08: Geographic Data

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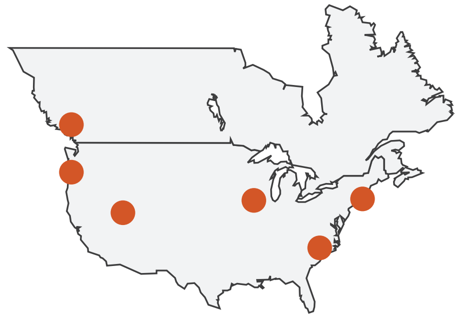
Credits:
material in these slides is partially taken from
- T. Munzner, University of British Columbia
- A. Lex, University of Utah
- P. Magillo, University of Genova

other credits in the slides

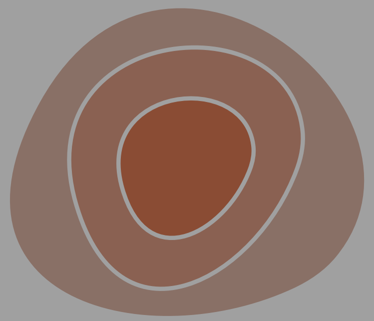
https://2020.aulaweb.unige.it/course/view.php?id=4293

Arrange spatial data

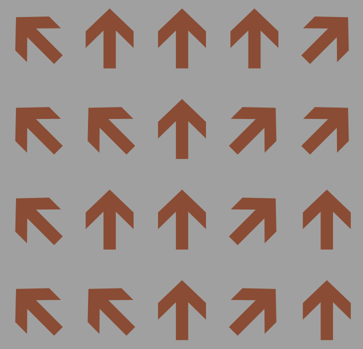
- **Use Given**
  - Geometry
    - *Geographic*
    - *Other Derived*



  - Spatial Fields
    - *Scalar Fields (one value per cell)*
      - *Isocontours*
      - *Direct Volume Rendering*



    - *Vector and Tensor Fields (many values per cell)*
      - *Flow Glyphs (local)*
      - *Geometric (sparse seeds)*
      - *Textures (dense seeds)*
      - *Features (globally derived)*



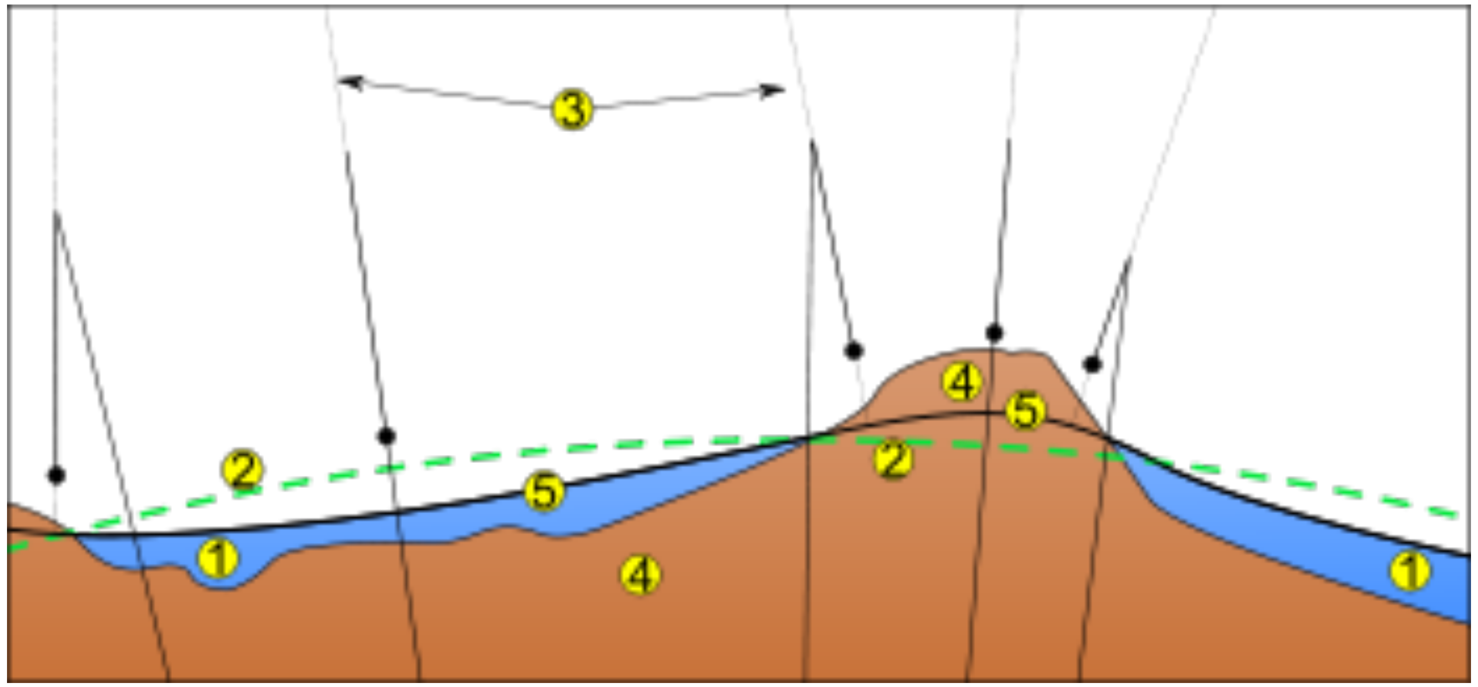
Given spatial position

- Reference space: spatial domain
- Data items have position/extension in spatial domain
  - attribute of primary importance
  - it constrains position channel
  - substrate for visual layout

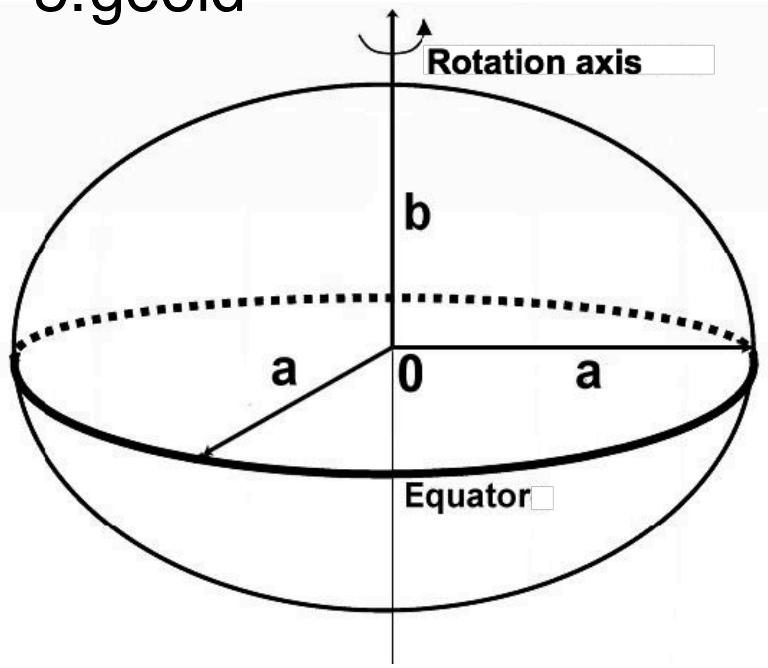
- 2D: non-planar reference space
  - geography: domain is the surface of the earth
  - need to unfold (project) reference space to the plane
  - projection induces distortion

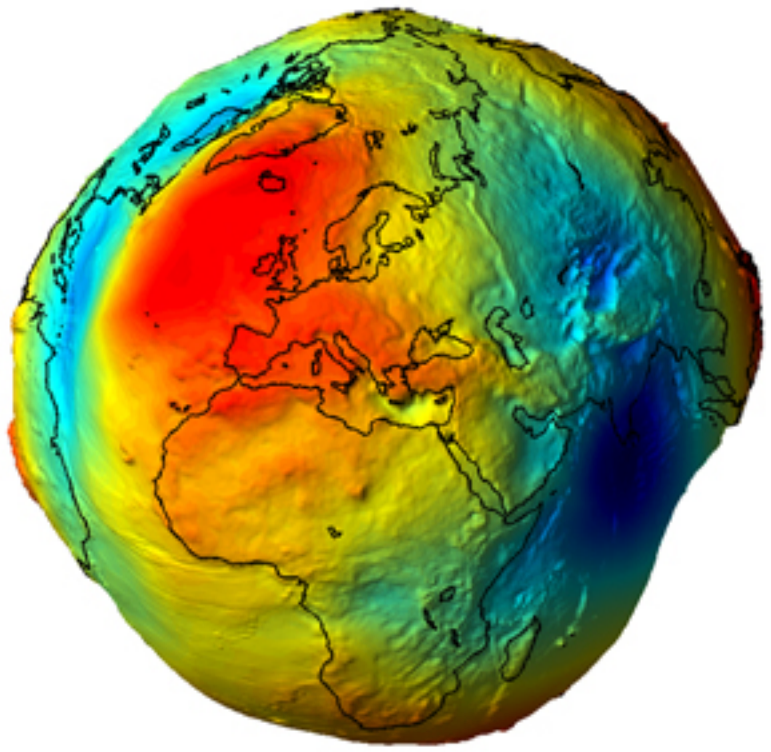
The Geoid

- Earth is not a sphere!
- Geoid:
  - surface normal to gravity force direction
  - and through average sea level
  - altitude: vertical distance from geoid
- Reference ellipsoid:
  - approximation of geoid
  - **a** radius at equator
  - **b** radius along rotation axis
  - α = (**a**-**b**)/**a** flattening ratio



1.ocean
2.reference ellipsoid
3.gravity force direction
4.land
5.geoid

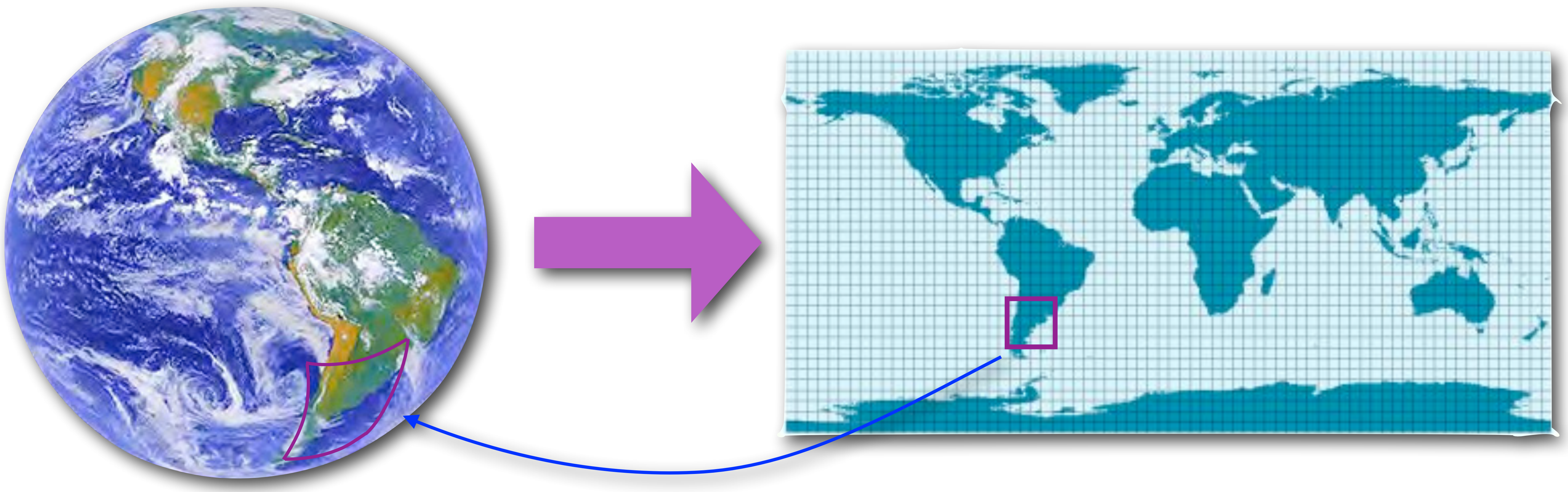




Geographic coordinates

- Latitude and longitude: spherical coordinates on the reference ellipsoid
  - latitude ϕ: angle between equatorial plane and point along a meridian
  - longitude λ: angle between a meridian through the point and reference meridian
- Datum: how the ellipsoid relates to geoid
  - parameters $\mathbf{a}$ and α of the ellipsoid
  - position of ellipsoid w.r.t. geoid
- Latitude and longitude are always referred to a datum
  - international ellipsoid (1924): $\mathbf{a}$ = 6378388m, α = 1/297
  - ED50 Datum (European): international ellipsoid & emanation point in Potsdam (Germany)
  - WGS84 Datum (global): $\mathbf{a}$ = 6378137m, α = 1/298.2572, center of ellipsoid at center of mass & minor axis at rotation axis
    - used for GPS

Cartographic projection



Cartographic projection

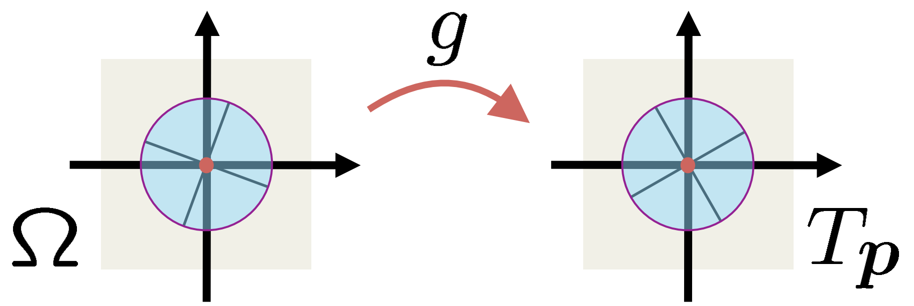
- Transformation from geographic coordinates to Cartesian plane
  - function $(x,y) = f(\phi,\lambda)$ (surface parametrization)
- Projection induces distortion (Theorema Egregium [C.F. Gauss])
  - only developable surfaces can be projected without distortion (plane, cone, cylinder)
  - distortion may affect:
    - area: equal area on the surface → different area on projection
    - shapes (angles): equal angles (similar shape) → different angles (dissimilar shapes)
    - distances: equal distances → different distances
    - direction, bearing: straight lines → curved lines
- Many types of projection
  - one projection may try to preserve some of the properties (but not all):
    - conformal: preserves angles (and similarity)
    - equiareal: preserves (ratio between) areas

$\left.\begin{array}{l}\text{conformal}\\\text{equiareal}\end{array}\right\}$ isometric: preserves distances (no distortion)

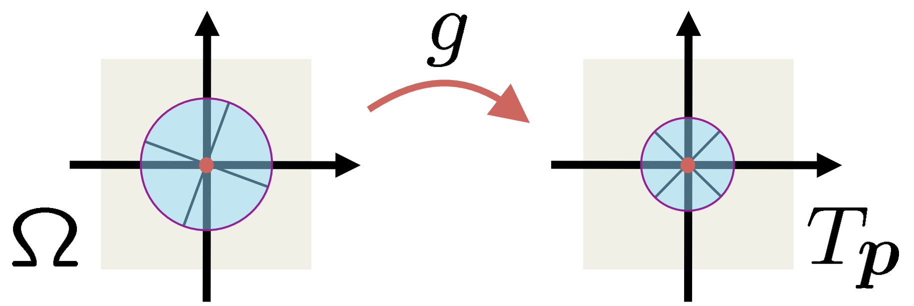
Notion of infinitesimal distortion

- Given a circle (infinitesimal) on the plane domain Ω
- Consider its projection on tangent plane T_p at the surface

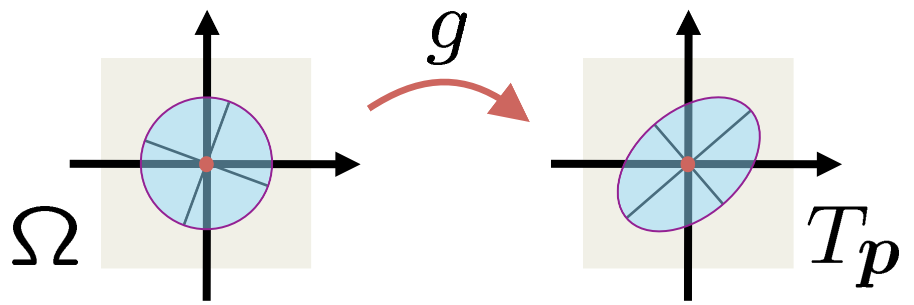
Isometric: image is circle of same size (at all points)



Conformal: image is circle of different size (at different points)



Equiareal: image is ellipse of same size (at all points)



Historical projection methods

orthographic
~ 500 B.C.

stereographic
~ 150 B.C.

