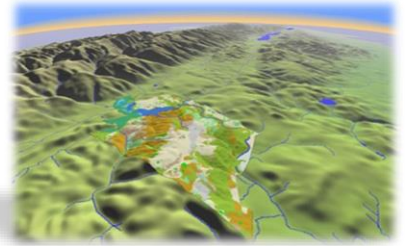




NICHOLAS SCHOOL OF THE  
ENVIRONMENT AND EARTH SCIENCES  
DUKE UNIVERSITY



# ENVIRON 761: Network Analysis

Instructor: John Fay

# Overview

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## What are 'network analyses'?

- Everyday examples of network analysis
- Using the Network Analyst extension in Arc

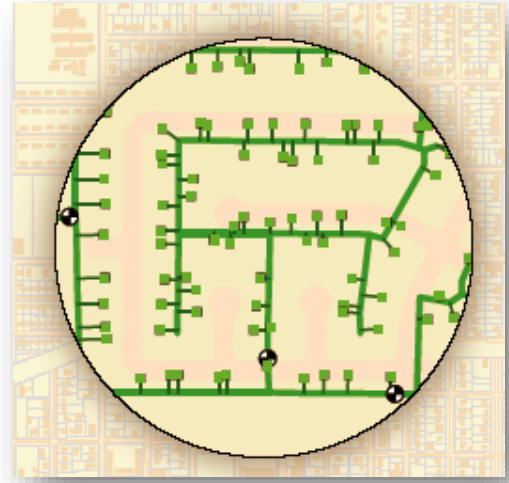
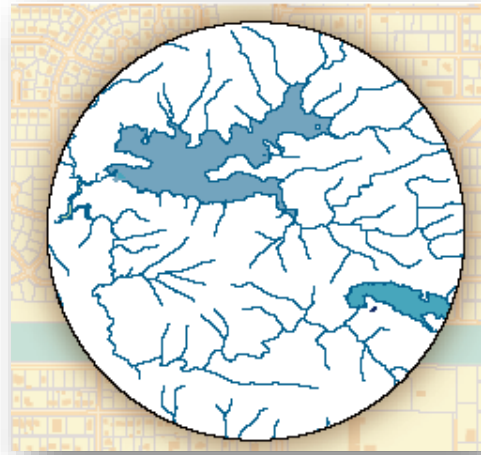
## How network analysis works

- Components of a network; graph theory
- Building a network dataset in Arc

## Environmental applications of networks

- Hydrologic analyses
- Ocean current analysis
- Habitat connectivity

# Networks: Channeled movement





# Example: Routes

Towerview Rd, Durham, NC 27705 to Raleigh-Durham International Airport (RDU), Raleigh, NC 27617 - Google Maps - Mozilla Firefox

File Edit View History Bookmarks Tools Help

http://maps.google.com/

Towerview Rd, Durham, NC 27705 to ...

Web Images Videos Maps News Shopping Gmail more

Google maps Towerview Road, Durham, NC to RDU Search Maps Show search options

Get Directions My Maps

Towerview Road, Durham, NC

RDU

Driving directions to Raleigh-Durham International Airport (RDU), Raleigh, NC 27617

Suggested routes

N Carolina 147 S	23 mins
I-40 E	29 mins
N Carolina 55 E and I-40 E	29 mins

1. Head east on Towerview Rd toward Union Dr 0.3 mi

2. At the traffic circle, continue straight to stay on Towerview Rd 0.2 mi

3. Turn left at Duke University Rd 0.9 mi

4. Continue straight onto W Chapel Hill St 0.5 mi

5. Turn right to merge onto N Carolina 147 S toward Research Triangle Park/Raleigh/Airport 7.8 mi

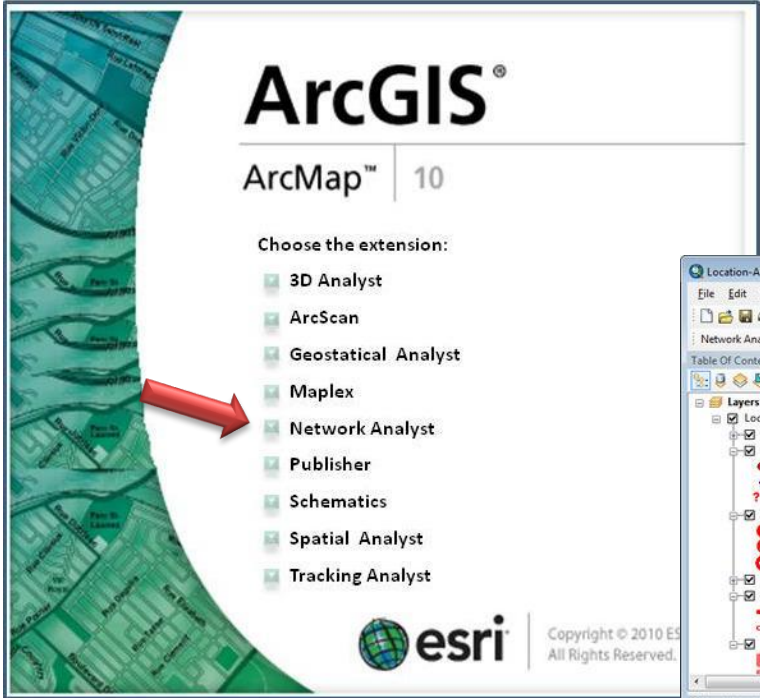
6. Take exit 5A on the left to merge onto I-40 E toward RDU Airport/Raleigh 4.7 mi

7. Take exit 284B for Airport Blvd E toward RDU International Airport 0.2 mi

8. Turn right at Airport Blvd 1.4 mi

9. Keep right at the fork to continue toward Airport Blvd 0.2 mi

# Network Analyst for ArcGIS



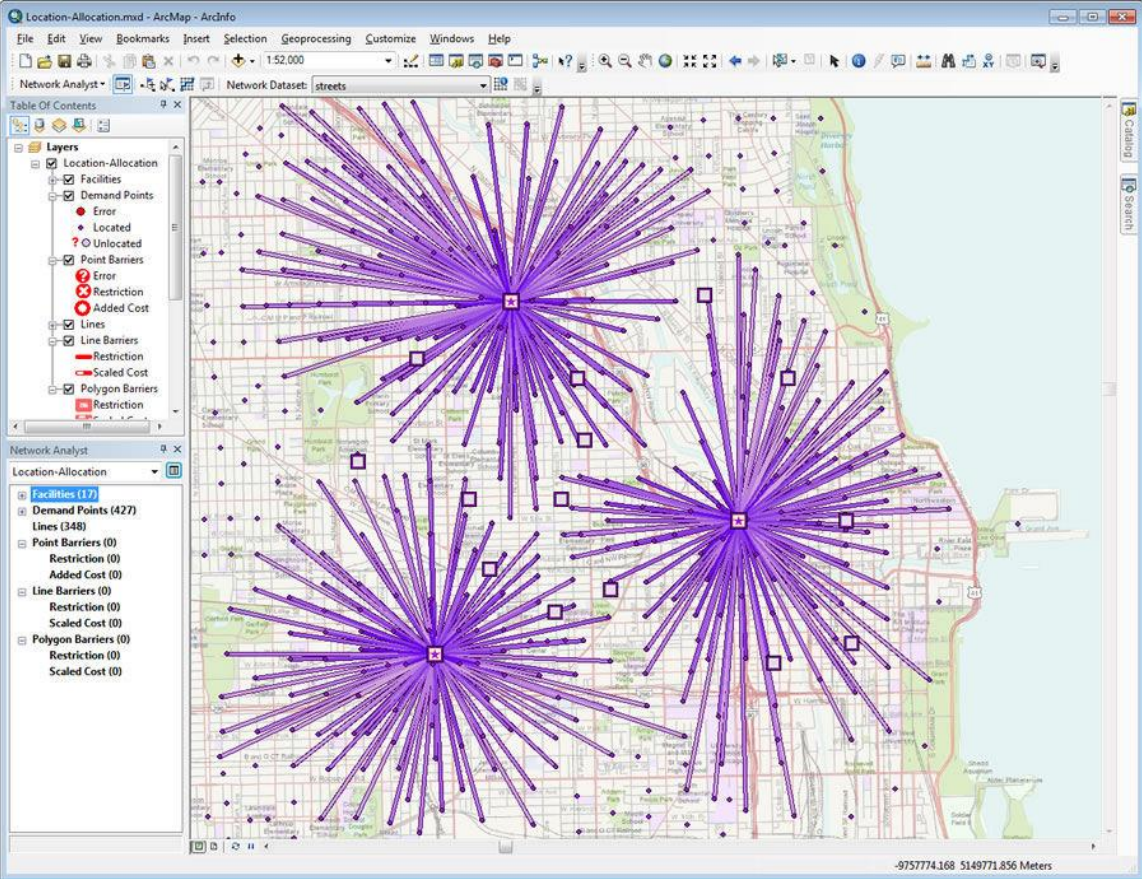
**ArcGIS®**  
ArcMap™ | 10

Choose the extension:

- 3D Analyst
- ArcScan
- Geostatistical Analyst
- Maplex
- Network Analyst
- Publisher
- Schematics
- Spatial Analyst
- Tracking Analyst

