

Map Inference in the Face of Noise and Disparity

James Biagioni and Jakob Eriksson

Map making

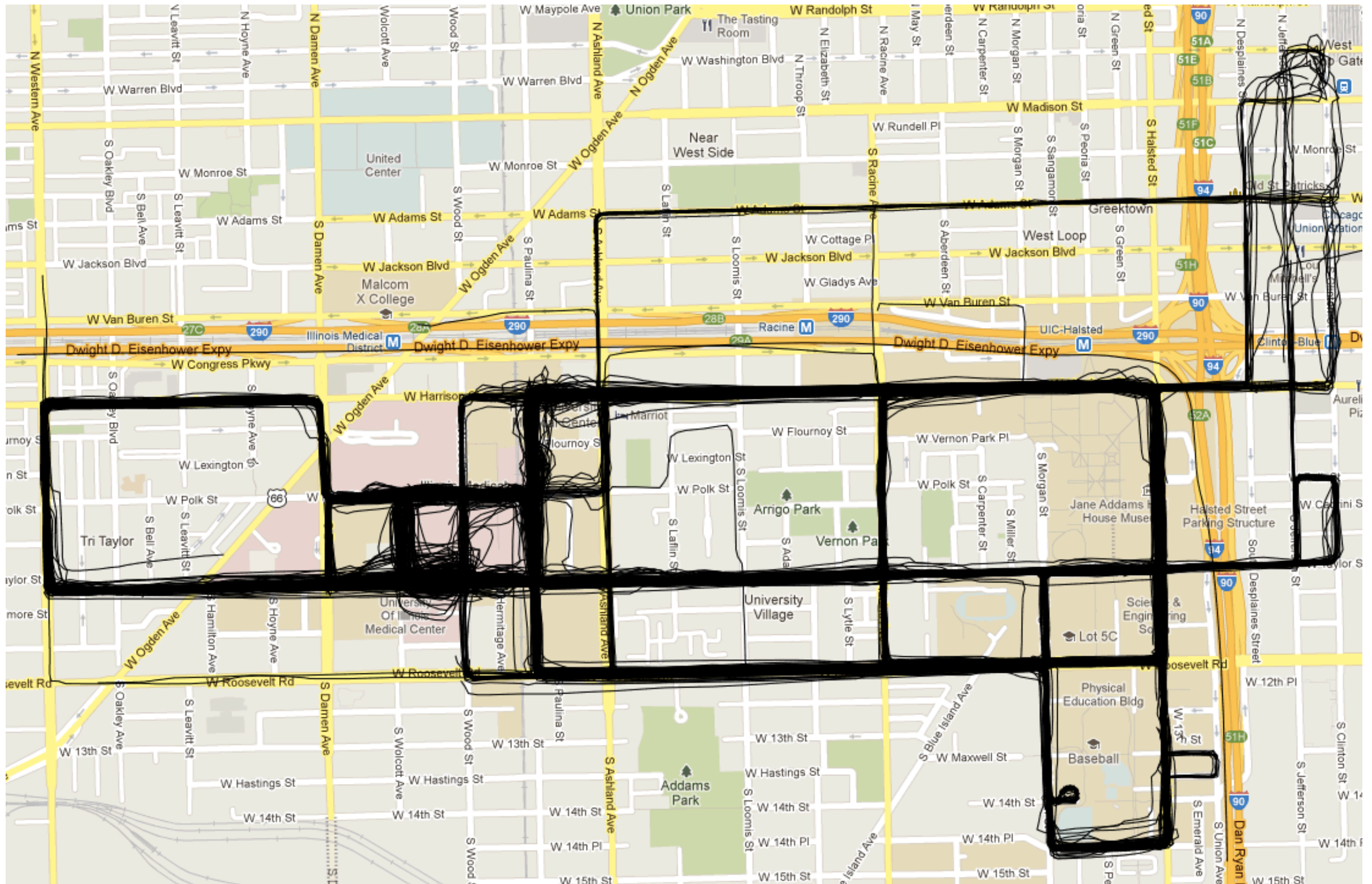


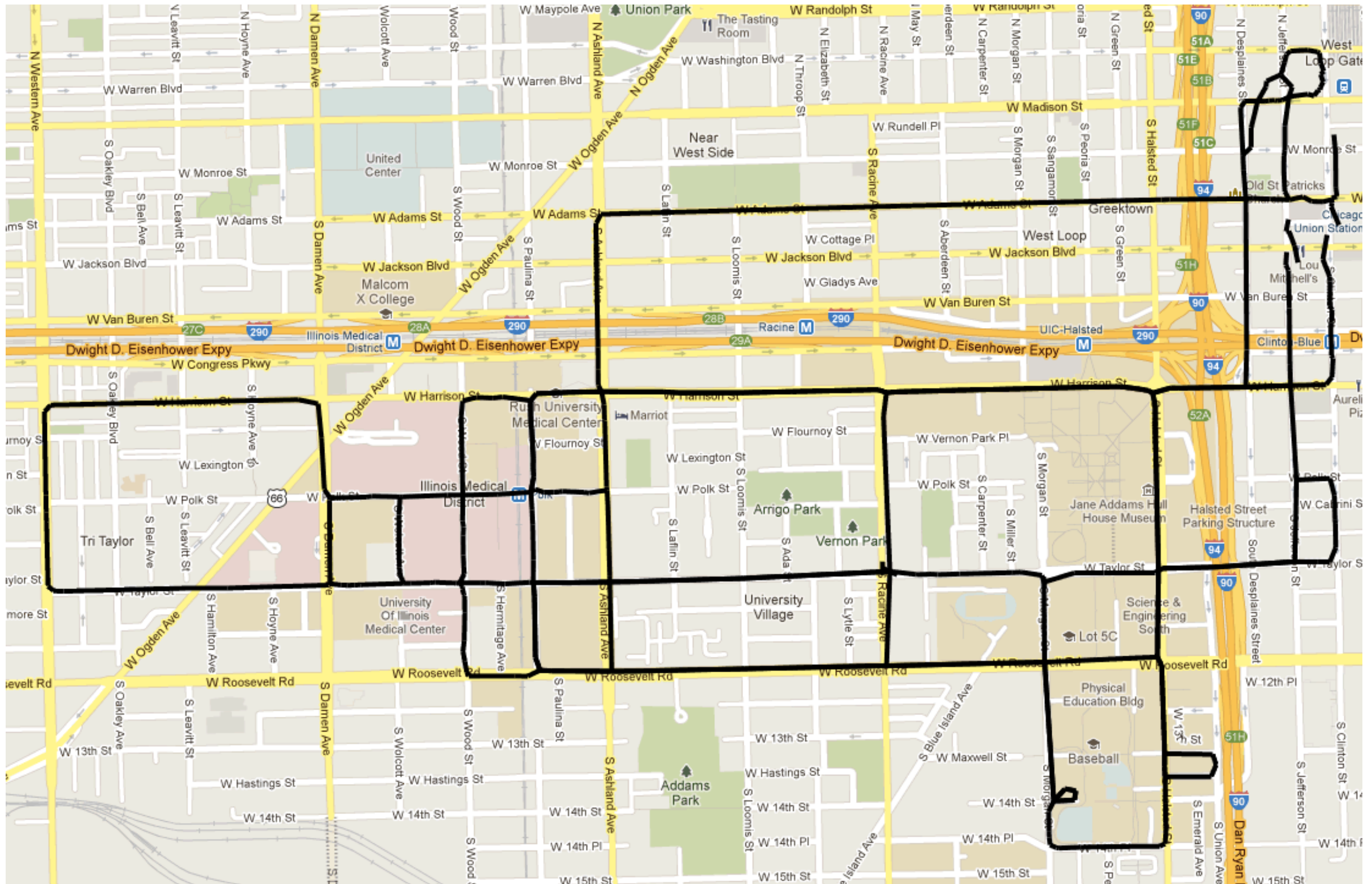
Opportunistic data collection



Opportunistic data collection



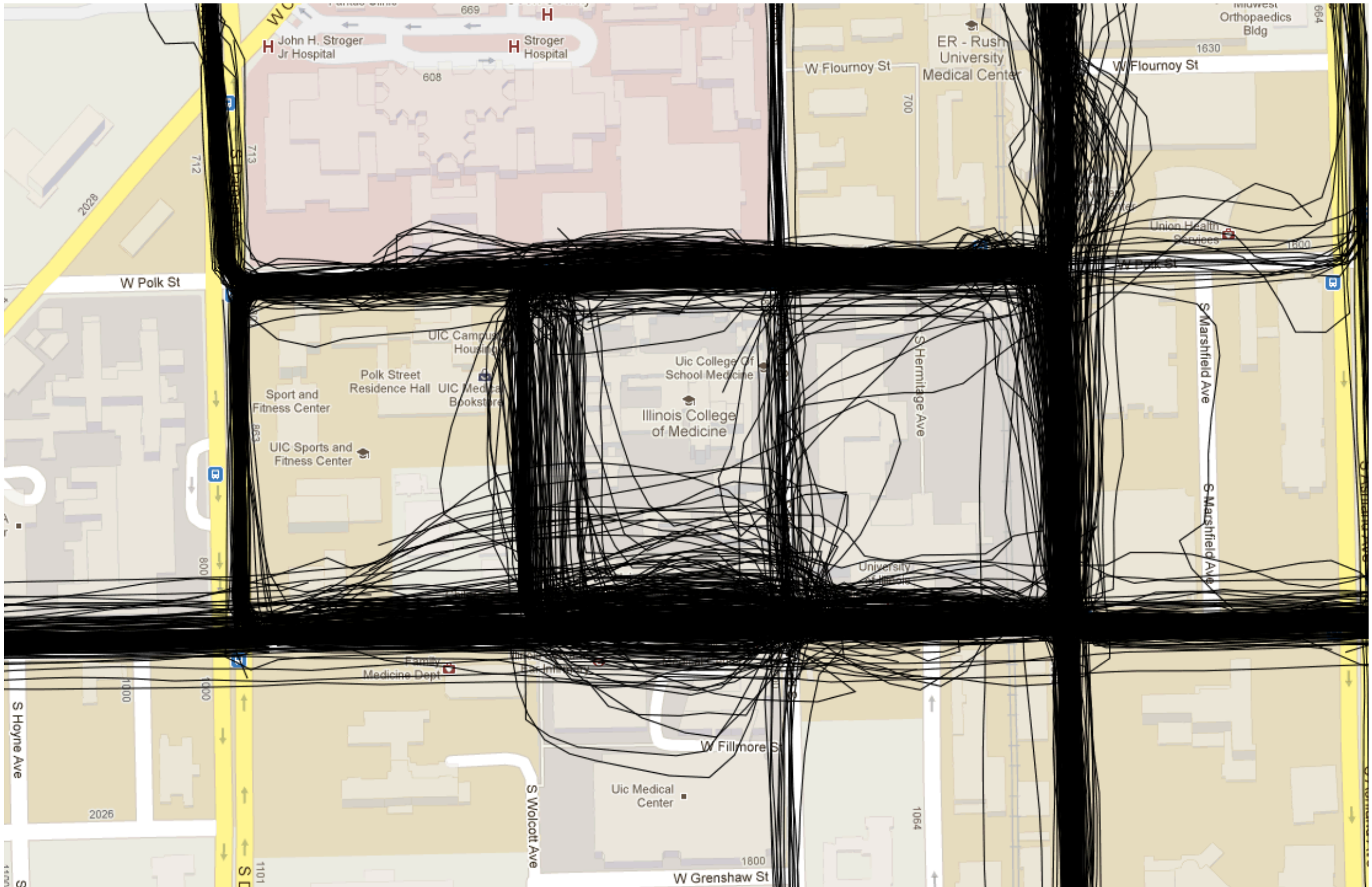


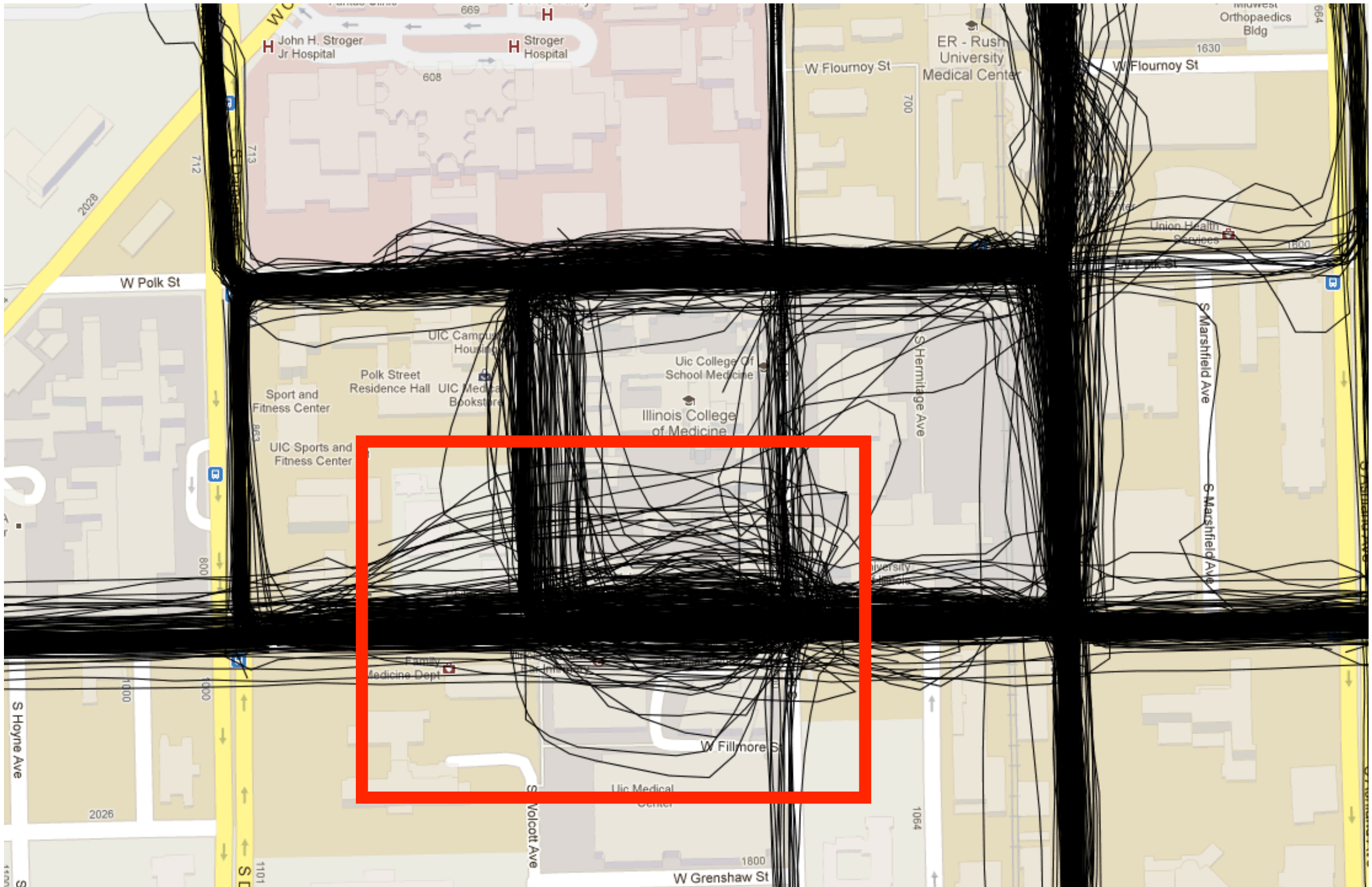


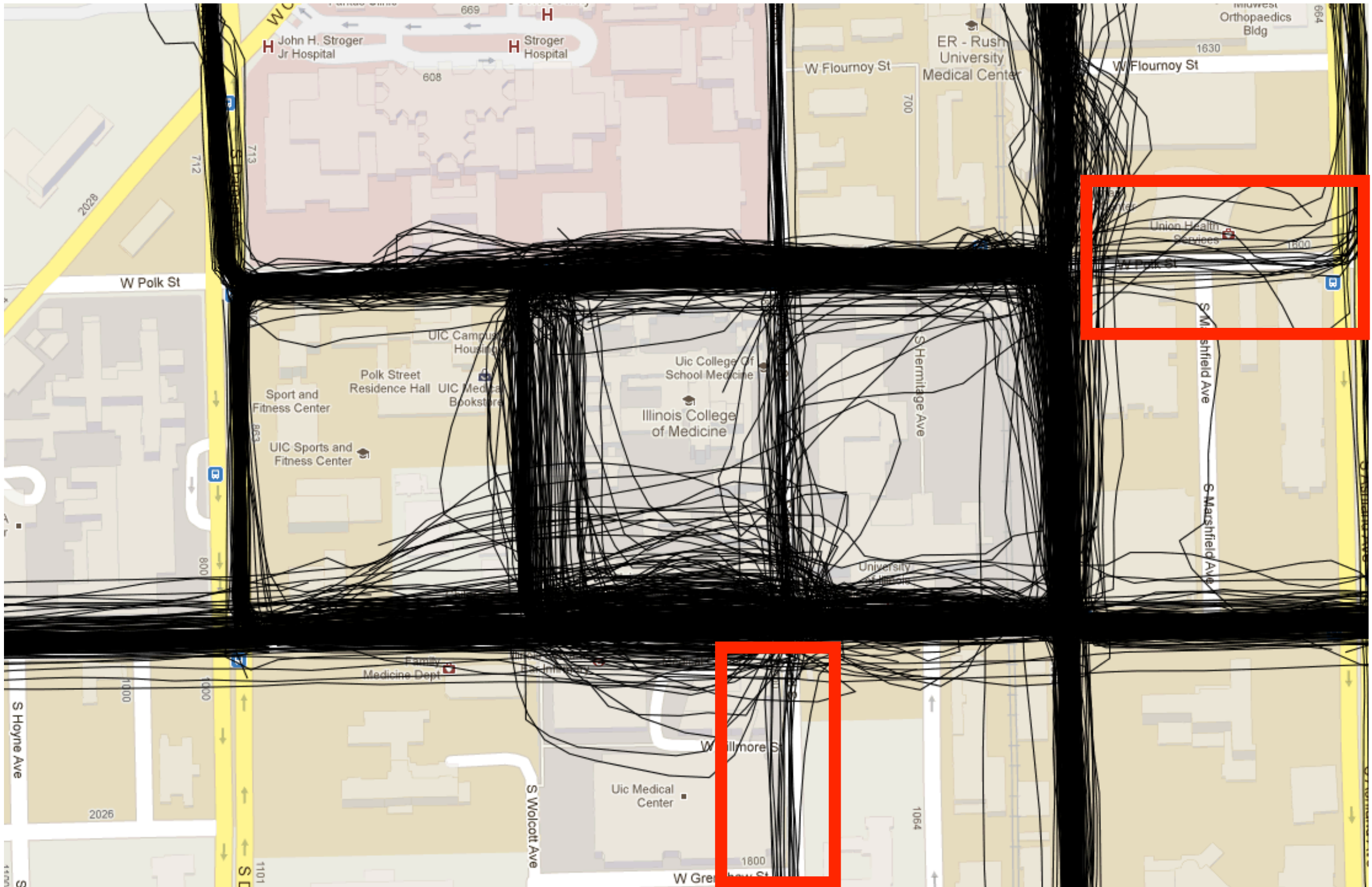
Making maps is hard



“Turn left and drive off the bridge onto the 280”







A couple of questions...



Why infer maps?

Road surveys



Rural/developing areas



New road construction



Road closures



Road closures

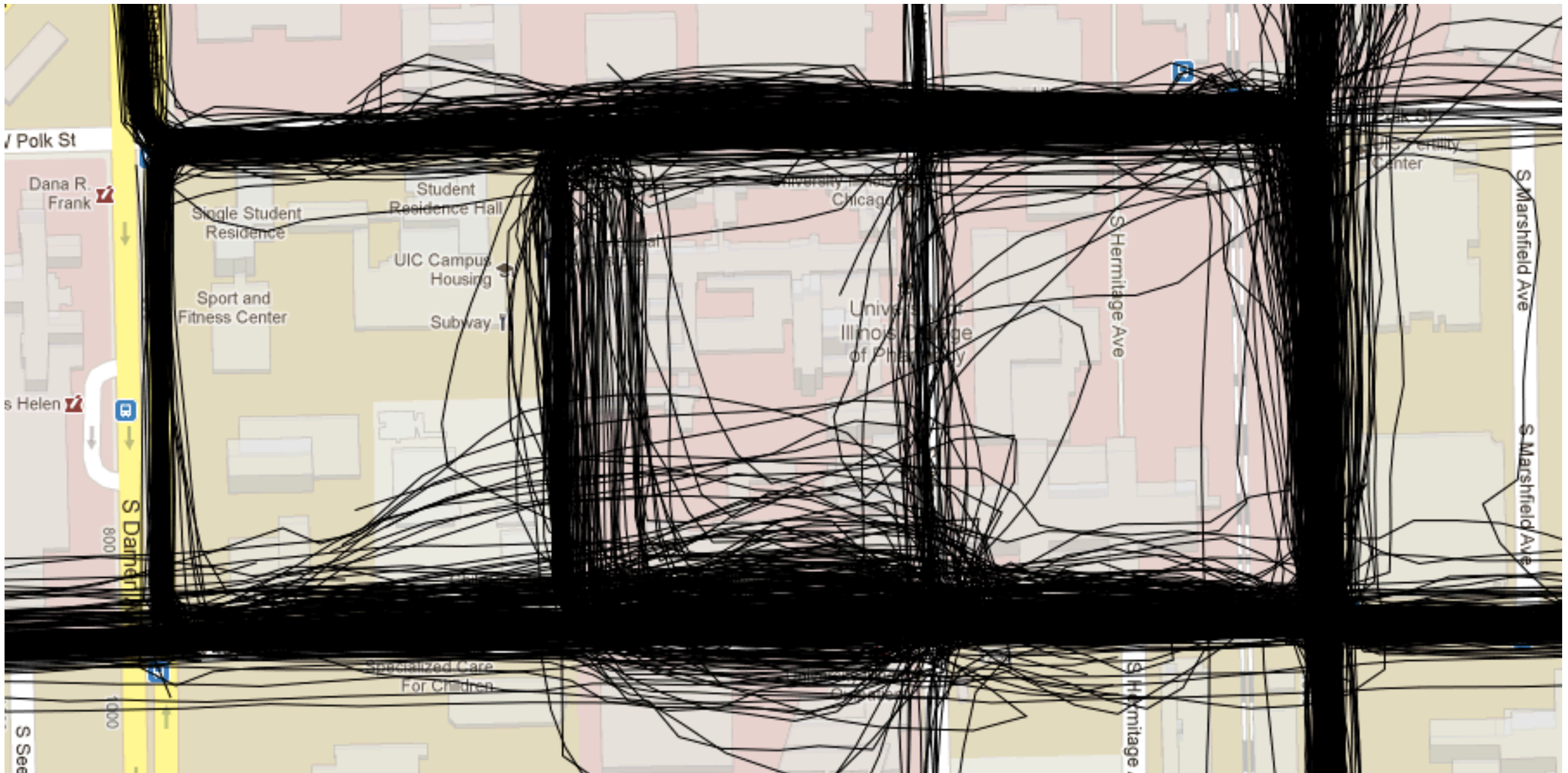


Are noise and disparity
actually problems?

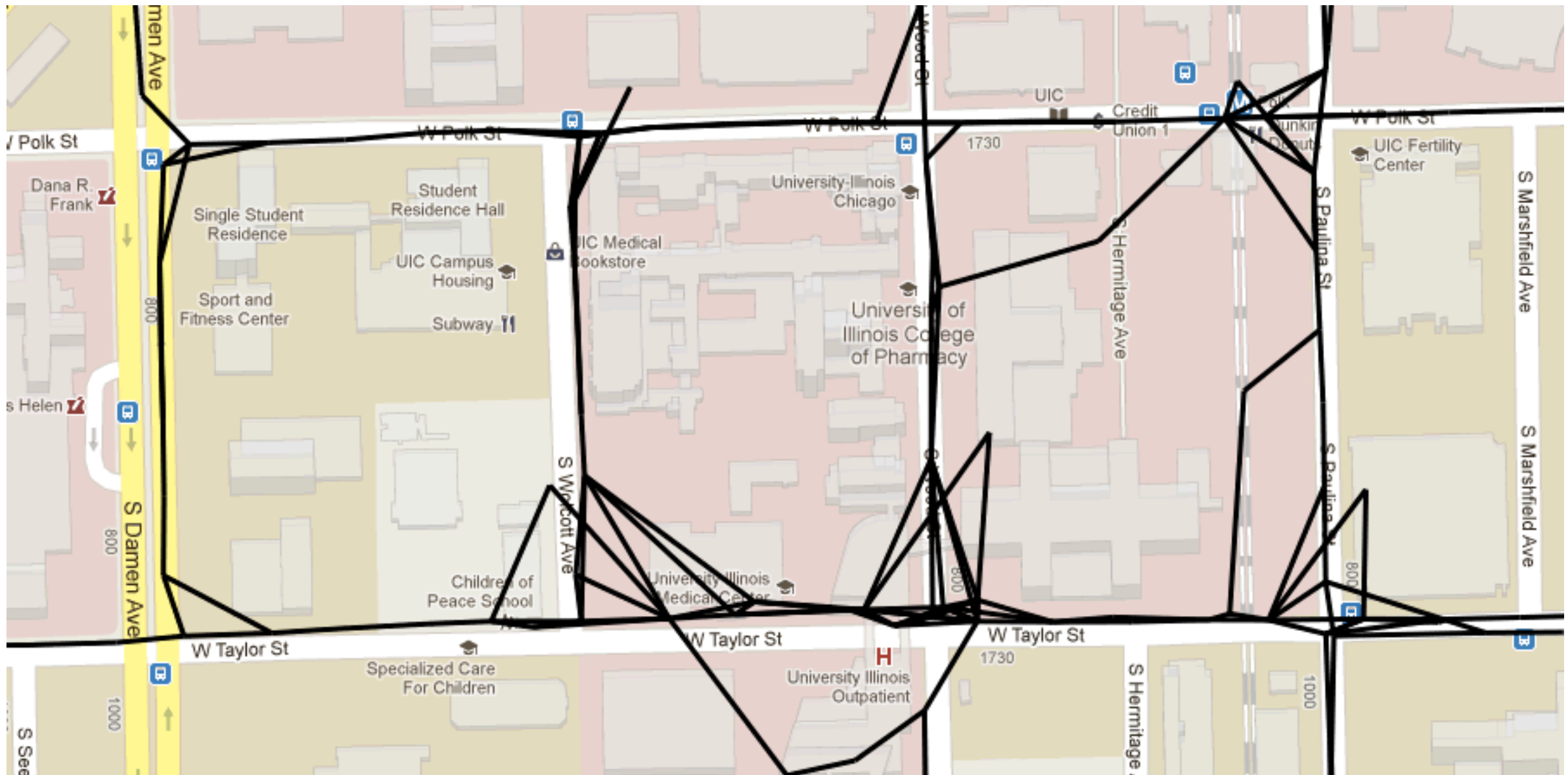
Current state of the art

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

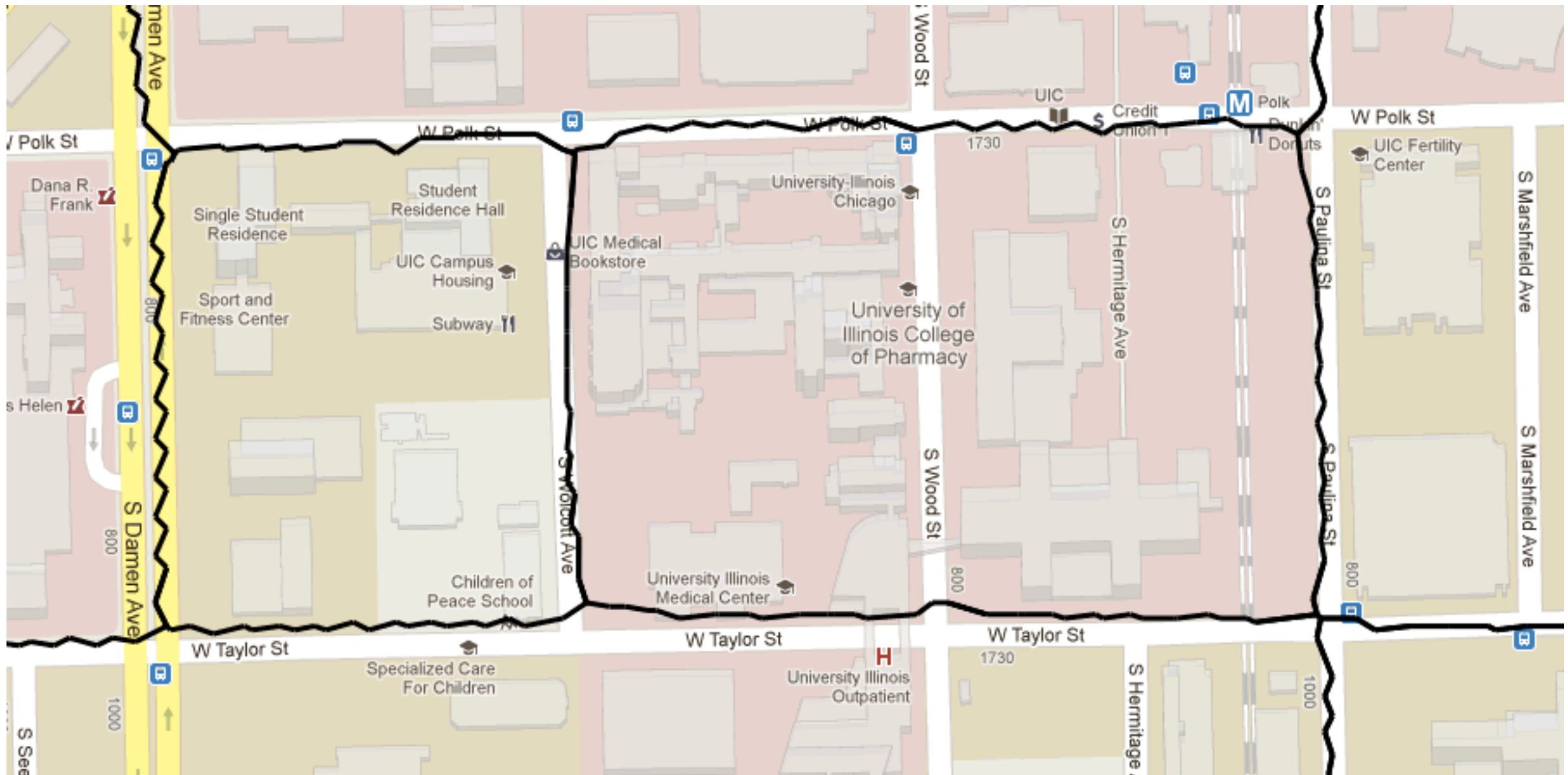
Noisy, disparate GPS data



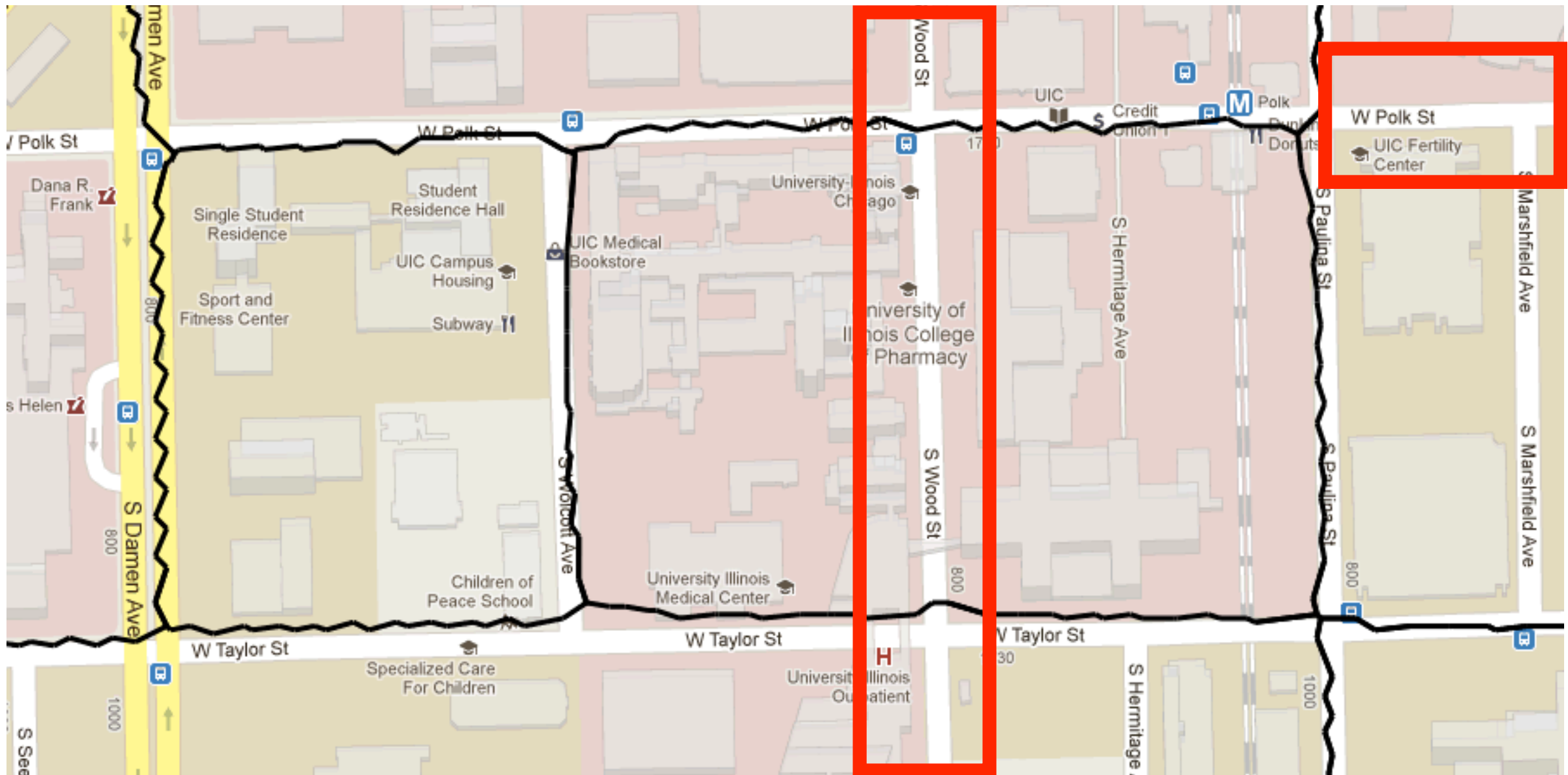
Edelkamp & Schrödl (2003)



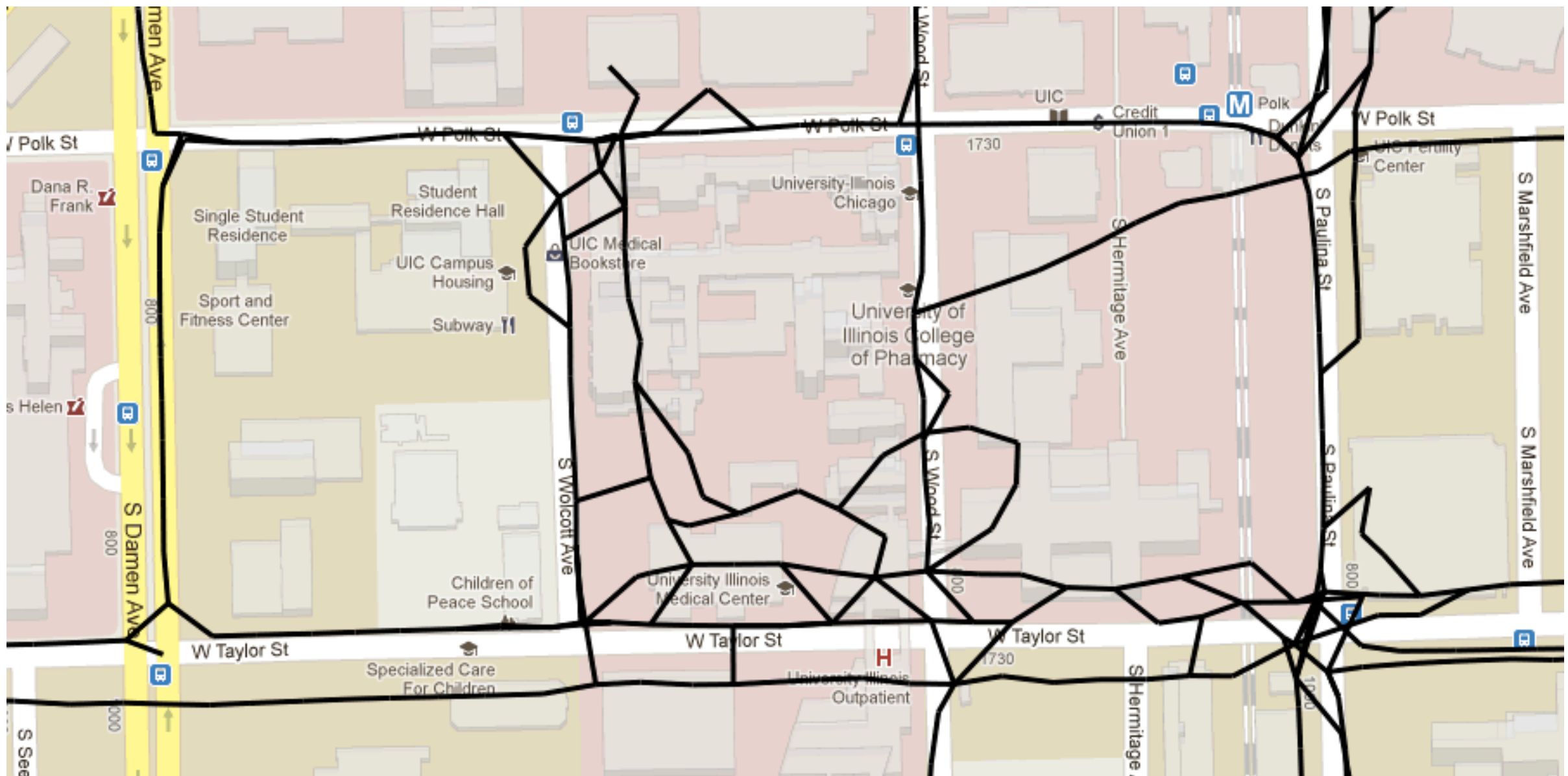
Davies et al. (2006)



Davies et al. (2006)



Cao & Krumm (2009)



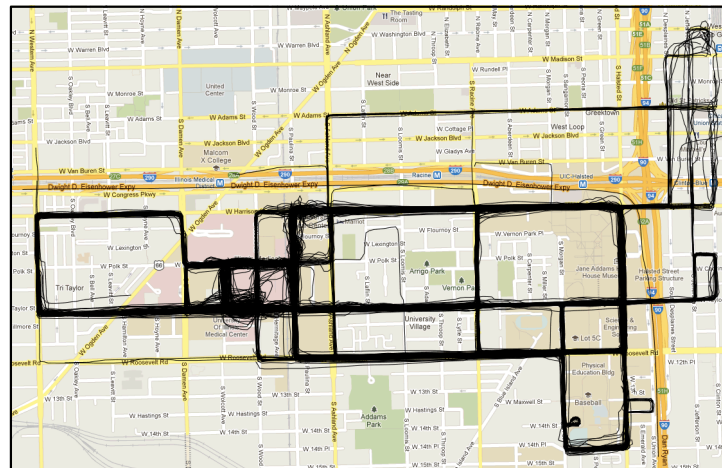
Lessons learned

- 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

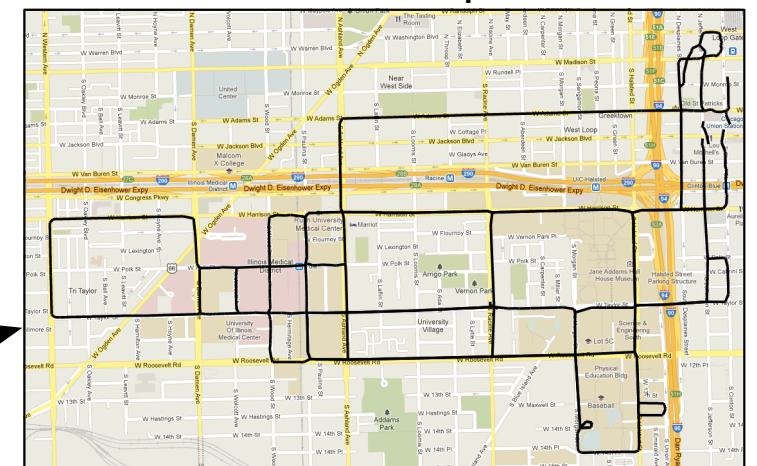
Initial Map Generation

Trace Map Matching

Topology Refinement

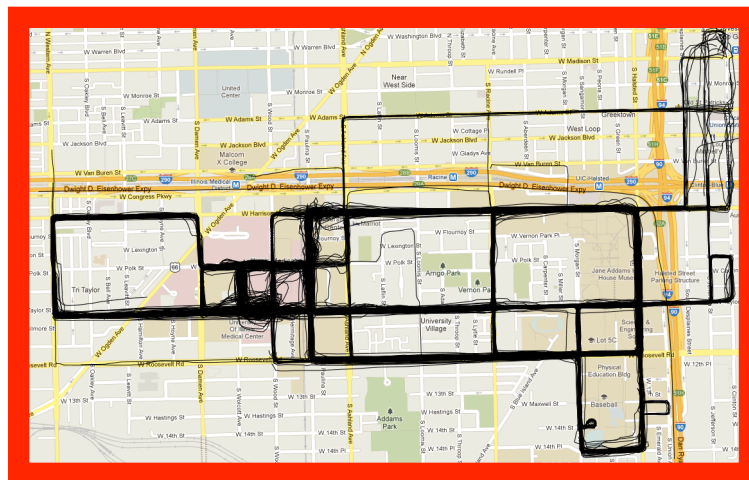
Geometry Refinement

Final map



A hybrid approach

Raw GPS traces



Density Estimation

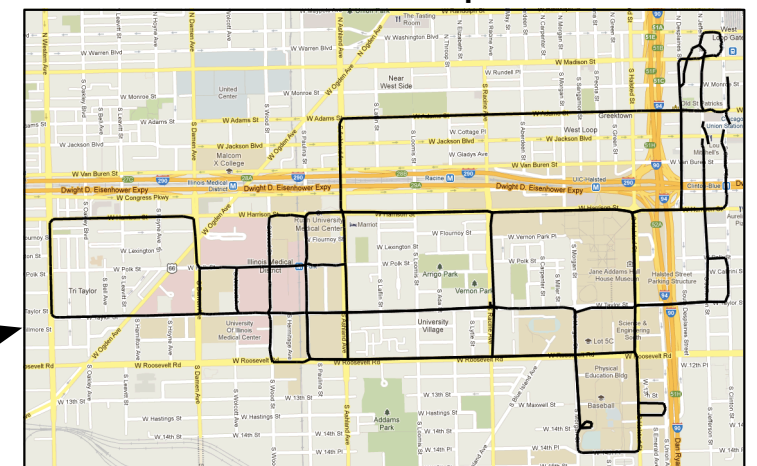
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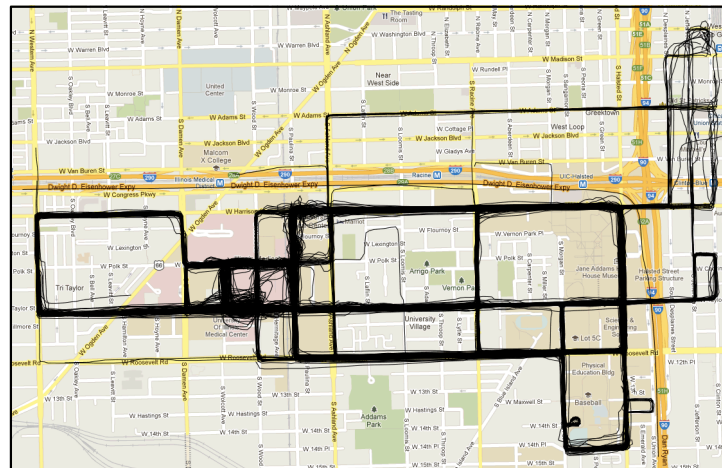
Geometry Refinement

