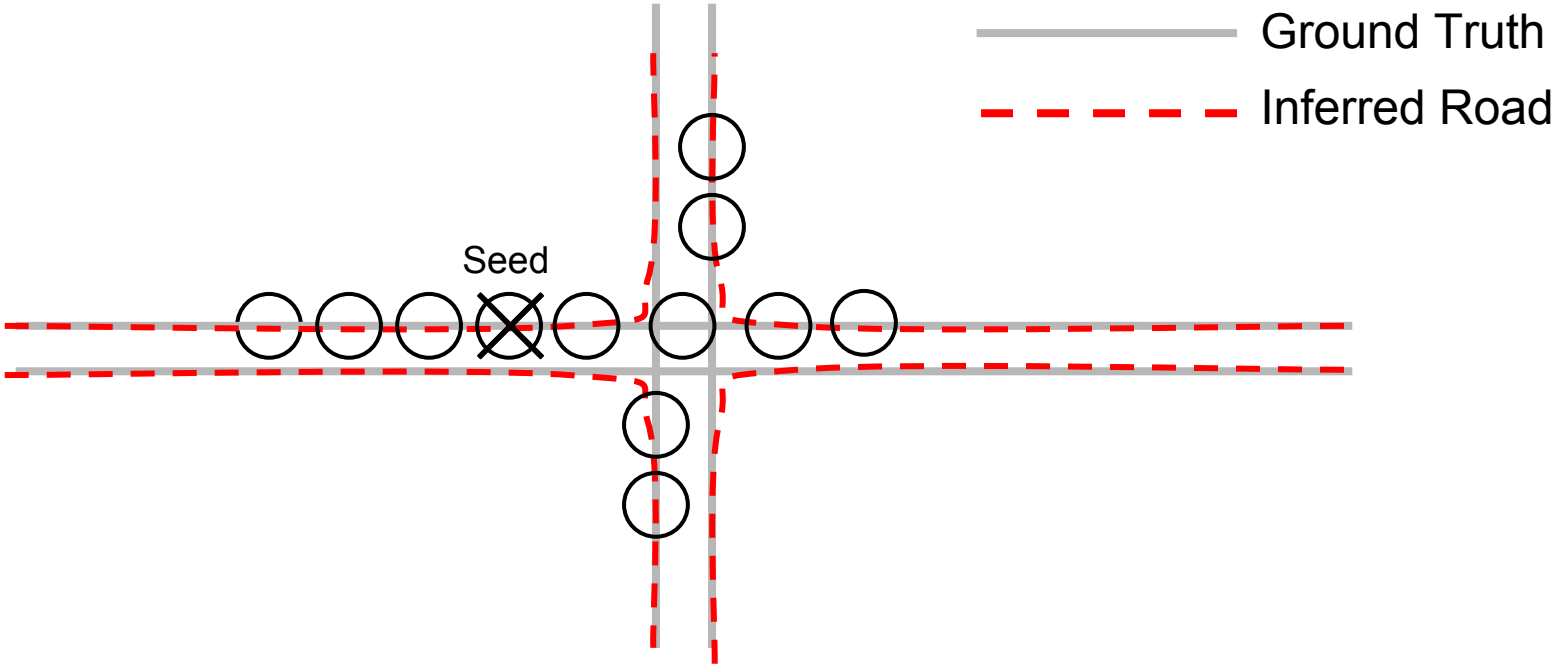
FIGURE 4 Overview of map comparison algorithm. (a) Holes are dropped at even intervals along edges of the ground truth map. (b) Marbles are dropped at even intervals along edges of the generated map. (c) Marbles from generated map fill holes where the maps overlap.

Eriksson, Jakob. "INFERRING ROAD MAPS FROM GPS TRACES: SURVEY AND COMPARATIVE EVALUATION 2 James Biagioni* 3 Ph. D. Student 4 Department of Computer Science 5."

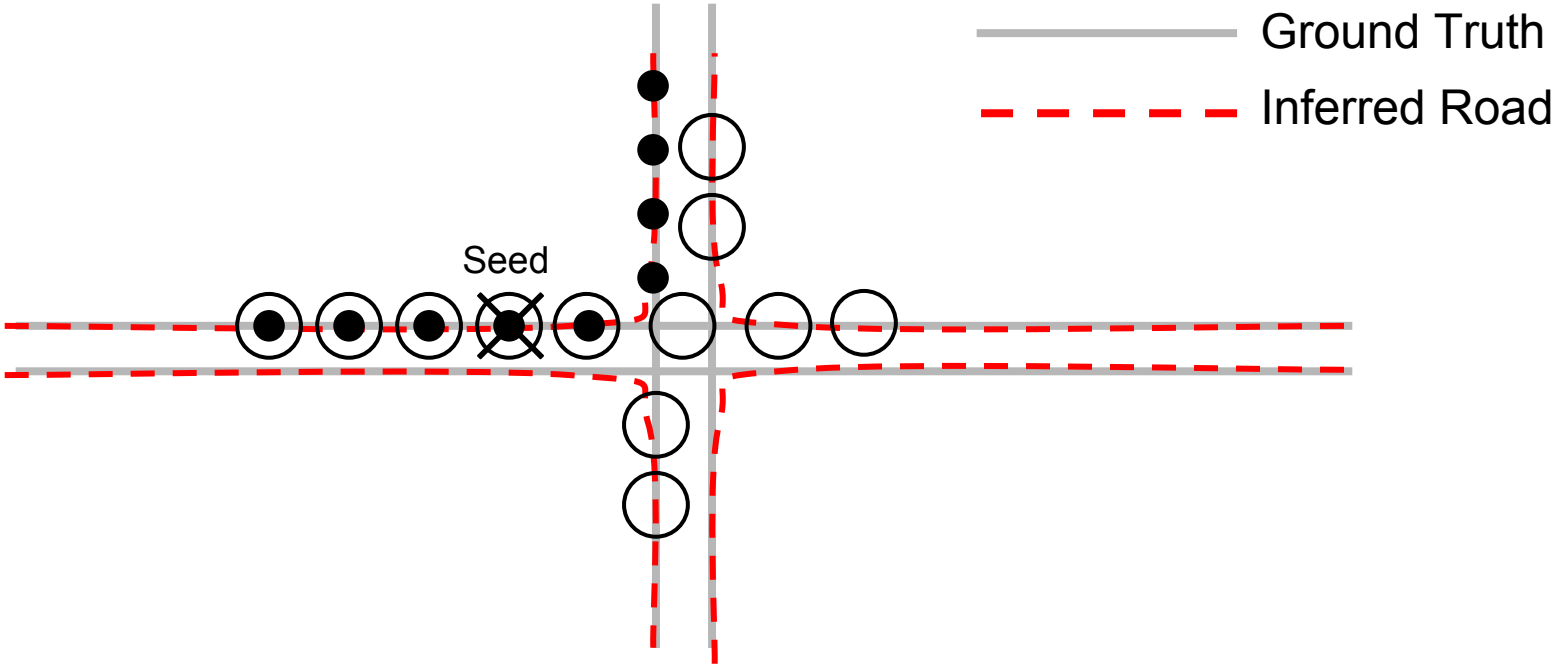
Graph-Sampling Based Distance (TOPO)



Graph-Sampling Based Distance (TOPO)

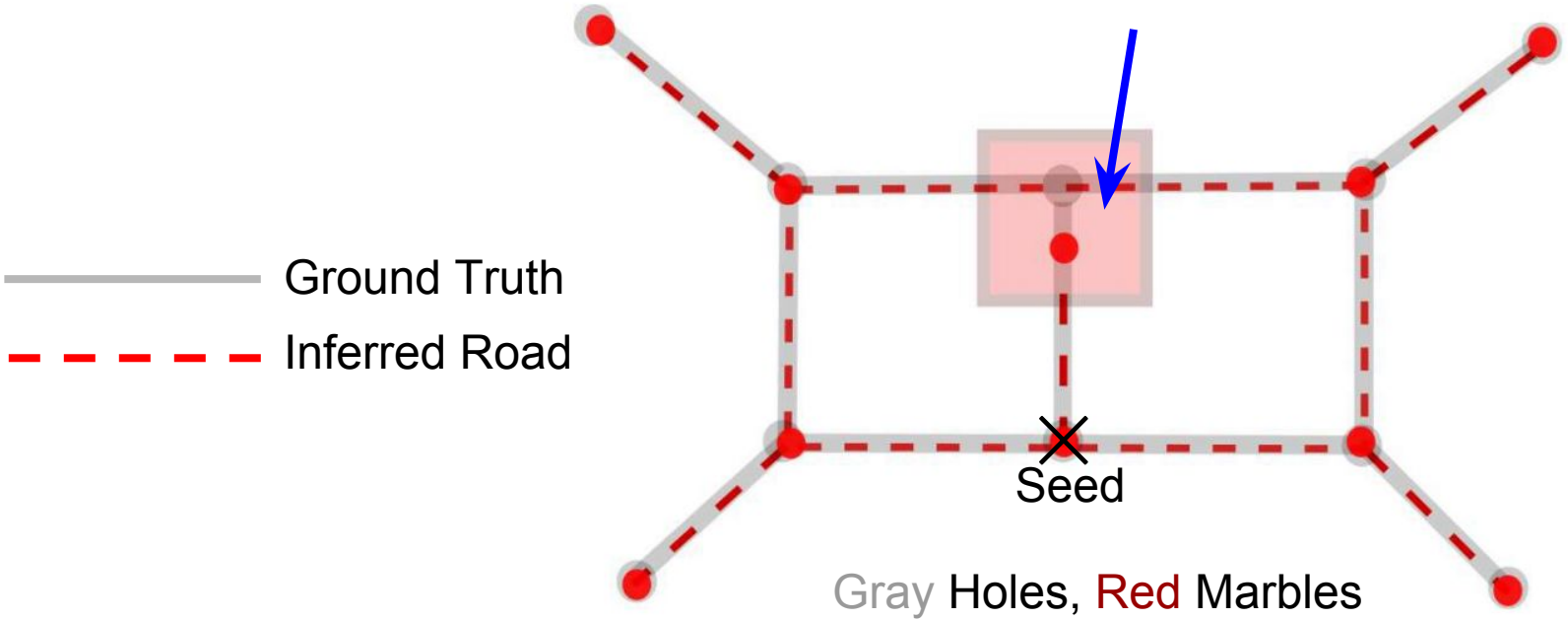


Graph-Sampling Based Distance (TOPO)



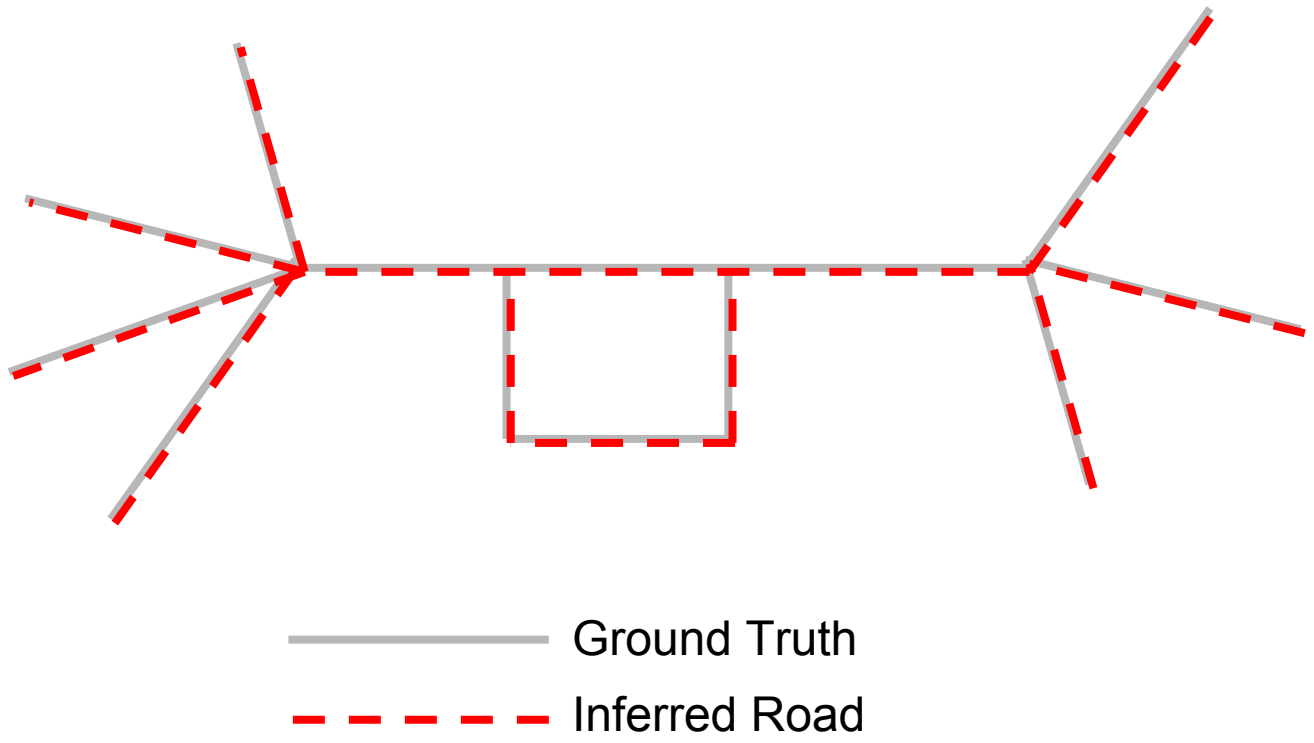
Graph-Sampling Based Distance (TOPO) Limitation

TOPO may fail to capture the broken connection

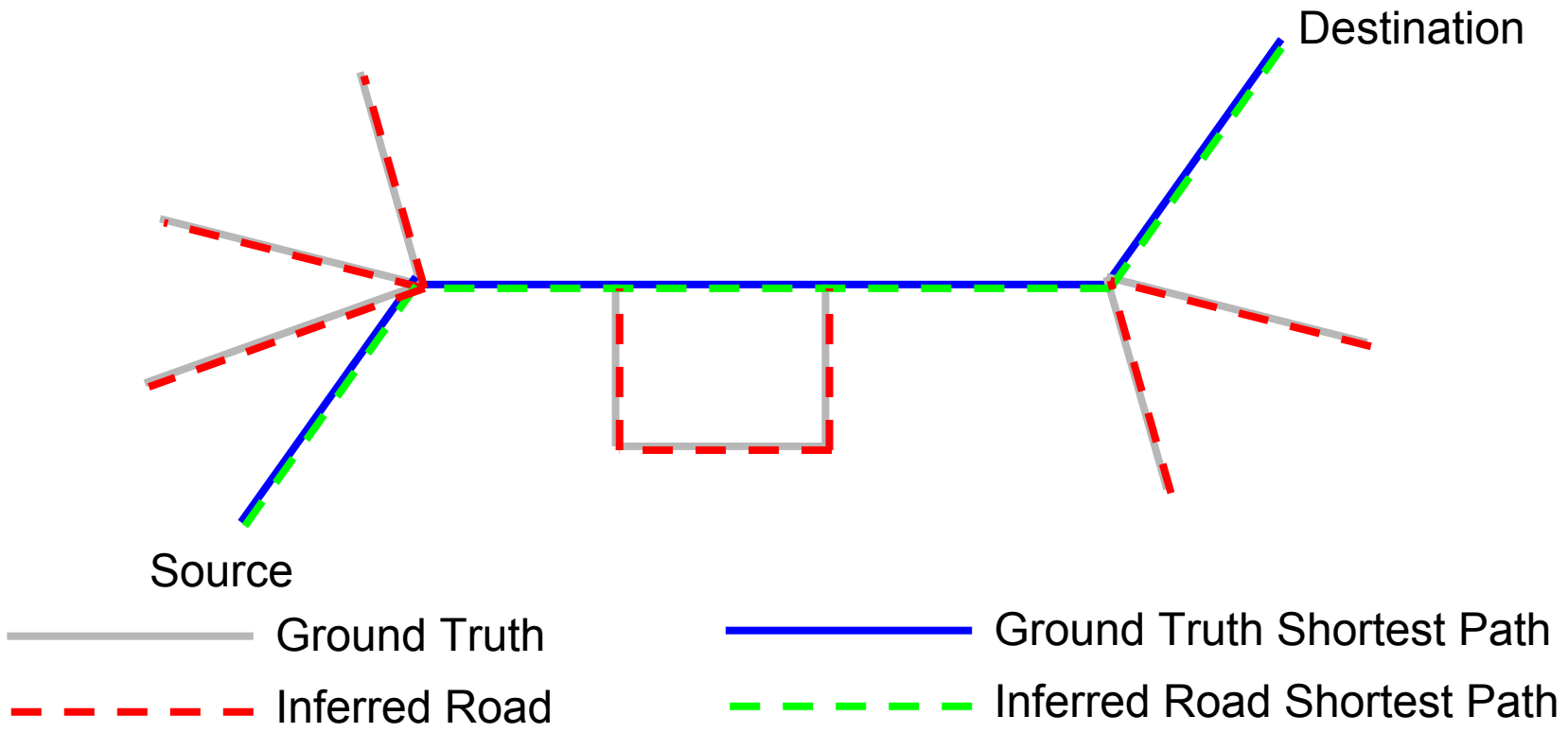


Ahmed, Mahmuda, et al. "A comparison and evaluation of map construction algorithms using vehicle tracking data." *GeoInformatica* 19.3 (2015): 601-632.

