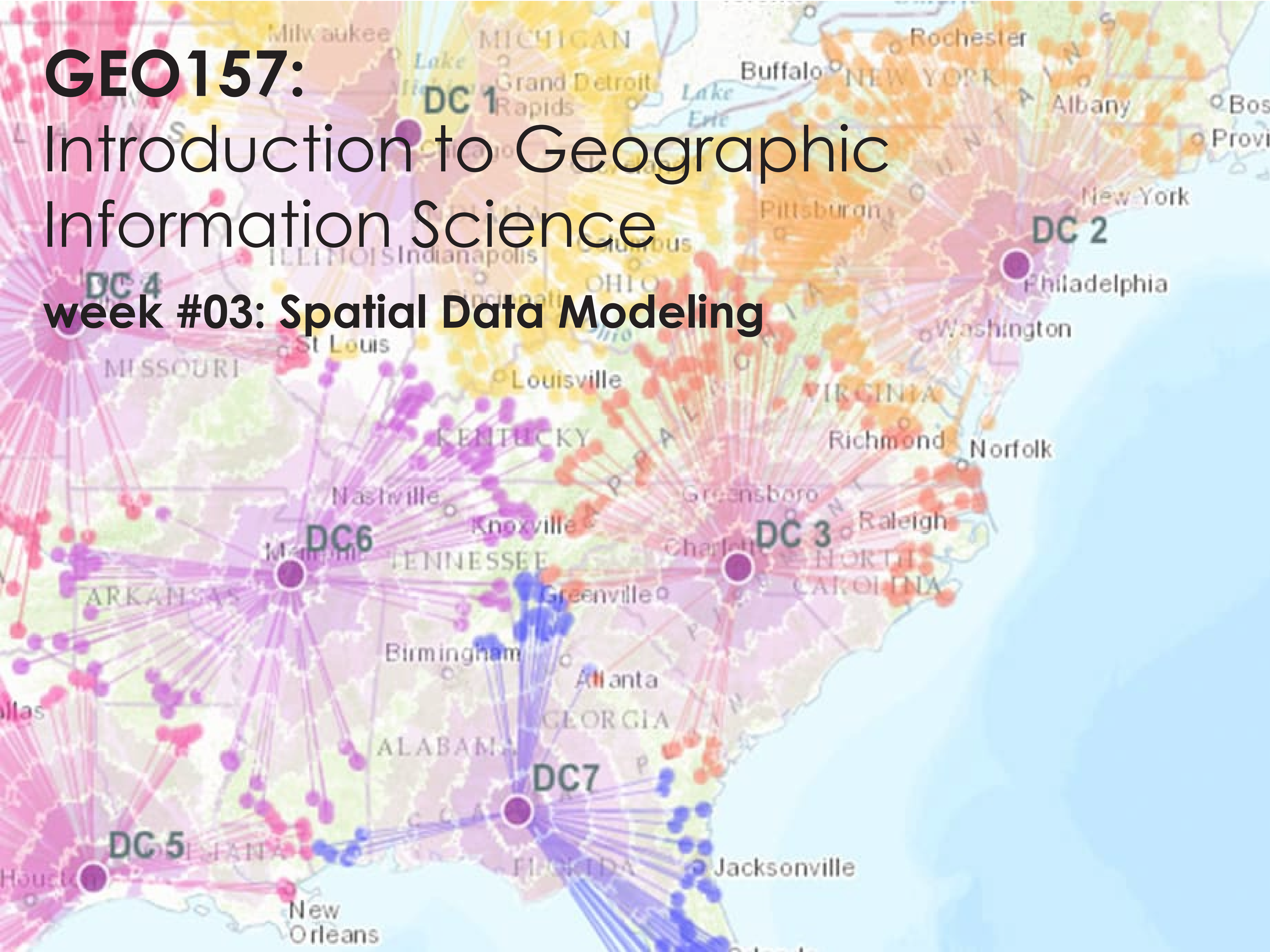
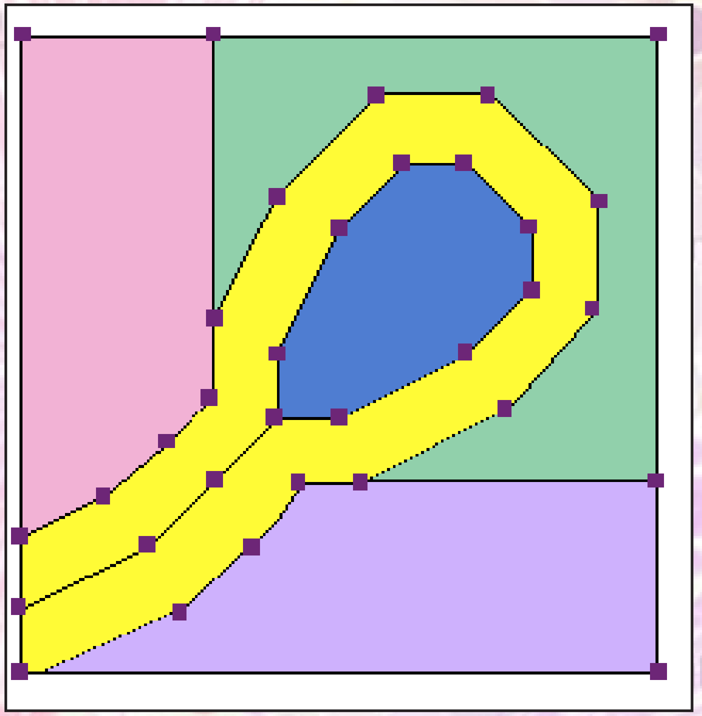
GEO157: Introduction to Geographic Information Science

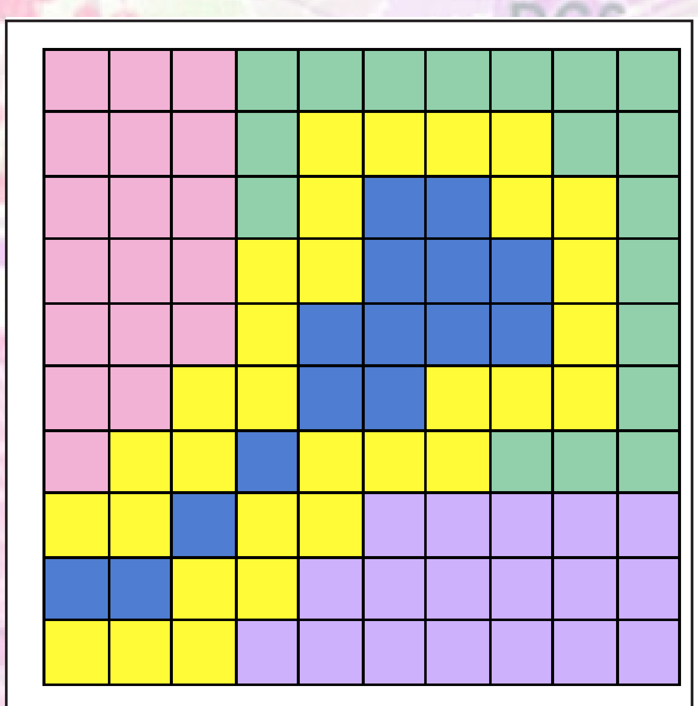
week #03: Spatial Data Modeling



Spatial Data Modeling

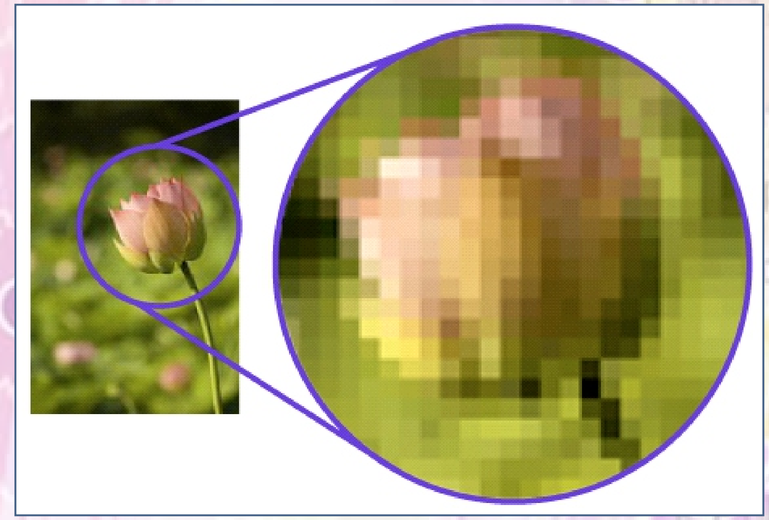


- **Raster** model: ***Grid cells*** represent a given region of interest. Gives 'Wall-to-wall' coverage.



- **Vector** Model: Defines discrete elements such as ***points***, ***lines***, and ***polygons*** to represent real-world entities.

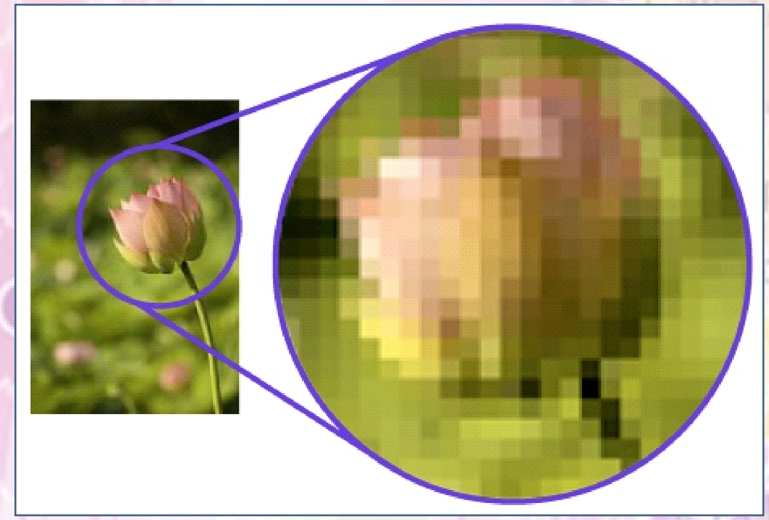
Spatial Data Modeling



real world **computer model**

- Remember, GIS is a *computer model* of reality
  - A model of spatial form
    - *Structures and distribution of features in geographical space*
  - A model of spatial processes
    - *Interaction between the spatial features*

Spatial Data Modeling



real world **computer model**

Human:

- Efficient at recognizing shapes and forms.
- Can make decisions about how to display data.

Computer:

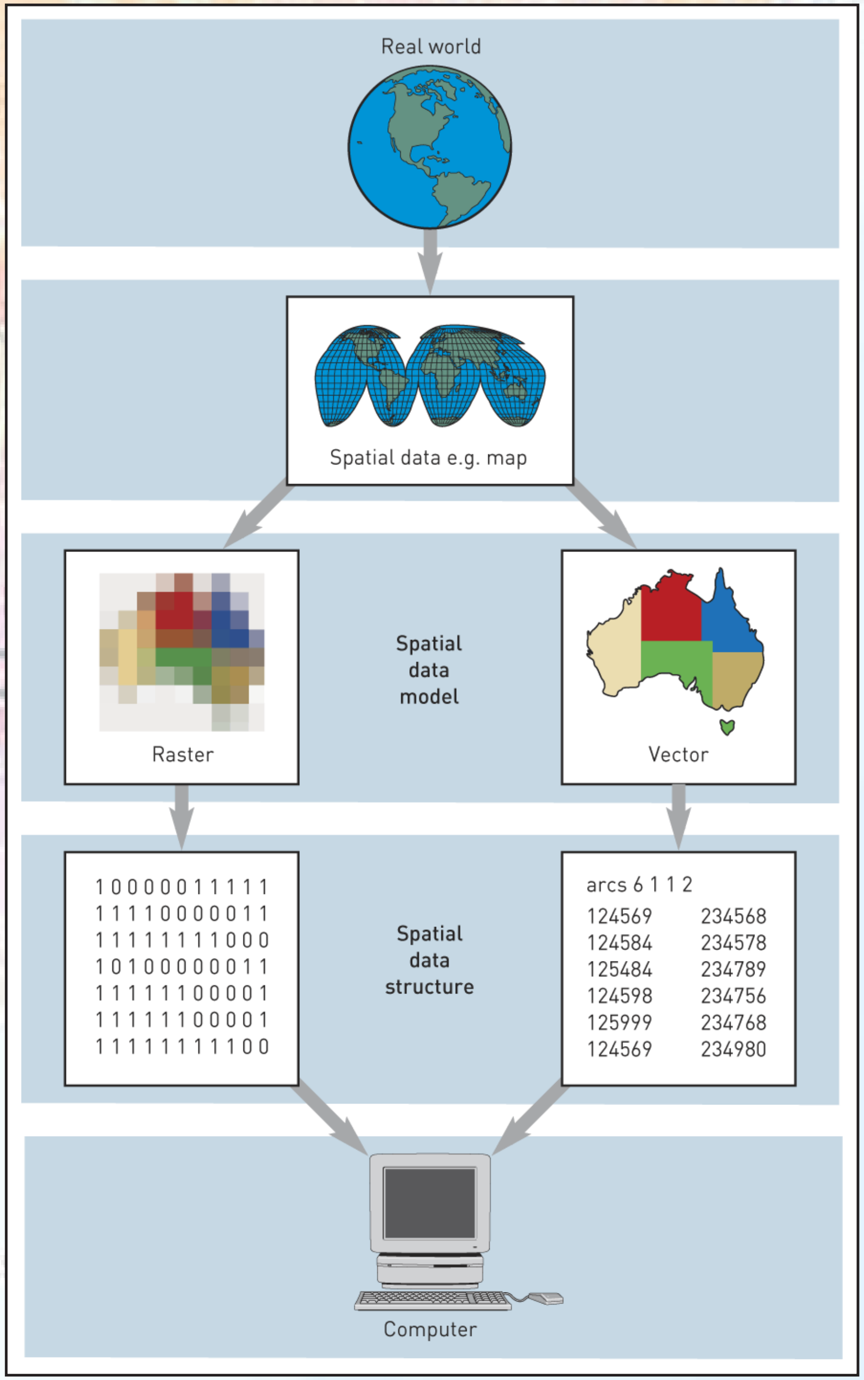
- Needs exact instructions about how to display and handle spatial data.
- Quantitative data only.

Spatial Data Modeling – Making a Model

1. Identify the spatial features from the real world that are of interest in your problem
   - how to represent them in a conceptual model?

