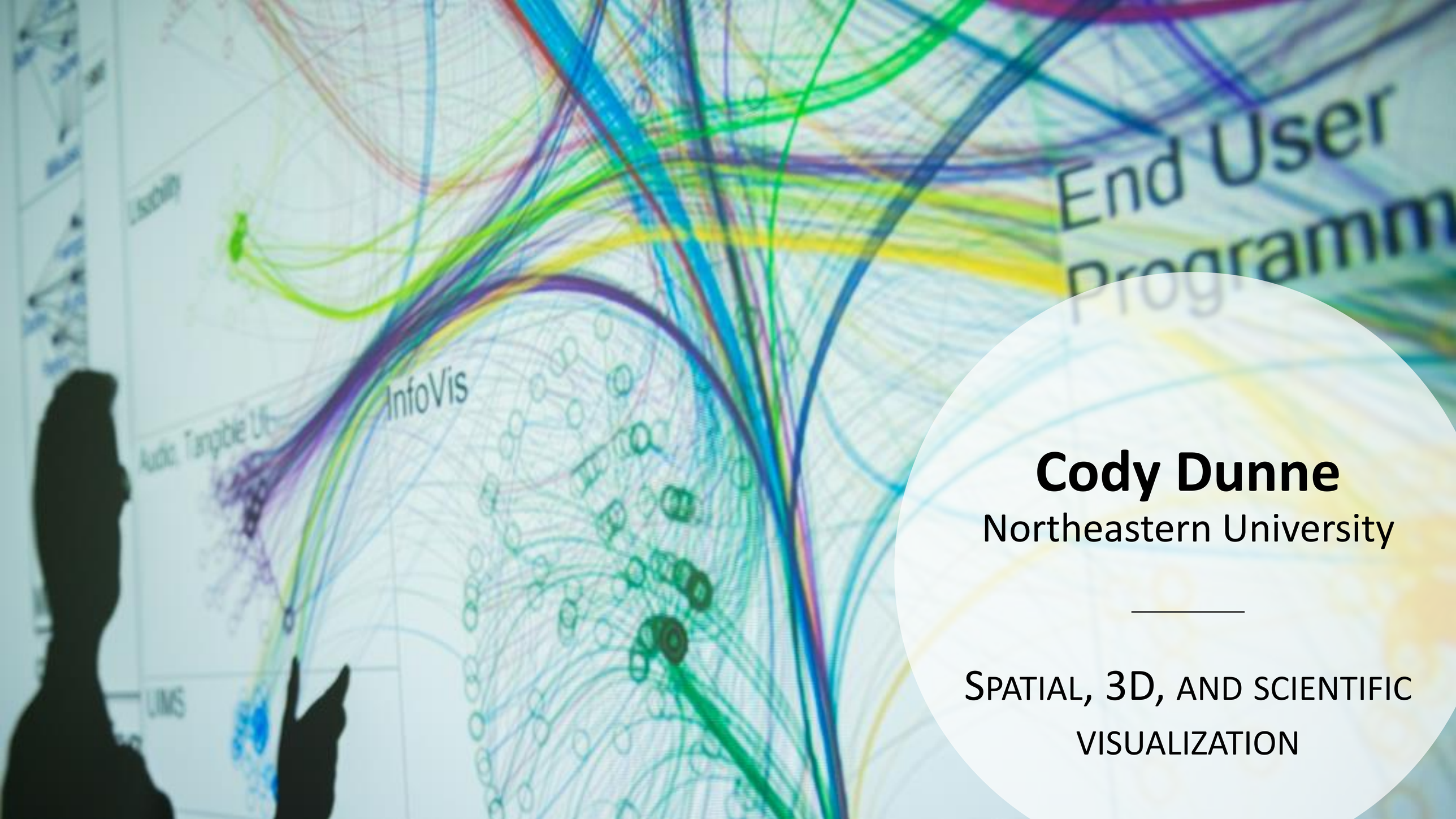


Cody Dunne

Northeastern University

SPATIAL, 3D, AND SCIENTIFIC VISUALIZATION

READING QUIZ

Q3—Arrange spatial data

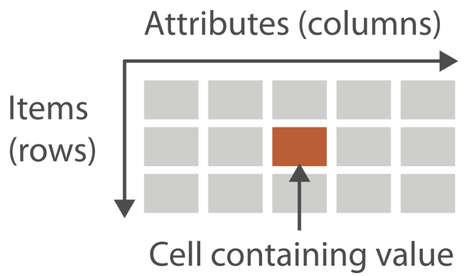
Maps

Goals for Today

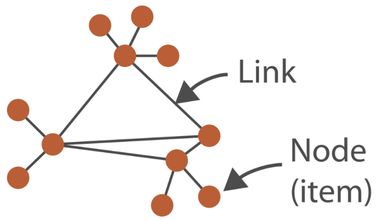
- Learn what elements visually encode data in maps.
- Learn about different projections, and understand the (dis)advantages of each.
- Learn about different map types, and how they relate to tasks.

Dataset Types

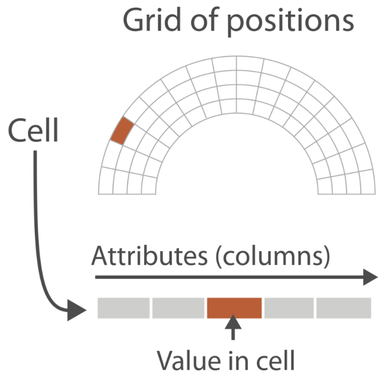
Tables



Networks

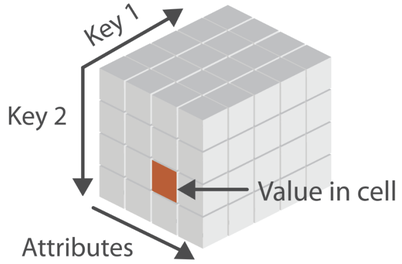


Fields (Continuous)

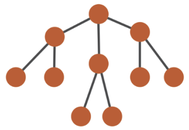


Geometry (Spatial)

Multidimensional Table



Trees



Arrange Spatial Data

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

Oldest Maps (i.e., old visualizations!)

Lascaux cave paintings - over 16,000 years old!

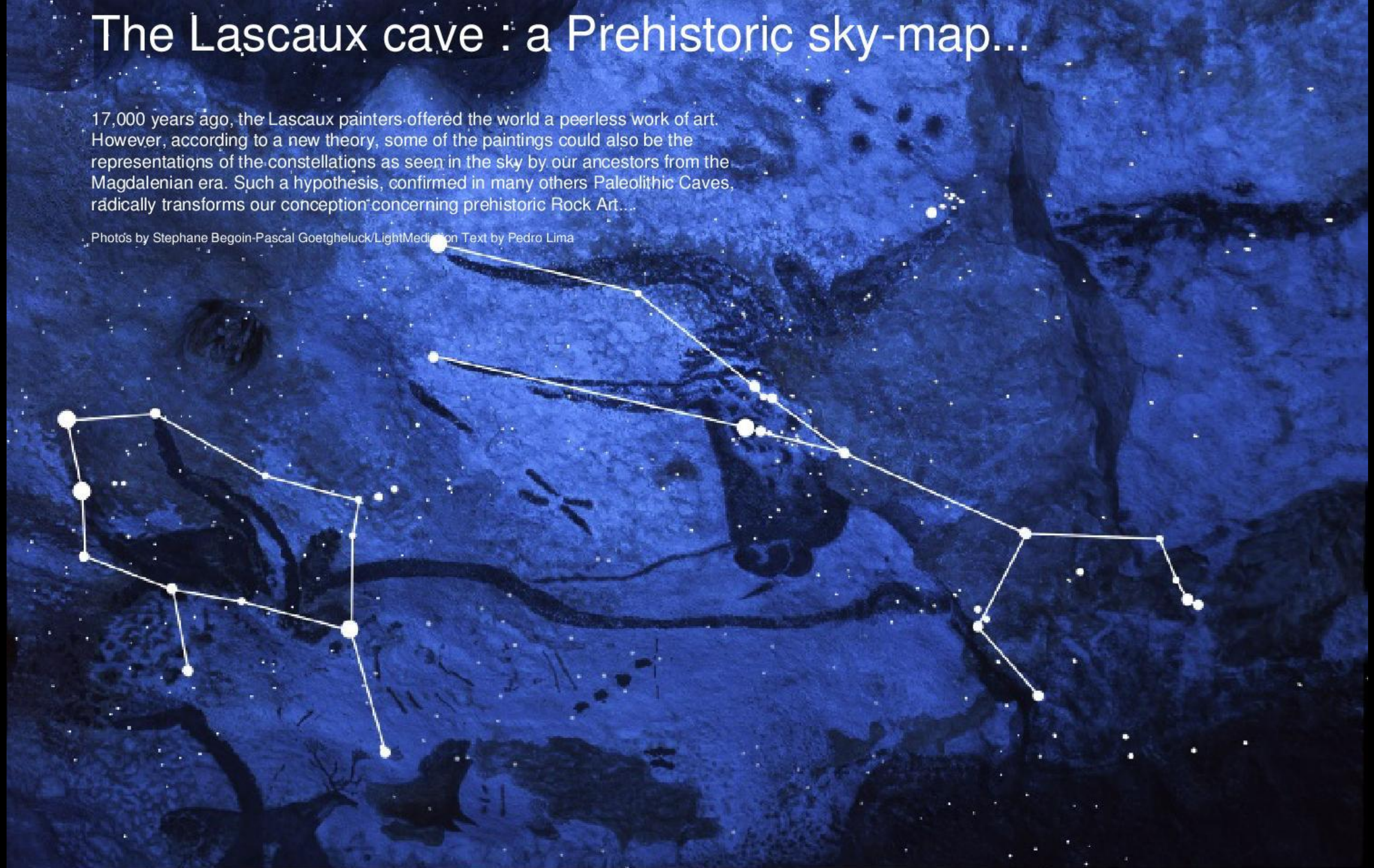
Vega, Deneb, and Altair

Lightmediation, 2008; Whitehouse, 2000

The Lascaux cave : a Prehistoric sky-map...

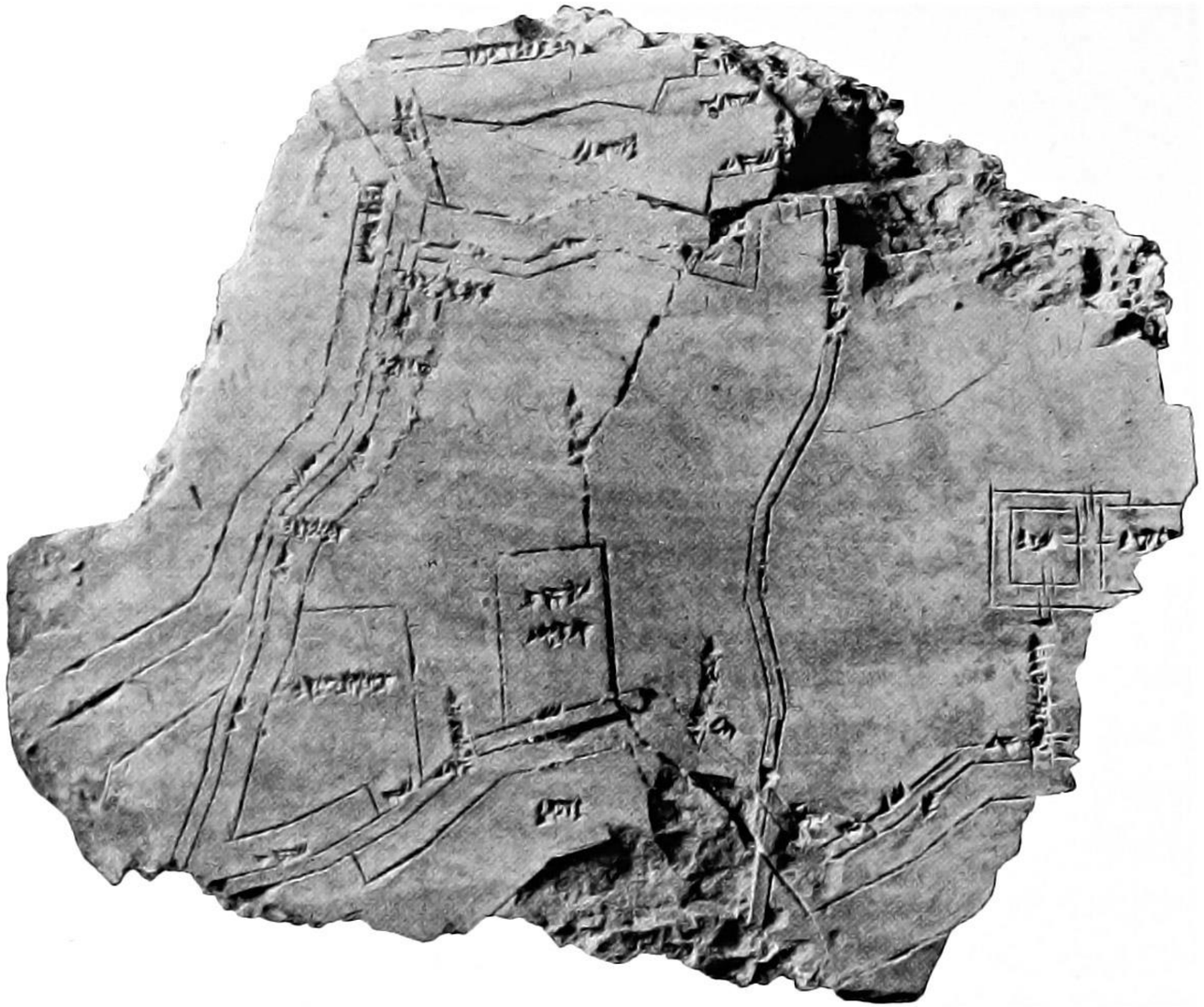
17,000 years ago, the Lascaux painters offered the world a peerless work of art. However, according to a new theory, some of the paintings could also be the representations of the constellations as seen in the sky by our ancestors from the Magdalenian era. Such a hypothesis, confirmed in many others Paleolithic Caves, radically transforms our conception concerning prehistoric Rock Art...

Photos by Stephane Begoin-Pascal Goetgheluck/LightMedia - Text by Pedro Lima



Oldest Maps (i.e., old visualizations!)

Clay tablet
with map of
the Babylonian
city of Nippur
(ca. 1400 BC)

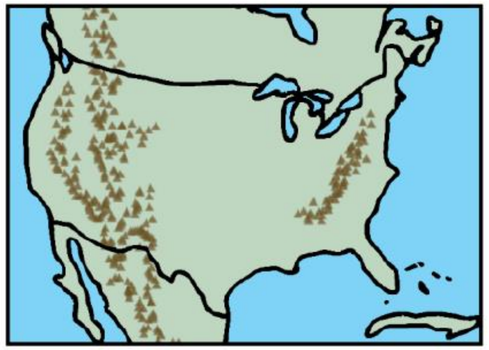


Hilprecht, 1903

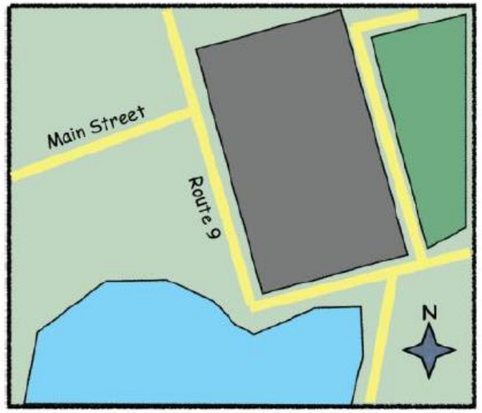
Map

Geographic Map

Geographic Map



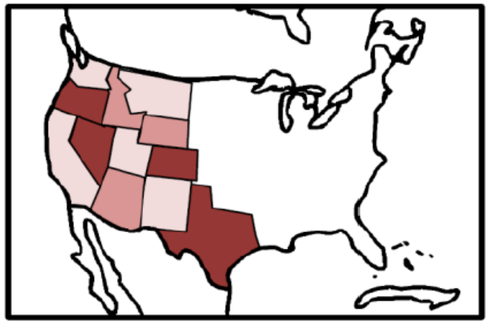
Street Map



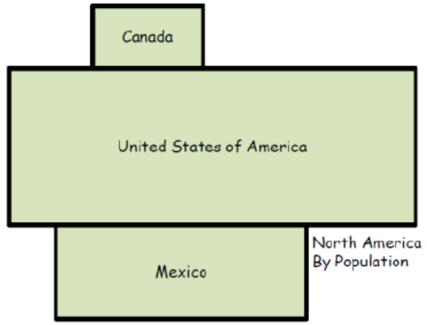
Flow Map

Statistical Map

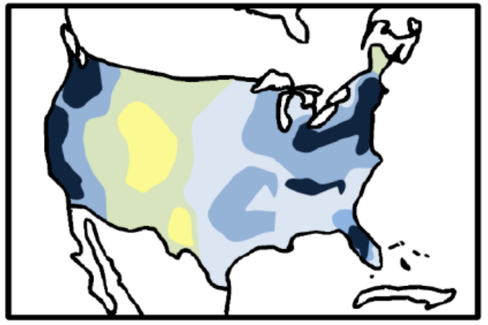
Choropleth Map



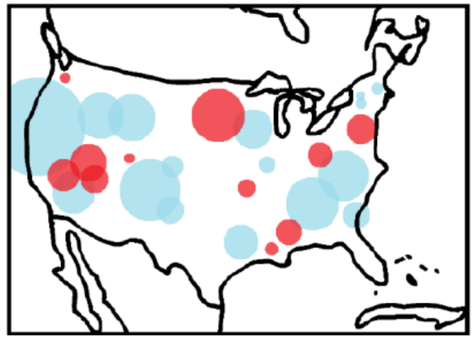
Distorted Map (Cartogram)



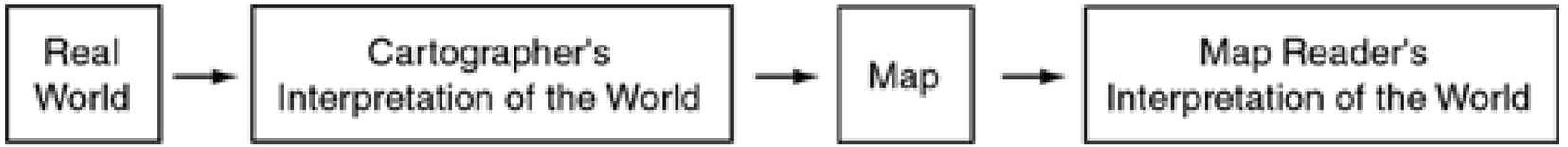
Contour Map (Isopleth)



Statistical Plot Map



Geographic Map Tasks & Users



Make sure the map representation, data encodings, data plotted, and dimensionality reduction is appropriate for the viewers and their tasks.

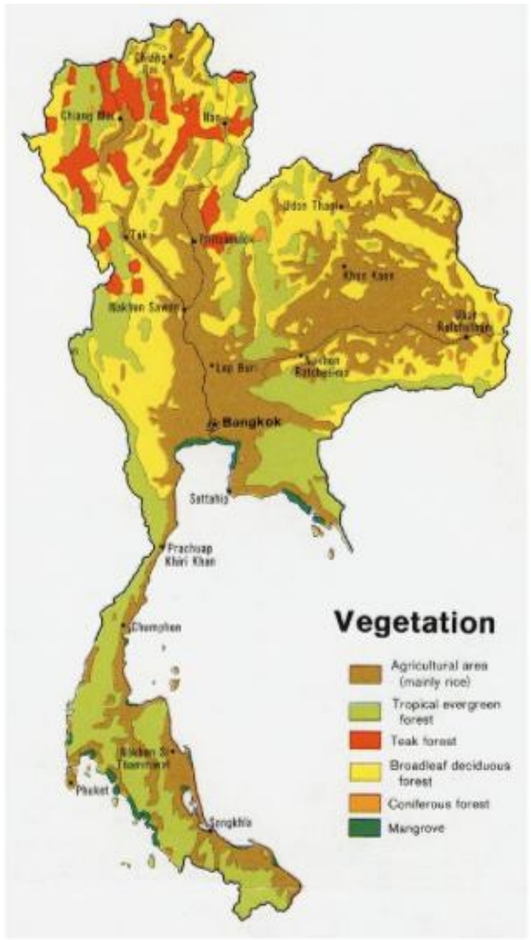
Fritz Kessler, 2018

Types of Geographic Maps

Three broad categories of maps:

Reference maps

Thematic maps



Special-purpose maps

[Fritz Kessler, 2018]

Types of Geographic Maps

Three broad categories of maps:

Reference maps

A map that plots several types of spatial data without specific emphasis on one type over another.

Thematic maps

A map with a specific theme or focus. Typically display attributes of features that vary spatially in a qualitative (e.g., precipitation) or nominal way (e.g., categories of land cover).

Special-purpose maps

Typically thematic maps but are task/user specific (i.e., used like reference maps but for specific tasks or specific types of data).