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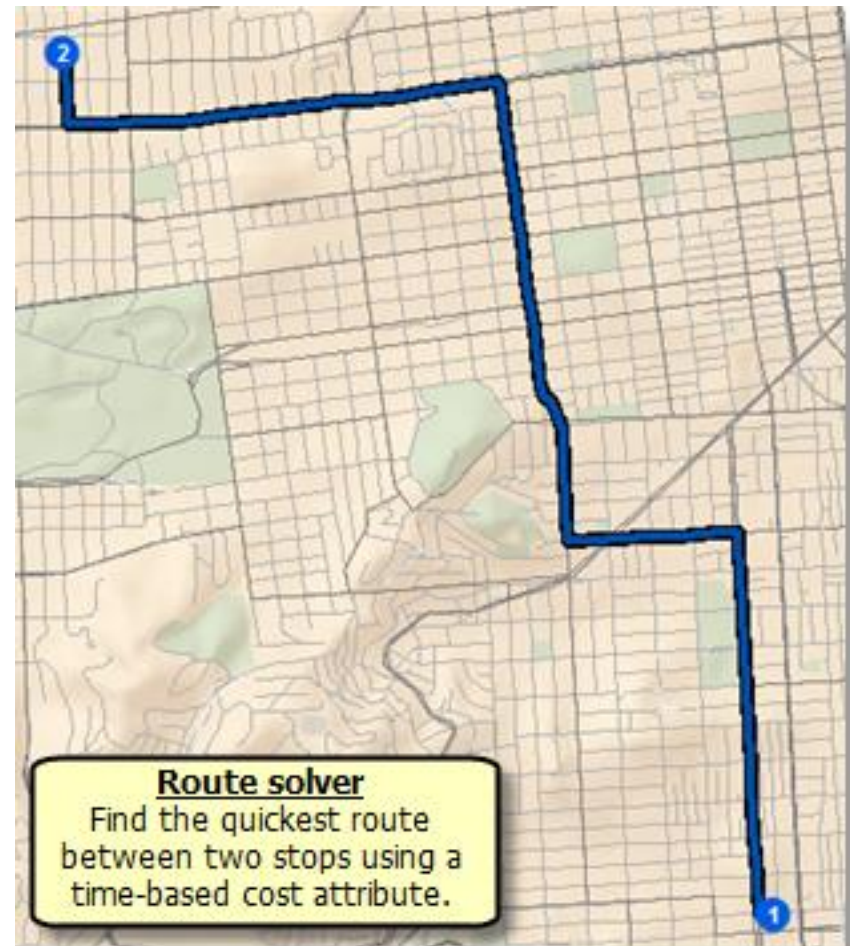
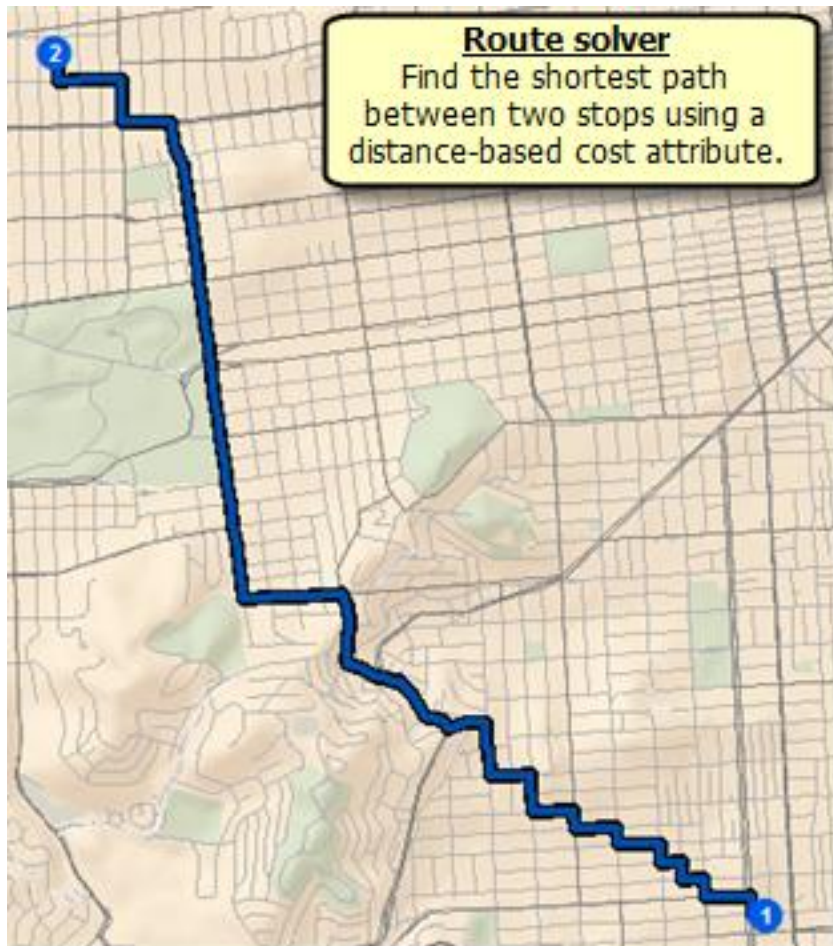
A red arrow points from the 'Network Analyst' option to the right.





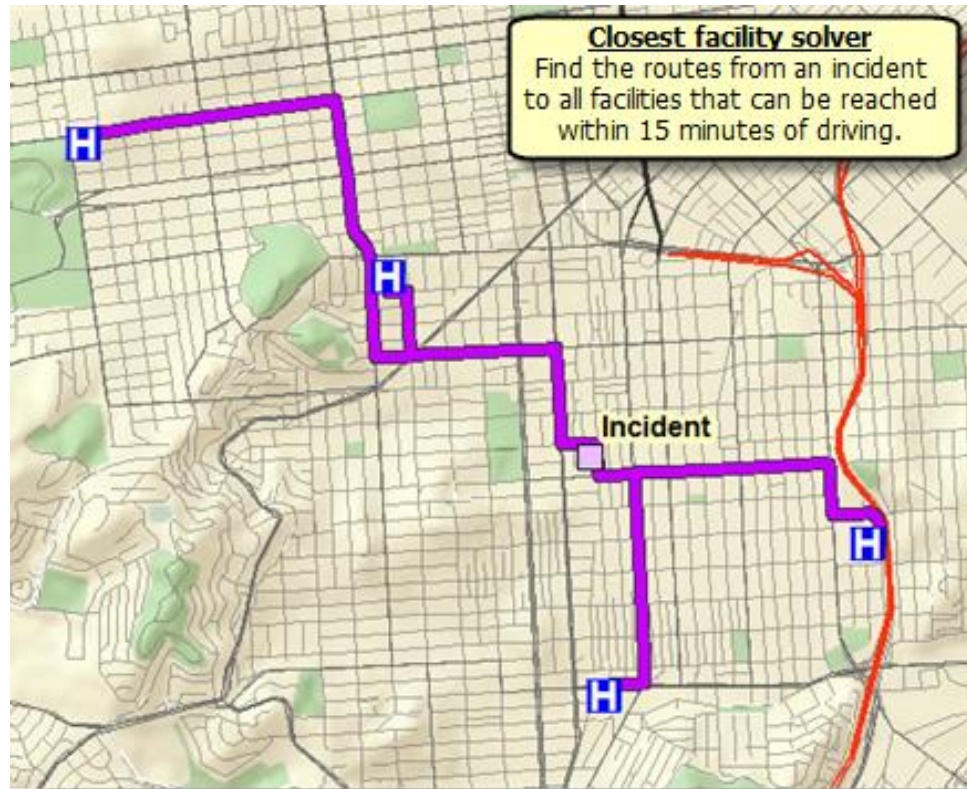
# Examples: Routes

- What is the shortest/quickest way to get from point A to B



# Examples: Closest Facility

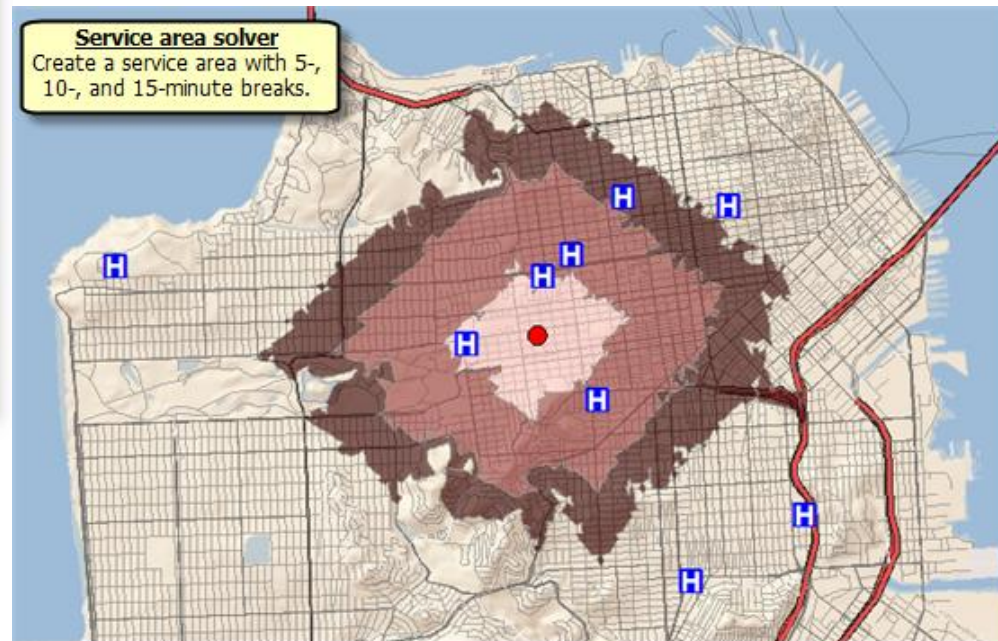
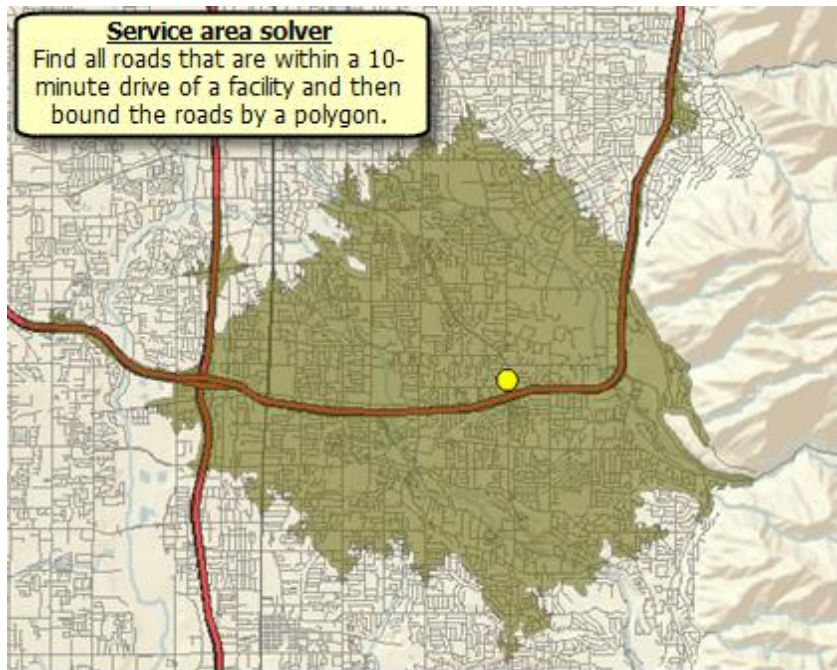
- A person wants to visit a store. Which branch should the potential customer visit to minimize travel time?
- Which ambulances or patrol cars can respond quickest to an incident?





# Examples: Service Areas

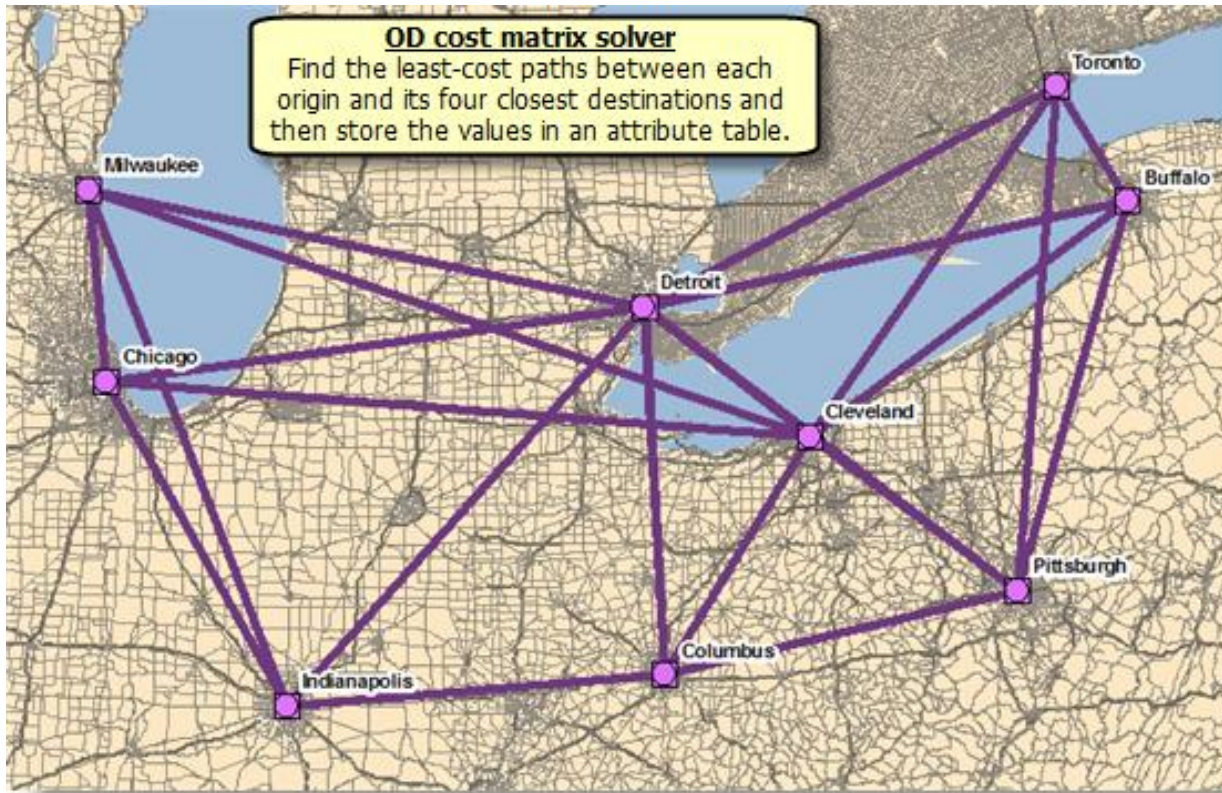
- Which houses are within five minutes of a fire station?
- What market areas does a business cover?





