



An Introduction to Cartography

Maps Maps Maps Maps

Agenda

- **Why** should we learn about mapping?
- **What** cartography principles do we need to know?
- **How** do we draw maps?
- **Where** can I go for more?

Why mapping?

Cartography

- Cartography: the **practice**, **science**, and **art** of drawing maps
 - Like most data visualization, cartography can be performed
 - **Well** *or*
 - **Poorly**
 - How do good maps go bad?
 - Substance, perception, aesthetics

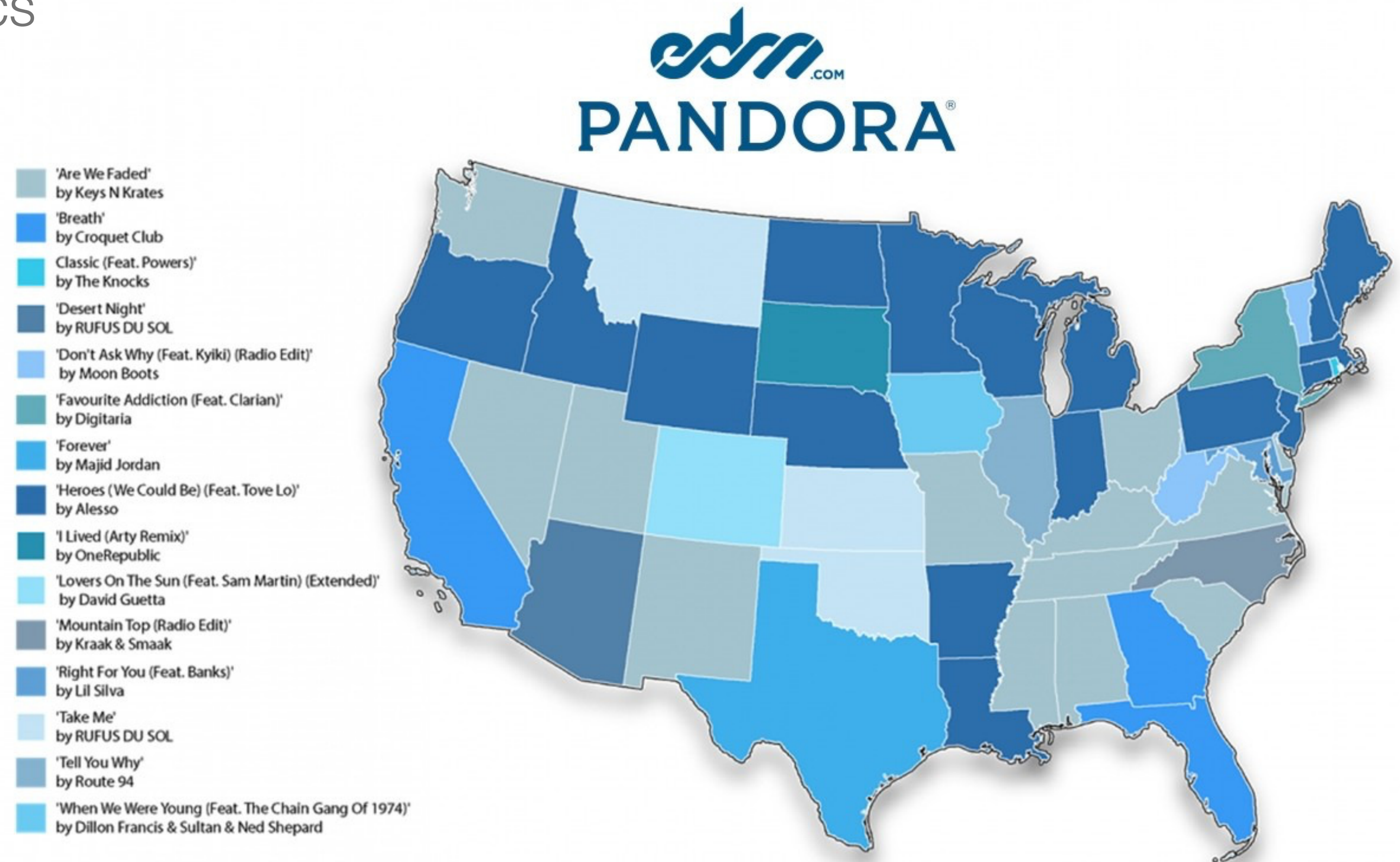
How do good maps go bad?

- By not paying attention to the mode of graphics reproduction



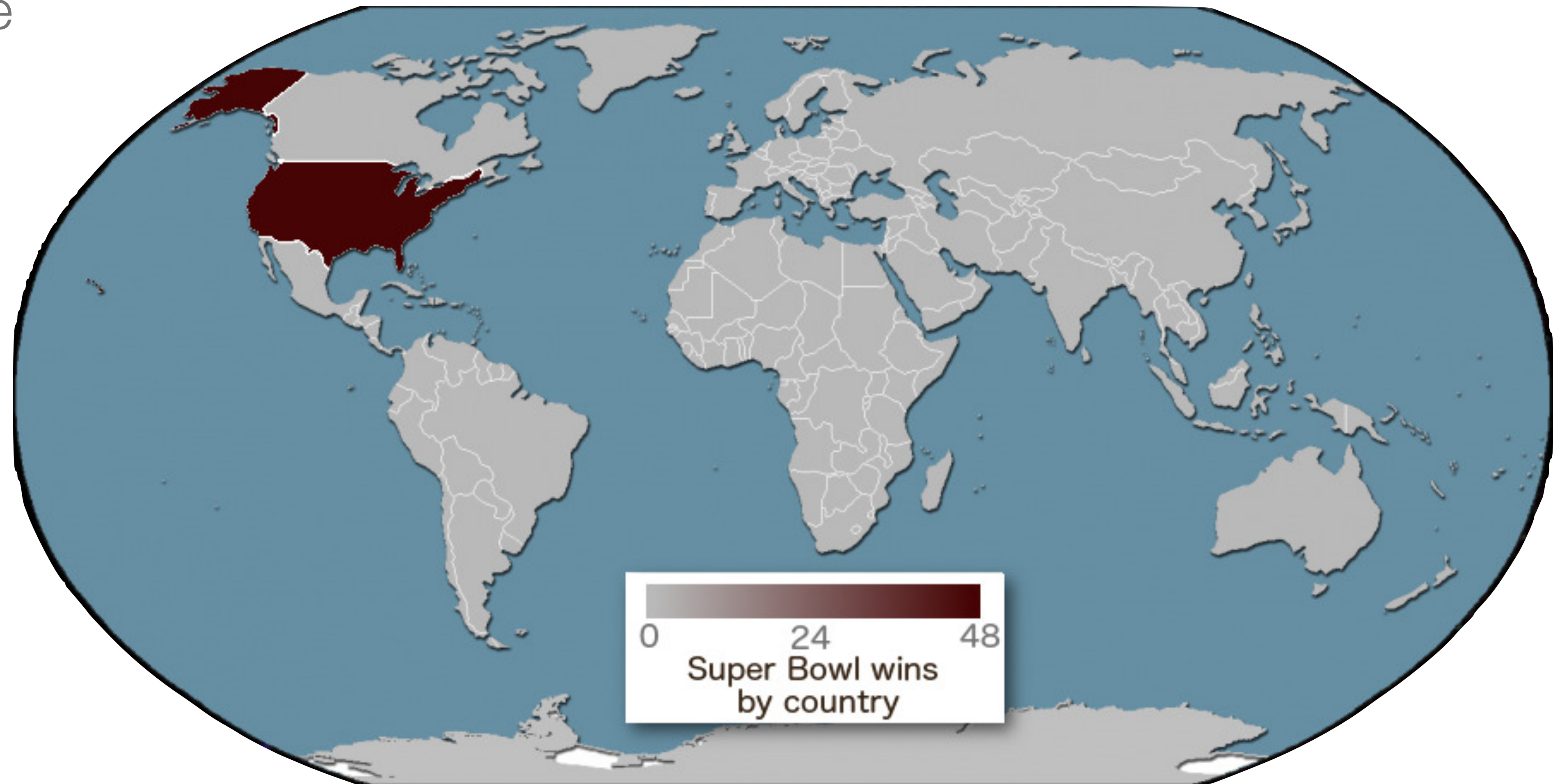
How do good maps go bad?

- By prioritizing aesthetics over perception



How do good maps go bad?

- Poor substance



How do good maps go bad?

- Poor substance



How do good maps go bad?

- Poor substance.
 - *For the record:*
 - Stops are not flights
 - What exactly do the numbers on the bottom represent?
 - London is not in Spain



How do good maps go bad?

- Errors with the production process
- And a failure to double check
- “Hong Kong”



How do good maps go bad?

- Errors with the production process
- And a failure to double check
- Tripoli is the capital of Libya, not Lebanon



How do good maps go bad?

- Errors with the production process
- And a failure to double check
- That is not Cannes, nor is it France



How do good maps go bad?

- Errors with the production process
- And a failure to double check
- **Pakistan, not Ukraine**



How do good maps go bad?

- Errors with the production process
- And a failure to double check
- **Yugoslavia reunited;
called Bulgaria**



How do good maps go bad?

- Errors with the production process
- And a failure to double check
- **Niger, not Nigeria**



How do good maps go bad?

- Errors with the production process
- And a failure to double check
- “Egypt”



How do good maps go bad?

- Errors with the production process
- And a failure to double check
- **Czechoslovakia lives!**



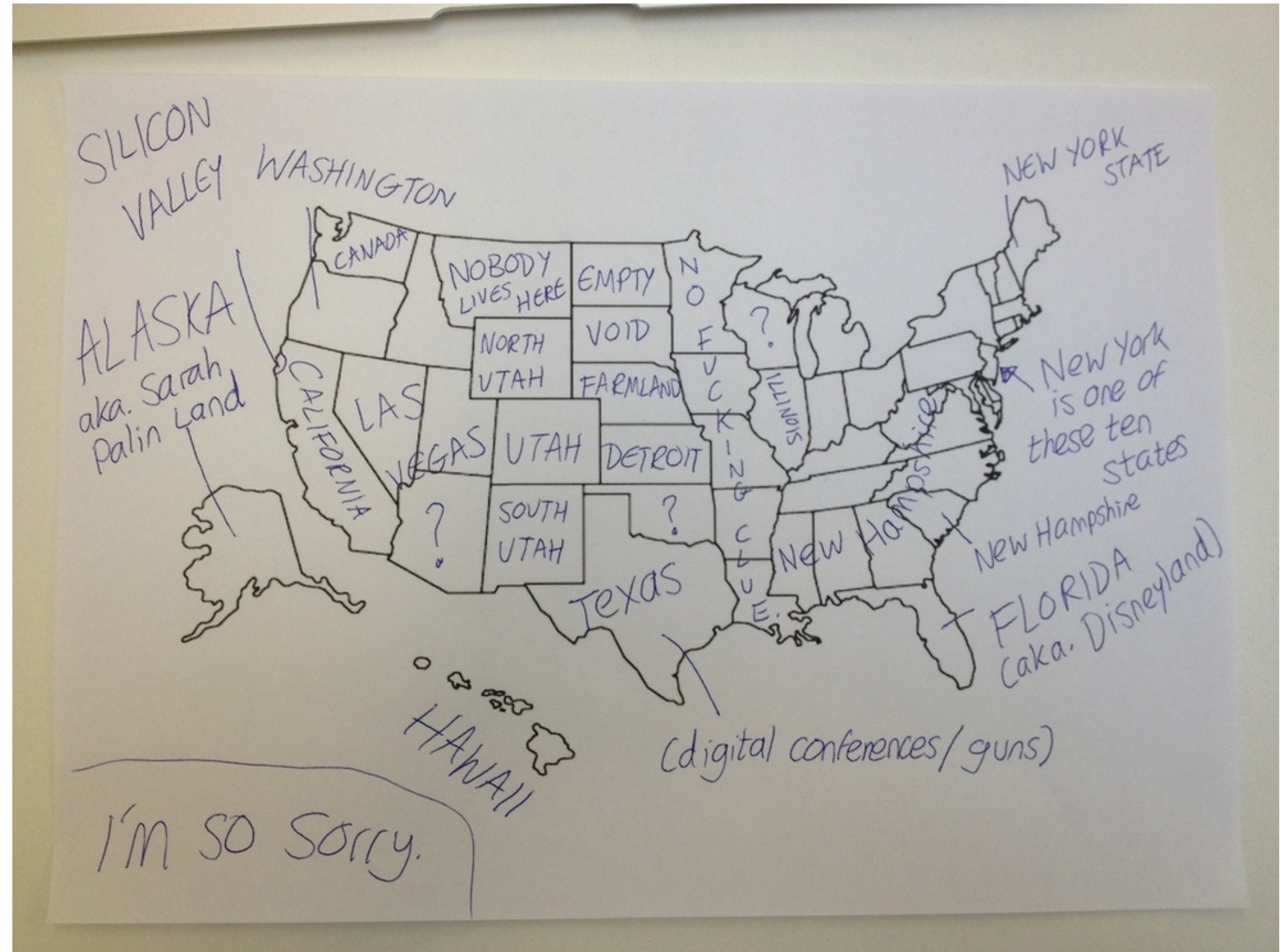
How do good maps go bad?

- Errors with the production process
 - And a failure to double check
- We're not even immune in our own country. Sorry, uh, "Idaho"



How do good maps go bad?

- Now, much of this comes from an understandable lack of knowledge of geography
- “A Brit tries to label the United States”



- Now, much of this comes from an understandable lack of knowledge of geography

- Which is fair for an average citizen. **But if you're making a data graphic, you owe it to yourself to double check**



How do we make a good map?

- Attention to core graphics principles (Healy)
 - Perception
 - Substance
 - Aesthetics
- With special focus on the constraints and constructs of cartography

What cartography principles do I need to know?

Outline

- I. What is a map?
- II. Elements of Maps
- III. Coordinates
- IV. Projection
- V. Areal Units
- VI. Color and Contrast
- VII. Overall Design

I. What is cartography?

Cartography 101: What is a **map**?

- A map is a **model** of **space**
 - All models abstract, eliminate detail, simplify, and emphasize



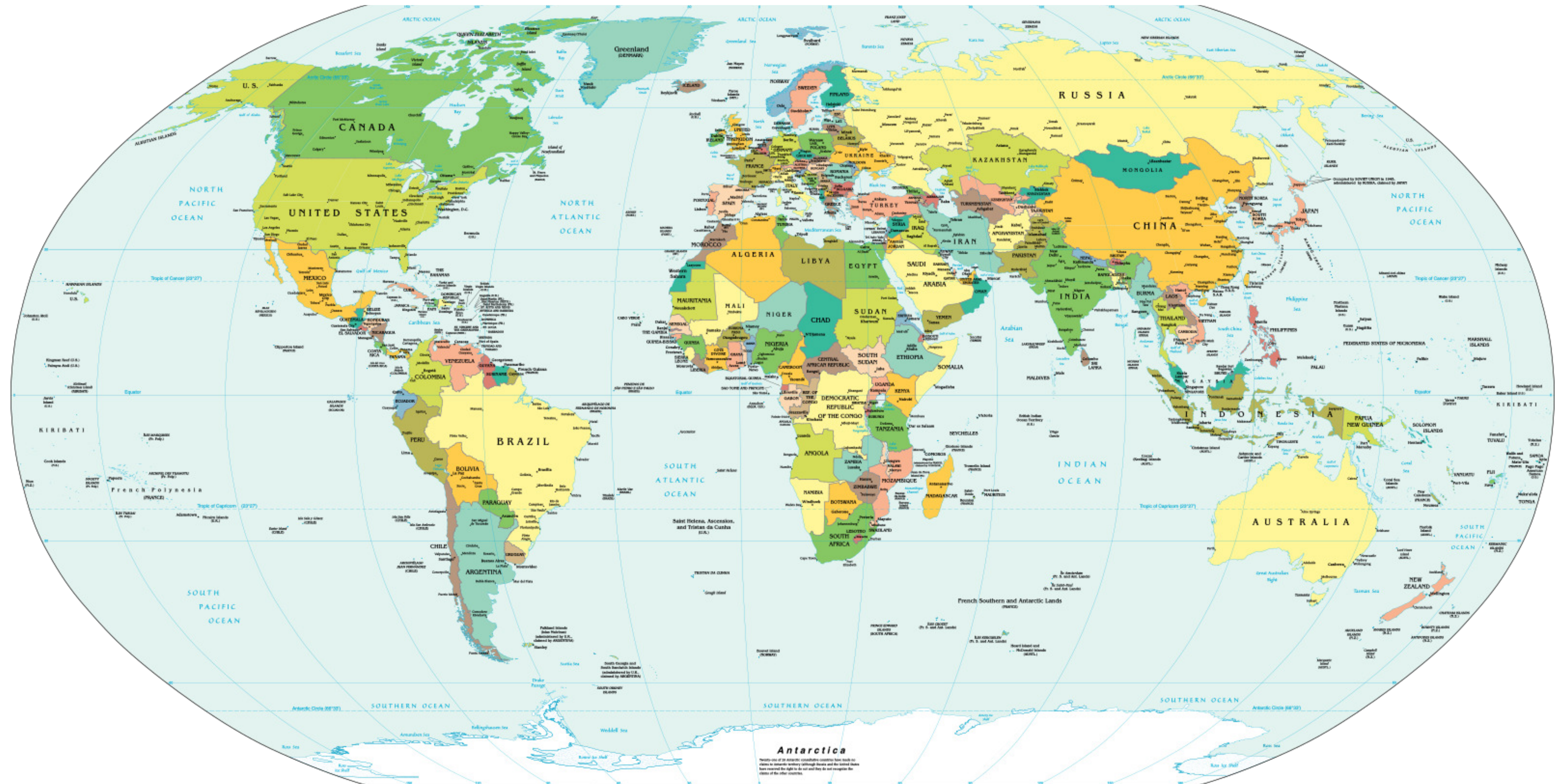
“All models are wrong.”

–attributed to George Box (statistician)

“Some models are usefully wrong.”

– also attributed to George Box

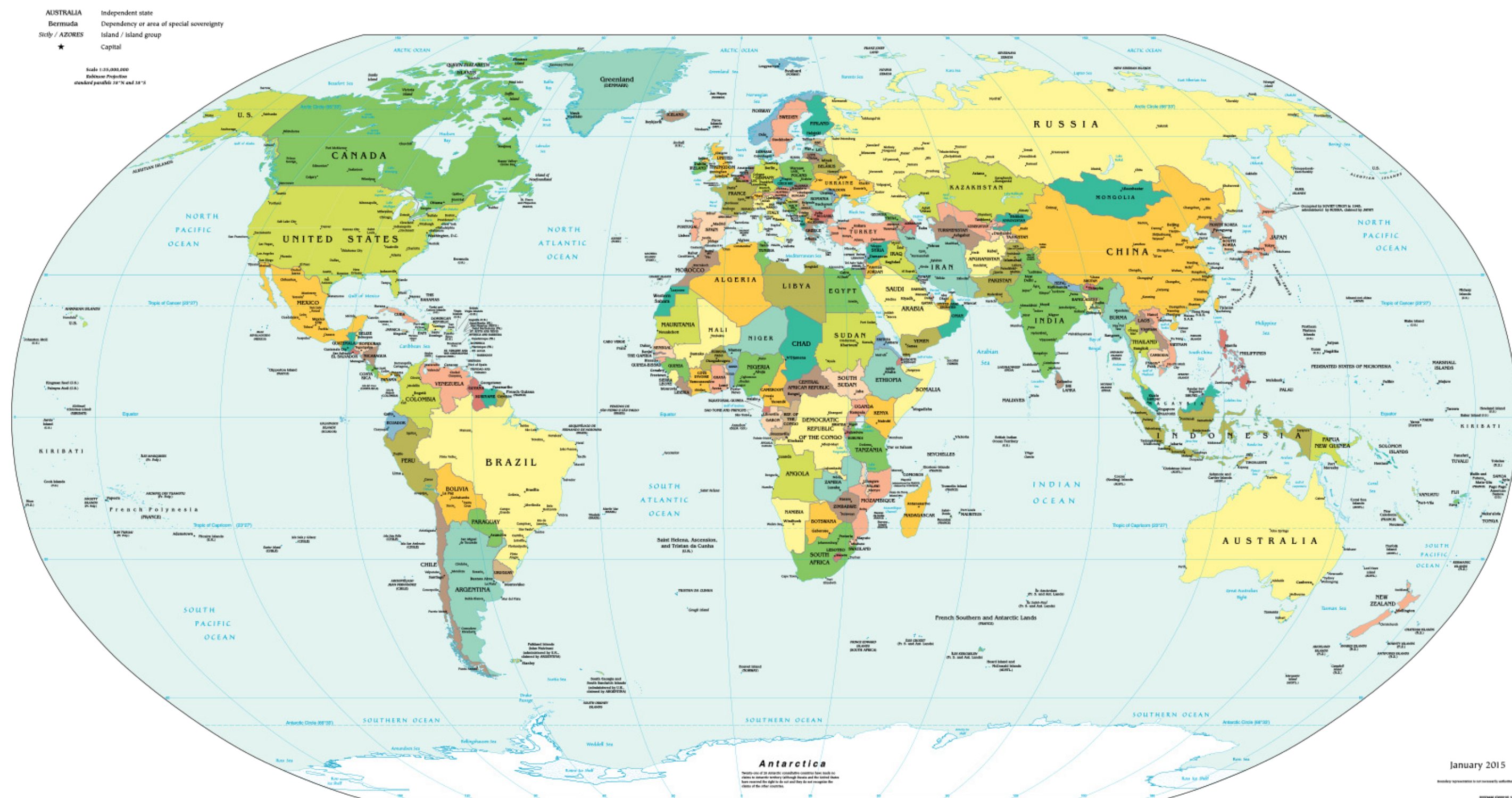
A simple political model of the world



What's omitted here?

- **Everything** (almost)
- Topography
- Demography
- Economy
- Non-large water
- Any politics not an international boundary
- *the list goes on*

Political Map of the World, January 2015



"A map is not the territory it represents, but, if correct, it has a similar structure to the territory, which accounts for its usefulness."

- Alfred Korzybski

“Map is not Territory”

- What are we trying to illustrate? What function are we trying to perform?
 - Navigate roads, seas, or backcountry?
 - Analyze or visualize spatial relationships?
 - Tell a story?
 - Persuade?
 - Create art?

“Map is not Territory”

- We will always omit data - **map is not territory** - but a good map:
 - **Illustrates** its fundamental contrasts and serves its primary purpose while
 - **Not misleading** its audience about either
 - The fundamental data relationships it is trying to show
 - Other related data relationships in the territory

II. Elements of Maps

Fundamental Elements

- Point - locations of interest
- Lines - connections, routes, links, borders
- Polygon - area, area characteristics

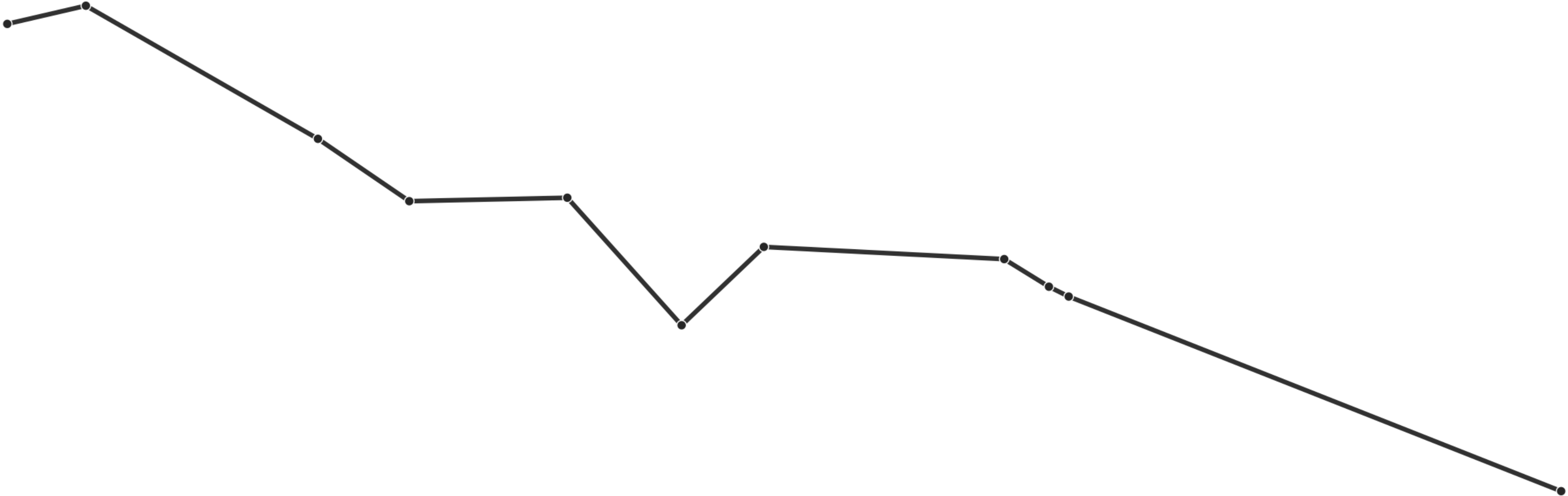
Styling and Informational Elements

- Color
 - Often, our primary mechanism for encoding contrast
 - Categorical vs Continuous
- Labels
- Scale
 - Relationship between map distance and real-world distance

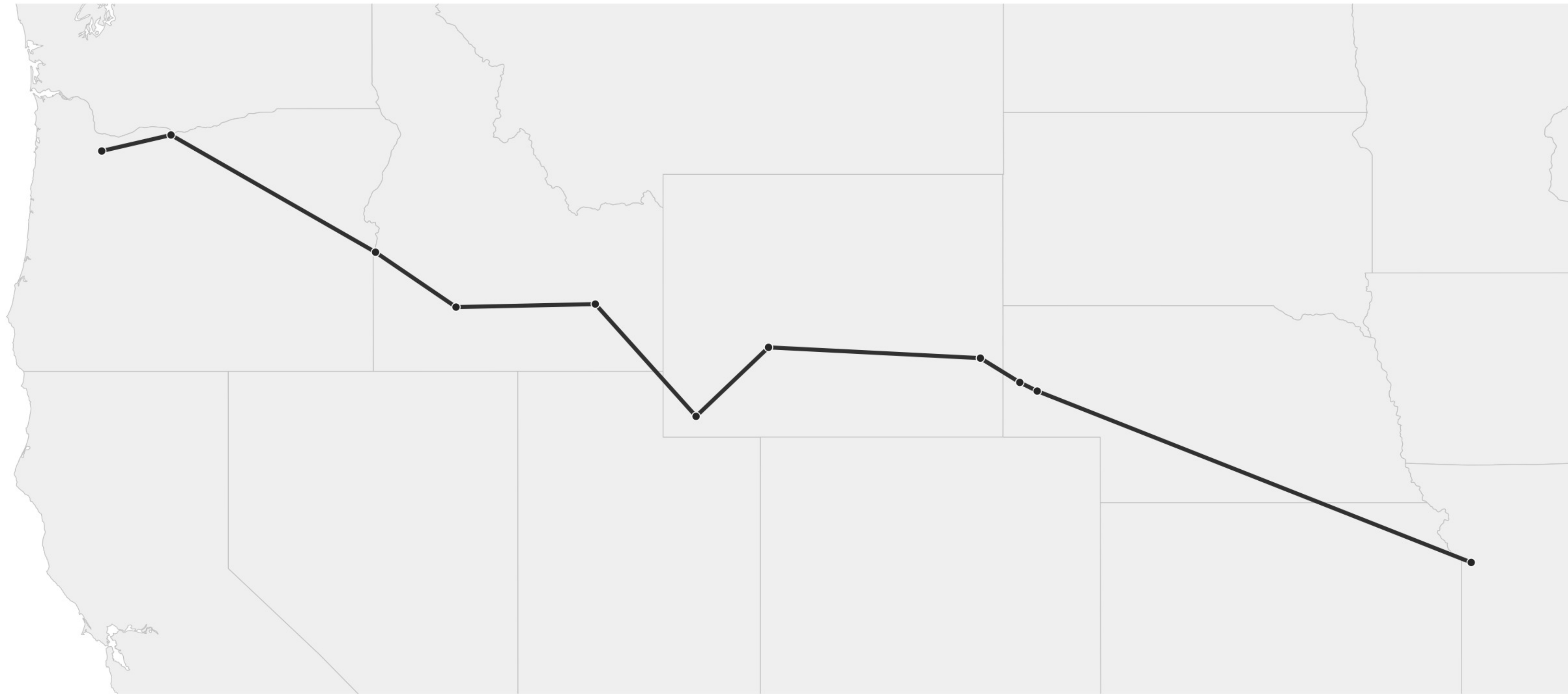
Points



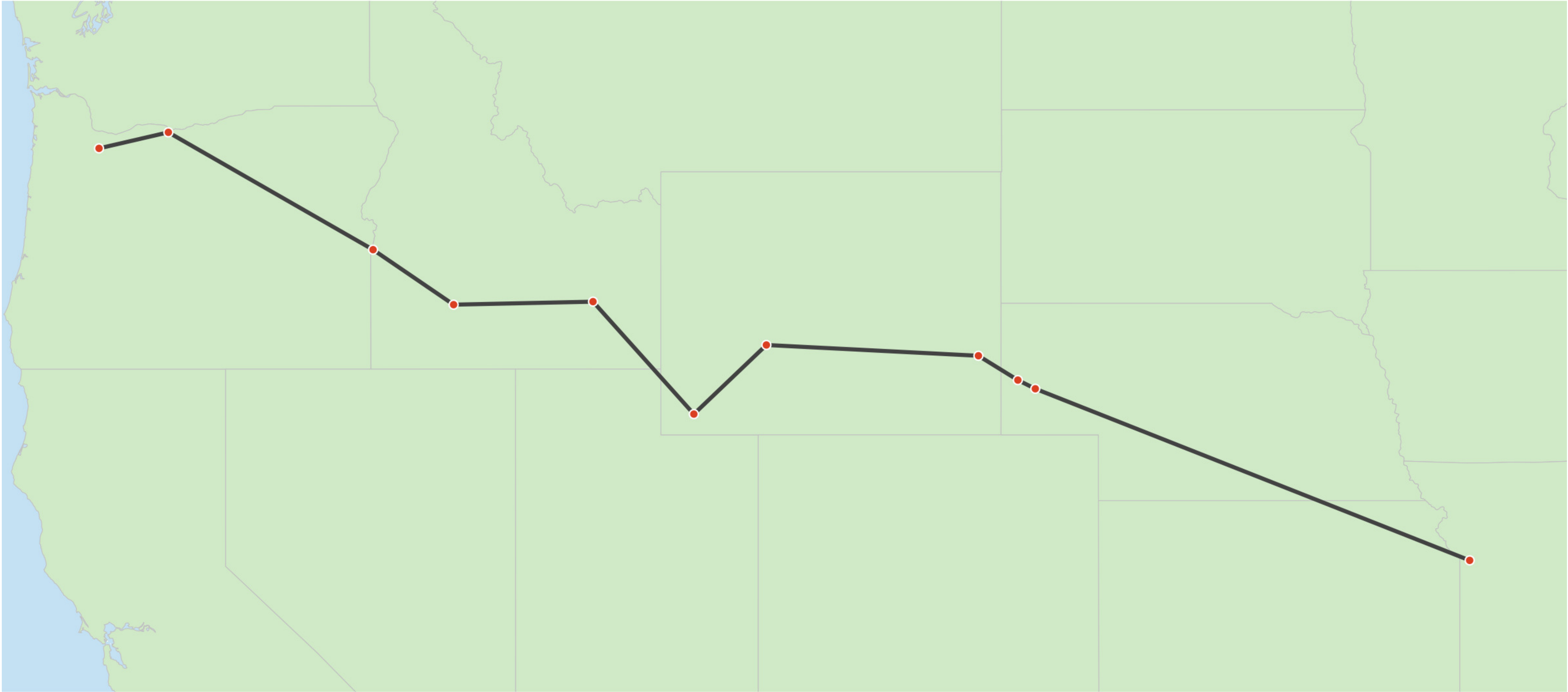
Lines



Polygon



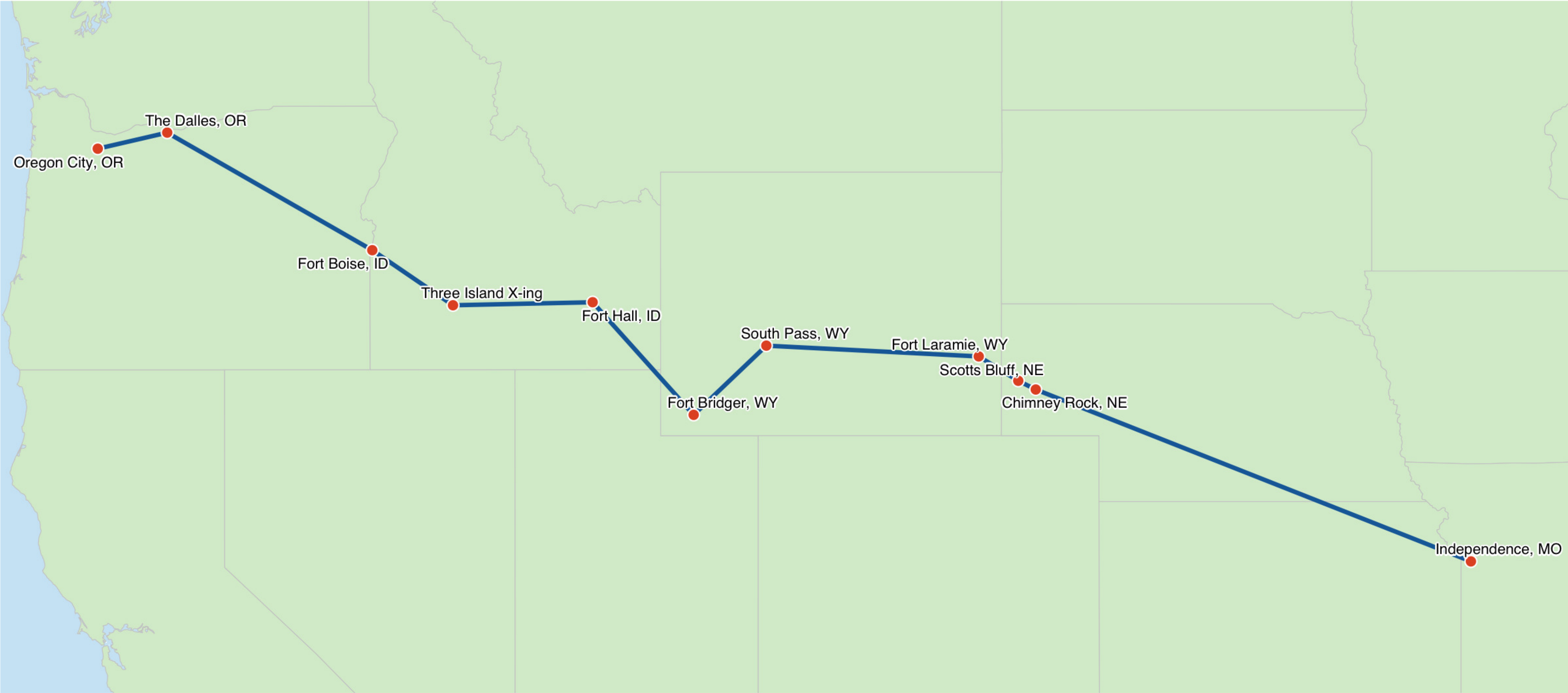
Styling options: color



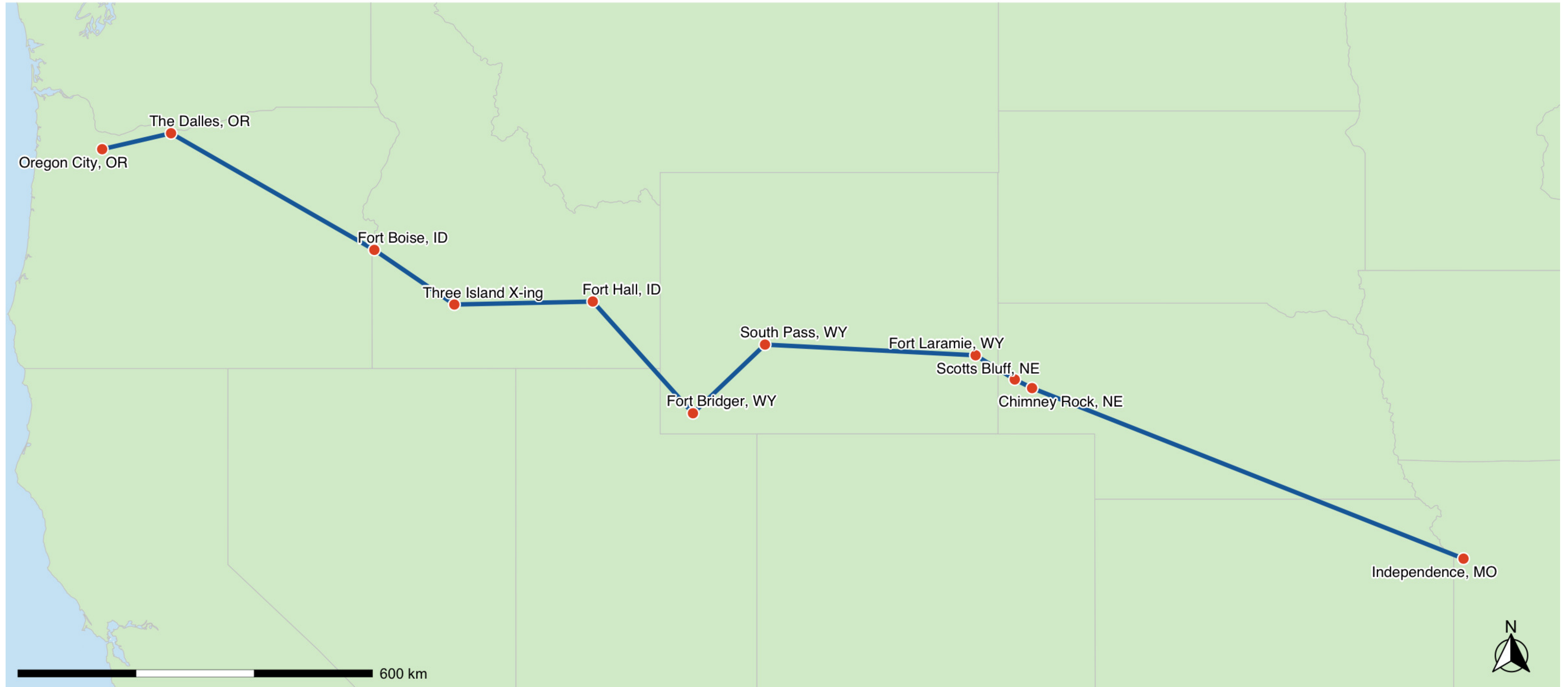
Styling options: point labels



Styling options: combining point labels and color



Adding scale, data, and orientation information



Data: naturalearth (states). Waypoints are approximate.