2. Decide on an appropriate spatial data model
   - raster vs. vector?

3. Select a spatial data structure to store the model
   - the way the entities are coded for storage and manipulation



Spatial Data Modeling – Making a Model

Step 1 – Defining a Spatial Entity

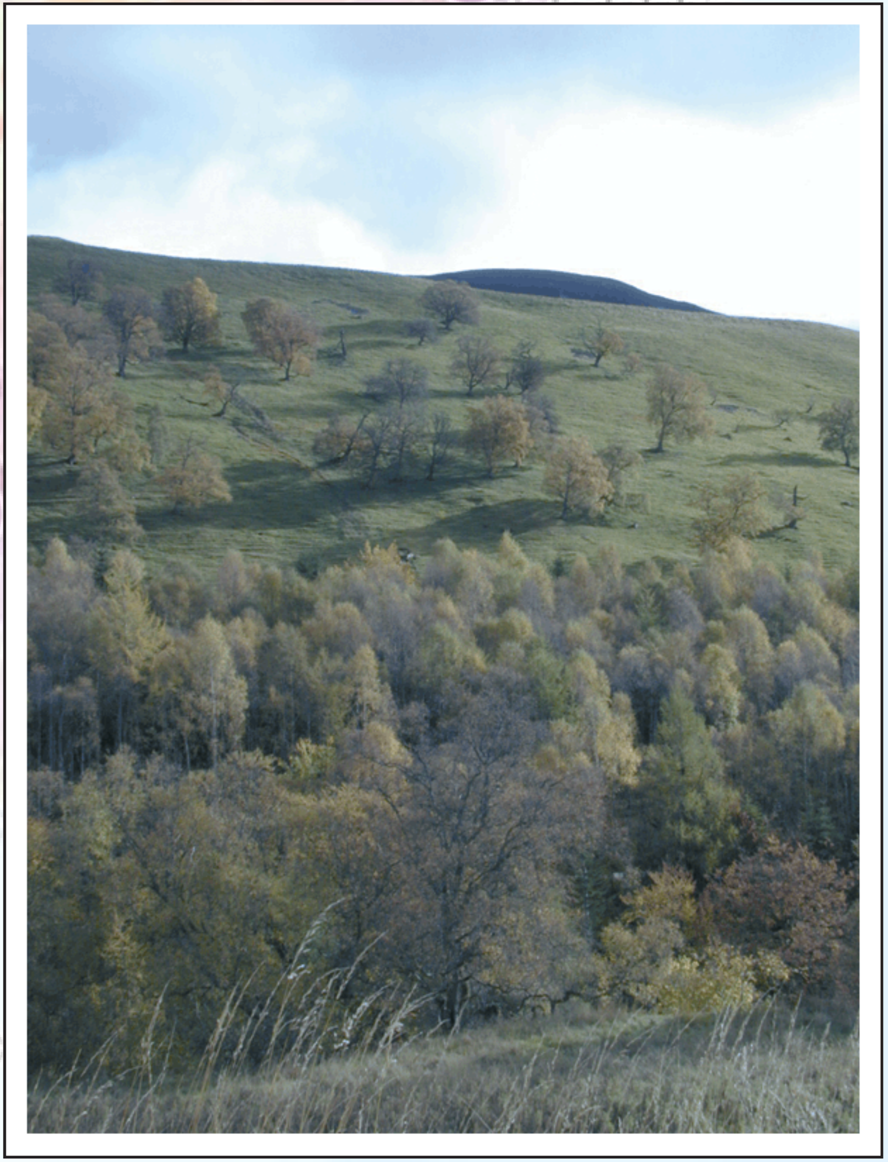
Dynamic (non static) nature of the real world.

Identification of discrete and continuous features.

Scale of a particular problem (different questions and users may require different degrees of detail).

e.g. considerations for a forest:

- Points vs. area
- Fuzzy boundary
- Growth or decline



Spatial Data Modeling – Making a Model

Step 1 – Defining a Spatial Entity

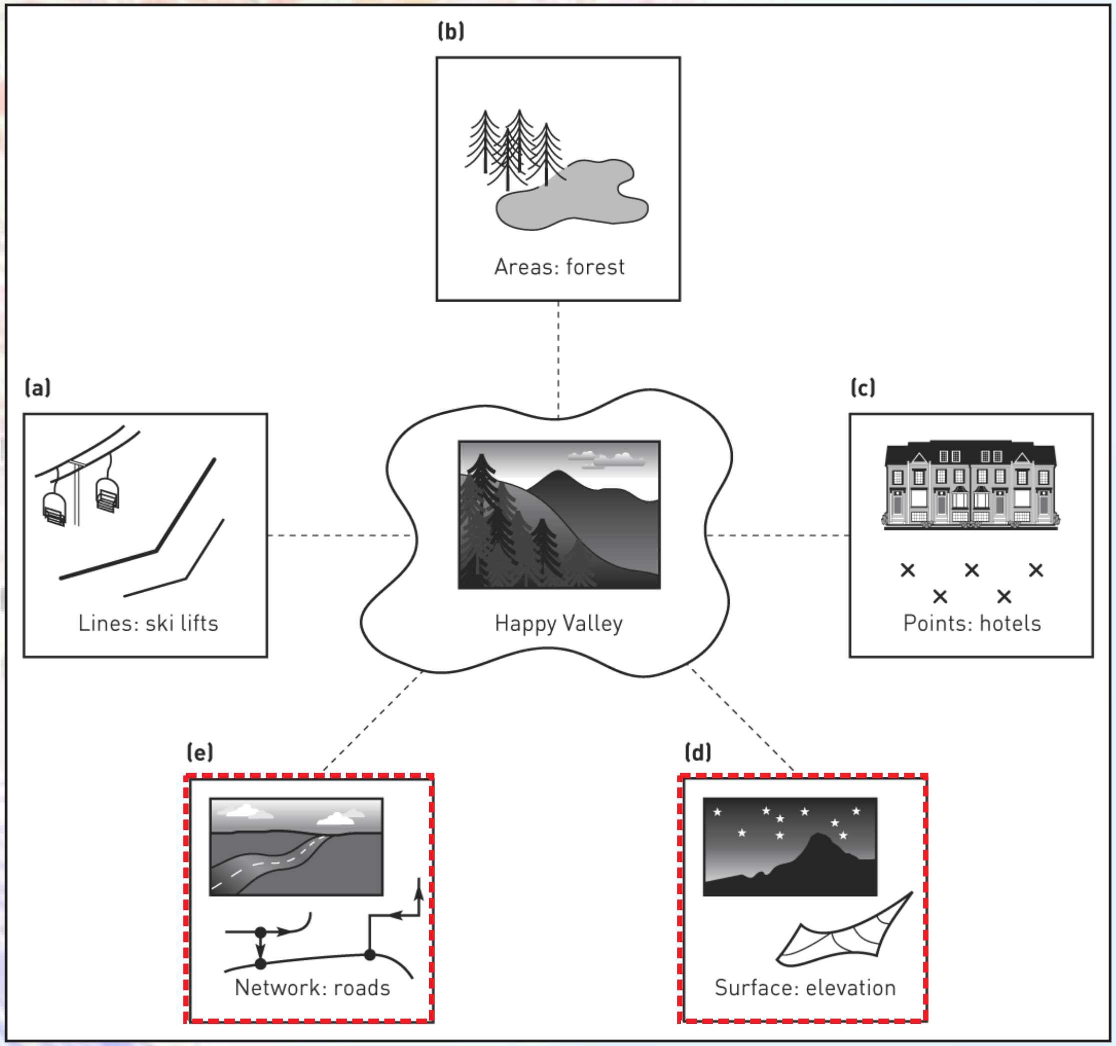
1. Points

2. Lines (arcs)

3. Areas (polygons)

4. Networks
– series of interconnected lines along which there is a flow of data, objects or materials

5. Surfaces
– used to represent continuous features or phenomena



Spatial Data Modeling – Making a Model

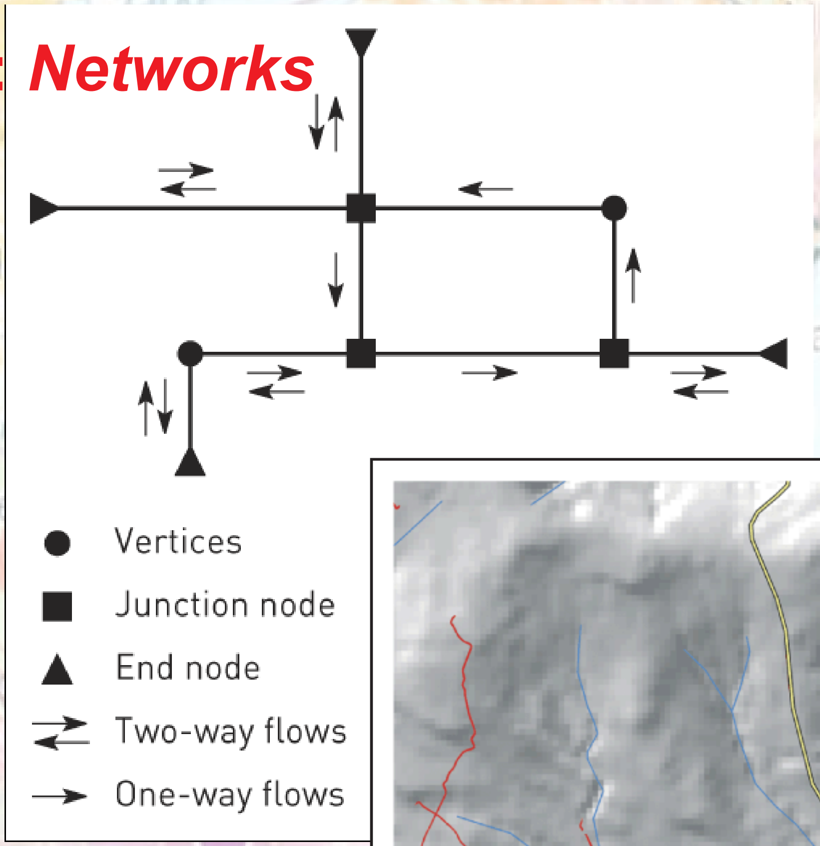
Step 1 – Defining a Spatial Entity: *Networks*

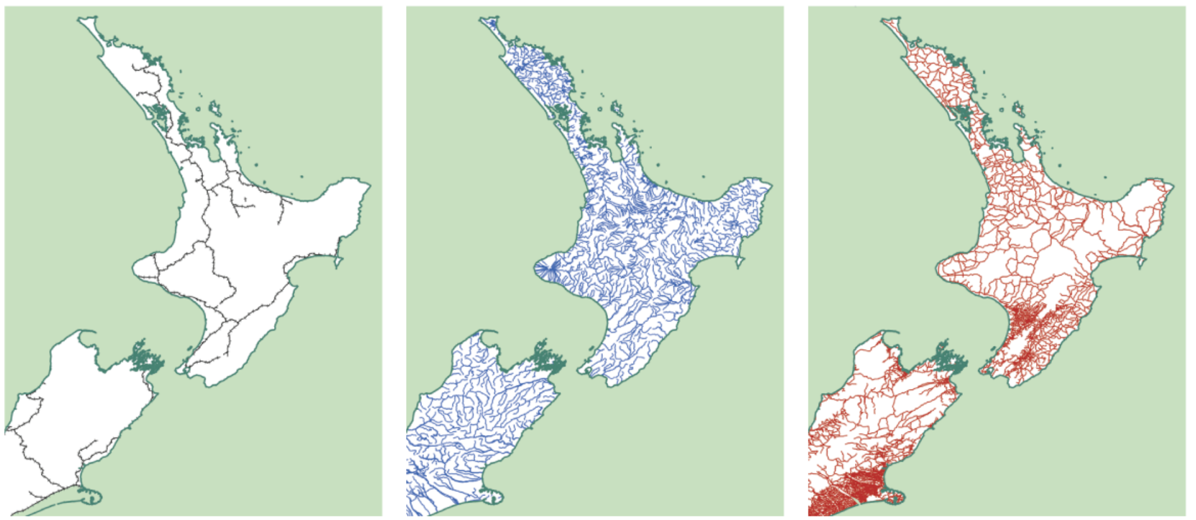
Set of interconnected linear features though which

- Material, goods and people are transported
- Communication of information is achieved

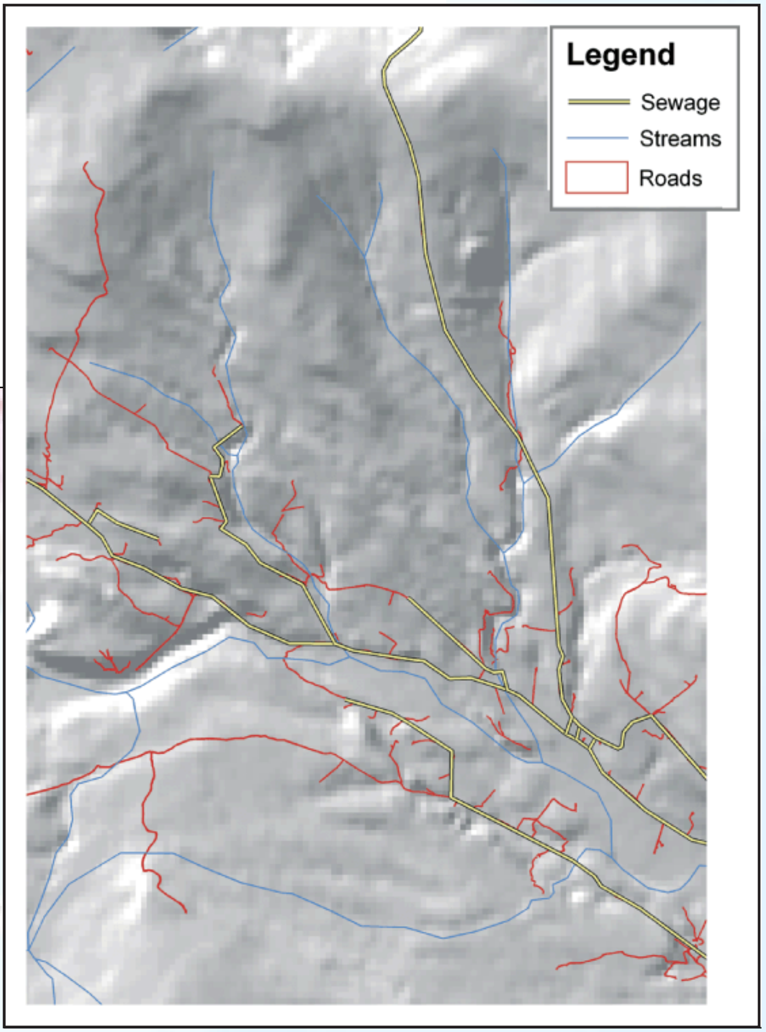
Adaptations of vector data model

- Made up of line segments (arcs)
- Node elements
- Addition of special attributes





(a) Railways (b) Rivers (c) Roads



Spatial Data Modeling – Making a Model

Step 1 – Defining a Spatial Entity: *Networks*

Arcs/Line Segments

– Represent network links

– Roads, streams, etc.

Nodes

– Represent network nodes, stops and centers

– Network nodes: endpoints of links

– Stops: locations on links where exchanges take place

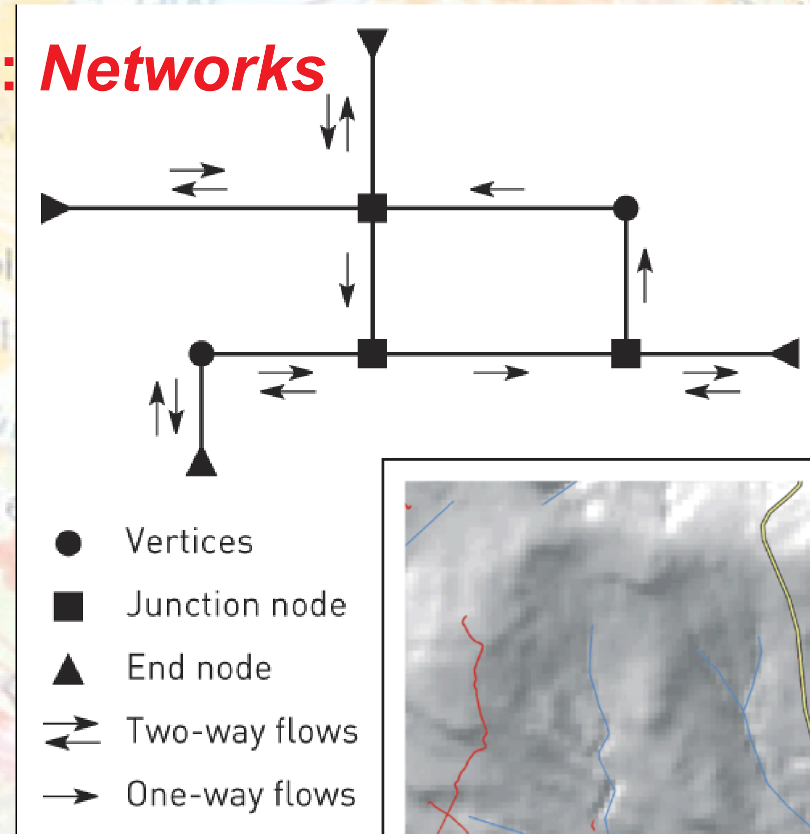
– Centers: locations on links for resource supplies

