



Finding, Extracting, and Integrating Data from Maps



Craig Knoblock

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and
Geosemble Technologies



Acknowledgements

- **Finding Maps**

- Joint work with Matthew Michelson, Vipul Verma (IIT IIT Kharagpur), Aman Goel, and Sneha Desai

- **Extracting Data From Maps**

- Joint work with Yao-Yi Chiang, Jason Chen (Geosemble), Cyrus Shahabi

- **Integrating Maps with Satellite Imagery**

- Joint work with Jason Chen (Geosemble) and Cyrus Shahabi

- **Research Sponsors:**

- Air Force Office of Scientific Research
 - Microsoft

Problem: How to Find, Extract, and Align Maps and Imagery

Lat / Long



Lat / Long

?





Why This is Important

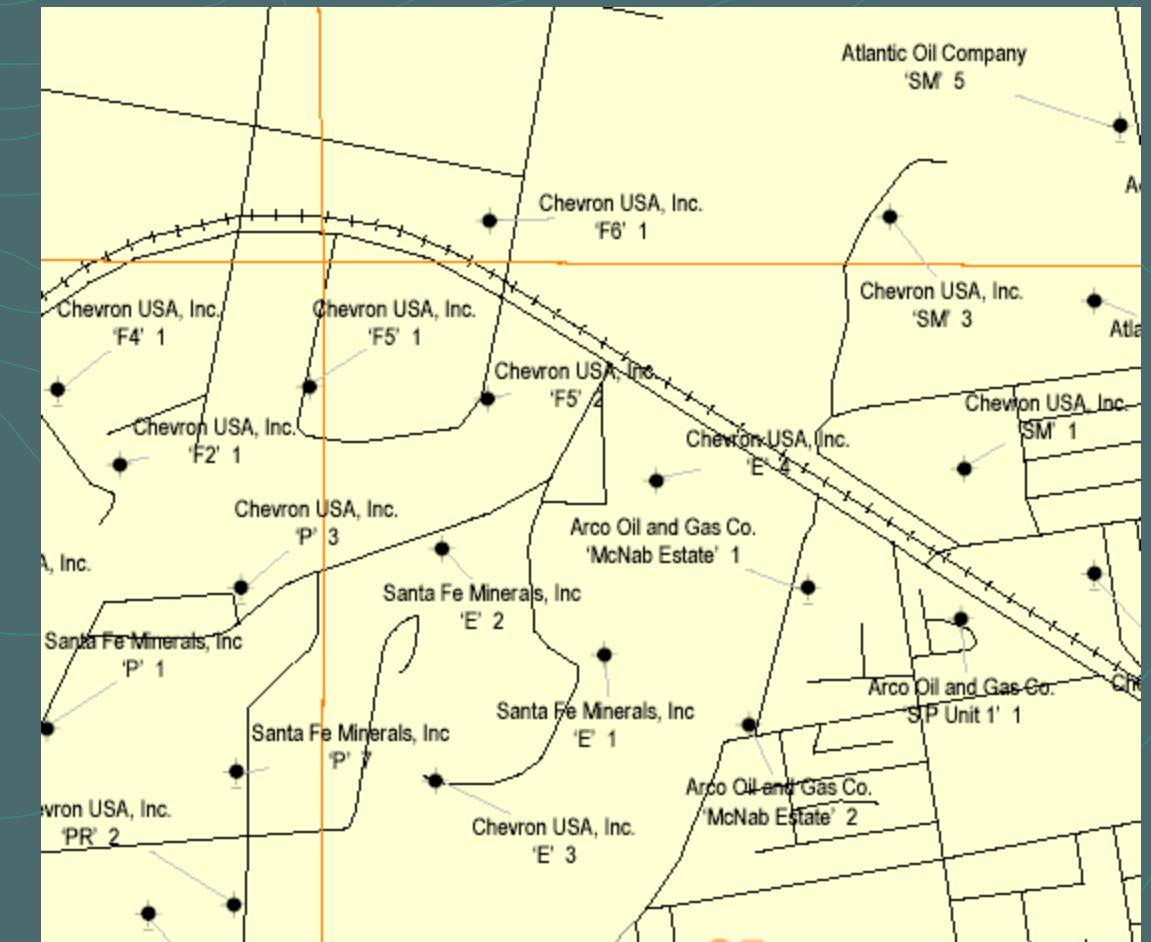
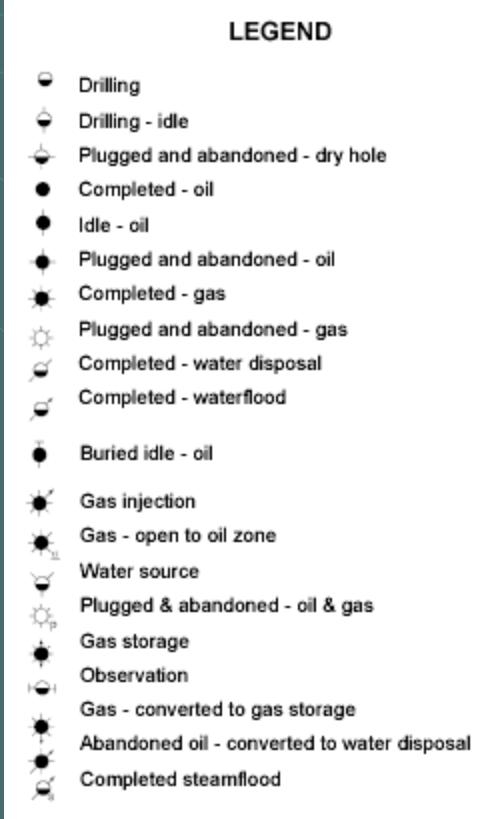
- There is lots of map data available in mapping systems, such as GoogleMaps, Mapquest, etc., but
 - These systems don't cover the world (no coverage for Iraq in GoogleMaps)
 - There are many types of maps that are not available in these systems (parcel maps, oil field maps, utility maps)
- There is a great deal of information locked up in raster maps
 - Road networks, utility lines, locations of abandoned oil wells, etc.
 - Names of features: roads, buildings, rivers, parks, etc.

Washington DC Transportation Map

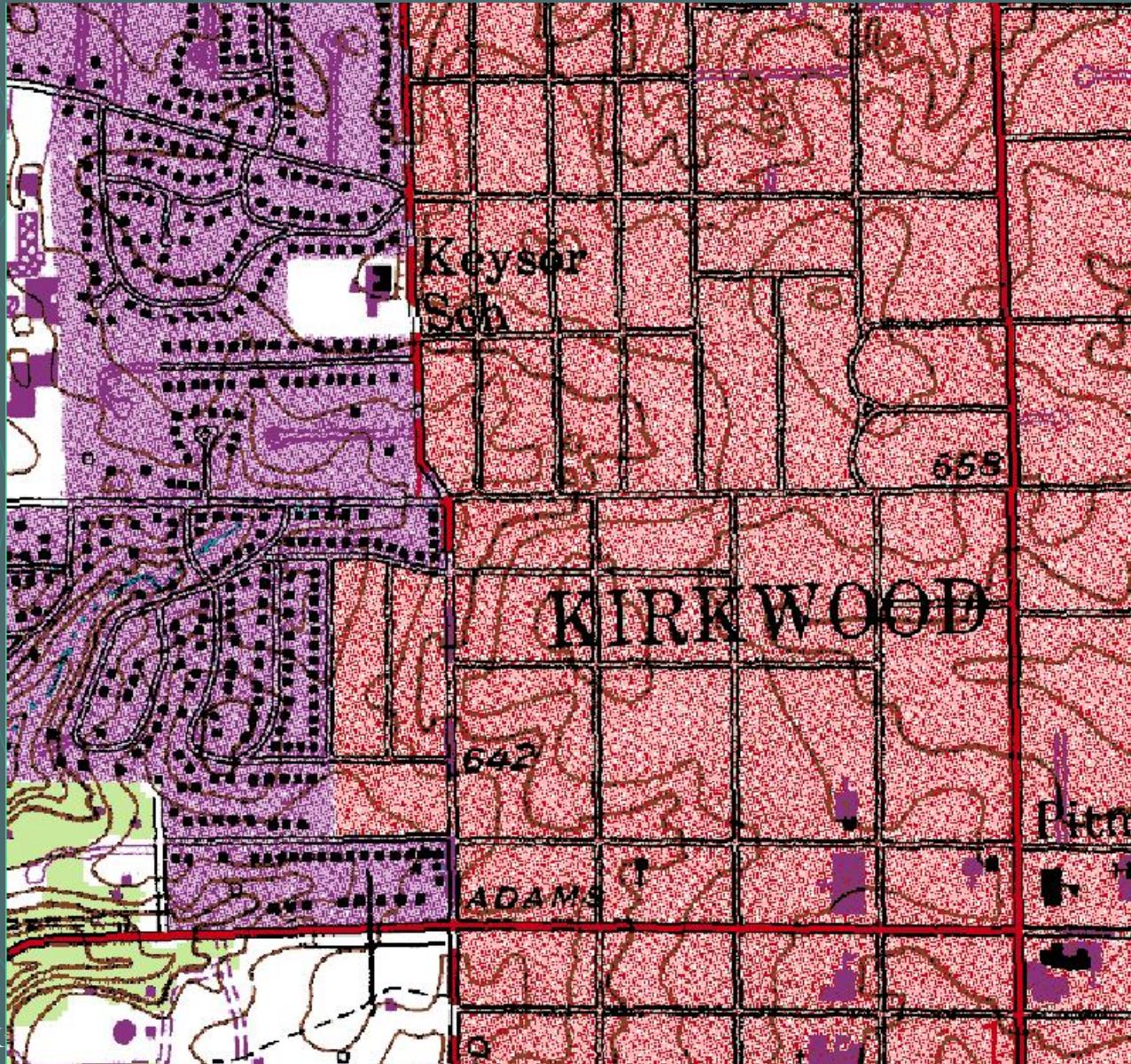


Oil Field Map

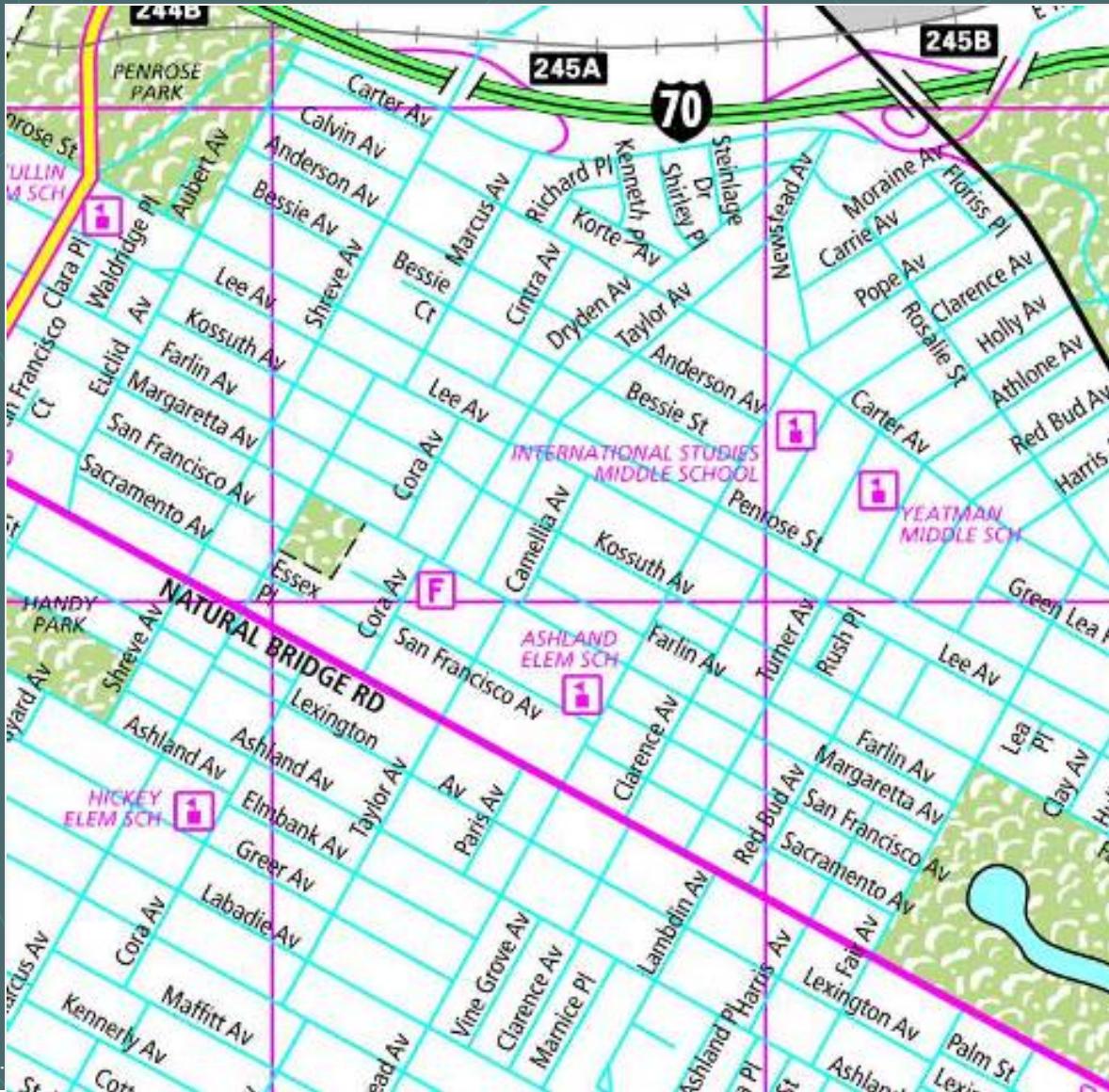
California Dept. of Conservation



USGS Topographic Map



Rand McNally Map



Craig A.



Outline

- Finding Maps
- Aligning Maps with Imagery
 - Extracting intersections
 - Point pattern matching
- Extracting Separate Layers from Maps
- Conclusions

Introduction and Motivation

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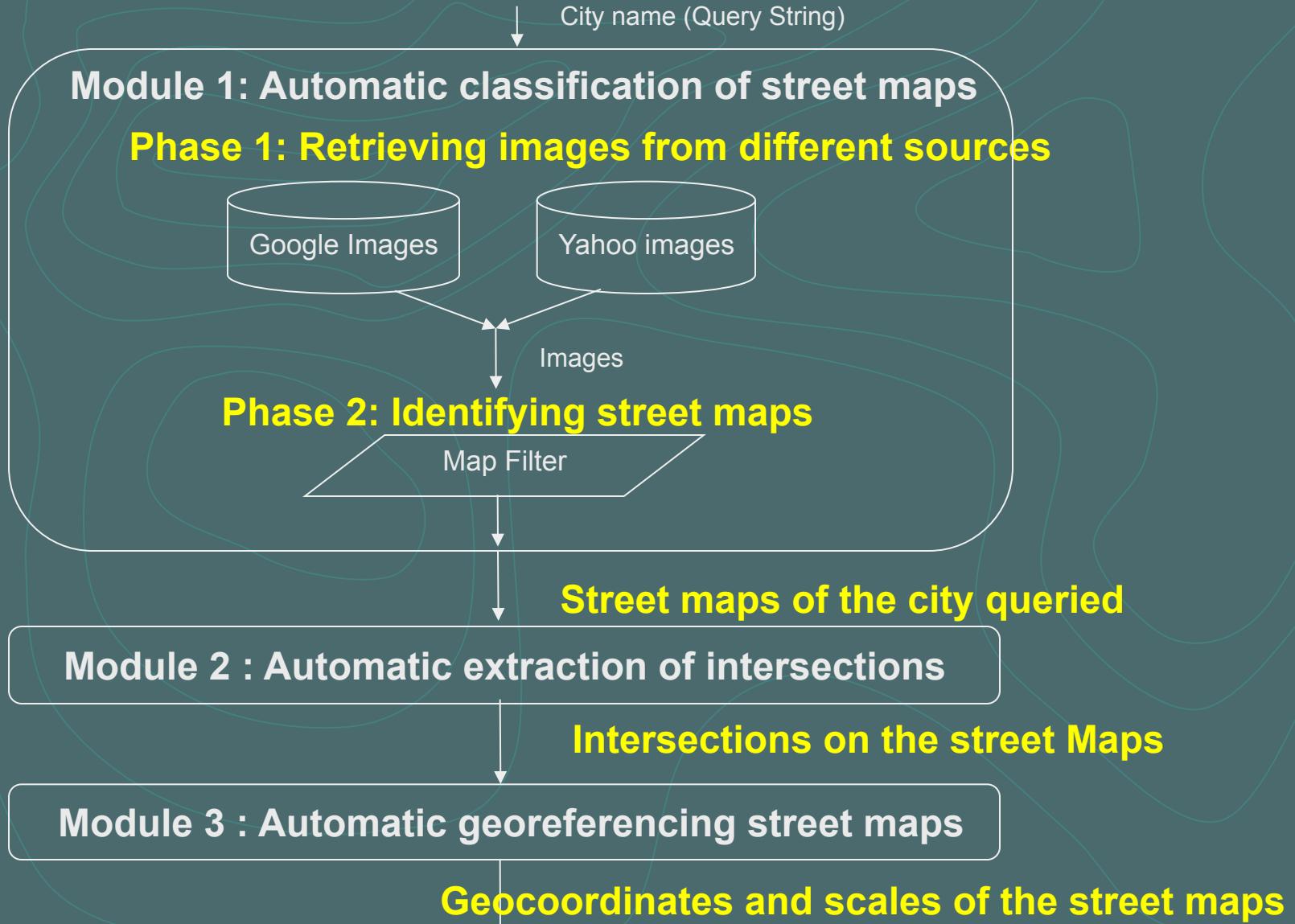
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Photographs

Political, state, area maps

Overall Approach





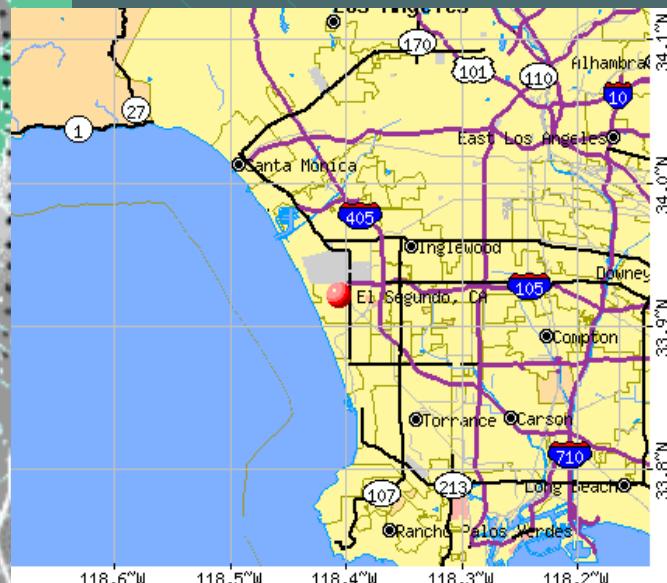
Identifying Street Maps

- Law's Texture Classification Algorithm
 - (K. Laws. 1980)
- Street maps have unique textures
 - lines, labels, characters
- Generate 75 different attributes (25R,25G,25B) to distinguish these textures on the images

Law's Texture Classification Algorithm

(K. Laws. 1980)

- Use different types of masks on the image to identify different textures for example,
 - For horizontal lines :

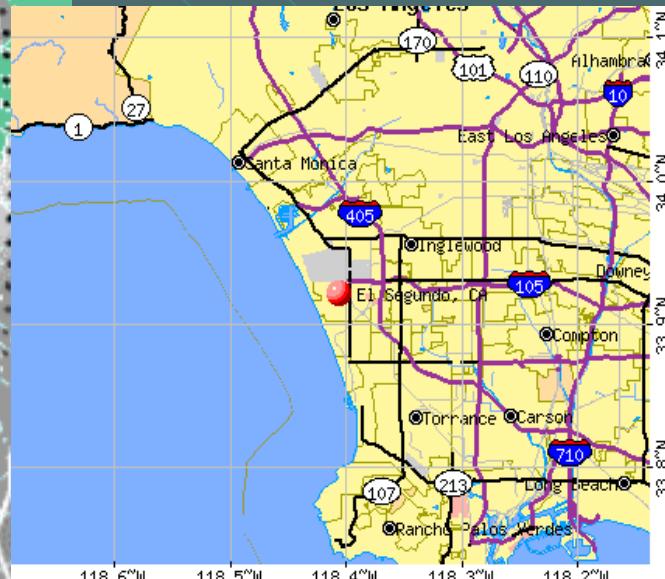


Original Image

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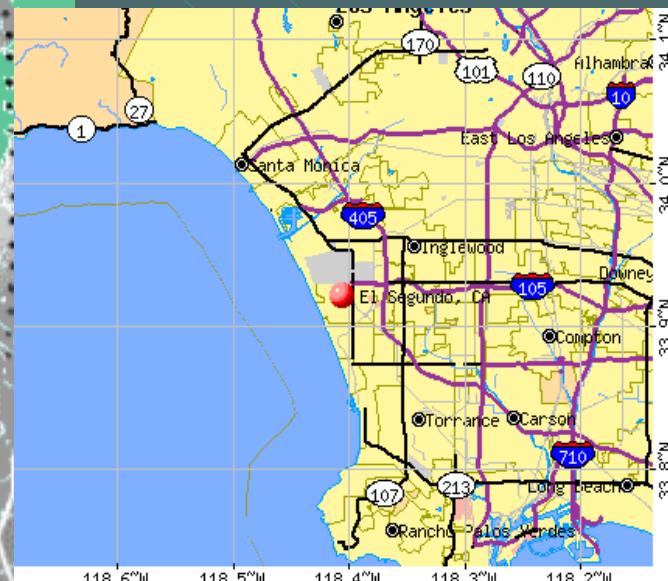
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-1	0	-1

Apply mask

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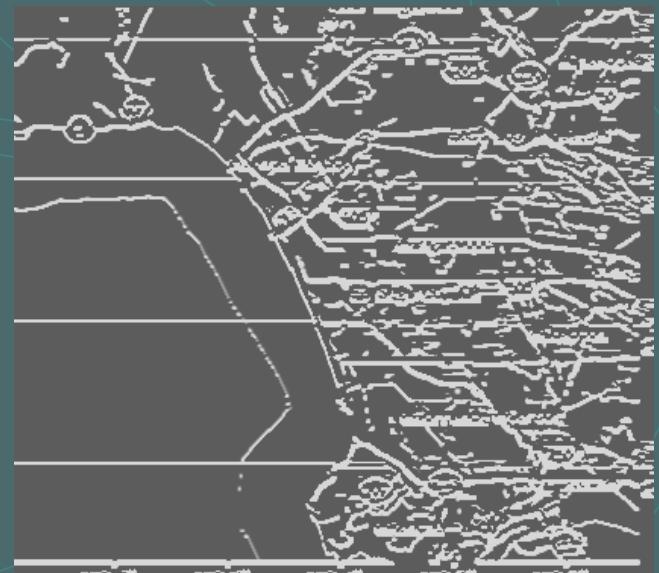
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Original Image

-1	0	-1
2	0	2
-1	0	-1

Apply mask



Resulting Image with horizontal lines



Identifying Street Maps

- Support Vector Machine (Joachims, 1999)
 - Machine learning classification
 - Given training examples labeled either "yes" or "no", SVM creates a hyperplane to separate data into two classes
 - The dimension of the hyperplane is the number of attributes



Identifying Street Maps

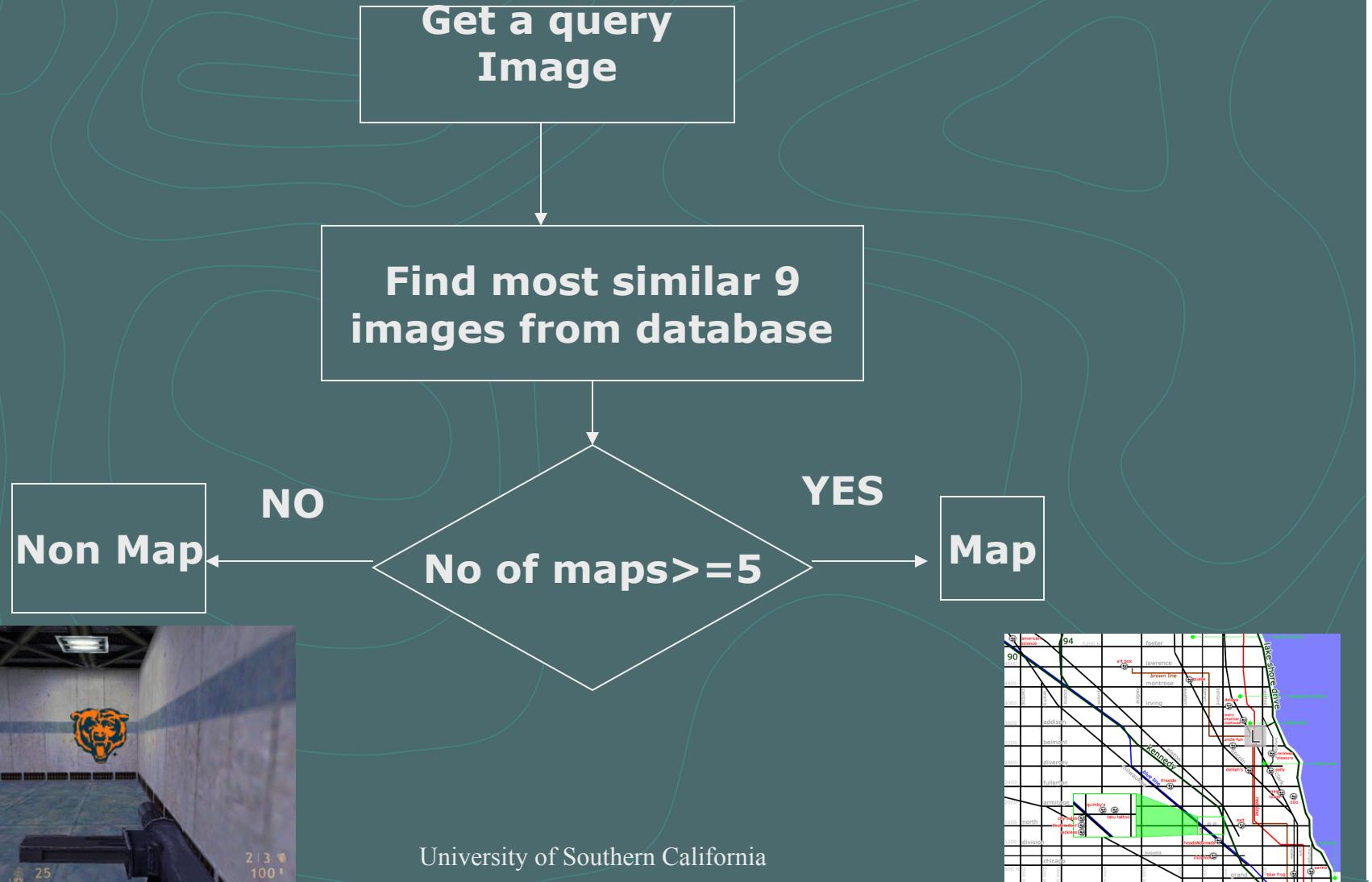
- We train on one set of images and test on a separate set of images
- Training :
 - We provided 1150 different positive and negative examples of images
 - 75 attributes per image
- Classification:
 - Using the trained SVM model to classify test images



Initial Results [Desai et al, 2005 ACMGIR]

- Worked well for identifying specific types of maps with 93% recall and 100% precision, but...
- When we trained on a wider range of maps the recall went up and the precision went down
- So we are moving to a new classification approach...

Content-Based Information Retrieval



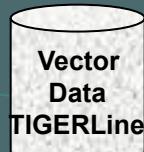
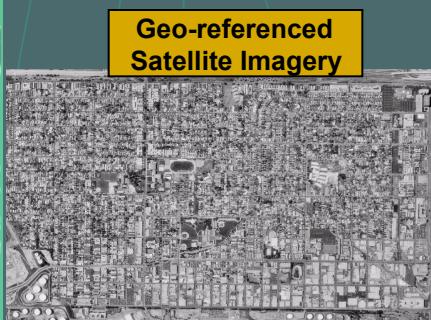


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- Aligning Maps with Imagery
 - Extracting intersections
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Aligning Maps with Imagery