III. Coordinate systems

Mathematics of map drawing

- We're used to drawing graphs with X and Y variables
- This is how we use ggplot
 - Declare an x and a y in the core command
 - Map it with a geom and apply labels and aesthetics

```
ggplot(df, aes(x = years, y = values)) +  
  geom_line(color = "blue", linewidth = 1) +  
  geom_point(color = "red", size = 3) +  
  labs(title = "Line Graph (ggplot2)",  
        x = "Year", y = "Value") +  
  theme_minimal()
```


Mathematics of map drawing

- Mapping relies on similar X and Y, but are less abstract:
 - We use coordinate systems (like latitude and longitude)

```
ggplot(data = us_states,  
       mapping = aes(x = long, y = lat, group=group)) +  
  geom_polygon(fill = "white", color = "black")
```

- Simple, right?
 - *Not so fast.*

We have many, many coordinate reference systems

- Geographic coordinate system
- Geocentric coordinate system
- Projected coordinate system
- Engineering coordinate system
- Vertical reference frame

We have multiple coordinate reference systems

- Even within the nice frames of the geographic coordinate system (latitude and longitude), we have different encodings and standards.

• *From wikipedia*



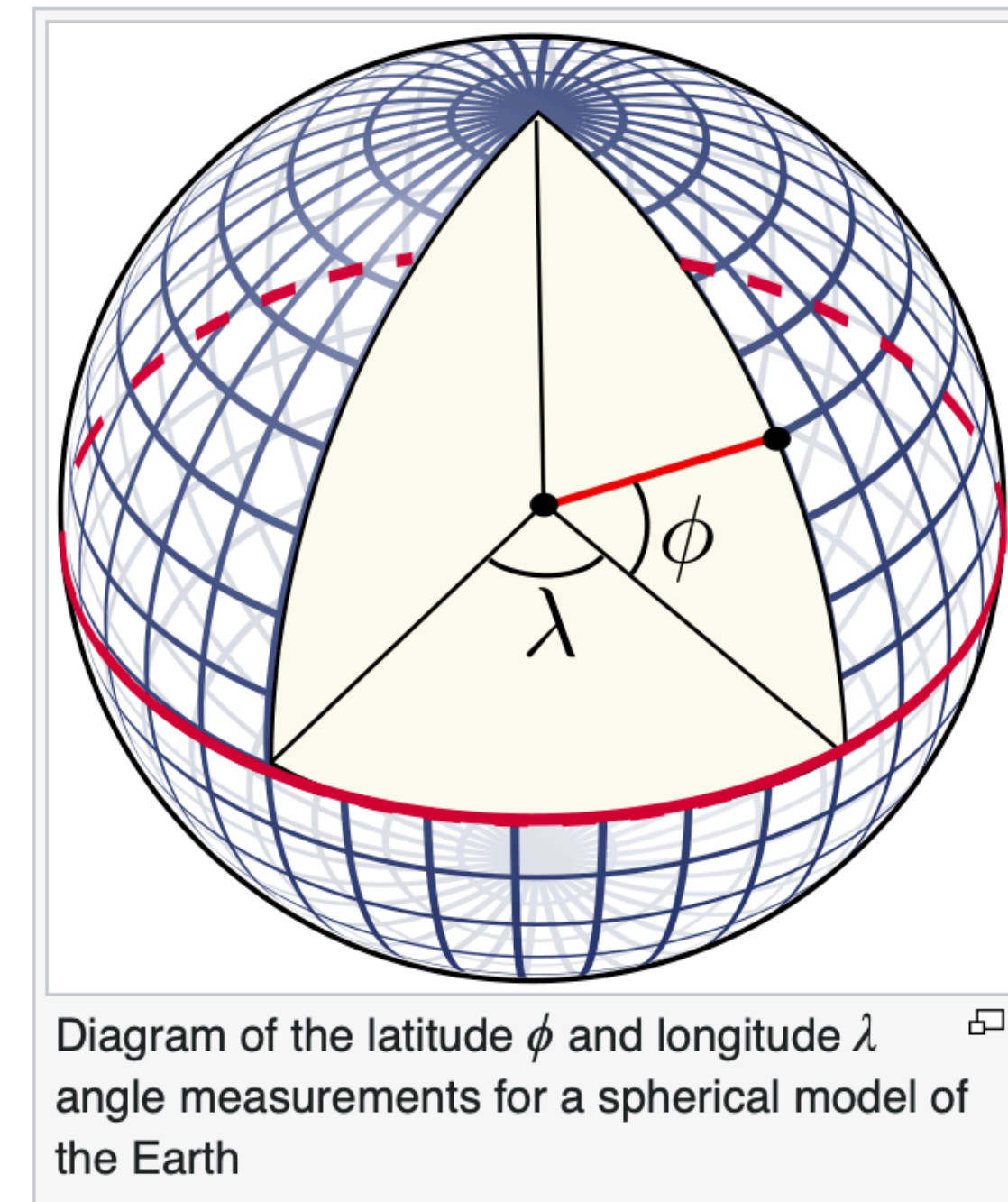
- For now, our goal isn't to dive into all of this. It's just to acknowledge its presence

Latitude and longitude

Main articles: [Latitude](#) and [Longitude](#)

The *latitude* ϕ of a point on Earth's surface is defined in one of three ways, depending on the type of coordinate system. In each case, the latitude is the angle formed by the plane of the equator and a line formed by the point on the surface and a second point on equatorial plane. What varies between the types of coordinate systems is how the point on the equatorial plane is determined:

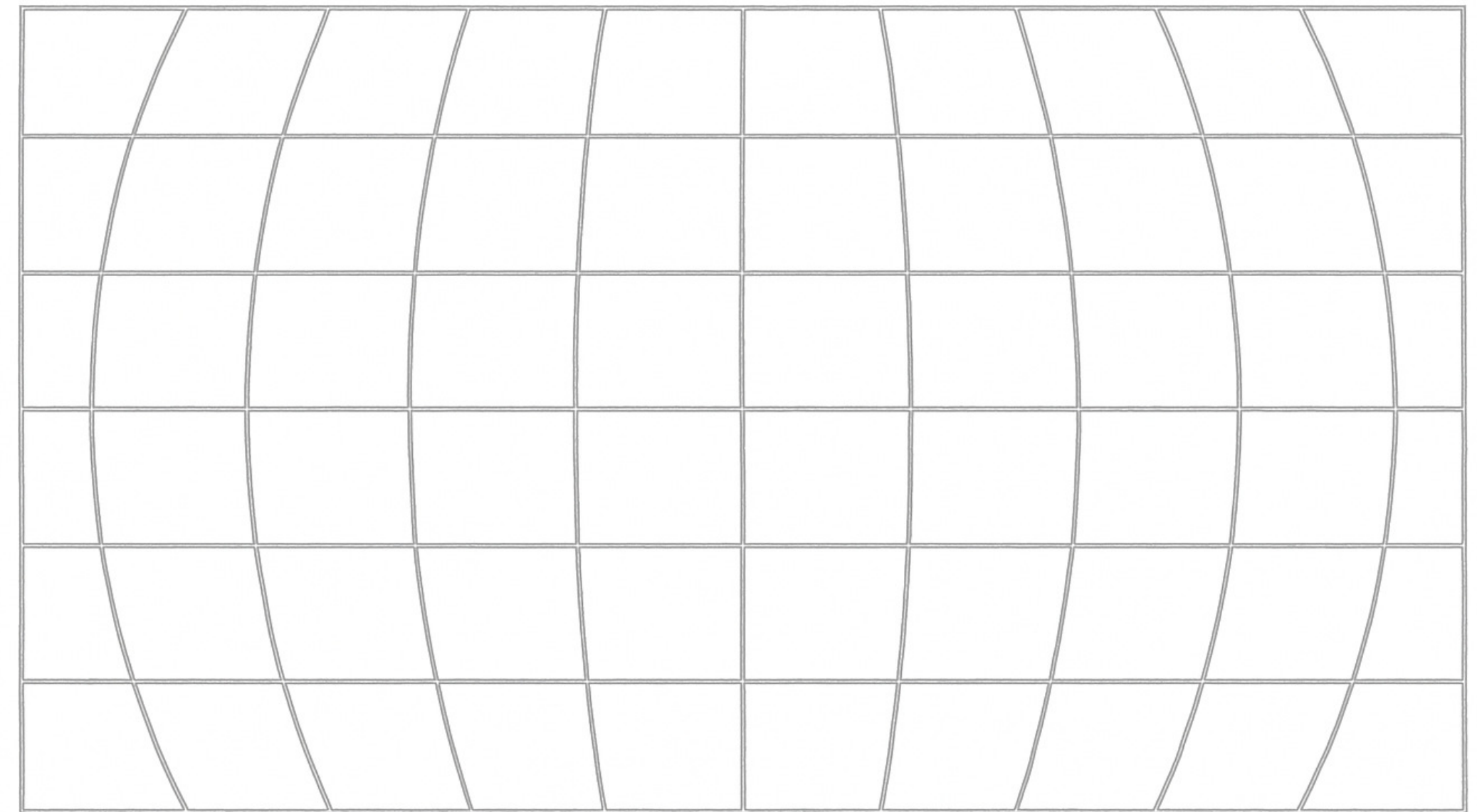
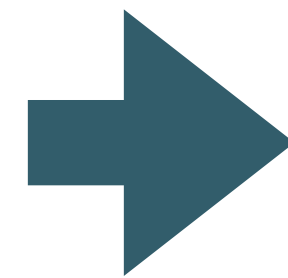
- In an astronomical coordinate system, the second point is found where the extension of the [plumb bob](#) vertical from the surface point intersects the equatorial plane.
- In a geodetic coordinate system, the second point is found where the [normal vector](#) from the surface of the ellipsoid at the surface point intersects the equatorial plane.
- In a geocentric coordinate system, the second point is the center of Earth.



IV. Projection

Problem 2: geometry

- Maps **project** a **spherical** area onto a **flat** surface



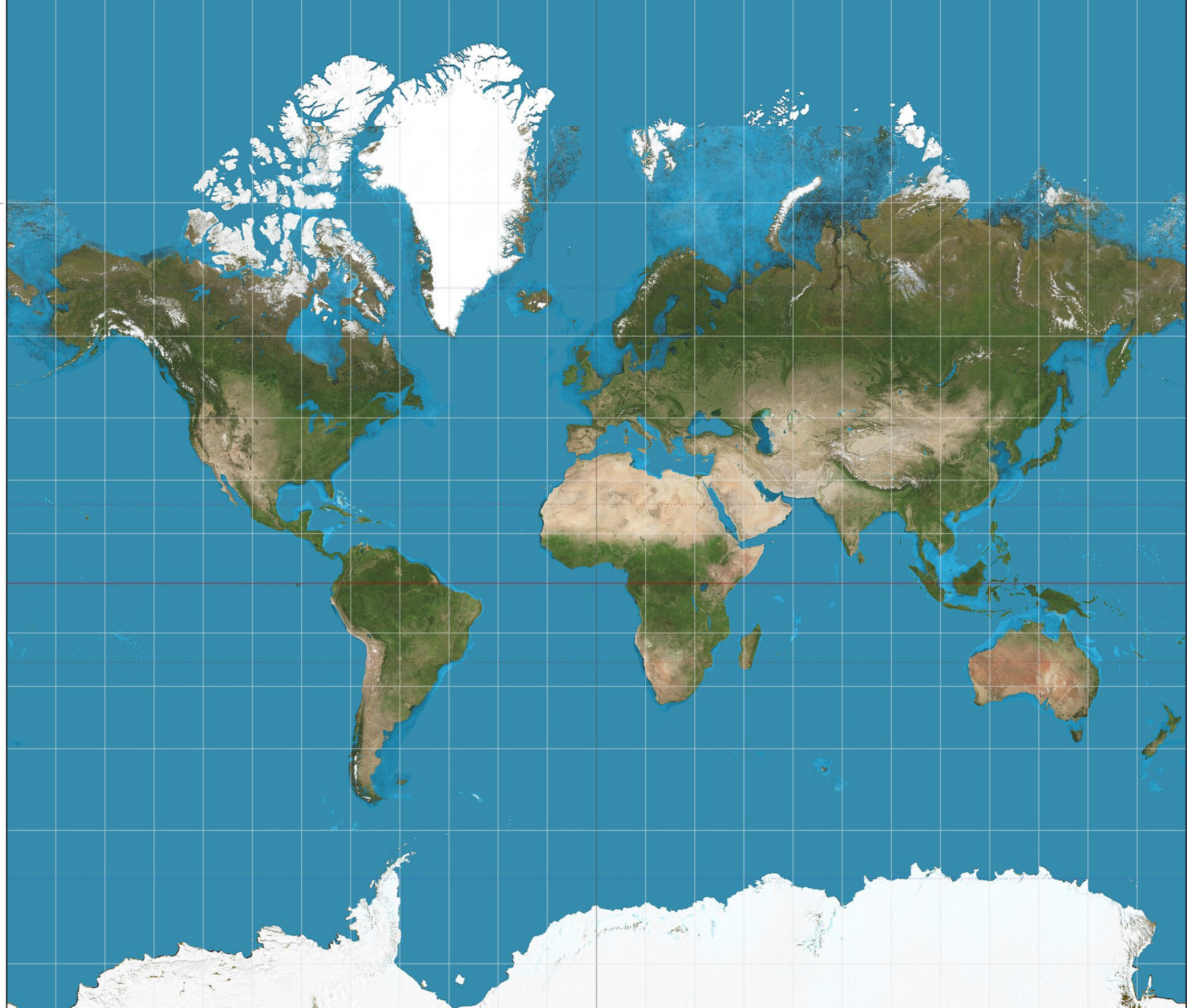
- We call this a map ***projection***

Mercator

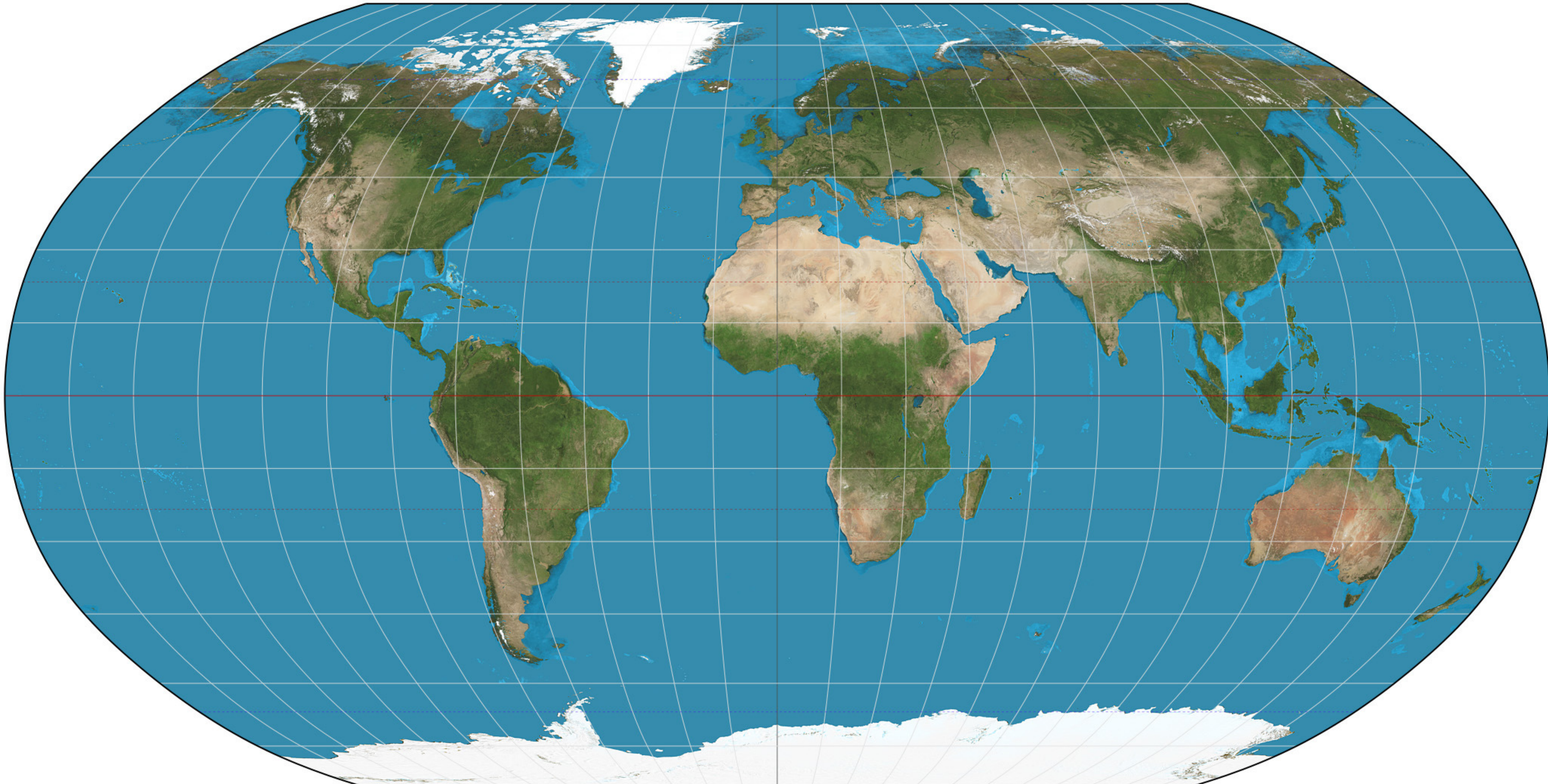


Mercator

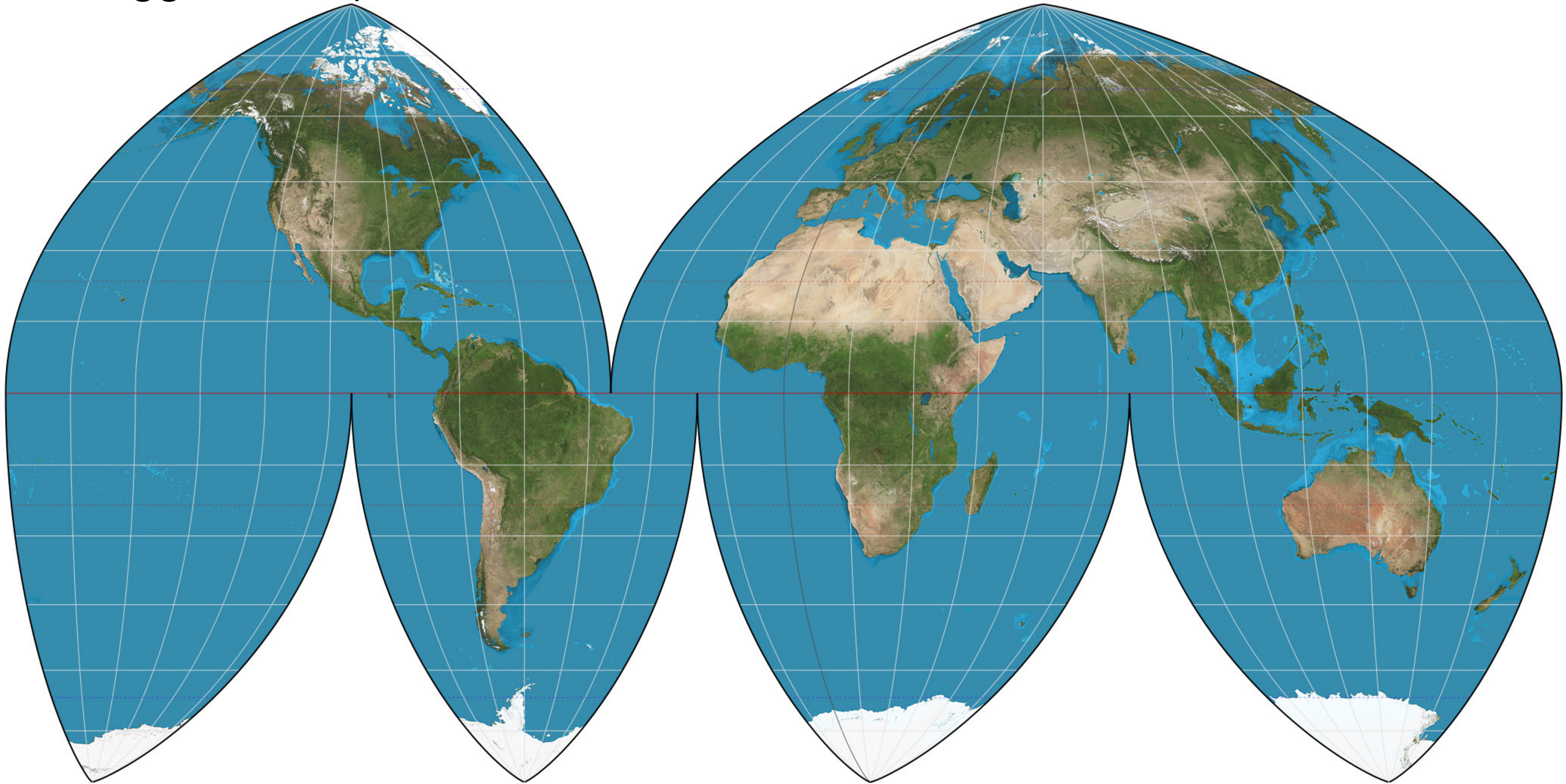
- Often shown more like this



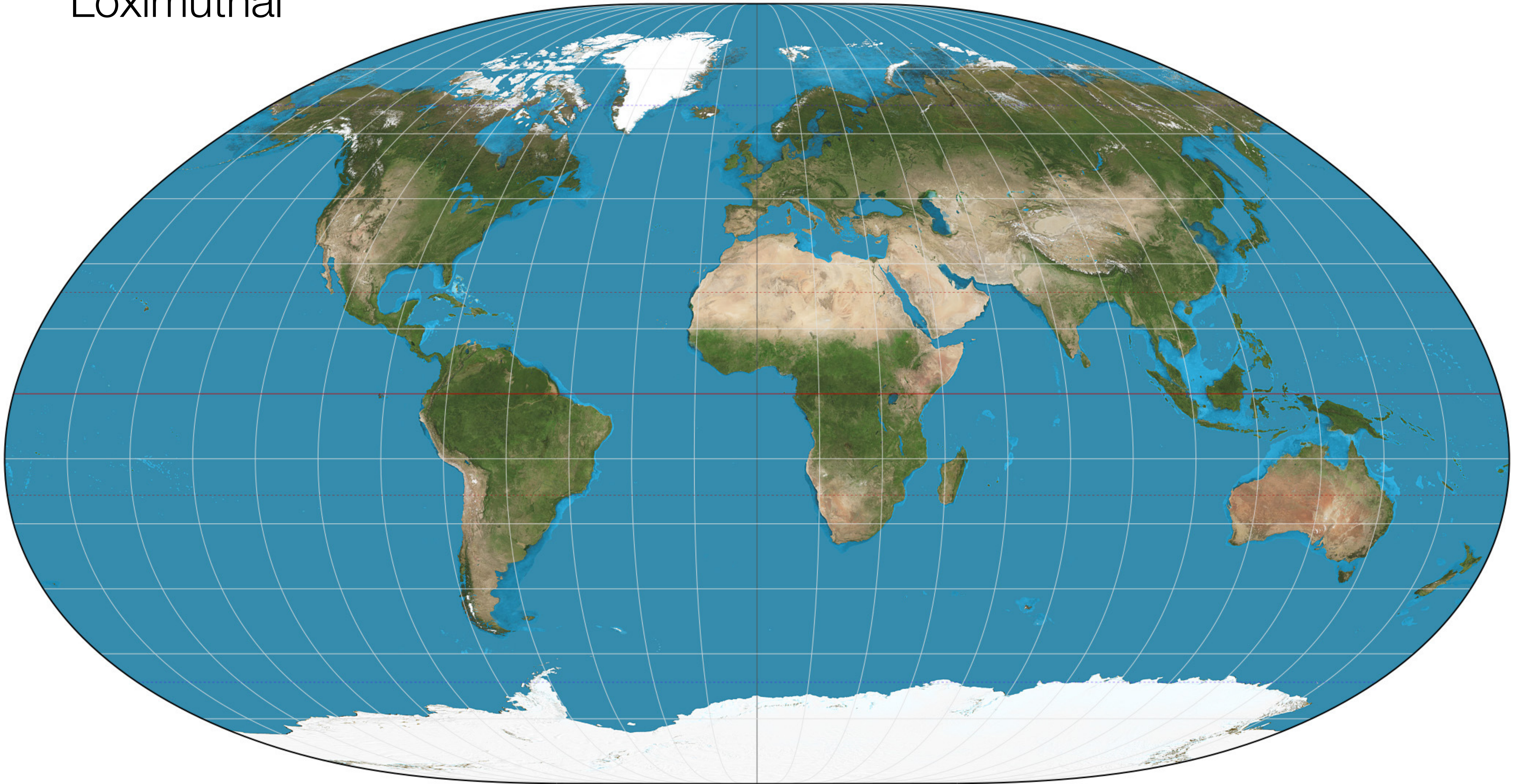
Robinson



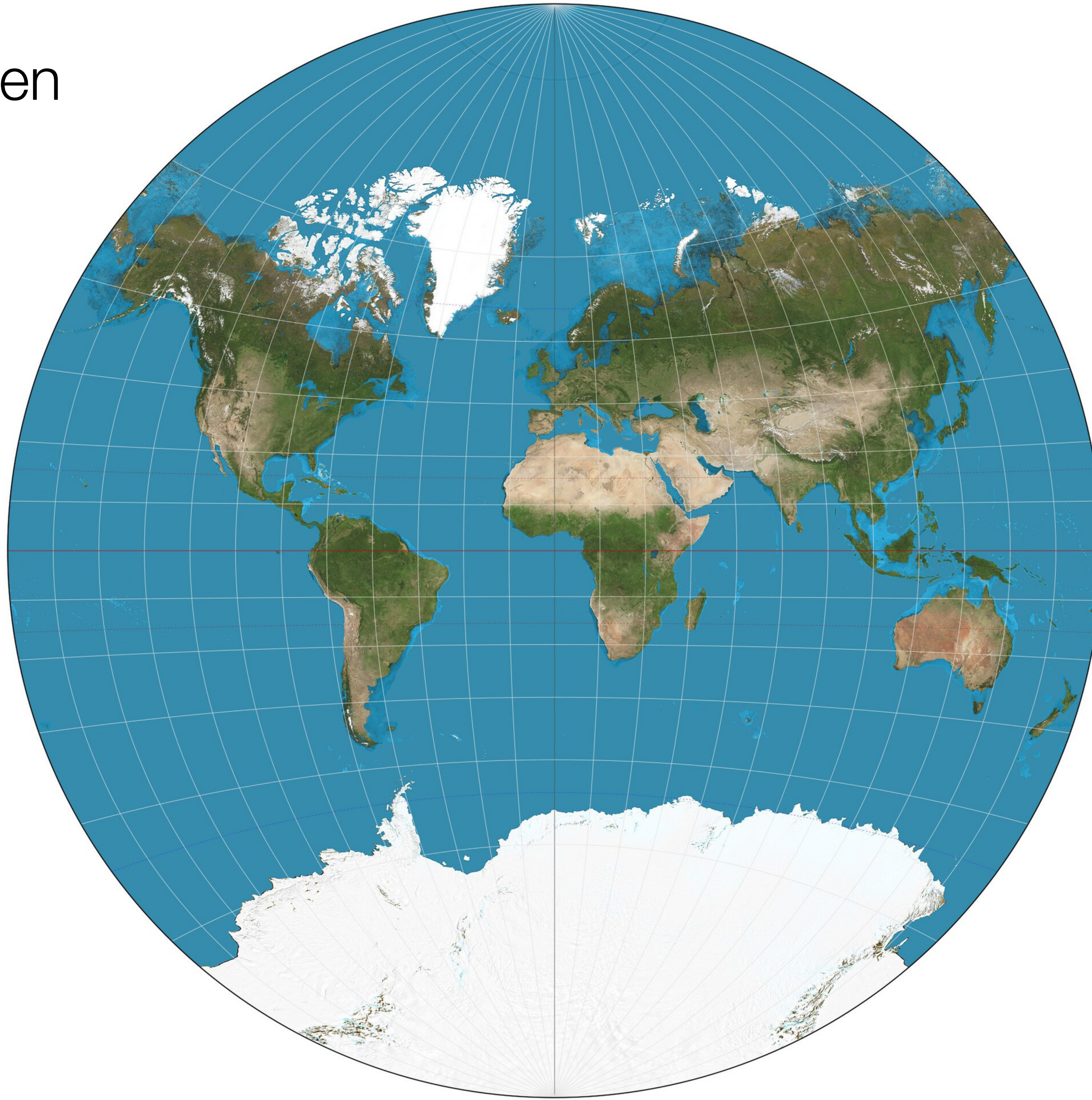
Boggs Eumorphic



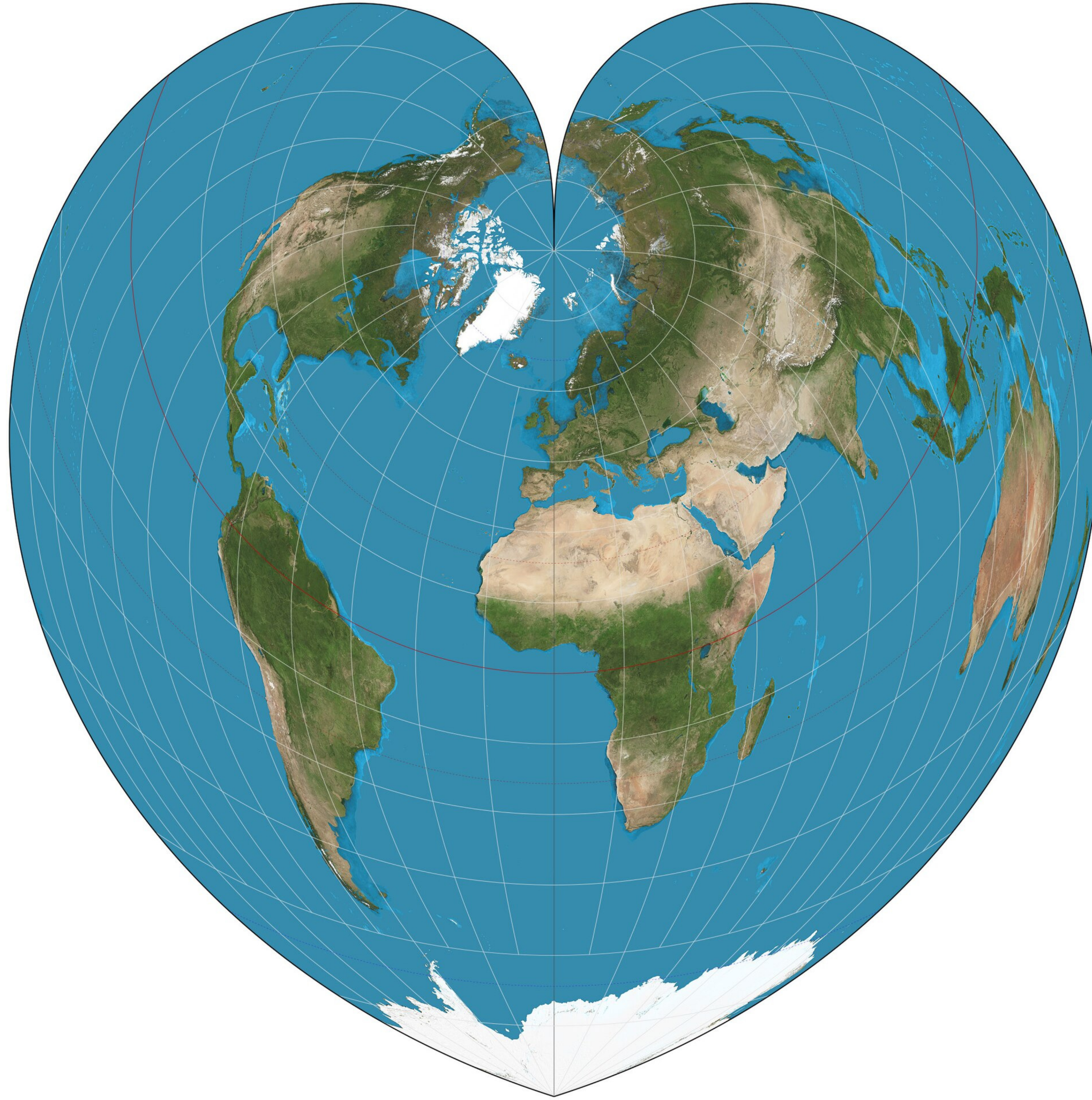
Loximuthal



Van der Grinten

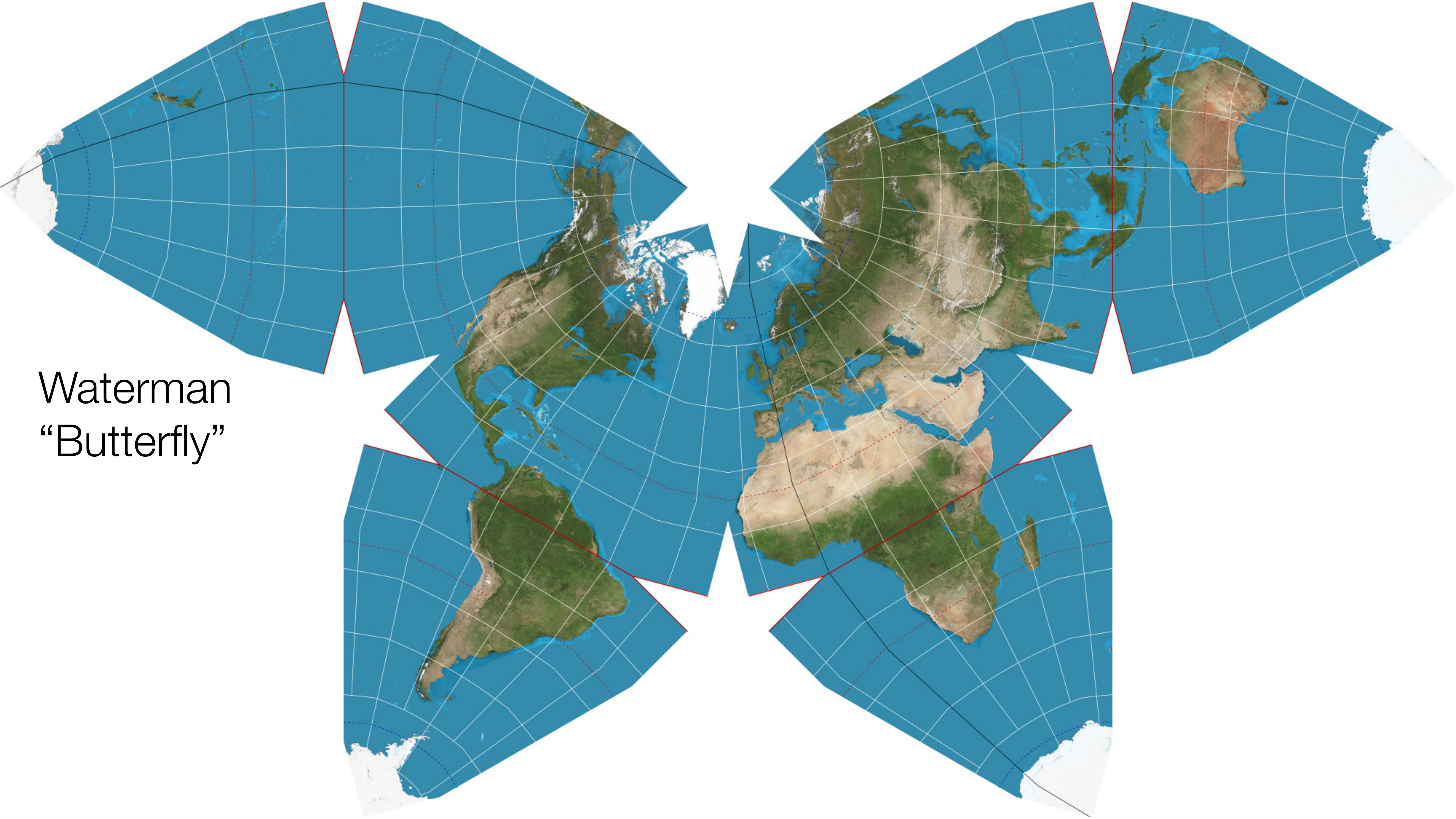


Werner



Bonne



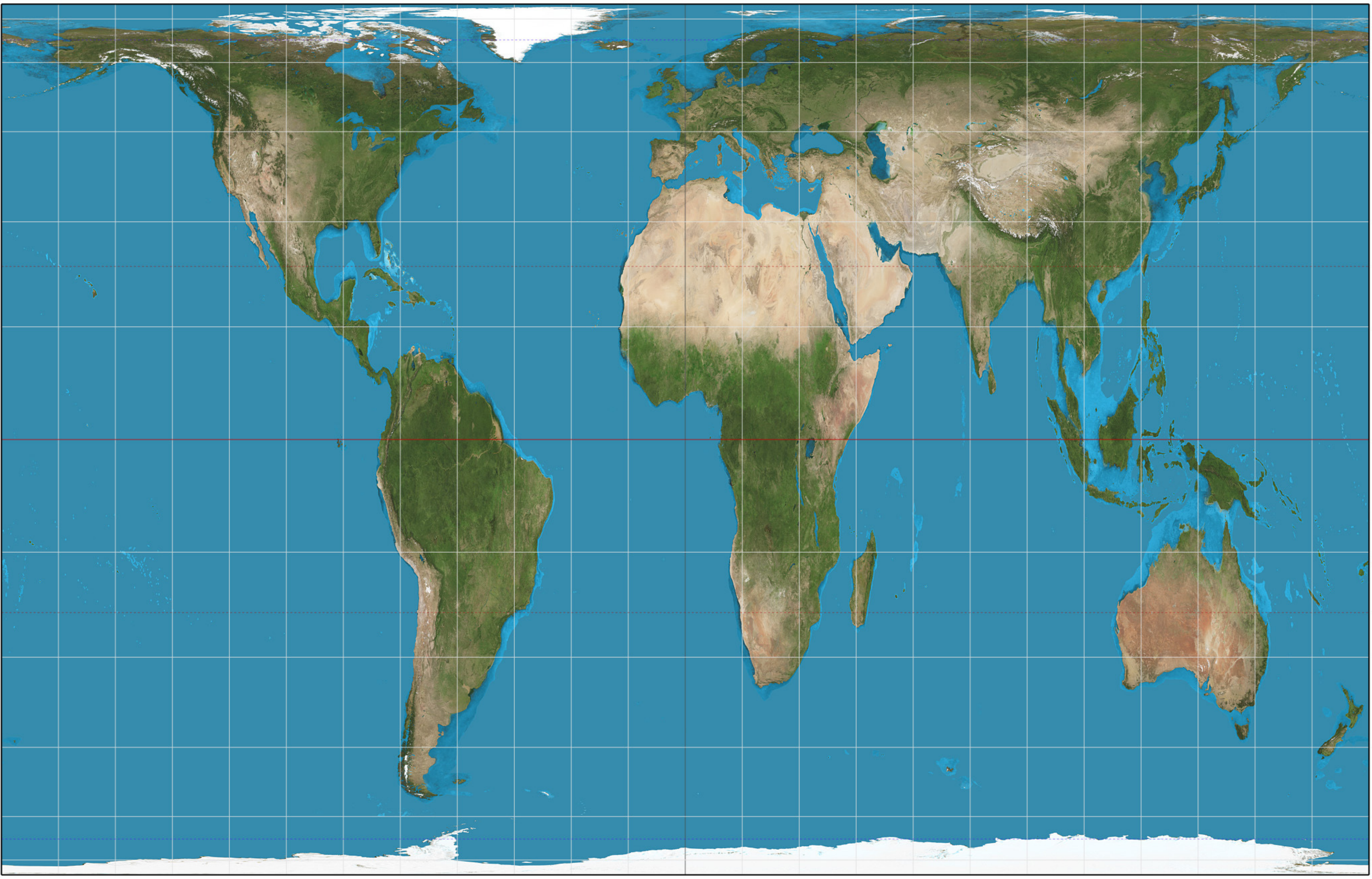


Waterman
“Butterfly”

