University of Zurich[UZH]

URPP Evolution in Action

# URPP tutorial

## Principles of data visualization

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# Outline

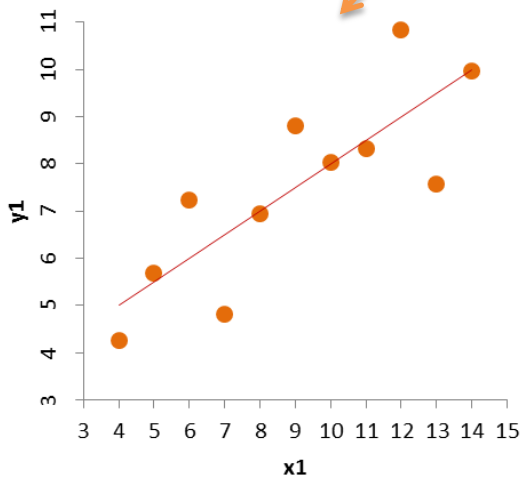
1. The properties of the data or information (HTL)
2. Use of salience, colors, consistency and layout (HTL)
3. The rules mapping data to images (SW)
4. Examples of effective visualizations in biological sciences (SW)
5. Presentation and discussion of “good” and “bad” graphics (HTL & SW)

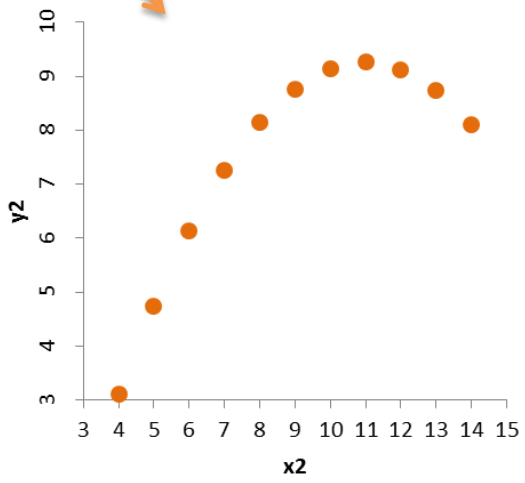
# Information visualization

2 main objectives:

- Data analysis
  - Understand the data
  - Derive information from them
  - The goal is to generate hypotheses that can be tested
- Communication
  - Of information
  - Involves simplification
    - → don't distort what the data has to say
    - → What information does the reader need to be successful?

| x1 | y1 | x2 | y2 |
|---|---|---|---|
| 10 | 8.04 | 10 | 9.14 |
| 8 | 6.95 | 8 | 8.14 |
| 13 | 7.58 | 13 | 8.74 |
| 9 | 8.81 | 9 | 8.77 |
| 11 | 8.33 | 11 | 9.26 |
| 14 | 9.96 | 14 | 8.1 |
| 6 | 7.24 | 6 | 6.13 |
| 4 | 4.26 | 4 | 3.1 |
| 12 | 10.84 | 12 | 9.13 |
| 7 | 4.82 | 7 | 7.26 |
| 5 | 5.68 | 5 | 4.74 |

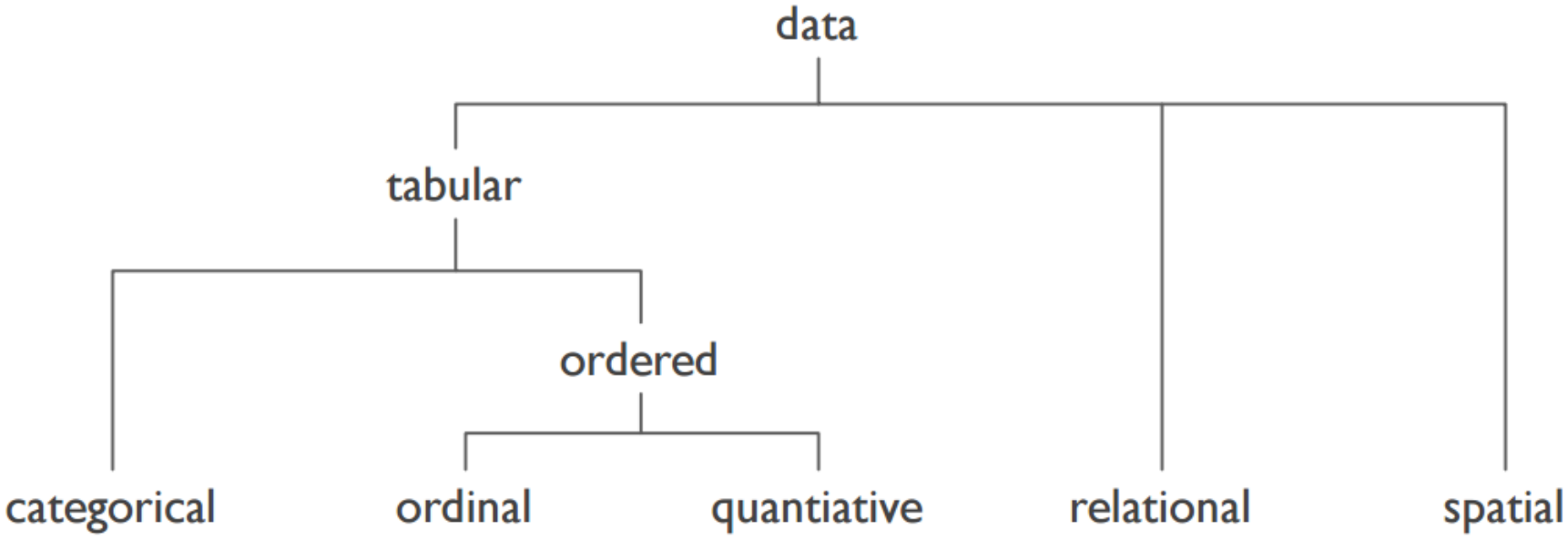


# Information visualization

- Common data visualization issues:
  - Inappropriate display choices that distort reality (i.e. pie charts, 3D charts)
  - Too much information
  - Poorly designed display choices that use noisy fill patterns, line styles or saturated/bright colours
  - Encoding quantitative data inaccurately
  - Inconsistent ordering and placement
  - Inconsistent or reversed scales
  - Proportional axis scaling
  - Using counts (not percentages) when comparing different totals

