Chapter 6.3 – Colour

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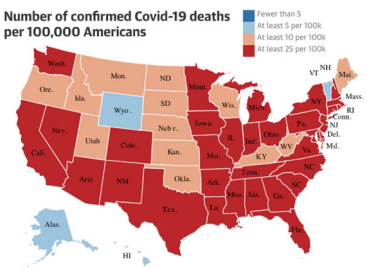
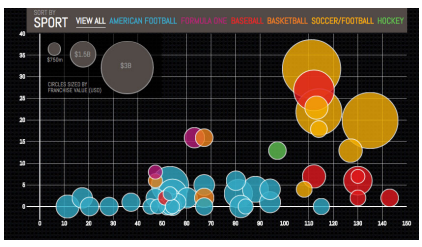
- Colour Perception
- Additive and Subtractive Colour Systems
- Colour Models
- Data Legibility of Colour
- Inclusive Use of Colour
- Colour in Data Visualisation

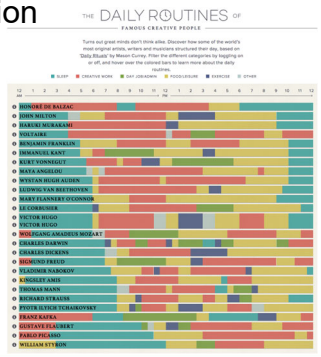
Colour Perception

Living Colours

- The ability to perceive colours has been crucial for the **survival** of early hunters and gathers as it helps them spot lurking dangers, look and identify edible food.
- The ecological role of colour perception in humans suggests that it can also play an important role in the design of effective information visualisation (see the effective use of colour in these visualisation examples)[1].







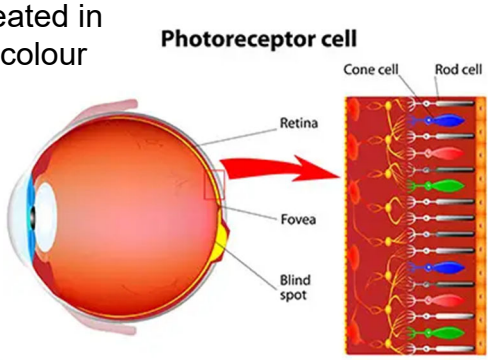
Images from examples in [1]

[1] Ross Crooks, The Power of Data Visualization Plus Examples of Good and Bad Visuals (2021) - https://blog.hubspot.com/marketing/great-data-visualization-examples

Colour Perception

What is Colour?

- The perception of **colour** in humans is due to the stimulation of **photoreceptor** cells (in particular cone cells) by electromagnetic radiation in the visible spectrum, which can be either **reflected** of an object surface or **emitted** from a light source.
- However, the colour we eventually perceive is created in our **brain**. For example, it is able to maintain the colour of an object in a relatively stable manner despite changes in illumination due to shadows[2].
- It is also for this reason the visual attribute of colour is **complex** and its perception can be influenced by numerous factors such as the background, other adjacent colours, etc.



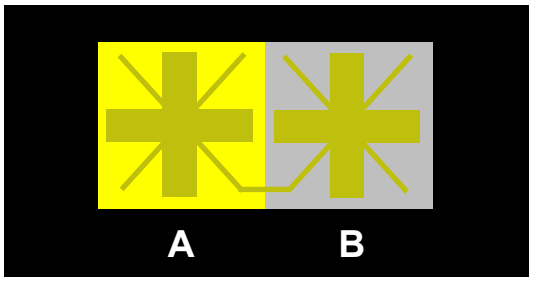
[2] Scientific American, Illusory Color & the Brain (2008) - https://www.scientificamerican.com/article/illusory-color-andamp-the-brain-2008-05/

Photoreceptor Cells in the Retina
Image from American Academy of Ophthalmology

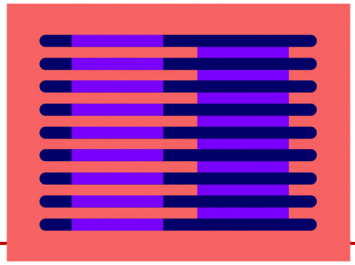
Colour Perception

Colour Appearance

- The **colour contrast** of the **background** can change the way we perceived the actual colour of an object.
- The **Bezold effect** was first reported by Wilhelm von Bezold, a German professor of meteorology.
- Bezold discovered that a colour may appear different depending on its relation to **adjacent colours**. It happens when small areas of colour are interspersed.



