Map Inference in the Face of Noise and Disparity

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Bits Networked Systems Laboratory
COLLEGE OF ENGINEERING

Map making

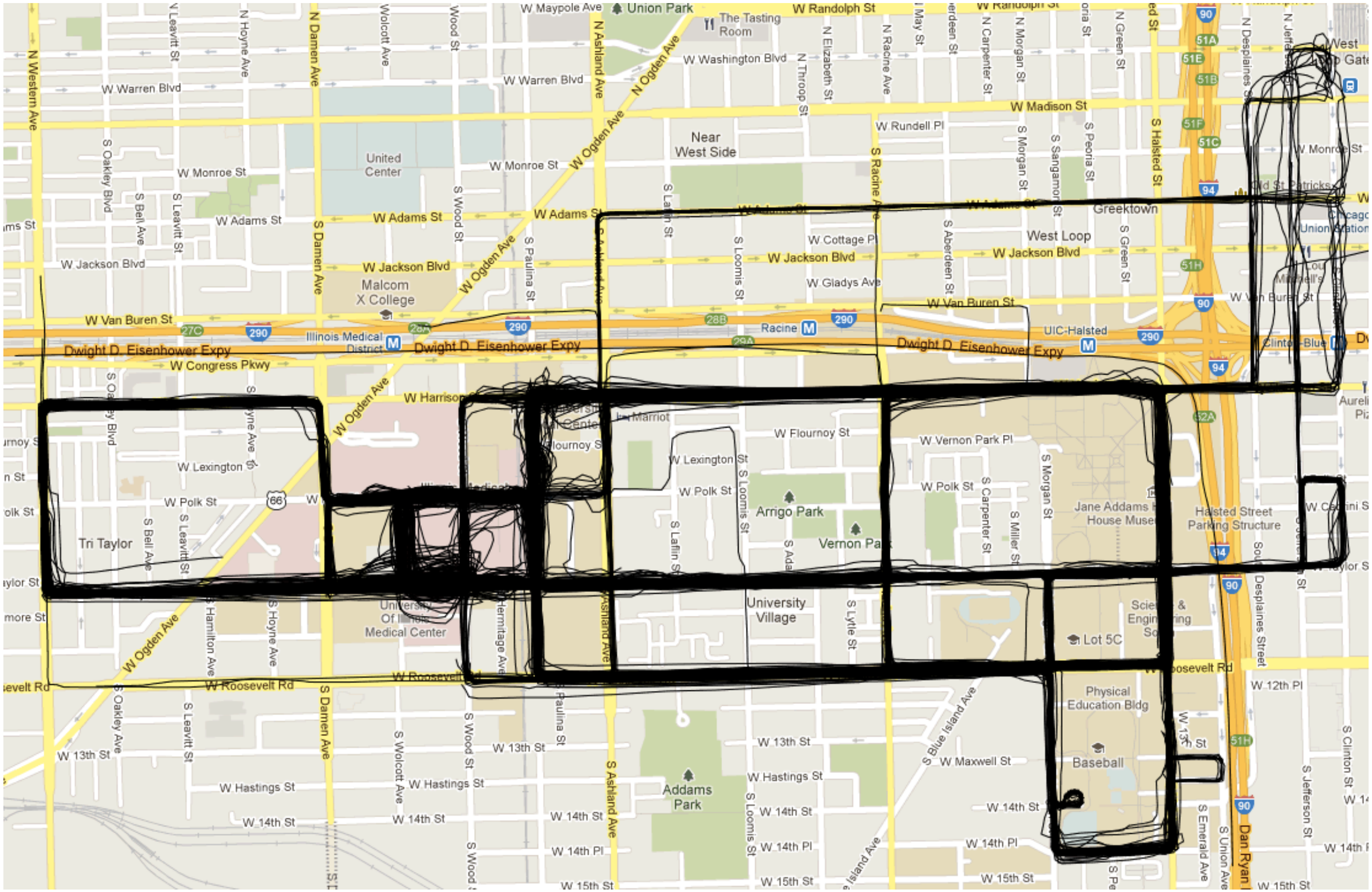


Opportunistic data collection



Opportunistic data collection

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Near West Side
United Center
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W Adams St
W Jackson Blvd
Malcom X College
W Van Buren St
Illinois Medical District
Dwight D. Eisenhower Expy
W Congress Pkwy
W Harrison St
Racine
UIC-Halsted
Greektown
West Loop
W Cottage Pl
W Gladys Ave
W Flournoy St
W Vernon Park Pl
W Lexington St
W Polk St
Arrigo Park
Vernon Park
Jane Addams House Museum
Halsted Street Parking Structure
Tri Taylor
University Village
University Of Illinois Medical Center
Lot 5C
Physical Education Bldg
Baseball
W Roosevelt Rd
W 13th St
W Hastings St
W 14th St
W 14th Pl
W 15th St
W Maxwell St
Addams Park
W 12th Pl
N Western Ave
N Damen Ave
N Ashland Ave
N Ogden Ave
S Damen Ave
S Ashland Ave
S Racine Ave
S Halsted St
S Loomis St
S Wood St
S Paulina St
S Hoyne Ave
S Leavitt St
S Oakley Blvd
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S Hamilton Ave
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Desplaines Street
Union Station
Clinton-Blue
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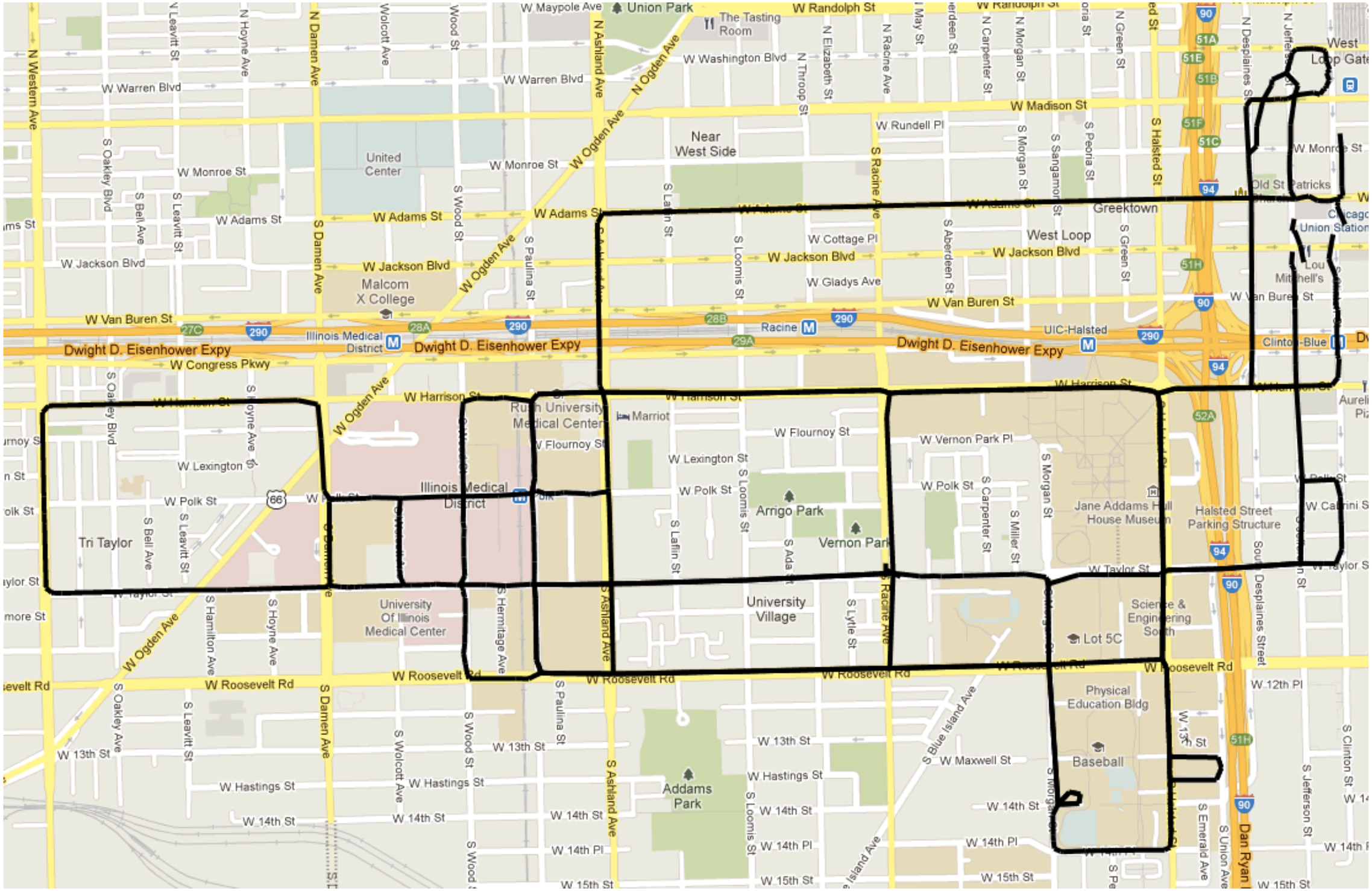

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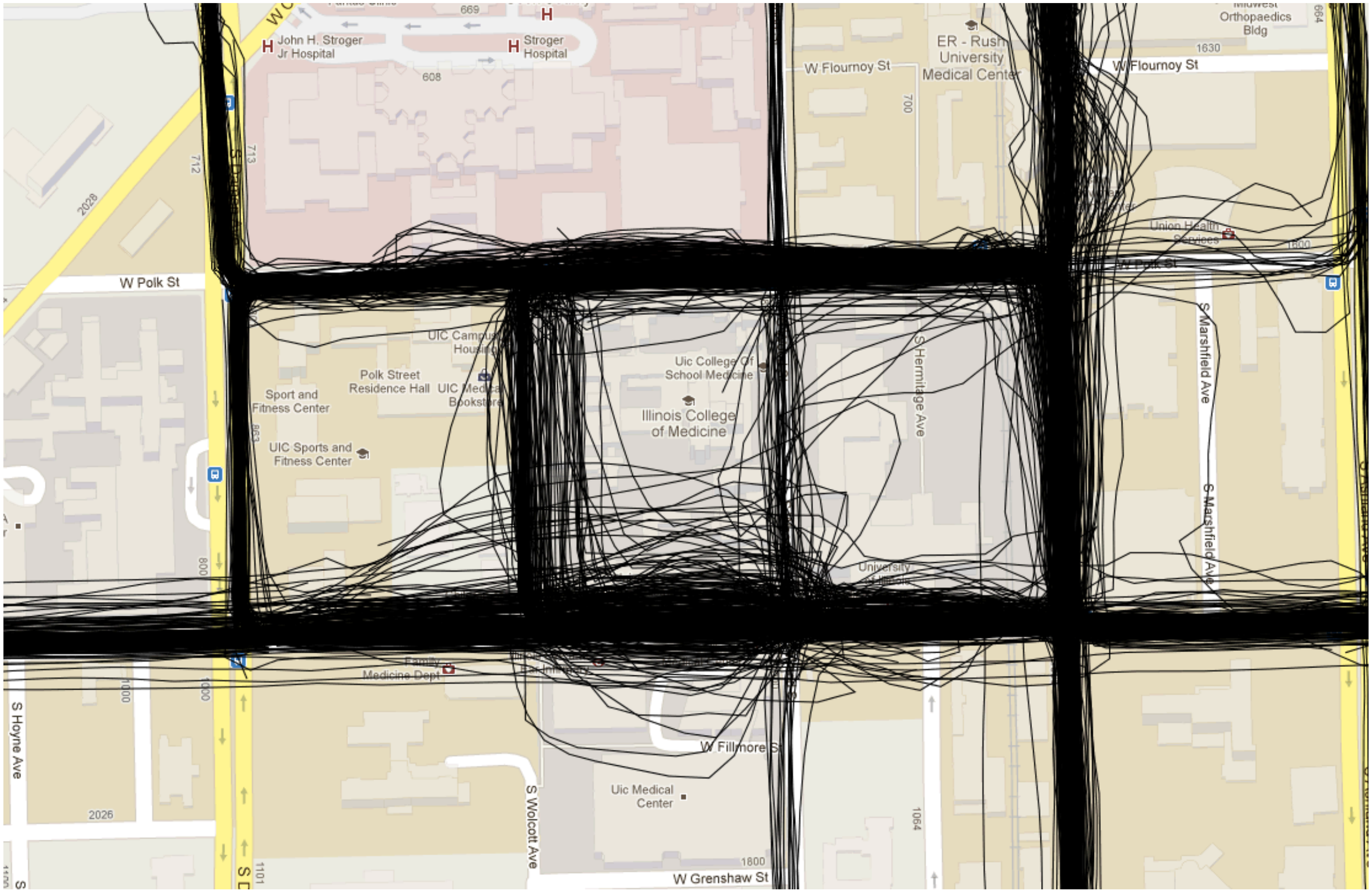
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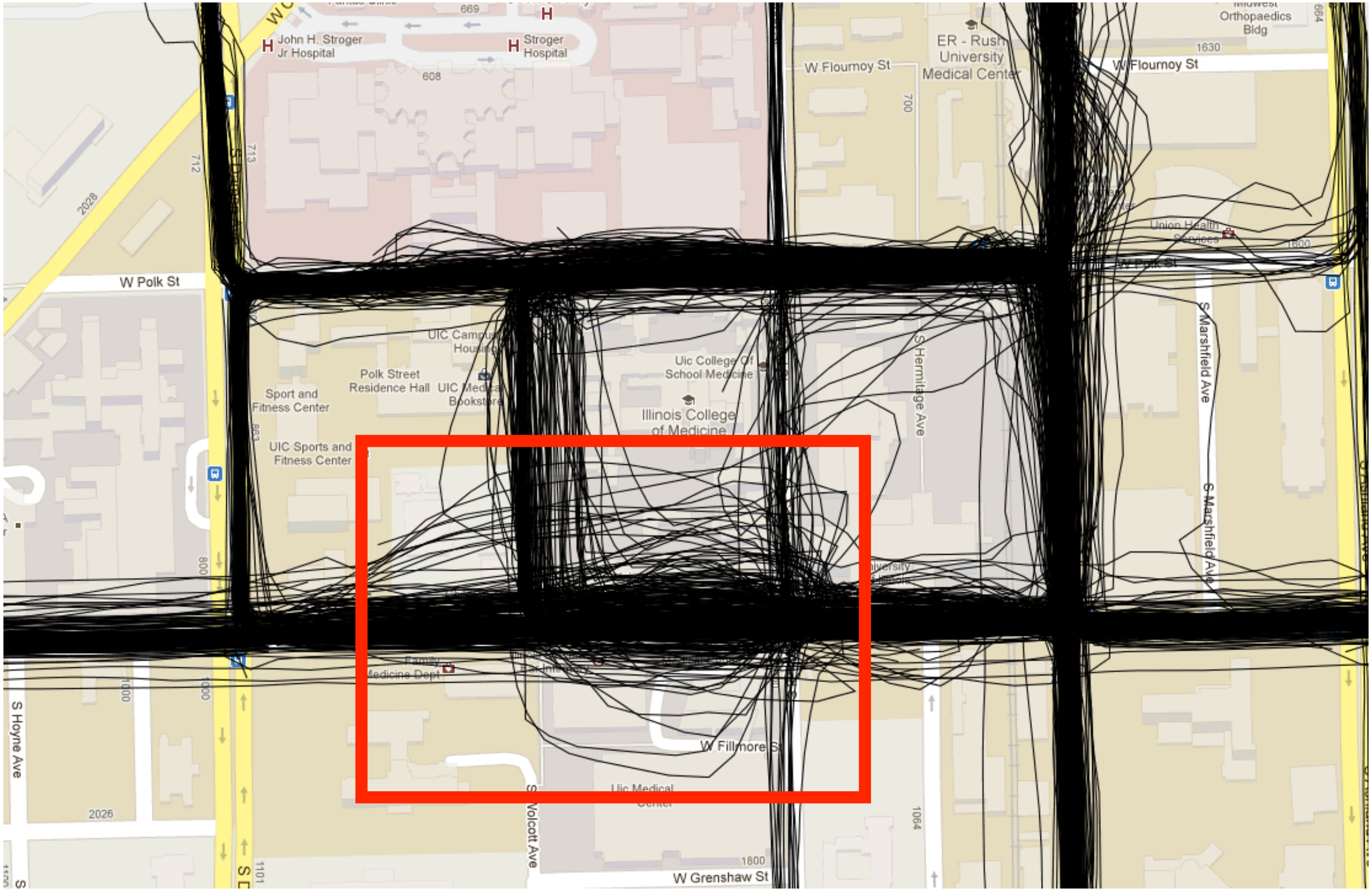
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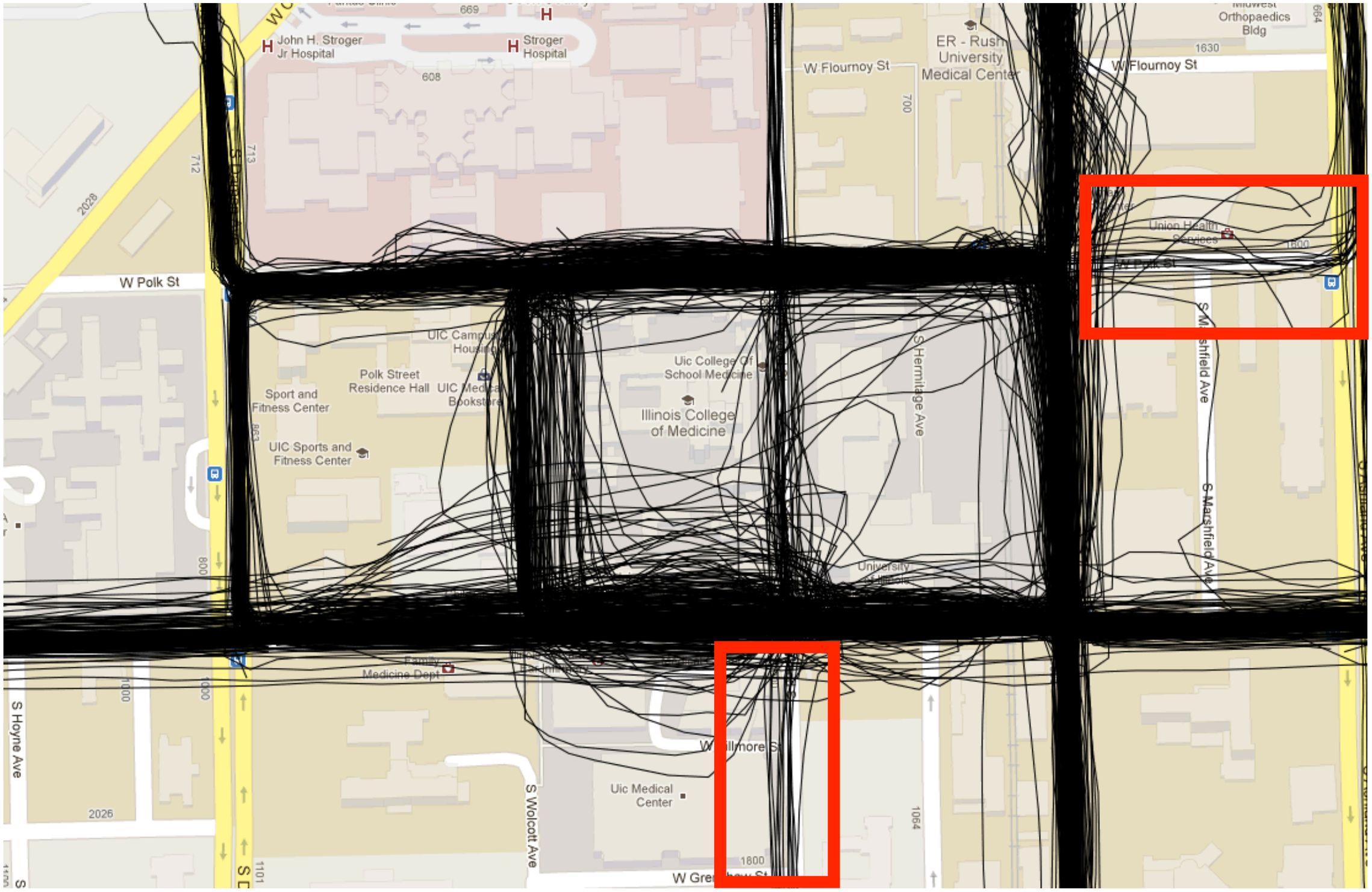
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Why infer maps?

Road surveys



Rural/developing areas



New road construction



Road closures



Road closures

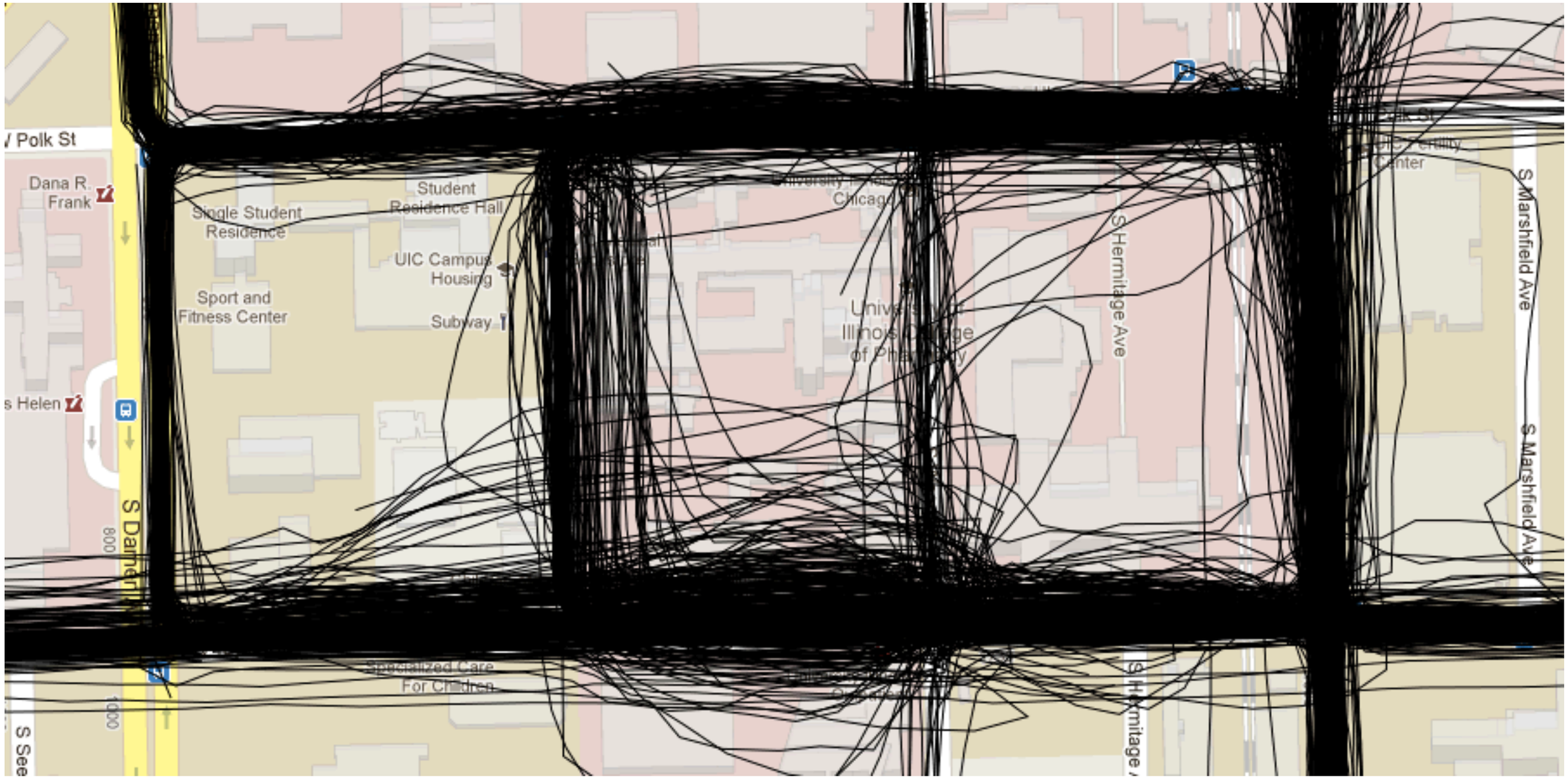


Are noise and disparity actually problems?

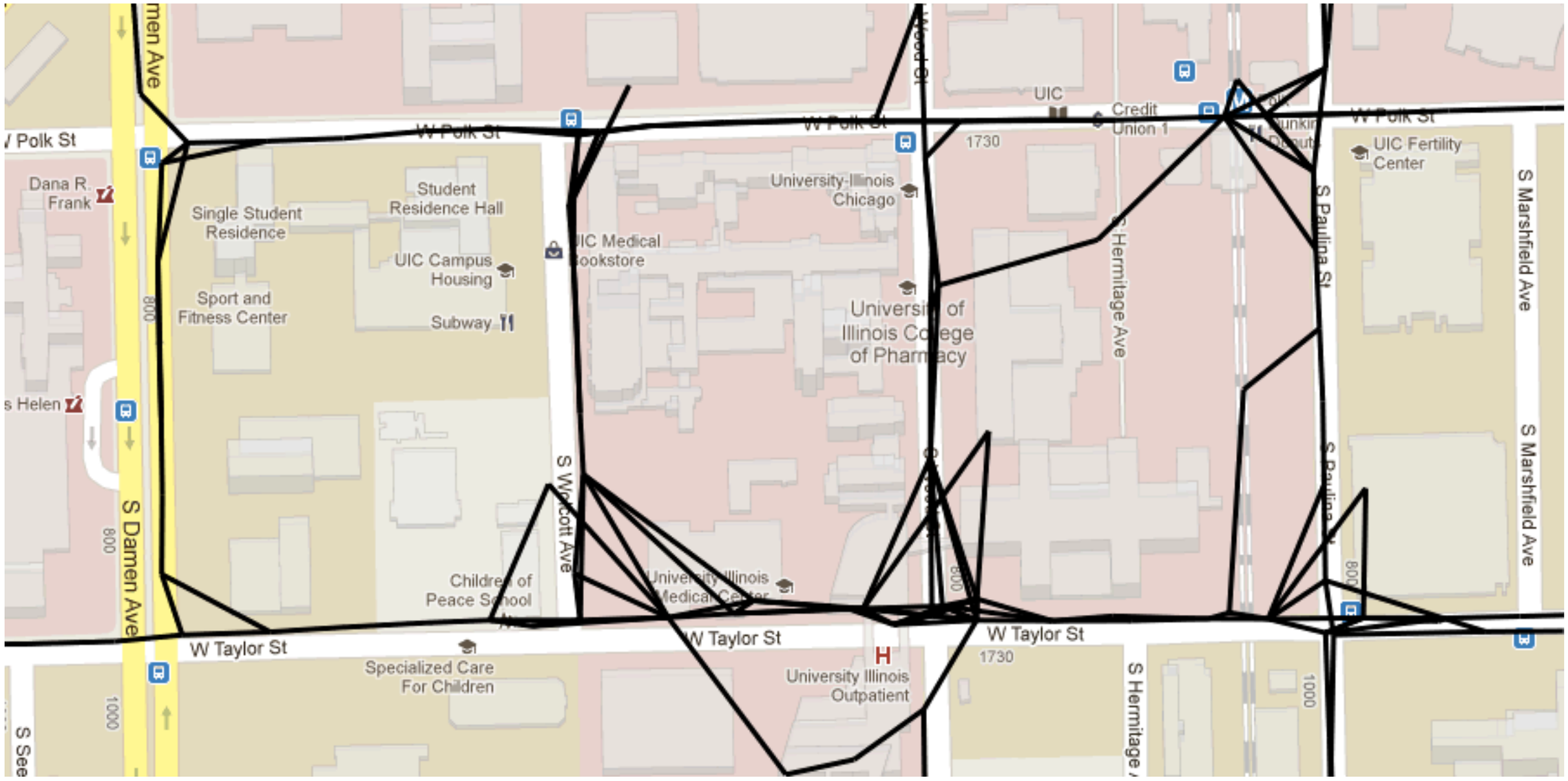
Current state of the art

- *k*-Means clustering
  - Edelkamp & Schrödl (2003)
- Kernel density estimation
  - Davies et al. (2006)
- Trace merging
  - Cao & Krumm (2009)

Noisy, disparate GPS data



Edelkamp & Schrödl (2003)



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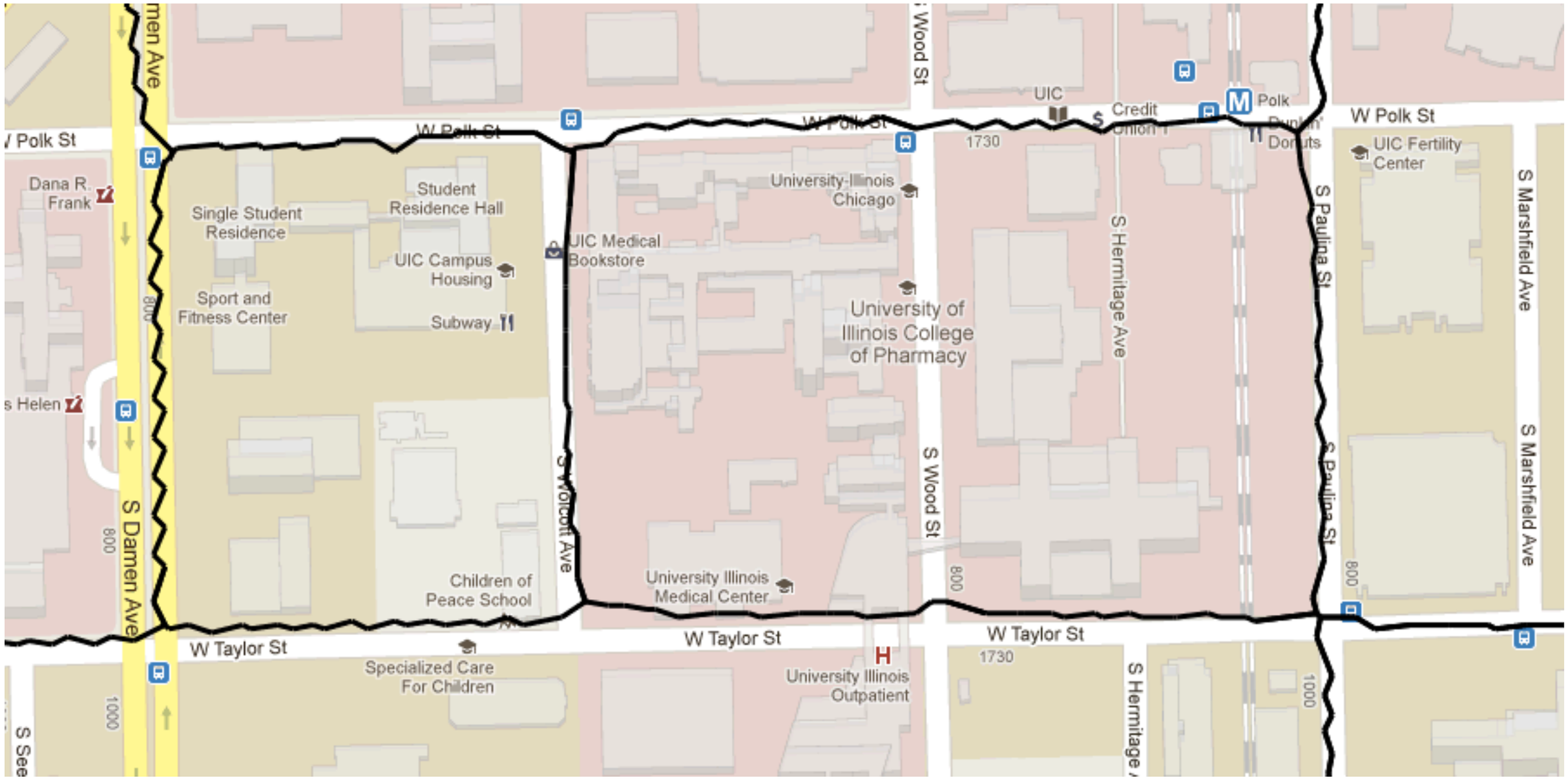

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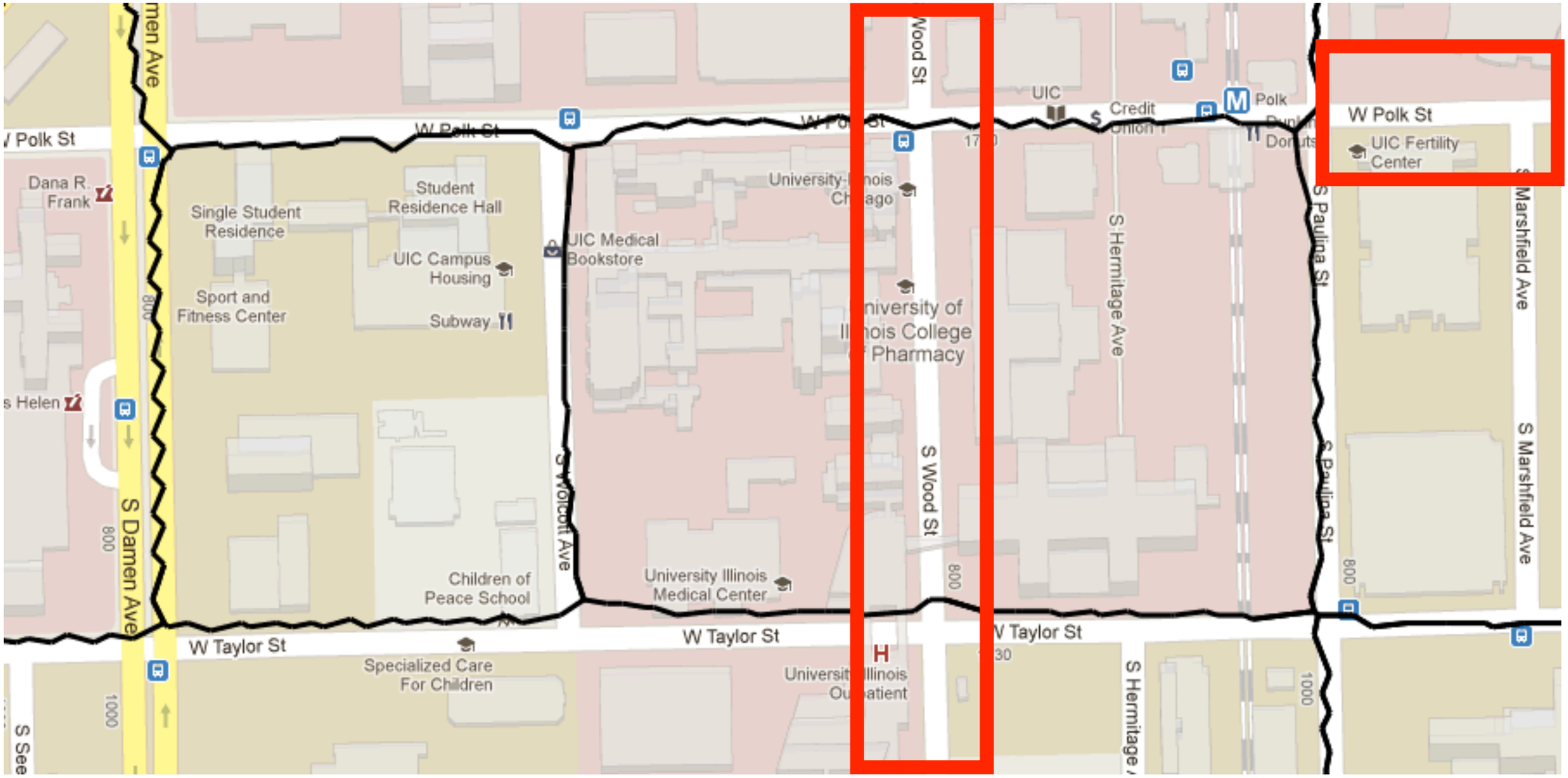
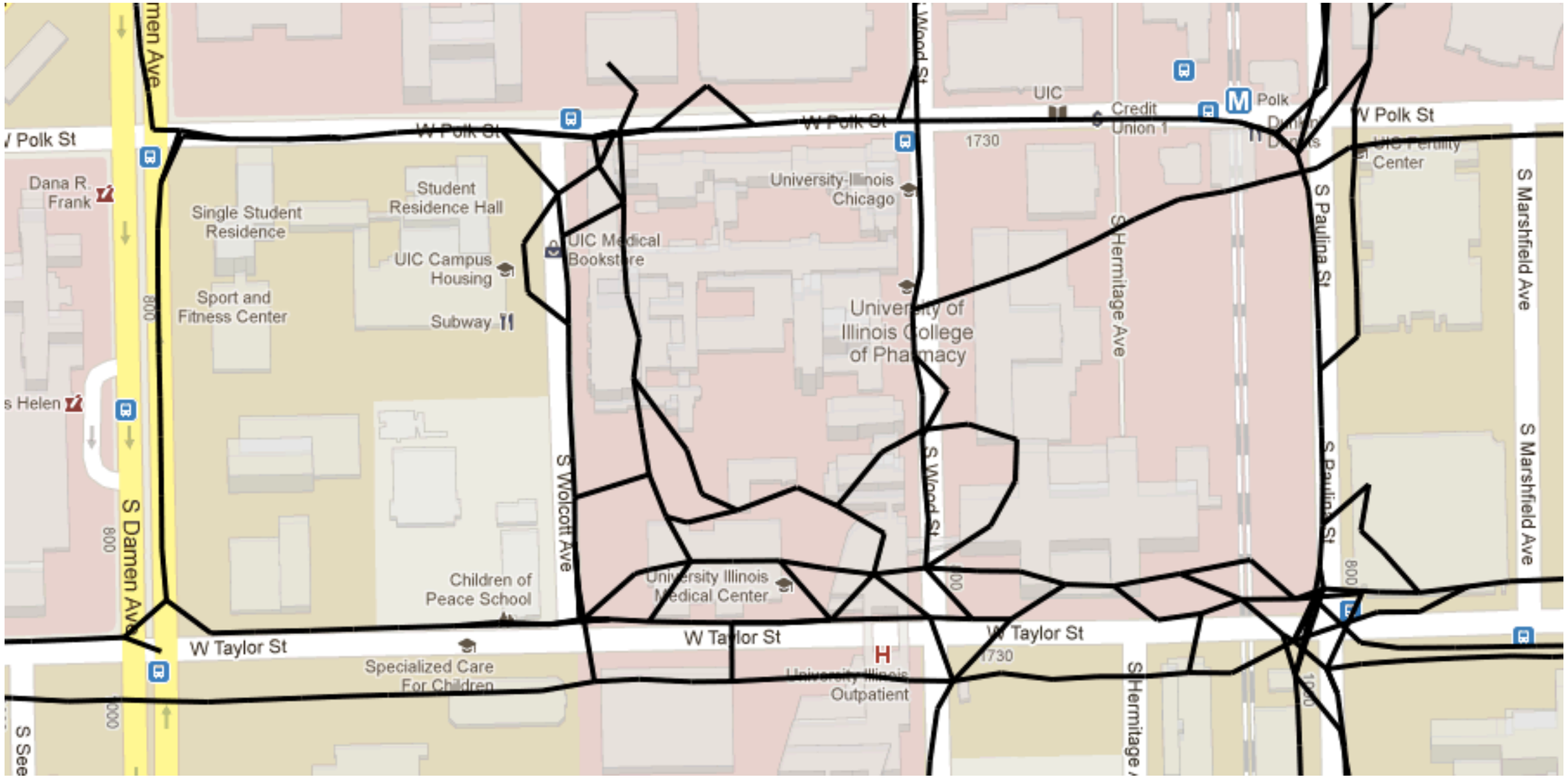


