

Visual Encoding Principles

Laura Koesten

Schedule

- Last week:
 - Data(set) Types and Semantics
- Today: Visual Encoding Principles
 - Marks and channels
 - Channel effectiveness
 - Channel characteristics
- Follow-up:
 - Task Abstraction

Schedule

Week	Date	Tuesday	Friday
1	Feb 28/Mar 03	No lecture	Introduction (TM,FW) pdf [Munzner Ch. 1] Rosling at TED 2006; Krulwich at RadioLab
2	Mar 07/10	Design Principles (AC) pdf	D3 Tutorial (BJ) zip browser
3	Mar 14/17	Data(set) Types and Semantics (LK) pdf Task Typology	No lecture
	Mar 19	Due: A1 (23:55)	
4	Mar 21/24	Visual Encoding Principles (LK) pdf [Munzner Ch. 5+10] Learning perceptual kernels for vis design Livingstone: What Art can tell us about the brain (Vis 2008 keynote);	Tableau Tutorial
5	Mar 28/31	Arrange Tables + Spatial Data (SR) pdf [Munzner Ch. 7+8]	Arrange Tables + Spatial Data (SR) pdf [Munzner Ch. 7+8]
	Apr 02	Due: A2 (23:55)	
	Apr 04/07	Easter	Easter
	Apr 11/14	Easter	Easter
6	Apr 18/21	Rhetorics (LK)	D3 Tutorial (BJ)
7	Apr 25/28	Facet into Multiple Views (AC) pdf [Munzner Ch. 12] Improvise	Q&A - D3 Tutorial
	Apr 30	Due: A3 (23:55)	
8	May 02/05	Tasks (FW) pdf [Munzner Ch. 2+3] Task Typology	Q&A Design Assignment
9	May 09/12	Design Studies (FW) pdf [Munzner Ch. 4] (MixBee) An example of a design study	VIS in Digital Humanities I (FW) pdf
	May 14	Due: A4 (23:55)	
10	May 16/19	Arrange Networks / Trees (CK) pdf [Munzner Ch. 9+10] Example: GraphDiaries by Bach et al.	VIS in Digital Humanities II (FW) pdf [Collection Visualization Survey] Survey
11	May 23/26	Arrange Networks / Trees (CK) pdf [Munzner Ch. 9+10]	No lecture
	May 30 / Jun 02	No Lecture	No Lecture
12	Jun 06/09	Reduce Items & Attributes (TM) pdf [Munzner Ch. 13] DimStiller	No Lecture
13	Jun 13/16	Manipulate View, Embed: Focus+Context (TS) pdf [Munzner Ch. 11+14]	TextVis for DH (AC, FW) pdf
	Jun 18	Due: A5 (23:55)	
14	Jun 20/23	TextVis (TM) pdf	Final 2
15	Jun 27/30	A5 Presentations	A5 Presentations

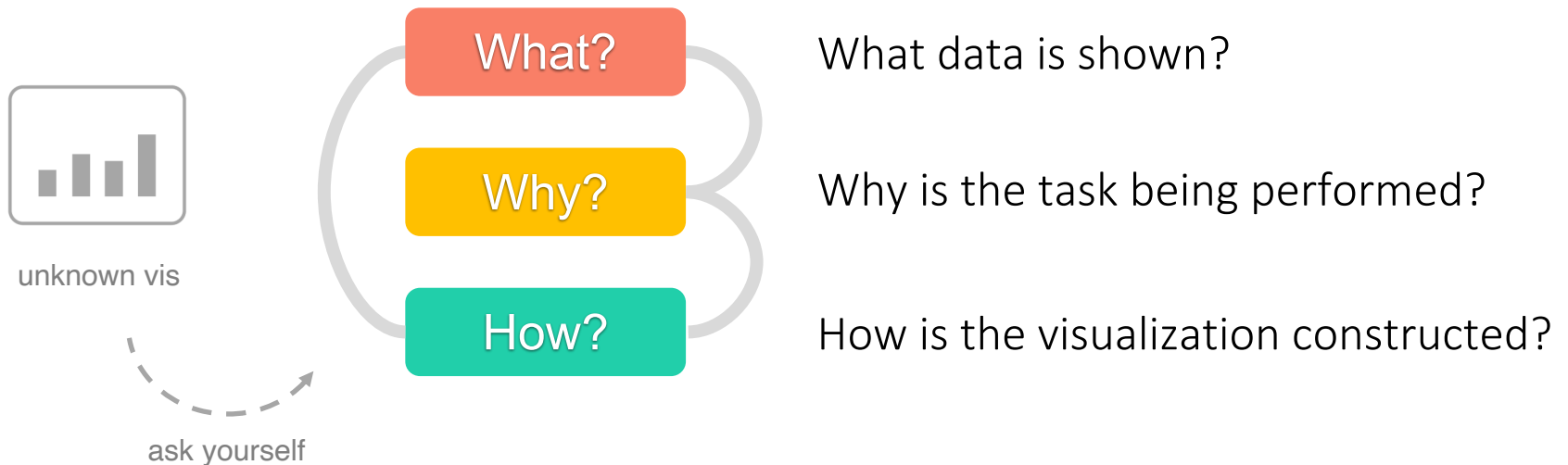
Tableau

- For experimenting along
 - Install Tableau Desktop on your computer
<http://www.tableau.com/academic/students>
 - Or Tableau Public open
<https://public.tableau.com>
 - Dataset on „world happiness“:
http://vda.univie.ac.at/Teaching/Vis/21w/data/20w_data_happiness_development.csv
- Learning Resource:
 - Sahann and Kralj, Tableau Tutorial
https://github.com/christoph/VIS_Tableau_Tutorial

Readings

- Munzner, “Visualization Analysis and Design”:
 - Chapter 5 (Marks and Channels)
 - Chapter 10 (Map Color and Other Channels)
- Ware, “Information Visualization – Perception for Design”:
 - Chapter 4 (Color)
 - Chapter 5 (Visual Salience and Finding Information)
- Ward, Grinstein and Keim, “Interactive Data Visualization”:
 - Chapter 3 (Human Perception and Information Processing)
 - Chapter 4 (Visualization Foundations)
- Mackinlay, “Automating the design of graphical presentations of relational information”, ACM ToG, 5(2), 110-141, 1986, doi: [10.1145/22949.22950](https://doi.org/10.1145/22949.22950)

Three-part analysis framework to analyze any existing visualization



Munzner, Visualization Analysis and Design, 2014, p. 17 ff.

Three-part analysis framework to analyze any existing visualization

What?

- What? – Data Abstraction

Why?

- Why? – Task Abstraction

How?

- How? – Visual Encoding
 - Marks and channels
Examples, Channel types, Mark types, Expressiveness + Effectiveness
 - Channel effectiveness
Accuracy, Discriminability, Separability, Popout
 - Channel characteristics
Spatial position, Relative vs. absolute, Color (Color theory basics, Perception issues & deficiencies, Categorical, Ordinal)

Marks and channels

Examples

Channel types

Mark types

Expressiveness + Effectiveness

Channel effectiveness

Accuracy

Discriminability

Separability

Popout

Channel characteristics

Spatial position

Relative vs. absolute

Color

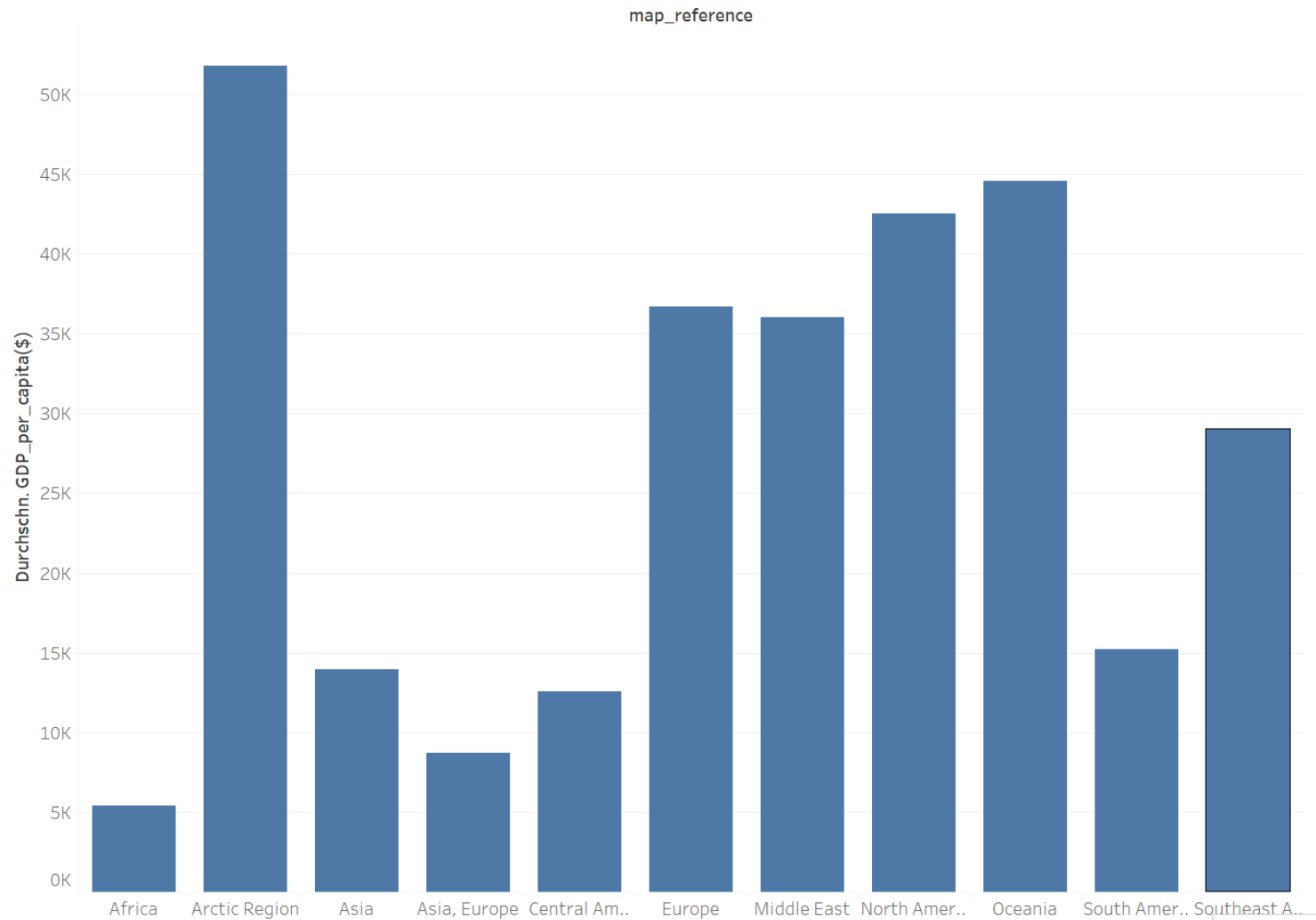
Perception/Color theory basics

Perception issues & deficiencies

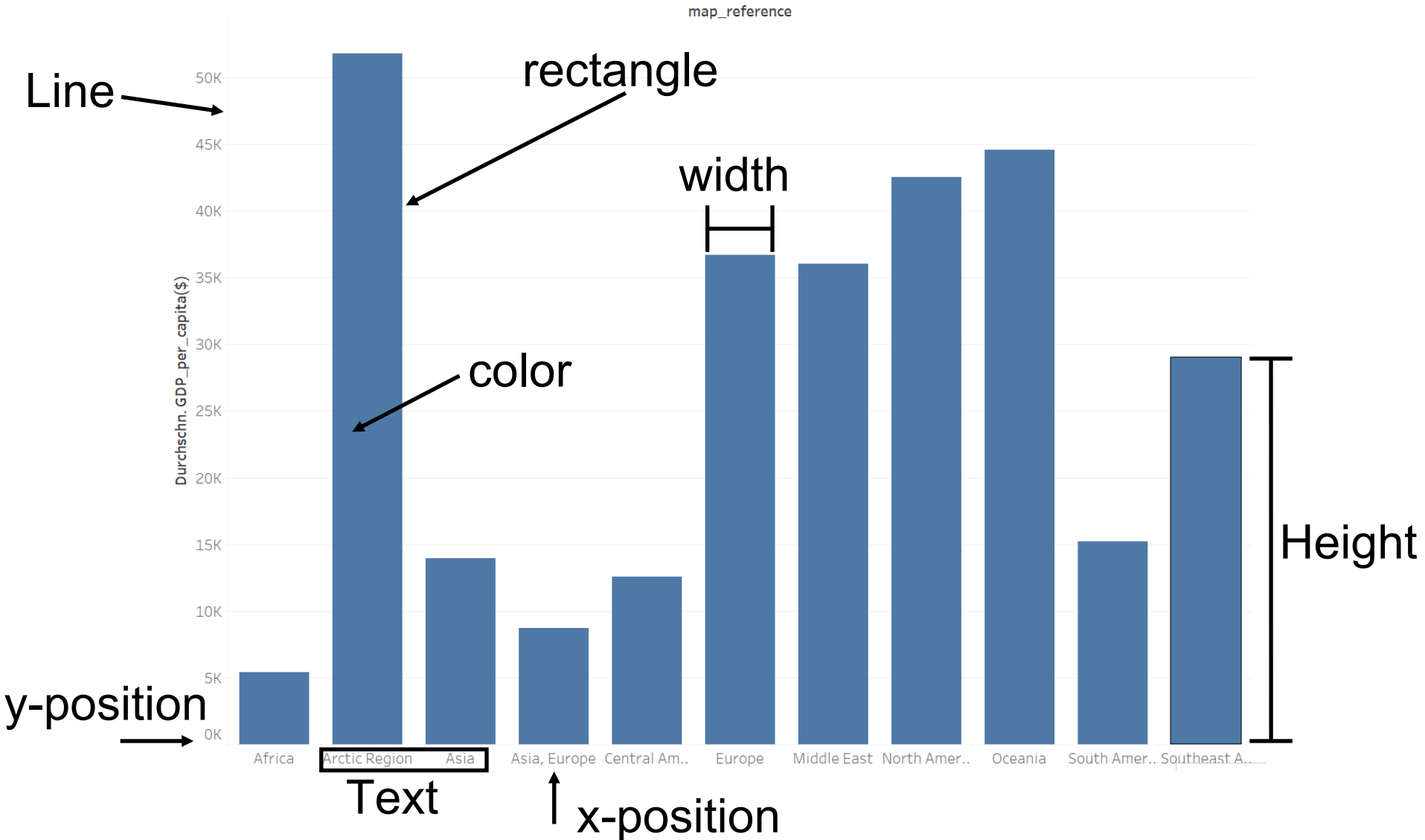
Categorical/Ordinal/Quantitative

Marks and channels

Parts of a visualization



Parts of a visualization



Visual language is a sign system

- Image perceived as a set of signs
- Sender encodes information in signs
- Receiver decodes information from signs

- Jacques Bertin
 - French cartographer [1918-2010]
 - Semiology of Graphics [1967]
 - Theoretical principles for visual encodings



Bertin, Semiology of Graphics, 1983

According to Bertin ...

Marks

Points Lines Areas

Channels

Position

Size

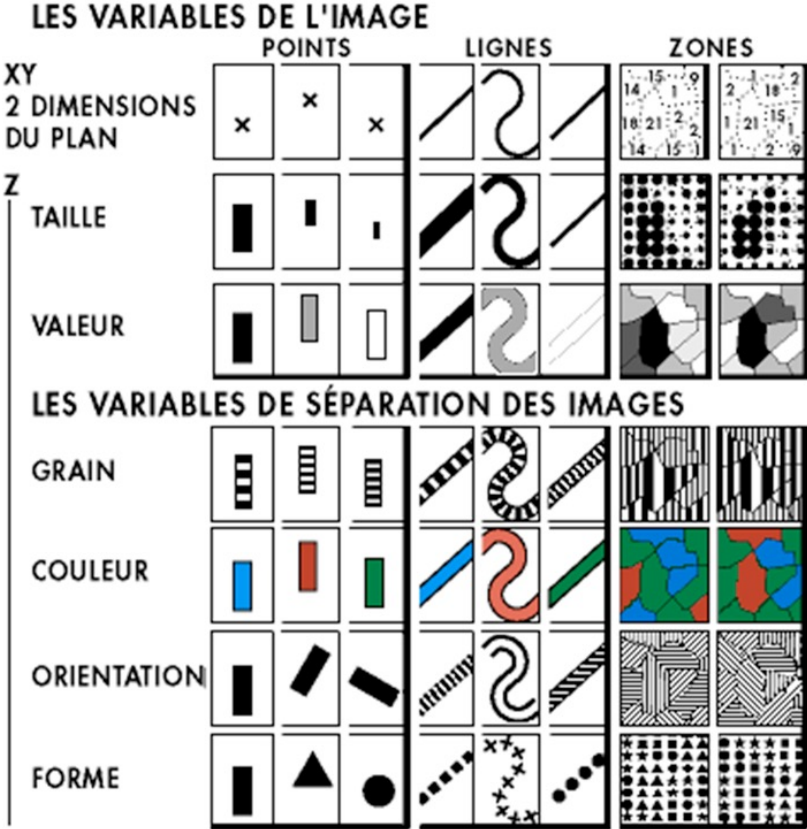
(Grey)Value

Texture

Color

Orientation

Shape

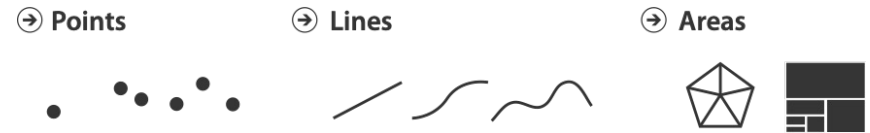


Bertin, Semiology of Graphics, 1983

Marks and Channels (Munzner)

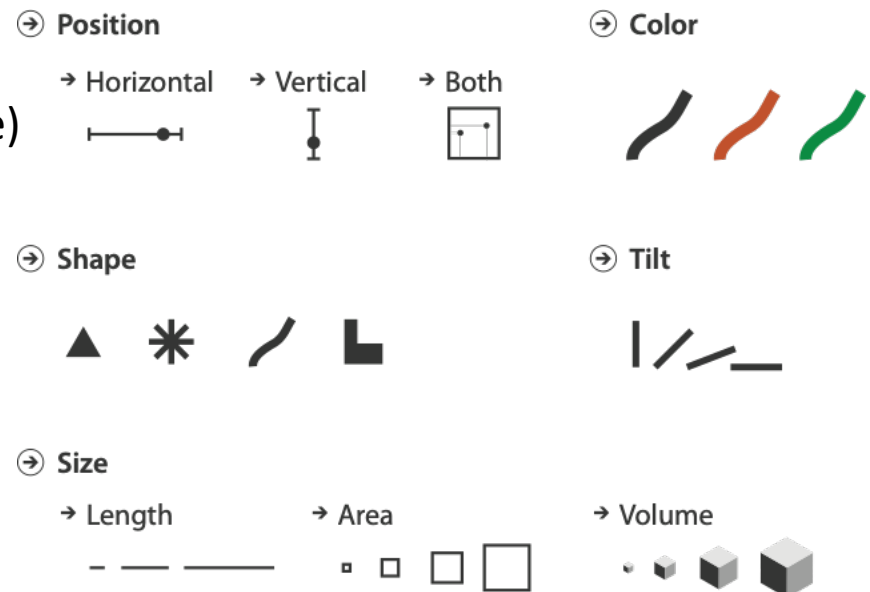
- Mark: basic graphical element / geometric primitive:

- point (0D)
- line (1D)
- area (2D)
- volume (3D)









- Channel: control appearance (of a mark)

- position
- color (hue, saturation, luminance)
- shape
- tilt / angle
- size (length, area, volume)
- curvature
- motion
- etc.



Marks and Channels in Polaris

(predecessor to Tableau)

property	marks	ordinal/nominal mapping	quantitative mapping
shape	glyph	○ □ + △ S U	
size	rectangle, circle, glyph, text		
orientation	rectangle, line, text		
color	rectangle, circle, line, glyph, y-bar, x-bar, text, gantt bar		

[Stolte and Hanrahan, Polaris: A System for Query, Analysis and Visualization of Multi-dimensional Relational Databases, 2000](#)

Marks and Channels:

Tableau example

- Let us now use different visual encodings
- Dataset:
 - [World Happiness dataset \(description\)](#)
composed from multiple sources:
 - The [World Happiness Report](#): scores based on answers to a life evaluation question, where respondents rate the quality of their current lives on a scale from 0 to 10.
 - The [CIA Factbook](#) contains almanac style information about the countries of the world, such as population, GDP family income, internet access, cell phone subscriptions, etc.
 - The [Human Development Index](#)
 - The [Inequality-adjusted Human Development Index](#)
- Create new chart(s) using the following fields: Country, GDP per capita, Internet Access, Happiness Score, Generosity

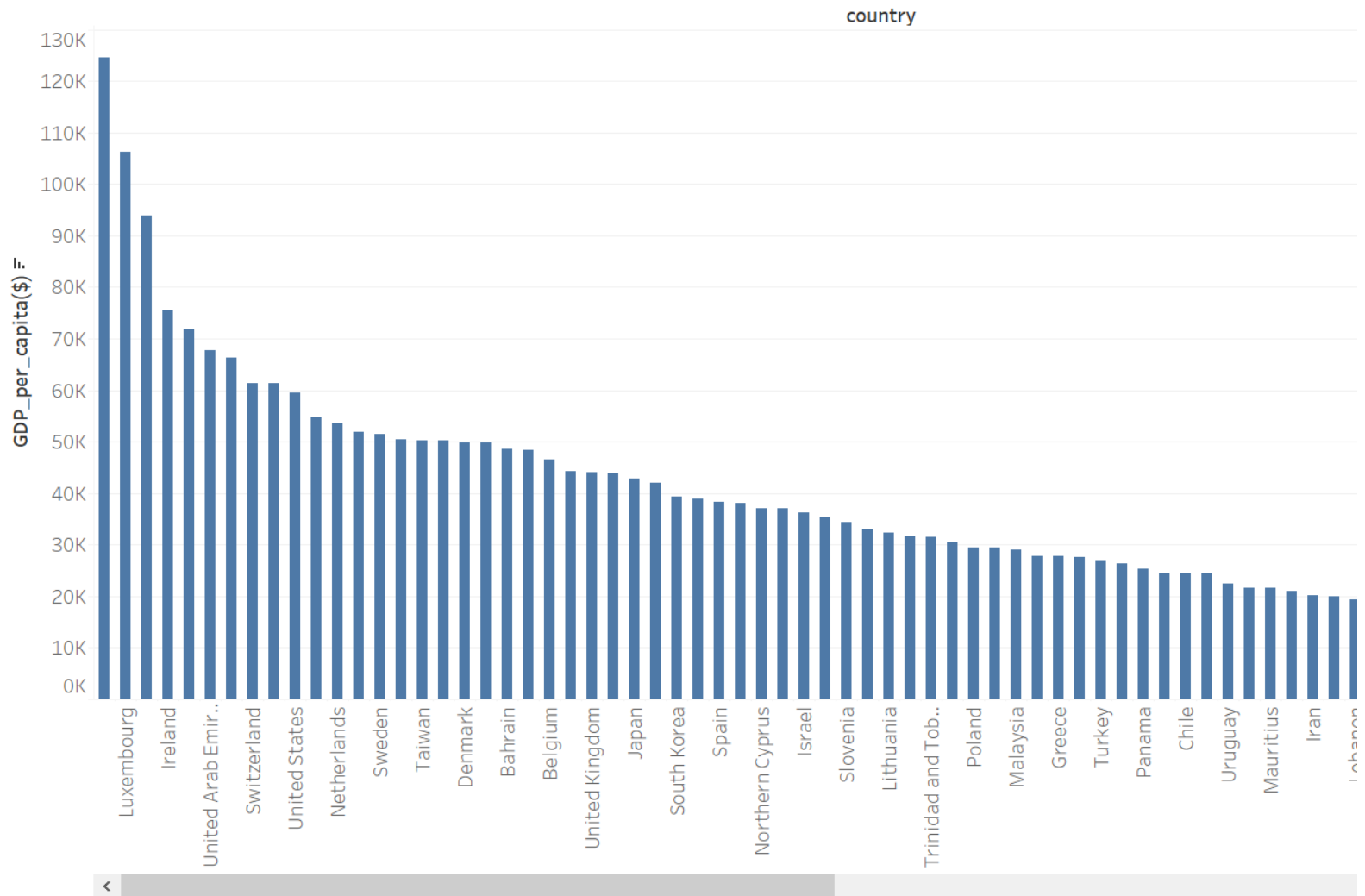
Marks and Channels:

Tableau example

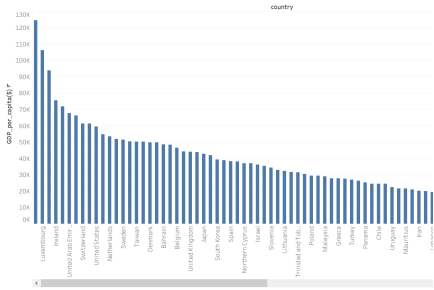
- Use a rectangle mark, length channel for GDP of each country
- Use point marks and position channels for **GDP** and **Internet Access**. Is there a correlation (visually) between the two?
- Which countries have low **Happiness** but a high **GDP**?
- Which countries have low **GDP**, but still high **Generosity**?

