SEST-6577

Geographic Information Systems for Security Studies

Lecture 08 (Remote Sensing and Satellite Data)

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Remote sensing and public policy

Definitions

What is remote sensing?

Information obtained through long-range observation (e.g. from satellites, aircraft)

1. Collection of raw imagery from the surface of the Earth
   a. *passive sensors*: collect information on emitted light/radiation
      - examples: photography, infrared
   b. *active sensors*: emit energy, collect information on reflected light/radiation
      - examples: radar, LiDAR
2. Image processing
   a. raw images are *georeferenced* to ground control points
   b. emitted/reflected light matched to *specific spectral signatures*
      - examples: types of vegetation, land cover, CO_2 emissions
   c. processed data are stored as pixels in raster datasets

Advantages:

- remote sensing is sometimes cheaper and safer than direct observation (e.g. hard-to-reach areas, conflict zones)
- measurement is consistent across regional, national borders

Remote sensing = raster data

- not all raster data are derived from remote sensing imagery
- but all remote sensing imagery originates as raster data

Raster data structure ≠ vector data structure

- vectors store information in "attribute tables" (N features × K fields)
- rasters store information in a grid of pixels (N_R rows × N_C columns)
    - pixels are of constant size, shape, area
    - each pixel represents a unique location
    - each pixel contains just one value (e.g. precipitation, land use)
    - size of pixels determines resolution (e.g. 1 meter, 1 km, 1 degree)
- rasters usually have larger file size than vectors, but not necessarily more precision

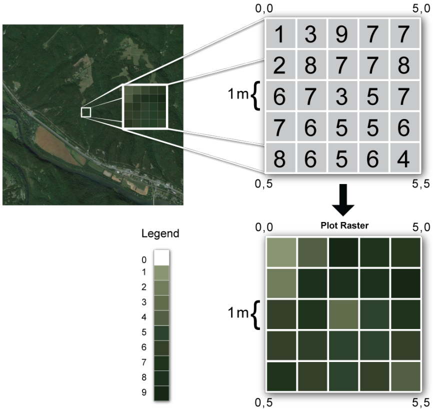

Figure 1: Raster data structure

Applications

Many **variables of interest** to public policy originate as remote sensing imagery

- weather (precipitation, temperature)
- climate model forecasts
- flooding depth and risk
- active fires
- night light emissions
- elevation, slope, line of sight
- pollution and air quality
- cloud cover
- vegetation indices
- soil quality, fertility
- land use and land cover (LULC)
- built-up areas
- population density (derived from above)

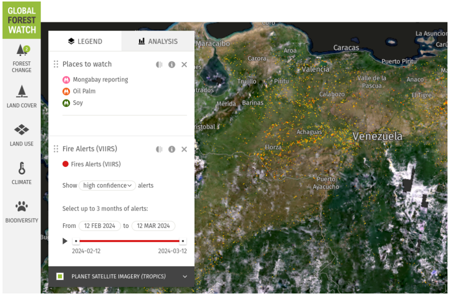

Figure 2: Example use case

But raster data were **not** (originally) **built for social science and public policy** applications

- original policy purpose: military reconnaissance, damage assessment
- original scientific purpose: natural sciences (e.g. geology, ecology, biology)
- no sensor systems, spectral measurements were designed for dedicated monitoring of social, economic processes
- reliance on indirect/proxy measures

Divergent data structures, approaches

- social science: "vector view" of world (e.g. organize data into discrete units)
- natural science: "raster view" of world (e.g. organize data into regular lattice)
- integrating raster and vector data requires *interdisciplinary* cooperation

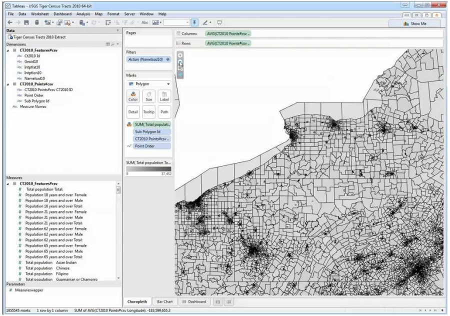

Figure 3: Social science prefers vectors

Raster data analysis

Rasterization and Vectorization

In social science and public policy, raster data integration requires that we either

1. Rasterize the vector data
   - convert discrete features into continuous field
   - examples:
     a. frequency/density of features
     b. presence/absence of feature
     c. distance to features
     d. assignment to feature
2. Vectorize the raster data
   - summarize values of continuous field at each feature
   - examples:
     a. zonal statistics (e.g. mean, max cell values)
     b. image tracing (e.g. of georeferenced maps – we covered this earlier)

Point-to-raster: suppose points are locations of 100 events (e.g. wolf attacks)

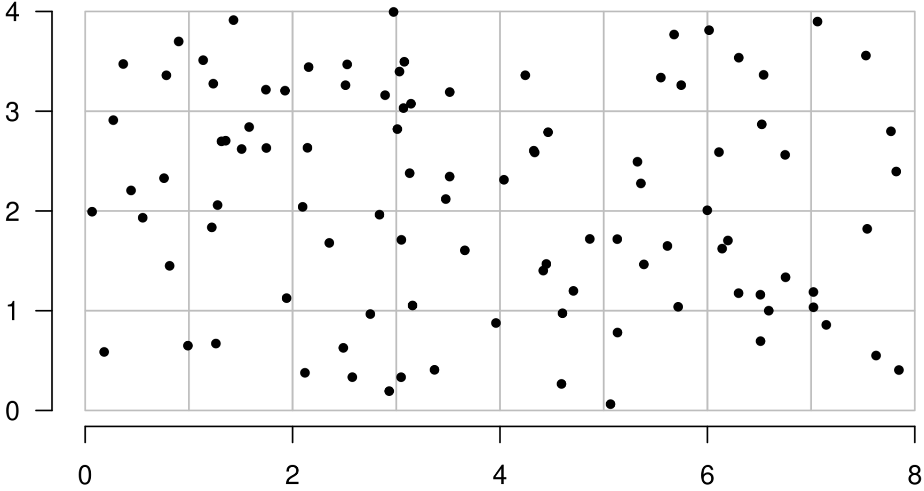

Figure 4: Point geometries

Study: Wolf Attacks Still Leading Cause Of Death In U.S.

Published April 23, 2013

BETHESDA, MD—According to a new study released Monday by the National Institutes of Health, for the 25th straight year, violent wolf attacks remain the leading cause of death in the United States.