Does cross A or B have a darker shade?



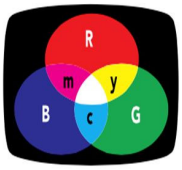
Bezold Effect image from [3]

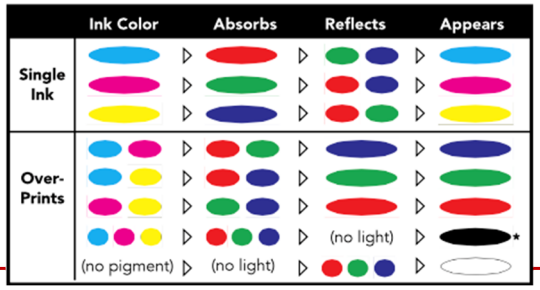
[3] L. Giovanni and H. Kellen, Is Seeing Really Believing? (2019)- https://dailydolphin.hbcsd.org/6151/science-and-technology/is-seeing-really-believing/

Additive and Subtractive Colour Systems

Display versus Print

- **Additive** and **subtractive** colour systems use a **different** but **small** combination of **primary colours** to produce a whole gamut of colours.
- A display monitor uses the **additive** colour system because they are **emissive devices**. It starts with darkness and add red, green & blue light to create the spectrum of colours[4].
- Printers render colours on paper and must work with **reflected light**. They thus employ the opposing **subtractive primaries** of cyan, magenta & yellow[4].
- In subtractive colour printing, a 4th black colour (K, which stands for key) is added to make four-colour printing (**CMYK**).





Additive & Subtractive Colour Systems, Images from [4]

[4] Tim Mouw, Additive vs. Subtractive Color Models - https://www.xrite.com/blog/additive-subtractive-color-models

Colour Models

HSL and HSV Colour Models

- The RGB colour model is the way displays (and some drawing applications) specify colours, but it is not realistic to think in RGB terms when considering colour choices for visualisation design[5].
- A more accessible colour model for data visualisation design is the **HSL** (Hue, Saturation, Lightness)[5] or the **HSV** (Hue, Saturation, Value) models.
- The 3 dimensions combine to form a **cylindrical-coordinate** colour representation of the RGB colour model.

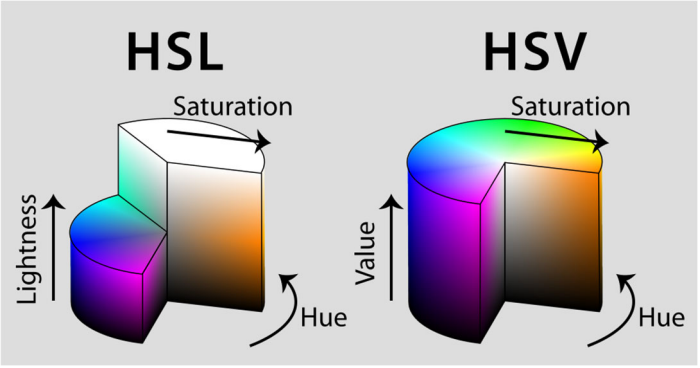


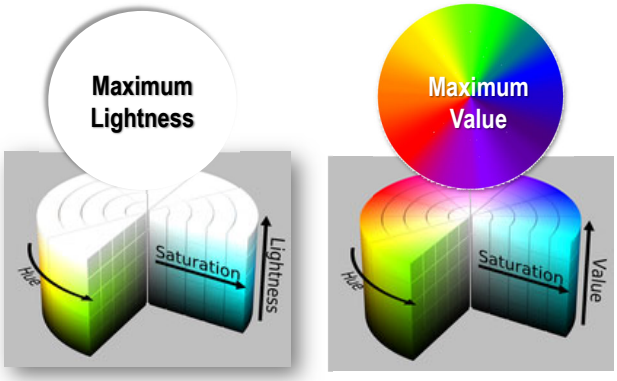
Image taken from Wikipedia

[5] Andy Kirk, Data Visualisation, A Handbook for Data Driven Design, SAGE Publications (2016).

Colour Models

HSL versus HSV

- The **HSL** colour model mimics the way different paints mix together to create colour in the real world, with the **lightness** dimension resembling the varying amounts of black or white paint in the mixture.
- The **HSV** model depict how colours appear as the **value** representing the amount of light falling on it varies.
- The colour with maximum lightness in **HSL** is **pure white**, but a colour with maximum value in **HSV** is **pure hue**, as if the coloured object is illuminated by the brightest white light.