Cao & Krumm (2009)



Lessons learned

1) KDE method looks promising
   - Noise resistant, robust centerline extraction

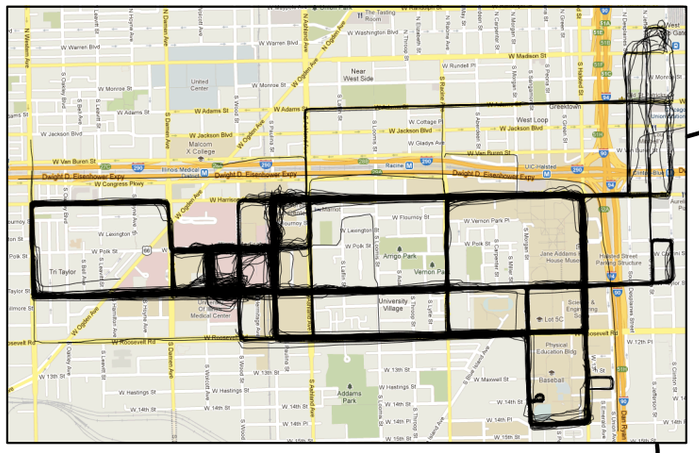
2) Not without its problems
   - Threshold selection, single centerline

3) Trajectory data is valuable
   - Road geometry and topology

A hybrid approach

A hybrid approach

Raw GPS traces



Density Estimation

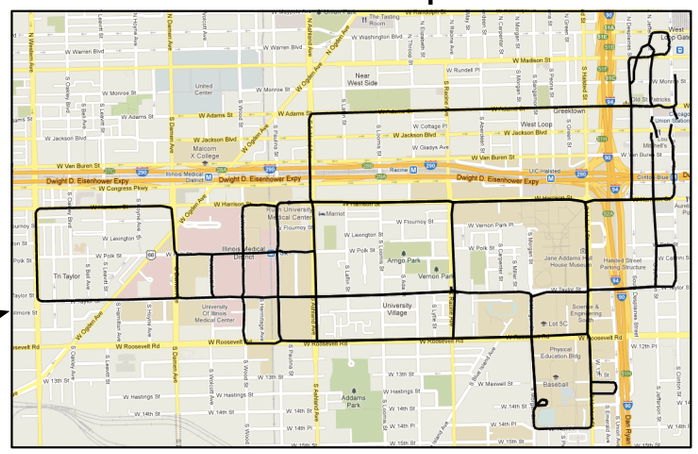
Initial Map Generation

Trace Map Matching

Topology Refinement

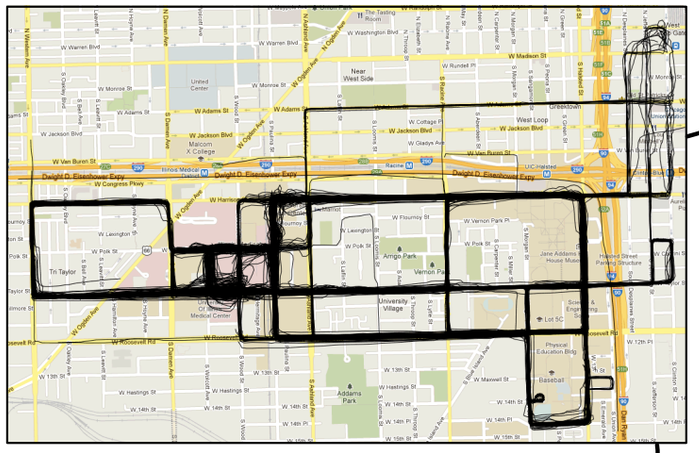
Geometry Refinement

Final map



Map inference pipeline

Raw GPS traces



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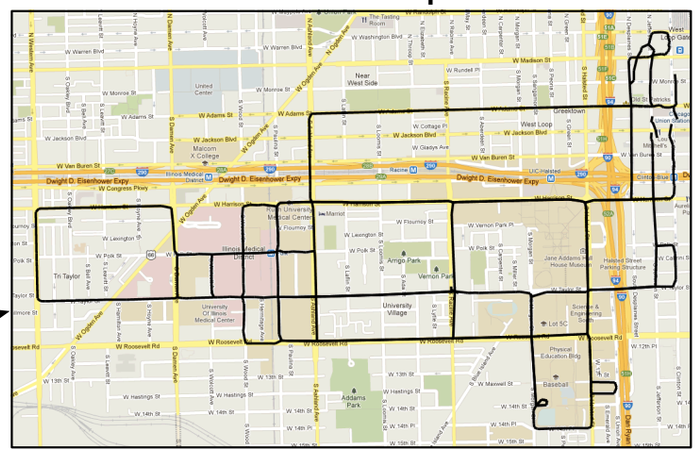

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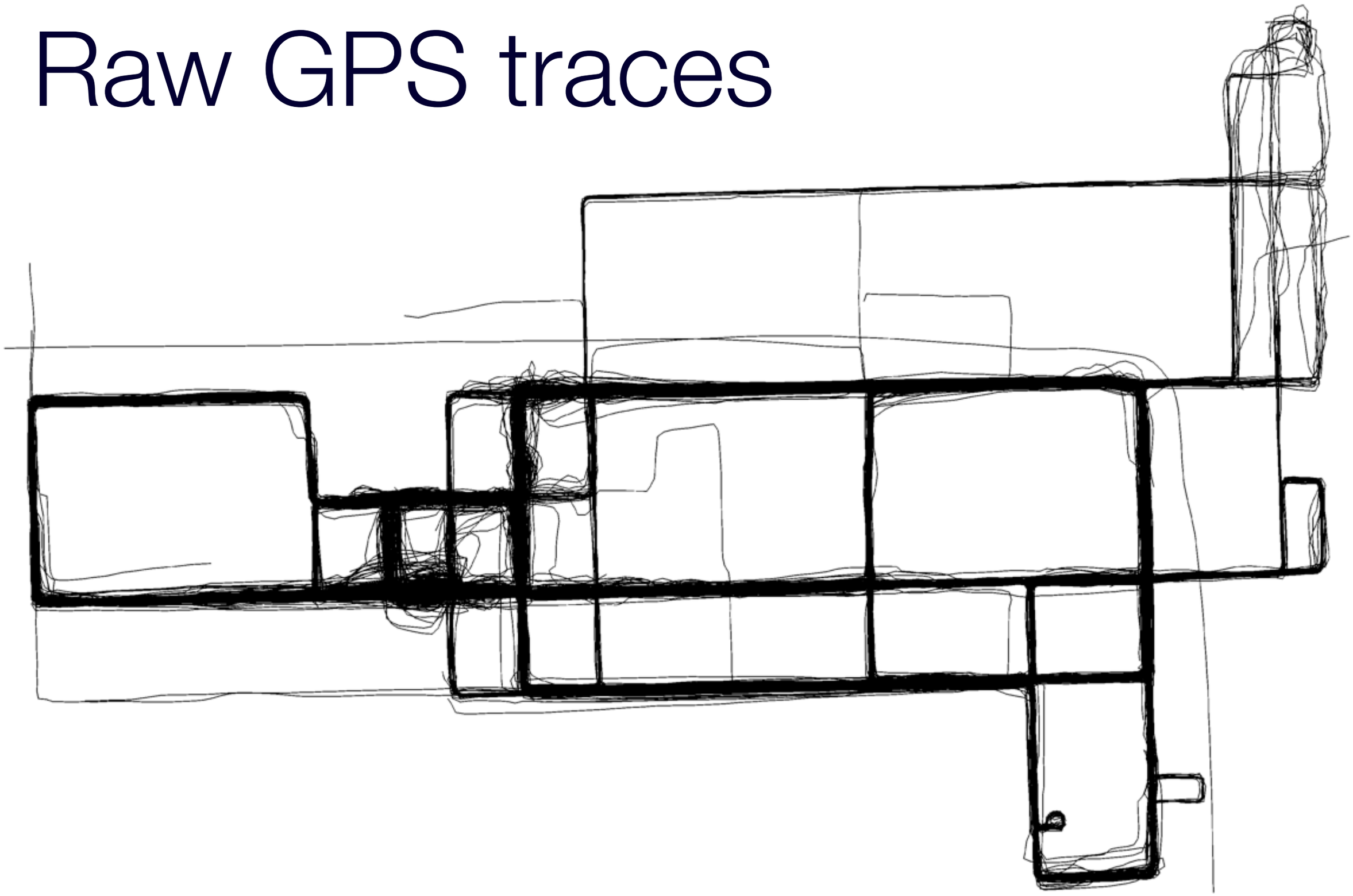

2-D histogram



Density estimate



Map inference pipeline

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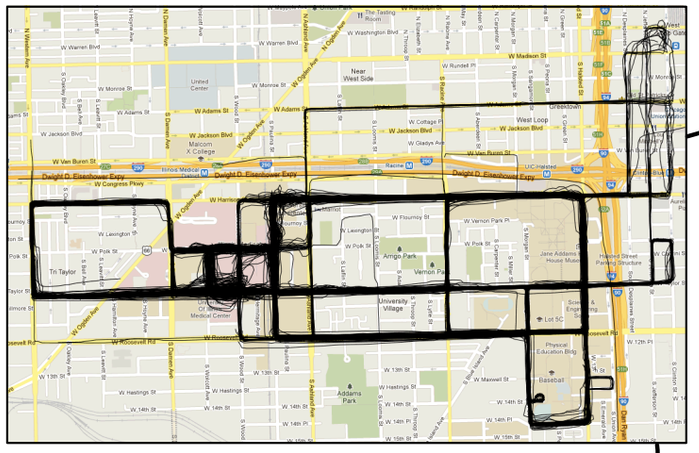

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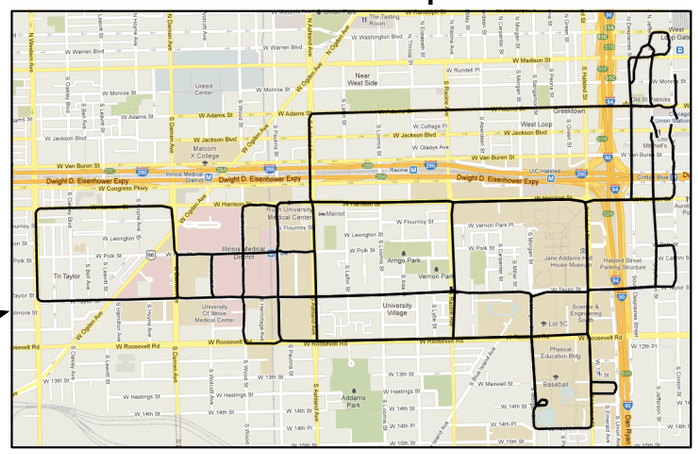

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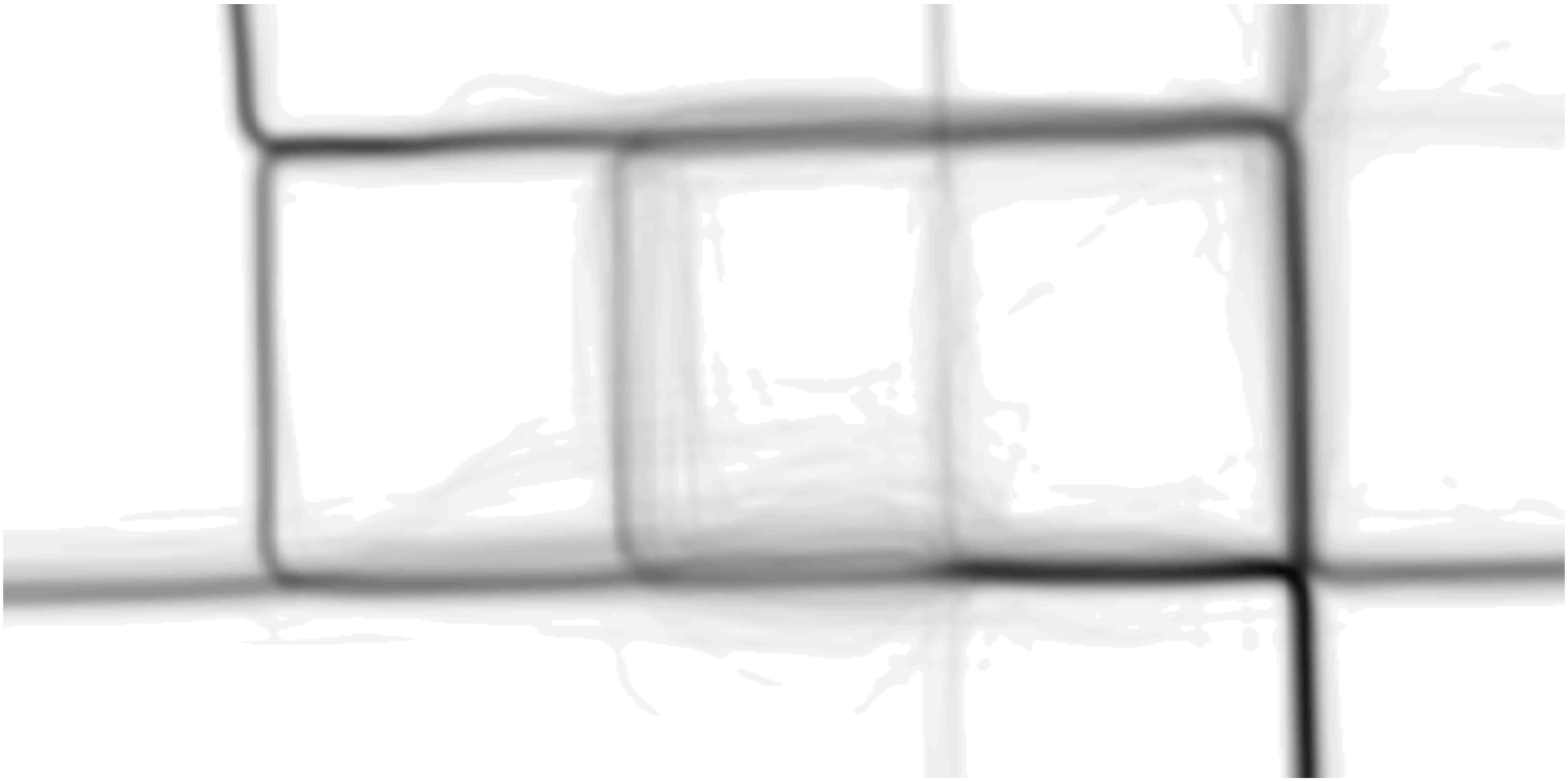
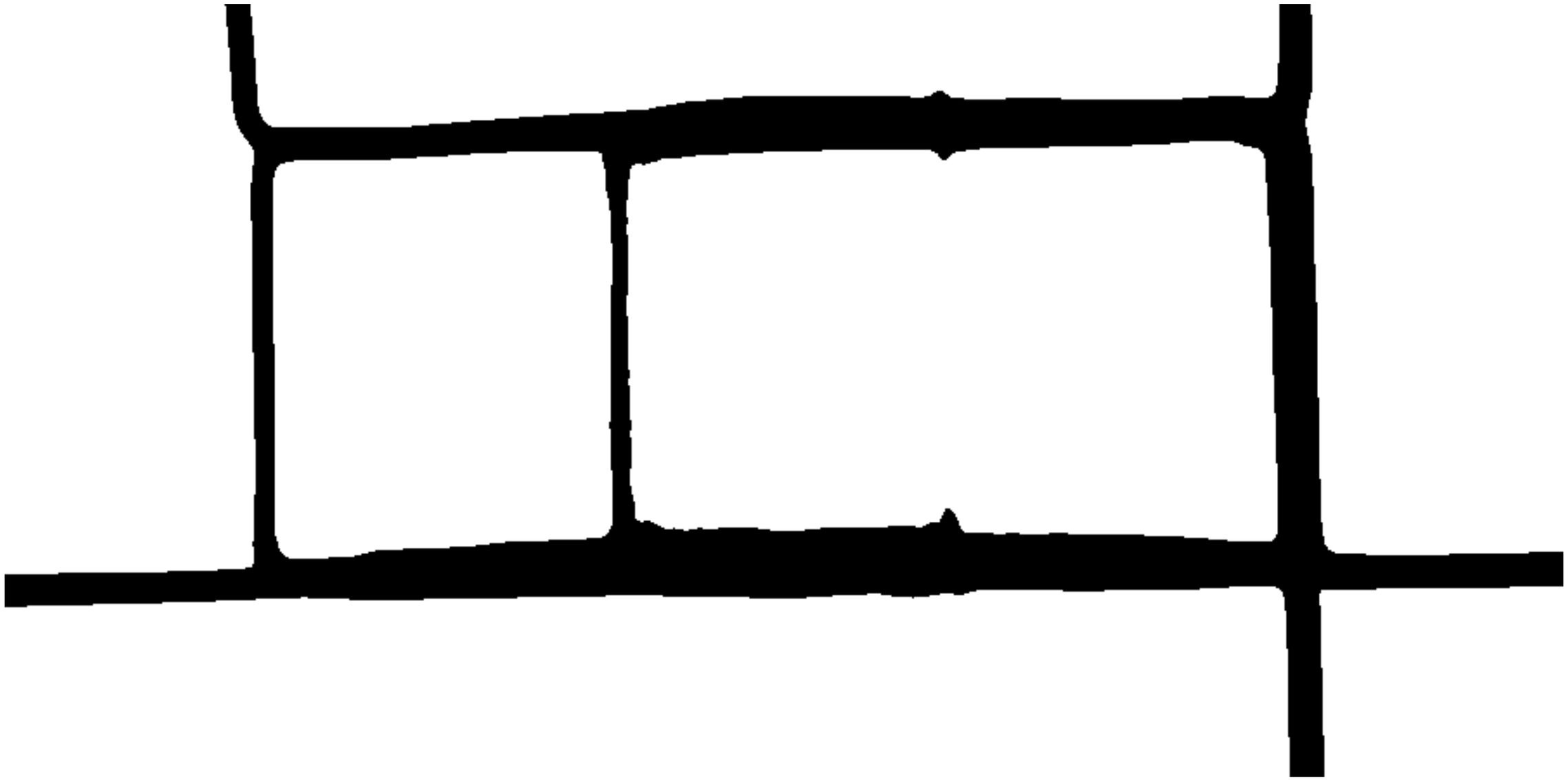
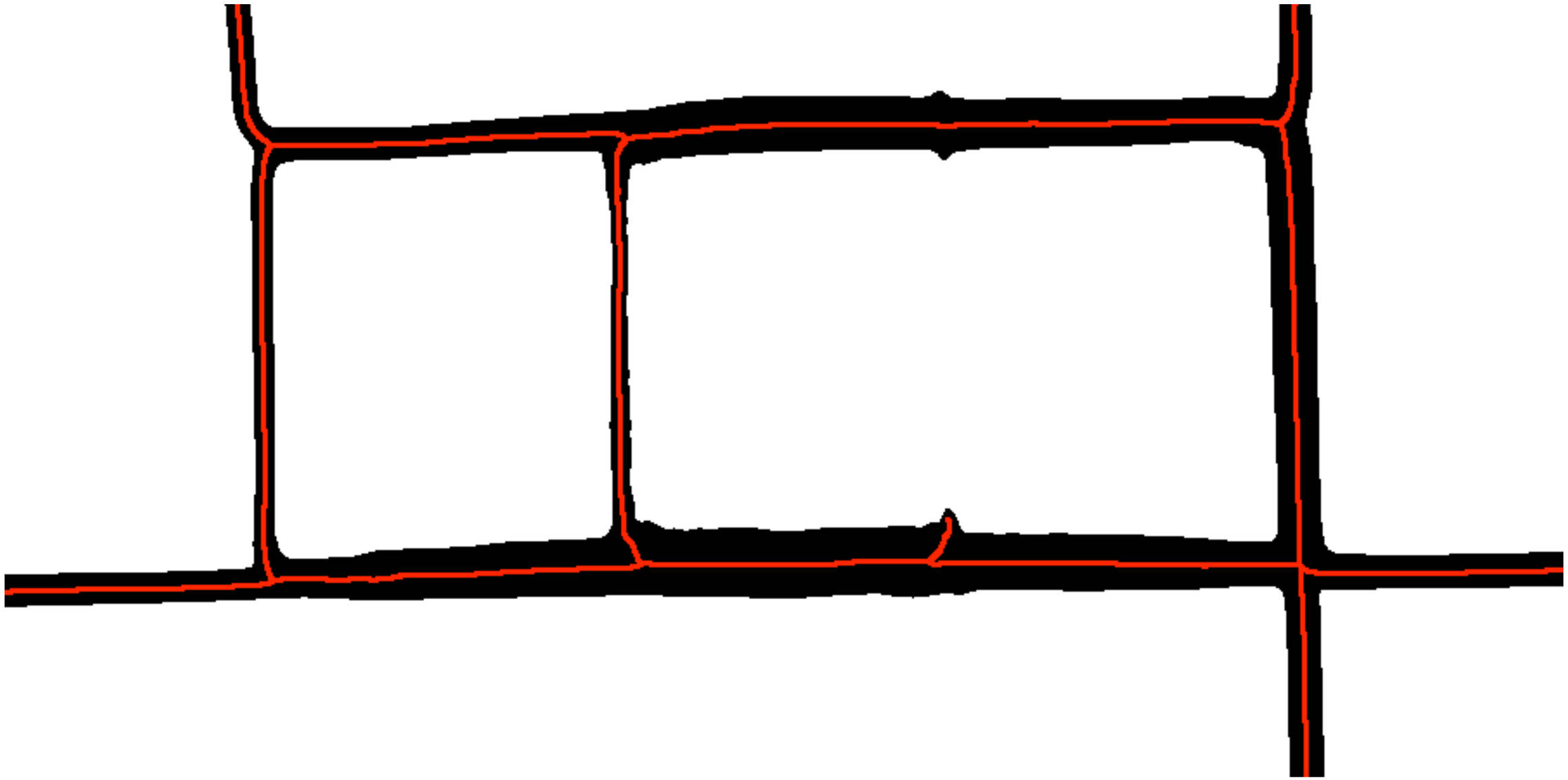


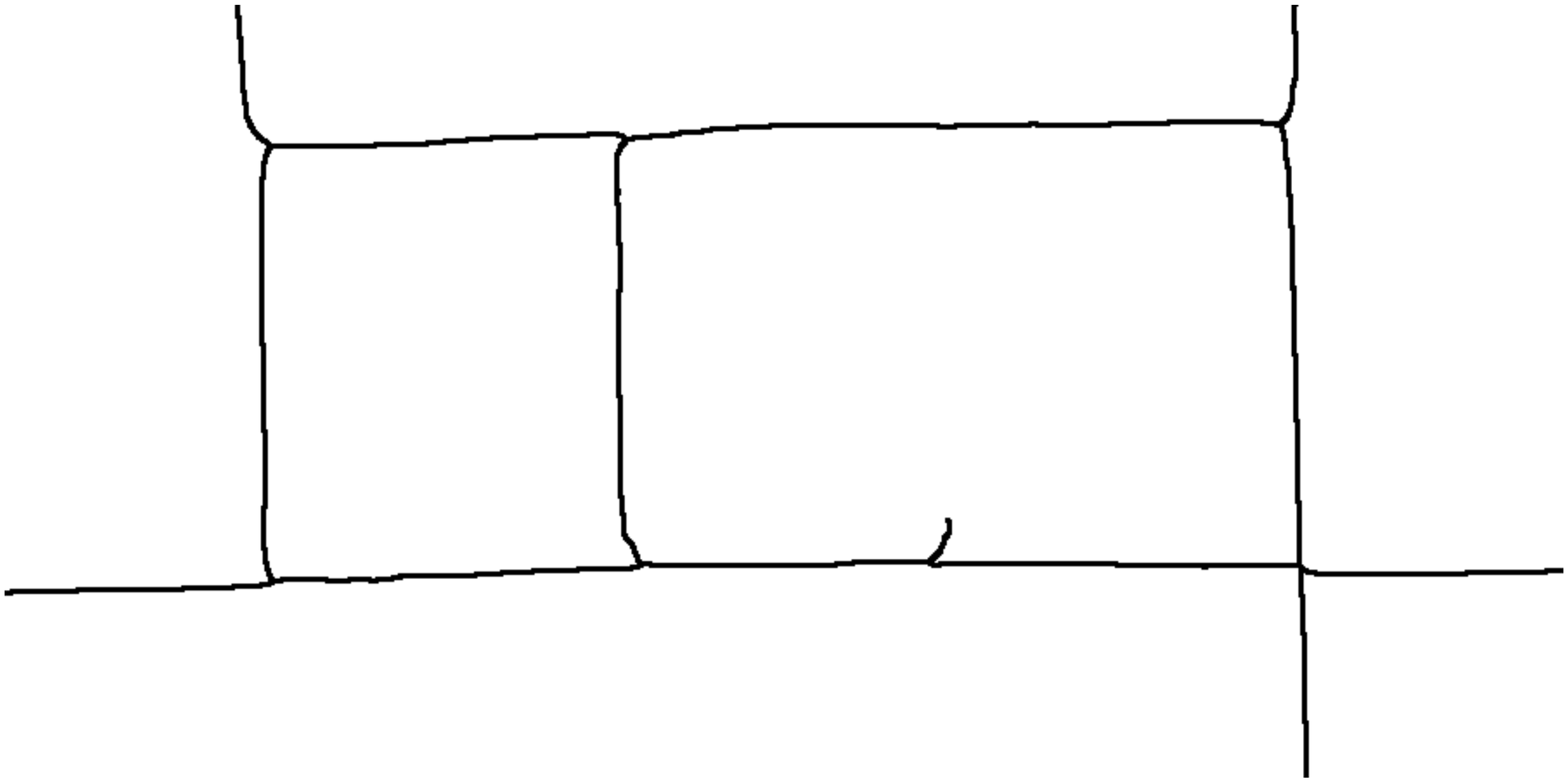
Apply (high) threshold



Binary skeletonization



Generated map



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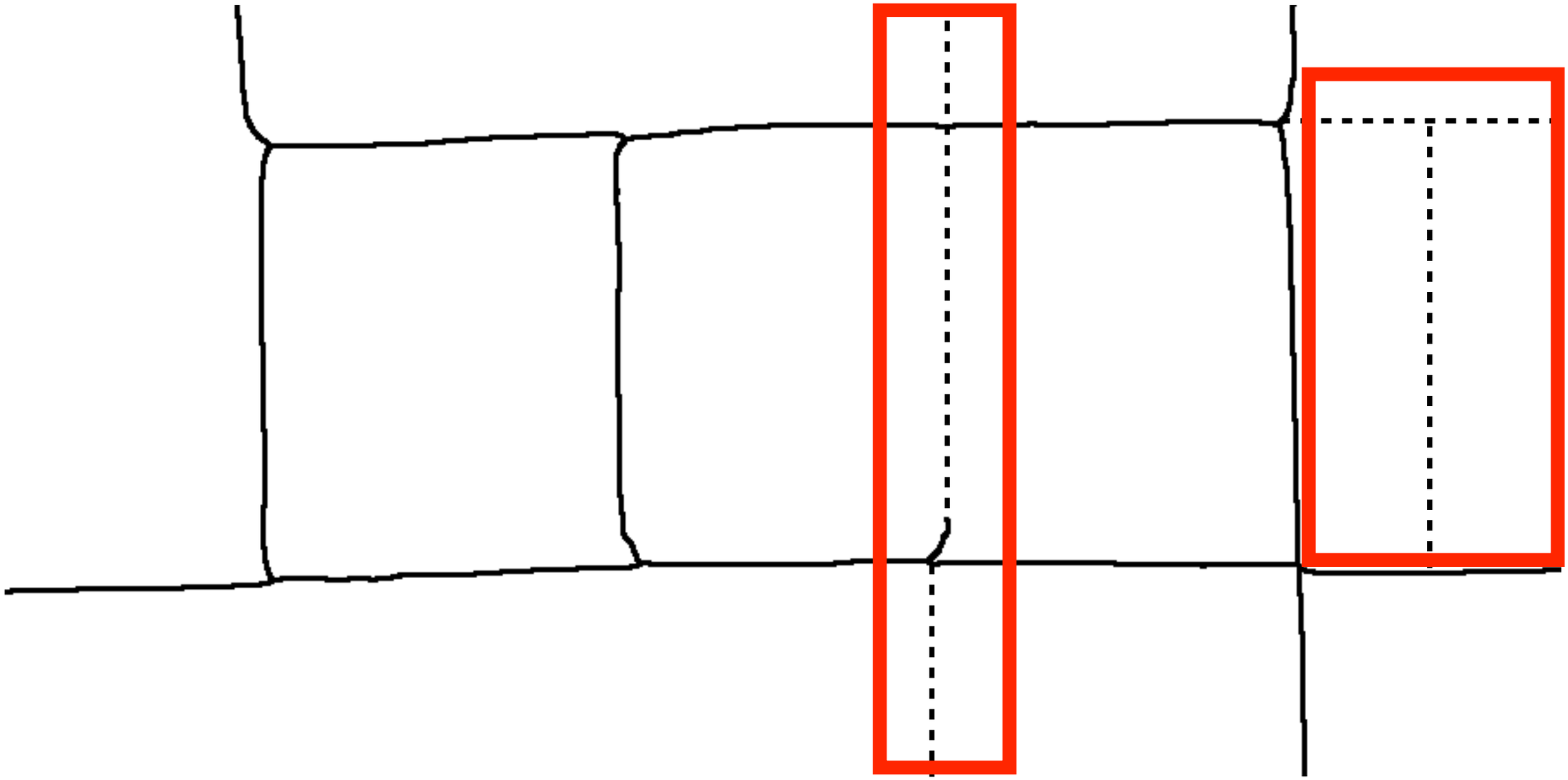
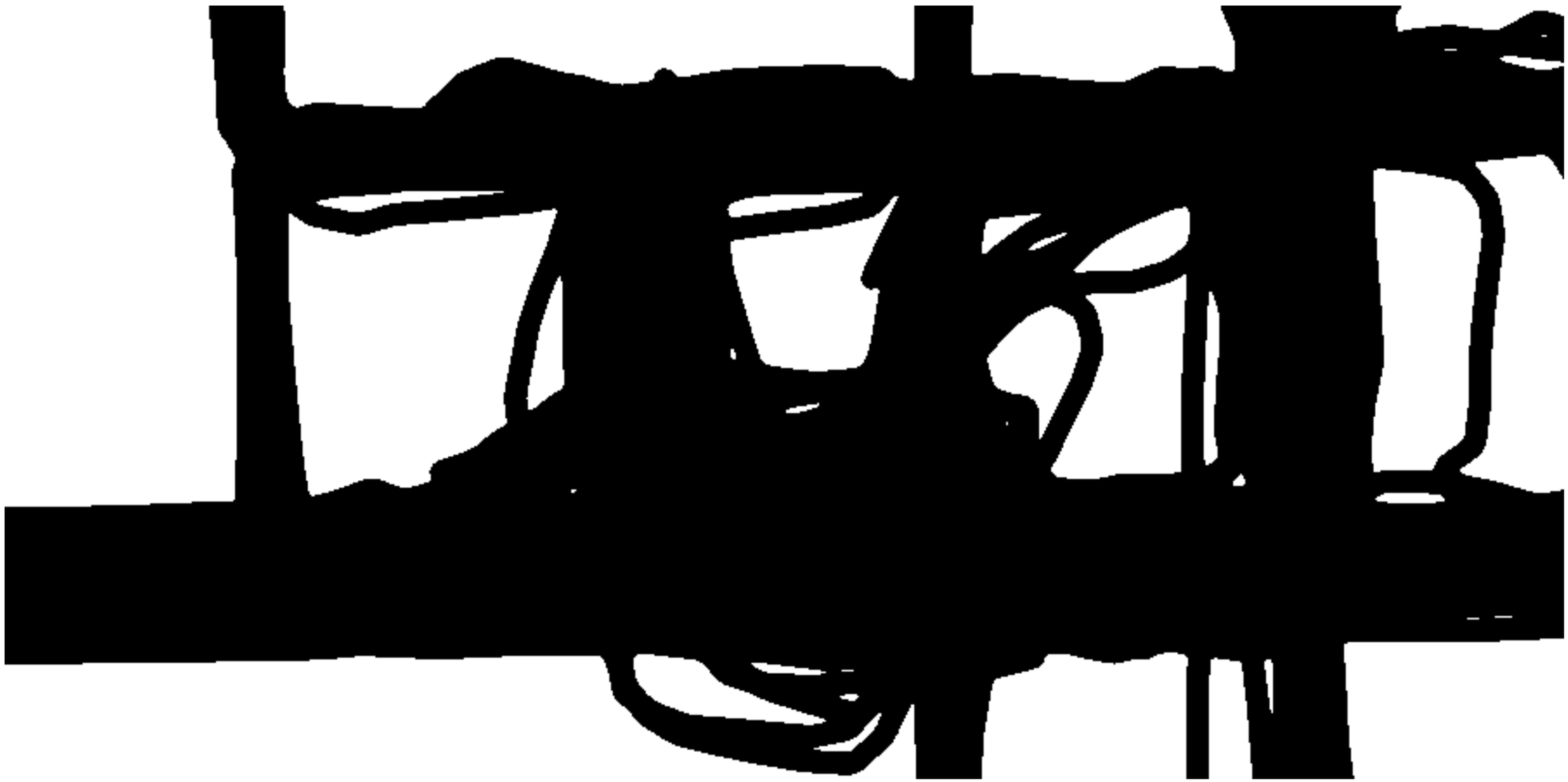


Apply (low) threshold



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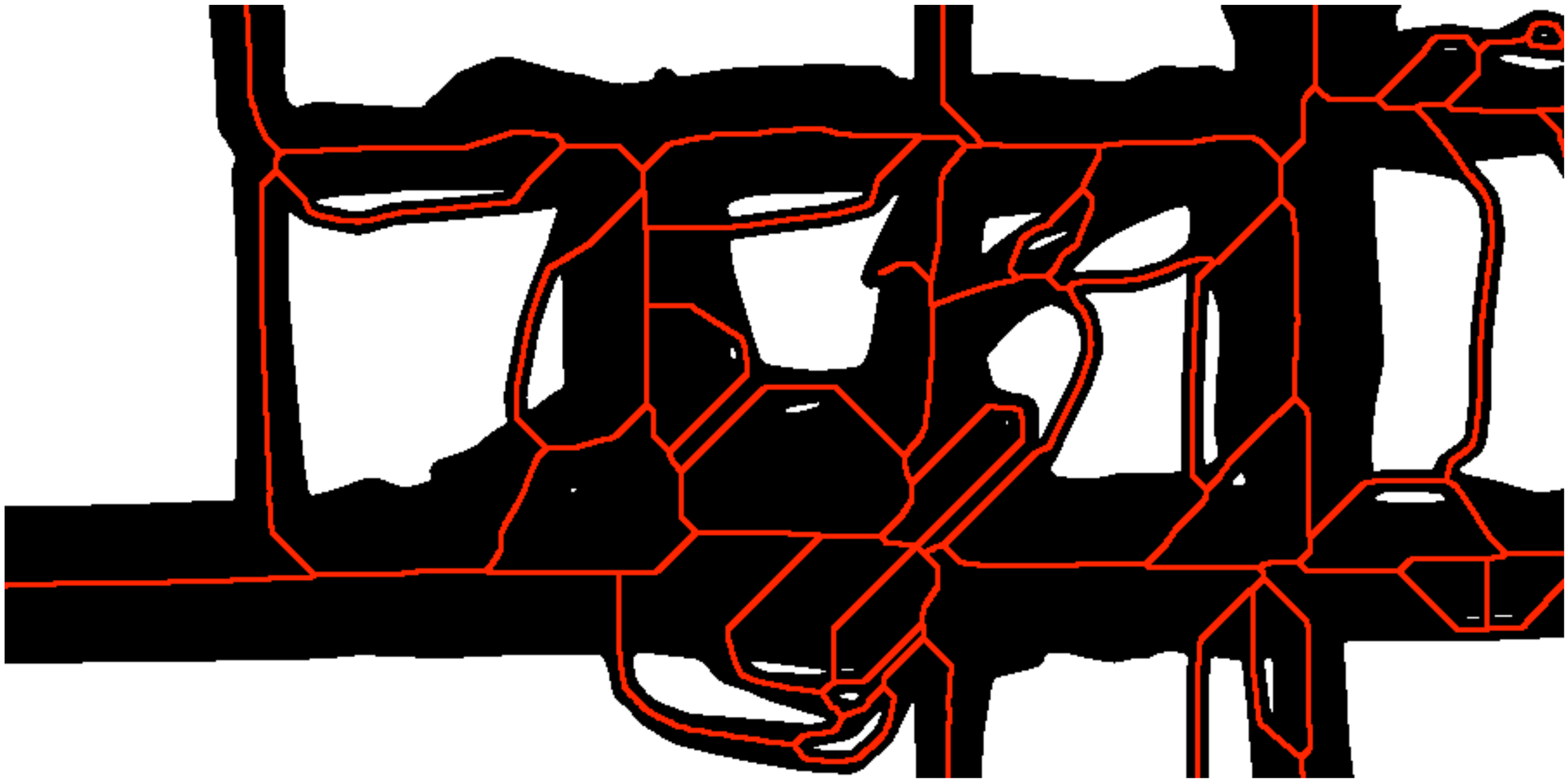