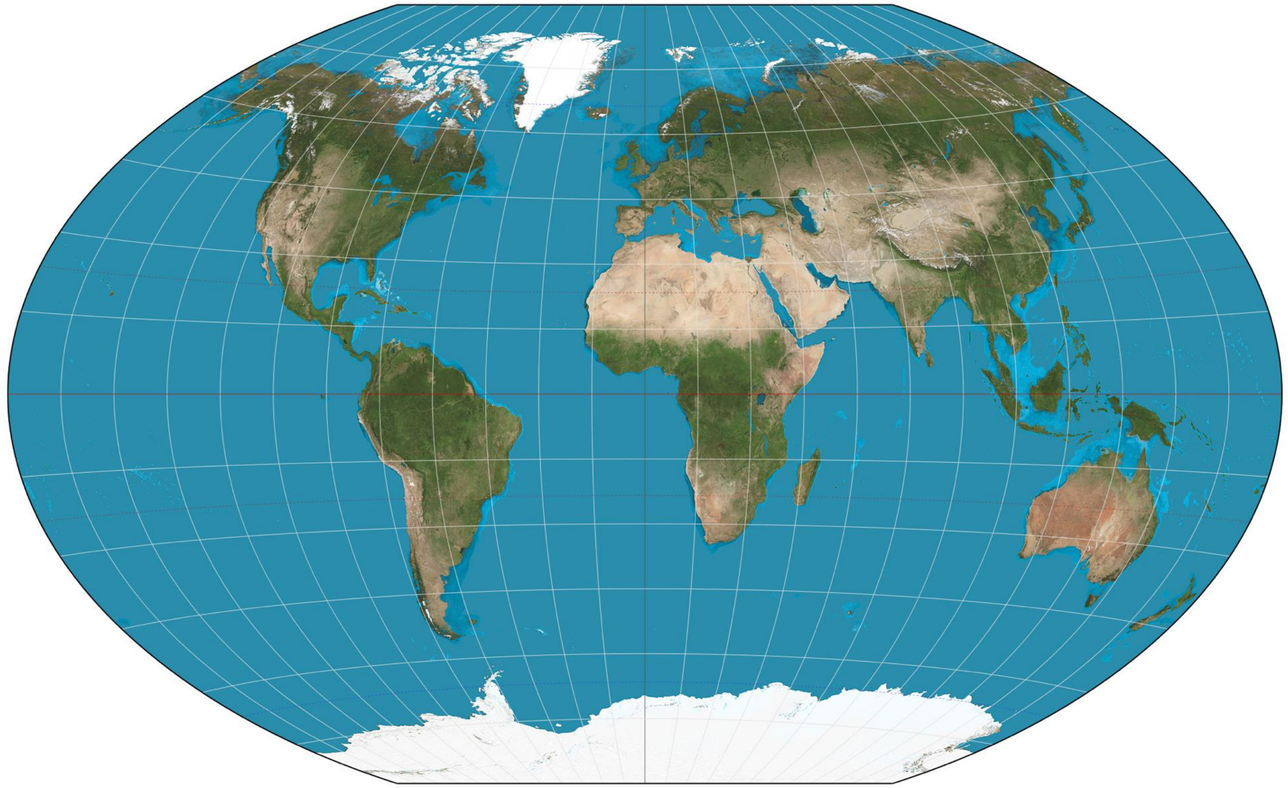
Fritz Kessler, 2018

Geographic Map Projections

Dimensionality reduction

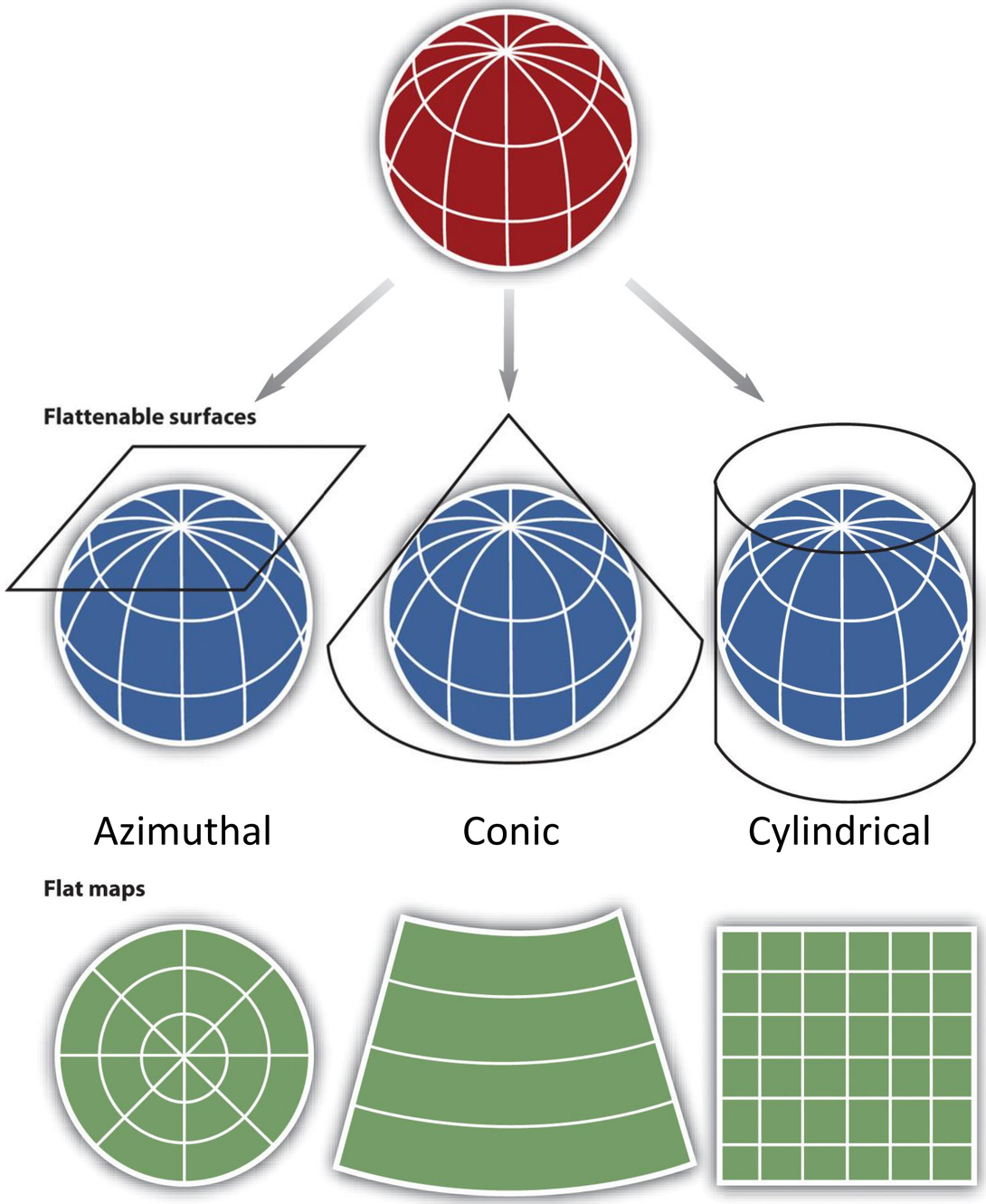
3D

2D



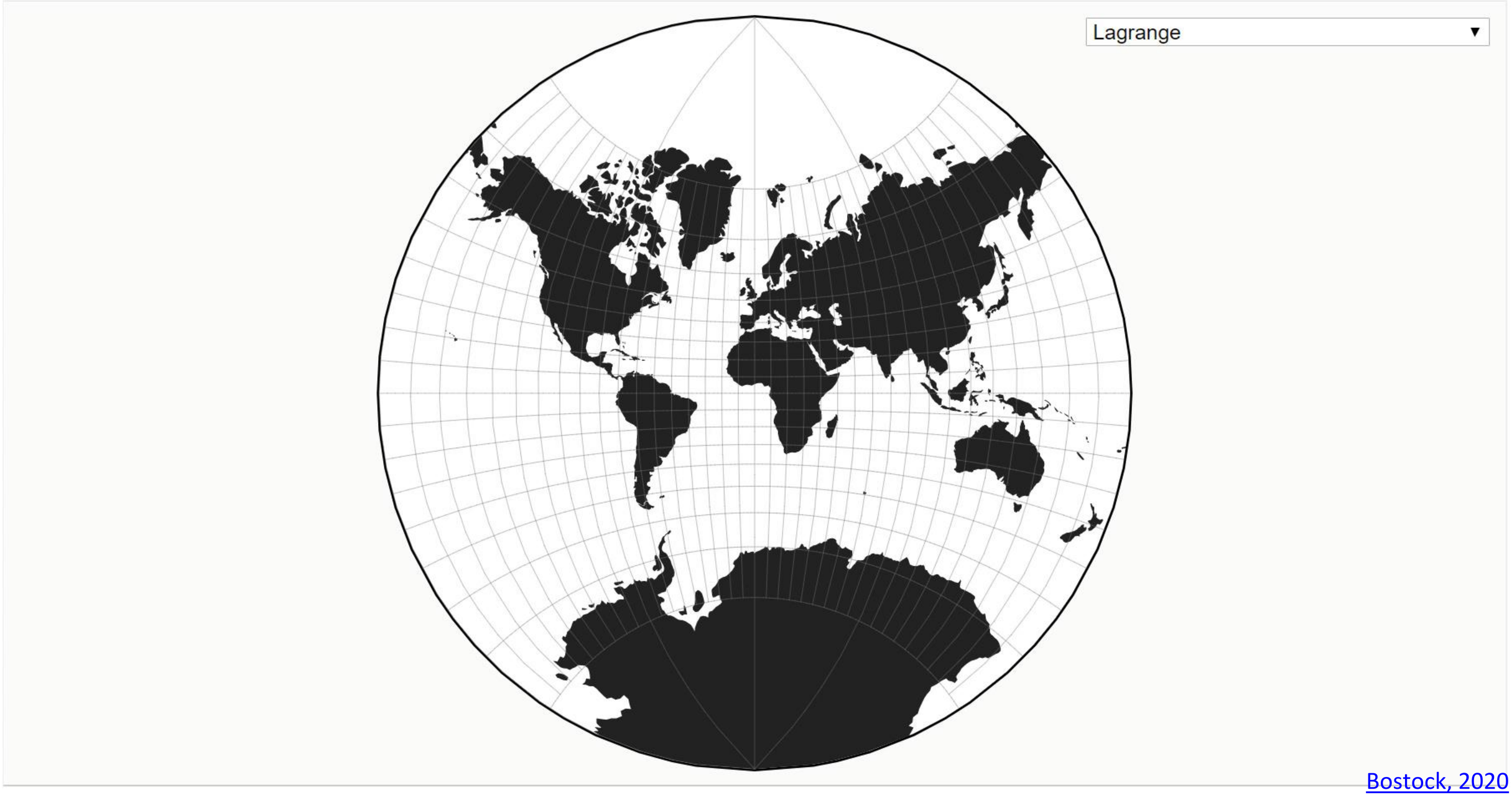
Vox

Dimensionality reduction



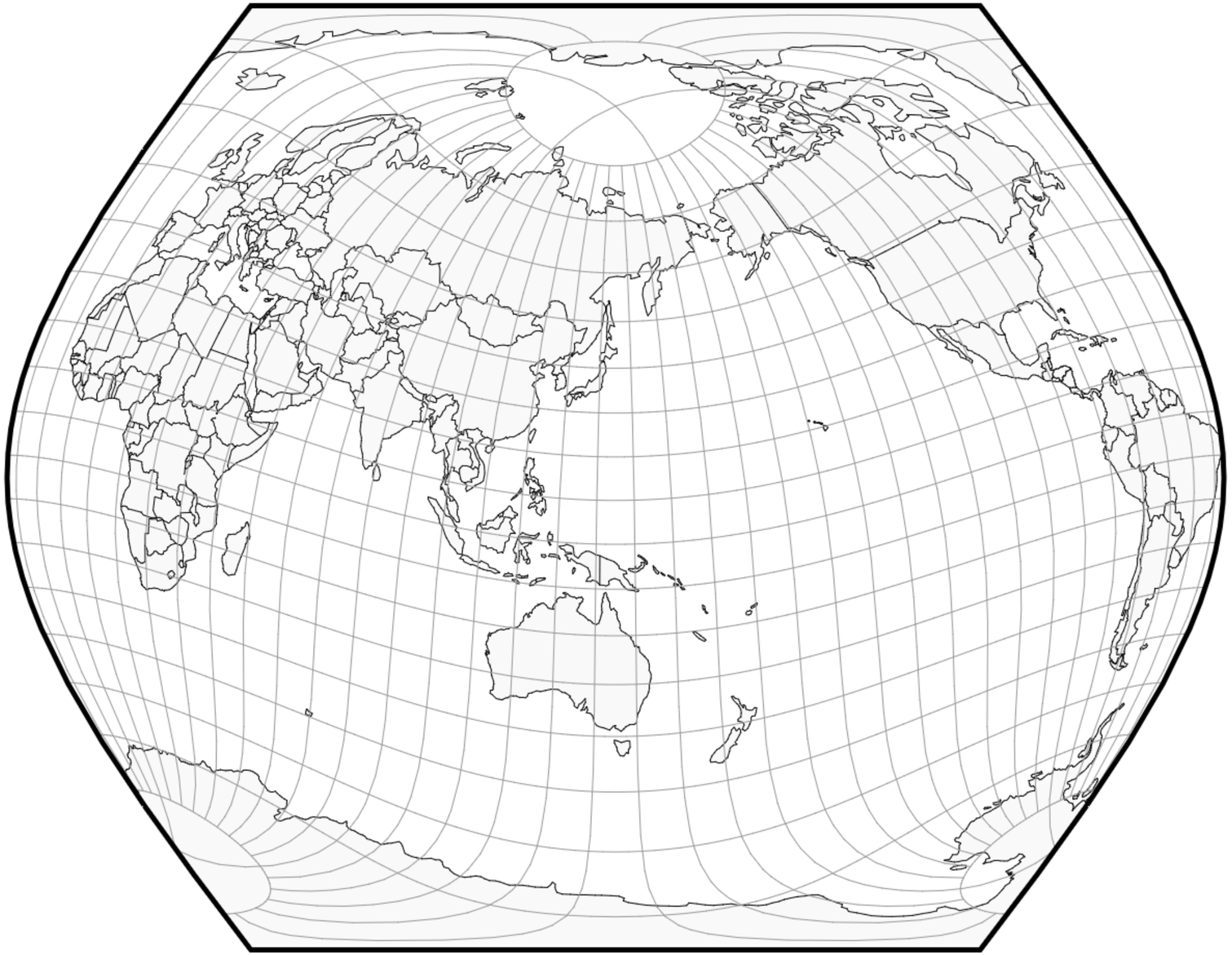
Unknown author, < 2012

Projection Transitions



Bostock, 2020

Map Projection Transitions



Jason Davies, 2013

Maps can deceive...

Mercater Projection. Credit: Strebe/Wikimedia

HUMANS

It's Official: Boston's Public Schools Have Ditched This Distorted And Misleading World Map

BEC CREW 20 MARCH 2017

Last Thursday, social studies teachers in Boston's public schools ditched the widely used - but horribly distorted - Mercator Projection map in favour of a more accurate depiction of the world's landmasses.

The move puts an end to more than four centuries of misleading representations of the world, because the map you're used to seeing on the news and in atlases makes South America look like it's the same size as Europe - when it's almost twice as large - and Greenland looks equal to Africa, when it's actually 14 times smaller.

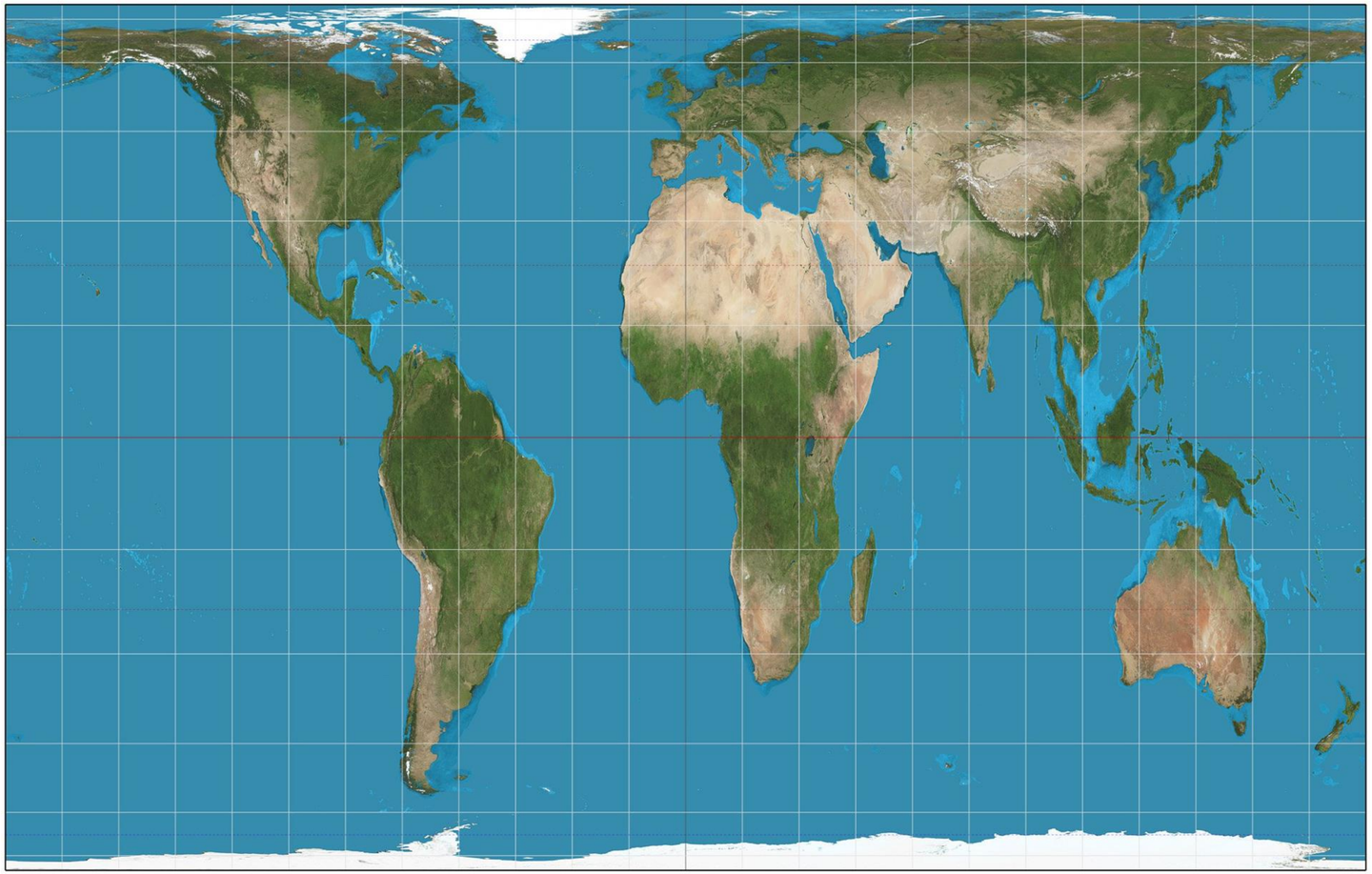
The shift towards the more accurate Gall-Peters Projection sees Boston's public schools follow the lead of the United Nations, which has advocated the map as a more 'fair', less Eurocentric representation of the world, as have several aid agencies.

Bec Crew, 2017

Mercator Projection

Great for ocean navigation,
but dramatically exaggerates poles.

Gall-Peters Projection



More accurate land areas.
(Officially endorsed by the UN.)

Bec Crew, 2017

Maps can deceive...

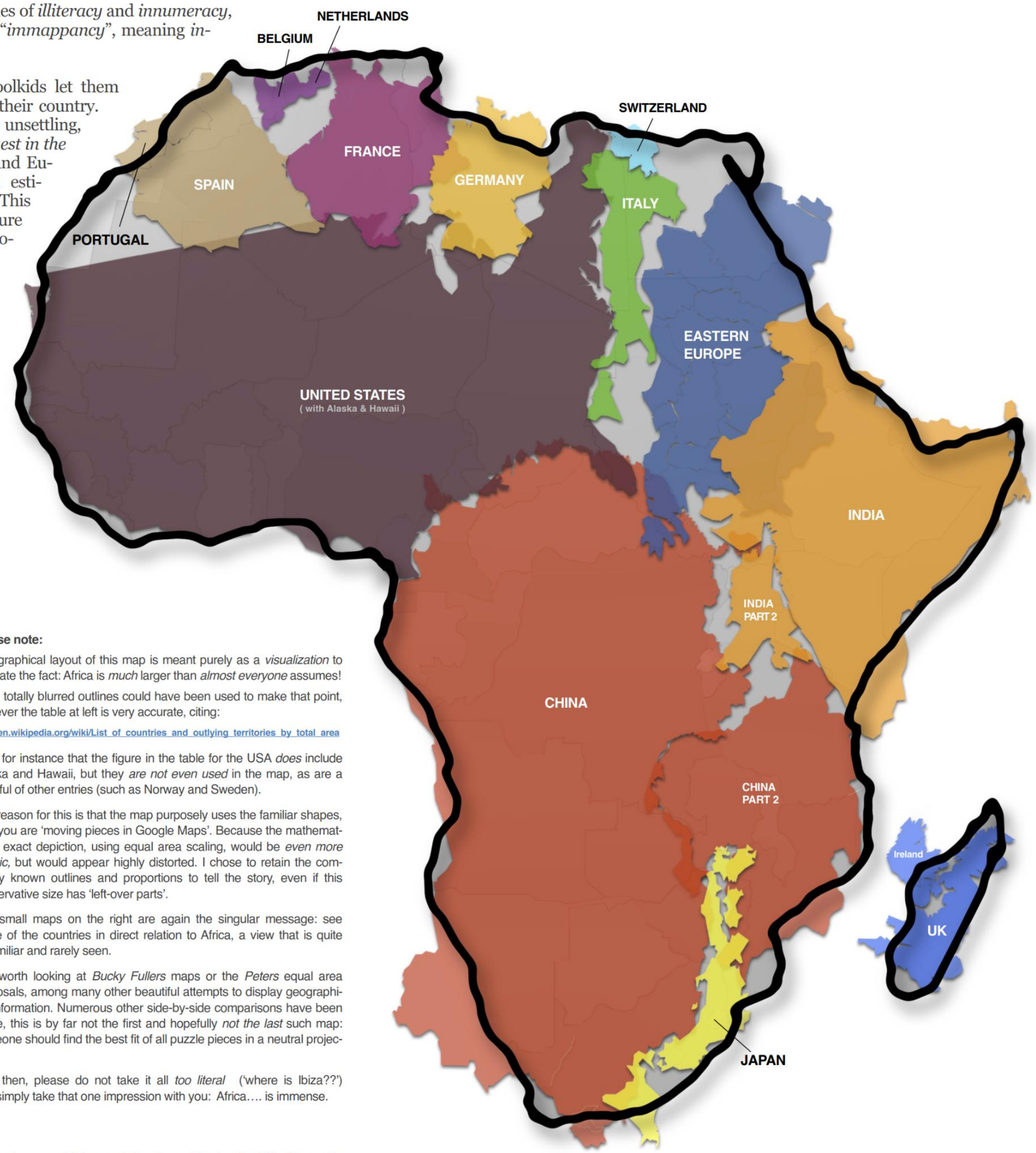
The **True Size** of **Africa**

A small contribution in the fight against rampant *Immappancy,* by **Kai Krause**

In addition to the well known social issues of *illiteracy* and *innumeracy*, there also should be such a concept as "*immappancy*", meaning *insufficient geographical knowledge.*

A survey with random American schoolkids let them guess the population and land area of their country. Not entirely unexpected, but still rather unsettling, the majority chose *"1-2 billion"* and *"largest in the world"*, respectively. Even with Asian and European college students, geographical estimates were often off by factors of *2-3*. This is partly due to the highly distorted nature of the predominantly used mapping projections (such as *Mercator*).

A particularly extreme example is the worldwide misjudgement of the true size of Africa. This single image tries to embody the massive scale, which is larger than the *USA*, *China*, *India*, *Japan* and *all of Europe - combined!*



COUNTRY	AREA x 1000 km²
USA	9.629
China	9.573
India	3.287
Mexico	1.964
Peru	1.285
France	633
Spain	506
Papua New Guinea	462
Sweden	441
Japan	378
Germany	357
Norway	324
Italy	301
New Zealand	270
United Kingdom	243
Nepal	147
Bangladesh	144
Greece	132
TOTAL	**30.102**
AFRICA	**30.221**
Just for Reference: The Surface of the MOON	37.930

Please note:

The graphical layout of this map is meant purely as a *visualization* to illustrate the fact: Africa is *much* larger than *almost everyone* assumes!

Even totally blurred outlines could have been used to make that point, however the table at left is very accurate, citing:

http://en.wikipedia.org/wiki/List_of_countries_and_outlying_territories_by_total_area

Note for instance that the figure in the table for the USA *does* include Alaska and Hawaii, but they *are not even used* in the map, as are a handful of other entries (such as Norway and Sweden).

The reason for this is that the map purposely uses the familiar shapes, as if you are 'moving pieces in Google Maps'. Because the mathematically exact depiction, using equal area scaling, would be *even more drastic,* but would appear highly distorted. I chose to retain the commonly known outlines and proportions to tell the story, even if this conservative size has 'left-over parts'.

The small maps on the right are again the singular message: see some of the countries in direct relation to Africa, a view that is quite unfamiliar and rarely seen.

It is worth looking at *Bucky Fullers* maps or the *Peters* equal area proposals, among many other beautiful attempts to display geographical information. Numerous other side-by-side comparisons have been made, this is by far not the first and hopefully *not the last* such map: someone should find the best fit of all puzzle pieces in a neutral projection.

Until then, please do not take it all *too literal* ('where is Ibiza??') and simply take that one impression with you: Africa…. is immense.

creative commons **No Rights Reserved** This work is placed in the **Public Domain**

Top 100 Countries

Area in square kilometers, Percentage of World Total
Sources: Britannica, Wikipedia, Almanac 2010

