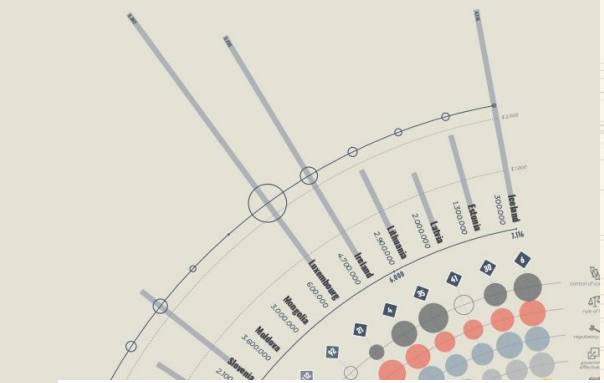
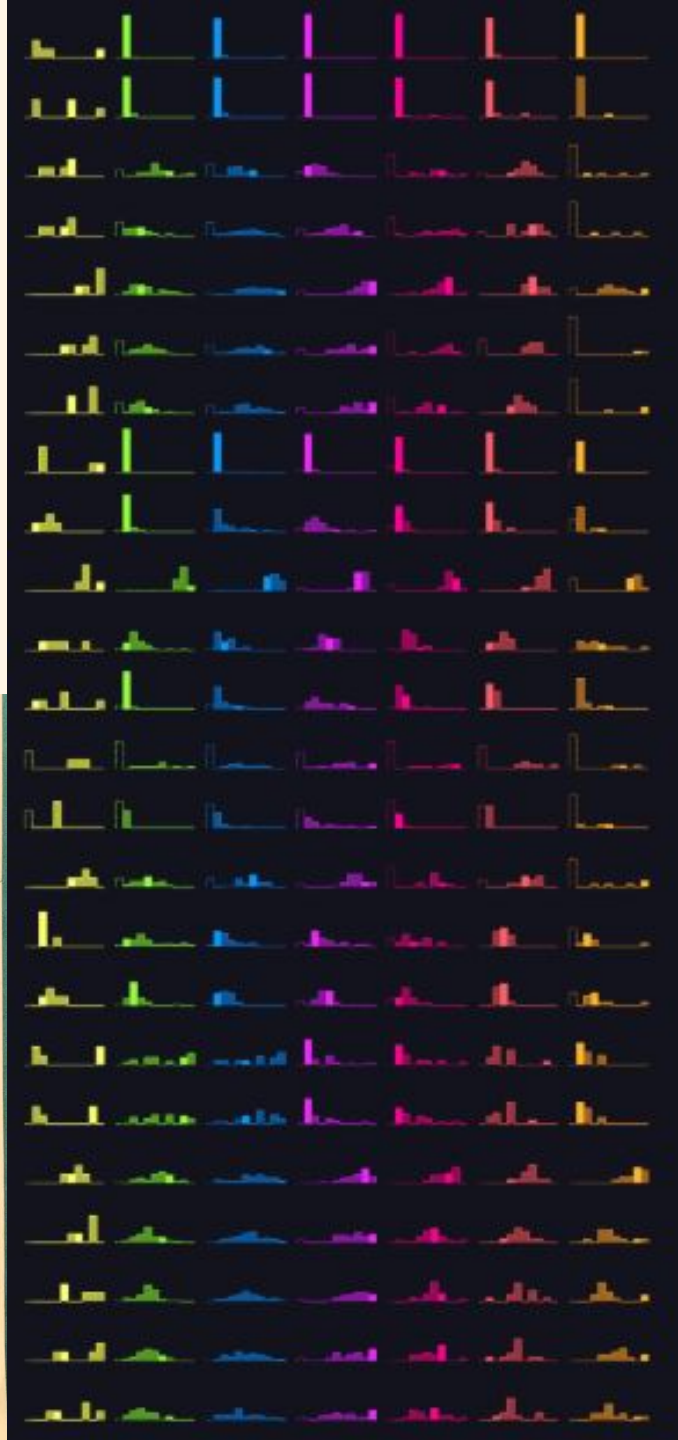
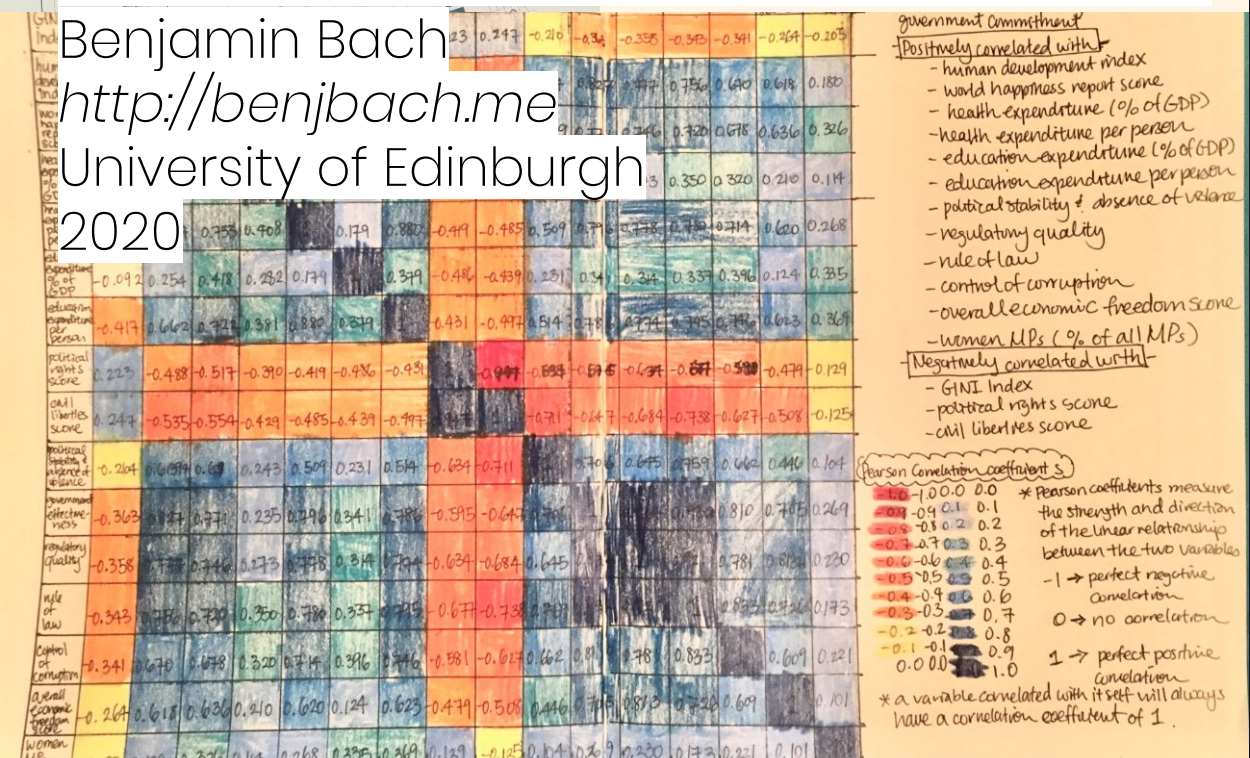




Foundations

Color for Data Vis

Benjamin Bach
http://benjbach.me
University of Edinburgh
2020



Outline

What is color?

Color in visualization

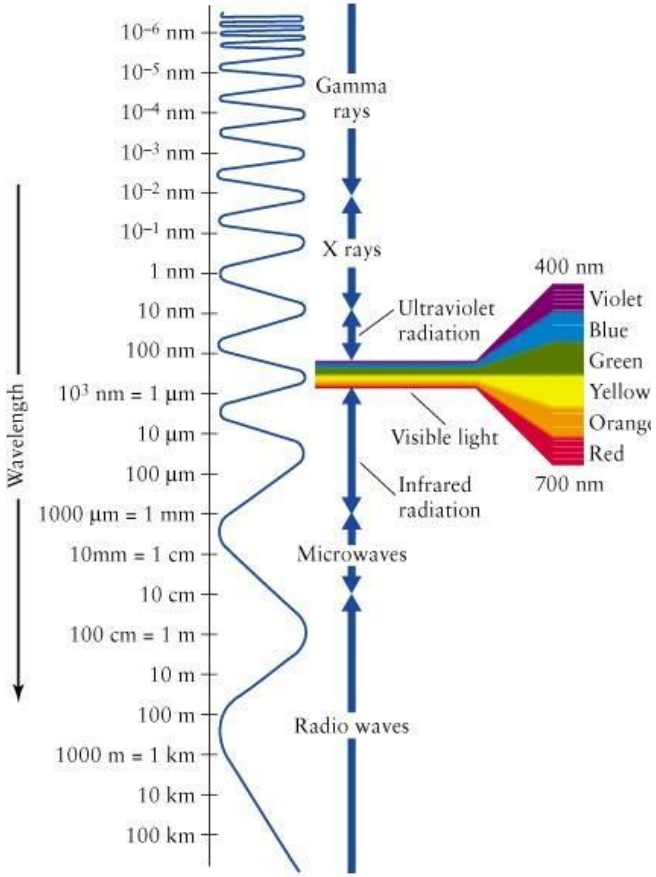
Color Scales

Sequential, diverging, categorical scales

Rainbow color map

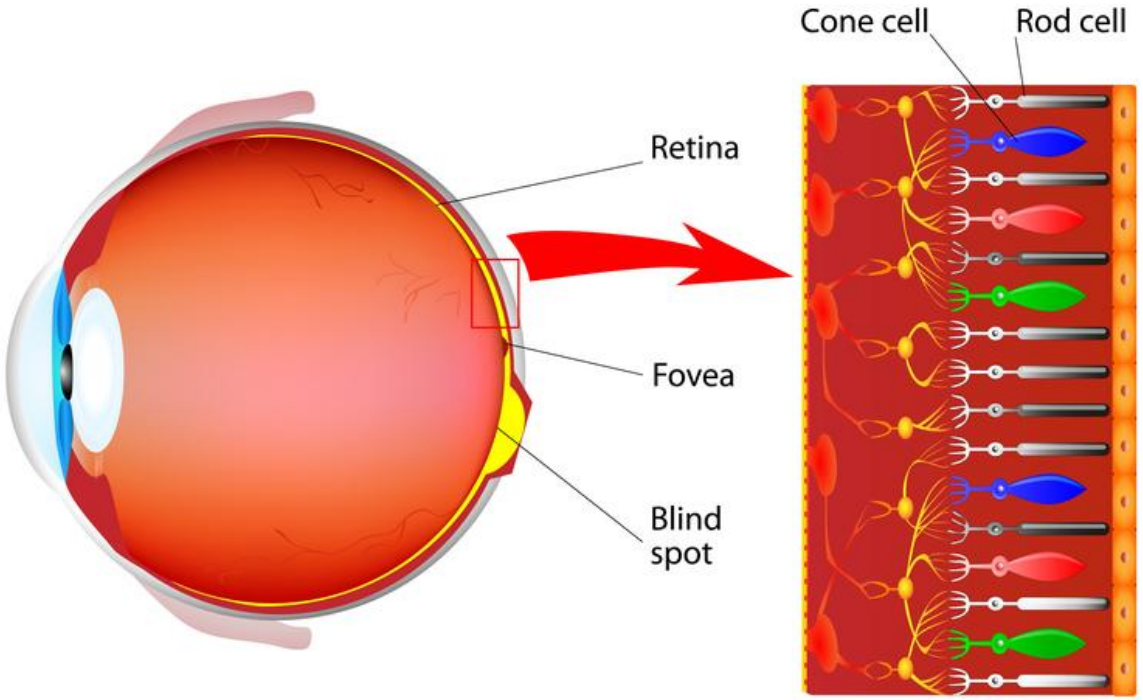
Color blindness

What is Color?

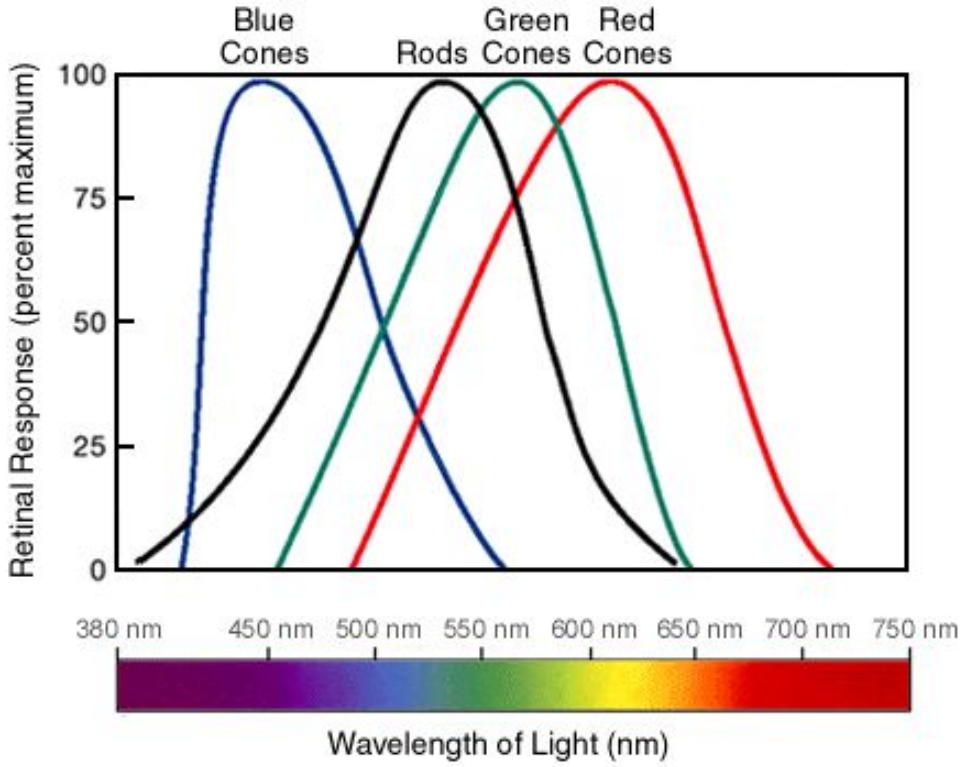


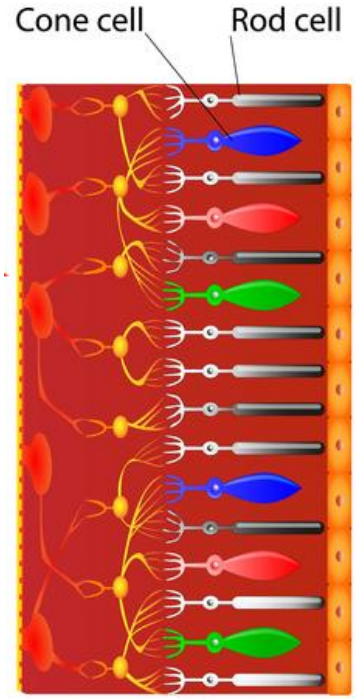
400-700nm

Photoreceptor cell

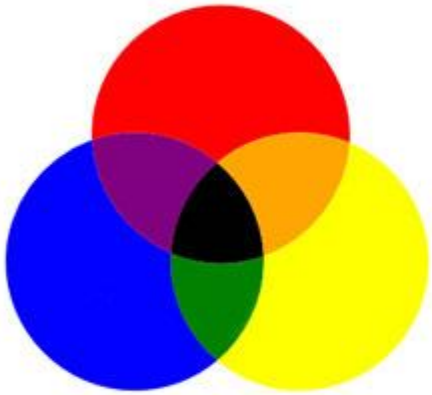


~120 million rods
~6 million cones


Blue Cones
Rods
Green Cones
Red Cones
Retinal Response (percent maximum)
100
75
50
25
0
380 nm
450 nm
500 nm
550 nm
600 nm
650 nm
700 nm
750 nm
Wavelength of Light (nm)


Cone cell
Rod cell

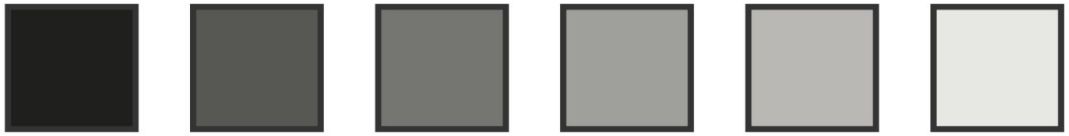
Color Models



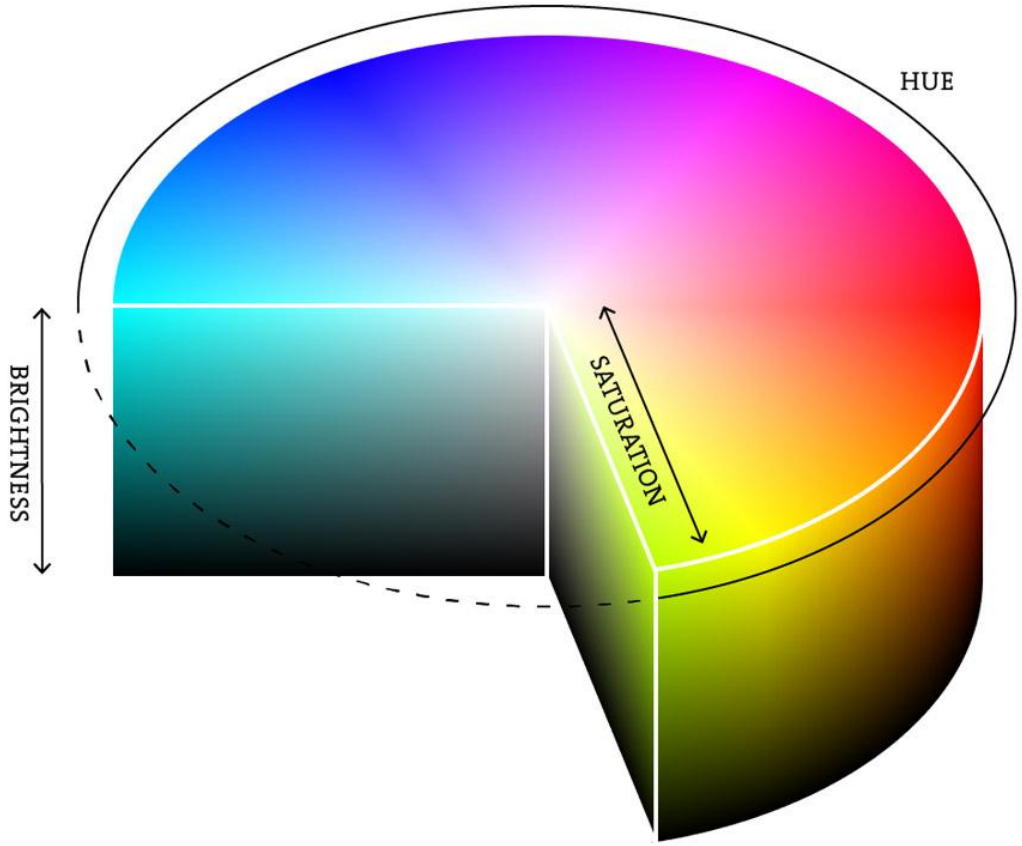
RYB

What is color?

Luminance



HSB Model: Hue, Saturation, Brightness

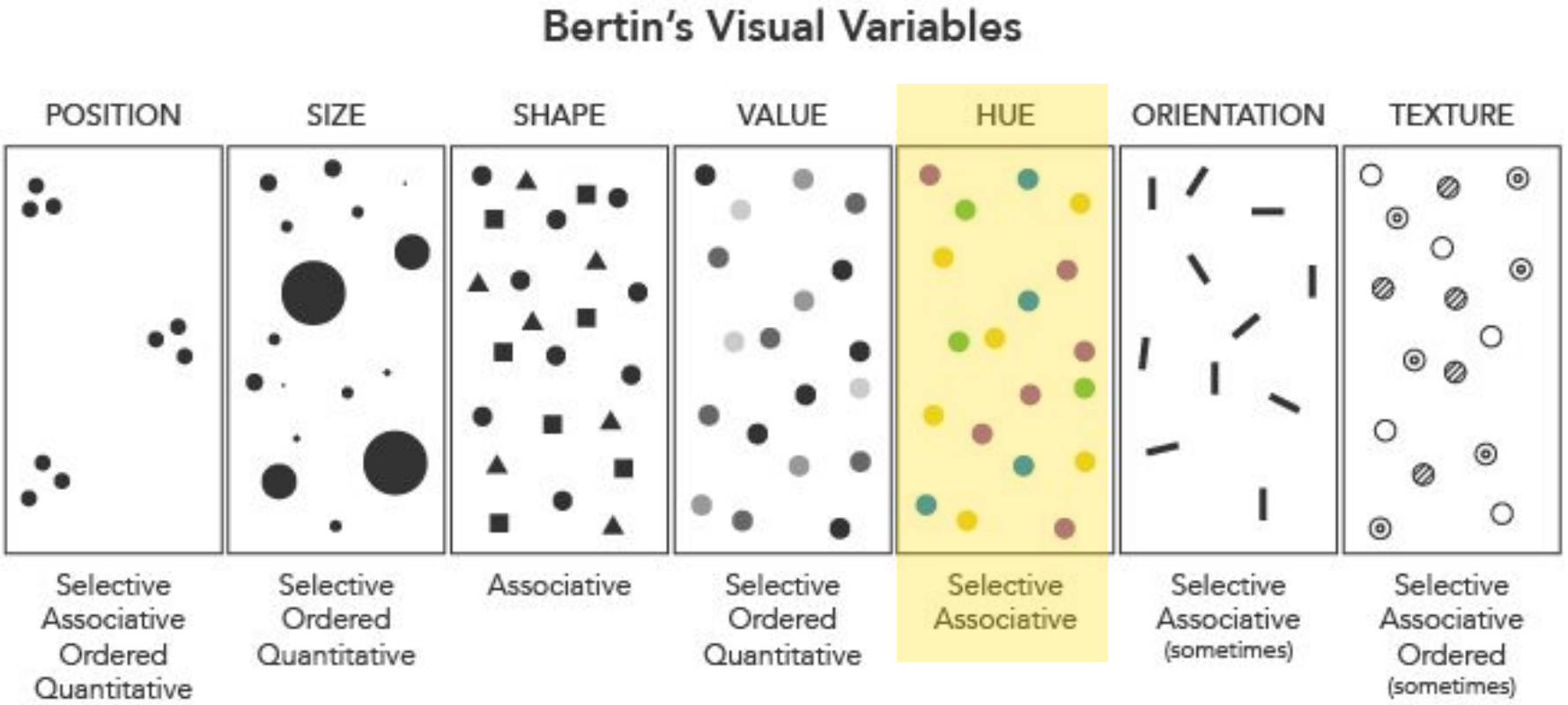


Color = (Brightness/Lightness, Saturation, Hue)

