PERCEPTION IN VIS

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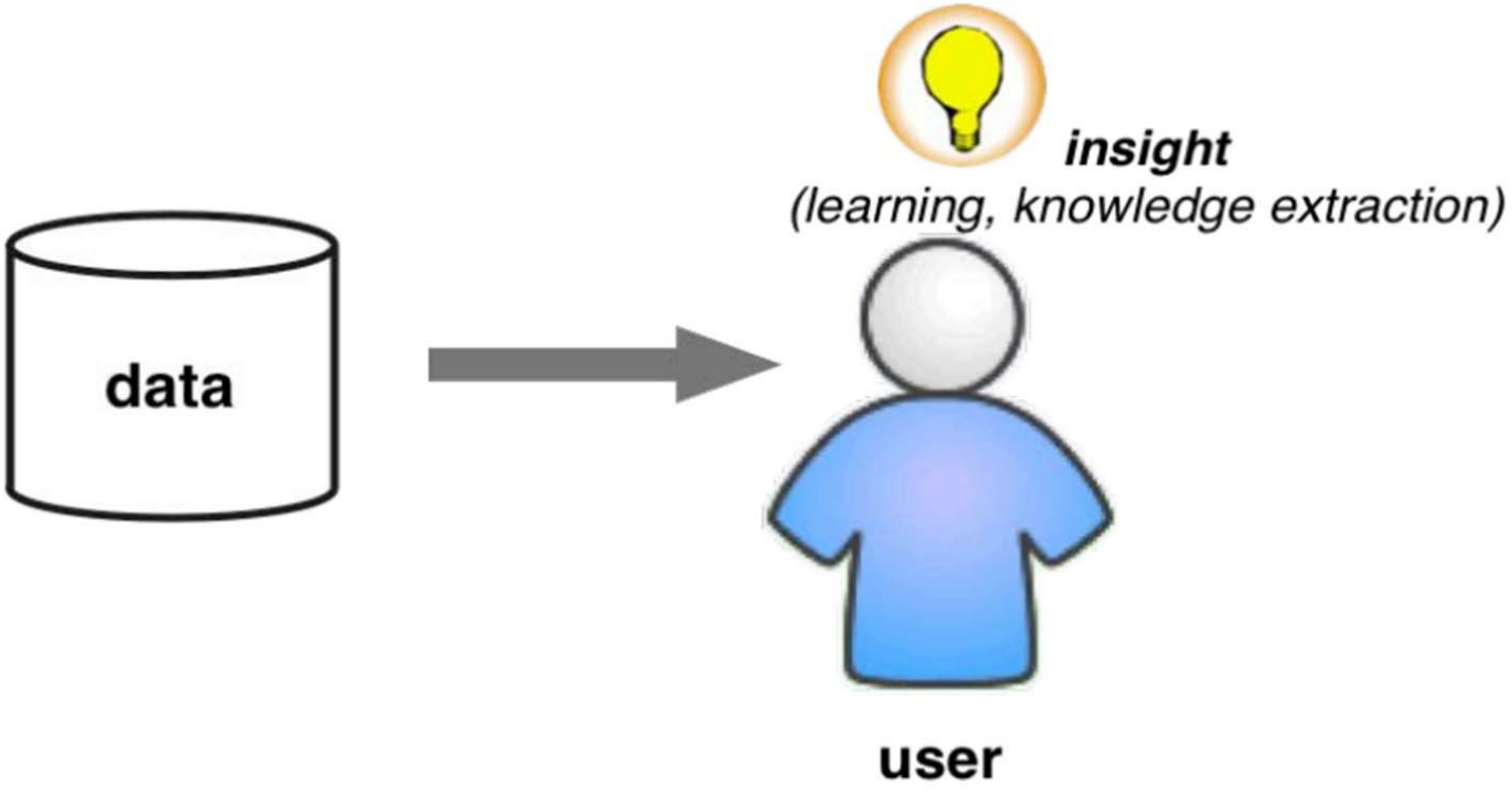
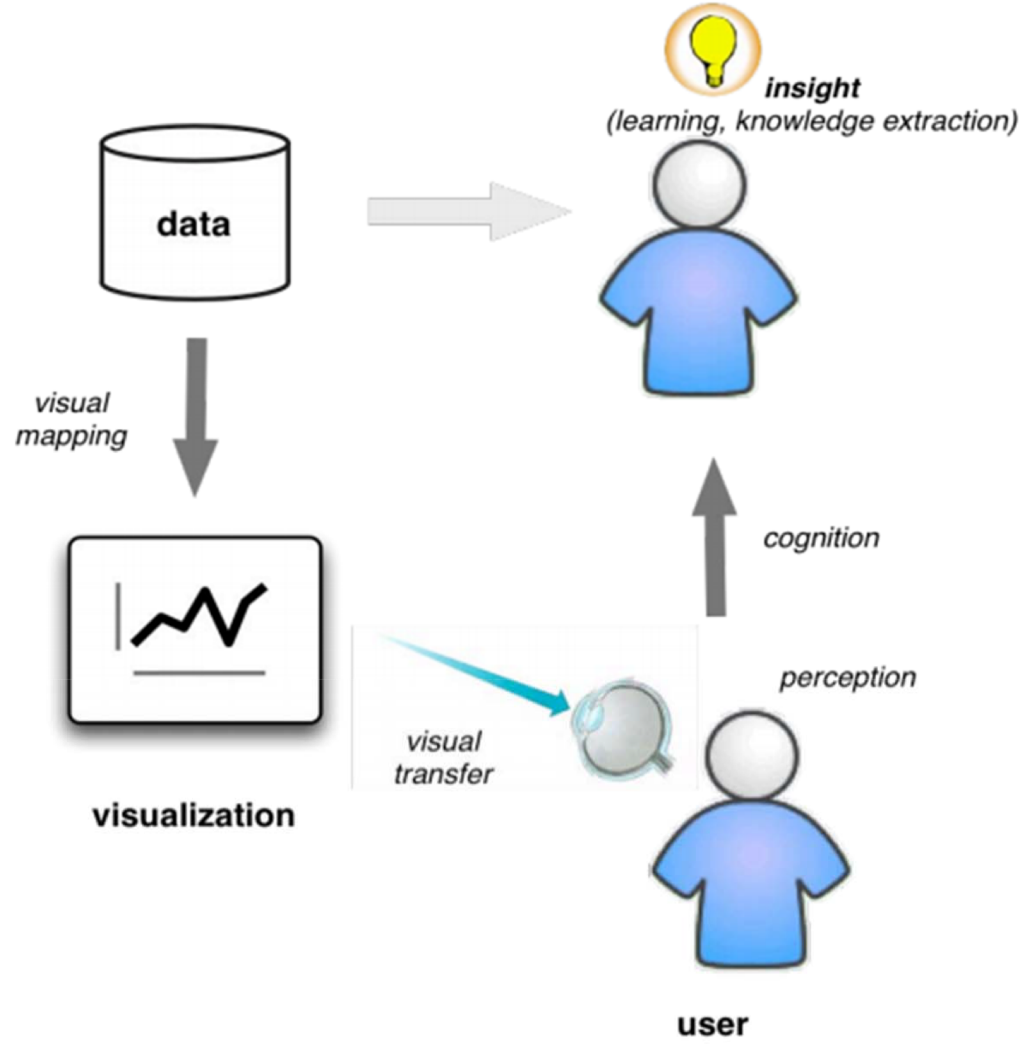
OUTLINE

- *Recap*
- *Introduction*
- *Preattentive Processing*
- *Perception Laws*
- **Applying Perception in Visualization**

APPLYING PERCEPTION IN VISUALIZATION

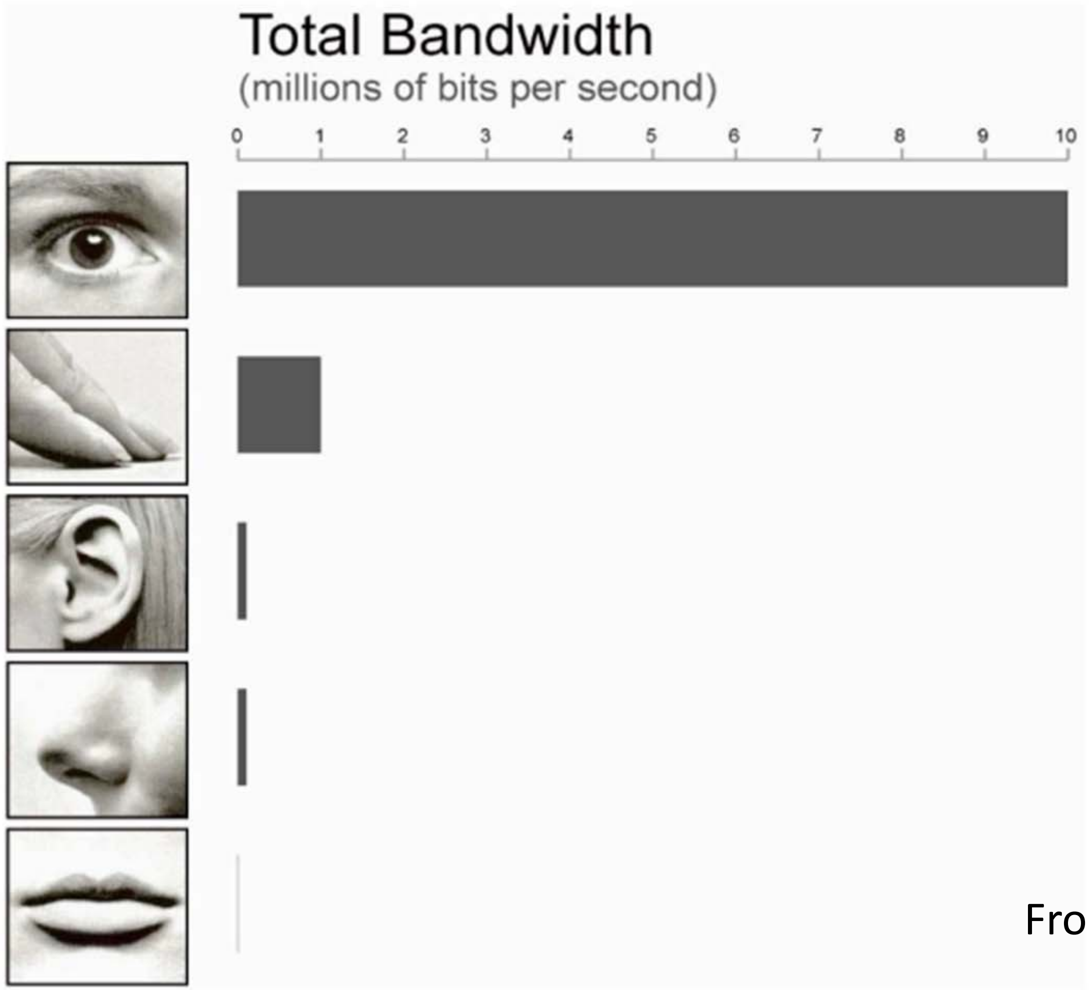


APPLYING PERCEPTION IN VISUALIZATION



APPLYING PERCEPTION IN VISUALIZATION

- Need of visualization

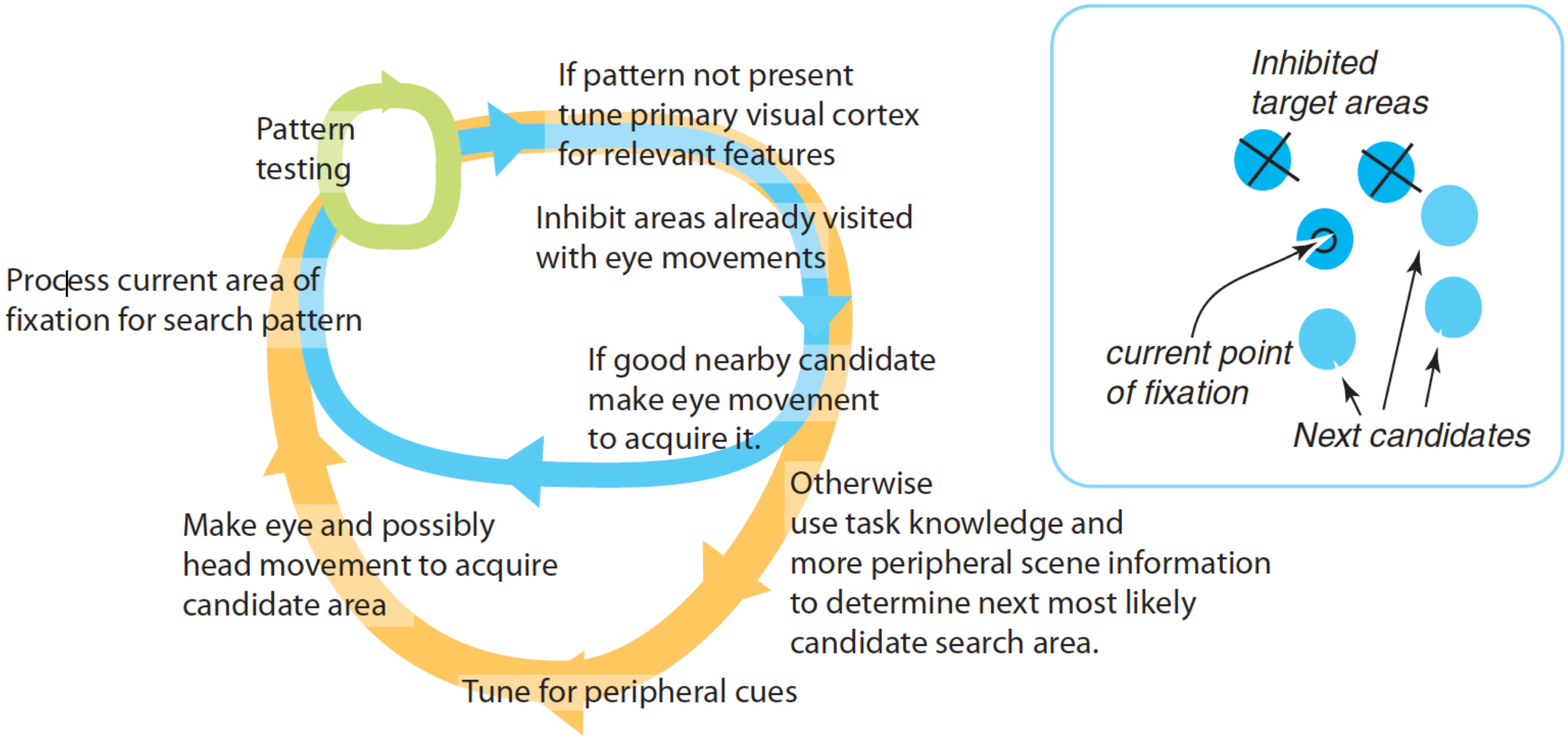


From Few, 2006

APPLYING PERCEPTION IN VISUALIZATION

- Visual search is hierarchical
  - Move and scan loop: initial search (if we know what we are looking for), with the biasing mechanism
  - Eye movement control loop: planning and executing eye movements (1-3 times per second), search for new candidates
    - Our brain keeps a map with the 5-6 last visited regions
  - Pattern testing loop: further analysis (test if it is what we were looking for) on promising areas.
    - Takes one twentieth of a second to make each test