United States

Europe

India

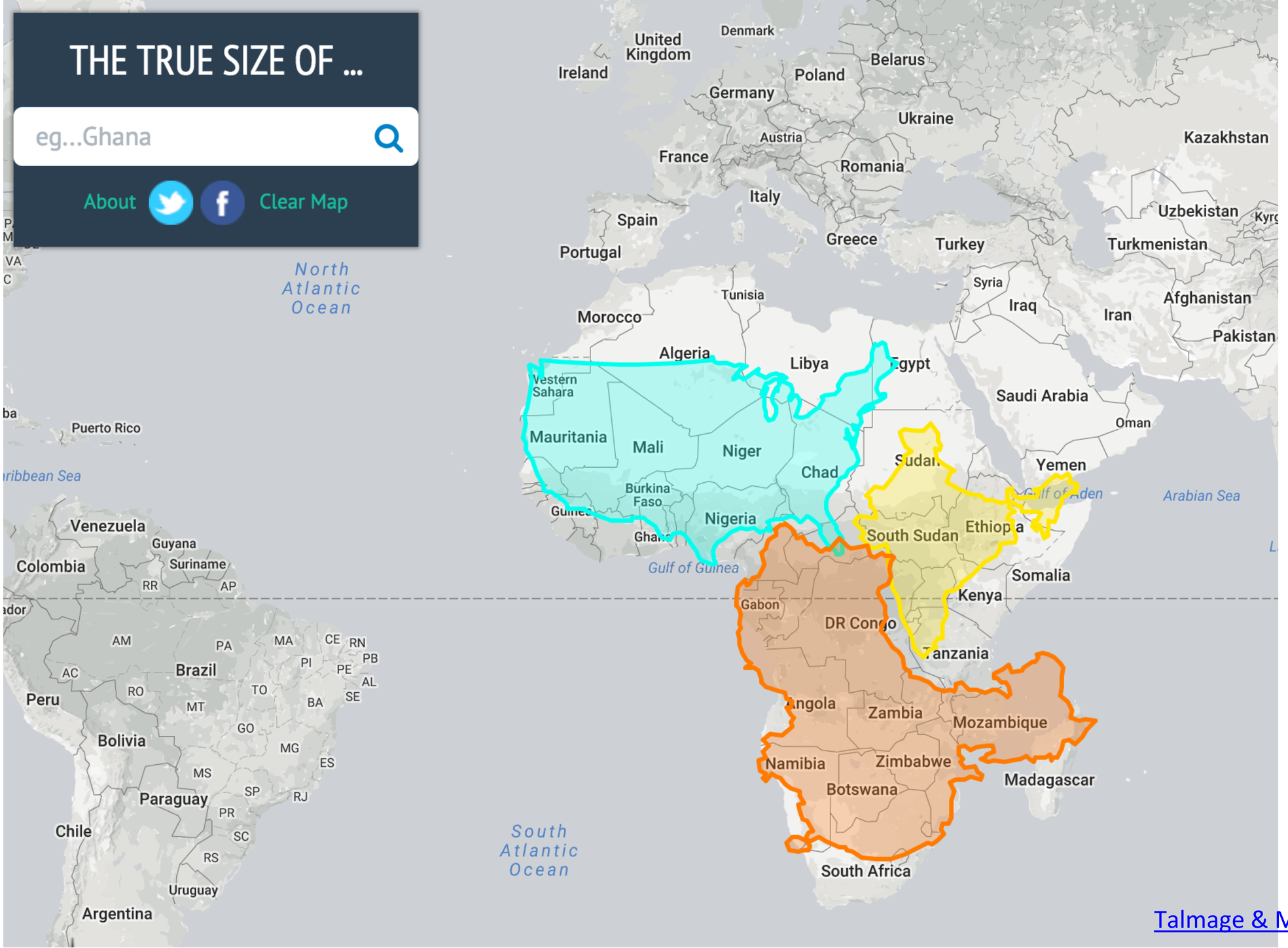
Japan

China

		AREA km²	%
1	Russia	17.098.242	11,50
2	Canada	9.984.670	6,70
3	China	9.596.961	6,40
4	United States	9.629.091	6,40
5	Brazil	8.514.877	5,70
6	Australia	7.692.024	5,20
7	India	3.287.263	2,30
8	Argentina	2.780.400	2,00
9	Kazakhstan	2.724.900	1,80
10	Sudan	2.505.813	1,70
11	Algeria	2.381.741	1,60
12	Congo	2.344.858	1,60
13	Greenland	2.166.086	1,50
14	Saudi Arabia	2.149.690	1,40
15	Mexico	1.964.375	1,30
16	Indonesia	1.860.360	1,30
17	Libya	1.759.540	1,20
18	Iran	1.628.750	1,10
19	Mongolia	1.564.100	1,10
20	Peru	1.285.216	0,86
21	Chad	1.284.000	0,86
22	Niger	1.267.000	0,85
23	Angola	1.246.700	0,85
24	Mali	1.240.192	0,83
25	South Africa	1.221.037	0,82
26	Colombia	1.141.748	0,76
27	Ethiopia	1.104.300	0,74
28	Bolivia	1.098.581	0,74
29	Mauritania	1.025.520	0,69
30	Egypt	1.002.000	0,67
31	Tanzania	945.087	0,63
32	Nigeria	923.768	0,62
33	Venezuela	912.050	0,61
34	Namibia	824.116	0,55
35	Mozambique	801.590	0,54
36	Pakistan	796.095	0,53
37	Turkey	783.562	0,53
38	Chile	756.102	0,51
39	Zambia	752.612	0,51
40	Myanmar	676.578	0,45
41	Afghanistan	652.090	0,44
42	Somalia	637.657	0,43
43	France	632.834	0,43
44	C. African Rep	622.984	0,42
45	Ukraine	603.500	0,41
46	Madagascar	587.041	0,39
47	Botswana	582.000	0,39
48	Kenya	580.367	0,39
49	Yemen	527.968	0,35
50	Thailand	513.120	0,34
51	Spain	505.992	0,34
52	Turkmenistan	488.100	0,33
53	Cameroon	475.442	0,32
54	Papua New Guinea	462.840	0,31
55	Uzbekistan	447.400	0,30
56	Morocco	446.550	0,30
57	Sweden	441.370	0,30
58	Iraq	438.317	0,29
59	Paraguay	406.752	0,27
60	Zimbabwe	390.757	0,26
61	Japan	377.930	0,25
62	Germany	357.114	0,24
63	Rep o.t. Congo	342.000	0,23
64	Finland	338.419	0,23
65	Vietnam	331.212	0,22
66	Malaysia	330.803	0,22
67	Norway	323.802	0,22
68	Côte d'Ivoire	322.463	0,22
69	Poland	312.685	0,21
70	Oman	309.500	0,21
71	Italy	301.336	0,20
72	Philippines	300.000	0,20
73	Burkina Faso	274.222	0,18
74	New Zealand	270.467	0,18
75	Gabon	267.668	0,18
76	Western Sahara	266.000	0,18
77	Ecuador	256.369	0,20
78	Guinea	245.857	0,17
79	United Kingdom	242.900	0,16
80	Uganda	241.038	0,16
81	Ghana	238.539	0,16
82	Romania	238.391	0,16
83	Laos	236.800	0,16
84	Guyana	214.969	0,14
85	Belarus	207.600	0,14
86	Kyrgyzstan	199.951	0,13
87	Senegal	196.722	0,13
88	Syria	185.180	0,12
89	Cambodia	181.035	0,12
90	Uruguay	176.215	0,12
91	Suriname	163.820	0,11
92	Tunisia	163.610	0,11
93	Nepal	147.181	0,10
94	Bangladesh	143.998	0,10
95	Tajikistan	143.100	0,10
96	Greece	131.957	0,09
97	Nicaragua	130.373	0,09
98	North Korea	120.538	0,08
99	Malawi	118.484	0,08
100	Eritrea	117.600	0,08
	TOP 100 TOTAL	132.632.524	89,34

[Kai Krause, 2010](#)

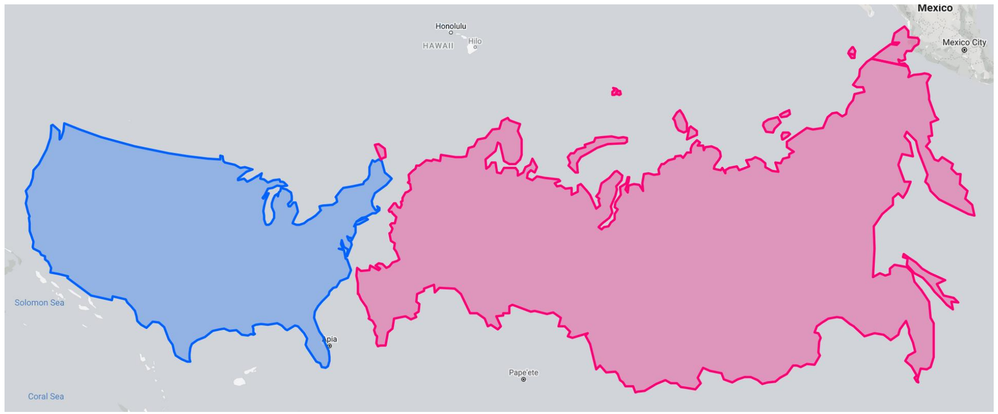
In-Class Exercise: The True Size



Talmage & Maneice, 2014

In-Class Exercise: The True Size

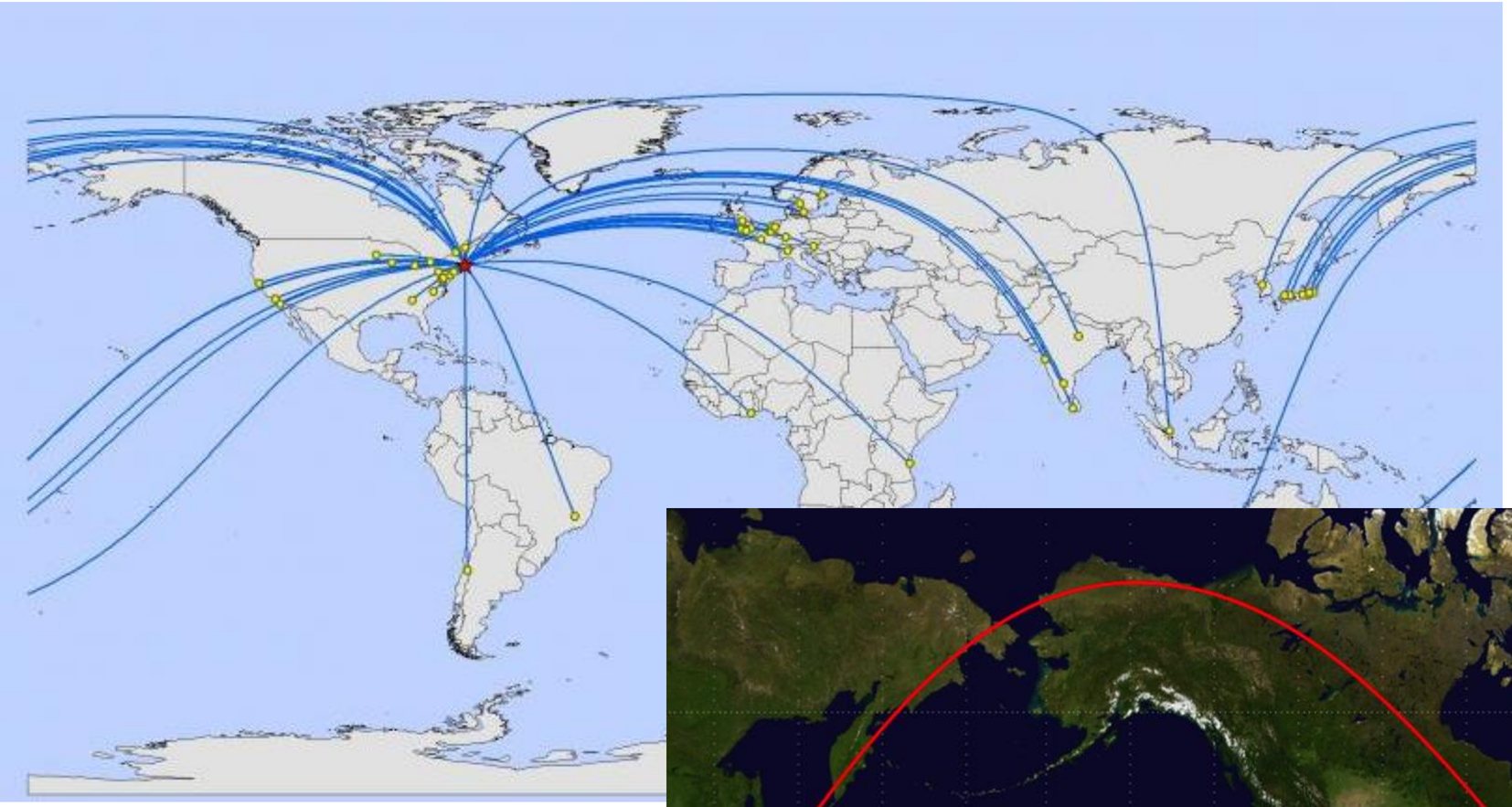
15m

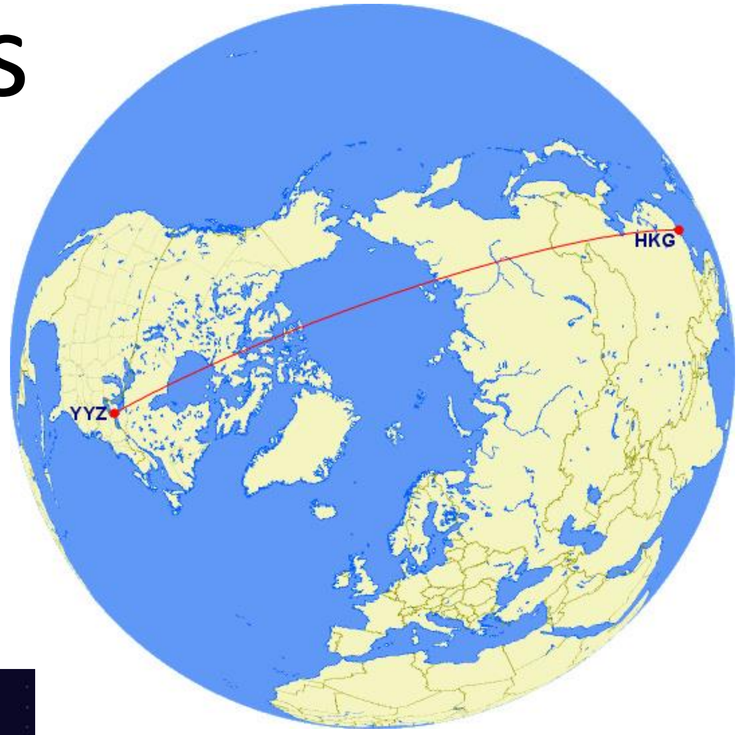


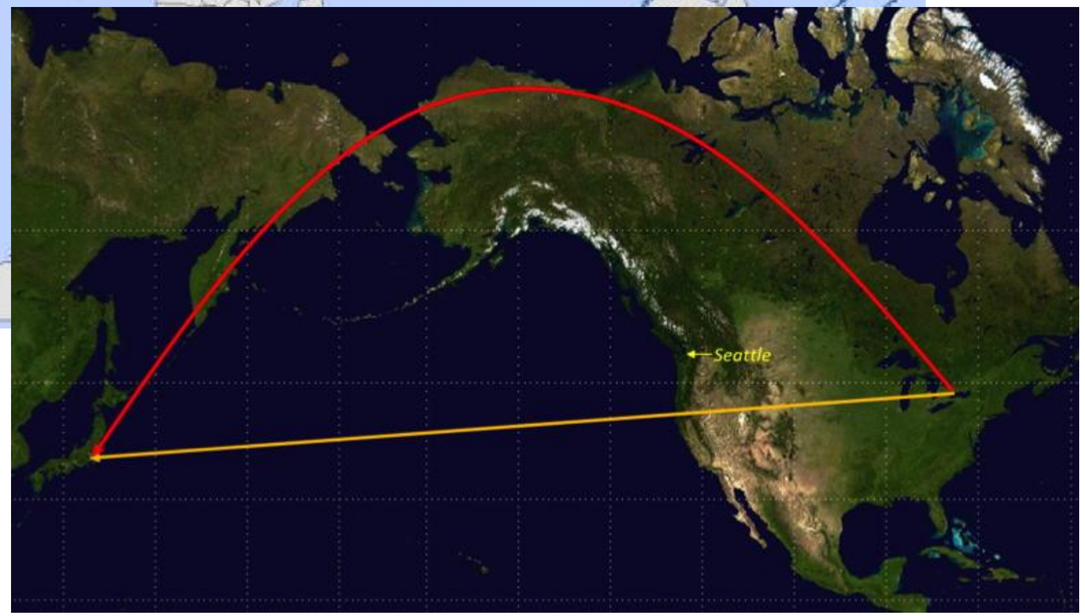
INSTRUCTIONS:

- Go to https://thetruesize.com
- Clear the map.
- Find at least two countries using the search bar.
- Position them at the equator near each other, e.g., the U.S. and Russia at the right.
- Does this match your perception of the shape and size of that country?
- Try putting your countries at other locations on the map closer to the poles. How does this affect the shape and size?
- See if you can find the worst possible distortion you can between the original map and a more accurate view at the equator. Post those in the chat or speak up and let everyone know!

Great Circle Routes





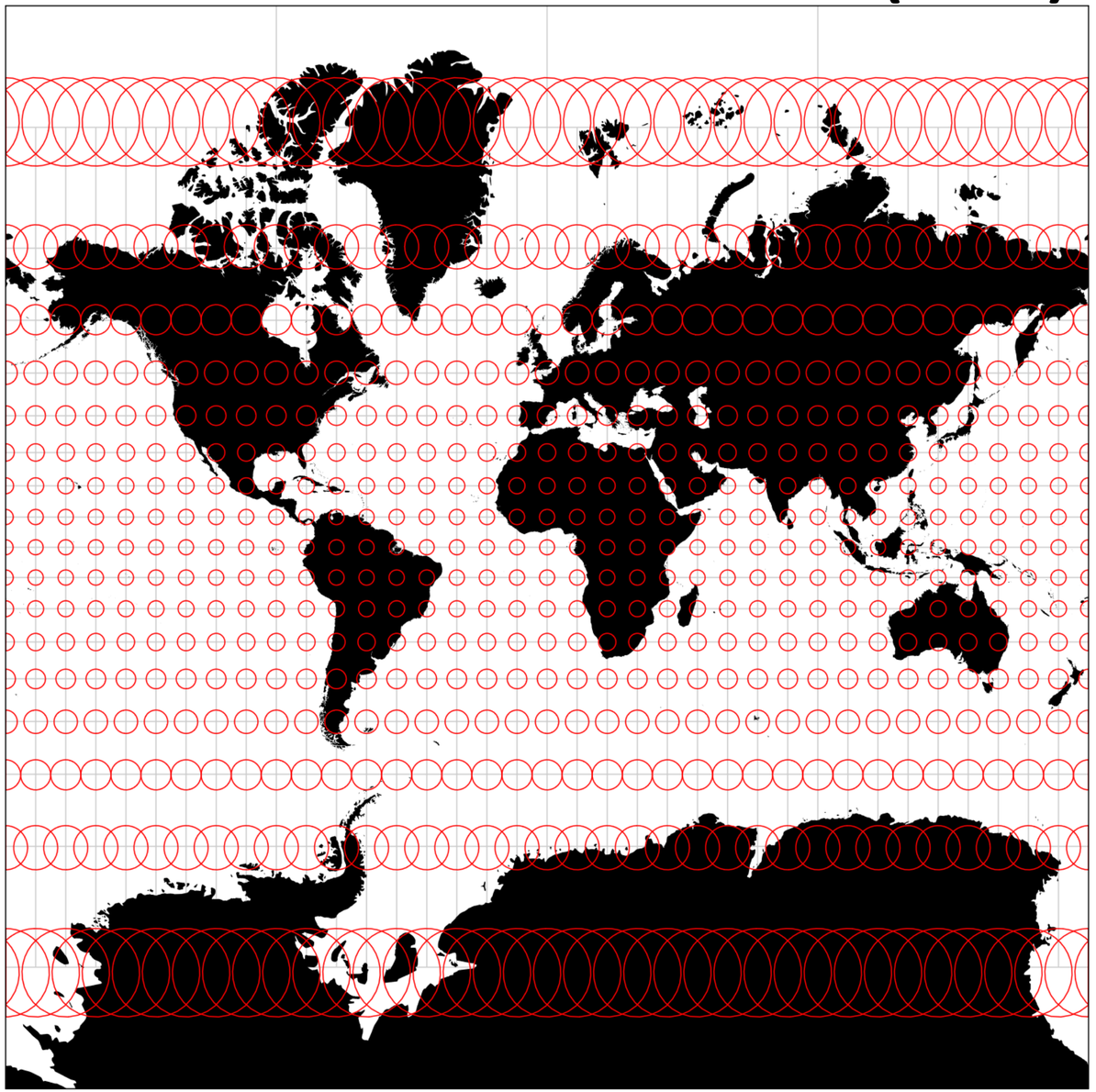


Subramanian, 2010; Swartz, 2010, Levy, 2013

World map used in Australian schools (joke)

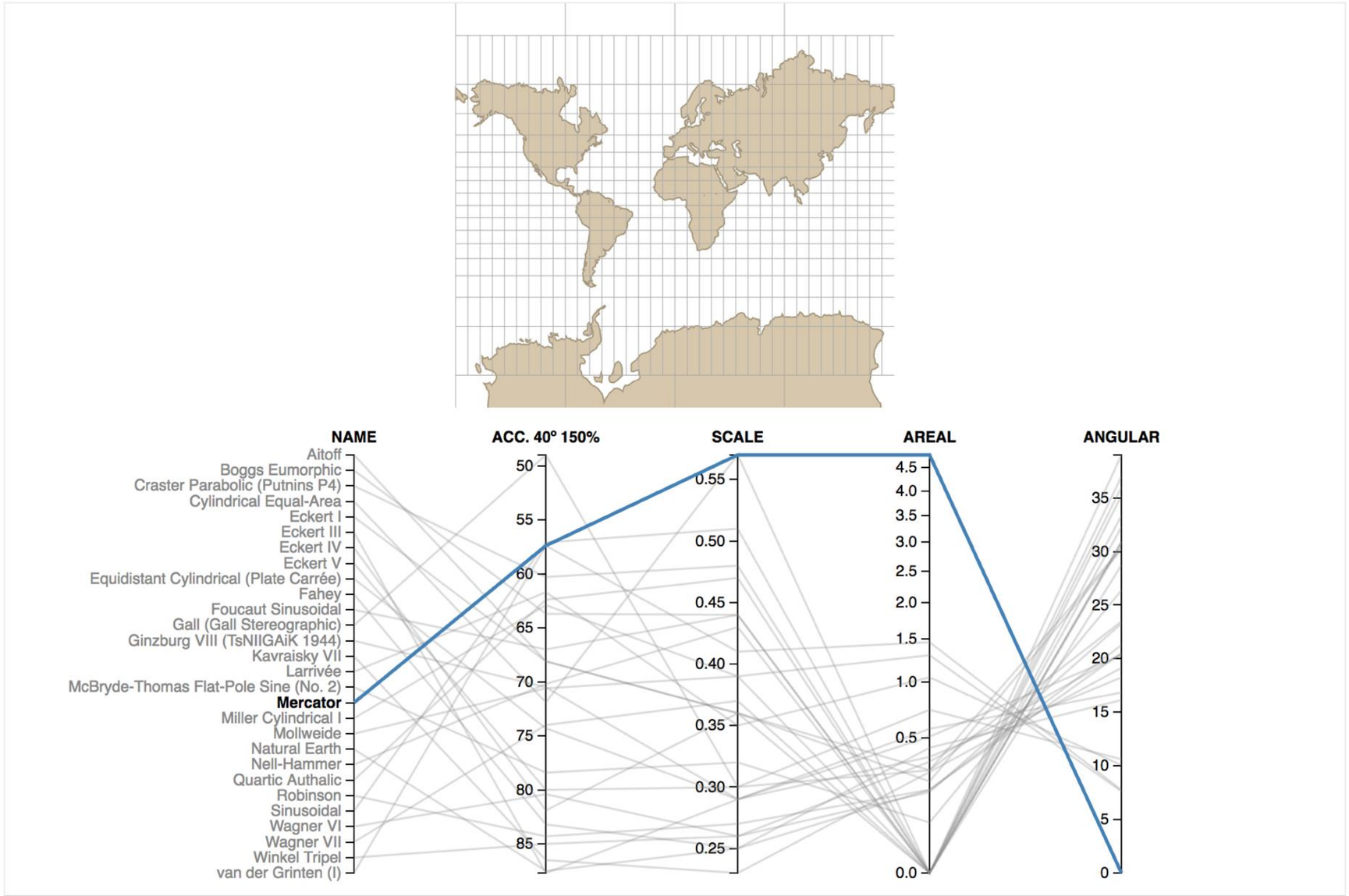
[Prokuror ID, 2013](); [Stopera, 2013]()

Tissot’s Indicatrix (ish)



Bostock, 2019

Comparing Map Projections



Kai/syntagmatic, 2017

GIS

GIS = geographic information system

spatio-temporal geographic information (x, y, z, t)

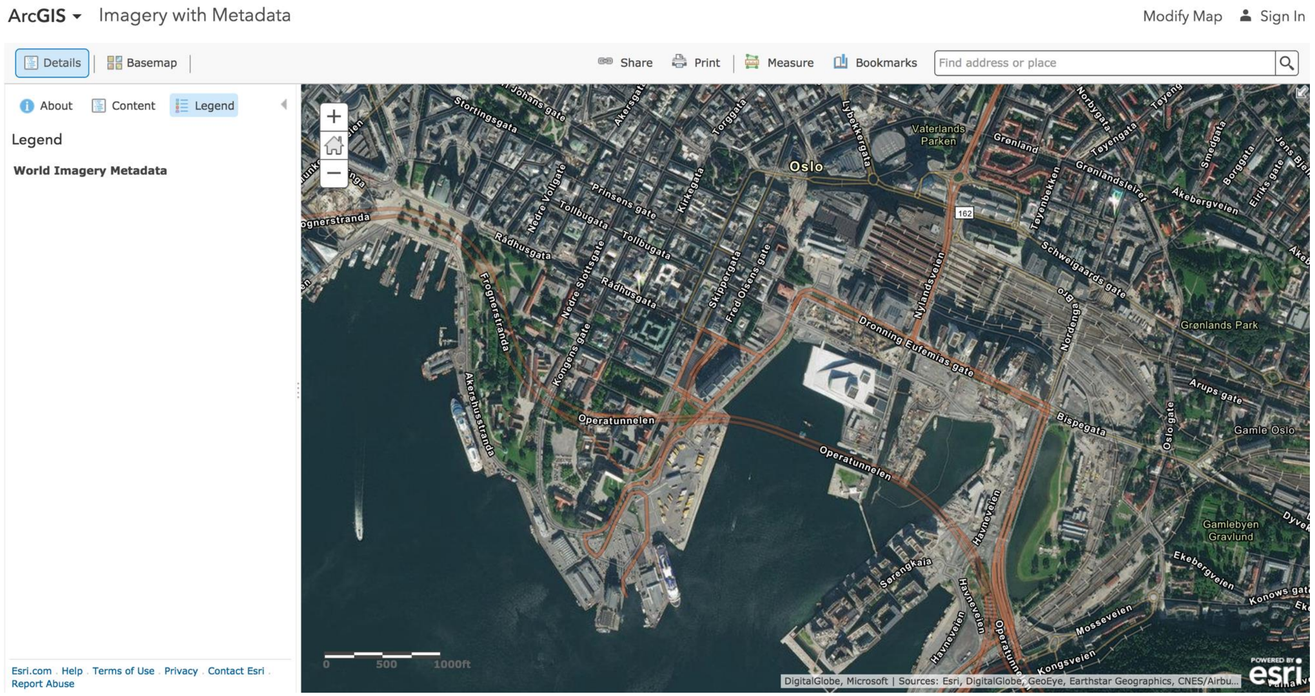
latitude, longitude, elevation, time + other relevant attributes

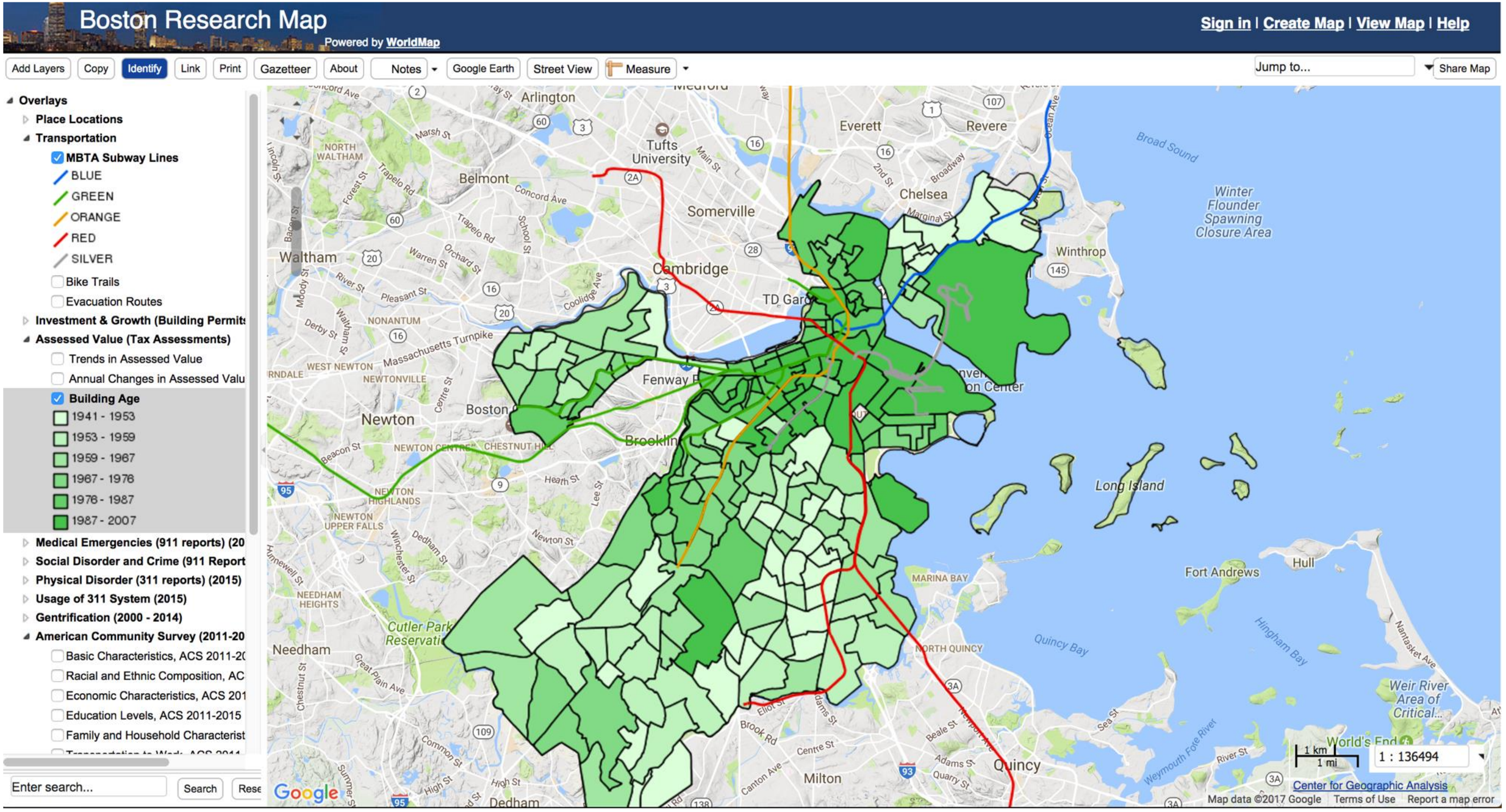
Lots of toolkits, e.g., [ArcGIS]

GIS Specialist

Questions about GIS, spatial analysis, or digital mapping?