Mercator
1569

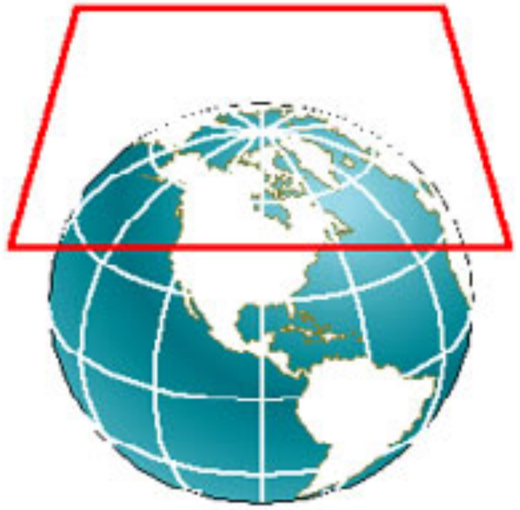
Lambert
1772

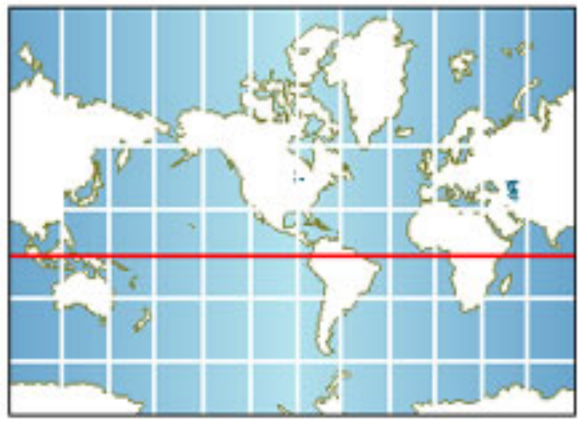
conformal
(angle-preserving)

equiareal
(area-preserving)

Classes of projection

- Planar (azimuthal) projections:
  - project onto tangent plane to the ellipsoid
  - suitable for polar zones
  - parallels lines become concentrical circles
  - meridians become circumference diameters
- Cylindrical projections:
  - orthogonally project onto a cylinder
  - conformal
  - meridians remain equally spaced
  - parallels increase mutual distance towards poles
- Conical projections:
  - project meridians onto conical surface
  - parallels become rings on the cone

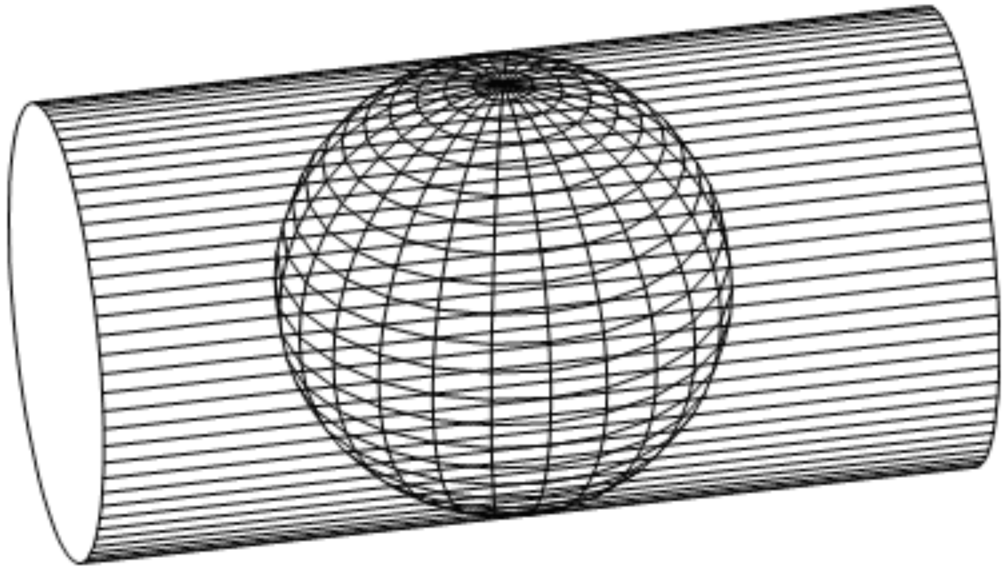


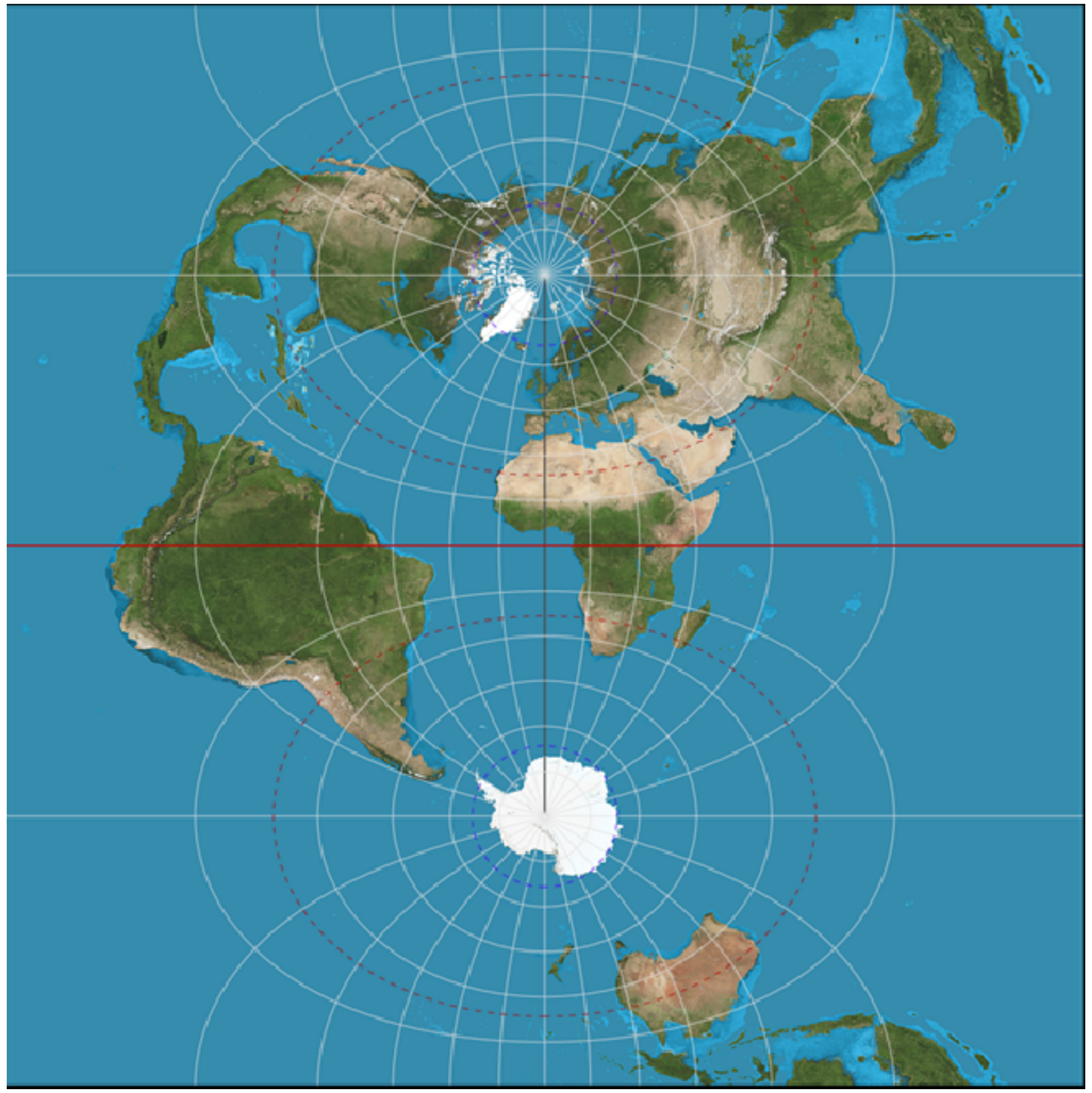
Mercator projection

- Gerardus Mercator, 1569
- From ellipsoid onto cylinder tangent at equator (conformal)
- Lines with constant angle with meridians → straight lines
  - suitable for nautical maps
- Reasonably reliable shapes and distances within 15° from Equator
- Great distortion at high latitudes
- Distortion not a problem at state/city level

Transverse Mercator (Gauss-Krüger)



- Cylindrical, with cylinder axis aligned to parallels
  - conformal
  - cylinder tangent at central meridian (user-selected)
  - only central meridian and is a straight line
  - all other meridians are curved
  - parallels are ellipses
  - parallels and meridians intersect at right angles
  - accurate in the proximity of the central meridian



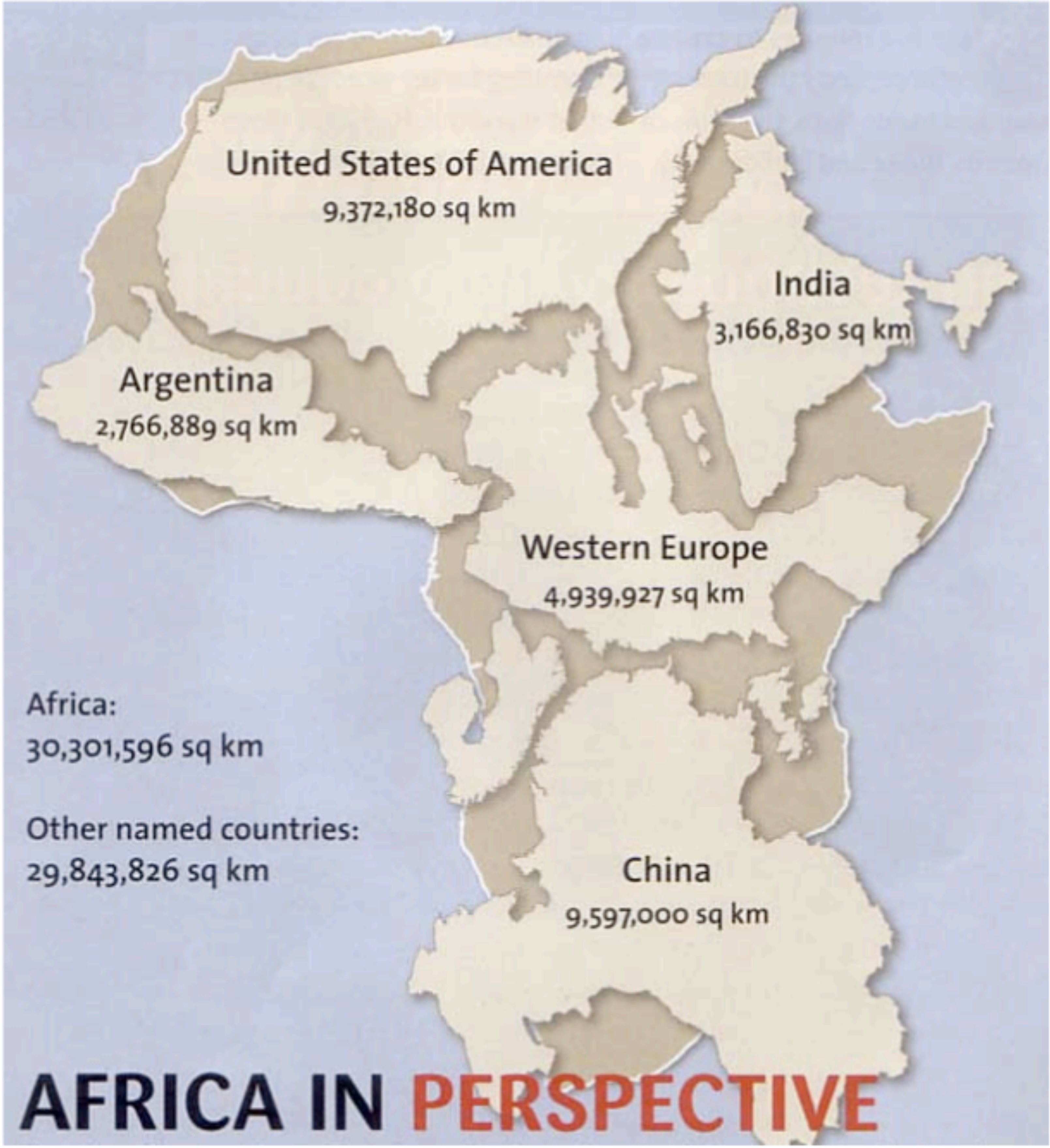
Mercator criticism

- Traditional map
- Massive distortion of area distant from equator
- *“unfair to the Global South, making places that are mostly trees, snow, and better-off white people look huge, and the places where most of the world’s population lives look puny”*
- *“Mercator works really great if you’re, say, Ferdinand Magellan looking for a compass bearing that will take you around Cape Horn, because all of the latitude and longitude lines and angles in between lay out nice and straight on the map like we experience them in real life. It also works well if you’re Google and you want a map image that you can neatly slice up into little squares that your server sends to a customer’s browser. North is always up, your hometown doesn’t look squished or slanted when you zoom in to it, and everybody’s happy.”*

http://giscollective.org/slippy-map-projections-explained/

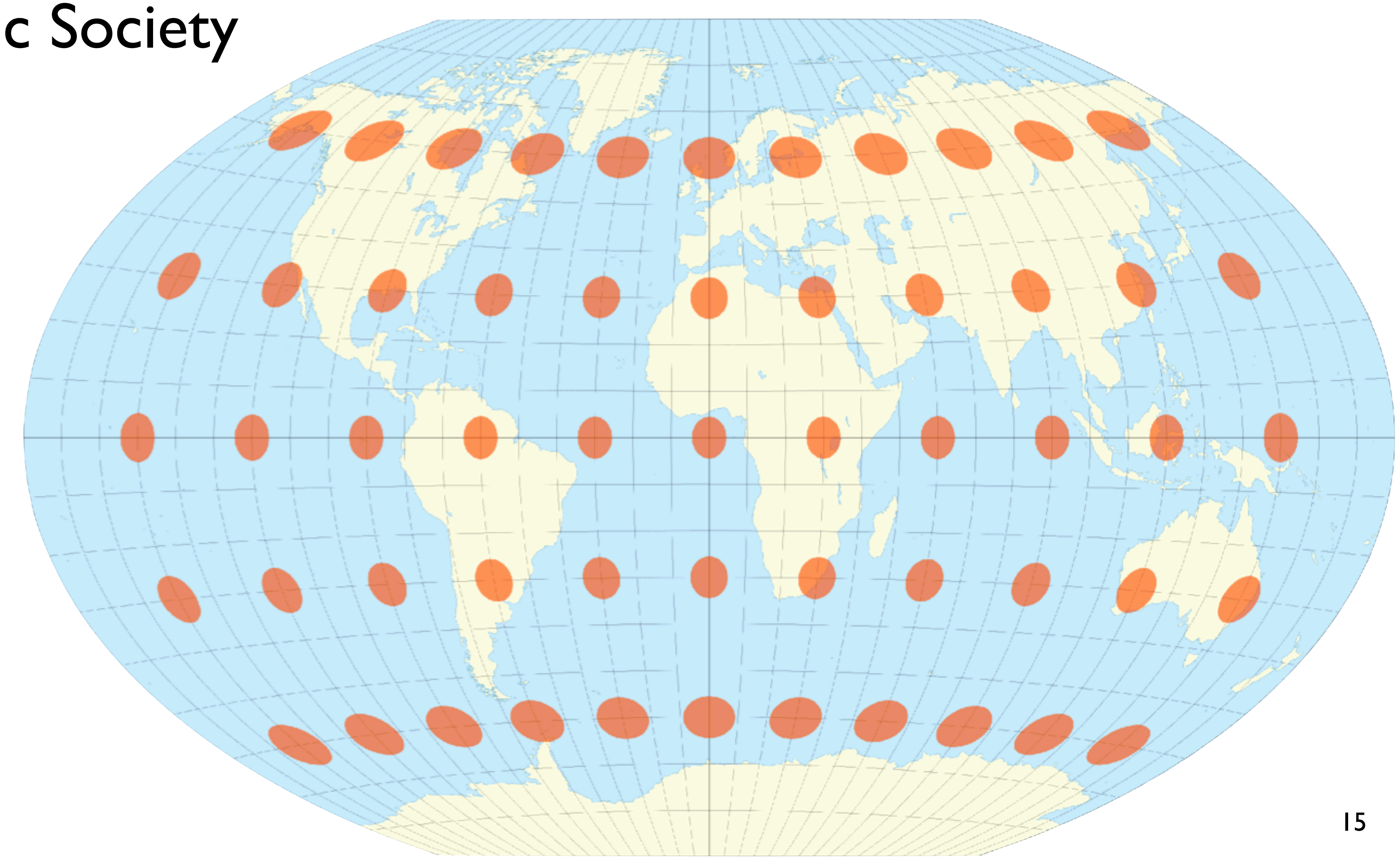
Mercator's effect on our beliefs

- Some countries/continents are much larger/smaller than we think



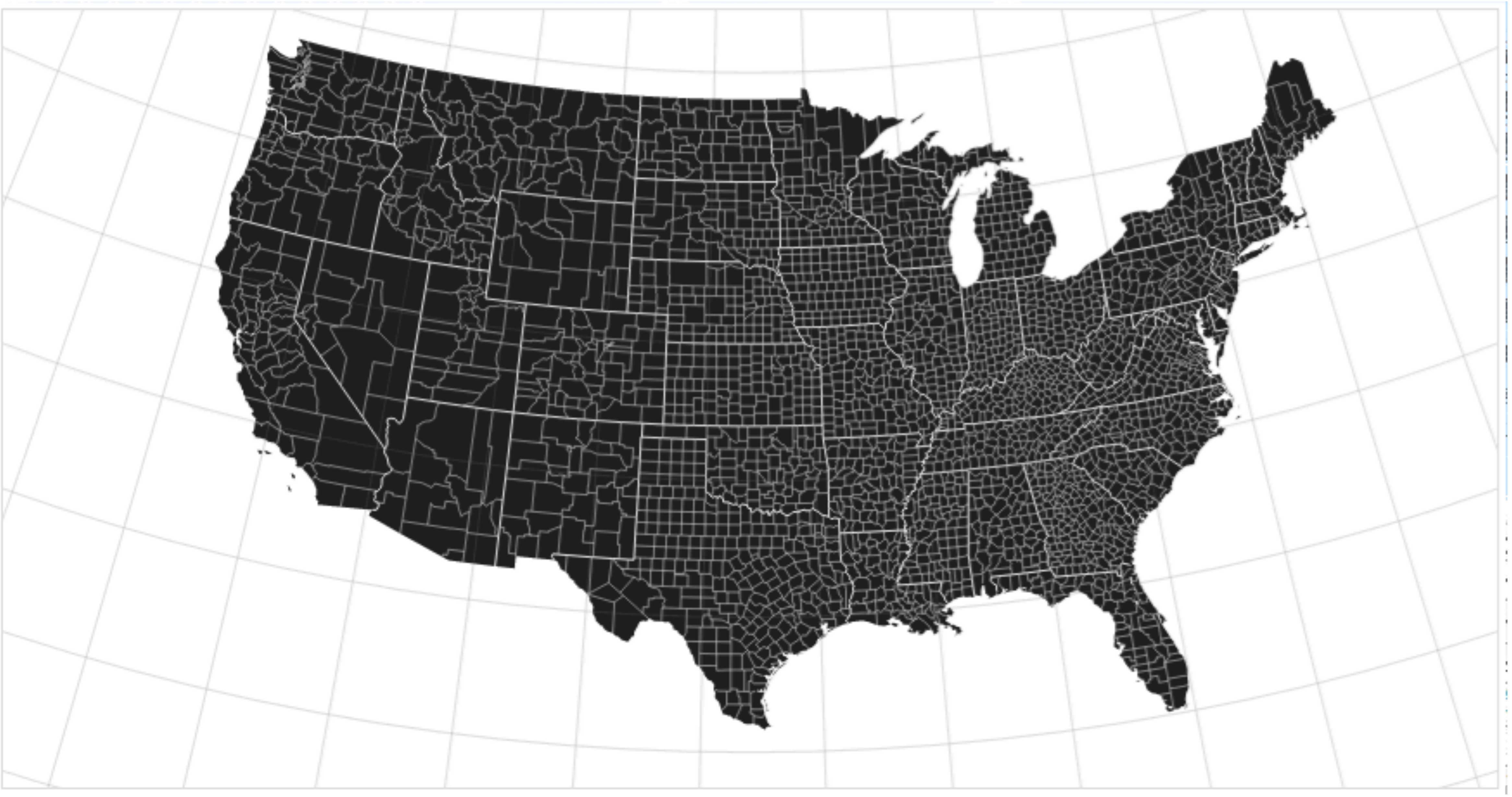
Winkel Tripel projection

- Modified azimuthal map projection averaged to cylindrical projection
- Minimizing three kinds of distortion: area direction distance
- Considered good projection for world maps
  - endorsed by National Geographic Society
  - used in Textbooks



