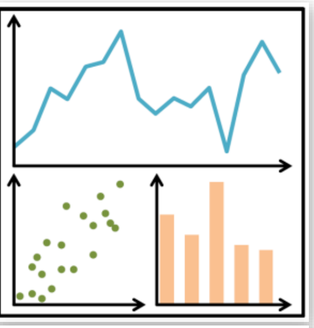
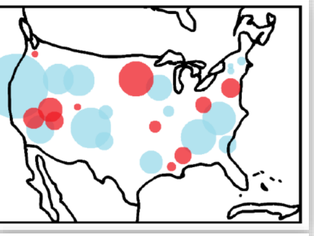
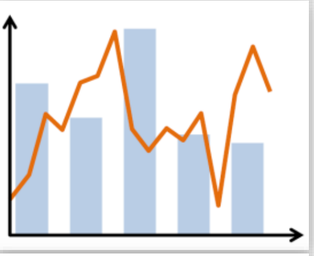
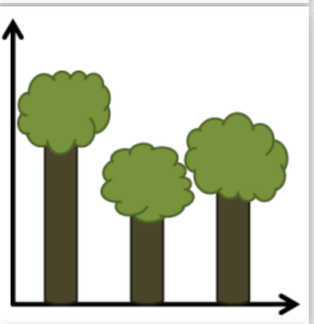
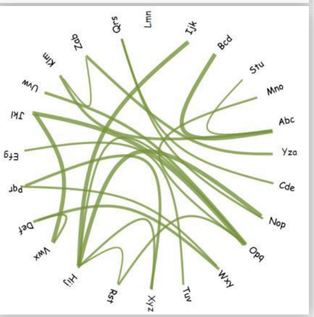






Trees and Networks, Maps, Spatial & Scientific Vis.

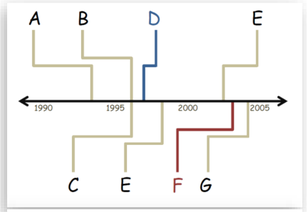
CS 7250

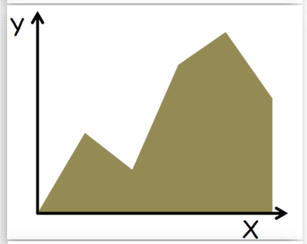
SPRING 2020

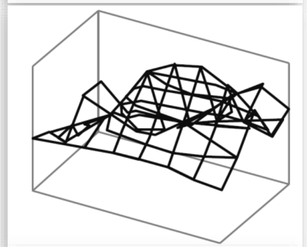
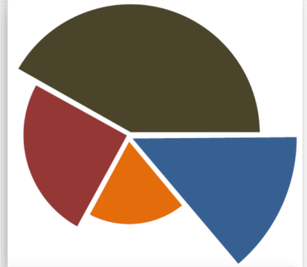
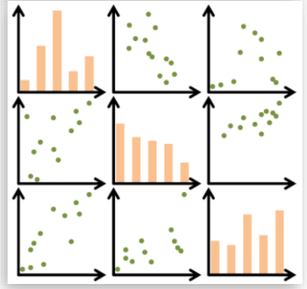
Prof. Cody Dunne

NORTHEASTERN UNIVERSITY

Slides and inspiration from Michelle Borkin, Krzysztof Gajos, Hanspeter Pfister, Miriah Meyer, Jonathan Schwabish, and David Sprague



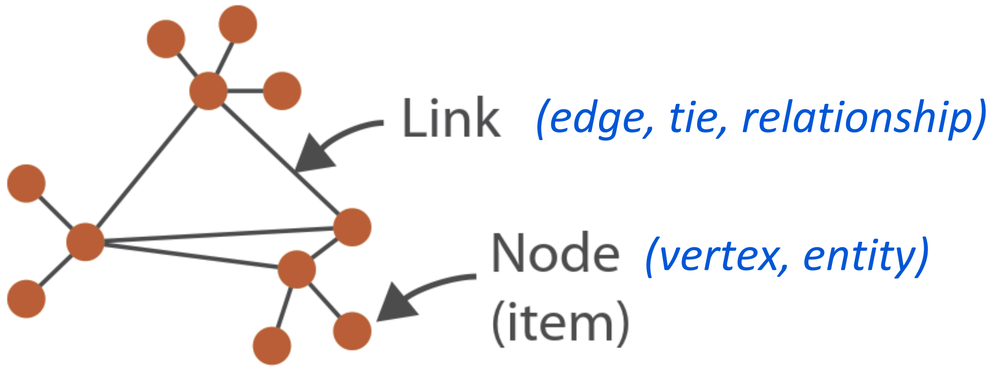


Burning Questions?

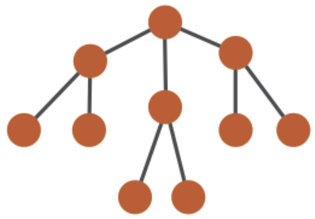
Previously, on CS 7250…

➔ Networks *(graphs)*



Network = entities and relationships between them

➔ *Trees*



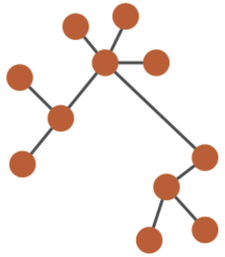
Tree = *undirected*, *connected*, *acyclic* network

Arrange Networks and Trees

Node–Link Diagrams

Connection Marks

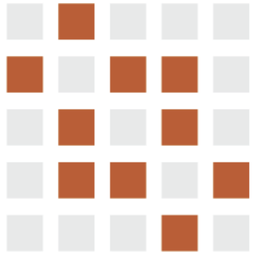
✔ NETWORKS ✔ TREES



Adjacency Matrix

Derived Table

✔ NETWORKS ✔ TREES



Enclosure

Containment Marks

✘ NETWORKS ✔ TREES

"Treemap"

Spatial Layout

Channels: Expressiveness Types and Effectiveness Ranks

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)

Most

Effectiveness

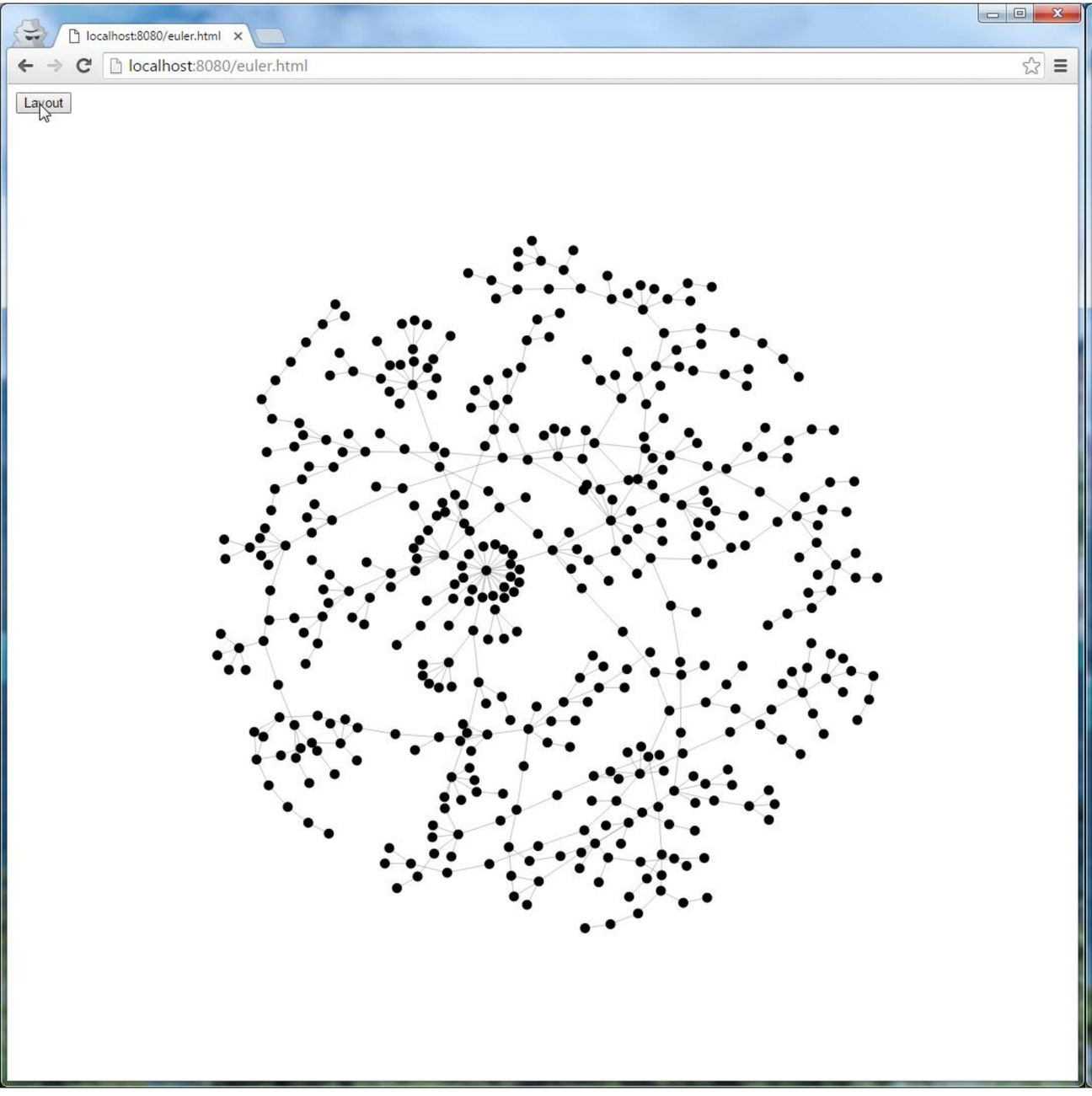
Least

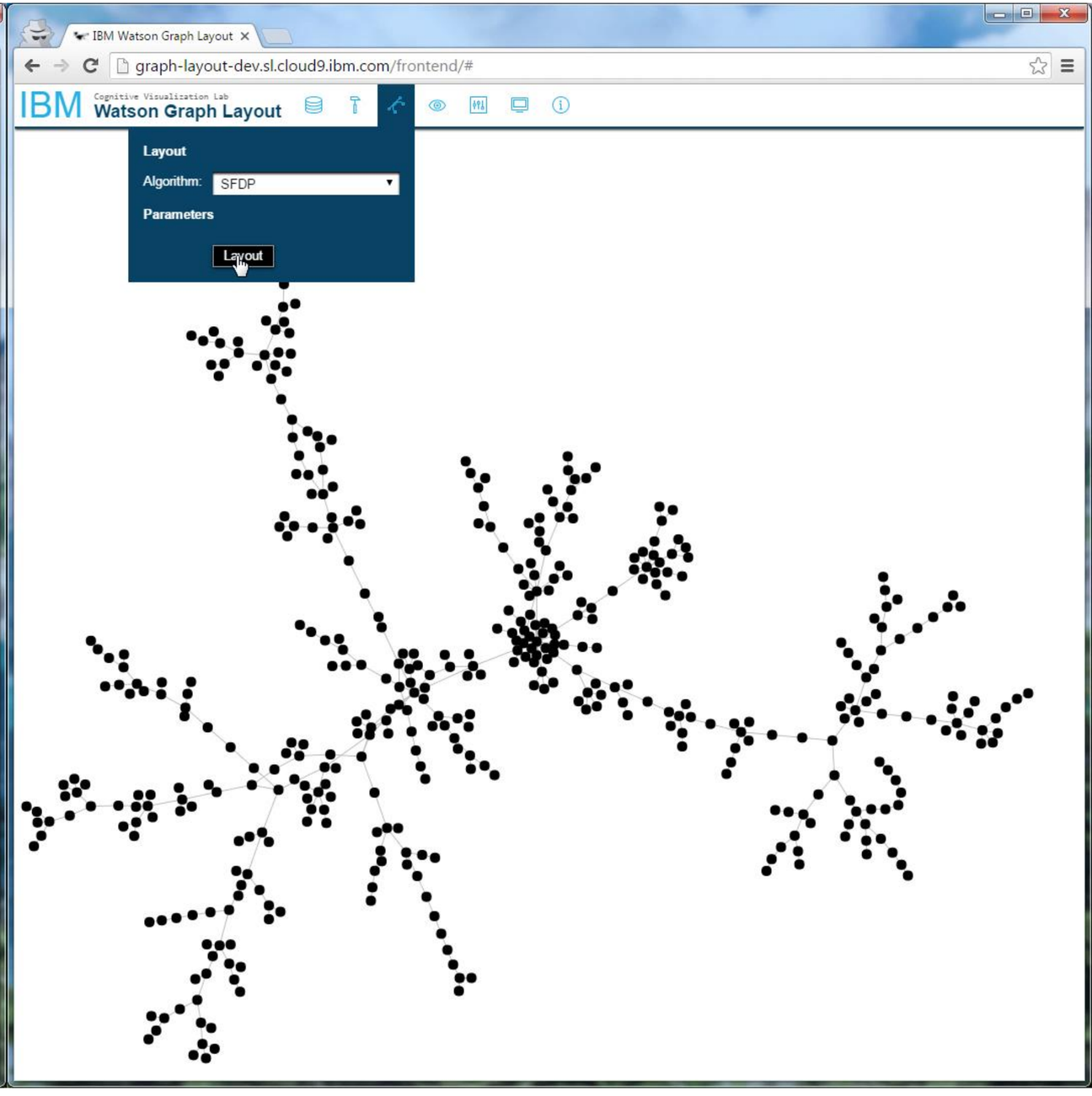
Same

Same

Identity Channels: Categorical Attributes

- Spatial region
- Color hue
- Motion
- Shape


localhost:8080/euler.html
localhost:8080/euler.html
Layout


IBM Watson Graph Layout
graph-layout-dev.sl.cloud9.ibm.com/frontend/#
IBM
Cognitive Visualization Lab
Watson Graph Layout
Layout
Algorithm:
SFDP
Parameters
Layout

Now, on CS 7250…

TREES & (MAINLY) NETWORKS

Goals for Today

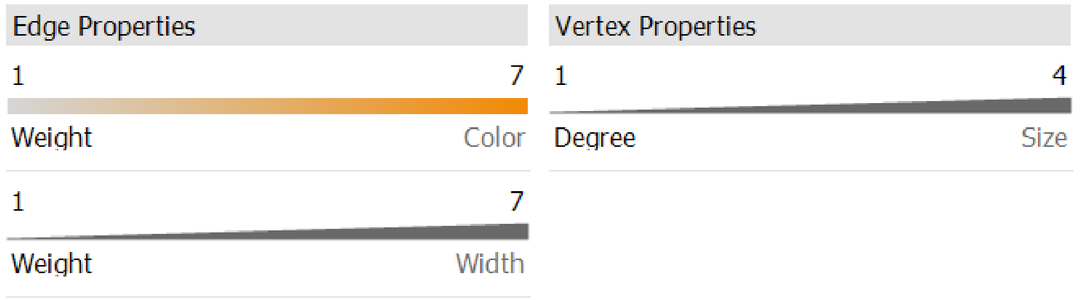
- Learn the definition of a network (including node, edge)
- Learn the definition of a tree
- Learn common visual encoding techniques for network data (i.e., node-link diagram, adjacency matrix), and the advantages of each one.

Hall of Fame or Hall of Shame

In-Class Drawing: Node-Link Visualization

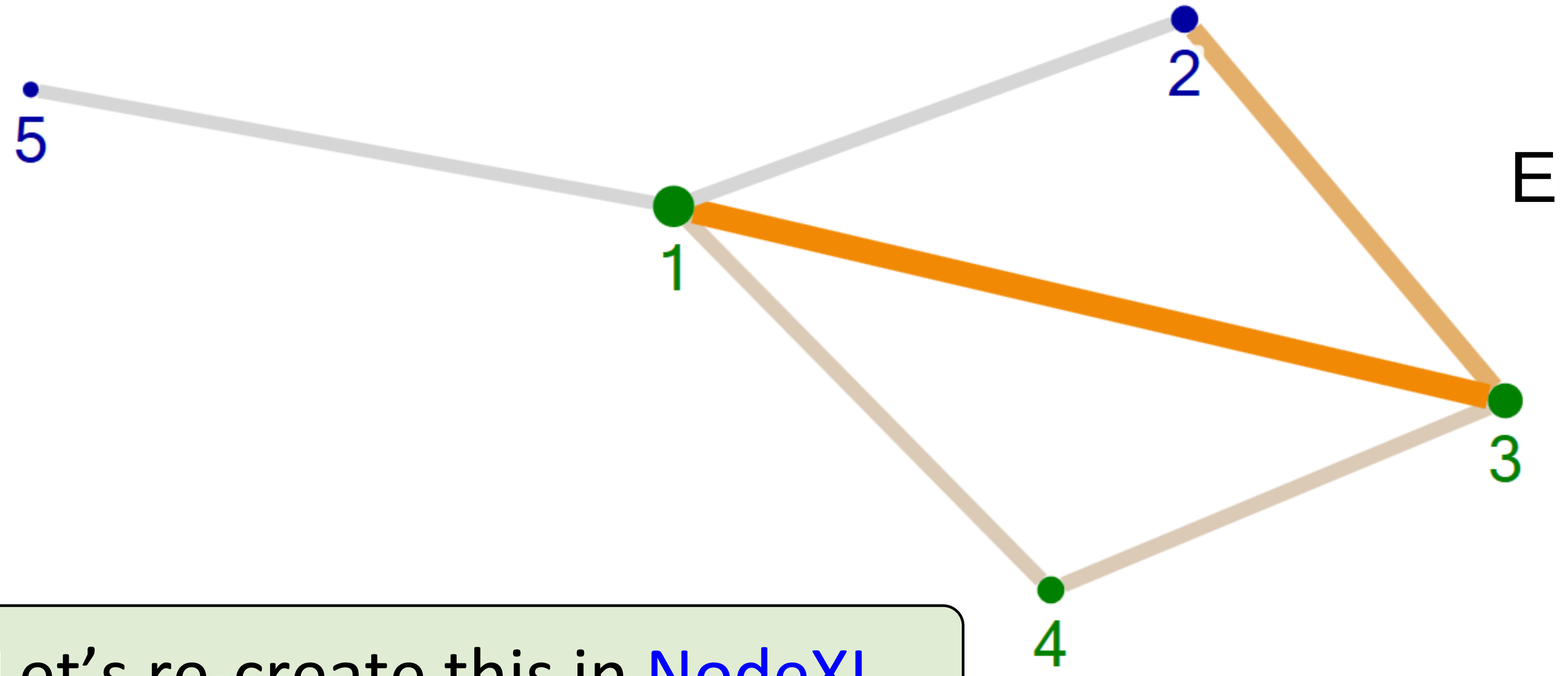
~25 min

In-Class Drawing: Node-Link Visualization



Nodes:

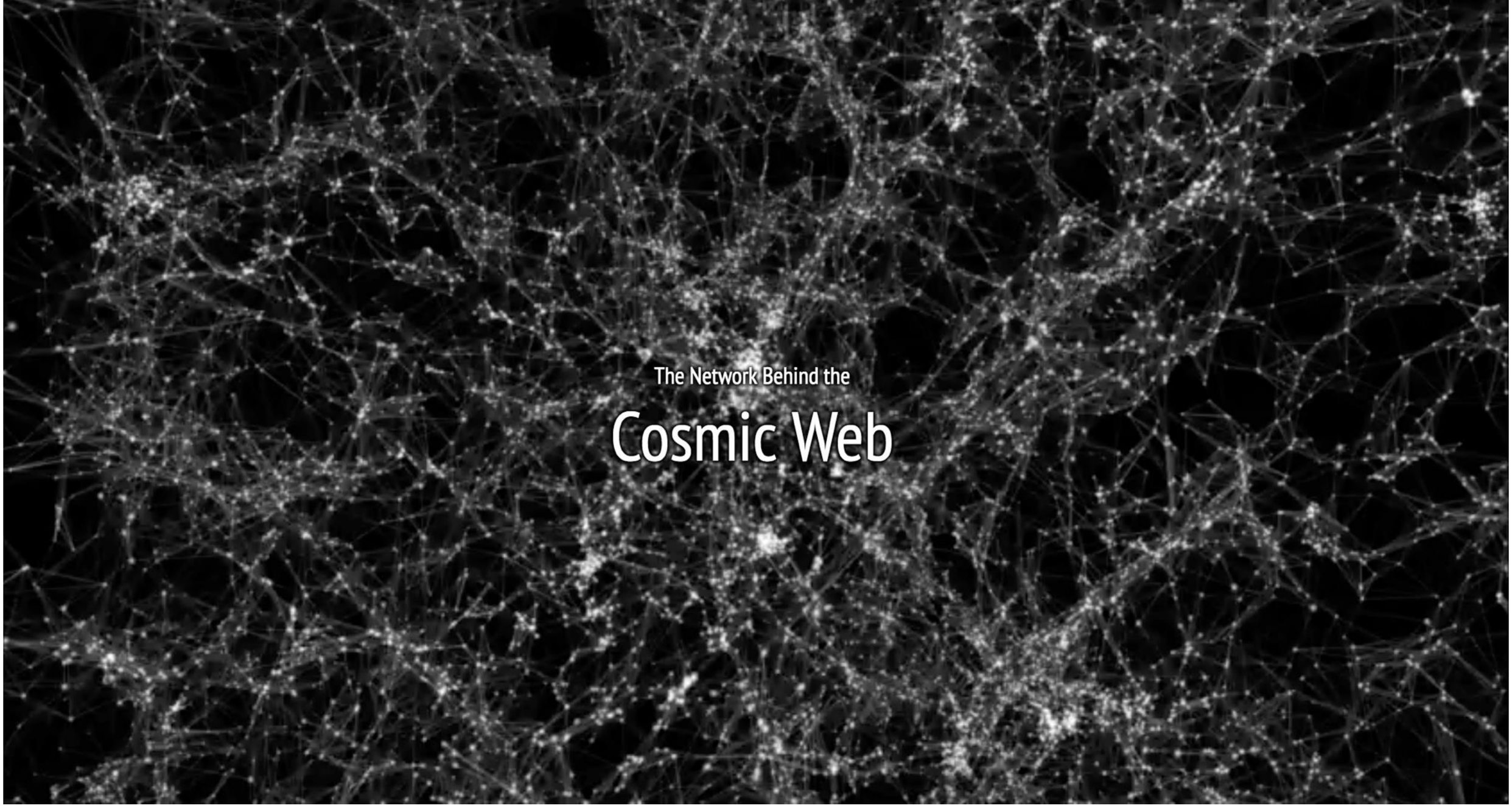
ID	Type
1	A
2	B
3	A
4	A
5	B



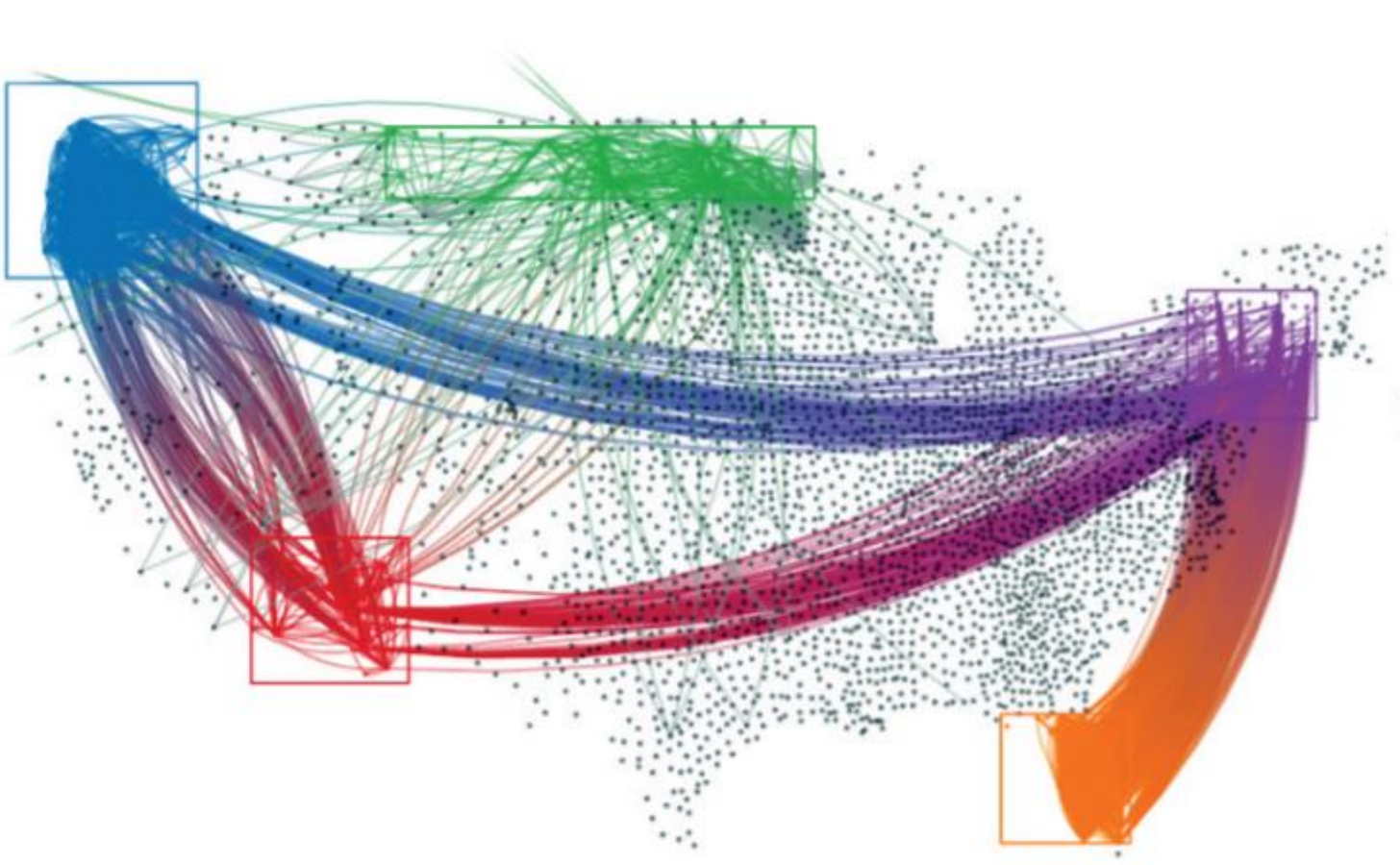
Edges:

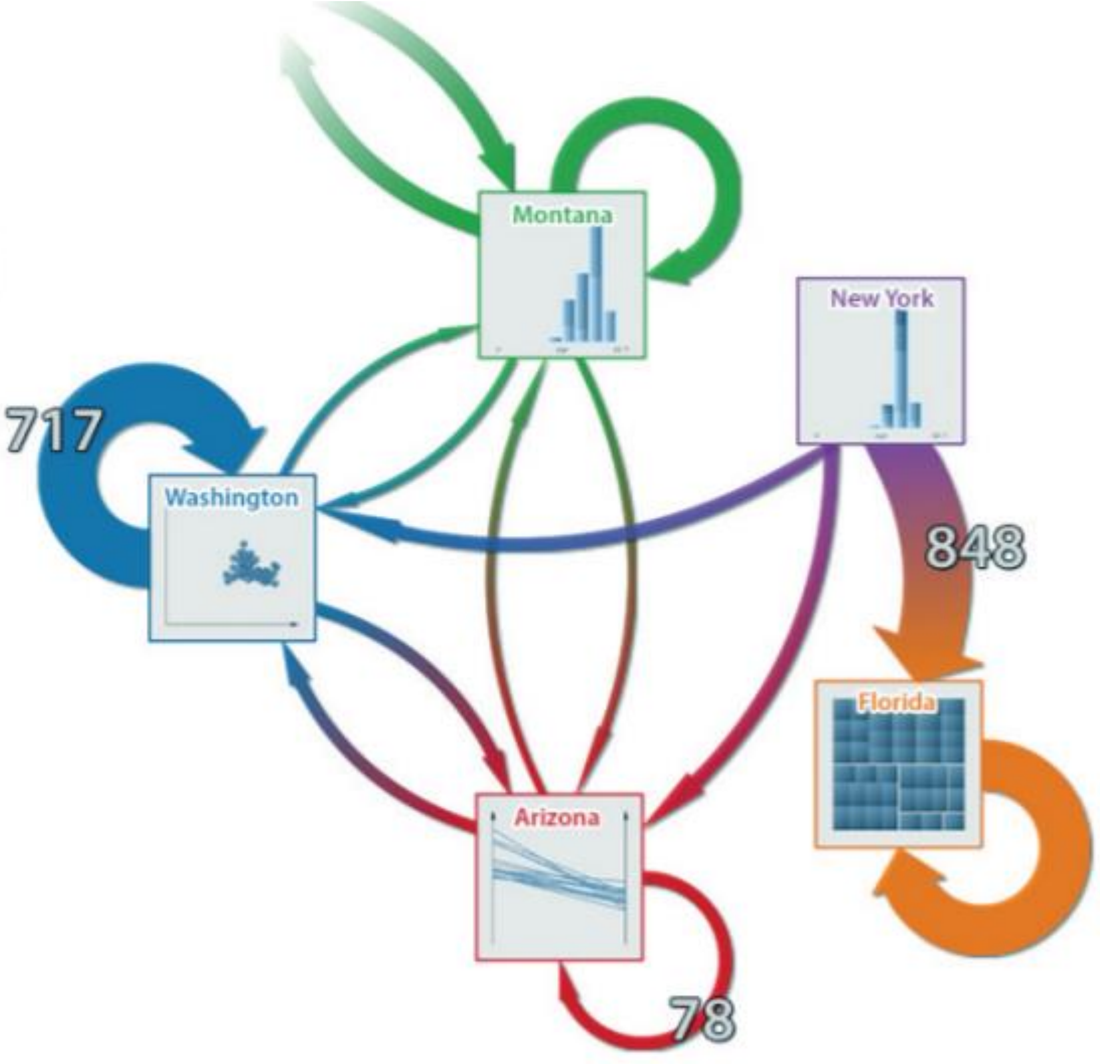
Source	Target	Weight
1	2	1
1	3	7
2	3	4
3	4	2
4	1	2
5	1	1

Let's re-create this in NodeXL…

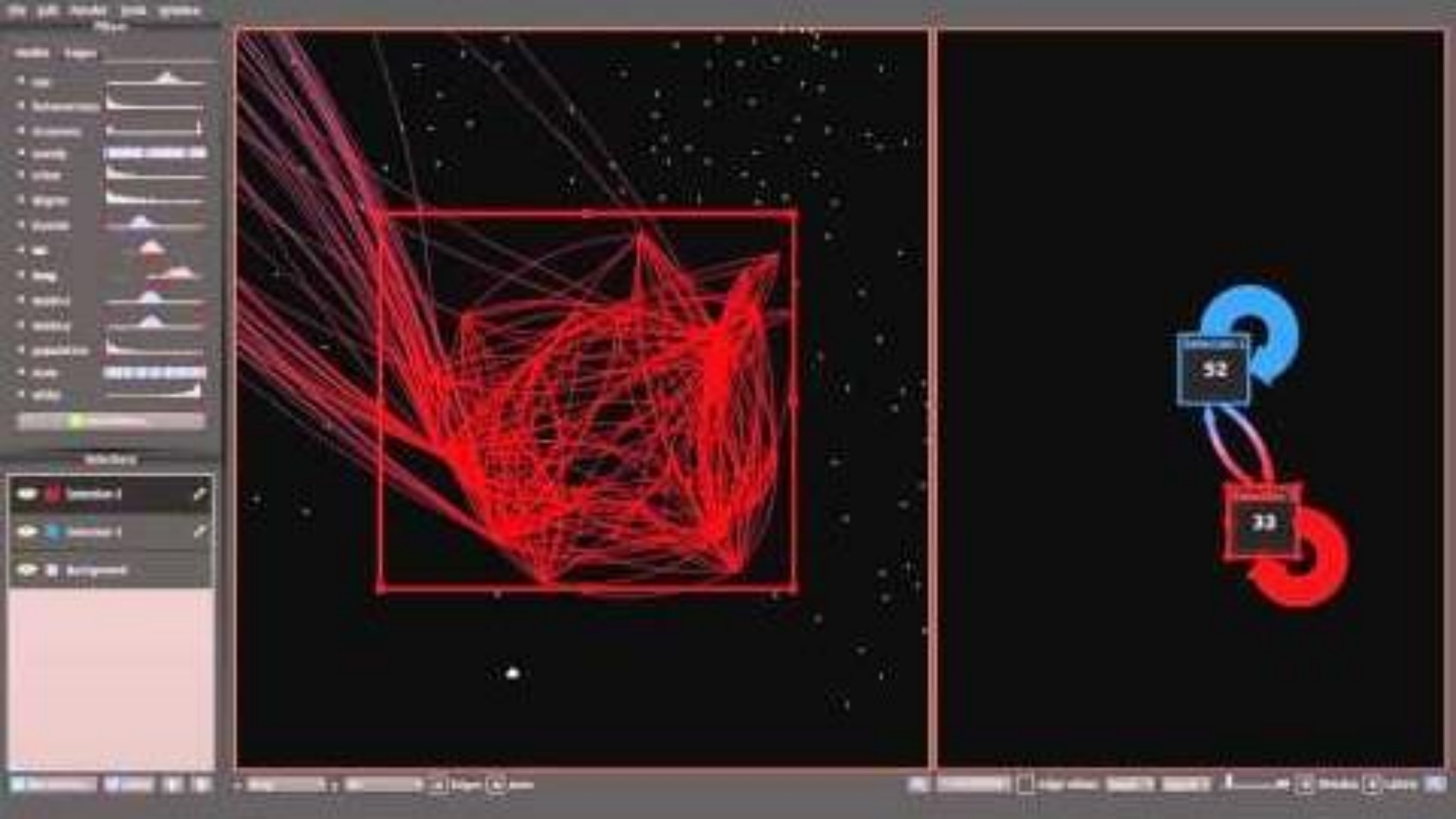


Albrecht et al., 2016

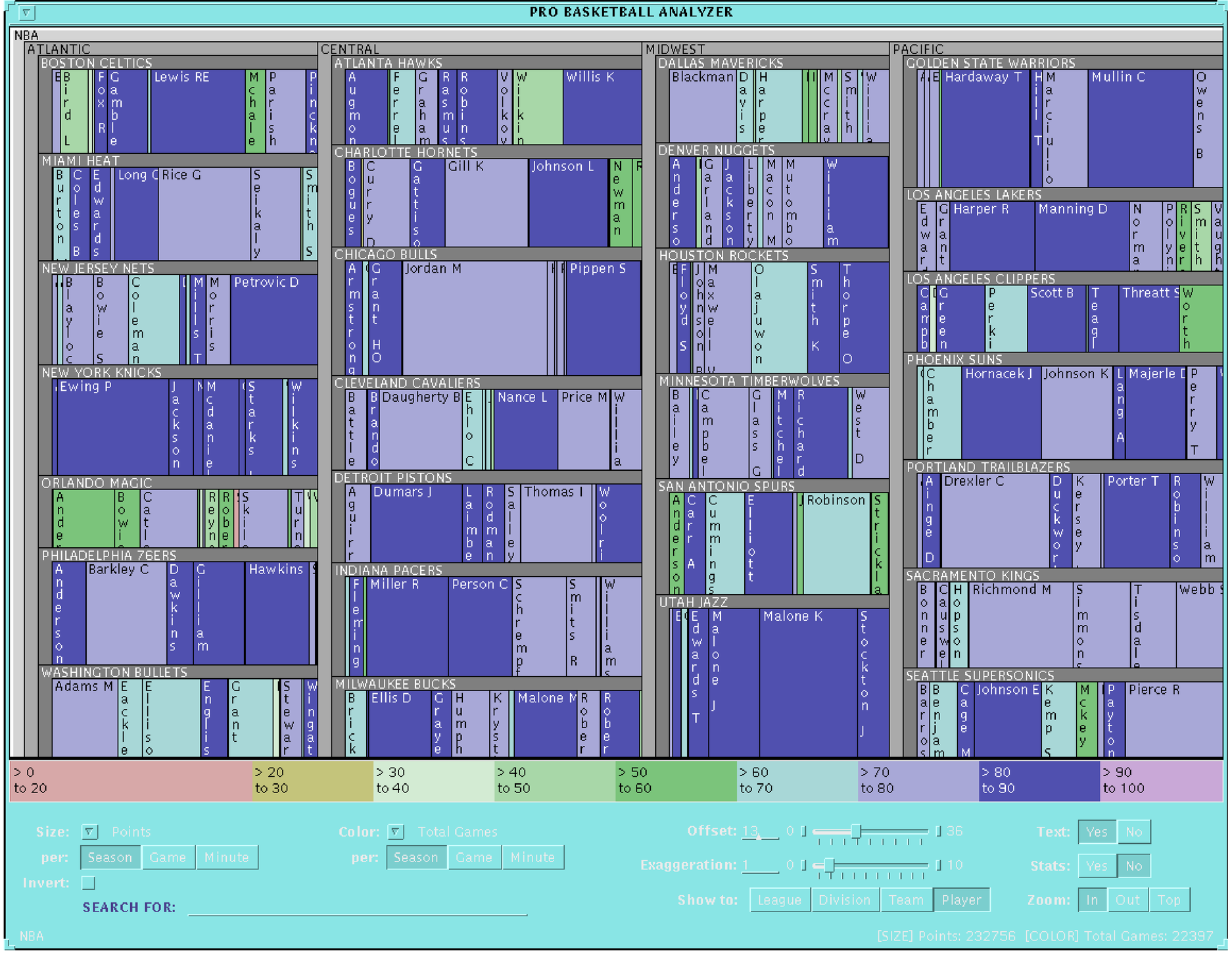




van den Elzen & van Wijk, 2014


52
33

Slice and Dice Treemaps



Turo & Shneiderman, 1993

Cluster / Squarified Treemaps

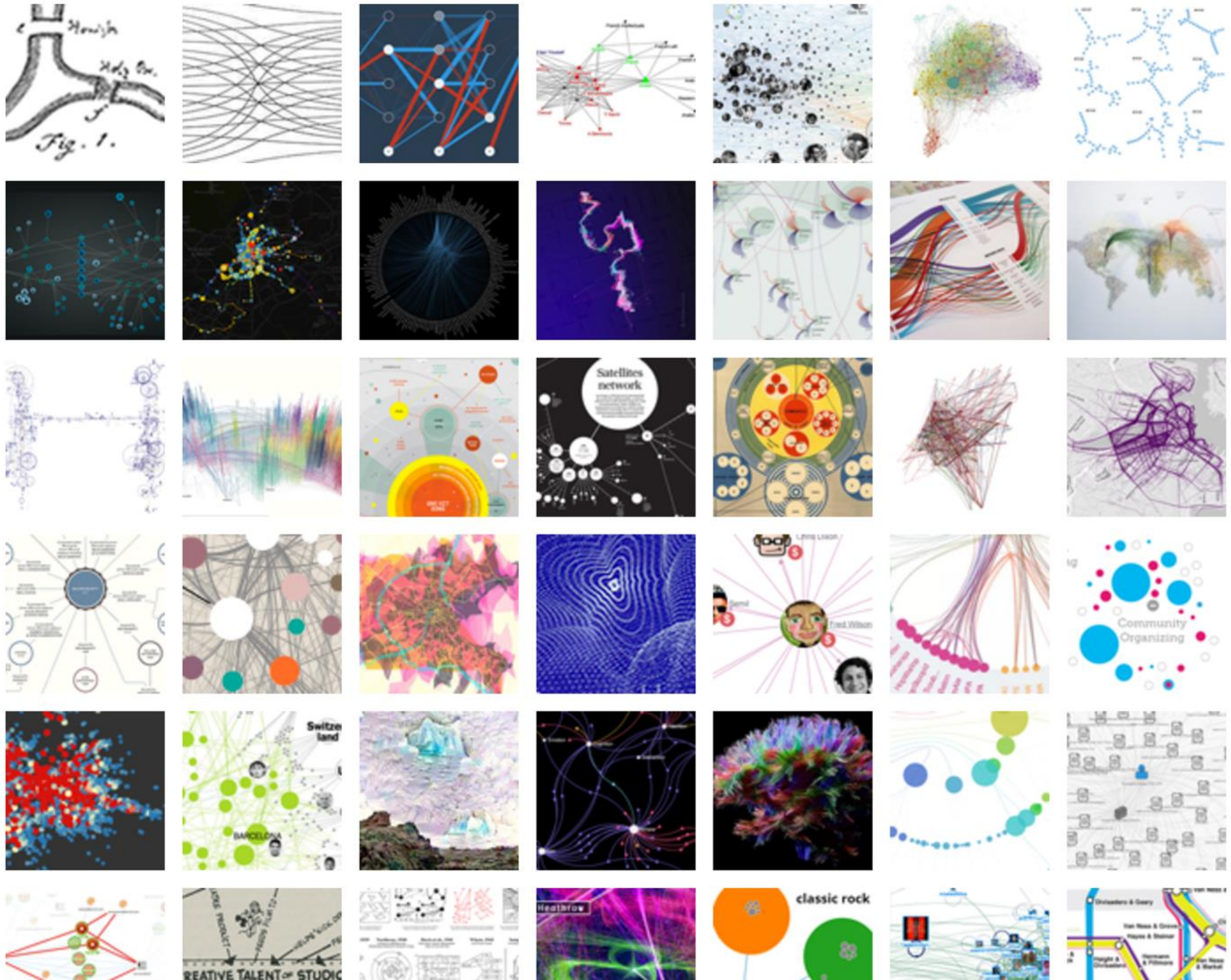
[Wattenberg, 1999](); [Bruls et al., 2000](); [finviz live site](); Snapshot: [finviz, 2020]()

visual complexity

Search the VC database: GO

Latest Projects:

Indexing **1000** projects

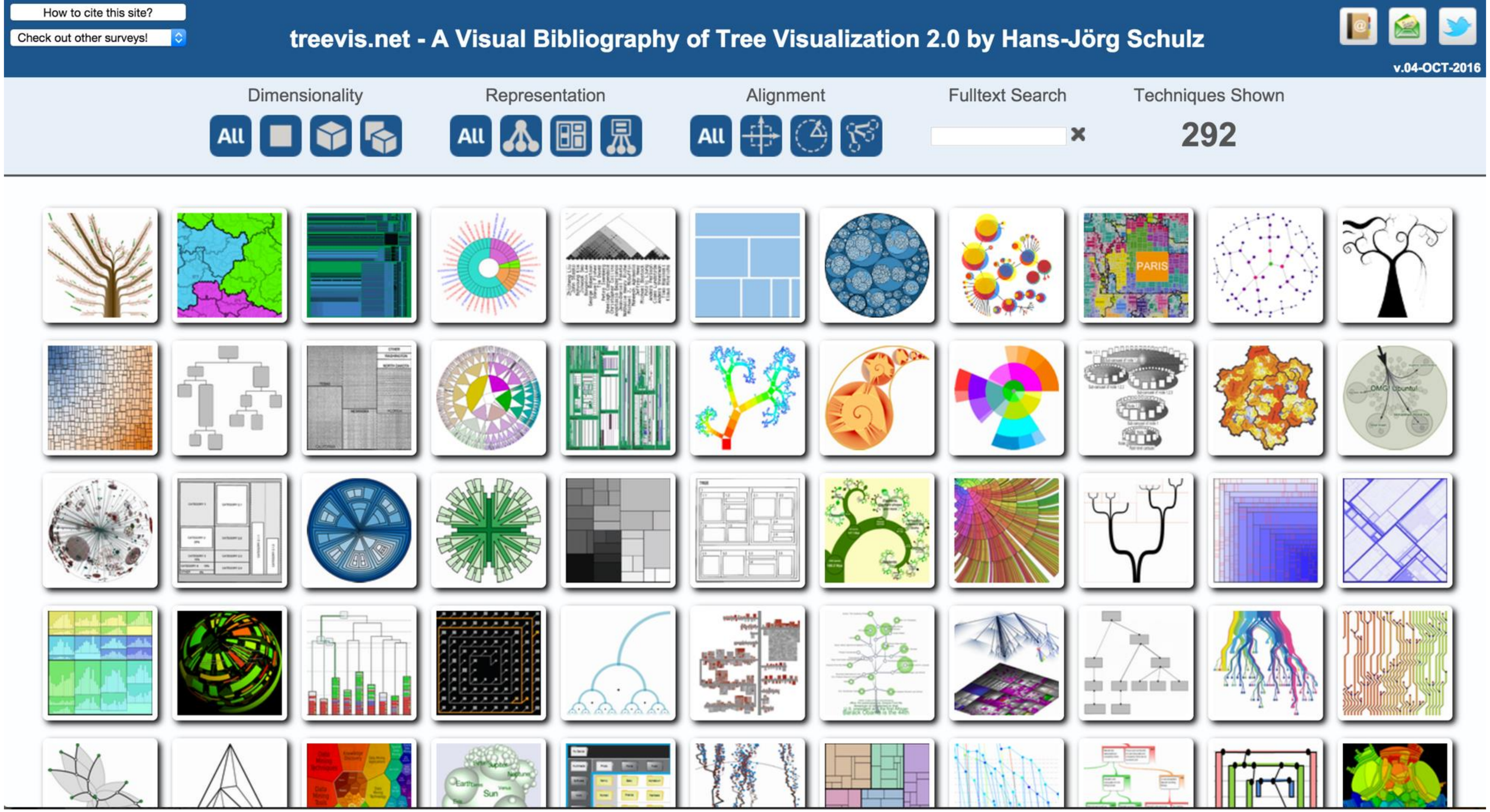


Filter by: SUBJECT

- Art (74)
- Biology (60)
- Business Networks (50)
- Computer Systems (39)
- Food Webs (16)
- Internet (35)
- Knowledge Networks (141)
- Multi-Domain Representation (70)
- Music (47)
- Others (77)
- Pattern Recognition (53)
- Political Networks (34)
- Semantic Networks (44)
- Social Networks (135)
- Transportation Networks (70)
- World Wide Web (55)

See All (1000)

Lima, 2005


How to cite this site?
Check out other surveys!
treevis.net - A Visual Bibliography of Tree Visualization 2.0 by Hans-Jörg Schulz
v.04-OCT-2016
Dimensionality
All
Representation
All
Alignment
All
Fulltext Search
Techniques Shown
292
PARIS

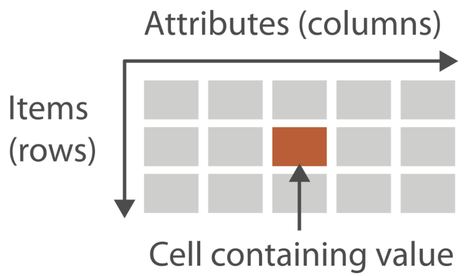
Maps

Goals for Today

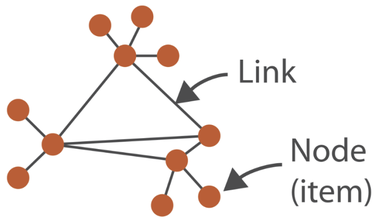
- Learn what elements visually encode data in maps.
- Learn about different projections, and understand the (dis)advantages of each.
- Learn about different map types, and how they relate to tasks.

Dataset Types

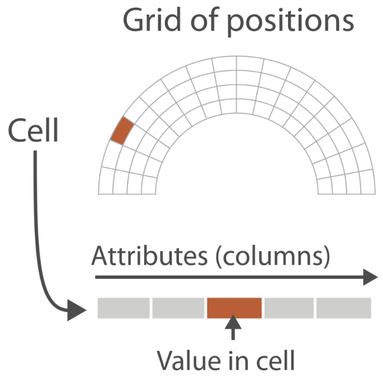
Tables



Networks

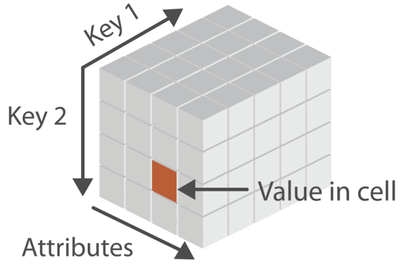


Fields (Continuous)

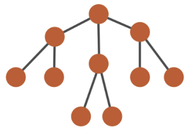


Geometry (Spatial)

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!

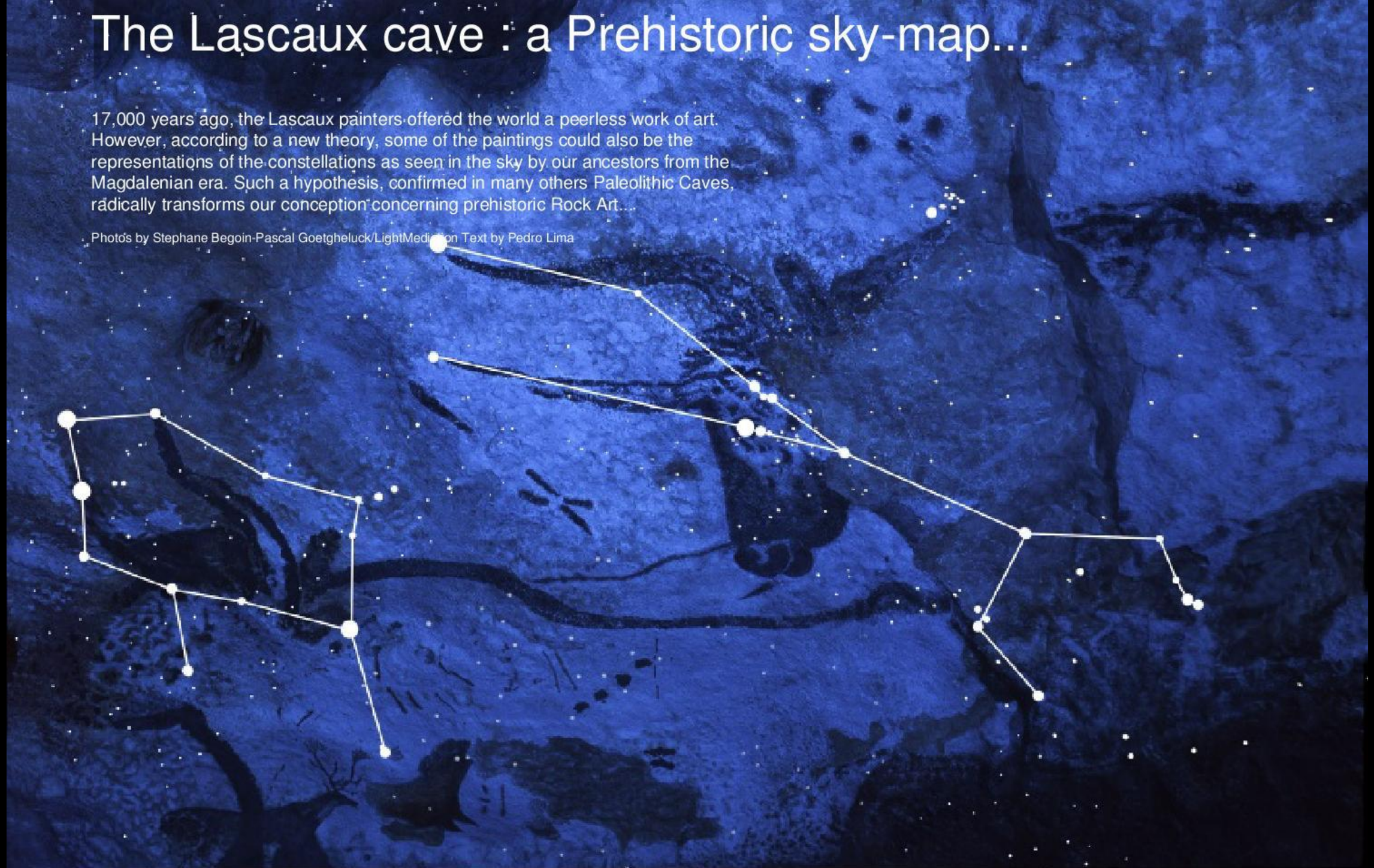
Vega, Deneb, and Altair

Lightmediation, 2008; Whitehouse, 2000

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

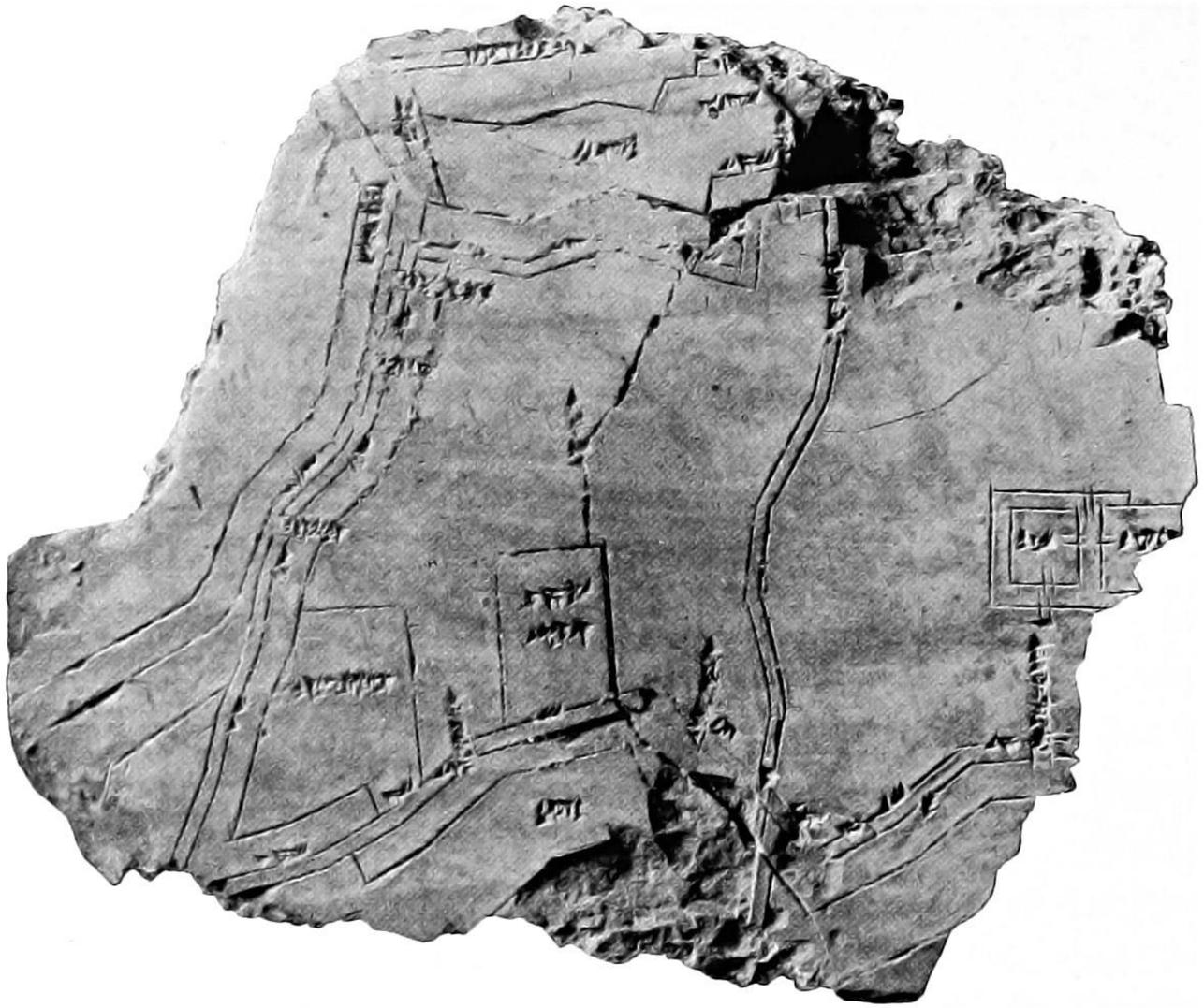
17,000 years ago, the Lascaux painters offered the world a peerless work of art. However, according to a new theory, some of the paintings could also be the representations of the constellations as seen in the sky by our ancestors from the Magdalenian era. Such a hypothesis, confirmed in many others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