- Utilize vector data as “glue” to automatically conflate imagery with maps

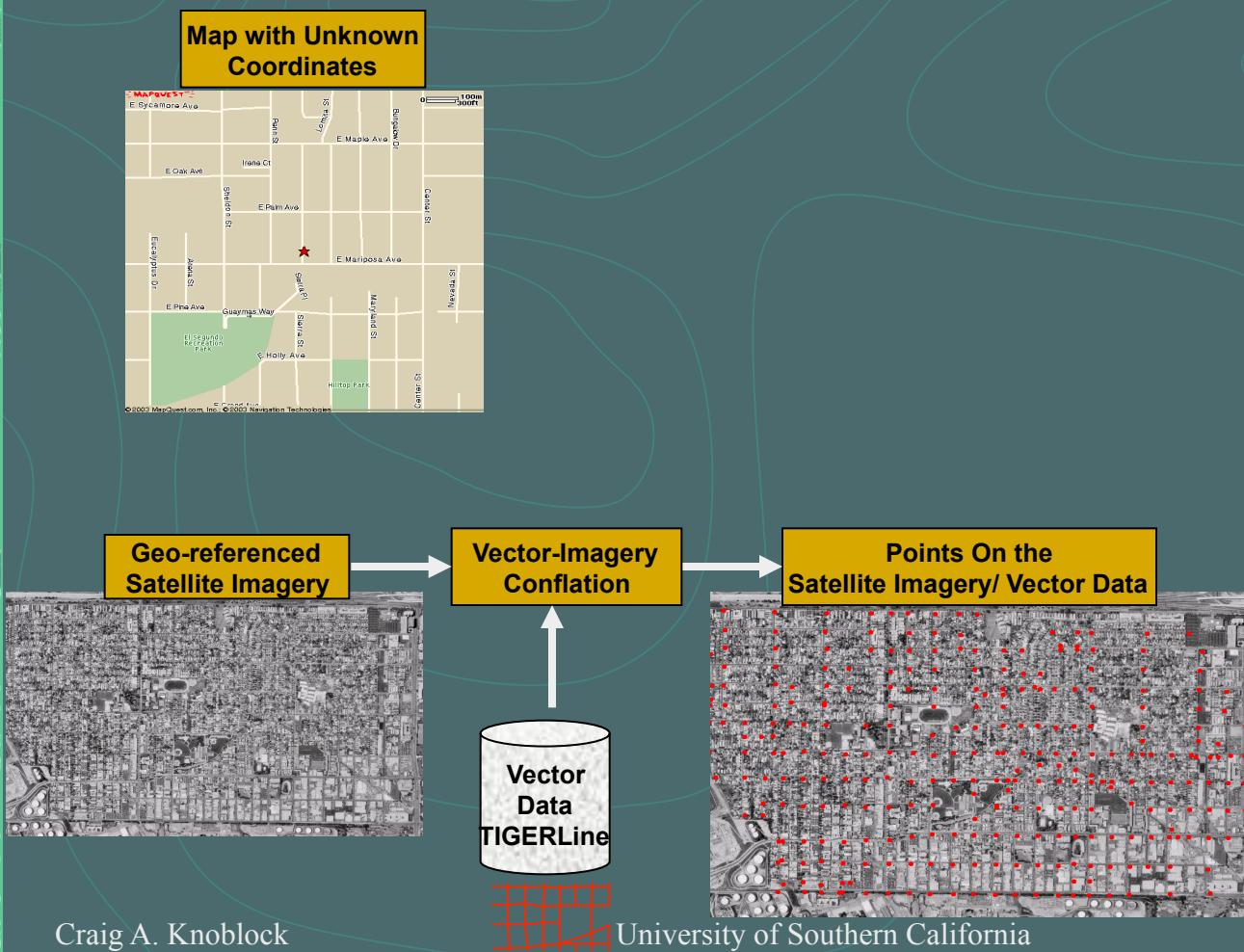


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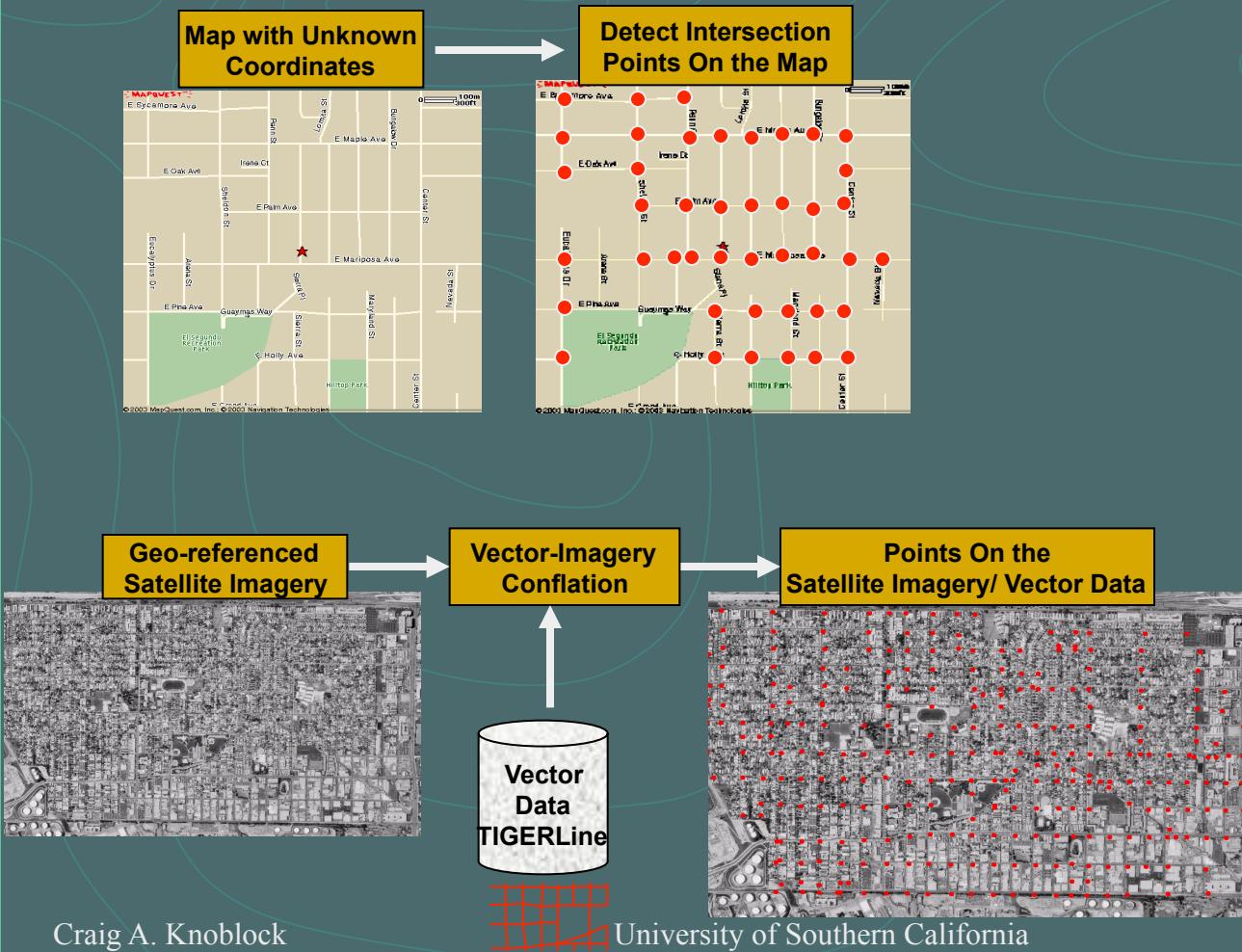
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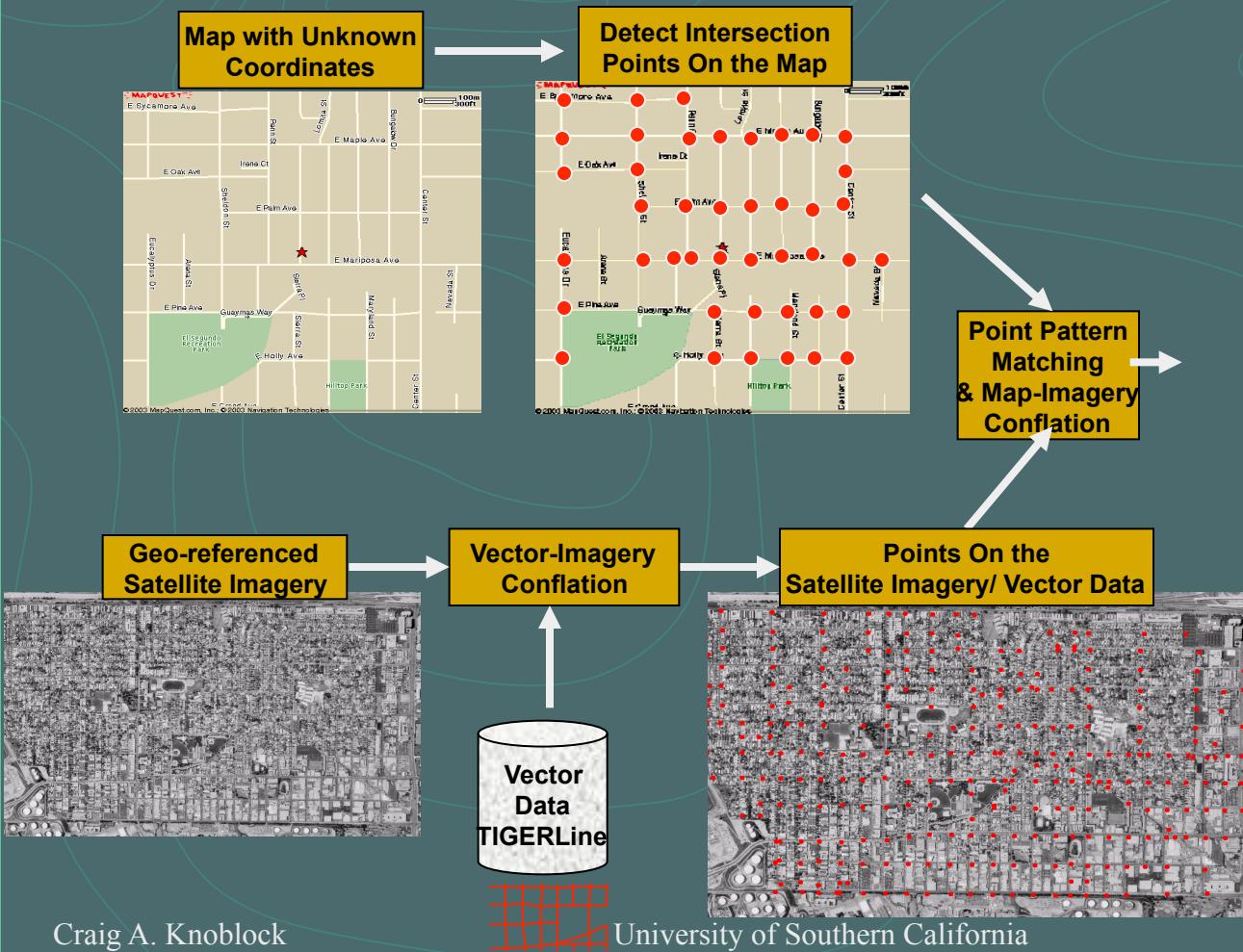
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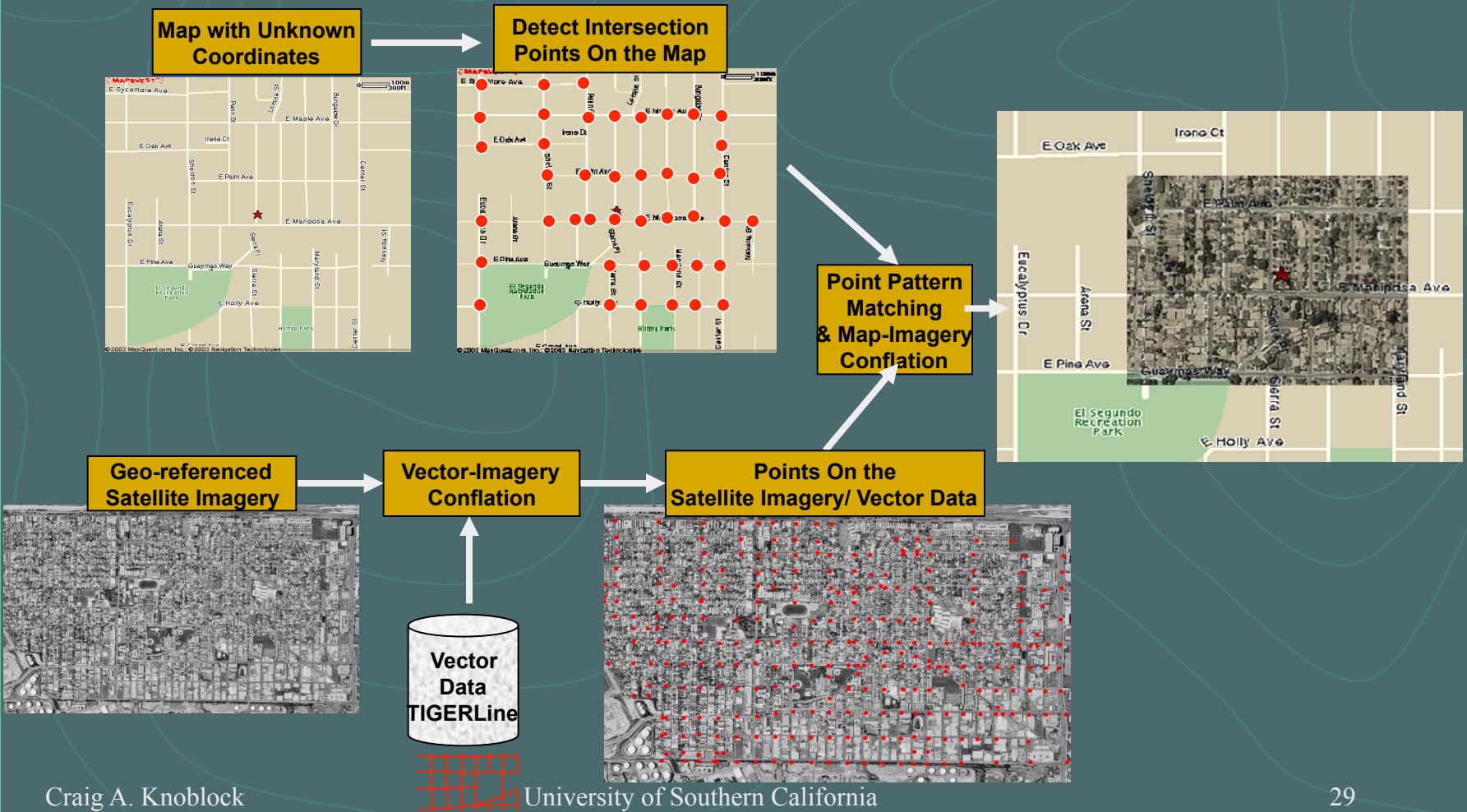
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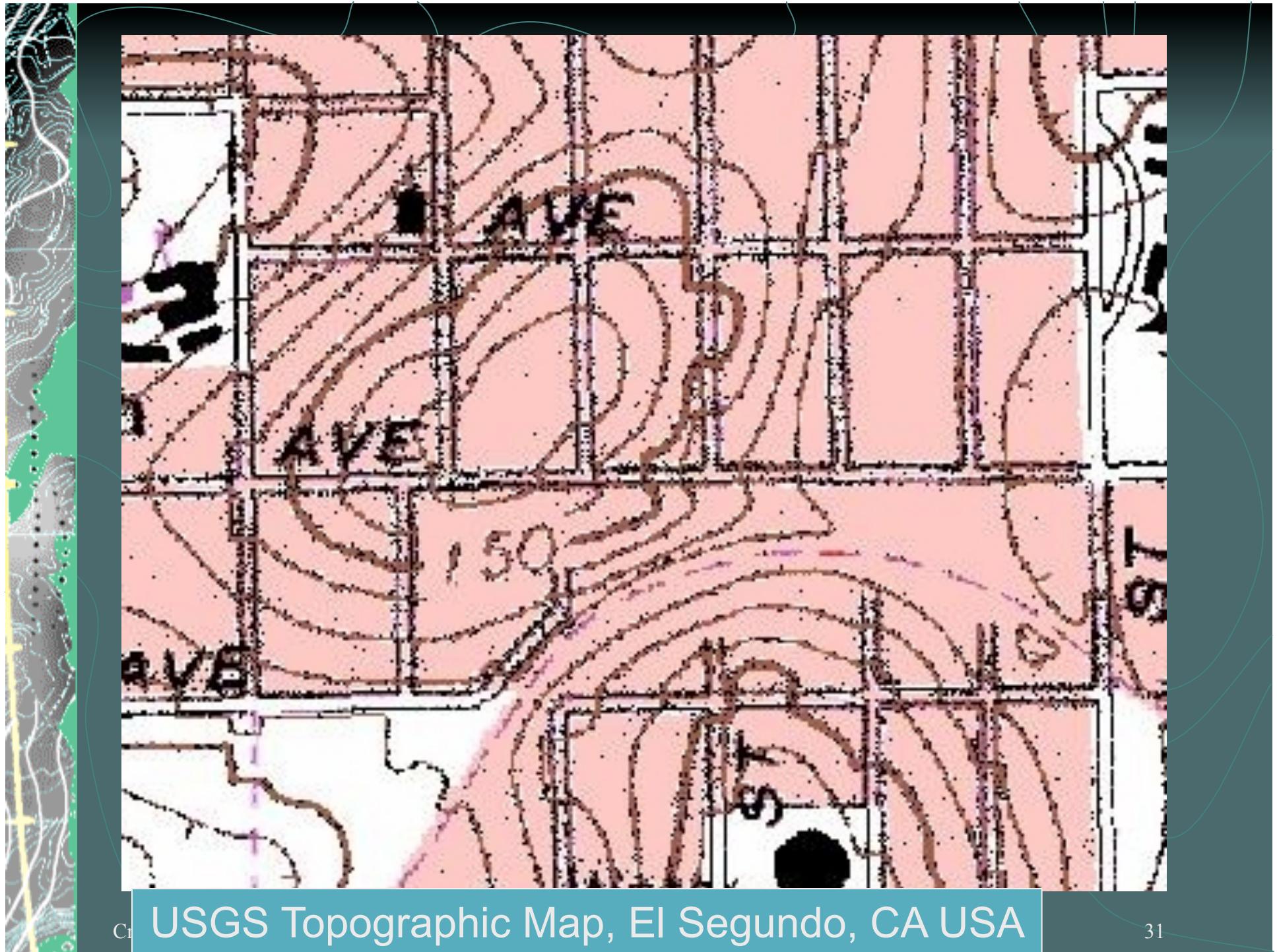
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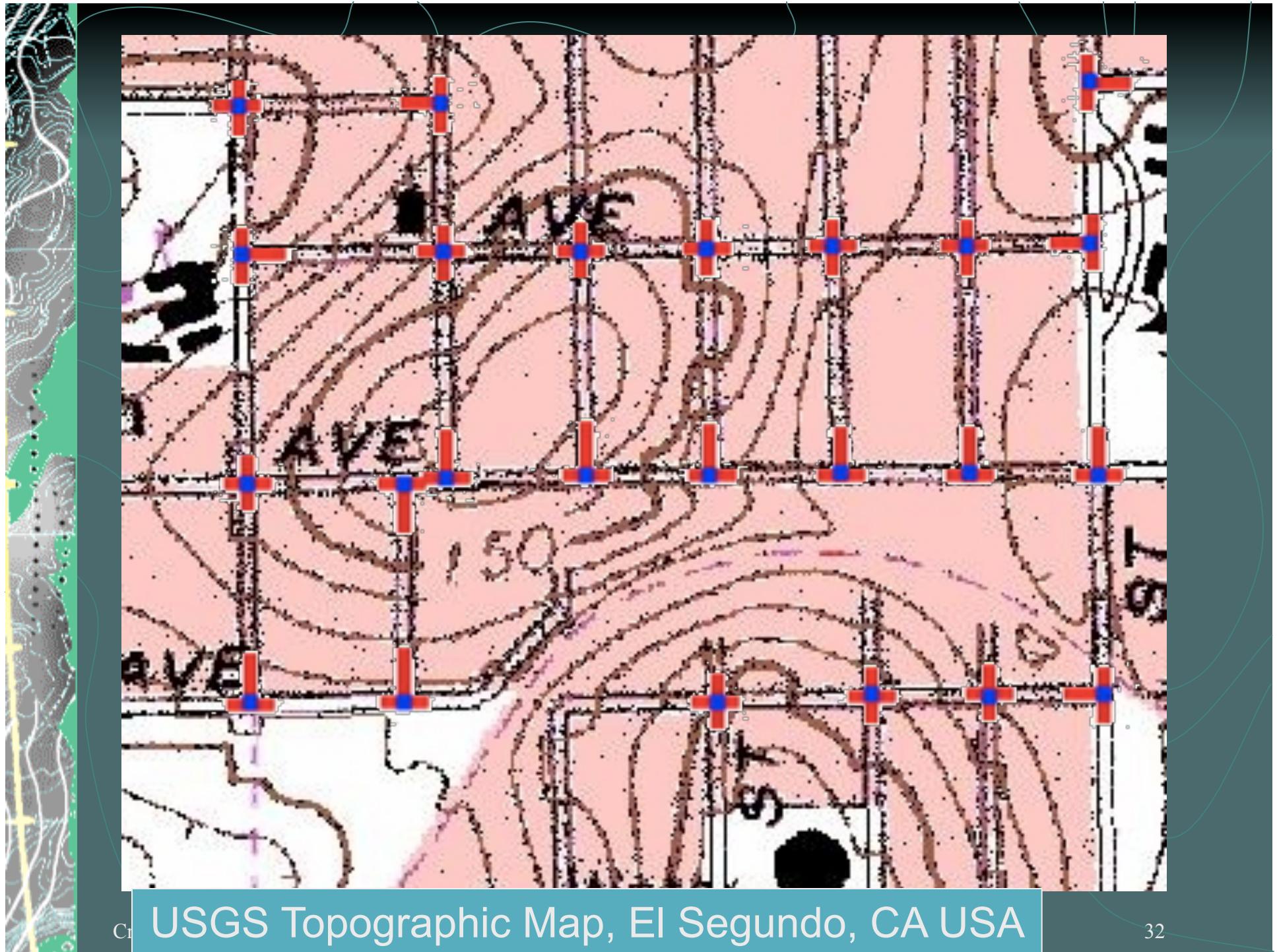


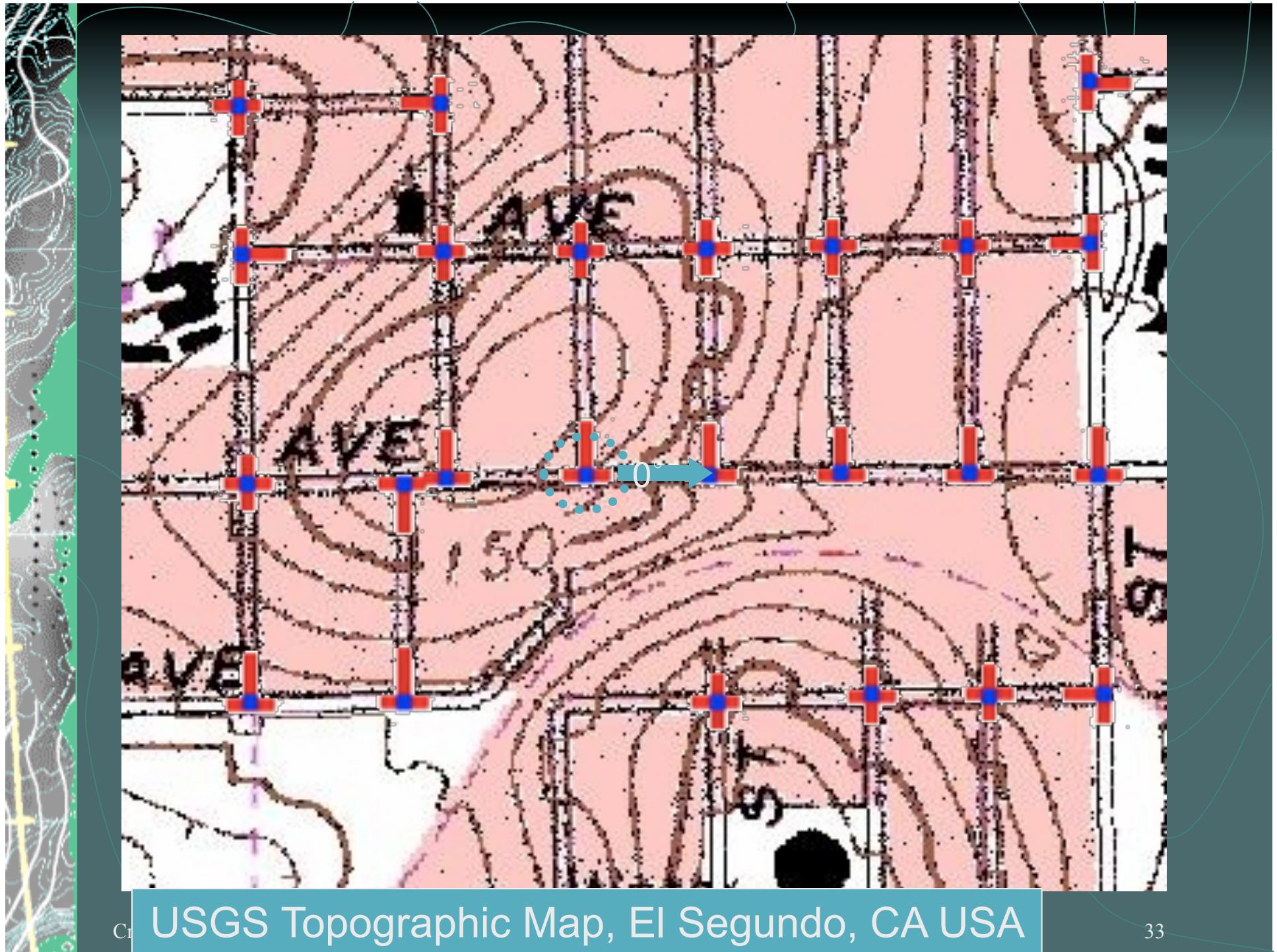


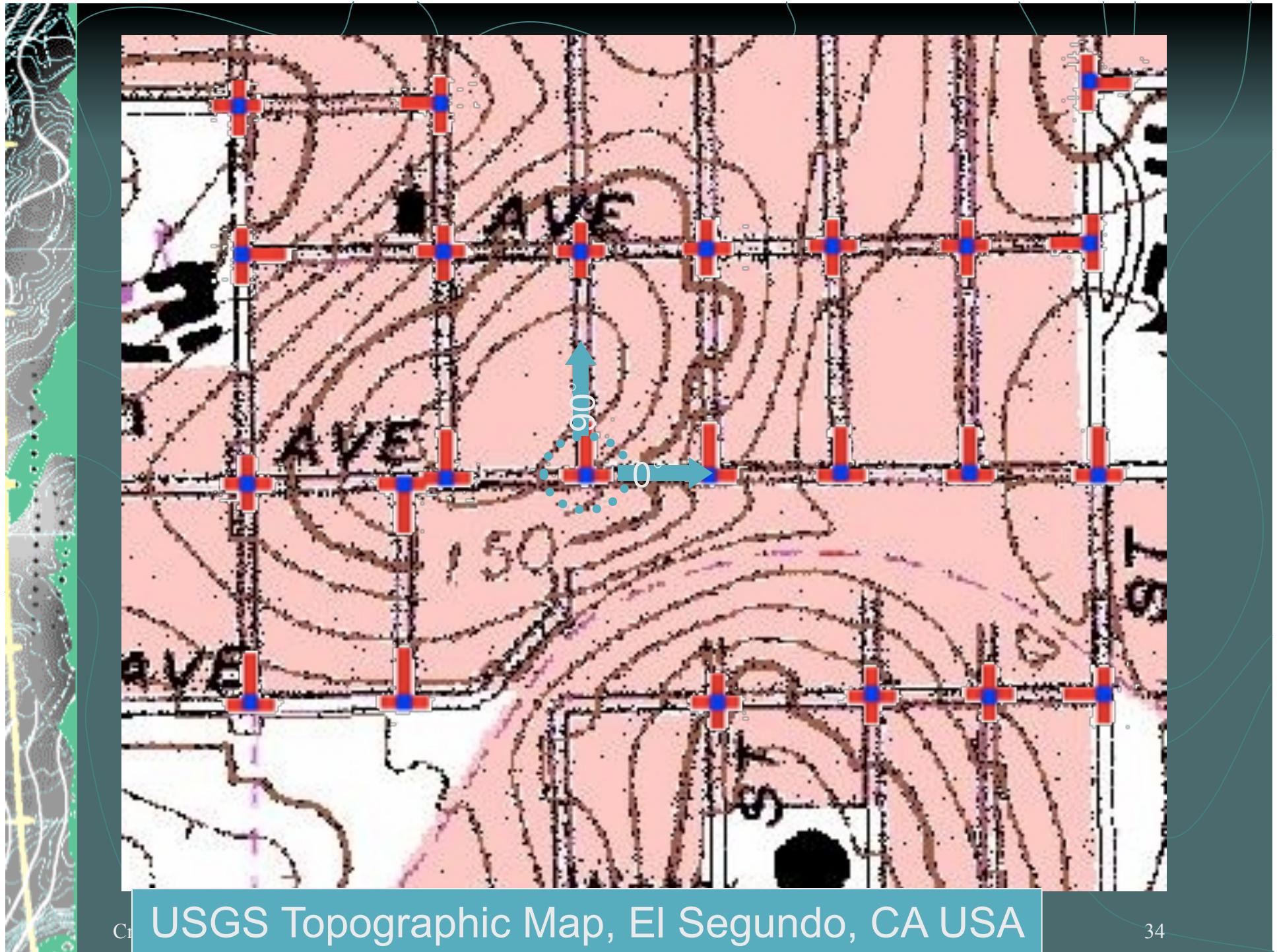
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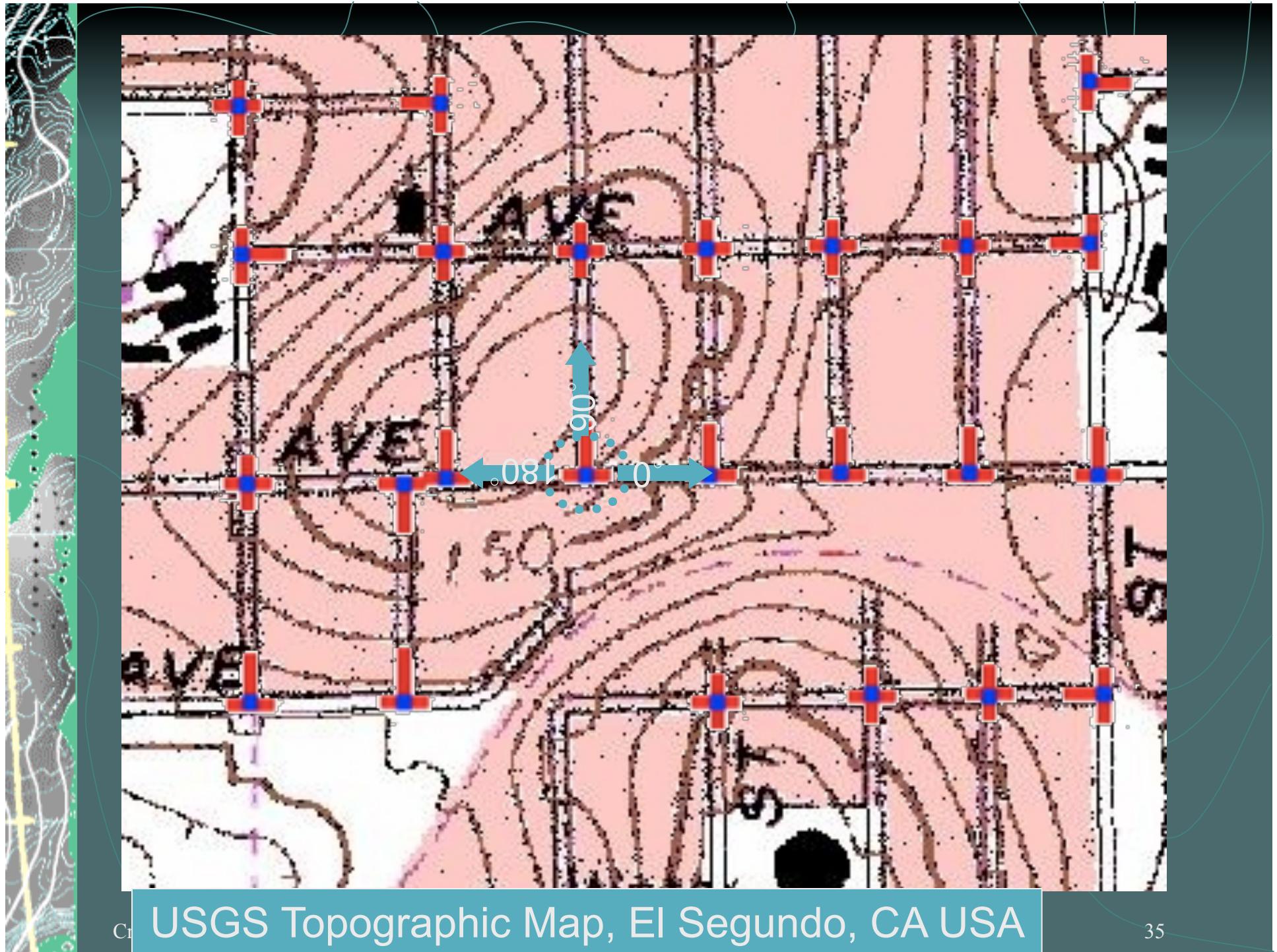
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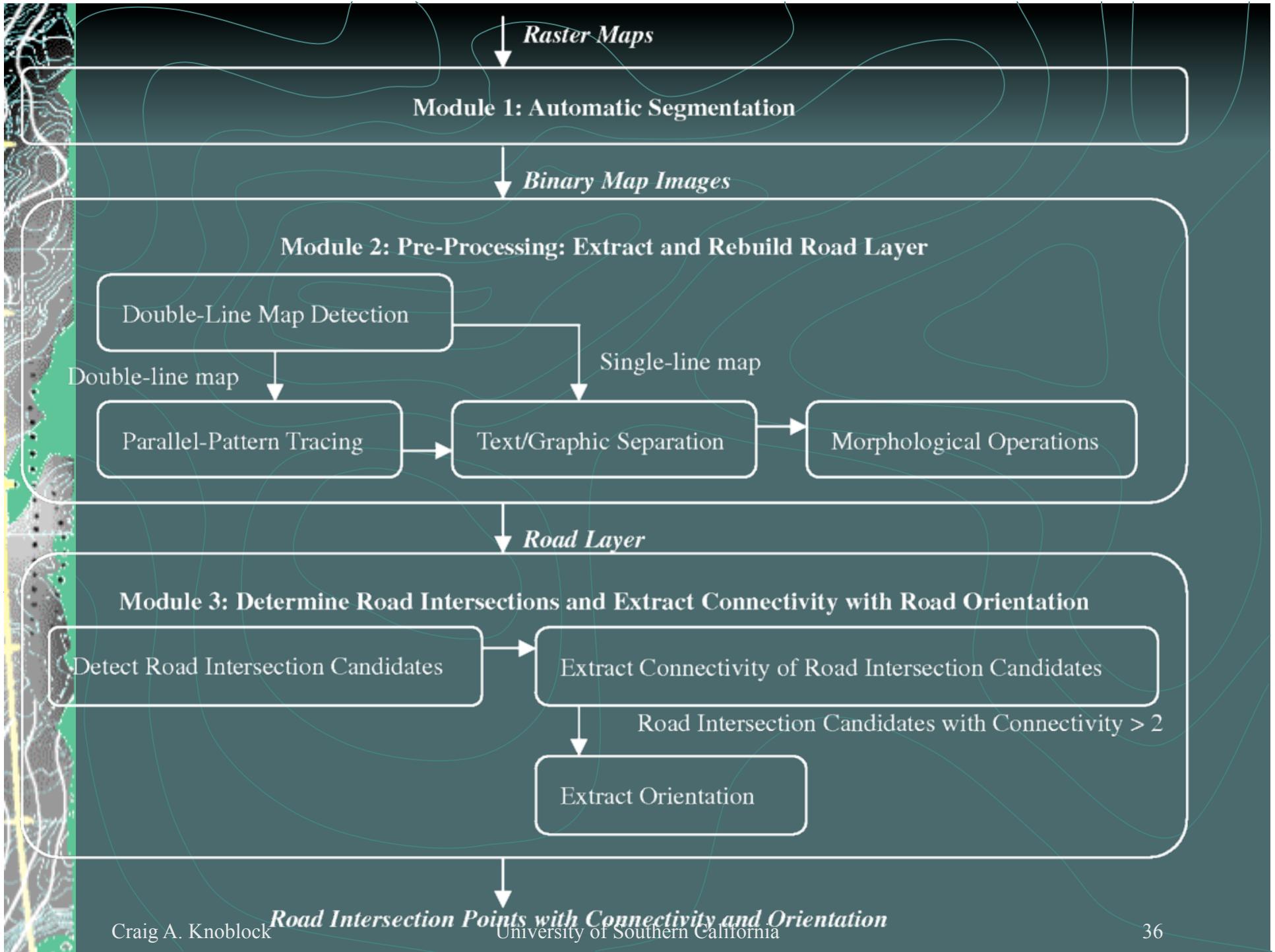