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Density Estimation

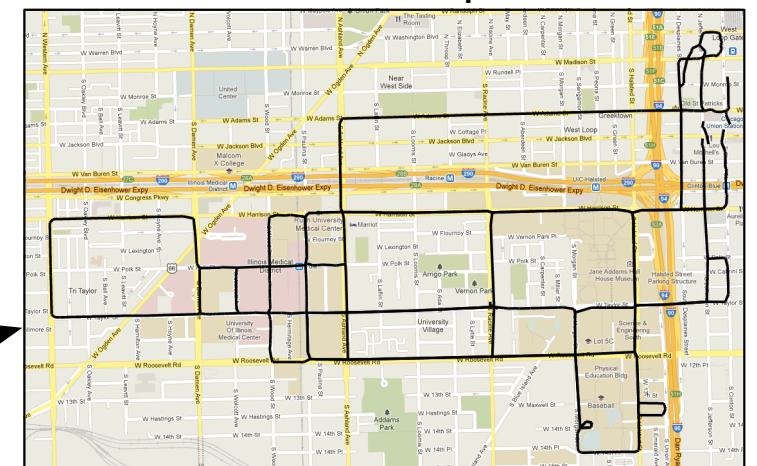
Initial Map Generation

Trace Map Matching

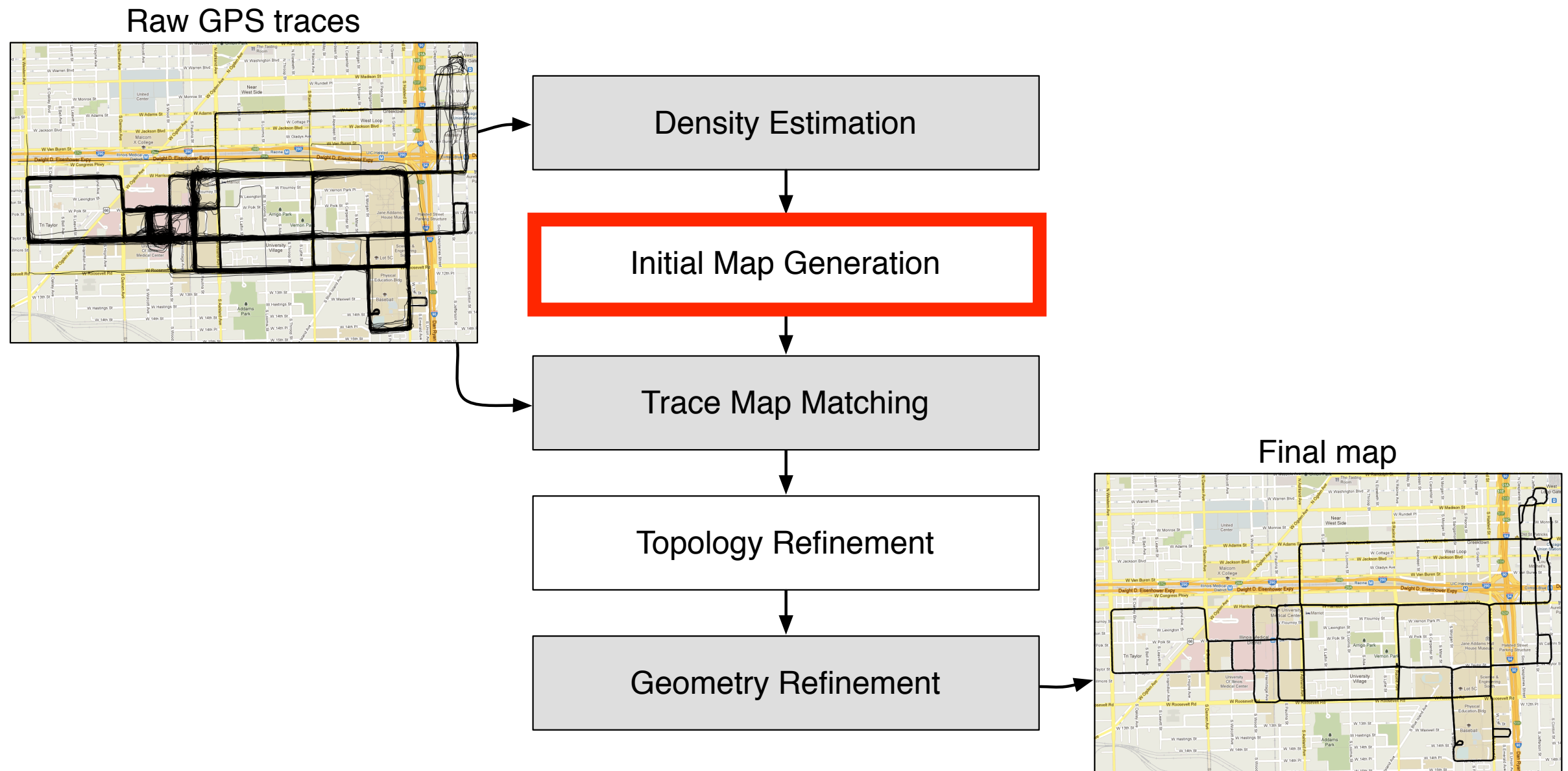
Topology Refinement

Geometry Refinement

Final map

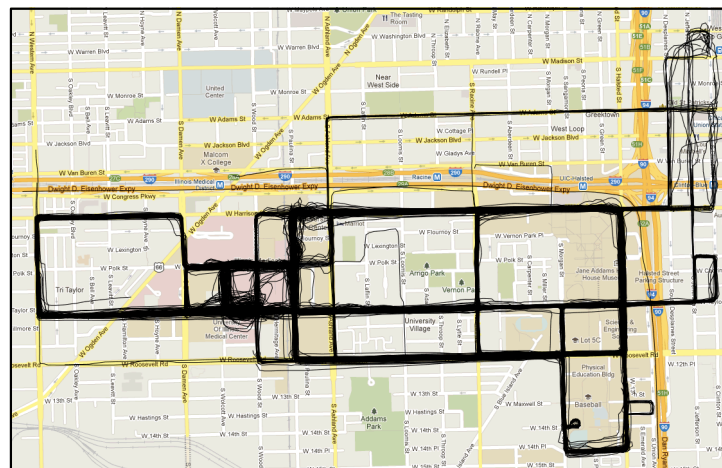


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Raw GPS traces



Density Estimation

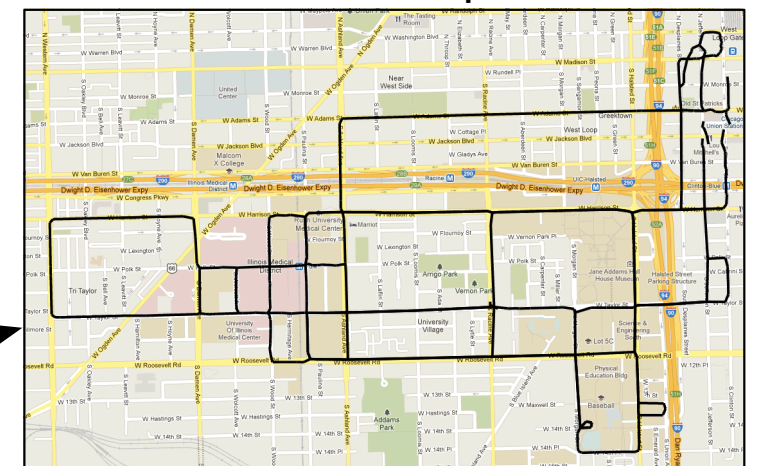
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Trace Map Matching

