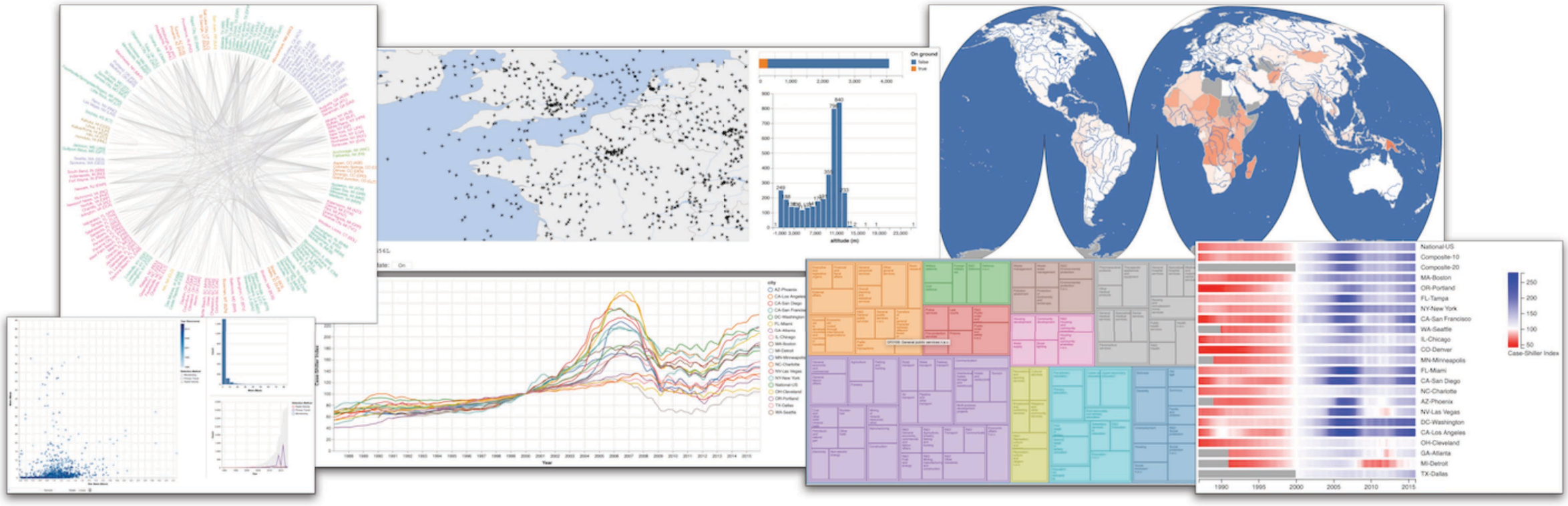
Data Visualization

INF552 (2023-2024)

Session 06
Geovisualization, Multiscale Navigation

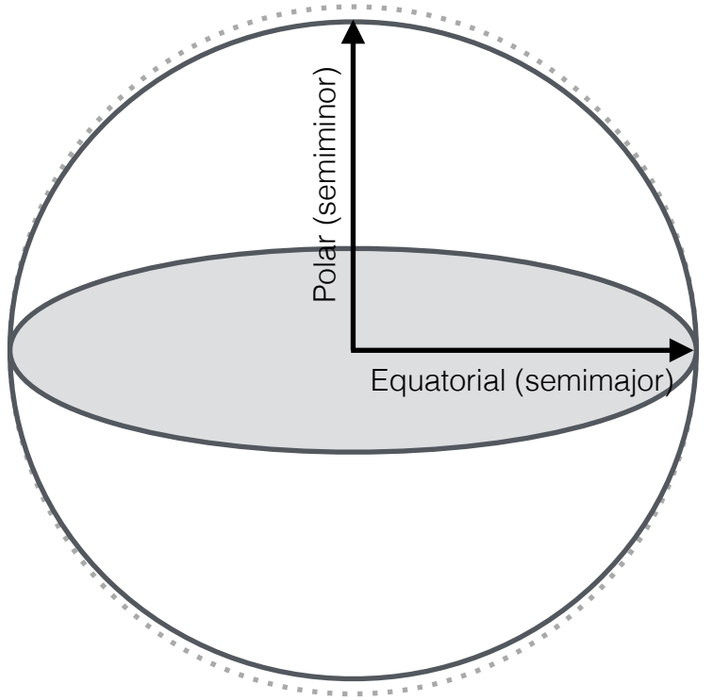


emmanuel.pietriga@inria.fr

Cartography / Projections

The Earth is a spheroid (polar radius < equatorial radius)

$$\frac{a-b}{a} = \frac{1}{298.257}$$



Geographic coordinate system = geodetic datum + coordinate system

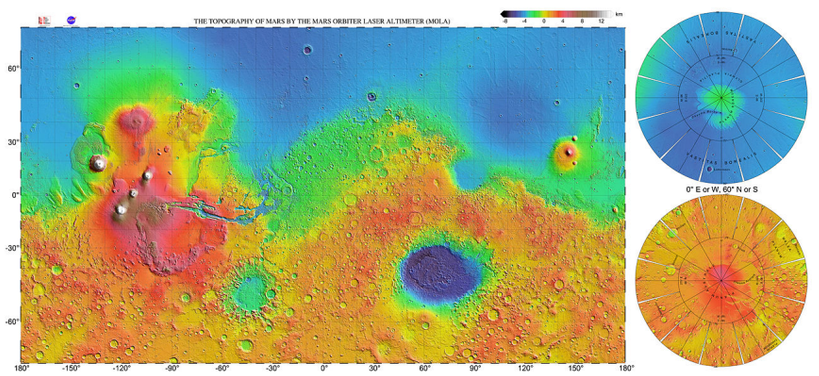
Example: WGS84/EPSG:4326

longitude λ, latitude ϕ, elevation

prime meridian

	length (km)
1° lon @ equator	≈111.3
1° lon @ 60° lat	≈55.8

Applies to other astronomical bodies such as, *e.g.*, Mars, where the zero-elevation datum is defined in terms of a constant atmospheric pressure

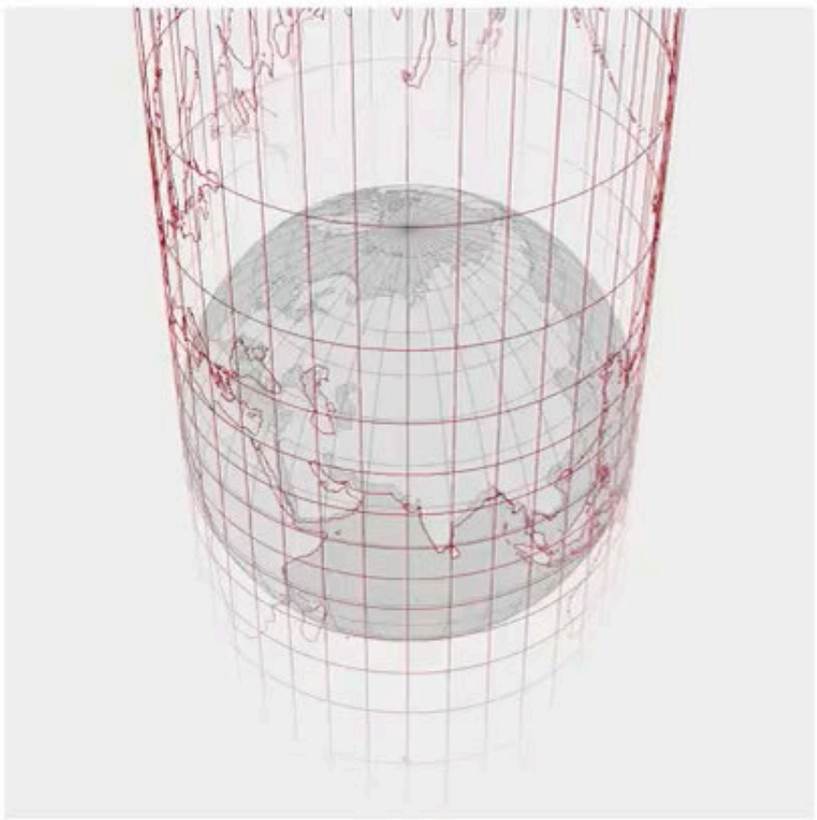


Cartography / Projections

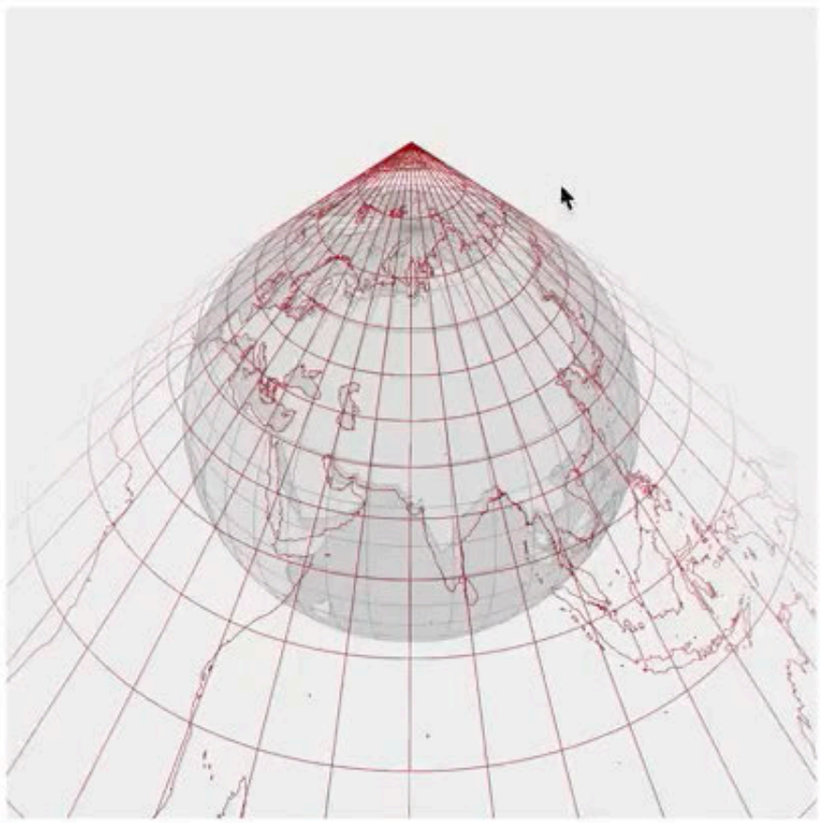
Process of projecting to a developable surface, and then flattening that surface.

Developable surface: simple geometric surface that can be flattened without introducing additional distortion such as stretching or shearing.

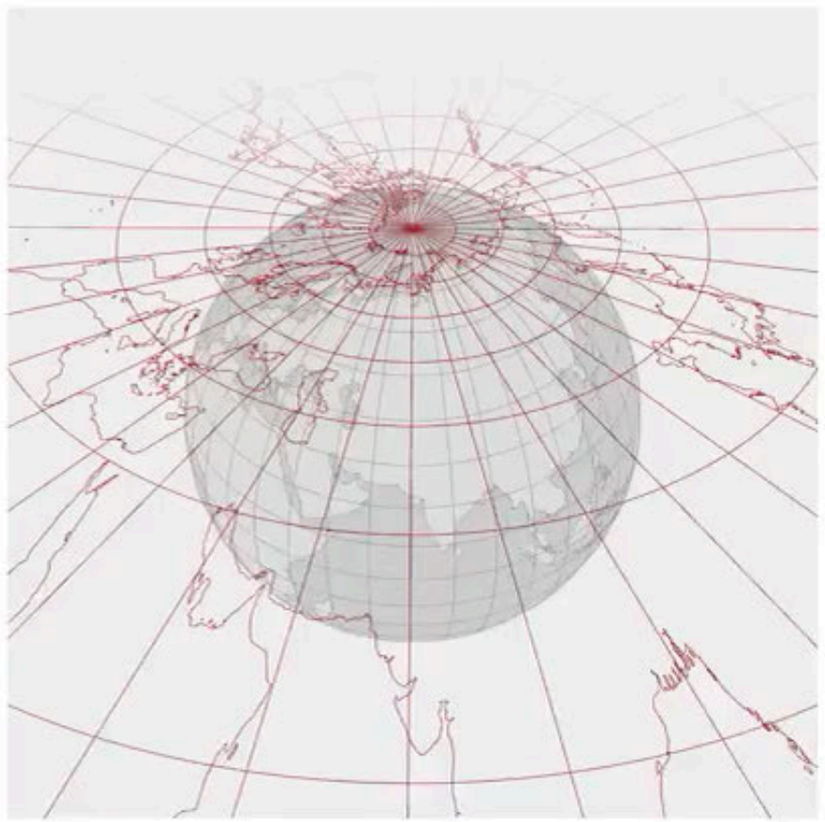
[Source: Anton Minizov, 2019, https://mercator.tass.com]



Cylindrical

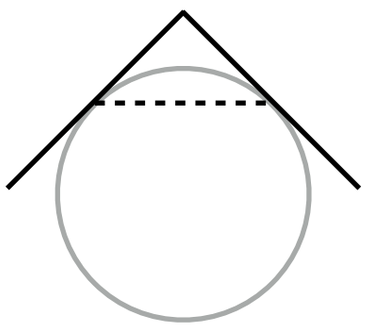


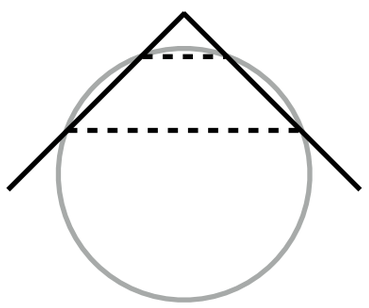
Conic



Azimuthal

Tangent *vs.* secant:

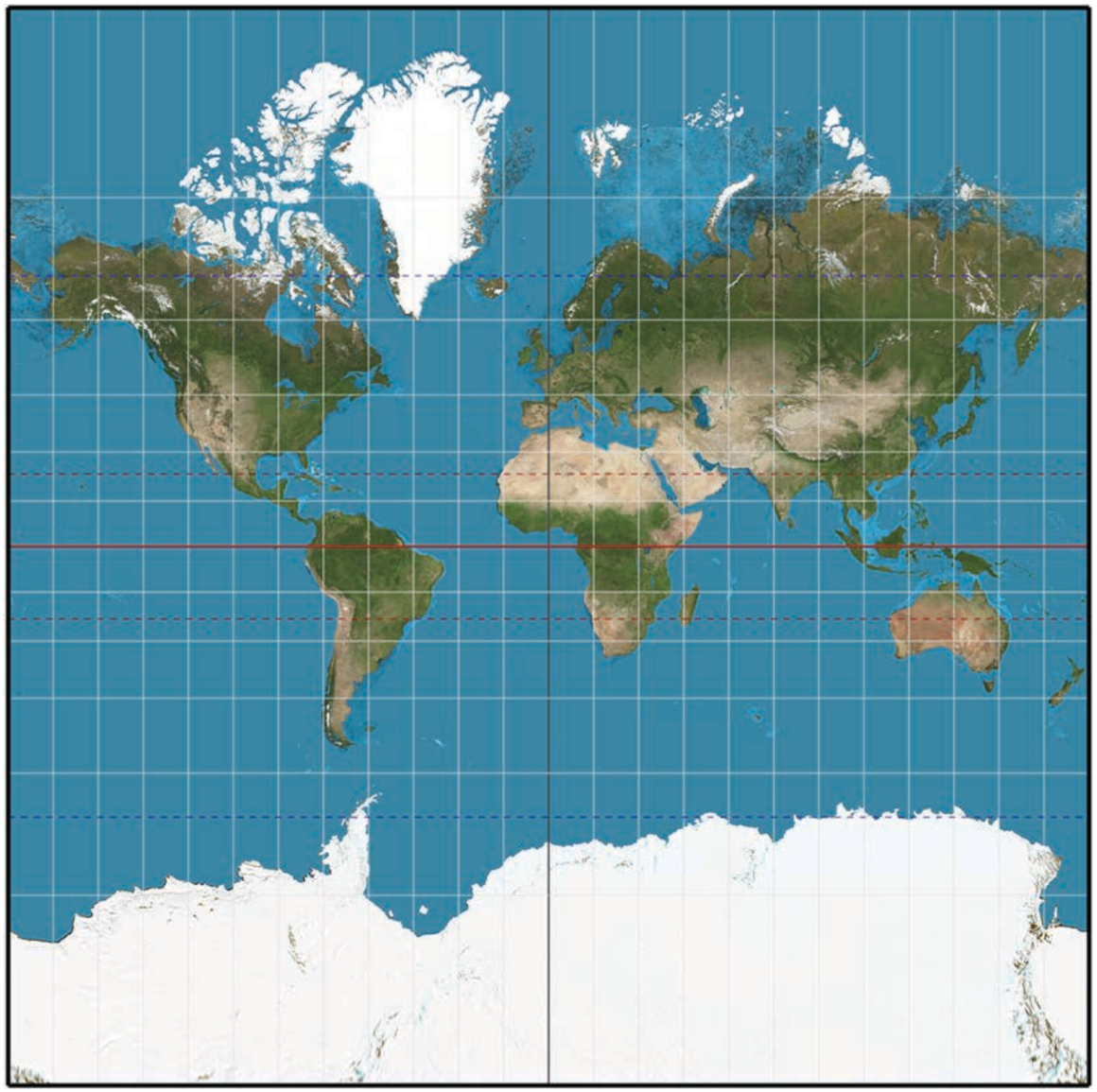


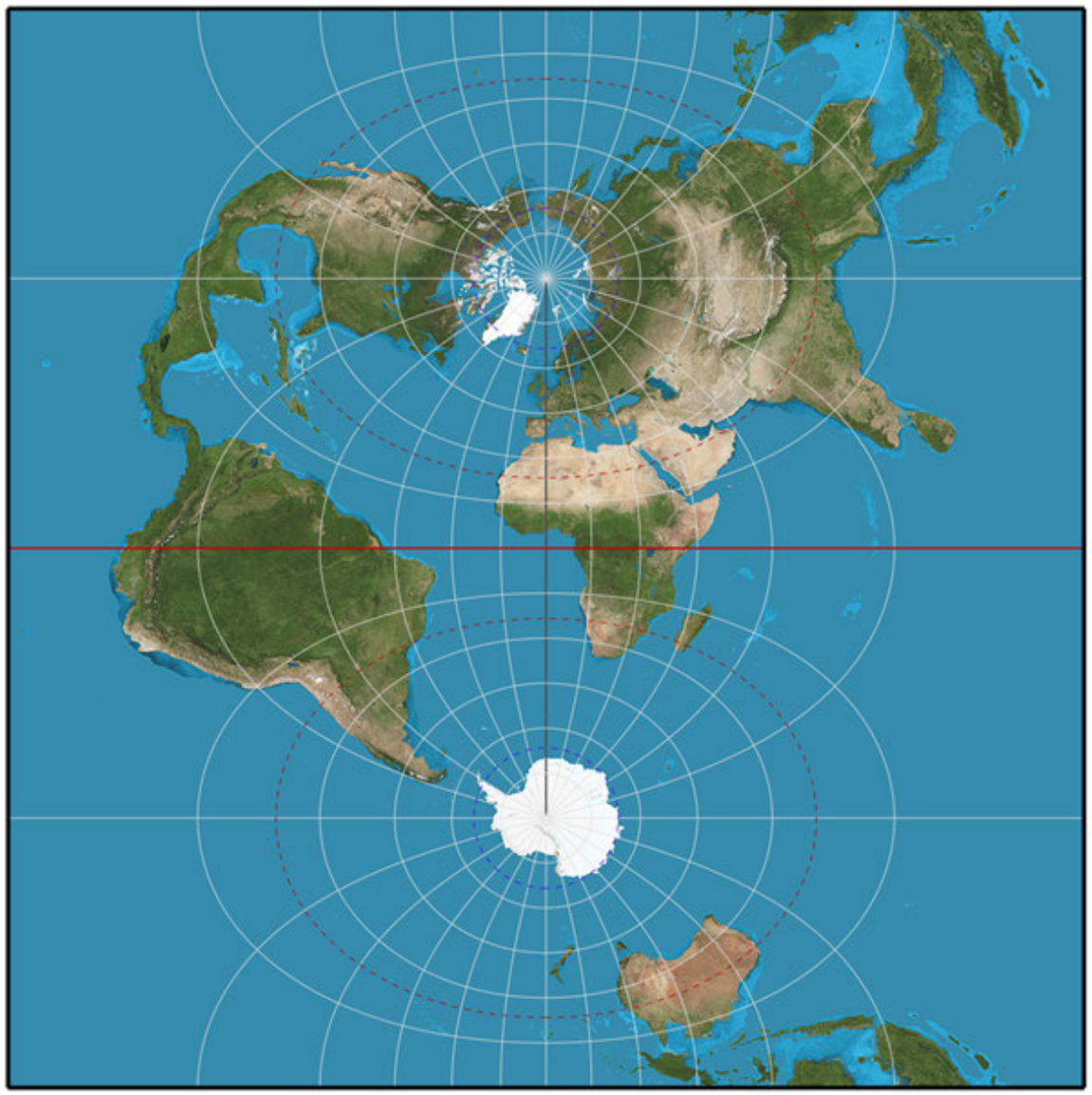


Cartography / Projections

Normal, Transverse & Equatorial, Oblique

Example on a cylindrical projection: normal *vs.* transverse:



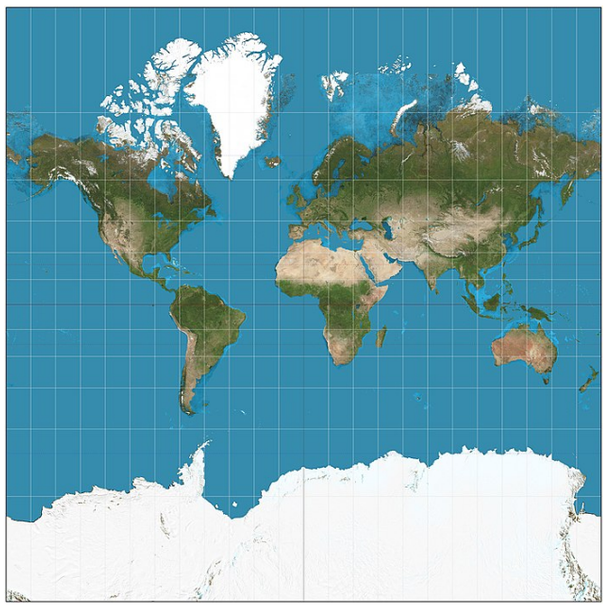


Cartography / Projections

- Map projections necessarily distort the surface (spheroid)

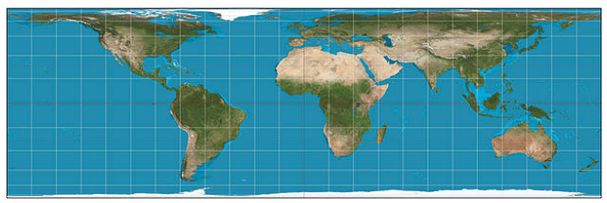
- Make choices between preserving local angles (conformal), areas (equal-area), distances (equidistant):

Conformal

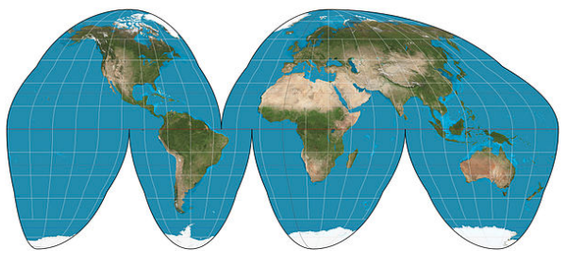


Mercator

Equal-area

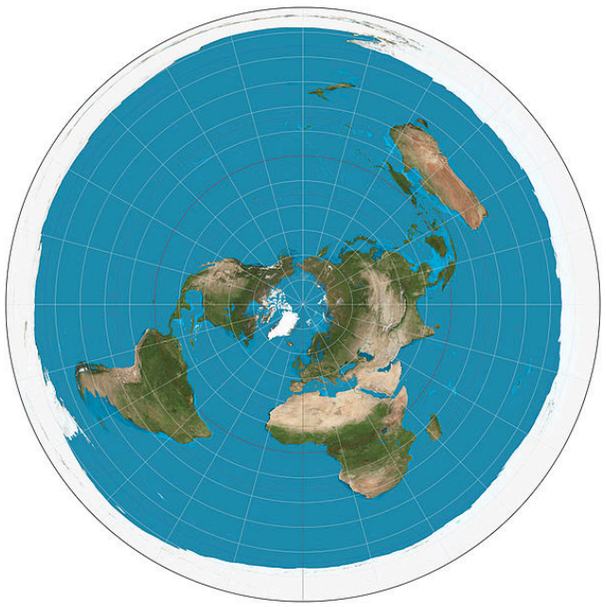


Lambert cylindrical



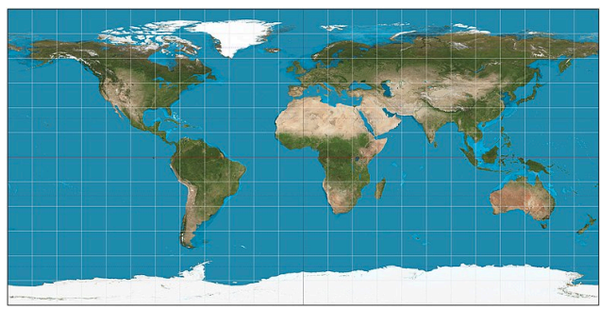
Goode Homolosine

Equidistant



Azimuthal eq.

None (compromise)



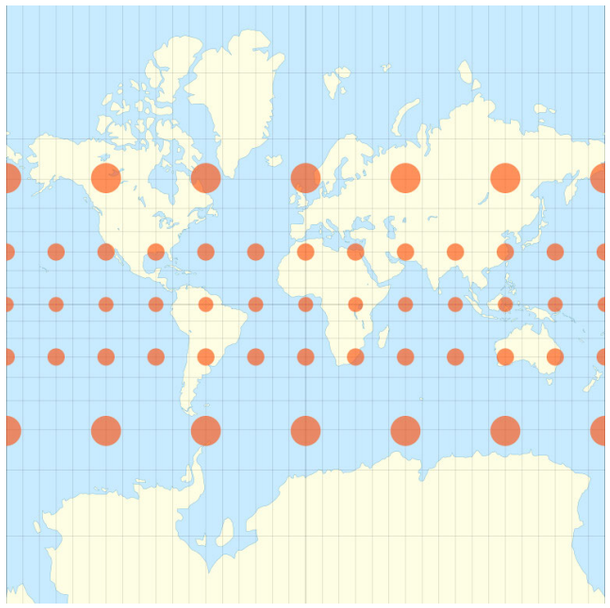
Equirectangular

Cartography / Projections

- Map projections necessarily distort the surface (spheroid)

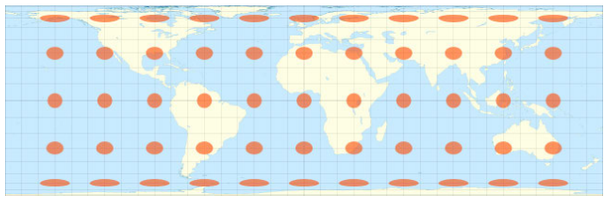
- Make choices between preserving local angles (conformal), areas (equal-area), distances (equidistant):

Conformal

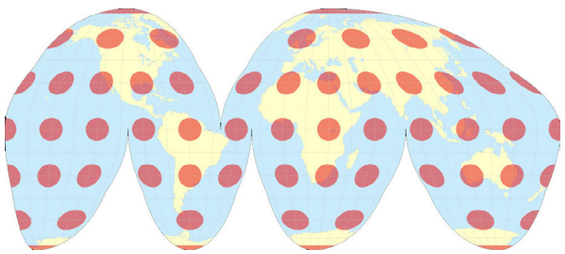


Mercator

Equal-area

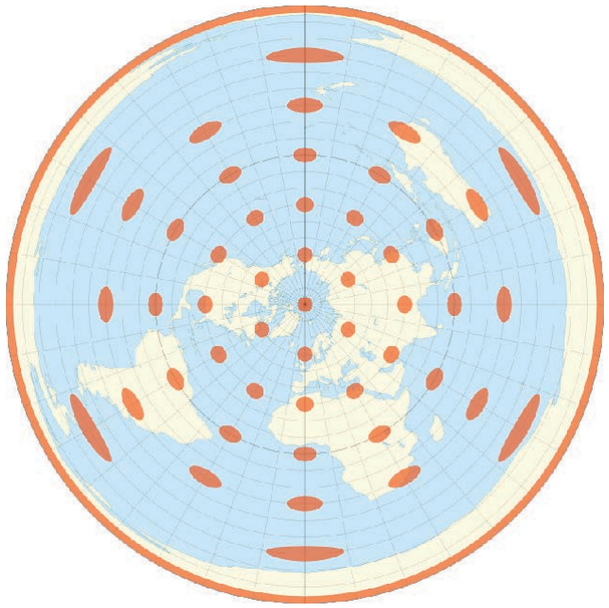


Lambert cylindrical



Goode Homolosine

Equidistant



Azimuthal eq.

None (compromise)

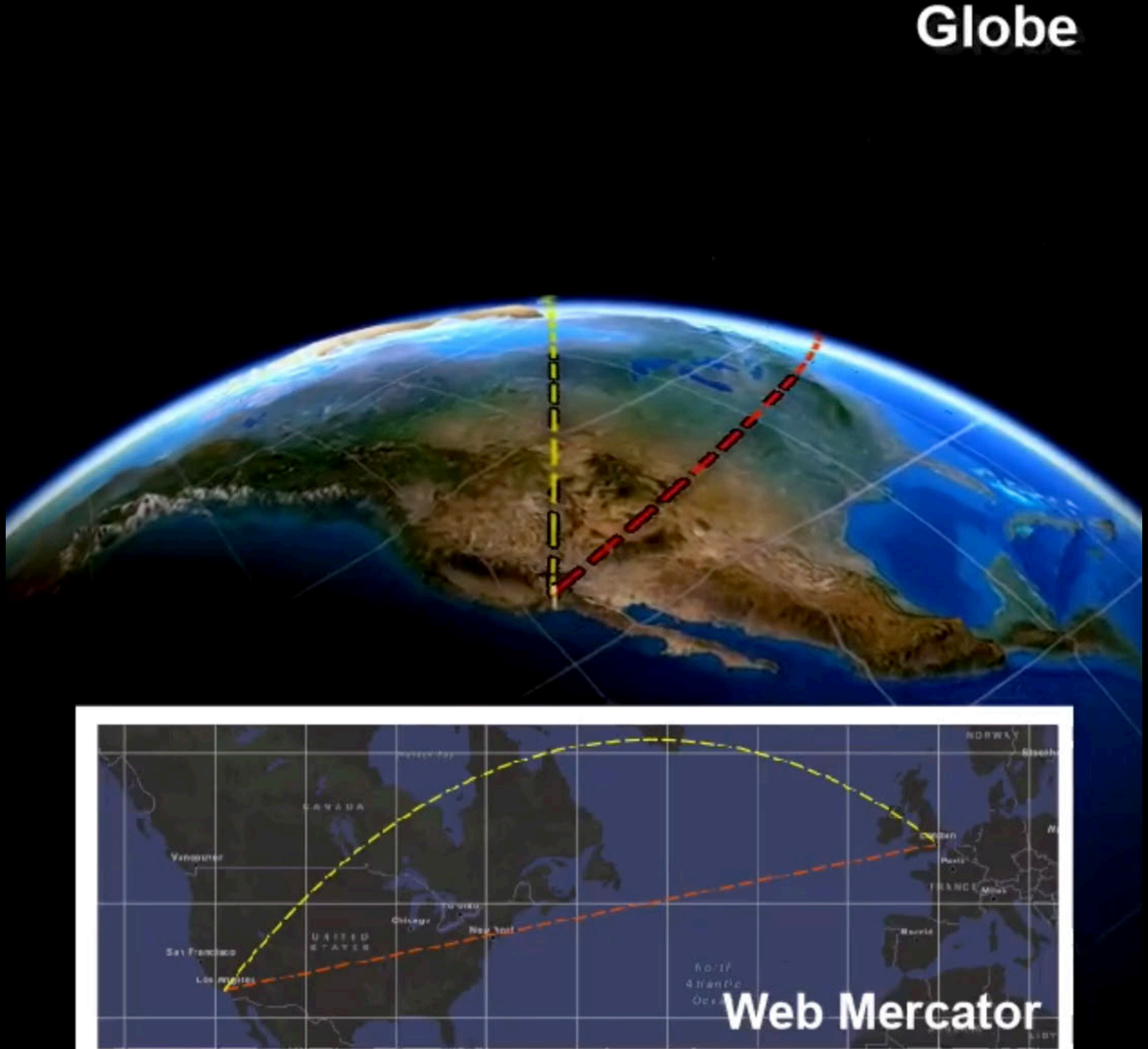
Equirectangular

Mercator


At the equator, the distortions are minimal

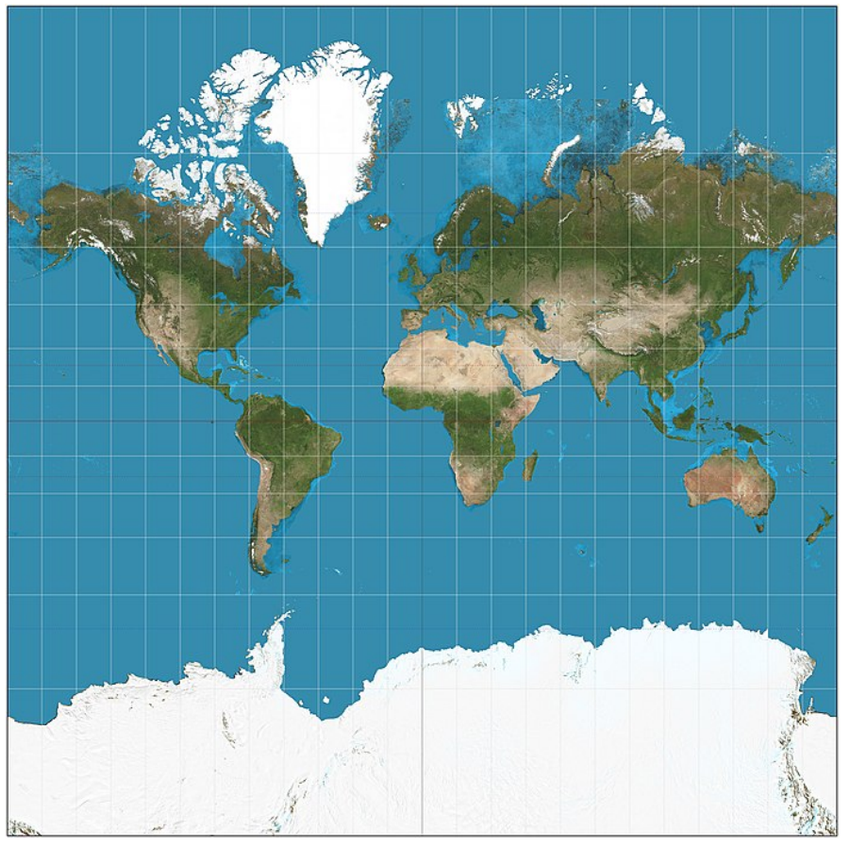

180°
120°W
60°W
0°
60°E
120°E
180°

Animation by Nathan Shephard using ArcGIS Pro
https://twitter.com/NathanCShephard/status/1521593914611798016



Cartography / Projections

Mercator



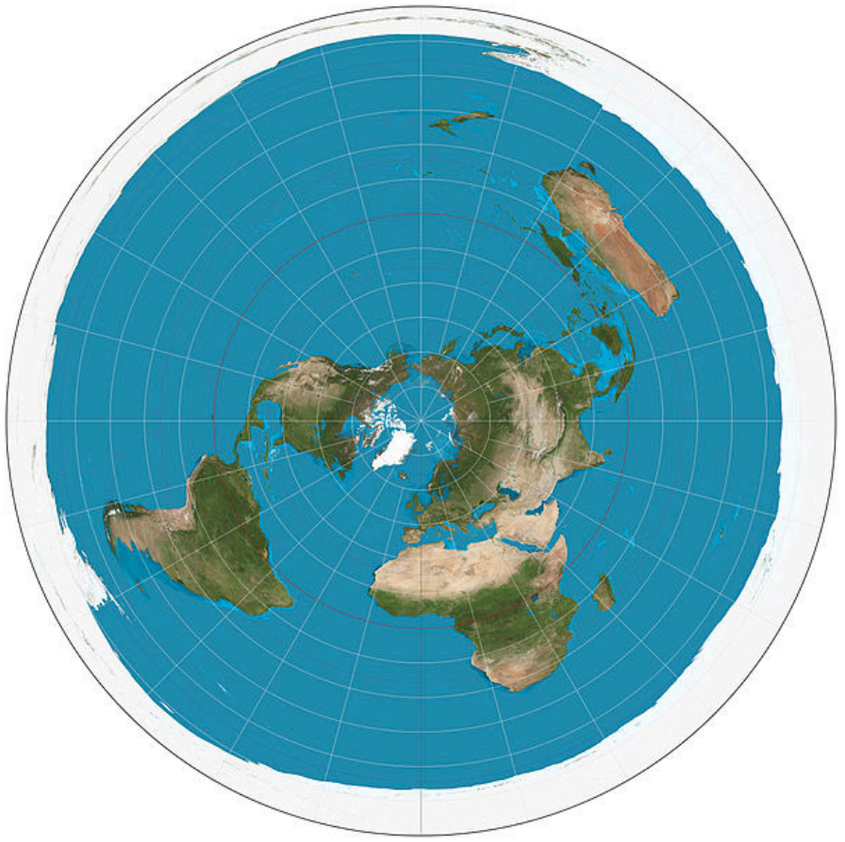
Cylindrical projection

Conformal

$$x = R(\lambda - \lambda_0)$$

$$y = R \cdot ln[tan(\frac{\pi}{4} + \frac{\phi}{2})]$$

Azimuthal Equidistant



Azimuthal projection

Equidistant

$$x = \rho \cdot sin\theta$$

$$y = -\rho \cdot cos\theta$$

At North pole:

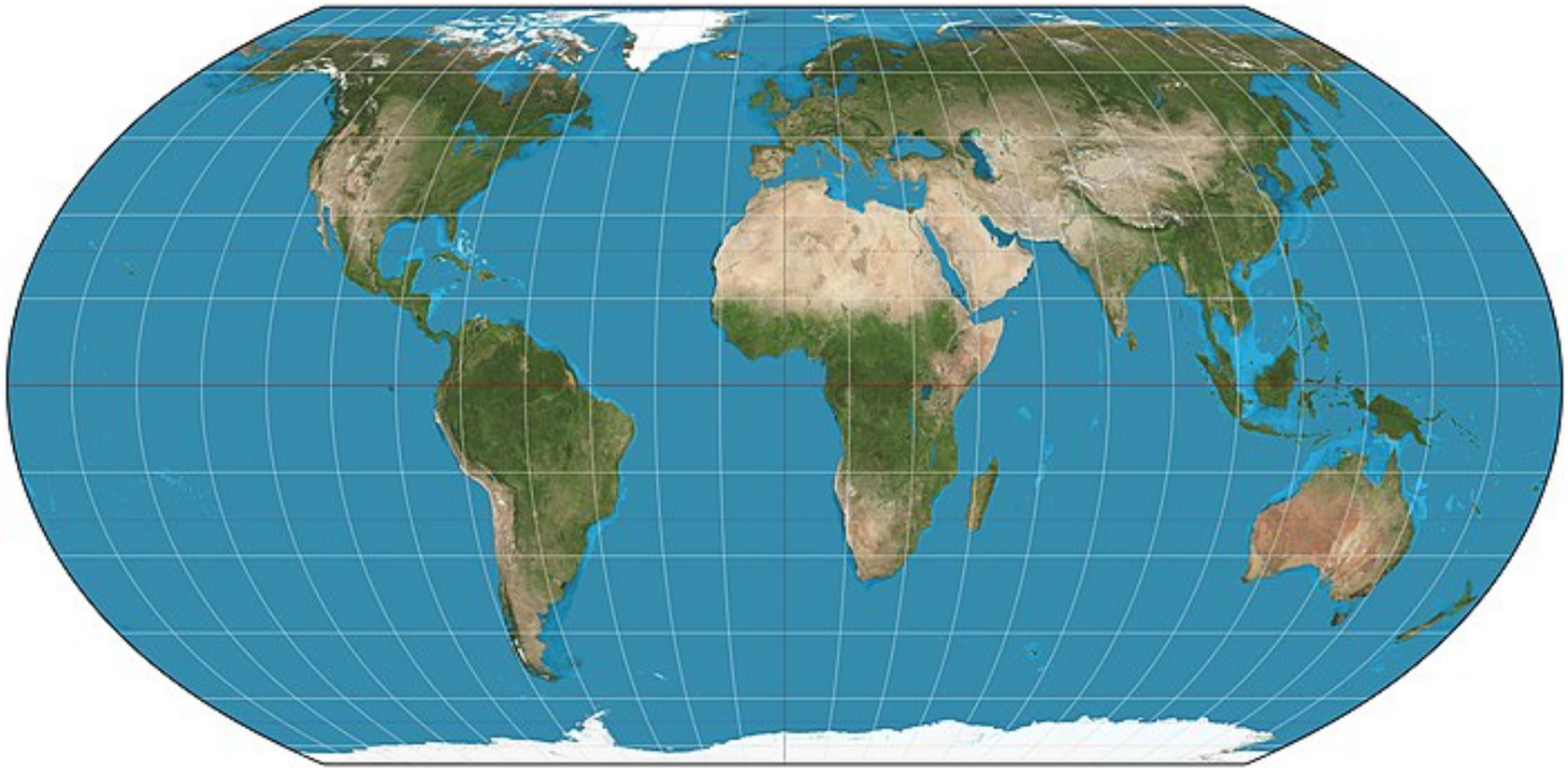
$$\rho = R(\frac{\pi}{2} - \phi)$$

$$\theta = \lambda$$

longitude λ, latitude ϕ, Earth radius R

Cartography / Projections

Recently introduced: Equal Earth



Compromise projection

Equal area

Easy to implement, fast to compute

$$x = \frac{2\sqrt{(3)} \cdot \lambda \cdot cos\phi}{3(9A_4\theta^8 + 7A_3\theta^6 + 3A_2\theta^2 + A_1)}$$

$$y = A_4\theta^9 + A_3\theta^7 + A_2\theta^3 + A_1\theta$$

$$sin\theta = \frac{\sqrt{3}}{2} sin\phi$$

$$A_1 = 1.340264$$

$$A_2 = -0.081106$$

$$A_3 = 0.000893$$

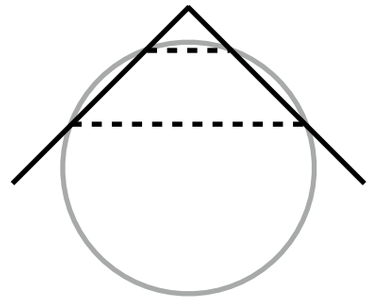
$$A_4 = 0.003796$$

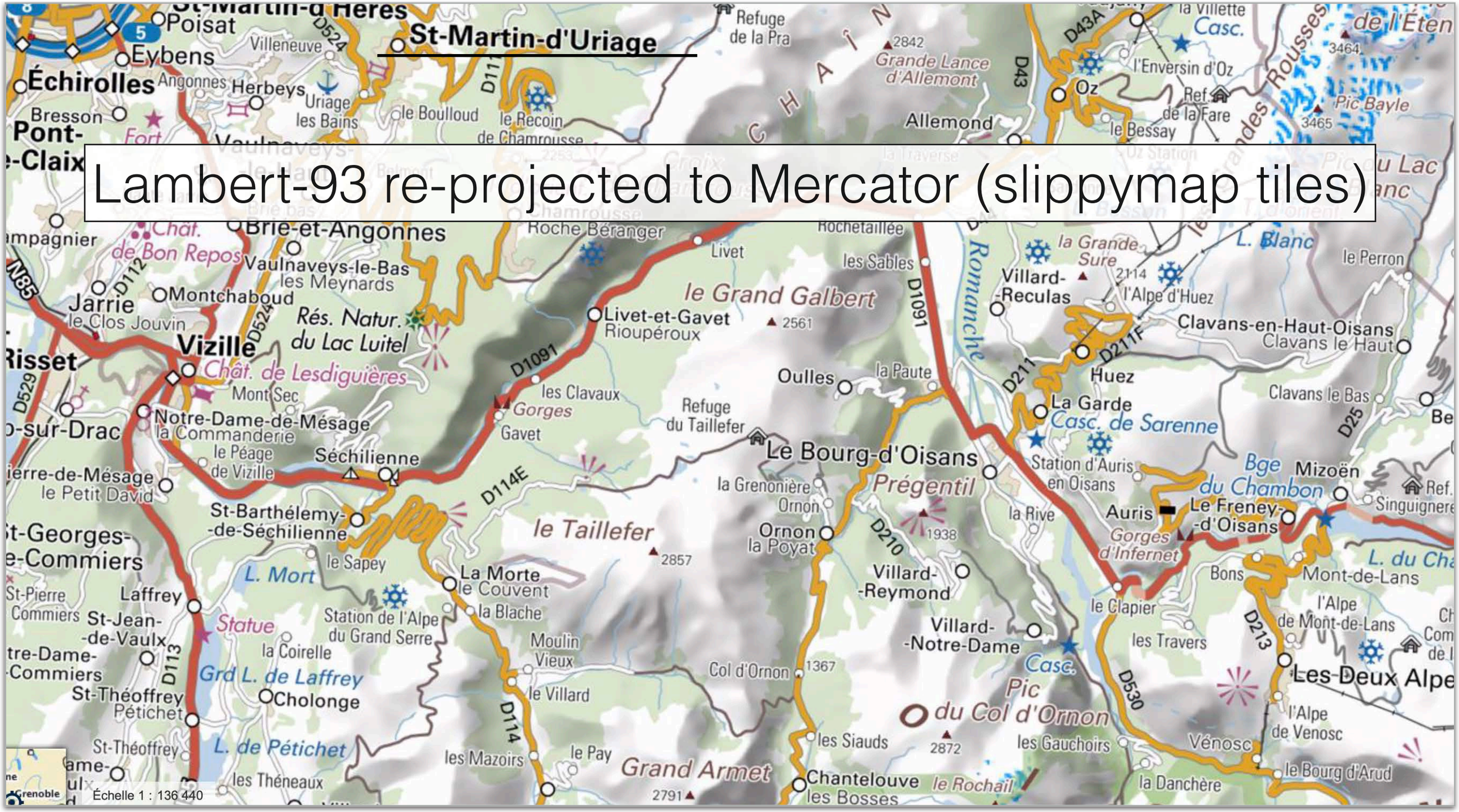
[Šavrič et al. The Equal Earth map projection, International Journal of Geographical Information Science: 1–12, 2018]

Cartography / Projections

In France (among others): Lambert Conic Projection using the RGF93 datum.