Please contact Bahare Sanaie-Movahed, the GIS Specialist, for further assistance.




Boston Research Map
Powered by WorldMap
Sign in | Create Map | View Map | Help
Add Layers
Copy
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Gazetteer
About
Notes
Google Earth
Street View
Measure
Jump to...
Share Map
Overlays
Place Locations
Transportation
MBTA Subway Lines
BLUE
GREEN
ORANGE
RED
SILVER
Bike Trails
Evacuation Routes
Investment & Growth (Building Permits
Assessed Value (Tax Assessments)
Trends in Assessed Value
Annual Changes in Assessed Valu
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1987 - 2007
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Social Disorder and Crime (911 Report
Physical Disorder (311 reports) (2015)
Usage of 311 System (2015)
Gentrification (2000 - 2014)
American Community Survey (2011-20
Basic Characteristics, ACS 2011-2(
Racial and Ethnic Composition, AC
Economic Characteristics, ACS 201
Education Levels, ACS 2011-2015
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Somerville
Everett
Revere
Chelsea
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Winter Flounder Spawning Closure Area
Long Island
Fort Andrews
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Quincy Bay
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NORTH QUINCY
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Milton
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Cutler Park Reservati
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NEWTON UPPER FALLS
WEST NEWTON
NEWTONVILLE
NONANTUM
NEWTON CENTRE
CHESTNUT HILL
Massachusetts Turnpike
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1 mi
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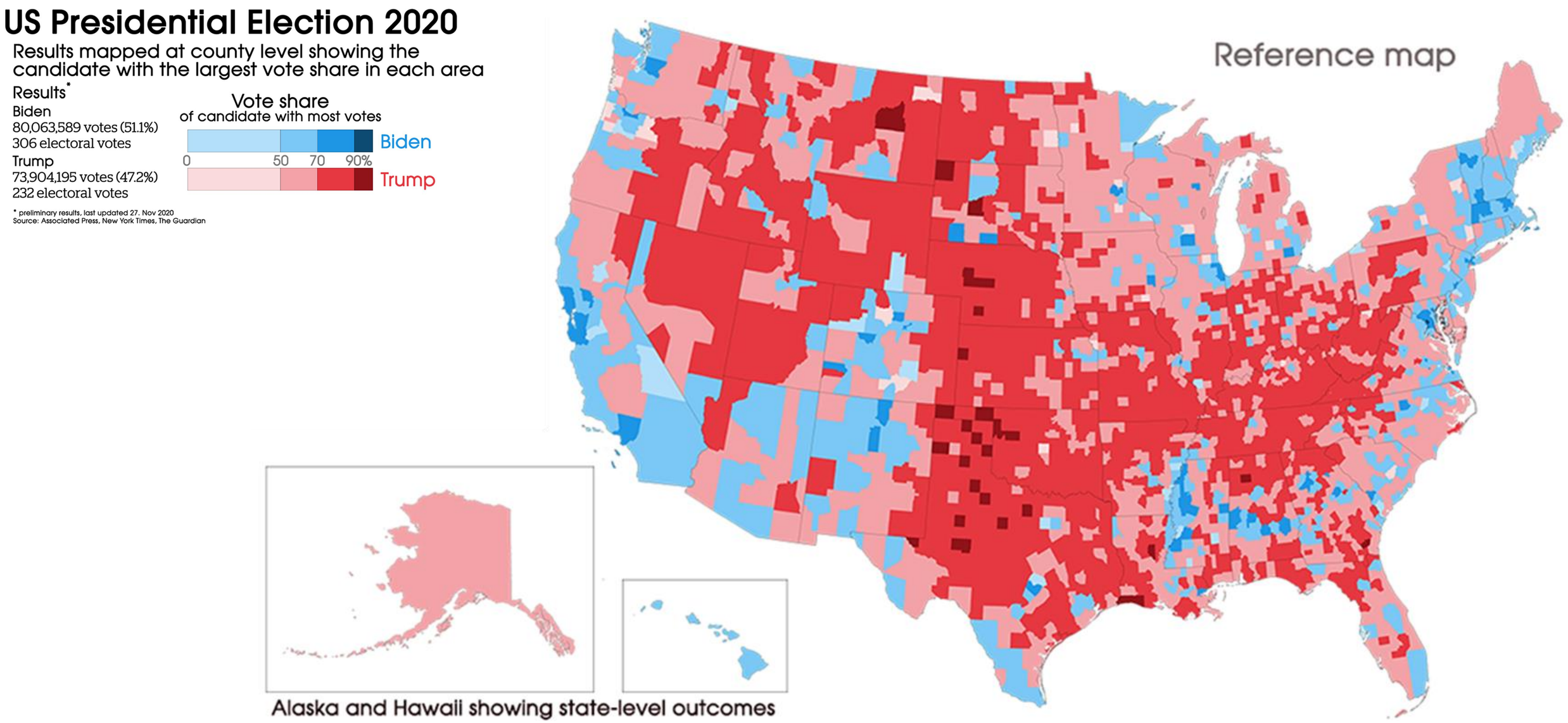
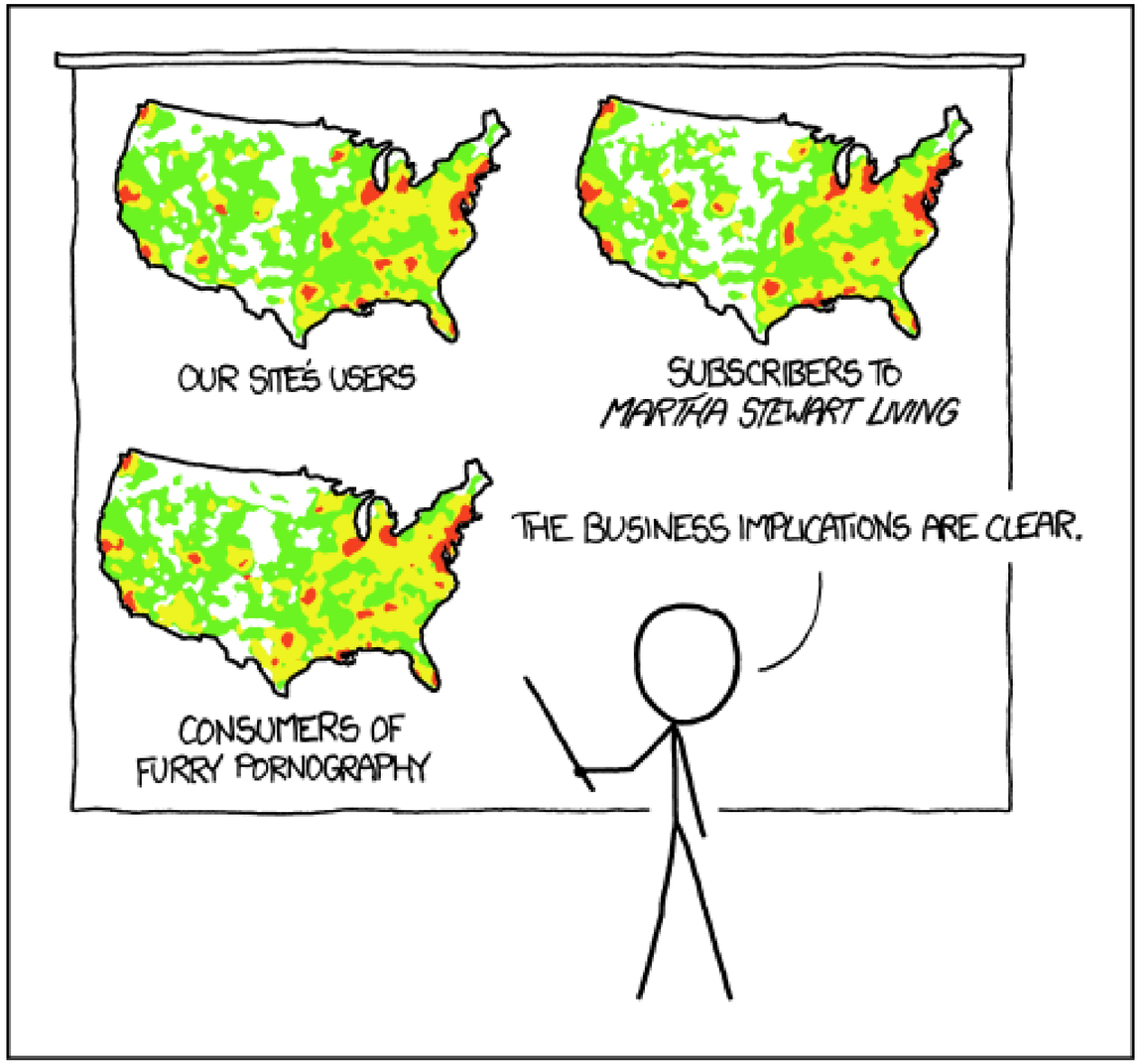
Center for Geographic Analysis
Map data ©2017 Google
Terms of Use
Report a map error
Google

Thematic/statistical map: choropleth



[Bloch et al., 2015]

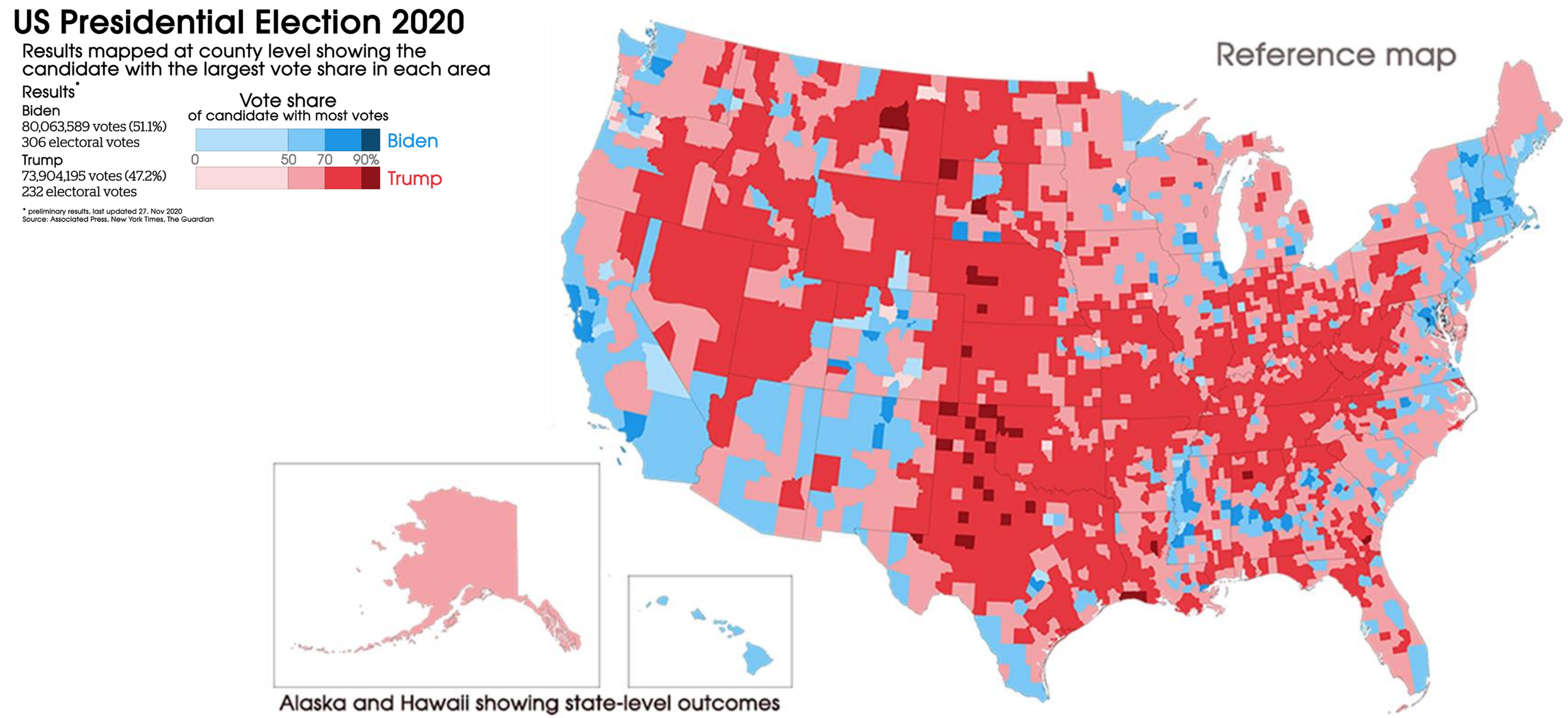
Maps can be deceiving! Failure to normalize



PET PEEVE #208:
GEOGRAPHIC PROFILE MAPS WHICH ARE BASICALLY JUST POPULATION MAPS

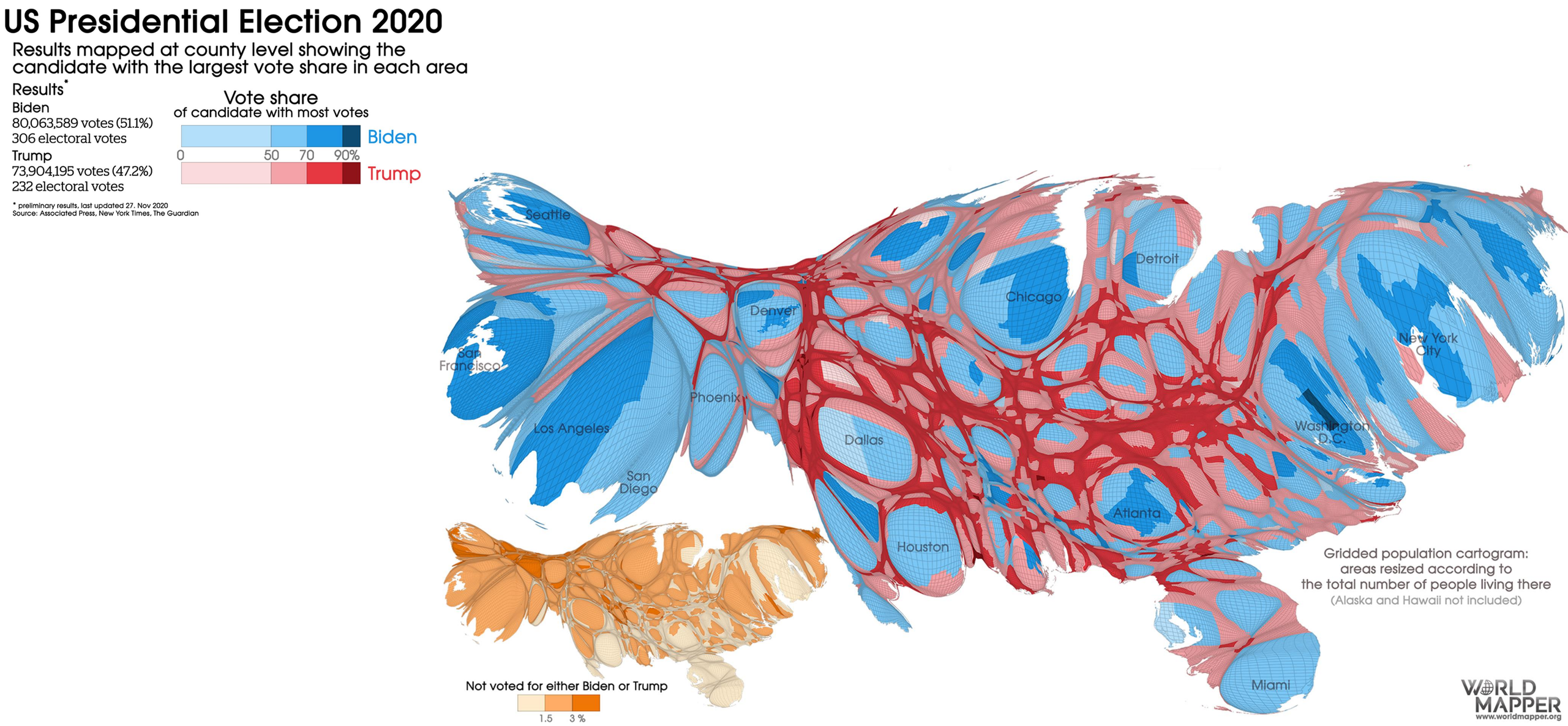
xkcd

Thematic/statistical map: choropleth



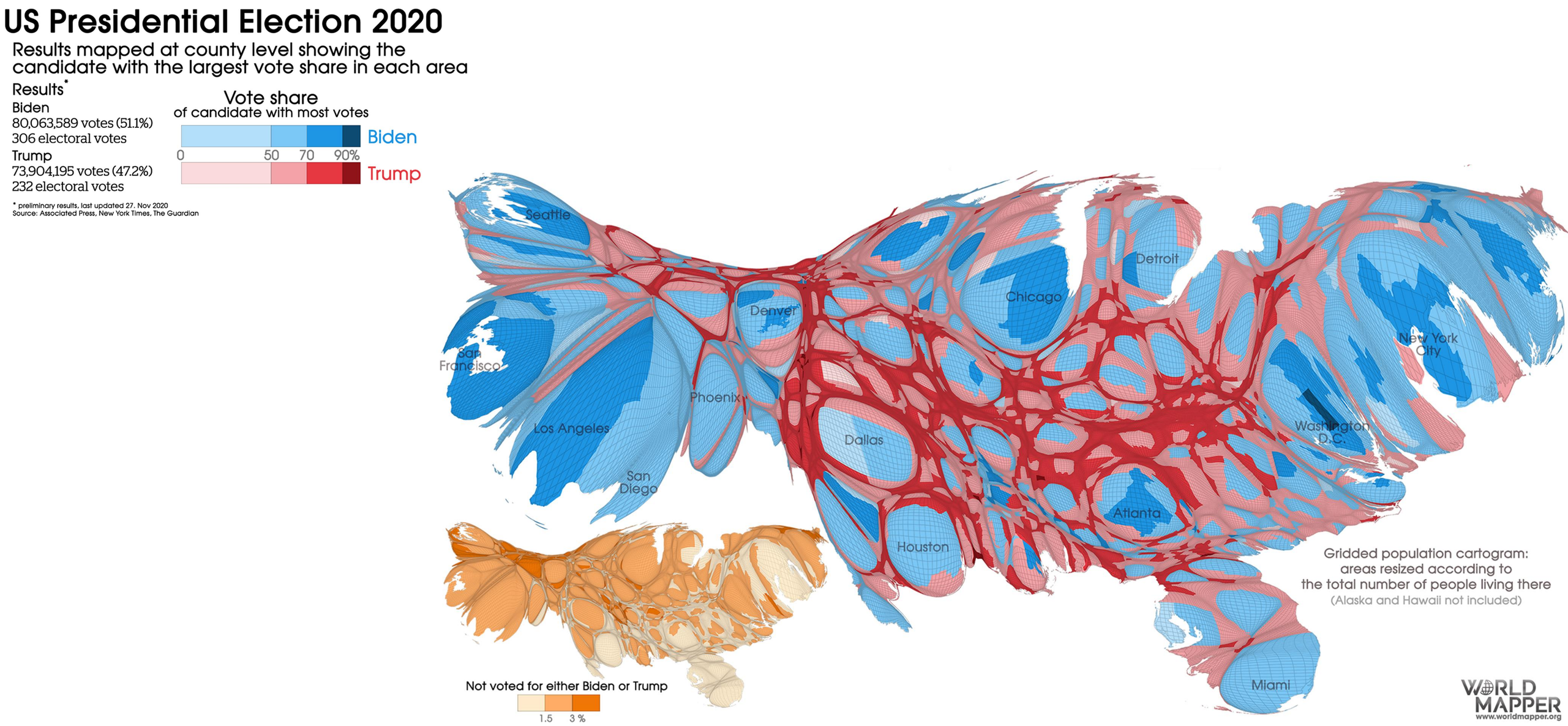
[Bloch et al., 2015]

Thematic/statistical map: continuous cartogram



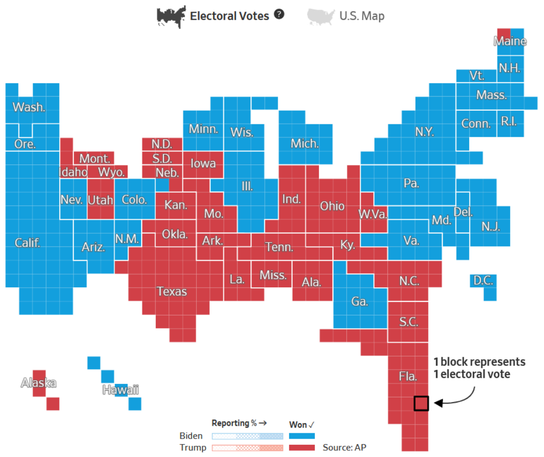
Bloch et al., 2015

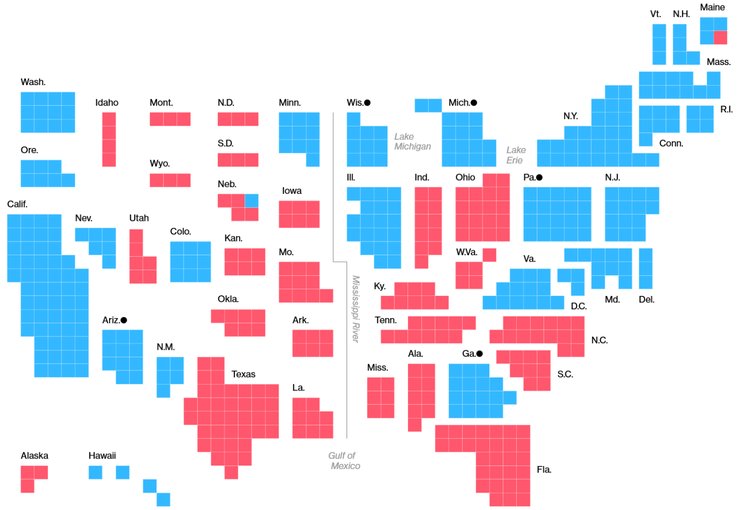
Thematic/statistical map: grid cartogram