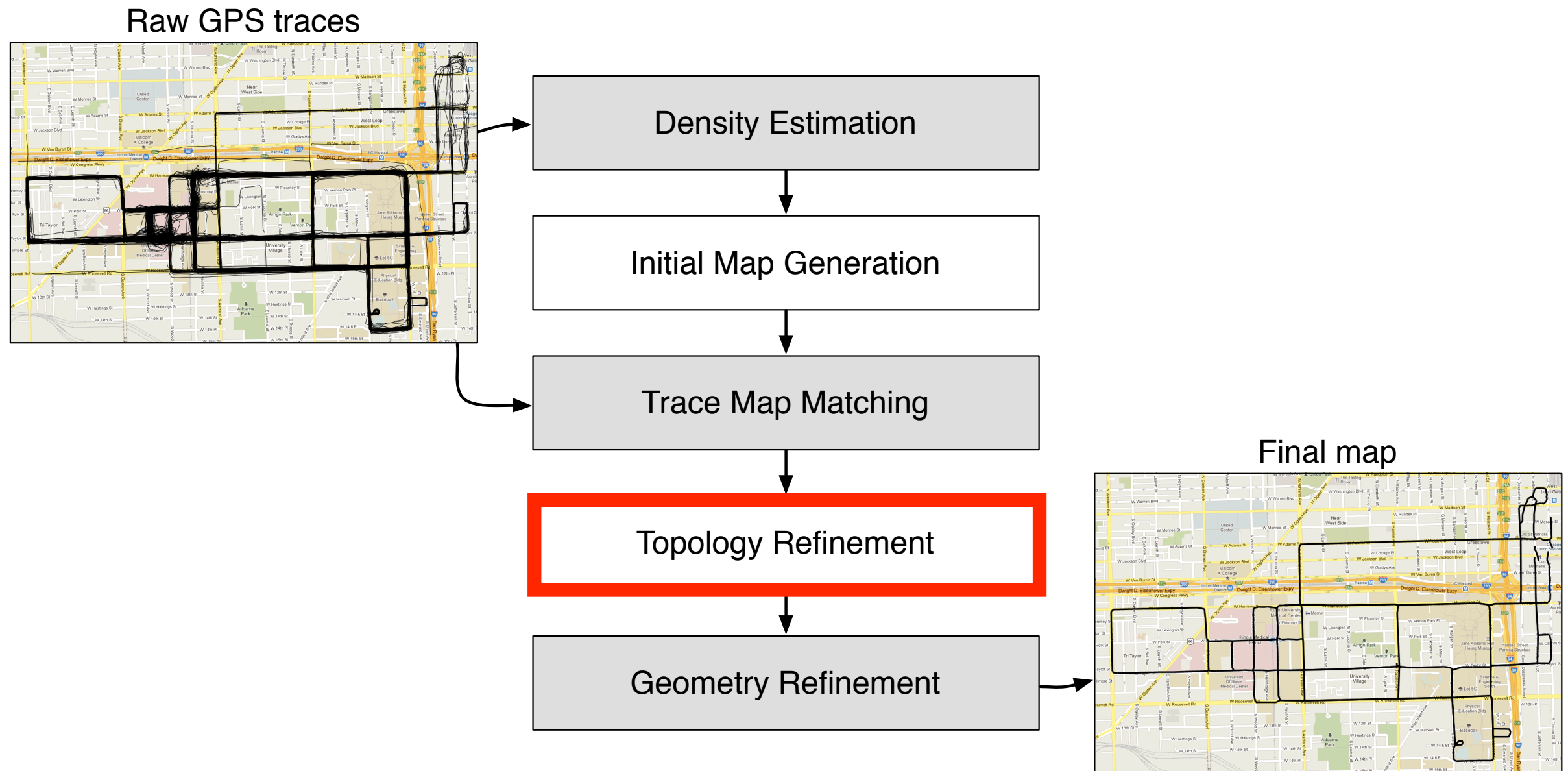
Topology Refinement

Geometry Refinement

Final map

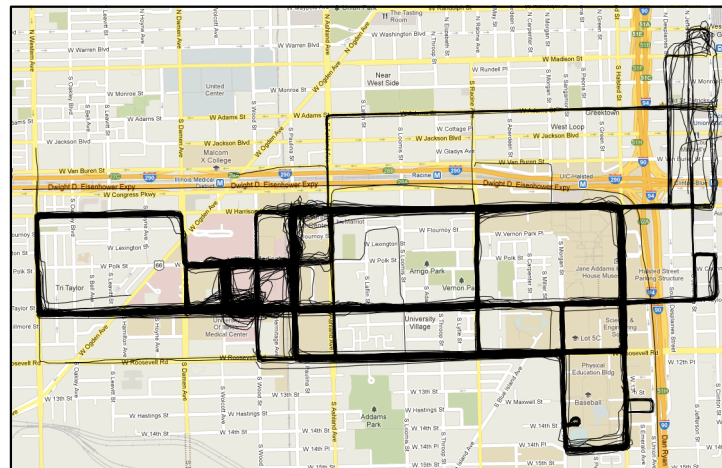


A hybrid approach



A hybrid approach

Raw GPS traces



Density Estimation

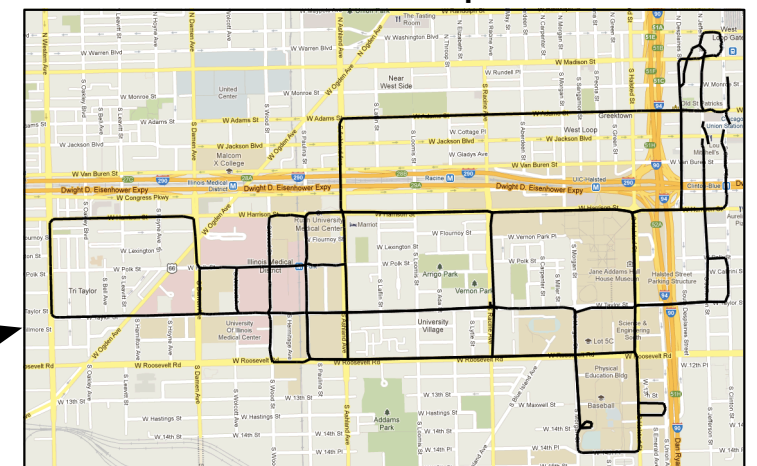
Initial Map Generation

Trace Map Matching

Topology Refinement

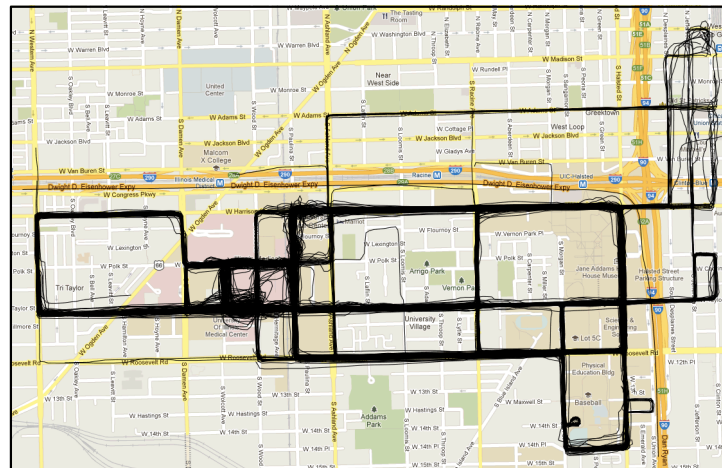
Geometry Refinement

Final map



A hybrid approach

Raw GPS traces



Density Estimation

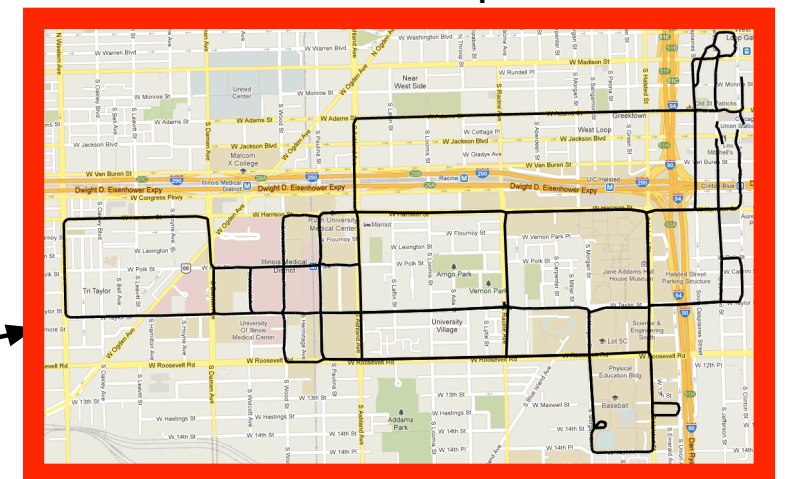
Initial Map Generation

Trace Map Matching

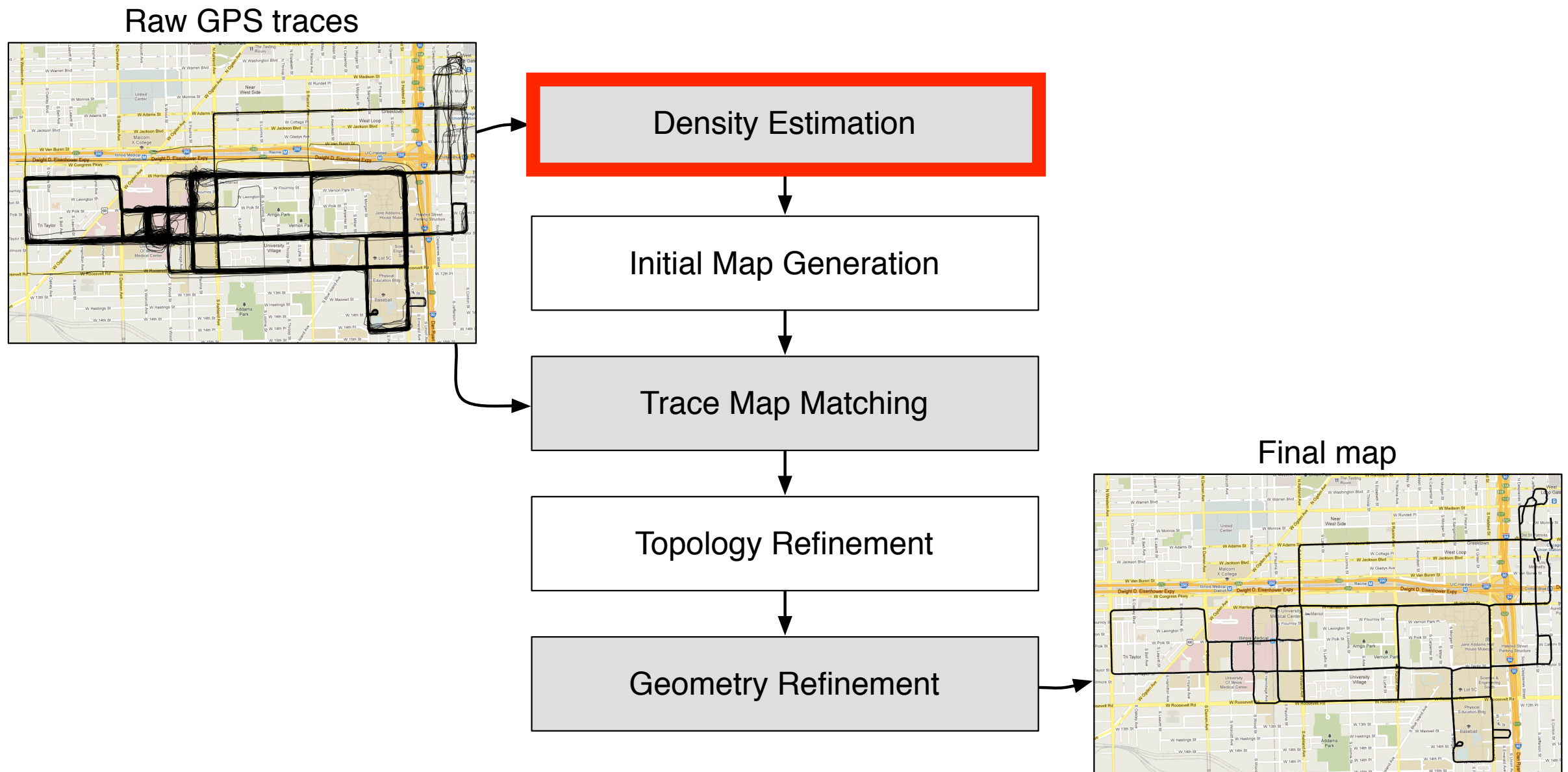
Topology Refinement

Geometry Refinement

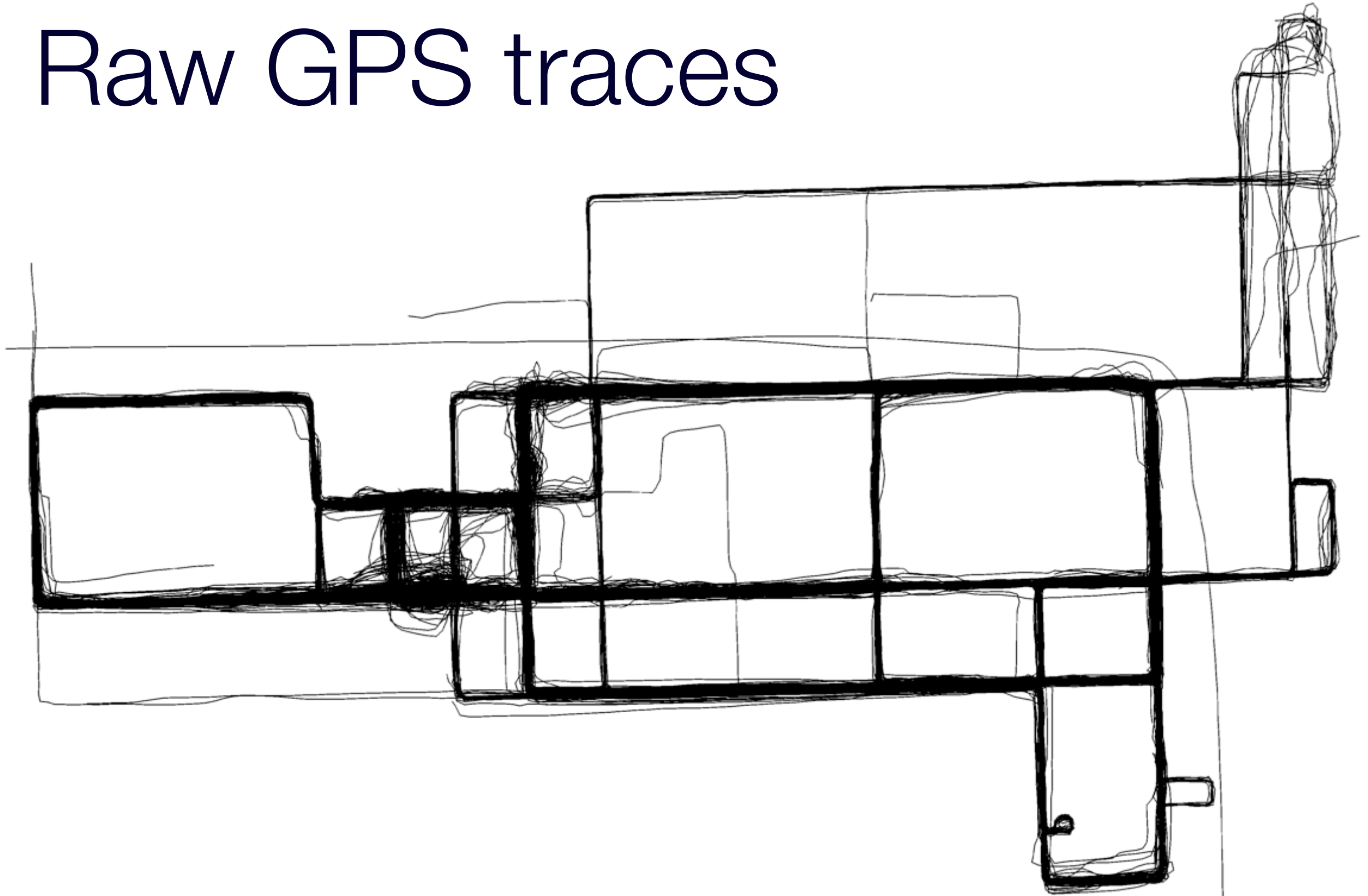
Final map



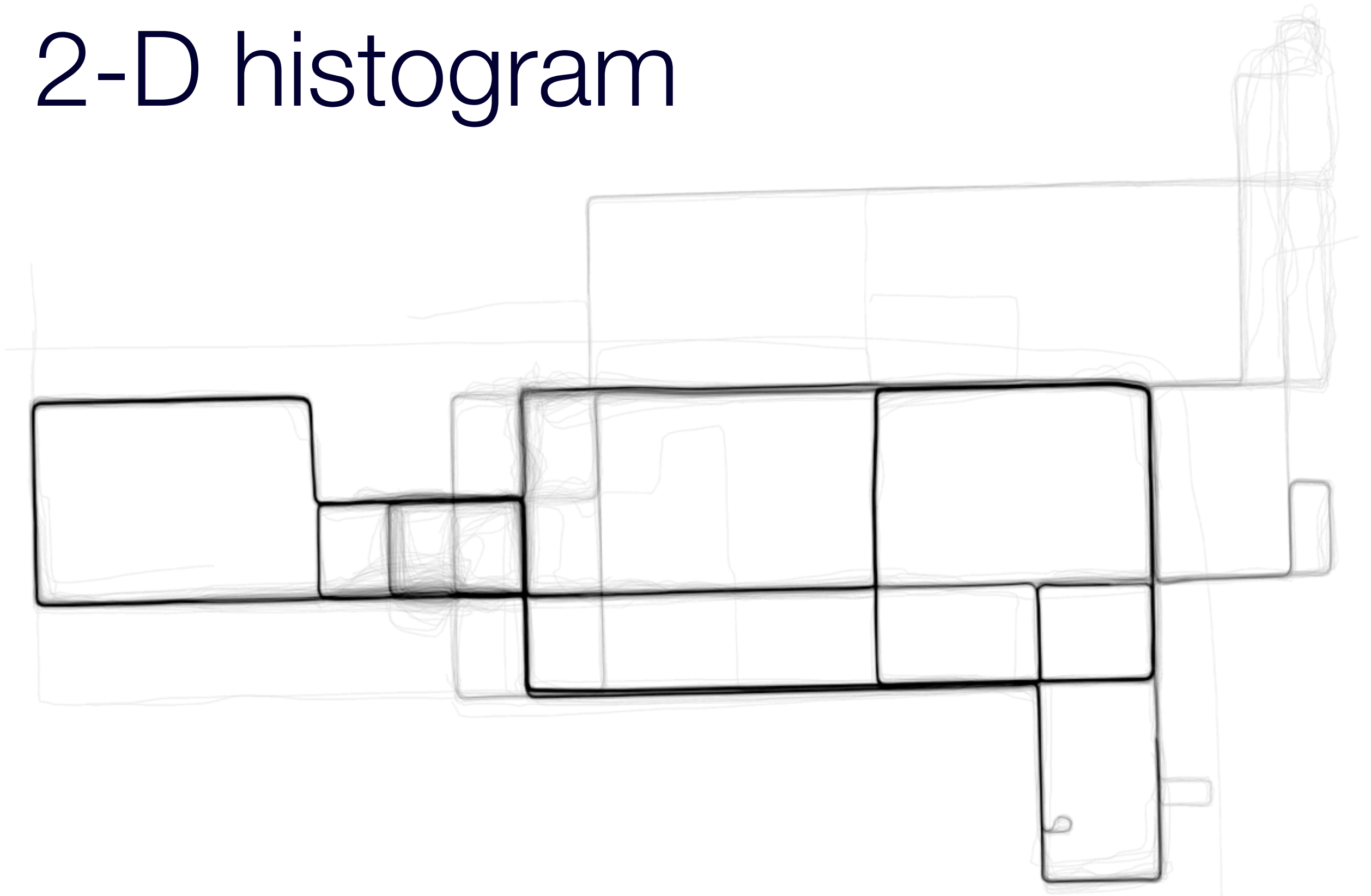
Map inference pipeline



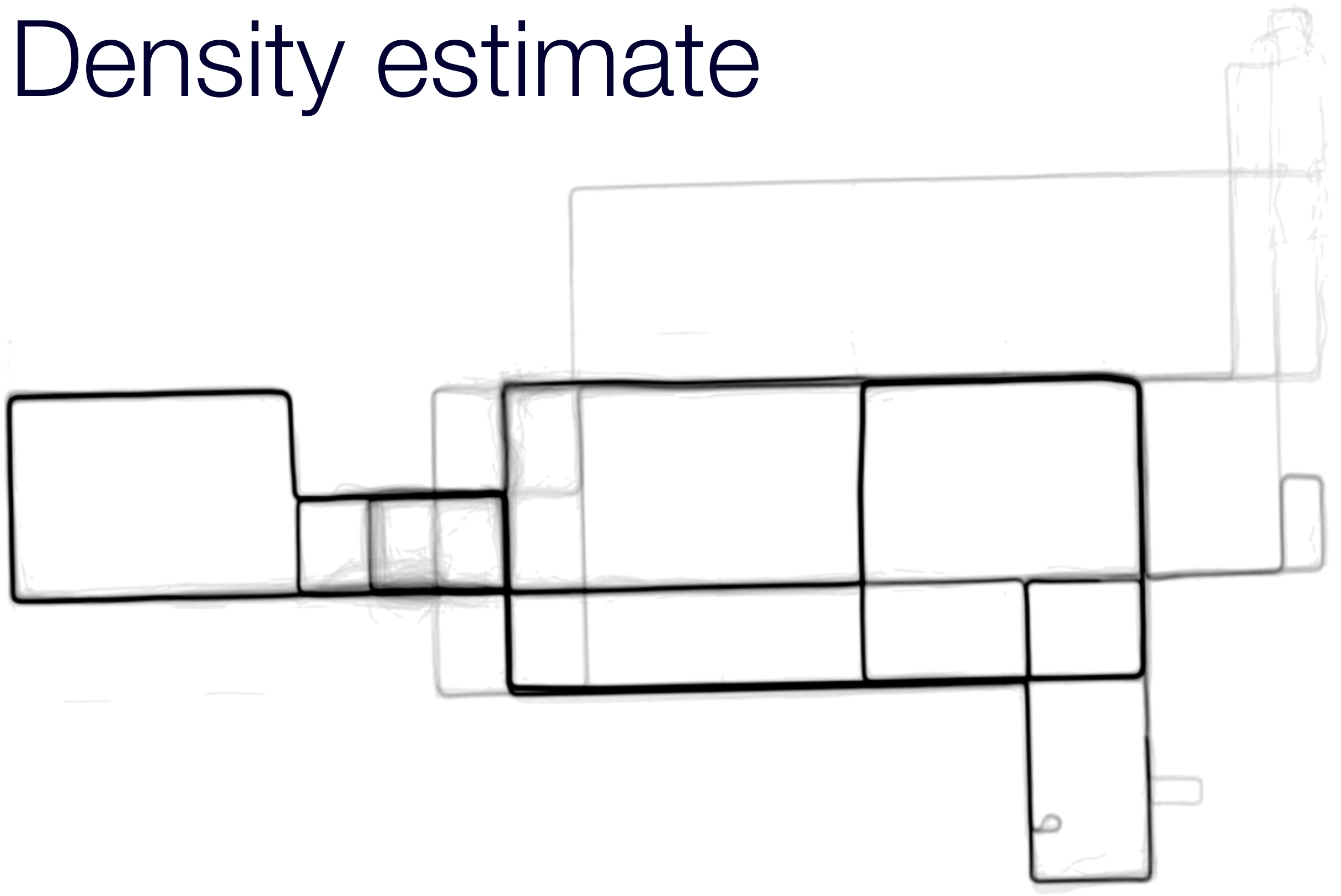
Raw GPS traces



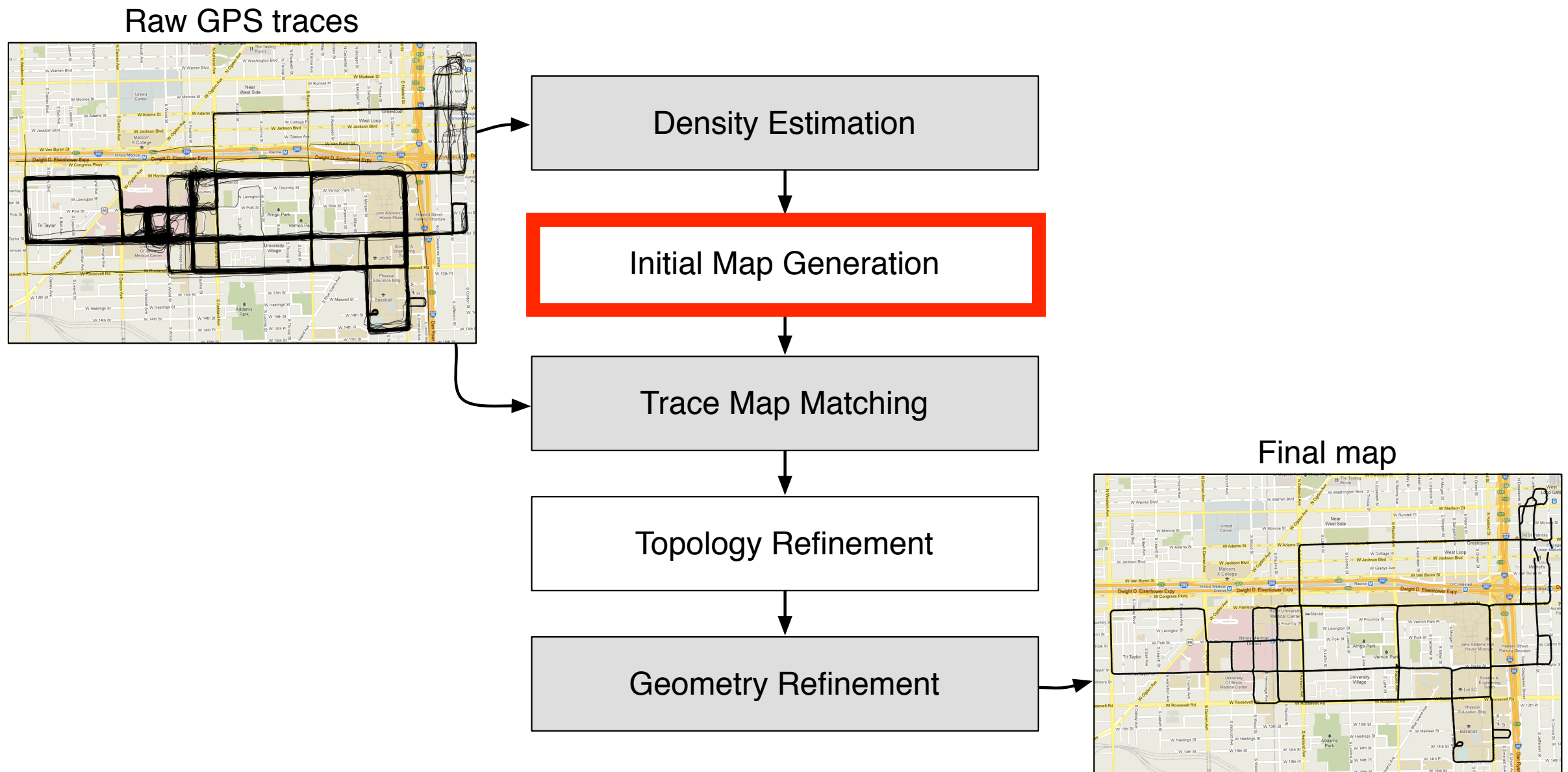
2-D histogram



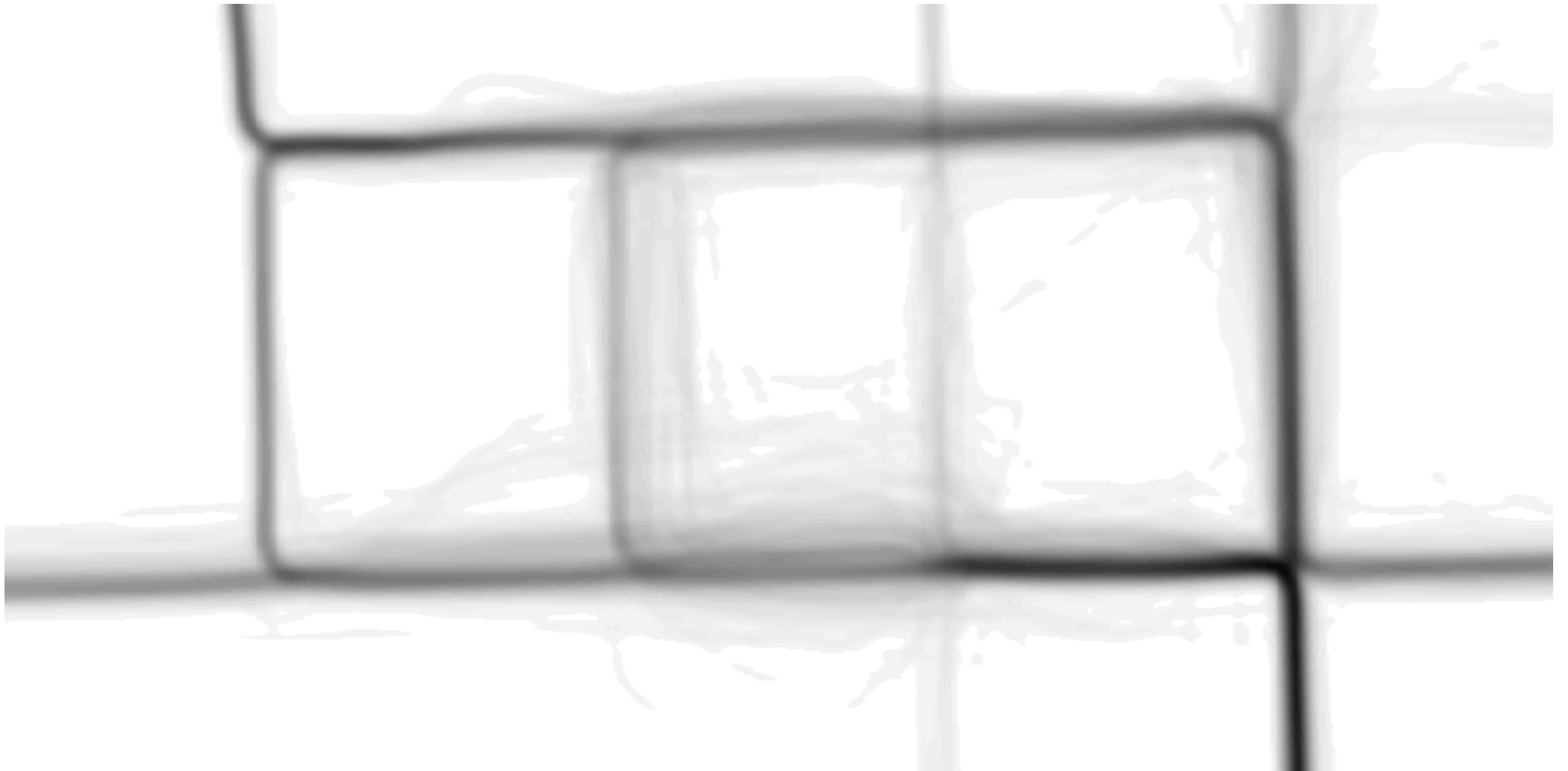
Density estimate



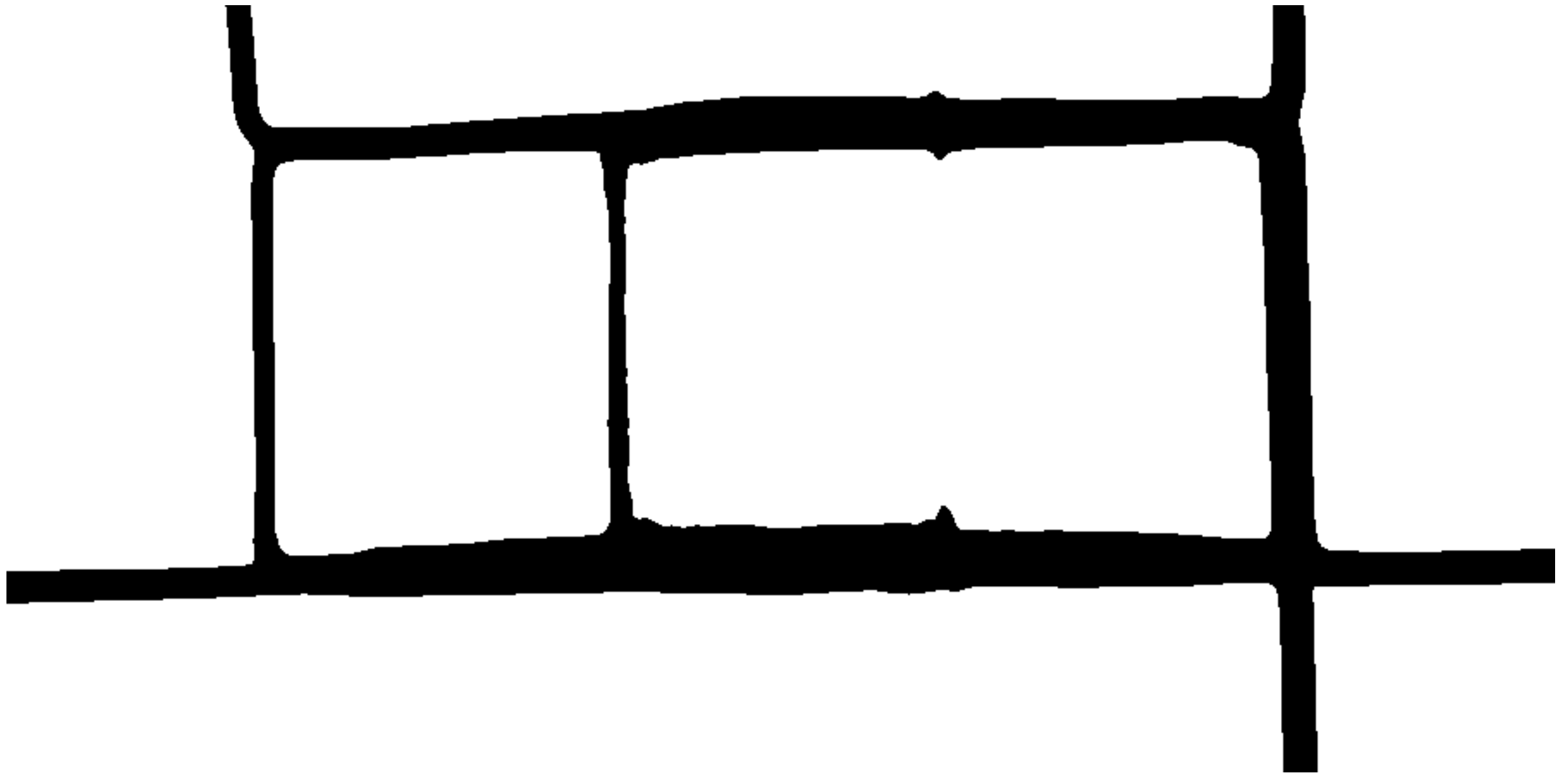
Map inference pipeline



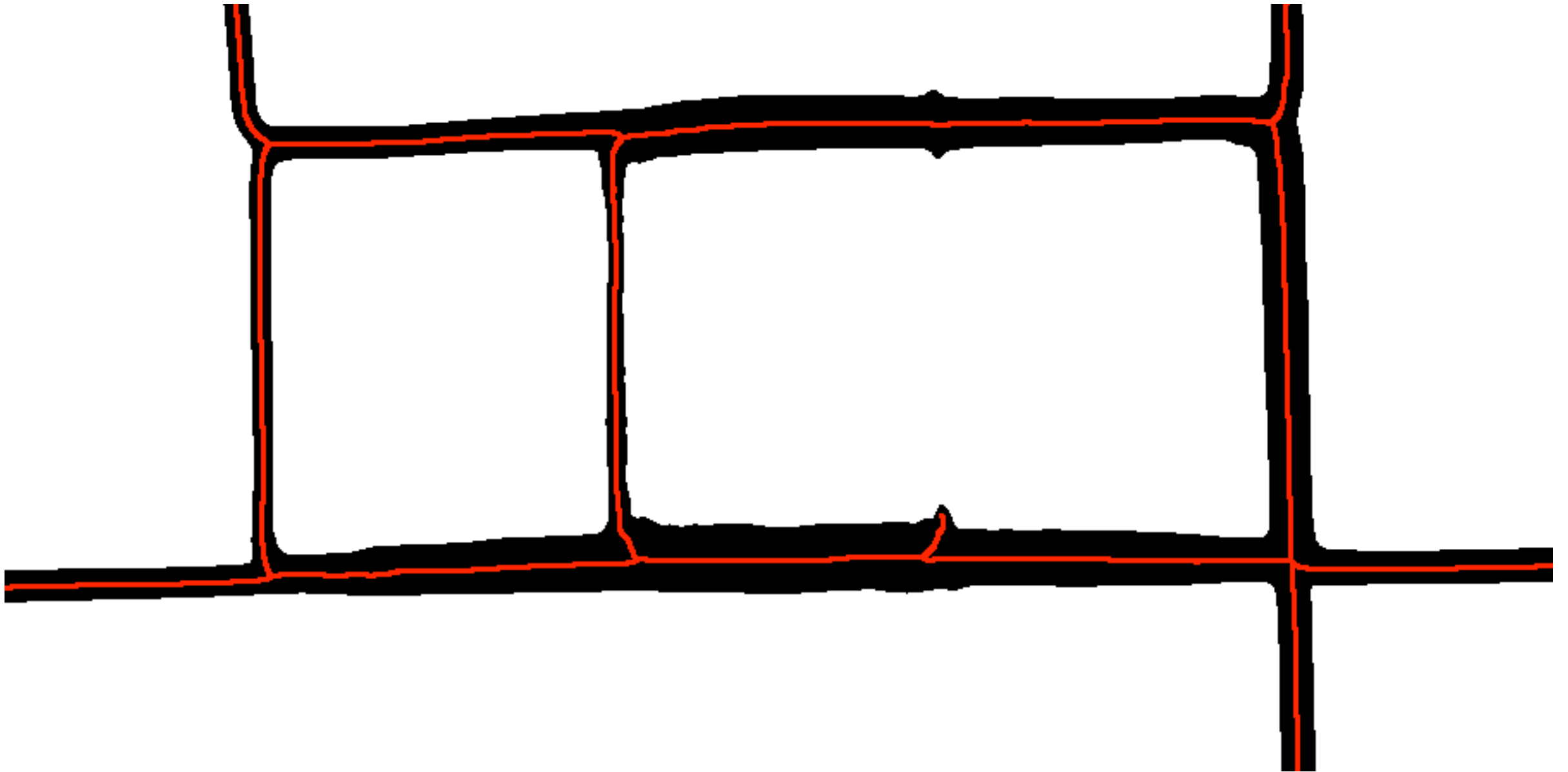
Density estimate



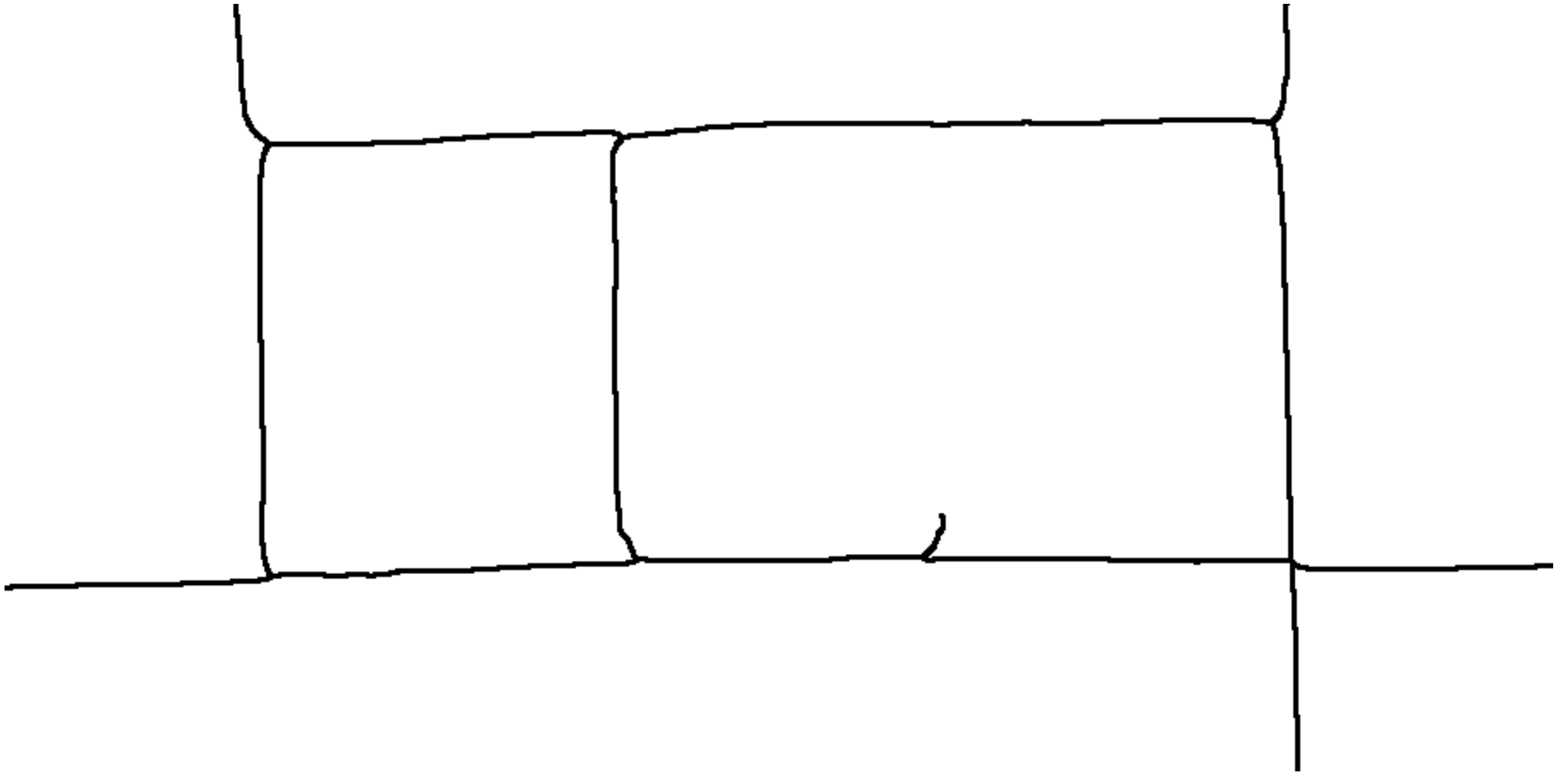
Apply (high) threshold



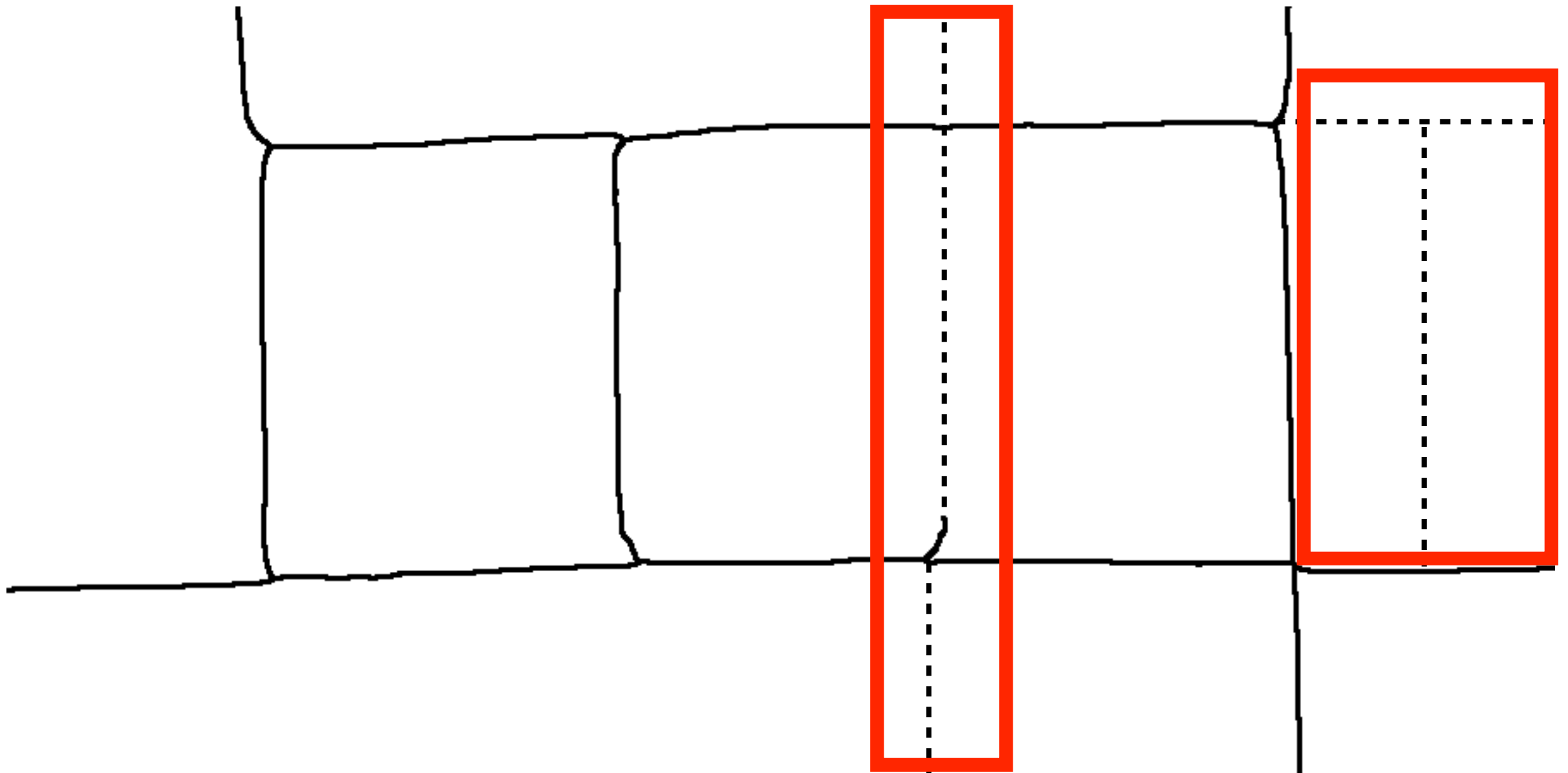
Binary skeletonization



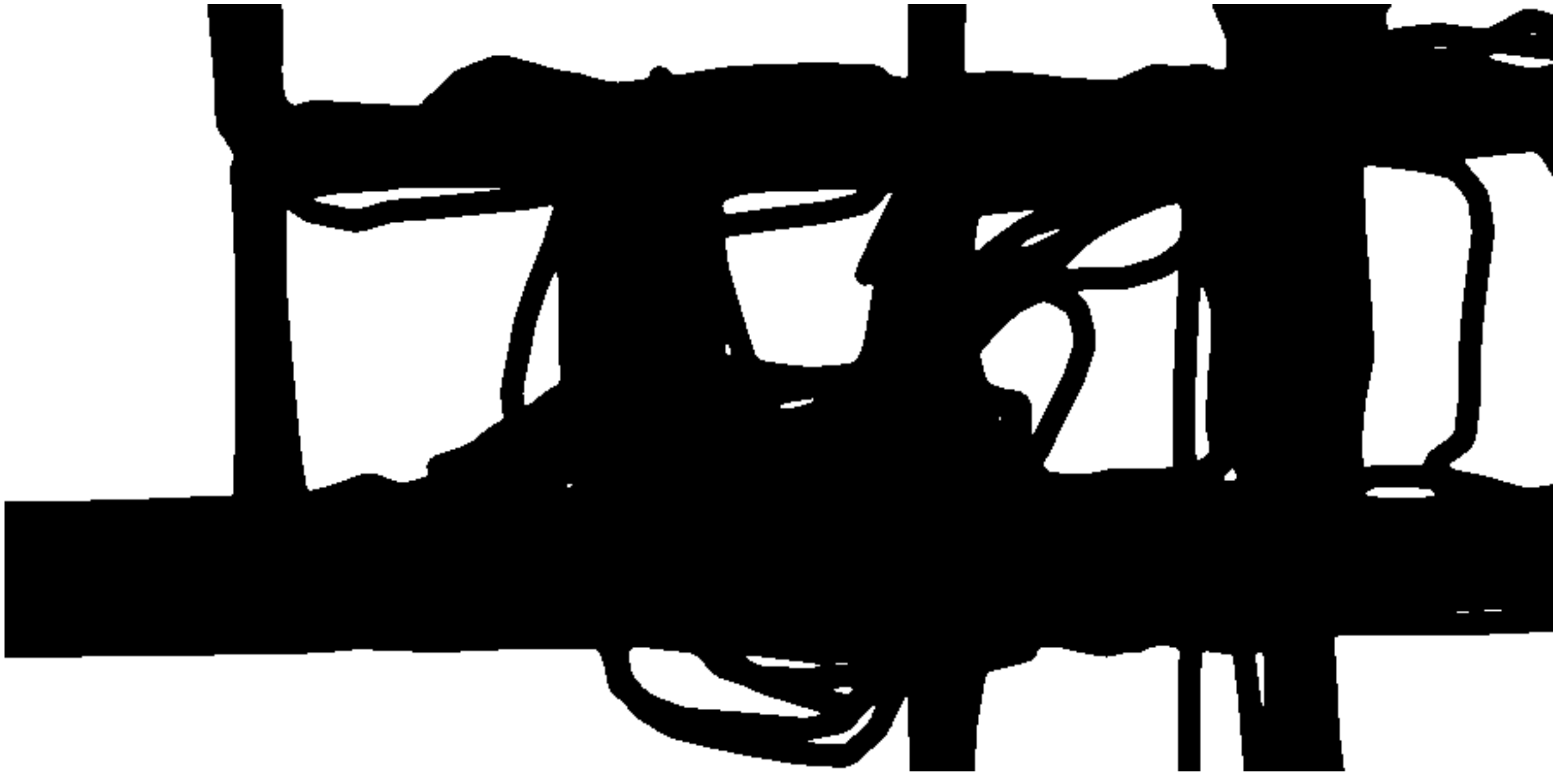
Generated map



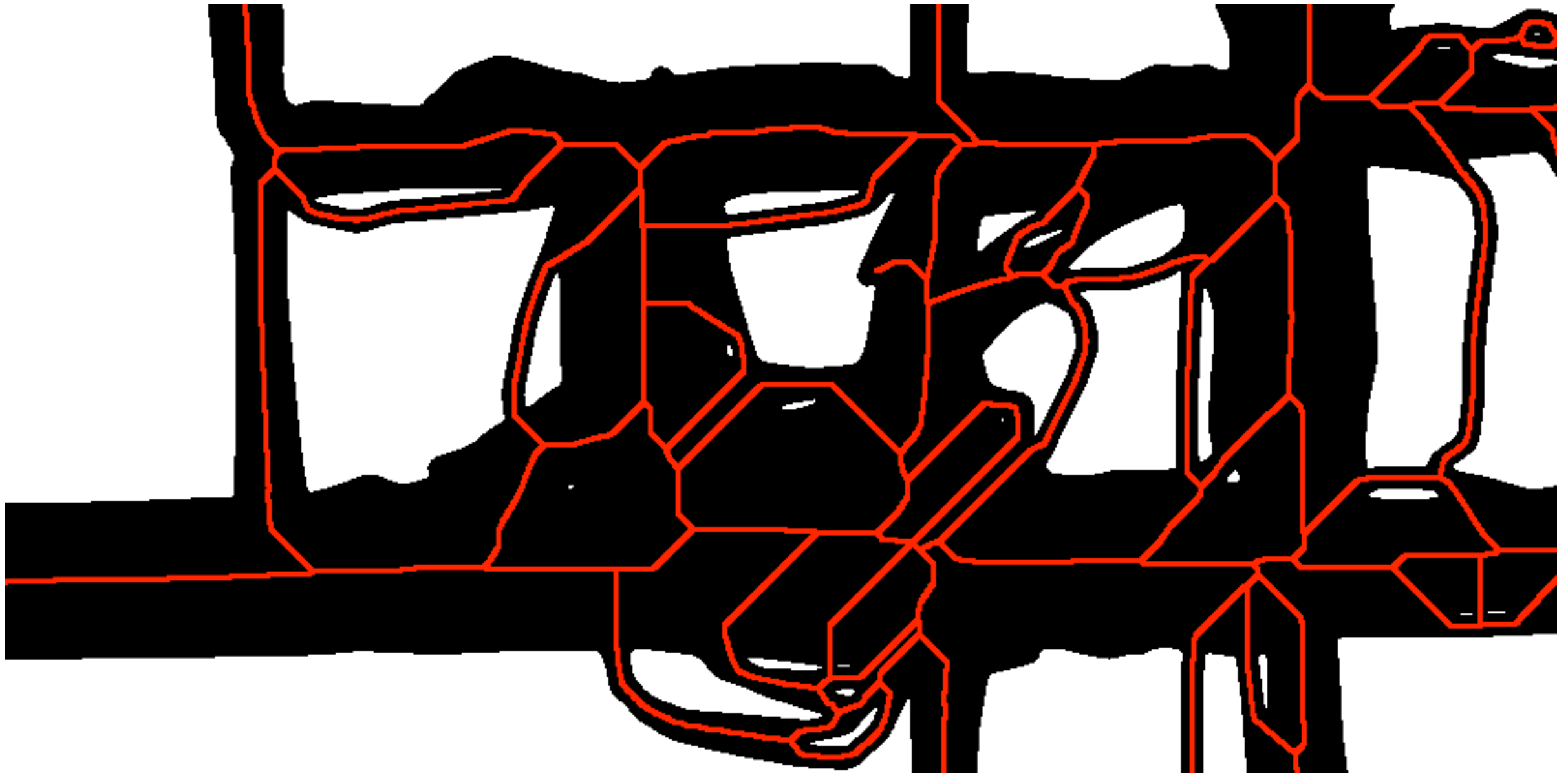
Generated map



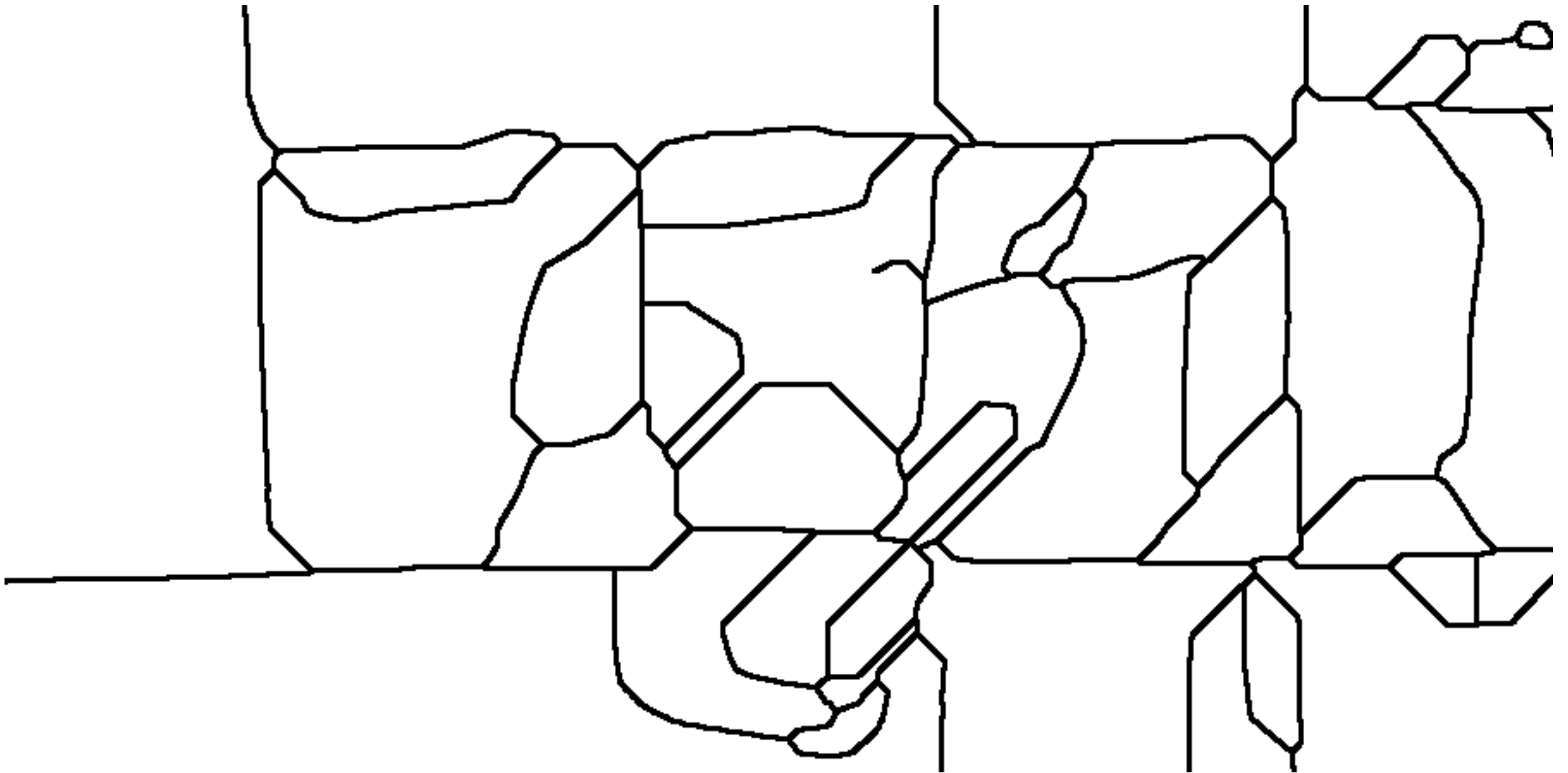
Apply (low) threshold



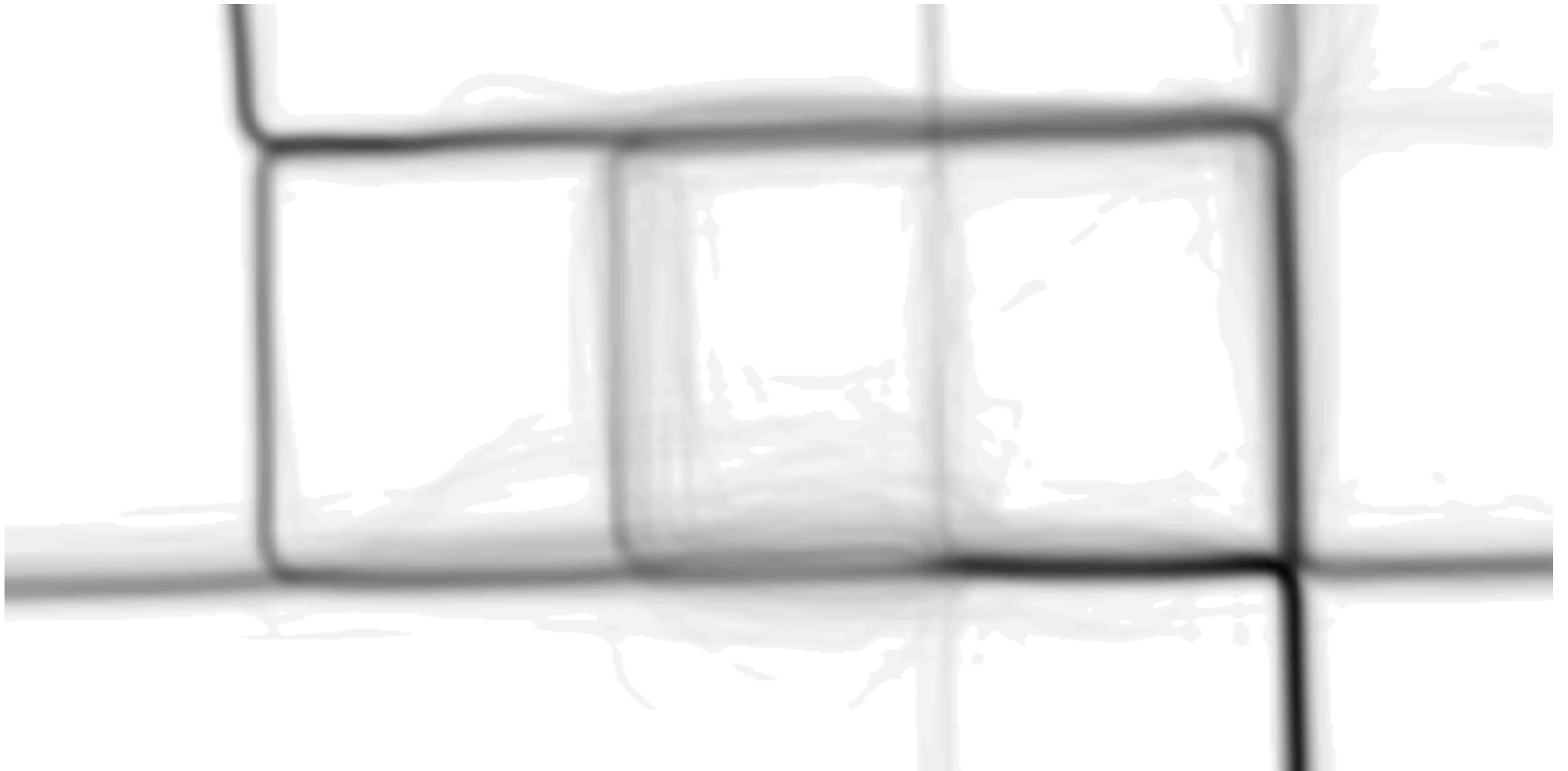
Binary skeletonization



Generated map



Grayscale skeletonization



1) Threshold



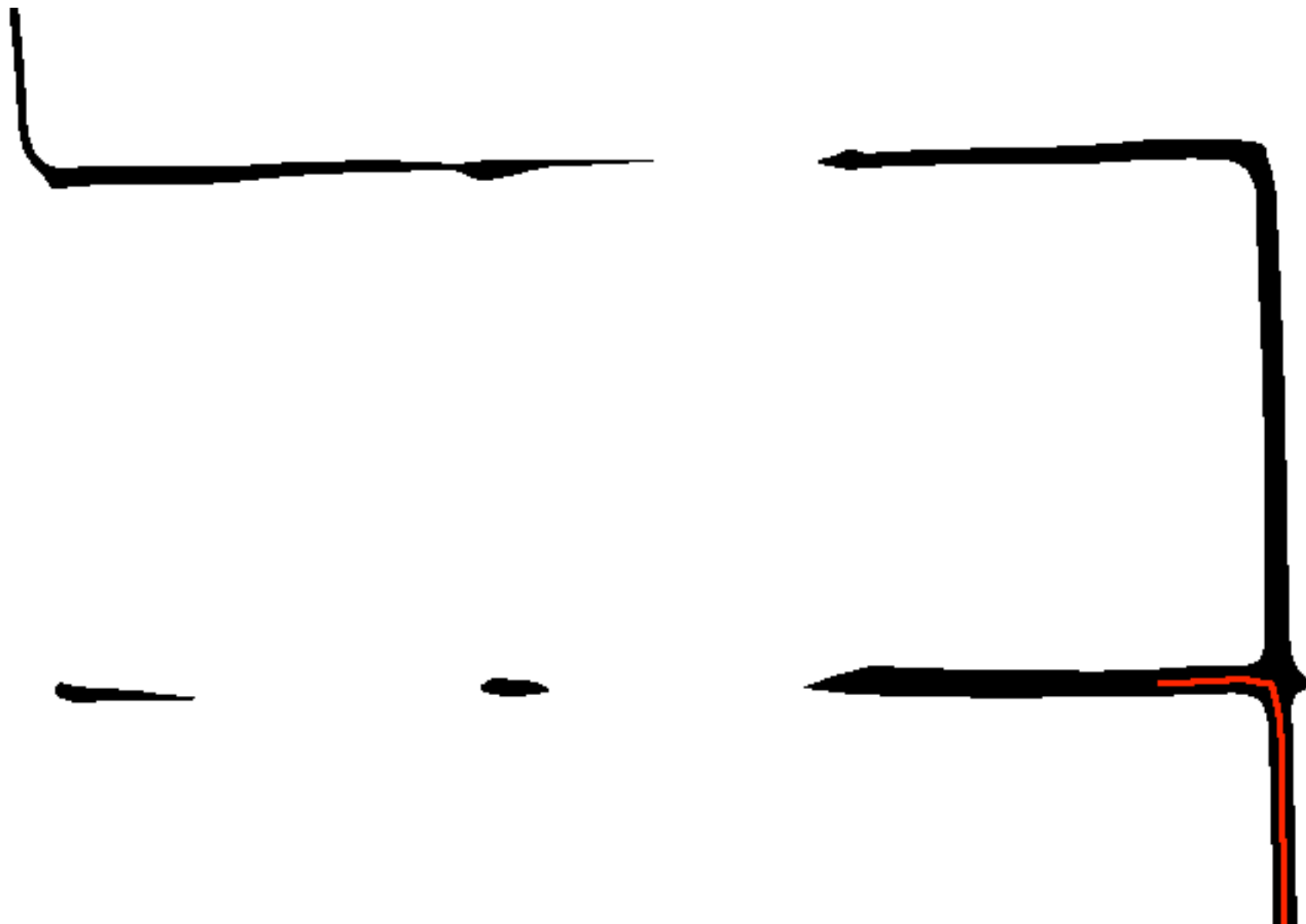
2) Skeletonize



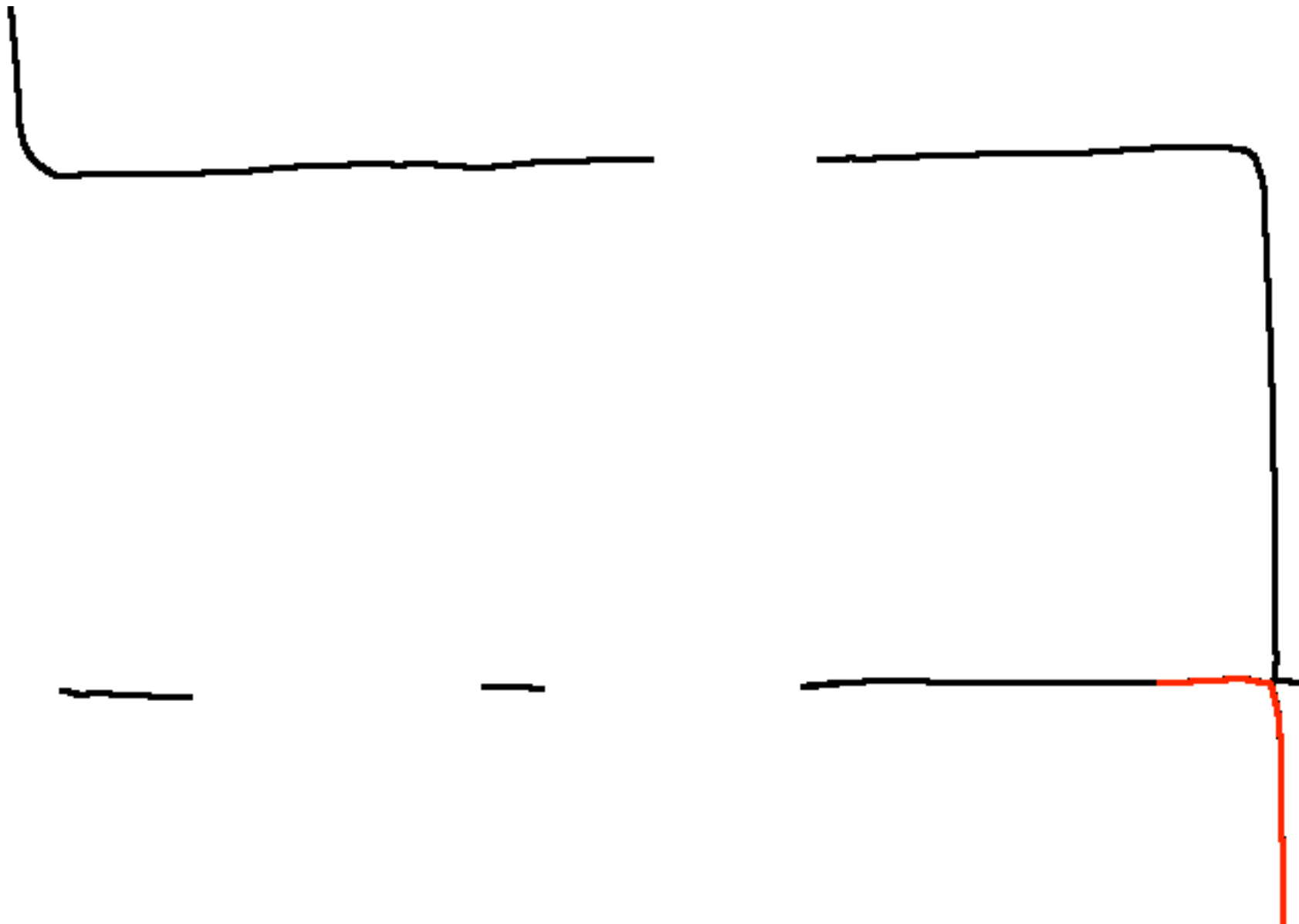
3) “Lock in”



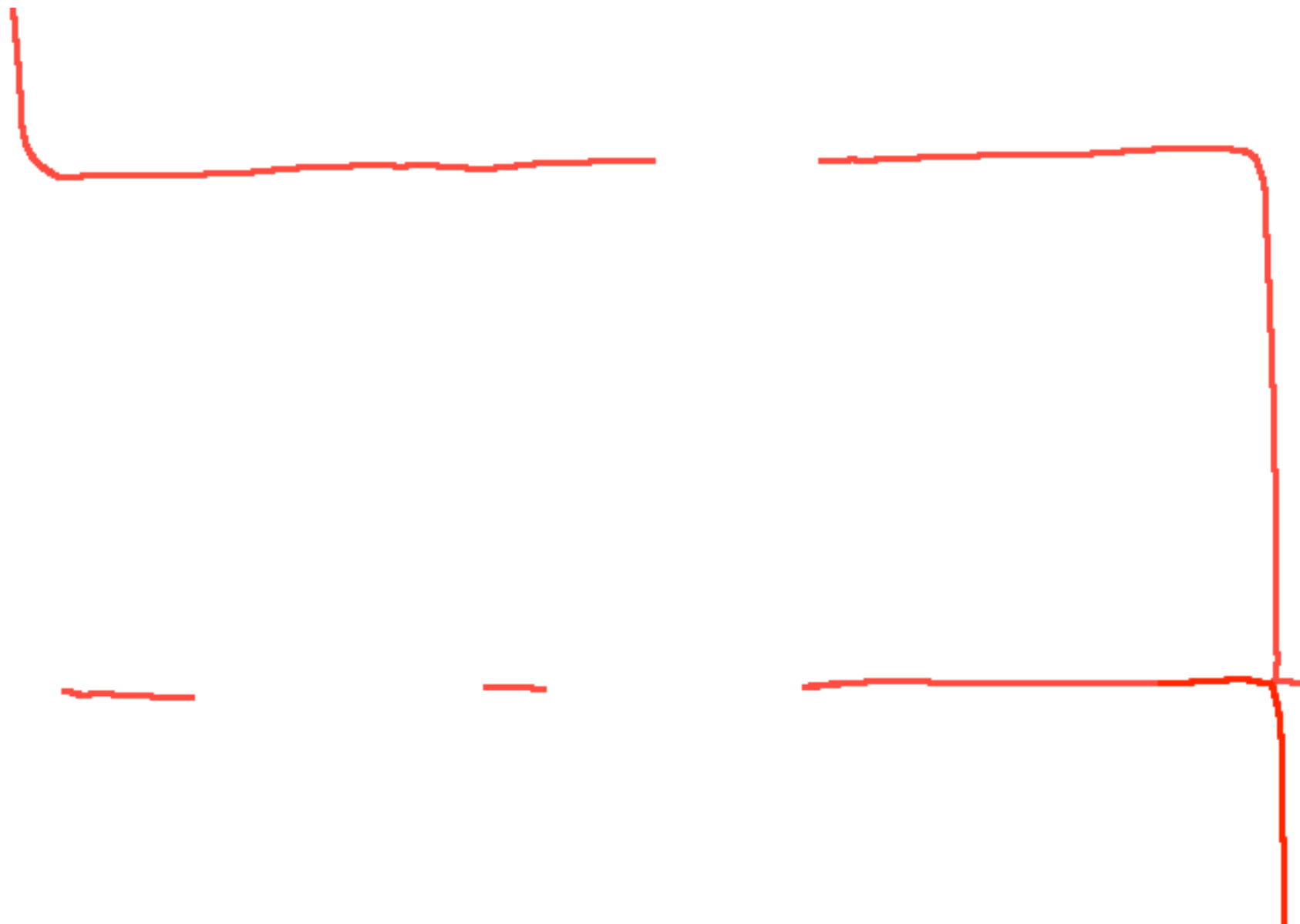
1) Threshold



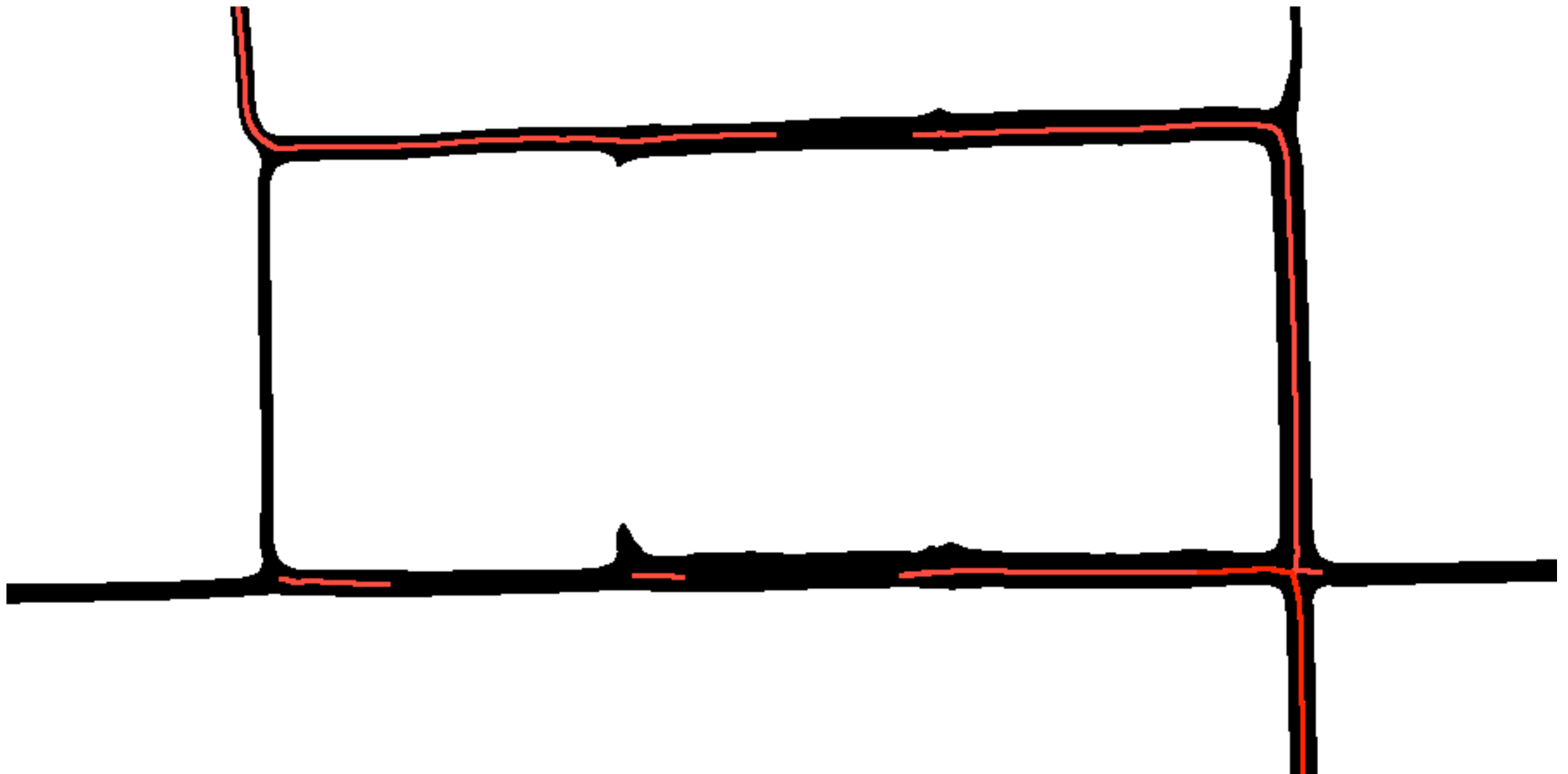
2) Skeletonize



3) “Lock in”



