

# Lecture 16: Spatial, 3D, and Scientific Visualization

CS 7250  
SPRING 2021  
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NORTHEASTERN UNIVERSITY

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

# CHECKING IN

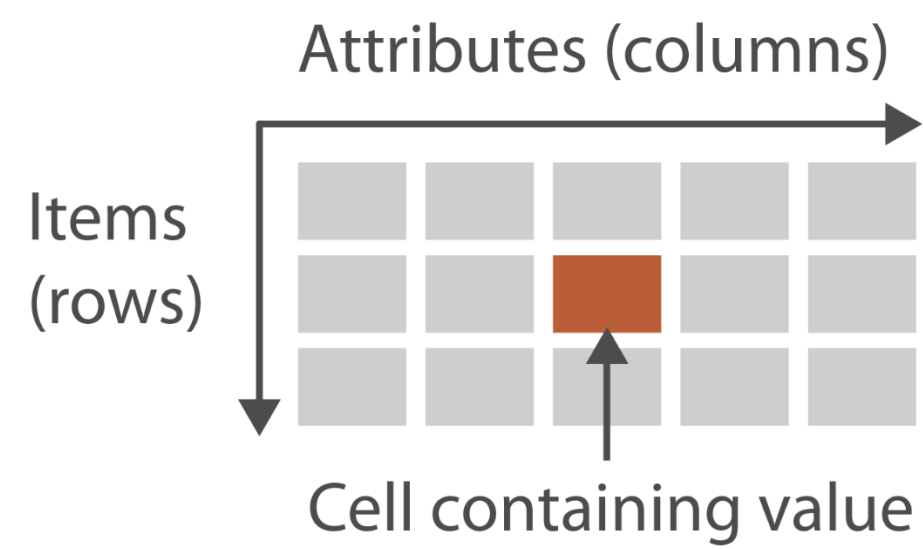
# MAPS

# GOALS FOR TODAY

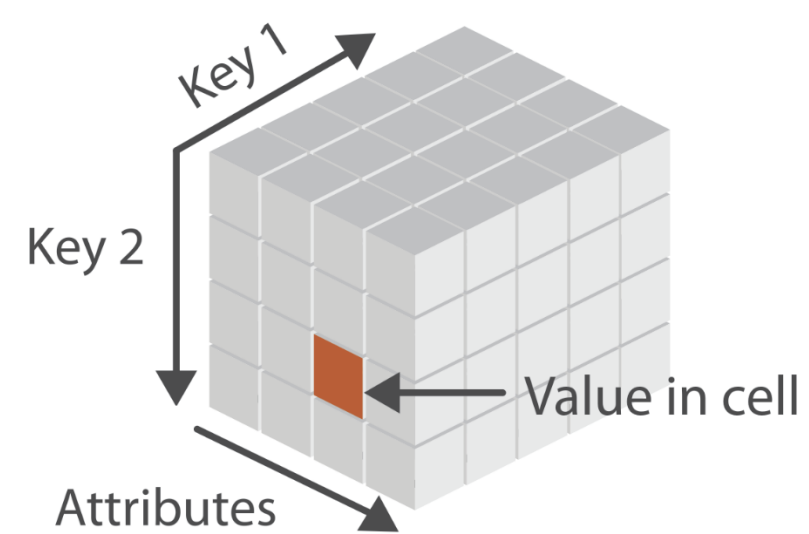
- Learn what elements visually encode data in maps.
- Learn about different projections, and understand the (dis)advantages of each.
- Learn about different map types, and how they relate to tasks.

## ➔ Dataset Types

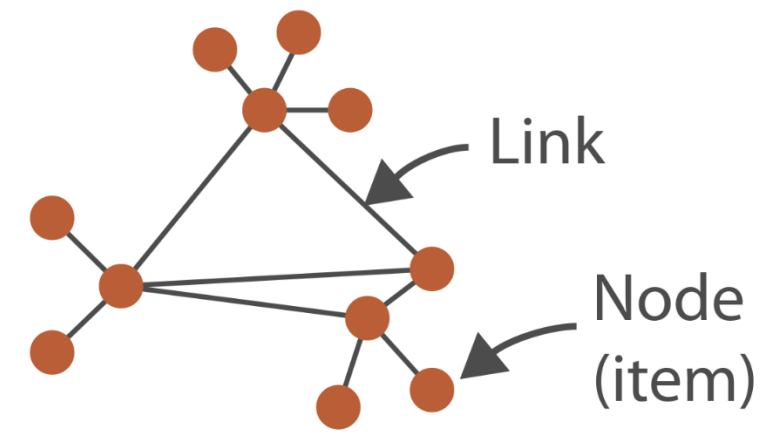
### ➔ Tables



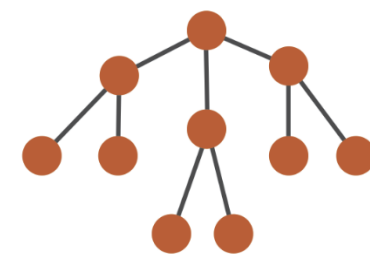
### ➔ *Multidimensional Table*



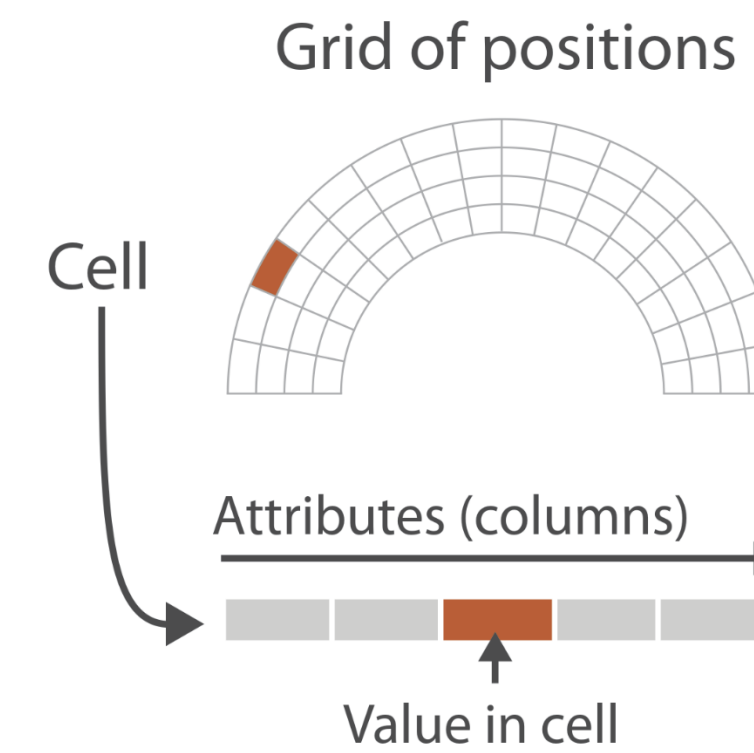
### ➔ Networks



### ➔ Trees



### ➔ Fields (Continuous)



### ➔ Geometry (Spatial)



# Arrange Spatial Data

## ① Use Given

### → Geometry

→ *Geographic*

→ *Other Derived*



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



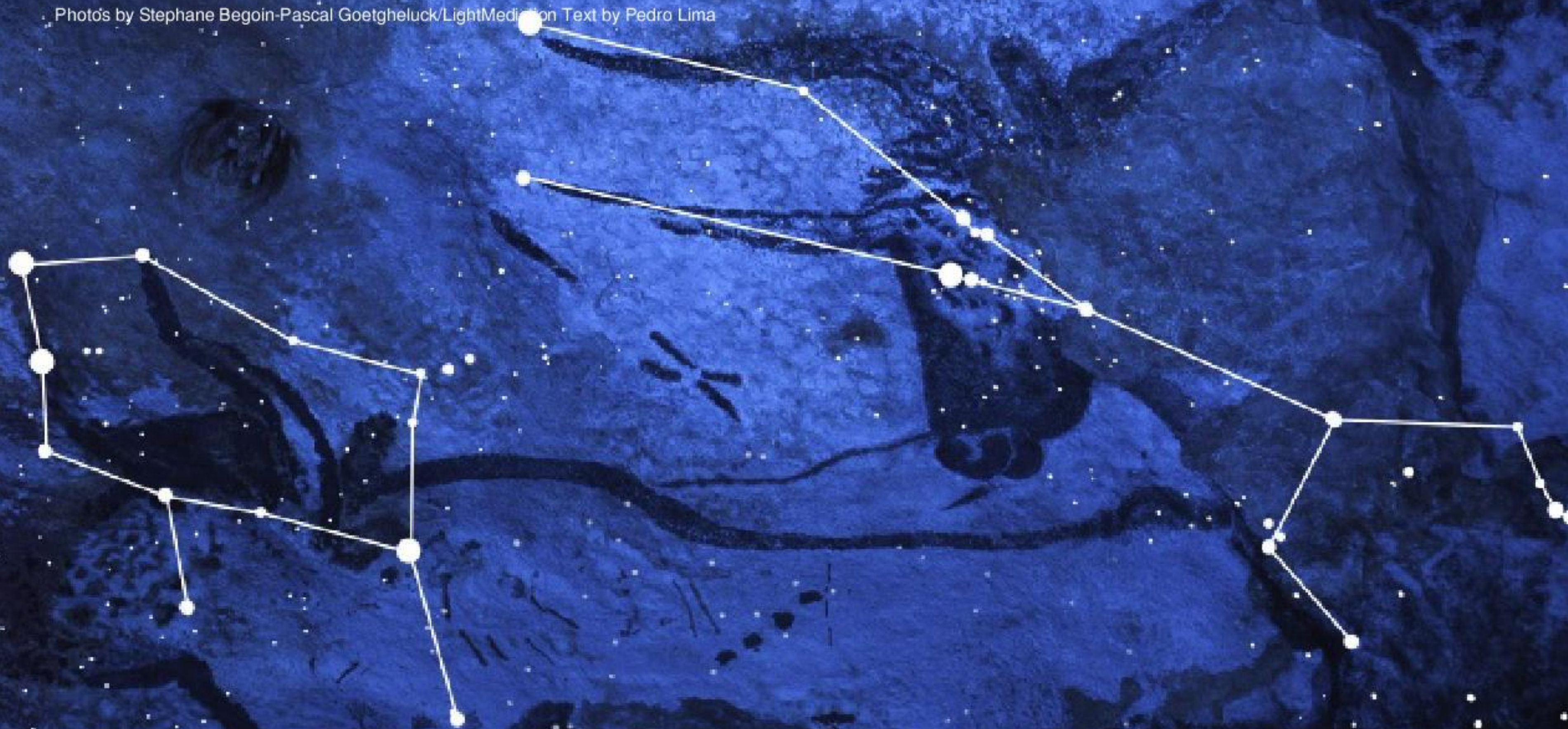
Vega, Deneb, and Altair

Lascaux cave paintings - over 16,000 years old!

# 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...

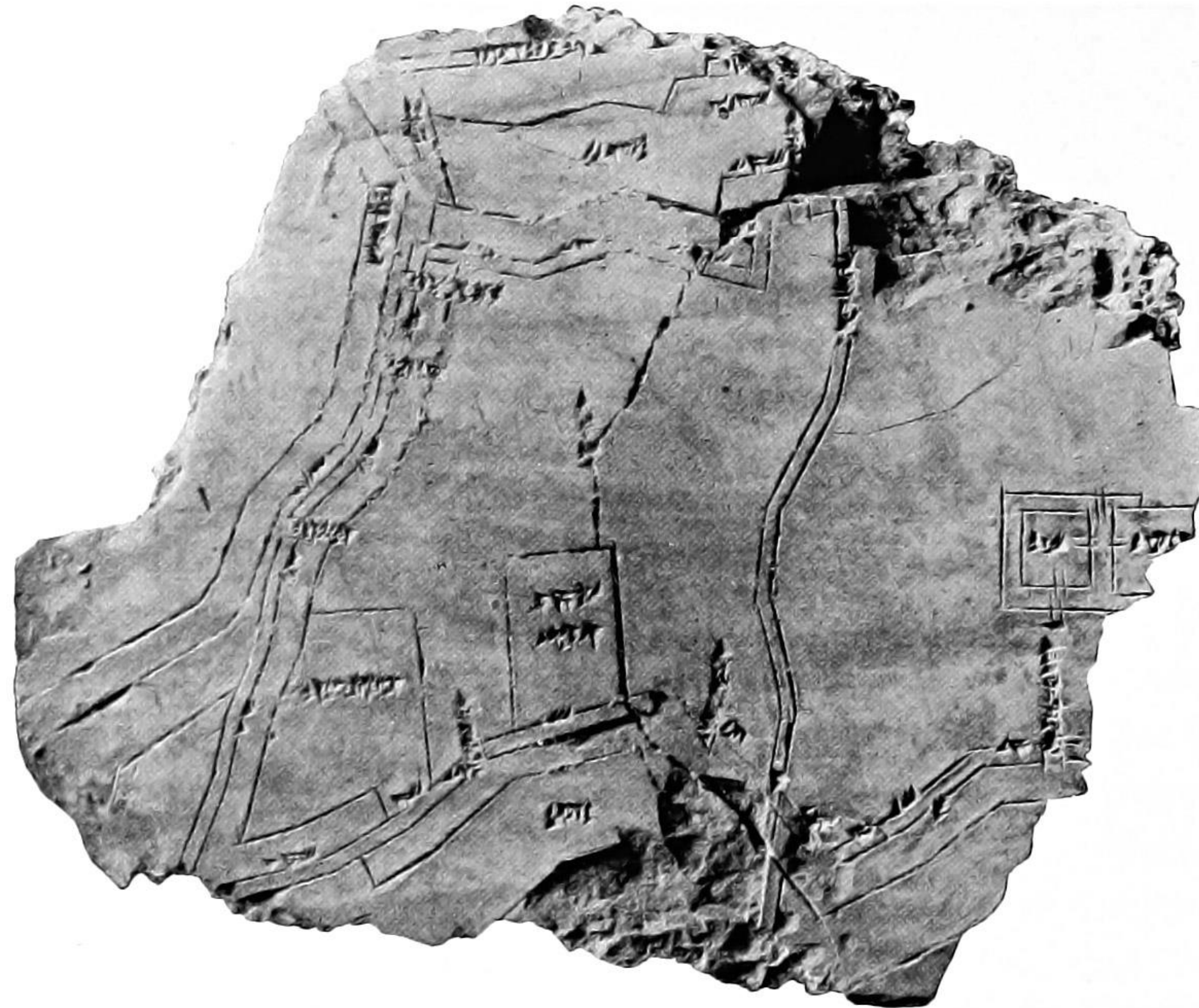
Photos by Stephane Begoin-Pascal Goetgheluck/LightMediation Text by Pedro Lima





