# Lecture 14

## Map Structures and Attributes: Vectors and Rasters

GEOG 489

SPRING 2020

# Quiz 5

**Write a function to remove "NA" from a string**
**For example:**
**Input: x <- "Programming NA GIS NA"**
**Output: y <- "Programming  GIS "**

```
RMNA <- function(x){
  y = gsub("NA", "", x)
  return(y)
}

RMNA <- function(x){
  y = paste(unlist(strsplit(x, "NA")), collapse = '')
  return(y)
}

x <- "Programming NA GIS NA"
RMNA(x)
```

# Assignment 3

Your goal is to write a function that calculates a set of descriptive statistics for a data frame, and return the output in a list format.

**Input:** x=data frame, probs=quantile probabilities, na.rm (logical)

**Output:** list, one list component per column, named after the data frame columns
Sublist components (the components should be named "mean","median","sd", and "quantiles"):

    #   mean: the column's mean
    #   median: the column's median
    # sd: the column's standard deviation
    # quantiles: a matrix of probs vs. the quantile of x for those probs.
    # The matrix should have one prob/quantile per row.
    # The first column should be named "prob" and the second "quantile".

Assignment 3 will be due by the end of today (March 10)

# Basic Definitions: GIS

**Geographic Information System (GIS):**

1. A database.
2. **Spatial information.**
3. A way of linking the database and spatial information and using these links.

# Data Models

GIS uses two basic data models:

- **Vector**
- **Raster**

LEARN THE DIFFERENCE BETWEEN **VECTOR** AND **RASTER**.

# Features and Maps

A GIS map is a scaled-down digital representation of point, line, area, and volume features.

Most GIS can handle raster AND vector.

However, only one at a time can be used for the internal organization of spatial data.

Different display and analysis functions favor one or the other model; i.e. “vector functions” vs. “raster functions”.

# Basic Definitions: GIS

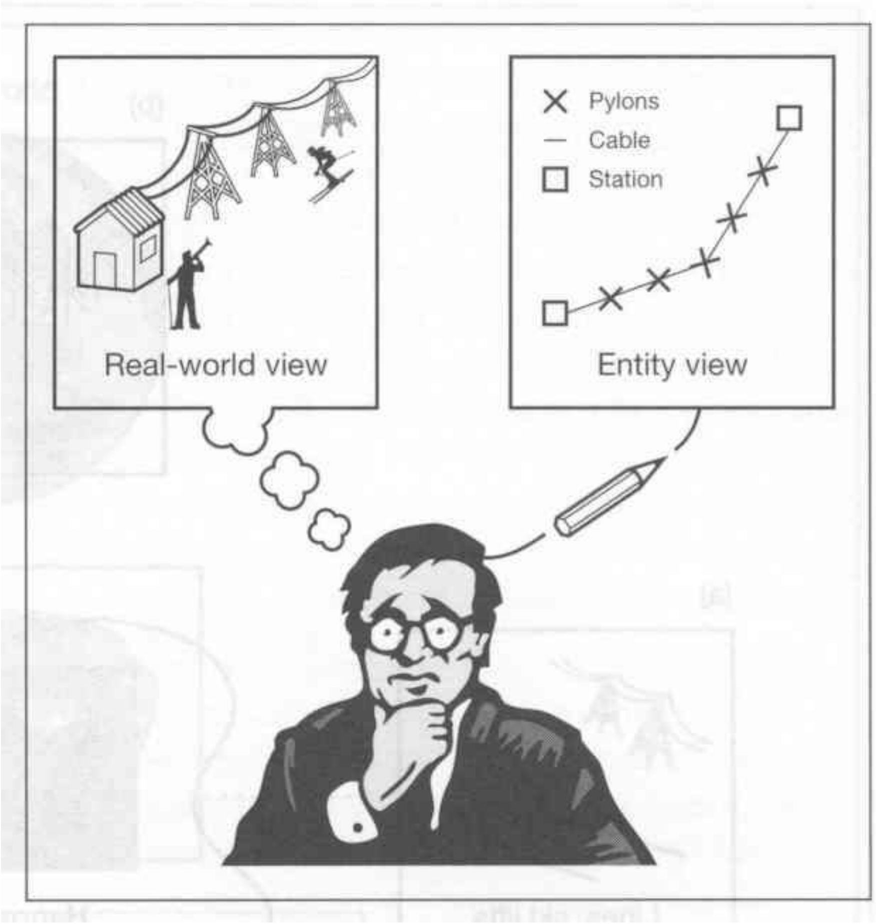
**Geographic Information System (GIS):**

1. A database.
2. Spatial information (**vector** or **raster** data model).
3. A way of linking the database and spatial information and using these links.

# Vector

Definition: “A map data structure using the point or node and the connecting segment as the basic building block for representing geographical features.”

# Vector Data Model




- Entities: spatial information is described by coordinates.

- Attributes: descriptions of each of the features.

# Vector Data Model

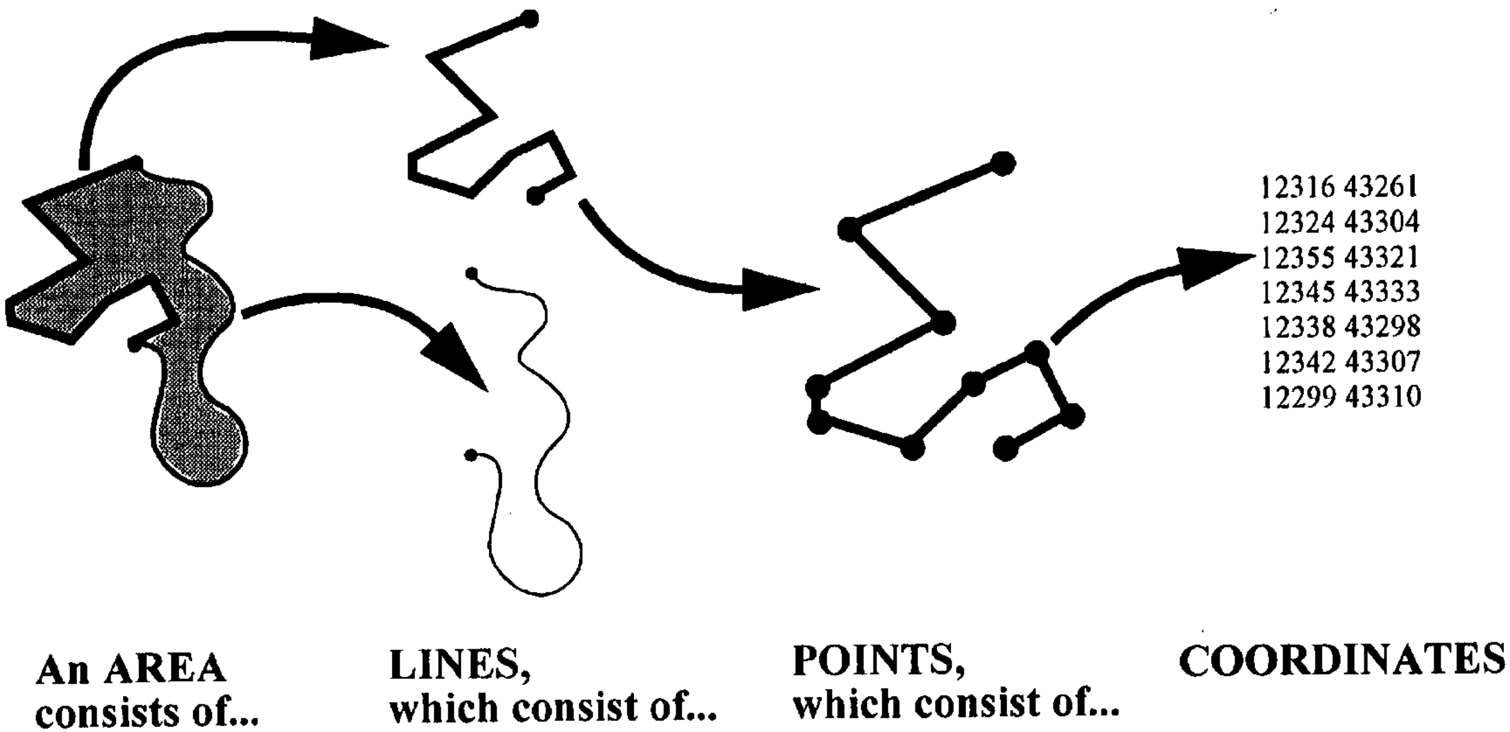
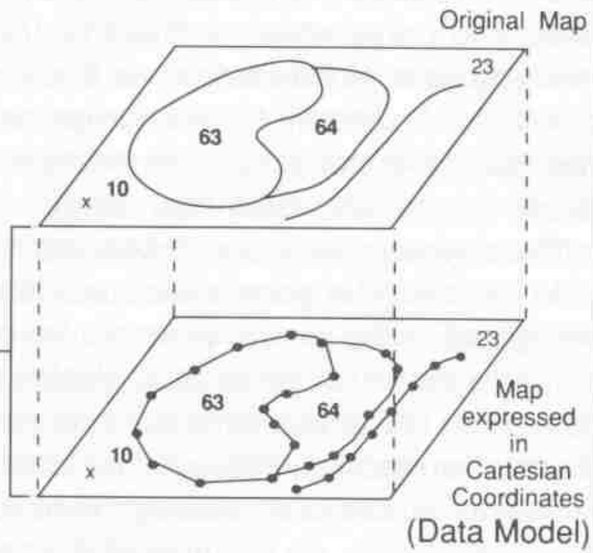



**Figure 2.16** Geographic information has *dimension.* Areas are two-dimensional and consist of lines, which are one-dimensional and consist of points, which are zero- dimensional and consist of a coordinate pair.

# graphic Spaghetti

THE "SPAGHETTI" DATA MODEL




**Data Structure**

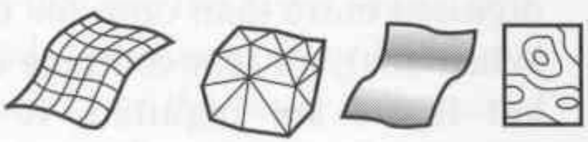
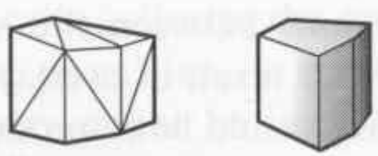
| FEATURE | NUMBER | LOCATION |
|---|---|---|
| Point | 10 | X Y (Single Point) |
| Line | 23 | $X_1 Y_1, X_2 Y_2 \ldots\ldots X_n Y_n$ (String) |
| Polygon | 63 | $X_1 Y_1, X_2 Y_2 \ldots\ldots X_1 Y_1$ (Closed Loop) |
| | 64 | $X_1 Y_1, X_2 Y_2 \ldots\ldots X_1 Y_1$ (Closed Loop) |

**Points** represented by an ID and a single coordinate

**Lines** represented by an ID and a set of ordered coordinates

**Polygons** represented by an ID and a set of ordered coordinates, and the last coordinate is the same as the first coordinate.

# Vector Data Model

| Type | Examples of Graphic Representation | Digital Representation |
|---|---|---|
| Point |  | Coordinates:<br>(x,y) in 2D; (x,y,z) in 3D |
| Line |  | (i) Ordered list of coordinates (chain)<br>(ii) Mathematical function |
| Area |  | (i) Line in which the first point equals the last<br>(ii) Set of lines if an area has holes |
| Surface |  | (i) Matrix of points<br>(ii) Triangulated set of points (TIN)<br>(iii) Mathematical functions<br>(iv) Contour lines |
| Volume |  | Set of surfaces |

# Basic Definitions: GIS

**Geographic Information System (GIS):**

1. **A database (attribute data).**
2. Spatial information (vector or raster data model).
3. A way of linking the database and spatial information and using these links.

# Attribute Data

Definition: a characteristic of a feature that contains a measurement or value for the feature.

Can be labels, categories, numbers, dates, etc.