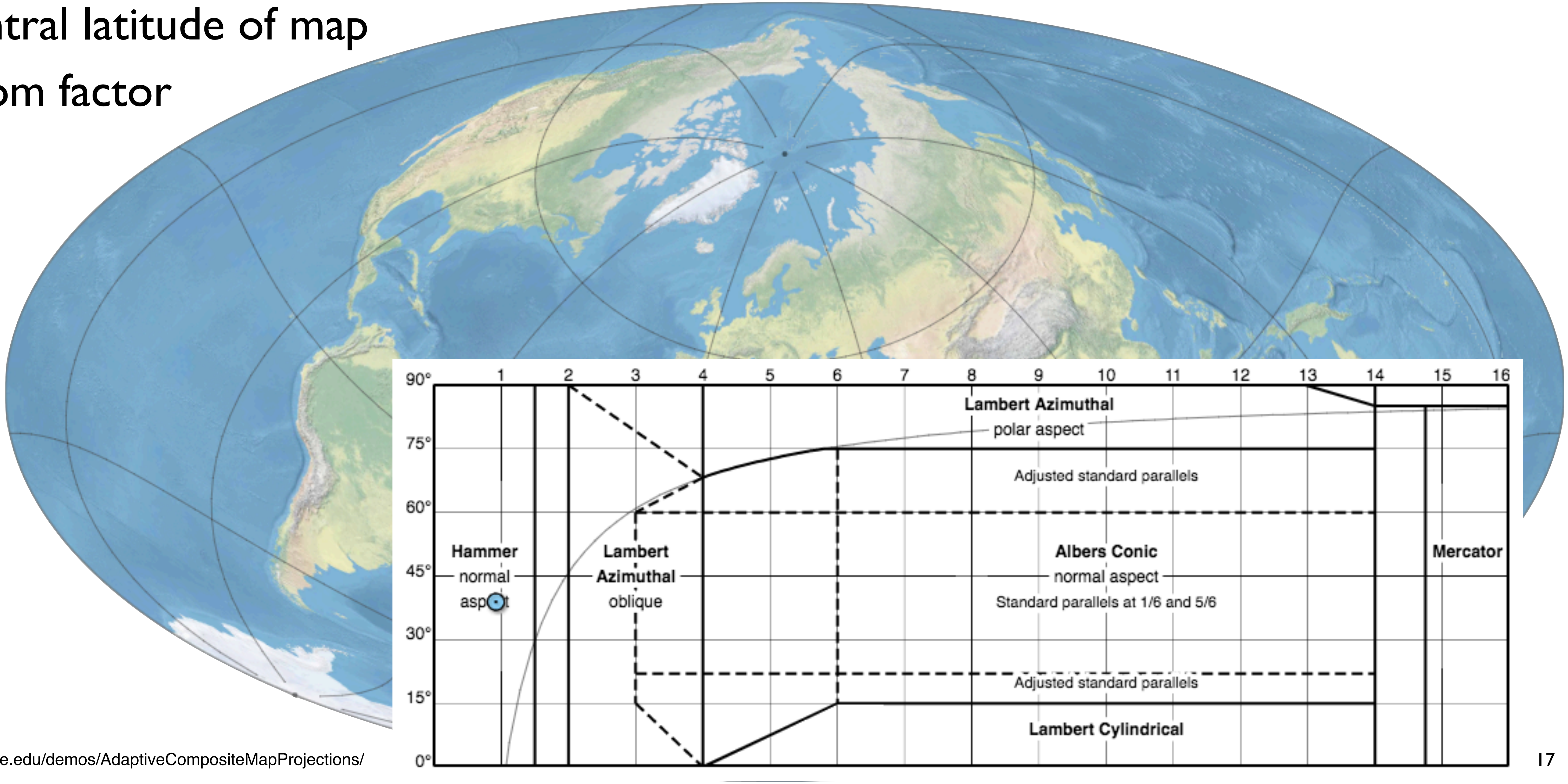
Albers equal area

- Shows areas correctly
- Distorts distances and shapes



Composite projections

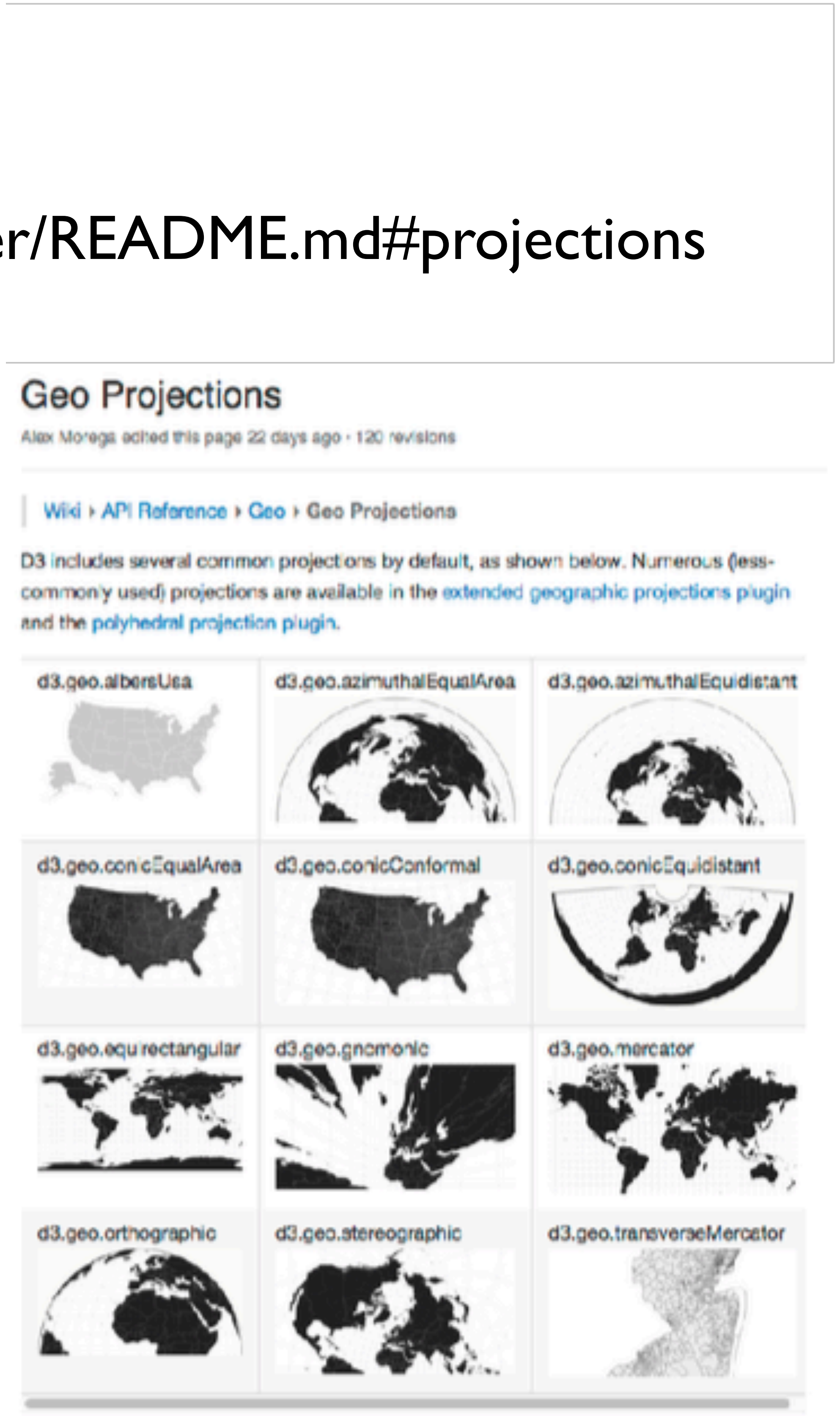
- Idea: use different map projections combined, depending on:
  - central latitude of map
  - zoom factor



cartography.oregonstate.edu/demos/AdaptiveCompositeMapProjections/

Projections in D3

- Lots of projections included
  - https://github.com/d3/d3-geo/blob/ master/README.md#projections
  - https://github.com/d3/d3-geo-projection/



Geometry vs Topology

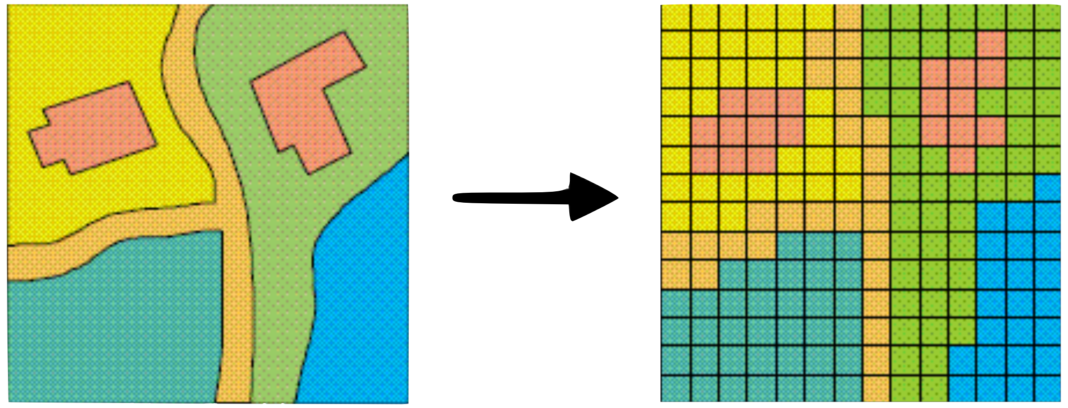
- Basic entities in 2D:
  - point
    - location in reference space
    - spatial coordinates needed
  - line
    - curve, polilyne: chain of control points
  - region
    - surrounded by line(s), polygon(s)
    - simply-connected / with holes / disconnected

- Spatial relations in 2D:
  - adjacency, incidence
  - containment, covering
  - intersection, equality, disjointness
- Arrangements of lines:
  - line network: lines join at common endpoints
  - overlay: lines may intersect
- Arrangements of regions:
  - space subdivisions: regions adjacent at common boundaries
  - overlays: regions may overlap

Vector vs Raster

- Object-based approach:
  - geometry of each entity is encoded
  - more accurate
  - scale-independent (in principle)
  - queries start at objects and find:
    - its properties
    - its shape
  - topological relationships and/or browsing needed to explore its neighborhood

- Space-based approach:
  - space is subdivided in cells
  - each cell is classified as belonging to one or more objects
  - discrete, scale-dependent
  - queries start at space and find:
    - objects in there
    - objects in the neighborhood
  - object = aggregate of cells
    - not explicitly represented

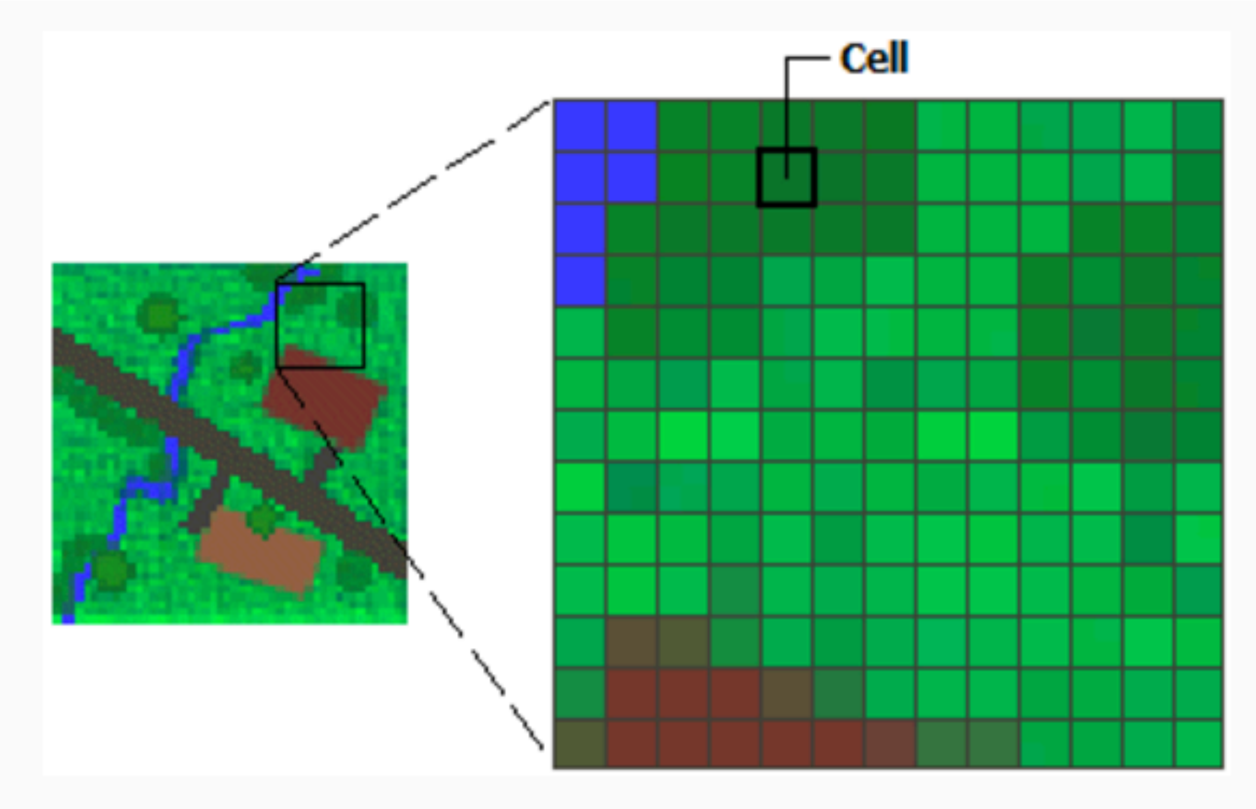


Structure of data: Vector

- Collection of items (aka “Spaghetti model”):
  - geometry is just another attribute
  - no relation between different items encoded
- Topological model:
  - topological relations are relevant (possibly encoded)
  - descending from mutual relations of geometries associated to items
  - arbitrarily complex - examples:
    - line network (roads, rivers)
    - space subdivision - partition of domain into regions: adjacency, borders
    - overlay: intersection of different layers containing spaghetti / networks / subdivisions
  - algorithms use topology and may derive data for Vis
    - e.g.: road planning