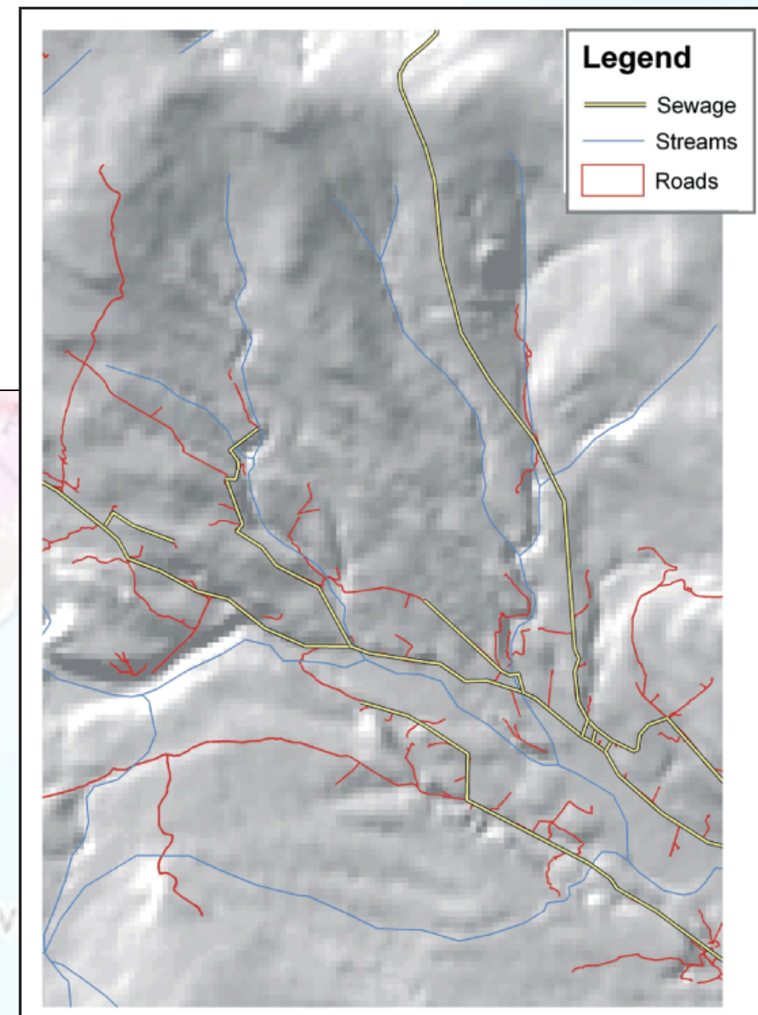
Attributes

– Characteristics of network links, nodes, stops, and centers

– ‘Impedance’

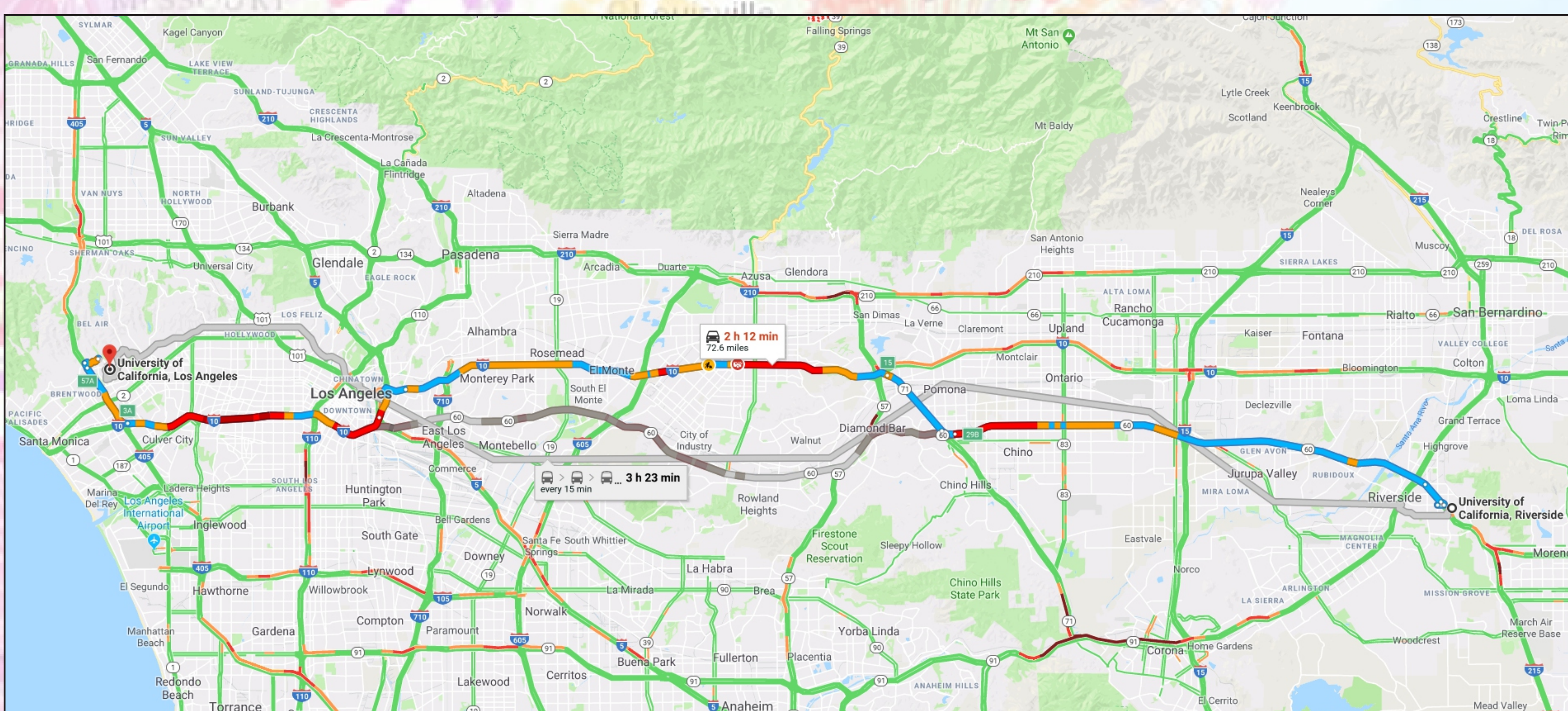
e.g. link impedances sucha s 1-way or 2-way flow, fast/slow traffic flow





Spatial Data Modeling – Making a Model

Step 1 – Defining a Spatial Entity: *Networks*



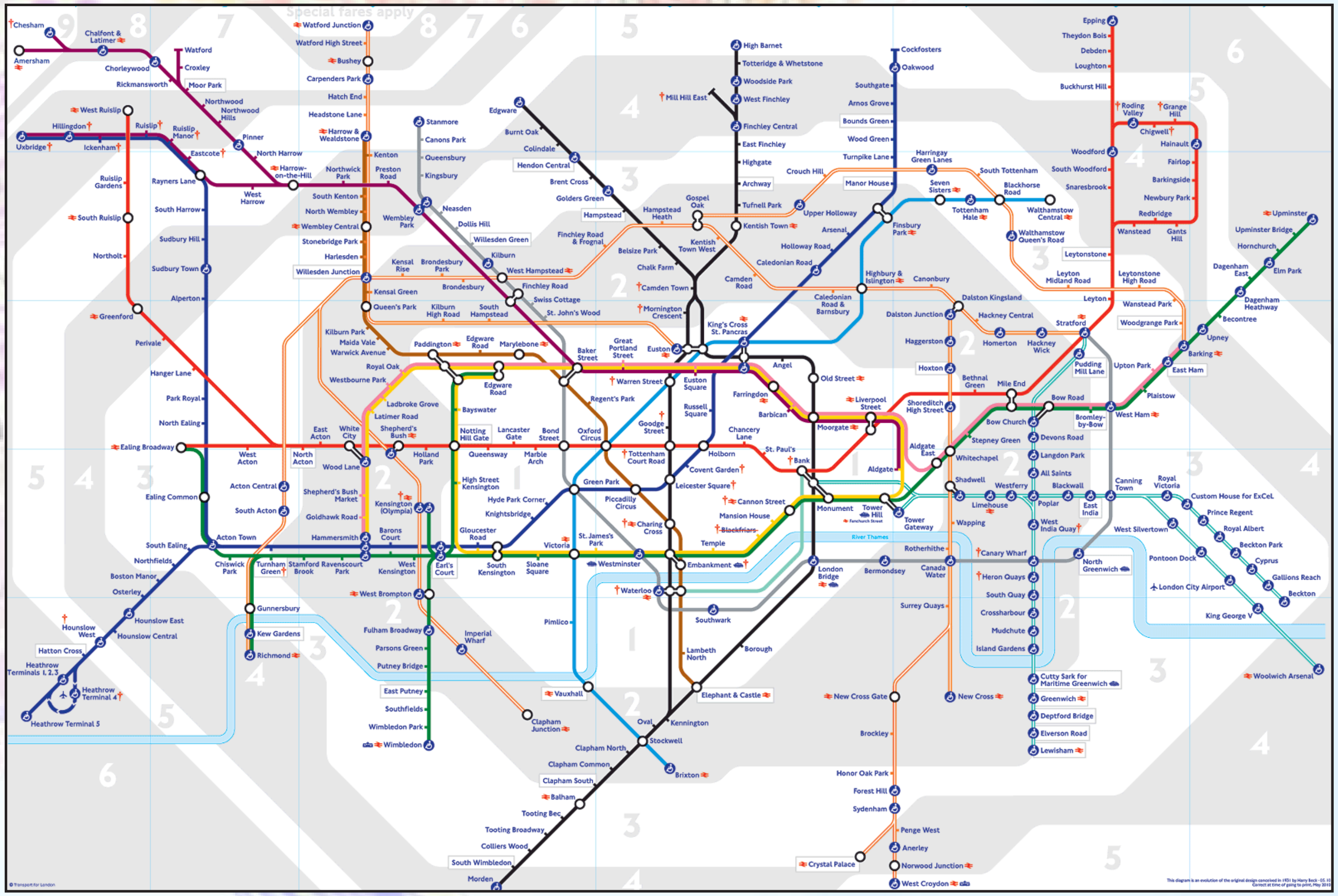
Spatial Data Modeling – Making a Model

Step 1 – Defining a Spatial Entity: *Networks*

Key attributes such as impedance and distance should be preserved

Clear information about the network connectivity is important for user understanding

Correct geographical representation is not as important



Spatial Data Modeling – Making a Model

Step 1 – Defining a Spatial Entity: *Networks*

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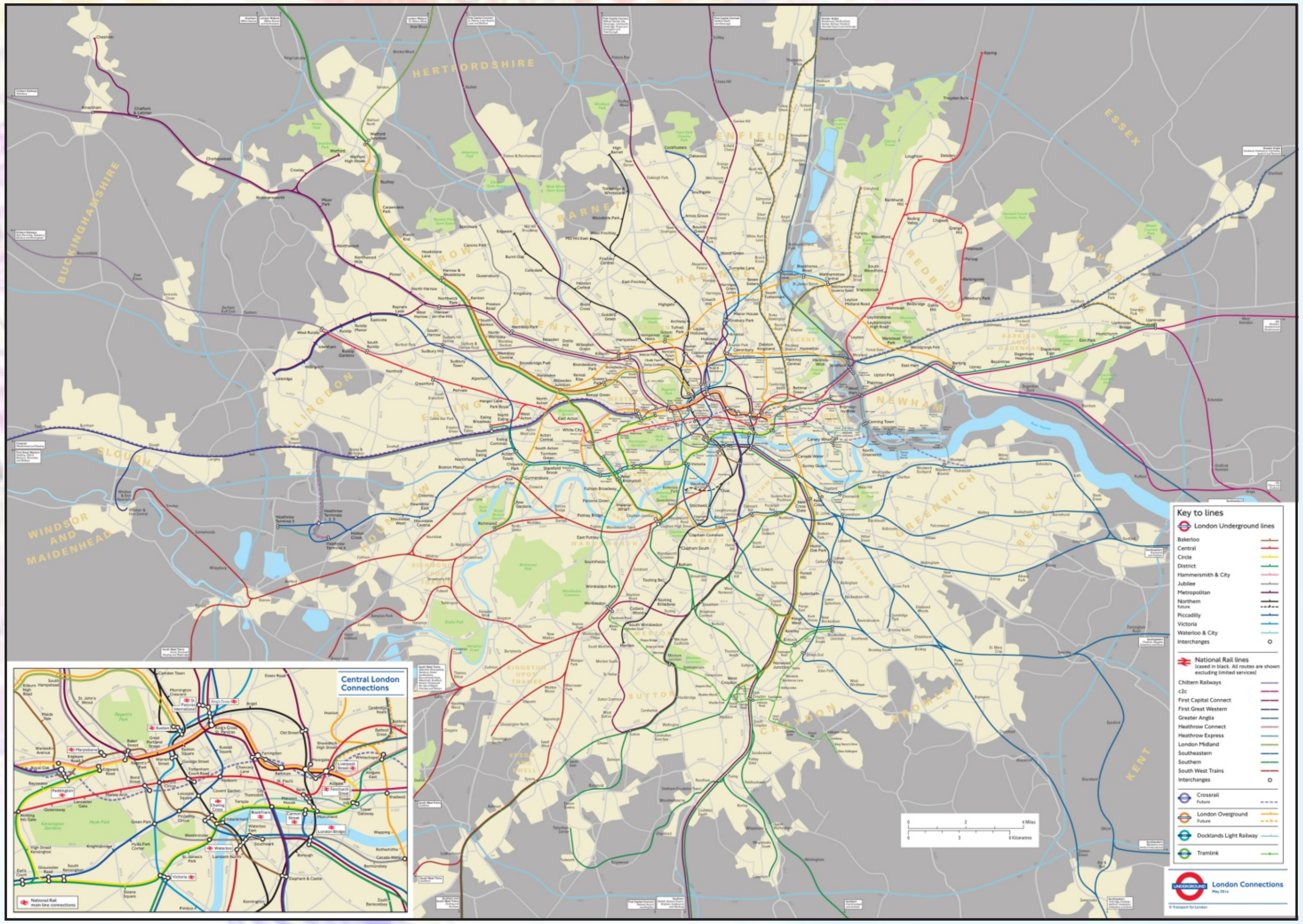
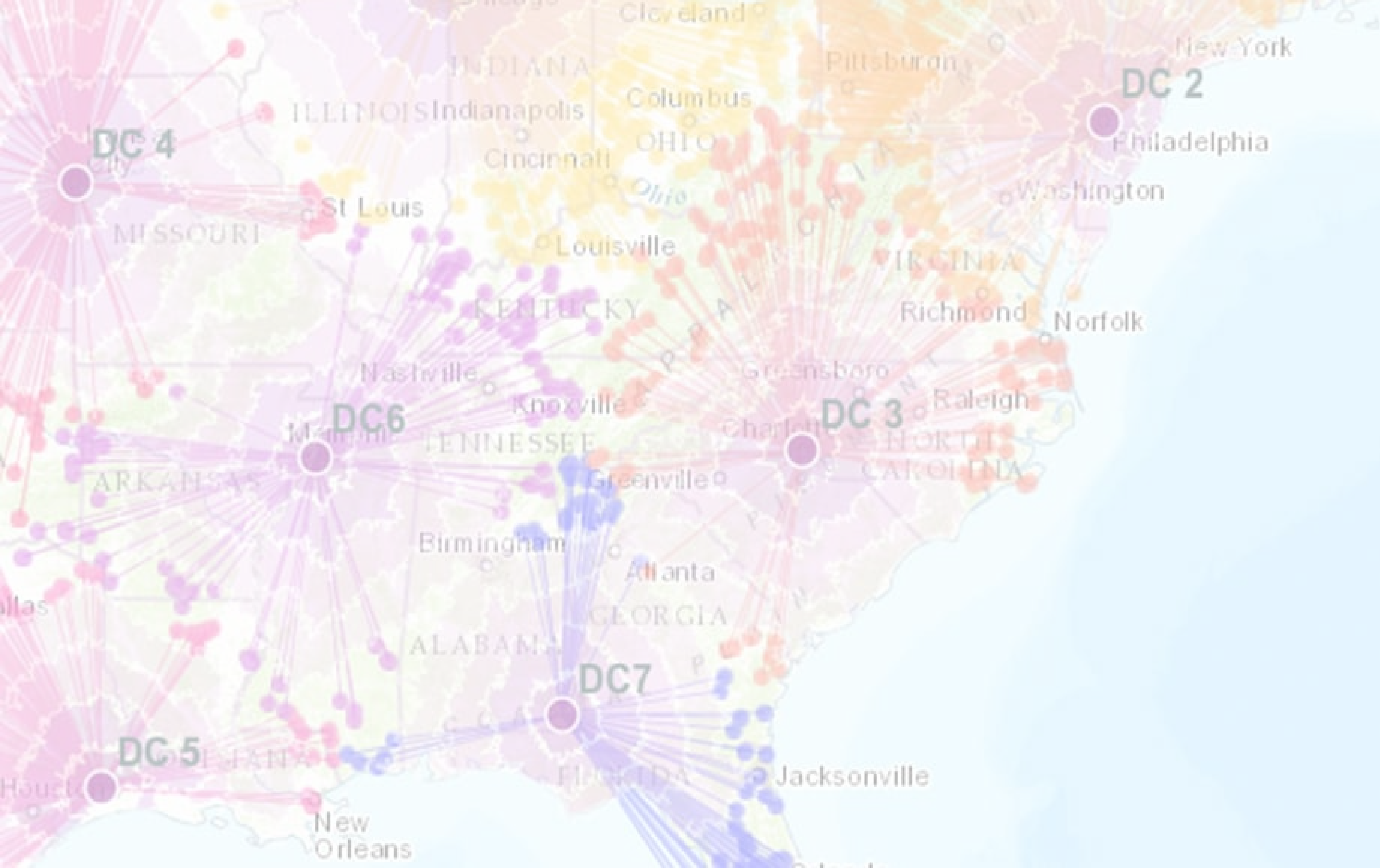