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

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



# Visualization Building Blocks

## MARKS:

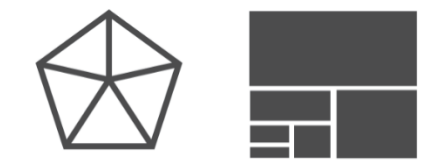
→ Points



→ Lines



→ Areas



## CHANNELS :

→ Position

→ Horizontal



→ Vertical



→ Both



→ Color



→ Shape



→ Tilt



→ Size

→ Length



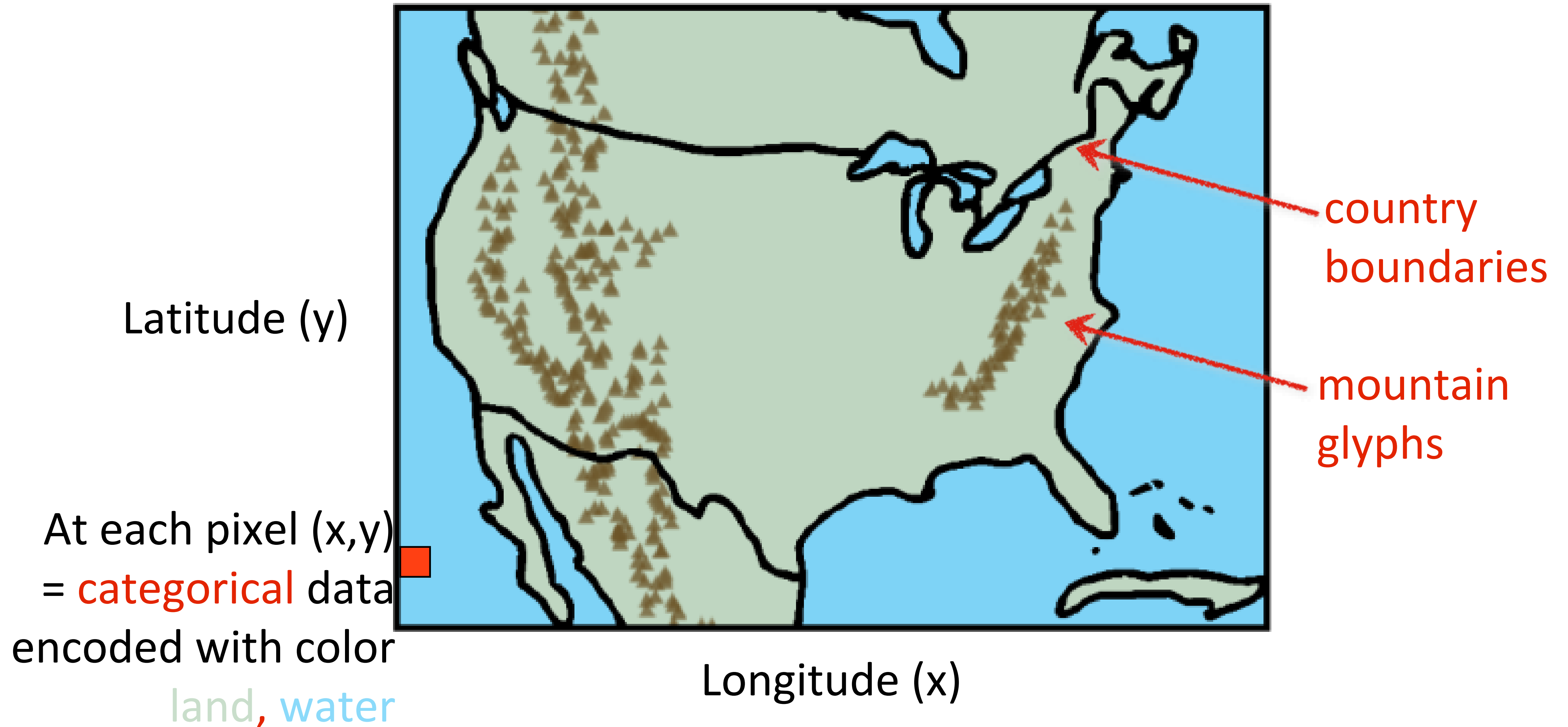
→ Area



→ Volume



# Visualization Building Blocks

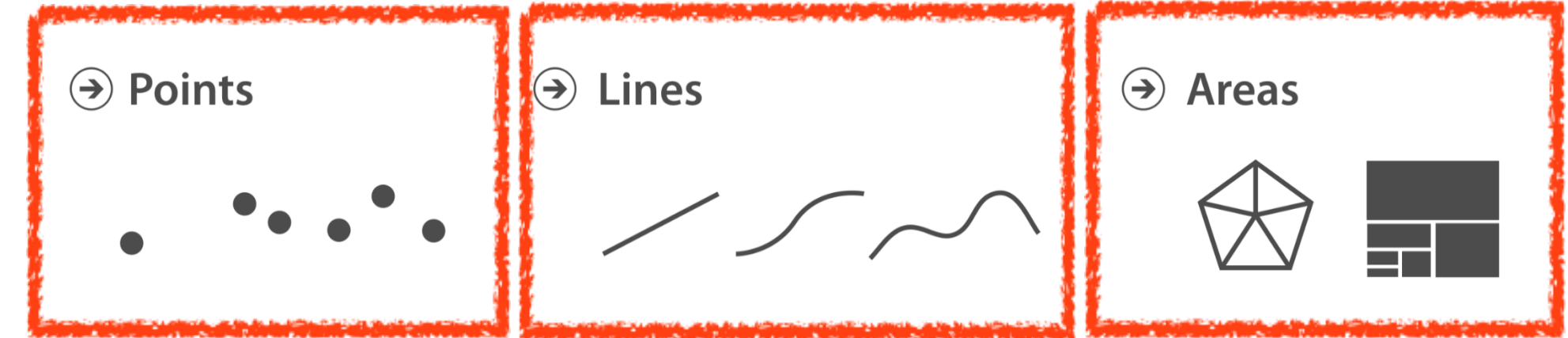


# Visualization Building Blocks

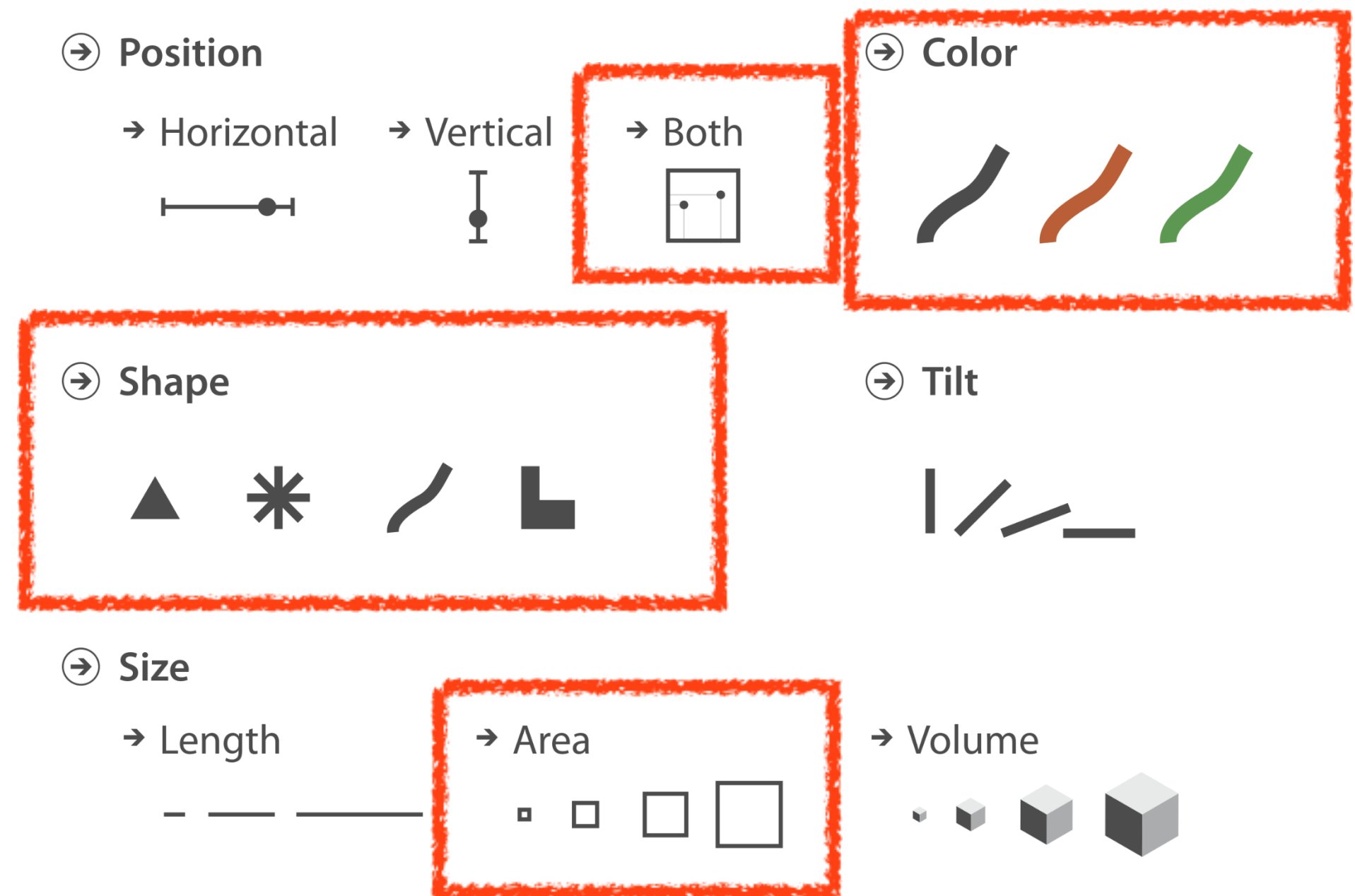
# of attributes encoded: 5



## MARKS:



## CHANNELS :



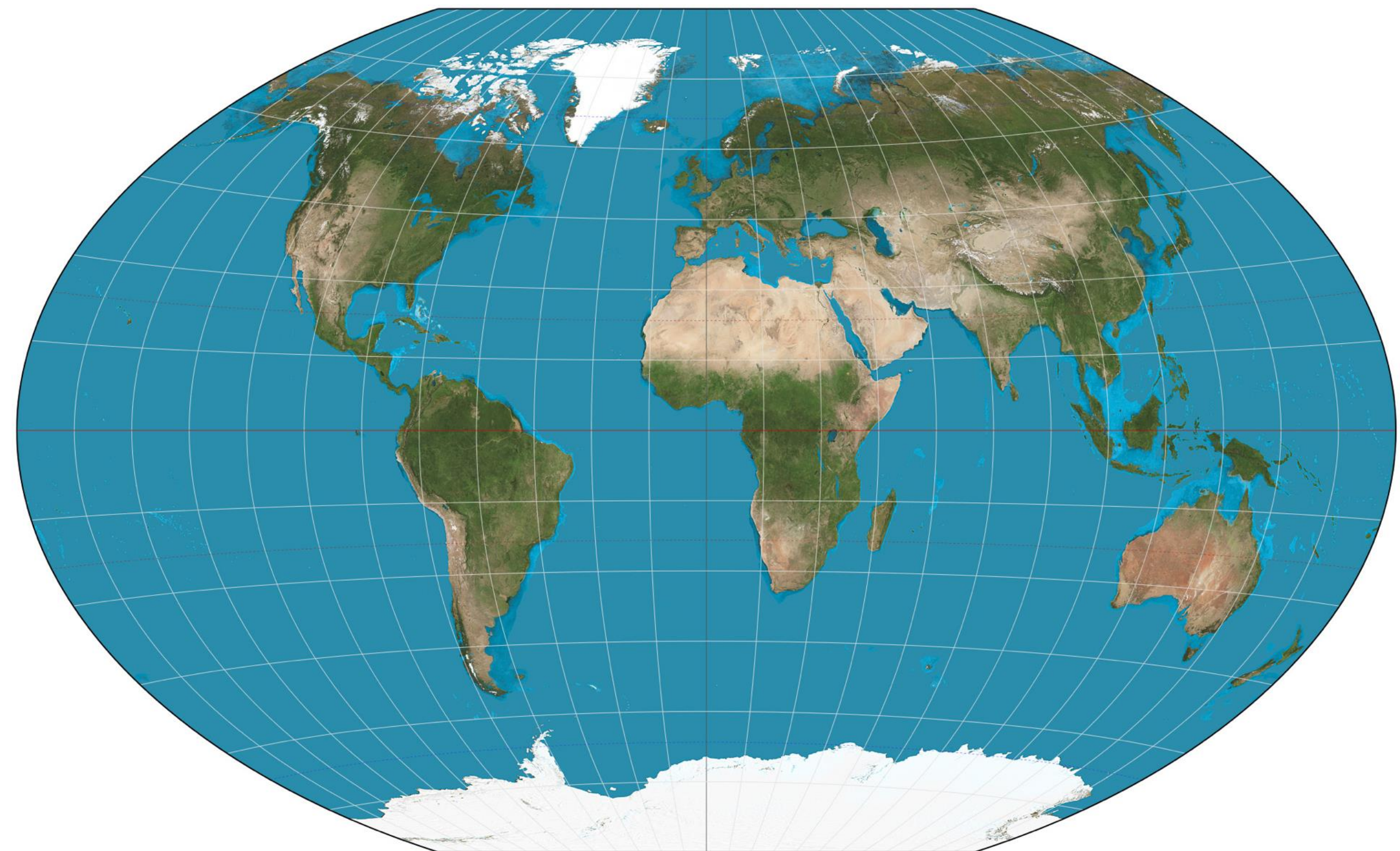
# Map Projections

Dimensionality reduction

3D



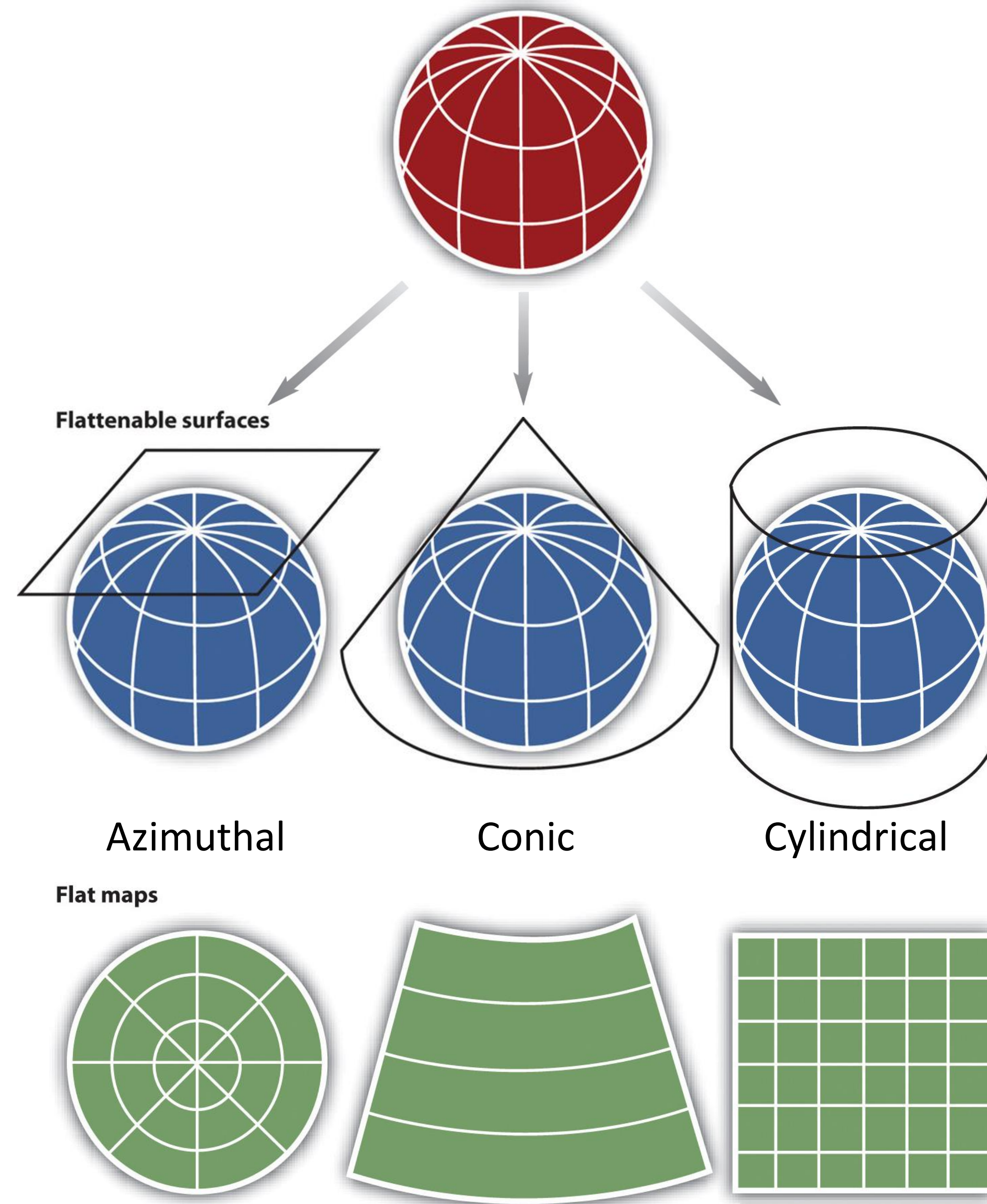
2D



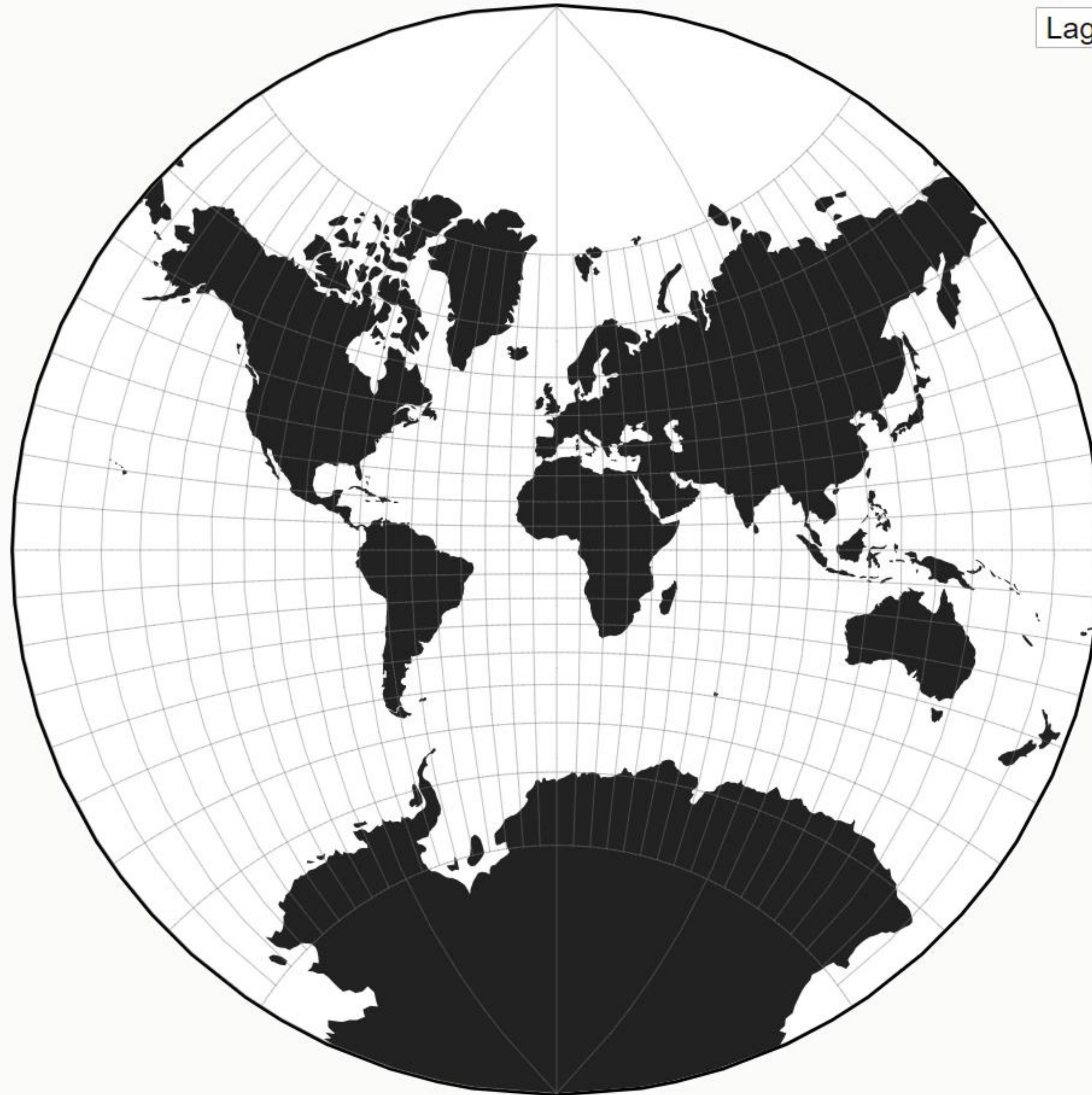


*Vox*

# *Dimensionality reduction*



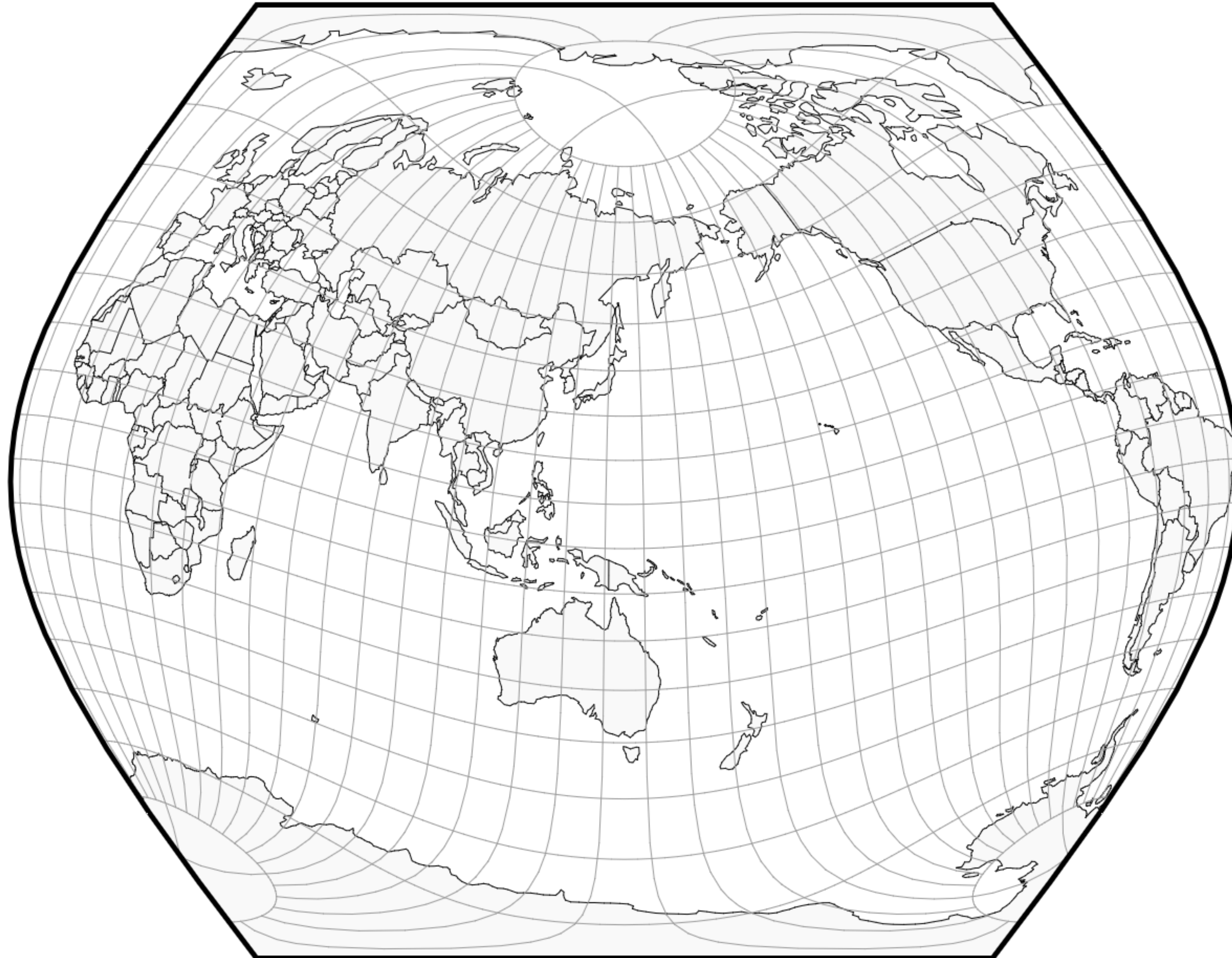
# Projection Transitions



Lagrange ▼



# Map Projection Transitions



*Maps can deceive...*



## 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](#).

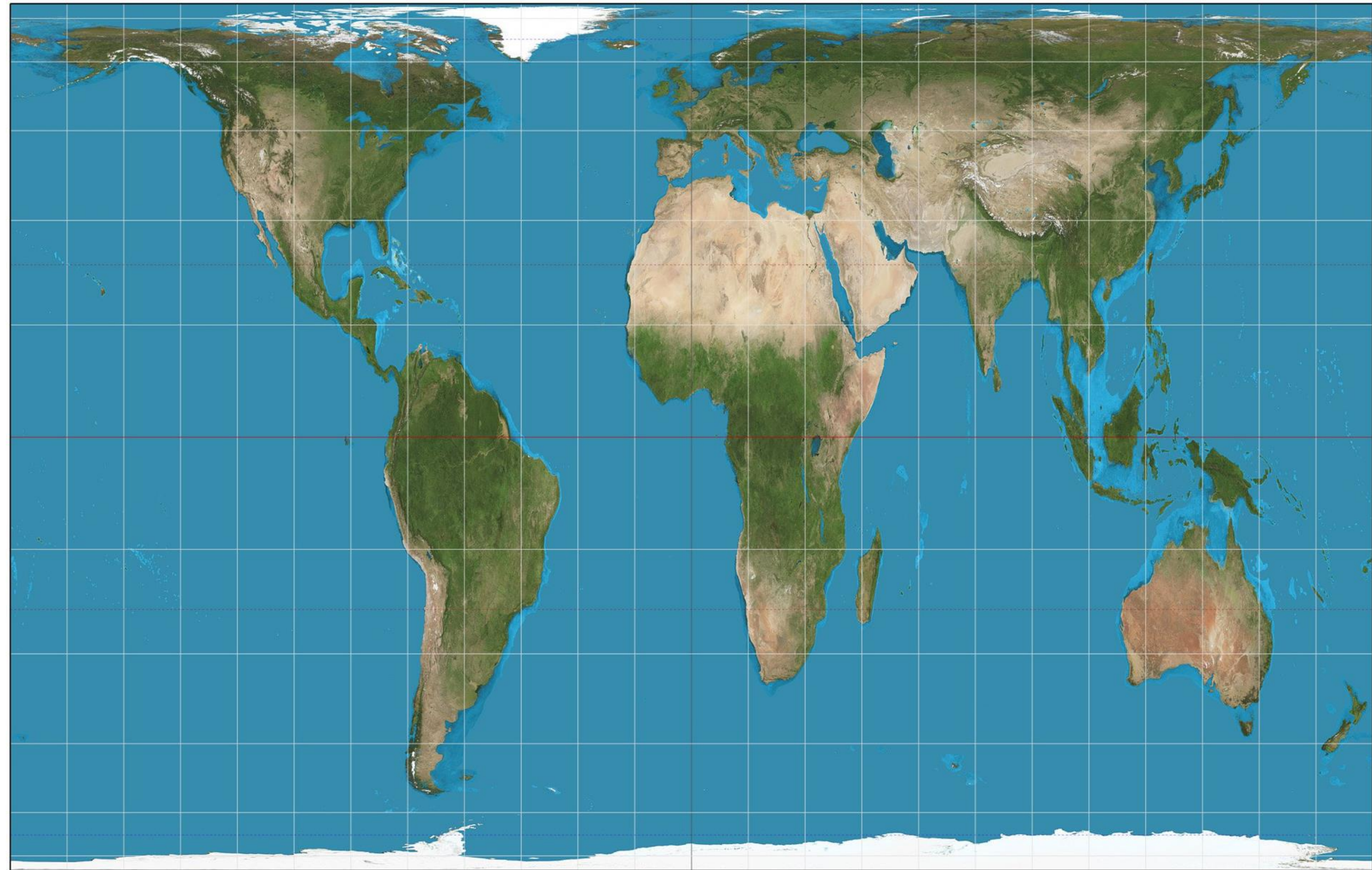
The shift towards the more accurate [Gall-Peters Projection](#) sees Boston's public schools follow the lead of the [United Nations](#), which has advocated the map as a more 'fair', less [Eurocentric](#) representation of the world, as have [several aid agencies](#).

## Mercator Projection



Great for ocean navigation,  
but dramatically exaggerates poles.

## Gall-Peters Projection



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

# 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 *in-sufficient 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 km <sup>2</sup>
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
<b>TOTAL</b>	<b>30.102</b>
<b>AFRICA</b>	<b>30.221</b>
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](http://en.wikipedia.org/wiki/List_of_countries_and_outlying_territories_by_total_area)

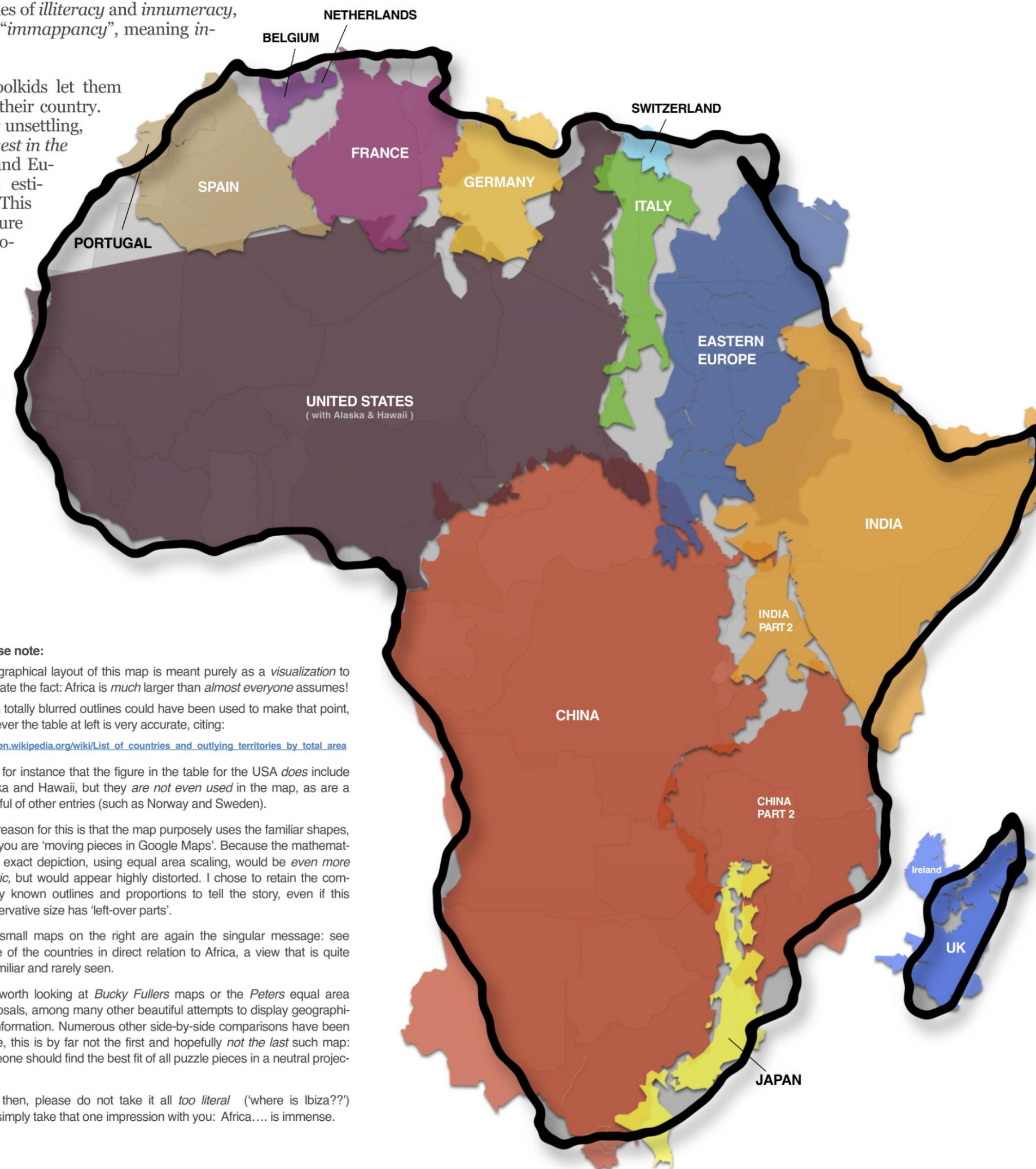
Note for instance that the figure in the table for the USA *does* include Alaska and Hawaii, but they *are not even used* in the map, as are a handful of other entries (such as Norway and Sweden).

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 km <sup>2</sup>	%	
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
<b>TOP 100 TOTAL</b>	<b>132.632.524</b>	<b>89,34</b>	



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# In-Class Exercise: The True Size

# THE TRUE SIZE OF ...

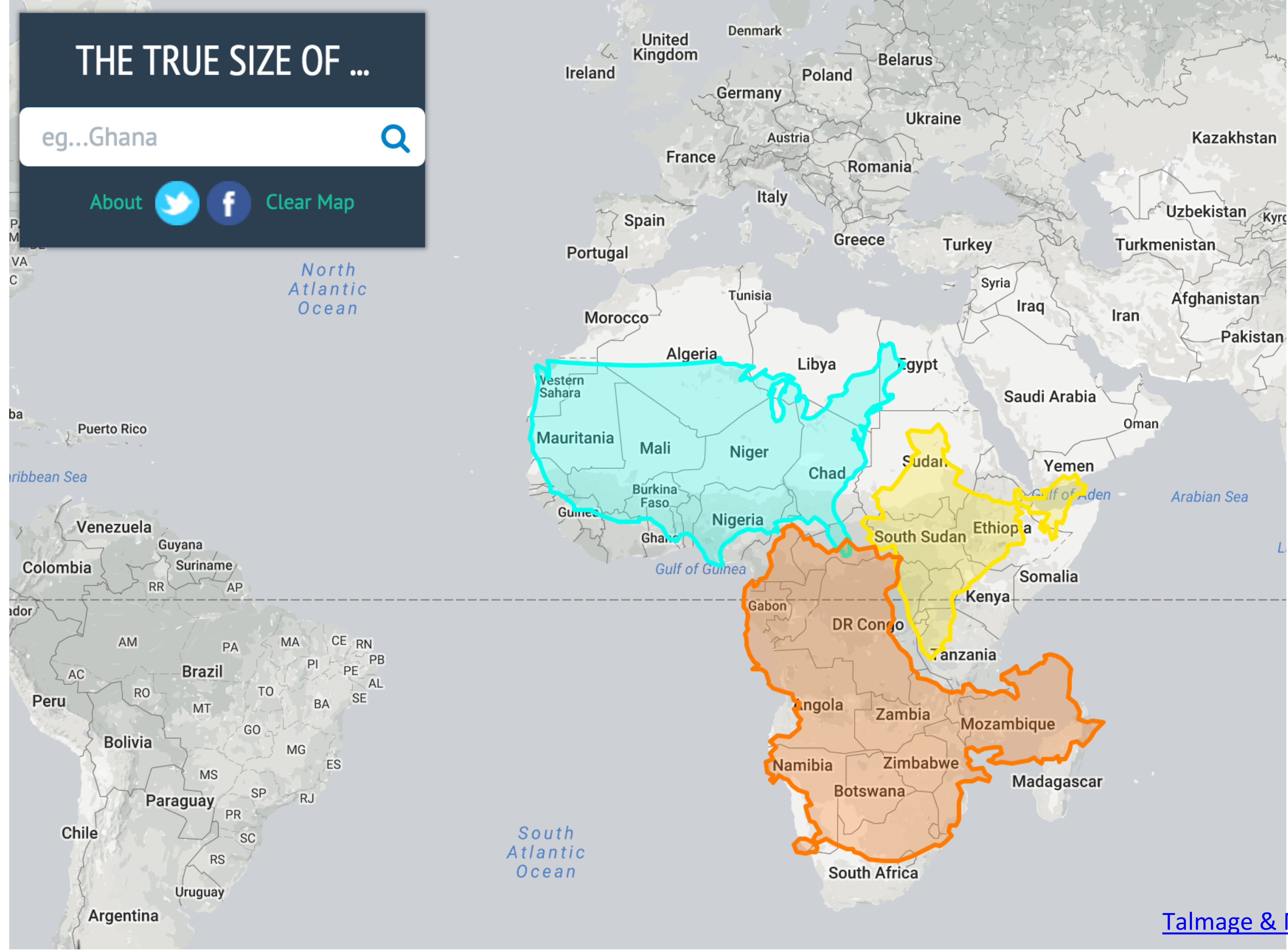
eg...Ghana



About



Clear Map

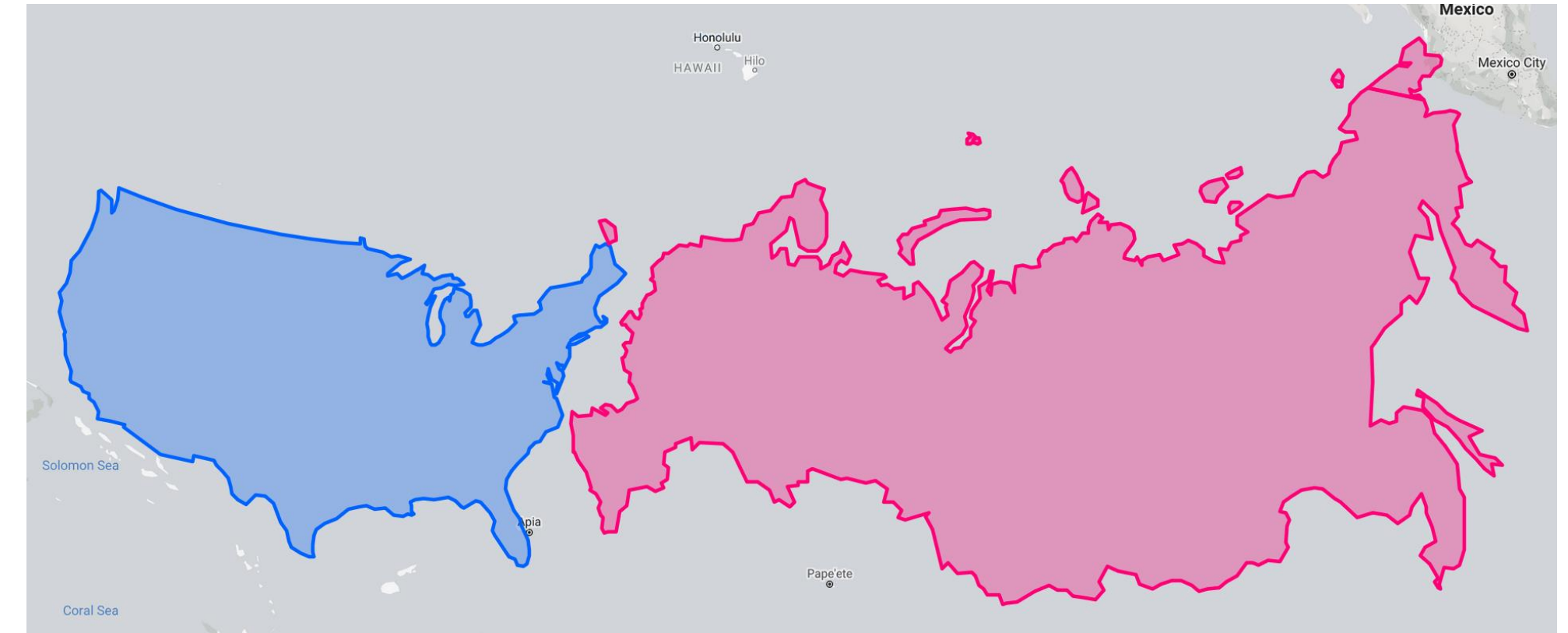


# In-Class Exercise: The True Size

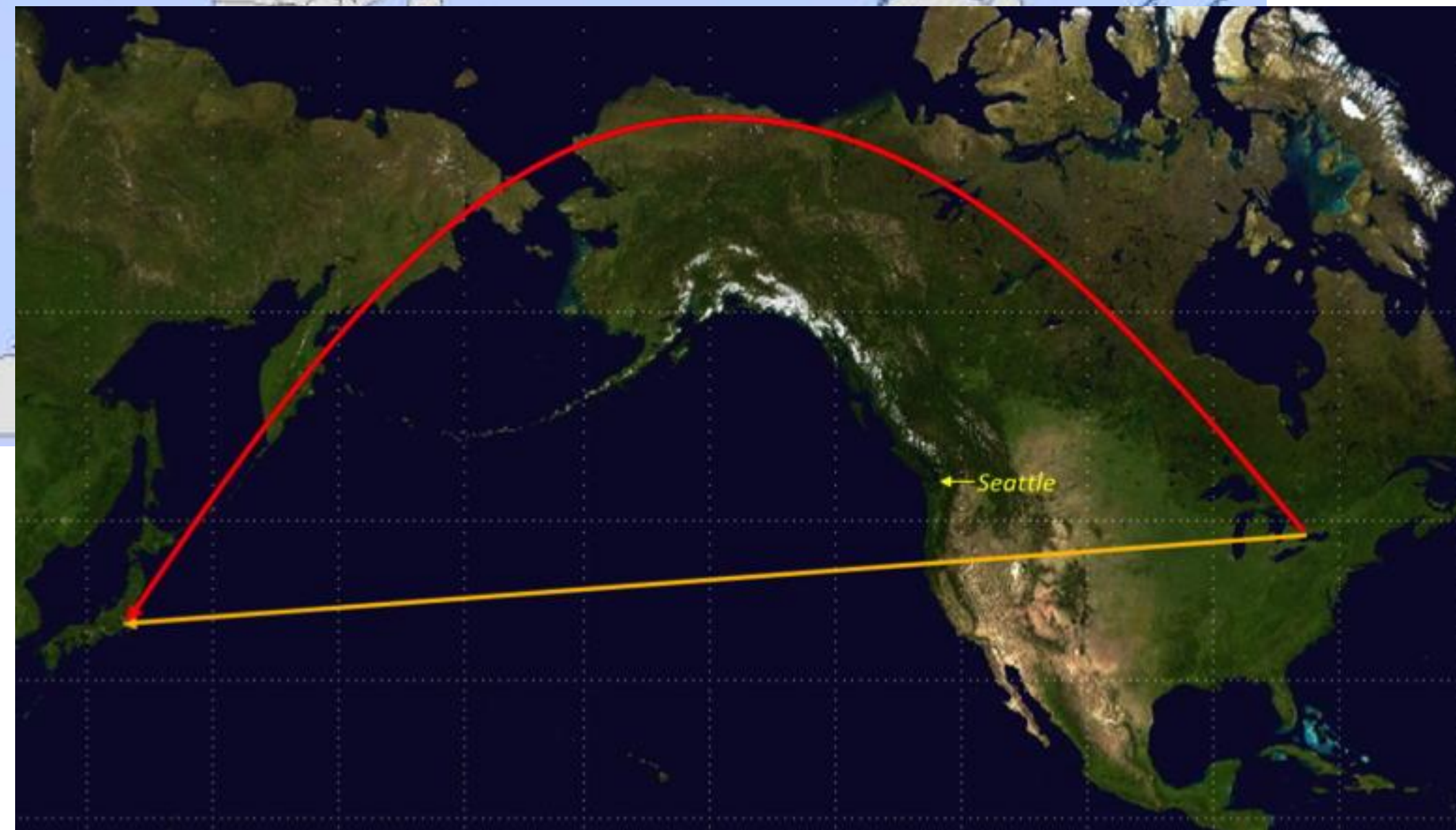
15m

## 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

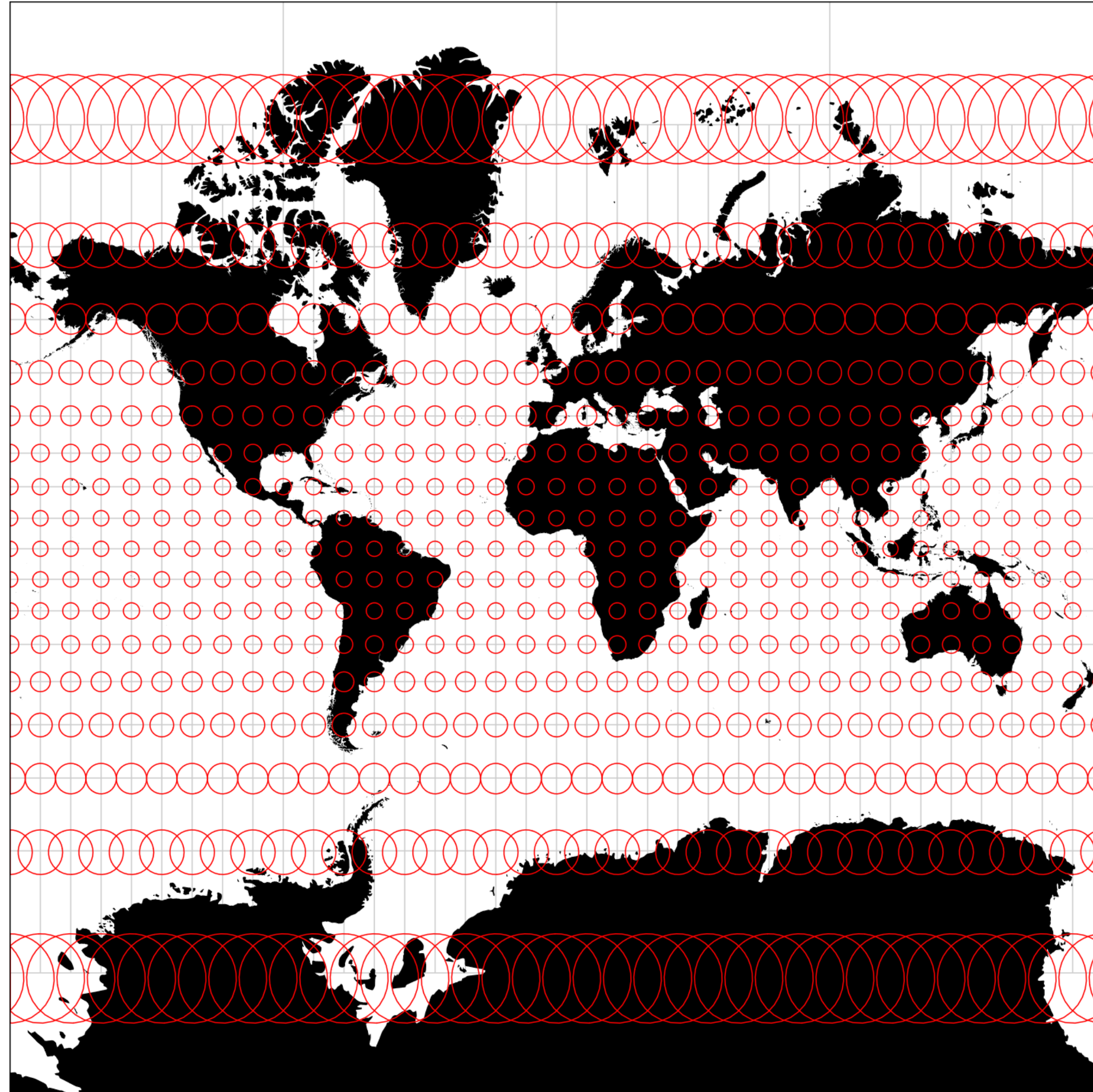




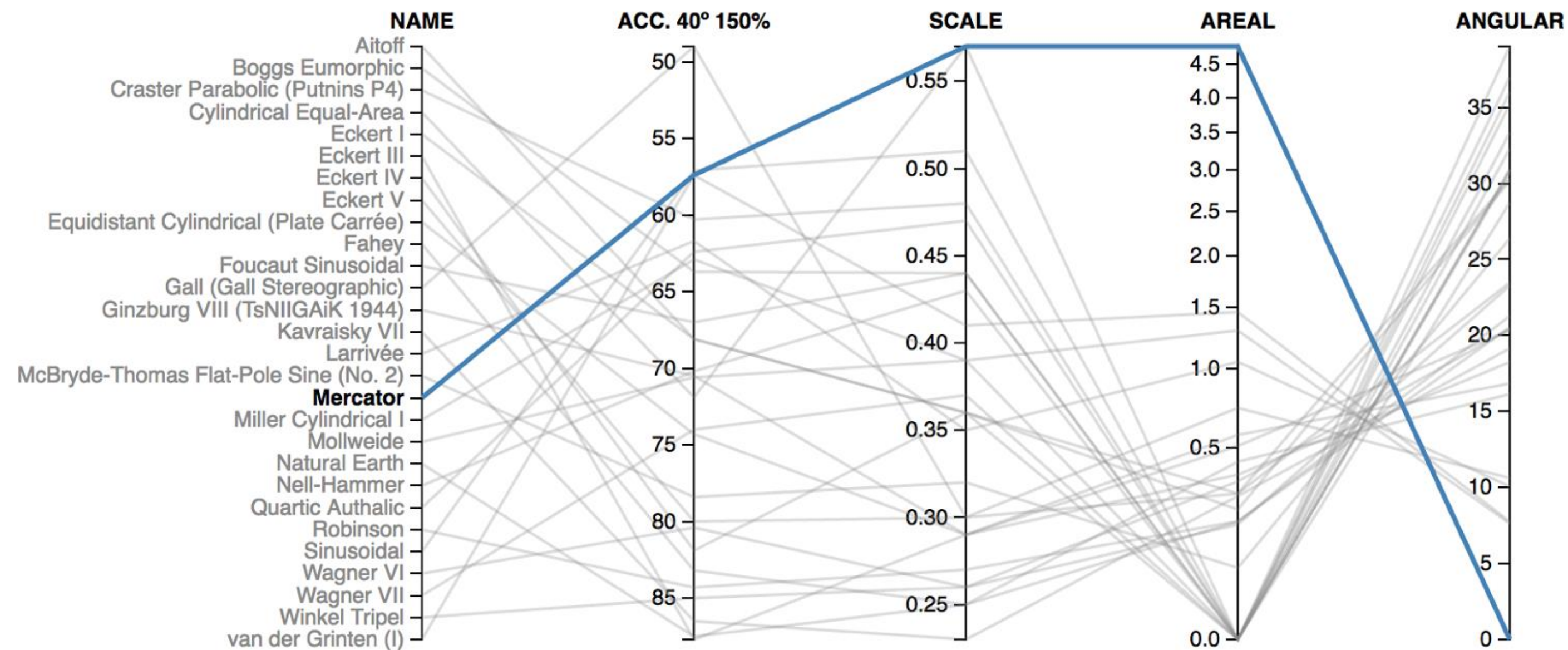
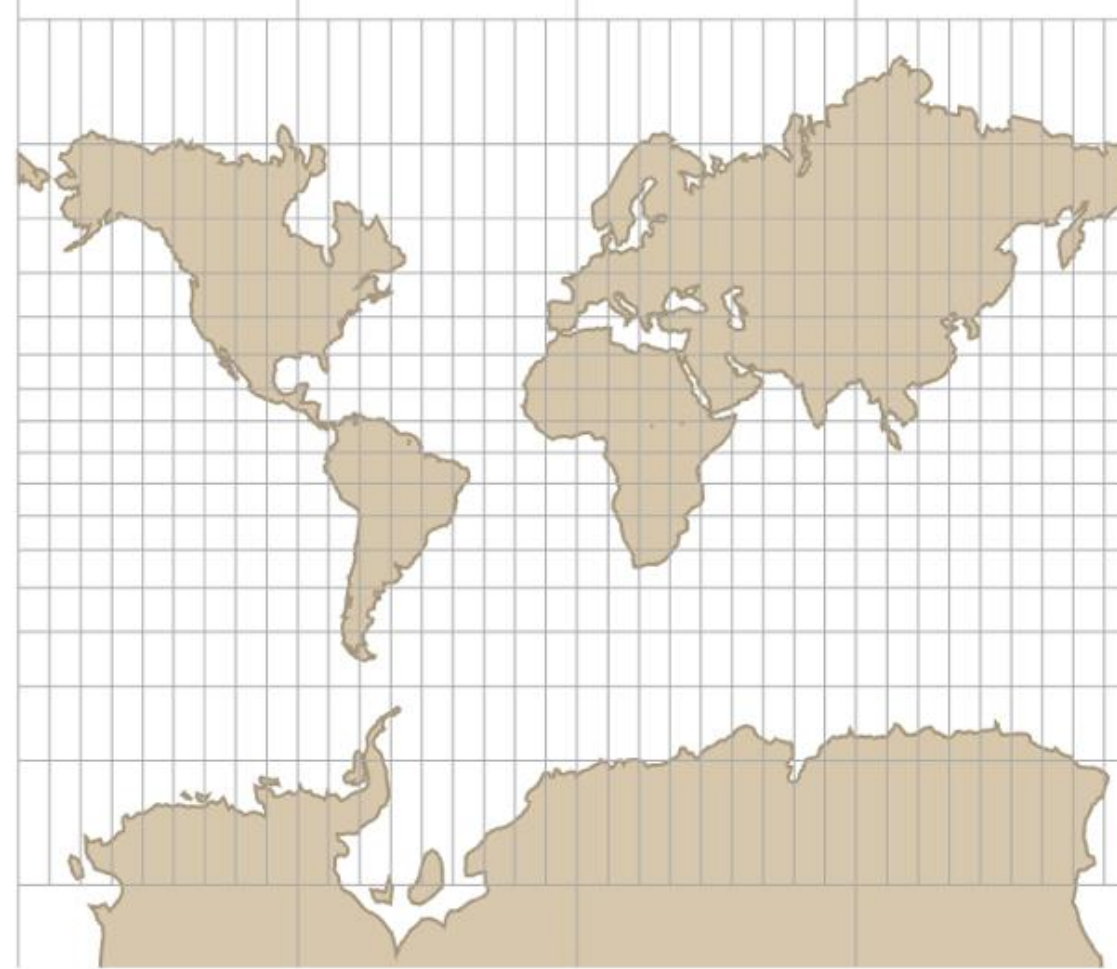