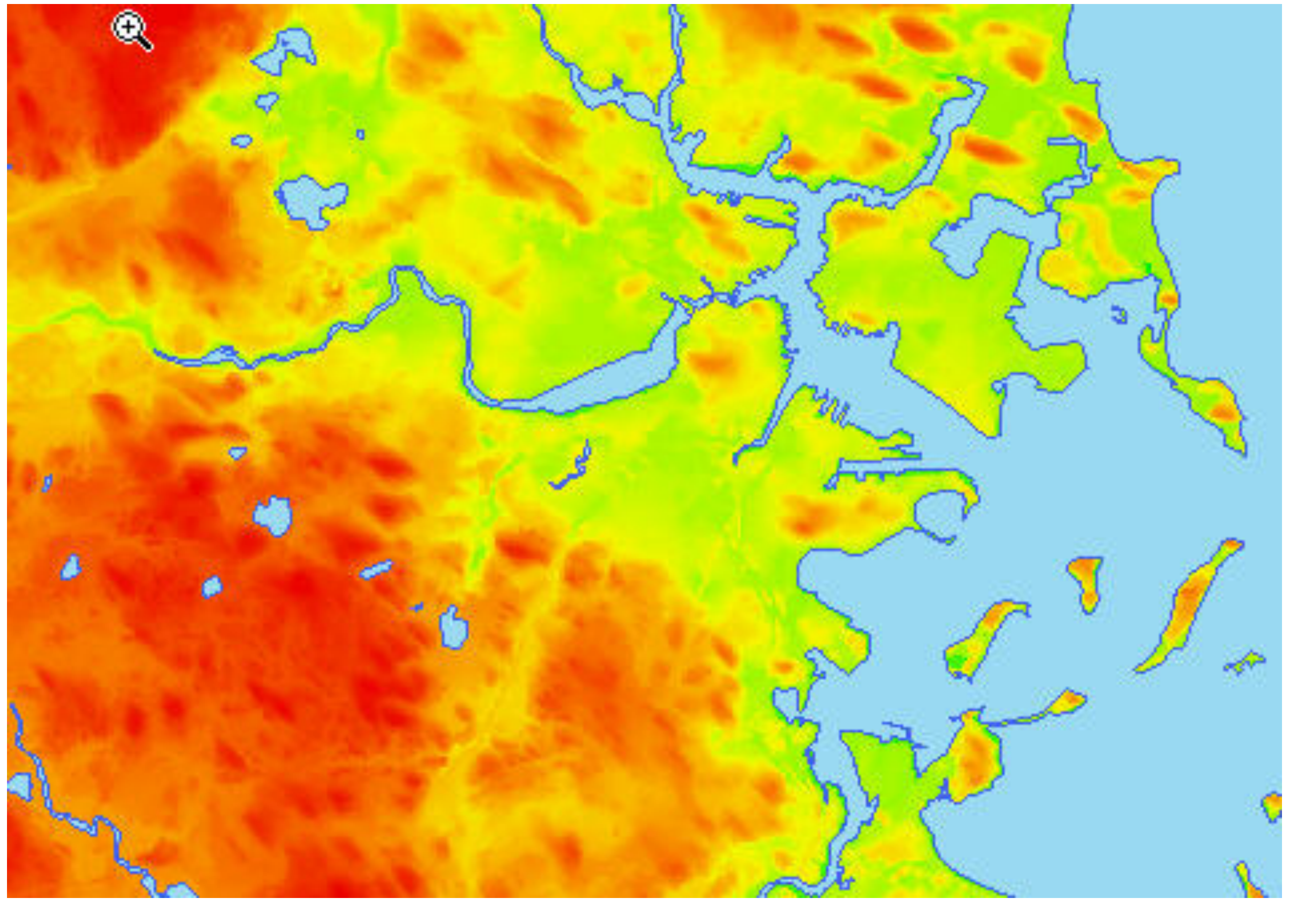
Structure of data: Raster

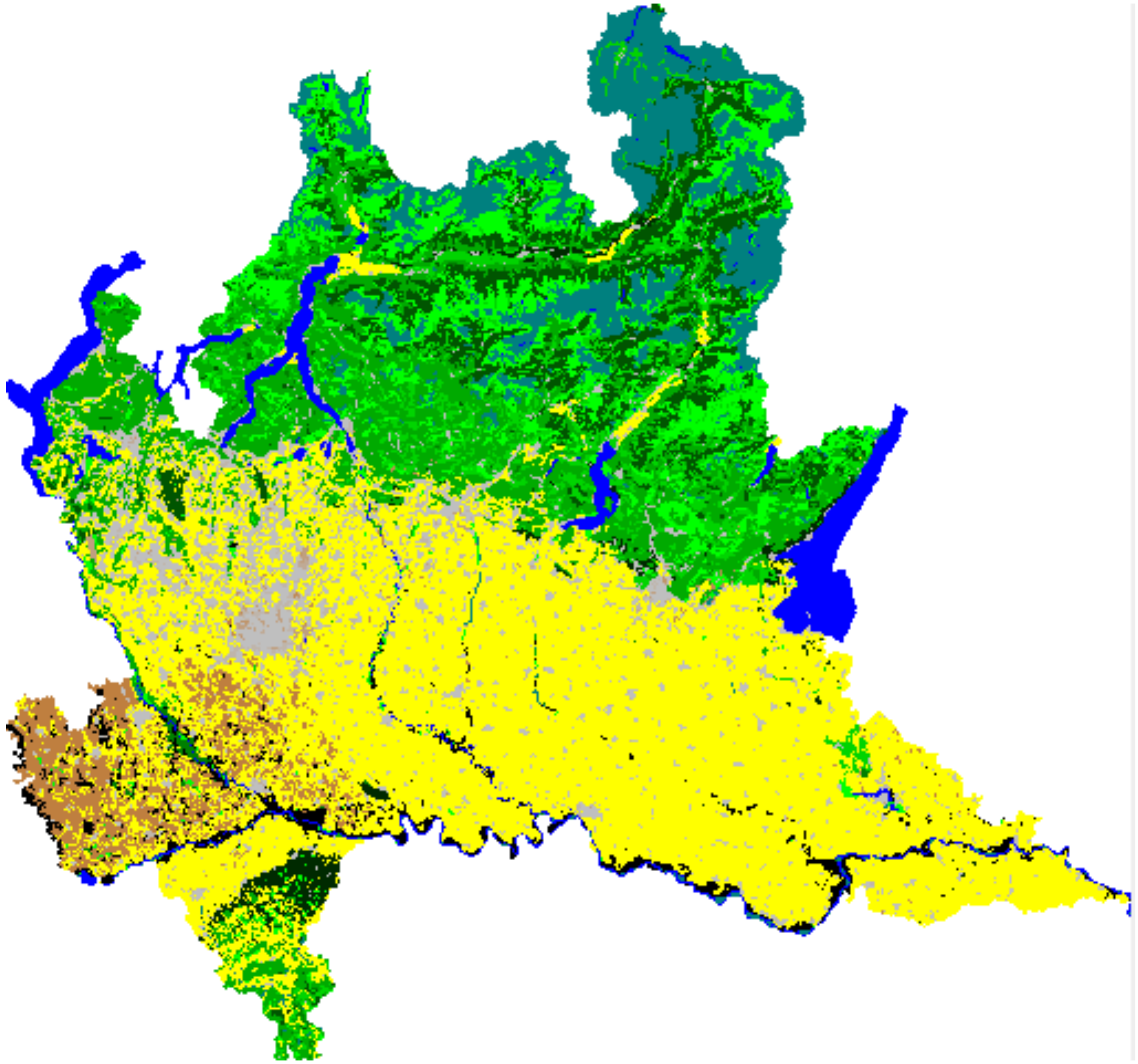
- Regular grid (georeferenced):
  - square grid / triangular grid / hexagonal grid
  - access to grid cells through geographic / projection coordinates
  - each cell contains information (links) for all objects intersecting it
  - geometry of an object must be recovered by collecting all cells overlapping it
- Topology:
  - derived from regular grid topology
  - supports navigation by adjacency of cells
- Pros: extremely easy to encode
- Cons:
  - not suitable to object-based tasks
  - not adaptive: grid resolution may be insufficient or highly redundant (or both!)



Raster maps and Heatmpas

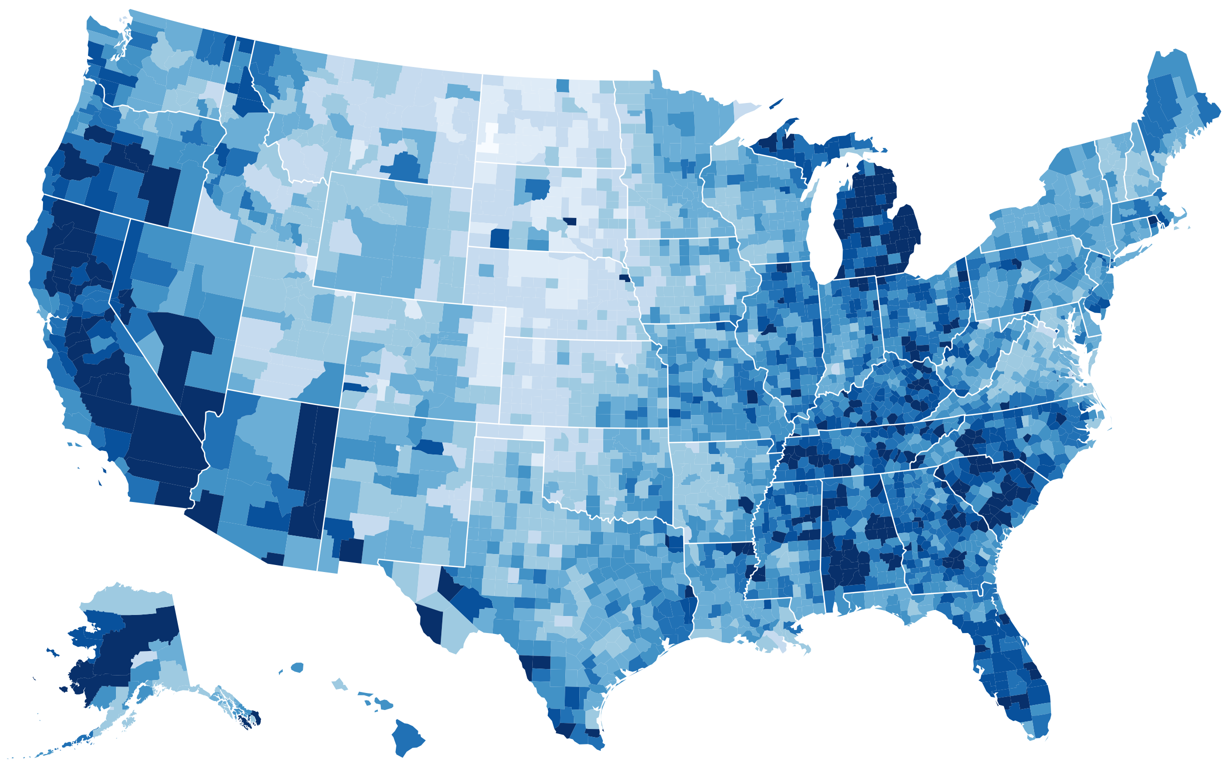
- Heatmap is the natural choice to visualize a Raster map
  - use one color / hatching / symbol per cell
  - ok for space subdivisions (each cell contains at most one object)
  - problems with overlays



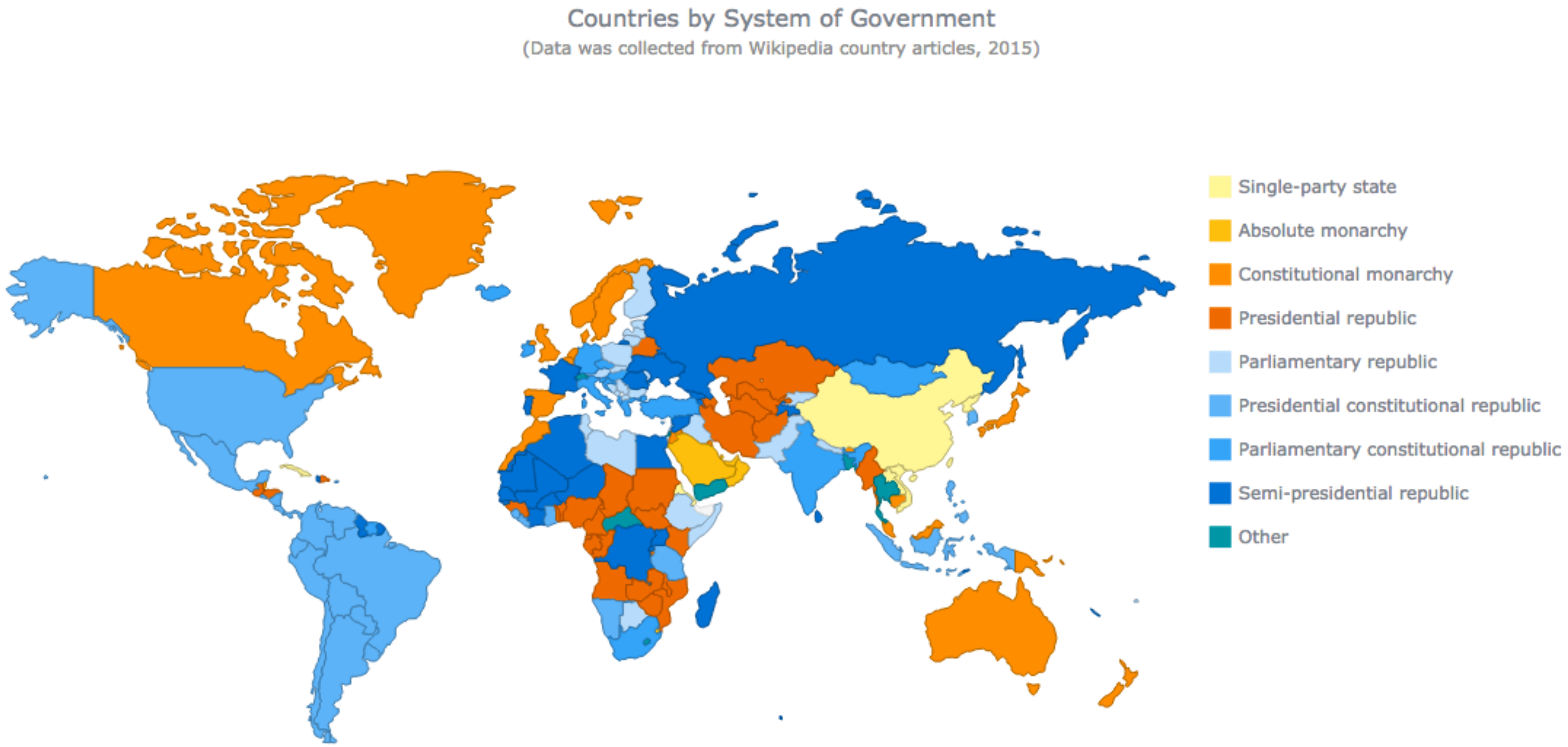


Idiom: **choropleth map**

- use given spatial data
  - when central task is understanding spatial relationships
- data
  - geographic geometry (regions)
  - no topology
  - table with 1 attribute per region
- encoding
  - use given geometry for area mark boundaries
  - colormap to encode attribute
    - categorical / ordinal