APPLYING PERCEPTION IN VISUALIZATION



From Ware's Information Visualization. Perception for Design, 2012

APPLYING PERCEPTION IN VISUALIZATION

- Visual search. Thief example:
  - Initial search will classify big elements (e.g. furniture) and discard them
  - Then, groups of small objects will be scanned for (might contain jewelry)
  - Individual analysis (to search for valuable objects) of each small group will be performed

APPLYING PERCEPTION IN VISUALIZATION

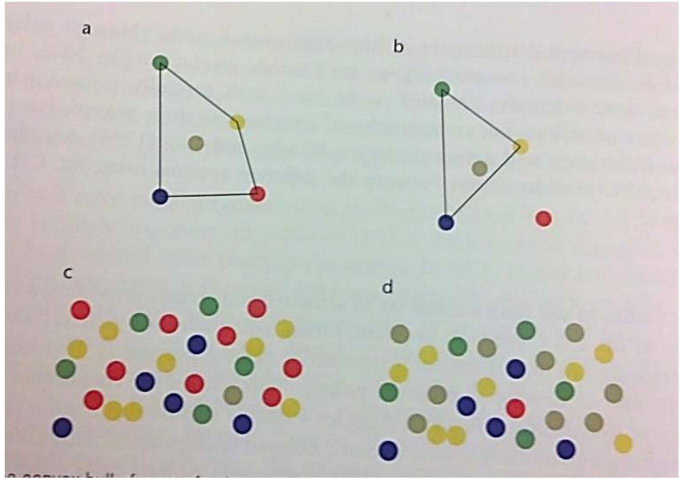
- Applying feature hierarchy in visualization
  - Organize the layout from large to small
    - Keep structure at each level
  - Makes search much more efficient
  - Most important bit of information encoded in most sensitive channel
  - There will always be competition between channels
    - Conjunction search, not enough free channels, size, environment/background…

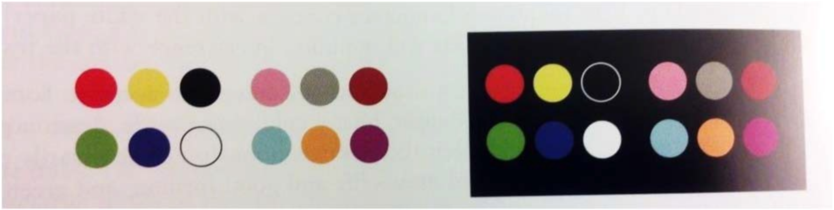
APPLYING PERCEPTION IN VISUALIZATION

- Each visual variable is different
  - Different properties
    - E.g., with colors we can use lightness, hue, saturation…
  - When selecting a visual variable to encode information several factors play a role
    - Number of distinct levels, interaction with other elements…
    - Depending on the variable, different factors must be considered

APPLYING PERCEPTION IN VISUALIZATION

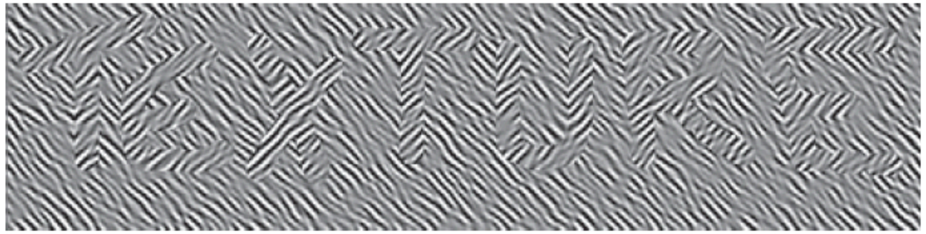
- Color choice. Factors to consider
  - Distinctness
  - Unique hues
  - Contrast with background
  - Number -> Difference
  - Field Size
  - Color blindness, Conventions



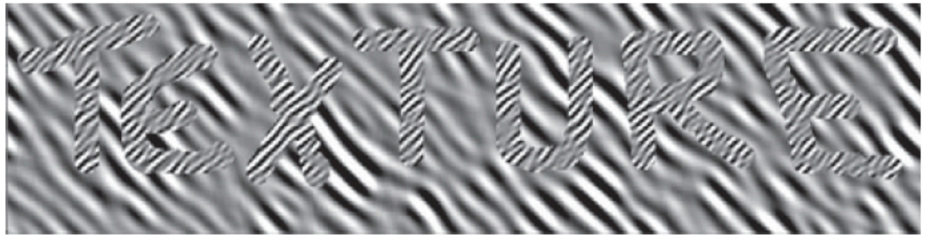


APPLYING PERCEPTION IN VISUALIZATION

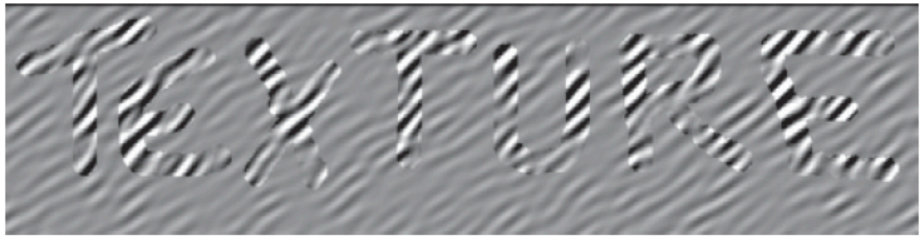
- Texture. Factors:
  - Orientation, size, contrast…
  - For textures to be visually distinct
    - Dominant spatial features should differ by at least factor of 3 or 4
    - Dominant orientations should differ by more than 30 degrees



Orientation



Orientation + spatial frequency

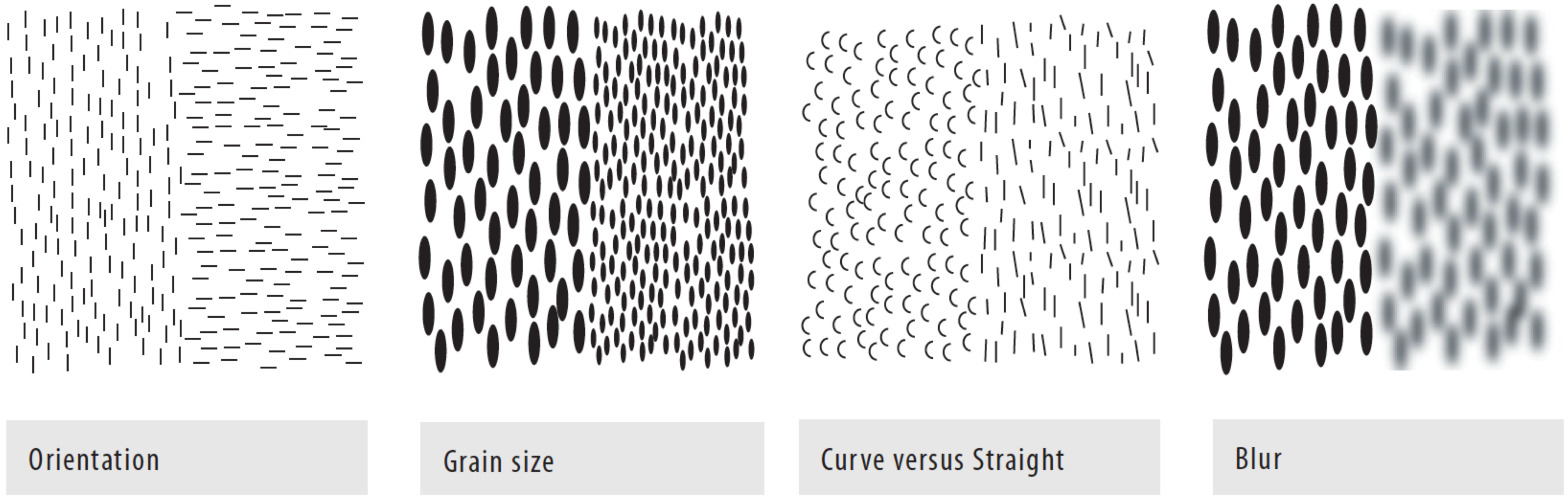


Contrast

From Ware's Information Visualization. Perception for Design, 2012

APPLYING PERCEPTION IN VISUALIZATION

- Texture



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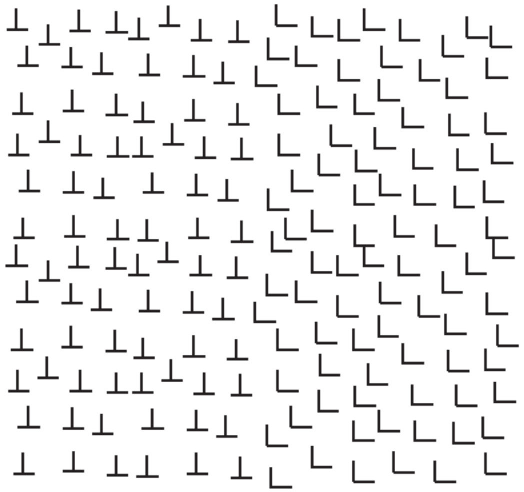
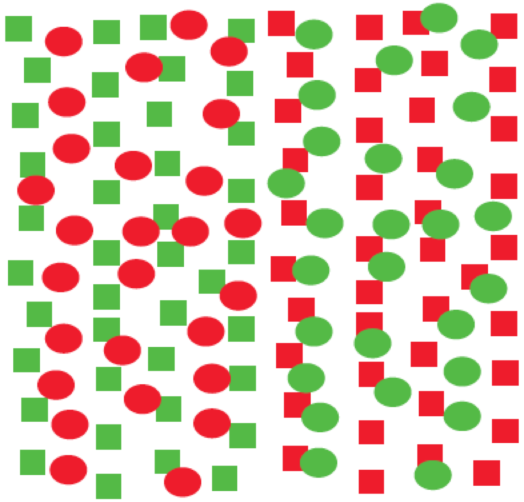
APPLYING PERCEPTION IN VISUALIZATION

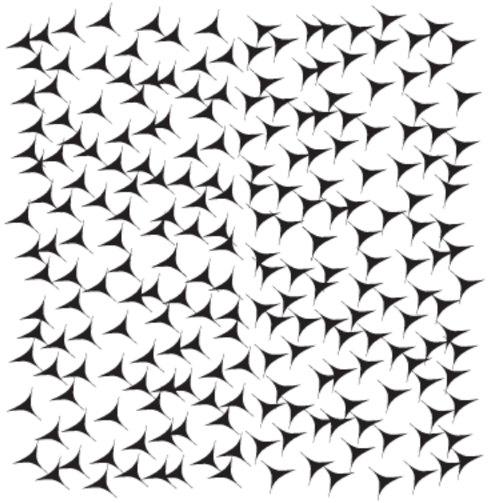
- Texture



Ts and Ls have the same line components.



Red circles and green rectangles versus green circles and red rectangles.

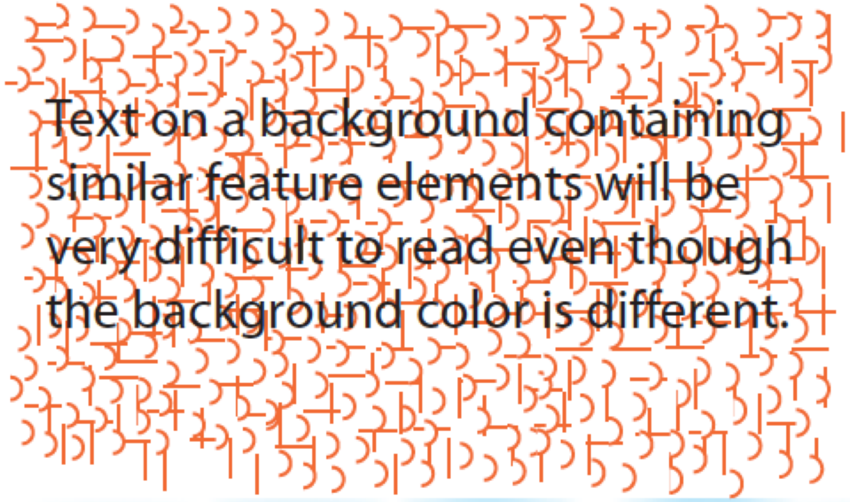


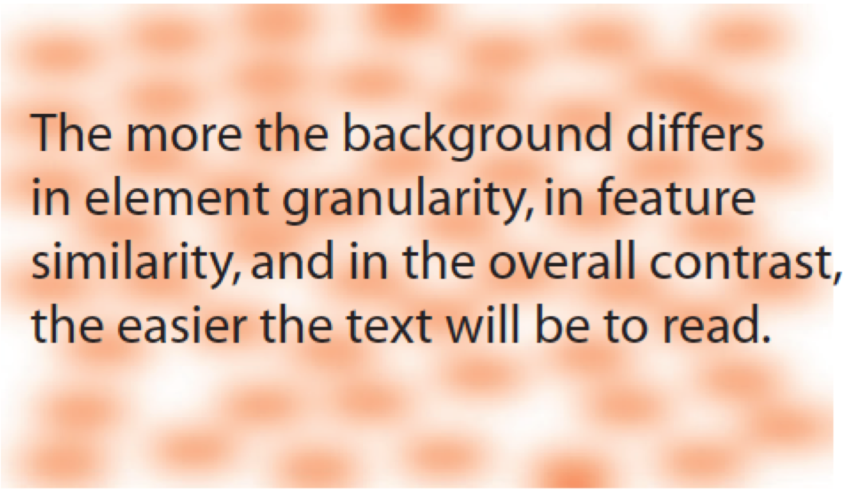
The spikes are oriented differently; the field of orientations is the same.