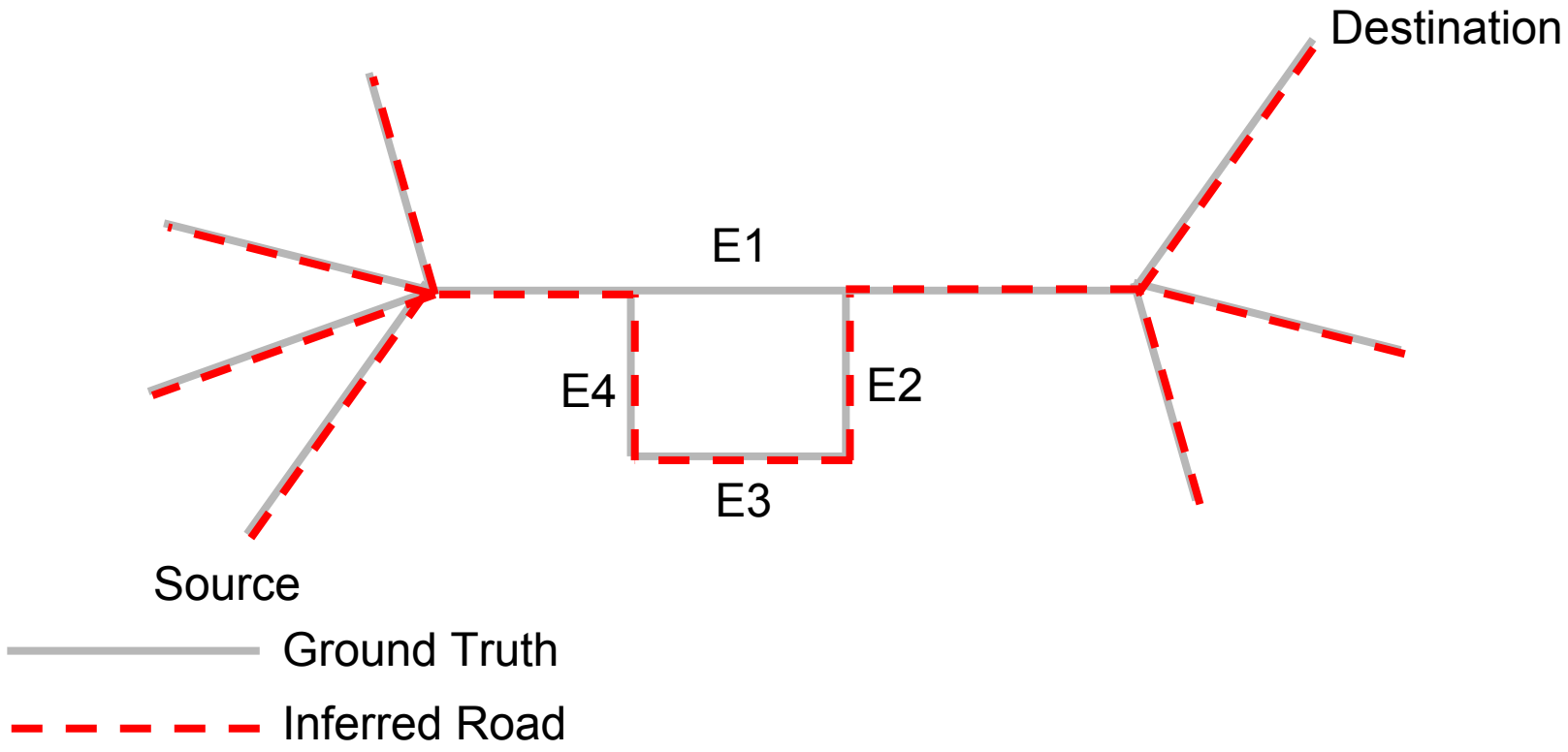
Shortest Path Based Distance



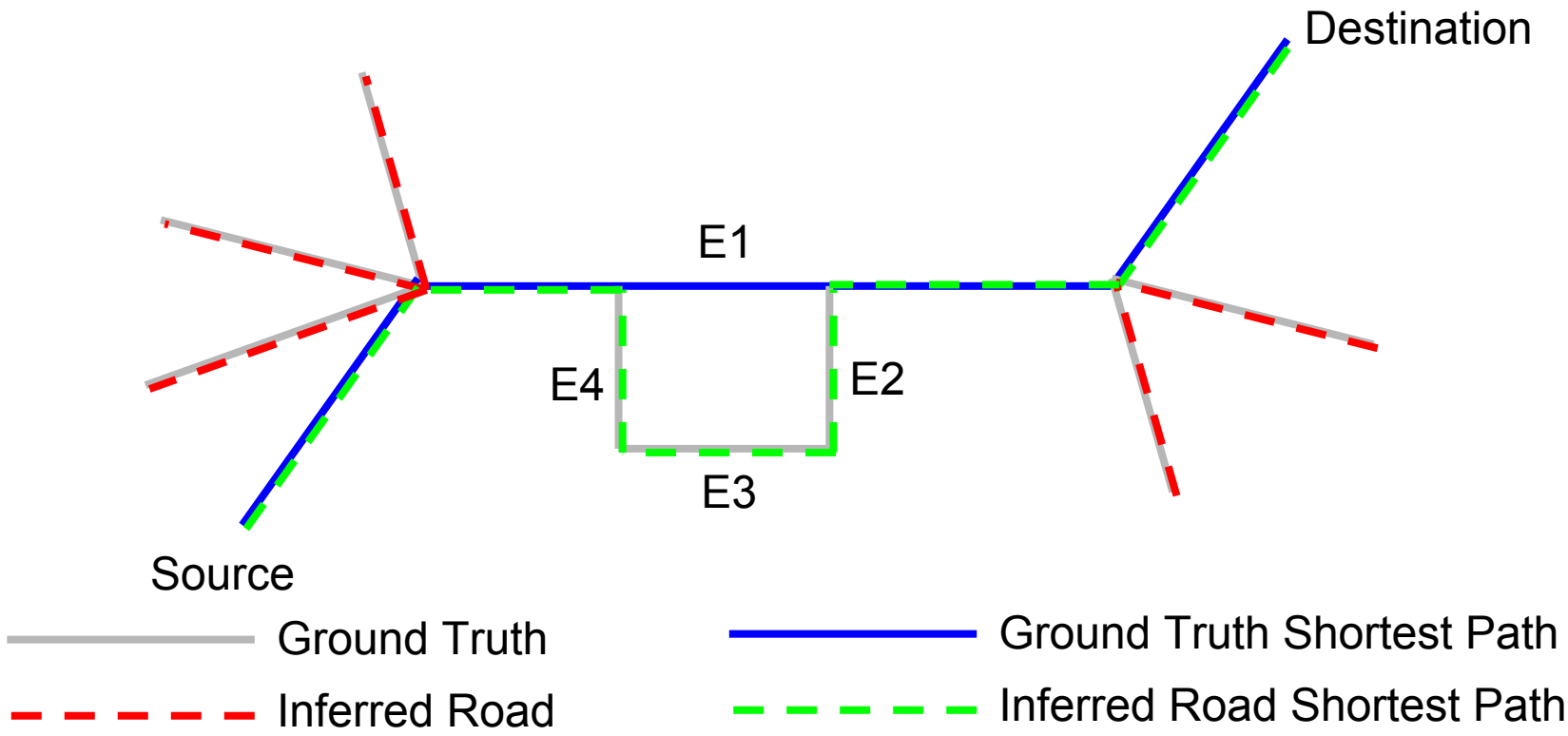
Shortest Path Based Distance



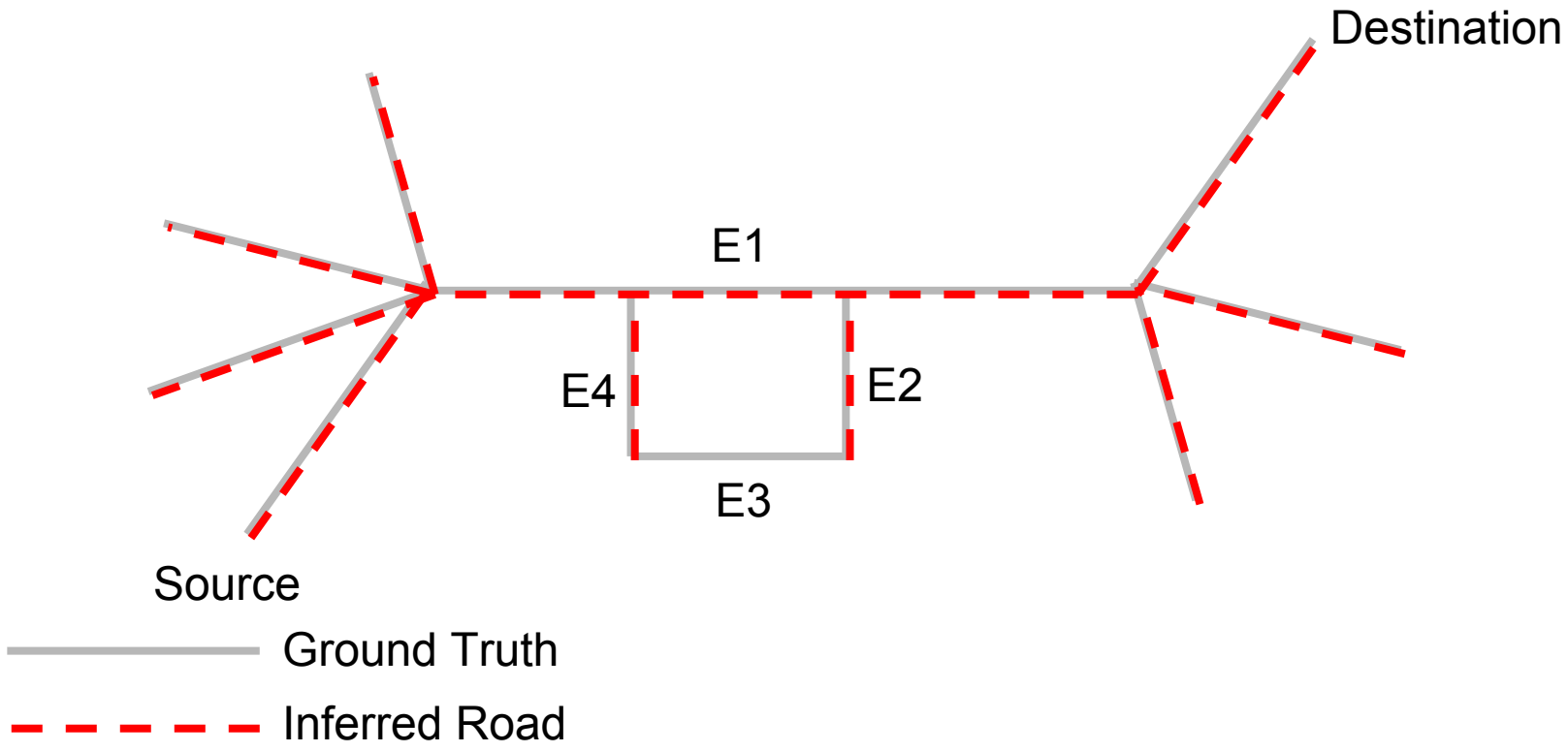
Shortest Path Based Distance



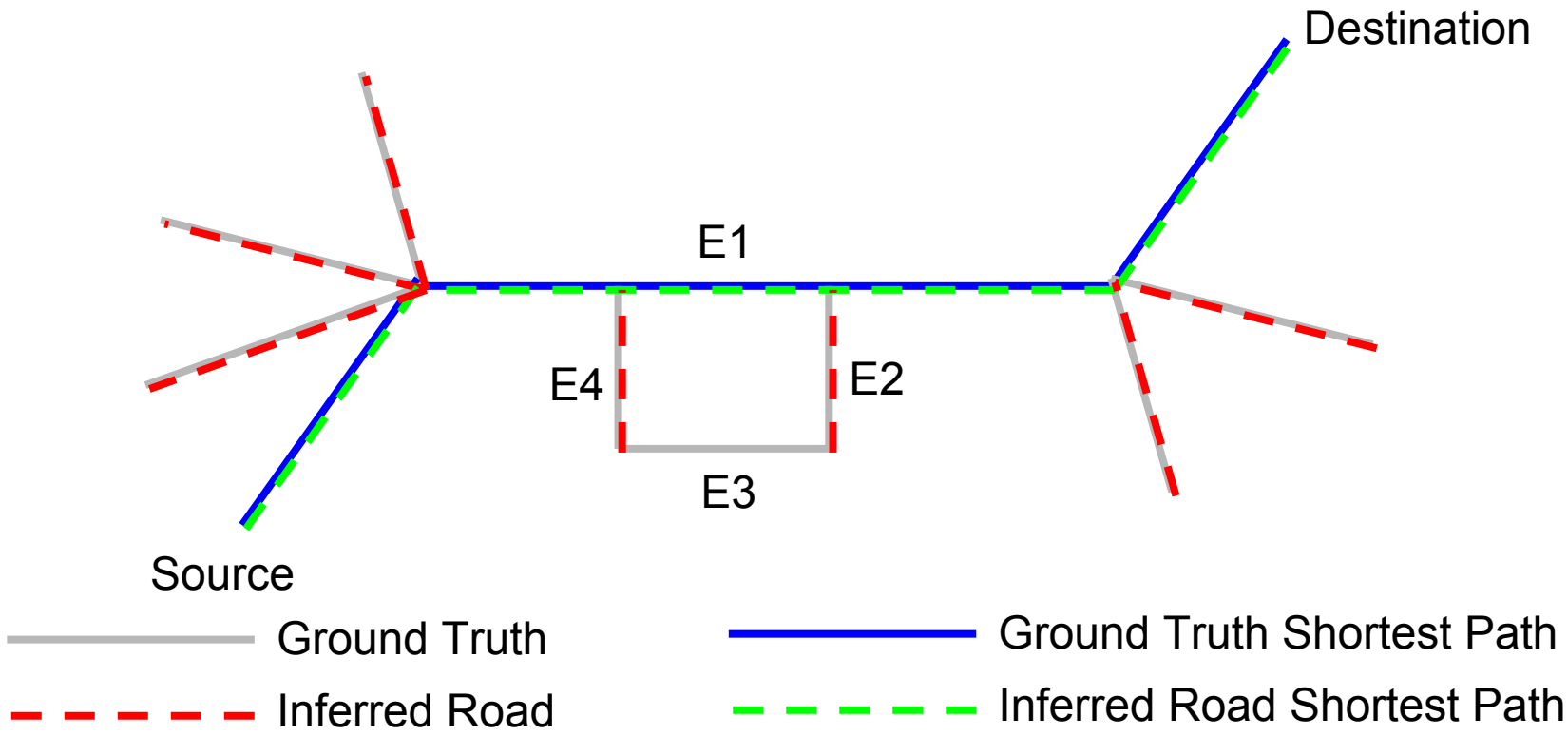
Shortest Path Based Distance



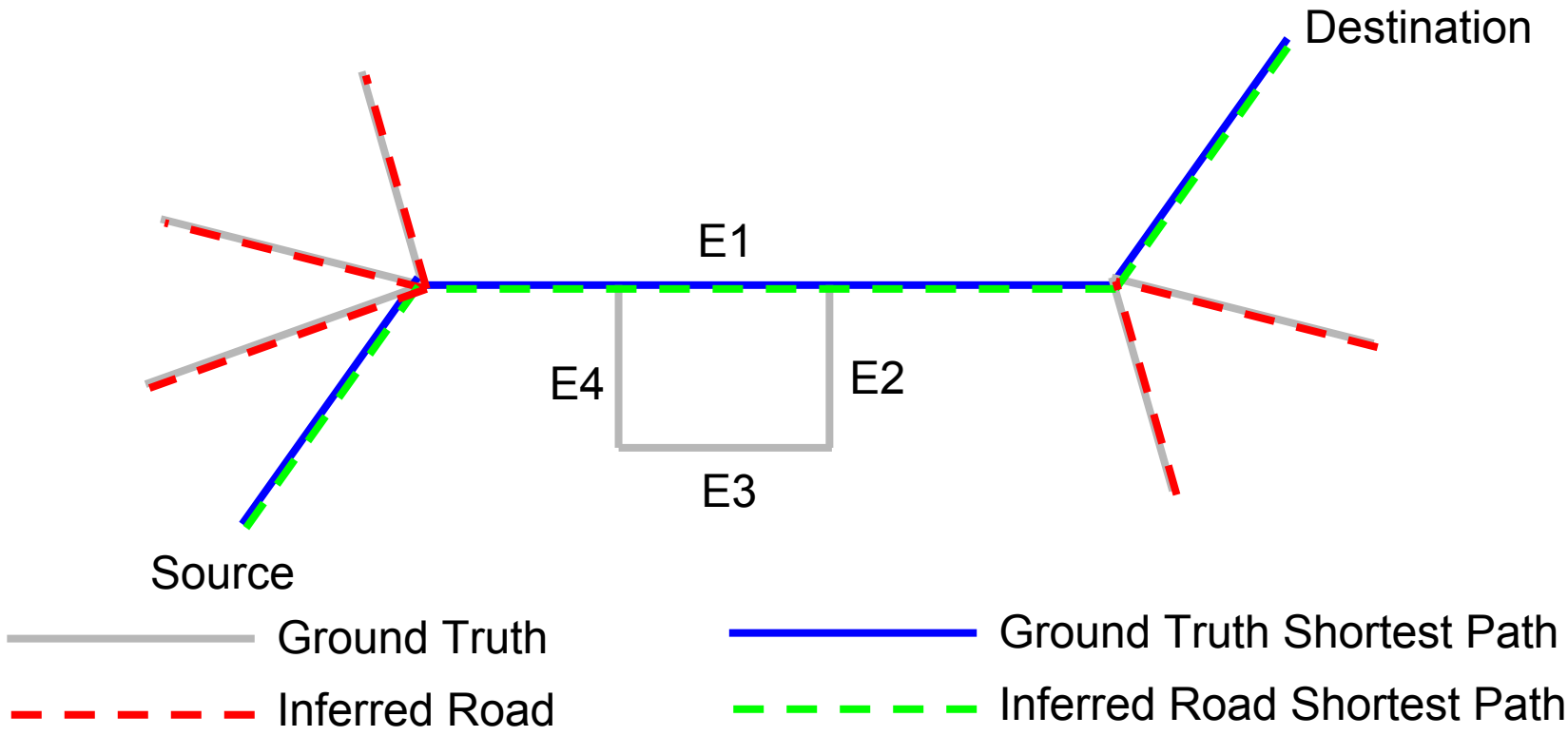
Shortest Path Based Distance



Shortest Path Based Distance



Shortest Path Based Distance



Similar Approaches