Figure 5: A major public policy problem

Option 1: count number of features in each raster pixel/cell

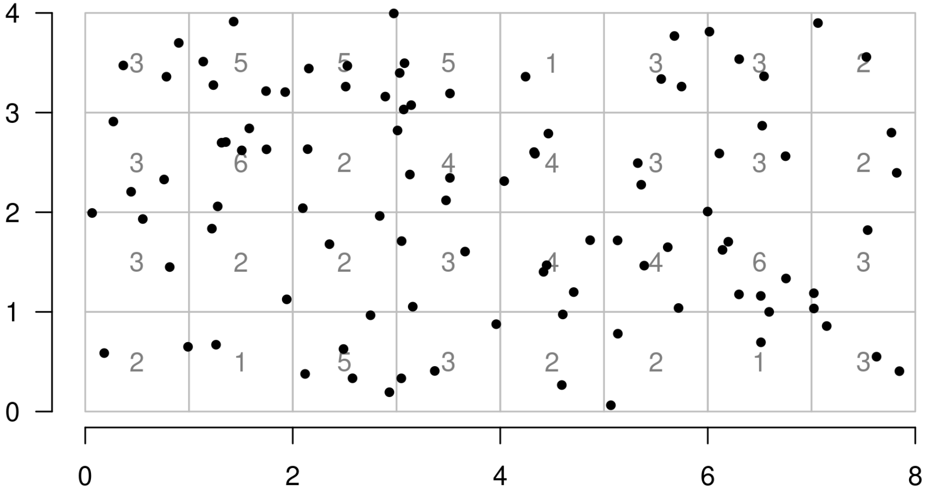

Figure 6: Point counts per cell

Pixels values are local frequency (number of points) or point density (number/area)

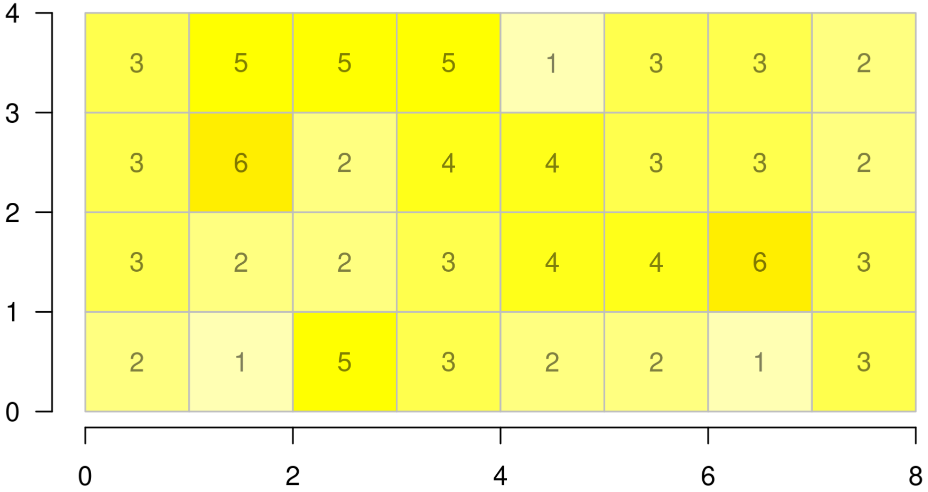

Figure 7: Local point frequency

Line-to-raster: suppose this line is an infrastructural object (e.g. road, power line)