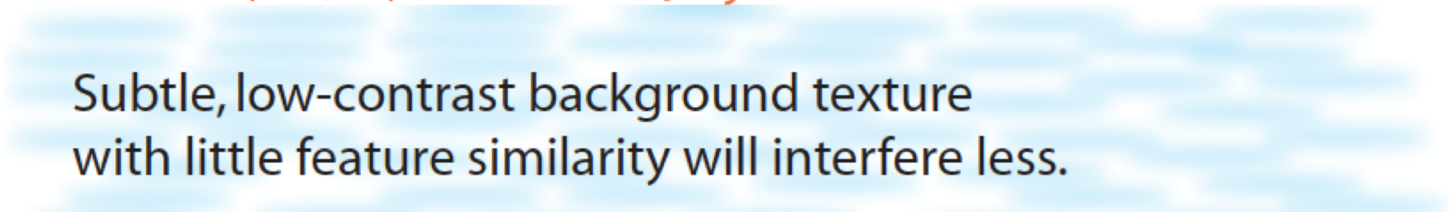
From Ware’s Information Visualization. Perception for Design, 2012

APPLYING PERCEPTION IN VISUALIZATION

- Texture
  - Contrast may affect the appearance of the texture and its meaning



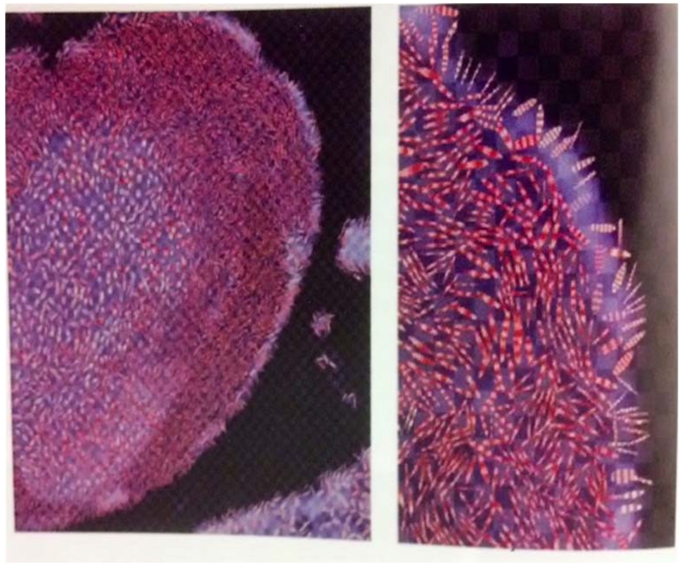




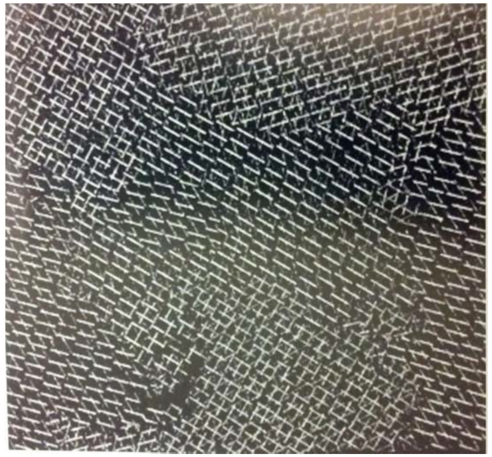
APPLYING PERCEPTION IN VISUALIZATION

- Texture

Combination of properties

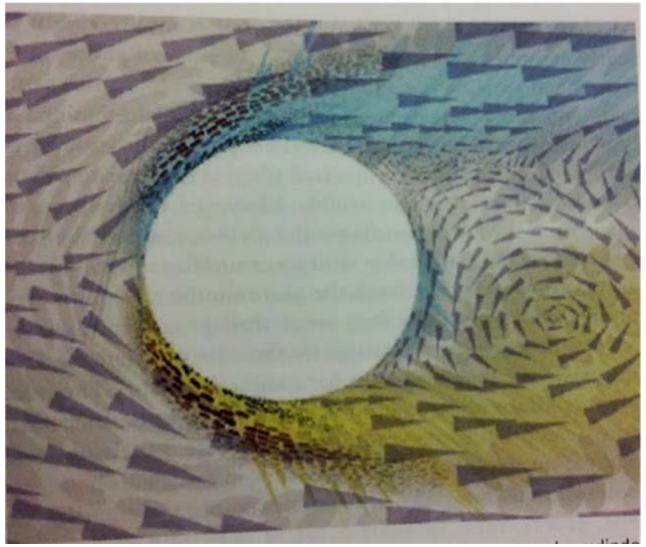


sliver plot with 3 orientations, color for 4th variable



Sliver plot with 8 orientations

Flow



APPLYING PERCEPTION IN VISUALIZATION

- Glyphs for multivariate data
  - Use a shape to show multiple attributes
  - One or more quantitative data attributes are mapped in a systematic way to the different graphical properties of an object
    - E.g., one variable encoded in length, another in color…
  - Different variables have different interactions
    - Must ensure that the different visual cues encoded in the glyph are perceived properly
    - Theory of *integral and separable dimensions* (Garner, 1974)
      - Related to the channels

APPLYING PERCEPTION IN VISUALIZATION

- Perceptual independence of the display dimensions:
  - **Integral dimensions:** it is not possible to perceive or attend to only one dimension without attending to the other
    - E.g.: a rectangular shape is perceived as a combination of width and height
  - **Separable dimensions:** it is possible to perceive or attend to only one dimension without attending to the other
    - E.g., size and orientation of a line, size and color of a ball

APPLYING PERCEPTION IN VISUALIZATION

- Restricted classification task:
  - Users are asked to classify objects that they think belong to the same class

Integral dimensions

Separable dimensions

Group by overall shape similarity

Group by color (can be clearly separated)

APPLYING PERCEPTION IN VISUALIZATION

- How to determine that dimensions are separable or not:
  - Speeded classification task:
  - Users are asked to quickly classify objects according to one of the visual attributes
  - Integral dimensions interfere a lot, separable dimensions interfere less

APPLYING PERCEPTION IN VISUALIZATION

Width interferes with height

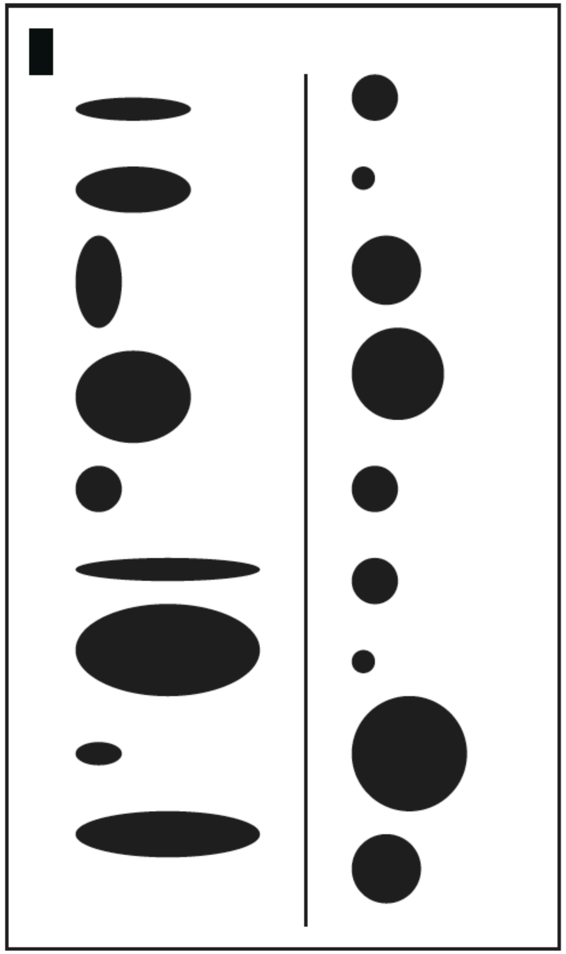
Redundant size speeds up classification

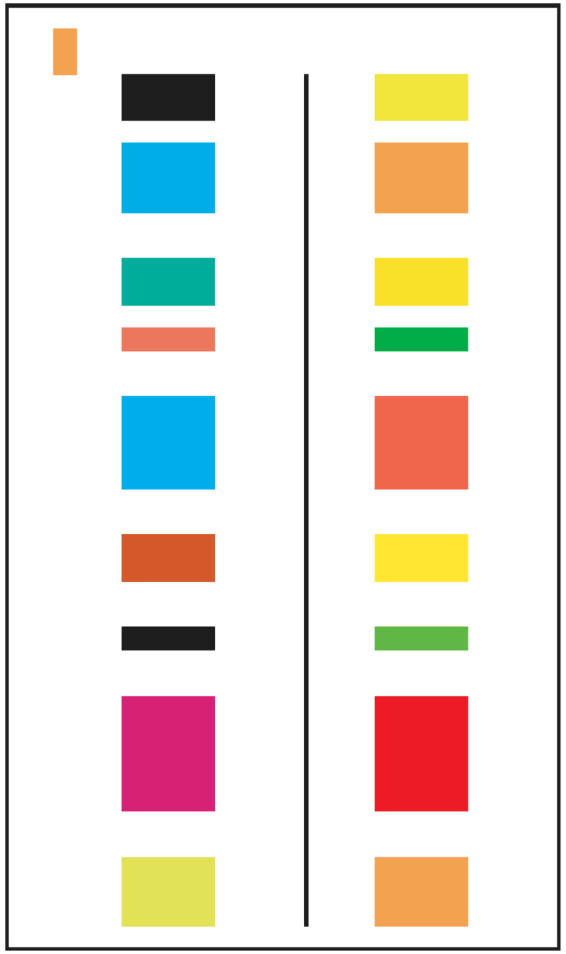
Color does not interfere

Redundant color does not help

Task: Look for shapes with the same height than the top left vertical bar

Integral dimensions



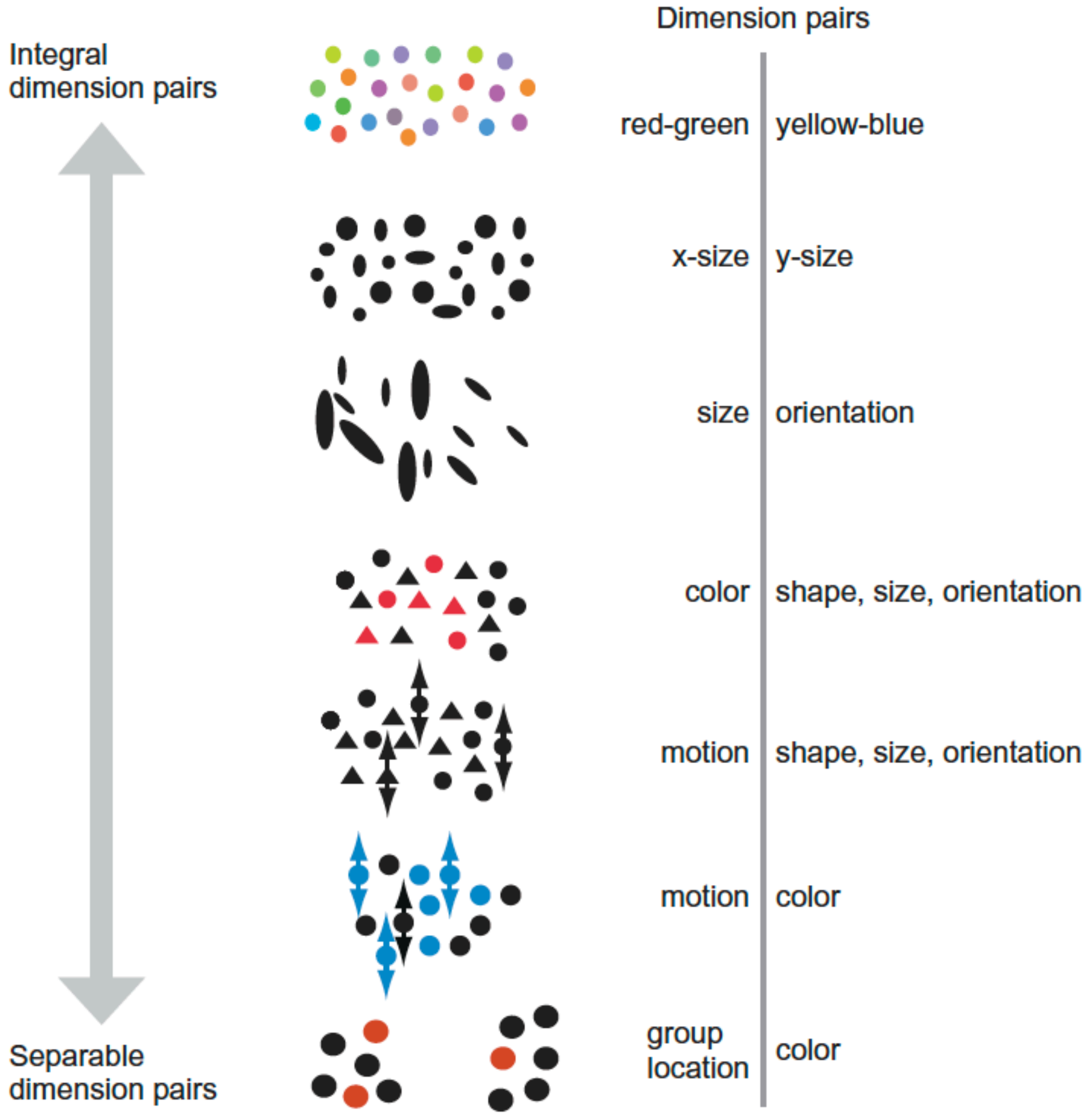


Separable dimensions

From Ware's Information Visualization. Perception for Design, 2012

APPLYING PERCEPTION IN VISUALIZATION

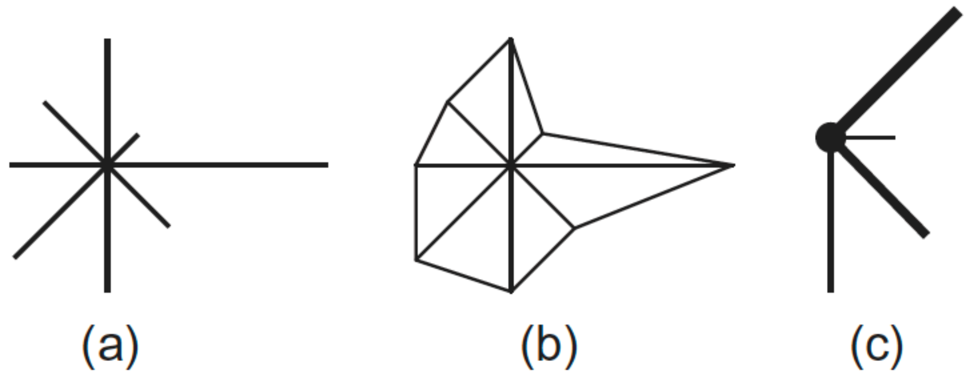
- Dimensions. Key points
  - If we want users to respond **holistically**, use integral dimensions
  - If we want users to respond **analytically**, understanding one variable at a time, use separable dimensions
    - Consider color blindness