Marks and Channels: Tableau example

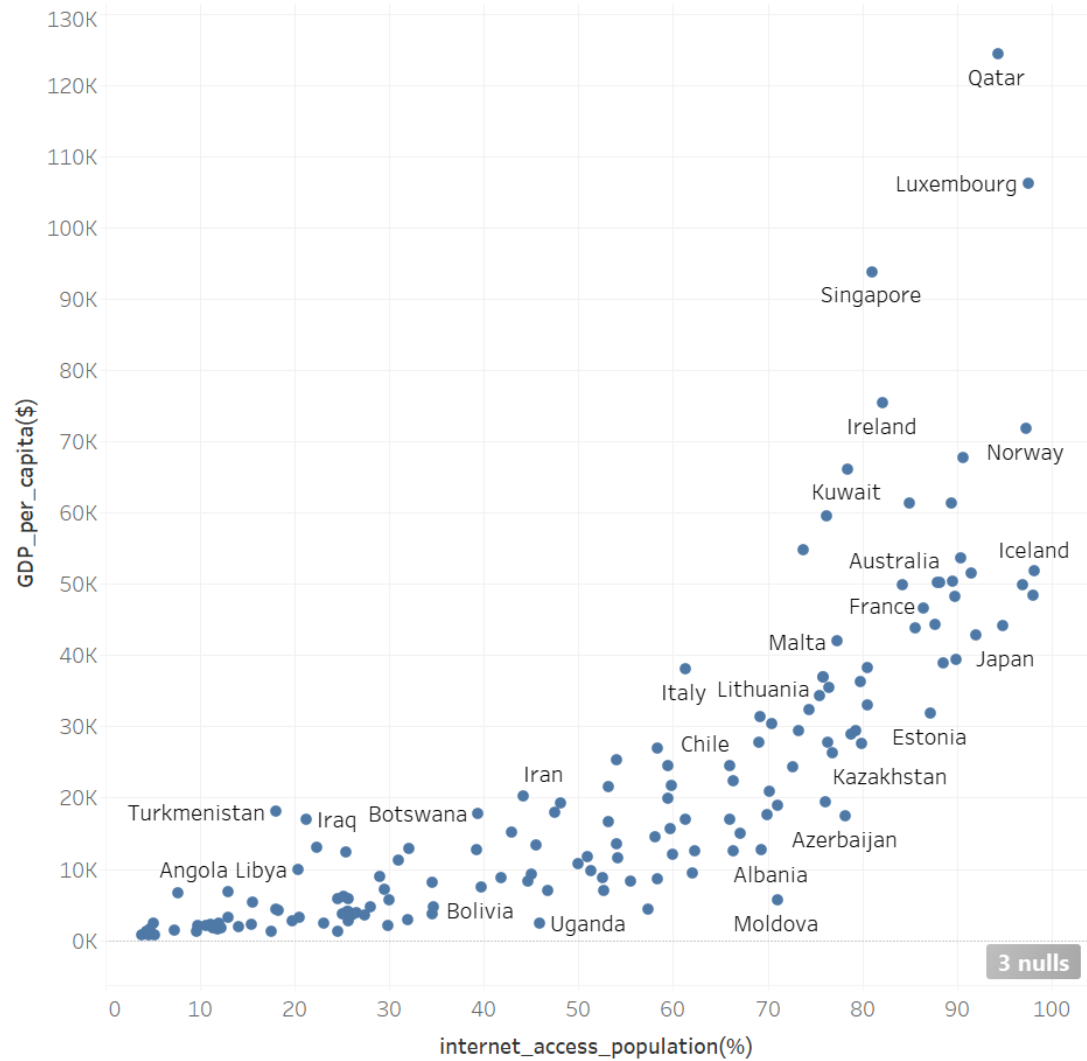
GDP per capita for all countries?



Marks and Channels: Tableau example



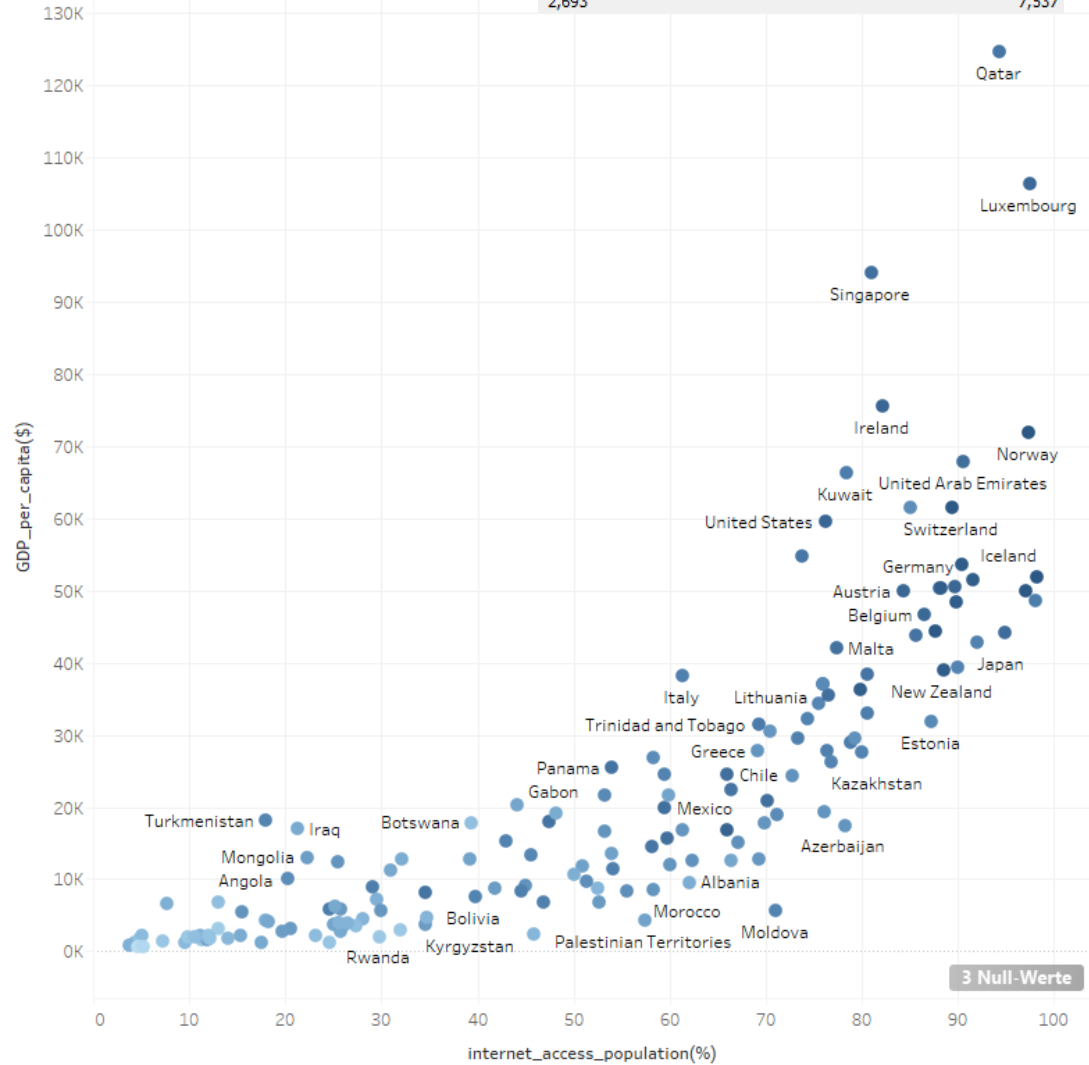
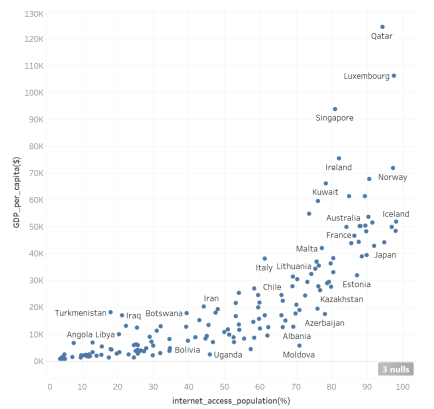
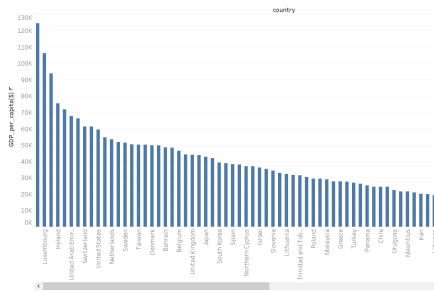
Internet access vs. GDP?



Marks and Channels:

Tableau example

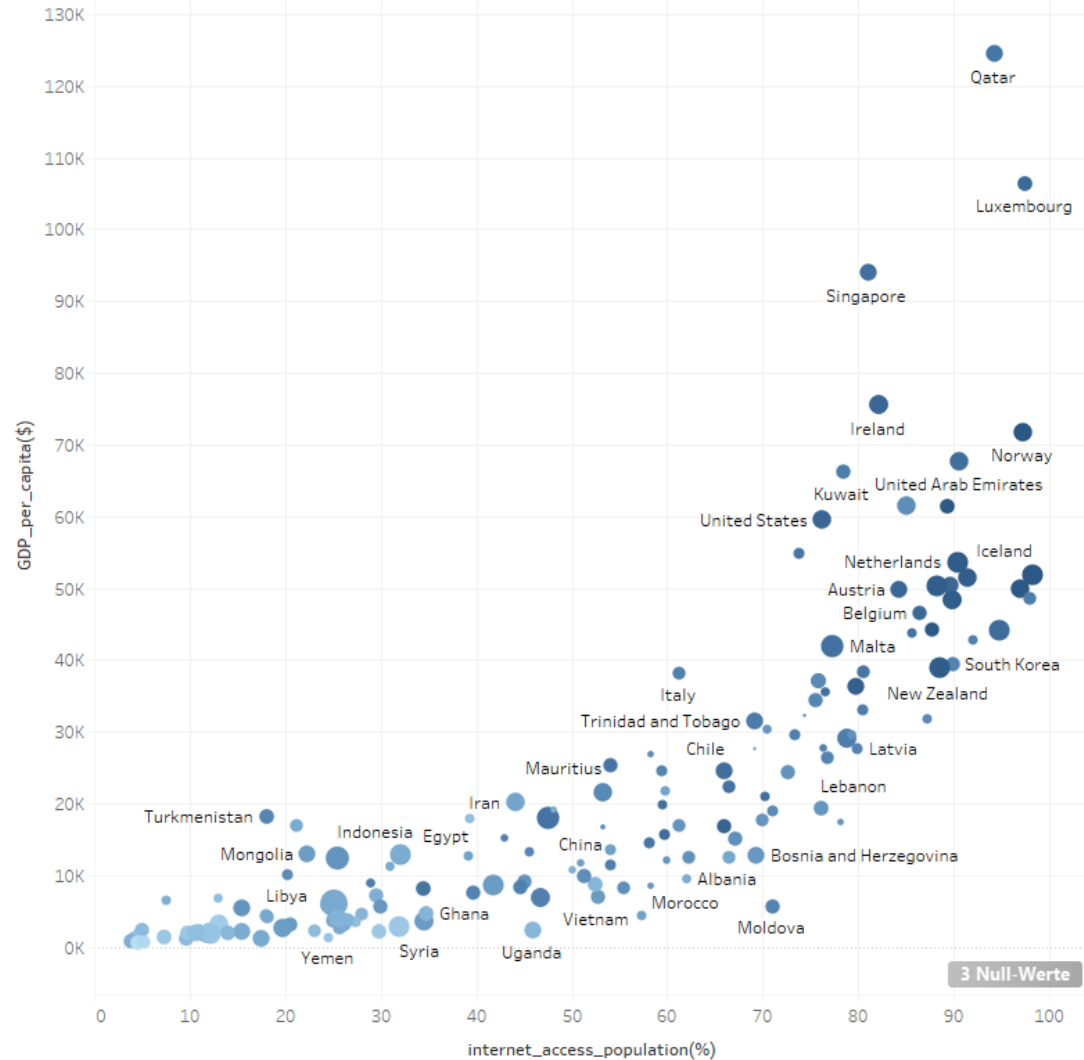
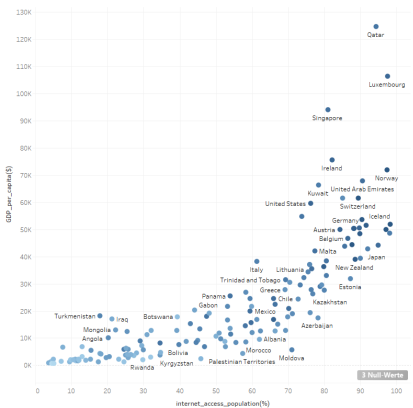
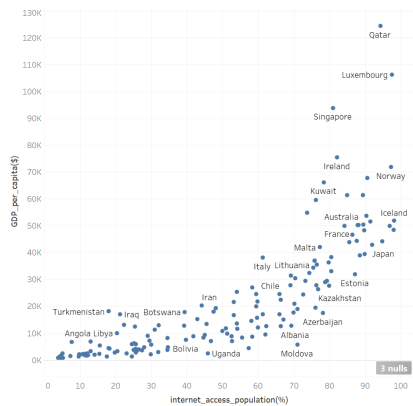
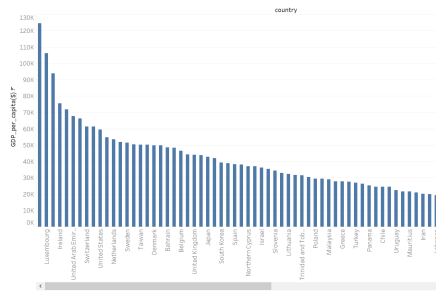
Low Happiness Score, high GDP?



based on © Munnzner/Moeller et al.

Marks and Channels: Tableau example

Low GDP, high Generosity?



based on © Munzner/Möller et al.

Marks and Channels:

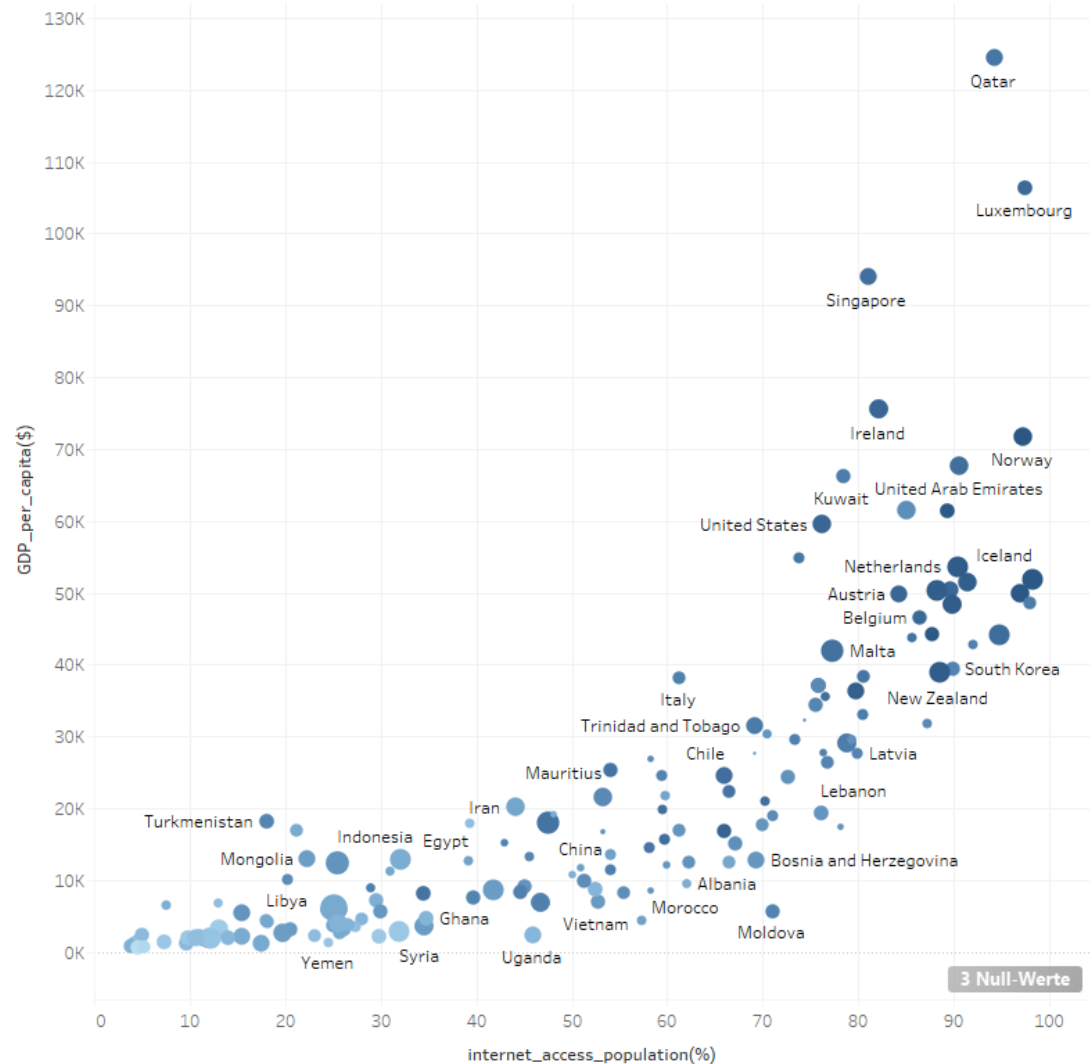
Tableau example

Marks:

- Circles - Countries

Channels:

- Rows (position along y axis): GDP per Capita (\$)
- Columns (position along x axis): Internet access %
- Color (saturation/luminance): Happiness score
- Size: Generosity



Channel types

- *What*: **categorical**
- *How Much*: **ordered** (ordinal, quantitative)

Channel types

- *What*: **categorical**
 - shape
 - spatial region
 - color (hue)
- *How Much*: **ordered** (ordinal, quantitative)

Channel types

- ***What*: categorical**
 - shape
 - spatial region
 - color (hue)
- ***How Much*: ordered (ordinal, quantitative)**
 - length (1D)
 - area (2D)
 - volume (3D)
 - tilt
 - position
 - color (lightness)

Mark types

- Tables: item = point
- Network: node+link
- Link types:
 - **Connection:** relationship between two nodes
 - **Containment:** hierarchy

Marks as Items/Nodes

→ Points



→ Lines



→ Areas



Marks as Links

→ Containment



→ Connection

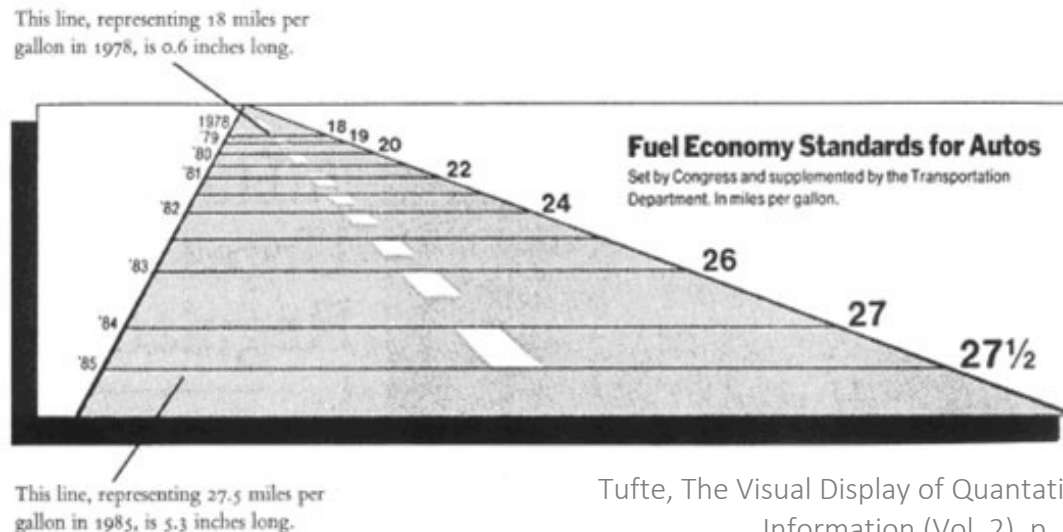


Munzner, Visualization
Analysis and Design, 2014,
p. 100

Expressiveness + Effectiveness

Expressiveness principle:

- Visual encoding should express **all of, and only**, the information in the dataset attributes
- Lie factor

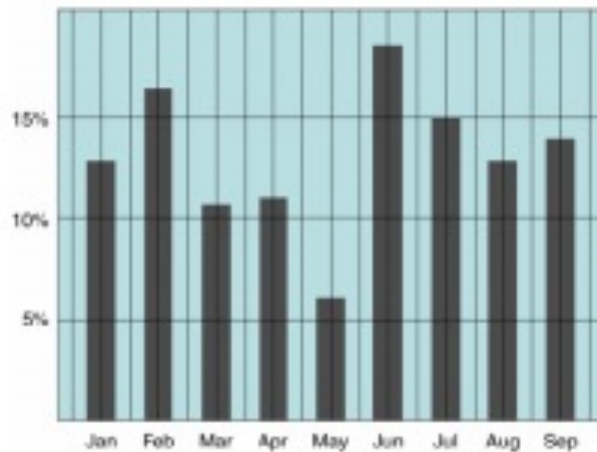


Tufte, The Visual Display of Quantative Information (Vol. 2), p. 57

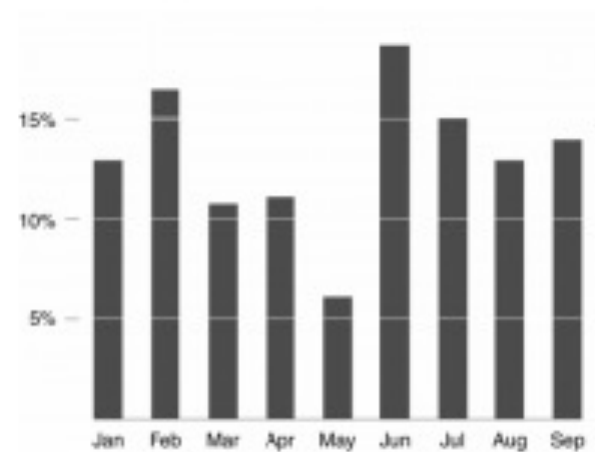
Expressiveness + Effectiveness

Effectiveness principle:

- Importance of the attribute should match the salience of the channel
- Data-ink ratio



Low Data/Ink



High Data/Ink

Marks and channels

Examples

Channel types

Mark types

Expressiveness + Effectiveness

Channel effectiveness

Accuracy

Discriminability

Separability

Popout

Channel characteristics

Spatial position

Relative vs. absolute

Color

Perception/Color theory basics

Perception issues & deficiencies

Categorical/Ordinal/Quantitative

Channel effectiveness

Which channel is most accurate?*

- Color
- Shape
- Curvature
- Area
- Motion
- Length
- Angle
- Position
- Depth
- Volume

* for the task of comparing two values

Which channel is most accurate?*

* for the task of comparing two values

- Color
- Shape
- Curvature
- Area
- Motion
- **Length** ← Ordered attributes
- Angle
- **Position** ← Ordered attributes
- Depth
- Volume

Effectiveness ranking

➔ 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) 

Effectiveness

Most

Least

Same

➔ Identity Channels: **Categorical** Attributes

Spatial region 

Color hue 

Motion 

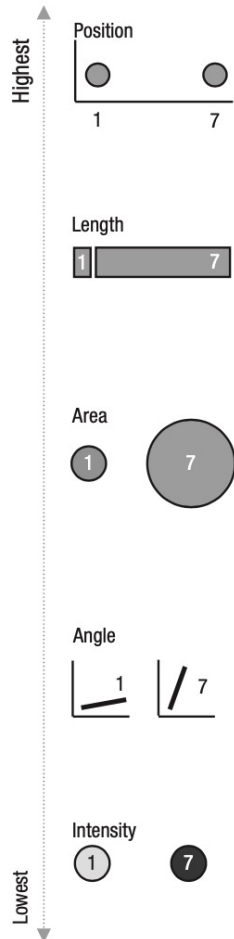
Shape 

by Munzner, Visualization Analysis and Design, 2014, pp. 94
Synthesis of

- Cleveland & McGill, Graphical Perception: Theory, Experimentation, and Application to the Development of Graphical Methods, 1984, doi: [10.1080/01621459.1984.10478080](https://doi.org/10.1080/01621459.1984.10478080)
- Cleveland, A Model for Studying Display Methods of Statistical Graphics, 1993, doi: [10.1080/10618600.1993.10474616](https://doi.org/10.1080/10618600.1993.10474616)
- Mackinlay, Automating the Design of Graphical Presentations of Relational Information, 1986, doi: [10.1145/22949.22950](https://doi.org/10.1145/22949.22950)
- Ware, Information Visualization: Perception for Design, 2013
- MacEachren, How Maps Work: Representation, Visualization, and Design. Guilford Press, 1995.
- Heer & Bostock, Crowdsourcing graphical perception: using mechanical turk to assess visualization design, 2010, doi: [10.1145/1753326.1753357](https://doi.org/10.1145/1753326.1753357)
- Maguire et al., Taxonomy-Based Glyph Design—with a Case Study on Visualizing Workflows of Biological Experiments, 2012, doi: [10.1109/TVCG.2012.271](https://doi.org/10.1109/TVCG.2012.271)
- Borgo et al., Glyph-based Visualization: Foundations, Design Guidelines, Techniques and Applications, 2013, doi: [10.2312/conf/EG2013/stars/039-063](https://doi.org/10.2312/conf/EG2013/stars/039-063)

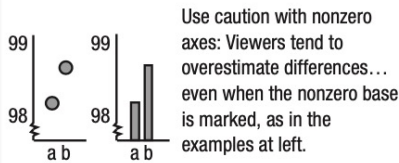
Absolute Precision Ranking for Seeing a Single Ratio

Visual estimation of the 1:7 ratio is noisier toward bottom

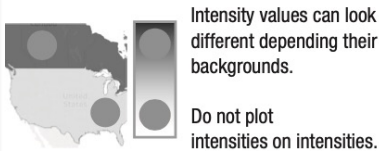
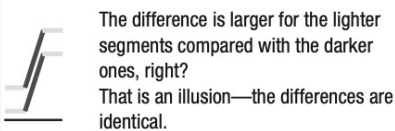
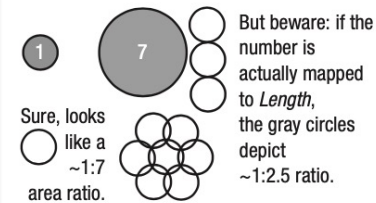
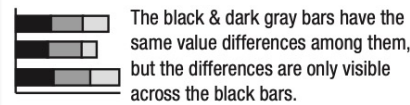


Common Illusions That Distort Data

Caveats for the visual encoding in each row

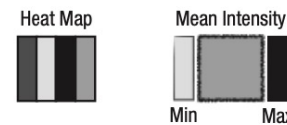
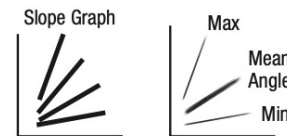
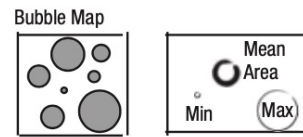
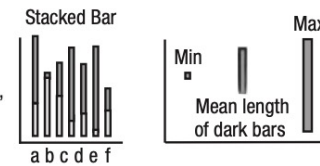
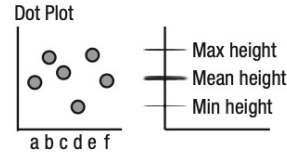


Stacked bar: Bars on baseline are position-coded = more precise perception.