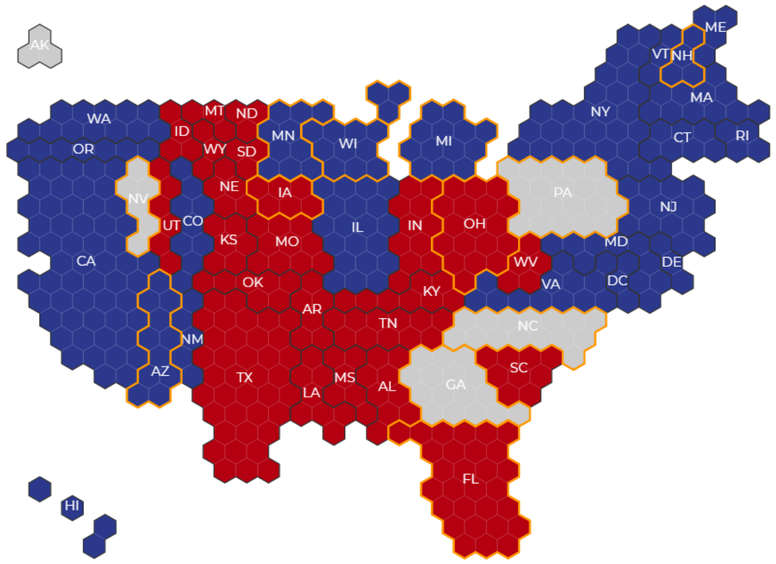
Bloch et al., 2015

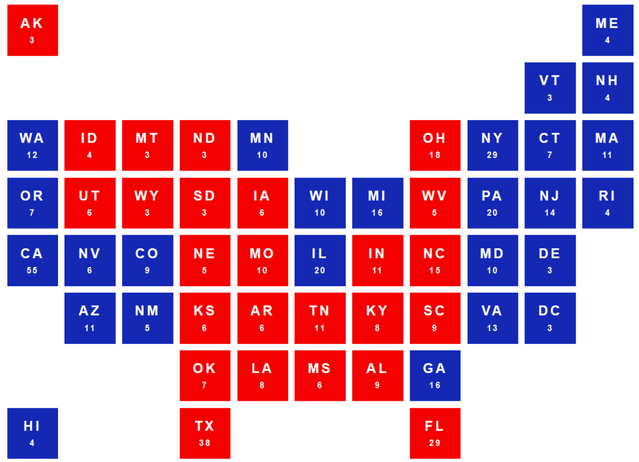
Thematic/statistical map: cartograms





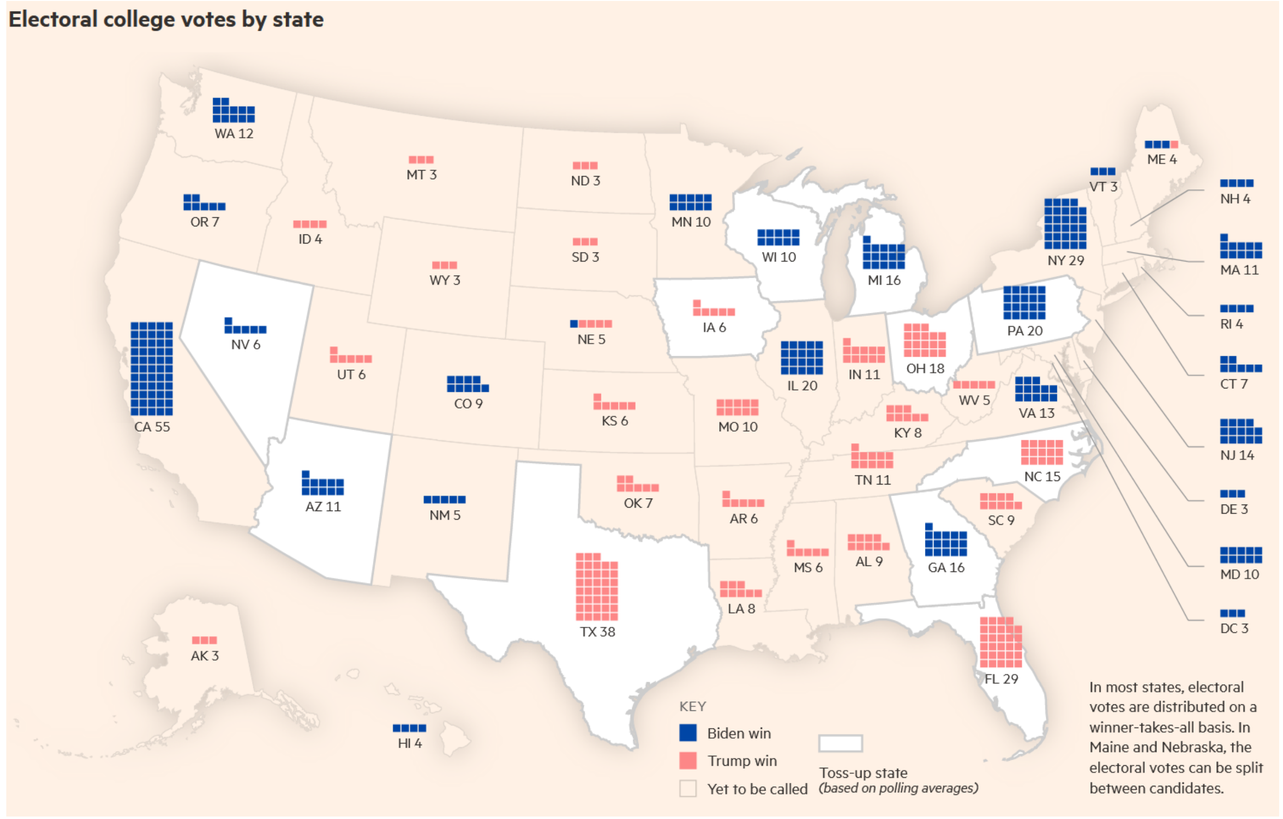
Note: In addition to awarding electoral votes to the winner statewide, Maine and Nebraska award an elector to the winner in each congressional district.

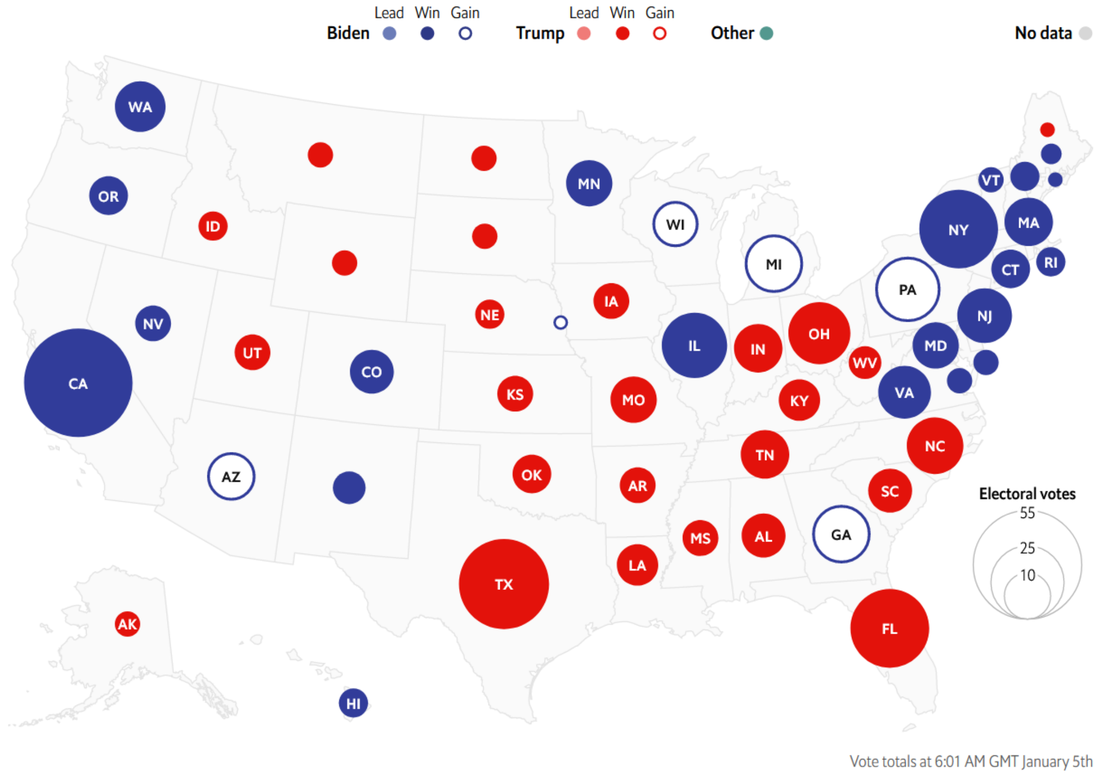




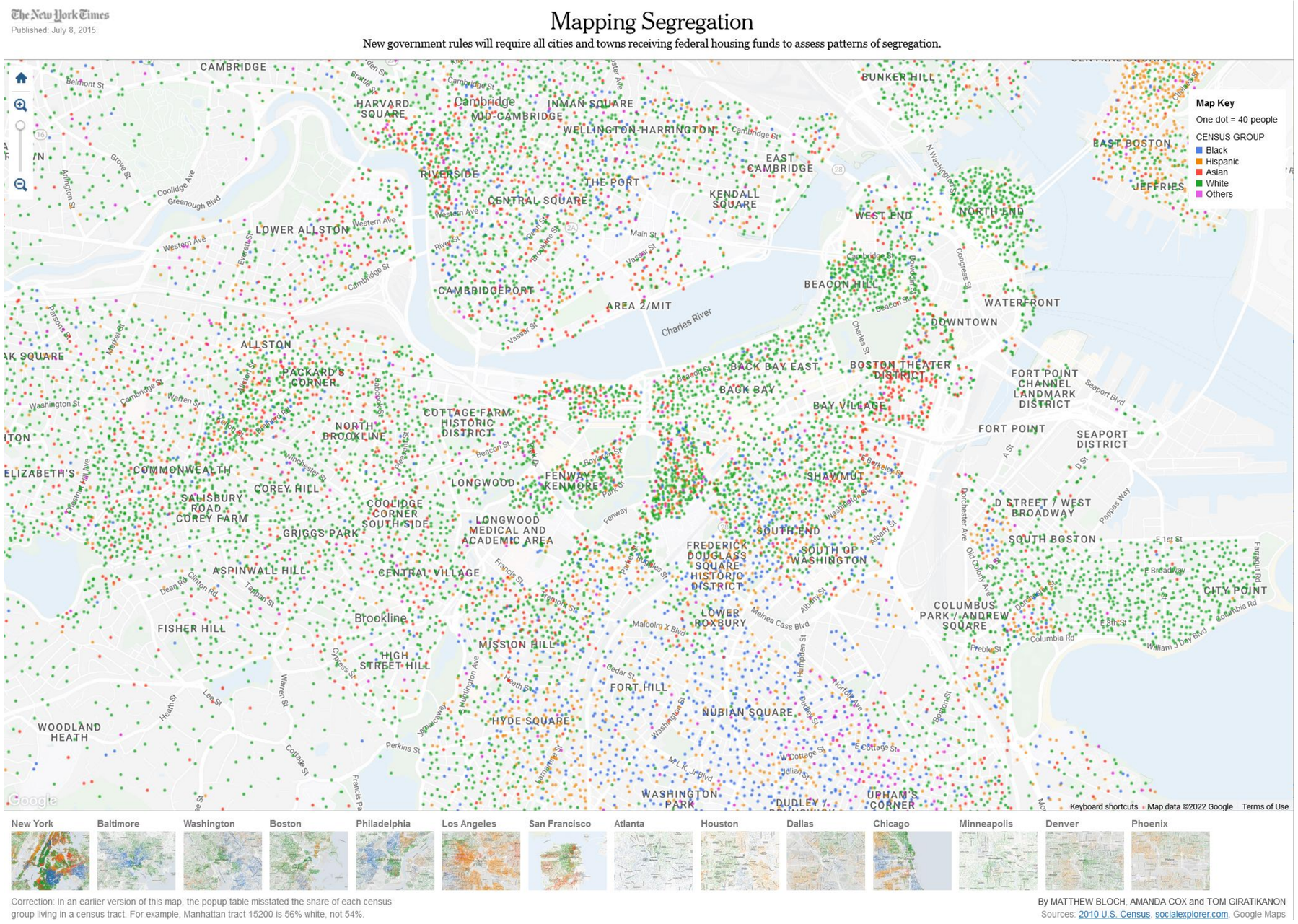
[Bloomberg](), [Al Jazeera](), [CBS](), [WSJ]()

Thematic/statistical map: symbol map





Thematic/statistical map: dot density



Bloch et al., 2015

Spatial and Scientific Visualization

Goals for Today

- Understand the concept of spatial fields, and how to visually encode.
- Learn about vector (and higher dimensional) representations.
- Learn about the two main ways to render 3D spatial data (isosurfaces and volume rendering).

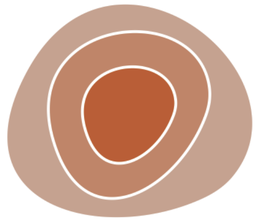
SPATIAL DATA

Arrange Spatial Data

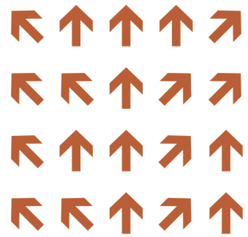
Use Given

- 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)*



SPATIAL FIELDS

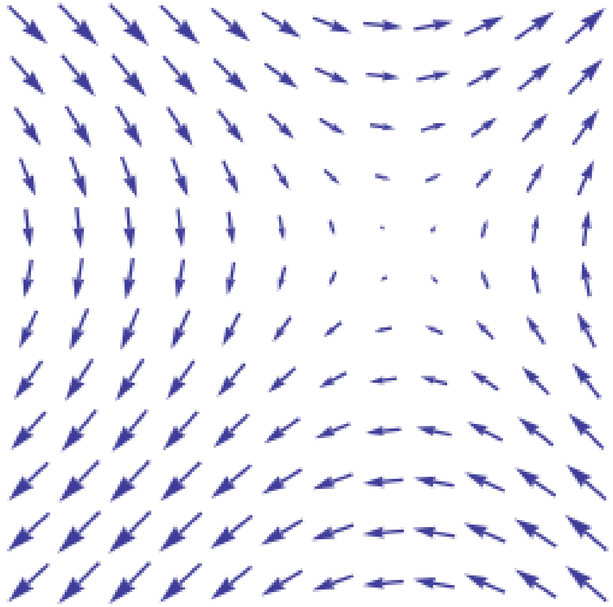
Spatial Fields

Scalar field = one value per cell

Vector or Tensor field = many values per cell

1	3	4	9	4	8	8	1	0
5	6	7	8	8	8	8	8	1
9	7	5	5	5	5	5	5	8
1	3	4	9	4	8	8	1	0
5	6	7	8	8	8	8	8	1
9	7	5	5	5	5	5	5	8
7	7	5	5	6	5	5	5	8
1	1	1	1	5	6	6	6	8
2	2	2	1	5	6	6	6	8

Scalar
(magnitude)



Vector
(magnitude and direction)

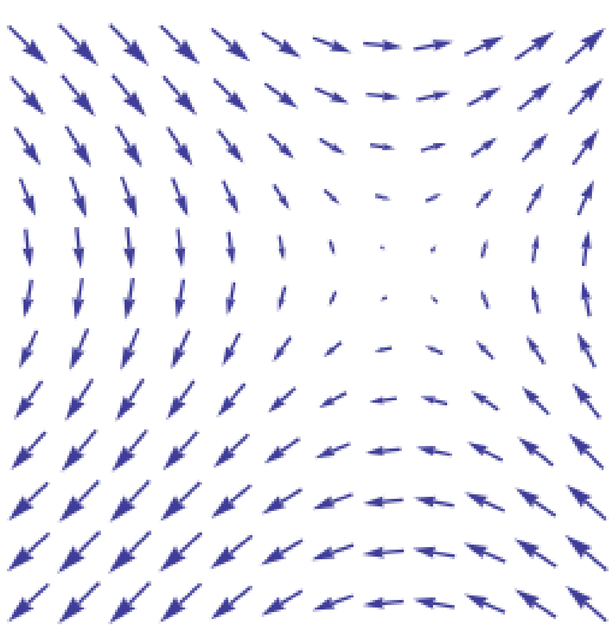
Spatial Fields

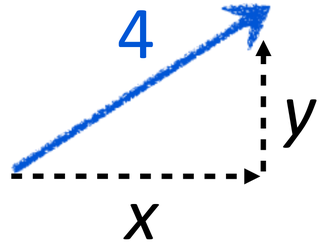
Scalar field = one value per cell

Vector or Tensor field = many values per cell

1	3	4	9	4	8	8	1	0
5	6	7	8	8	8	8	8	1
9	7	5	5	5	5	5	5	8
1	3	4	9	4	8	8	1	0
5	6	7	8	8	8	8	8	1
9	7	5	5	5	5	5	5	8
7	7	5	5	6	5	5	5	8
1	1	1	1	5	6	6	6	8
2	2	2	1	5	6	6	6	8

Scalar
(magnitude)

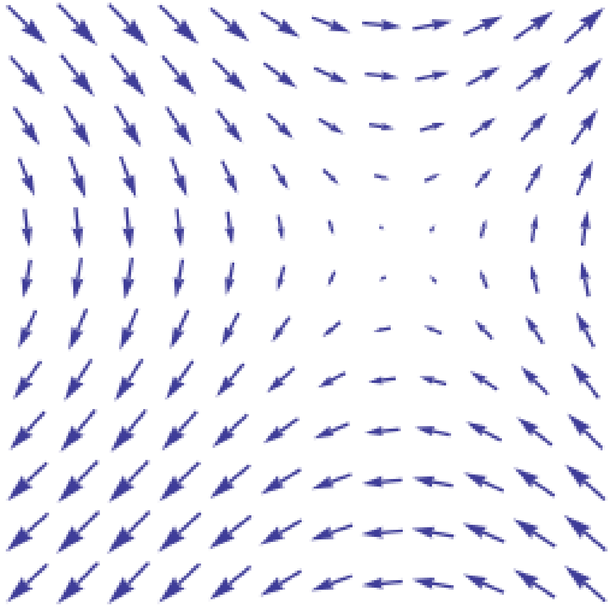




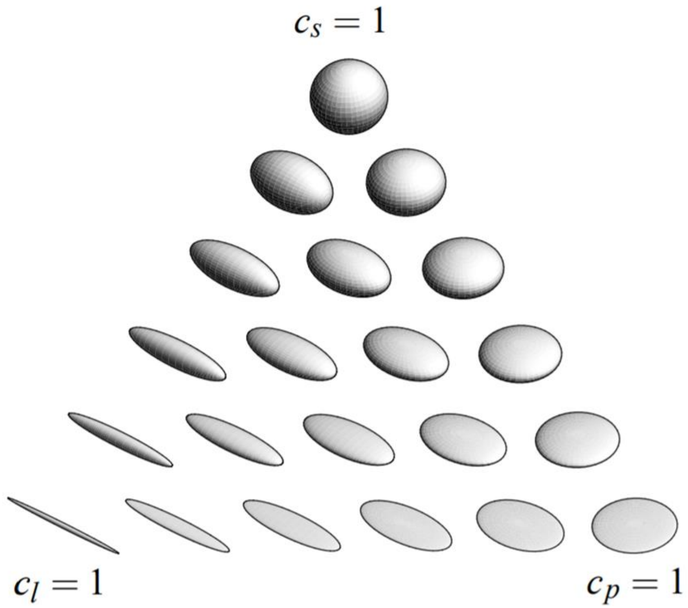
Vector
(magnitude and direction)

Spatial Fields

Vector or Tensor field = many values per cell

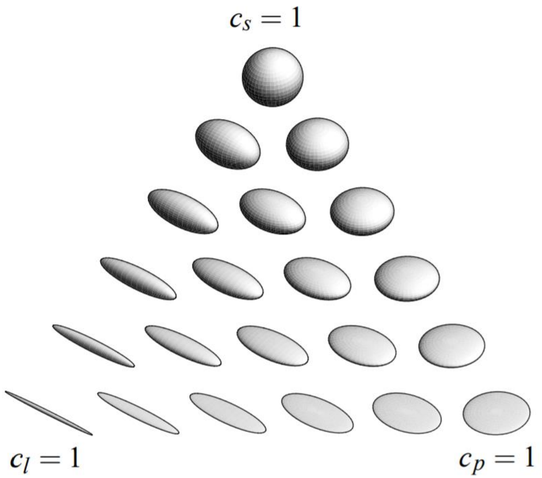


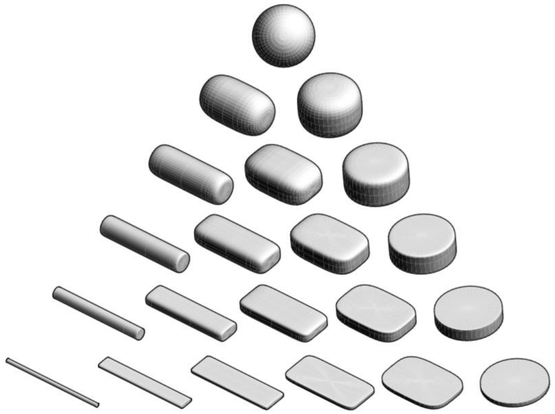
Vector
(magnitude and direction)

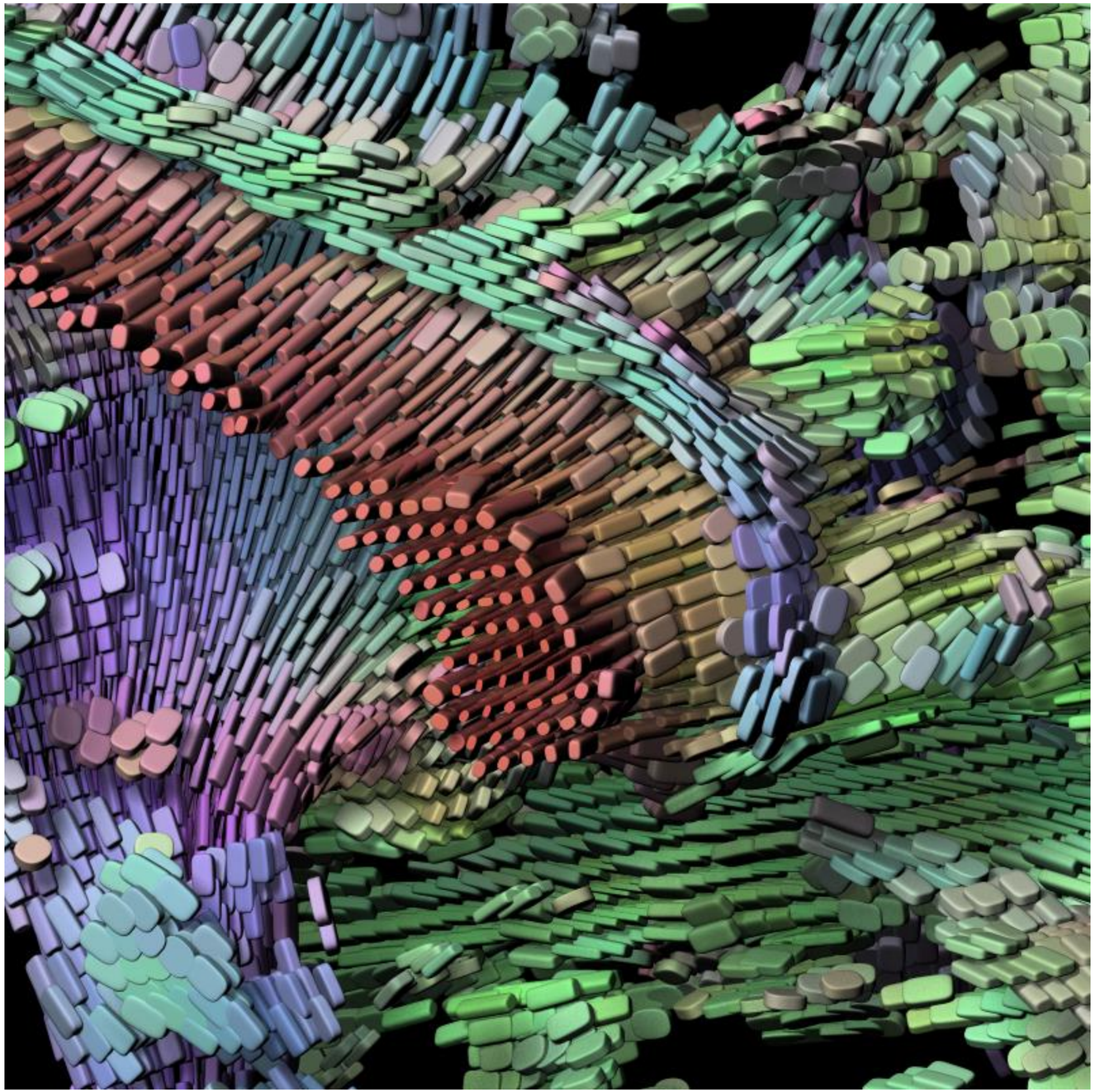


Tensor
(multiple variables with magnitude and direction)