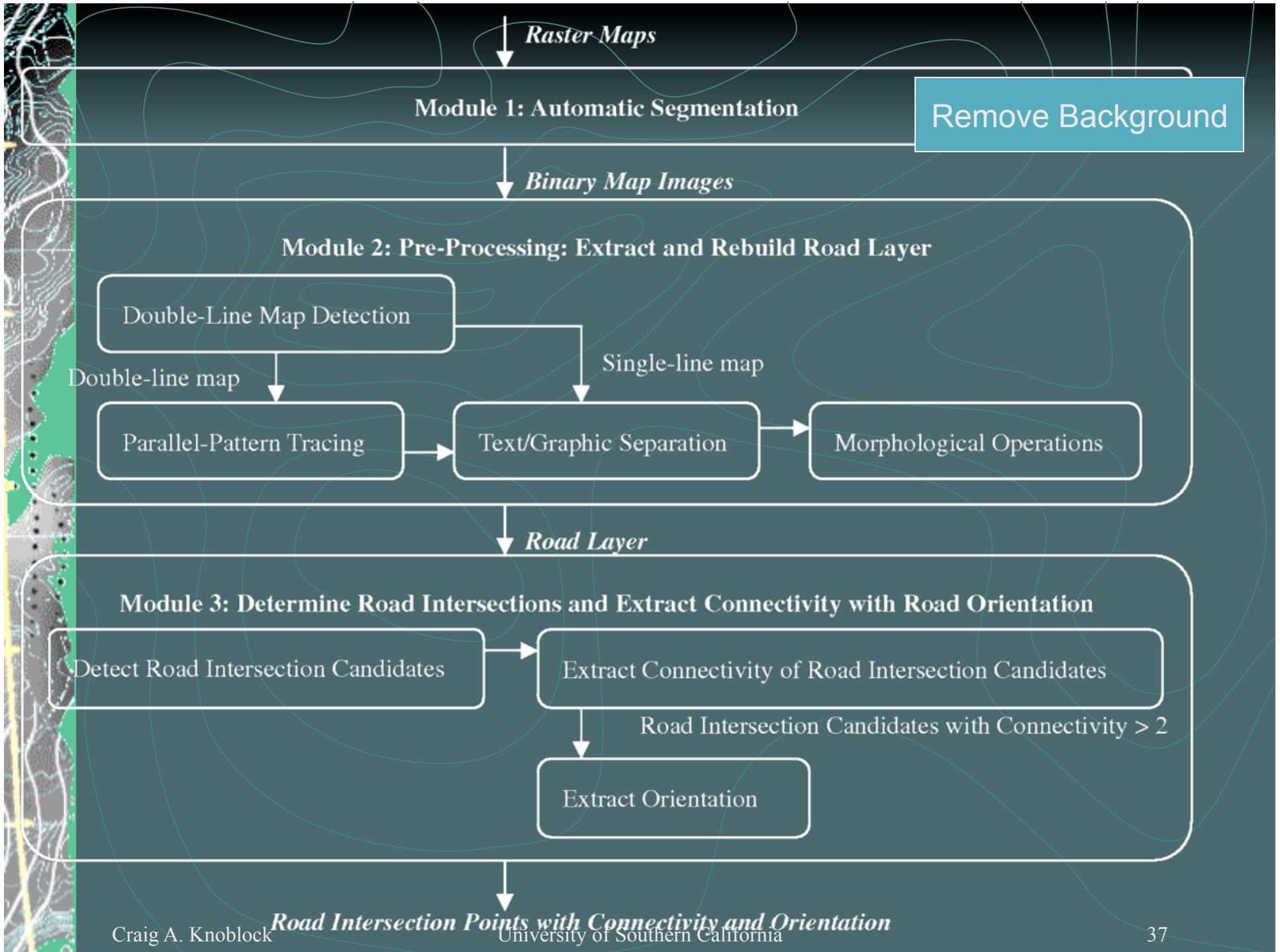


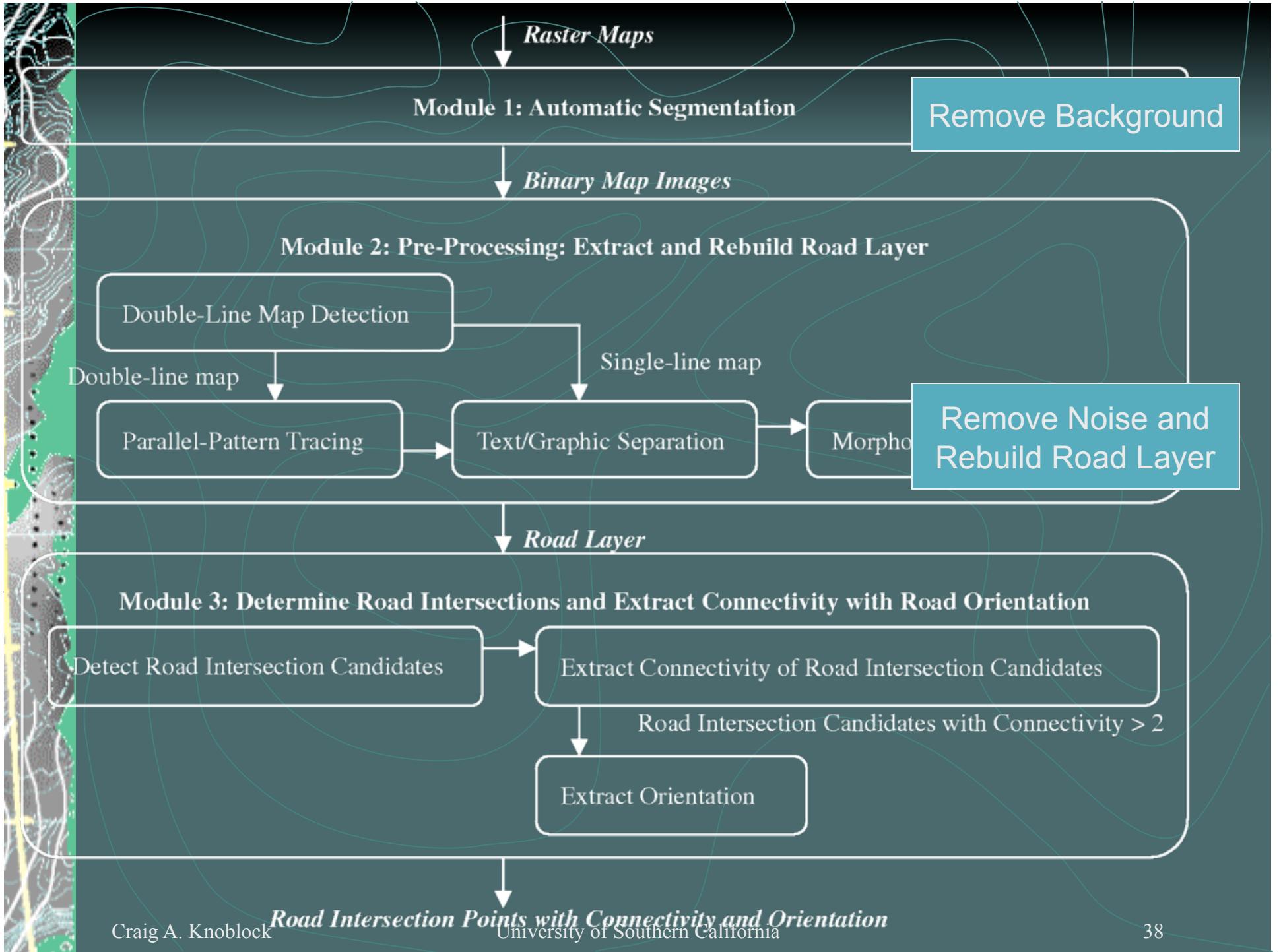


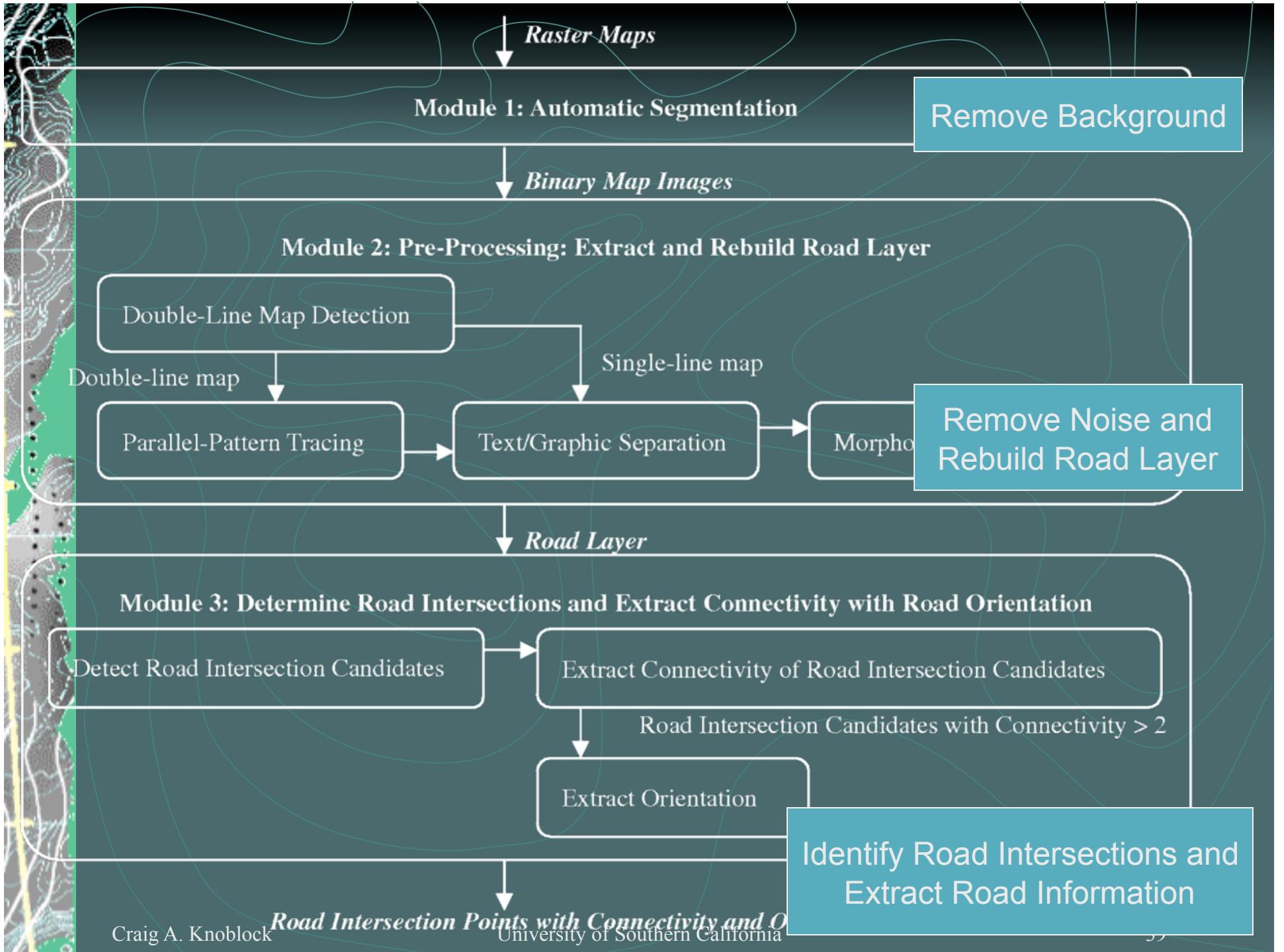






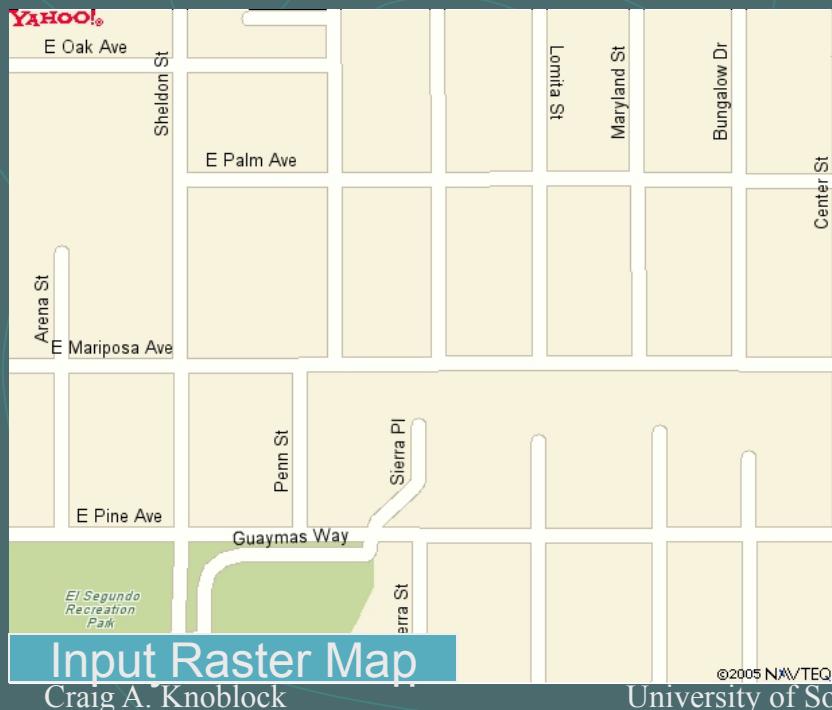






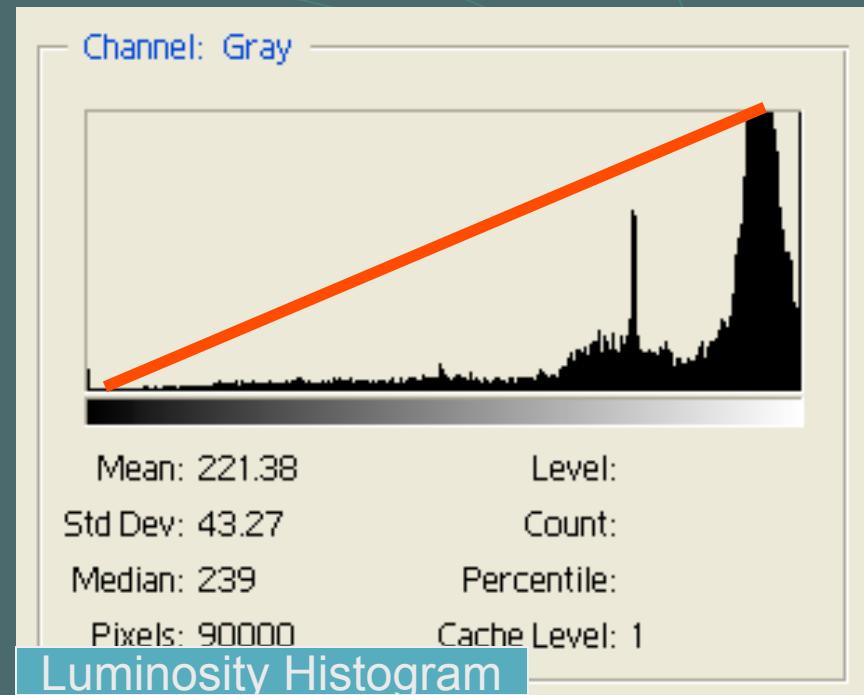
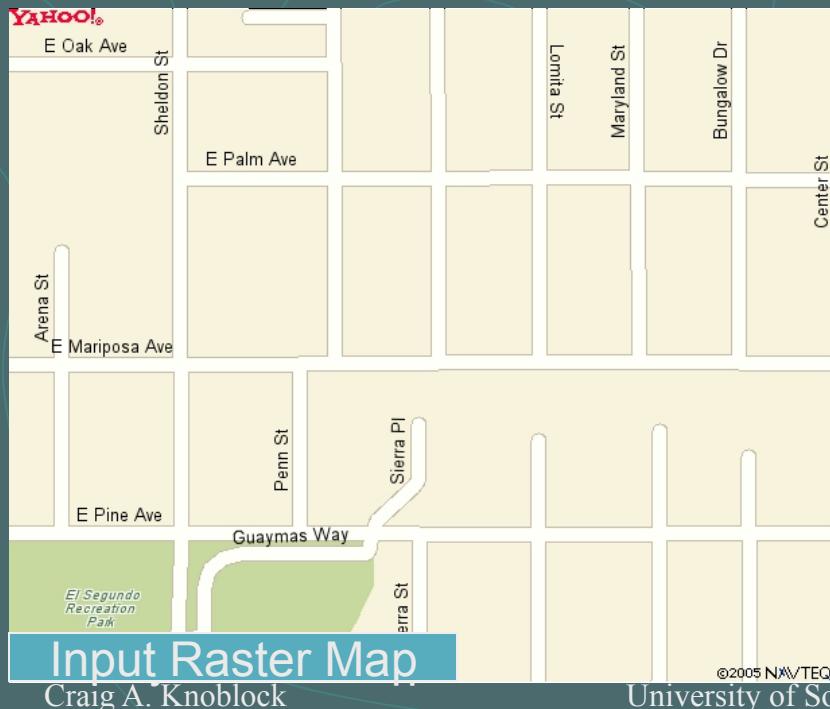
Remove Background

- Use Triangle method (Zack, 1977) to locate luminosity clusters in the histogram
- Remove the dominate cluster



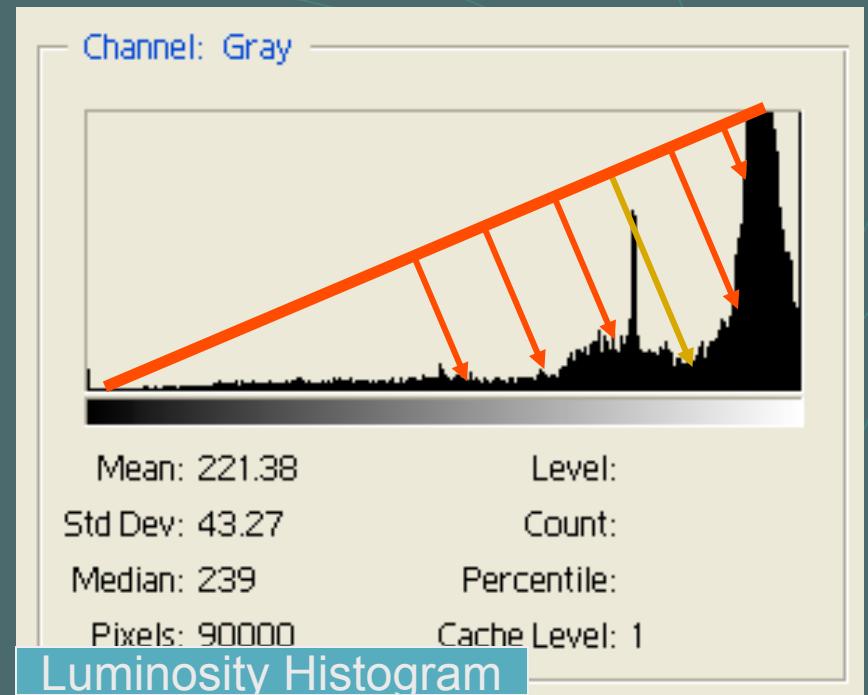
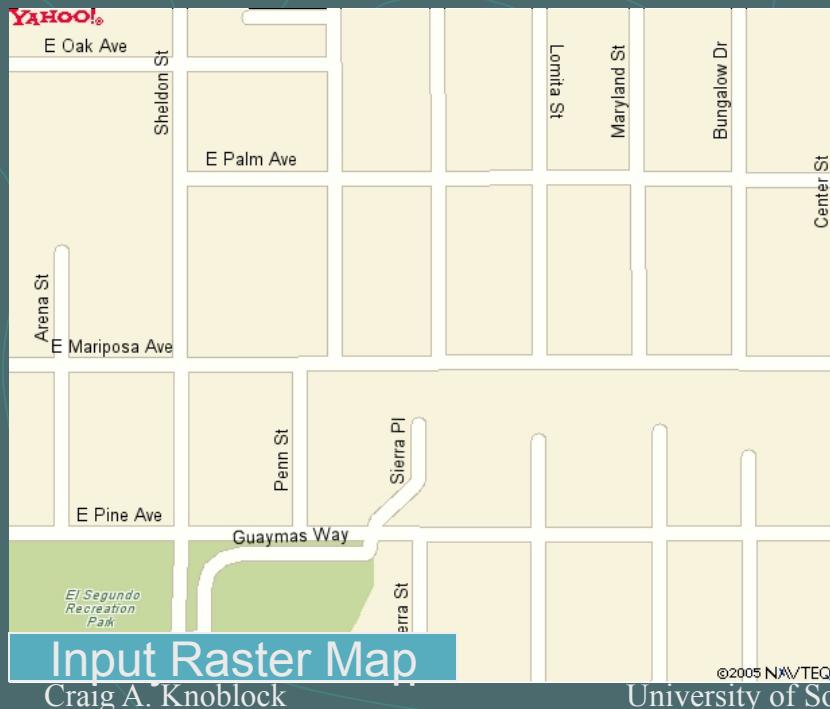
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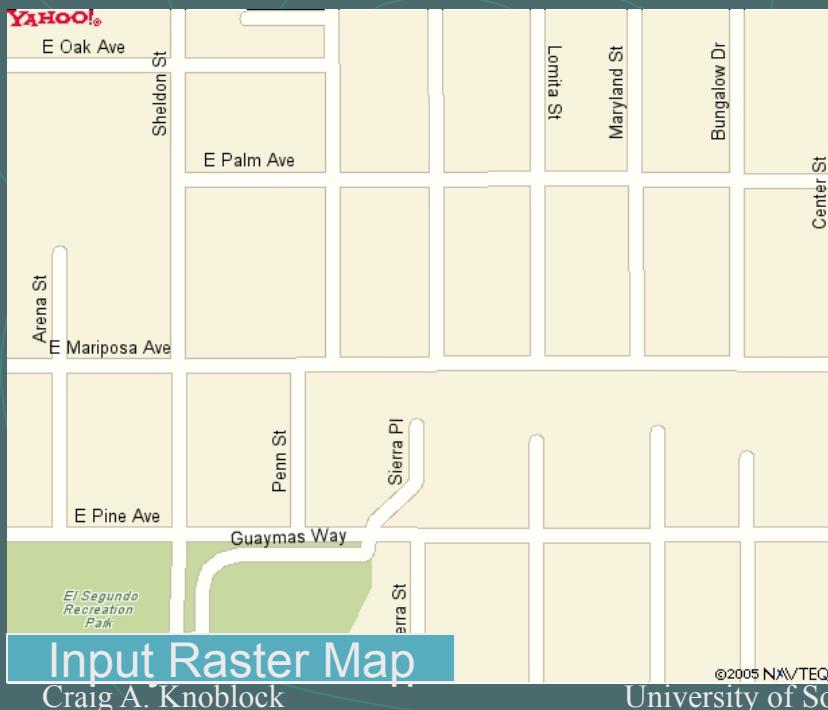
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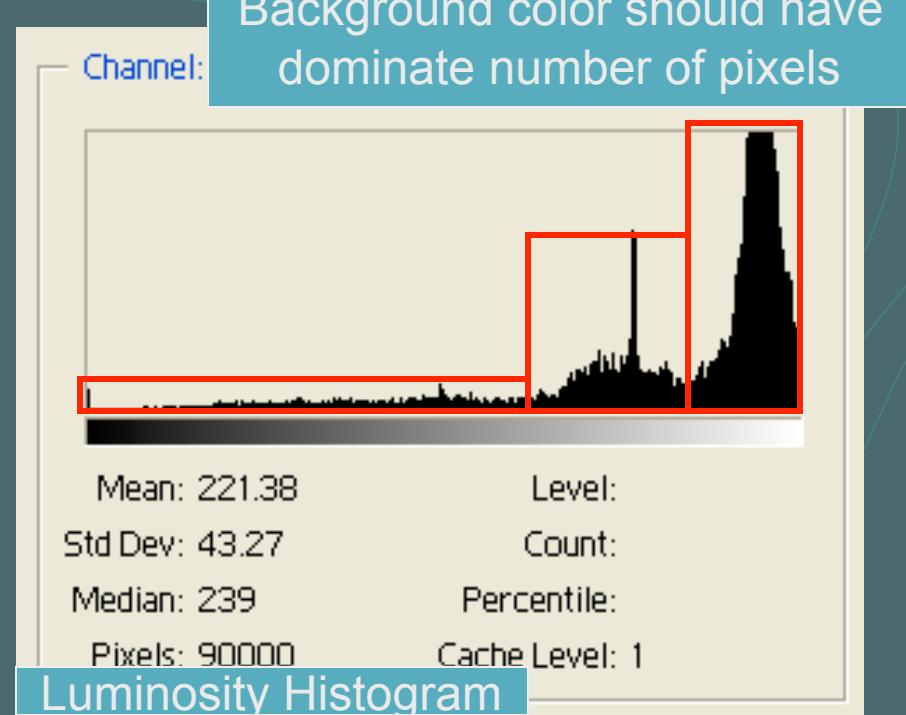


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- Remove the dominate cluster

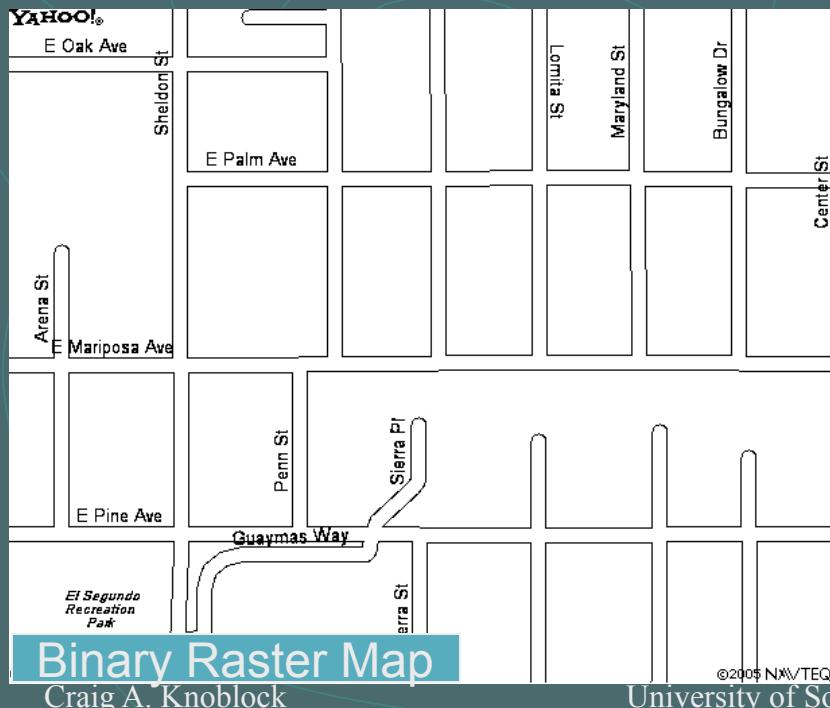


Background color should have
dominate number of pixels

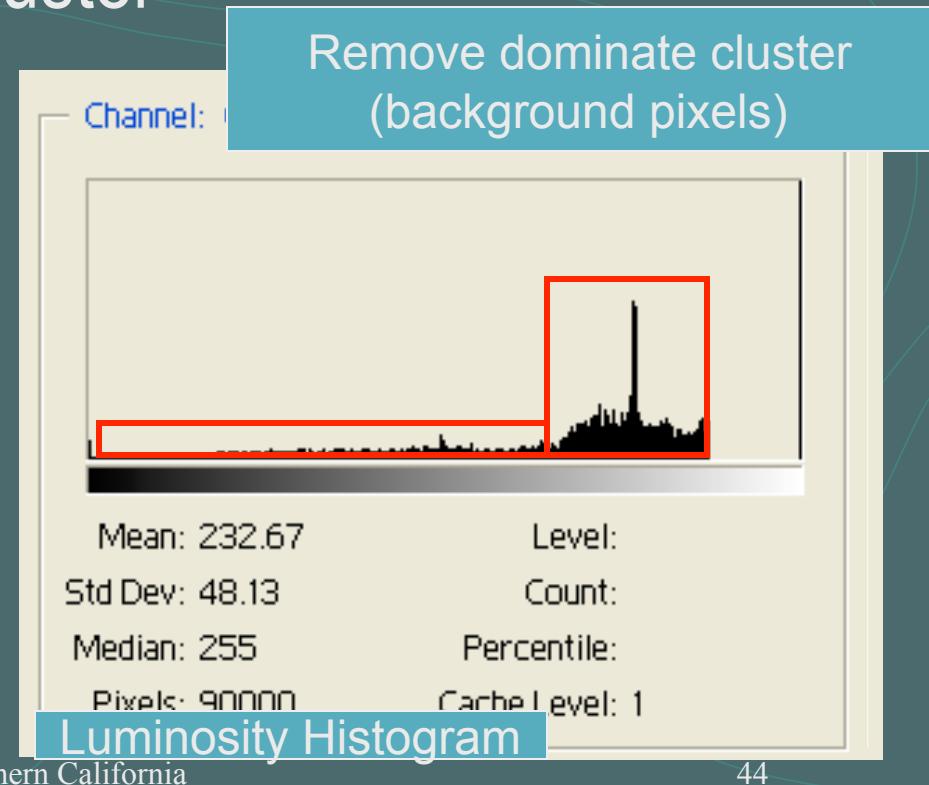


Remove Background

- Use Triangle method (Zack, 1977) to locate luminosity clusters in the histogram
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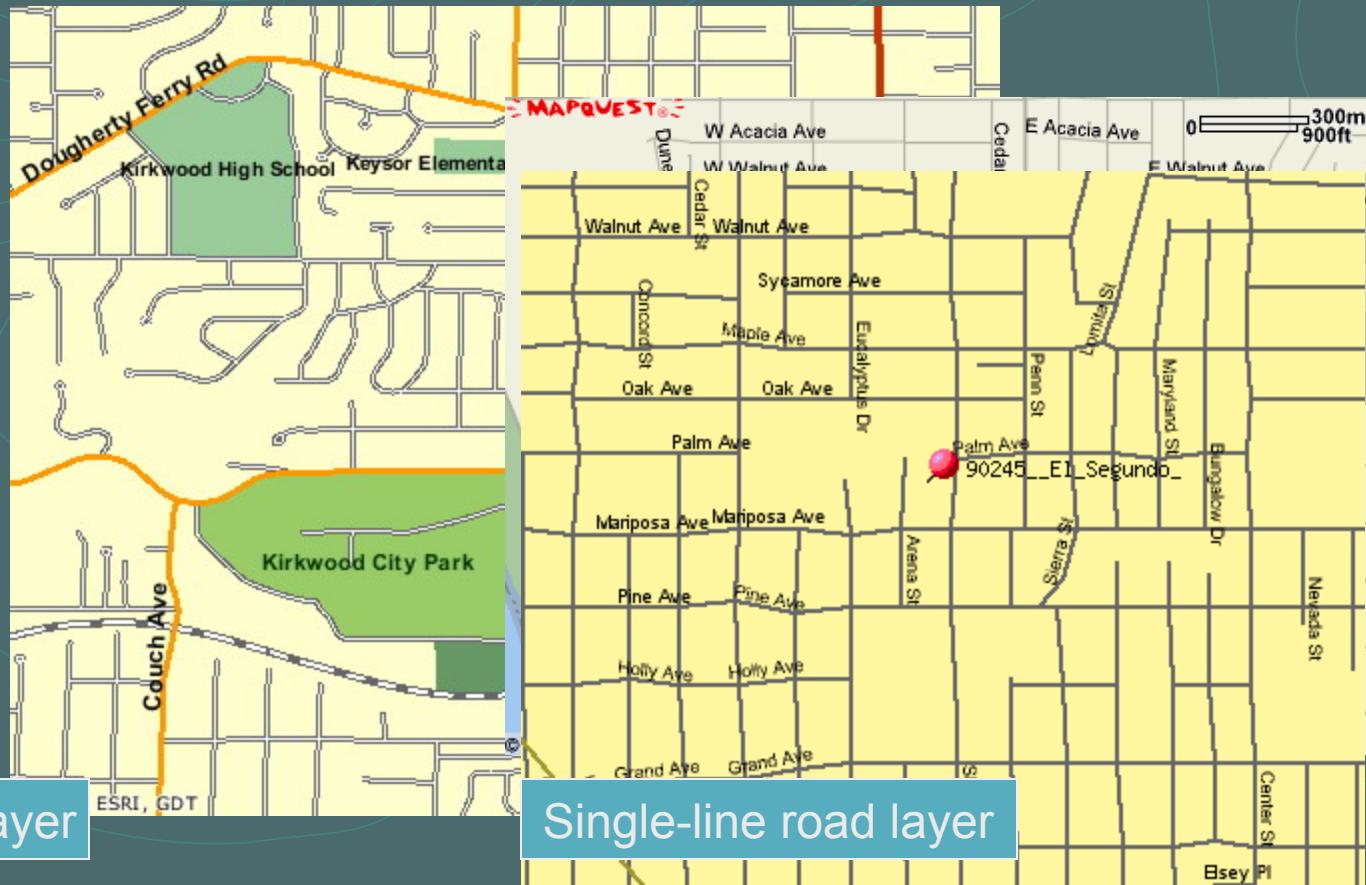


Remove dominate cluster
(background pixels)



Remove Noise & Rebuild Road Layer

- Before we extract the intersections, we separate the road layer



Double-line road layer

Single-line road layer

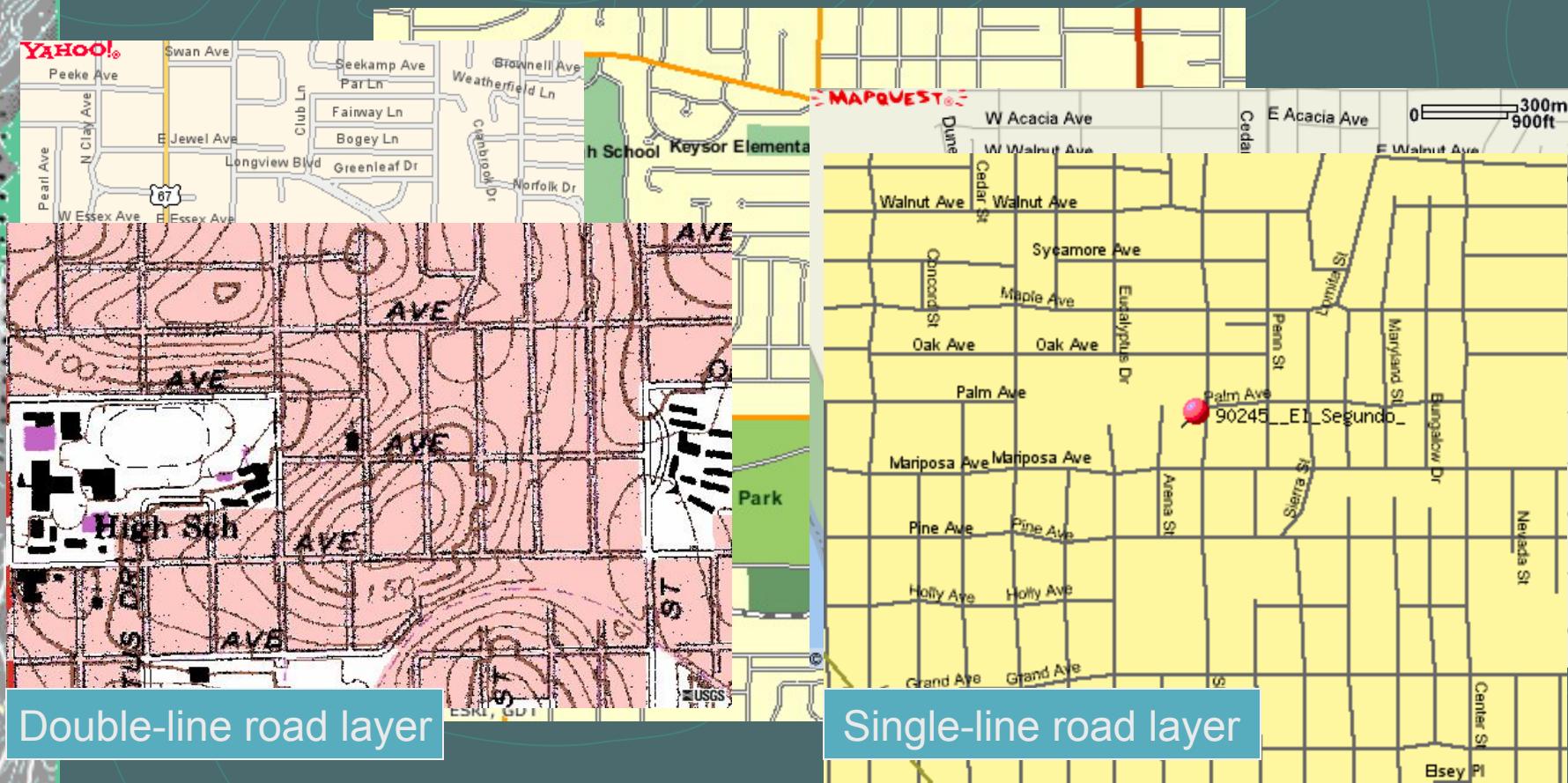
Remove Noise & Rebuild Road Layer

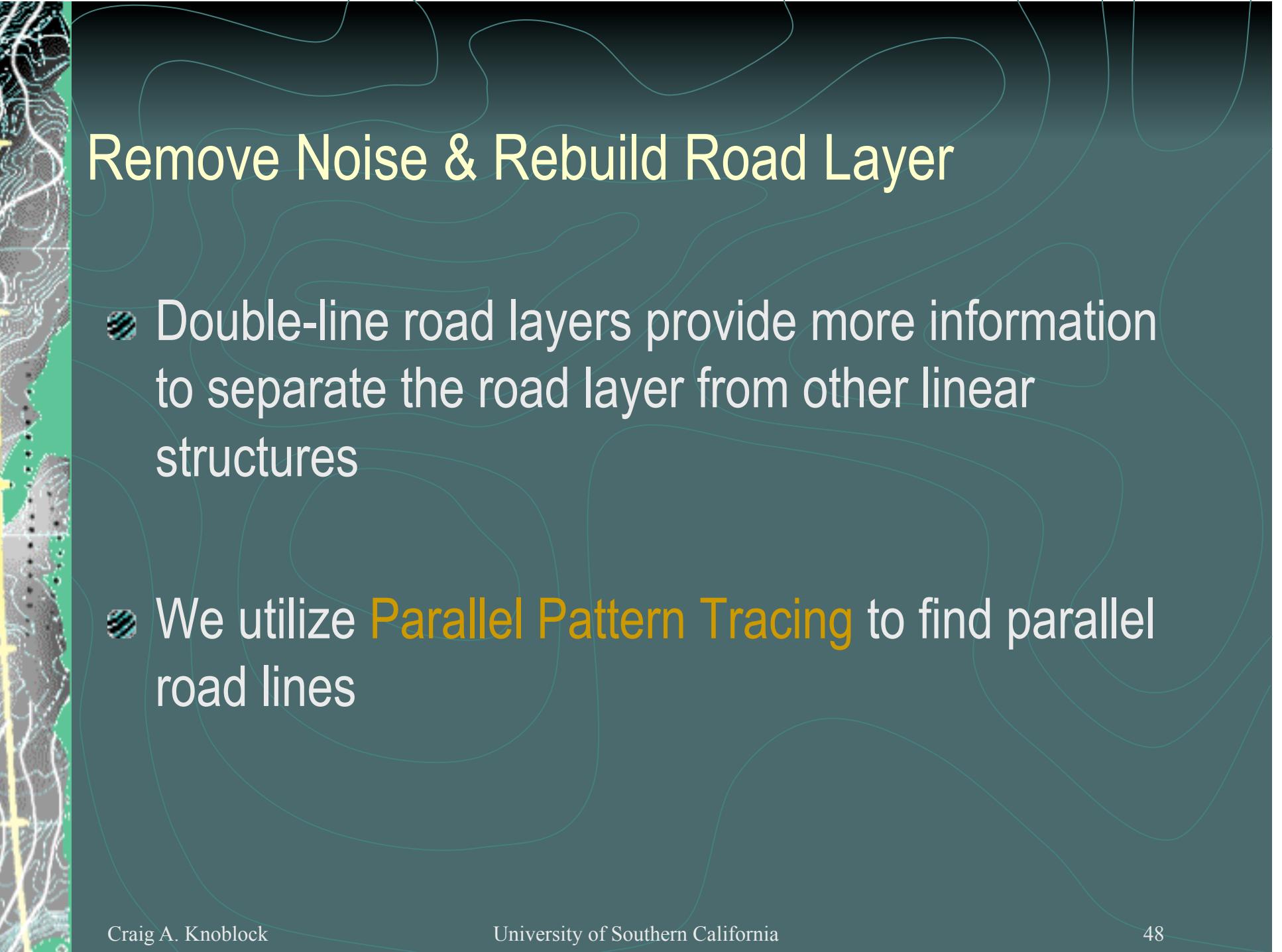
- Before we extract the intersections, we separate the road layer



Remove Noise & Rebuild Road Layer

- Before we extract the intersections, we separate the road layer





Remove Noise & Rebuild Road Layer

- Double-line road layers provide more information to separate the road layer from other linear structures
- We utilize **Parallel Pattern Tracing** to find parallel road lines



Parallel Pattern Tracing

- Zoom in to pixel level:
 - 8 directions connect to one pixel
 - 4 possible straight lines
- If a pixel is on a double line layer with **road width=3 pixels**, we should be able to find:
 - At least 1 pixel on the original road line
 - At least 1 corresponding pixel on the other road line

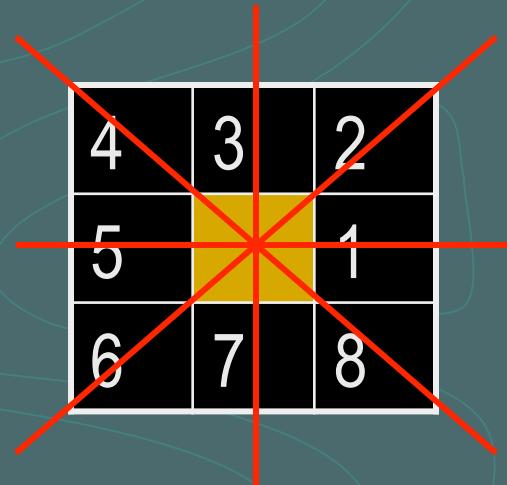
4	3	2
5		1
6	7	8

A 3x3 grid of numbers. The middle column (3, 5, 7) is highlighted in yellow. A horizontal red line passes through the middle row (4, 3, 2), intersecting the yellow cell at position 5.