1) Threshold



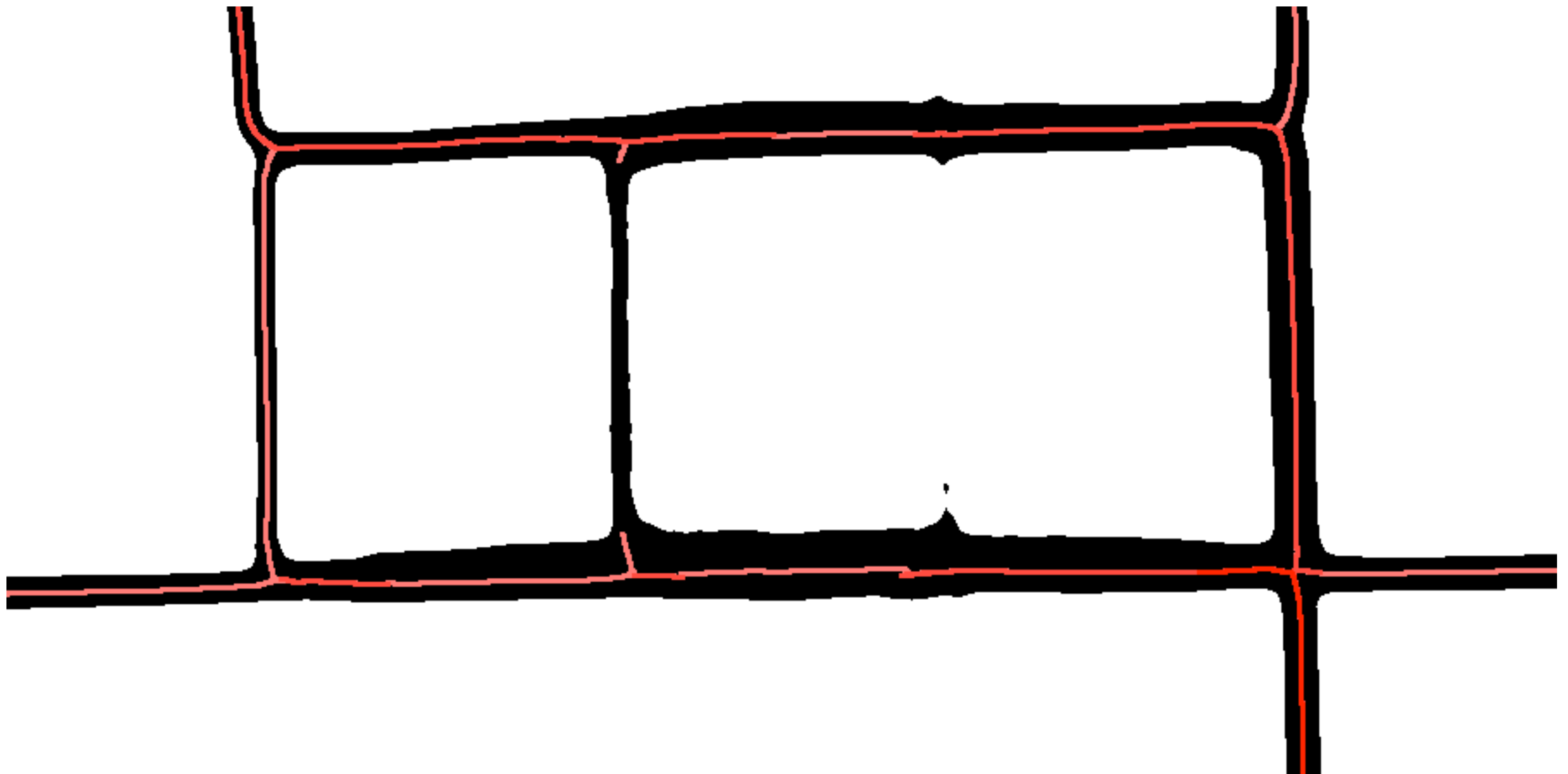
2) Skeletonize



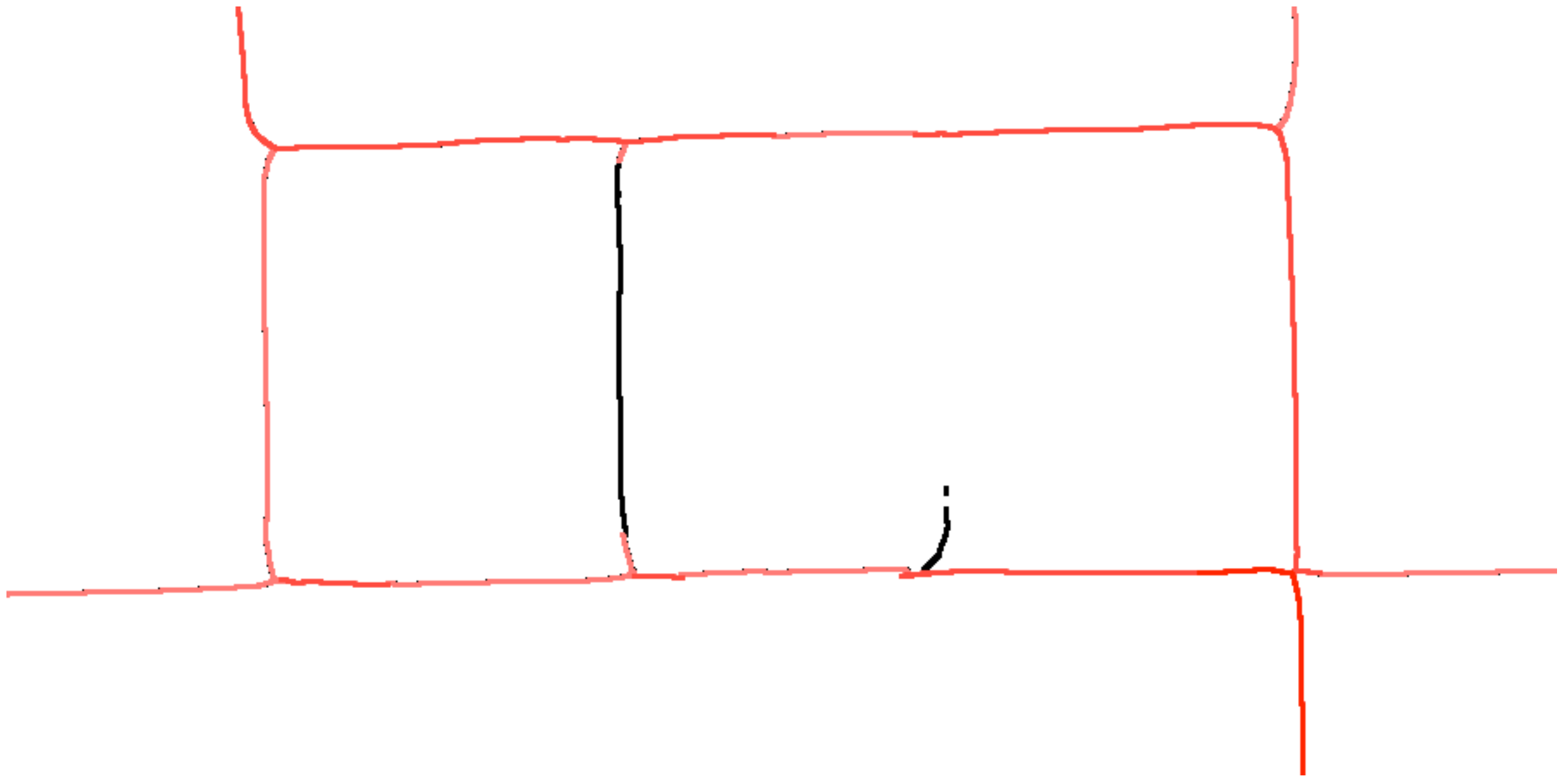
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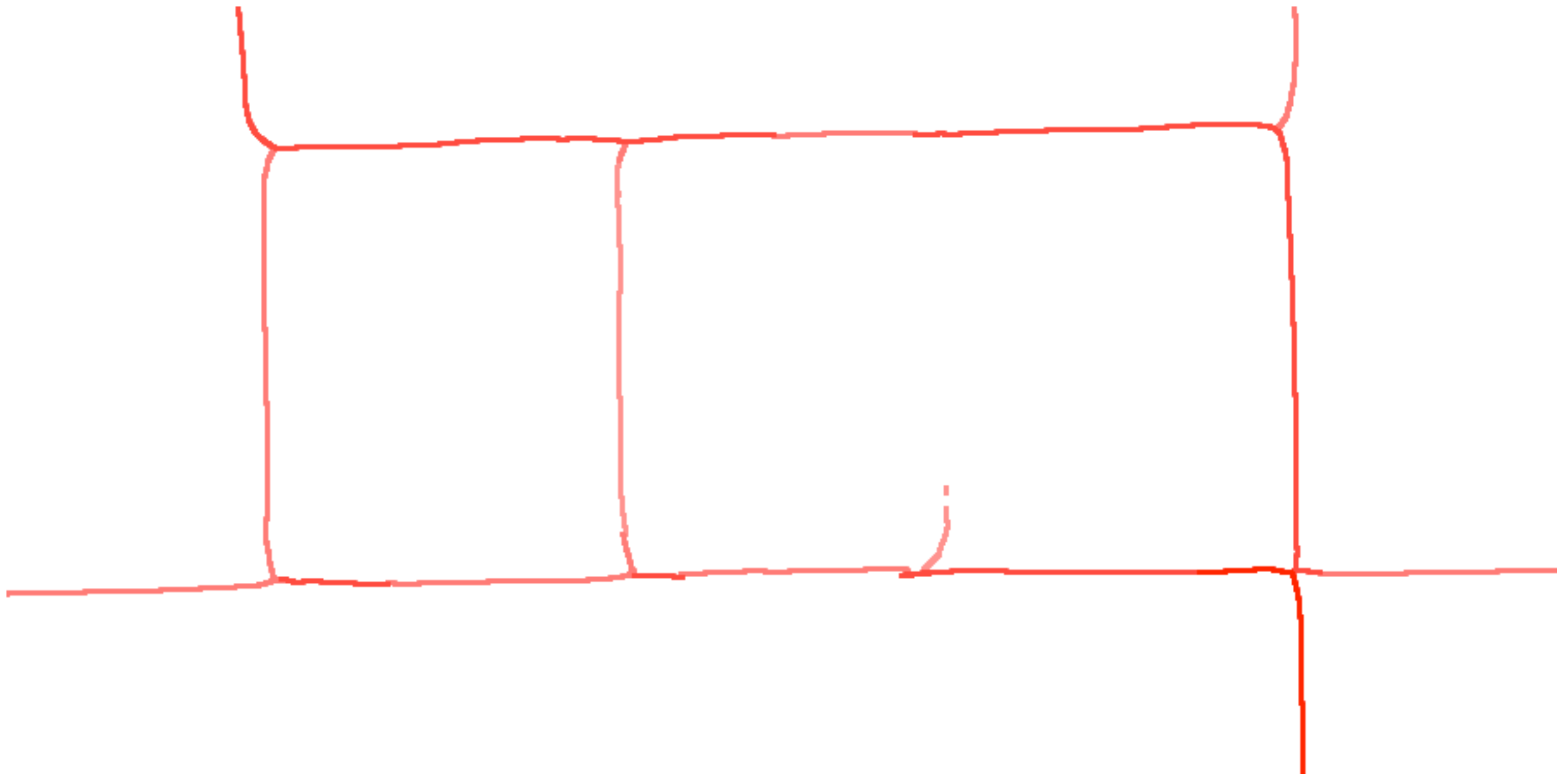
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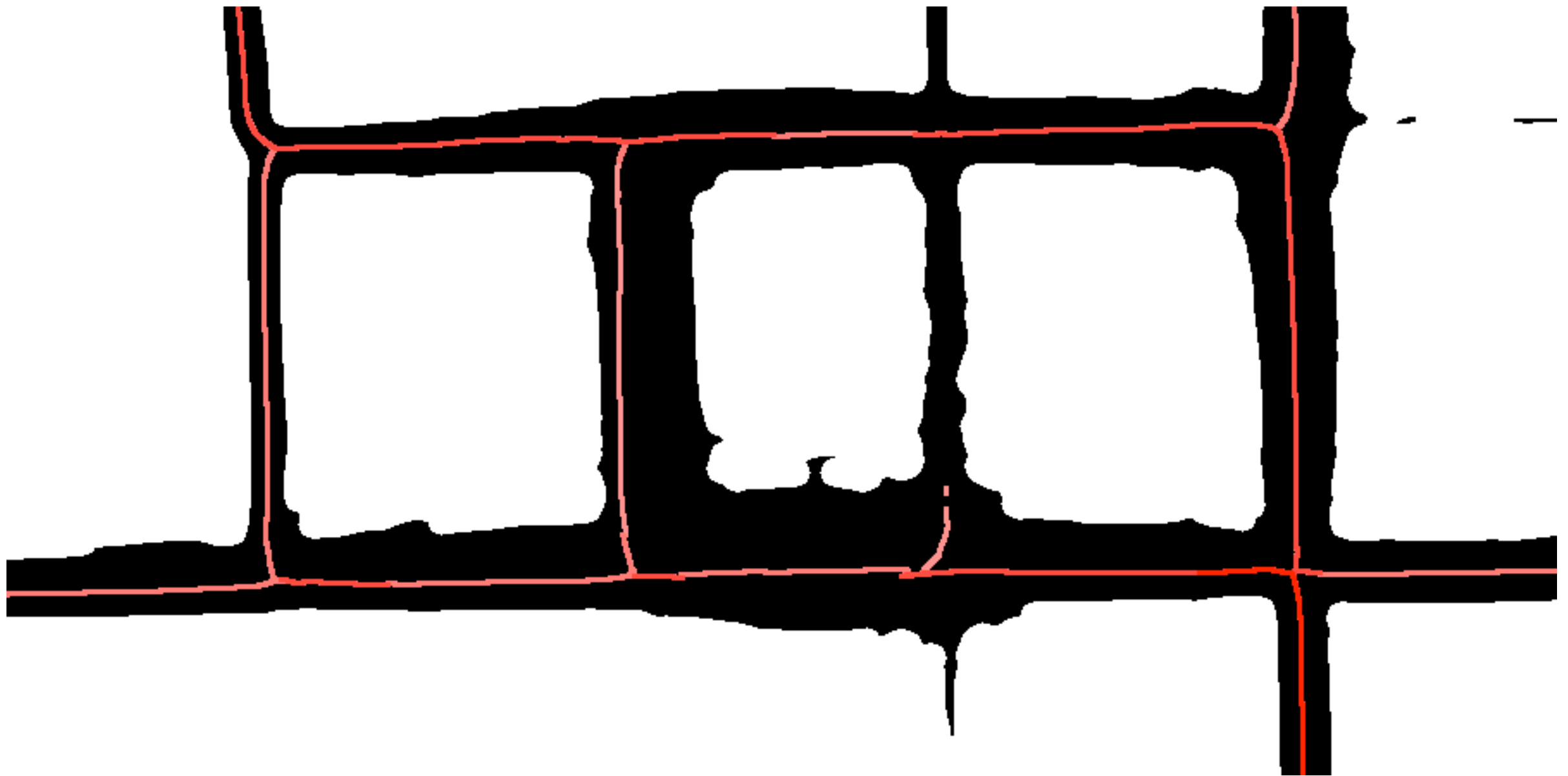
2) Skeletonize



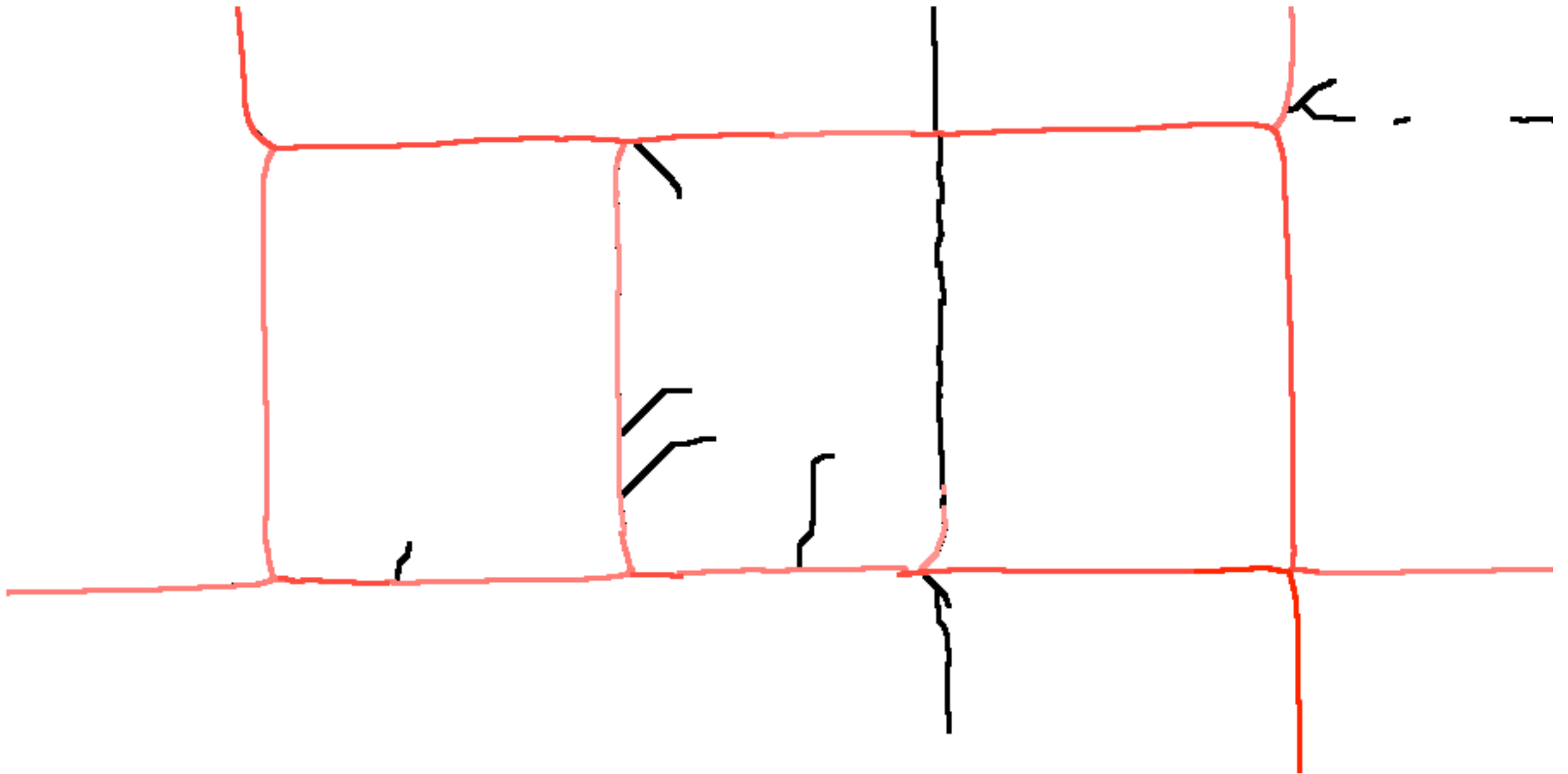
3) “Lock in”



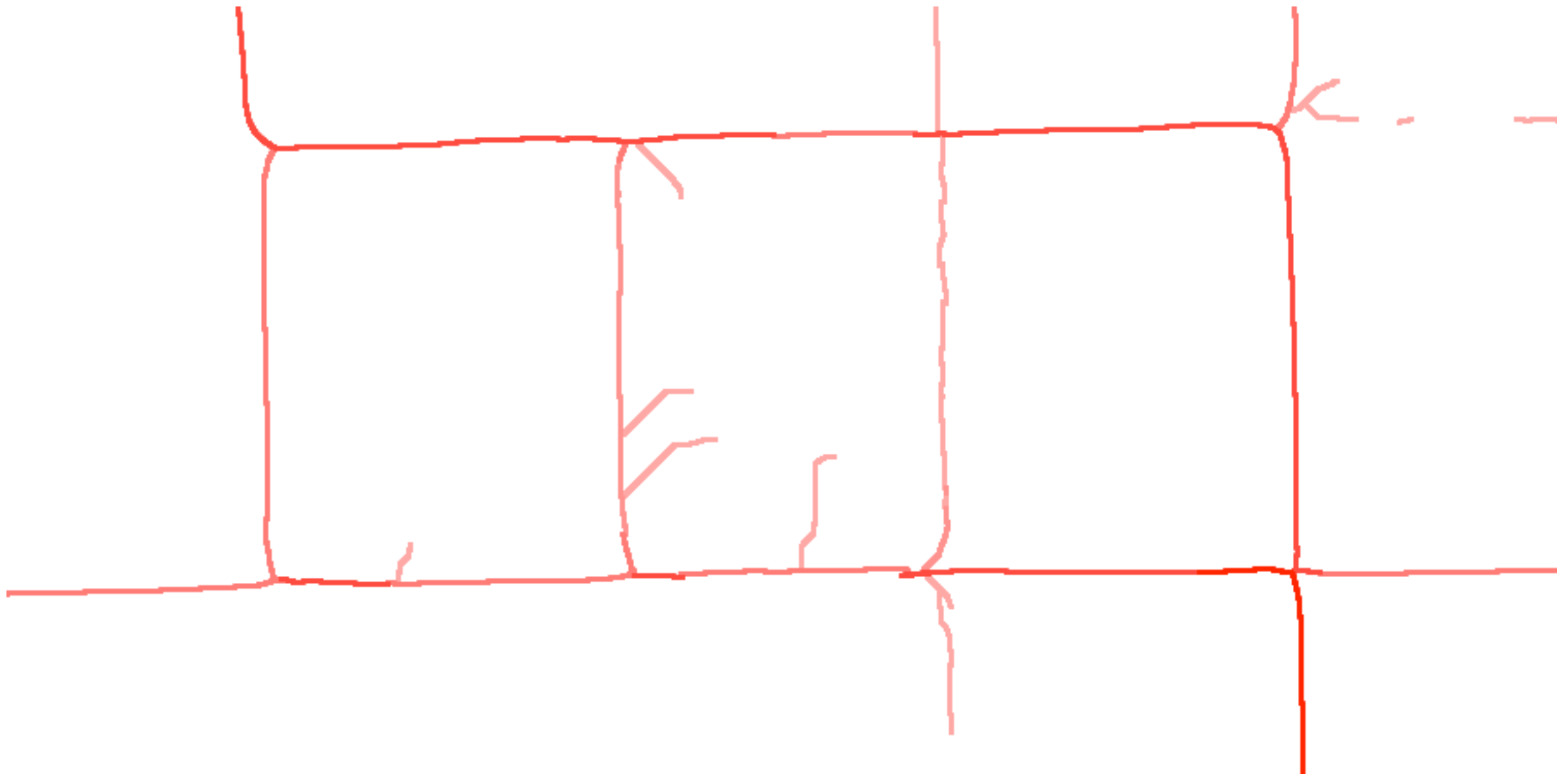
1) Threshold



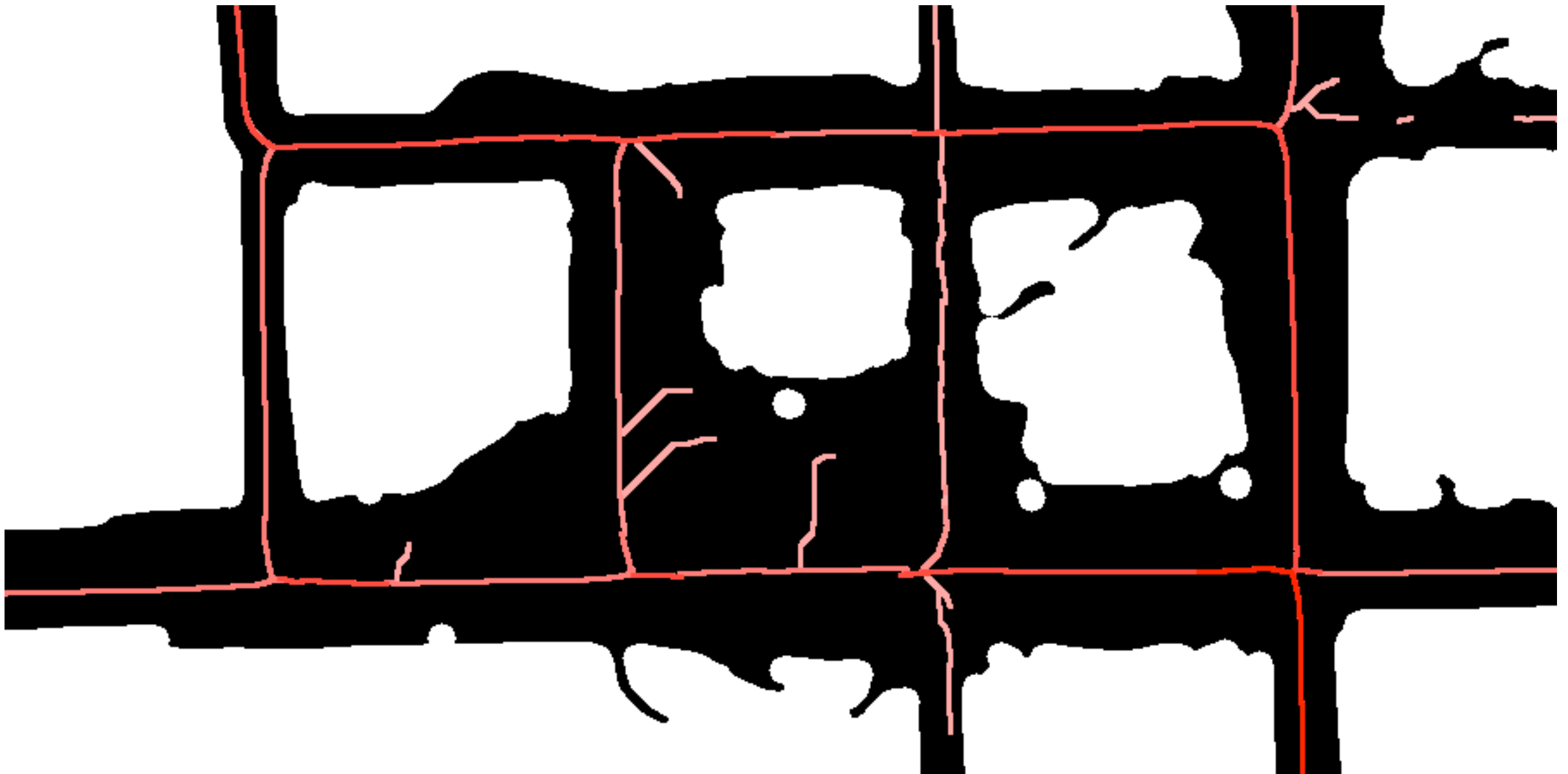
2) Skeletonize



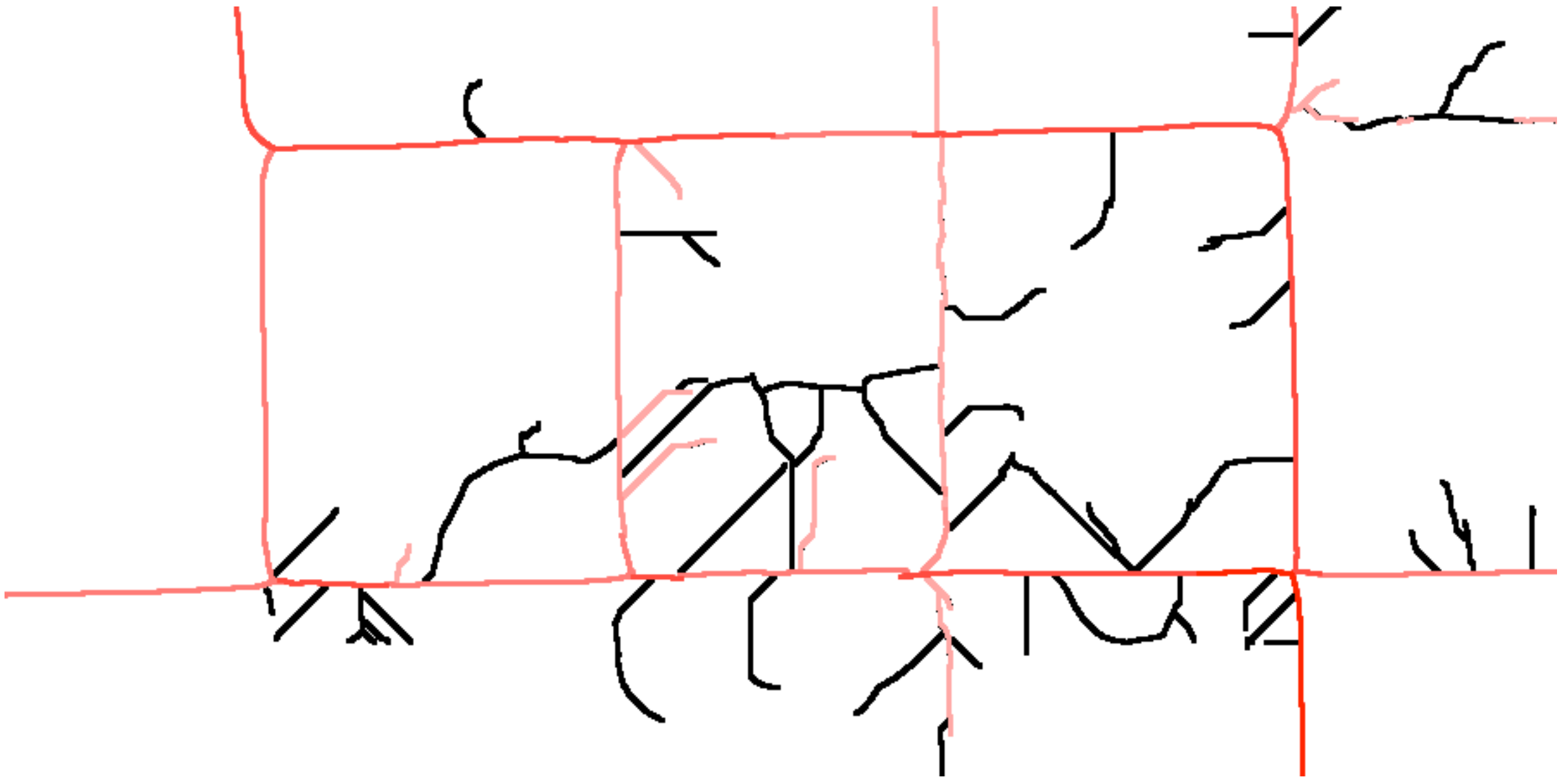
3) “Lock in”



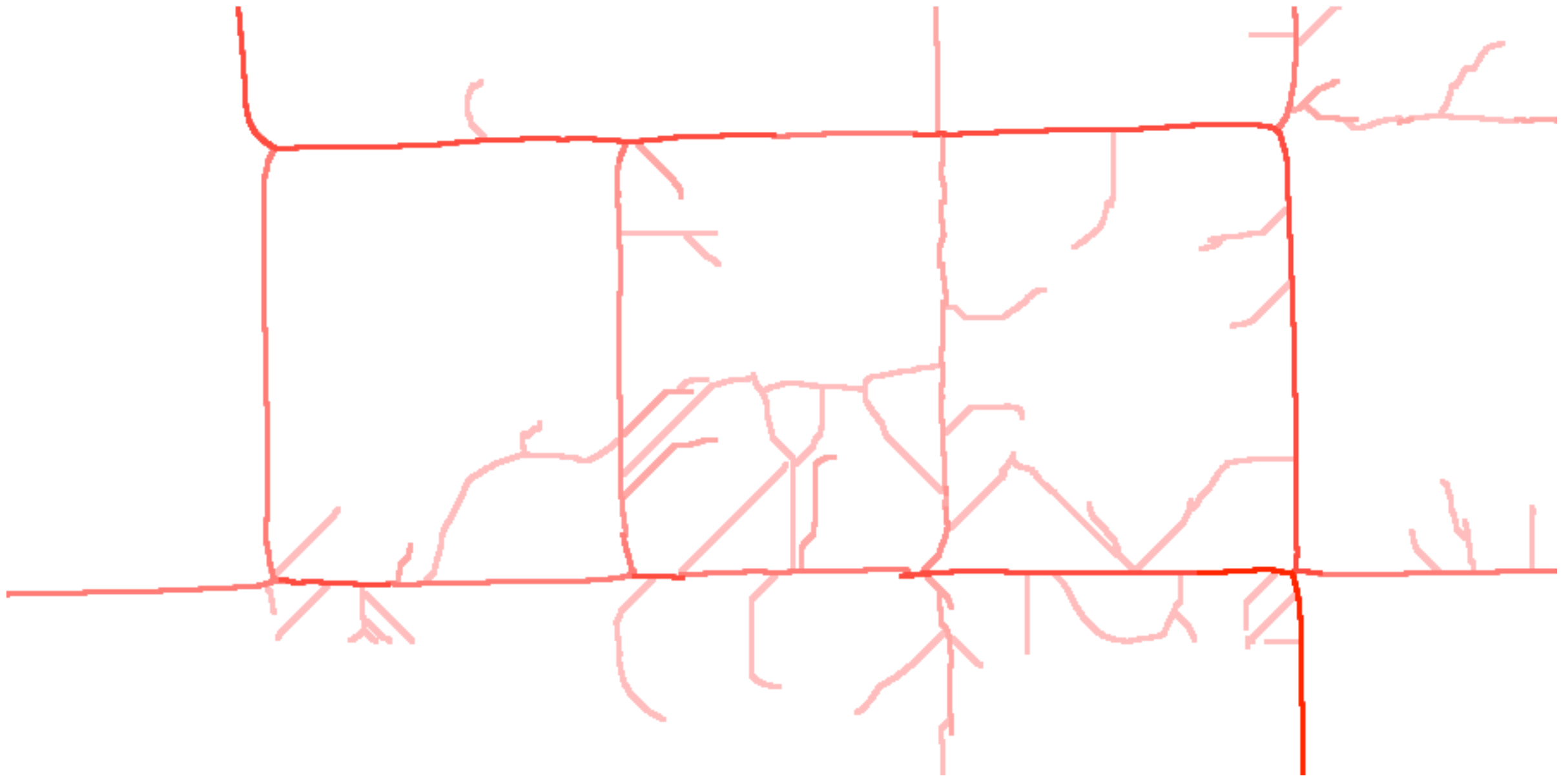
1) Threshold



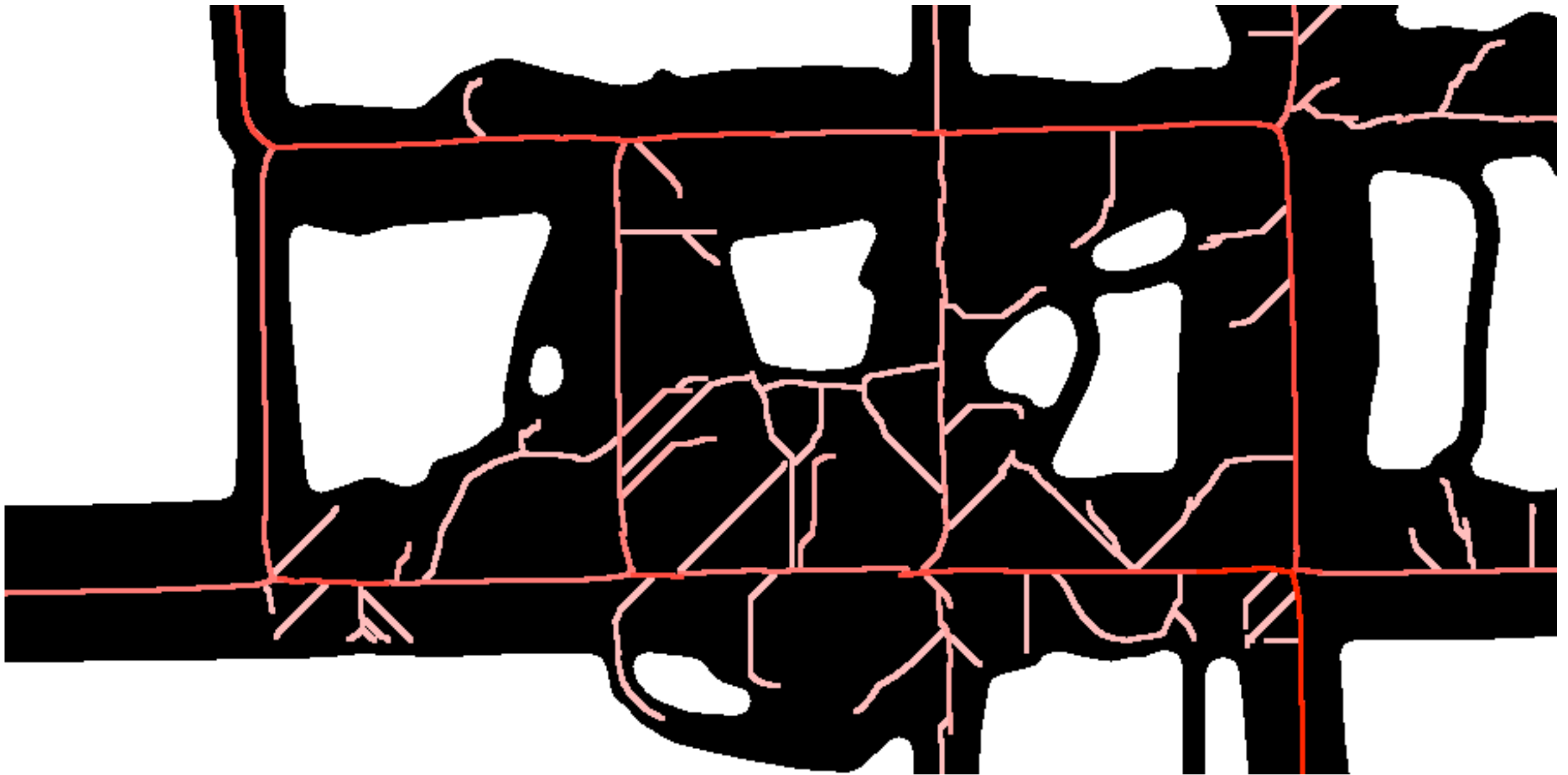
2) Skeletonize



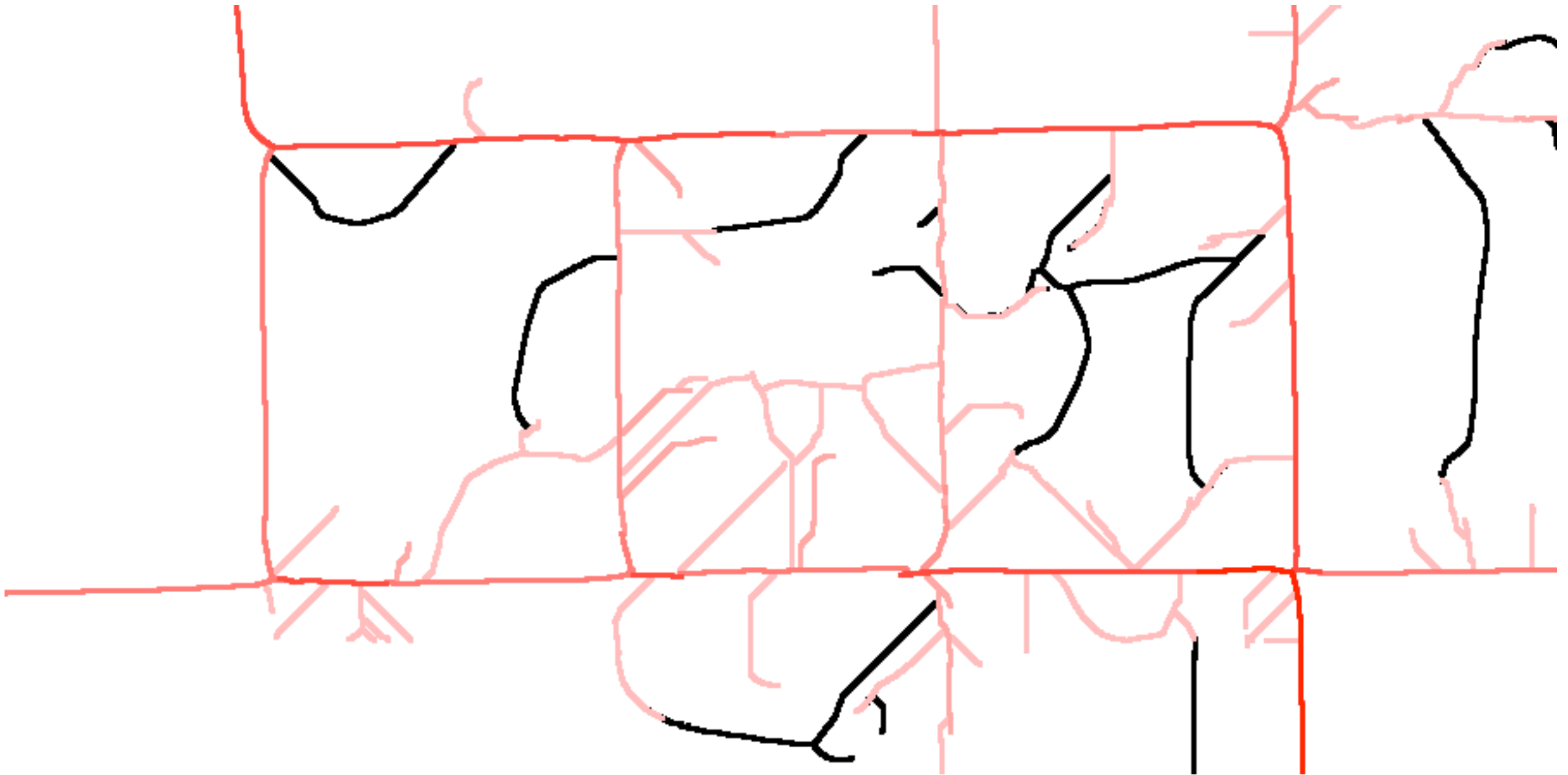
3) “Lock in”