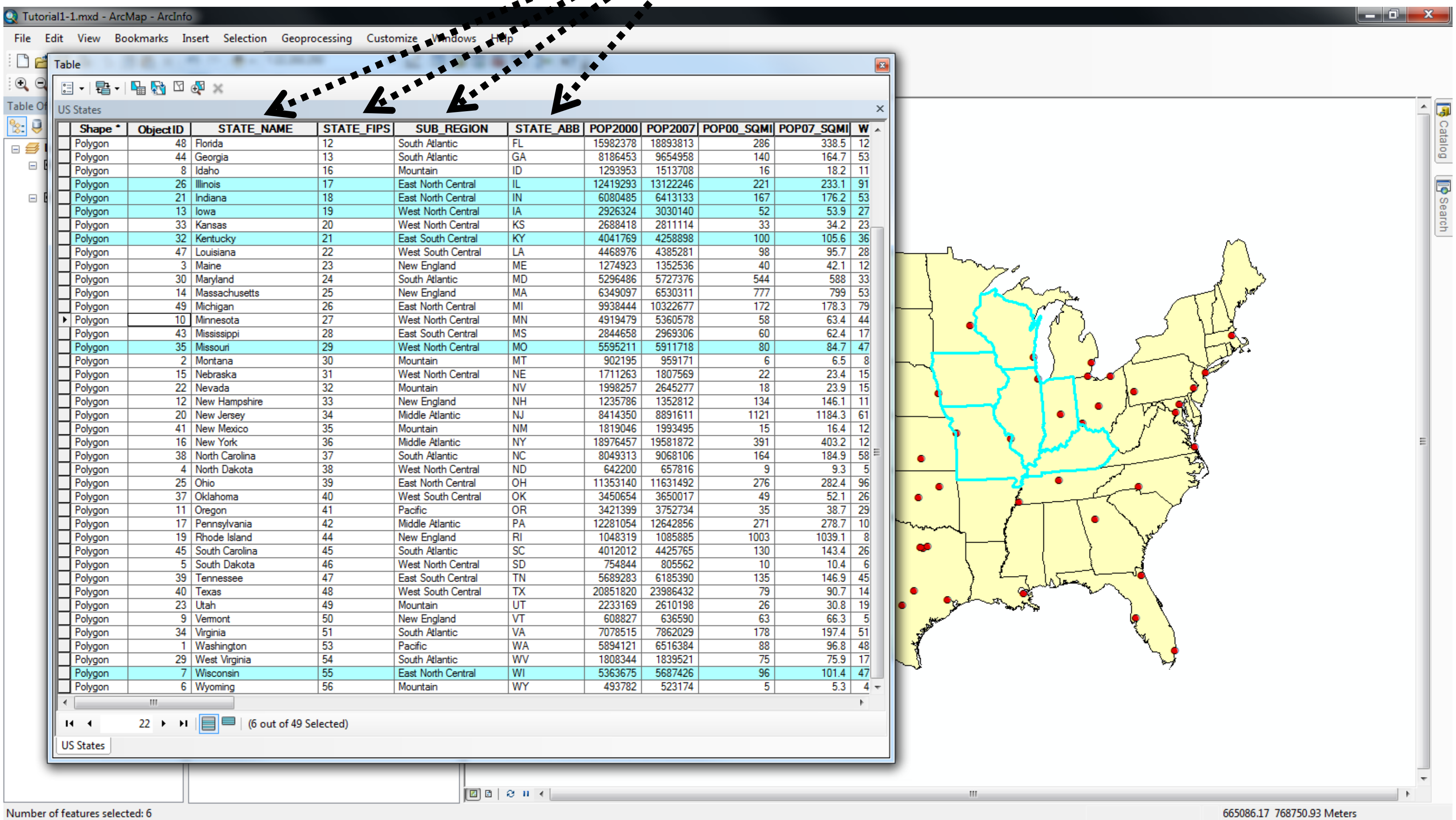
“Spreadsheet” definition: a column in a table.

The **NON-SPATIAL** part of a GIS feature.

Some (almost) synonyms you will hear:

- Spreadsheet
- Table
- Flat file
- Matrix

# Attribute Data




| Shape * | ObjectID | STATE_NAME | STATE_FIPS | SUB_REGION | STATE_ABB | POP2000 | POP2007 | POP00_SQMI | POP07_SQMI | W |
|---|---|---|---|---|---|---|---|---|---|---|
| Polygon | 48 | Florida | 12 | South Atlantic | FL | 15982378 | 18893813 | 286 | 338.5 | 12 |
| Polygon | 44 | Georgia | 13 | South Atlantic | GA | 8186453 | 9654958 | 140 | 164.7 | 53 |
| Polygon | 8 | Idaho | 16 | Mountain | ID | 1293953 | 1513708 | 16 | 18.2 | 11 |
| Polygon | 26 | Illinois | 17 | East North Central | IL | 12419293 | 13122246 | 221 | 233.1 | 91 |
| Polygon | 21 | Indiana | 18 | East North Central | IN | 6080485 | 6413133 | 167 | 176.2 | 53 |
| Polygon | 13 | Iowa | 19 | West North Central | IA | 2926324 | 3030140 | 52 | 53.9 | 27 |
| Polygon | 33 | Kansas | 20 | West North Central | KS | 2688418 | 2811114 | 33 | 34.2 | 23 |
| Polygon | 32 | Kentucky | 21 | East South Central | KY | 4041769 | 4258898 | 100 | 105.6 | 36 |
| Polygon | 47 | Louisiana | 22 | West South Central | LA | 4468976 | 4385281 | 98 | 95.7 | 28 |
| Polygon | 3 | Maine | 23 | New England | ME | 1274923 | 1352536 | 40 | 42.1 | 12 |
| Polygon | 30 | Maryland | 24 | South Atlantic | MD | 5296486 | 5727376 | 544 | 588 | 33 |
| Polygon | 14 | Massachusetts | 25 | New England | MA | 6349097 | 6530311 | 777 | 799 | 53 |
| Polygon | 49 | Michigan | 26 | East North Central | MI | 9938444 | 10322677 | 172 | 178.3 | 79 |
| Polygon | 10 | Minnesota | 27 | West North Central | MN | 4919479 | 5360578 | 58 | 63.4 | 44 |
| Polygon | 43 | Mississippi | 28 | East South Central | MS | 2844658 | 2969306 | 60 | 62.4 | 17 |
| Polygon | 35 | Missouri | 29 | West North Central | MO | 5595211 | 5911718 | 80 | 84.7 | 47 |
| Polygon | 2 | Montana | 30 | Mountain | MT | 902195 | 959171 | 6 | 6.5 | 8 |
| Polygon | 15 | Nebraska | 31 | West North Central | NE | 1711263 | 1807569 | 22 | 23.4 | 15 |
| Polygon | 22 | Nevada | 32 | Mountain | NV | 1998257 | 2645277 | 18 | 23.9 | 15 |
| Polygon | 12 | New Hampshire | 33 | New England | NH | 1235786 | 1352812 | 134 | 146.1 | 11 |
| Polygon | 20 | New Jersey | 34 | Middle Atlantic | NJ | 8414350 | 8891611 | 1121 | 1184.3 | 61 |
| Polygon | 41 | New Mexico | 35 | Mountain | NM | 1819046 | 1993495 | 15 | 16.4 | 12 |
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| Polygon | 4 | North Dakota | 38 | West North Central | ND | 642200 | 657816 | 9 | 9.3 | 5 |
| Polygon | 25 | Ohio | 39 | East North Central | OH | 11353140 | 11631492 | 276 | 282.4 | 96 |
| Polygon | 37 | Oklahoma | 40 | West South Central | OK | 3450654 | 3650017 | 49 | 52.1 | 26 |
| Polygon | 11 | Oregon | 41 | Pacific | OR | 3421399 | 3752734 | 35 | 38.7 | 29 |
| Polygon | 17 | Pennsylvania | 42 | Middle Atlantic | PA | 12281054 | 12642856 | 271 | 278.7 | 10 |
| Polygon | 19 | Rhode Island | 44 | New England | RI | 1048319 | 1085885 | 1003 | 1039.1 | 8 |
| Polygon | 45 | South Carolina | 45 | South Atlantic | SC | 4012012 | 4425765 | 130 | 143.4 | 26 |
| Polygon | 5 | South Dakota | 46 | West North Central | SD | 754844 | 805562 | 10 | 10.4 | 6 |
| Polygon | 39 | Tennessee | 47 | East South Central | TN | 5689283 | 6185390 | 135 | 146.9 | 45 |
| Polygon | 40 | Texas | 48 | West South Central | TX | 20851820 | 23986432 | 79 | 90.7 | 14 |
| Polygon | 23 | Utah | 49 | Mountain | UT | 2233169 | 2610198 | 26 | 30.8 | 19 |
| Polygon | 9 | Vermont | 50 | New England | VT | 608827 | 636590 | 63 | 66.3 | 5 |
| Polygon | 34 | Virginia | 51 | South Atlantic | VA | 7078515 | 7862029 | 178 | 197.4 | 51 |
| Polygon | 1 | Washington | 53 | Pacific | WA | 5894121 | 6516384 | 88 | 96.8 | 48 |
| Polygon | 29 | West Virginia | 54 | South Atlantic | WV | 1808344 | 1839521 | 75 | 75.9 | 17 |
| Polygon | 7 | Wisconsin | 55 | East North Central | WI | 5363675 | 5687426 | 96 | 101.4 | 47 |
| Polygon | 6 | Wyoming | 56 | Mountain | WY | 493782 | 523174 | 5 | 5.3 | 4 |

# Attribute Data Storage

Attribute data is often stored separately from the spatial data.

Simple attribute data is often stored as a table.

Complex attribute data is often stored in a database.

# Basic Definitions: GIS

**Geographic Information System (GIS):**

1. A database (attribute data).
2. Spatial information (vector or raster data model).
3. **A way of linking the database and spatial information** and using these links.

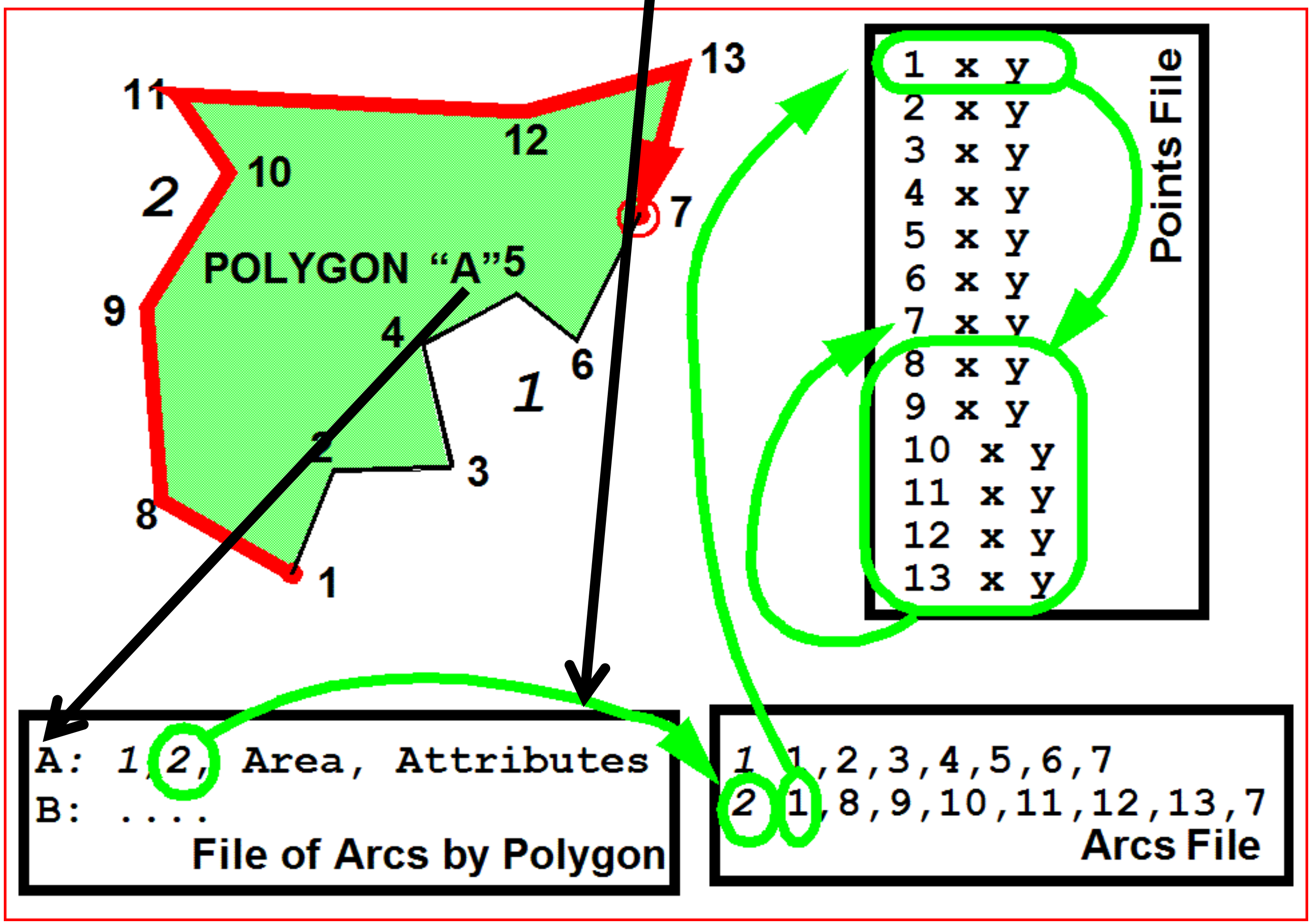
# Linking Attributes to Arc/Node

Recall that each vector type has a “feature ID” (aka “FID”):