Parallel Pattern Tracing

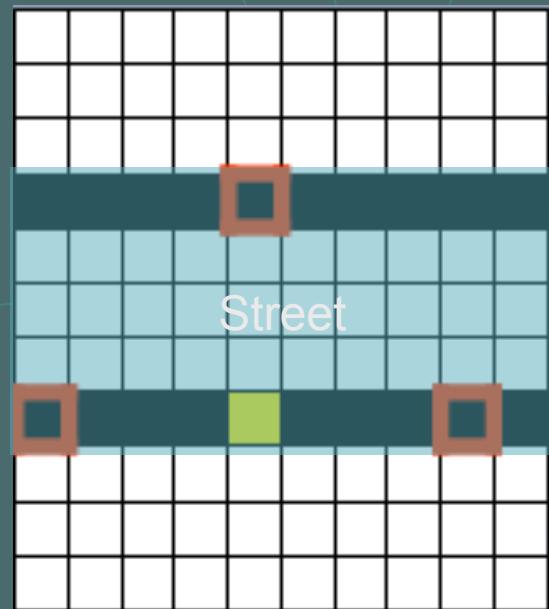
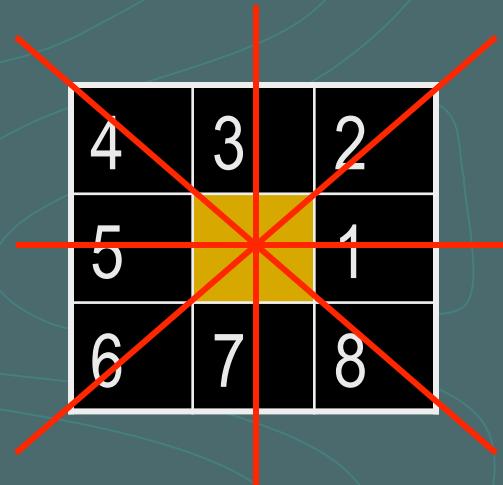
- Zoom in to pixel level:
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 - At least 1 pixel on the original road line
 - At least 1 corresponding pixel on the other road line





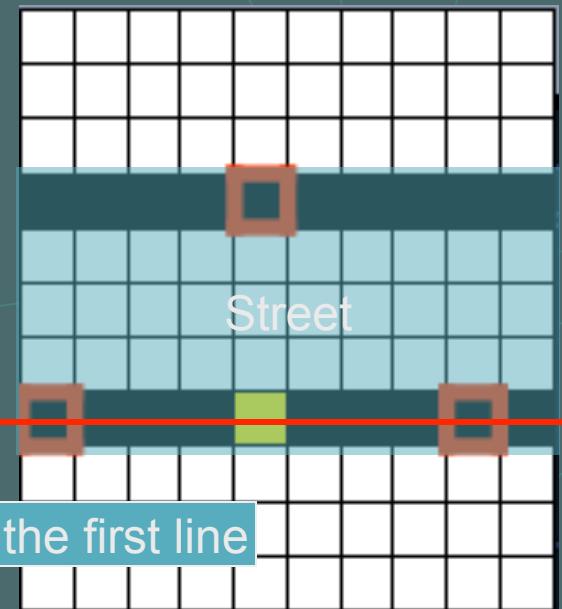
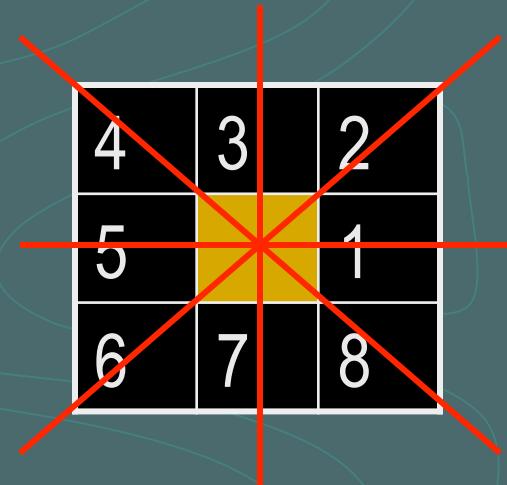
Parallel Pattern Tracing

- Zoom in to pixel level:
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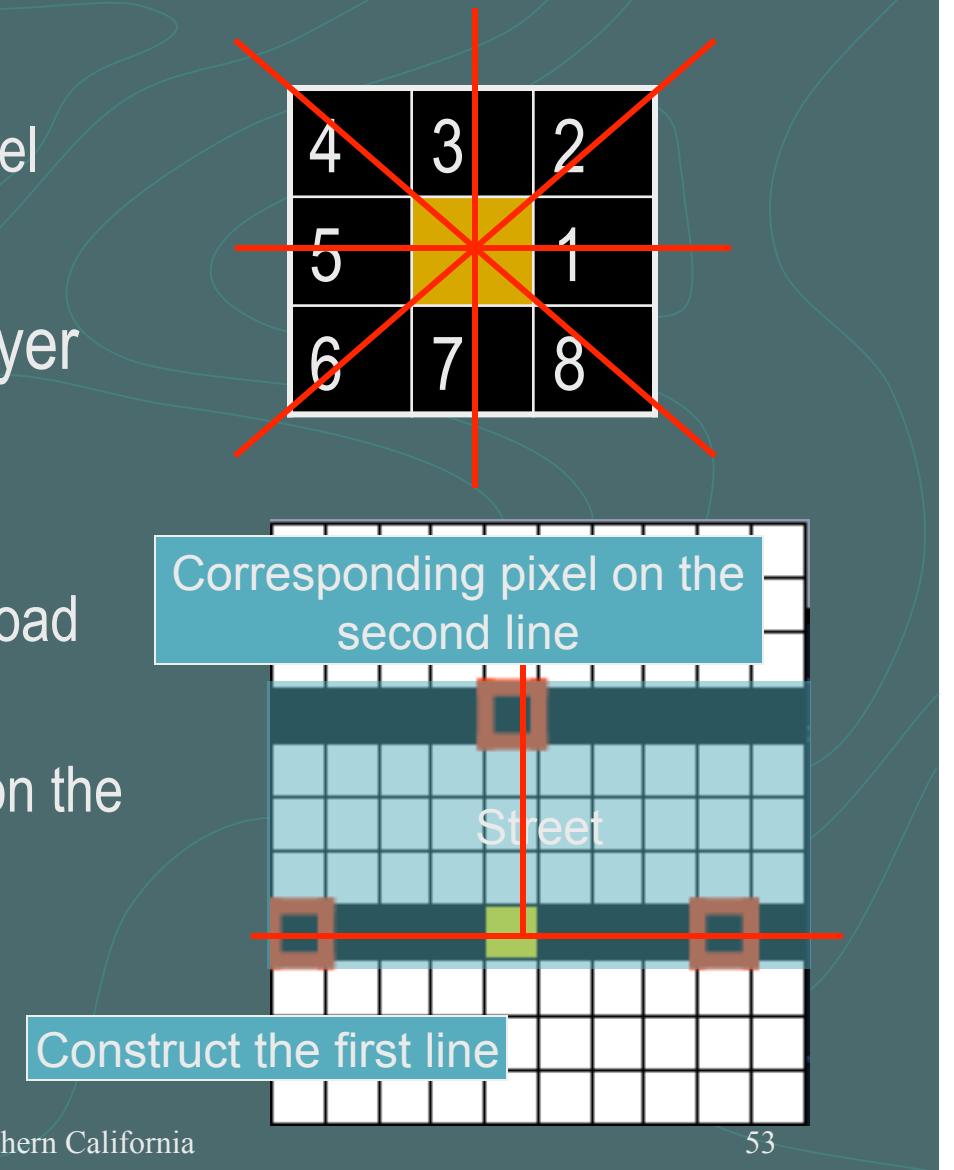
Parallel Pattern Tracing

- Zoom in to pixel level:
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- If a pixel is on a double line layer with **road width=3 pixels**, we should be able to find:
 - At least 1 pixel on the original road line
 - At least 1 corresponding pixel on the other road line



Parallel Pattern Tracing

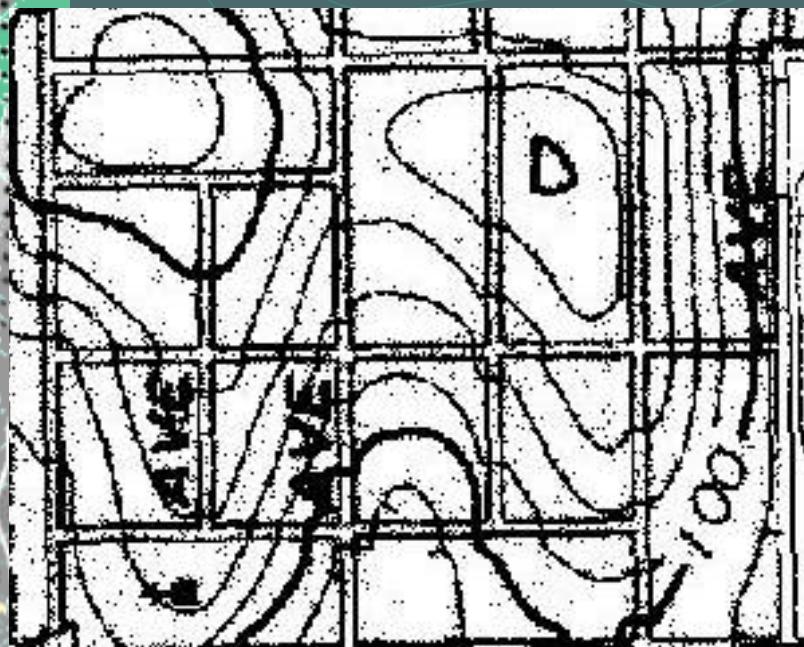
- Zoom in to pixel level:
 - 8 directions connect to one pixel
 - 4 possible straight lines
- If a pixel is on a double line layer with **road width=3 pixels**, we should be able to find:
 - At least 1 pixel on the original road line
 - At least 1 corresponding pixel on the other road line



Parallel Pattern Tracing

Detect the type of road layer, the road width

Remove linear structures other than parallel roads



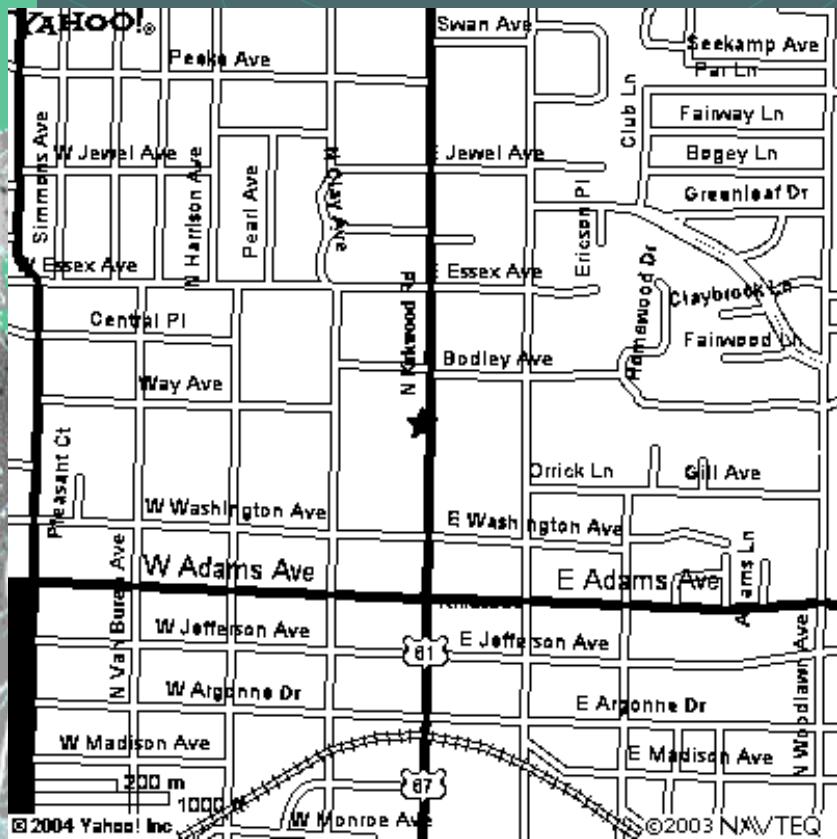
USGS Topographic Map



Road Layer after PPT

Remove Noise & Rebuild Road Layer

- Text/Graphics Separation (Cao et al. 2001)
- Separate linear structures from other objects

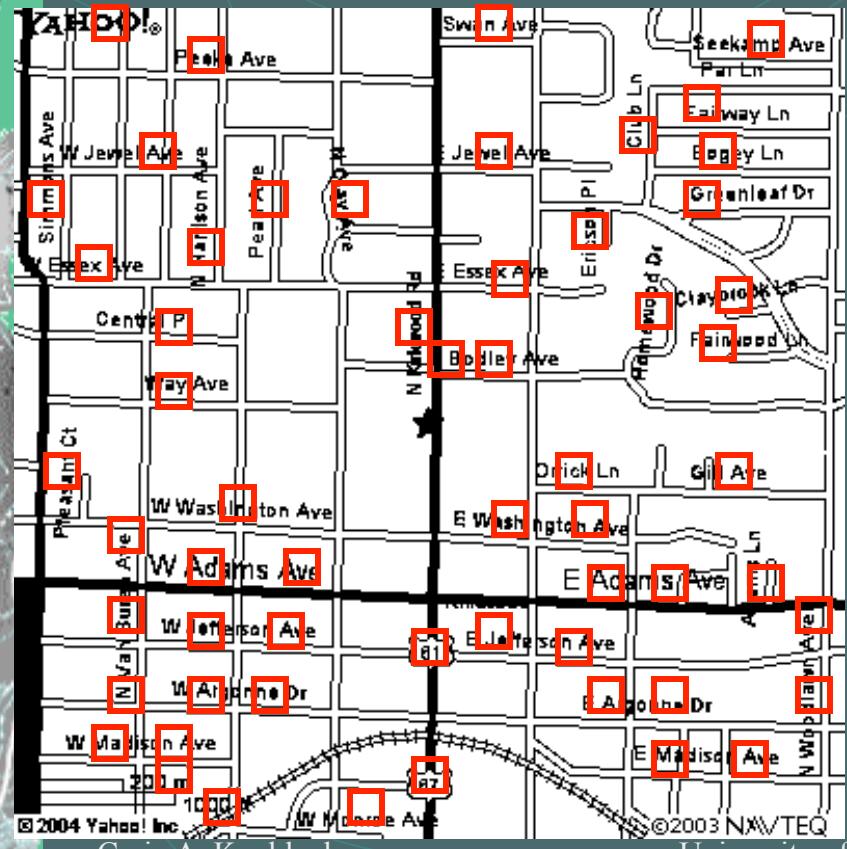


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Remove Noise & Rebuild Road Layer

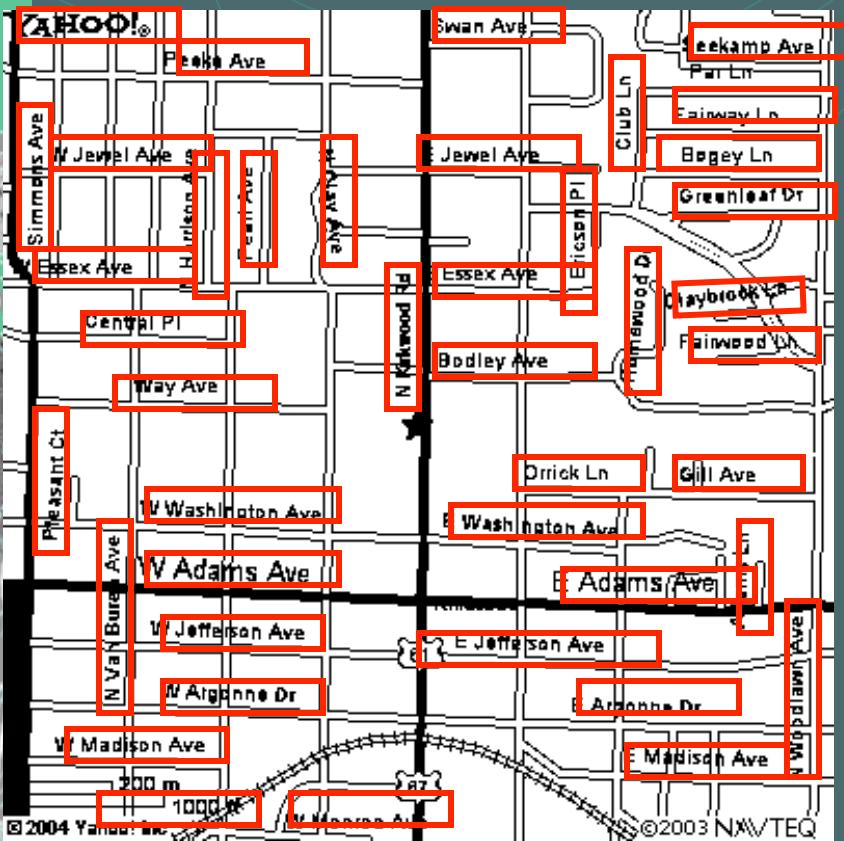
- Text/Graphics Separation (Cao et al. 2001)
- Separate linear structures from other objects



Find small connected objects - character

Remove Noise & Rebuild Road Layer

- Text/Graphics Separation (Cao et al. 2001)
- Separate linear structures from other objects

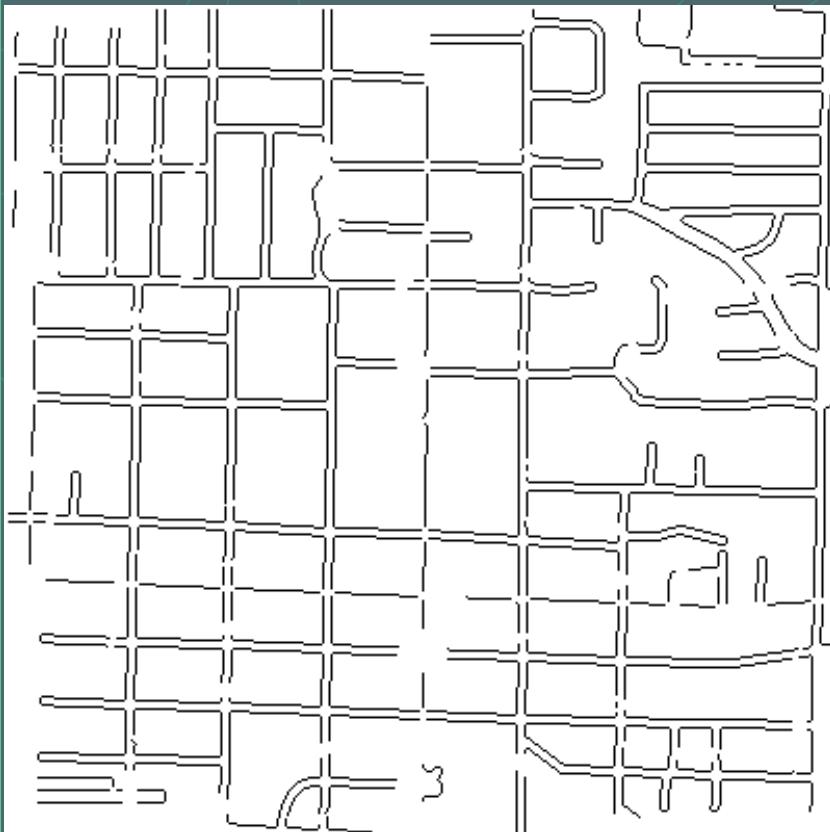


Find small connected objects - character

Group small connected objects - string

Remove Noise & Rebuild Road Layer

- Text/Graphics Separation (Cao et al. 2001)
 - Separate linear structures from other objects



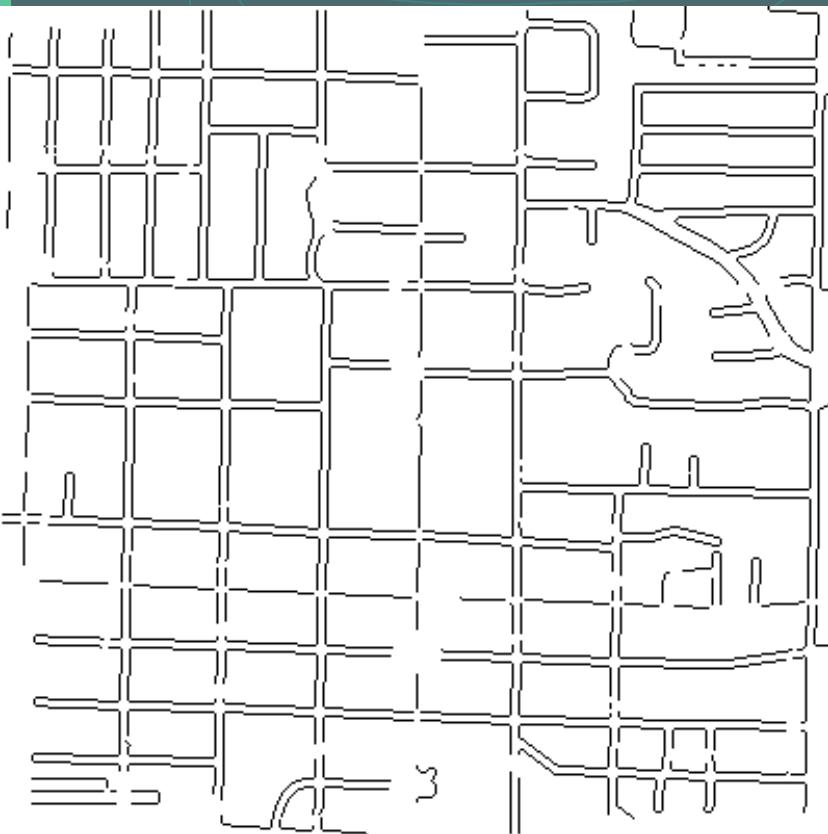
Find small connected objects - character

Group small connected objects - string

Remove small connected object groups

Remove Noise & Rebuild Road Layer

- Text/Graphics Separation (Cao et al. 2001)
 - Separate linear structures from other objects



Find small connected objects - character

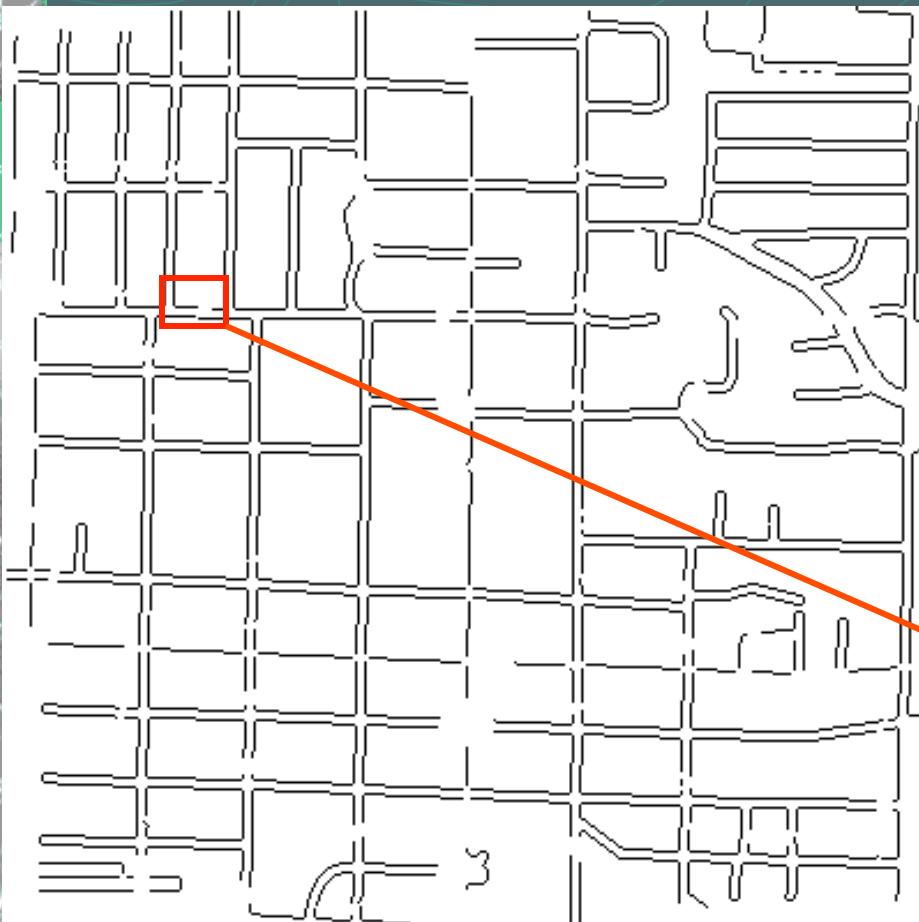
Group small connected objects - string

Remove small connected object groups

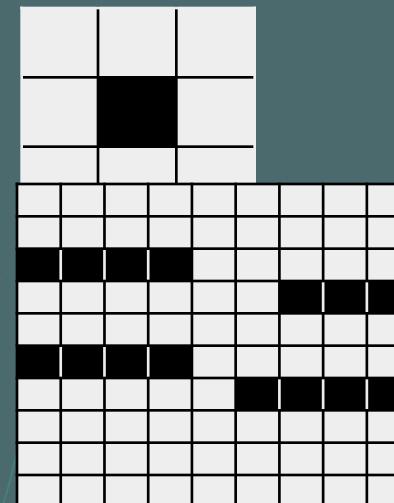
After the removal of
objects touching road lines,
the road network is broken

Rebuild Road Layer

- General Dilation operator
 - Reconnect the broken road layer

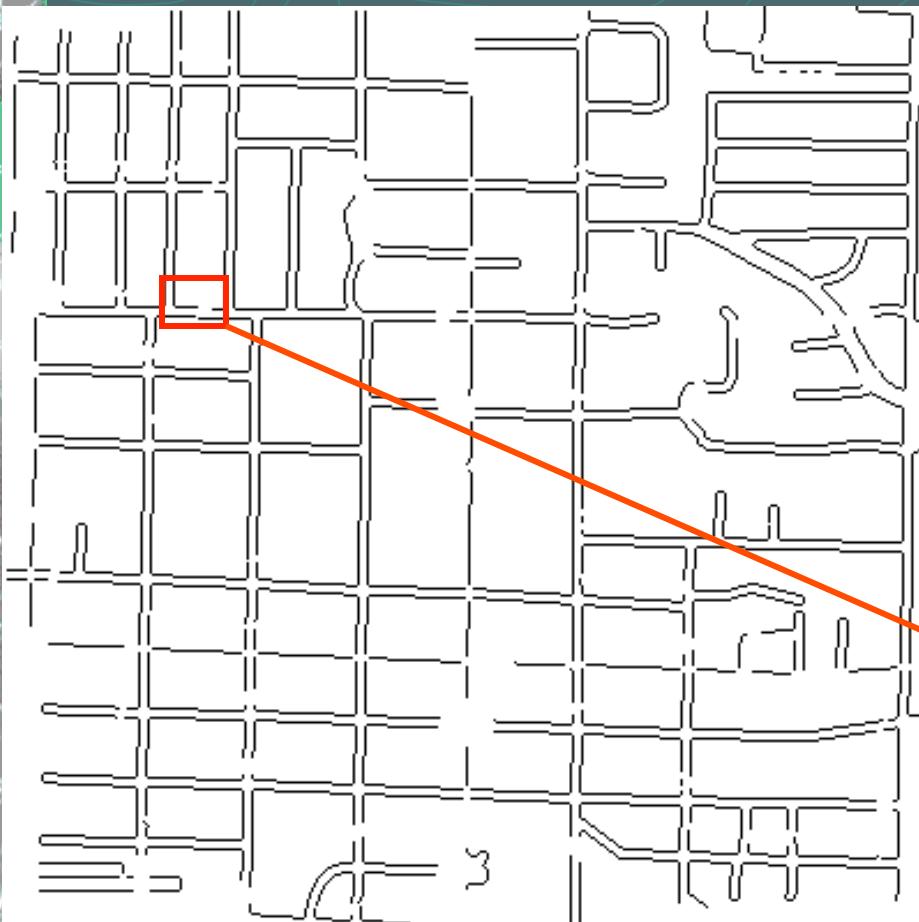


Generalized Dilation



Rebuild Road Layer

- General Dilation operator
 - Reconnect the broken road layer

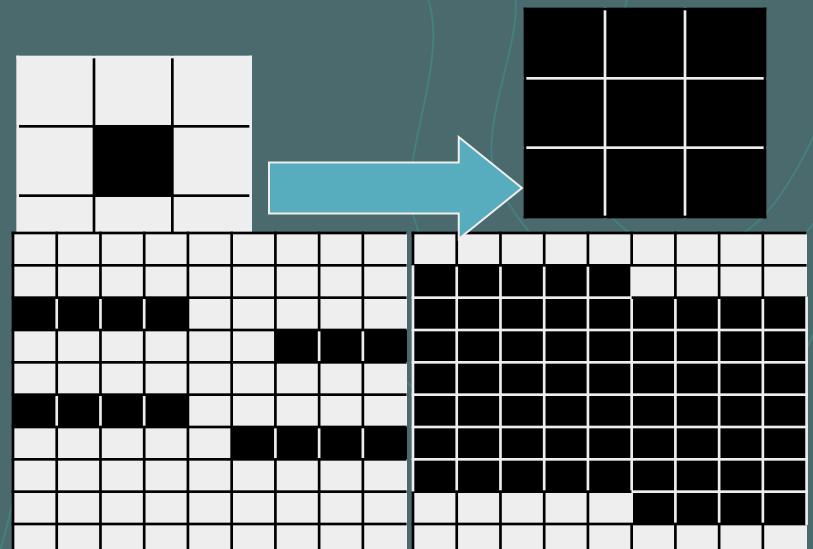


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Generalized Dilation

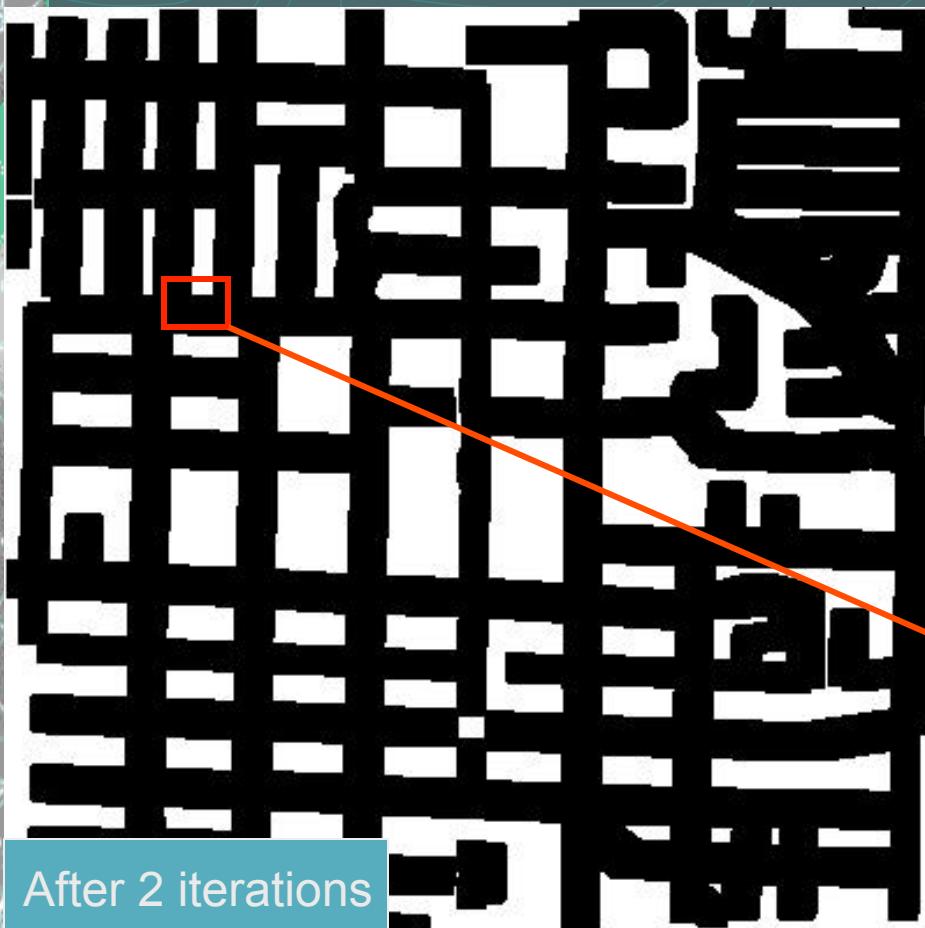
For every foreground pixel, fill up its eight neighboring pixels.



1st iteration

Rebuild Road Layer

- General Dilation operator
 - Reconnect the broken road layer

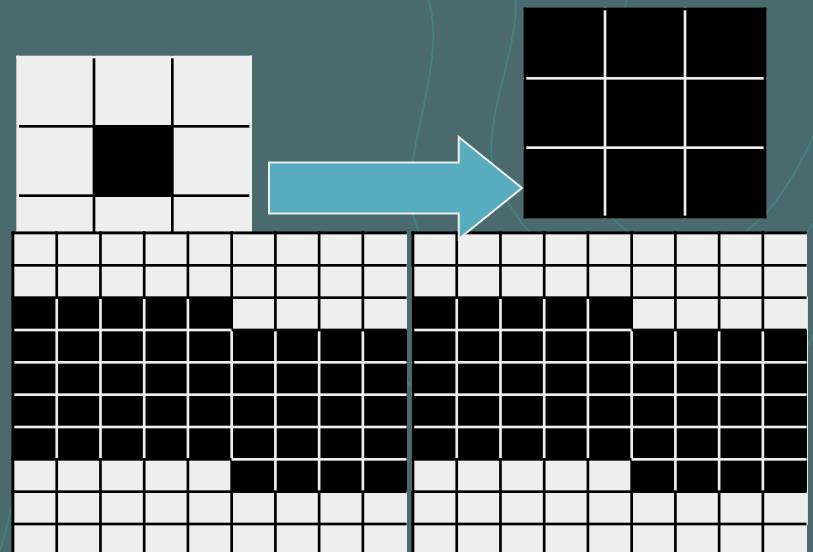


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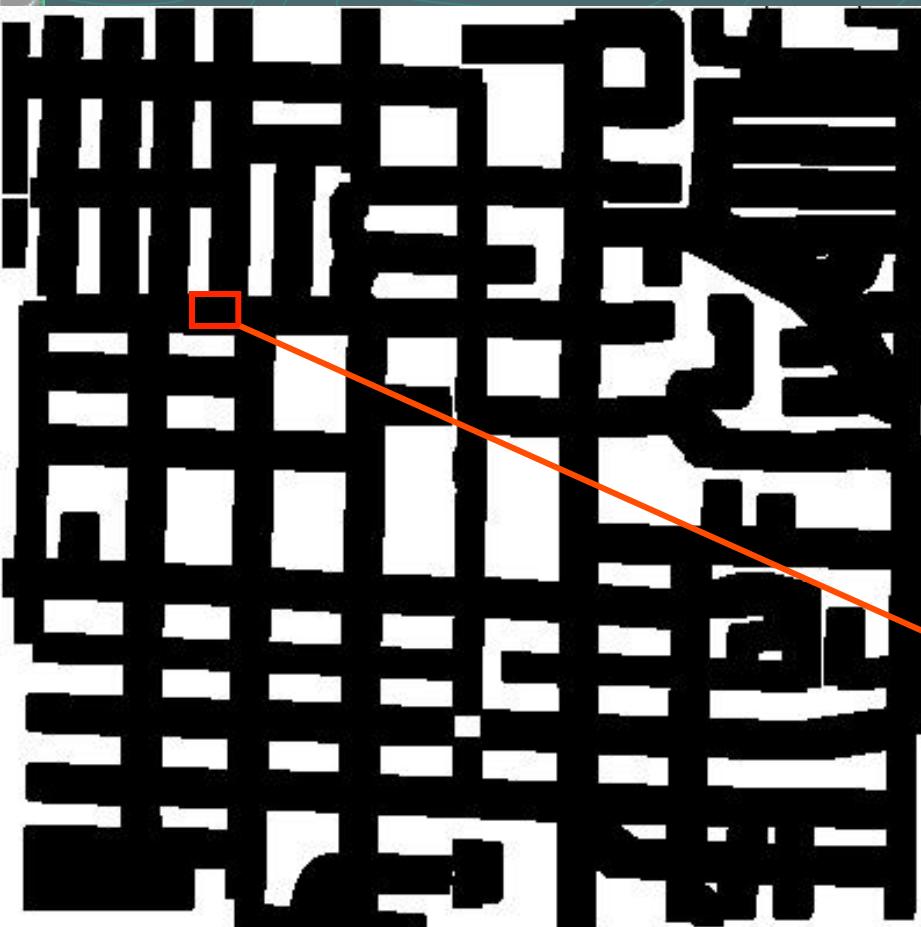
Generalized Dilation

For every foreground pixel, fill up its eight neighboring pixels.

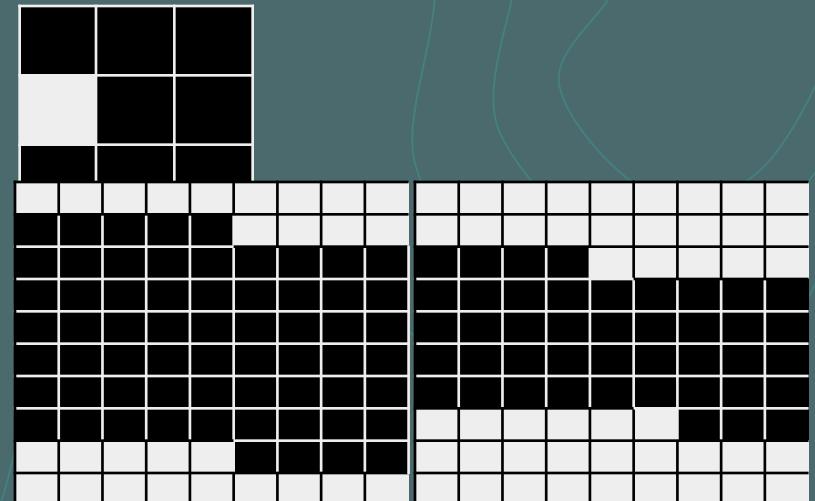


Rebuild Road Layer

- General Erosion operator
 - Thin road lines and maintain the original orientation

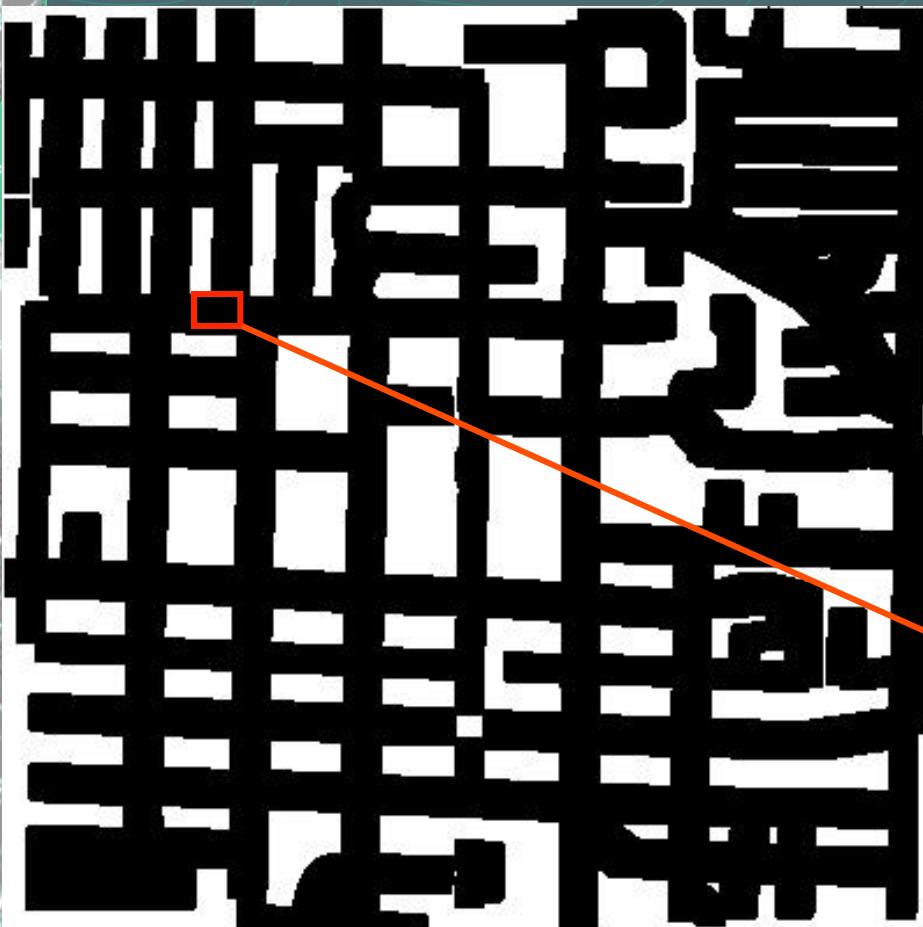


Generalized Erosion



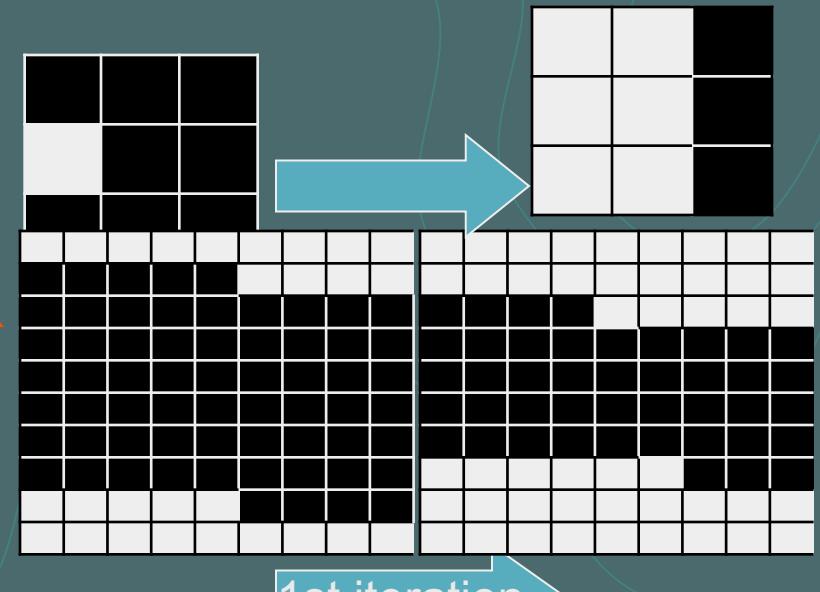
Rebuild Road Layer

- General Erosion operator
 - Thin road lines and maintain the original orientation



Generalized Erosion

For every foreground pixel, erase it if any neighboring pixel is white.