From Ware's Information Visualization. Perception for Design, 2012

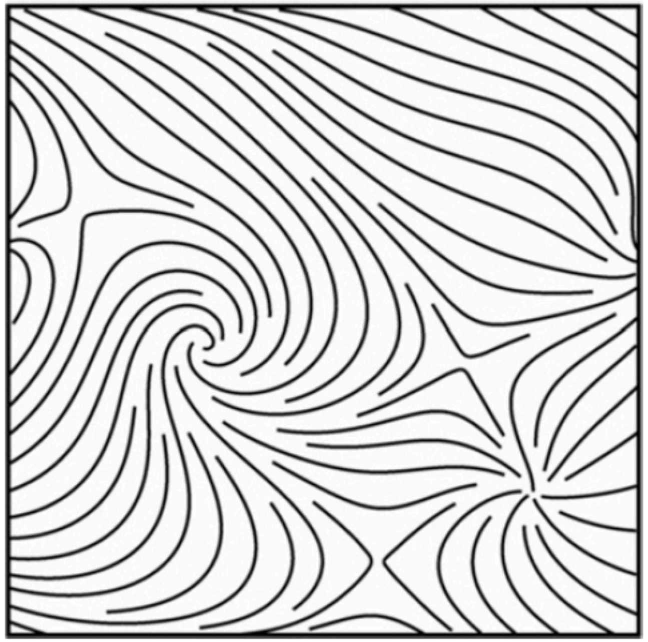
APPLYING PERCEPTION IN VISUALIZATION

- Preattentive processing, “early visual processing”, integral & separable dimensions suggest a limited set of visual attributes
  - Whiskers, Stars…
    - Can use colors

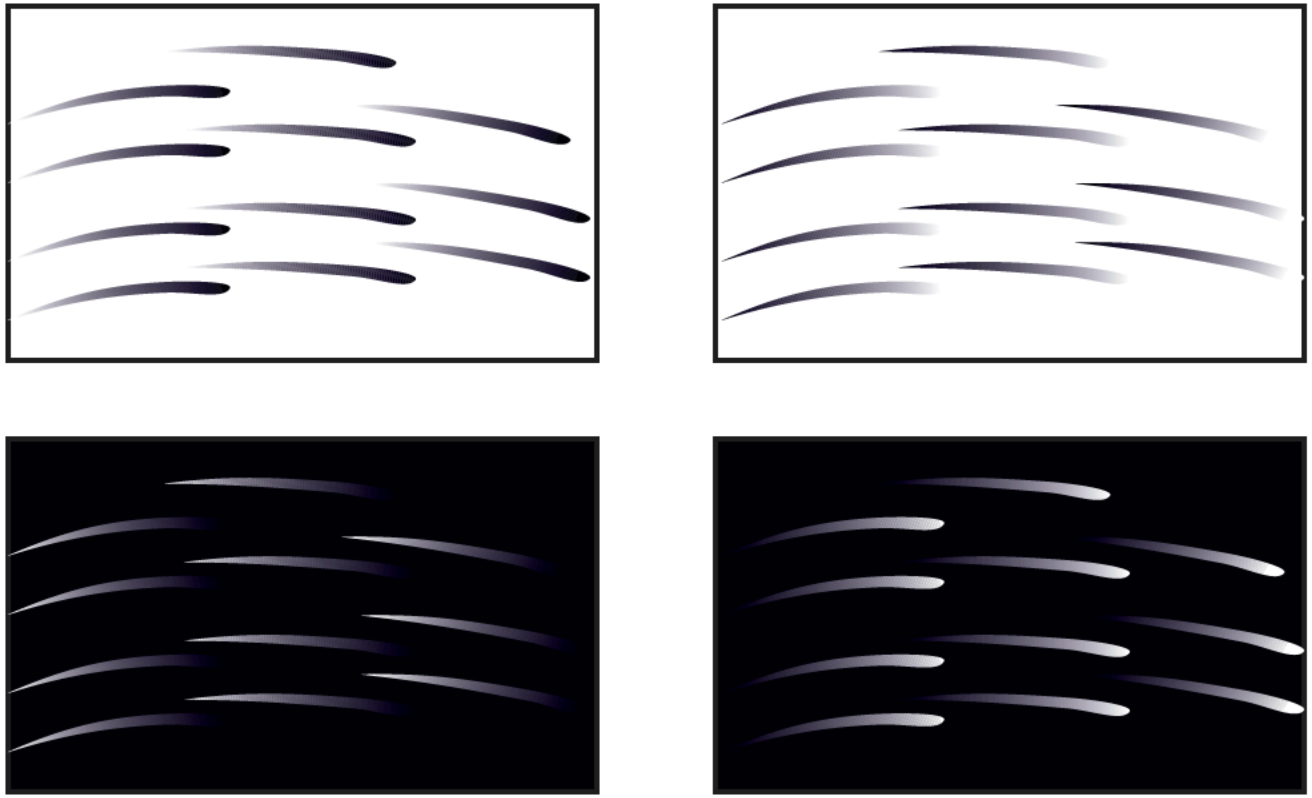


APPLYING PERCEPTION IN VISUALIZATION

- Perceiving directions



Vector Field Streamlines
(direction is ambiguous,
magnitude not shown)

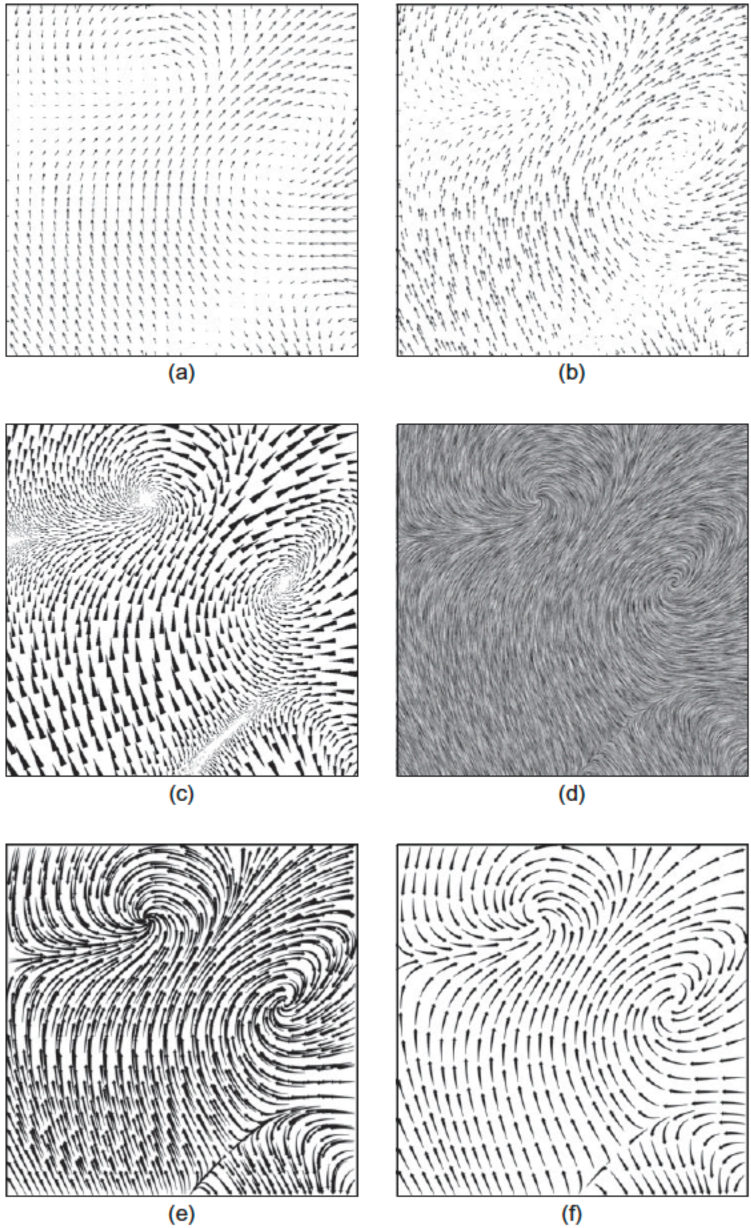


Vector direction w.r.t background
(orientation weakened)

From Ware's Information Visualization.
Perception for Design, 2012

APPLYING PERCEPTION IN VISUALIZATION

- Perceiving directions. 2D flow visualization
  - Factors to consider while making choices:
    - Identification of location and nature of critical points
    - Judging the flow – “advection trajectory”
    - Perceiving patterns of high and low velocity
    - Perceiving patterns of high and low vorticity (curl)
    - Perceiving patters of high and low turbulence



From Ware’s Information Visualization.
Perception for Design, 2012

APPLYING PERCEPTION IN VISUALIZATION

- Transparency
  - Represent data in layered form
    - GIS, Web Interfaces
  - Factors to consider: Continuity and ratio of colors

From Ware's Information Visualization. Perception for Design, 2012

APPLYING PERCEPTION IN VISUALIZATION

- Transparency
  - **Laciness:** Conditions in which image is perceived as two distinct layers instead of one fused
  - General interference rules apply
    - Play with combinations of colors, texture, motion, etc.

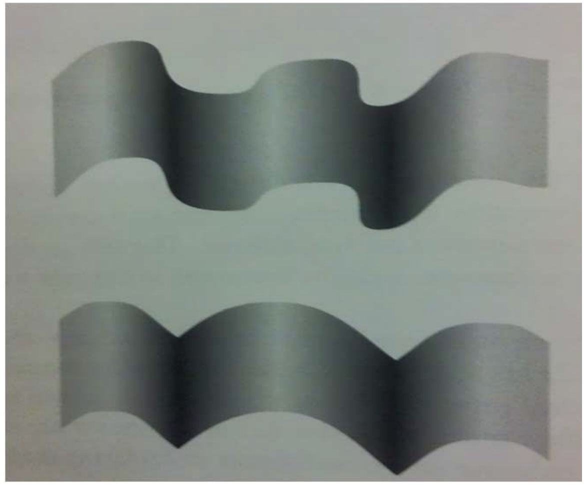
From Ware's Information Visualization. Perception for Design, 2012

APPLYING PERCEPTION IN VISUALIZATION

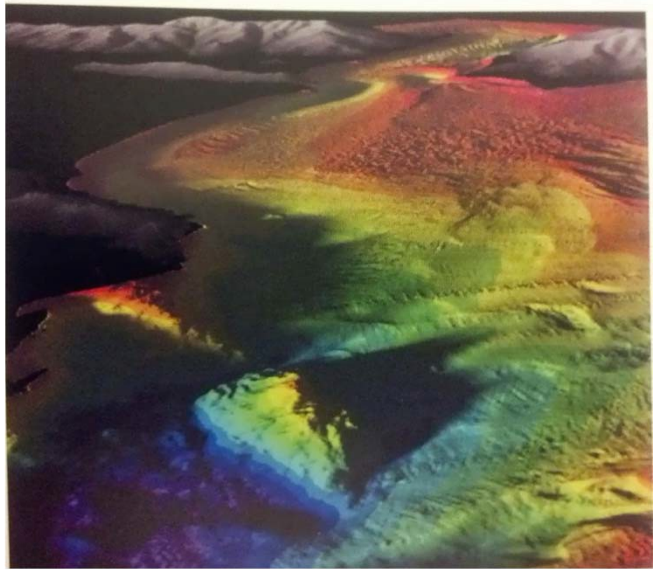
- Pattern learning
  - Use the fact that people observe patterns in data to present relations
  - Some people may take time to “learn” but then it will be easy
  - **Familiarity:** Can make use of patterns that are familiar to people (example: lines between points)
    - Use patterns familiar to skills/research
    - Show examples ahead of time for them to notice later

APPLYING PERCEPTION IN VISUALIZATION

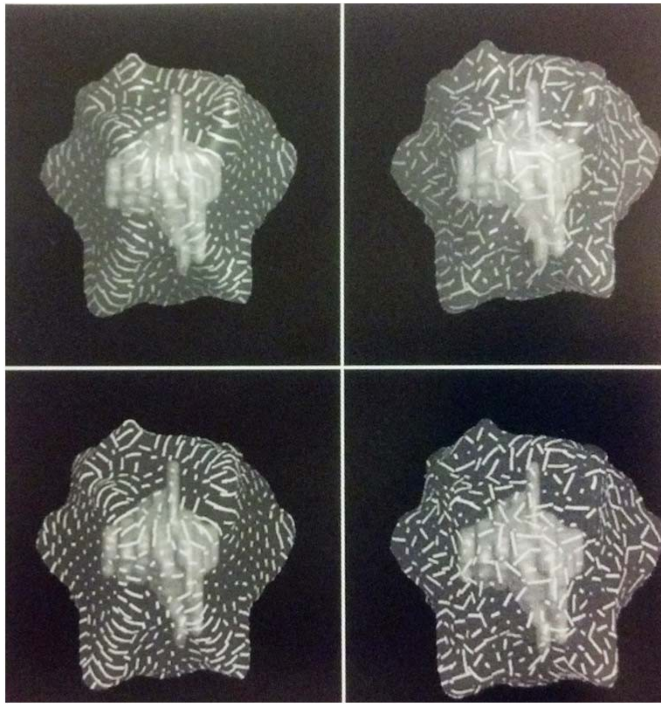
- Perceiving surface shapes
  - Some spatial cues are effective