Spatial Data Modeling – Making a Model

https://traintimes.org.uk/map/tube/

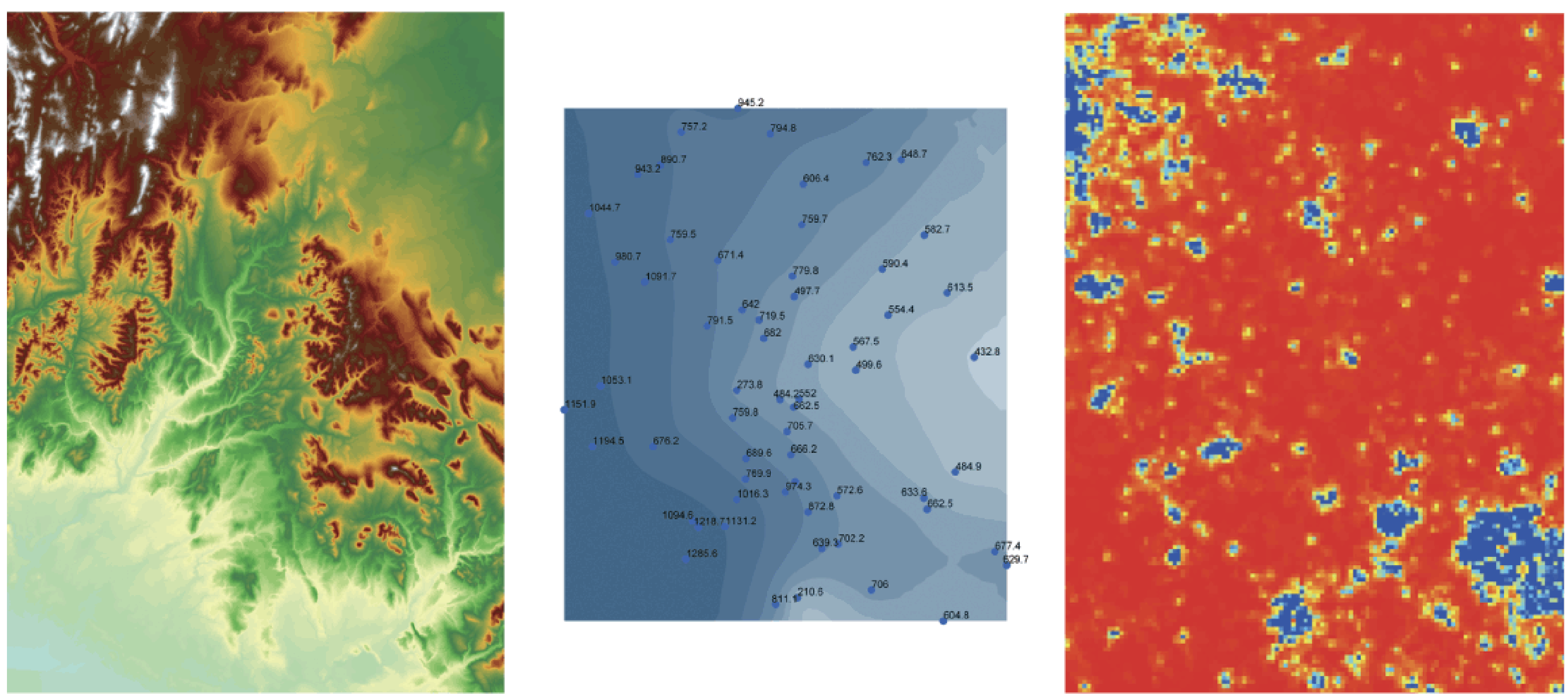


Spatial Data Modeling – Making a Model

Step 1 – Defining a Spatial Entity: *Surfaces*

Surfaces

– used to represent continuous features or phenomena



(a) Terrain (b) Rainfall (c) Population

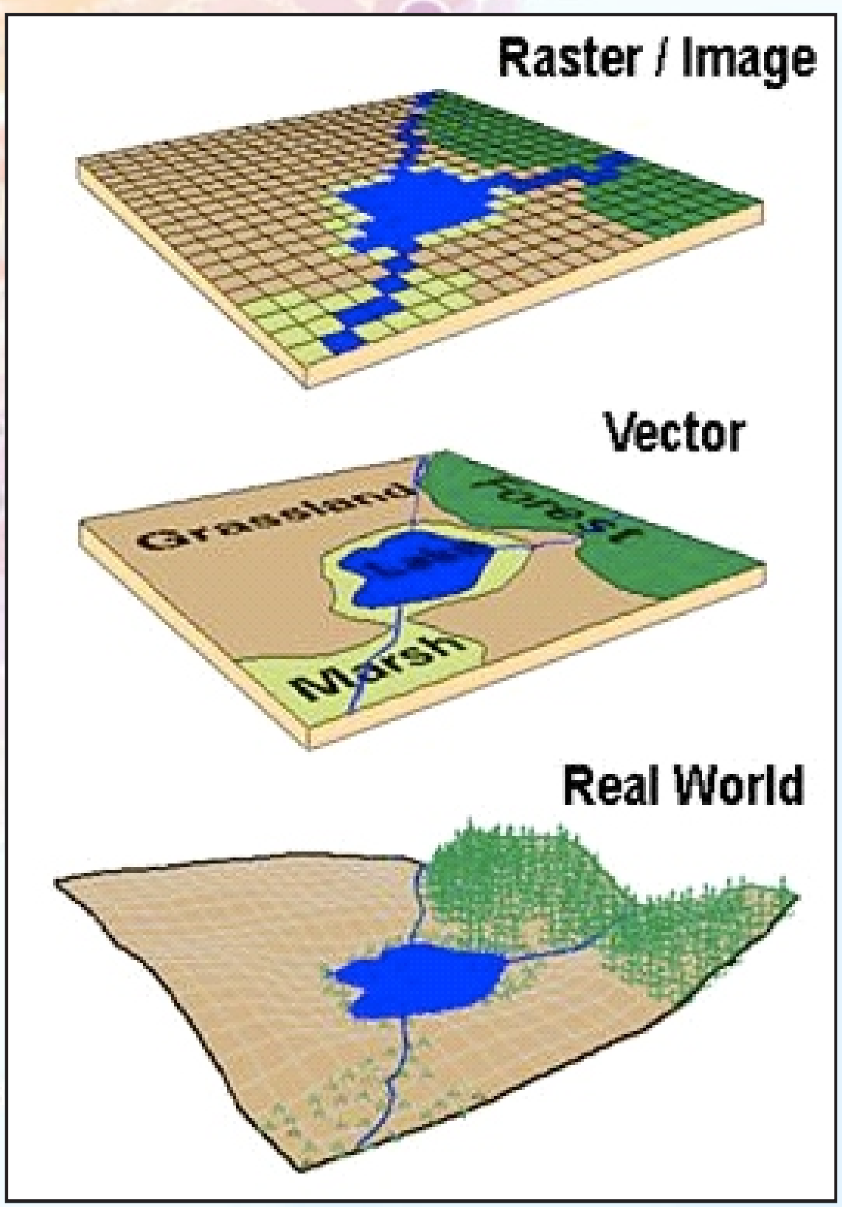
Spatial Data Modeling – Making a Model

Step 2 – Spatial Data Model

How to turn data about spatial entities into graphical representations

Raster: cells are building blocks for creating images of points, lines, areas, surfaces

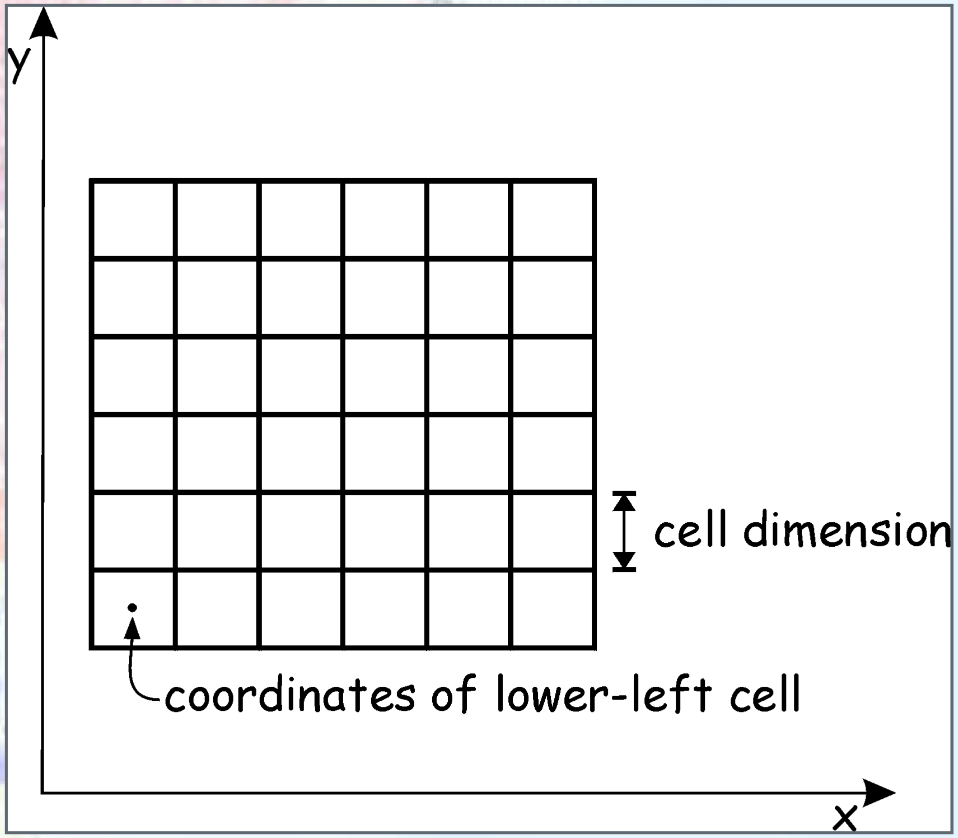
Vector: 2-D Cartesian coordinates store the shape of the entity



Spatial Data Modeling – Making a Model

Step 2 – Spatial Data Model: *Raster model*

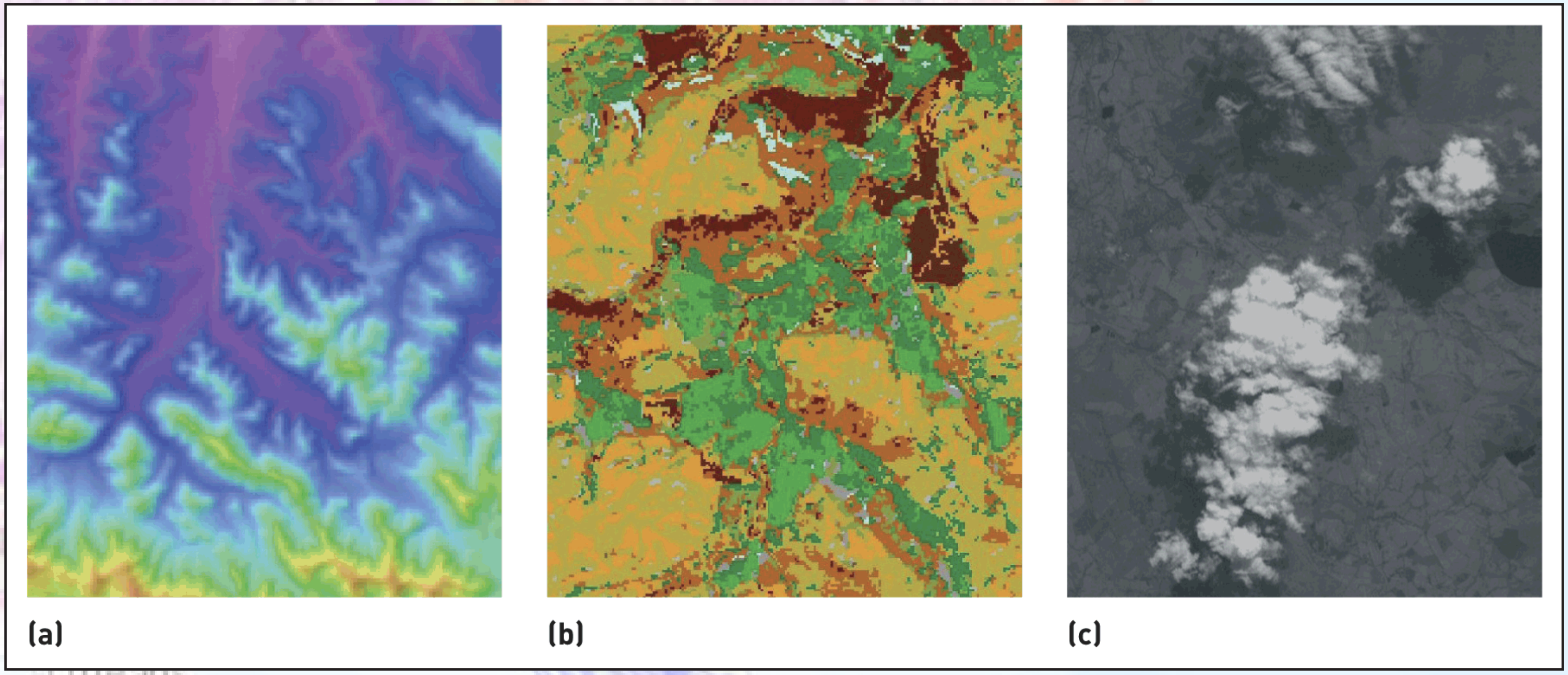
- Raster Model
  - Square and evenly spaced cells in a grid pattern.
  - Best for continuous spatial features (i.e elevation, precipitation, etc.)
  - Cell dimension is the length and width of a cell.
  - Location of cell is based on the center of the cell.