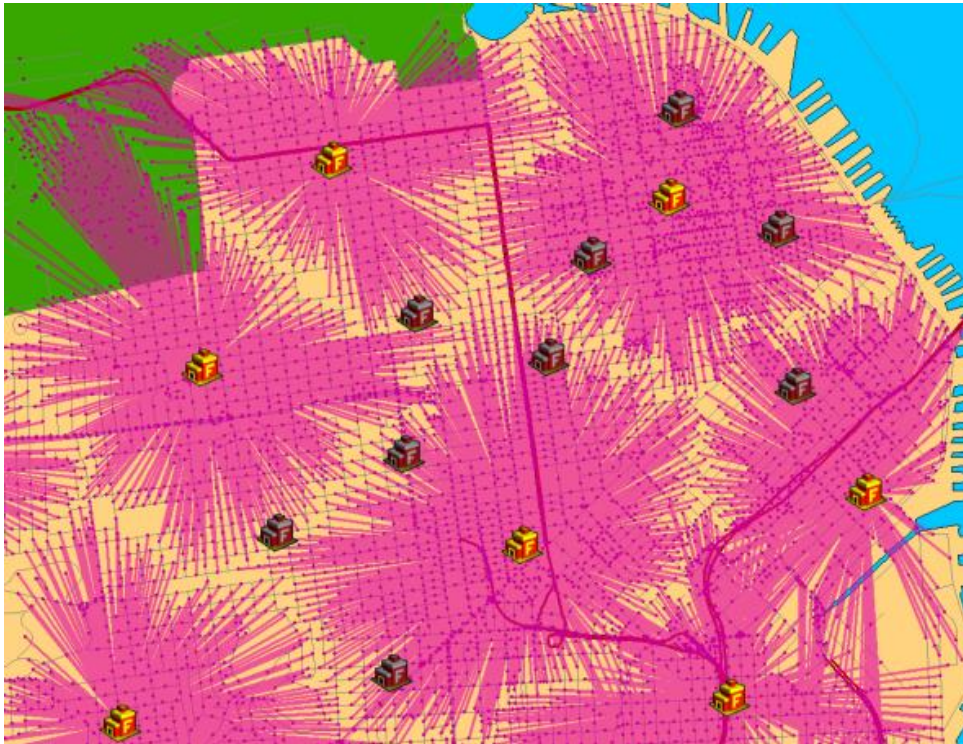
# Examples: Cost/Distance Matrix

- List the costs/distances between pairs of origins and destinations...



# Examples: Location/Allocation

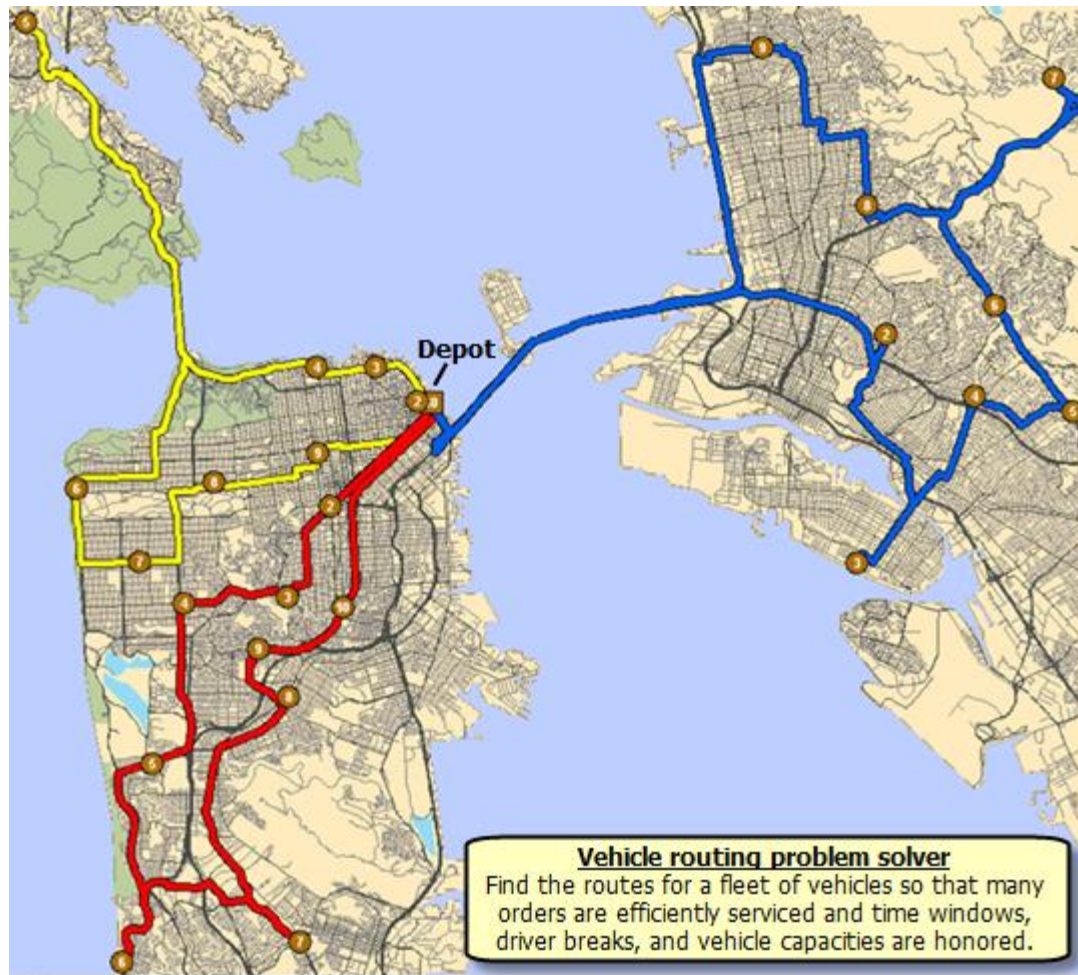
- Given a set of existing fire stations, which site for a new fire station would provide the best response times for the community?
- If a retail company has to downsize, which stores should it close to maintain the most overall demand?





# Examples: Vehicle Routing Optimization

- How can a fleet of delivery or service vehicles improve customer service and minimize transportation costs?







# Network analysis for conservation

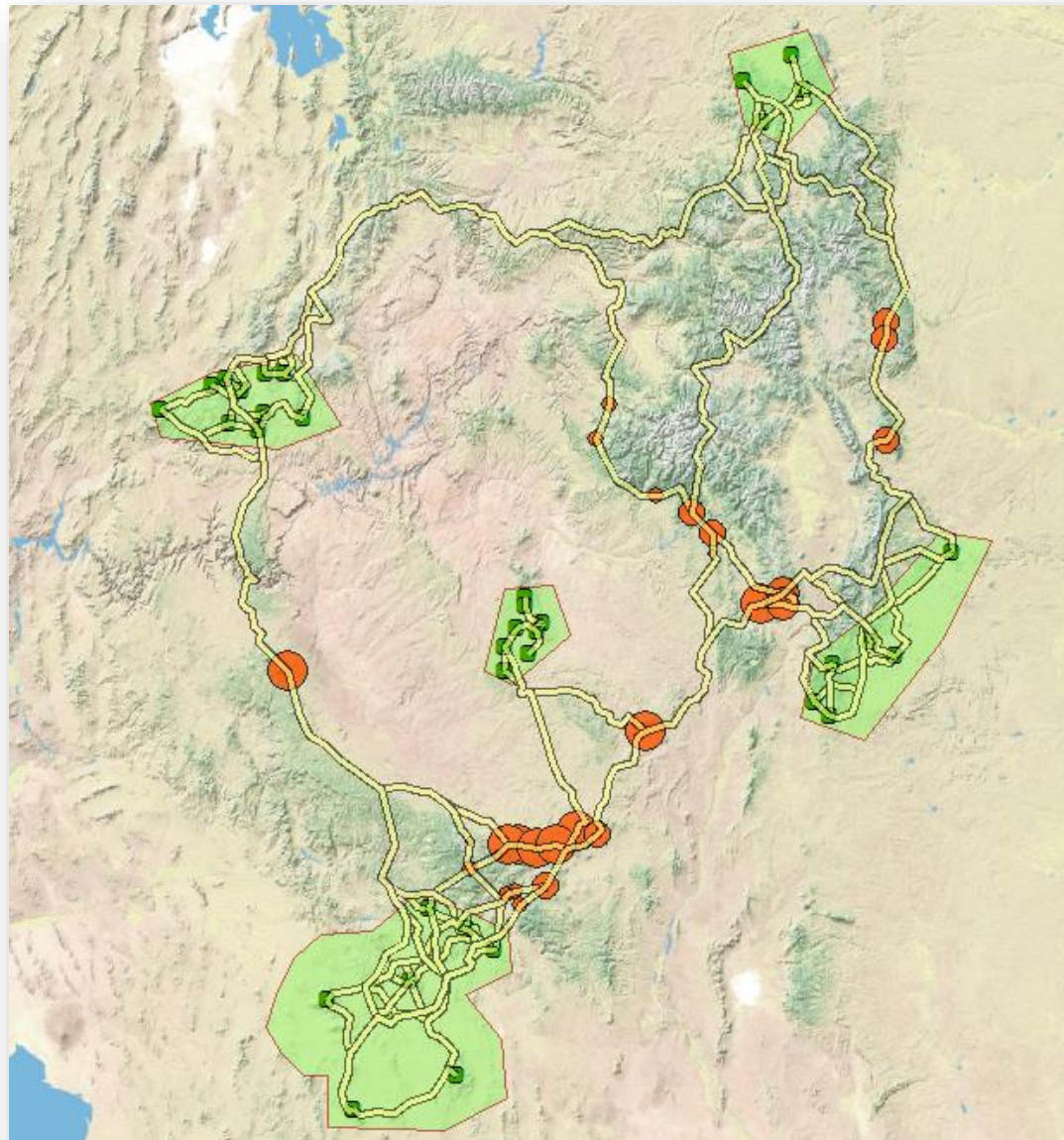
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- Ecohydrology
  - Upstream analysis (alternative to raster-based)
- Connectivity
  - Identifying patch centrality
- Other...
  - Access to parks/recreation centers
  - Food deserts