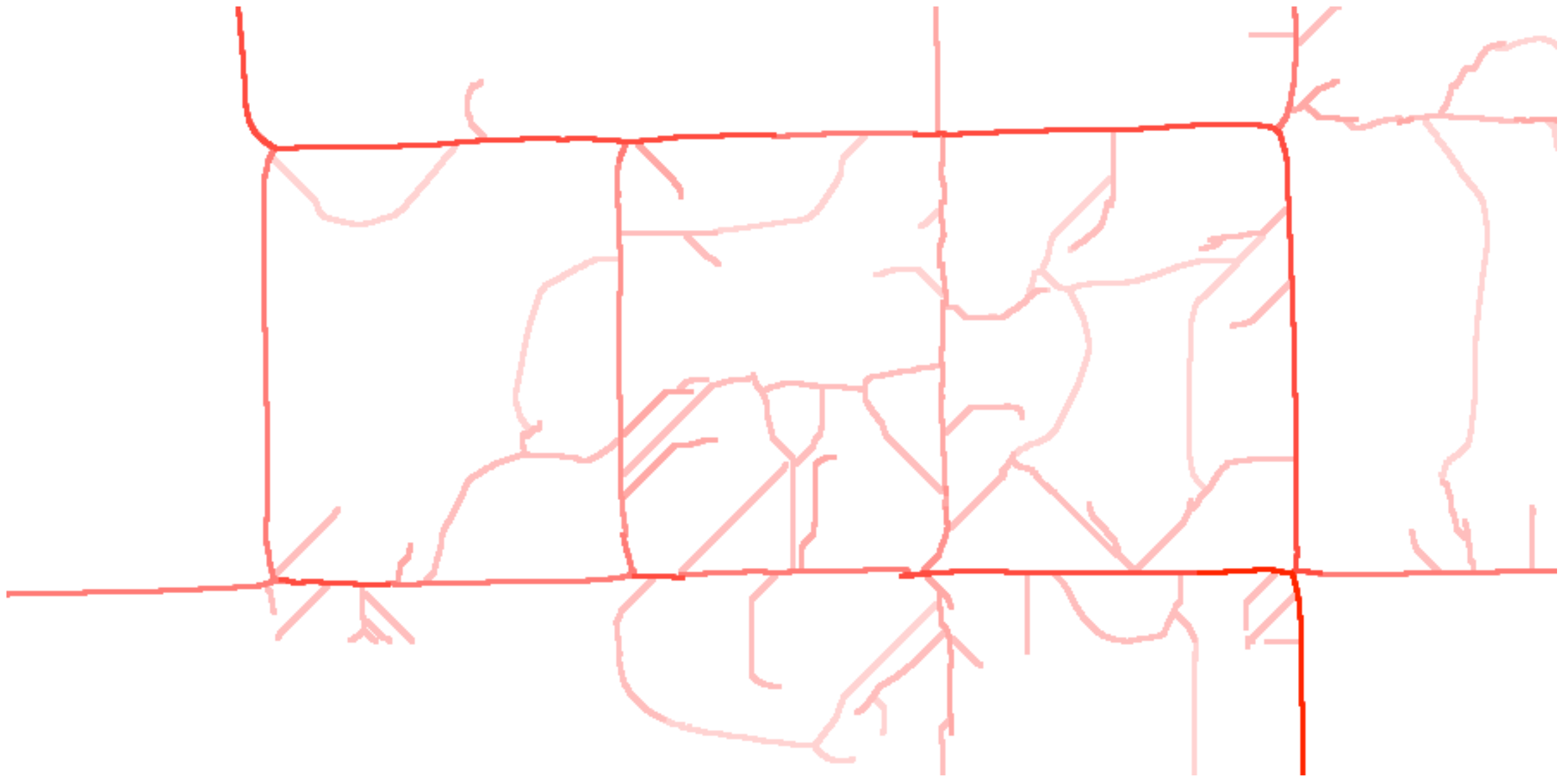
1) Threshold



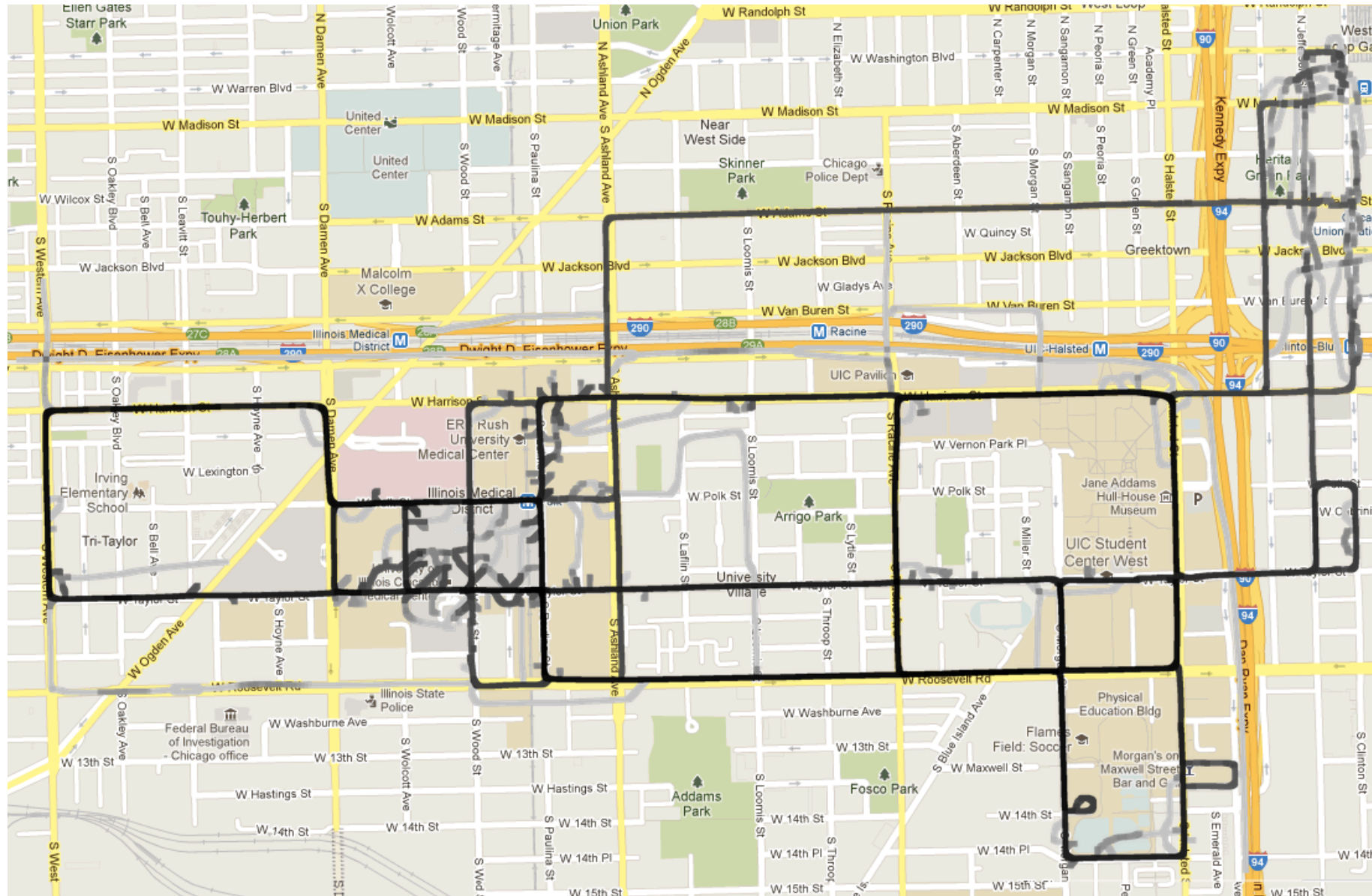
2) Skeletonize



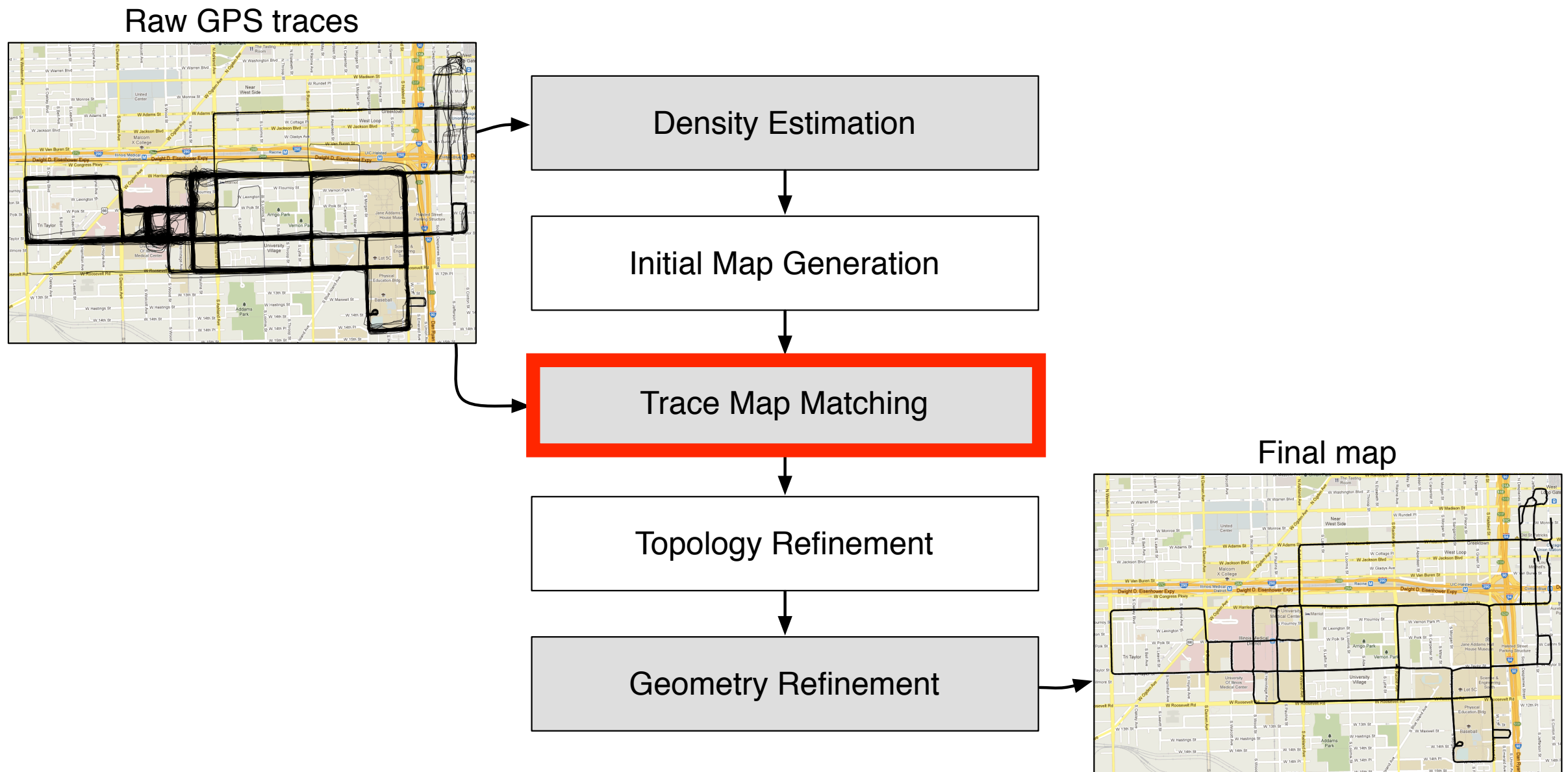
3) “Lock in”



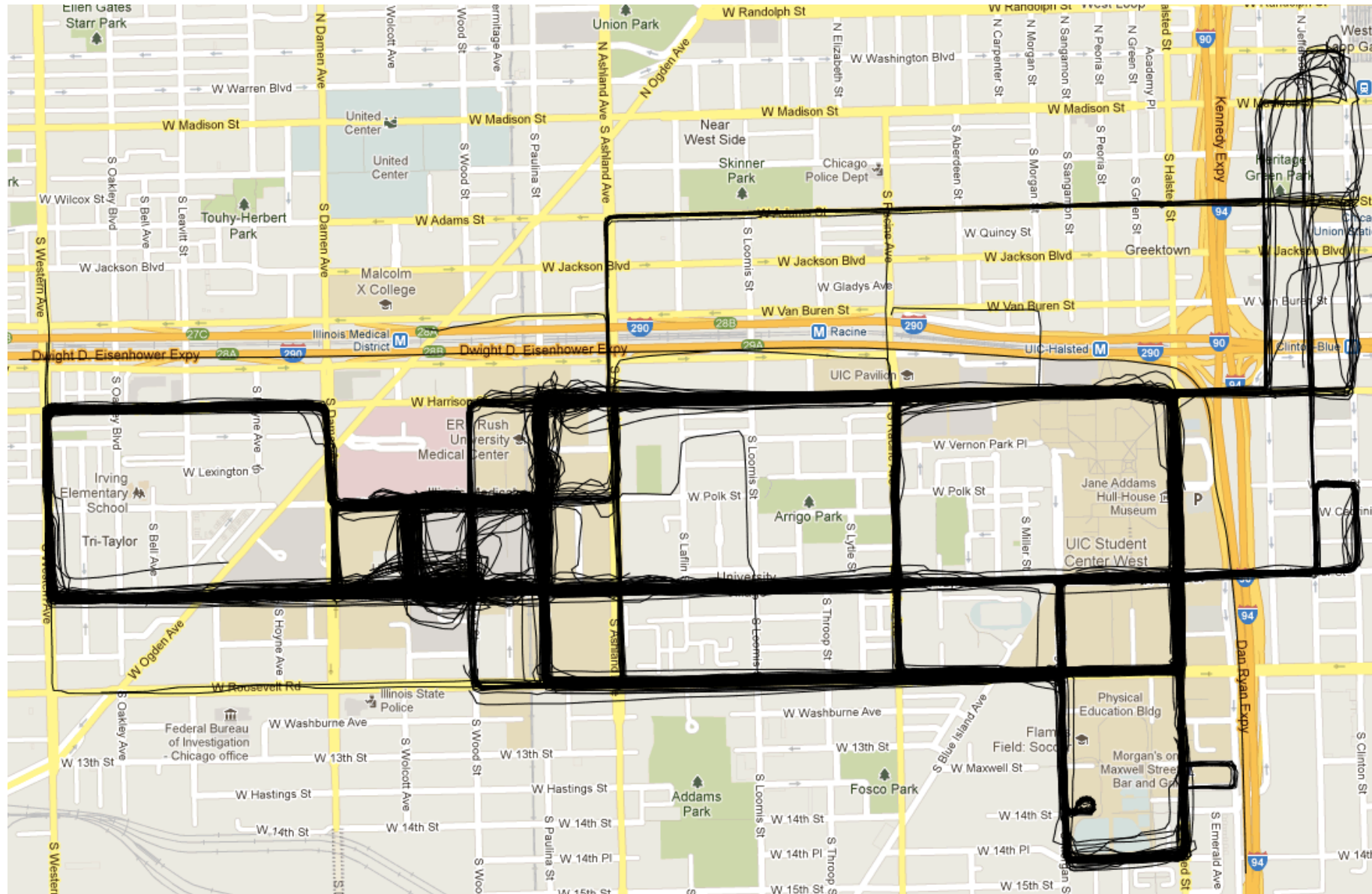
Initial generated map



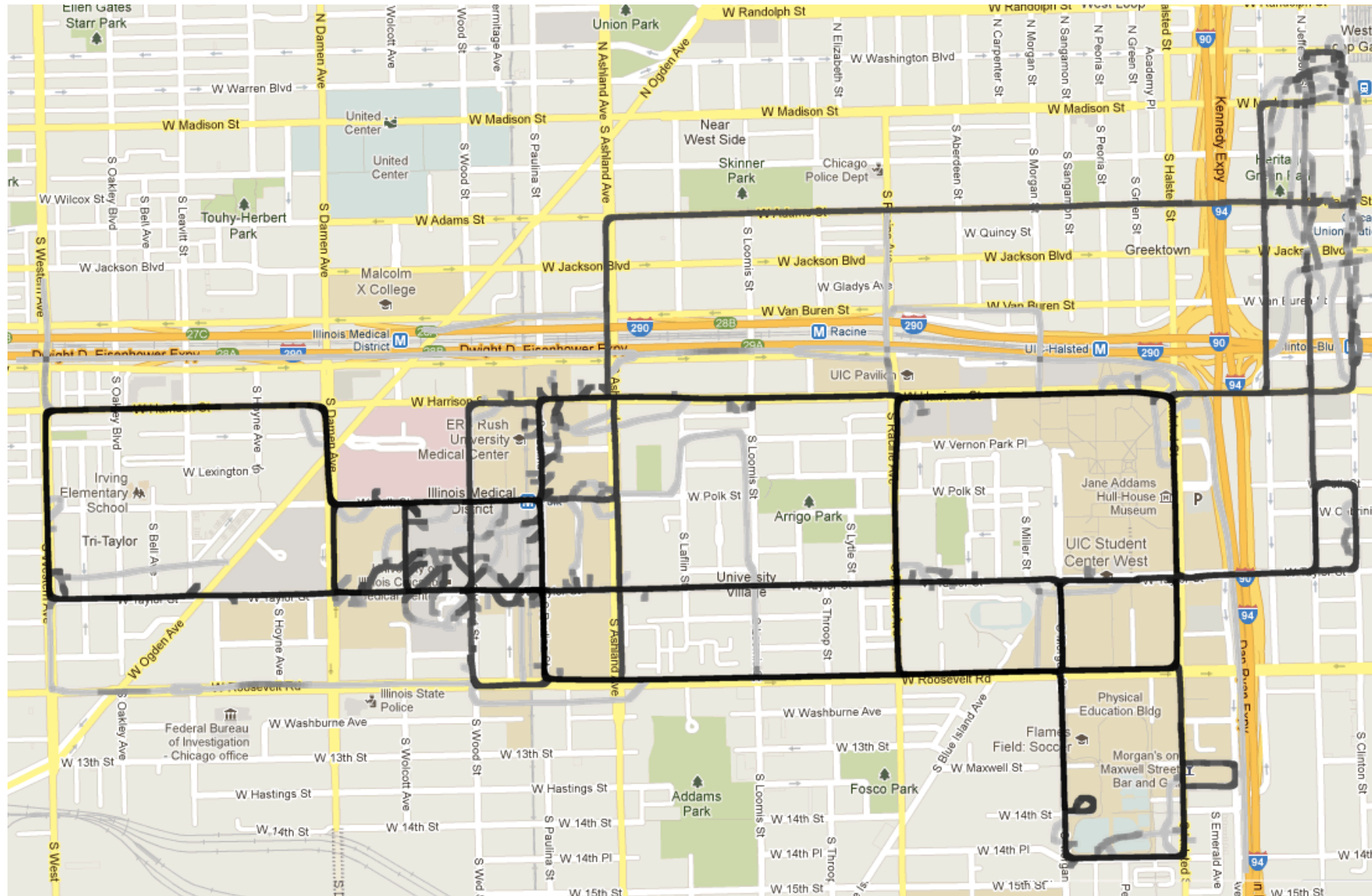
Map inference pipeline



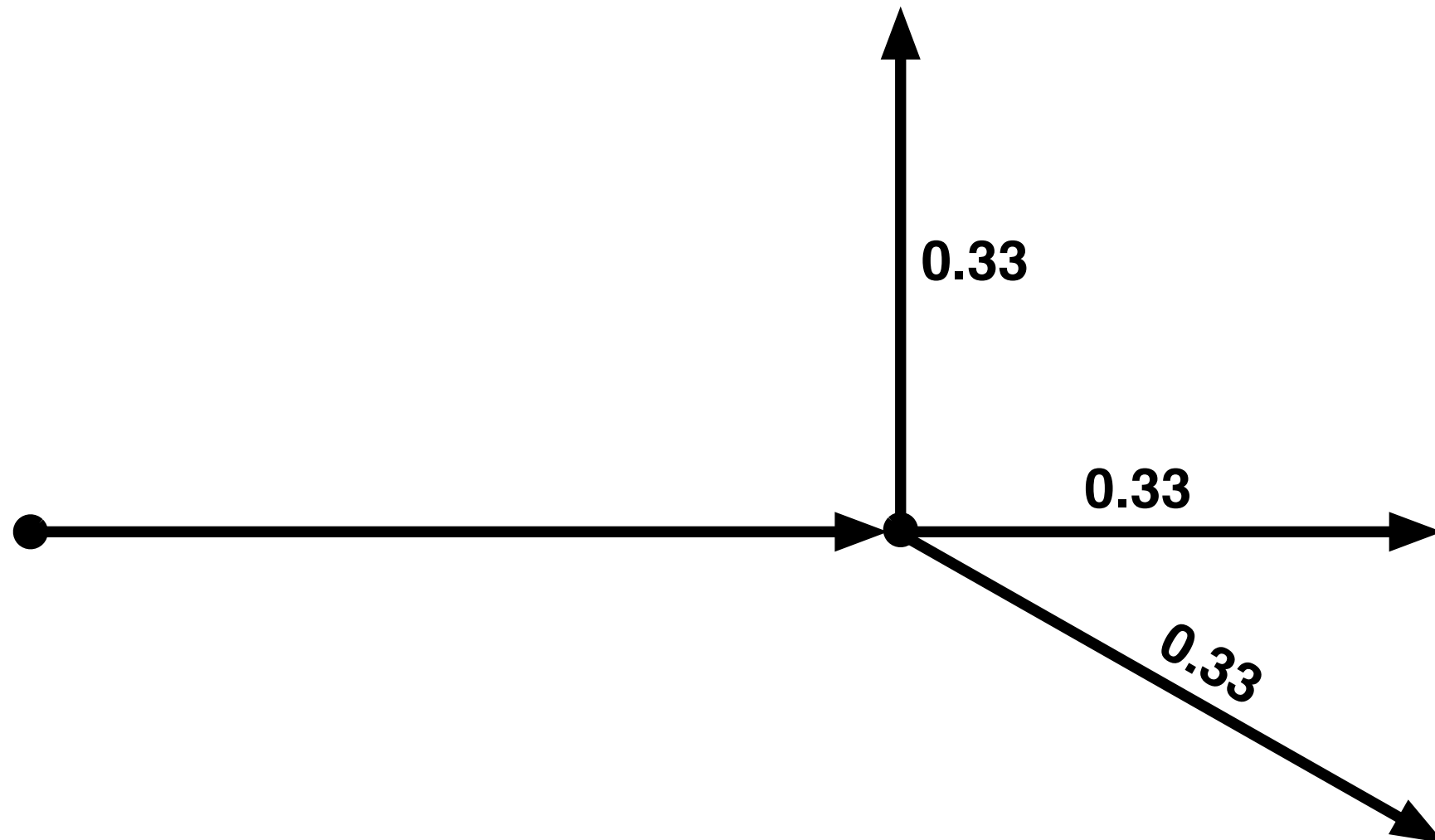
Raw GPS traces



Initial generated map

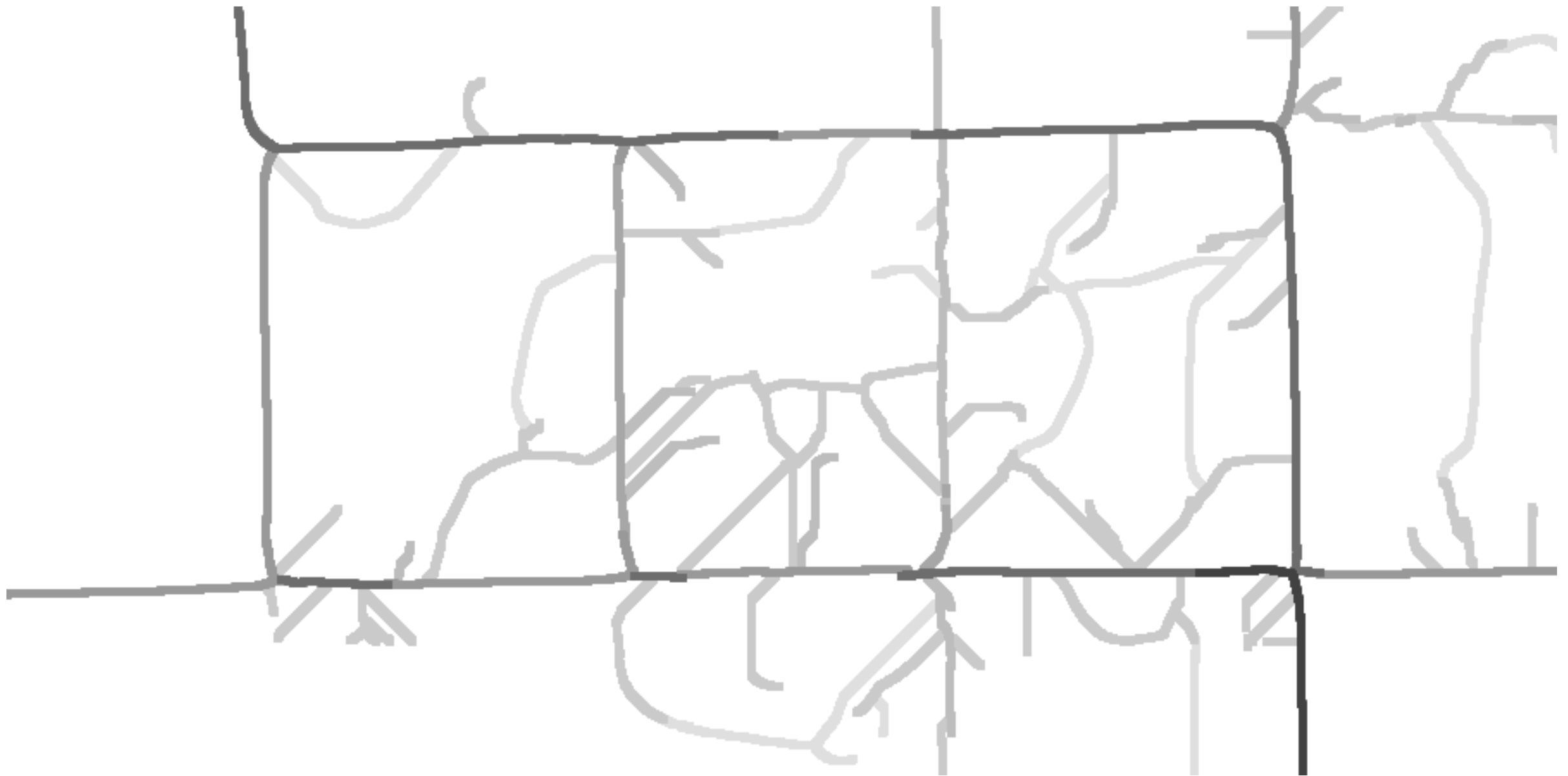


Uniform transition probabilities

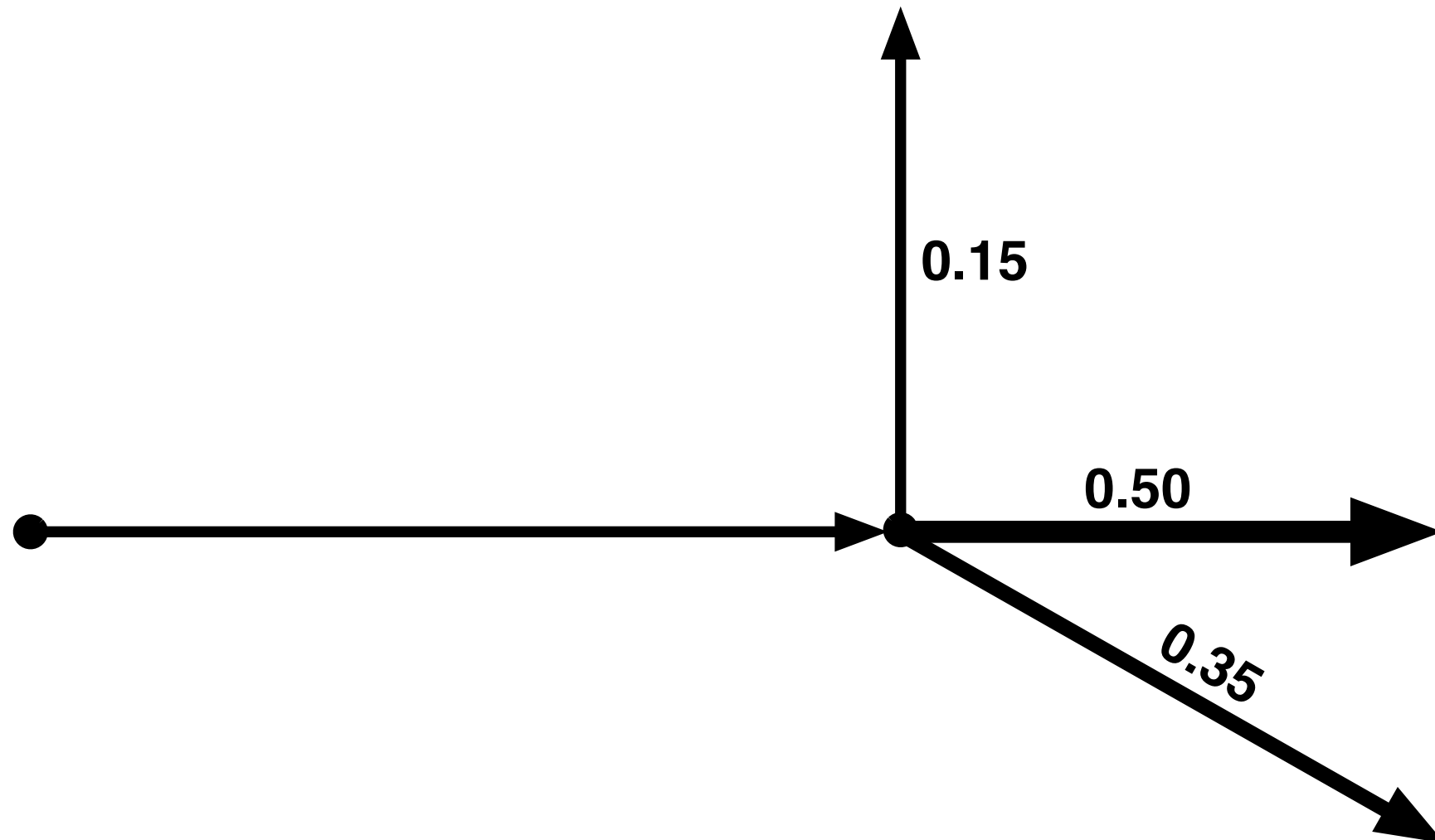


- ▶ HMM-based map-matching
 - Based on VTrack (Thiagarajan et al., 2009)

Density weighted roads

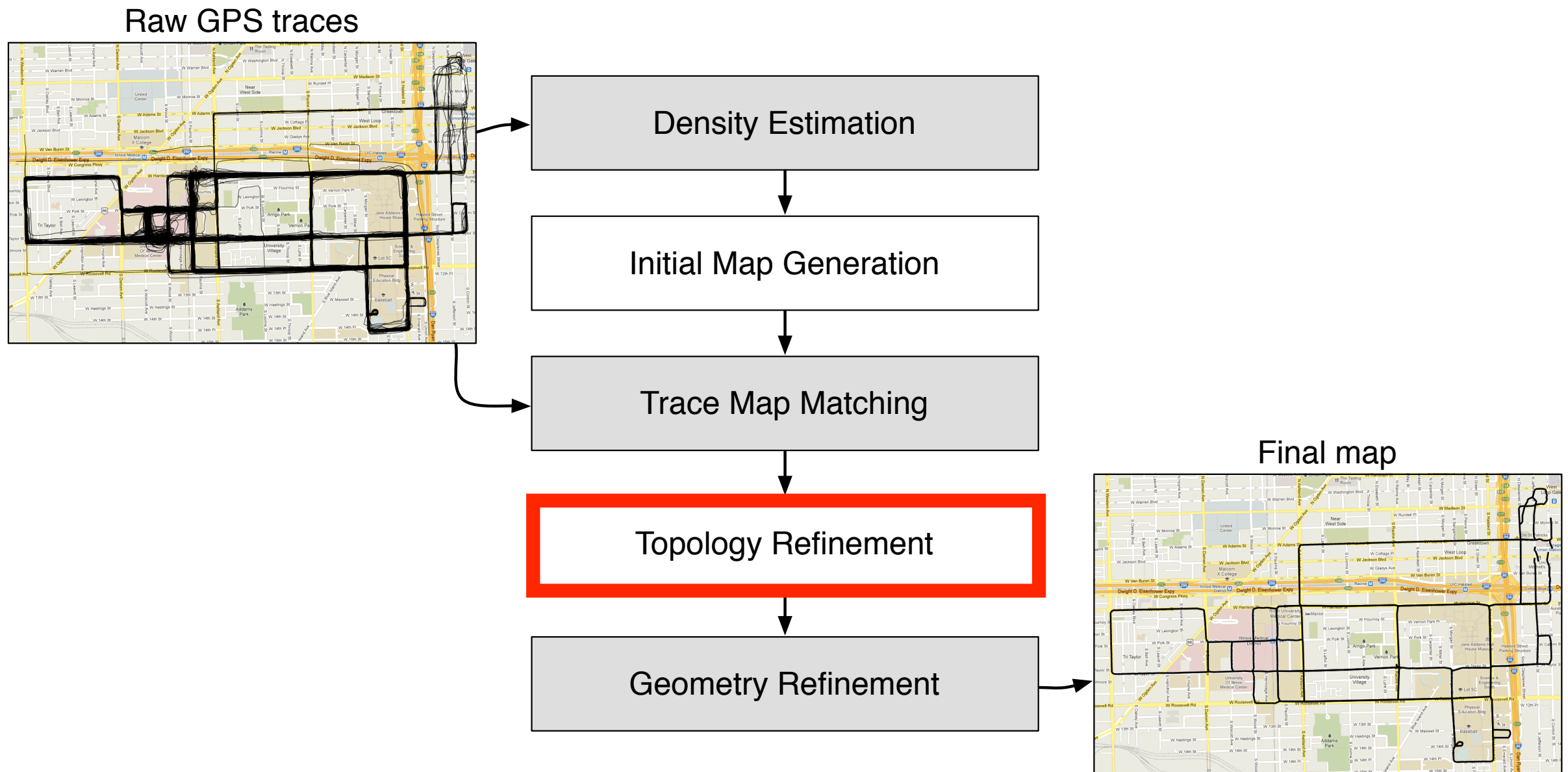


Weighted transition probabilities

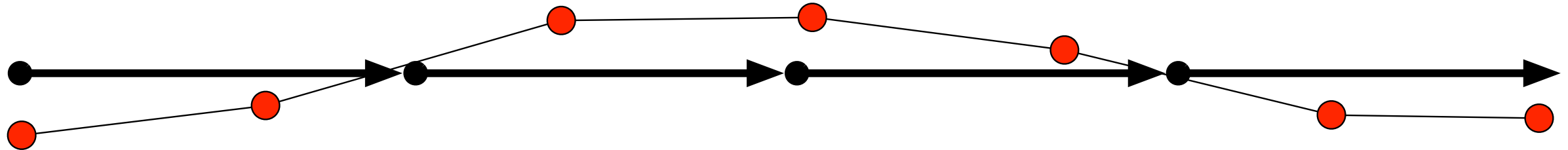


- ▶ HMM-based map-matching
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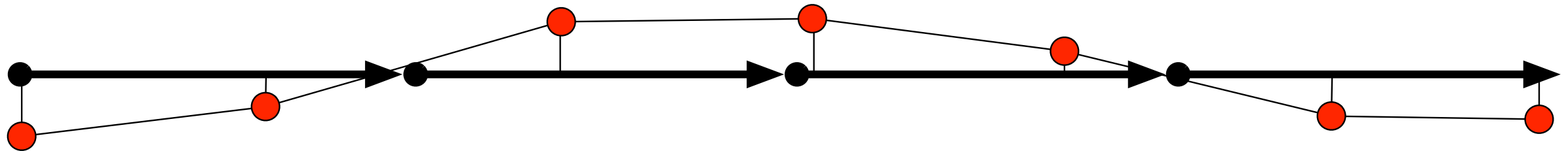
Map inference pipeline