Spatial Data Modeling – Making a Model

Step 2 – Spatial Data Model: *Raster model*

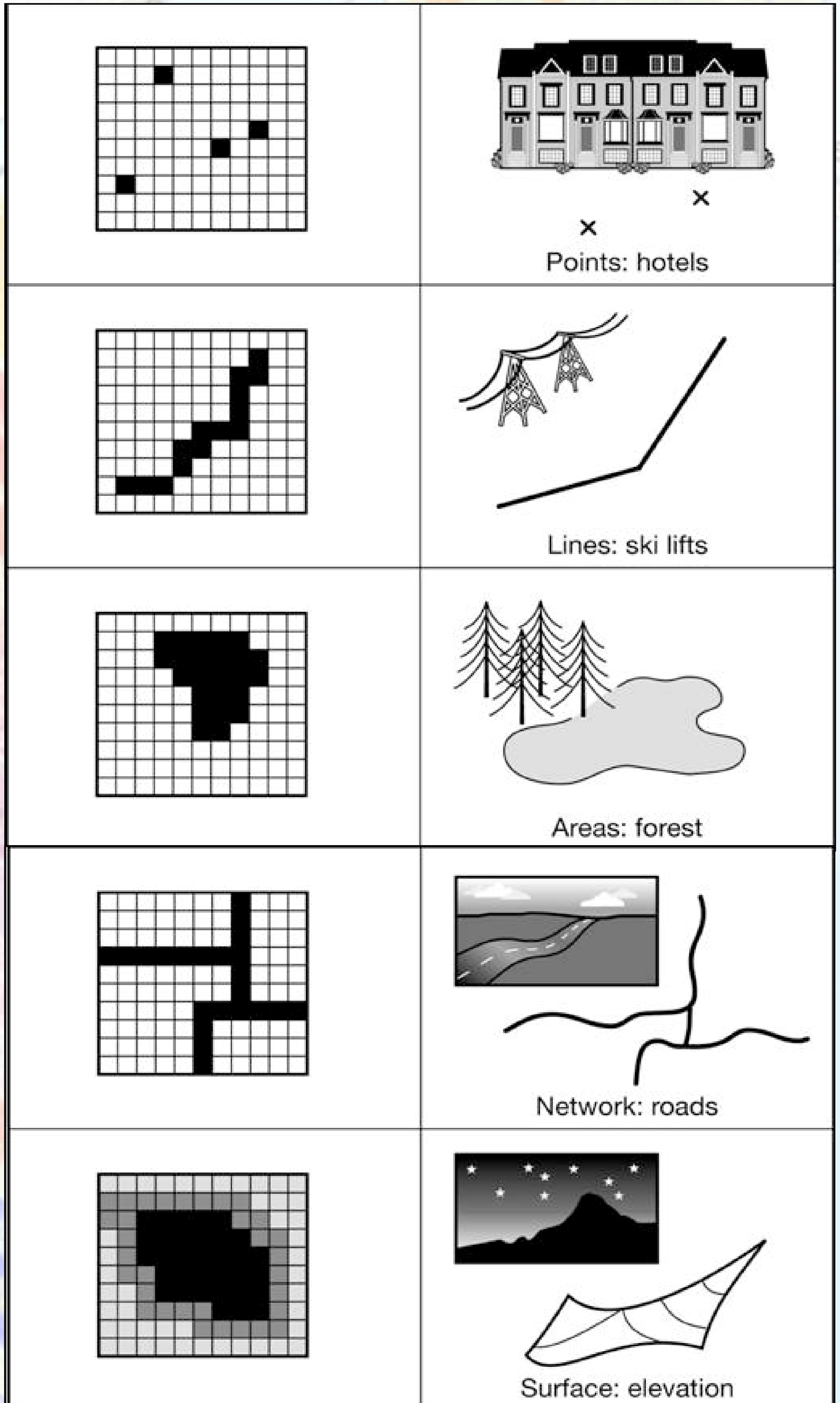
- Commonly used with variables that change continuously across a region.
- Possible limitations
  - Grid size limits resolution
  - Points and Lines have areal extent that may not represent the true size of the object



Spatial Data Modeling

Step 2 – Spatial Data Model

- Grid cells represent
  - Points
  - Lines
  - Polygons
  - Networks (though typically vector models)
  - Surfaces



Spatial Data Modeling – Making a Model

Step 2 – Spatial Data Model: *Vector model*

- **Points:**
  - Defined by a single coordinate pair with attribute data
  - Used for objects that are considered to have no dimension

(a) Postbox (b) Tree (c) Lamp post

Spatial Data Modeling – Making a Model

Step 2 – Spatial Data Model: *Vector model*

- **Lines:**
  - Represented as an ordered set of coordinate pairs
  - Start and end points are referred to as *nodes*
  - Intermediate points are referred to as *vertices*
  - Attributes can be attached to the whole line, line segments, nodes or vertices.

(a) Road (b) Power line (c) River

Spatial Data Modeling – Making a Model

Step 2 – Spatial Data Model: *Vector model*

- **Polygons:**
  - Closed polygons formed by connected lines.
  - Polygons have boundaries and interior regions.

(a) Field (b) Building (c) Lake

Spatial Data Modeling – Making a Model

Step 3 – Spatial Data Structures

Raster Benefits:

- Good for datasets that change frequently in space.
- Data structures are simpler, especially when fixed cell size is used
- Easy to overlay themes
- Most practical for digital image data

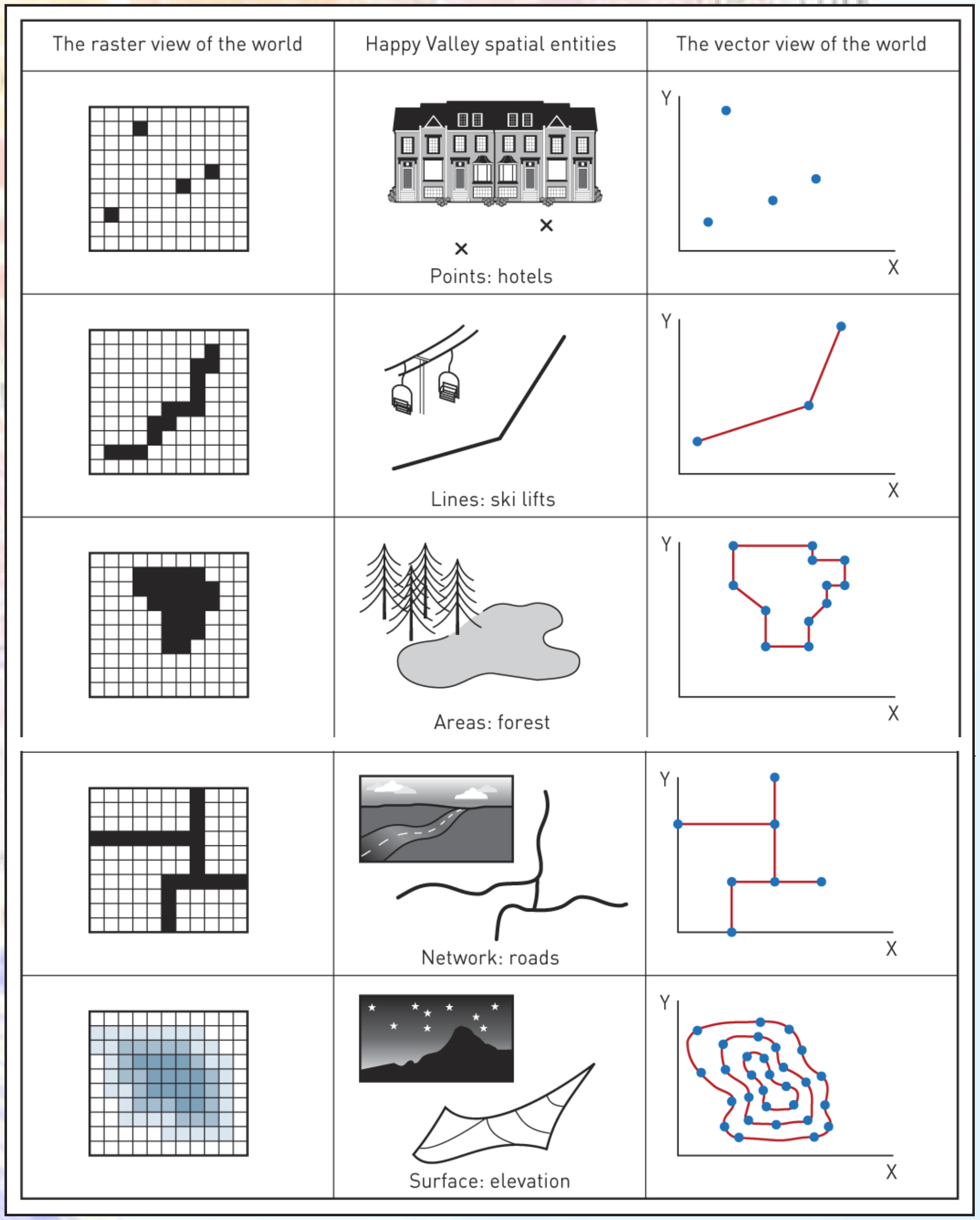
Vector Benefits:

- More compact data storage for discrete objects
- Better at representing networks and connected linear features

Spatial Data Modeling – Making a Model

Step 3 – Spatial Data Structures

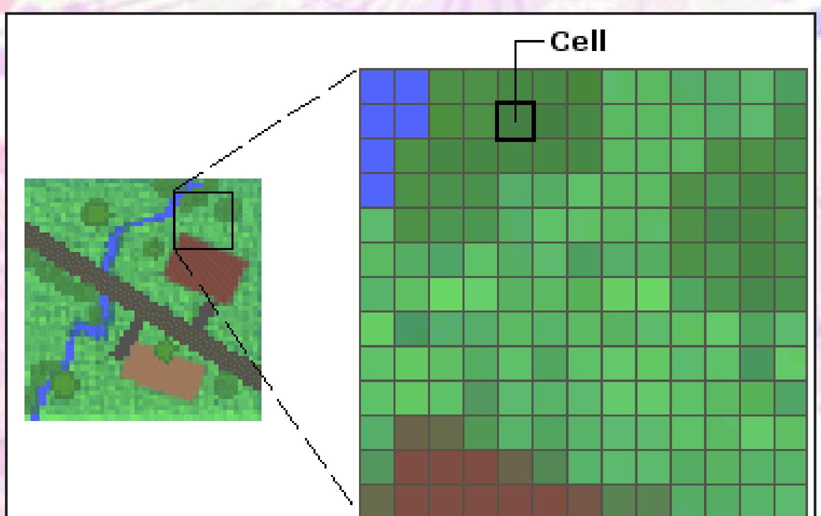
- Provide information that computer uses to reconstruct model in digital form
- Many different types of structures in use in GIS
- Creates problems exchanging data between GIS softwares
- Structures different for vector and raster data



Spatial Data Modeling – Making a Model

Step 3 – Spatial Data Structures: *Rasters*

- Raster cells typically hold numeric or single-letter characters that define the cell.
- A single code can be found in many cells.
- Raster cells often represent the average of values in the cell, but could represent median, maximum or another statistic.

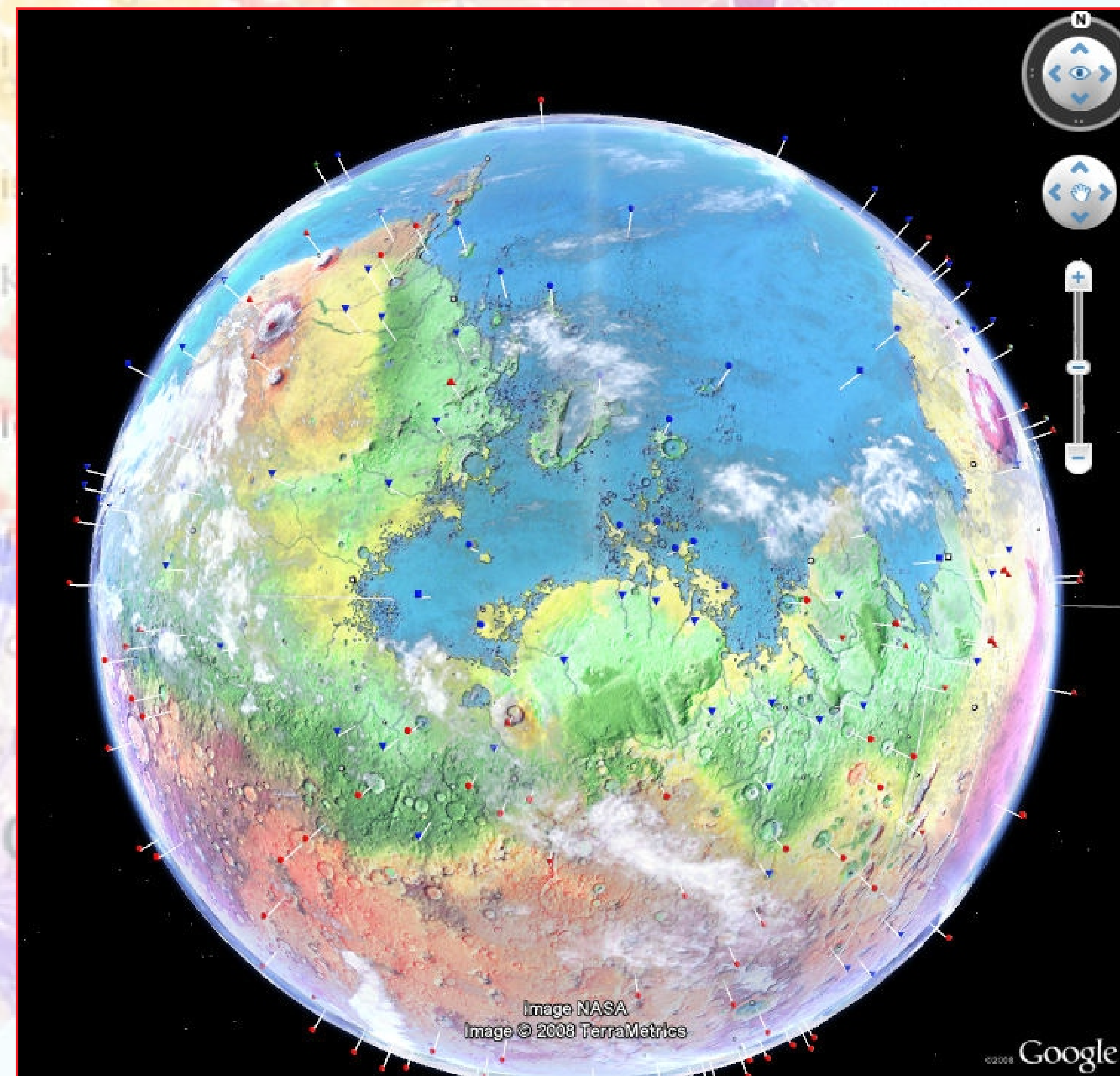


a	a	a	a	r	f	f	a	a	a	a	a
a	a	a	a	r	f	f	a	a	a	a	a
a	a	a	f	r	f	f	a	a	a	a	a
a	a	a	r	r	f	f	a	a	a	a	a
a	a	a	r	f	f	f	a	a	a	a	a
a	f	f	r	f	f	f	a	a	a	a	a
a	f	f	r	f	u	f	a	a	a	a	a
h	h	h	h	h	h	h	h	h	h	h	h
f	f	r	u	u	u	u	a	a	a	a	a
f	f	r	f	u	u	a	a	a	a	a	a
f	f	f	r	f	f	a	a	a	a	a	a
f	f	f	f	r	f	a	a	a	a	a	a

a = agriculture
f = forest
h = highways
u = developed
r = river

Spatial Data Modeling – Making a Model

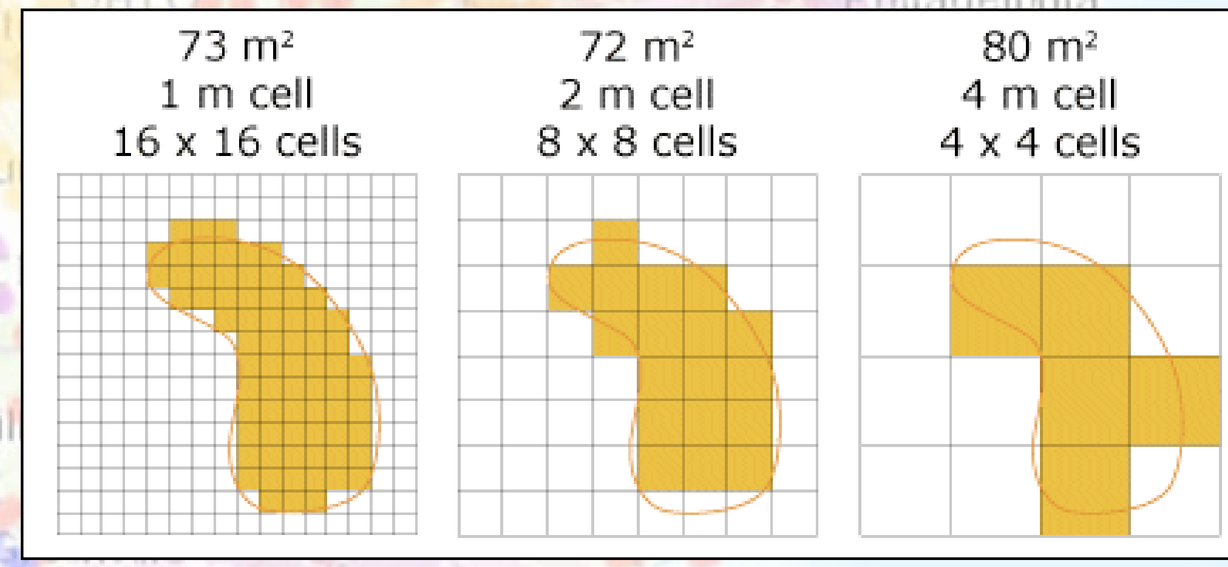
Step 3 – Spatial Data Structures: *Rasters*



Spatial Data Modeling – Making a Model

Step 3 – Spatial Data Structures: *Rasters*

- ***Spatial Detail*** vs. ***Data Volume***:
  - The number of cells increases by the square of the reduction in cell dimensions.
  - Smaller cells give greater spatial detail at the cost of larger data sets.
  - Positional accuracy is no better than one-half of the cell size.



