Data Visualisation

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Chapter 6 – Visual Perception

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- Gestalt Principles in Data Visualisation
- Colour Perception

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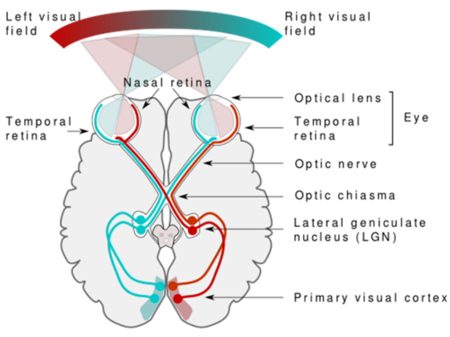
Chapter 6.1 – Human Visual Perception

Contents

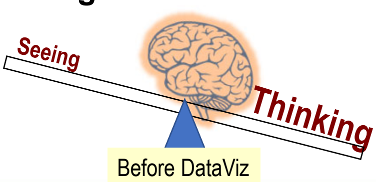
The Visual Brain

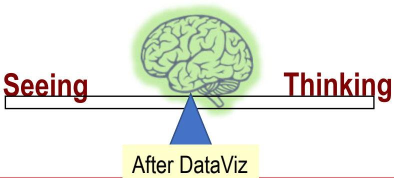
The Picture Tells the Story

- The reality is that we see with our **brains** and not our eyes.
- Our eyes receive light signals, and these are relayed via electrical impulses along various neural pathways to the brain, where the **perception** and **sense-making** occurs.
- Designing effective visualisation requires us to **understand** how the human brain **perceives**, **organises** and **make sense** of visual information [1].



Visual System
image from Wikipedia





[1] Stephen Few, Data Visualization for Human Perception - https://www.interaction-design.org/literature/book/the-encyclopedia-of-human-computer-interaction-2nd-ed/data-visualization-for-human-perception

The Visual Brain

The Memory Model

- Human visual processing is supported by **iconic** memory (sensory memory), **short-term** memory (working memory) and **long-term** memory; each having different roles and characteristics[2].