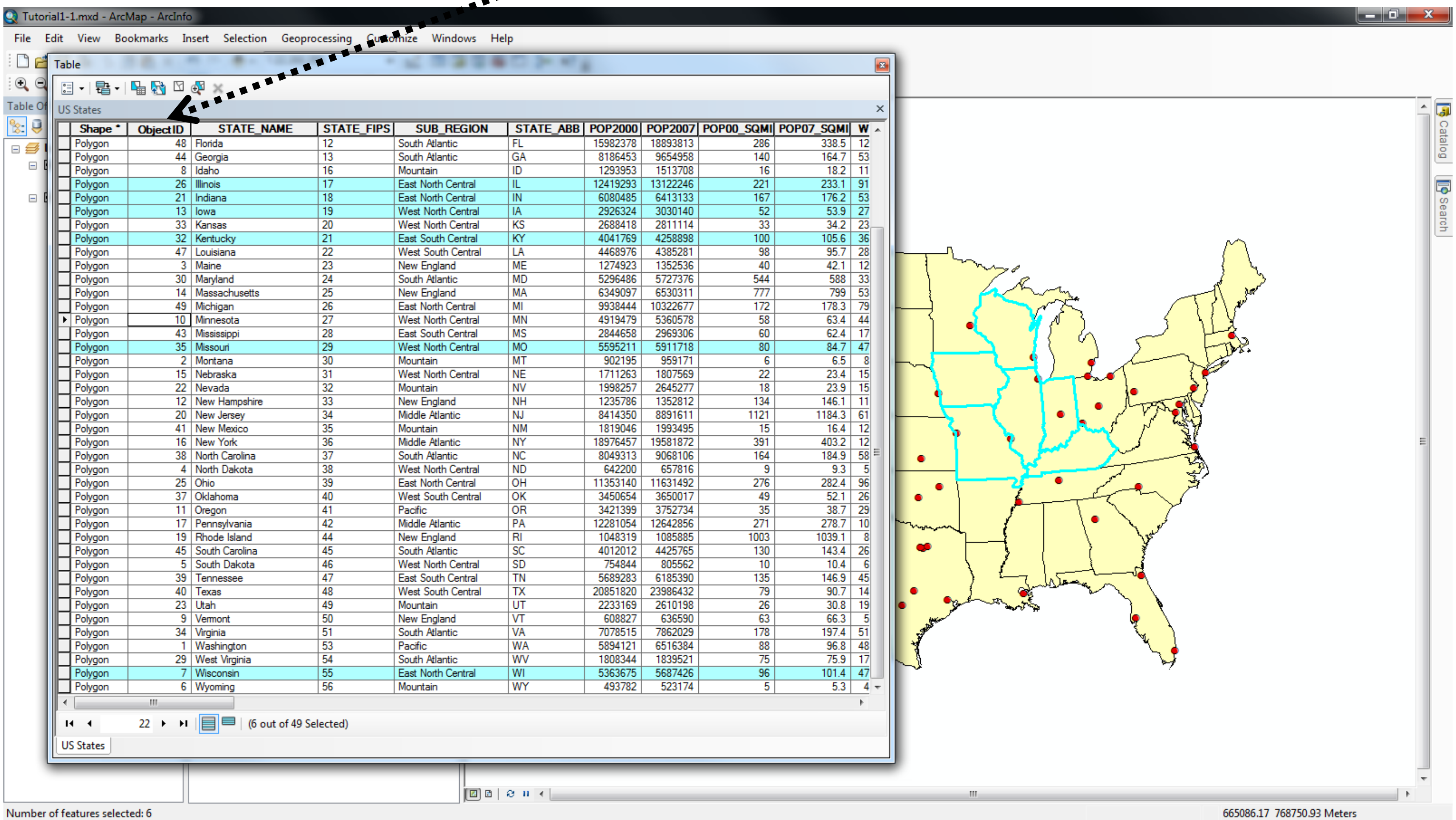
- Point ID
- Line ID
- Polygon ID
- Triangle ID (TINs)

These feature IDs can be used to both link points to arcs to polygons, but also to attribute data via the ObjectID field.

# Linking Attributes to Arc/Node



# Linking Attributes to Arc/Node

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The ObjectID is a unique value for each feature in a layer.

# Rasters…

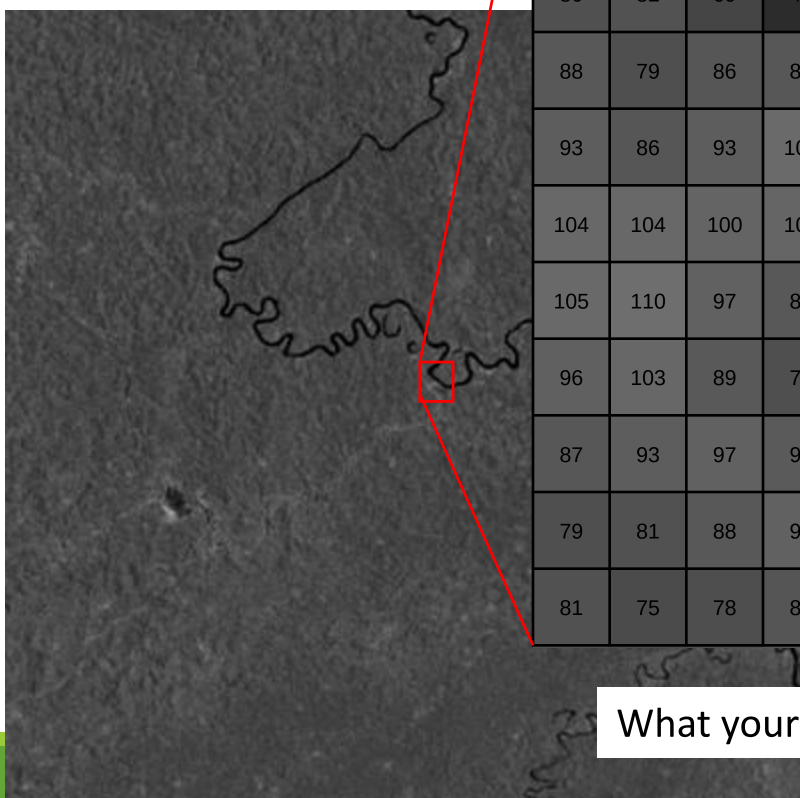
First, some synonyms:

- Rasters
- Grids
- Images
- Matrices
- Arrays
- Digital images or digital photographs

# What Is A Digital Image?

Digital Number (DN)

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 70 | 53 | 41 | 64 | 84 | 85 | 81 | 88 | 91 | 87 |
| 79 | 77 | 45 | 38 | 59 | 77 | 84 | 86 | 85 | 85 |
| 80 | 82 | 69 | 44 | 32 | 45 | 72 | 86 | 82 | 78 |
| 88 | 79 | 86 | 87 | 65 | 40 | 41 | 75 | 79 | 78 |
| 93 | 86 | 93 | 106 | 106 | 84 | 56 | 43 | 58 | 75 |
| 104 | 104 | 100 | 101 | 95 | 91 | 83 | 51 | 39 | 56 |
| 105 | 110 | 97 | 88 | 84 | 85 | 87 | 77 | 59 | 44 |
| 96 | 103 | 89 | 79 | 79 | 75 | 77 | 79 | 74 | 72 |
| 87 | 93 | 97 | 90 | 82 | 76 | 70 | 67 | 61 | 71 |
| 79 | 81 | 88 | 97 | 93 | 85 | 78 | 74 | 70 | 72 |
| 81 | 75 | 78 | 85 | 94 | 97 | 92 | 84 | 80 | 72 |



What your computer sees…

Digital numbers (DNs) typically range from 0 to 255; 0 to 511; 0 to 1023, etc. These ranges are binary scales: $2^8$=256; $2^9$=512; $2^{10}$=1024.

# Rasters (Grids)

Rasters are rectangular (fixed number of columns and rows).

Rasters can have several “bands” (layers) to add a third dimension.

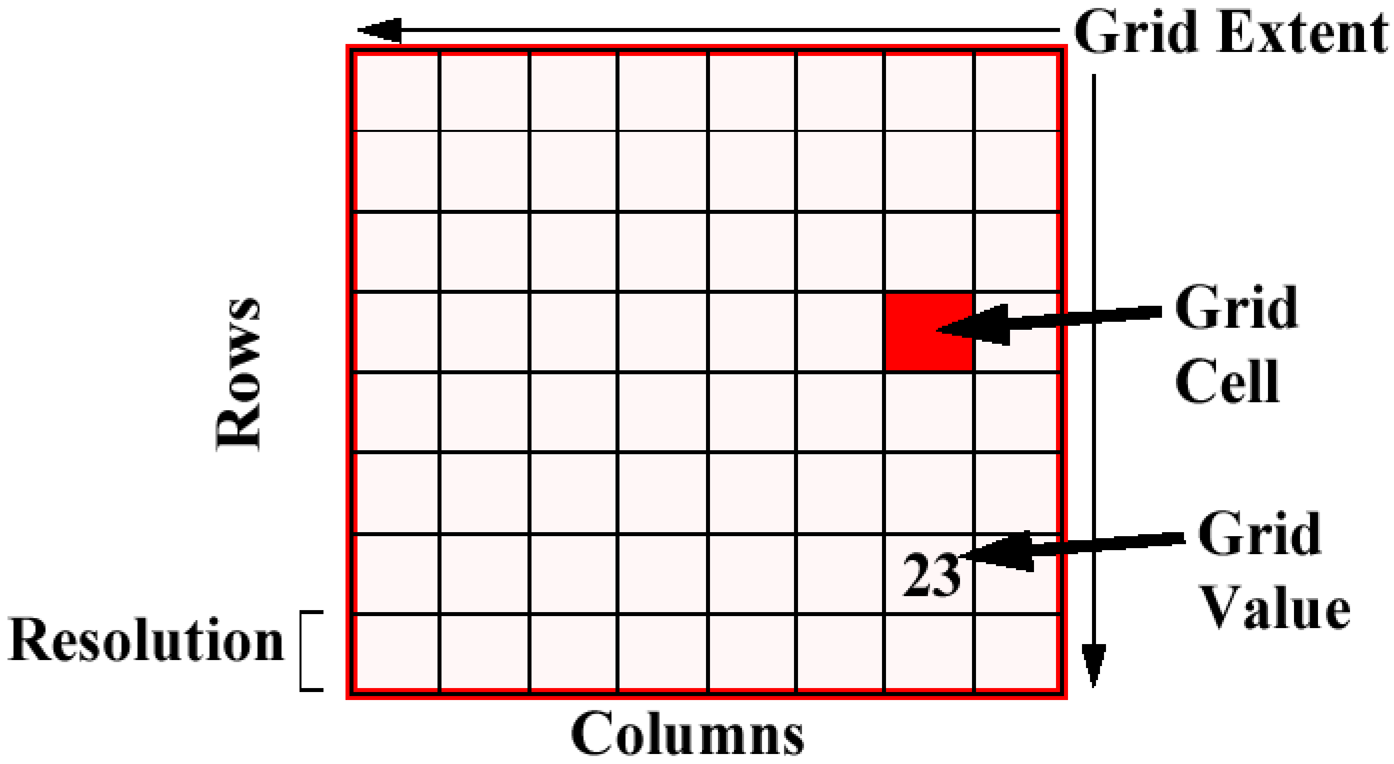
The “building block” of a raster is the **cell** (aka “pixel”).

Each cell (pixel) represents an **area**.

Each cell holds **one** numerical attribute.

Every cell in the raster has a value, even if the value is “missing”.

# Structure of a 2-D Raster (Grid)



# Some Parameters of a Raster

**Number of columns** (ncol) and **number of rows** (nrow)

**Number of cells**= ncol x nrow

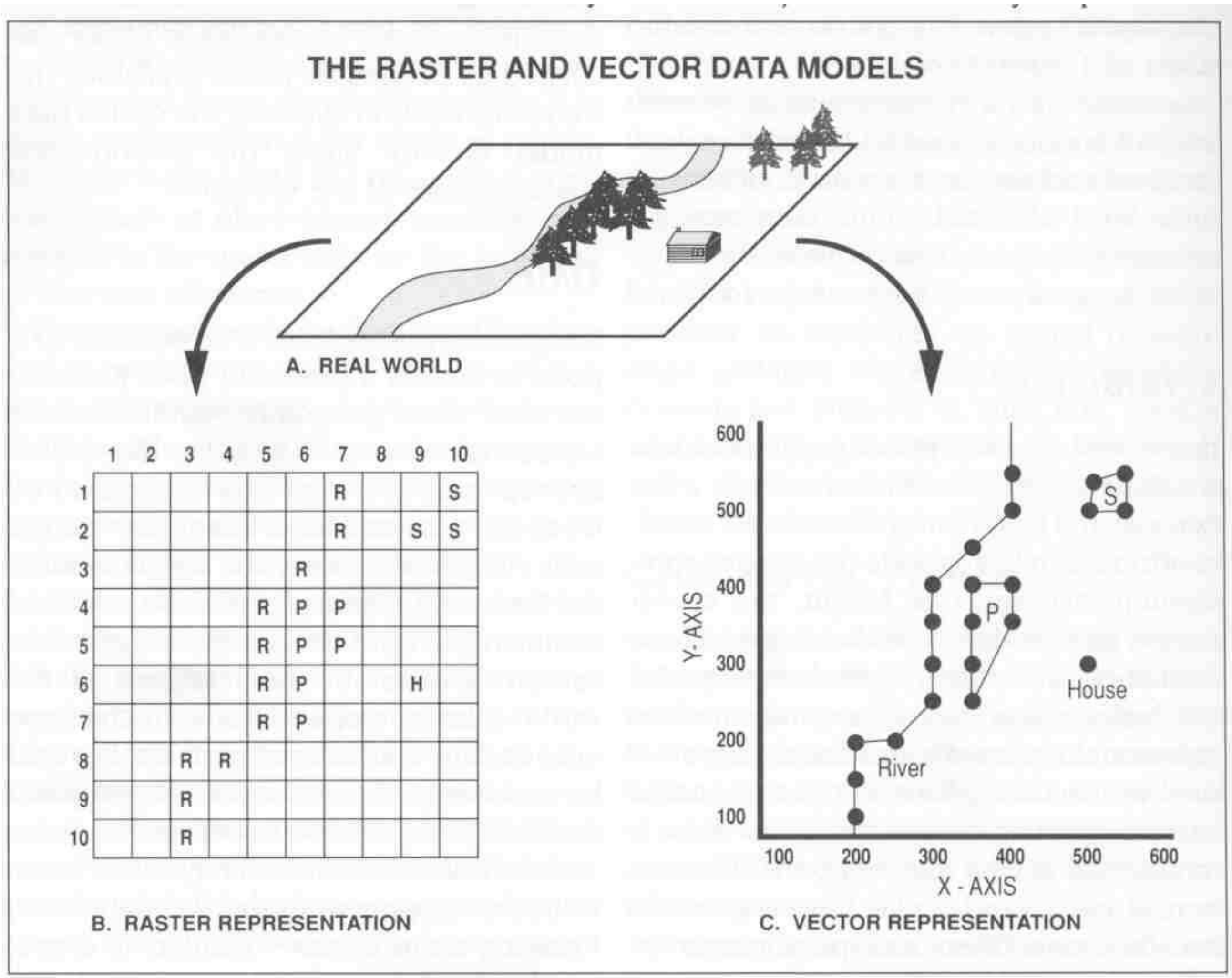
**Cell size** = the **resolution** of the cell.