- Map Update
- Satellite Images

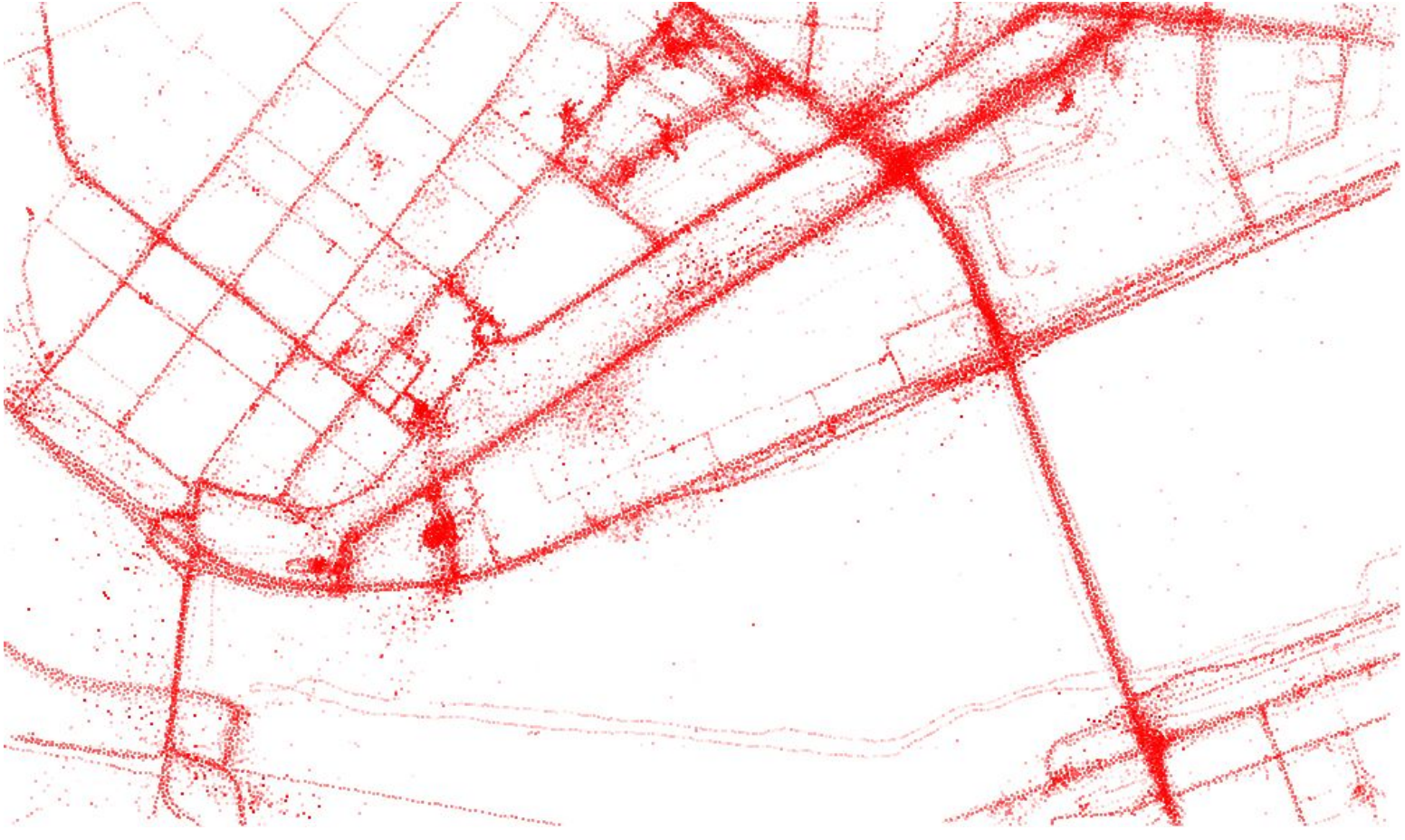
(a) G (b) G_{RG} (c) $G+G_{RG}$

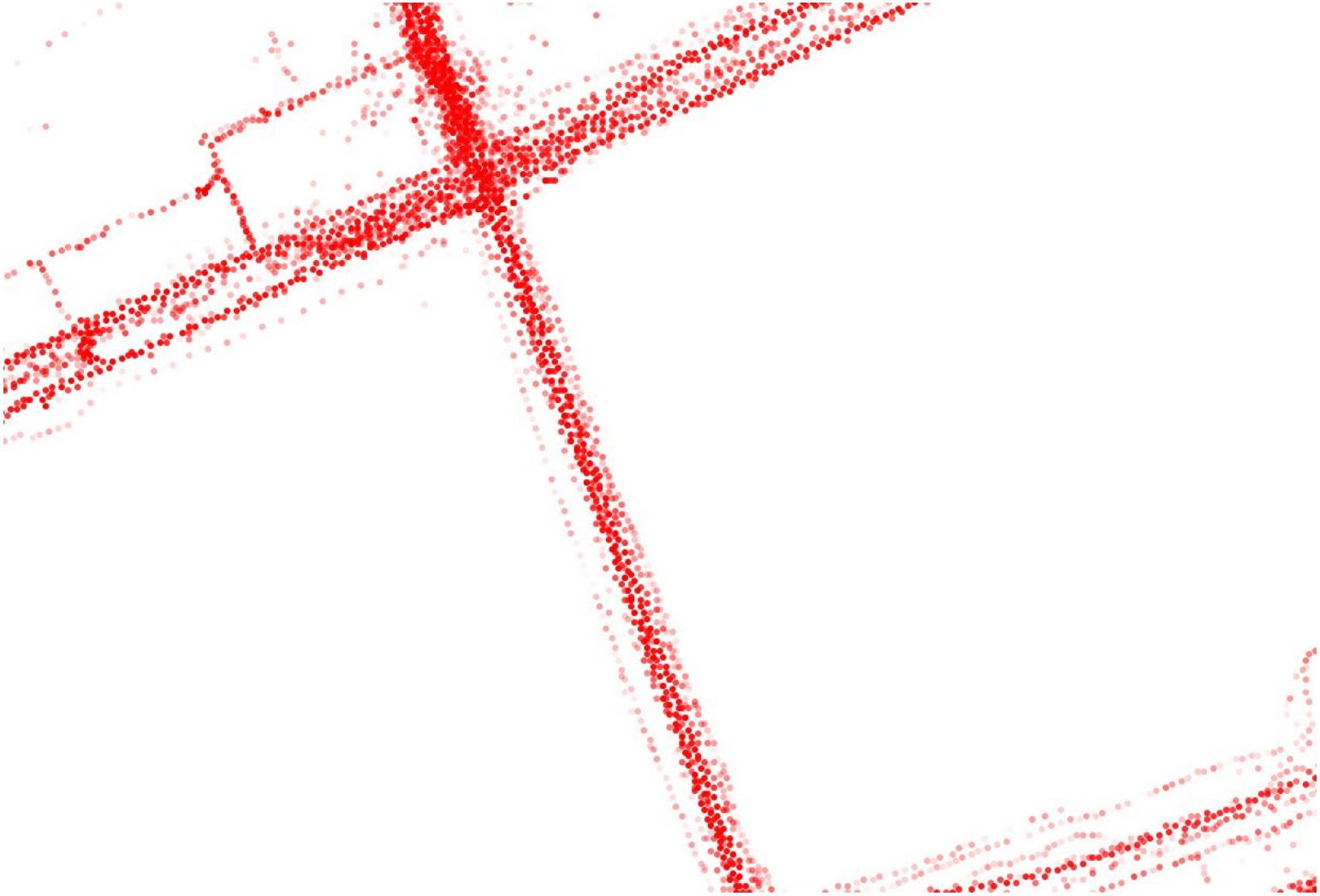
Figure 1. An example of the map update processing

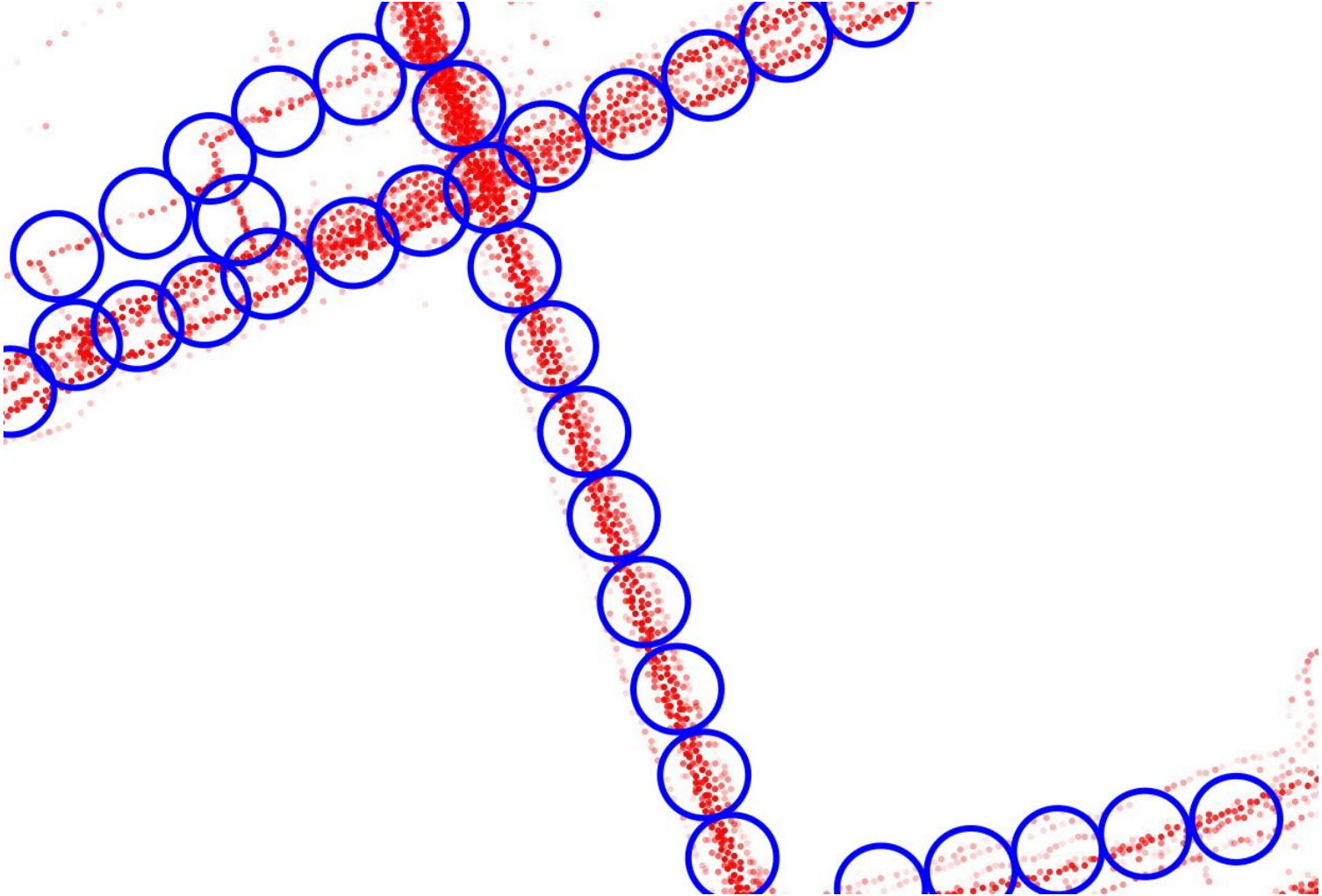
Lab 4

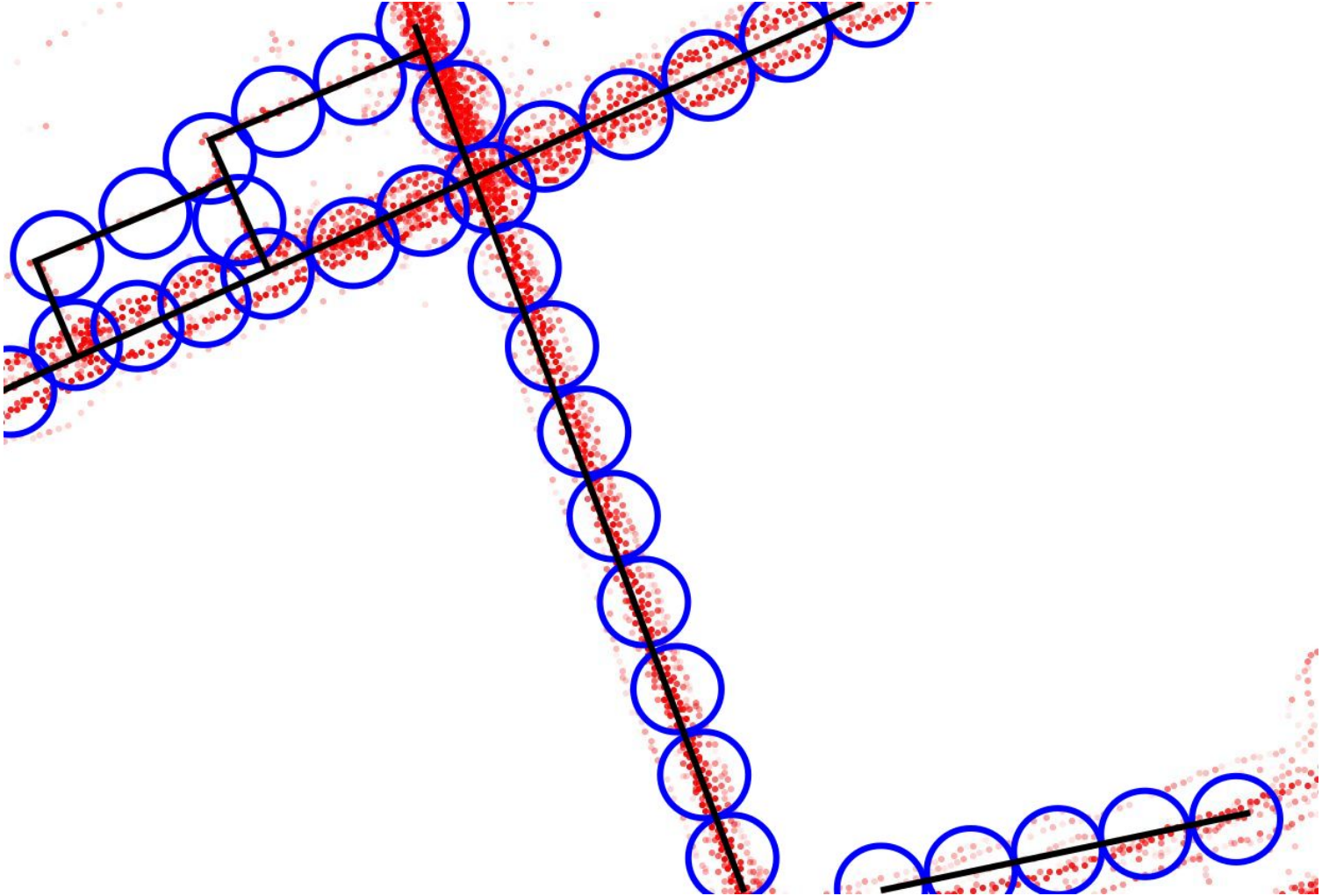
- Implement a simplified clustering-based map inference algorithm
- Design and implement an evaluation metric
- Compare with Biagioni/Eriksson algorithm