Standard parallels: 44°N and 49°N





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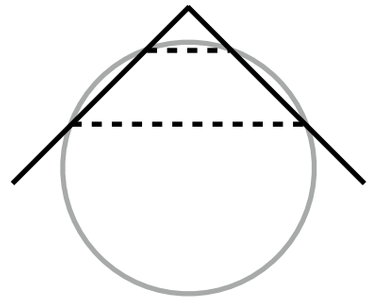
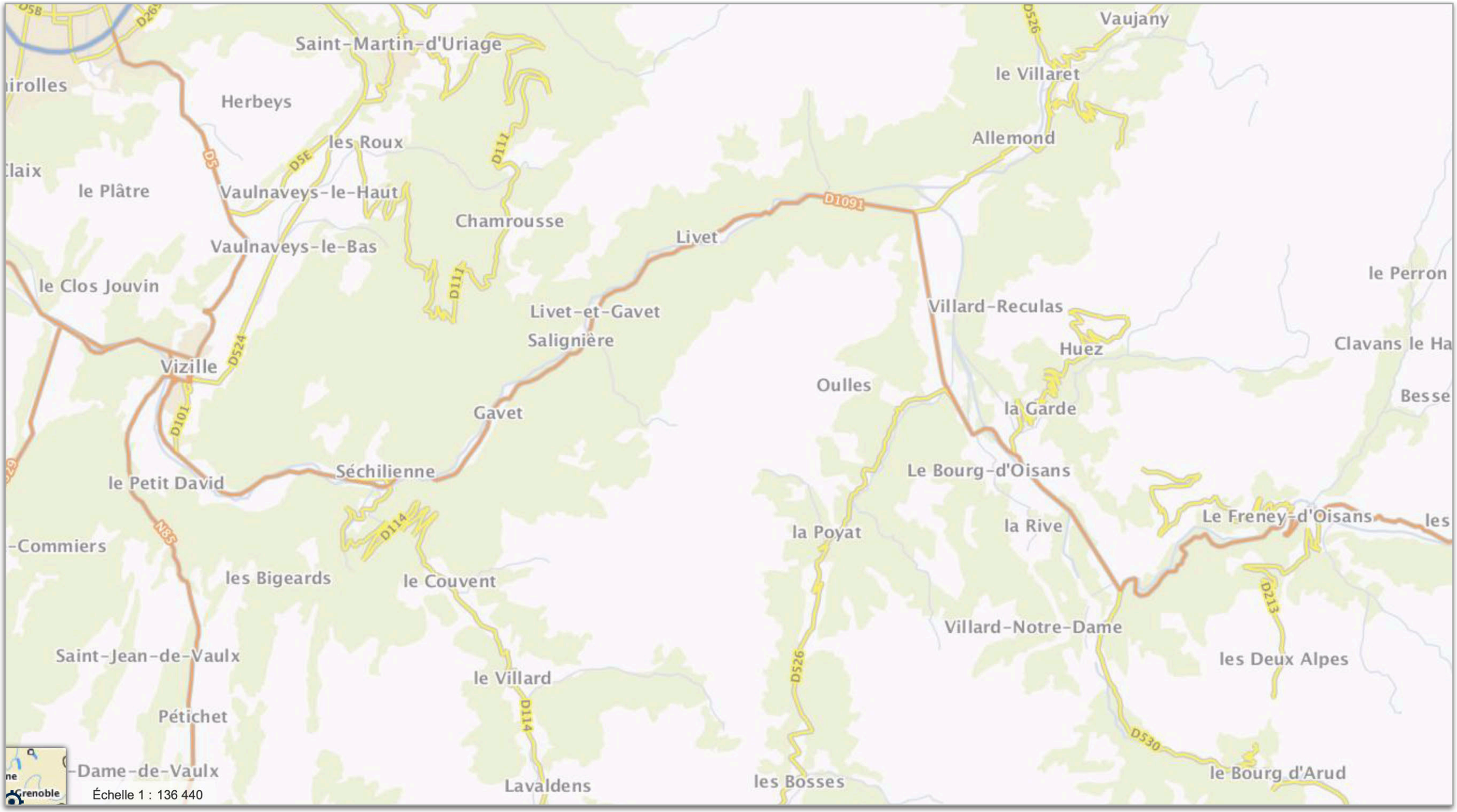
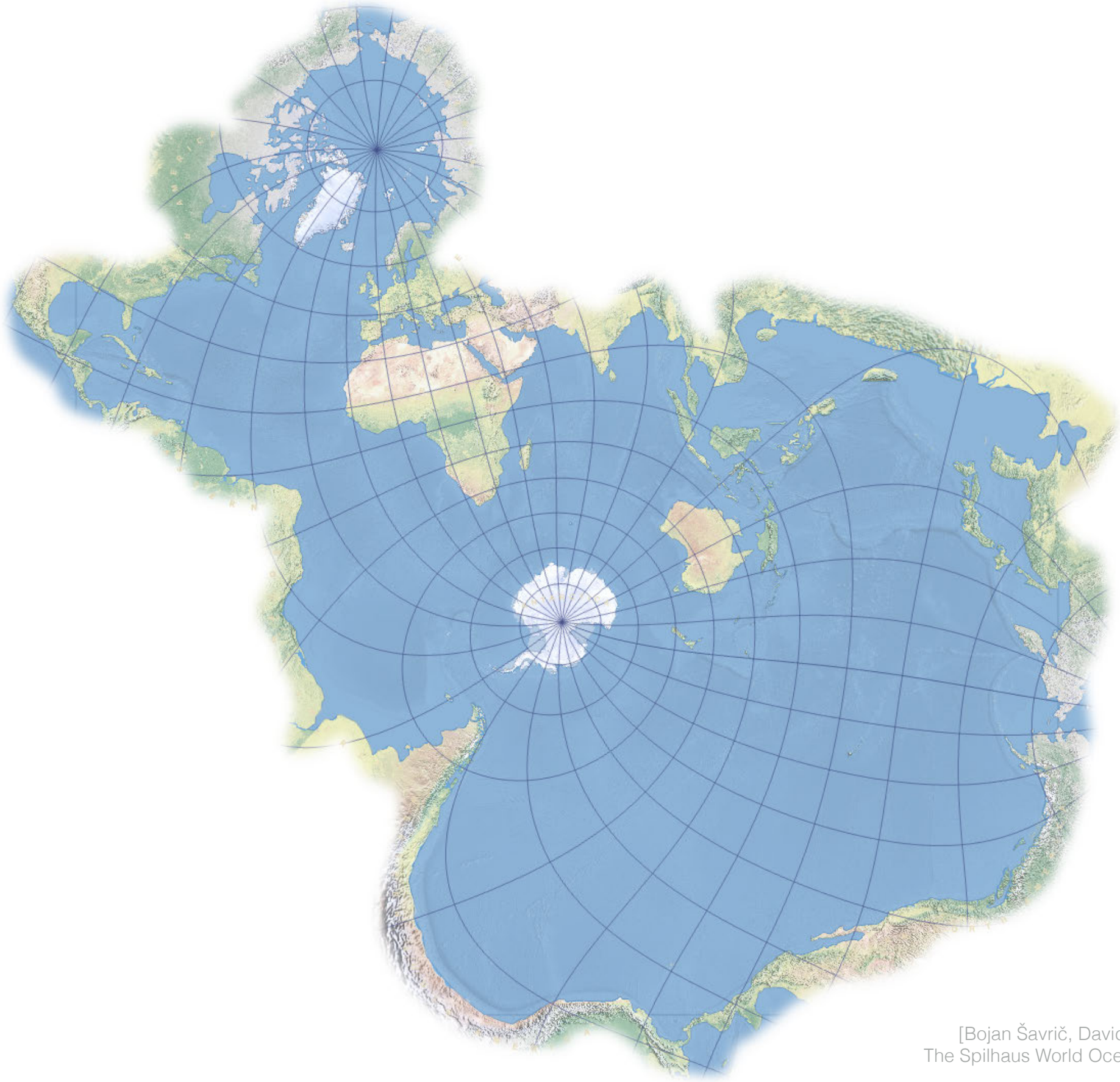


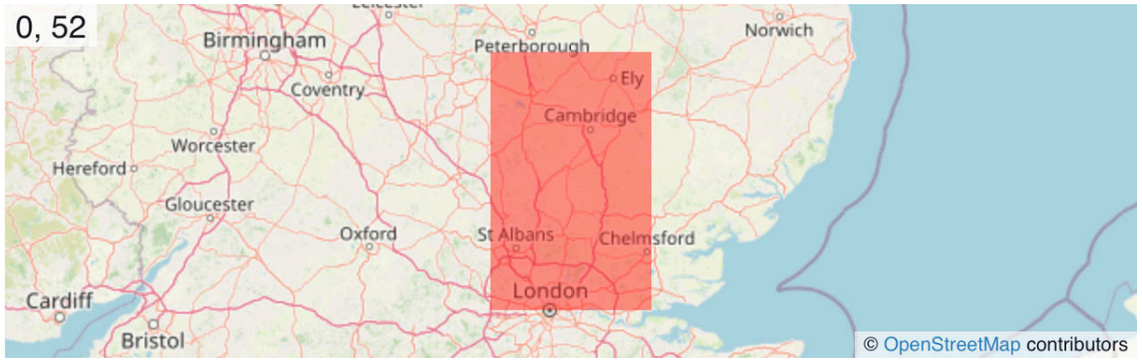


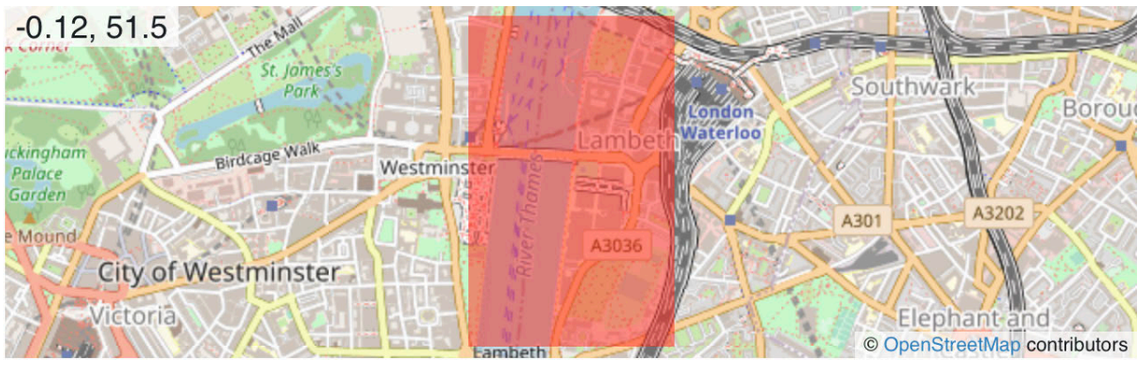
Cartography / Projections

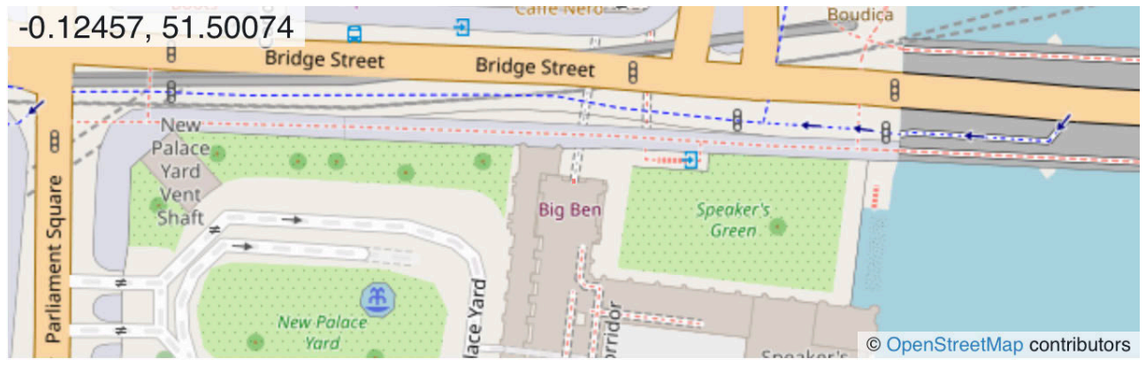


[Bojan Šavrič, David Burrows, Melita Kennedy:
The Spilhaus World Ocean Map in a Square, 2020]

Lat/lon Precision



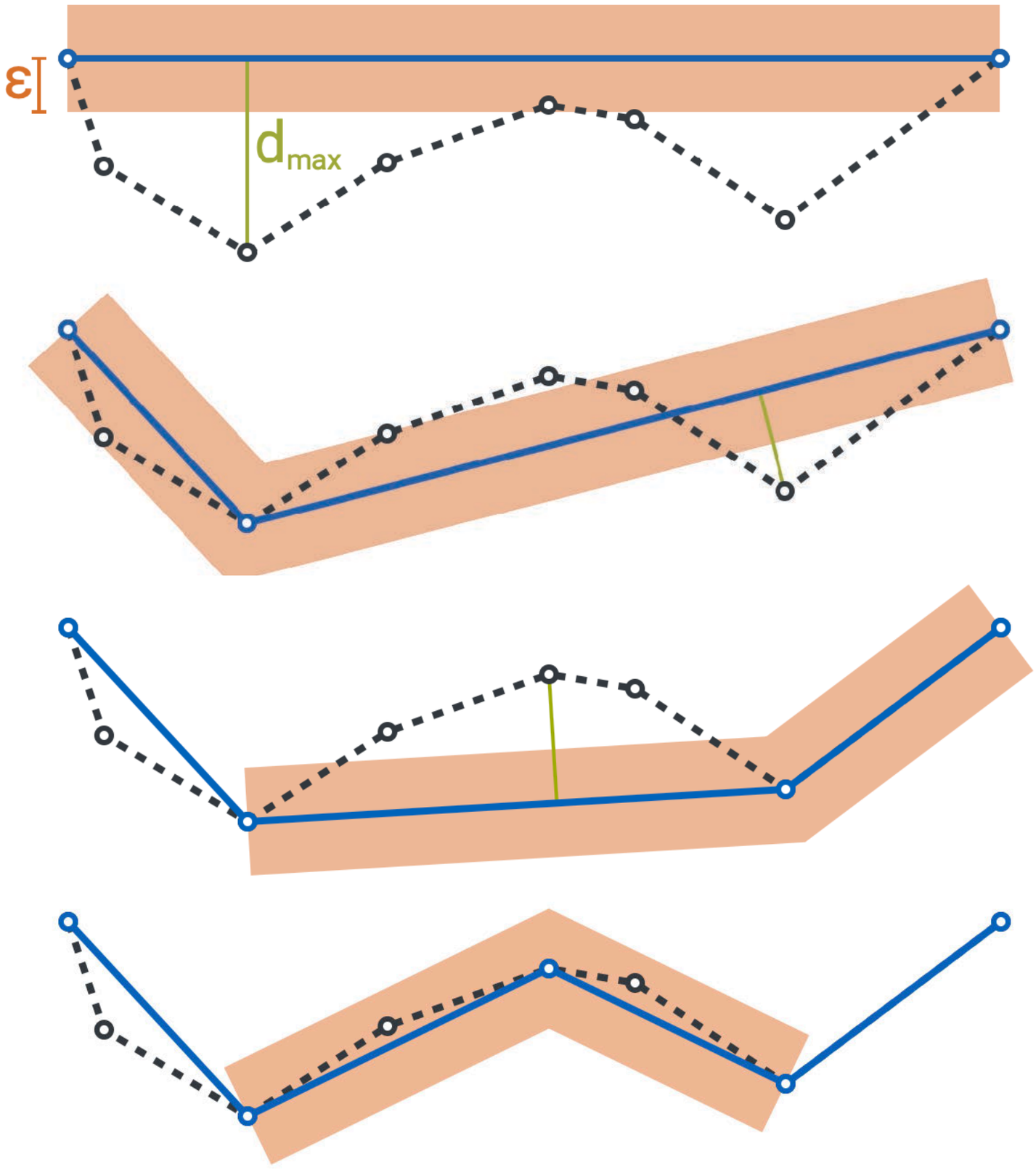




[Source: V. Agafonkin, 2021, https://observablehq.com/@mourner/latitude-and-longitude-precision]

Cartography / Polyline simplification

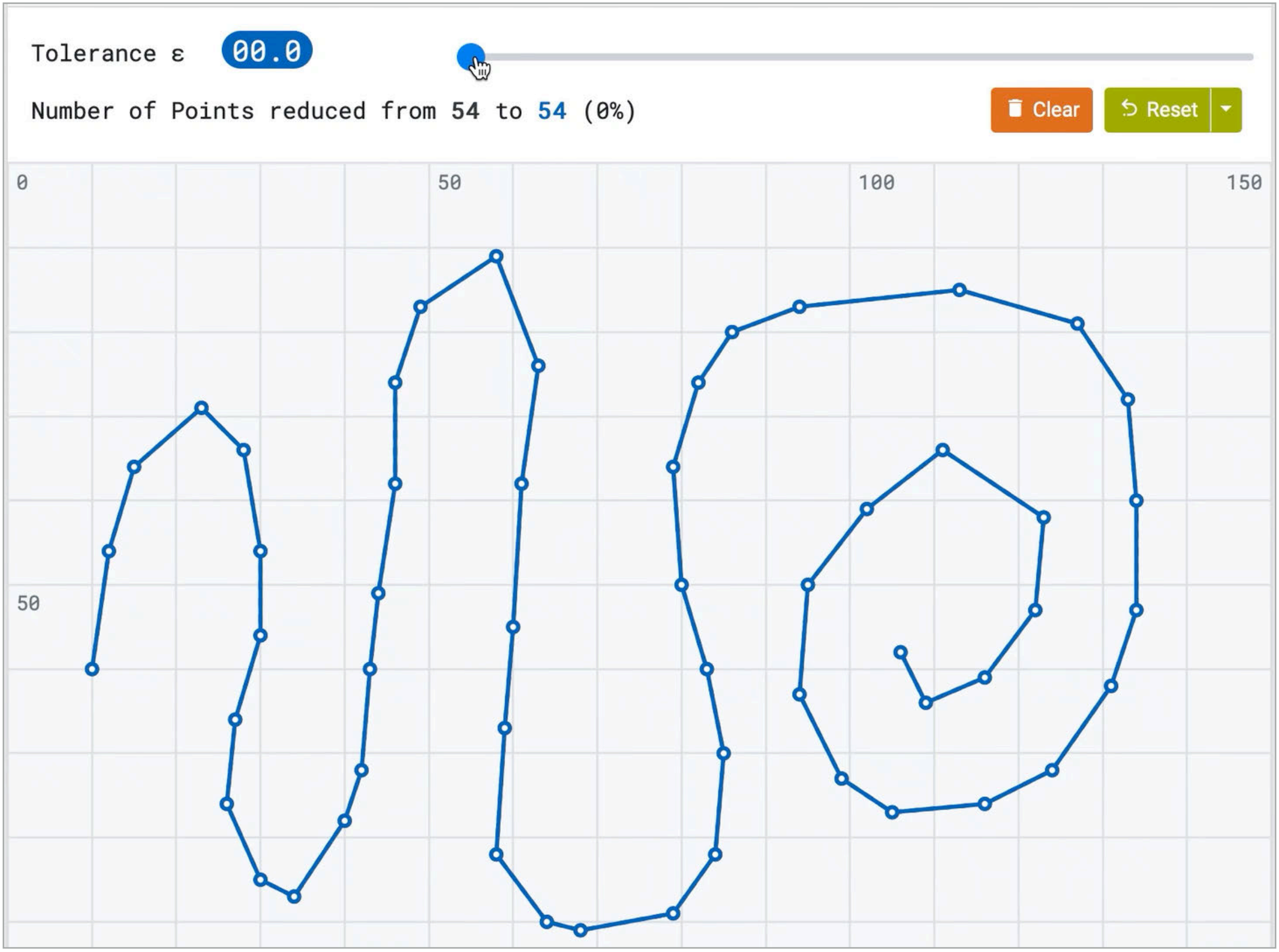
Douglas & Peucker's algorithm



[Source: Moritz Brunnengräber, Technical University of Munich, Cartography Playground, 2018]

Cartography / Polyline simplification

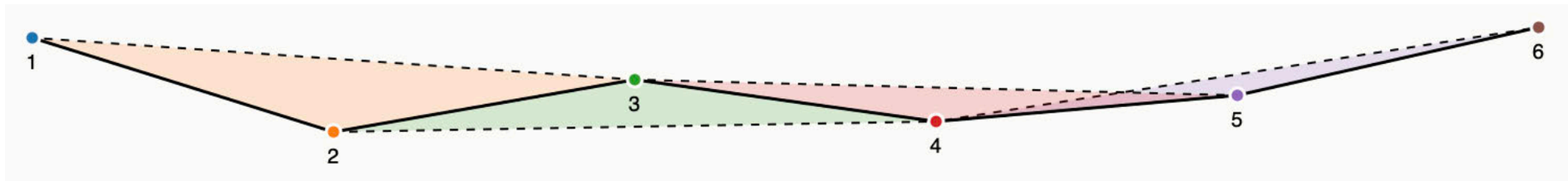
Douglas & Peucker's algorithm

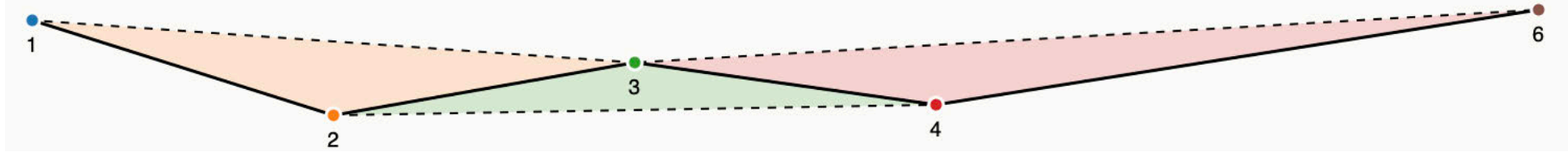


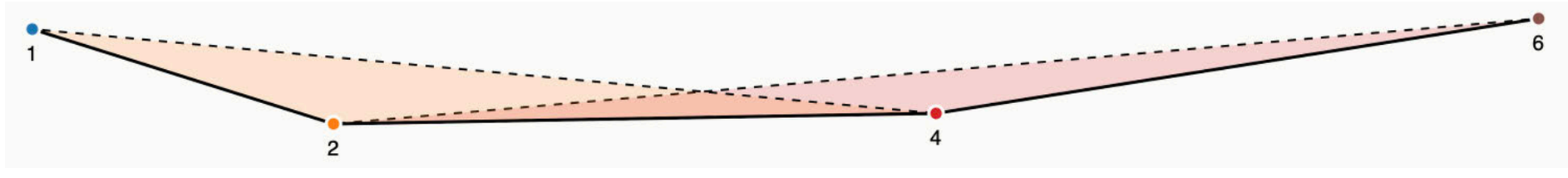
[Source: Moritz Brunnengräber, Technical University of Munich, Cartography Playground, 2018]

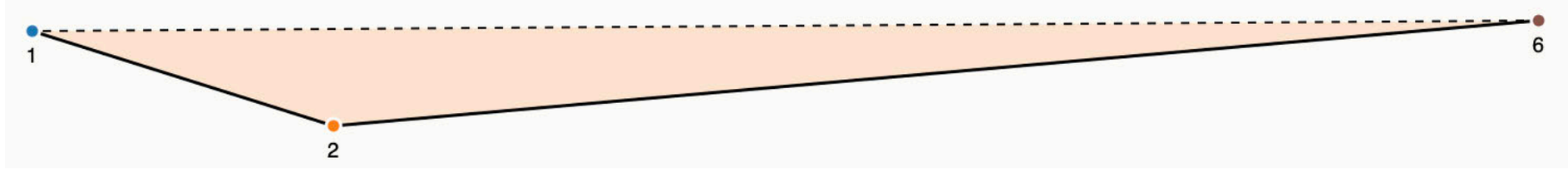
Cartography / Polyline simplification

Visvalingam's algorithm: remove least perceptible change





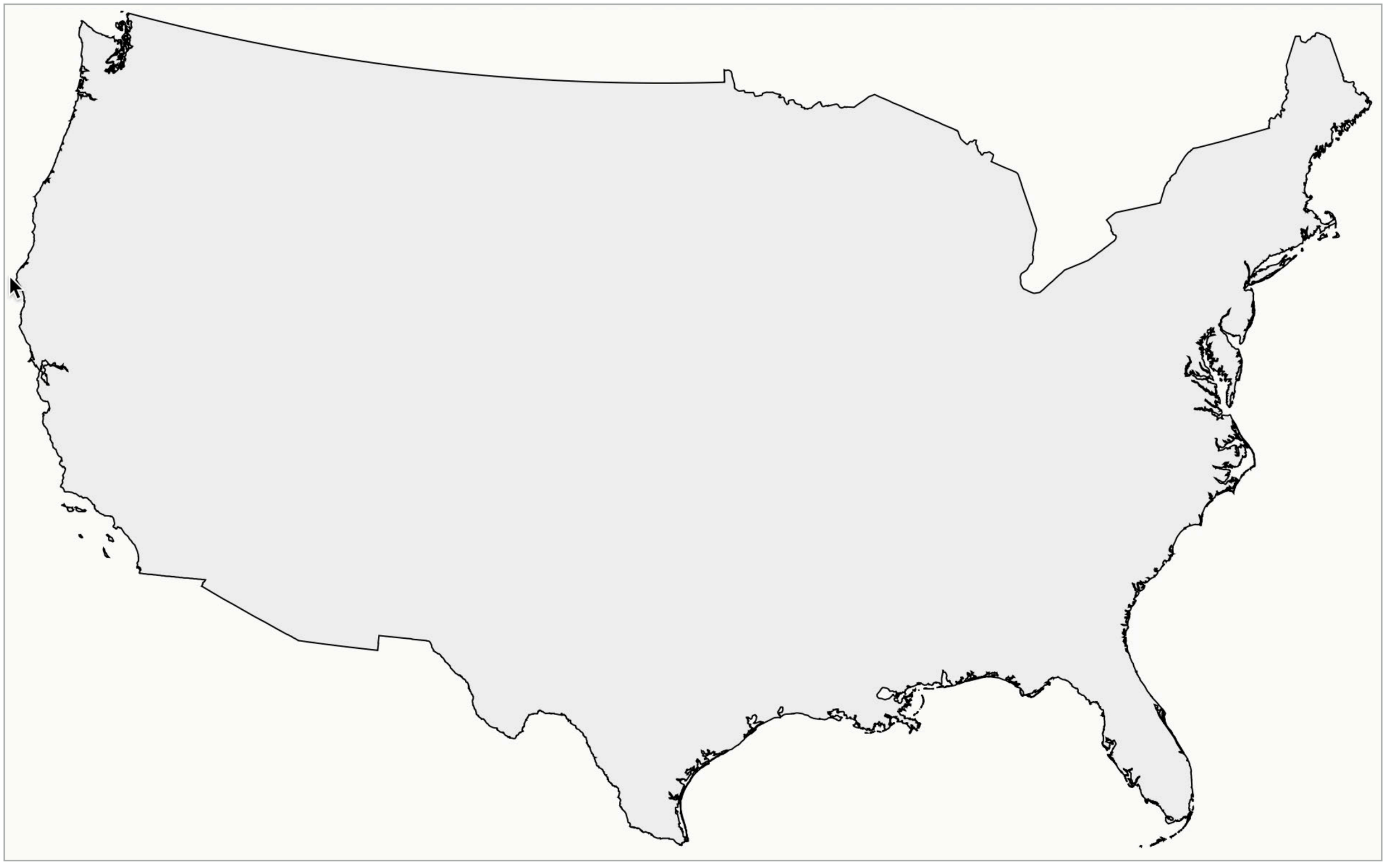




[Source: M. Bostock, line Simplification, 2012, https://bost.ocks.org/mike/simplify/]

Cartography / Polyline simplification

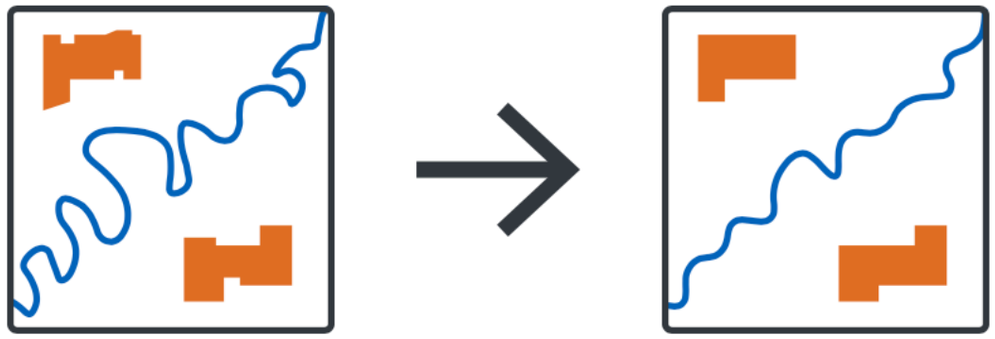
Visvalingam's algorithm: remove least perceptible change



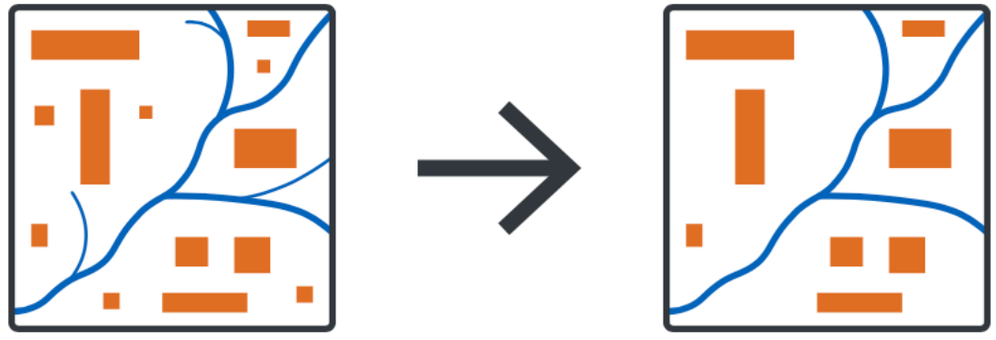
[Source: M. Bostock, line Simplification, 2012, https://bost.ocks.org/mike/simplify/]

Cartography / Generalization

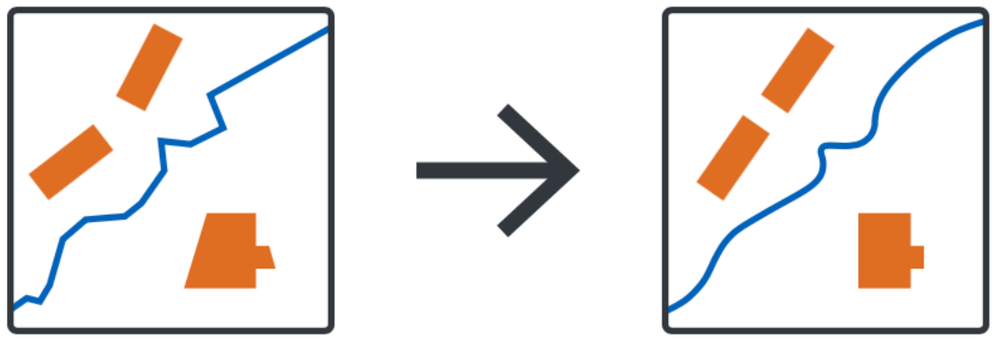
Simplification



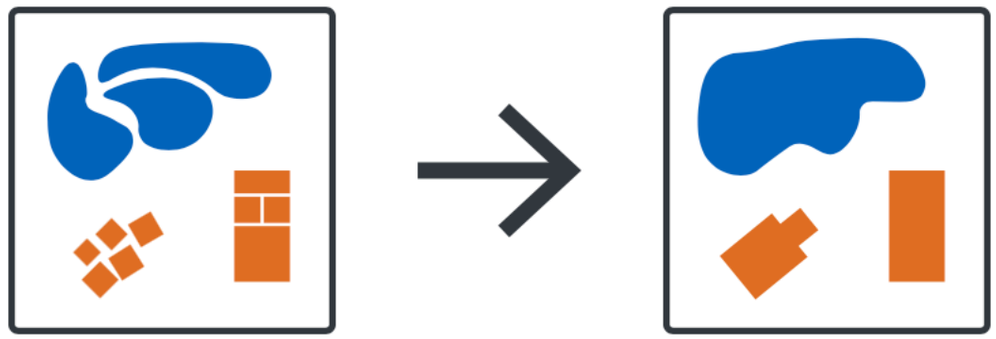
Selection



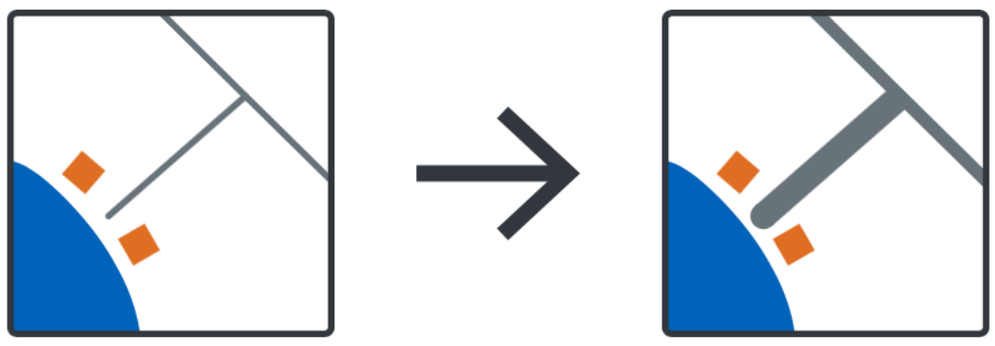
Smoothing



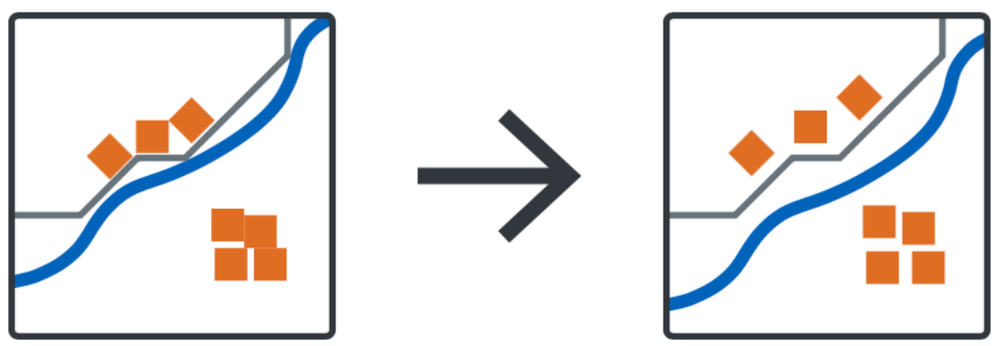
Aggregation



Exaggeration



Displacement



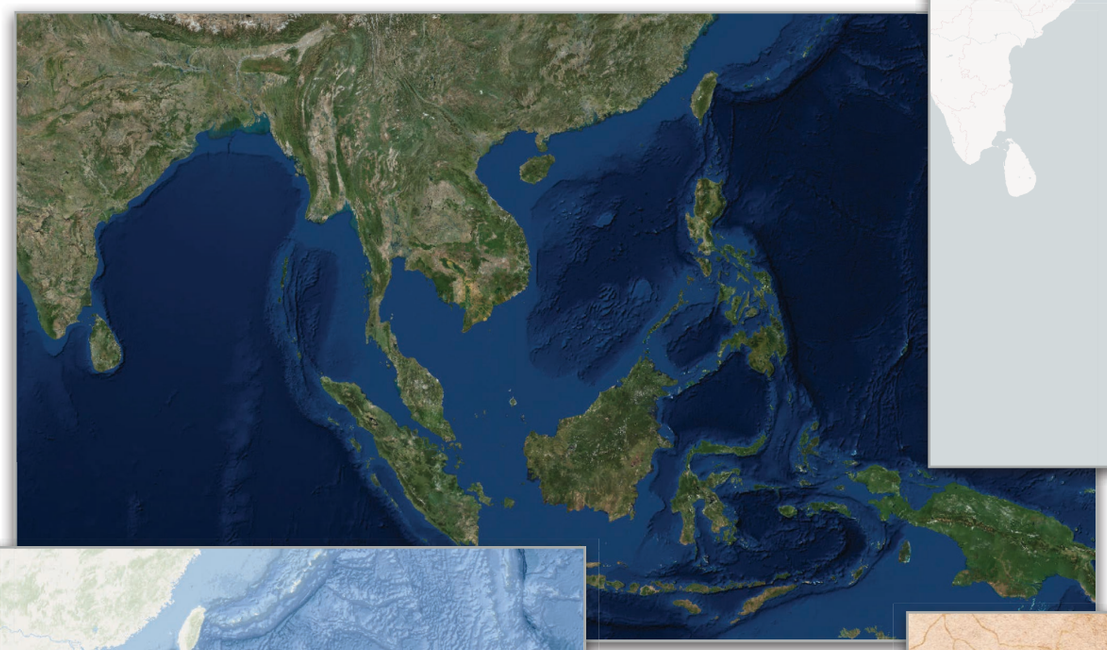
[Source: Moritz Brunnengräber, Technical University of Munich, Cartography Playground, 2018]