World map used in Australian schools (joke)

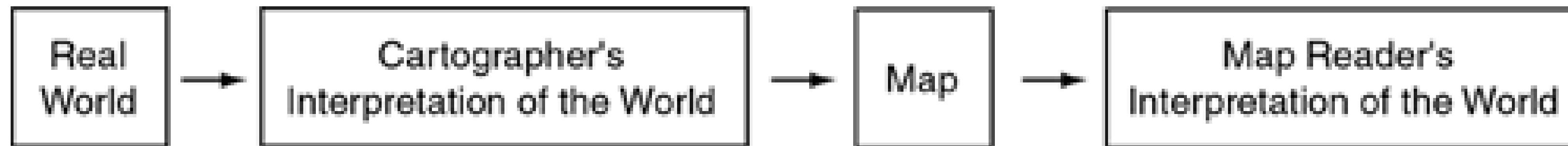
# Tissot's Indicatrix (ish)



# Comparing Map Projections



# Tasks & Users



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

# 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).

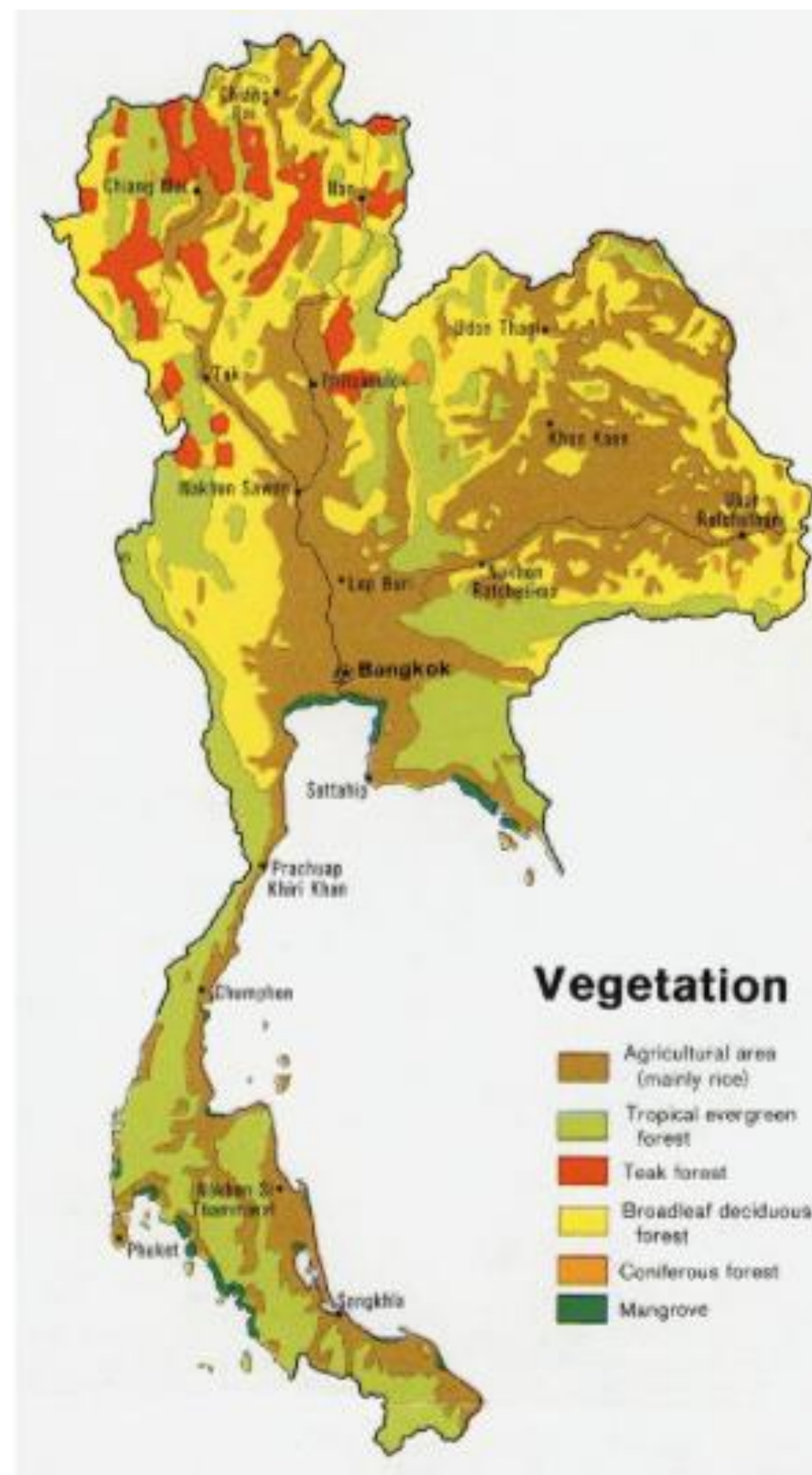
# Types of Maps

THREE BROAD CATEGORIES OF MAPS:

REFERENCE MAPS



THEMATIC MAPS



SPECIAL-PURPOSE MAPS



# Map

## Geographic Map



## Flow Map



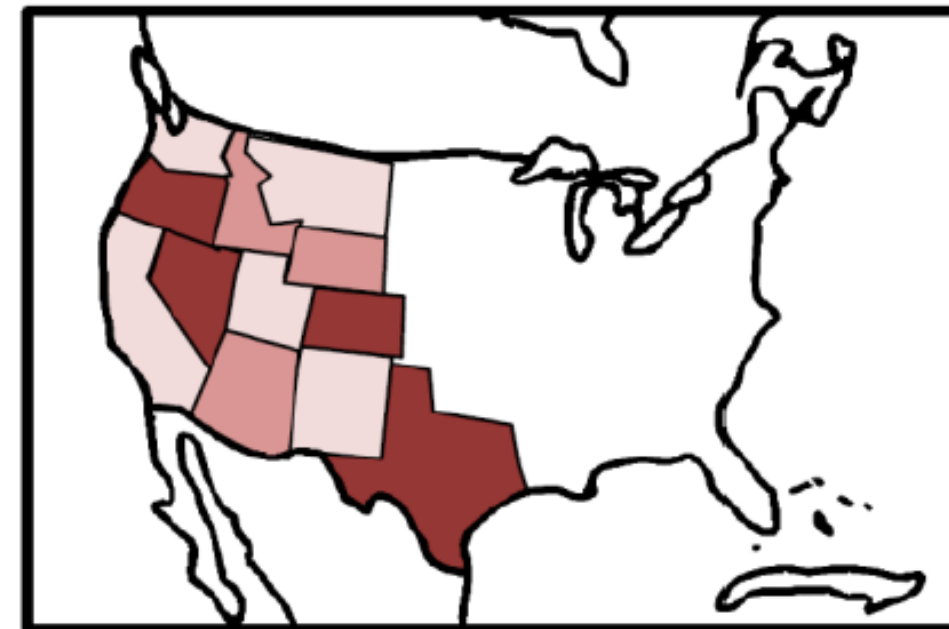
## Geographic Map

## Statistical Map

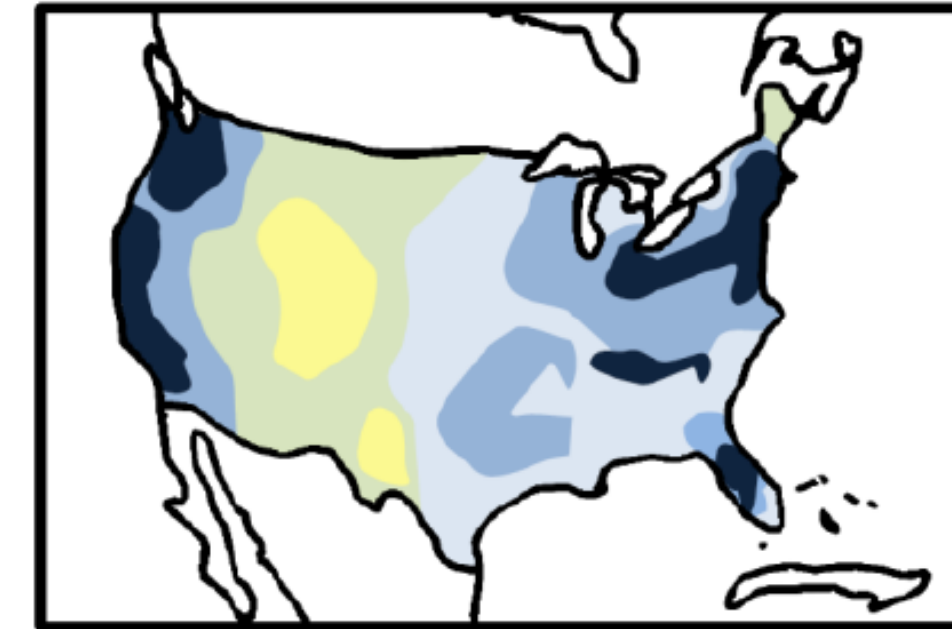
## Street Map



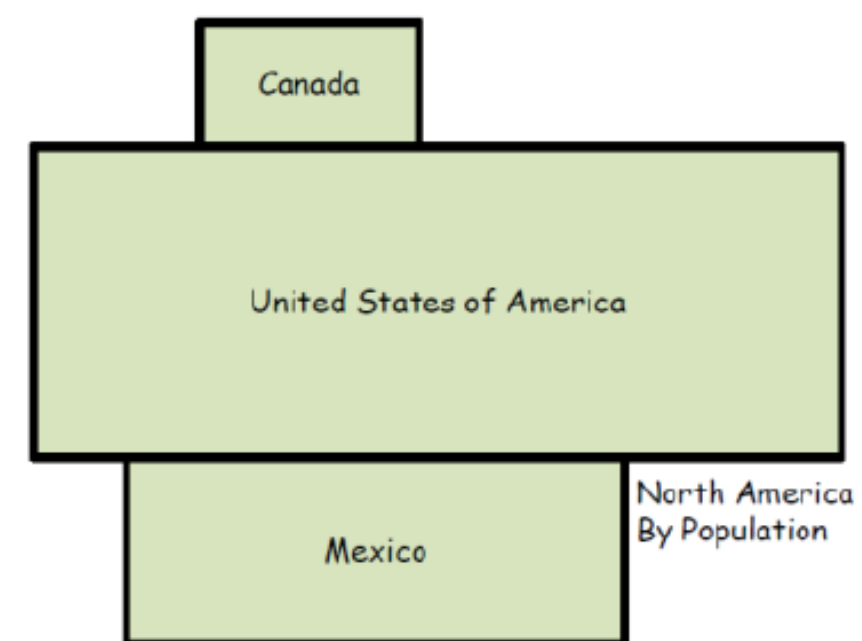
## Choropleth Map



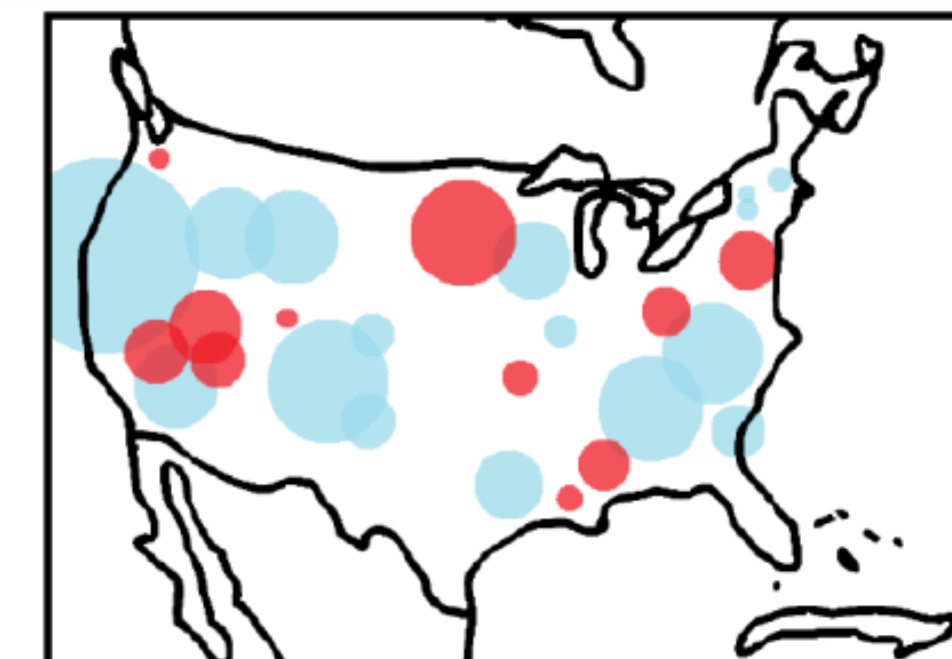
## Contour Map (Isopleth)

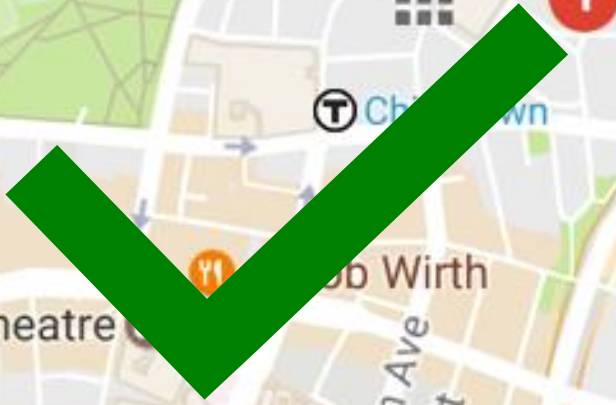
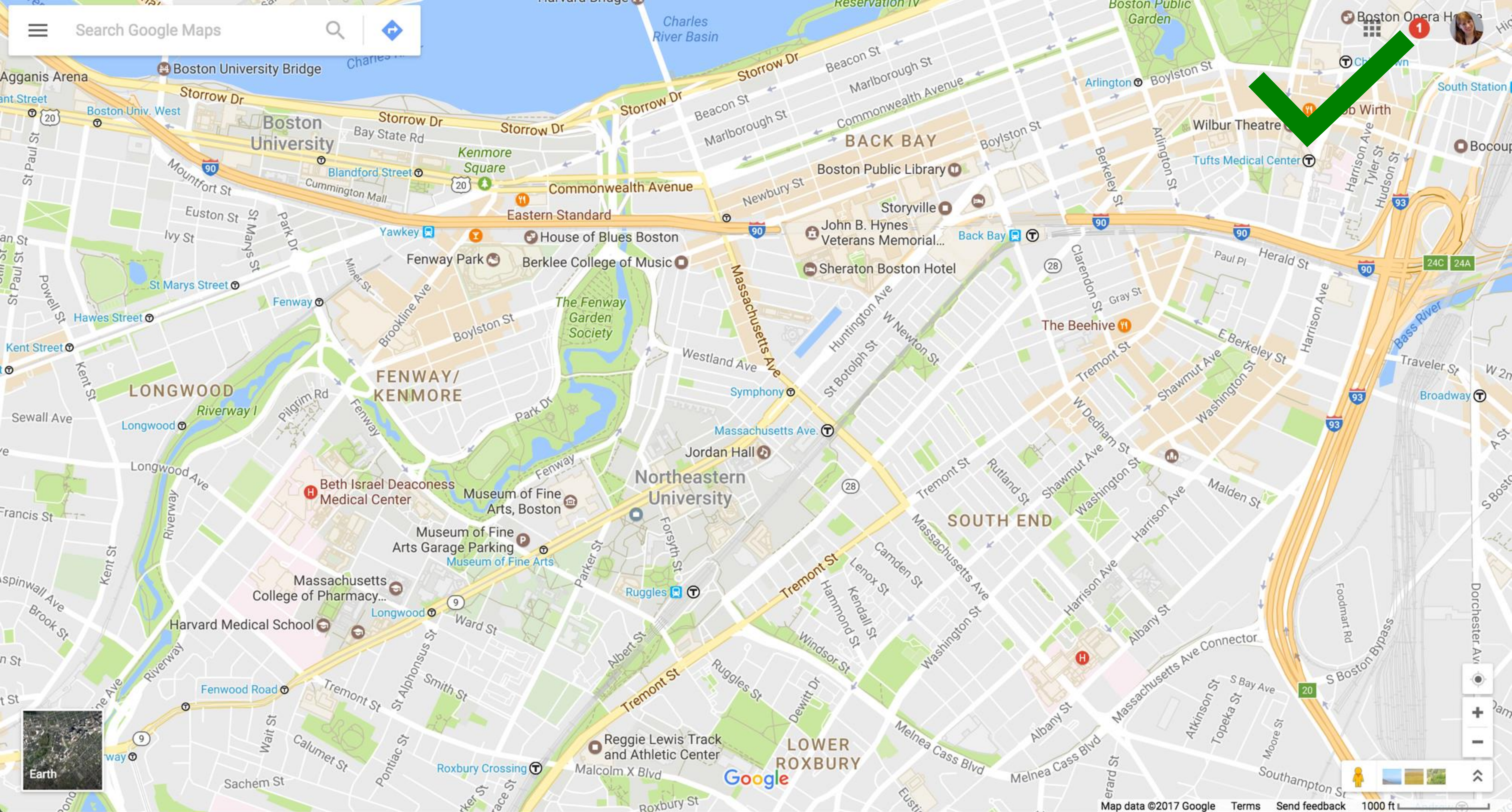


## Distorted Map (Cartogram)



## Statistical Plot Map







# wind map

past patterns

<previous next>

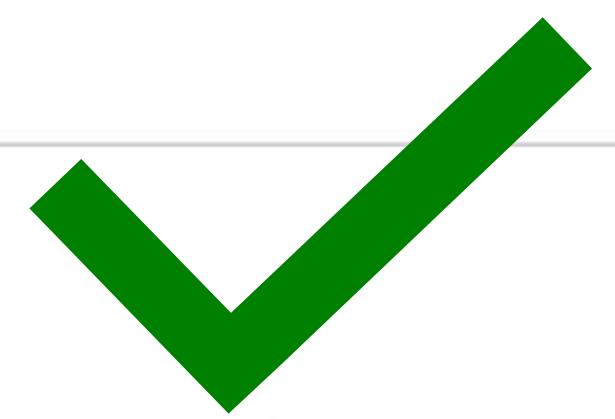
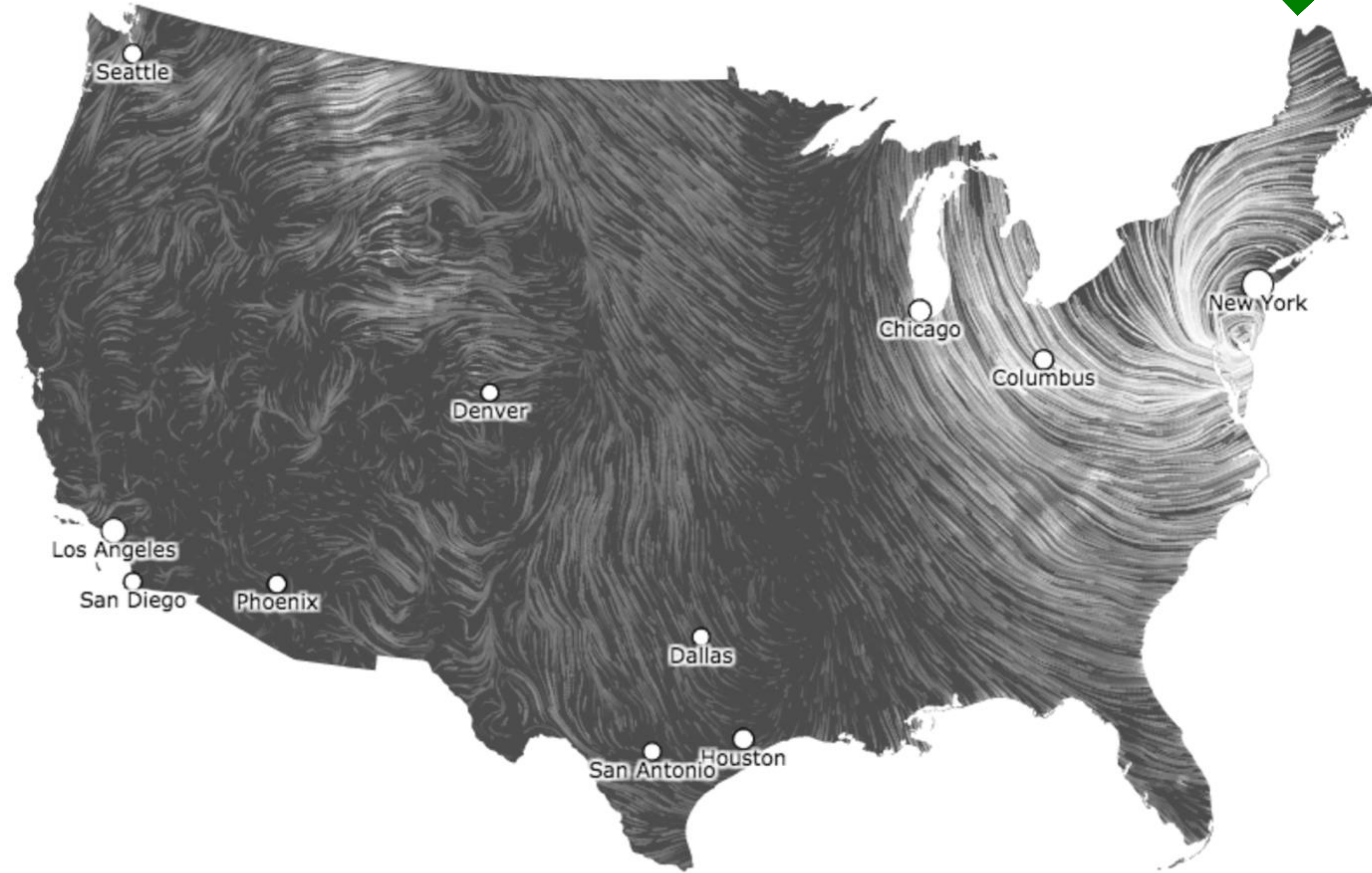
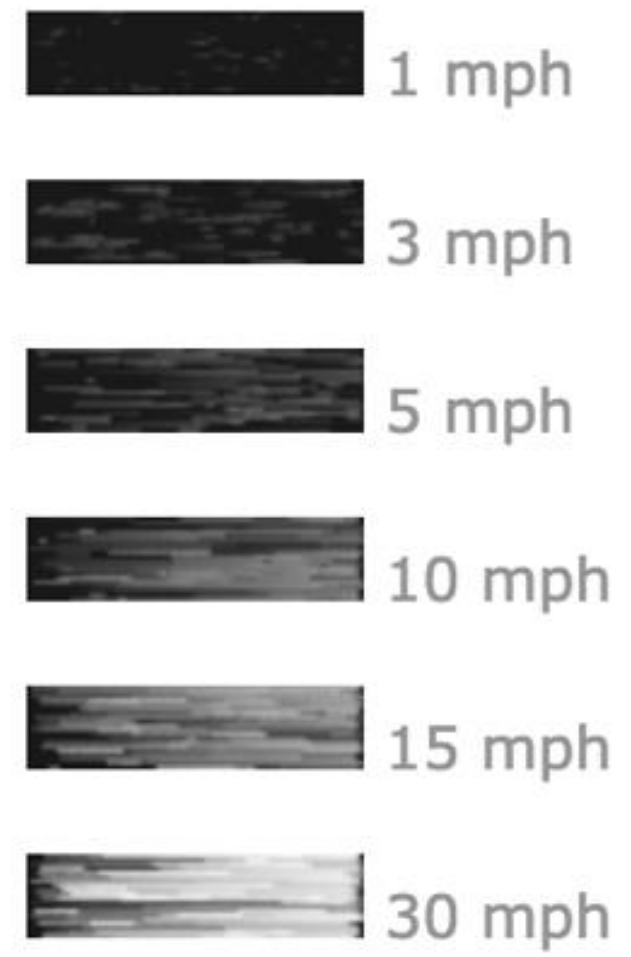
**October 29, 2012**