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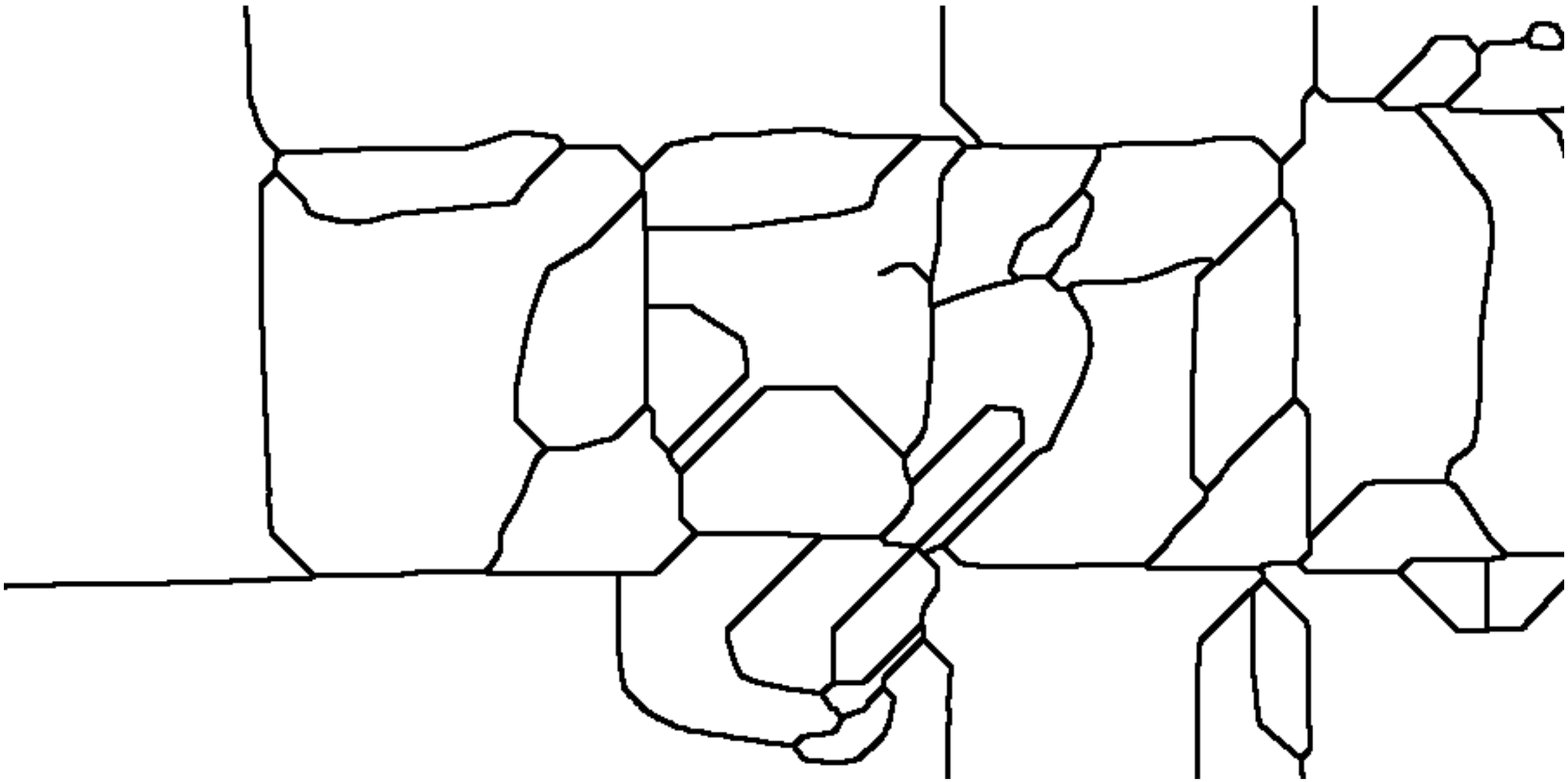
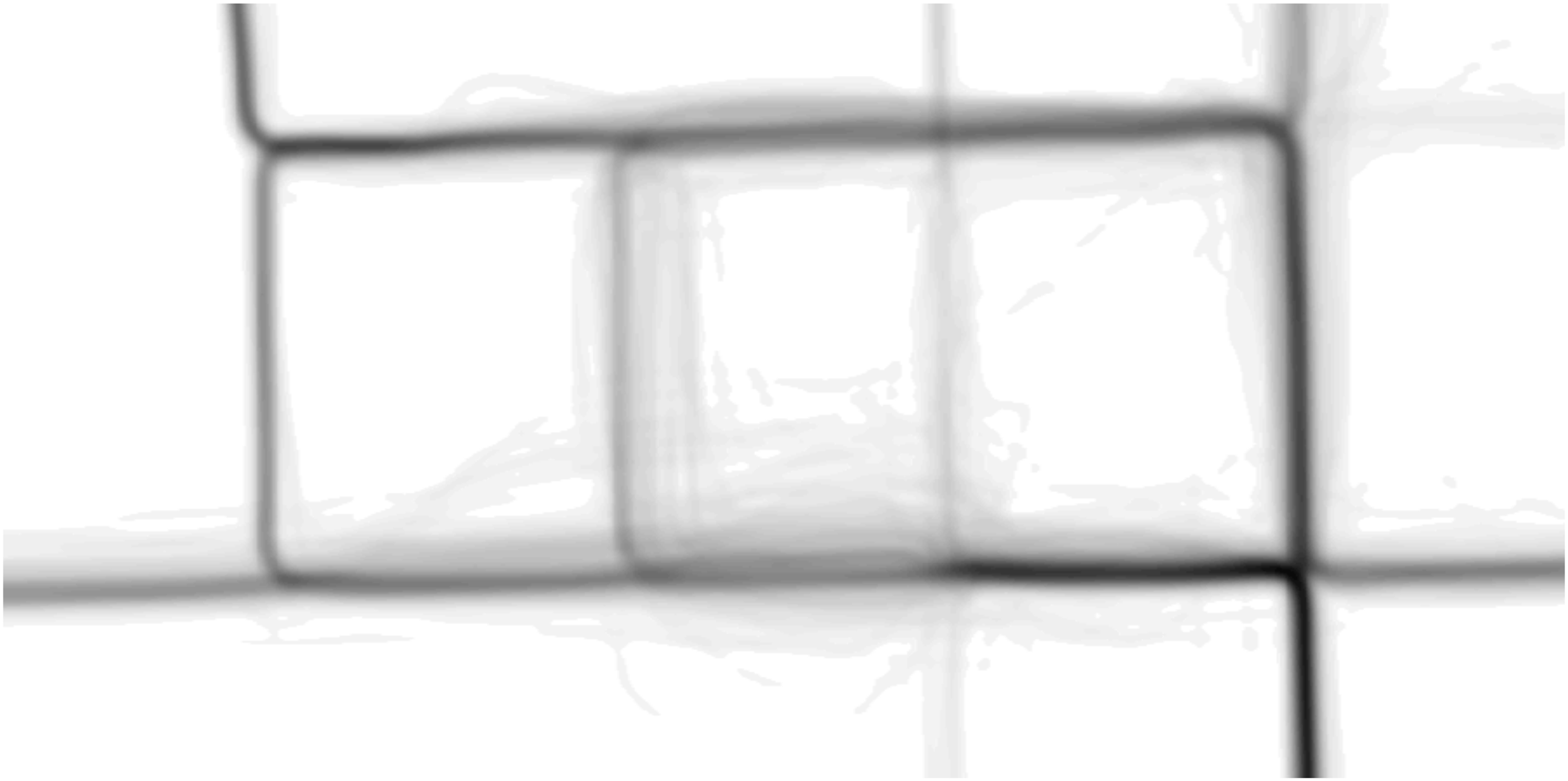


Grayscale skeletonization



1) Threshold



2) Skeletonize



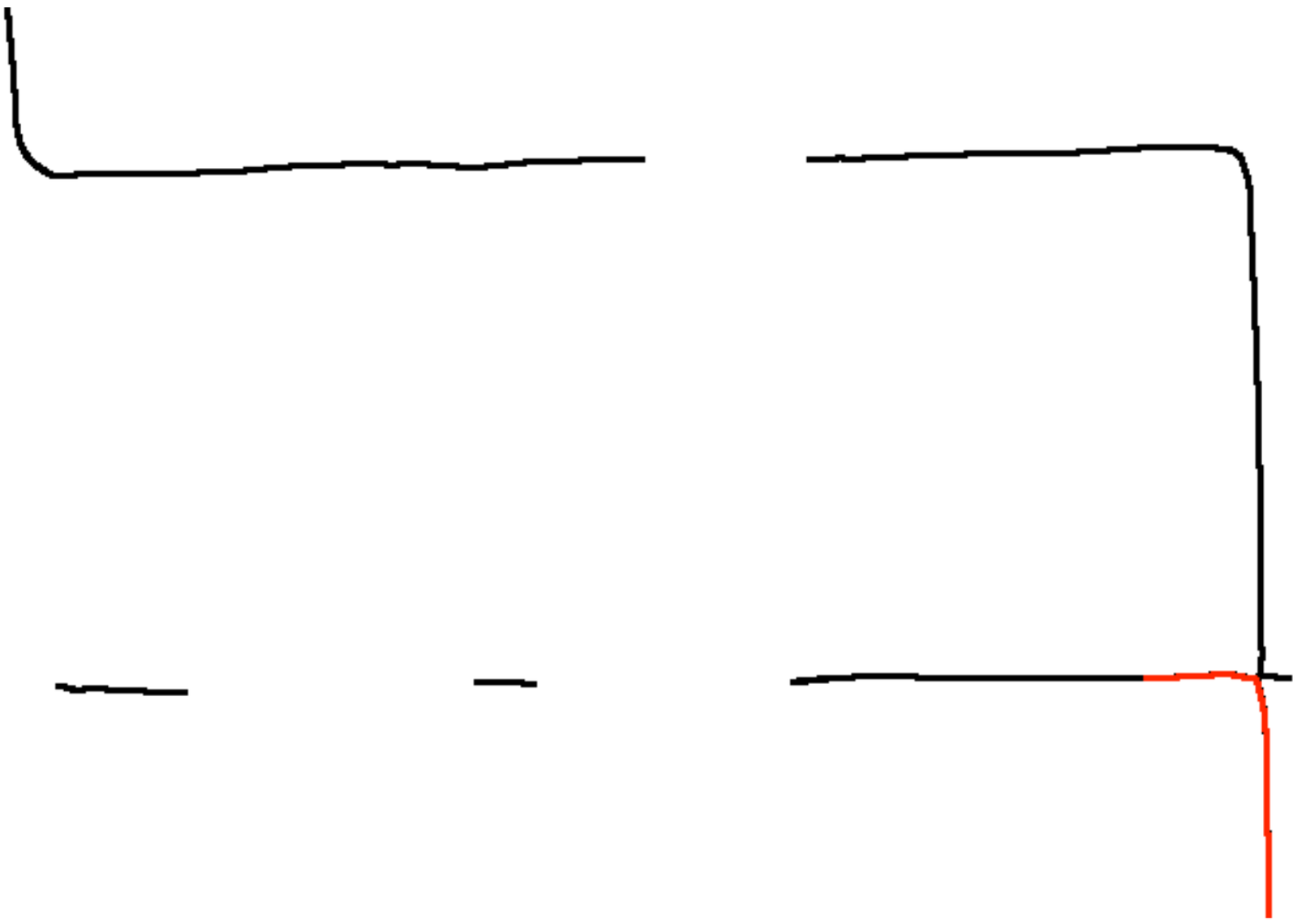
3) “Lock in”



1) Threshold



2) Skeletonize



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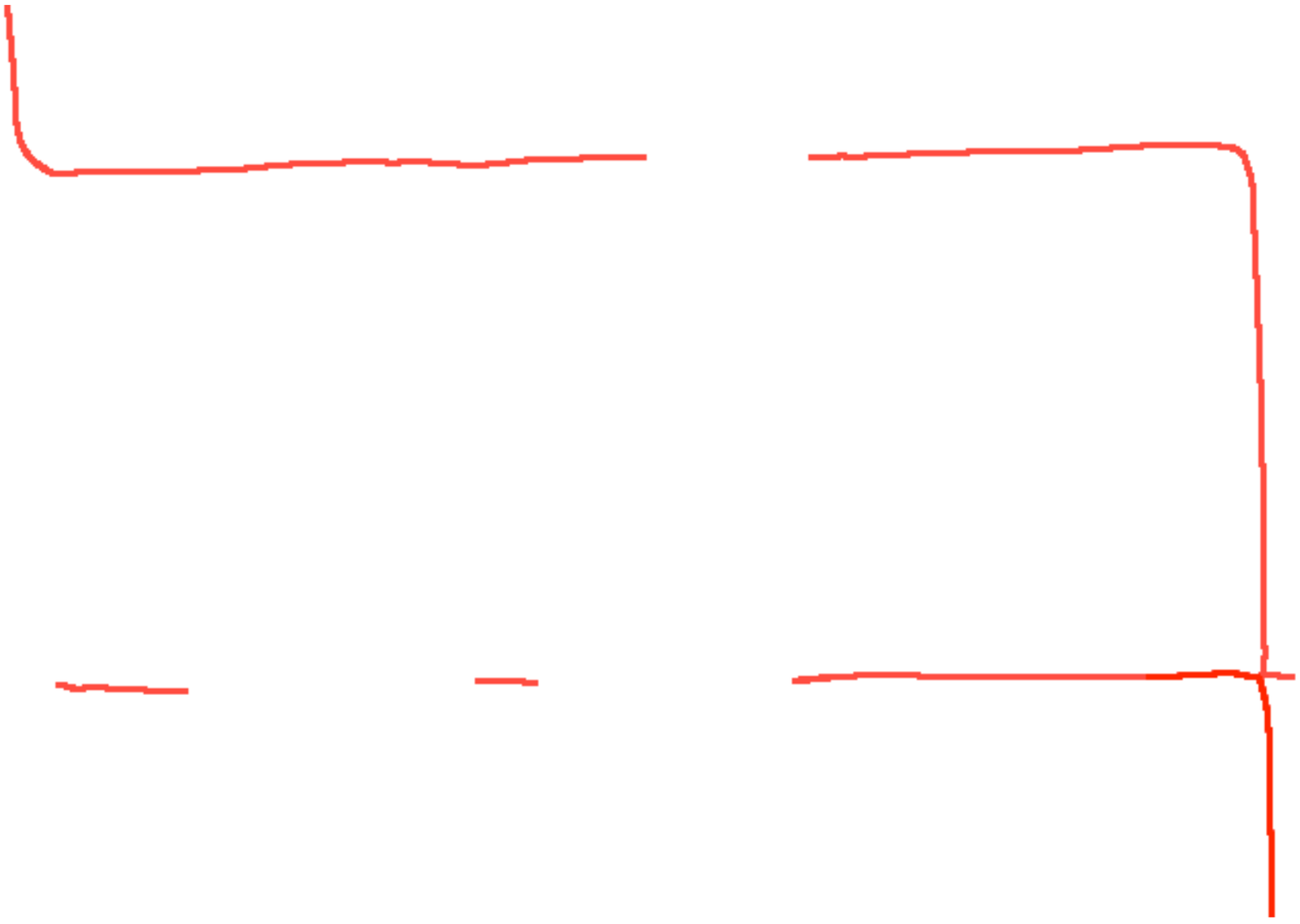

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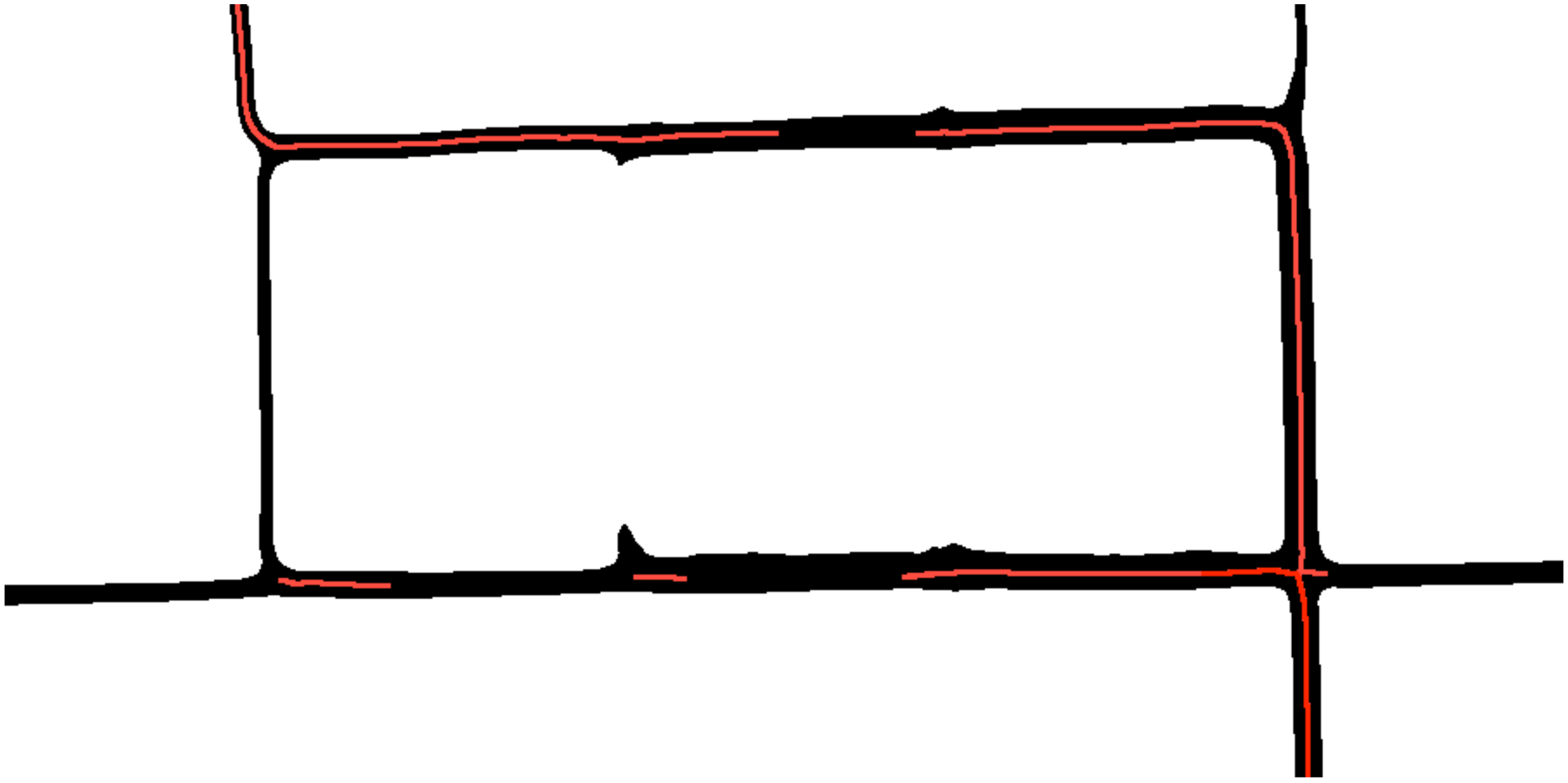

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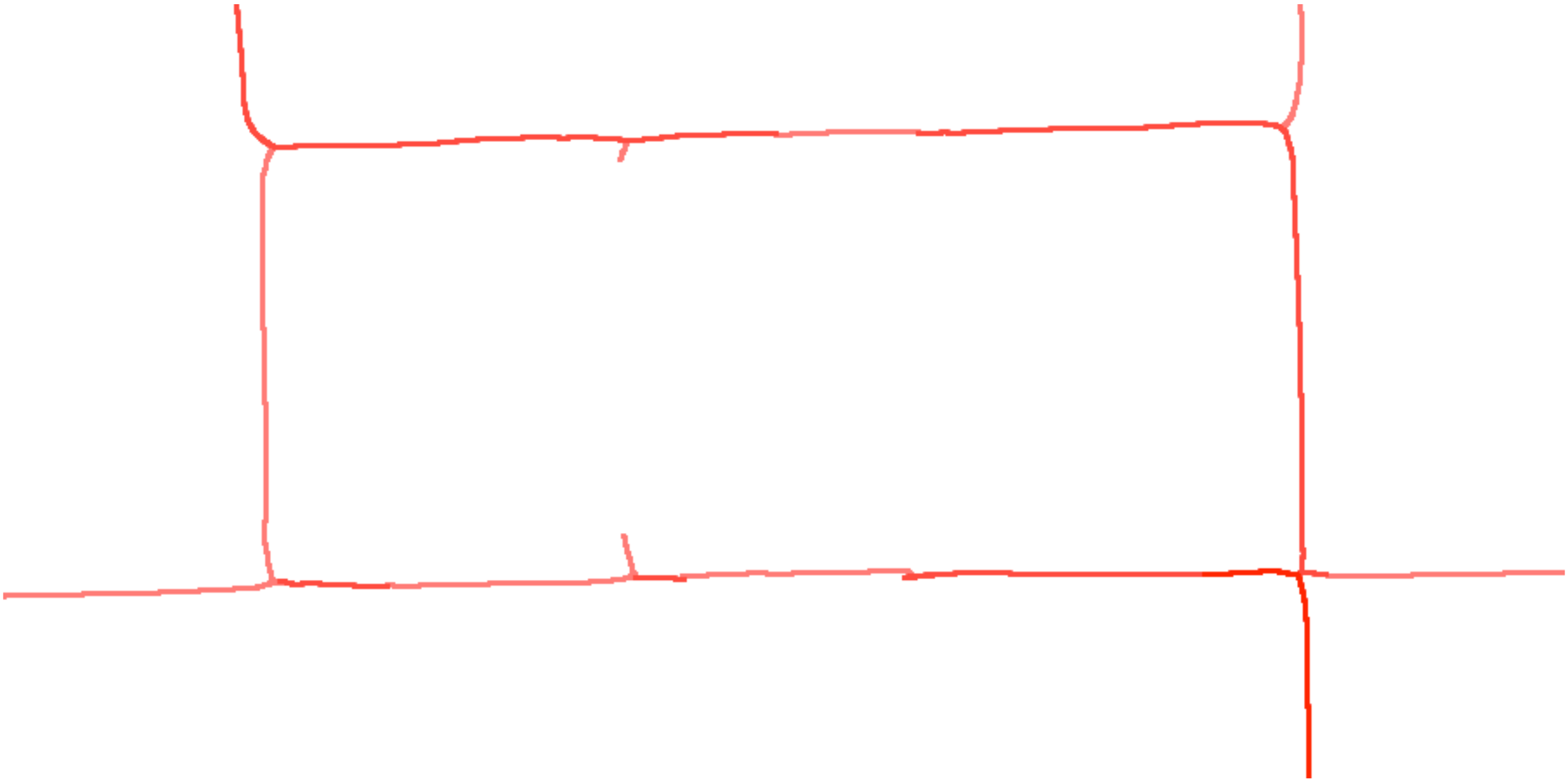

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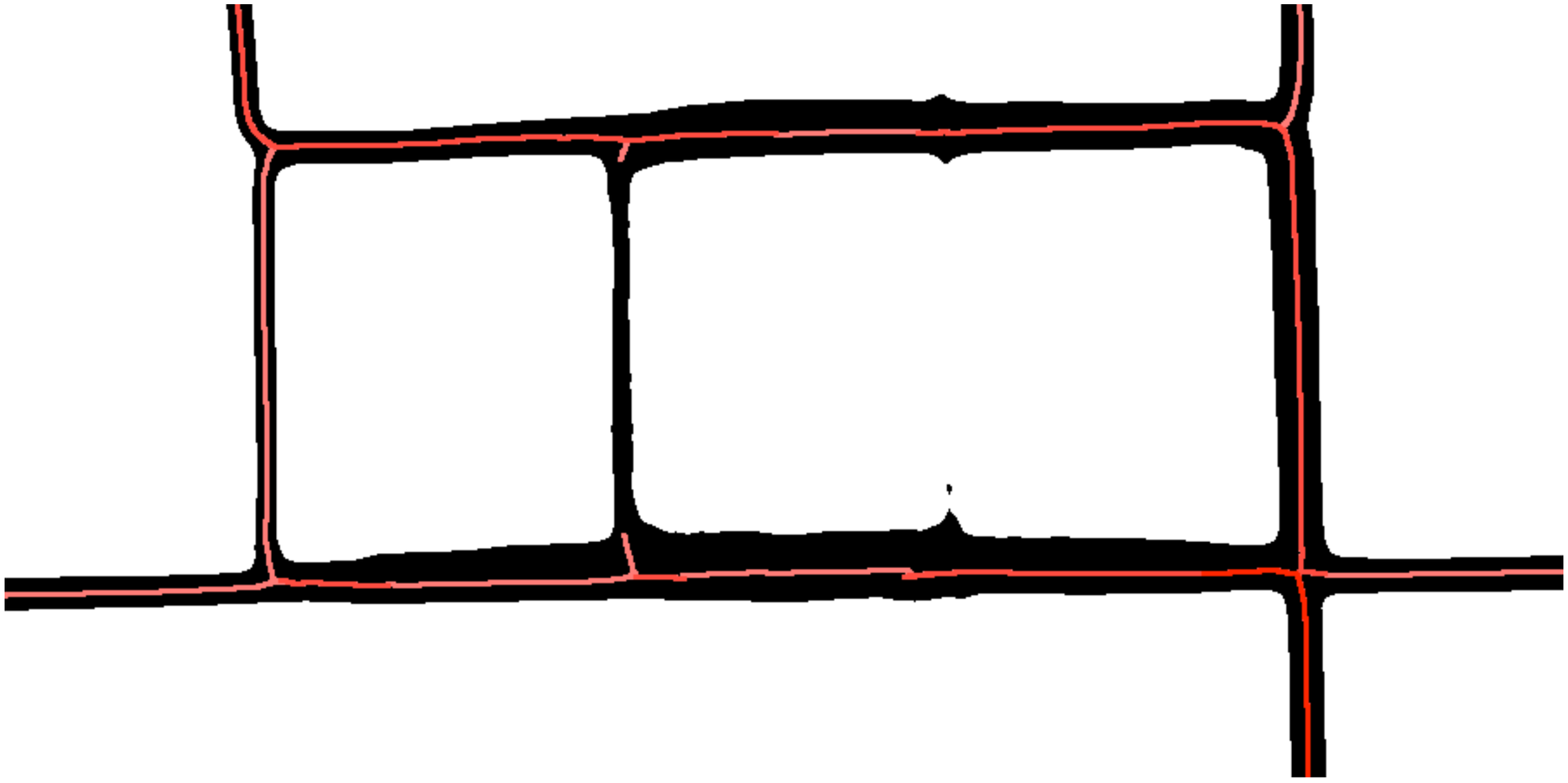

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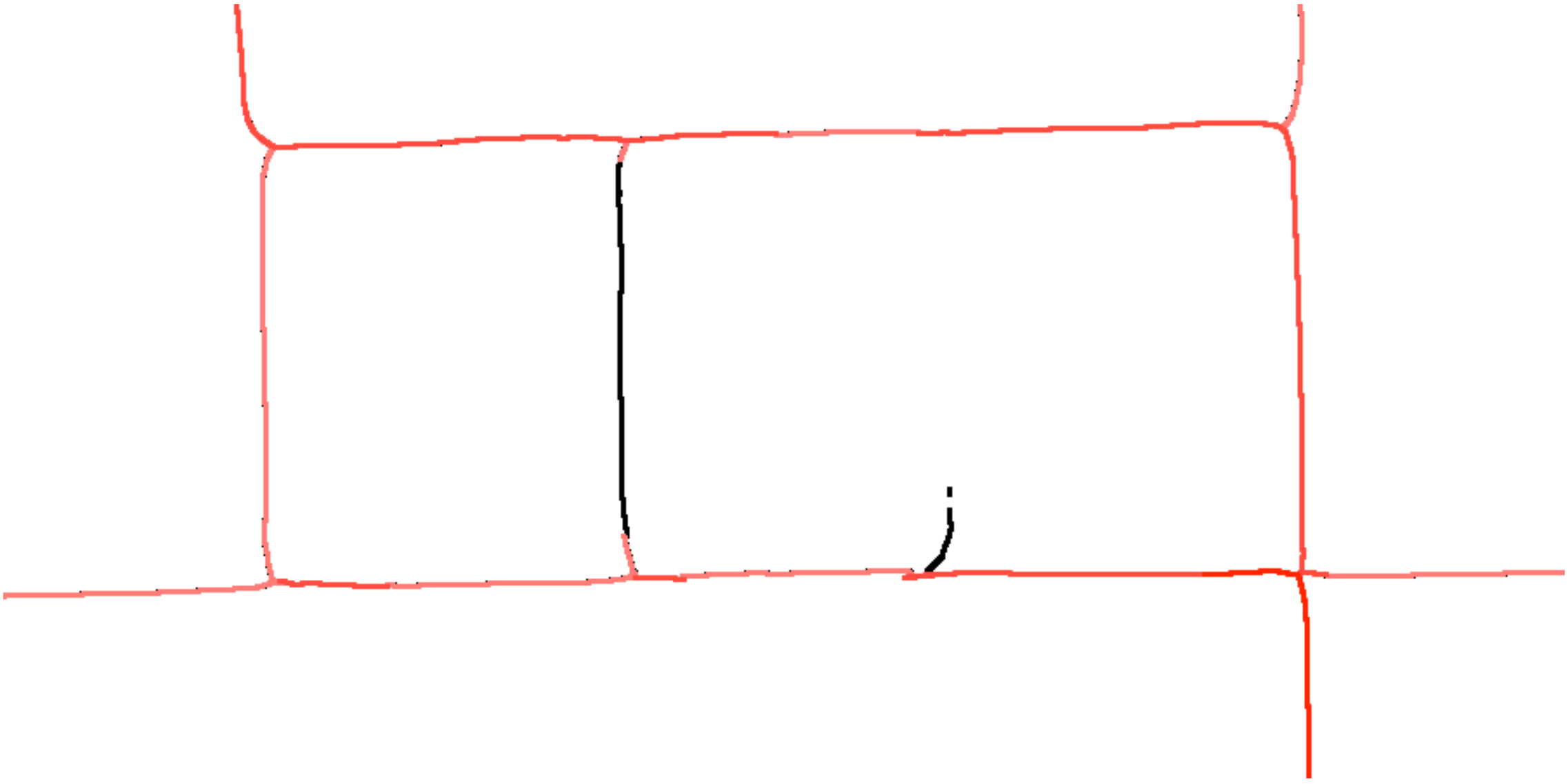

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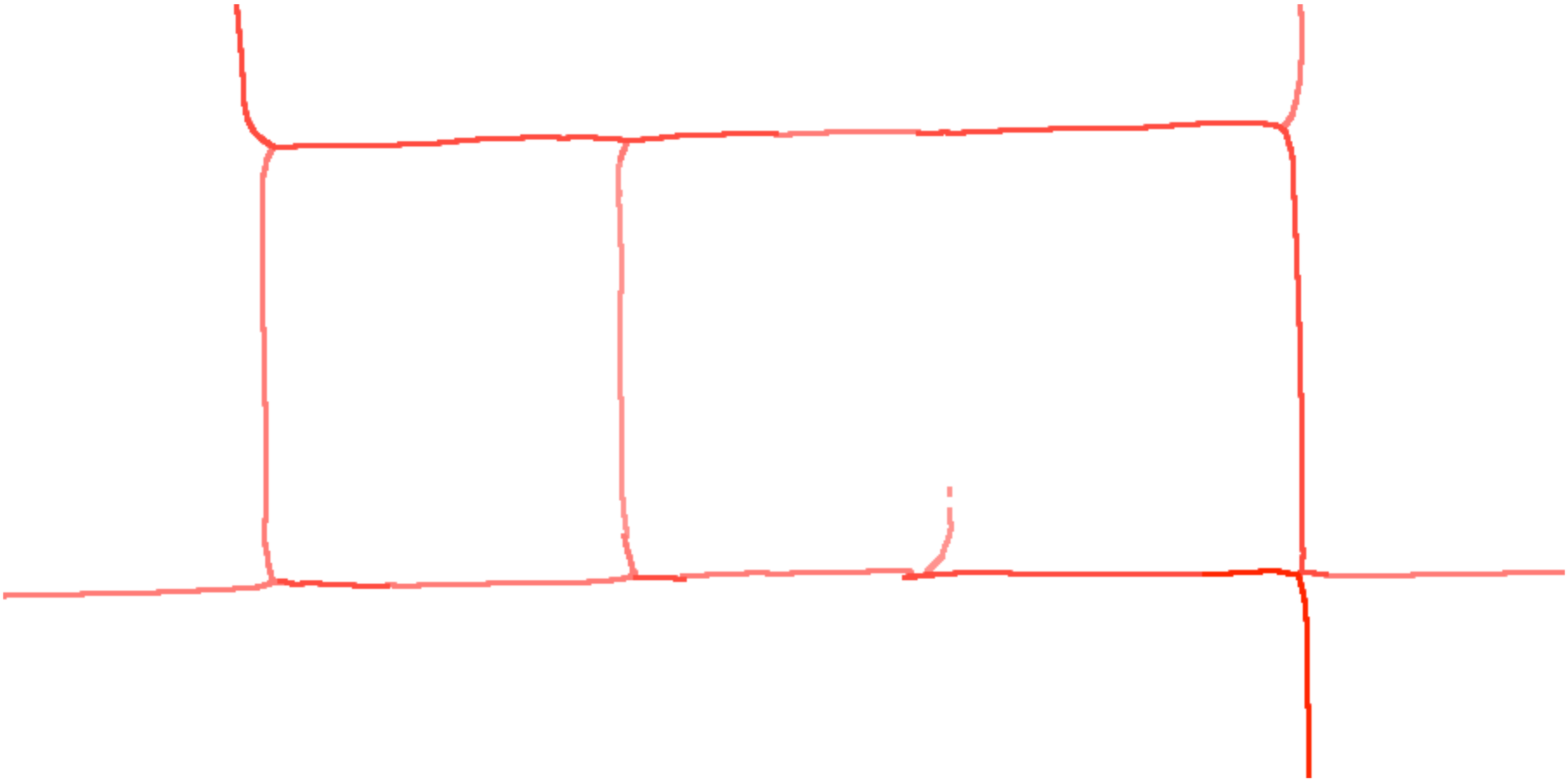

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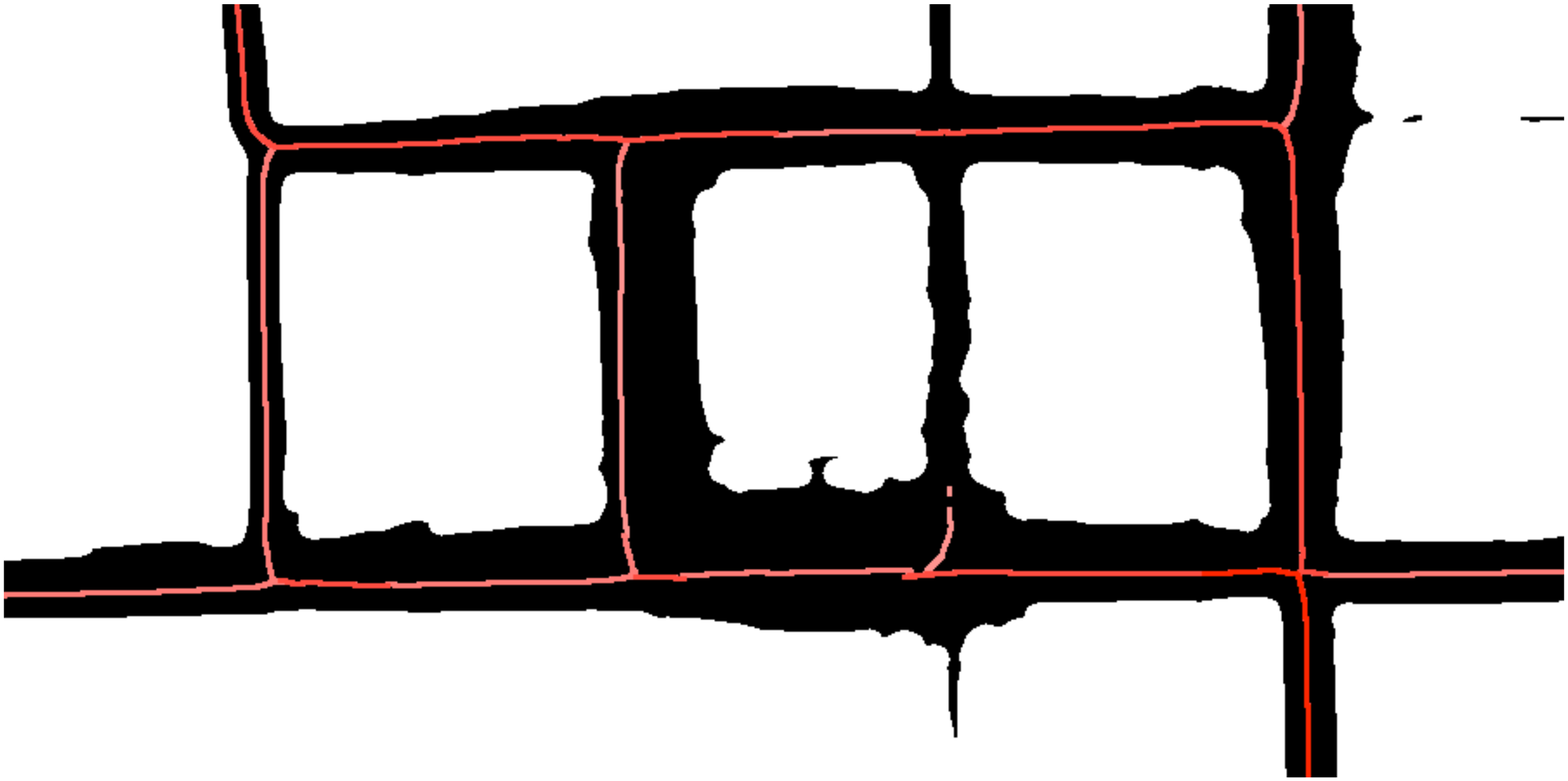