Trace goodness of fit



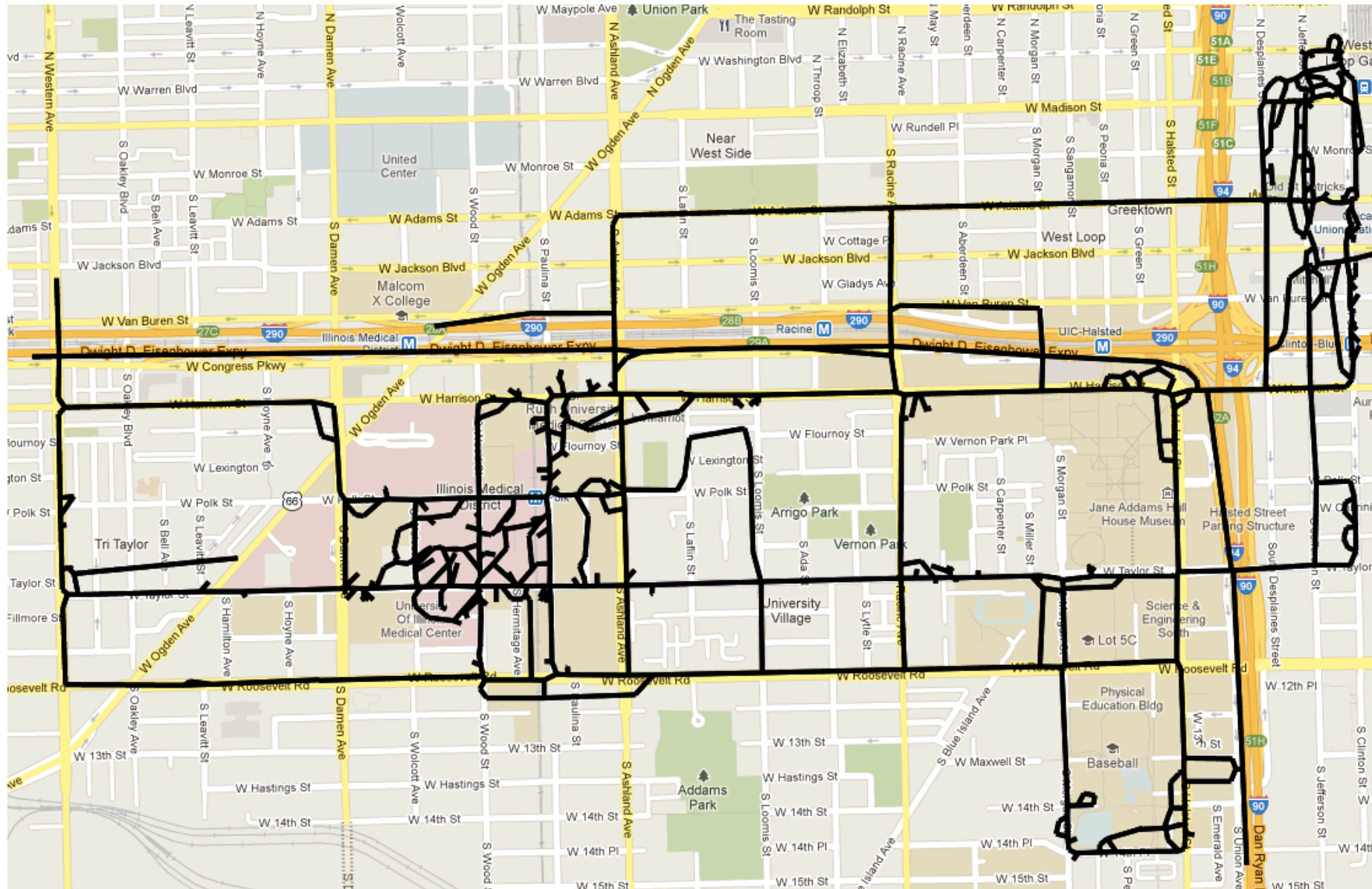
Trace goodness of fit



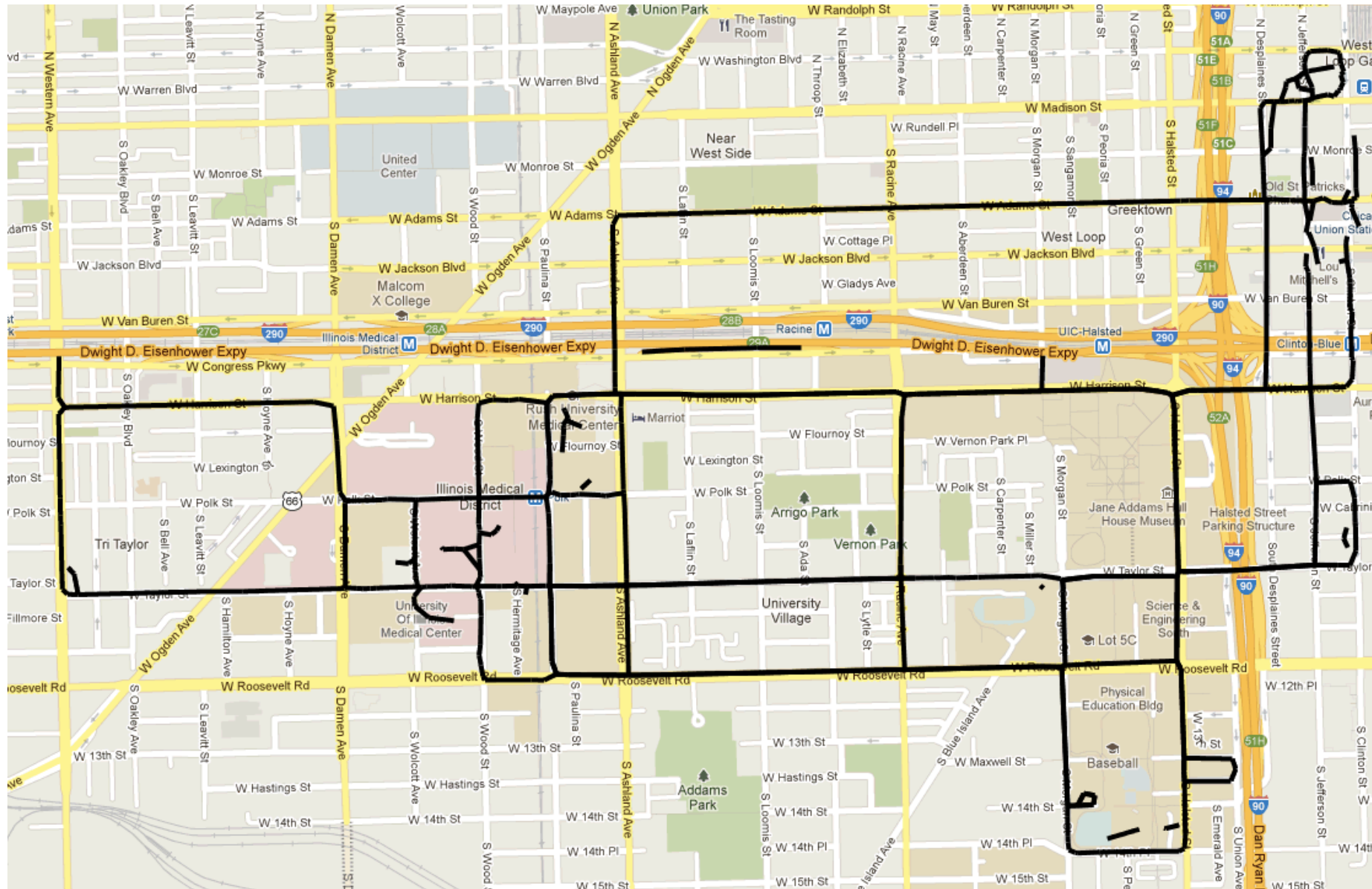
$$RMSD(\tau, e) = \sqrt{\frac{1}{|\tau|} \sum_{p \in \tau} dist(p, e)^2}$$

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

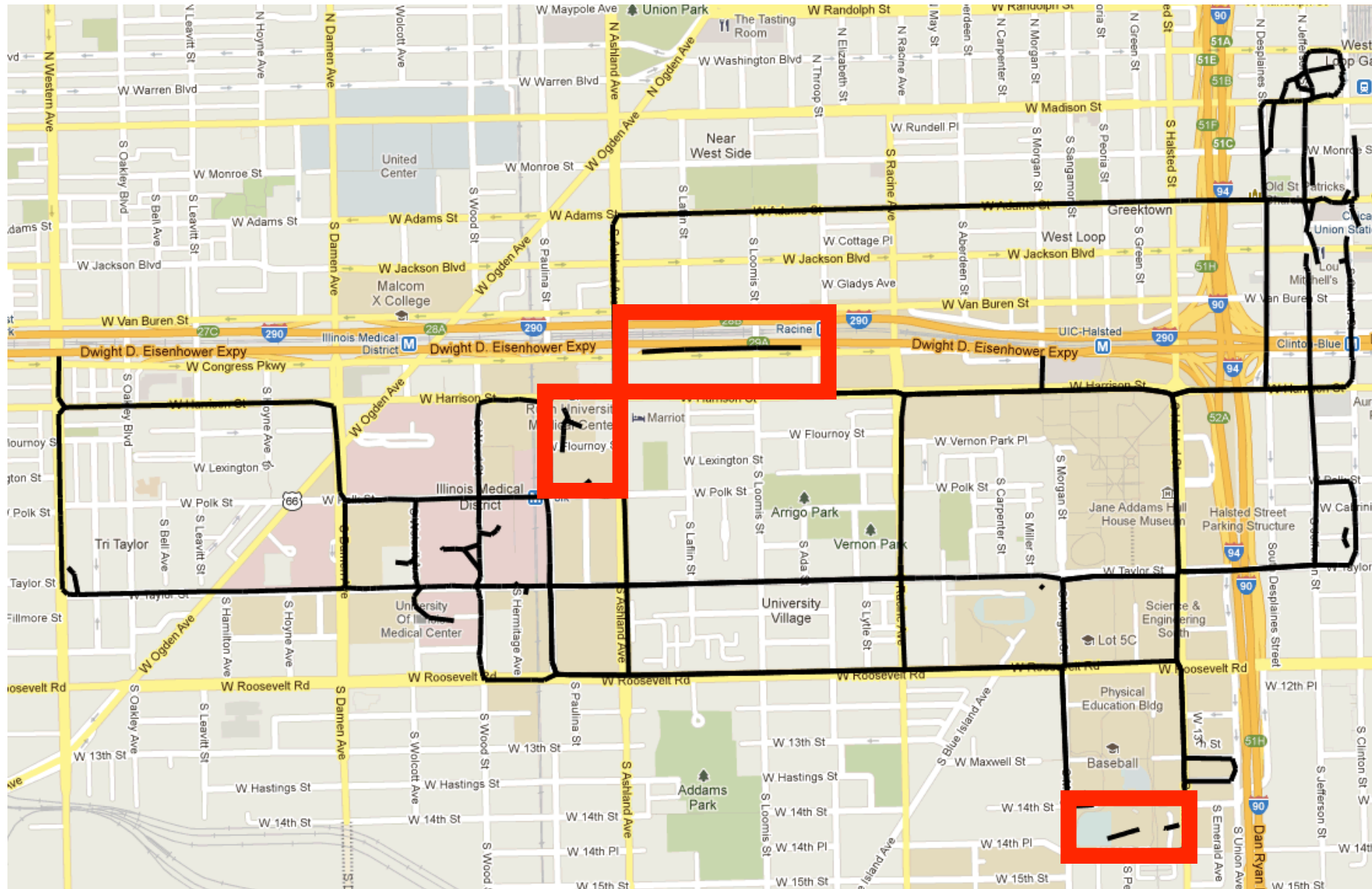
Map before pruning



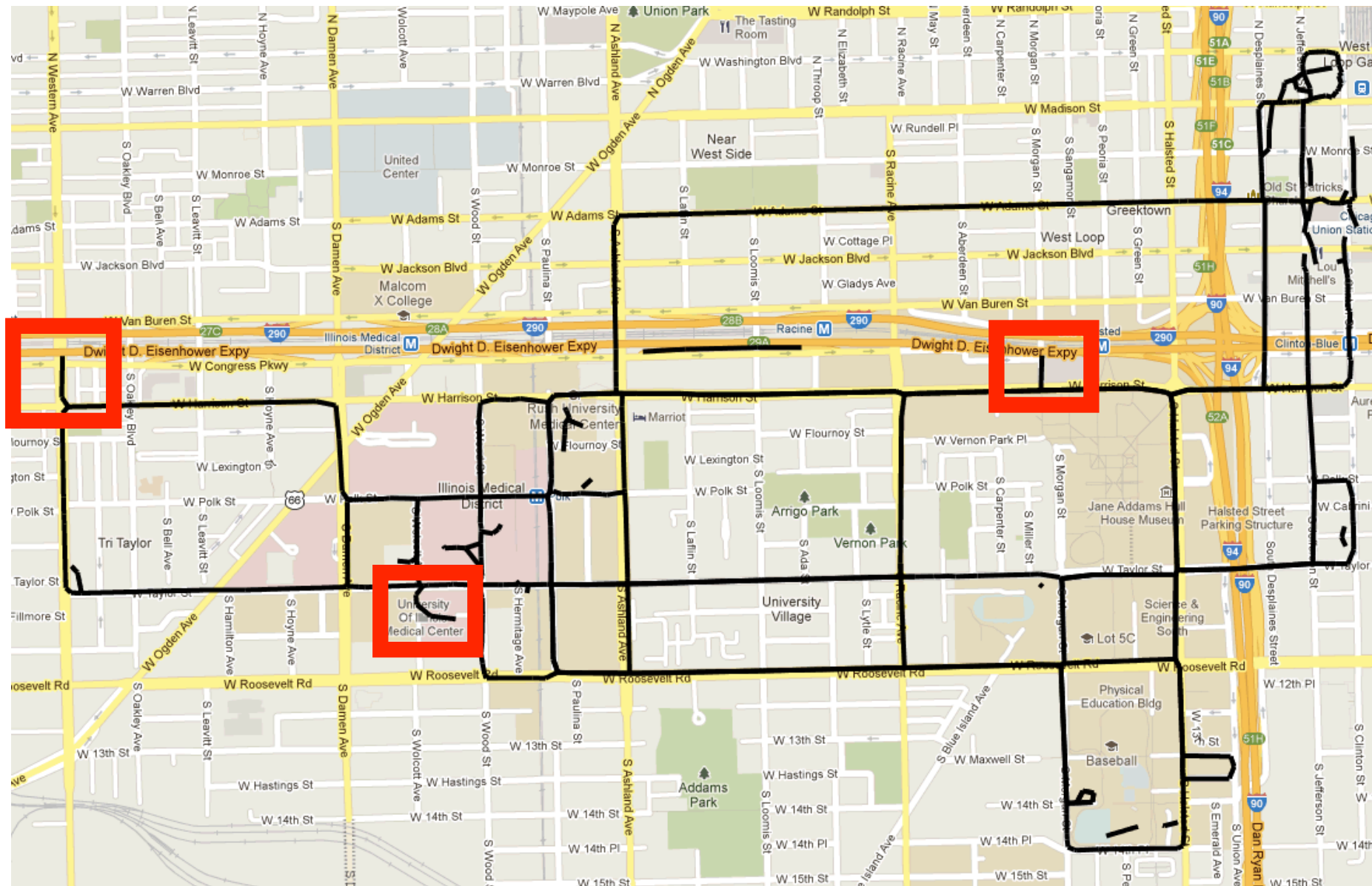
Map after pruning



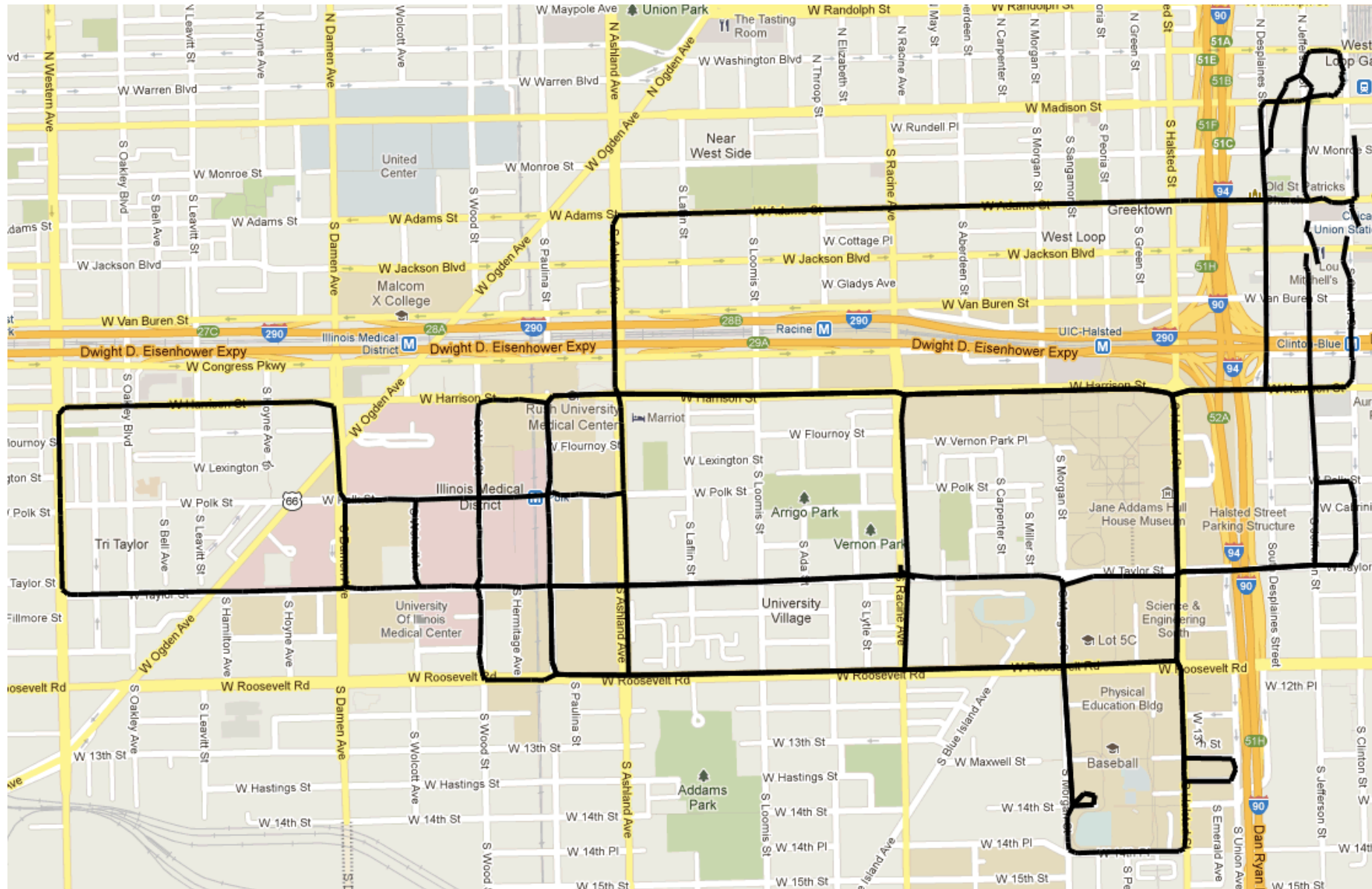
Orphaned road segments



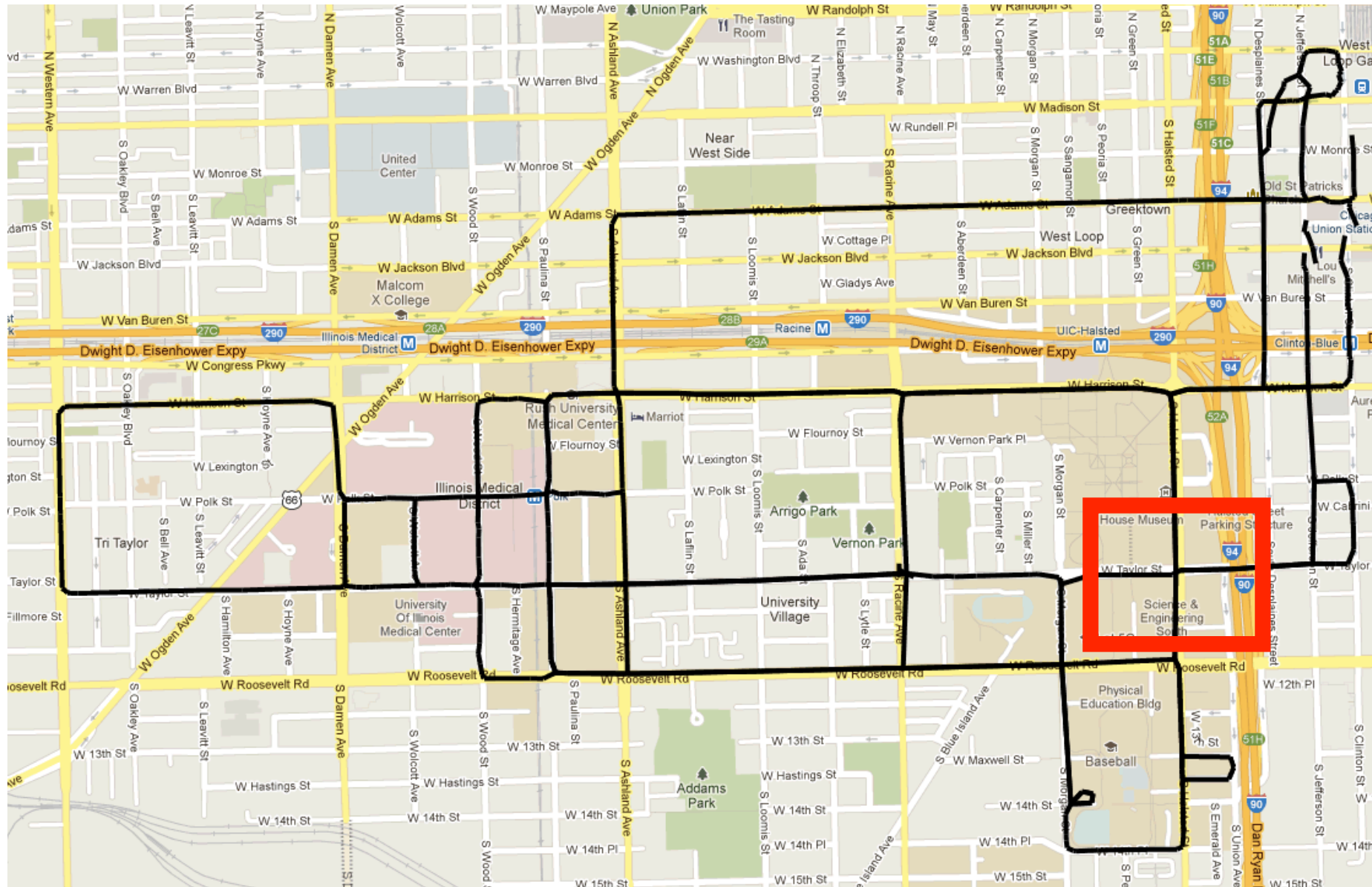
Road segment “spurs”