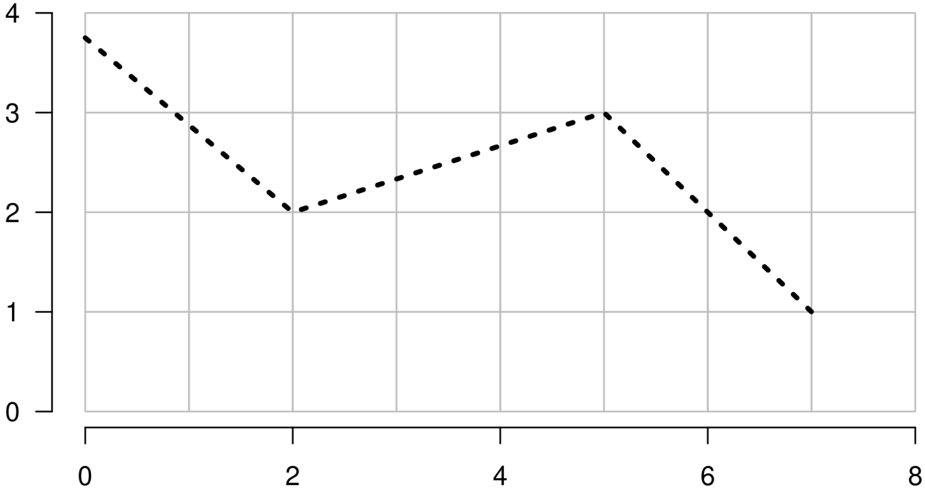

Figure 8: Line geometries

Option 2: presence/absence of features at each raster pixel/cell

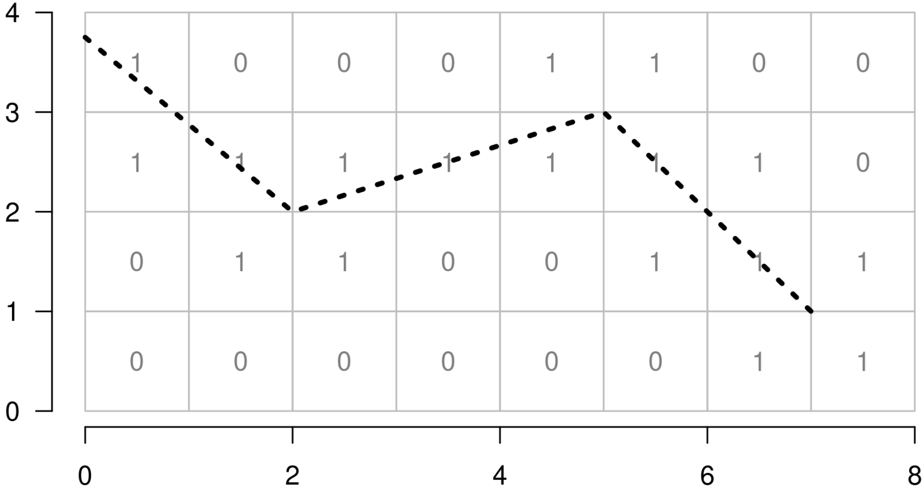

Figure 9: Line presence/absence per cell

Pixels values are indicators of whether an object is locally present/accessible

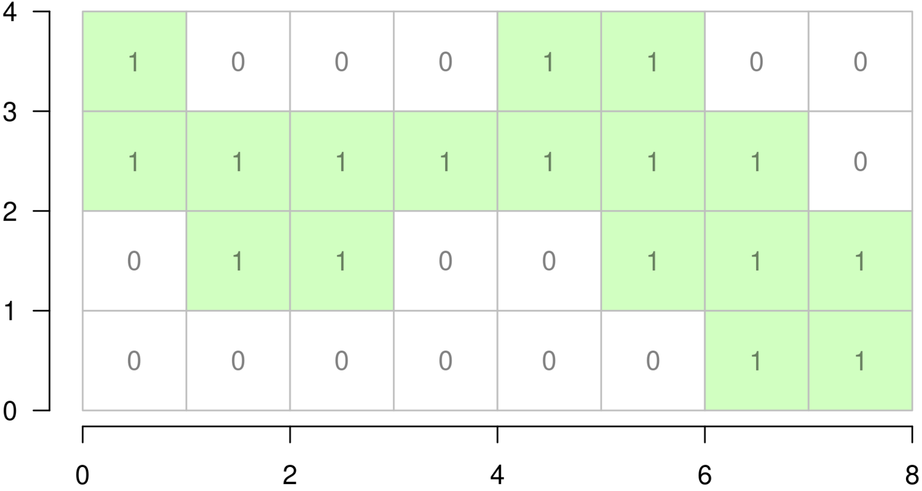

Figure 10: Local line access

Option 3: distance from feature to each raster pixel/cell

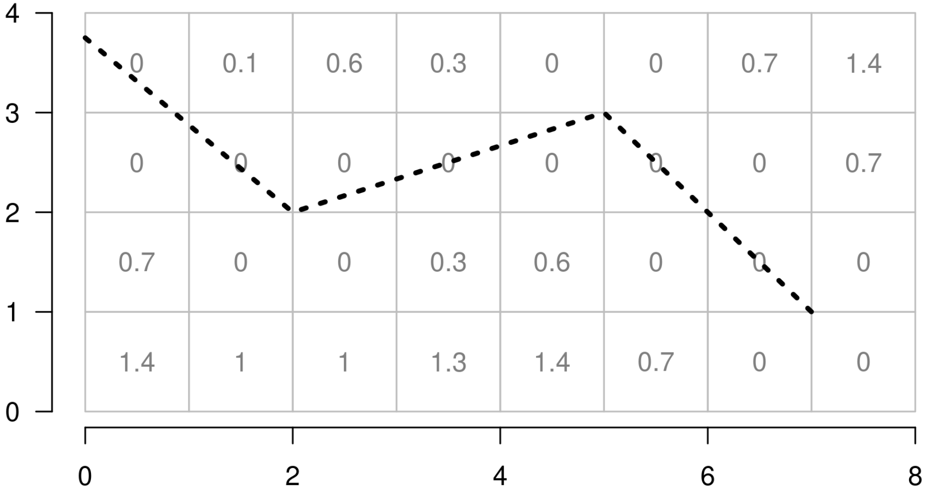

Figure 11: Distance from line to cell

Pixels values represent proximity

Figure 12: Local distance

Polygon-to-raster: suppose polygons are 4 administrative areas (e.g. districts)

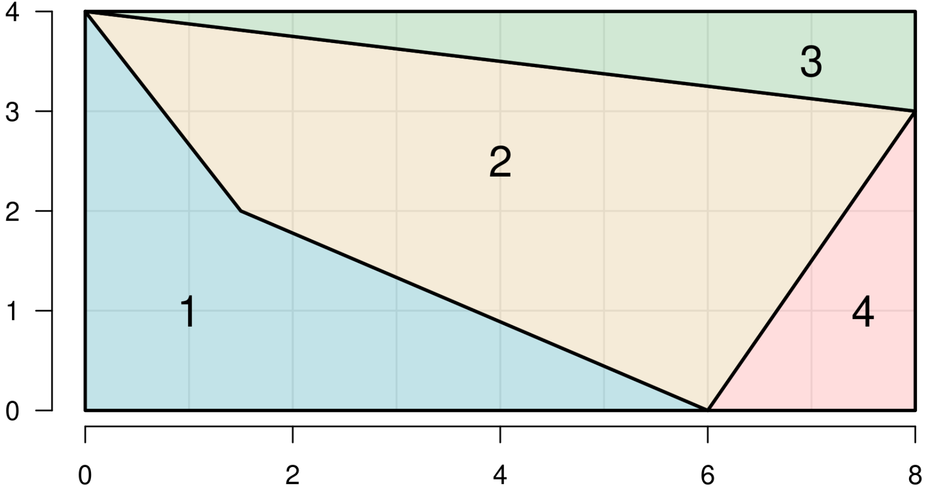

Figure 13: Polygon geometries

Option 4: assign pixels to overlapping features (e.g. by center of cell)

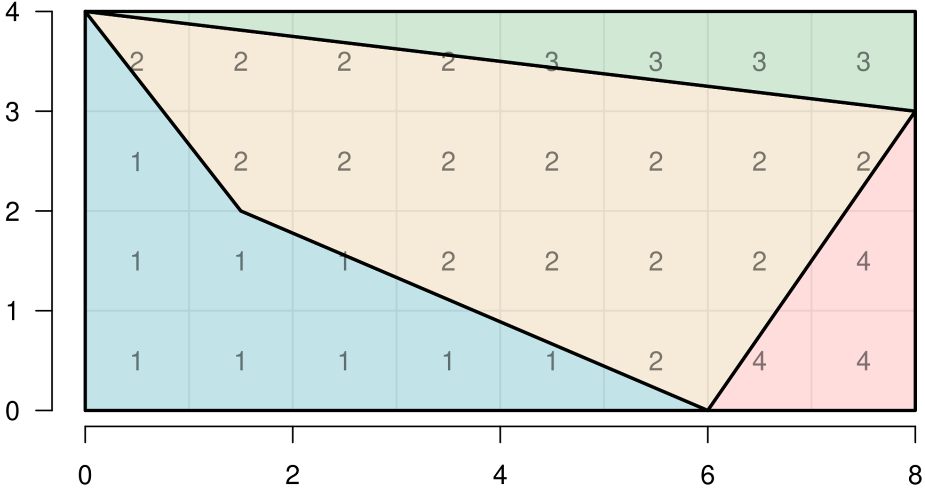

Figure 14: Polygon assignment by centroid

Pixel values are polygon labels or attributes (e.g. assumed constant)

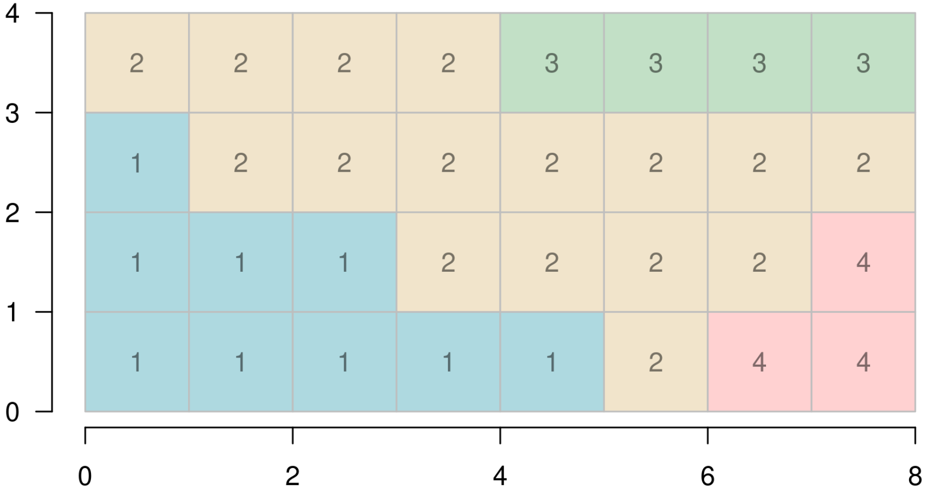

Figure 15: Local polygon assignment

Rasterization overview

These operations can be done on *all types of vector data*

1. count/density of points/lines/polygons
2. presence/absence of points/lines/polygons
3. distance to points/lines/polygons
4. assignment to points/lines/polygons (with tie-breaking rule)

But problem: why do this?