# Types of data



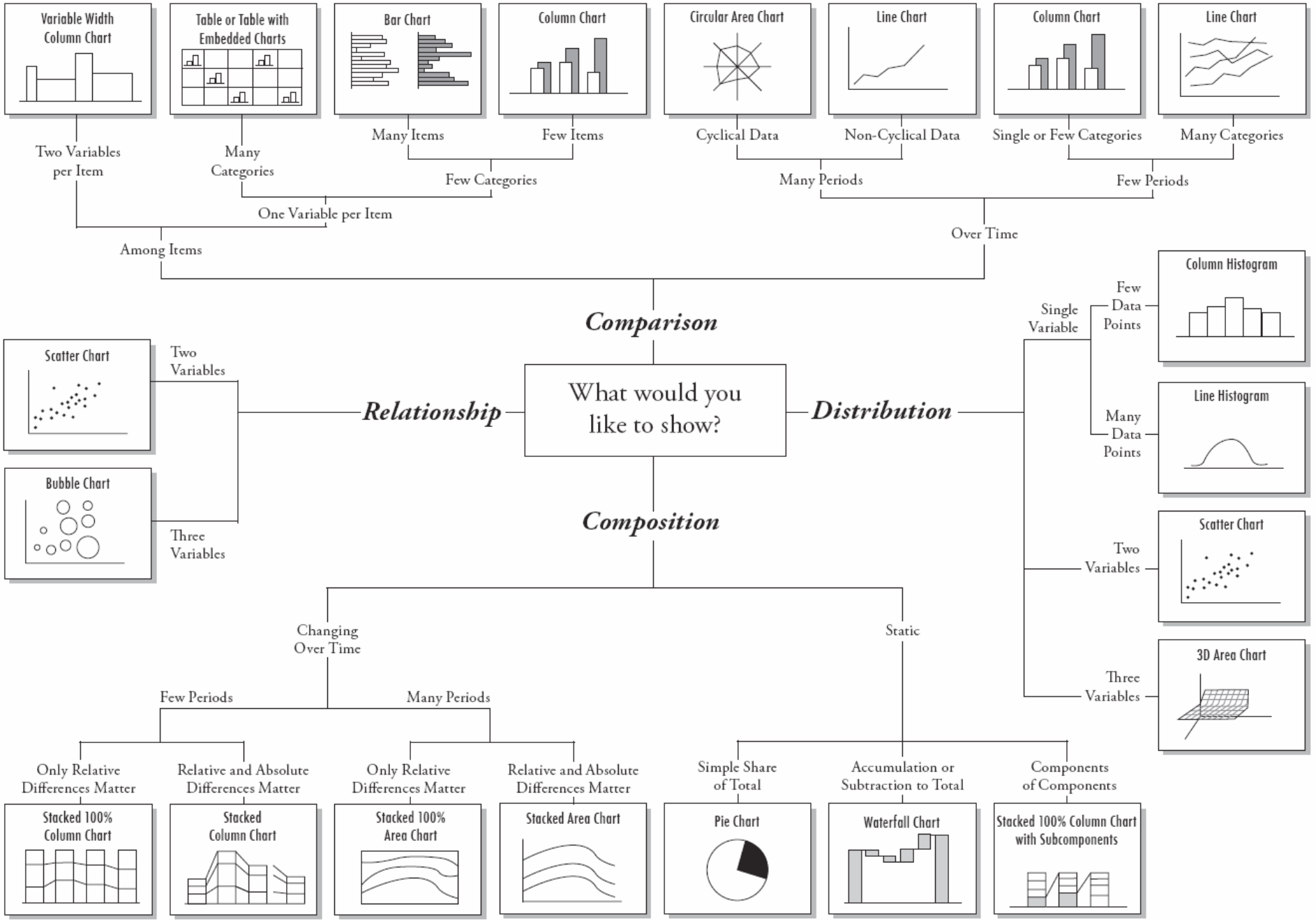

- Sex: male, female
- Genotype: AA, AT, AG, …

- Days: Mon, Tue, …
- Abundance: common, rare, …

- Length: 7, 15, 23 mm, …
- Expression level

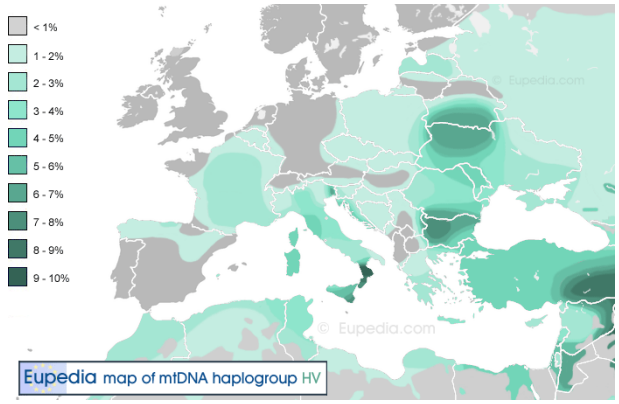
- Trees
- Networks

- Maps

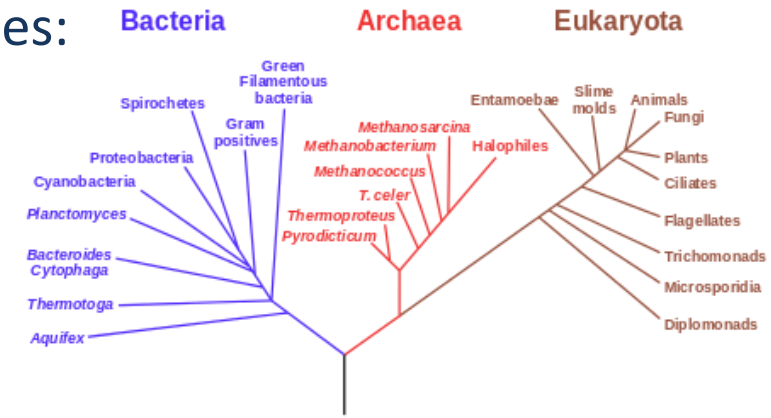


# Data type taxonomy

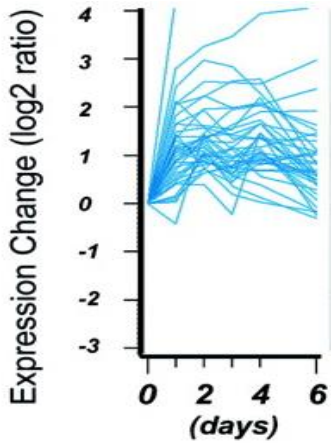
- 1D: GAT AAAT CT GGTCTTATTTCC
- 2D:



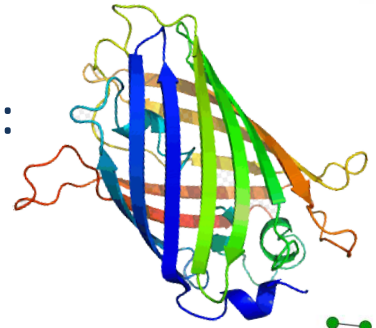

- Trees:



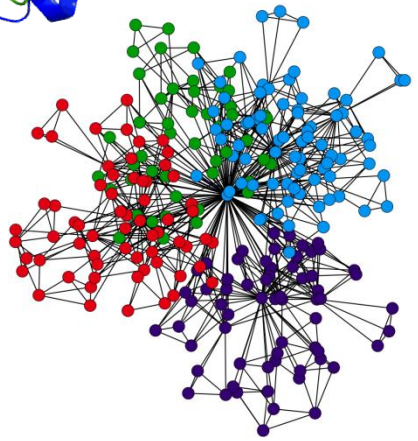

- Temporal:




- 3D:

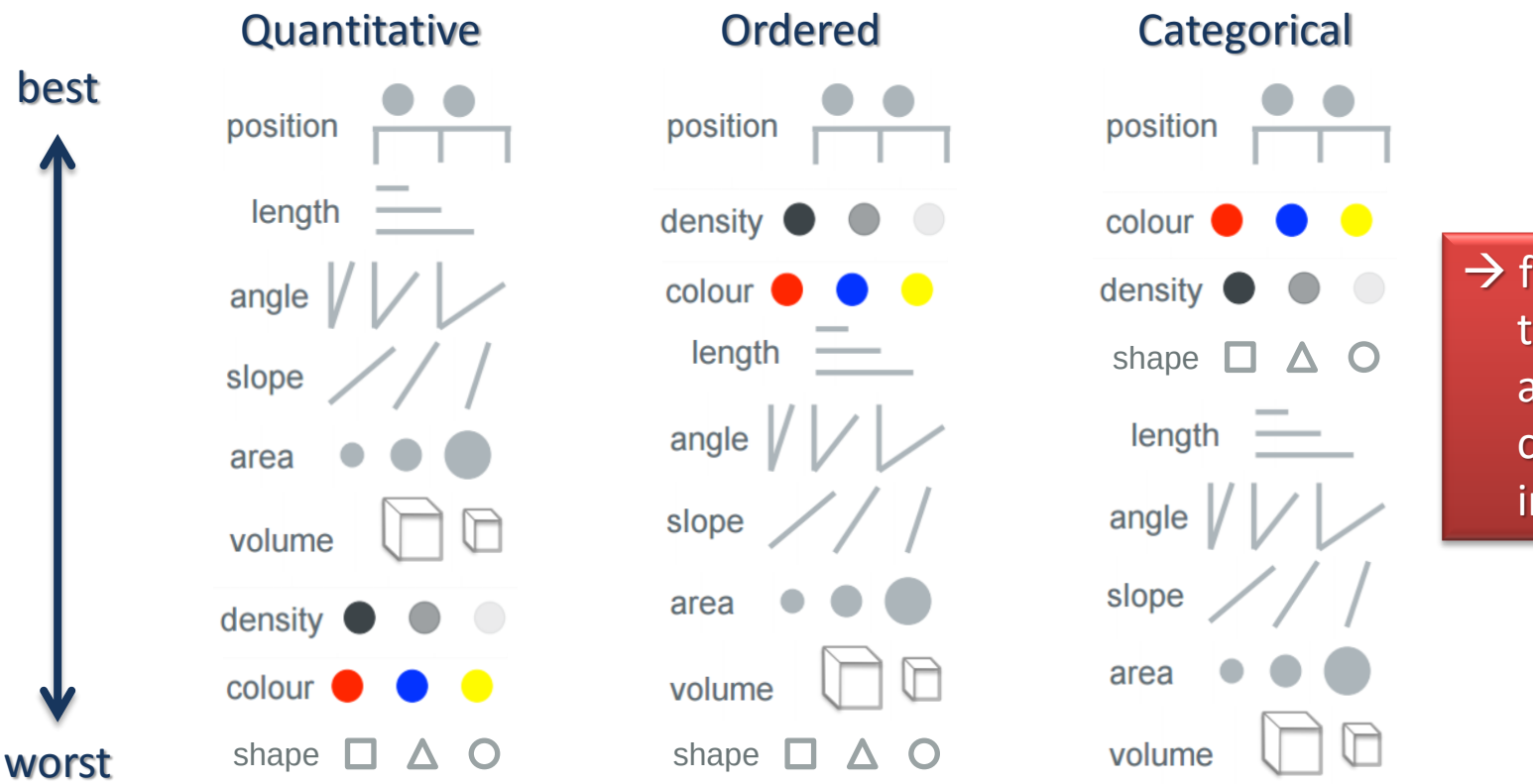


- Networks:



# Language of graphics

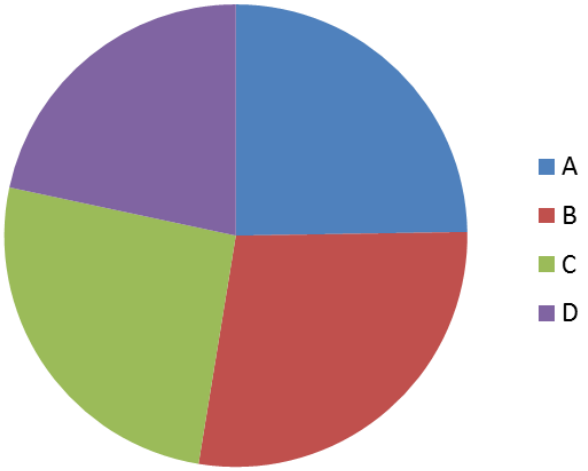
- Graphics can be thought of as forming a sign system:
  - Each mark (point, line, or area) represents a data element
  - Choose visual variables to encode relationships between data elements