- Either described in terms of area of the cell (e.g. $m^2$)…
- …or in terms of a length **if the cell is square** (e.g. m)

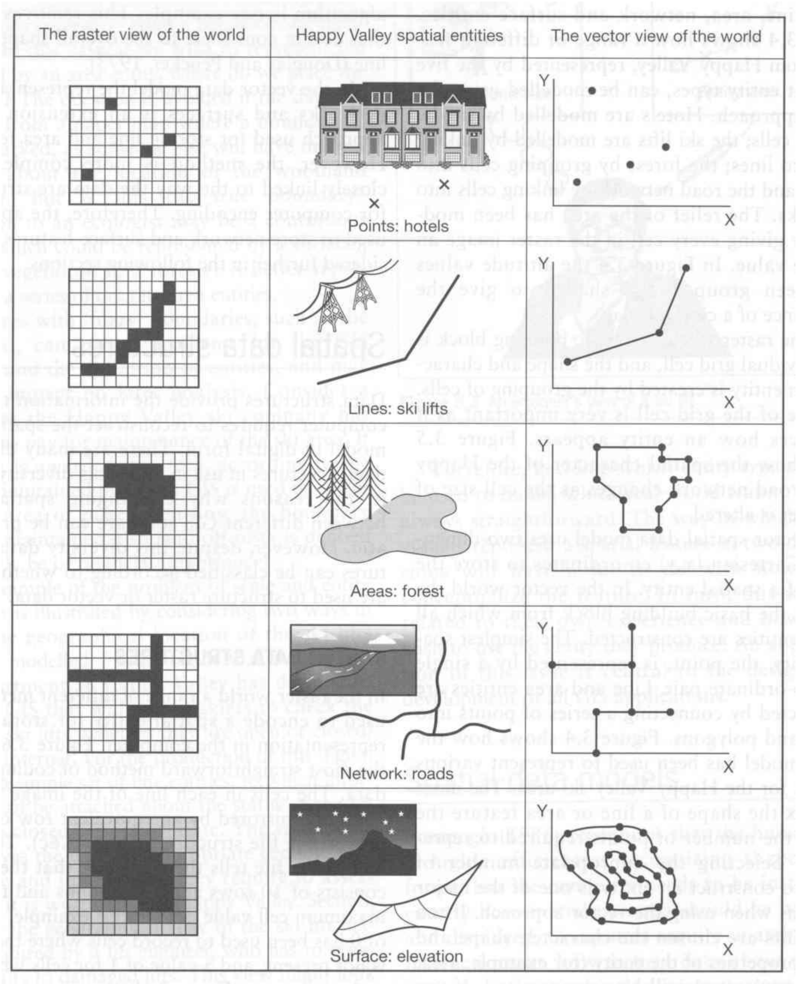
**Extent**:

- Either the total area of the raster (number of cells * cell area)…
- …or the corner coordinates of the raster (the **bounding box**).

# Raster vs. Vector



# Raster vs. Vector




Information must be coerced to a raster grid cell.

Points, lines and areas are not explicitly stored; they are implicit.

# Rasters: the Good and the Bad

**The Good:**

Represent surfaces well.

Localized topology.

Scanned or remotely sensed data is "natively" raster.

Easy to read/write.

Easy to display.

Maps directly onto programming structures (array); many raster operations are easily parallellized.

Can be highly compressed.

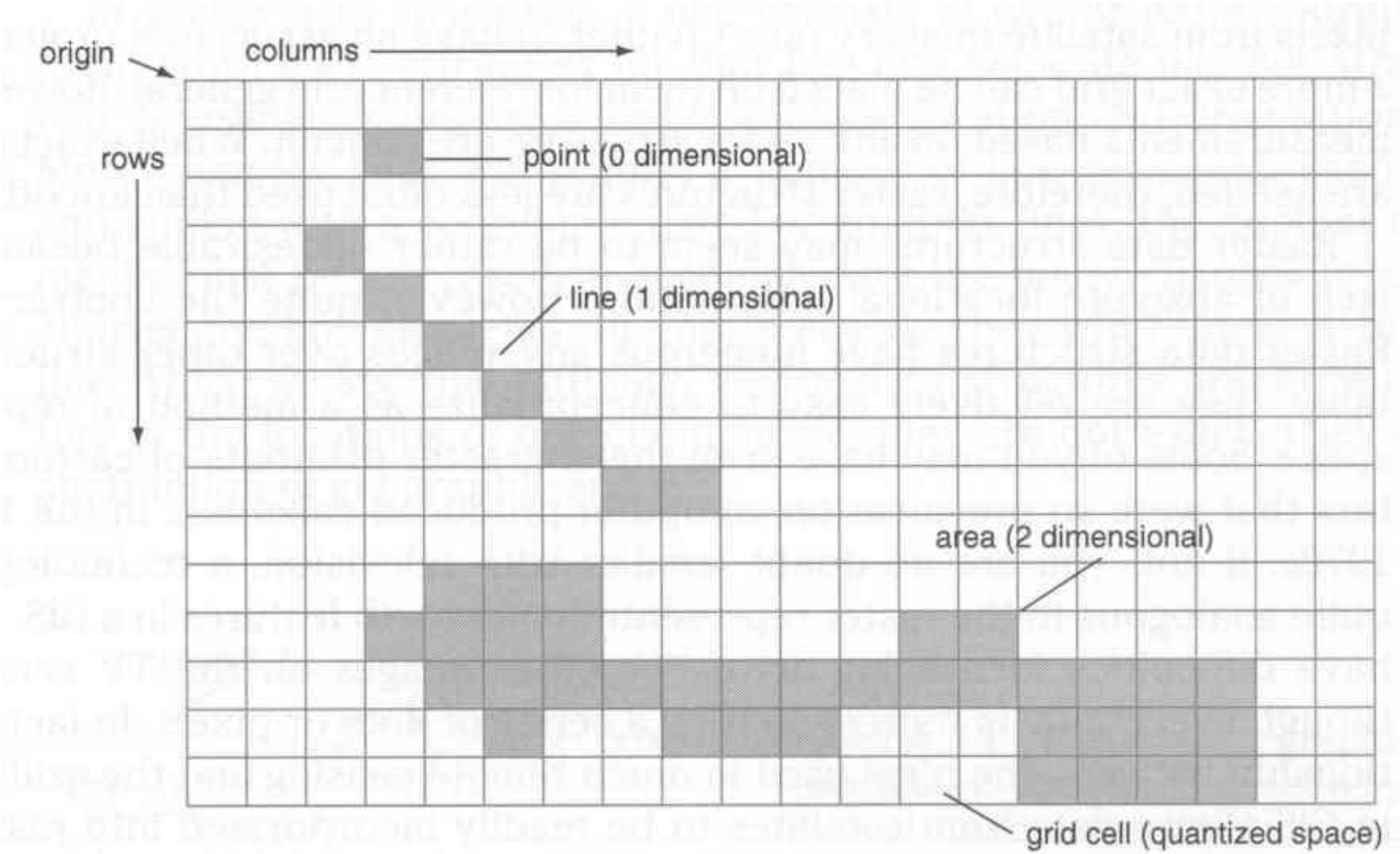
**The Bad:**

Represent points, lines and areas poorly.

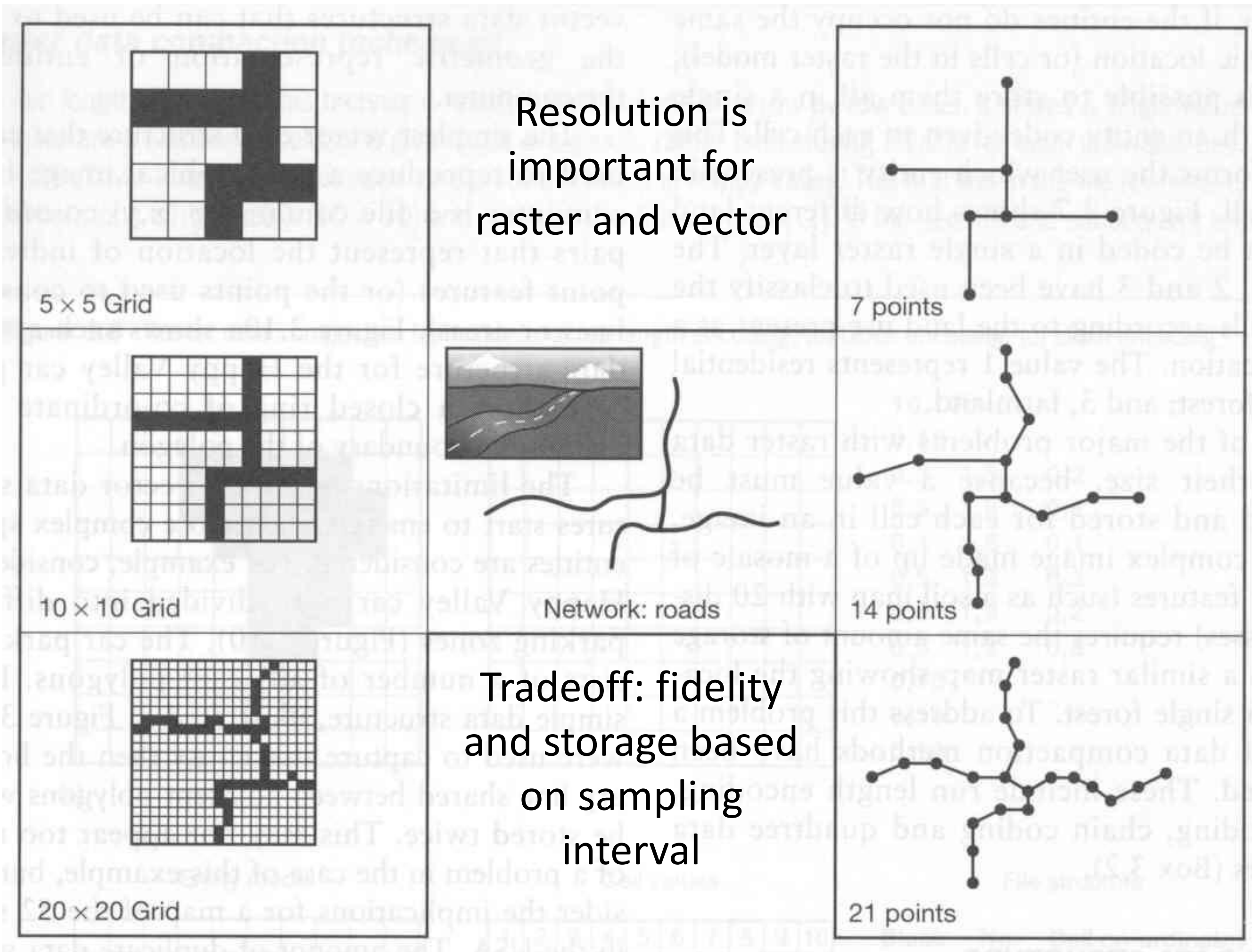
Mixed pixel problem.

Lots of redundant or missing data that must be stored.

# Rasterizing Points, Lines and Areas



# Spatial Resolution




Resolution is important for raster and vector

Tradeoff: fidelity and storage based on sampling interval

# 3-d Rasters

Rasters can store multiple “bands”.