Demo

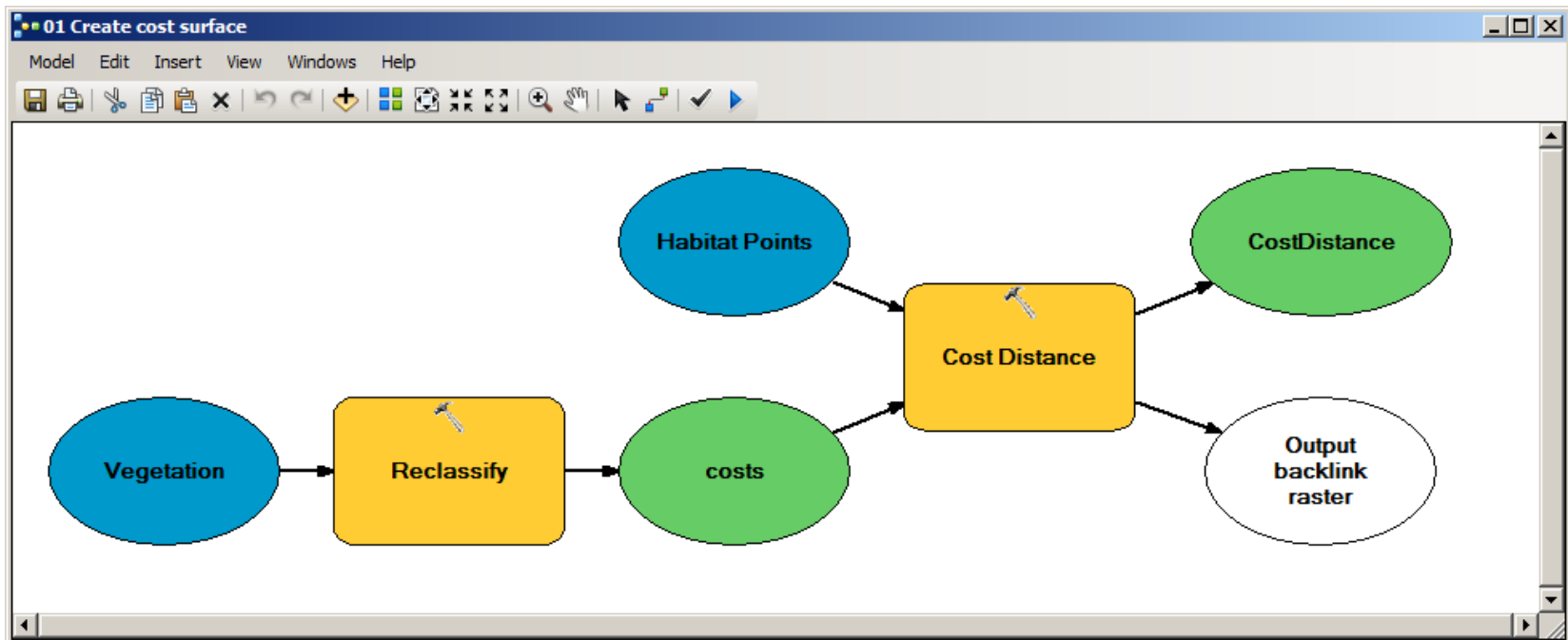


# Network analysis & habitat connectivity



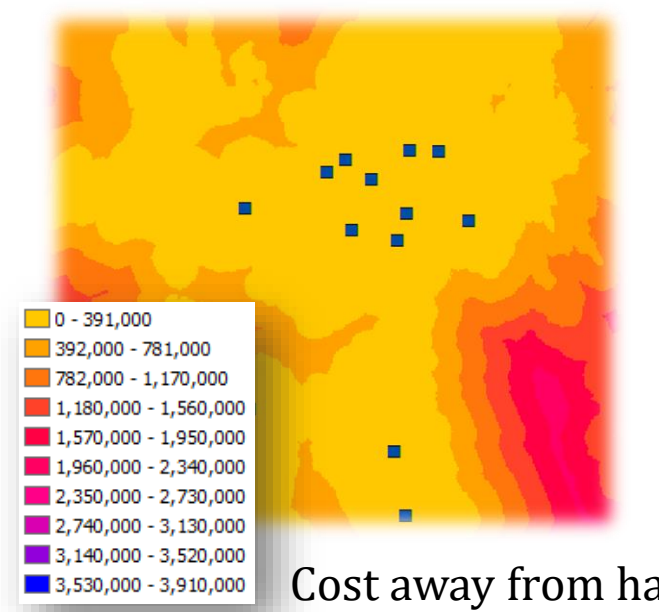
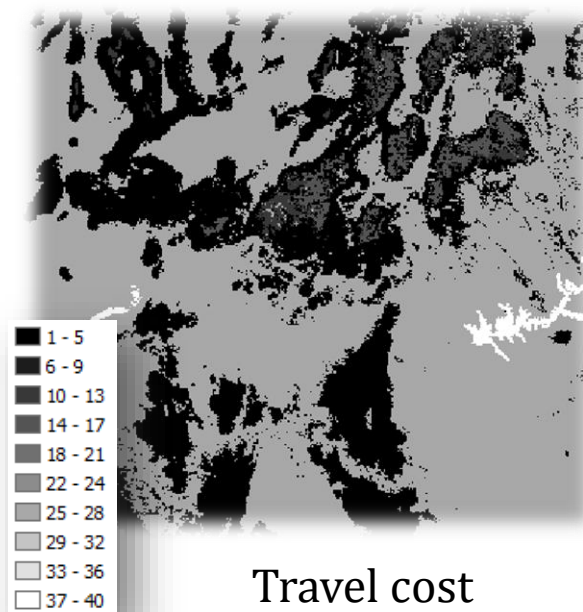
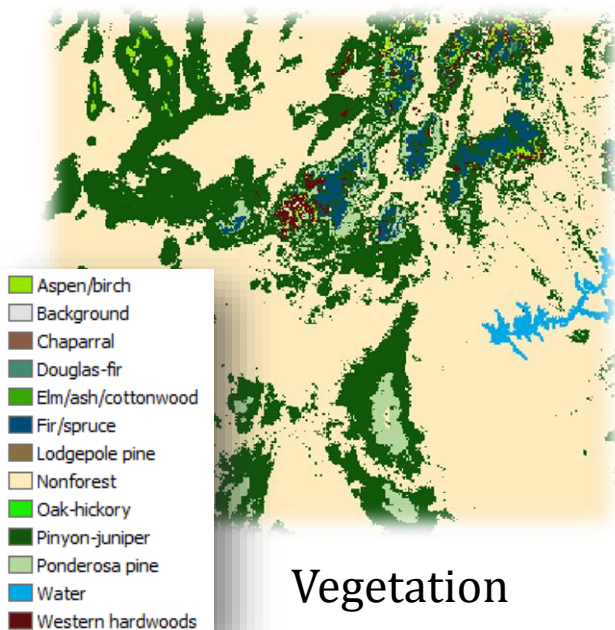
# 1. Creating a cost surface

- Determine cost (e.g. from land cover)
- Calculate travel away from habitat patches



# 1. Creating a cost surface

- Determine cost (e.g. from land cover)
- Calculate travel away from habitat patches