Scale 1:20,000
Cell size: 15 m

Scale 1:20,000
Cell size: 15.24 cm

Spatial Data Modeling – Making a Model

Step 3 – Spatial Data Structures: *Rasters*

- ***Spatial Detail*** **vs.** ***Data Volume***:
  - The number of cells increases by the square of the reduction in cell dimensions.
  - Smaller cells give greater spatial detail at the cost of larger data sets.
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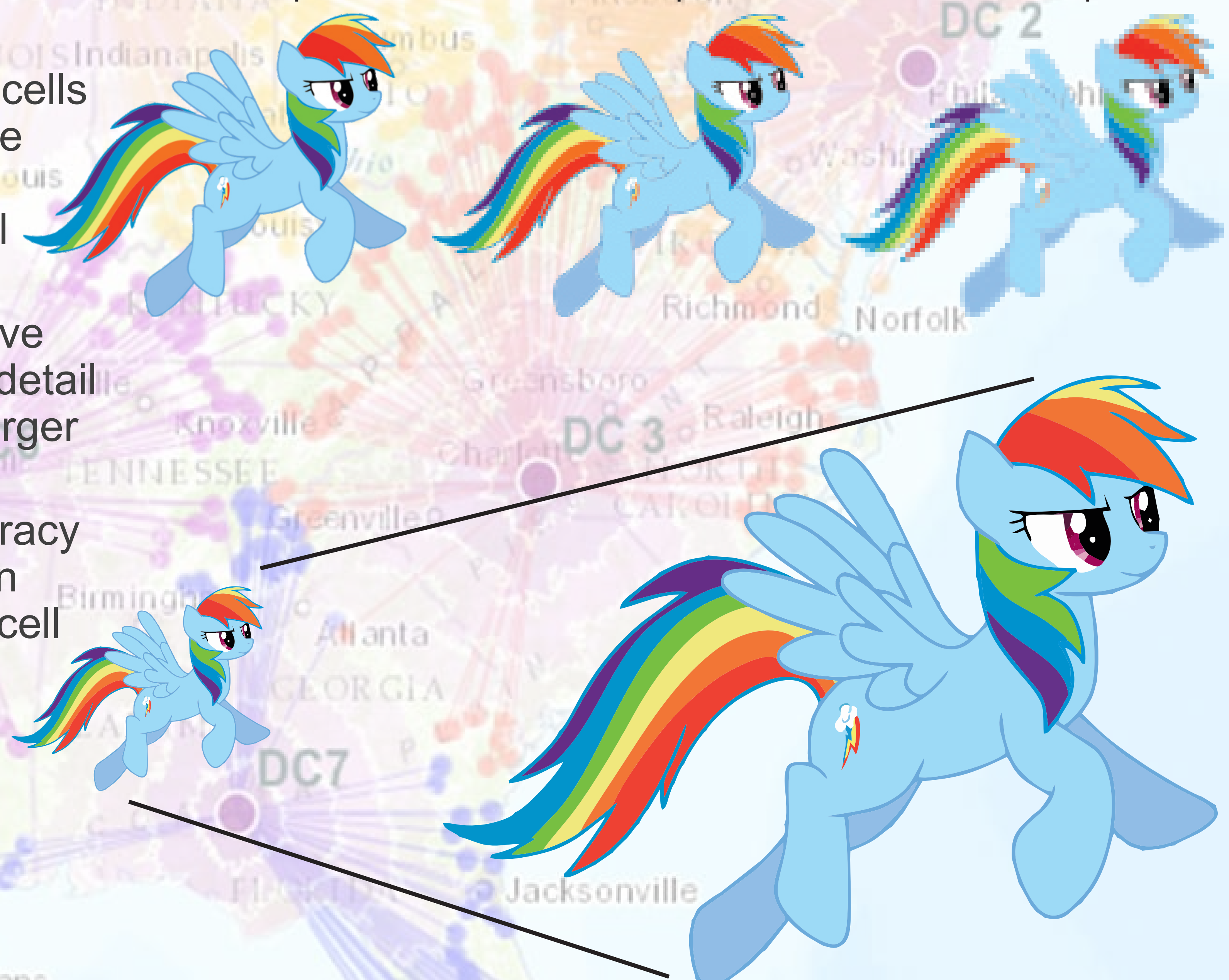
300 dpi 60 dpi 30 dpi



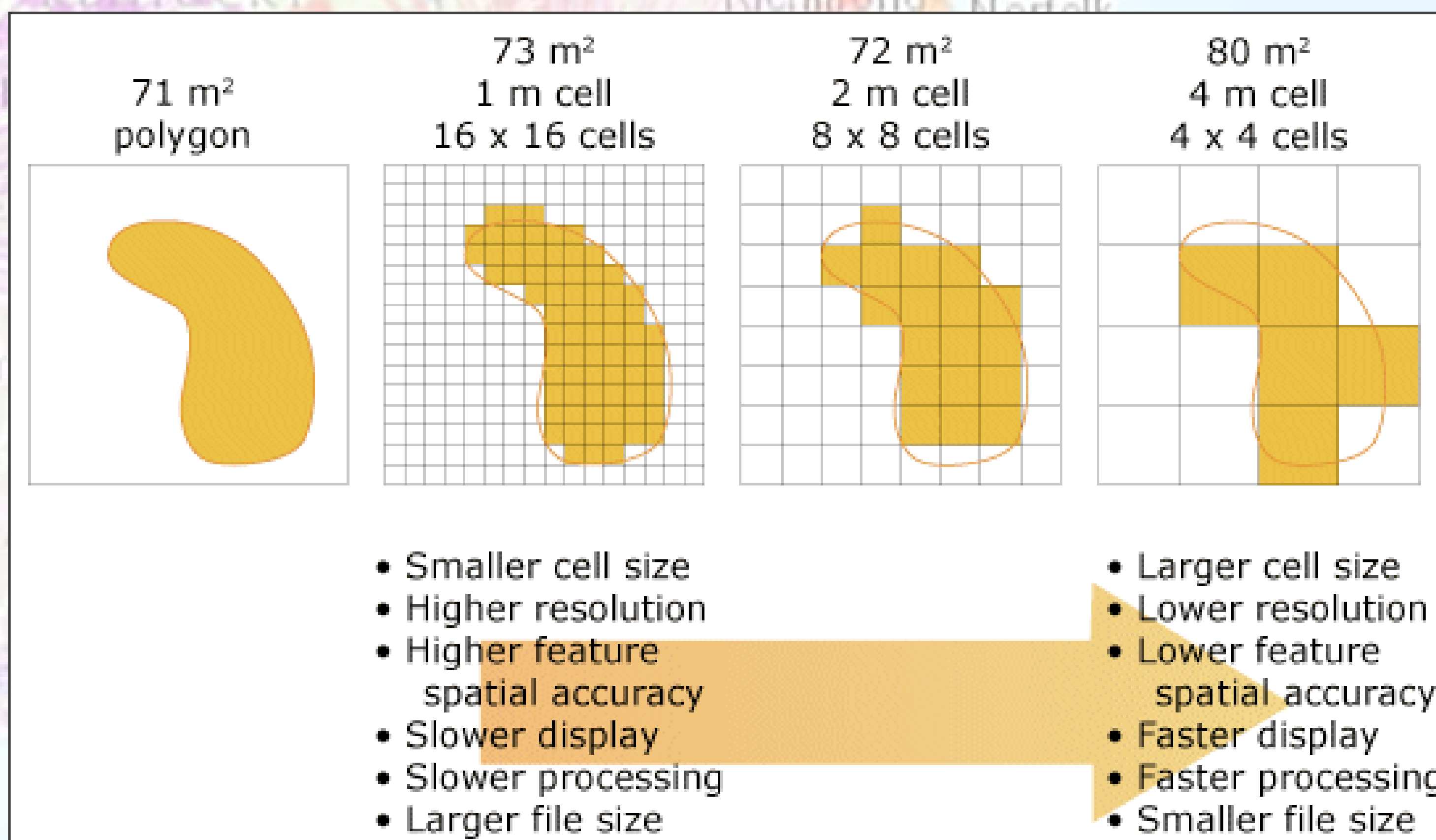
Spatial Data Modeling – Making a Model

Step 3 – Spatial Data Structures: *Rasters*

Too many points/cells then you are storing unnecessary & duplicate information.

Too few points/cells chosen then the character, shape and spatial properties of the entity will be compromised.

Automatic methods have been developed to automatically thin the number of points to the optimal level.



Spatial Data Modeling – Making a Model

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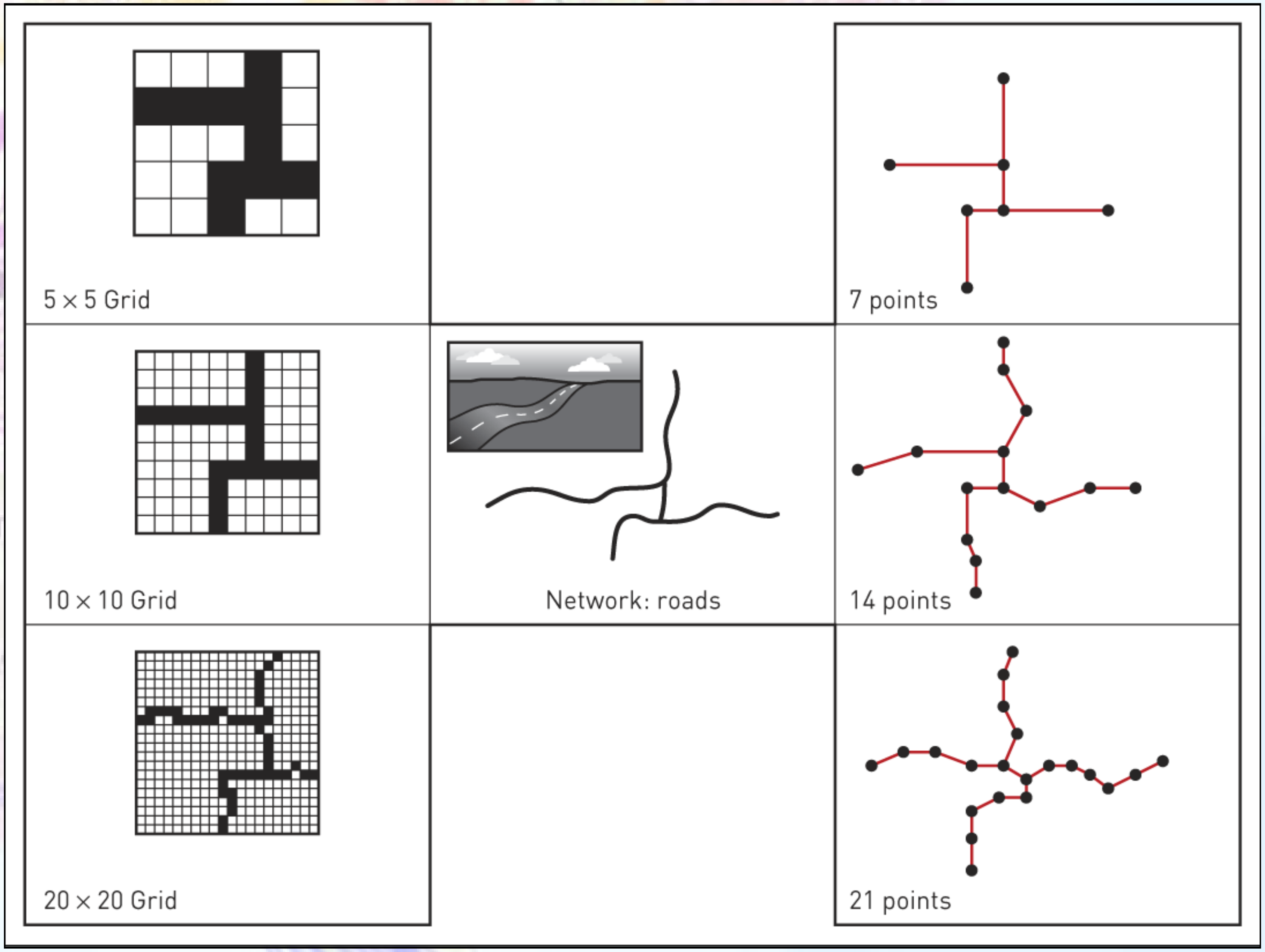
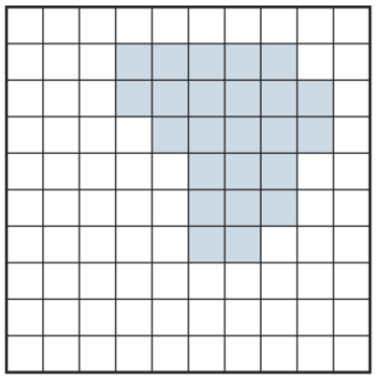


Spatial Data Modeling – Making a Model

Step 3 – Spatial Data Structures: *Storing Rasters*

Simple binary system can be used for some problems



(a) Entity model

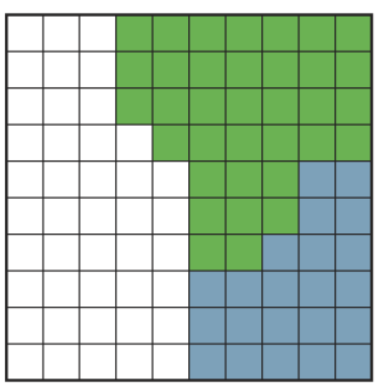
0	0	0	0	0	0	0	0	0	0
0	0	0	1	1	1	1	1	0	0
0	0	0	1	1	1	1	1	1	0
0	0	0	0	1	1	1	1	1	0
0	0	0	0	0	1	1	1	0	0
0	0	0	0	0	1	1	1	0	0
0	0	0	0	0	1	1	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0

(b) Cell values

10,10,1
0,0,0,0,0,0,0,0,0,0
0,0,0,1,1,1,1,1,0,0
0,0,0,1,1,1,1,1,1,0
0,0,0,0,1,1,1,1,1,0
0,0,0,0,0,1,1,1,0,0
0,0,0,0,0,1,1,1,0,0
0,0,0,0,0,1,1,0,0,0
0,0,0,0,0,0,0,0,0,0
0,0,0,0,0,0,0,0,0,0
0,0,0,0,0,0,0,0,0,0

(c) File structure

Or, different entities can be assigned different numbers



(a) Entity model

1	1	1	2	2	2	2	2	2	2
1	1	1	2	2	2	2	2	2	2
1	1	1	2	2	2	2	2	2	2
1	1	1	1	2	2	2	2	2	2
1	1	1	1	1	2	2	2	3	3
1	1	1	1	1	2	2	2	3	3
1	1	1	1	1	2	2	3	3	3
1	1	1	1	1	3	3	3	3	3
1	1	1	1	1	3	3	3	3	3
1	1	1	1	1	3	3	3	3	3

(b) Cell values

10,10,3
1,1,1,2,2,2,2,2,2,2
1,1,1,2,2,2,2,2,2,2
1,1,1,2,2,2,2,2,2,2
1,1,1,1,2,2,2,2,2,2
1,1,1,1,1,2,2,2,3,3
1,1,1,1,1,2,2,2,3,3
1,1,1,1,1,2,2,3,3,3
1,1,1,1,1,3,3,3,3,3
1,1,1,1,1,3,3,3,3,3
1,1,1,1,1,3,3,3,3,3

(c) File structure

Spatial Data Modeling – Making a Model

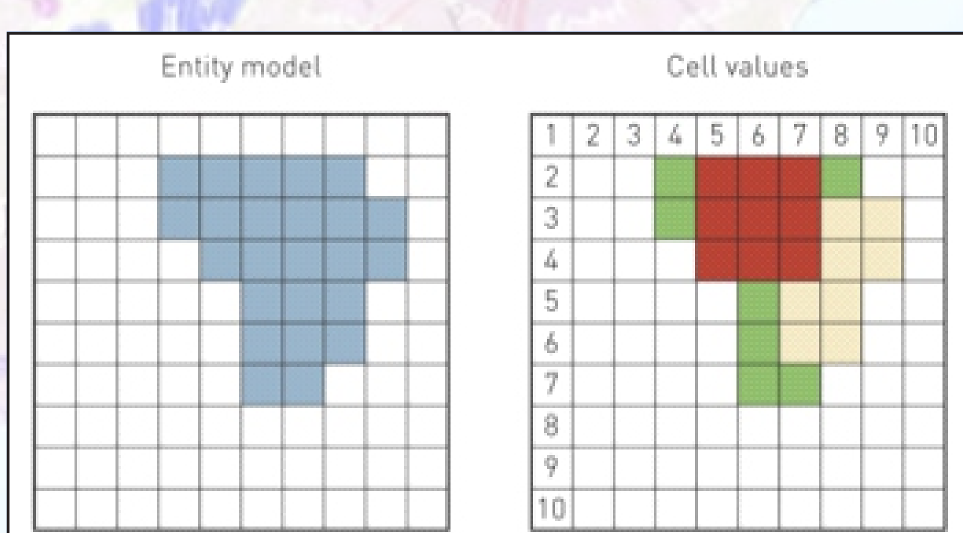
Step 3 – Spatial Data Structures: *Storing Rasters*

Raster Compaction:

How do we reduce the size of our map without reducing the resolution?