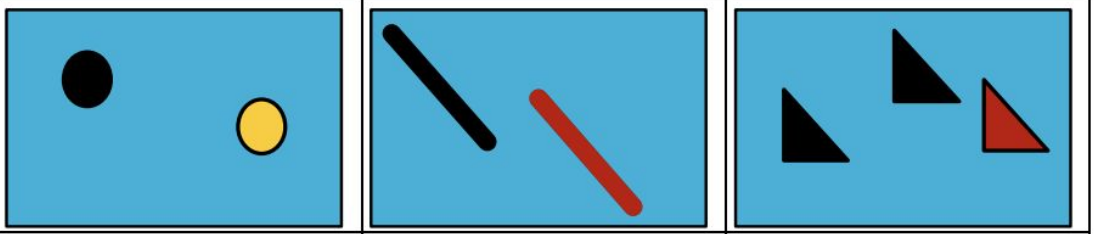
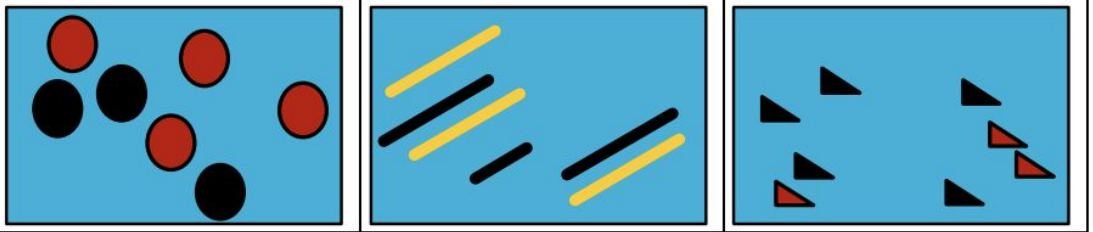
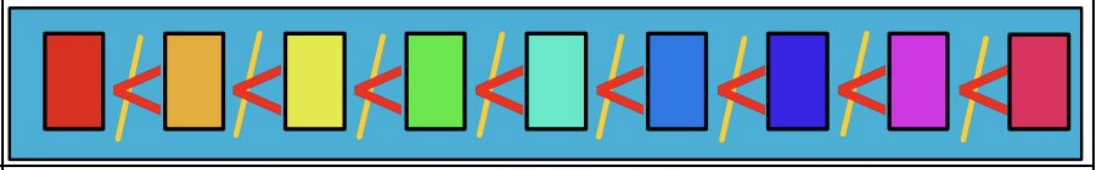
HSB Color Picker

Color in Visualization

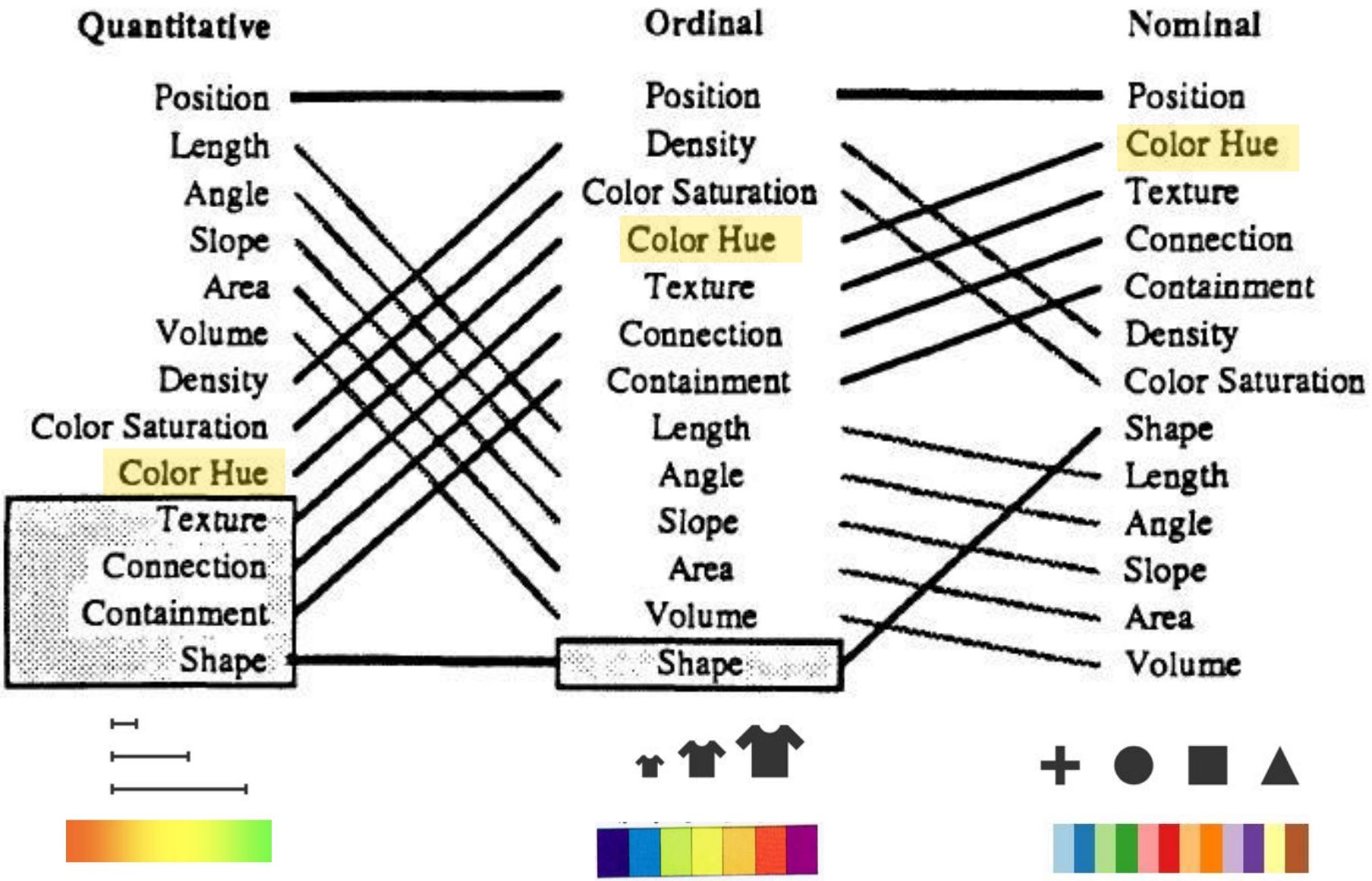
Visual Variables



Visual Variable: Colour

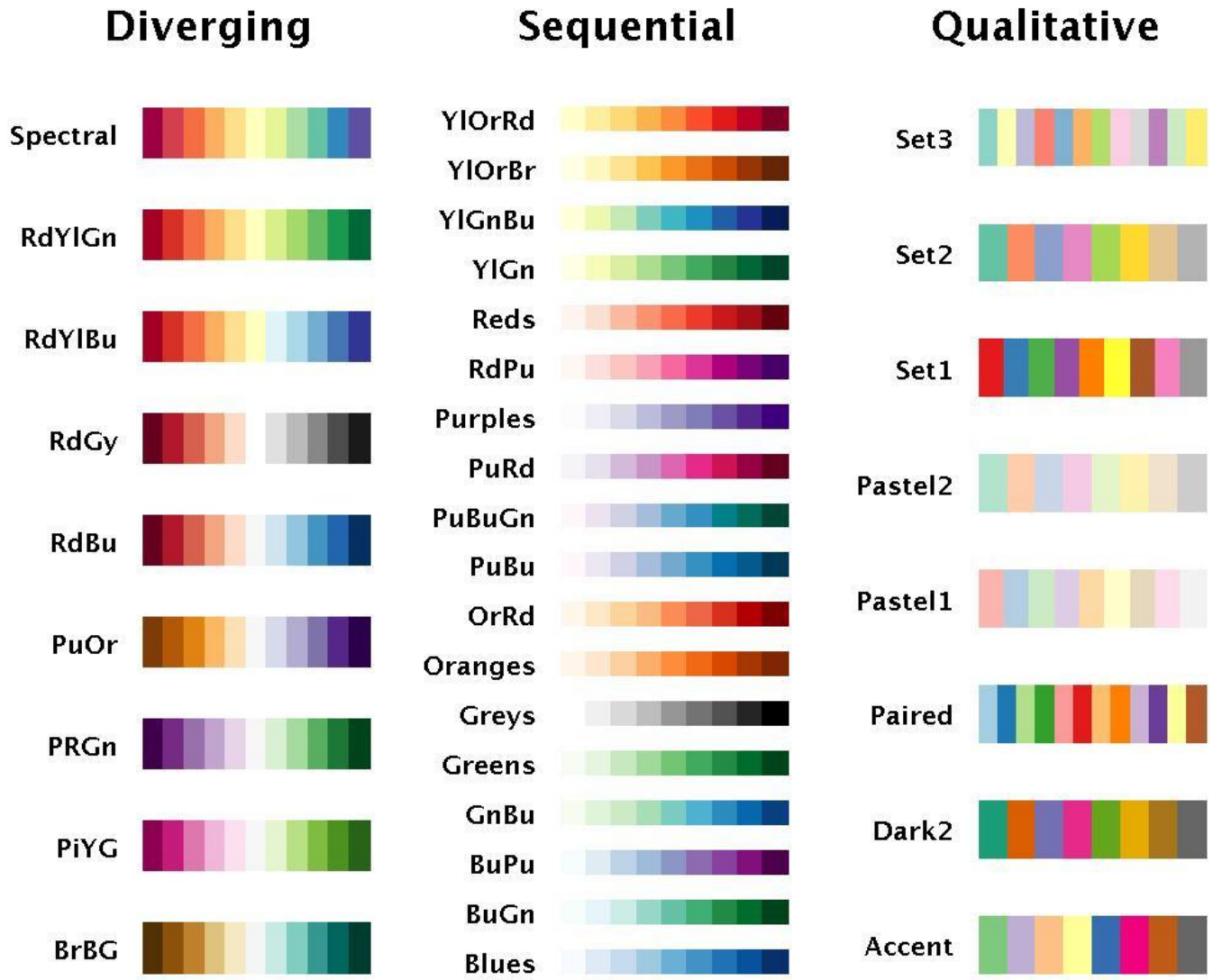
	selective	
	associative	
	quantitative	
	order	
	length	 • theoretically infinite but practically limited • association and selection ~ < 7 and distinction ~ 10

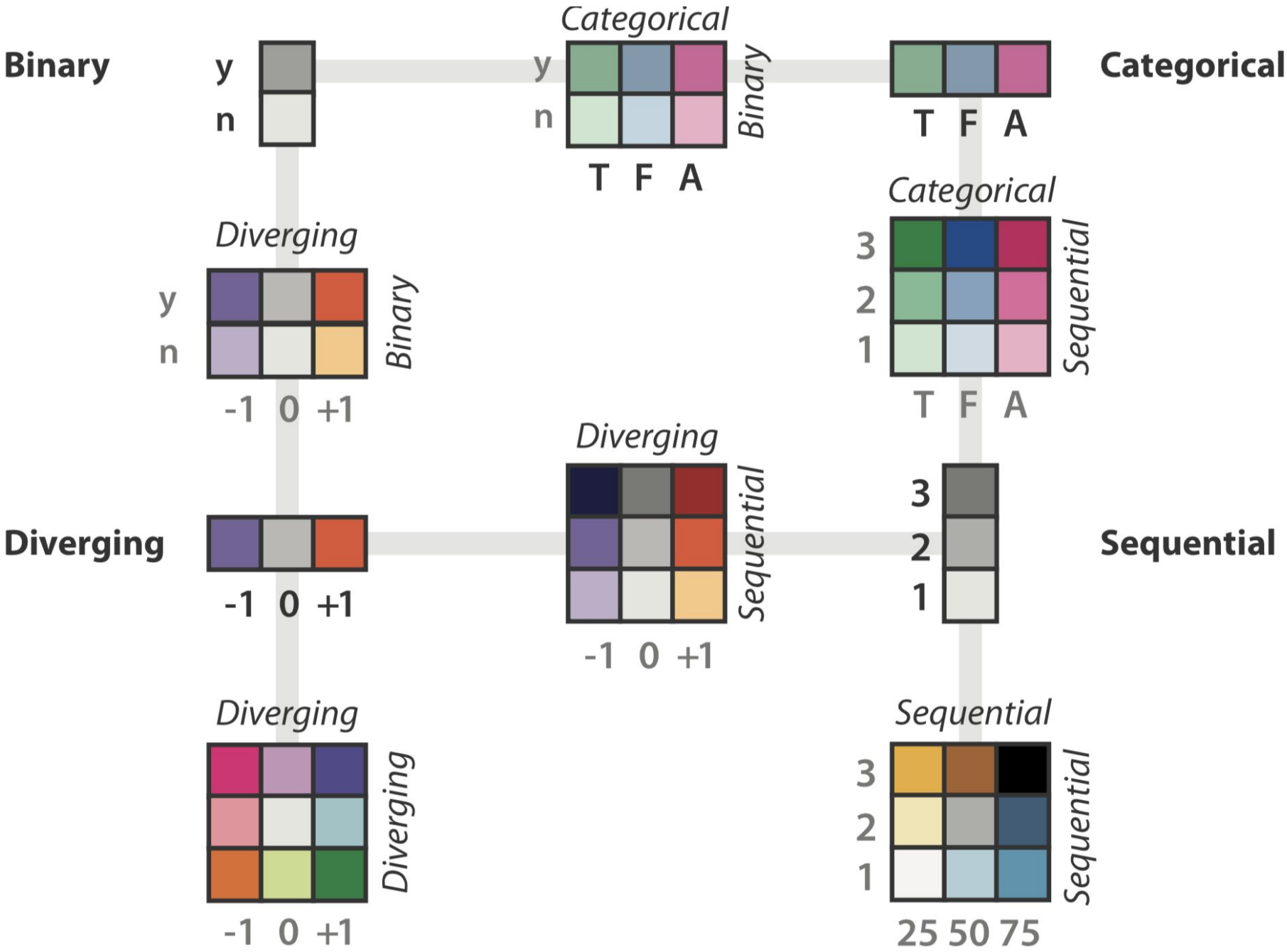
http://innovis.cpsc.ucalgary.ca/innovis/uploads/Publications/Publications/Carpendale_visual_variables.pdf


Quantitative
Ordinal
Nominal
Position
Length
Angle
Slope
Area
Volume
Density
Color Saturation
Color Hue
Texture
Connection
Containment
Shape
Position
Density
Color Saturation
Color Hue
Texture
Connection
Containment
Length
Angle
Slope
Area
Volume
Shape
Position
Color Hue
Texture
Connection
Containment
Density
Color Saturation
Shape
Length
Angle
Slope
Area
Volume

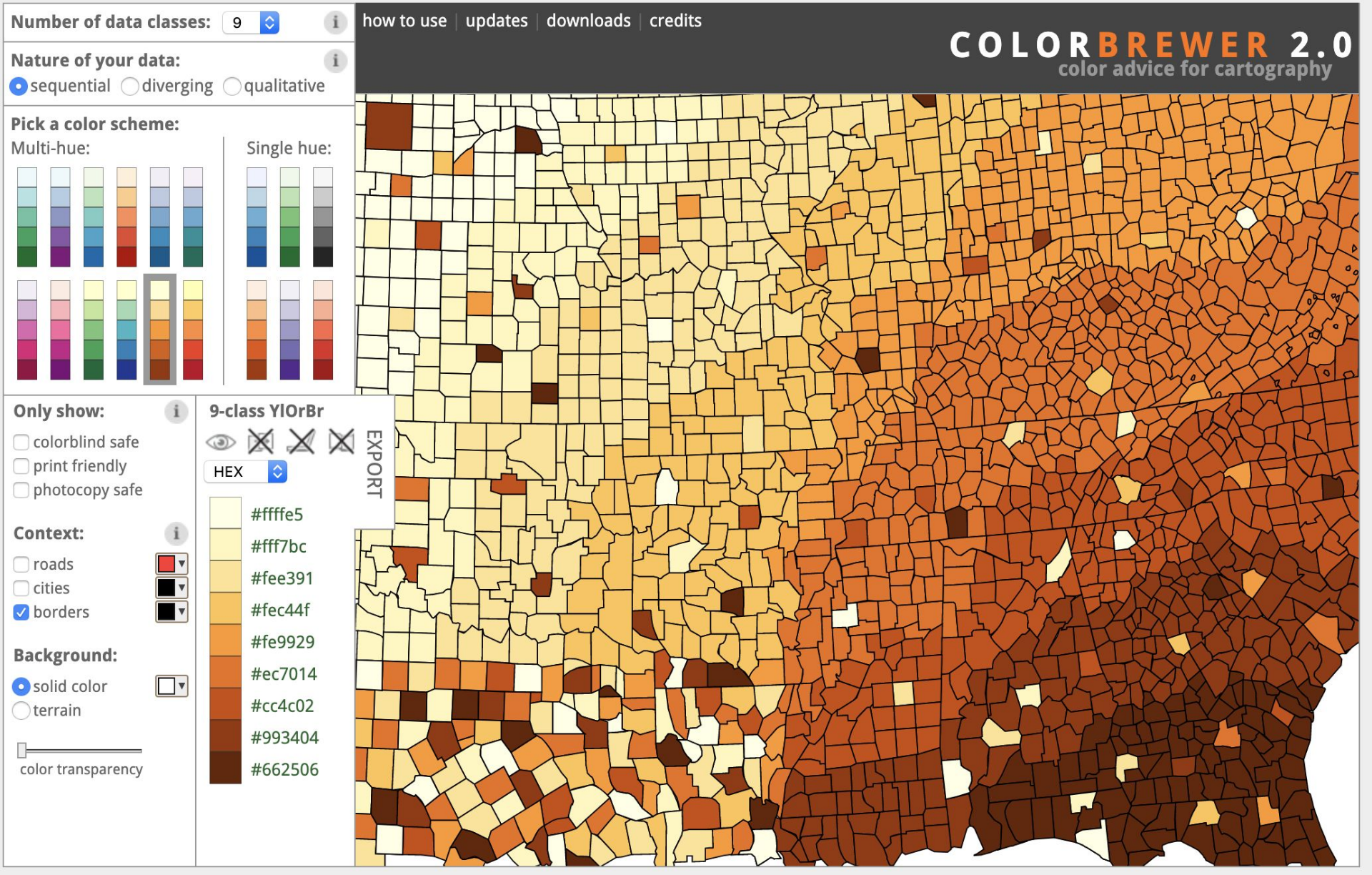
Color Scales

More examples of color scales (ColorBrewer)




Binary
y
n
Categorical
y
n
T F A
Binary
T F A
Categorical
Diverging
y
n
-1 0 +1
Binary
Categorical
3
2
1
Sequential
T F A
Diverging
-1 0 +1
Diverging
Sequential
-1 0 +1
3
2
1
Sequential
Diverging
Diverging
-1 0 +1
Sequential
3
2
1
Sequential
25 50 75

Colorbrewer.org

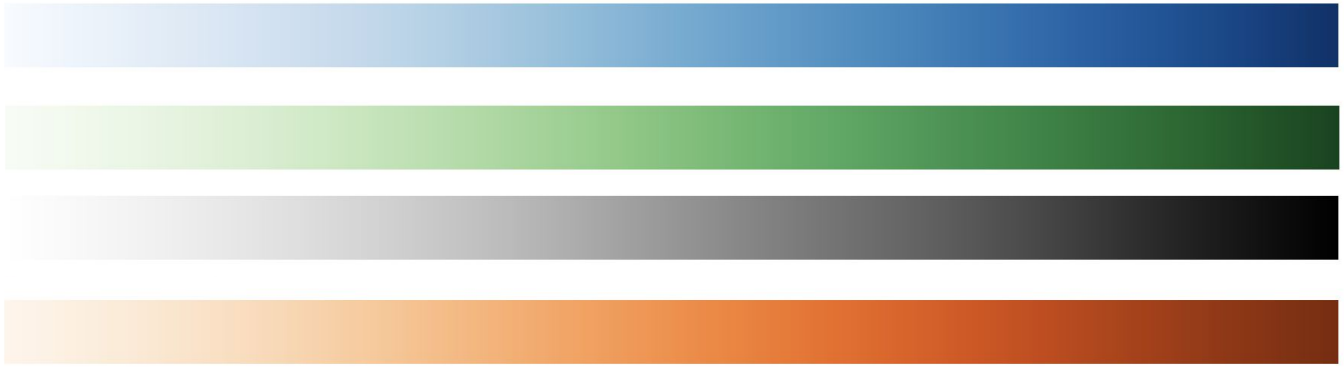


Sequential Scales

More examples of color scales (ColorBrewer)

Sequential color scales

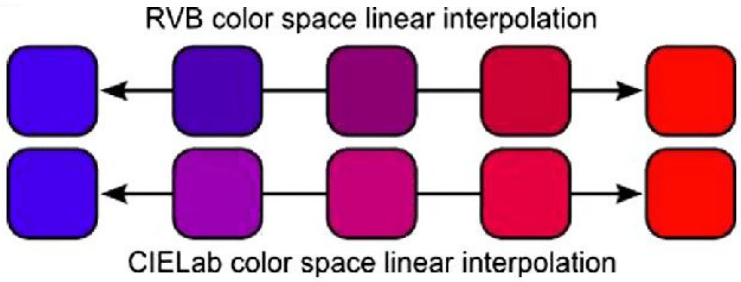
Single hue:



Multi hue:

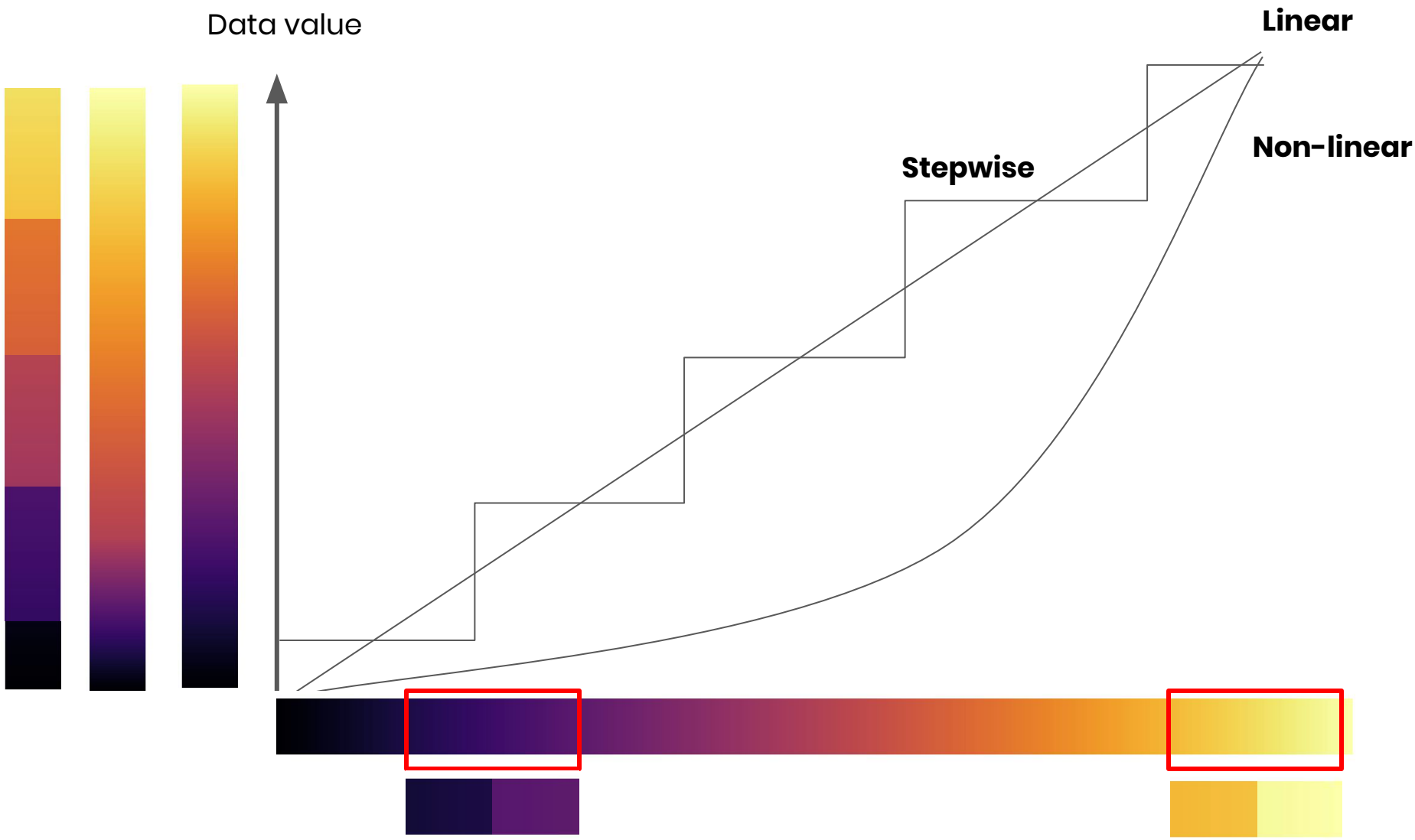
d3.**interpolateViridis**(*t*) <>

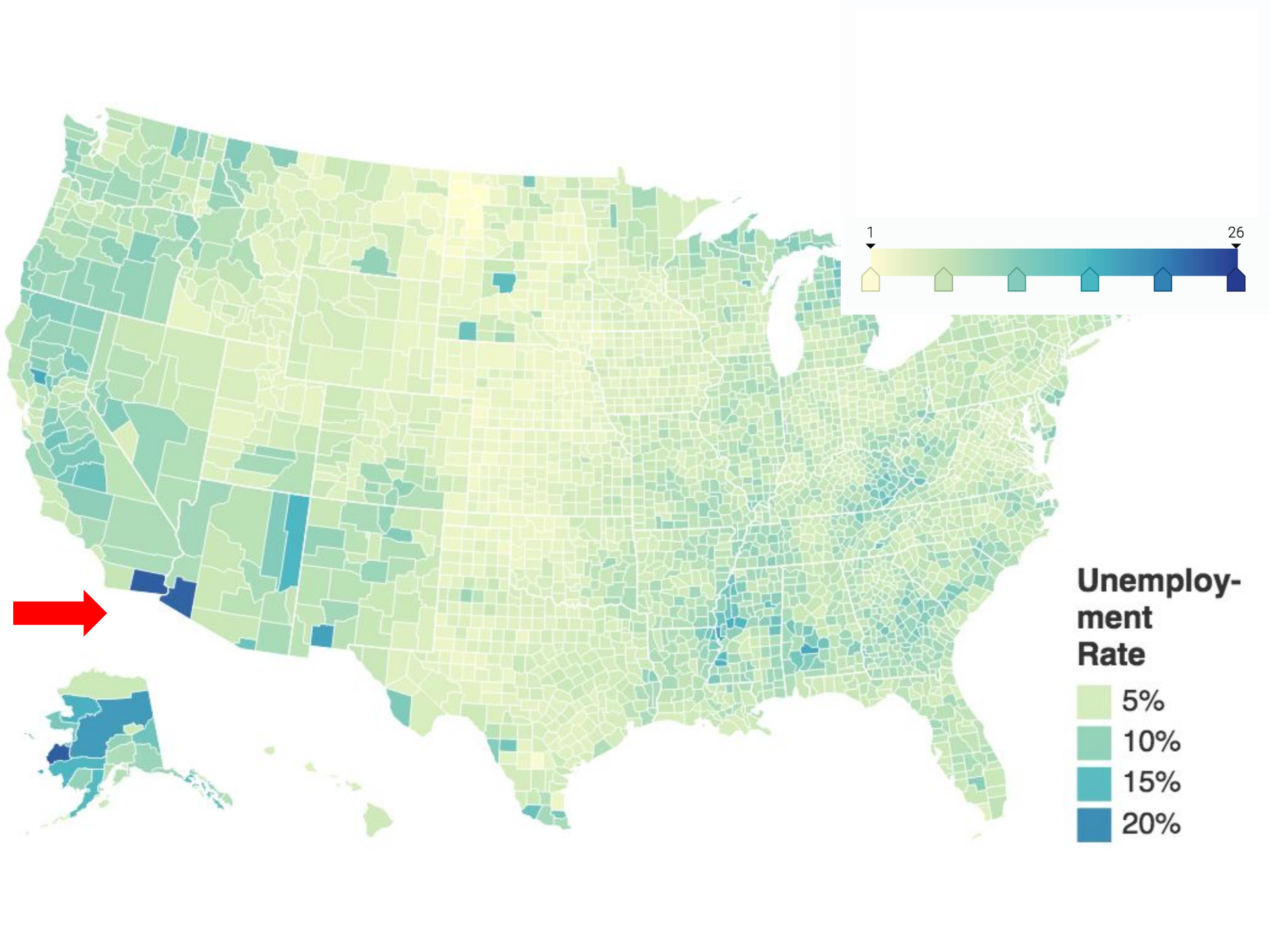
d3.**interpolateInferno**(*t*) <>

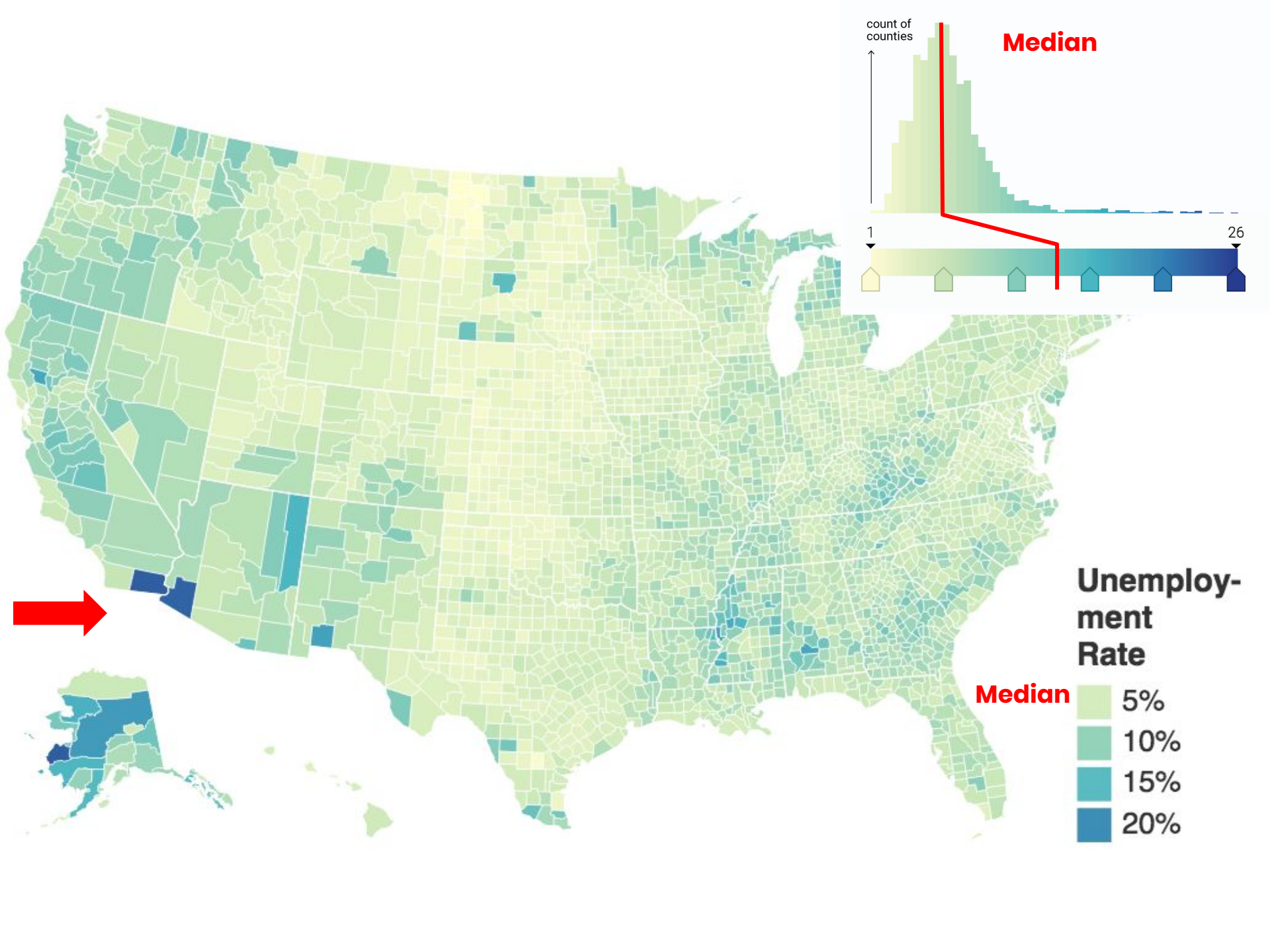


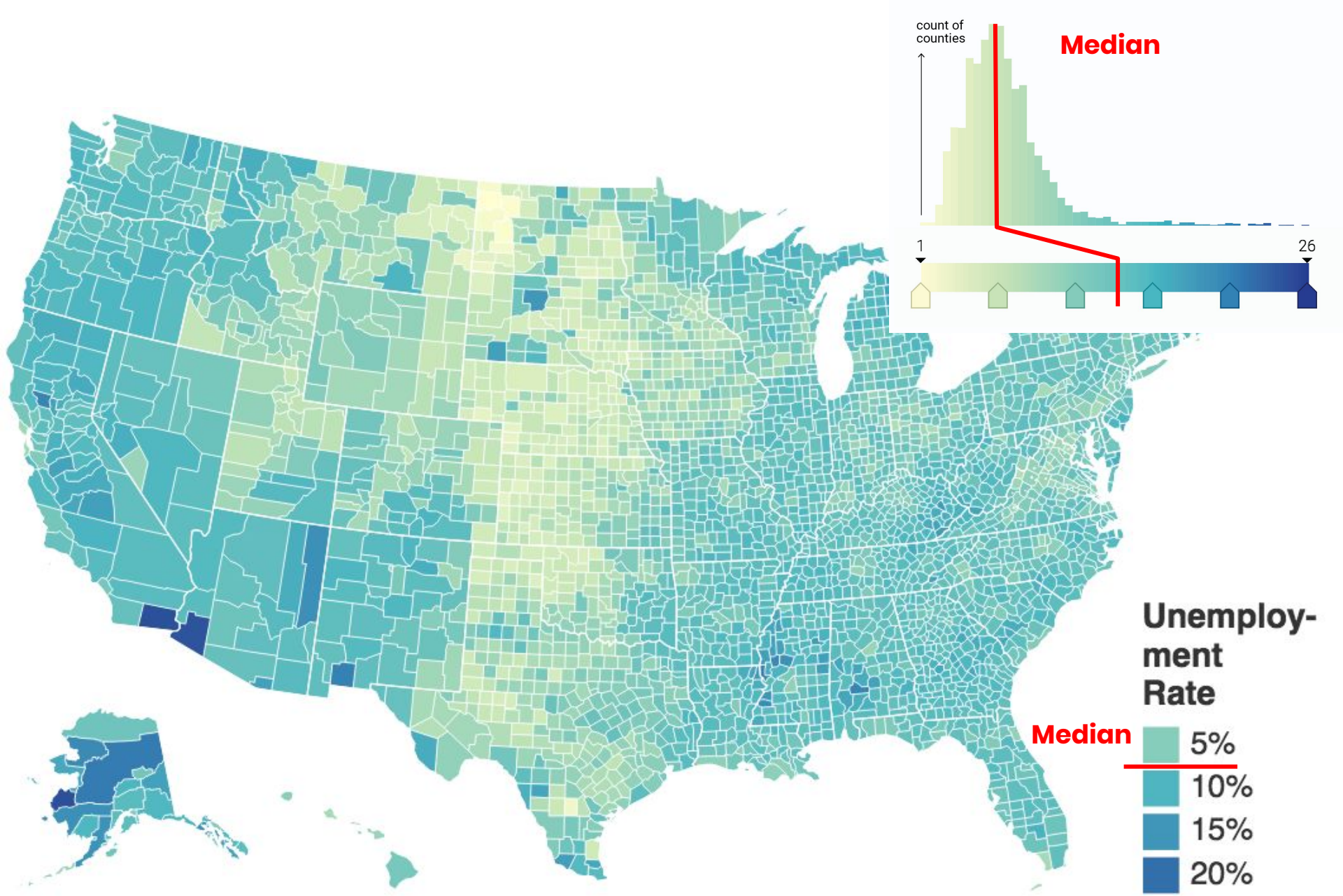
https://github.com/d3/d3-scale-chromatic