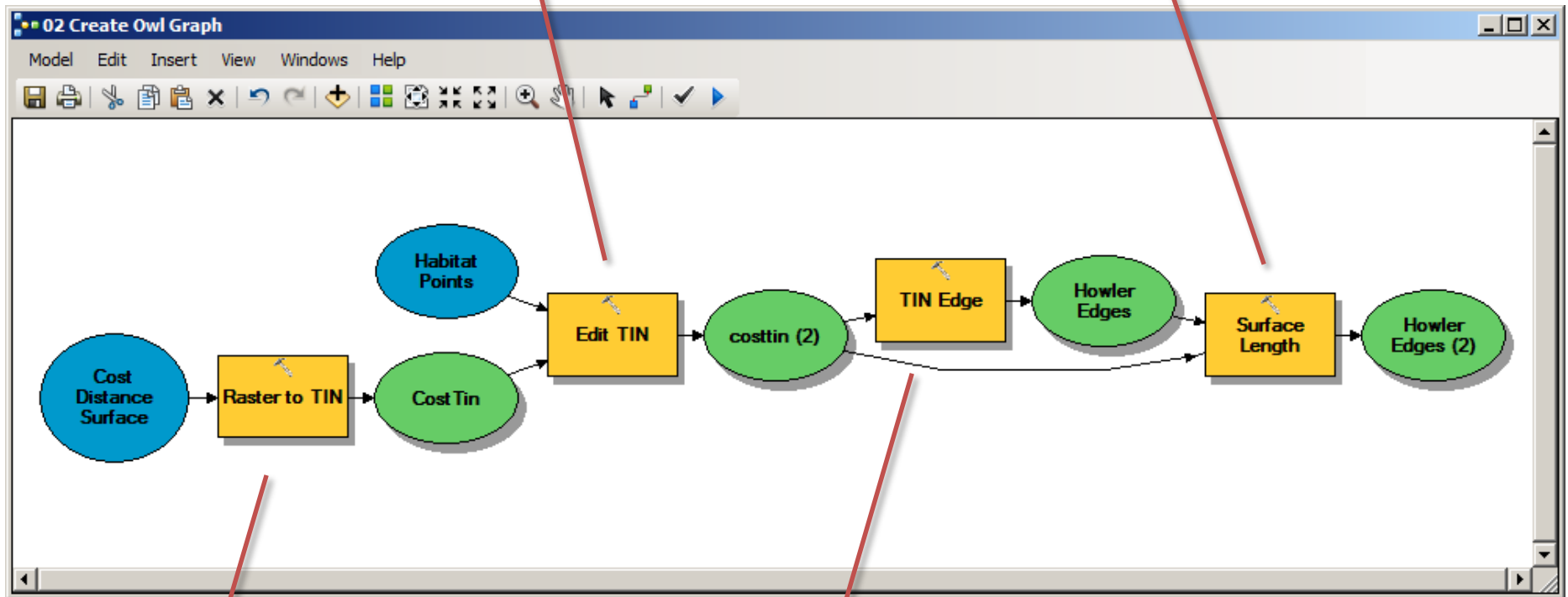




# 2. Creating the graph

"Pin" habitat patch centroids into TIN

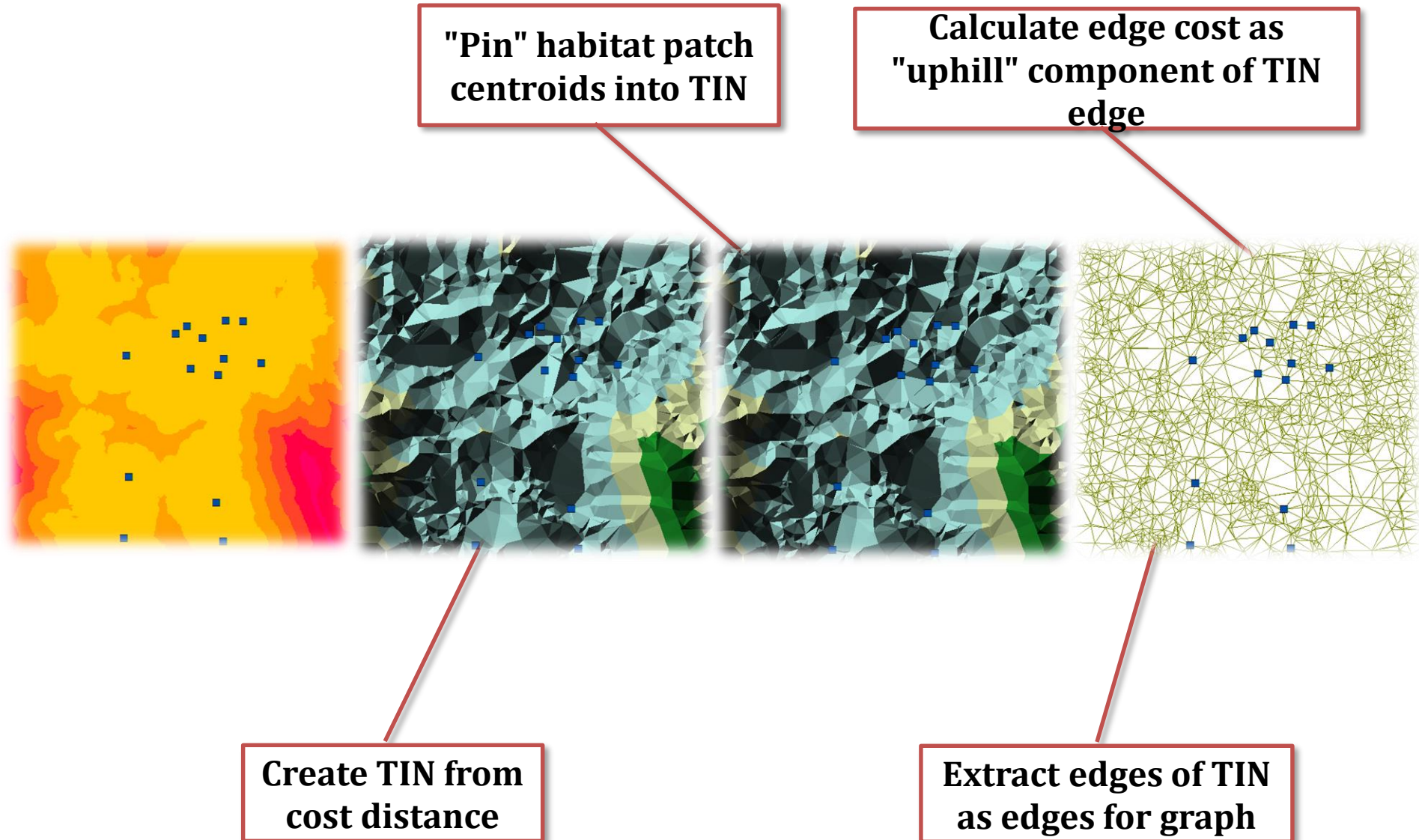
Calculate edge cost as "uphill" component of TIN edge



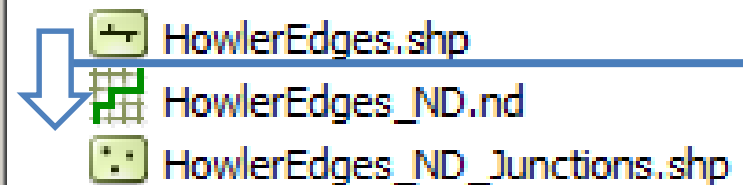
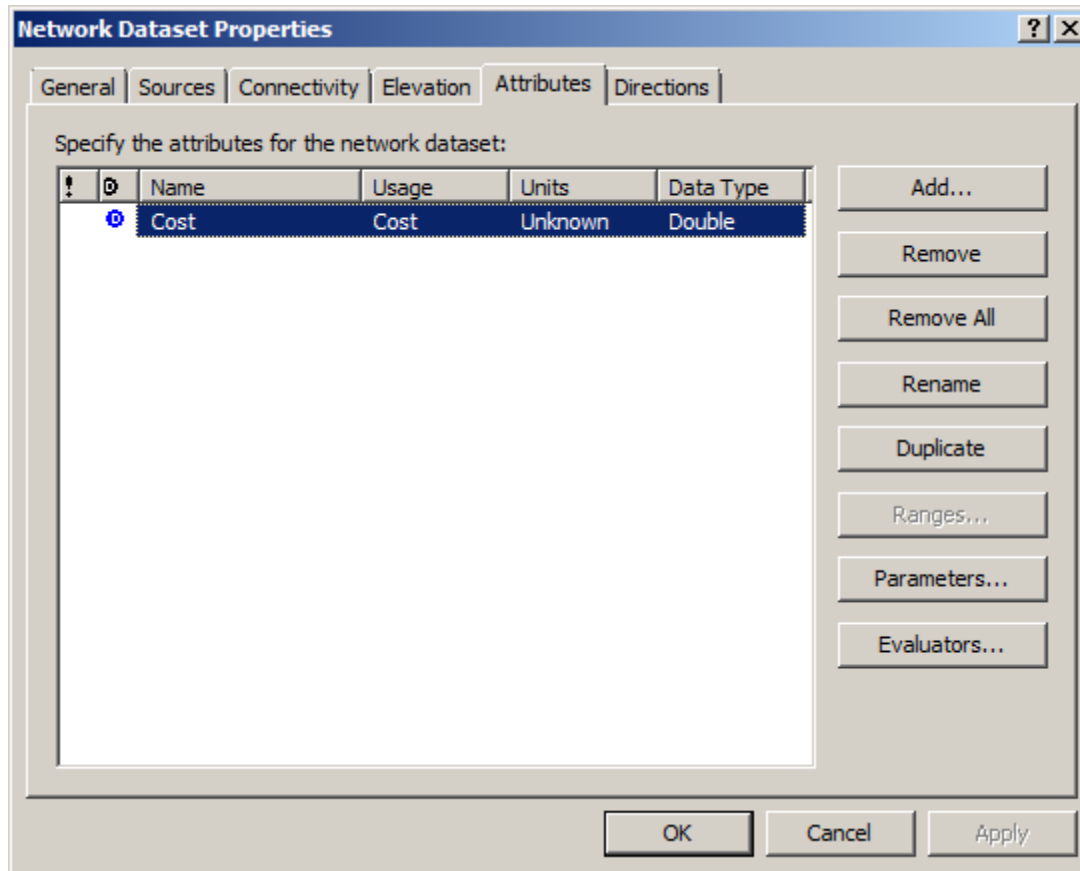
Create TIN from cost distance

Extract edges of TIN as edges for graph

## 2. Creating the graph



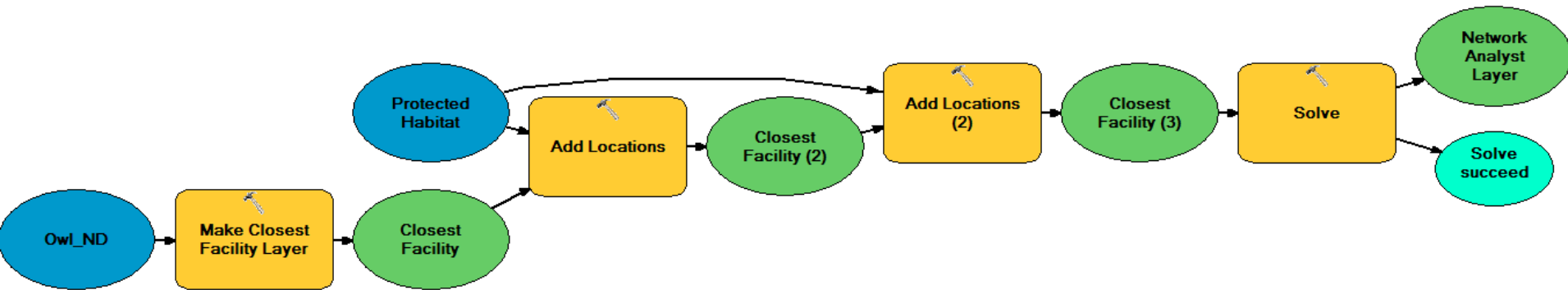
# From graph to network dataset



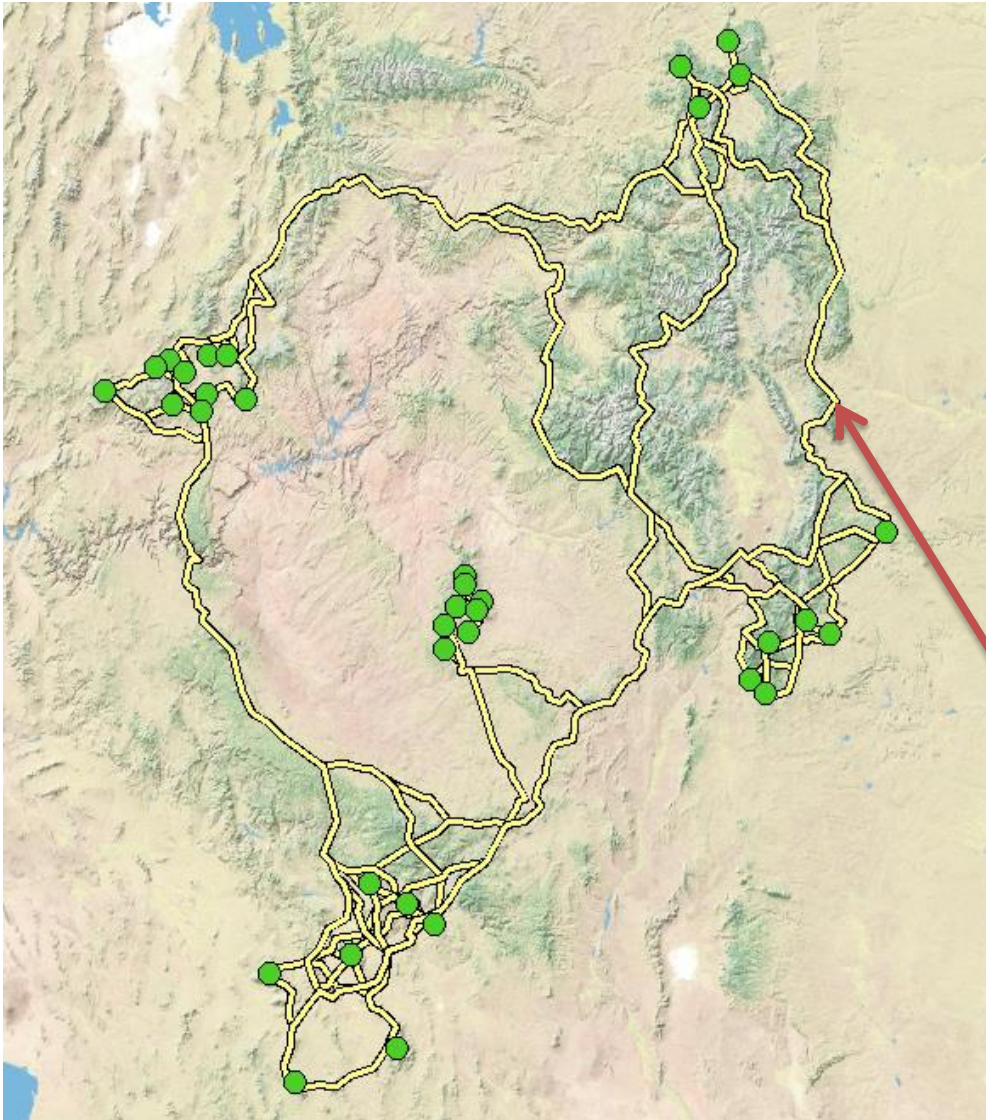


# 3. Calculating least cost paths

- Create a Closest Facility analysis layer
- Add all sites as both facilities and incidents
- Solve: solution contains least cost paths among all patch pairs



# 3. Calculating least cost paths



Click on any path to get a list of all the habitat patch pairs that use that path as a least cost pathway among them.