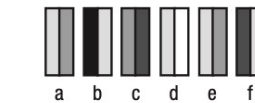
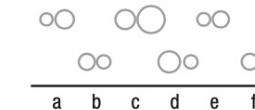
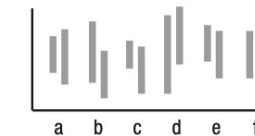
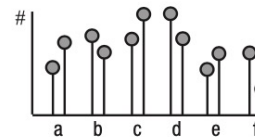
Vision Is Powerful for Global Statistics

For each visualization, statistics are available quickly



Vision Is Sluggish for Comparisons

Isolating pairs with “larger second values” is tough...



So guide viewers to the right comparisons

Tool: Shortcut comparisons by adding direct depictions of the deltas, as below



“a, c, & e have increased”

Tool: Highlight and annotate the right comparisons for your viewers, as above.

Tool: You and your viewers will (generally) compare values that

(a) are close together or connected and (b) have similar colors, in that priority order.

For color heat maps, depict deltas as blue (+) & red (-)

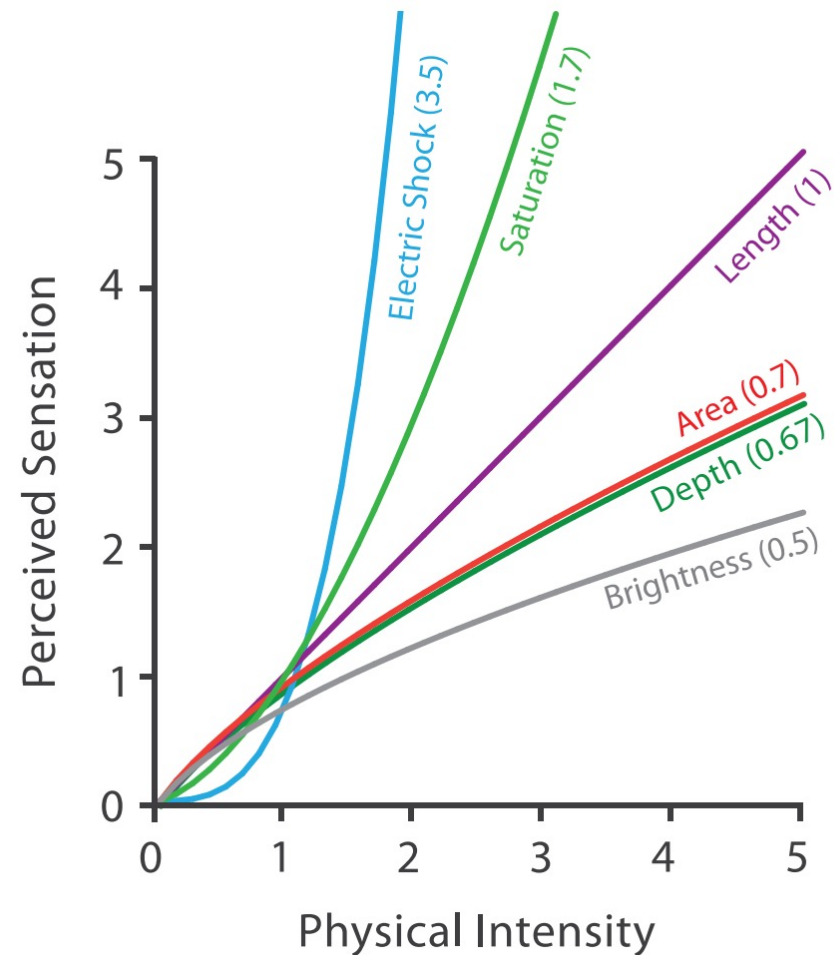
+ - + - + -

[green/red is unsafe for colorblindness]

Fig. 2. A summary of the power and limits of visual data processing. The two columns on the left show a quick reference guide to channels that can depict data visually and common illusions for each channel. The column in the center presents a summary of how visual statistics are powerful. The two columns on the right illustrate how comparisons are severely limited and present a set of design techniques that focus viewers on the “right” ones.

Effectiveness: Accuracy

- perceptual judgement vs. stimulus
- Weber's law:
 $S = I^n$



Data: Stevens, Psychophysics: introduction to its perceptual, neural, and social prospects, 1975

Figure: Munzner, Visualization Analysis and Design, 2014, p. 104 ff.

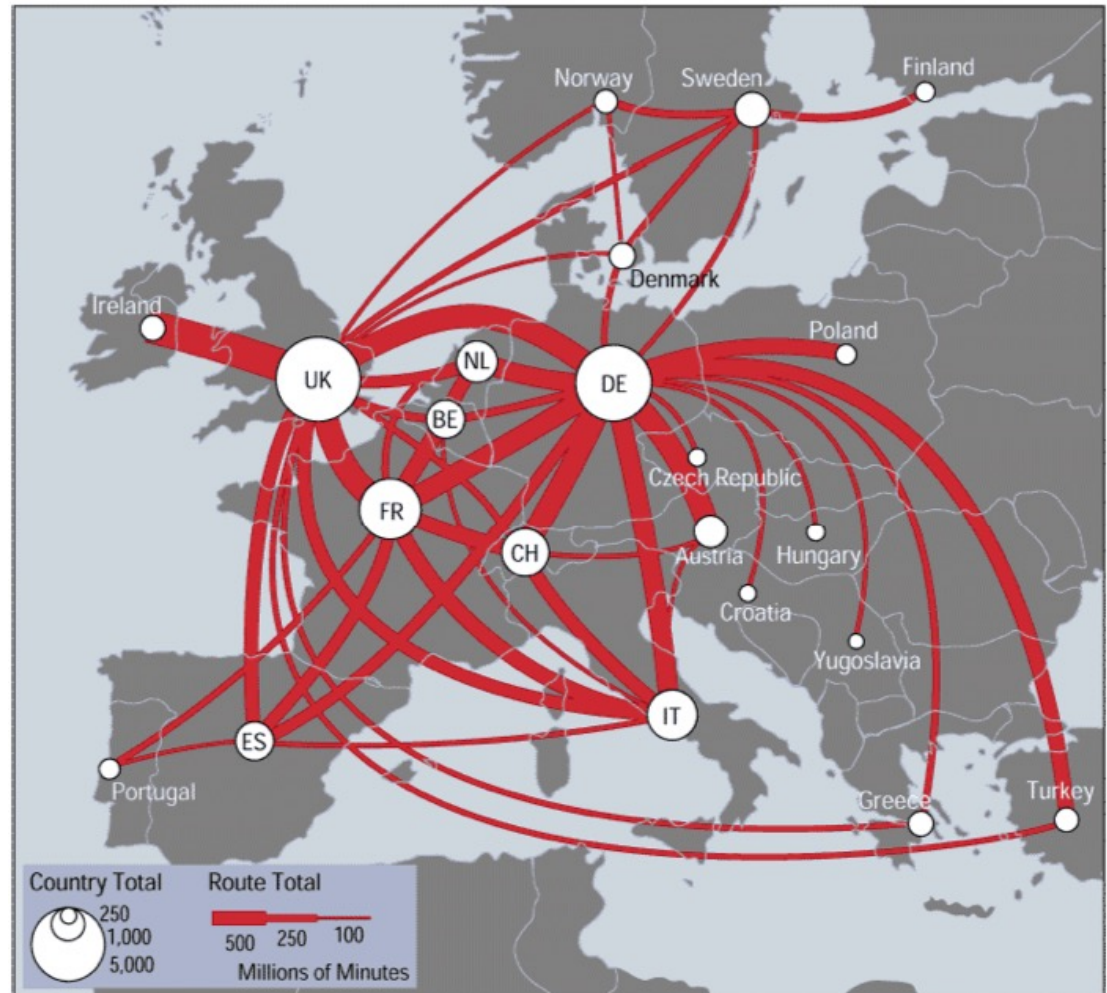
Effectiveness: Discriminability

- How many colors can I tell apart?
- How many levels of grey etc.
- Example: line width



Effectiveness: Discriminability

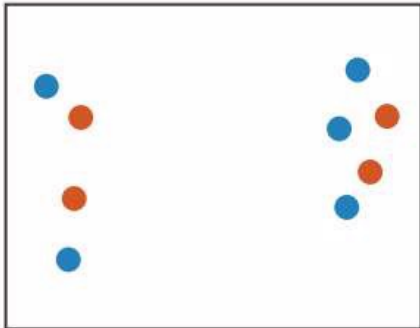
- How many colors can I tell apart?
- How many levels of grey etc.
- Example: line width



Effectiveness: Separability

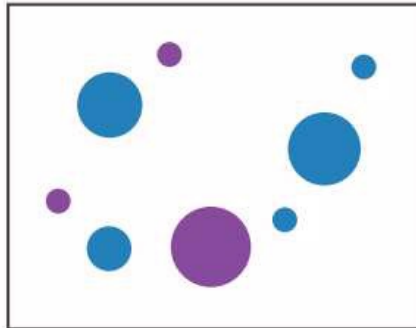
- Separable vs. integral channels

Position
+ Hue (Color)



Fully separable

Size
+ Hue (Color)

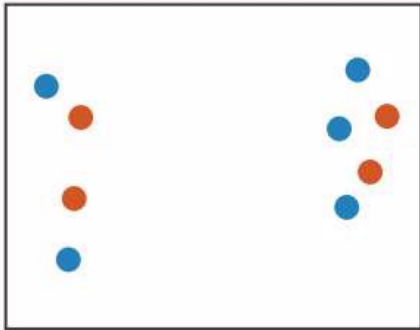


Some interference

Effectiveness: Separability

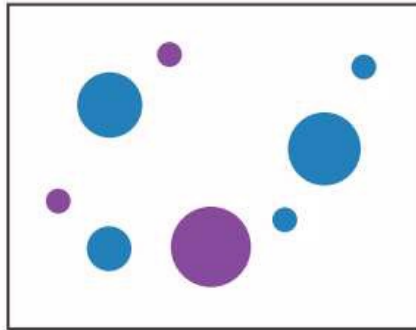
- Separable vs. integral channels

Position
+ Hue (Color)



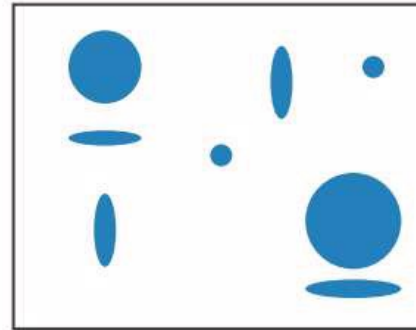
Fully separable

Size
+ Hue (Color)



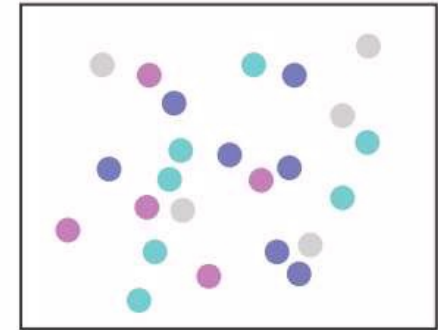
Some interference

Width
+ Height



Some/significant
interference

Red
+ Green



Major interference

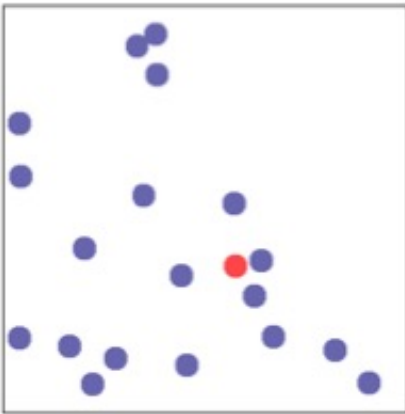
Effectiveness: Popout

Preattentive processing

Find the red dot.

Effectiveness: Popout

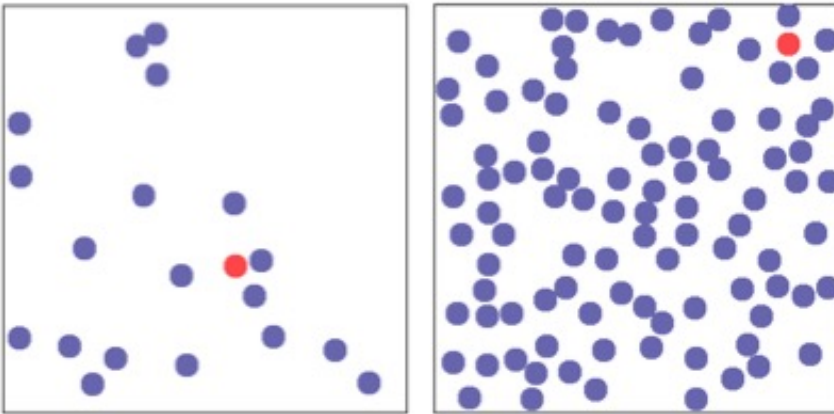
Preattentive processing



Find the red dot.

Effectiveness: Popout

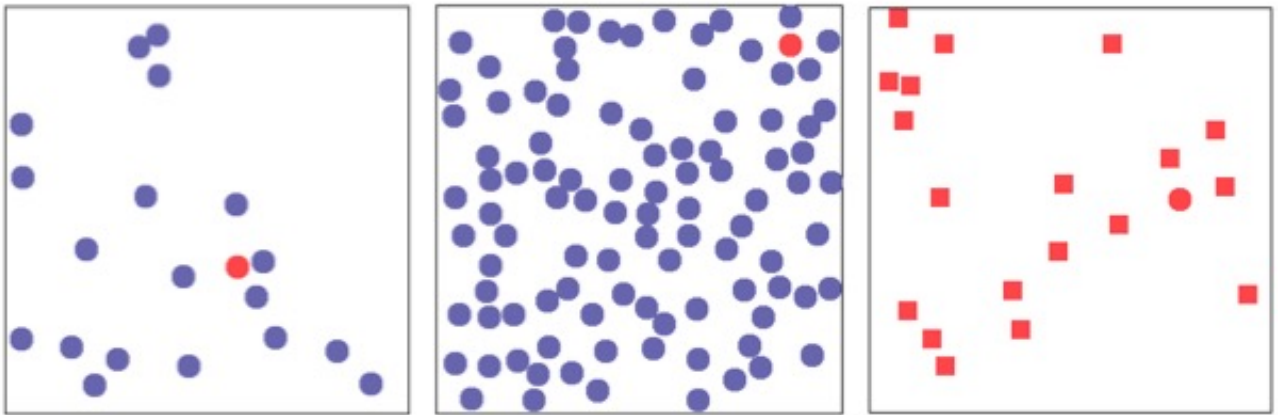
Preattentive processing



Find the red dot.

Effectiveness: Popout

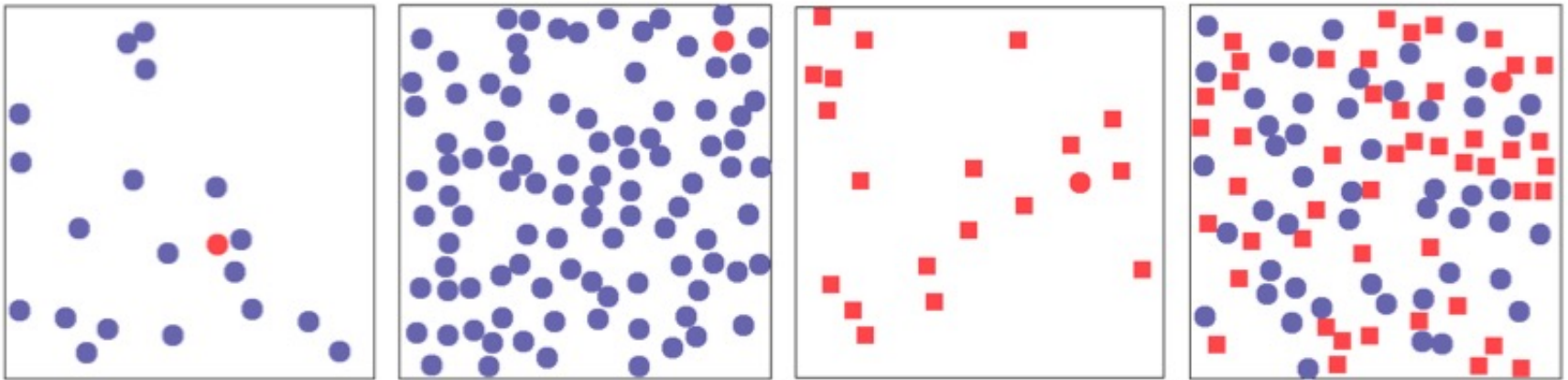
Preattentive processing



Find the red dot.

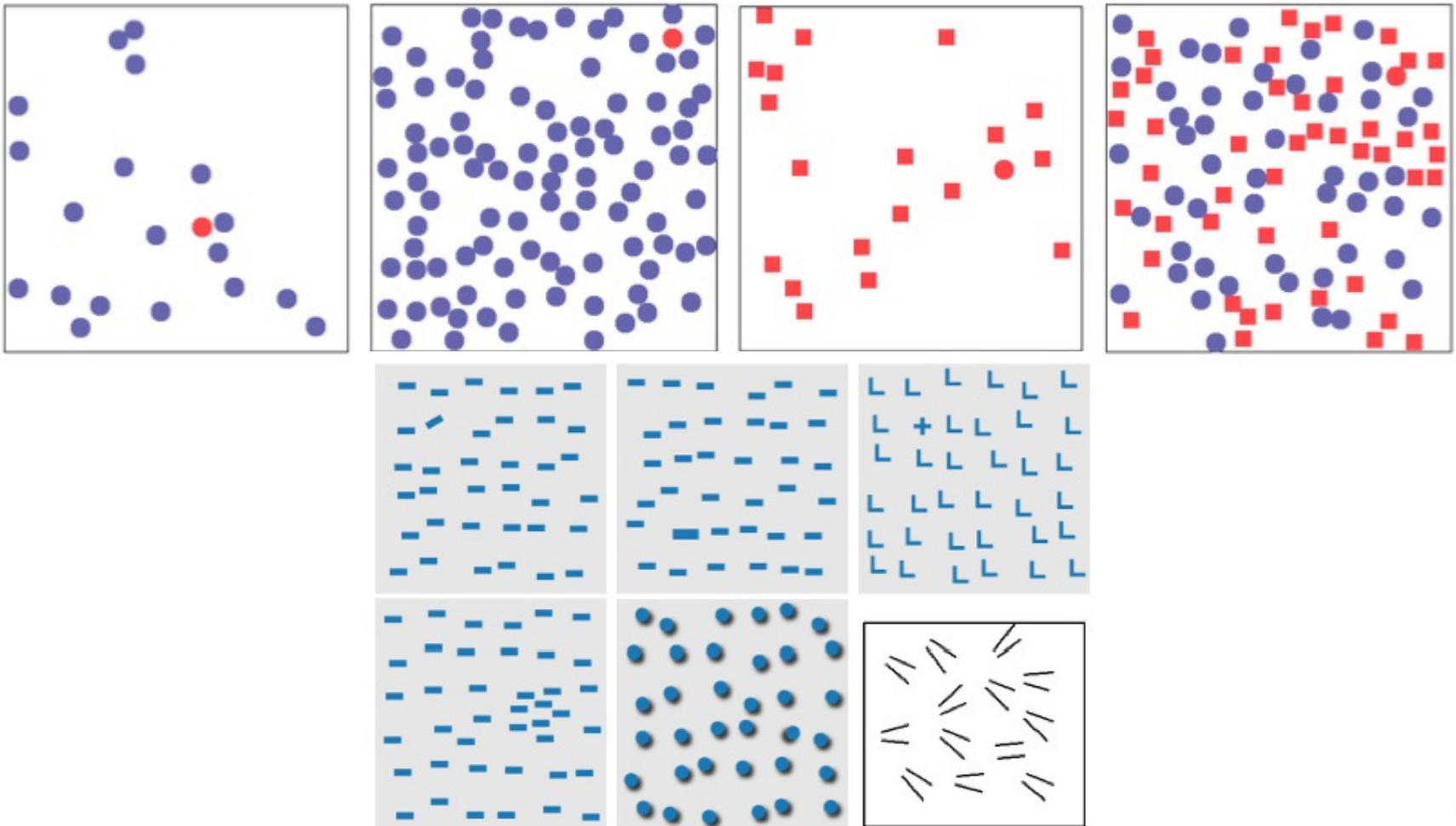
Effectiveness: Popout

Preattentive processing



Effectiveness: Popout

Preattentive processing

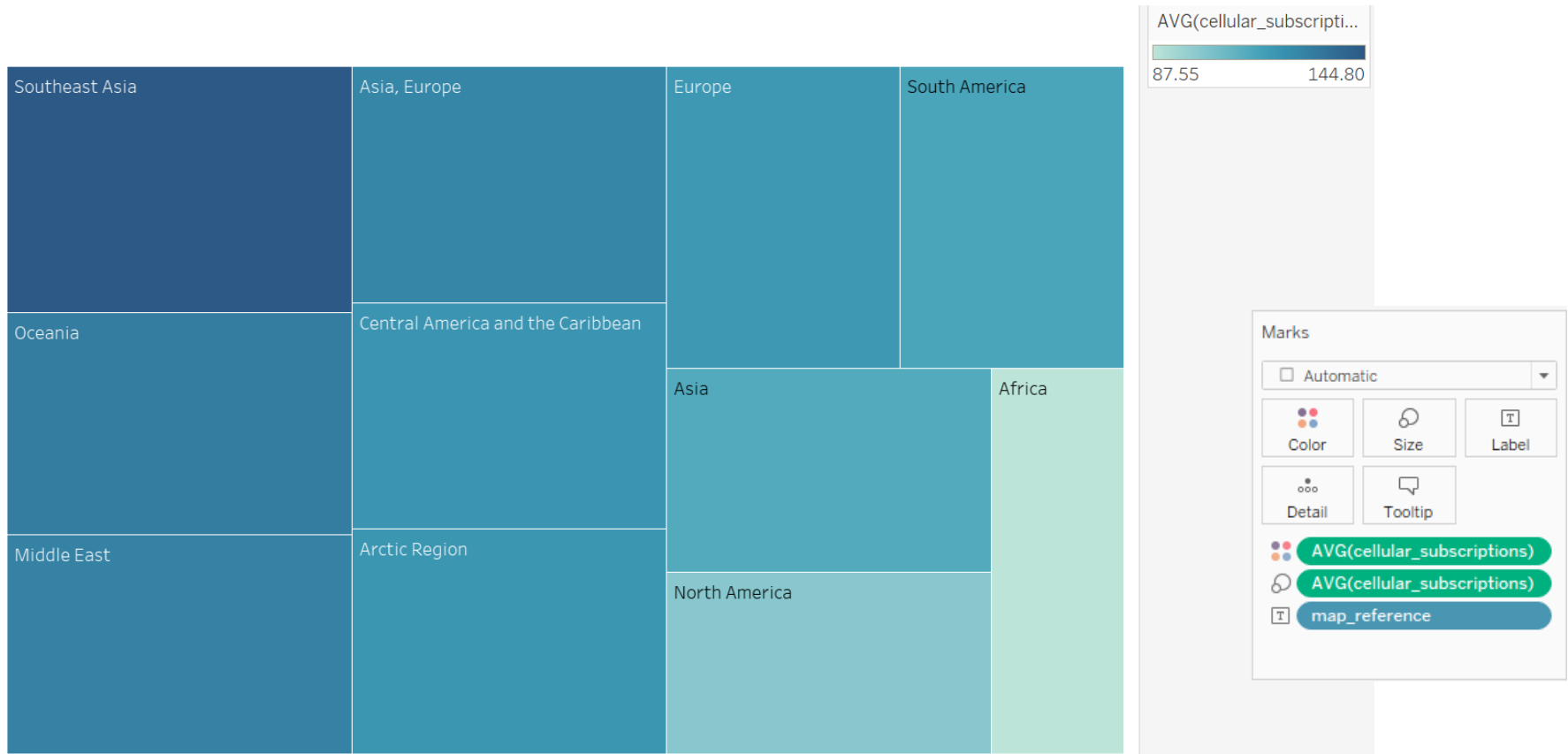


Effectiveness:

Tableau example

- Let us test such difference by comparing area and length as channels for a quantitative value
- Let's look at the **Cellular Subscriptions** per continent (**Map Reference**)
- We will use a Heat Map as area encoding and a bar chart as length encoding
- Which one is easier to read?