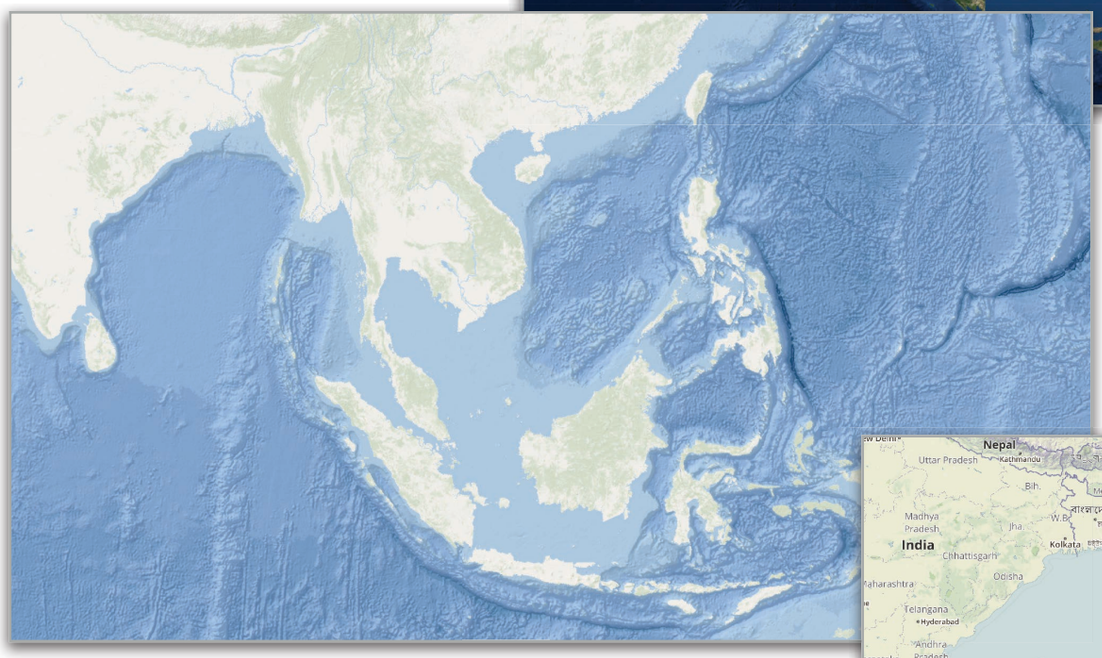
Terminology

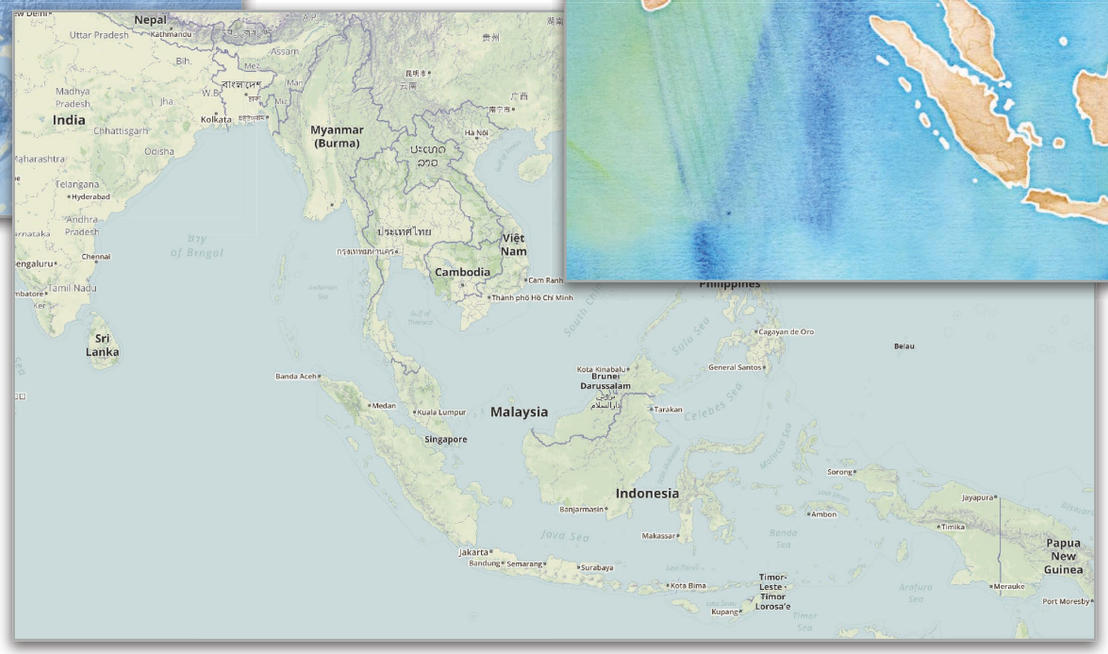
- Base map
  provides context, should not overload the visualization with unnecessary detail
- Layers: raster and vector data
- Thematic cartography

Base map

[Series compiled using:
https://www.nps.gov/lib/npmap.js/2.0.0/examples/baselayer-presets.html]







Base map

Strong impact on legibility:

[Bing Hybrid]

[Series compiled using: https://www.nps.gov/lib/npmap.js/2.0.0/examples/baselayer-presets.html]

Base map

Strong impact on legibility:

[CartoDB Positron (no labels)]

[Series compiled using: https://www.nps.gov/lib/npmap.js/2.0.0/examples/baselayer-presets.html]

Web-based mapping services

APIs:

- https://leafletjs.com
- https://openlayers.org
- https://developers.google.com/maps/documentation
- https://cesiumjs.org

Reference tile-sets directly:

```
https://%s/%d/%d/%d.png % (url, z, x, y)
```

```
https://a.tile.openstreetmap.org/2/2/1.png
```

```
https://a.tiles.mapbox.com/v4/mapbox.streets/5/11/17.png?access_token=???
```

Multi-scale maps

Quadtree: pyramid of (pre-rendered) tiles

(though now we see more & more vector tiles)

Web Mercator projection

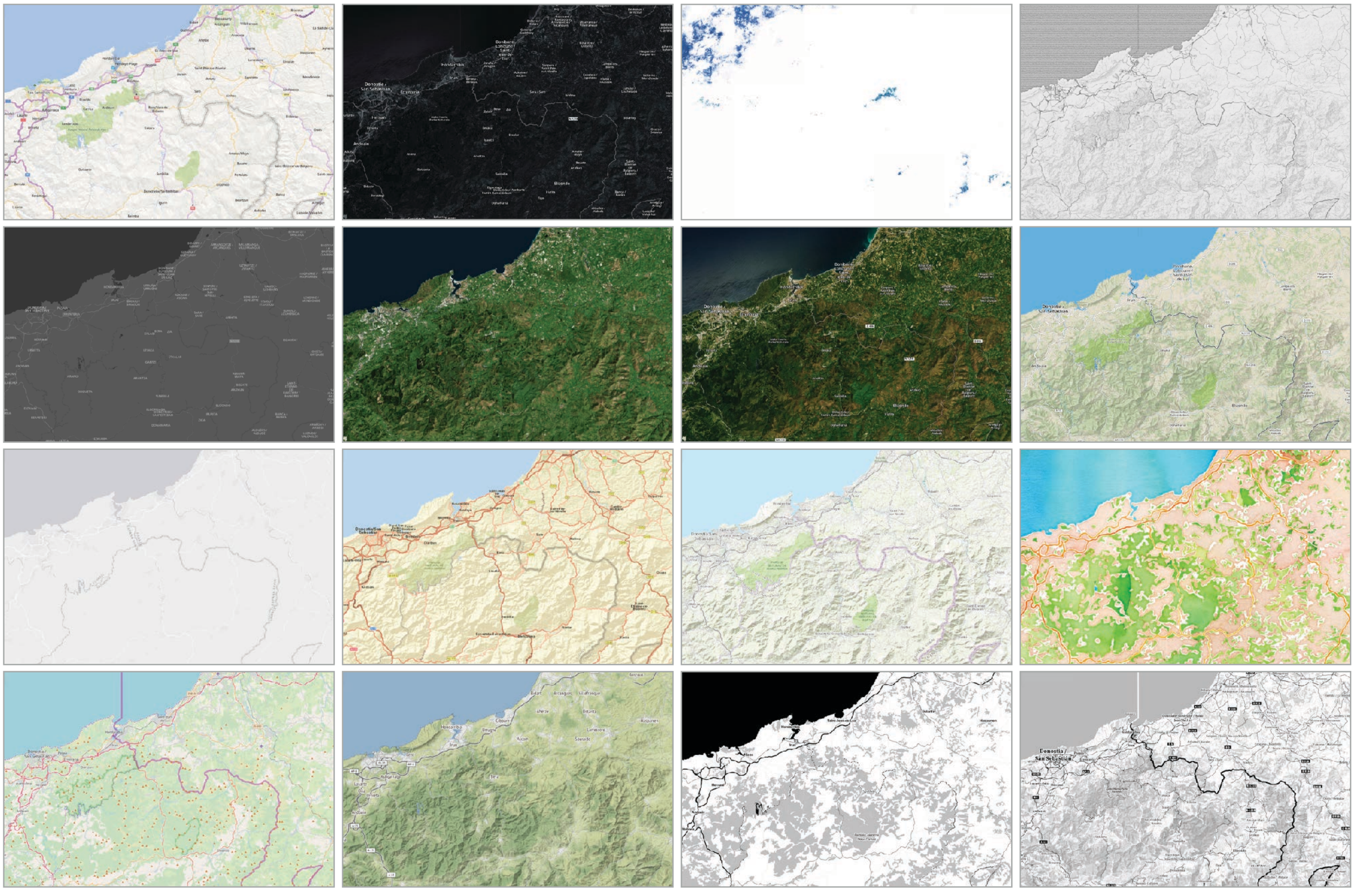
Zoom 0	Zoom 1	Zoom 2

$$tileSize \times 2^{z}$$

e.g., OSM, tileSize = 256, zoom = 19: $256 \times 2^{19} = 134{,}217{,}728$

Web-based mapping services

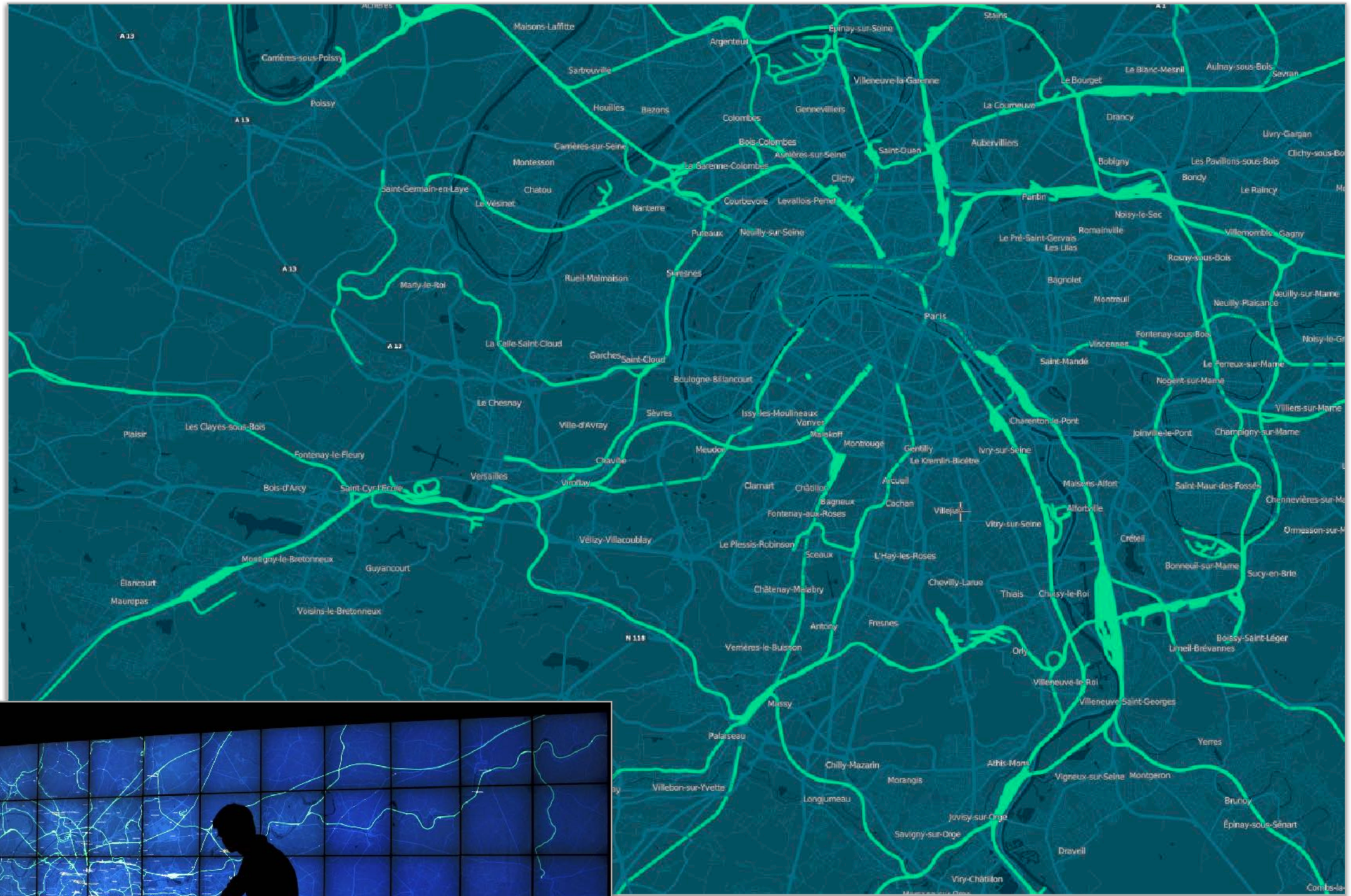
Many tile sets available, including both maps and ortho-imagery:



[Source: https://www.nps.gov/lib/npmap.js/2.0.0/examples/baselayer-presets.html]

Web-based mapping services

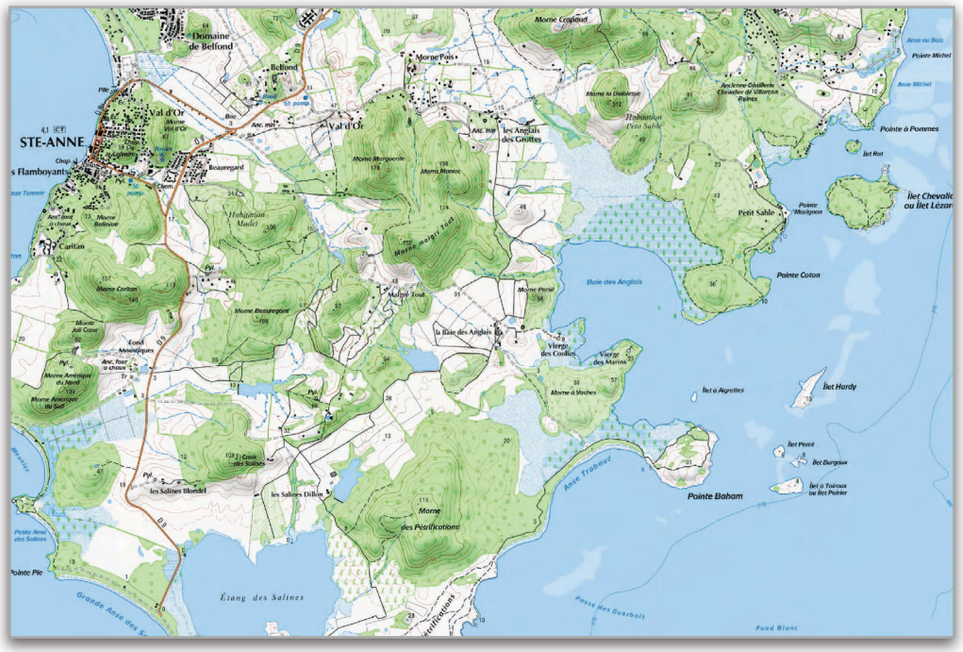
CartoCSS styling



Terminology

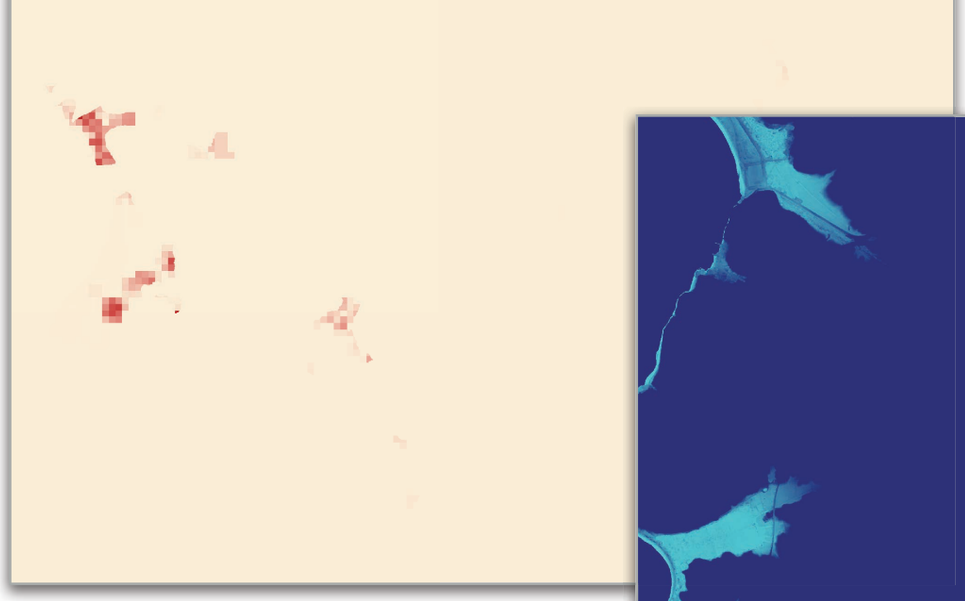
- Base map
  provides context, should not overload the visualization with unnecessary detail
- Layers: raster and vector data
- Thematic cartography

Raster & Vector Layers

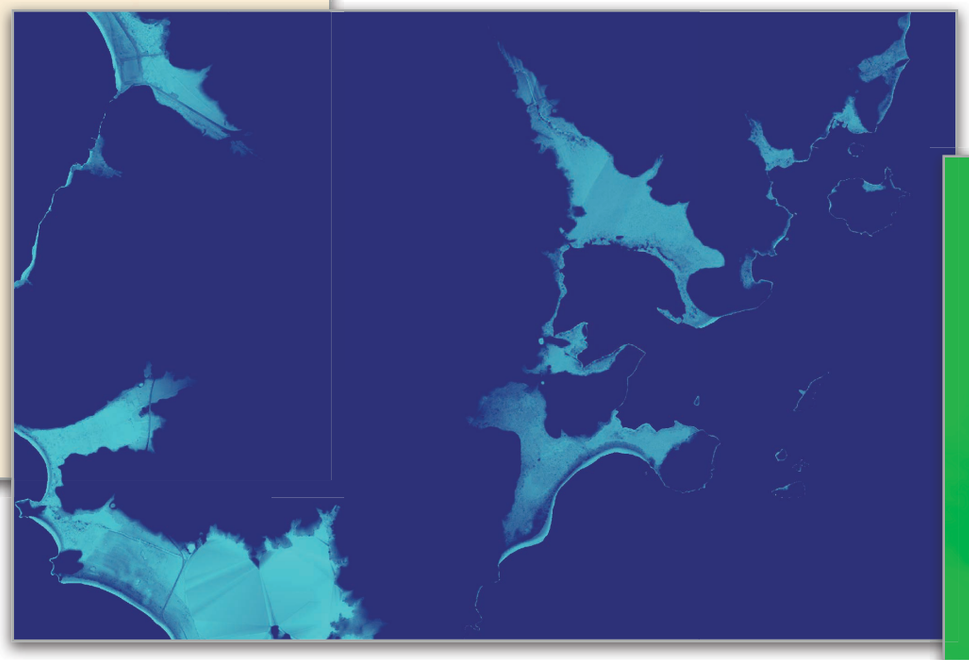


IGN SCAN25

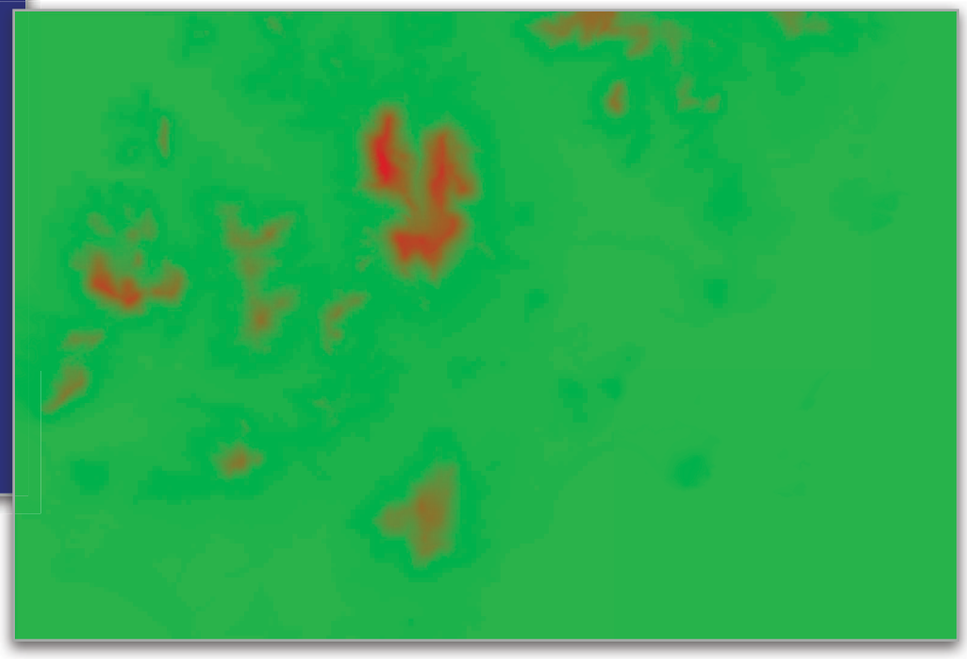
BD Ortho



INSEE population density

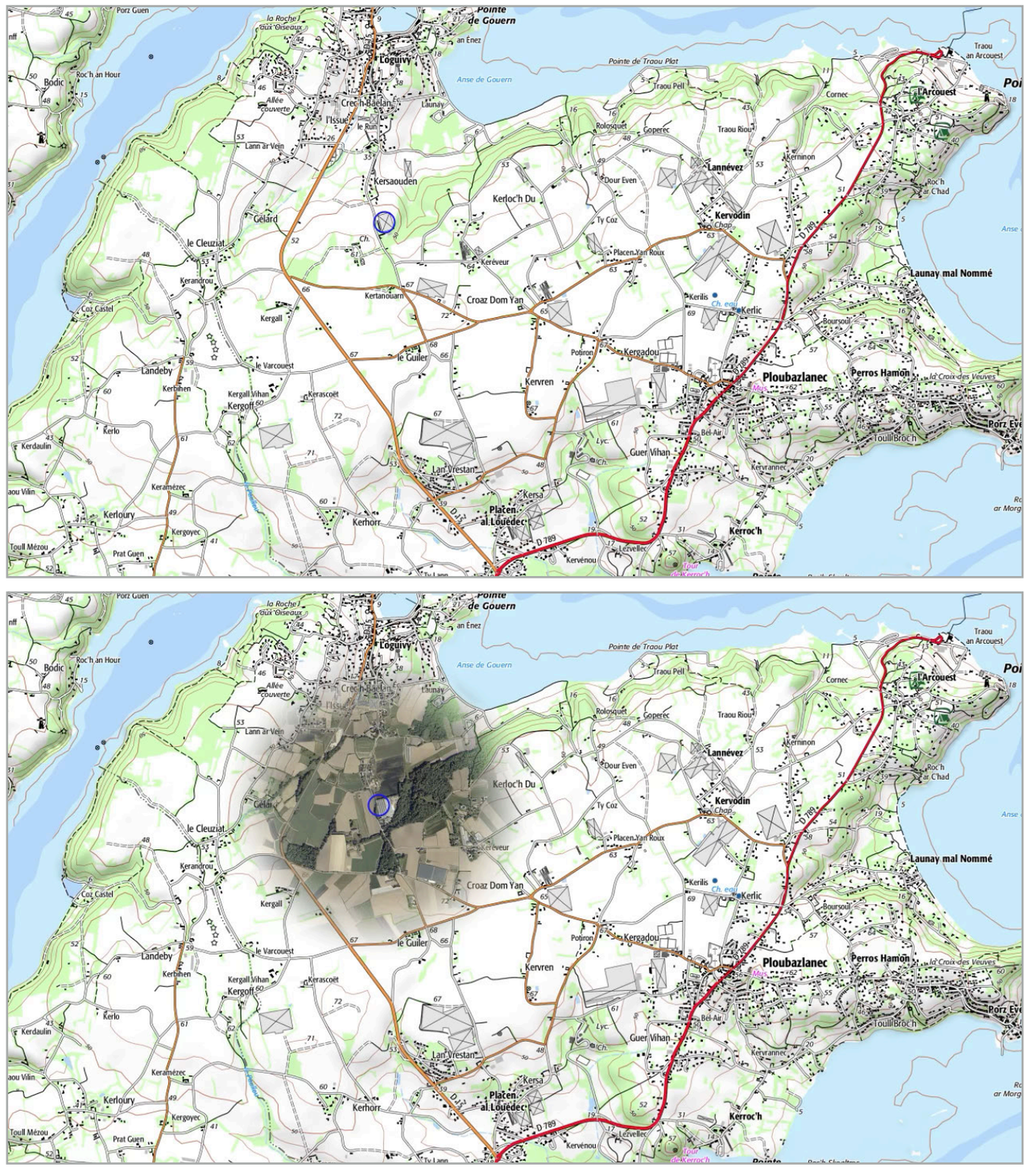


Water rise simulation



DEM

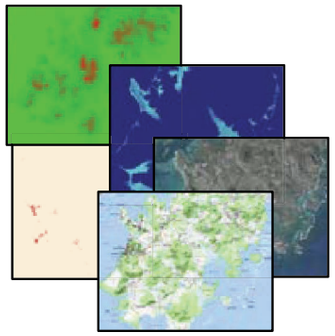
Layer composition strategies



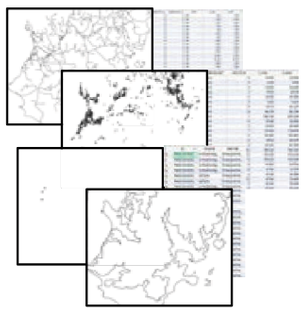
[M.-J. Lobo et al., An Evaluation of Interactive Map Comparison Techniques, CHI '15: Proceedings of the 33rd SIGCHI conference on Human Factors in computing systems, pages 3573-3582, 2015]

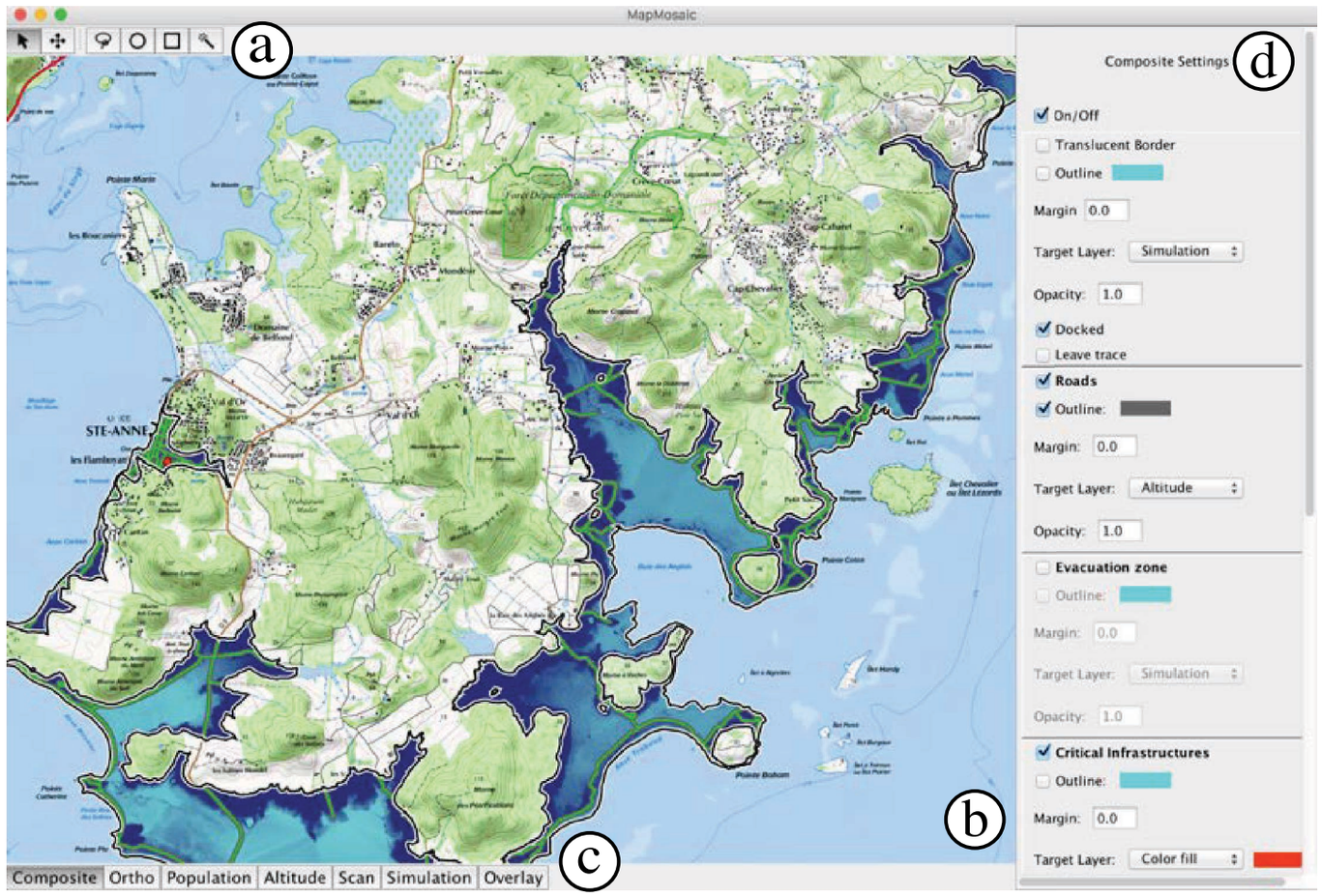
Dynamic Compositing

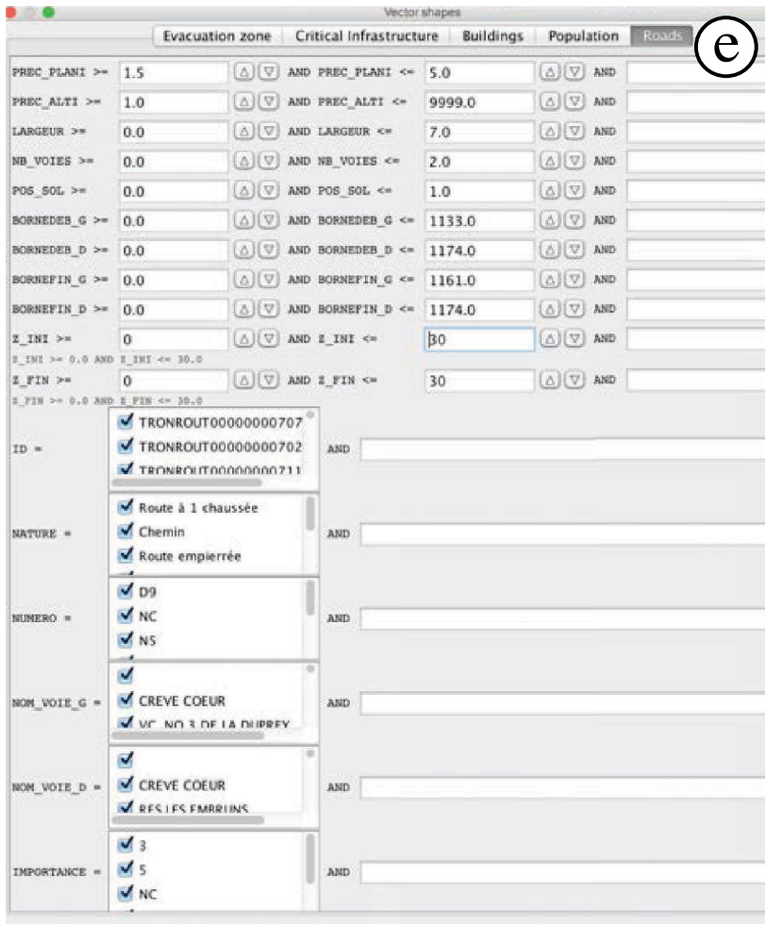
Raster data

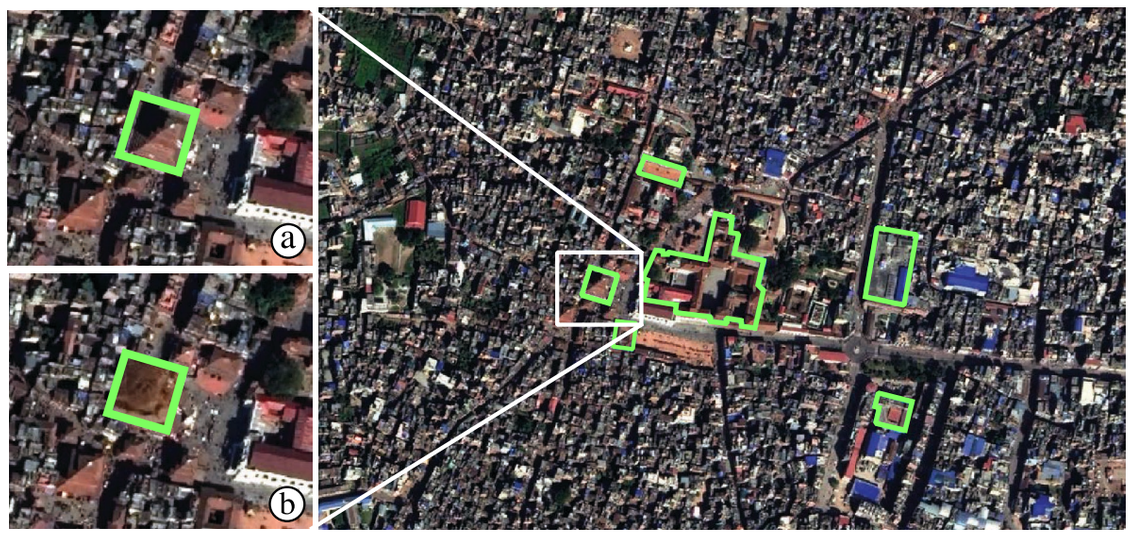


Vector data



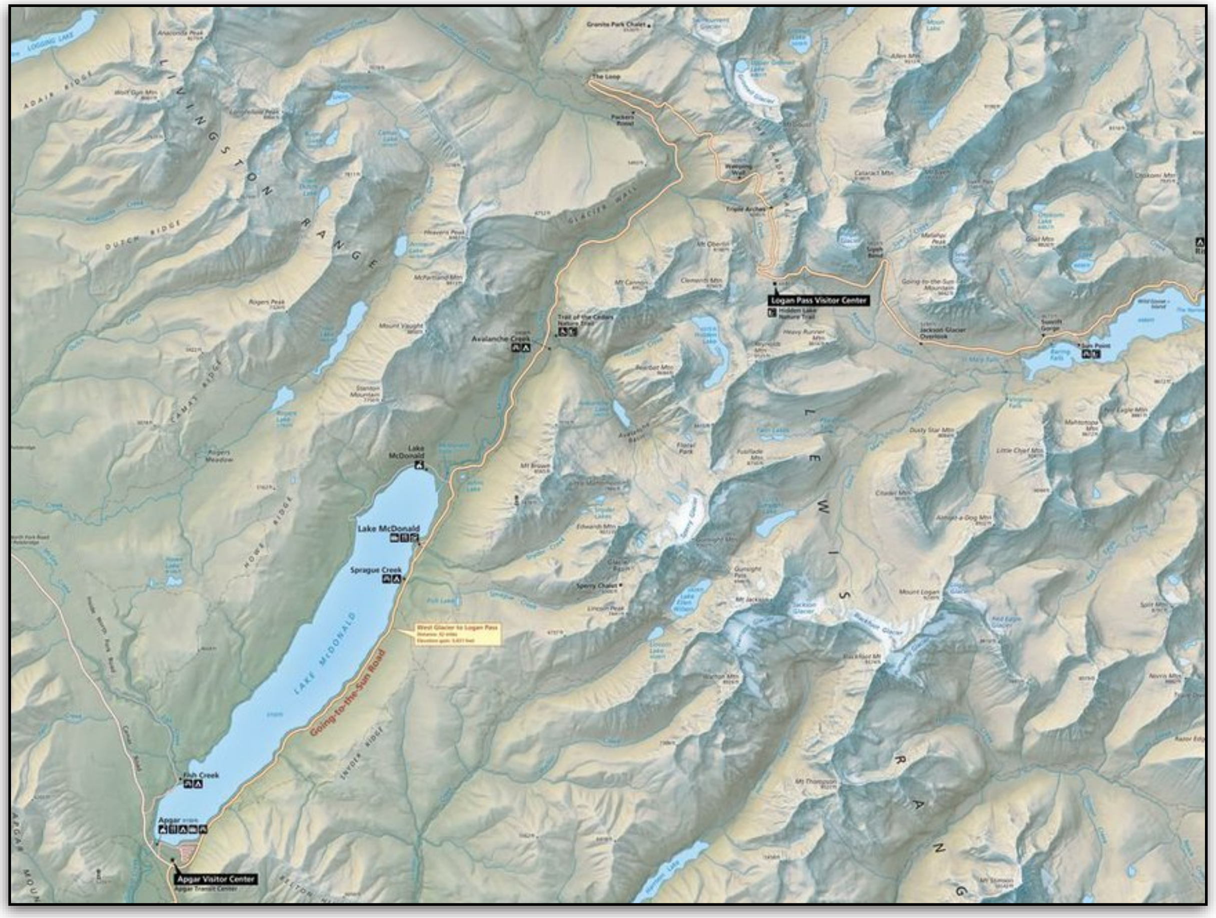




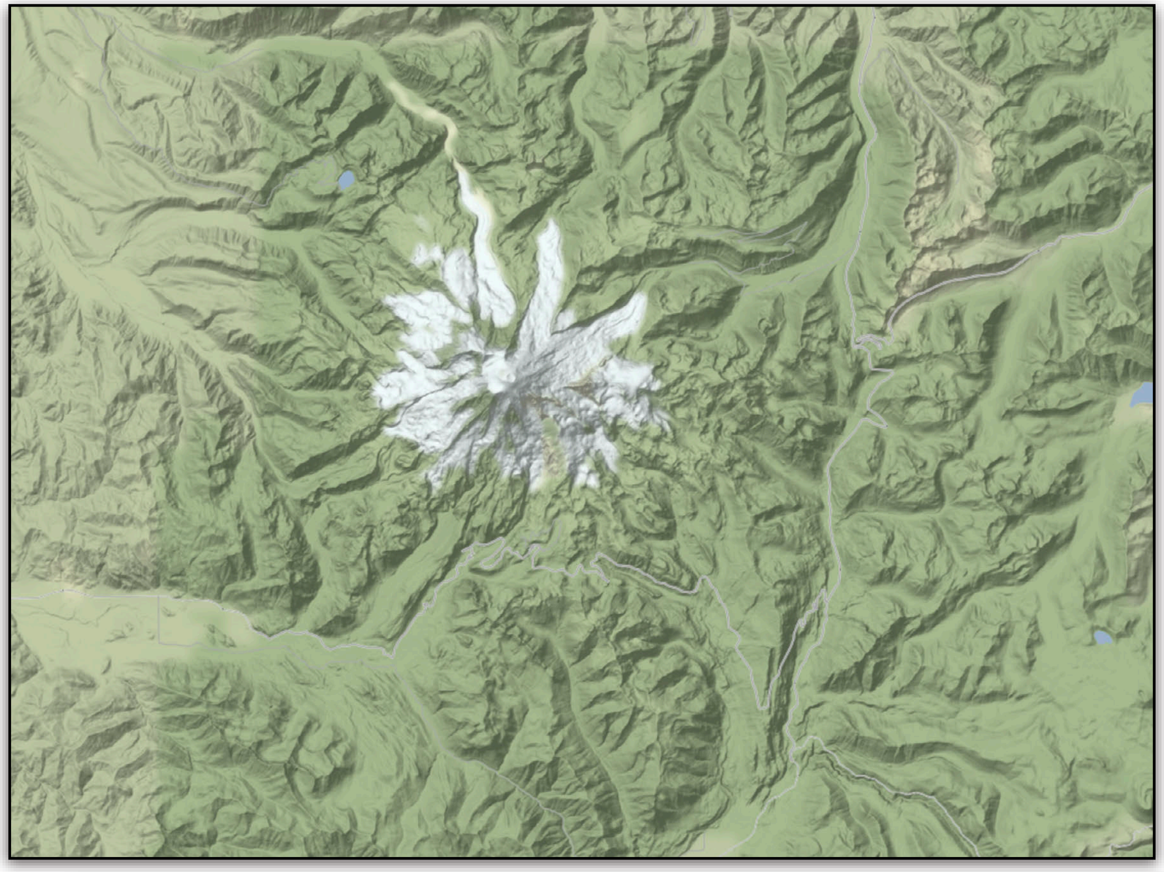


[M.-J. Lobo et al, MapMosaic: Dynamic Layer Compositing for Interactive Geovisualization, International Journal of Geographical Information Science (IJGIS), Volume 31, Number 9, pages 1818-1845, May 2017.]