8:59 pm EST

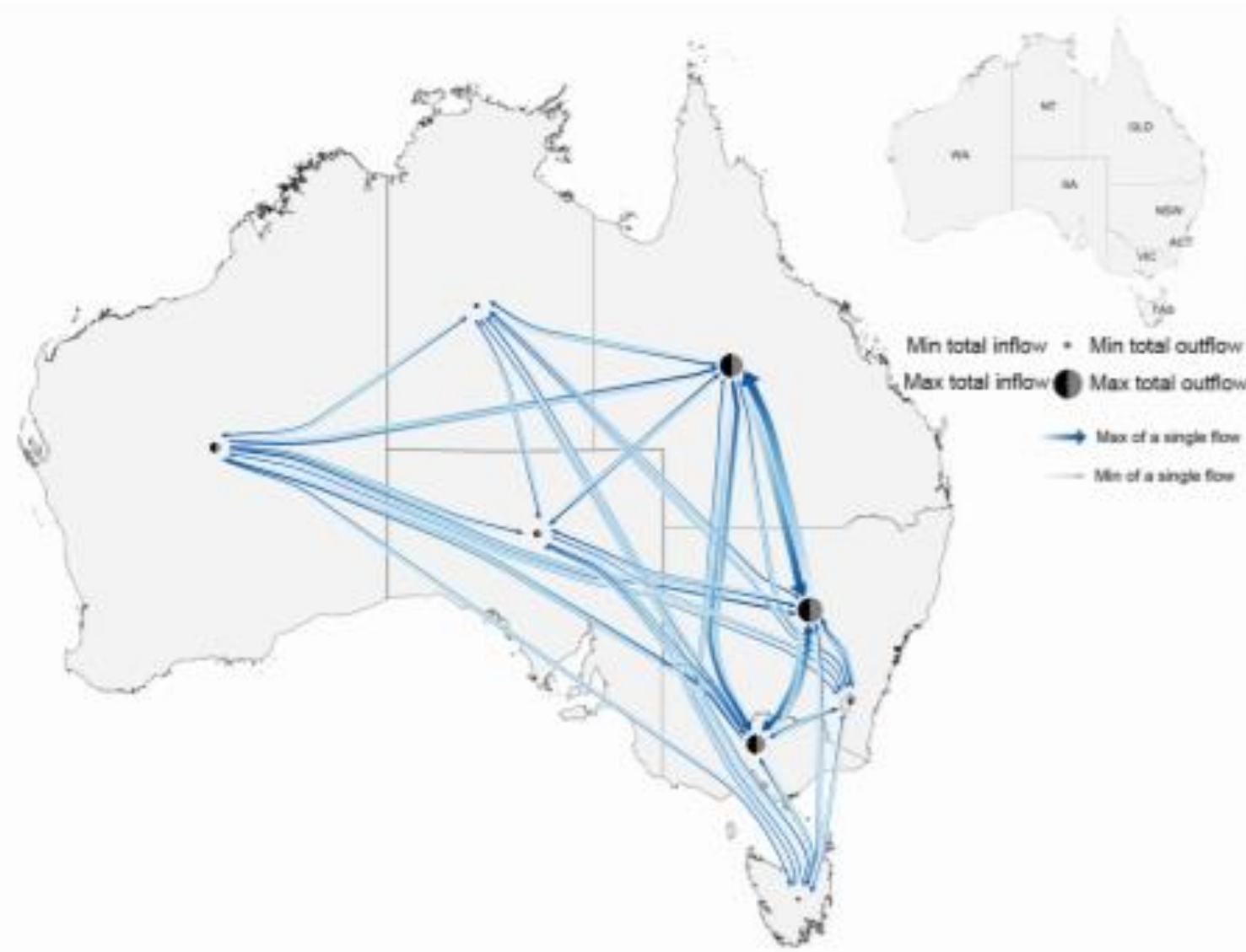
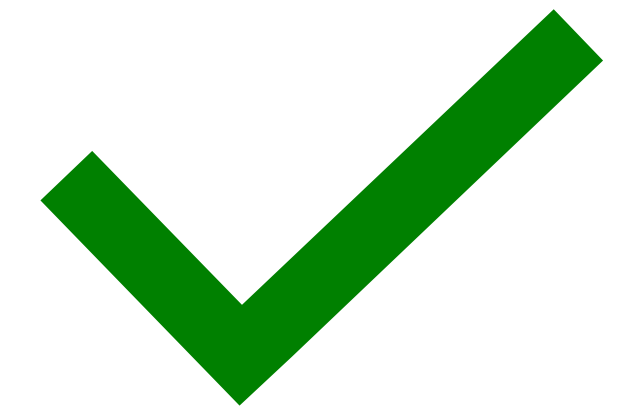
(time of forecast download)

top speed: **45.1 mph**

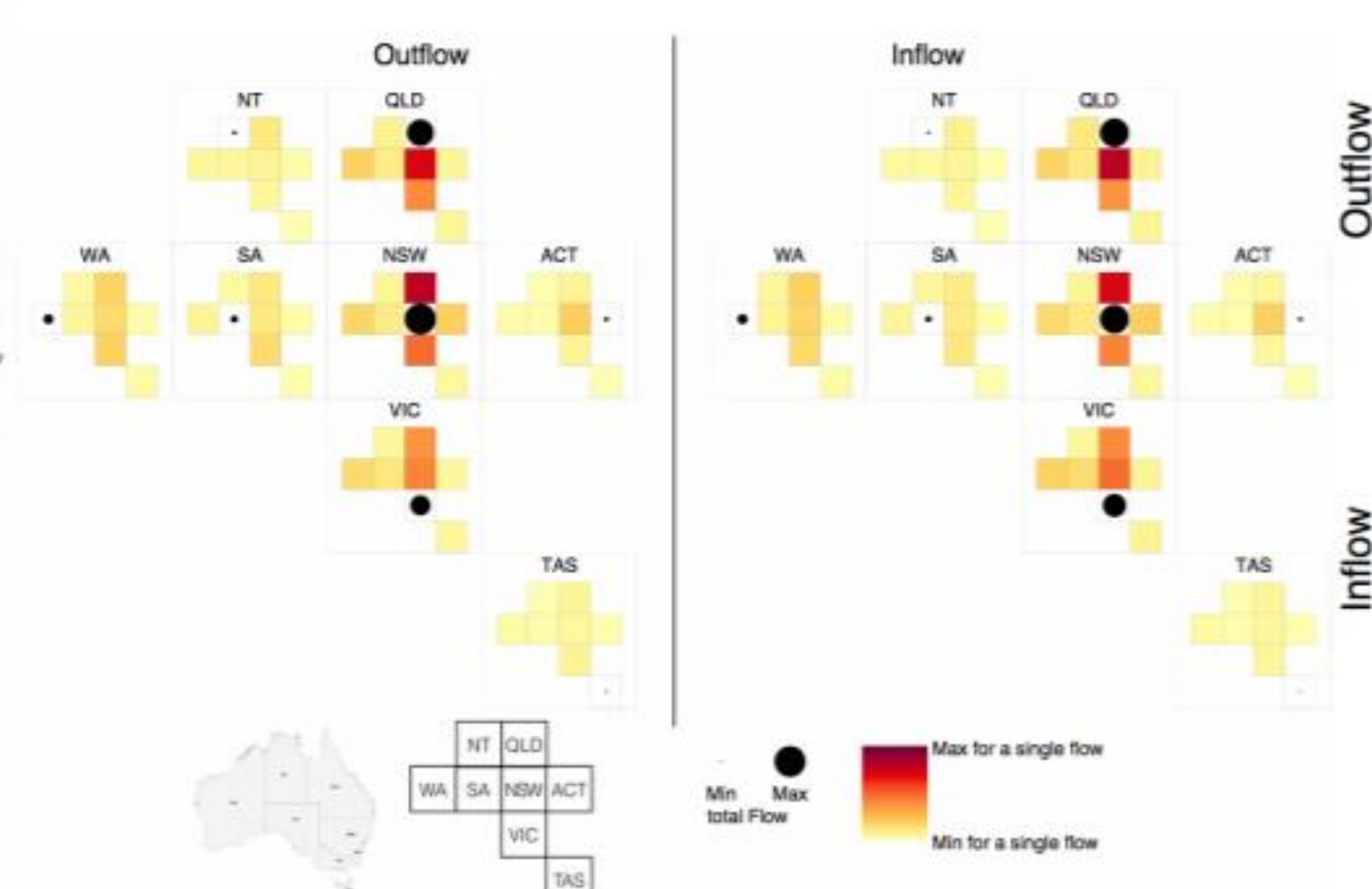
average: **9.4 mph**



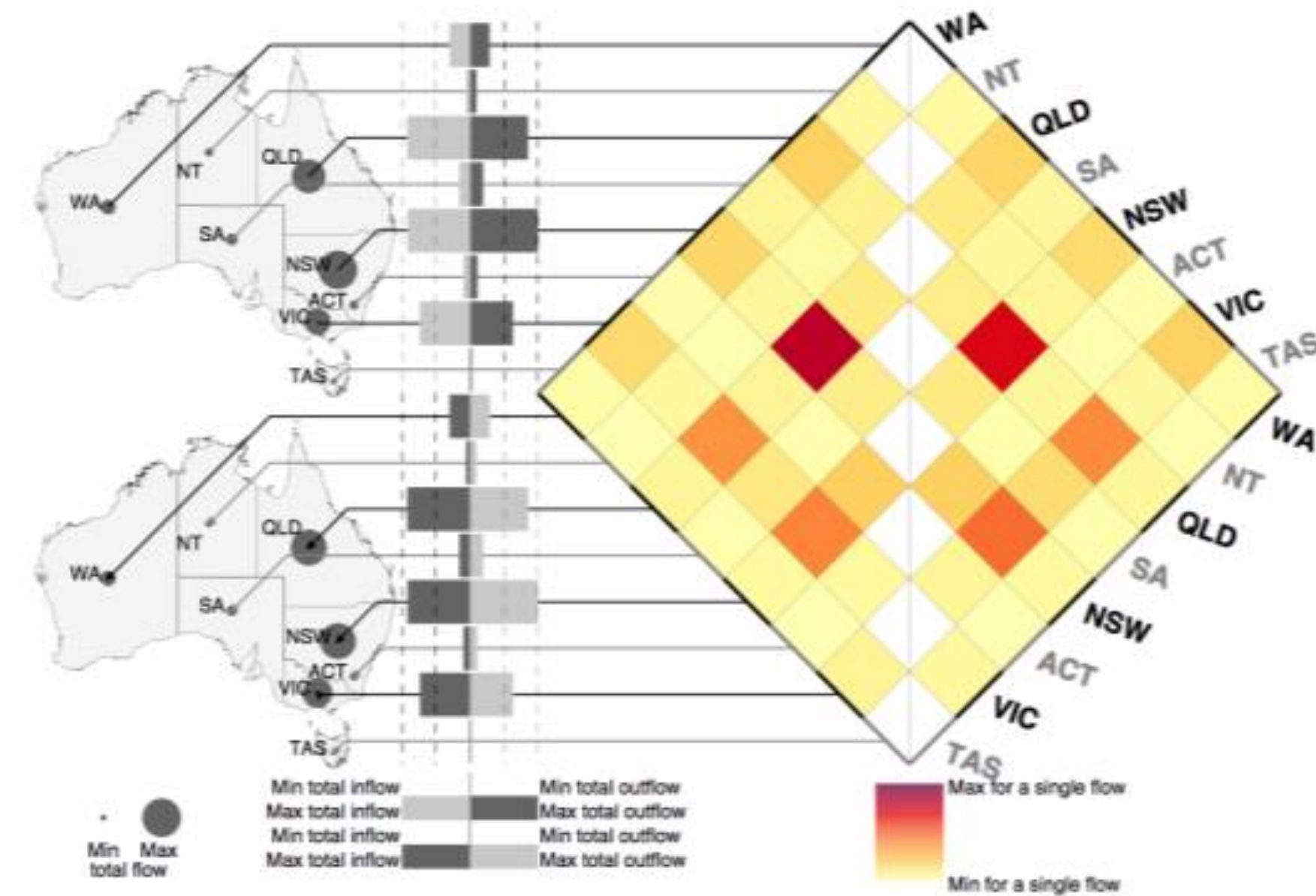
# MapTrix



(a) Bundled Flow Map



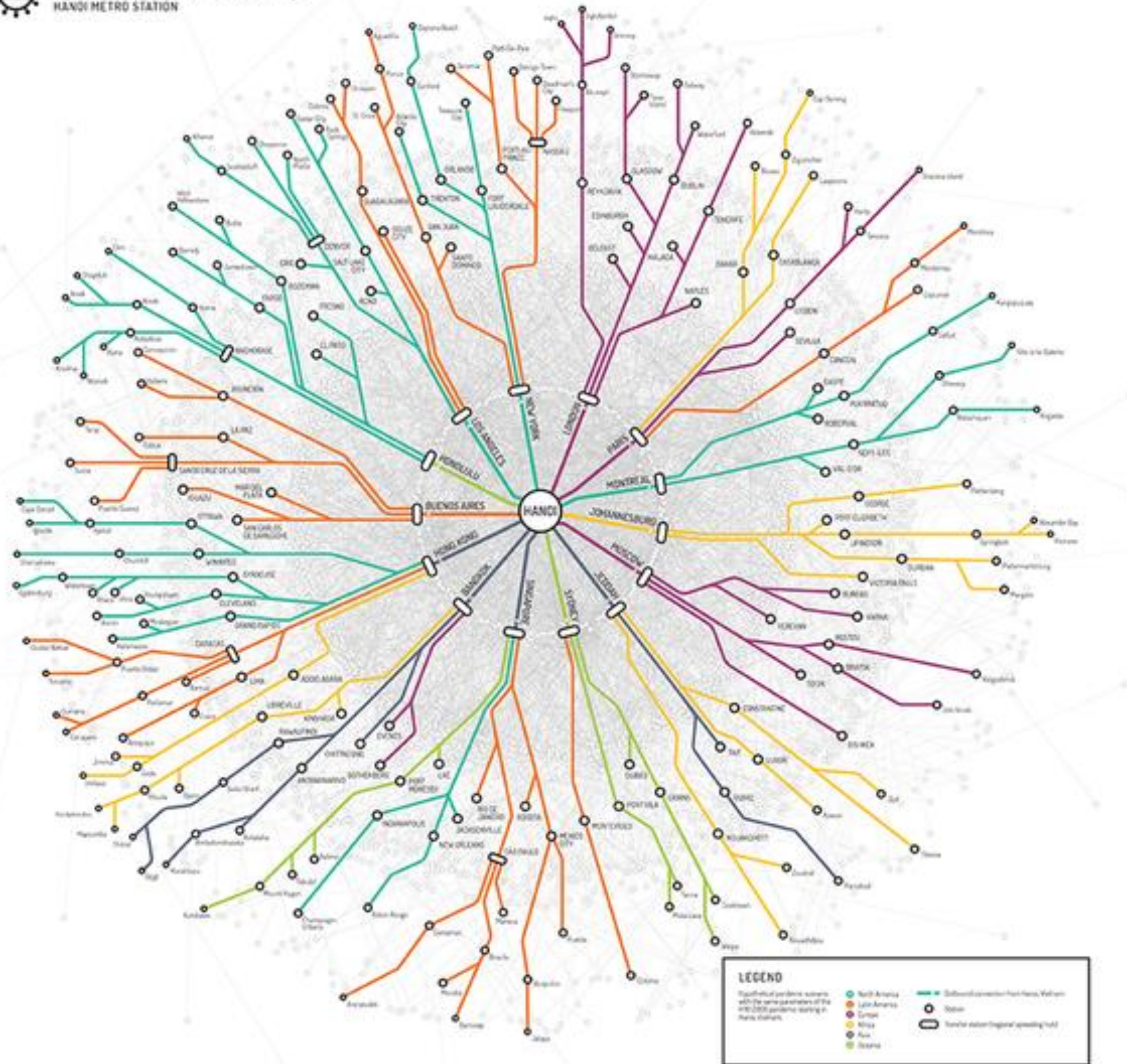
(b) OD Map

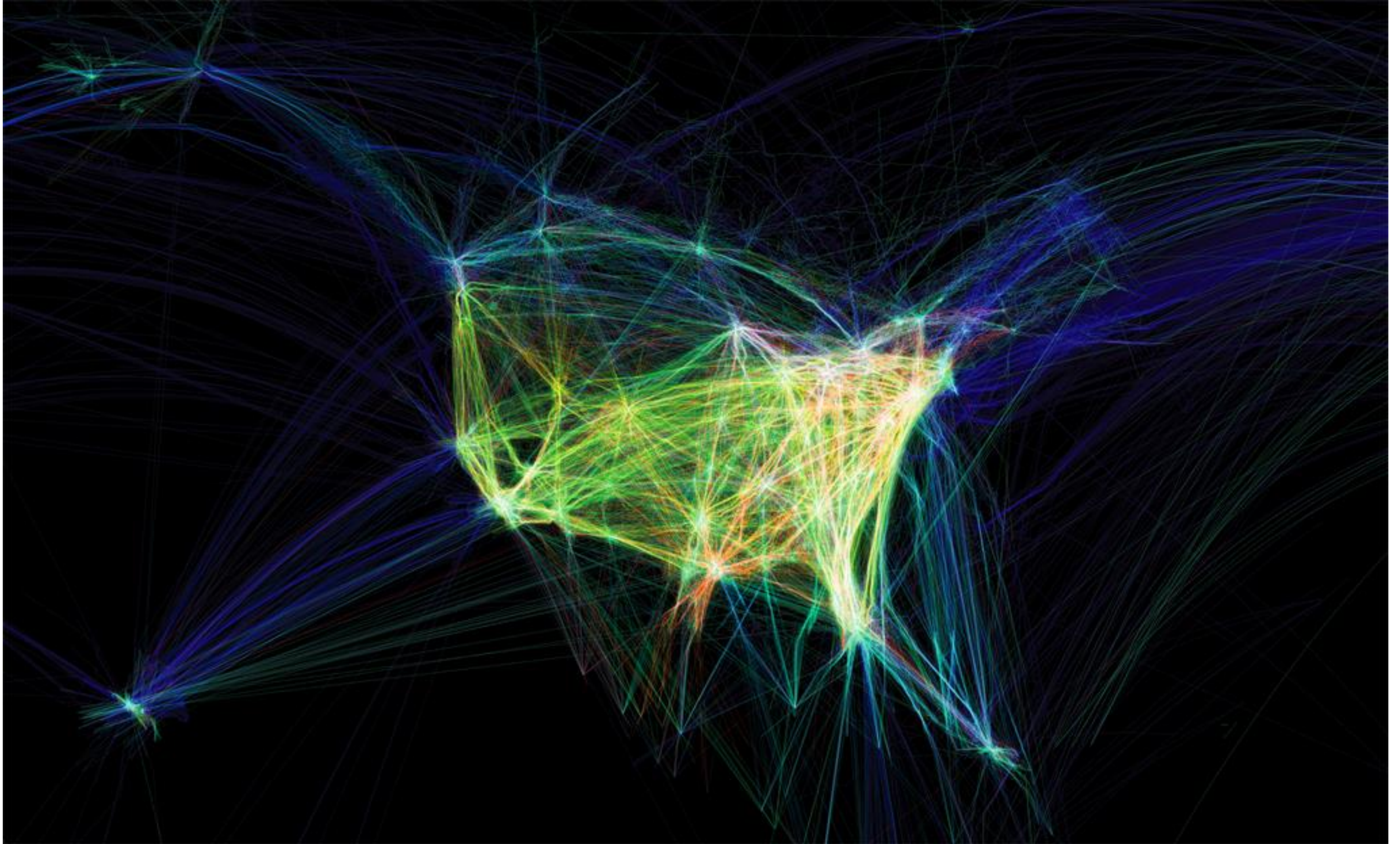


(c) MapTrix

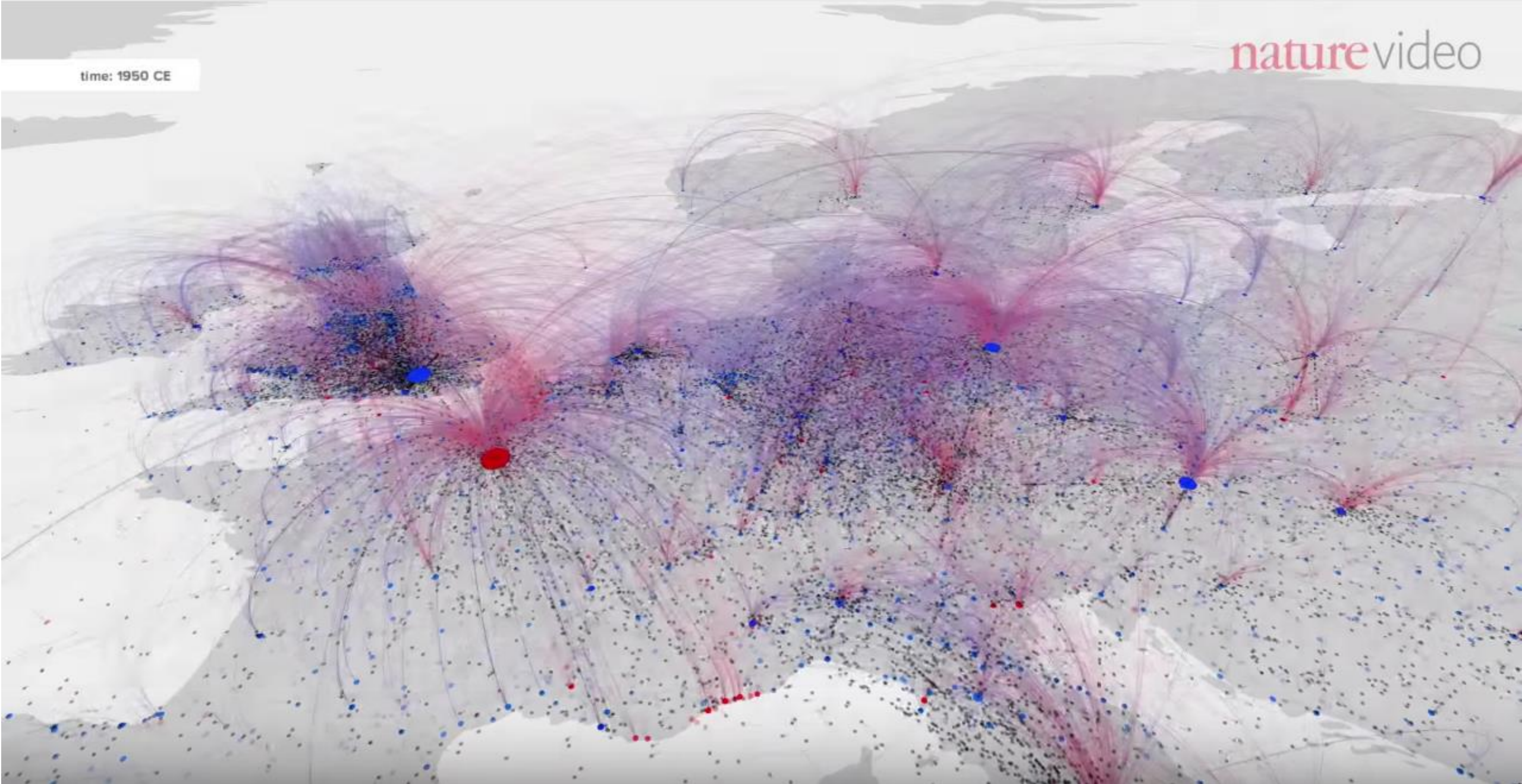
<https://vimeo.com/182970812>  
<https://vimeo.com/278433529>

[Yang et al., 2016; Demo](#)





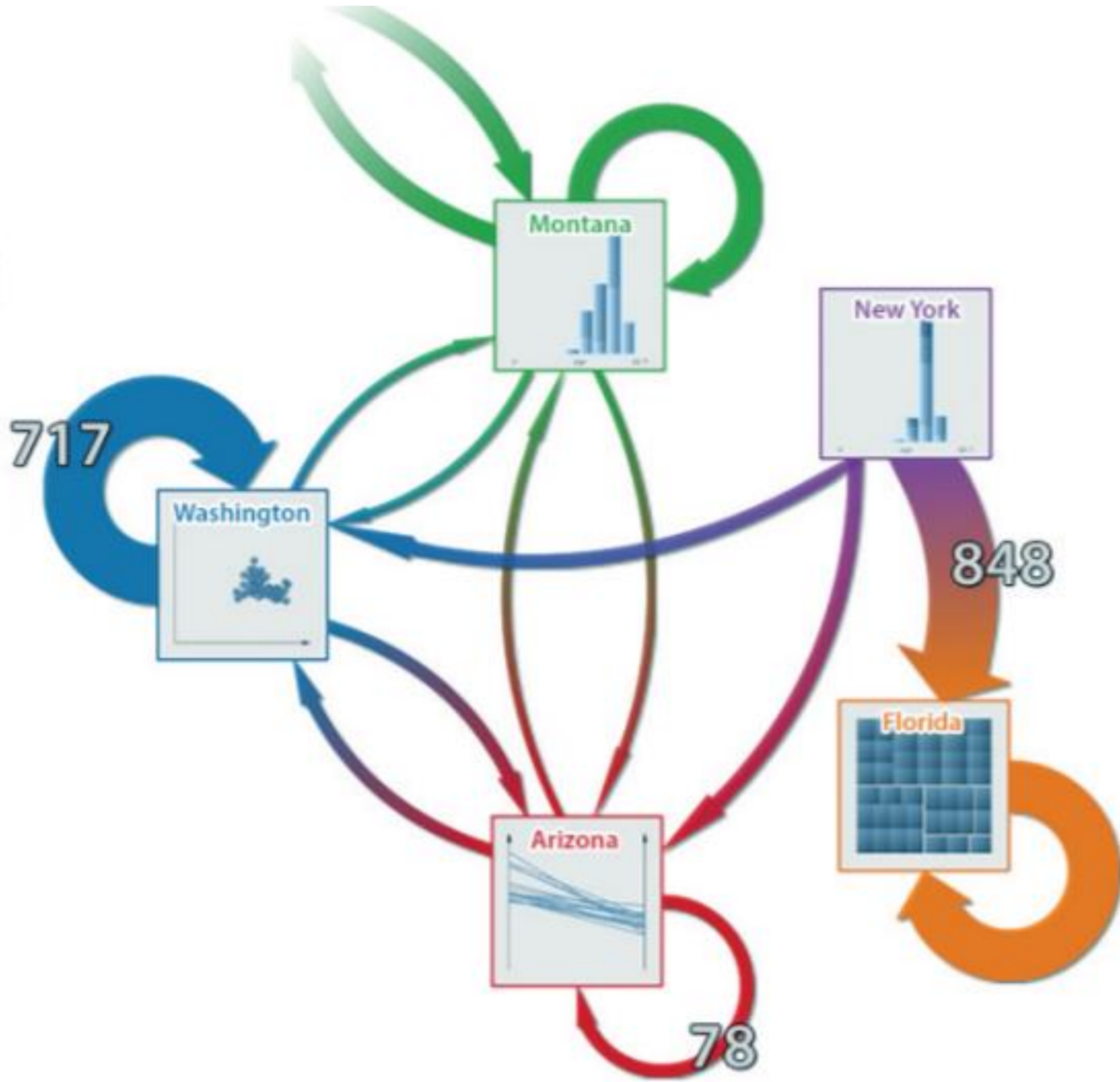
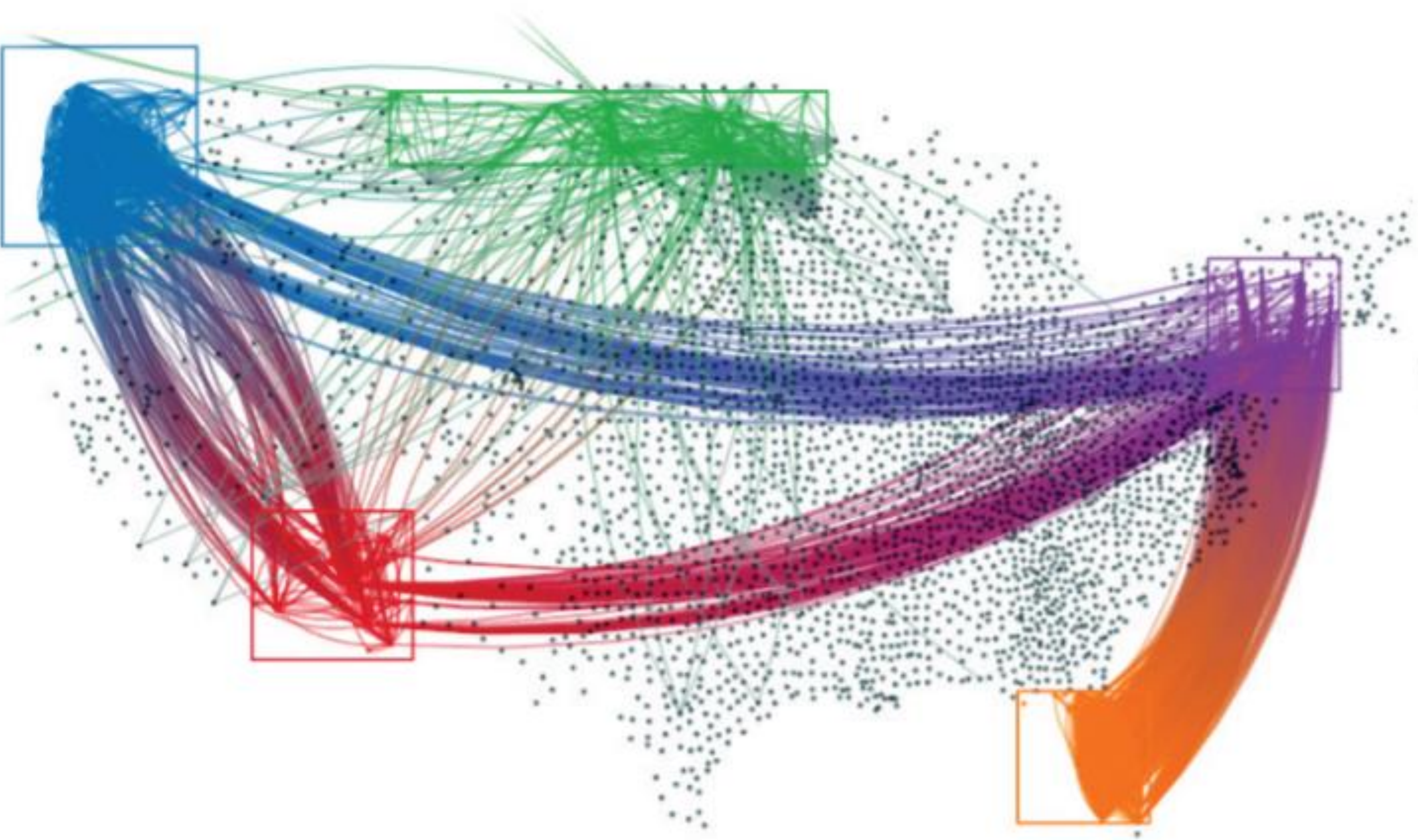
time: 1950 CE

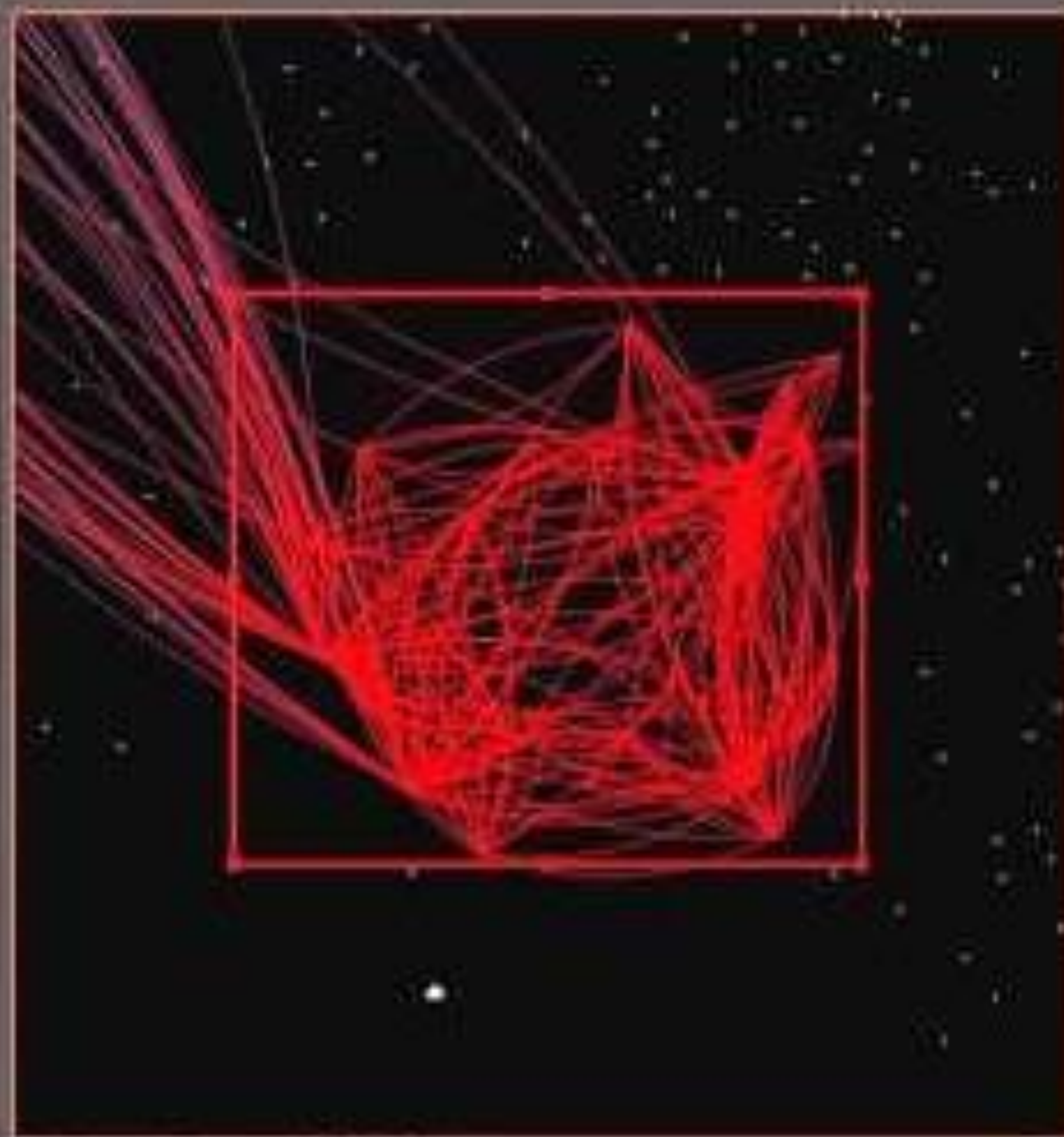
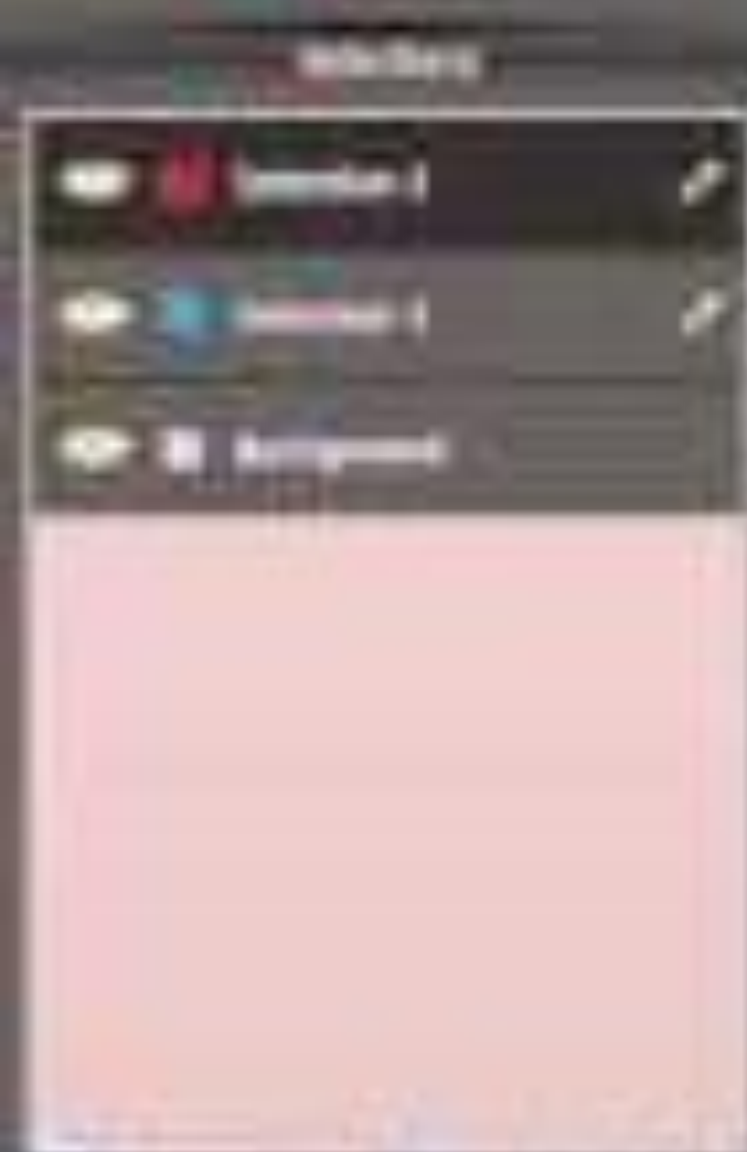