Shading and contours



Shading models - Lighting



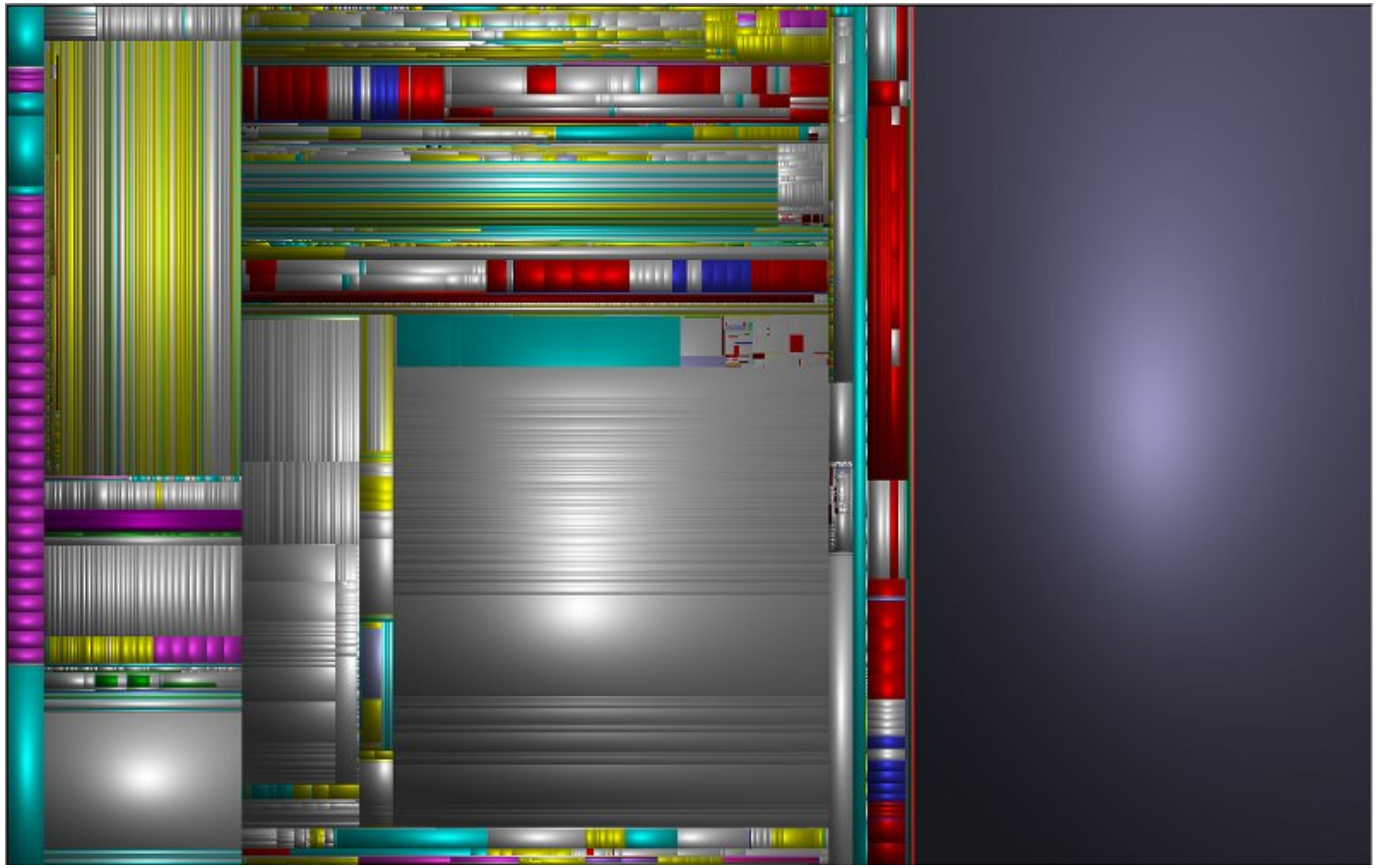
Surface Texture - Lacing

APPLYING PERCEPTION IN VISUALIZATION

- Perceiving surface shapes. Guidelines:
  - Simple lighting model should be normally used
  - Inter-reflection must be avoided
  - Specular reflection is useful to reveal fine details
  - *Shadow casting* can be used **only** if they don't interfere with other information
  - Surfaces may be textured, but low contrast to avoid interference with shading information

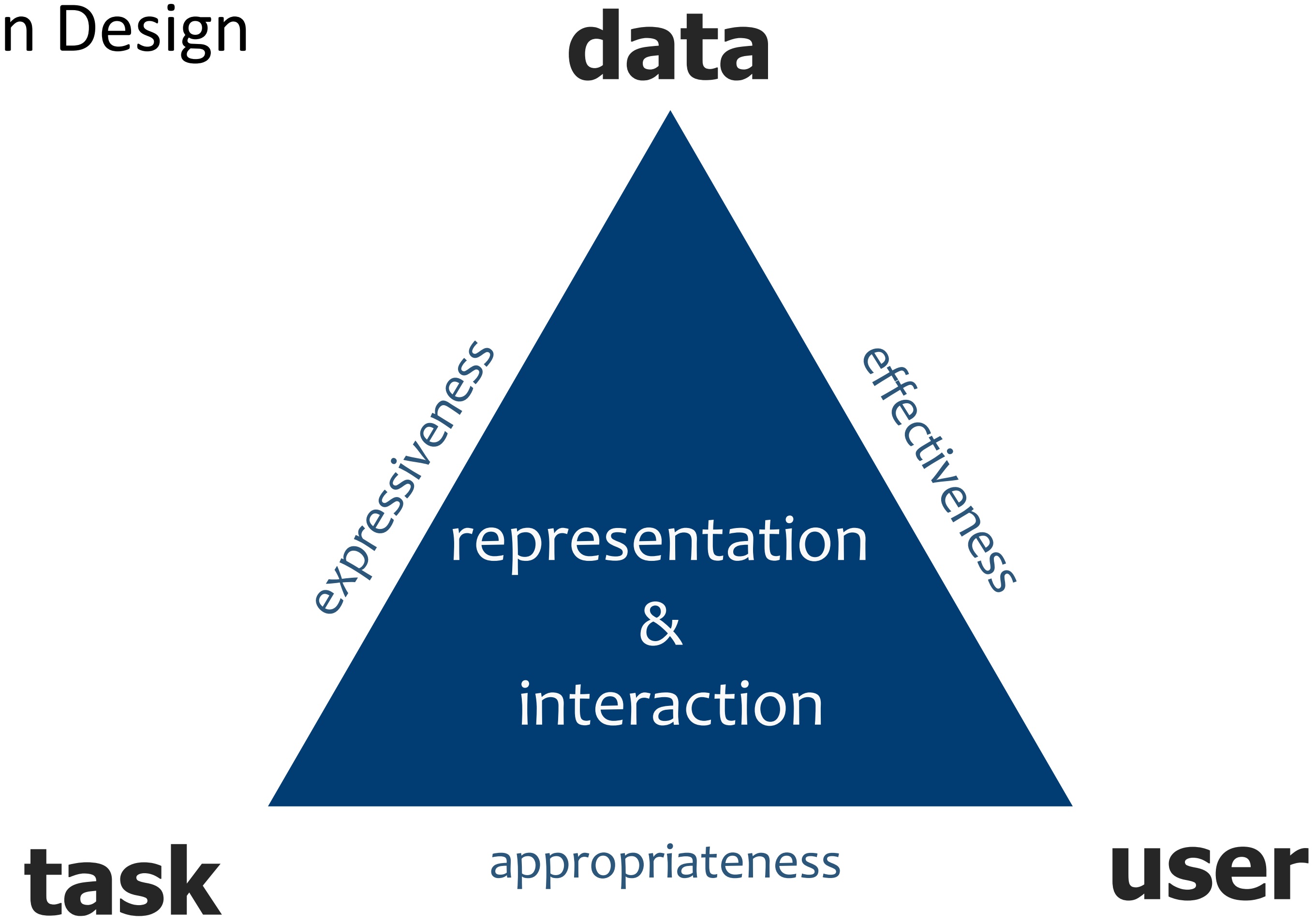
APPLYING PERCEPTION IN VISUALIZATION

- Perceiving surface shapes. Cushion treemap



APPLYING PERCEPTION IN VISUALIZATION. RECAP

- Visualization Design



APPLYING PERCEPTION IN VISUALIZATION. RECAP

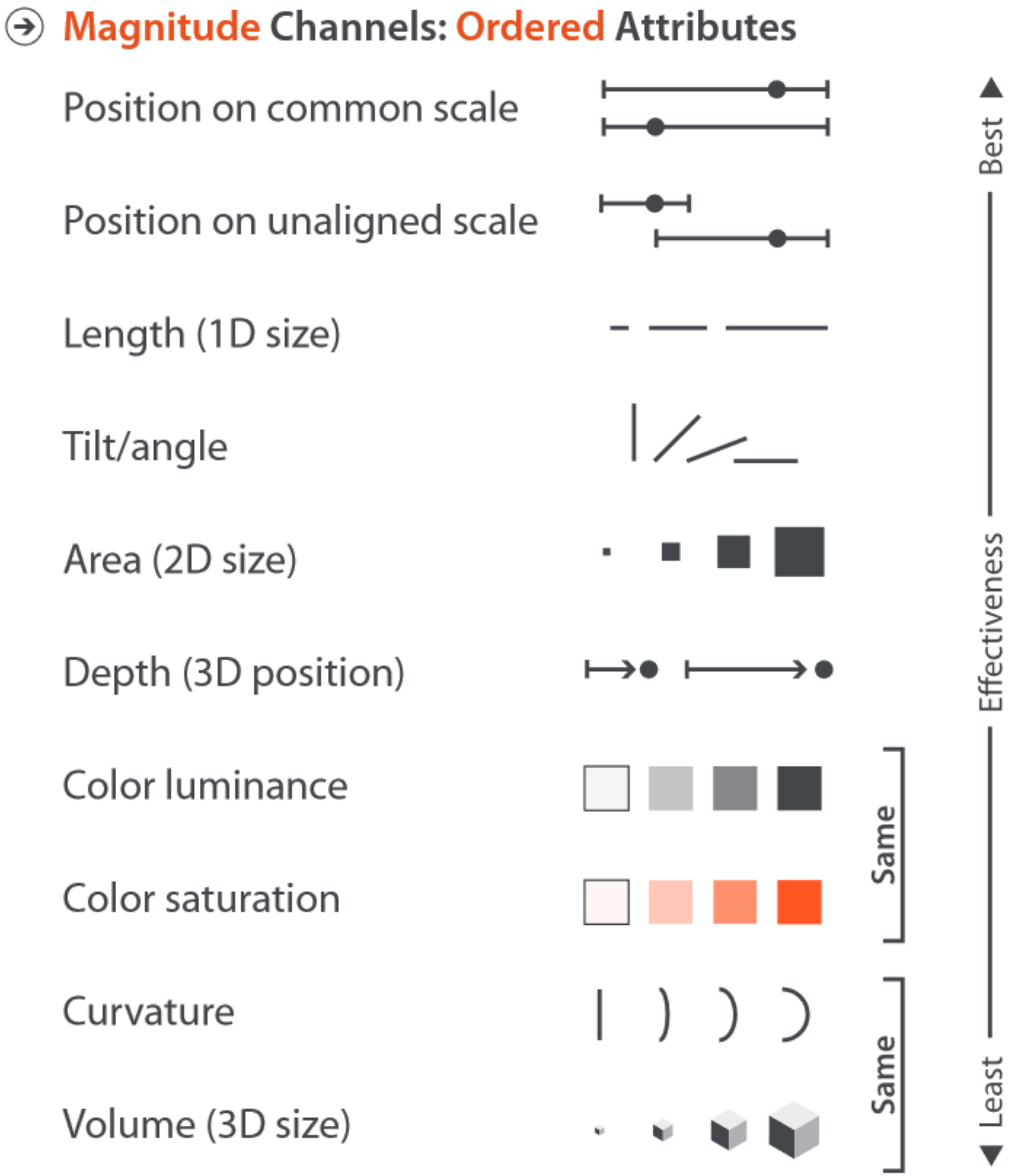
- Visualization Design. Expressiveness
  - The **relevant information** of a dataset (and only this) **is expressed by the visualization**.
    - **Relevant:** expressiveness can only be assessed regarding a **particular user** working with the visual representation to achieve **certain goals**
  - *"A visualization is said to be* ***expressive if and only if it*** *encodes* ***all the data relations*** *intended and* ***no other*** *data relations."* [Card, 2008, p. 523]

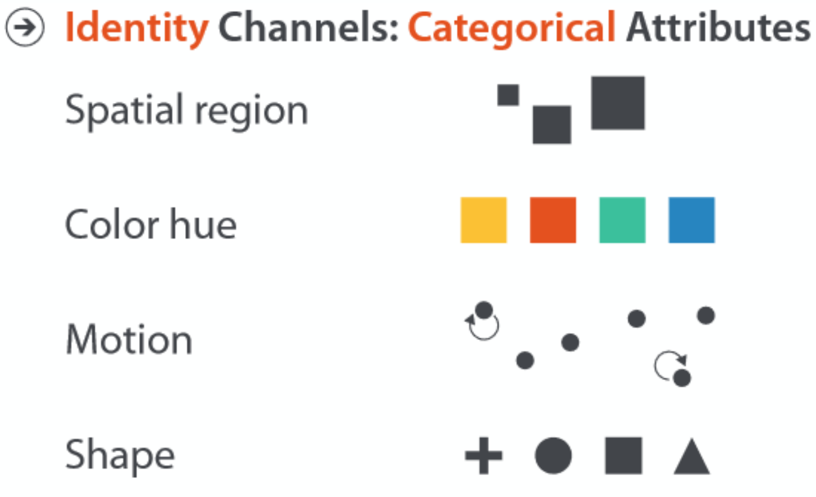
APPLYING PERCEPTION IN VISUALIZATION. RECAP

- Visualization Design. Effectiveness
  - It **addresses the capabilities of the human visual system**.
    - Effectiveness is user-dependent.
    - Nonetheless, some general rules for effective visualization have been established in the visualization community.