HSL colour model **HSV colour model**

Image taken from Wikipedia

Colour Models

HSL Colour Model

- **Hue(H)** is considered true colour. When a **colour** is **described** or labelled, it is most commonly referred to by its hue (e.g. red, blue, yellow, orange)[5].
- **Saturation(S)** is a **scale** that defines the purity or colourfulness of a hue. From intense **pure colour** (high saturation) to a no-colour state of **grey** (low saturation)[5].
- **Lightness(L)** is a scale that defines the contrast of a single hue from **dark** to **light**. It is a scale of light tints (adding white) through to dark shades (adding black)[5].
- **H**,**S** or **L** and its combination can be varied depending on the visualisation design.

Image taken from [6]

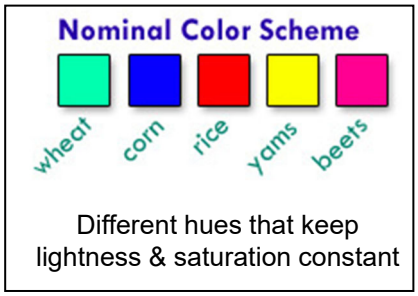
[5] Andy Kirk, Data Visualisation, A Handbook for Data Driven Design, SAGE Publications (2016).
[6] Understanding Hue, Saturation & Lightness (HSL) for Photo Retouching - https://purple11.com/basics/hue-saturation-lightness/

Data Legibility of Colour

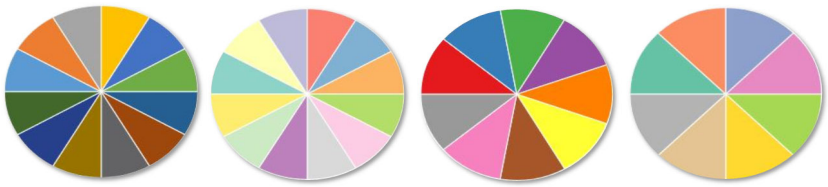
Nominal Scale

- Data legibility concerns the use of colour attributes to **encode data** values in charts.
- The colour selection for data with **nominal** scale should be to classify different **categorical** values that are qualitative and have no particular order.
- The goal in the colour scheme is to create visible **distinctions** between each category, while facilitating **efficient** and **accurate** discernment of the categories.

Image taken from [7]



Different hues that keep lightness & saturation constant



Default Colours | Light Colours | Strong Colours | Colourblind Safe

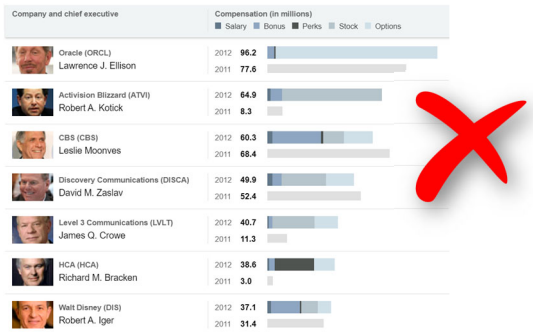
Palette Images taken from [8]

[7] Axis Maps, Using Colors on Maps - https://www.axismaps.com/guide/using-colors-on-maps
[8] Carmen Chan, Choosing Color Palettes in Displayr - https://www.displayr.com/choosing-color-palettes-in-displayr/

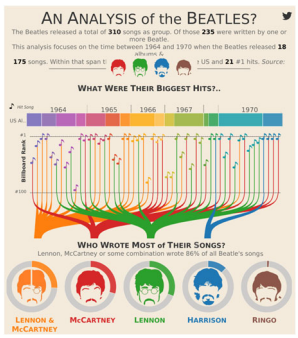
Data Legibility of Colour

Nominal Scale – Creating Contrast

- Creating **contrast** is the main aim of representing nominal data. Varying the **hue** is the most effective means of achieving this goal. Variation in colour tone (**saturation**) may also be considered but varying **lightness** will not be sufficiently discernible[5].



Images taken from [9]



Images taken from [10]

[9] Barry Ritholtz, Executive Pay by the Numbers - https://ritholtz.com/2013/07/executive-pay-by-the-numbers/
[10] Adam E McCann, Beatles Analysis - https://public.tableau.com/app/profile/adam.e.mccann/viz/BeatlesAnalysis/BeatlesAnalysis

Data Legibility of Colour

Nominal Scale – Too Many Colours

- As category count increases, the ability to maintain clear colour differentiation diminishes. The rule of thumb is that no more than 12 categories can be comfortably distinguished based on different colours[5].
- Additional visual attributes like texture or patterns can be added to create further visible distinction but consider its use carefully as the visual may look cluttered and confusing.