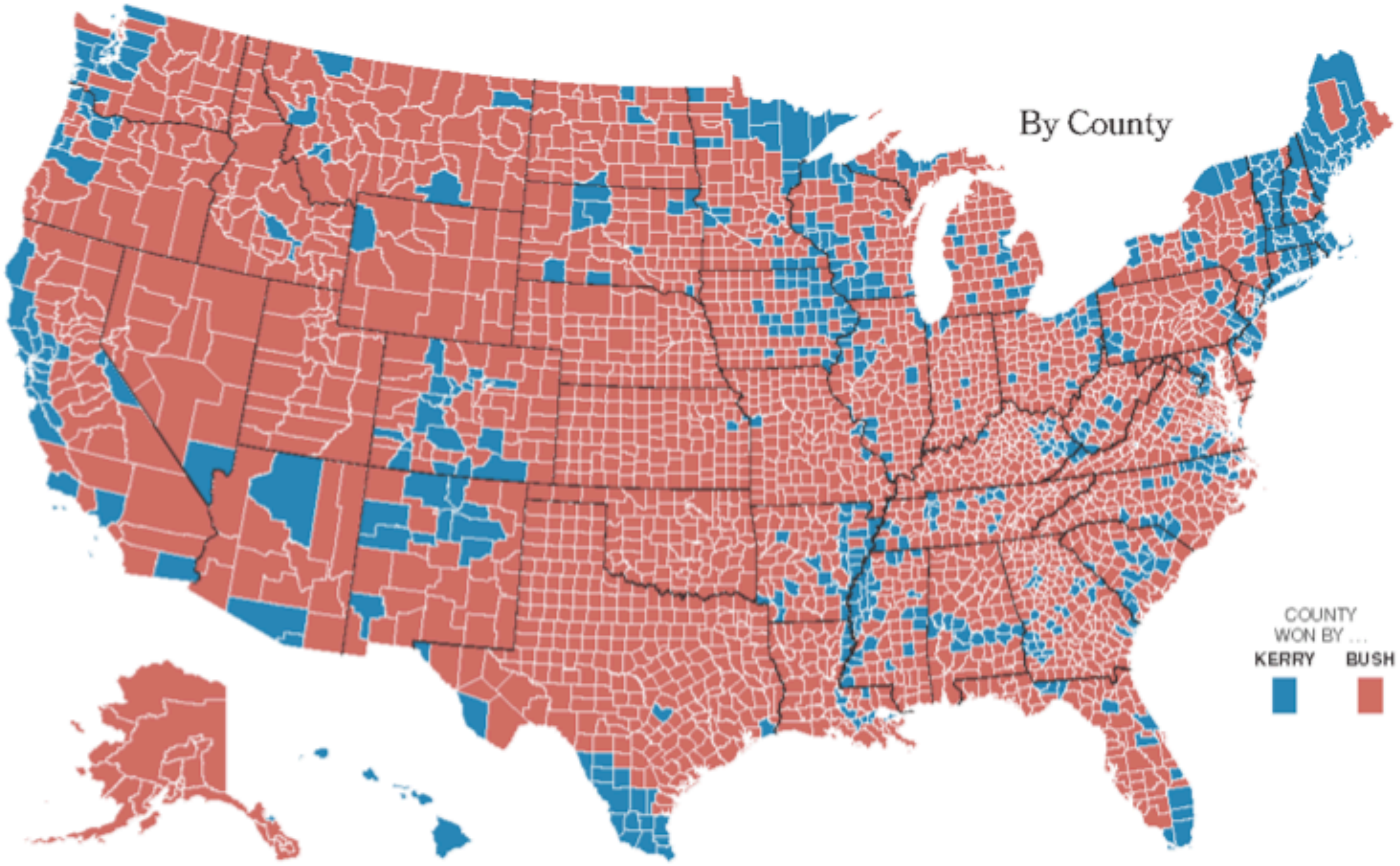


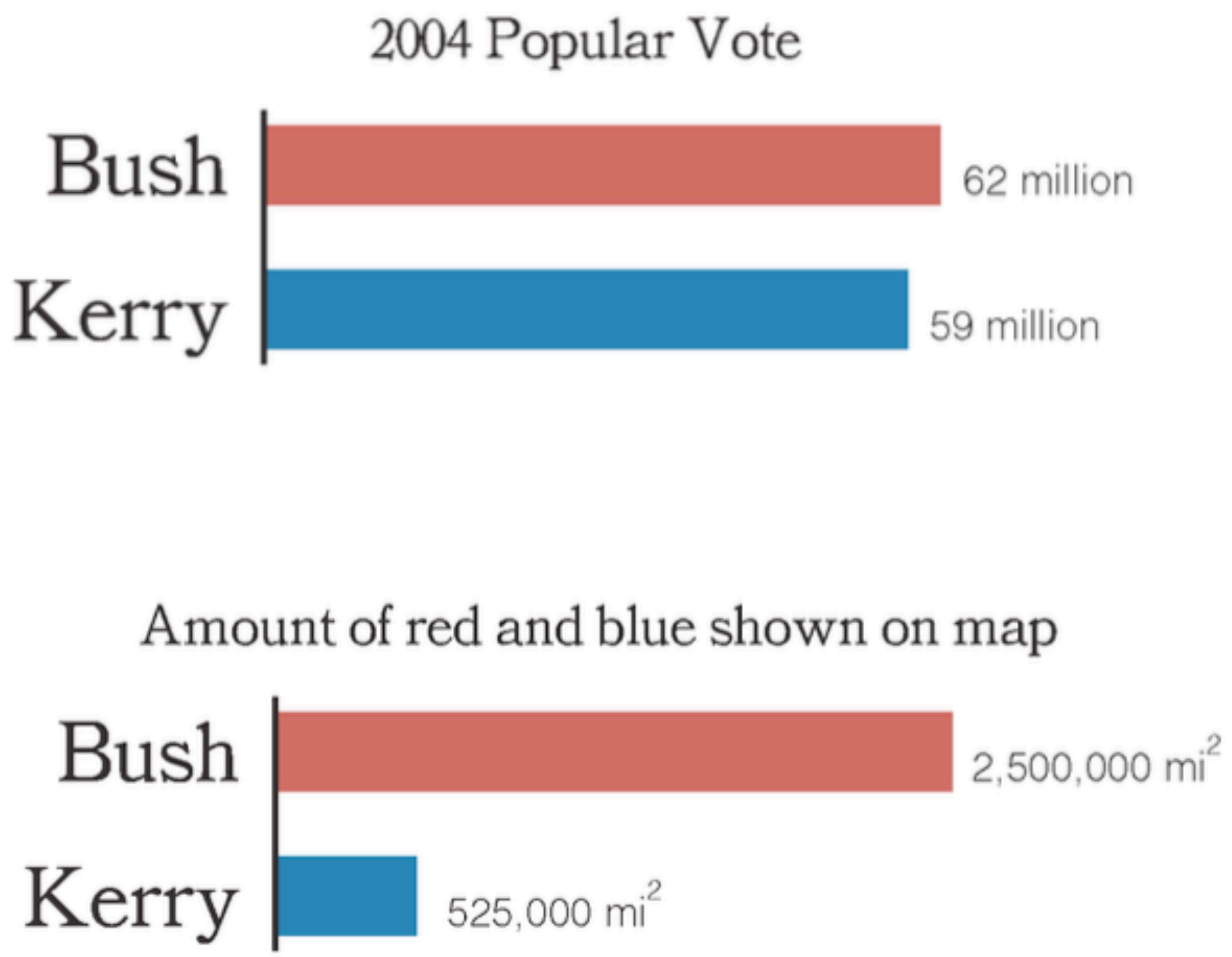
http://bl.ocks.org/mbostock/4060606



Choropleth map: Magnitude of effect vs Perceived effect

- Ex.: Kerry vs Bush, 2004





Matthew Ericson, NY TImes

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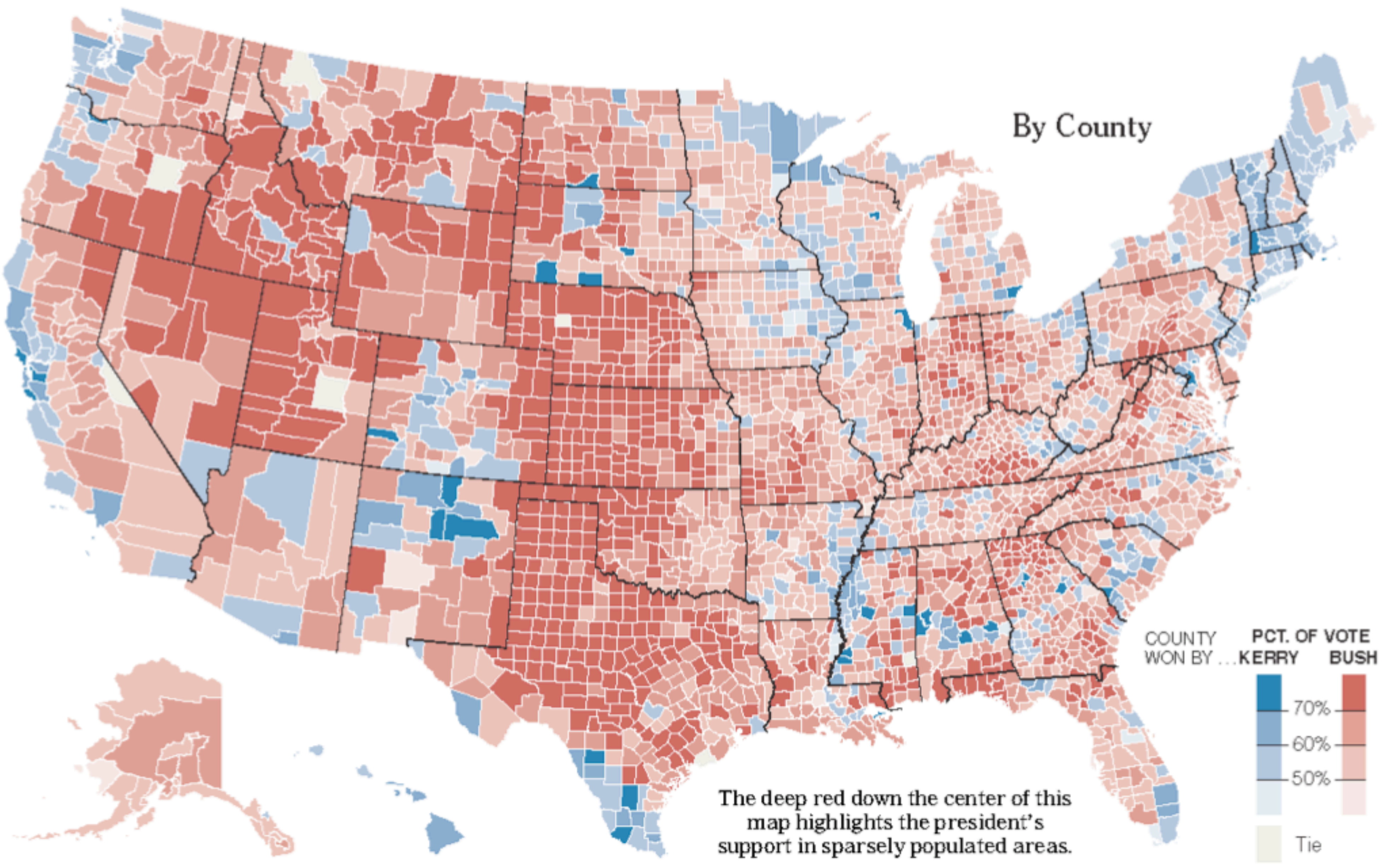

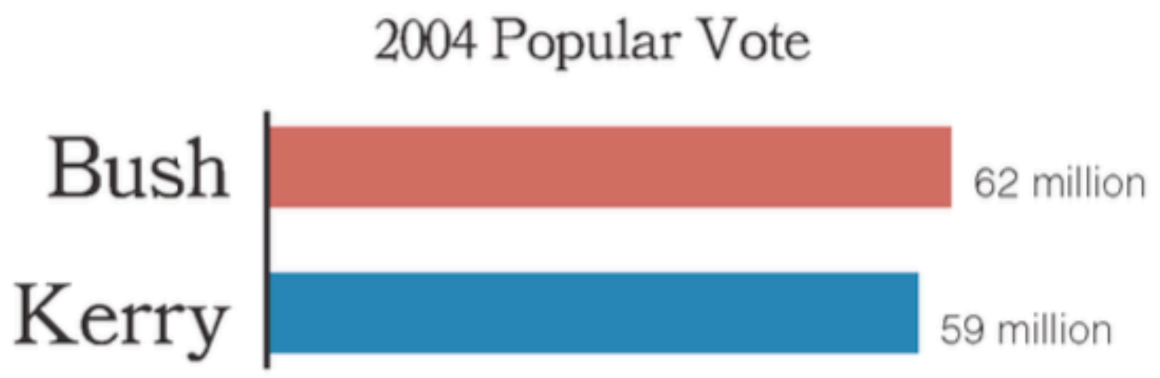

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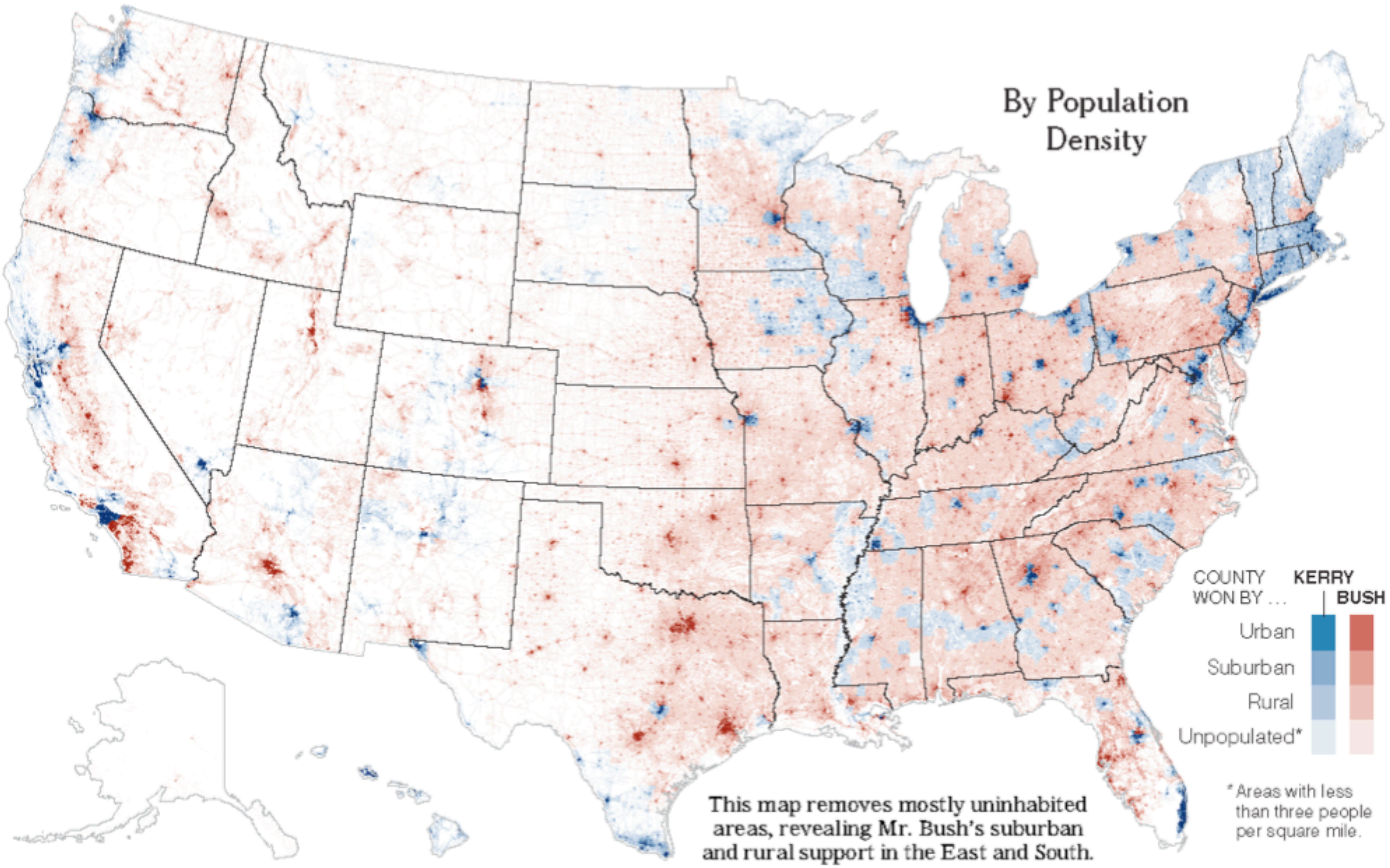

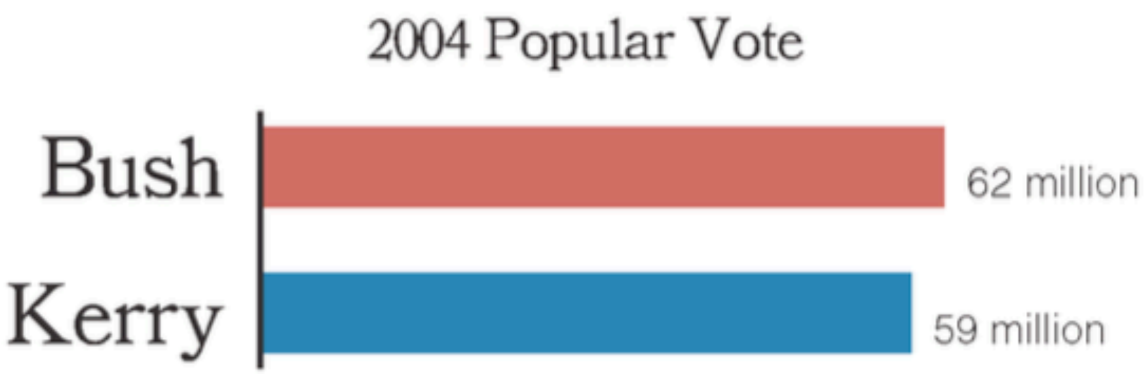

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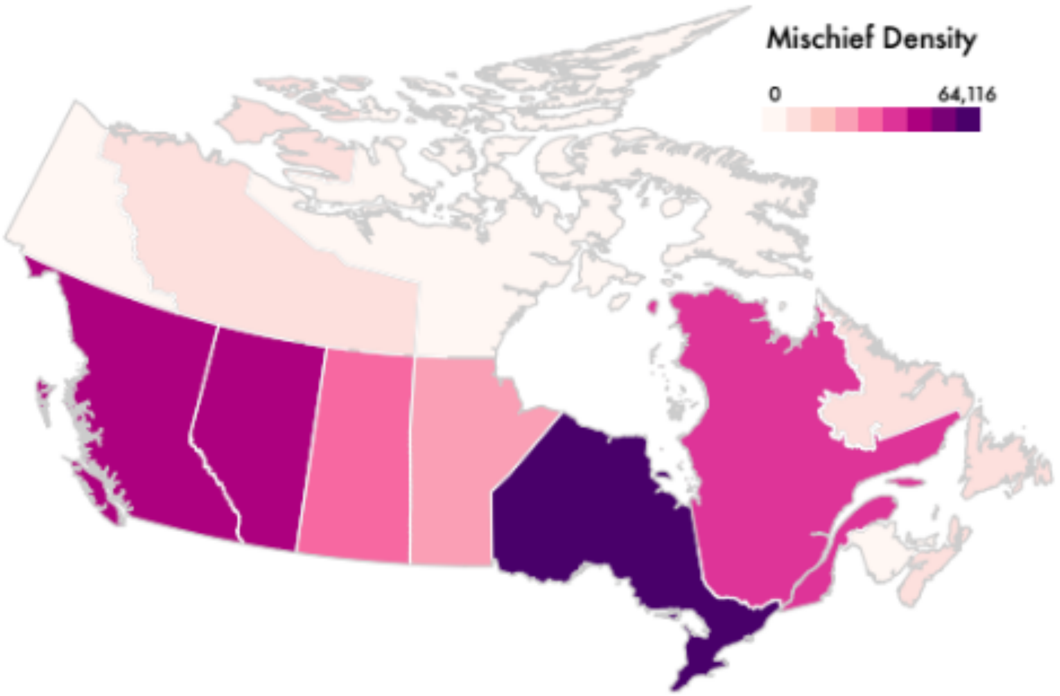
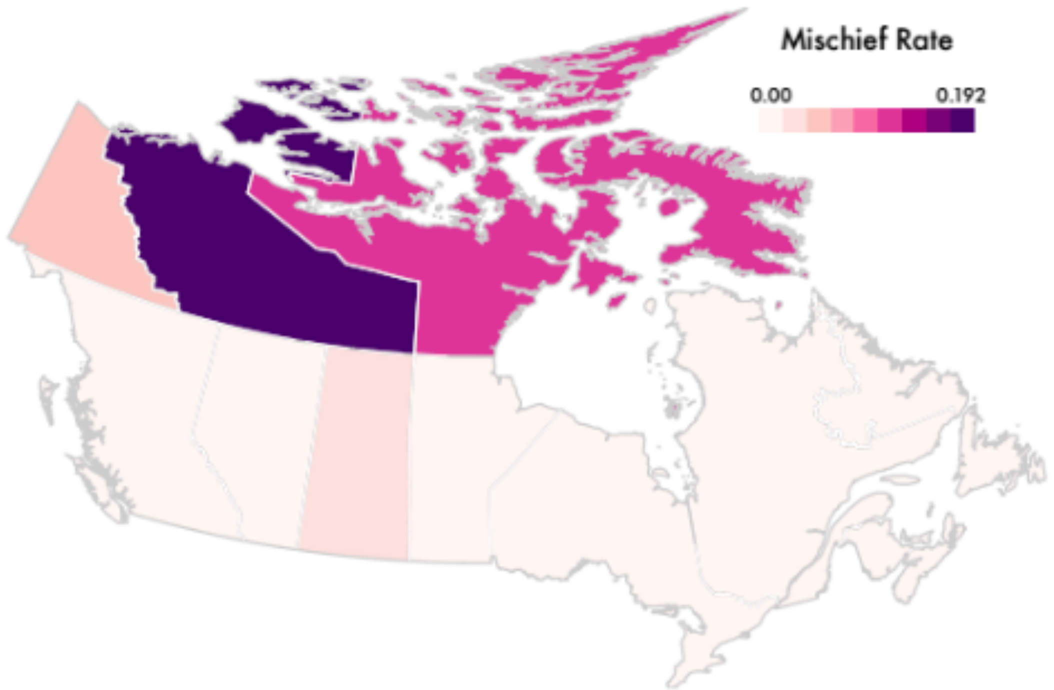
Choropleth map: Magnitude of effect vs Perceived effect

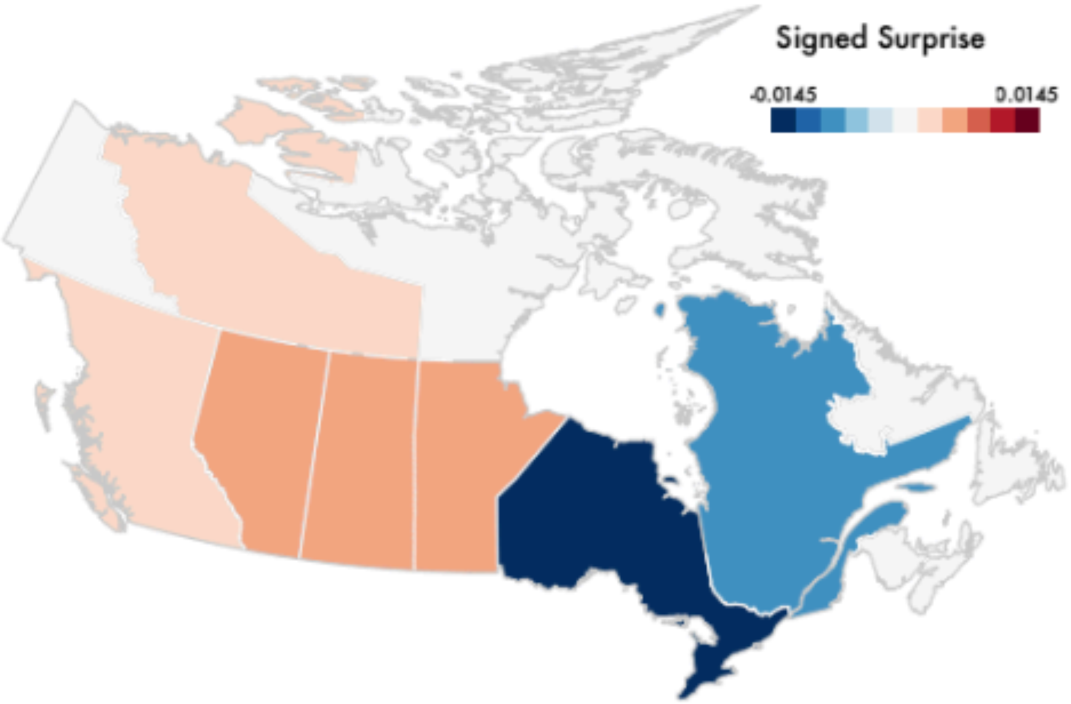
- Use a prior, show difference



(a) The **Event Density** of "mischief" in Canada.



(b) The per-capita **Event Rate** of mischief.