- pixels are not meaningful spatial units for public policy
- policymakers don't think of the world as a "continuous field"
- policy is made in discrete geographic jurisdictions, with well-defined borders
- more common approach to analysis: *convert raster to vector*

Raster-to-polygon: suppose raster represents a continuous variable (e.g. elevation)

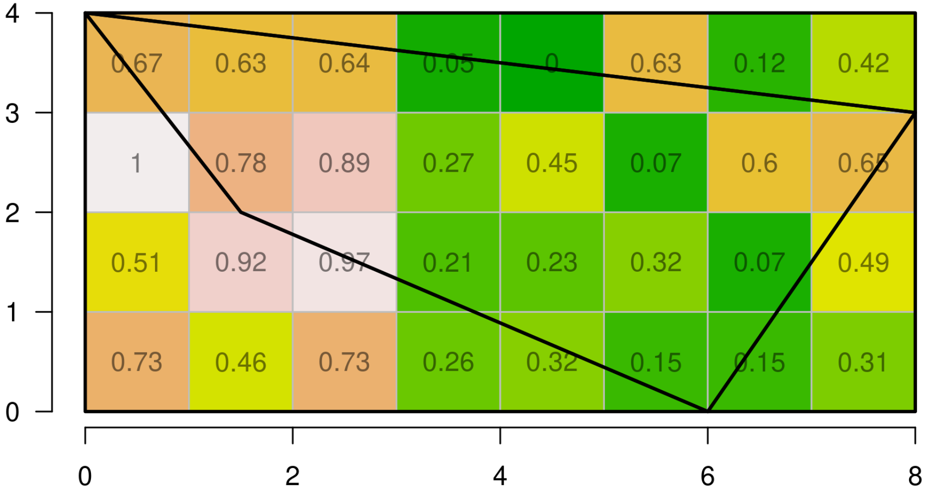

Figure 16: Raster cell values

Option 1: calculate zonal statistics (e.g. average cell values) for each polygon

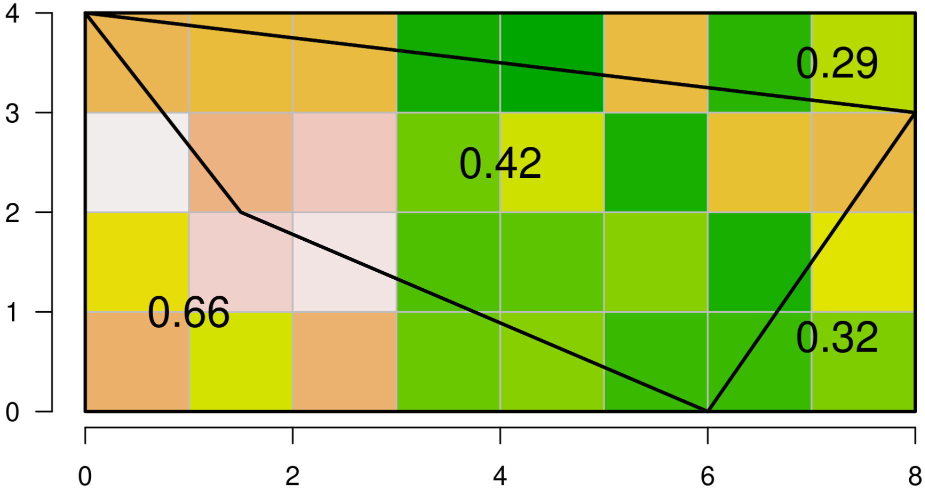

Figure 17: Zonal statistics: mean cell values

Average cell values are added to attribute table for polygons

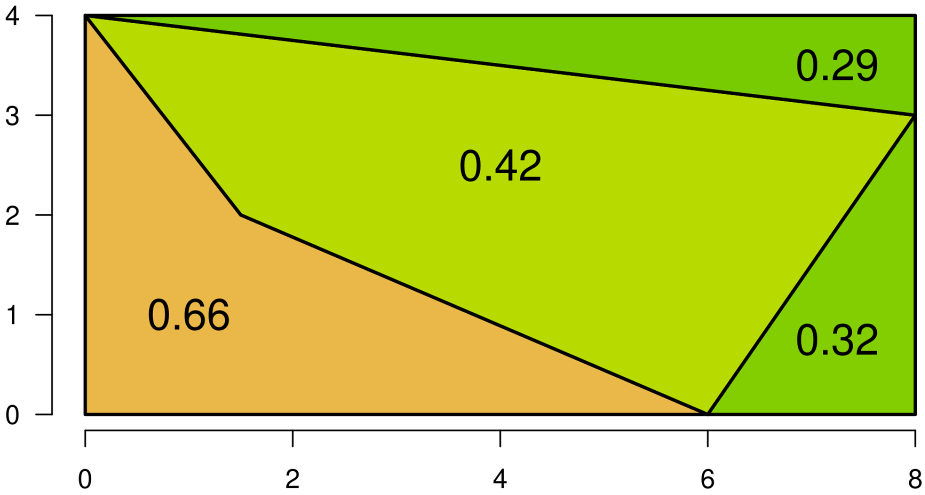

Figure 18: Mean cell values for each polygon

Same operation could be used to obtain maximum cell values...