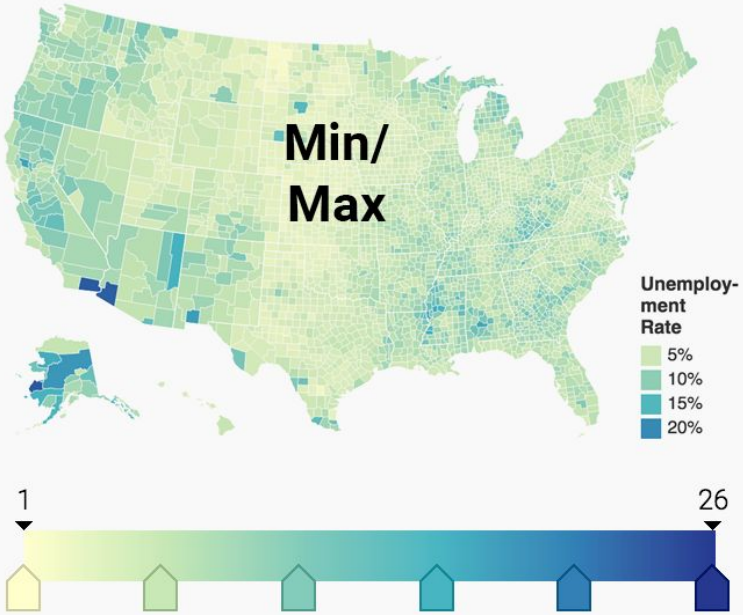
Mapping color scales

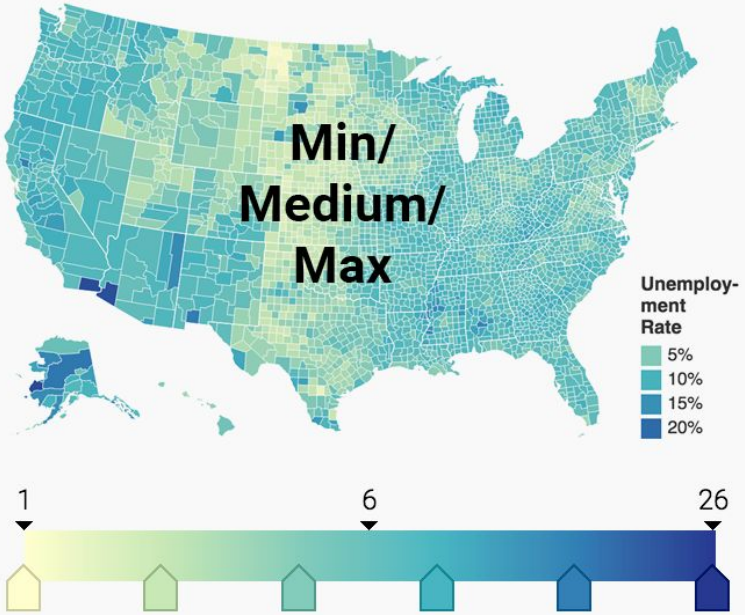


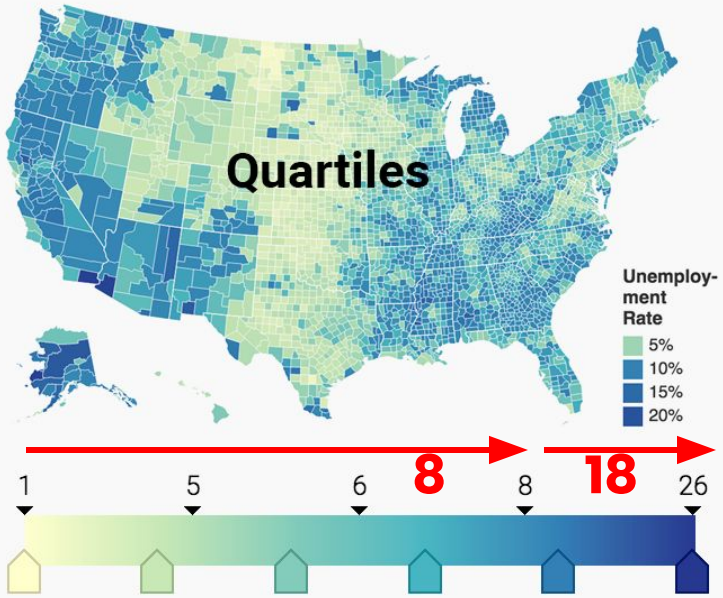

1
26
Unemploy-
ment
Rate
5%
10%
15%
20%

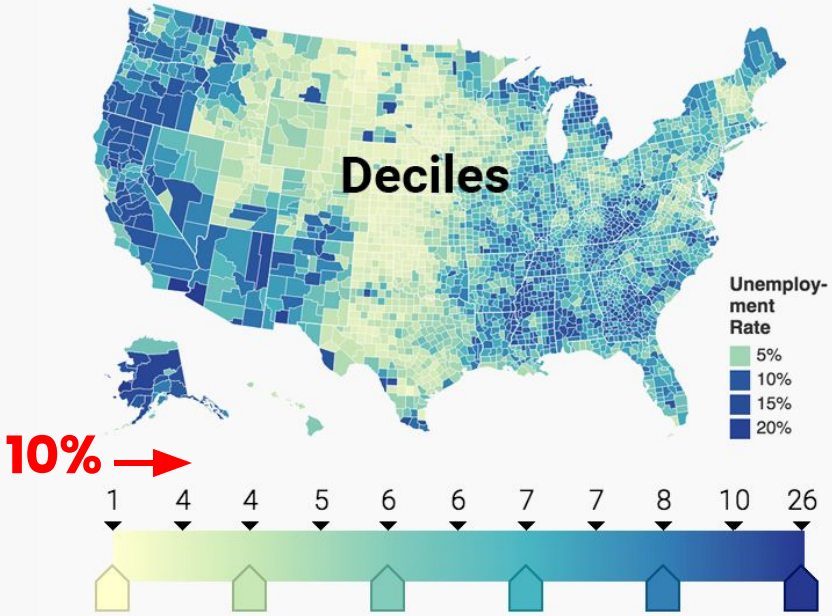

count of counties
Median
1
26
Unemploy-ment Rate
Median
5%
10%
15%
20%

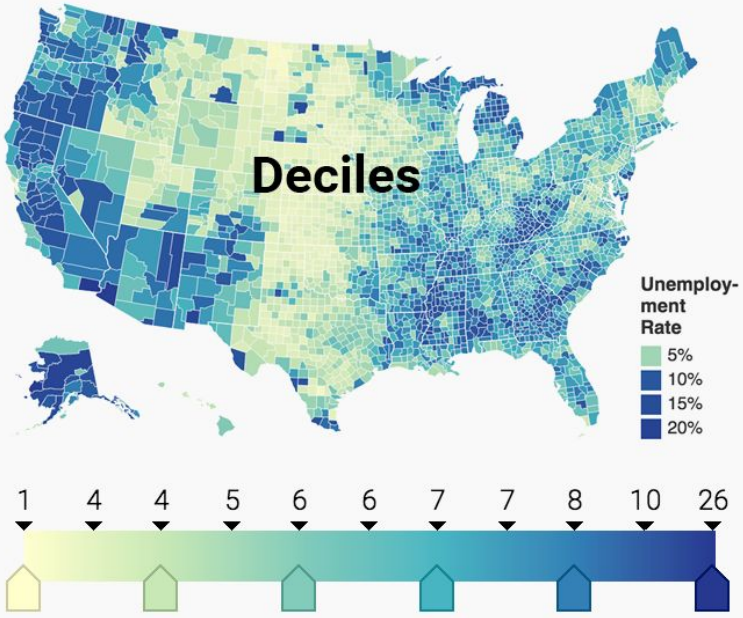

count of counties
Median
1
26
Unemploy-ment Rate
Median
5%
10%
15%
20%

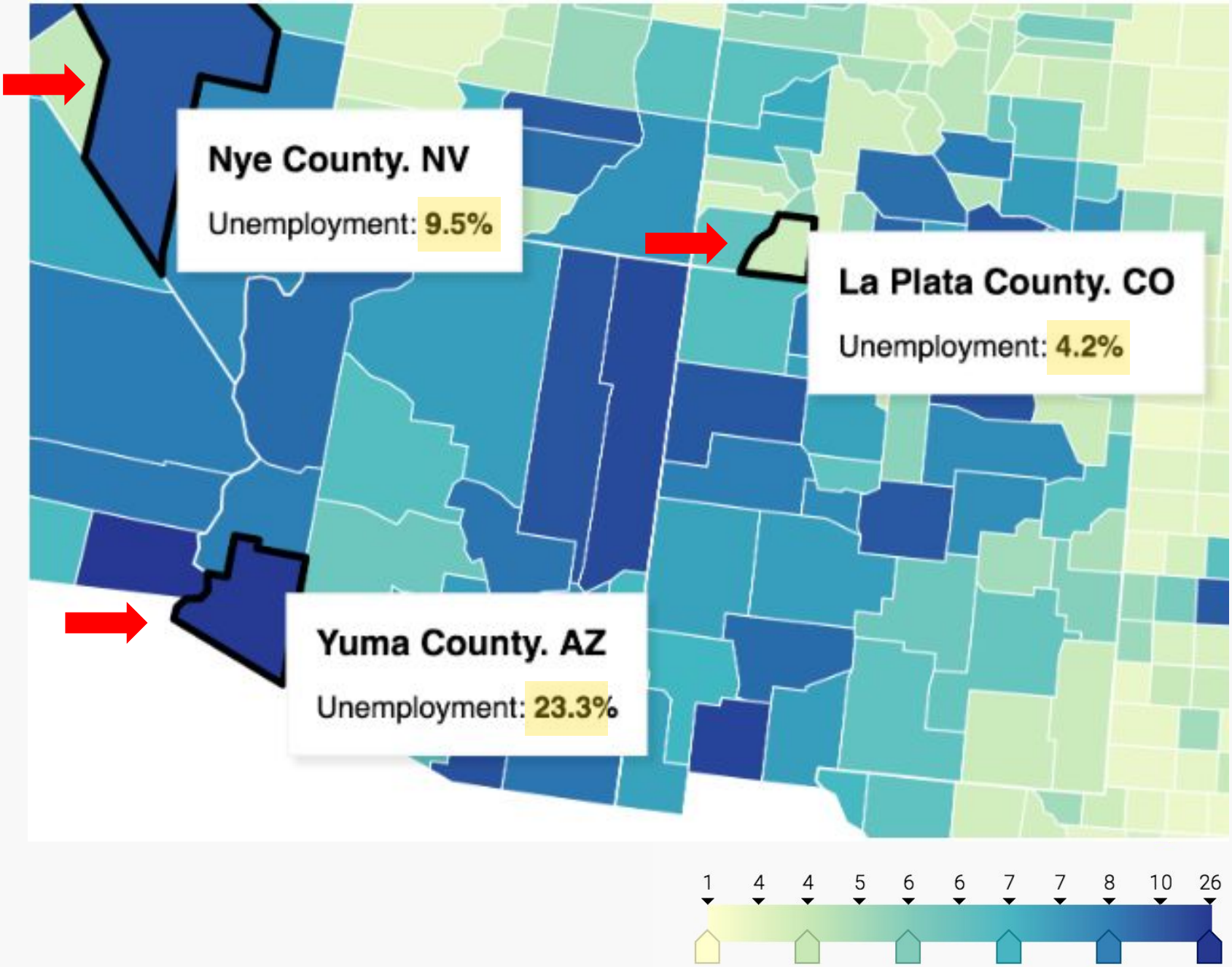

Min/
Max
Unemploy-
ment
Rate
5%
10%
15%
20%
1
26

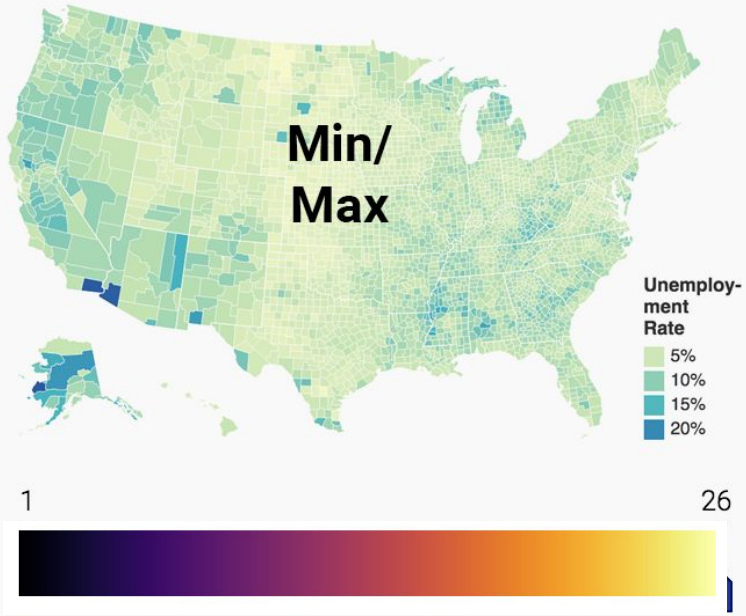

Min/
Medium/
Max
Unemploy-
ment
Rate
5%
10%
15%
20%
1
6
26

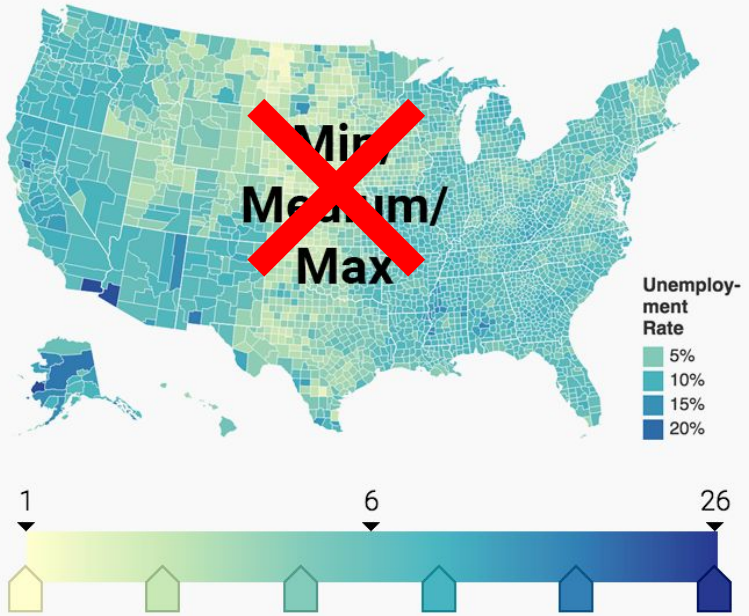

Quartiles
Unemploy-
ment
Rate
5%
10%
15%
20%
8
18
1
5
6
8
26

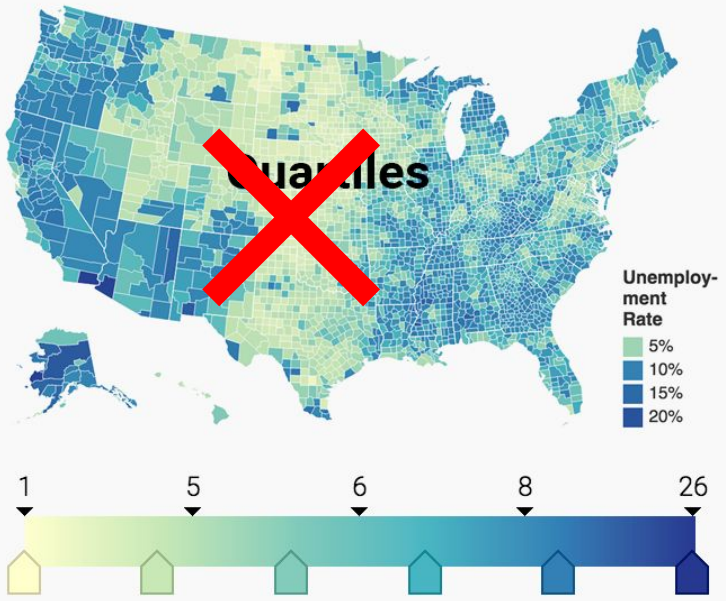

Deciles
Unemploy-
ment
Rate
5%
10%
15%
20%
10%
1
4
4
5
6
6
7
7
8
10
26

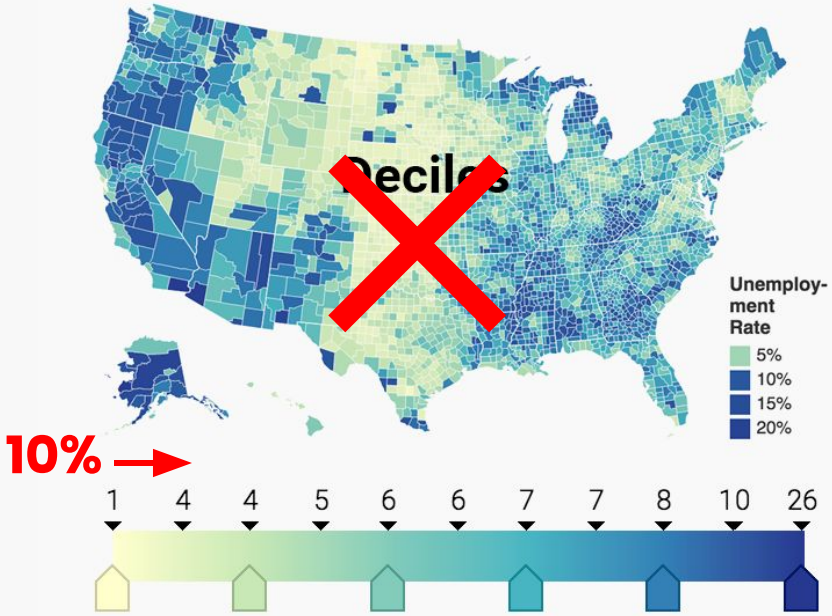

Deciles
Unemploy-
ment
Rate
5%
10%
15%
20%
1
4
4
5
6
6
7
7
8
10
26


Nye County. NV
Unemployment: 9.5%
La Plata County. CO
Unemployment: 4.2%
Yuma County. AZ
Unemployment: 23.3%
1
4
4
5
6
6
7
7
8
10
26


Min/
Max
Unemploy-
ment
Rate
5%
10%
15%
20%
1
26

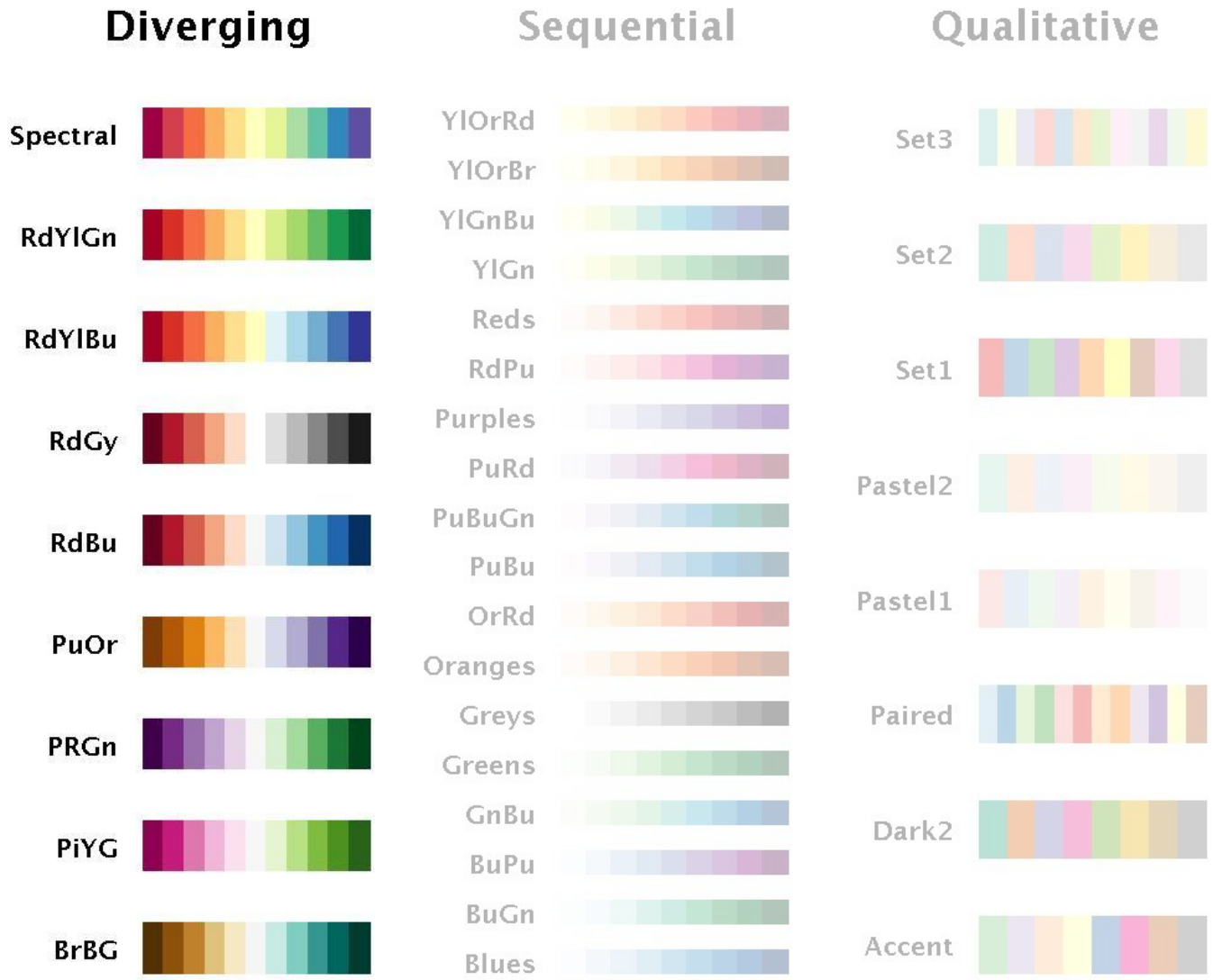

Min/
Medium/
Max
Unemploy-
ment
Rate
5%
10%
15%
20%
1
6
26


Quartiles
Unemploy-
ment
Rate
5%
10%
15%
20%
1
5
6
8
26

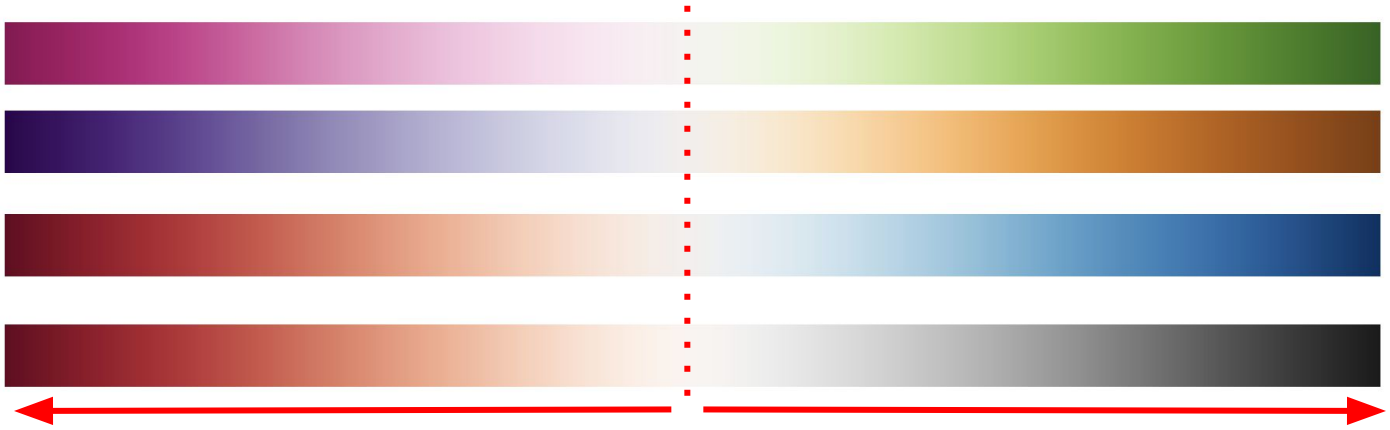

Deciles
Unemploy-
ment
Rate
5%
10%
15%
20%
10%
1
4
4
5
6
6
7
7
8
10
26

Diverging Scales

More examples of color scales (ColorBrewer)



Diverging color scale



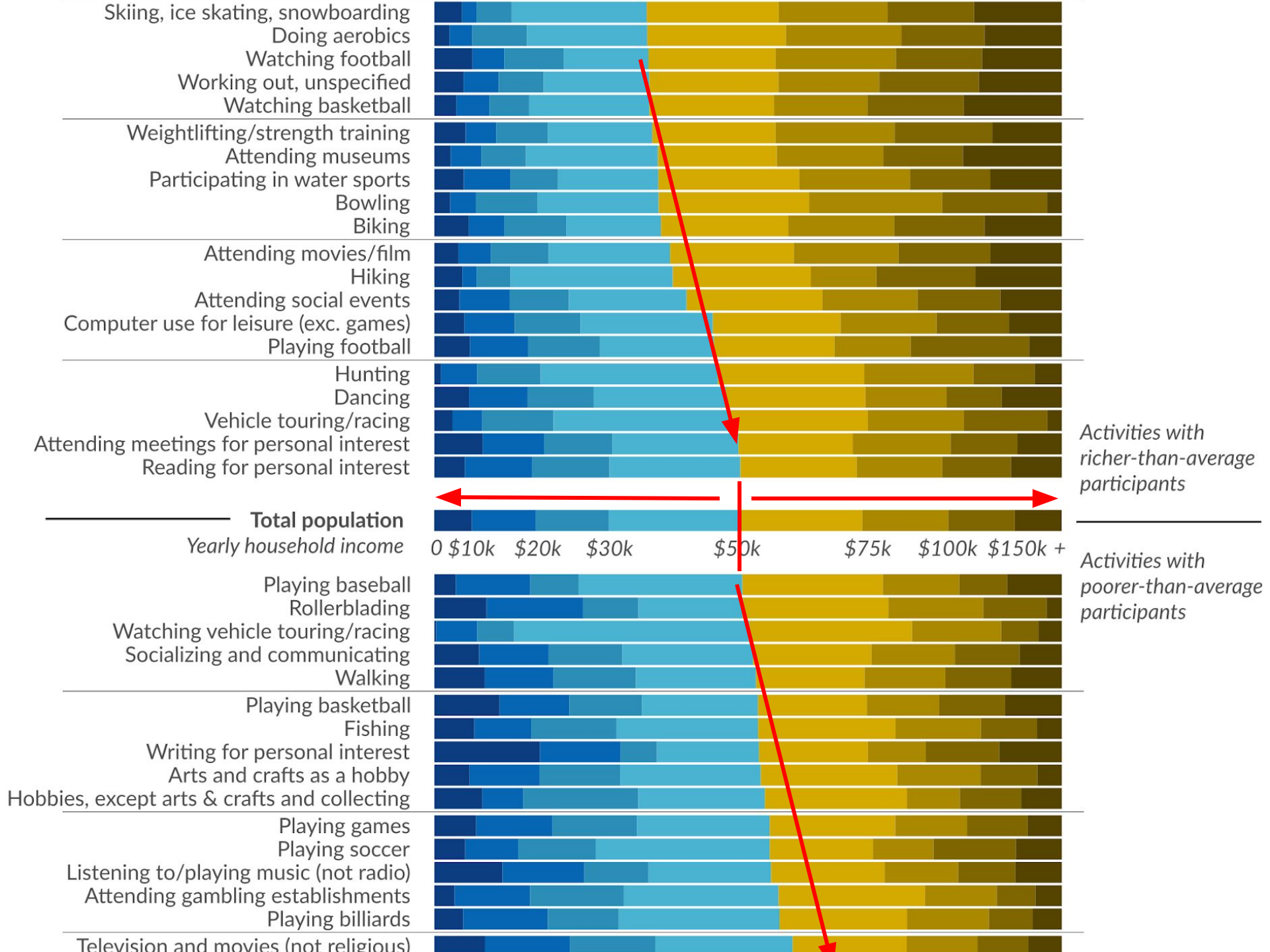
Multi hue:

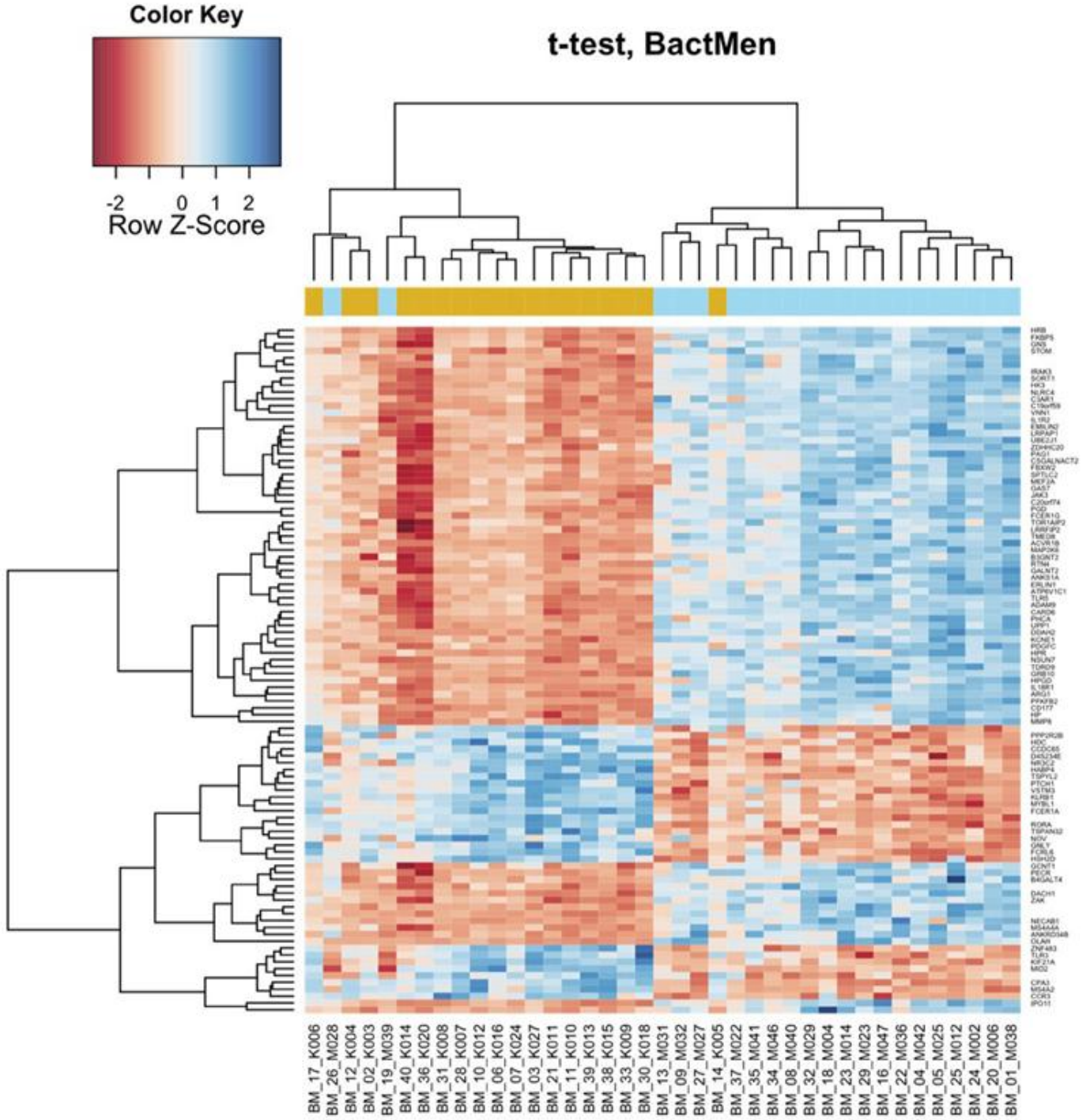
d3.interpolateViridis(*t*) <>

d3.interpolateInferno(*t*) <>

d3.interpolateMagma(*t*) <>

d3.interpolateCividis(*t*) <>


Skiing, ice skating, snowboarding
Doing aerobics
Watching football
Working out, unspecified
Watching basketball
Weightlifting/strength training
Attending museums
Participating in water sports
Bowling
Biking
Attending movies/film
Hiking
Attending social events
Computer use for leisure (exc. games)
Playing football
Hunting
Dancing
Vehicle touring/racing
Attending meetings for personal interest
Reading for personal interest
Activities with richer-than-average participants
Total population
Yearly household income
0 $10k
$20k
$30k
$50k
$75k
$100k
$150k +
Activities with poorer-than-average participants
Playing baseball
Rollerblading
Watching vehicle touring/racing
Socializing and communicating
Walking
Playing basketball
Fishing
Writing for personal interest
Arts and crafts as a hobby
Hobbies, except arts & crafts and collecting
Playing games
Playing soccer
Listening to/playing music (not radio)
Attending gambling establishments
Playing billiards
Television and movies (not religious)