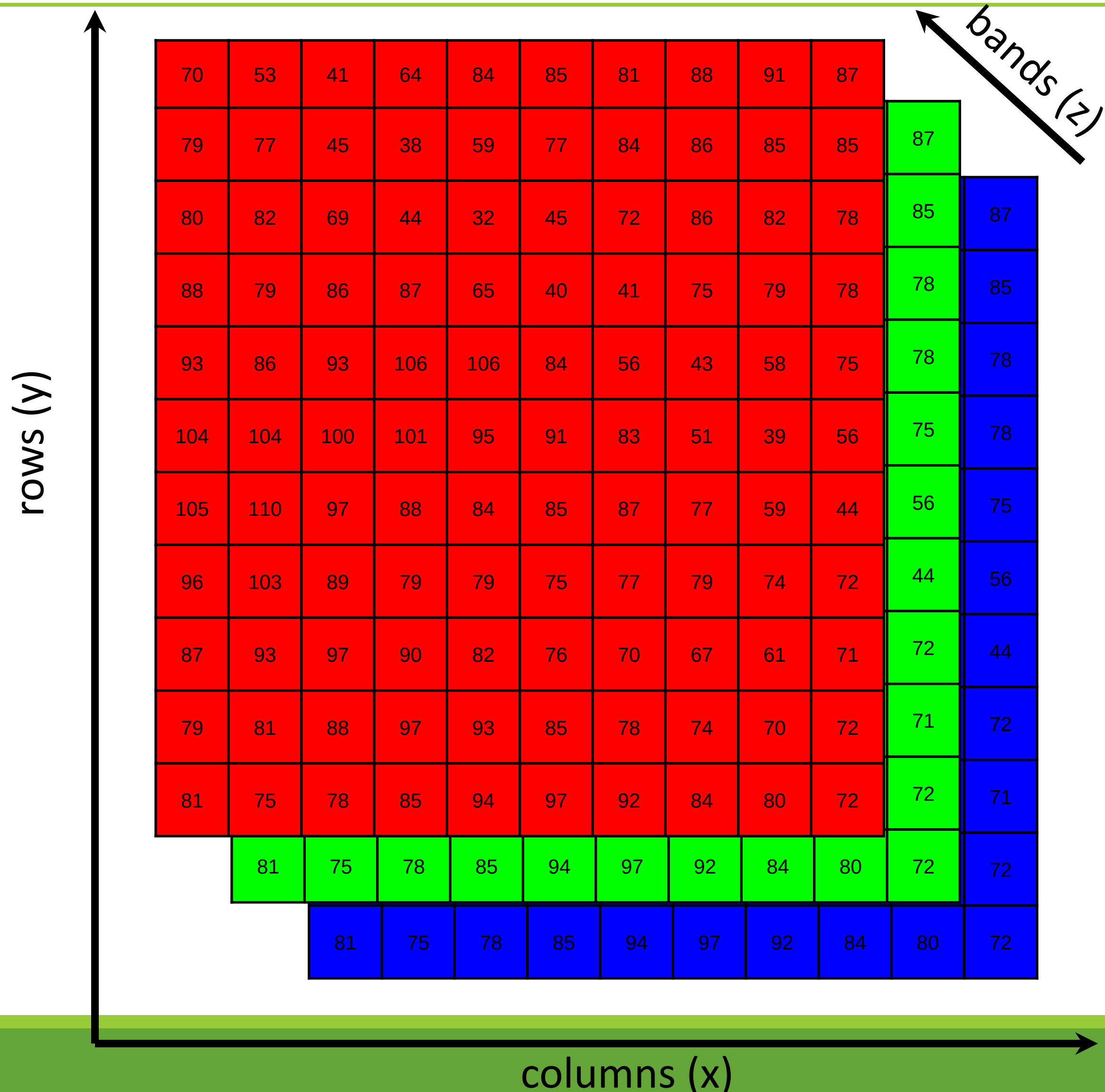
Each band has the same number of rows and columns (and data type, pixel size, etc.)

The header will add a new parameter: **number of bands**

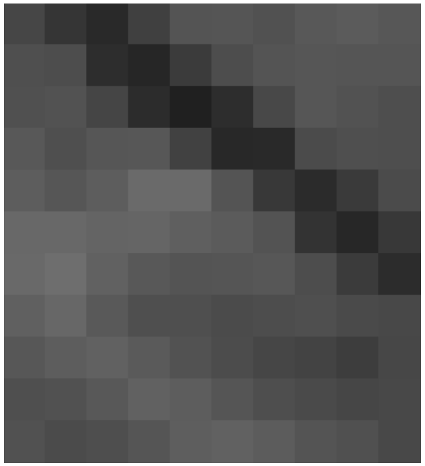
A digital camera stores three bands, representing “red”, “green” and “blue”.

Some remote sensing devices can collect over 200 (!) different colors and store them in a single raster image.

# 3-d Rasters

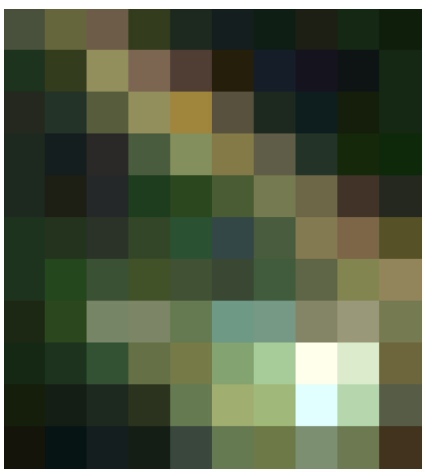

bands (z)
rows (y)
columns (x)
70 53 41 64 84 85 81 88 91 87
79 77 45 38 59 77 84 86 85 85
80 82 69 44 32 45 72 86 82 78
88 79 86 87 65 40 41 75 79 78
93 86 93 106 106 84 56 43 58 75
104 104 100 101 95 91 83 51 39 56
105 110 97 88 84 85 87 77 59 44
96 103 89 79 79 75 77 79 74 72
87 93 97 90 82 76 70 67 61 71
79 81 88 97 93 85 78 74 70 72
81 75 78 85 94 97 92 84 80 72
87 85 78 78 75 56 44 72 71 72 72
81 75 78 85 94 97 92 84 80
87 85 78 78 75 56 44 72 71 72 72
81 75 78 85 94 97 92 84 80 72

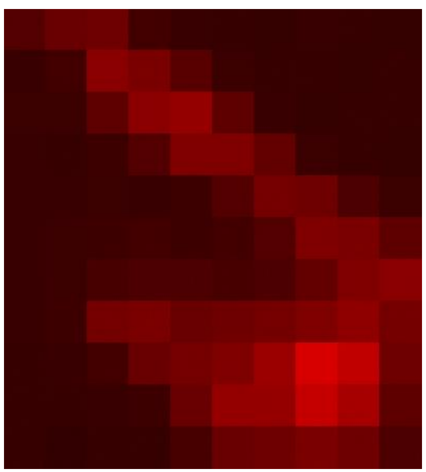
# Greyscale vs. RGB

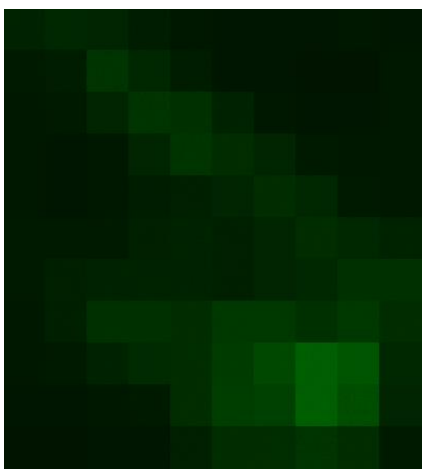


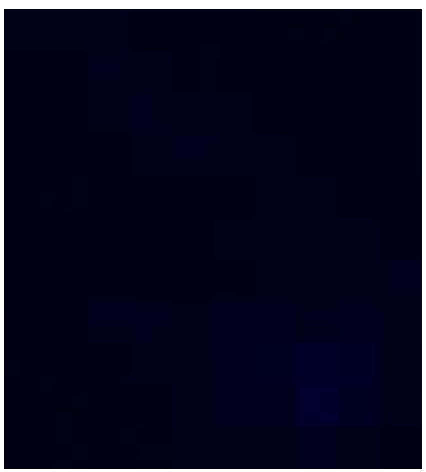
**Greyscale** is typically used to display a *single band*…

…while **RGB** (“Red”, “Green”, “Blue”) images can display *3 bands*, corresponding to the red, green and blue phosphors on a monitor. Computer monitor colors are *additive*, meaning “true” red + green + blue = white.









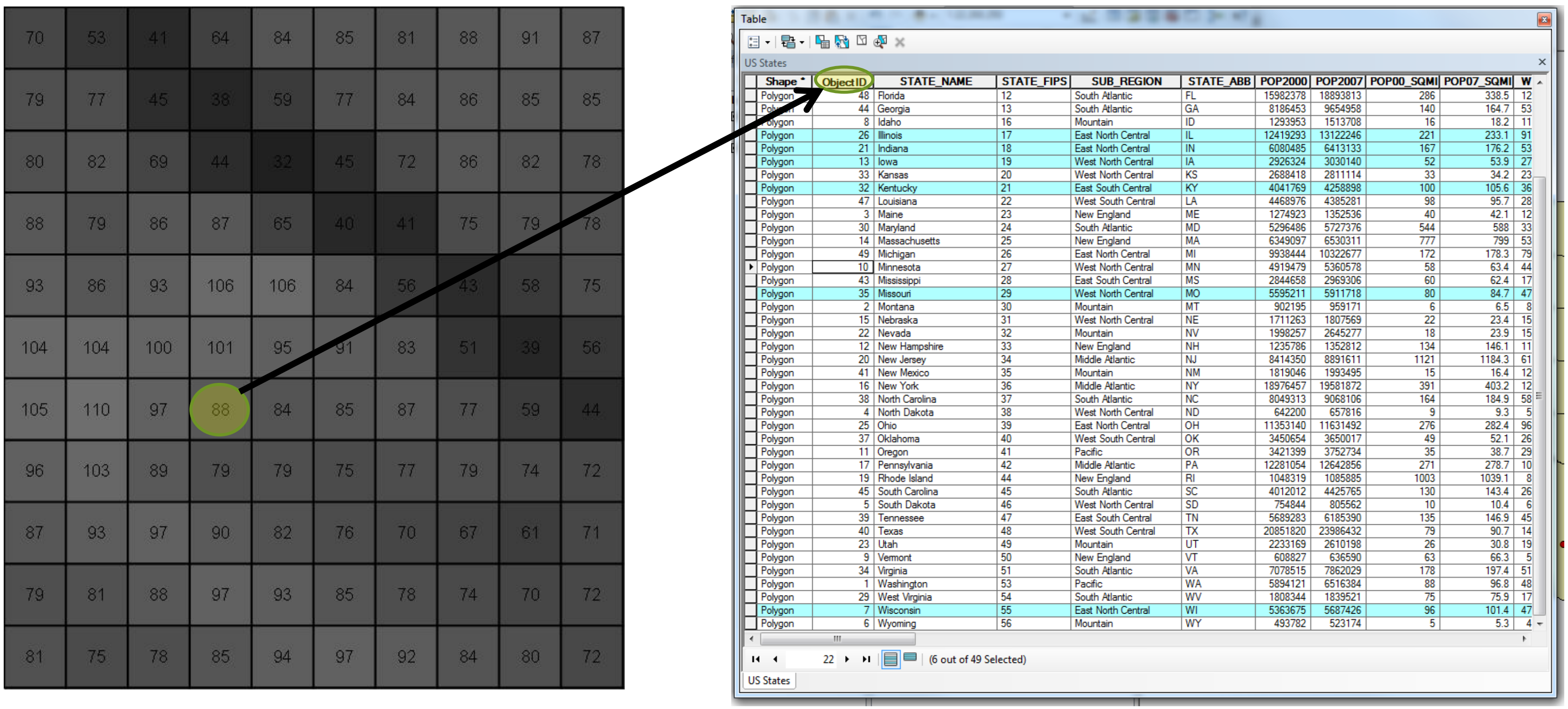
# Raster Attributes

Rasters can be linked to attribute tables just like vectors.

The raster cells must represent “IDs”.

Often, however, rasters encode a single attribute without the need for a separate attribute table.