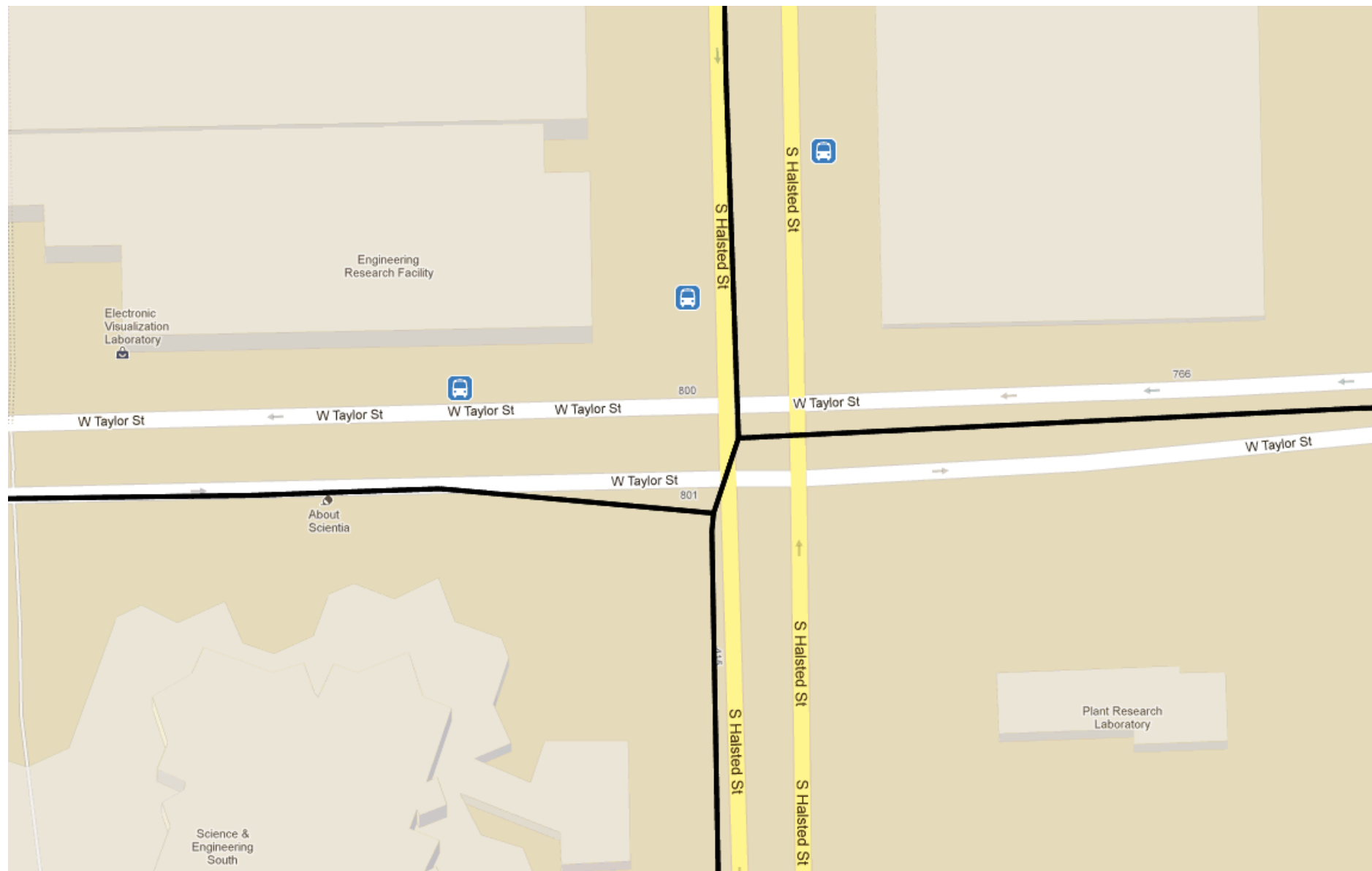
Map after pruning... again



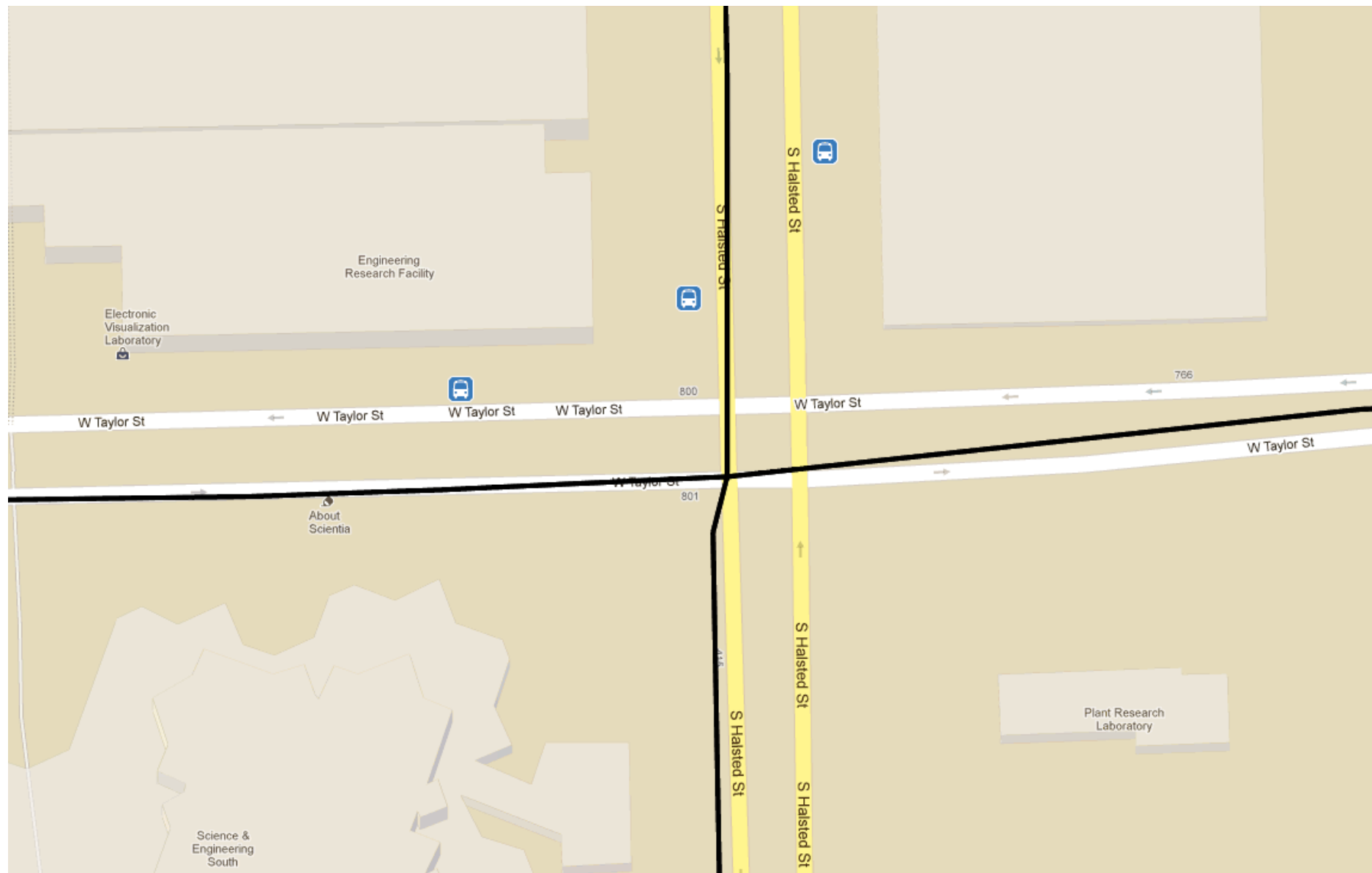
Map after pruning



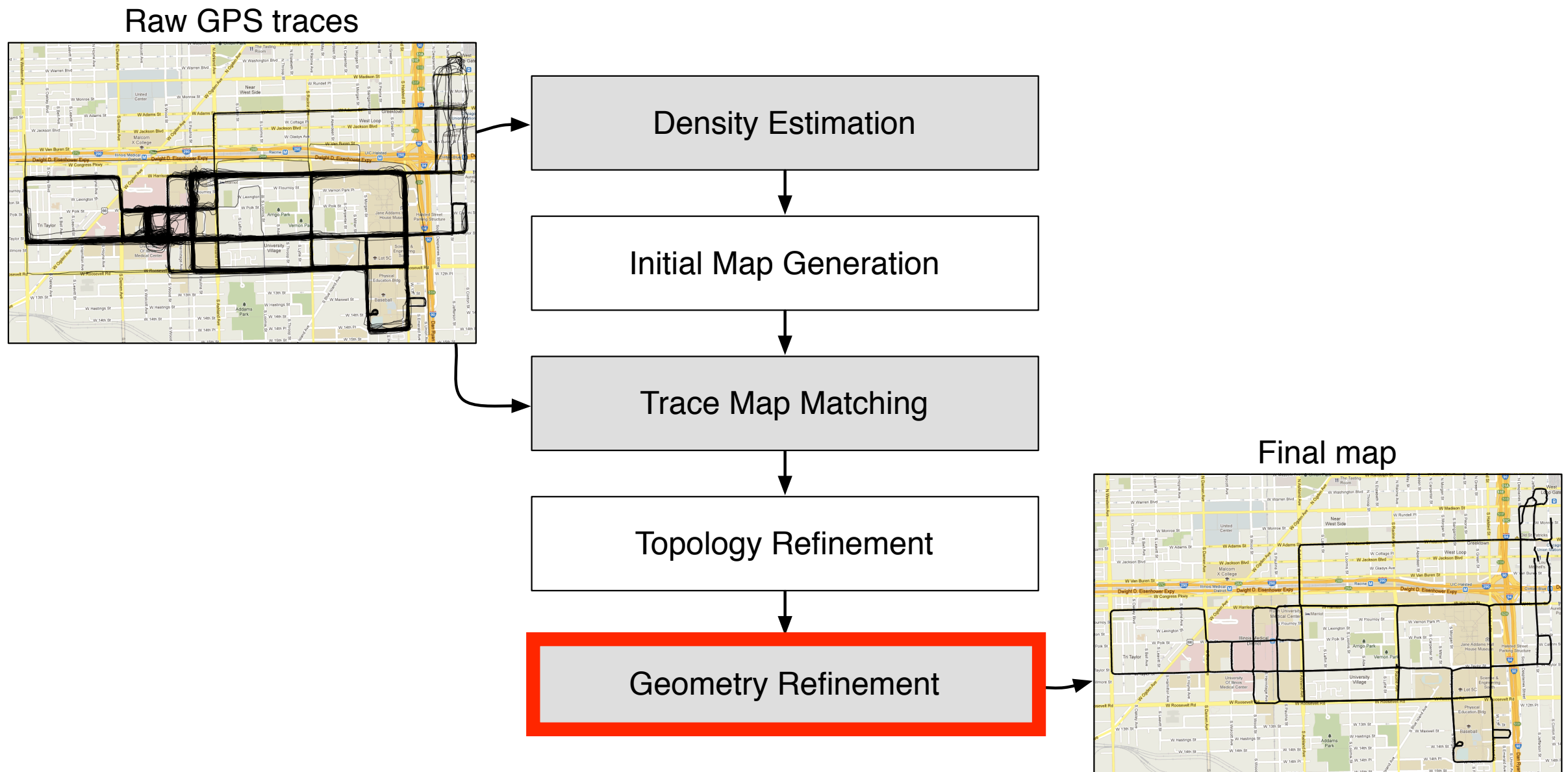
Incorrect topology



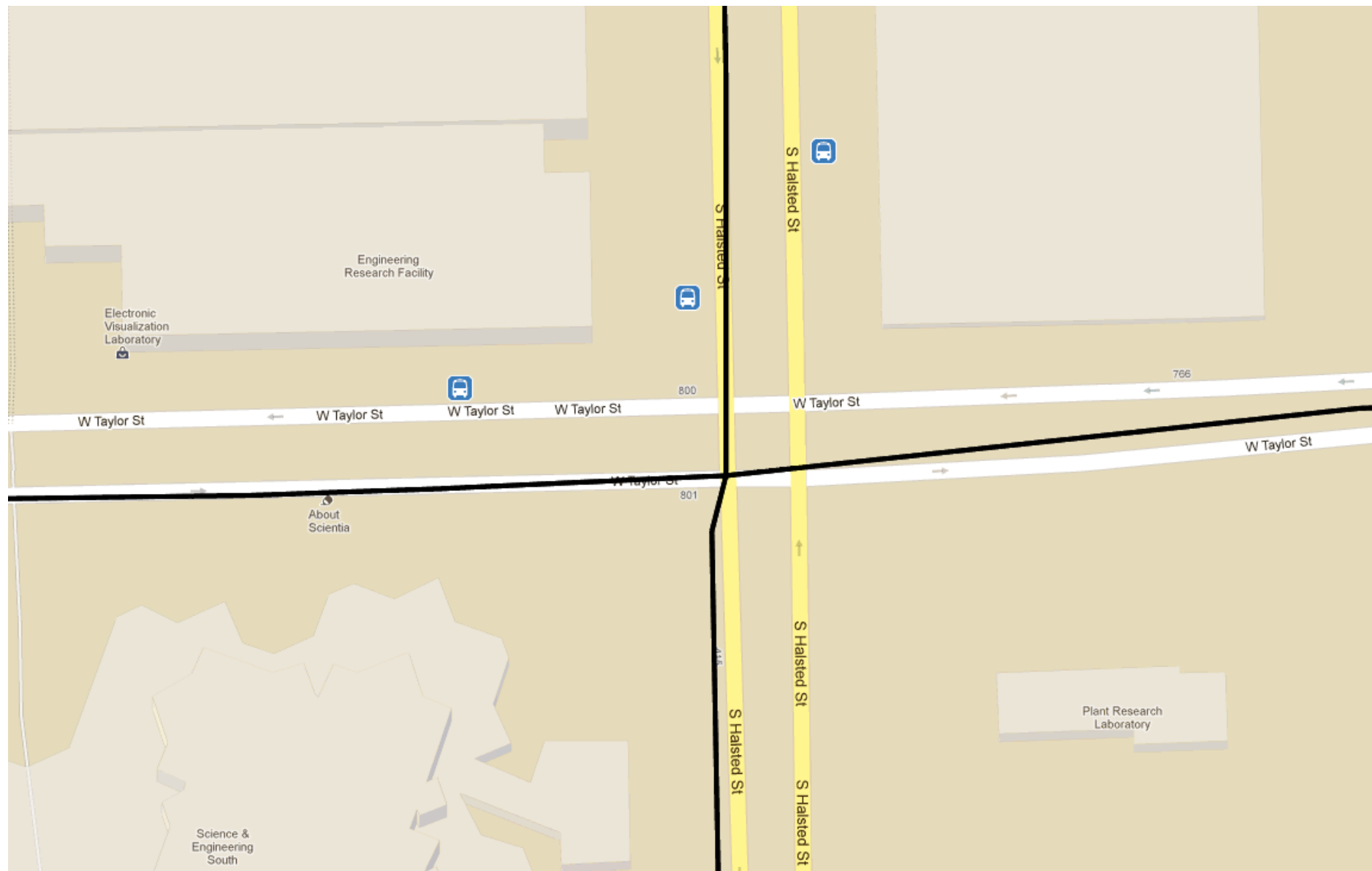
Collapsed intersection



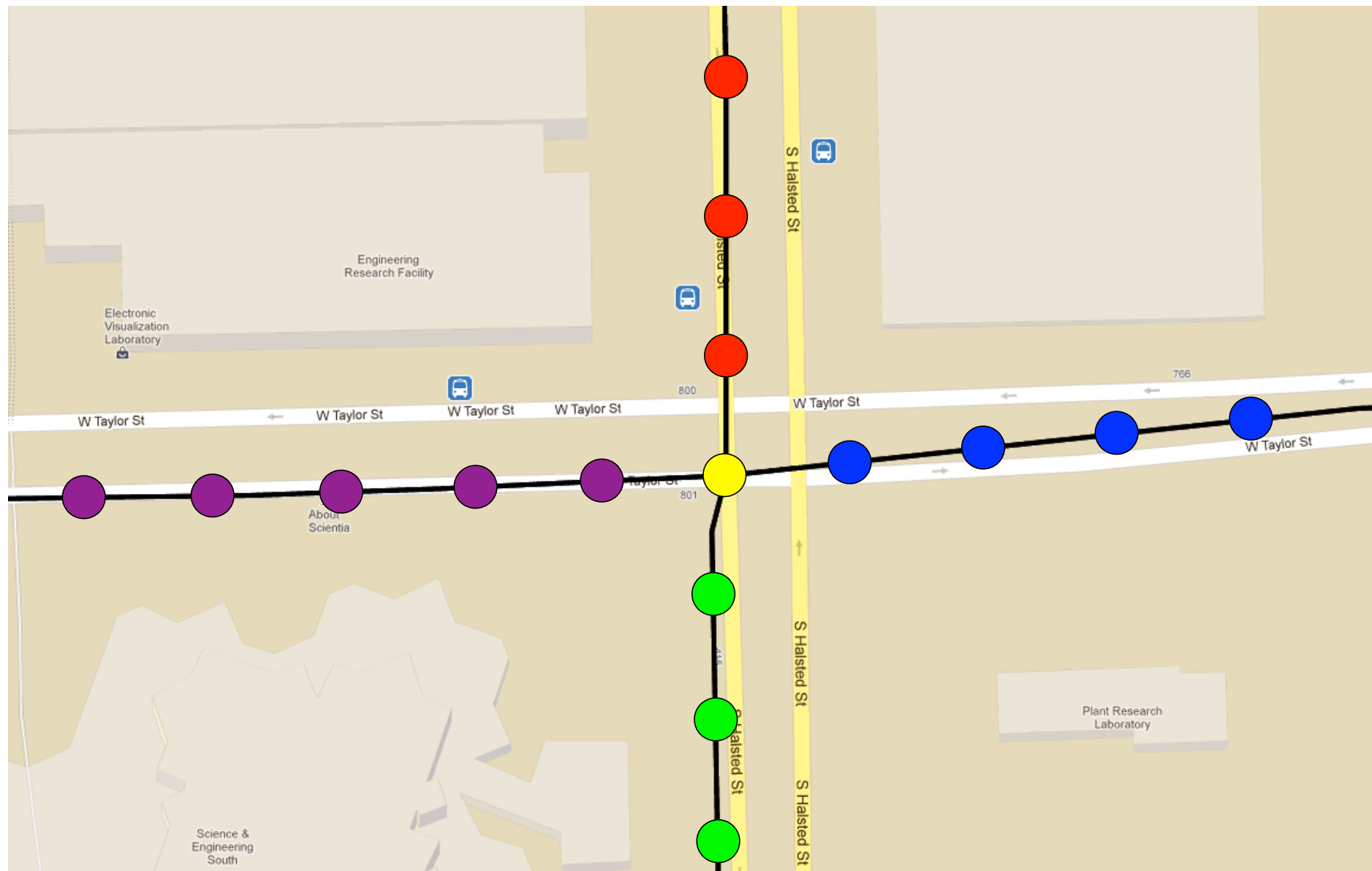
Map inference pipeline



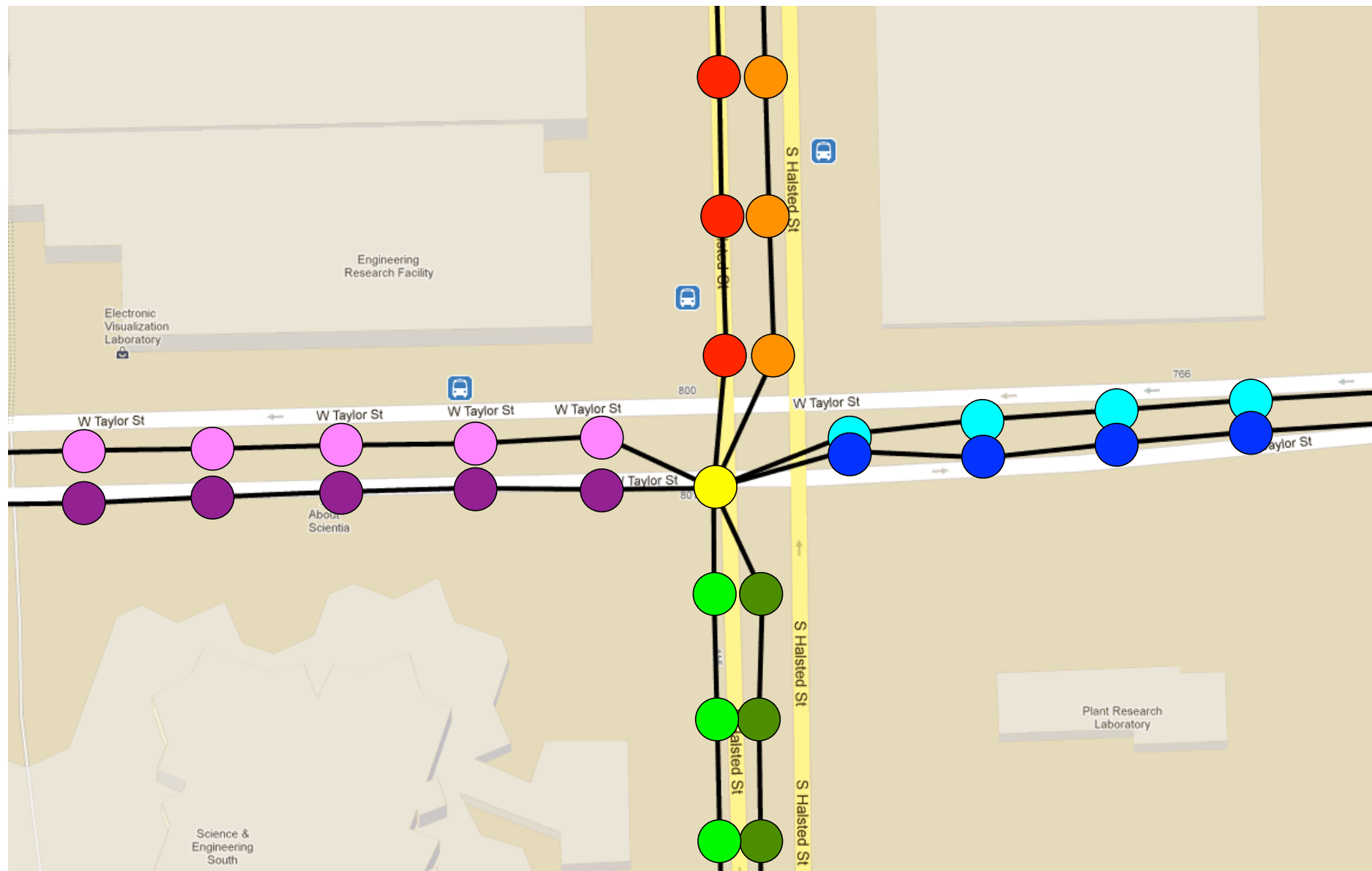
Simple geometry



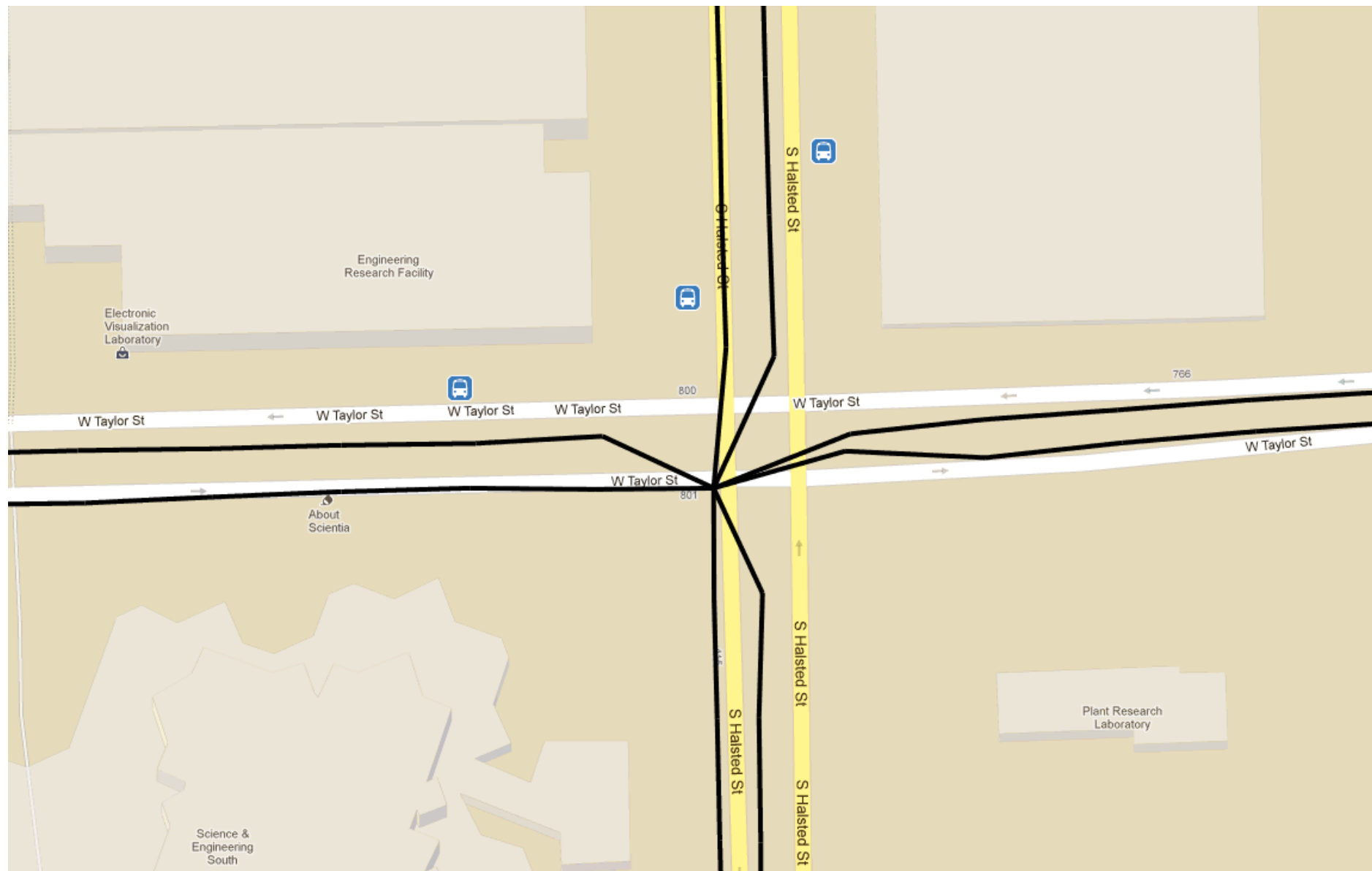
Initial cluster locations



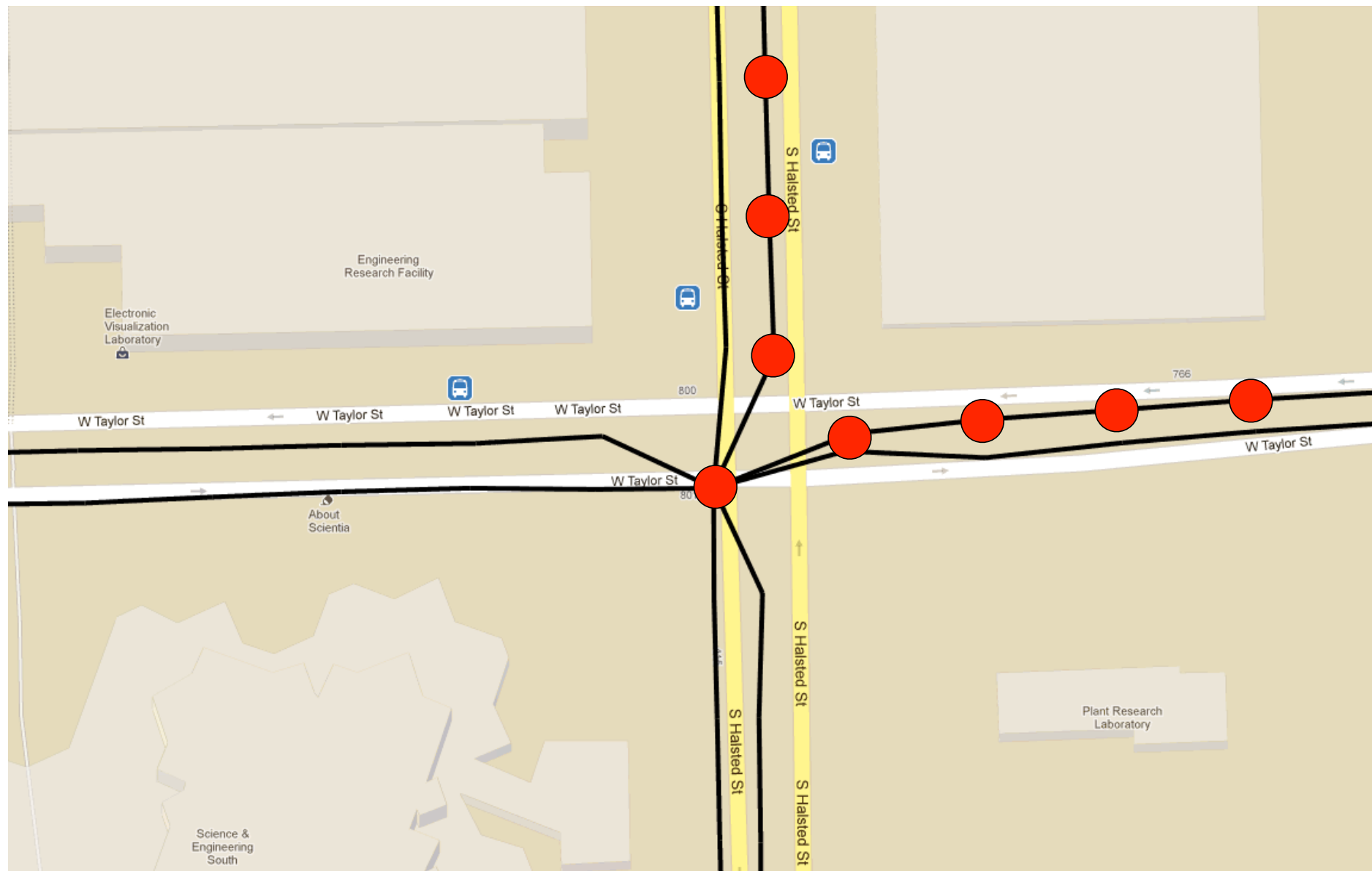
Settled cluster locations



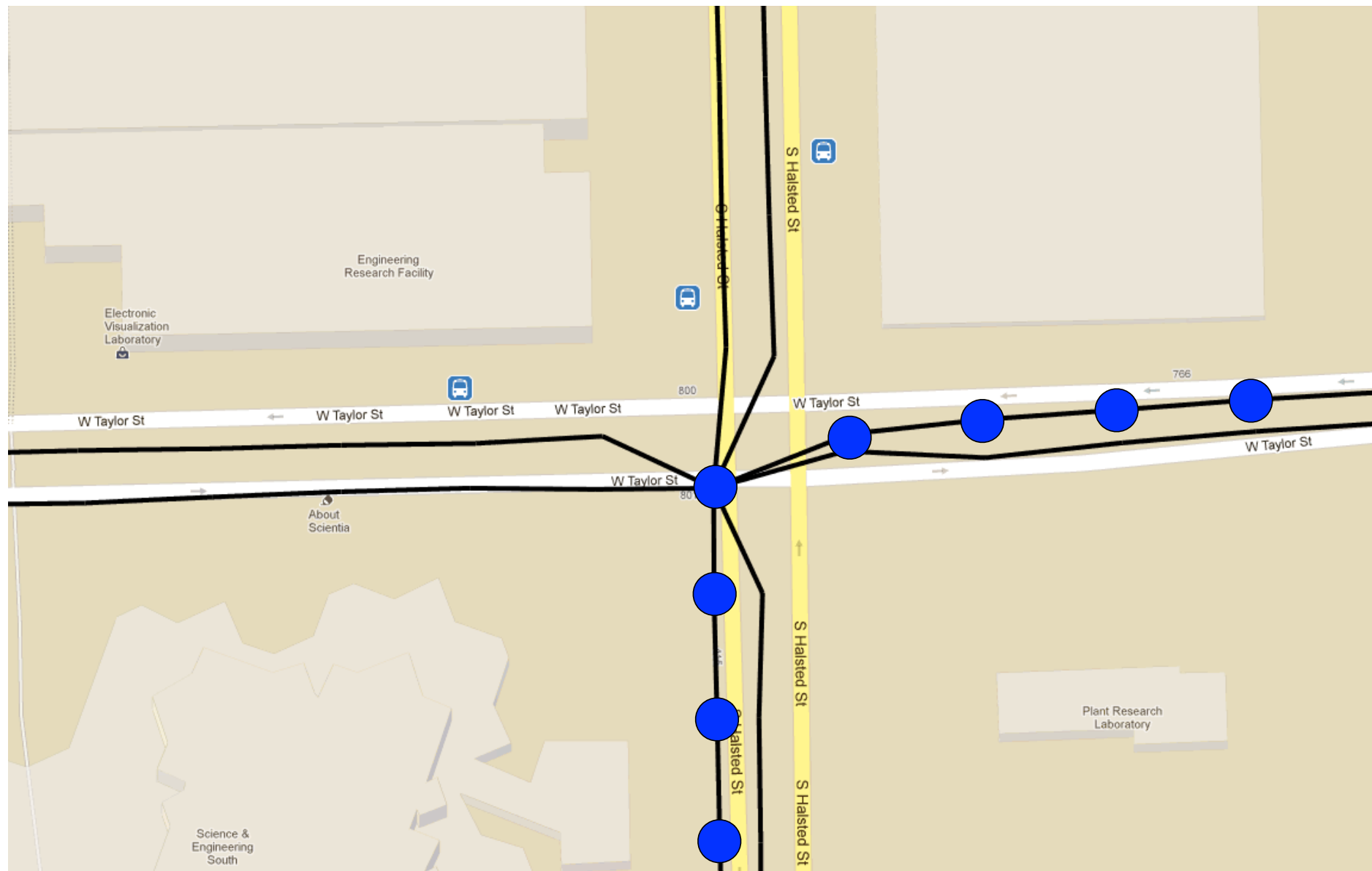
Refined lane geometry



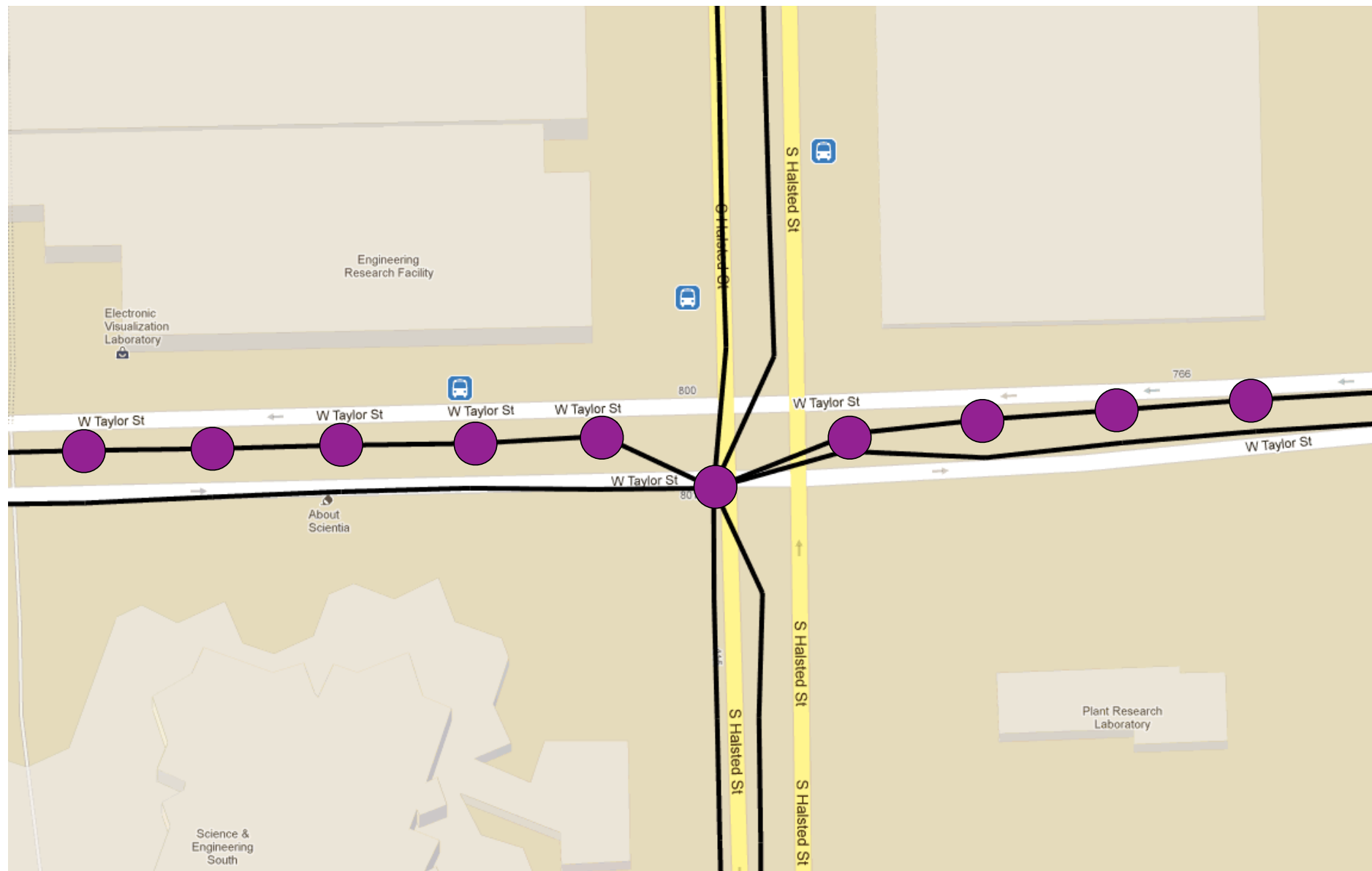
Intersection refinement



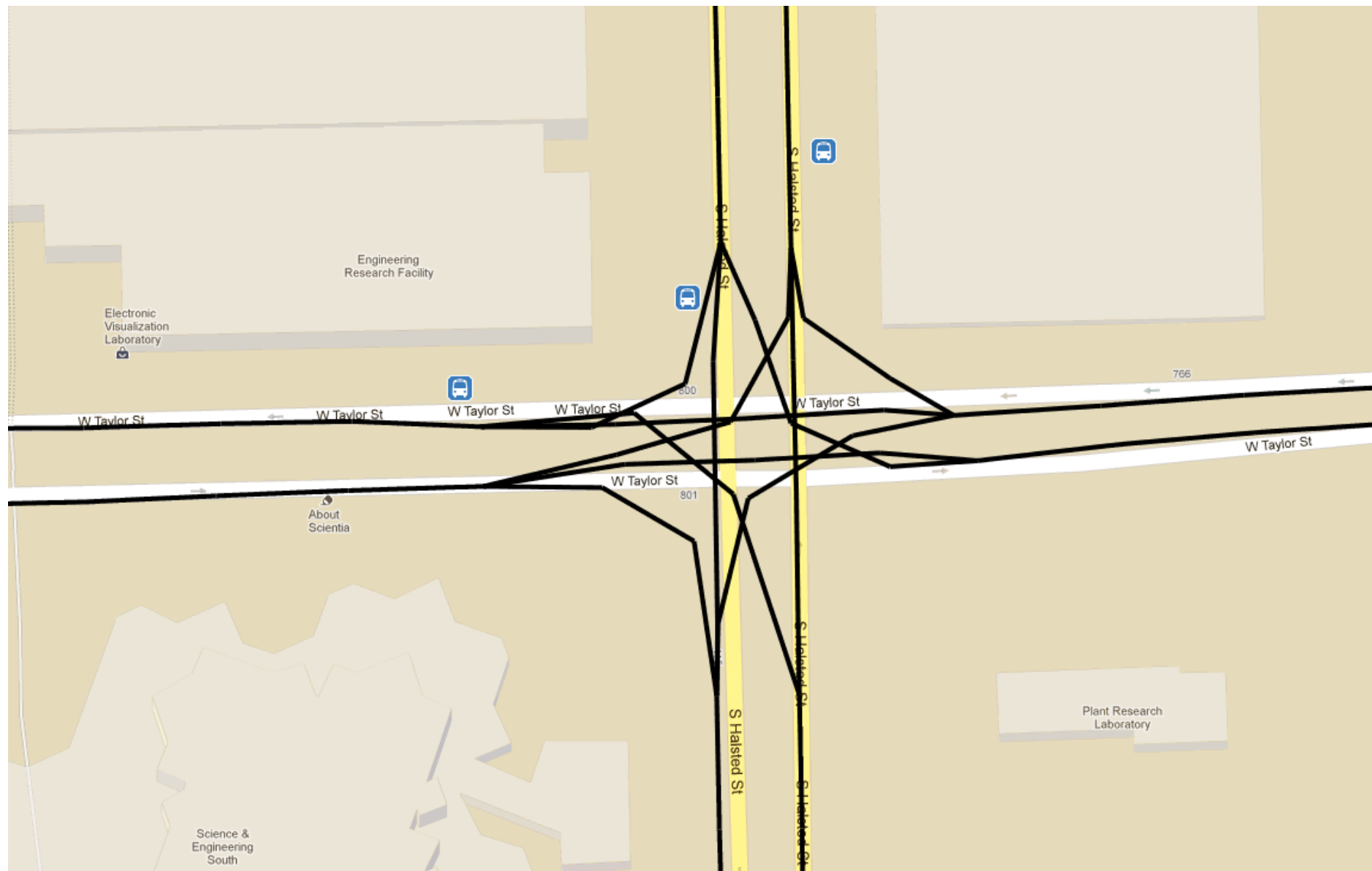
Intersection refinement



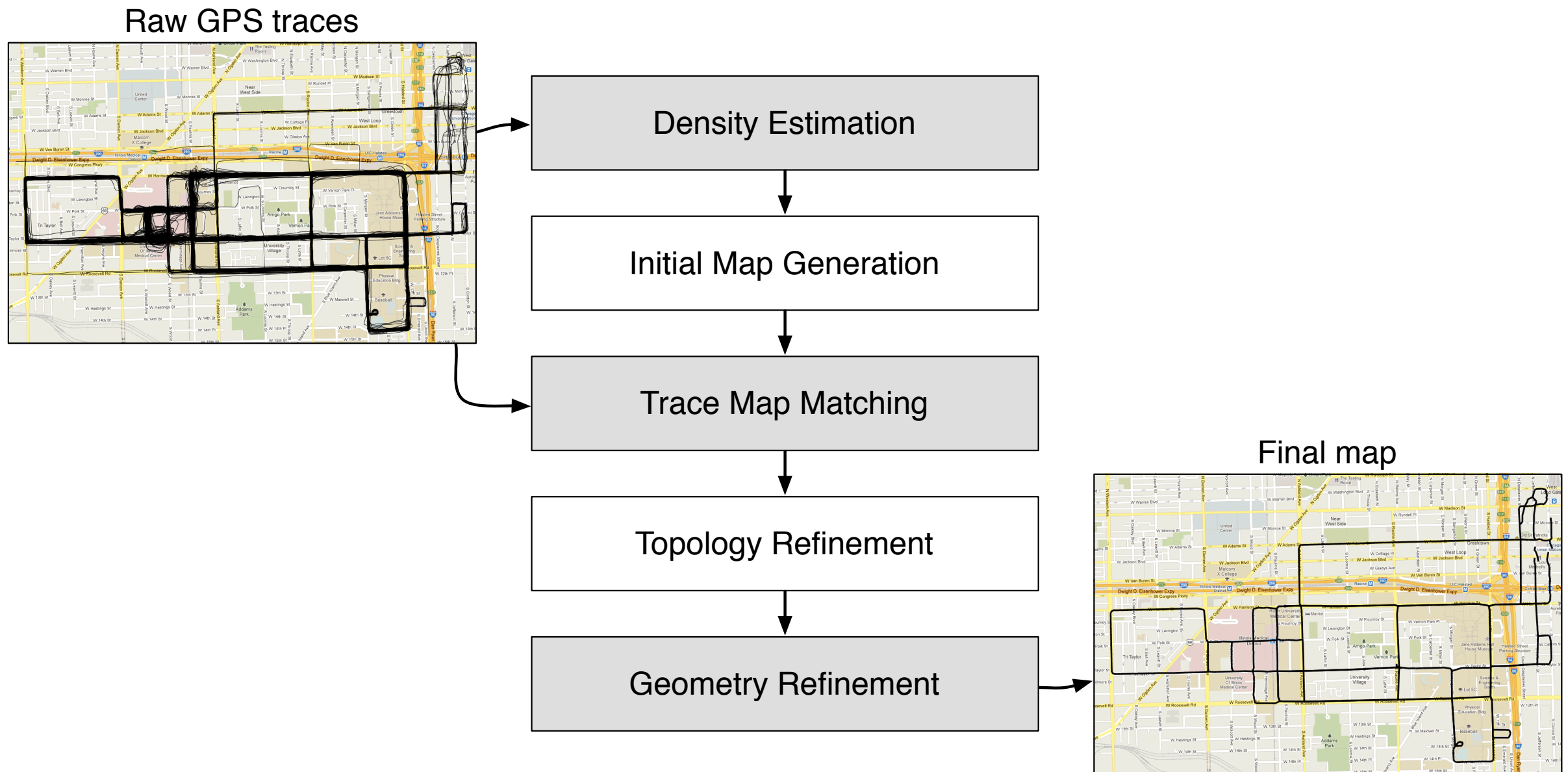
Intersection refinement



Refined intersection geometry



Map inference pipeline



Quantitative Evaluation

Evaluation metrics

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

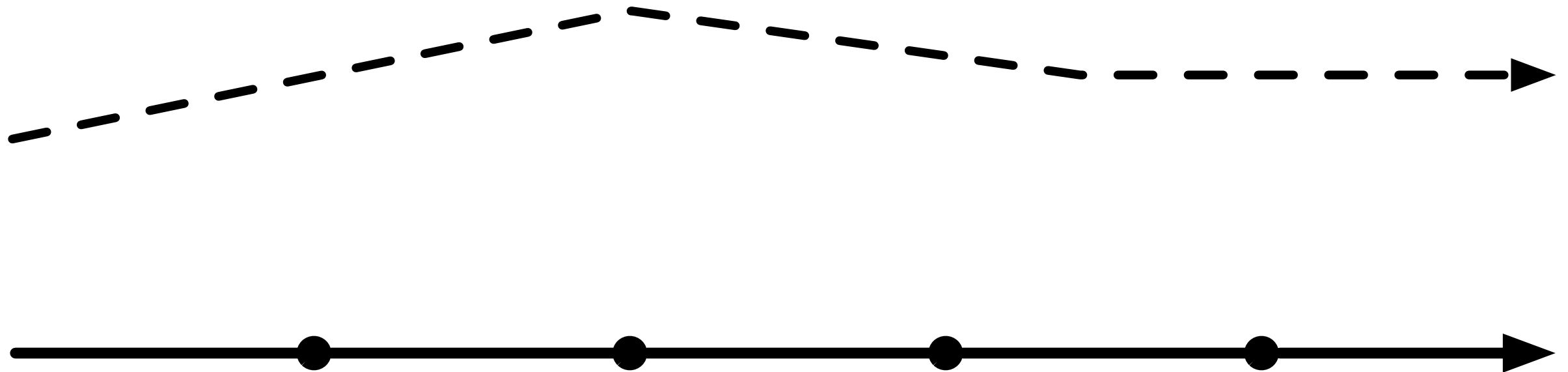
Ground truth segment



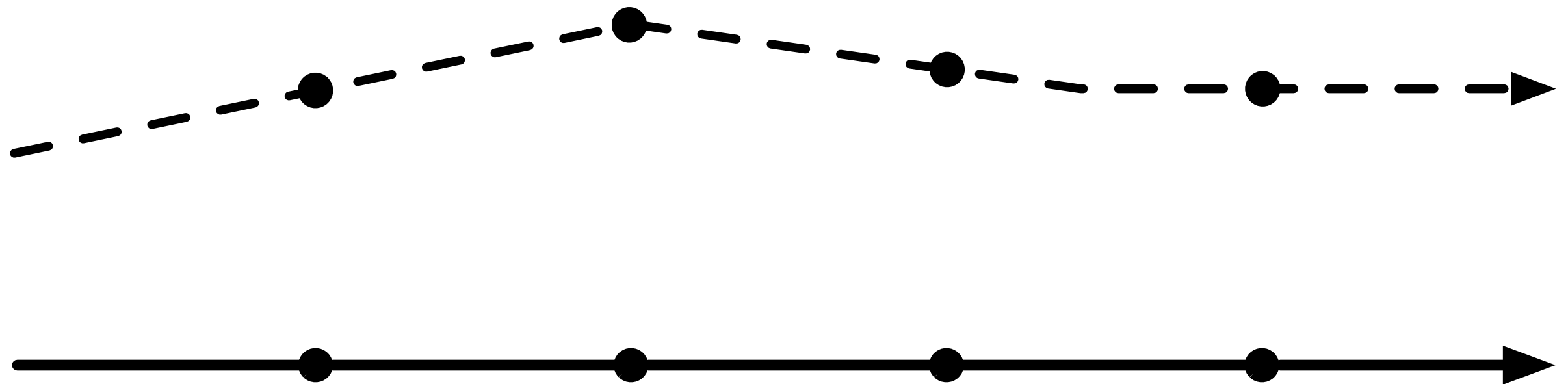
Ground truth samples



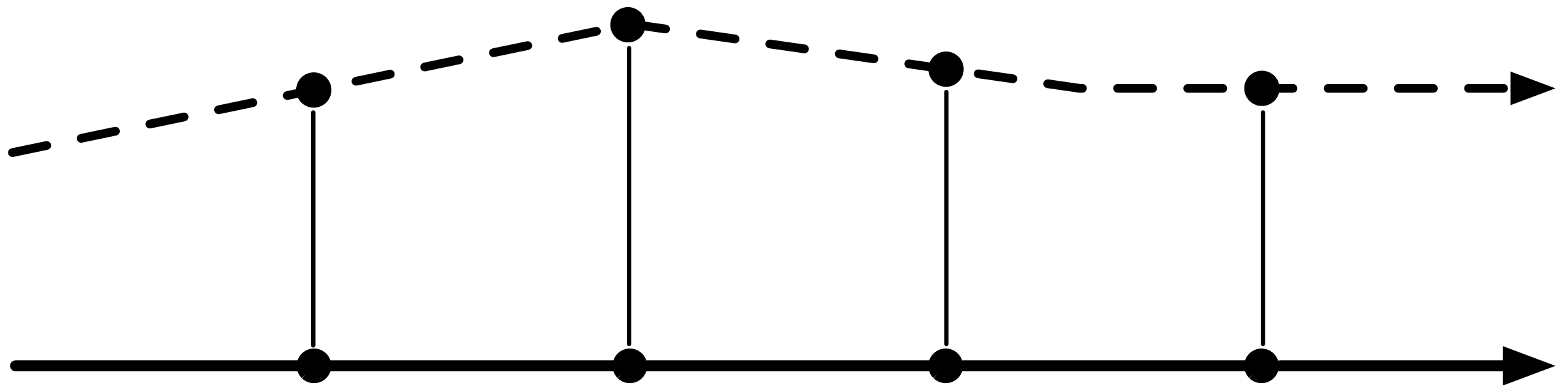
Inferred map segment



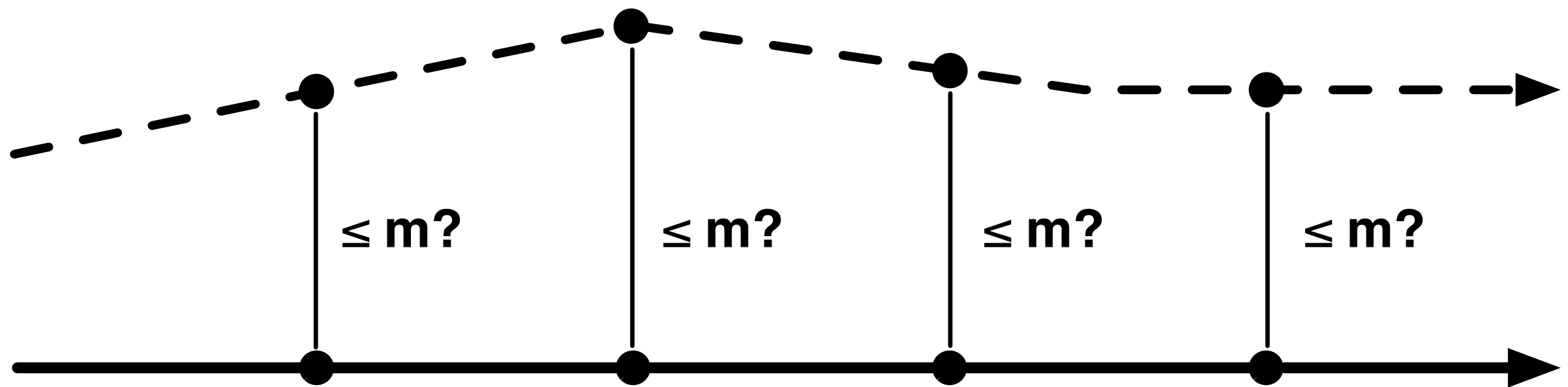
Inferred map samples



Samples compared

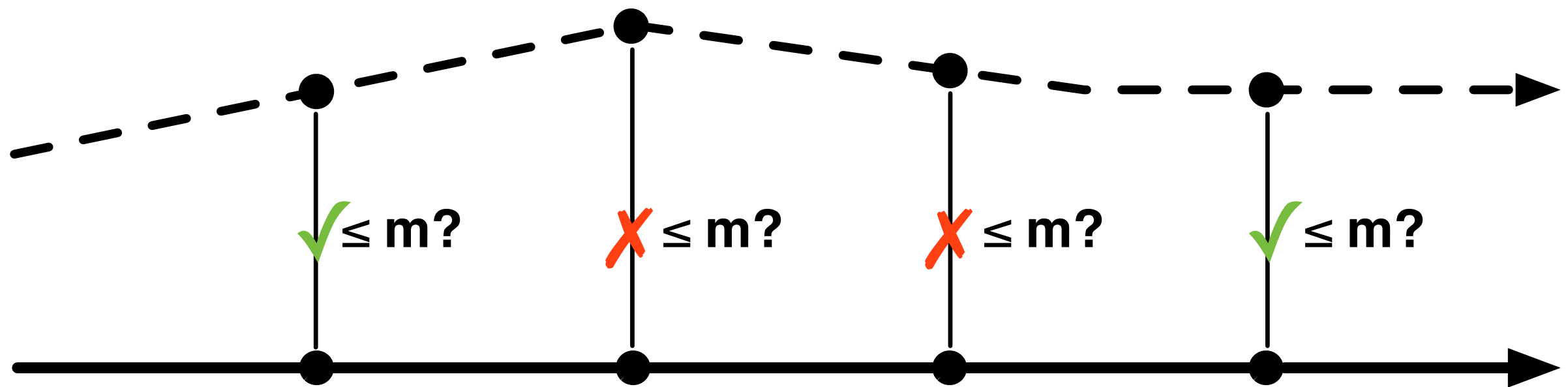


Matching threshold



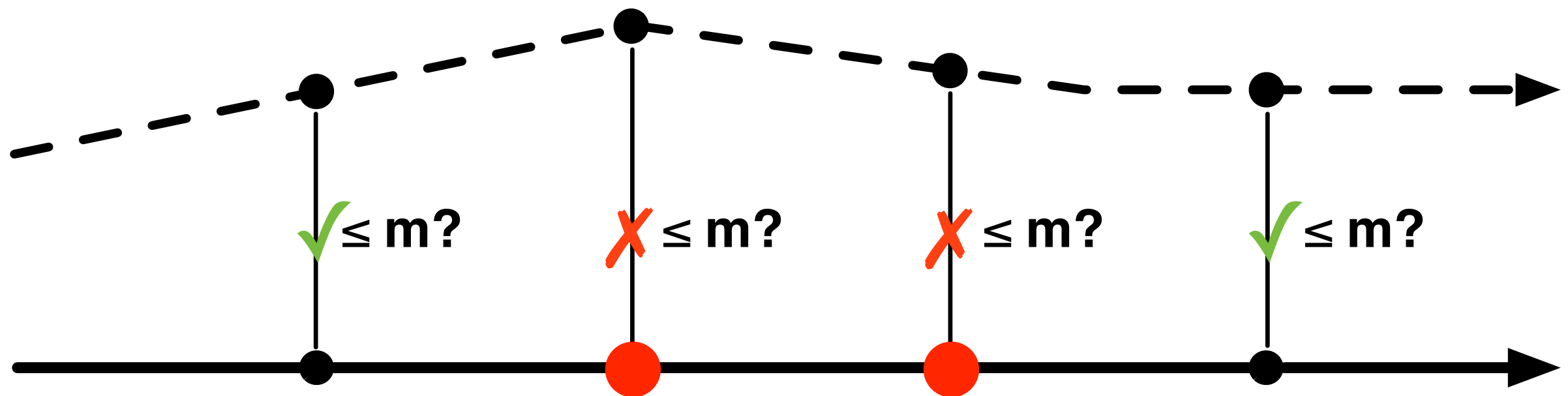
m = matching threshold

Matching threshold



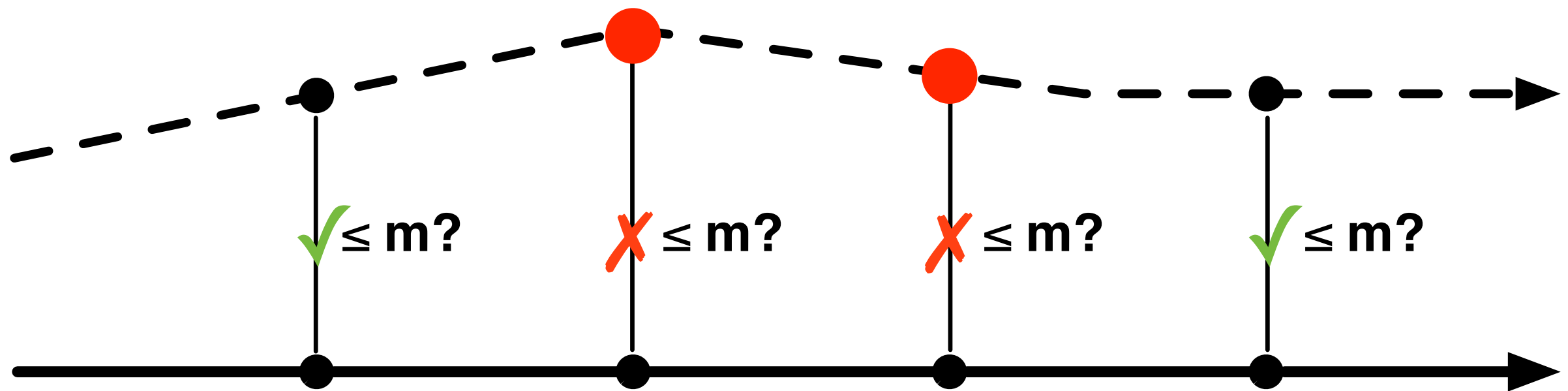
m = matching threshold

“Missing”



m = matching threshold

“Spurious”



m = matching threshold

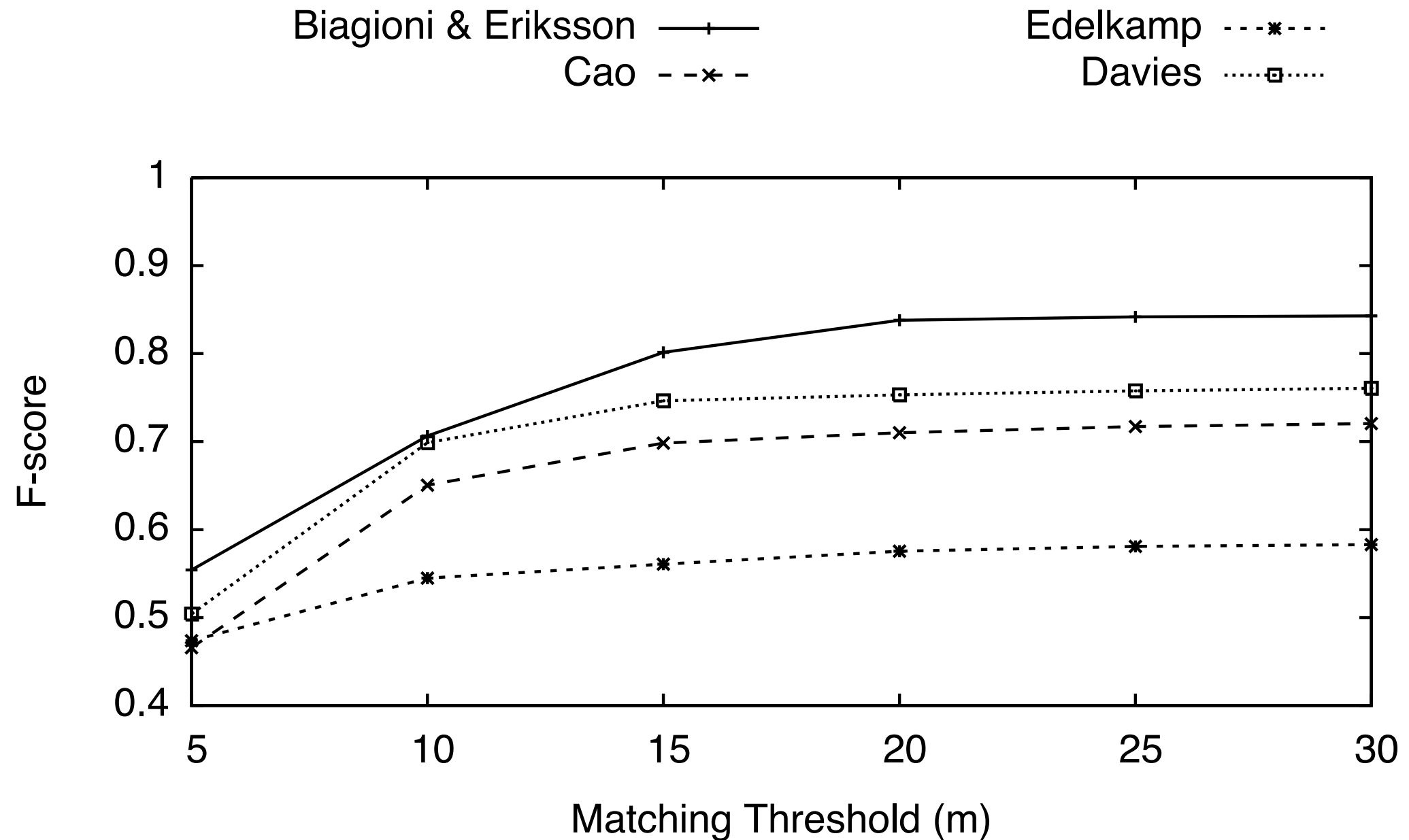
Overall performance

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

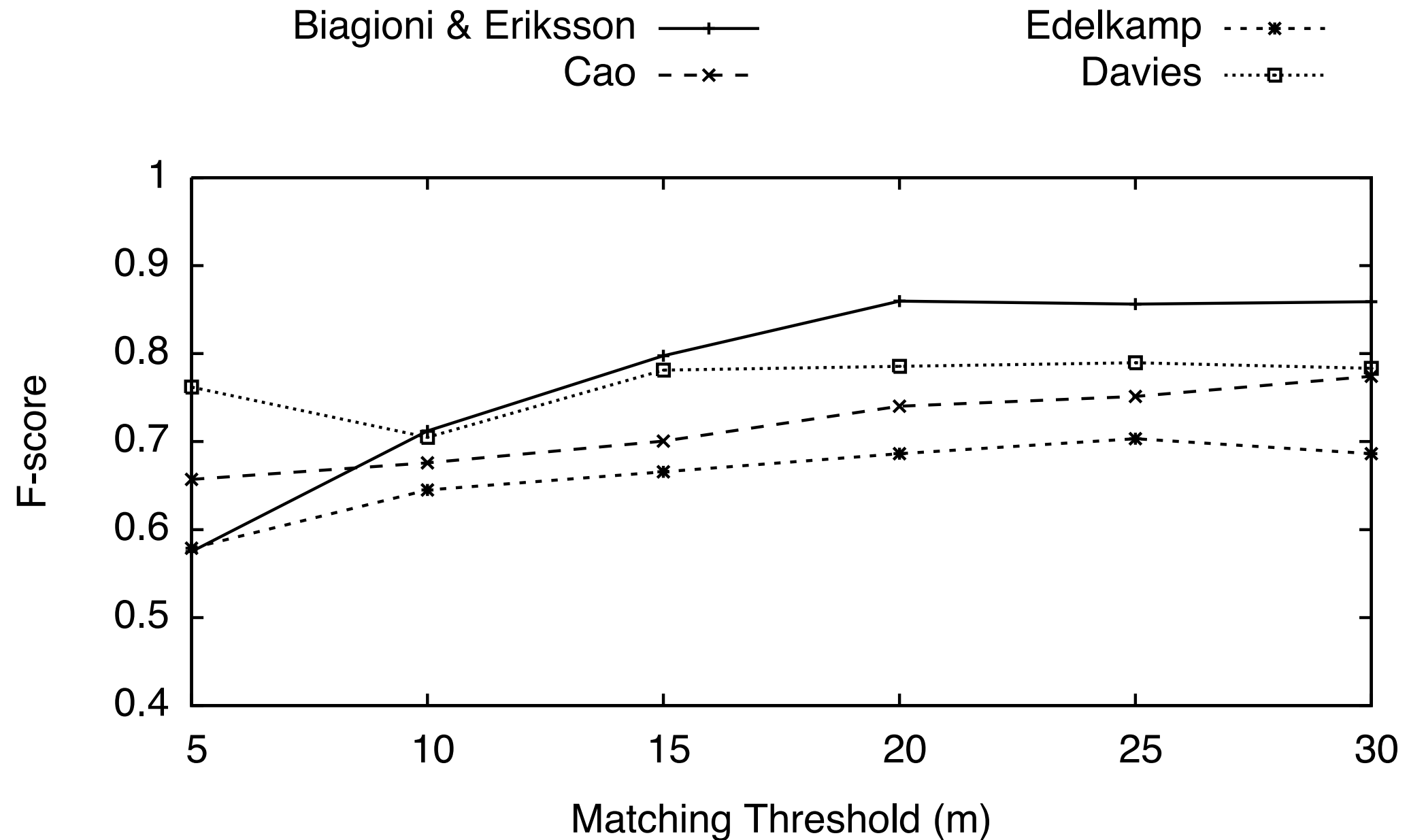
$$\textit{precision} = 1 - \frac{|\textit{spurious samples}|}{|\textit{inferred samples}|}$$