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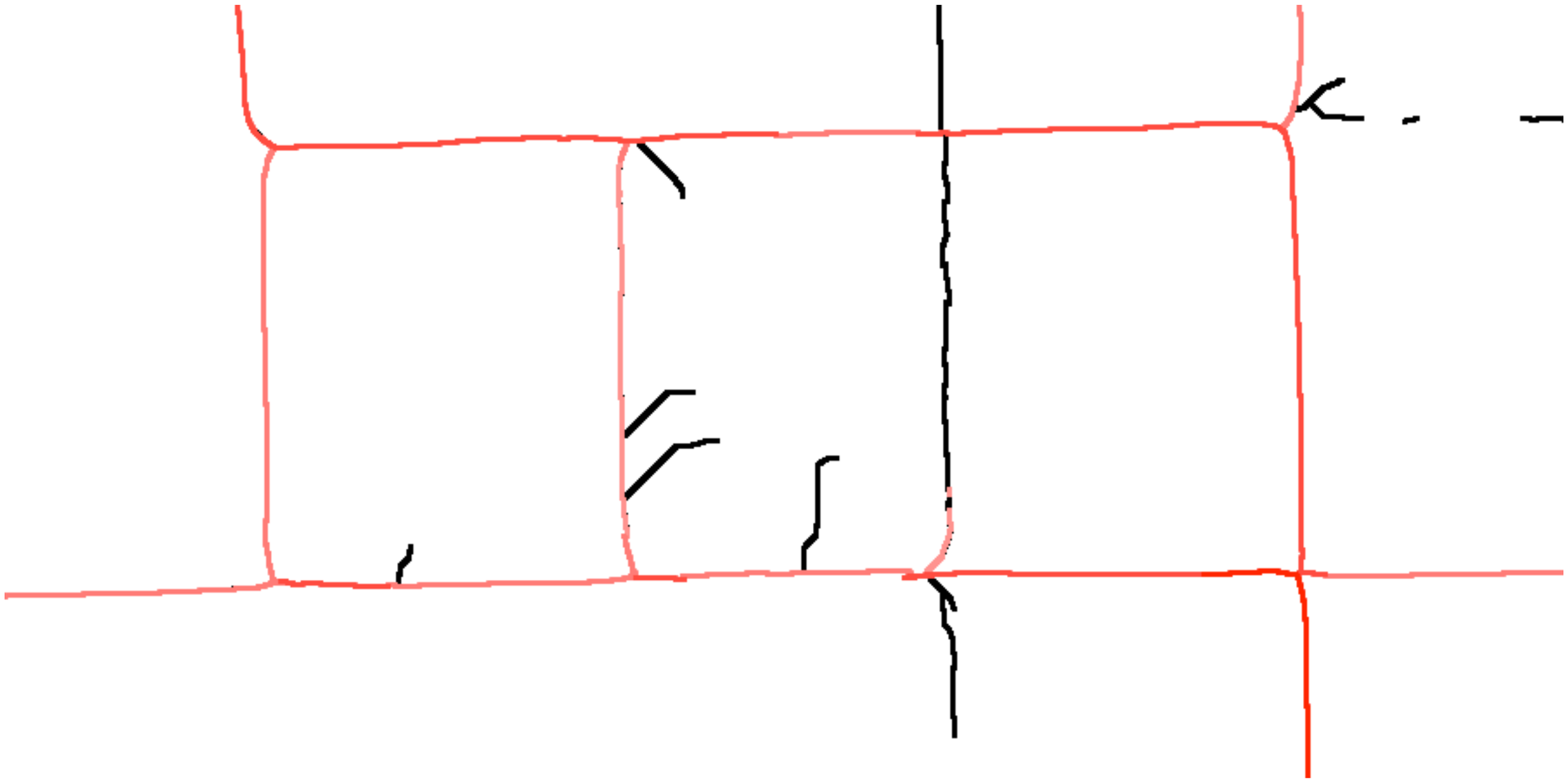

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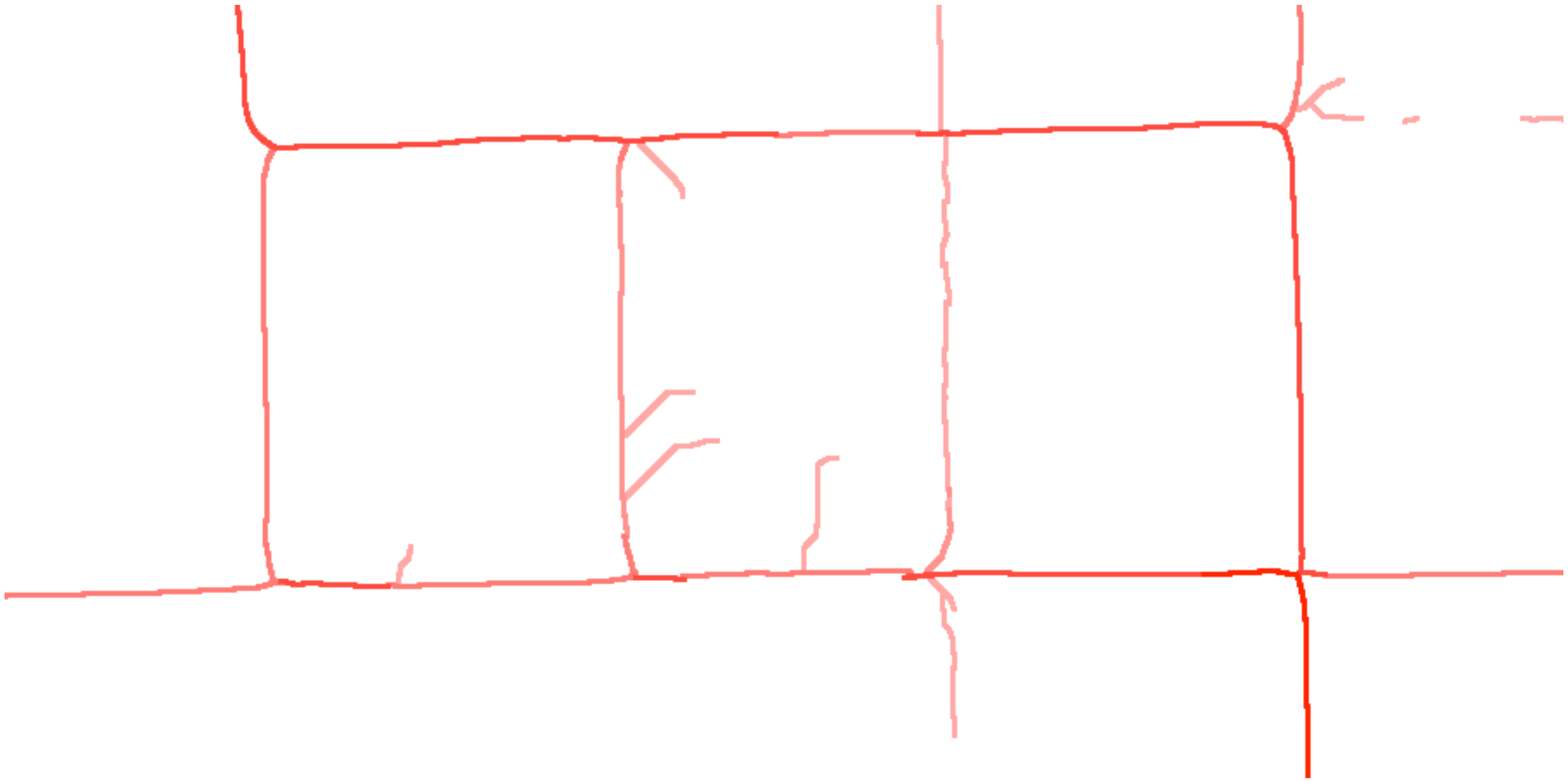

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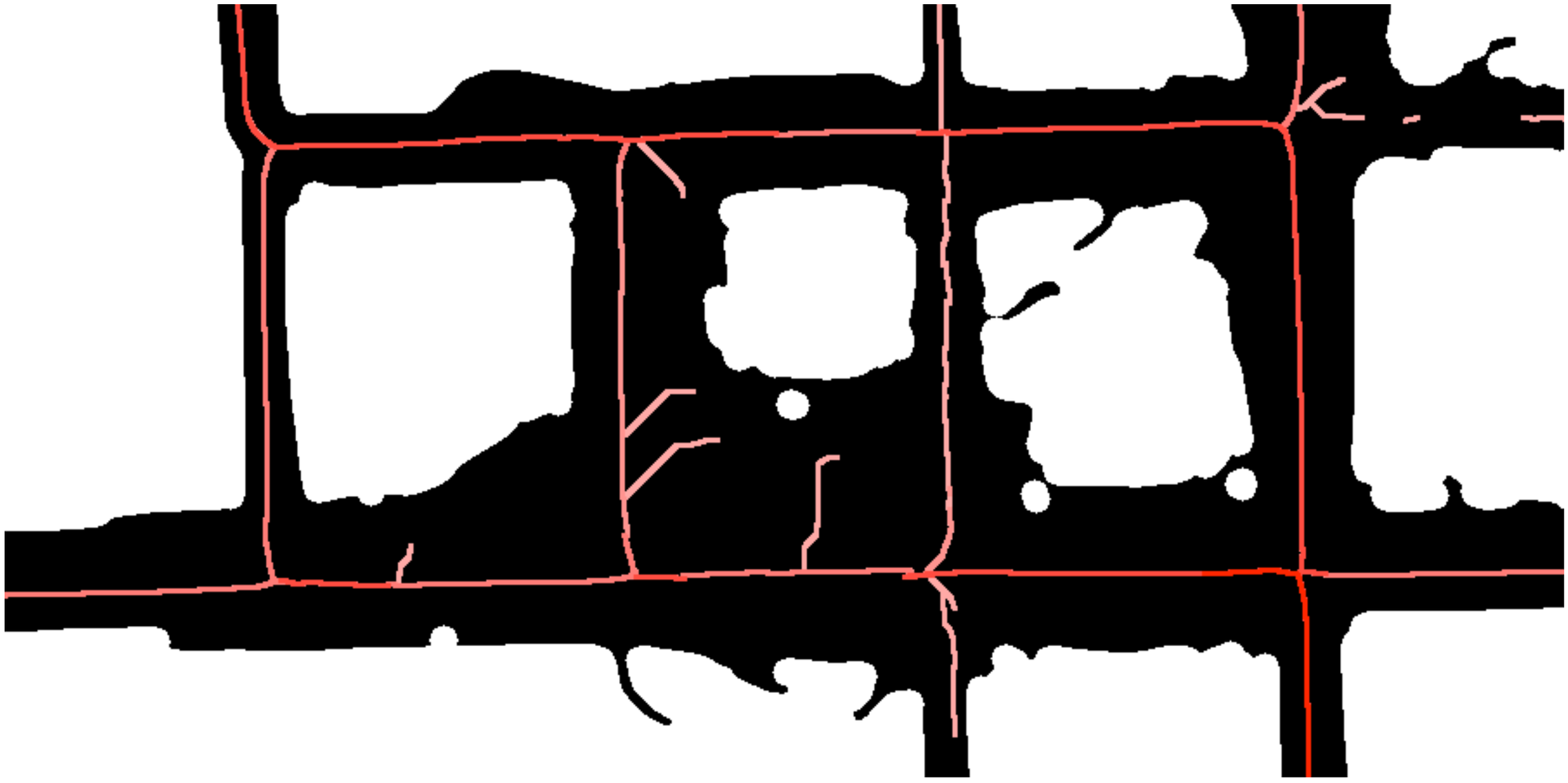

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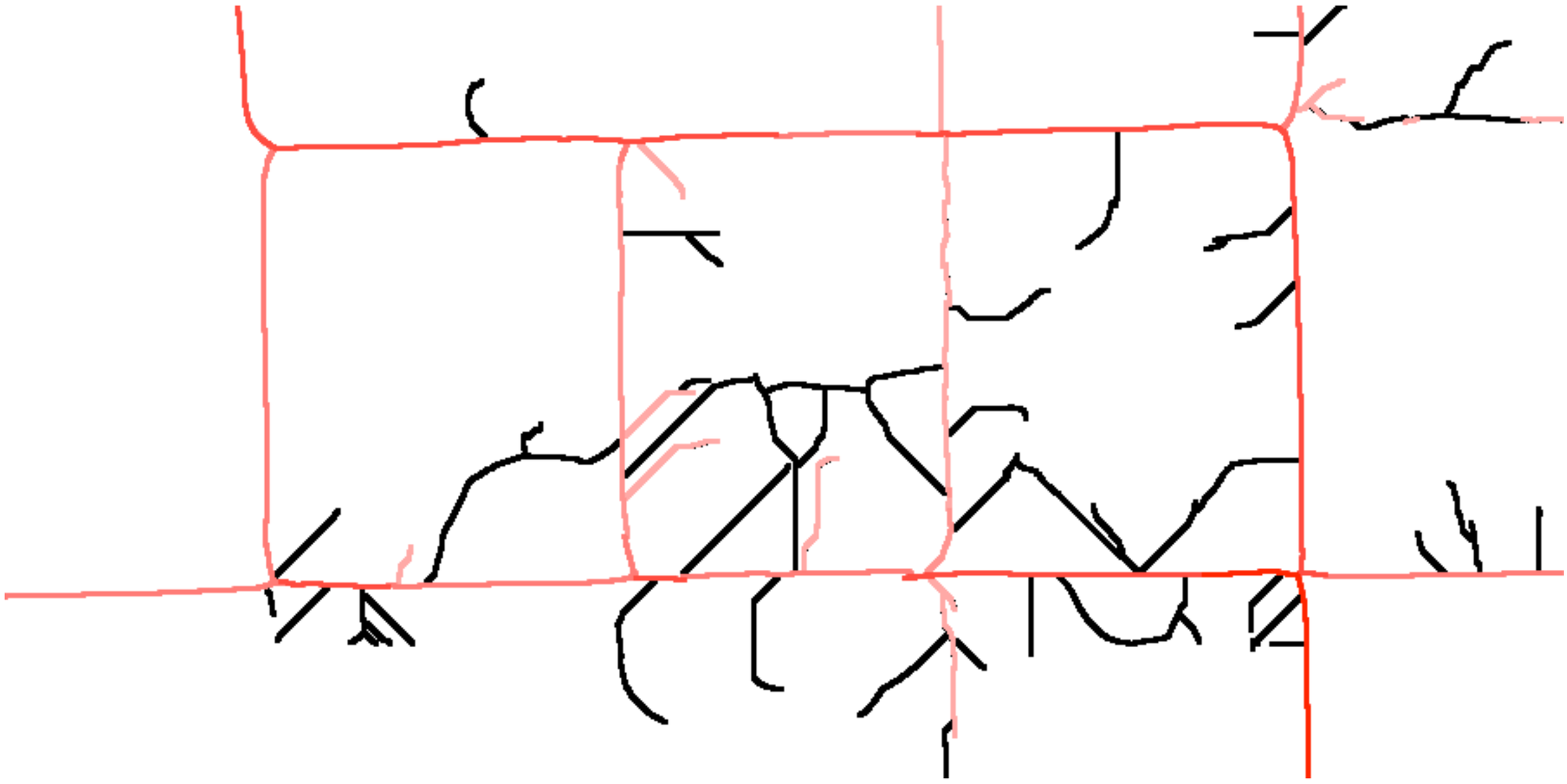

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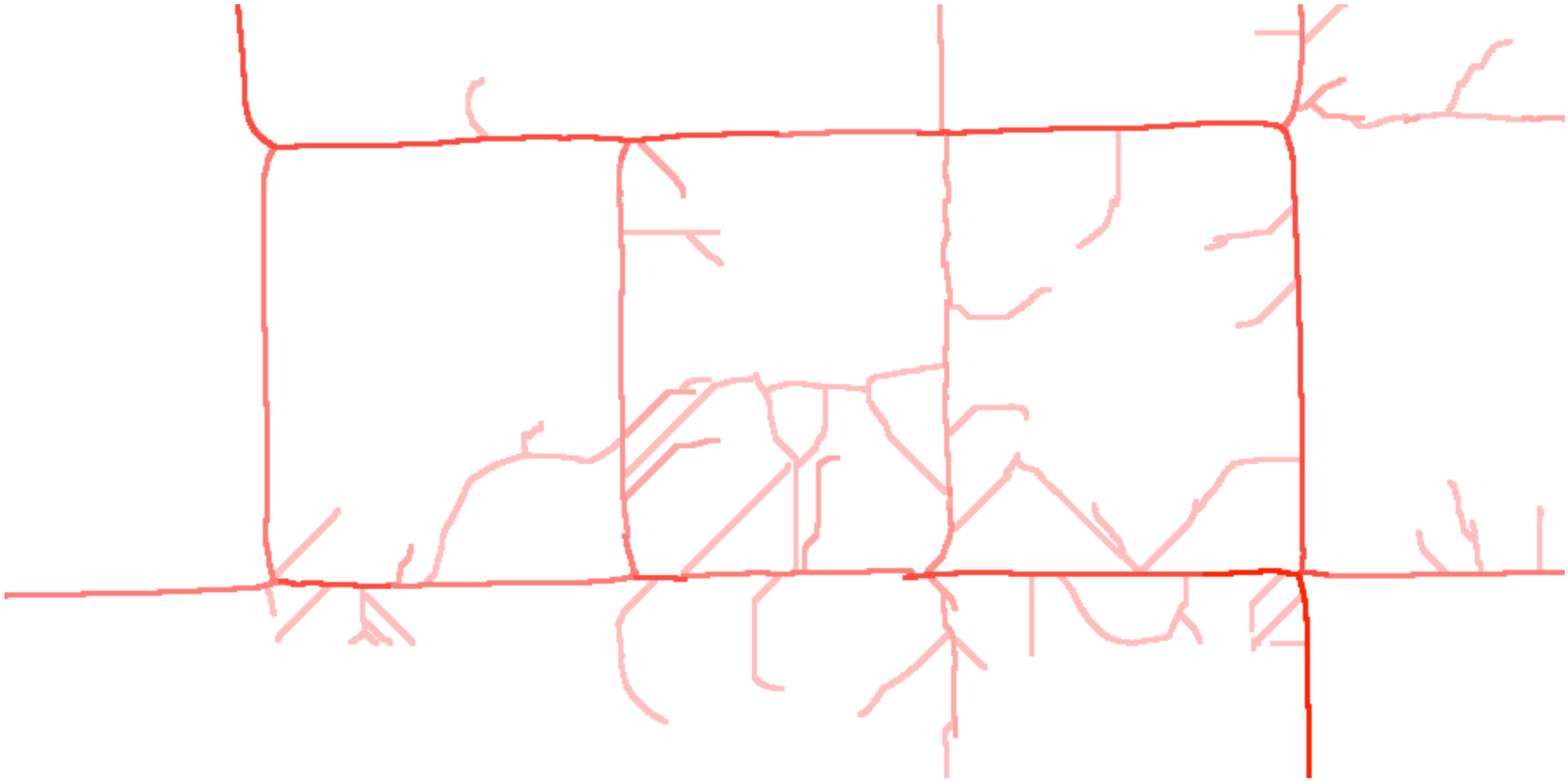

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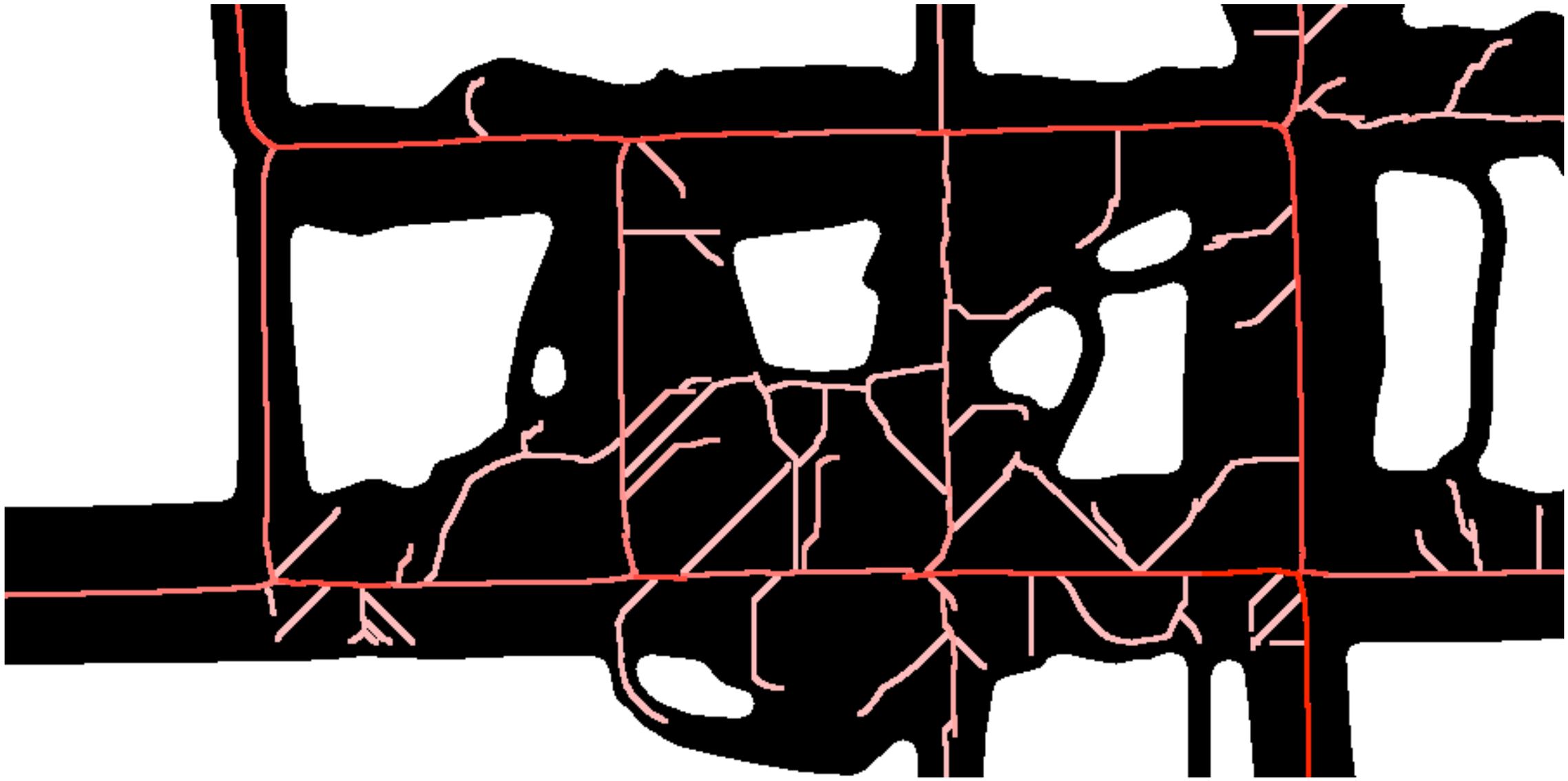

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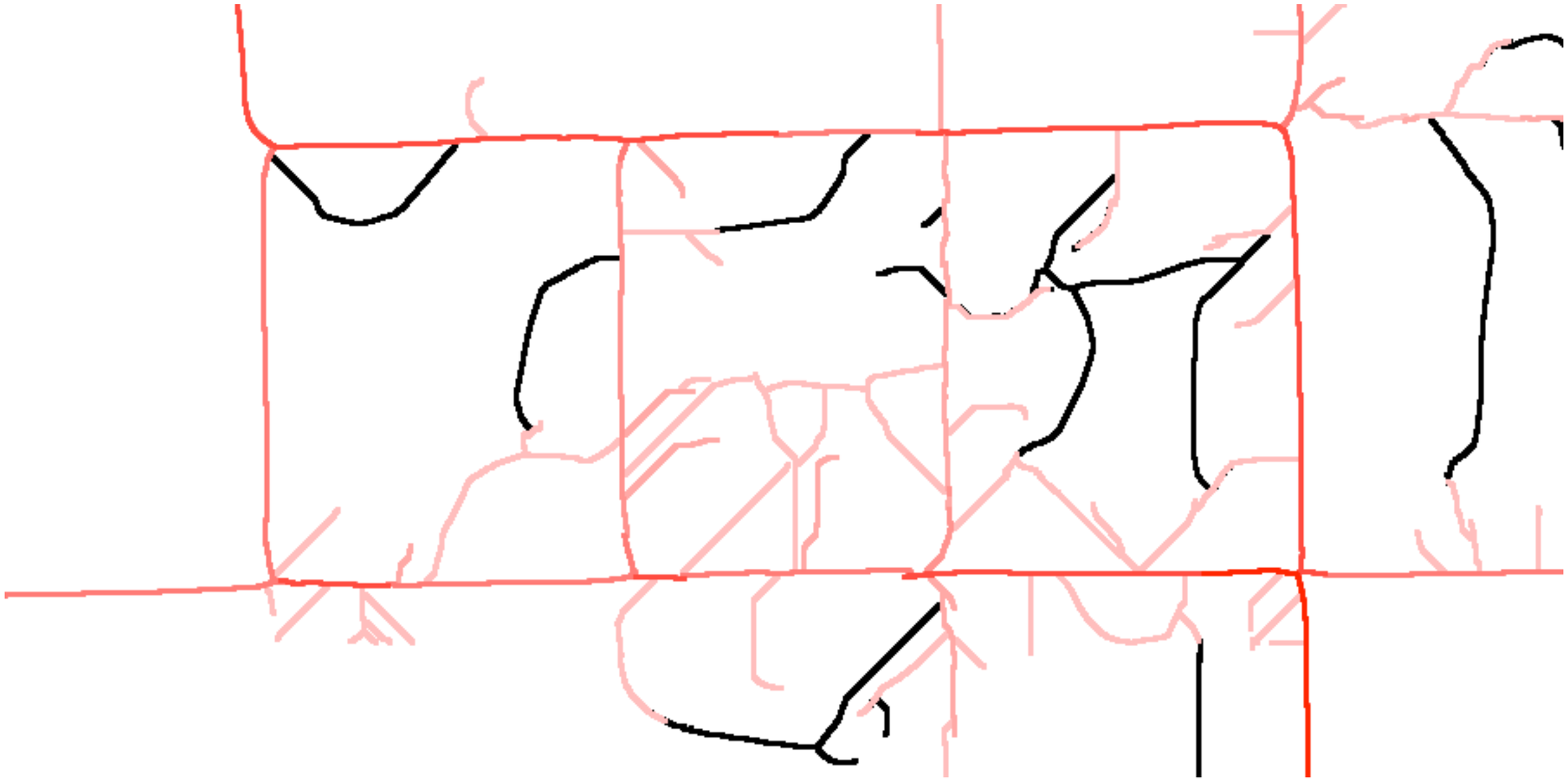

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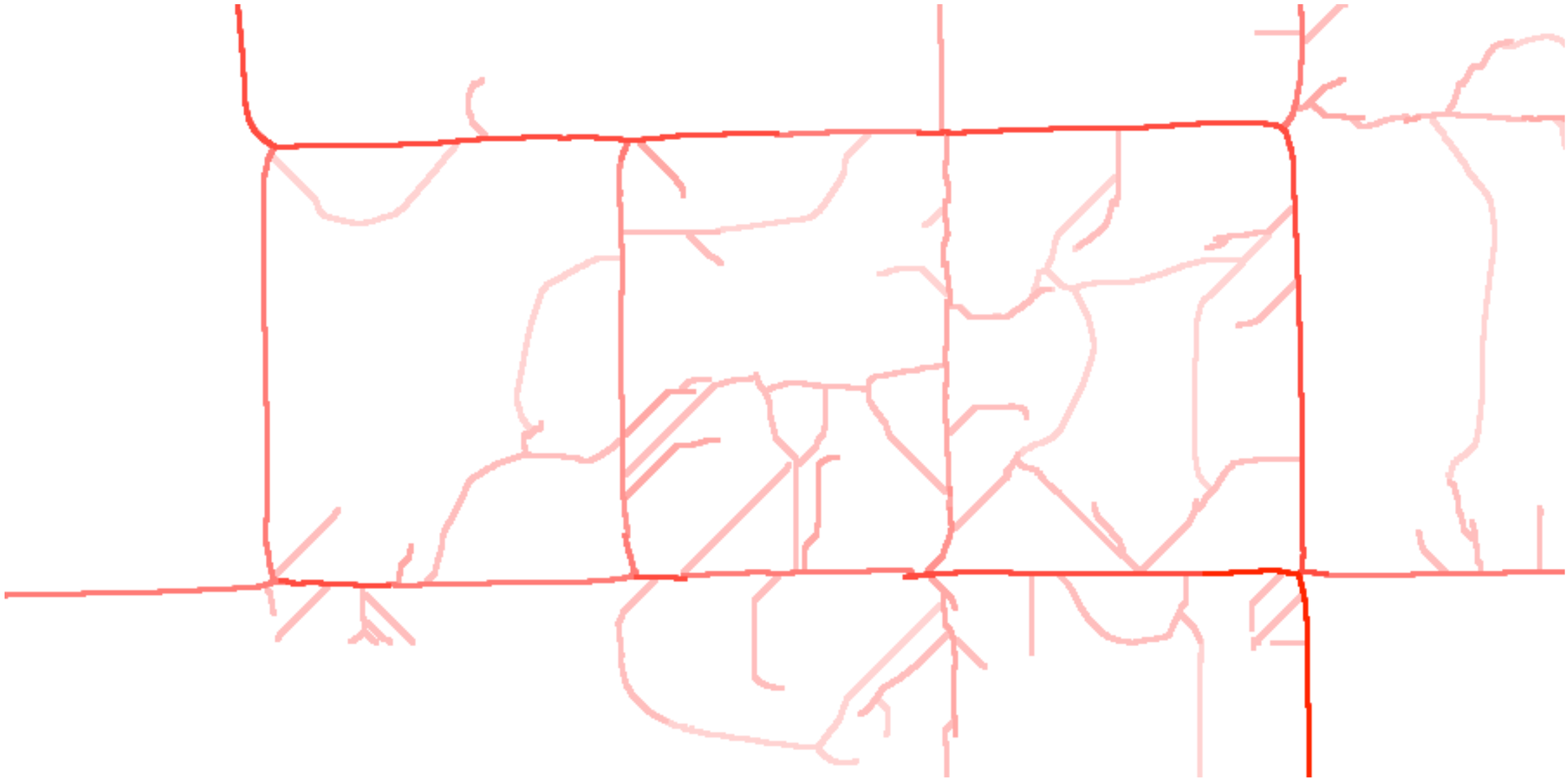
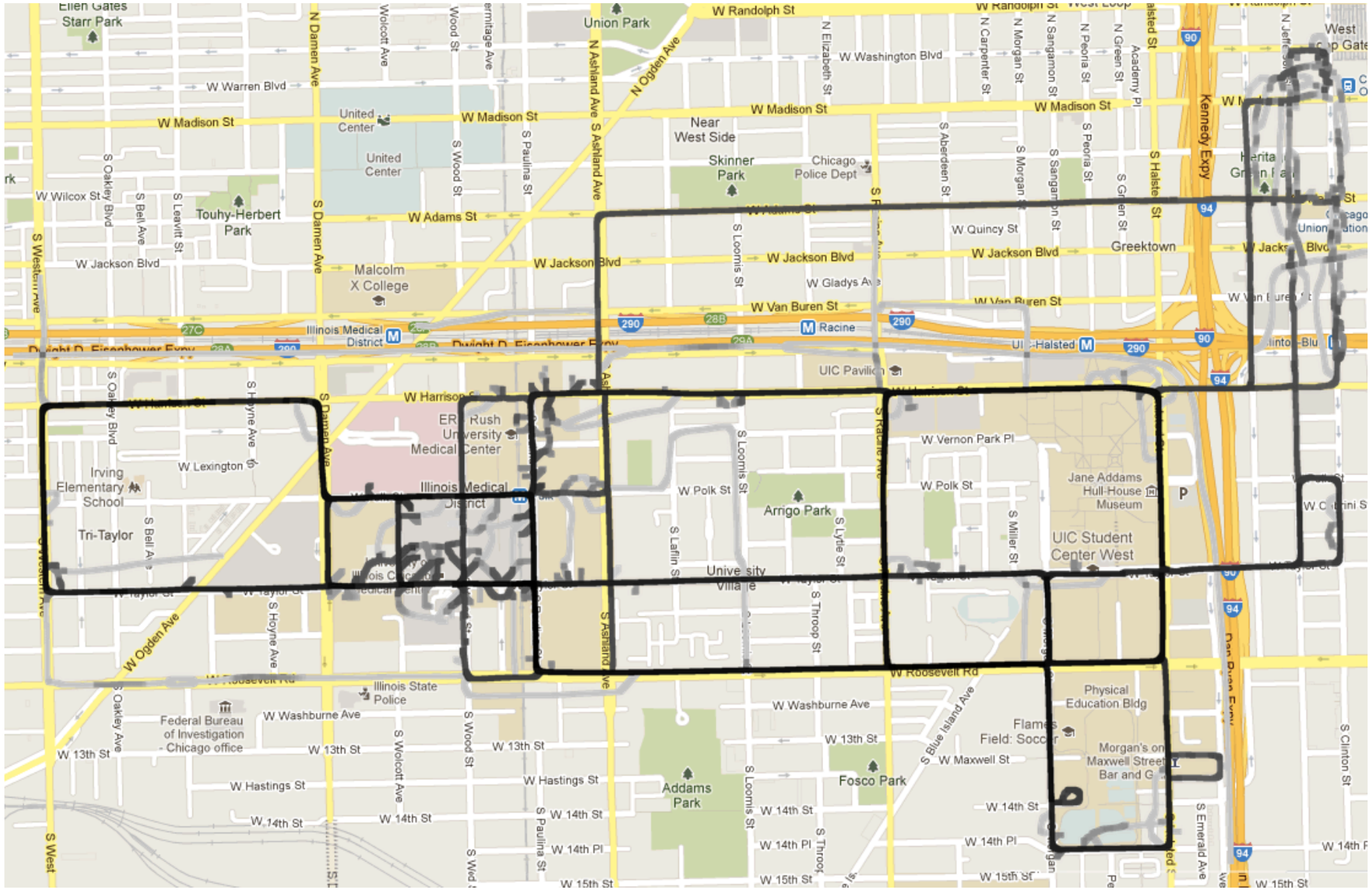
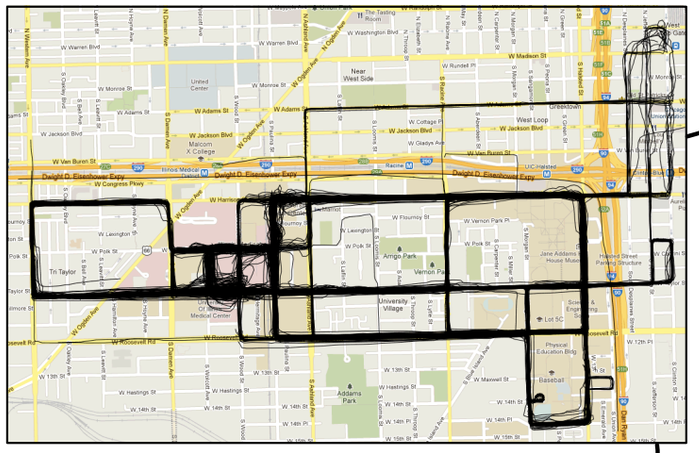


Initial generated map



Map inference pipeline

Raw GPS traces



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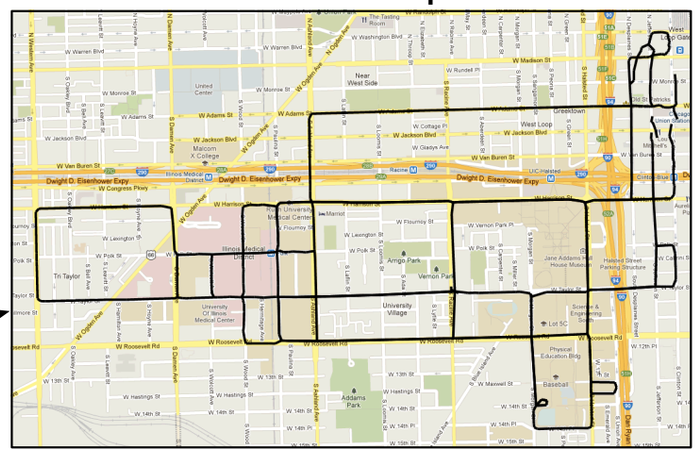