# Raster Attributes



| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 70 | 53 | 41 | 64 | 84 | 85 | 81 | 88 | 91 | 87 |
| 79 | 77 | 45 | 38 | 59 | 77 | 84 | 86 | 85 | 85 |
| 80 | 82 | 69 | 44 | 32 | 45 | 72 | 86 | 82 | 78 |
| 88 | 79 | 86 | 87 | 65 | 40 | 41 | 75 | 79 | 78 |
| 93 | 86 | 93 | 106 | 106 | 84 | 56 | 43 | 58 | 75 |
| 104 | 104 | 100 | 101 | 95 | 91 | 83 | 51 | 39 | 56 |
| 105 | 110 | 97 | 88 | 84 | 85 | 87 | 77 | 59 | 44 |
| 96 | 103 | 89 | 79 | 79 | 75 | 77 | 79 | 74 | 72 |
| 87 | 93 | 97 | 90 | 82 | 76 | 70 | 67 | 61 | 71 |
| 79 | 81 | 88 | 97 | 93 | 85 | 78 | 74 | 70 | 72 |
| 81 | 75 | 78 | 85 | 94 | 97 | 92 | 84 | 80 | 72 |

Table

US States

| Shape * | ObjectID | STATE_NAME | STATE_FIPS | SUB_REGION | STATE_ABB | POP2000 | POP2007 | POP00_SQMI | POP07_SQMI | W |
|---|---|---|---|---|---|---|---|---|---|---|
| Polygon | 48 | Florida | 12 | South Atlantic | FL | 15982378 | 18893813 | 286 | 338.5 | 12 |
| Polygon | 44 | Georgia | 13 | South Atlantic | GA | 8186453 | 9654958 | 140 | 164.7 | 53 |
| Polygon | 8 | Idaho | 16 | Mountain | ID | 1293953 | 1513708 | 16 | 18.2 | 11 |
| Polygon | 26 | Illinois | 17 | East North Central | IL | 12419293 | 13122246 | 221 | 233.1 | 91 |
| Polygon | 21 | Indiana | 18 | East North Central | IN | 6080485 | 6413133 | 167 | 176.2 | 53 |
| Polygon | 13 | Iowa | 19 | West North Central | IA | 2926324 | 3030140 | 52 | 53.9 | 27 |
| Polygon | 33 | Kansas | 20 | West North Central | KS | 2688418 | 2811114 | 33 | 34.2 | 23 |
| Polygon | 32 | Kentucky | 21 | East South Central | KY | 4041769 | 4258898 | 100 | 105.6 | 36 |
| Polygon | 47 | Louisiana | 22 | West South Central | LA | 4468976 | 4385281 | 98 | 95.7 | 28 |
| Polygon | 3 | Maine | 23 | New England | ME | 1274923 | 1352536 | 40 | 42.1 | 12 |
| Polygon | 30 | Maryland | 24 | South Atlantic | MD | 5296486 | 5727376 | 544 | 588 | 33 |
| Polygon | 14 | Massachusetts | 25 | New England | MA | 6349097 | 6530311 | 777 | 799 | 53 |
| Polygon | 49 | Michigan | 26 | East North Central | MI | 9938444 | 10322677 | 172 | 178.3 | 79 |
| Polygon | 10 | Minnesota | 27 | West North Central | MN | 4919479 | 5360578 | 58 | 63.4 | 44 |
| Polygon | 43 | Mississippi | 28 | East South Central | MS | 2844658 | 2969306 | 60 | 62.4 | 17 |
| Polygon | 35 | Missouri | 29 | West North Central | MO | 5595211 | 5911718 | 80 | 84.7 | 47 |
| Polygon | 2 | Montana | 30 | Mountain | MT | 902195 | 959171 | 6 | 6.5 | 8 |
| Polygon | 15 | Nebraska | 31 | West North Central | NE | 1711263 | 1807569 | 22 | 23.4 | 15 |
| Polygon | 22 | Nevada | 32 | Mountain | NV | 1998257 | 2645277 | 18 | 23.9 | 15 |
| Polygon | 12 | New Hampshire | 33 | New England | NH | 1235786 | 1352812 | 134 | 146.1 | 11 |
| Polygon | 20 | New Jersey | 34 | Middle Atlantic | NJ | 8414350 | 8891611 | 1121 | 1184.3 | 61 |
| Polygon | 41 | New Mexico | 35 | Mountain | NM | 1819046 | 1993495 | 15 | 16.4 | 12 |
| Polygon | 16 | New York | 36 | Middle Atlantic | NY | 18976457 | 19581872 | 391 | 403.2 | 12 |
| Polygon | 38 | North Carolina | 37 | South Atlantic | NC | 8049313 | 9068106 | 164 | 184.9 | 58 |
| Polygon | 4 | North Dakota | 38 | West North Central | ND | 642200 | 657816 | 9 | 9.3 | 5 |
| Polygon | 25 | Ohio | 39 | East North Central | OH | 11353140 | 11631492 | 276 | 282.4 | 96 |
| Polygon | 37 | Oklahoma | 40 | West South Central | OK | 3450654 | 3650017 | 49 | 52.1 | 26 |
| Polygon | 11 | Oregon | 41 | Pacific | OR | 3421399 | 3752734 | 35 | 38.7 | 29 |
| Polygon | 17 | Pennsylvania | 42 | Middle Atlantic | PA | 12281054 | 12642856 | 271 | 278.7 | 10 |
| Polygon | 19 | Rhode Island | 44 | New England | RI | 1048319 | 1085885 | 1003 | 1039.1 | 8 |
| Polygon | 45 | South Carolina | 45 | South Atlantic | SC | 4012012 | 4425765 | 130 | 143.4 | 26 |
| Polygon | 5 | South Dakota | 46 | West North Central | SD | 754844 | 805562 | 10 | 10.4 | 6 |
| Polygon | 39 | Tennessee | 47 | East South Central | TN | 5689283 | 6185390 | 135 | 146.9 | 45 |
| Polygon | 40 | Texas | 48 | West South Central | TX | 20851820 | 23986432 | 79 | 90.7 | 14 |
| Polygon | 23 | Utah | 49 | Mountain | UT | 2233169 | 2610198 | 26 | 30.8 | 19 |
| Polygon | 9 | Vermont | 50 | New England | VT | 608827 | 636590 | 63 | 66.3 | 5 |
| Polygon | 34 | Virginia | 51 | South Atlantic | VA | 7078515 | 7862029 | 178 | 197.4 | 51 |
| Polygon | 1 | Washington | 53 | Pacific | WA | 5894121 | 6516384 | 88 | 96.8 | 48 |
| Polygon | 29 | West Virginia | 54 | South Atlantic | WV | 1808344 | 1839521 | 75 | 75.9 | 17 |
| Polygon | 7 | Wisconsin | 55 | East North Central | WI | 5363675 | 5687426 | 96 | 101.4 | 47 |
| Polygon | 6 | Wyoming | 56 | Mountain | WY | 493782 | 523174 | 5 | 5.3 | 4 |

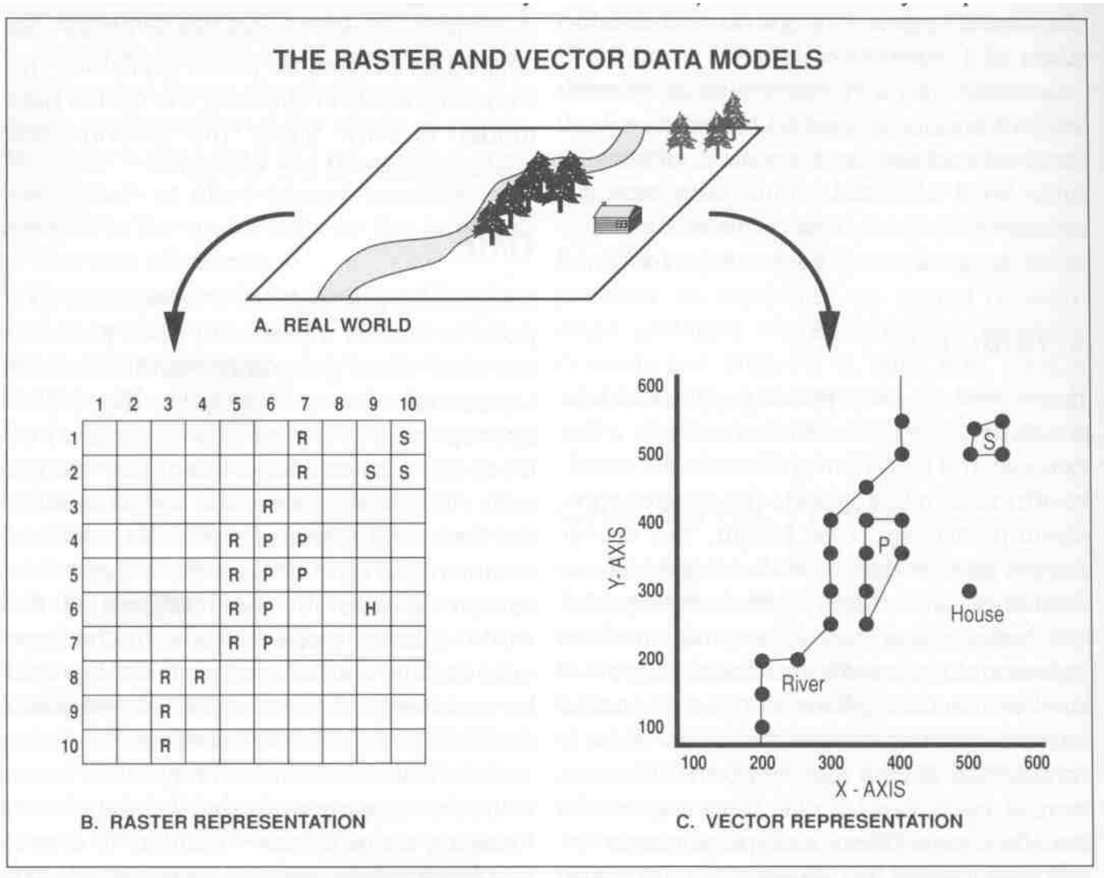
22 (6 out of 49 Selected)

US States

Rasters can be linked by their cell values

# Review of Rasters vs. Vectors

Both formats are abstractions of the real world.



# Review of Vectors vs. Rasters

Both formats store information about their components' positions in two-dimensional space (**coordinates**).

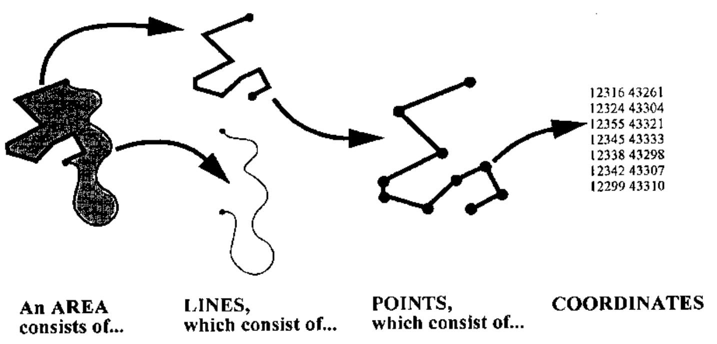
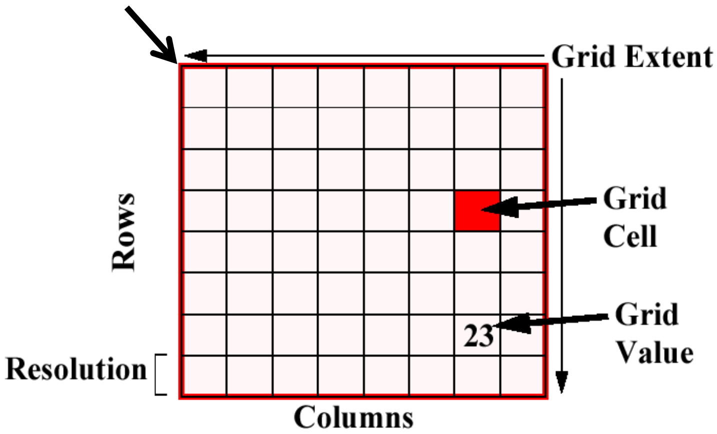



**Figure 2.16** Geographic information has *dimension.* Areas are two-dimensional and consist of lines, which are one-dimensional and consist of points, which are zero- dimensional and consist of a coordinate pair.

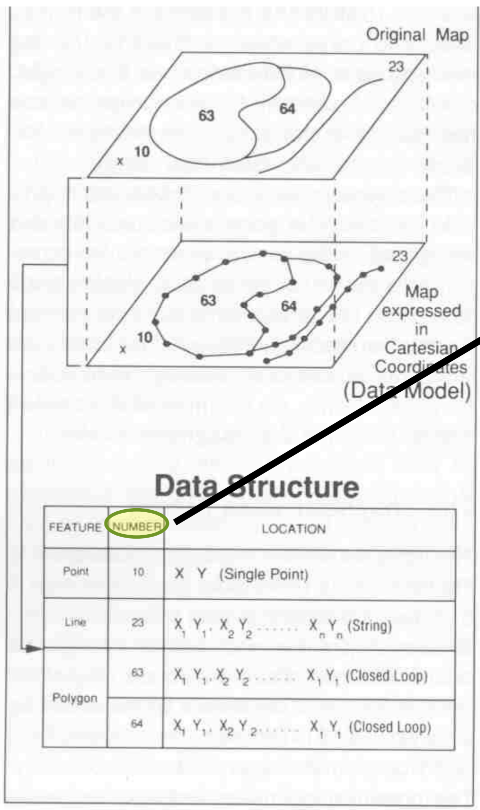
Vector coordinates are determined by knowing the coordinates of the nodes.