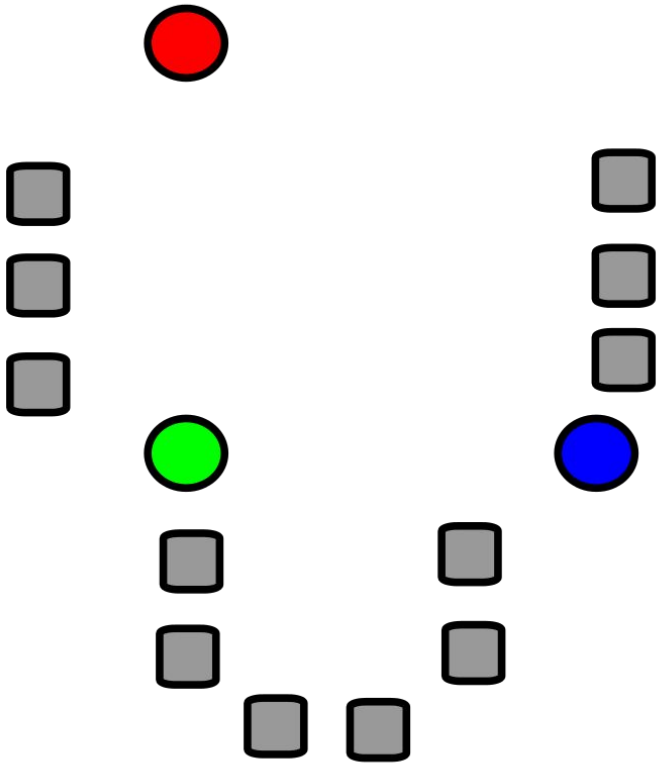
k-means Clustering



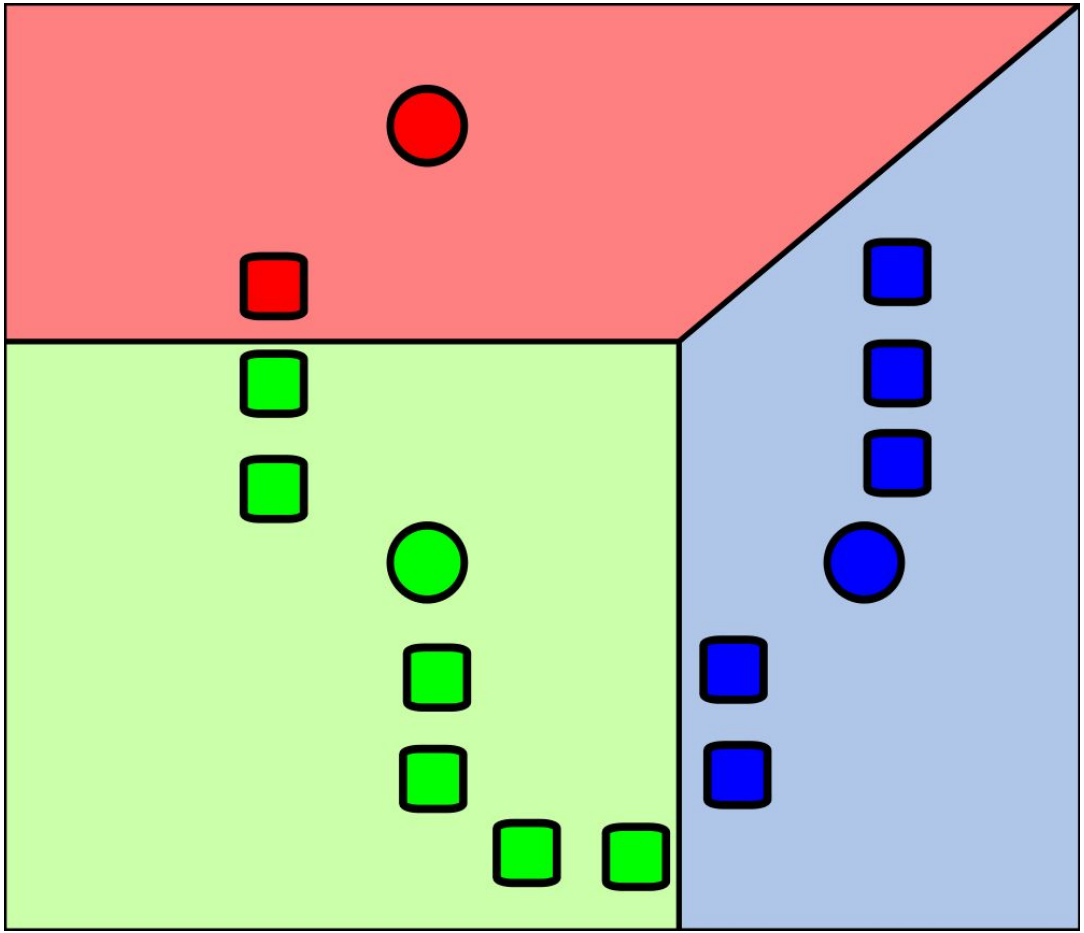




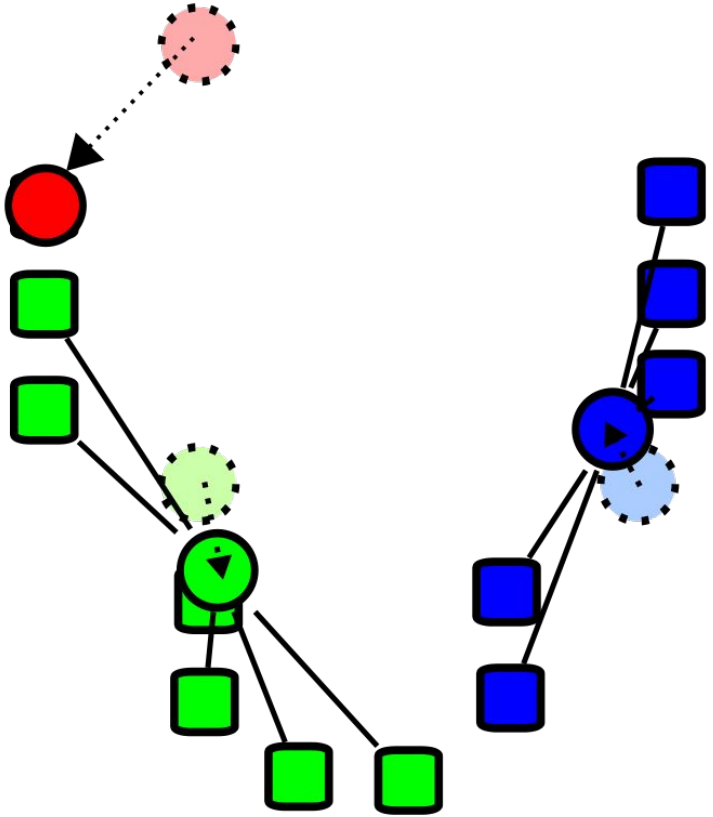




Images from Wikipedia “k-means clustering”



Images from Wikipedia “k-means clustering”



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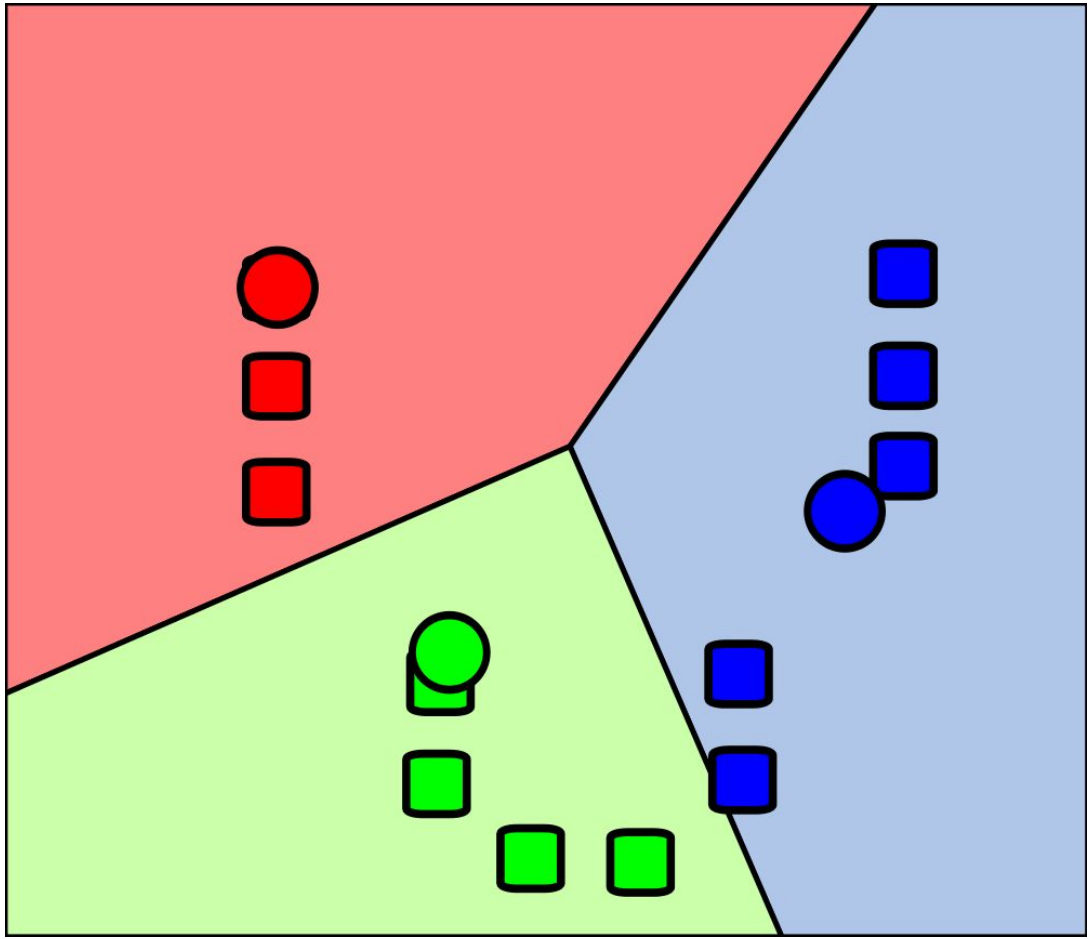
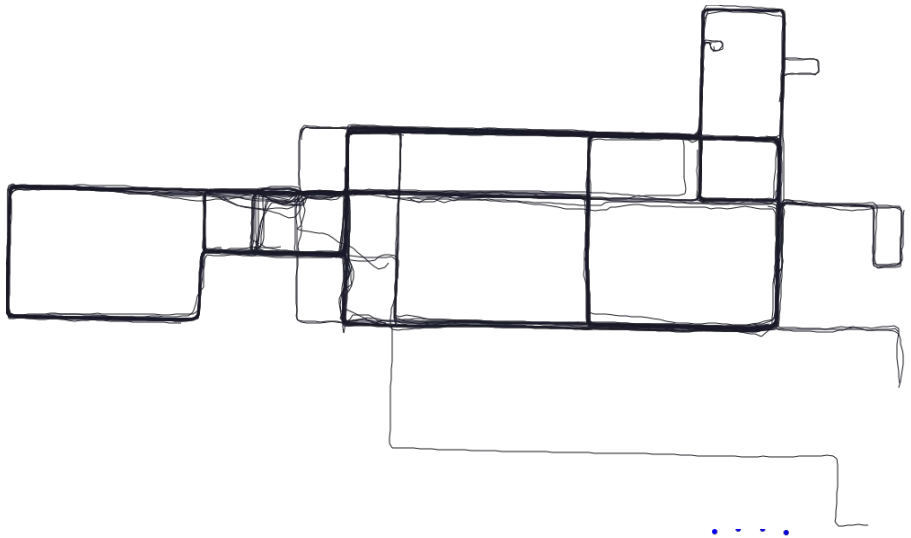
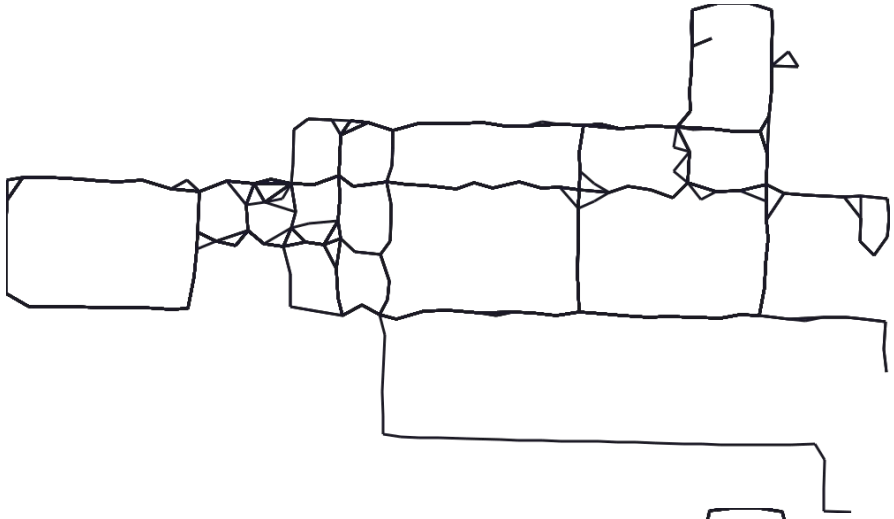
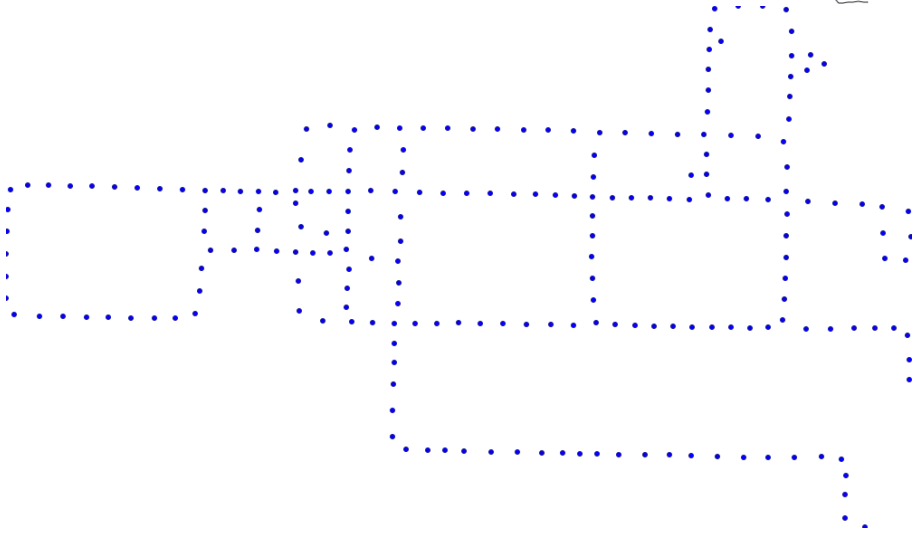
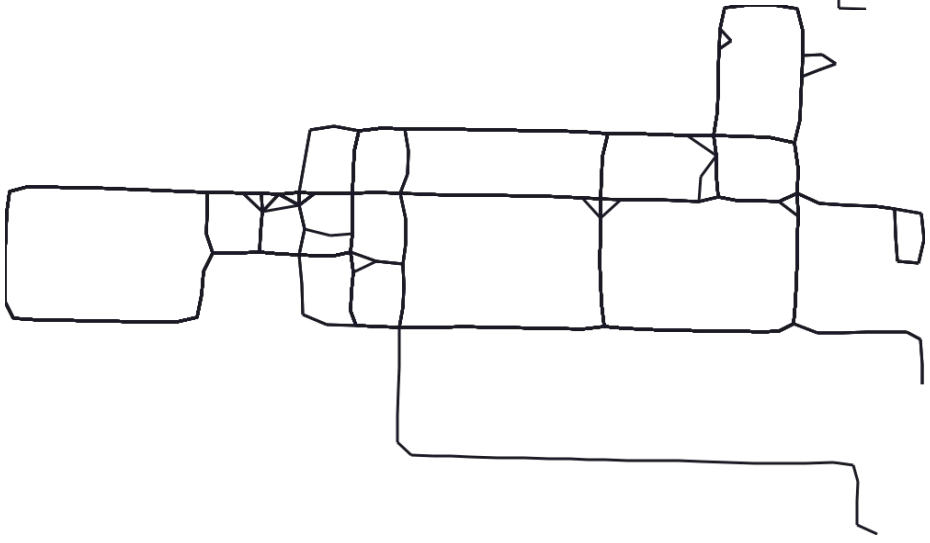


Images from Wikipedia “k-means clustering”









Following are some discarded slides ….