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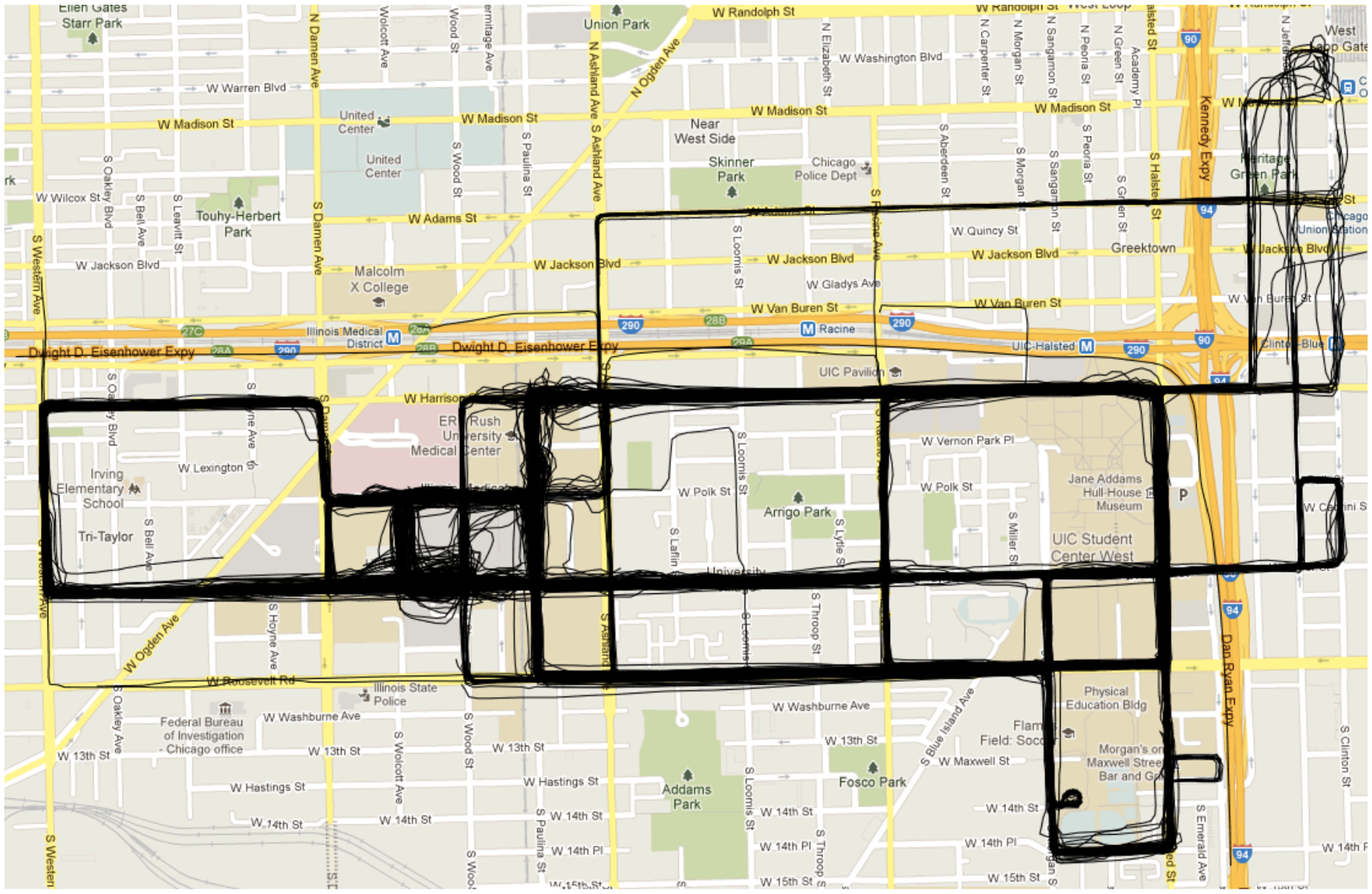

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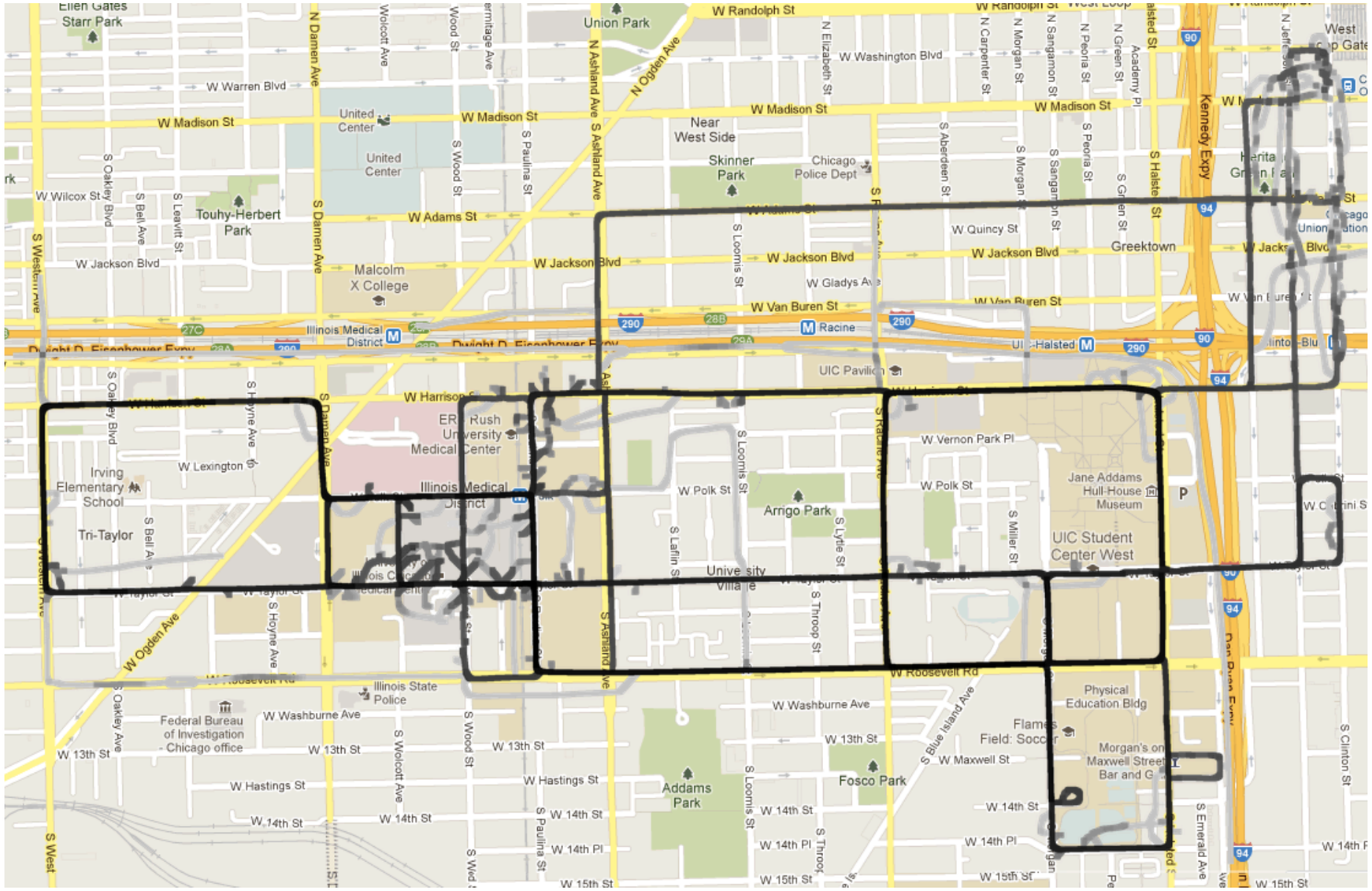
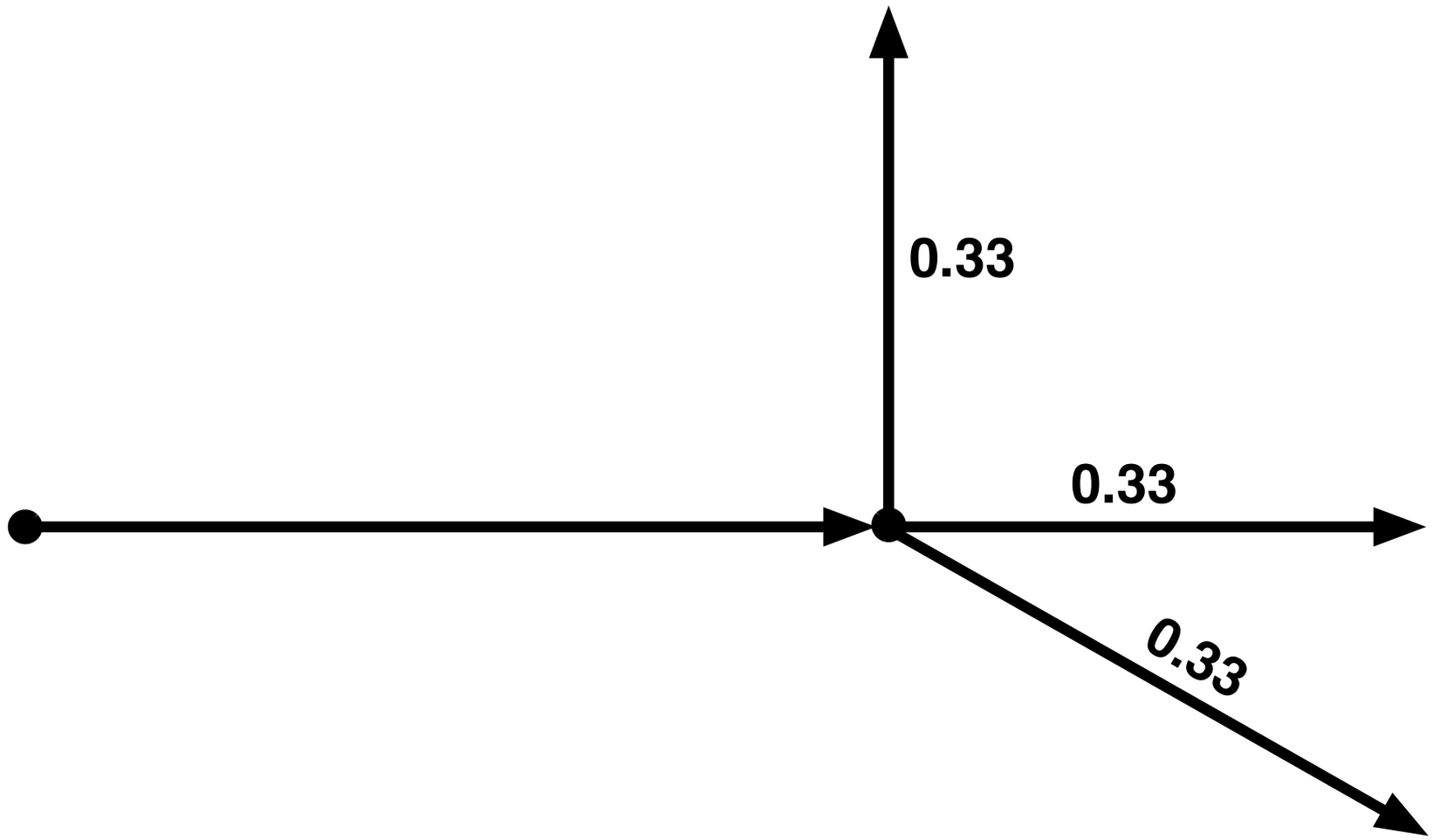
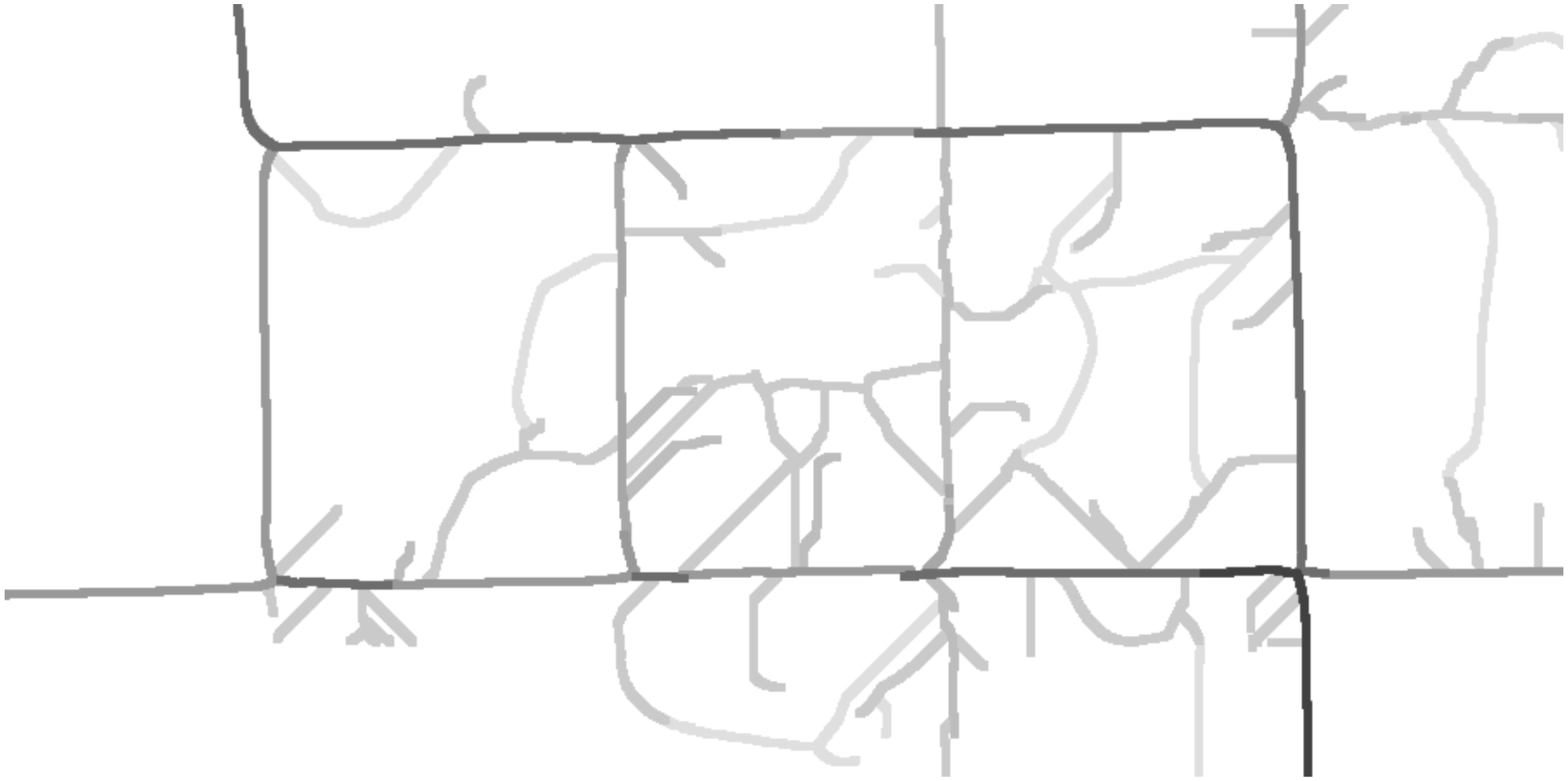


Uniform transition probabilities

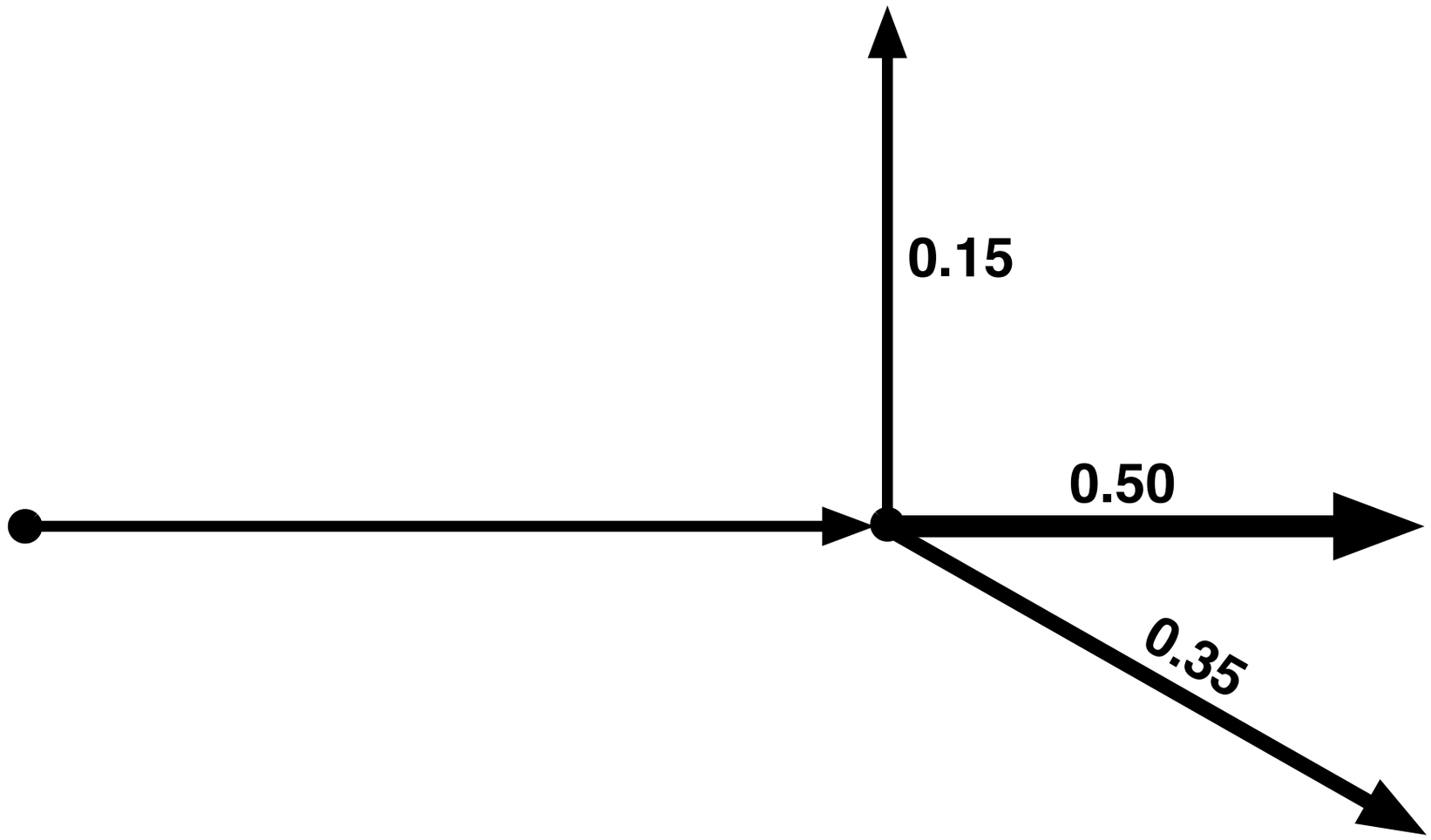


- HMM-based map-matching
  - Based on VTrack (Thiagarajan et al., 2009)

Density weighted roads



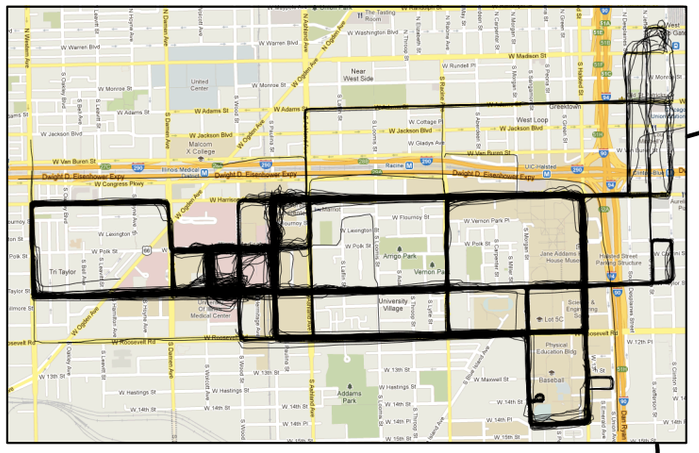
Weighted transition probabilities



- HMM-based map-matching
  - Based on VTrack (Thiagarajan et al., 2009)

Map inference pipeline

Raw GPS traces



Density Estimation

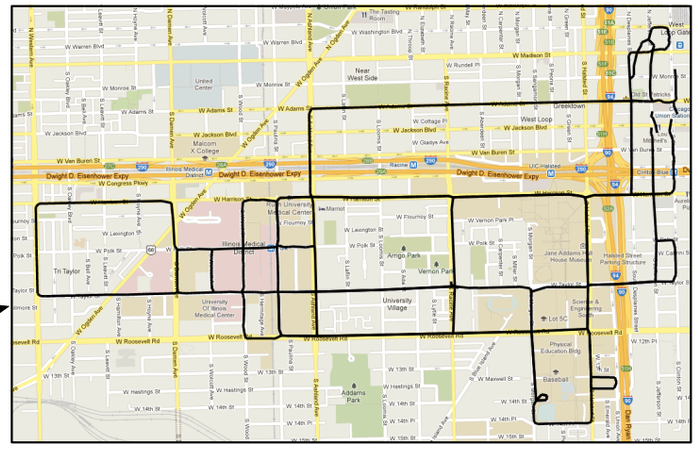
Initial Map Generation

Trace Map Matching

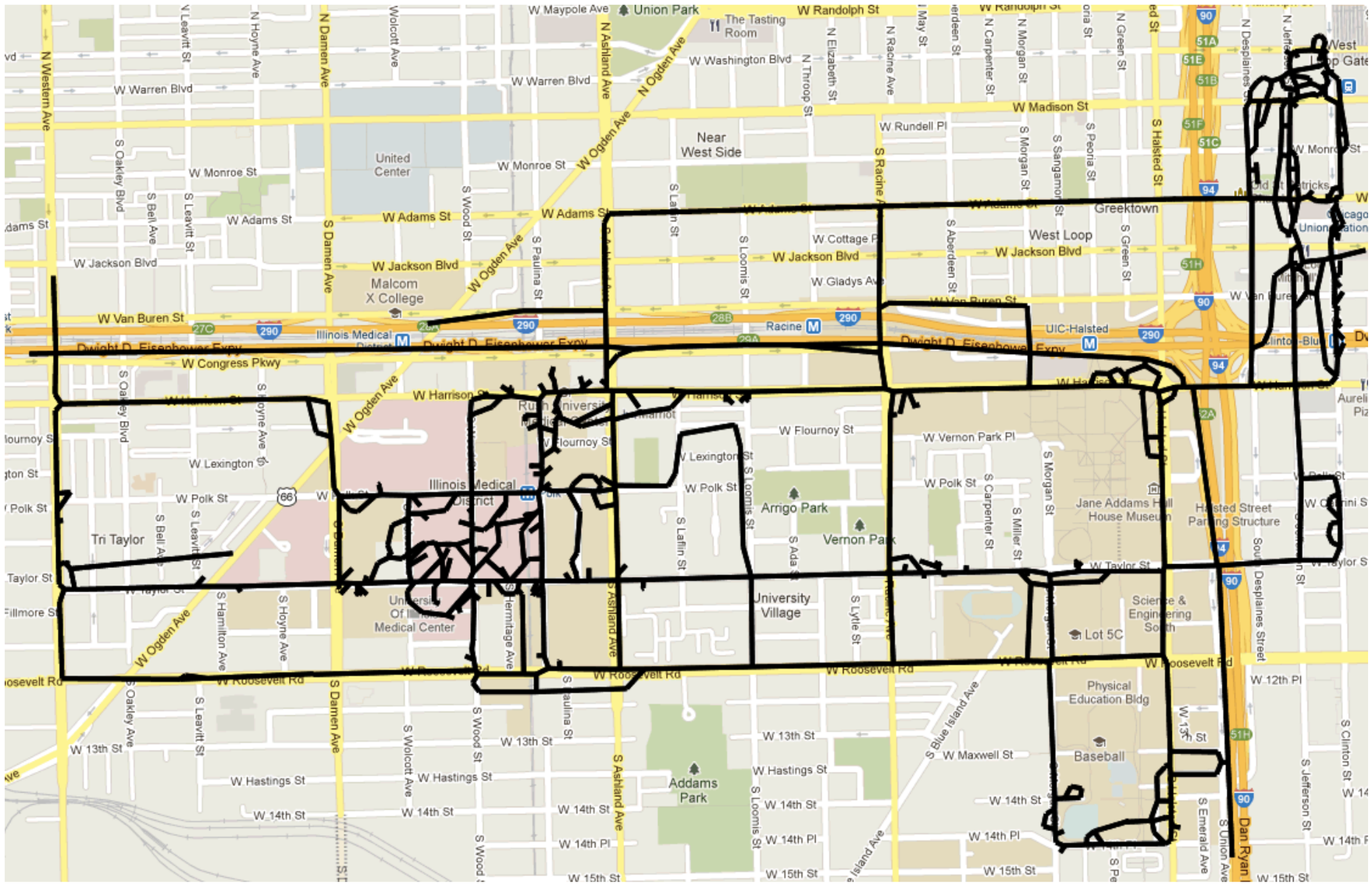
Topology Refinement

Geometry Refinement

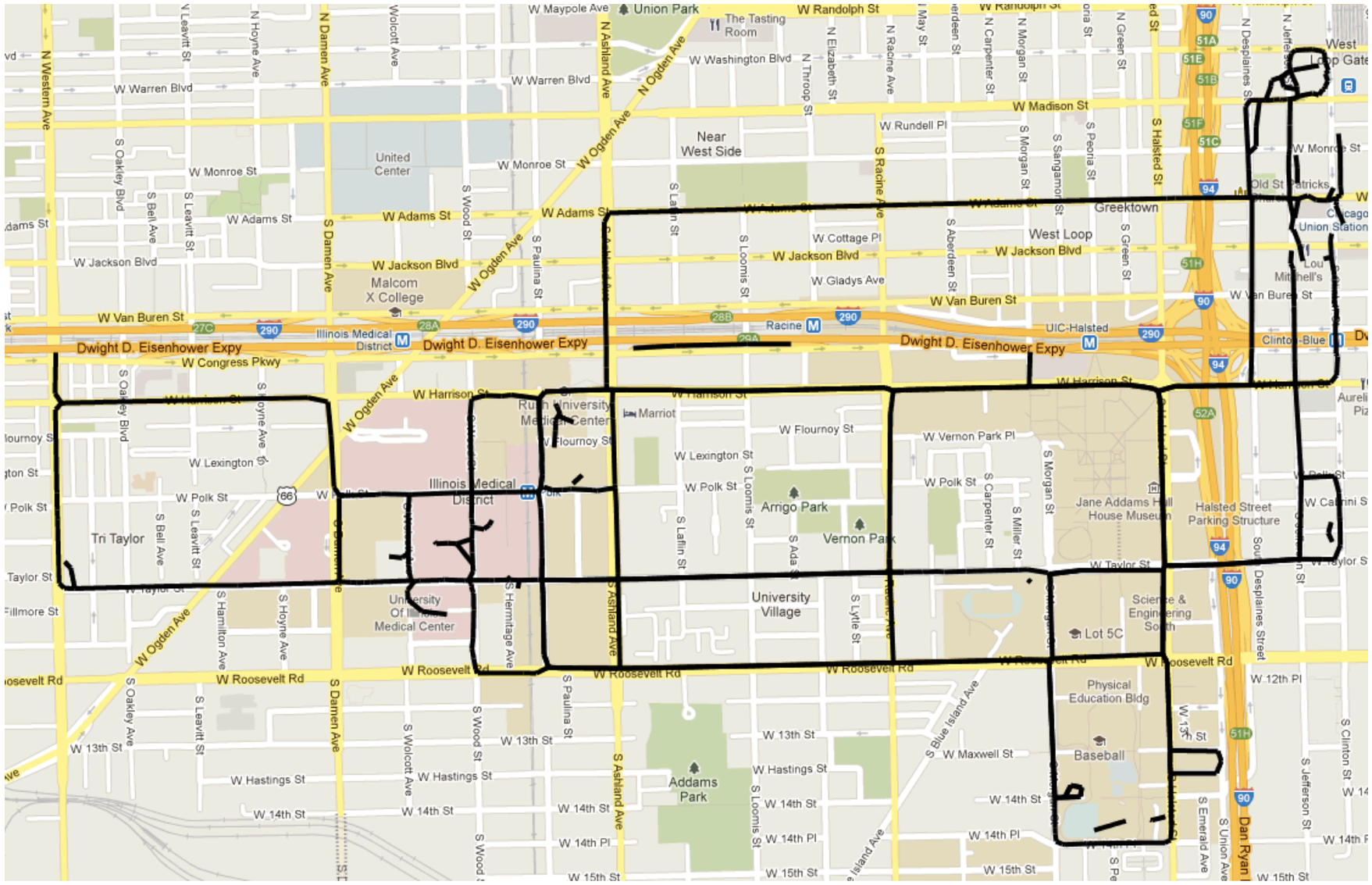
Final map



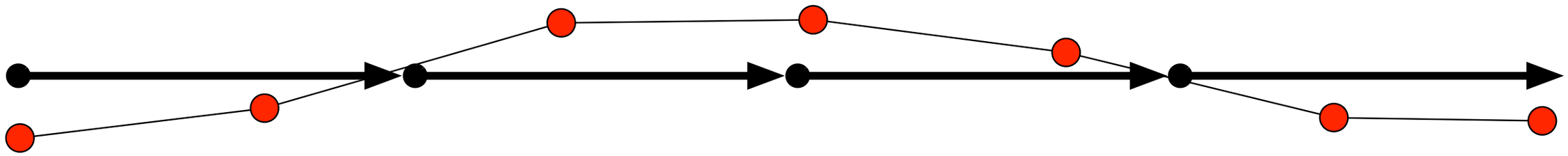
Map before pruning



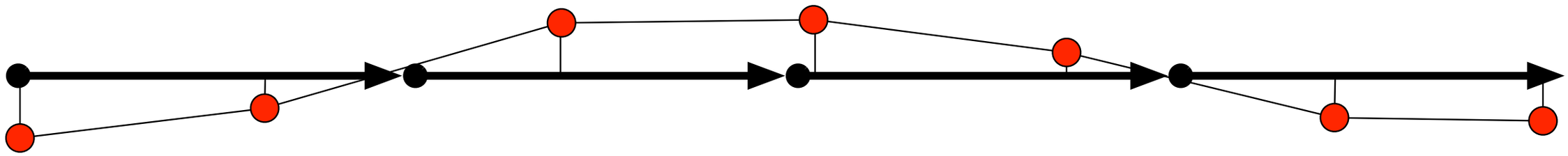
Map after pruning



Trace goodness of fit



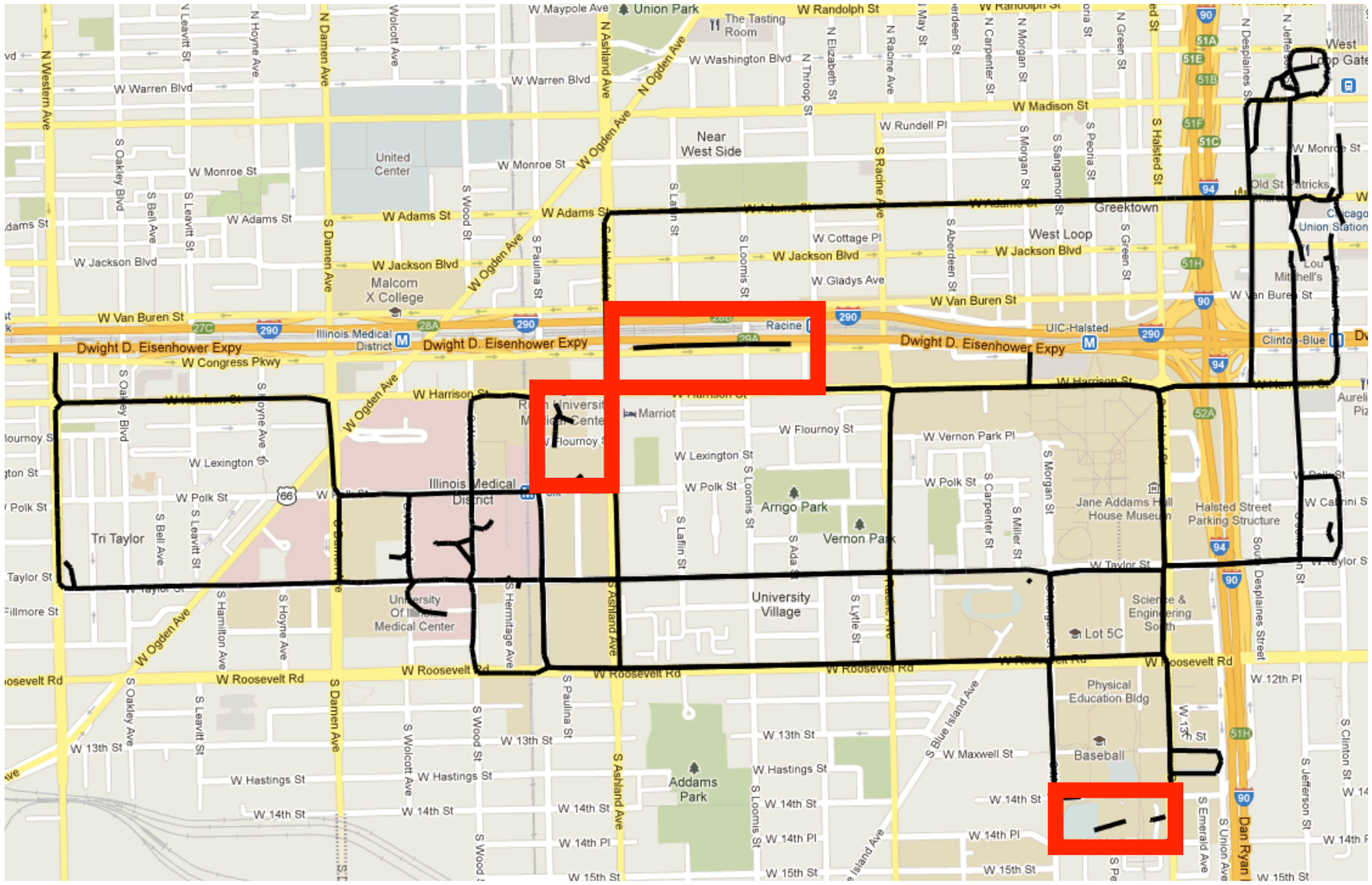
Trace goodness of fit



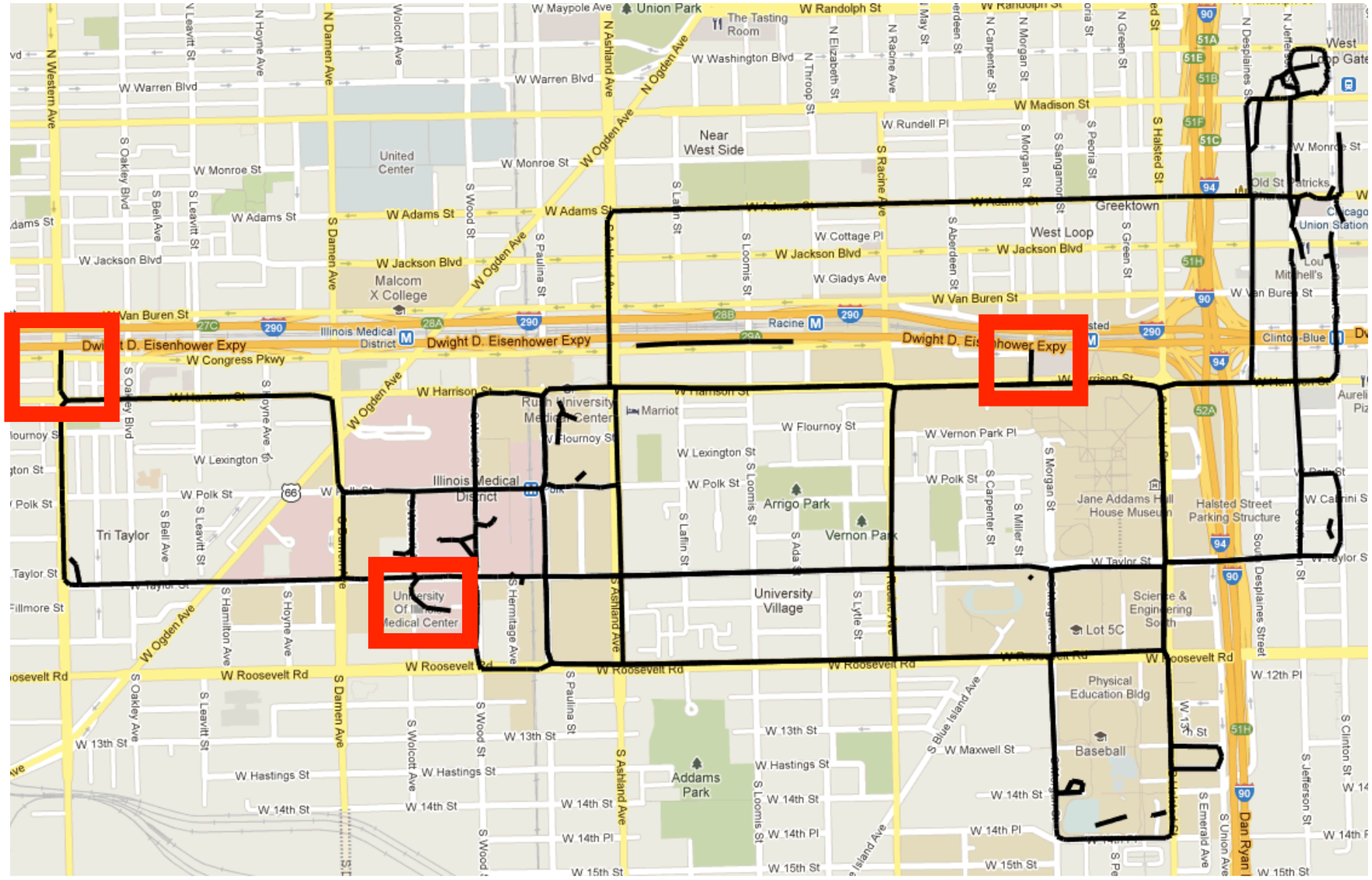
$$RMSD(\tau, e) = \sqrt{\frac{1}{|\tau|} \sum_{p \in \tau} dist(p, e)^2}$$