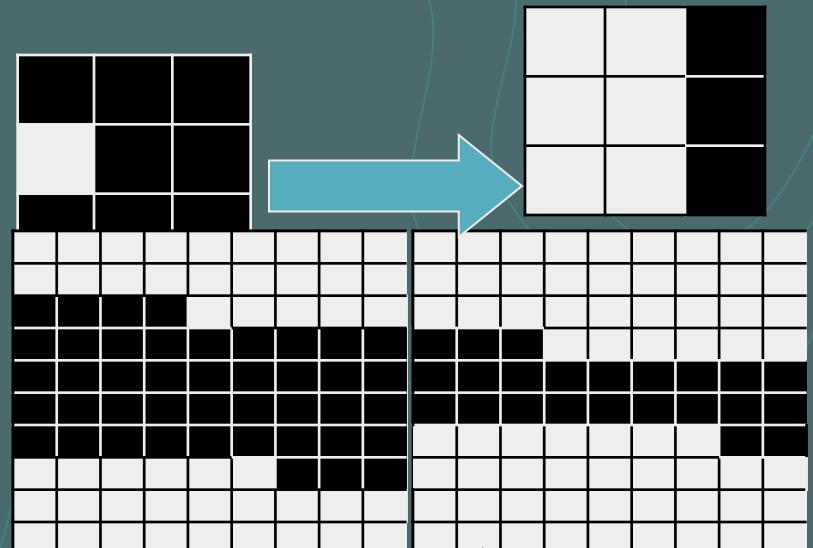
Rebuild Road Layer

- General Erosion operator
 - Thin road lines and maintain the original orientation



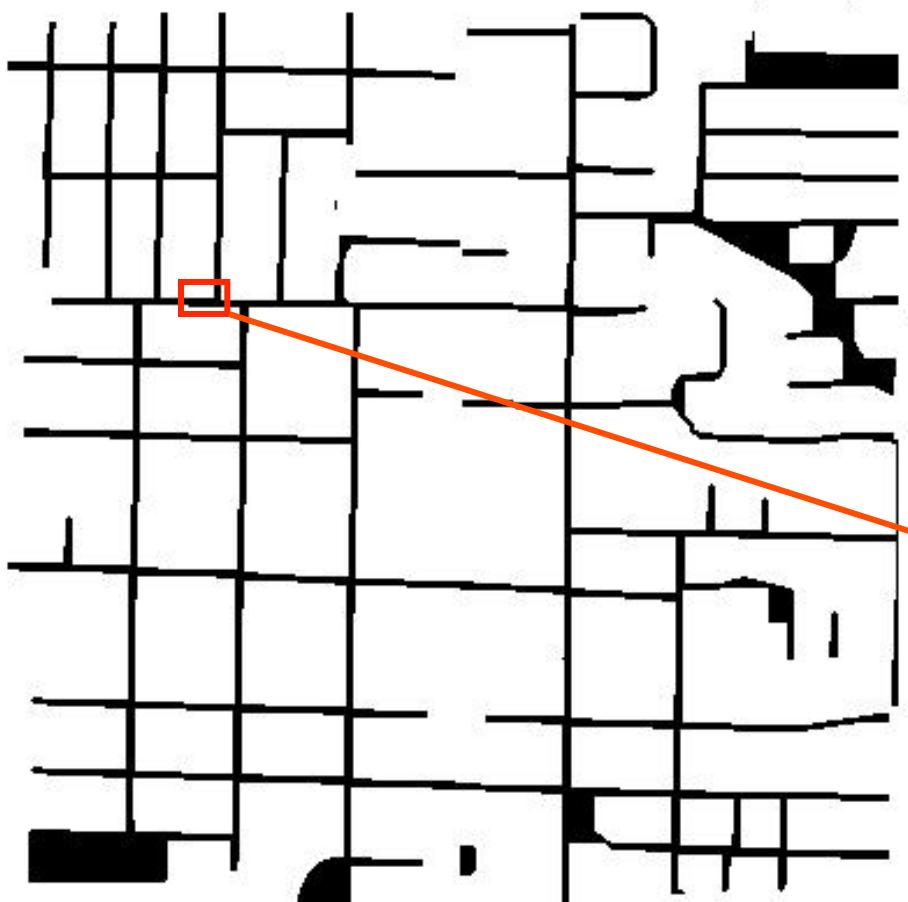
Generalized Erosion

For every foreground pixel, erase it if any neighboring pixel is white.



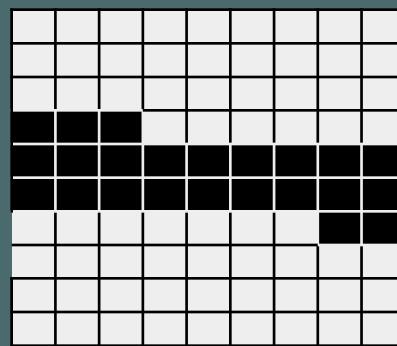
Rebuild Road Layer

- Thinning operator
 - Produce one pixel width road lines



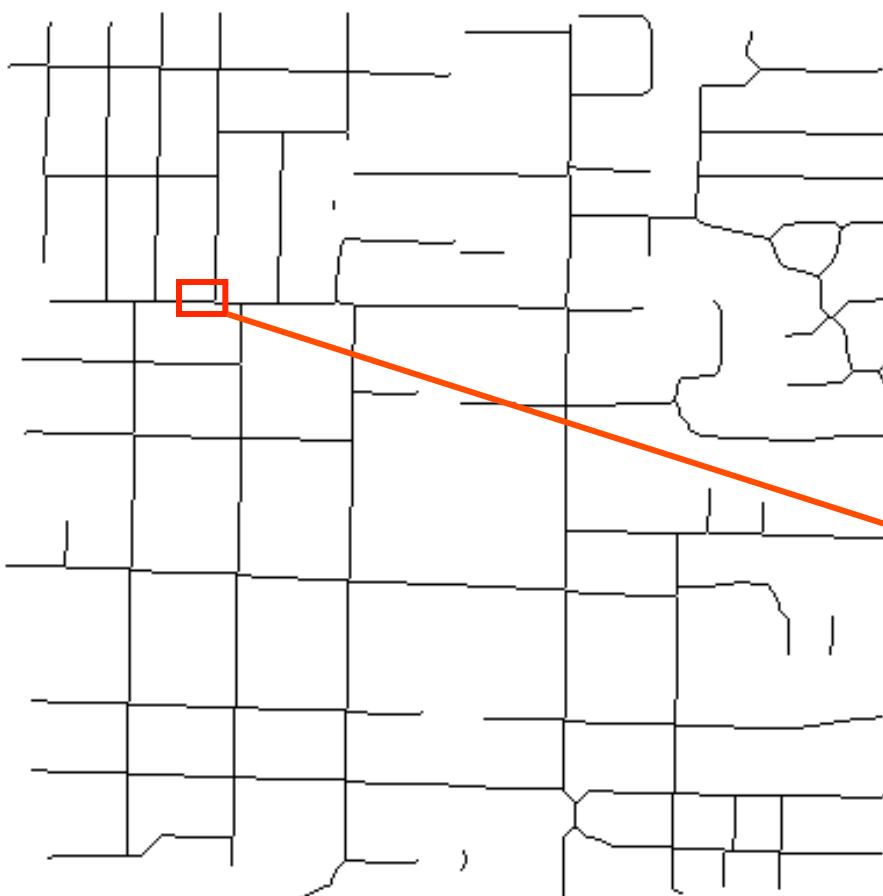
Thinning

Thin each road line until they are all one pixel width.



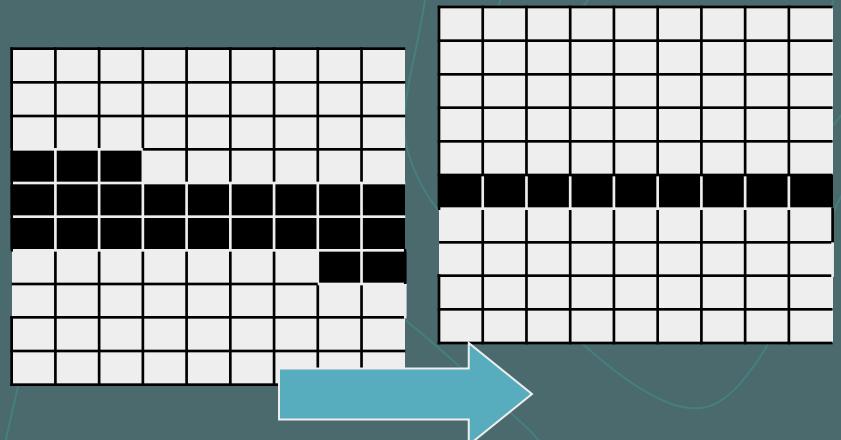
Rebuild Road Layer

- Thinning operator
 - Produce one pixel width road lines



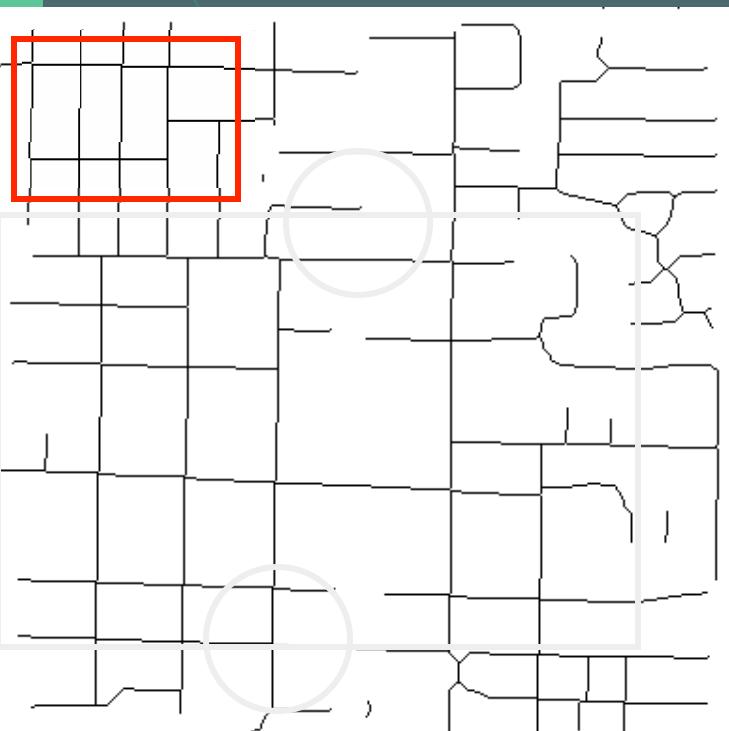
Thinning

Thin each road line until they are all one pixel width.



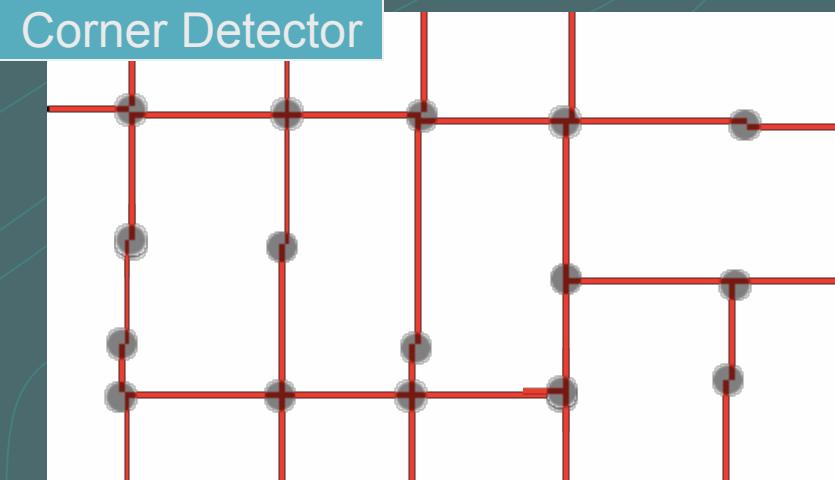
Identify Road Intersections and Extract Road Information

- Corner detector (OpenCV)
 - Find intersection candidates
- Compute the **connectivity** and **orientation** to determine correct intersections



Identify Road Intersections and Extract Road Information

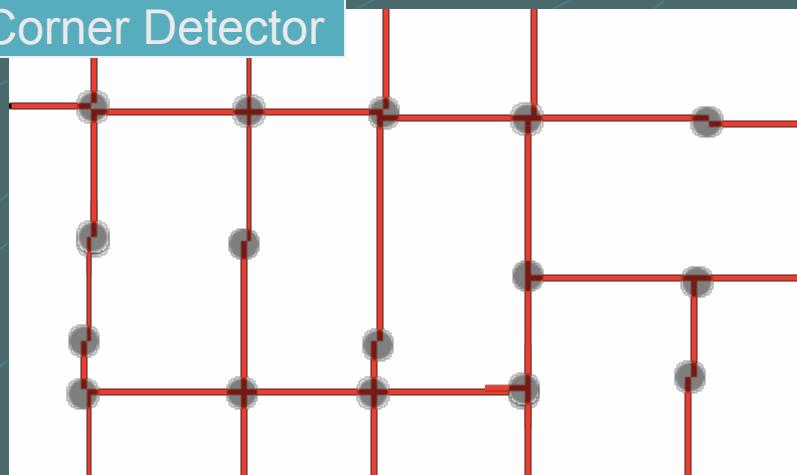
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Identify Road Intersections and Extract Road Information

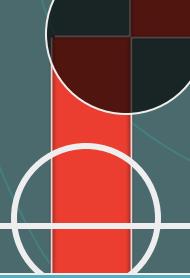
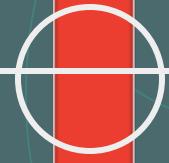
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Corner Detector



Identify Road Intersections and Extract Road Information

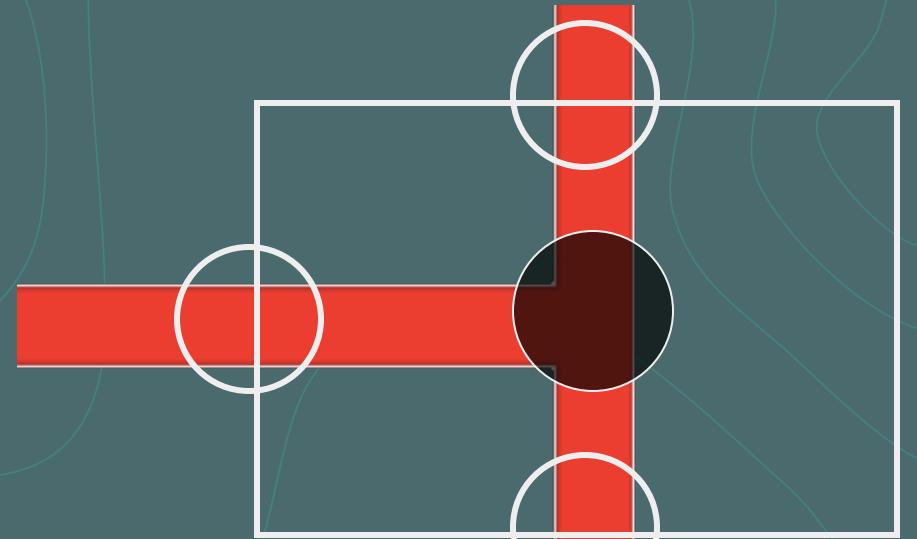
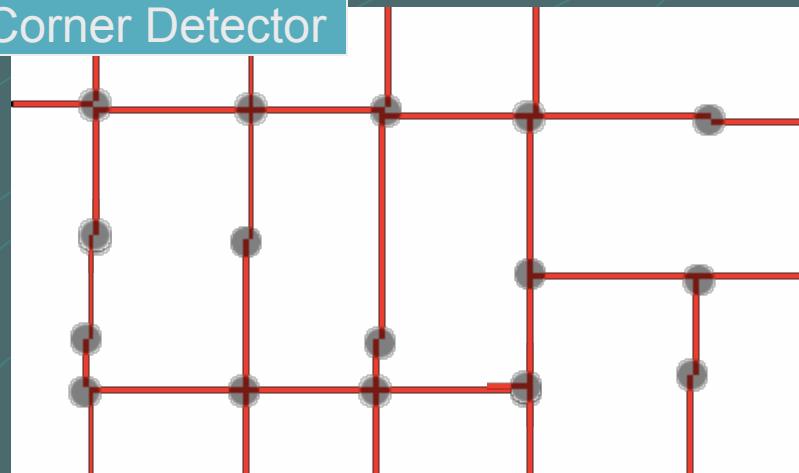
- Corner detector (OpenCV)
 - Find intersection candidates
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Connectivity < 3, discard

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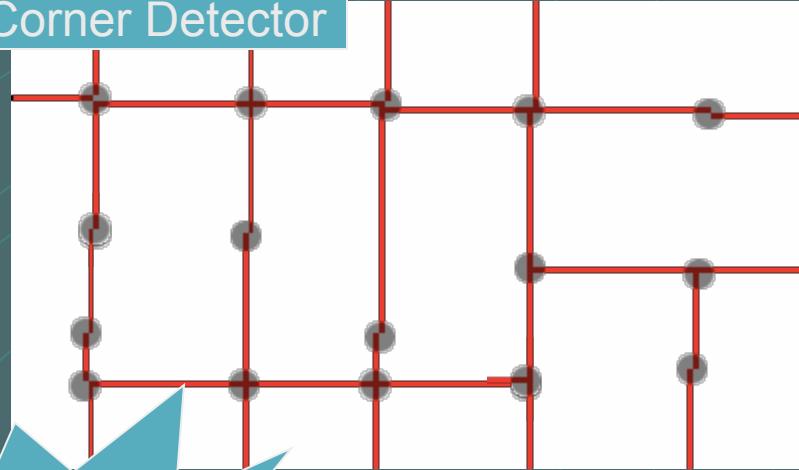
Corner Detector



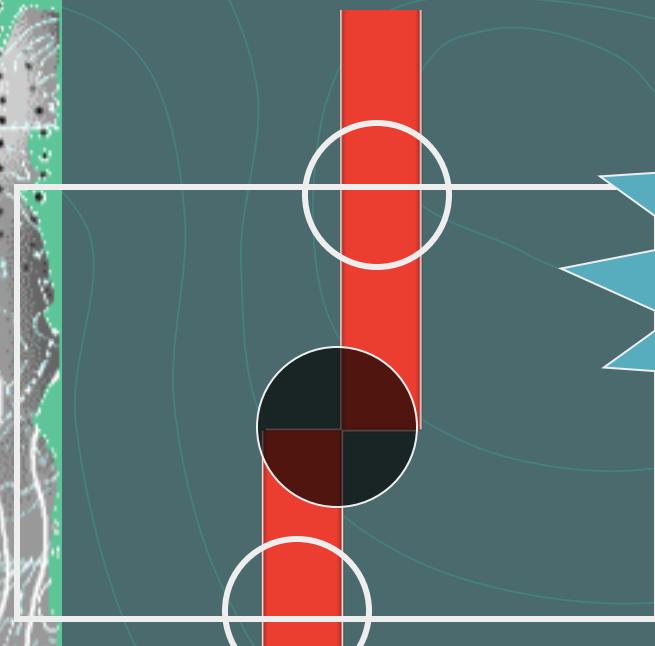
Identify Road Intersections and Extract Road Information

- Corner detector (OpenCV)
 - Find intersection candidates
- Compute the **connectivity** and **orientation** to determine correct intersections

Corner Detector



Road Intersection!!



Connectivity<3, discard

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Connectivity ≥ 3 , compute road orientations

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180°

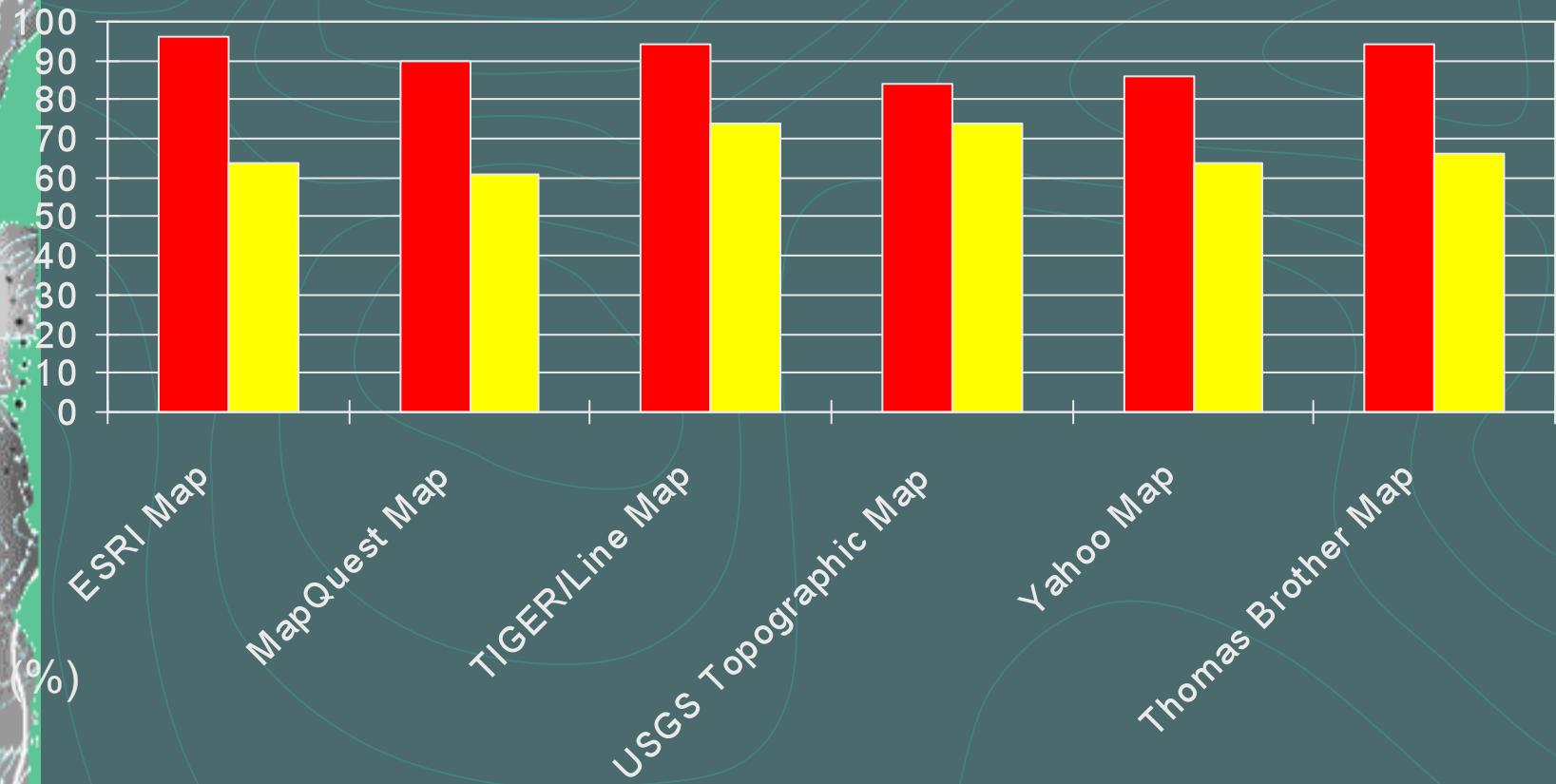
90°

270°

Experimental Results – Precision and Recall

Total 56 raster maps from 6 different sources with various resolution.

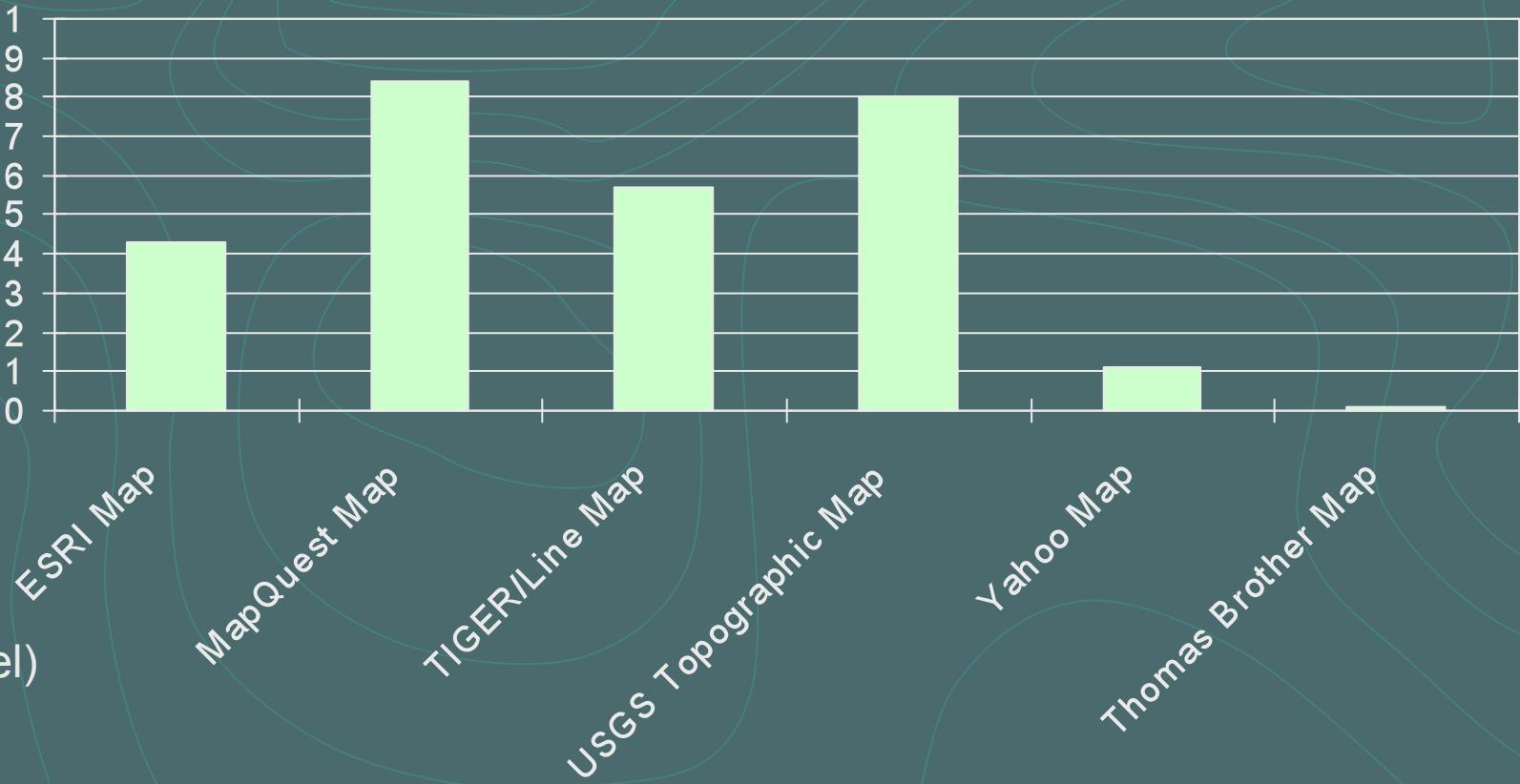
■ Precision (%)
■ Recall (%)



Experimental Results – Positional Accuracy

Total 56 raster maps from 6 different sources with various resolution.

■ Positional Accuracy (pixel)





Experimental Results - Performance

- Computation time:
 - Platform/Machine: Windows 2000 Server, Intel Xeon 1.8 GHZ Dual-Processor with 1 GB memory
 - 800x600 topographic map with resolution 2m/pixel: **less than 1 minutes**
 - Other simpler maps: **less than 20 seconds**

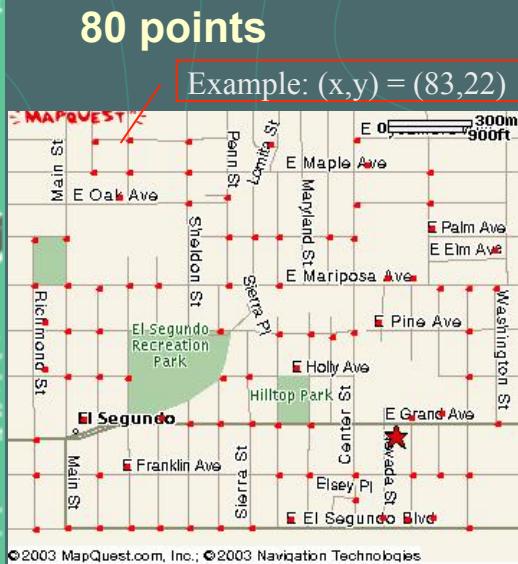


Outline

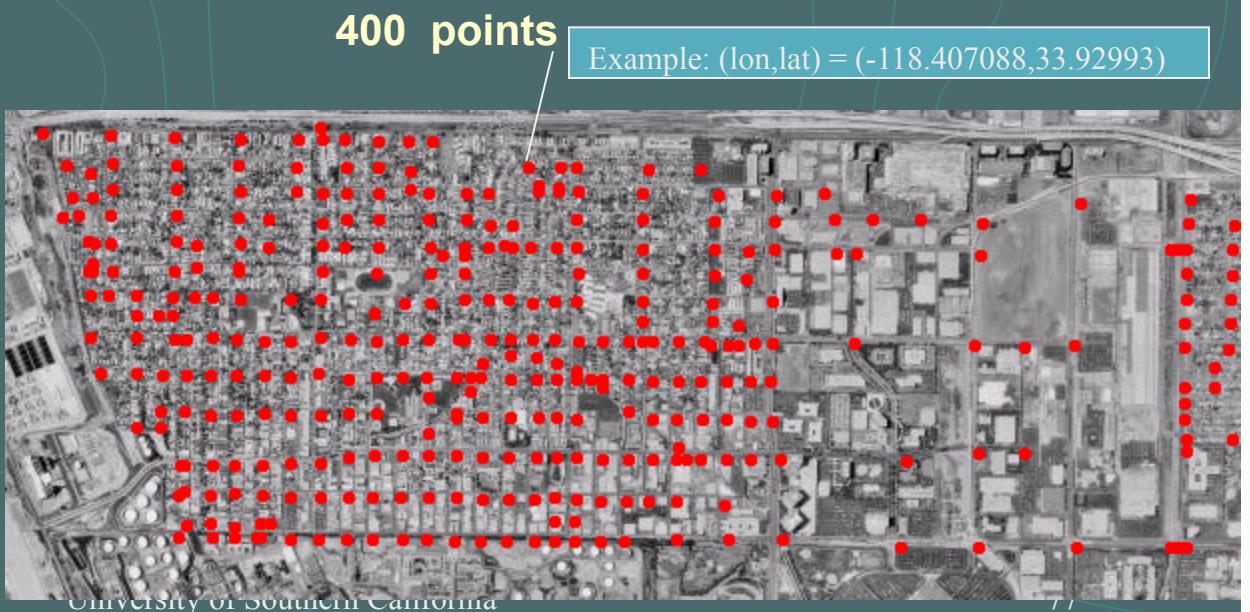
- Finding Maps
- Aligning Maps with Imagery
 - Extracting intersections
 - Point pattern matching
- Extracting Separate Layers from Maps
- Conclusions

Point Pattern Matching: Overview

- Find the mapping between these points
 - Why ? To generate a set of control point pairs



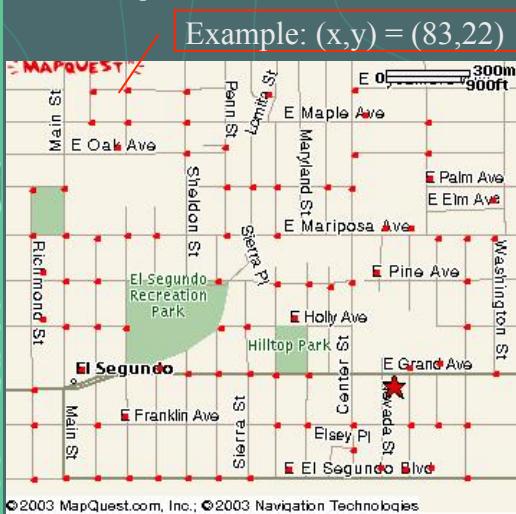
Craig A. Knoblock



Point Pattern Matching: Overview

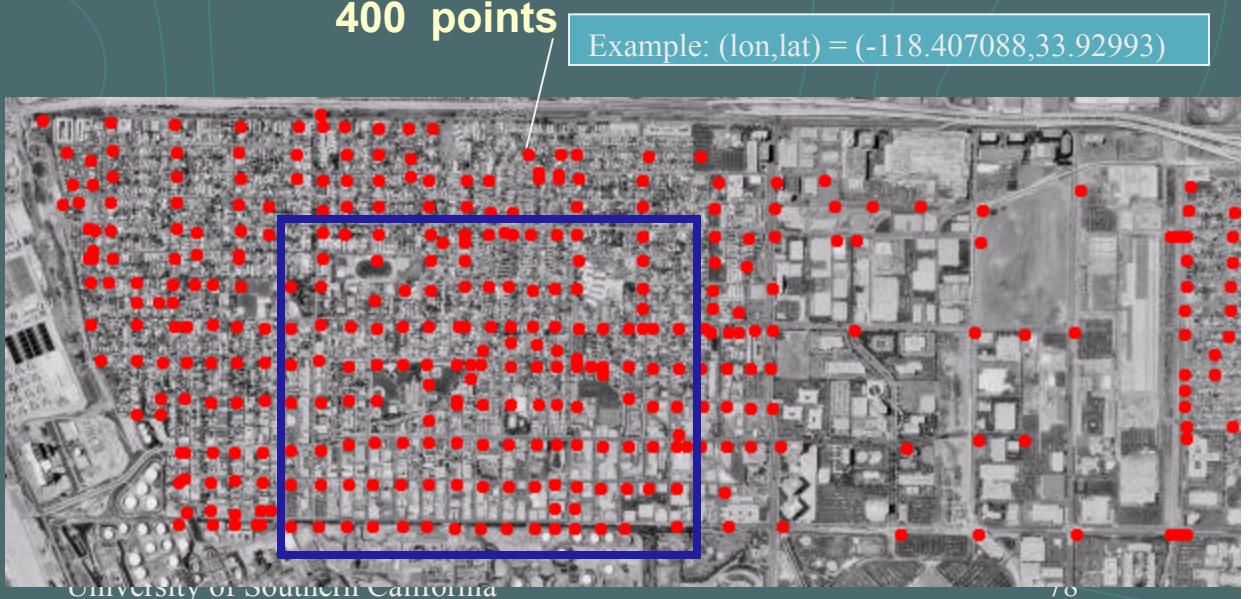
- Find the mapping between these points
 - Why ? To generate a set of control point pairs
- How to solve the point sets matching problem :
 - A geometric point sets matching problem
 - Find the transformation T between the layout (with relative distances) of the two point sets

80 points

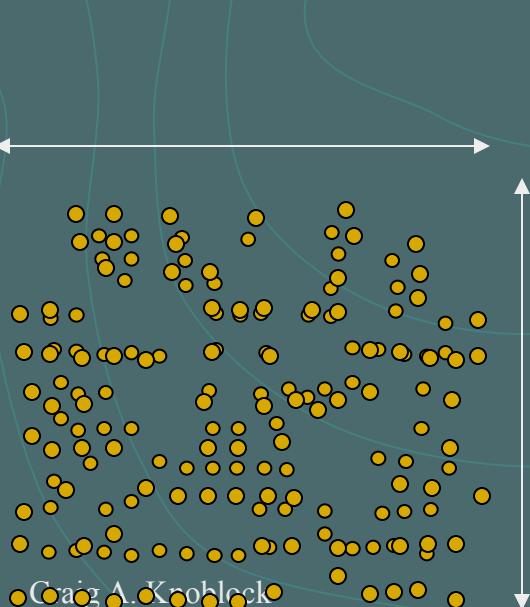
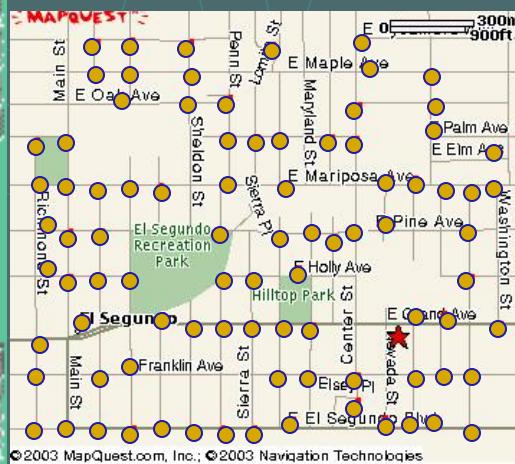


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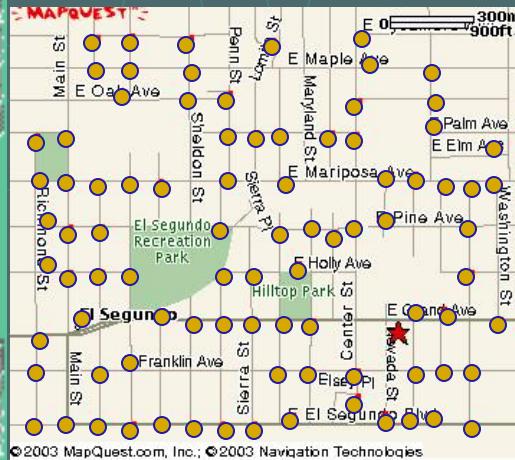
400 points



Point Pattern Matching: Finding the Transformation [Chen et al., 2004, ACMGIS]