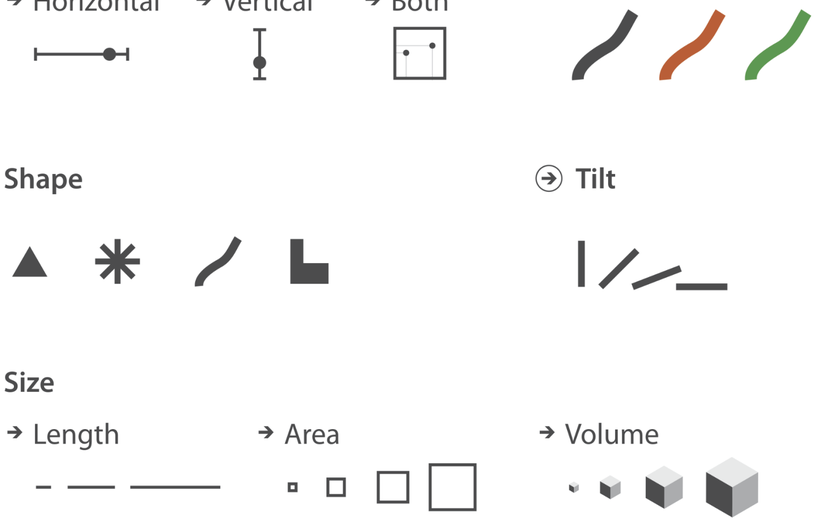
Visualization Building Blocks

MARKS:

- Points
- Lines
- Areas

CHANNELS :

- Position
  - Horizontal
  - Vertical
  - Both
- Color
- Shape
- Tilt
- Size
  - Length
  - Area
  - Volume



Visualization Building Blocks

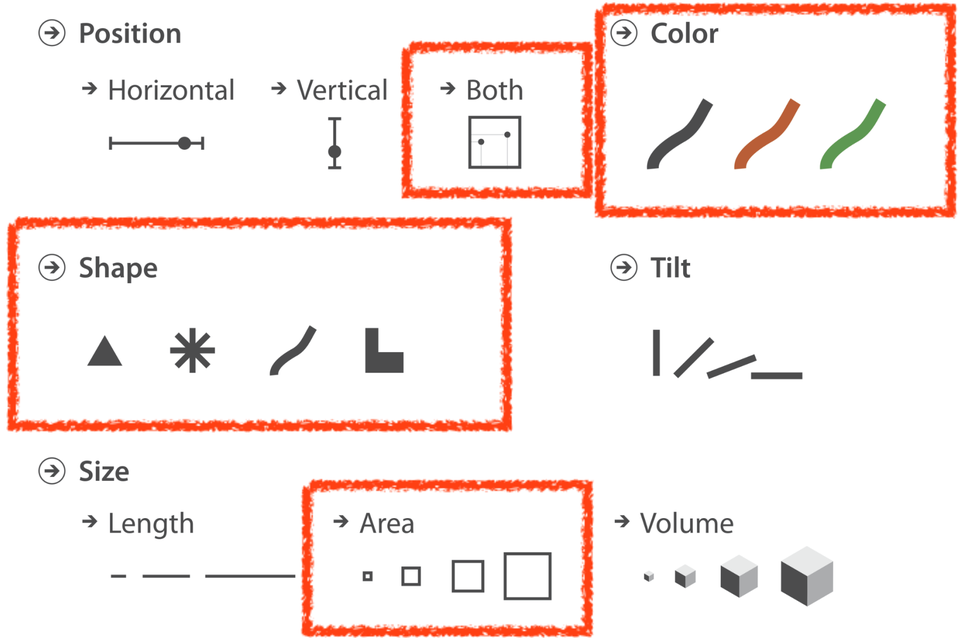
At each pixel (x,y)
= categorical data
encoded with color
land, water

Visualization Building Blocks

of attributes encoded: 5

MARKS:

CHANNELS :

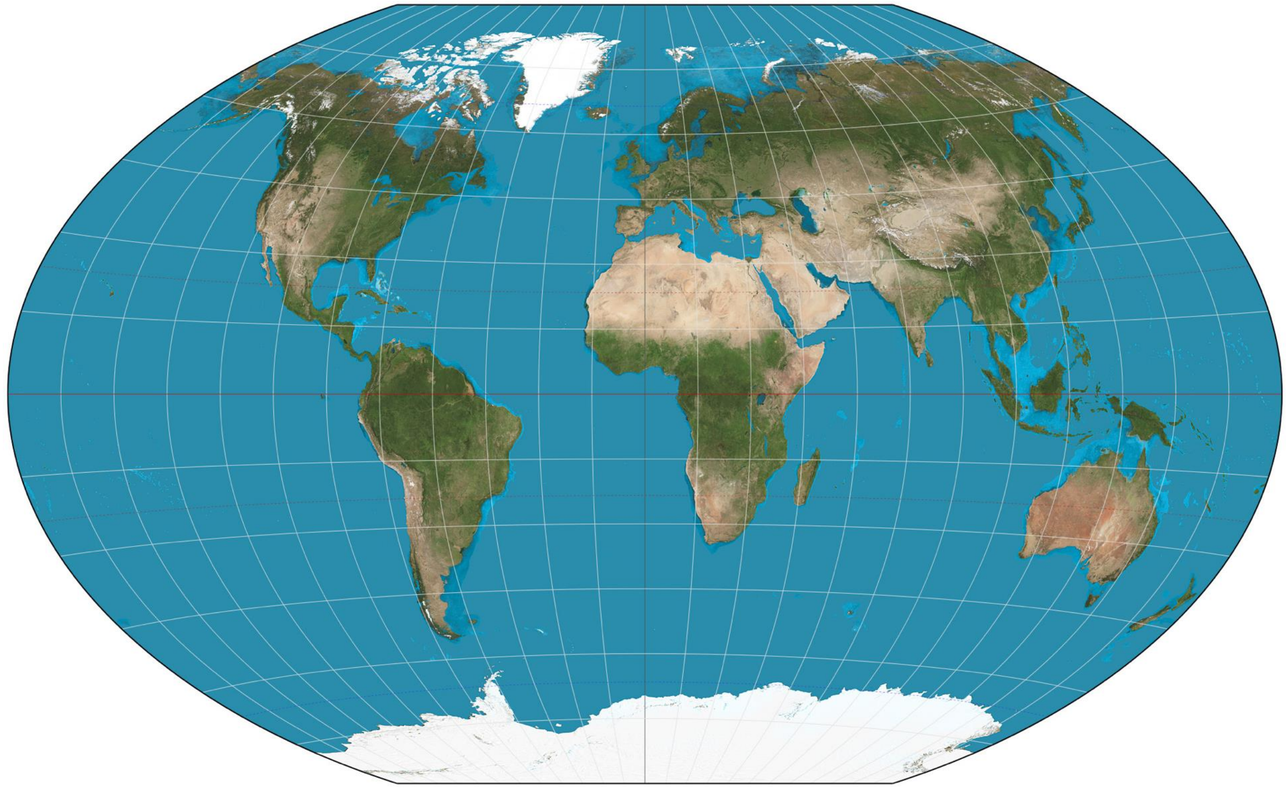


Map Projections

Dimensionality reduction

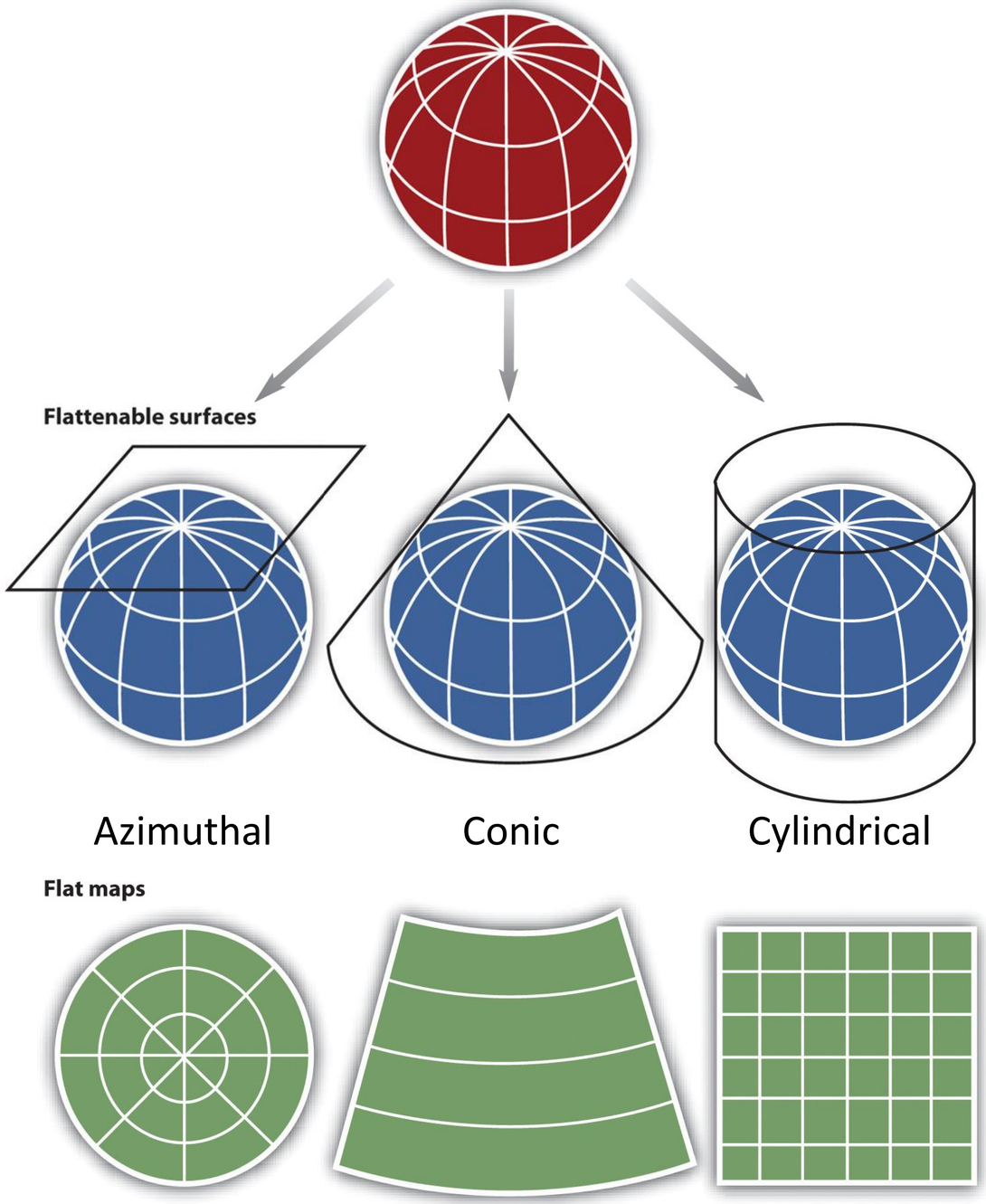
3D

2D



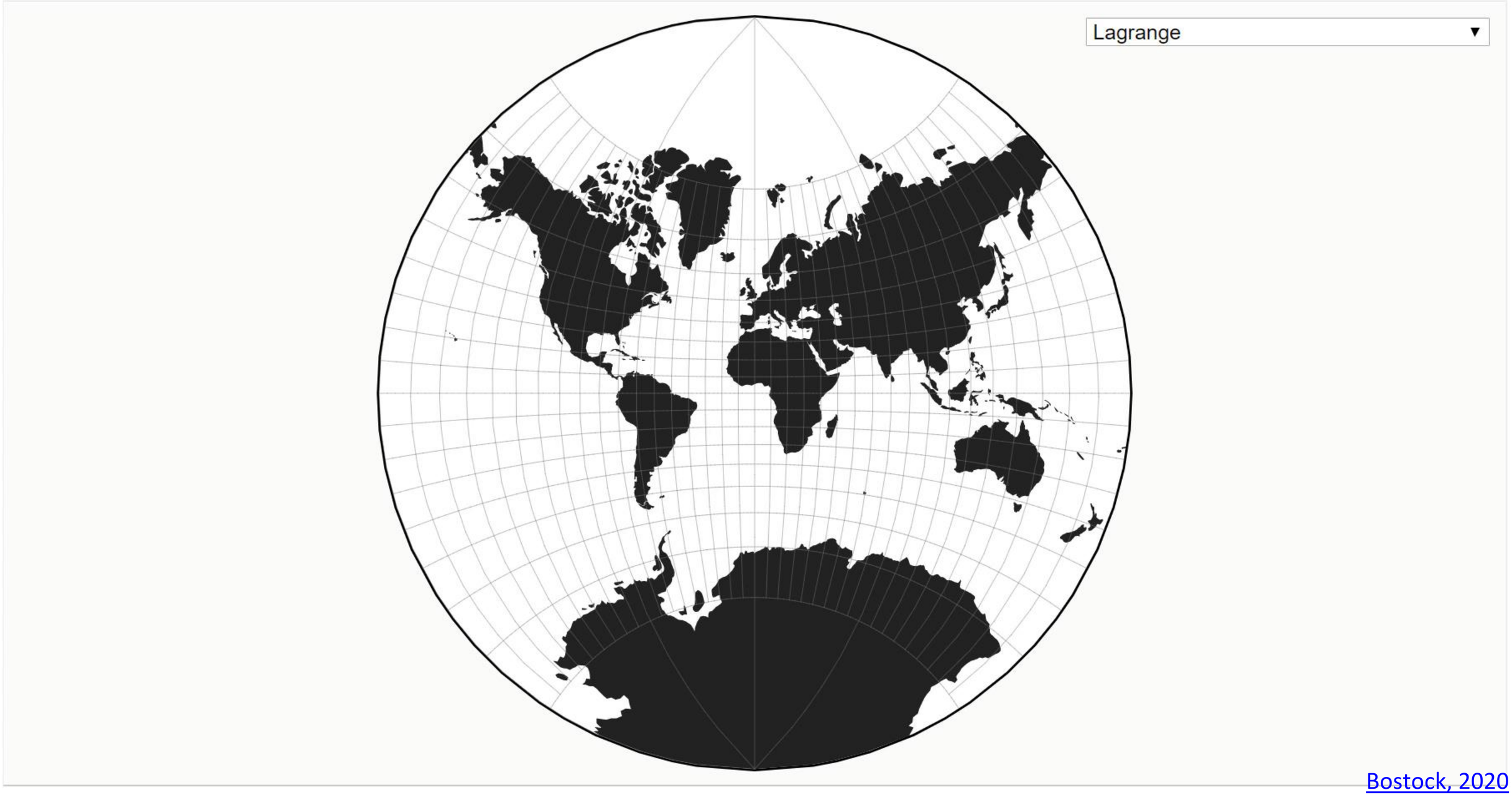

Vox

Dimensionality reduction



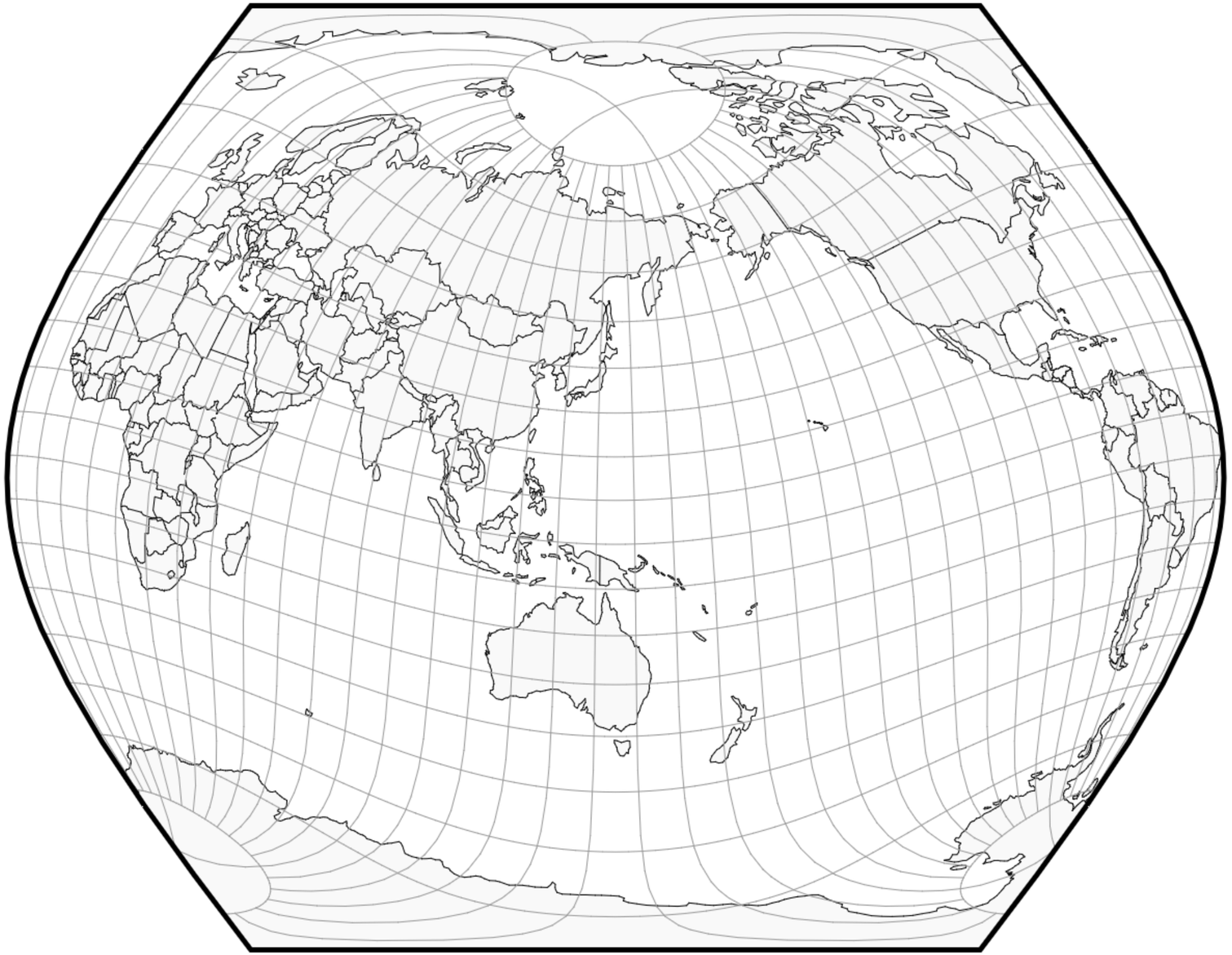
Unknown author, < 2012

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.

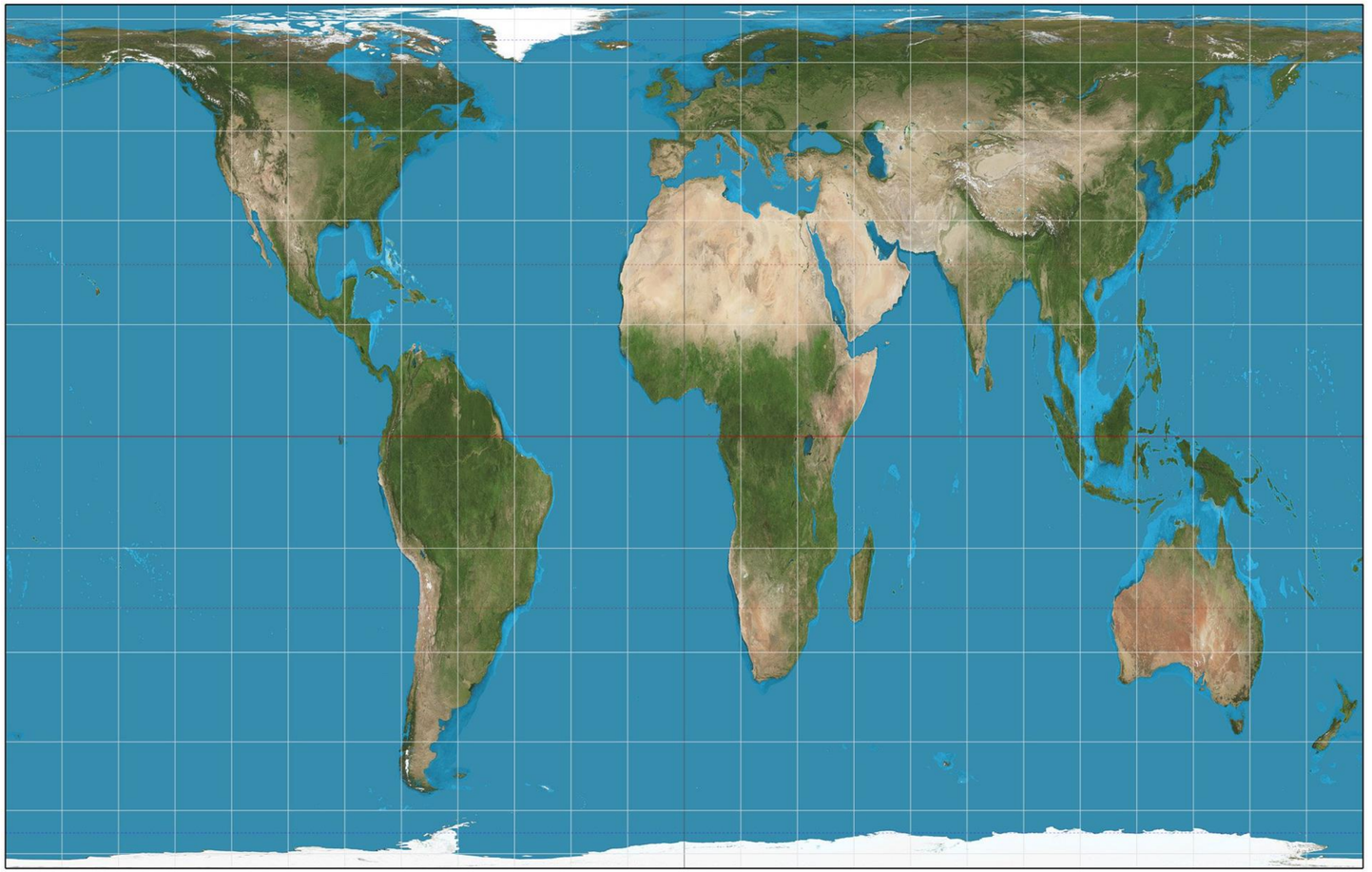
The shift towards the more accurate Gall-Peters Projection sees Boston's public schools follow the lead of the United Nations, which has advocated the map as a more 'fair', less Eurocentric representation of the world, as have several aid agencies.

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**

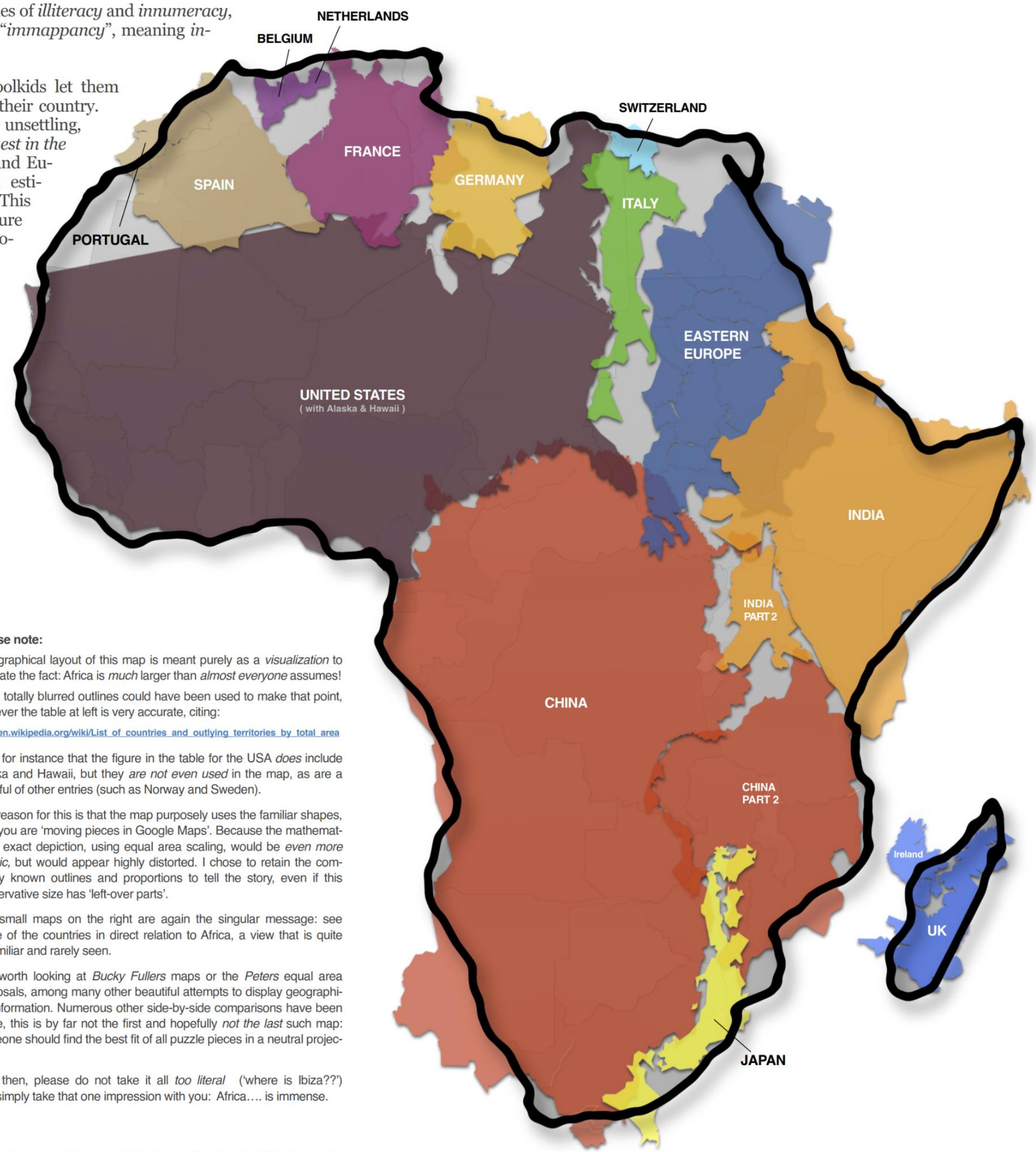
A small contribution in the fight against rampant *Immappancy,* by **Kai Krause**

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.