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

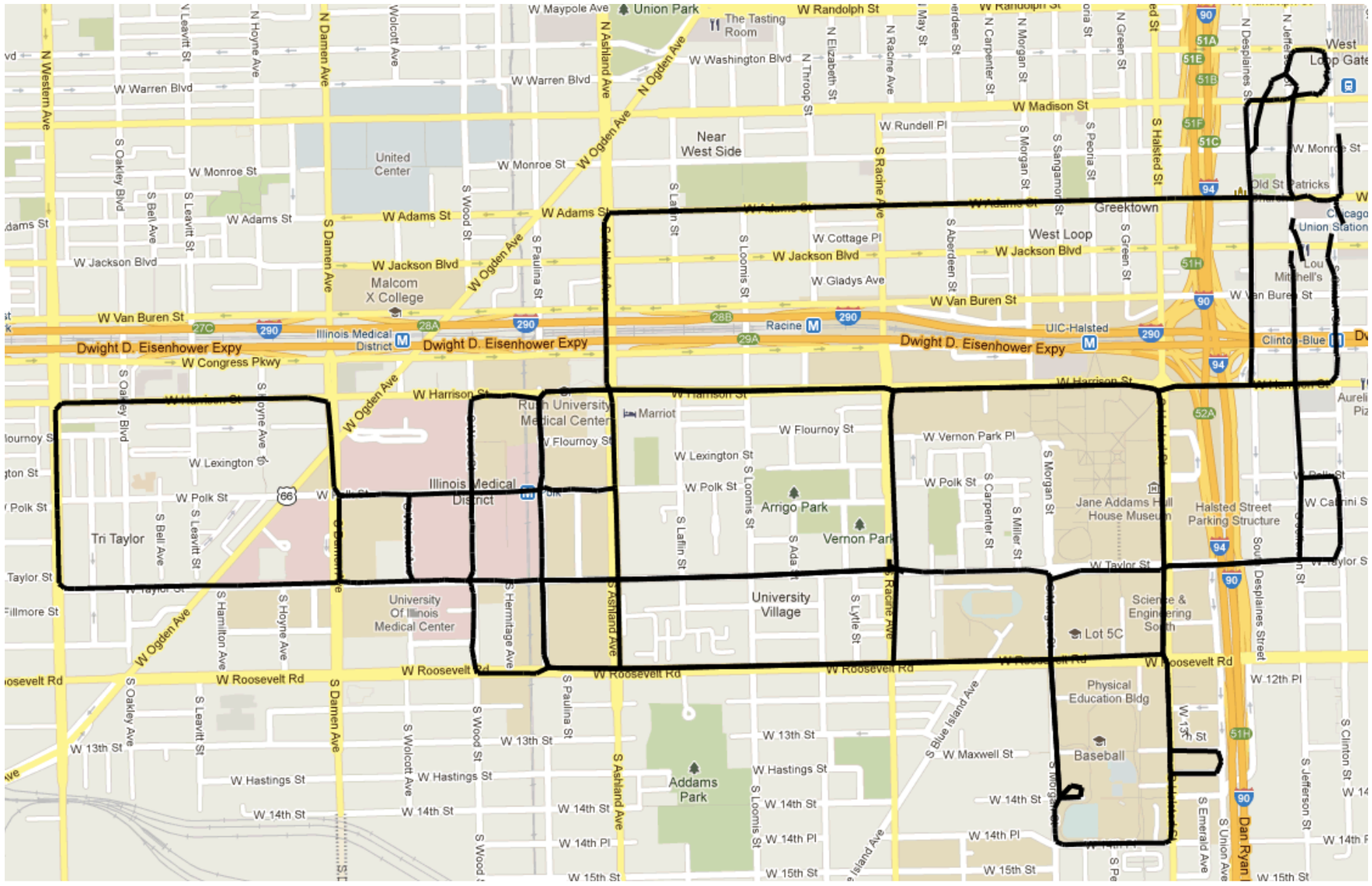
Orphaned road segments



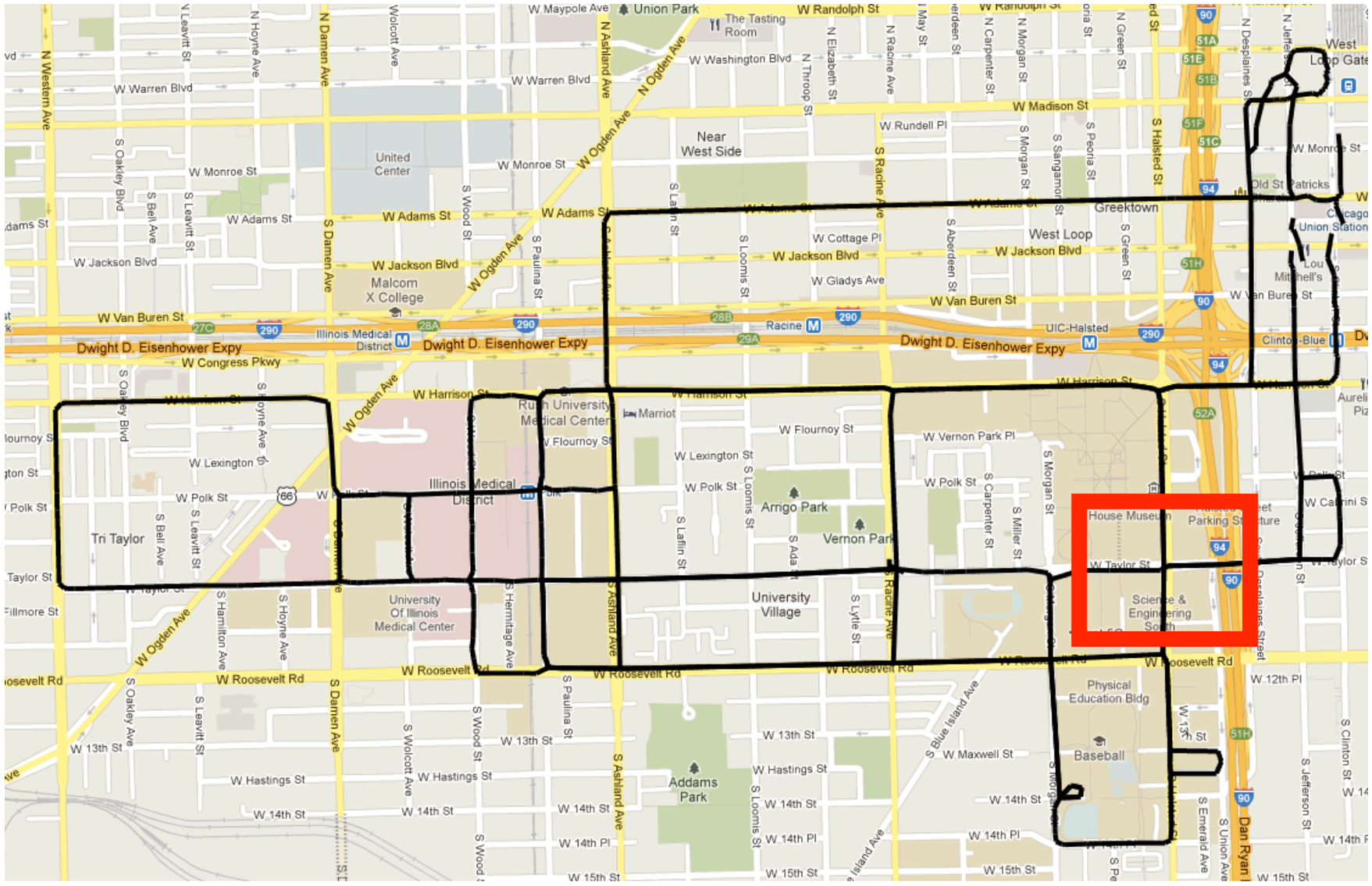
Road segment “spurs”



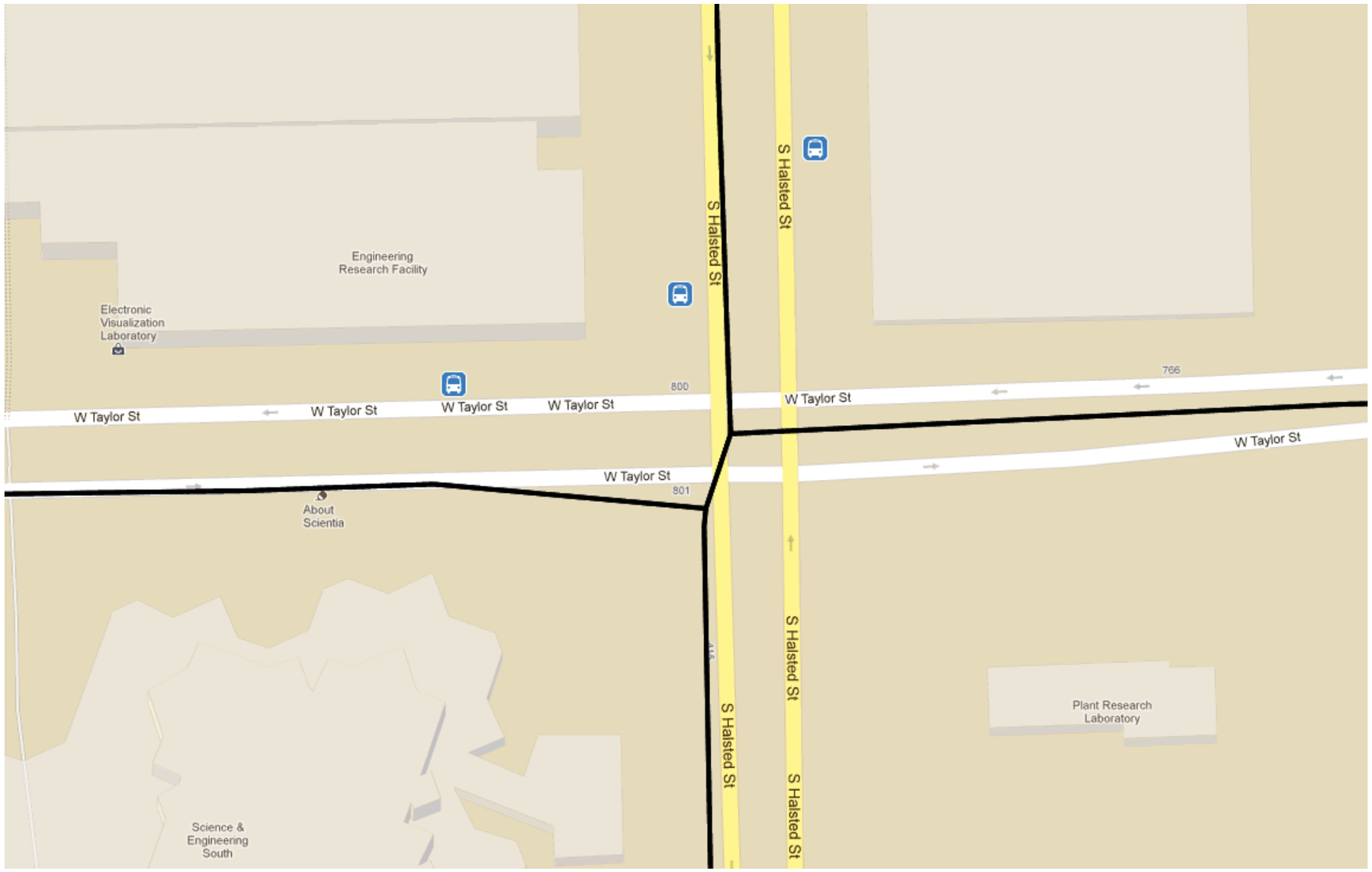
Map after pruning... again



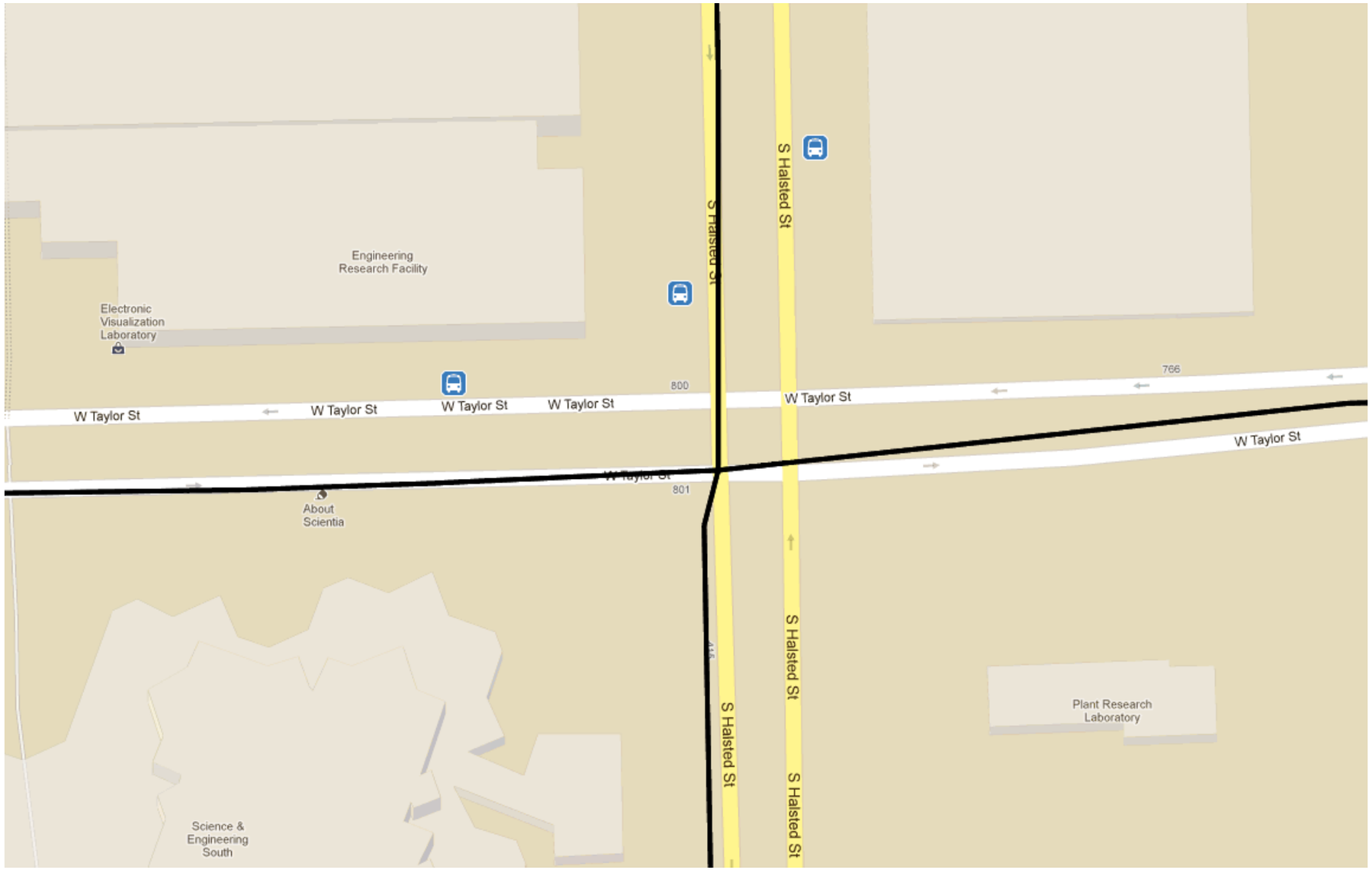
Map after pruning



Incorrect topology

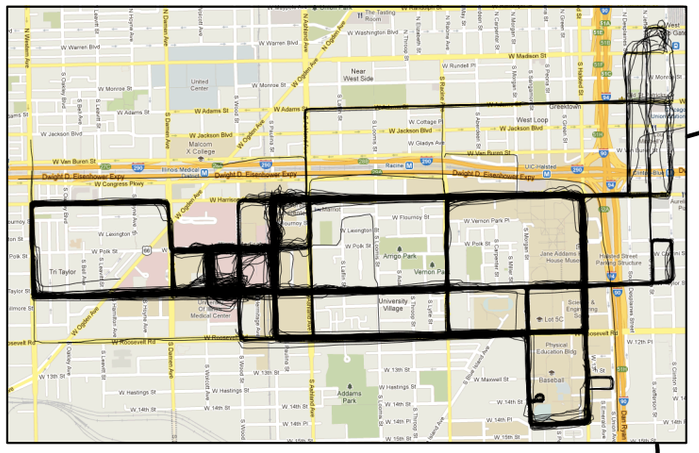


Collapsed intersection



Map inference pipeline

Raw GPS traces



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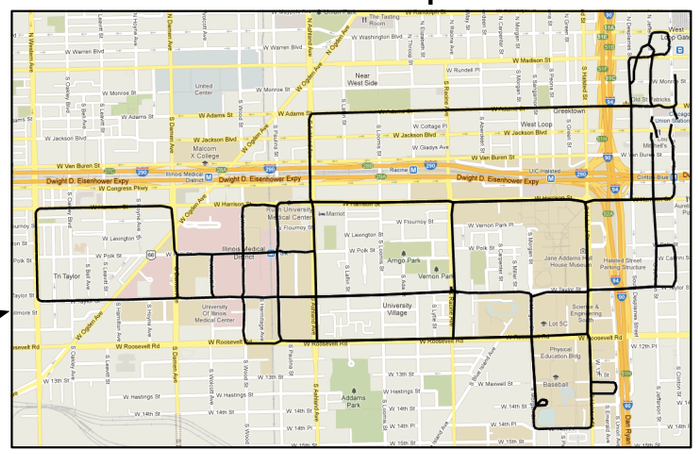
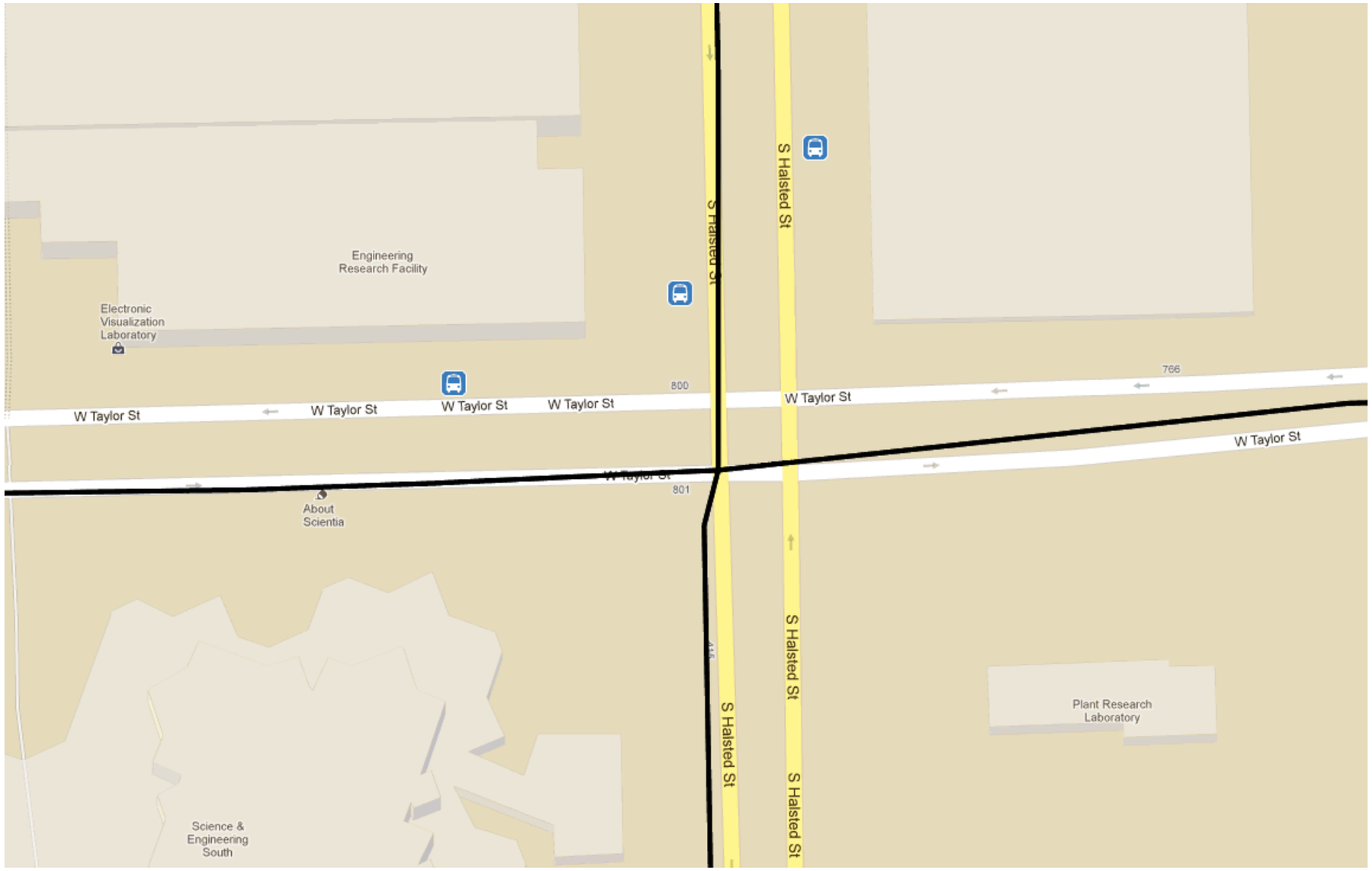
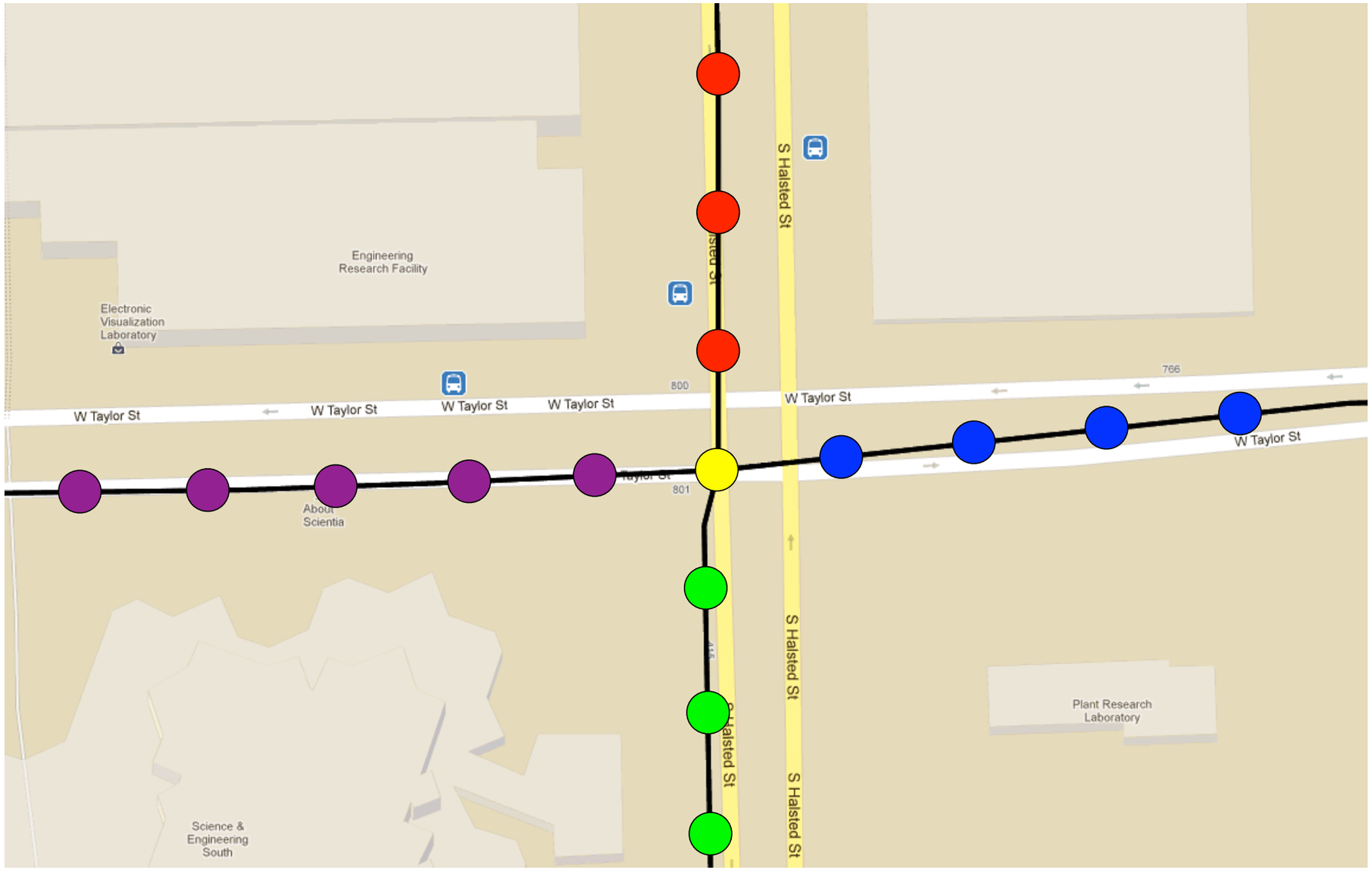