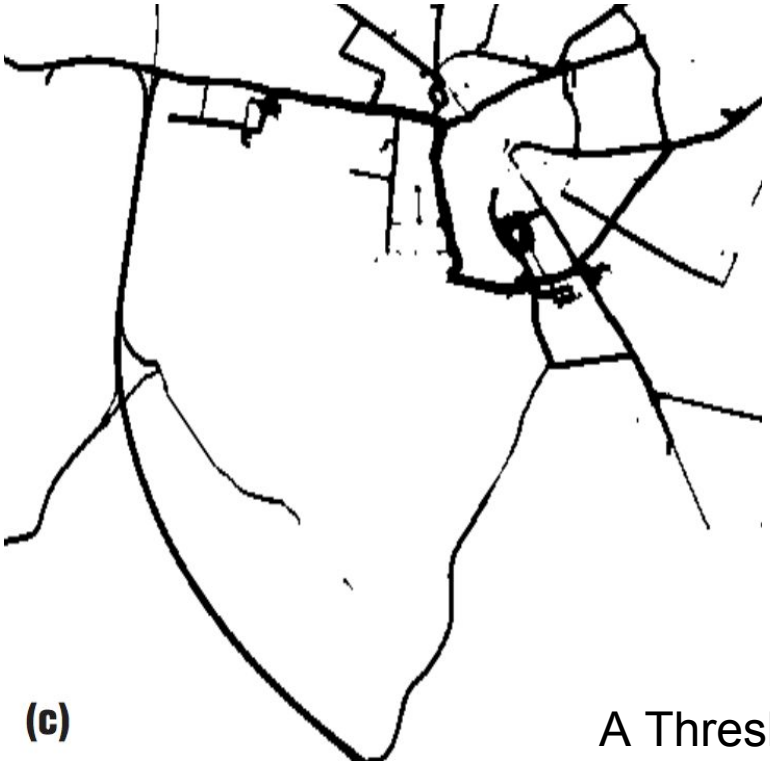
Basic KDE Algorithm - Density Estimation

Histogram

Blurred Histogram

Davies, Jonathan J., Alastair R. Beresford, and Andy Hopper. "Scalable, distributed, real-time map generation." *IEEE Pervasive Computing* 5.4 (2006): 47-54.

Basic KDE Algorithm - Density Estimation

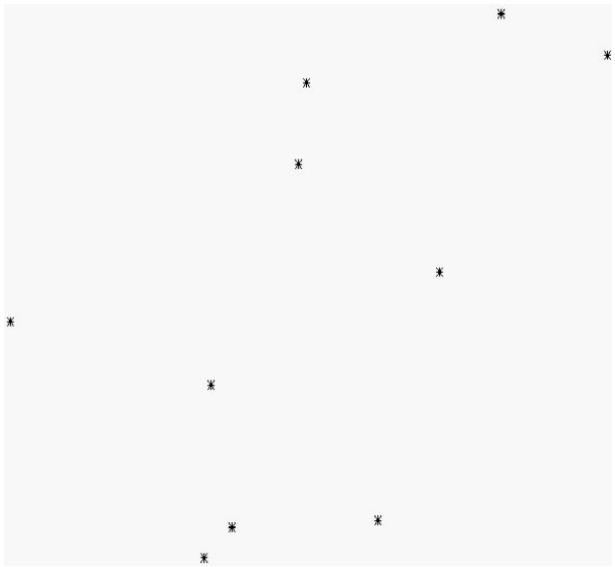


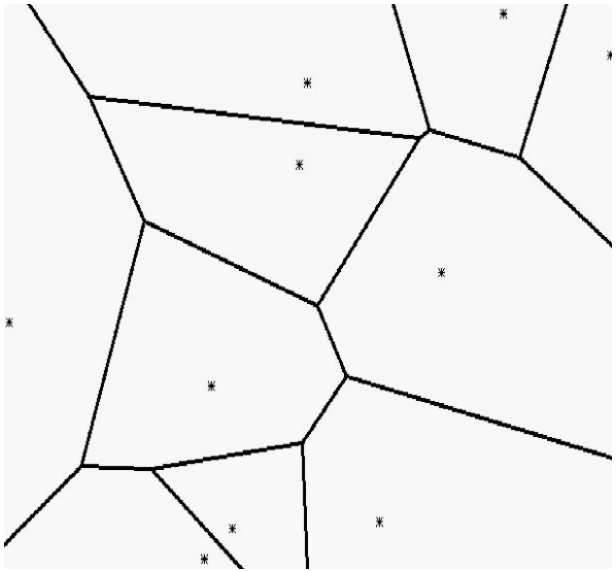
A Threshold Histogram

Davies, Jonathan J., Alastair R. Beresford, and Andy Hopper. "Scalable, distributed, real-time map generation." *IEEE Pervasive Computing* 5.4 (2006): 47-54.

Basic KDE Algorithm - Extract Centerlines

- Voronoi diagram

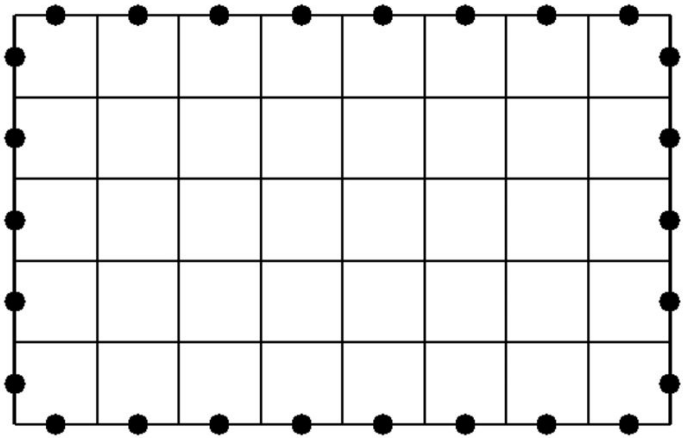


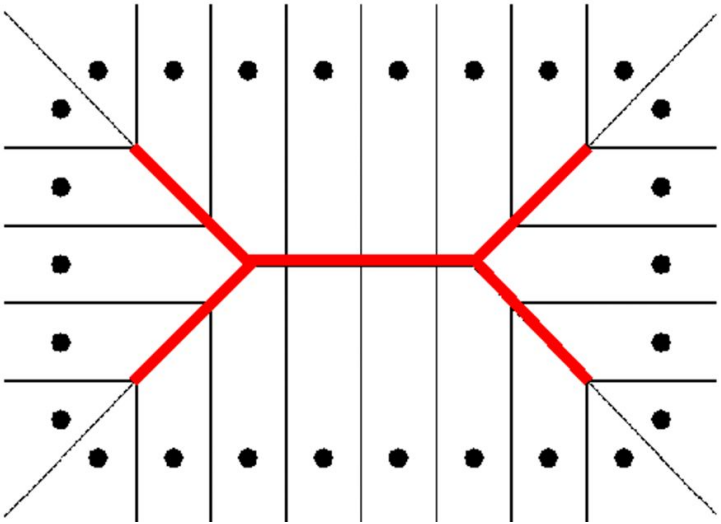


http://www.inf.u-szeged.hu/~palagyi/skel/skel.html

Basic KDE Algorithm - Extract Centerlines

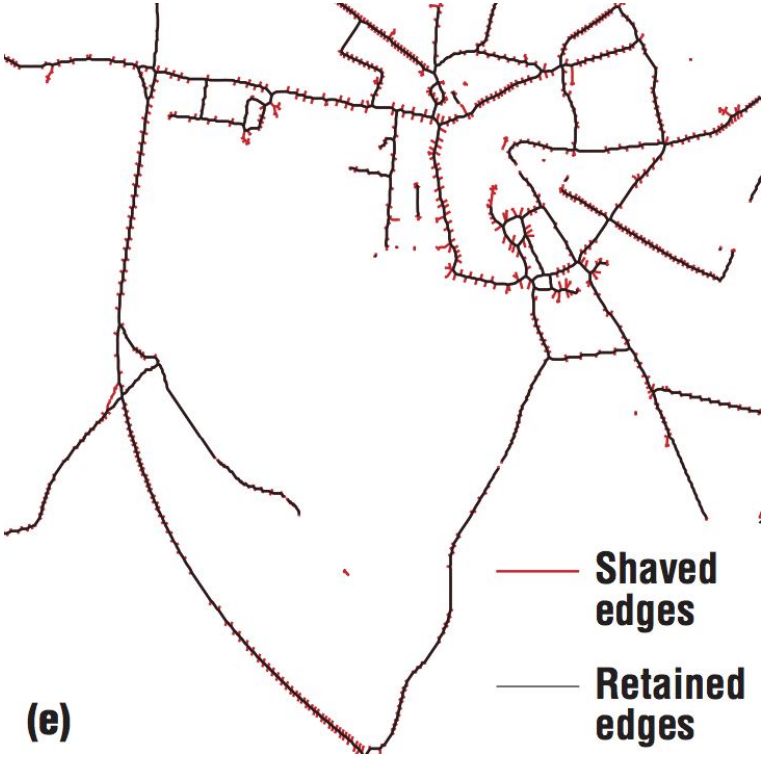
- Voronoi diagram

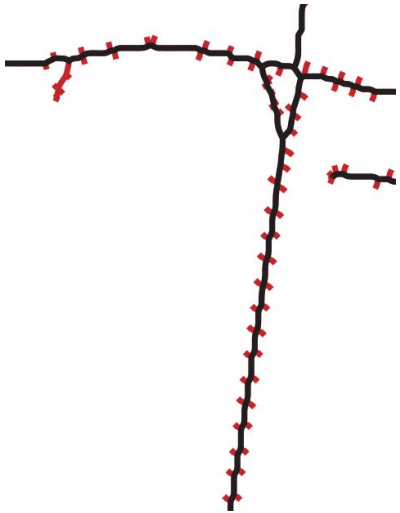




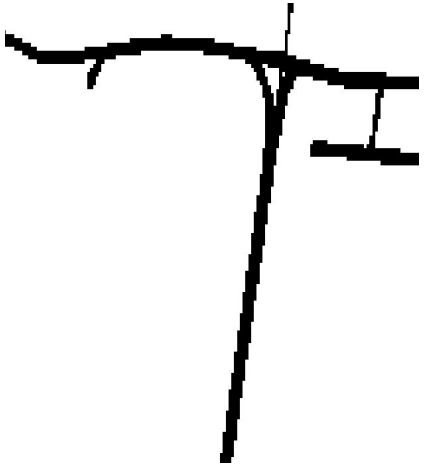
http://www.inf.u-szeged.hu/~palagyi/skel/skel.html

Basic KDE Algorithm - Extract Centerlines





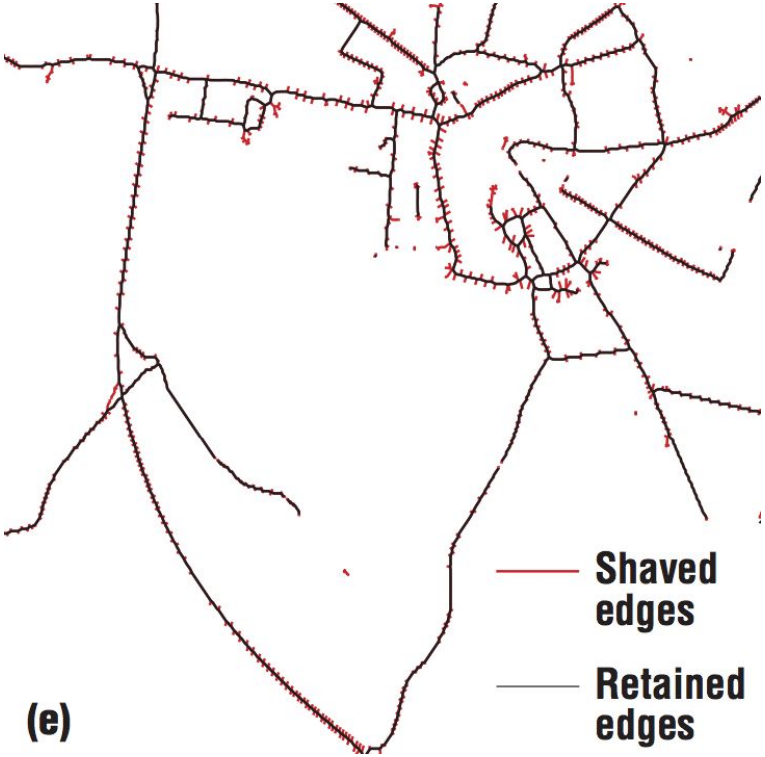
“Hairy” appearance

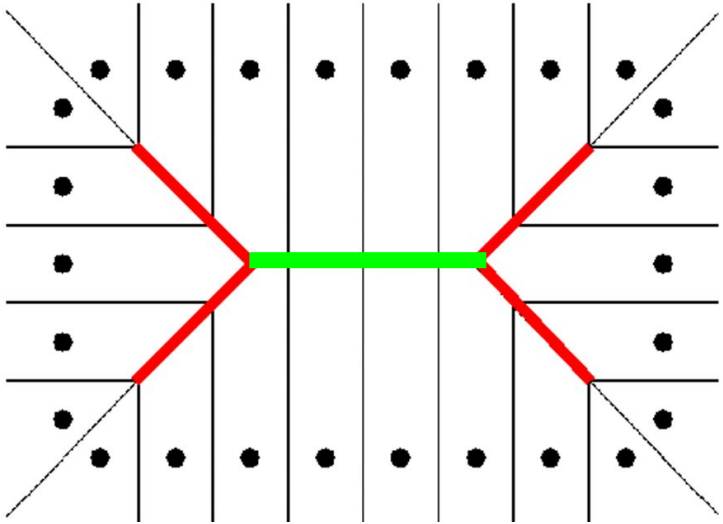


Edges are not smooth

Davies, Jonathan J., Alastair R. Beresford, and Andy Hopper. "Scalable, distributed, real-time map generation." *IEEE Pervasive Computing* 5.4 (2006): 47-54.

Basic KDE Algorithm - Extract Centerlines

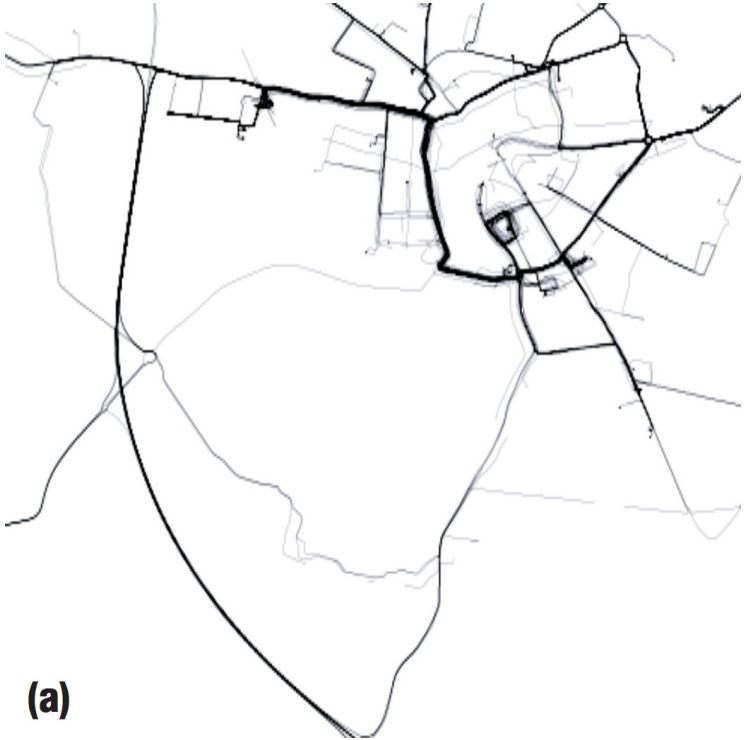


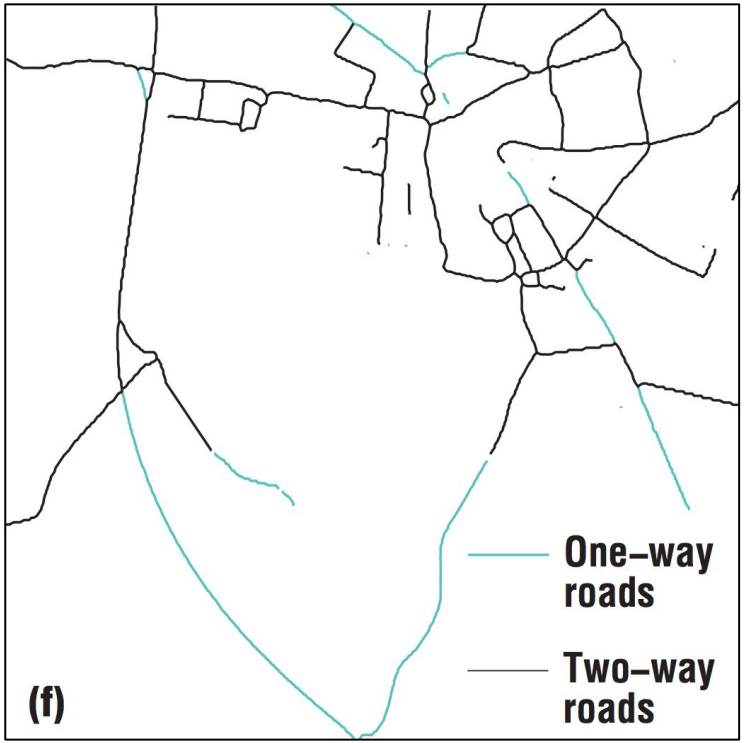


"Hairy"

Davies, Jonathan J., Alastair R. Beresford, and Andy Hopper. "Scalable, distributed, real-time map generation." *IEEE Pervasive Computing* 5.4 (2006): 47-54.