Top 100 Countries

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

United States

Europe

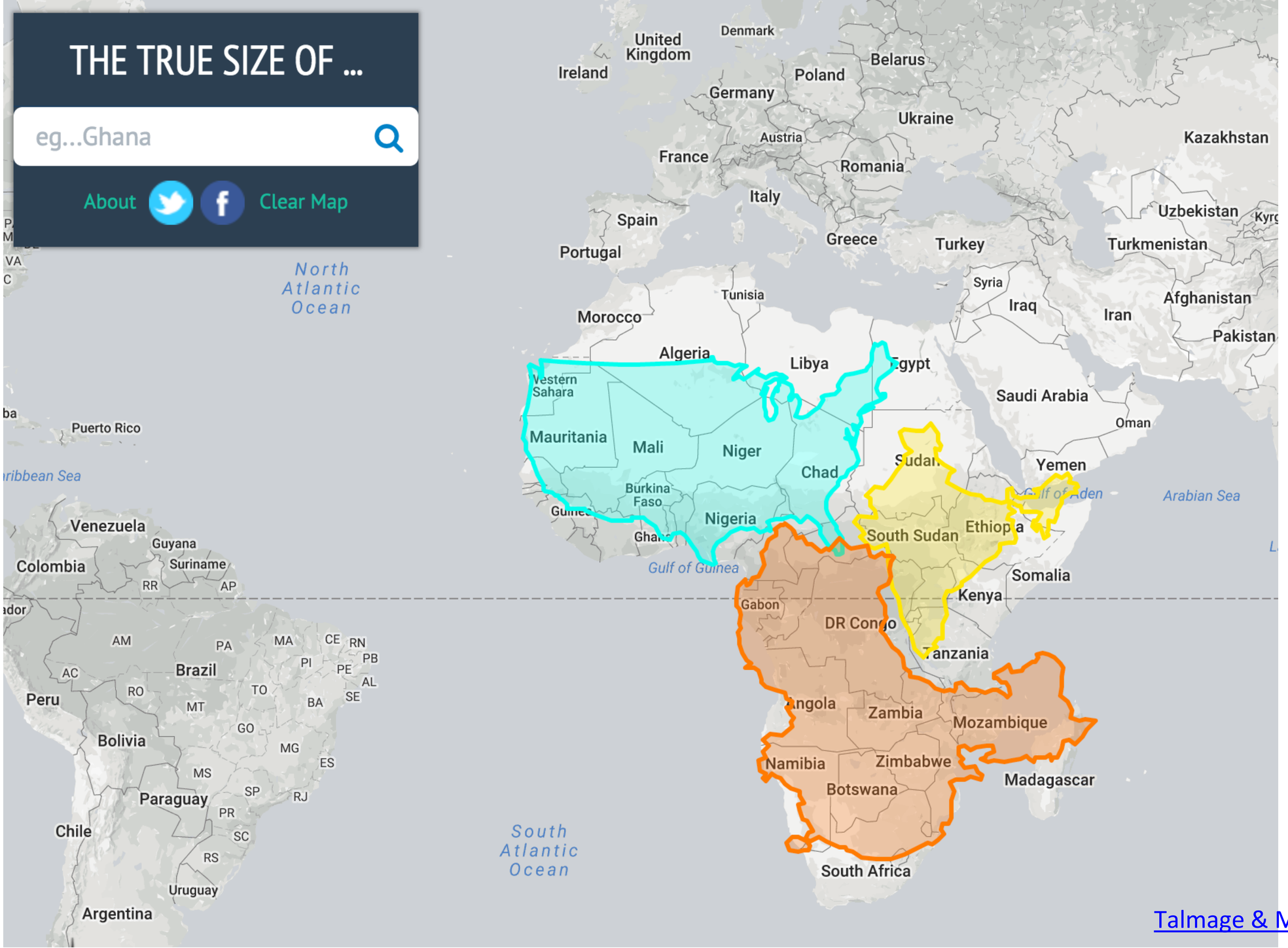
India

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

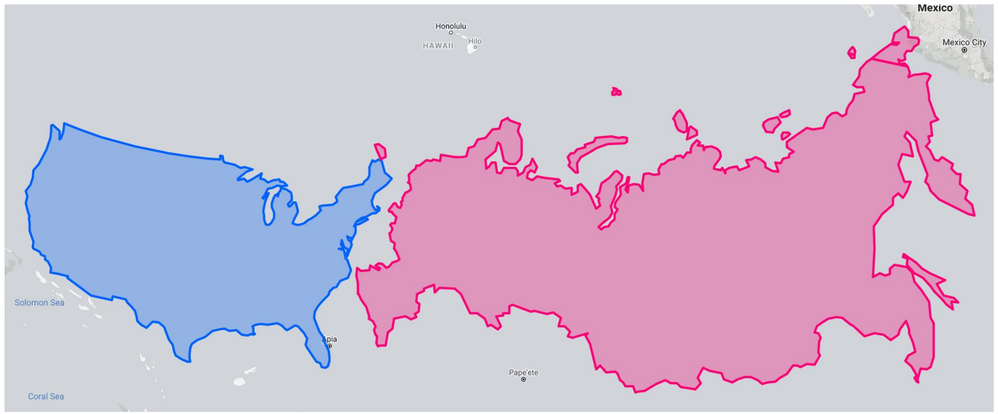
In-Class Exercise: The True Size



Talmage & Maneice, 2014

In-Class Exercise: The True Size

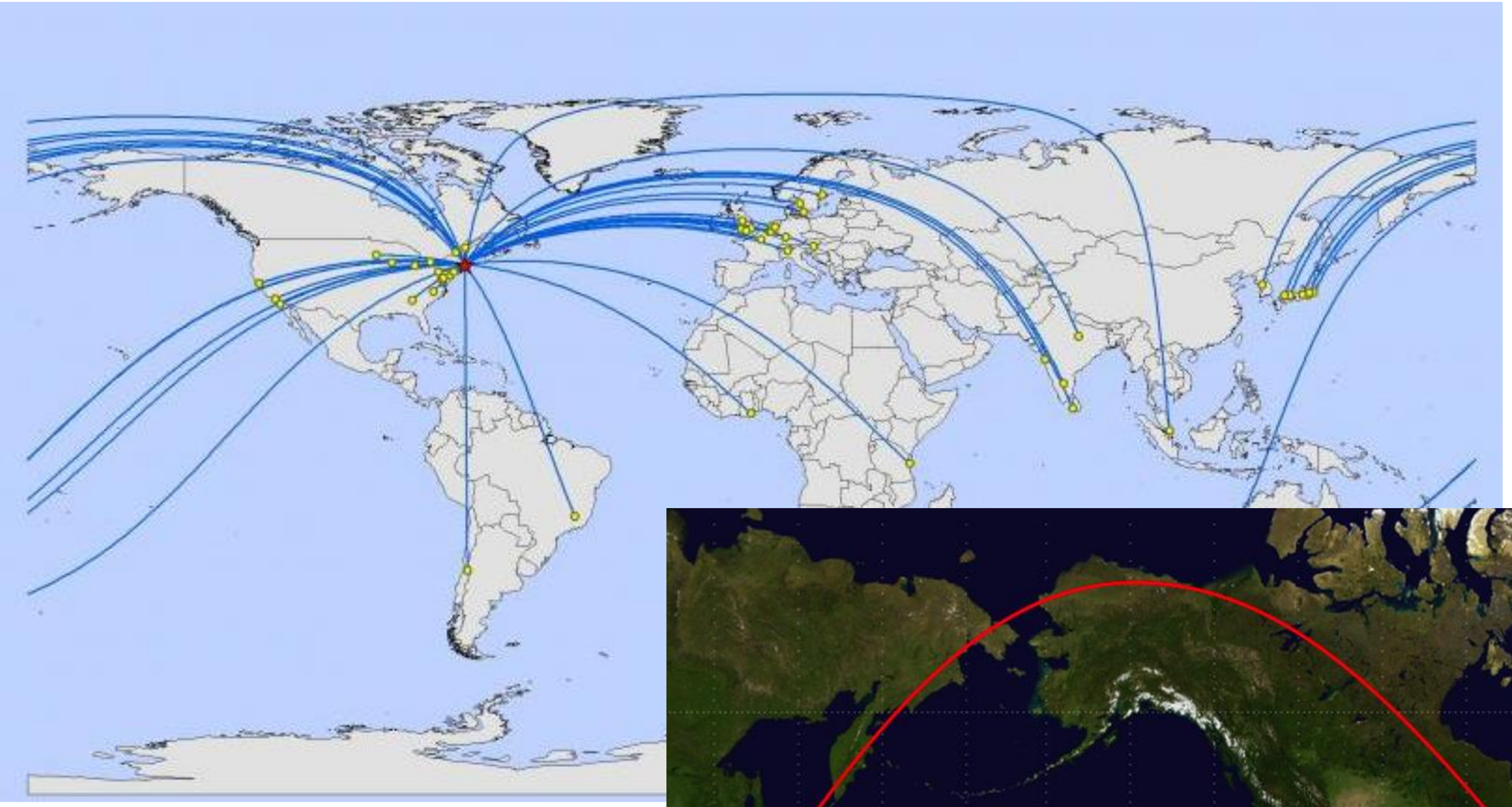
15m

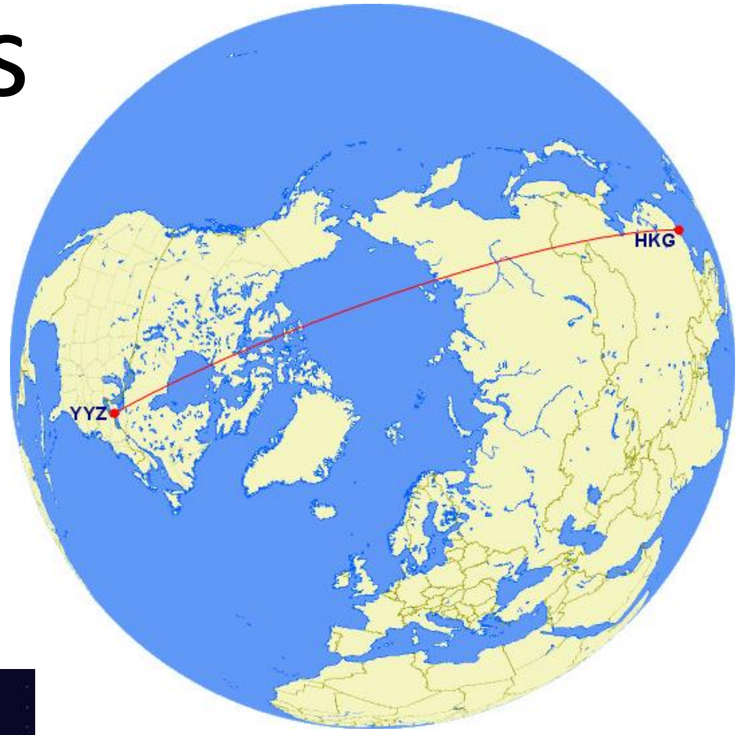


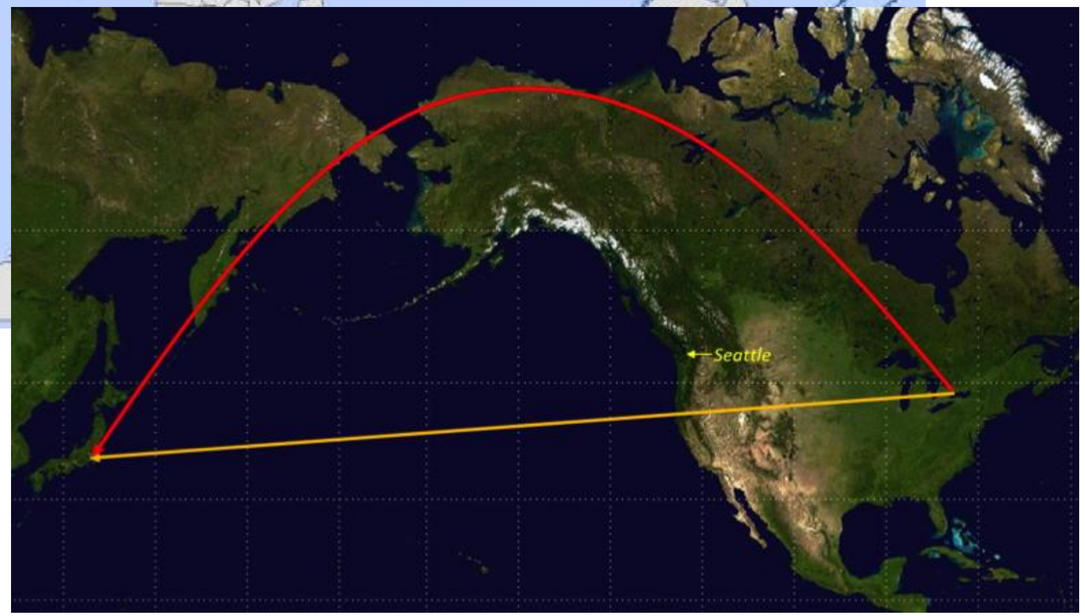
INSTRUCTIONS:

- 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.

Great Circle Routes





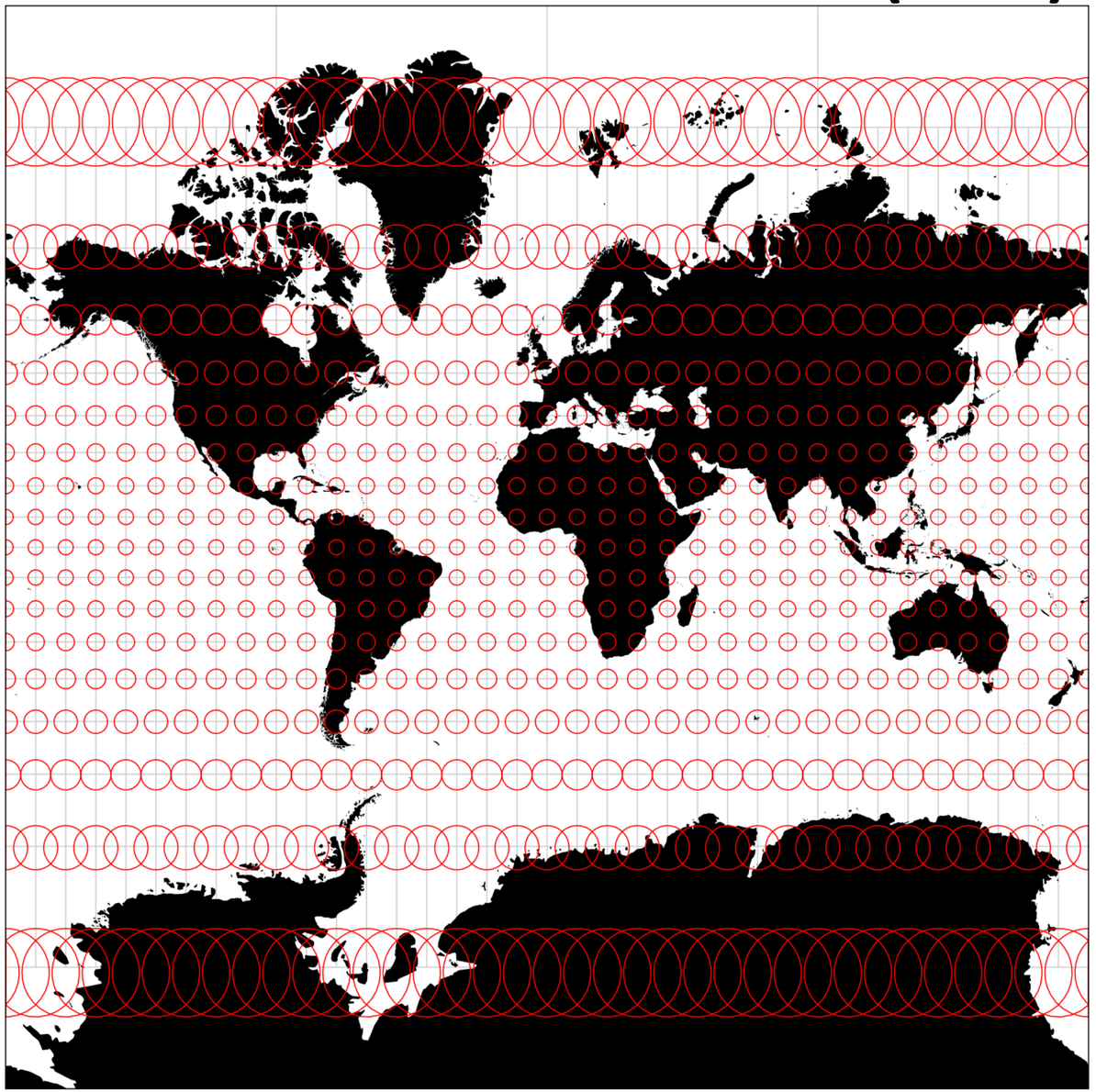


Subramanian, 2010; Swartz, 2010, Levy, 2013

World map used in Australian schools

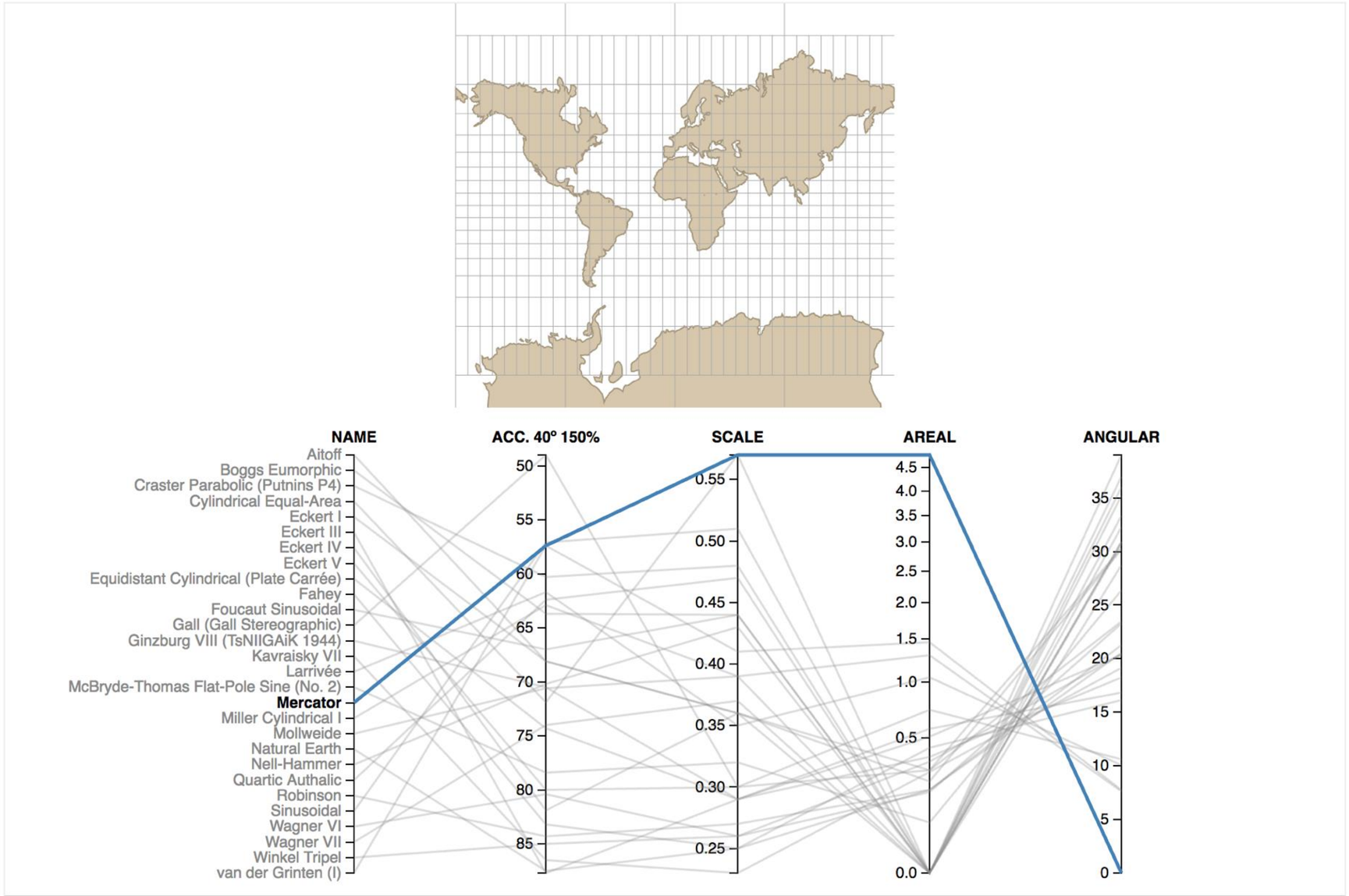
[Prokuror ID, 2013](); [Stopera, 2013]()

Tissot’s Indicatrix (ish)



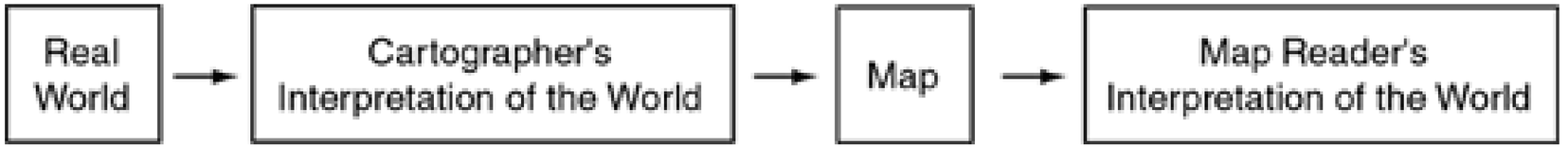
Bostock, 2019

Comparing Map Projections



Kai/syntagmatic, 2017

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 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).

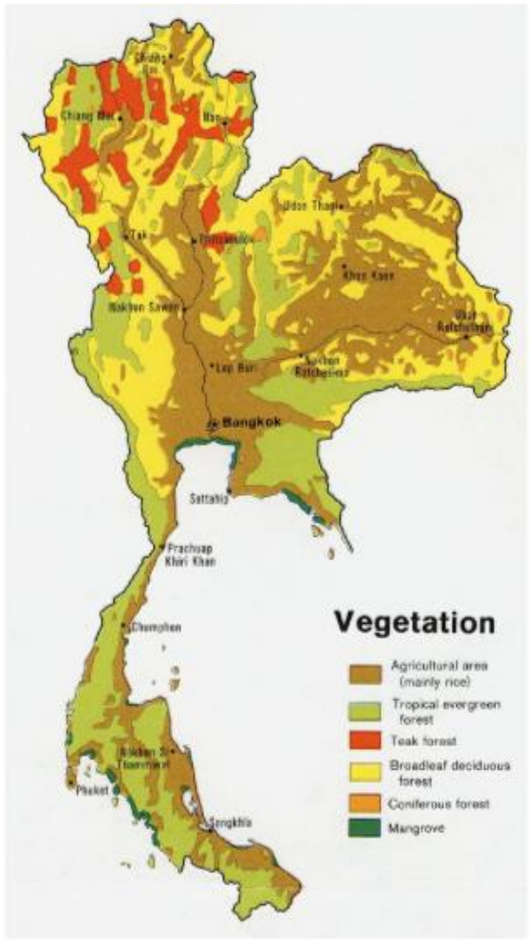
Fritz Kessler, 2018

Types of Maps

Three broad categories of maps:

Reference maps

Thematic maps



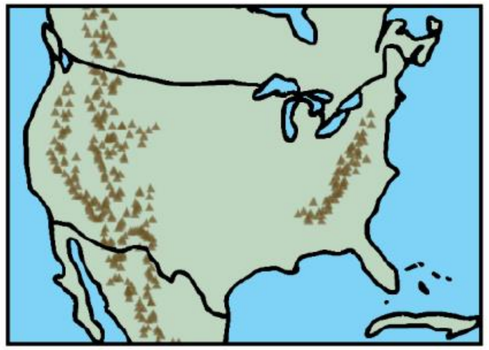
Special-purpose maps

Fritz Kessler, 2018

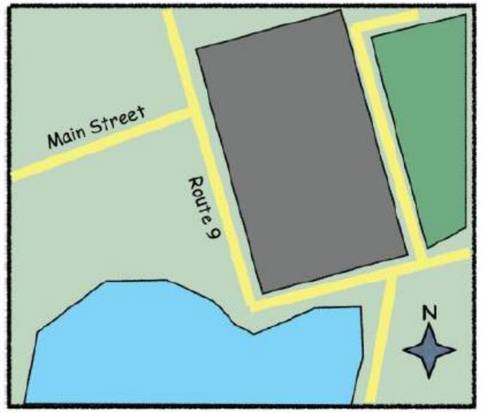
Map

Geographic Map

Geographic Map



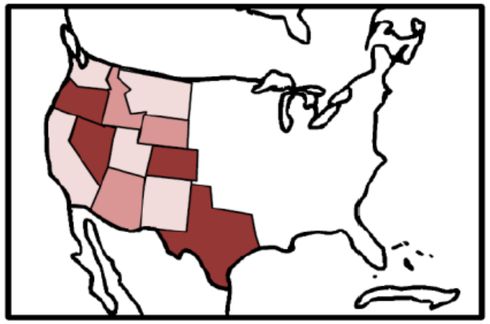
Street Map



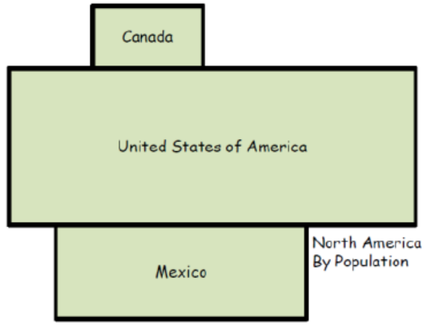
Flow Map

Statistical Map

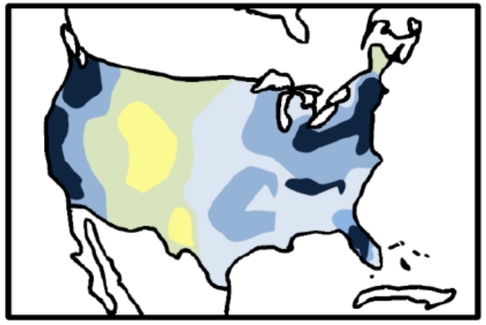
Choropleth Map



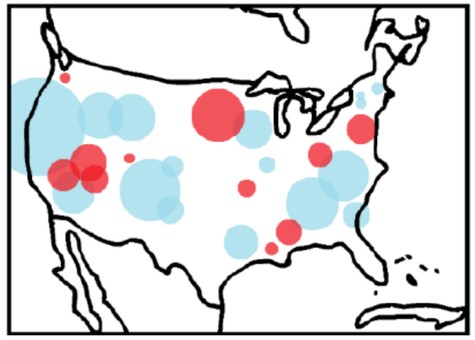
Distorted Map (Cartogram)