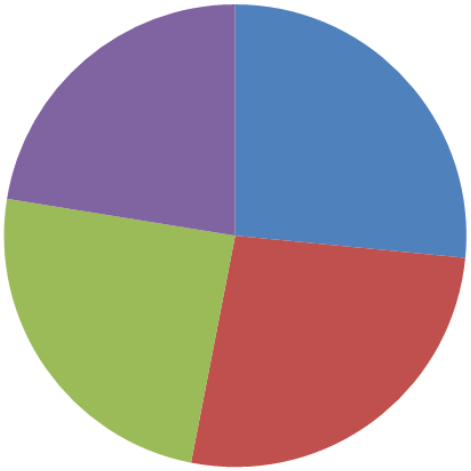

→ find images that express and effectively convey the information

# Ranking example

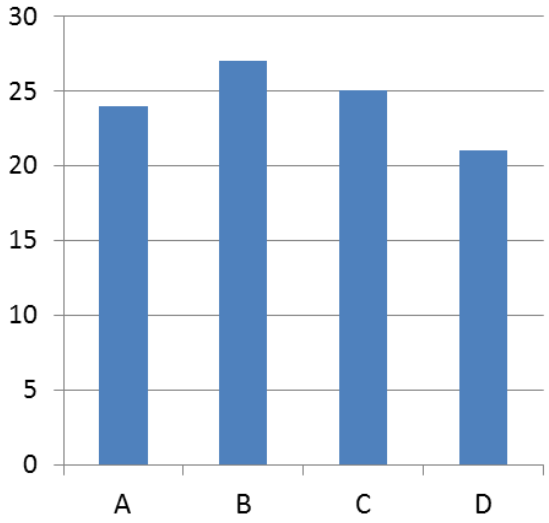
Year 1

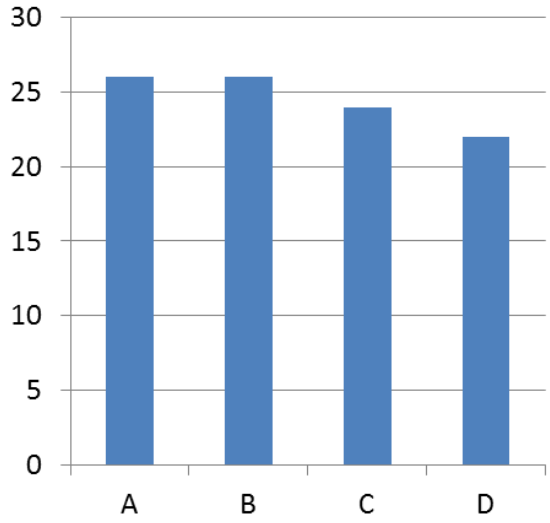



Year 2



→ Difficult to see differences

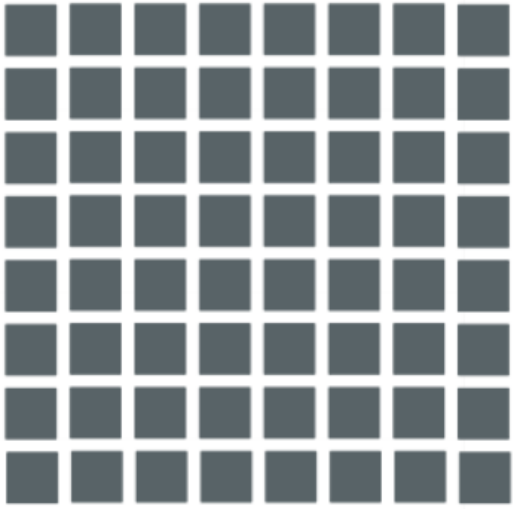


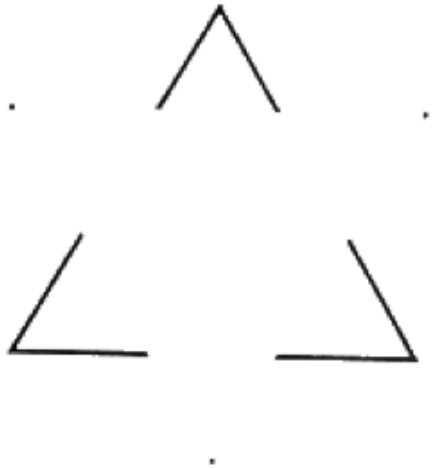




→ Much better!

# Gestalt principles

- Gestalt theory: principles of pattern recognition
  - "The whole is greater than the sum of its parts"
  - The mind visually perceives objects in a certain way collectively
  - Tries to structure/organize what we see into patterns

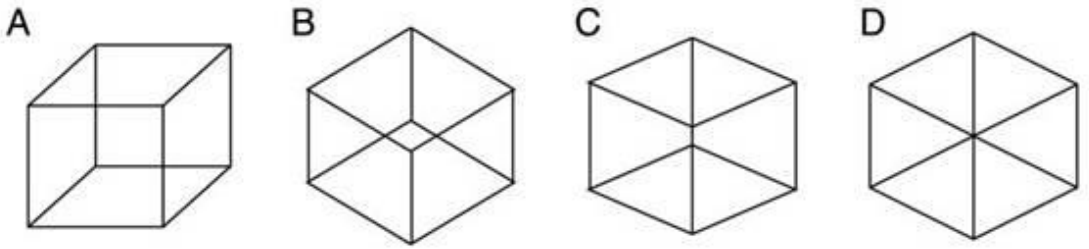




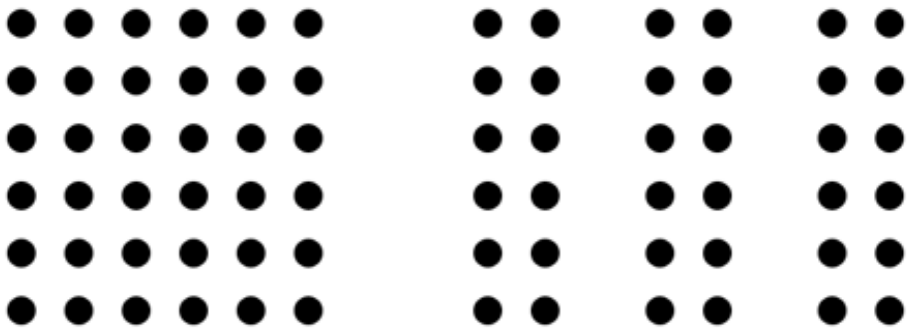
# Gestalt effects

Main principles:

- **Simplicity:**
  Every pattern is seen such that the resulting structure is as simple as possible
  - Different projections perceived as 2 or 3D
  - depending on the simpler interpretation

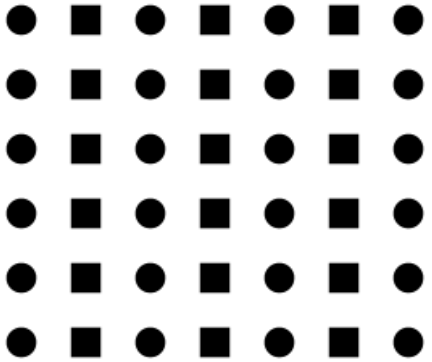



- **Proximity:**
  Things that are near to each other appear to be grouped together

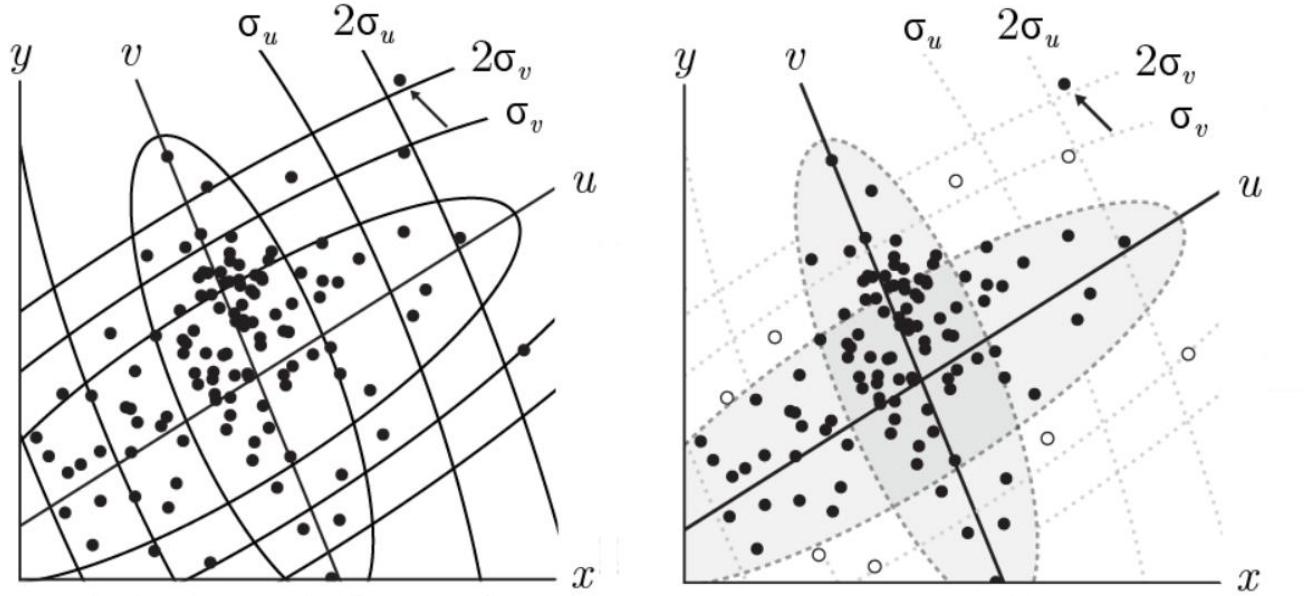


# Gestalt effects

- **Similarity:**
  Similar things appear to be grouped together



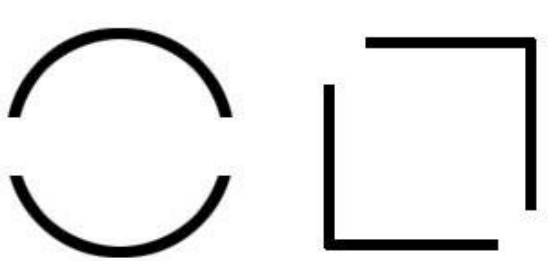
  - Use of similarity of lines and transparency to clarify images:

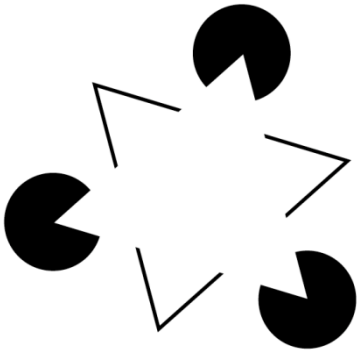



M. Krzwinski, behind every great visualization is a design principle, 2012

# Gestalt effects

- **Closure:**
  We perceptually close up or complete, objects that are not complete



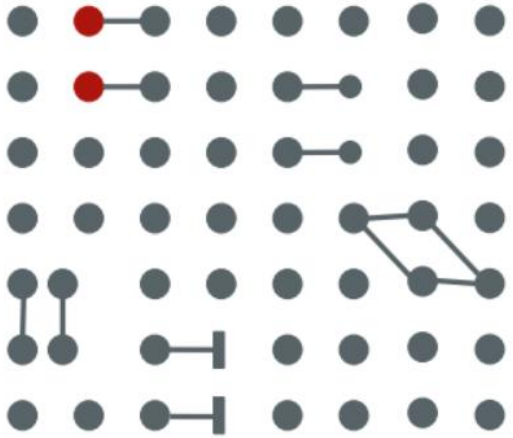


→ We automatically connect graphics, although they may be independent!