Cassini



Gall-
Peters



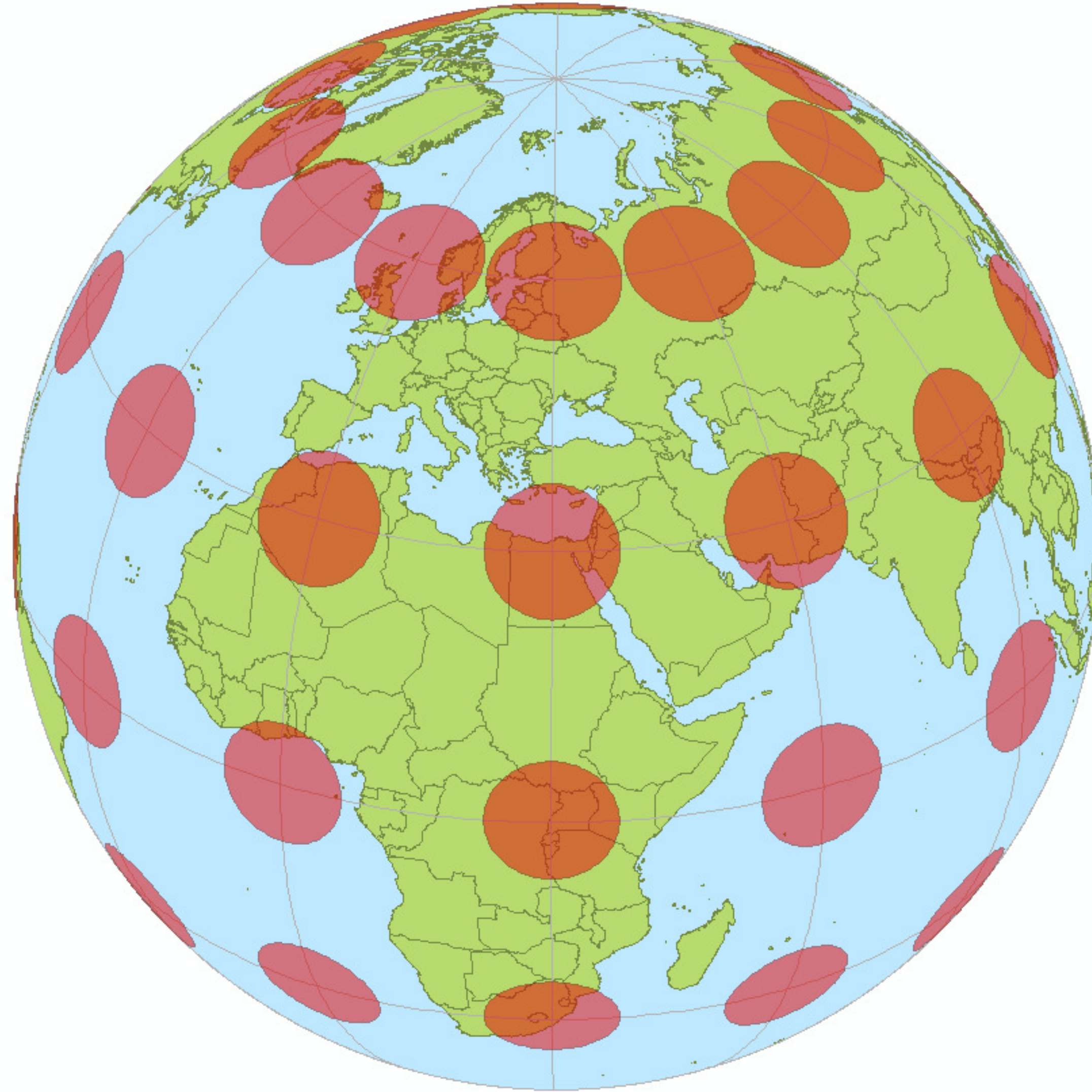
Geometry frustrations

- No map exists that:
 - Shows the whole earth
- And does not distort at least one of:
 - Shape
 - Size/area
 - Distance
 - Direction

*If you want to get mathy about it,
this is an implication of Gauss'*

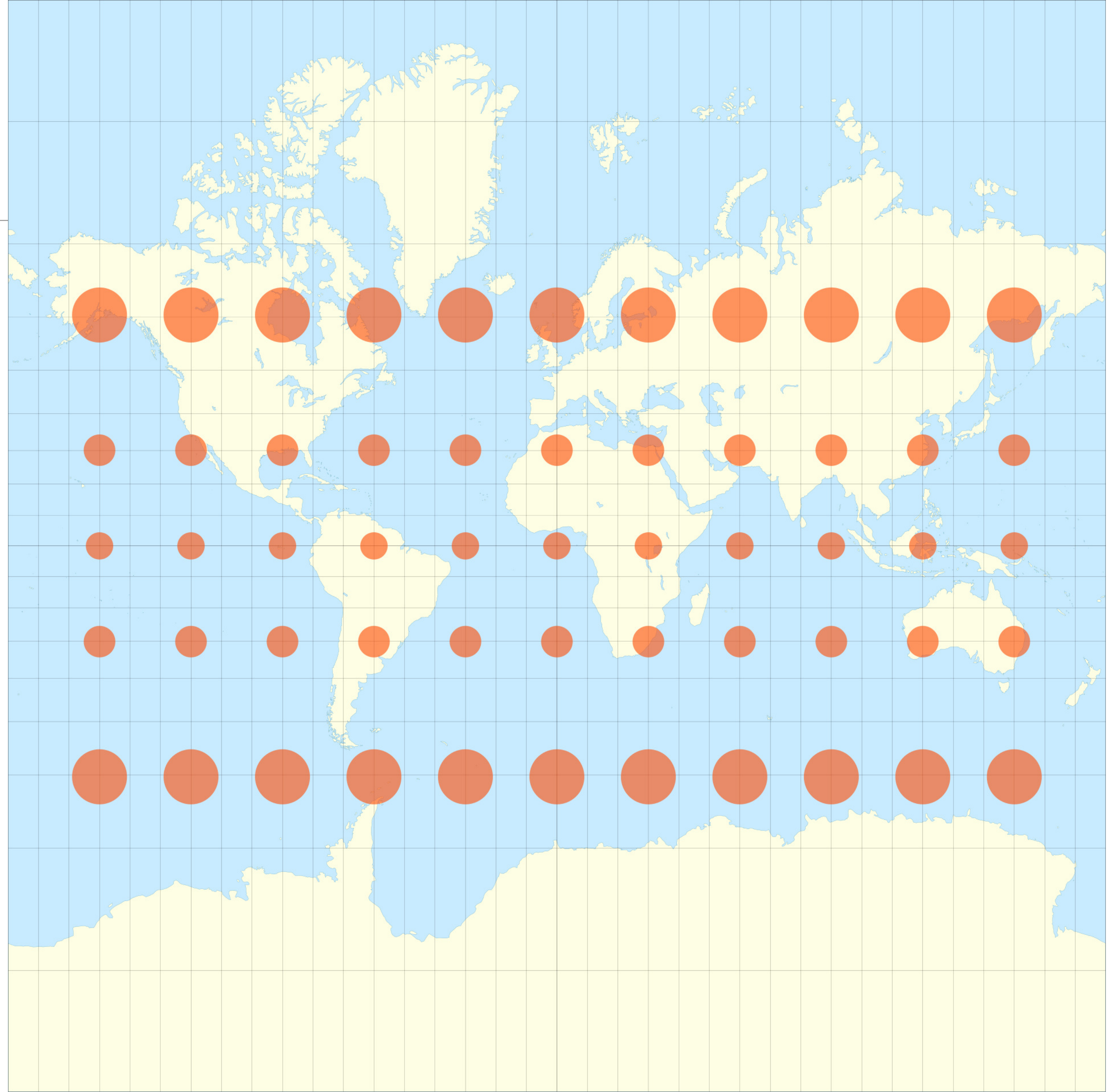
Theorema Egregium
*(aka "Remarkable Theorem") in
differential geometry*

The Globe



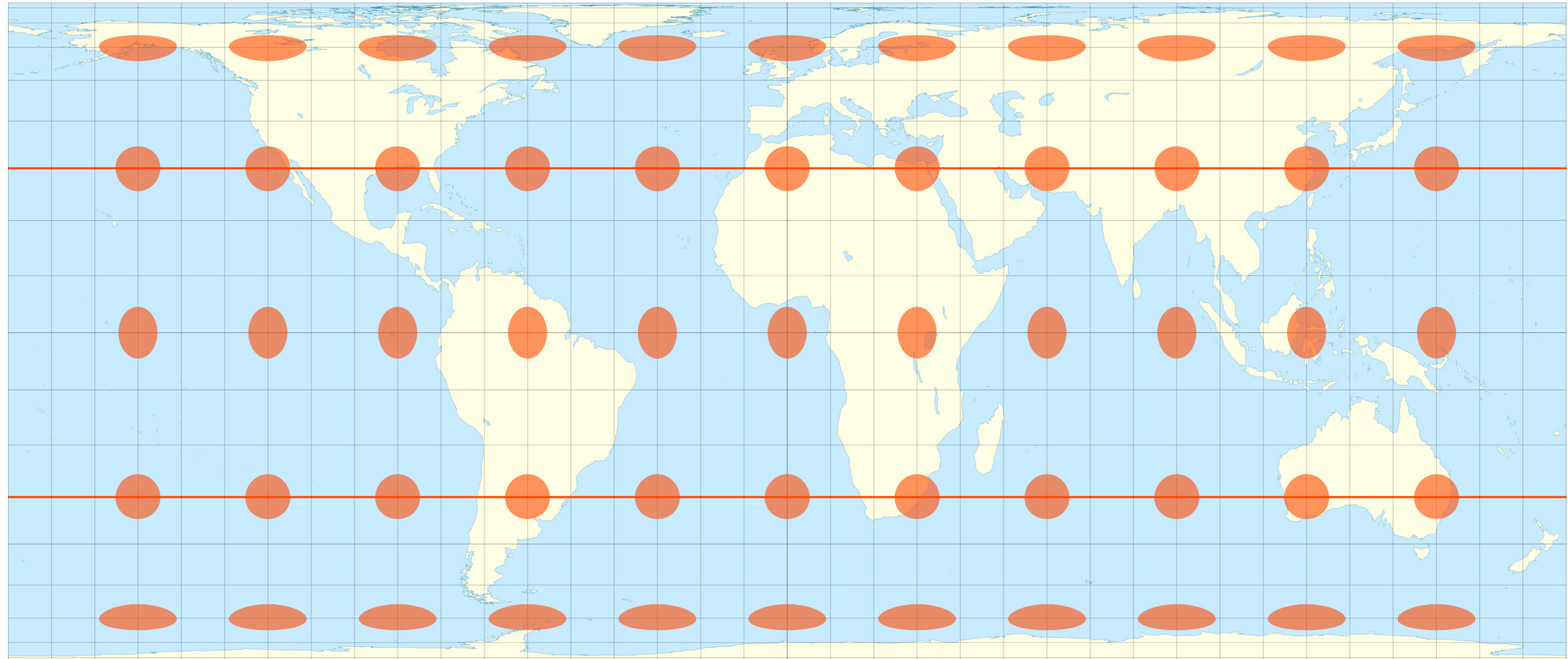
Mercator

- Preserves angle (direction) but not area
- Good for navigation
- Not good for implicit comparisons of size

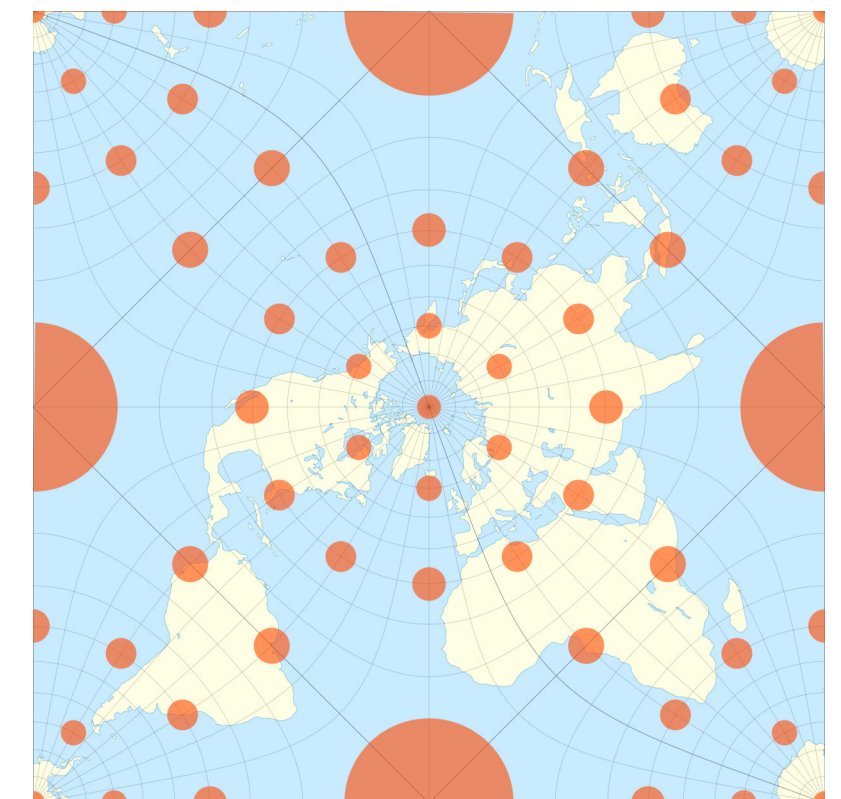
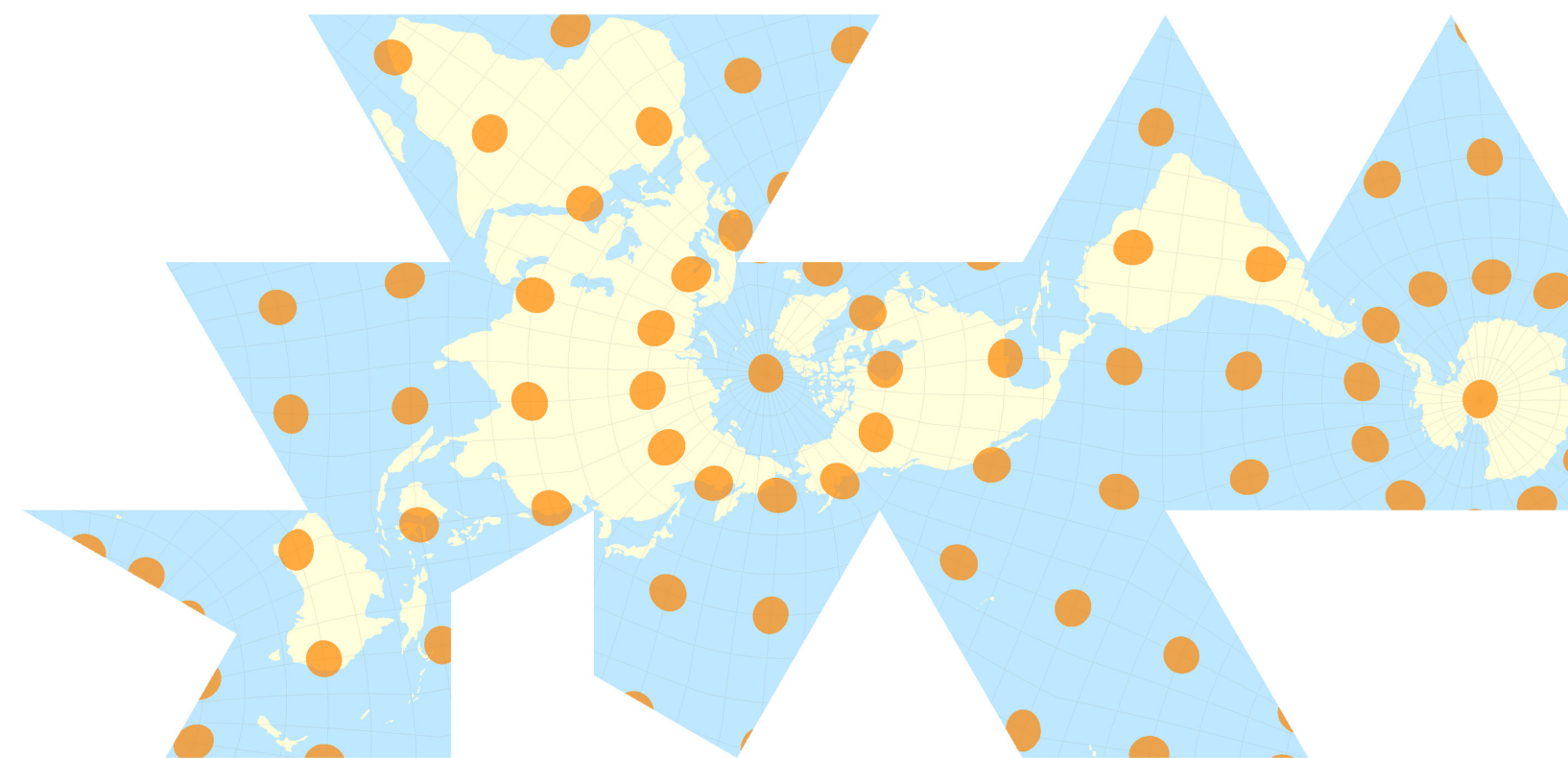
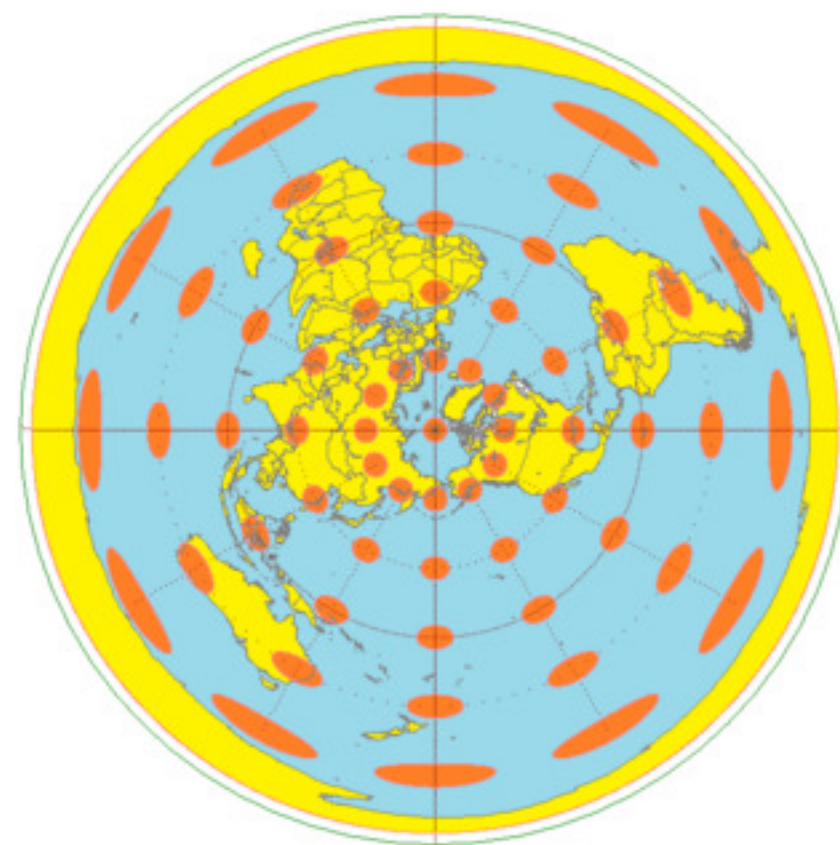
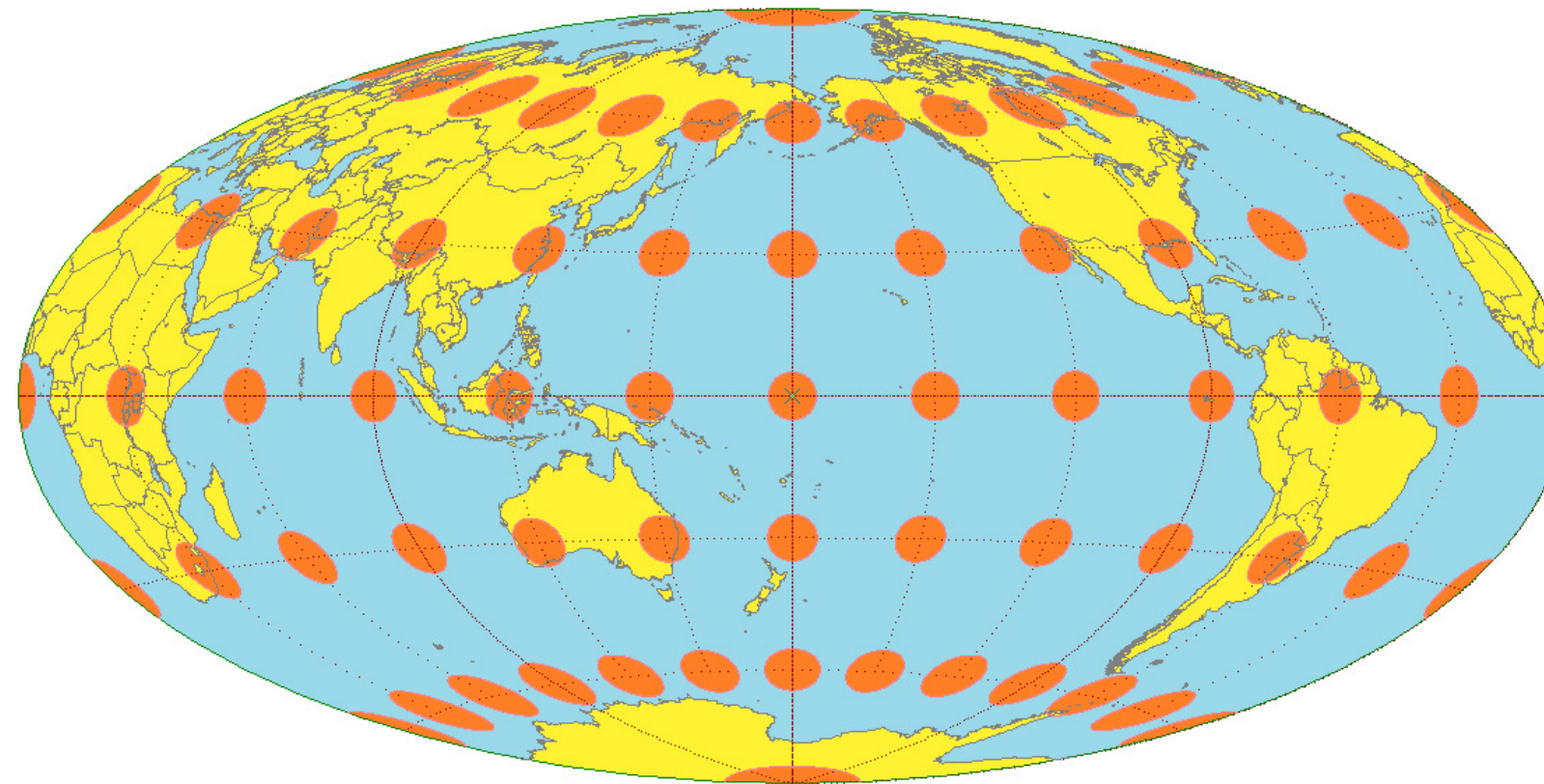
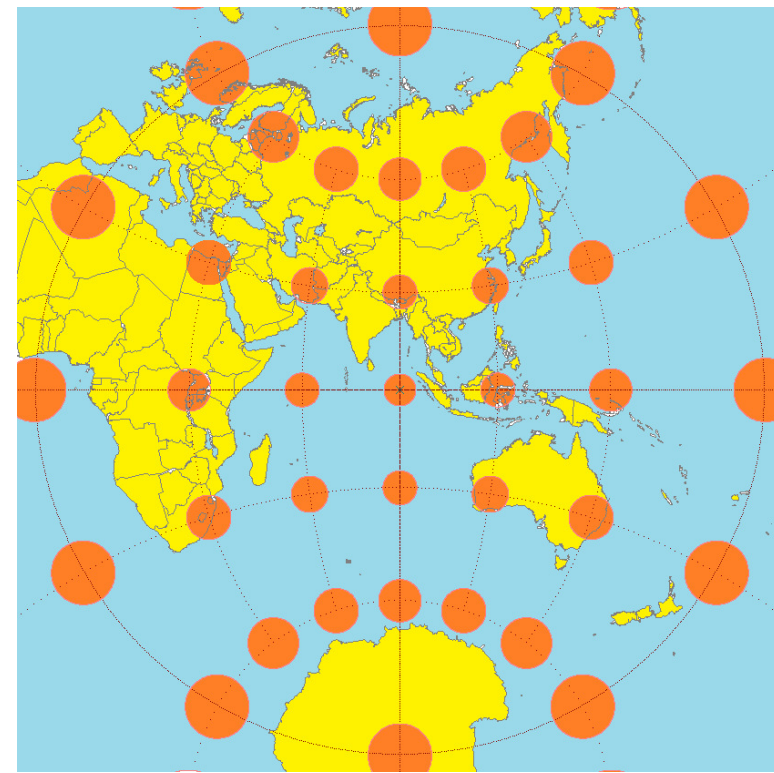


Behrmann

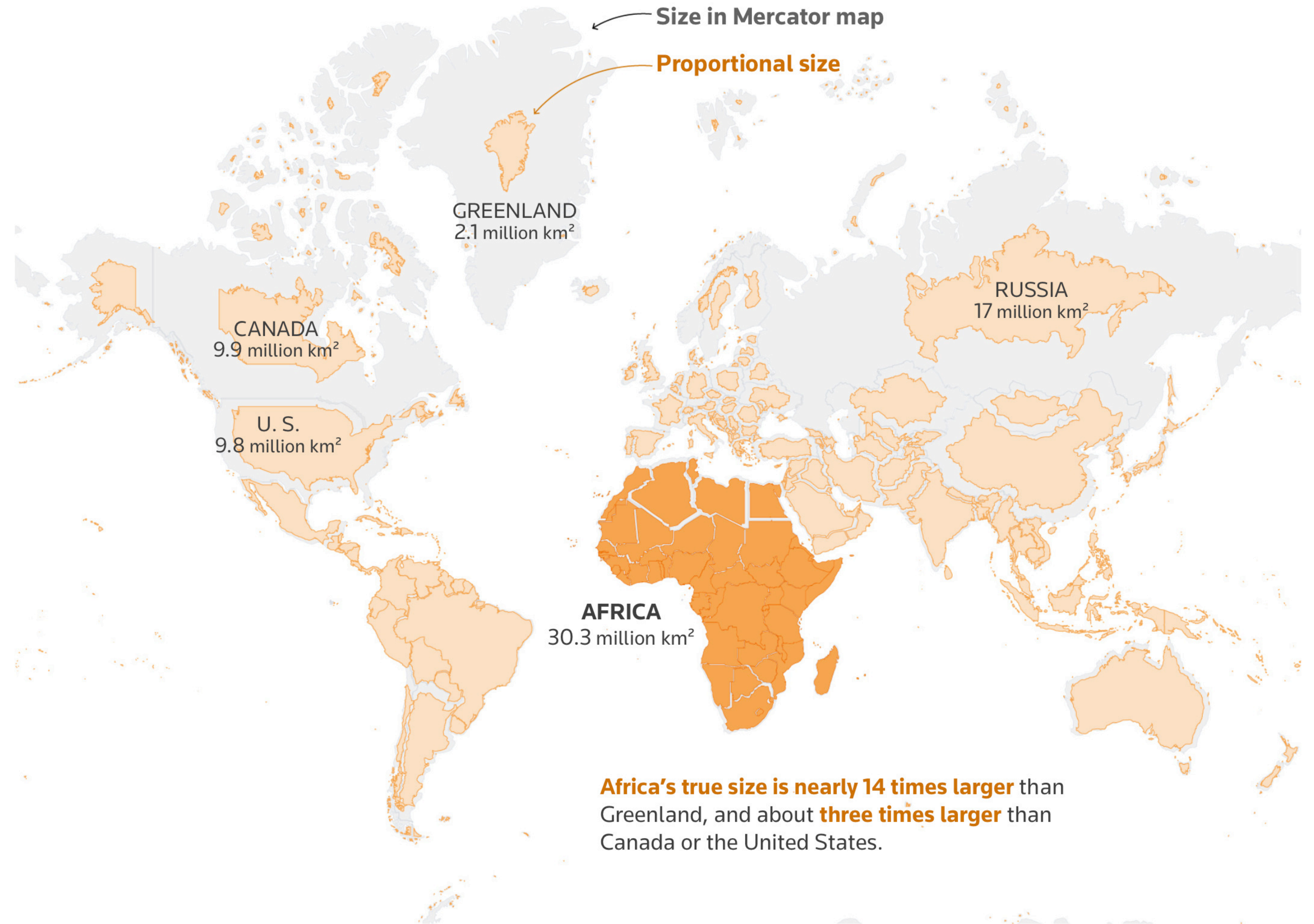
- Preserves angle (direction) and area
- But not shape



Other projection distortions



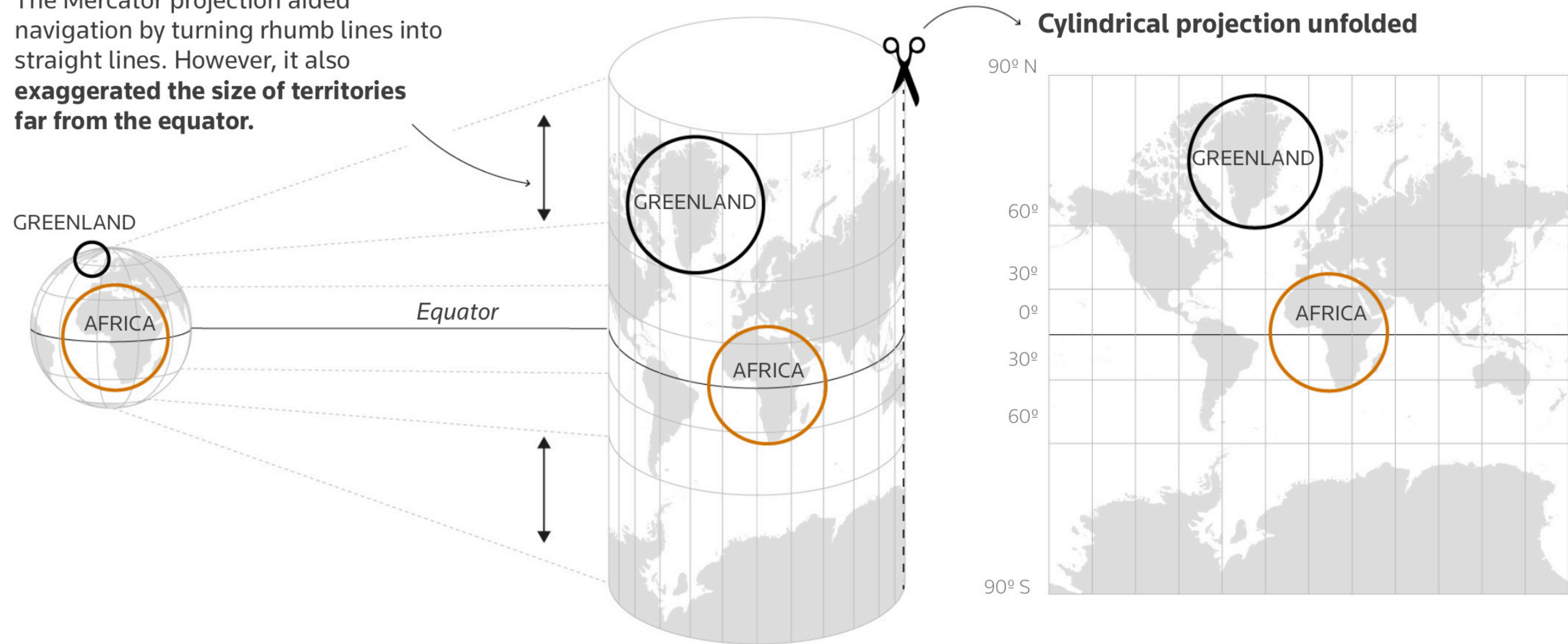
This has real world consequences



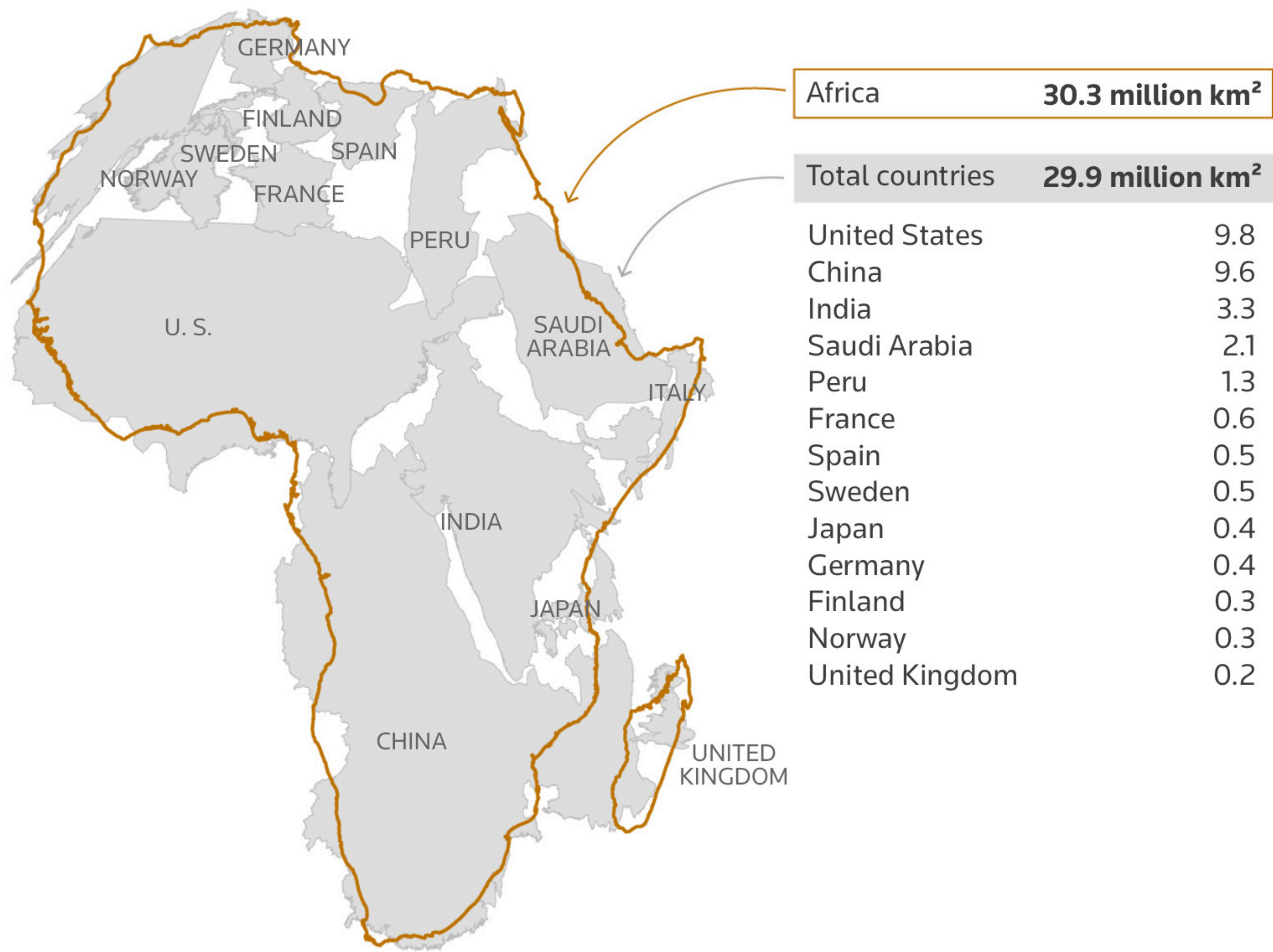
Note: This graphic fixes the distortion created by the Mercator map, which exaggerates the size of countries far from the equator. By scaling each country according to its latitude, the map reveals their true proportions.