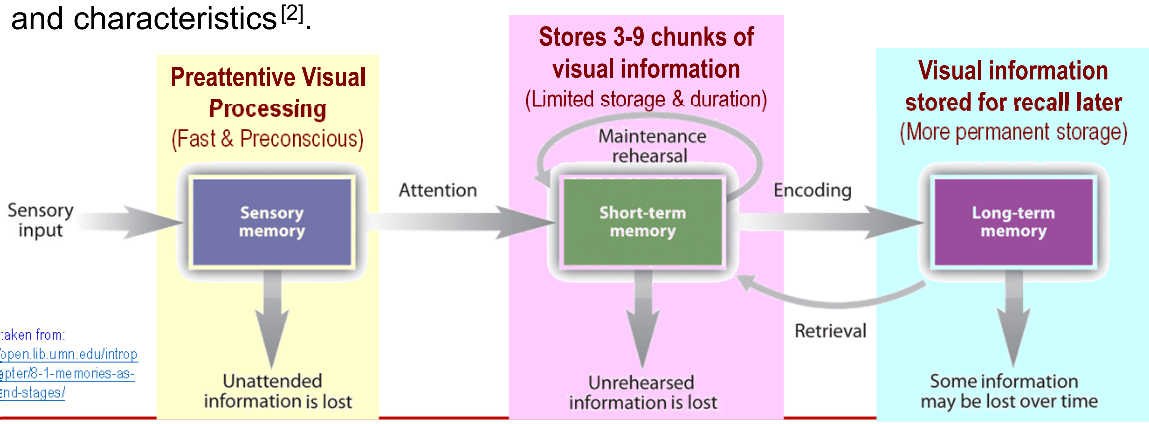


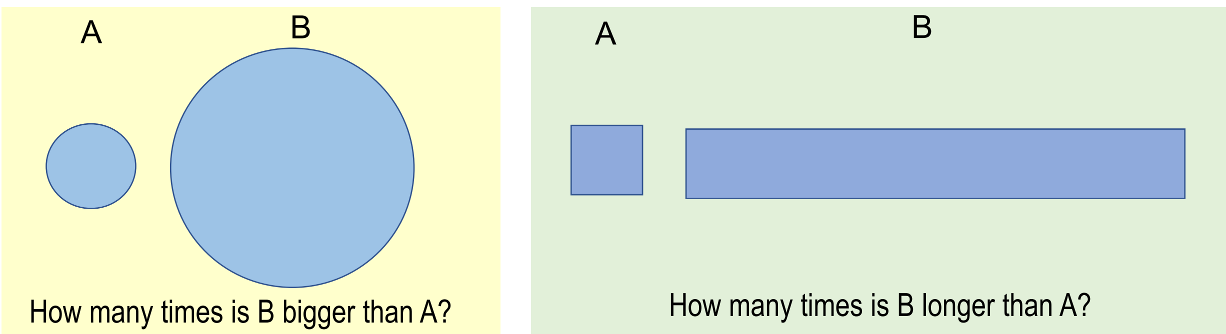
Image taken from: https://open.lib.umn.edu/intropsyc/chapter/8-1-memories-as-types-and-stages/

[2] R.C. Atkinson, R.M. Shiffrin, Human memory: A proposed system and its control processes. in K. Spence (Ed.), The psychology of learning and motivation (Vol. 2). Oxford, England: Academic Press (1968).

Estimating Magnitude

Big, Bigger, Biggest

- The human visual system is much better at **estimating magnitude** based on visual **length** than visual **area**.
- For this reason, bar charts are much better in presenting accurate visual information than bubble charts, even though they may be prettier to look at[3].



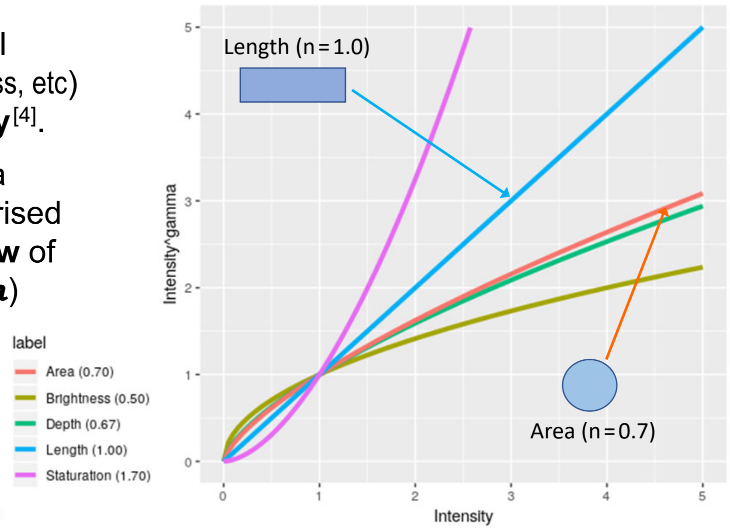
[3] Steve Wexler, Why the f**k do we see so many bar charts? (2021), https://www.linkedin.com/pulse/why-fk-do-we-see-so-many-bar-charts-steve-wexler

Estimating Magnitude

Stevens's Power Law

- Humans perceive different visual channels (e.g. length, area, brightness, etc) with **different** levels of **accuracy**[4].
- Our perceived sensation (***S***) of a physical intensity (***I***) is characterised by the psychophysical **power law** of **Stevens**, where the exponent (***n***) depends on the exact sensory modality of the measured ***I***.

$$S = I^n$$

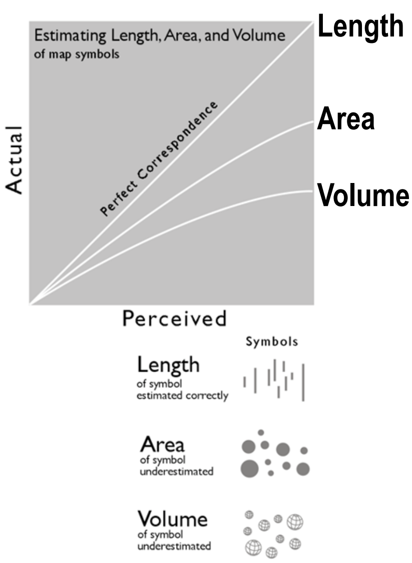


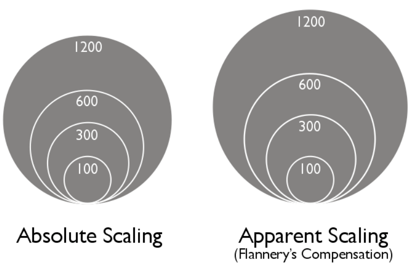
[4] T. Munzner, Visualization Analysis & Design, CRC Press (2015)