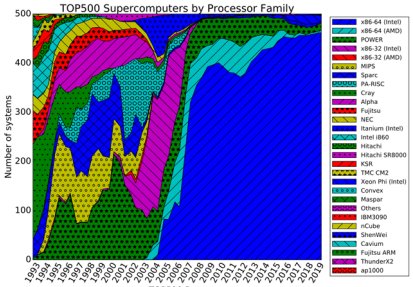
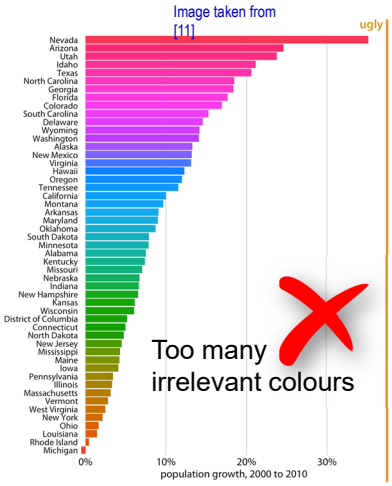


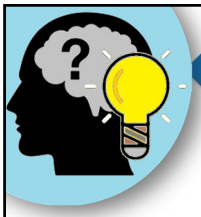
Image taken from https://en.wikipedia.org/wiki/Infographic

Image taken from [11]



Too many irrelevant colours

[5] Andy Kirk, Data Visualisation, A Handbook for Data Driven Design, SAGE Publications (2016).
[11] Claus O. Wilke, Fundamentals of Data Visualization, Color Pitfalls - https://clauswilke.com/dataviz/color-pitfalls.html

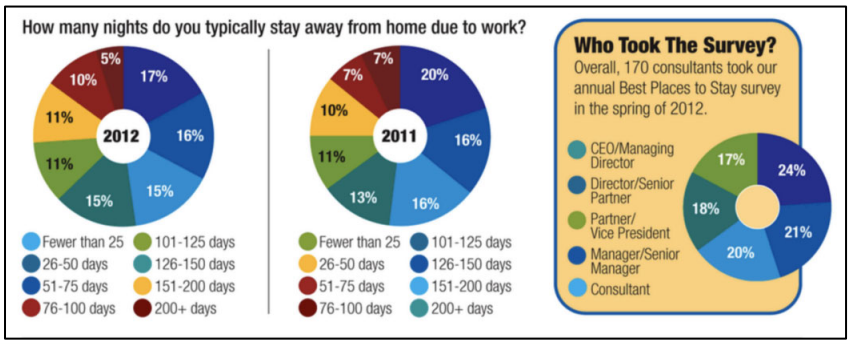


Think and Apply

Less Colour But More Clarity

- List down what you think are poorly designed aspects of the visualisation that compromised the **accessibility** of the information presented.
- Can you redesign an improved version with no constraints?
- Can you redesign an improved version with only one colour?

(excluding black for text & borders, white for background)



A poorly designed visual that was featured in https://towardsdatascience.com/color-in-data-visualization-less-how-more-why-348514a3c4d8

Data Legibility of Colour

Ordinal Scale

- Ordinal data has categories that have a natural sense of **ordering** or **hierarchy**.
- The colour scheme aims to create a **visible distinction** between these categories as well as imply a **sense of order** or magnitude through the colour variations.
- The colour dimensions used to achieve this is usually a variation of the **saturation** or **lightness** or both[5].
- The **sequential** colours are for a unidirectional ordinal scale. A **diverging** palette is used for dual direction ordering (e.g. Likert scale survey of positive & negative sentiments).

Sequential ("`Greys`")

Sequential ("`Blues`")

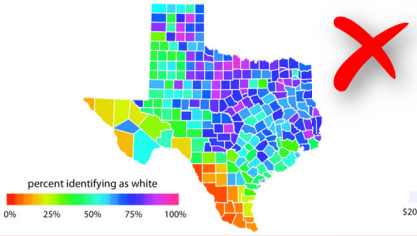
Diverging ("`vlag`")[12]