Real-world consequences

The Mercator projection aided navigation by turning rhumb lines into straight lines. However, it also **exaggerated the size of territories far from the equator.**



This has real world consequences



“All models are wrong.”

“All models are wrong.”

“Map is not territory.”

“All models are wrong.”

“Map is not territory.”

“All maps lie - but they lie in different ways”

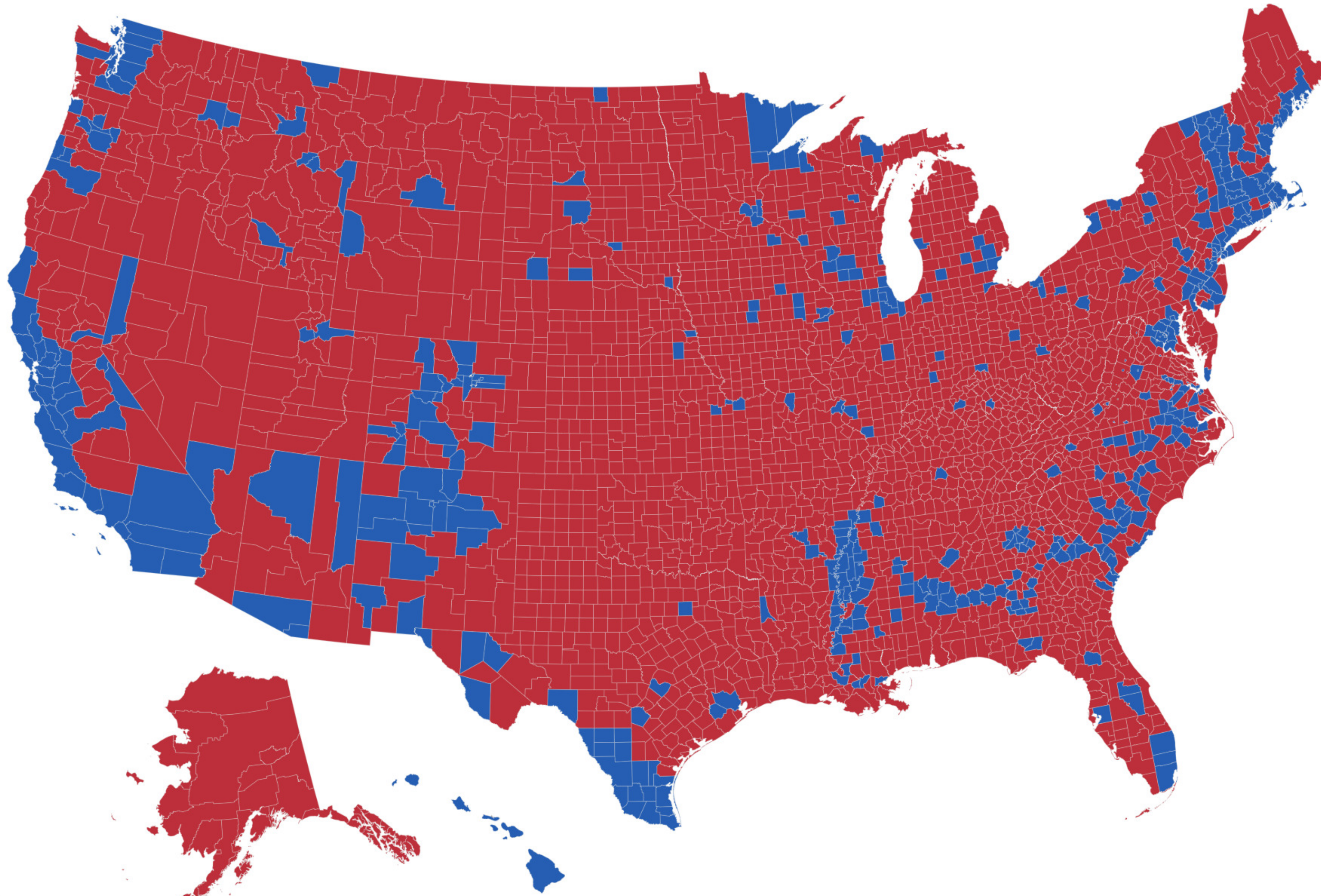
- **Attributed to many**

V. Areal Units

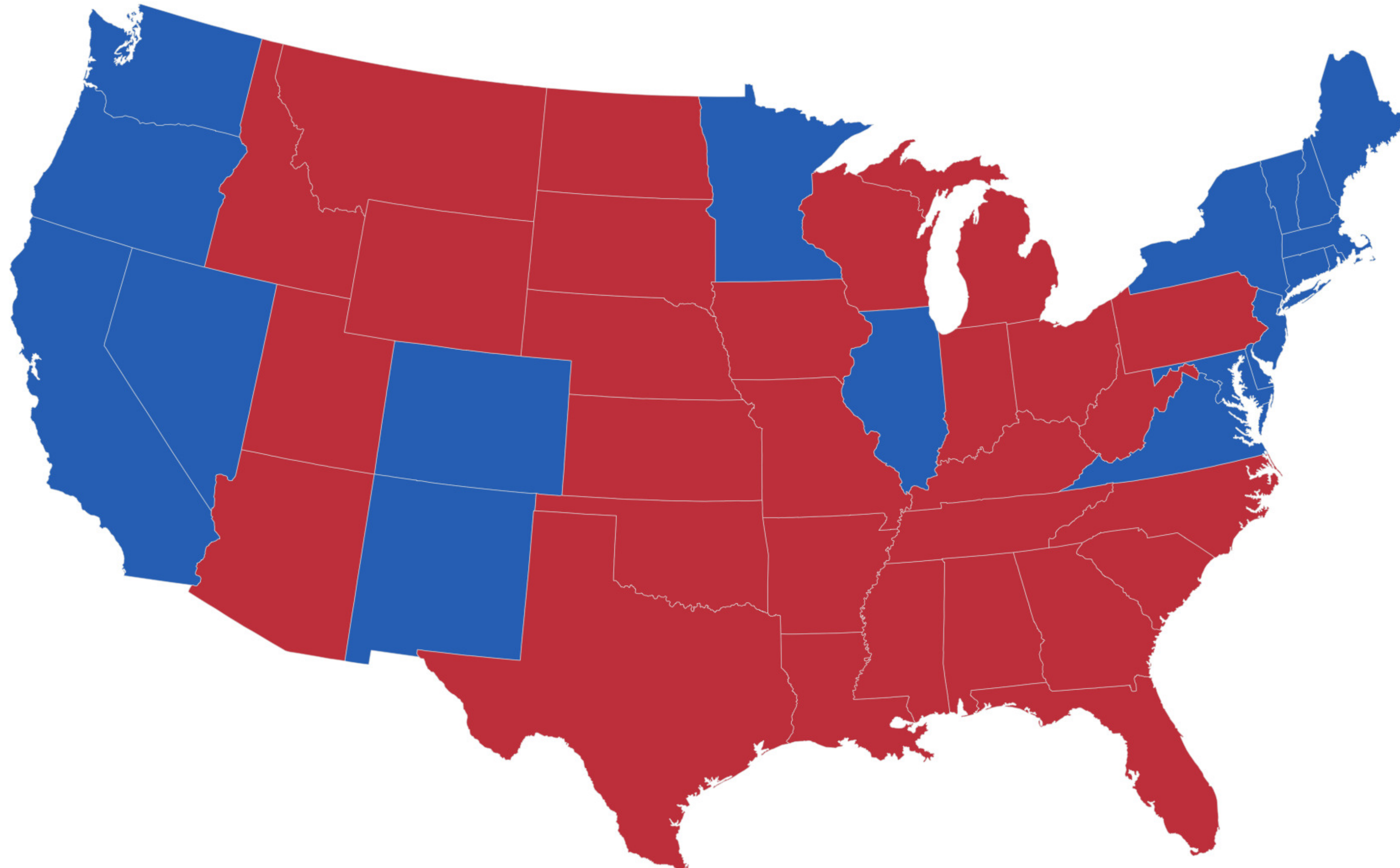
Areal Units

- Lots of the time, we'll map incidence of phenomena across space
- In doing so, we need to block that space into units
- We tend to use units familiar to us:
 - Counties
 - States
 - Countries
- The problem: the **way** we block our units **change** the way we perceive variation

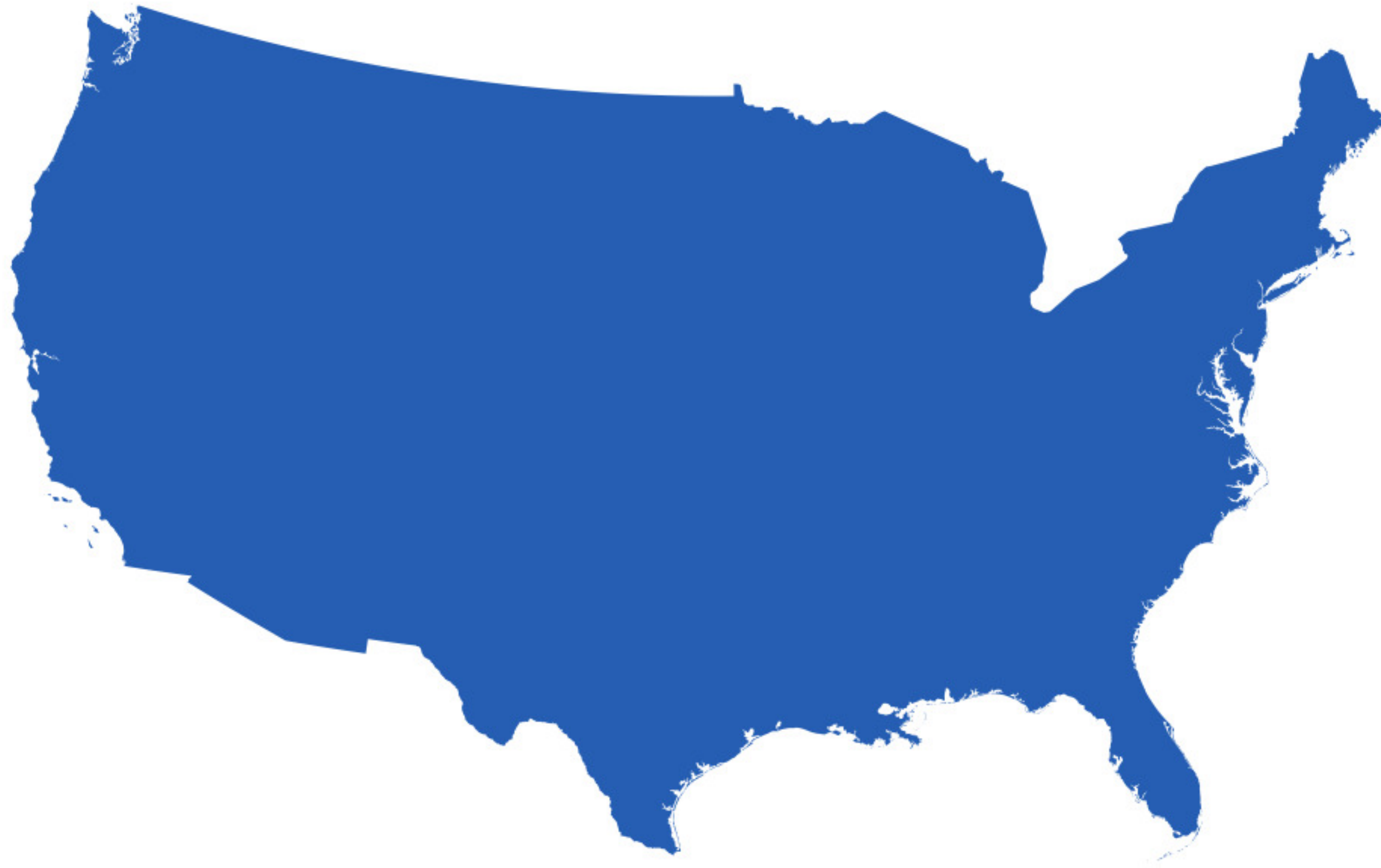
An overly simple example: 2016 president by county



An overly simple example: 2016 president by state

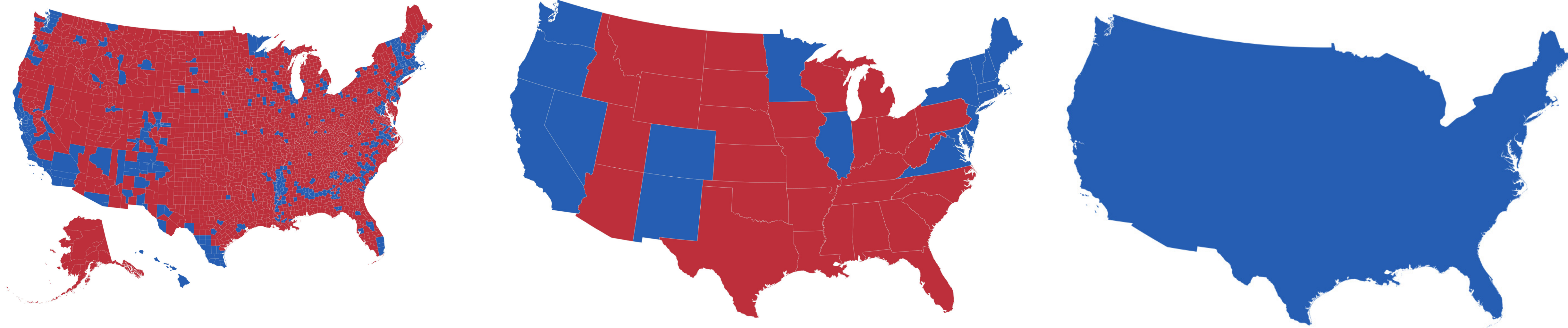


An overly simple example: 2016 president by country



The ecological fallacy

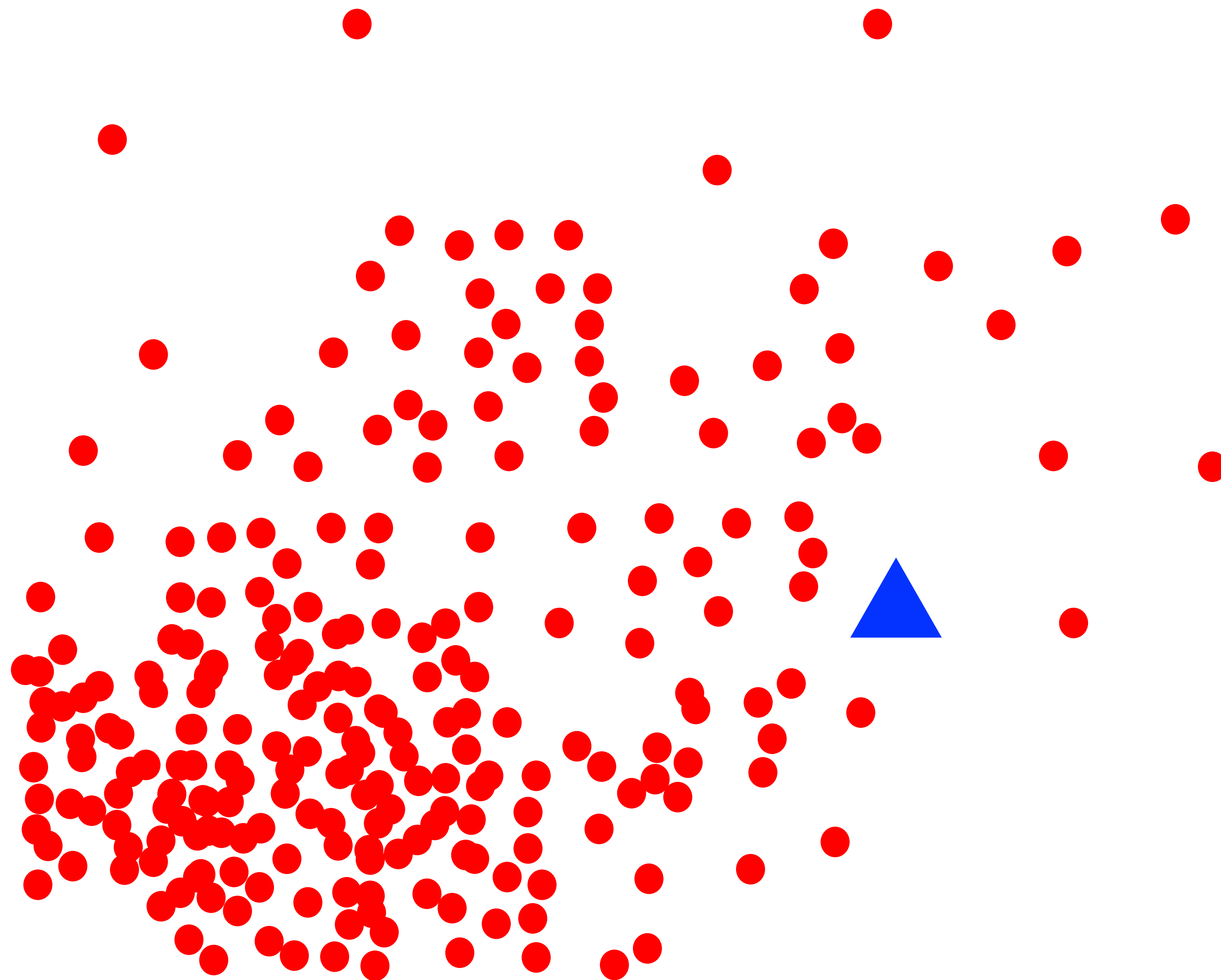
- Inferring lower level (individual) behavior from higher-level behavior



- Maps often encourage us to do this. *We should resist this*

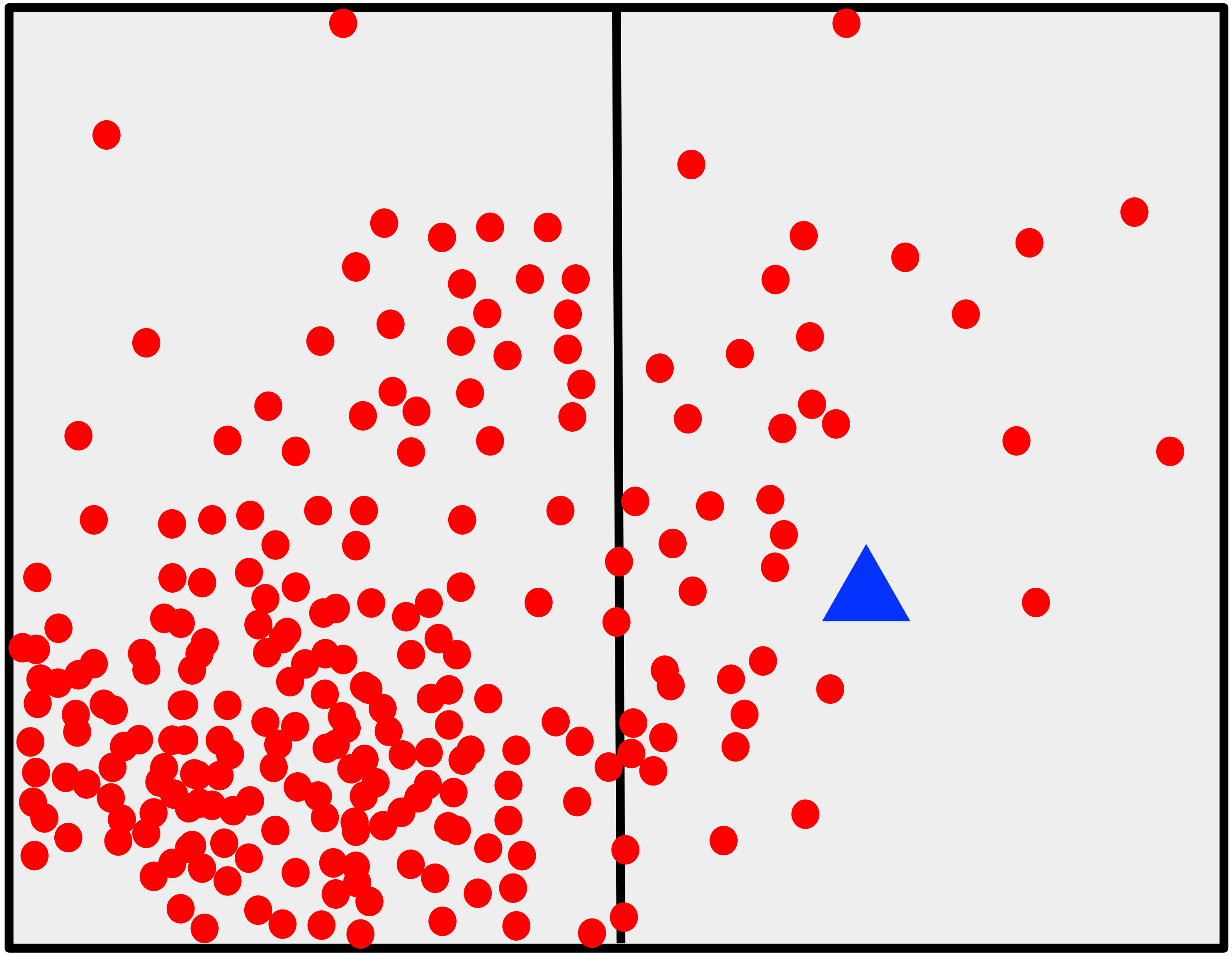
The Modifiable Areal Unit Problem (MAUP)

- It's tempting to think that the answer is to “always go smaller”
- But it's not just about going smaller. The way boundaries are drawn matters, too
- Let's say we're trying to measure population density



A classic MAUP

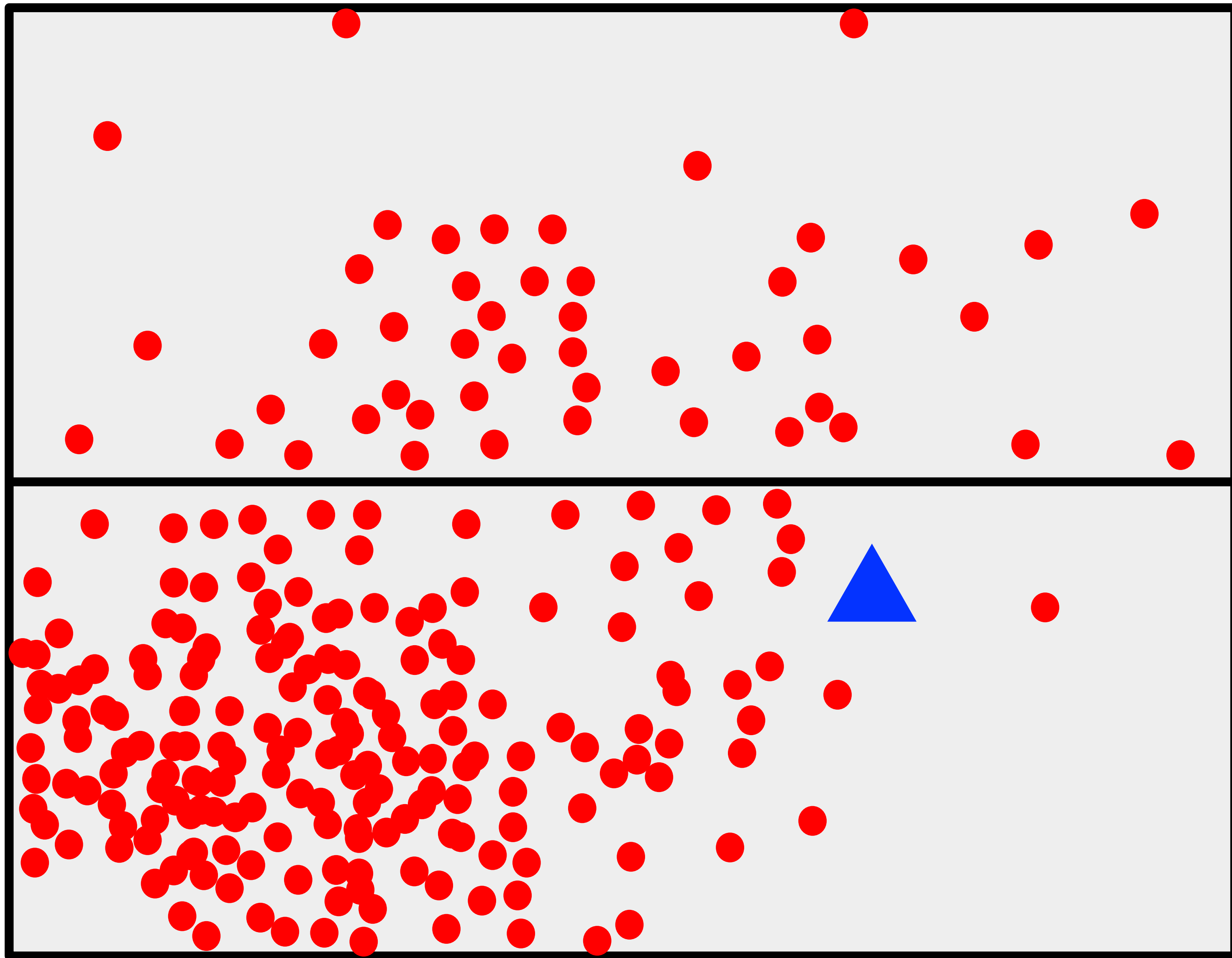
County A
Size = 200
Density = 100/km²



County B
Size = 50
Density = 25/km²

A classic MAUP

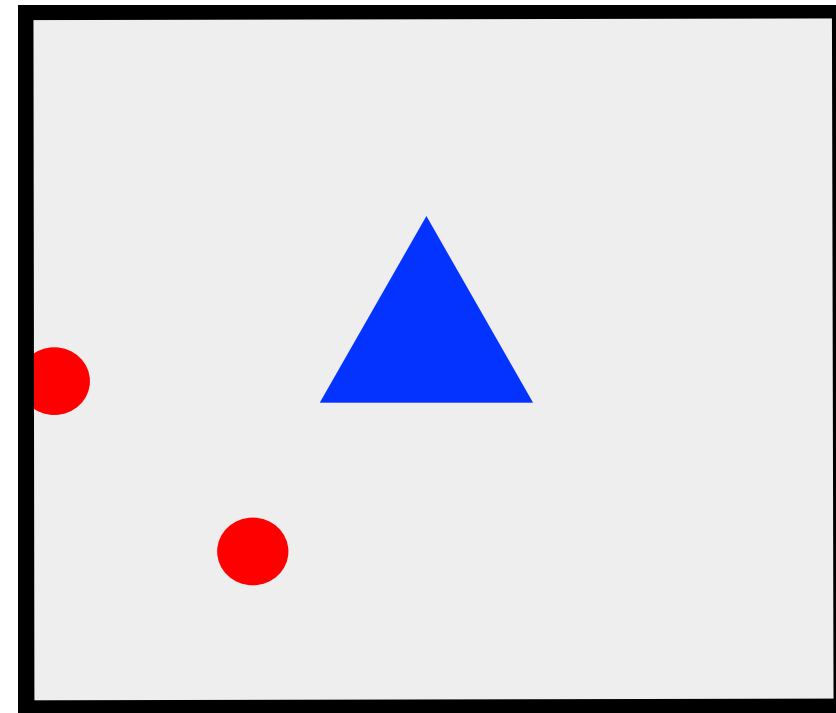
County A
Size = 50
Density = 25/km²



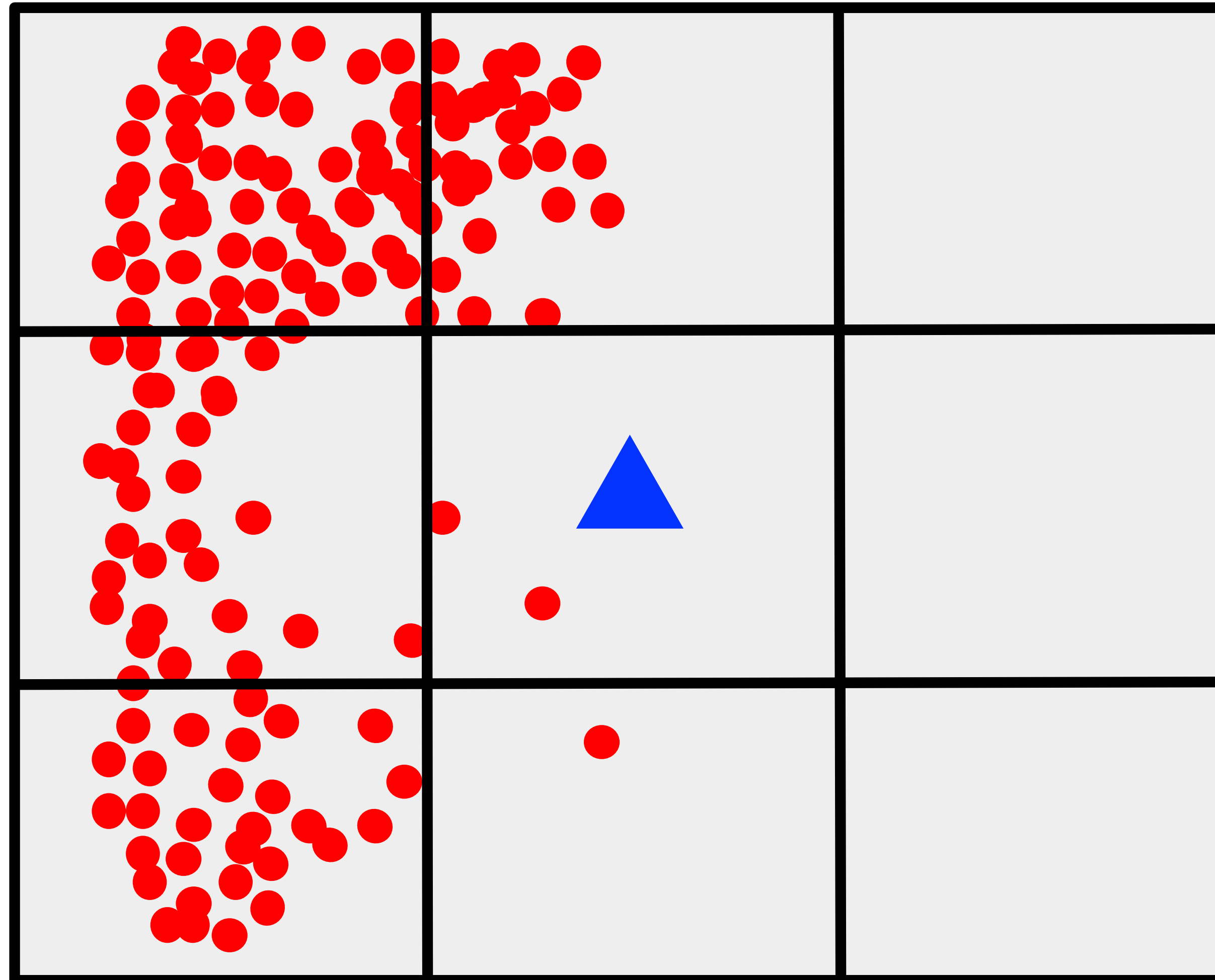
County B
Size = 200
Density = 100/km²

A classic MAUP

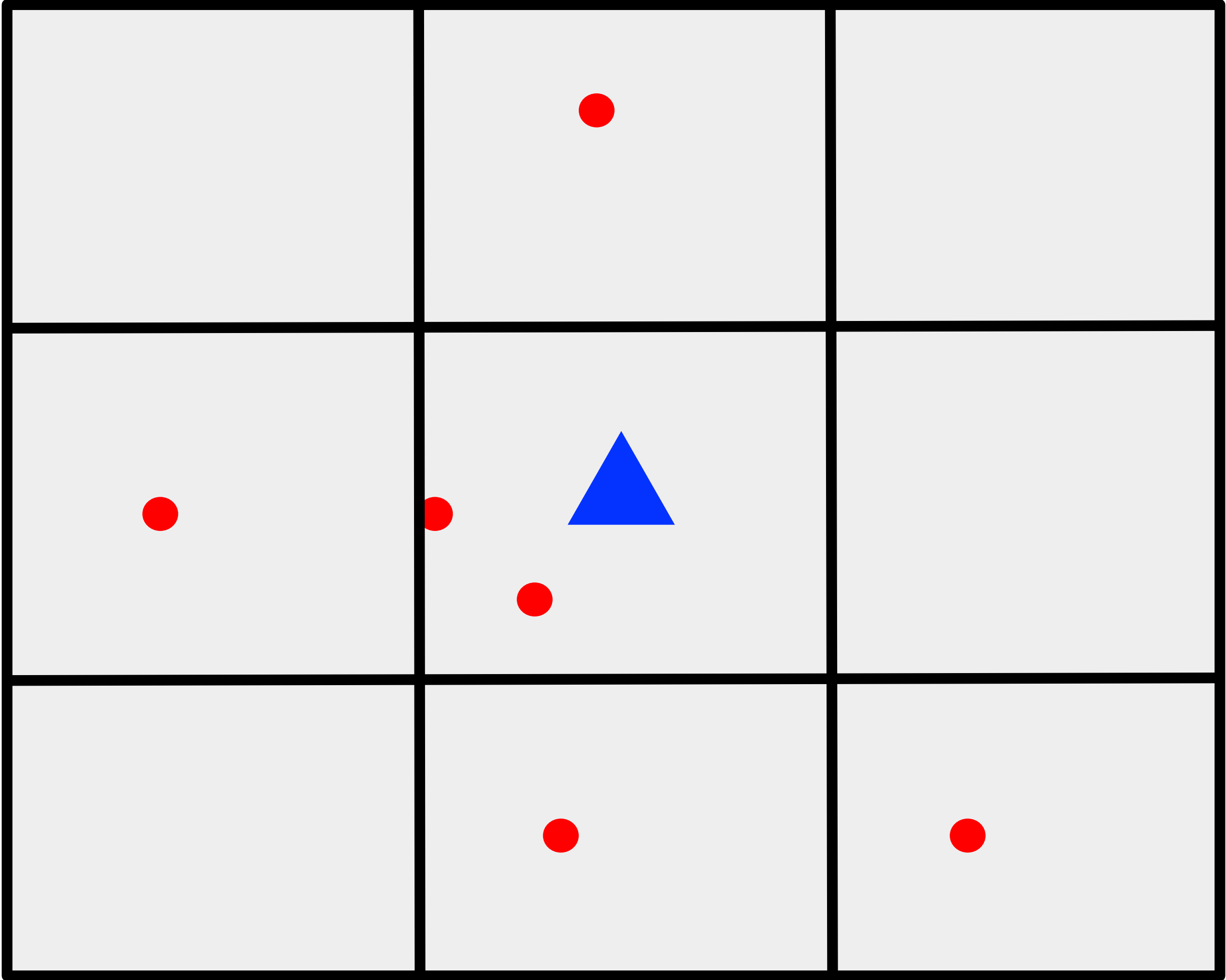
Smaller units obscure contextual information