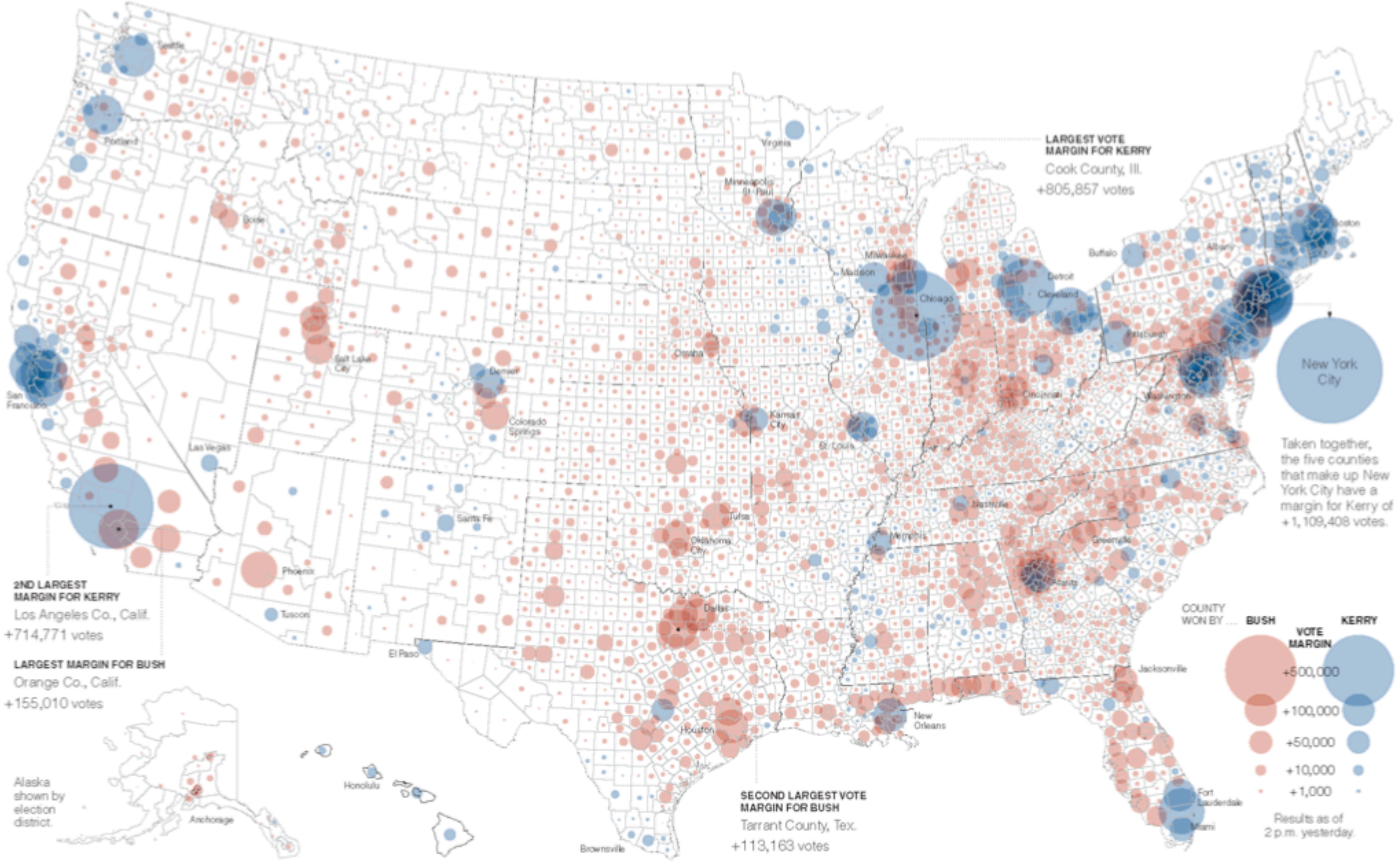
(c) The **Surprise Map** of mischief.

model of population density + accounting for variability when analyzing small numbers

[M. Corell, J. Heer, Surprise! Bayesian Weighting for De-Biasing Thematic Maps, 2017]

Idiom: **proportional symbol map**

- alternative to choropleth map
- use symbol & size instead of color



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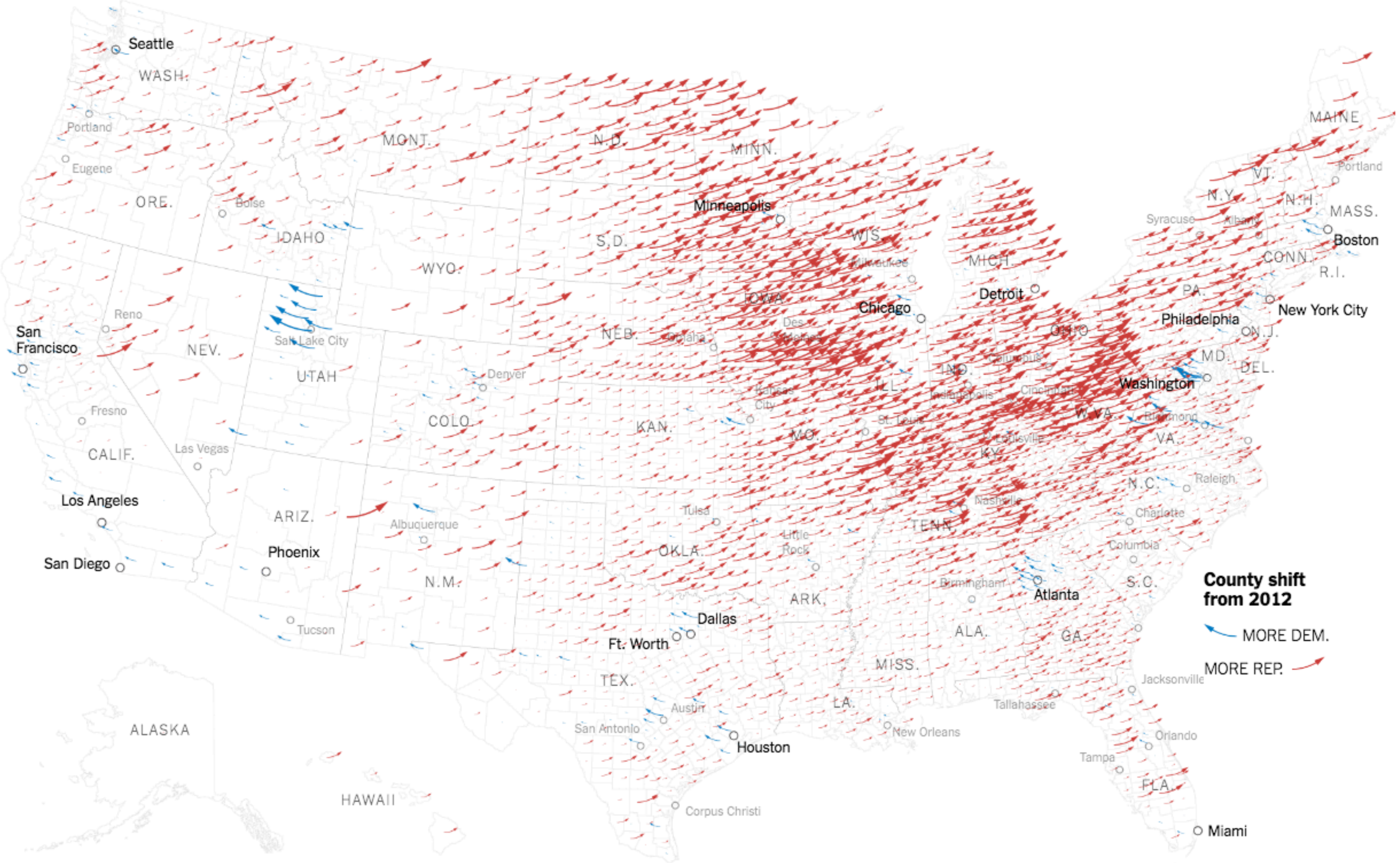
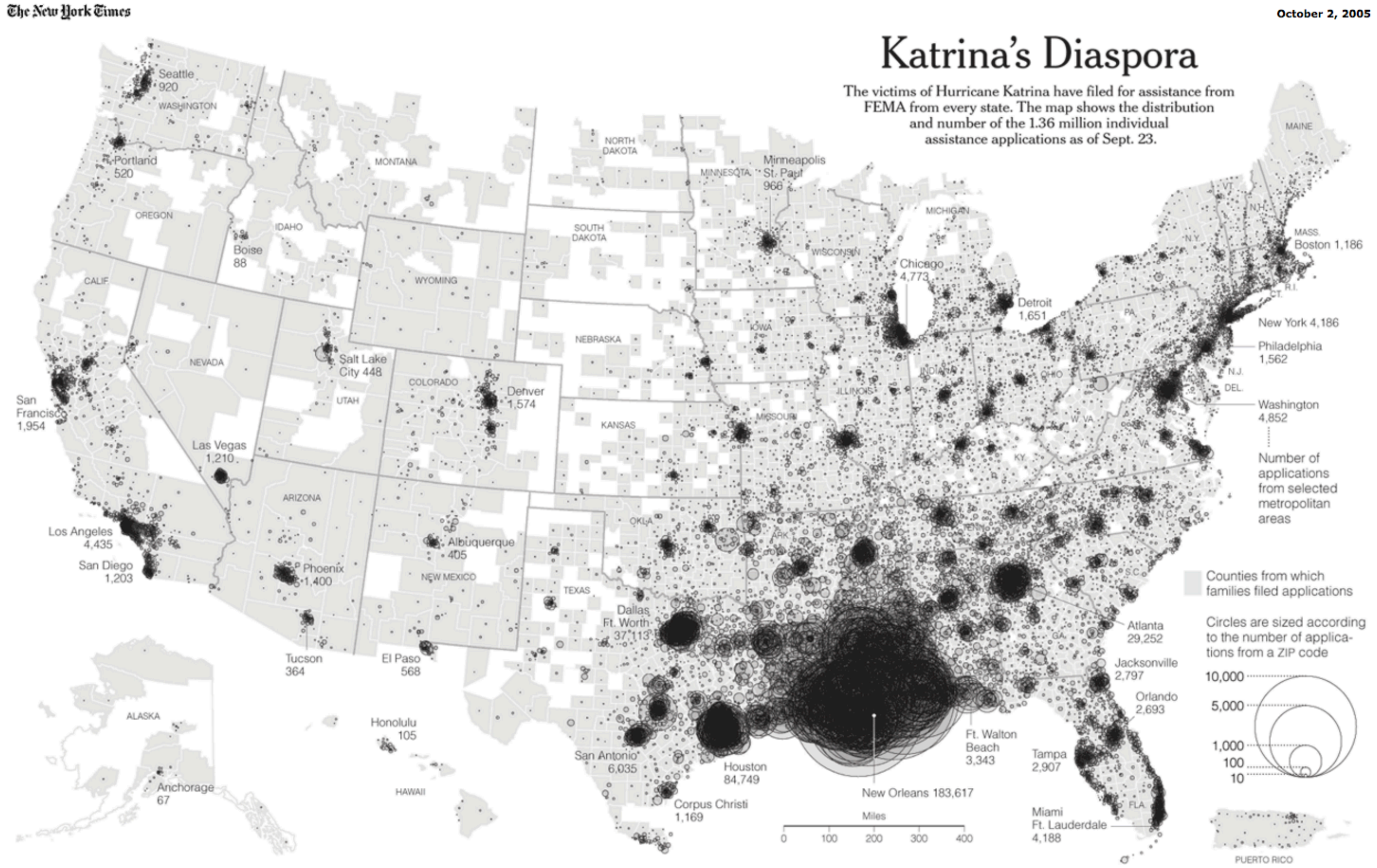
Idiom: **proportional symbol map**



L. Buchanan et al., NY TImes

Idiom: **proportional symbol map**



M. Ericson, NY TImes

Cartographic generalization (semantic zooming)

- Traditional problem in cartography:
  - too many items to show
    - all data in a (selected area of a) database
  - too small space to depict them
    - available display area (depending on scale)
- Solutions:
  - filtering (selection): items are shown only in a certain range of scales
  - simplification: geometry is represented differently depending on scale
- Example: a city
  - represented at the level of single building on a local map (may be even at level of single wall for cadastral maps)
  - shrinks to blocks - neighborhoods - single polygon - large mark - small mark - point
  - possibly not shown (filtered out) at very large scales

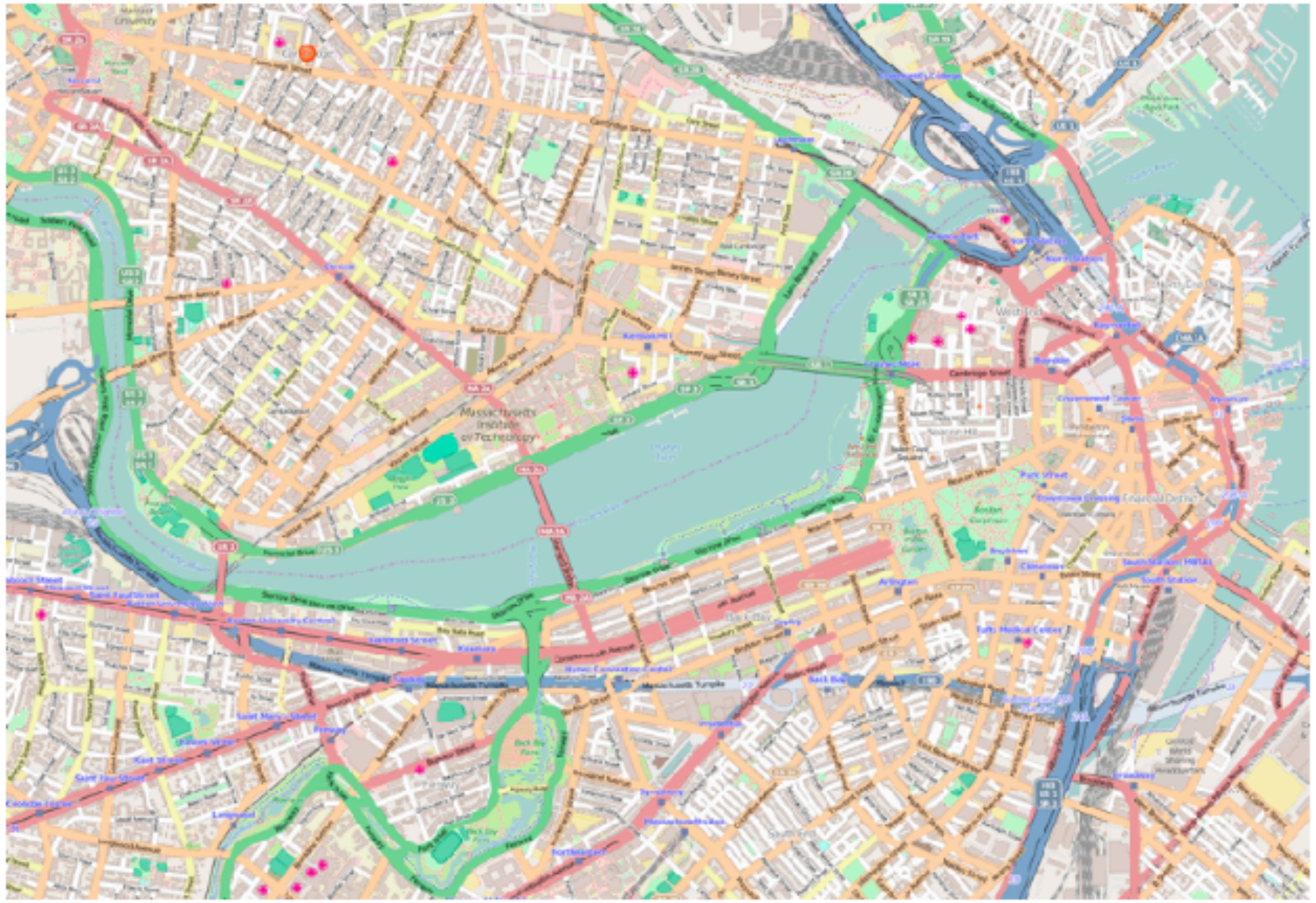
Cartographic generalization (semantic zooming)

OpenStreetMap

Cartographic generalization (semantic zooming)

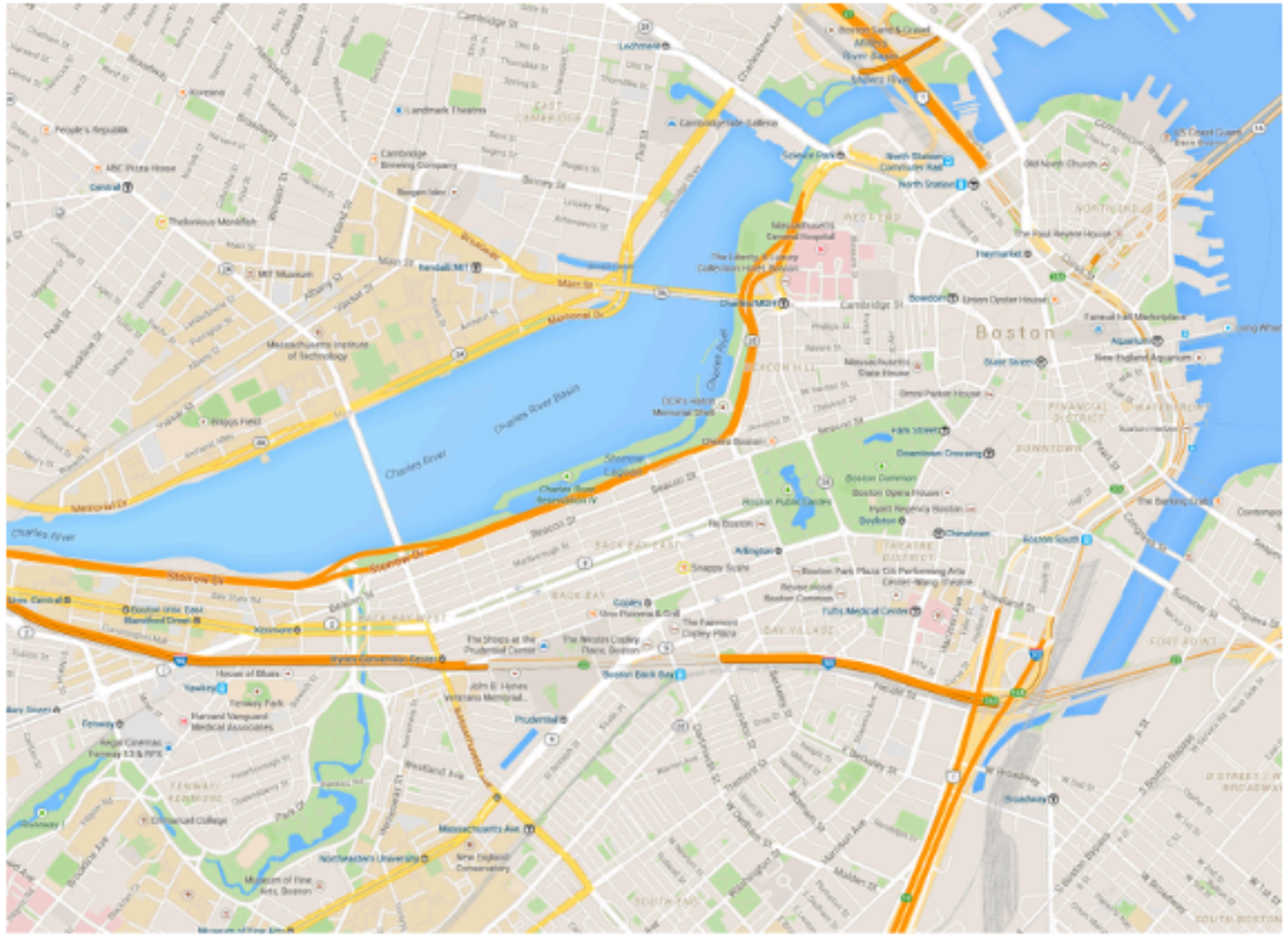
- Hard problem:
  - filtering depends on semantics, not just on size
  - small but important items may be highlighted at large scales
    - their marks take a larger area → occlusion of other items
  - simplification may require aggregation of objects to form larger entities
  - displacement may be needed to avoid conflicts (different items concurring for the same space)
- Simplified context: discrete Level of Detail
  - each item is assigned a range of scales and a set of geometries / marks
  - each scale in the range is associated to a given geometry / mark to show
  - no direct support to aggregation:
    - aggregated entities are just new items with a different range of scales than their constituents
  - no support to topology: each item is encoded separately

Mapping software



Open StreetMap

(open source)