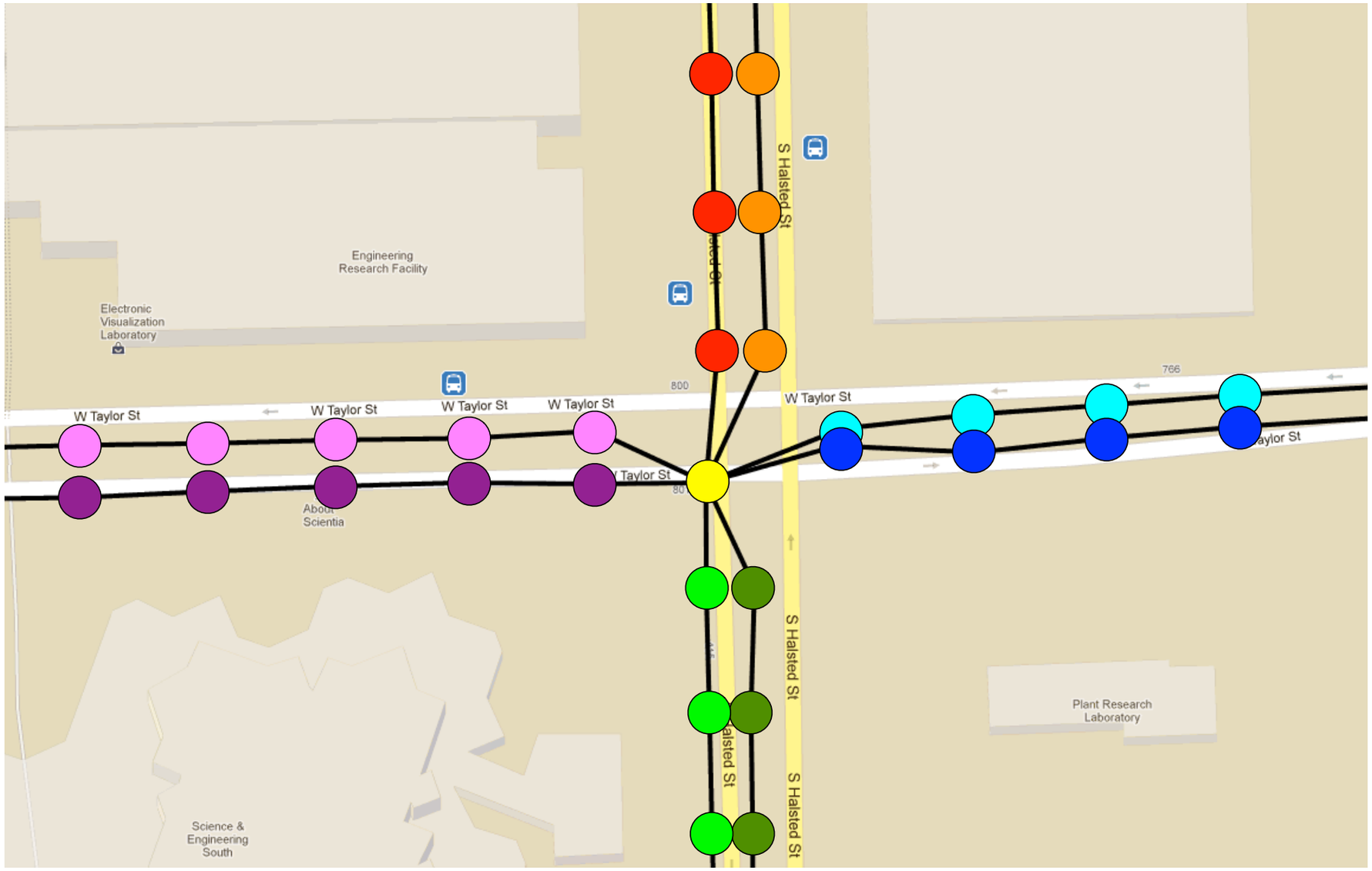
Simple geometry



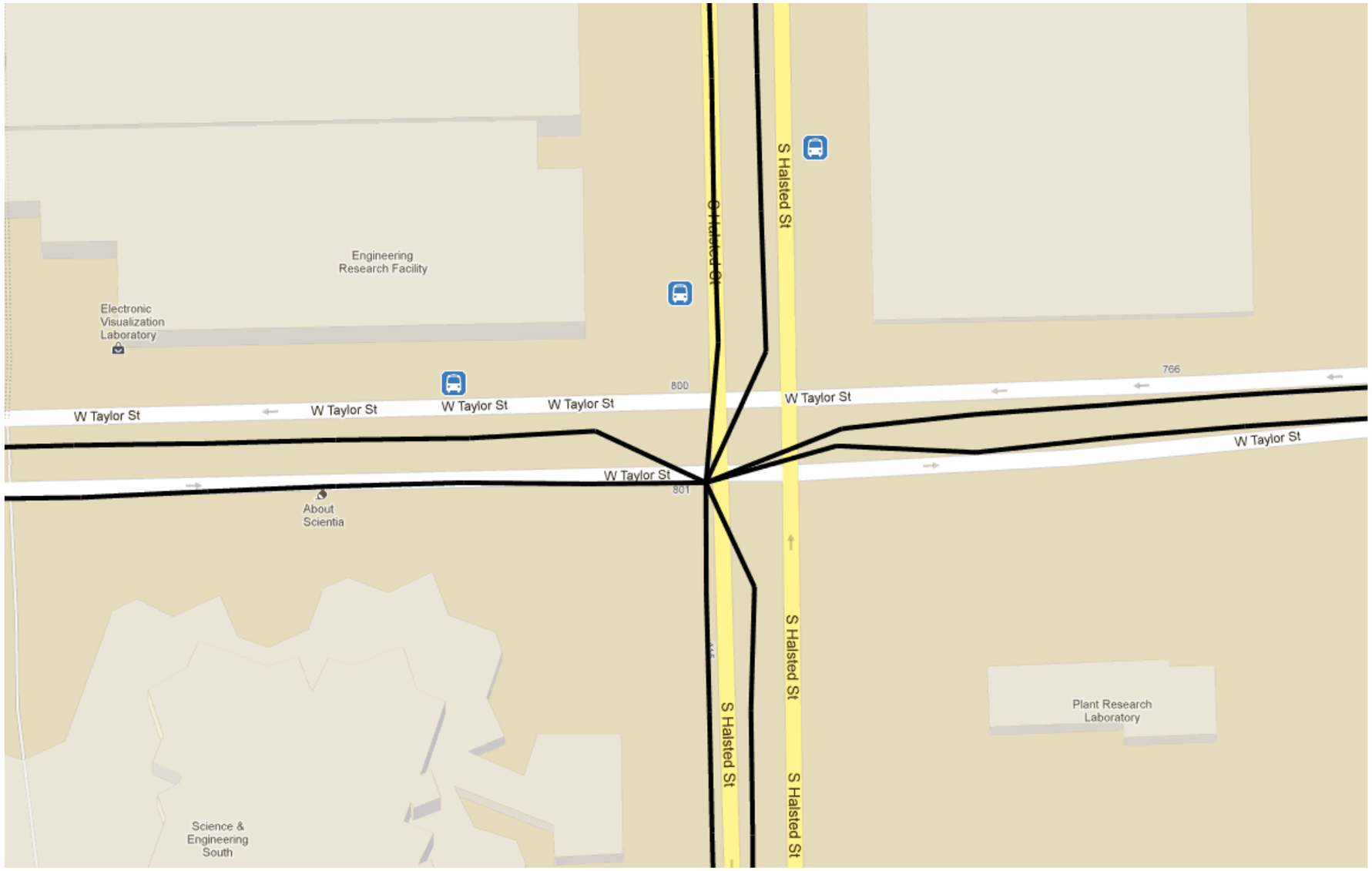
Initial cluster locations



Settled cluster locations



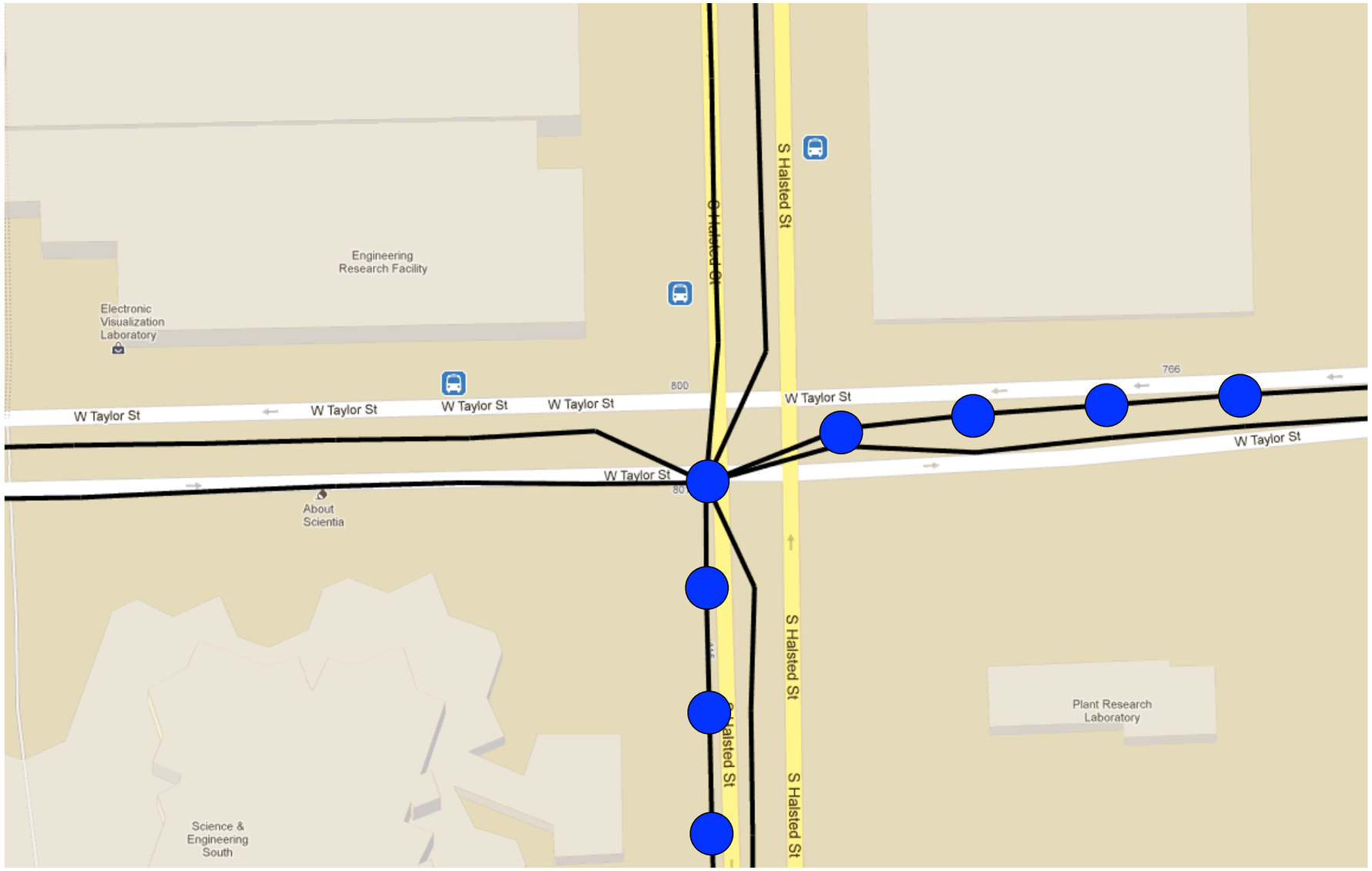
Refined lane geometry



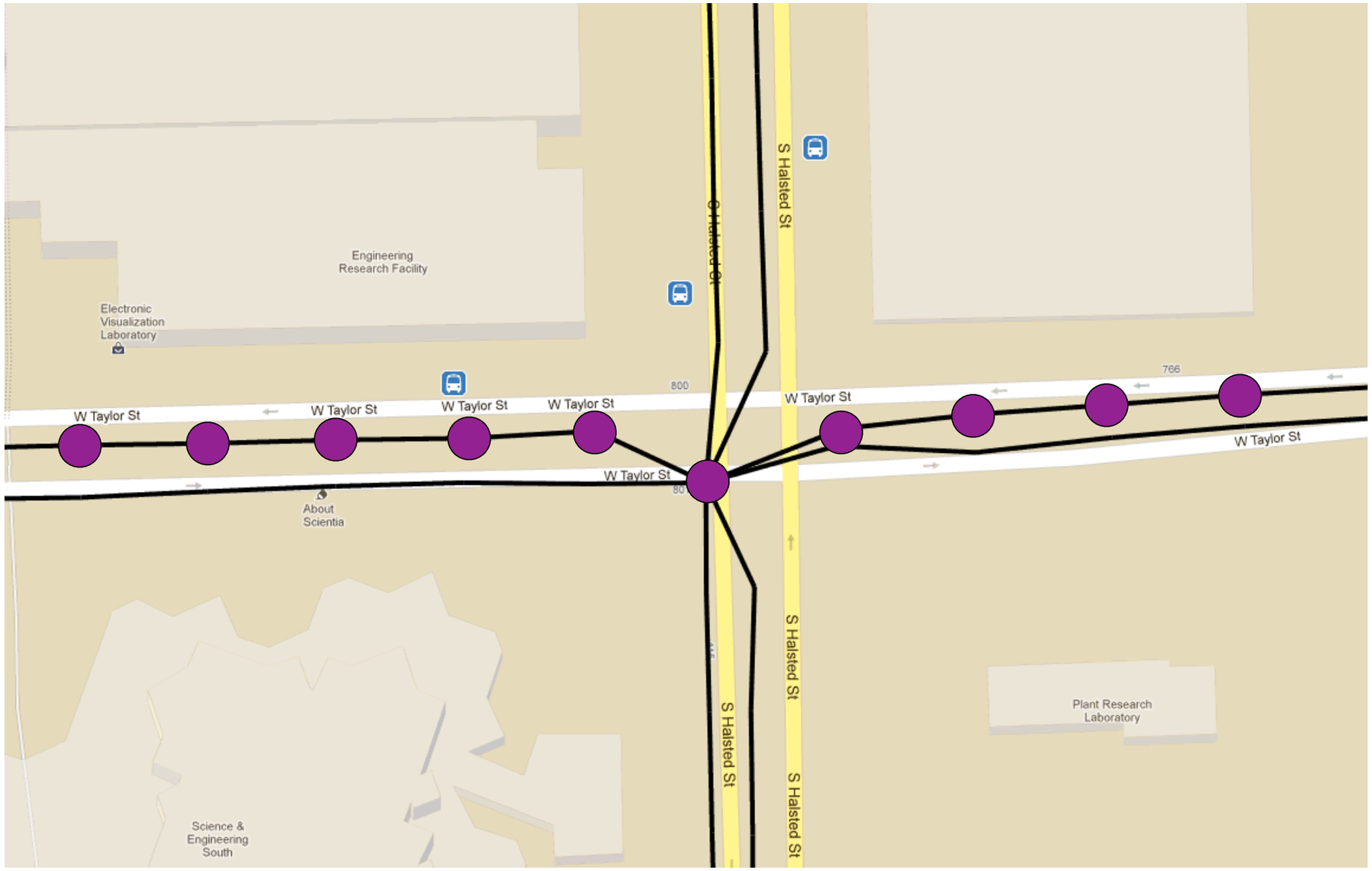
Intersection refinement



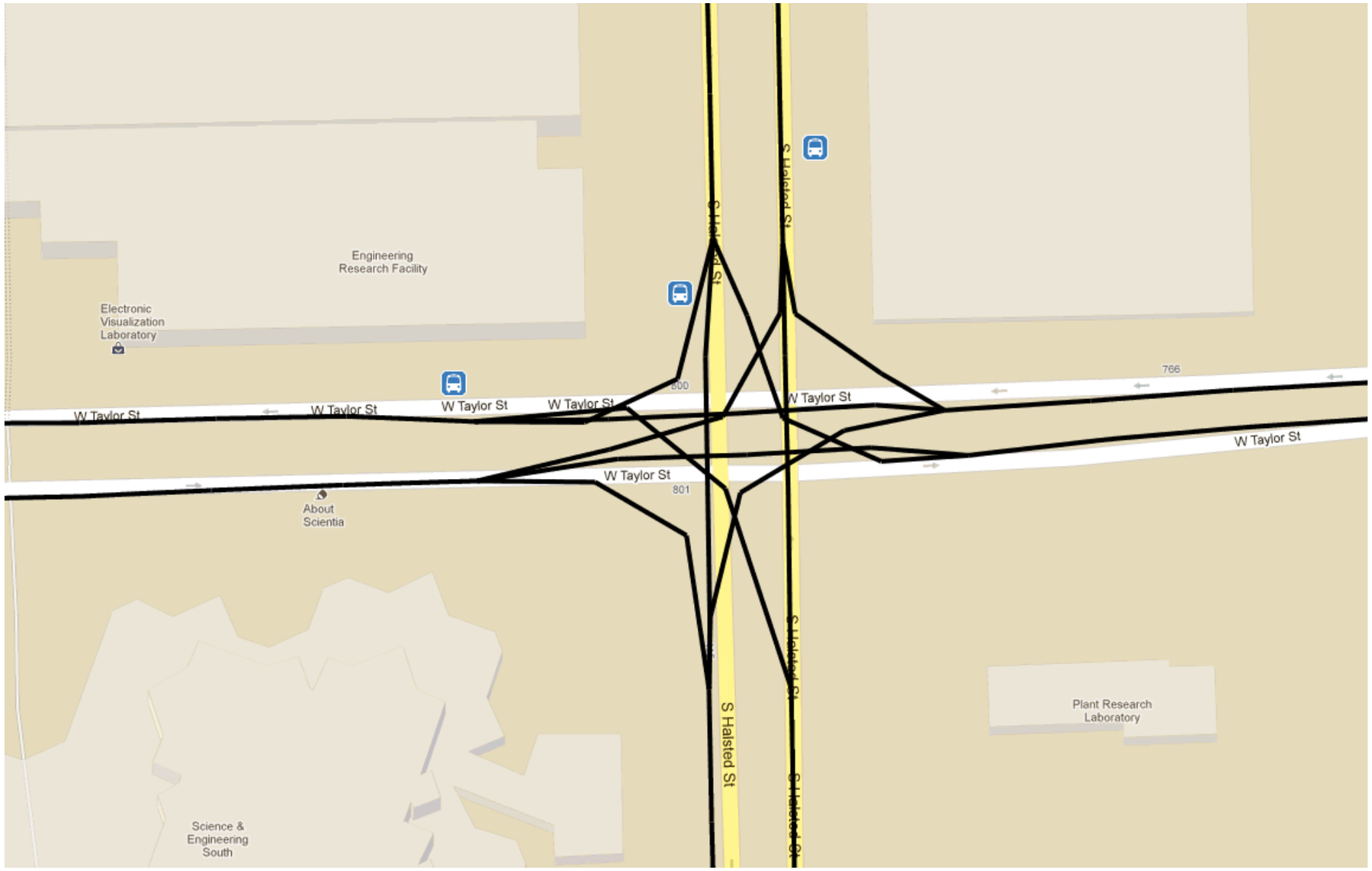
Intersection refinement



Intersection refinement

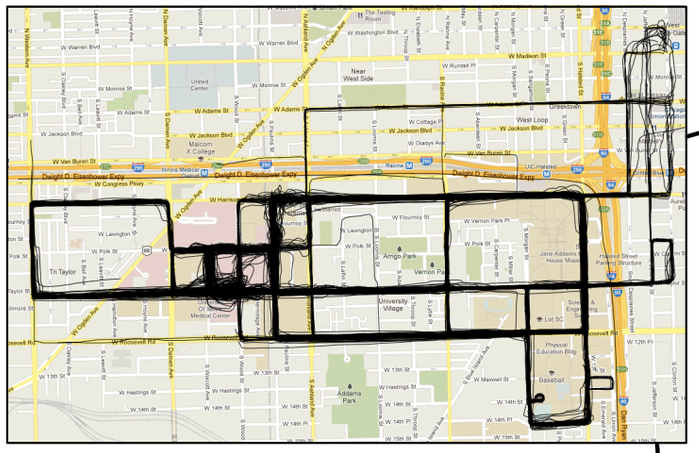


Refined intersection geometry



Map inference pipeline

Raw GPS traces



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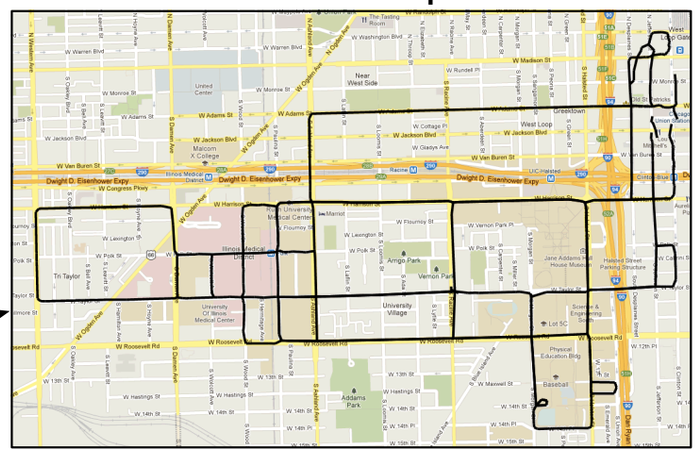


Quantitative Evaluation

Evaluation metrics

- Geometric evaluation
  - Liu et al. (2012)
- Topological evaluation
  - Biagioni & Eriksson (2012)

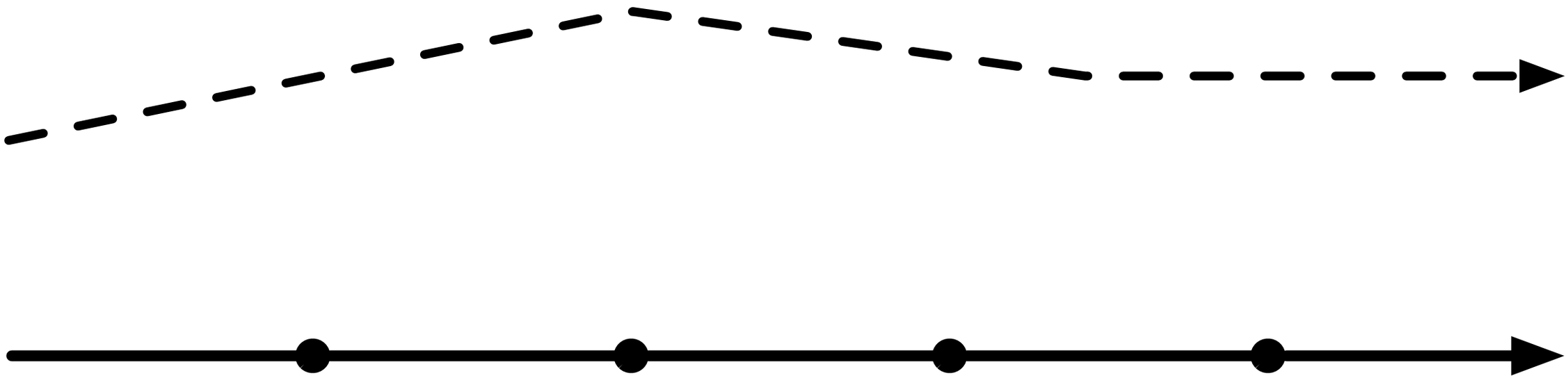
Ground truth segment



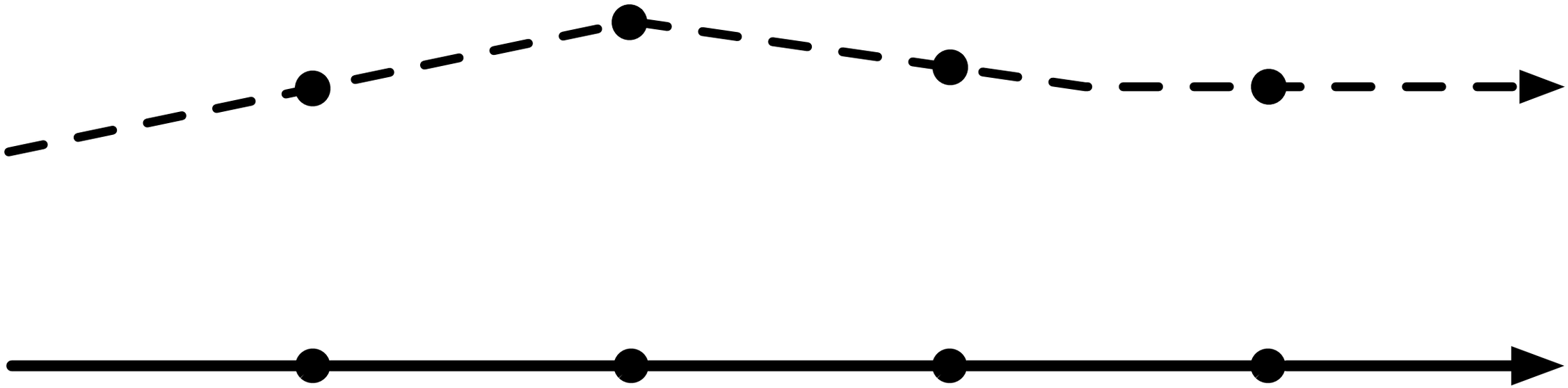
Ground truth samples



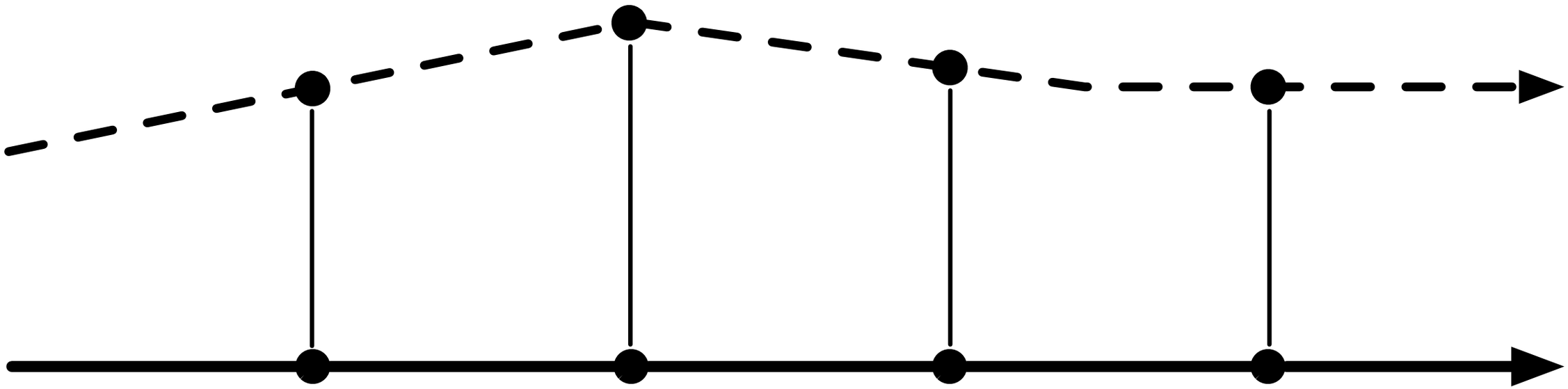
Inferred map segment



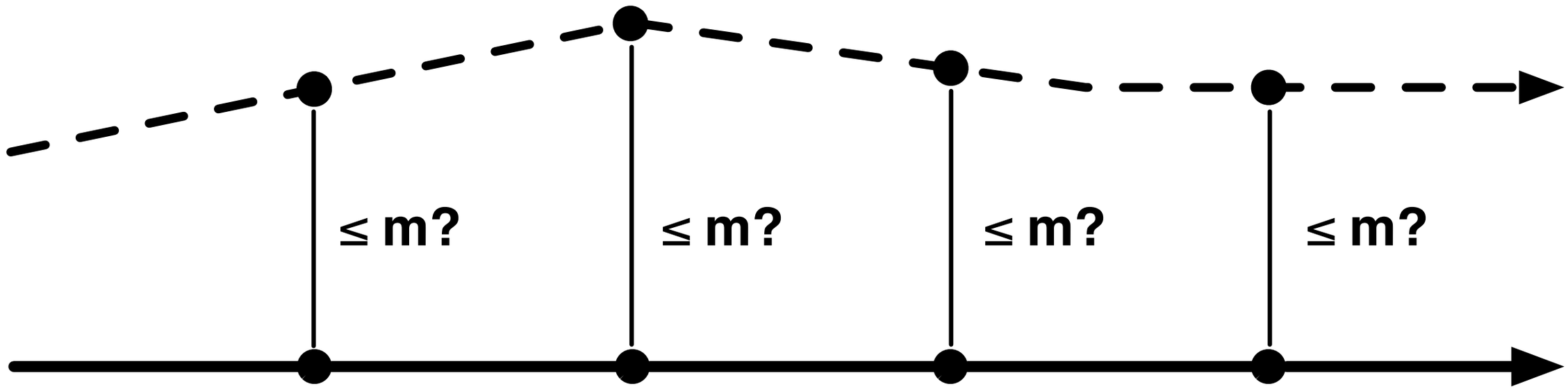
Inferred map samples



Samples compared

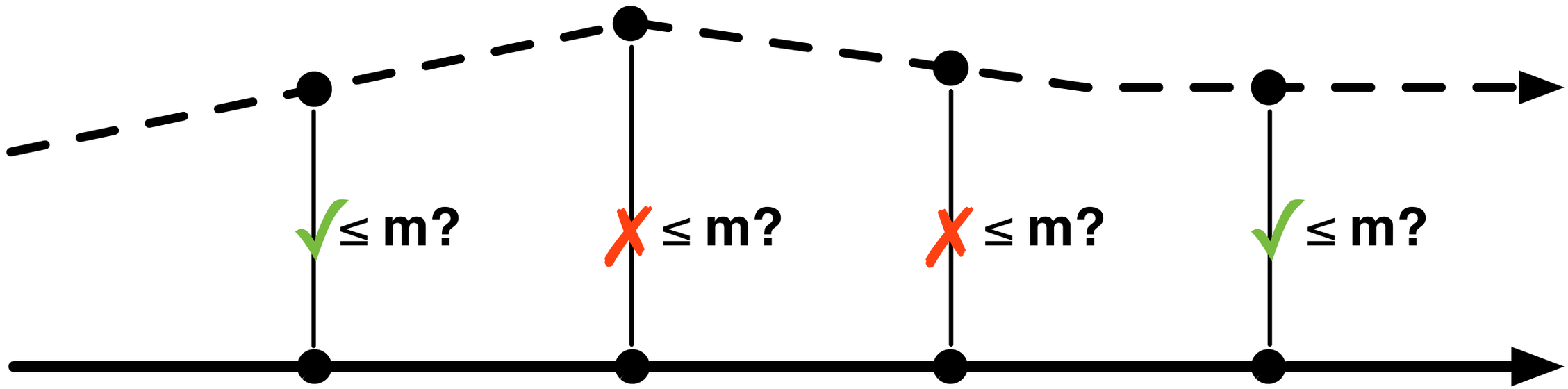


Matching threshold



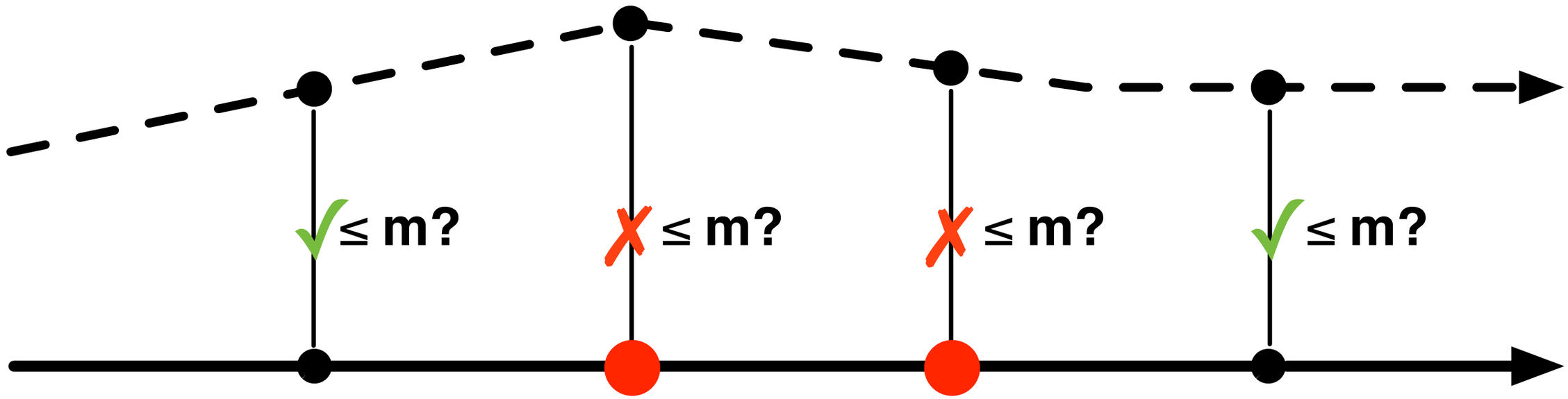
m = matching threshold

Matching threshold



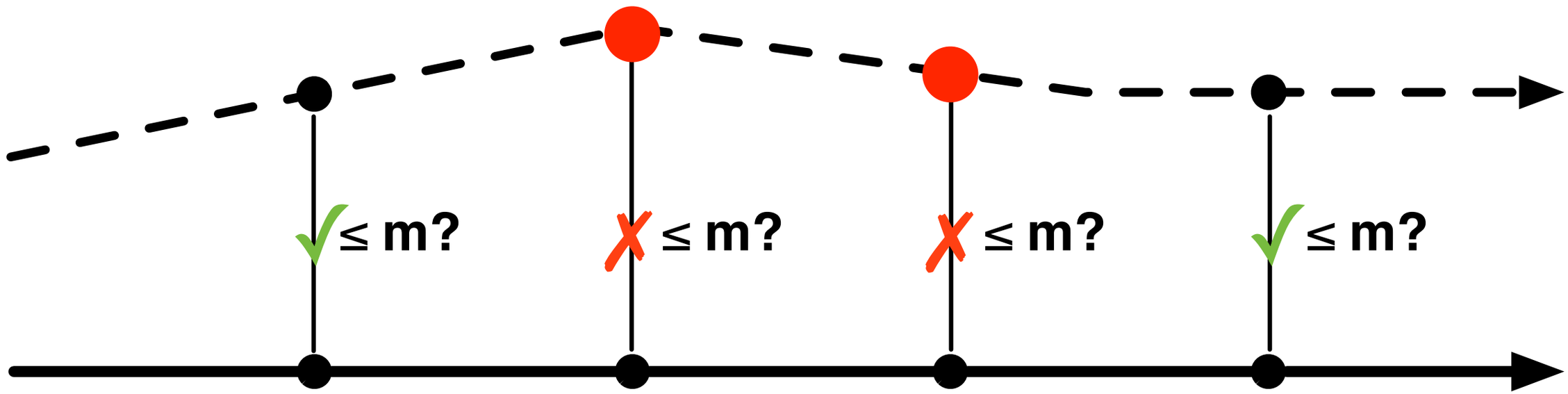
m = matching threshold

“Missing”



m = matching threshold

“Spurious”



m = matching threshold

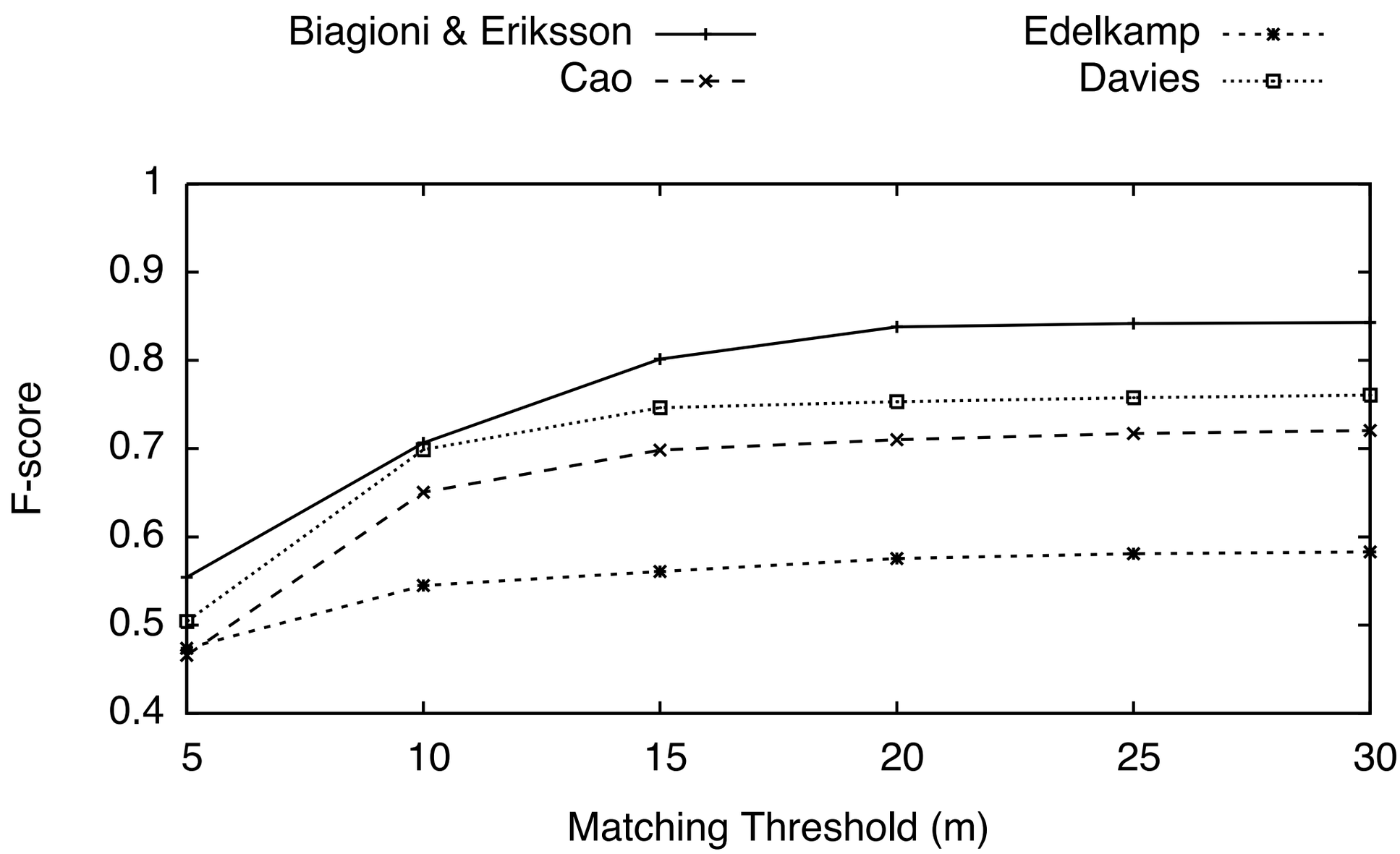
Overall performance

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

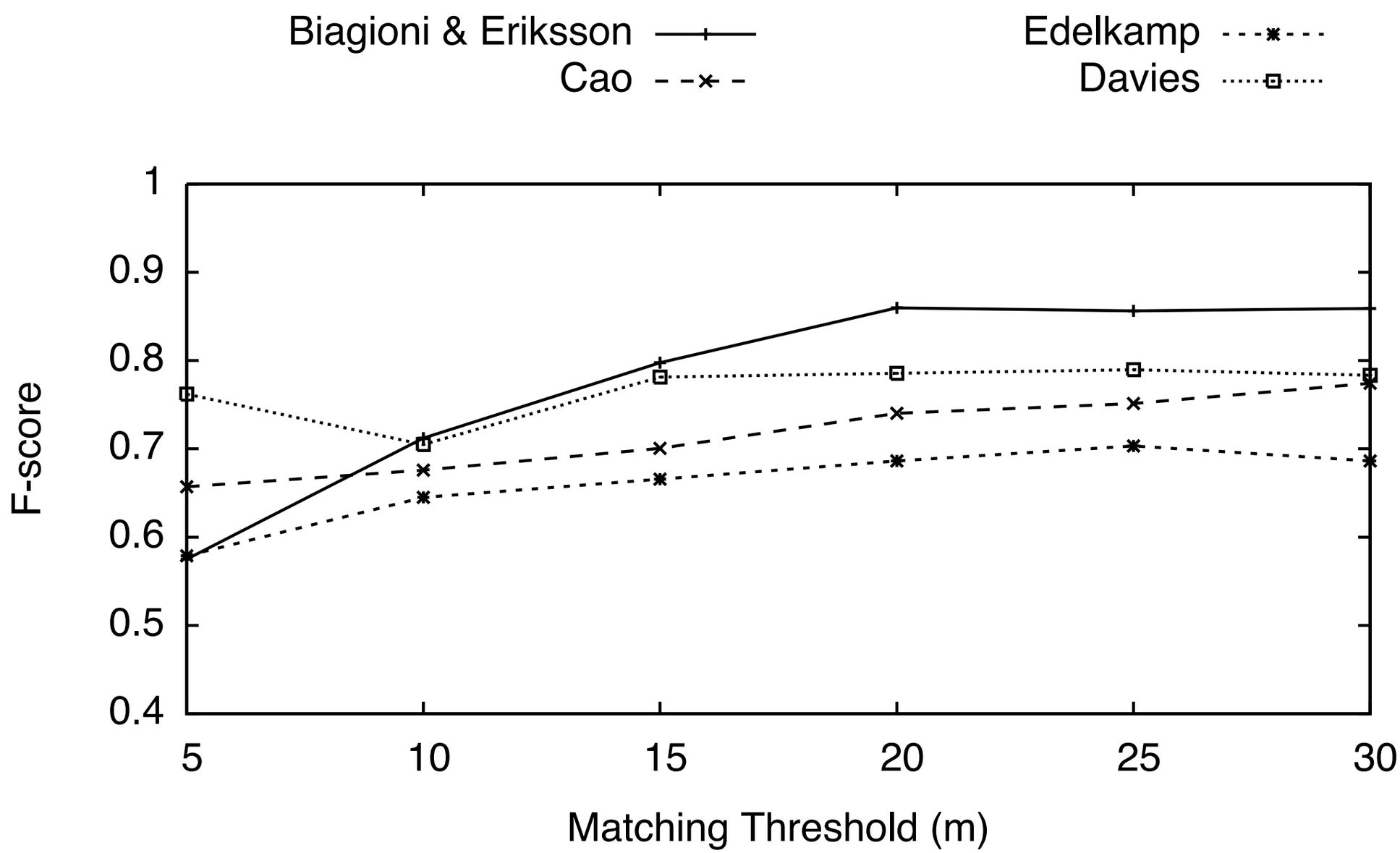
$$precision = 1 - \frac{|spurious\ samples|}{|inferred\ samples|}$$