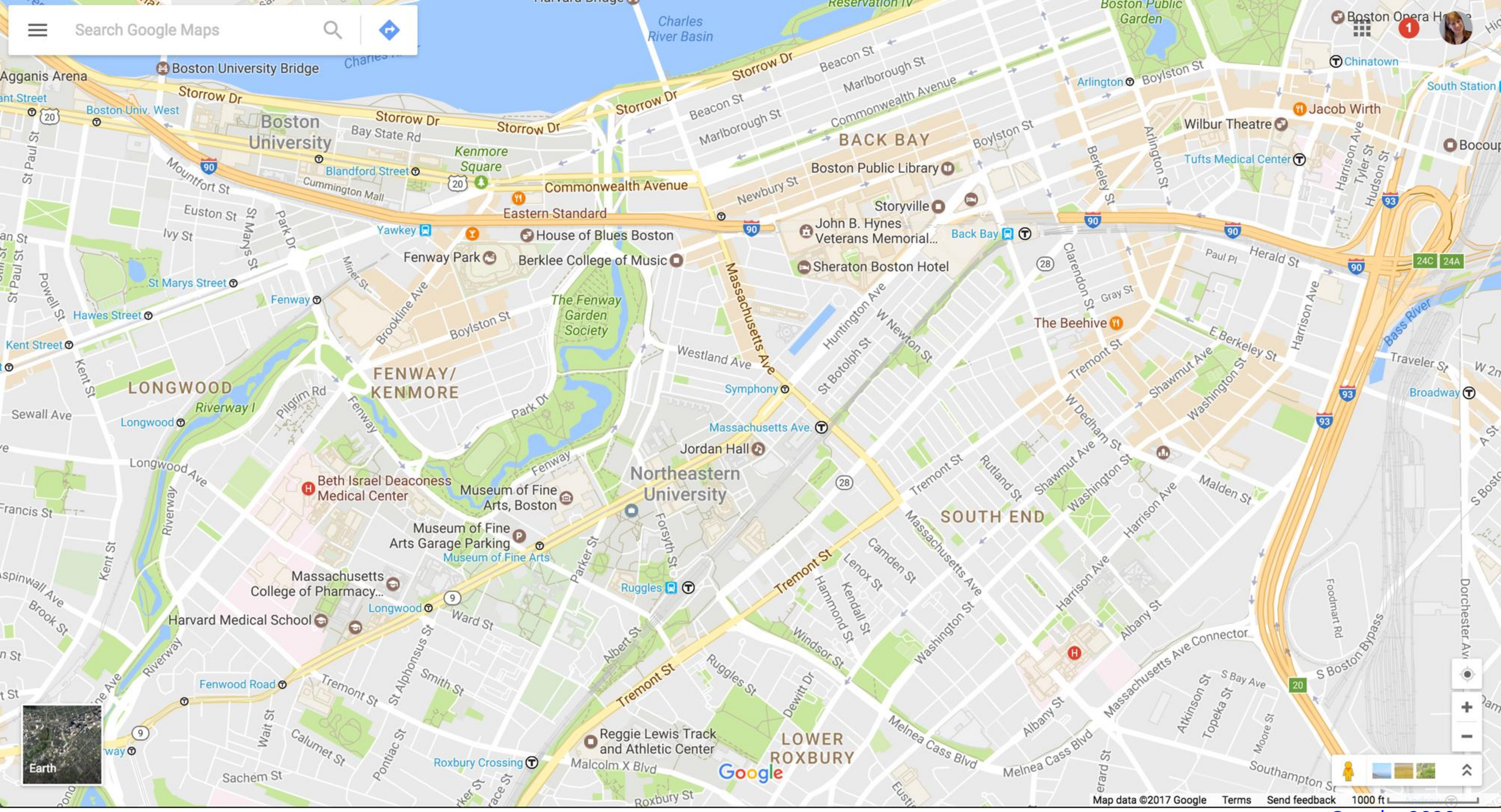


Contour Map (Isopleth)



Statistical Plot Map




Search Google Maps
Charles River Basin
Boston University Bridge
Agganis Arena
Boston University
Boston Univ. West
Storrow Dr
Bay State Rd
Kenmore Square
Blandford Street
Commonwealth Avenue
Cummington Mall
Mountfort St
Euston St
Ivy St
St Marys St
Park Dr
Eastern Standard
Yawkey
House of Blues Boston
Fenway Park
Berklee College of Music
St Marys Street
Fenway
Hawes Street
Kent Street
Powell St
St Paul St
Brookline Ave
Boylston St
The Fenway Garden Society
Miner St
FENWAY/ KENMORE
LONGWOOD
Riverway
Pilgrim Rd
Longwood
Longwood Ave
Sewall Ave
Francis St
Kent St
Riverway
Beth Israel Deaconess Medical Center
Museum of Fine Arts, Boston
Museum of Fine Arts Garage Parking
Museum of Fine Arts
Massachusetts College of Pharmacy...
Harvard Medical School
Longwood
Ward St
Fenwood Road
Tremont St
St Alphonsus St
Smith St
Wait St
Calumet St
Pontiac St
Roxbury Crossing
Sachem St
Malcolm X Blvd
Roxbury St
Reggie Lewis Track and Athletic Center
LOWER ROXBURY
Ruggles St
Dewitt Dr
Albert St
Parker St
Forsyth St
Ruggles
Northeastern University
Jordan Hall
Massachusetts Ave.
Symphony
Westland Ave
Massachusetts Ave
Huntington Ave
St Botolph St
W Newton St
Newbury St
BACK BAY
Boston Public Library
Storyville
John B. Hynes Veterans Memorial...
Sheraton Boston Hotel
Back Bay
Commonwealth Avenue
Marlborough St
Beacon St
Boylston St
Arlington
Arlington St
Berkeley St
Clarendon St
Dartmouth St
Gray St
Paul Pl
Herald St
The Beehive
Tremont St
E Berkeley St
Shawmut Ave
W Dedham St
Washington St
Harrison Ave
Rutland St
Malden St
SOUTH END
Camden St
Lenox St
Hammond St
Kendall St
Windsor St
Albany St
Melnea Cass Blvd
Massachusetts Ave Connector
S Bay Ave
Atkinson St
Topeka St
Moore St
Southampton St
S Boston Bypass
Foodmart Rd
Dorchester Ave
Broadway
Traveler St
Bass River
Chinatown
South Station
Boston Public Garden
Boston Opera House
Jacob Wirth
Wilbur Theatre
Tufts Medical Center
Bocoup
Harrison Ave
Tyler St
Hudson St
Arlington St
Earth
Google
Map data ©2017 Google
Terms
Send feedback
1000 ft

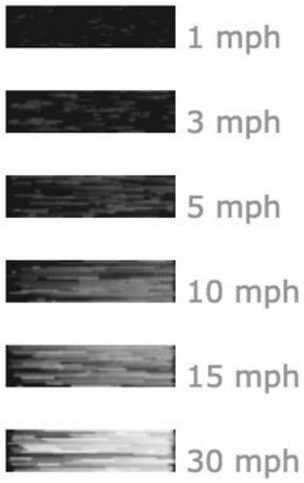
Google, 2020

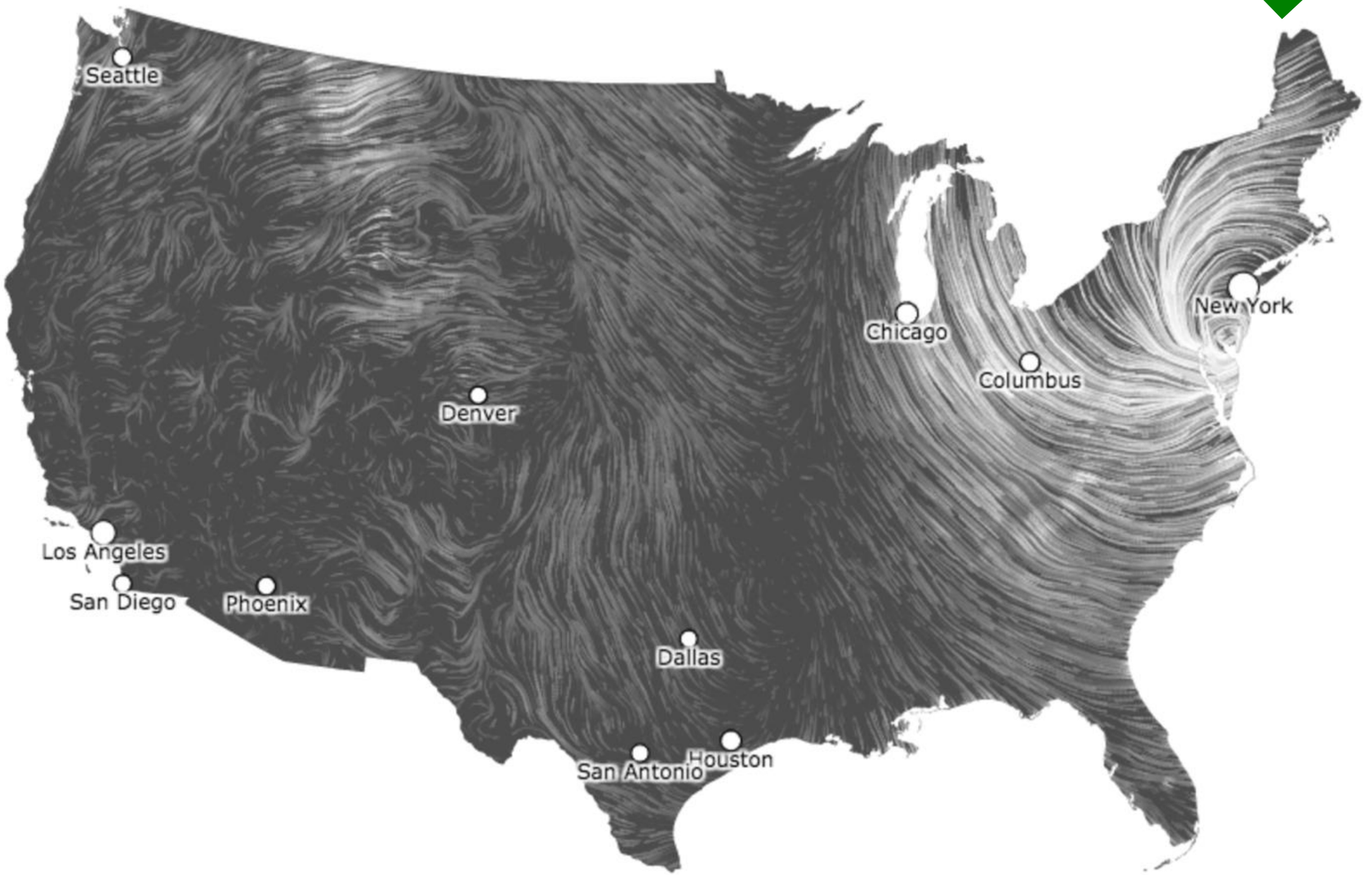
wind map

past patterns <previous next>

October 29, 2012
8:59 pm EST
(time of forecast download)

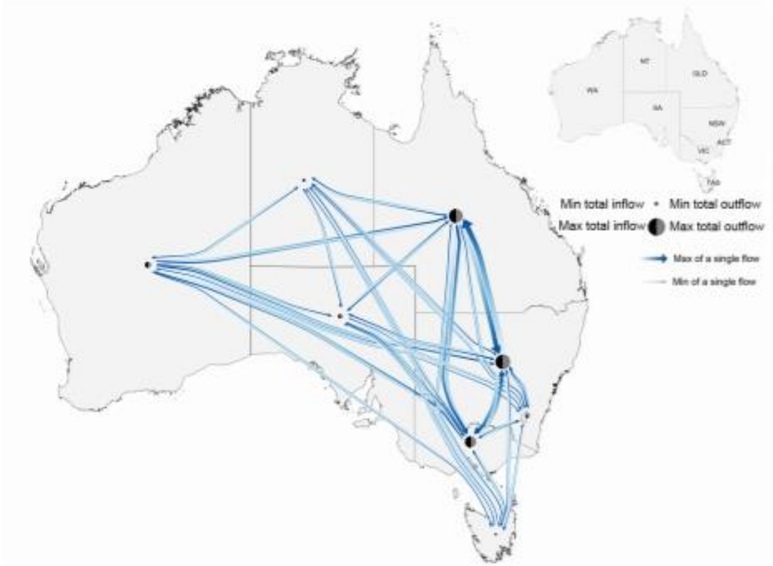
top speed: **45.1 mph**
average: **9.4 mph**



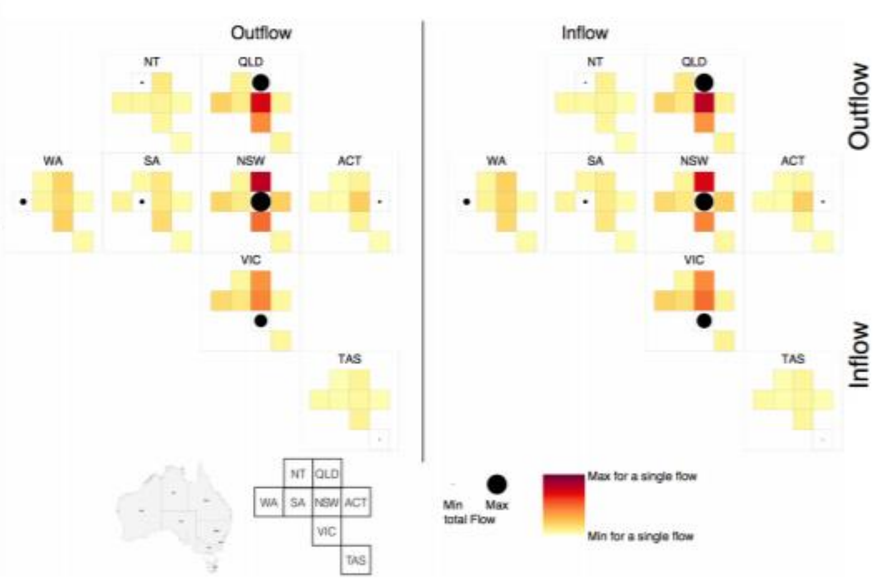


http://hint.fm/wind/gallery/oct-29.js.html

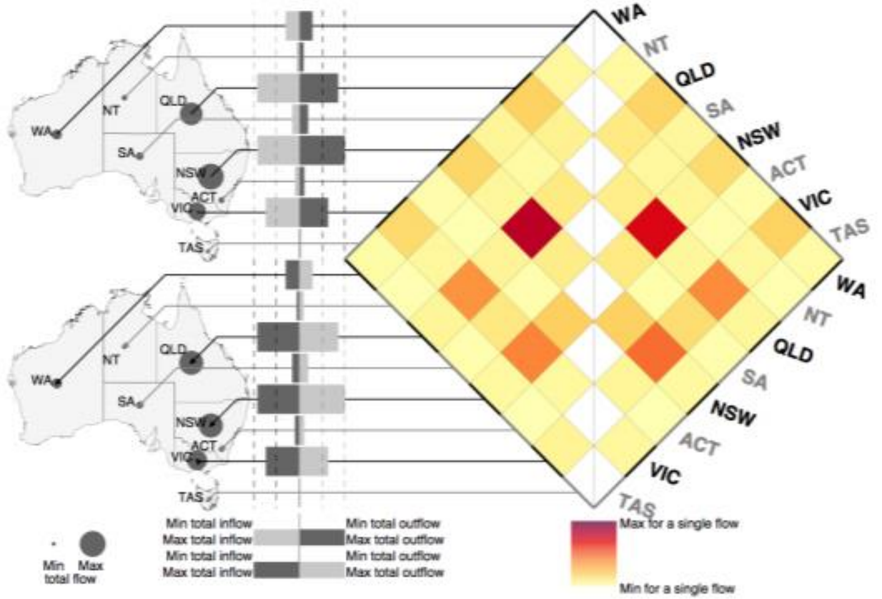
MapTrix



(a) Bundled Flow Map



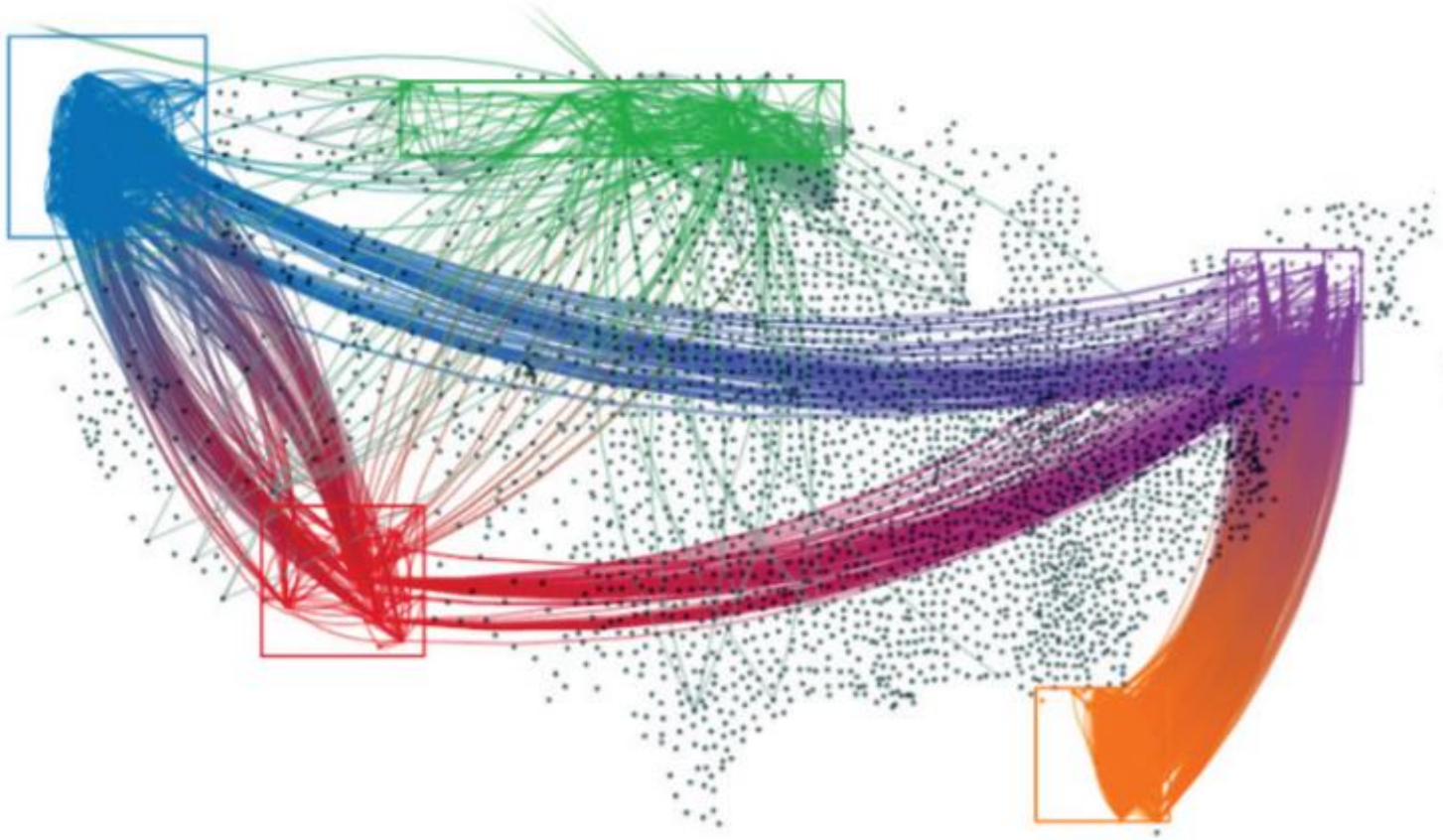
(b) OD Map

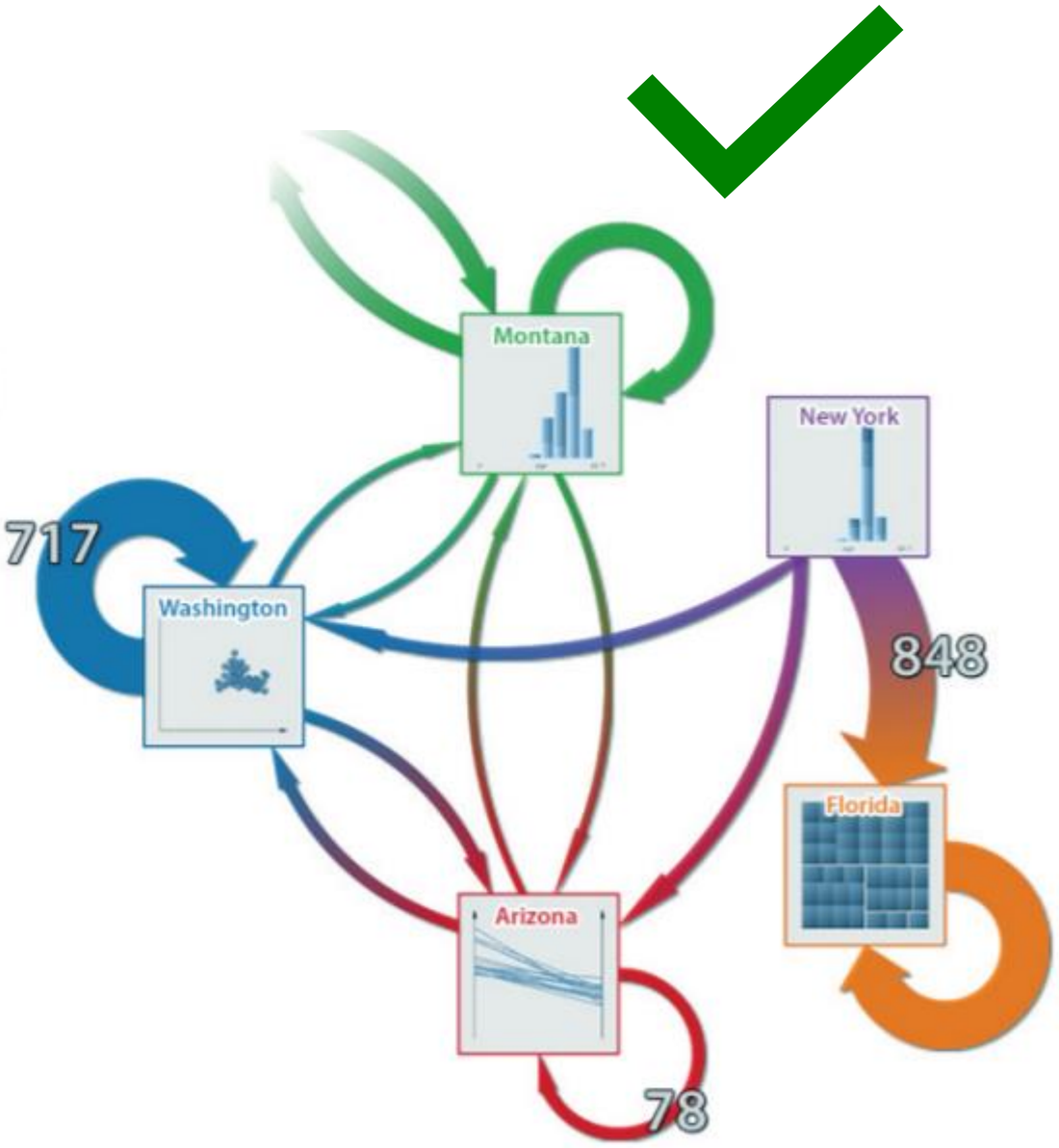


(c) MapTrix

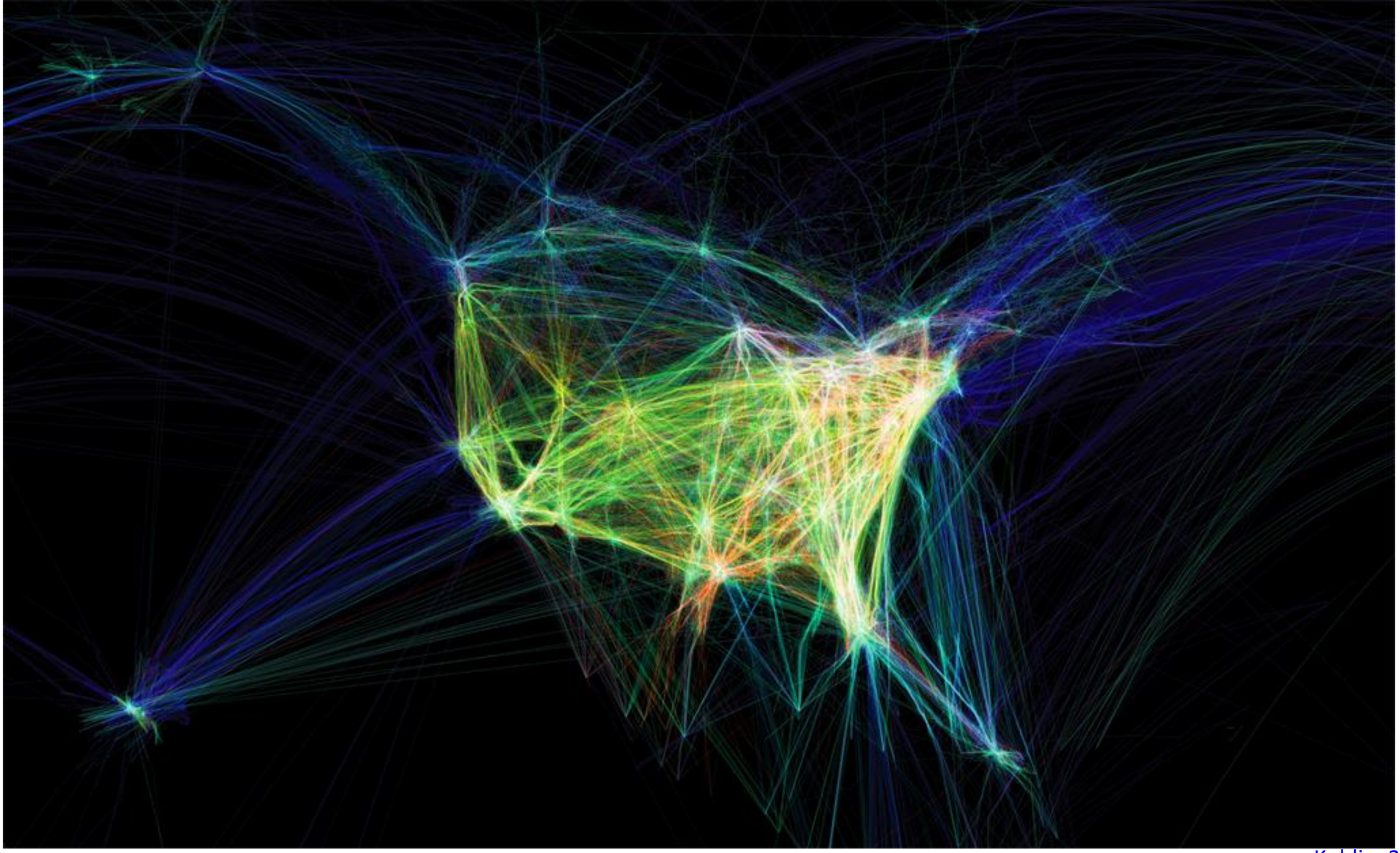
https://vimeo.com/182970812
https://vimeo.com/278433529