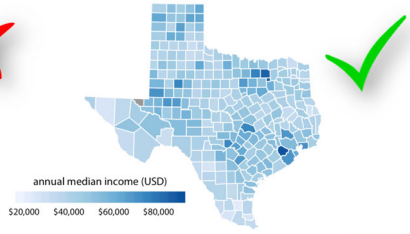
[5] Andy Kirk, Data Visualisation, A Handbook for Data Driven Design, SAGE Publications (2016).
[12] Seaborn, General principles for using color in plots - https://seaborn.pydata.org/tutorial/color_palettes.html

Data Legibility of Colour

Interval and Ratio (Quantitative) Scale

- With **quantitative** scale data, the goal is to use colour variations to distinguish the **relative values** or **magnitude** of the data variable.
- To improve the ease of reading value ranges from their associate colour shade, the data values are divided up into **discrete** classification or 'bins'[5].
- Avoid colour variations using **hue alone** (rainbow scale) as there is little sense of order in hue. Variations in **colour saturation** generally create more intuitive visuals[11].





[5] Andy Kirk, Data Visualisation, A Handbook for Data Driven Design, SAGE Publications (2016).
[11] Claus O. Wilke, Fundamentals of Data Visualization, Color Pitfalls - https://clauswilke.com/dataviz/color-pitfalls.html

Inclusive Use of Colour

Colour Blindness

- Colour blindness or colour deficiency affects around 1 in 12 men and 1 in 200 women worldwide[13]. The most common type is the red/green colour blindness (e.g. people with Protanopia or Deuteranopia have problem seeing red or green respectively).
- Data visualisation designers should be **mindful** of how colours are used so that charts created are **inclusive** and meaningful to as large an audience as possible.

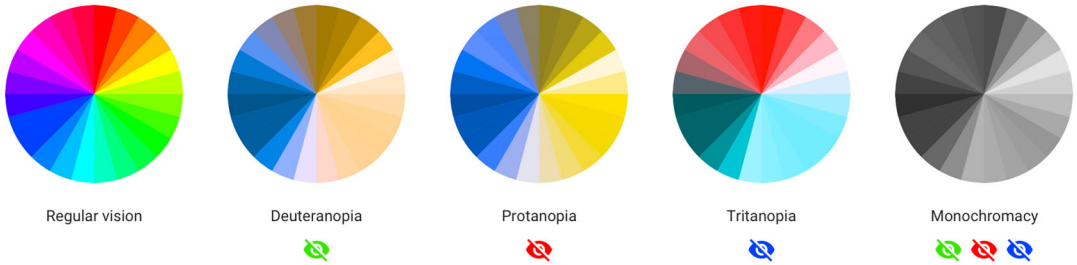


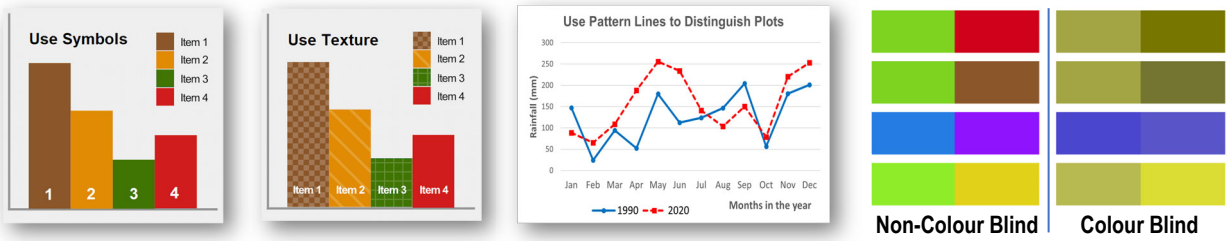
Image taken from [14]

[13] Robyn Collindge, How to Design for Color Blindness (2017) - https://usabilla.com/blog/how-to-design-for-color-blindness/
[14] Ian Tuchkov, Color blindness: how to design an accessible user interface (2018) - https://uxdesign.cc/color-blindness-in-user-interfaces-66c27331b858

Inclusive Use of Colour

Designing for Colour Blindness

- Data interpretation should not be based solely on colour. Both **colour** and **symbols** (e.g. text annotations) can be employed in a redundant manner for better clarity[13].
- Different **textures** or **patterns** (e.g. dotted and dashed lines) can also be added to the coloured areas or lines for different data variables[13].
- Avoid using too **many colours** (limit to 2 to 3) and avoid bad **colour combinations** (e.g. Green & Red, Green & Brown, Blue & Purple, Green & Blue, Blue & Grey, Green & Yellow)[13].