Year: 1875 CE

11









## 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 Value

#### Building Age

1941 - 1953

1953 - 1959

1959 - 1967

1967 - 1976

1976 - 1987

1987 - 2007

### Medical Emergencies (911 reports) (20)

### 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 2011-20

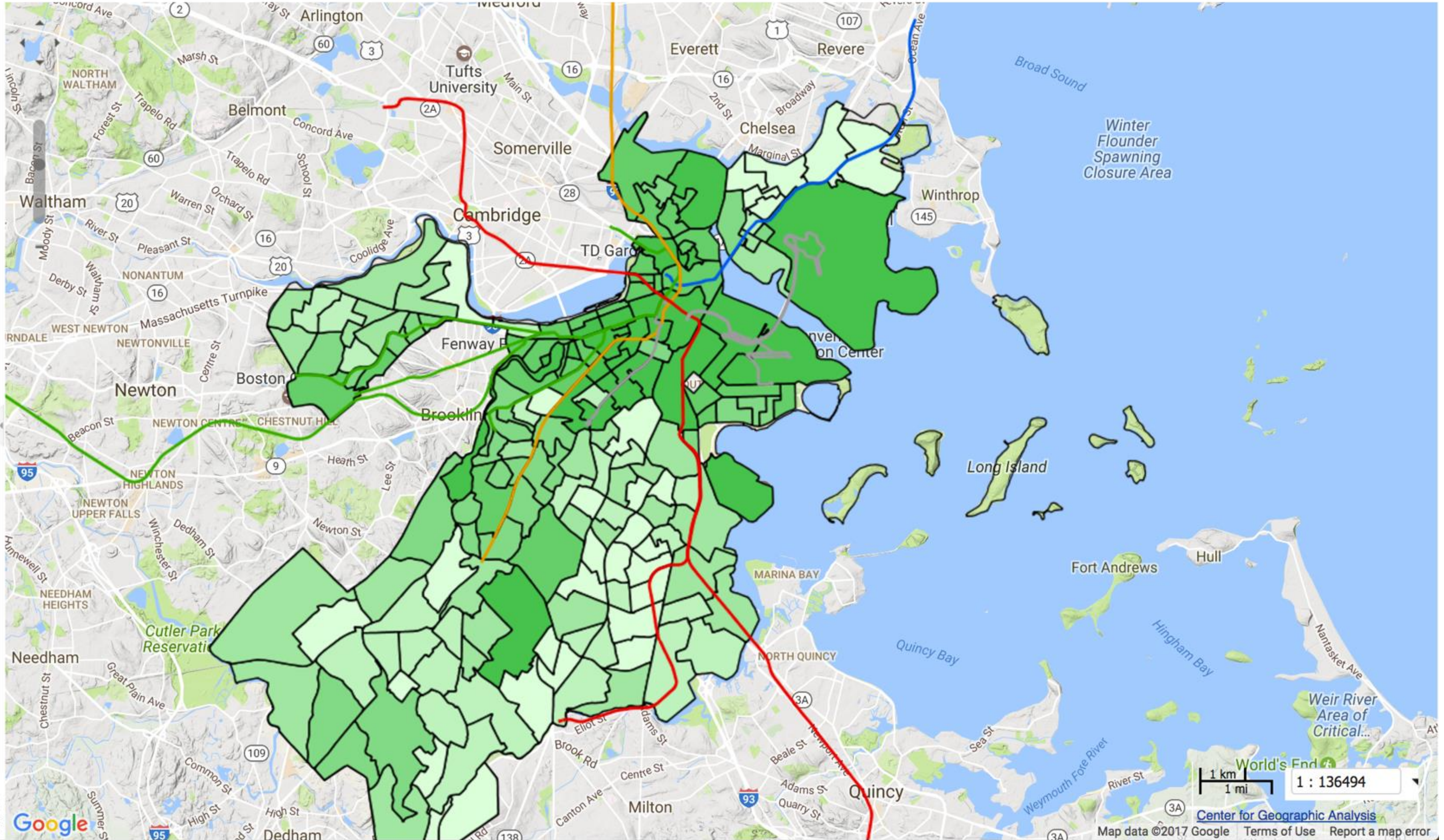
Racial and Ethnic Composition, AC

Economic Characteristics, ACS 201

Education Levels, ACS 2011-2015

Family and Household Characterist

Transportation to Work, ACS 2011



# GIS



Questions about GIS, spatial analysis, or digital mapping?

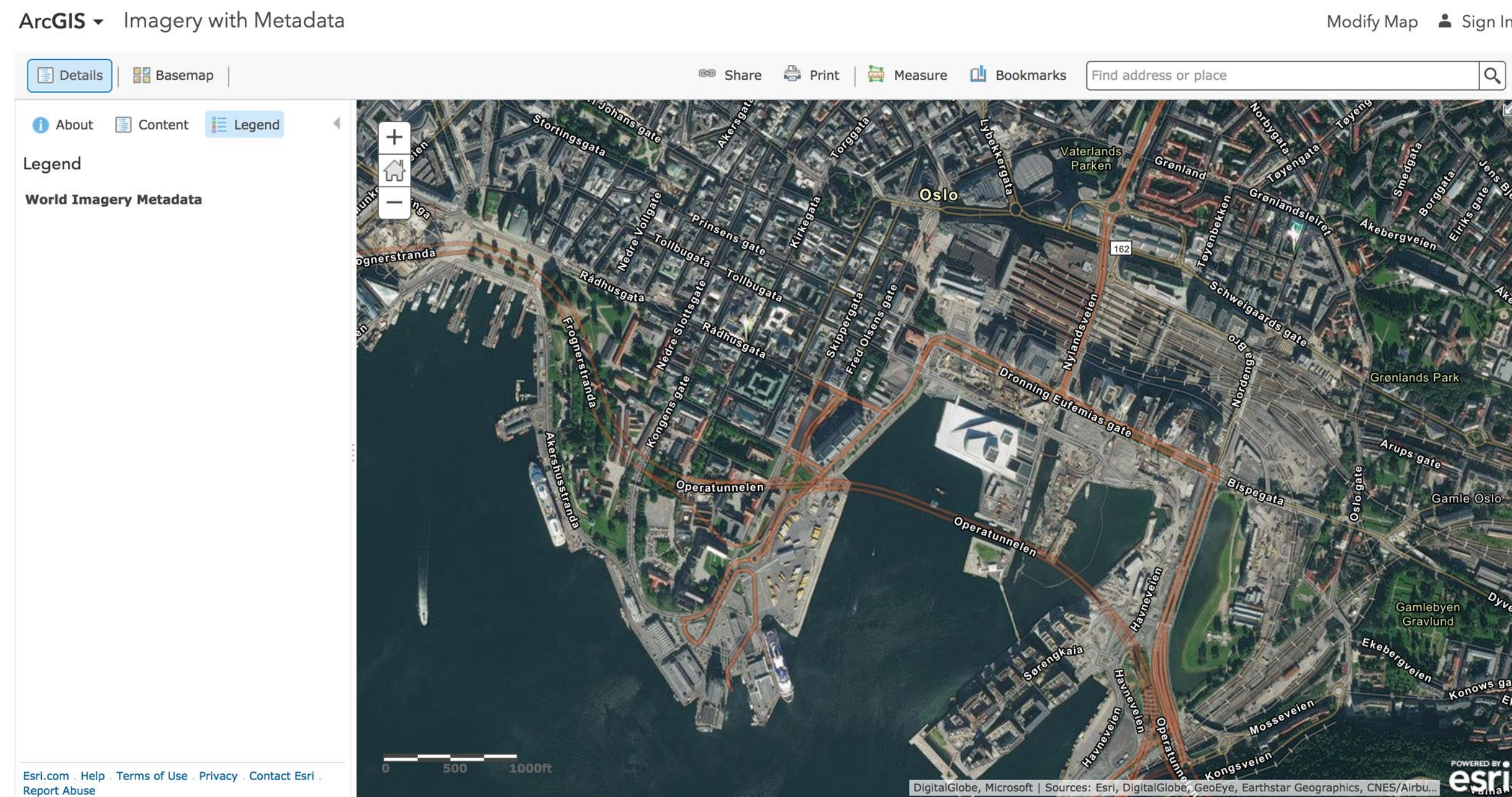
Please contact [Bahare Sanaie-Movahed](#), the GIS Specialist, for further assistance.

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](#)



# 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

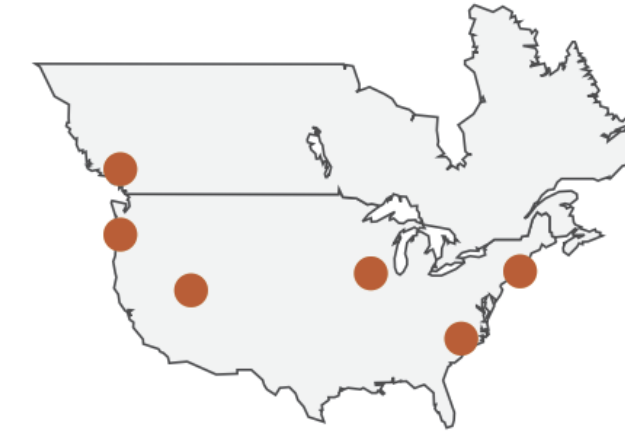
# Arrange Spatial Data

## → Use Given

### → Geometry

→ *Geographic*

→ *Other Derived*

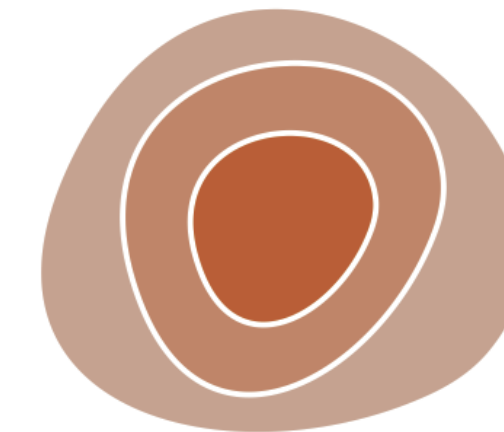


### → Spatial Fields

→ *Scalar Fields (one value per cell)*

→ *Isocontours*

→ *Direct Volume Rendering*



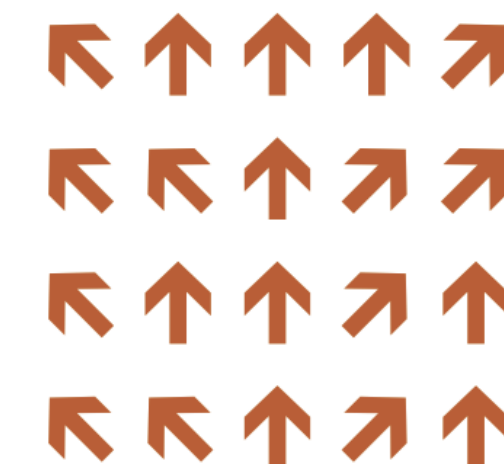
→ *Vector and Tensor Fields (many values per cell)*

→ *Flow Glyphs (local)*

→ *Geometric (sparse seeds)*

→ *Textures (dense seeds)*

→ *Features (globally derived)*



# SPATIAL FIELDS

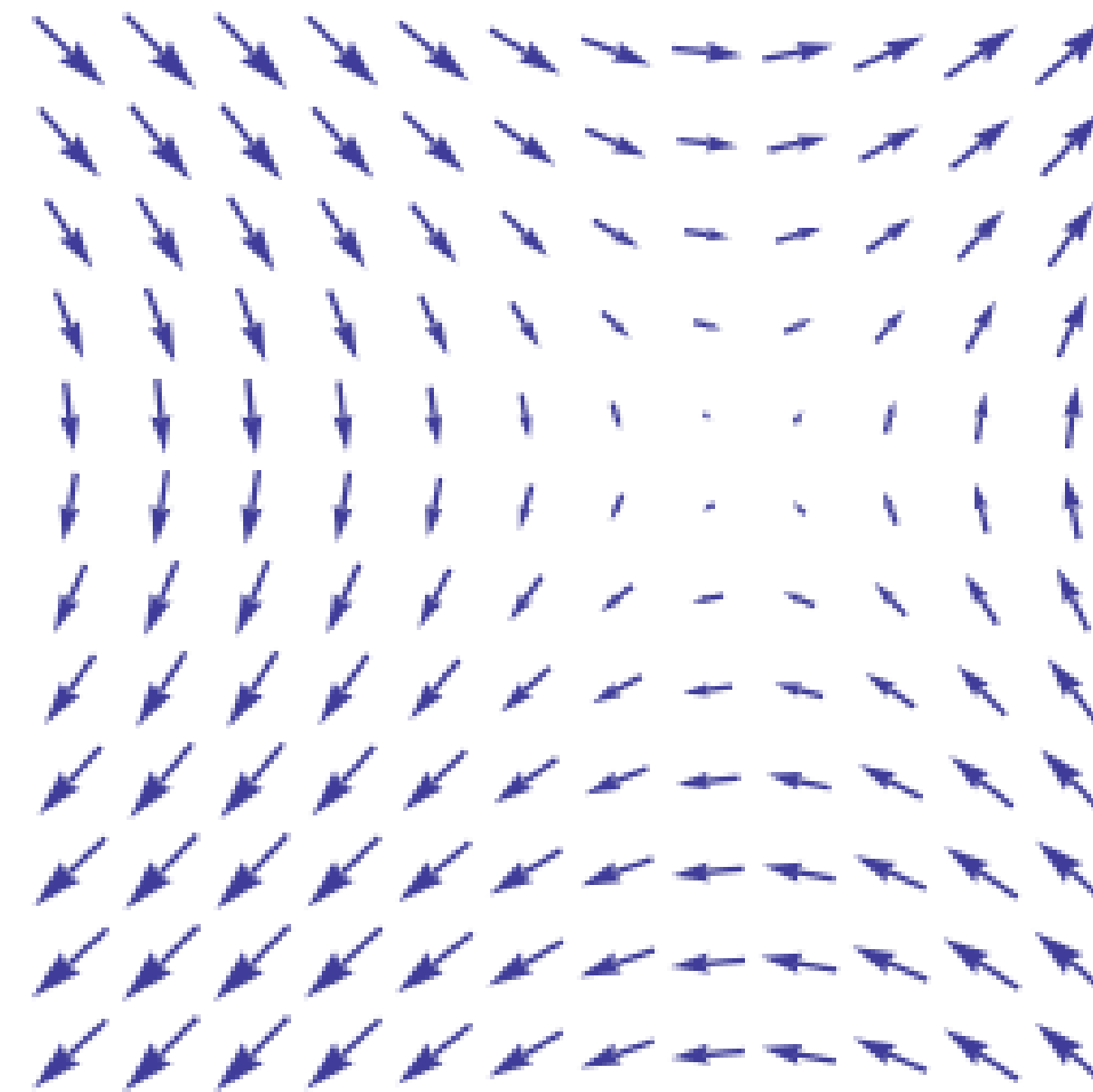
# Spatial Fields

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)*



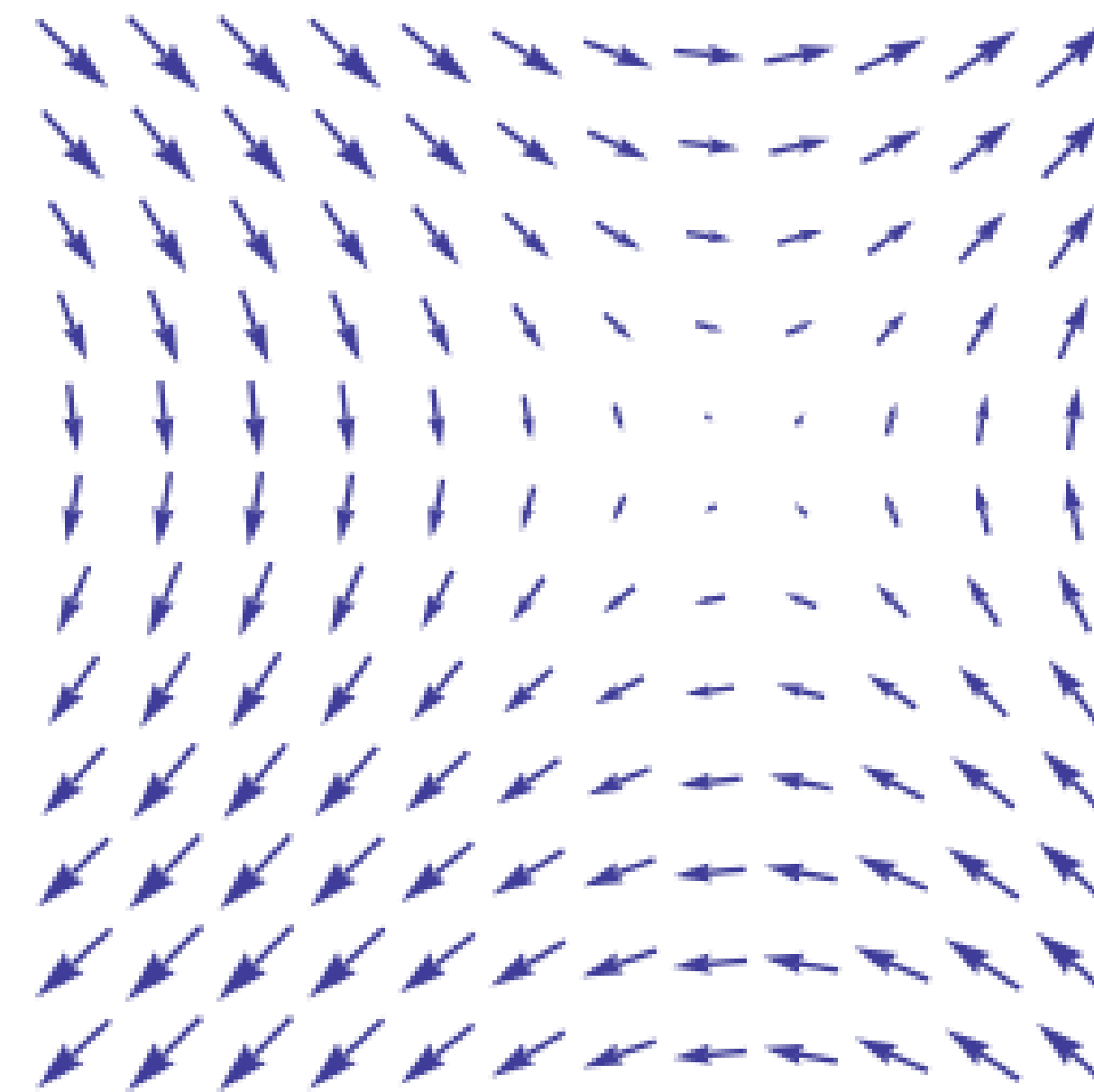
# Spatial Fields

Scalar field = one value per cell

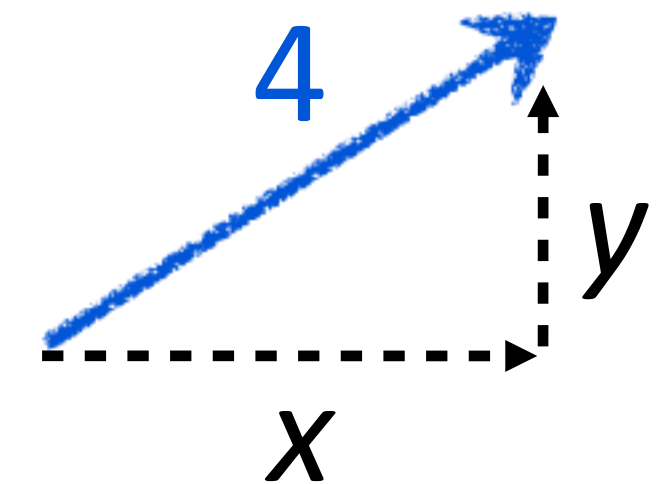
Vector or Tensor field = many values per cell

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)*

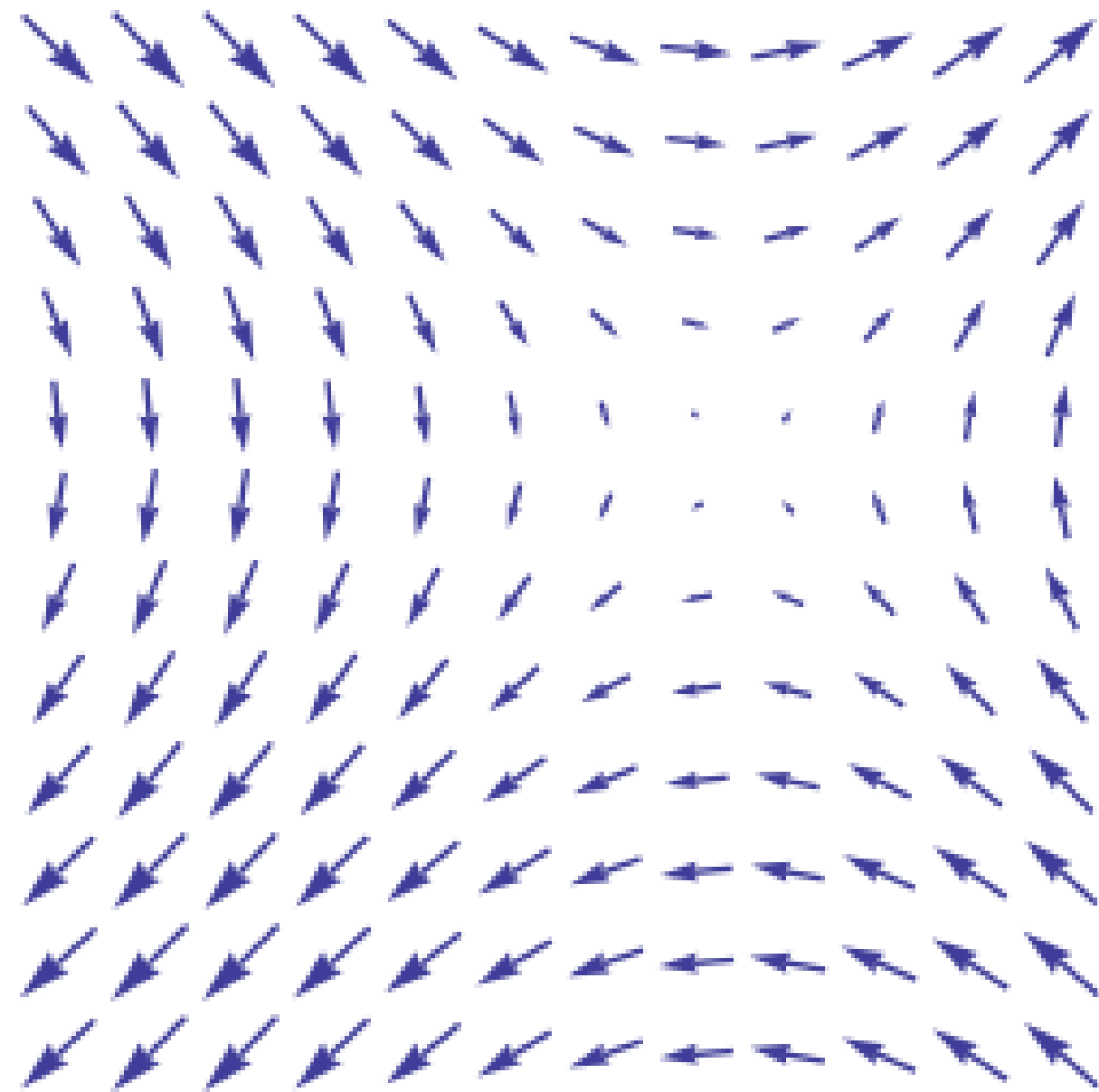


Vector  
*(magnitude and direction)*

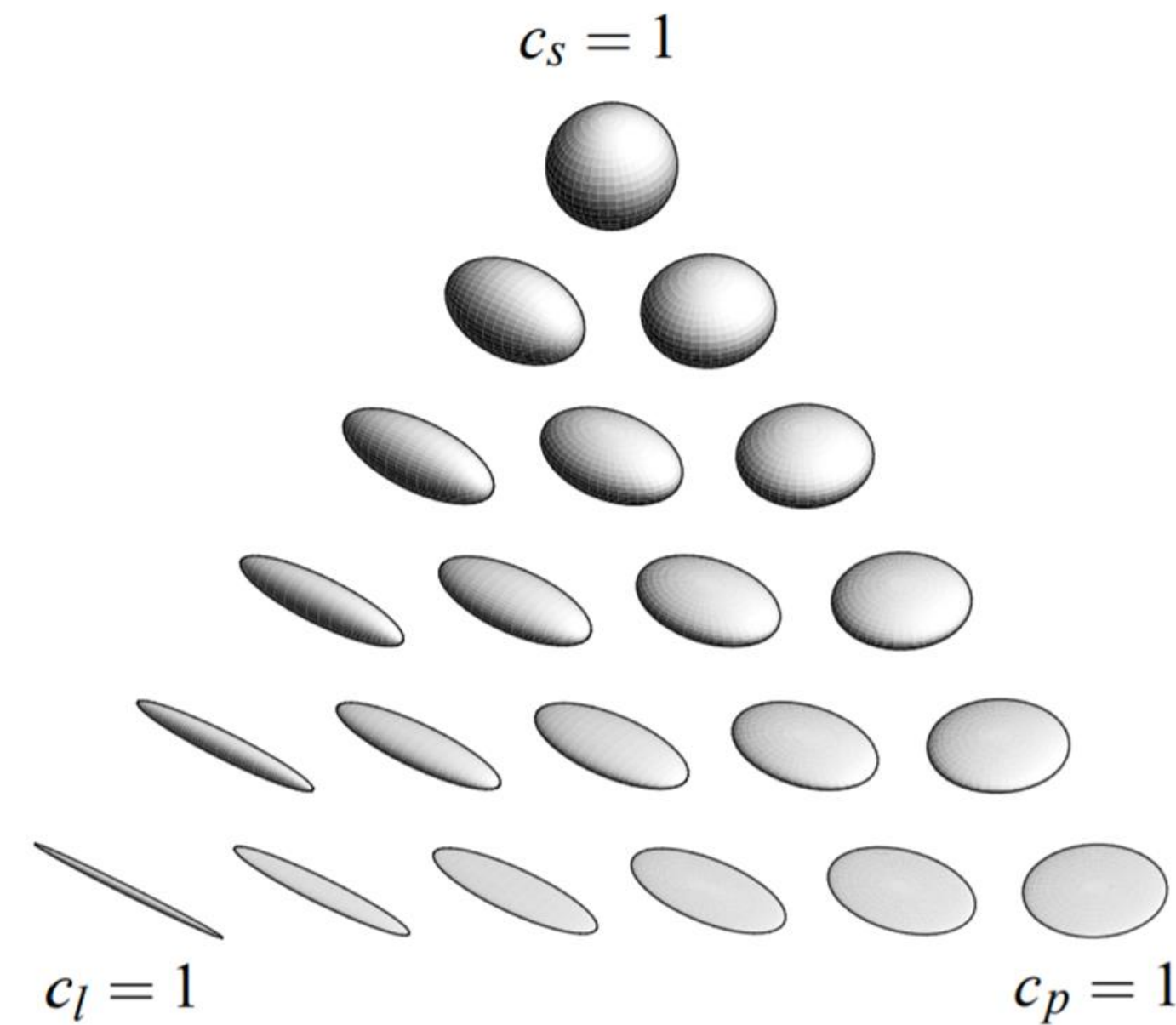


# Spatial Fields

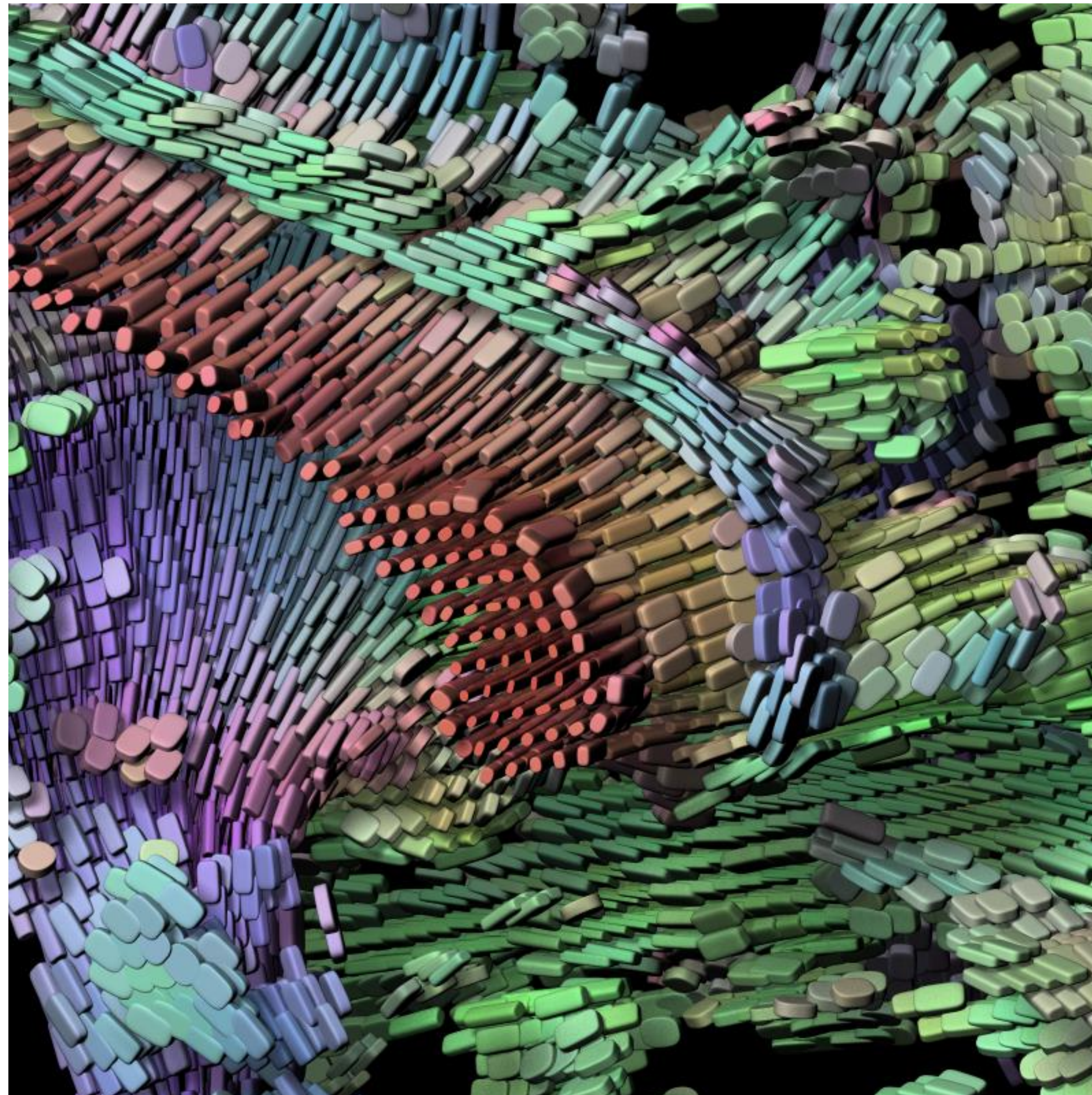
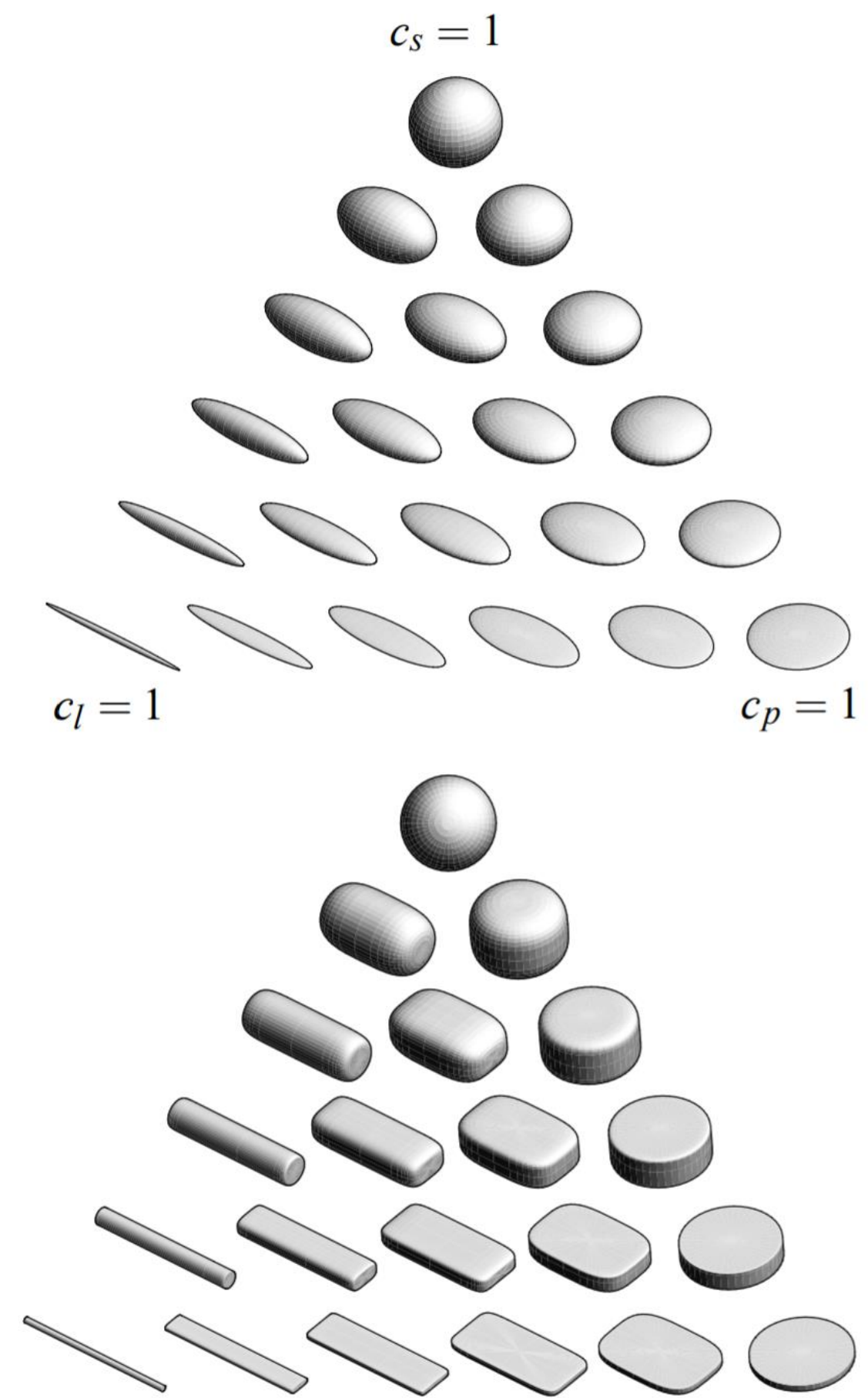
Vector or Tensor field = many values per cell