Effectiveness: Tableau example



Effectiveness:

Tableau example

- On the right side is a **Show Me** button, there you can easily change the encoding



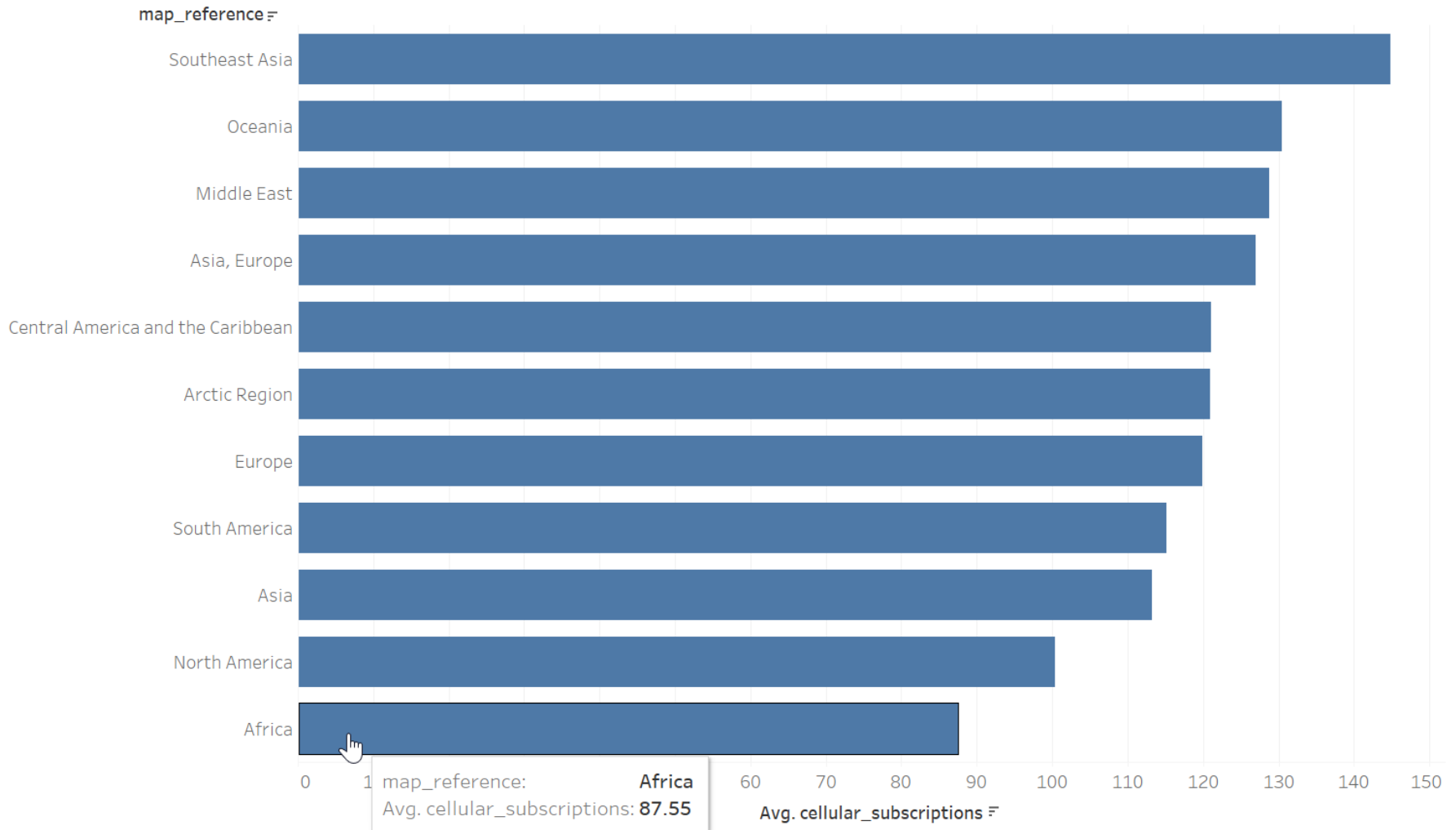
The image shows the 'Show Me' interface in Tableau, which provides a grid of various chart and visualization options. A blue box highlights a specific chart option, which is a horizontal bar chart. Below the grid, there are instructions for configuring the chart:

For **horizontal bars** try

0 or more **Dimensions**

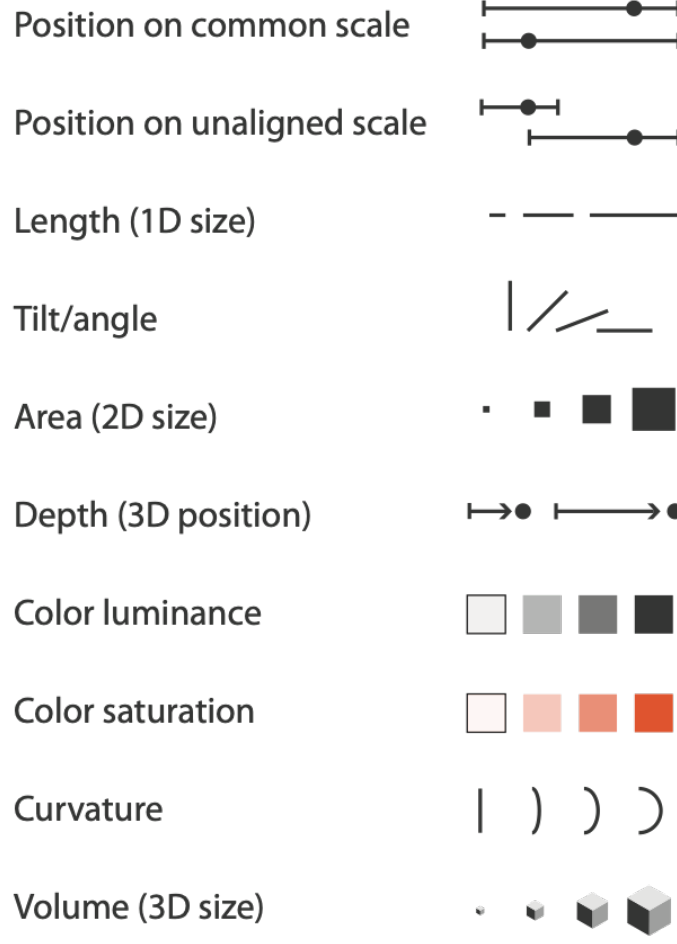
1 or more **Measures**

Effectiveness: Tableau example



Effectiveness ranking

➔ Magnitude Channels: **Ordered** Attributes



➔ Identity Channels: **Categorical** Attributes



Effectiveness

Most

Least

by Munzner, Visualization Analysis and Design, 2014, pp. 94
Synthesis of

- Cleveland & McGill, Graphical Perception: Theory, Experimentation, and Application to the Development of Graphical Methods, 1984, doi: [10.1080/01621459.1984.10478080](https://doi.org/10.1080/01621459.1984.10478080)
- Cleveland, A Model for Studying Display Methods of Statistical Graphics, 1993, doi: [10.1080/10618600.1993.10474616](https://doi.org/10.1080/10618600.1993.10474616)
- Mackinlay, Automating the Design of Graphical Presentations of Relational Information, 1986, doi: [10.1145/22949.22950](https://doi.org/10.1145/22949.22950)
- Ware, Information Visualization: Perception for Design, 2013
- MacEachren, How Maps Work: Representation, Visualization, and Design. Guilford Press, 1995.
- Heer & Bostock, Crowdsourcing graphical perception: using mechanical turk to assess visualization design, 2010, doi: [10.1145/1753326.1753357](https://doi.org/10.1145/1753326.1753357)
- Maguire et al., Taxonomy-Based Glyph Design—with a Case Study on Visualizing Workflows of Biological Experiments, 2012, doi: [10.1109/TVCG.2012.271](https://doi.org/10.1109/TVCG.2012.271)
- Borgo et al., Glyph-based Visualization: Foundations, Design Guidelines, Techniques and Applications, 2013, doi: [10.2312/conf/EG2013/stars/039-063](https://doi.org/10.2312/conf/EG2013/stars/039-063)

Marks and channels

Examples

Channel types

Mark types

Expressiveness + Effectiveness

Channel effectiveness

Accuracy

Discriminability

Separability

Popout

Channel characteristics

Spatial position

Relative vs. absolute

Color

Perception/Color theory basics

Perception issues & deficiencies

Categorical/Ordinal/Quantitative

Channel characteristics

Available Channels

How Much?

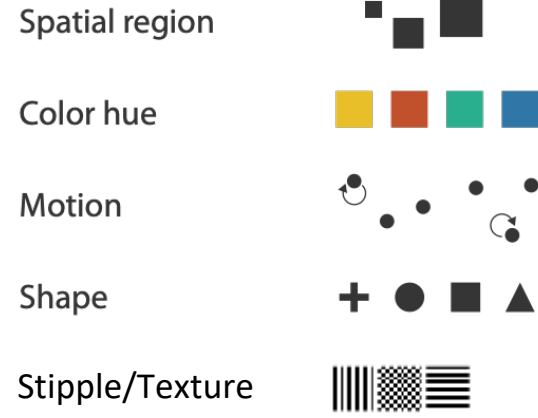
① **Magnitude Channels: Ordered Attributes**



interact with others

What?

② **Identity Channels: Categorical Attributes**



↑ Most
↓ Least
Effectiveness

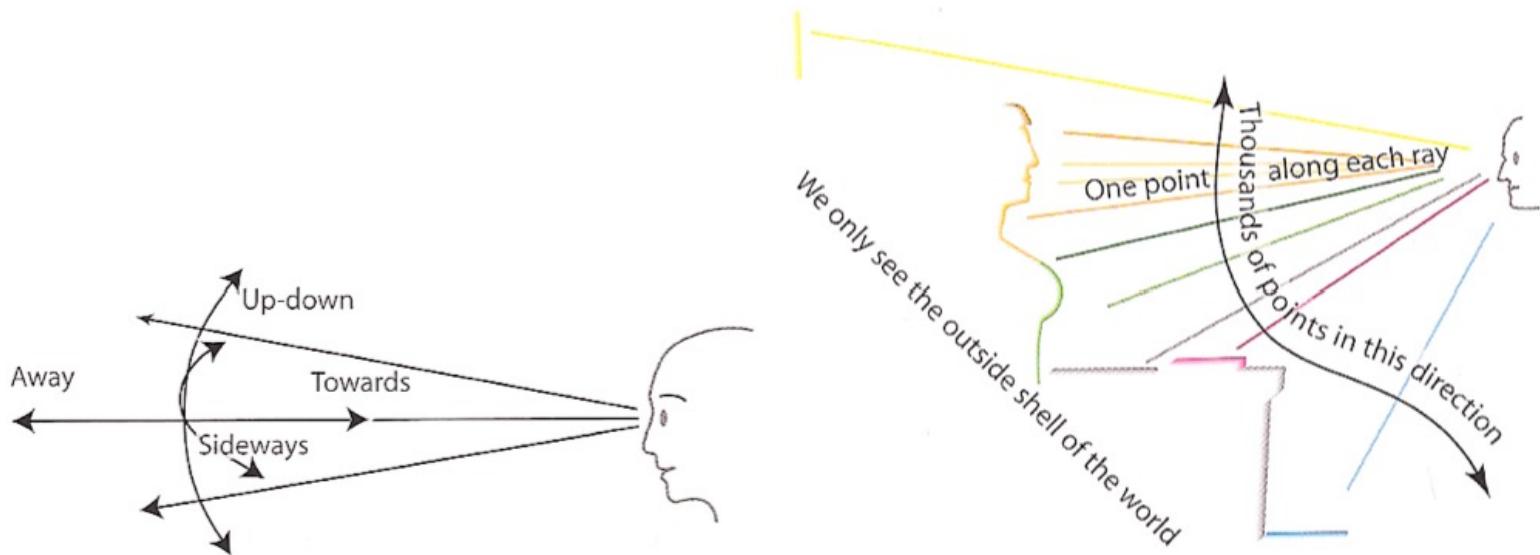
Same

Same

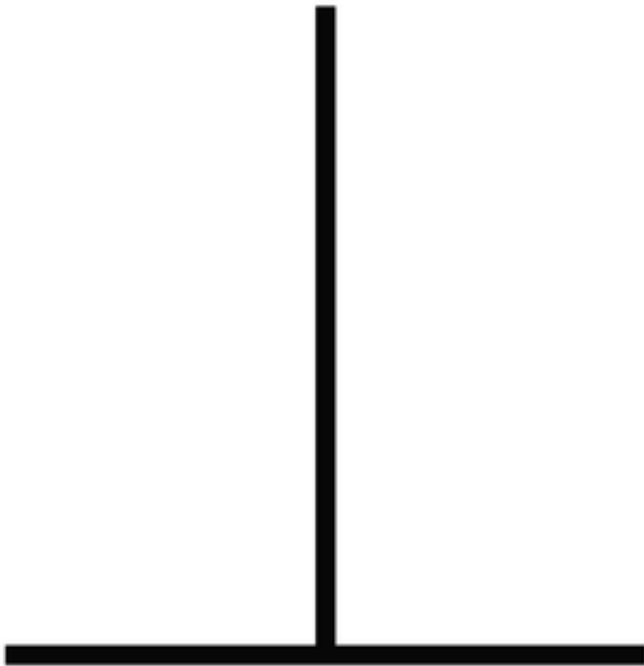
Munzner, Visualization Analysis and Design, 2014, p. 94

Spatial position

- Most effective for all data types
- But: only in left/right and up/down direction
- We only see in „2.05D“



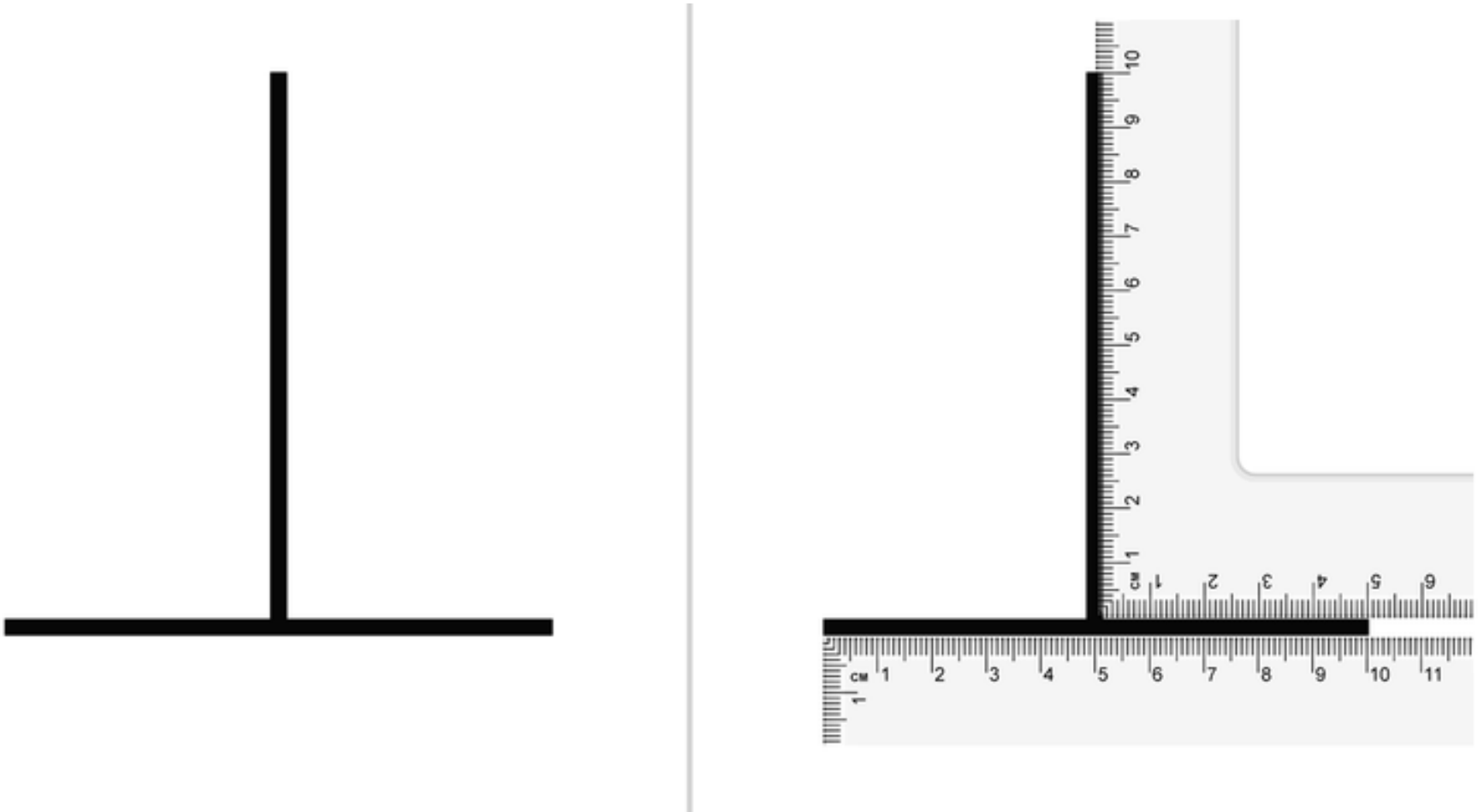
Which bar is longer?



- Horizontal
- Vertical
- Both have the same length



Vertical-horizontal illusion

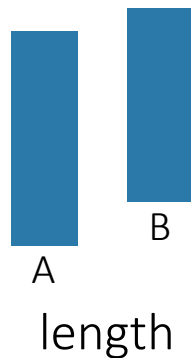


https://en.wikipedia.org/wiki/Vertical-horizontal_illusion

Relative vs. absolute judgement

- Weber's law says that everything is relative, i.e. the "intensity" depends on the background signal

unframed,
unaligned



Relative vs. absolute judgement

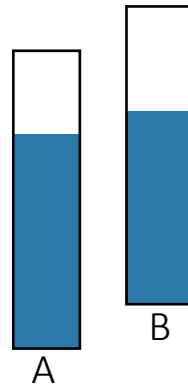
- Weber's law says that everything is relative, i.e. the "intensity" depends on the background signal

unframed,
unaligned



length

framed,
unaligned



position along
unaligned
common scale

Relative vs. absolute judgement

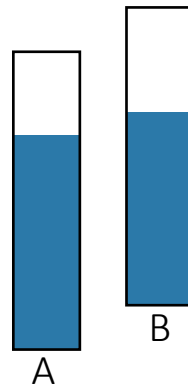
- Weber's law says that everything is relative, i.e. the "intensity" depends on the background signal

unframed,
unaligned



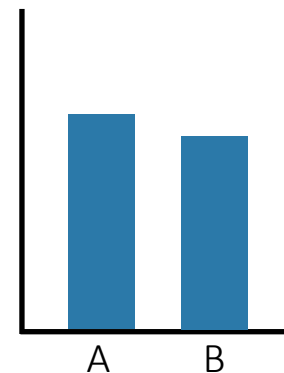
length

framed,
unaligned



position along
unaligned
common scale

unframed,
aligned

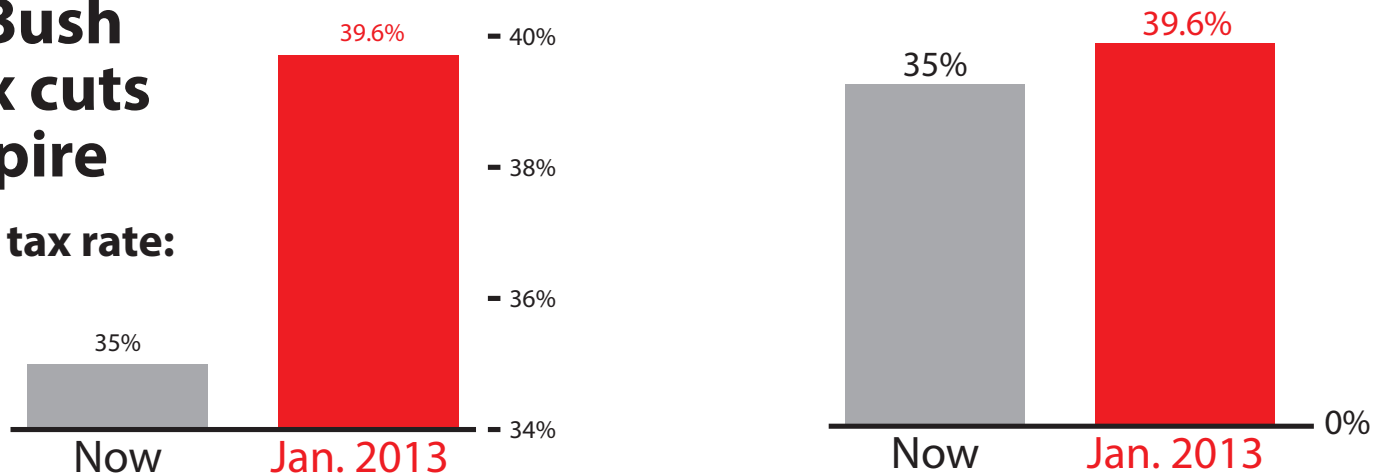


position along
aligned scale

Relative vs. absolute judgement

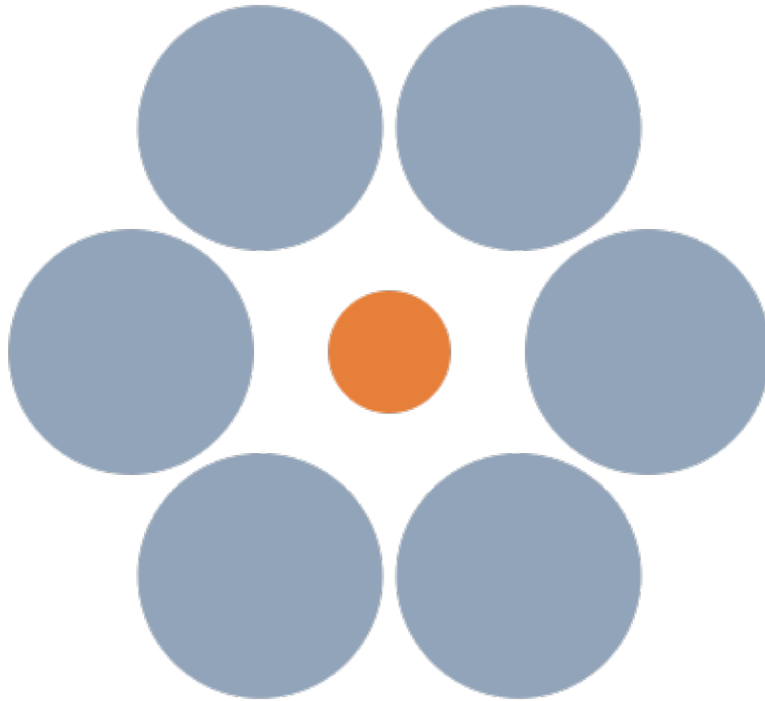
**If Bush
tax cuts
expire**

Top tax rate:



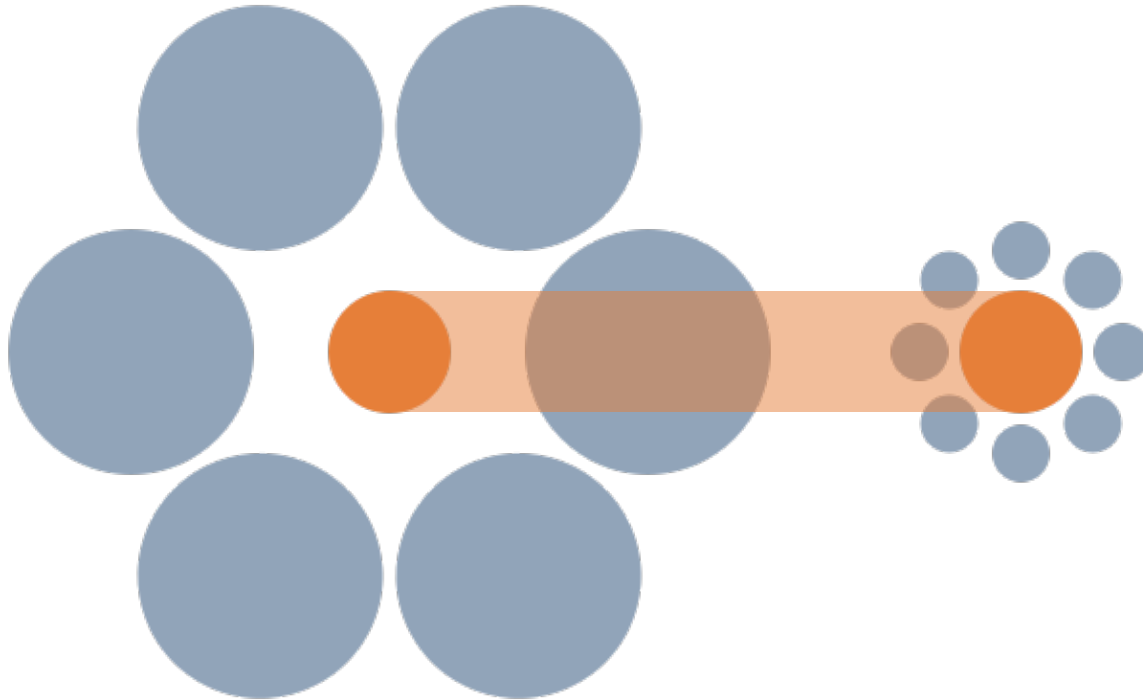
From Alberto Cairo, HOW CHARTS LIE

Which orange circle is larger?