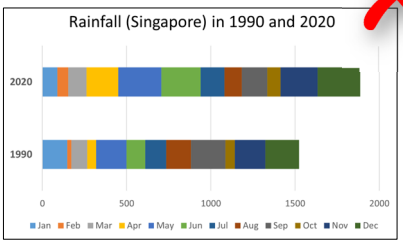
[13] Robyn Collindge, How to Design for Color Blindness (2017) - https://usabilla.com/blog/how-to-design-for-color-blindness/

Colour in Data Visualization

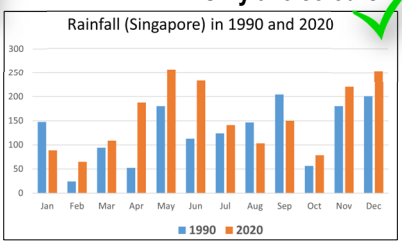
Colour – Friend or Foe?

- Colour is too often seen as a tool to make pretty charts when it should be used primarily to **inform** and **communicate** the essential point or the story being told.
- Too often we asked **how** we should use colour in our visualisation when we should be asking **why** we are using colour[15].
- It is an error to **overused** colours when the same message can be said with fewer.

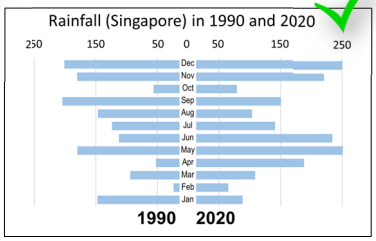
Poor use of colours



Only two colours



Just one colour

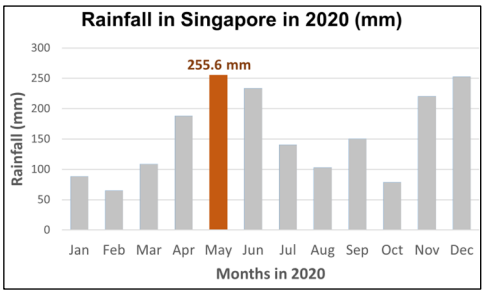


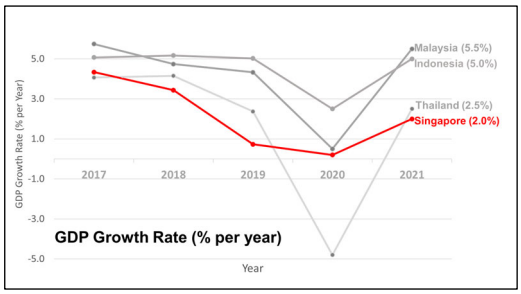
[15] Connor Rothschild, Color in Data Visualization: Less How, More Why – https://towardsdatascience.com/color-in-data-visualization-less-how-more-why-348514a3c4d8

Colour in Data Visualization

Colour Allows us to Differentiate

- Colour can be used to **draw attention** to a data point of interest.
- An effective way to enhance this effect is to employ **grey** as the primary colour for visualising the data and a **strong colour** to **highlight** the data of interest. The **absence of colour** draws the viewer's eyes to whatever is not grey[15].



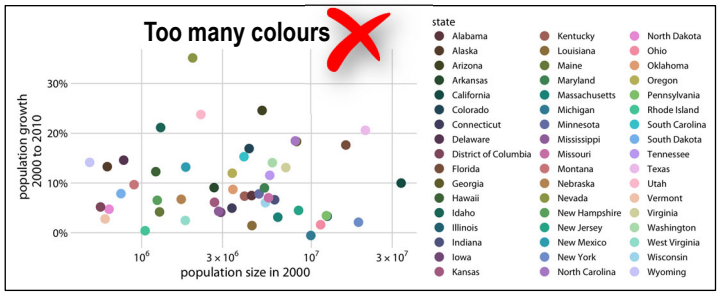


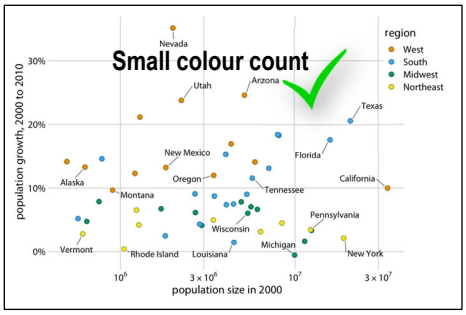
[15] Connor Rothschild, Color in Data Visualization: Less How, More Why – https://towardsdatascience.com/color-in-data-visualization-less-how-more-why-348514a3c4d8

Colour in Data Visualization

Colour Allows us to Explore

- Colour can be used as a tool to **explore** how a variety of **different categories** of data points that are mapped to **different colours** related to each other.
- Effective exploration requires the **colour count** to be kept **small** so patterns in the data groups can emerge without having to constantly reference the colour legend[15].