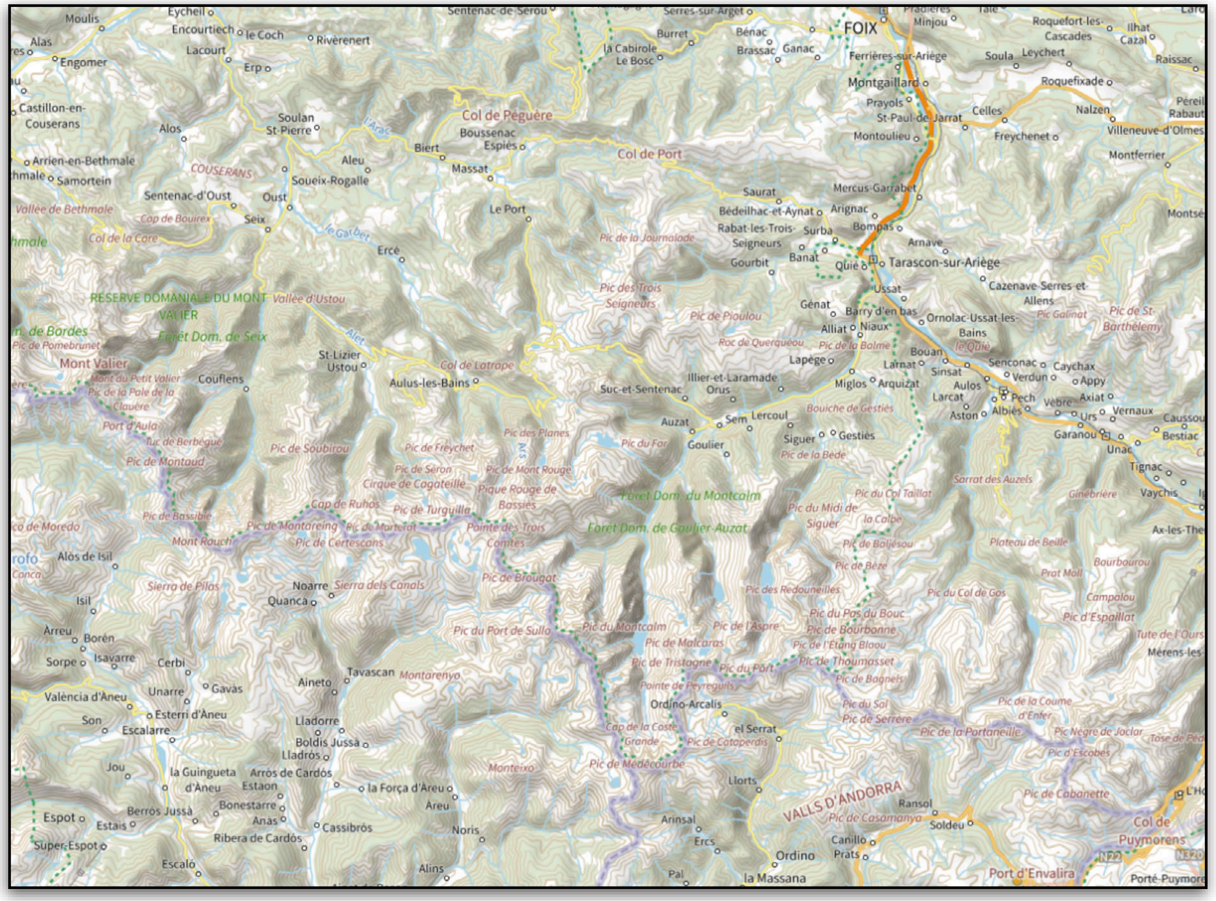
Relief shading



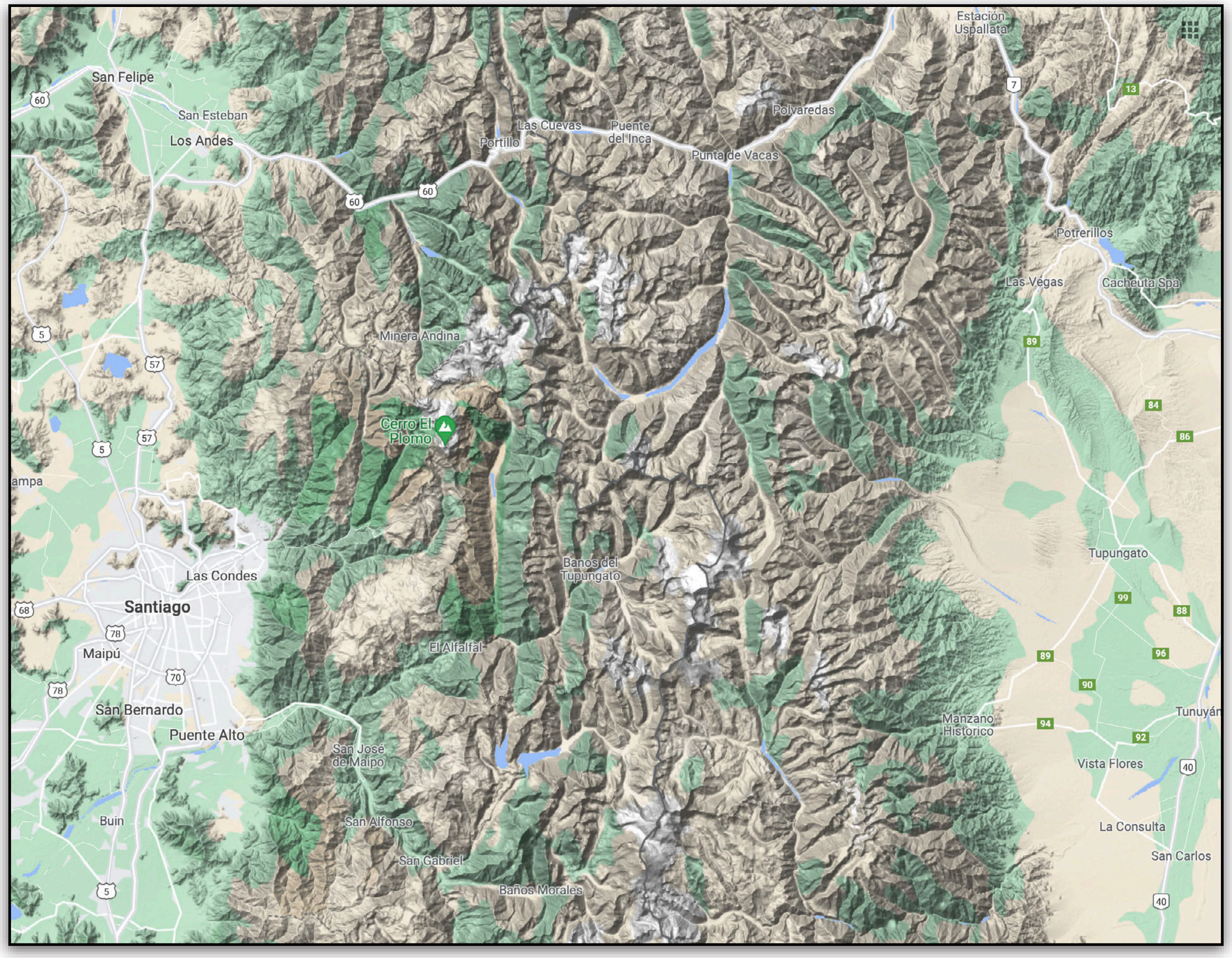
[Map source: Tom Patterson, US National Parks]



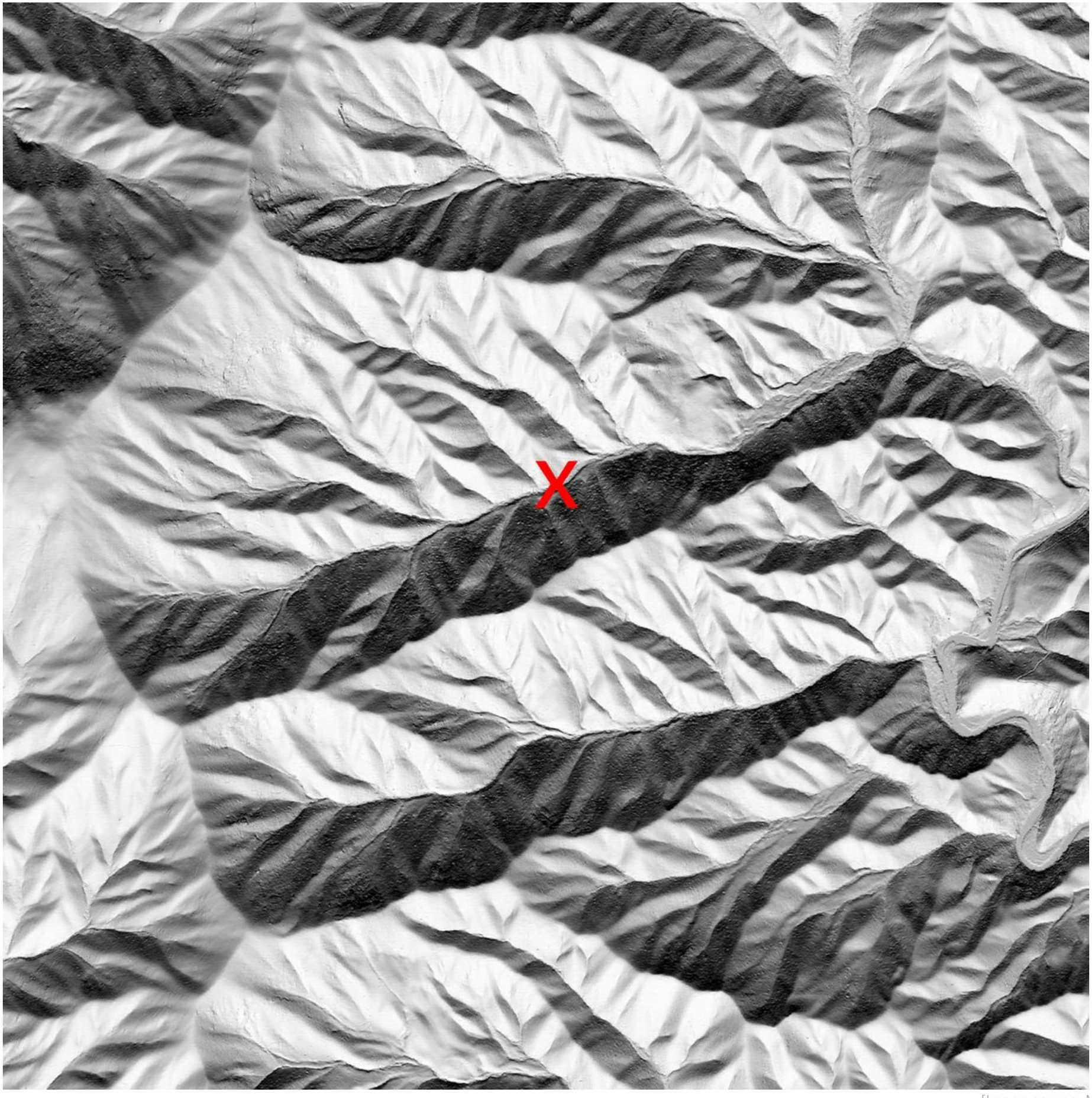
[Map source: Stamen Terrain]



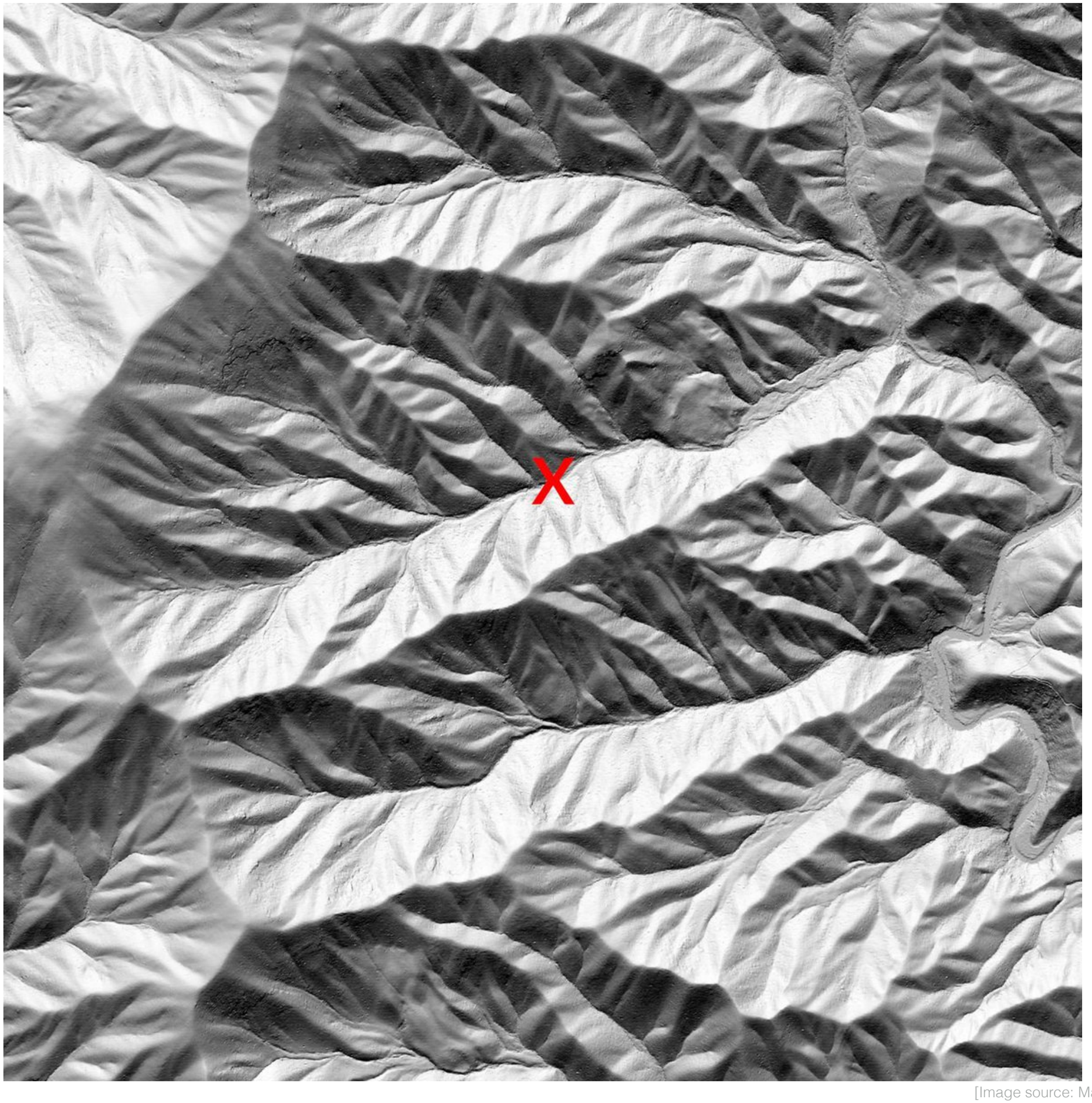
[Map source: IGN SCAN25]



[Map source: Google Maps]

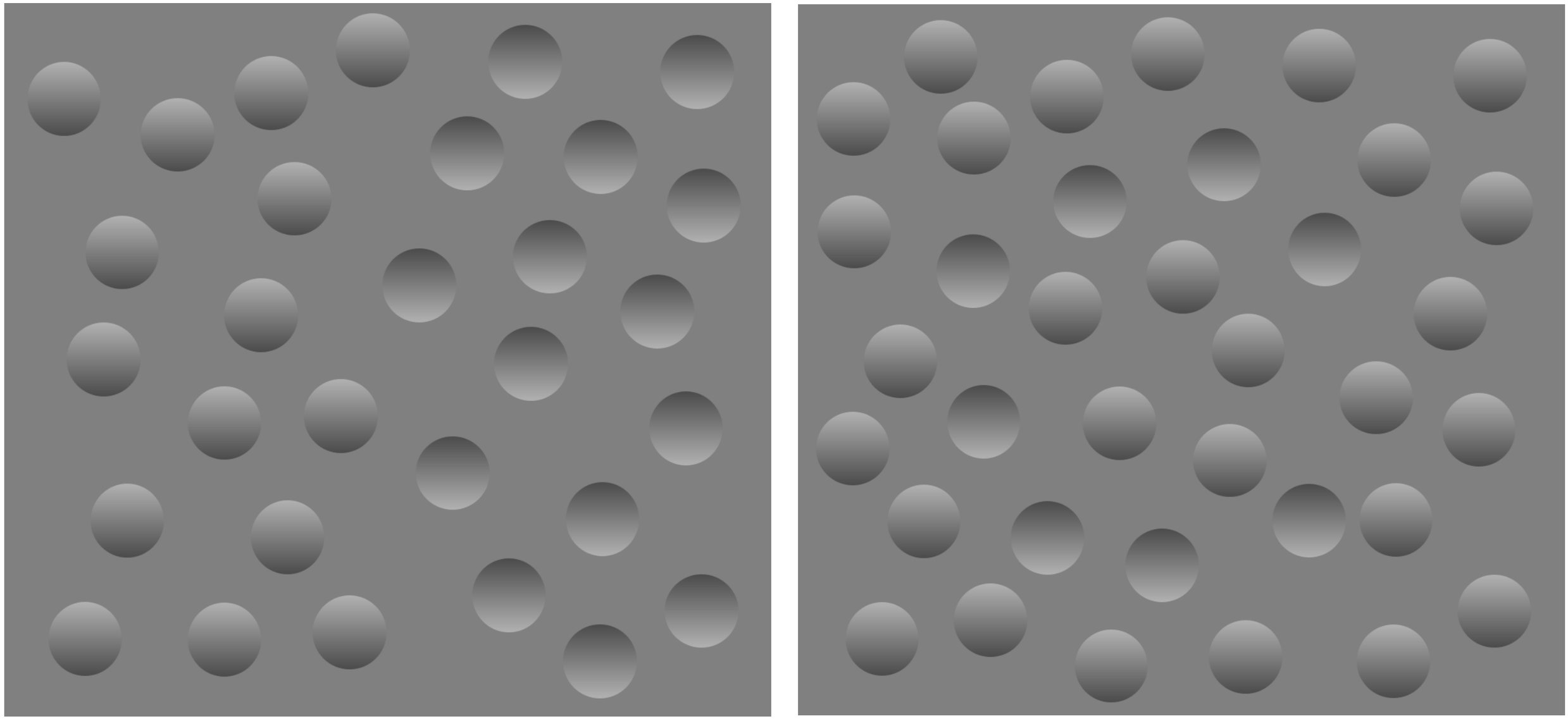


[Image source: Matt Parrilla, Ramble Blog, 2021]



[Image source: Matt Parrilla, Ramble Blog, 2021]

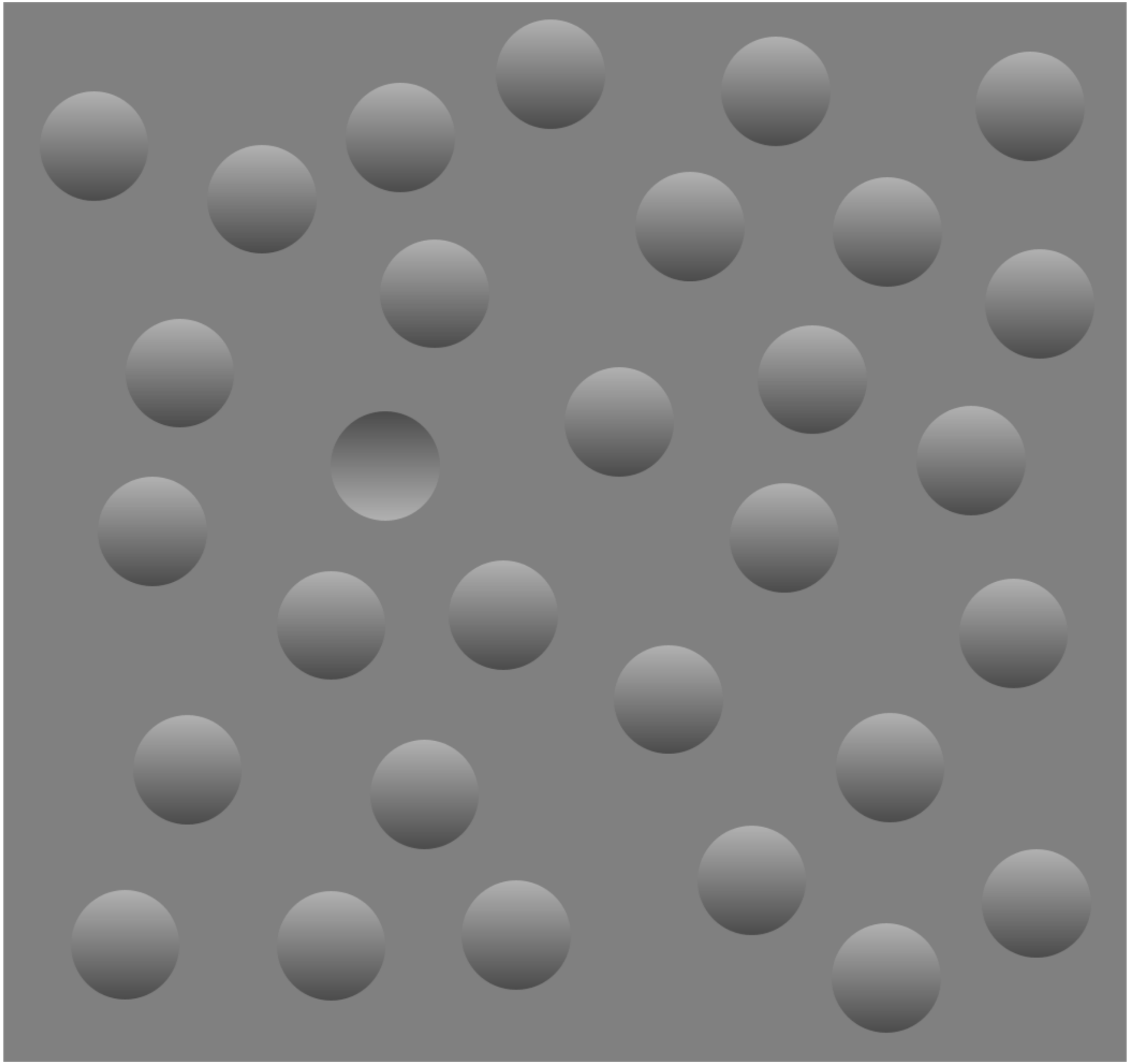
Shading can be a pretty salient visual cue



Associativity

[Image source: Steve Haroz, https://twitter.com/sharoz/status/1196782561948774400]

and Selectivity
as well

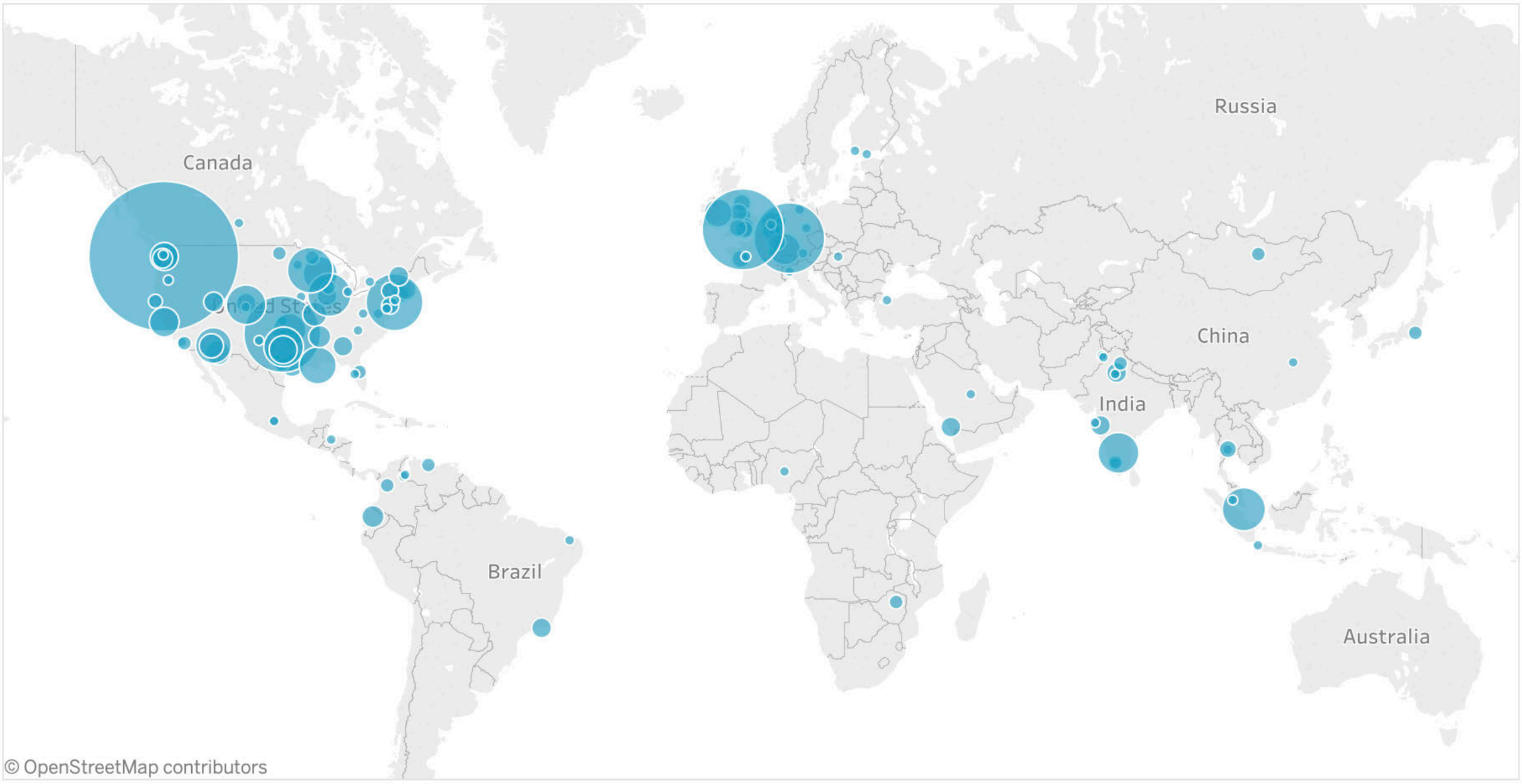


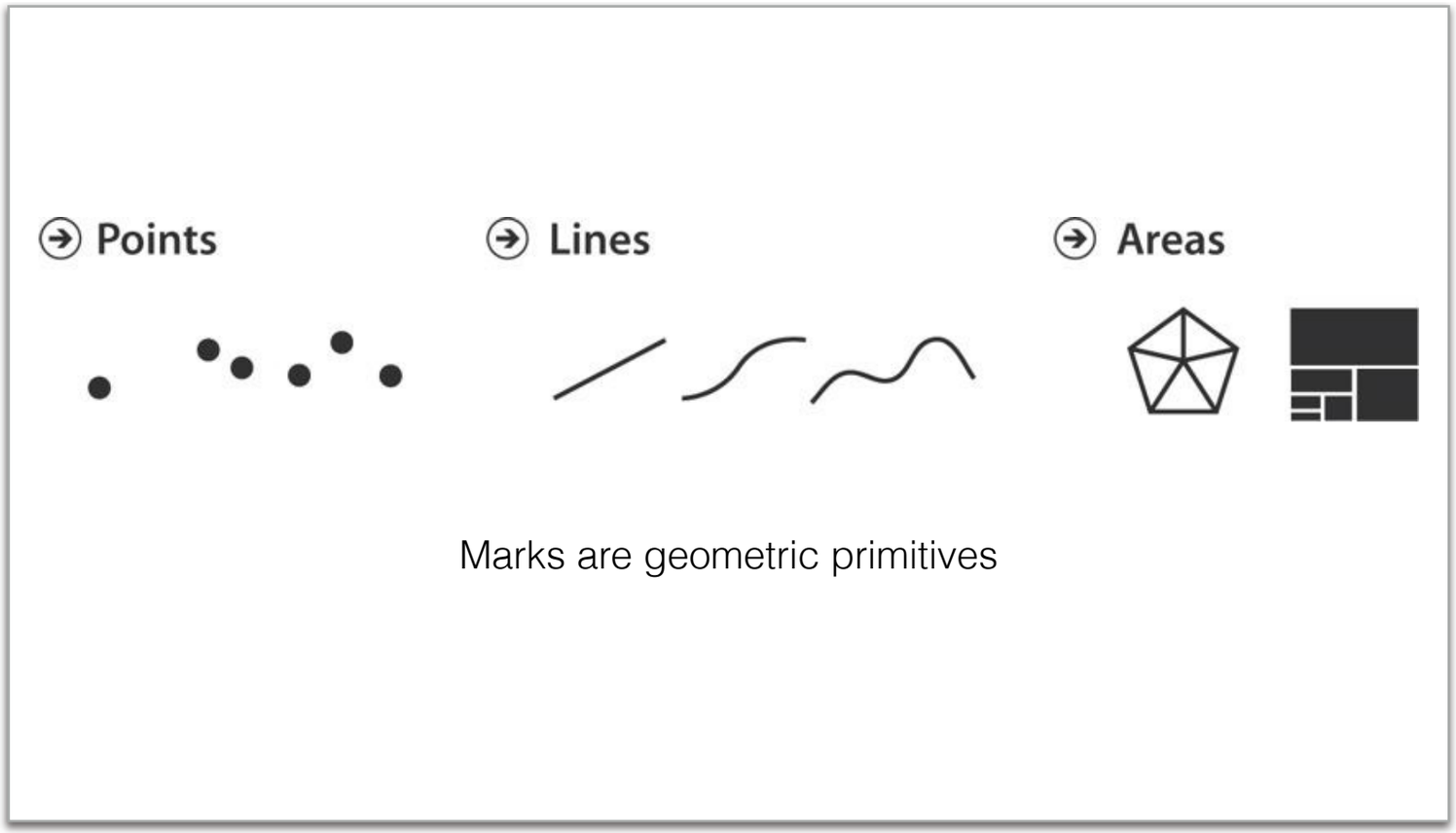
[Image source: Steve Haroz, https://twitter.com/sharoz/status/1196782561948774400]

Terminology

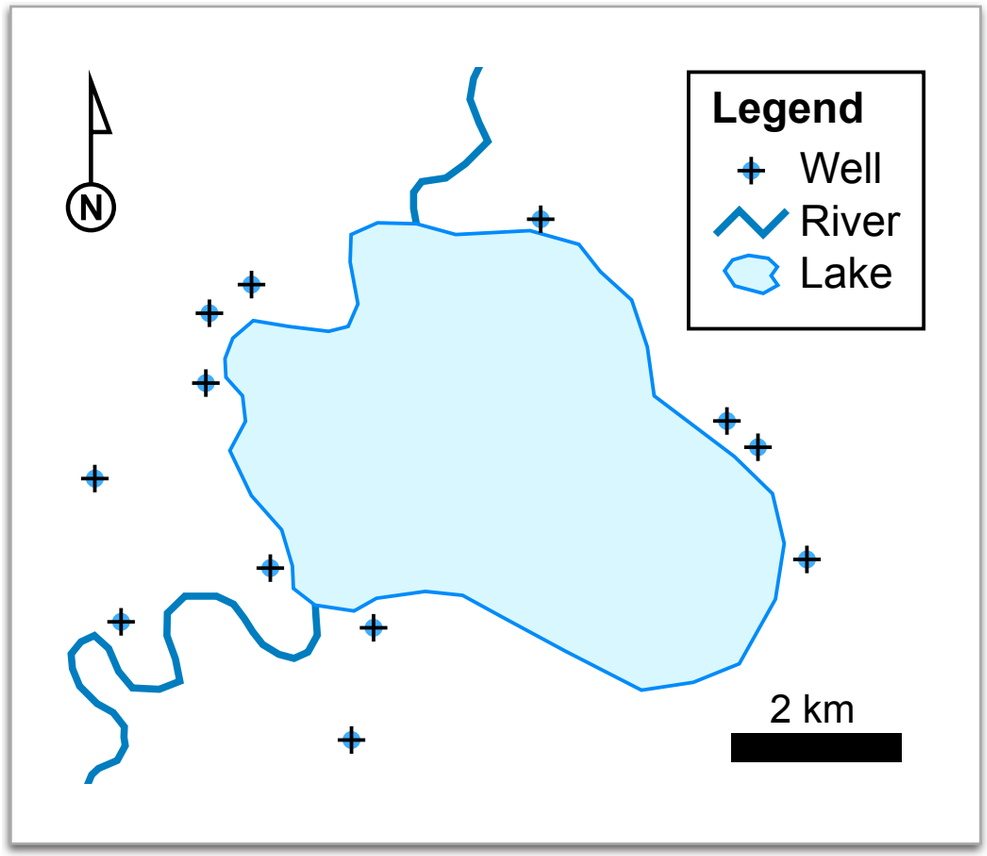
- Base map
  provides context, should not overload the visualization with unnecessary detail
- Layers: raster and vector data
- Thematic cartography

Thematic cartography





[Source: Visualization Analysis & Design, Munzner 2014]



[Source: https://commons.wikimedia.org/wiki/File:Simple_vector_map.svg] CC SOME RIGHTS RESERVED

Encoding channels

Magnitude Channels: Ordered Attributes

Position on common scale

Position on unaligned scale

Length (1D size)

Tilt/angle

Area (2D size)

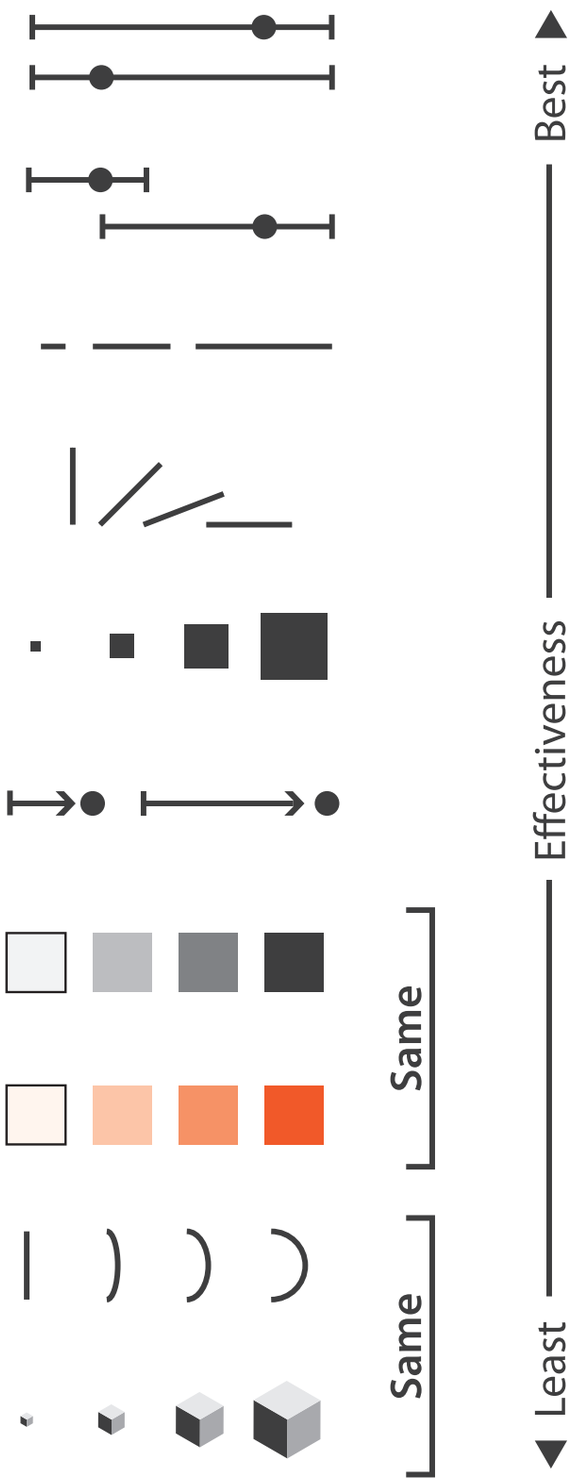
Depth (3D position)

Color luminance

Color saturation

Curvature

Volume (3D size)



Identity Channels: Categorical Attributes

Spatial region

Color hue

Motion

Shape

[Image source: Visualization Analysis and Design. Tamara Munzner, with illustrations by Eamonn Maguire. A K Peters Visualization Series, CRC Press, 2014]

Available encoding channels for spatial data: points

Magnitude Channels: Ordered Attributes

Position on common scale

Position on unaligned scale

Length (1D size)

Tilt/angle

Area (2D size)

Depth (3D position)

Color luminance

Color saturation

Curvature

Volume (3D size)

Same

Same

Effectiveness

Best

Least

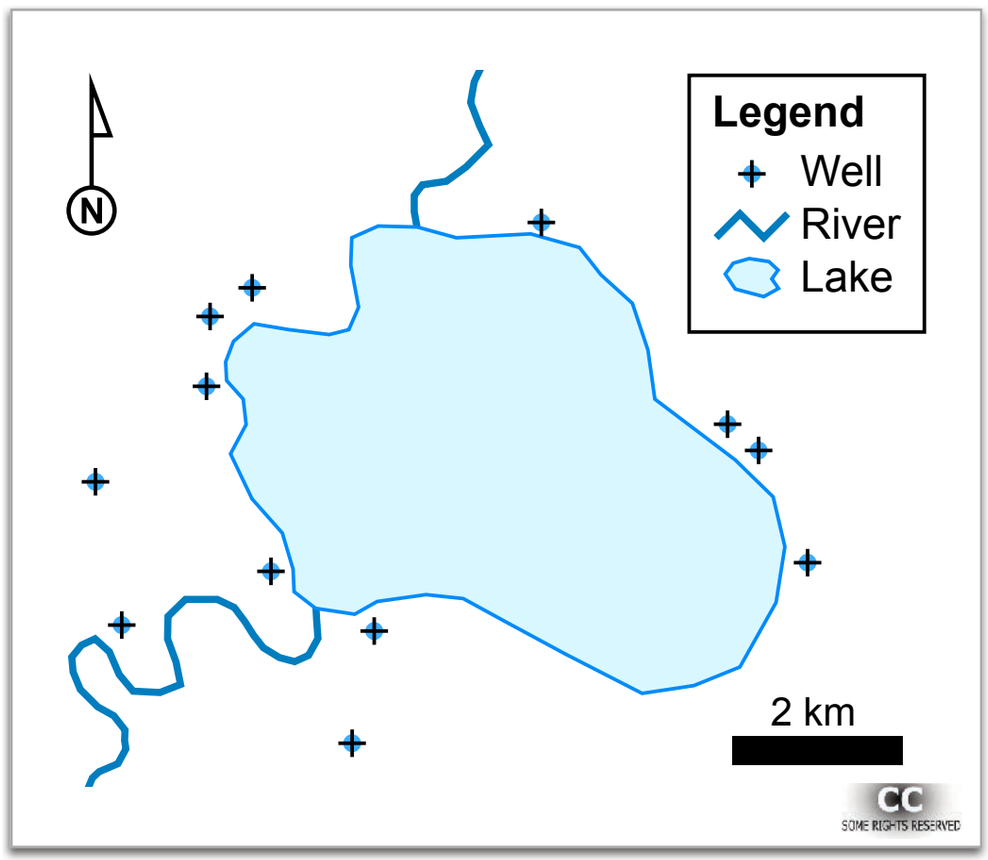
Identity Channels: Categorical Attributes

Spatial region

Color hue

Motion

Shape



[Image source: Visualization Analysis and Design. Tamara Munzner, with illustrations by Eamonn Maguire. A K Peters Visualization Series, CRC Press, 2014]

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Available encoding channels for spatial data: lines

Magnitude Channels: Ordered Attributes

Position on common scale

Position on unaligned scale

Length (1D size)

Tilt/angle

~~Area (2D size)~~

stroke-width

Depth (3D position)

Color luminance

Color saturation

Curvature

Volume (3D size)

Best

Effectiveness

Least

Same

Same

Identity Channels: Categorical Attributes

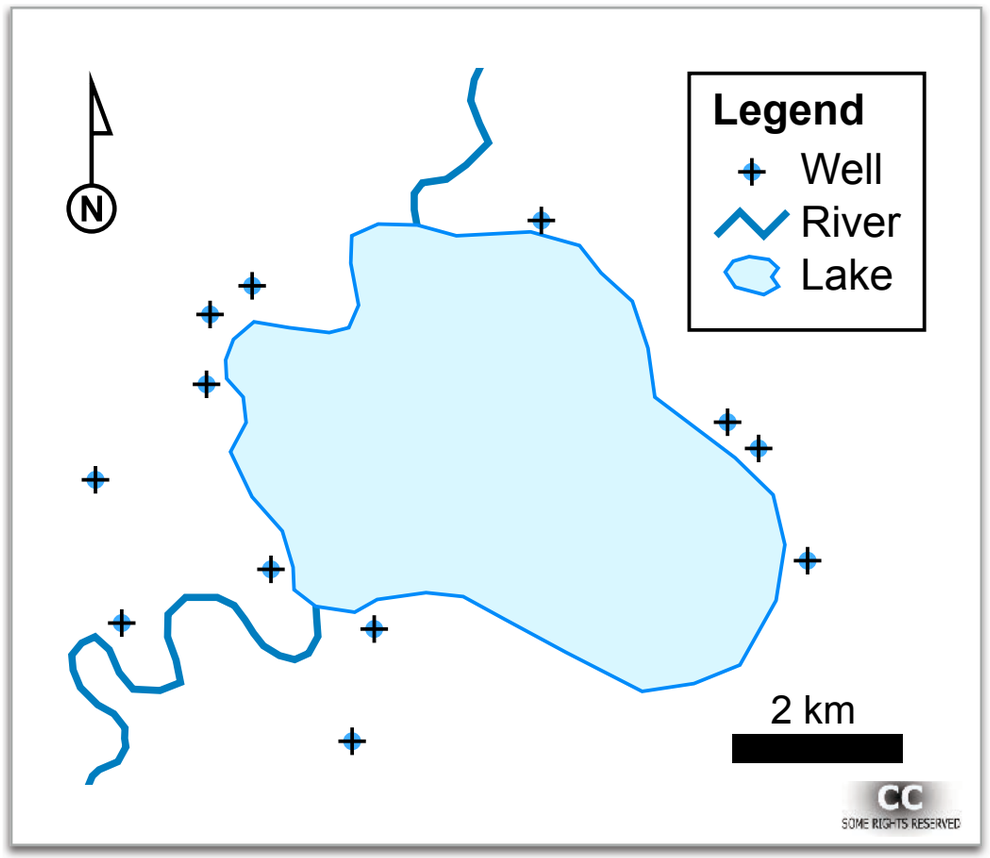
Spatial region

Color hue

Motion

~~Shape~~

stroke-pattern / symbol



[Image source: Visualization Analysis and Design. Tamara Munzner, with illustrations by Eamonn Maguire. A K Peters Visualization Series, CRC Press, 2014]

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Available encoding channels for spatial data: areas

Magnitude Channels: Ordered Attributes

Position on common scale

Position on unaligned scale

Length (1D size)

Tilt/angle

Area (2D size)

stroke-width

Depth (3D position)

Color luminance

Color saturation

Curvature

Volume (3D size)