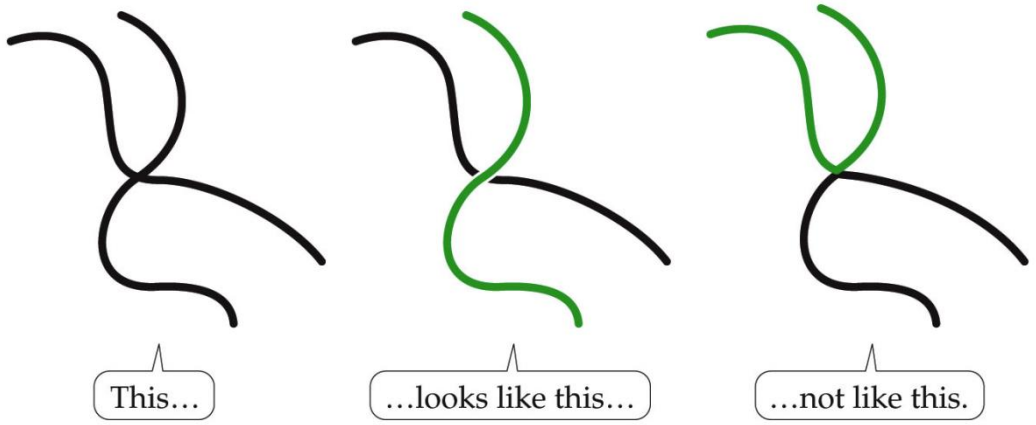
- **Symmetry:**
  Symmetrical objects are grouped together [ ]{ }[ ]

# Gestalt effects

- **Connectedness:**
  Things that are physically connected are perceived as a unit
  → stronger than colour, shape, proximity or size

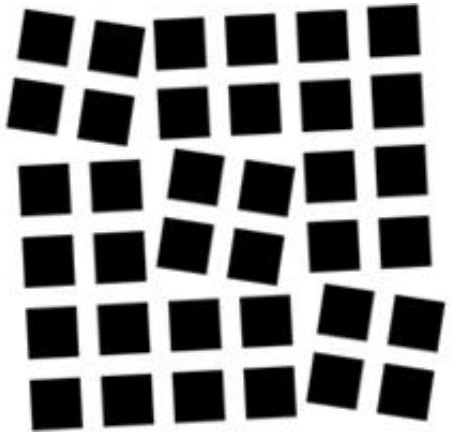


- **Continuity:**
  Points connected in a straight or smoothly curving lines are seen as belonging together
  → lines tend to be seen as to follow the smoothest path



# Gestalt effects

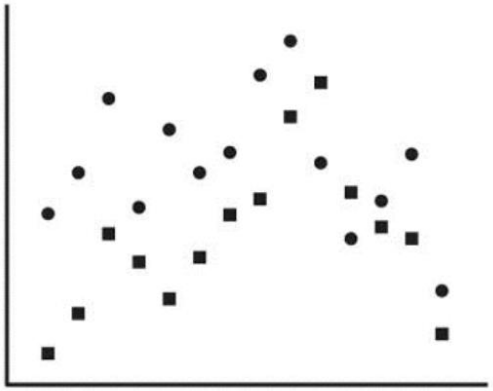
- **Common fate:**
  Things that are moving in the same direction appear to be grouped together

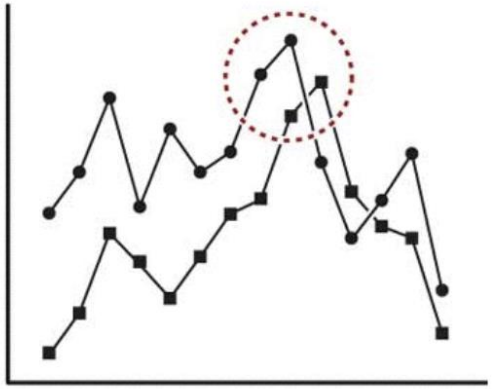


- **Background & smallness:**
  Smaller areas are seen as figures against larger background

# Gestalt effects – Examples

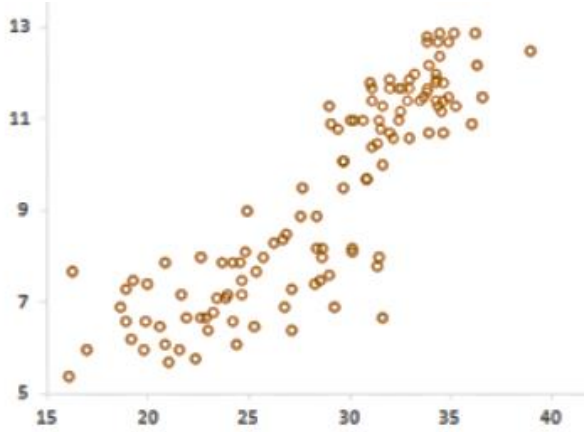
Use connectedness to make it clearer:



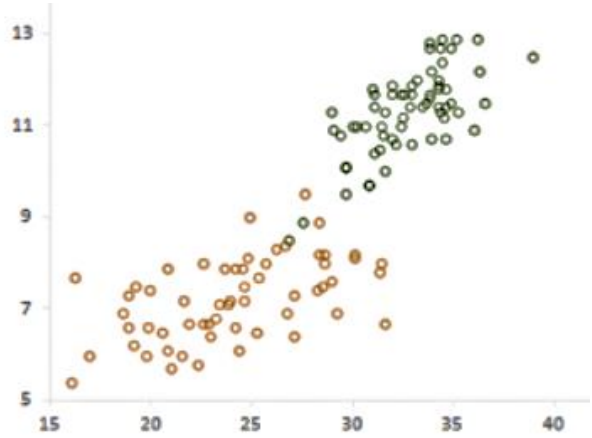


Grouping:

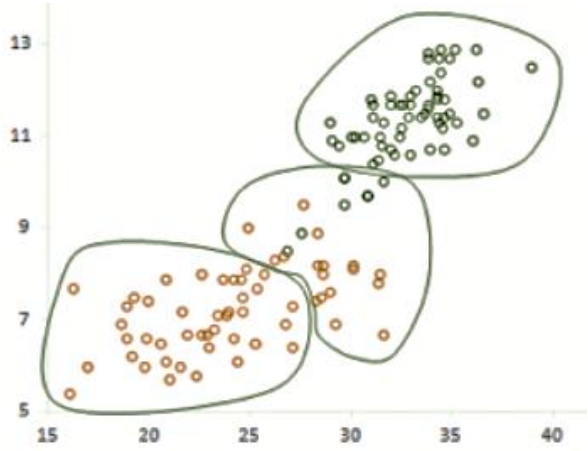
Proximity:




Similarity:

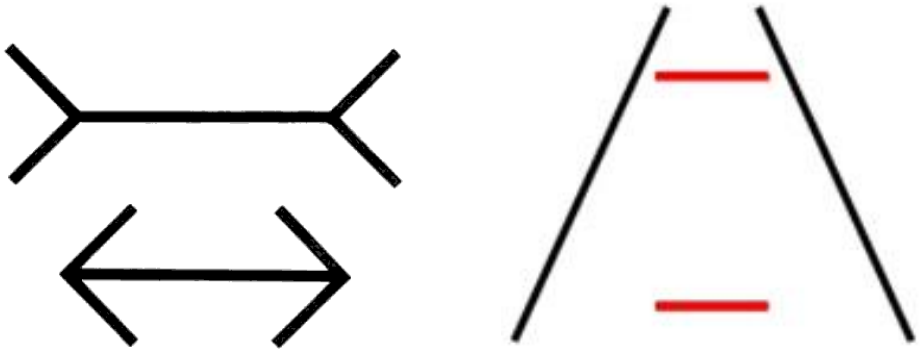



Enclosure:

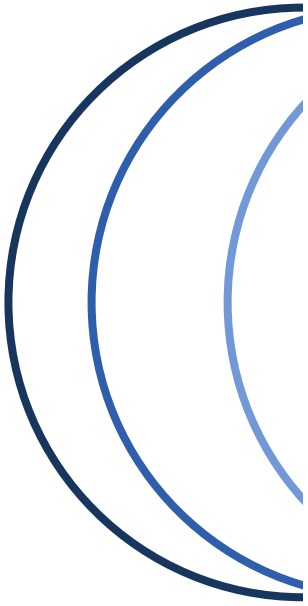


# Context affects perceptual tasks

- Comparing values:
  - Length



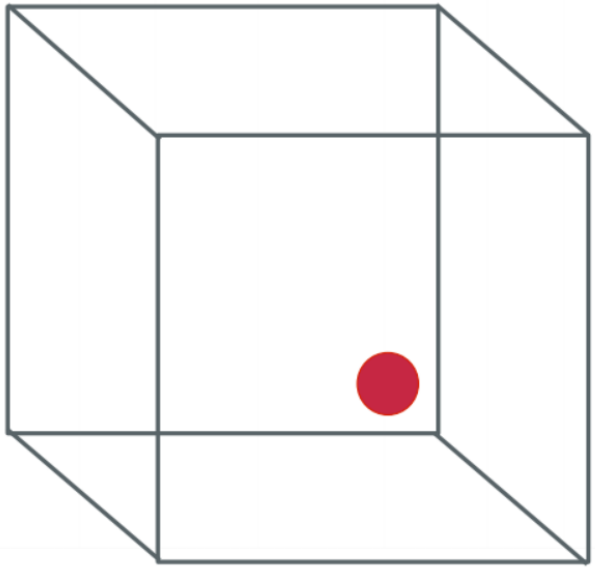
  - Curvature



# Context affects perceptual tasks

- Area

- Position in 3D



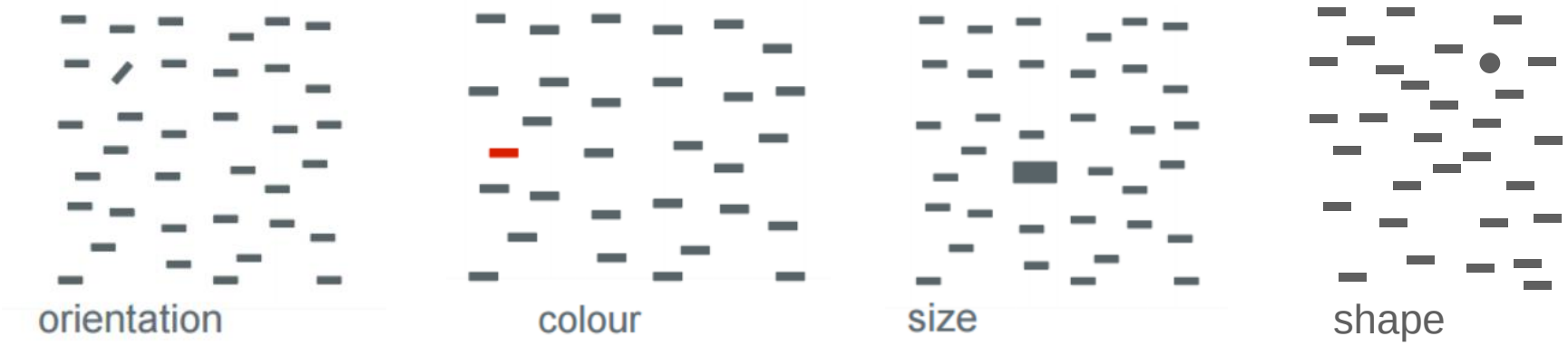
→ 3D effects reduce comprehension

# Preattentive visual features

## Preattentive Visual Features

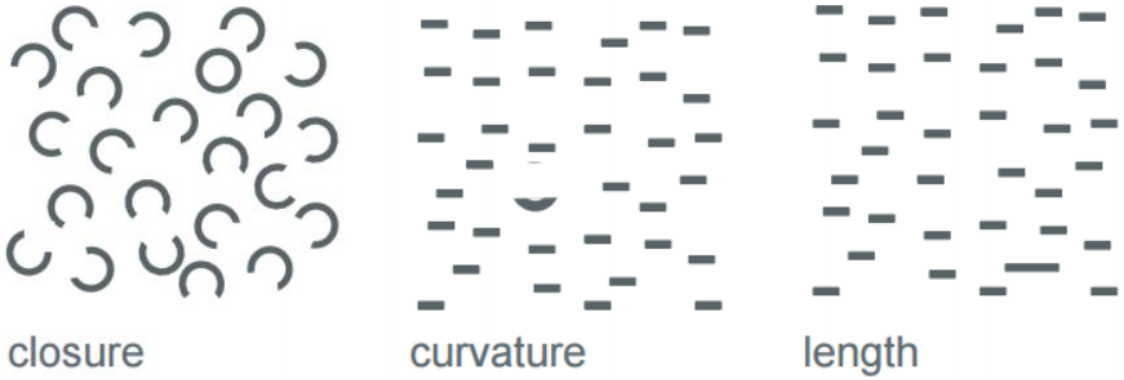
- Ability of human visual system to rapidly identify certain basic visual properties (< 200 -250 ms)
- A unique visual property is processed preattentively (e.g.: color red)

- This is important for design of visualizations
  - What can be perceived immediately?
  - Which properties are good discriminators?
  - What can mislead viewers?



# Preattentive visual features

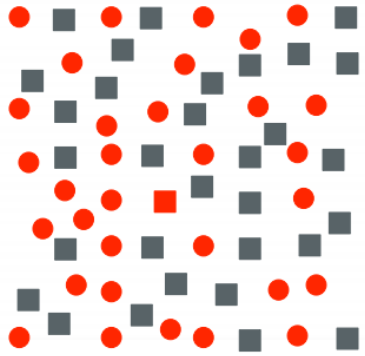
- Some are less effective:




- Some properties are asymmetric
  - Sloped line among vertical lines is preattentive
  - Vertical line among sloped ones is not

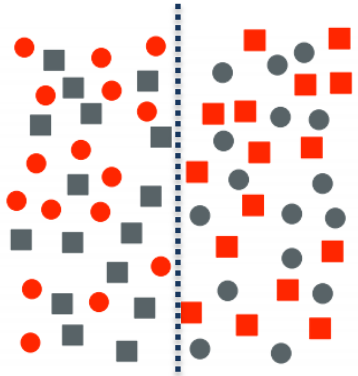
# More than 2 preattentive visual features

- Combination of 2 features→ cannot be detected preattentively



→ Difficult to detect the red square
→ Serial search required

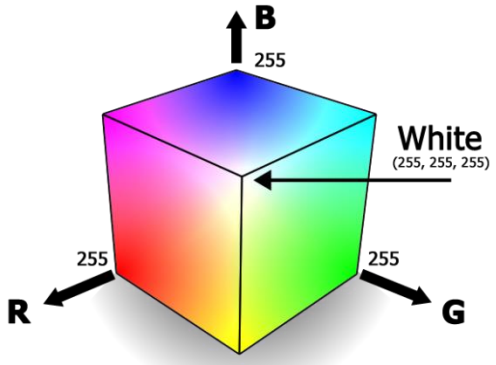
- Boundary detection
  - Users rapidly and accurately detect texture boundary between two groups of elements



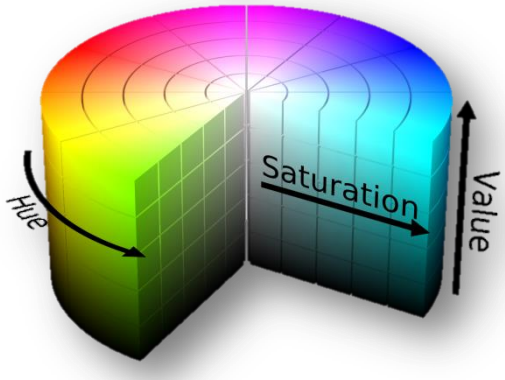
→ all elements in each group need a common visual property

# Colour

- "Colour used poorly is worse than no colour at all" *Edward Tufte*
- Colour can cause the wrong information to stand out
  → make meaningful information difficult to see
- Colour space:
  - RGB: computer use



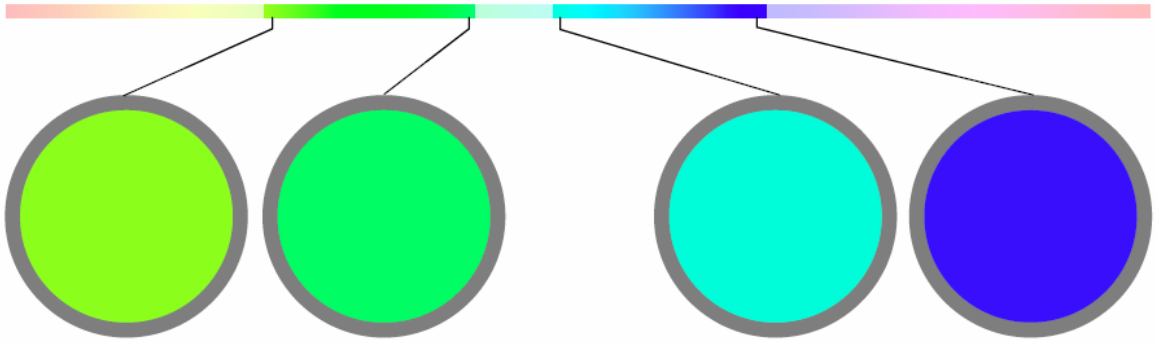

  - HSV: describe colour in terms of
    - Hue (colour)
    - Saturation
    - Lightness (value)



# Perceptual differences

- Our eyes do not response linear to colours

  → play attention in quantitative encoding!



| HSB COLOR SPACE | ΔH = 60 | | ΔH = 60 | |
|---|---|---|---|---|
| HUE | 83 | 143 | 171 | 231 |
| SATURATION | 1 | 1 | 1 | 1 |
| BRIGHTNESS | 1 | 1 | 1 | 1 |

Mimics nonlinear eye ← perception

| Lab COLOR SPACE | $\Delta E_{ab} = 35$ | | $\Delta E_{ab} = 176$ | |
|---|---|---|---|---|
| L | 91 | 88 | 90 | 35 |
| a | -59 | -81 | -58 | 70 |
| b | 87 | 60 | 4 | -102 |