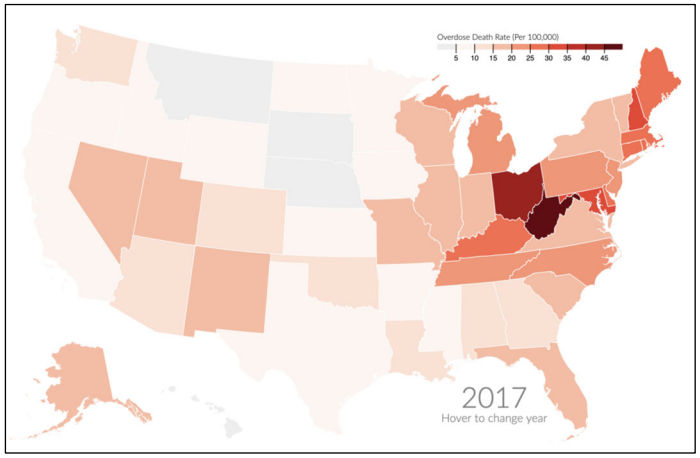


[15] Connor Rothschild, Color in Data Visualization: Less How, More Why – https://towardsdatascience.com/color-in-data-visualization-less-how-more-why-348514a3c4d8

Colour in Data Visualization

Colour Allows us to Explore

- Another common use of colour for exploratory purposes is to show data progressing across a **sequential colour gradient** (e.g. low to high, bad to good, cold to warm)[15].
- Colour shading in **Choropleth maps** facilitate the exploration of **regional variation** in severity or intensity of a particular variable[15].

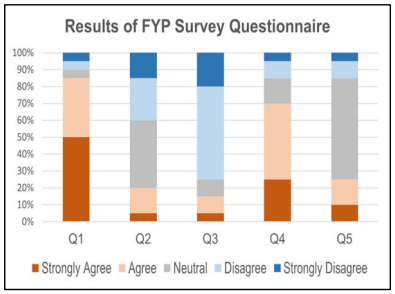


[15] Connor Rothschild, Color in Data Visualization: Less How, More Why – https://towardsdatascience.com/color-in-data-visualization-less-how-more-why-348514a3c4d8

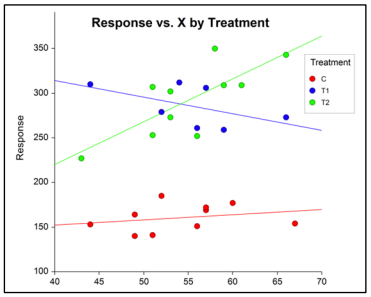
Colour in Data Visualization

Colour Allows us to Compare

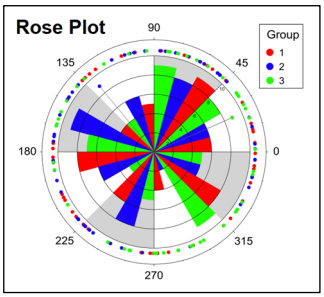
- As colour allows us to easily distinguish between data points, it can be used in aiding **visual comparison** between the characteristics of **different data groups.**
- For effective comparison, the colours should be **distinct** and their numbers limited.



Comparing Likert scale distributions across different questions



Comparing slopes and intersections of data groups[16]



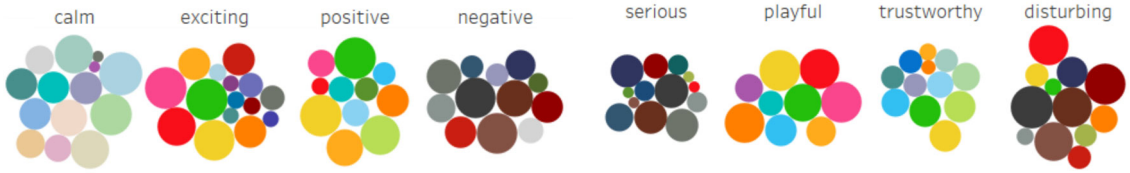
Comparative analysis of circular of angular data[16]

[16] NCSS 2021, Data Analysis & Graphics - https://www.ncss.com/software/ncss/ncss-plots-and-graphs/

Colour in Data Visualization

Colour Allows us to Convey Emotions

- Colours have association with **emotions** and if used effectively, it can make the message embedded in the visualisation more **readily accessible**.
- Studies have shown that if the visualisation goal is to create a **calm** affect**, light, cool, pastel** colours should be use. If the goal is to create a **disturbing** affect, then **dark colours**, especially **reds**, are better[17].
- However, it is good to be mindful that the types of emotions associated with different colours do have **cultural** and **contextua**l variations.