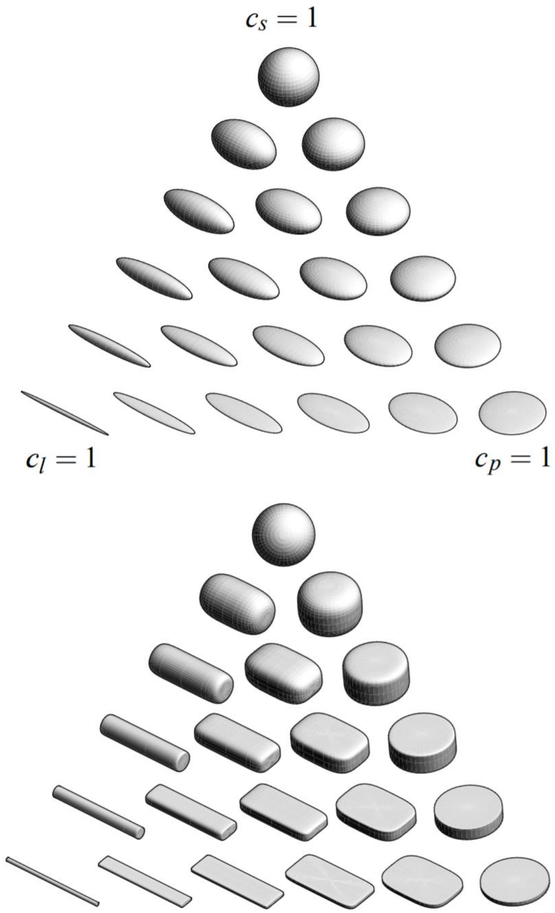
Kindlmann (2004)



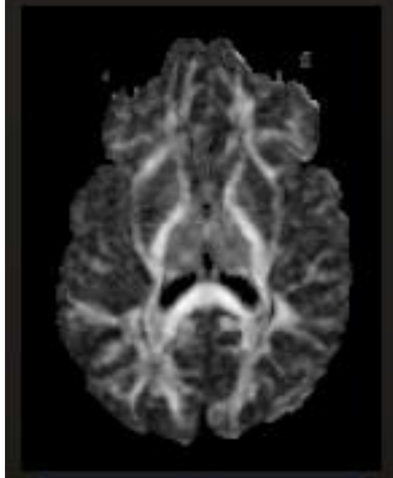


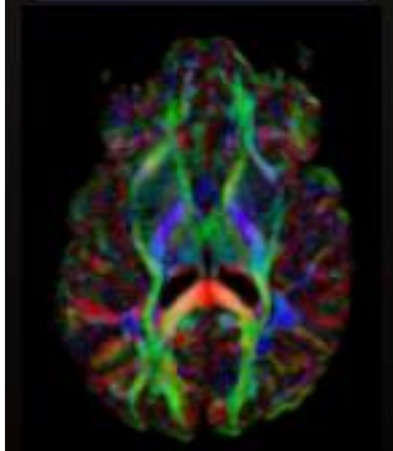


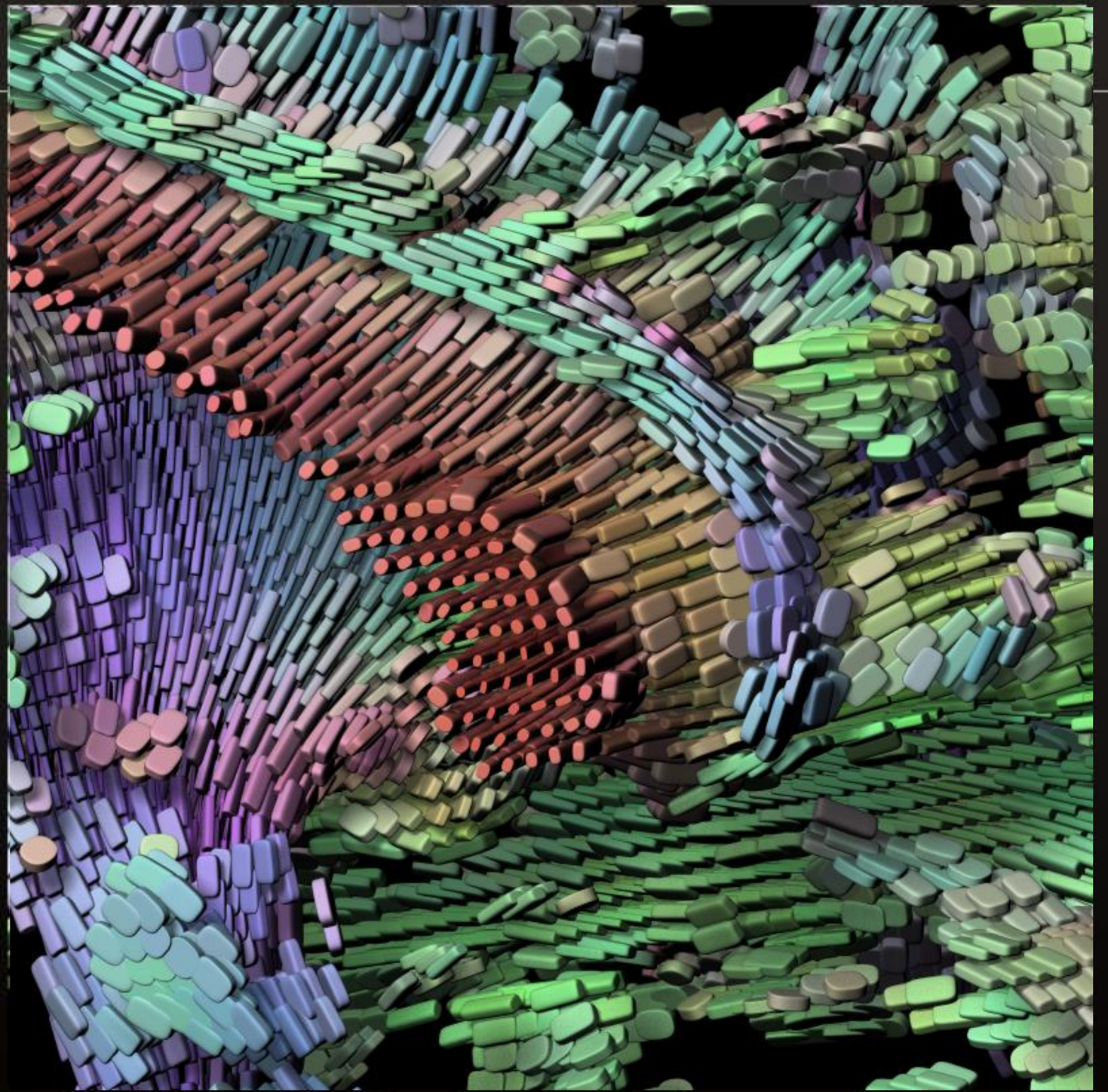
[Kindlmann (2004)]

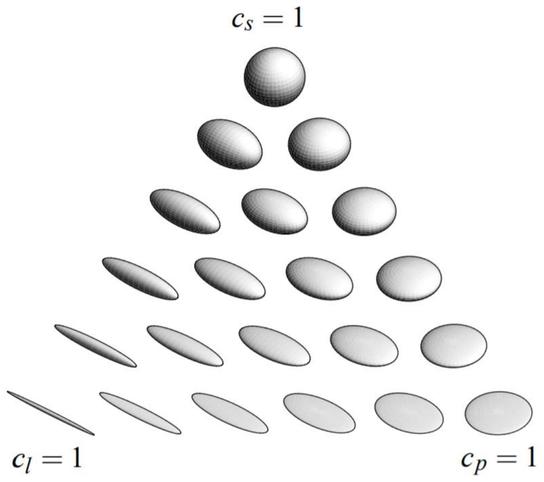


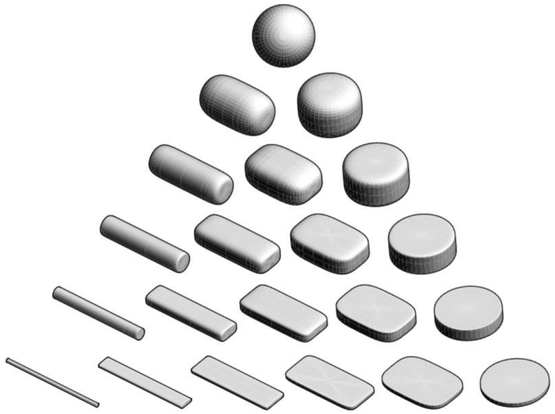
Results

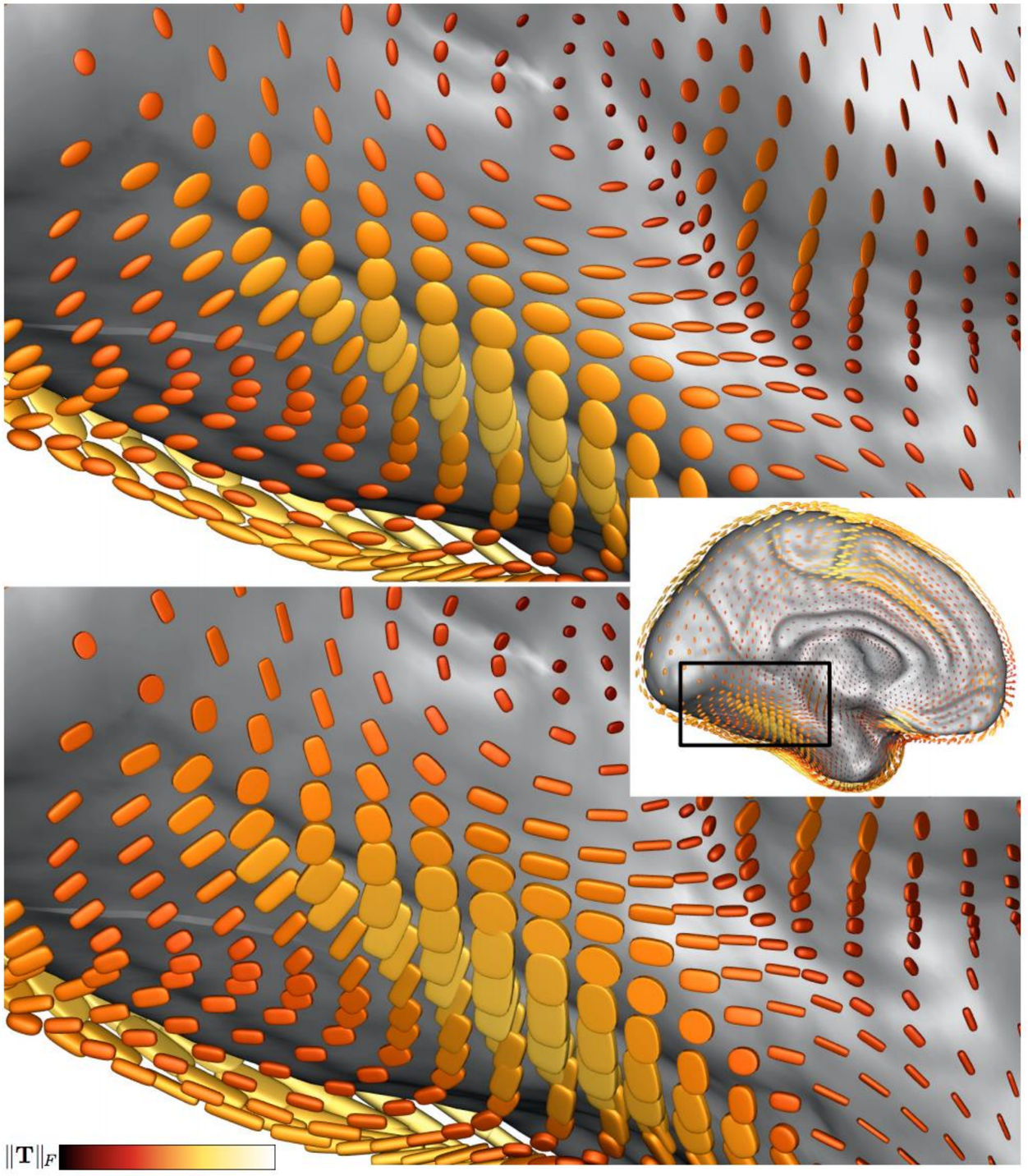






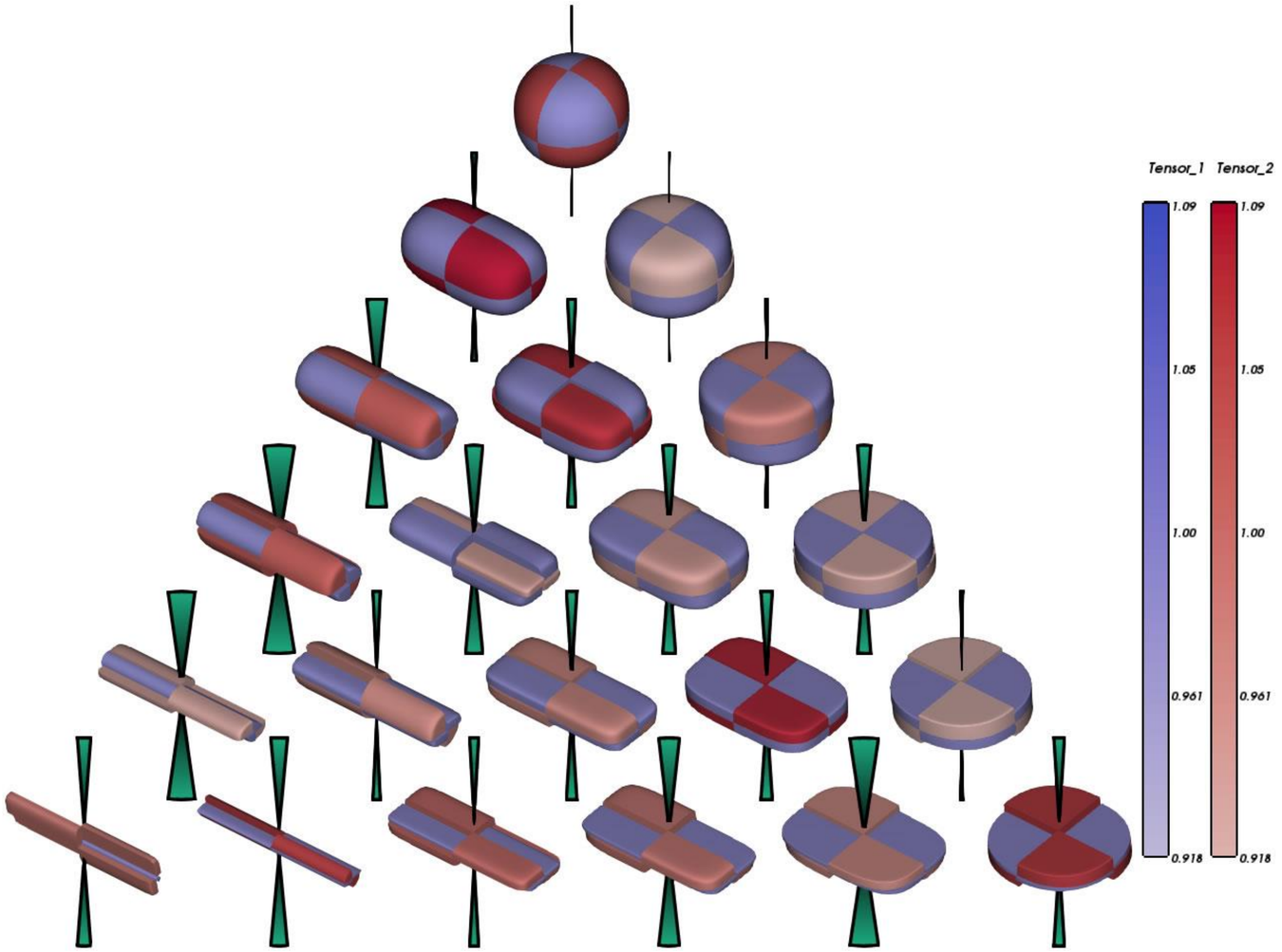






[Kindlmann (2004)]

Comparing Tensor Fields



[Zhang et al. 2016]

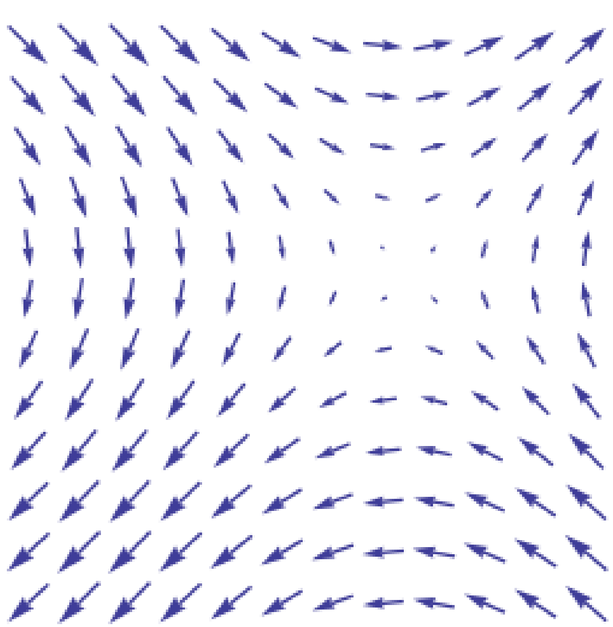
Spatial Fields

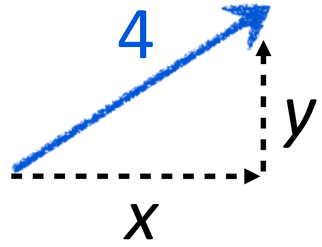
Scalar field = one value per cell

Vector or Tensor field = many values per cell

1	3	4	9	4	8	8	1	0
5	6	7	8	8	8	8	8	1
9	7	5	5	5	5	5	5	8
1	3	4	9	4	8	8	1	0
5	6	7	8	8	8	8	8	1
9	7	5	5	5	5	5	5	8
7	7	5	5	6	5	5	5	8
1	1	1	1	5	6	6	6	8
2	2	2	1	5	6	6	6	8

Scalar
(magnitude)

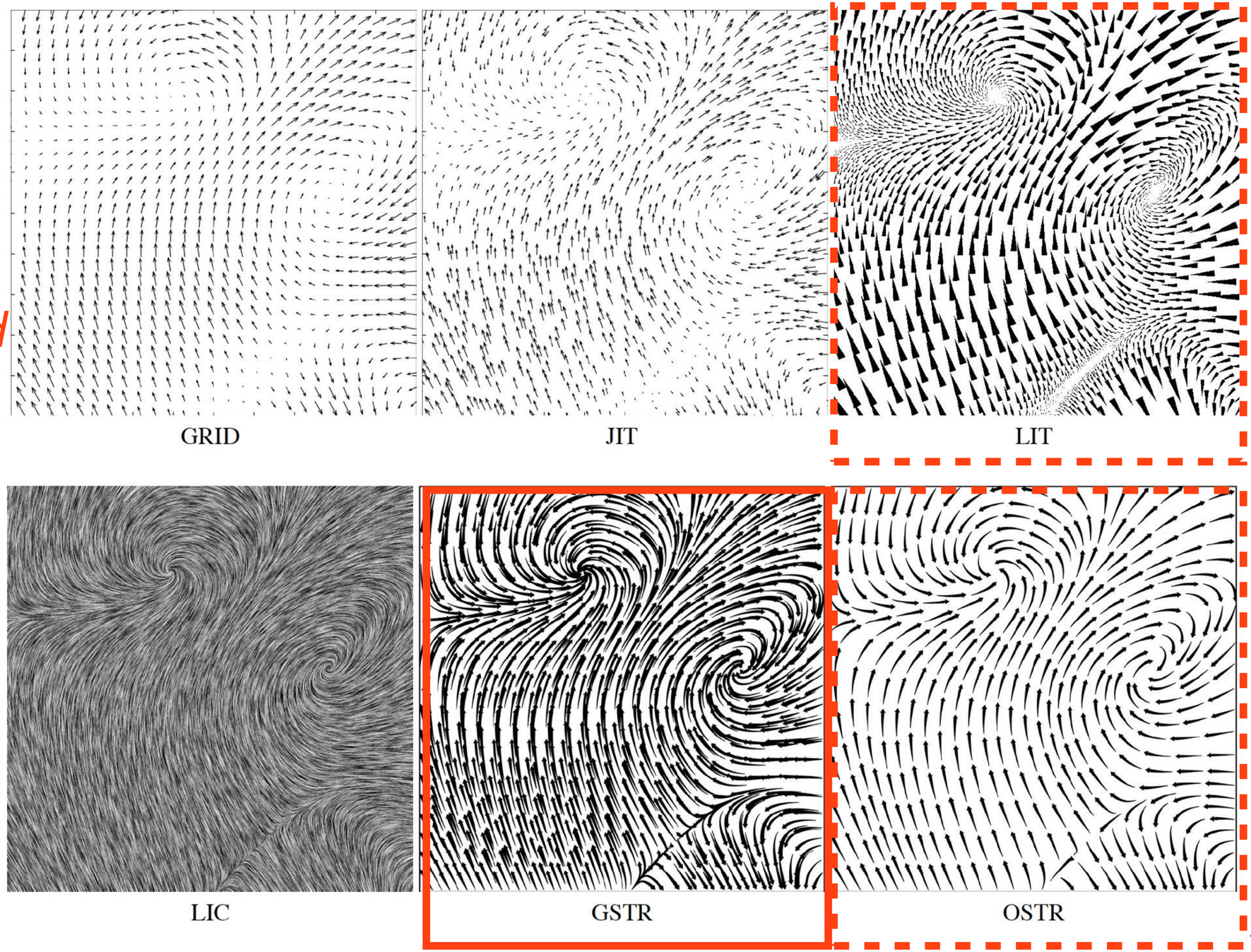




Vector
(magnitude and direction)

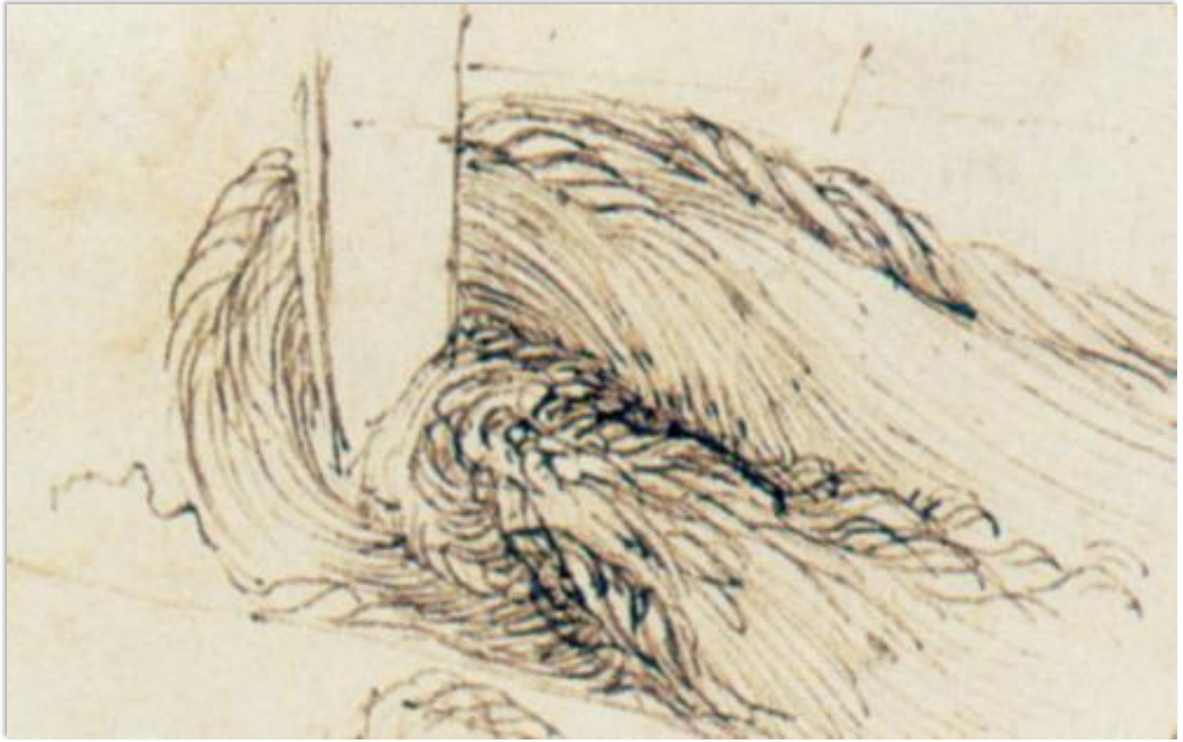
Vector Field Encoding Examples:

Most accurate and efficient for certain spatial tasks



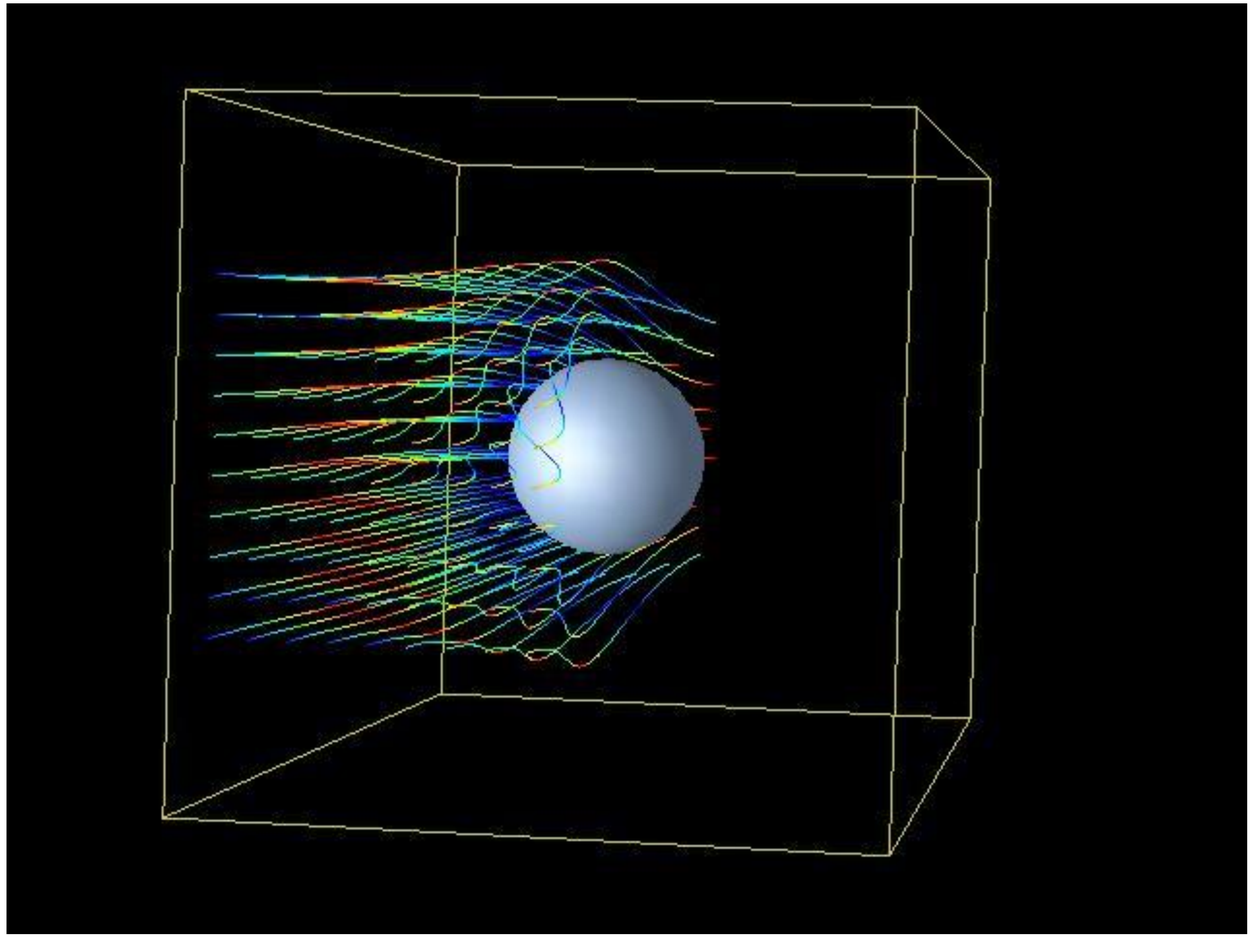
Laidlaw, et al. 2001

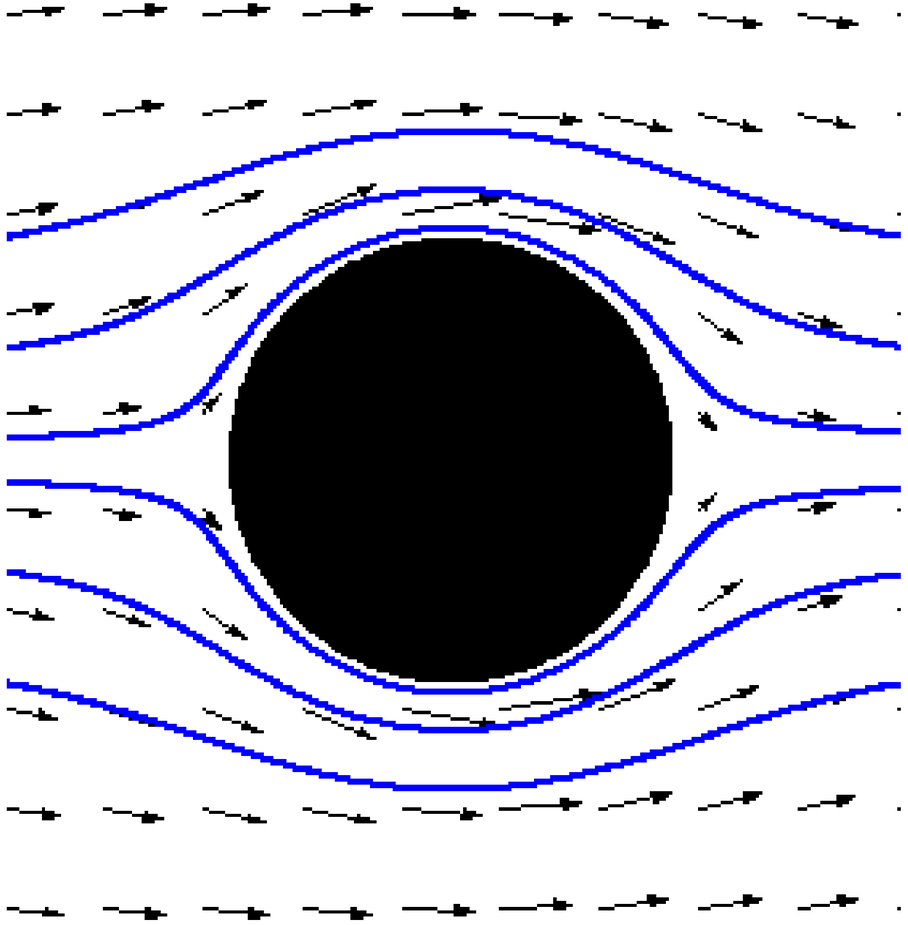
Example: Fluid Flow Visualization



Leonardo DaVinci

Example: Fluid Flow Visualization

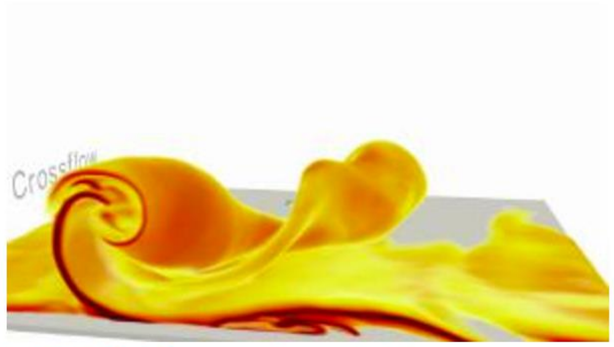




Example: Fluid Flow Visualization

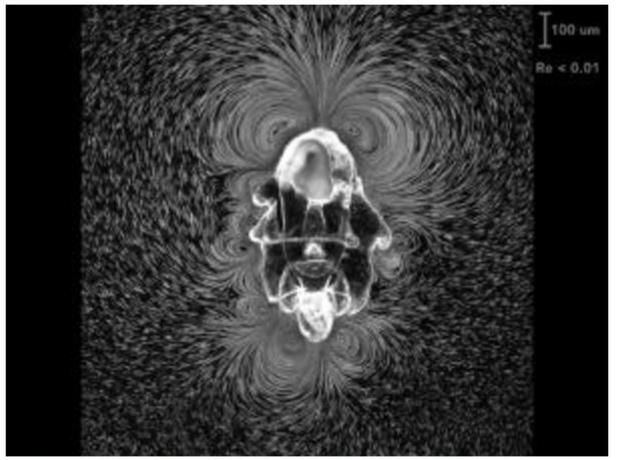
http://gfm.aps.org/meetings/dfd-2016

2016 APS/DFD Milton van Dyke Award Winners (Video)



V0076: Sweeping Jet from a Fluidic Oscillator in Crossflow

V0095: The shear joy of watching paint dry



V0055: Eat, Prey, Swim: Dynamic vortex arrays created by starfish larvae

Simulated Blood Flow through a Patient's Coronary Arteries

Michelle Borkin, Amanda Peters, Dimitrios Mitsouras, Hanspeter Pfister, and Efthimios Kaxiras *(Harvard University)*

The Multiscale Hemodynamics project is a collaboration of doctors, physicists, and computational scientists working together with the goals of gaining a better understanding of heart disease through fundamental fluid mechanics, and developing a method to non-invasively detect regions of atherosclerotic lesion formation and areas of rapid disease progression. By identifying high risk areas in the coronary arteries, a doctor is able to facilitate targeted interventions (e.g., stent placement) to prevent further disease progression possibly leading to a heart attack.

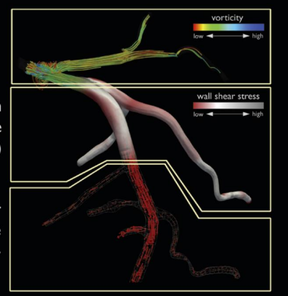
To this end, the project has collected computed tomography angiography (CTA) data from patients in order to obtain coronary geometries and then accurately model human blood flow through the coronary arteries. The CTA data is gathered using a 320 detector row Toshiba AquilionONE scanner and then the data is registered and segmented. The end result is a series of 3D surfaces representing the heart and coronary arteries. These geometries are then loaded into MUPHY, a multi-physics and multi-scale code combining microscopic Molecular Dynamics (MD) with a hydro-kinetic Lattice Boltzmann (LB) method, to model the blood flow through the static geometries. The result is a full 3D representation over time of the simulated blood flow and associated properties indicative of disease progression including endothelial shear stress (ESS), which cannot be measured in a living patient, for an entire arterial tree.

To learn more about the project, go to: **http://hemo.seas.harvard.edu**

The streamlines follow the velocity vector field of the blood flow, and the color represents the magnitude of the vorticity.

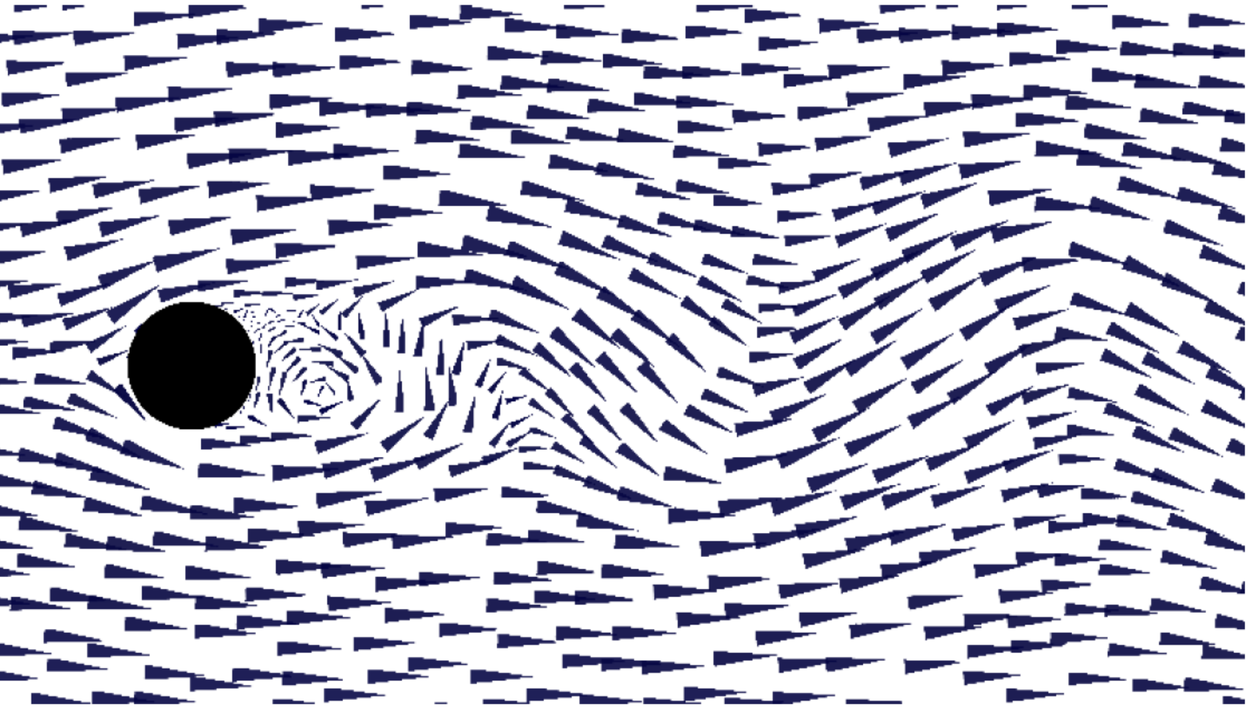
The surface representation shows the lumen of the artery, and the color represents the magnitude of the endothelial (i.e., inner wall) shear stress.

The 3D arrows show the velocity vector field with the arrow oriented along the vector field and scaled in size by the magnitude of the velocity.



Special thanks to the entire Multiscale Hemodynamics team including Frank Rybicki, Charles Feldman, and Simone Melchionna. This research was supported by the Initiative in Innovative Computing at Harvard and by the CyberInfrastructure (CI) Lab at the Harvard School of Engineering and Applied Sciences. M. Borkin is supported by the Department of Defense (DoD) through the National Defense Science & Engineering Graduate Fellowship (NDSEG) Program, and A. Peters is supported by the Department of Energy through the Computational Science Graduate Fellowship (DOE CSGF) Program.

Example: Fluid Flow Visualization



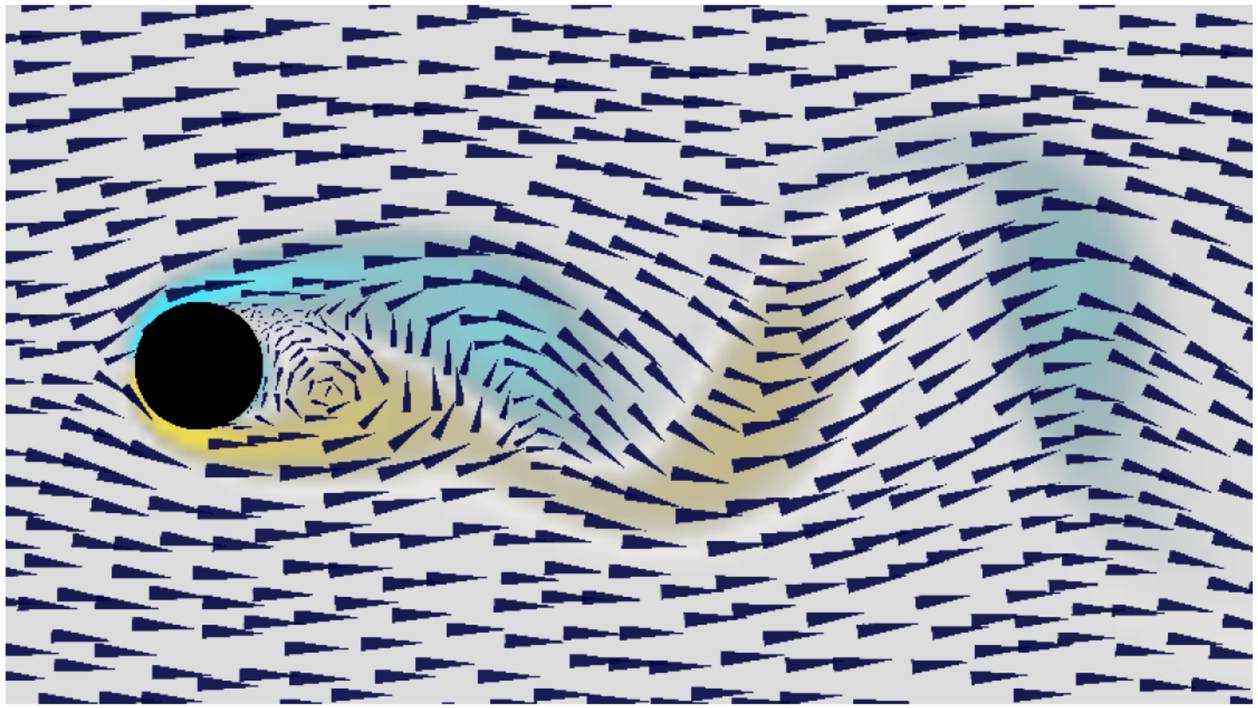
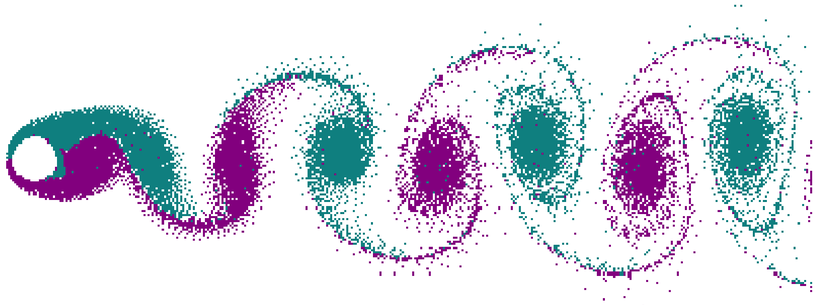
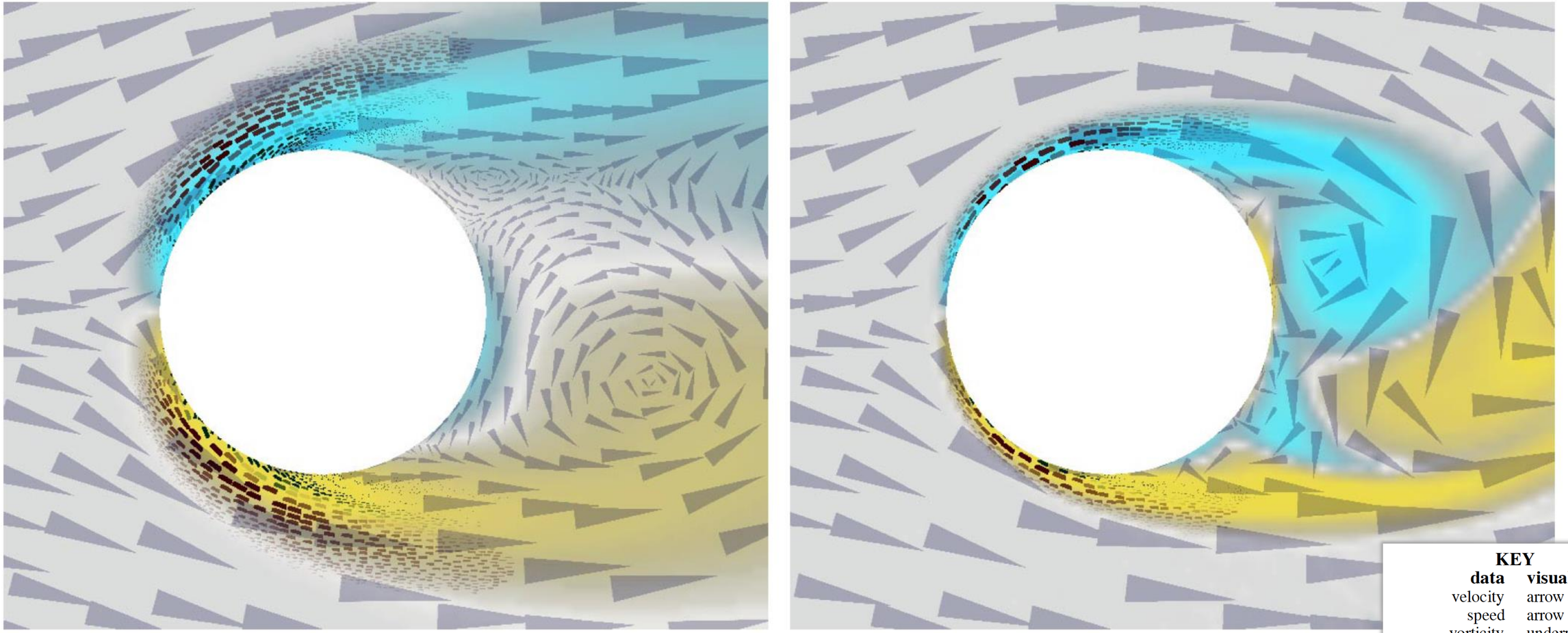


Figure 1: Typical visualization methods for 2D flow past a cylinder at Reynolds number 100. On the left, we show only the velocity field. On the right, we simultaneously show velocity and vorticity. Vorticity represents the rotational component of the flow. Clockwise vorticity is blue, counterclockwise yellow.



Wikimedia

Kirby, et al. 1999



Reynolds number 100

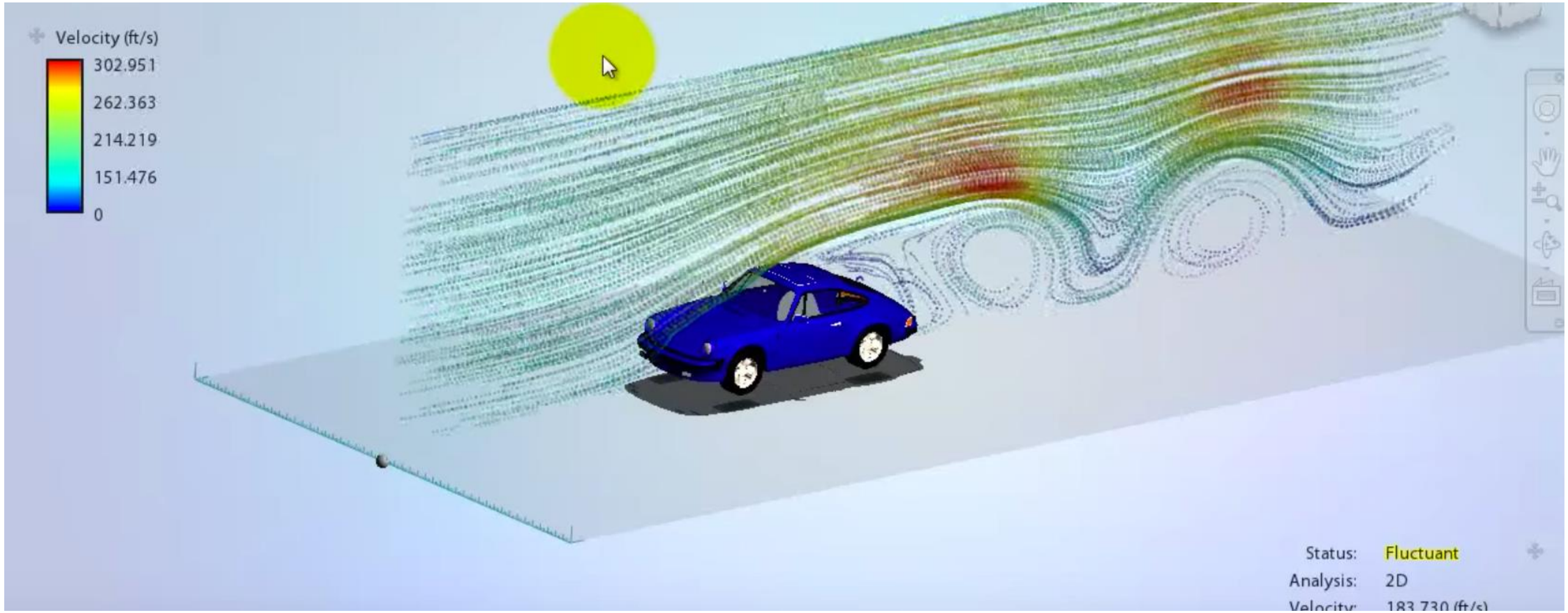
Reynolds number 500

Figure 4: Close up visualization of the turbulent charge and the turbulent current at Reynolds number 100 and 500 (left and right). We are able to see the high concentrations of negative charge at the places where vorticity is being generated.