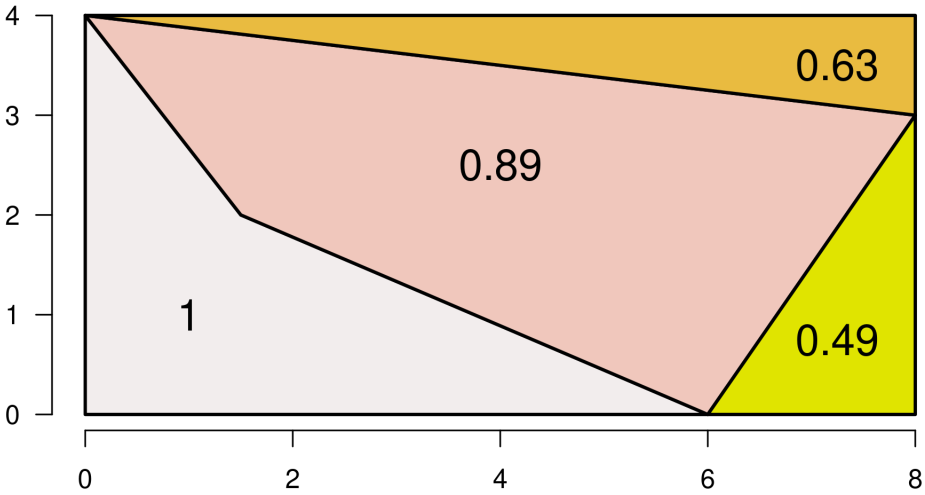

Figure 19: Maximum cell values for each polygon

...or minimum values (or any other summary statistic)

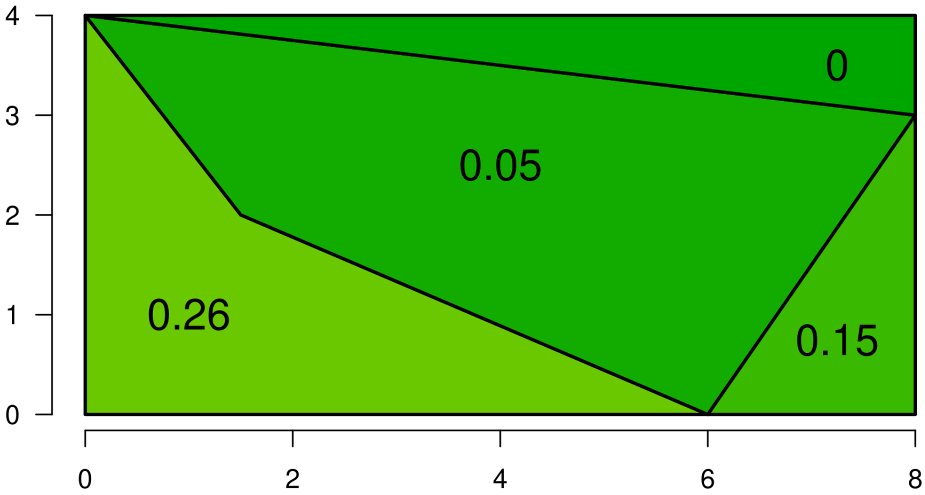

Figure 20: Minimum cell values for each polygon

But what if raster represents a categorical variable (e.g. land use)?

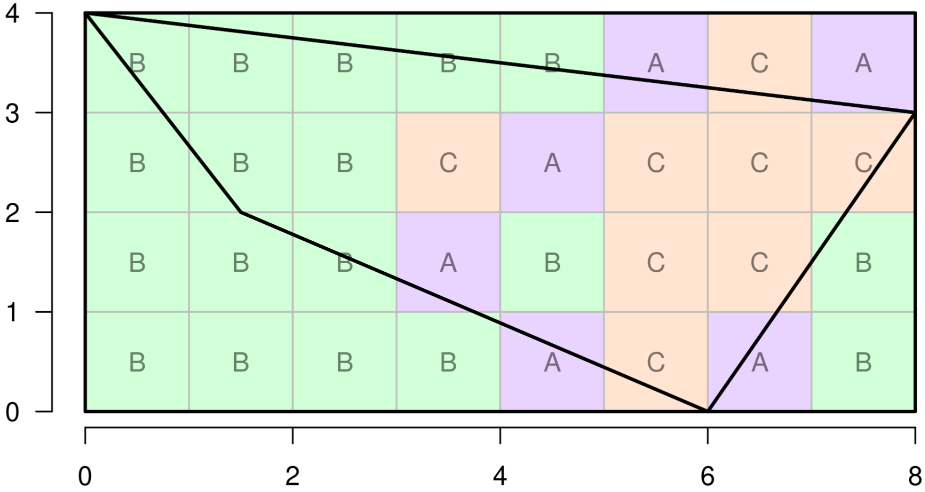

Figure 21: Raster cell values

Option 2: reclassify raster to binary (e.g. 1 if land use "A", 0 otherwise)

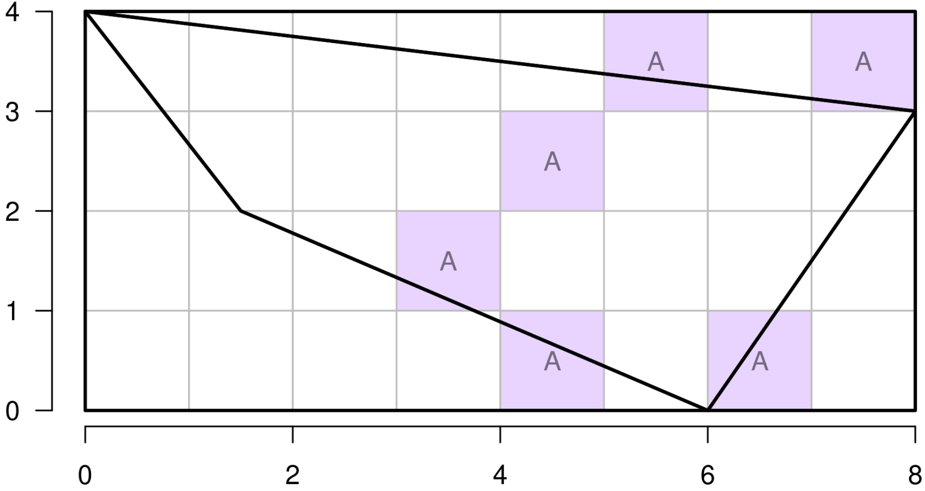

Figure 22: Reclassified raster

Calculate zonal statistics: percent of each polygon with cell values of "A"