**Identify**

Identify from: <Top-most layer>

Location: 1,539,322.065 1,308,528.454 Metrs

Field	Value
ObjectID	5
Shape	Polyline M
FacilityID	15
FacilityRank	5
Name	23 - 3475
IncidentCurbApproach	Left side of vehicle
FacilityCurbApproach	Left side of vehicle
IncidentID	1
Total_Cost	1111095.647237

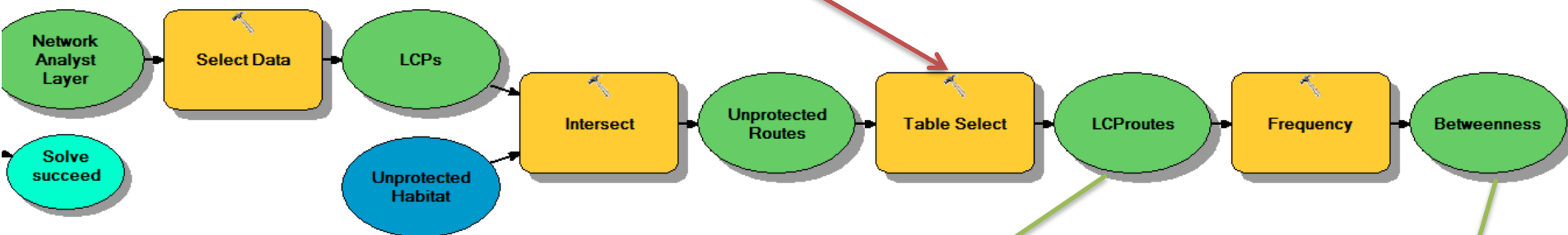
Routes

- 23 - 3475
- 23 - 3260
- 23 - 4130
- 23 - 4165
- 23 - 4348
- 23 - 4457
- 23 - 4185
- 23 - 3917
- 23 - 3905
- 23 - 3886
- 23 - 3910
- 23 - 3844
- 23 - 3743
- 23 - 5965
- 23 - 5760
- 23 - 3996
- 23 - 5240
- 23 - 6143
- 23 - 6246
- 23 - 6371
- 23 - 6426
- 68 - 3475
- 68 - 3260
- 68 - 4130

Identified 138 features

# 4. Determining betweenness

- Intersect candidate sites with least cost paths
- Count how many times a candidate site appears among all least cost paths
  - Can omit paths above a cost threshold...

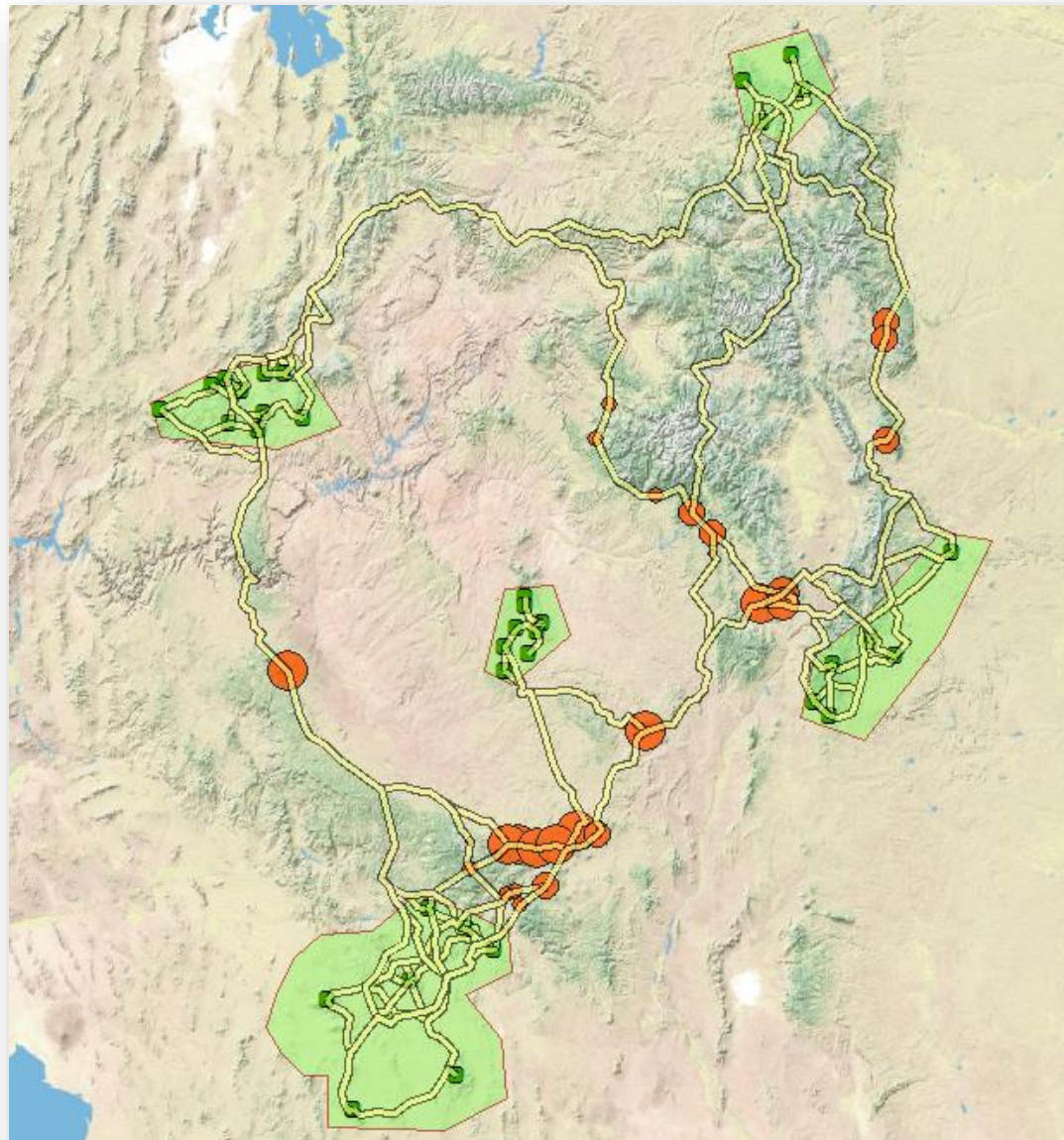


OBJECTID *	FacilityID	Name	IncidentID	Total_Cost	ID	POINT_X	POINT_Y
1	31	23 - 5965	1	2591262.279599	565	1179723	762505.09
2	31	68 - 5965	2	2795583.497655	565	1179723	762505.09
3	31	45 - 5965	3	2556721.032606	565	1179723	762505.09
4	31	411 - 5965	4	2701700.264361	565	1179723	762505.09
5	31	3475 - 5965	15	1649330.631071	565	1179723	762505.09

OBJECTID *	FREQUENCY	ID
1	114	1250
2	114	1886
3	72	2416
4	72	2779
5	114	2862
6	72	3084



# 4. Determining betweenness



# Graph theory...

1736

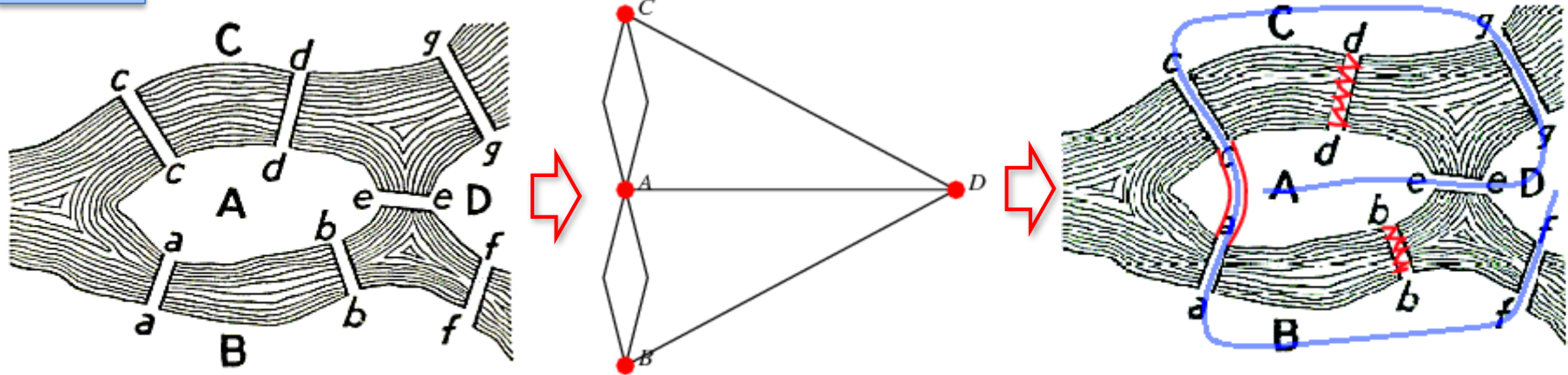


FIGURE 98. *Geographic Map: The Königsberg Bridges.*



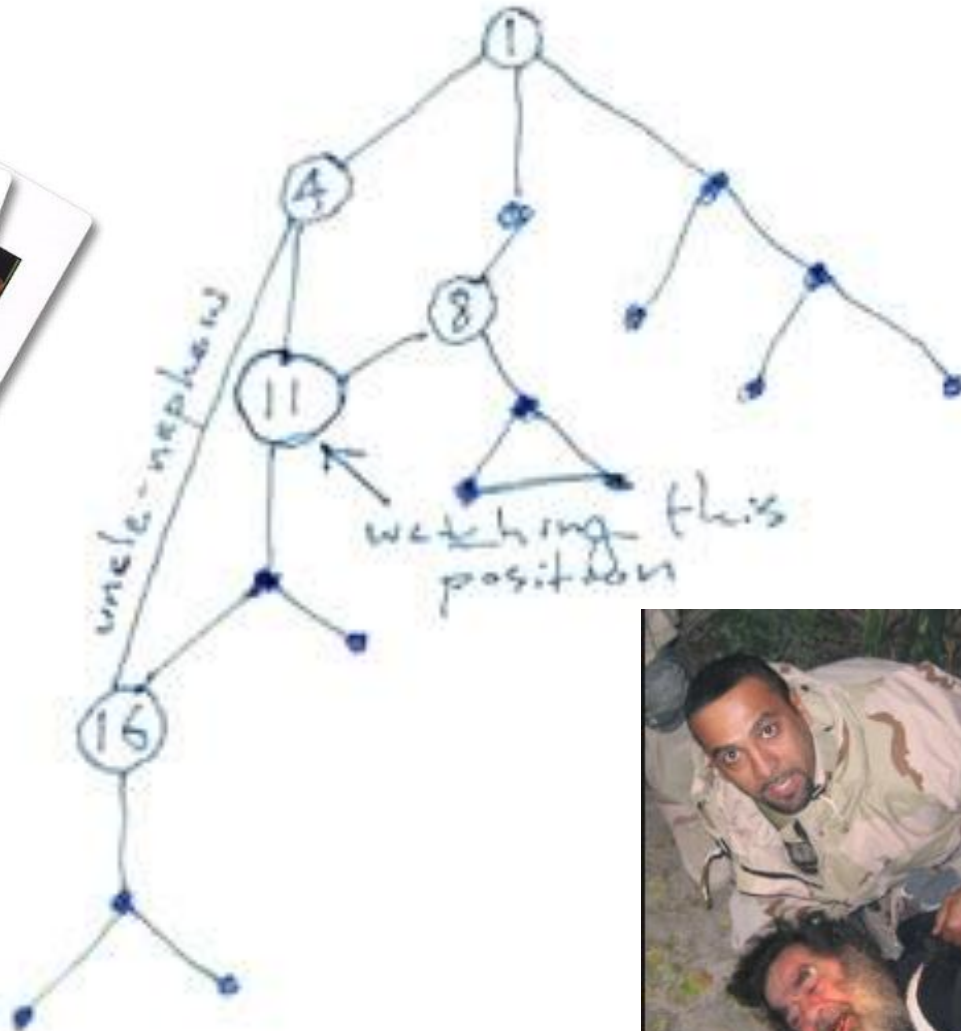
2016

Brain Imaging and Behavior  
DOI 10.1007/s11682-016-9528-3

ORIGINAL RESEARCH

**“Small World” architecture in brain connectivity and hippocampal volume in Alzheimer’s disease: a study via graph theory from EEG data**