The Reynolds number is the ratio of inertial forces to viscous forces within a fluid which is subjected to relative internal movement due to different fluid velocities

Kirby, et al. 1999

Example: Fluid Flow Visualization



https://www.youtube.com/watch?v=KUz0G09TGrI

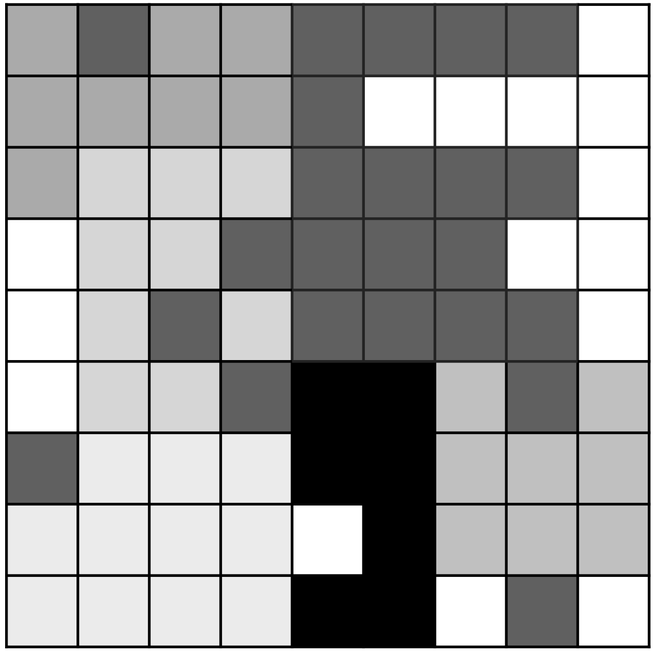
Spatial Fields

Scalar field = one value per cell

Encoding options:

1	3	4	9	4	8	8	1	0
5	6	7	8	8	8	8	8	1
9	7	5	5	5	5	5	5	8
1	3	4	9	4	8	8	1	0
5	6	7	8	8	8	8	8	1
9	7	5	5	5	5	5	5	8
7	7	5	5	6	5	5	5	8
1	1	1	1	5	6	6	6	8
2	2	2	1	5	6	6	6	8

Scalar
(magnitude)

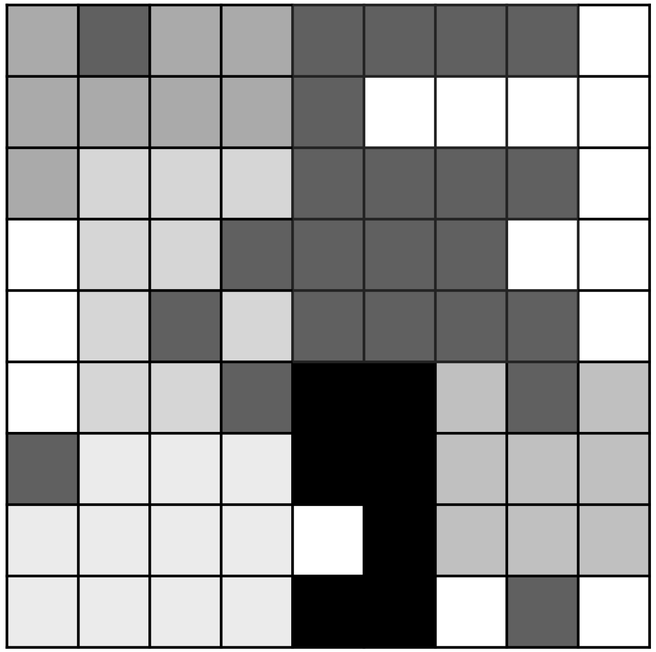


Image

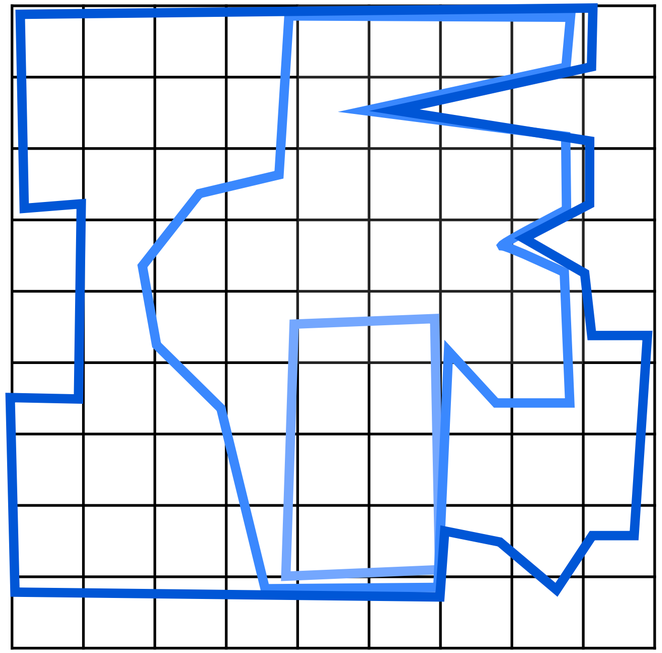
Spatial Fields

Scalar field = one value per cell

Encoding options:



Image



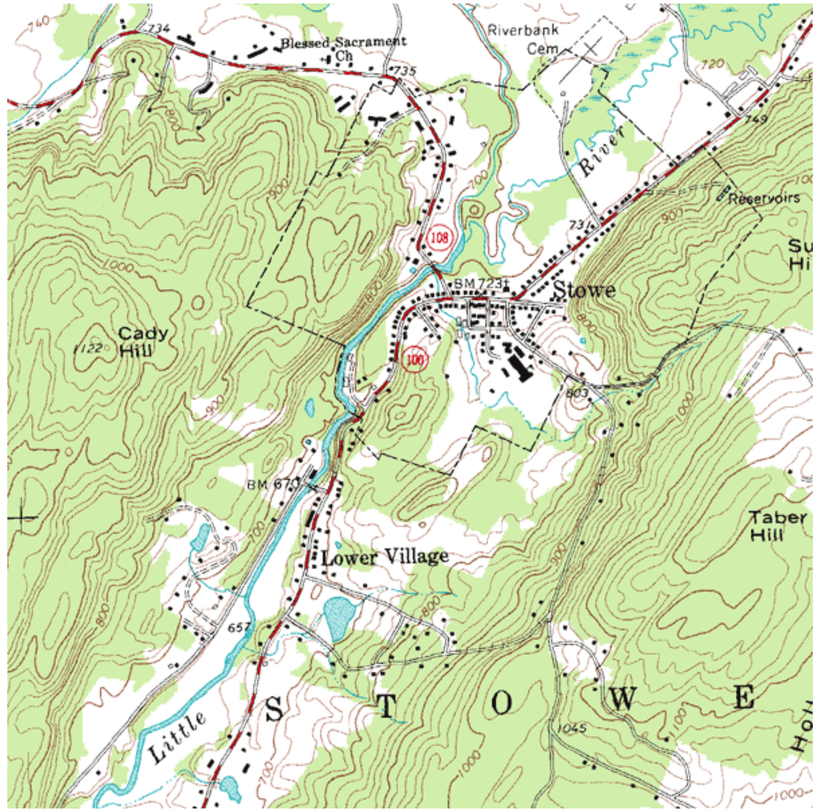
Isocontours

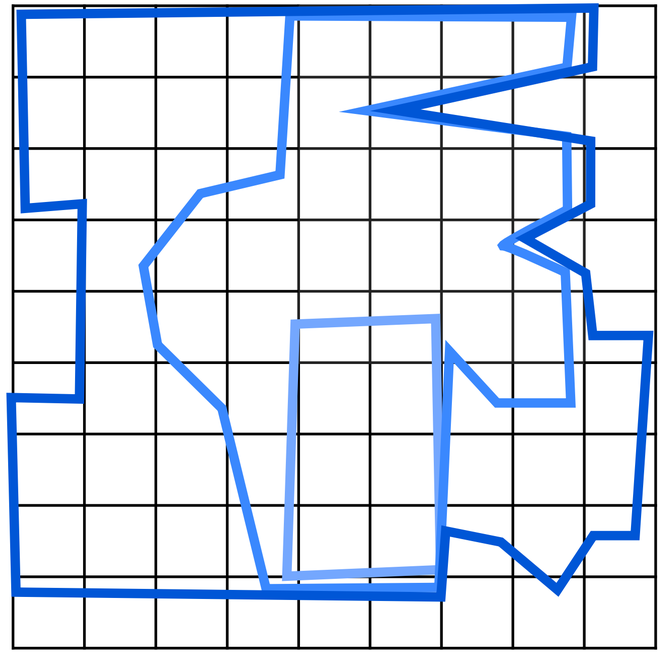
(Contour line as single scalar threshold value)

Spatial Fields

Scalar field = one value per cell

Encoding options:





Isocontours

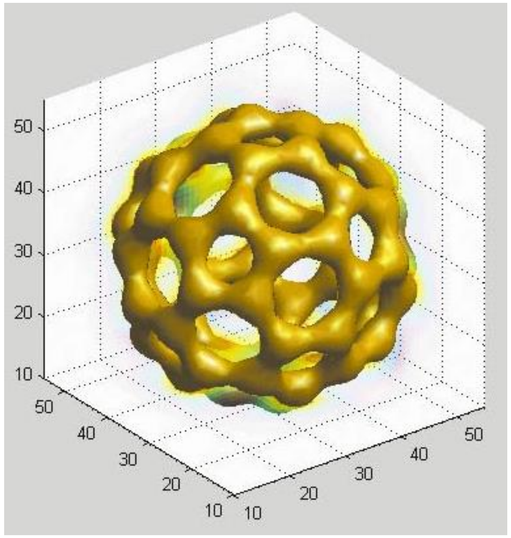
(Contour line as single scalar threshold value)

3D Spatial Fields

Scalar field = one value per cell

Encoding options:

Isosurface



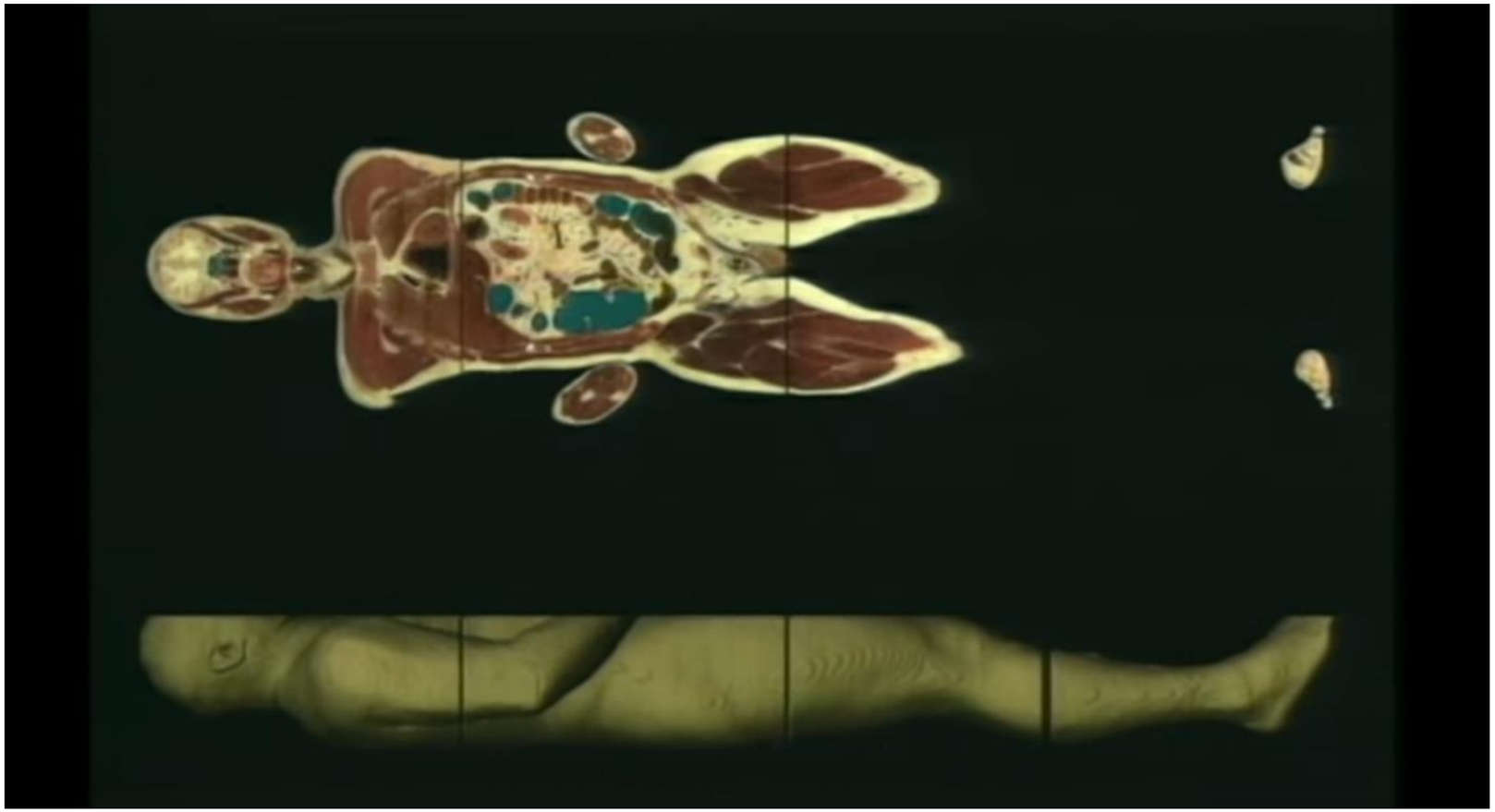
Surface that represents points of a constant value

Volume Rendering

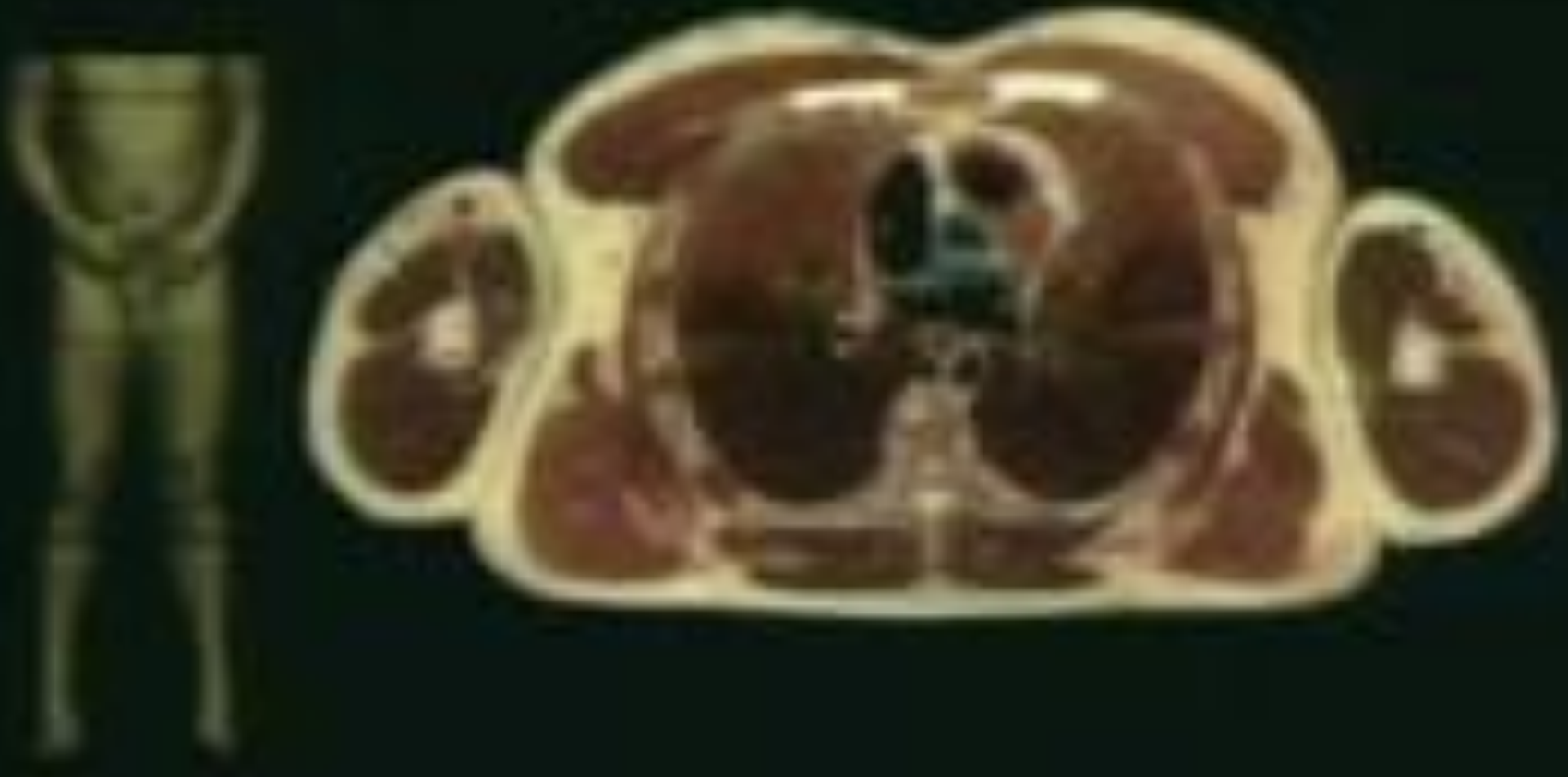
Every value is mapped to an opacity and a color via a "transfer function"

Isosurfaces & Volume Rendering

Visible Human Project

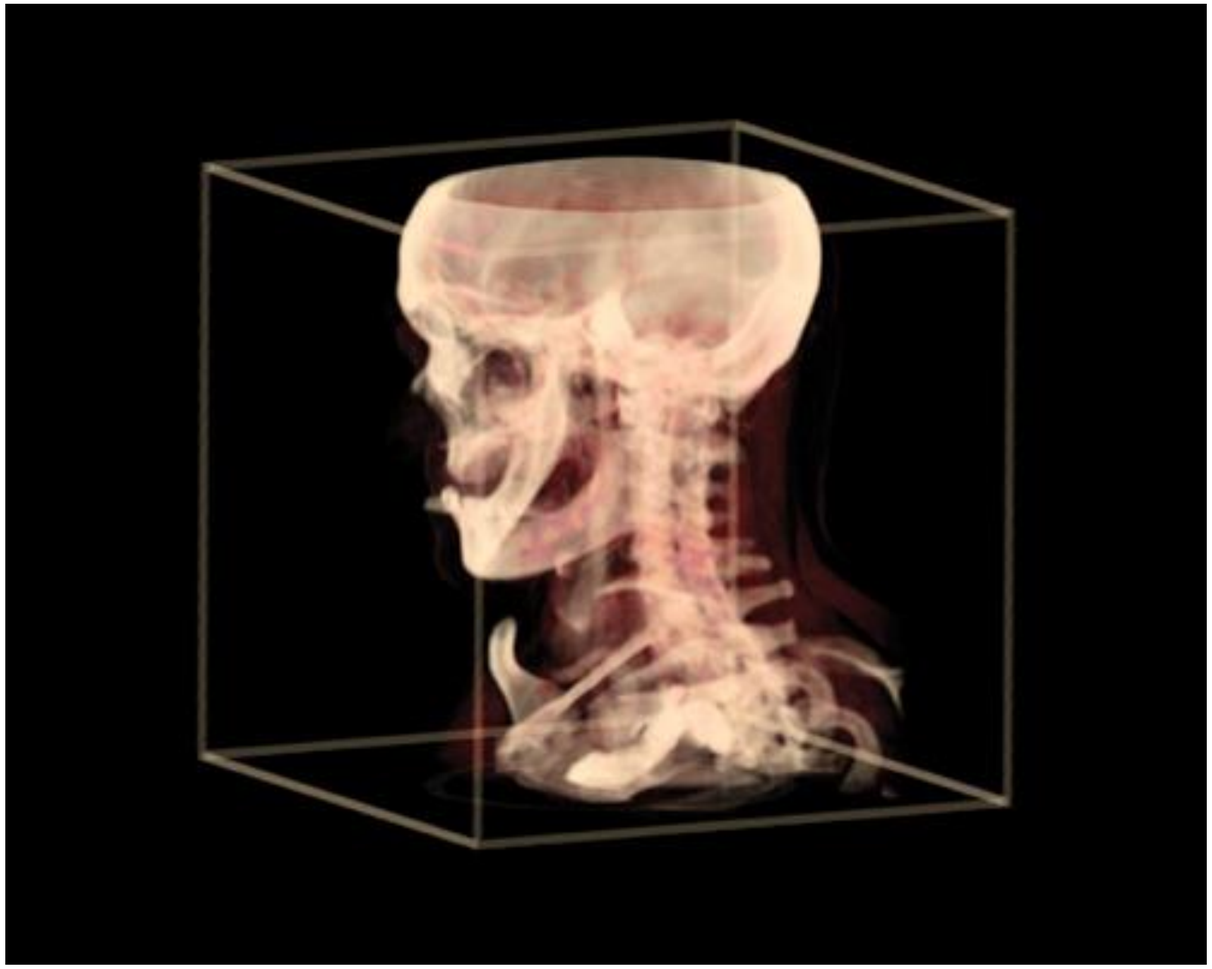


https://www.youtube.com/watch?v=7GPB1sjEhIQ



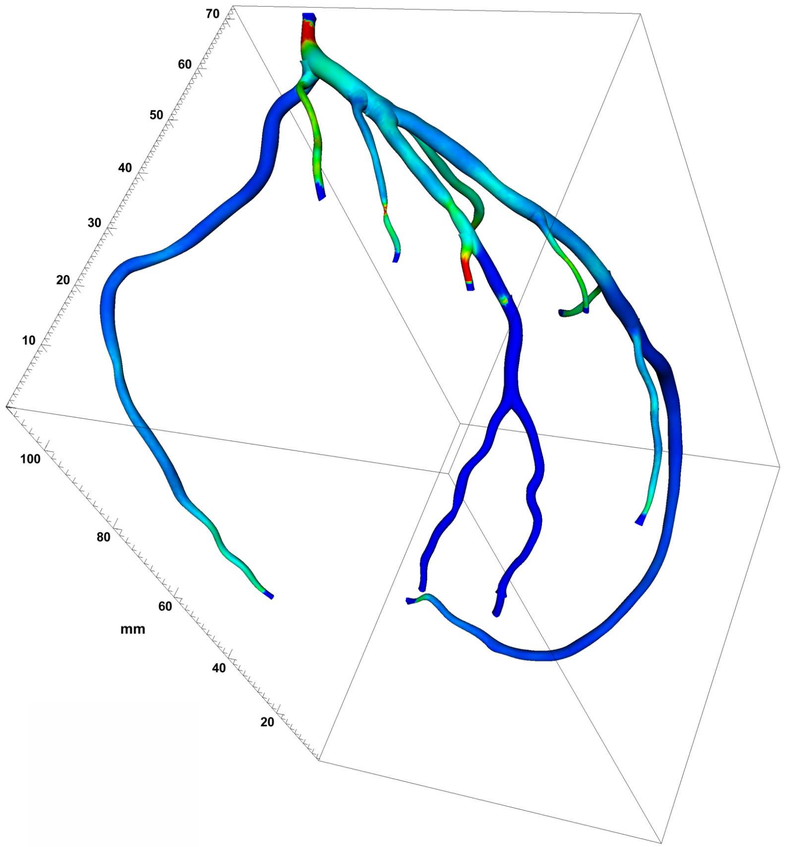
Isosurfaces vs. Volume Rendering

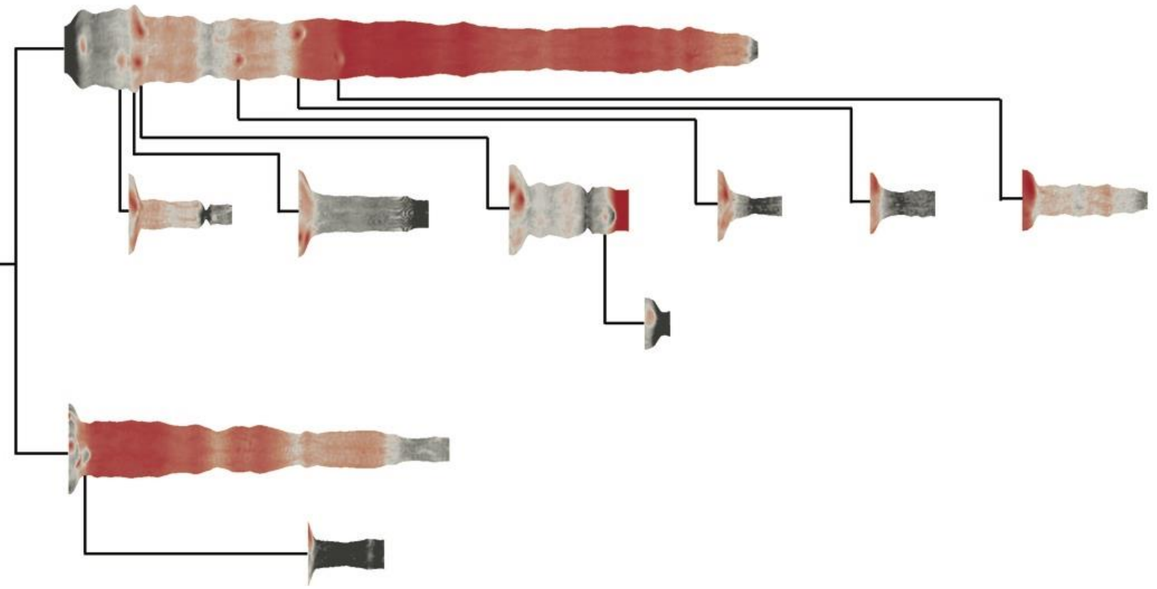
distinct objects
distinct thresholds (surfaces)

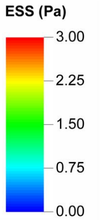


indistinct objects
blending or transparency important

Isosurfaces vs. Abstracted







[Borkin et al., 2011]

For Next Time

neu-ds-4200-s22.github.io/schedule

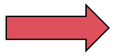
Look at the upcoming assignments and deadlines

- Textbook, Readings, & Reading Quizzes—Variable days
- In-Class Activities—If due, they are due 11:59pm the same day as class

Everyday Required Supplies:

- 5+ colors of pen/pencil
- White paper
- Laptop and charger

Use Canvas Discussions for general questions, email codydunne-and-tas@ccs.neu.edu for questions specific to you.



Week	Topics	Assignments
#1: Jan 17–21	What is visualization Design rules of thumb	A1—Setting up
#2: Jan 24–28	JS development, projects Marks & channels	A2—Encodings & xenographics
#3: Jan 31–Feb 04	Data types and tasks, Tableau D3 tutorial 1/2	P1—Pitches★
#4: Feb 07–11	In-class group formation D3 tutorial 2/2	A3—Tableau analysis P2—Proposal★
#5: Feb 14–18	Altair and JupyterLab Practice Design Study	A4—D3 basic charts
#6: Feb 21–25	Arrange Tables Color, pop-out, illusions	A5—Altair basic charts P3—Interview & tasks
#7: Feb 28–Mar 04	Interaction & animation In-class project meetings 1/2	A6—D3 event handling P4—Data and sketches
#8: Mar 07–11	In-class project meetings 2/2 Trees & networks	P5—Final sketches & plan★
Mar 14–18	*Spring Break*	
#9: Mar 21–25	Spatial, 3D, and scientific vis. TBD	A7—D3 Brushing⧗ P6—Implementation 1
#10: Mar 28–Apr 01	Validation & evaluation Flex day	A8—Brushing & linking⧗ 2 P7—Implementation 2
#11: Apr 04–08	Project usability testing, how to give a talk Storytelling	
#12: Apr 11–15	Project presentations 1/2 Project presentations 2/2	P8—Presentations★⧗
#13: Apr 18–22	Flex day	P9—Presentation peer review
#14: Apr 25–29	Reflecting & project work	
May 02–06		P10—Video & Final Deliverables★⧗