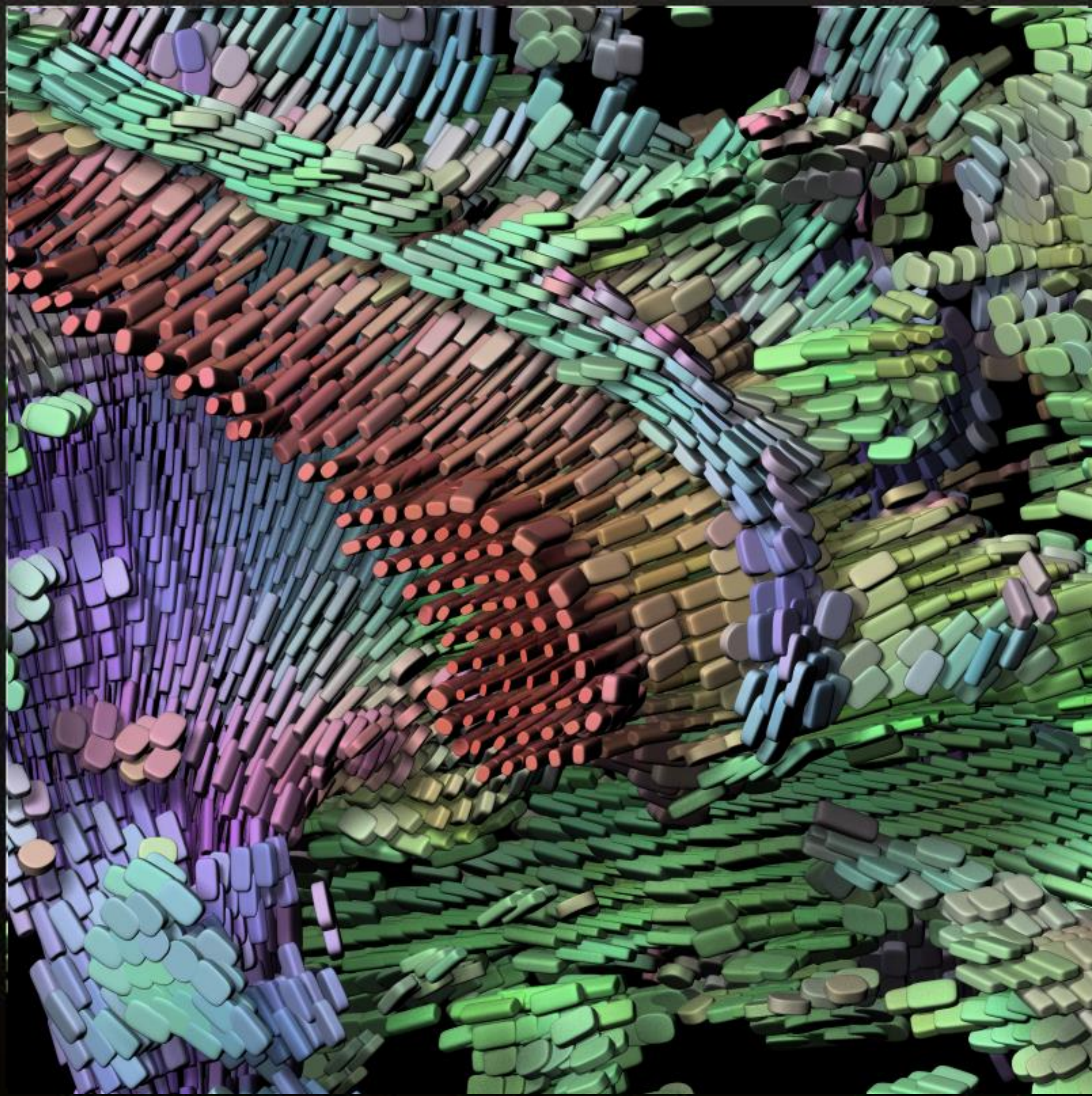
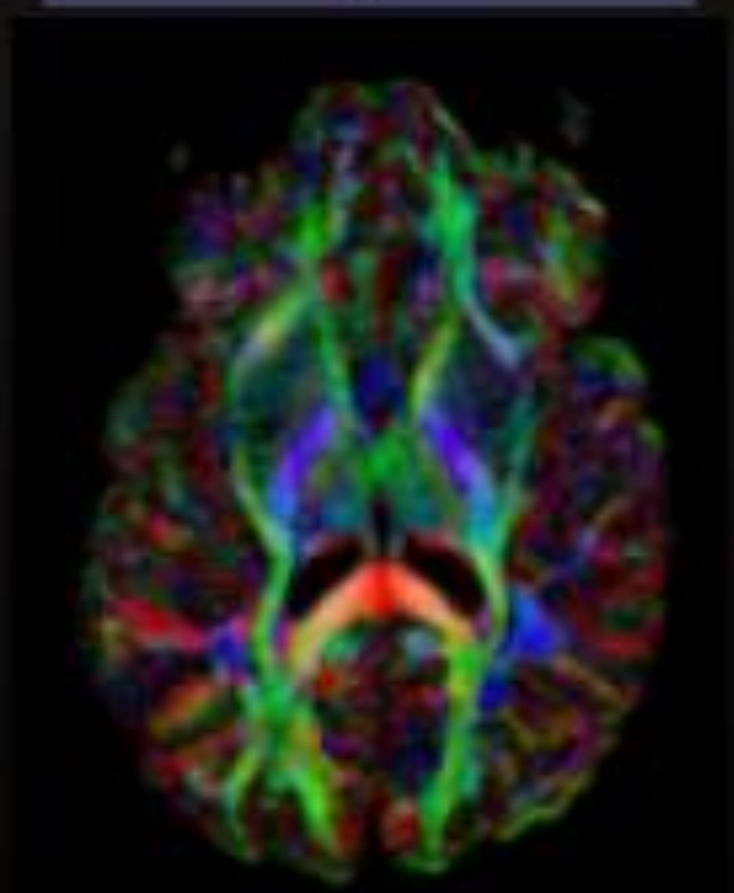
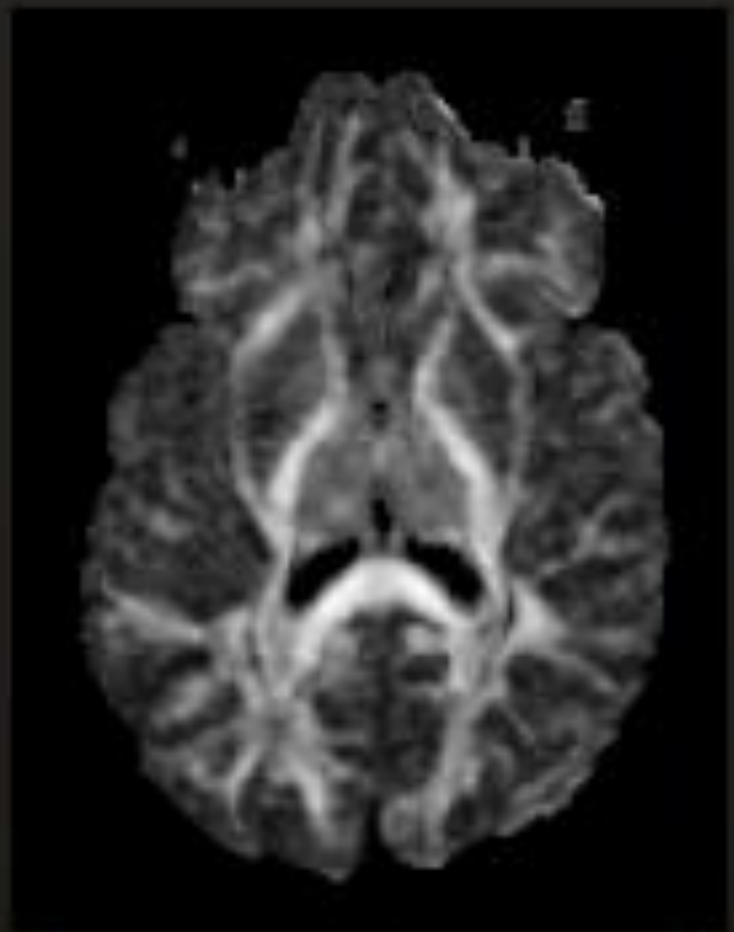
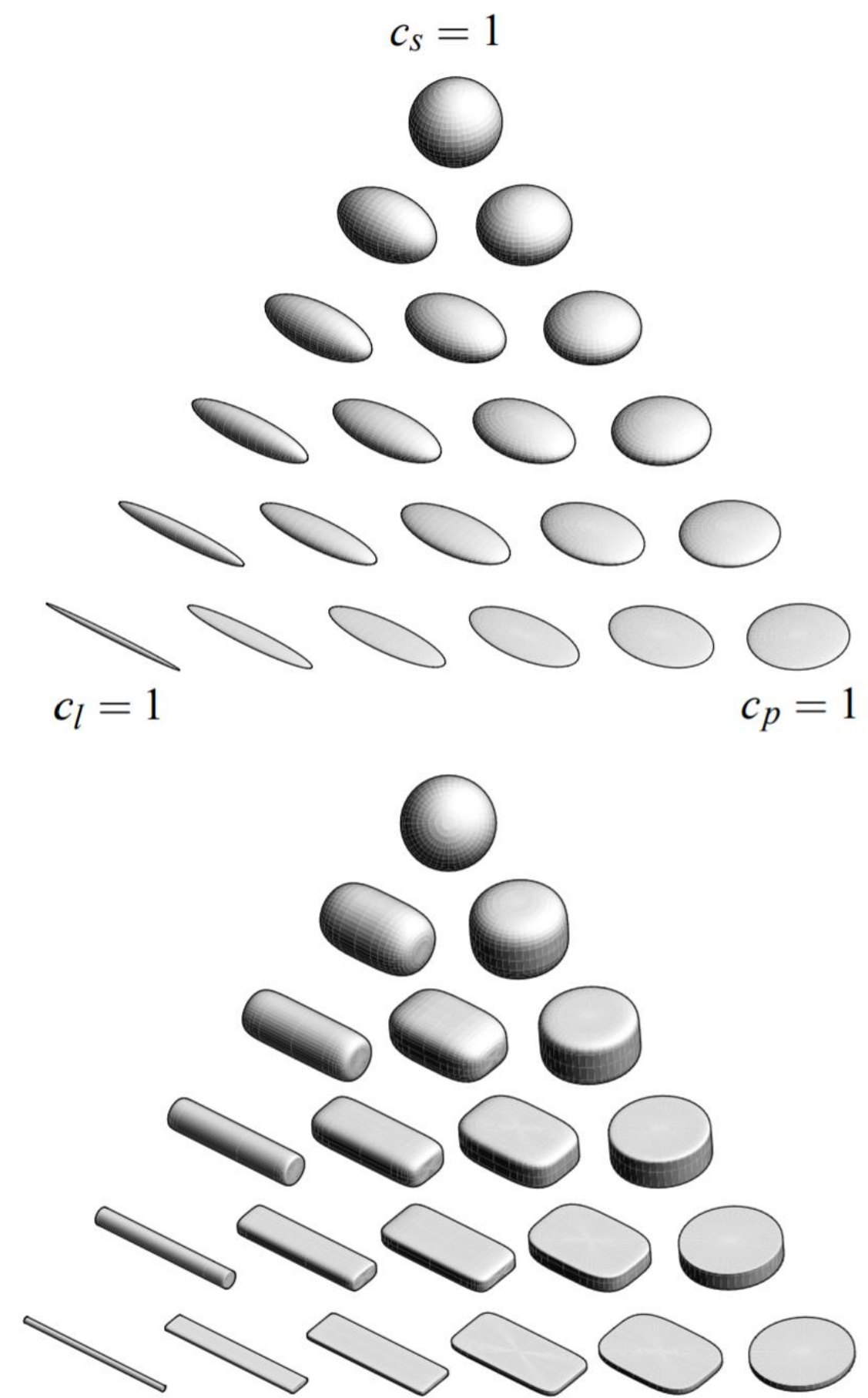
Vector  
*(magnitude and direction)*

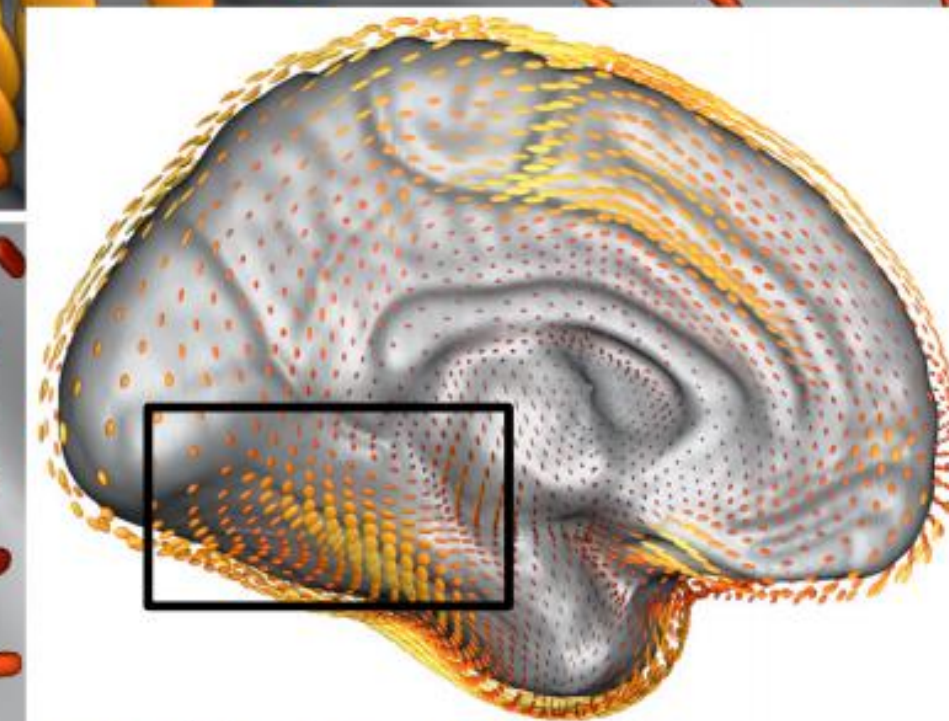
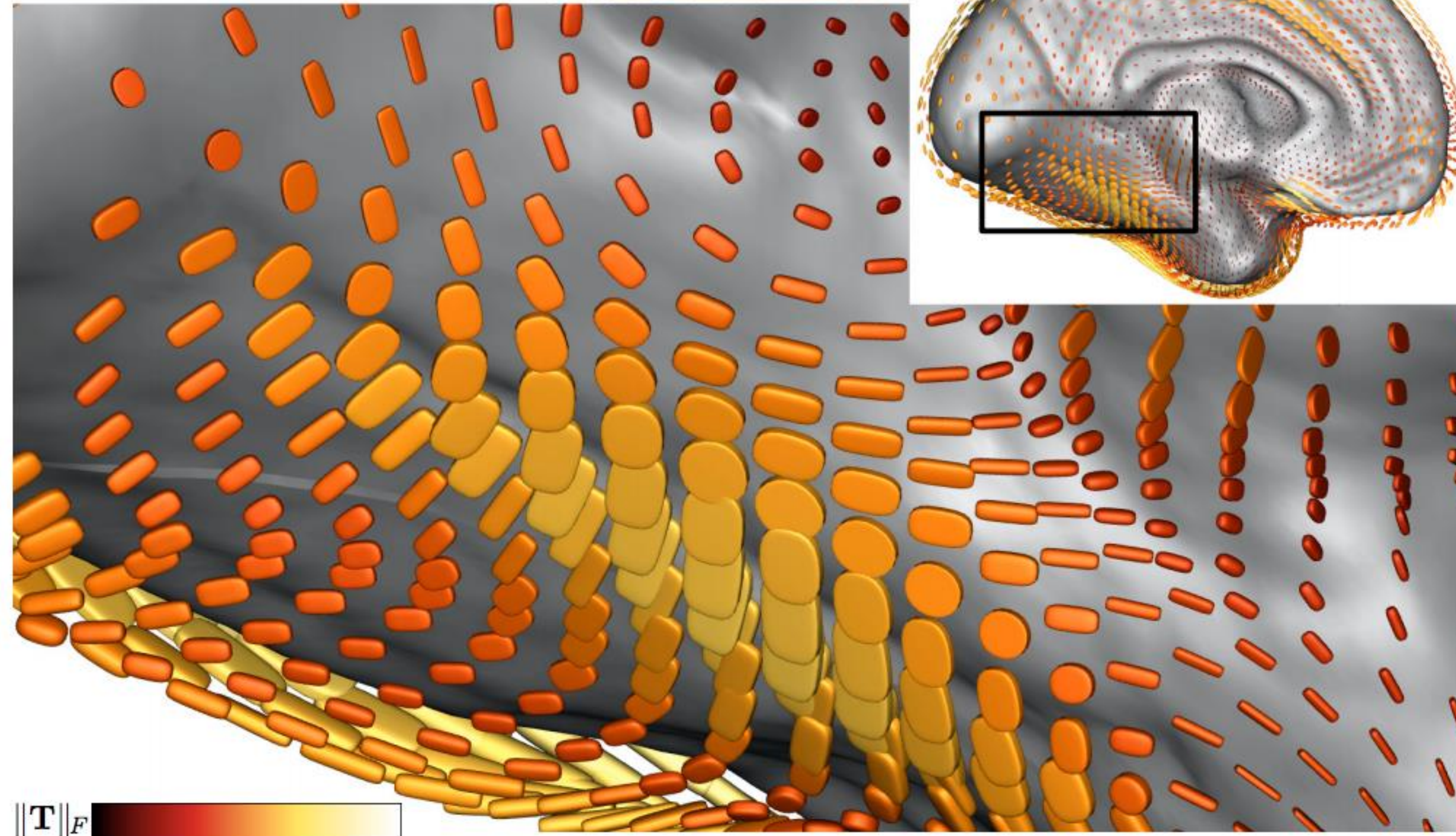
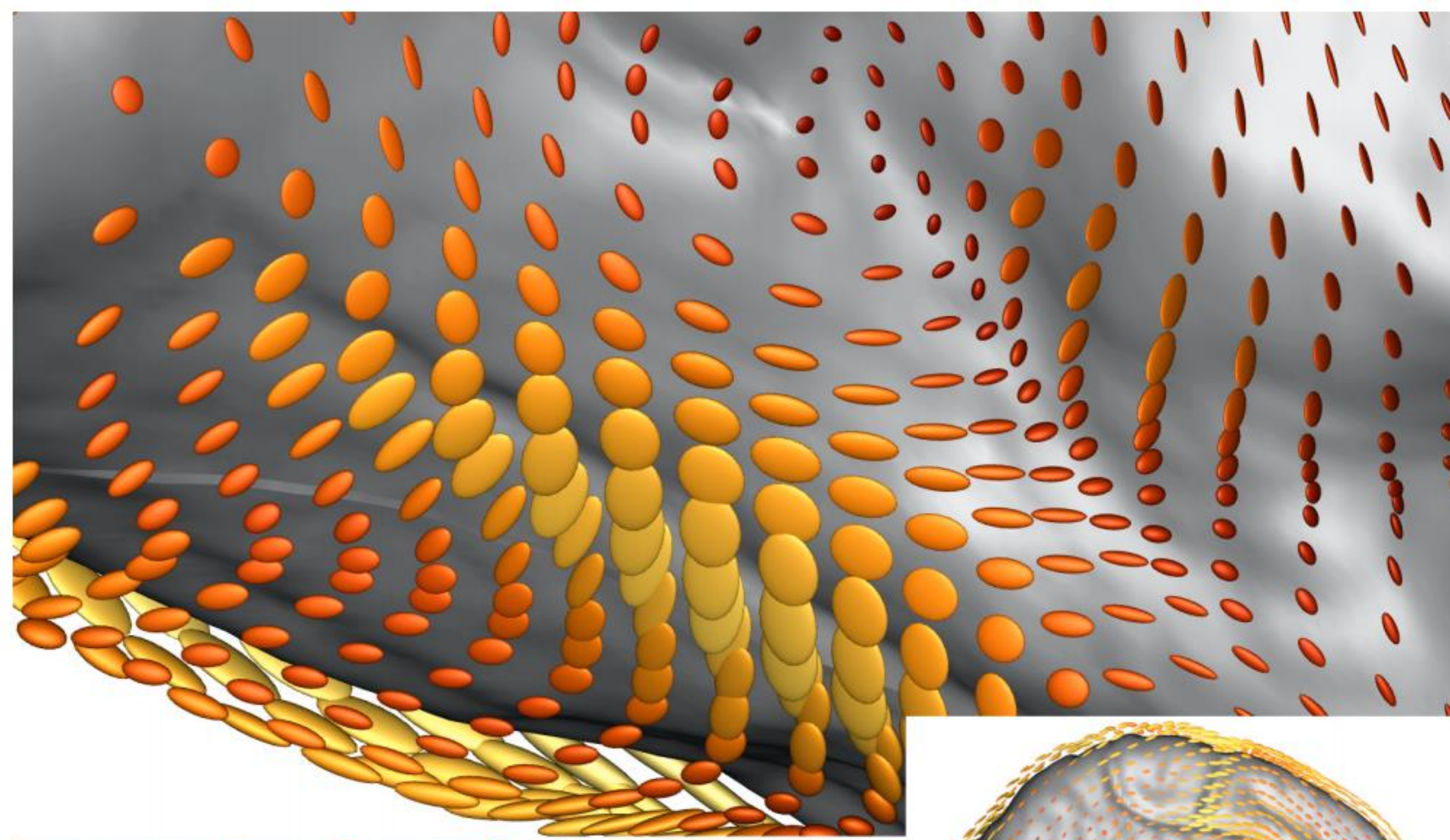
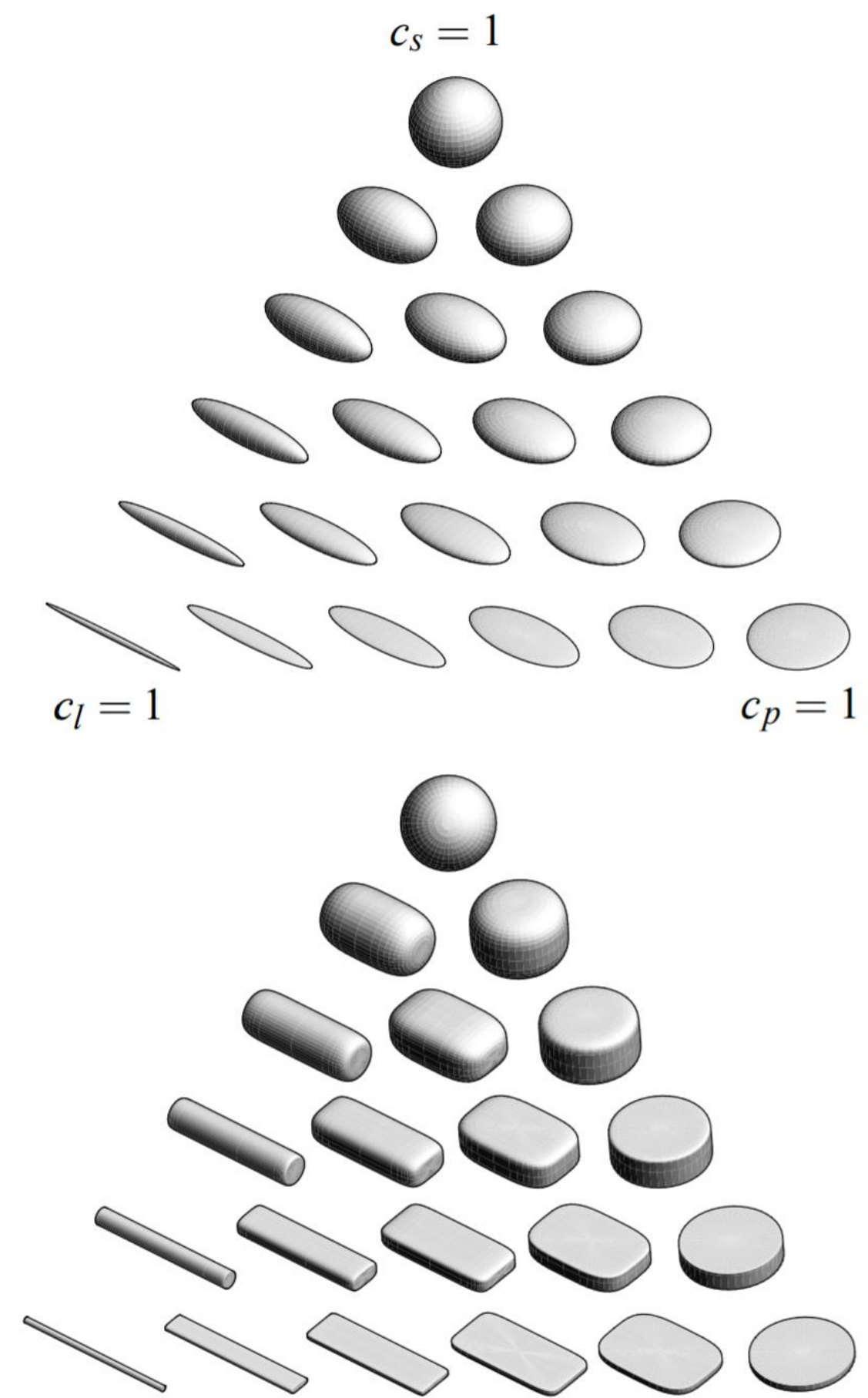