Same

Same

Best

Effectiveness

Least

Identity Channels: Categorical Attributes

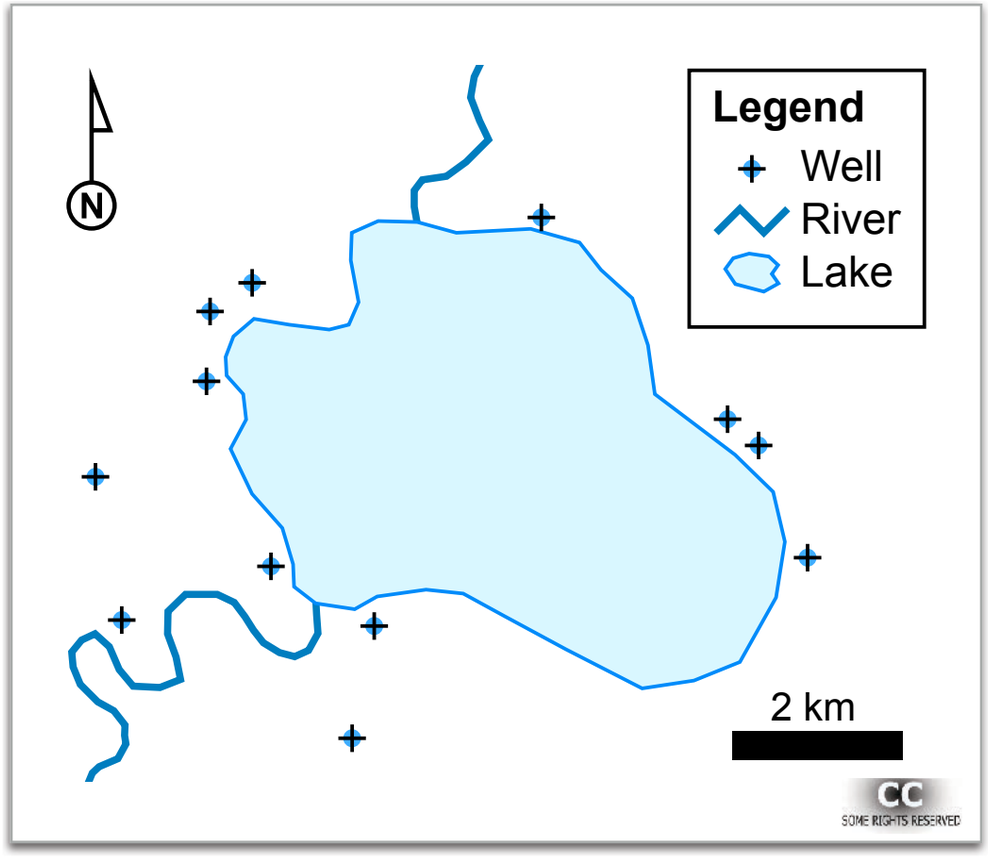
Spatial region

Color hue

Motion

Shape

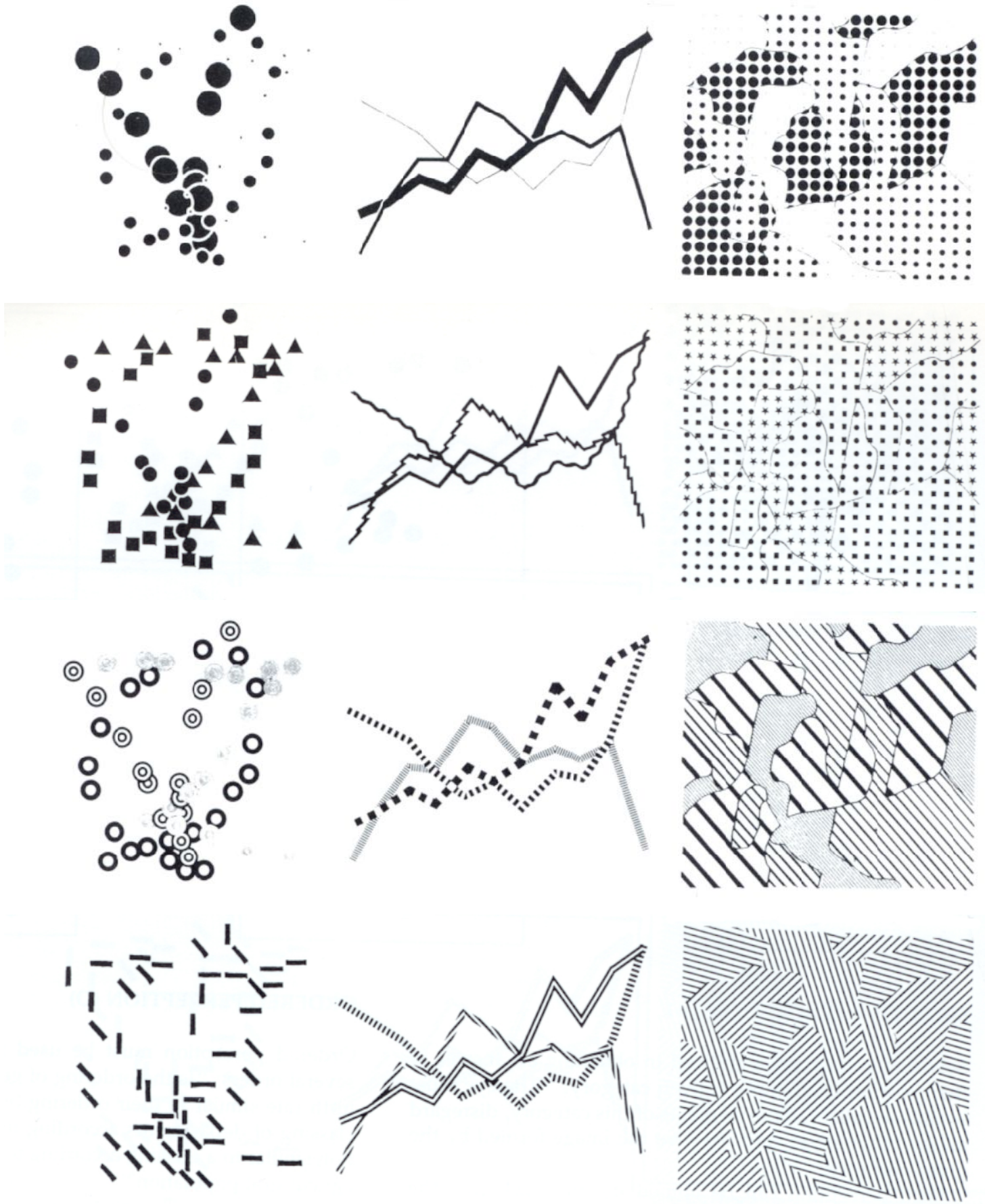
stroke-pattern / symbol



[Image source: Visualization Analysis and Design. Tamara Munzner, with illustrations by Eamonn Maguire. A K Peters Visualization Series, CRC Press, 2014]

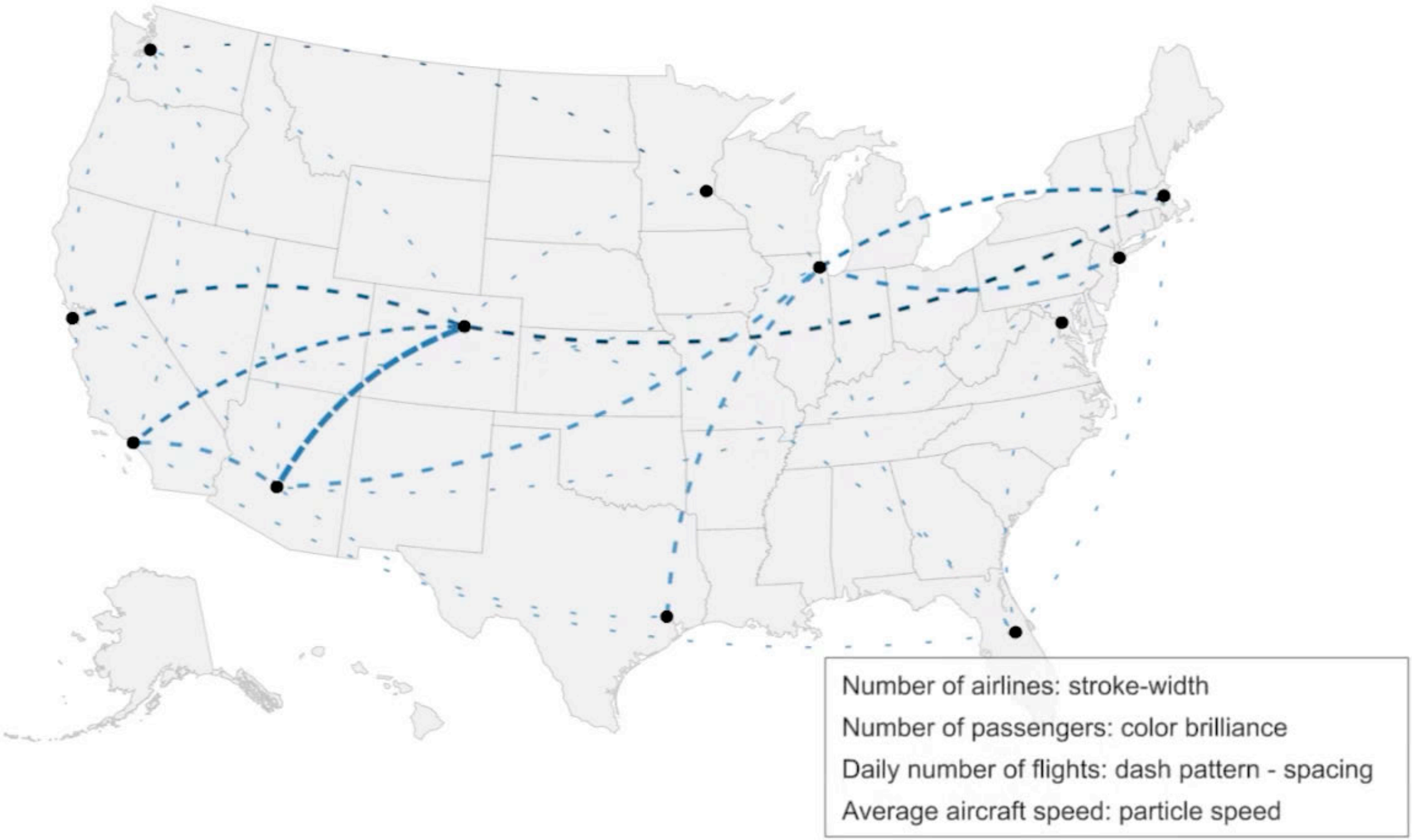
Available encoding channels for spatial data: areas & textures

2D size / stroke-width



symbol, texture, tilt, stroke-pattern

Available encoding channels for spatial data: motion & flow

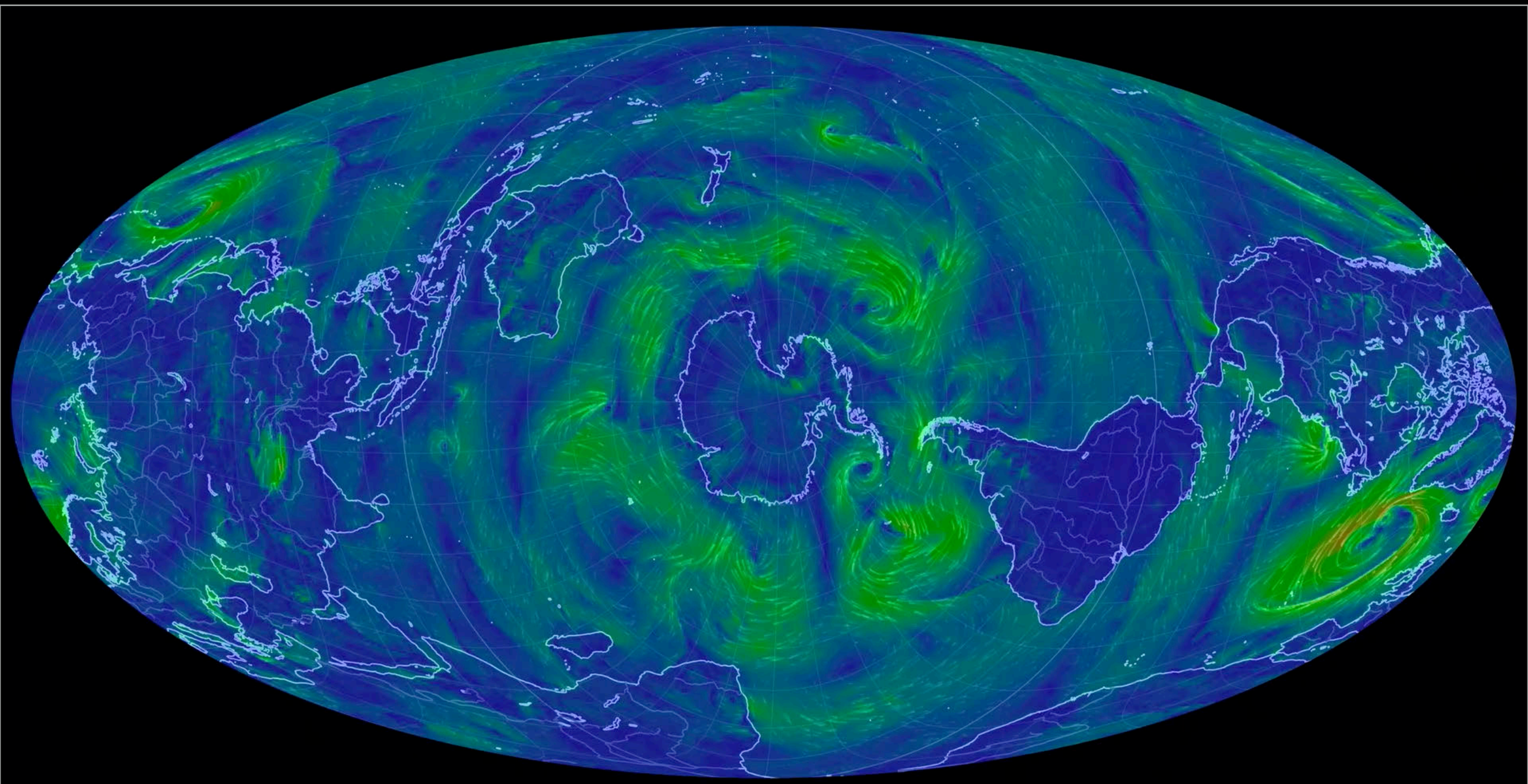


[H. Romat et al., Animated Edge Textures in Node-Link Diagrams: a Design Space and Initial Evaluation, CHI '18: Proceedings of the 36th SIGCHI conference on Human Factors in computing systems, pages 187:1–187:13, April 2018,]

Available encoding channels for spatial data: motion & flow

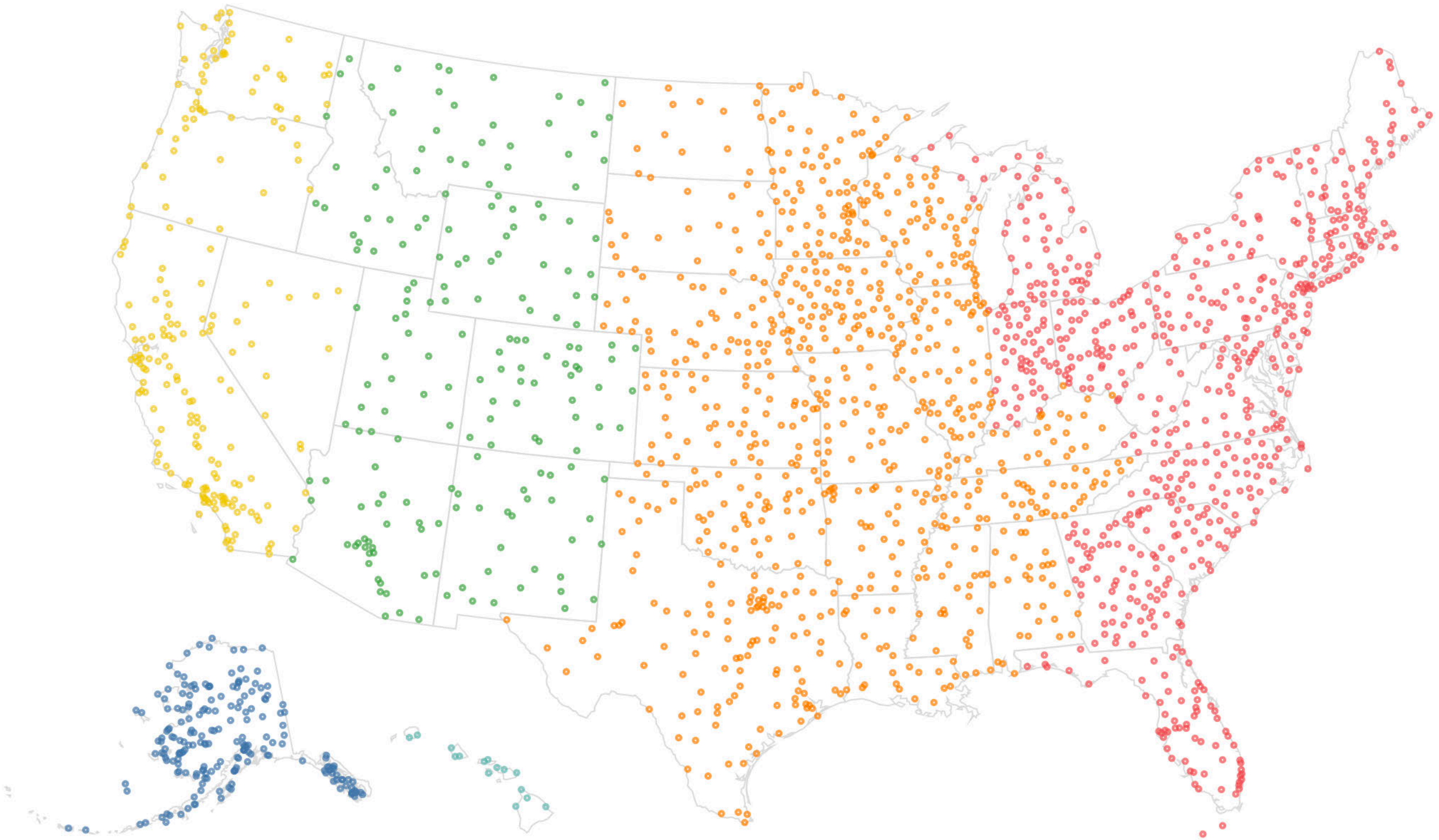
[Source: NATS, UK, 2014, https://vimeo.com/88093956]

Available encoding channels for spatial data: motion & flow



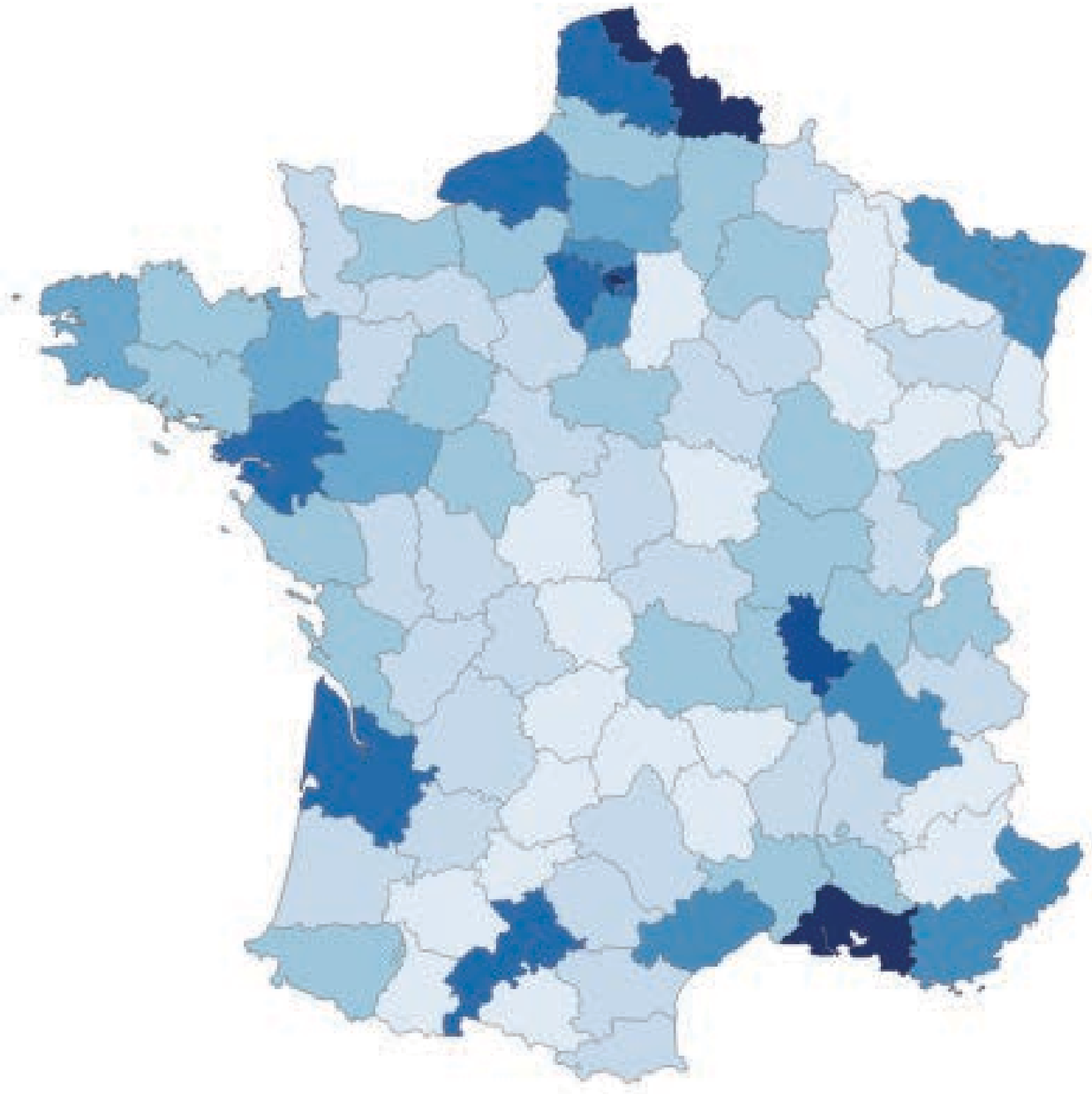
[Source: https://earth.nullschool.net]

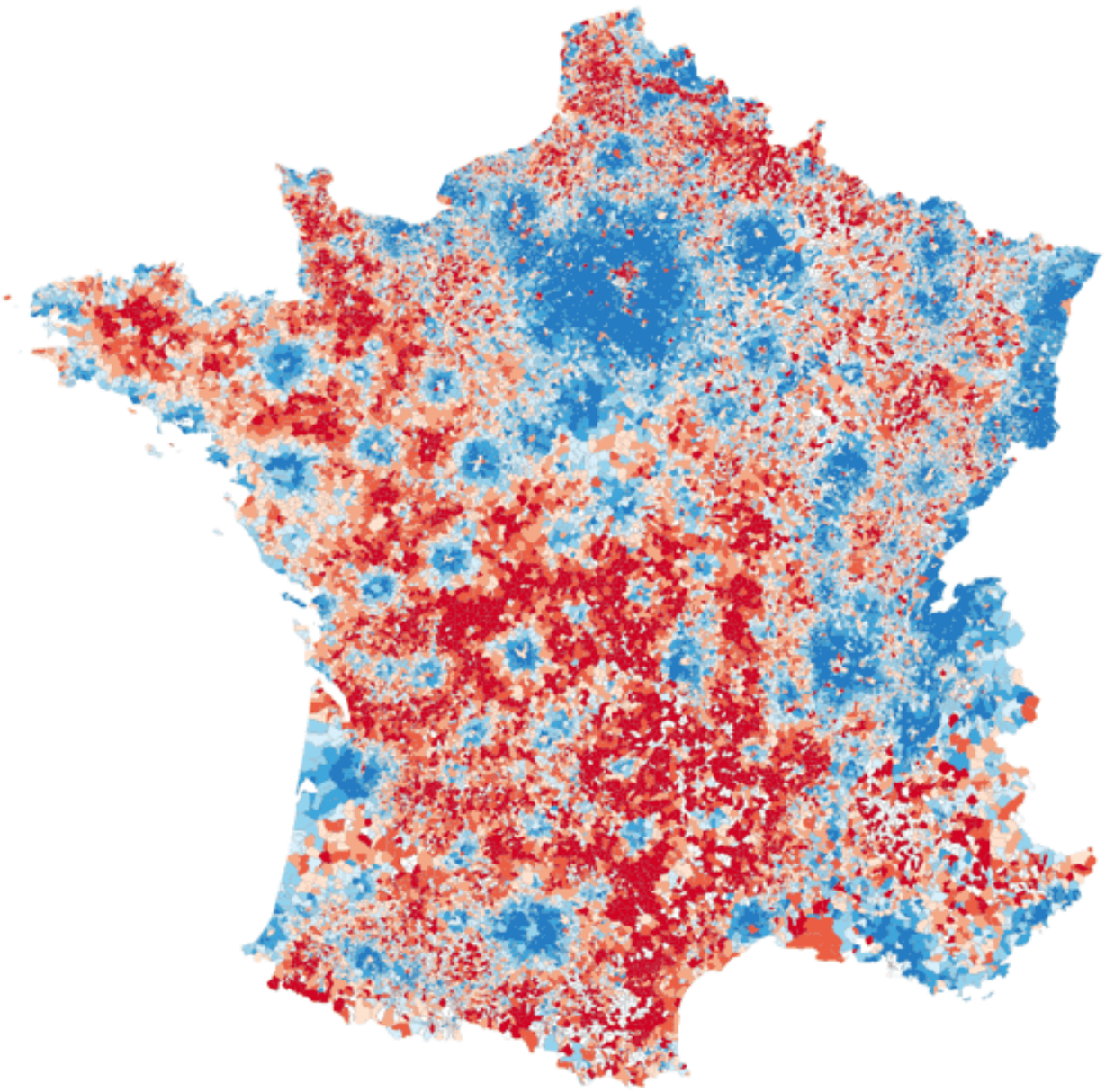
Thematic map types: dot-plot maps



Like a scatterplot, where y and x are mapped to geospatial position (lat/lon).

Thematic map types: choropleth maps





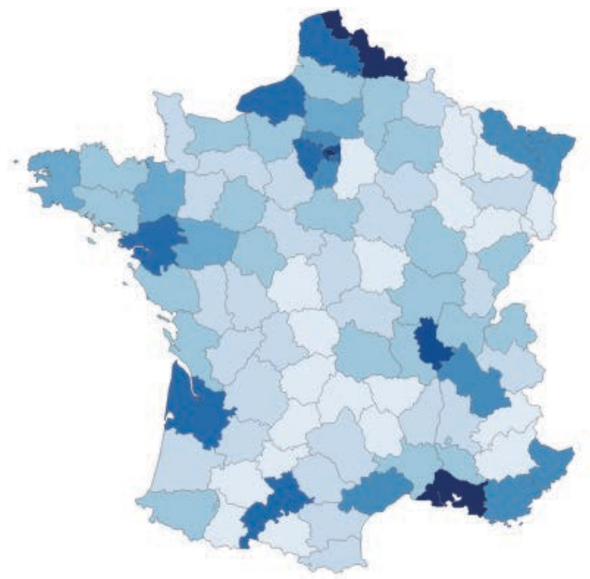
Visually encode values per area (typically administrative divisions) using color

Choropleth maps - Design guidelines

From earlier sessions: we perceive larger areas to correspond to larger amounts.

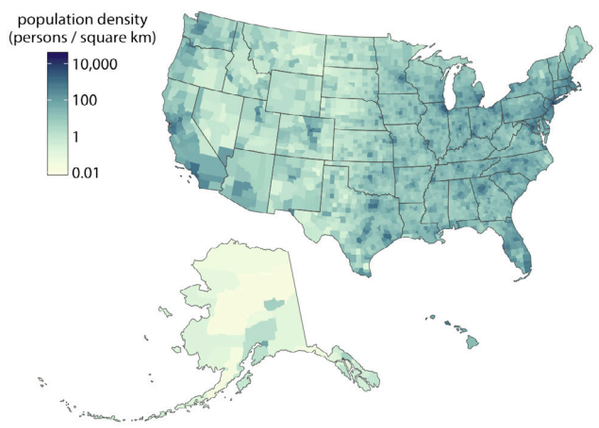
⇓

Large geographical features might draw disproportionate attention simply due to their size, regardless of the value.



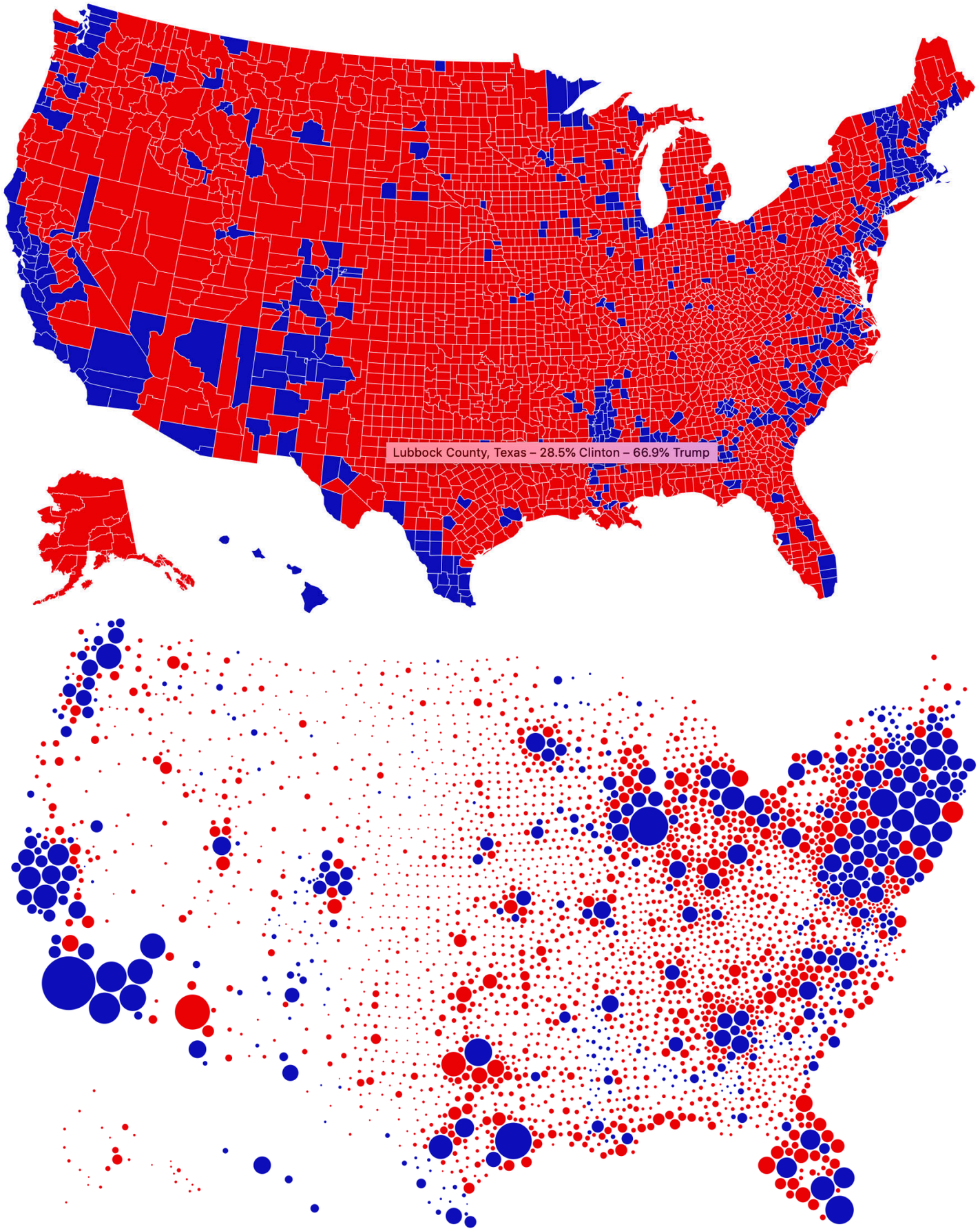
Not a problem if all areas have approximately the same size and shape.

Not a problem if the encoded value is a density, *i.e.*, a quantity divided by the corresponding surface area.

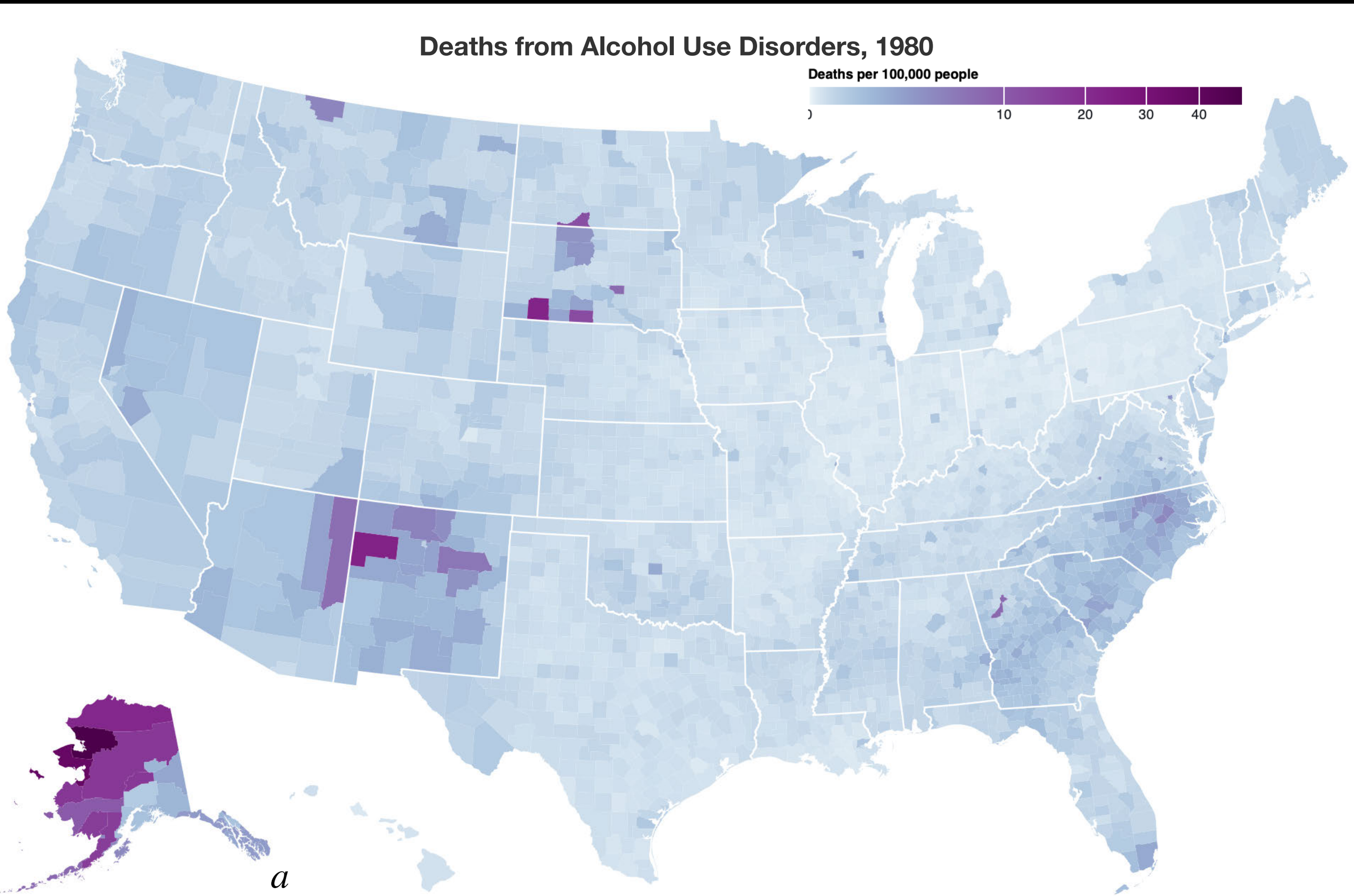


Choropleth maps

Choropleth maps



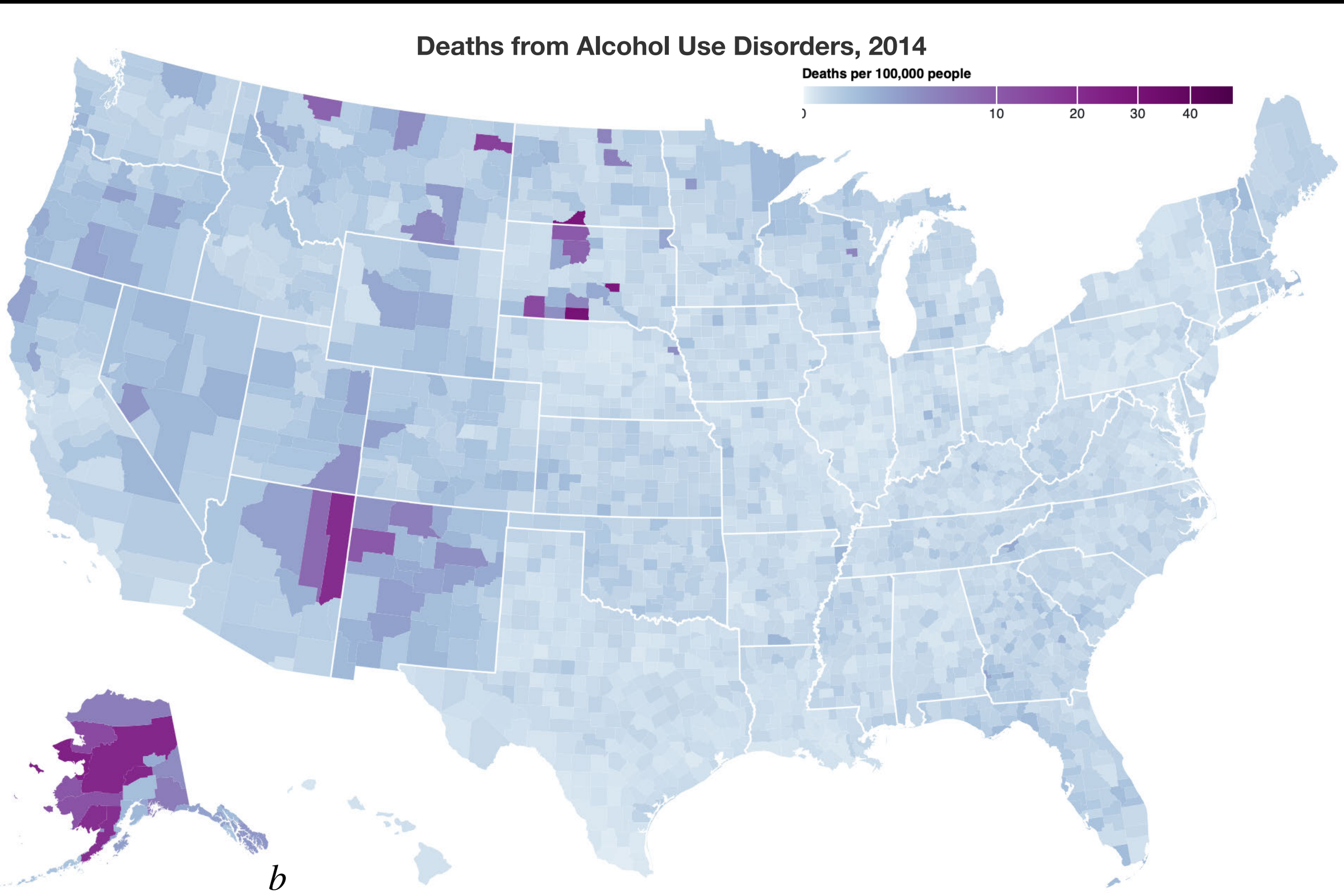
Comparison in choropleths: side-by-side or swap



a

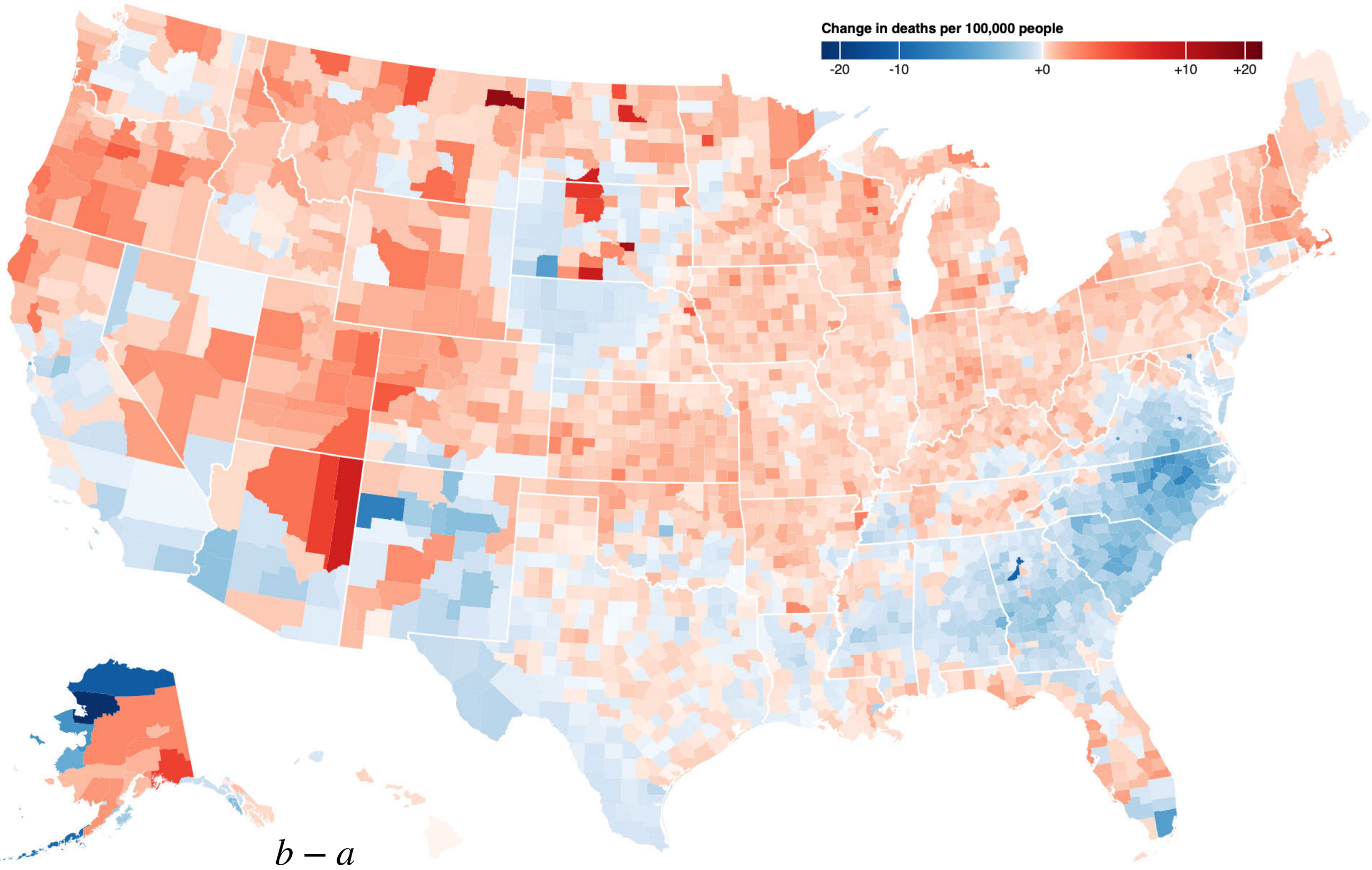
[Source: M. Bostock, 2018, https://observablehq.com/@mbostock/methods-of-comparison-compared]