  - *"Effectiveness criteria identify which of these graphical languages [that are expressive], in a **given situation**, is the most effective at **exploiting the capabilities** of the output **medium** and the **human visual system**."* [Mackinlay, 1986]

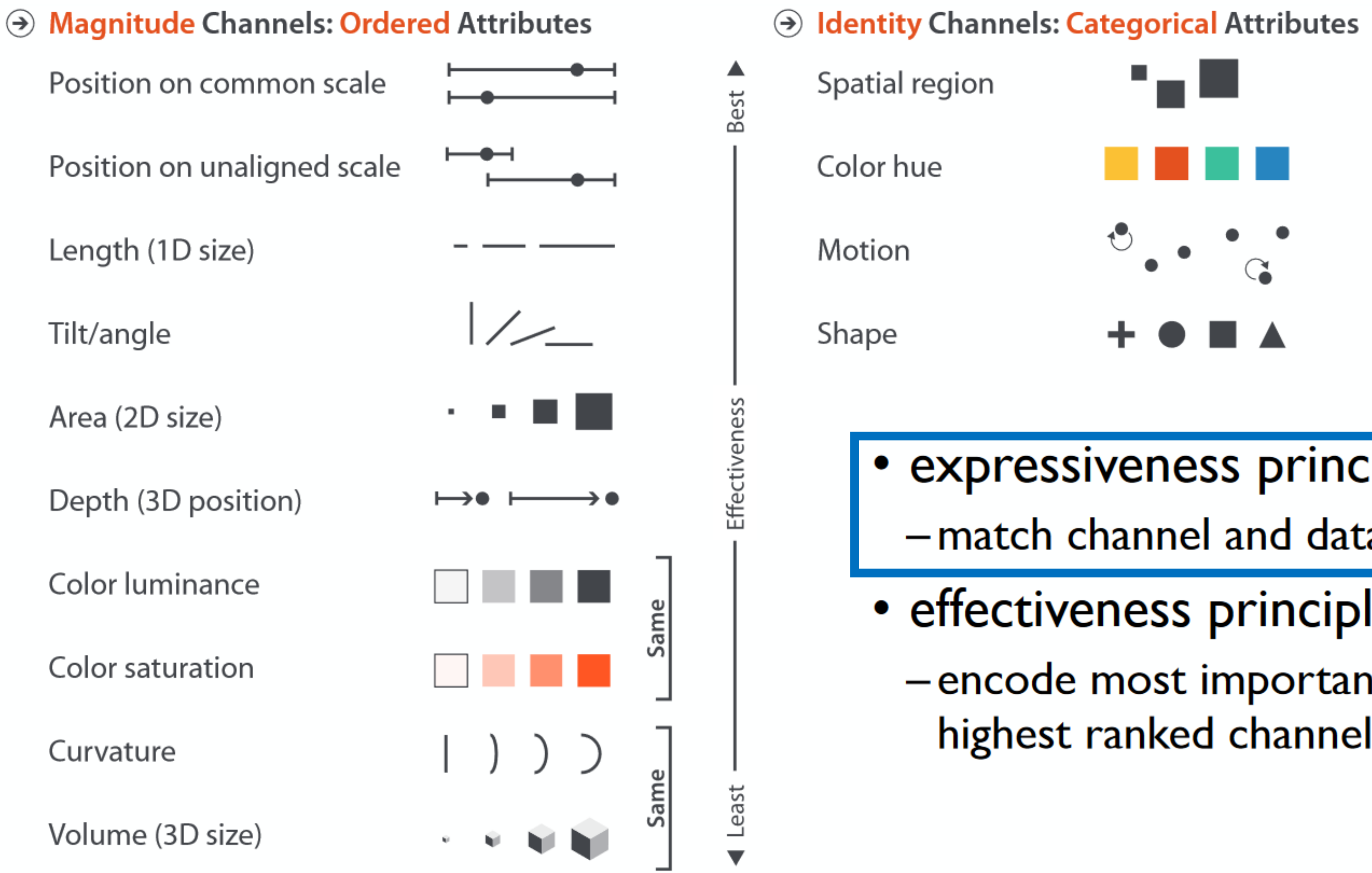
APPLYING PERCEPTION IN VISUALIZATION





- expressiveness principle
  - match channel and data characteristics
- effectiveness principle
  - encode most important attributes with highest ranked channels

APPLYING PERCEPTION IN VISUALIZATION



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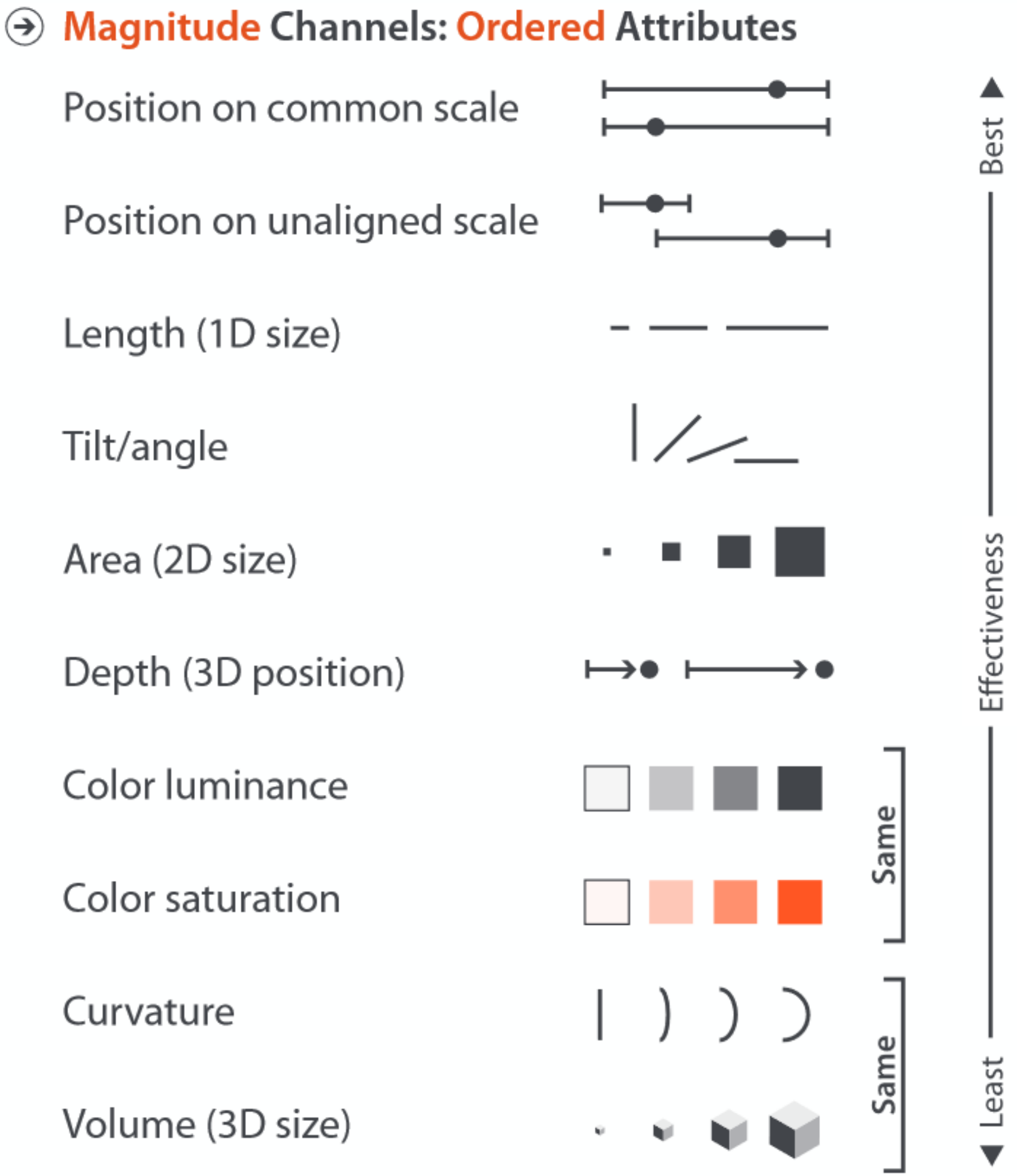
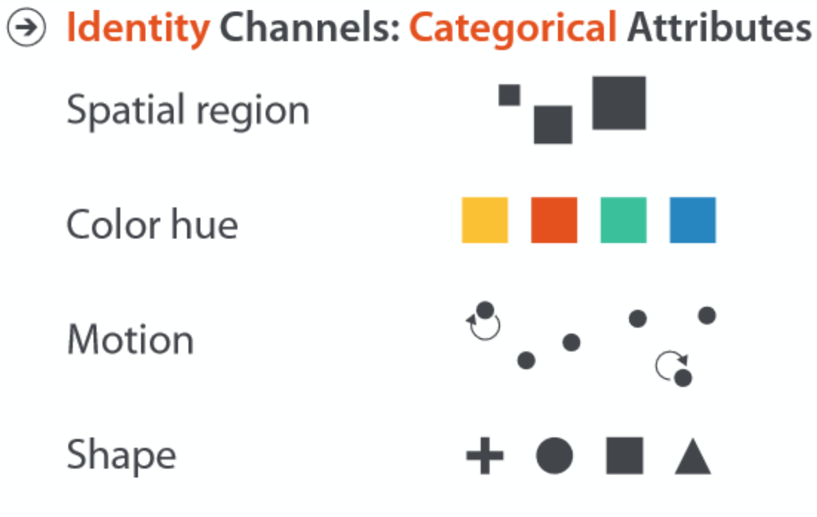
APPLYING PERCEPTION IN VISUALIZATION





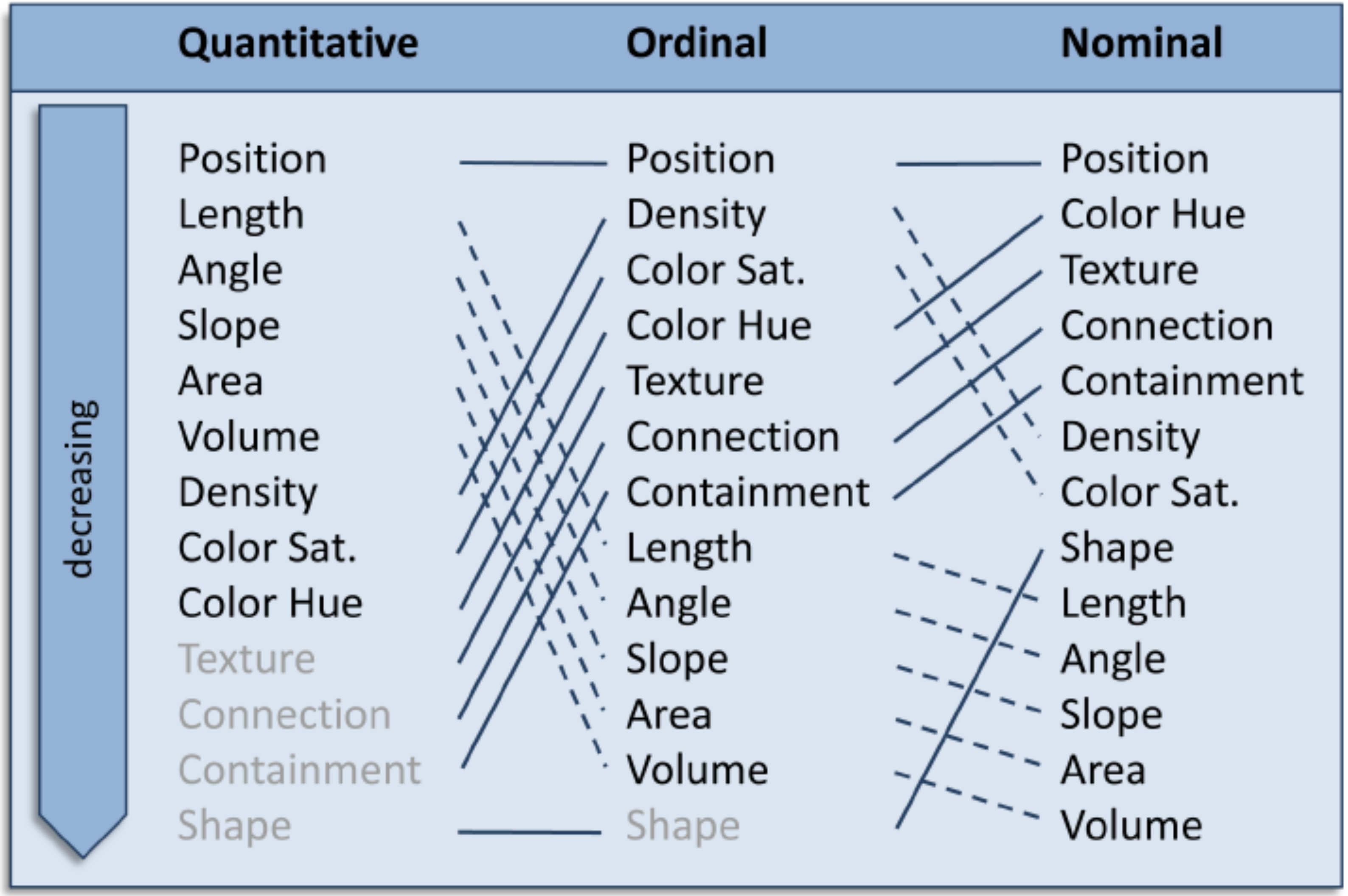
- expressiveness principle
  - match channel and data characteristics
- effectiveness principle
  - encode most important attributes with highest ranked channels

APPLYING PERCEPTION IN VISUALIZATION

- Visualization Design. Appropriateness
  - The design decisions **reflect their intent**
    - Appropriateness is task-dependent
  - Does it serve the user to address the necessary tasks?
    - We can evaluate empirically

APPLYING PERCEPTION IN VISUALIZATION

Ranking of visual variables



APPLYING PERCEPTION IN VISUALIZATION

- Relative judgments
  - Which of the two bars is longer?