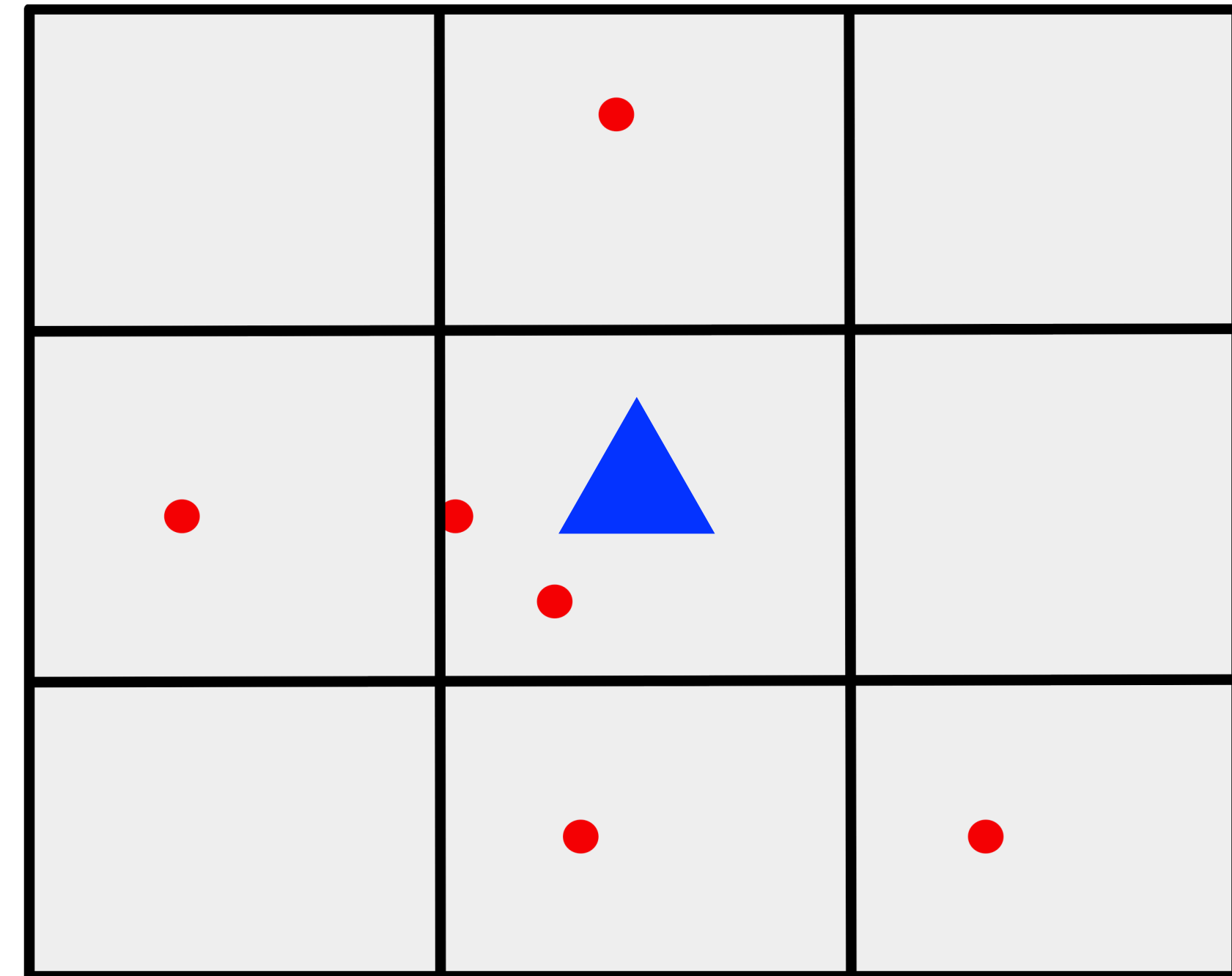
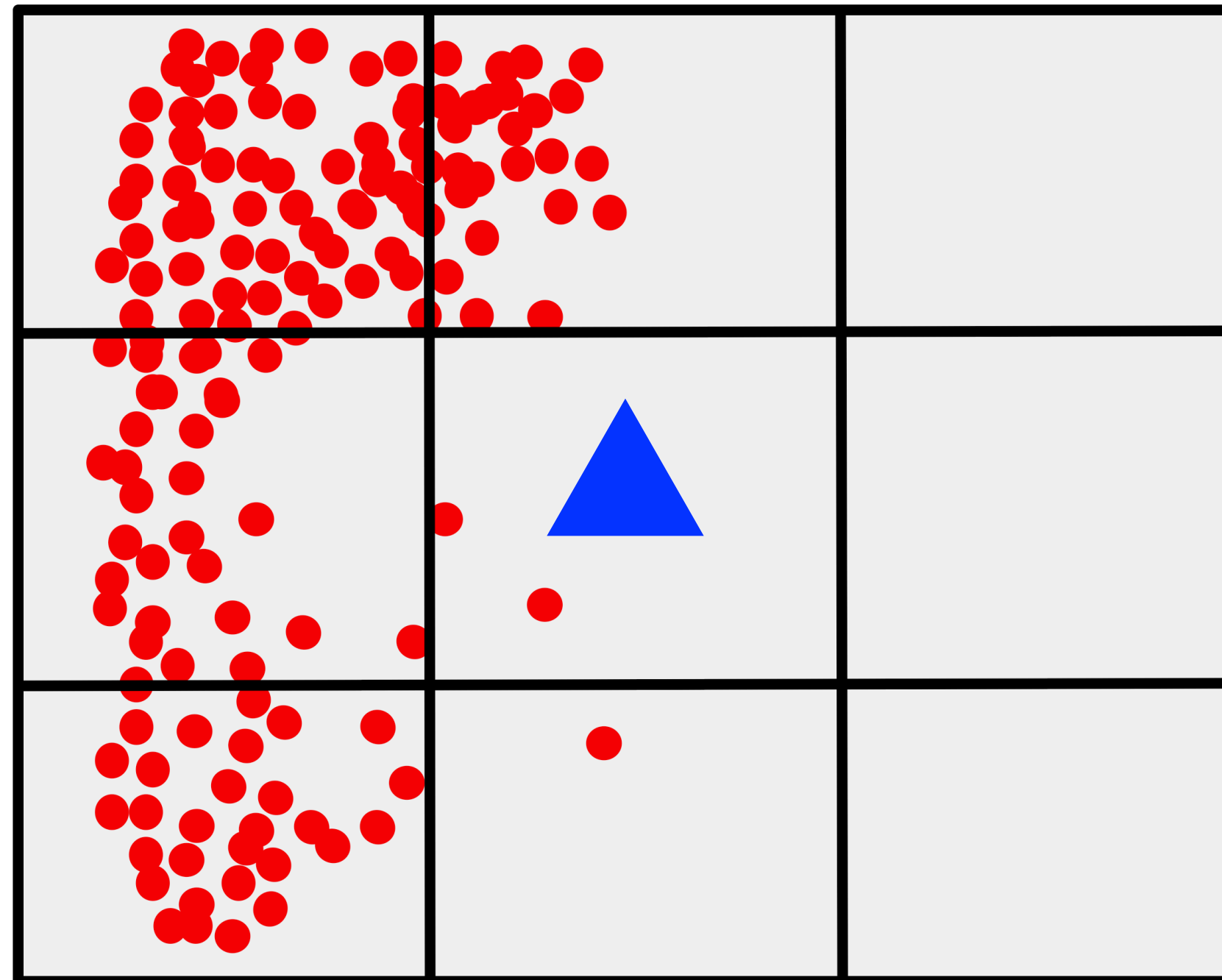
Smaller units obscure contextual information



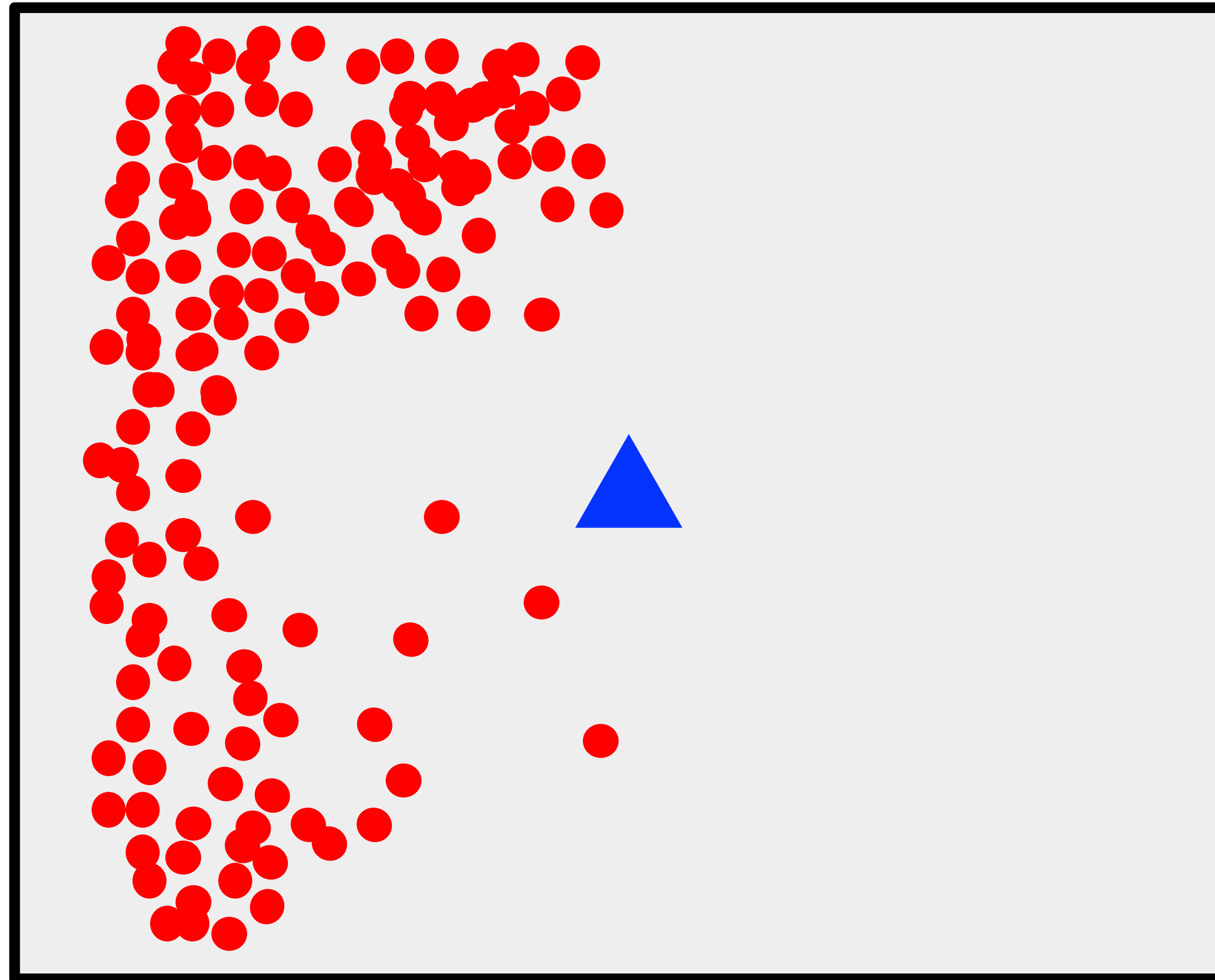
Smaller units obscure contextual information



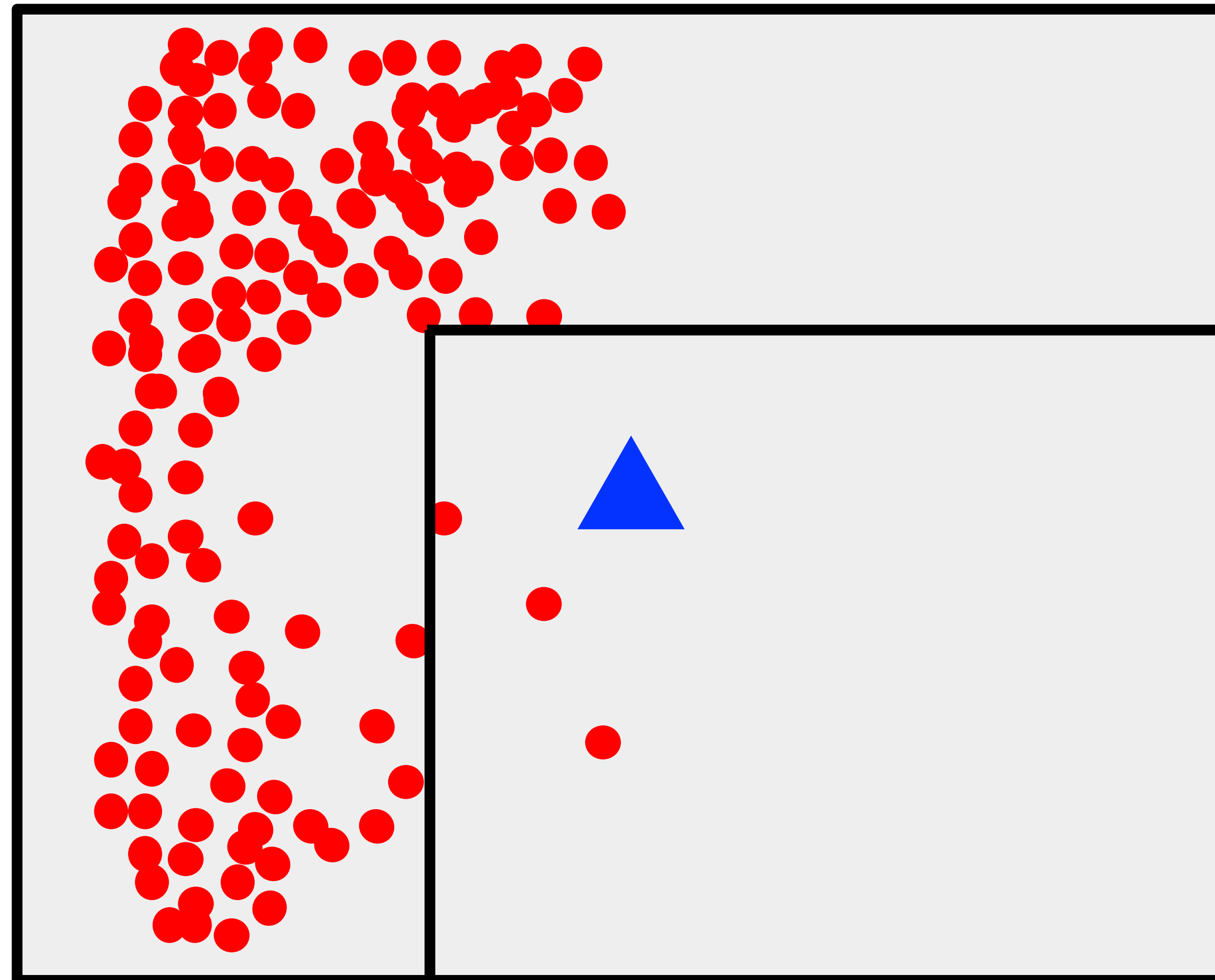
Smaller units obscure contextual information



You can use these two features to really obscure, if you want



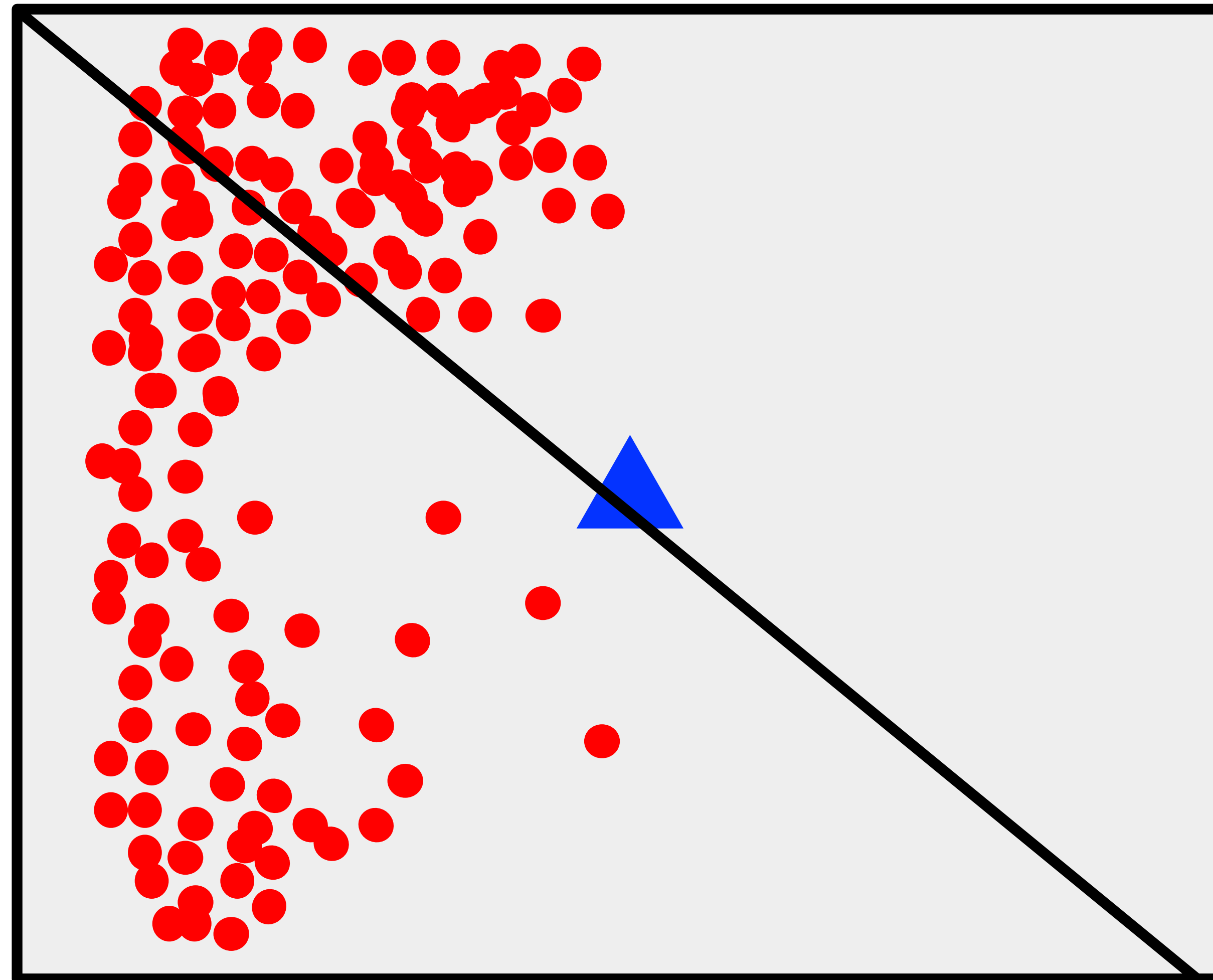
You can use these two features to really obscure, if you want



Area A
very dense!

Area B
very rural!

You can use these two features to really obscure, if you want



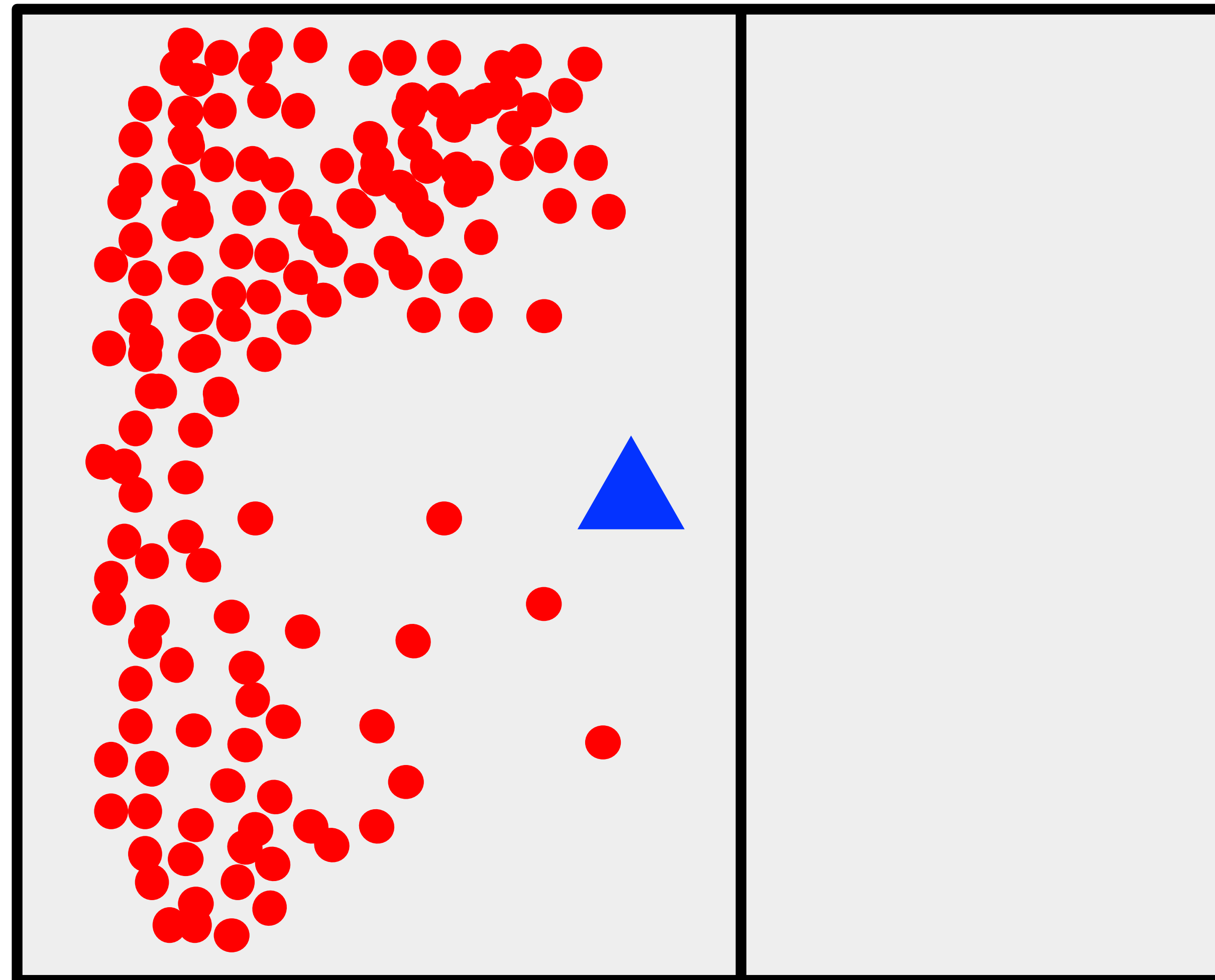
Area A

moderately dense!

Area B

moderately dense!

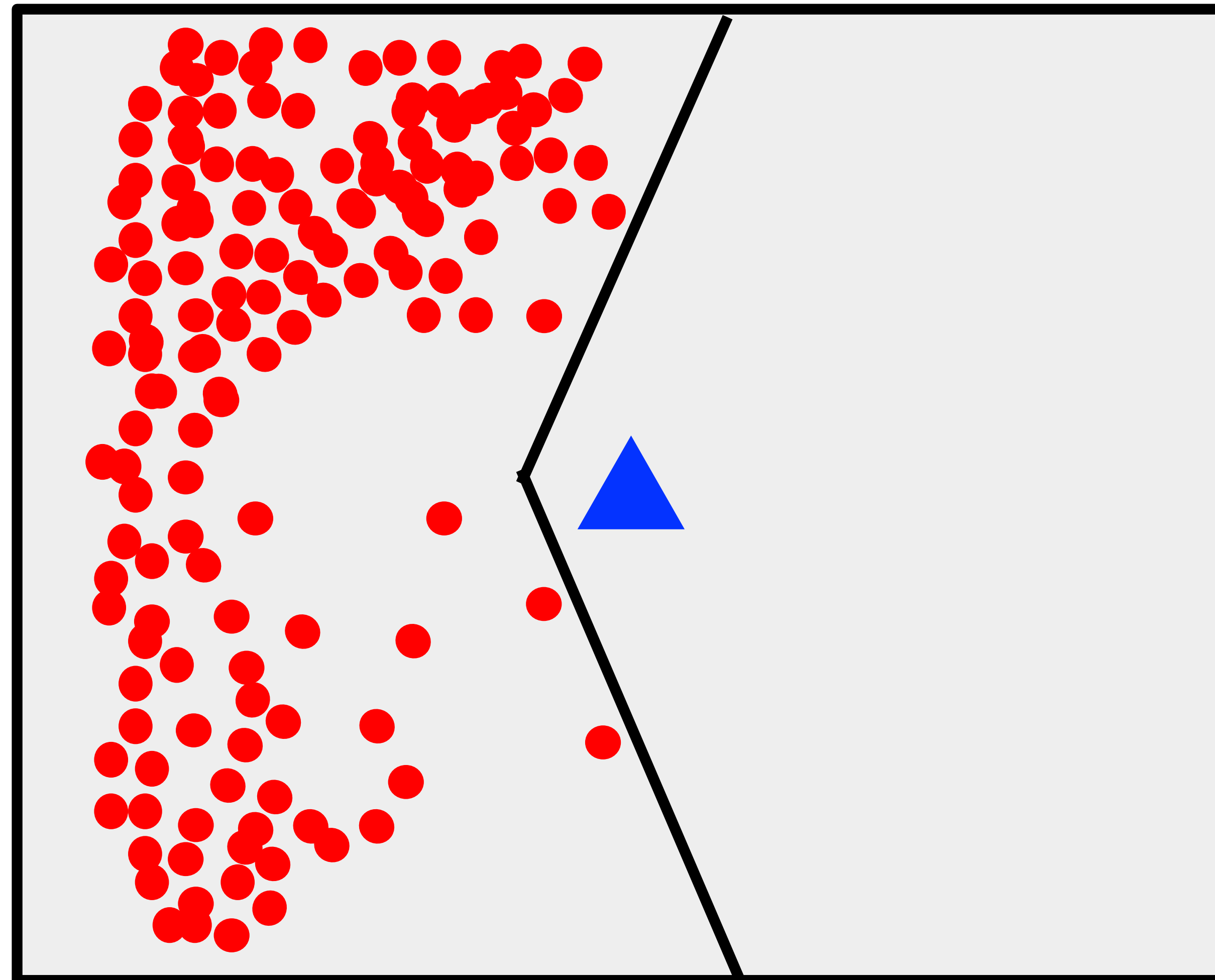
You can use these two features to really obscure, if you want



Area A
everyone!

Area B
no one!

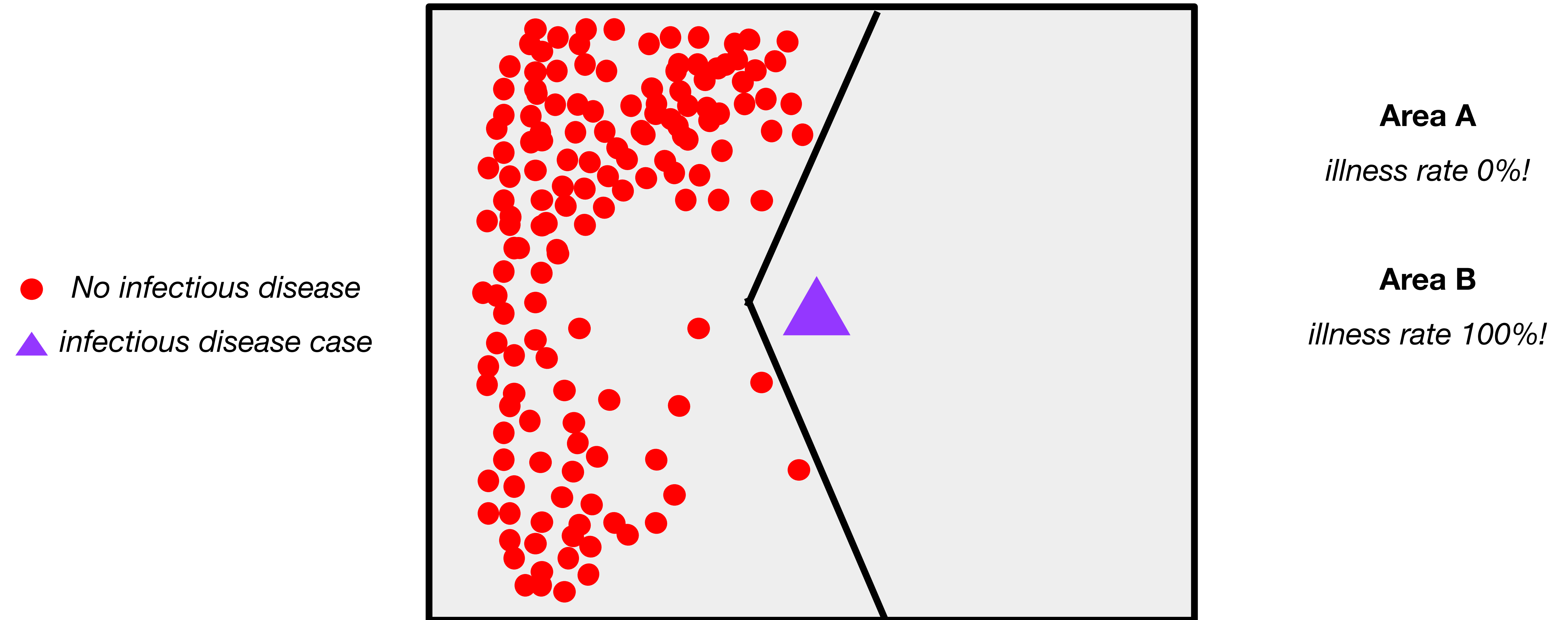
You can use these two features to really obscure, if you want



Area A
everyone!

Area B
one lonely person!

This is all fun and games until important policy becomes involved



Boundaries matter



A boundary in Dar es Salaam, Tanzania

Boundaries matter

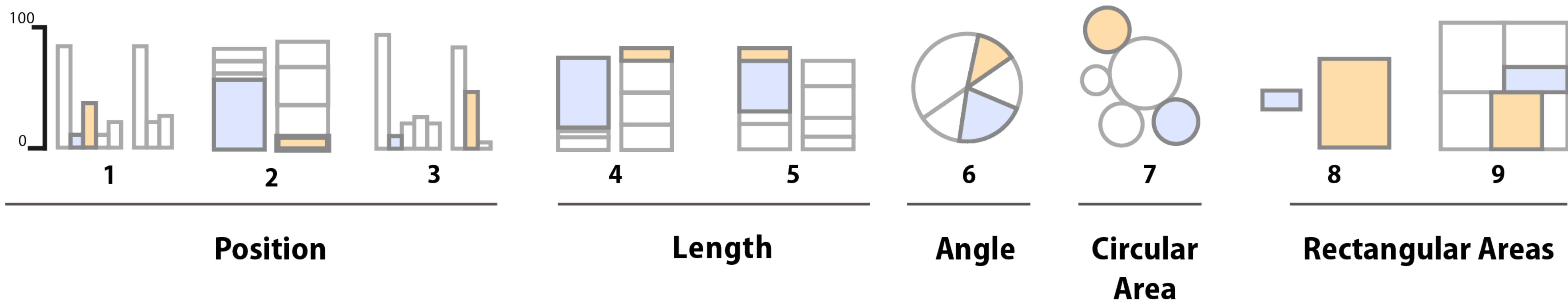
- The Haiti-Dominican Republic Border on Hispaniola



VI. Color and Contrast

Color and contrast

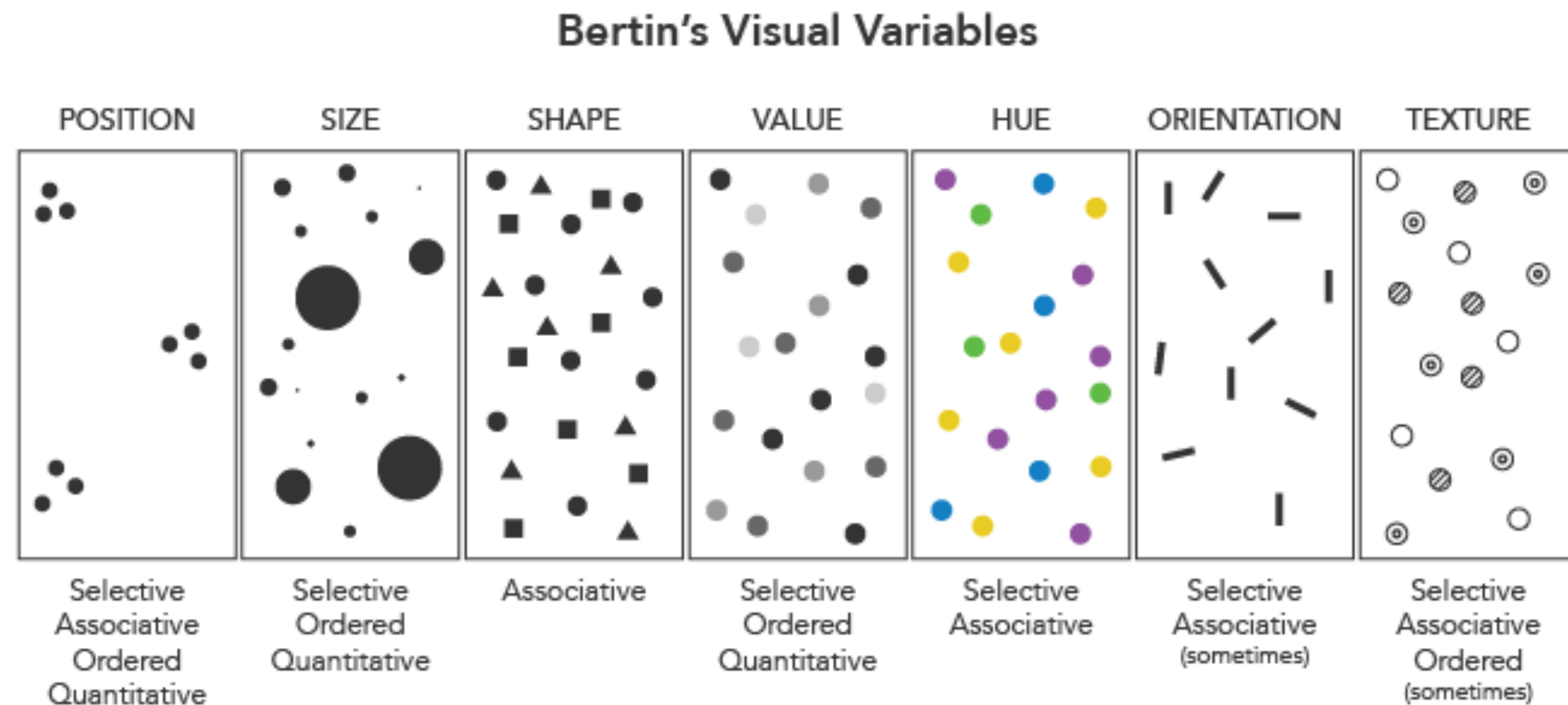
- We engage in visualization to draw similarity and contrast
- In the world of regular visualization, we have:



- But note how the constraints of cartography make these less applicable

Color and contrast

- Enter Jacques Bertin, french cartographer.
- *Semiologie Graphique*



Guidelines

- Match graphical element to usage

- **Point:** size, shape, color (hue and value)



- **Line:** size, color, pattern/texture



- **Area:** color (hue and value), texture



- Match data type to visual encoding

- **Categorical** data: shape, texture, color

- **Continuous** data: color hue, color spectrum

Color theory

- There are three main kinds of color schemes
 - Sequential
 - Diverging
 - Qualitative