Block Encoding

– uses a series of square blocks to store data. Need to store block size, number of blocks and coordinates



File structure

Block size	No.	Cell co-ordinates
1	7	4,2 8,2 4,3 6,5 6,6 6,7 7,7
4	2	8,3 7,5
9	1	5,2

Spatial Data Modeling – Making a Model

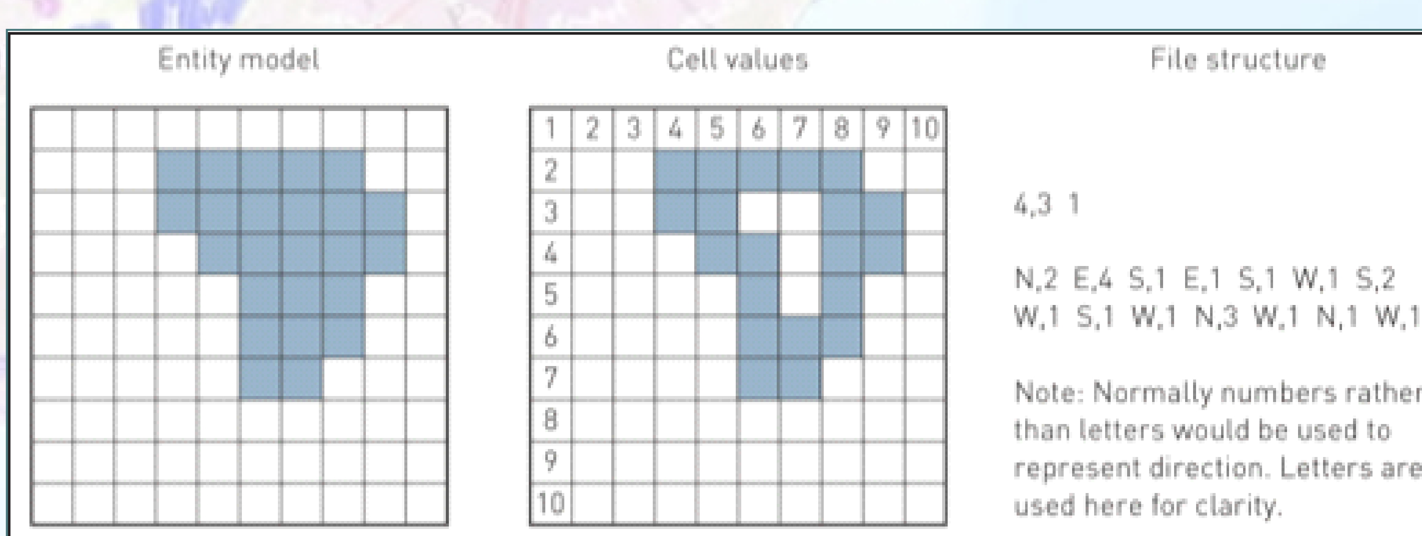
Step 3 – Spatial Data Structures: *Storing Rasters*

Raster Compaction:

How do we reduce the size of our map without reducing the resolution?

Chain Encoding

– defines the boundary of the entity, using a sequence of cells to start and return to the origin



Spatial Data Modeling – Making a Model

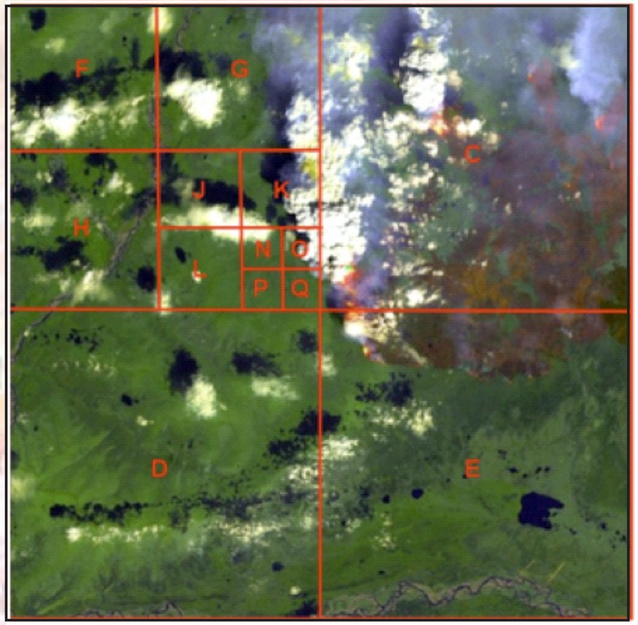
Step 3 – Spatial Data Structures: *Storing Rasters*

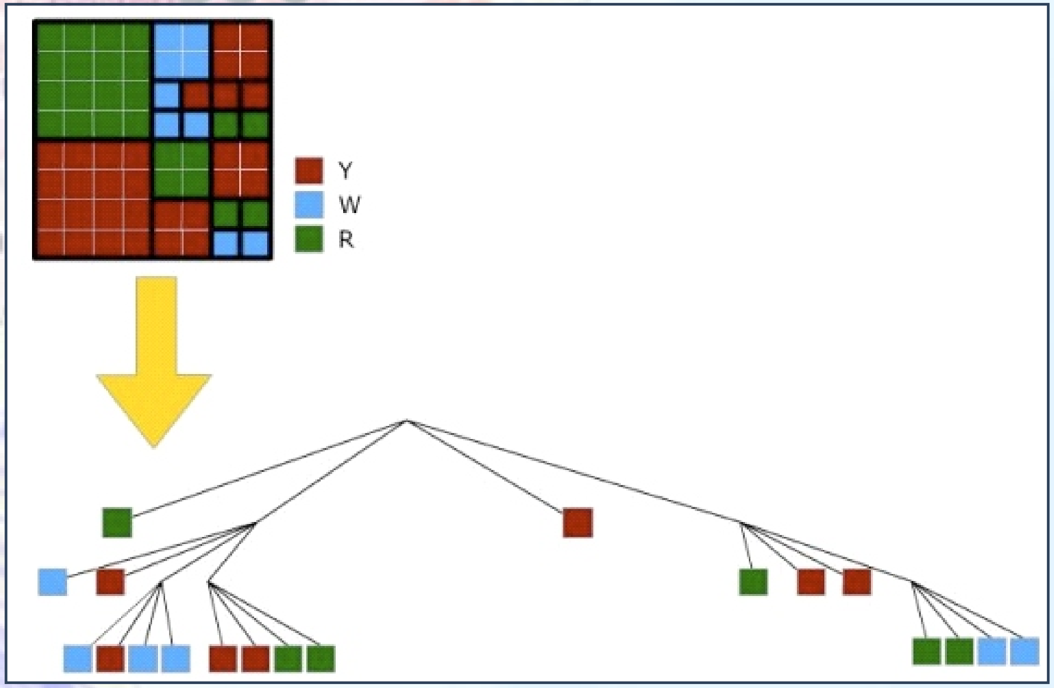
Raster Compaction:

How do we reduce the size of our map without reducing the resolution?

Quadtree

– recursively subdivides the cells in an image into quads (or quarters), subdivision continues until a spatial entity is either present or absent in the quad

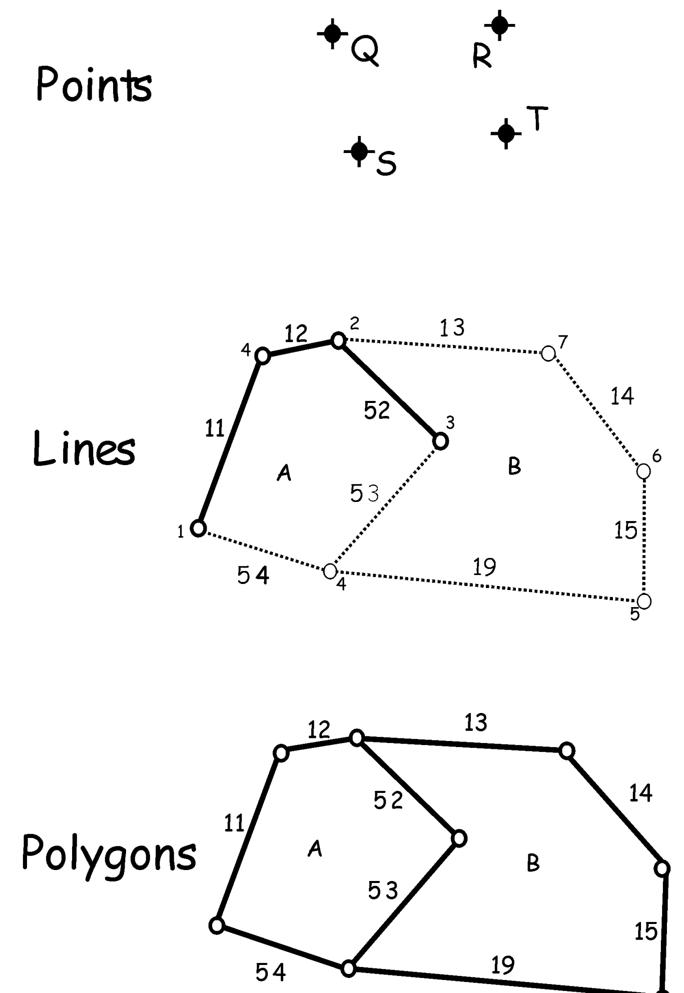




Spatial Data Modeling – Making a Model

Step 3 – Spatial Data Structures: *Vectors*

- Tables are used to organize the attributes with links between rows in the table and the spatial data in the topological data layer.



Point ID	X	Y
Q	32.7	45.6
R	76.3	19.5
S	22.7	15.8
etc...		

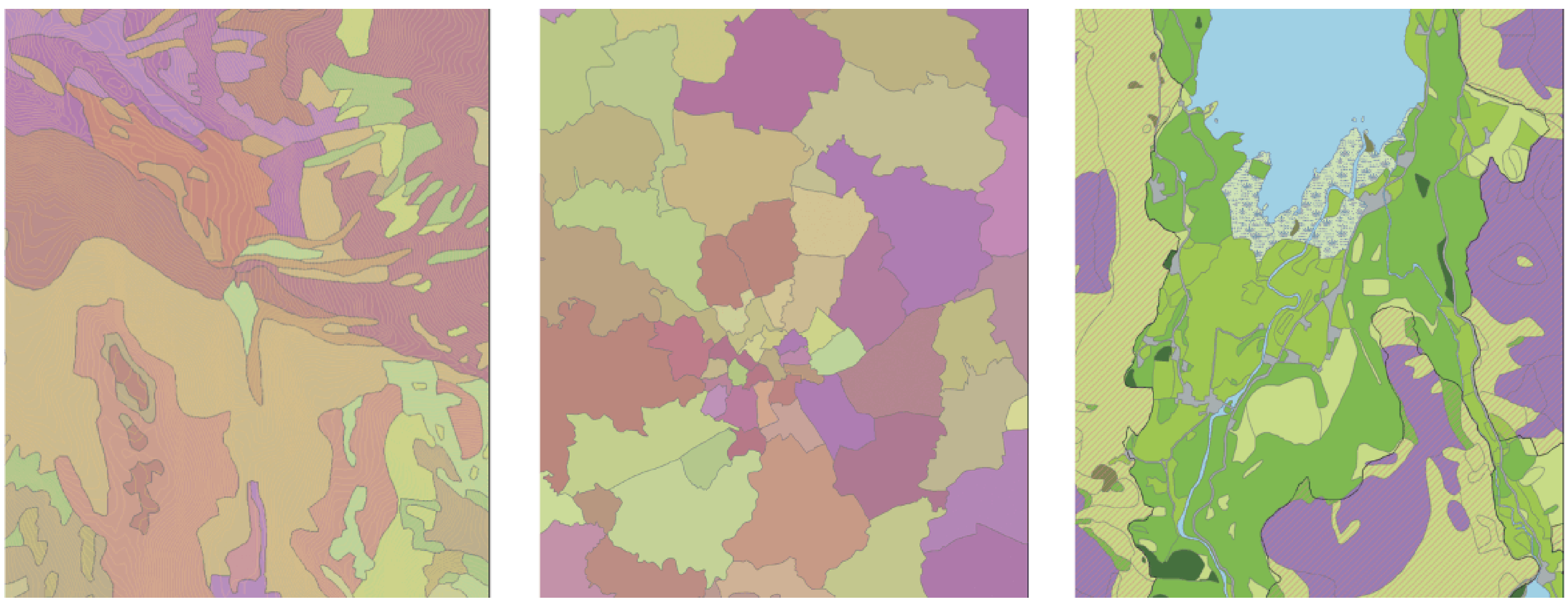
Line ID	Begin node	End node	Left poly	Right poly
11	1	4	...	A
12	4	2	...	A
52	2	3	B	A
etc ..				

Polygon ID	Lines
A	11,12,52,53,54
B	52,53,19, 15,14,13

Spatial Data Modeling – Making a Model

Step 3 – Spatial Data Structures: *Vectors*

- Possible limitations:
  - Boundary is represented by a line that has no width even if one area may grade into another
  - 3D objects are represented by points and lines that have no area.