Yang et al., 2016; Demo

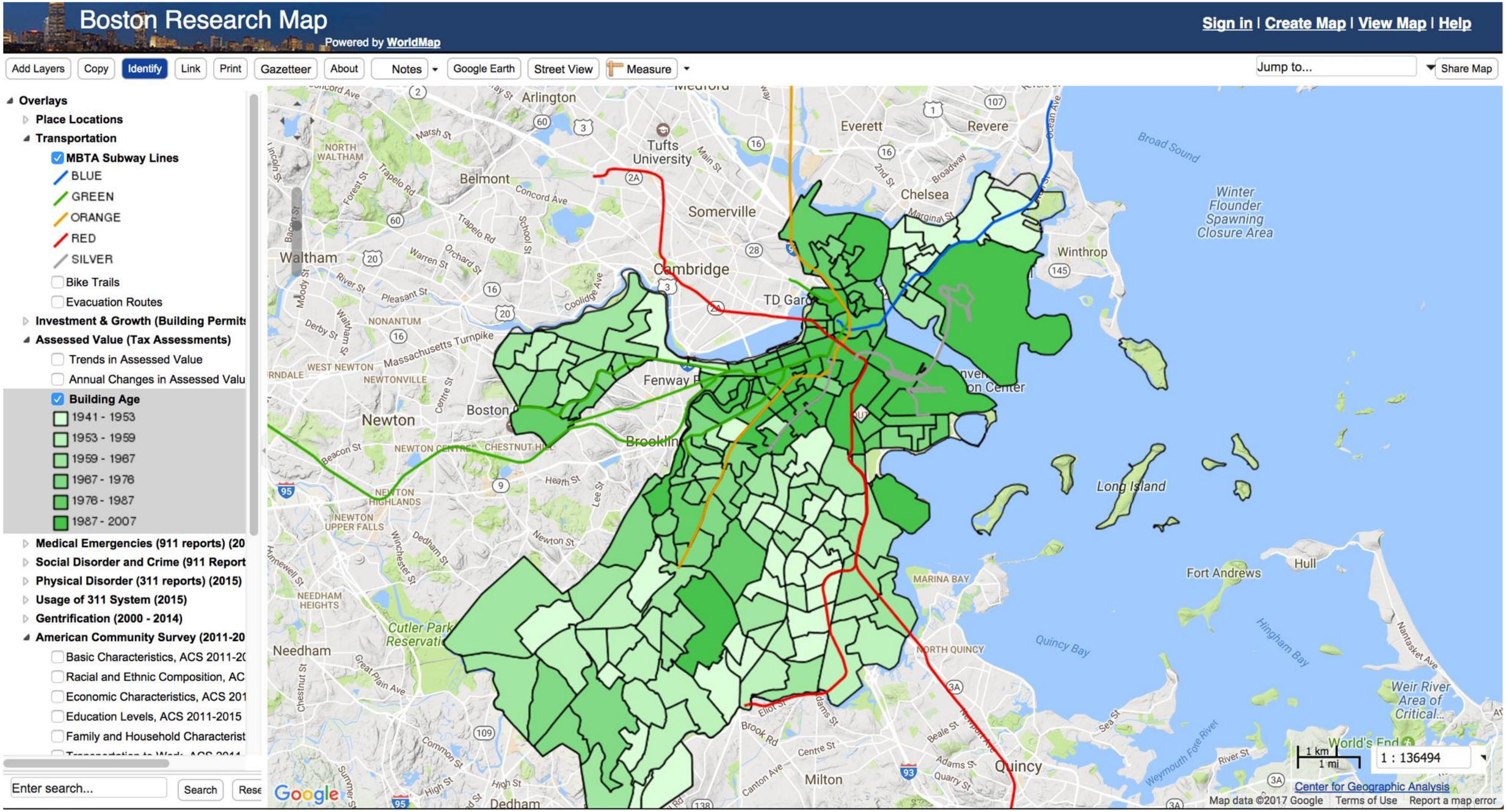




van den Elzen & van Wijk, 2014



Koblin, 2009



Bari/Worldmap, 2011 59

GIS

GIS = geographic information system

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

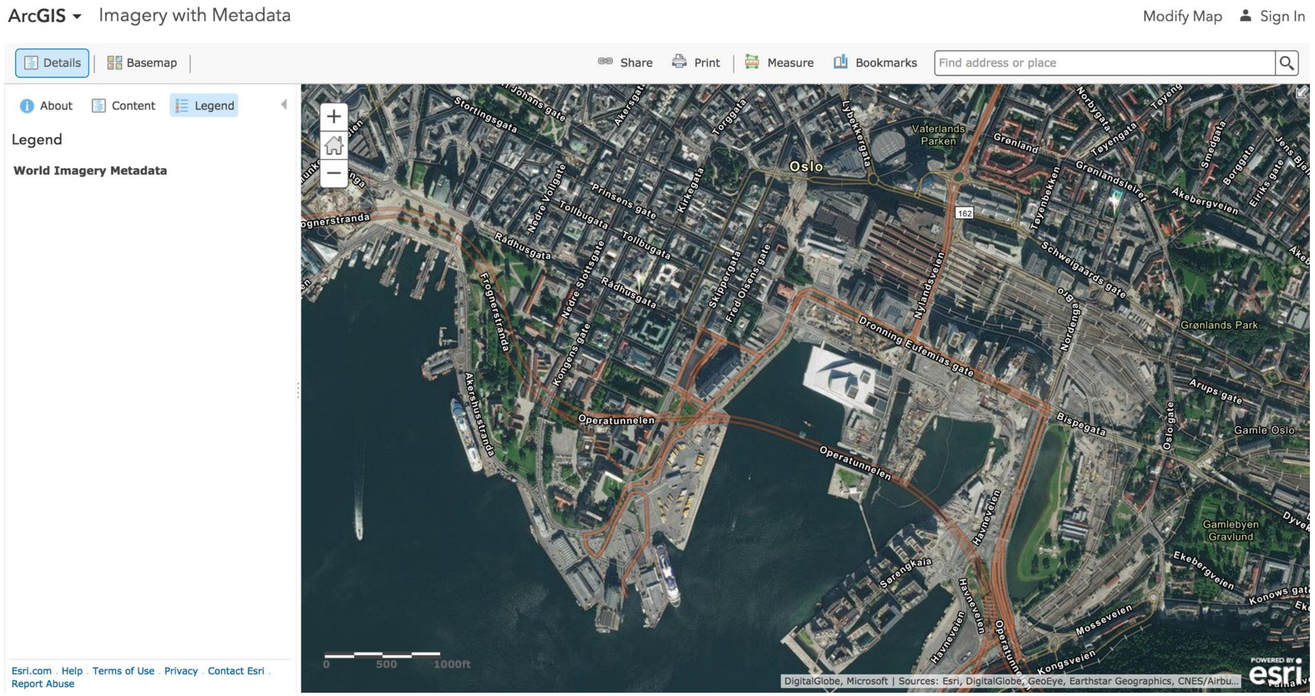
latitude, longitude, elevation, time + other relevant attributes

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.



Spatial and Scientific Visualization

Goals for Today

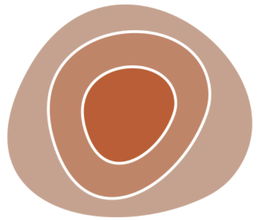
- Understand the concept of spatial fields, and how to visually encode.
- Learn about vector (and higher dimensional) representations.
- Learn about the two main ways to render 3D spatial data (isosurfaces and volume rendering).

SPATIAL DATA

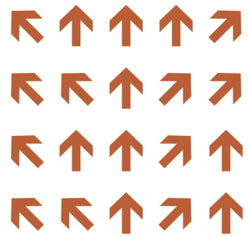
Arrange Spatial Data

- **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

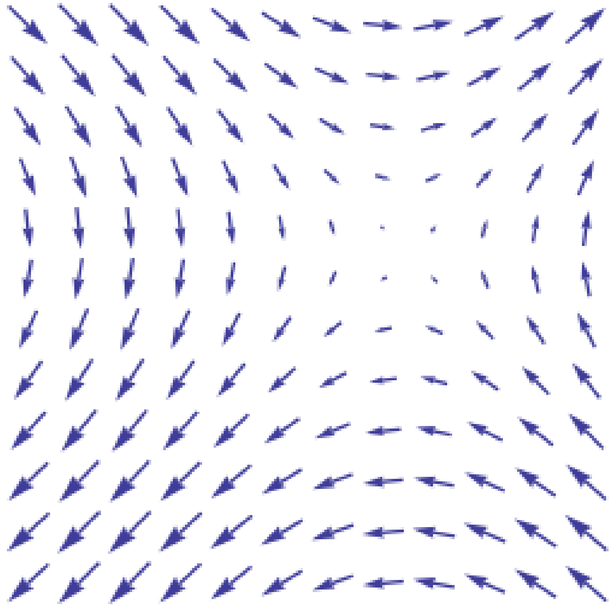
Scalar field = one value per cell

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

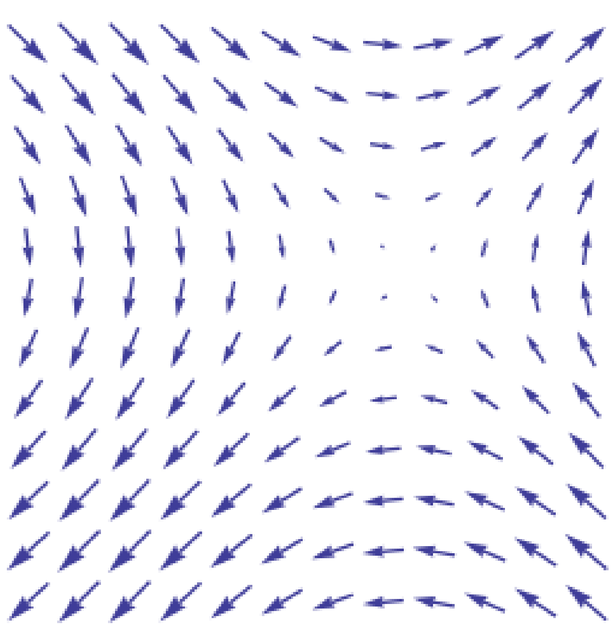
Scalar field = one value per cell

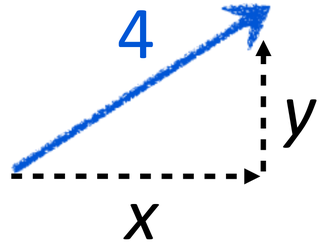
Vector or Tensor field = many values per cell

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)



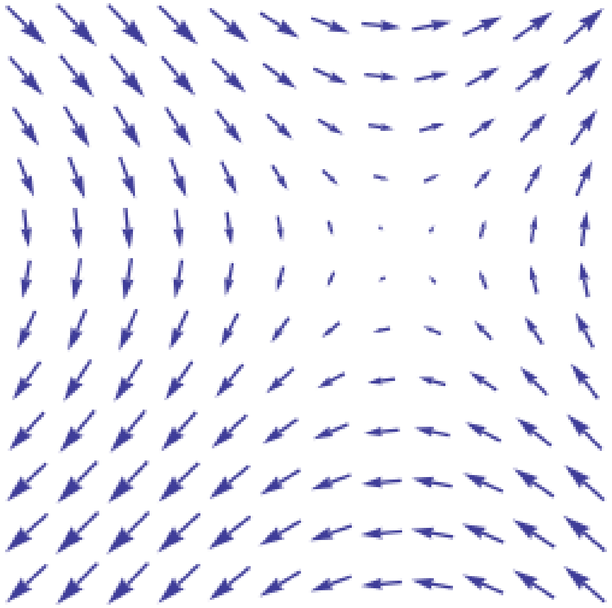


Vector

(magnitude and direction)

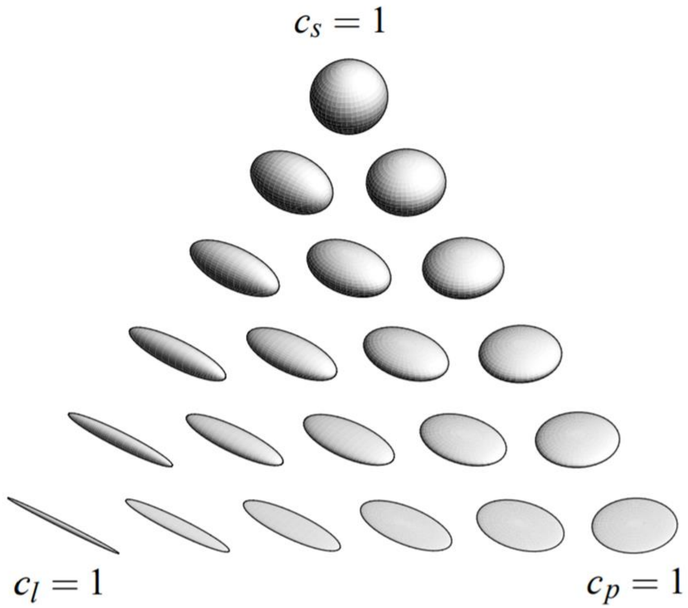
Spatial Fields

Vector or Tensor field = many values per cell



Vector

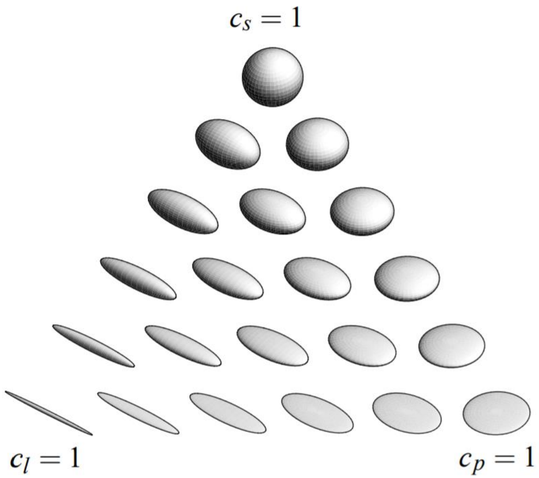
(magnitude and direction)

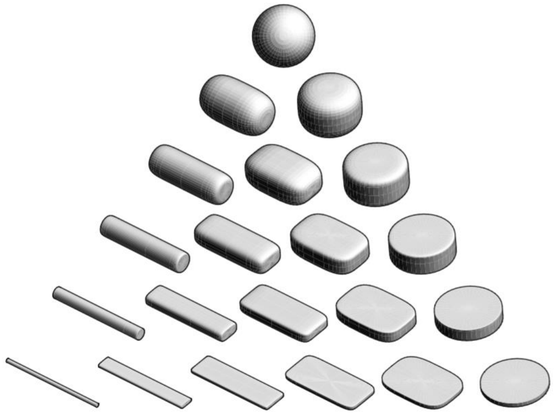


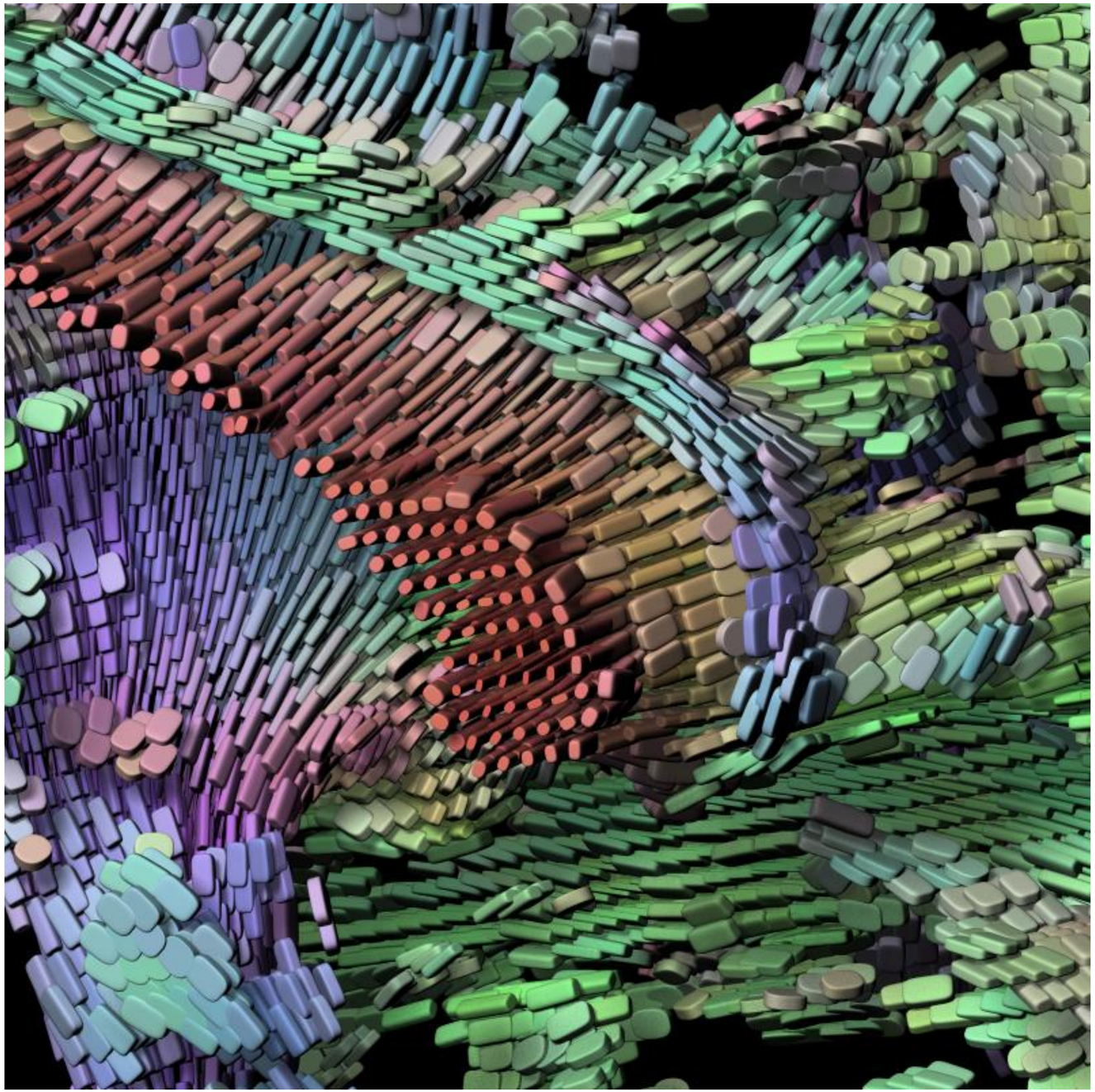
Tensor

(multiple variables with magnitude and direction)

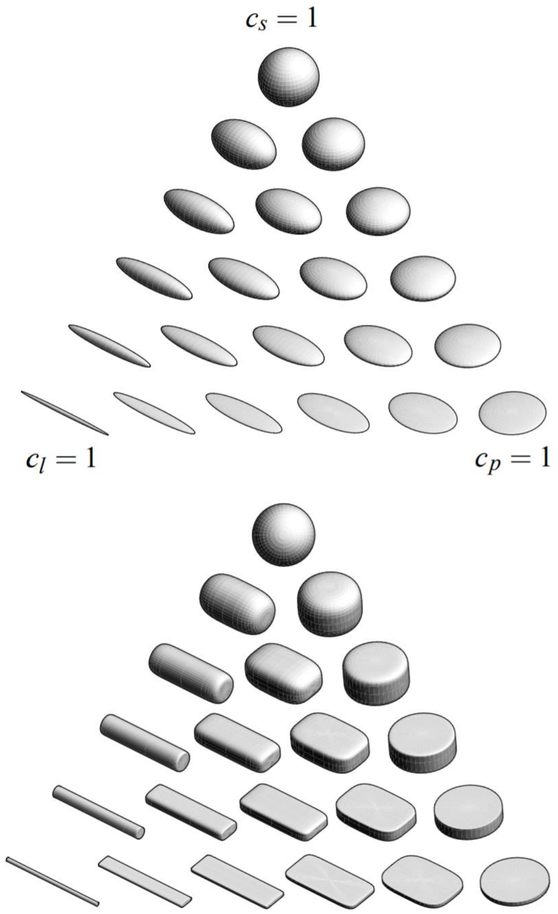
Kindlmann (2004)



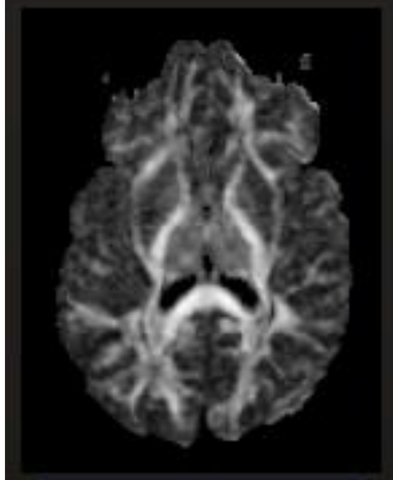


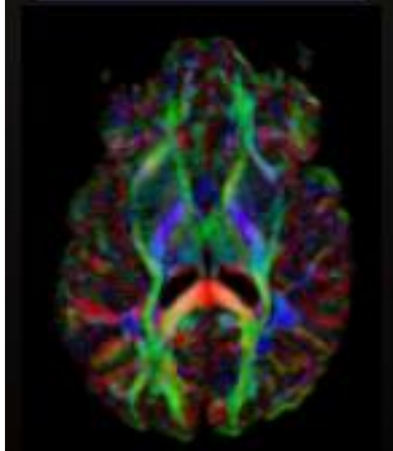


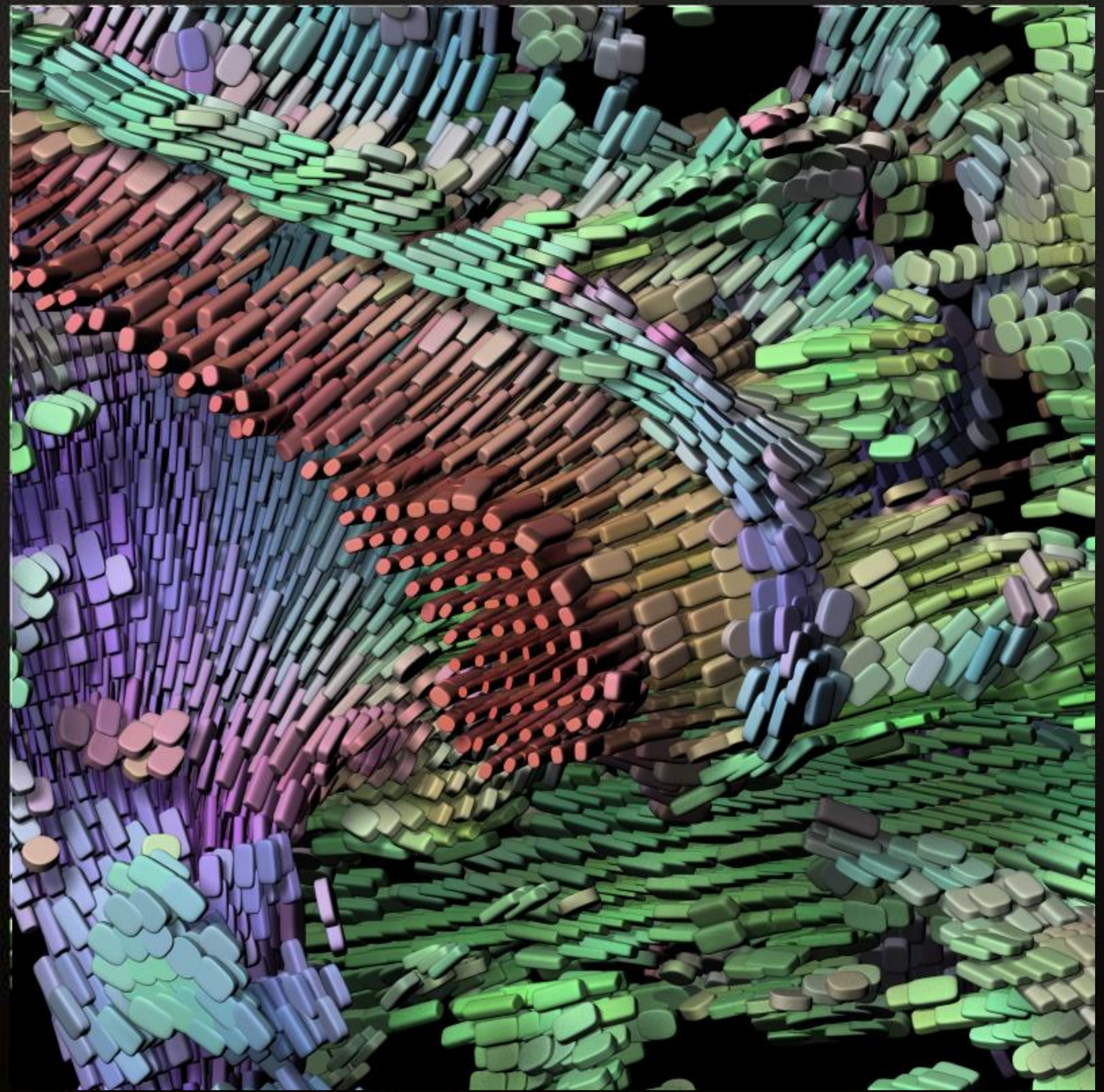
[Kindlmann (2004)]