Sequential Color Schemes

- Using only color



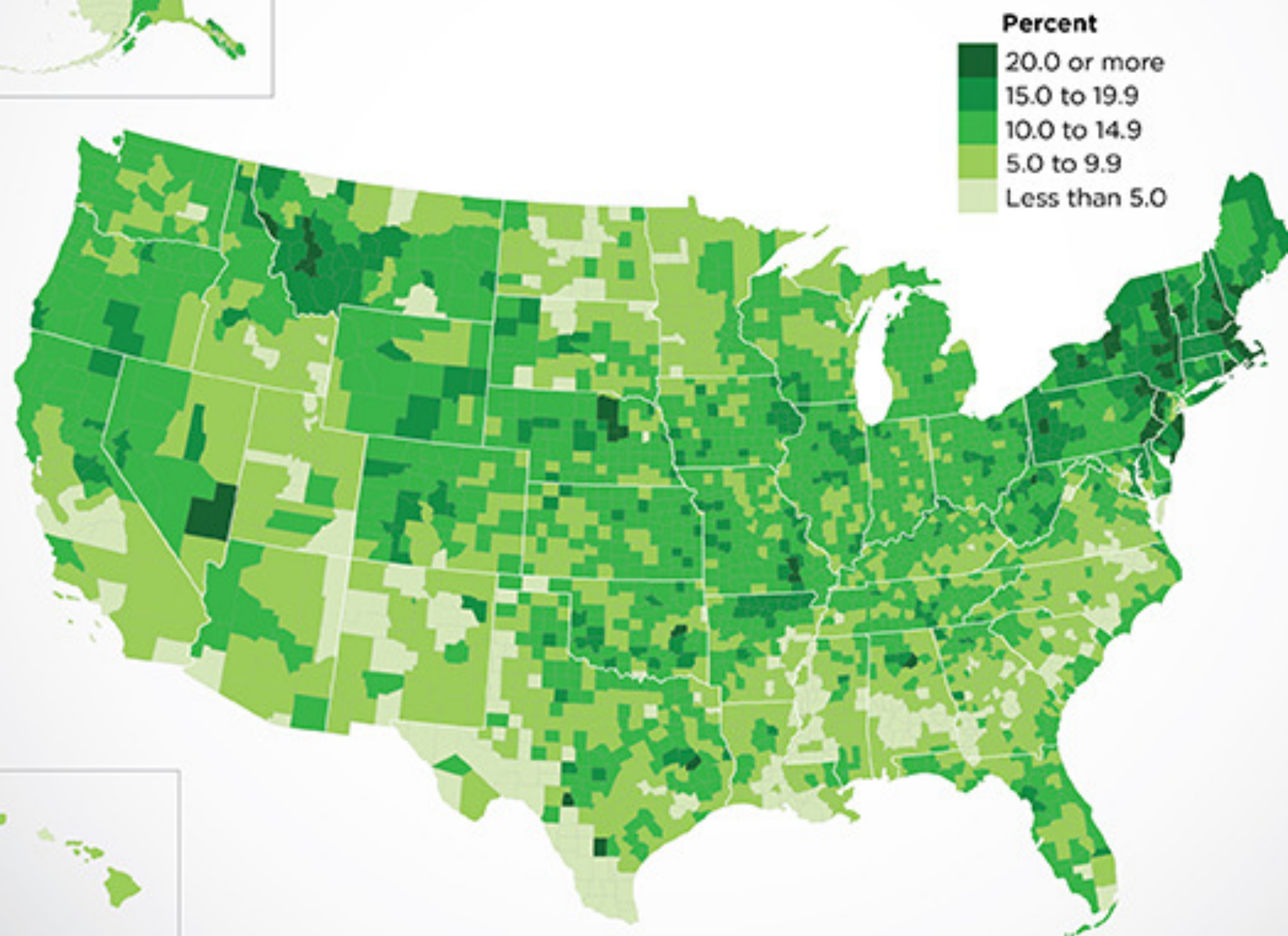
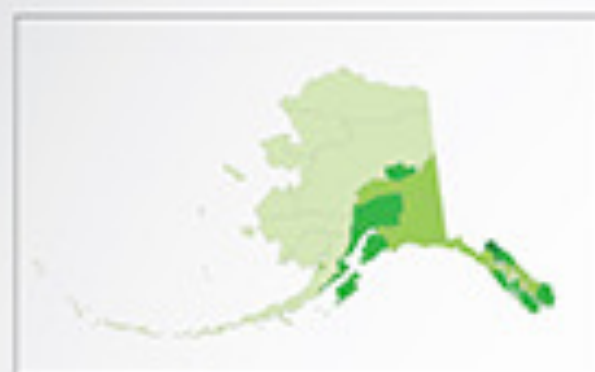


Where Irish Eyes Are Smiling



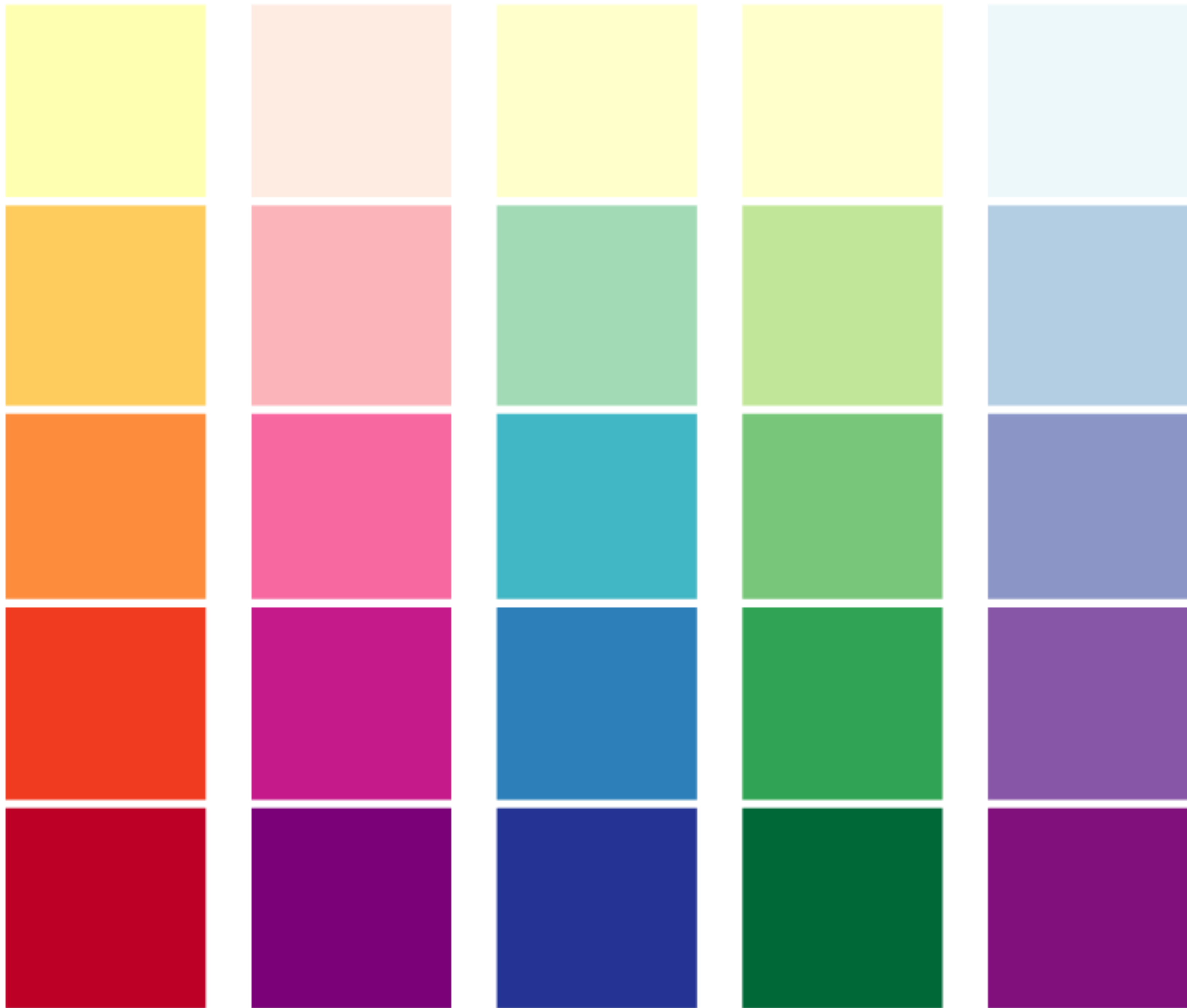
U.S. percentage Irish ancestry: 10.1%

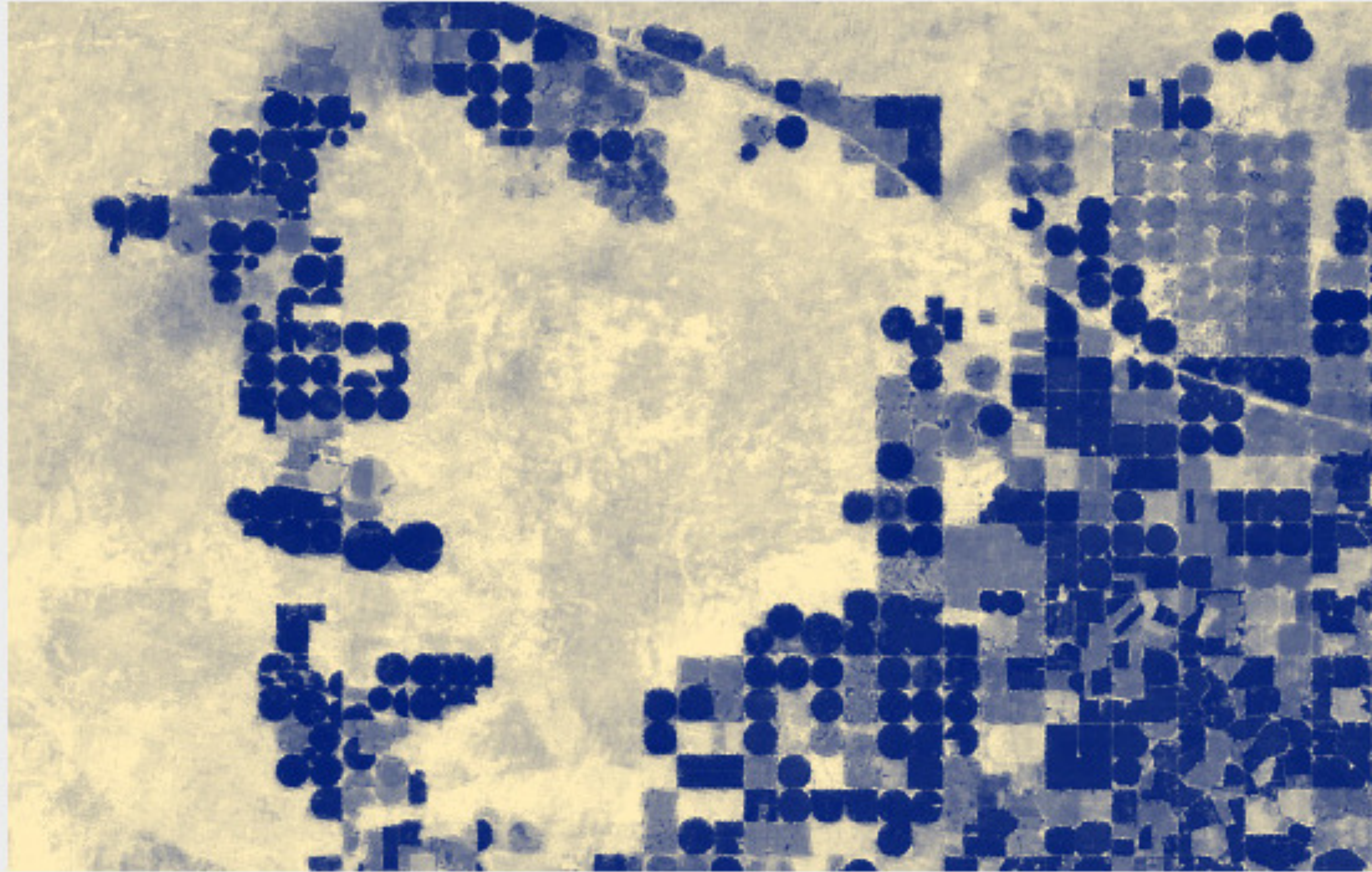
Irish ancestry as a percentage
of each county's population



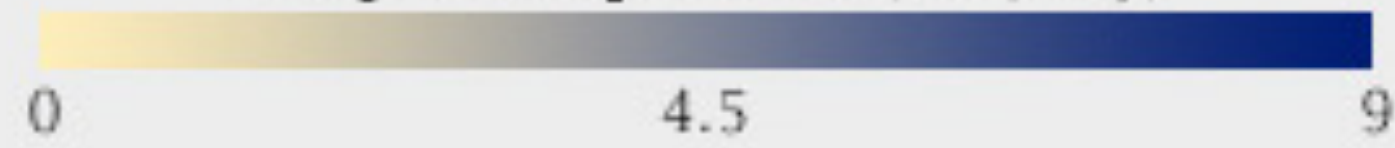
Sequential Color Schemes

- Using color and hue





Evapotranspiration (mm/day)



Diverging Color Schemes

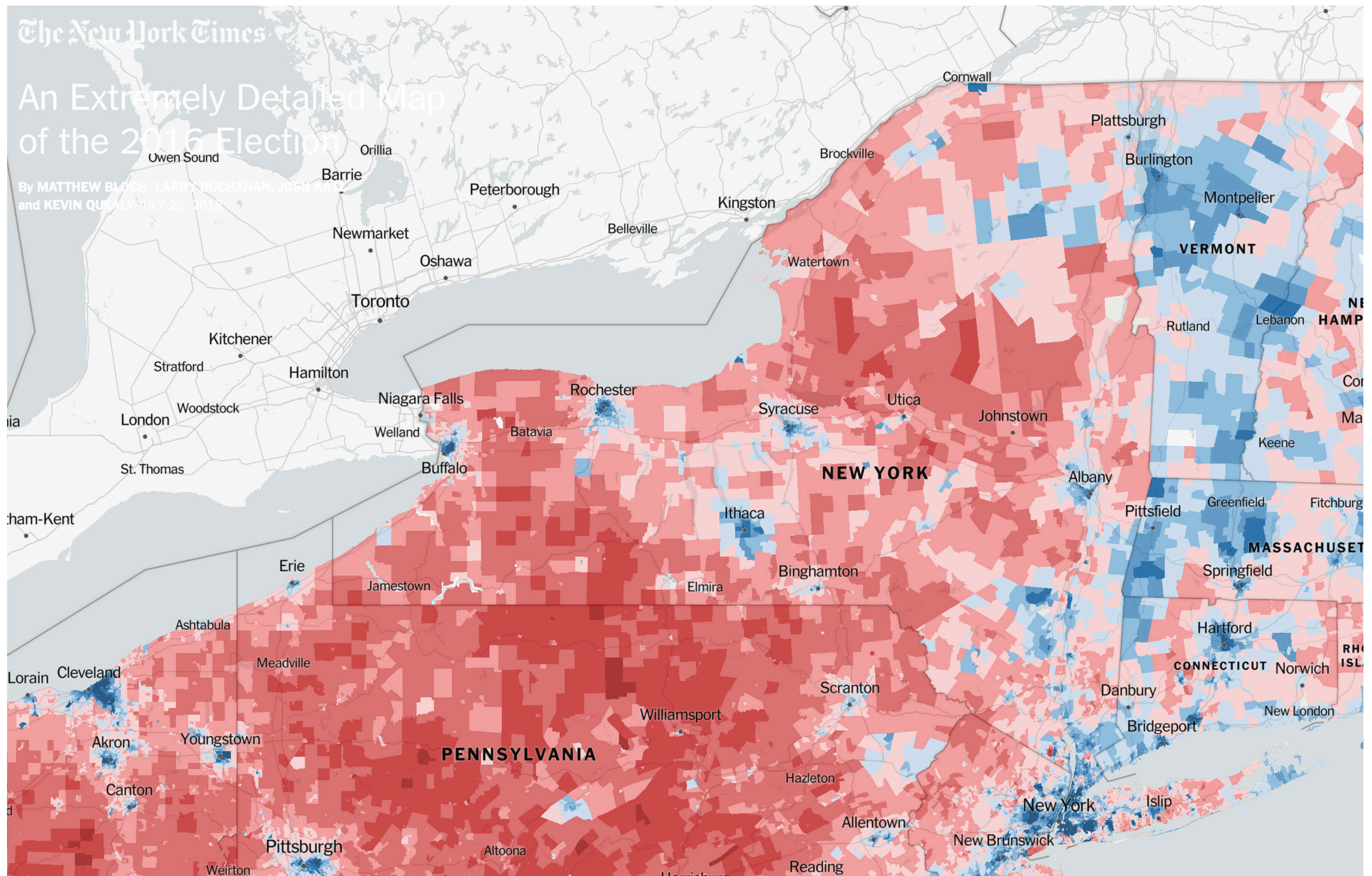
- For scales that have a natural zero or midpoint



The New York Times

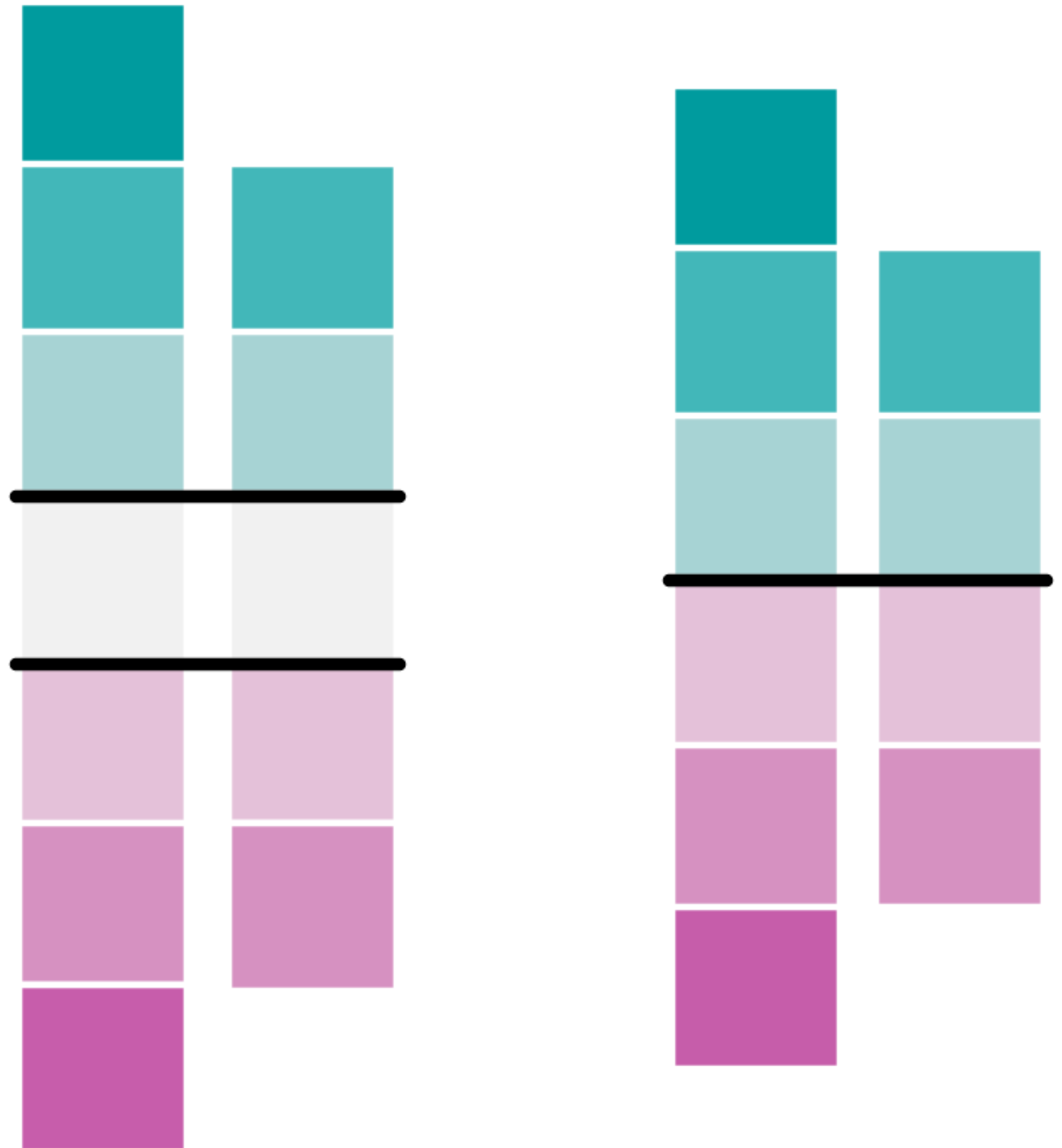
An Extremely Detailed Map of the 2016 Election

By MATTHEW BLOCH, LARRY BUCHANAN, JOSH KATZ
and KEVIN QUEALY JULY 25, 2018

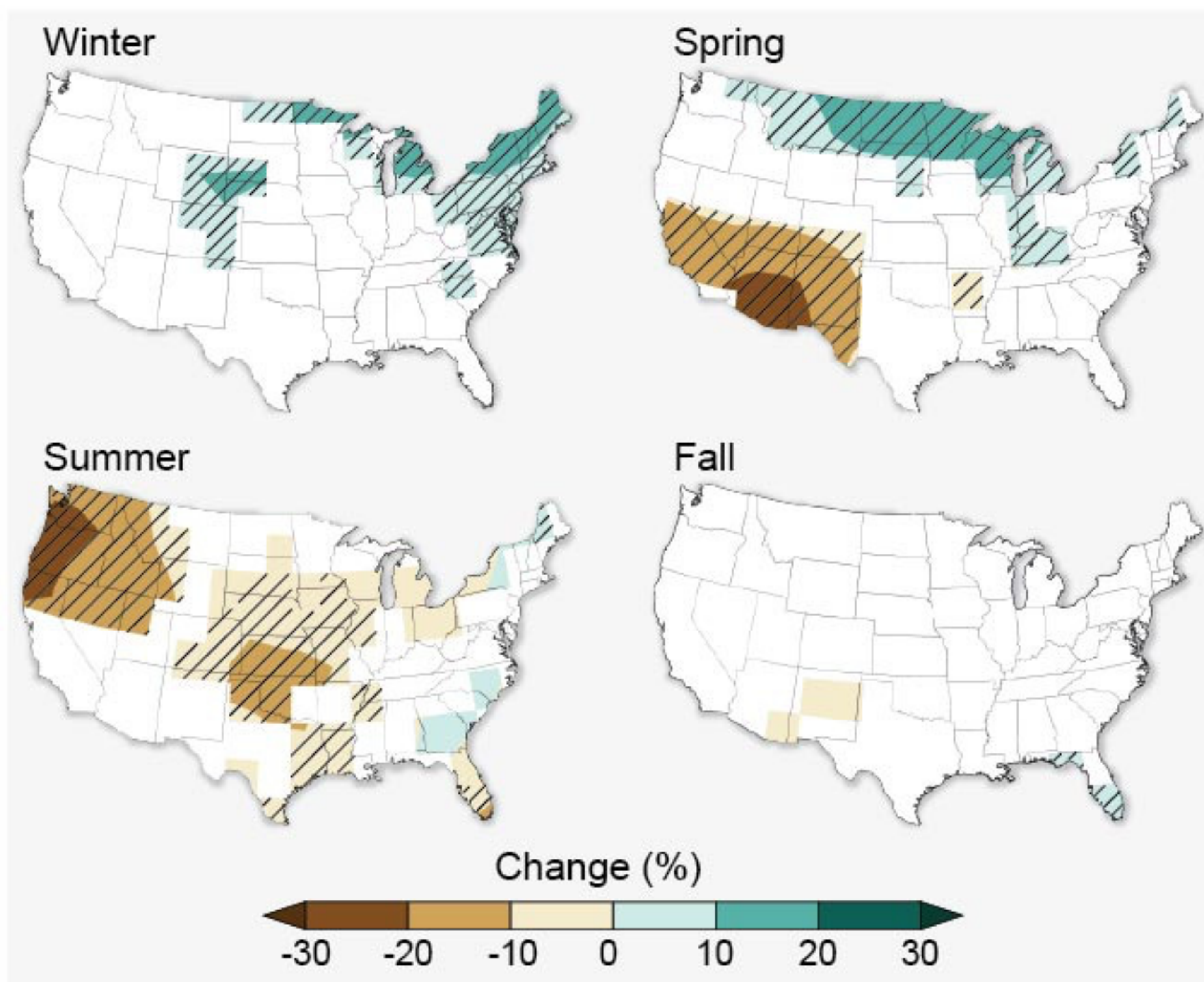


Diverging Color Schemes

- For scales that have a natural zero or midpoint
- With and without midpoint categories

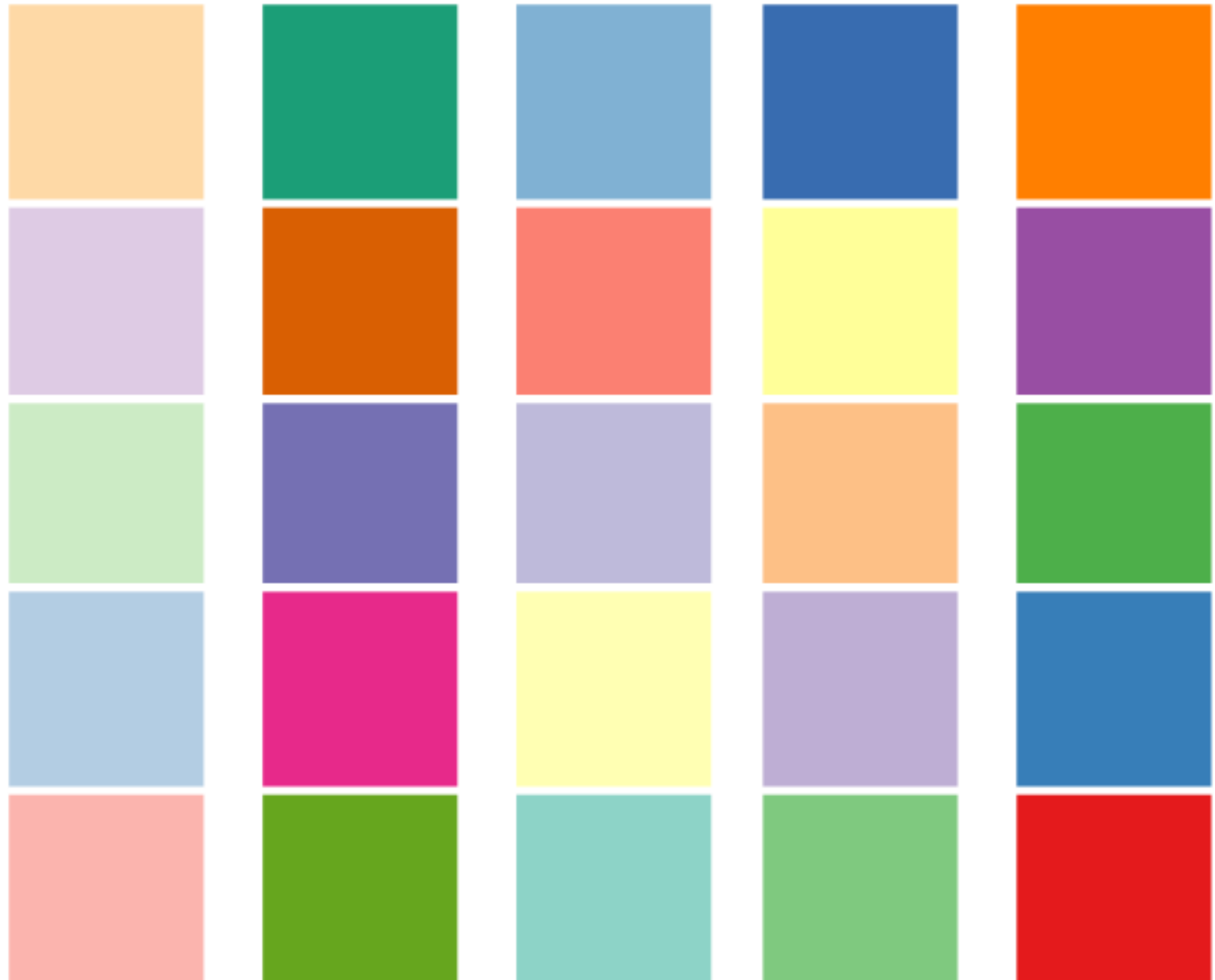


Projected Changes in Seasonal Precipitation

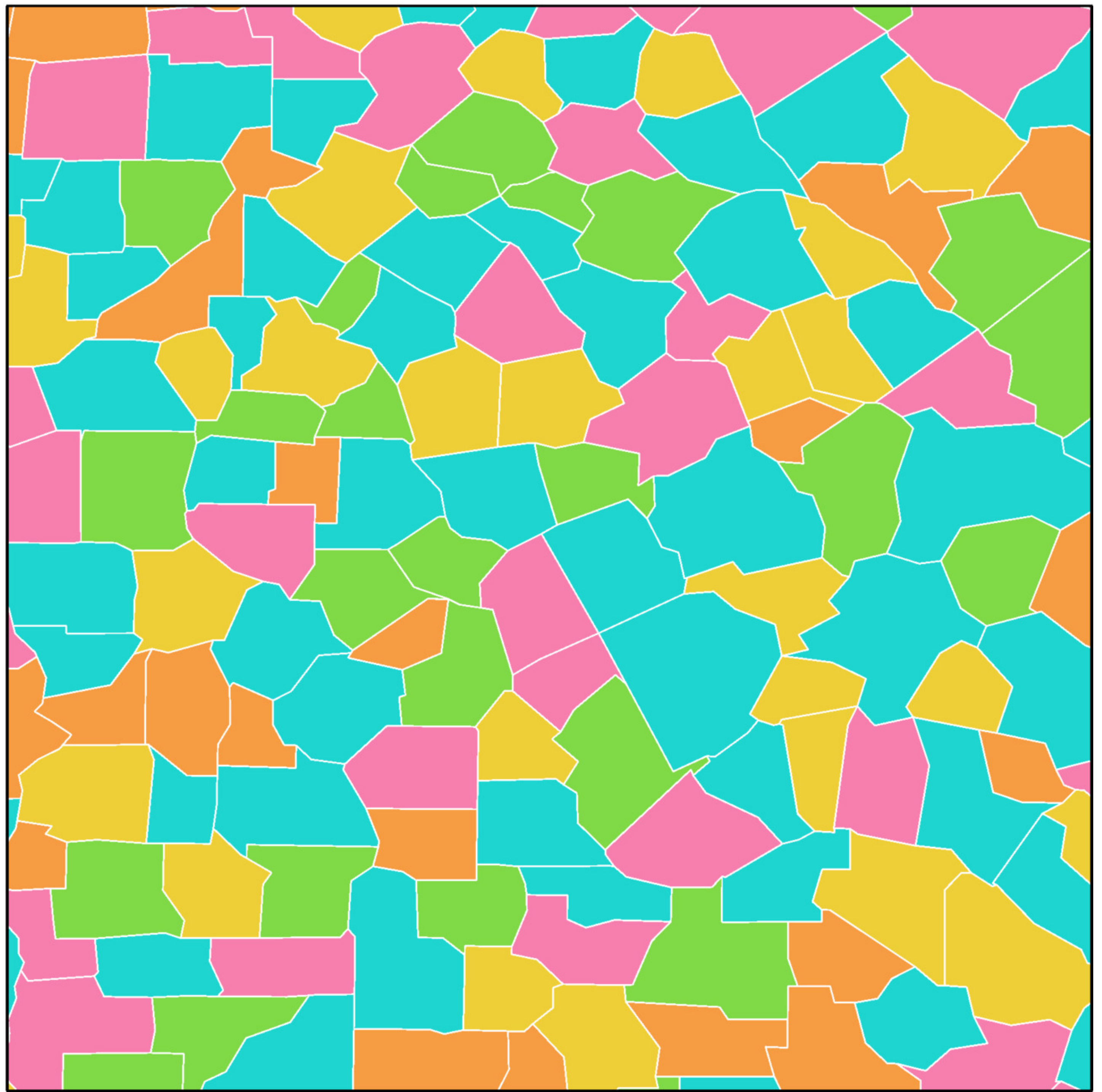


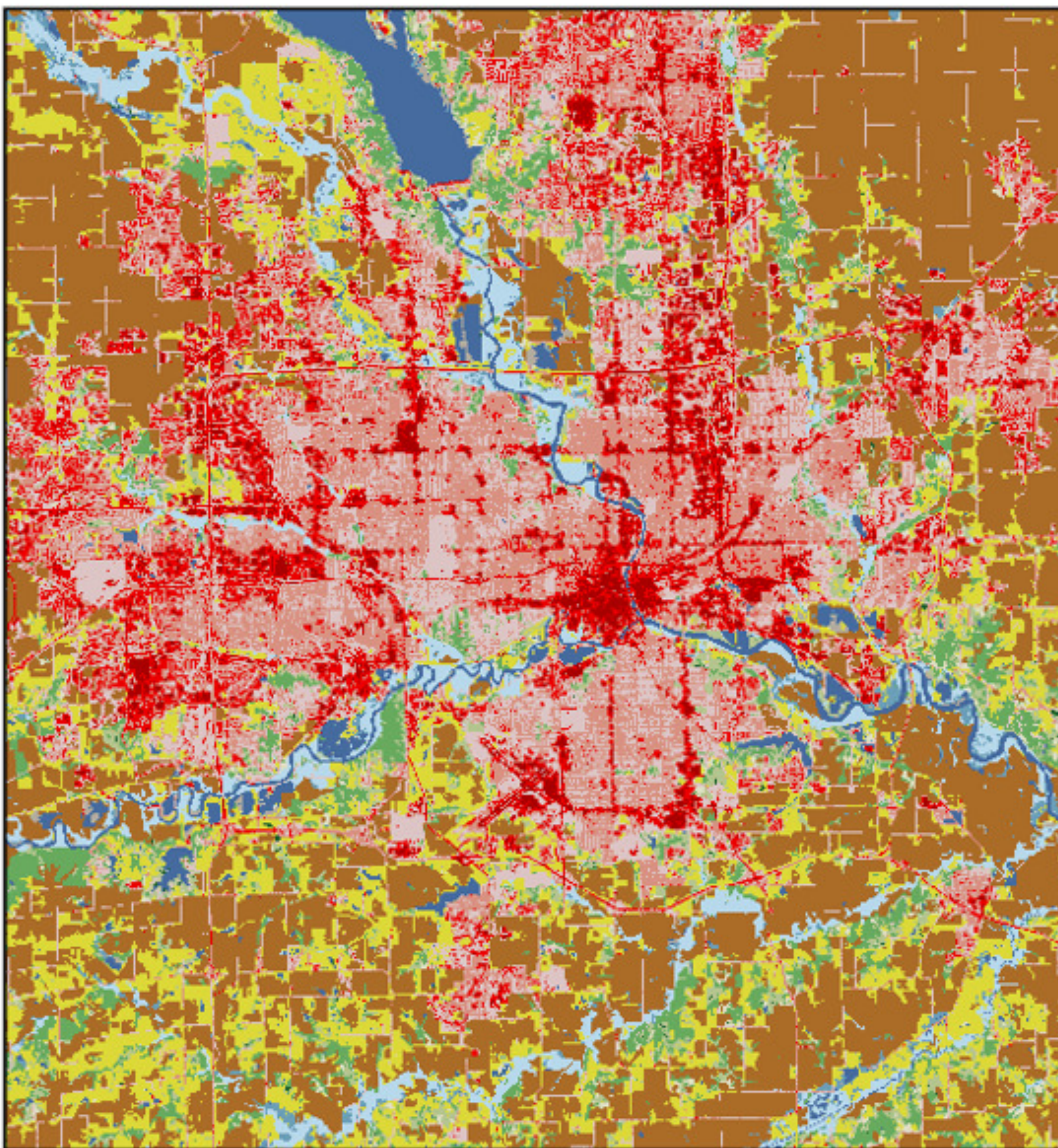
Qualitative Color Schemes

- For nominal data
- Encourage clear contrasts



Most Popular Kind of Dessert





Land Cover

NLCD class

- Open Water
- Perennial Ice/Snow
- Developed, Open Space
- Developed, Low Intensity
- Developed, Medium Intensity
- Developed, High Intensity
- Bare Rock/Sand/Clay
- Deciduous Forest
- Evergreen Forest
- Mixed Forest
- Shrub/Scrub
- Grasslands/Herbaceous
- Pasture/Hay
- Row Crops
- Woody Wetlands
- Emergent Herbaceous Wetlands

This is a lot. How do I specify these kinds of things?

- <https://colorbrewer2.org/>

The screenshot displays the ColorBrewer 2.0 web application interface. The top navigation bar includes links for "how to use", "updates", "downloads", and "credits". The main title "COLORBREWER 2.0" is prominently displayed, with the subtitle "color advice for cartography" below it.