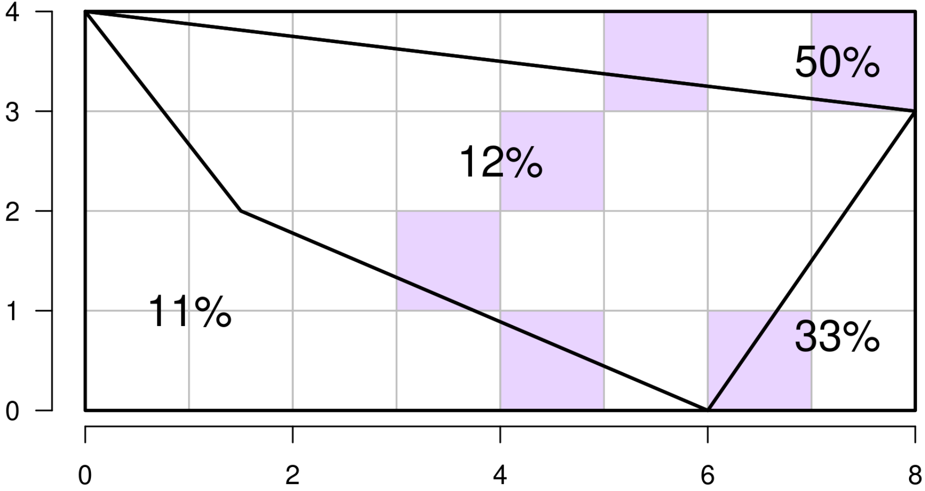

Figure 23: Zonal statistics: value "A" as percent of overlapping cells

Percentages are added to attribute table for polygons

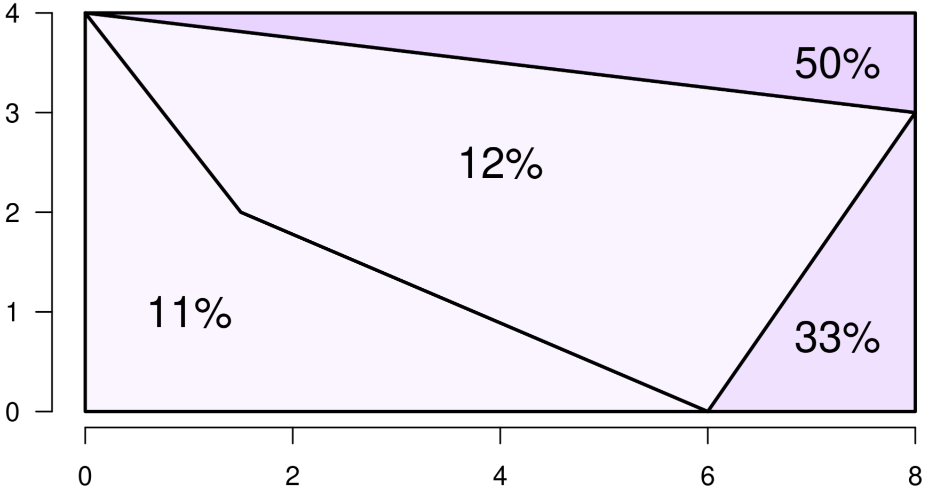

Figure 24: Percent "A" per polygon

Scale-dependence

Scale-Pattern-Process

1. Scale of analysis (spatial, temporal) impacts which patterns are observable
    - these observations shape inferences we draw about underlying social processes
2. Processes drive patterns whose observation is scale-dependent
    - some research questions require high spatial resolution:
        a. urban/neighborhood policy
        b. bomb damage assessment
    - some research questions require high temporal resolution:
        a. emergency response
        b. weather forecasting
    - some questions can be answered at low resolution (e.g. long-term, large-scale)
        a. economic development
        b. deforestation, changes in land use

Trade-offs

- lower resolution (large pixels) = more information loss
- higher resolution (small pixels) = higher collection, storage, computation costs

How scale impacts rasterization and vectorization

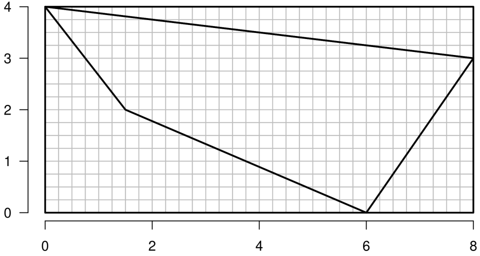

Figure 25: High resolution (small pixels)

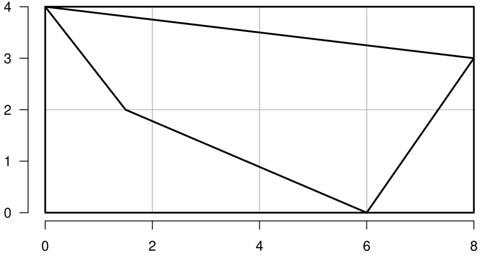

Figure 26: Low resolution (large pixels)

Point-to-raster: same underlying point pattern, two very different rasters

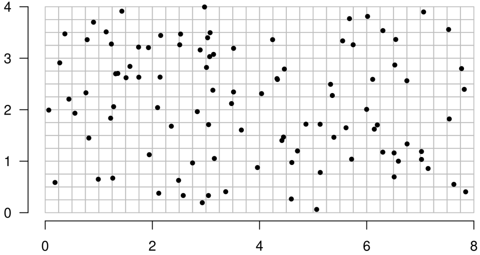

Figure 27: High resolution (small pixels)

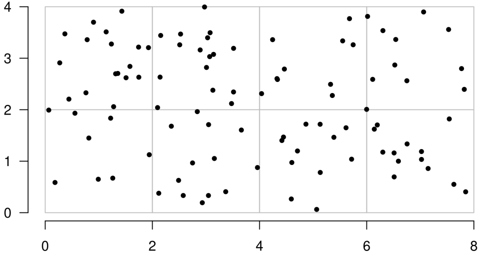

Figure 28: Low resolution (large pixels)

Counts, densities will appear sparser (more intense) in high-(low-)resolution rasters

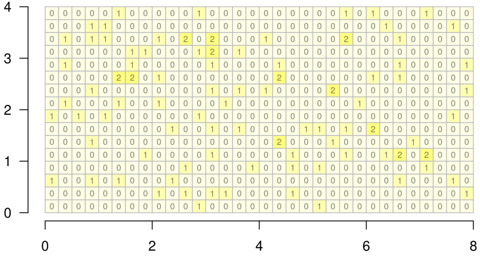

Figure 29: High resolution (small pixels)

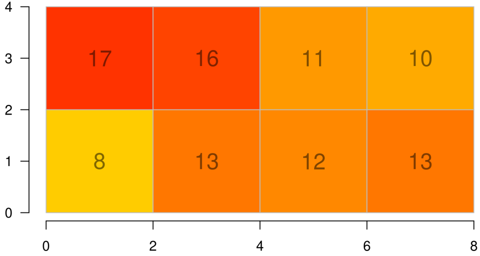

Figure 30: Low resolution (large pixels)

Line-to-raster: same line features, two very different rasters

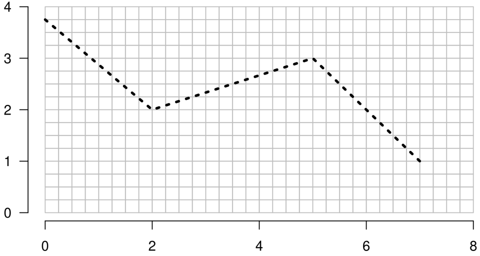

Figure 31: High resolution (small pixels)