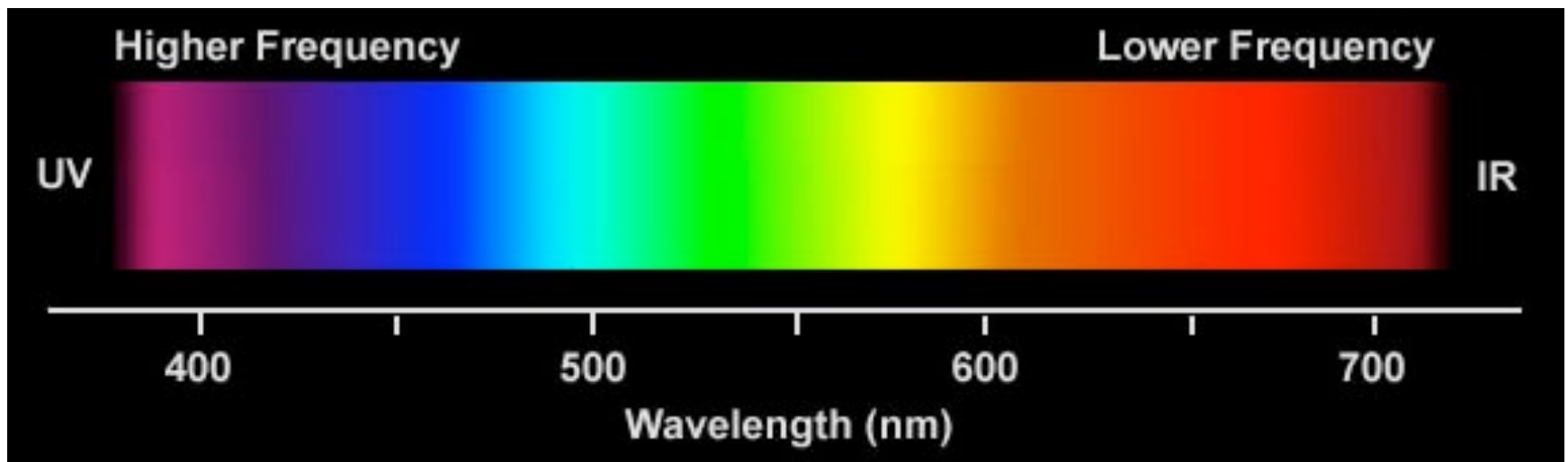
- Left
- Right
- Both are the same size

Ebbinghaus illusion

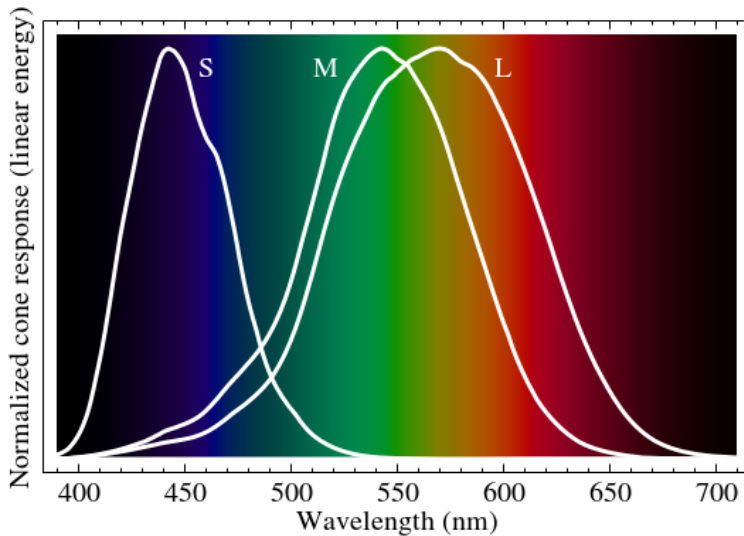


https://en.wikipedia.org/wiki/Ebbinghaus_illusion

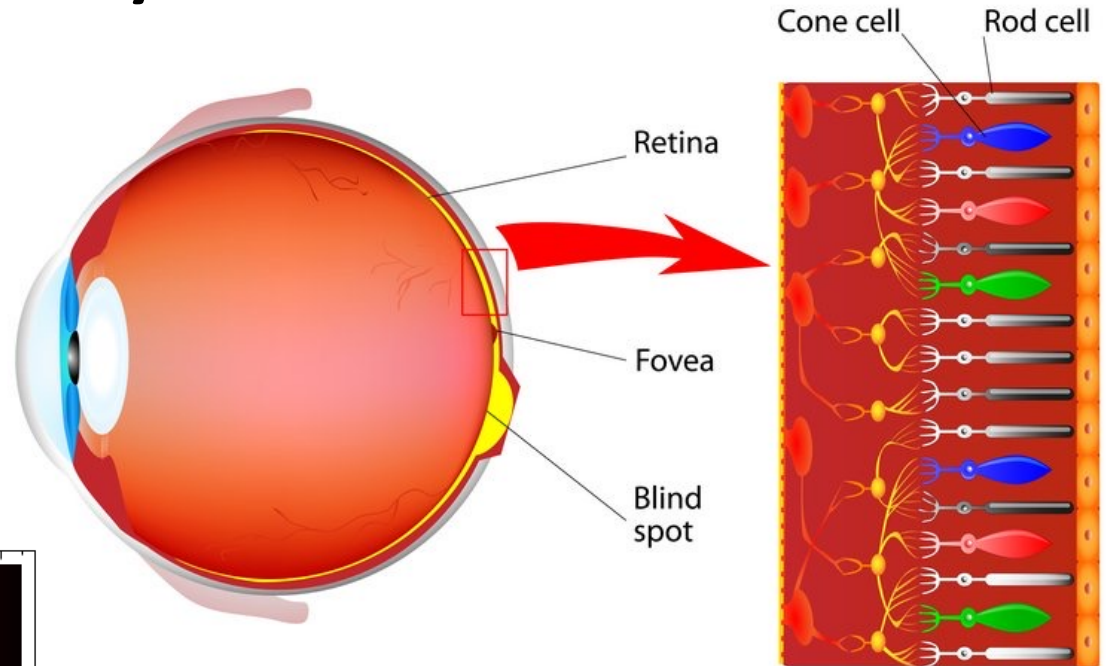
Perception/Color theory basics



Perception/Color theory basics: Human visual system

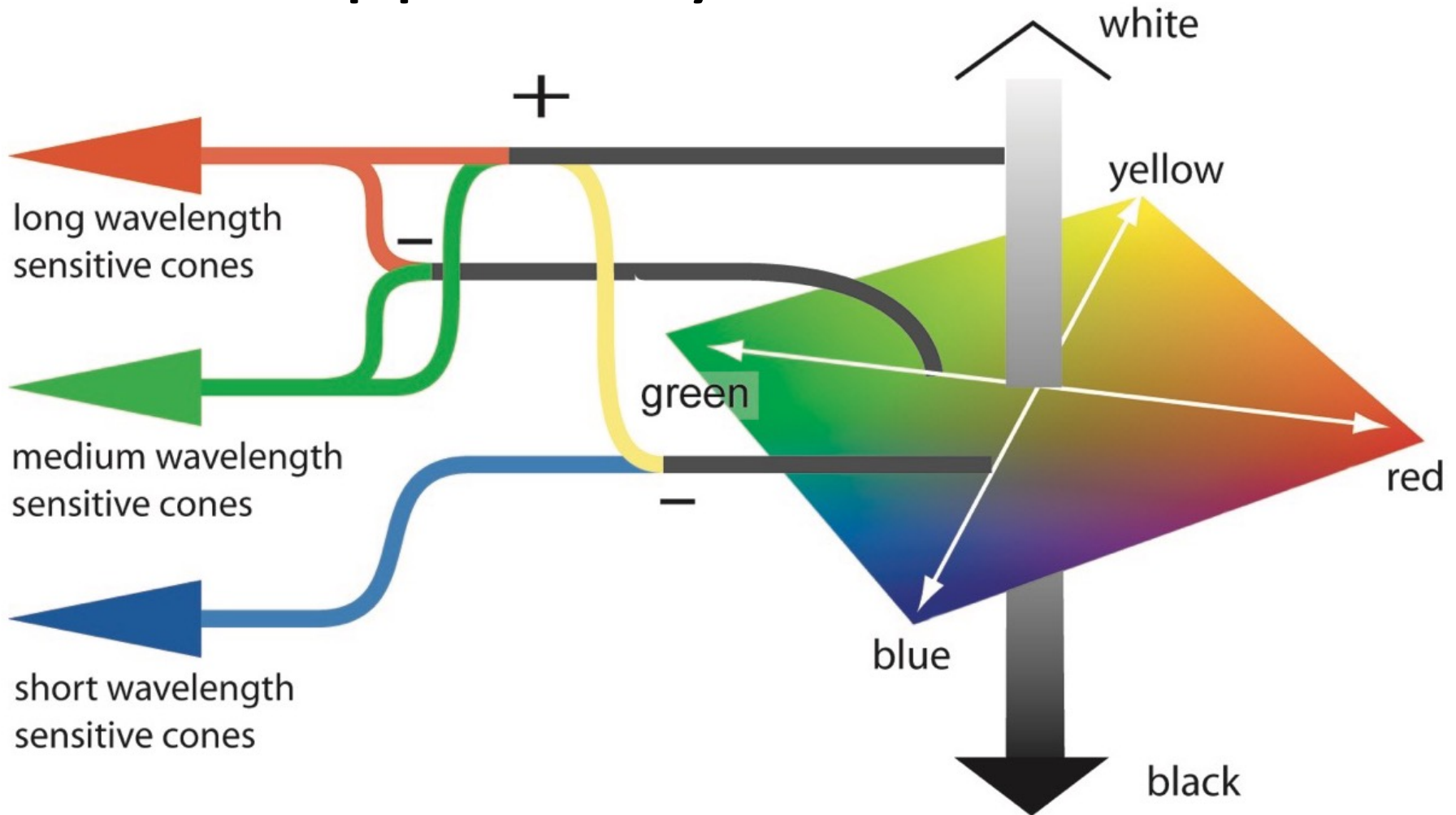


https://en.wikipedia.org/wiki/Color_vision



<https://www.webrn-maculardegeneration.com/rods-and-cones.html>

Perception/Color theory basics: Color opponency

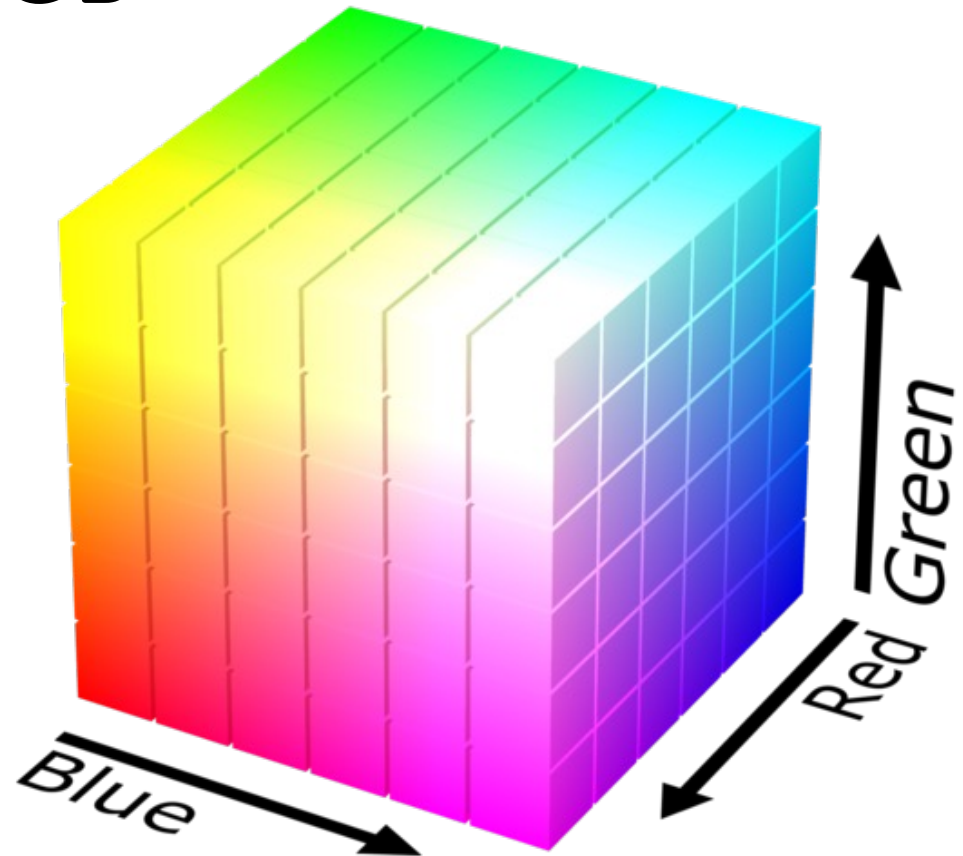


Ware, Visual thinking for design

Perception/Color theory basics

Color models: RGB

- Additive system
- Colors that can be represented by computer monitors
- Not perceptually uniform

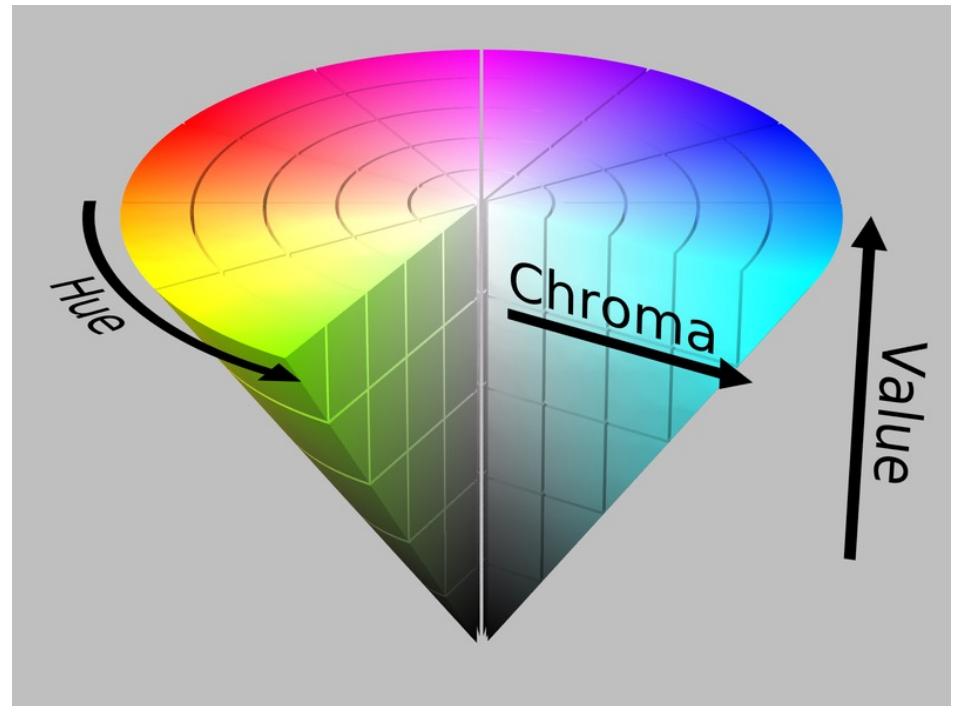


https://en.wikipedia.org/wiki/RGB_color_model

Perception/Color theory basics

Color models: HSL/HSV

- Hue
- Saturation (Chroma)
- Lightness (Value)
- Not perceptually uniform



Corners of the RGB
color cube



L from HSL
All the same



Luminance



https://en.wikipedia.org/wiki/HSL_and_HSV

Munzner, Visualization Analysis and Design, p. 221

Perception/Color theory basics

Luminance, Saturation, Hue

- Luminance



- *How Much* channel
- discriminability: ~2-4 bins
- contrast important

- Saturation



- *How Much* channel
- discriminability: ~3 bins

- Hue



- *What* channel
- discriminability: ~6-12

Color: Perception issues + deficiencies

Order of the squares?



Color: Perception issues + deficiencies

Do all boxes have the same color?



- Left is different
- Center is different
- Right is different
- All are exactly the same

Color: Perception issues + deficiencies

What do you see?



Thanks to Moritz Wustinger
Smiley based on http://upload.wikimedia.org/wikipedia/commons/b/bd/A_Smiley.jpg

Color: Perception issues + deficiencies

Do all boxes have the same color?



Left is different!

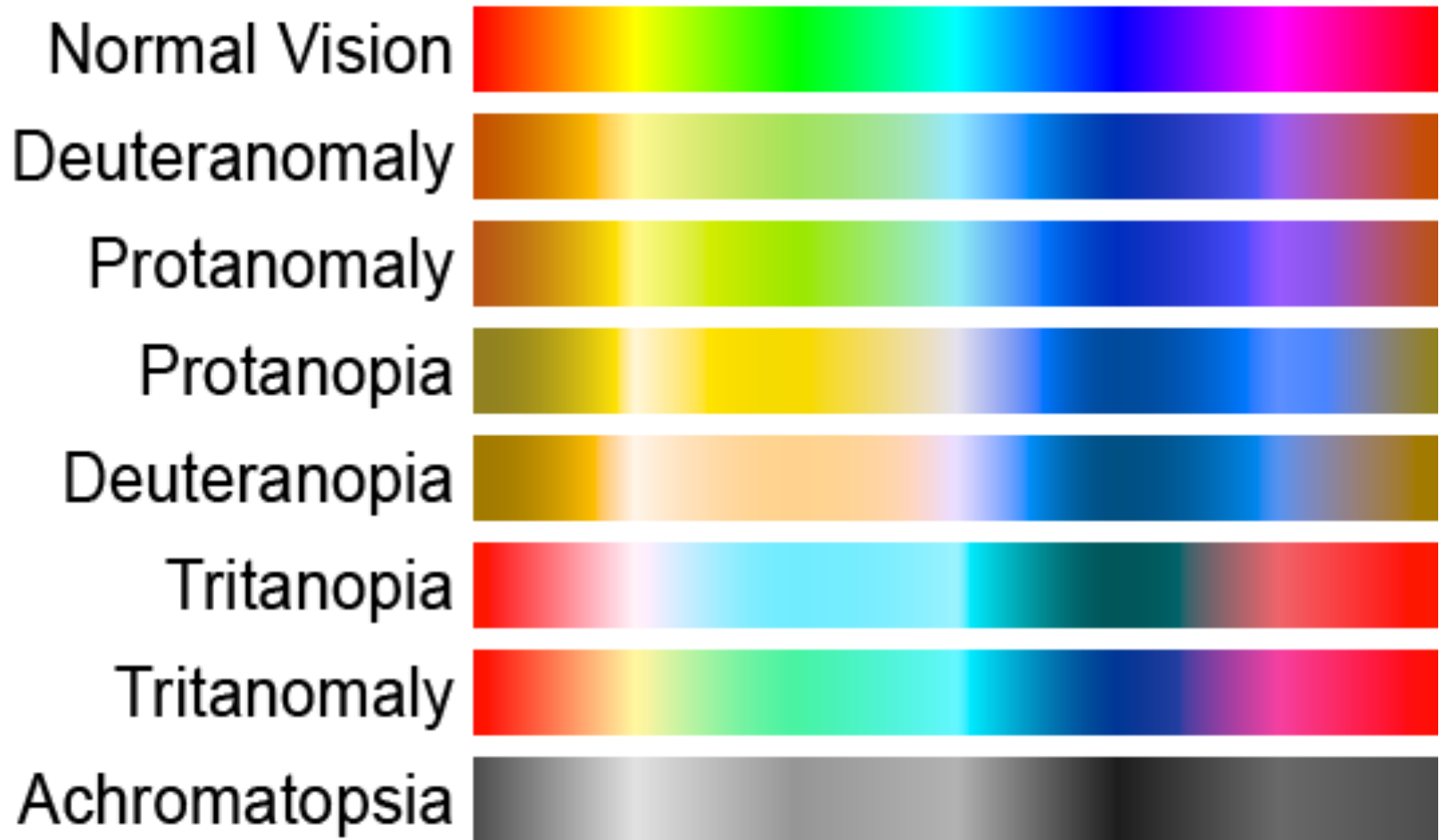
Color: Perception issues + deficiencies

Color blindness

- Affects opponent color processing
 - Red-green (deuteranopia, protanopia)
 - Blue-yellow possible (tritanopia)
 - Luminance channel (Monochromacy, Achromatopsia)
- Prevalence ~8% male, ~0.5% female
- Can be simulated
 - Brettel et al., Computerized simulation of color appearance for dichromats, 1997, doi: [10.1364/josaa.14.002647](https://doi.org/10.1364/josaa.14.002647)
 - Online Tools:
 - <https://www.toptal.com/designers/colorfilter>
 - <https://www.color-blindness.com/coblis-color-blindness-simulator/>
 - <https://pilestone.com/pages/color-blindness-simulator-1>

Color: Perception issues + deficiencies

Color blindness



https://en.wikipedia.org/wiki/Color_blindness

Color: Perception issues + deficiencies

Color blindness

Source: M. Stone



Protanope
(no L-cones)

Deuteranope
(no M-cones)

Tritanope
(no S-cones)