# Graph theory...

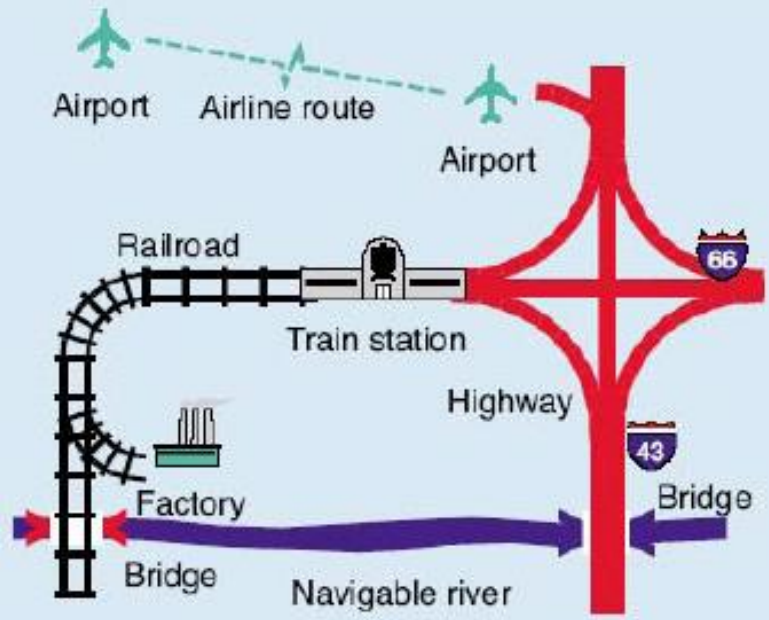




# How network analysis works

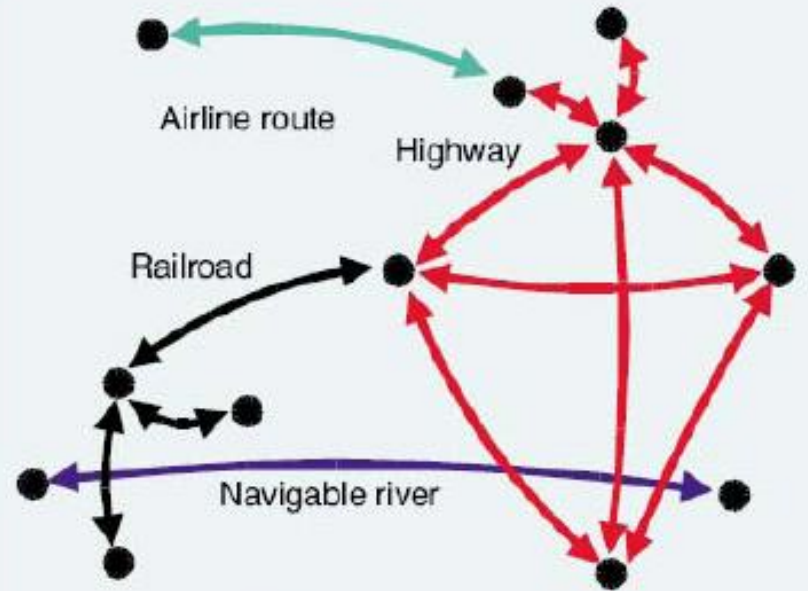
## Two views of a network

You can view a network as a collection of geographic objects such as rails, roads, stations, and bridges and also as a pure network of edges and junctions.



**Geographic view**

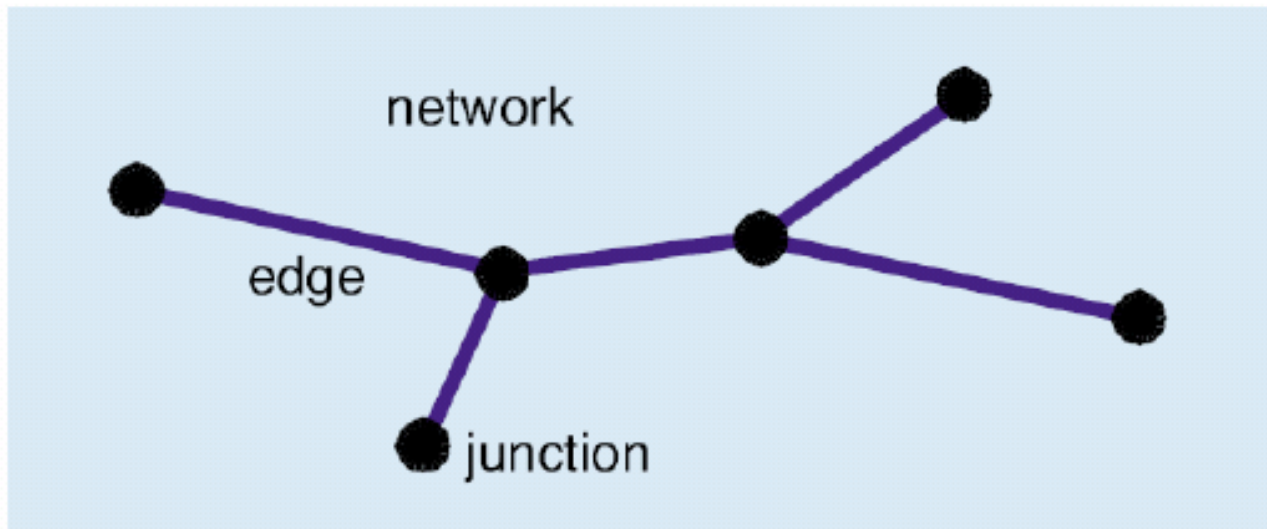
A geometric network is the representation of geographic features that comprise a network.



**Network view**

A logical network is a pure graph of junction elements and edge elements.

# Geometric Networks / Graphs

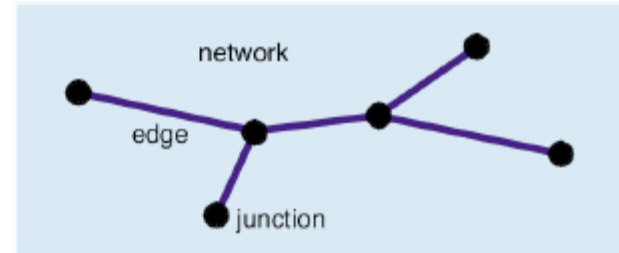


**Edges:** linear features (streams, roads, pipes...)

**Junctions:** intersections (connections, nodes, hubs...)

# Geometric Networks / Graphs

## THE GEOMETRIC NETWORK



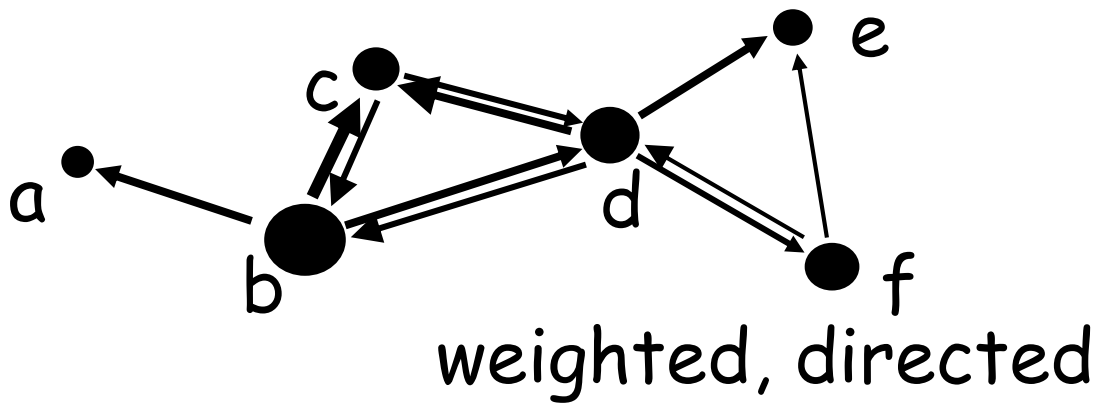
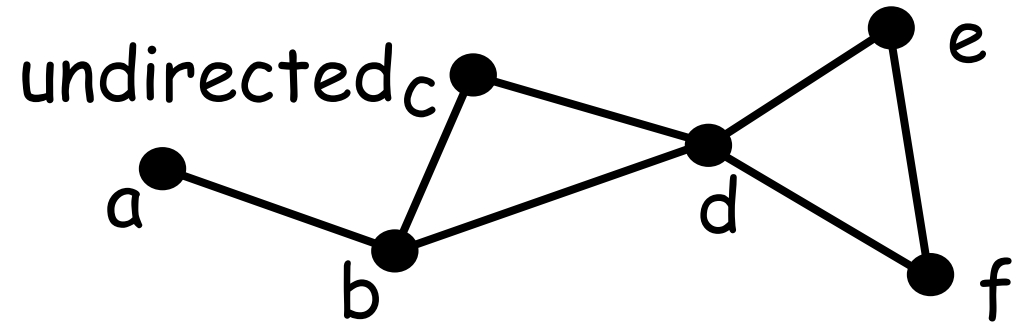
A **geometric network** is a collection of features that comprise a connected system of *edges* and *junctions*. An edge has two junctions and a junction can be connected to any number of edges.

Edge **features** can cross in two-dimensional space without intersecting. An example is a bridge over a road. This is called *nonplanarity*.



# Edge attributes

- Directionality
- Cost/weights



*Direction/weights affect connectivity and shortest path...*

# Cost attributes: Edges



*Best Route: 8:00 a.m.*

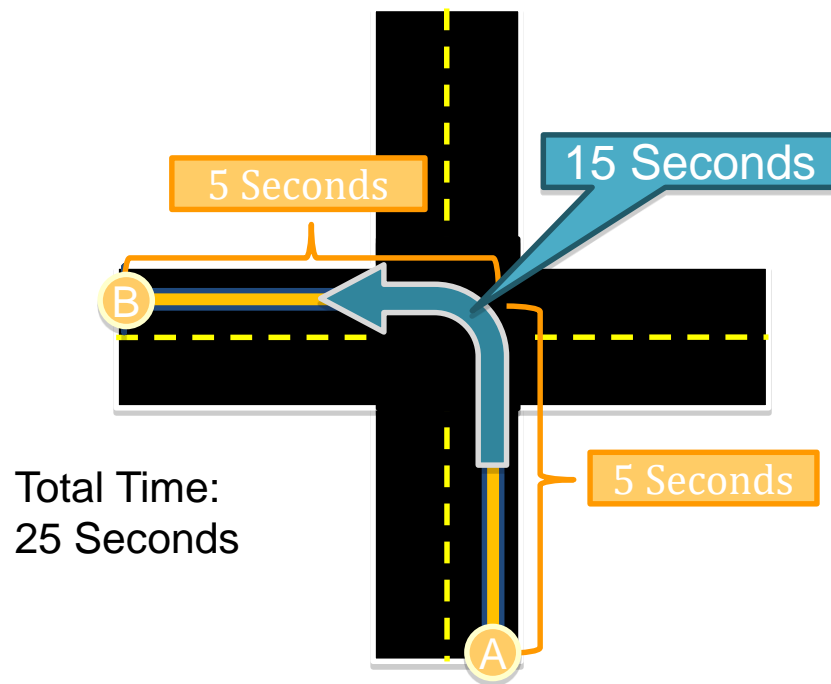


*Best Route: 6:00 p.m.*

- If cost = *distance*, then you are finding the shortest path...
- If cost = *time*, then you are finding the fastest path... 31