Estimating Magnitude

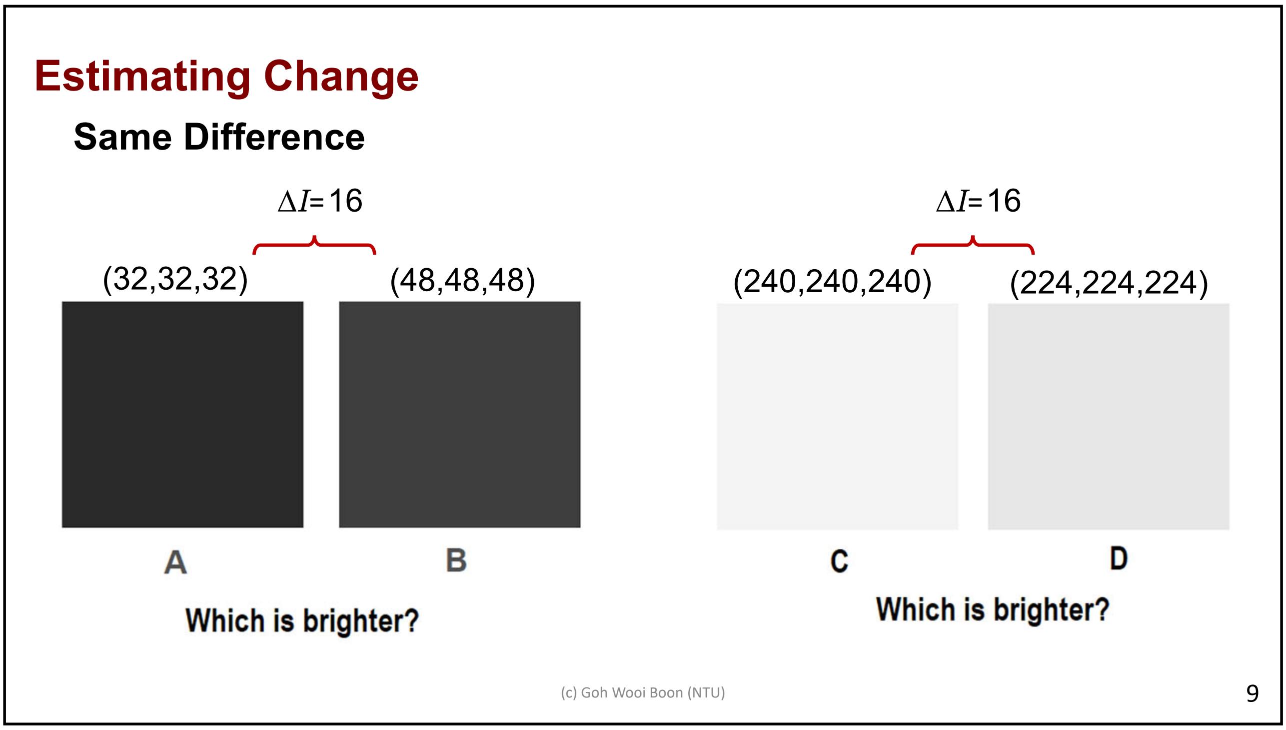
Implication of Stevens's Power Law

- Psychophysical research revealed that people tend to correctly estimate lengths but they **underestimate** areas and volumes[5].
- ArcGIS, a geographic information system (GIS) uses James Flannery's **Appearance Compensation**[5] method to scale up proportional circles (i.e. the larger the circle, the more the scaling).
- **Note:** Edward Tufte[6] only supports **absolute scaling** for faithfulness to the data.





[5] John Krygler, Perceptual Scaling of Map Symbols - https://makingmaps.net/2007/08/28/perceptual-scaling-of-map-symbols/
[6] Edward Tufte, The Visual Display of Quantitative Information Graphic Press, 2nd Ed (2001)