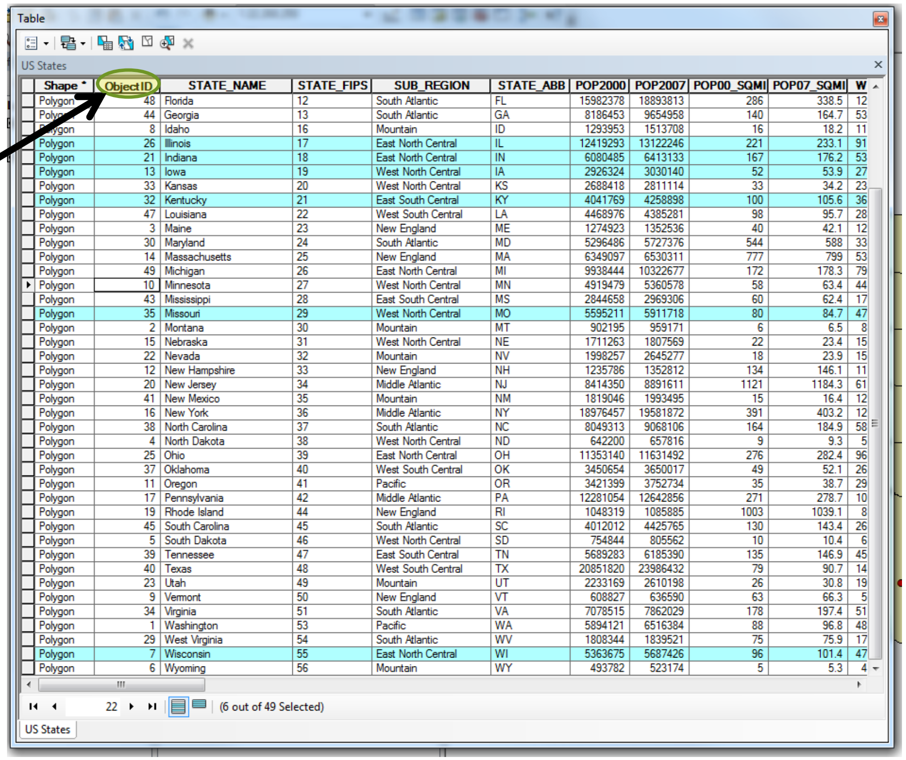

Grid cell coordinates are determined by knowing the coordinates of the upper left corner and the cell resolution.

# Review of Vectors vs. Rasters

Both formats can be linked to an attribute table.




Vectors are linked by their feature IDs (FIDs)



Table

US States

| Shape * | ObjectID | STATE_NAME | STATE_FIPS | SUB_REGION | STATE_ABB | POP2000 | POP2007 | POP00_SQMI | POP07_SQMI | W |
|---|---|---|---|---|---|---|---|---|---|---|
| Polygon | 48 | Florida | 12 | South Atlantic | FL | 15982378 | 18893813 | 286 | 338.5 | 12 |
| Polygon | 44 | Georgia | 13 | South Atlantic | GA | 8186453 | 9654958 | 140 | 164.7 | 53 |
| Polygon | 8 | Idaho | 16 | Mountain | ID | 1293953 | 1513708 | 16 | 18.2 | 11 |
| Polygon | 26 | Illinois | 17 | East North Central | IL | 12419293 | 13122246 | 221 | 233.1 | 91 |
| Polygon | 21 | Indiana | 18 | East North Central | IN | 6080485 | 6413133 | 167 | 176.2 | 53 |
| Polygon | 13 | Iowa | 19 | West North Central | IA | 2926324 | 3030140 | 52 | 53.9 | 27 |
| Polygon | 33 | Kansas | 20 | West North Central | KS | 2688418 | 2811114 | 33 | 34.2 | 23 |
| Polygon | 32 | Kentucky | 21 | East South Central | KY | 4041769 | 4258898 | 100 | 105.6 | 36 |
| Polygon | 47 | Louisiana | 22 | West South Central | LA | 4468976 | 4385281 | 98 | 95.7 | 28 |
| Polygon | 3 | Maine | 23 | New England | ME | 1274923 | 1352536 | 40 | 42.1 | 12 |
| Polygon | 30 | Maryland | 24 | South Atlantic | MD | 5296486 | 5727376 | 544 | 588 | 33 |
| Polygon | 14 | Massachusetts | 25 | New England | MA | 6349097 | 6530311 | 777 | 799 | 53 |
| Polygon | 49 | Michigan | 26 | East North Central | MI | 9938444 | 10322677 | 172 | 178.3 | 79 |
| Polygon | 10 | Minnesota | 27 | West North Central | MN | 4919479 | 5360578 | 58 | 63.4 | 44 |
| Polygon | 43 | Mississippi | 28 | East South Central | MS | 2844658 | 2969306 | 60 | 62.4 | 17 |
| Polygon | 35 | Missouri | 29 | West North Central | MO | 5595211 | 5911718 | 80 | 84.7 | 47 |
| Polygon | 2 | Montana | 30 | Mountain | MT | 902195 | 959171 | 6 | 6.5 | 8 |
| Polygon | 15 | Nebraska | 31 | West North Central | NE | 1711263 | 1807569 | 22 | 23.4 | 15 |
| Polygon | 22 | Nevada | 32 | Mountain | NV | 1998257 | 2645277 | 18 | 23.9 | 15 |
| Polygon | 12 | New Hampshire | 33 | New England | NH | 1235786 | 1352812 | 134 | 146.1 | 11 |
| Polygon | 20 | New Jersey | 34 | Middle Atlantic | NJ | 8414350 | 8891611 | 1121 | 1184.3 | 61 |
| Polygon | 41 | New Mexico | 35 | Mountain | NM | 1819046 | 1993495 | 15 | 16.4 | 12 |
| Polygon | 16 | New York | 36 | Middle Atlantic | NY | 18976457 | 19581872 | 391 | 403.2 | 12 |
| Polygon | 38 | North Carolina | 37 | South Atlantic | NC | 8049313 | 9068106 | 164 | 184.9 | 58 |
| Polygon | 4 | North Dakota | 38 | West North Central | ND | 642200 | 657816 | 9 | 9.3 | 5 |
| Polygon | 25 | Ohio | 39 | East North Central | OH | 11353140 | 11631492 | 276 | 282.4 | 96 |
| Polygon | 37 | Oklahoma | 40 | West South Central | OK | 3450654 | 3650017 | 49 | 52.1 | 26 |
| Polygon | 11 | Oregon | 41 | Pacific | OR | 3421399 | 3752734 | 35 | 38.7 | 29 |
| Polygon | 17 | Pennsylvania | 42 | Middle Atlantic | PA | 12281054 | 12642856 | 271 | 278.7 | 10 |
| Polygon | 19 | Rhode Island | 44 | New England | RI | 1048319 | 1085885 | 1003 | 1039.1 | 8 |
| Polygon | 45 | South Carolina | 45 | South Atlantic | SC | 4012012 | 4425765 | 130 | 143.4 | 26 |
| Polygon | 5 | South Dakota | 46 | West North Central | SD | 754844 | 805562 | 10 | 10.4 | 6 |
| Polygon | 39 | Tennessee | 47 | East South Central | TN | 5689283 | 6185390 | 135 | 146.9 | 45 |
| Polygon | 40 | Texas | 48 | West South Central | TX | 20851820 | 23986432 | 79 | 90.7 | 14 |
| Polygon | 23 | Utah | 49 | Mountain | UT | 2233169 | 2610198 | 26 | 30.8 | 19 |
| Polygon | 9 | Vermont | 50 | New England | VT | 608827 | 636590 | 63 | 66.3 | 5 |
| Polygon | 34 | Virginia | 51 | South Atlantic | VA | 7078515 | 7862029 | 178 | 197.4 | 51 |
| Polygon | 1 | Washington | 53 | Pacific | WA | 5894121 | 6516384 | 88 | 96.8 | 48 |
| Polygon | 29 | West Virginia | 54 | South Atlantic | WV | 1808344 | 1839521 | 75 | 75.9 | 17 |
| Polygon | 7 | Wisconsin | 55 | East North Central | WI | 5363675 | 5687426 | 96 | 101.4 | 47 |
| Polygon | 6 | Wyoming | 56 | Mountain | WY | 493782 | 523174 | 5 | 5.3 | 4 |

22 (6 out of 49 Selected)

US States

# Review of Vectors vs. Rasters

Both formats can be linked to an attribute table.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 70 | 53 | 41 | 64 | 84 | 85 | 81 | 88 | 91 | 87 |
| 79 | 77 | 45 | 38 | 59 | 77 | 84 | 86 | 85 | 85 |
| 80 | 82 | 69 | 44 | 32 | 45 | 72 | 86 | 82 | 78 |
| 88 | 79 | 86 | 87 | 65 | 40 | 41 | 75 | 79 | 78 |
| 93 | 86 | 93 | 106 | 106 | 84 | 56 | 43 | 58 | 75 |
| 104 | 104 | 100 | 101 | 95 | 91 | 83 | 51 | 39 | 56 |
| 105 | 110 | 97 | 88 | 84 | 85 | 87 | 77 | 59 | 44 |
| 96 | 103 | 89 | 79 | 79 | 75 | 77 | 79 | 74 | 72 |
| 87 | 93 | 97 | 90 | 82 | 76 | 70 | 67 | 61 | 71 |
| 79 | 81 | 88 | 97 | 93 | 85 | 78 | 74 | 70 | 72 |
| 81 | 75 | 78 | 85 | 94 | 97 | 92 | 84 | 80 | 72 |

Rasters are linked by their cell values

Table

US States

| Shape * | ObjectID | STATE_NAME | STATE_FIPS | SUB_REGION | STATE_ABB | POP2000 | POP2007 | POP00_SQMI | POP07_SQMI | W |
|---|---|---|---|---|---|---|---|---|---|---|
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| Polygon | 30 | Maryland | 24 | South Atlantic | MD | 5296486 | 5727376 | 544 | 588 | 33 |
| Polygon | 14 | Massachusetts | 25 | New England | MA | 6349097 | 6530311 | 777 | 799 | 53 |
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| Polygon | 43 | Mississippi | 28 | East South Central | MS | 2844658 | 2969306 | 60 | 62.4 | 17 |
| Polygon | 35 | Missouri | 29 | West North Central | MO | 5595211 | 5911718 | 80 | 84.7 | 47 |
| Polygon | 2 | Montana | 30 | Mountain | MT | 902195 | 959171 | 6 | 6.5 | 8 |
| Polygon | 15 | Nebraska | 31 | West North Central | NE | 1711263 | 1807569 | 22 | 23.4 | 15 |
| Polygon | 22 | Nevada | 32 | Mountain | NV | 1998257 | 2645277 | 18 | 23.9 | 15 |
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| Polygon | 20 | New Jersey | 34 | Middle Atlantic | NJ | 8414350 | 8891611 | 1121 | 1184.3 | 61 |
| Polygon | 41 | New Mexico | 35 | Mountain | NM | 1819046 | 1993495 | 15 | 16.4 | 12 |
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| Polygon | 11 | Oregon | 41 | Pacific | OR | 3421399 | 3752734 | 35 | 38.7 | 29 |
| Polygon | 17 | Pennsylvania | 42 | Middle Atlantic | PA | 12281054 | 12642856 | 271 | 278.7 | 10 |
| Polygon | 19 | Rhode Island | 44 | New England | RI | 1048319 | 1085885 | 1003 | 1039.1 | 8 |
| Polygon | 45 | South Carolina | 45 | South Atlantic | SC | 4012012 | 4425765 | 130 | 143.4 | 26 |
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| Polygon | 39 | Tennessee | 47 | East South Central | TN | 5689283 | 6185390 | 135 | 146.9 | 45 |
| Polygon | 40 | Texas | 48 | West South Central | TX | 20851820 | 23986432 | 79 | 90.7 | 14 |
| Polygon | 23 | Utah | 49 | Mountain | UT | 2233169 | 2610198 | 26 | 30.8 | 19 |
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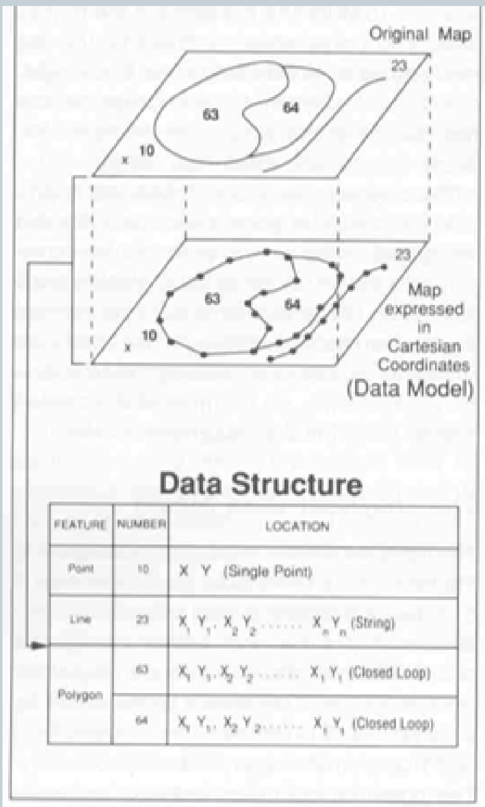
| Polygon | 6 | Wyoming | 56 | Mountain | WY | 493782 | 523174 | 5 | 5.3 | 4 |

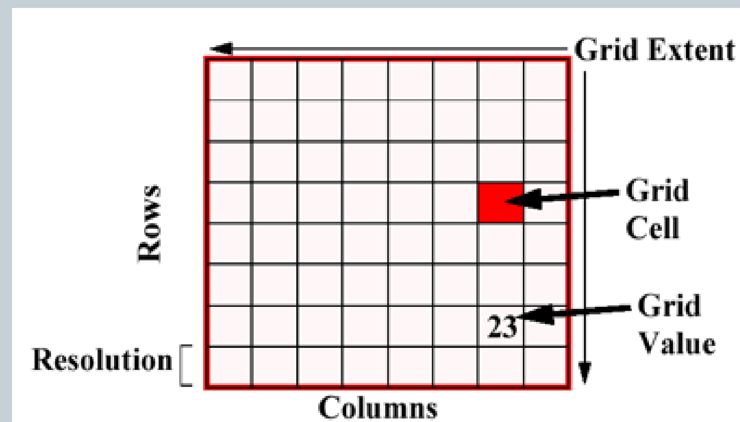
22 (6 out of 49 Selected)