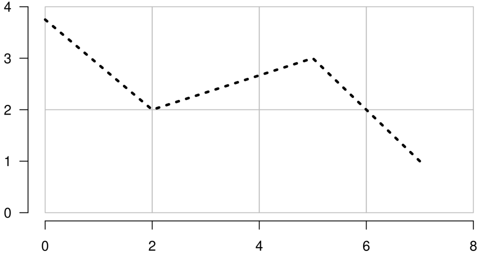

Figure 32: Low resolution (large pixels)

Absence/presence measures are more (less) variable in high-(low-)resolution rasters

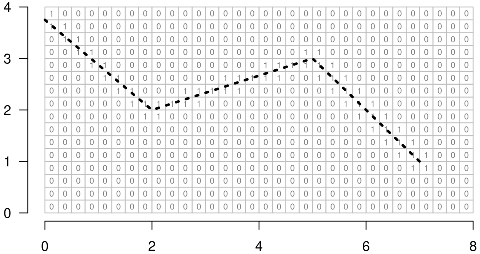

Figure 33: High resolution (small pixels)

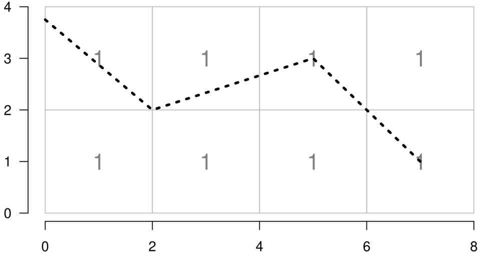

Figure 34: Low resolution (large pixels)

High-(low-)resolution rasters more (less) precisely reflect shape of vector geometries

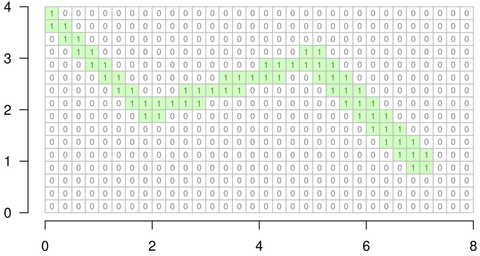

Figure 35: High resolution (small pixels)

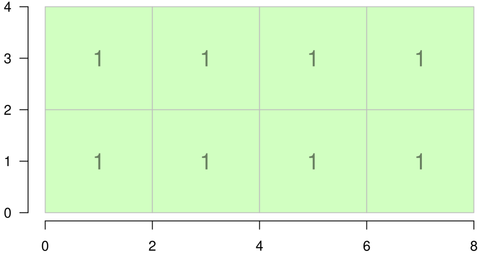

Figure 36: Low resolution (large pixels)

Distance measures also have more (less) variation in high-(low-)resolution rasters

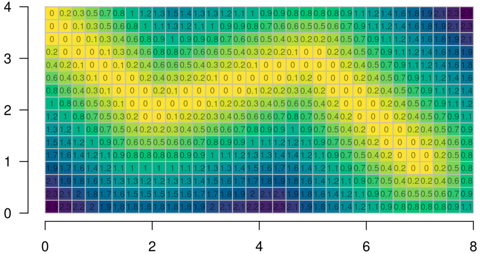

Figure 37: High resolution (small pixels)

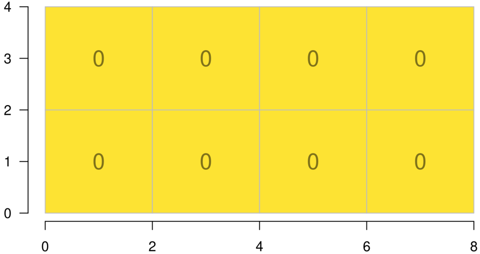

Figure 38: Low resolution (large pixels)

Polygon-to-raster: same polygon features, two very different rasters

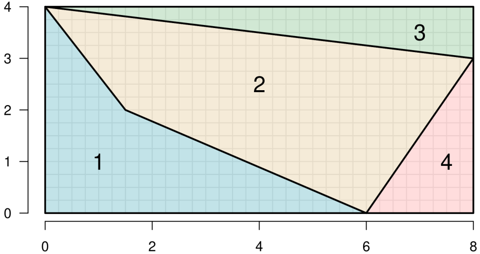

Figure 39: High resolution (small pixels)

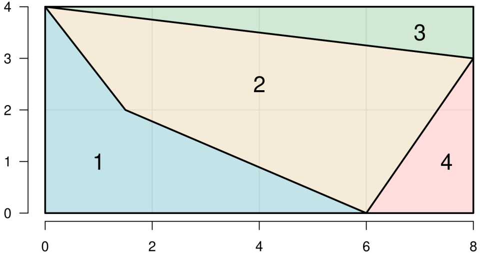

Figure 40: Low resolution (large pixels)

Assignment operations are more (less) coarse in low-(high-)resolution rasters

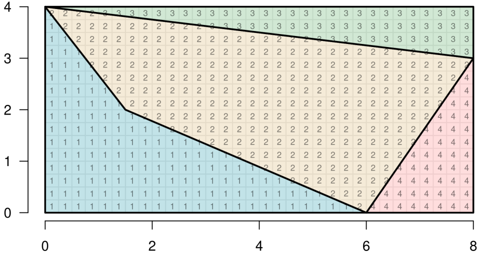

Figure 41: High resolution (small pixels)

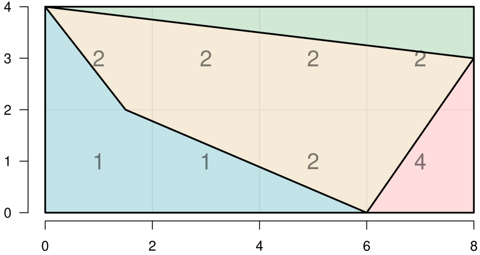

Figure 42: Low resolution (large pixels)

Some polygon features may disappear entirely in low-resolution rasters

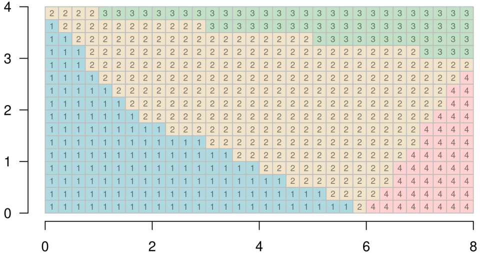

Figure 43: High resolution (small pixels)

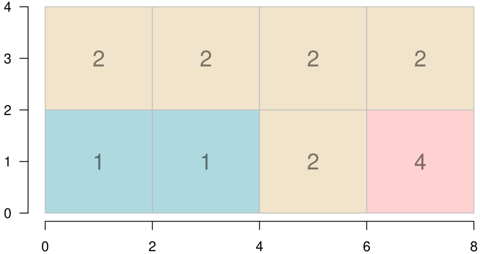

Figure 44: Low resolution (large pixels)