Estimating Change
Same Difference
$\Delta I = 16$
(32,32,32)
(48,48,48)
A
B
Which is brighter?
$\Delta I = 16$
(240,240,240)
(224,224,224)
C
D
Which is brighter?
(c) Goh Wooi Boon (NTU)
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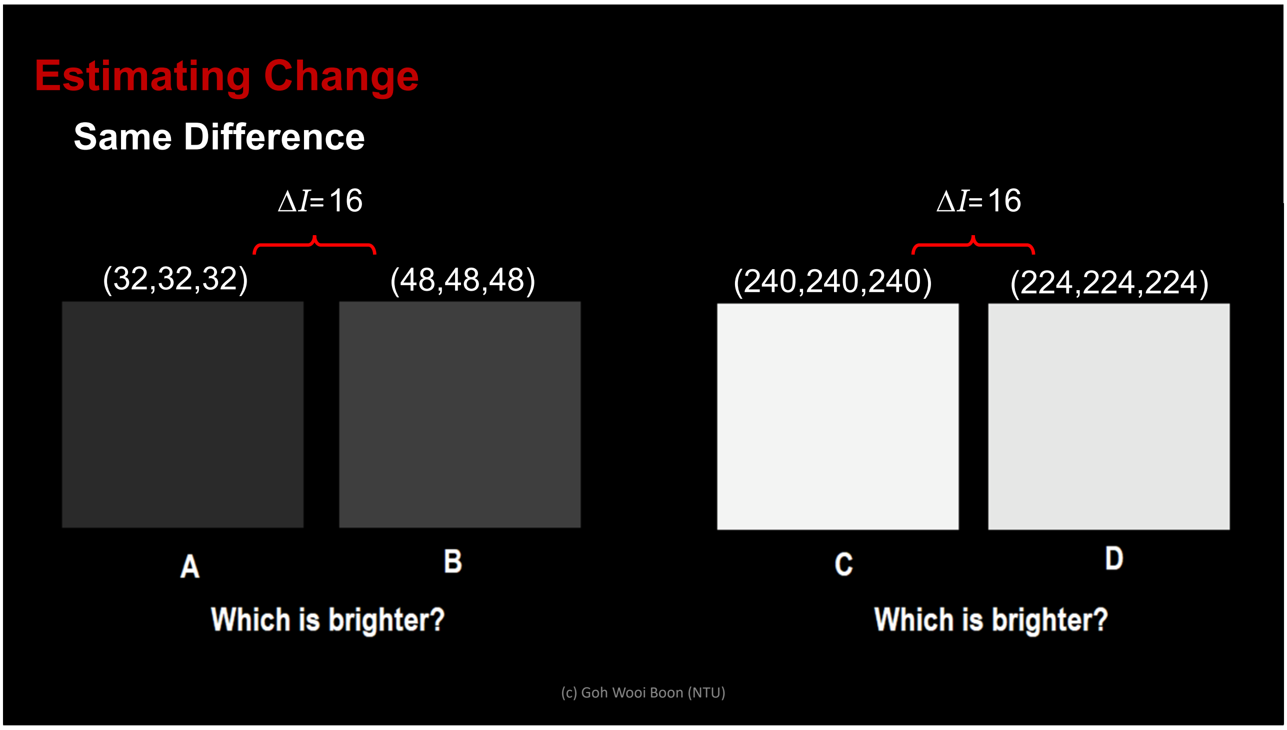
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Which is brighter?
(c) Goh Wooi Boon (NTU)

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Estimating Change

Same Difference

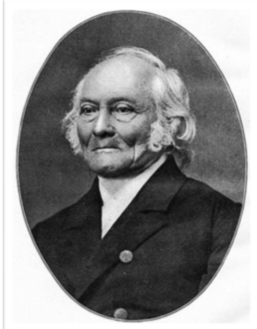
- The **Just Noticeable Difference** (JND) is the minimum amount by which stimulus intensity must be changed in order to produce a noticeable variation in sensory experience.
- Ernst Weber[7] observed that the size of the **difference threshold** appeared to be related to the initial **stimulus magnitude**.
- JND is govern Weber's Law and is given by

$$\frac{\Delta I}{I} = k$$

Addition to intensity I required for the change to be perceived → ΔI

Current intensity of stimulus → I

Weber constant → k



Ernst Heinrich Weber (24 Jun 1795 – 26 Jan 1878), German physician & early pioneer of Experimental Psychology

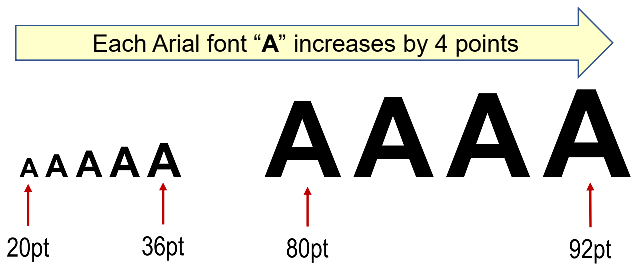
[7] Weber's Law - https://www.britannica.com/science/Webers-law

Estimating Change

Implication of Weber's Law

- According to Weber's Law, the higher the intensity (or length), the larger the disparity required for us to sense the change.
- Visualisation designs that takes such perceptual behaviour into account will facilitate more accurate visual comparison (e.g. framing long bar values to make their small difference more apparent)[8].