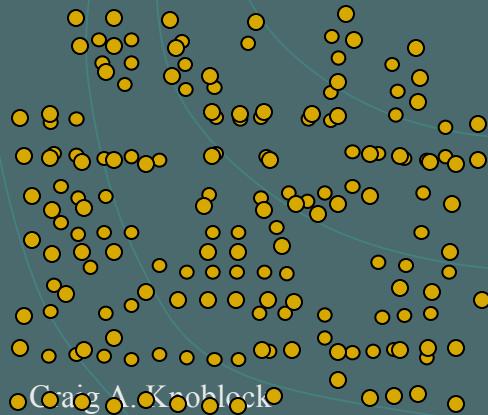
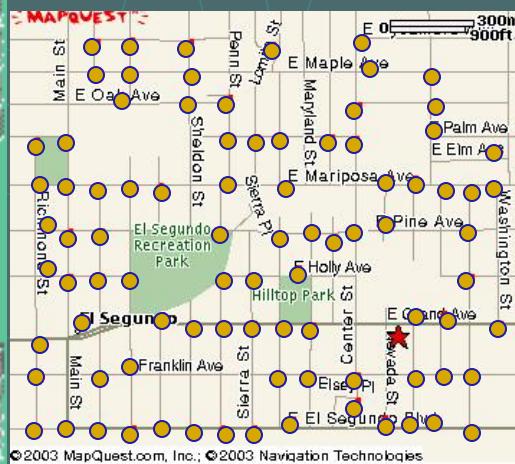


Point Pattern Matching: Finding the Transformation [Chen et al., 2004, ACMGIS]

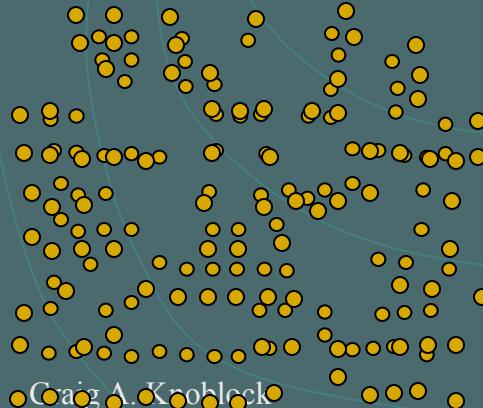
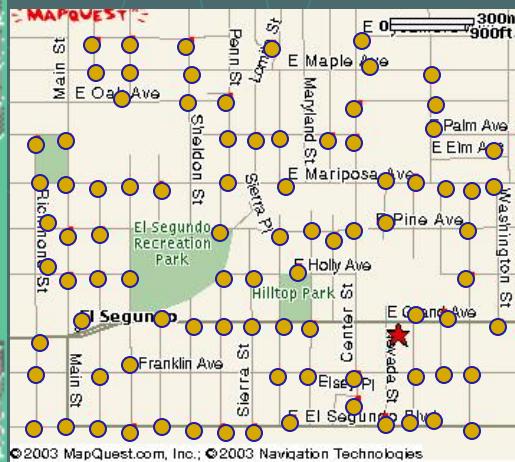


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Point Pattern Matching: Finding the Transformation [Chen et al., 2004, ACMGIS]



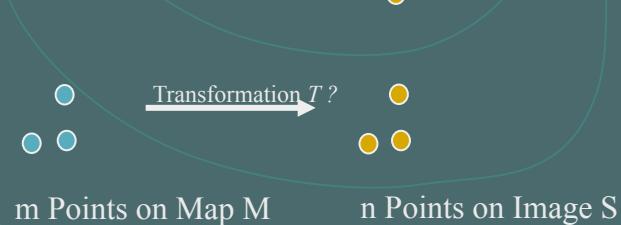
Point Pattern Matching: Finding the Transformation [Chen et al., 2004, ACMGIS]



- Transformation = Scaling + Translation
 - Transforms most points on map to points on imagery
 - Find matching point pairs to solve this transformation

Point Pattern Matching: A Brute-Force Algorithm

- Iterate all point pair in M, and for each chosen point pair in M examining all point pairs in S
 - Time-consuming : $O(m^3 n^2 \log n)$
 - Can we improve it by randomization ? Not always !
 - Noisy points on maps
 - Some missing points on imagery



Point Pattern Matching: A Brute-Force Algorithm

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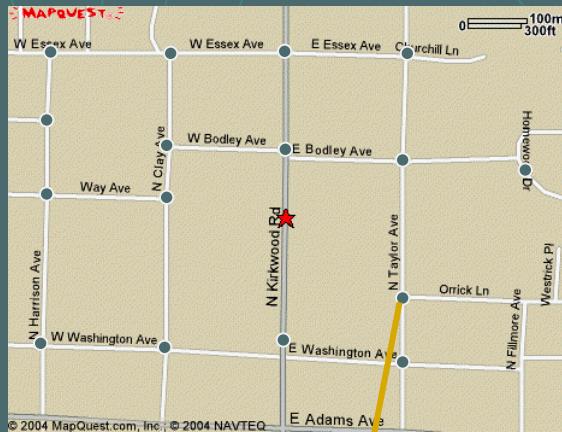
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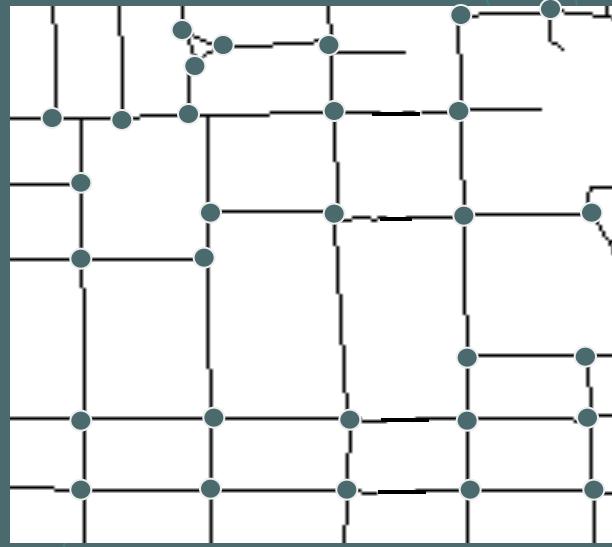


Geospatial Point Pattern Matching (GeoPPM): Exploit Geometric Info. Associated with Each Intersection

- Intersection degree: the number of intersected roads
- Directions of Intersected road segments

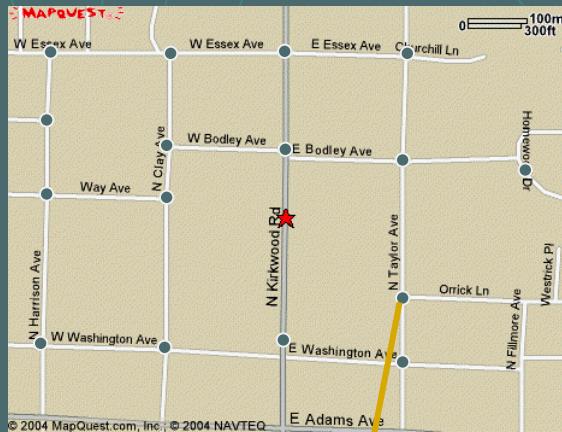


Degree:3;
Directions:0, 90, 270

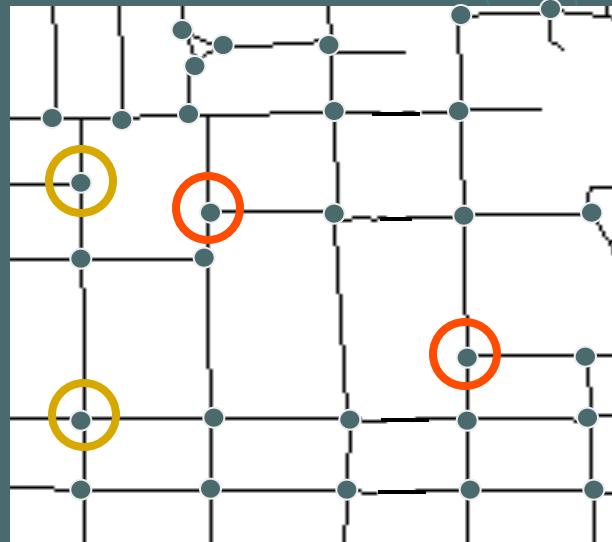


Geospatial Point Pattern Matching (GeoPPM): Exploit Geometric Info. Associated with Each Intersection

- Intersection degree: the number of intersected roads
- Directions of Intersected road segments



Degree:3;
Directions:0, 90, 270



Geospatial Point Pattern Matching (GeoPPM): Exploit Map Scale

- We need to consider translation only

$$O(m^3 n^2 \log n) \rightarrow O(m^2 n \log n)$$

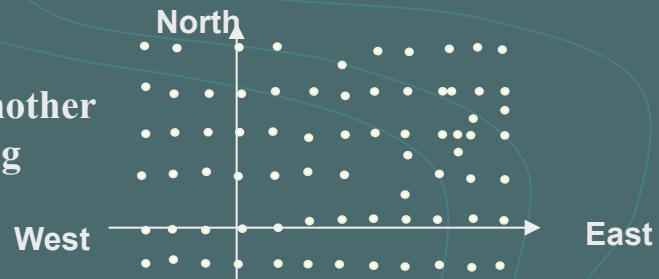
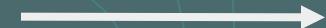
Point Pattern on Imagery



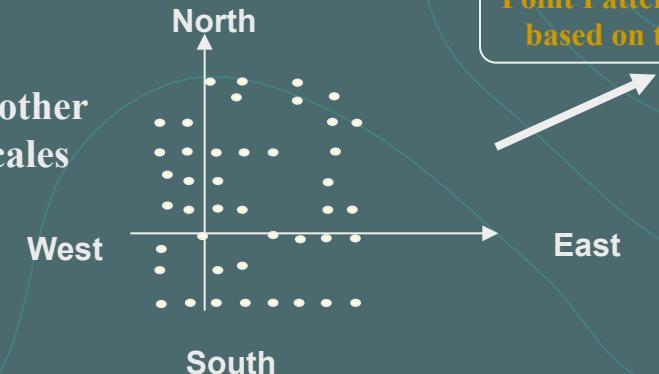
Point Pattern on Map



Transform points to another
space based lat/long



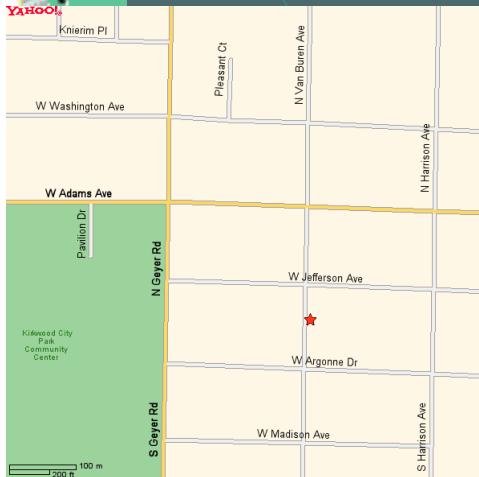
Transform points to another
space based on map-scales



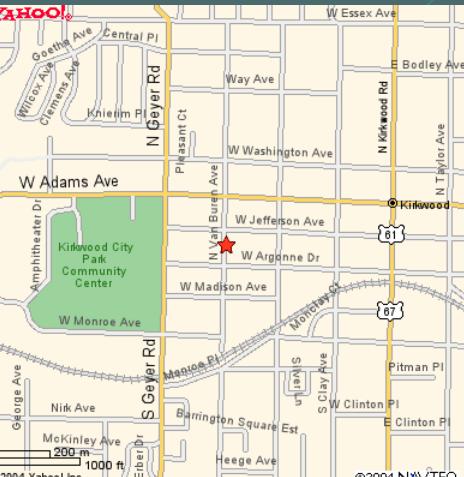
Point Pattern Matching
based on translation

Geospatial Point Pattern Matching (GeoPPM): For Map with Unknown Map Scale

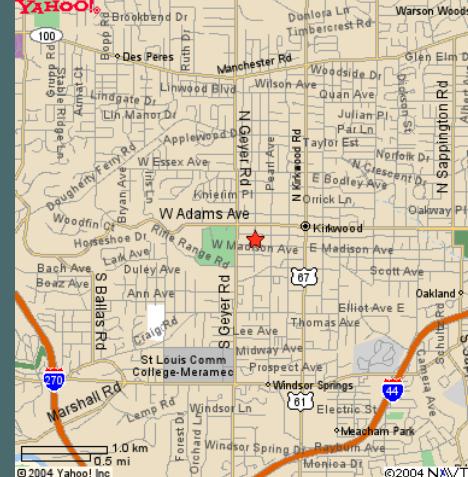
- Exploiting Point Density and Localized Distribution of Points
 - Assumption: we focus on medium to high resolution maps
 - We are conflating maps with high resolution imagery !



Level 1: 1.2 m/pixel



Level 2: 4.25 m/pixel



Level 3: 14.08 m/pixel



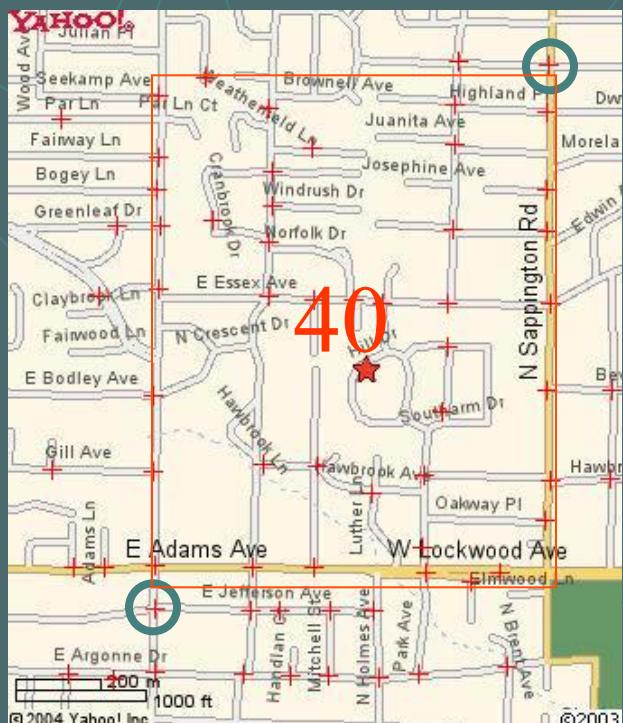
Level 4: 35 m/pixel

Coarse level map: map with smaller map-scale (low resolution)

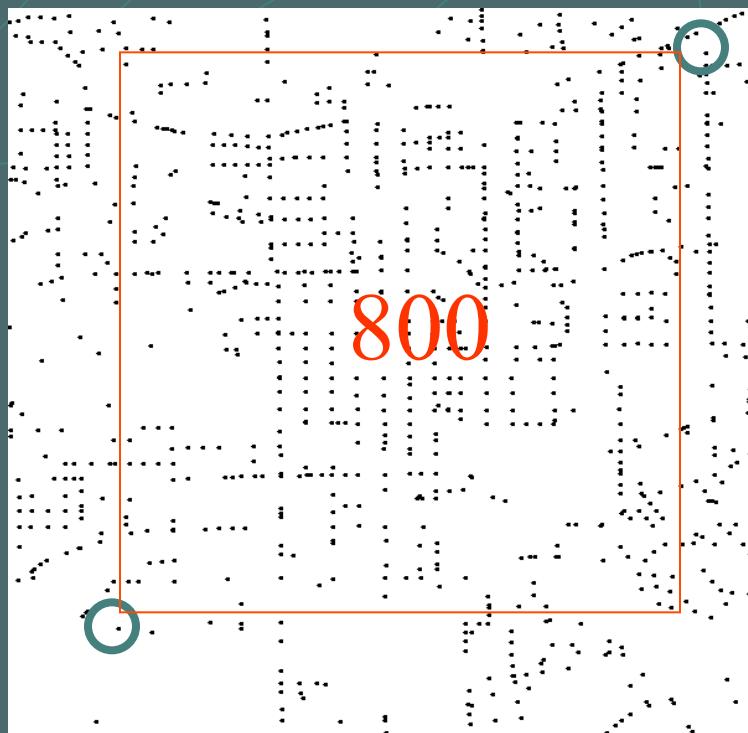
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Geospatial Point Pattern Matching (GeoPPM): Exploiting Point Density



55 points



1059 points

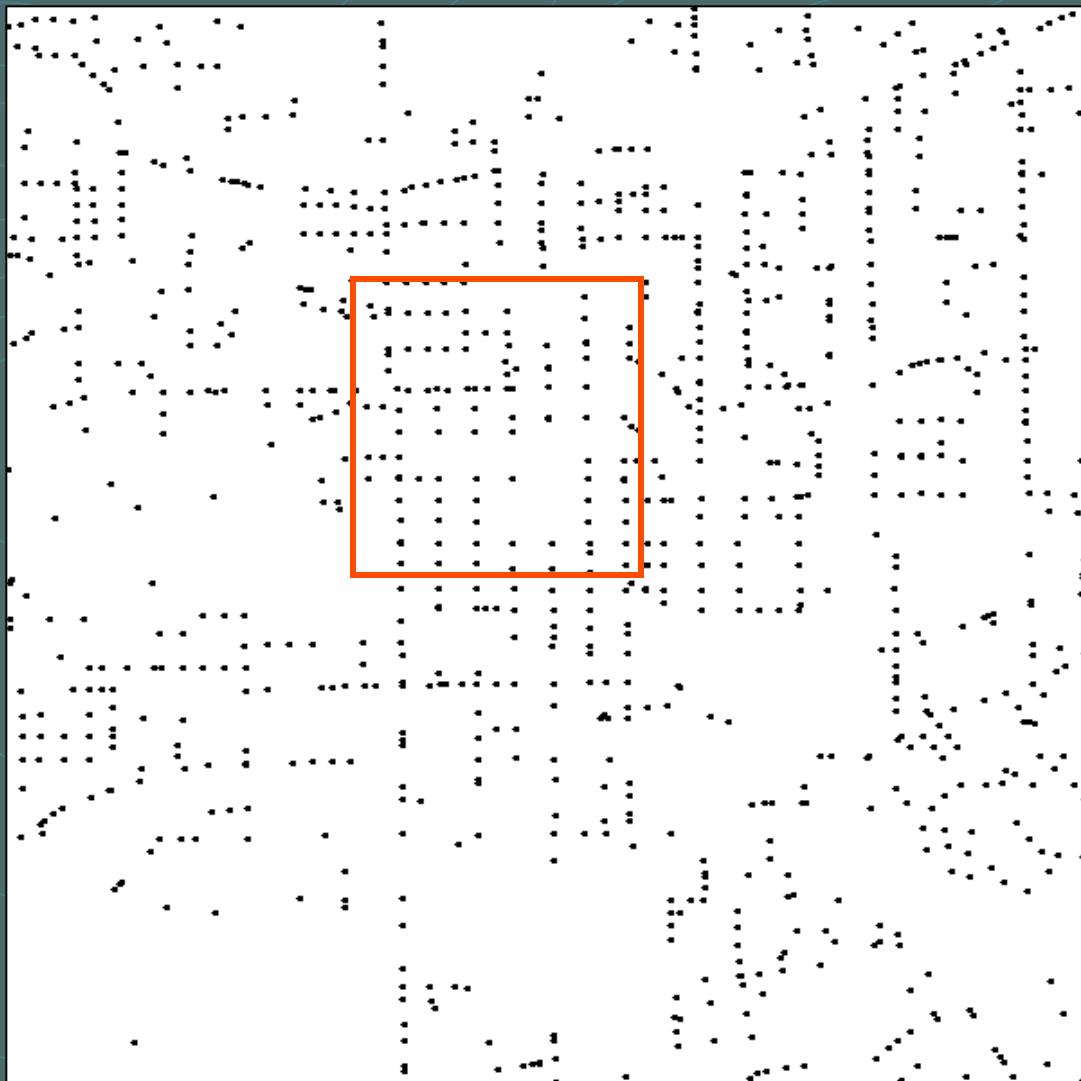
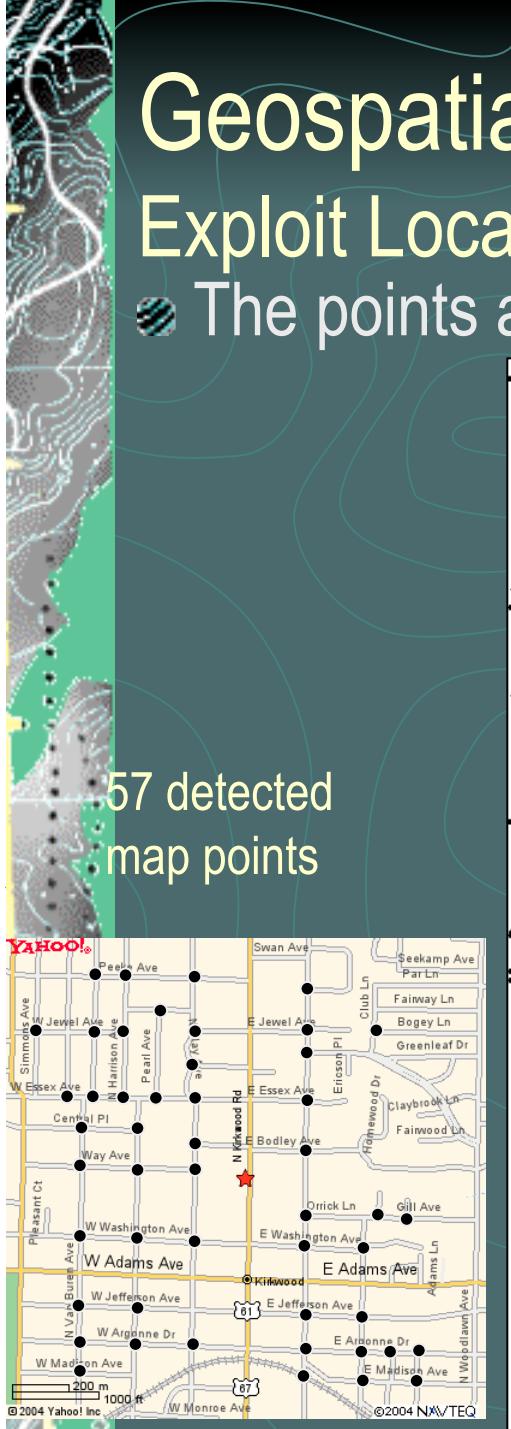
Geospatial Point Pattern Matching (GeoPPM): Exploit Localized Distribution of Points

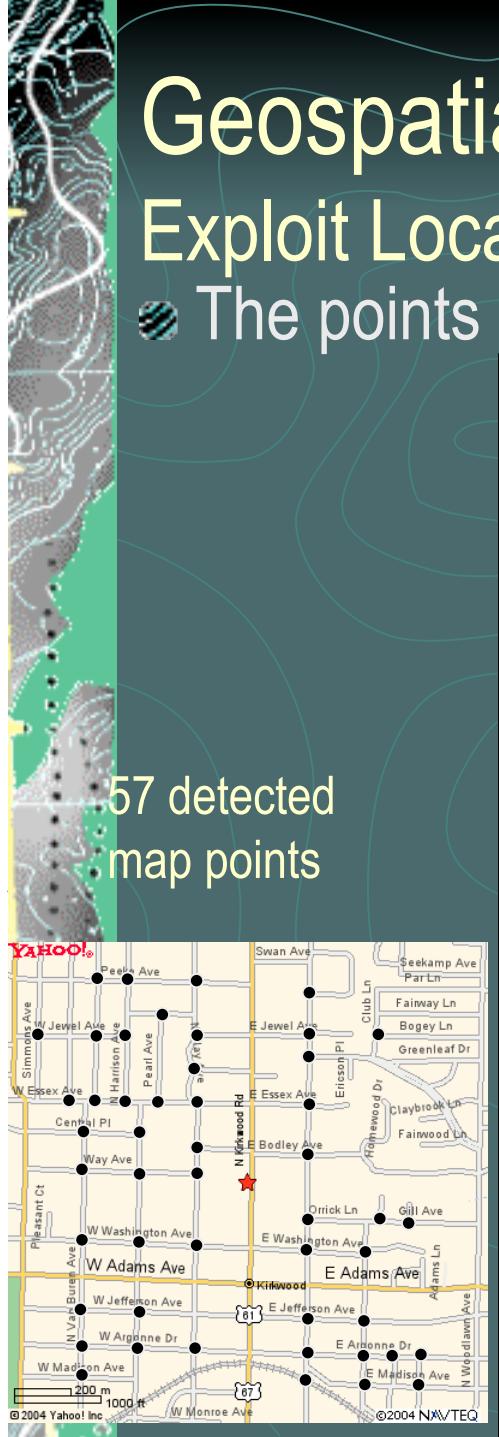
- The points are in a cluster !



Geospatial Point Pattern Matching (GeoPPM): Exploit Localized Distribution of Points

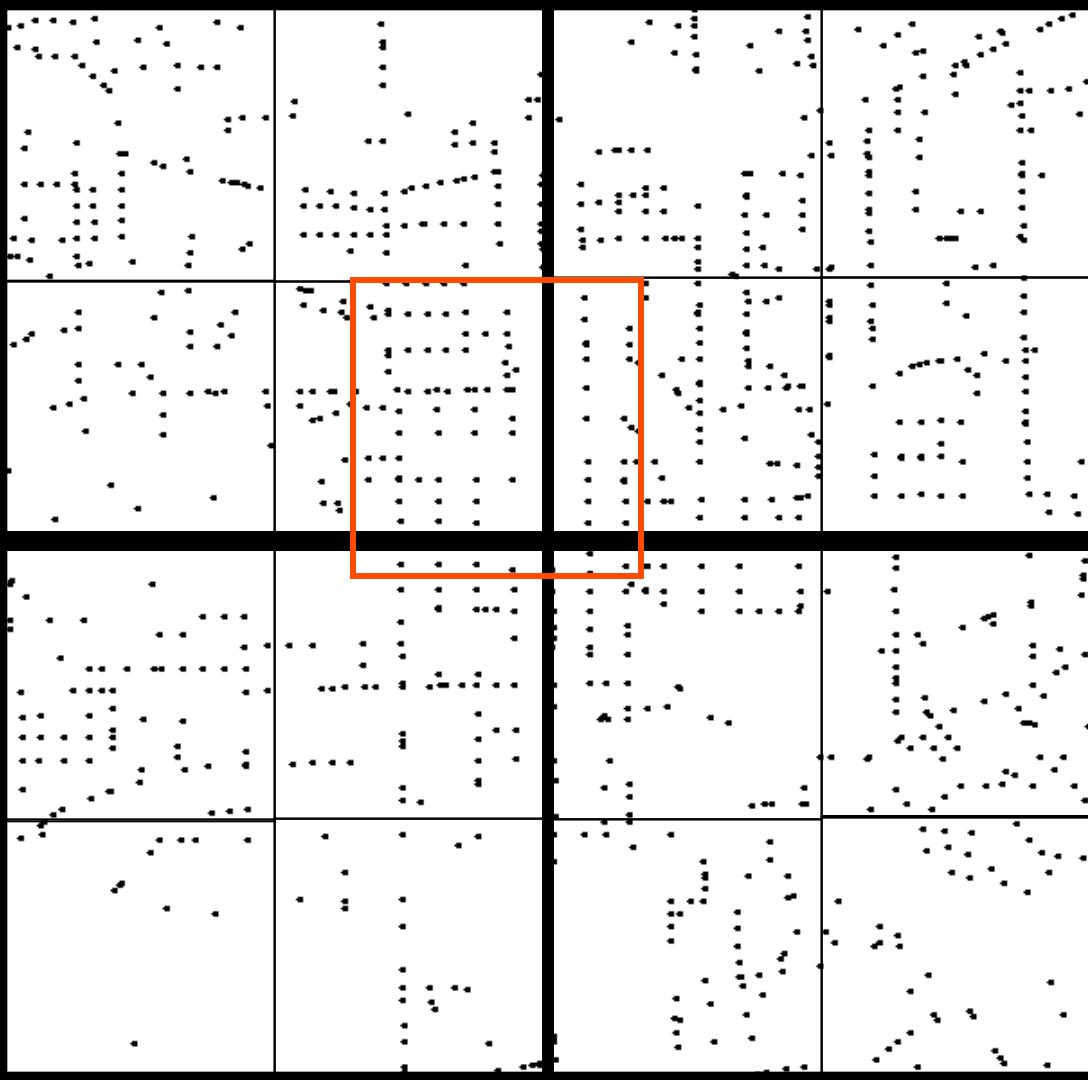
- The points are in a cluster !

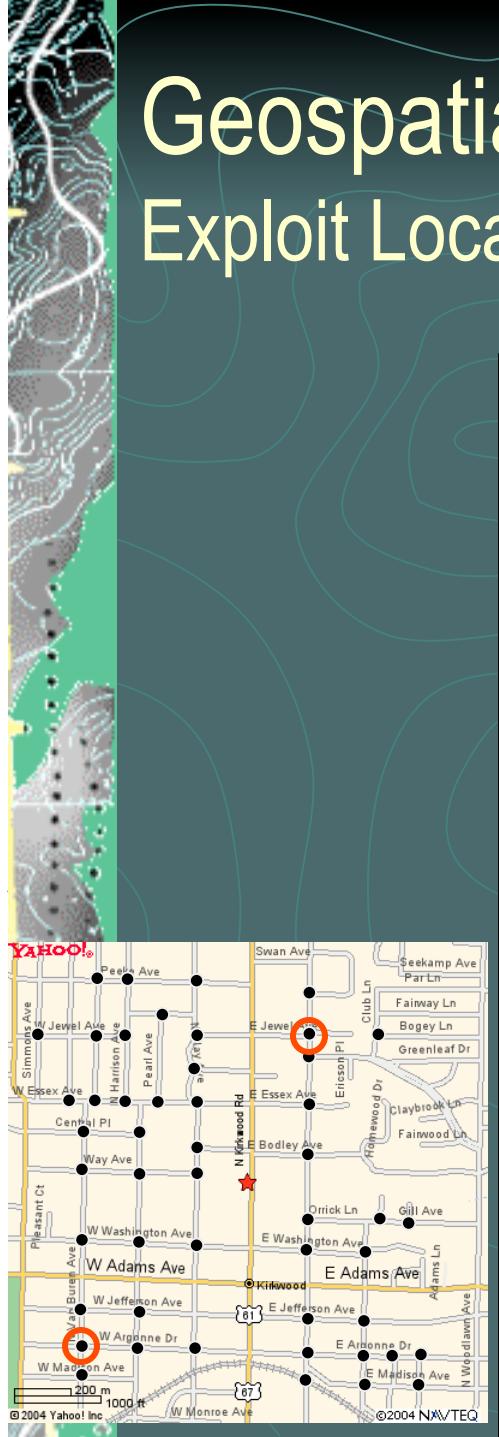




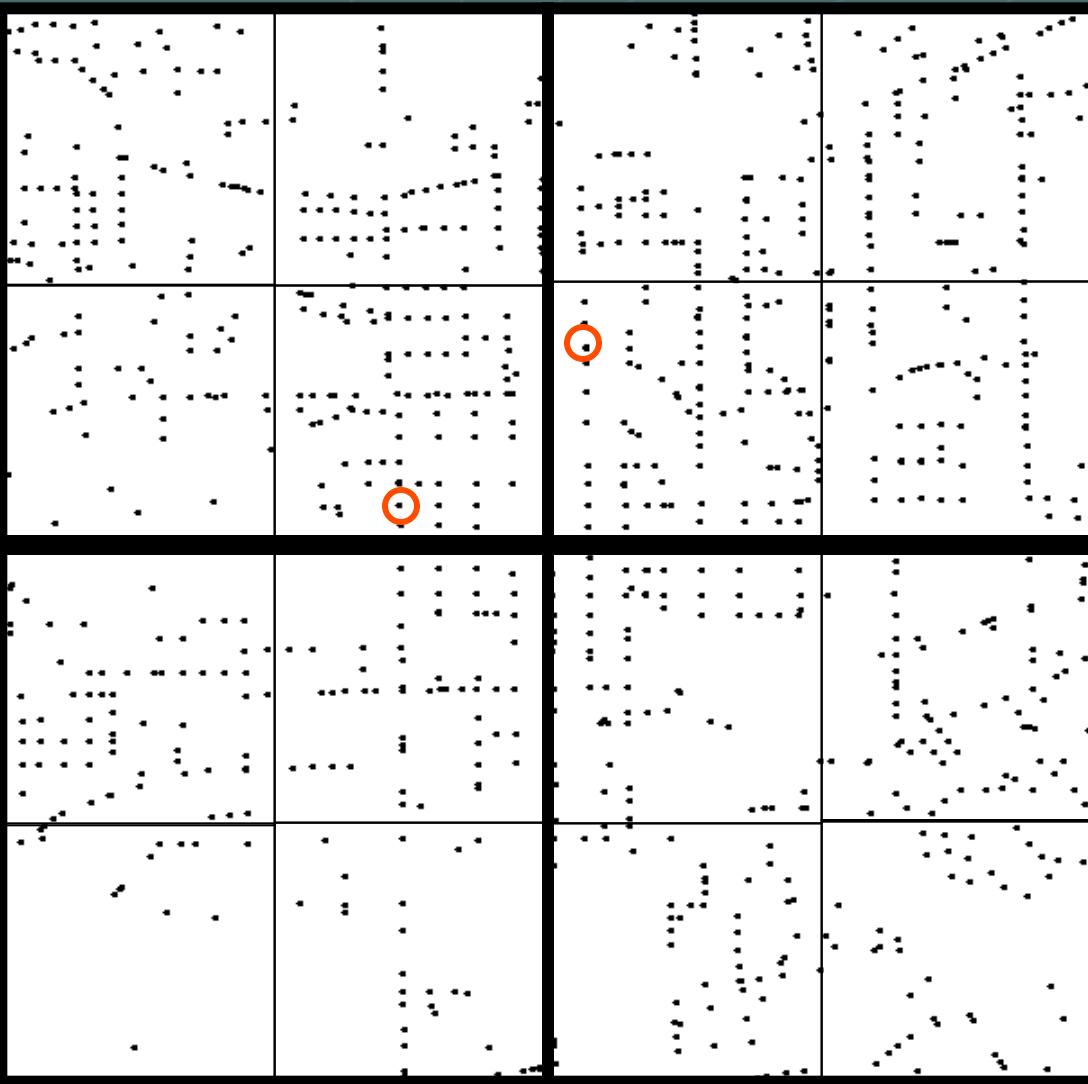
Geospatial Point Pattern Matching (GeoPPM): Exploit Localized Distribution of Points

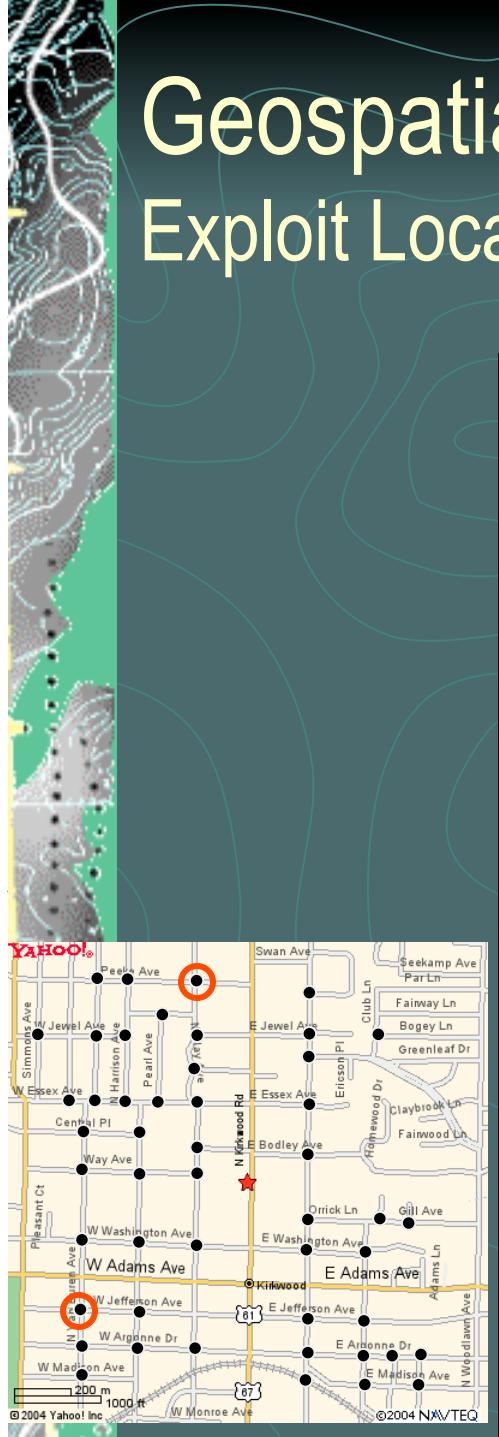
- The points are in a cluster !