Raster-to-polygon: suppose we have two rasters with same underlying data

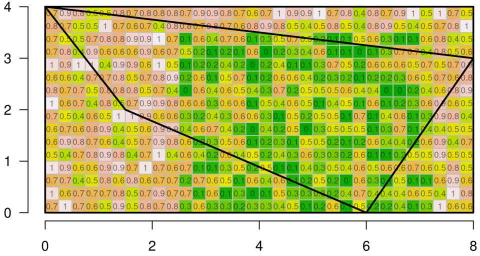

Figure 45: High resolution (small pixels)

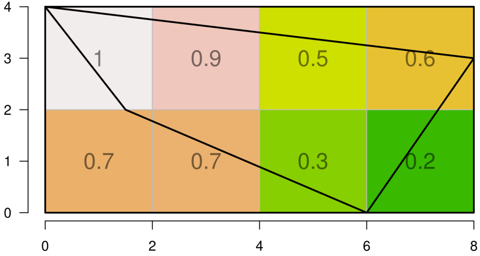

Figure 46: Low resolution (large pixels)

Zonal statistics on the high-resolution raster will be more precise

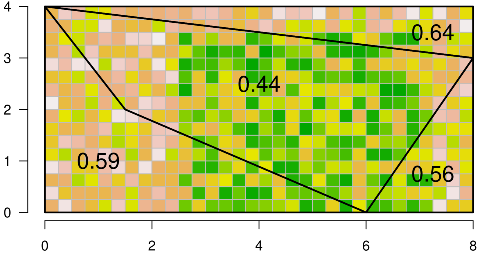

Figure 47: High resolution (small pixels)

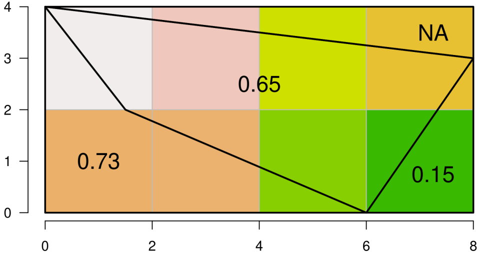

Figure 48: Low resolution (large pixels)

Low-resolution raster is more likely to generate missing values in polygon features

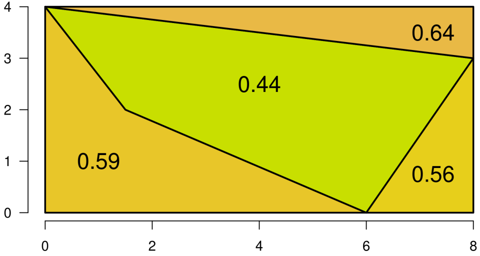

Figure 49: High resolution (small pixels)

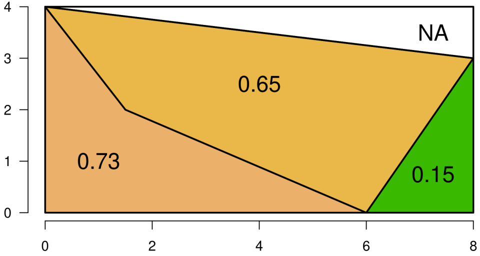

Figure 50: Low resolution (large pixels)

Similar problems arise with zonal statistics on rasters with categorical variables

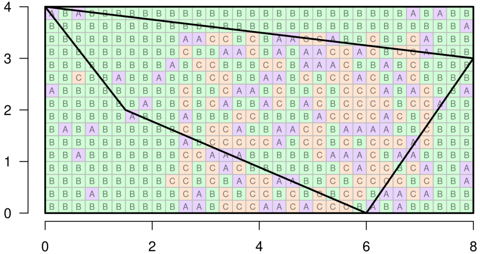

Figure 51: High resolution (small pixels)

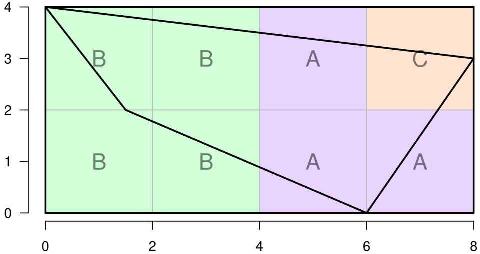

Figure 52: Low resolution (large pixels)

Lower resolution → fewer raster cells to calculate statistics over, less precision

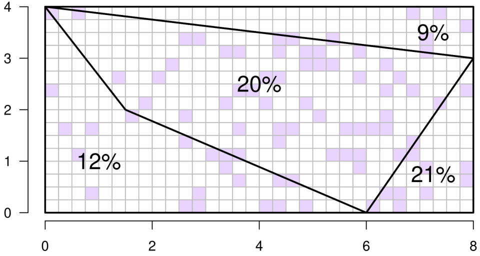

Figure 53: High resolution (small pixels)

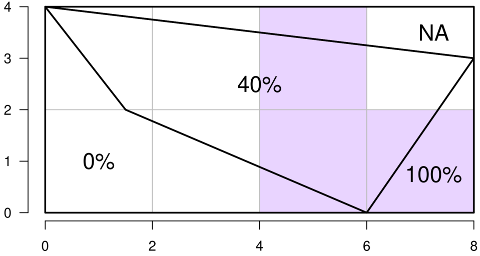

Figure 54: Low resolution (large pixels)

Low resolution rasters may sometimes also exaggerate amount of variation

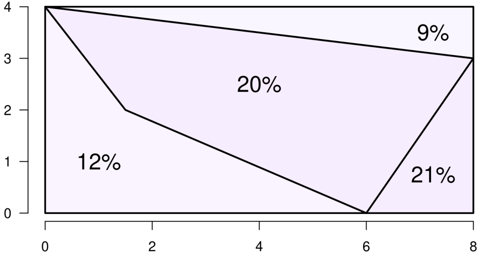

Figure 55: High resolution (small pixels)

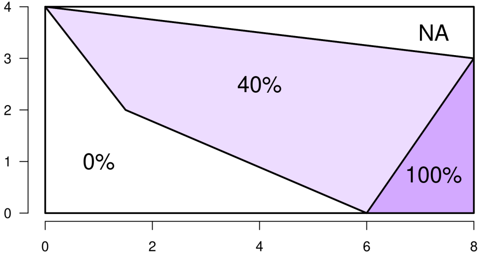

Figure 56: Low resolution (large pixels)

Why not always use highest-resolution raster data?

- high-res data may not exist (due to orbital requirements, low user demand)
- high-res satellite data are sometimes inaccessible (classified, proprietary)
- high-res data are expensive to collect, transmit, store (terabytes, petabytes)
- high-res data take up *a lot* of memory, need high-performance computing
- high-res data may not be needed to answer research question (don't need 1-meter resolution to study regional, national, global phenomena)

Figure 57: Which scale is right for me?