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

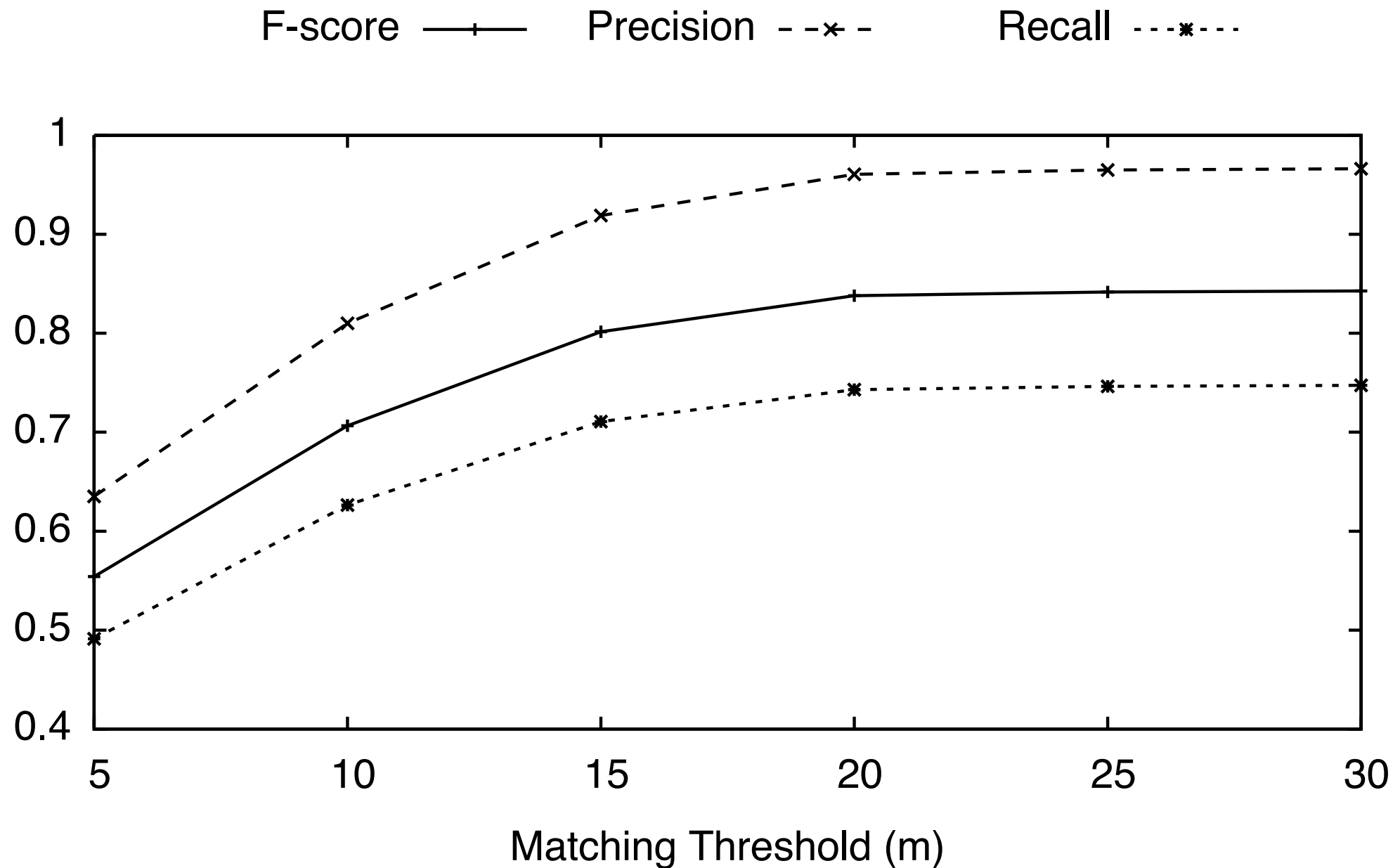
Geometric results



Topological results

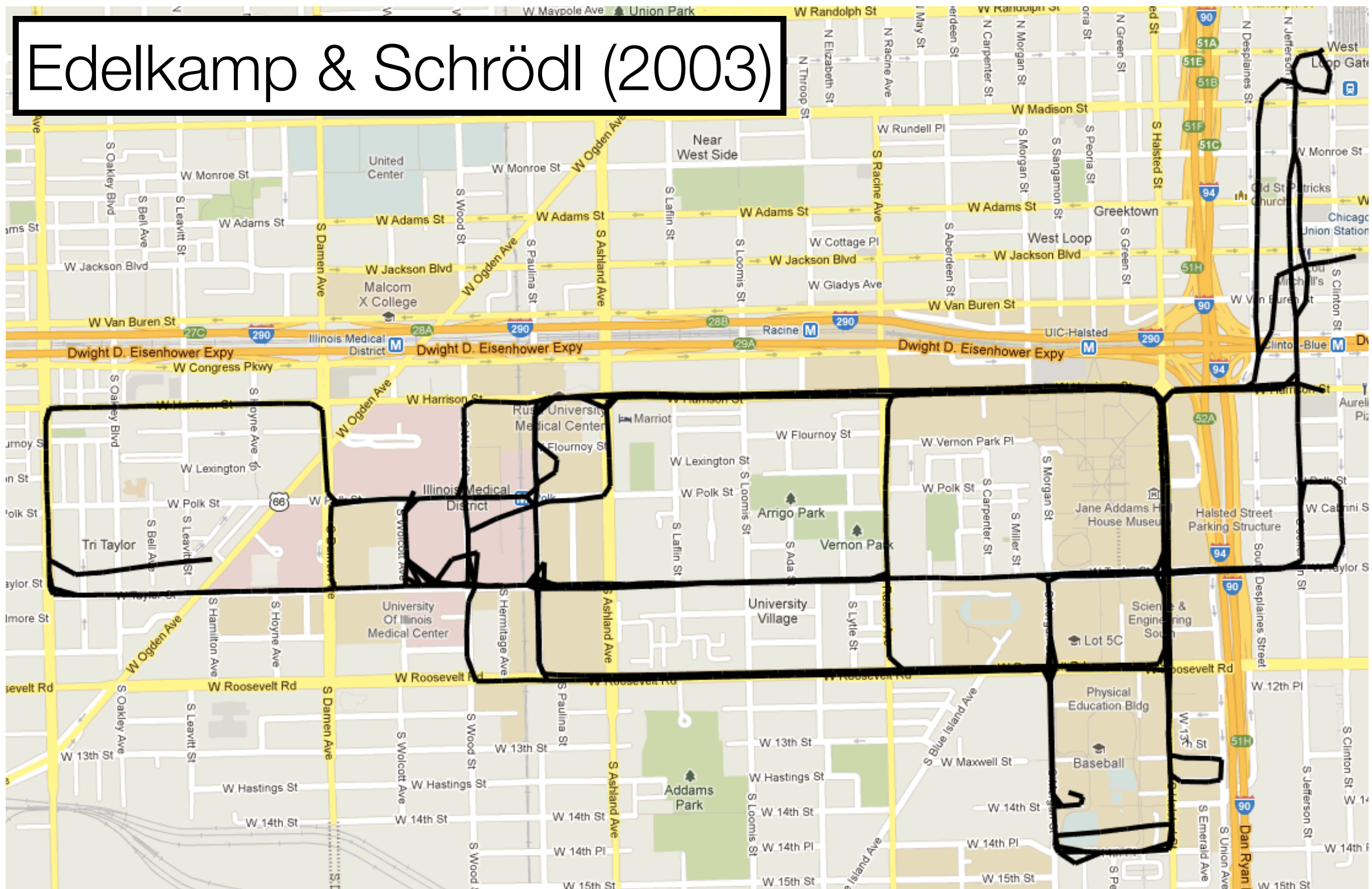


Precision/recall

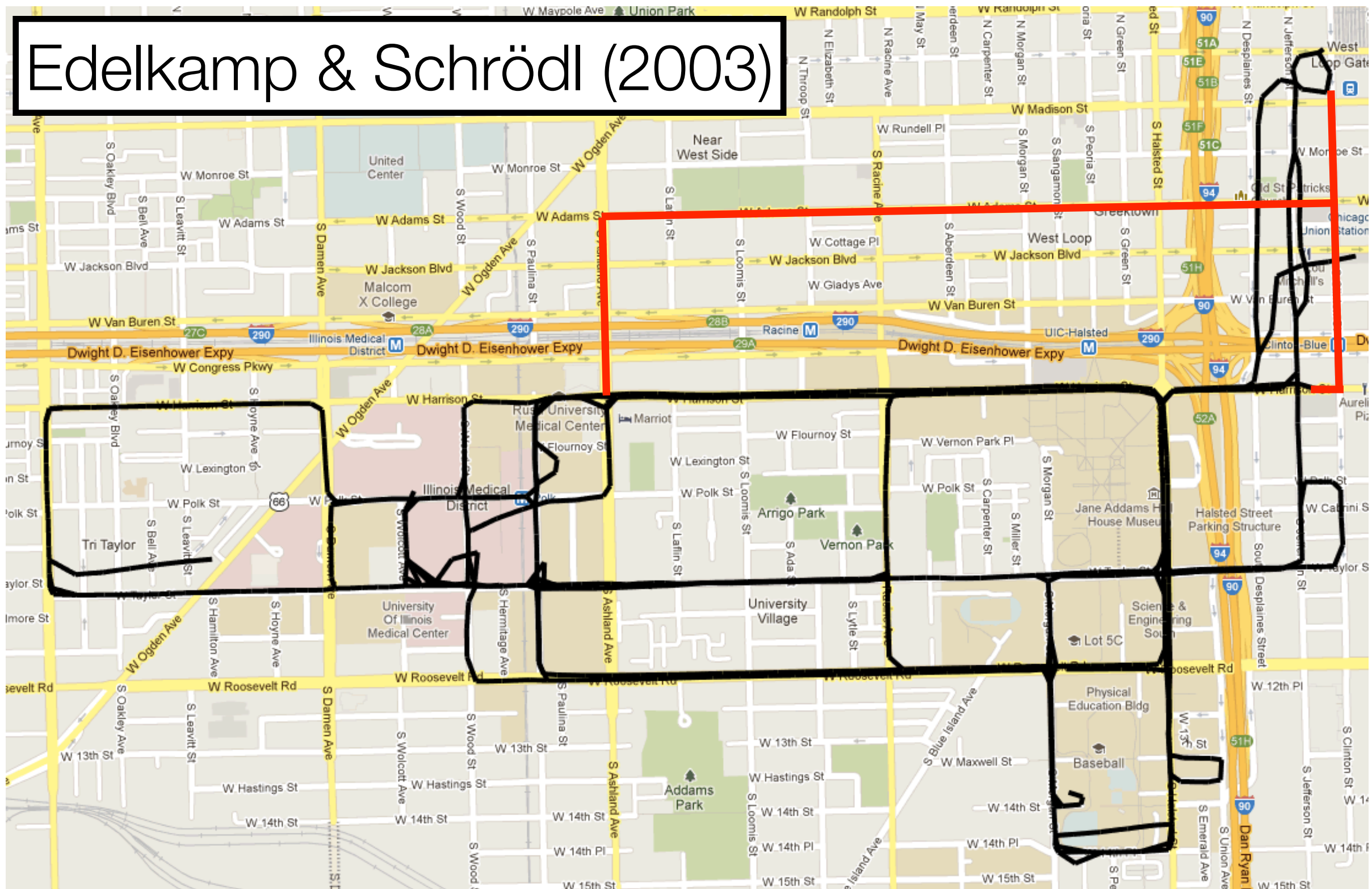


Qualitative Evaluation

Edelkamp & Schrödl (2003)



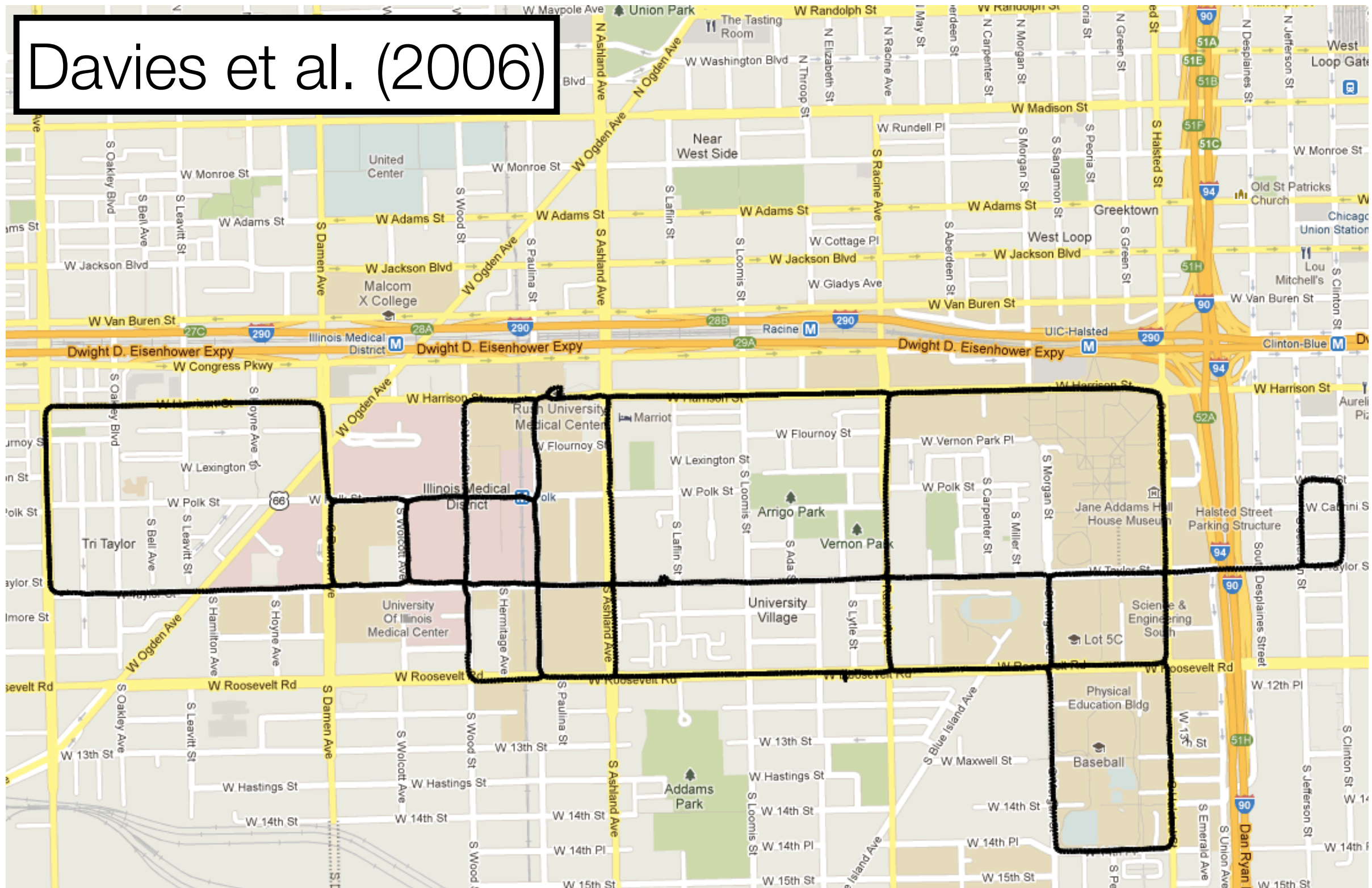
Edelkamp & Schrödl (2003)



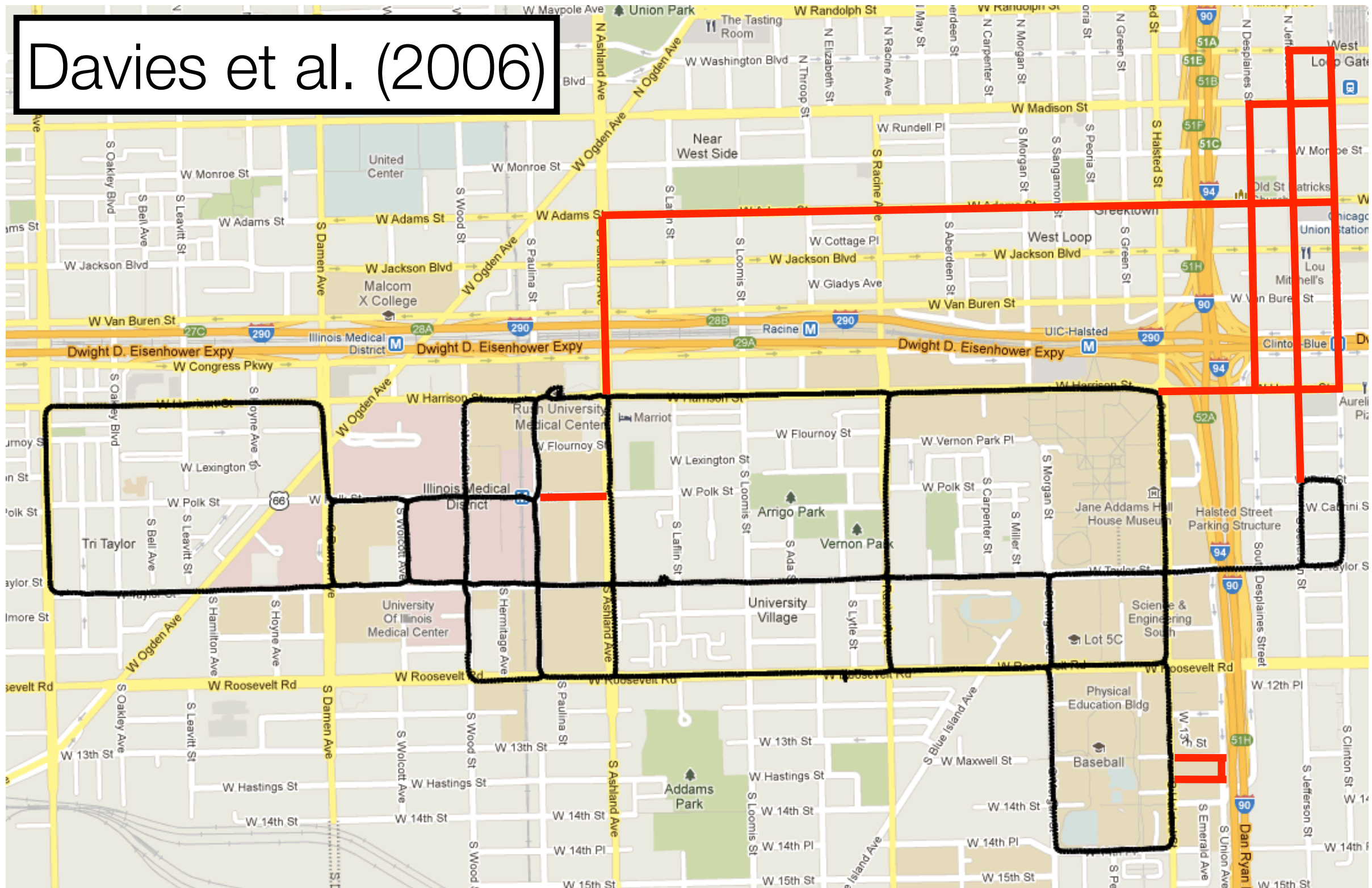
Edelkamp & Schrödl (2003)

The map shows a section of Chicago, Illinois, with a black outline delineating a specific urban area. Within this outlined area, a red rectangle highlights the Illinois Medical District. The map includes major roads such as the Dwight D. Eisenhower Expressway (I-55) and the Dan Ryan Expressway (I-90). Key landmarks and institutions are labeled, including the United Center, Malcom X College, Illinois Medical District, Rush University Medical Center, and various parks like Arrigo Park and Addams Park. The map also shows the locations of several hospitals and medical facilities, as well as the Chicago Union Station and the Chicago Loop Gate.

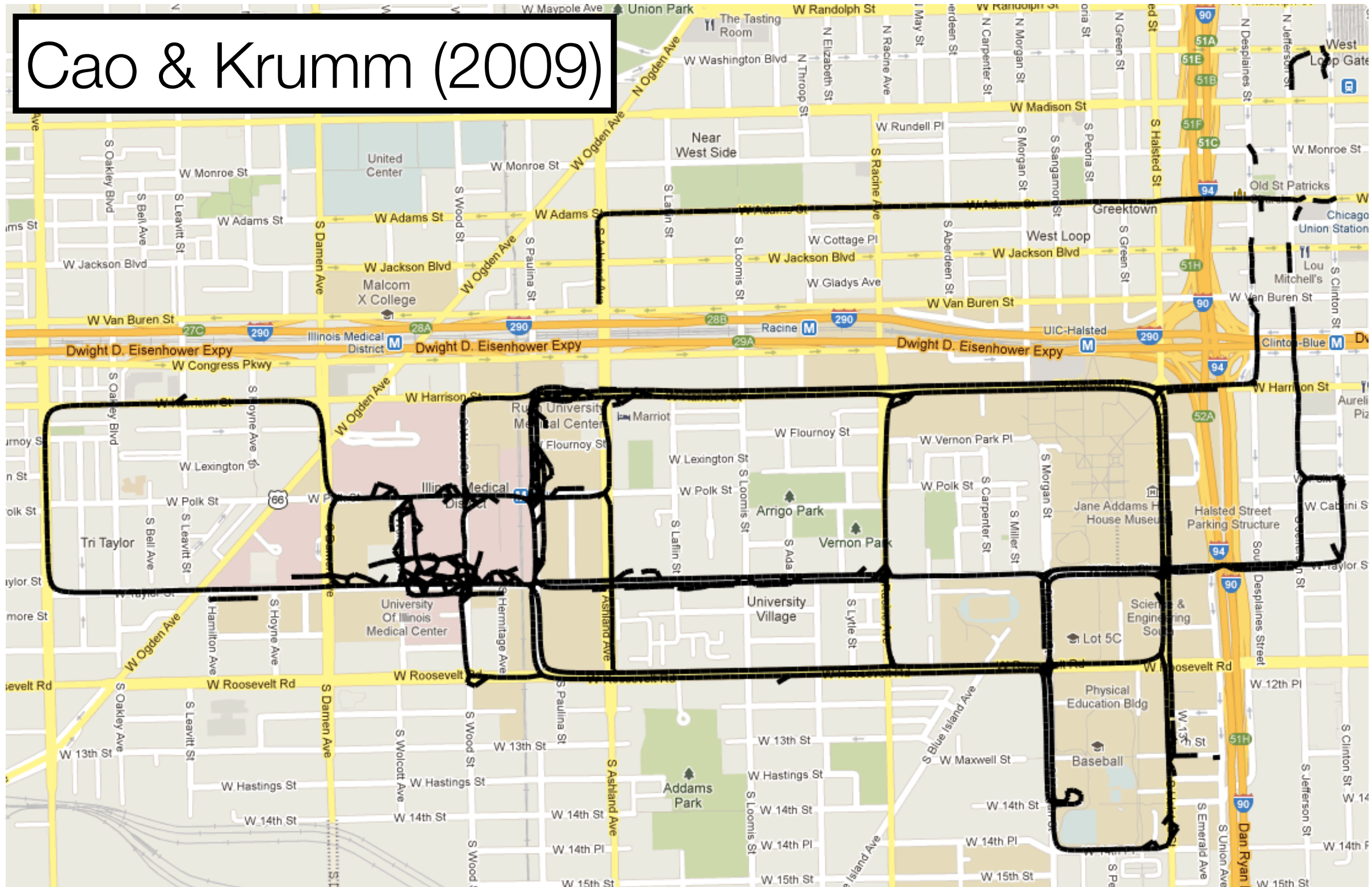
Davies et al. (2006)



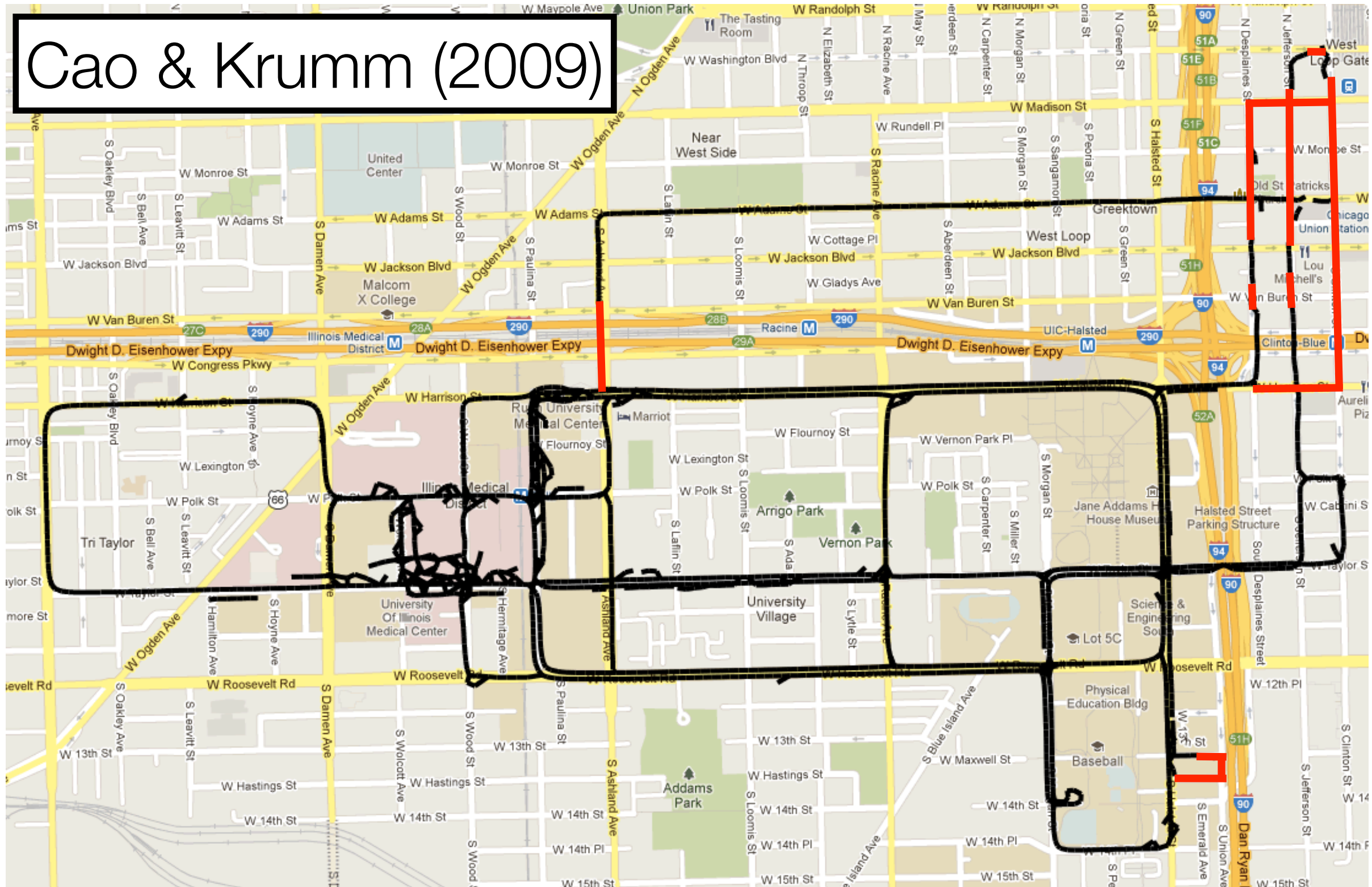
Davies et al. (2006)



Cao & Krumm (2009)



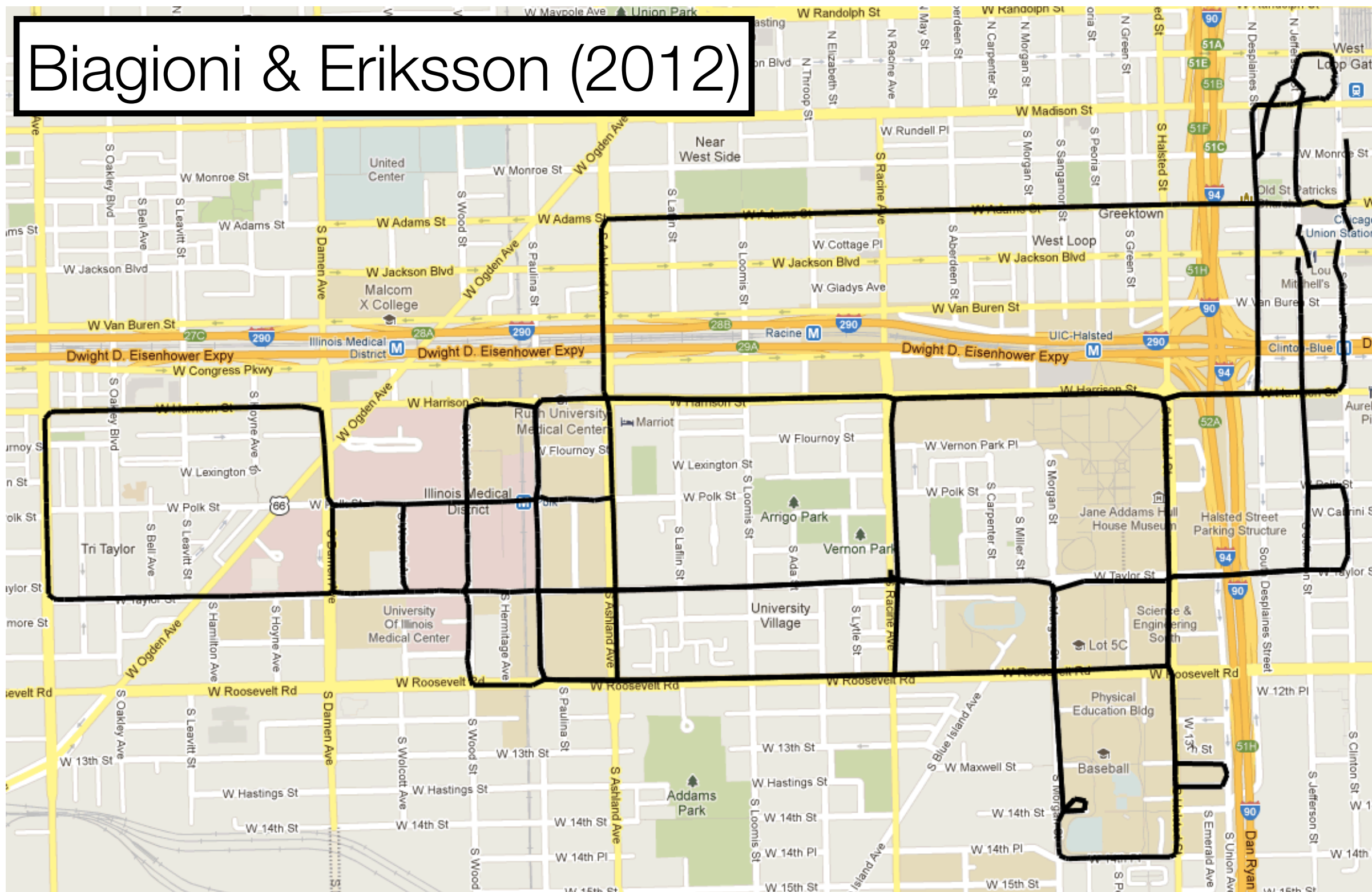
Cao & Krumm (2009)



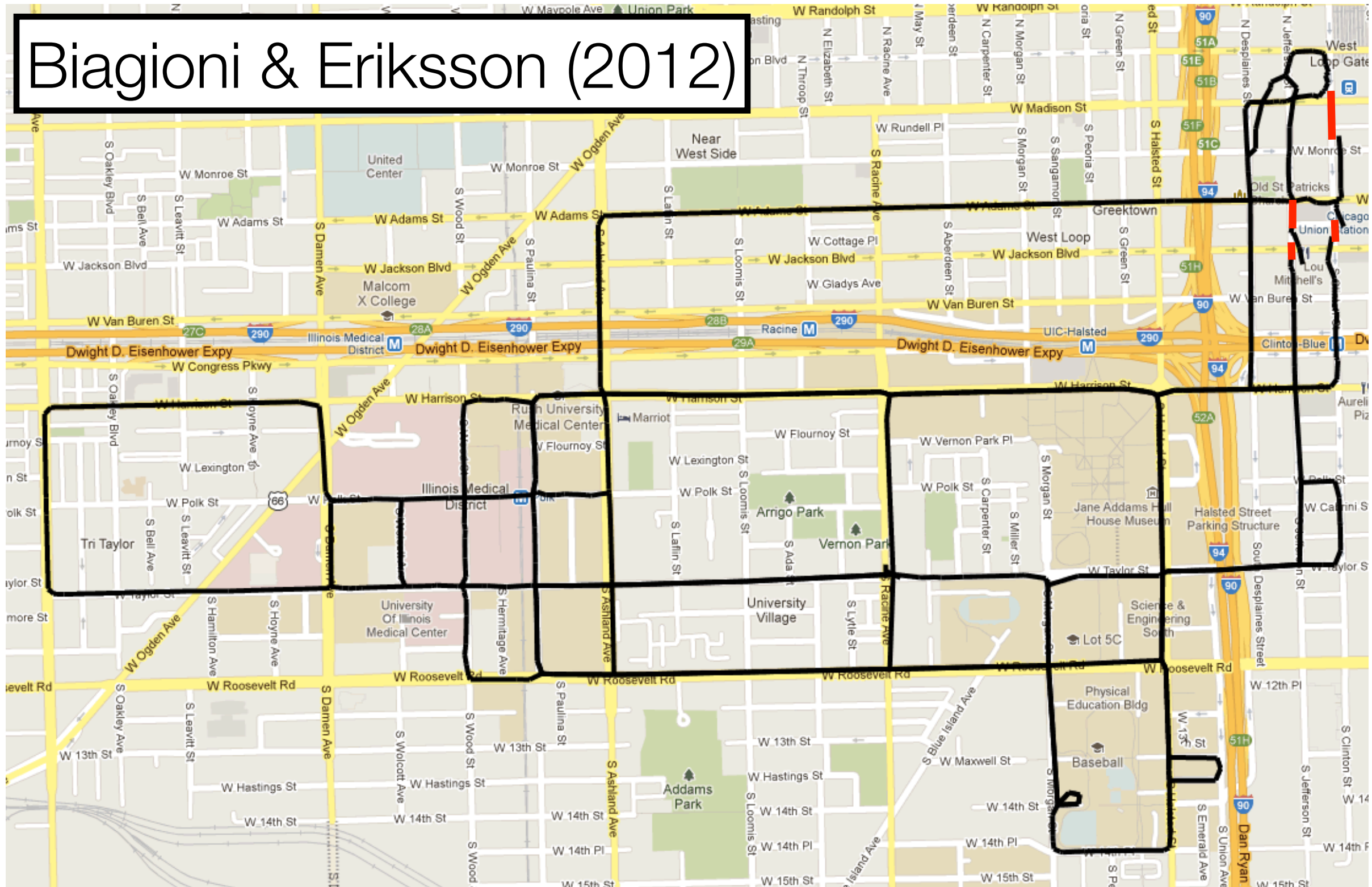
Cao & Krumm (2009)

The map displays the University City area in Chicago. A large black-outlined region covers the area from W Adams St to W 15th St and from S Oakley Ave to S Union Ave. A smaller red-outlined region is located within the black region, centered around the intersection of W Jackson Blvd and S Oakley Ave. The map includes labels for streets, parks, and landmarks.

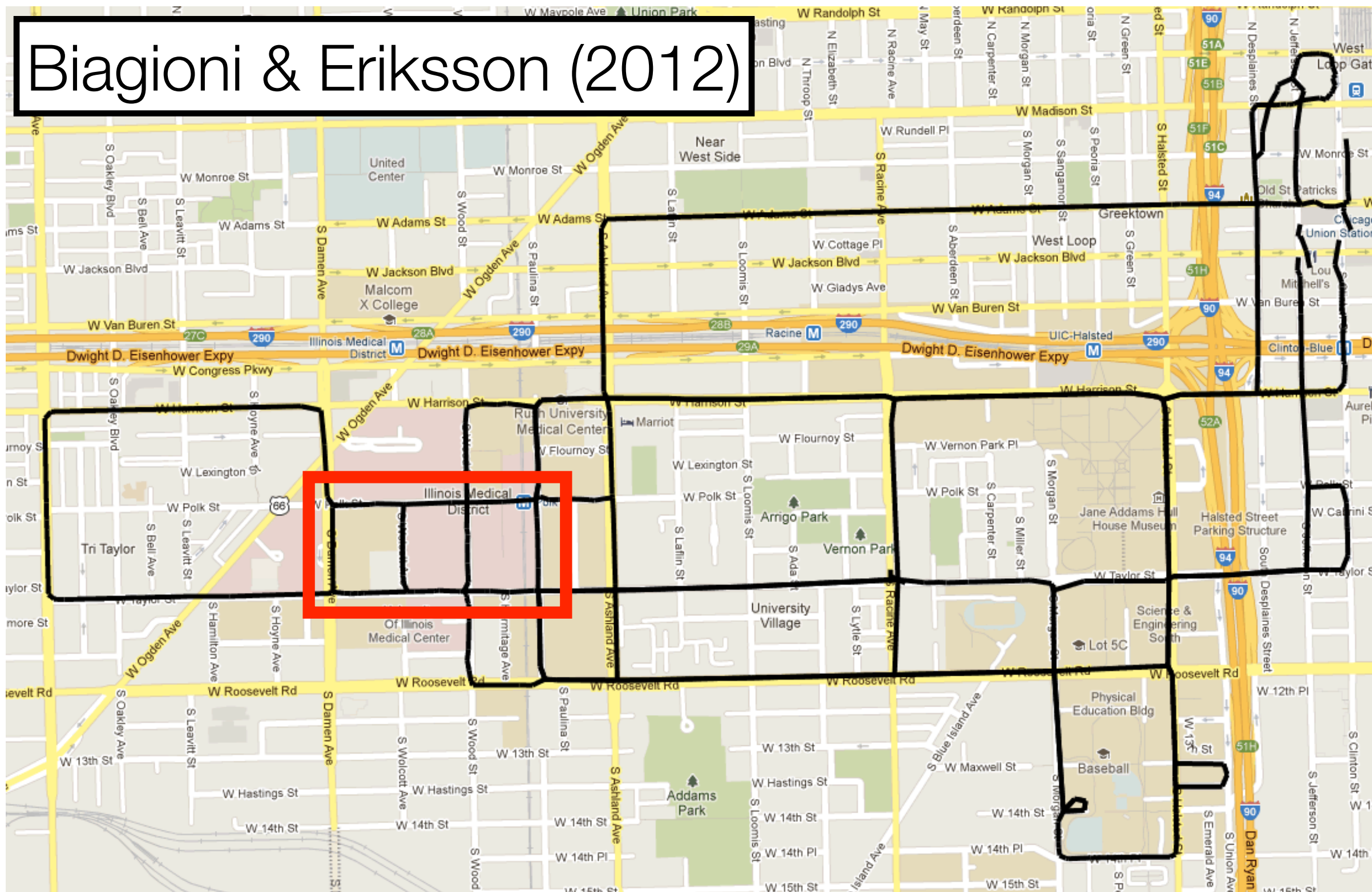
Biagioni & Eriksson (2012)



Biagioni & Eriksson (2012)



Biagioni & Eriksson (2012)



Future work



Thanks!

Questions?

Source code and data available

<http://bits.cs.uic.edu>