US States

# Review of Vectors vs. Rasters

| The building block of a vector is the node. | The building block of the raster is the cell. |
|---|---|



# Review of Vectors vs. Rasters

| Vectors store positions precisely | Raster positions are “snapped” to the cell |
|---|---|

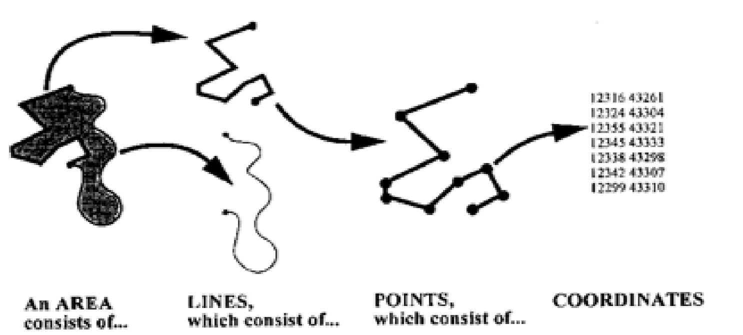
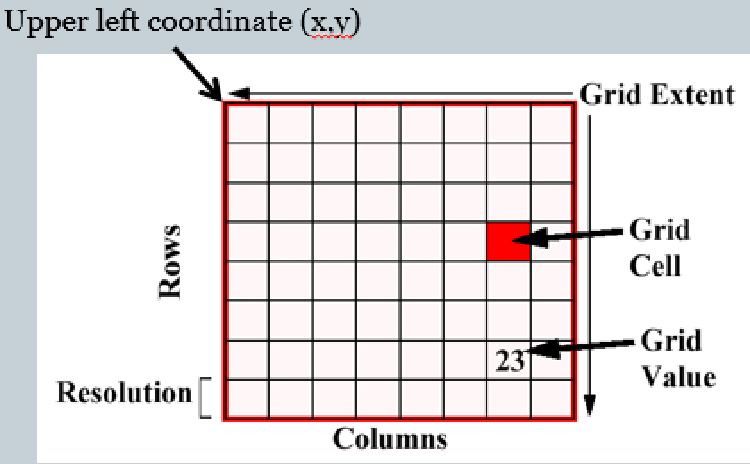
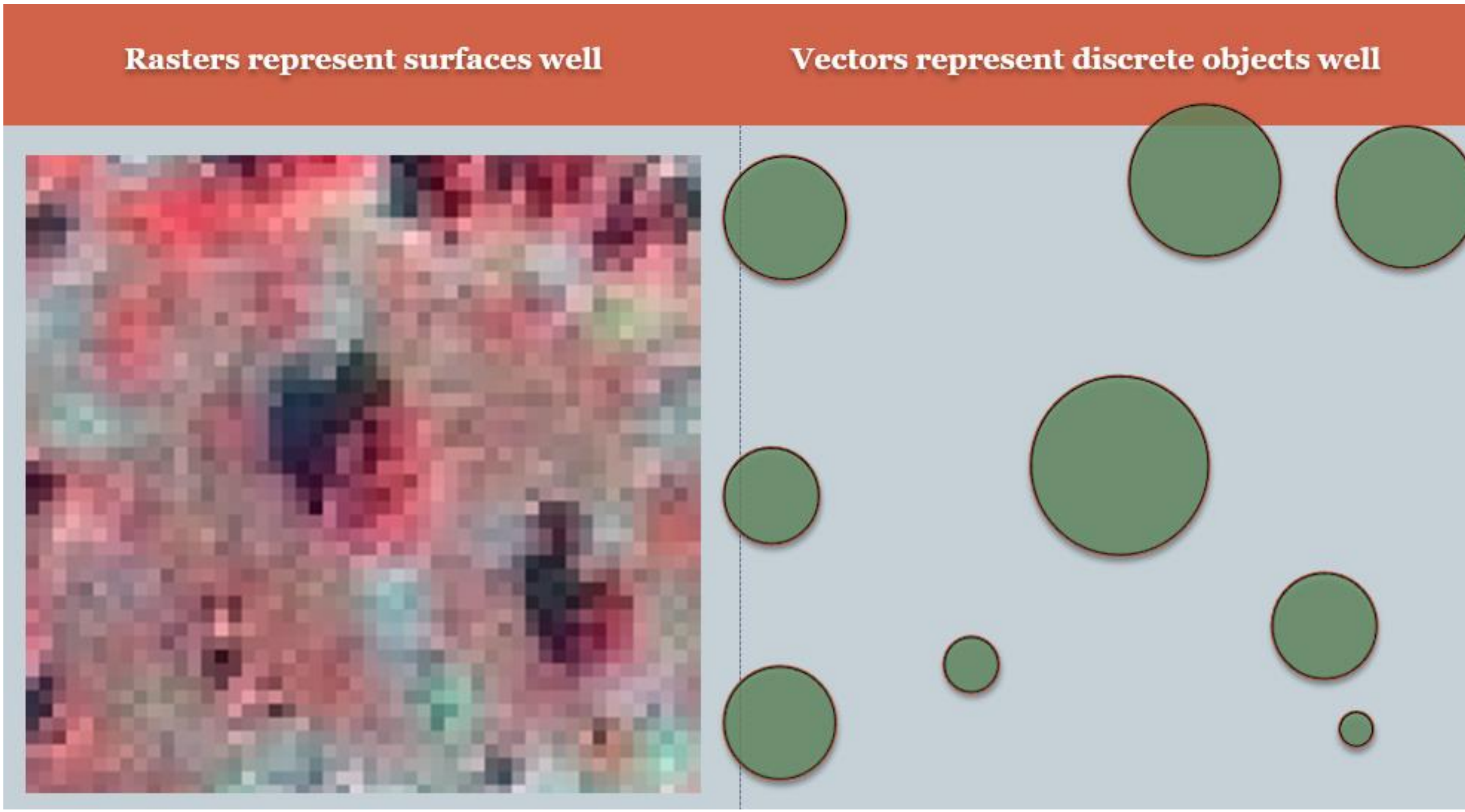



**Figure 2.16** Geographic information has *dimension*. Areas are two-dimensional and consist of lines, which are one-dimensional and consist of points, which are zero- dimensional and consist of a coordinate pair.

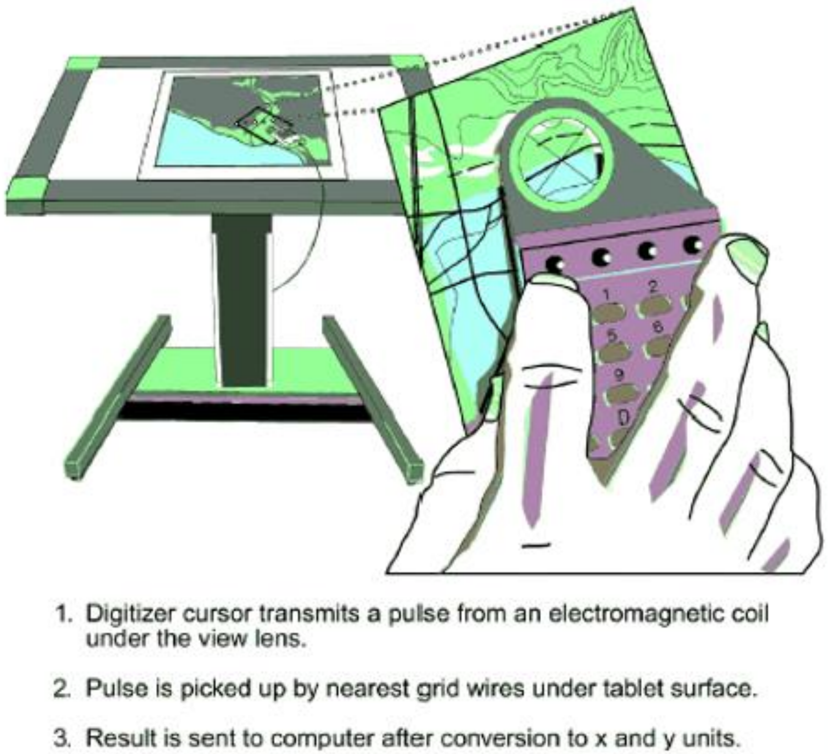


# Review of Vectors vs. Rasters



# Review of Vectors vs. Rasters

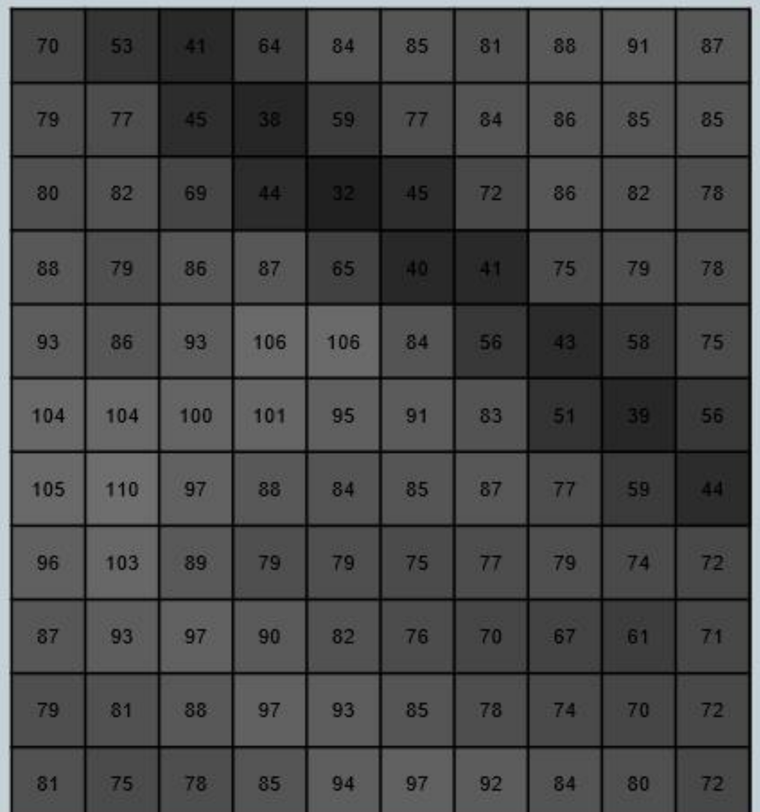
Vectors often come from digitizing




Rasters often come from remote sensing

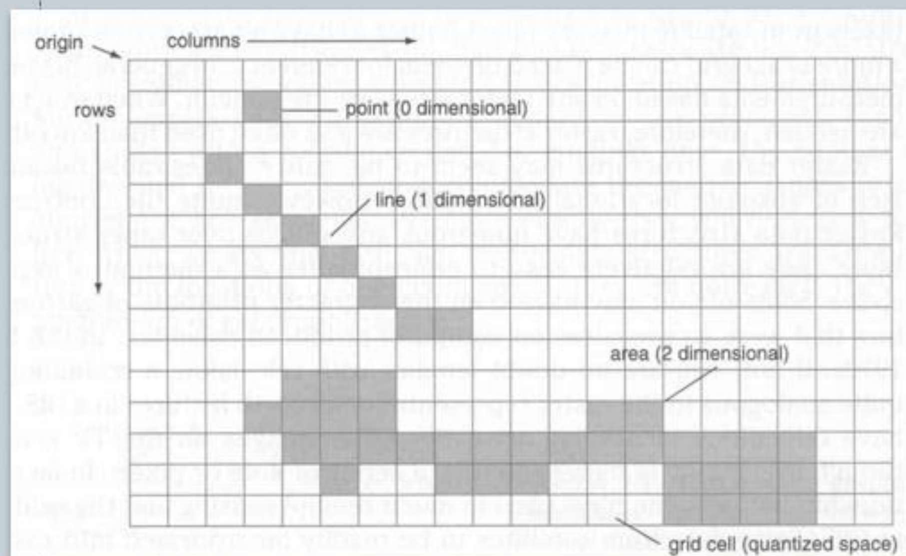
# Review of Vectors vs. Rasters

**Vectors can precisely represent rasters**




Each grid cell can be converted to a square polygon.

**Rasters cannot precisely represent vectors**




All vectors must be coerced to grid cells.

# Review of Vectors vs. Rasters

| Vector formats are relatively complex | Raster formats are relatively simple |
| --- | --- |
| • Multiple files representing arcs, nodes, polygons, topology, projection, and attribute information. | • Header file<br>• Raster data |

# Review of Vectors vs. Rasters

| Vector – HPC more difficult | Raster – HPC simple |
| --- | --- |
| • High performance computing (HPC) with vectors requires advanced topological and database algorithms (complex). | • High performance computing (HPC) with rasters usually just requires sending “chunks” of the raster to different processors (simple). |