- Weber's law also applies to choosing **shape** or **font sizes**. As the shapes or fonts get larger, the absolute difference must be made larger to allow changes to be noticeable.

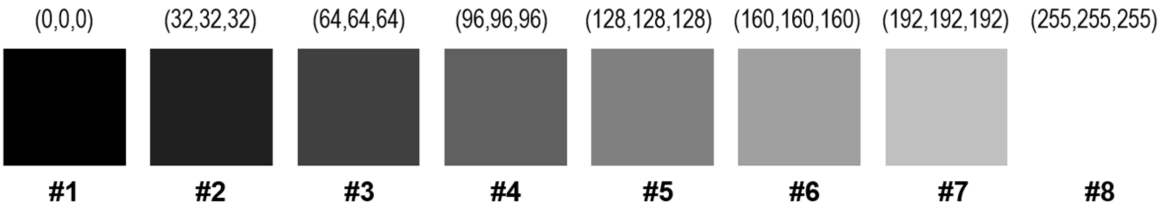


[8] W.S. Cleveland, The Elements of Graphing Data, Hobart Press (1994)

Think and Apply

Encoding Ordinal Data Using Grey Values

- Which two grey squares will be most difficult to tell apart with a white background?
- What if the background is black? What background colour can maximise the discriminability of all these grey levels if their values cannot be changed?
- How would you change the grey values to improve their discriminability in white background?

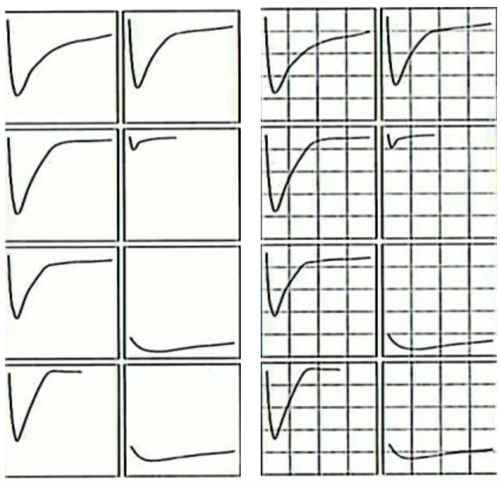


Eight grey squares with equal intensity differences

Estimating Change

Using Visual Reference Grids

- Weber's Law explains why visual reference grids enhance pattern perception.
- Without the grid, estimation of lengths with small percentage differences is difficult[8].
- The **grids shorten the base lengths** that are being compared, making it easier to compare highs, lows, and steady state behaviour[8].
- Graphs can be compared by **superimposing** them, but this only works for **limited numbers of plots** before clutter and line differentiation becomes problematic.

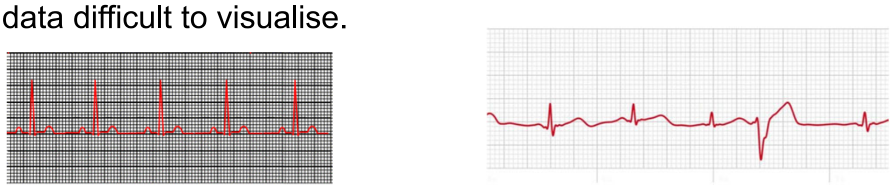


[8] W.S. Cleveland, The Elements of Graphing Data, Hobart Press (1994)

Estimating Change

Proper Layering of Visual Reference Grids

- If visual reference grids are not layered correctly, they can be distracting and make the actual data difficult to visualise.



Competing signal & background in two different electrocardiogram trace lines. The prominent gridlines & poor contrast makes the trace of the left more difficult to read than the one on the right.