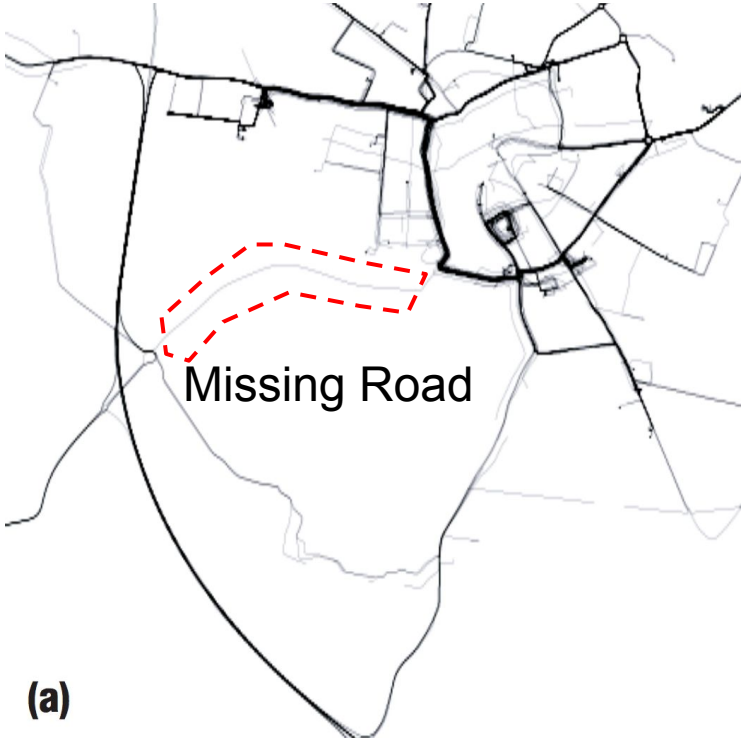
Basic KDE Algorithm - Final Result

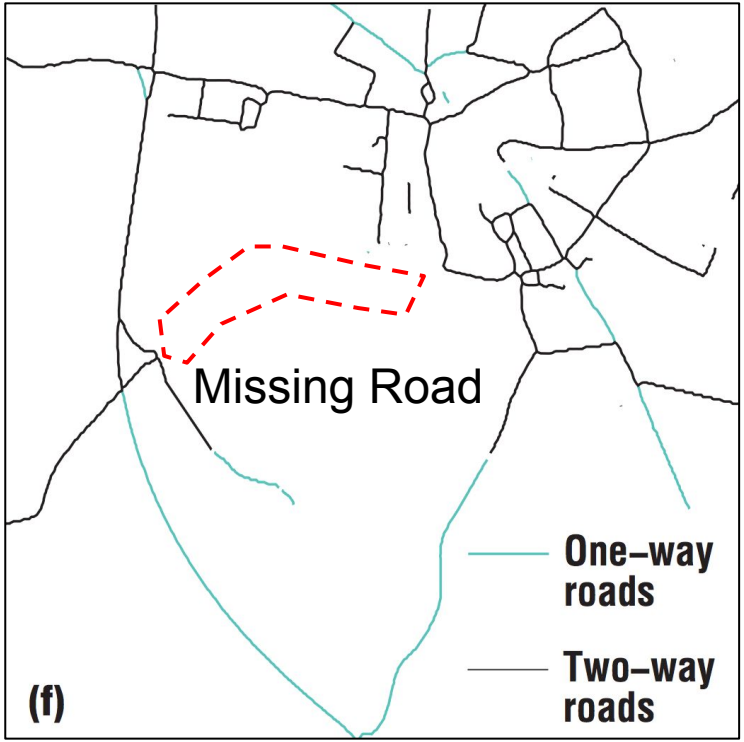




Davies, Jonathan J., Alastair R. Beresford, and Andy Hopper. "Scalable, distributed, real-time map generation." *IEEE Pervasive Computing* 5.4 (2006): 47-54.

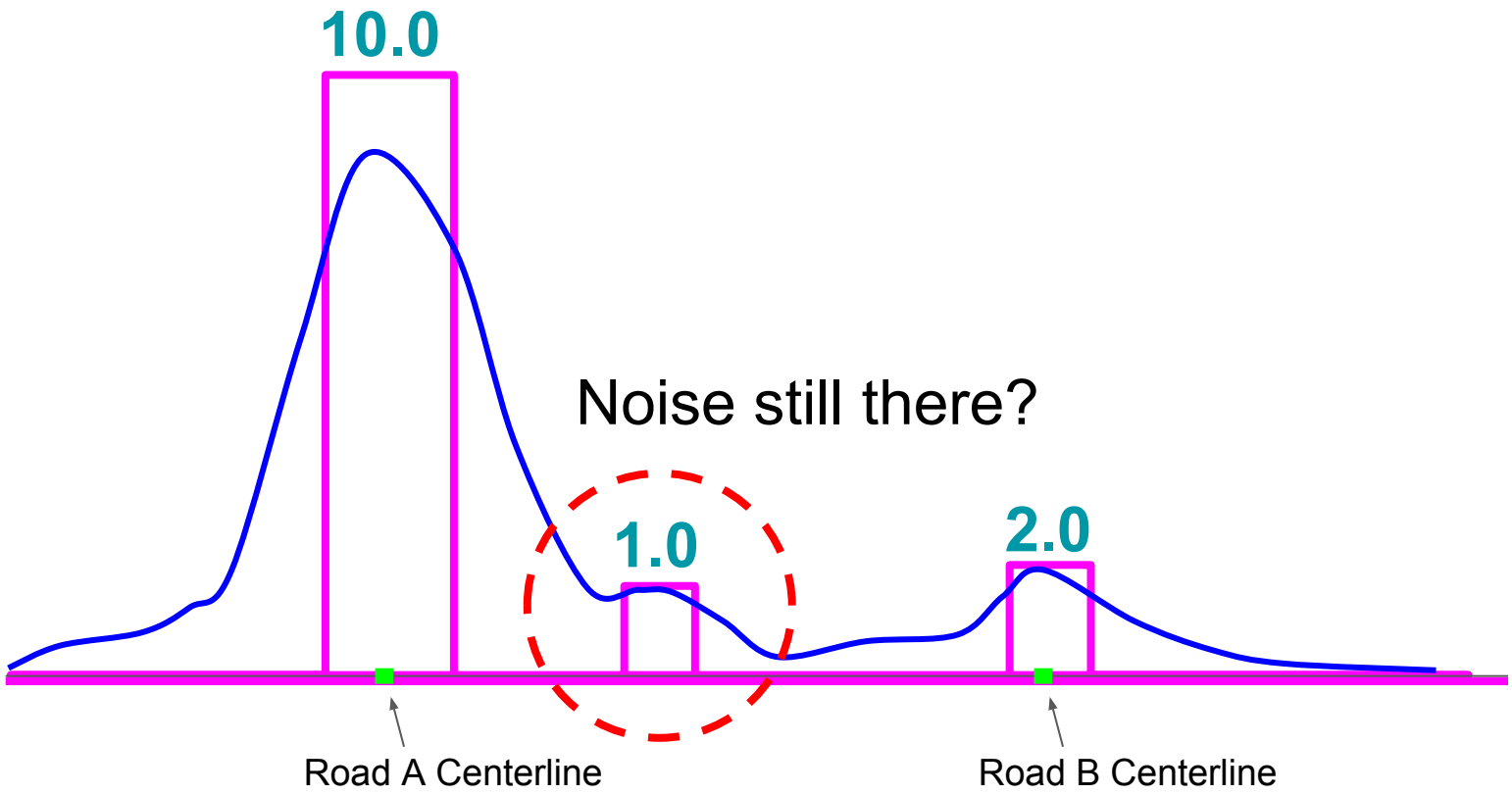
Basic KDE Algorithm - Final Result





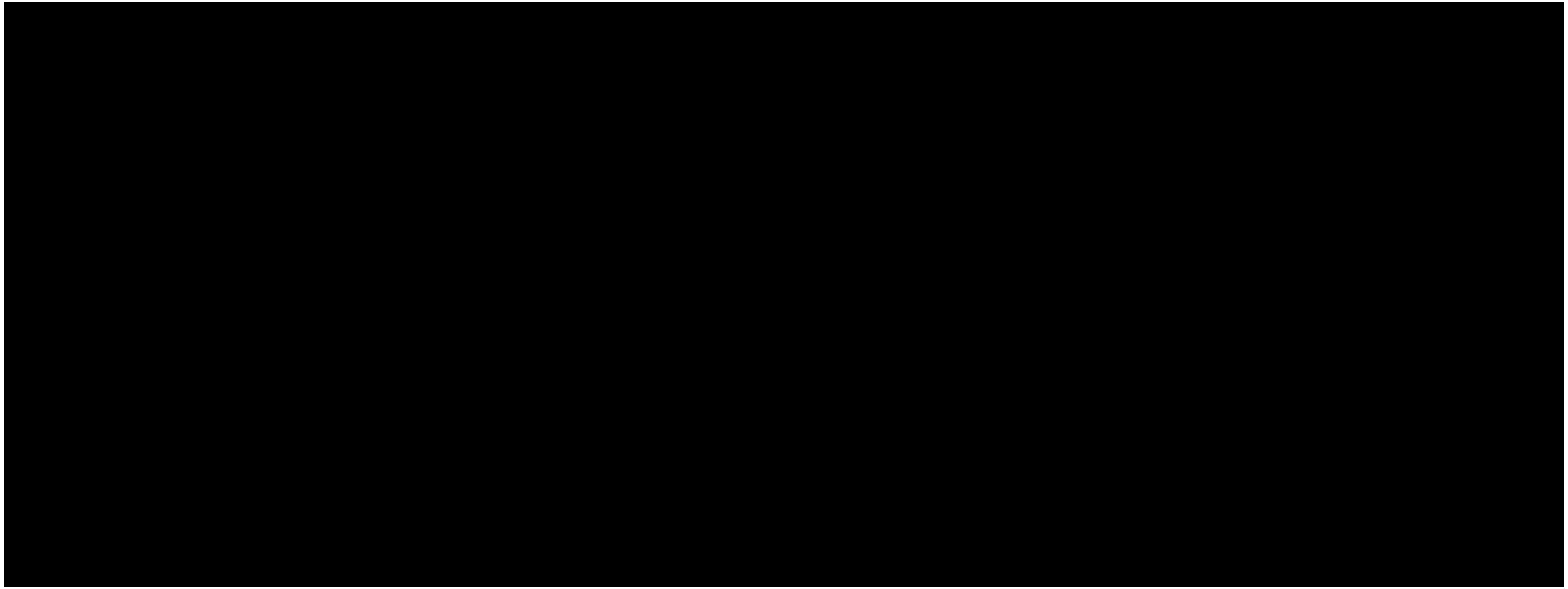
Davies, Jonathan J., Alastair R. Beresford, and Andy Hopper. "Scalable, distributed, real-time map generation." *IEEE Pervasive Computing* 5.4 (2006): 47-54.