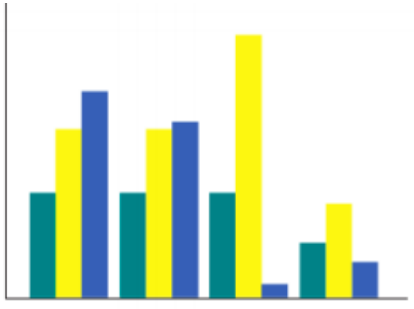
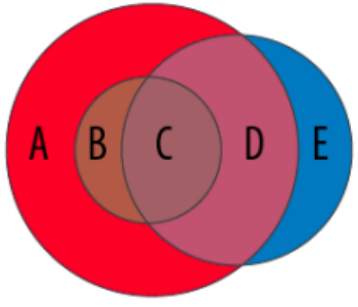
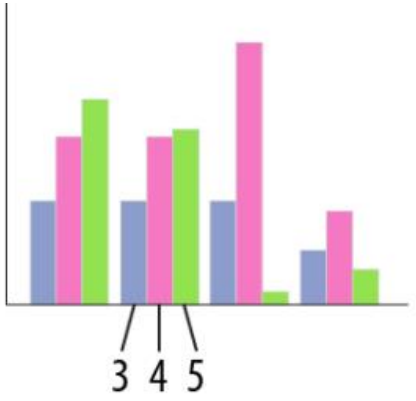
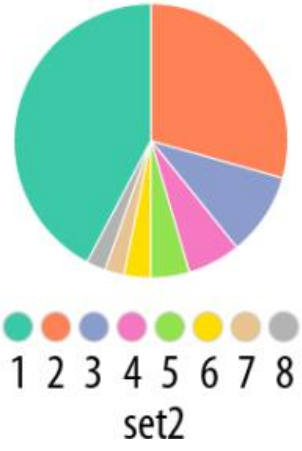
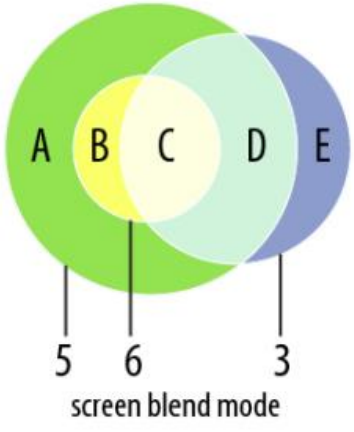
# Brewer palettes

- Brewer palettes provide a range of palettes based on HSV model, which make life easier for us

Avoid to use hue to encode quantitative variables!


Fig. Courtesy of M. Krzwinski,

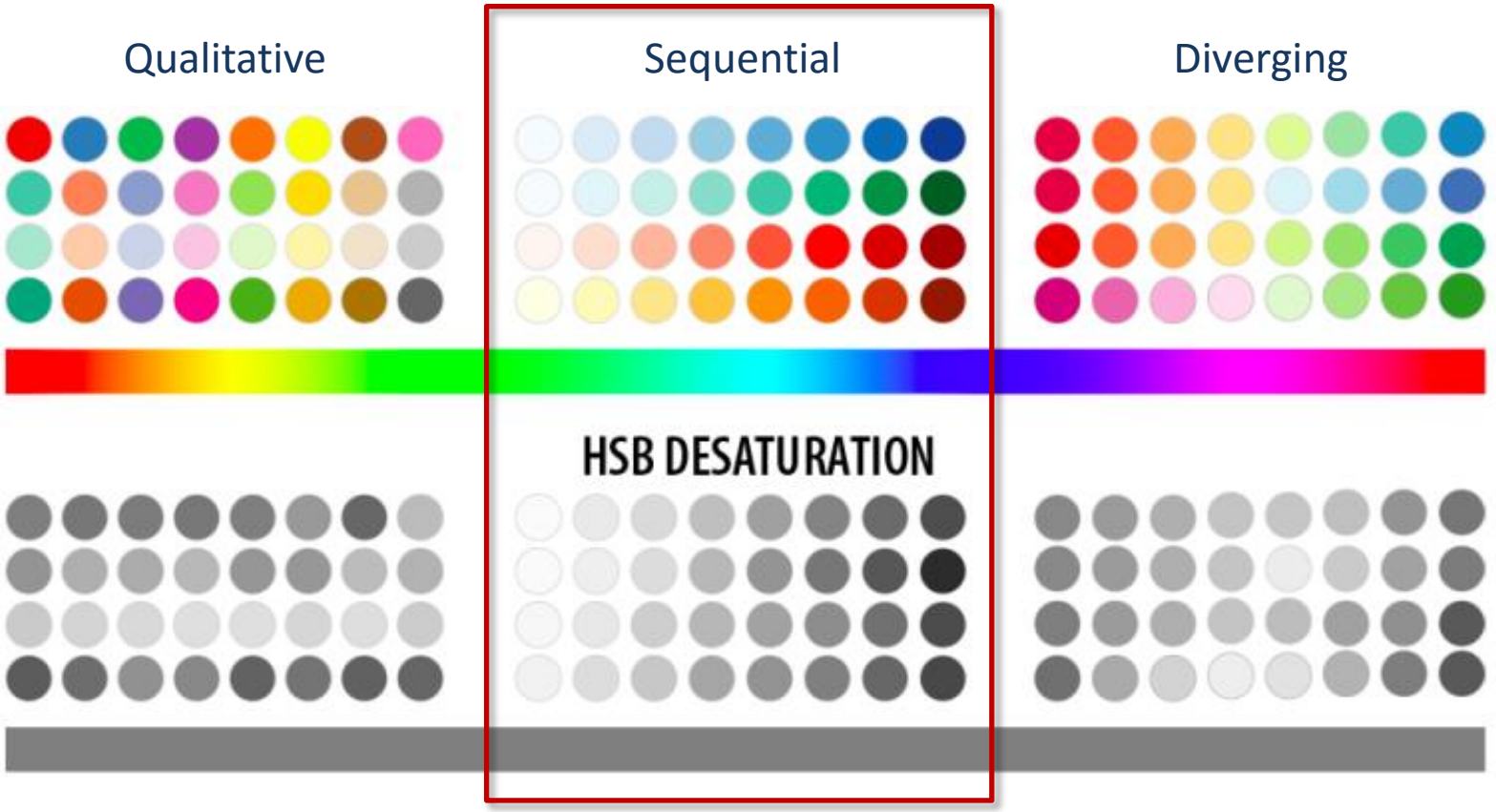
# Examples

| | One color dominant | Difficult to distinguish | Muddy and dark |
|---|---|---|---|
| Poor use of colour |  |  |  |
| Brewer colours |  |  |  |

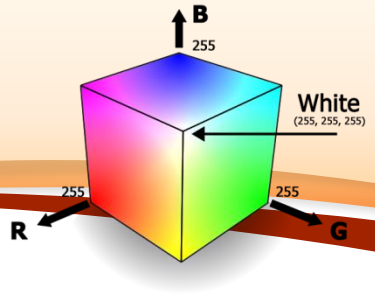
M. Krzwinski, behind every great visualization is a design principle, 2012

# Conversion to grey scale

- Ensure that chosen colour set work well in grey scale (for printing)
  → Sequential palette works well here

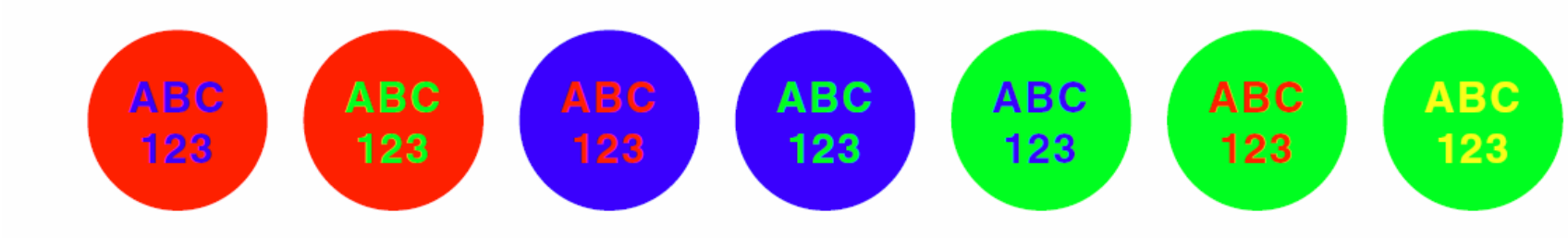


# Contrast



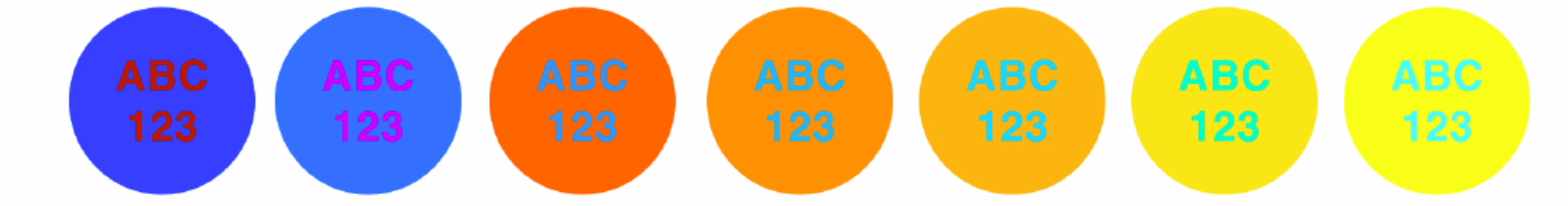

Contrast is determined by the difference in the color and brightness

- Avoid pure colors next to each other:




- Avoid adjacent colors with similar luminance (perceived brightness)

$$\Delta L = 0$$

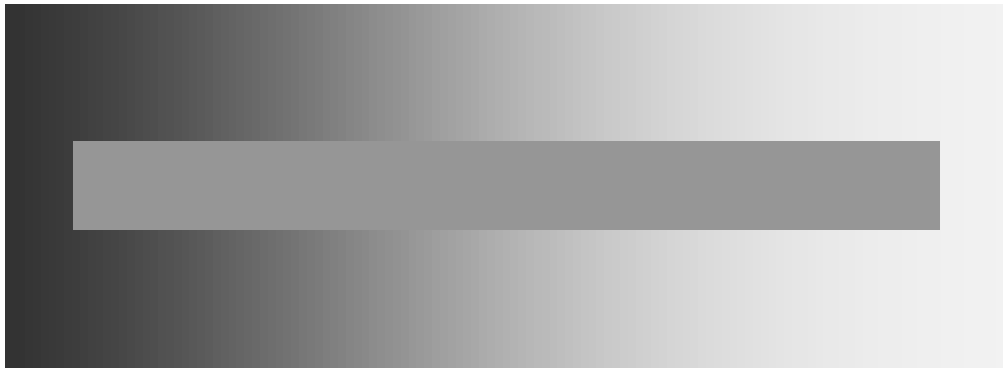


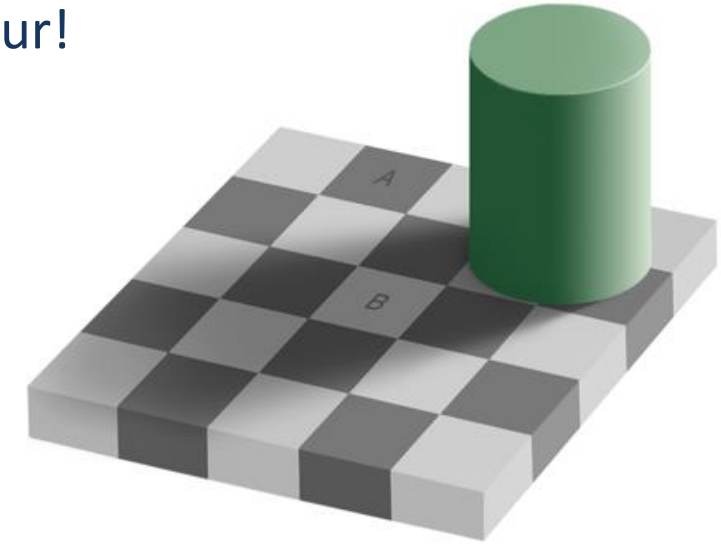
# Guidelines

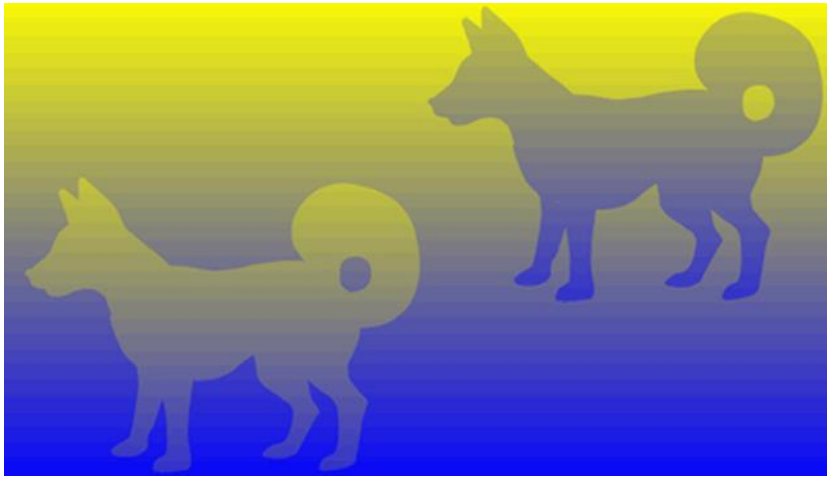
- Saturation and colour are not separable in small regions
  - in small regions use bright, highly saturated colors
- Saturation interacts strongly with size
  - more difficult to perceive in small regions
  - for points and lines use just two saturation levels
- Higher saturation makes large areas look bigger
  - use low saturation pastel colors for large regions and backgrounds
- Luminance and saturation are most effective for ordinal data because they have an inherent ordering
- Colour is great for categorical data because there is no inherent ordering
  - but limit number of colour to 6-12 for distinguishability

# Perceptual colour

- Be aware: context affects perceived colour!



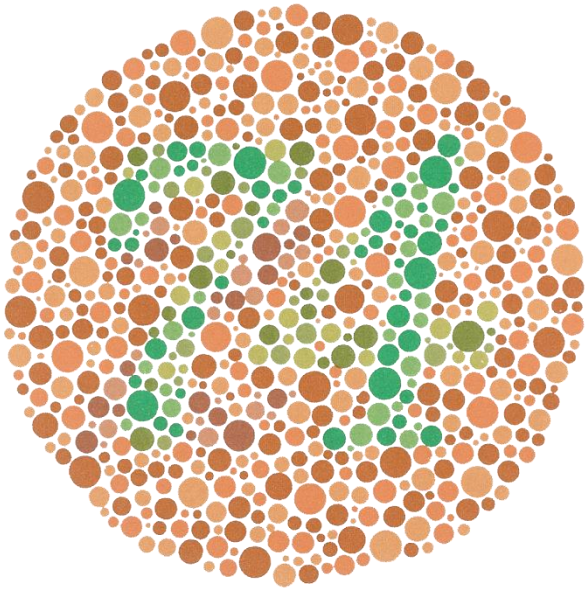


→ Especially heat maps may be affected!

| | | |
|---|---|---|
| 100 | 99 | 90 |
| 90 | 45 | 70 |
| 70 | 95 | 65 |
| 40 | 3 | 30 |
| 50 | 20 | 10 |
| 40 | 5 | 45 |
| 30 | 10 | 0 |

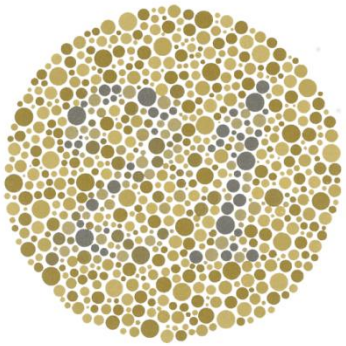
# Accessibility of colours

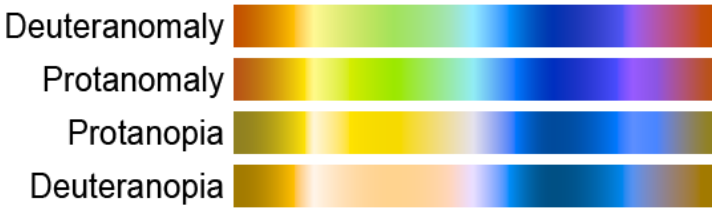


What do you see?

- 74: normal vision vision

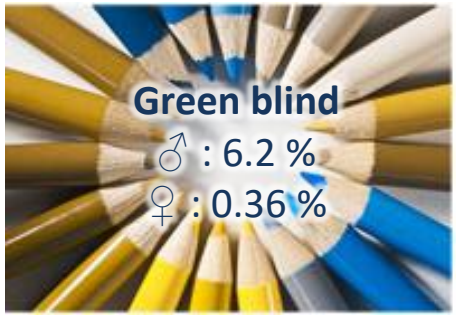
- 21: red/green blind

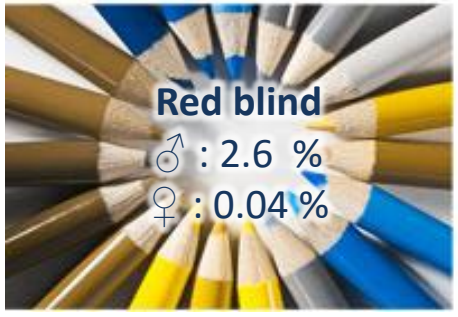





- Nothing: color blind


→ Be aware of (red/green) colour blind people!


# Colour blindness

problematic!