Tensor  
*(multiple variables with magnitude and direction)*

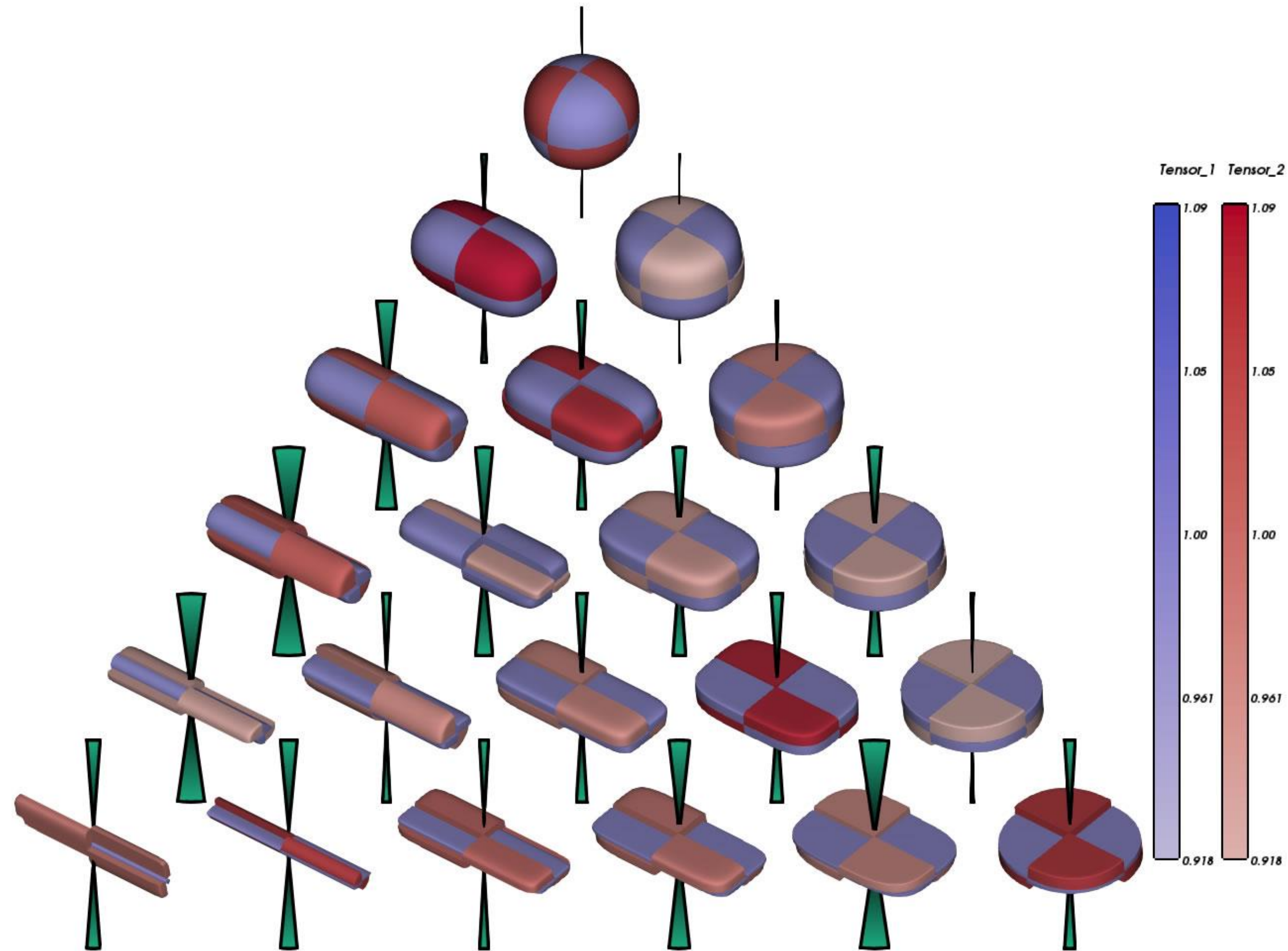


# Results





# Comparing Tensor Fields



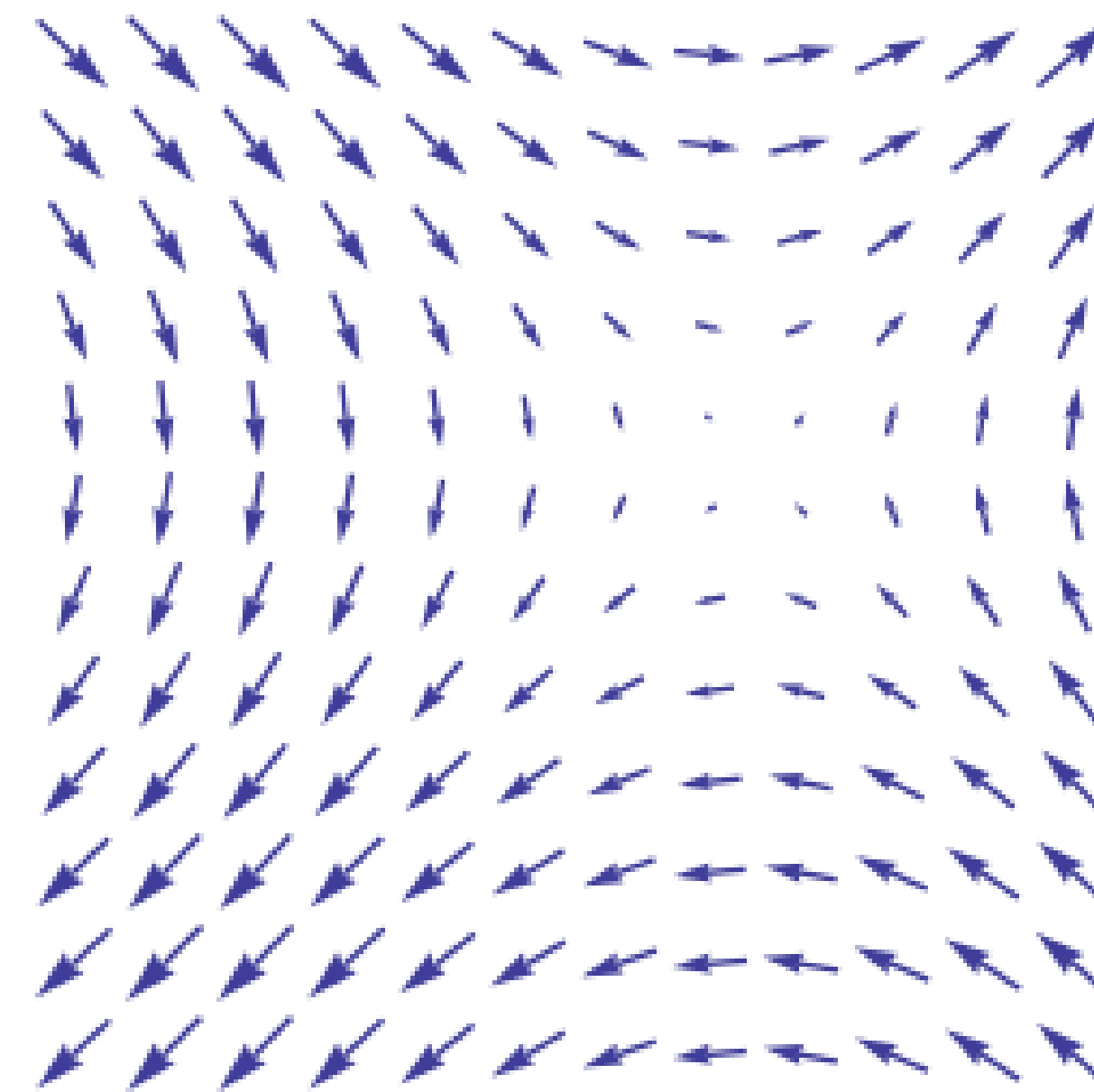
# Spatial Fields

Scalar field = one value per cell

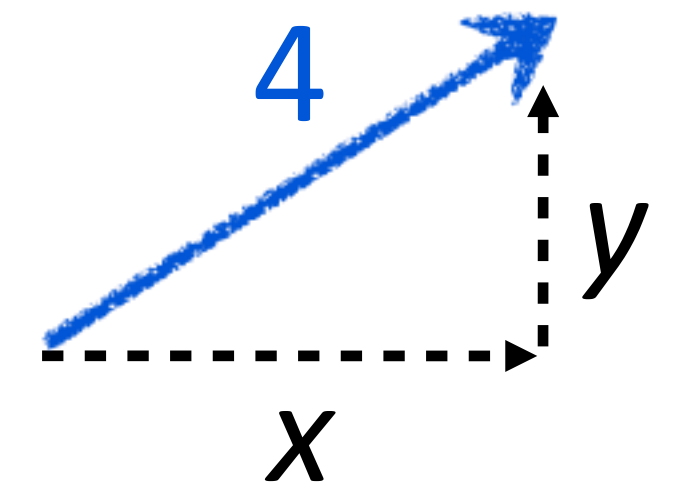
Vector or Tensor field = many values per cell

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)*

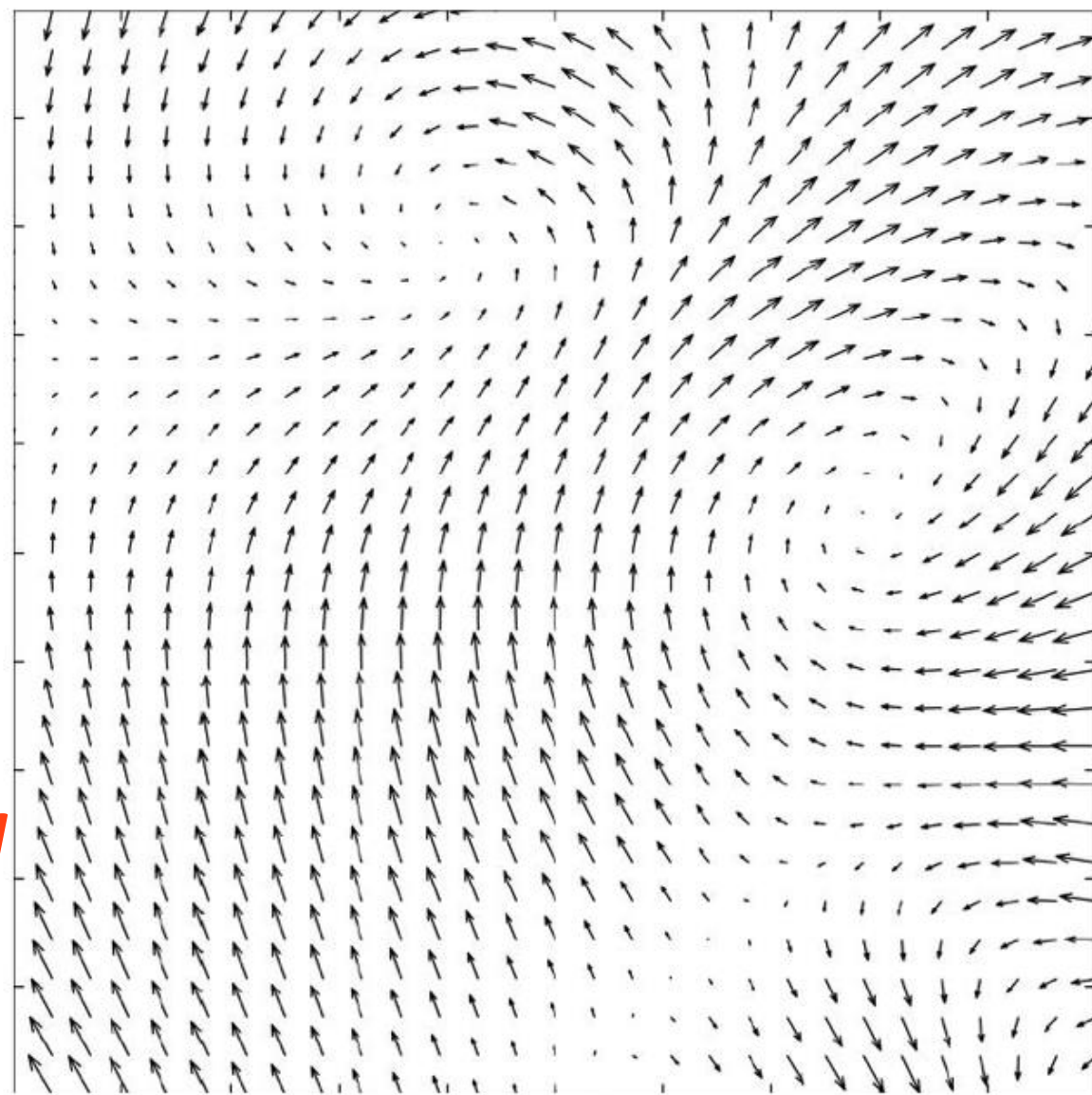


Vector  
*(magnitude and direction)*

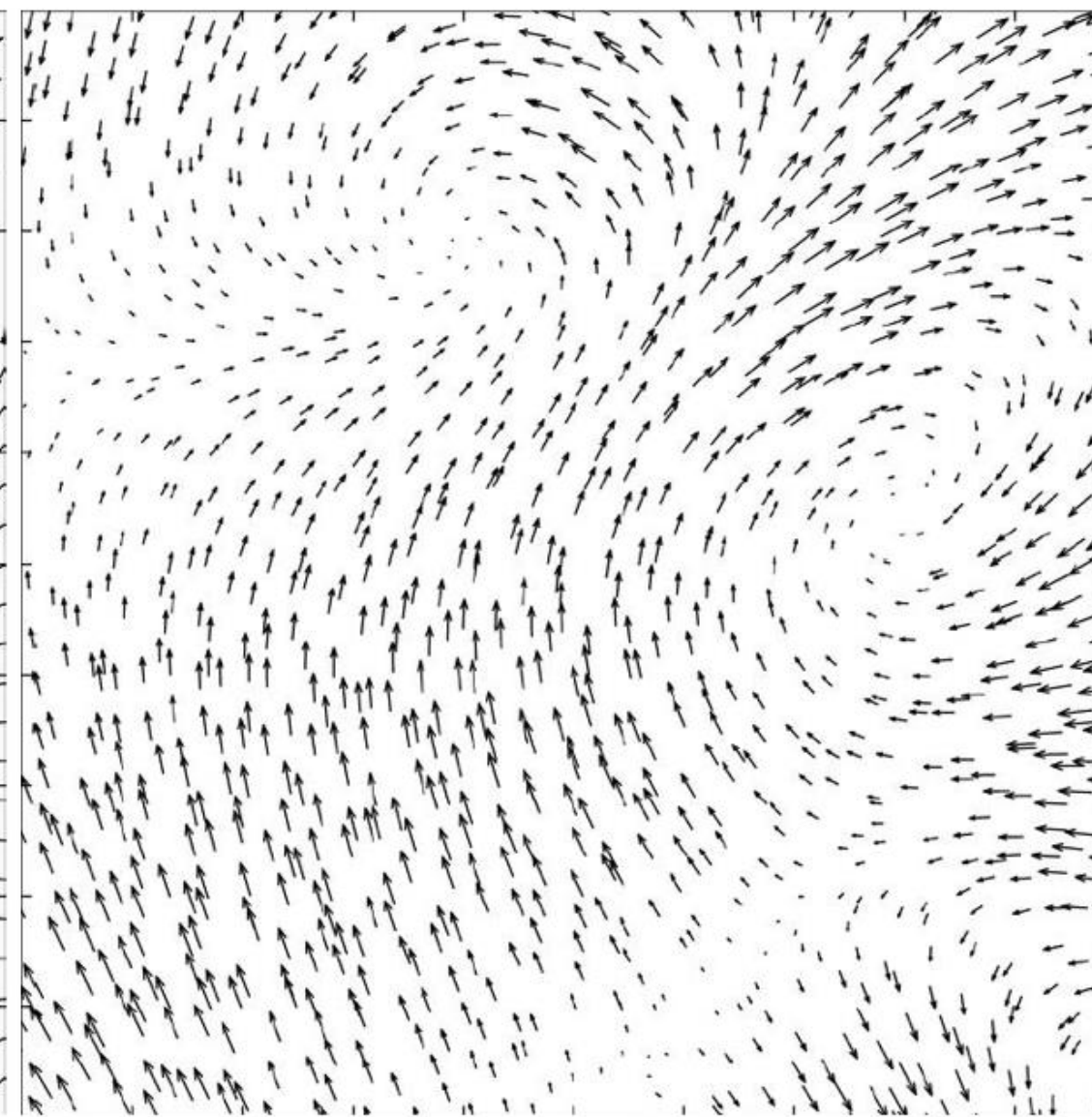


# Vector Field Encoding Examples:

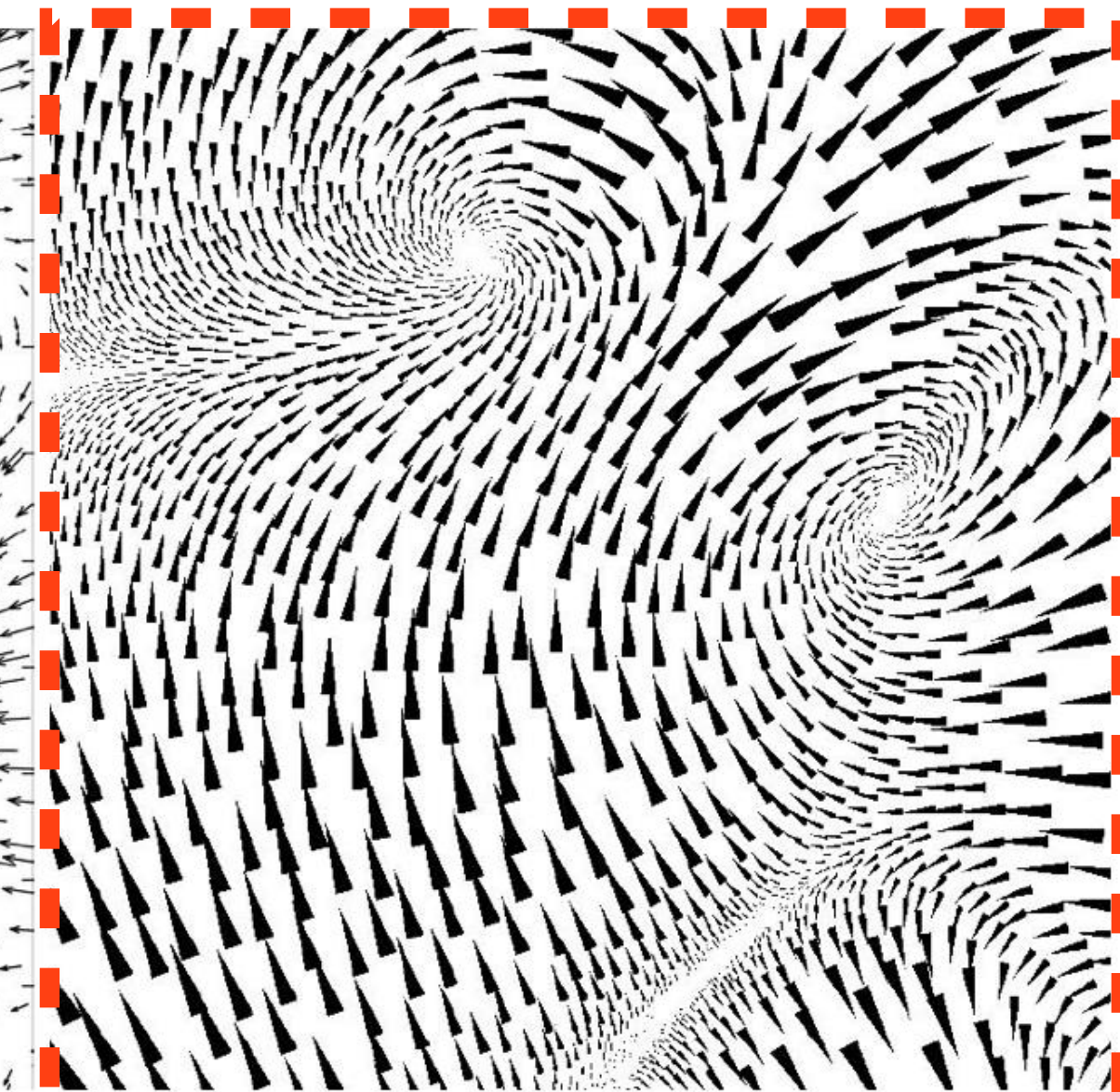
*Most  
accurate and  
efficient for  
certain  
spatial tasks*