Density Estimation - Gray-scale Skeletonization

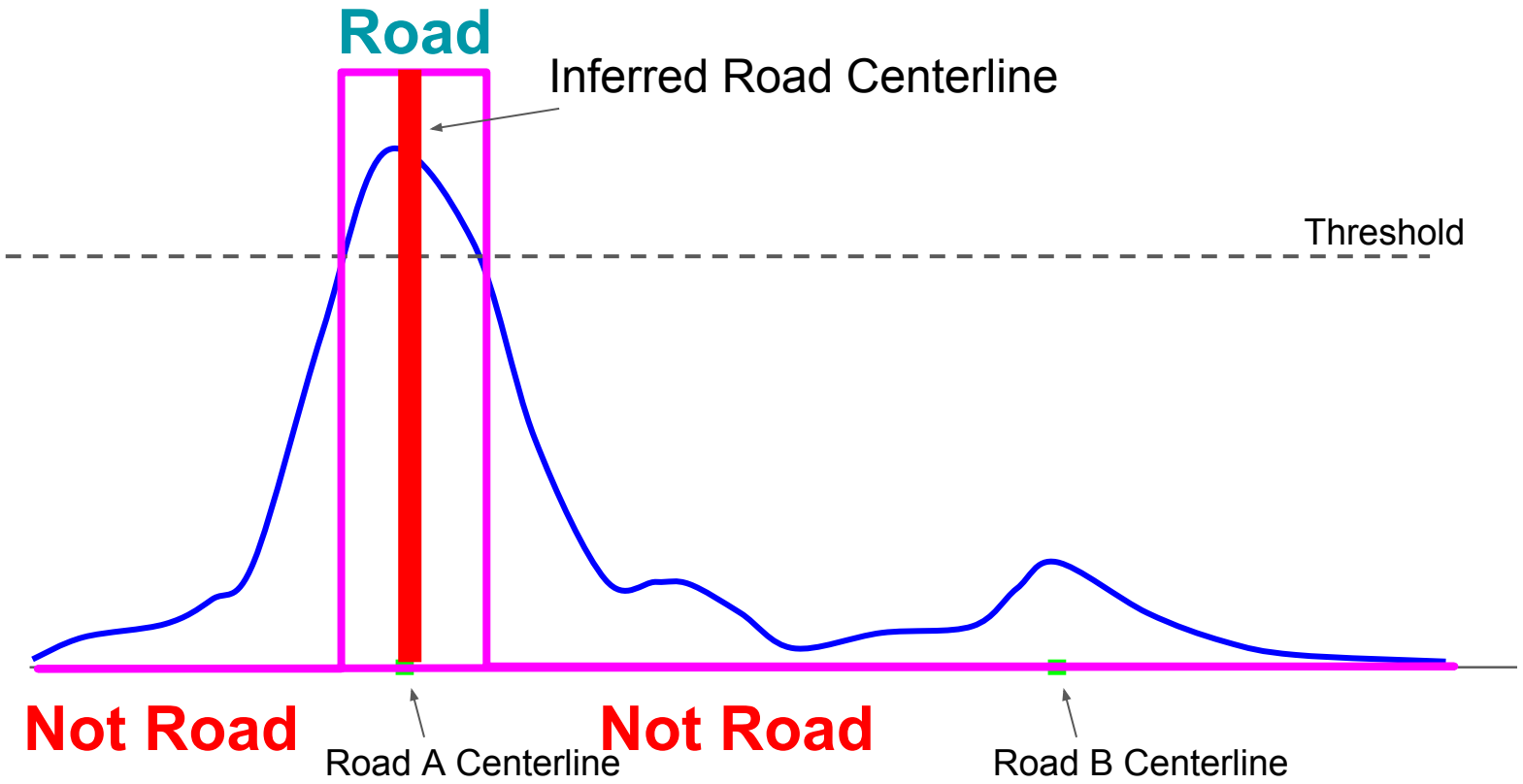


Map inference in the face of noise and disparity

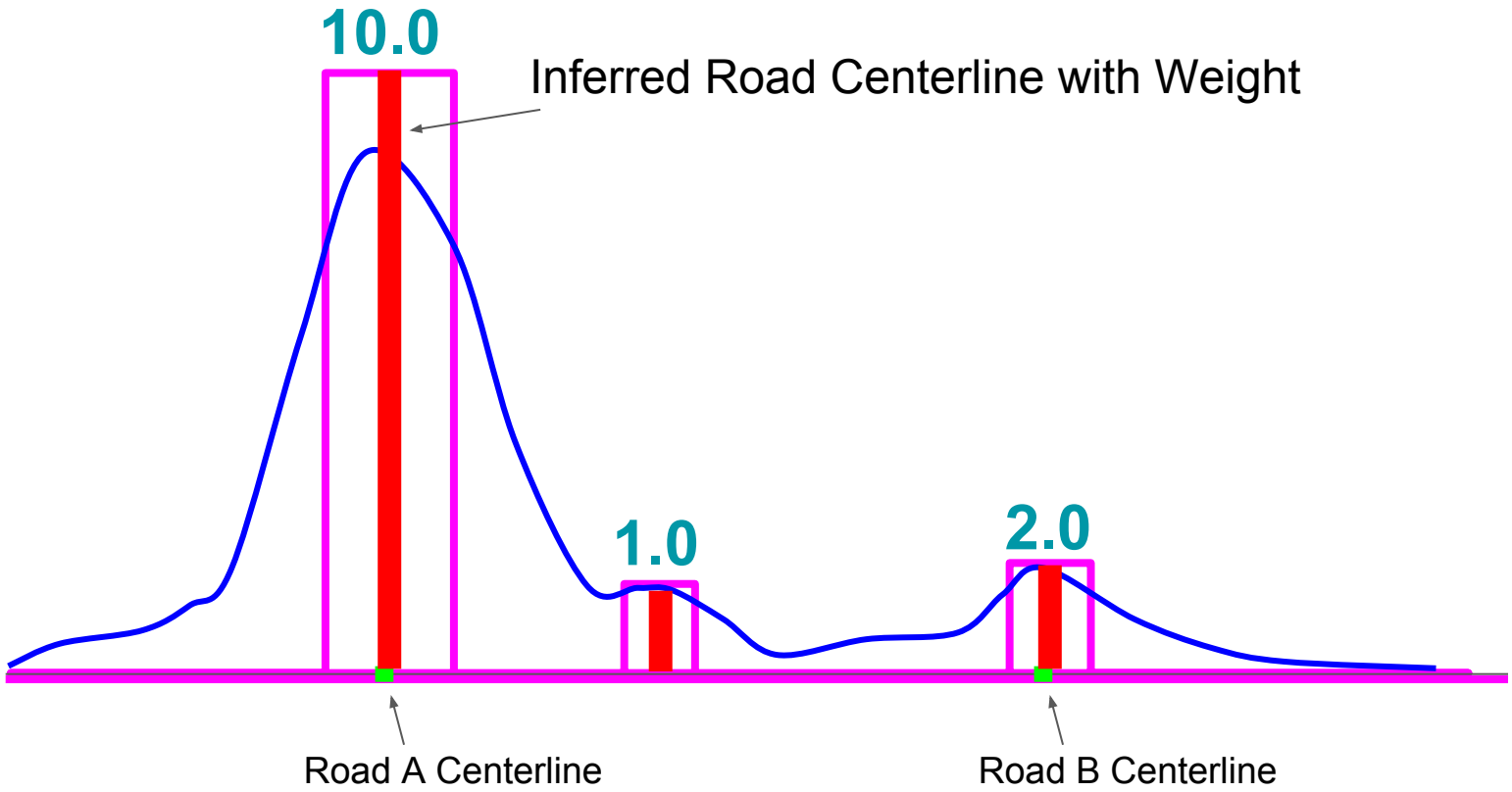
Trajectory data is valuable



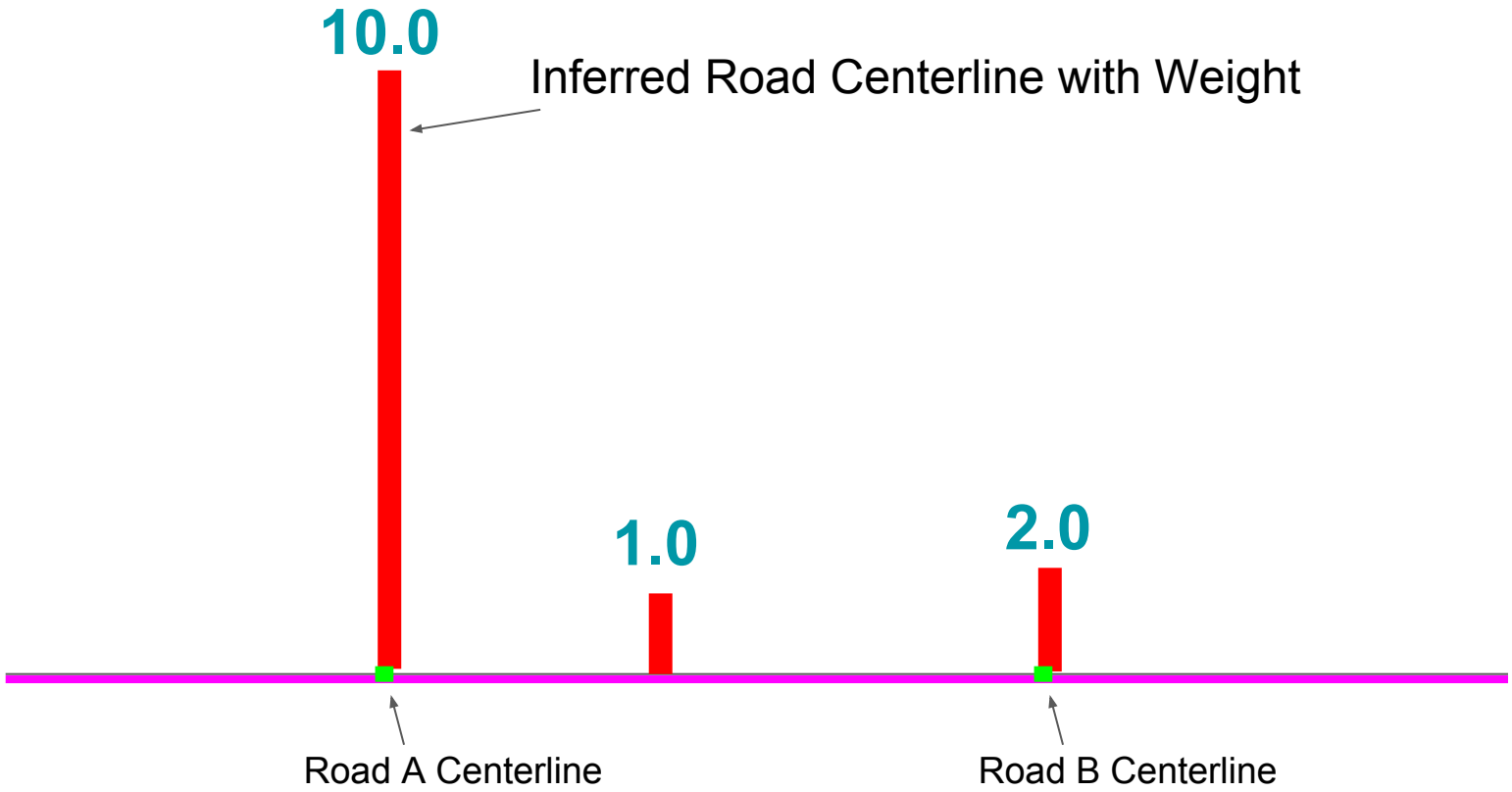
Density Estimation - Binary Skeletonization



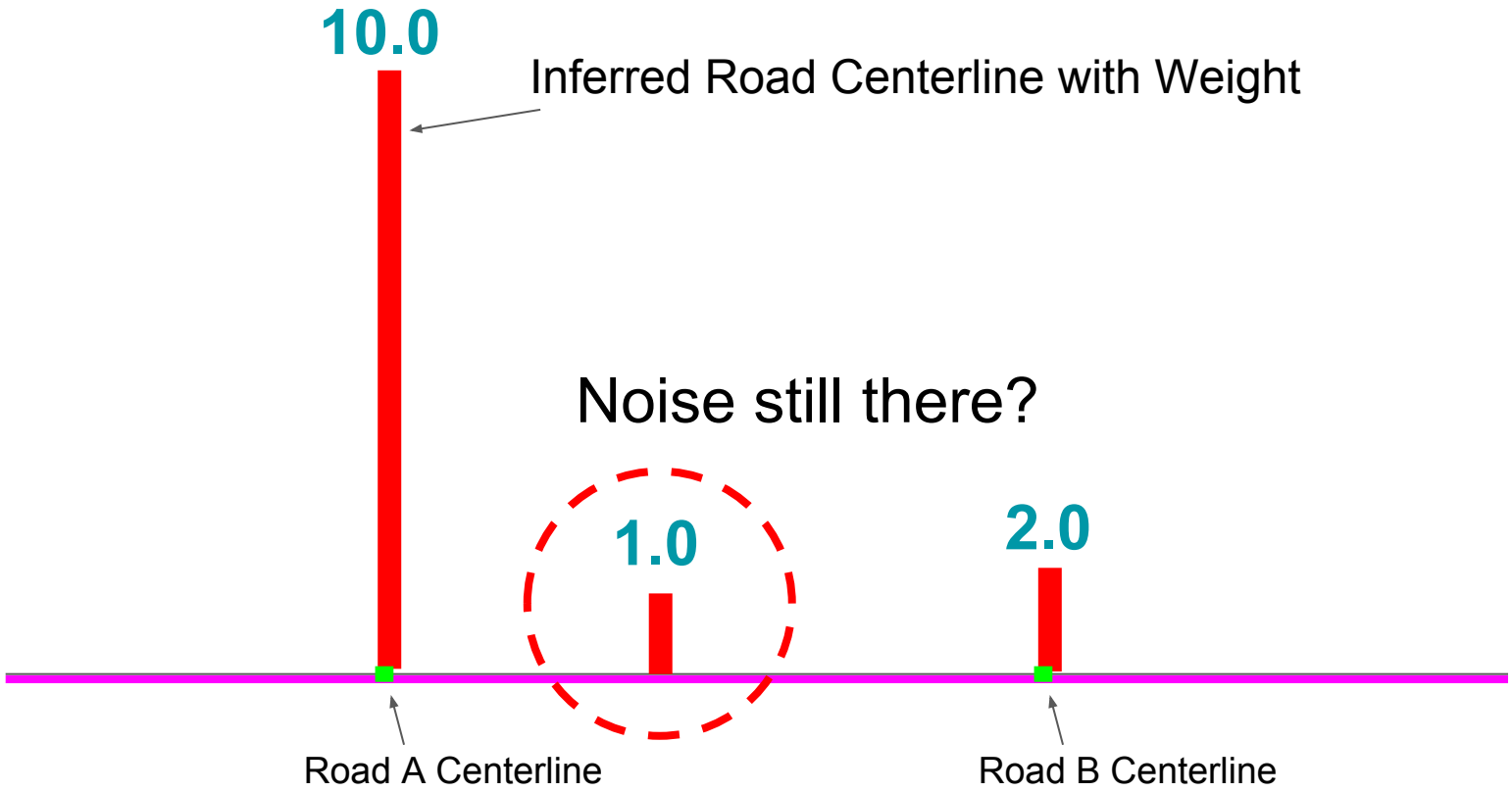
Density Estimation - Gray-scale Skeletonization



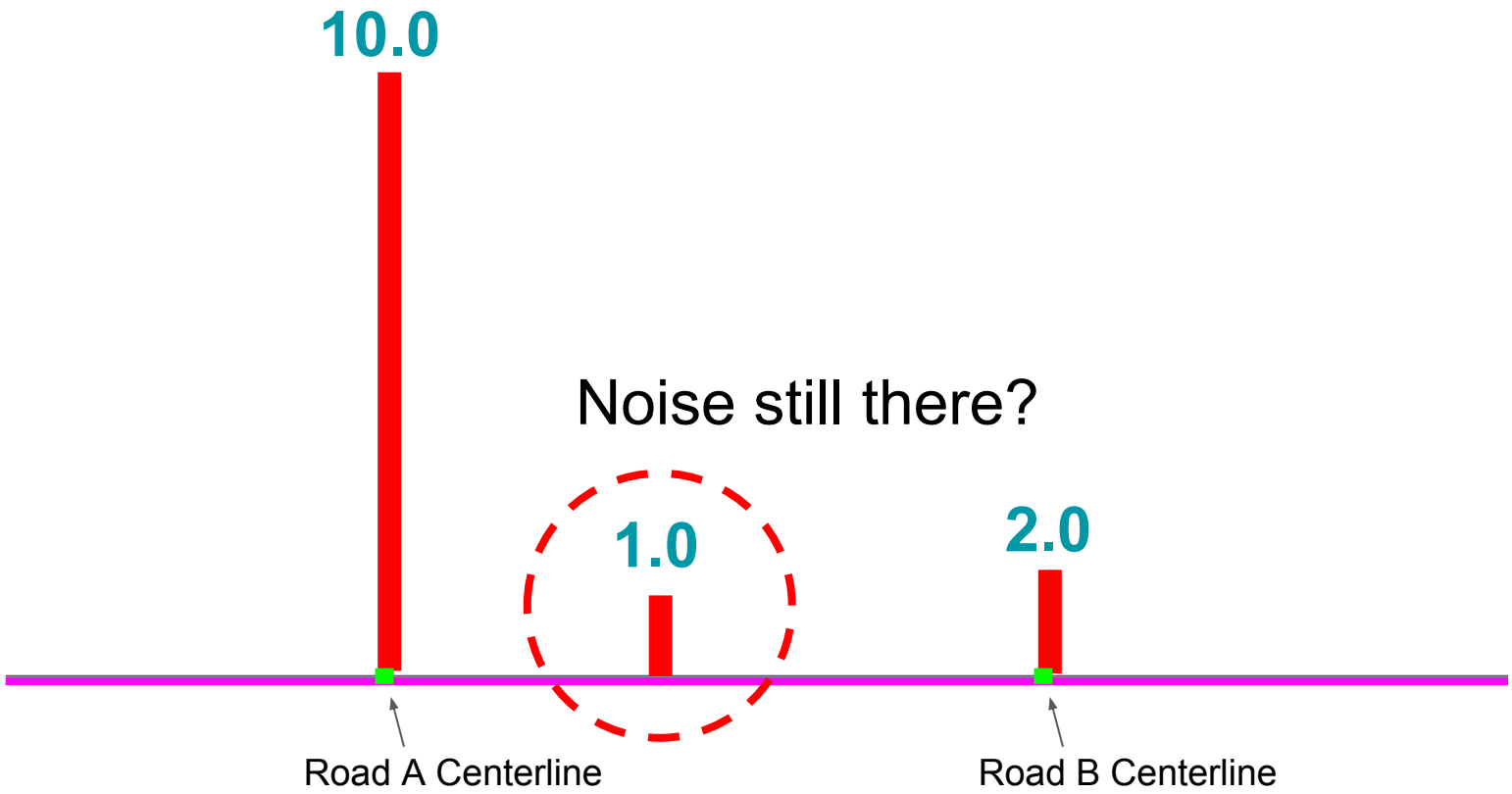
Density Estimation - Gray-scale Skeletonization



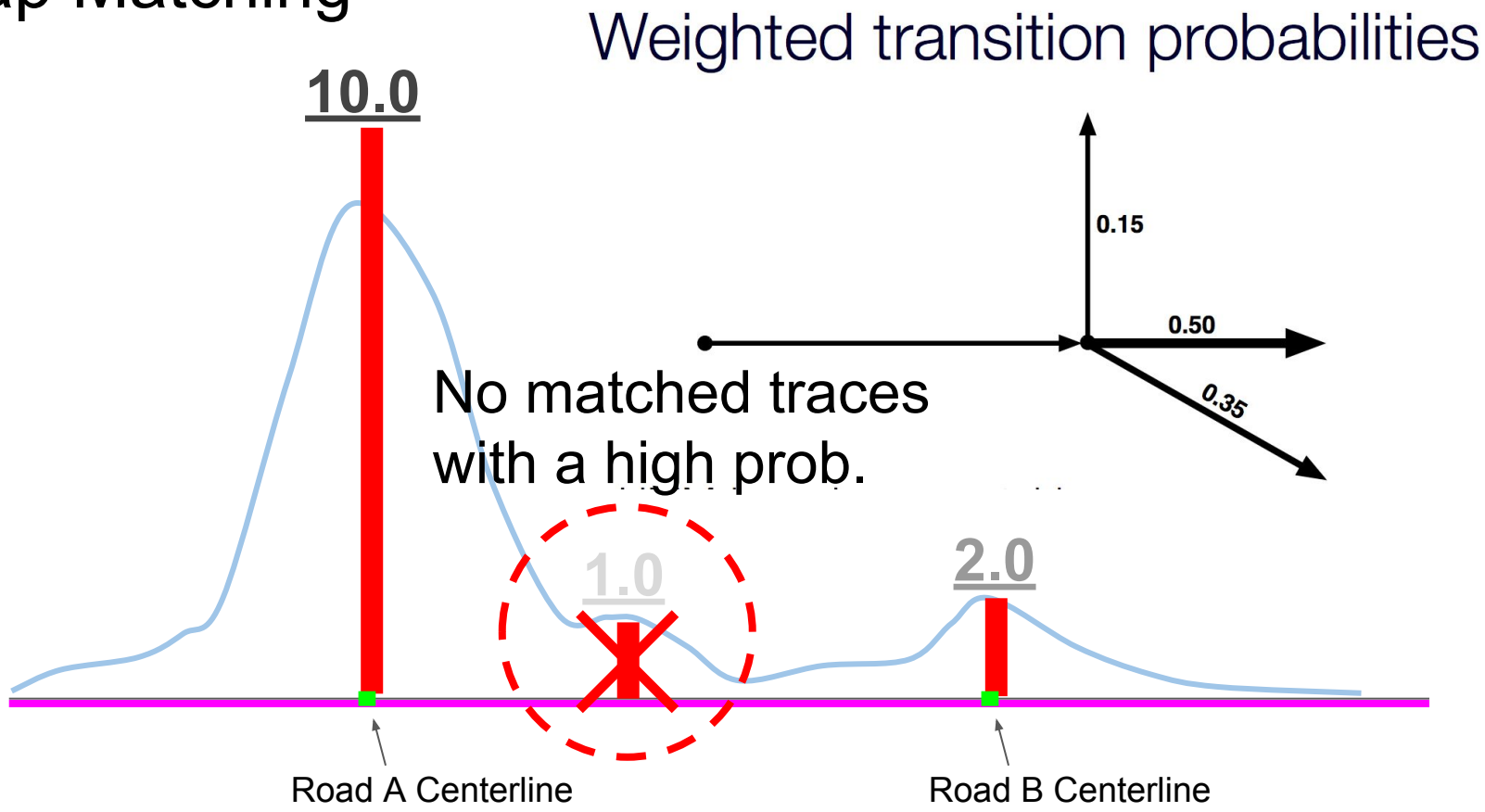
Density Estimation - Gray-scale Skeletonization