red / green
deficiencies

blue / yellow
deficiency

Color: Perception issues + deficiencies

Small areas

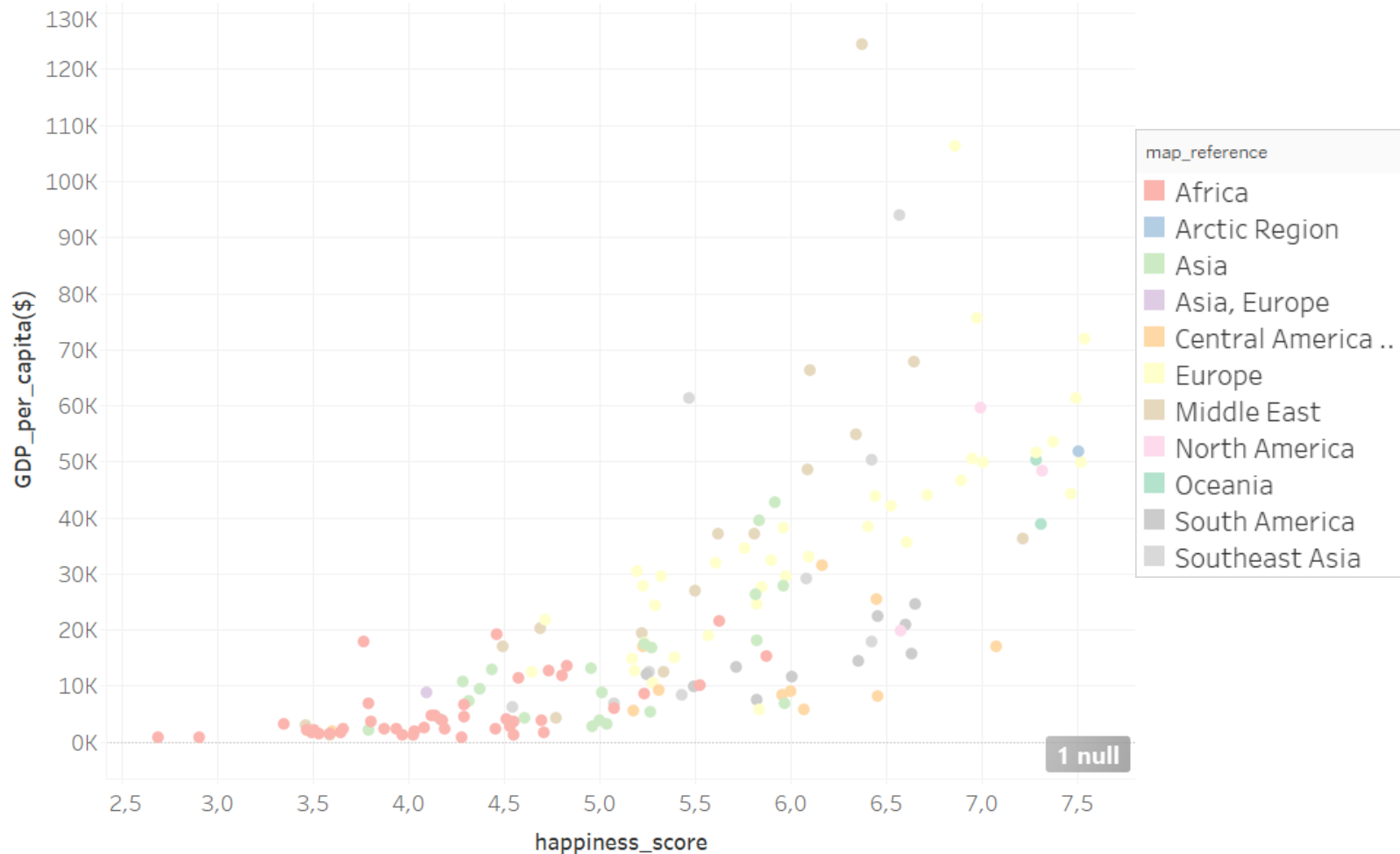


Tableau Software

Color: Perception issues + deficiencies

Small areas

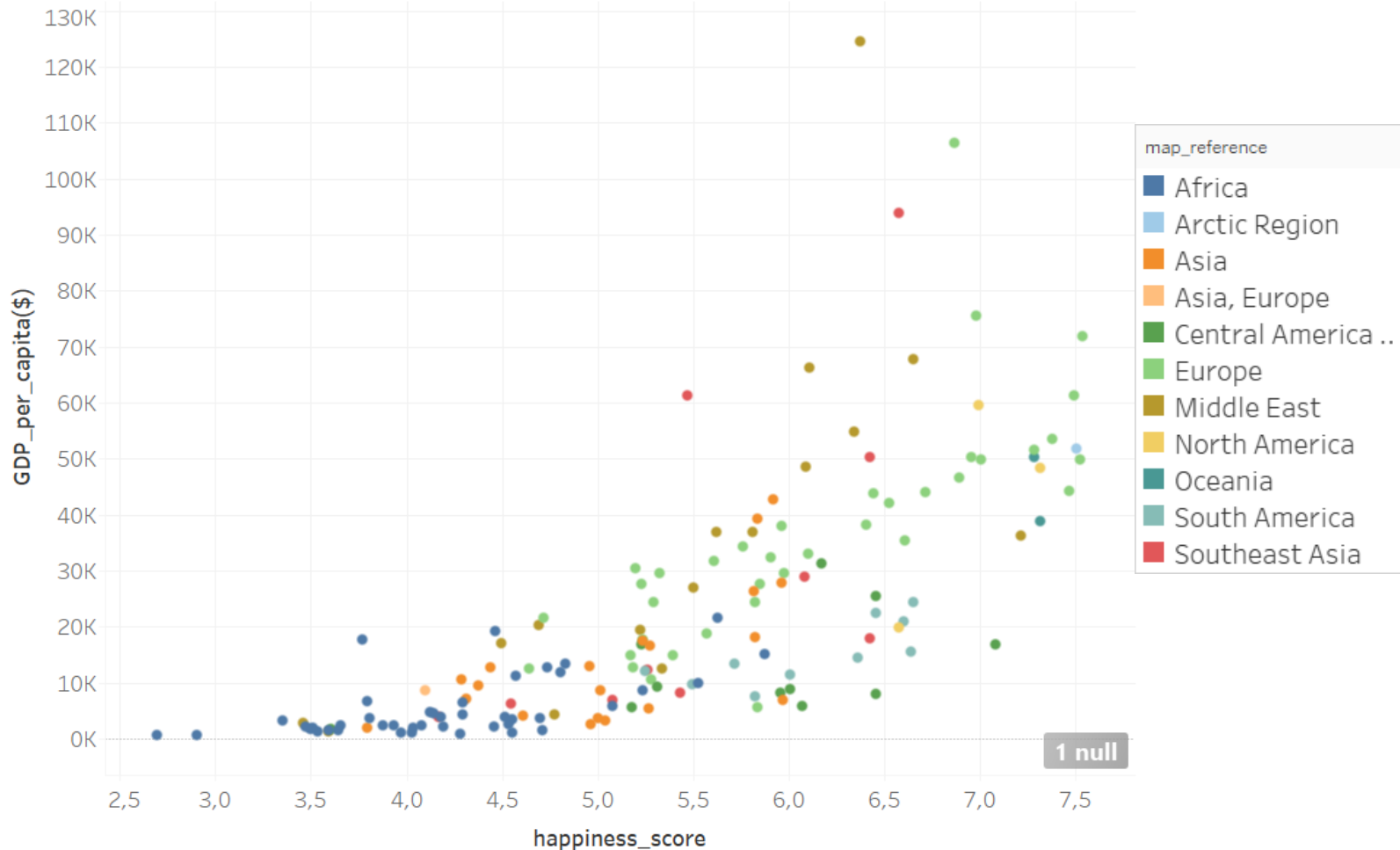
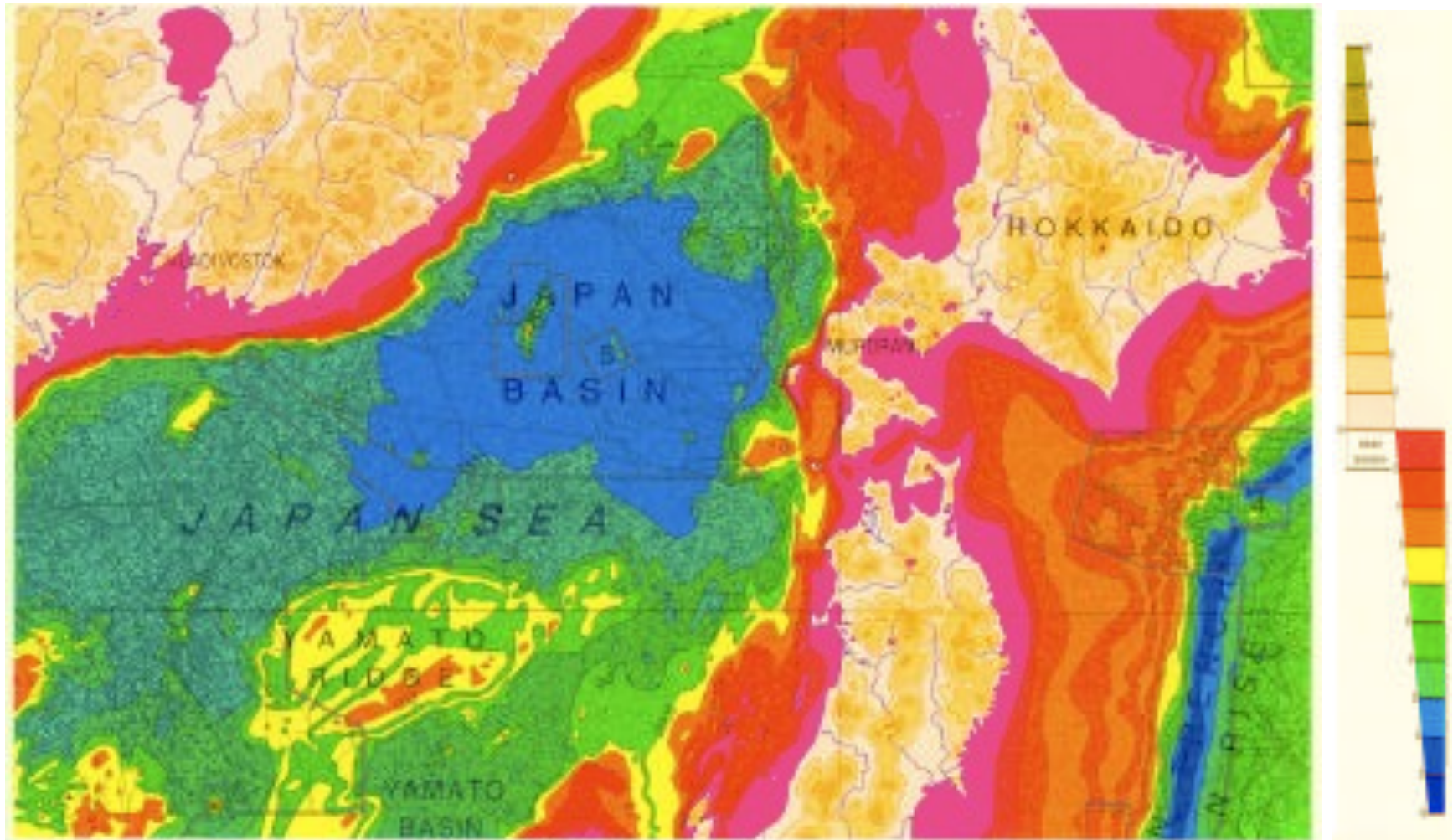


Tableau Software

Color: Perception issues + deficiencies

Large areas

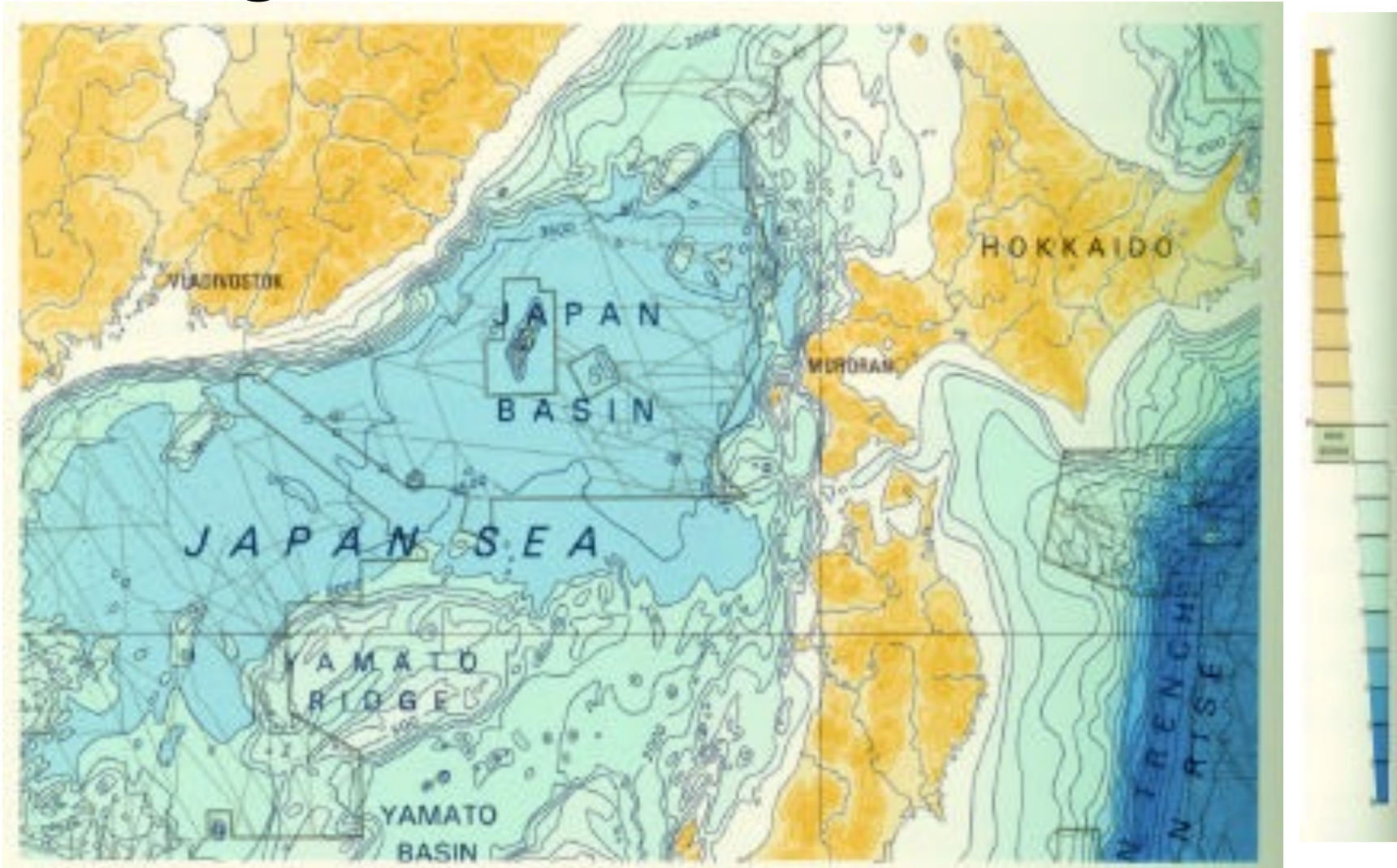


Tufte, The Visual Display of Quantative Information (Vol. 1), p. 77

based on © Munzner/Möller et al.

Color: Perception issues + deficiencies

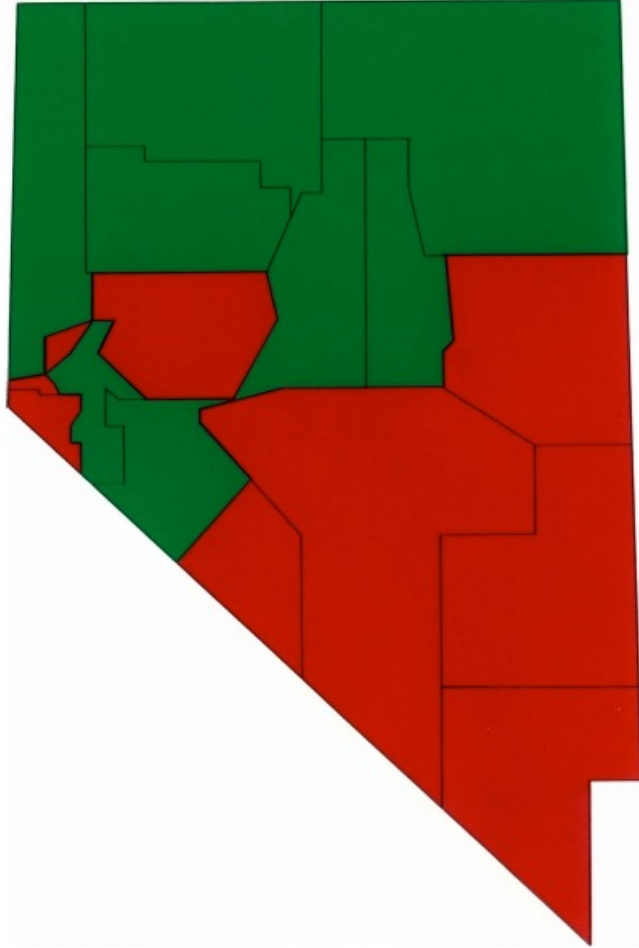
Large areas



Tufte, The Visual Display of Quantitative Information (Vol. 1), p. 77

based on © Munzner/Möller et al.

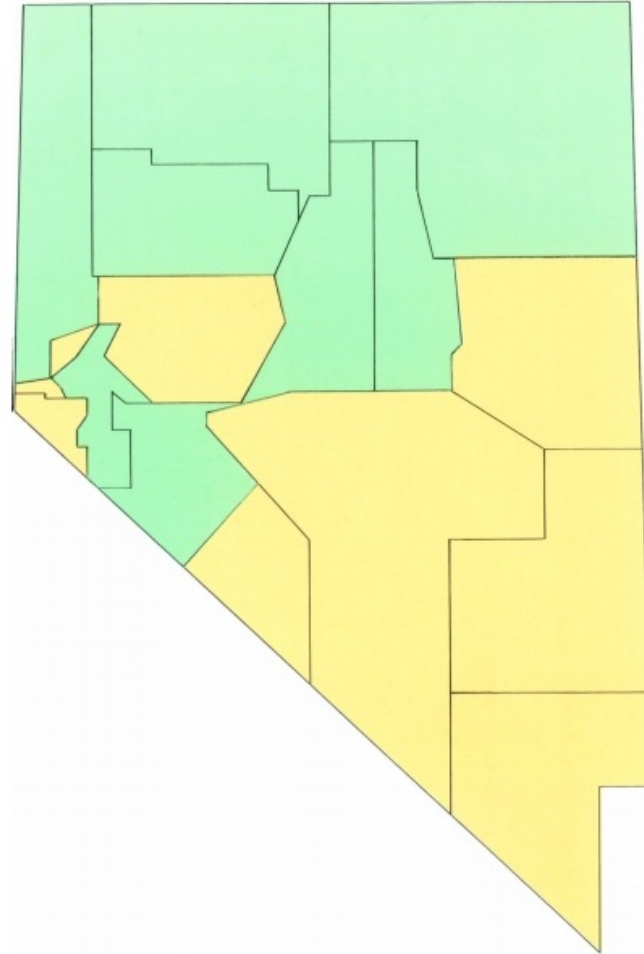
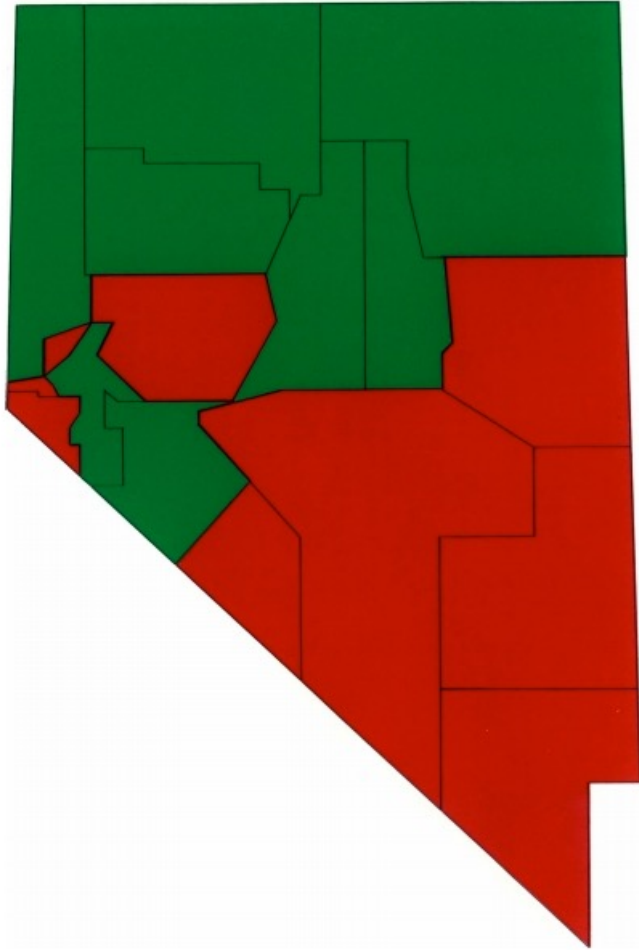
Which area is larger?



- Red is bigger
- Green is bigger
- Both are the same size

Color: Perception issues + deficiencies

Color size illusion



Cleveland & McGill, A Color-Caused Optical Illusion on a Statistical Graph, 1983,
doi: [10.1080/00031305.1983.10482720](https://doi.org/10.1080/00031305.1983.10482720), [link](#)

Color: Perception issues + deficiencies

Maps



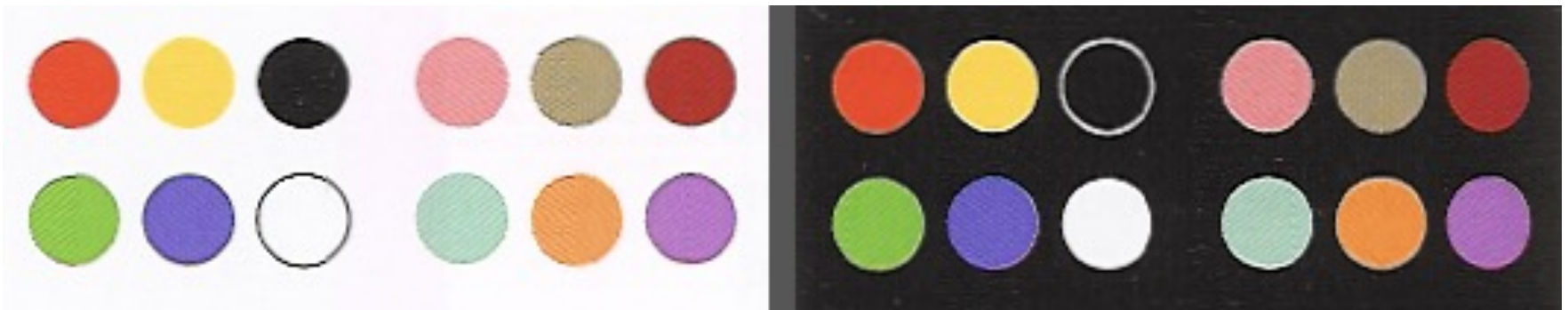
Ware, Visual Thinking for Design

Take-home message

- Test charts for discoloration / color blindness issues
- Color in small regions difficult to perceive
→ Use bright, saturated colors for small regions
- Large areas in some saturated colors appear bigger
→ Use low saturation, pastel colors for large regions and backgrounds

Color: Categorical data

- *What* channel
- Limited distinguishability (8-14)
 - Best with Hue
 - Also vary Luminance and/or Saturation to address perception deficiencies



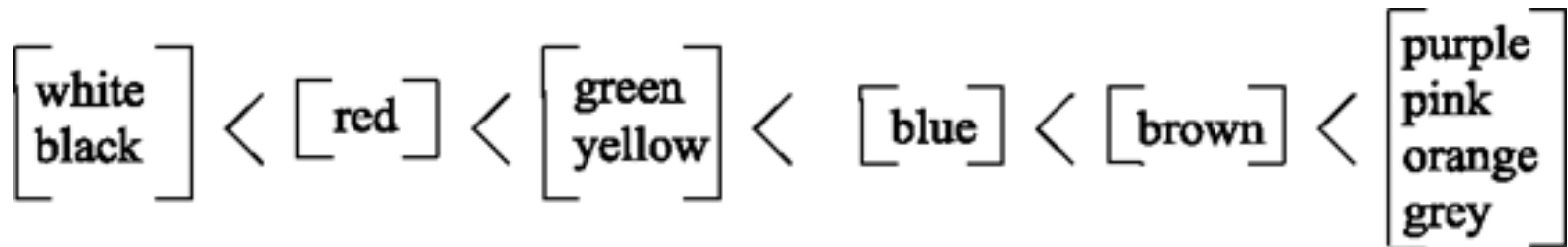
Ware, Information Visualization: Perception for Design

Color: Categorical data

Basic Colors

The evolution of basic color terms is remarkably consistent across cultures

Berlin & Kay's (1969) implicational hierarchy:



Source: Dowman, Explaining Color Term Typology With an Evolutionary Model, 2010, doi: 10.1080/03640210709336986.

Color: Categorical data

Take-home message

- Only a small number of colors can be used effectively as categorical labels
- Ideally use less than eight colors
- Also vary luminance/saturation to address deficiencies
- Use low saturation / gray backgrounds

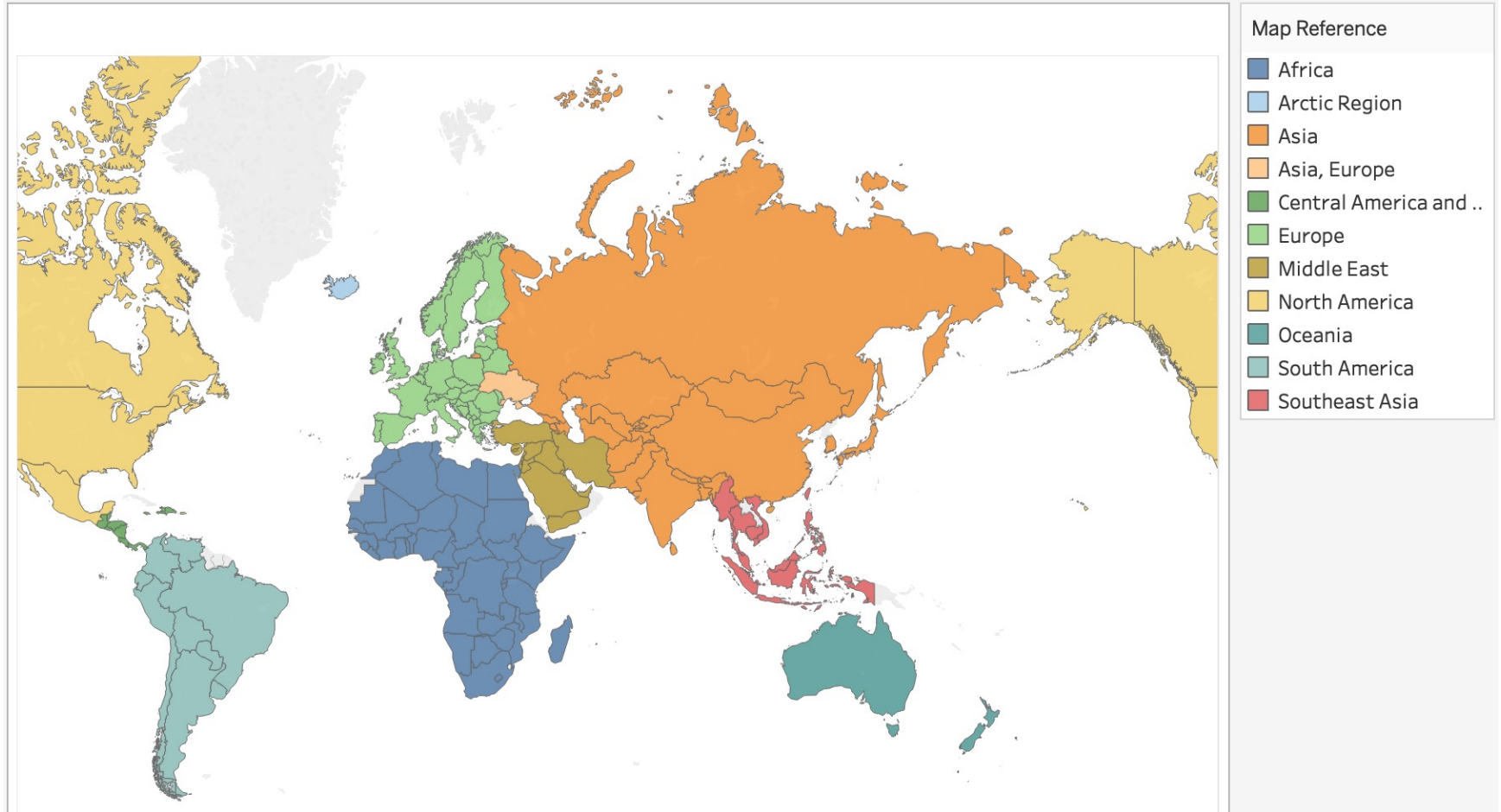
Color: Categorical data

Tableau example

- Let us use our map to test this!
- Try to use **Map Reference** or **Biggest official Language** as color for our map.
- What works and doesn't work?