Google Maps

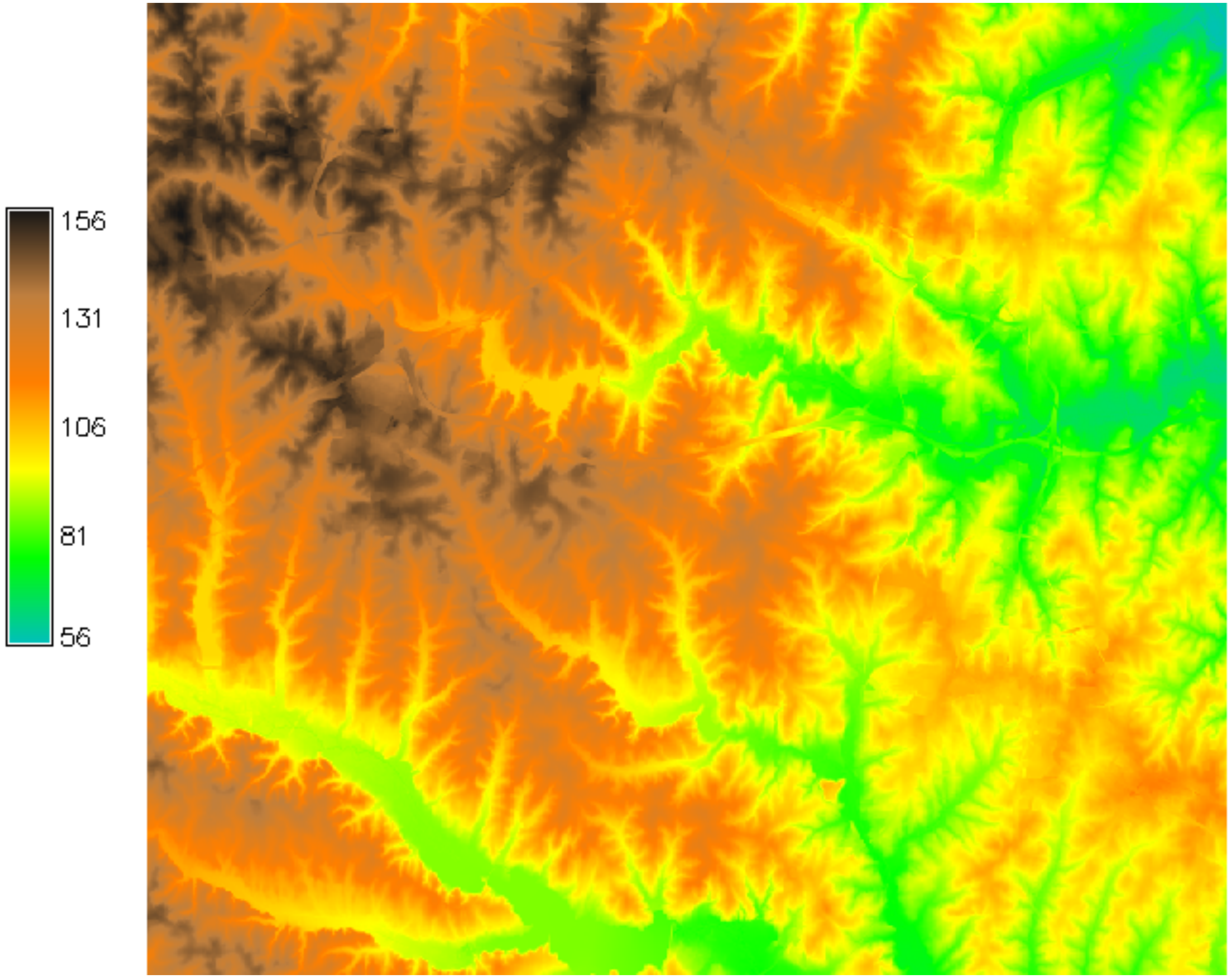
(proprietary)

Mapping software

- Complex arrangement of points, lines and areas
- Topology is most relevant
  - multiple layers
  - complex spatial queries supported
- Semantic zooming
- Mashup supported (combine features from different sources)
- Dedicated APIs:
  - mapping software can be integrated into a host Vis app

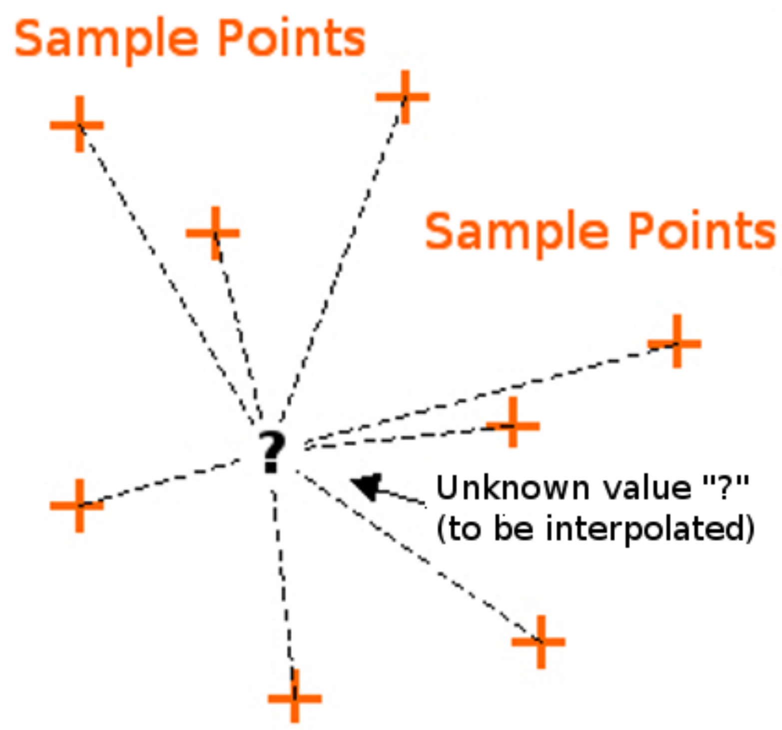
Elevation maps: field data

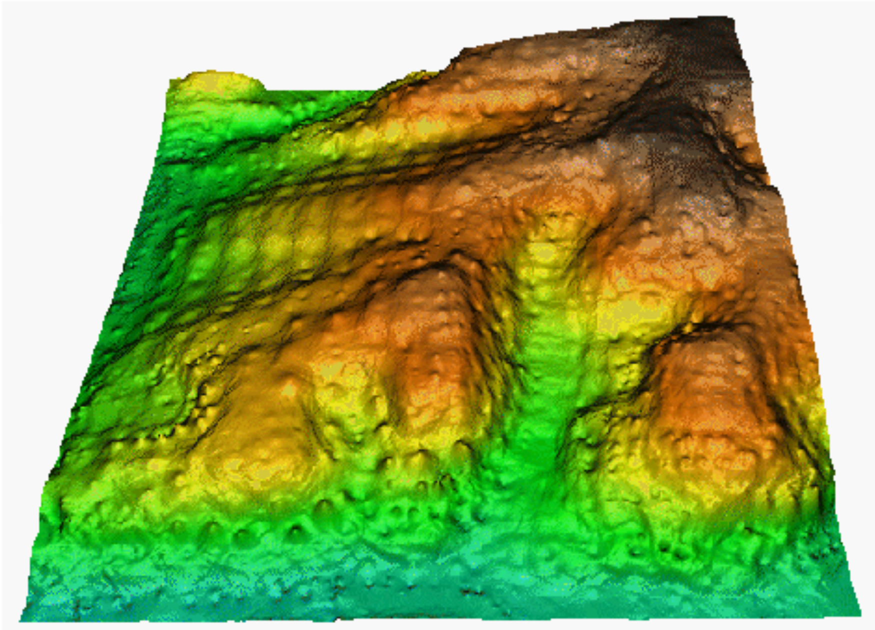
- data
  - scalar spatial field
    - 1 quant attribute per domain point
- raster model
  - field discretized (constant) per cell
    - 1 quant attribute per cell
  - idiom: heatmap

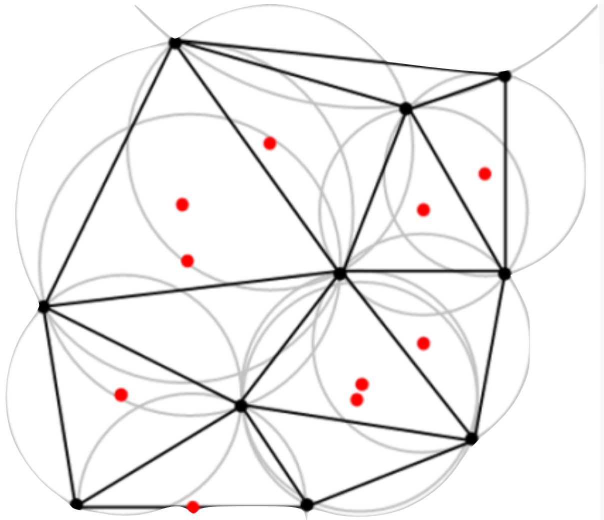


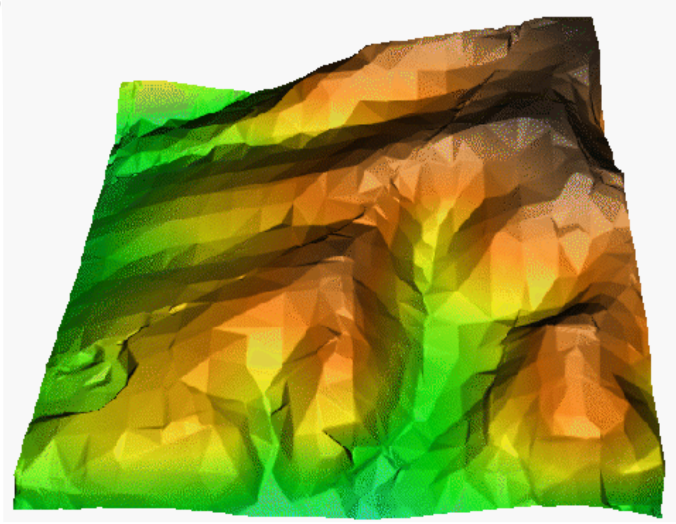
Elevation maps: field data

- data
  - scalar spatial field
    - 1 quant attribute per domain point
- continuous model
  - field known at a finite set of samples
  - needs interpolation scheme
  - Inverse Distance Weighted (IDW):
    - resample data on regular grid
    - estimate fields at new sample on the basis of neighbors
  - Triangular Irregular Network (TIN):
    - build triangle mesh with vertices at data points
    - linear interpolation inside each triangle
  - suitable to 3D Vis



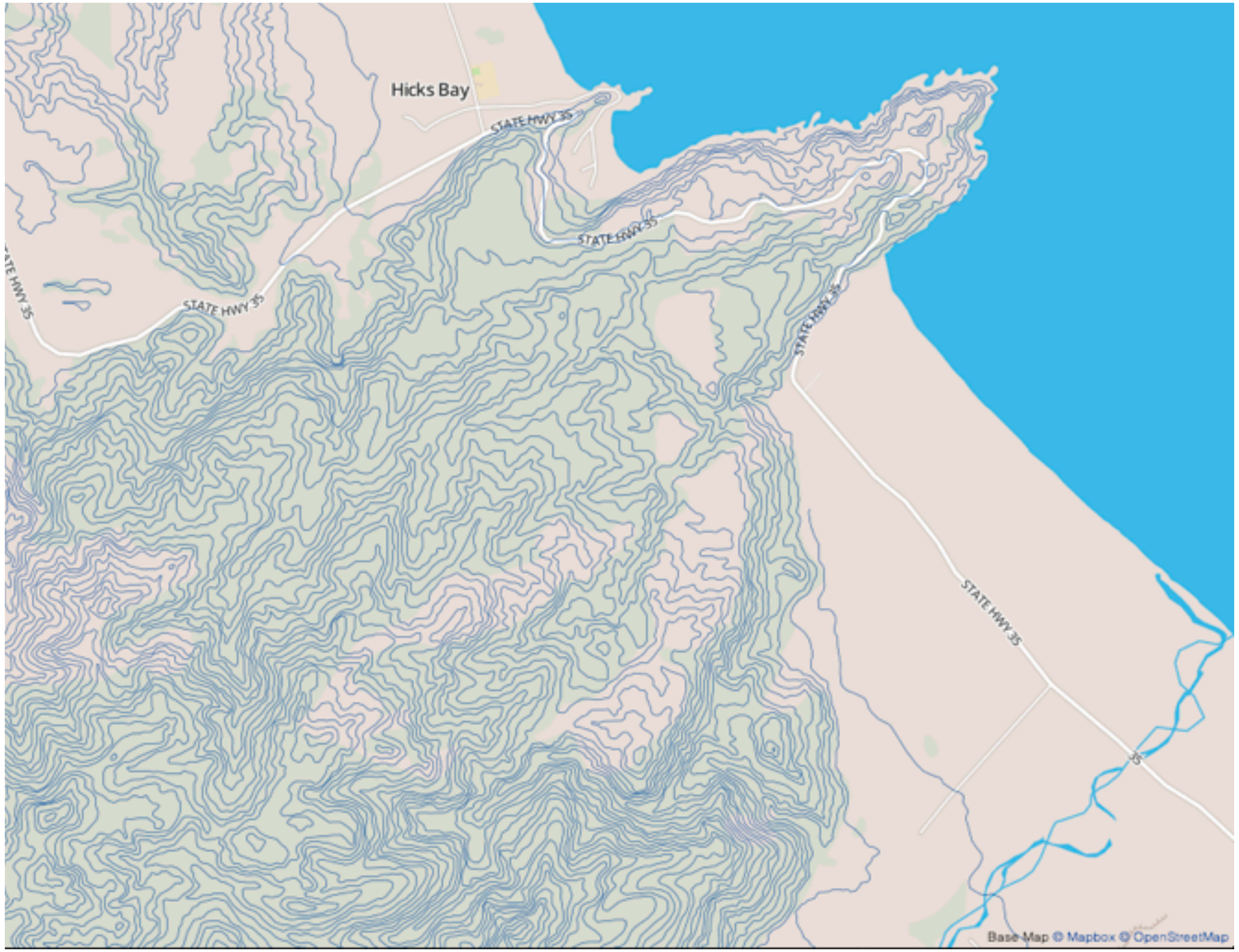






Idiom: **isopleth map**

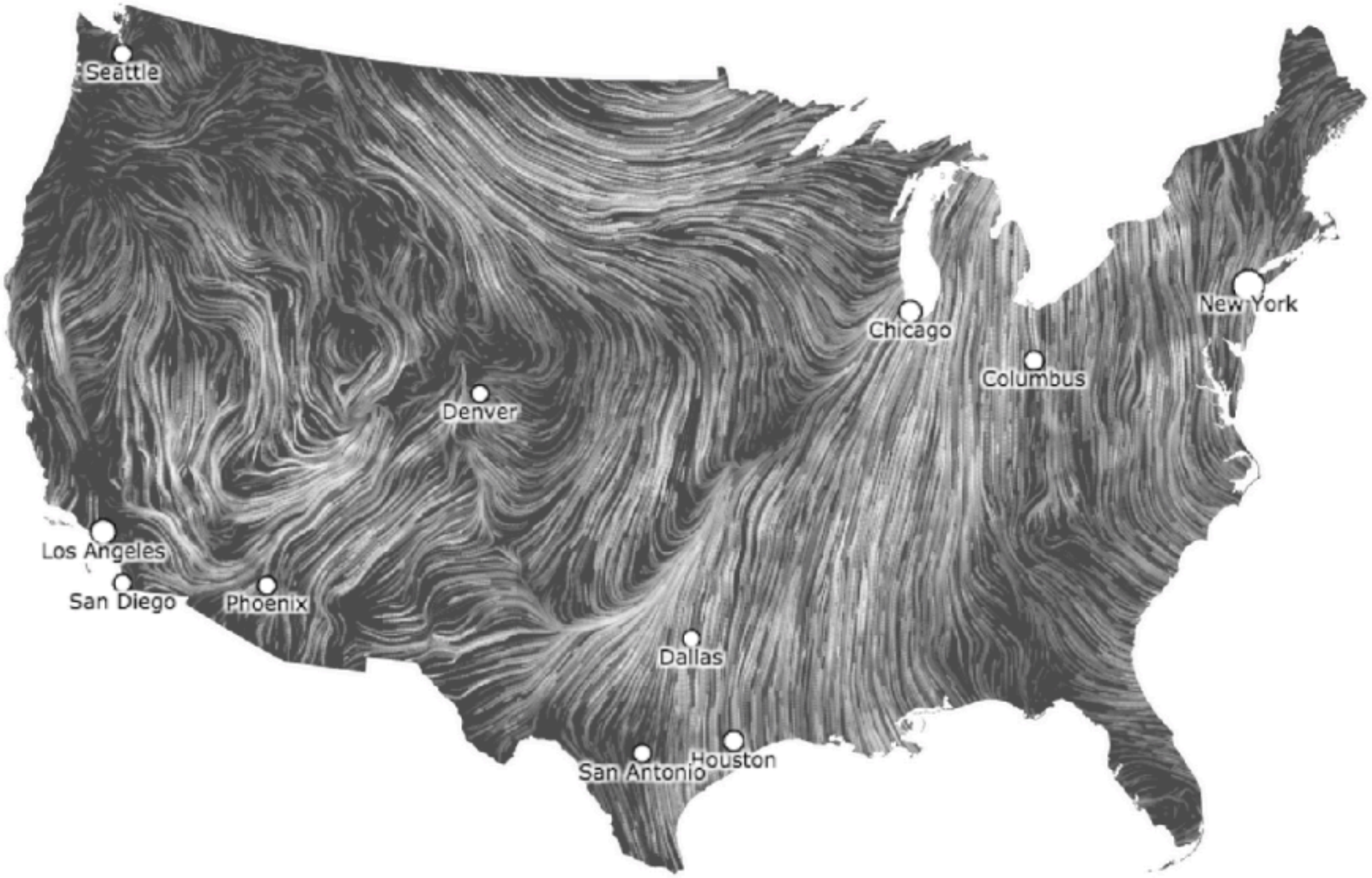
- data
  - scalar spatial field
    - 1 quant attribute per domain point
- derived data
  - isoline geometry
    - isocontours computed for specific levels of scalar values