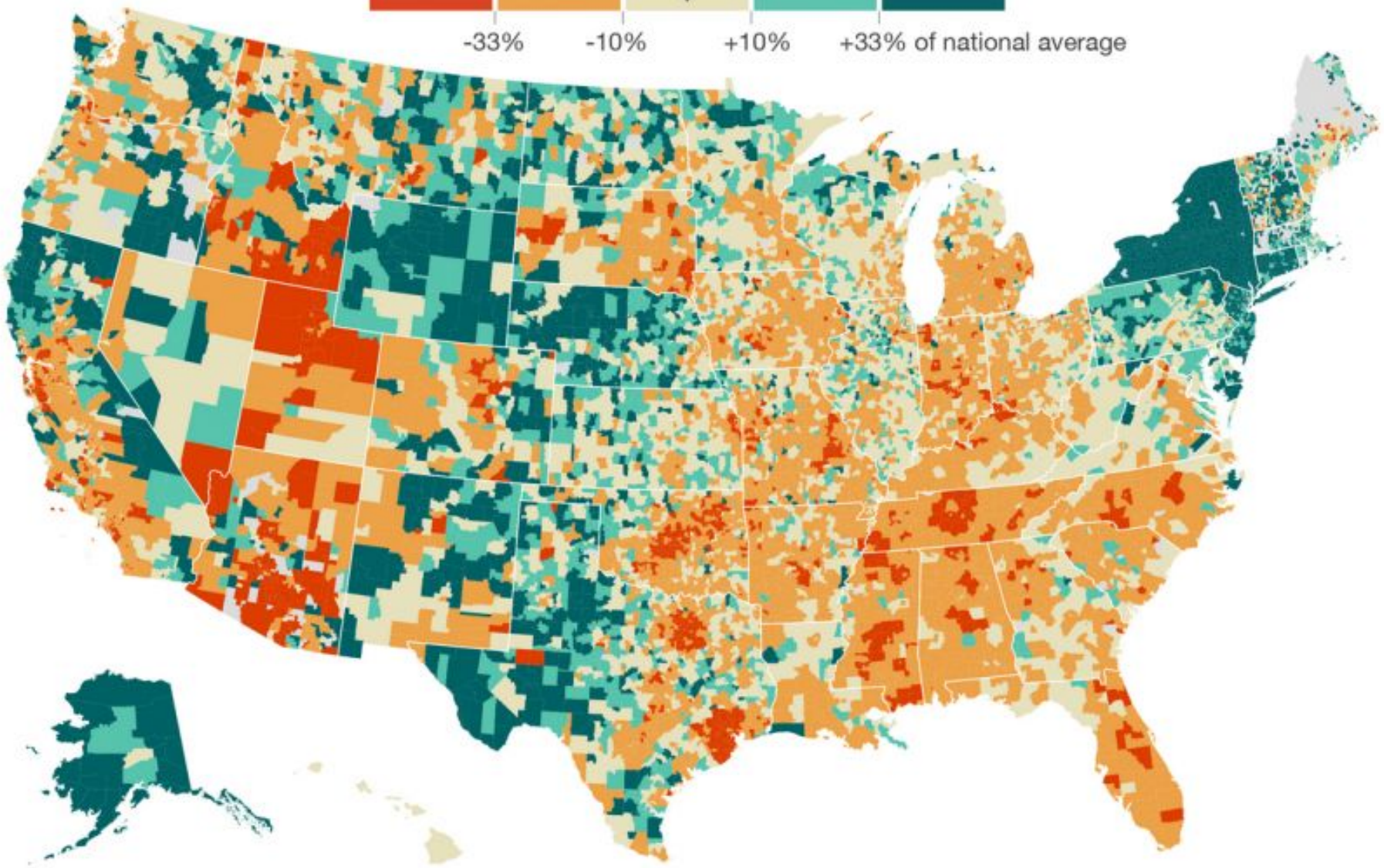

Color Key
-2
0
1
2
Row Z-Score
t-test, BactMen
BM_17_K006
BM_26_M028
BM_12_K004
BM_02_K003
BM_19_M039
BM_40_K014
BM_36_K020
BM_31_K008
BM_28_K007
BM_10_K012
BM_06_K016
BM_07_K024
BM_03_K027
BM_21_K011
BM_11_K010
BM_39_K013
BM_38_K015
BM_33_K009
BM_30_K018
BM_13_M031
BM_09_M032
BM_27_M027
BM_14_K005
BM_37_M022
BM_35_M041
BM_34_M046
BM_08_M040
BM_32_M029
BM_18_M004
BM_23_M014
BM_29_M023
BM_16_M047
BM_22_M036
BM_04_M042
BM_05_M025
BM_25_M012
BM_24_M002
BM_20_M006
BM_01_M038

SPENDING PER STUDENT, BY SCHOOL DISTRICT

Adjusted for regional differences, for primary and unified school districts

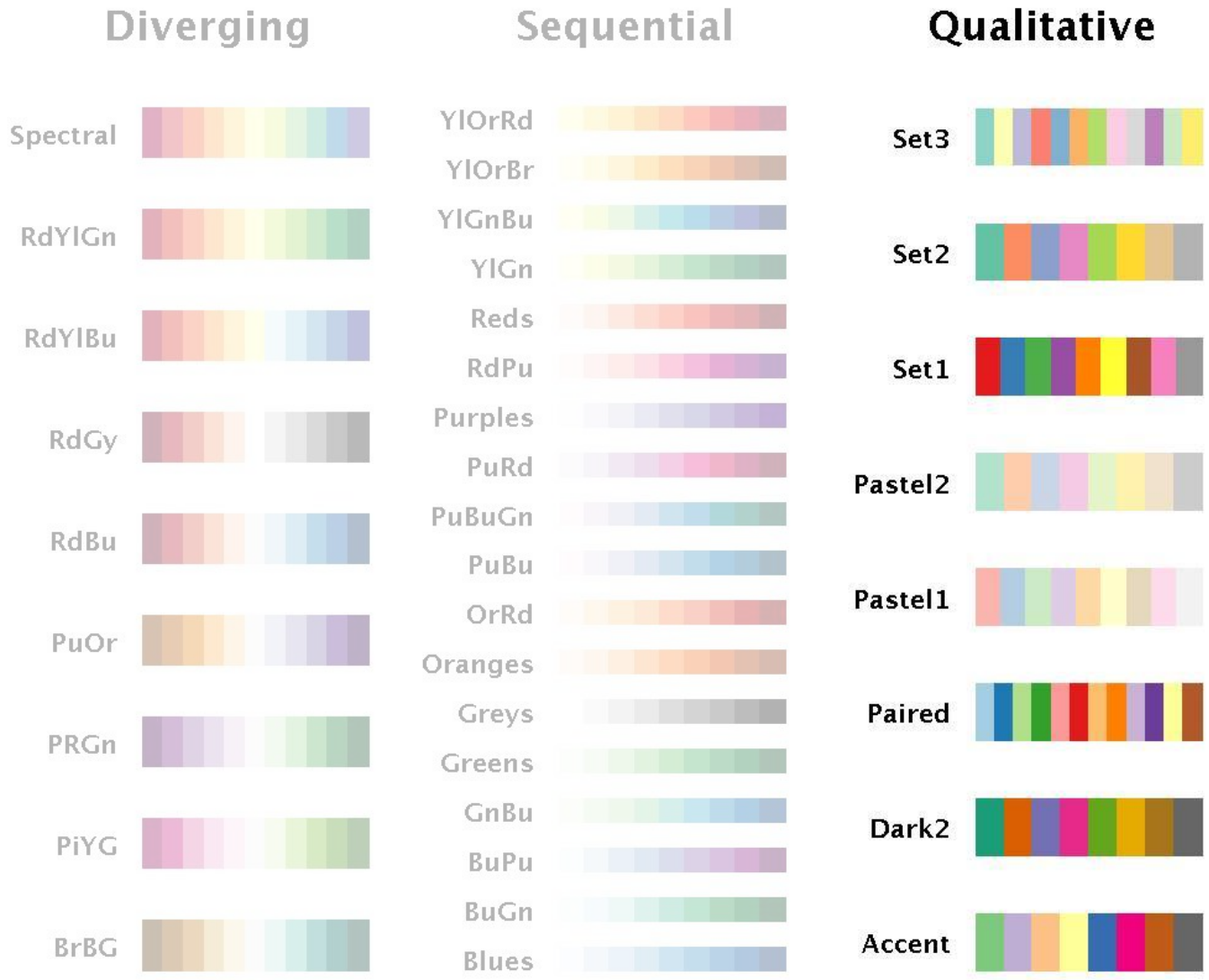
National average: $11,841

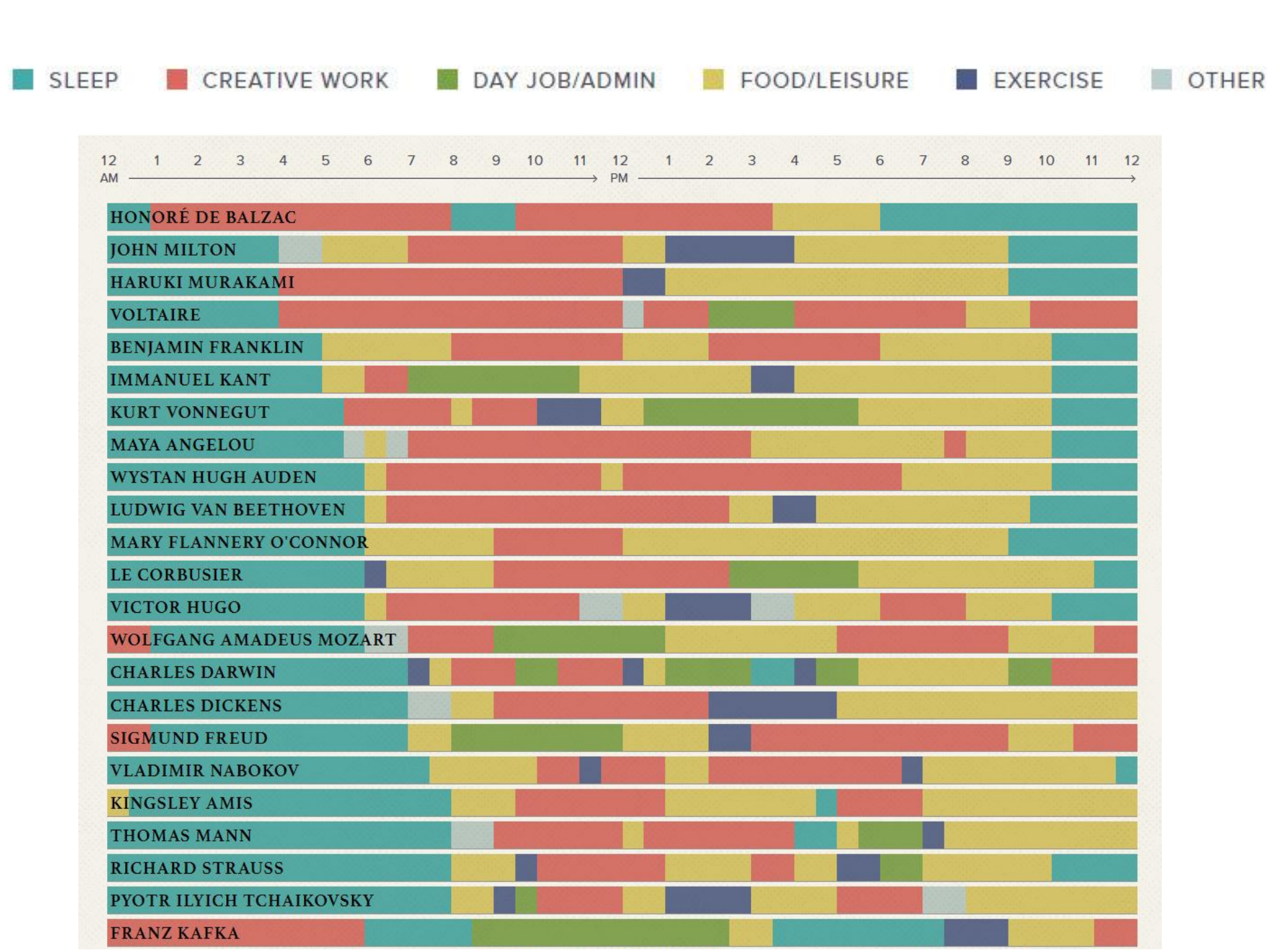
-33% -10% +10% +33% of national average

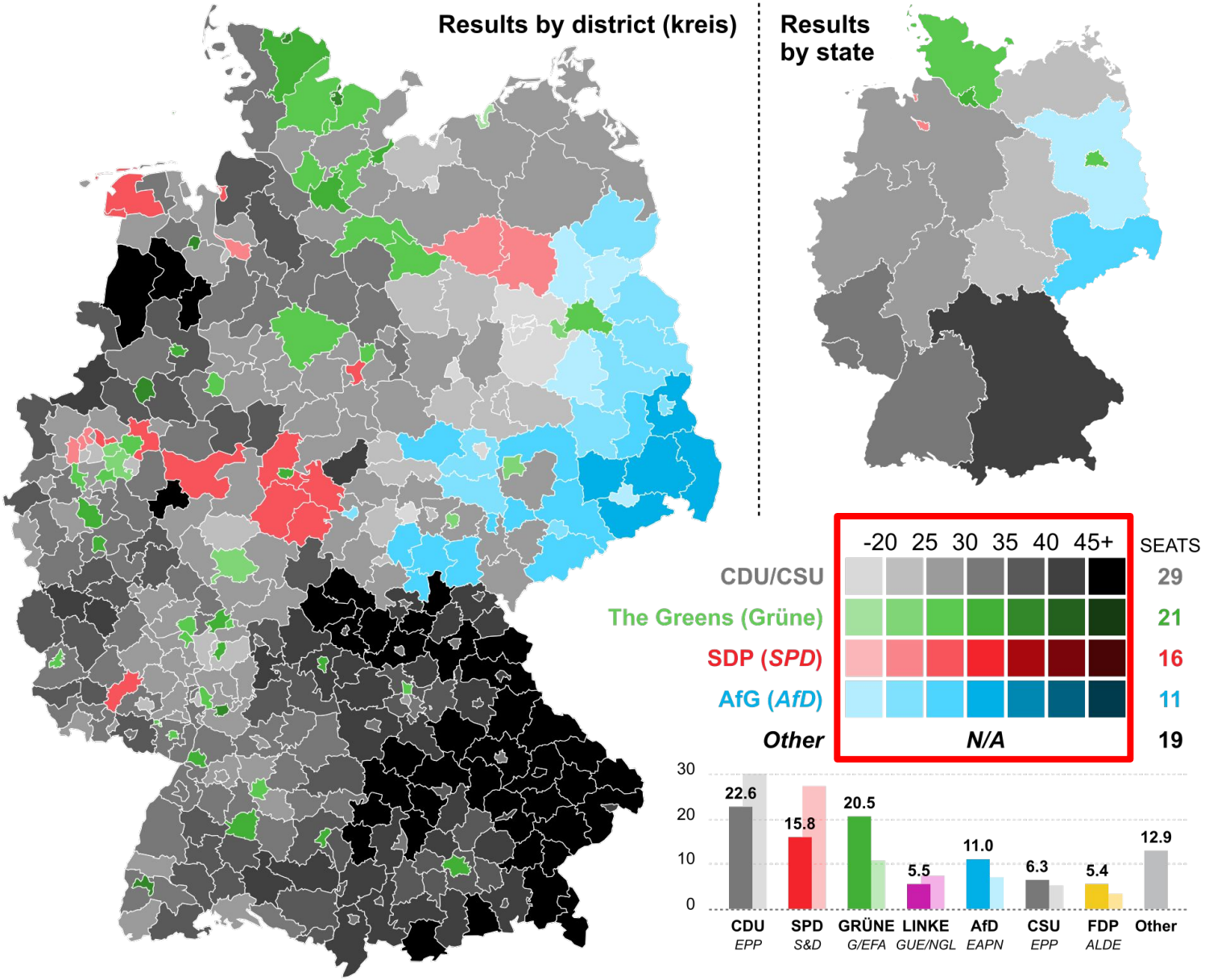


Categorical Scales

More examples of color scales (ColorBrewer)




SLEEP
CREATIVE WORK
DAY JOB/ADMIN
FOOD/LEISURE
EXERCISE
OTHER
12 AM
1
2
3
4
5
6
7
8
9
10
11
12 PM
1
2
3
4
5
6
7
8
9
10
11
12
HONORÉ DE BALZAC
JOHN MILTON
HARUKI MURAKAMI
VOLTAIRE
BENJAMIN FRANKLIN
IMMANUEL KANT
KURT VONNEGUT
MAYA ANGELOU
WYSTAN HUGH AUDEN
LUDWIG VAN BEETHOVEN
MARY FLANNERY O'CONNOR
LE CORBUSIER
VICTOR HUGO
WOLFGANG AMADEUS MOZART
CHARLES DARWIN
CHARLES DICKENS
SIGMUND FREUD
VLADIMIR NABOKOV
KINGSLEY AMIS
THOMAS MANN
RICHARD STRAUSS
PYOTR ILYICH TCHAIKOVSKY
FRANZ KAFKA


Results by district (kreis)
Results by state
-20 25 30 35 40 45+
SEATS
CDU/CSU 29
The Greens (Grüne) 21
SDP (SPD) 16
AfG (AfD) 11
Other 19
N/A
30
20
10
0
22.6
15.8
20.5
5.5
11.0
6.3
5.4
12.9
CDU EPP
SPD S&D
GRÜNE G/EFA
LINKE GUE/NGL
AfD EAPN
CSU EPP
FDP ALDE
Other

I Want Hue

i want hue

Colors for data scie

optimally distinct colors

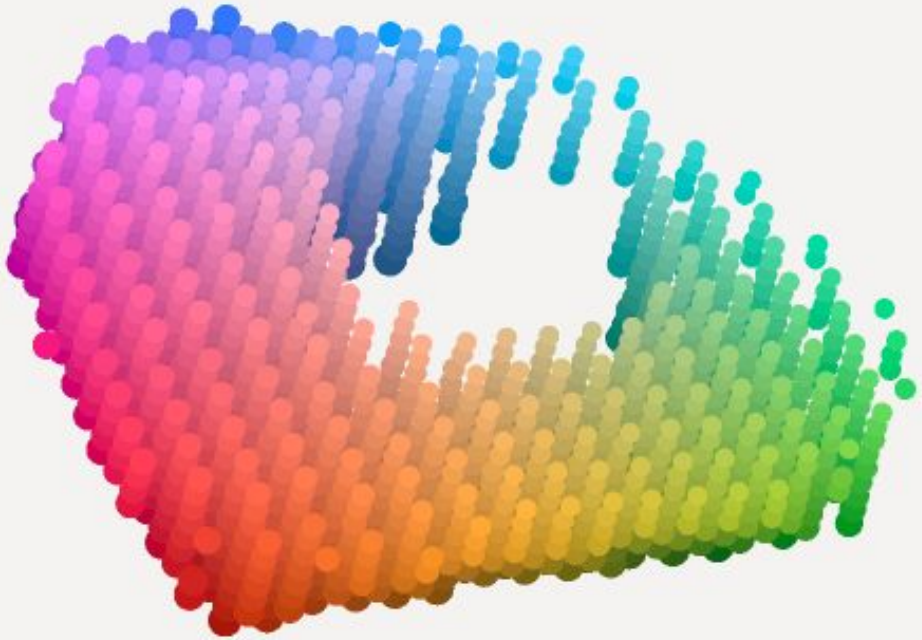
Color space

Default preset

H	0	360
C	30	80
L	35	80

☐ Improve for the **colorblind** (slow)

☐ Dark background



VIZ PALETTE

By: Elijah Meeks & Susie Lu

PICK

Use Chroma.js

Use Colorgorical

Use ColorBrewer

Add | Replace

ColorBrewer is developed by Cynthia Brewer

Go to this block to find colors, then paste them above.