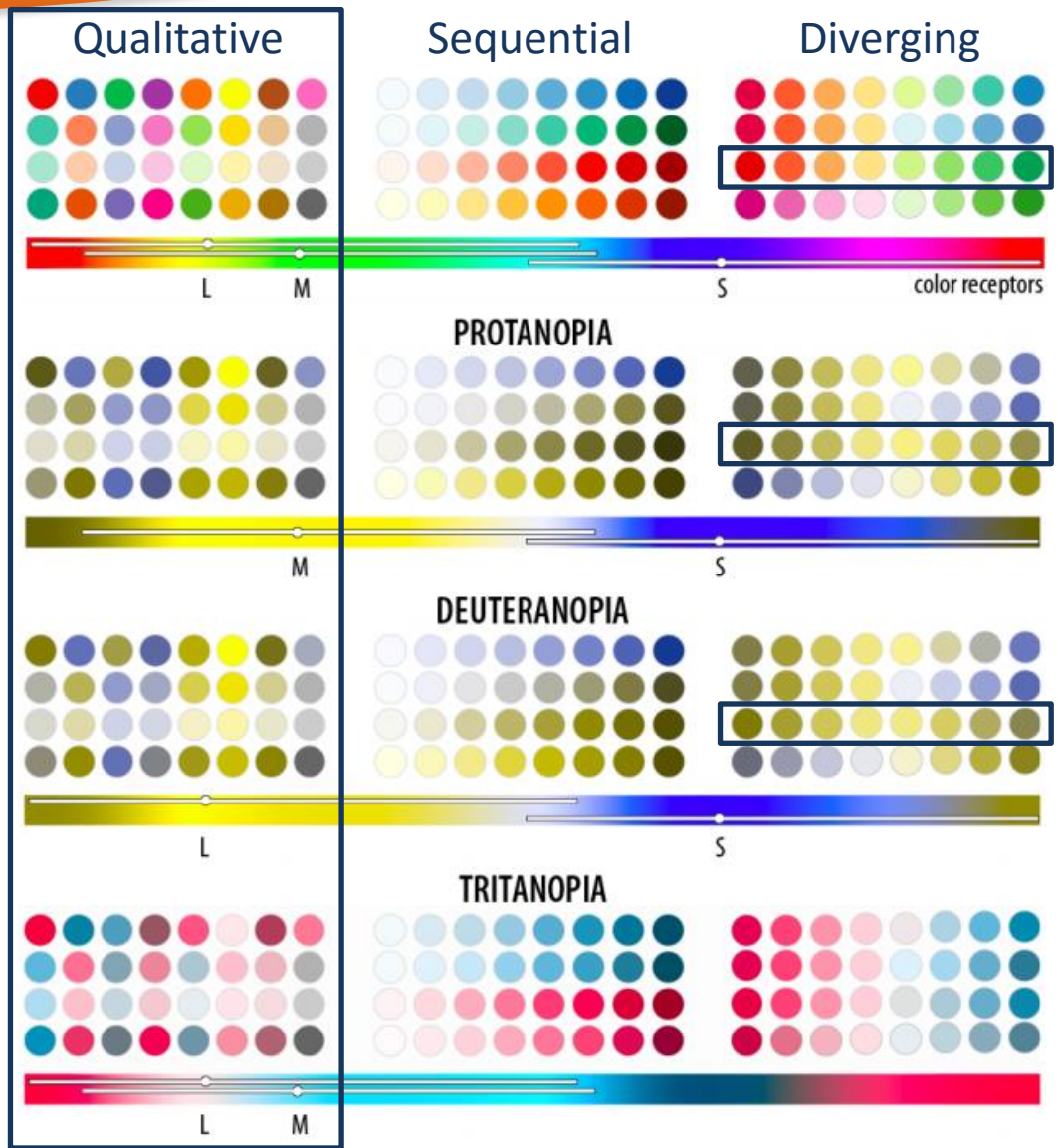



Fig. Courtesy of M Krzywinski

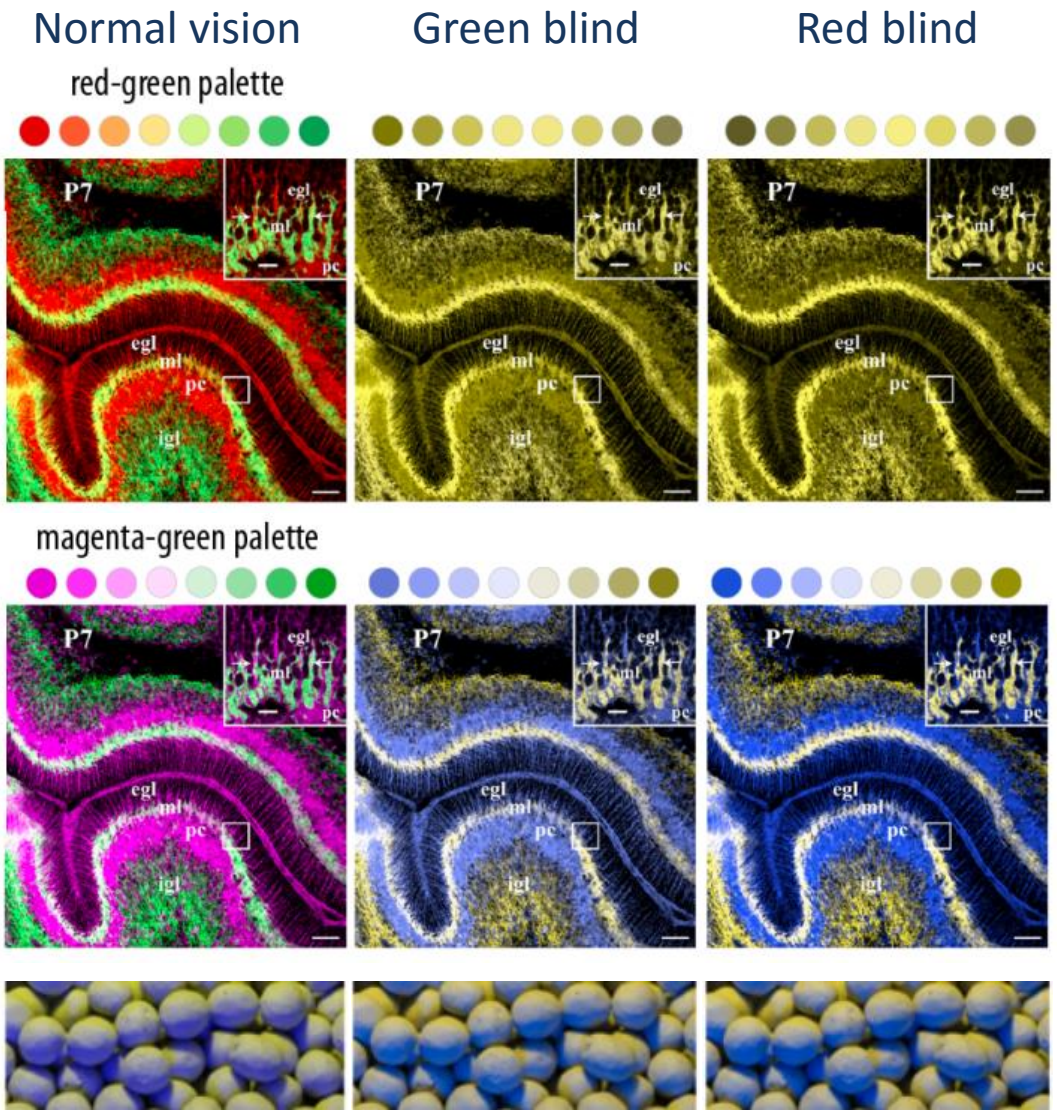
# Example

## Immunofluorescence images

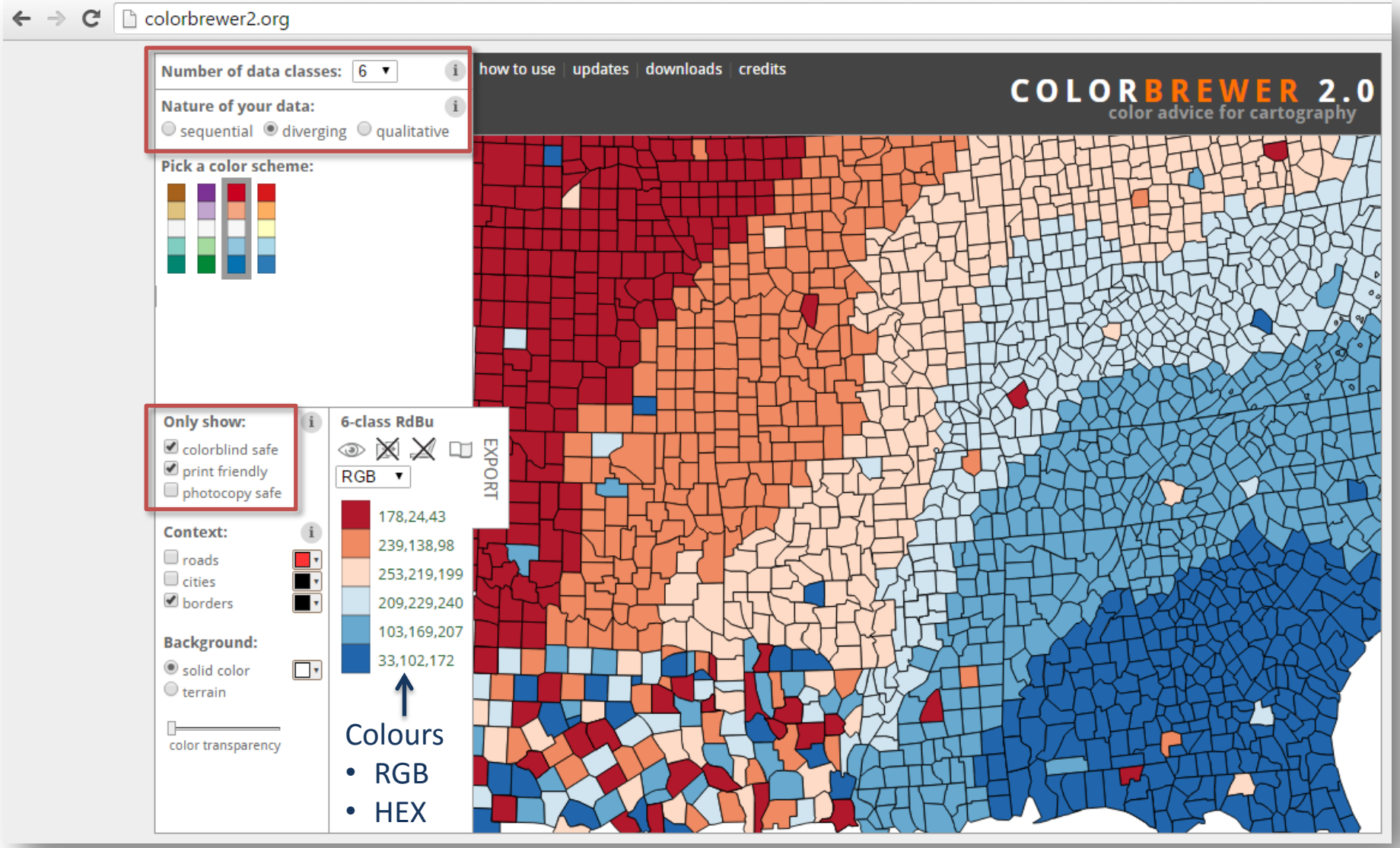
- Red-green image:

- Remapped to magenta-green:
  → suitable for red/green blindness

- Blue-yellow even better
  → talk about same colours



# colorbrewer.org



# Acknowledgment


- http://mkweb.bcgsc.ca/vizbi/2012/principles.pdf
- https://vizbi.org/2011/Presentations/Data_visualization_Nils_Gehlenborg.pdf