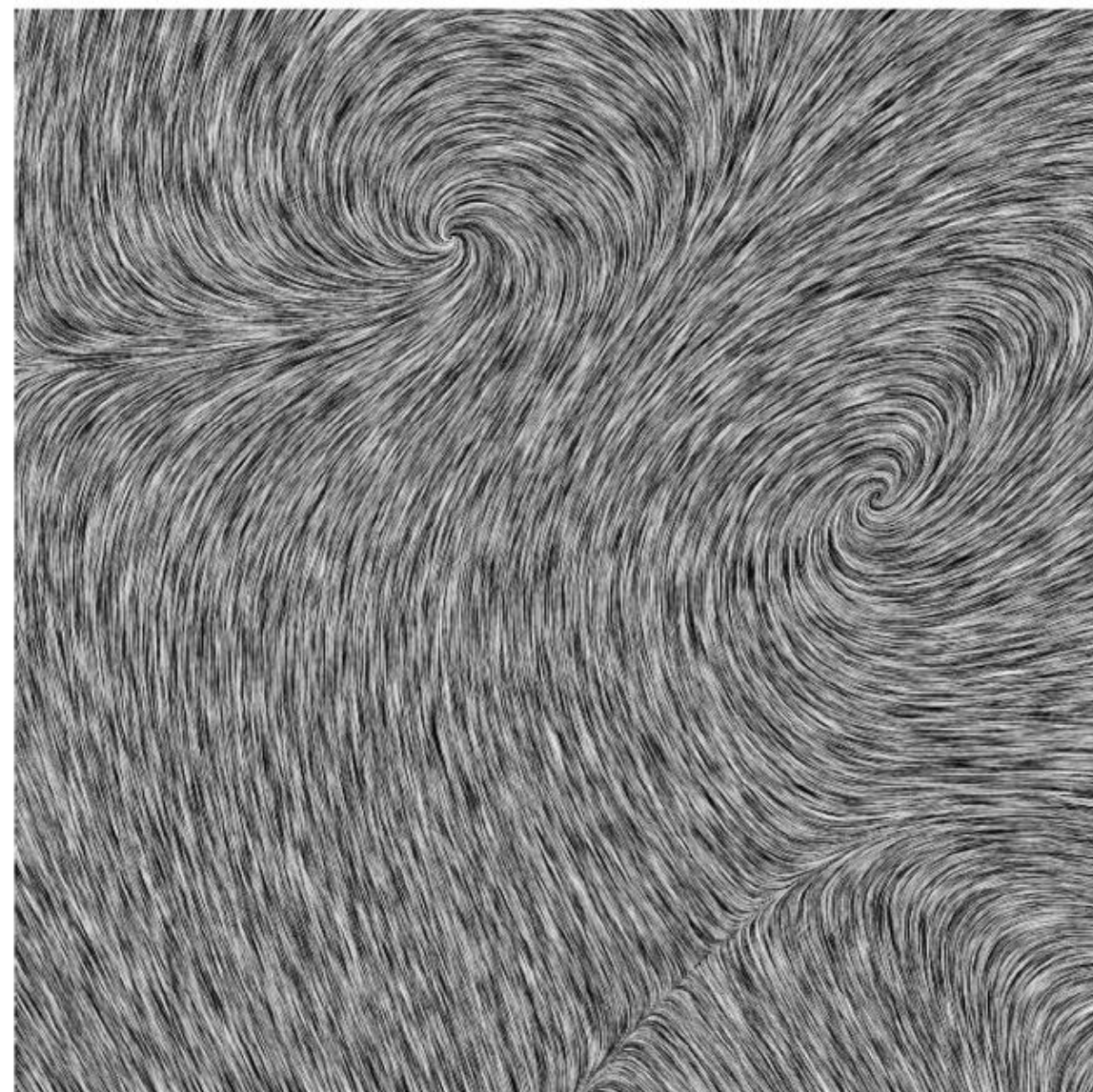
GRID



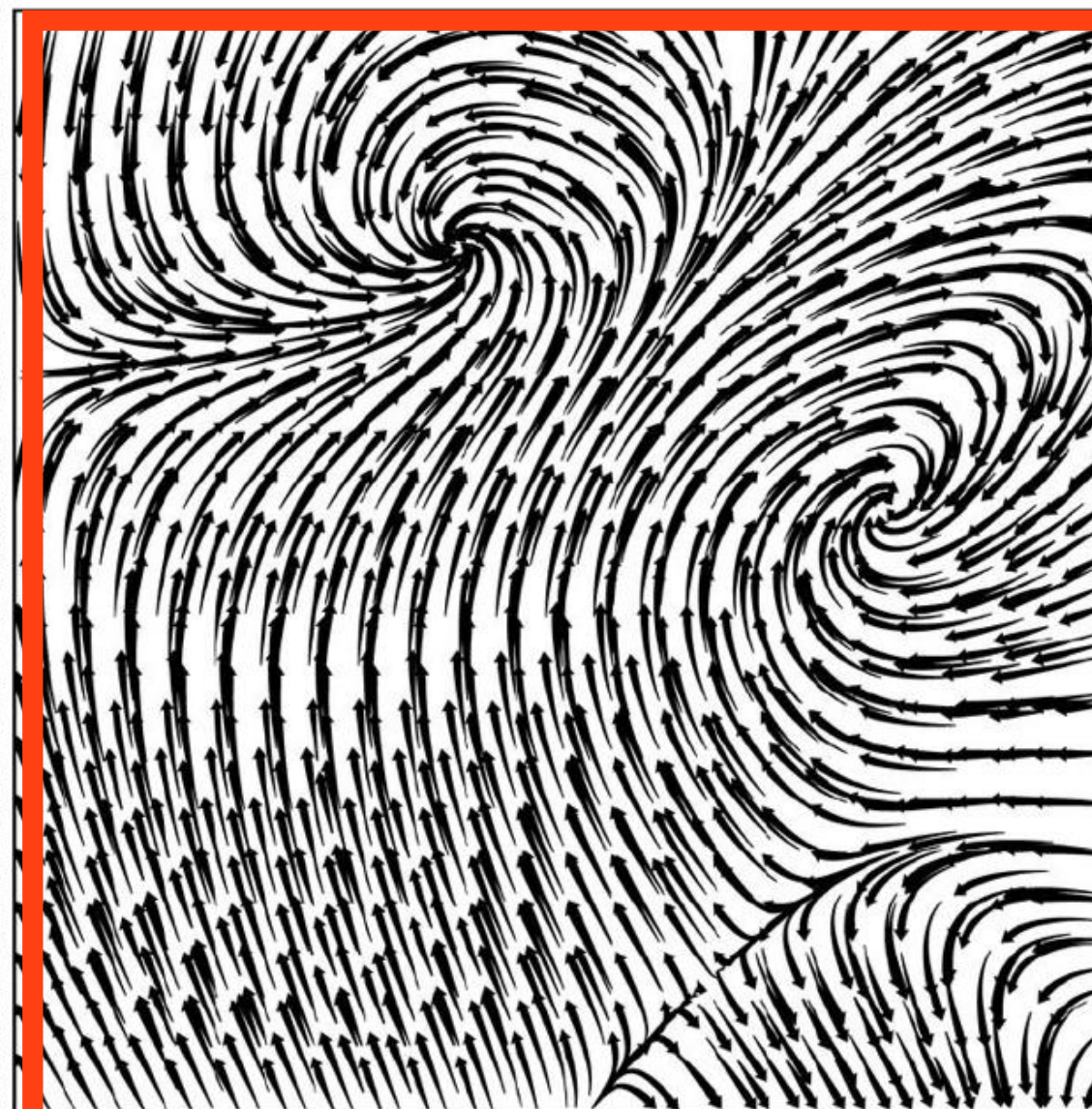
JIT



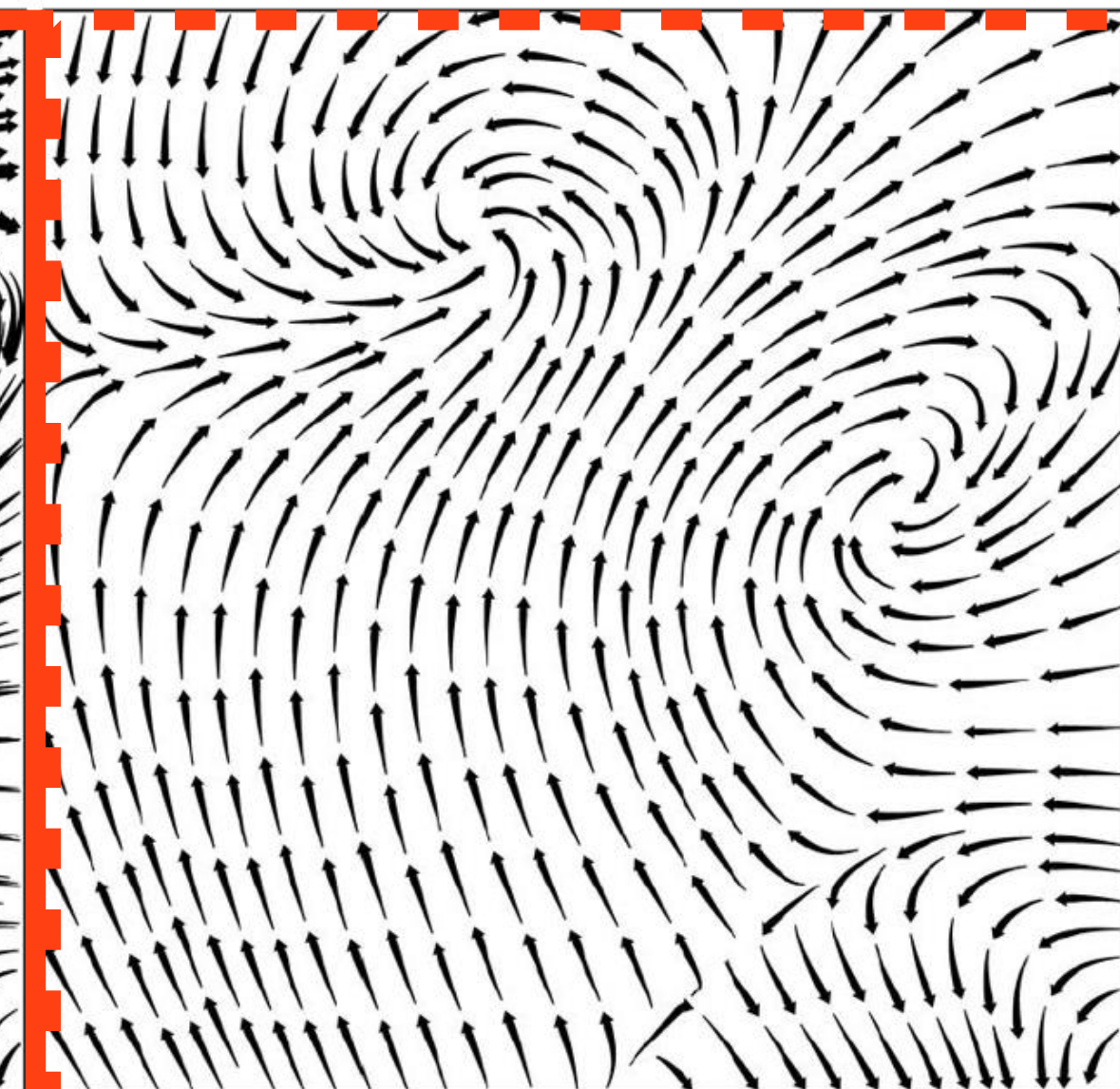
LIT



LIC



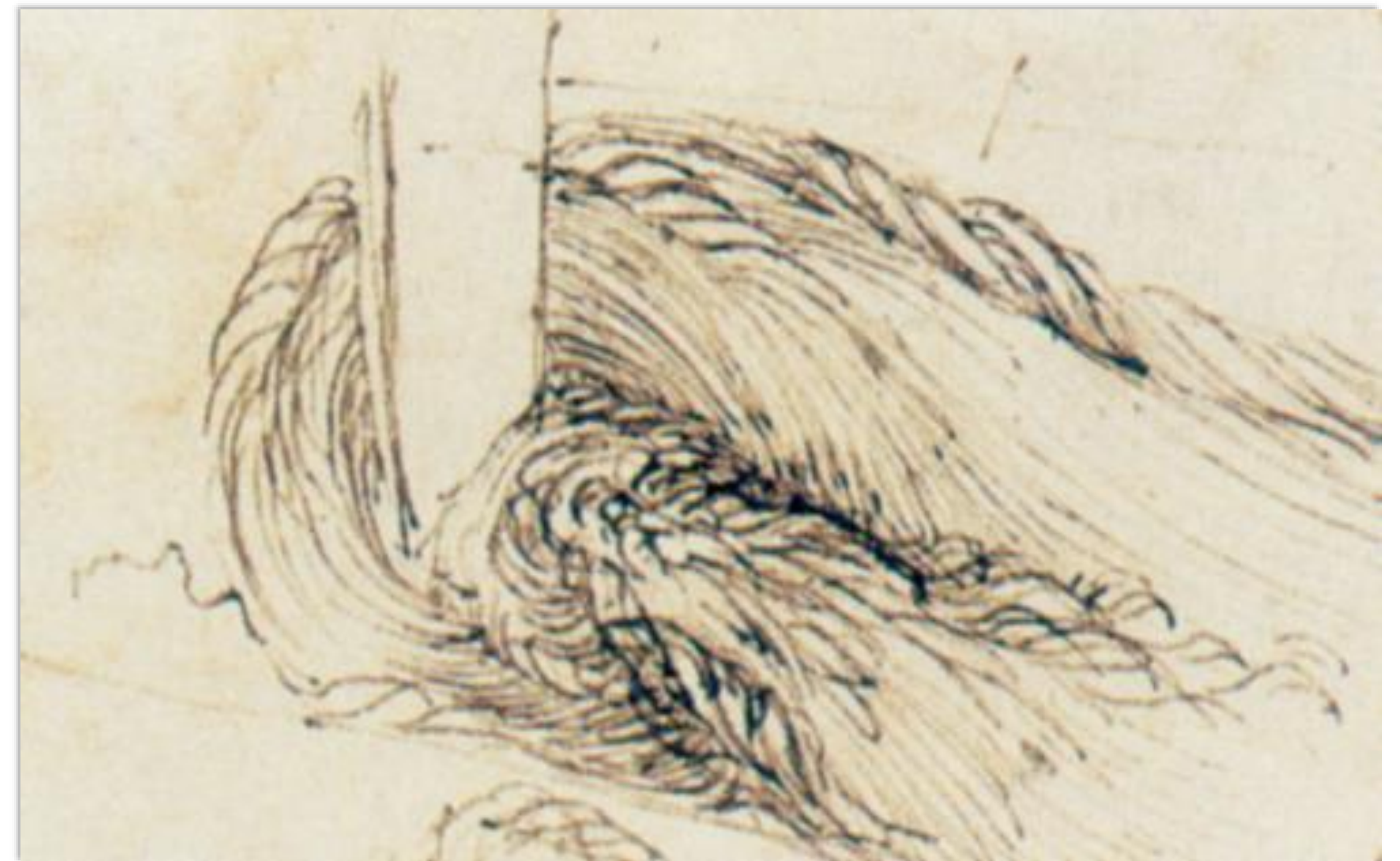
GSTR



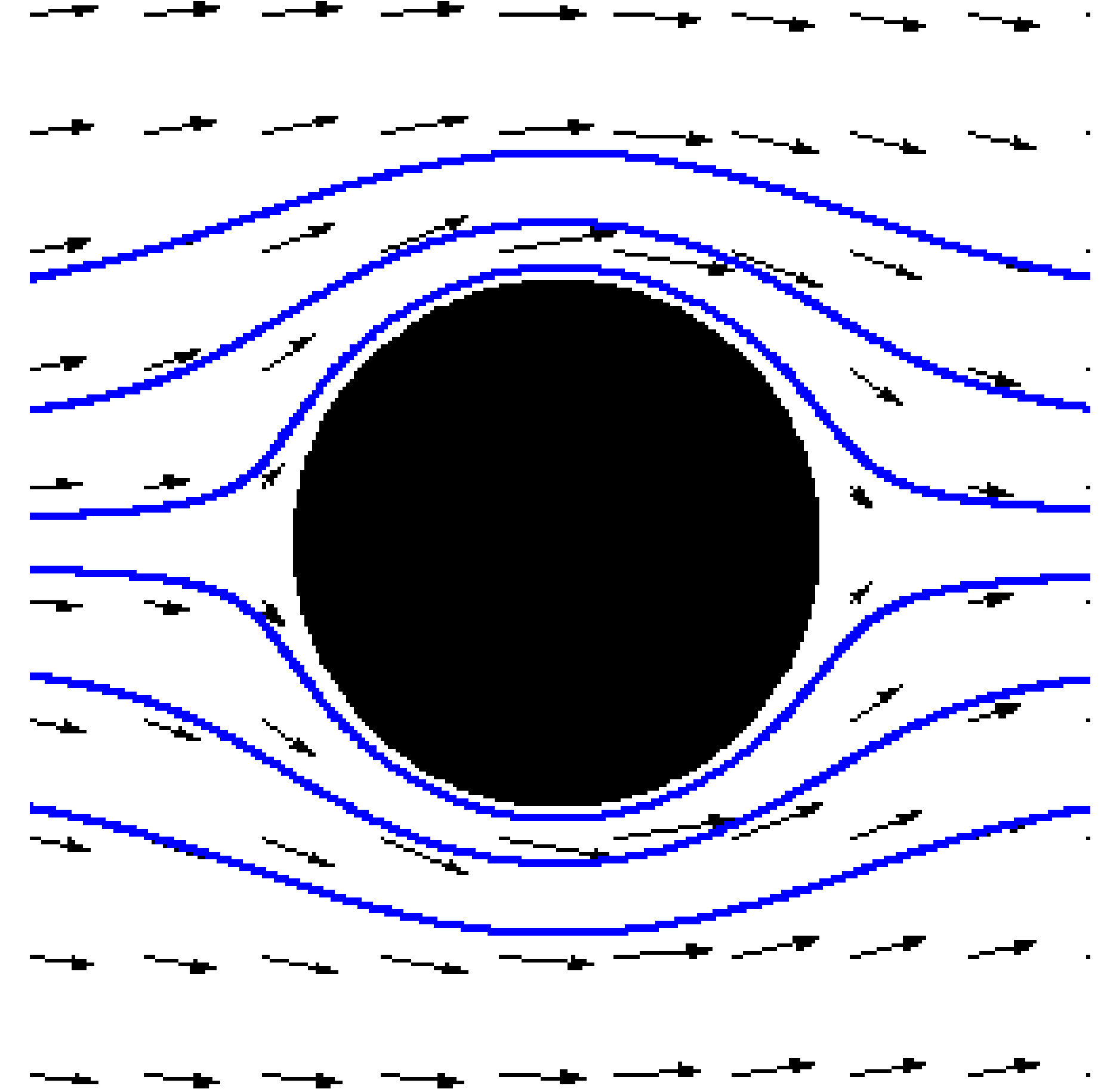
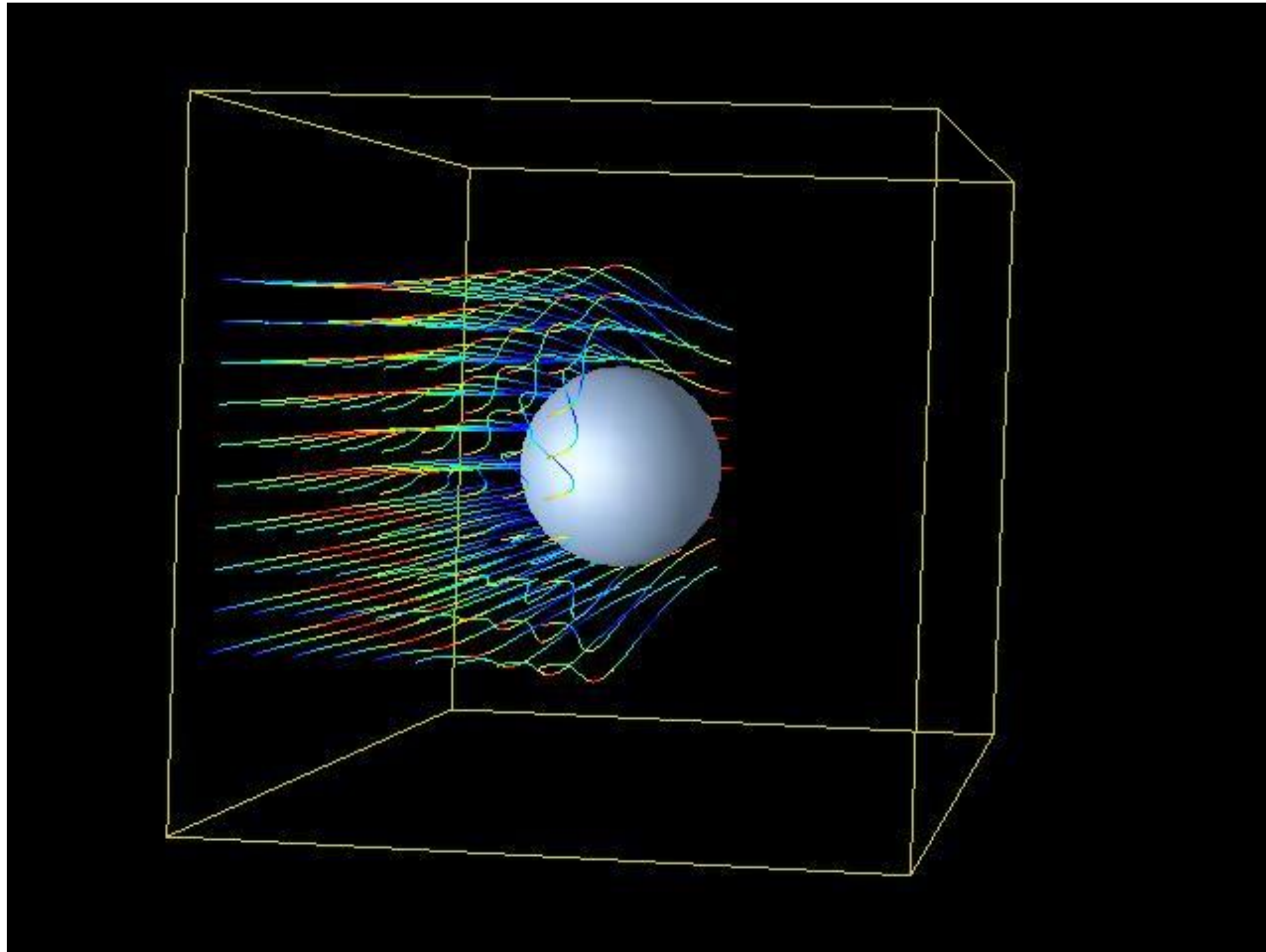
OSTR



# Example: Fluid Flow Visualization



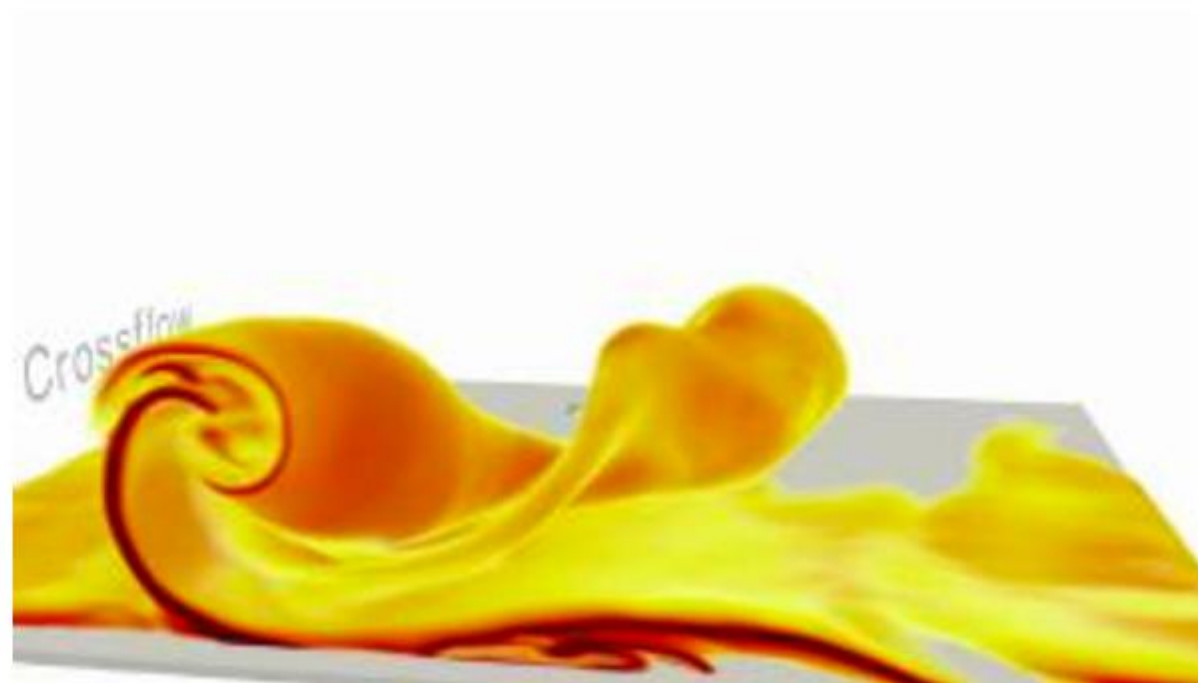
# Example: Fluid Flow Visualization



# Example: Fluid Flow Visualization

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

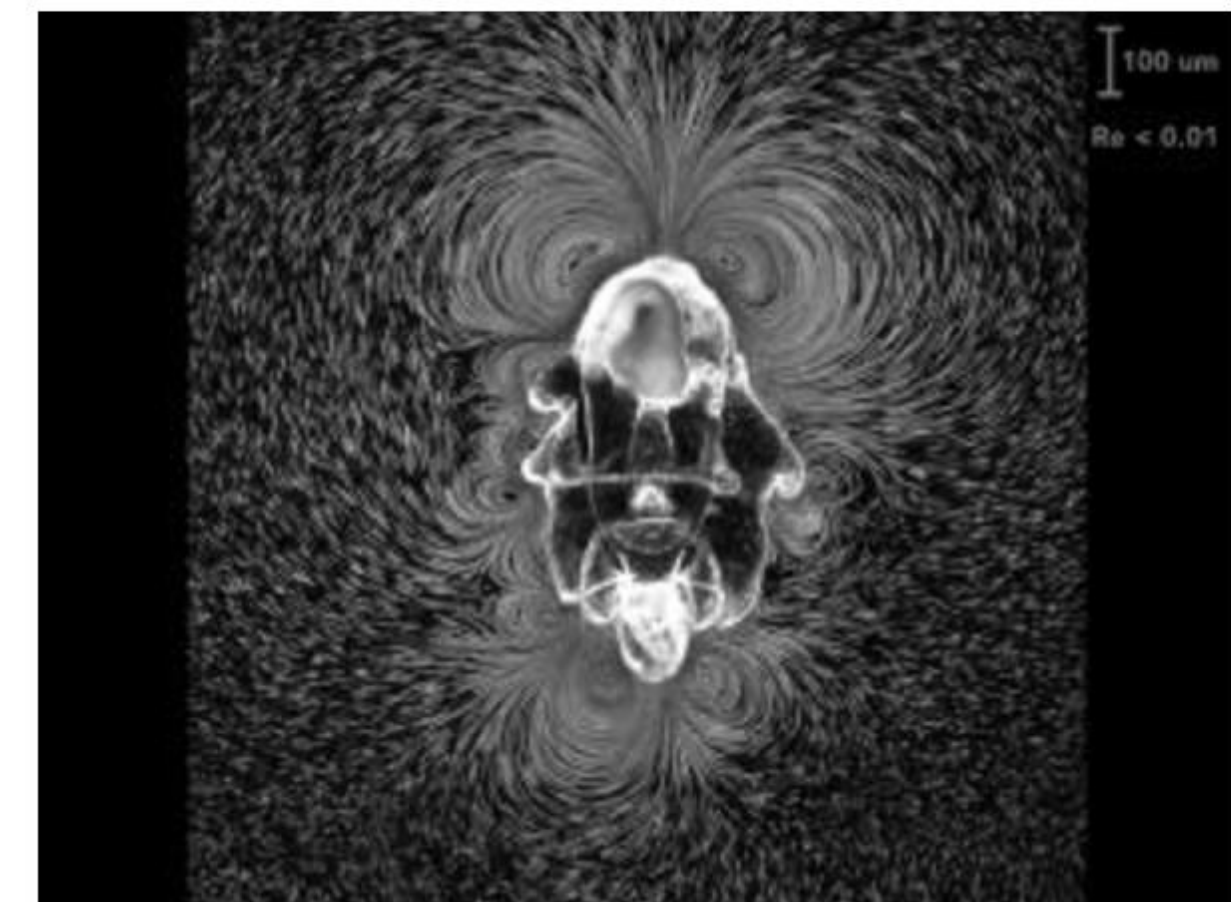
2016 APS/DFD Milton van Dyke Award Winners (Video)



V0076: Sweeping Jet from a Fluidic Oscillator in Crossflow



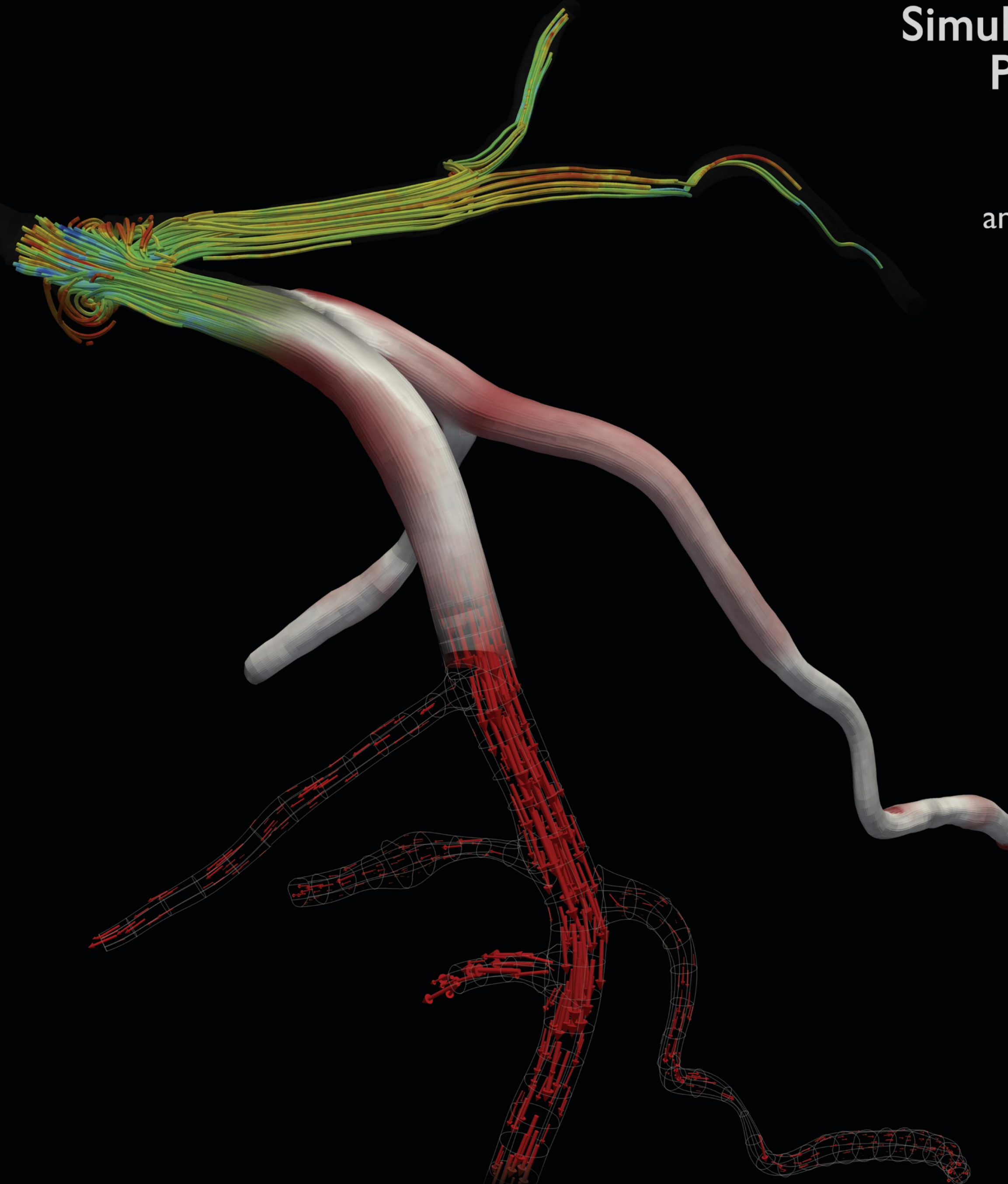
V0095: The shear joy of watching paint dry



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.

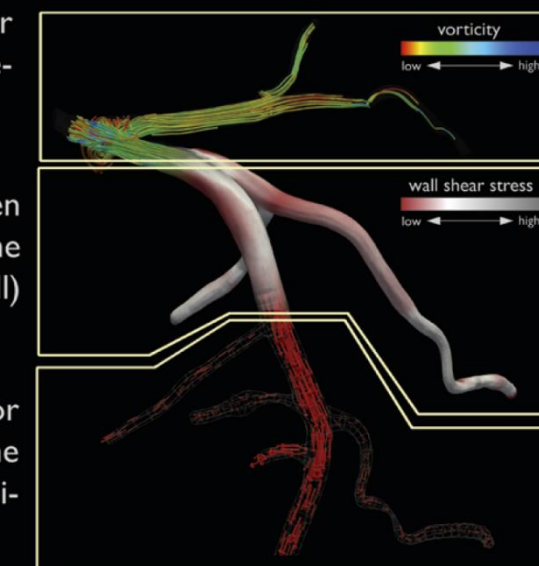
To this end, the project has collected computed tomography angiography (CTA) data from patients in order to obtain coronary geometries and then accurately model human blood flow through the coronary arteries. The CTA data is gathered using a 320 detector row Toshiba AquilionONE scanner and then the data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

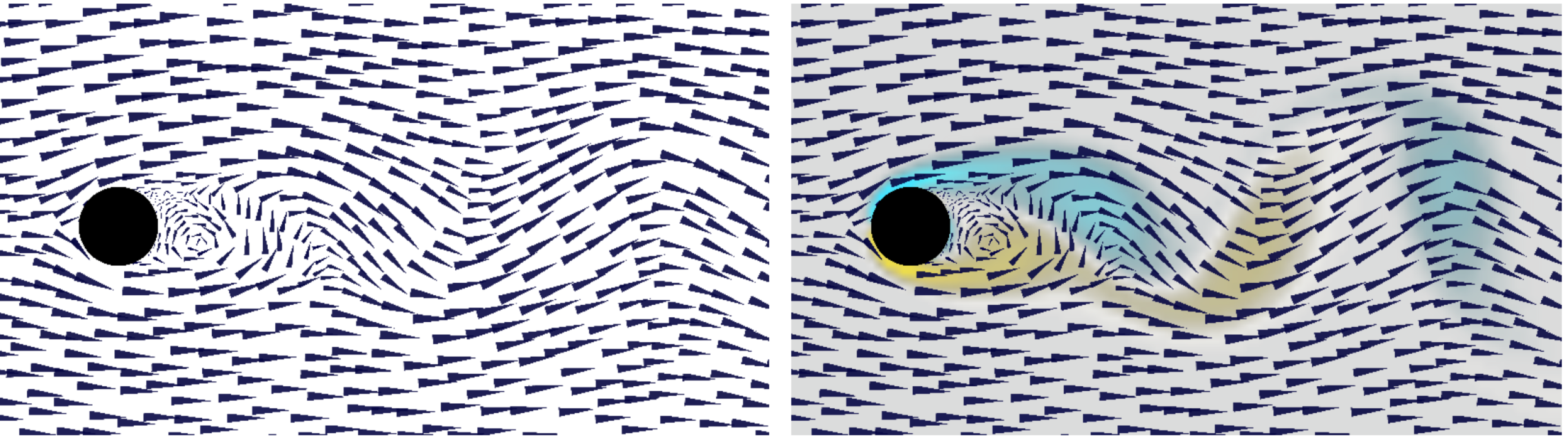
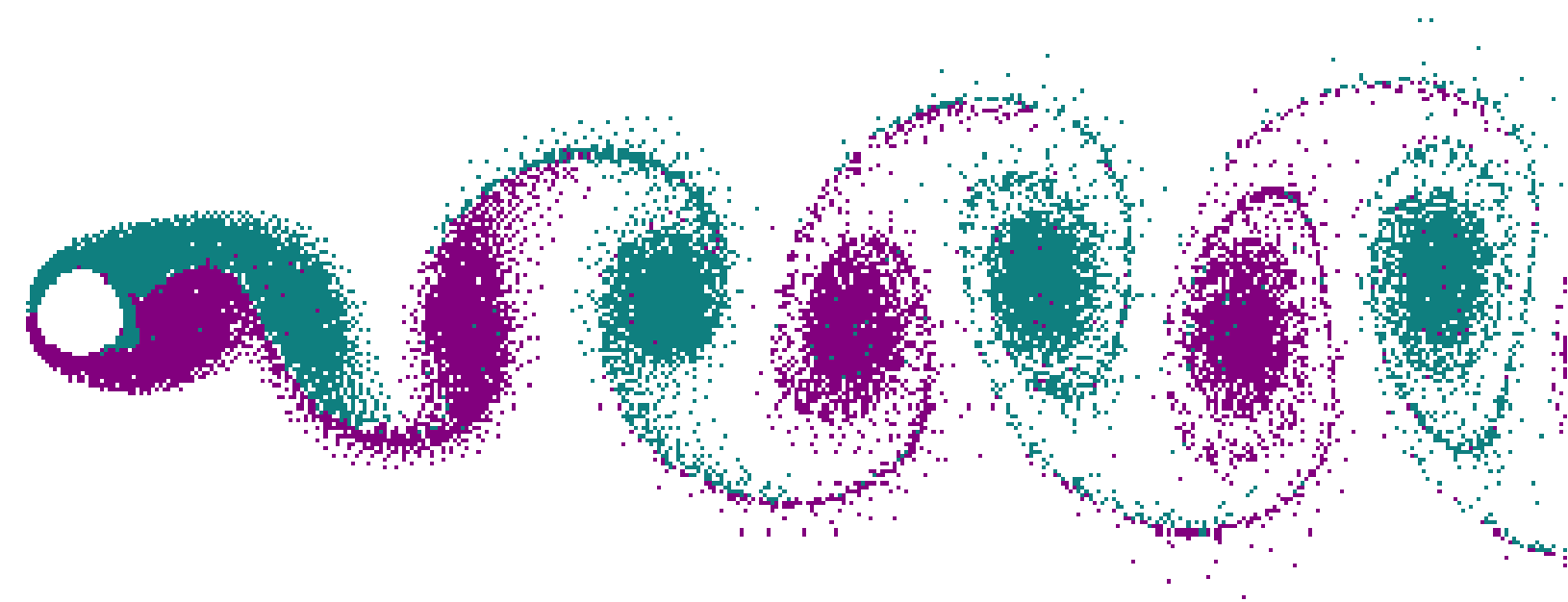
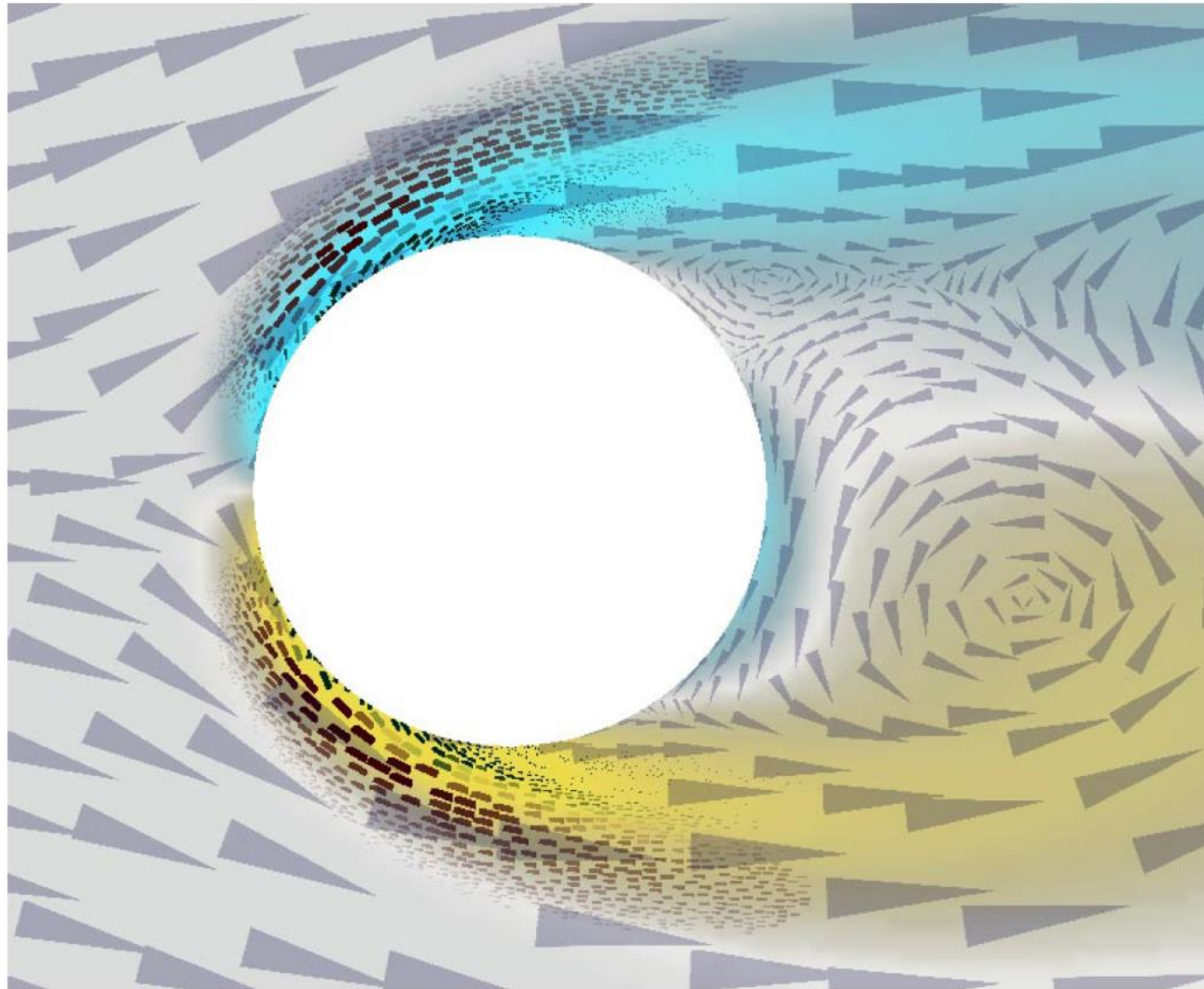
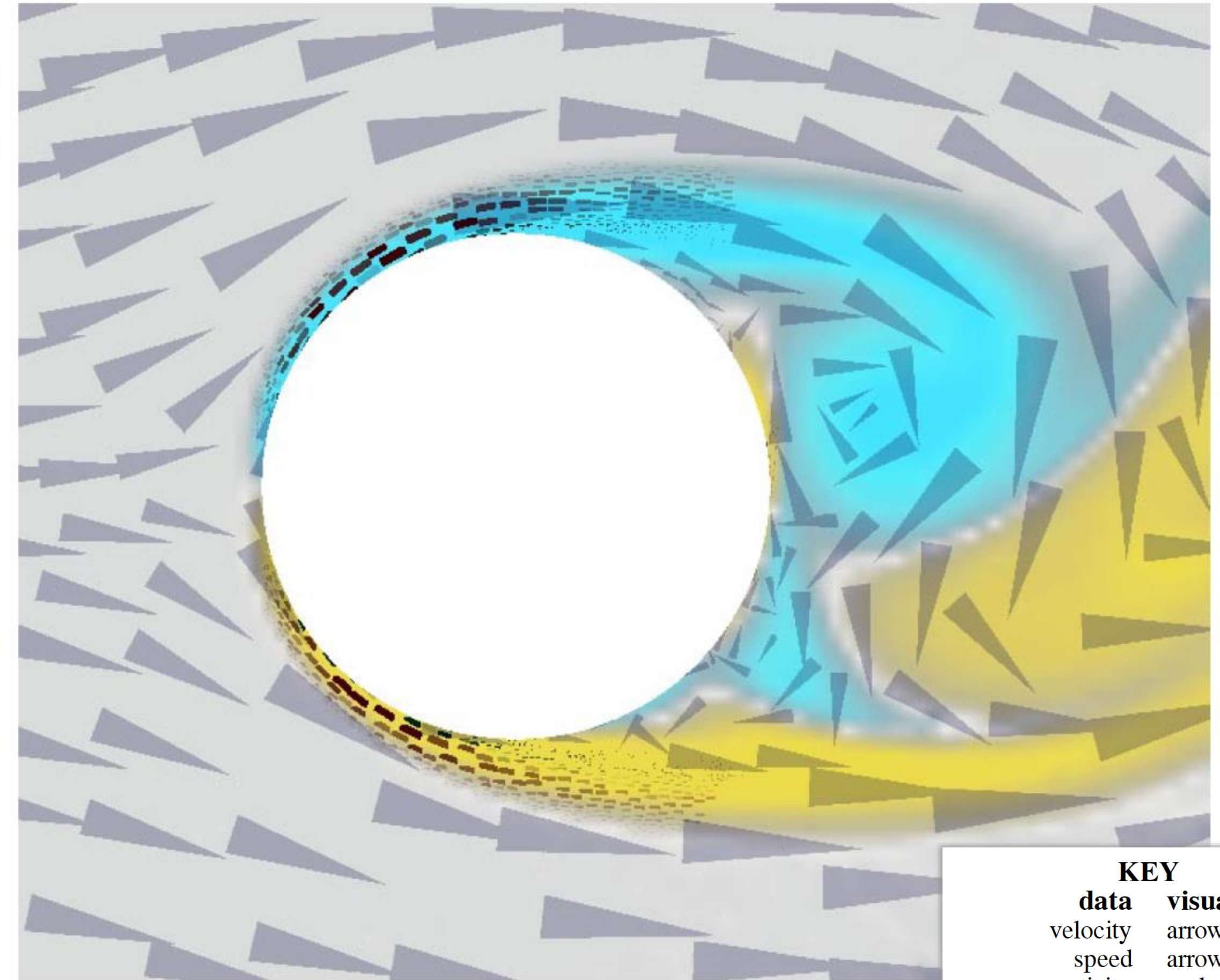


Figure 1: Typical visualization methods for 2D flow past a cylinder at Reynolds number 100. On the left, we show only the velocity field. On the right, we simultaneously show velocity and vorticity. Vorticity represents the rotational component of the flow. Clockwise vorticity is blue, counterclockwise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





Reynolds number 100



Reynolds number 500

KEY	
data	visualization
velocity	arrow direction
speed	arrow area
vorticity	underpainting: blue=cw, yellow=ccw
turbulent charge	stroke color
turbulent current	stroke direction/area

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

# Upcoming Assignments & Communication

Look at the upcoming assignments and deadlines regularly!

- Textbook, Readings, & Reading Quizzes — Variable days
- In-Class Activities — 11:59pm same day as class
  - T: Lecture overflow & In-Class Project Feedback Meetings & Work,
  - F: Lecture, T: Lecture, F: Lecture
- Assignments & Projects— Generally due **R 11:59pm**
  - R (6 days): Project 7 — Sprint 2 & Paper Draft
  - Next R (13 days): Project 8 — Sprint 3 & Prep for Usability Testing
  - Next F (14 days): In-Class Usability Testing
  - Next-Next R (20 days): Project 9 — Presentation and Video
  - Next-Next F (21 days): In-Class Project Presentations

Use Canvas Discussions for general questions, email the TAs/S-LTA/instructor for questions specific to you: [codydunne-and-tas@ccs.neu.edu](mailto:codydunne-and-tas@ccs.neu.edu). Include links!

If you're emailing about a particular assignment, please **include the URL of the Submission Details page**. ([Canvas documentation](#).)

If you have a project question, **give us your group number**. E.g., include: `Group ## — Topic` with `##` replaced by your group number and `Topic` replaced by your topic.