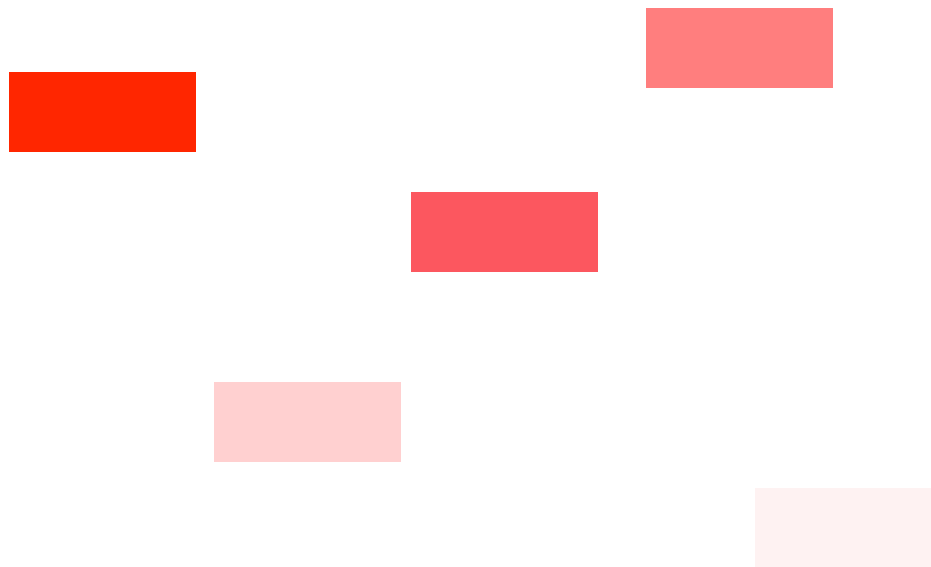
Color: Categorical data

Tableau example



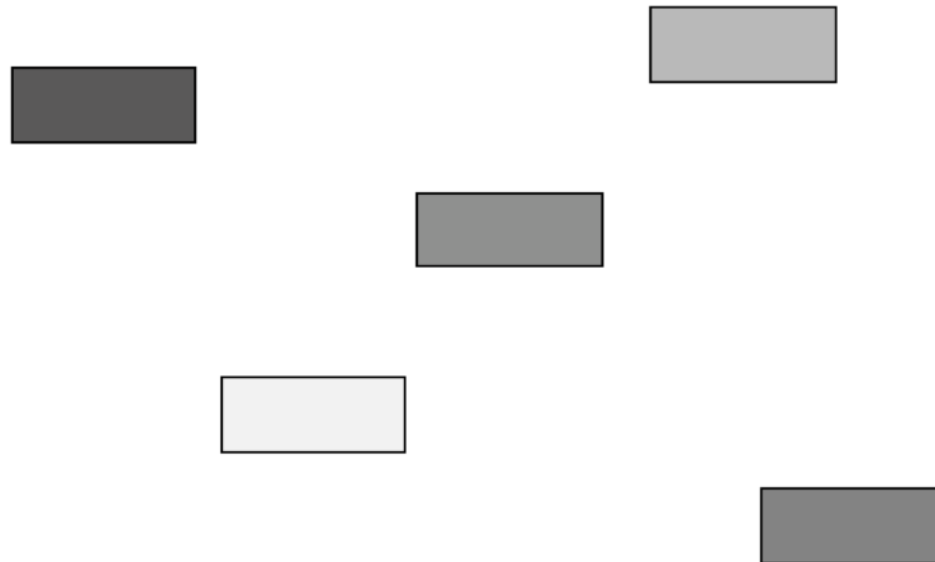
Color: Ordinal data

Order these colors



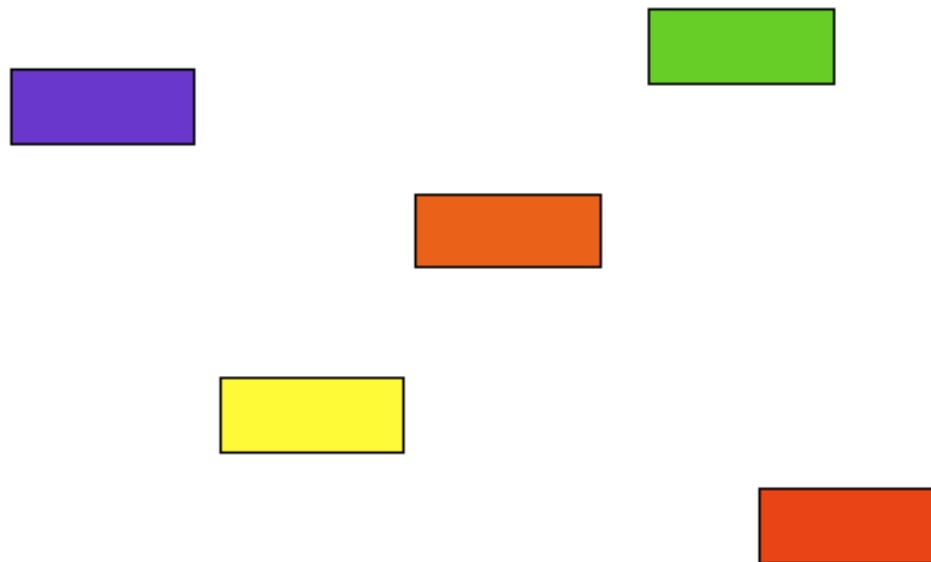
Color: Ordinal data

Order these colors



Color: Ordinal data

Order these colors



Color: Ordinal data

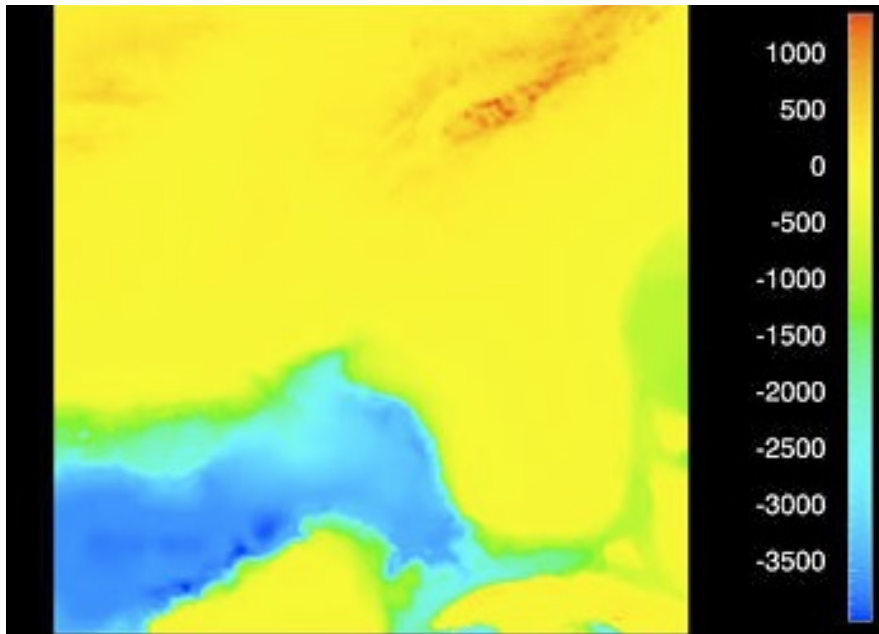
Take-home message

- Lightness and saturation are effective for ordinal data because they have an implicit perceptual ordering
- Show ordinal data with a discrete set of color values that change in lightness or saturation

Color: Quantitative data

Rainbow color map

How Much channel



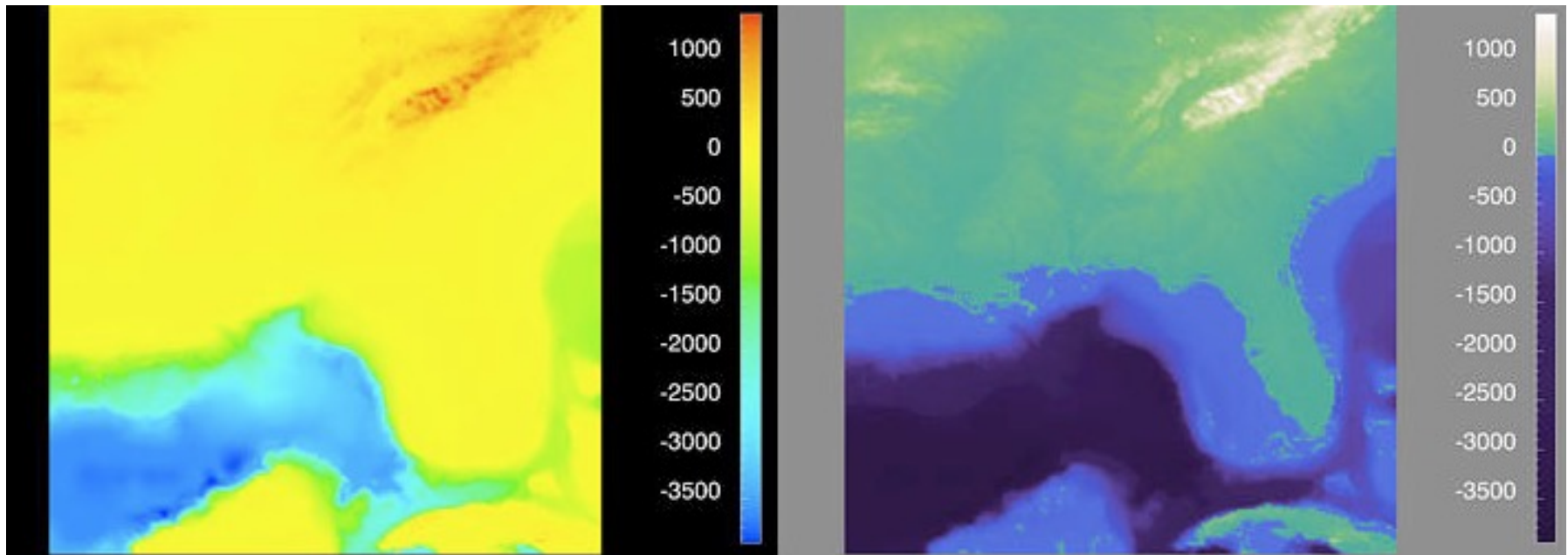
Which part of the world is visible here?

[Rogowitz and Treinish, „Data Visualization: The End of the Rainbow” / “Why should engineers and scientists be worried about color?”](#)

Color: Quantitative data

Rainbow color map

How Much channel



[Rogowitz and Treinish, „Data Visualization: The End of the Rainbow” / “Why should engineers and scientists be worried about color?”](#)

Color: Quantitative data

Rainbow color map

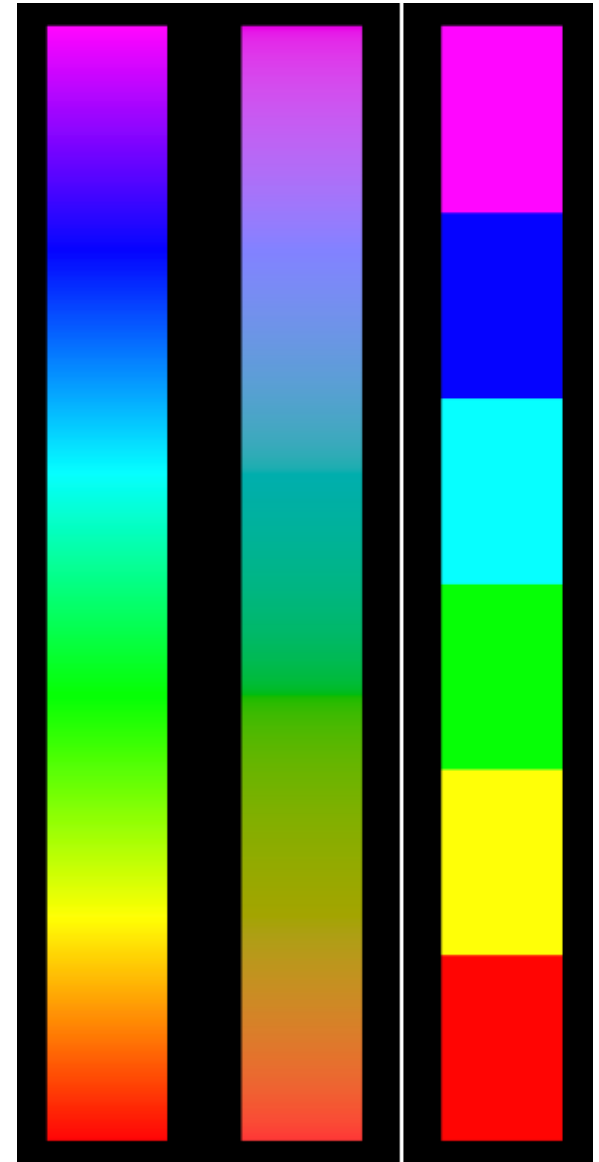
- Hue not ideal for ordinal data
- Not perceptually linear: Equal steps in the continuous range are not perceived as equal steps
- Not good for colorblind people



Color: Quantitative data

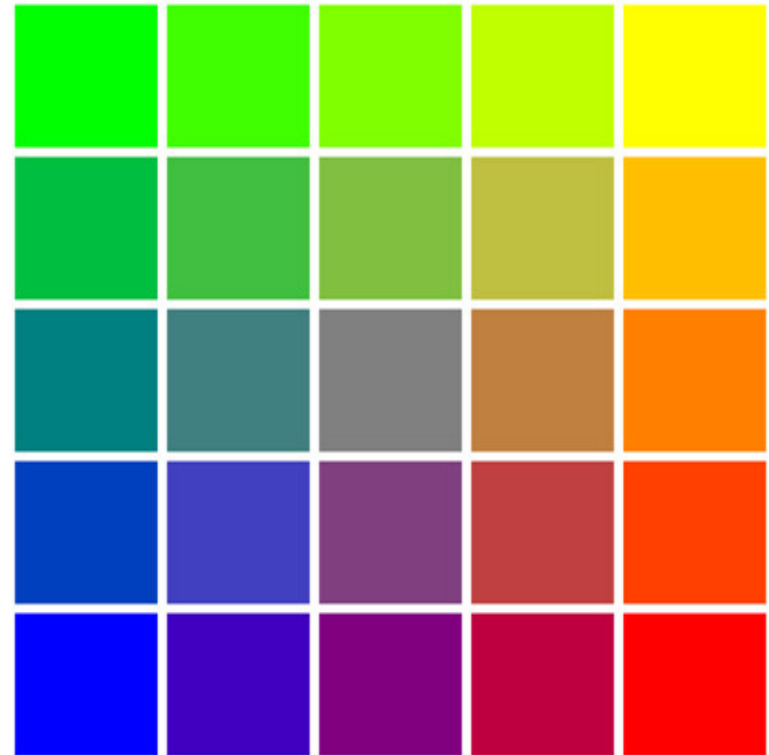
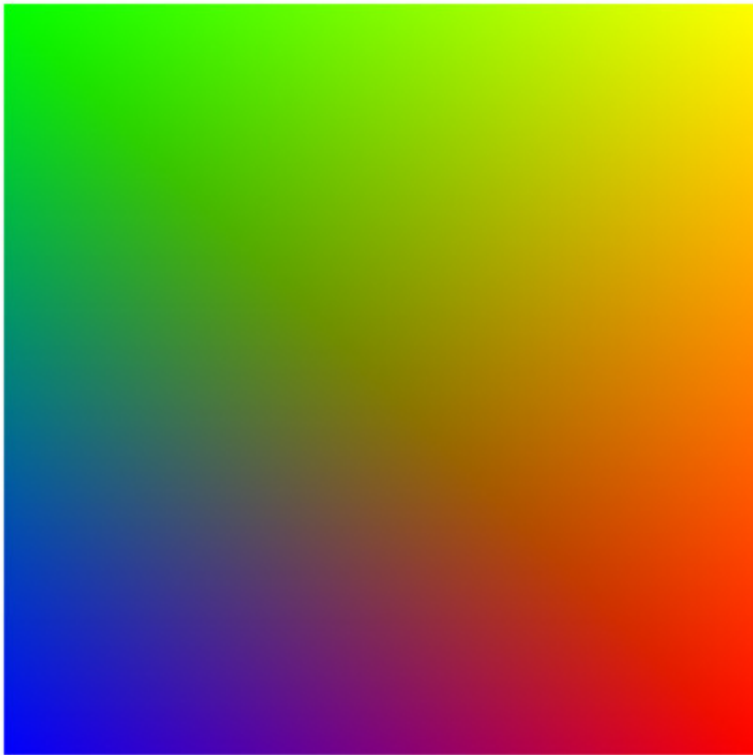
Rainbow color map

- Learned order
- Visually segmented
- Better:
 - Perceptually uniform colormaps (e.g. isoluminant rainbow)
 - Discretize colormap



Color: Quantitative data

Color segmentation



Ware, Visual Thinking for Design, 2010.

Color: Quantitative data

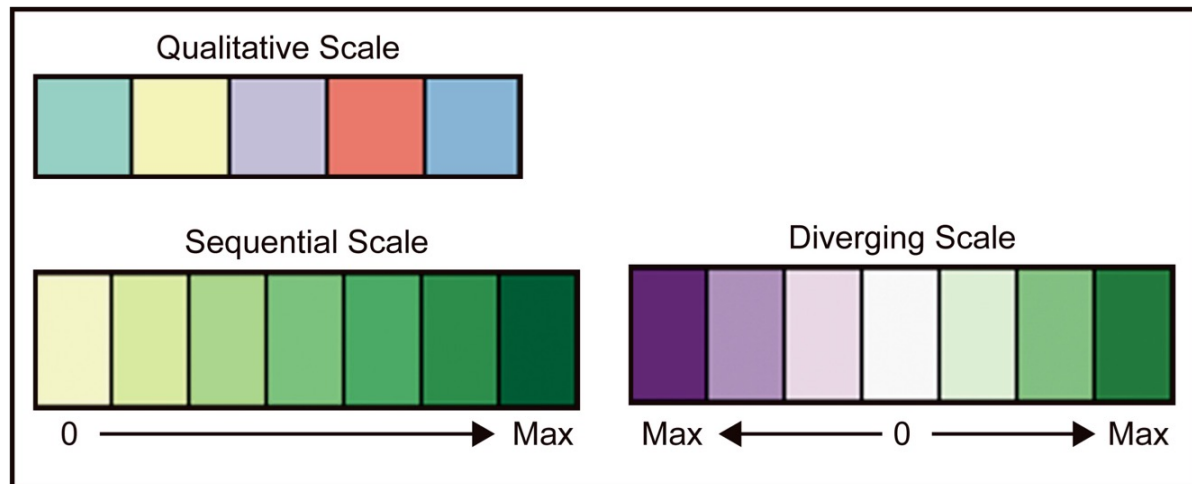
Take-home message

- Quantitative data can be shown with a discrete or continuous colormap
- Use colormaps with a limited hue palette and redundantly vary lightness and saturation
- Use discrete colormaps for accuracy

Brewer scales

Nominal
(Categorical)

Ordinal



What?

How-much?

[Brewer, Color Use Guidelines for Data Representation, 1999](#)


ColorBrewer

<https://colorbrewer2.org/#type=qualitative&scheme=Pastel1&n=5>

Number of data classes: 5 how to use | updates | downloads | credits

Nature of your data:
 sequential diverging qualitative

Pick a color scheme:

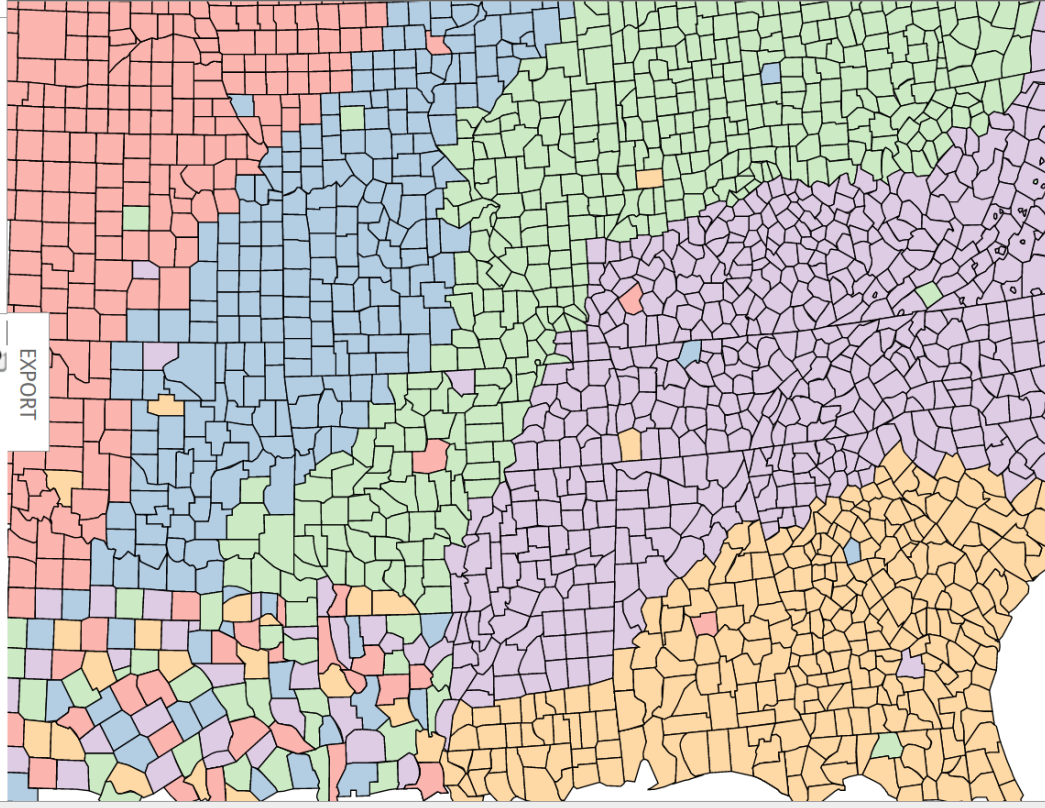


Only show:
 colorblind safe
 print friendly
 photocopy safe

Context:
 roads
 cities
 borders

Background:
 solid color
 terrain
color transparency

5-class Pastel1
EXPORT
HEX
#fbb4ae
#b3cde3
#cceb5
#decbe4
#fed9a6



COLORBREWER 2.0
color advice for cartography

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[Source code and feedback](#)
[Back to Flash version](#)
[Back to ColorBrewer 1.0](#)

axismaps

Qualitative color schemes for categorical data
(*What channel*)

<https://colorbrewer2.org>

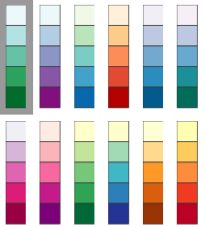
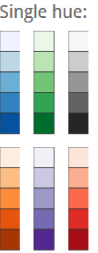
ColorBrewer

<https://colorbrewer2.org/#type=sequential&scheme=BuGn&n=3>

Number of data classes: 3 how to use updates downloads credits

COLORBREWER 2.0
color advice for cartography

Nature of your data:
 sequential diverging qualitative

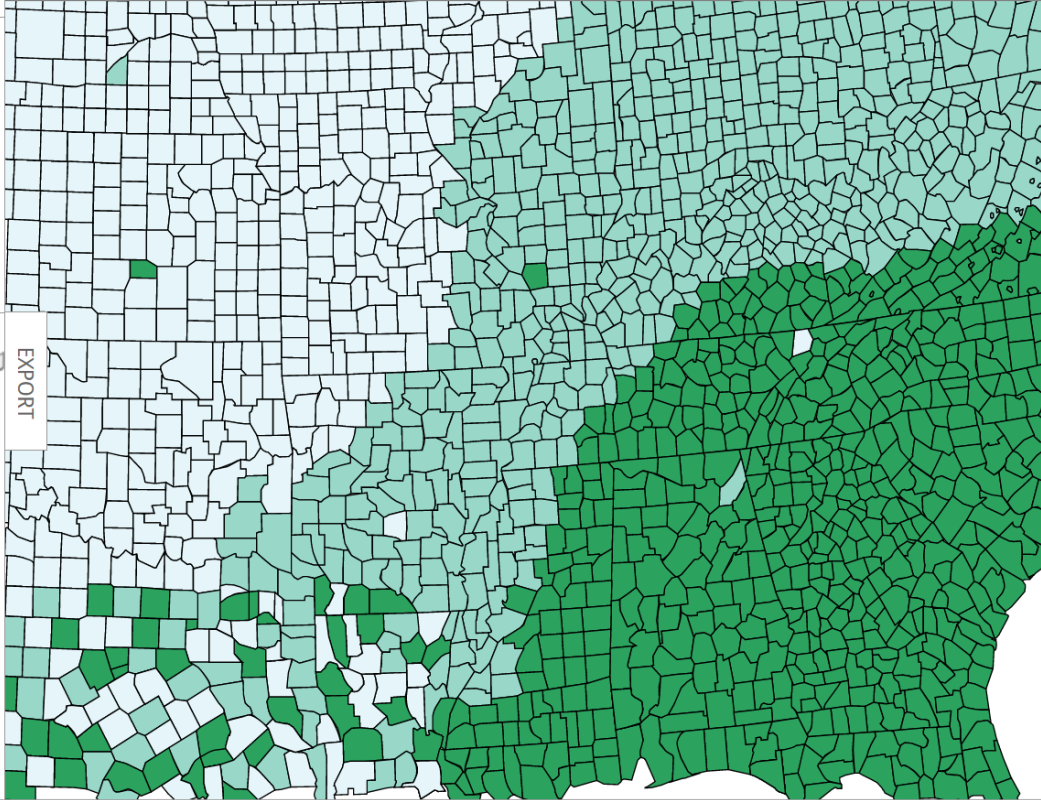
Pick a color scheme:
Multi-hue:  Single hue: 

Only show:
 colorblind safe
 print friendly
 photocopy safe

Context:
 roads
 cities
 borders

Background:
 solid color terrain
color transparency

3-class BuGn
EXPORT
HEX
#e5f5f9
#99d8c9
#2ca25f



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[Source code and feedback](#)

[Back to Flash version](#)

[Back to ColorBrewer 1.0](#)

 axismaps

Sequential color schemes for ordinal/continuous data
(How-much channel)

<https://colorbrewer2.org>

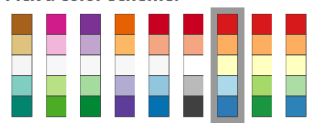
ColorBrewer

<https://colorbrewer2.org/#type=diverging&scheme=RdYlBu&n=5>

Number of data classes: 5 how to use updates downloads credits

Nature of your data:
 sequential diverging qualitative

Pick a color scheme:

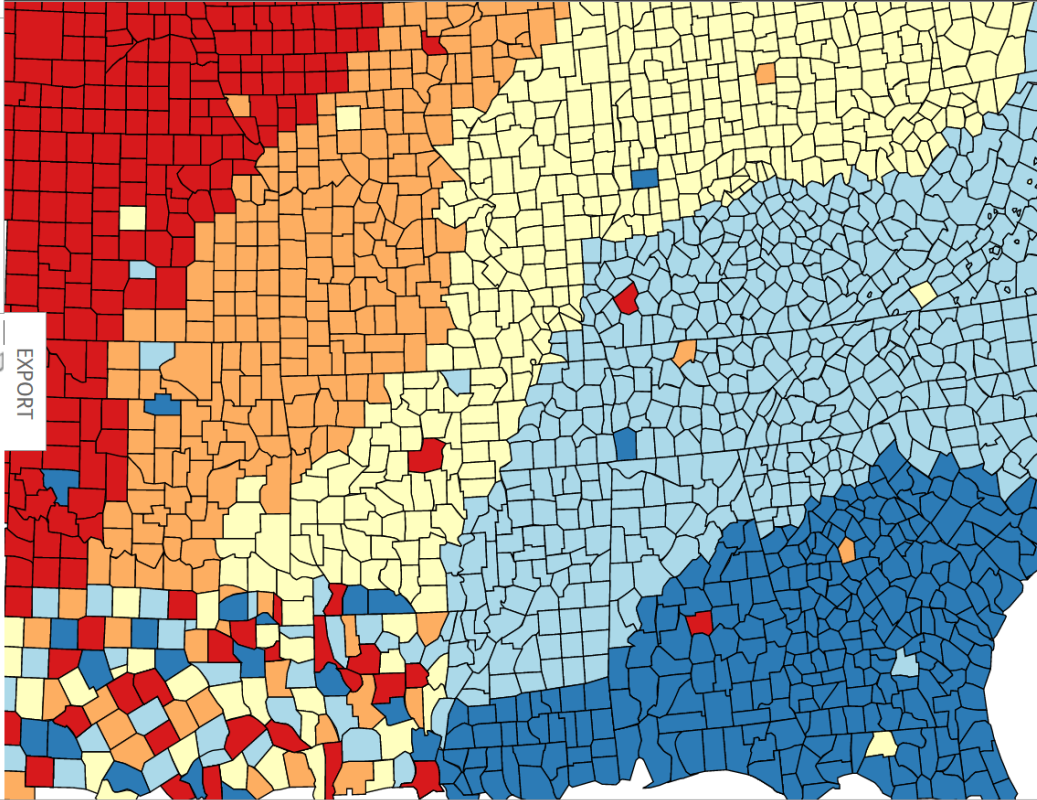


Only show:
 colorblind safe
 print friendly
 photocopy safe

Context:
 roads
 cities
 borders

Background:
 solid color
 terrain
color transparency

5-class RdYlBu



EXPORT

HEX

- #d7191c
- #fdae61
- #ffffbf
- #abd9e9
- #2c7bb6

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[Source code and feedback](#)
[Back to Flash version](#)
[Back to ColorBrewer 1.0](#)

axismaps

Diverging color schemes for ordinal/sequential data
diverging from a central value (*How-much* channel)

<https://colorbrewer2.org>

based on © Munzner/Möller et al.