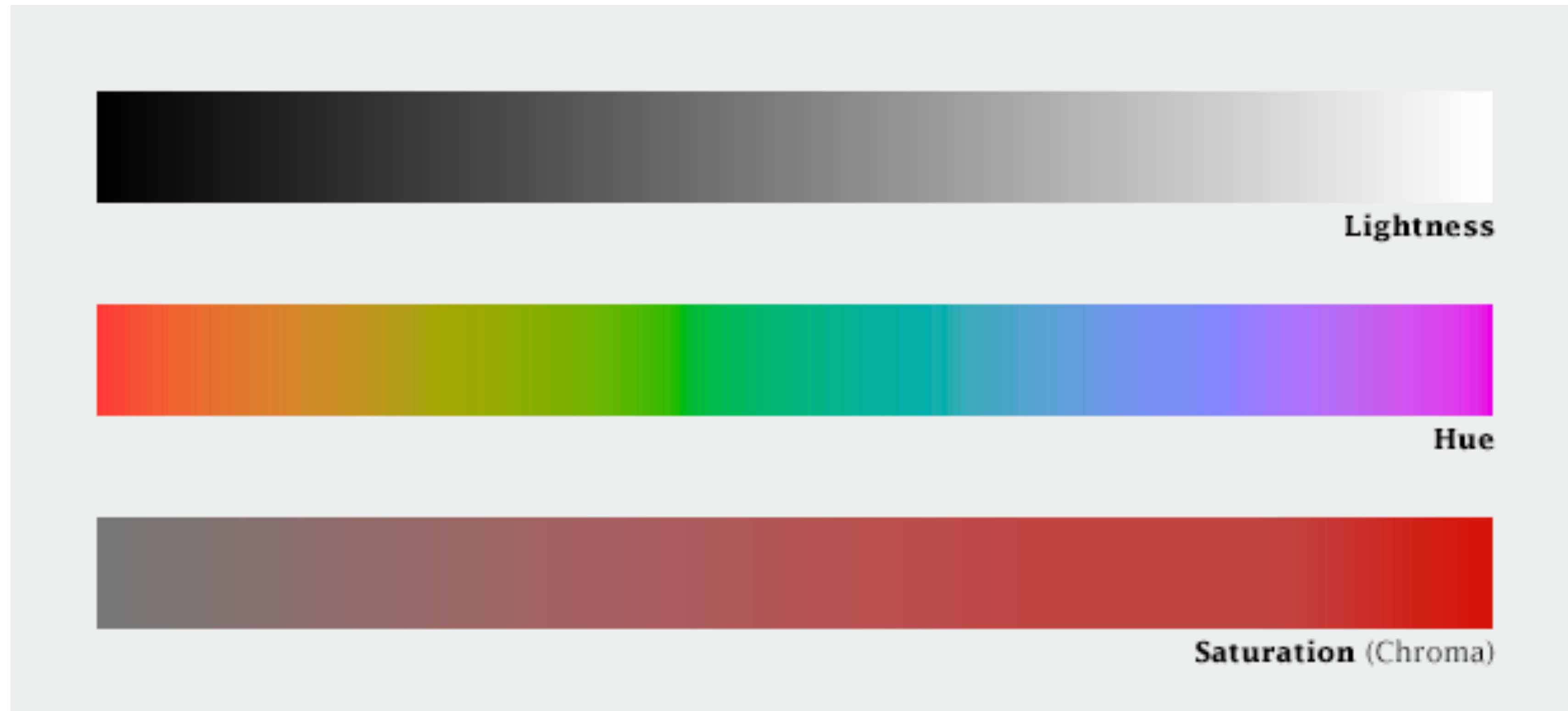
The interface is divided into several sections:

- Number of data classes:** Set to 3.
- Nature of your data:** Radio buttons for "sequential" (selected), "diverging", and "qualitative".
- Pick a color scheme:** Two columns of color swatches. The "Multi-hue" column shows various sequential schemes, and the "Single hue" column shows sequential schemes with a single hue.
- Only show:** Checkboxes for "colorblind safe", "print friendly", and "photocopy safe".
- Context:** Checkboxes for "roads", "cities", and "borders" (checked).
- Background:** Radio buttons for "solid color" (selected) and "terrain".
- Color transparency:** A slider control.
- 3-class BuGn:** A legend showing the selected color scheme with three classes: light blue (#e5f5f9), medium green (#99d8c9), and dark green (#2ca25f).
- EXPORT:** A button to export the map.

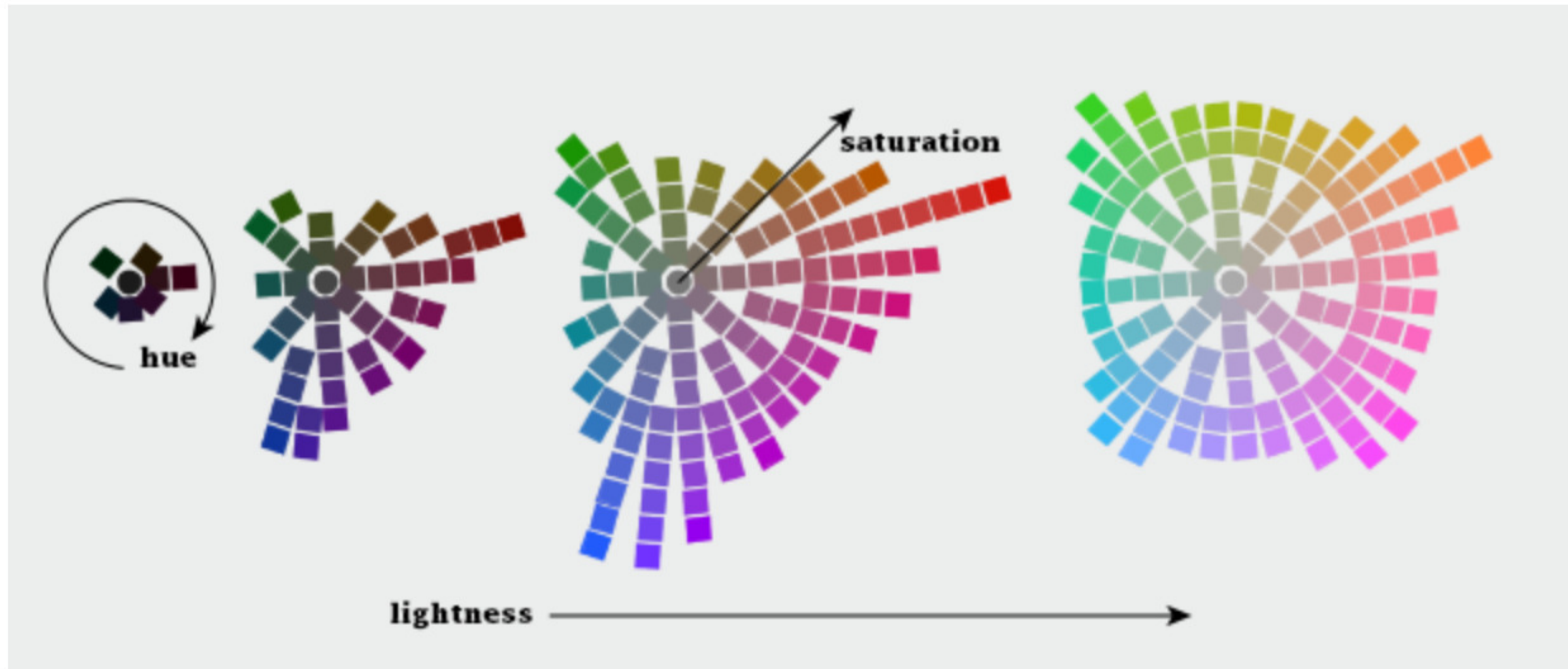
The main map area shows a map of the United States with county-level data colored according to the selected 3-class sequential scheme. The map is predominantly light blue, with some medium green and dark green areas.

At the bottom, the copyright notice reads: "© Cynthia Brewer, Mark Harrower and The Pennsylvania State University". Below this, there are links for "Source code and feedback", "Back to Flash version", and "Back to ColorBrewer 1.0". The "axismaps" logo is visible in the bottom right corner.

Describing color with language

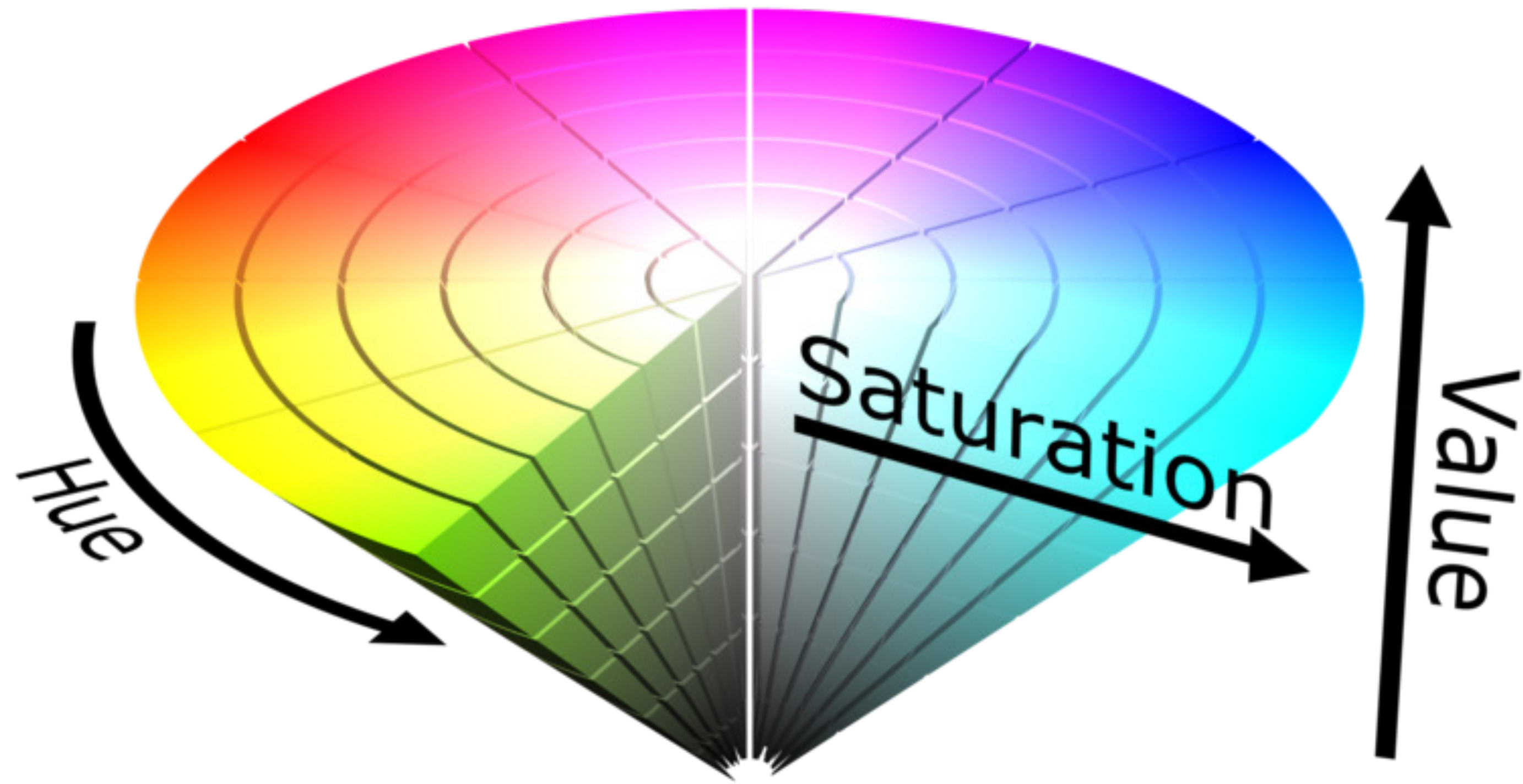


Color wheels



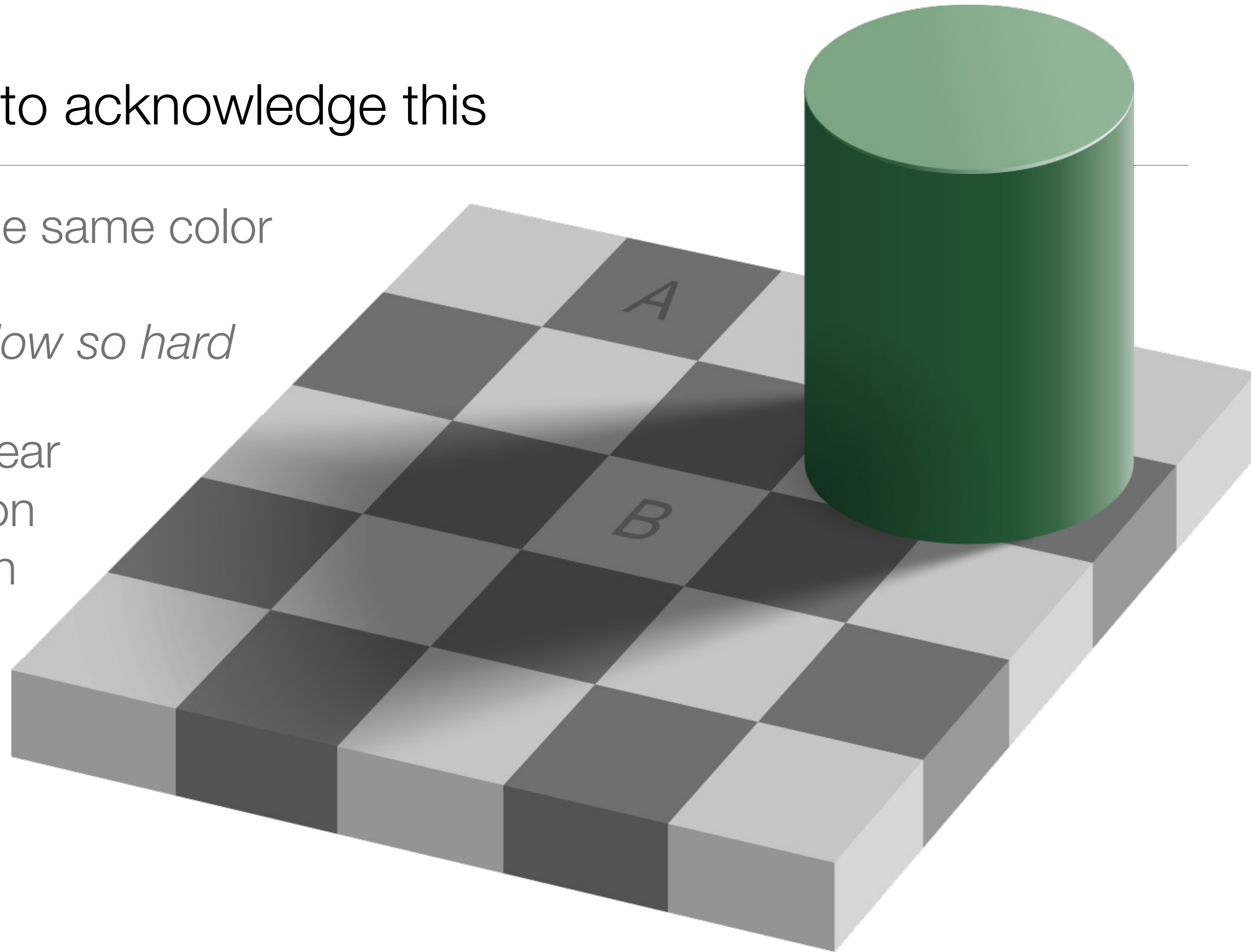
Color wheels

- Color wheels are particularly valuable for describing color to computers
- Humans, however, do not always perceive space on color wheels like computers do



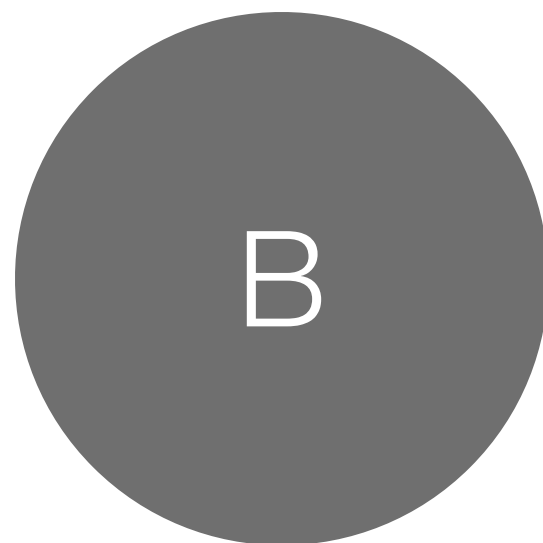
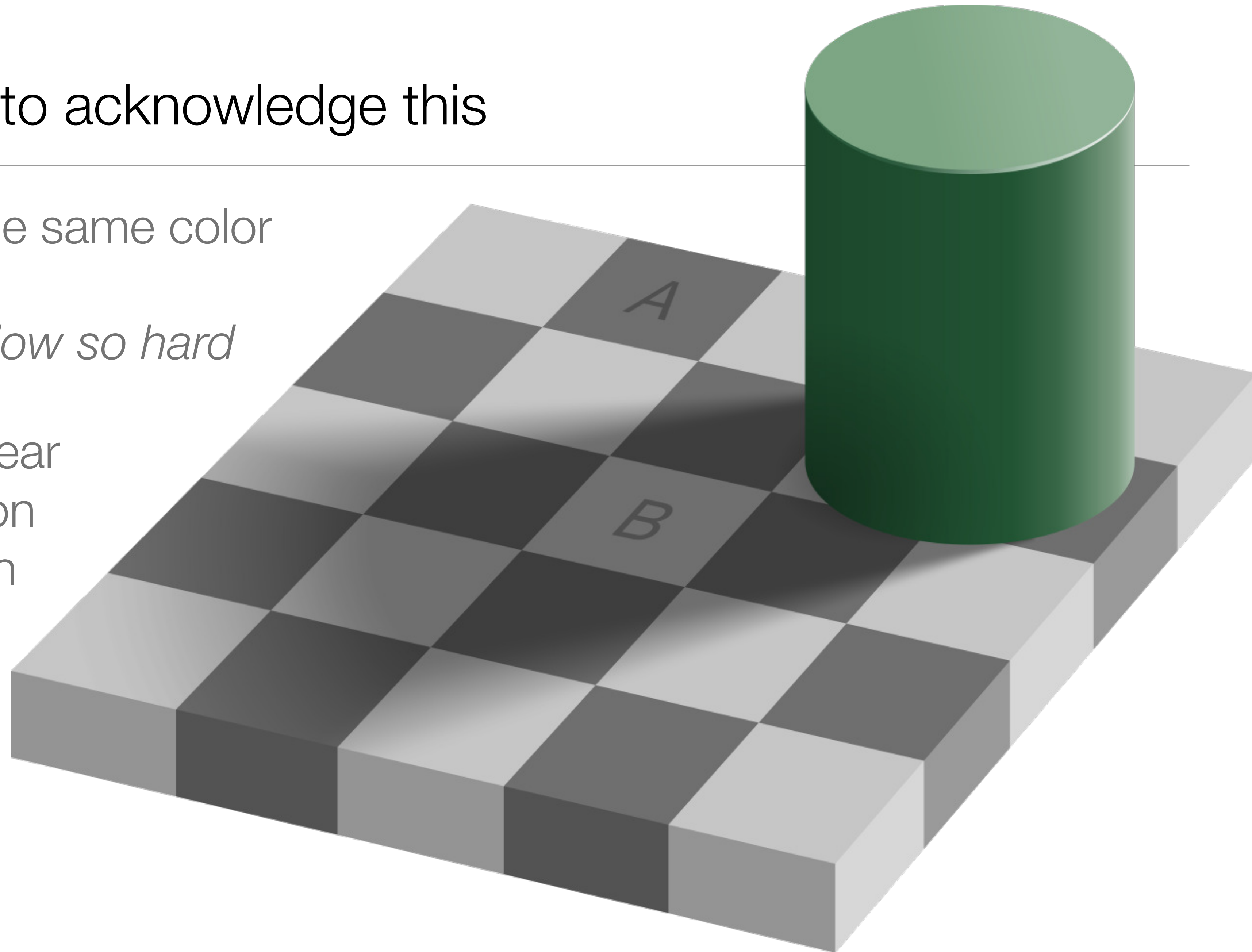
Your brain will refuse to acknowledge this

- Square A and B are the same color
- *We interpret that shadow so hard*
- **Induction:** colors appear differently depending on the backdrop on which they appear



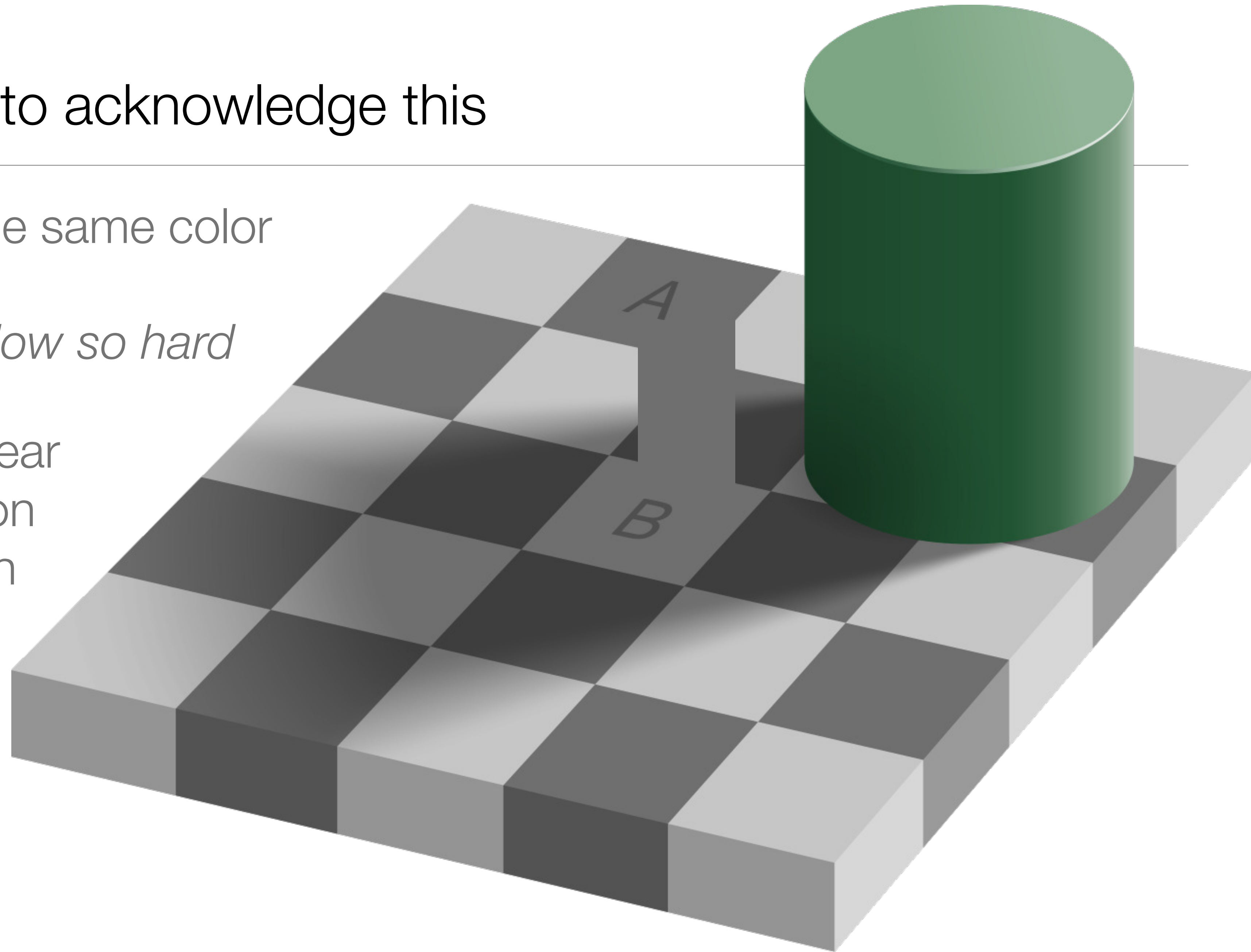
Your brain will refuse to acknowledge this

- Square A and B are the same color
- *We interpret that shadow so hard*
- **Induction:** colors appear differently depending on the backdrop on which they appear

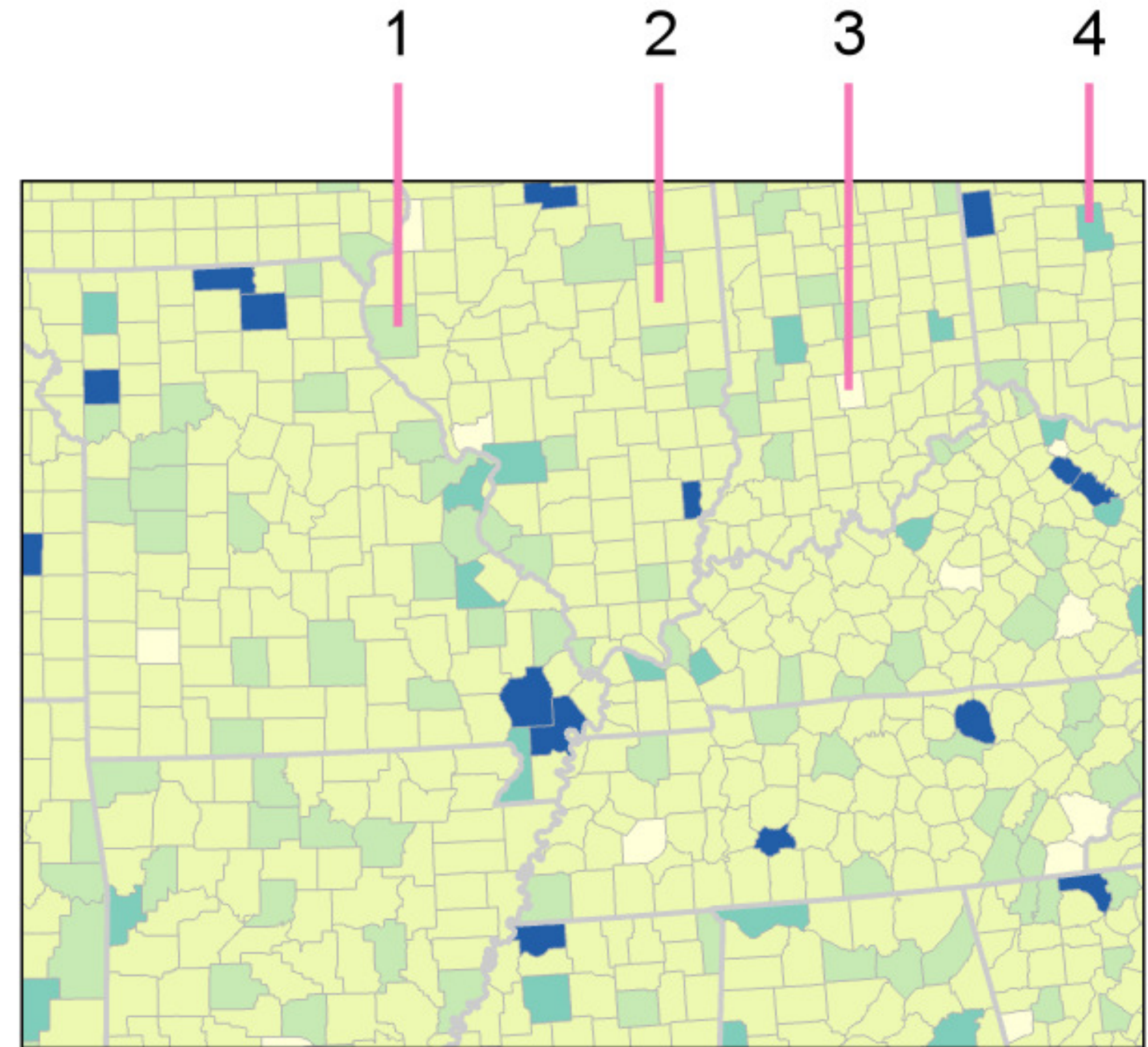
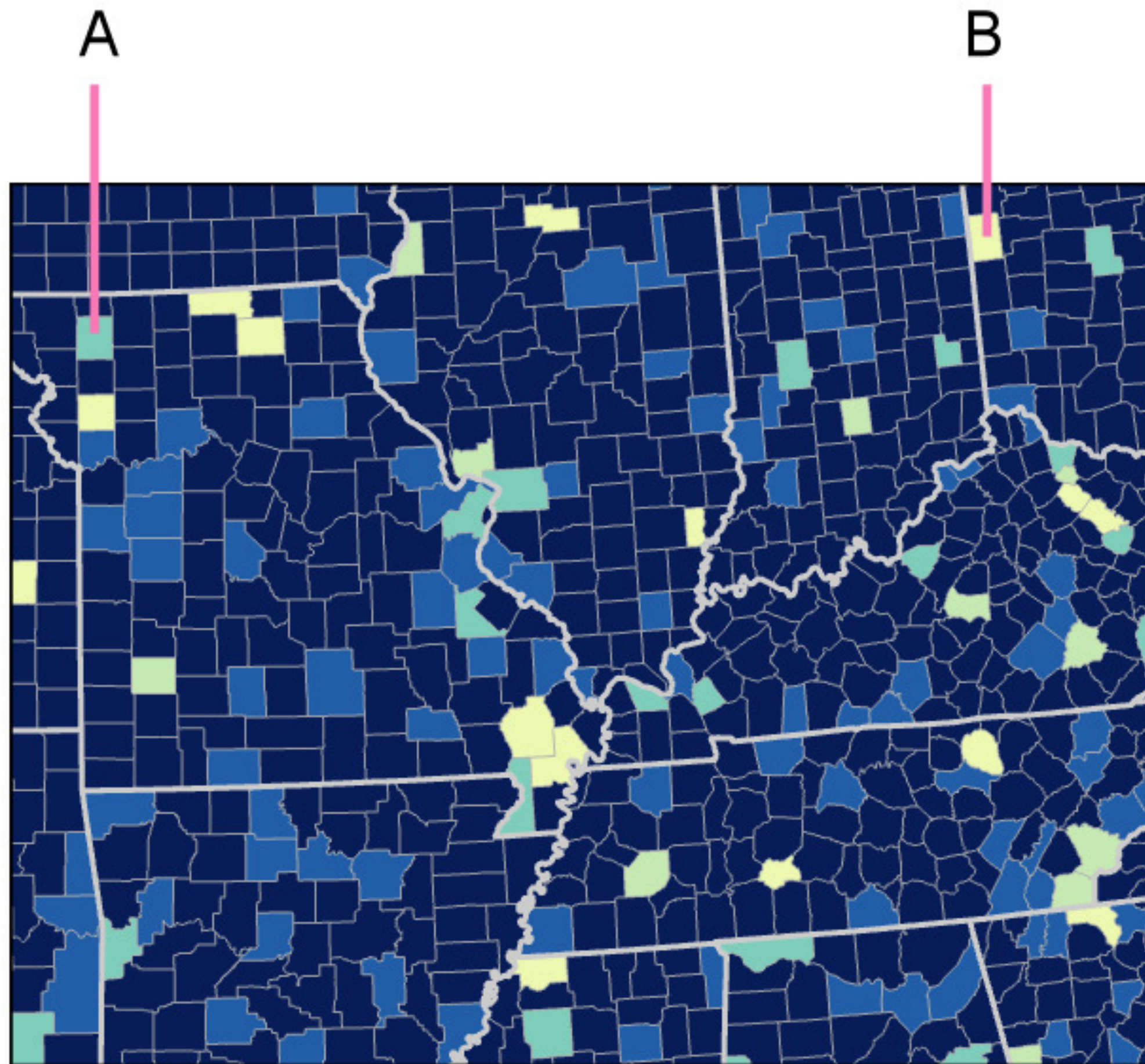


Your brain will refuse to acknowledge this

- Square A and B are the same color
- *We interpret that shadow so hard*
- **Induction:** colors appear differently depending on the backdrop on which they appear

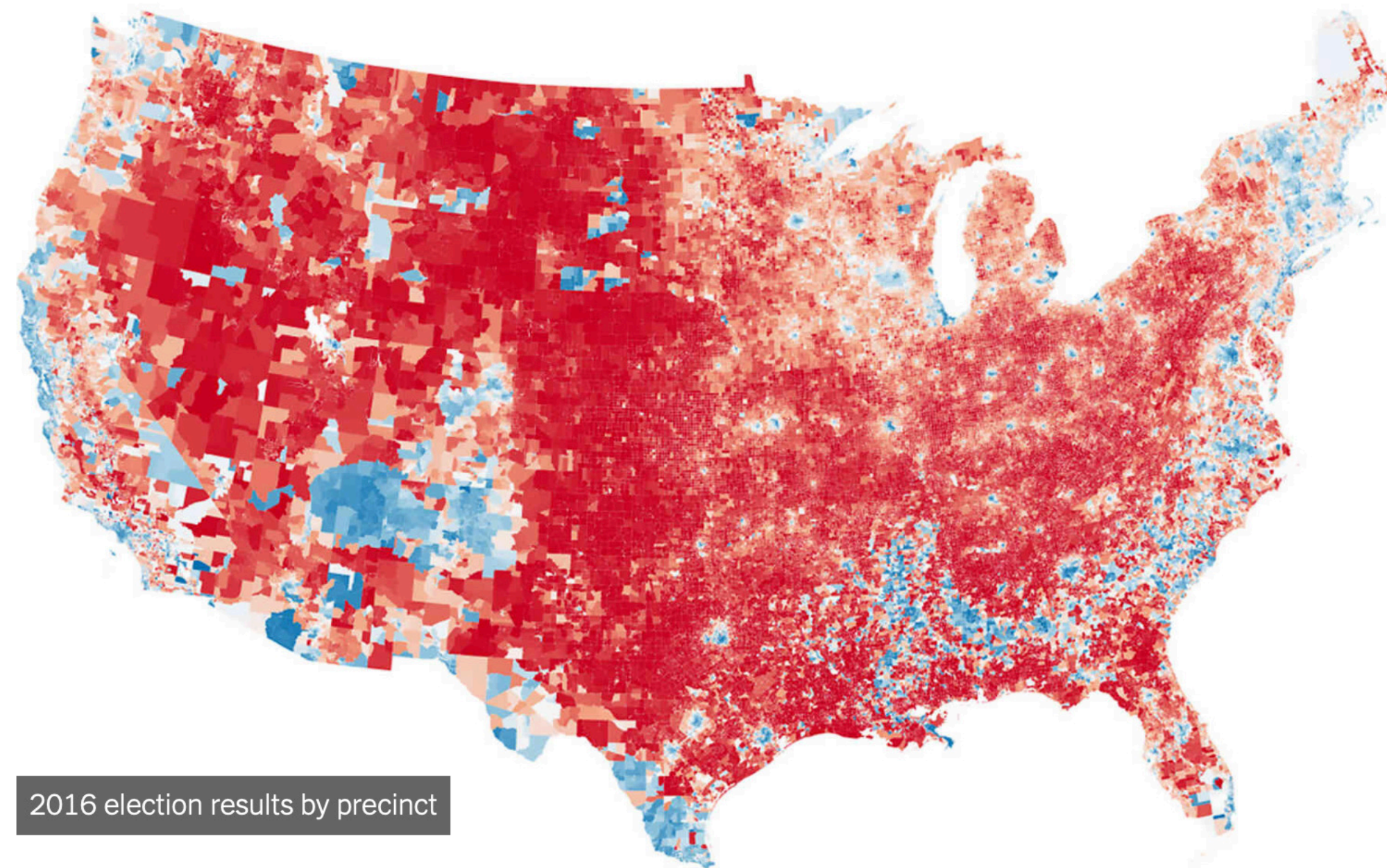


Induction in a map



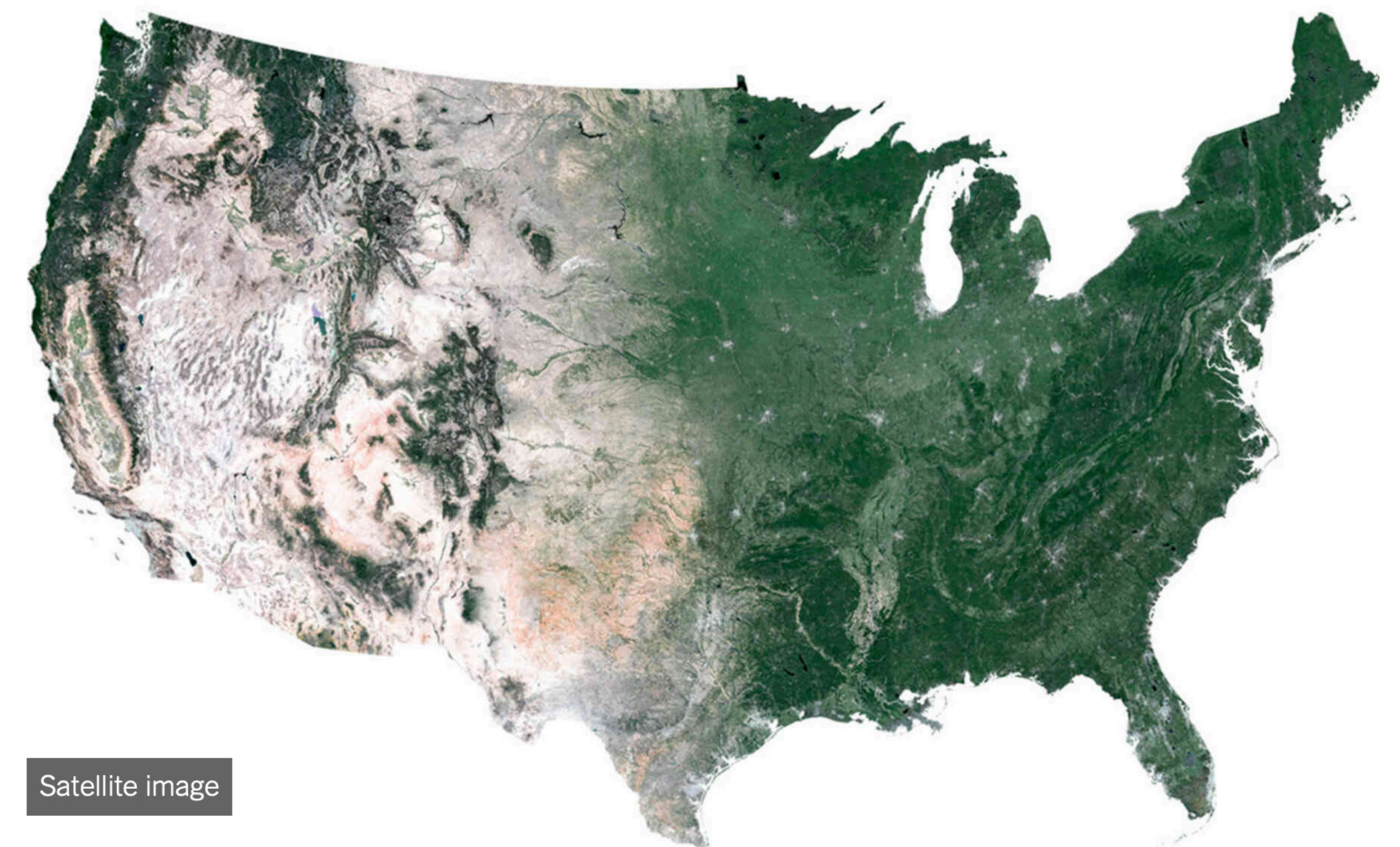
For fun: representing geographic space with color

- Visualizing the lived natural environment of voters



2016 election results by precinct

In the election map, Donald Trump won red areas, and Hillary Clinton won blue ones. ▀ Source: Descartes Labs; Precinct-level data compiled by Ryne Rohla, U.C.L.A.