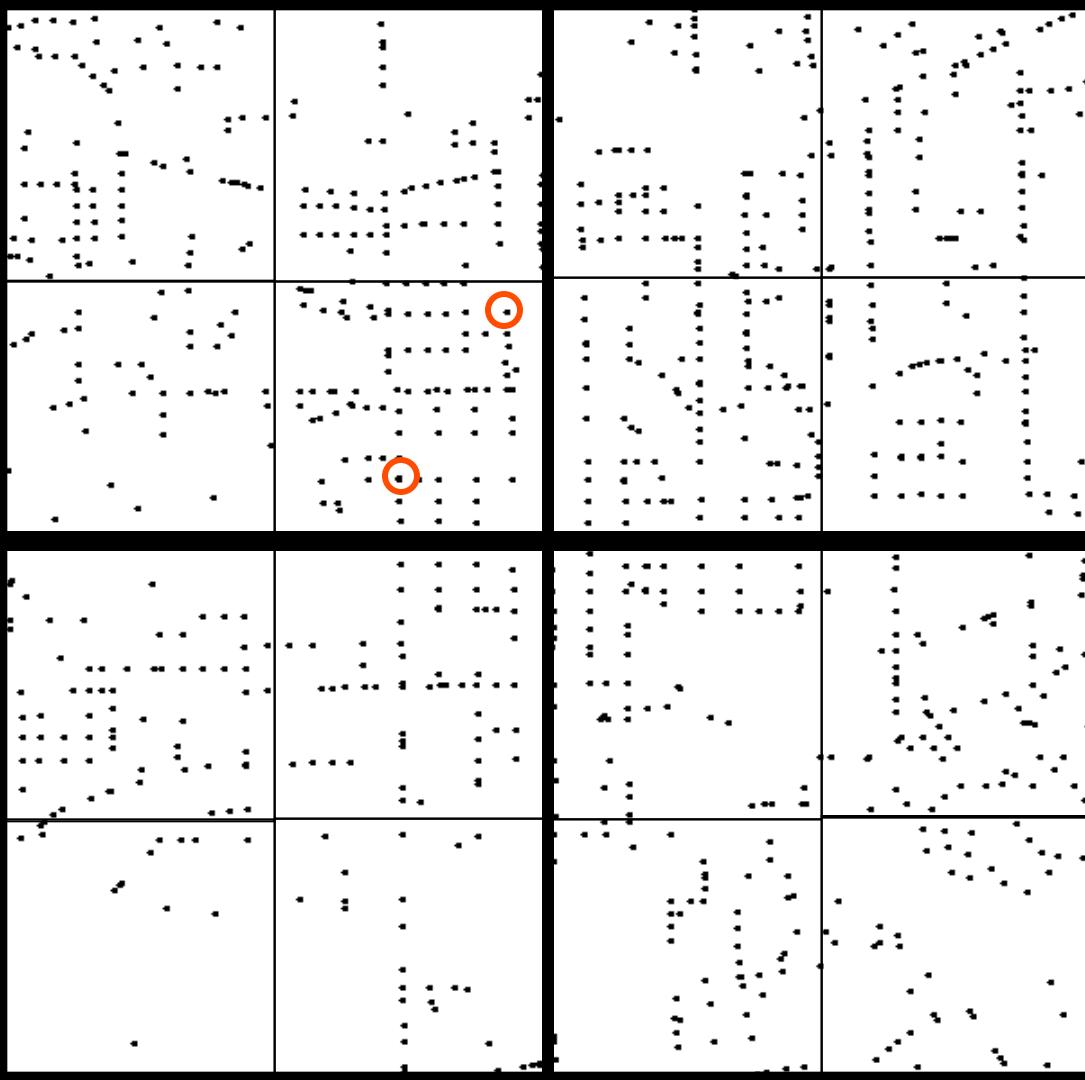


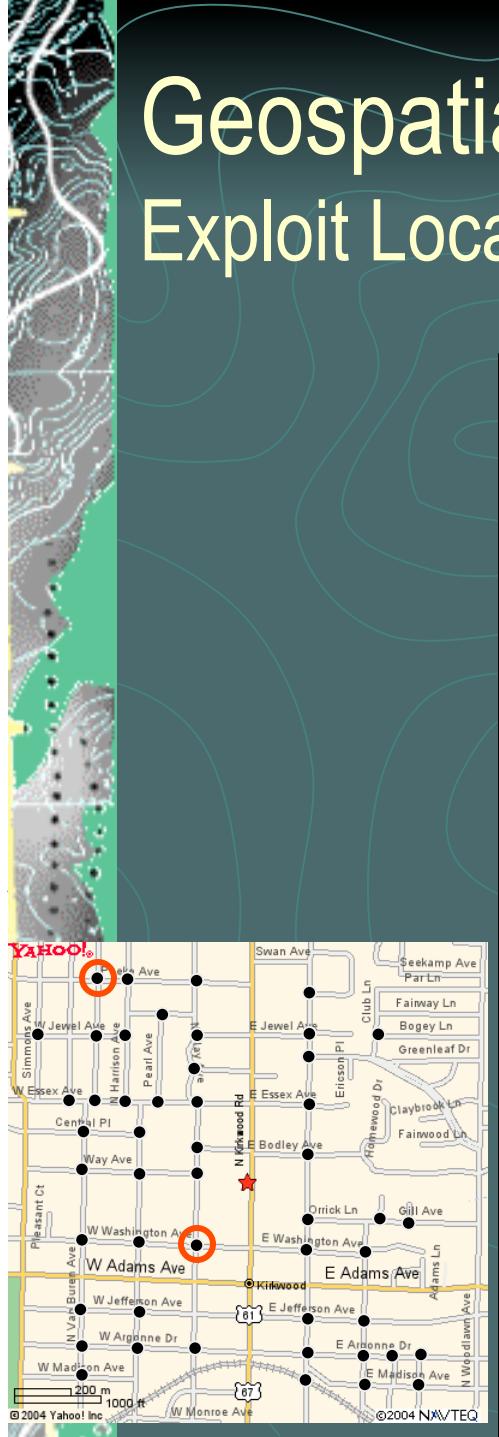
Geospatial Point Pattern Matching (GeoPPM): Exploit Localized Distribution of Points



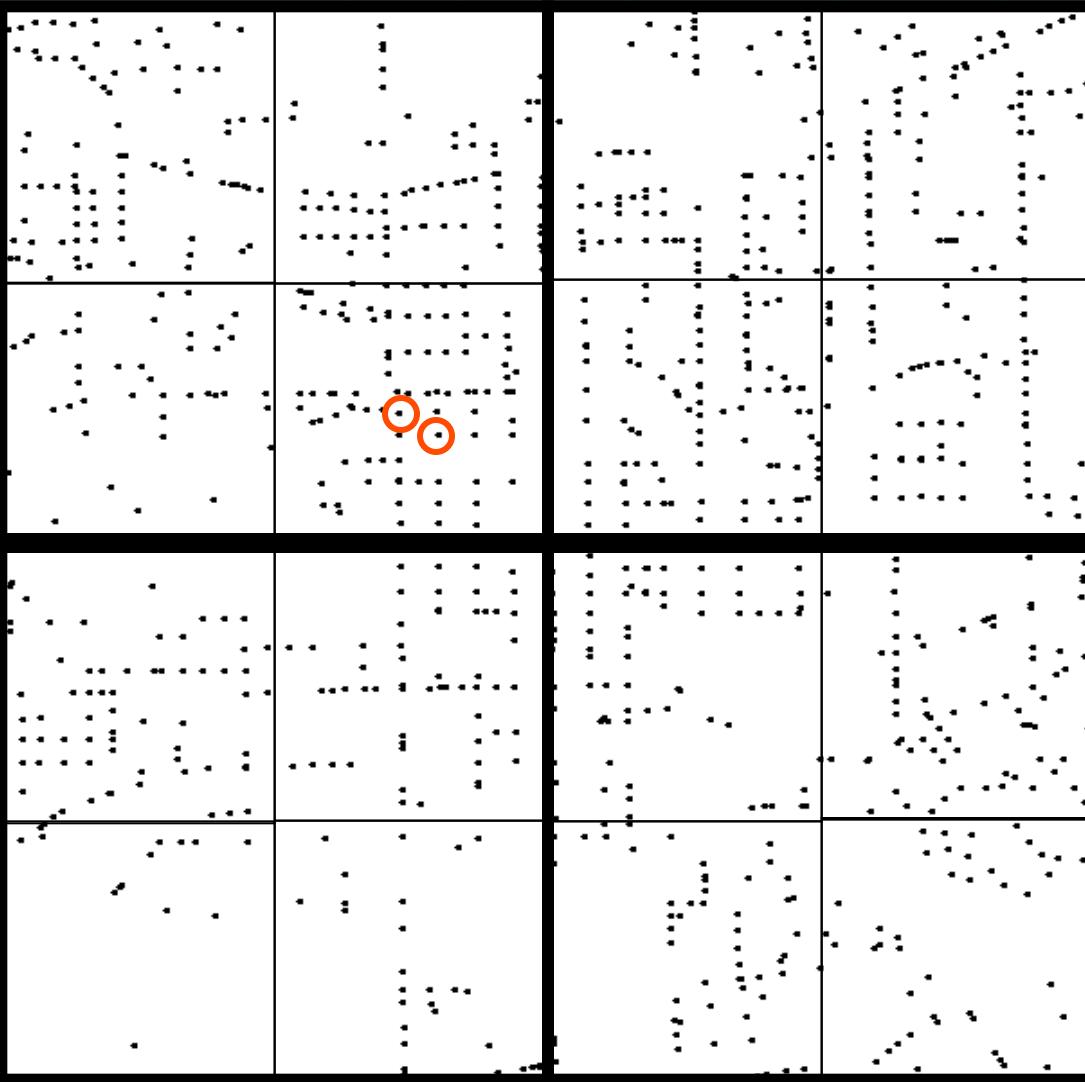


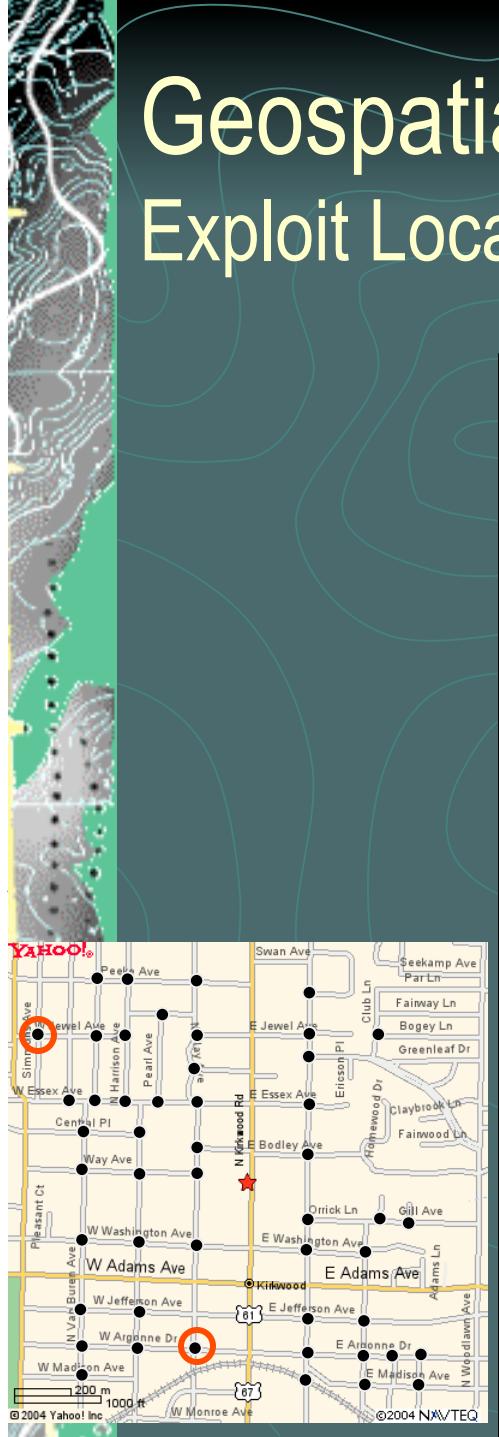
Geospatial Point Pattern Matching (GeoPPM): Exploit Localized Distribution of Points



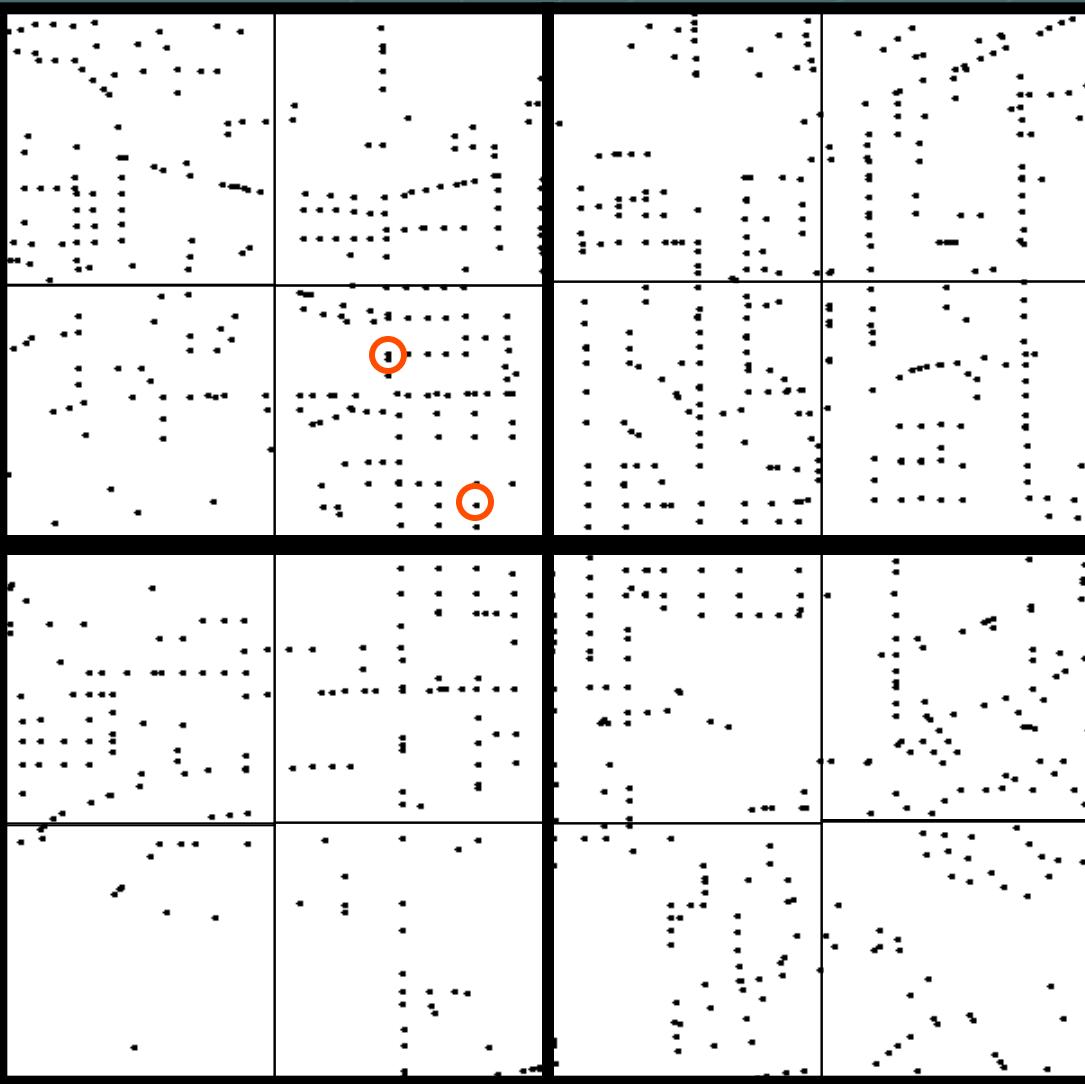


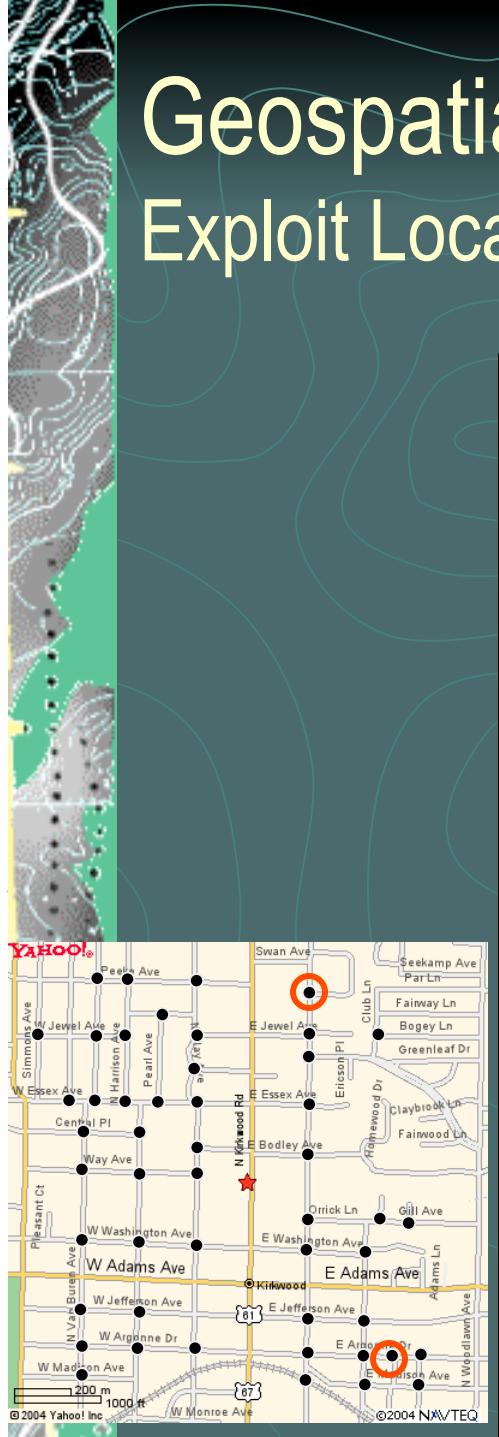
Geospatial Point Pattern Matching (GeoPPM): Exploit Localized Distribution of Points



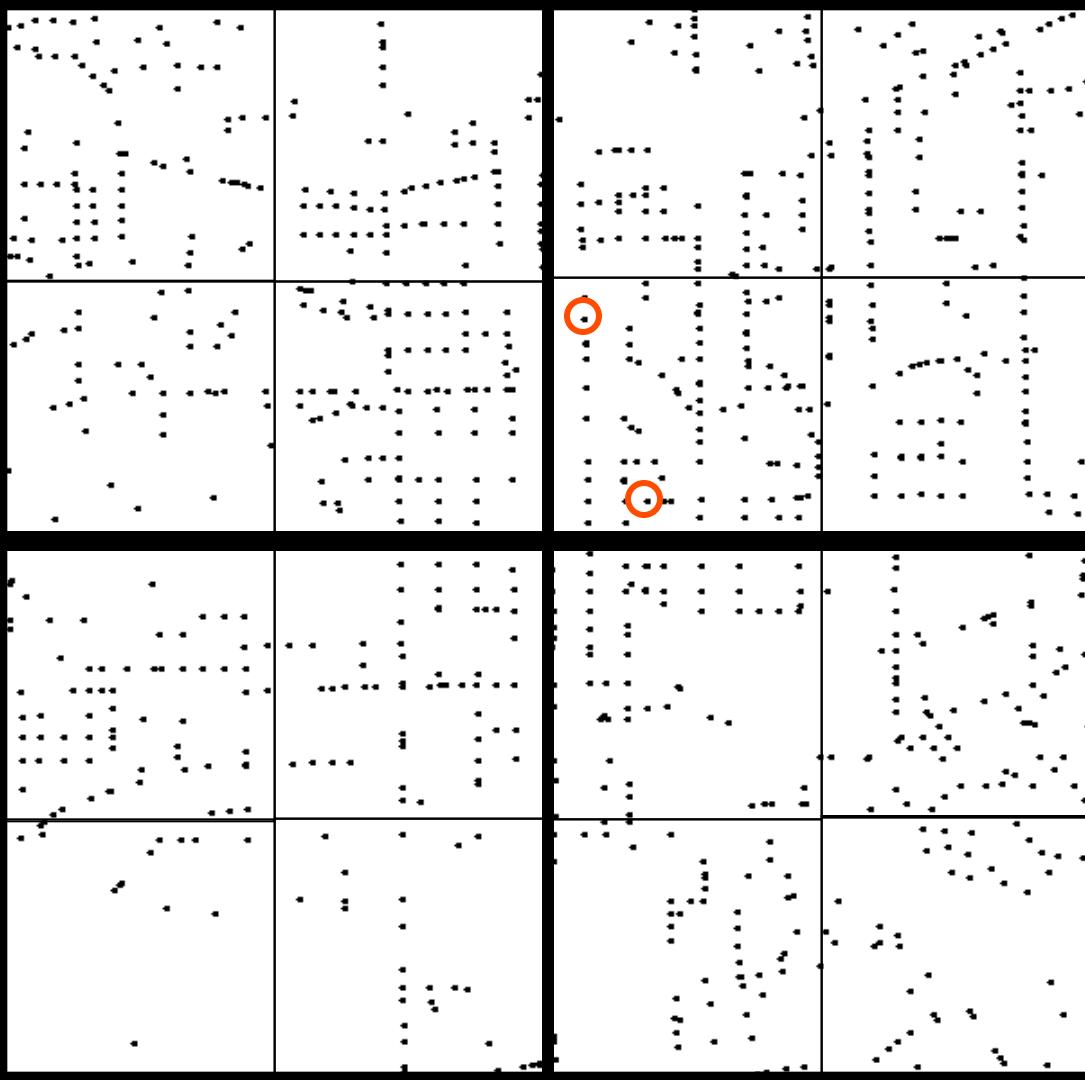


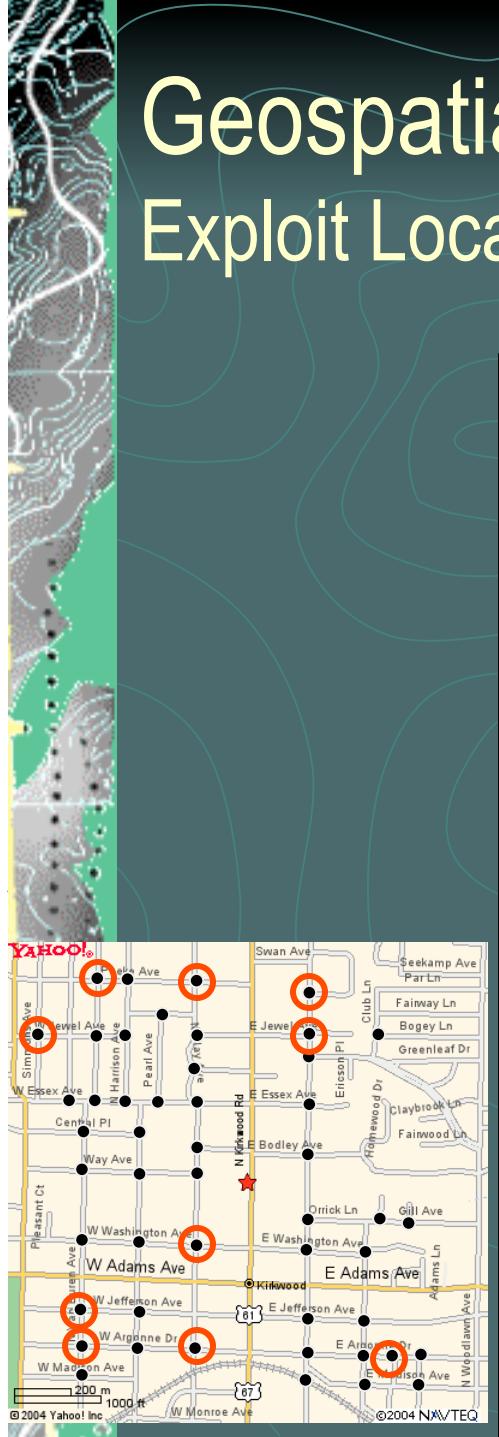
Geospatial Point Pattern Matching (GeoPPM): Exploit Localized Distribution of Points



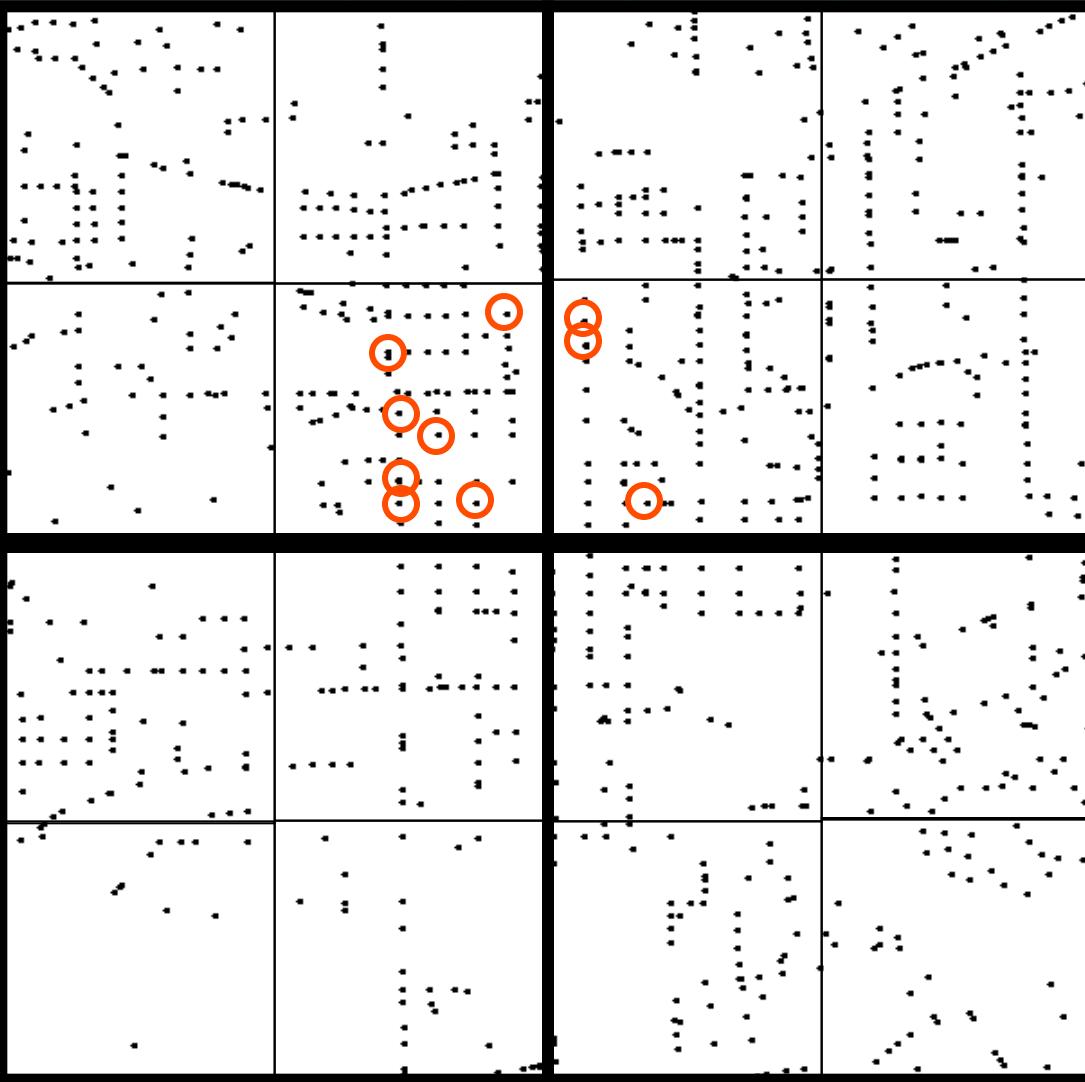


Geospatial Point Pattern Matching (GeoPPM): Exploit Localized Distribution of Points

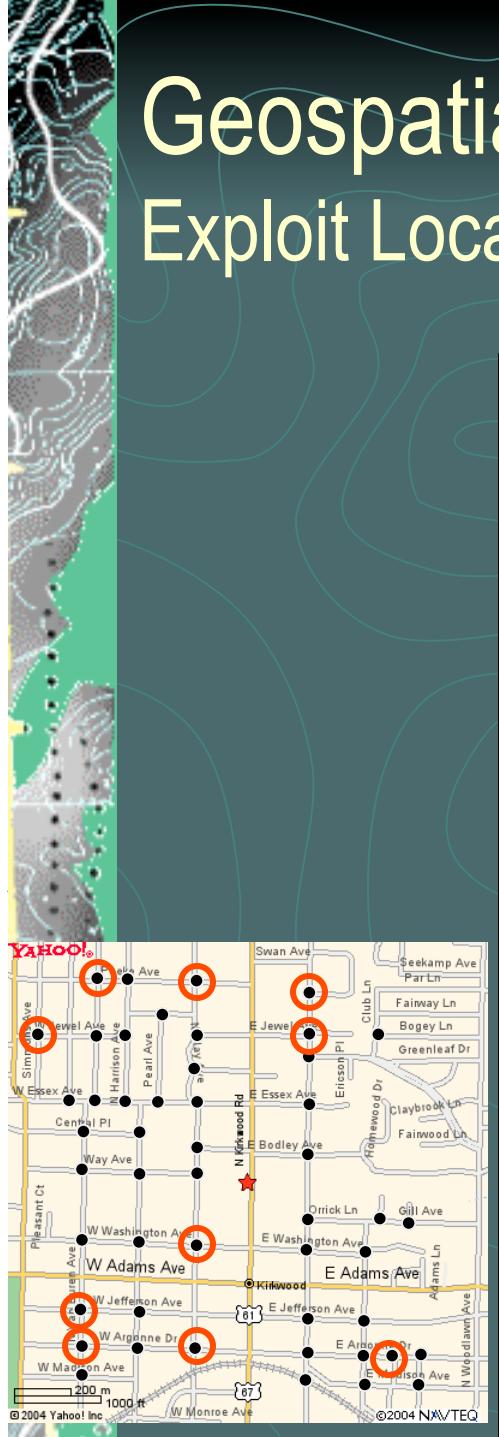




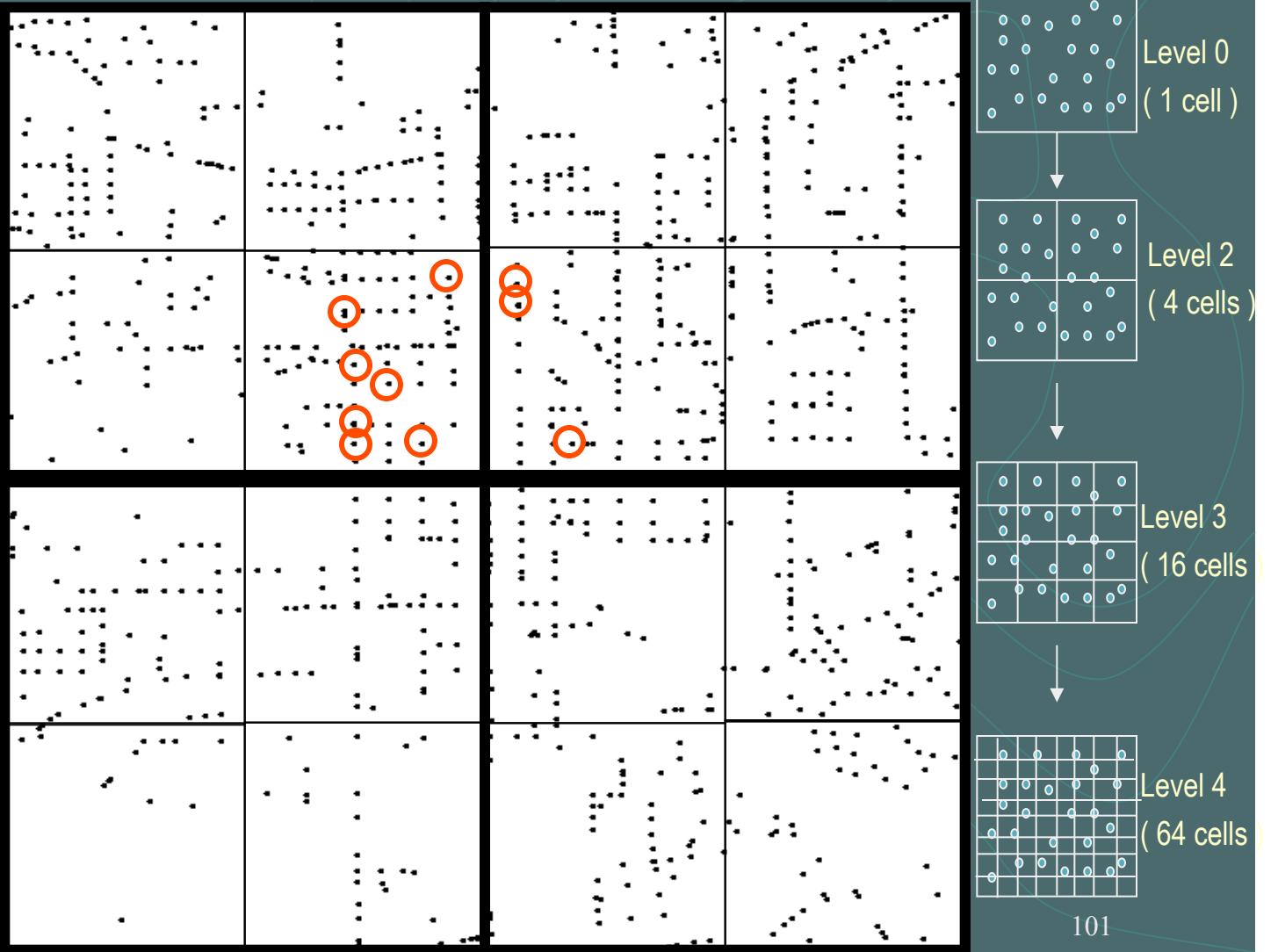
Geospatial Point Pattern Matching (GeoPPM): Exploit Localized Distribution of Points



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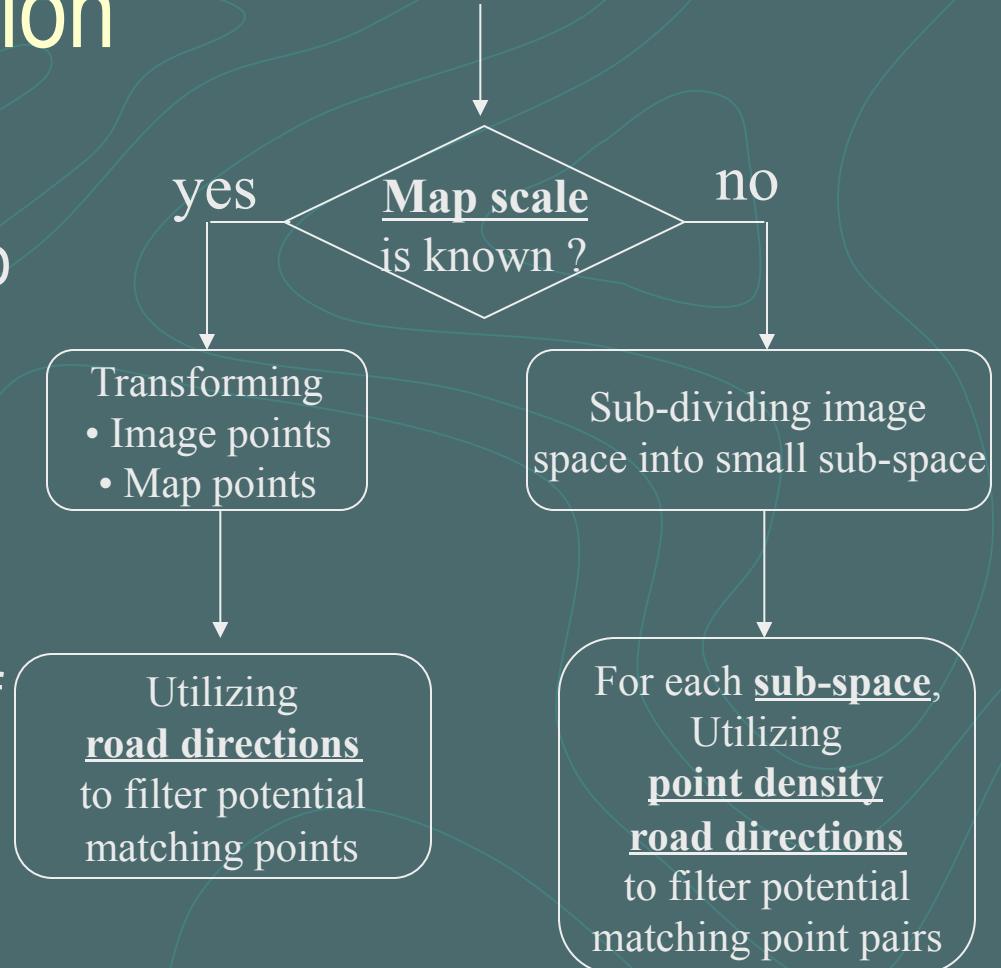


Geospatial Point Pattern Matching (GeoPPM): Exploit Localized Distribution of Points



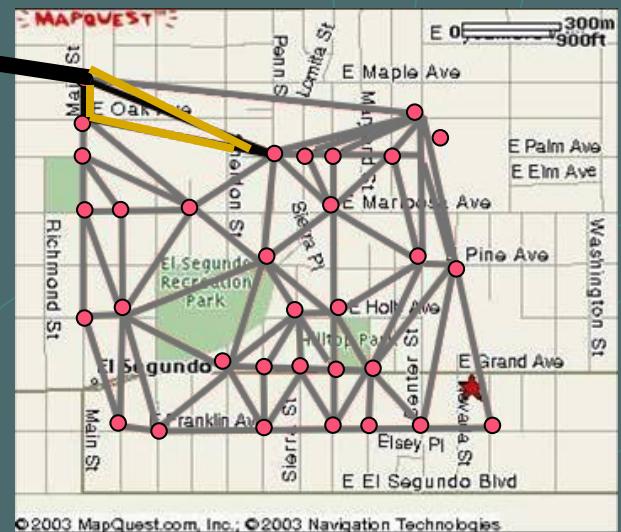
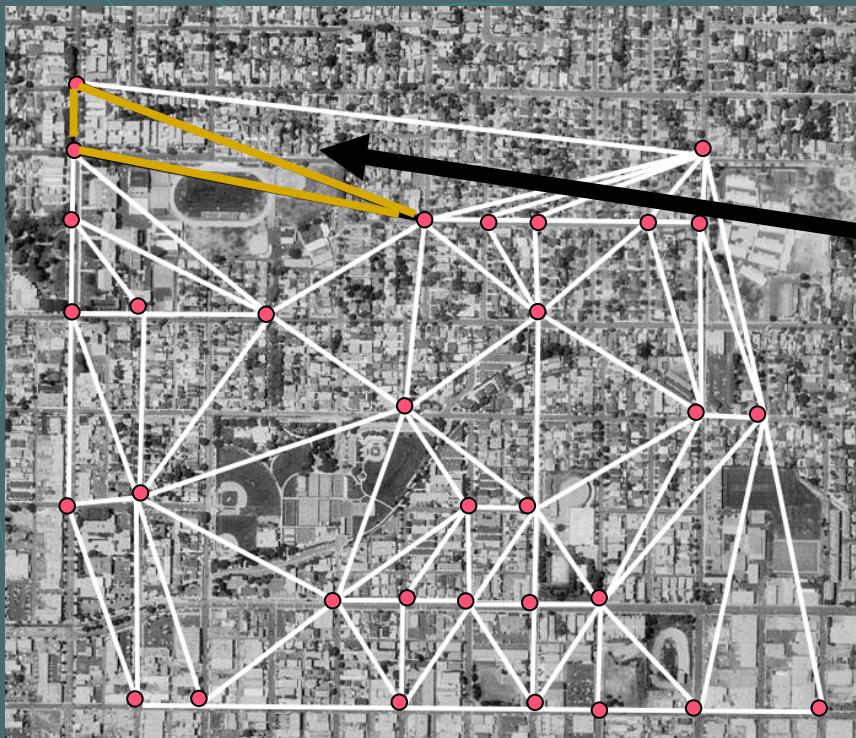
Geospatial Point Pattern Matching (GeoPPM): Current Implementation