EDIT

7 Colors

Add

#hex rgb hsl

1 #ffd700
2 #ffb14e
3 #fa8775
4 #ea5f94
5 #cd34b5
6 #9d02d7
7 #0000ff

GET

String quotes
Object with metadata

#hex rgb

```
["#ffd700",
"#ffb14e",
"#fa8775",
"#ea5f94",
"#cd34b5",
"#9d02d7",
"#0000ff"]
```

COLORS IN ACTION

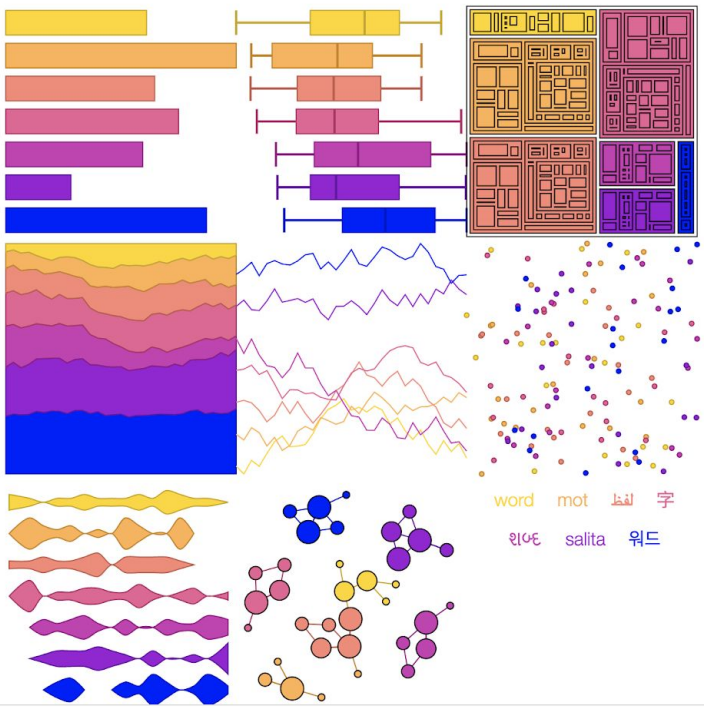
Font color: #000000

Charts made with Semiotic

Color Population:

No Color Deficiency - 96% | Deuteranomaly - 2.7% | Protanomaly - 0.66% | Protanopia - 0.59% | Deuteranopia - 0.56% | Greyscale

Sample font | Randomize Data | **Stroke:** Dark None



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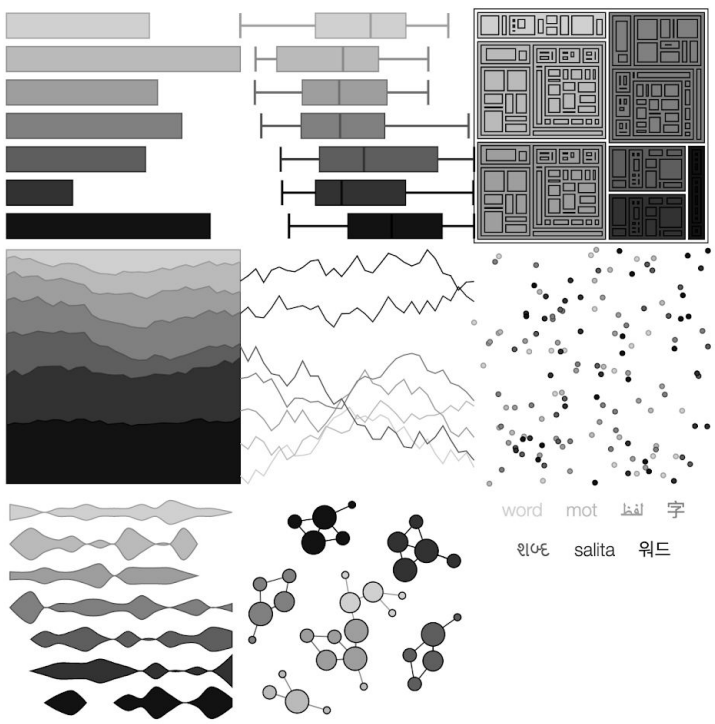

VIZ PALETTE

By: Elijah Meeks & Susie Lu

PICK

Use Chroma.js

Use Colorgorical

Use ColorBrewer

Add Replace

ColorBrewer is developed by Cynthia Brewer

Go to this block to find colors, then paste them above.

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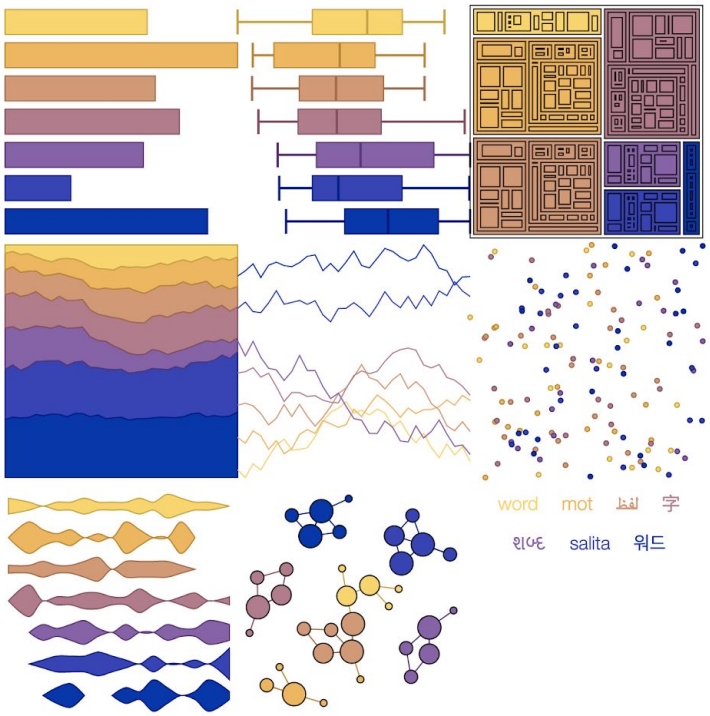
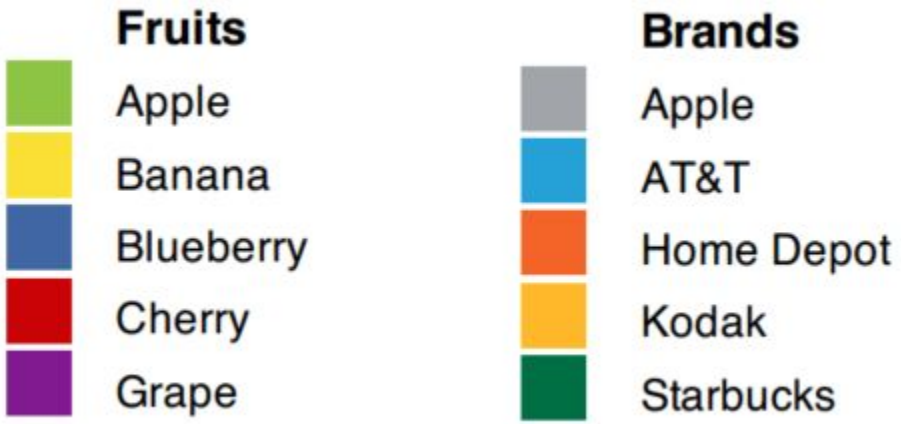
Sample font

Randomize Data

Stroke: Dark None



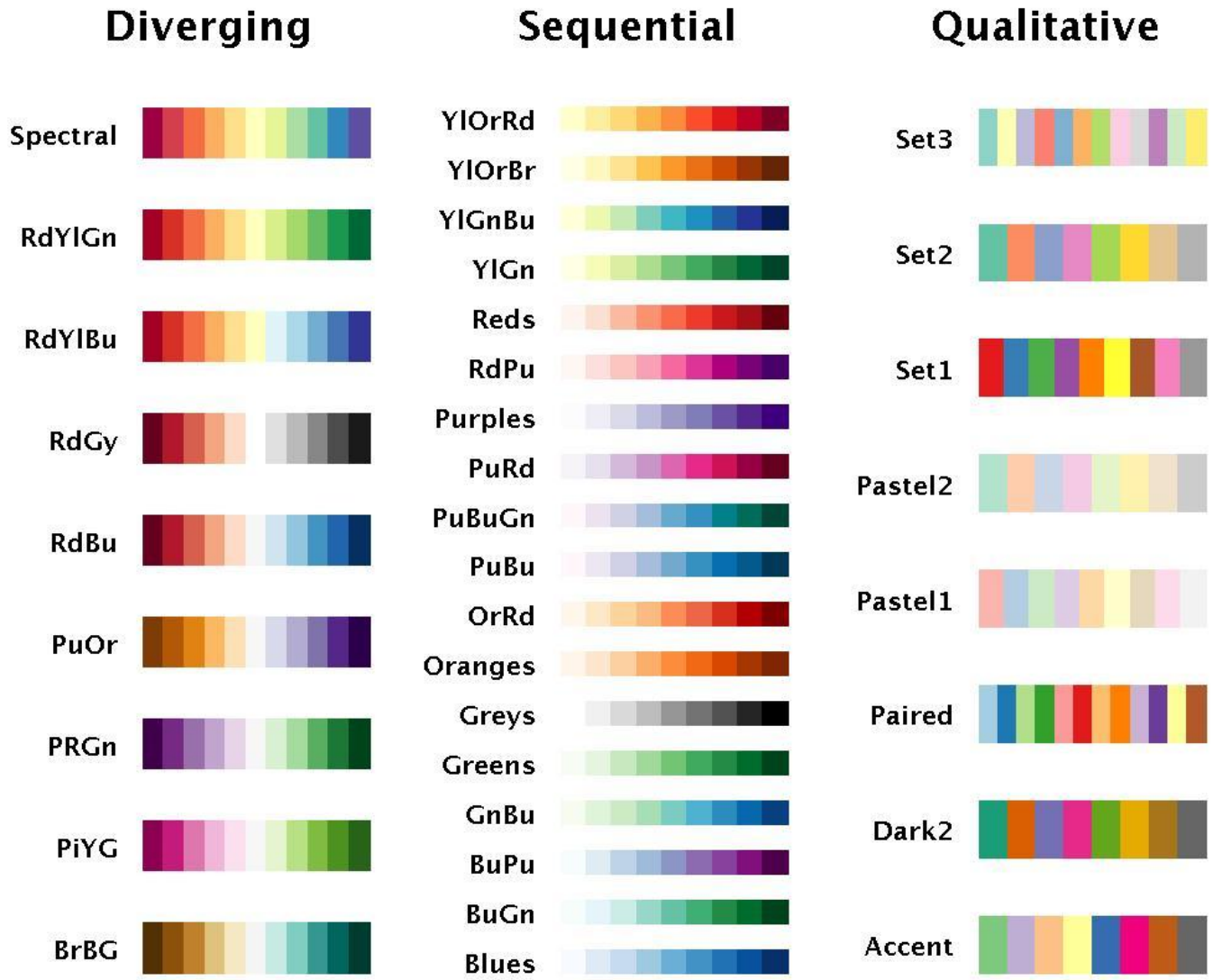
Basic color terms recur across languages



Lin et al. (2013) Selecting Semantically-Resonant Colors for Data Visualization

Rainbow Color Maps

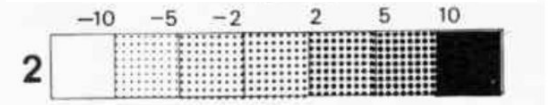
More examples of color scales (ColorBrewer)



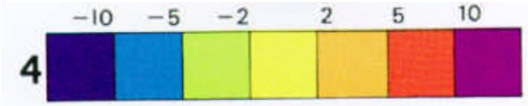
Rainbow Scale Considerations

Map 1

1



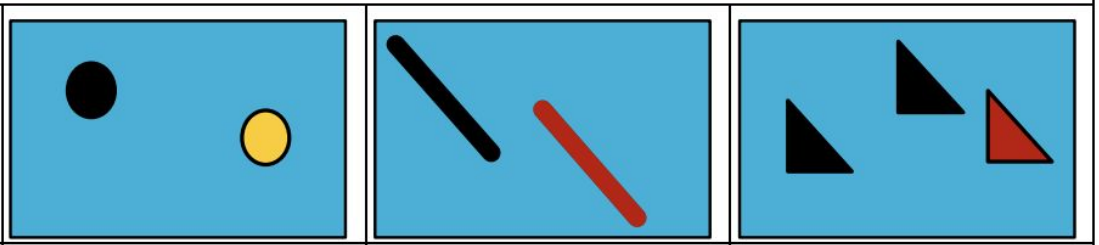
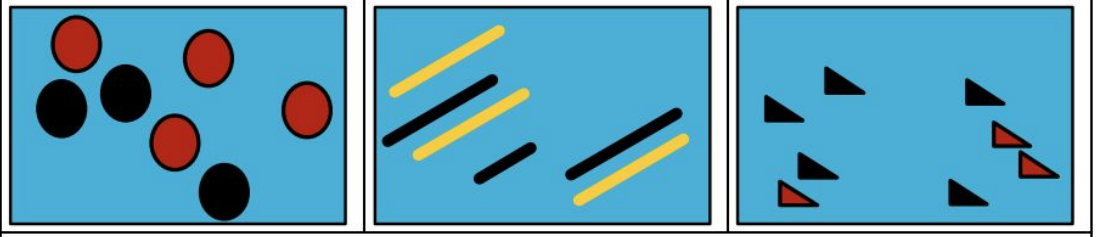
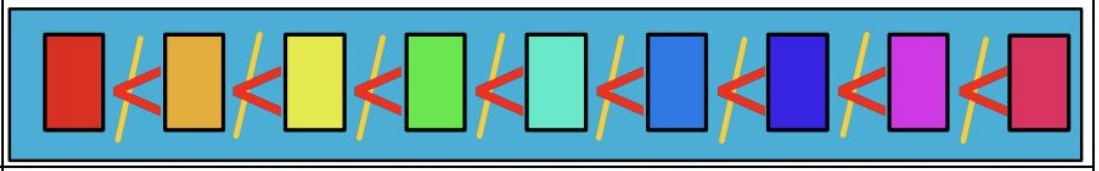
2



4

10

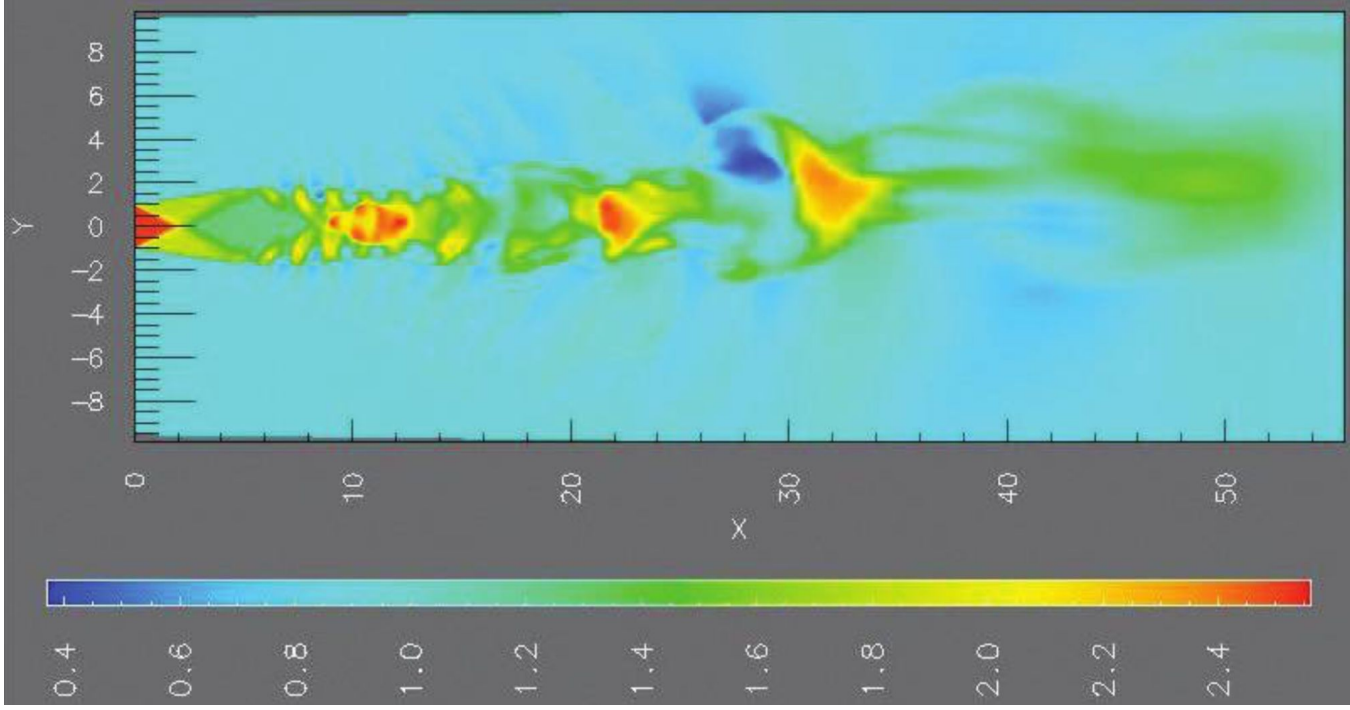
Visual Variable: Colour

✓	selective	
✓	associative	
≠	quantitative	
≠	order	
✓	length	 • theoretically infinite but practically limited • association and selection ~ < 7 and distinction ~ 10

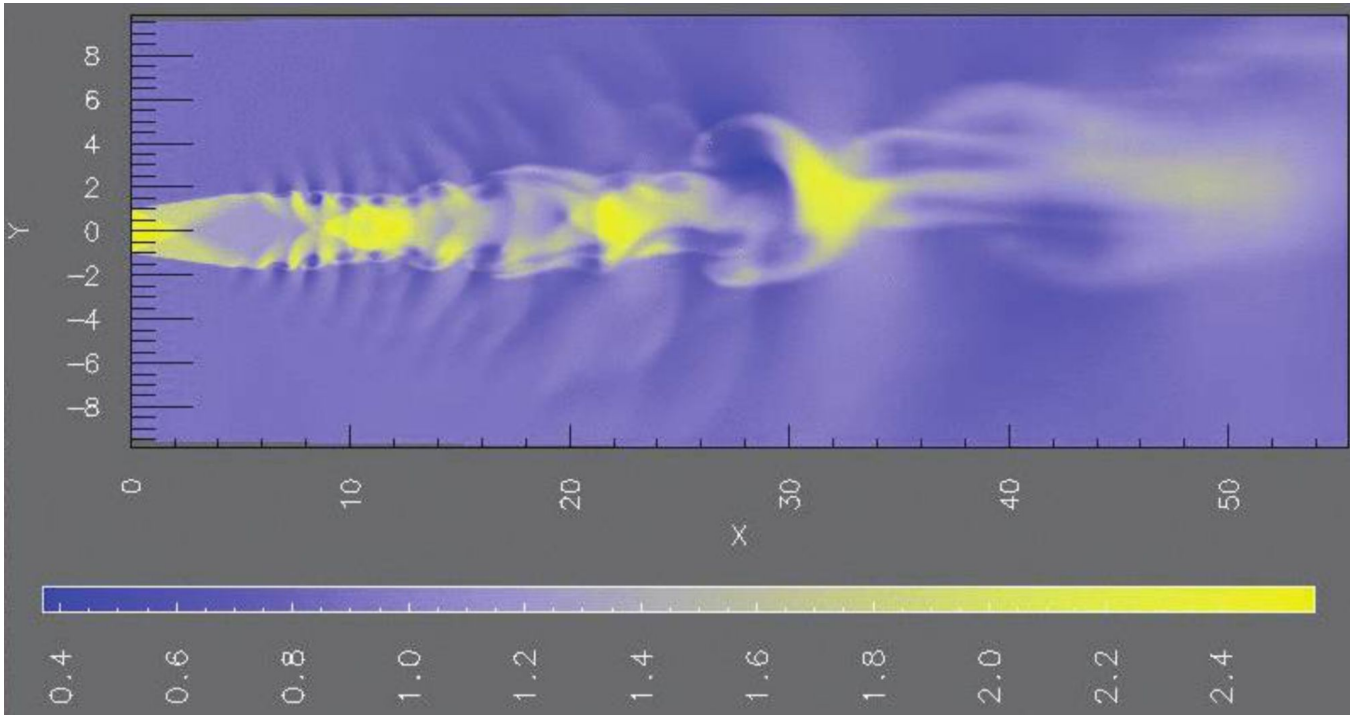
http://innovis.cpsc.ucalgary.ca/innovis/uploads/Publications/Publications/Carpendale_visual_variables.pdf

Color Maps

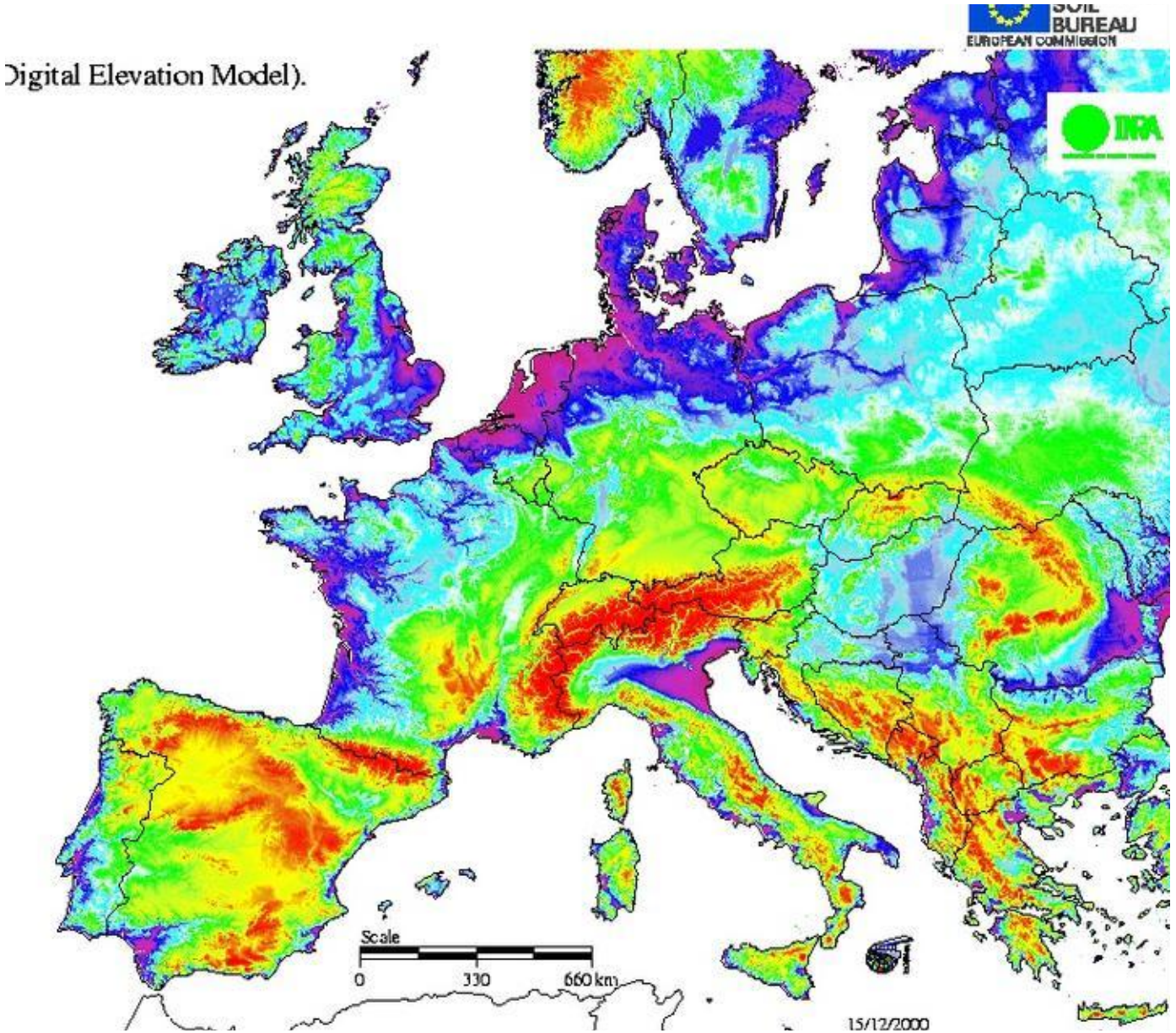
Rainbow:



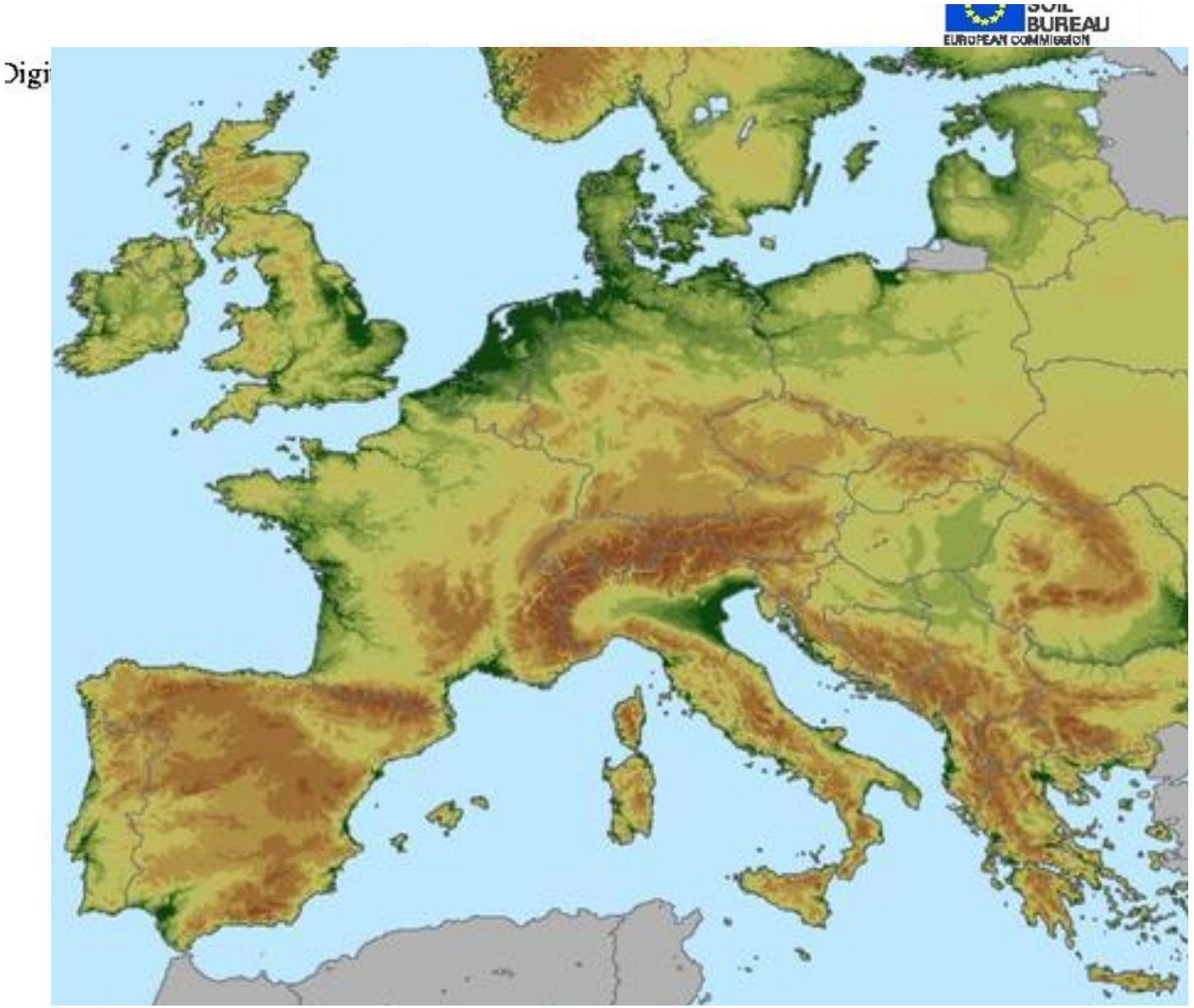
Diverging:



Rainbow Colormap



Rainbow Colormap



Color (mis)use

Country Level Sales Rank Top 5 Drugs

Rainbow distribution in color indicates sales rank in given country from #1 (red) to #10 or higher (dark purple)

Country	A	B	C	D	E
AUS	1	2	3	6	7
BRA	1	3	4	5	6
CAN	2	3	6	12	8
CHI	1	2	8	4	7
FRA	3	2	4	8	10
GER	3	1	6	5	4
IND	4	1	8	10	5
ITA	2	4	10	9	8
MEX	1	5	4	6	3
RUS	4	3	7	9	12
SPA	2	3	4	5	11
TUR	7	2	3	4	8
UK	1	2	3	6	7
US	1	2	4	3	5

Top 5 drugs: country-level sales rank

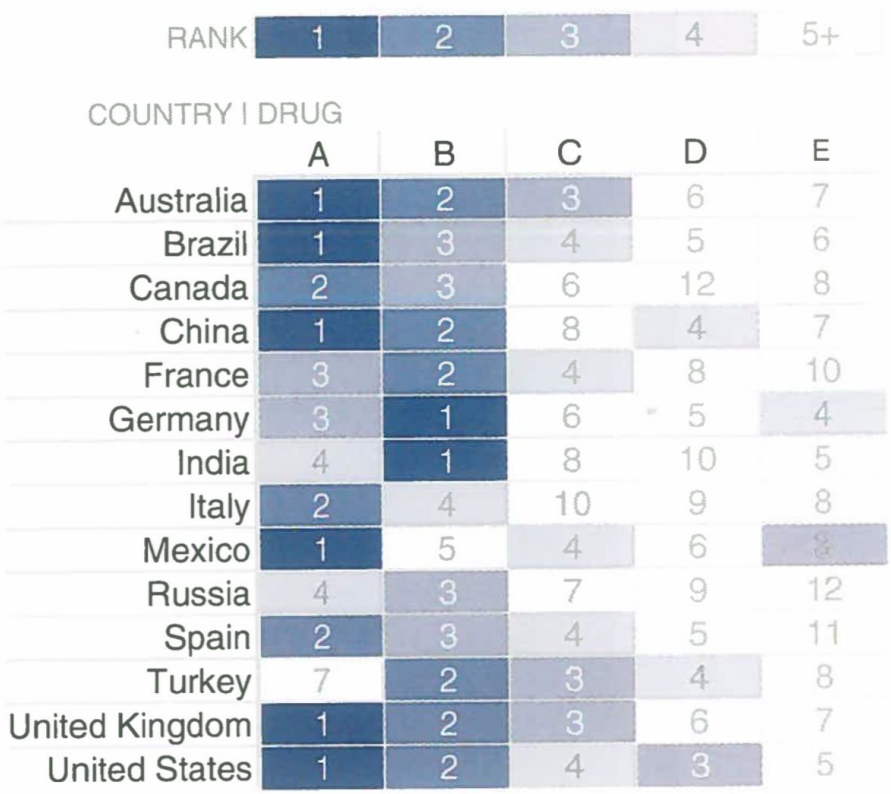
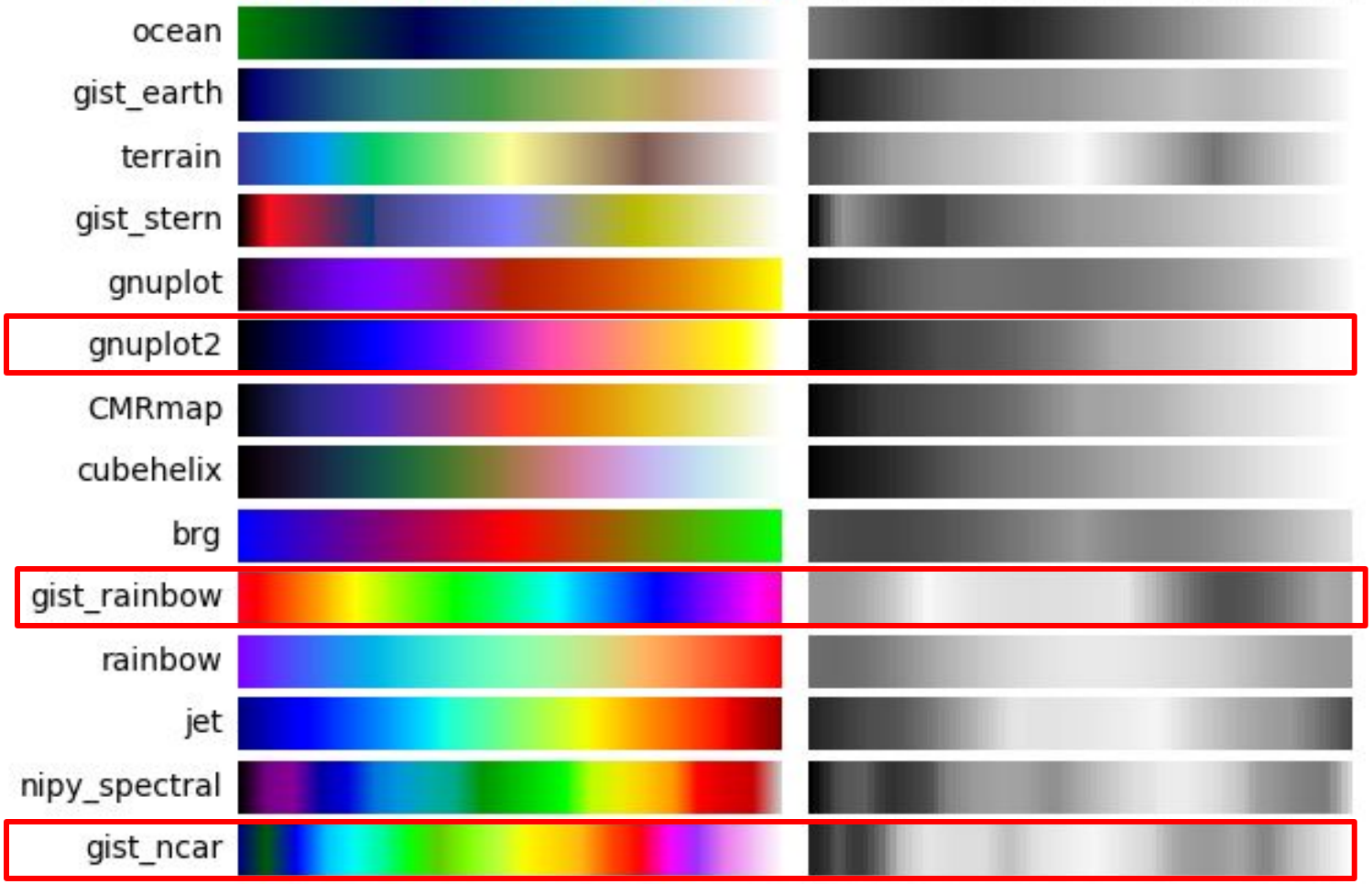


FIGURE 4.15 Use color sparingly

Lightness perception of rainbow color maps



Rainbow colormap

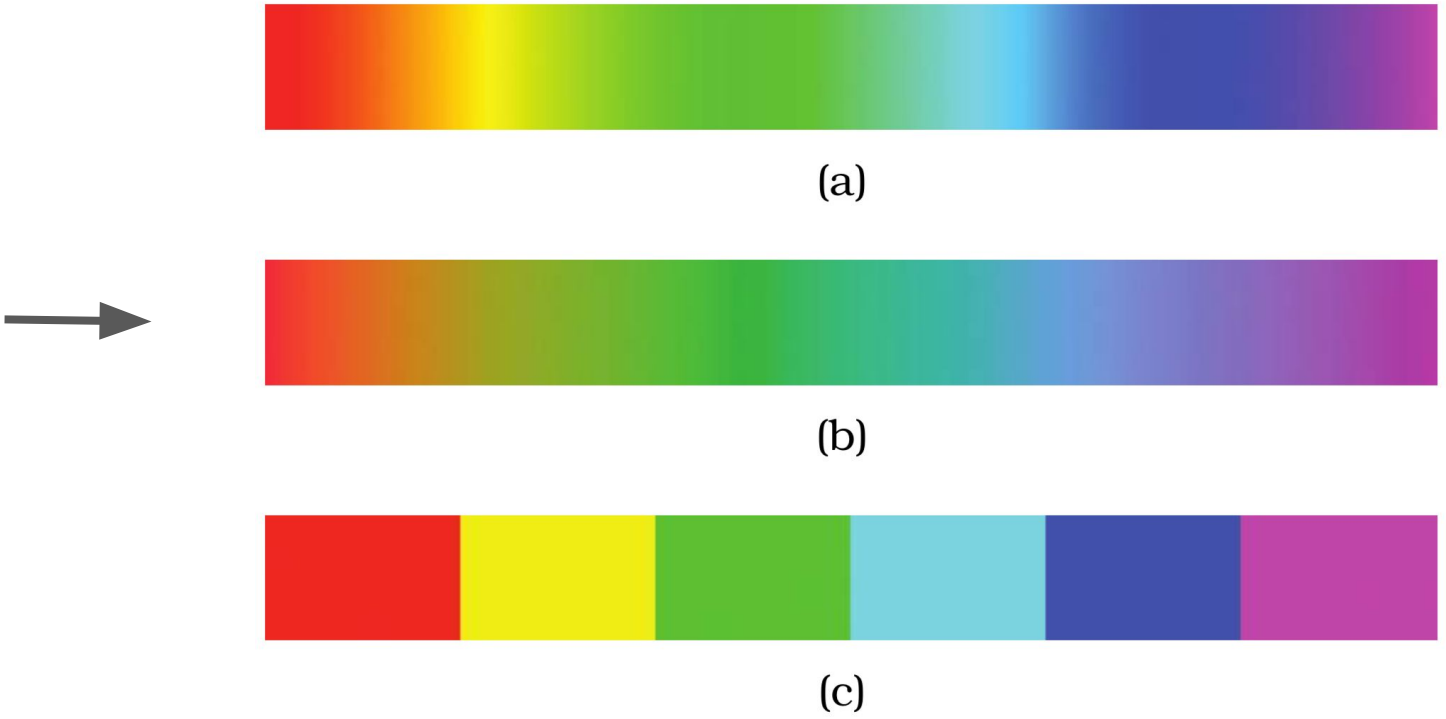
Pros:

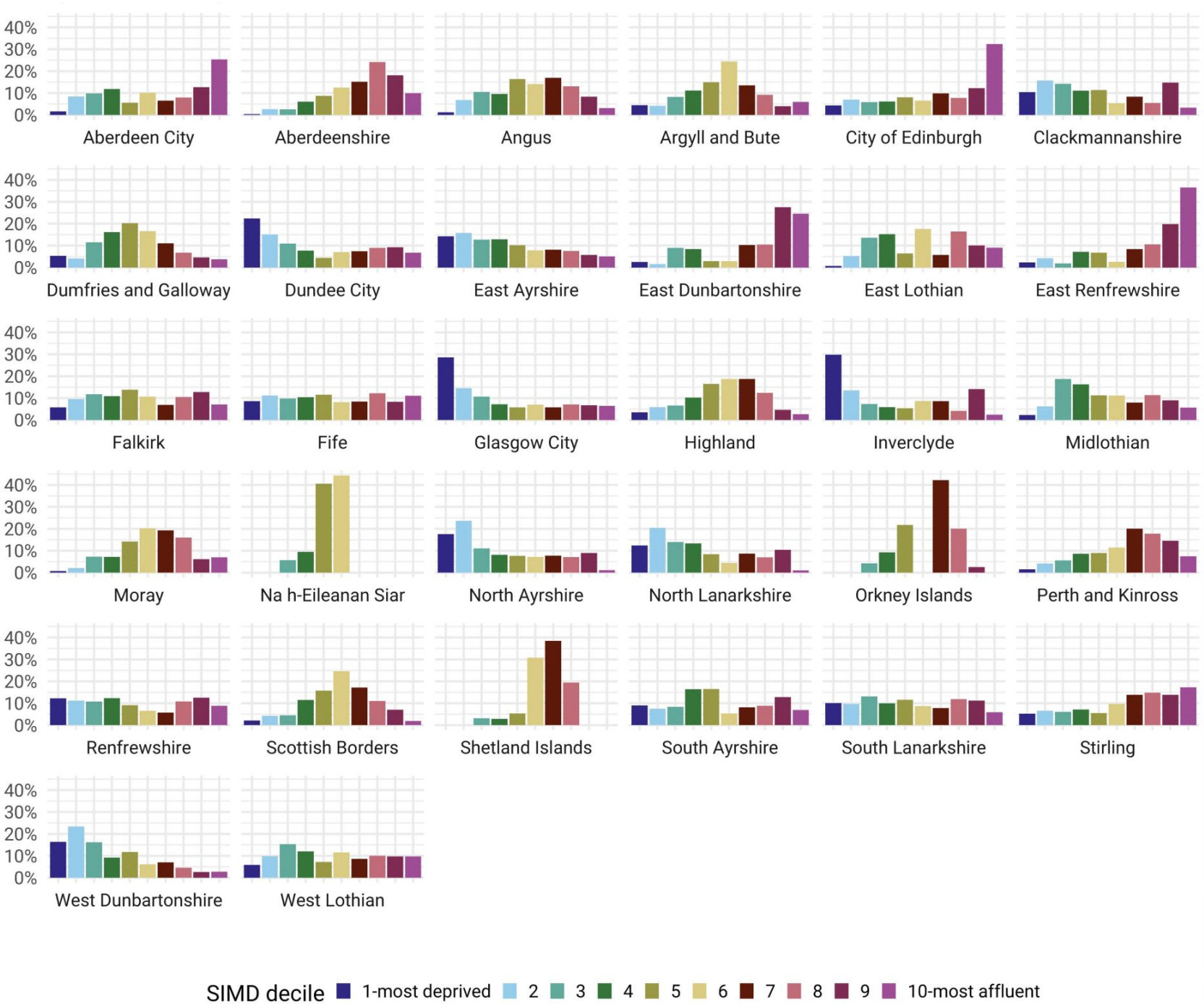
- Many different values
- Compare similar values

Cons:

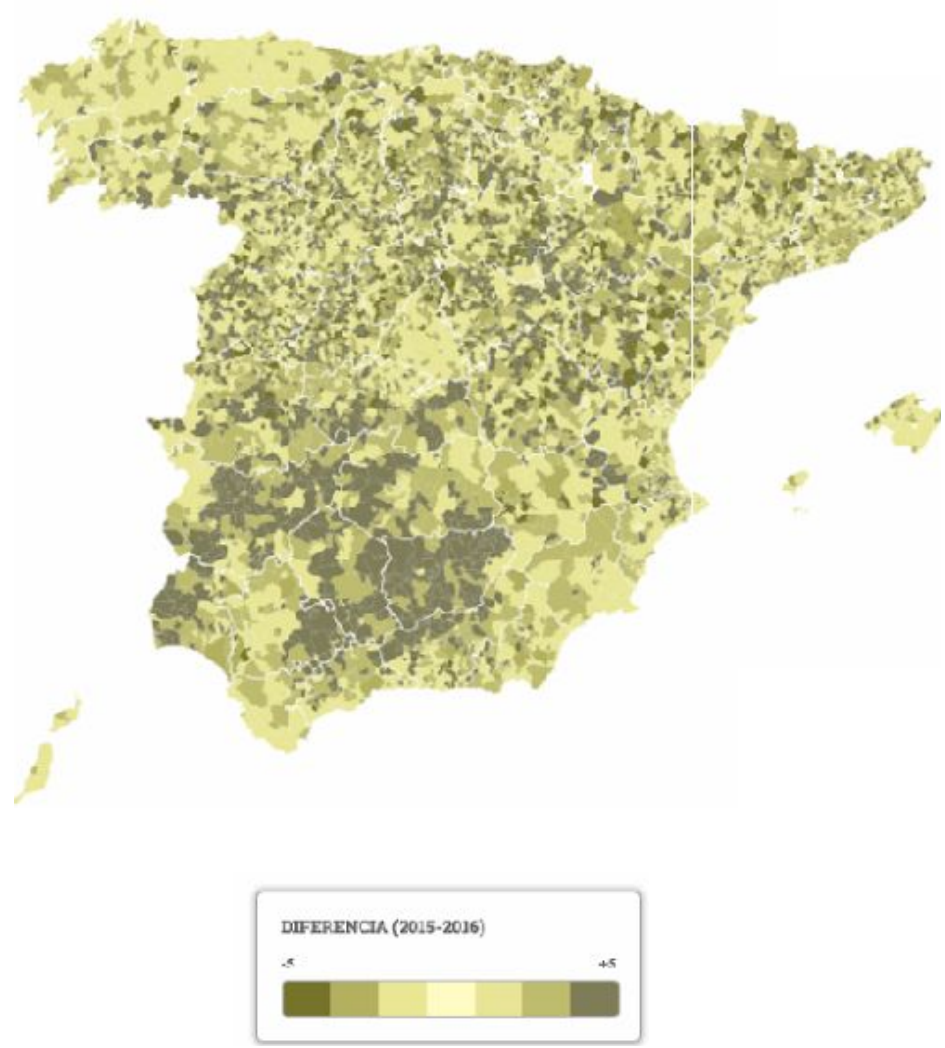
- Colors hardly orderable
- Introduces sharp jumps in values
- Hides overall patterns
- Overemphasizes certain values
- Is not black/white nor colorblind save!