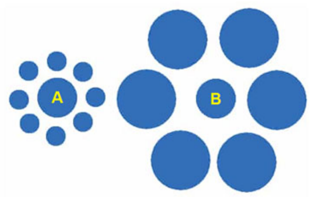
- Heer and Bostock[9] crowdsourced experiments on an acceptable luminance contrast settings for visual reference elements such as gridlines showed a safe **Alpha** setting of about **20%** (Alpha 0% = Total transparent, 100% = Opaque).

[9] J. Heer, M. Bostock, Crowdsourcing Graphical Perception: Using Mechanical Turk to Assess Visualization Design (CHI 2010) - http://www.pensivepuffin.com/dwmcphd/syllabi/insc547_wi13/papers/crowd/heer-crowdsourcing-CHI10.pdf

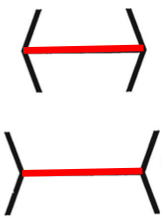
Estimating Magnitude

Context Matters

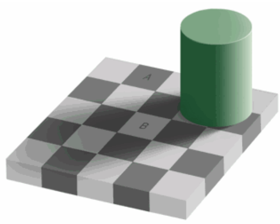
- Our ability to estimate the magnitude of visual attributes (e.g. length, size, colour, parallelism, etc) can be influenced by the context in which it is visualised.
- Be mindful of these contextual influences on human visual perception in your visualisation design.



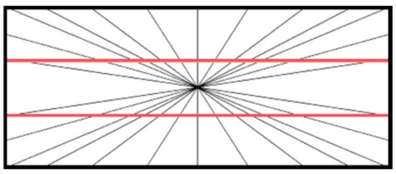
Titchener illusion



Müller-Lyer illusion



Adelson's Checker Shadow illusion

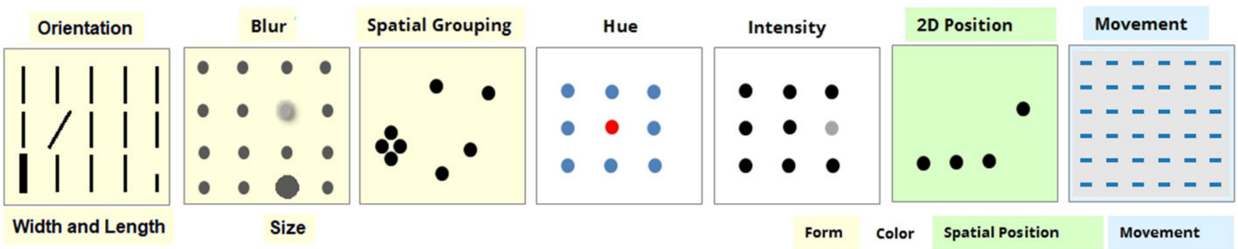


Hering illusion

Preattentive Visual Processing

Standing Out

- Preattentive processing occurs at the **early stage** of visual perception and is tuned to **rapidly detect** a specific set of visual attributes at a **sub-conscious** level[10].
- The **sequential attentive** processing used to find a specific visual target is **slower**.



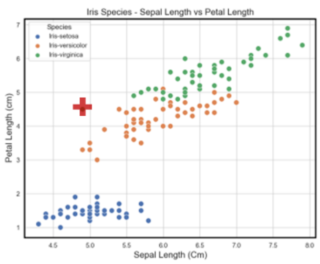
Some examples of the preattentive attributes of human visual perception

[10] Stephen Few, Information Dashboard Design, O'Reilly Media (2006)

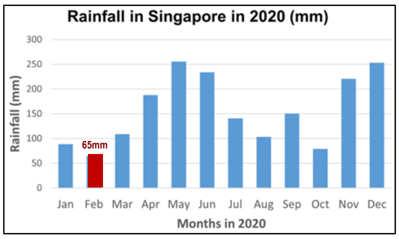
Preattentive Visual Processing

Exploiting Preattentive Processing

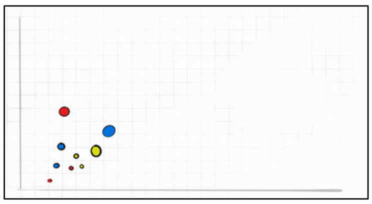
- Preattentive visual attributes can be used to **highlight** (i.e. make it pop out) particular data points of interest by making them **distinct** on a particular feature channel (e.g. coloured when the rest are grey scaled) or made more distinct by an **appropriate** redundant combination of **multiple preattentive attributes** (e.g. colour and size)[11].