- Utilizing these exploited information simultaneously to prune search space
 - Road directions
 - Map scale
 - Point density
 - Localized distribution of points

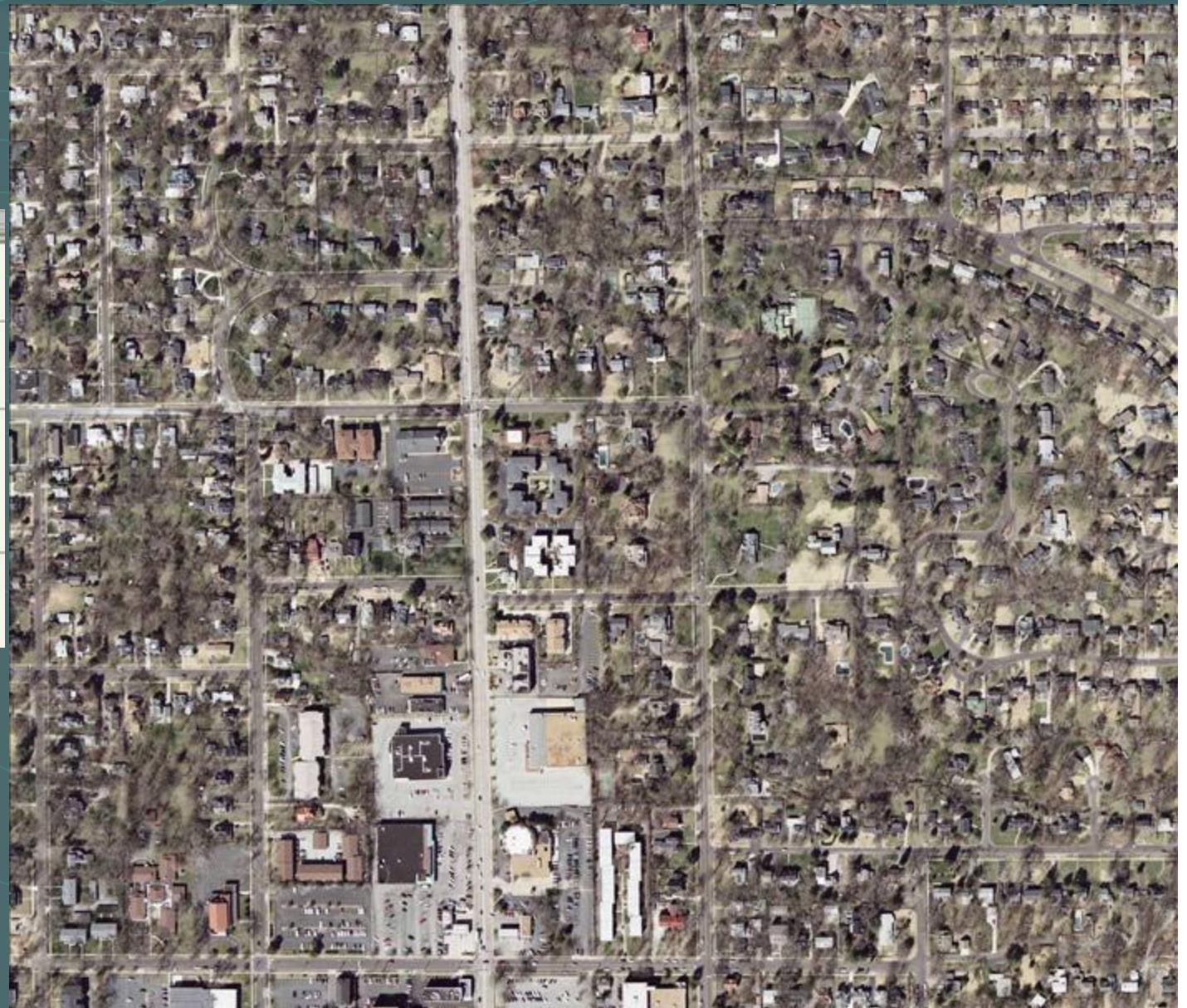


Aligning Maps and Imagery

- Using matched point pattern to align maps with imagery by Delaunay triangulation and rubber-sheeting [Saalfeld'88]
 - Space partition to build influence regions: Delaunay triangulation
 - Warping maps' pixels within each triangle to the corresponding pixels on imagery : based on Delaunay triangles and rubber-sheeting



Results

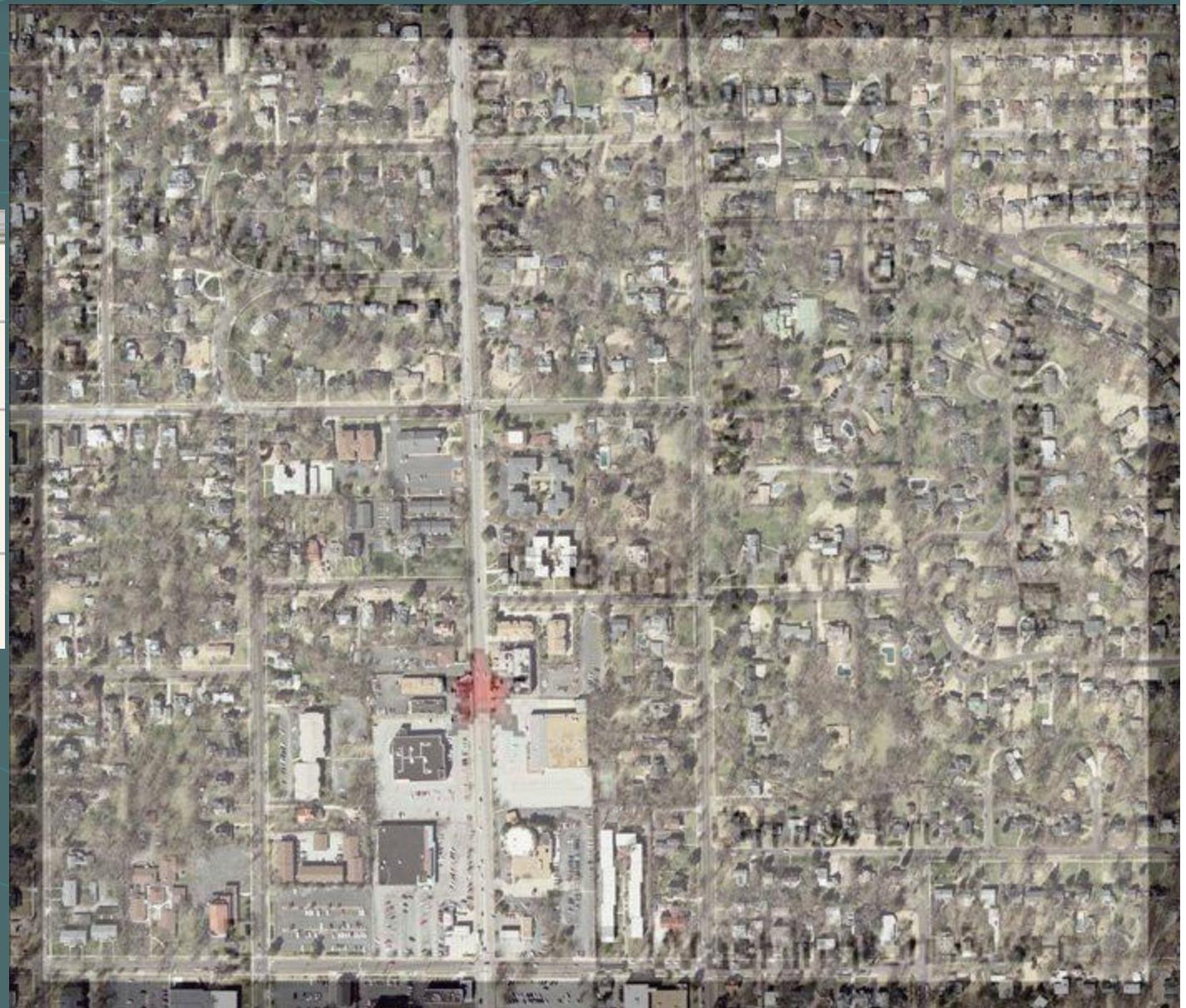


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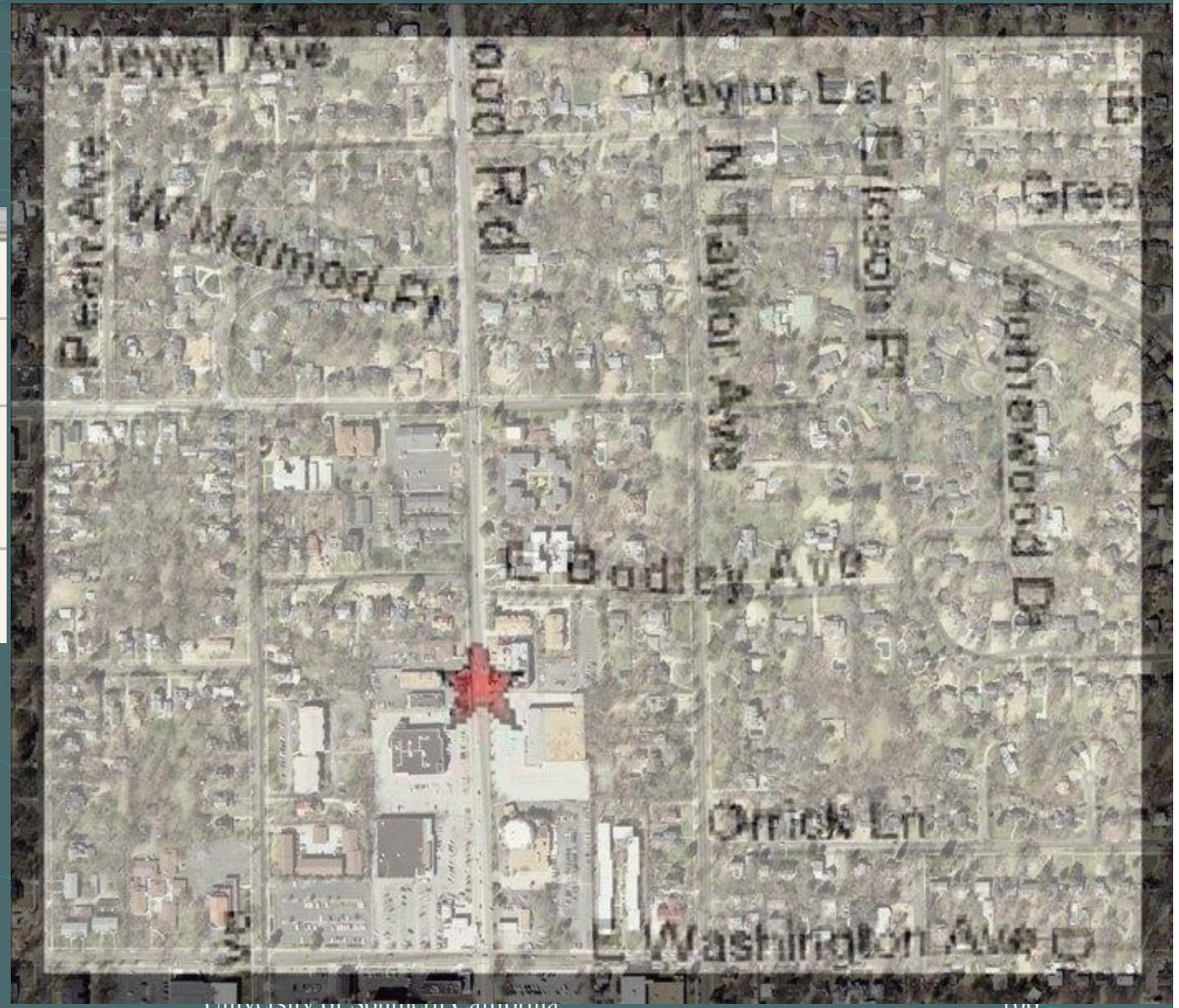
Results



Results



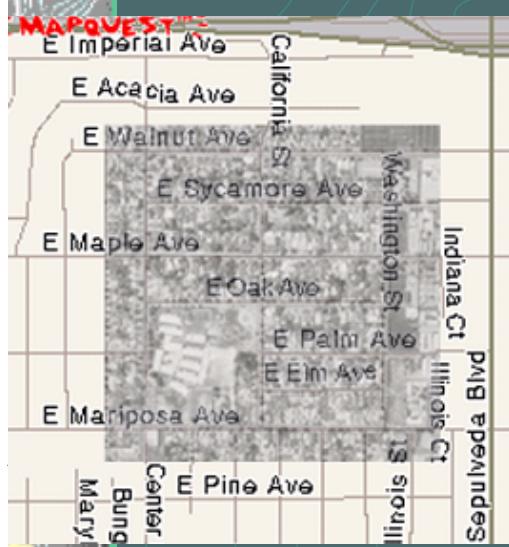
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Results

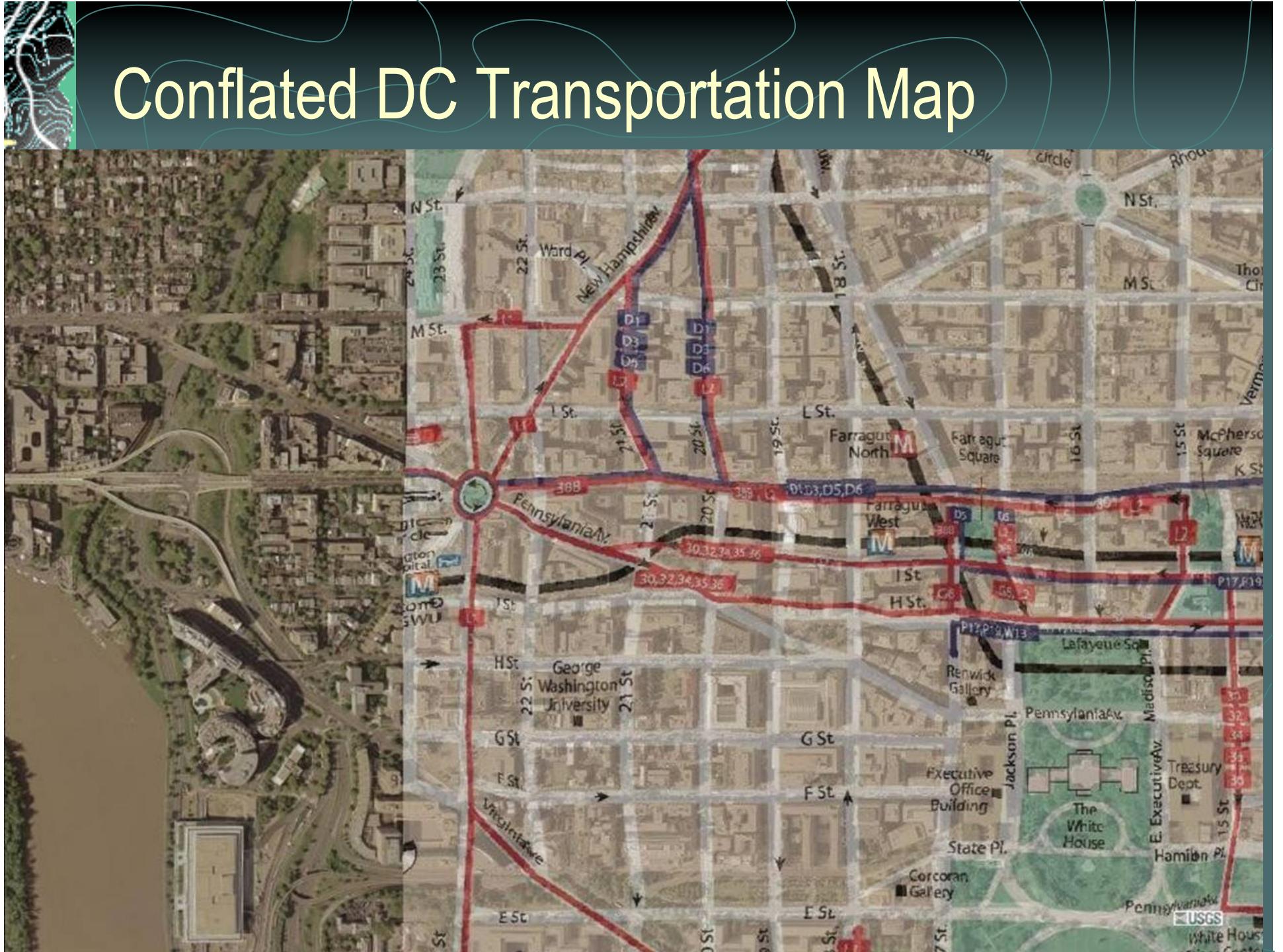


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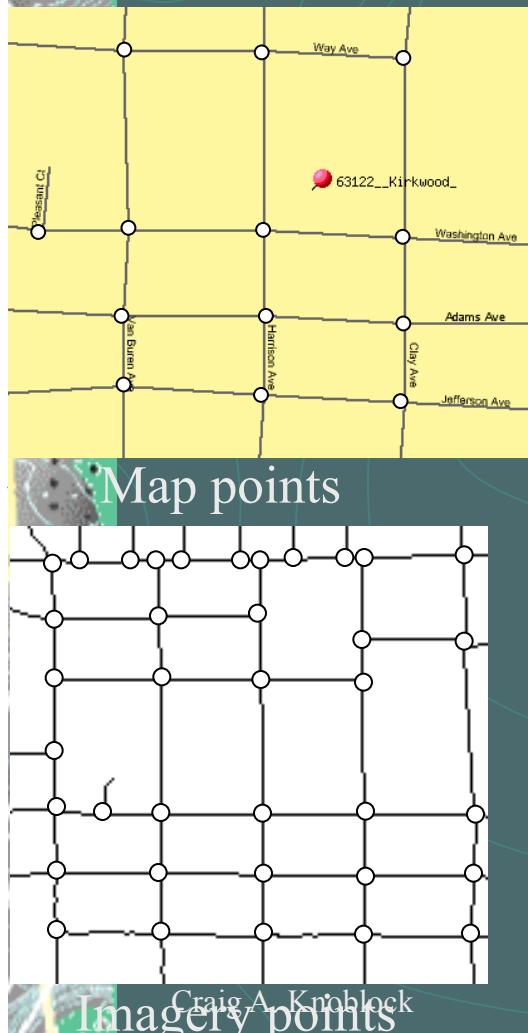
Evaluation: The performance of GeoPPM in Precision/Recall

	ESRI map	MapQuest map	Yahoo map	TIGER map	Topographic map
Precision	96.0%	95.2%	94.0%	84.2%	93.9%
Recall	80.2%	84.8%	88.3%	75.6%	80.94%

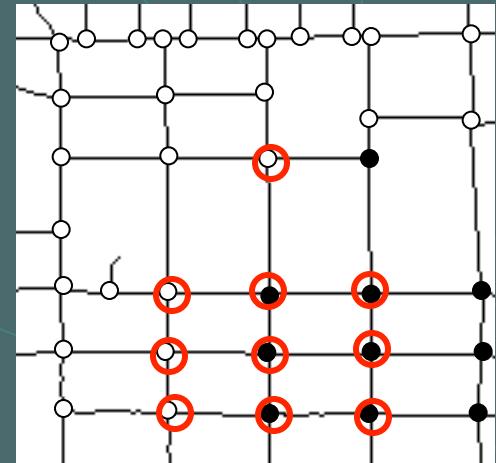
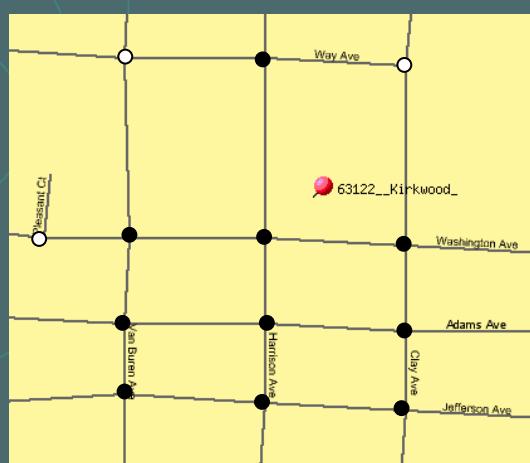
	Test data set 1 (El Segundo, CA)	Test data set 2 (St. Louis, MO)
Precision	91.9%	93.4%
Recall	84.6%	77.4%

	Precision	Recall
Res \leq 2m/pixel (38%)	87.4%	78.2%
2 < Res \leq 4 (18%)	92.9%	84.0%
4 < Res $<$ 7(33%)	96.4%	88.6%
Res $>$ 7 (13%)	91.6%	77.1%

Evaluation: The performance of GeoPPM



- One of our 50 tested maps where the intersection point set is not accurately aligned with the corresponding point pattern on the image

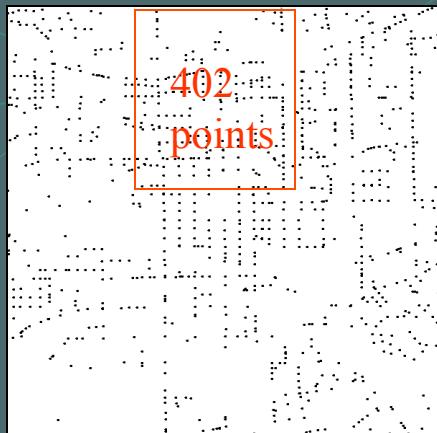


Evaluation: The running time of GeoPPM

- Platform: Windows 2000; CPU Xeon 1.8GHz with 1GMB memory
- Test on a Yahoo map with 57 points with varying number of image points



57 map points



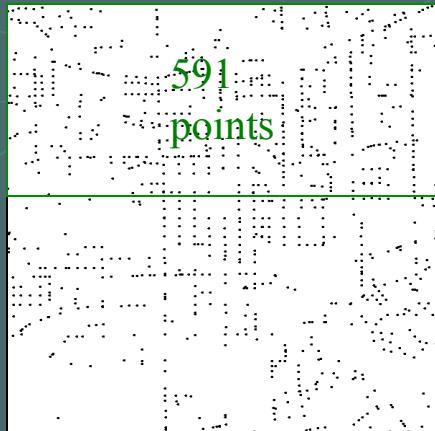
	Brute force algorithm	Using map scale only	Using map scale and road directions	Using road directions	Using HiGrid and road directions
402 imagery points	5 hours 58 minutes	171 seconds	16 seconds	503 seconds	11 seconds
591 imagery points	N/A	317 seconds	26 seconds	1049 seconds	17 seconds
800 imagery points	N/A	540 seconds	42 seconds	2449 seconds	26 seconds

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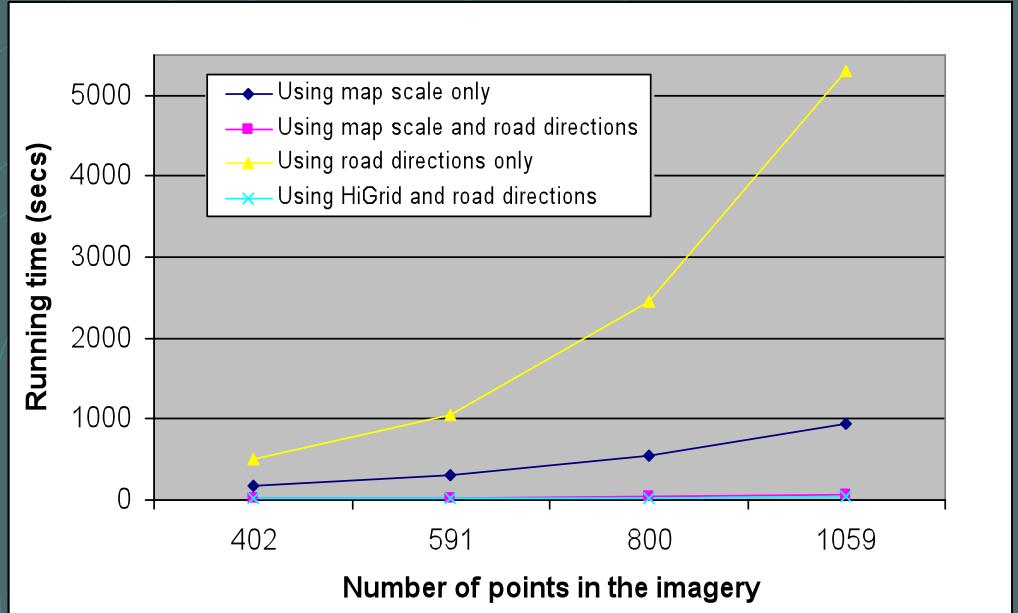
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1059 imagery points	N/A	934 seconds	70 seconds	5298 seconds	38 seconds

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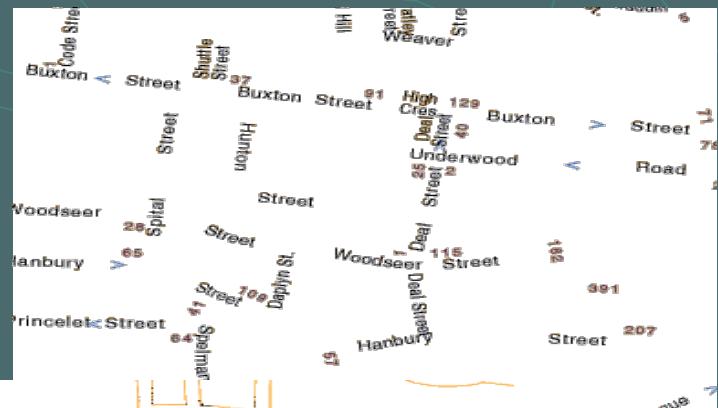
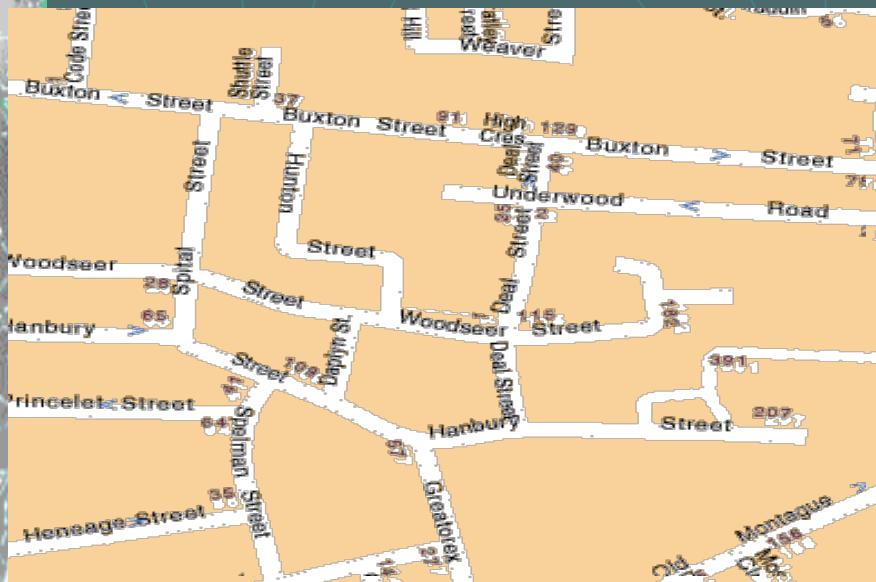


Outline

- Finding Maps
- Aligning Maps with Imagery
 - Extracting intersections
 - Point pattern matching
- Extracting Separate Layers from Maps
- Conclusions

Extracting the Layers of a Map

- Separate the road and text layers on a map

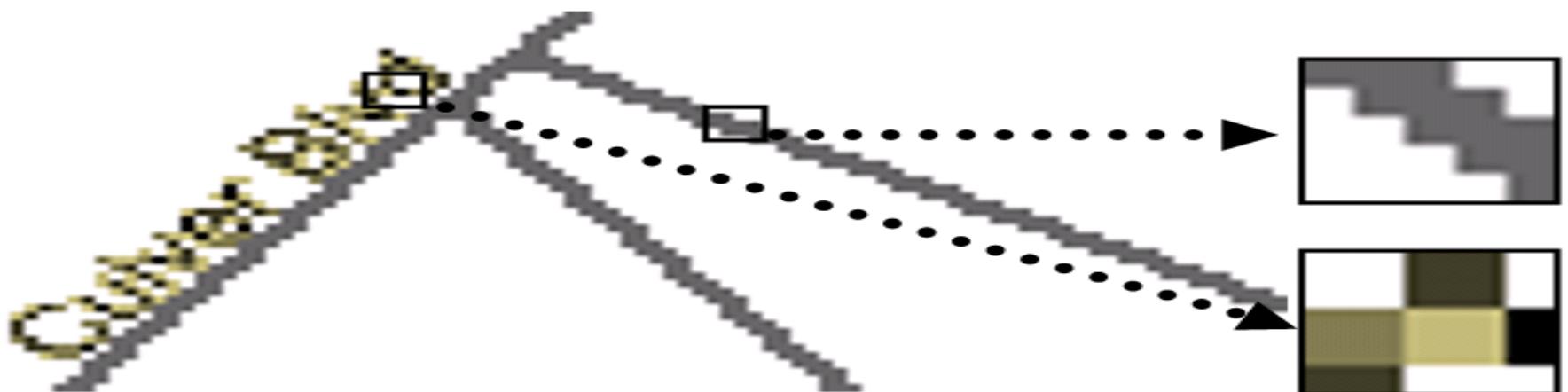


Previous Work

- Bixler 00', Fletcher 88', and Velazquez 03' assume that the line and character pixels are not overlapping
- Li et al. work in local areas to separate the characters from lines
- Cao et al. use the different length of line segments to separate characters from line arts
- We do not use geometric properties as the previous work**

Approach

- We use texture classification approach to classify pixels
- Features:
 - Discrete Cosine Transformation (DCT) coefficients
- Classifier:
 - Support vector machine



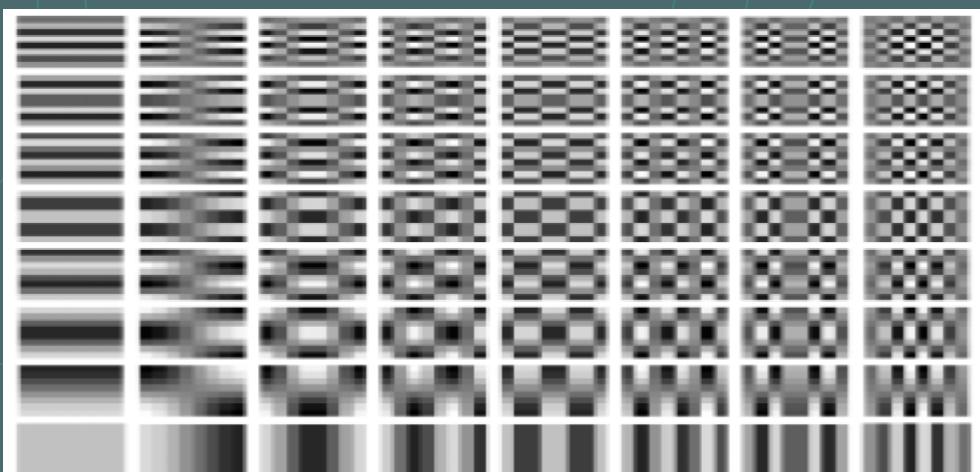


Discrete Cosine Transformation

- The DCT transformation gives us the strength of each component in the frequency domain for an image

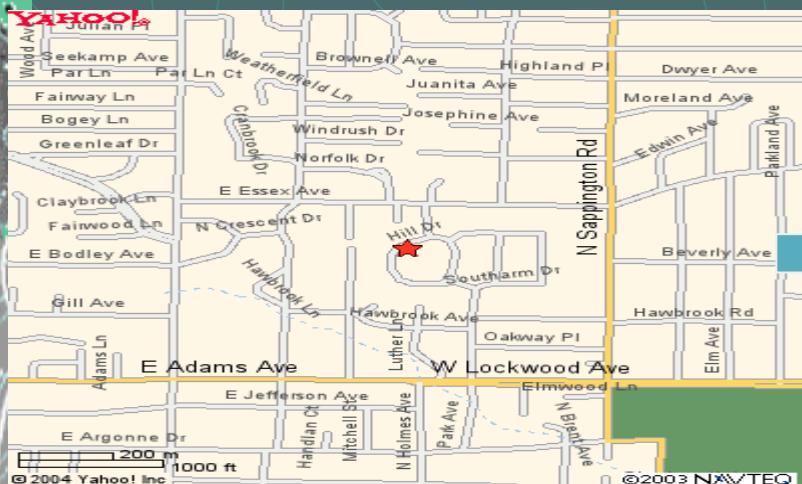


- The DCT coefficients represent the variation around each pixel



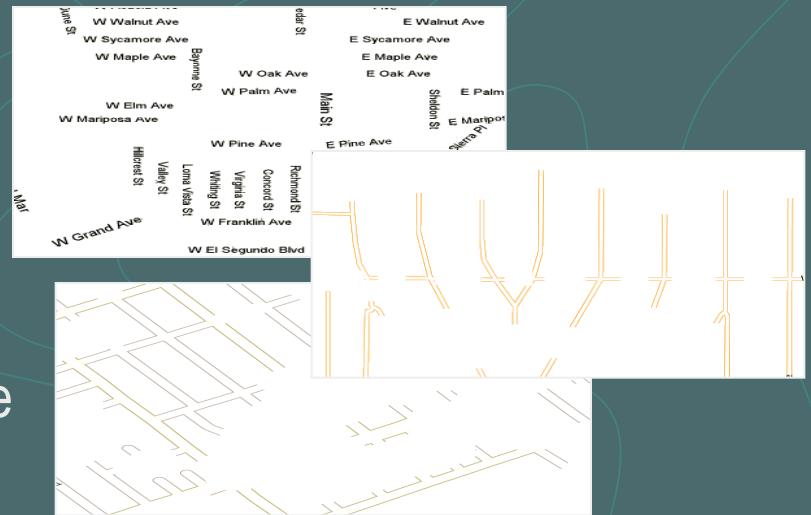
Remove Background

- Pixels with low variation around them are background pixels
- A color C in a map can only represent either background or foreground
- For a color C to be a background color: more than 50% pixels of color C are background pixels



Classify Line and Character pixels

- SVM Training
 - One MapQuest map for character sample; one Google map and one Viamichiline map for line samples
 - The testing maps are disjoint from the training samples
- Example of classification result



Results

Map Source	Precision/Recall of Classification			
	Line Pixels		Character Pixels	
	Ours	Cao's	Ours	Cao's
A9	99/91%	95/91%	79/98%	77/85%
MSN	99/79%	91/87%	75/99%	81/86%
Google	99/99%	95/99%	98/99%	95/72%
Yahoo	95/91%	70/96%	91/92%	88/30%
Mapquest	99/78%	88/73%	84/98%	76/85%
Map24	95/74%	97/70%	73/96%	70/98%
ViaMichelin	83/34%	44/57%	87/96%	90/68%
Multimap	89/82%	98/64%	63/90%	46/97%
TIGER/Line	99/94%	97/89%	83/99%	67/90%
Average	98/85%	85/82%	83/96%	71/71%

- Computation time:

- For a 400x400 Google Map:
 - 2 seconds to remove background
 - 4 seconds to classify line and character pixels

- No threshold needed



Outline

- Finding Maps
- Aligning Maps with Imagery
 - Extracting intersections
 - Point pattern matching
- Extracting Separate Layers from Maps
- Conclusions



Conclusions

- We have developed the capabilities to:
 - Automatically find maps for a given region
 - Extract the intersection features from a given map
 - Determine the exact location of the map
 - Integrate the map with satellite imagery
- Now building a system that given a location will generate a library of maps aligned with satellite imagery



Future Work

- Remaining challenges include:
 - Building a knowledge base of intersections to support the processing of maps anywhere in the world
 - Supporting poor quality scanned maps and compressed jpg maps
 - Scaling the matching algorithms to support larger areas
 - Building vector layers directly from raster maps
 - Developing OCR techniques to recognize the text



Publications

- Available online: <http://www.isi.edu/~knoblock>
- Finding maps
 - Sneha Desai, Craig A. Knoblock, Yao-Yi Chiang, Kandarp Desai, and Ching-Chien Chen. Automatically identifying and georeferencing street maps on the web. In Proceedings of the 2nd International Workshop on Geographic Information Retrieval (GIR'05), 2005.
- Extracting intersections
 - Yao-Yi Chiang, Craig A. Knoblock, and Ching-Chien Chen. Automatic extraction of road intersections from raster maps. In The 13th ACM International Symposium on Advances in Geographic Information Systems (ACM-GIS'05), 2005.
- Aligning maps with imagery
 - Ching-Chien Chen, Craig A. Knoblock, and Cyrus Shahabi. Automatically and accurately conflating raster maps with orthoimagery. *Geoinformatica*, 2007.
- Extracting Road Layers
 - Yao-Yi Chiang and Craig A. Knoblock. Classification of line and character pixels on raster maps using discrete cosine transformation coefficients and support vector machines. In Proceedings of the International Conference on Pattern Recognition (ICPR 2006), 2006.