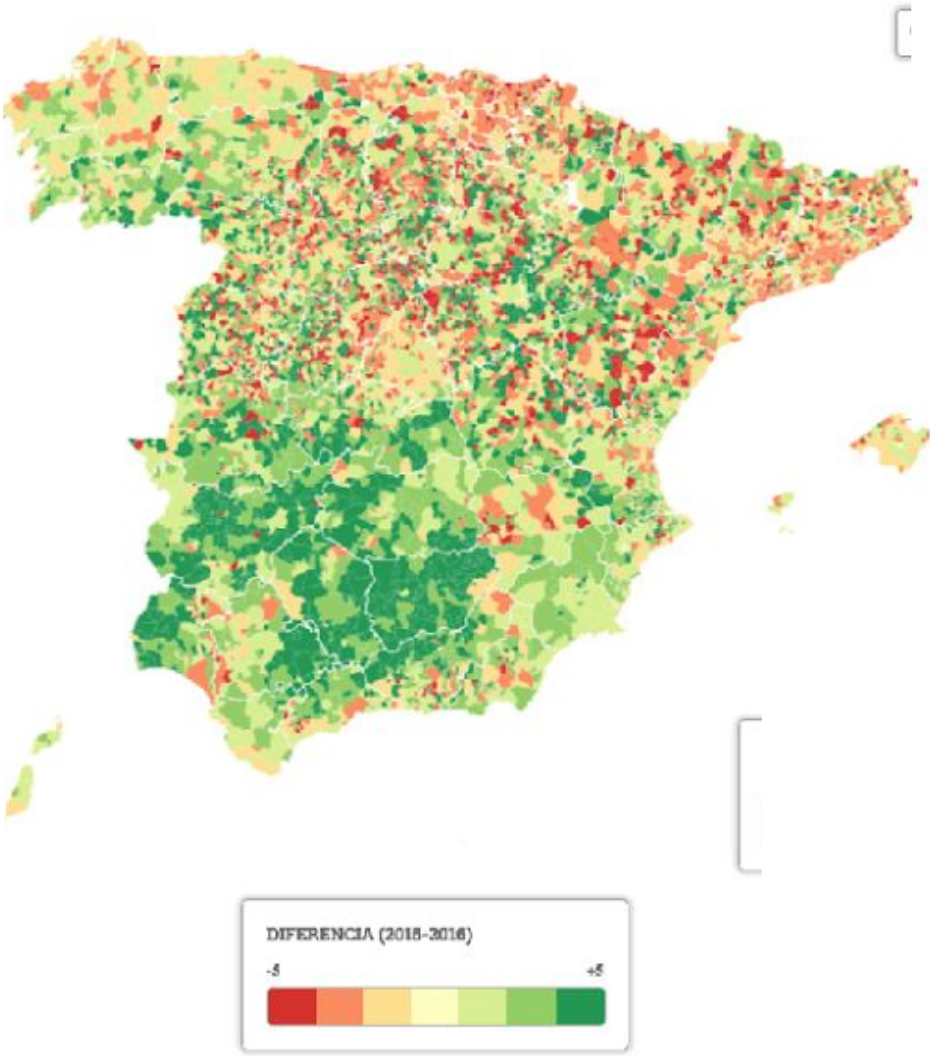
Linear Rainbow map

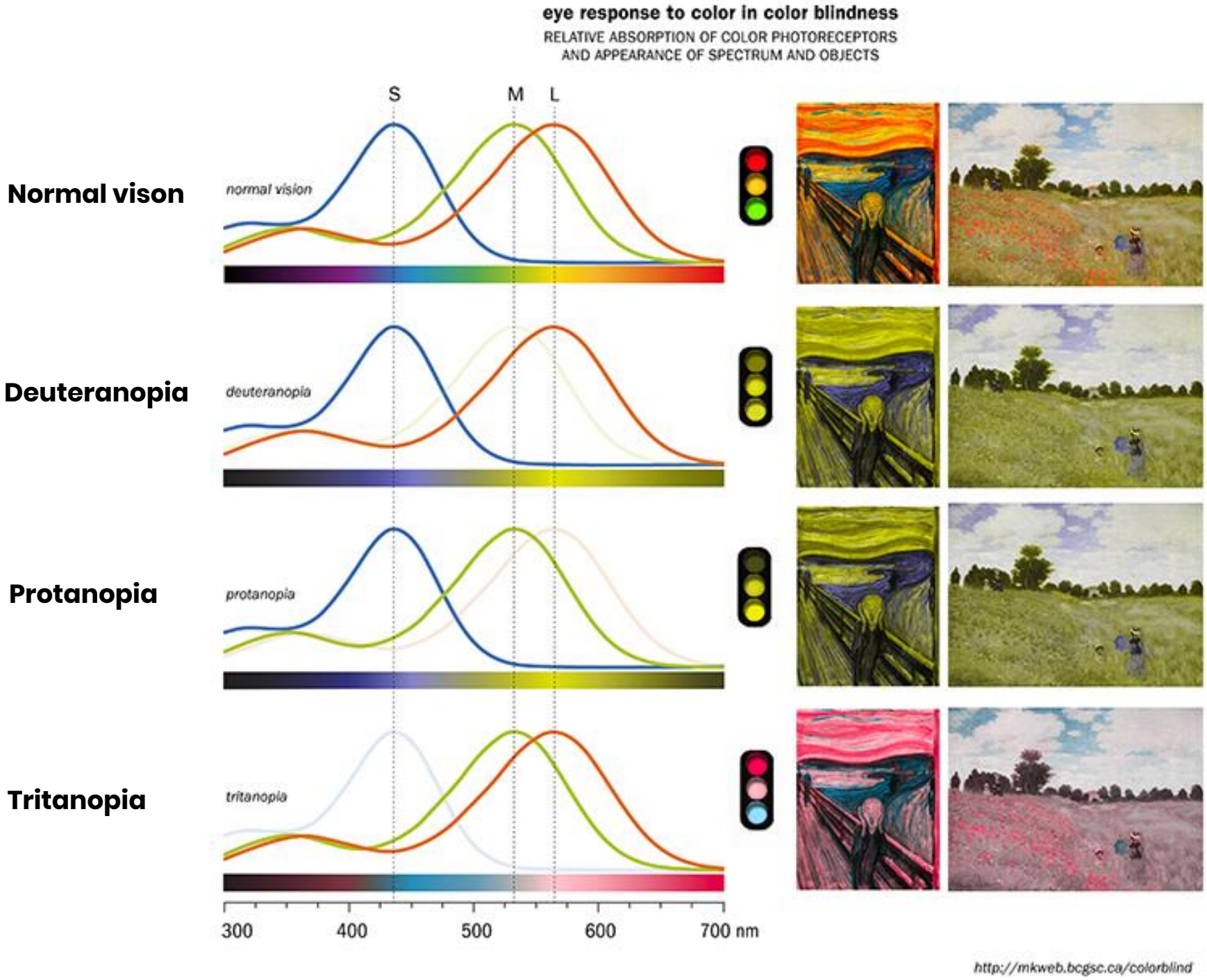



40%
30%
20%
10%
0%
Aberdeen City
Aberdeenshire
Angus
Argyll and Bute
City of Edinburgh
Clackmannanshire
Dumfries and Galloway
Dundee City
East Ayrshire
East Dunbartonshire
East Lothian
East Renfrewshire
Falkirk
Fife
Glasgow City
Highland
Inverclyde
Midlothian
Moray
Na h-Eileanan Siar
North Ayrshire
North Lanarkshire
Orkney Islands
Perth and Kinross
Renfrewshire
Scottish Borders
Shetland Islands
South Ayrshire
South Lanarkshire
Stirling
West Dunbartonshire
West Lothian
SIMD decile
1-most deprived
2
3
4
5
6
7
8
9
10-most affluent

Color Blindness


DIFERENCIA (2015-2016)
-5
+5

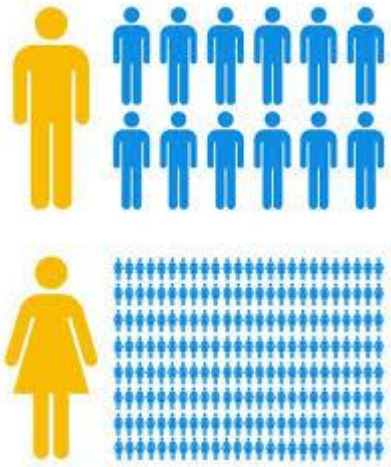

DIFERENCIA (2018-2016)
-5
+5


eye response to color in color blindness
RELATIVE ABSORPTION OF COLOR PHOTORECEPTORS
AND APPEARANCE OF SPECTRUM AND OBJECTS
S
M
L
normal vision
deuteranopia
protanopia
tritanopia
300
400
500
600
700 nm
Normal vison
Deuteranopia
Protanopia
Tritanopia
http://mkweb.bcgsc.ca/colorblind

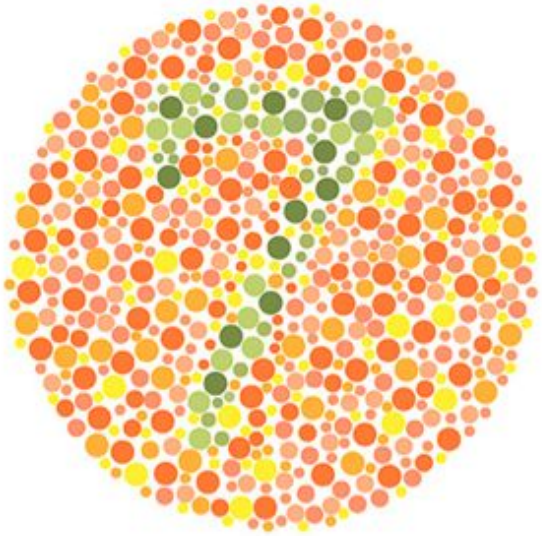
		Protanopia	Deuteranopia	Tritanopia
Men	91.4%	2.45%	6.1%	0.011%
Women	99.6%	0.04%	0.36%	0.04%
Overall	95.5%	1.25%	3.24%	0.025%

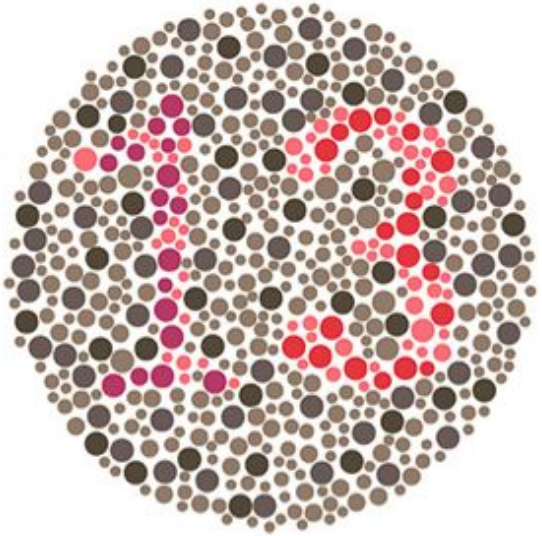
8%

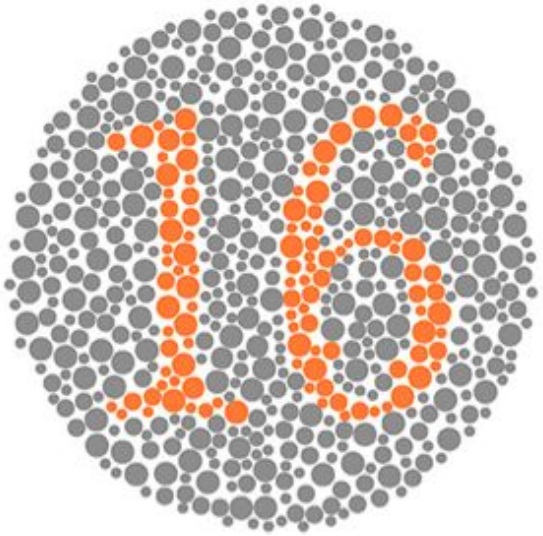
0.5%

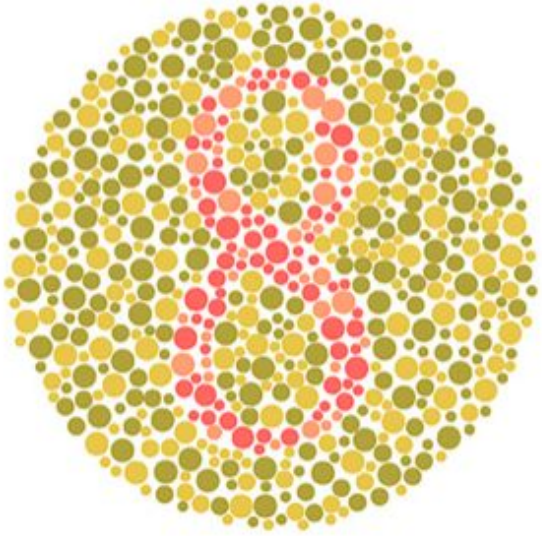


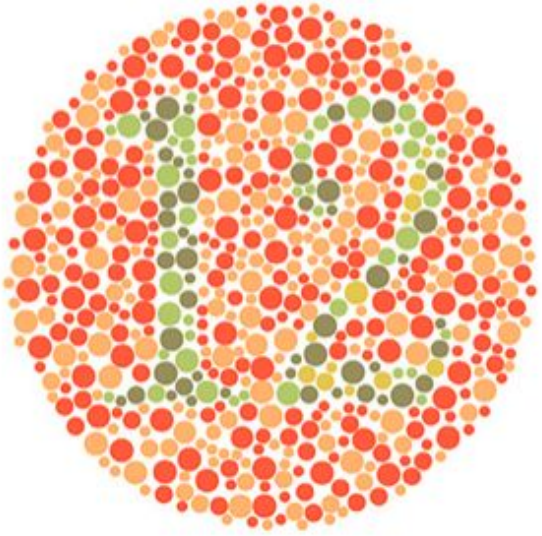
*"If a submitted manuscript happens to go to **three male reviewers** of Northern European descent, the chance that at least one will be color blind is **22 percent**."*

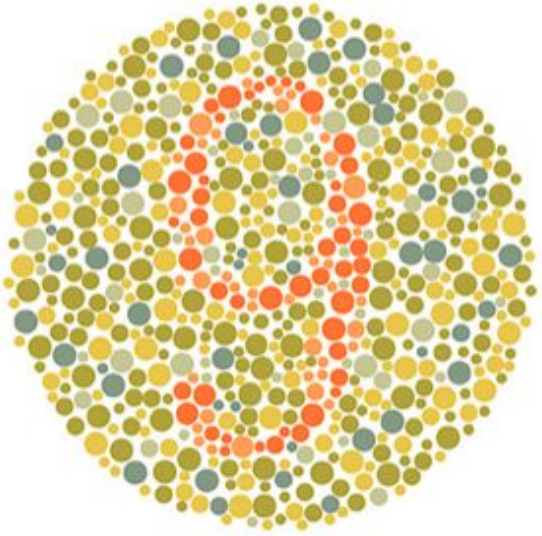




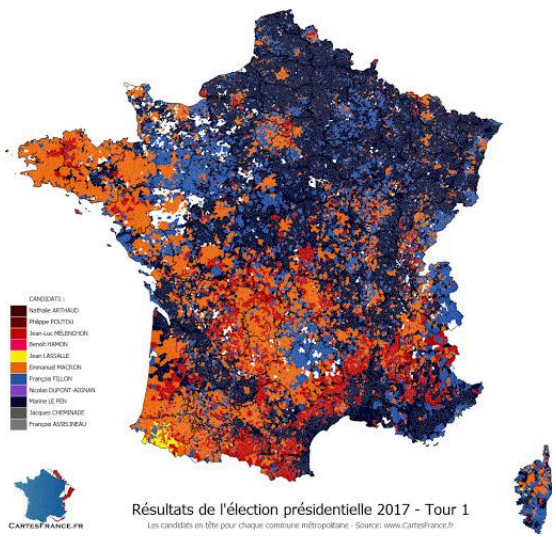


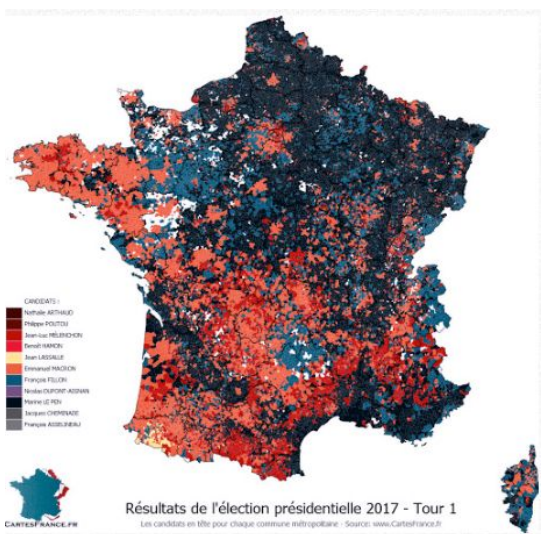


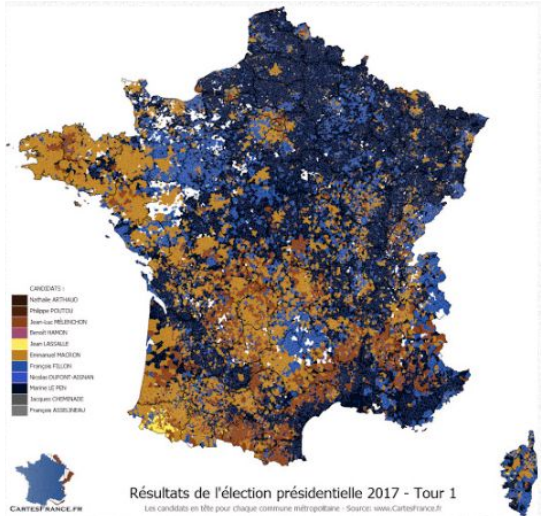




www.color-blindness.com

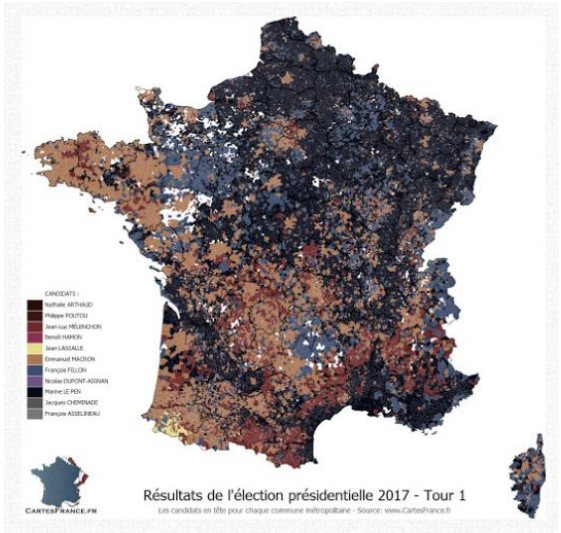


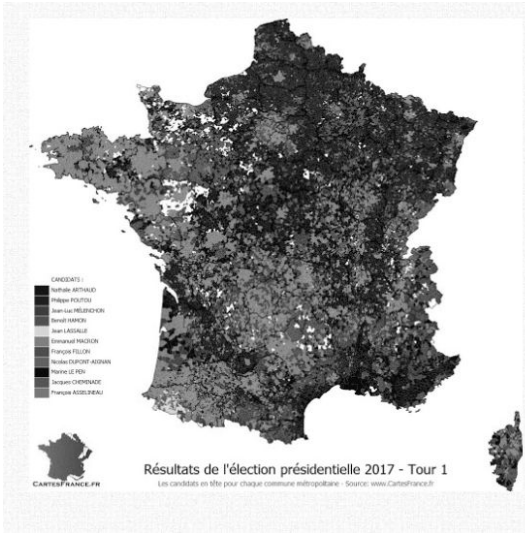




Normal

Types of color blindness

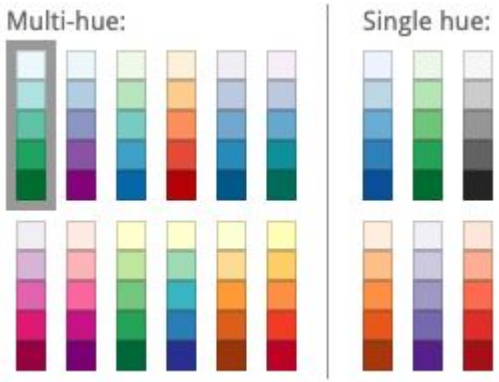




Colorblind safe palettes

Colorbrewer.org:

Diverging

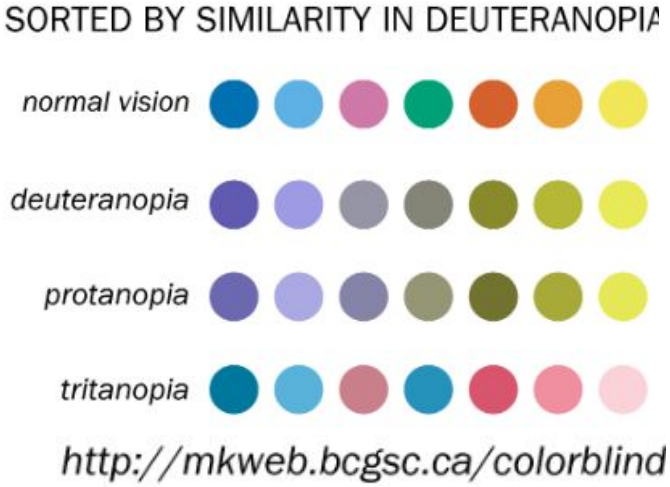


Sequential

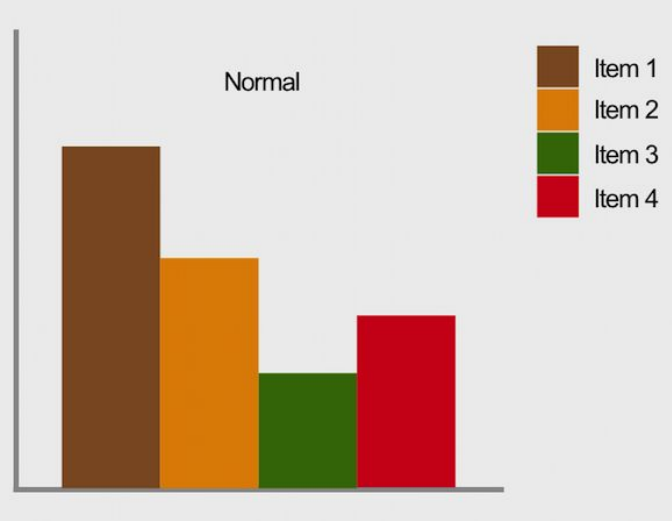
Categorical

Color	Color name	RGB (1–255)	CMYK (%)	P	D
	Black	0, 0, 0	0, 0, 0, 100		
	Orange	230, 159, 0	0, 50, 100, 0		
	Sky blue	86, 180, 233	80, 0, 0, 0		
	Bluish green	0, 158, 115	97, 0, 75, 0		
	Yellow	240, 228, 66	10, 5, 90, 0		
	Blue	0, 114, 178	100, 50, 0, 0		
	Vermillion	213, 94, 0	0, 80, 100, 0		
	Reddish purple	204, 121, 167	10, 70, 0, 0		

Wong, B. (2011) Points of view: Color blindness. Nature Methods 8:441.



Redundant encoding



Further applications in DataVis

Meaning of colors across cultures

	Western/ American	Japanese	Hindu	Native American	Chinese	Asian	Eastern European	Muslim	African	South American
Anger										
Art / Creativity										
Authority										
Bad Luck										
Balance										
Beauty										
Calm										
Celebration										
Children										
Cold										
Compassion										
Courage										
Cowardice										
Cruelty										
Danger										
Death										
Decadence										
Deceit										
Desire										
Earthy										
Energy										

chroma.js

chroma.js is a small-ish zero-dependency JavaScript library (13.5kB) for all kinds of color conversions and color scales.

build passing

Quick-start

Here are a couple of things chroma.js can do for you:

- read colors from a wide range of formats
- analyze and manipulate colors
- convert colors into wide range of formats
- linear and bezier interpolation in different color spaces

Here's an example for a simple read / manipulate / output chain:

```
chroma('pink').darken().saturate(2).hex()
```

```
"#ff6d93"
```

Aside from that, chroma.js can also help you **generate nice colors** using various methods, for instance to be used in color palette for maps or data visualization.

```
chroma.scale(['#fafa6e','#2A4858'])
    .mode('lch').colors(6)
```

```
[ , , , , , ]
```

Take home messages:

- Color = hue + lightness + saturation
- Chose a color scale that fits your data
- Avoid rainbow color palettes
- Test your color palettes for colorblindness

- Whatever increases accessibility for some fraction of the population, increases accessibilty overall.

Further reading

- Wong, Bang. "Points of view: Color blindness." (2011): 441.
- Tamara Munzner: Visualization Analysis and Design, 2016; Chapter 10: Map Color and Other Channels
- https://www.color-blindness.com/types-of-color-blindness
- Colin Ware: Information Visualization—Perception for Design, 2012