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APPLYING PERCEPTION IN VISUALIZATION

- Weber’s law: just noticeable difference (JND) is proportional to the intensity of the original stimulus
  - $JND(k) = \Delta I / I$

APPLYING PERCEPTION IN VISUALIZATION

- Weber's law: just noticeable difference (JND) is proportional to the intensity of the original stimulus
  - $JND(k) = \Delta I / I$

  - For most sensory modalities, JND is a fixed proportion of the reference value
  - JND is established by testing differences versus a reference value
    - JND taken when users detect difference in 50% of the trials

APPLYING PERCEPTION IN VISUALIZATION

- Weber's law: just noticeable difference (JND) is proportional to the intensity of the original stimulus
  - $JND(k) = \Delta I / I$

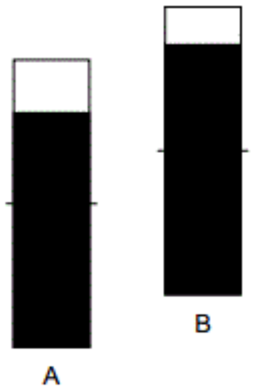
Small difference in
stimulus (bar length)

APPLYING PERCEPTION IN VISUALIZATION

- Weber’s law: just noticeable difference (JND) is proportional to the intensity of the original stimulus
  - $JND(k) = \Delta I / I$

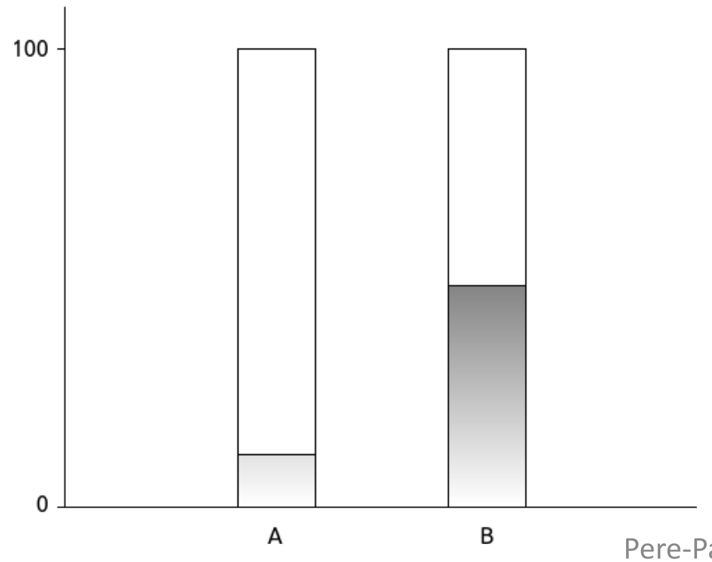
Small difference in stimulus (bar length)

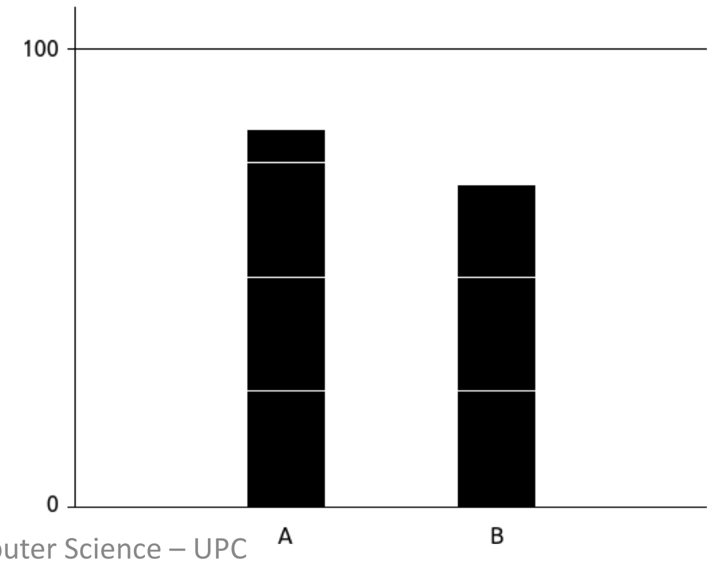
Larger difference in stimulus (enclosed white region)



APPLYING PERCEPTION IN VISUALIZATION

- Relative judgments can be improved by adding references
  - Relative position may influence
    - Aligned, one in top of the other…
  - Presence of gridlines: top line, inner marks…

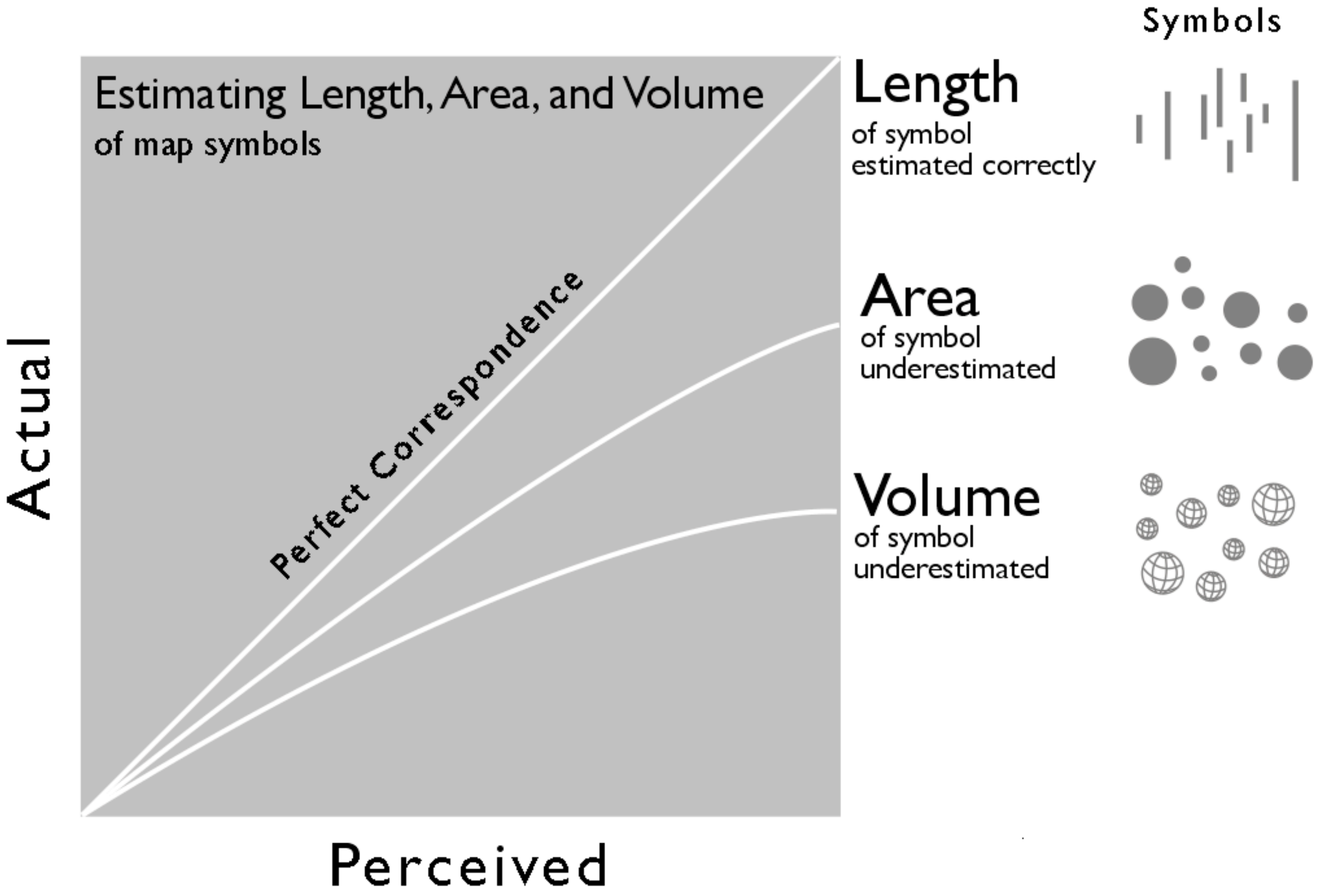




APPLYING PERCEPTION IN VISUALIZATION

- Stevens Law:
  - The apparent magnitude of all sensory channels follows a power function based on the stimulus intensity
  - Dimensions affect perception:
    - As the dimension of an attribute increases, the degree at which we underestimate it increases

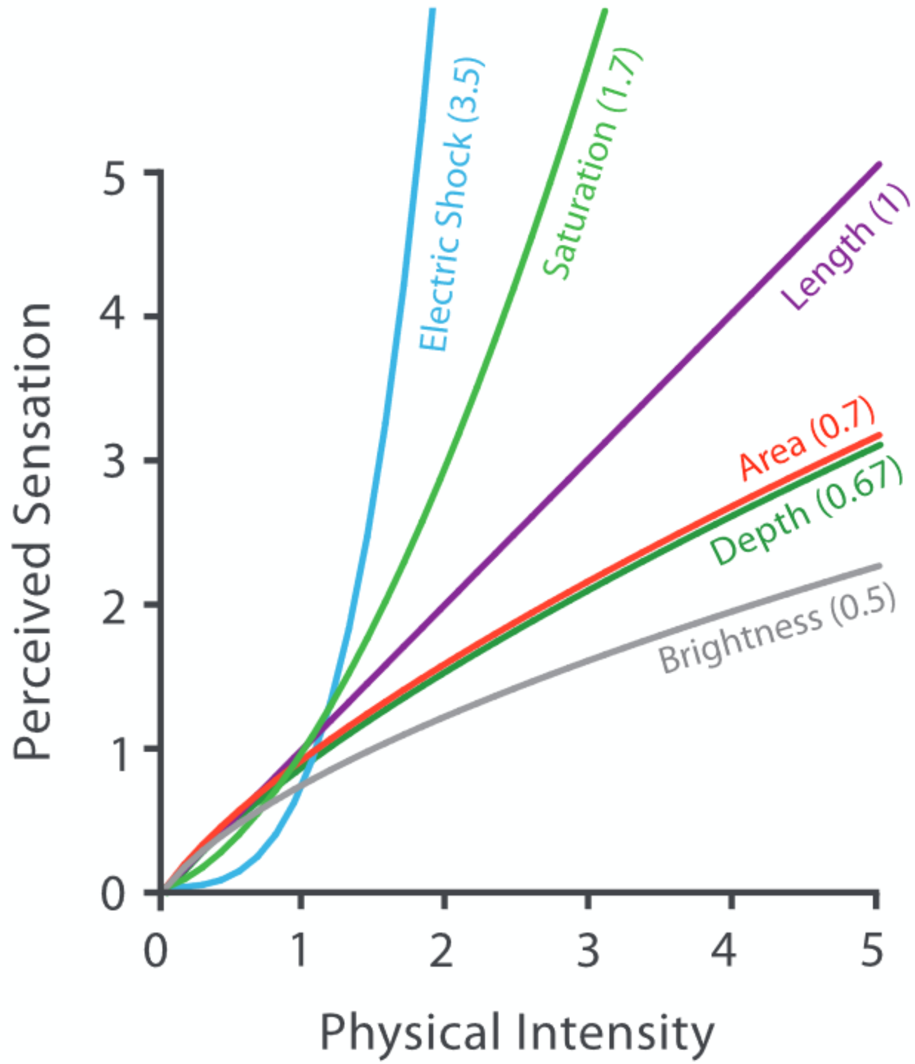
APPLYING PERCEPTION IN VISUALIZATION



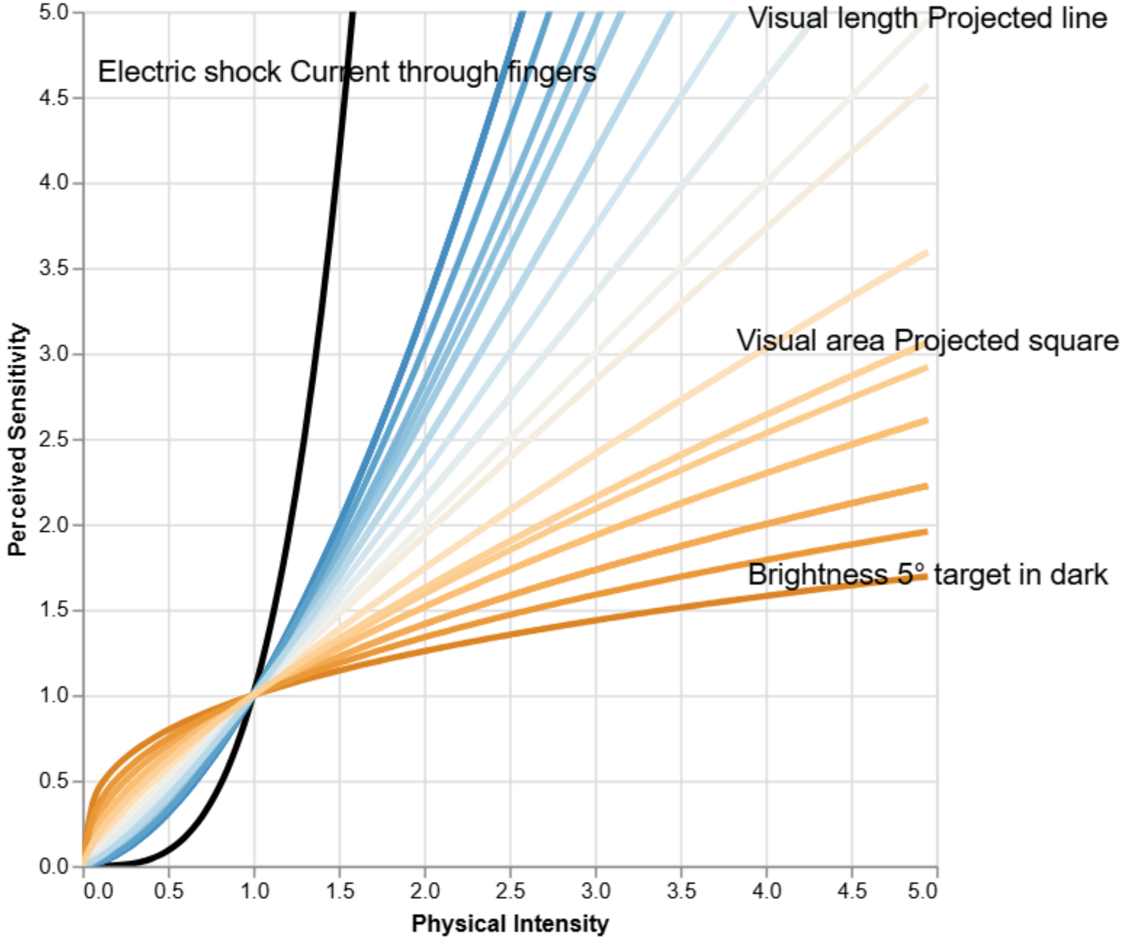
https://makingmaps.net/2007/08/28/perceptual-scaling-of-map-symbols/