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

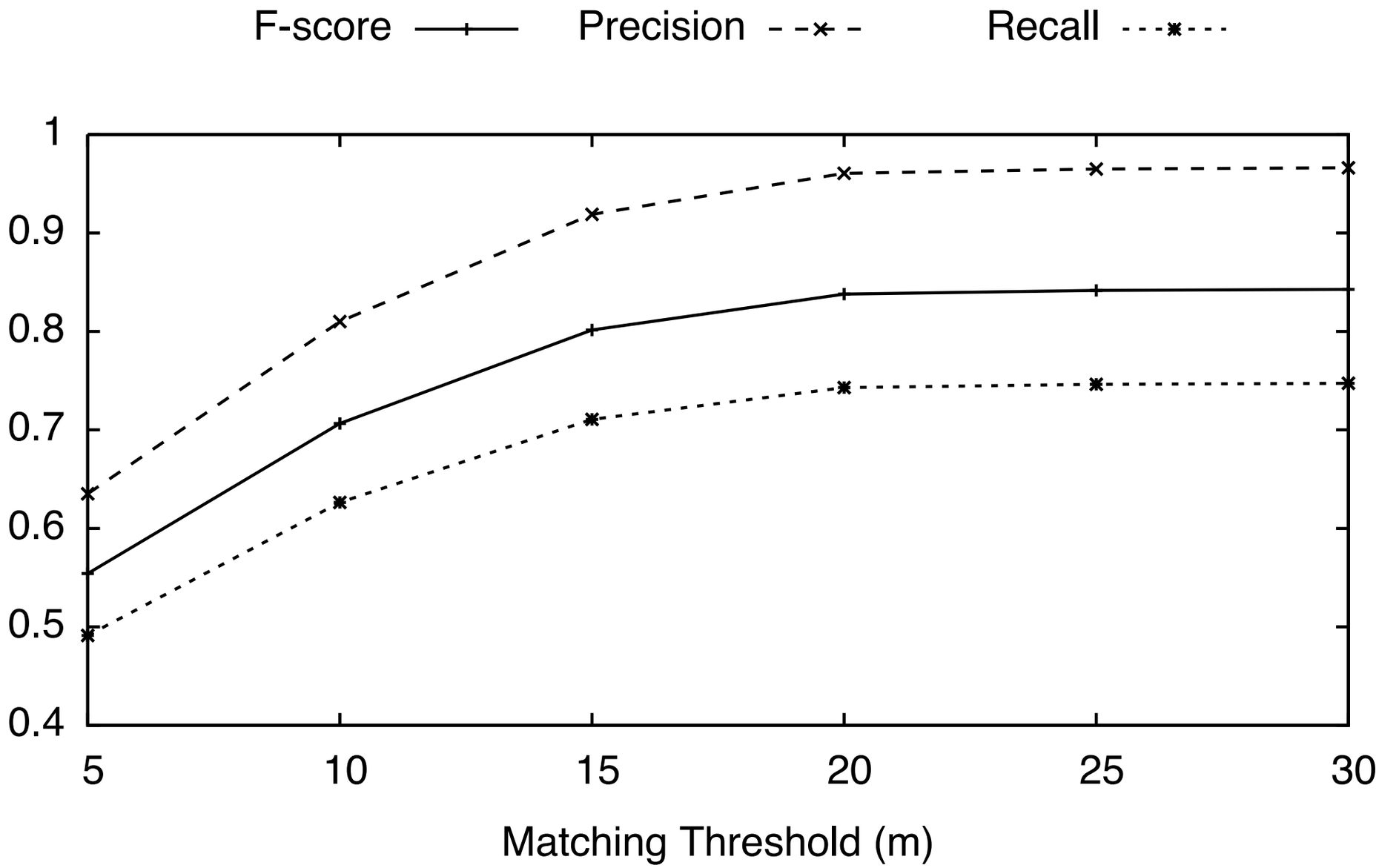
Geometric results



Topological results

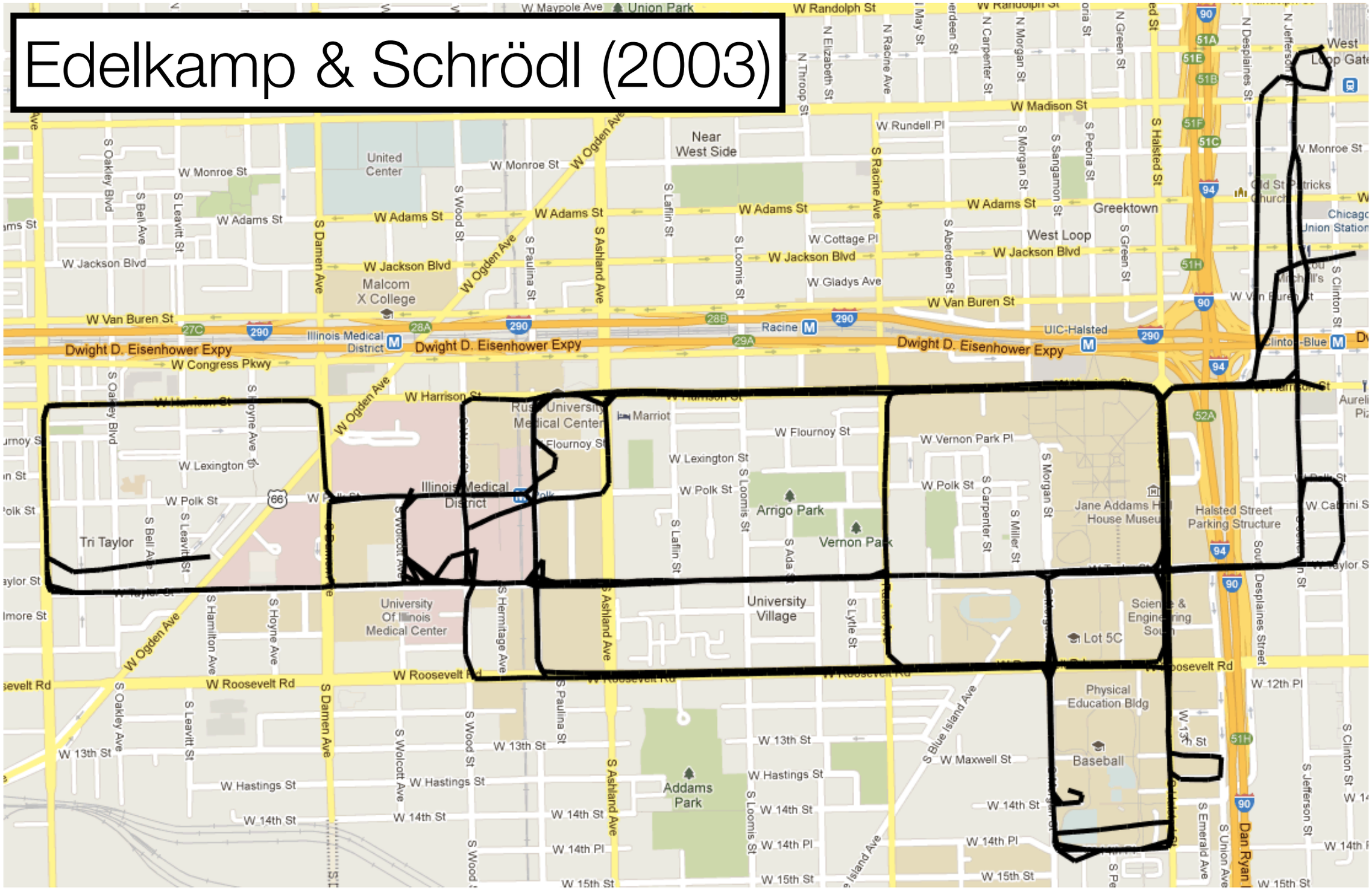


Precision/recall

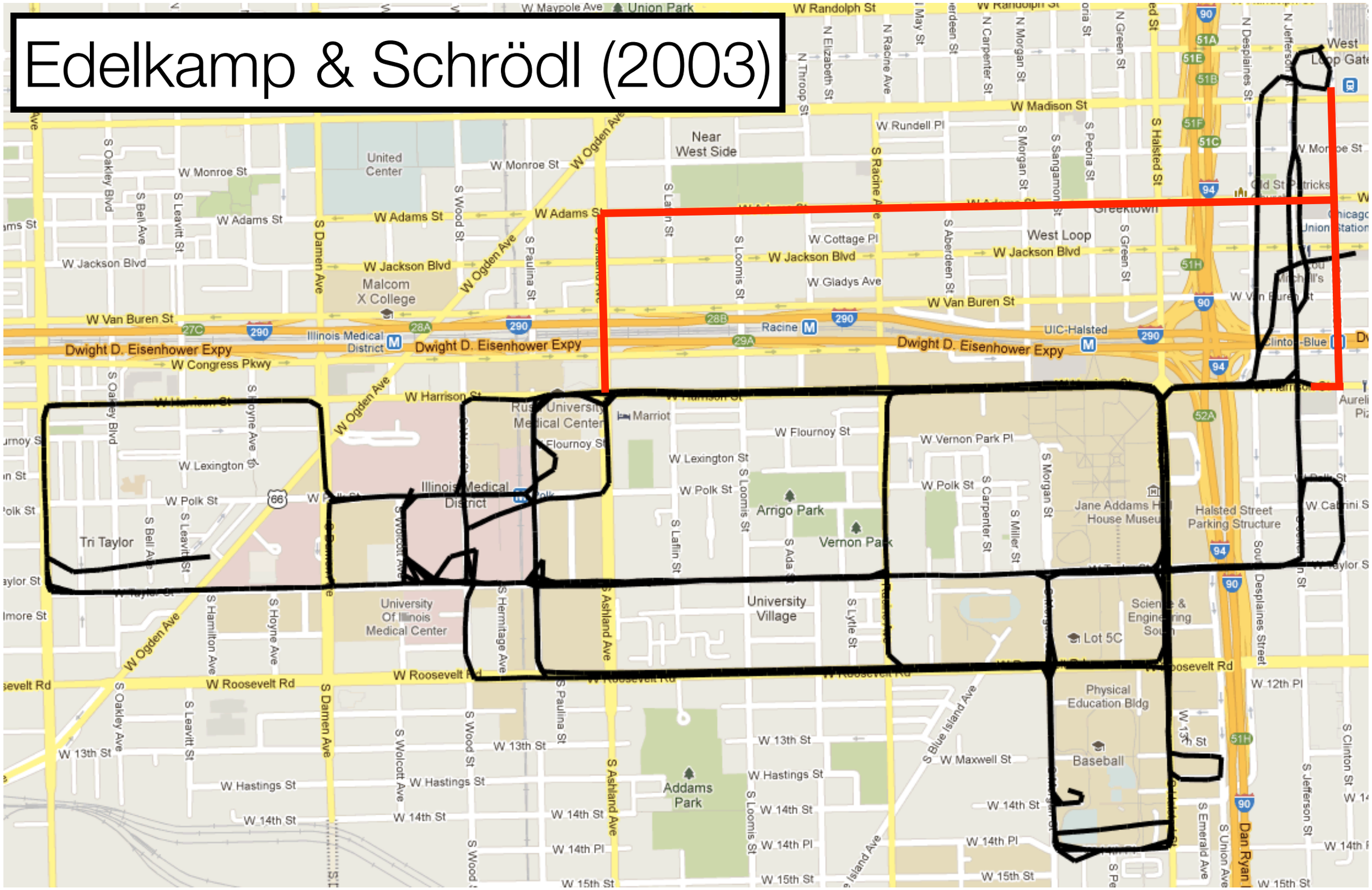


Qualitative Evaluation

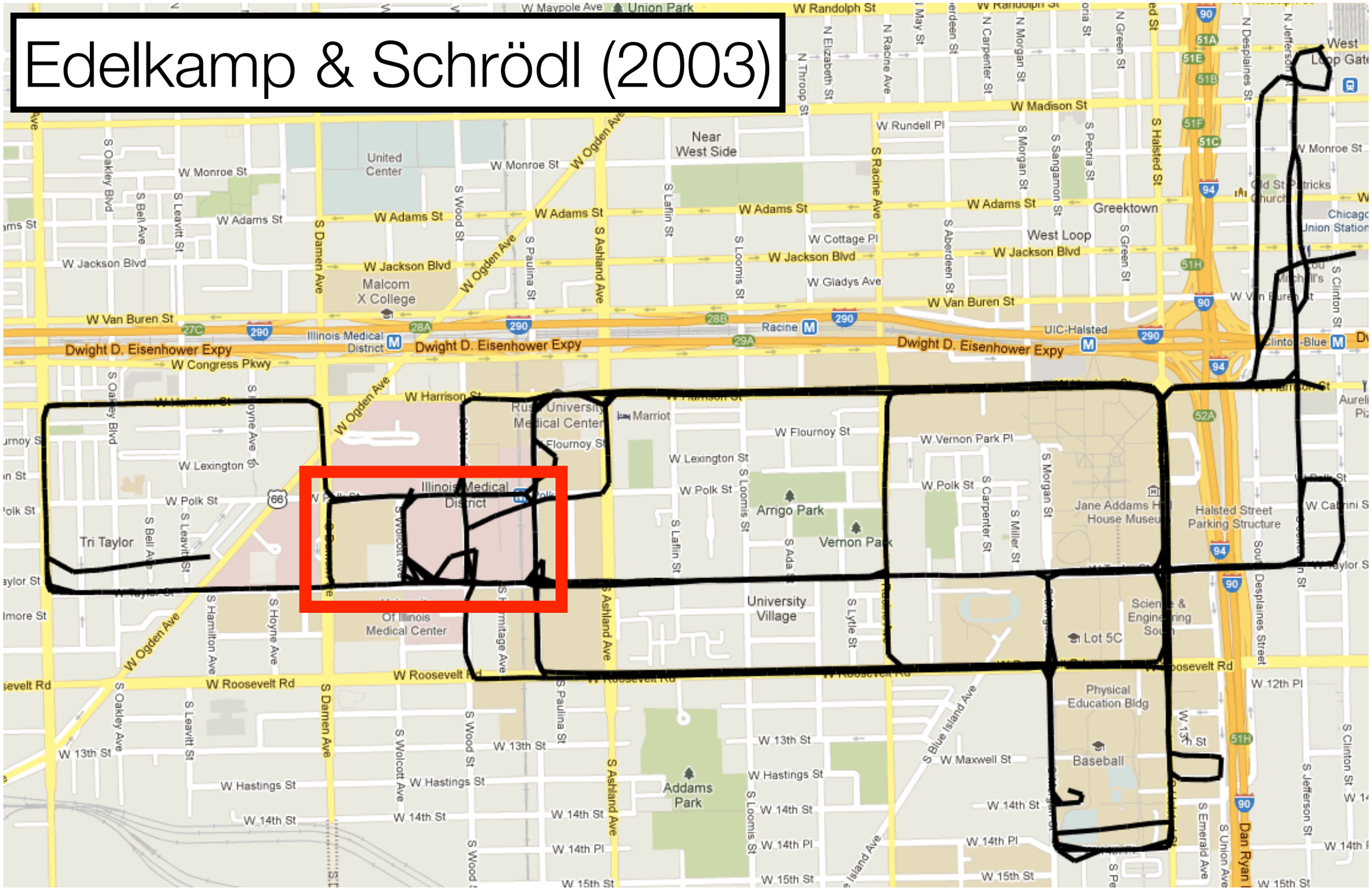
Edelkamp & Schrödl (2003)



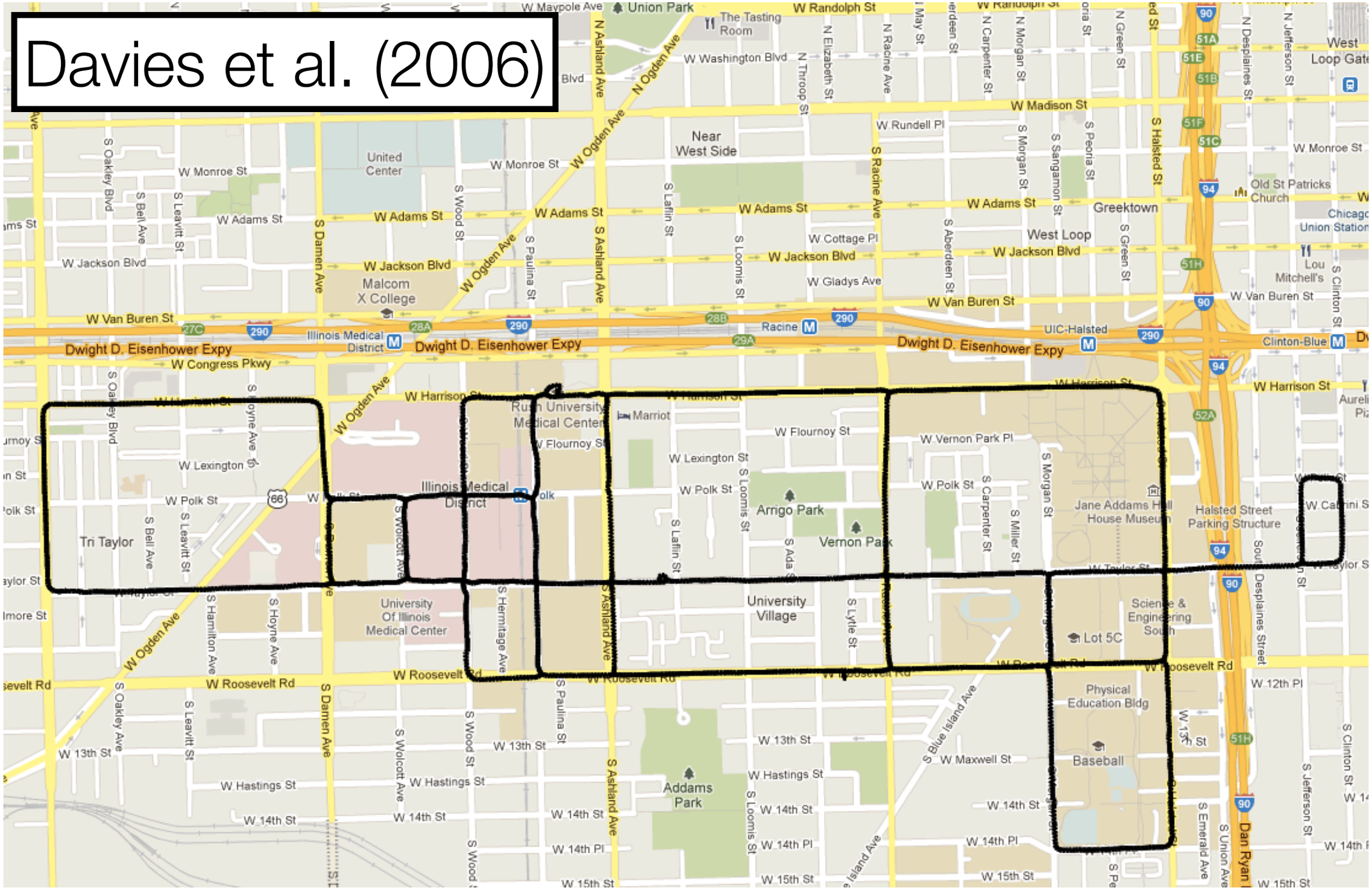
Edelkamp & Schrödl (2003)



Edelkamp & Schrödl (2003)



Davies et al. (2006)



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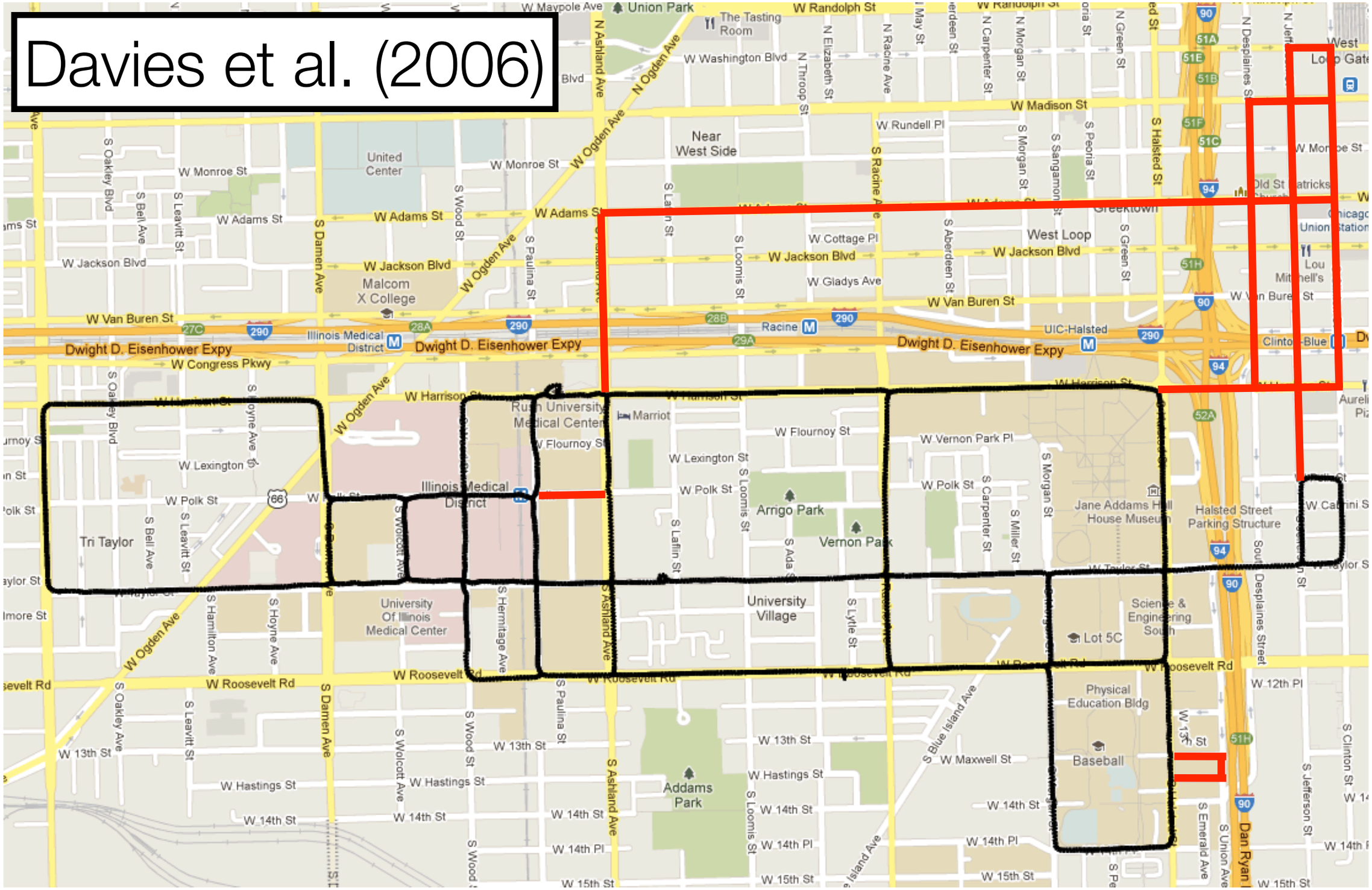
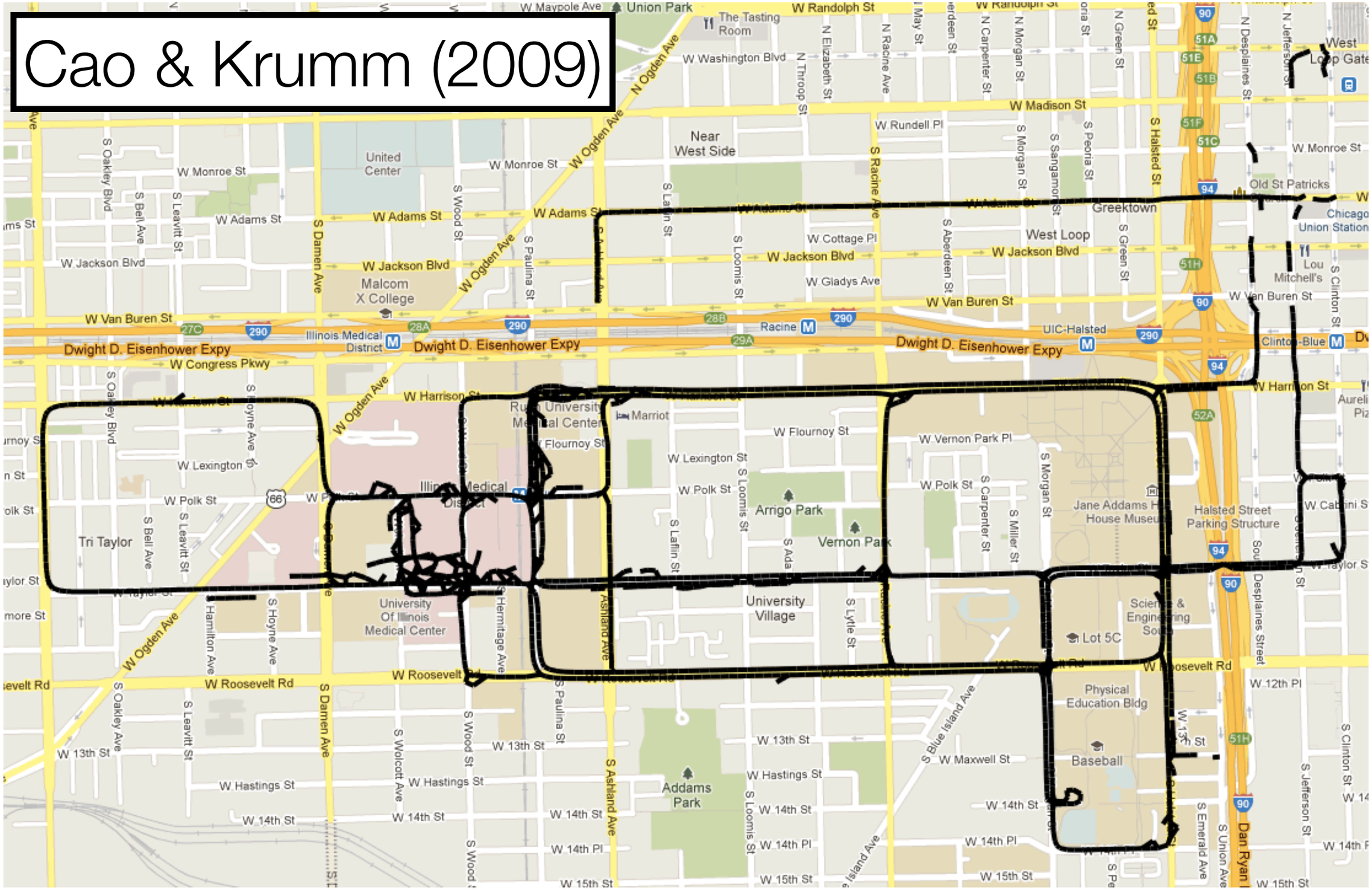
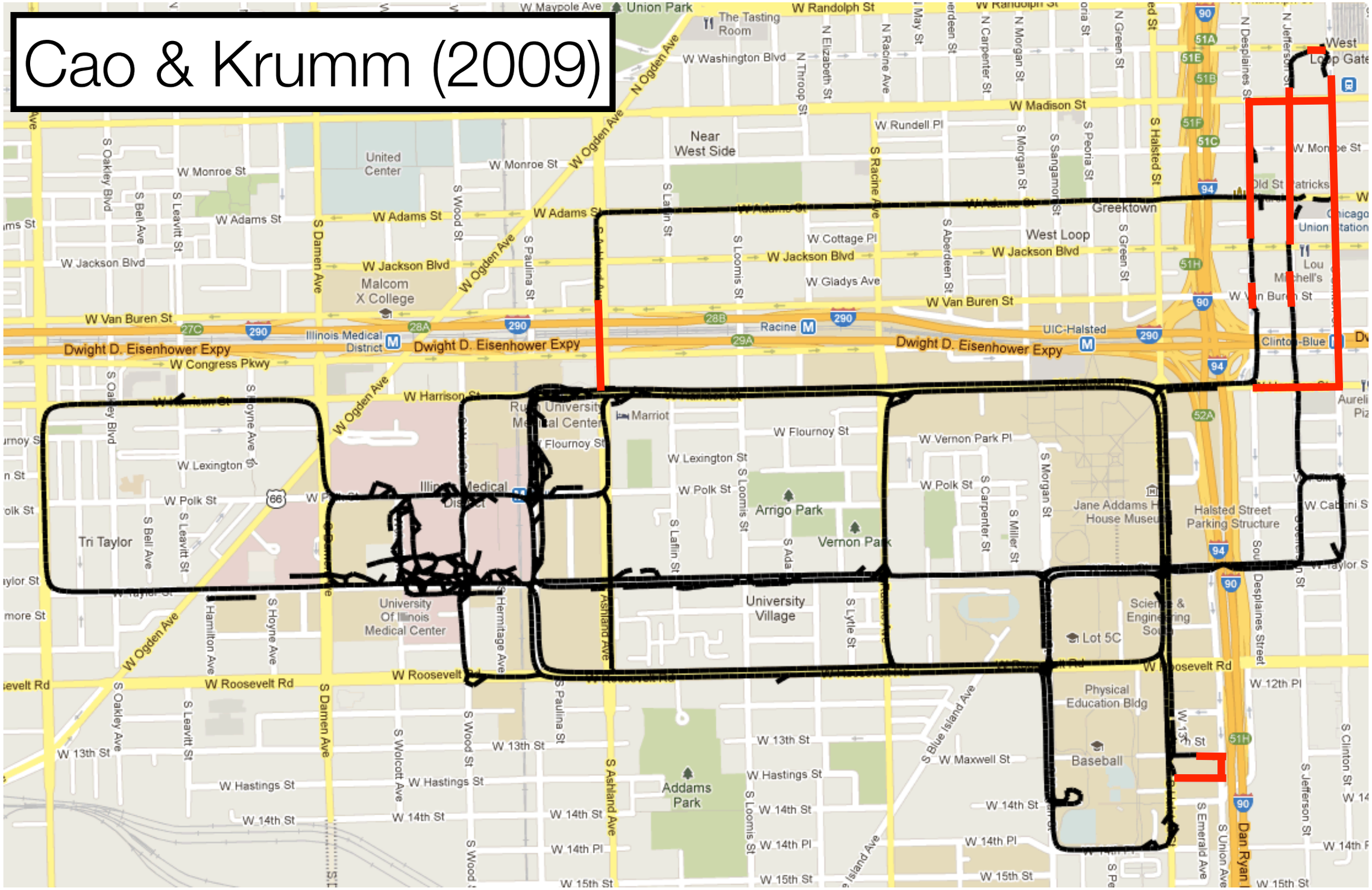


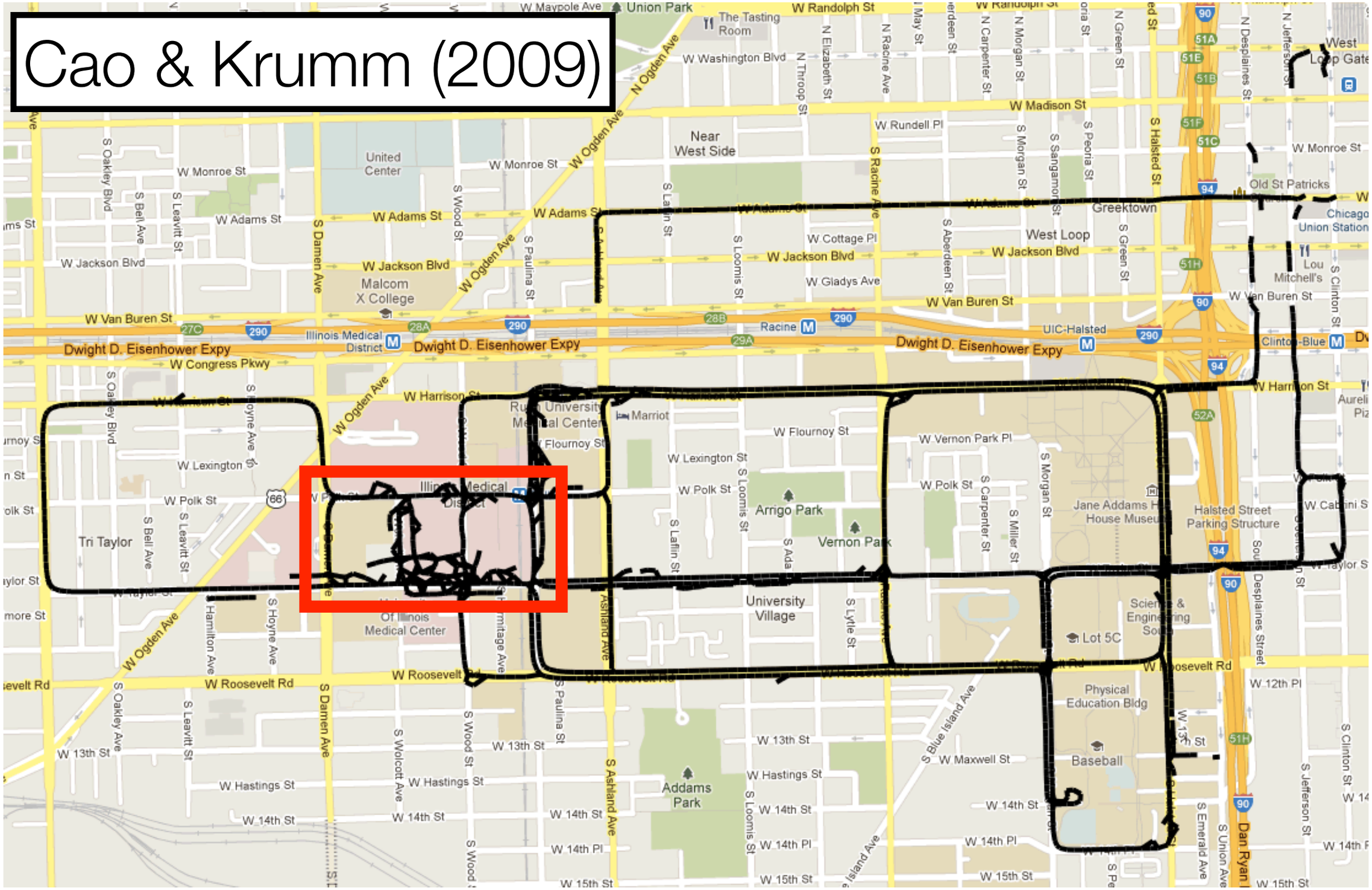
Cao & Krumm (2009)



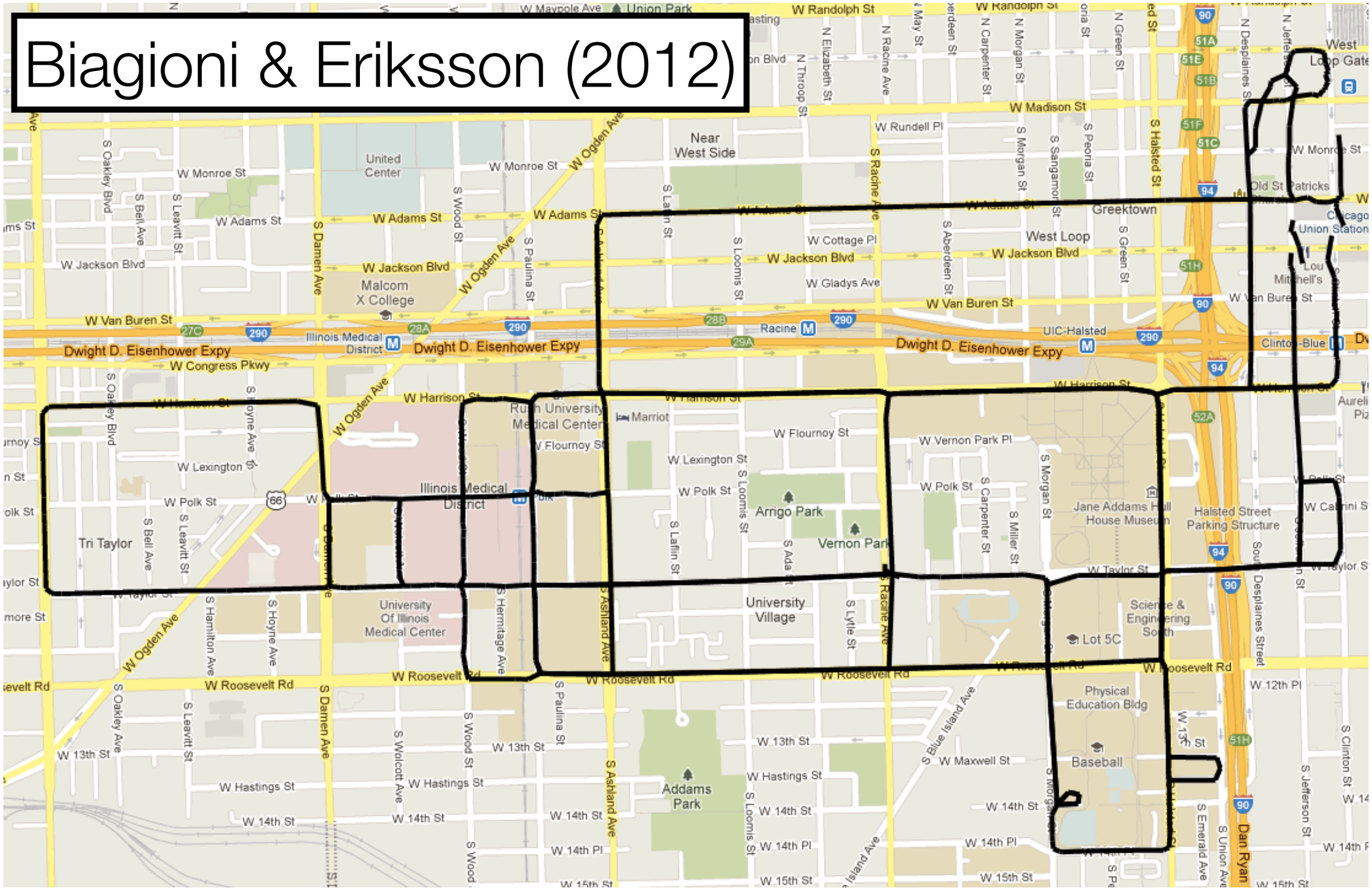
Cao & Krumm (2009)



Cao & Krumm (2009)



Biagioni & Eriksson (2012)



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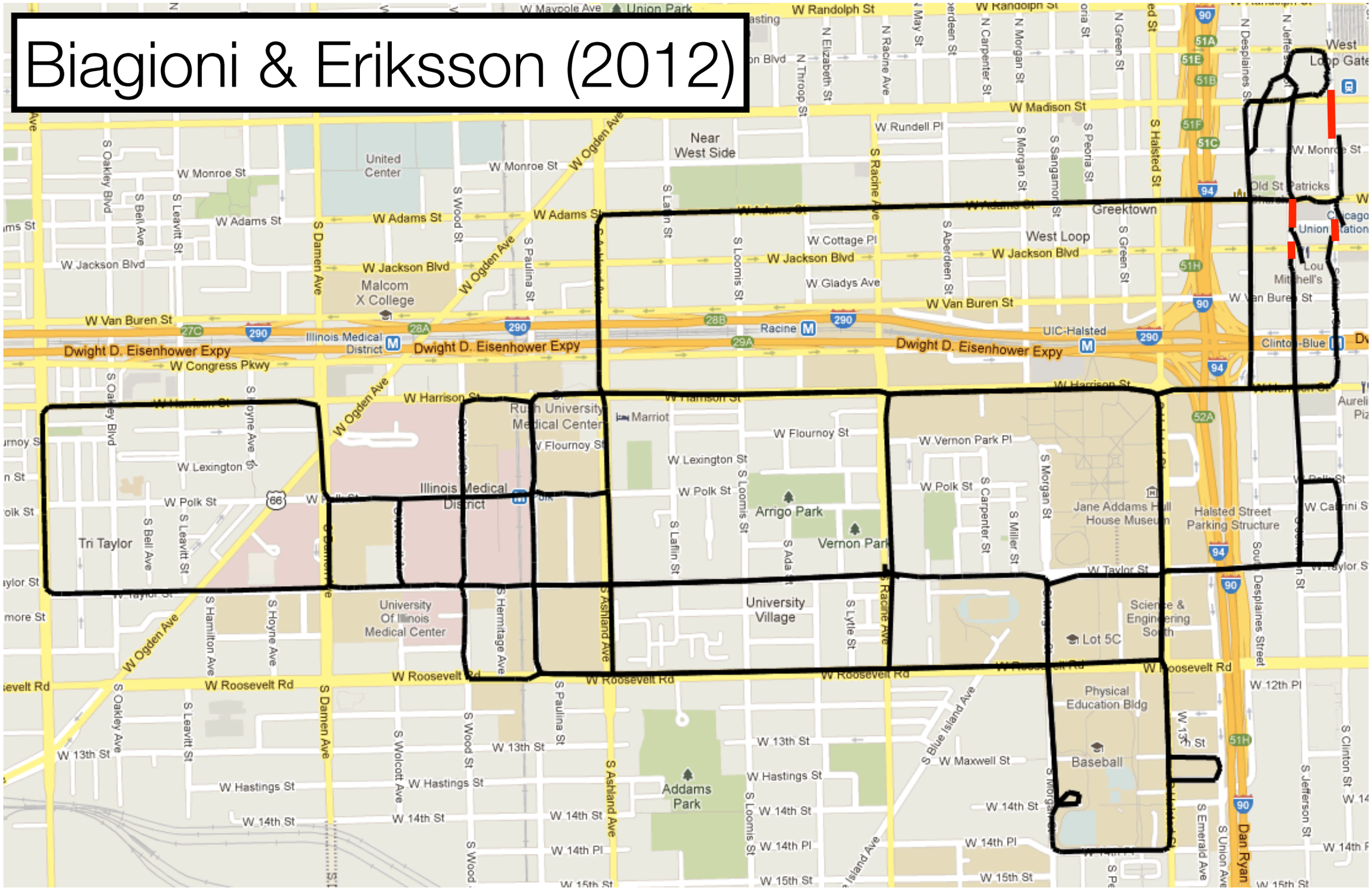

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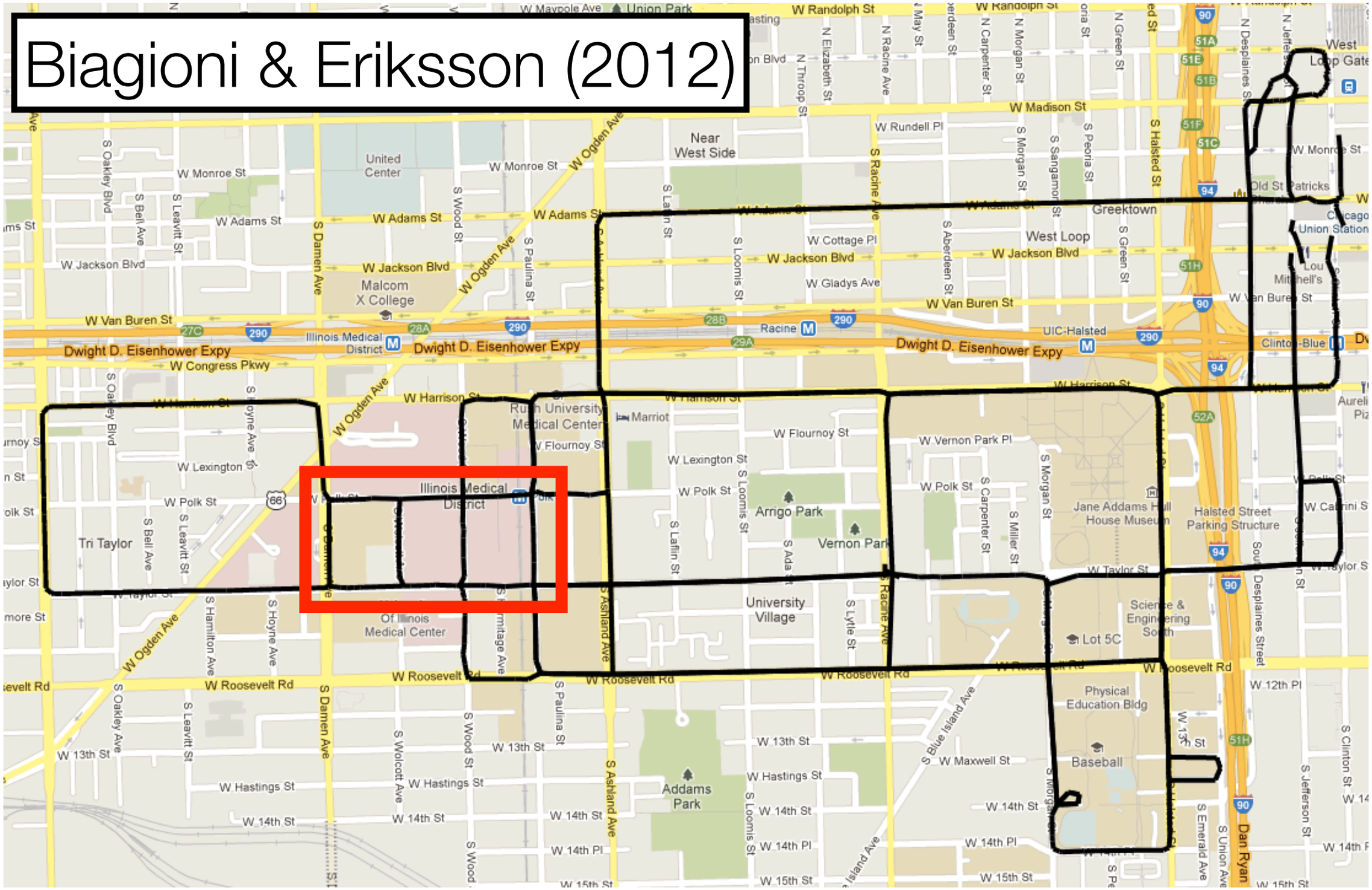

Future work



Thanks!

Questions?

Source code and data available
http://bits.cs.uic.edu

UIC UNIVERSITY OF ILLINOIS AT CHICAGO
Bits Networked Systems Laboratory
COLLEGE OF ENGINEERING