Comparison in choropleths: side-by-side or swap



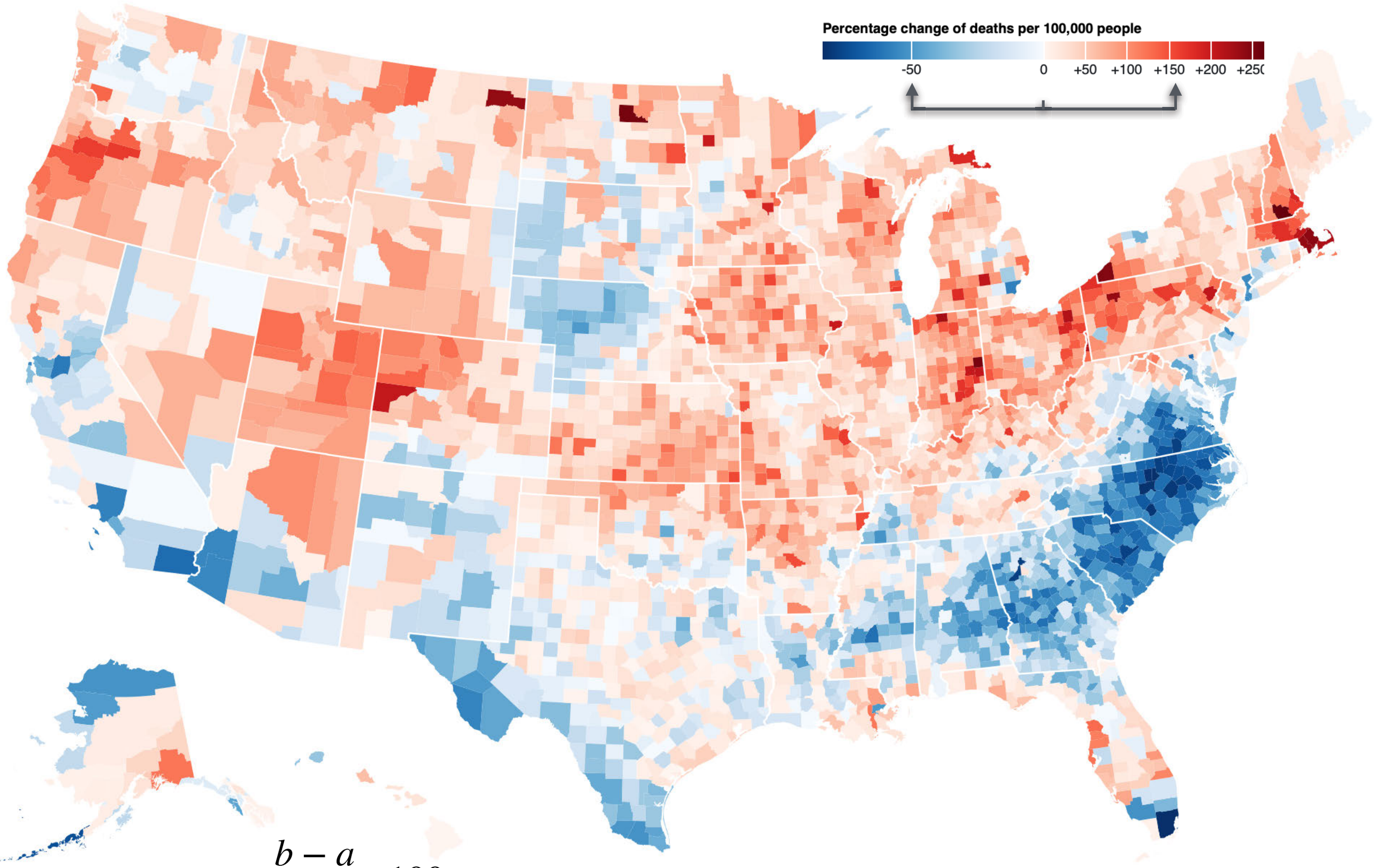
[Source: M. Bostock, 2018, https://observablehq.com/@mbostock/methods-of-comparison-compared]

Comparison in choropleths: explicit encoding (additive change)



[Source: M. Bostock, 2018, https://observablehq.com/@mbostock/methods-of-comparison-compared]

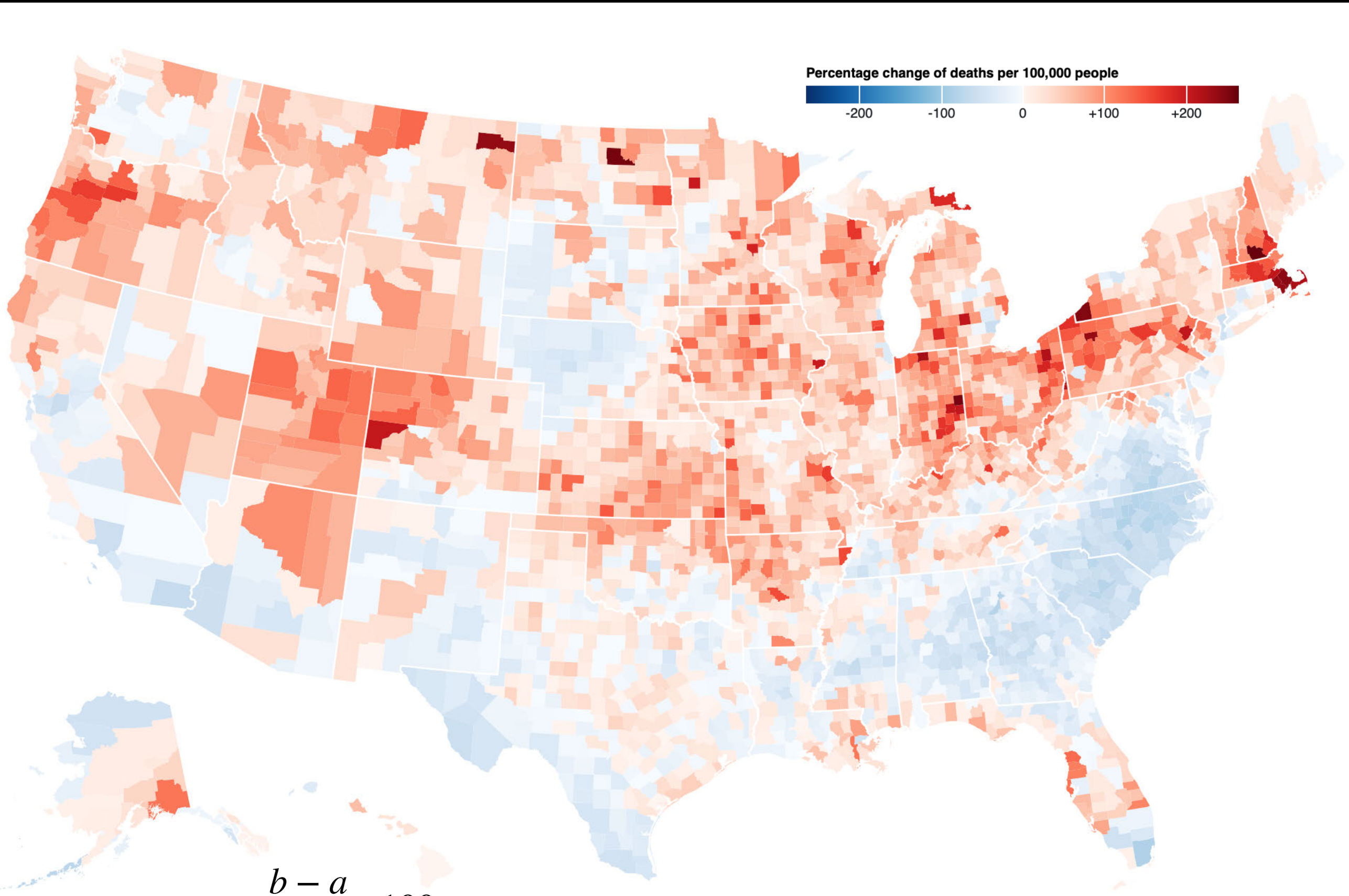
Comparison in choropleths: explicit encoding (relative change)



$$\frac{b-a}{a} \cdot 100$$

[Source: M. Bostock, 2018, https://observablehq.com/@mbostock/methods-of-comparison-compared]

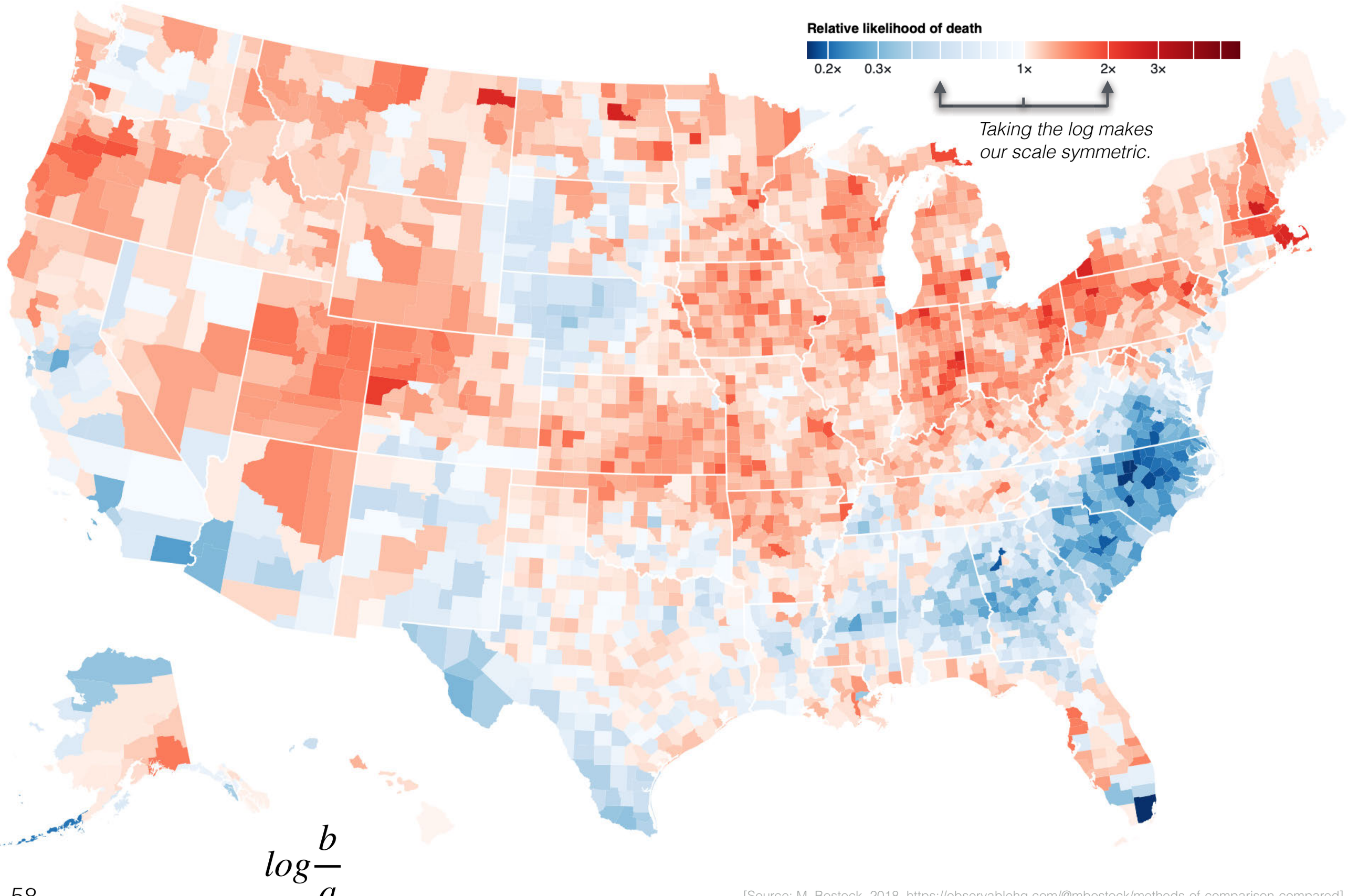
Comparison in choropleths: explicit encoding (relative change)



$$\frac{b-a}{a} \cdot 100$$

[Source: M. Bostock, 2018, https://observablehq.com/@mbostock/methods-of-comparison-compared]

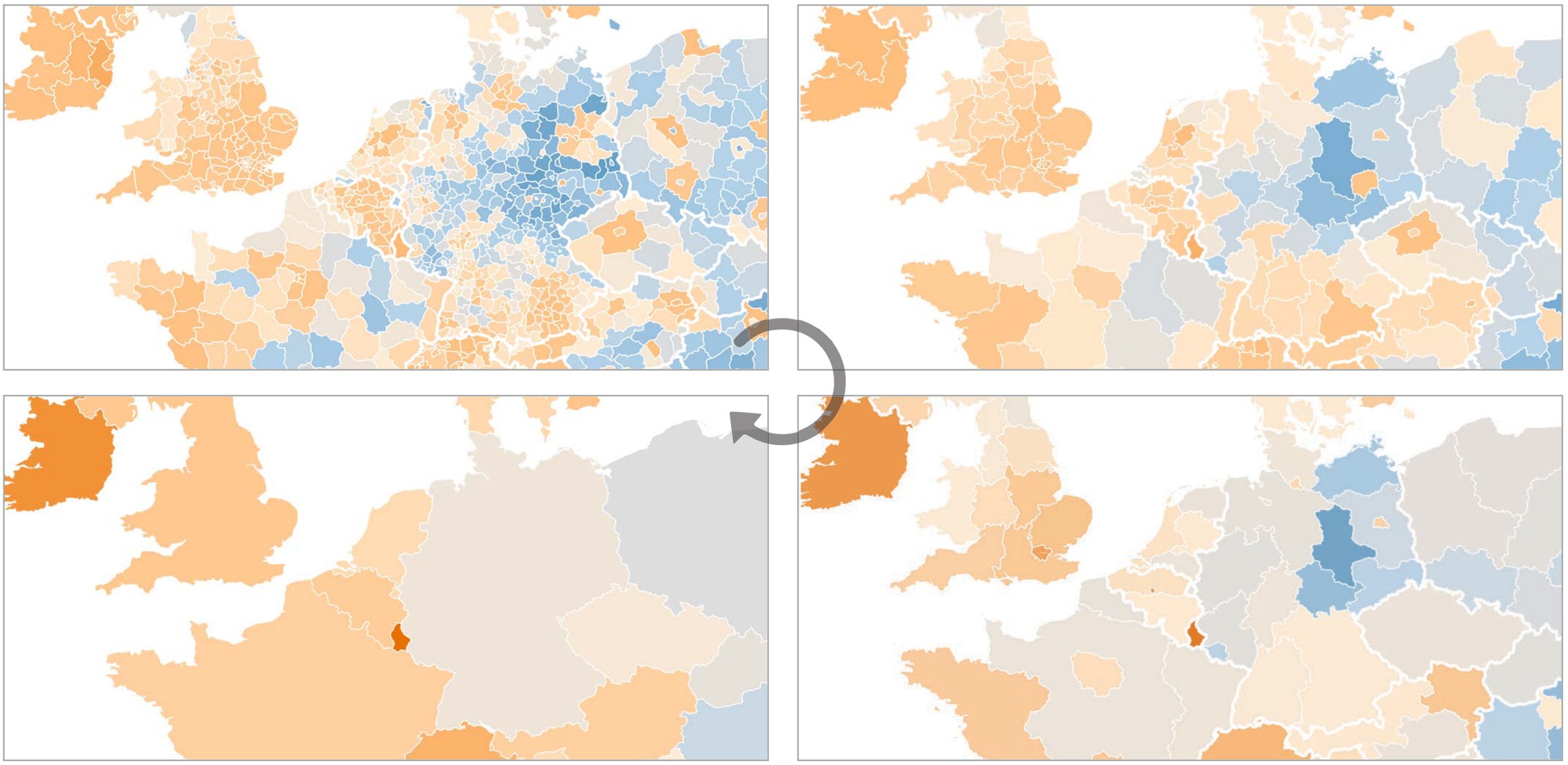
Comparison in choropleths: explicit encoding (multiplicative change)



$$log\frac{b}{a}$$

[Source: M. Bostock, 2018, https://observablehq.com/@mbostock/methods-of-comparison-compared]

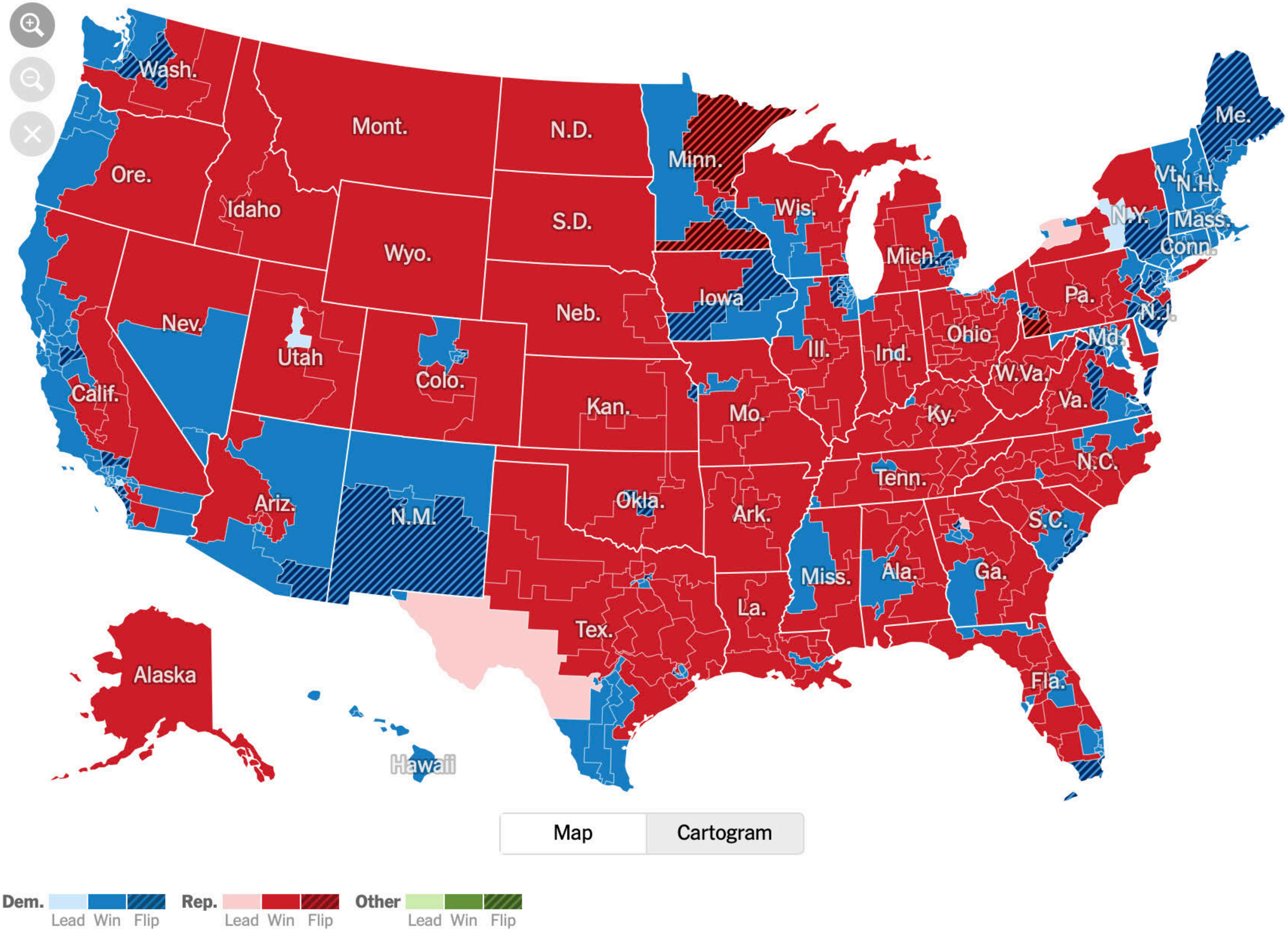
Aggregation in choropleth maps



Different area units will reveal different patterns

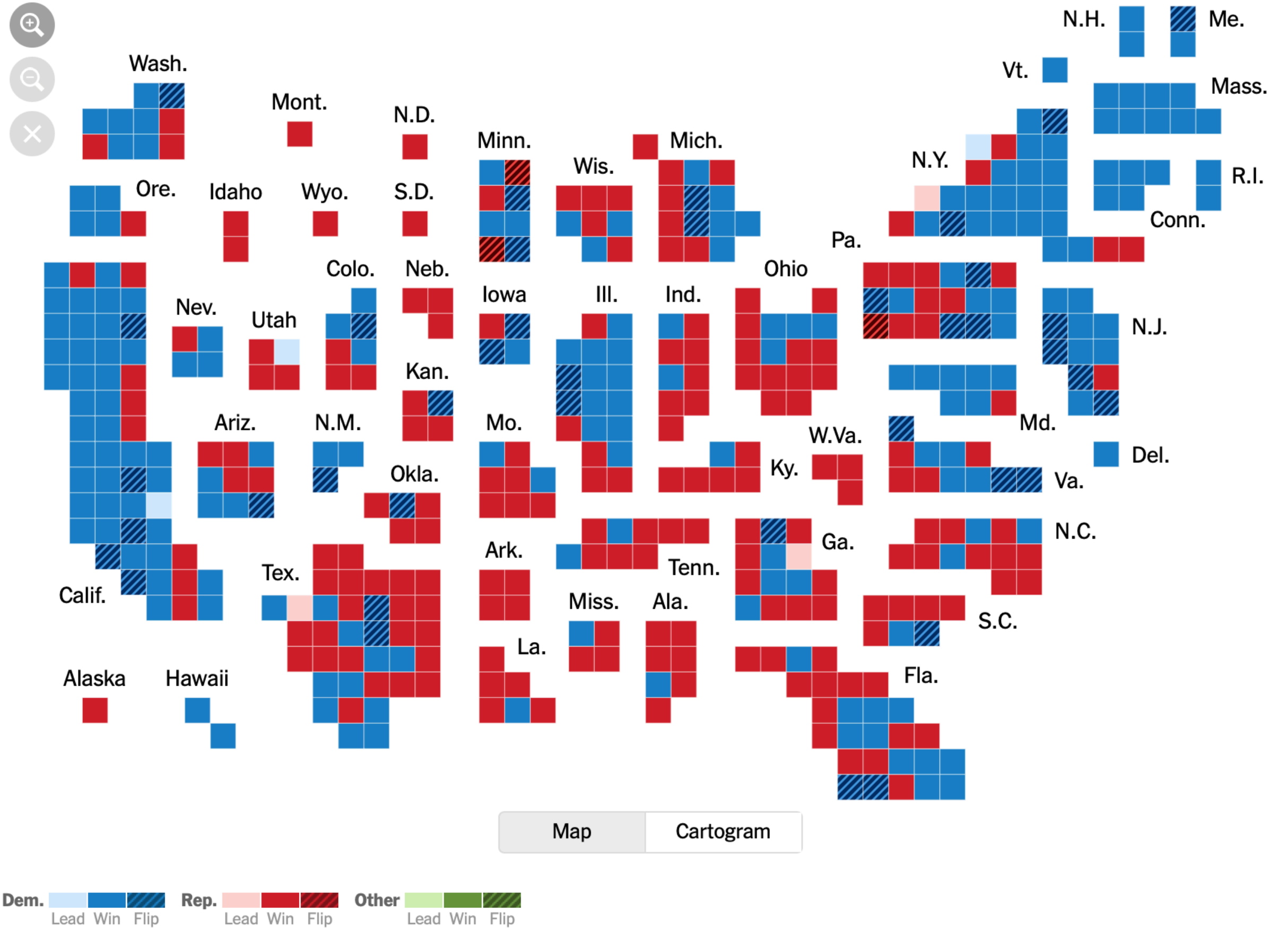
[Image source: https://blog.datawrapper.de/weekly-chart-europegrowth/]

(Bad) choropleth map



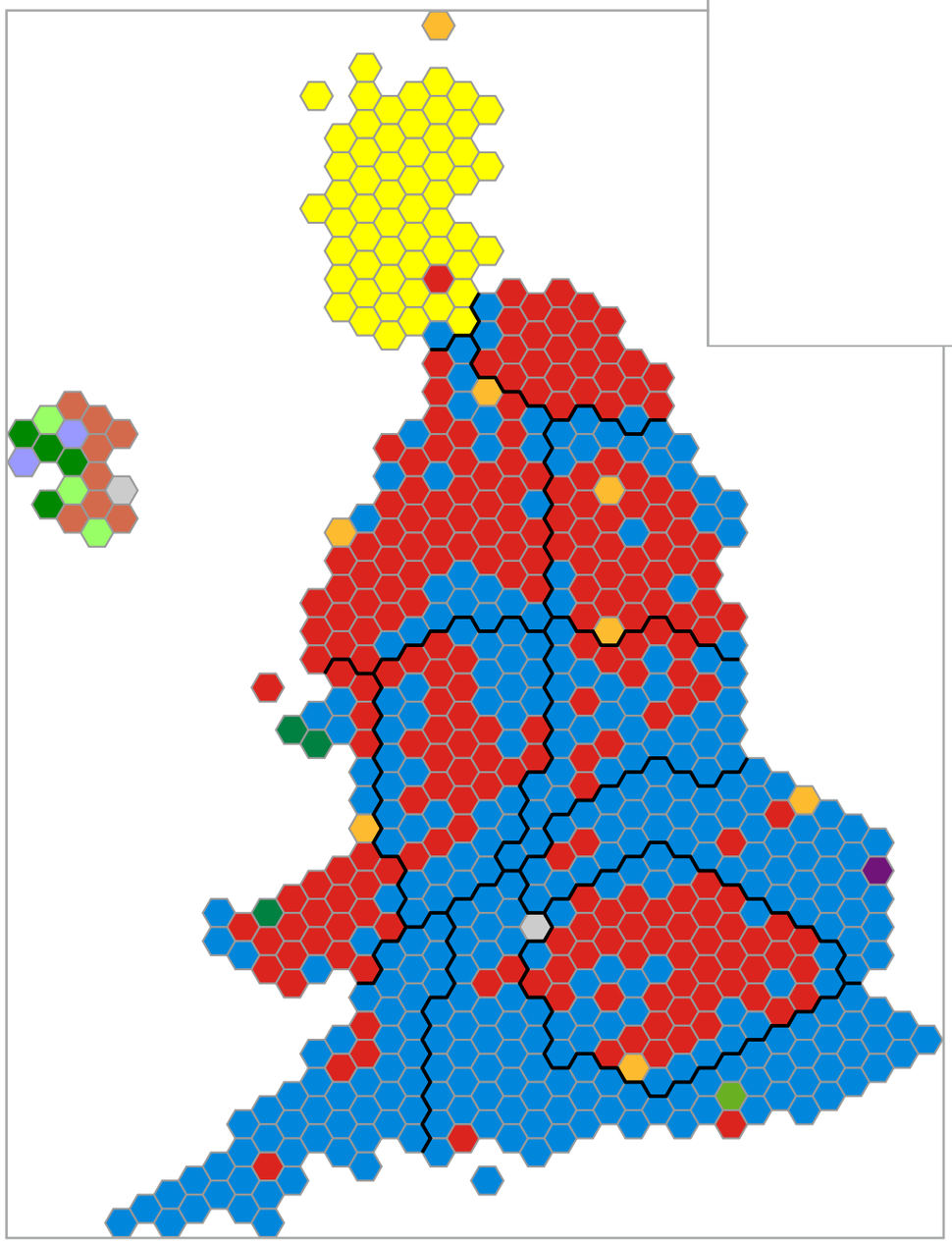
https://www.nytimes.com/interactive/2018/11/06/us/elections/results-house-elections.html

Thematic map types: anamorphic maps (cartograms)

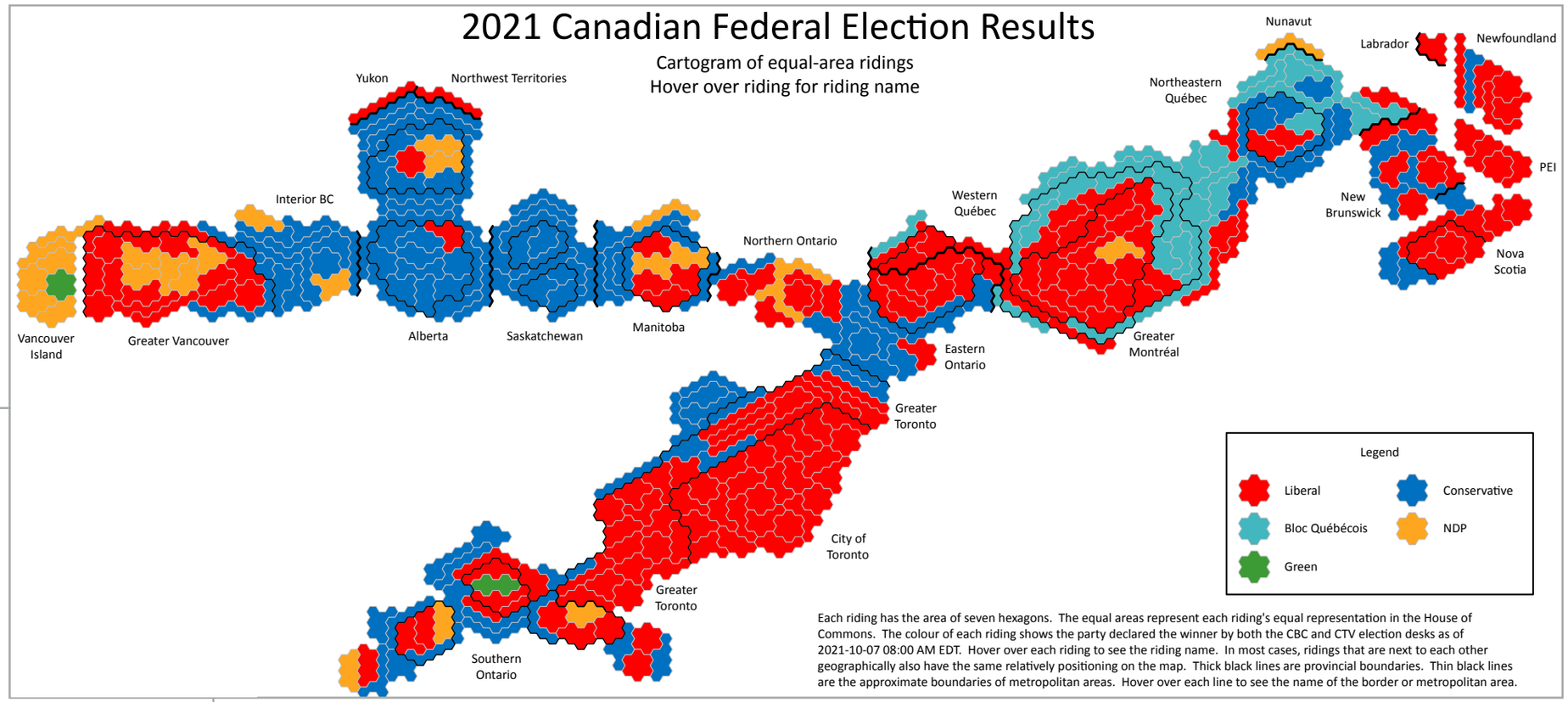


https://www.nytimes.com/interactive/2018/11/06/us/elections/results-house-elections.html

Thematic map types: anamorphic maps (cartograms)



[Image source: https://commons.wikimedia.org/wiki/File:2015_UK_general_election_constituency_map.svg



[Image source: https://commons.wikimedia.org/wiki/File:Canadian_Federal_Election_Cartogram_2021.svg]

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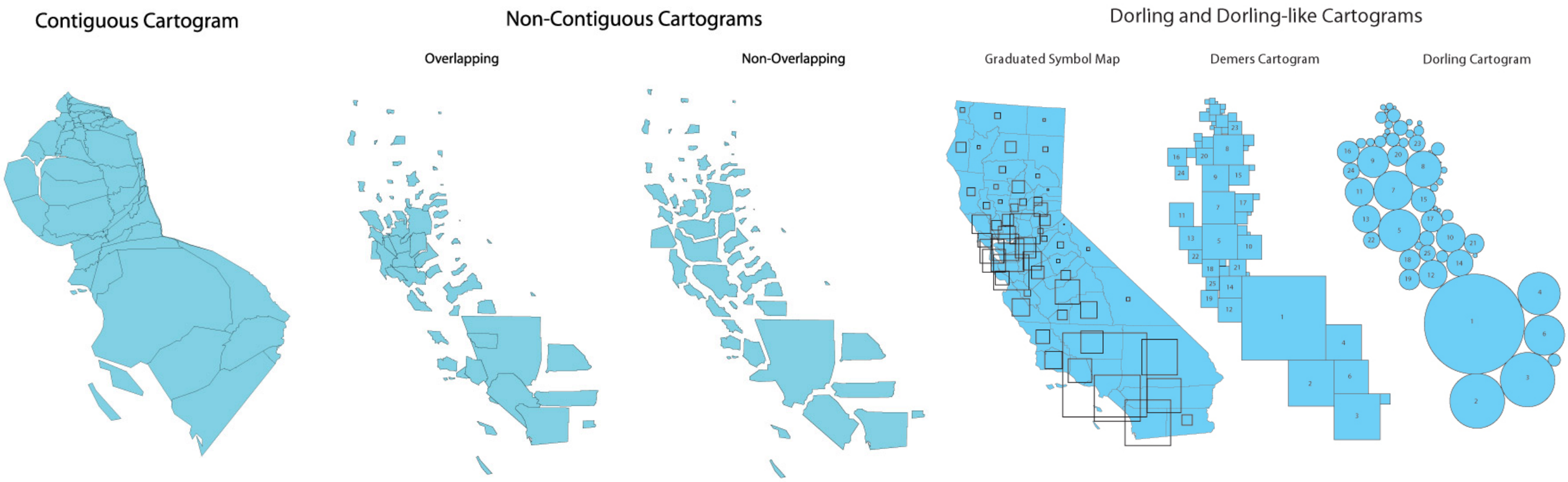
Thematic map types: anamorphic maps (cartograms)

Different types of cartograms:

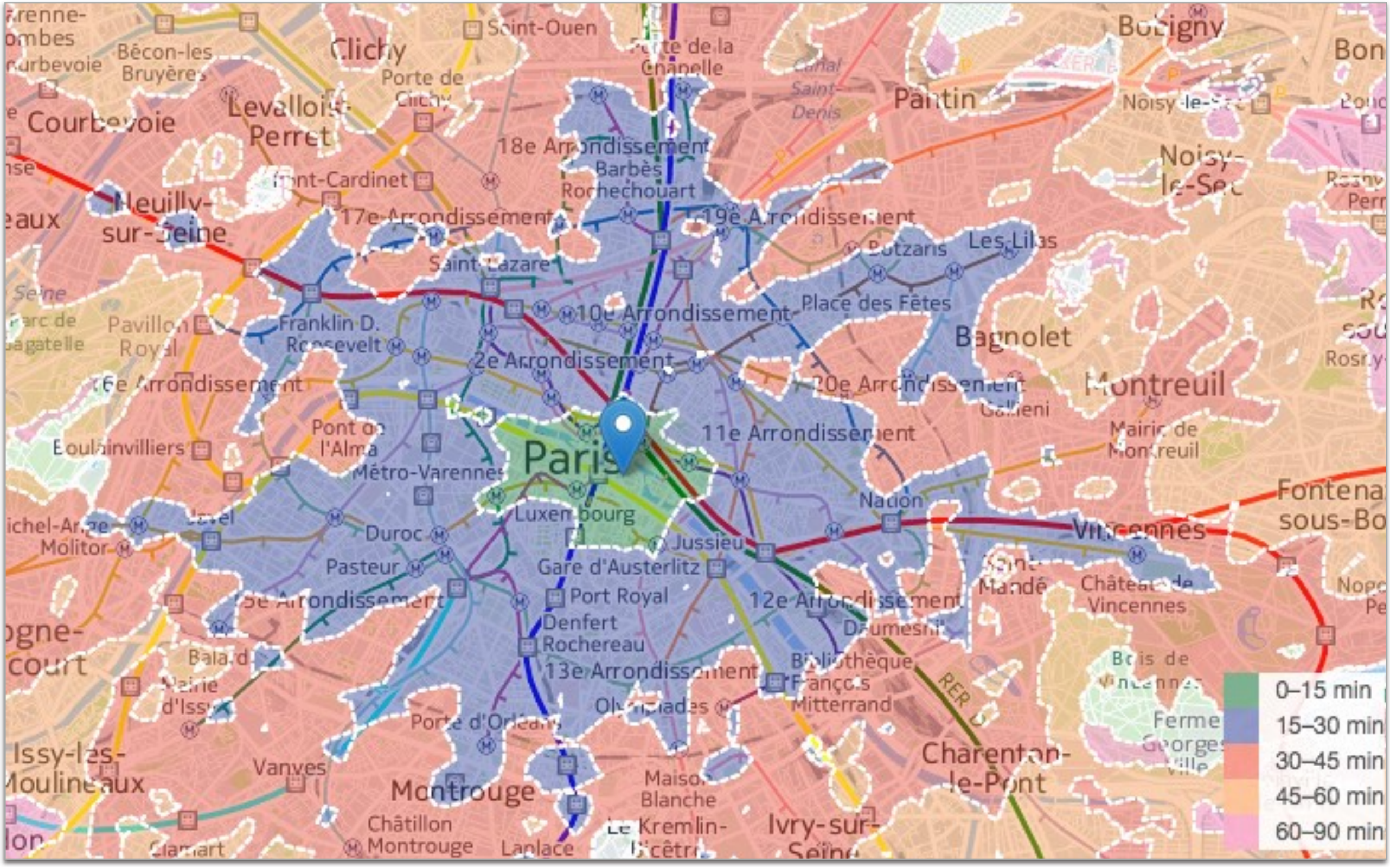


… have different properties in terms of shape, centroid, and topology preservation.

If no geographic pattern to illustrate, another type of chart might work better.

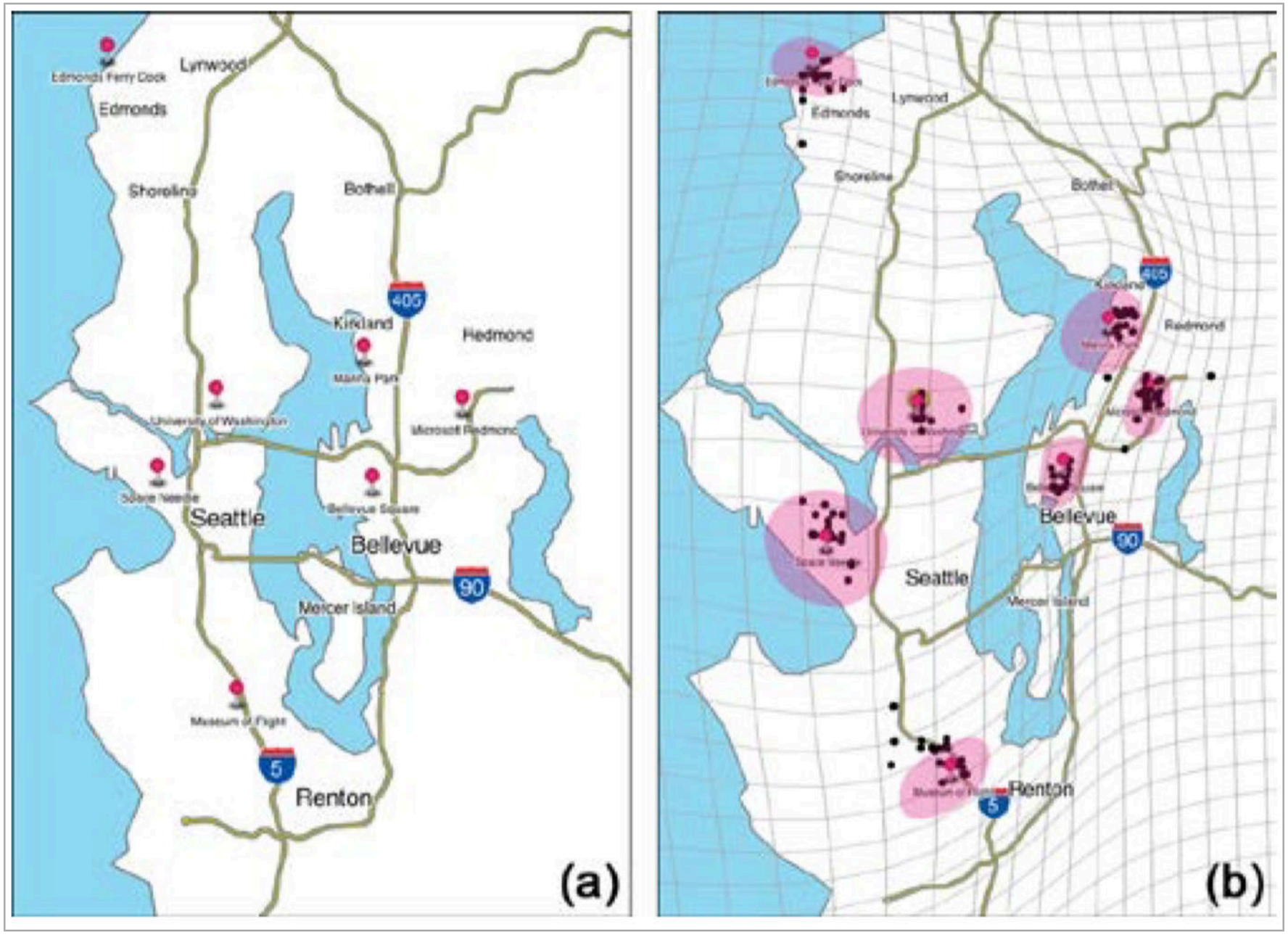
[Image source: http://www.ncgia.ucsb.edu/projects/Cartogram_Central]

Central point cartogram/isochrone maps



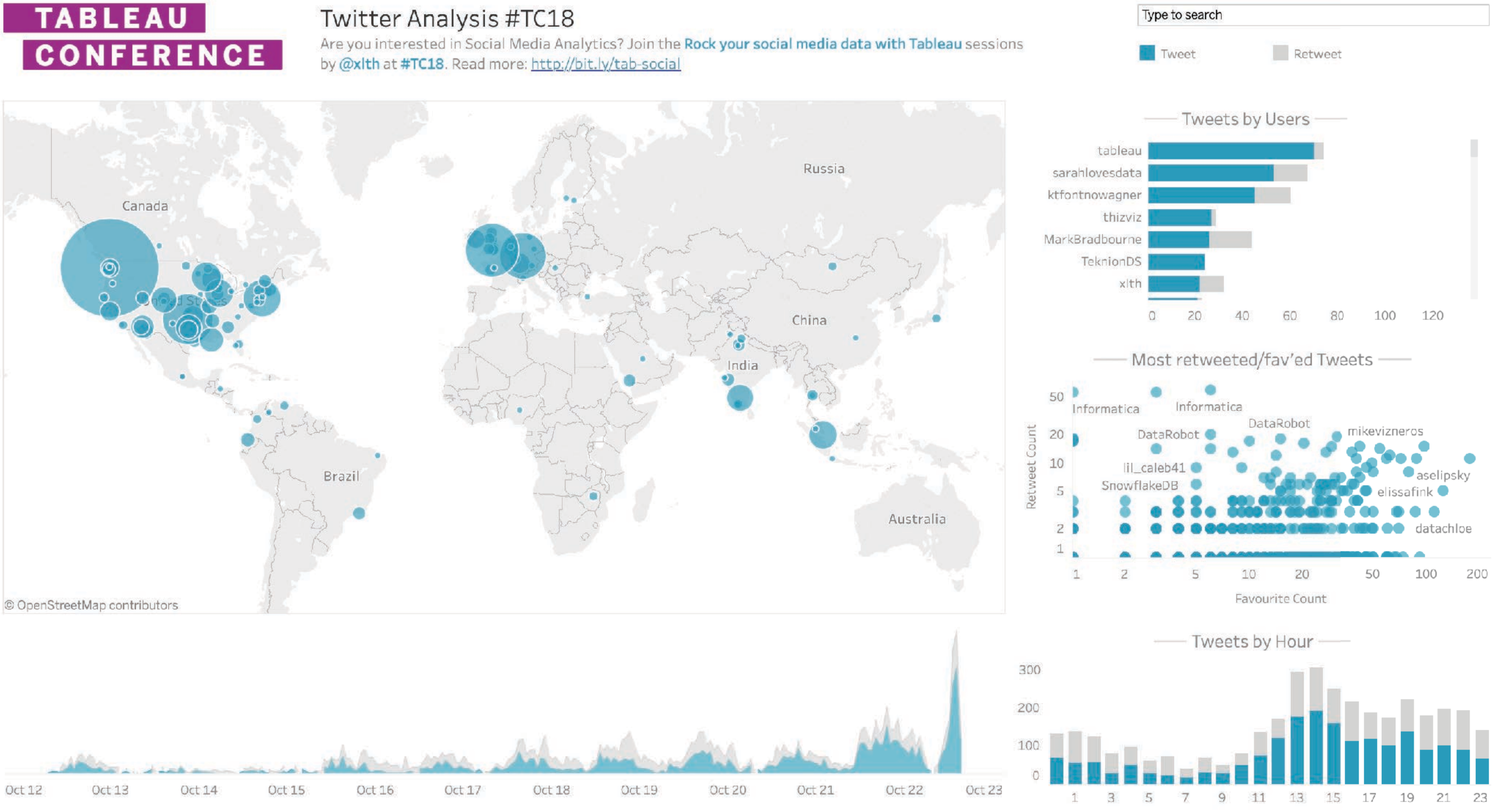
[Source: http://www.socialdynamics.it/2015/06/isochrone-maps/]