Distinct colour,shape & size to highlight interesting outlier



Distinct colour bar (with annotation) to denote driest month



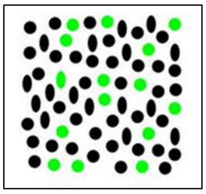
Flickering animation highlights data of interest

[11] Colin Ware, Information Visualization, Morgan Kaufmann, 3rd Ed (2012)

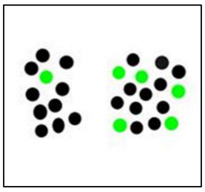
Preattentive Visual Processing

Conjunction Search

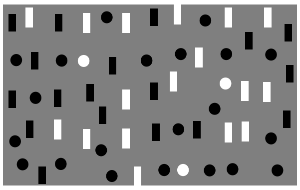
- Data points can be encoded with multiple visual attributes. A visual search for an object with more than one attribute (e.g. green ellipse) is a **conjunction search**. Conjunction searches are generally **not preattentive**[11].
- However, there are conjunction of some attributes that support preattentive search (e.g. position and colour or luminance polarity and shape)[11].



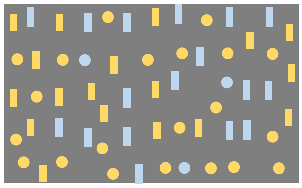
Search is slow with the conjunction of shape and colour



Search is fast with conjunction of position & colour (left green object)

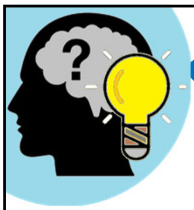


Luminance polarity with targets (**white circles**) lighter & darker than a grey backdrop supports preattentive conjunction



The same colour and shape encoding has no preattentive conjunction search property

[11] Colin Ware, Information Visualization, Morgan Kaufmann, 3rd Ed (2012)



Think and Apply

Telling It Like It Is – Effective Visual Story

- The table shows the average levels of an imaginary hormone Vitalis in a population based on age group, gender and BMI. The story you want to tell is that the only group with increasing levels of Vitalis as they age are females with BMI < 25.
- How would you design a chart to make this **story stand out** while providing all the information shown in the table.

Levels of the hormone Vitalis

	Males		Females	
Body Mass Index (BMI)	Under 60 years	60 years or over	Under 60 years	60 years or over
Under 25	255	230	380	550
25 or over	440	325	720	500

Summary

Human Visual Perception

- Human visual perception is **complex** because visual interpretation takes place in the **brain** and is **influenced** by many **factors** (e.g. our memories) besides the visual stimulus entering our eyes.
- Characteristics of the different visual channels based on Stevens's power law and Weber's law should influence the way we design **visual encoding** for data visualisation.
- Understanding **preattentive** visual processing can help us exploit its characteristics in designing visuals that can capture people's **attention** and avoid designing visuals that are **not effective** in communicating **useful meaning** in the data patterns.

References for Visual Encoding

[1] Stephen Few, Data Visualization for Human Perception - https://www.interaction-design.org/literature/book/the-encyclopedia-of-human-computer-interaction-2nd-ed/data-visualization-for-human-perception

[2] R.C. Atkinson, R.M. Shiffrin, Human memory: A proposed system and its control processes.,in K. Spence (Ed.), The psychology of learning and motivation (Vol. 2). Oxford, England: Academic Press (1968).

[3] Steve Wexler, Why the f**k do we see so many bar charts? (2021), https://www.linkedin.com/pulse/why-fk-do-we-see-so-many-bar-charts-steve-wexler

[4] T. Munzner, Visualization Analysis & Design, CRC Press (2015)

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[6] Edward Tufte, The Visual Display of Quantitative Information Graphic Press, 2nd Ed (2001)

[7] Weber's Law - https://www.britannica.com/science/Webers-law

[8] W.S. Cleveland, The Elements of Graphing Data, Hobart Press (1994)

[9] J. Heer, M. Bostock, Crowdsourcing Graphical Perception: Using Mechanical Turk to Assess Visualization Design (CHI 2010) - http://www.pensivepuffin.com/dwmcphd/syllabi/insc547_wi13/papers/crowd/heer-crowdsourcing-CHI10.pdf

[10] Stephen Few, Information Dashboard Design, O'Reilly Media (2006)

[11] Colin Ware, Information Visualization, Morgan Kaufmann, 3rd Ed (2012)

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