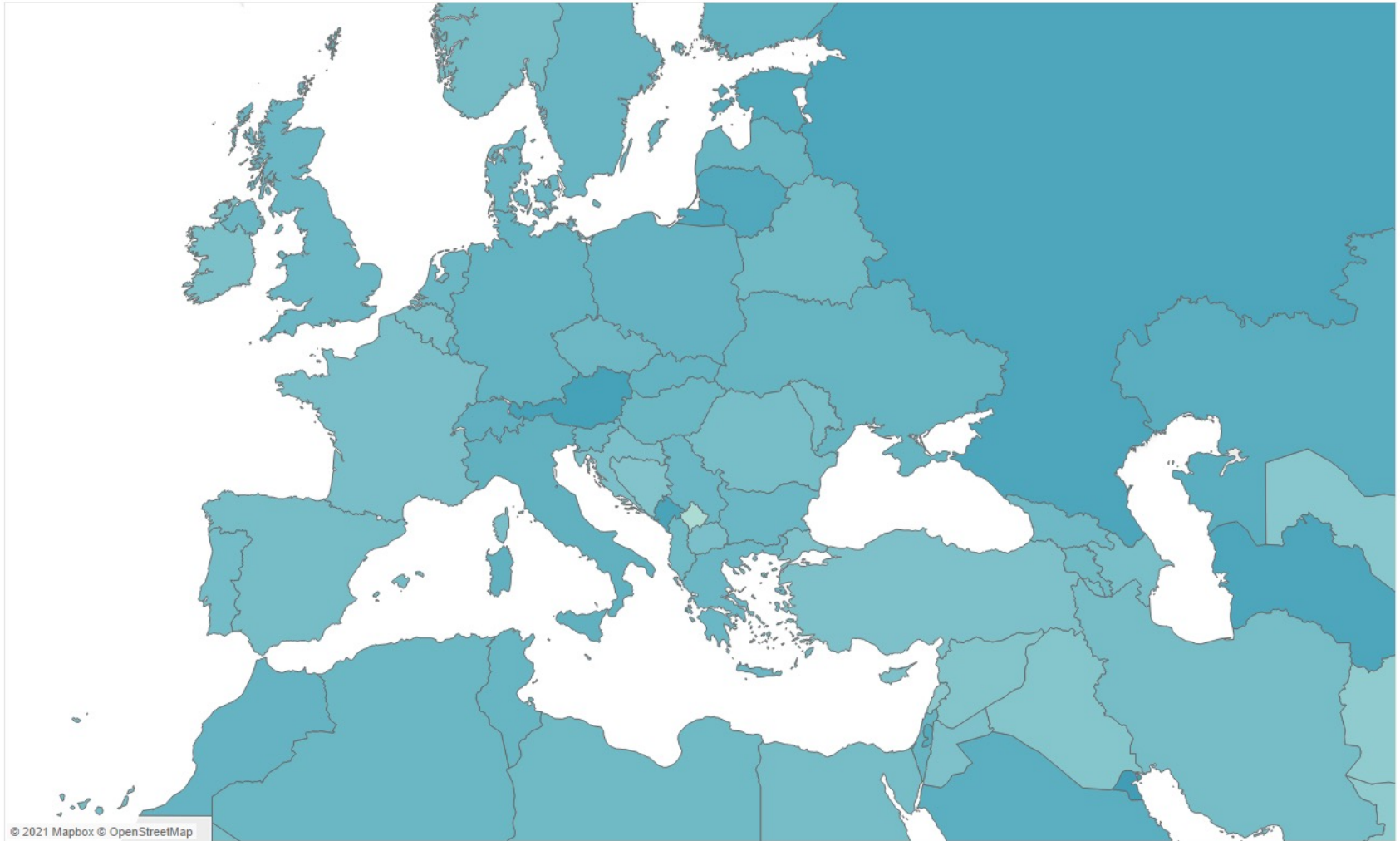
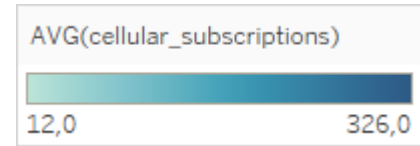
Color: Quantitative data

Tableau example

- Let us use a map to test different color scales by using **Cellular Subscriptions** as color
- Compare
 - A continuous color scale
 - To a discrete (stepped) color scale

Color: Quantitative data

Tableau example



Color: Quantitative data

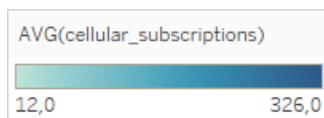
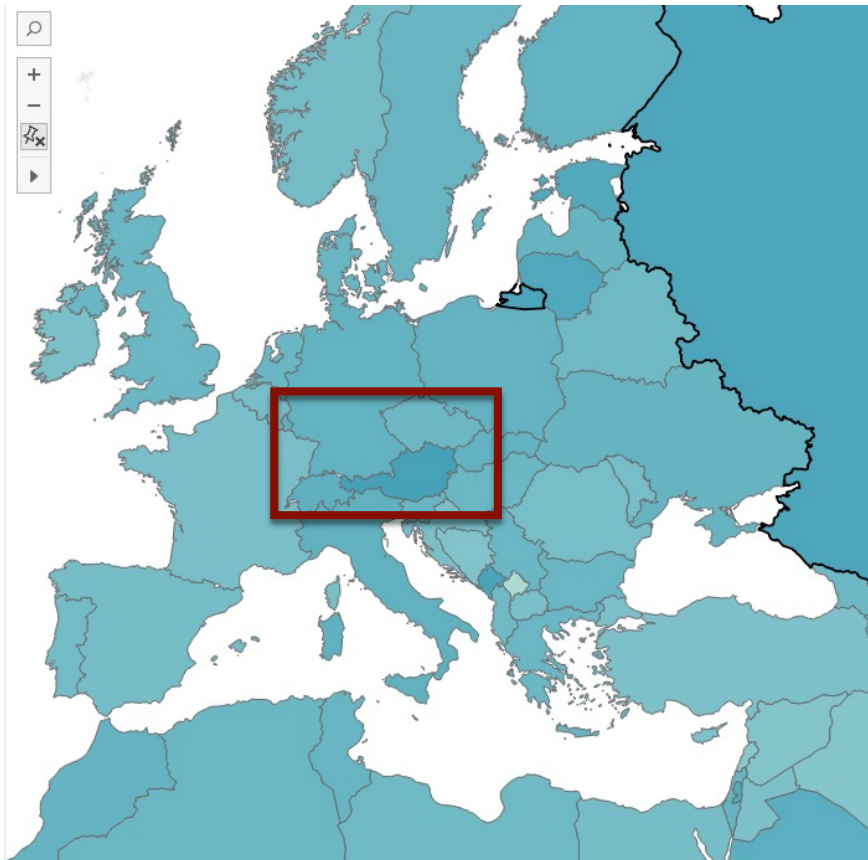
Tableau example

The image shows a Tableau interface with a map of Europe. The map is color-coded by region, with a color gradient from light teal to dark blue. A dialog box titled "Edit Colors [cellular_subscriptions]" is open, showing a color palette with 12 steps. The palette is labeled "Automatic" and has a range from 12 to 326. The dialog box also includes options for "Stepped Color" (checked, 7 steps), "Reversed", "Use Full Color Range", and "Include Totals". The "Advanced >>" button is visible. The background shows the Tableau Marks card with "Map" selected, and the Color, Size, and Label properties.

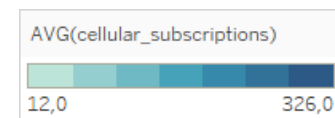
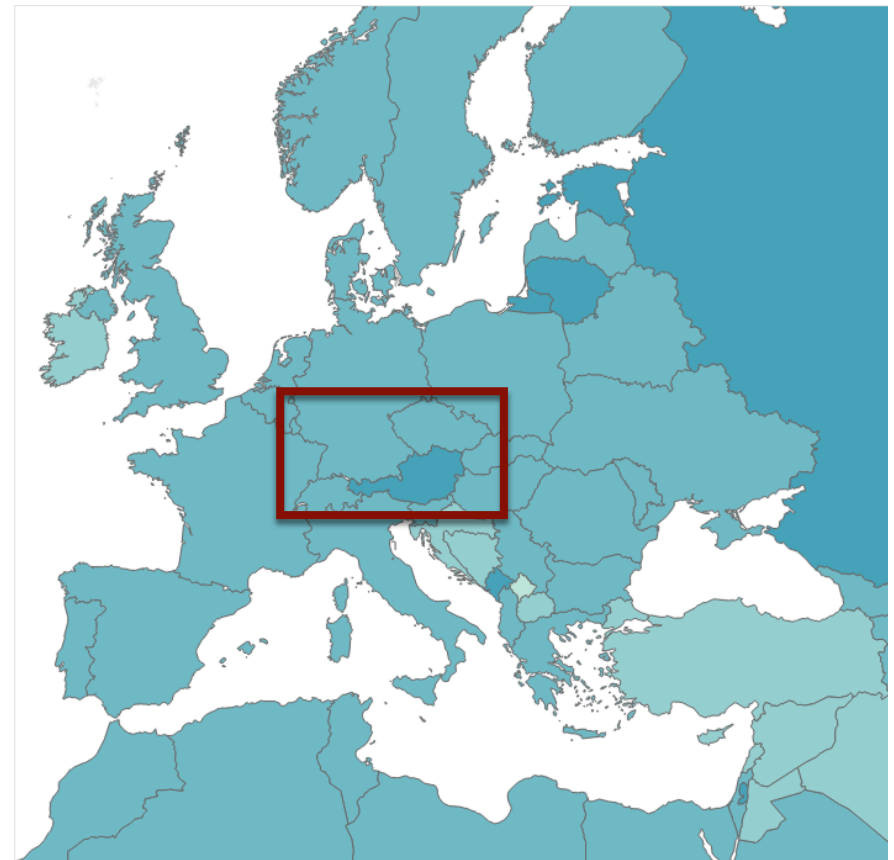
Color: Quantitative data

Tableau example

Continuous



Stepped



Color aesthetics:

DANGER!

? Inappropriate use of color can be disastrous to the application

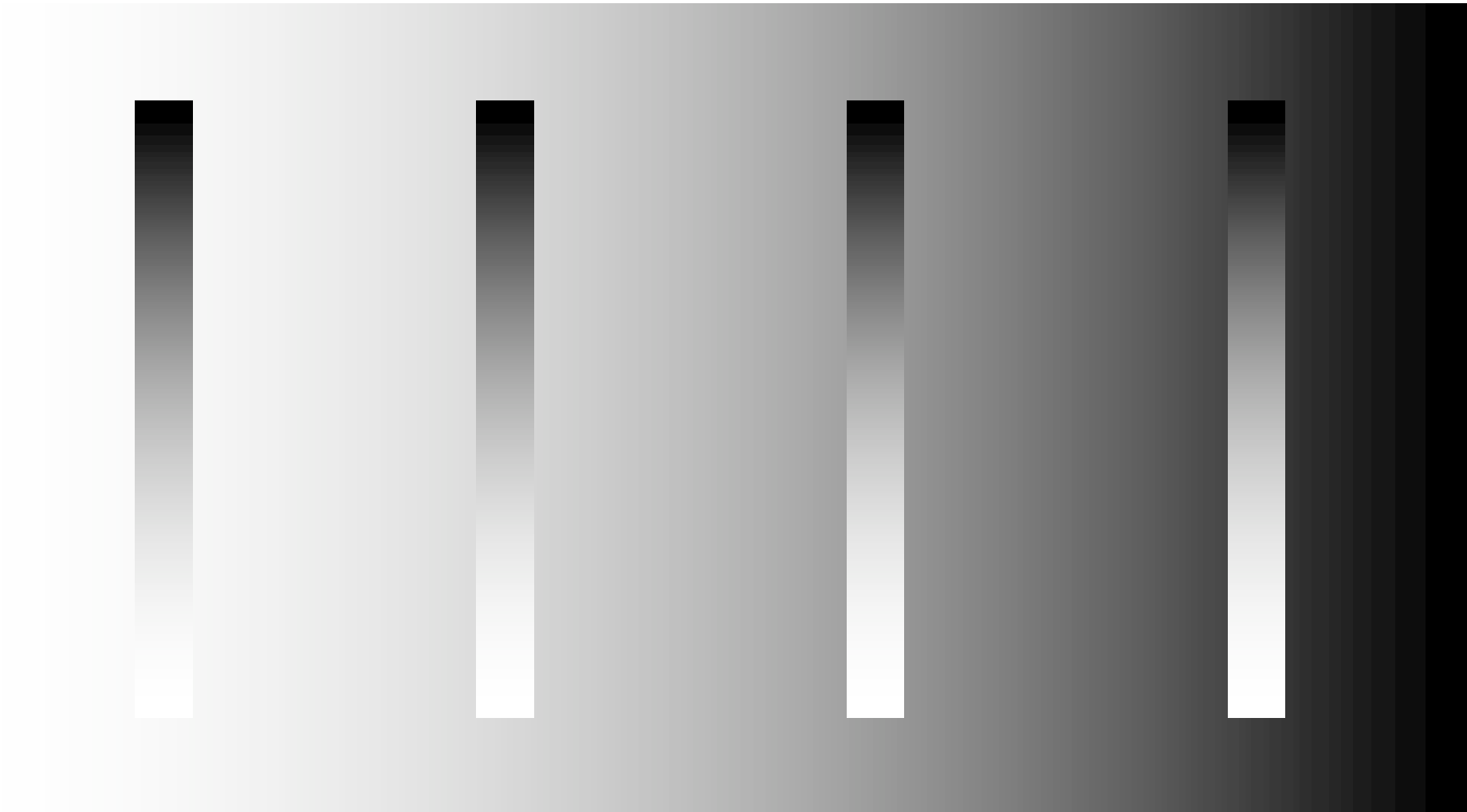
Color aesthetics:

Why should we care?

- Poorly designed color is confusing
 - Creates visual clutter
 - Misdirects attention
- Poor design devalues the information
 - Visual sophistication
 - Evolution of document and web design
- Don Norman:
“Attractive things work better”

Optical illusions:

Contrast crispening



Ware, Information Visualization Perception for Design, p. 90

based on © Munzner/Möller et al.

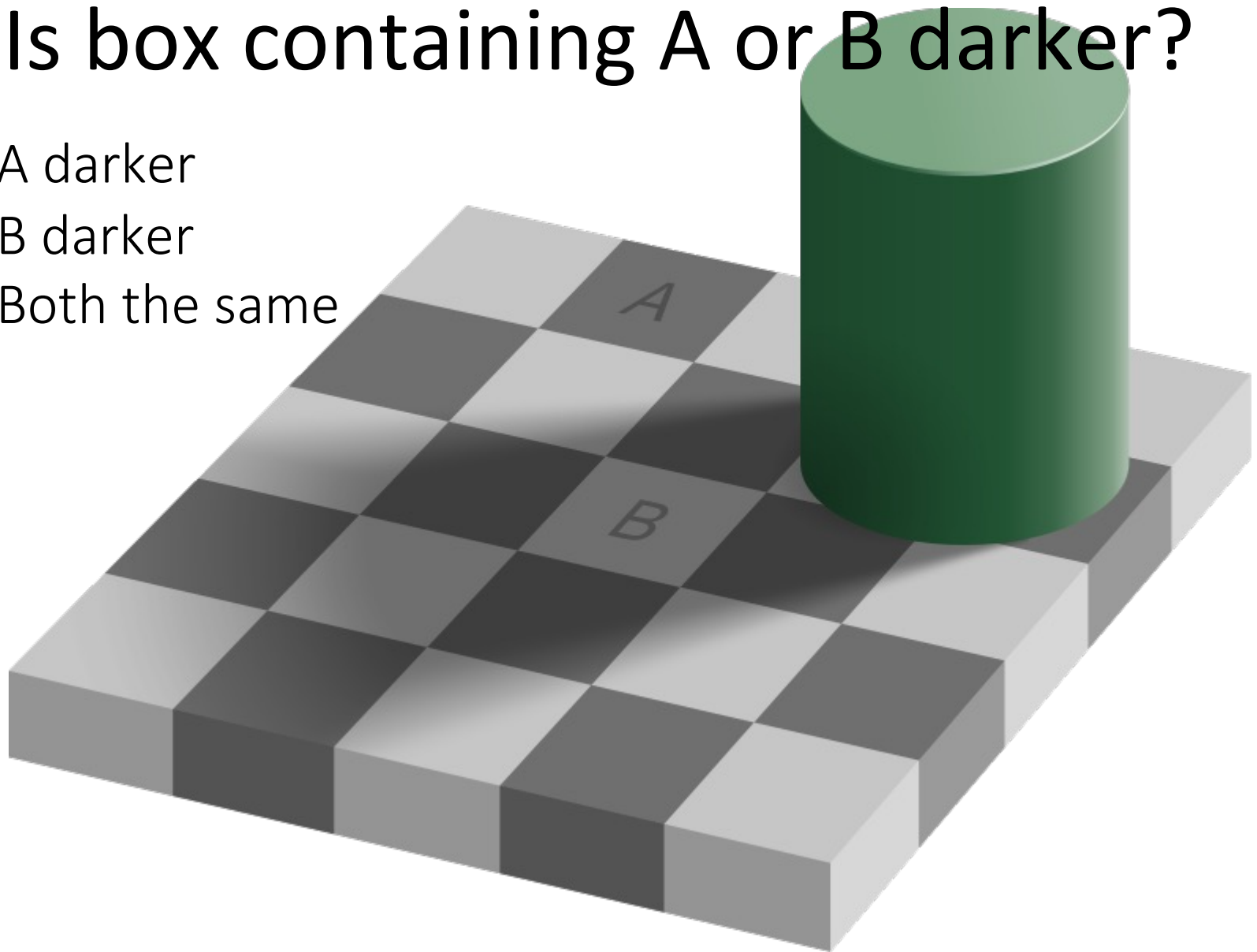
106

Is box containing A or B darker?

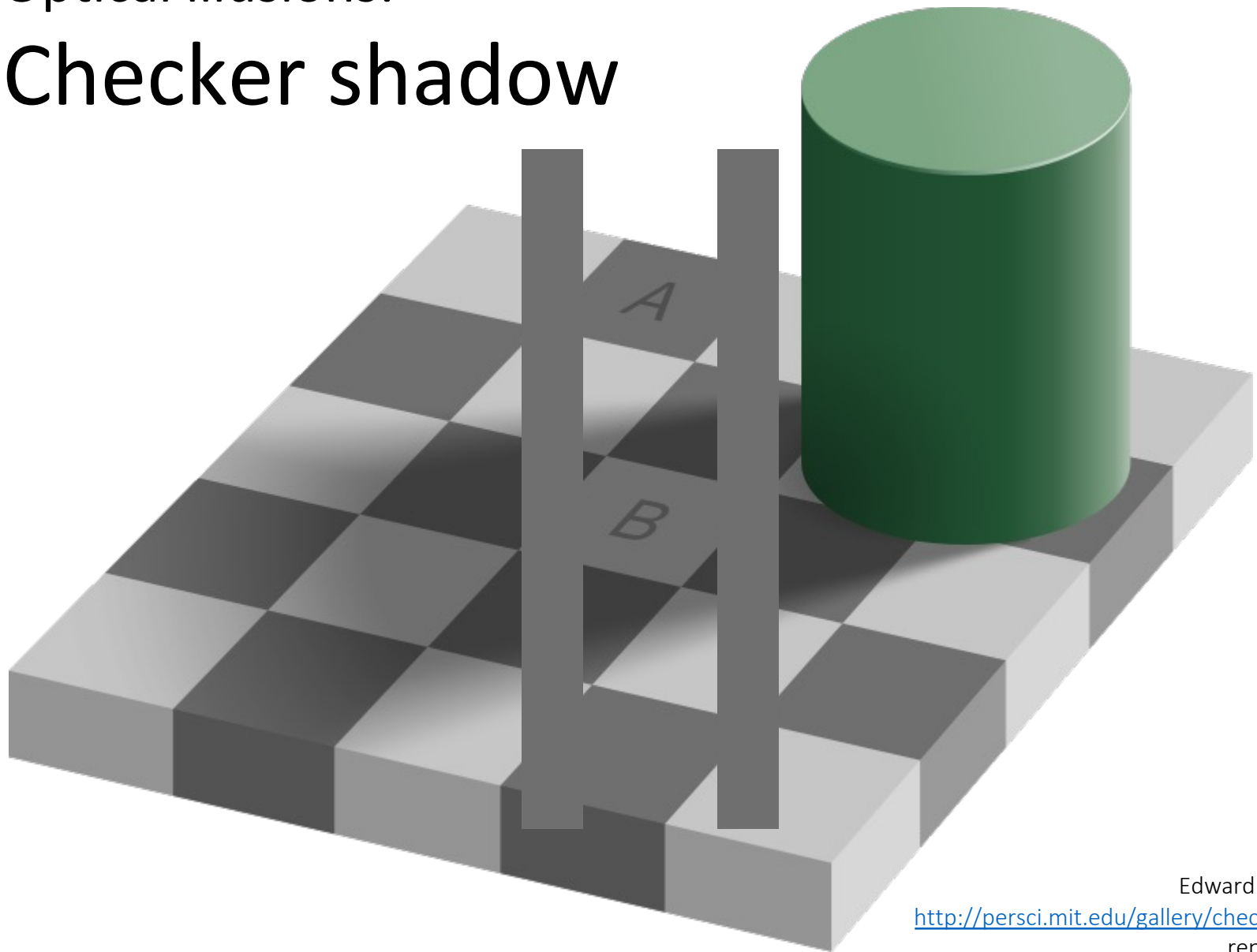
A darker

B darker

Both the same



Optical illusions: Checker shadow



Edward H. Adelson,
<http://persci.mit.edu/gallery/checkersshadow>,
reproduced by
https://en.wikipedia.org/wiki/Checker_shadow_illusion

In conclusion

- Visualizations are broken down into
 - Marks (elements), and
 - Channels (parameters)
 - Data is linked to the channels
- Take care in choosing channels:
 - Expressiveness: Encode all of, and only, information in dataset
 - Effectiveness: Most important data with most accurate channel
 - Which and how many channels (discriminability & separability)
- Be aware of channel characteristics, such as
 - Position
 - Relative vs. absolute judgement
 - Colors (Perceptual issues, e.g. color deficiencies, Aesthetics)