Central point cartogram/isochrone maps



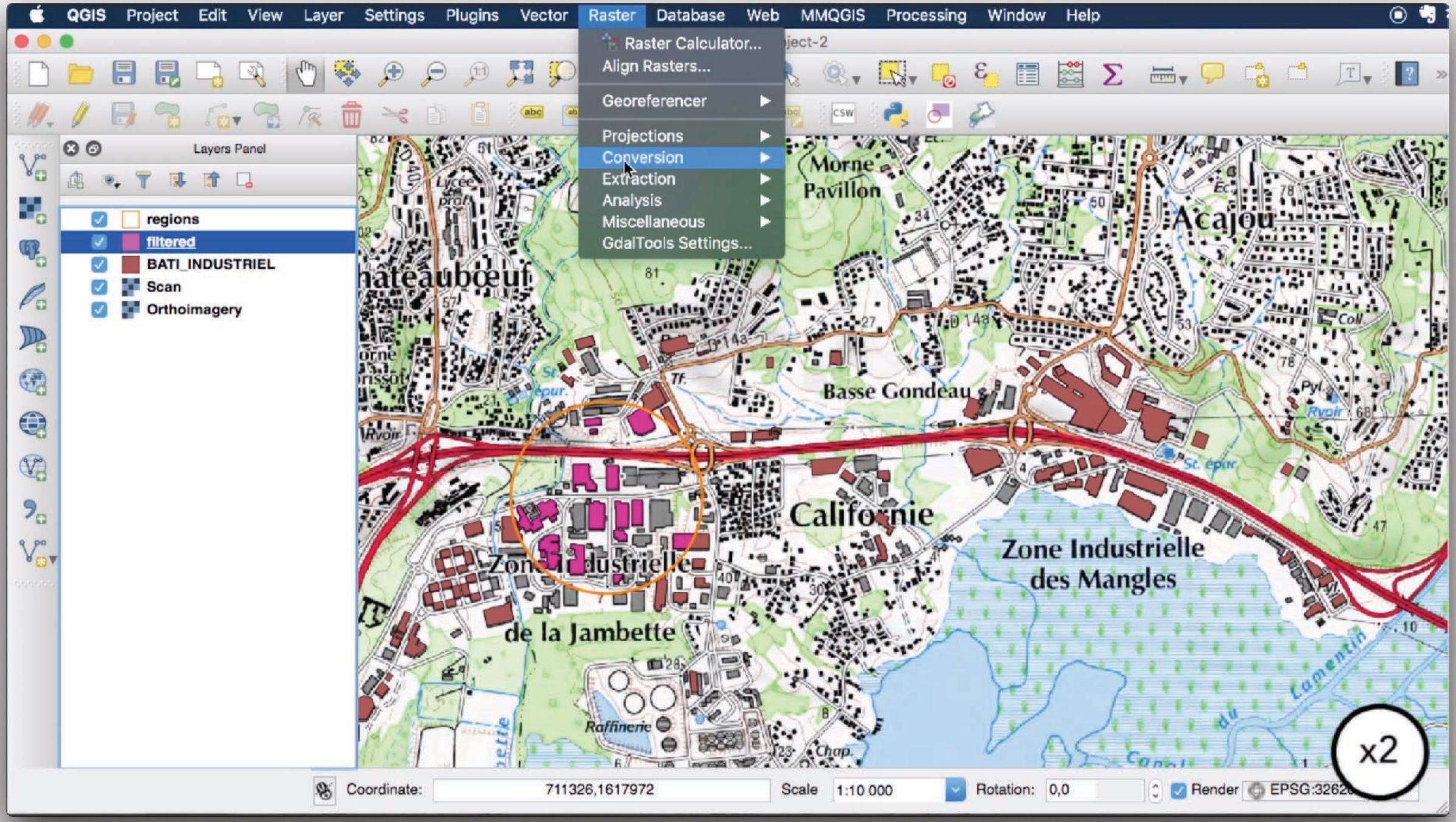
[S. Hong et al. 2014. Traffigram: distortion for clarification via isochronal cartography. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '14). ACM, 907-916]

Visualization Tools: Thematic Cartography



[Tableau: https://public.tableau.com/en-us/s/gallery/analyzing-tc18-twitter]

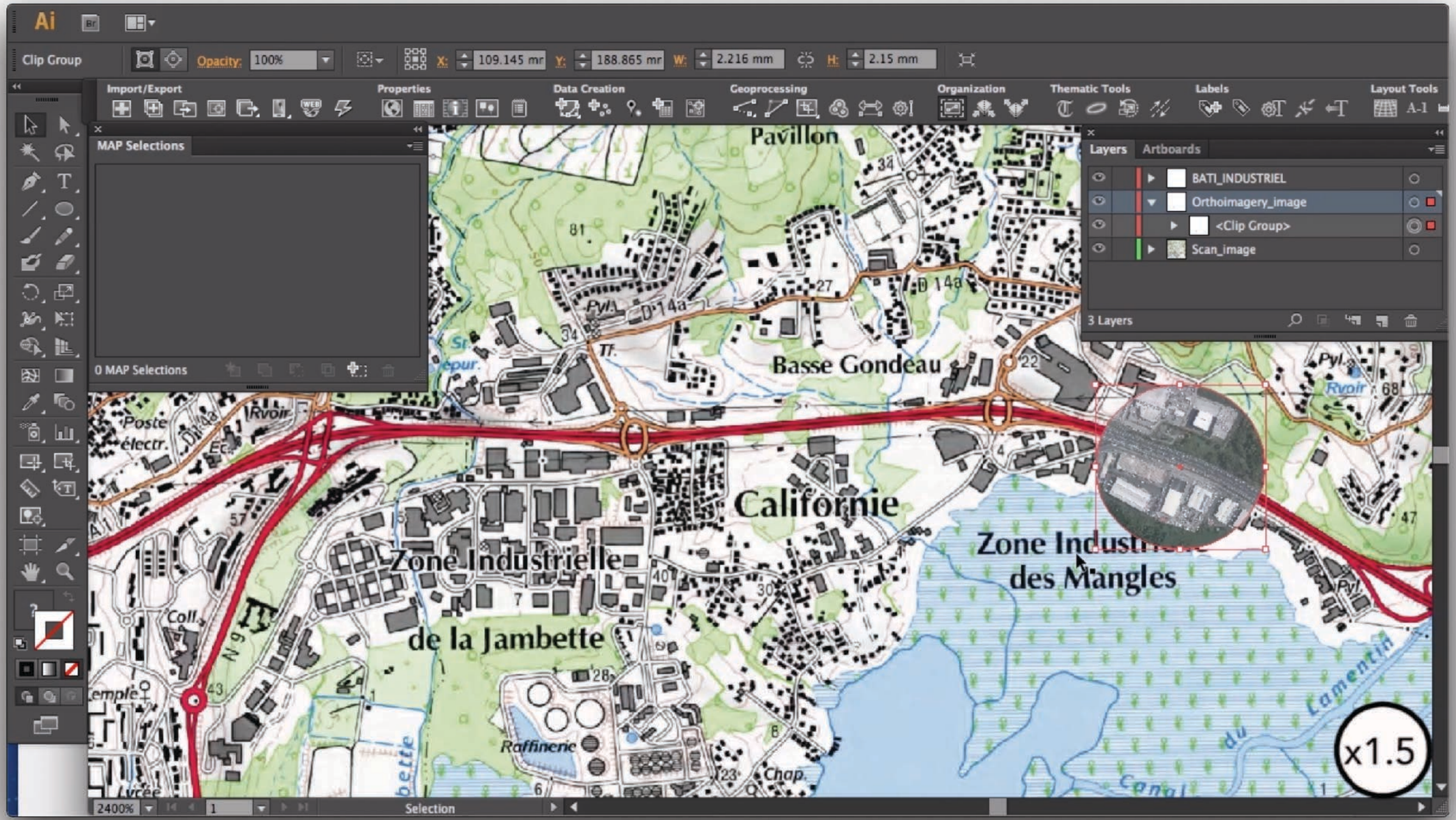
Visualization Tools: Desktop GIS



- Analyze and edit spatial information
- Compose maps from vector and raster layers
- Spatial registration
- Interface with geographic information databases

QGIS

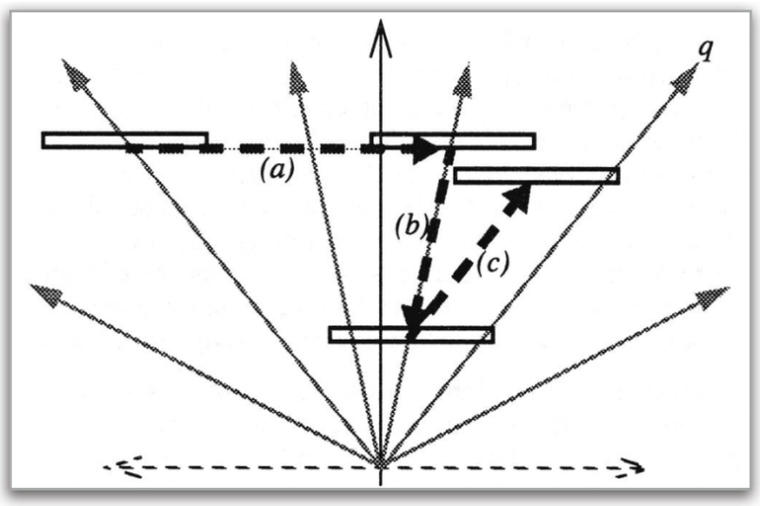
Visualization Tools: Cartographic editing

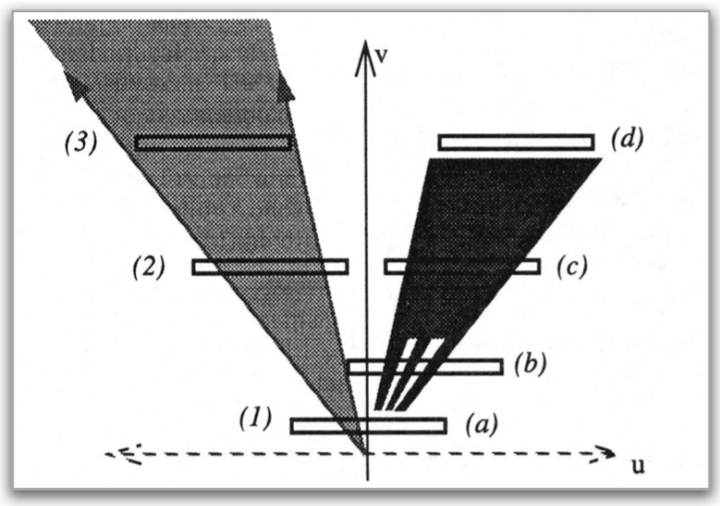


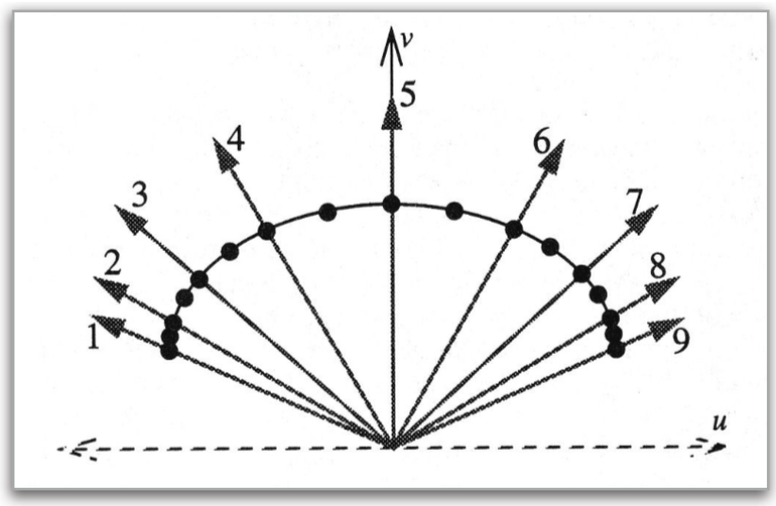
MAPublisher

- Seamlessly integrates GIS features in Adobe Illustrator

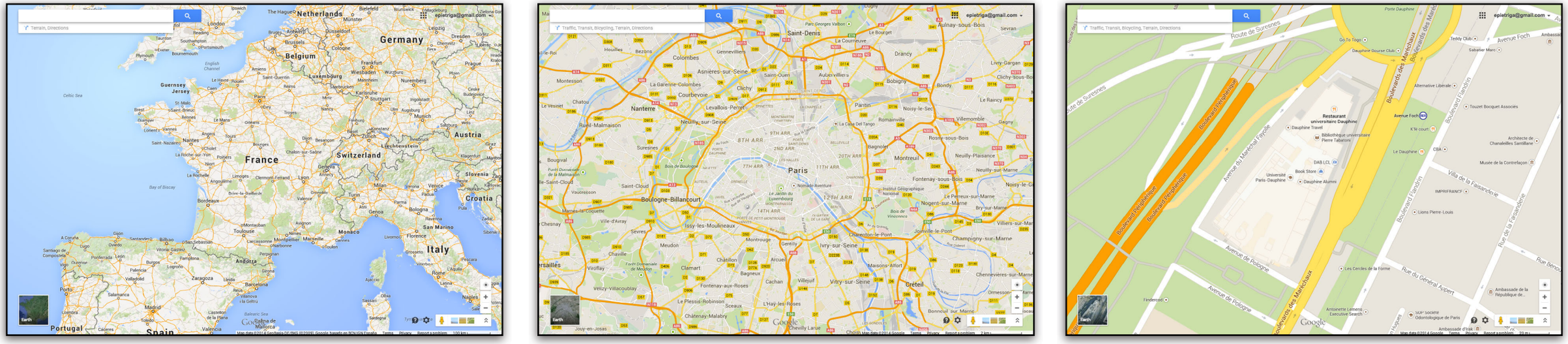
Multi-scale Navigation



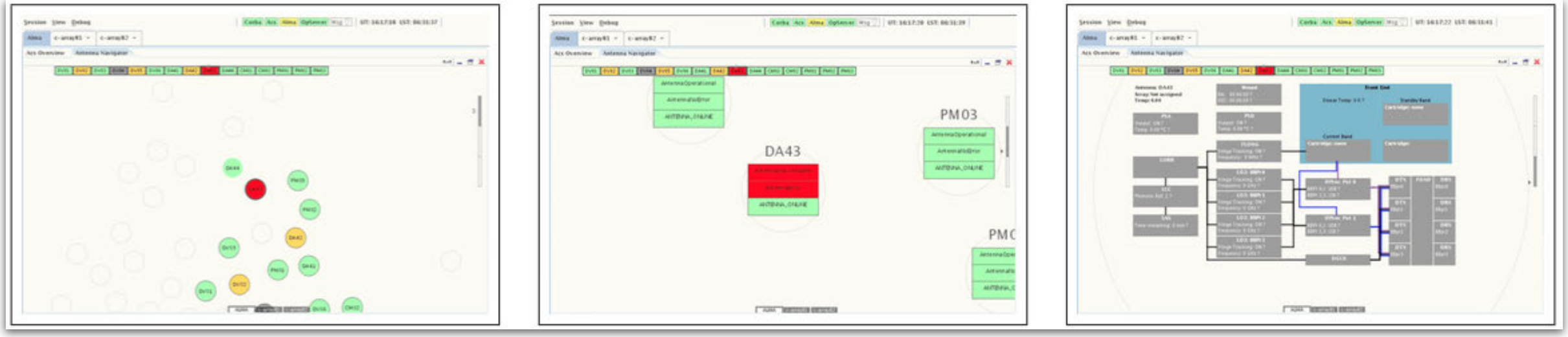




Multi-scale Navigation



ALMA-Navigator.mov

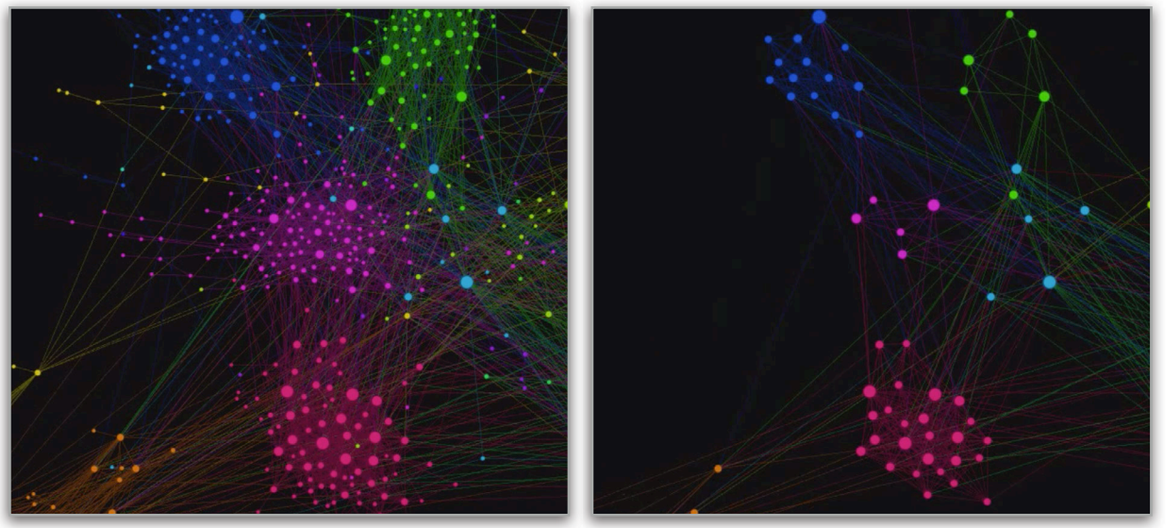


[E. Pietriga et al., Interaction Design Challenges and Solutions for ALMA Operations Monitoring and Control, invited paper, Astronomical Telescopes and Instrumentation, SPIE, pages 10:1-10:16, July 2012]

Item Reduction Strategies

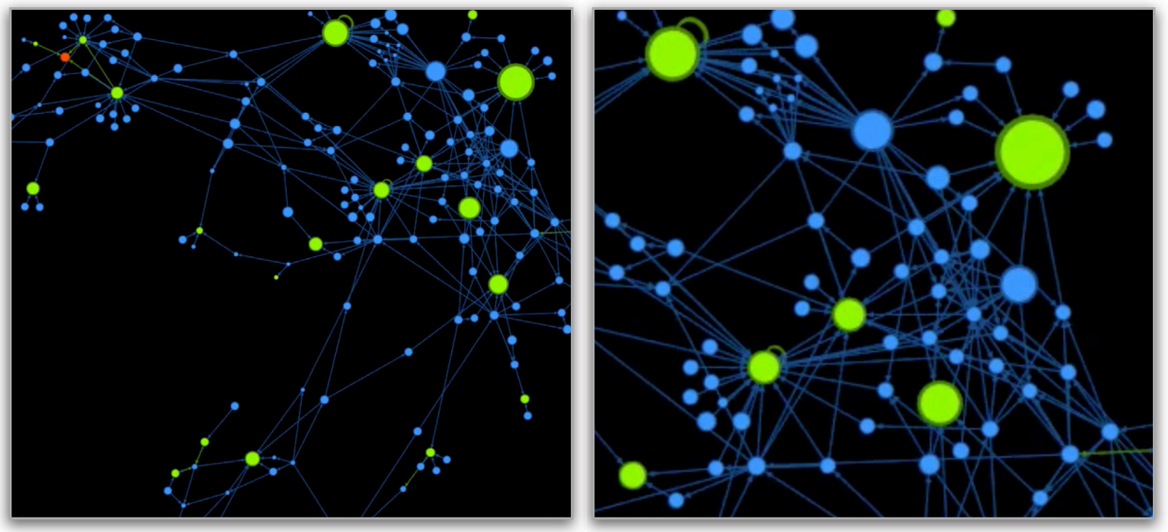
- Aggregate: merging items.

- Filter: removing items.



- Navigate: removing items, but in a different way.

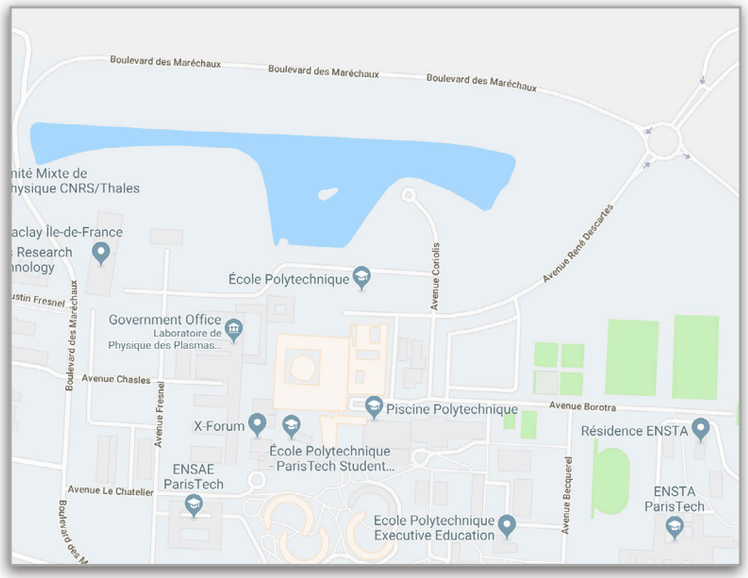
  Can be seen as a way of filtering by moving the viewpoint.

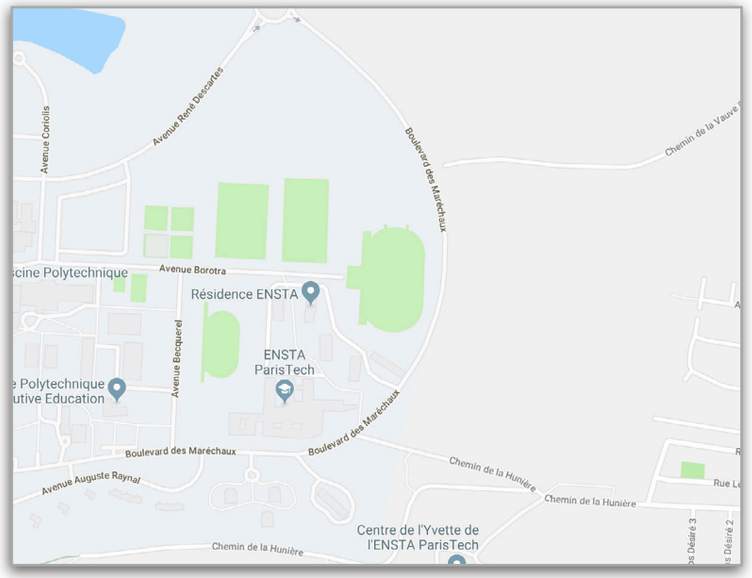


[Illustrated using Gephi snapshots]

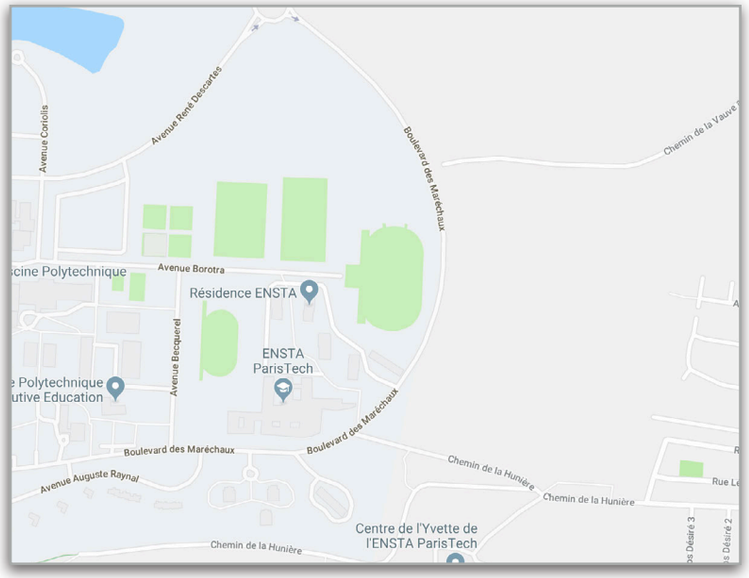
Multi-scale Navigation

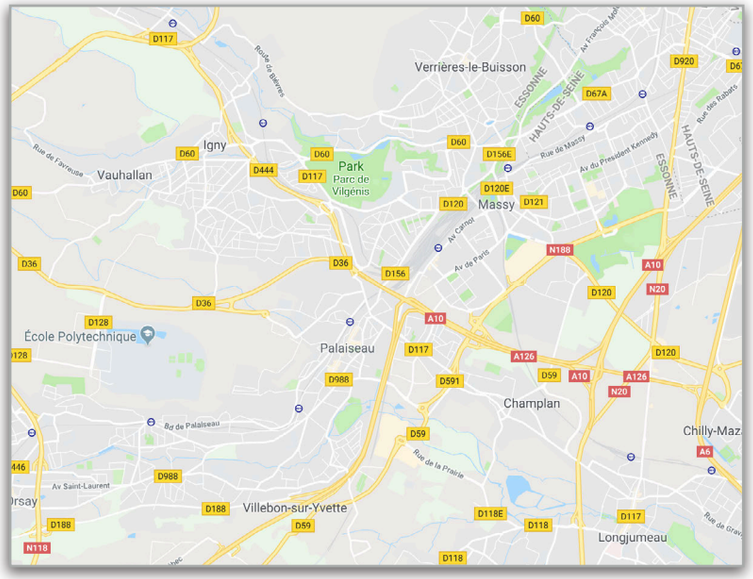
- Scrolling (1D), panning (2D)



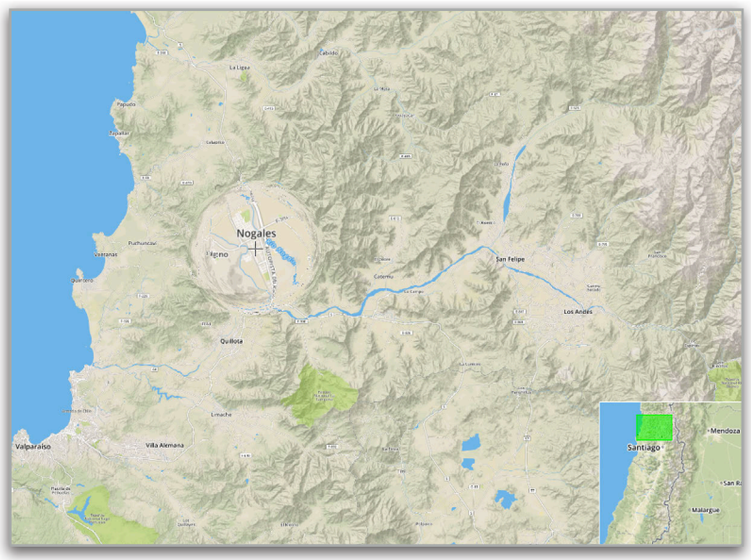


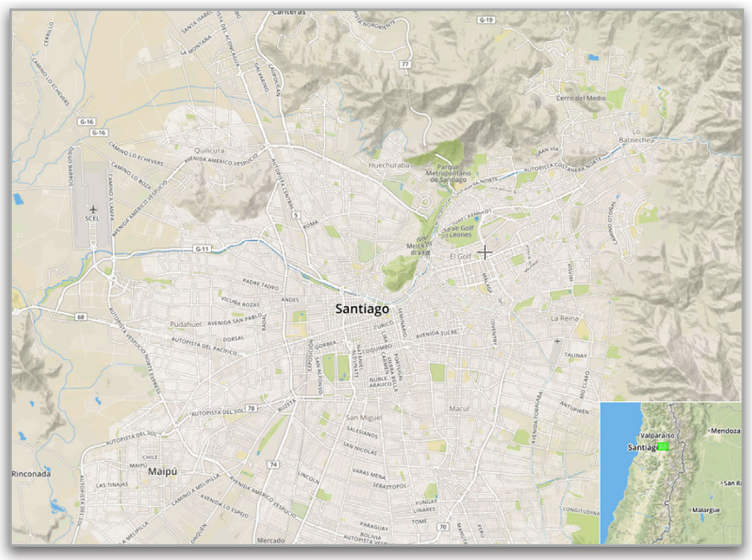
- Zooming (geometric, semantic)





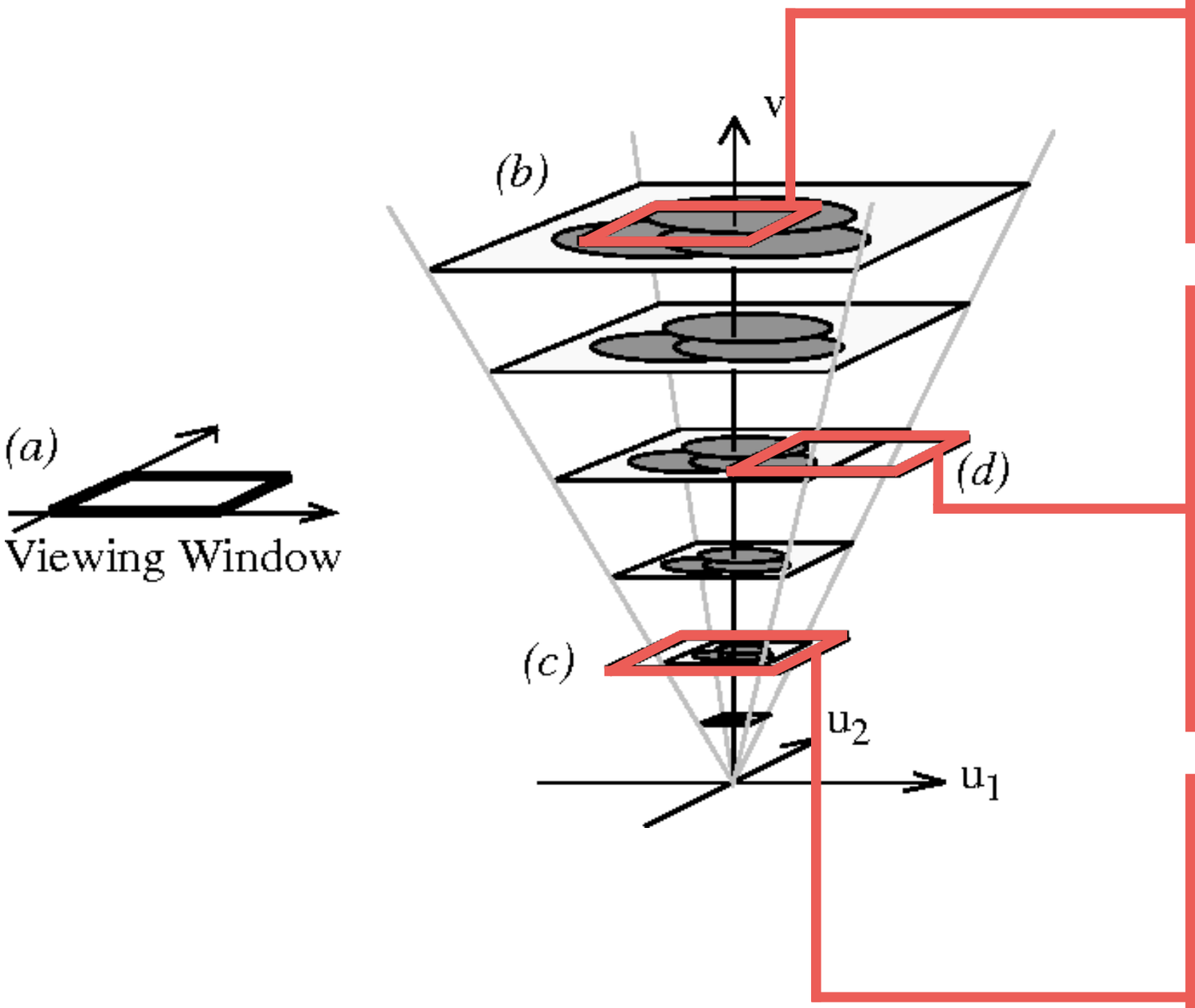
- Multiple views, at different scales
  - multiple foci
  - overview+detail
  - focus+context

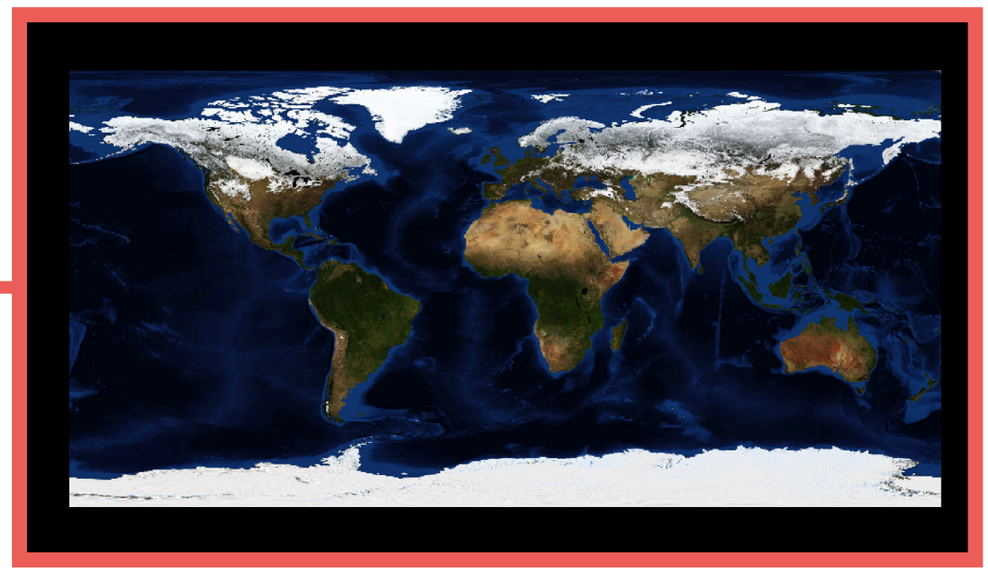




Space-scale Diagrams

Represent multi-scale information spaces,
interface schemes, and navigation trajectories

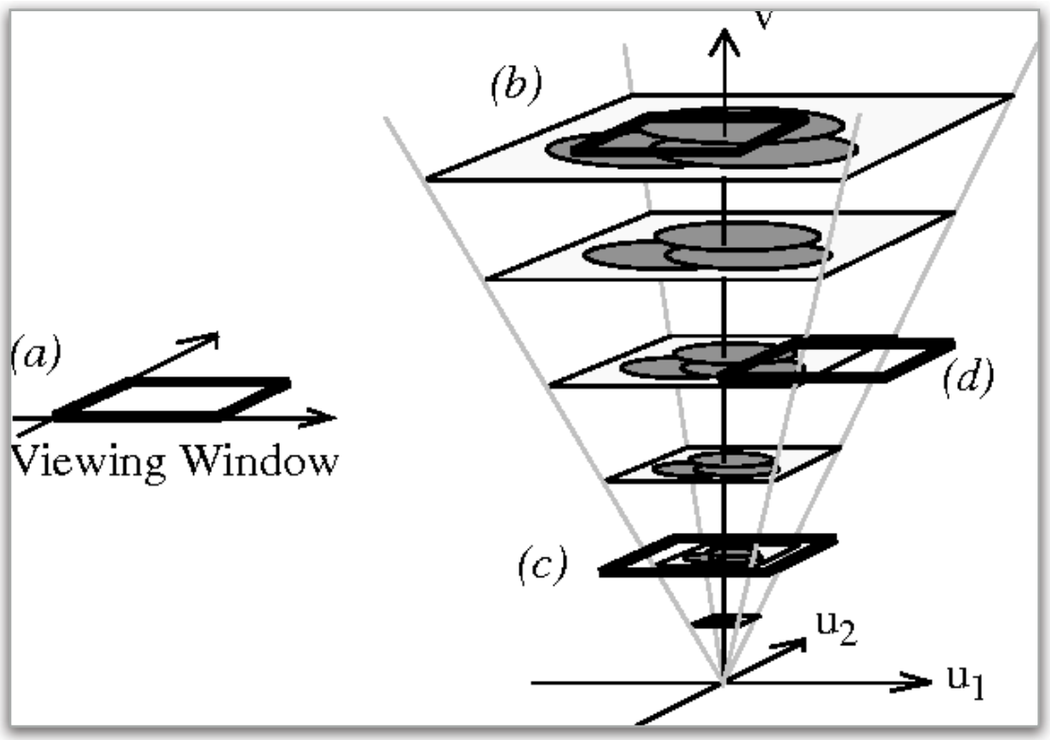


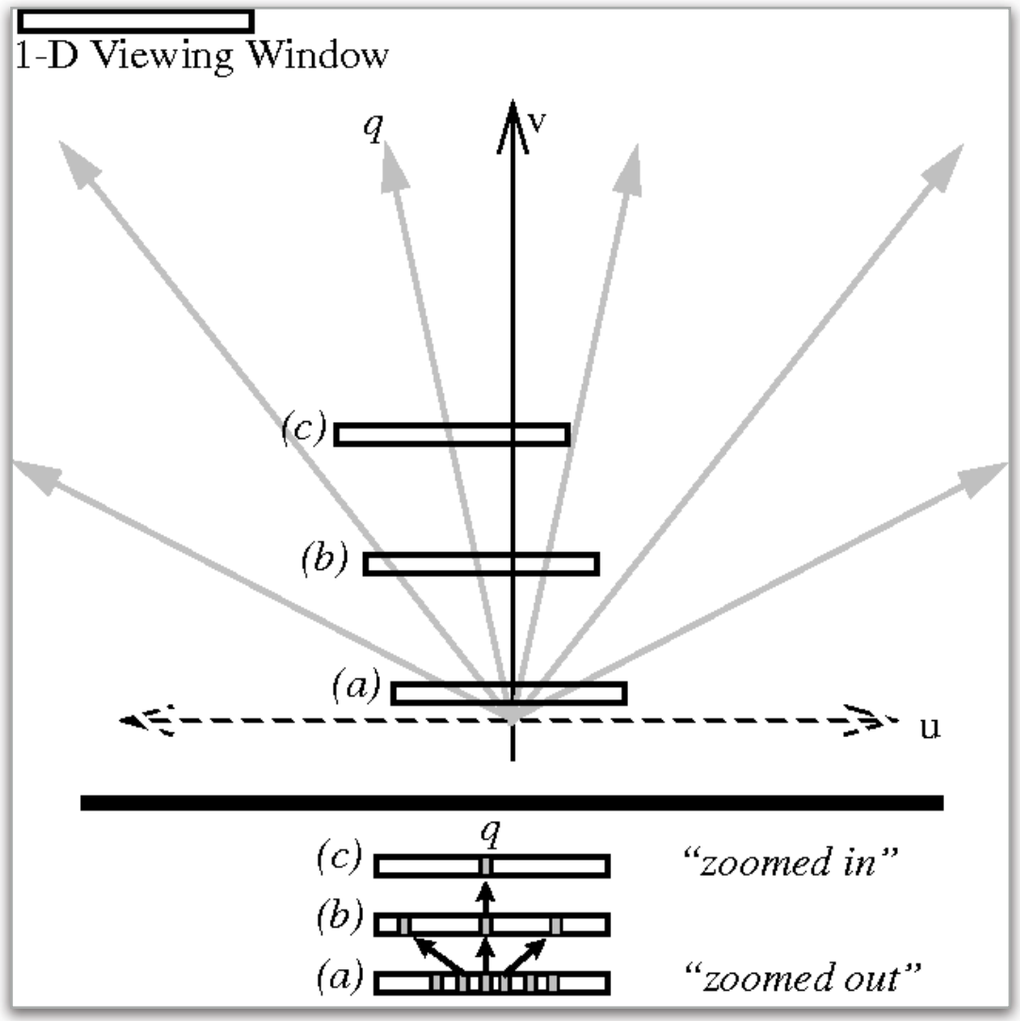


[G. Furnas and B. B. Bederson. 1995. Space-scale diagrams: understanding multiscale interfaces. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '95). ACM Press/Addison-Wesley, 234-241.]