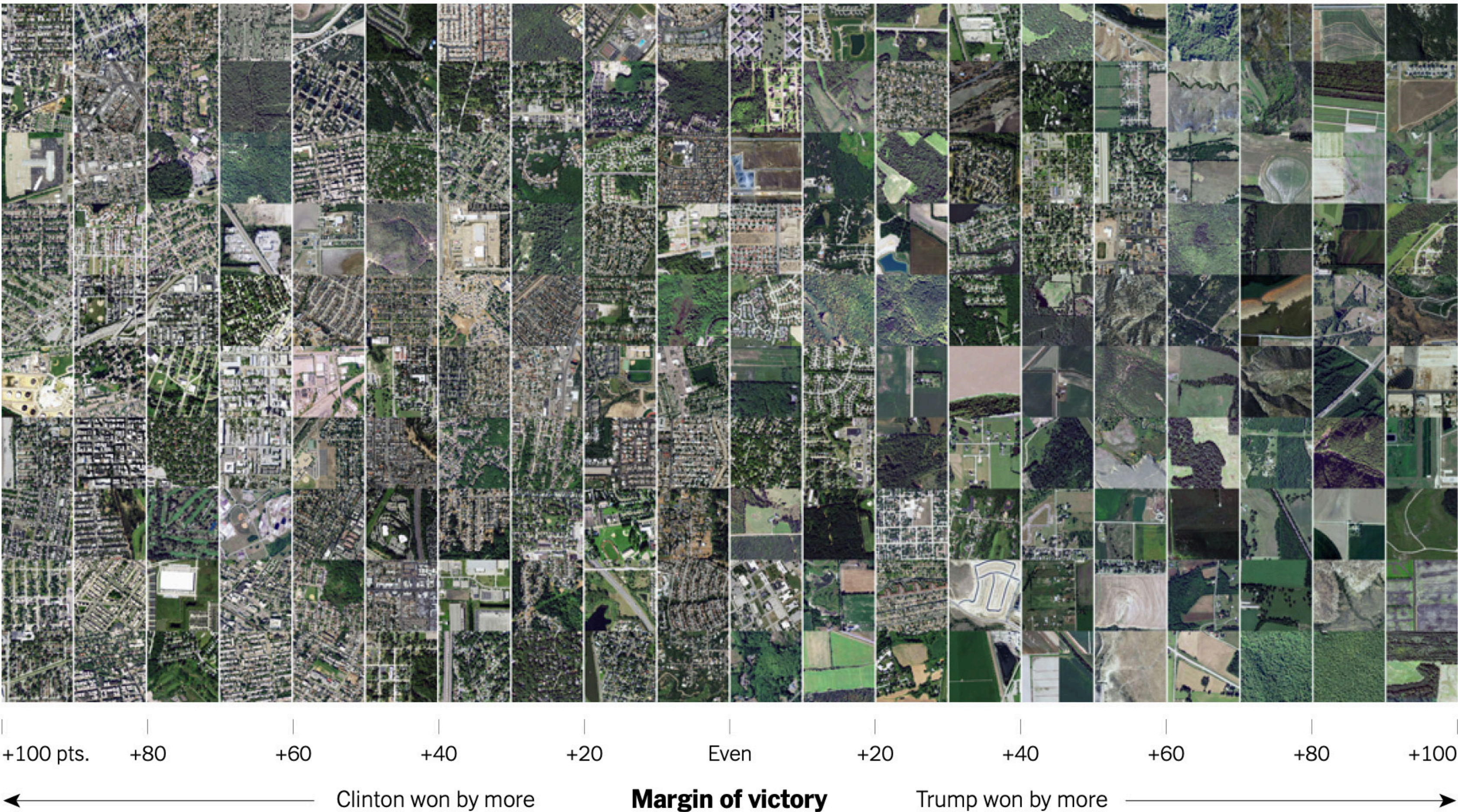


Satellite image

In the election map, Donald Trump won red areas, and Hillary Clinton won blue ones. ▀ Source: Descartes Labs; Precinct-level data compiled by Ryne Rohla, U.C.L.A.

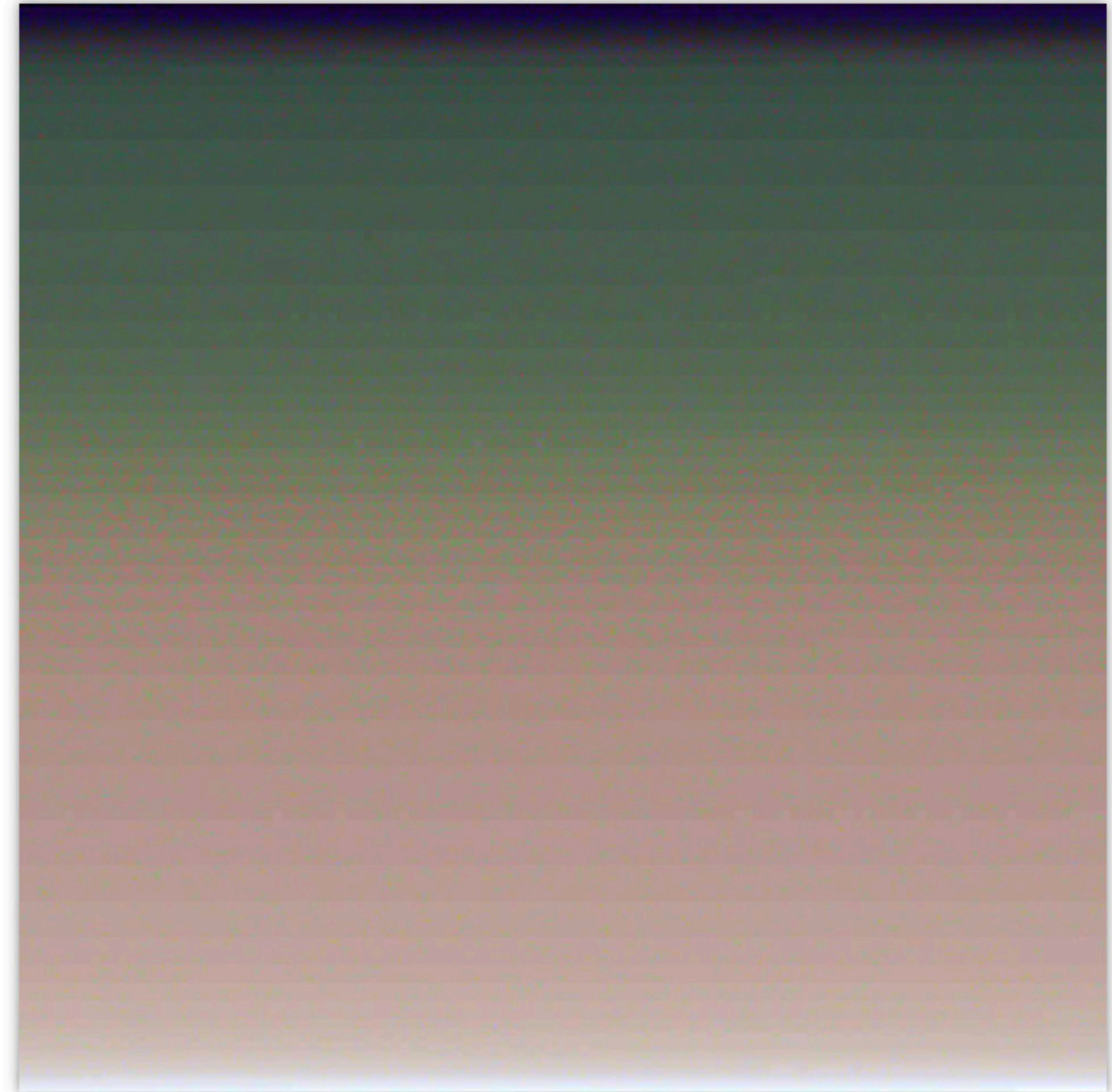
Visualizing the lived natural environment of voters

Aerial Images of Landscapes Across the Political Spectrum

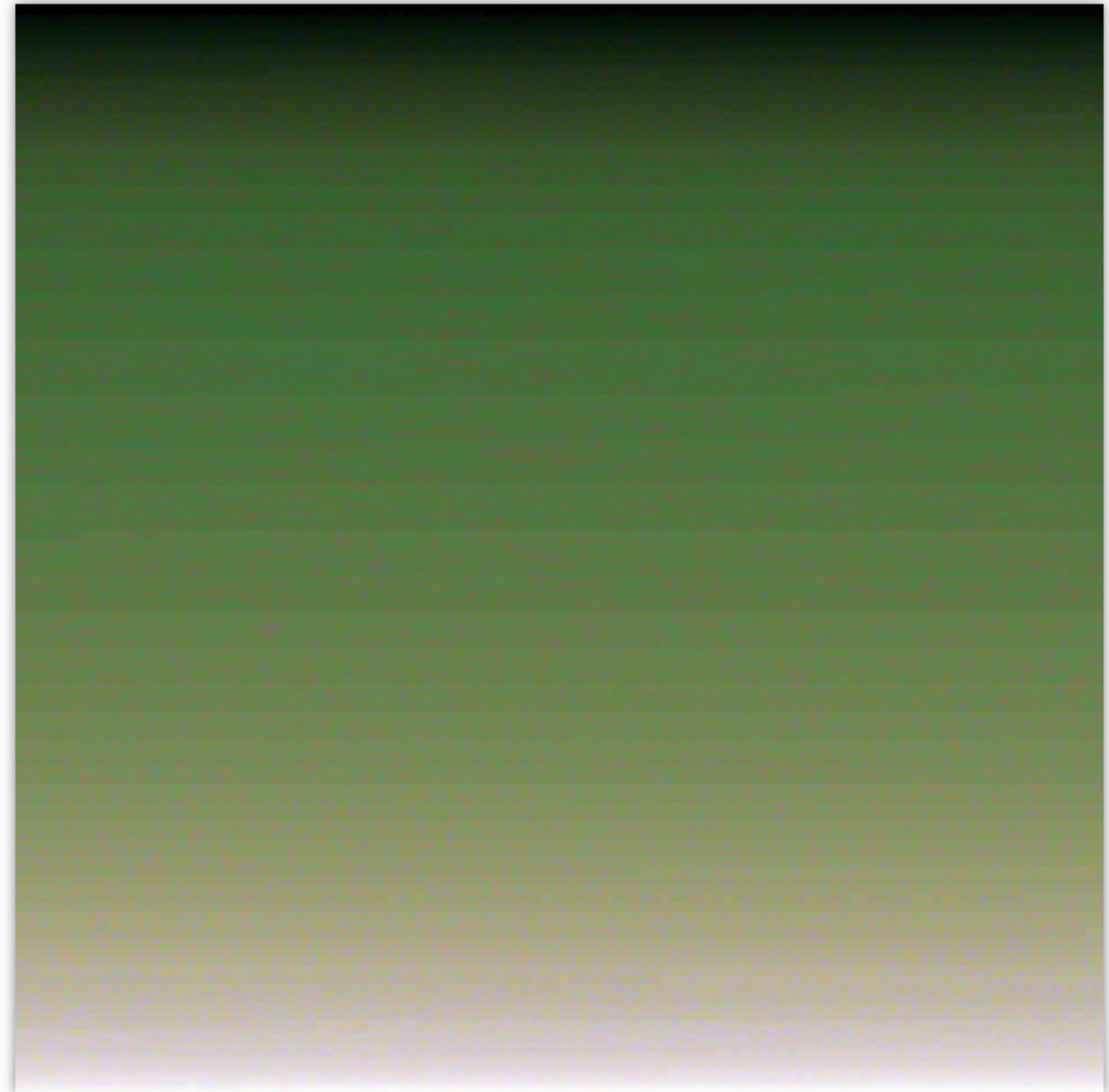
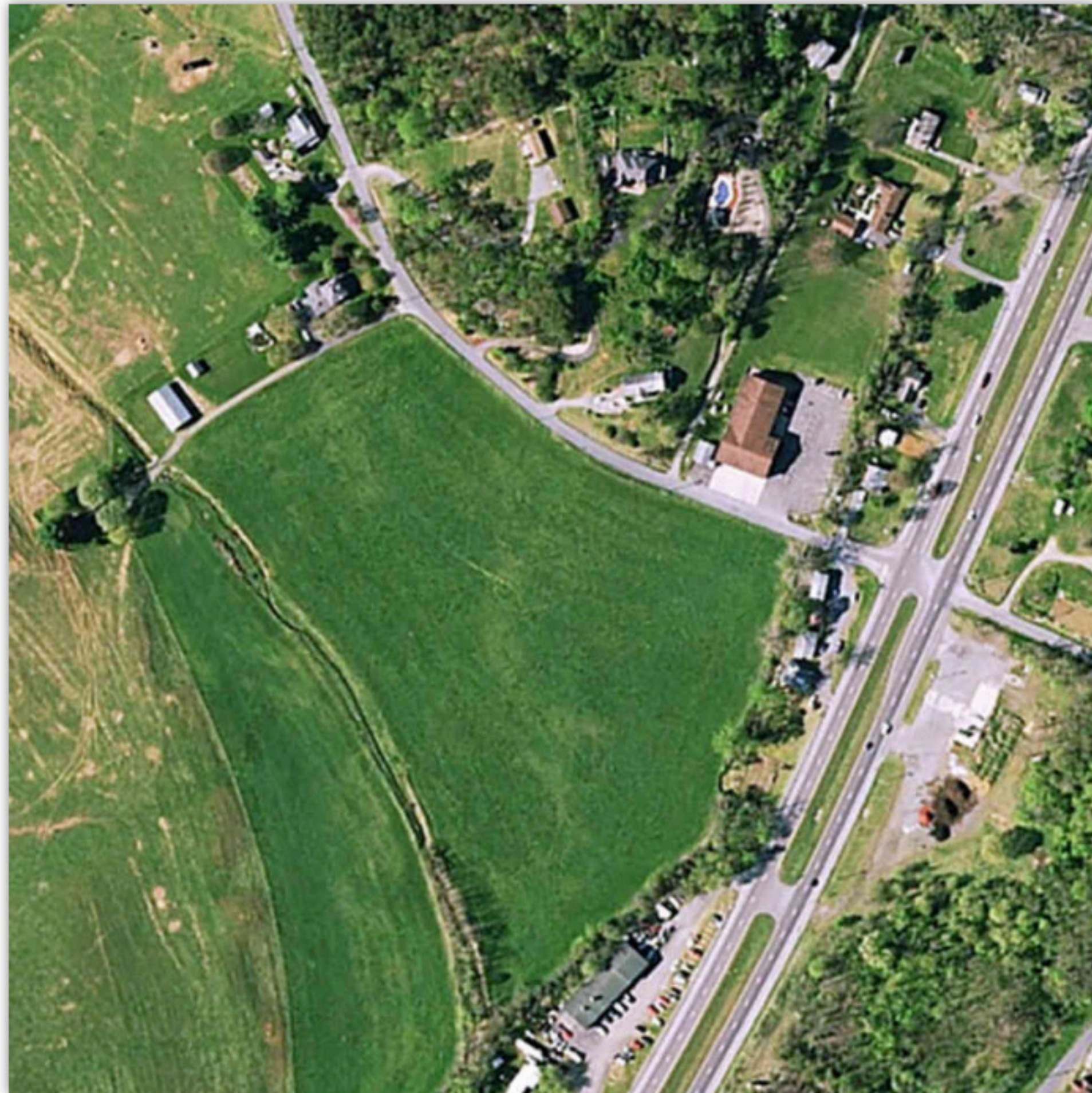


Each image shows an area 0.5 kilometers across.

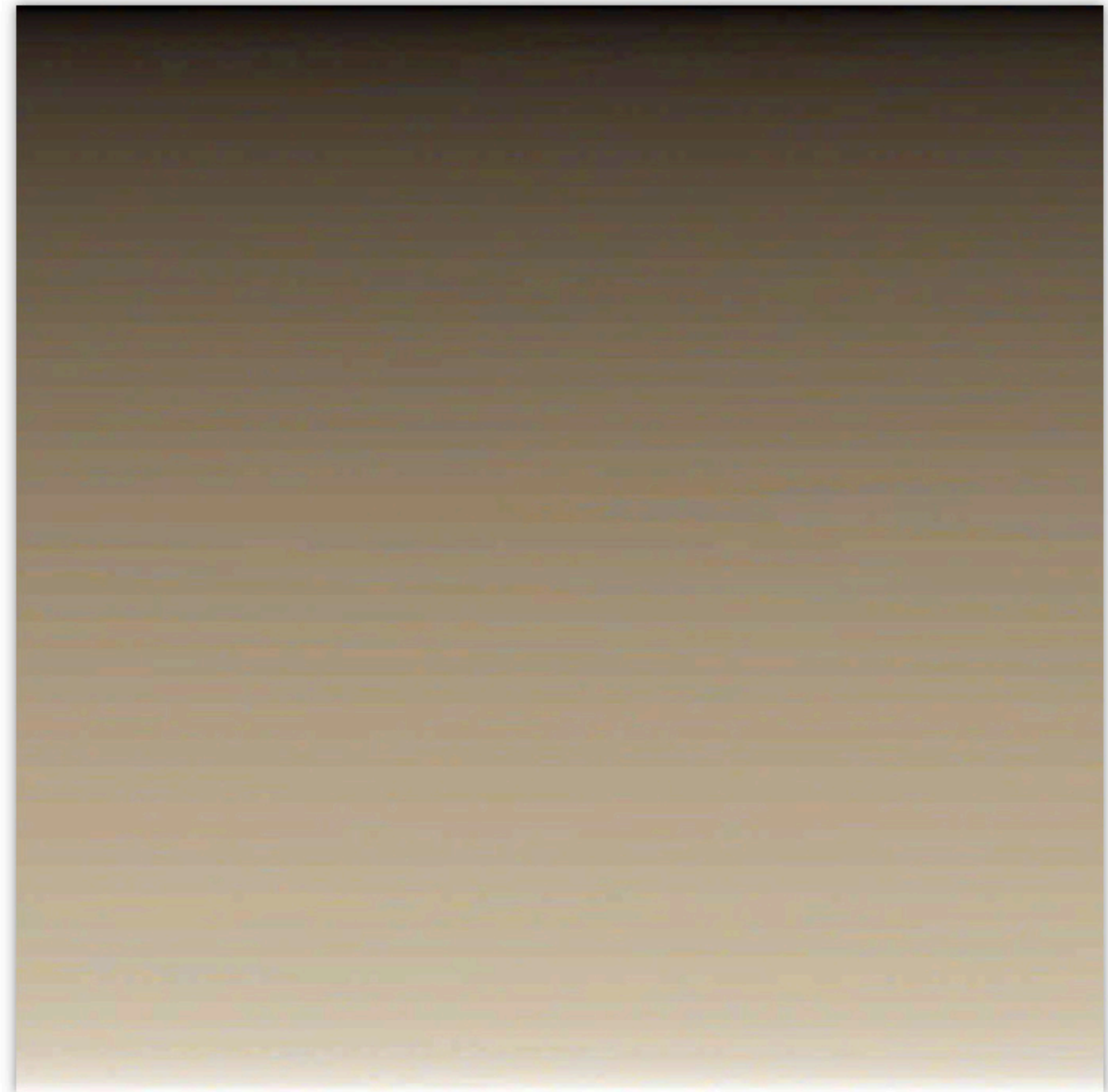
Finger Lakes, New York



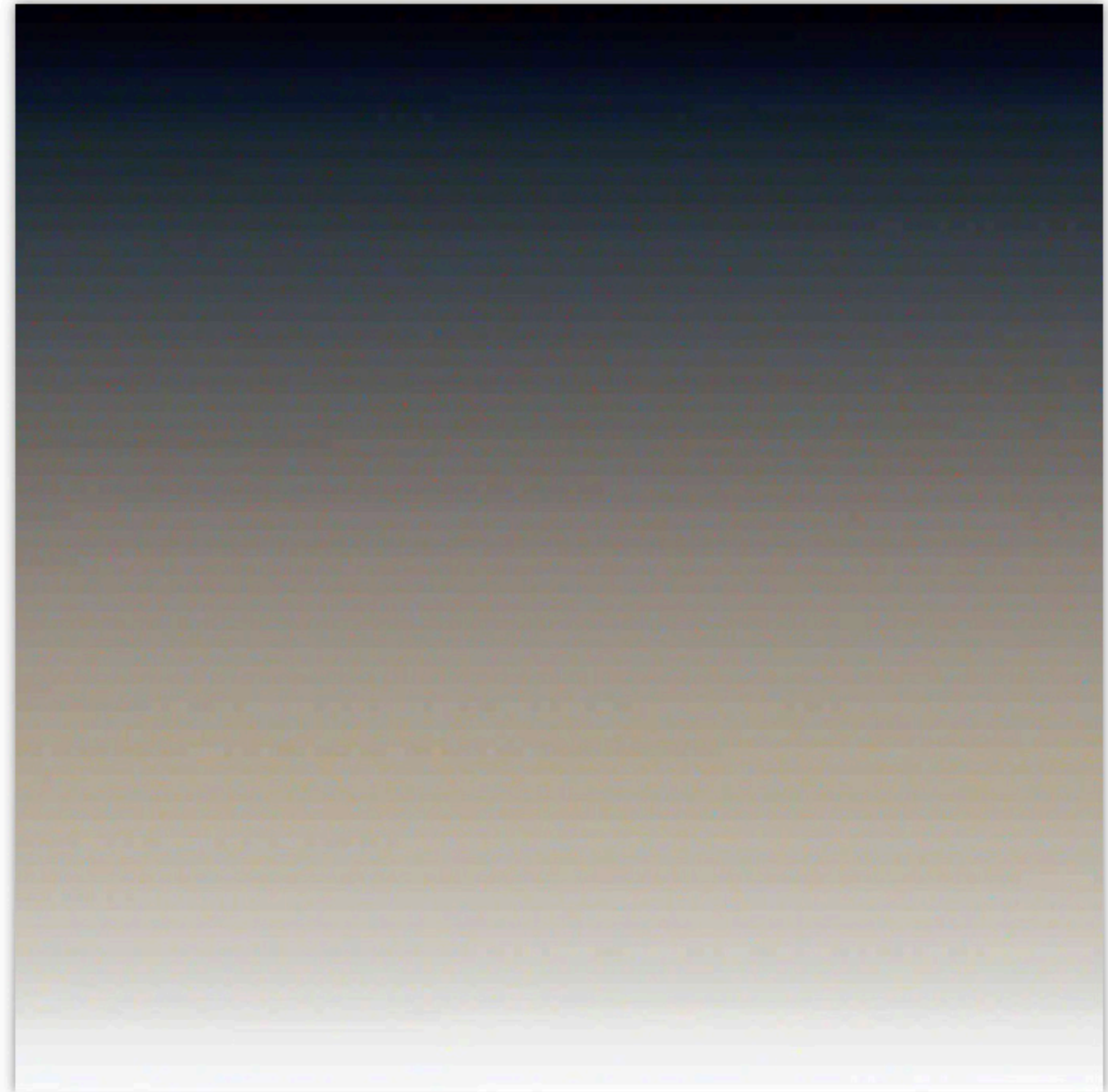
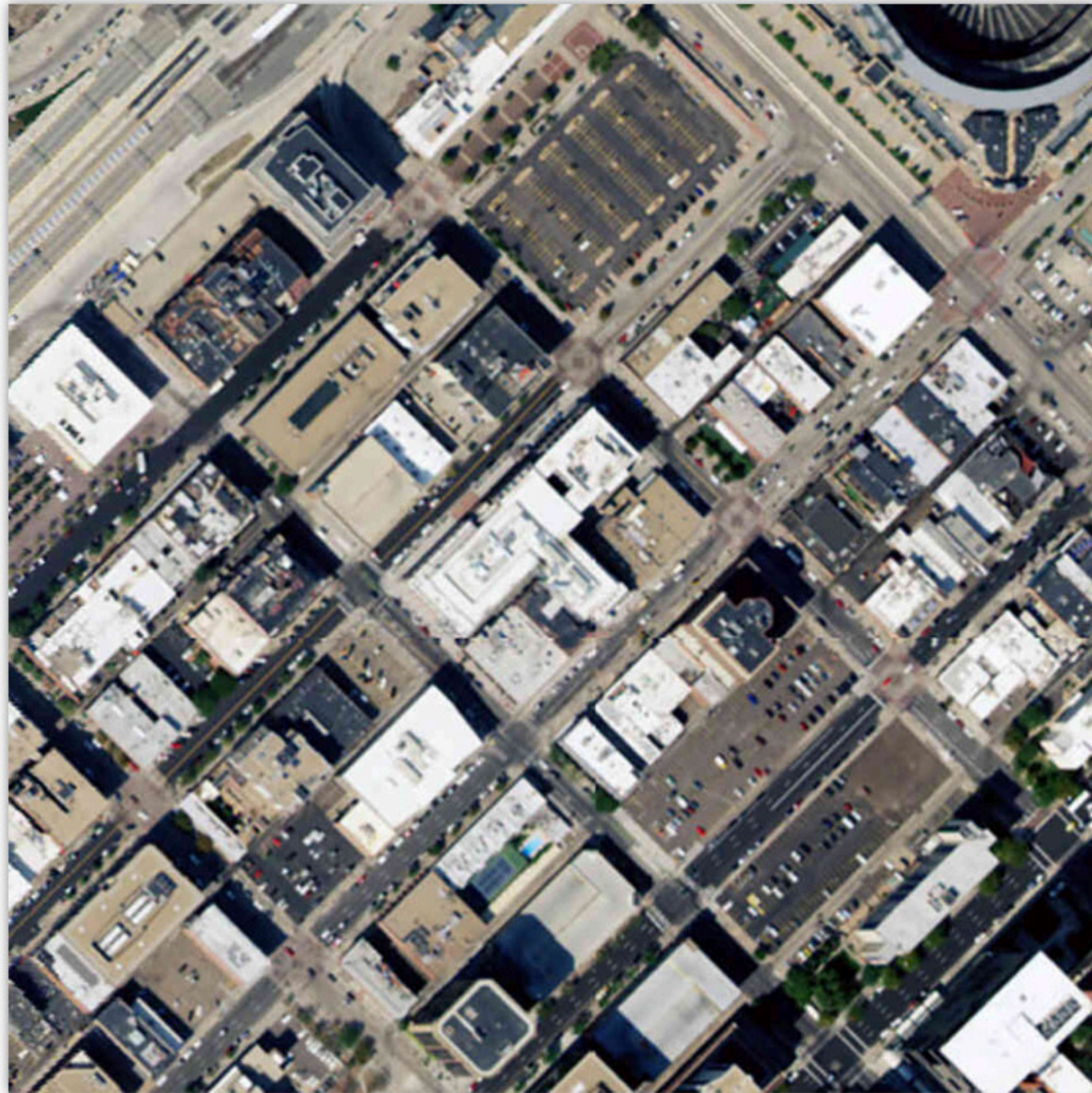
Blue Ridge, Virginia



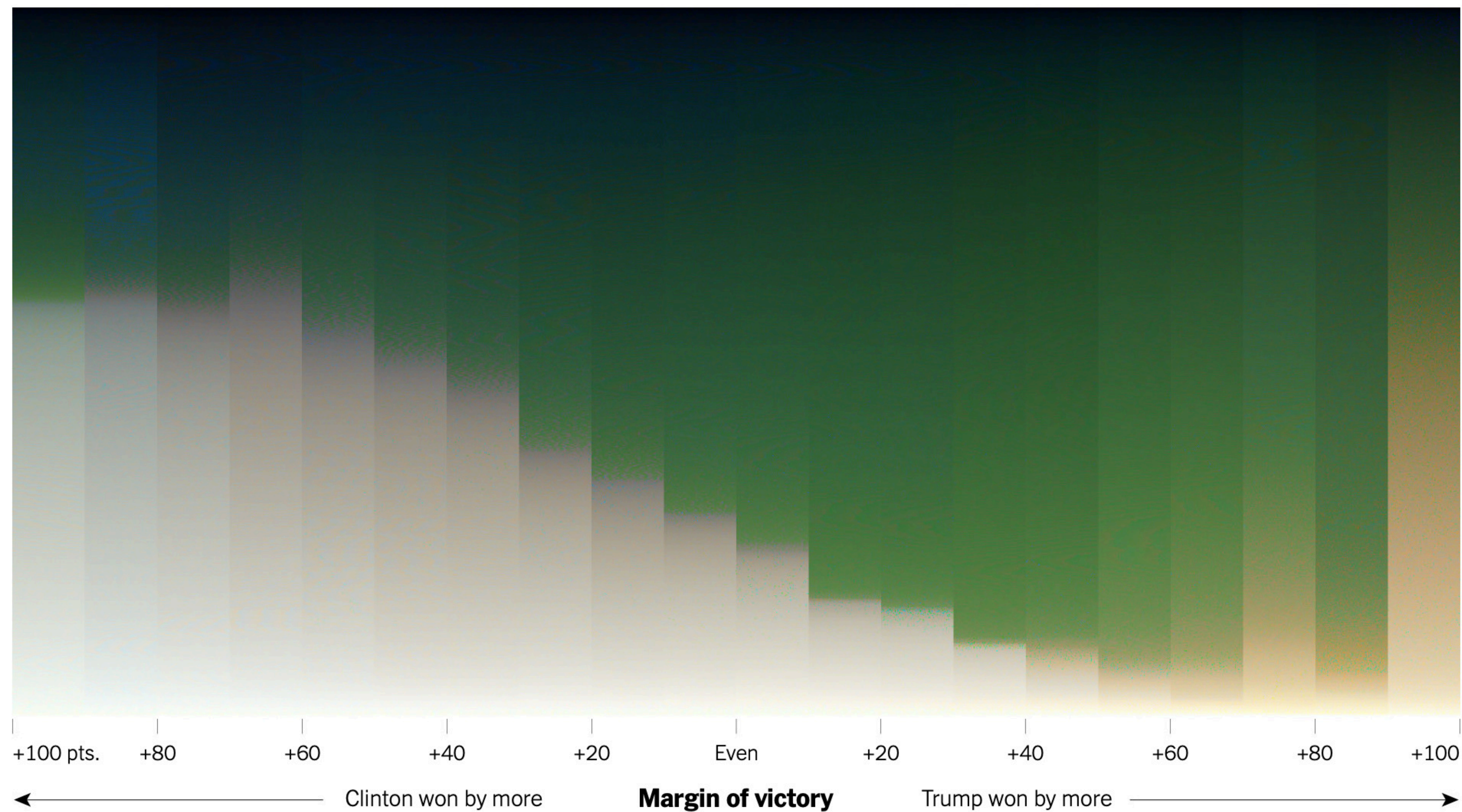
Mojave Desert, California



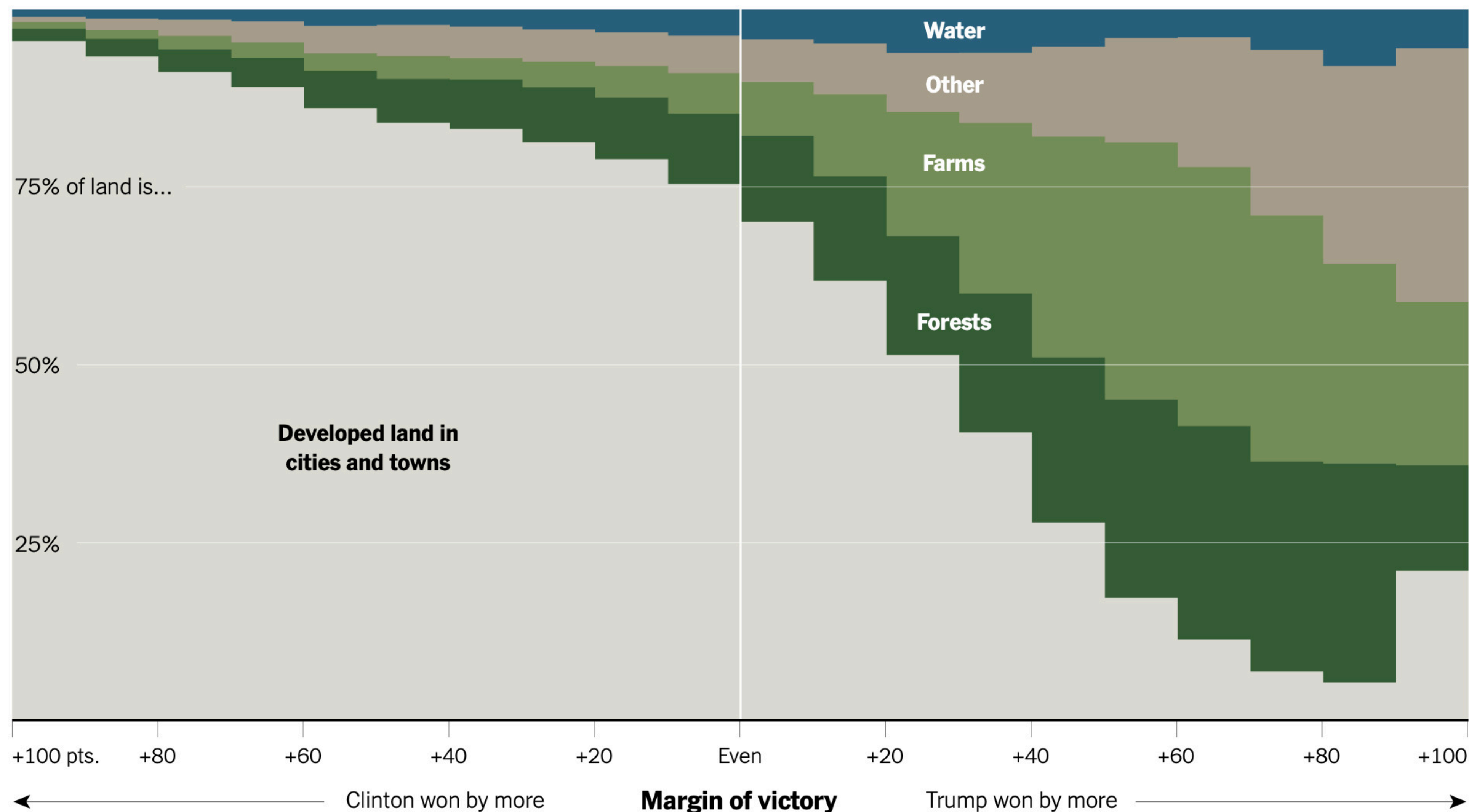
Denver, Colorado



The colors of Trump and Clinton precincts



Represented as color landscapes



VII. Design

Overall design and layout

- Largely aesthetic, but use your taste
 - Clean titles, labels, whitespace, map inserts, credits
- And consider purpose
 - Reference? Thematic/pattern focused? Storytelling? Artistic?
 - Pure reference: more context needed (roads, rivers, boundaries)
 - Patterns: orienting viewer to space, fewer reference points

How do we draw maps?

We have to save something for next time

- Workshop
 - Drawing maps in R
 - Social network show and tell
- Next Tuesday
 - Expanding our data mapping chops