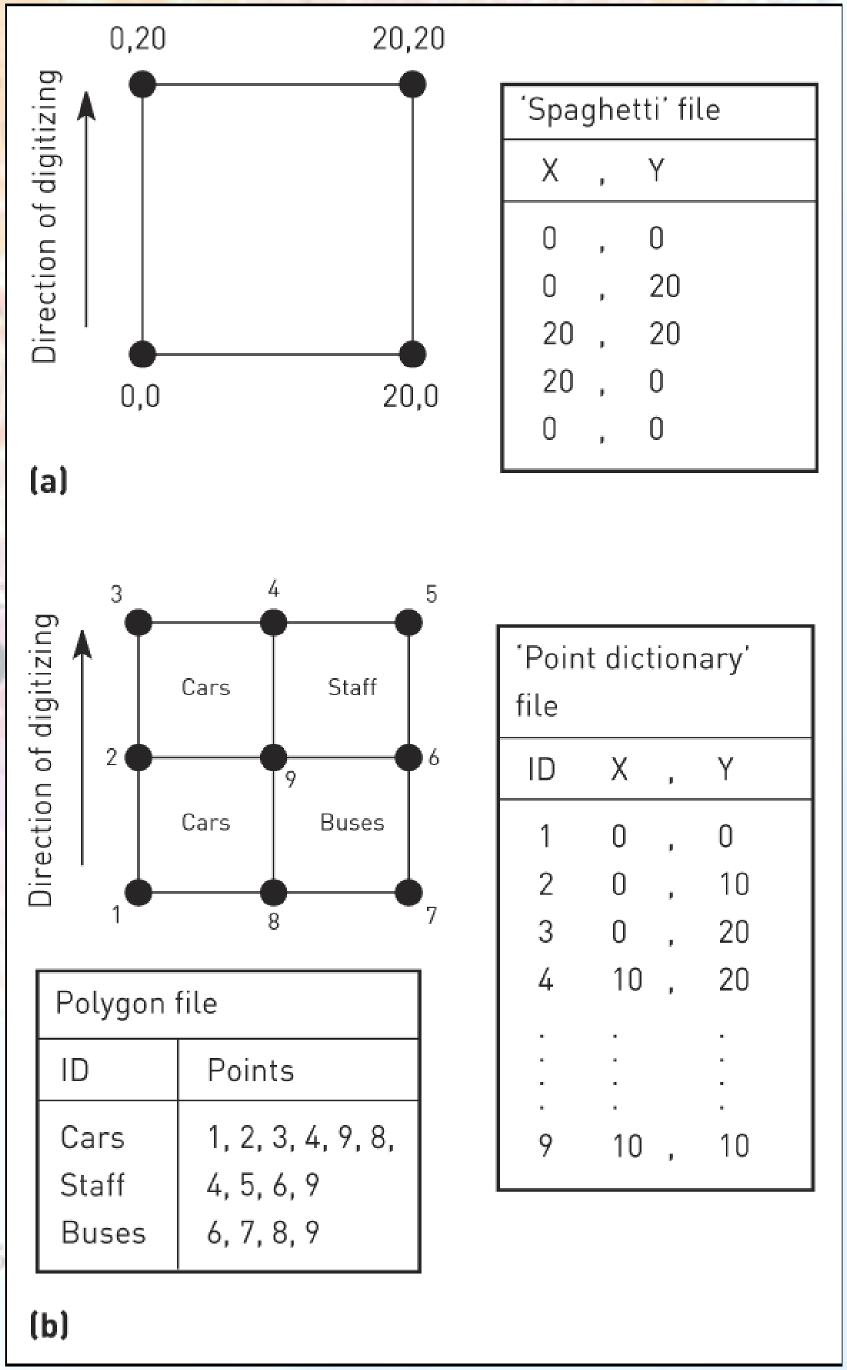


(f) (g) (h)

Spatial Data Modeling – Making a Model

Step 3 – Spatial Data Structures: *Storing Vectors*

- **Simplest/Spaghetti File:**
  - Coordinate pairs define point features that can be used to construct lines and polygons.
  - Results in duplicate borders - wasted space!
  - No linkage between points/lines (can't use for networks).
- **Point Dictionary:**
  - Adjacent polygons share common coordinate pairs.
  - Sequential numbering of data structure is required.



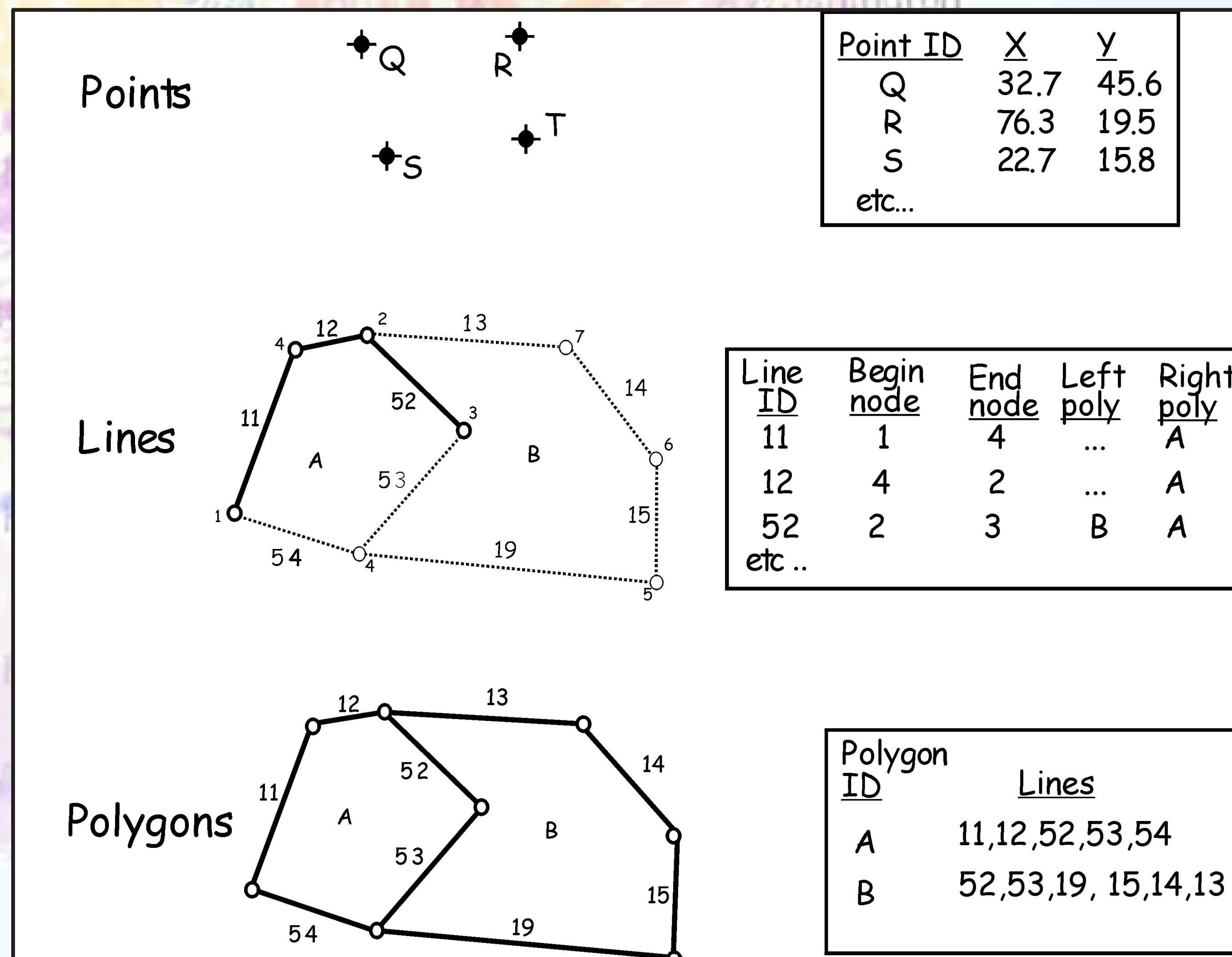
Spatial Data Modeling – Making a Model

Step 3 – Spatial Data Structures: *Topology*

- What is topolgy?
  - Describes the geometric characteristics of objects which do not change when transformed.

- Topological characteristics are independent of co-ordinate system or scale of measurement

- Consists of 3 elements:
  - adjacency
  - connectivity
  - containment



Point ID	X	Y
Q	32.7	45.6
R	76.3	19.5
S	22.7	15.8
etc...		

Line ID	Begin node	End node	Left poly	Right poly
11	1	4	...	A
12	4	2	...	A
52	2	3	B	A
etc ..				

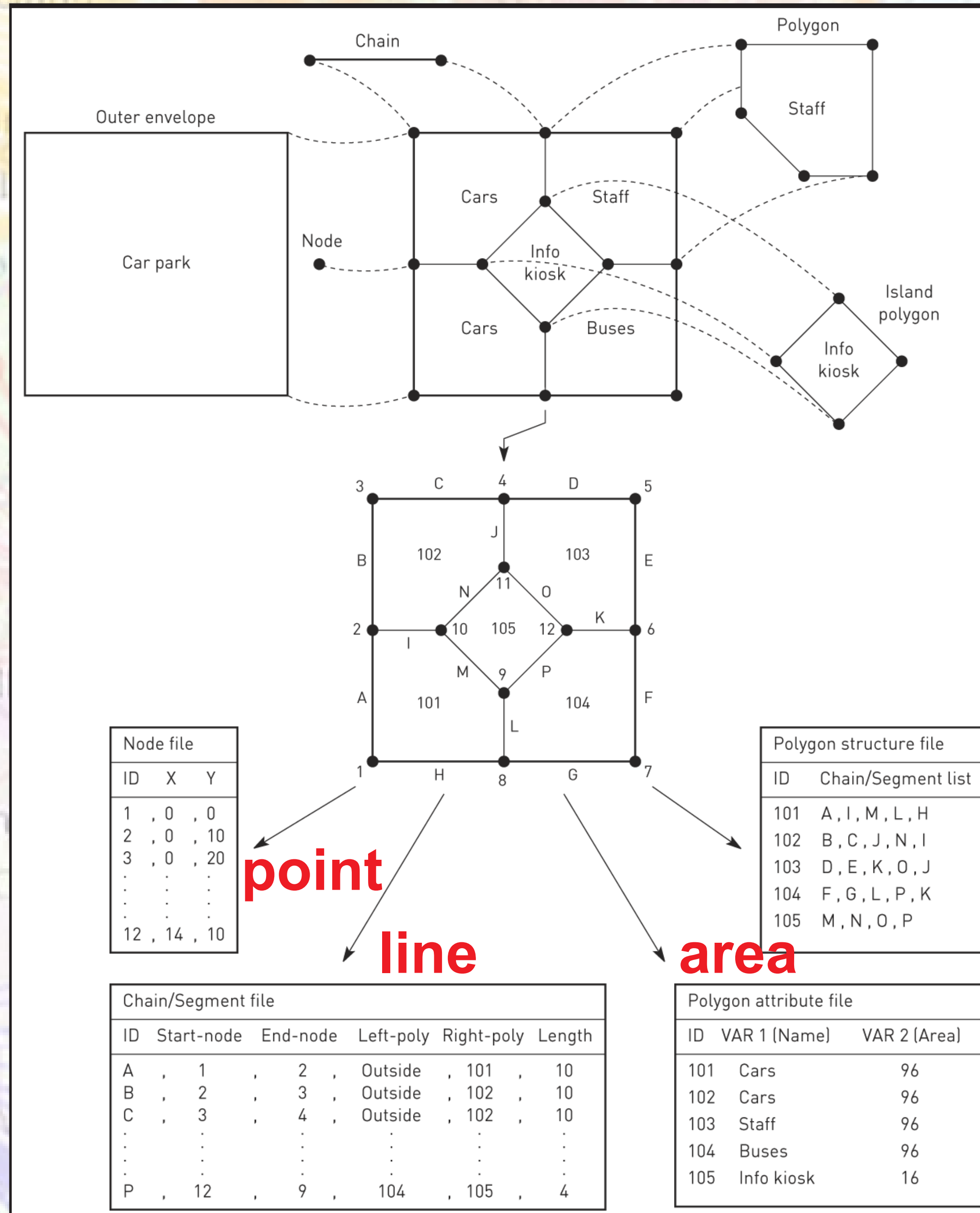
Polygon ID	Lines
A	11,12,52,53,54
B	52,53,19, 15,14,13

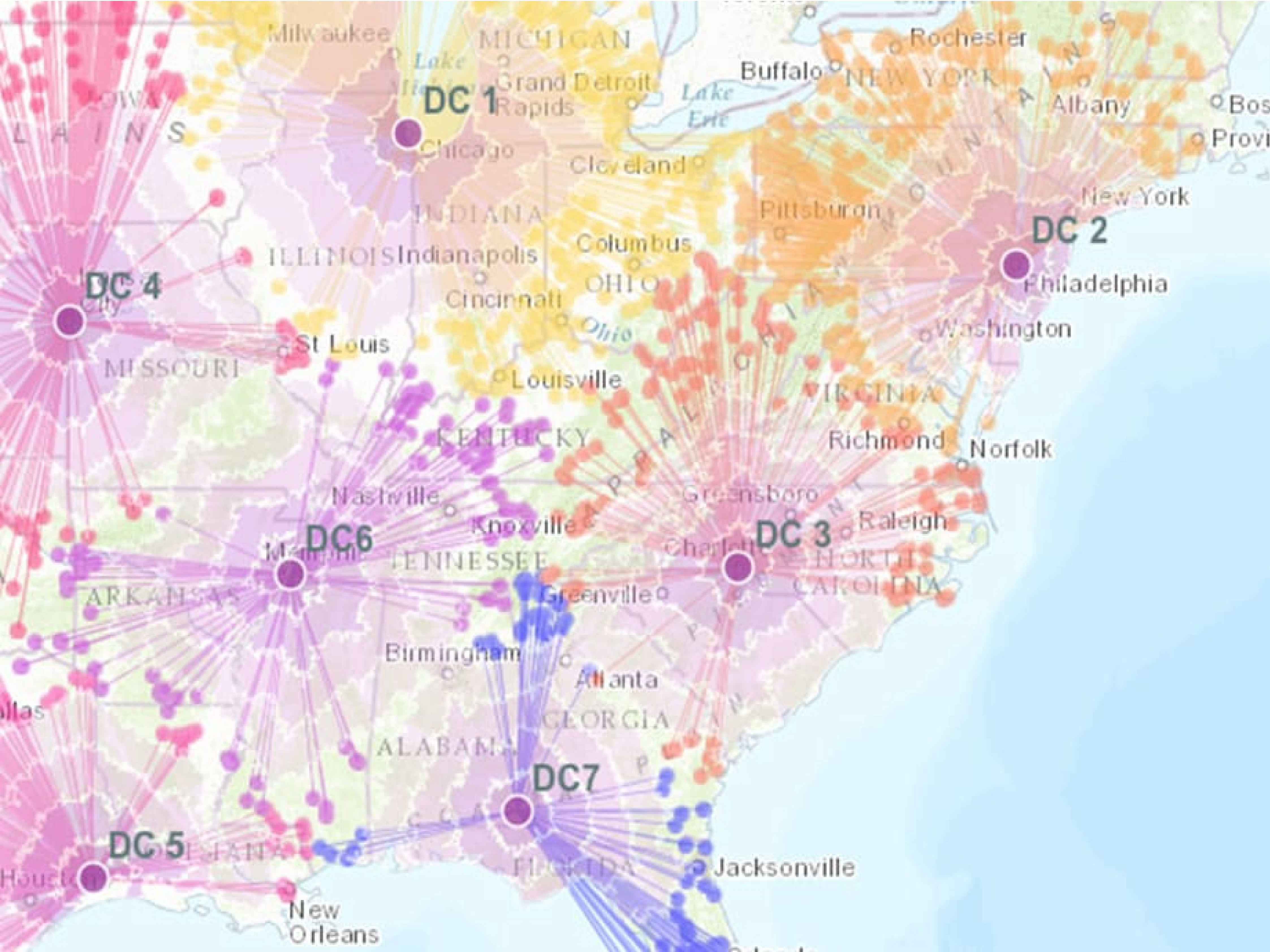
Spatial Data Modeling – Making a Model

Step 3 – Spatial Data Structures: *Topology*

All topological data structures should guarantee that:

1. Line segments and nodes can be referenced to more than one polygon.
2. All polygons have unique identifiers.
3. Island and hole polygons can be adequately represented.




DC 1
DC 2
DC 3
DC 4
DC 5
DC6
DC7
Milwaukee
MICHIGAN
Grand Rapids
Detroit
Chicago
Rochester
Buffalo
NEW YORK
Albany
Cleveland
Pittsburgh
New York
Philadelphia
INDIANA
ILLINOIS
Indianapolis
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Louisville
KENTUCKY
VIRGINIA
Richmond
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