[Image source: NASA, Blue Marble Next Generation, 2004
86,400 × 43,200]

Reasoning in 1D (2D representation of the space-scale diagram)





Taxonomy of Interface Schemes

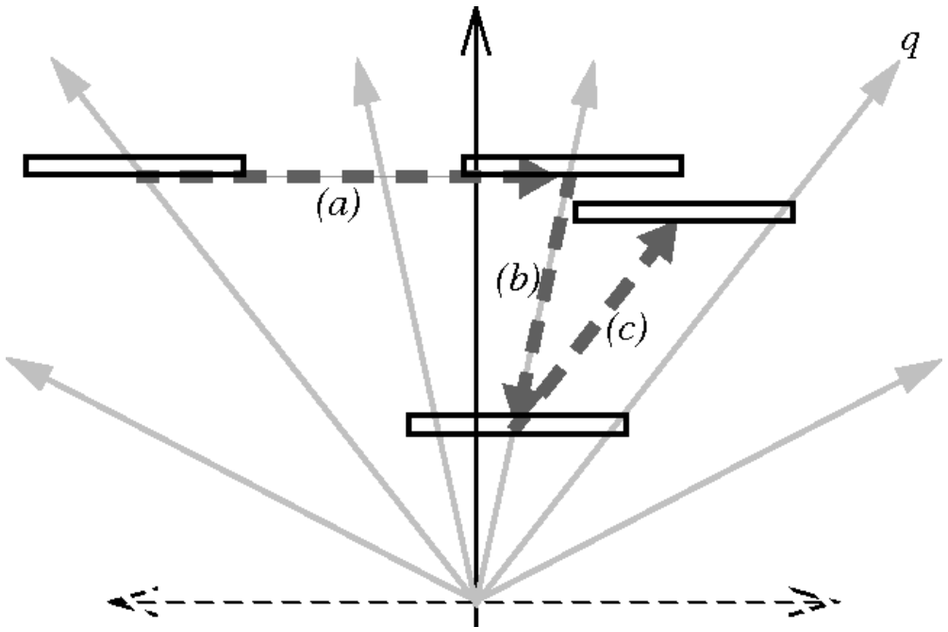
- Pan & Zoom: temporal separation

- Overview+detail: spatial separation

- Focus+context: smooth integration (embedding)

[Andy Cockburn et al. 2009. A review of overview+detail, zooming, and focus+context interfaces. ACM Comput. Surv. 41, 1, Article 2, 31 pages]

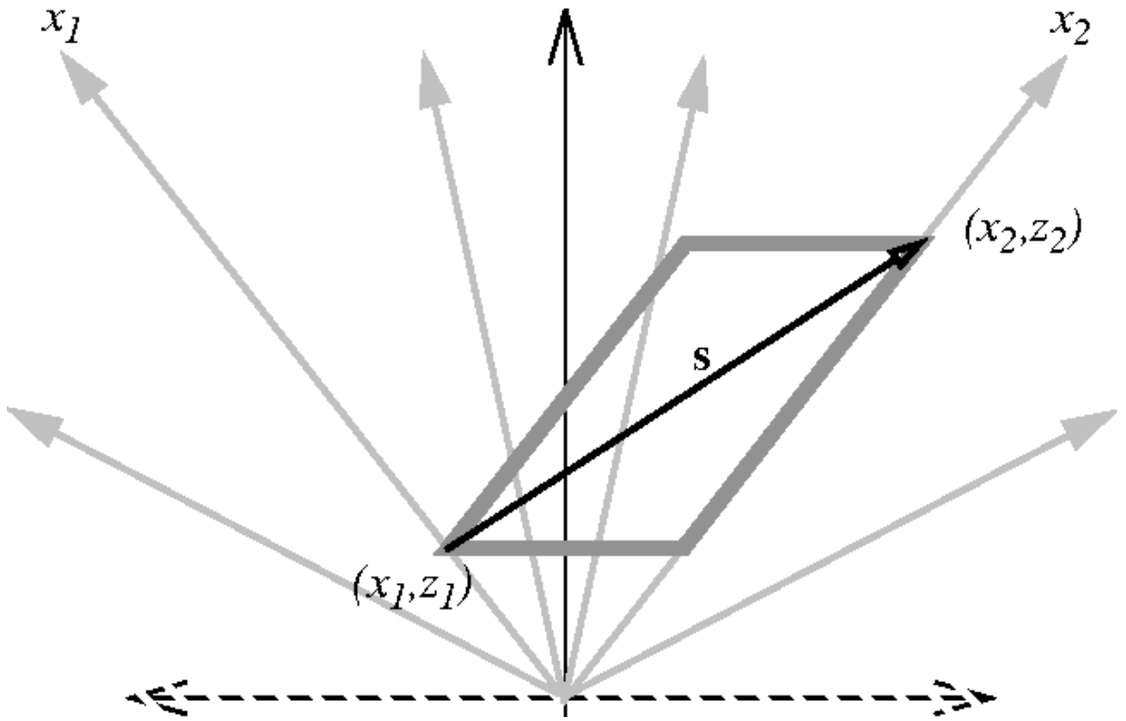
Pan & Zoom

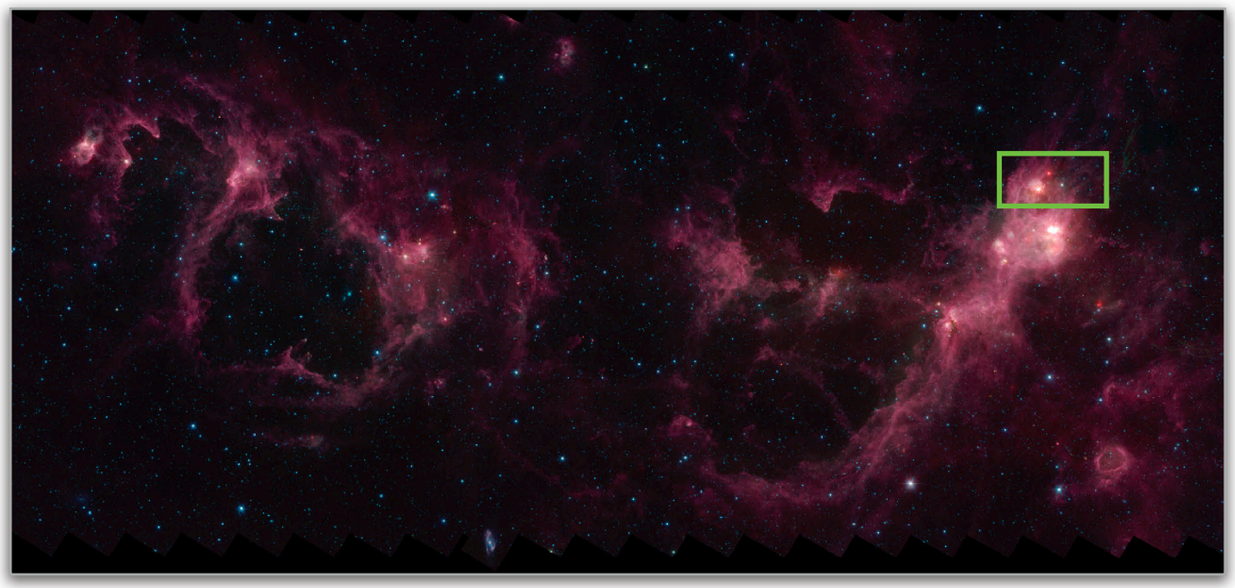


[Image source: Kolor, Paris 26 Gigapixels, 2010
354,200 × 75,570]

Pan & Zoom

Pan-zoom trajectory: integral nature of pan & zoom operations

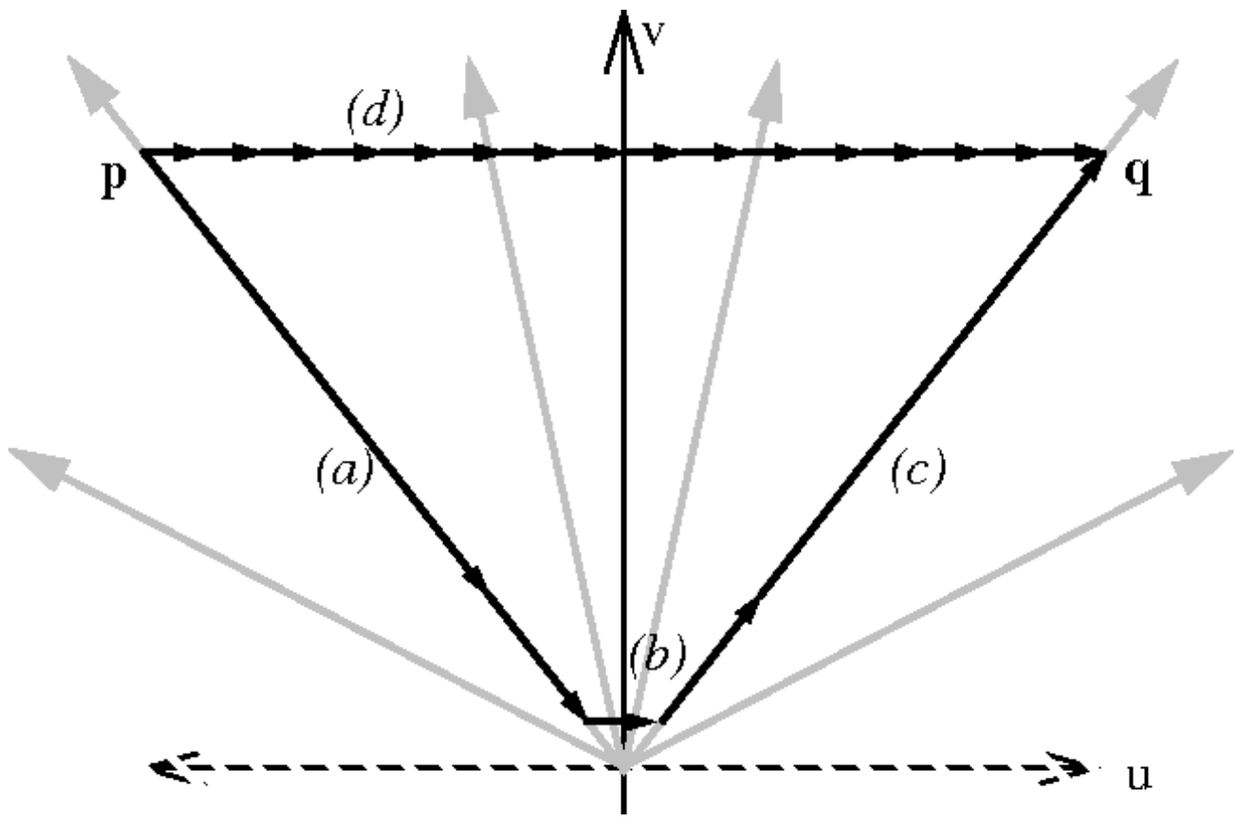


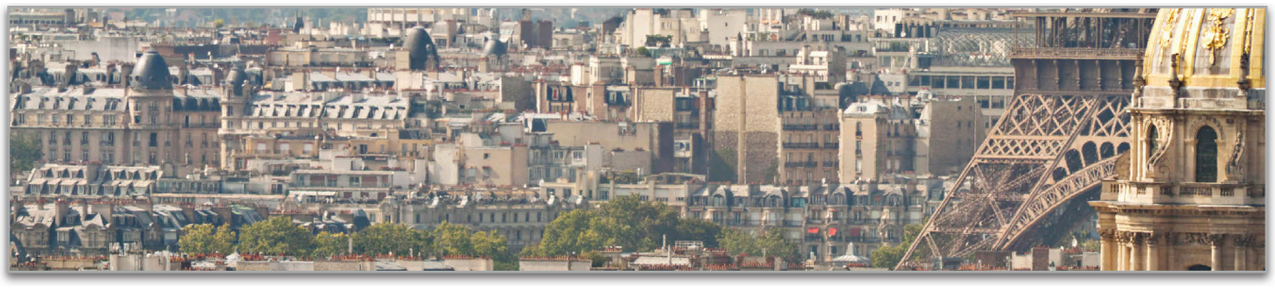


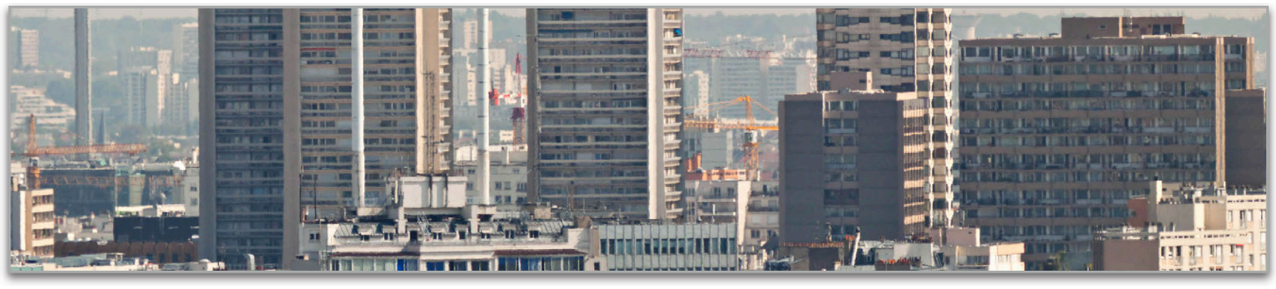
[Image source: NASA, GLIMPSE360, 2014
607,500 × 15,000]

Pan & Zoom

Pan-zoom trajectory: shortest path



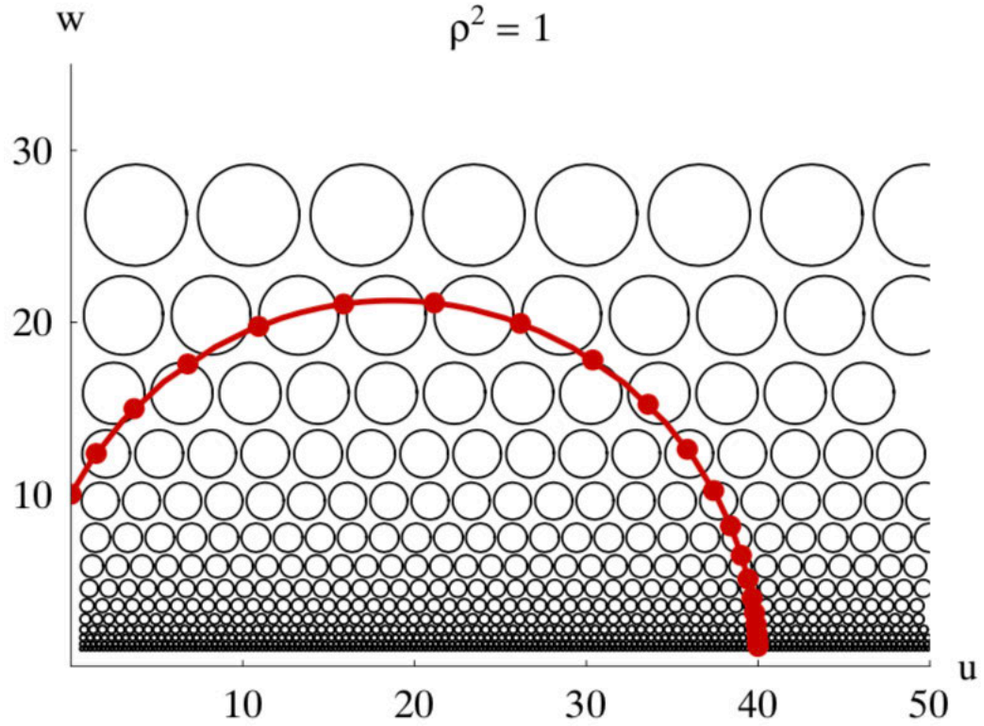




Pan & Zoom

Pan-zoom trajectory: smooth & efficient (perceived velocity)

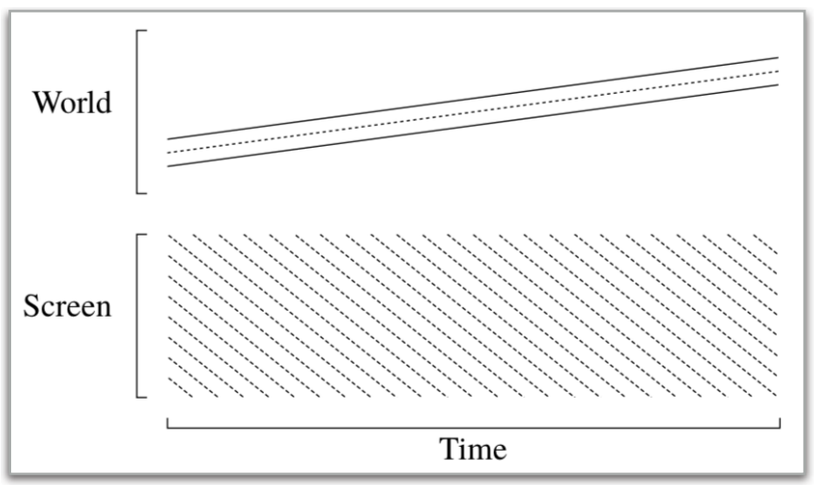
$$
\begin{aligned}
u(s) &= \frac{w_0}{\rho^2}\cosh r_0 \tanh(\rho s + r_0) - \frac{w_0}{\rho^2}\sinh r_0 + u_0, \\
w(s) &= w_0 \cosh r_0 / \cosh(\rho s + r_0), \\
S &= (r_1 - r_0)/\rho, \\
r_i &= \ln(-b_i + \sqrt{b_i^2 + 1}),\ i = 0, 1, \text{ and} \\
b_i &= \frac{w_1^2 - w_0^2 + (-1)^i \rho^4 (u_1 - u_0)^2}{2 w_i \rho^2 (u_1 - u_0)},\ i = 0, 1,
\end{aligned}
$$



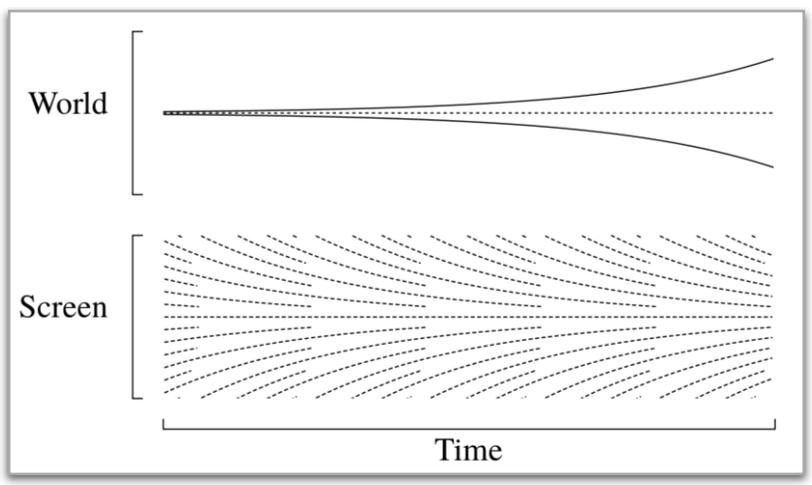
[J. J. van Wijk and W. A. A. Nuij. 2003. Smooth and efficient zooming and panning. In Proceedings of the 9th conference on Information visualization (InfoVis'03), IEEE, 15-22.]

Pan-zoom trajectory: smooth, efficient *& interruptible*

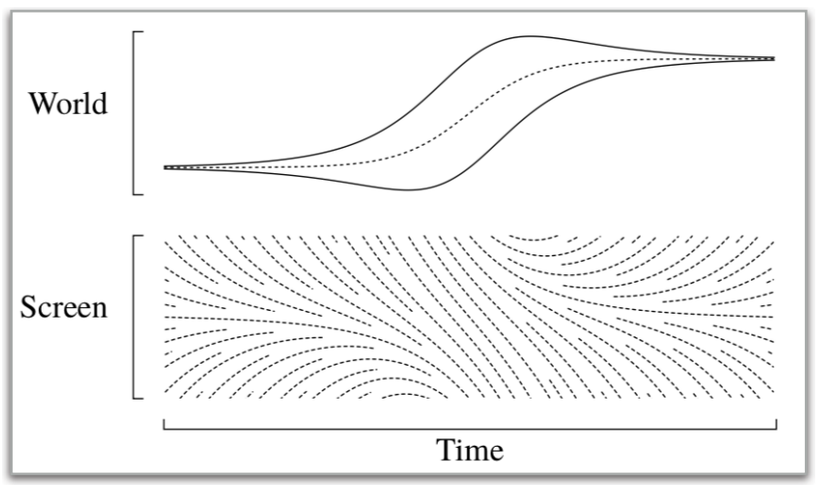
`sei_zoom.mp4`



pan



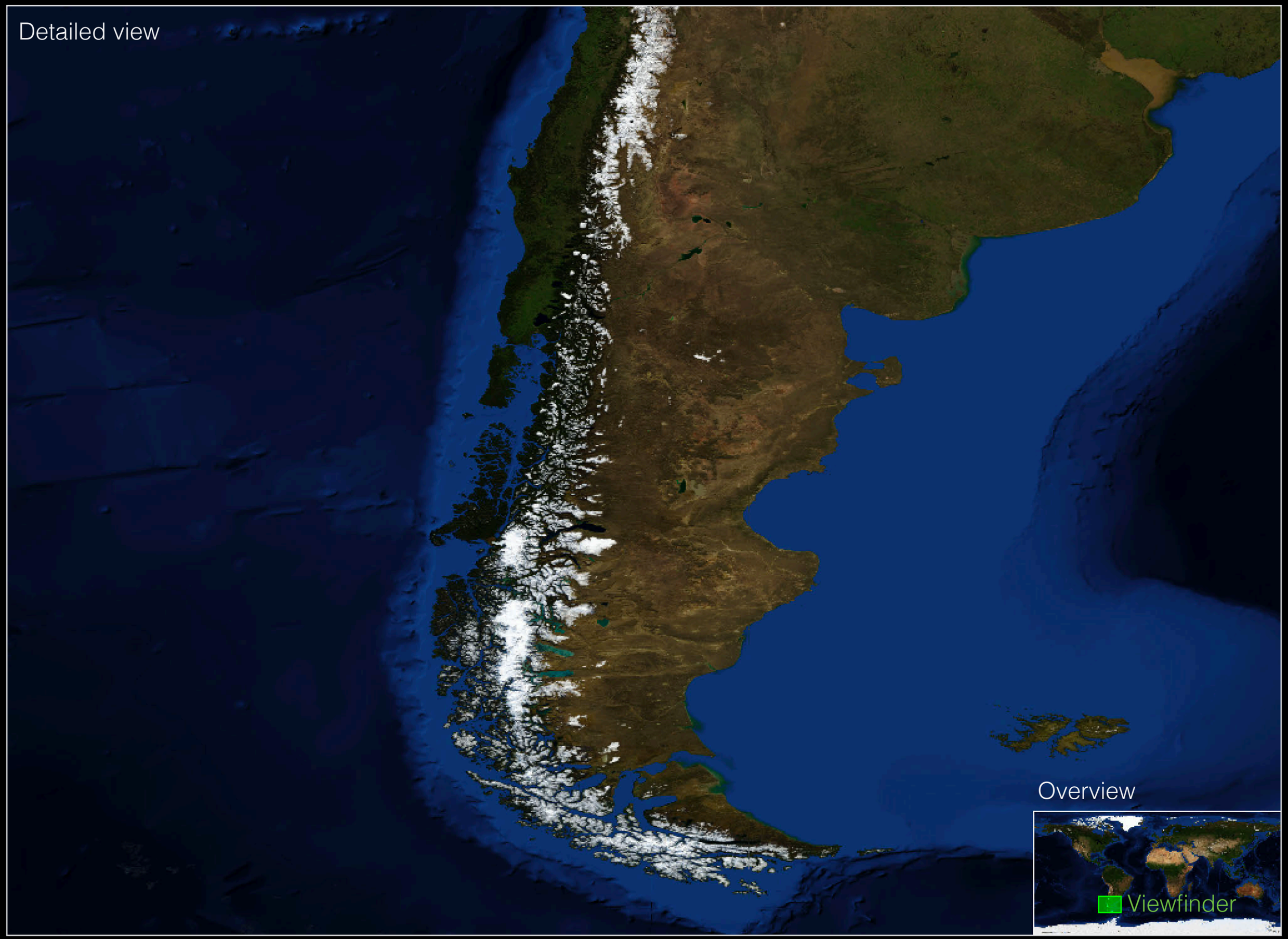
zoom out



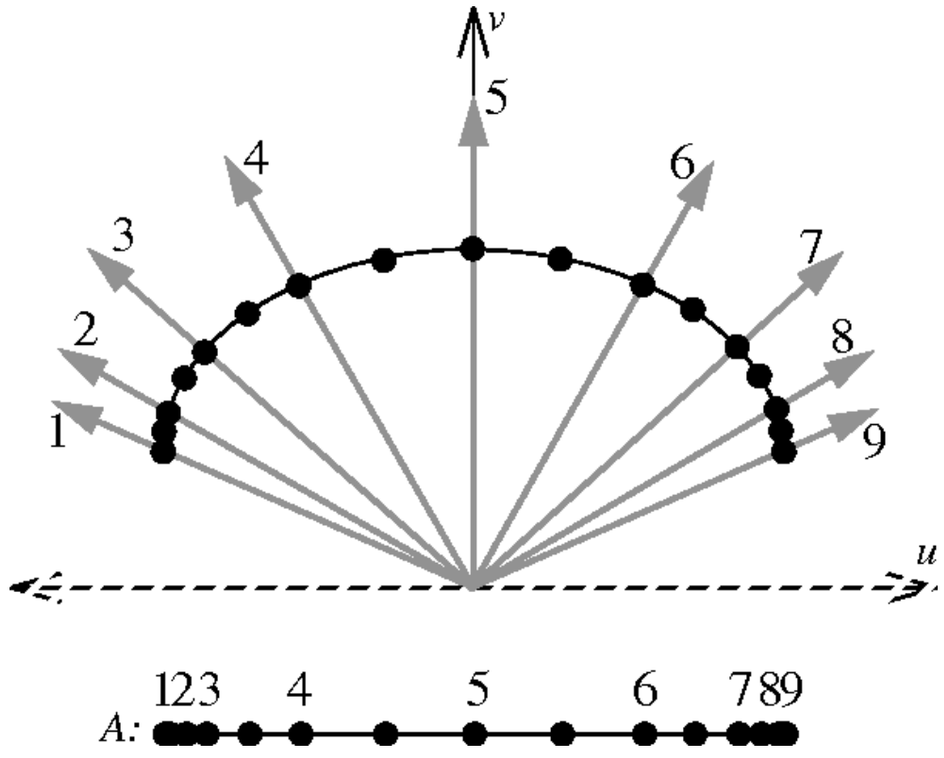
zoom out+pan/zoom-in+pan

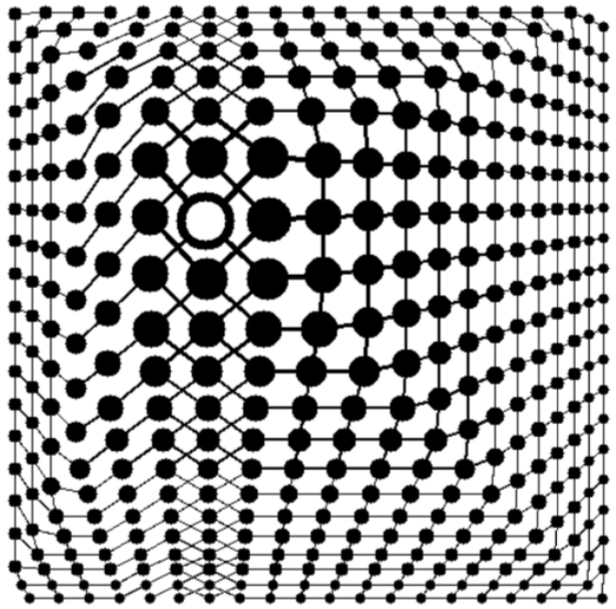
[A. McCaleb Reach and C. North. Smooth, efficient and interruptible zooming and panning. IEEE Transactions on Visualization and Computer Graphics (TVCG), early access, 2018]

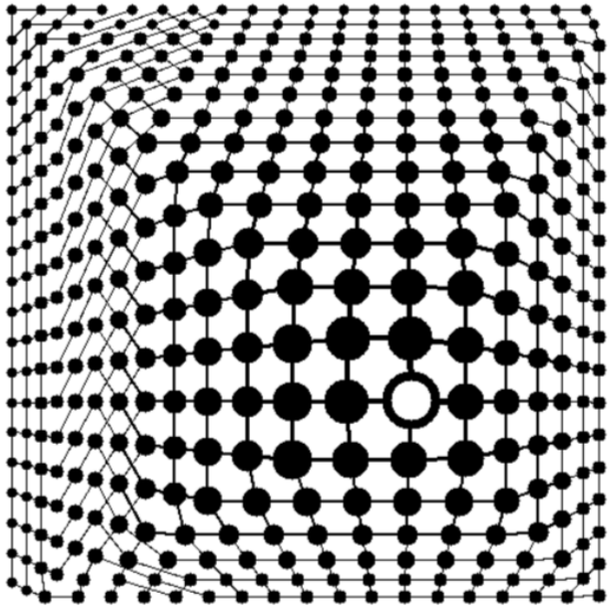
Overview + detail



Focus+context: Fisheye lenses

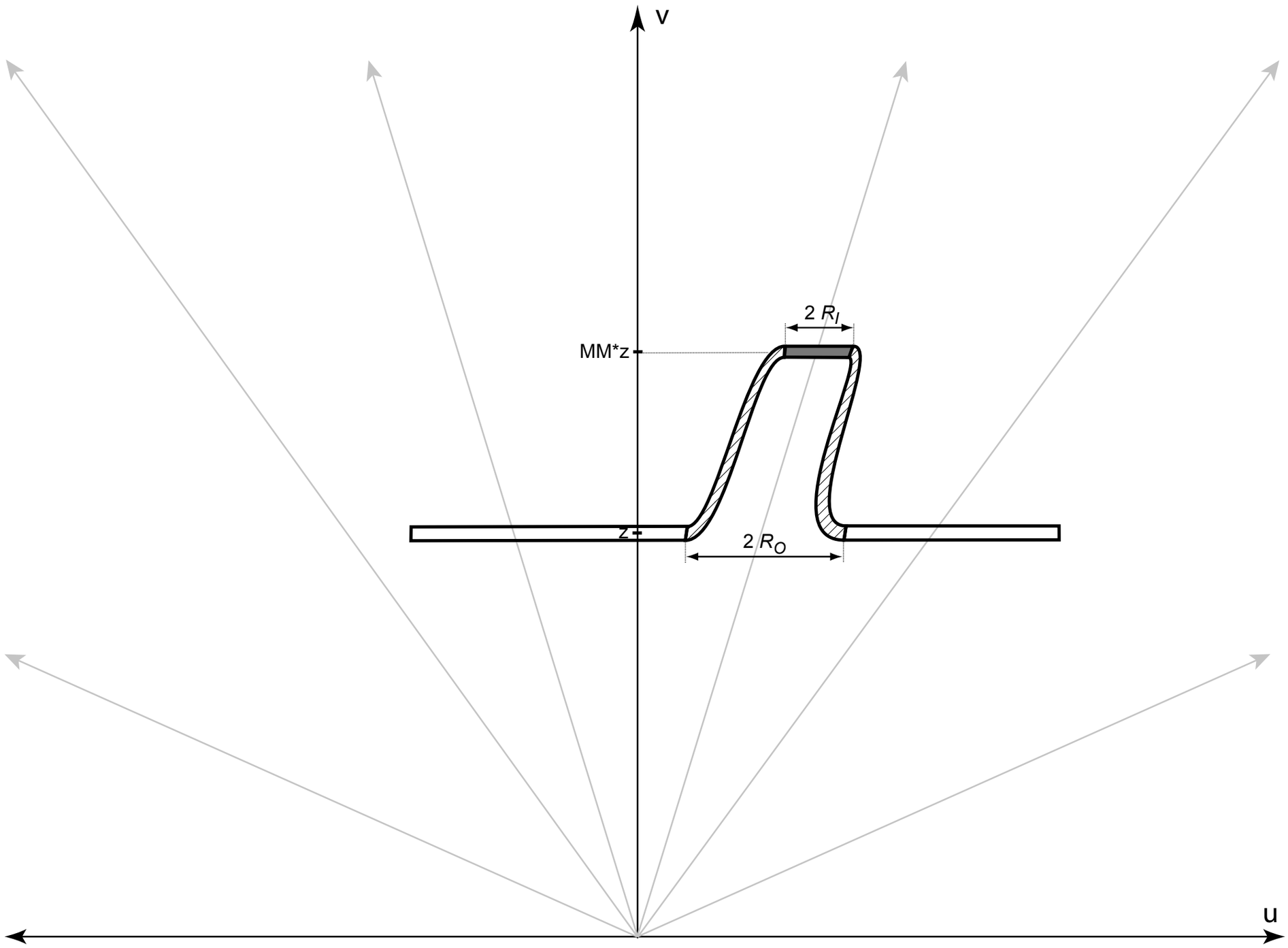






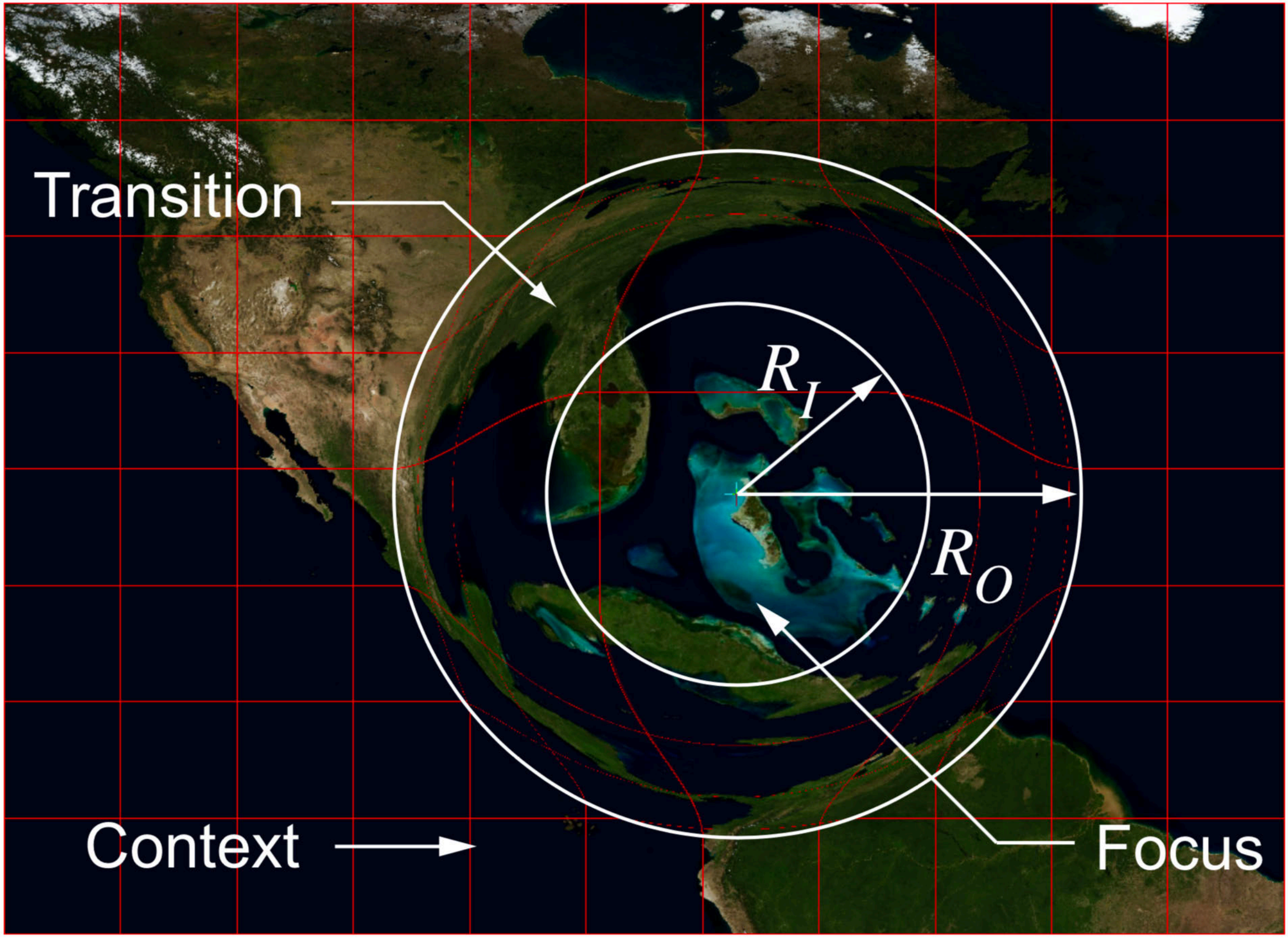
[M. Sarkar and M. H. Brown. Graphical fisheye views. Communications of the ACM 37, 12, 1994, 73-83]

Focus+context: locally-bounded fisheyes

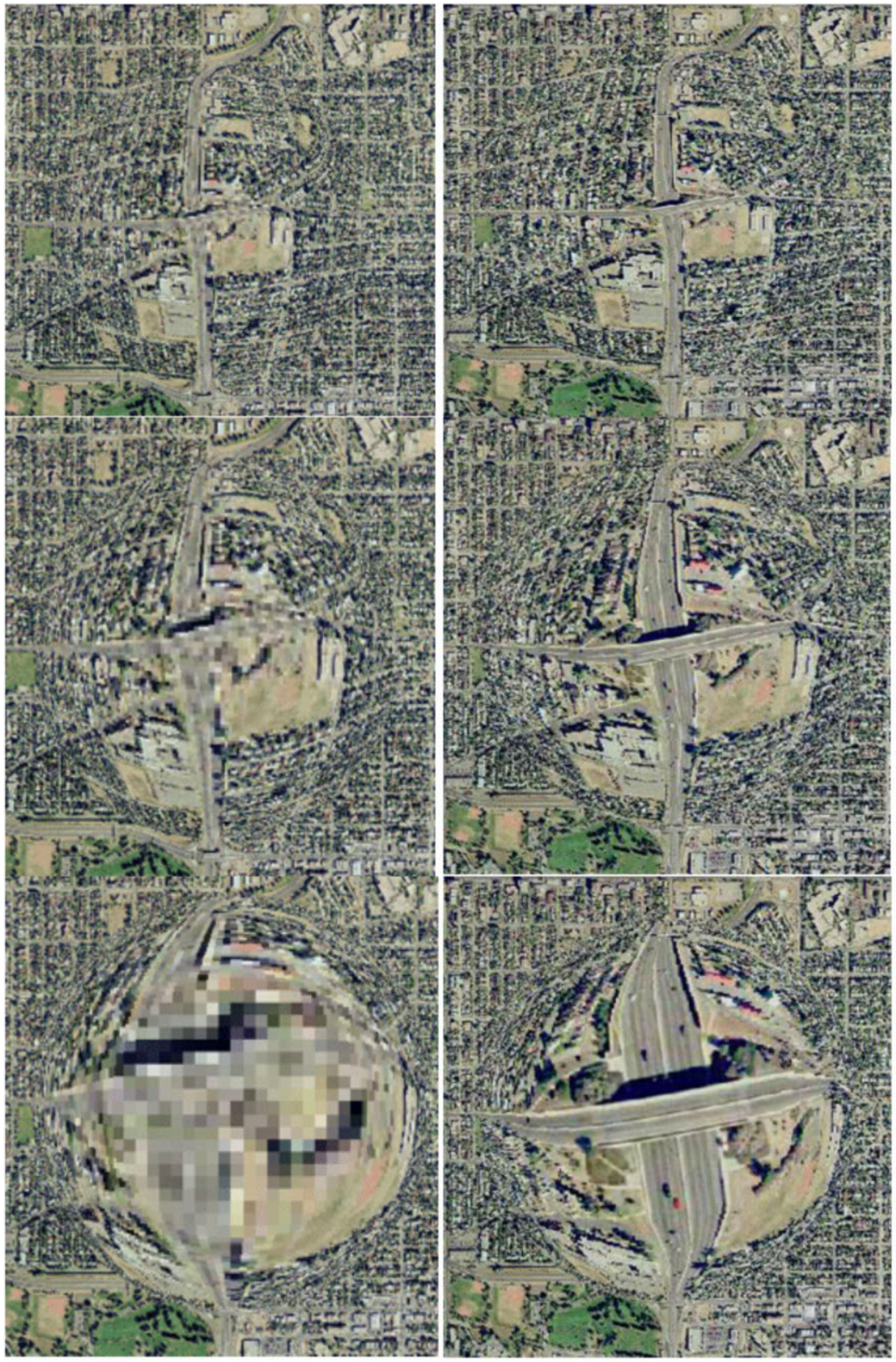


Many focus+context techniques use spatial distortion to smoothly transition between focus and context.

Focus+context



Focus+context: pliable surfaces



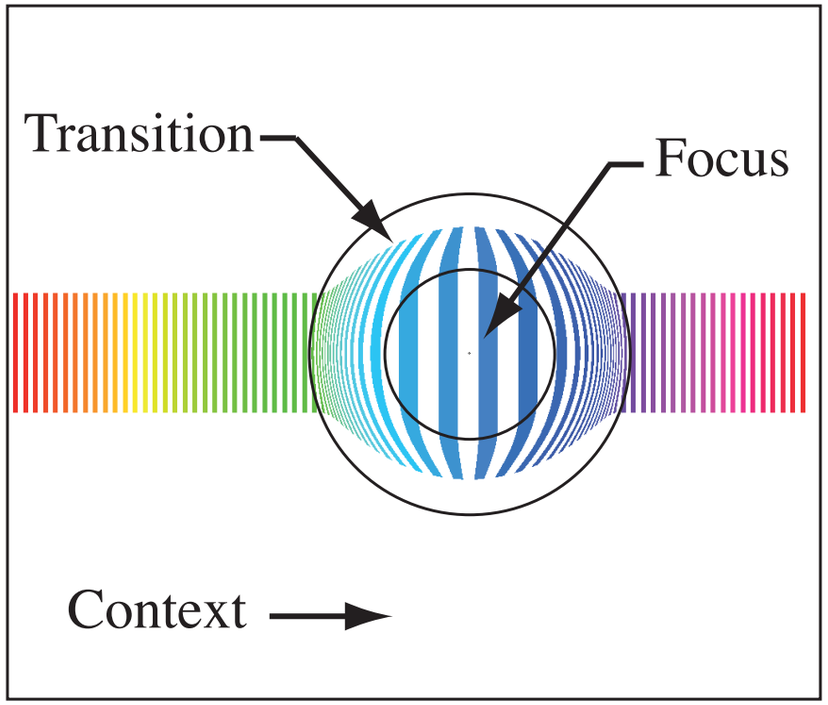
[S. Carpendale et al. 2004. Achieving higher magnification in context. In Proceedings of the 17th annual ACM symposium on User interface software and technology (UIST '04). ACM, 71-80]

Content-aware adaptable focus+context views

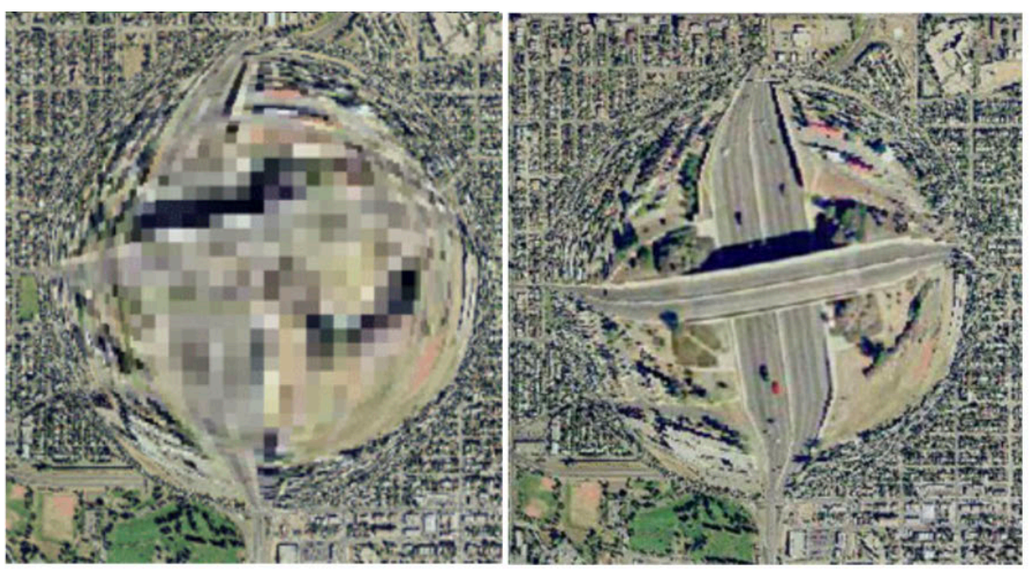
jelly-lenses-UIST2012.mov

[C. Pindat et al., JellyLens: Content-Aware Adaptive Lenses, UIST '12: Proceedings of the 25th Symposium on User Interface Software and Technology, pages 261-270, 2012]

Rendering



Rendering in the final 2D viewing window



[E. Pietriga et al., Representation-Independent In-Place Magnification with Sigma Lenses, IEEE Transactions on Visualization and Computer Graphics (TVCG), 16, 3, pages 455-467, 2010]