Land Information New Zealand Data Service

Vector field data

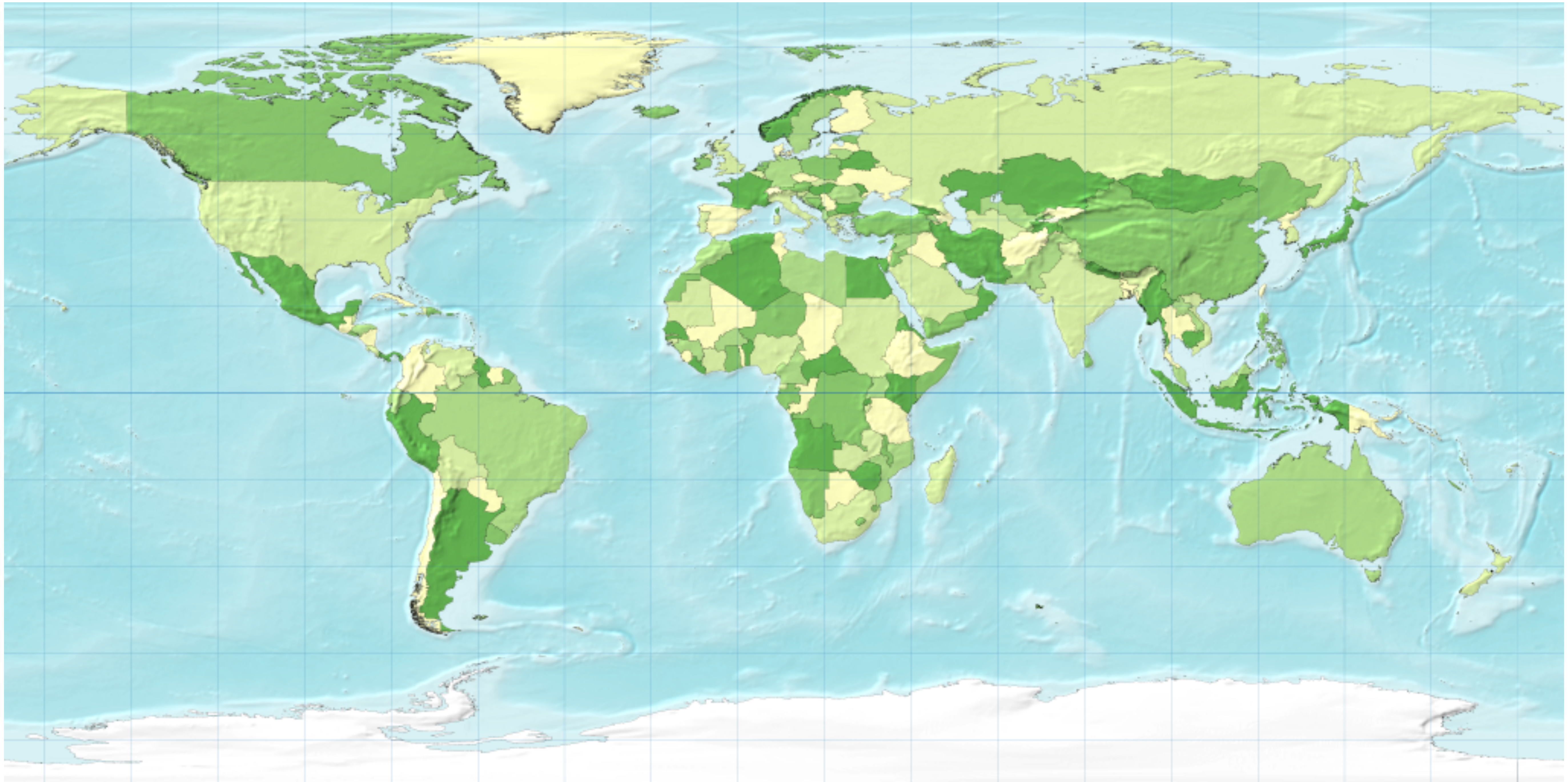
- Ex.: wind map
- Sophisticated techniques needed



Cartograms

- Idea: scale distance/area by data
- Sophisticated algorithms needed

Mark Newman, University of Michigan



Cartograms

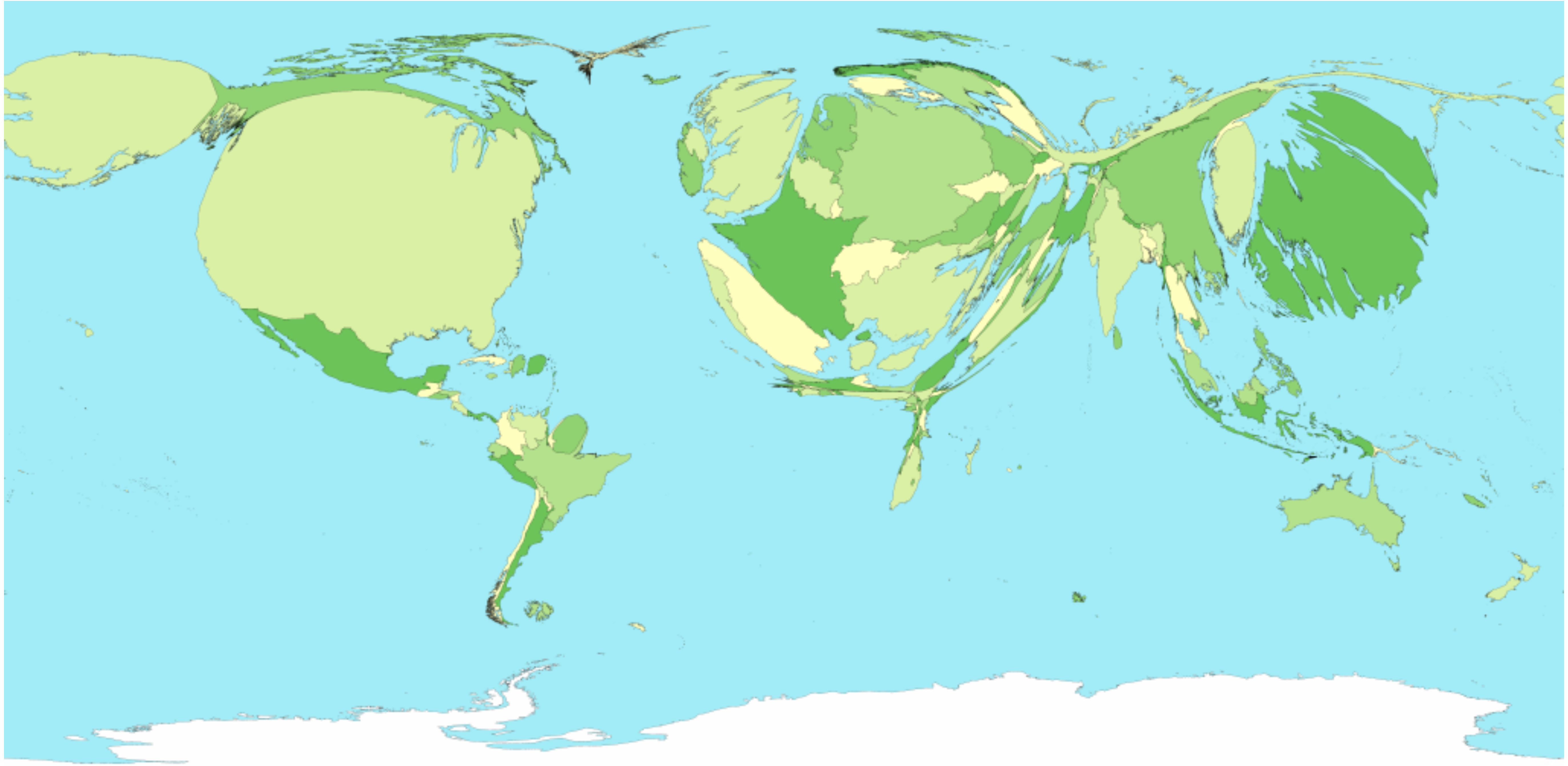
- Map scaled by population

Mark Newman, University of Michigan

Cartograms

- Map scaled by GDP

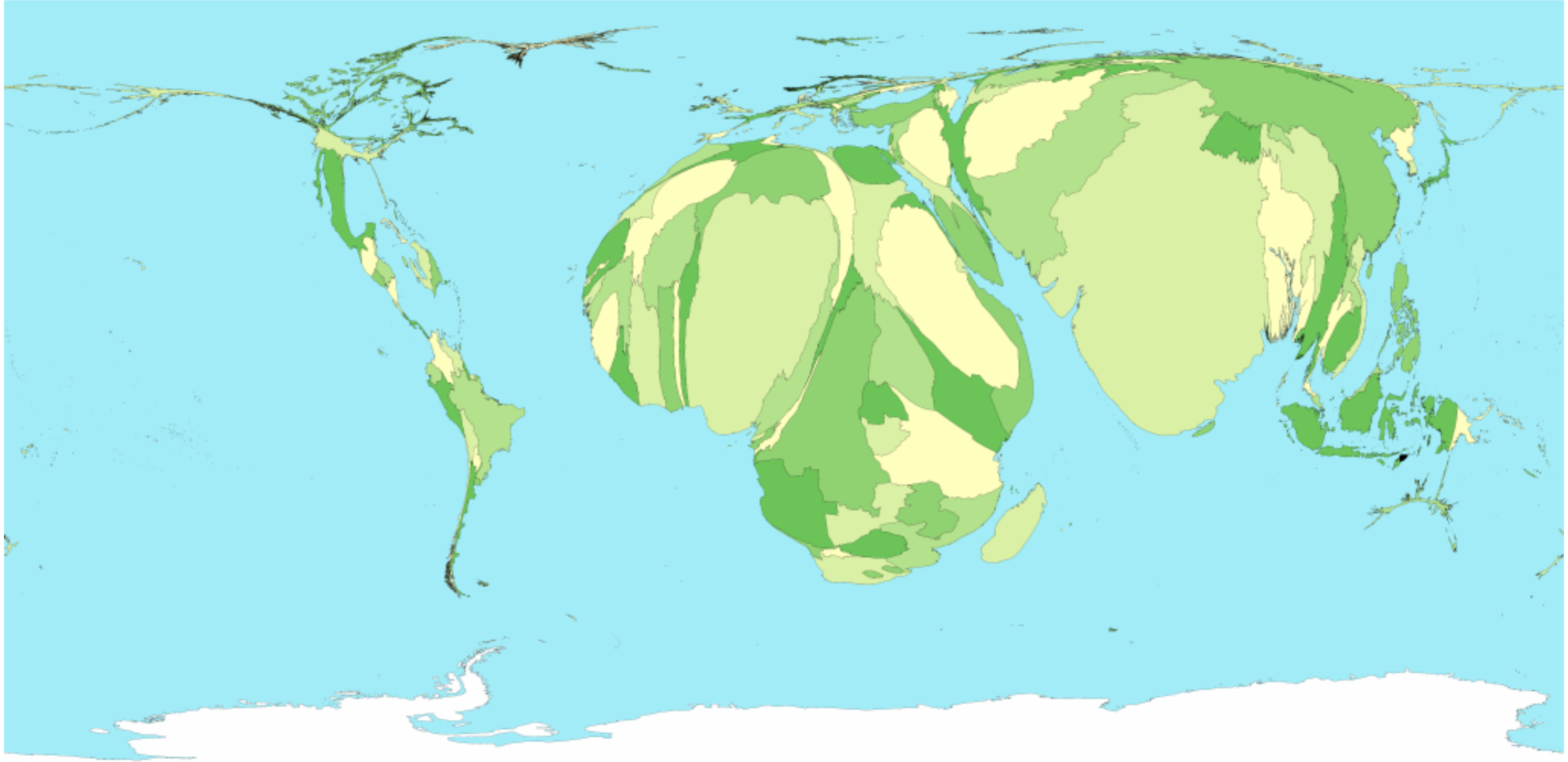
Mark Newman, University of Michigan



Cartograms

- Map scaled by child mortality

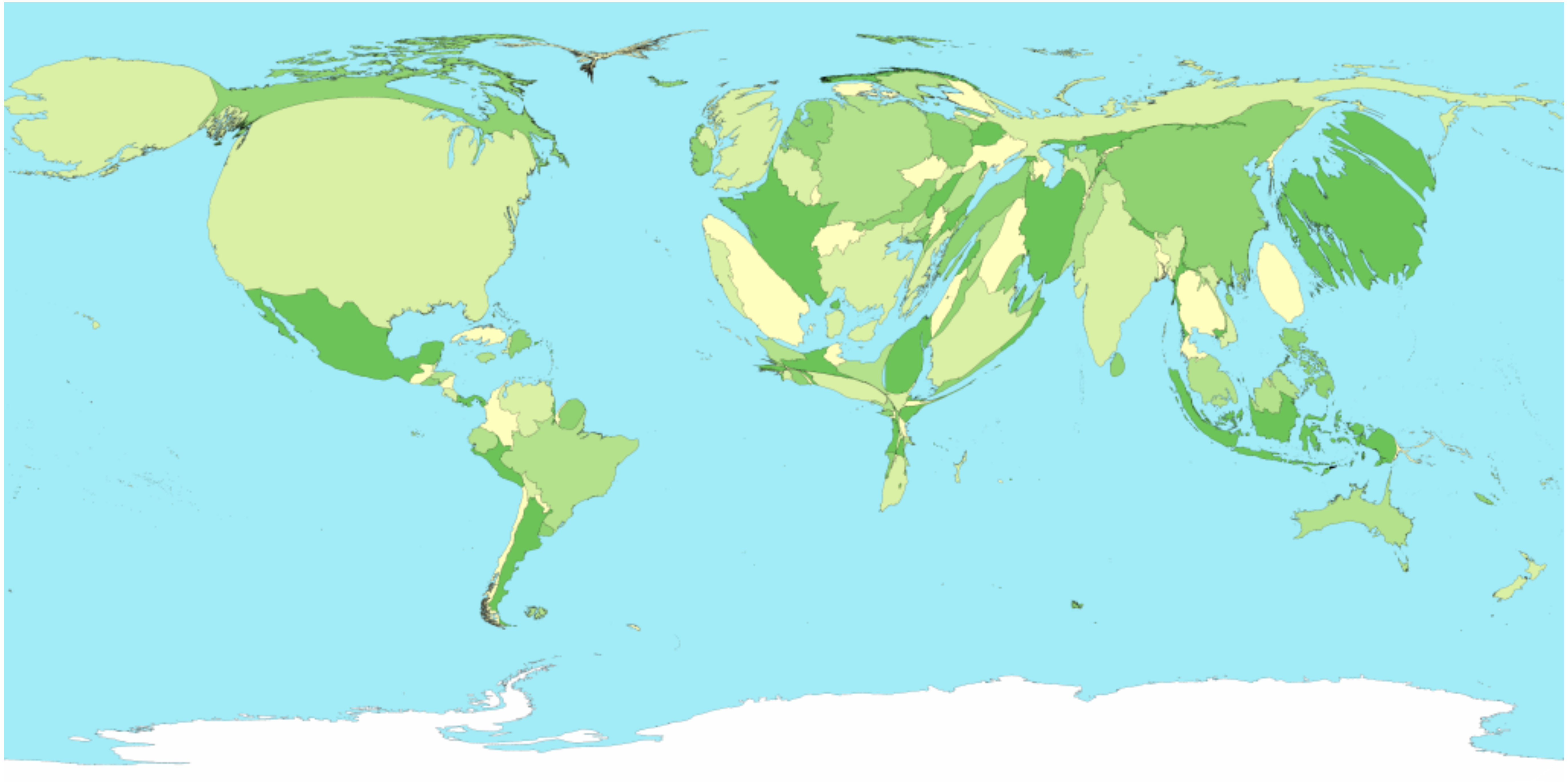
Mark Newman, University of Michigan



Cartograms

- Map scaled by energy consumption

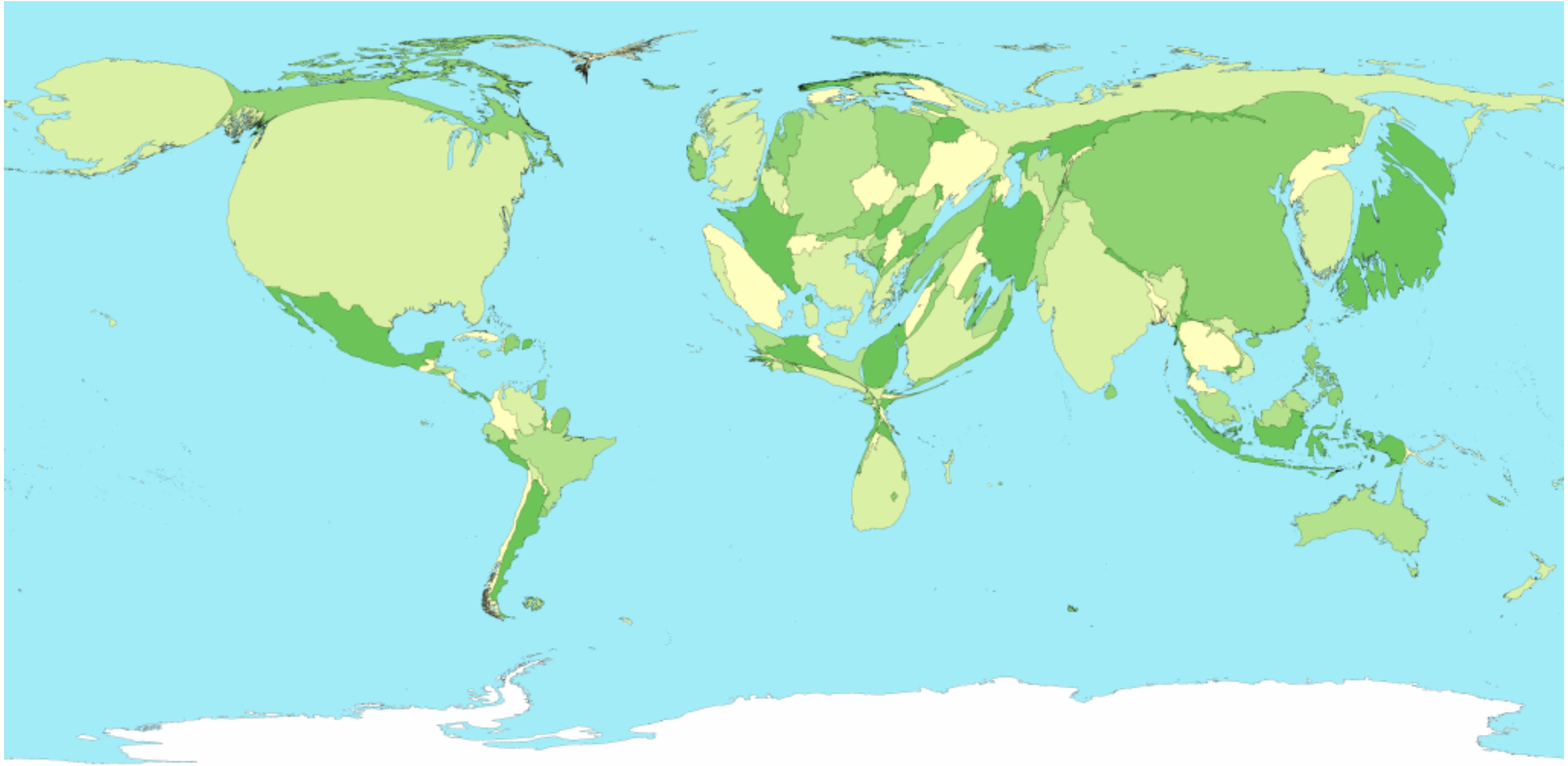
Mark Newman, University of Michigan



Cartograms

- Map scaled by greenhouse gas emission

Mark Newman, University of Michigan



Next Time

- to read
  - VAD Ch. 9: Arrange Networks and Trees