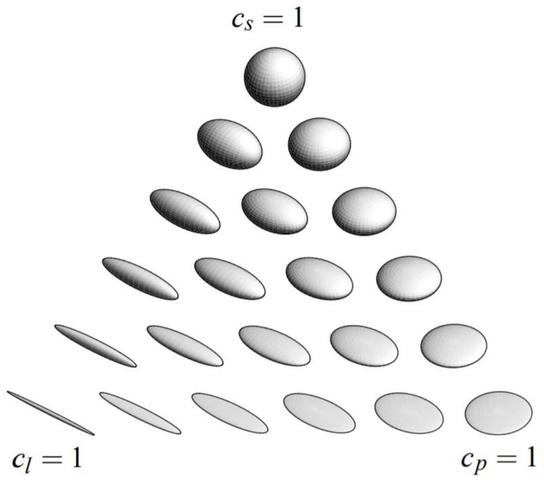


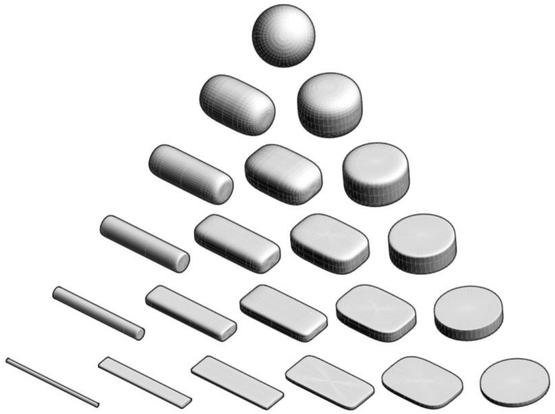
Results

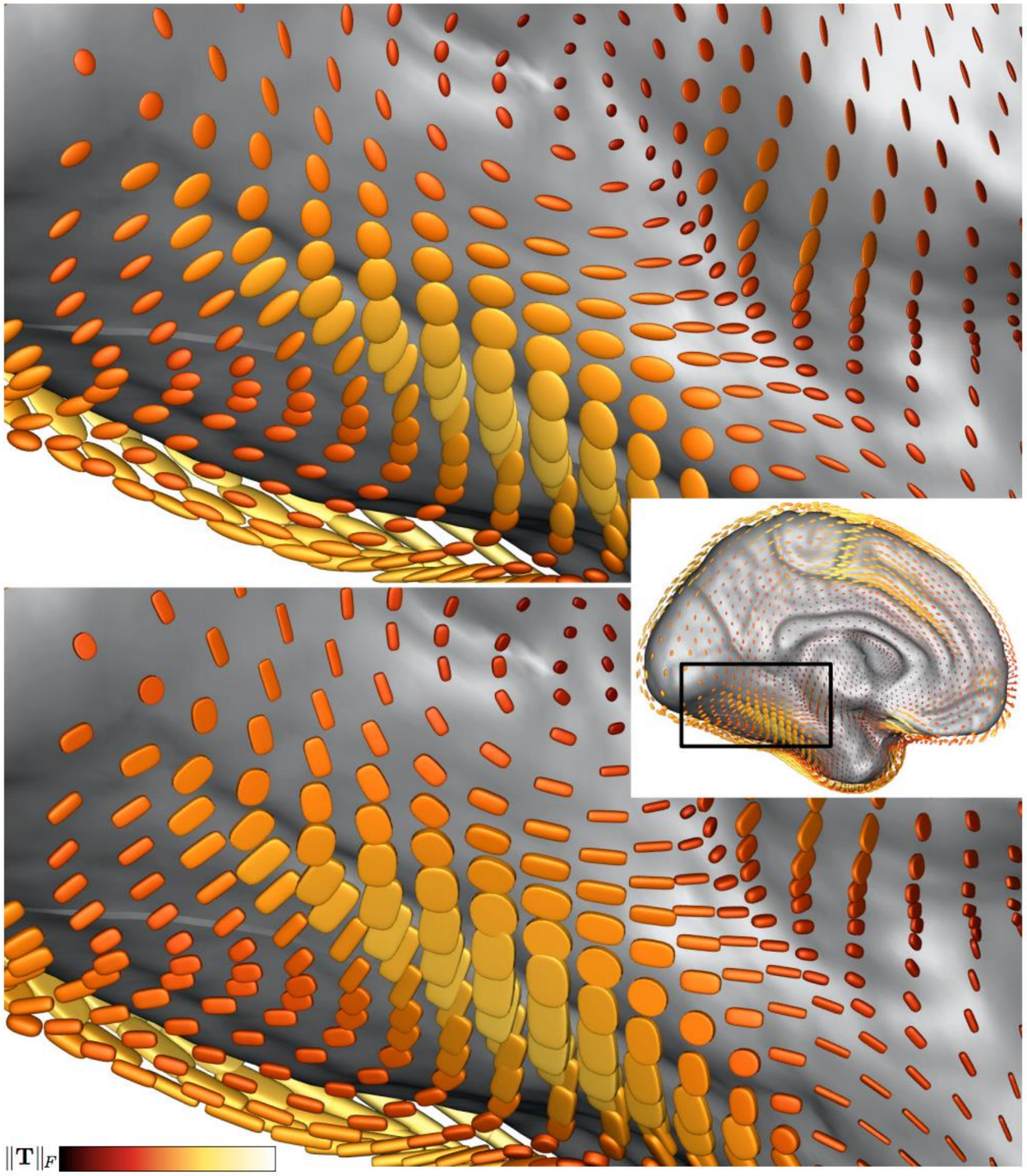






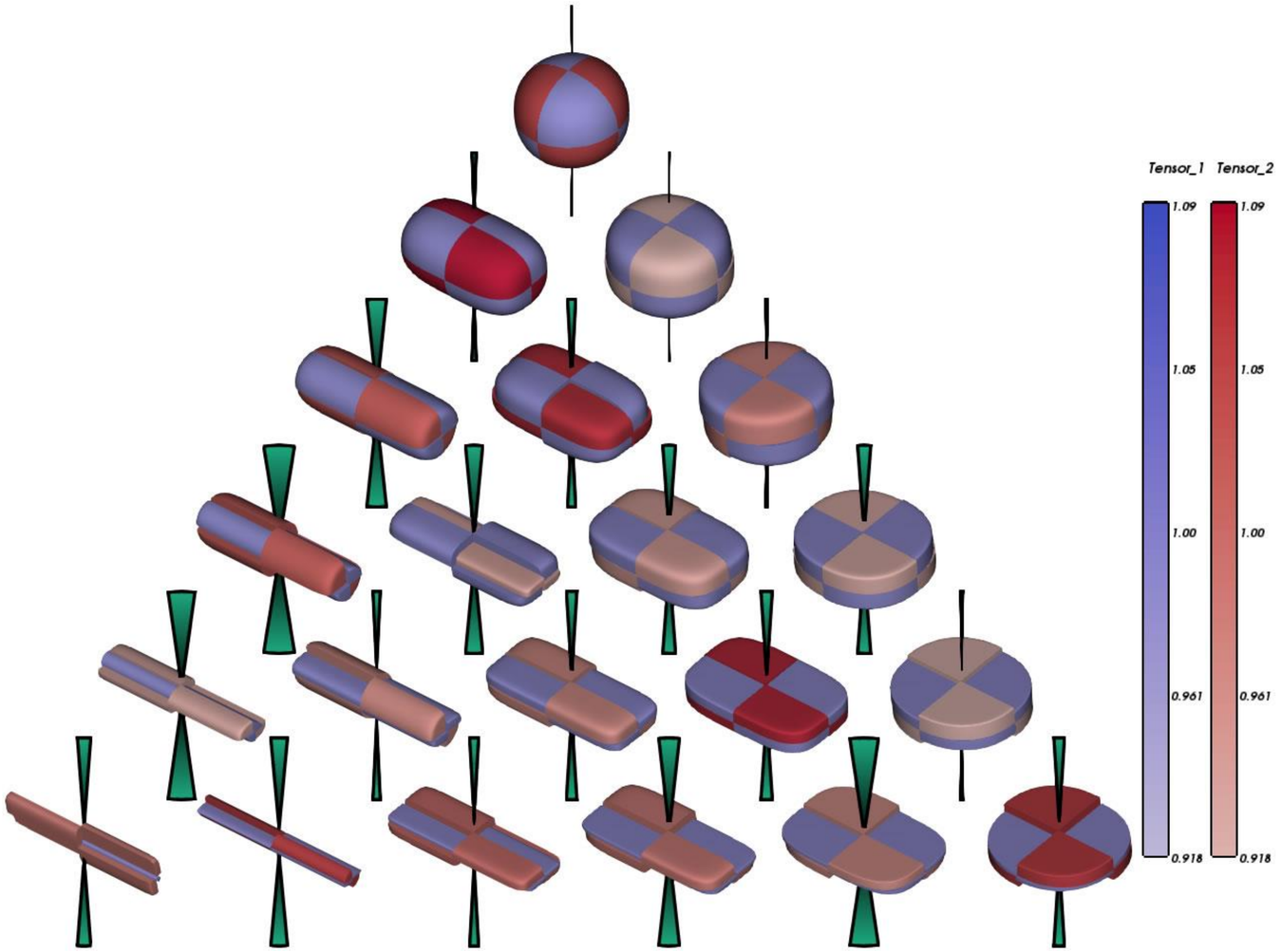






[Kindlmann (2004)]

Comparing Tensor Fields



[Zhang et al. 2016](#)

Spatial Fields

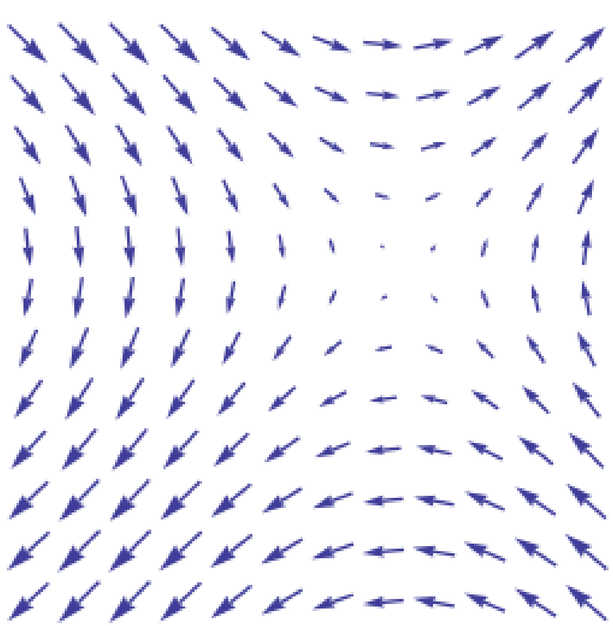
Scalar field = one value per cell

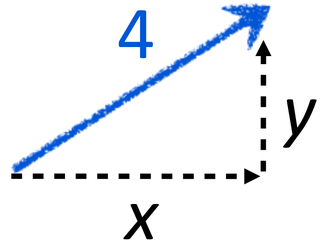
Vector or Tensor field = many values per cell

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)



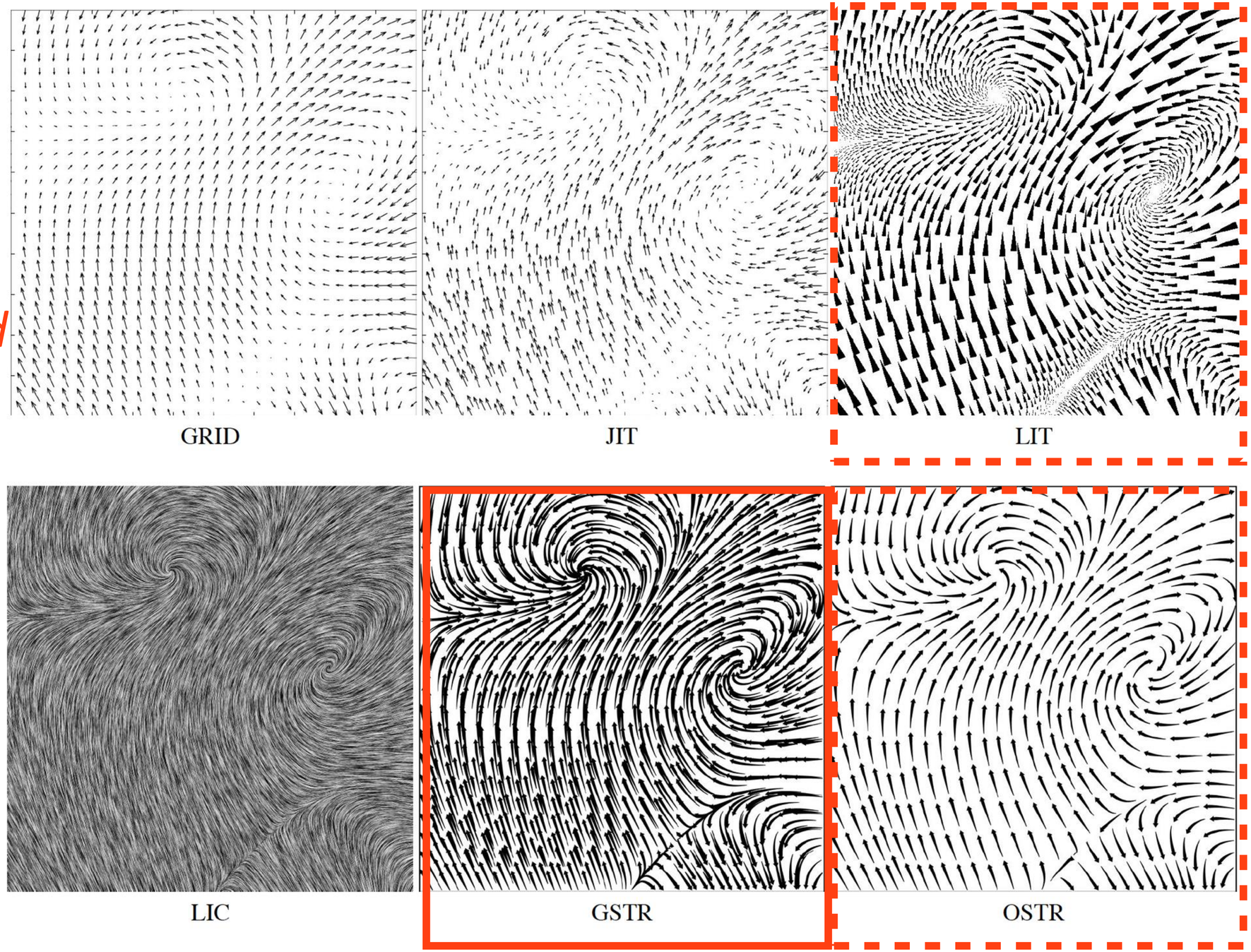


Vector

(magnitude and direction)

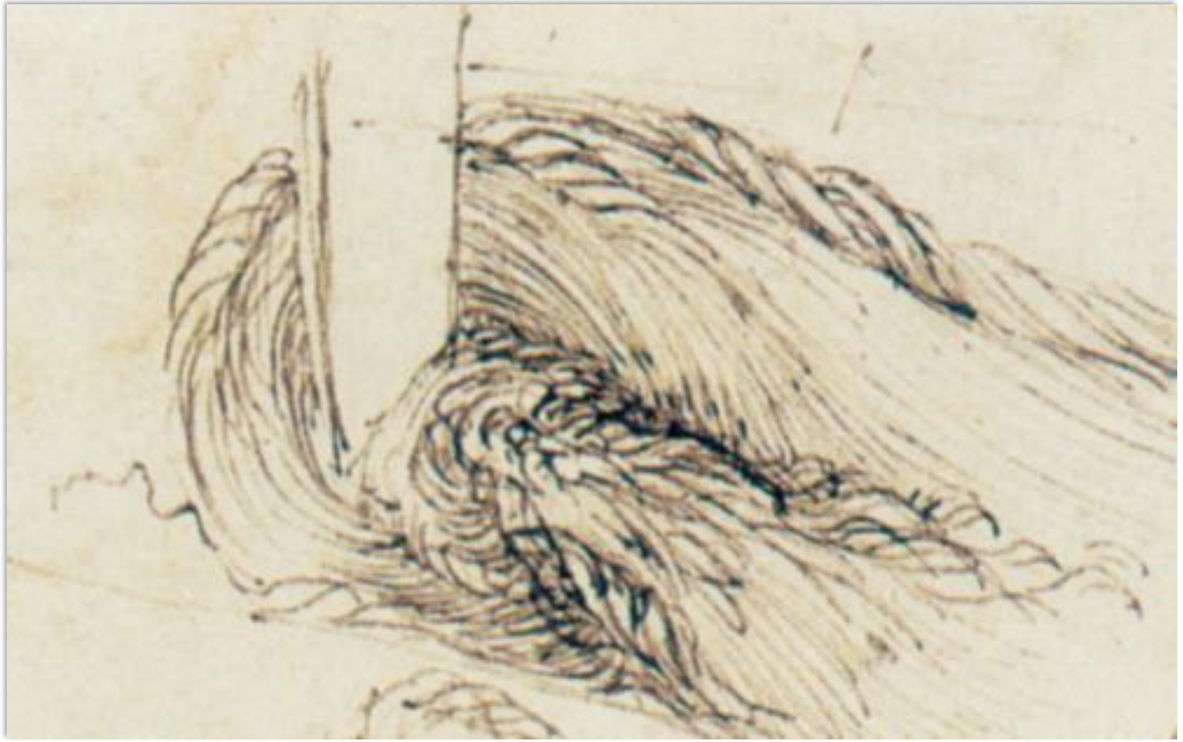
Vector Field Encoding Examples:

Most accurate and efficient for certain spatial tasks



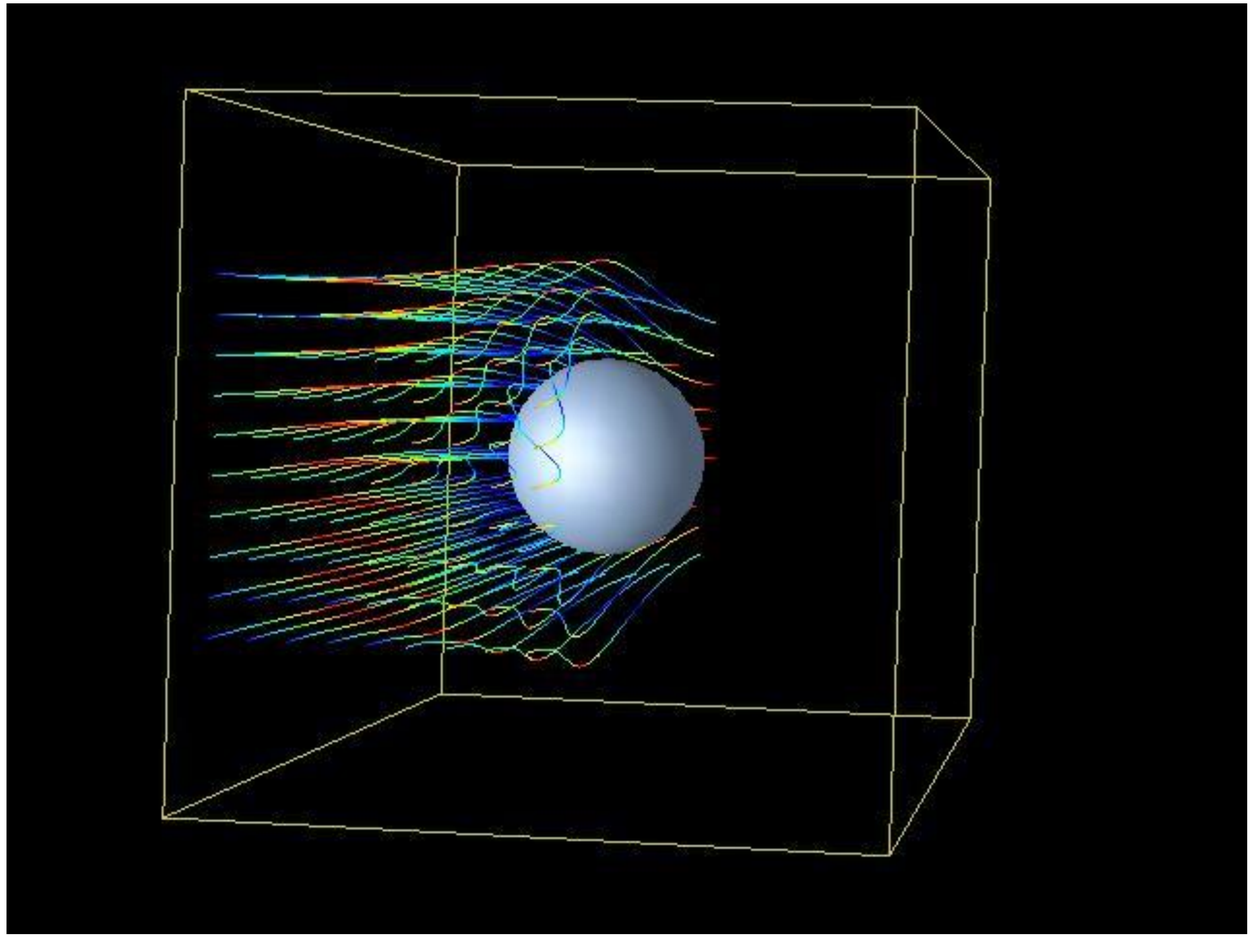
Laidlaw, et al. 2001

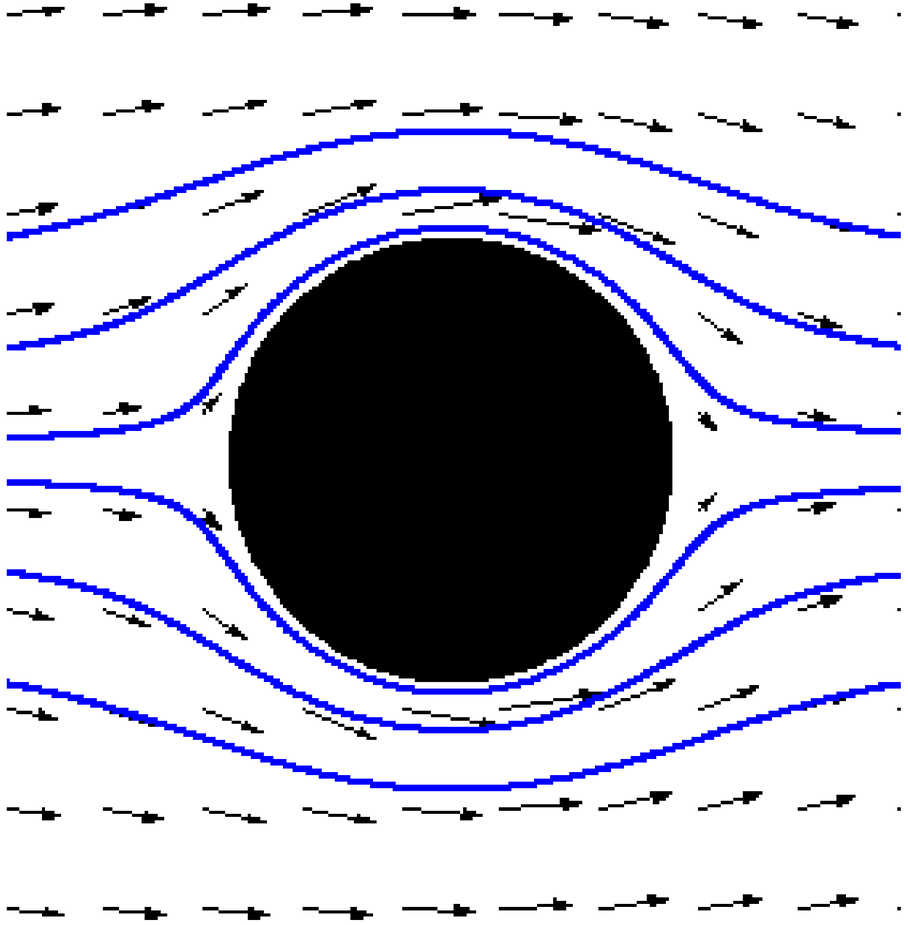
Example: Fluid Flow Visualization



Leonardo DaVinci

Example: Fluid Flow Visualization

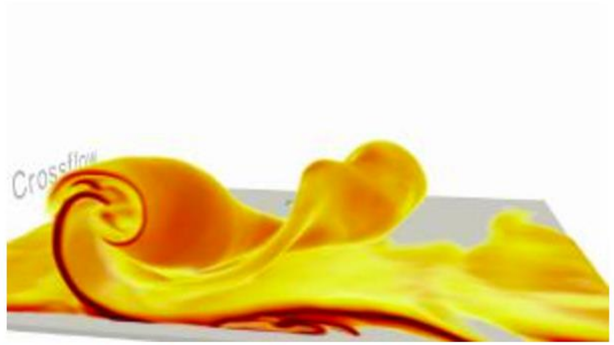




Example: Fluid Flow Visualization

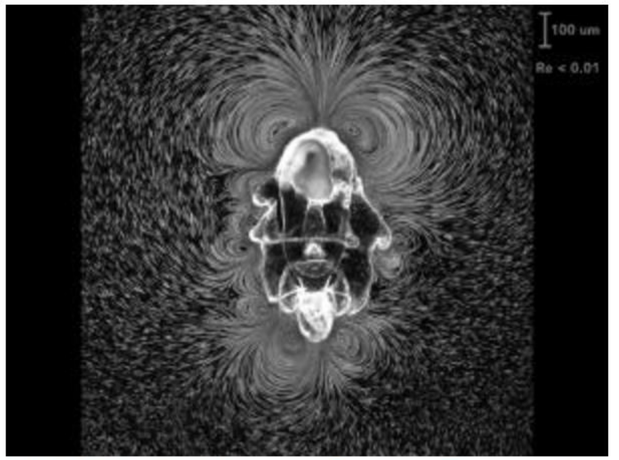
http://gfm.aps.org/meetings/dfd-2015
http://gfm.aps.org/meetings/dfd-2016

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.

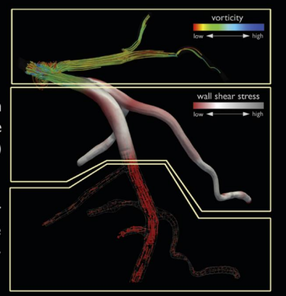
To this end, the project has collected computed tomography angiography (CTA) data from patients in order to obtain coronary geometries and then accurately model human blood flow through the coronary arteries. The CTA data is gathered using a 320 detector row Toshiba AquilionONE scanner and then the data 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.

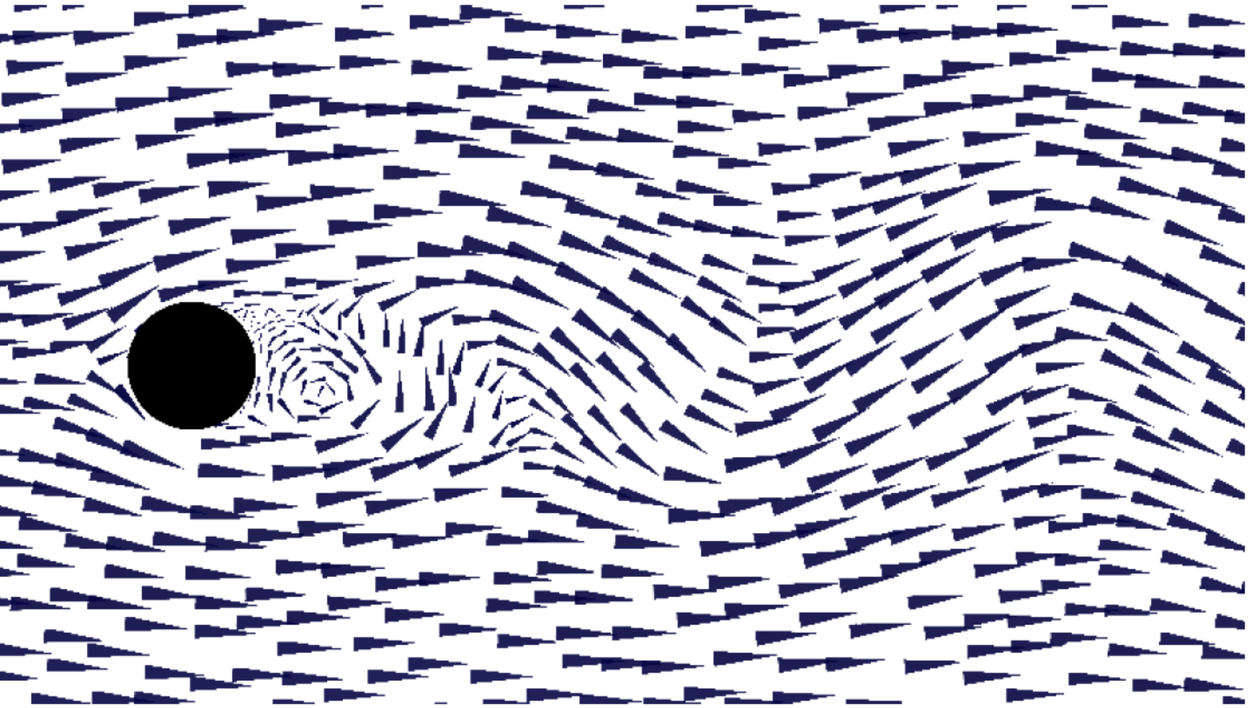
The surface representation shows the lumen of the artery, and the color represents the magnitude of the endothelial (i.e., inner wall) shear stress.