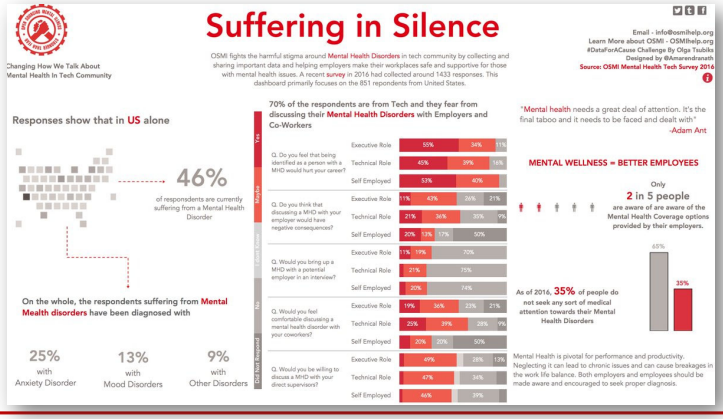
Colours from the palettes chosen as "Best" in the study [18]

[17] L. Bartram et al., Affective Color in Visualization (CHI 2017) - https://research.tableau.com/sites/default/files/Affective%20Color%20CHI%202017.pdf

Colour in Data Visualization

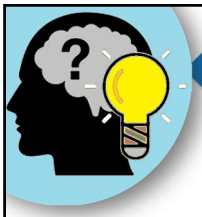
Colour Allows us to Convey Emotions

- Contrasting combination of calm and dull colours like grey with strong disturbing colours like dark red tones can make viewers feel the story that is being told[19].
- In this example, the **grey** colour is used to map out the background information and context. The main message (i.e. prevalence of mental health disorder) is presented in alarming **red**.
- This **affective colour contrast** works as a visual punch and **amplifies** the critical facts[19].



[18] Olga Tsubiks, Color in Data Visualization - The role of color in data storytelling - https://www.olgatsubiks.com/data-for-a-cause-visualizations

Visualisation by Amarendranath D



Think and Apply

Can You Do Better?

- Comment of the chart type and colours used for the purpose of **comparing** teaching performances of Prof A, B and C?
- Can you do better? Redesign it.

Likert Rating	Prof A	Prof B	Prof C
Strongly Agree	55%	5%	69%
Agree	29%	23%	15%
Neutral	8%	40%	5%
Disagree	6%	26%	4%
Strongly Disagree	2%	6%	7%

Table of each teaching score percentages

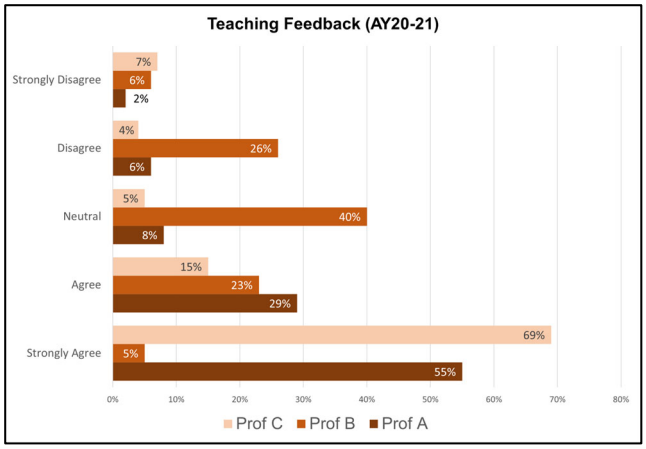


Chart Comparing Teaching Performances

Summary

Colour Perception

- Colour is a very **important visual attribute** in data visualisation and should be given **consideration** at the very start of your design.
- Colour must be used judiciously and **its purpose** in your visualisation design must be **clear** and **effective**.
- Choose an appropriate **colour palette** that fits the **characteristics** and **scale** of your data type; and if relevant, try to **blend** it with the visual **story** and the **emotional** theme you want to communicate.
- Make your visuals as **inclusive** as possible, bearing in mind that not everyone perceives colour in the same manner.

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Note: All online articles were accessed between May to June 2021