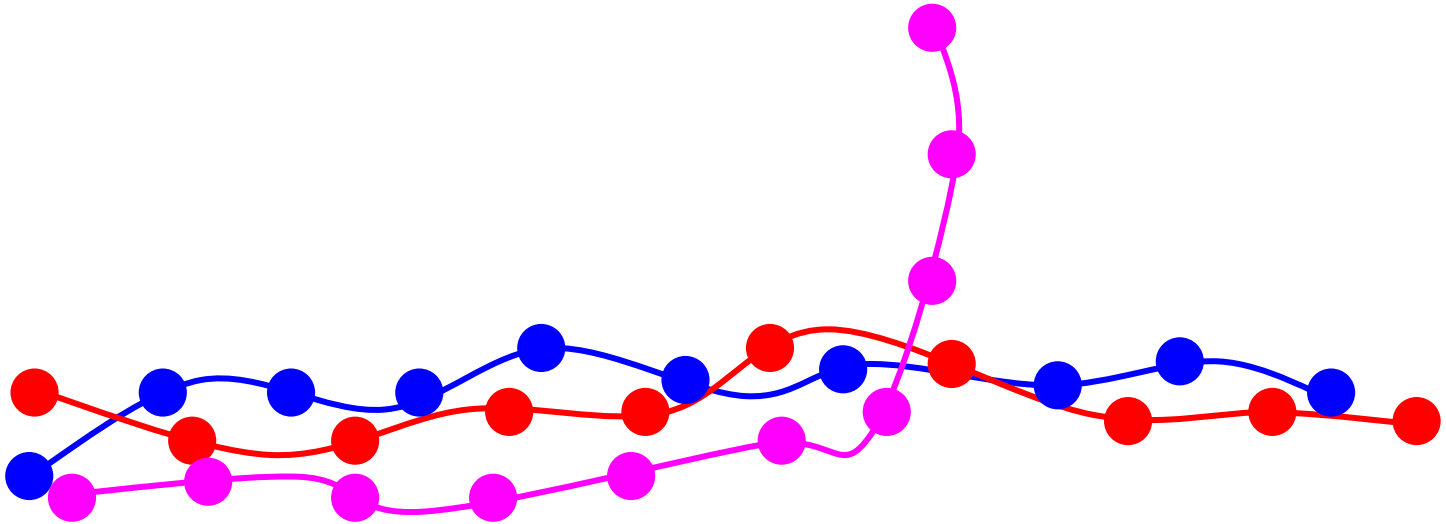
Density Estimation - Gray-scale Skeletonization



Map Matching

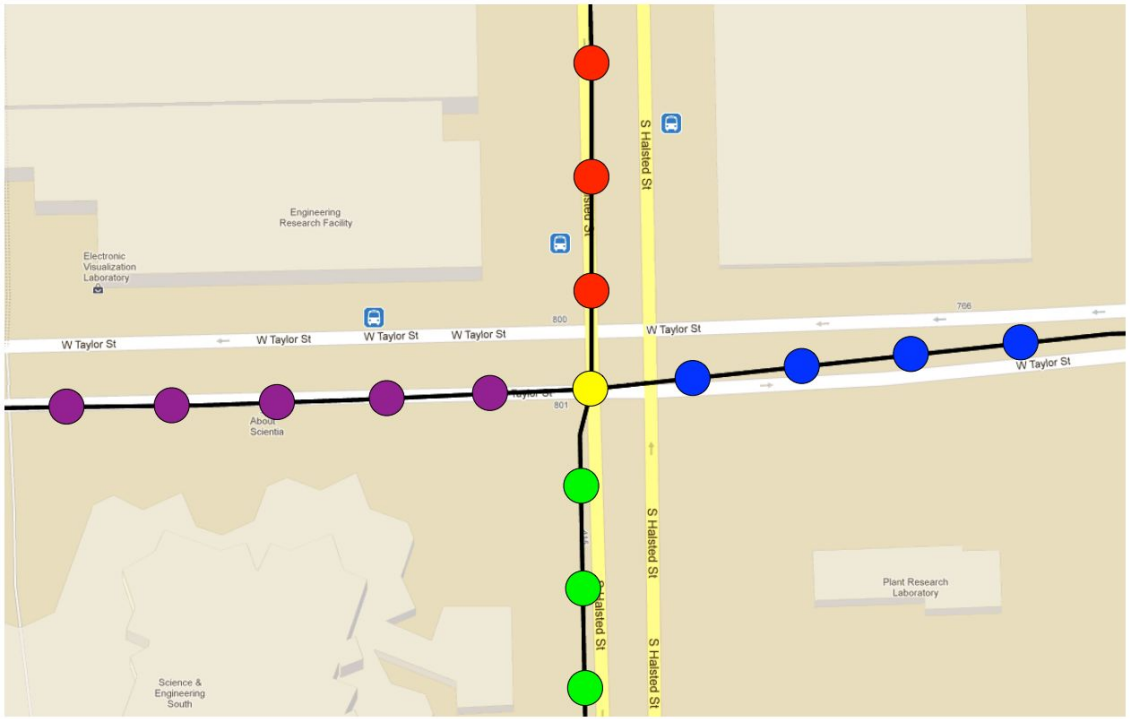


More Information if You Consider the Whole Trace



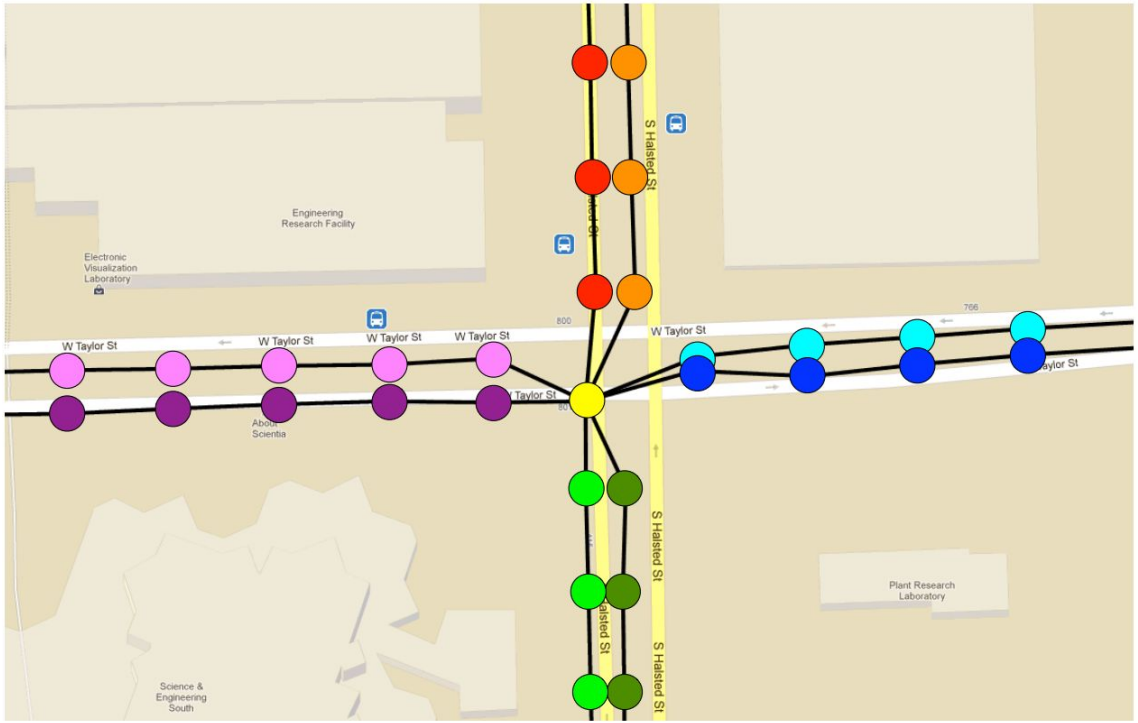
Geometry Refinement - Initial Cluster Locations

Assign GPS samples to “eligible” means



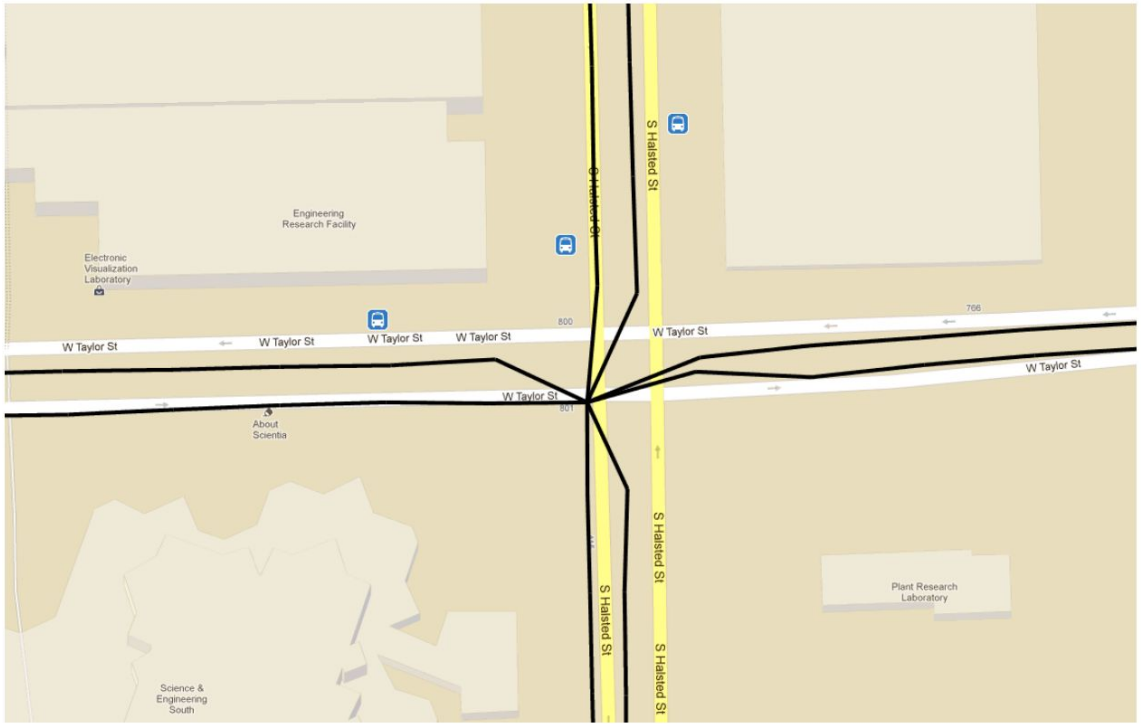
Geometry Refinement - Settled cluster locations

Assign GPS samples to “eligible” means



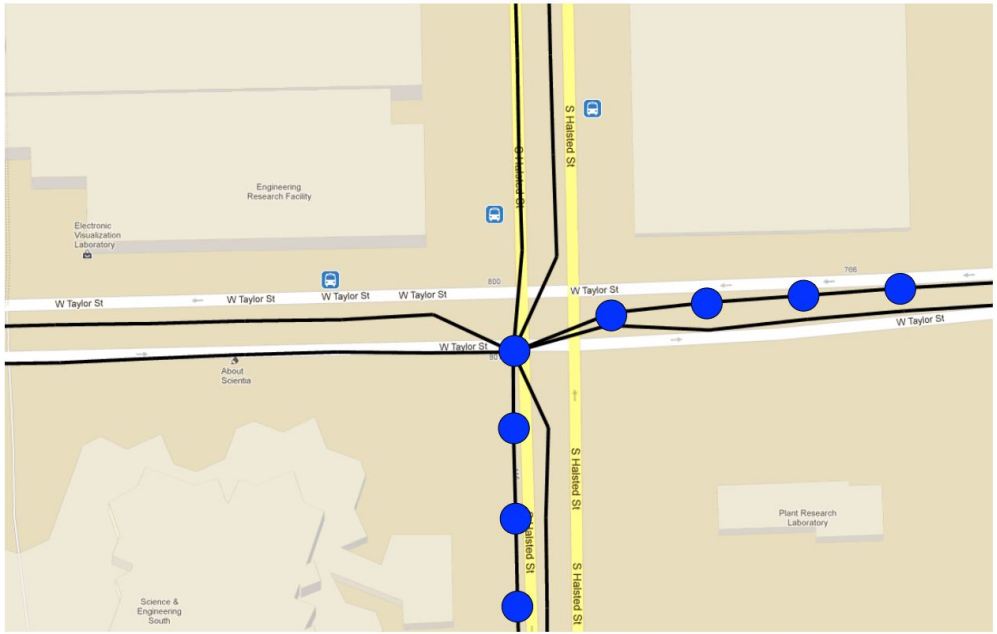
Geometry Refinement - Refined lane geometry

Assign GPS samples to “eligible” means



Geometry Refinement - Intersection Refinement

Assign GPS samples to “eligible” means



Geometry Refinement - Intersection Refinement

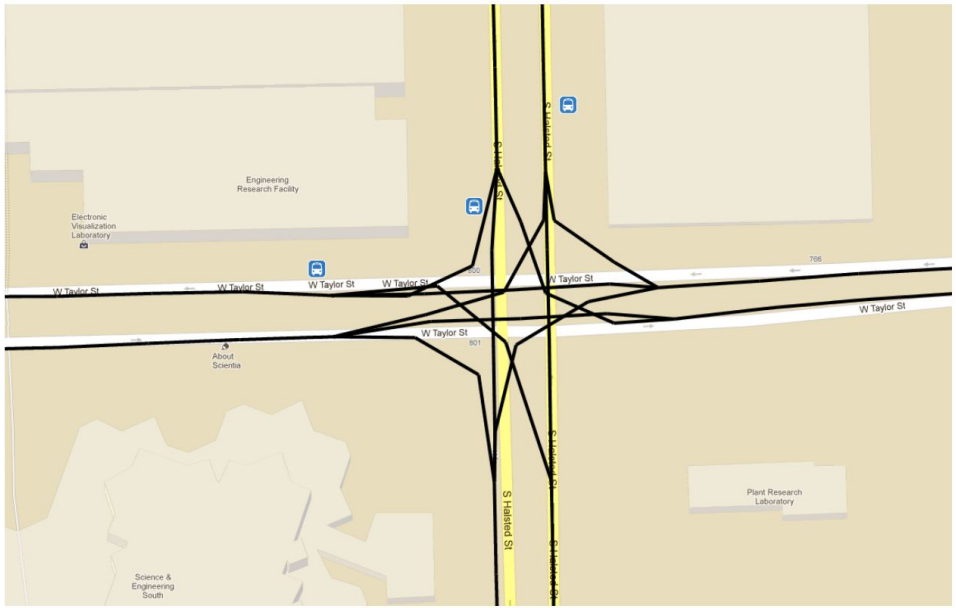
Assign GPS samples to “eligible” means

Geometry Refinement - Intersection Refinement

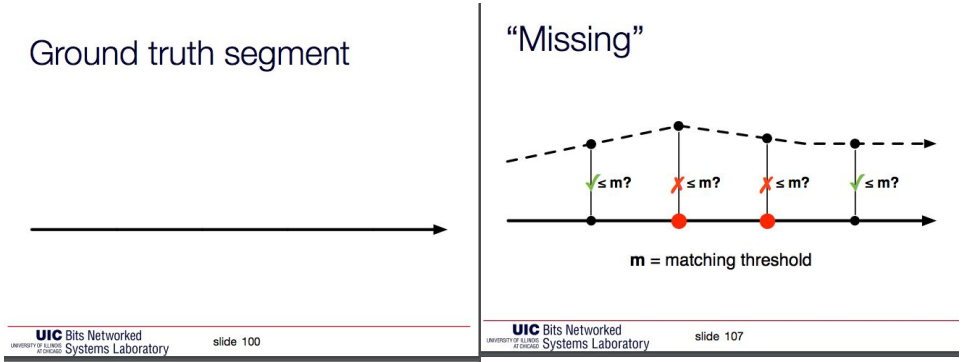
Assign GPS samples to “eligible” means

Geometry Refinement - Intersection Refinement

Assign GPS samples to “eligible” means



Geometric evaluation (GEO) TODO...



Overall performance

$$F = 2 \cdot \frac{precision \cdot recall}{precision + recall}$$

$$precision = 1 - \frac{|spurious\ samples|}{|inferred\ samples|}$$

$$recall = 1 - \frac{|missing\ samples|}{|ground\ truth\ samples|}$$