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



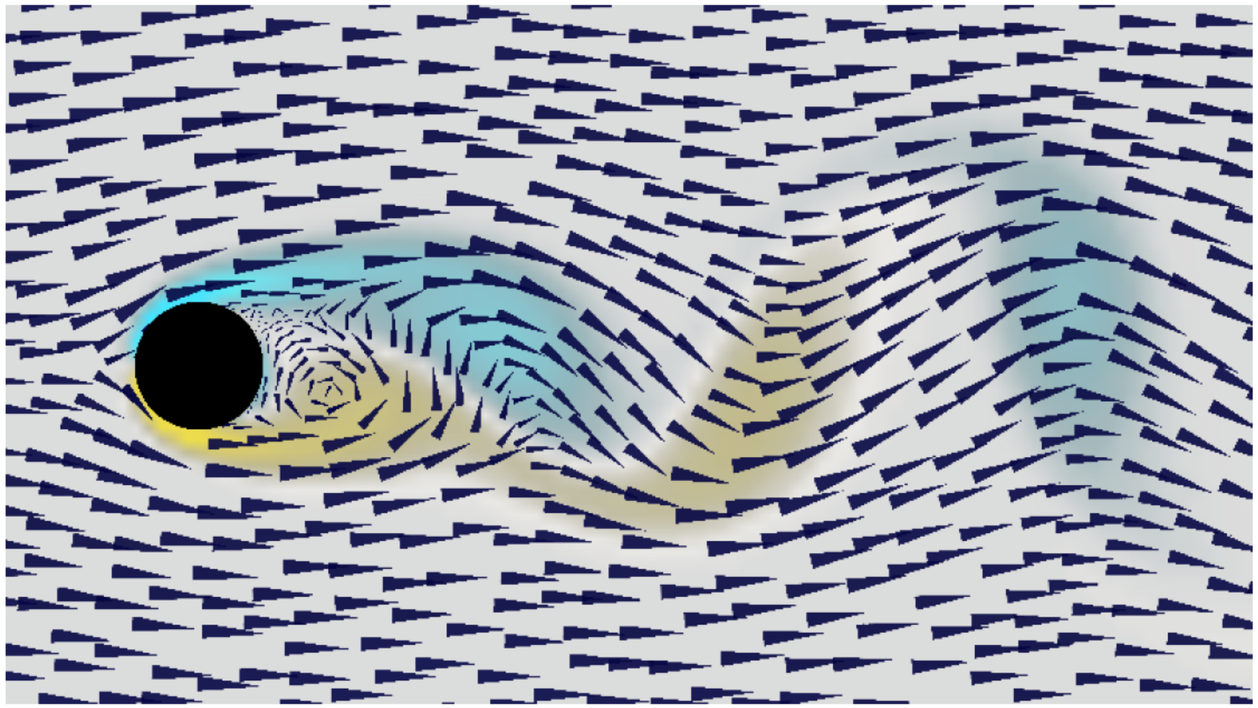
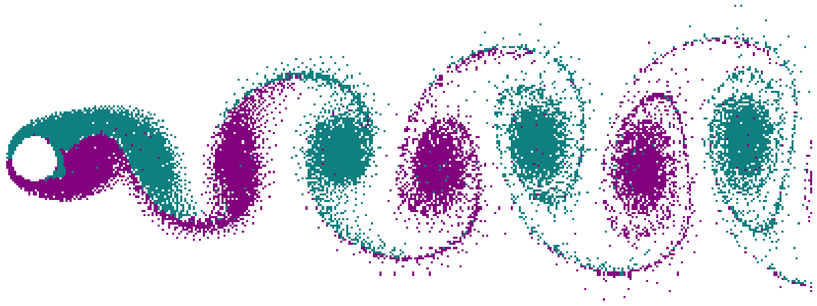
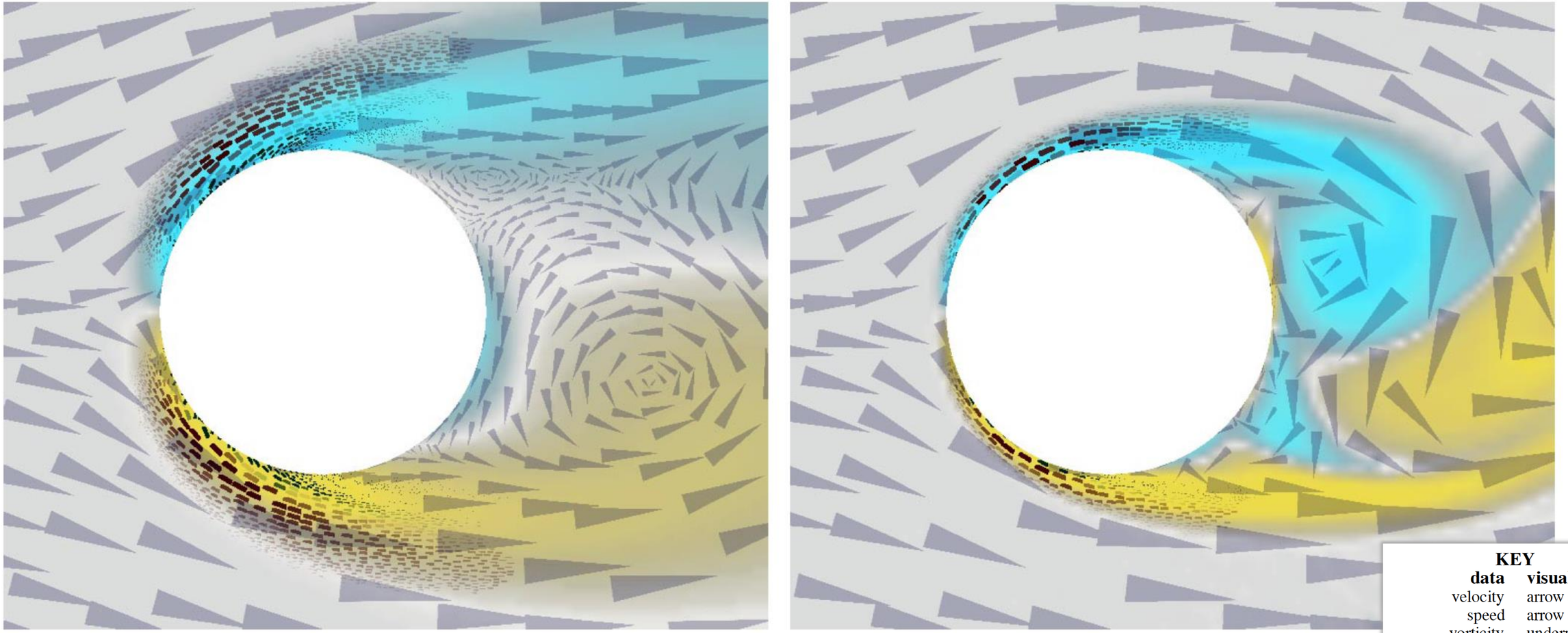


Figure 1: Typical visualization methods for 2D flow past a cylinder at Reynolds number 100. On the left, we show only the velocity field. On the right, we simultaneously show velocity and vorticity. Vorticity represents the rotational component of the flow. Clockwise vorticity is blue, counterclockwise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



Wikimedia

Kirby, et al. 1999



Reynolds number 100

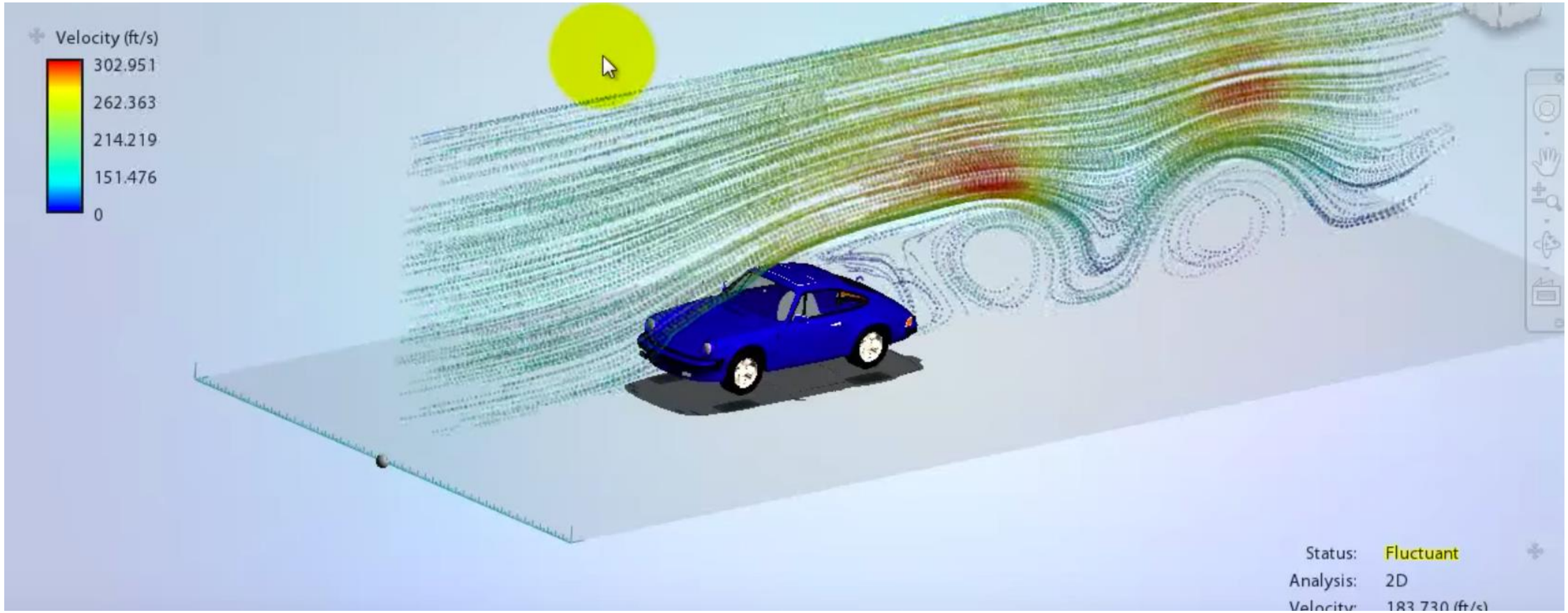
Reynolds number 500

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

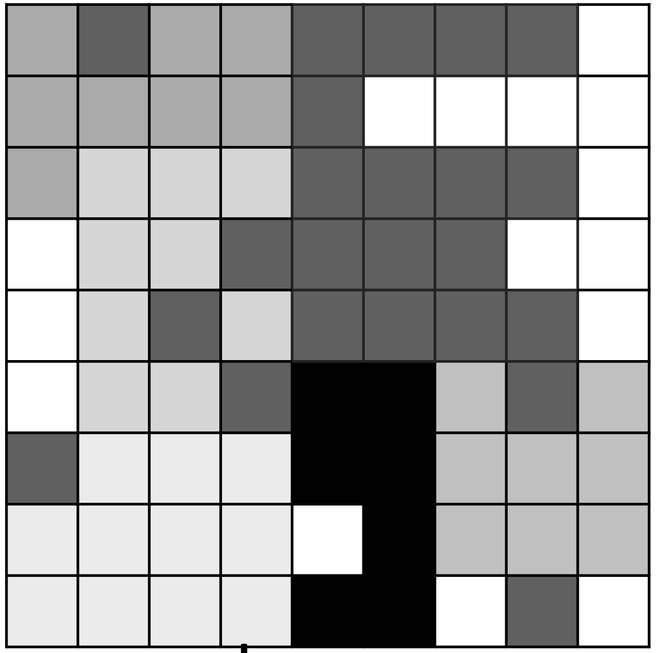
Scalar field = one value per cell

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)

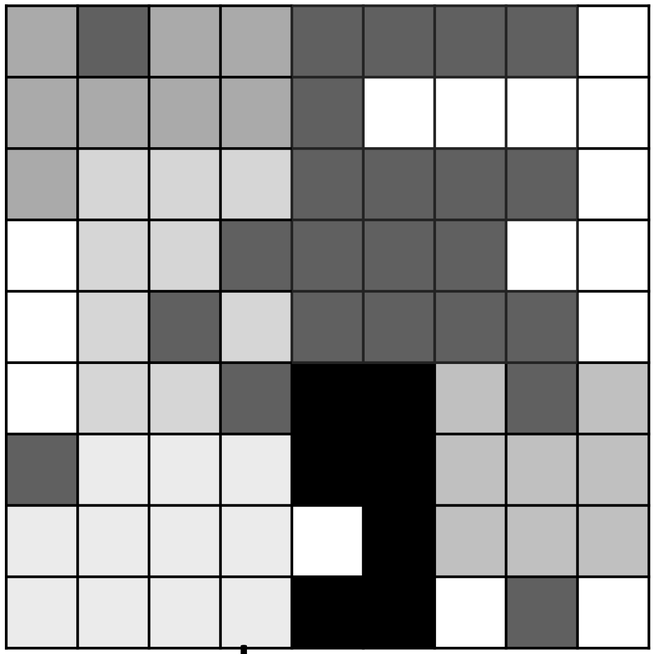


Image

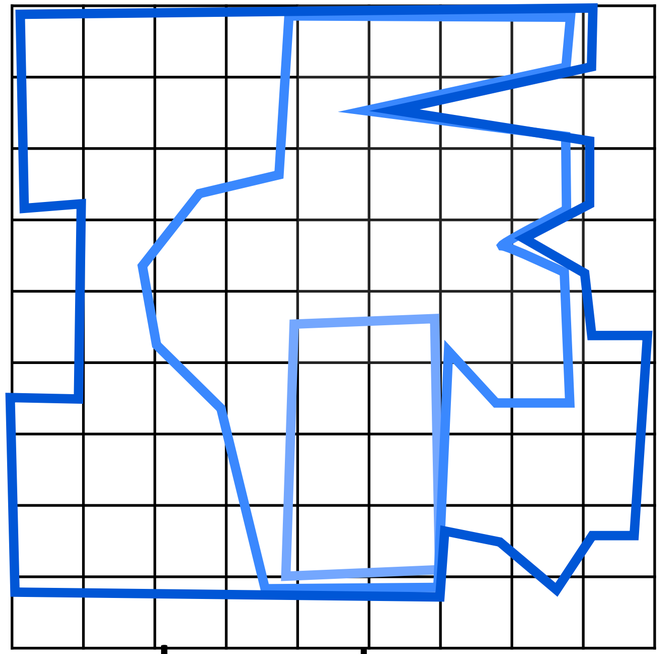
Spatial Fields

Scalar field = one value per cell

Encoding options:



Image



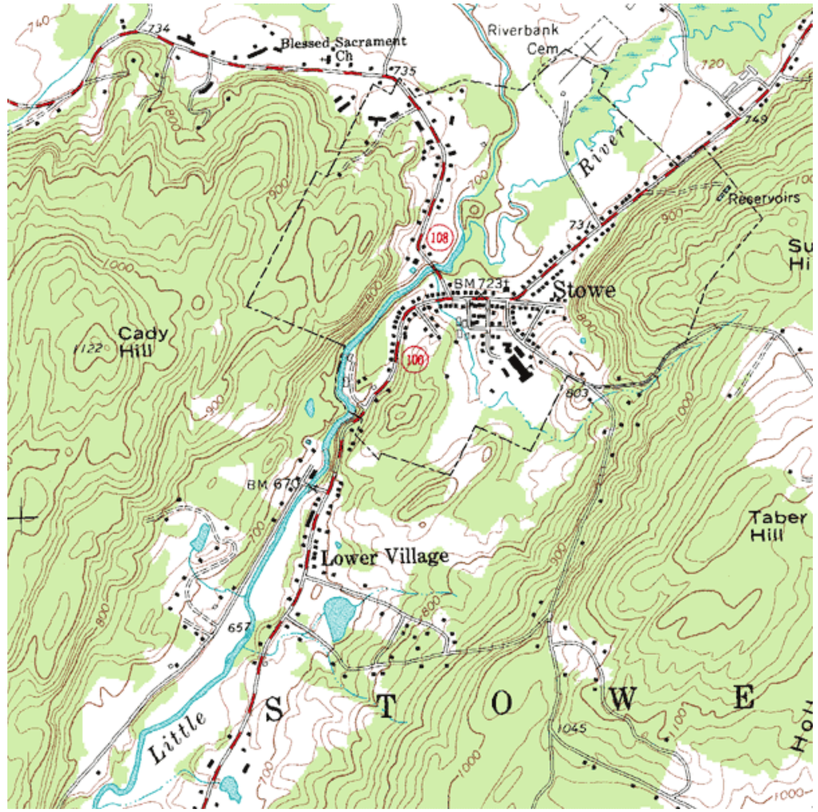
Isocontours

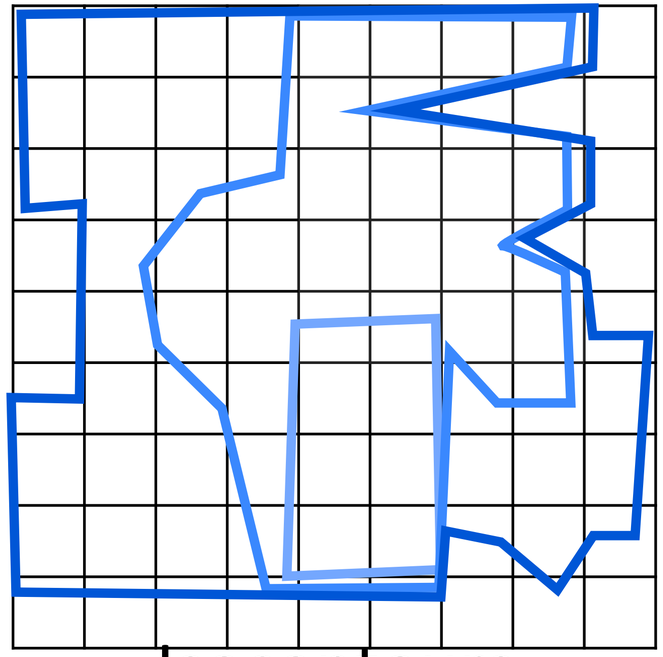
(Contour line as single scalar threshold value)

Spatial Fields

Scalar field = one value per cell

Encoding options:





Isocontours

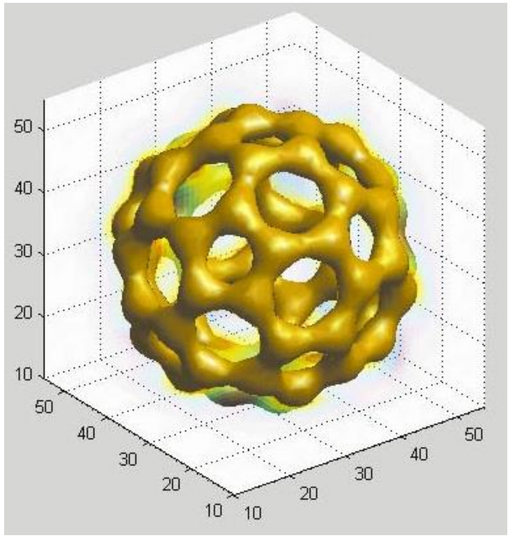
(Contour line as single scalar threshold value)

Spatial Fields

Scalar field = one value per cell

Encoding options:

Isosurface



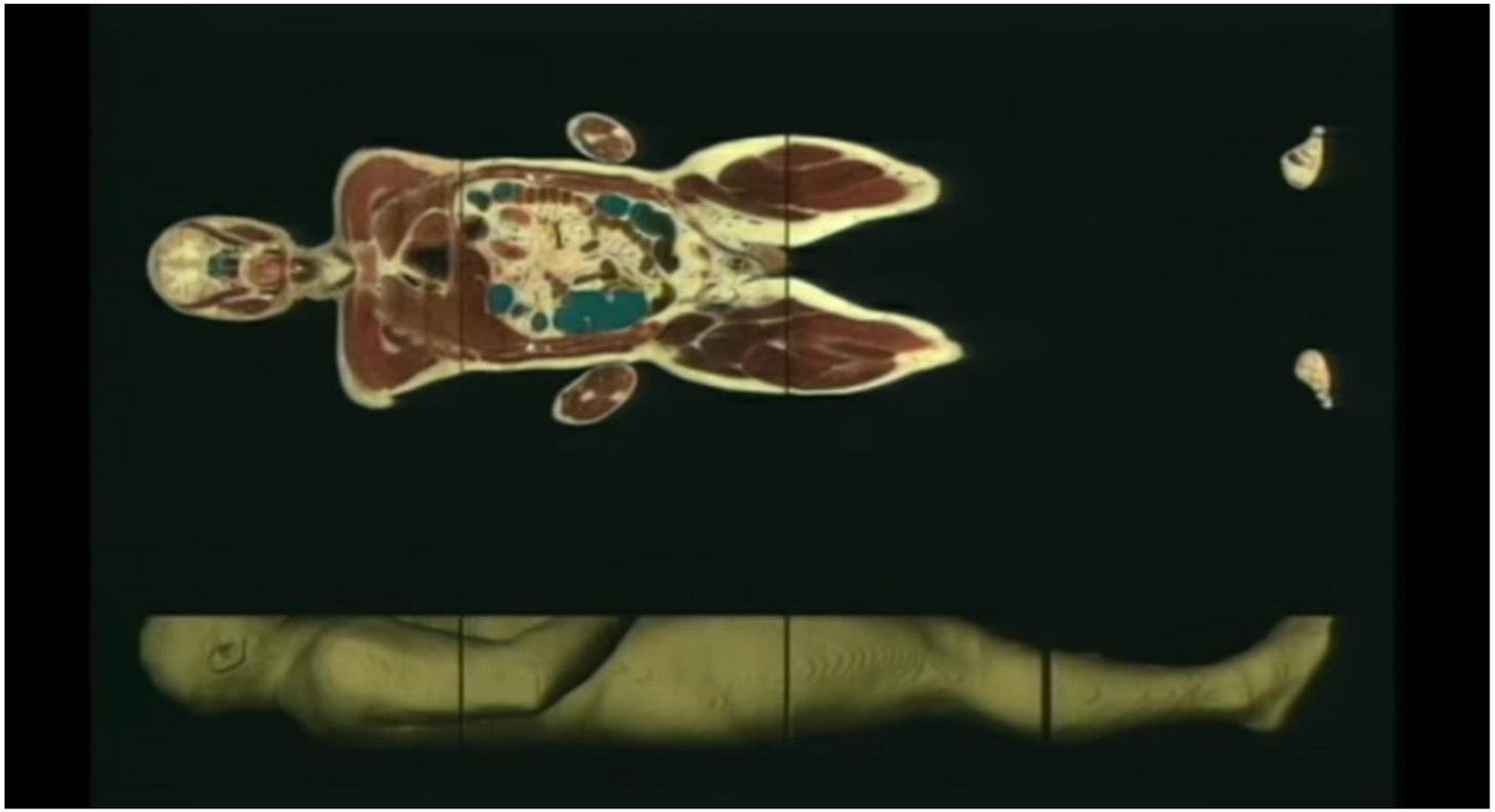
Surface that represents points of a constant value

Volume Rendering

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

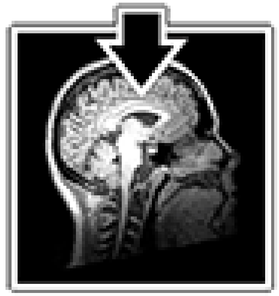
Isosurfaces & Volume Rendering

Visible Human Project



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

In-Class Exercise: Medical Imaging



Slice:Drop

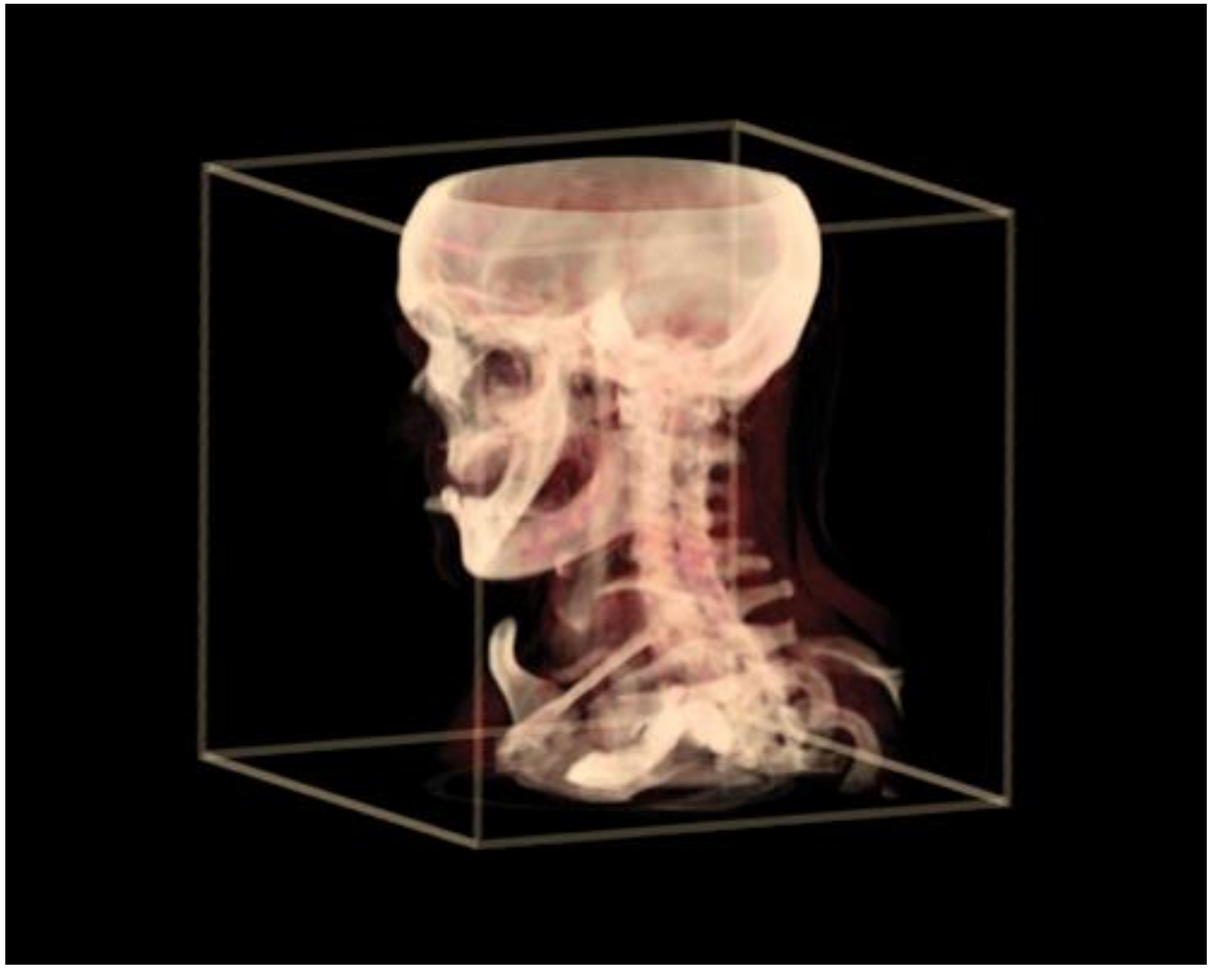
http://slicedrop.com/

Instructions:

1. Go to the Slice:Drop homepage (URL above) and click on the first example dataset in the top-right gallery “A 14 year old healthy male brain.”
2. Explore the different views of the data using the hidden toolbars along the left side of the image:
3. VOLUME: Explore the 2D and 3D view options.
4. VOLUME: Experiment with the brightness/contrast (“Window level”) and data range (“Threshold”) sliders. Also try to change the colors.
5. FIBERS: Experiment with the fiber threshold (i.e., data range).

Isosurfaces vs. Volume Rendering

distinct objects
distinct thresholds (surfaces)



indistinct objects
blending or transparency important