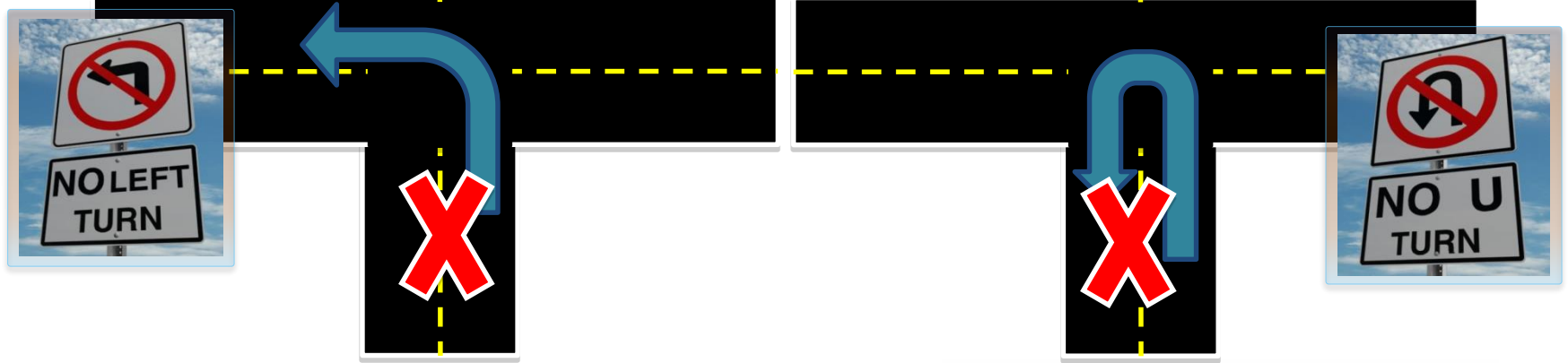
# Cost attributes: nodes

- Turn Delays
  - Add cost to a specific turn



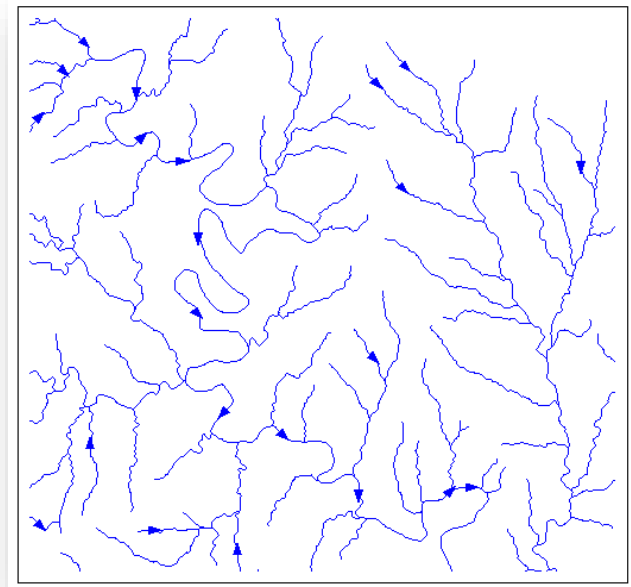


# Restriction attributes



Restrictions allow  
*directionality*

- Turn restrictions...
- One-way streets...
- Flow in stream networks...



# Descriptors attributes

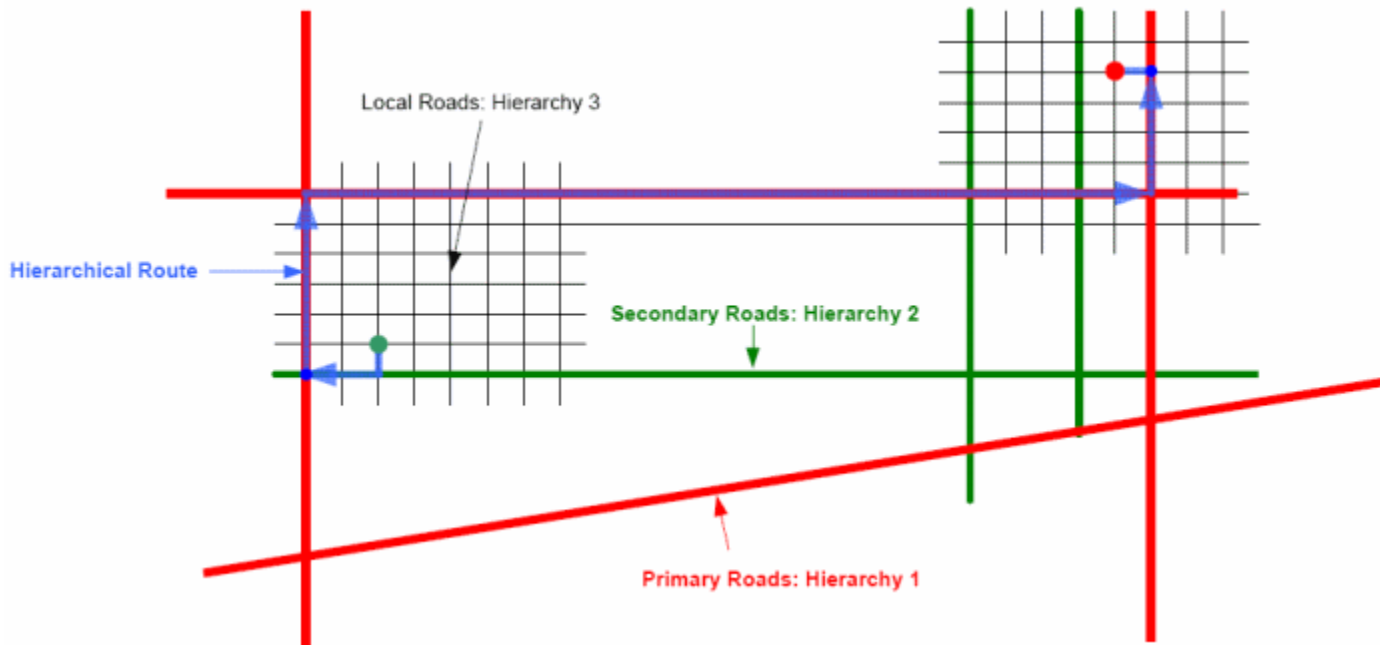
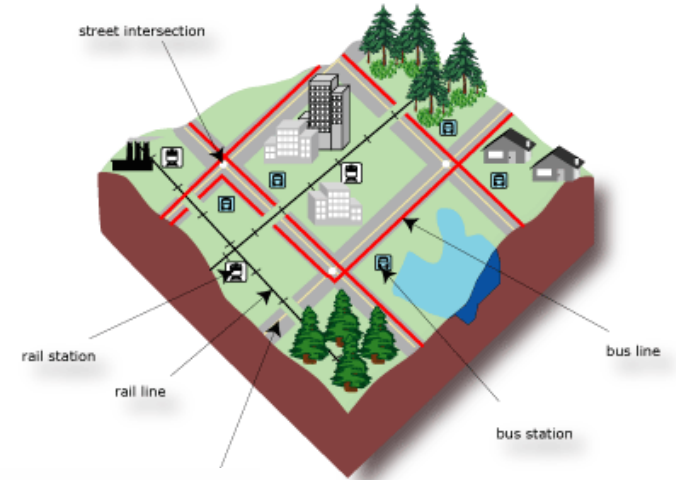
**Descriptors** are node/edge attributes that describe characteristics of the network or its elements.

**Descriptors** might be used in conjunction with distance to calculate costs. (Or not...)



# Edge Attributes: Hierarchies

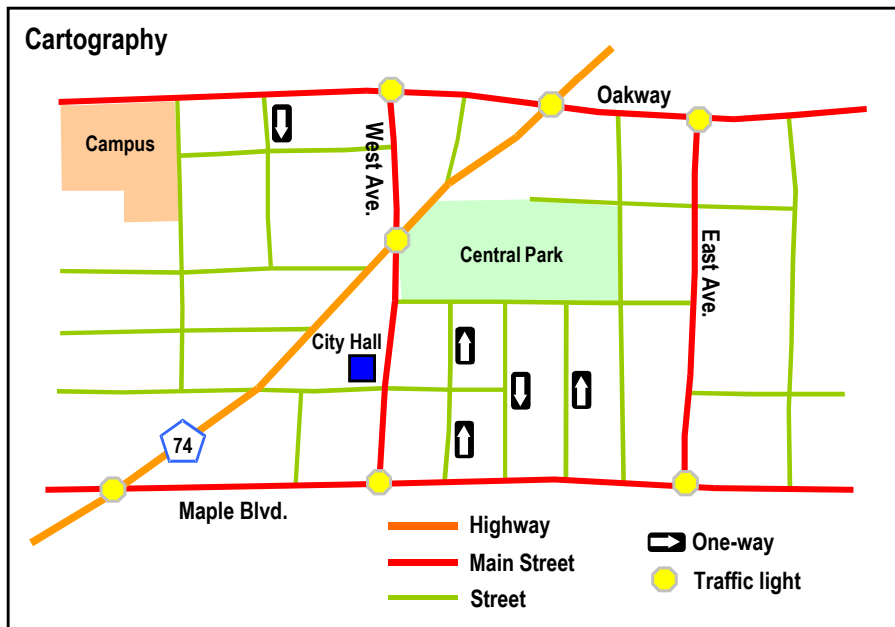
Assigning edge hierarchies allows for questions like “What’s the fastest way to get from Durham to Beaufort *without using the Interstate?*”





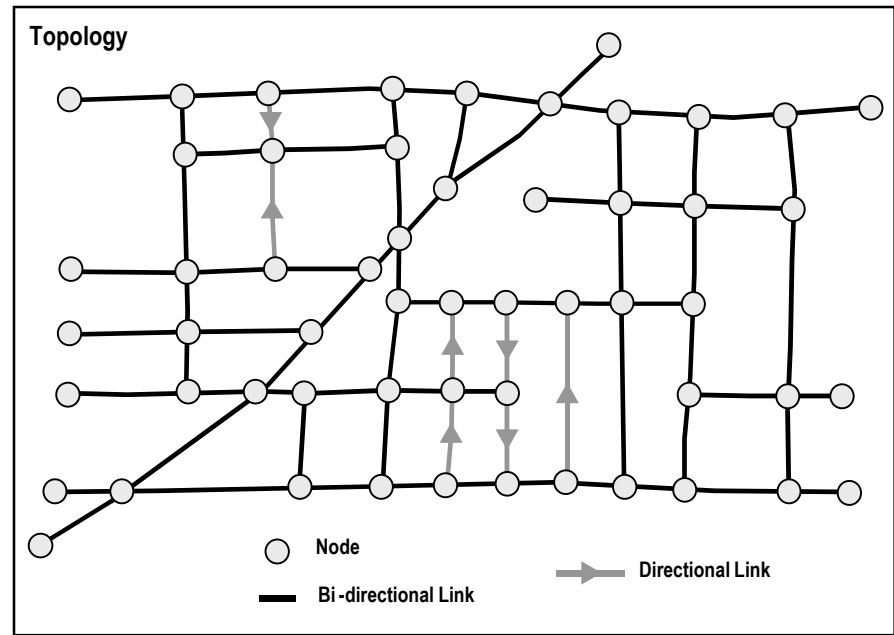
# How Network Analysis Works

## Cartography of a Network Data Model



Edge attributes  
Junction attributes

## Topology of a Network Data Model



# Review

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- Network analysis computes cumulative cost along a set of edges connected at junctions.
- Edge and node attributes can be used to optimize routes under different criteria:
  - Costs, restrictions, descriptors, hierarchies
- Results from network analysis can include:
  - Routes (and directions)
  - Service areas
  - Origin-destination mapping
  - Edge-list creation