APPLYING PERCEPTION IN VISUALIZATION

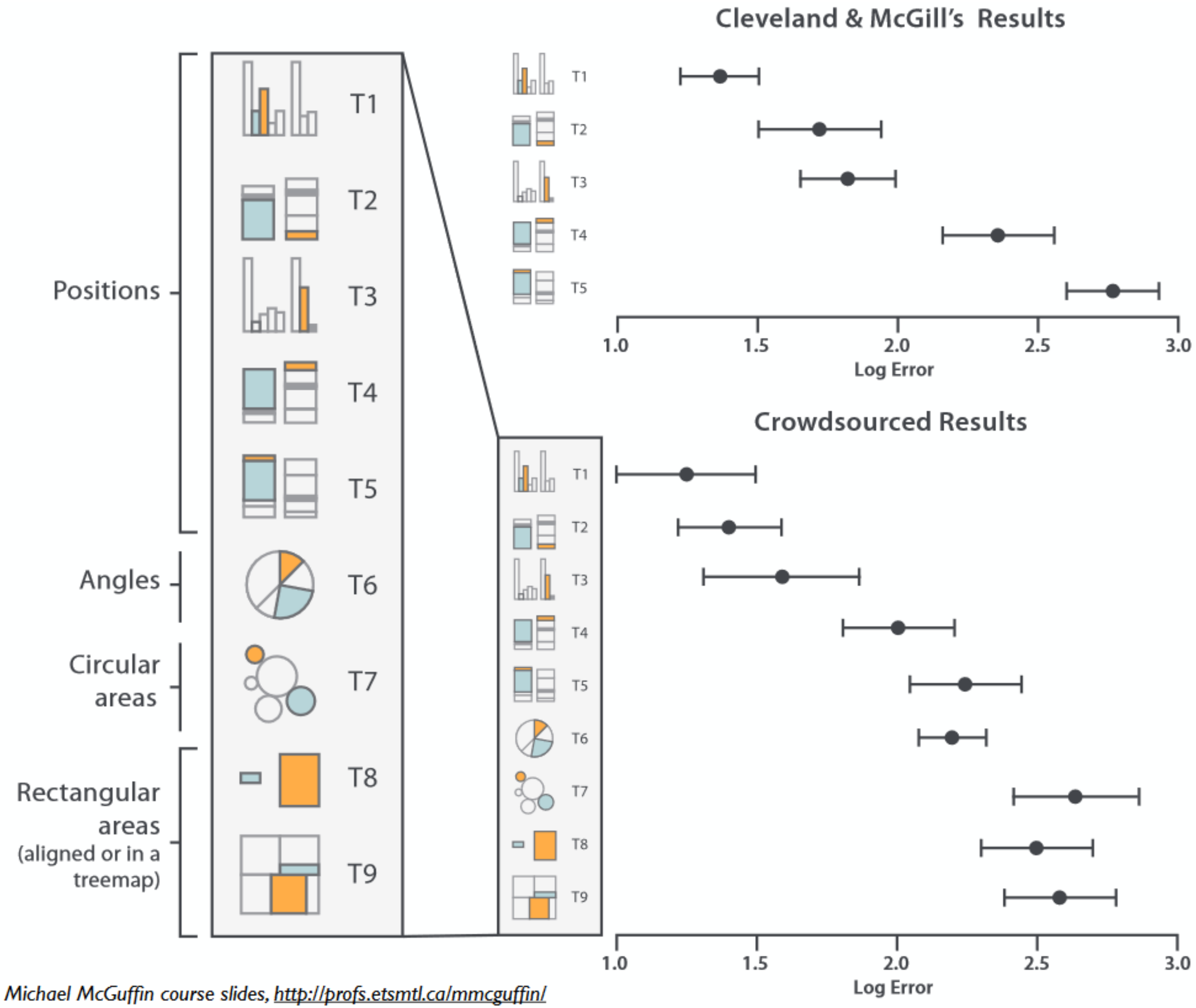
Steven's Psychophysical Power Law: $S = I^N$



APPLYING PERCEPTION IN VISUALIZATION



https://observablehq.com/@john-guerra/stevenss-power-law

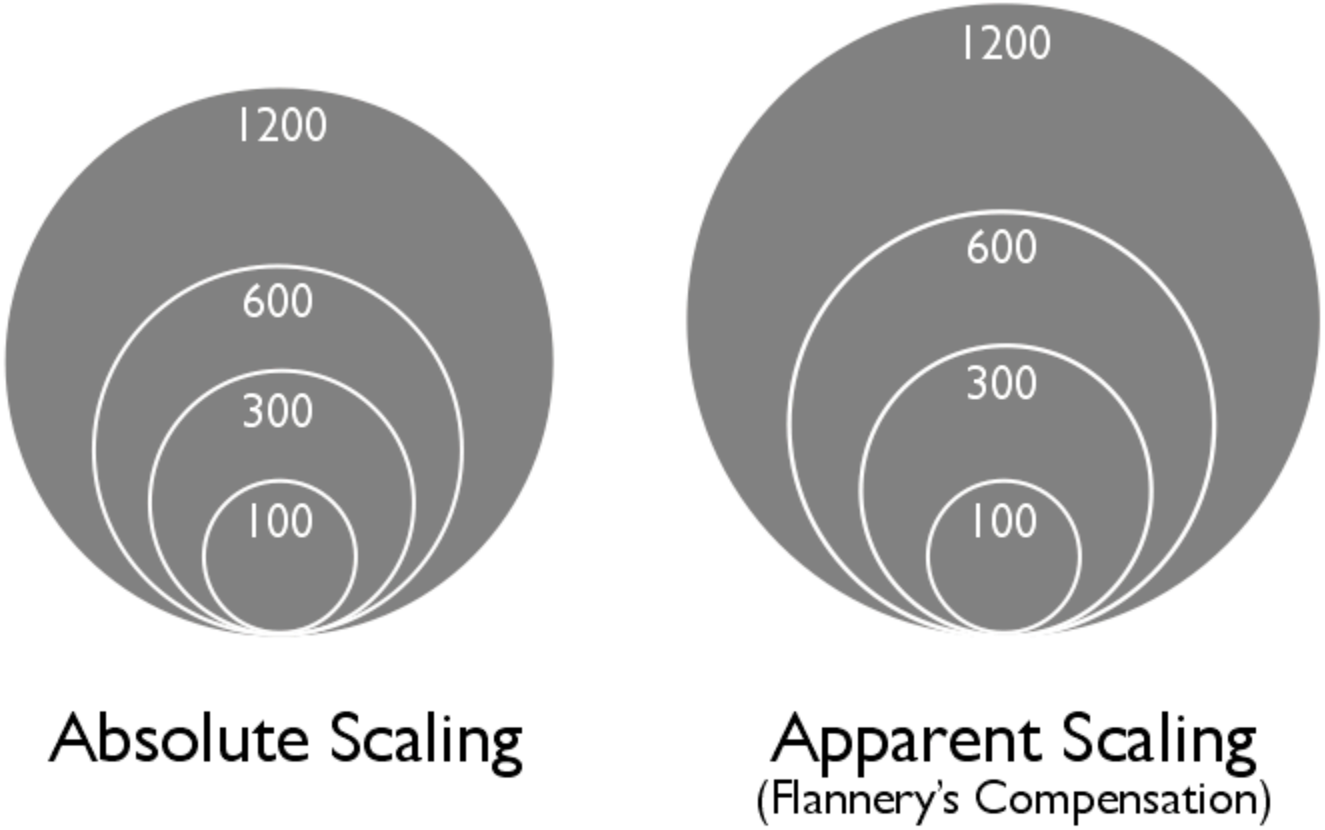


[Crowdsourcing Graphical Perception: Using Mechanical Turk to Assess Visualization Design. Heer and Bostock. Proc ACM Conf. Human Factors in Computing Systems (CHI) 2010, p. 203–212.]

· *Michael McGuffin course slides, http://profs.etsmtl.ca/mmcguffin/*

APPLYING PERCEPTION IN VISUALIZATION

- Flannery's compensation



https://makingmaps.net/2007/08/28/perceptual-scaling-of-map-symbols/

APPLYING PERCEPTION IN VISUALIZATION

- Measuring appropriateness
  - Tradeoff between efforts required for creating the visual representation and the benefits yielded by it
    - If it is balanced, the visualization is considered to be appropriate.

APPLYING PERCEPTION IN VISUALIZATION

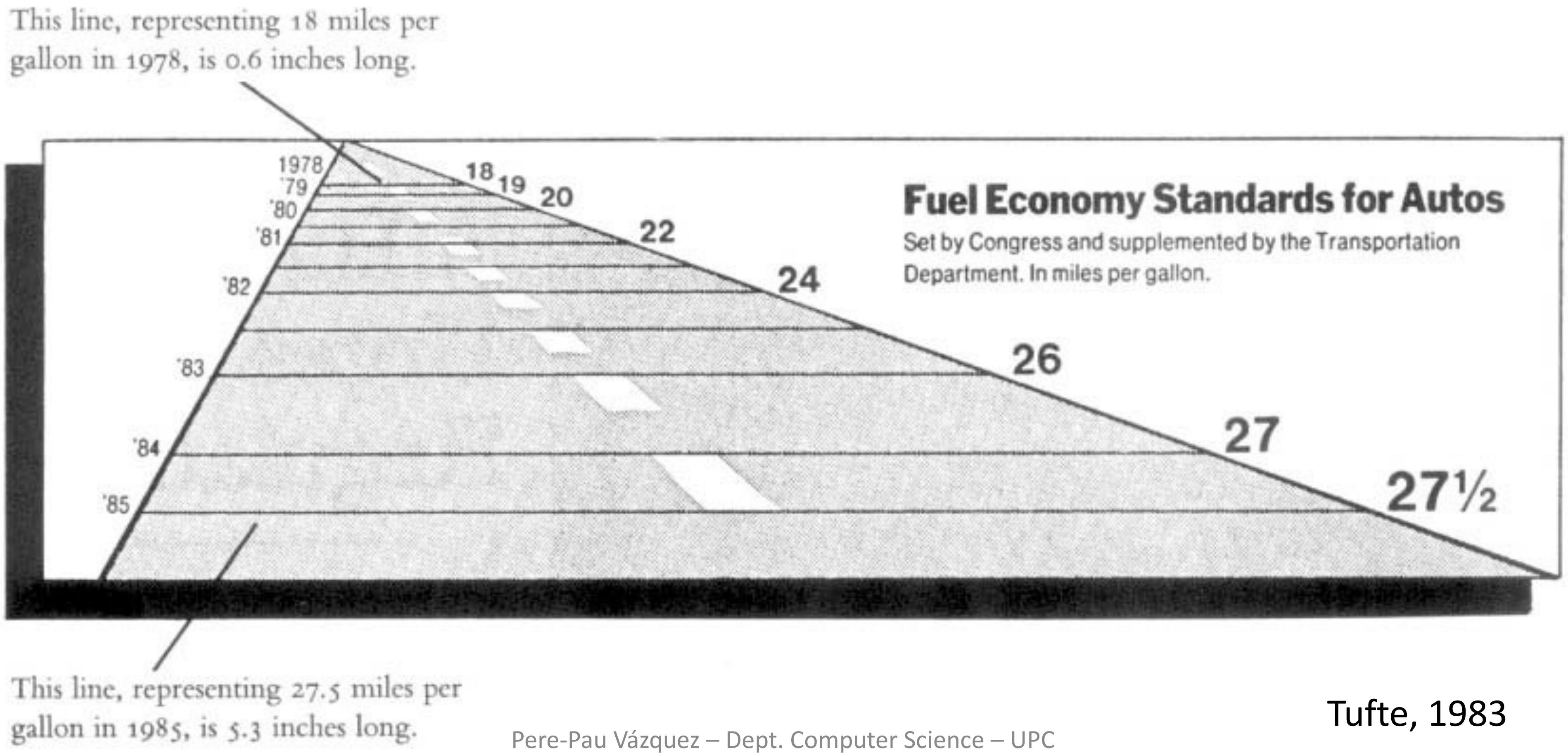
- Appropriateness. Model of Van Wijk:
  - *n* users use visualization *V* to visualize a data set m times each where each session takes *k* exploratory steps and time *T*
  - C_i ... Initial development costs
  - C_u ... Initial costs per user (e.g., selection, acquisition, learning, tailoring)
  - C_s ... Initial costs per session (e.g., data conversion, specification)
  - C_e ... Perception and exploration costs (e.g., spend time to view and understand, modify, and tune)
  - $W(\Delta K)$ ... Value of acquired knowledge $\Delta K = K(T) - K(0)$

APPLYING PERCEPTION IN VISUALIZATION

- Appropriateness. Model of Van Wijk:
    - $C = C_i + n*C_u + n*m*C_s + n*m*k*C_e$
  - Overall profit:
    - $F = n*m*(W(\Delta K) - C_s - k*C_e) - C_i - n*C_u$

APPLYING PERCEPTION IN VISUALIZATION. EXAMPLES

- Tell the truth about the data. Fuel economy example:

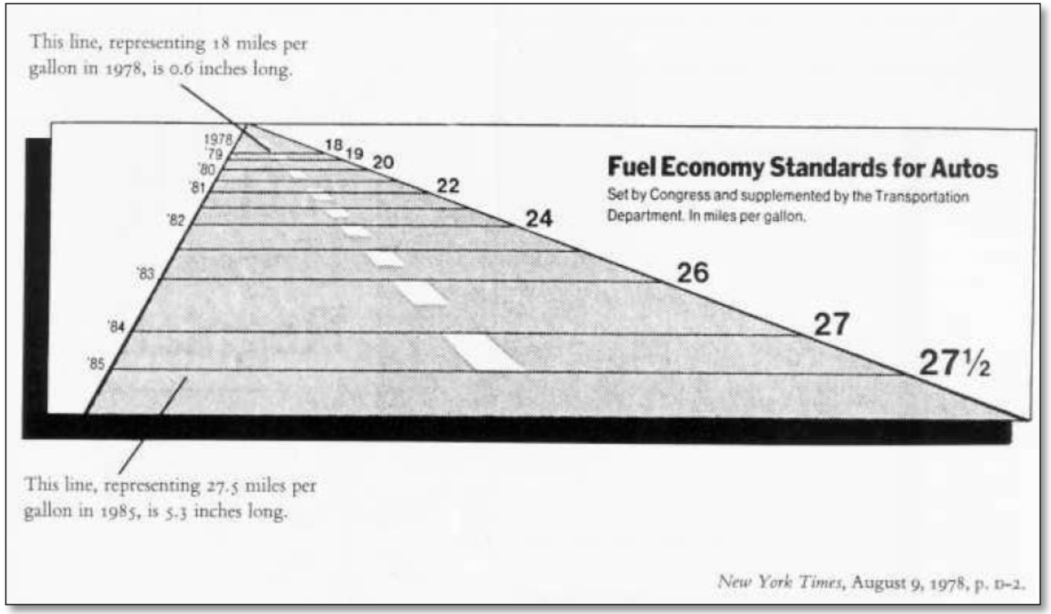


Tufte, 1983

APPLYING PERCEPTION IN VISUALIZATION. EXAMPLES

- Lie factor:
  - Size of effect shown in graphics / size of effect in data

APPLYING PERCEPTION IN VISUALIZATION. EXAMPLES



Discussed in [Tufte01]

Graphic

$$\frac{5.3-0.6}{0.6} * 100\% = 783\%$$

Data

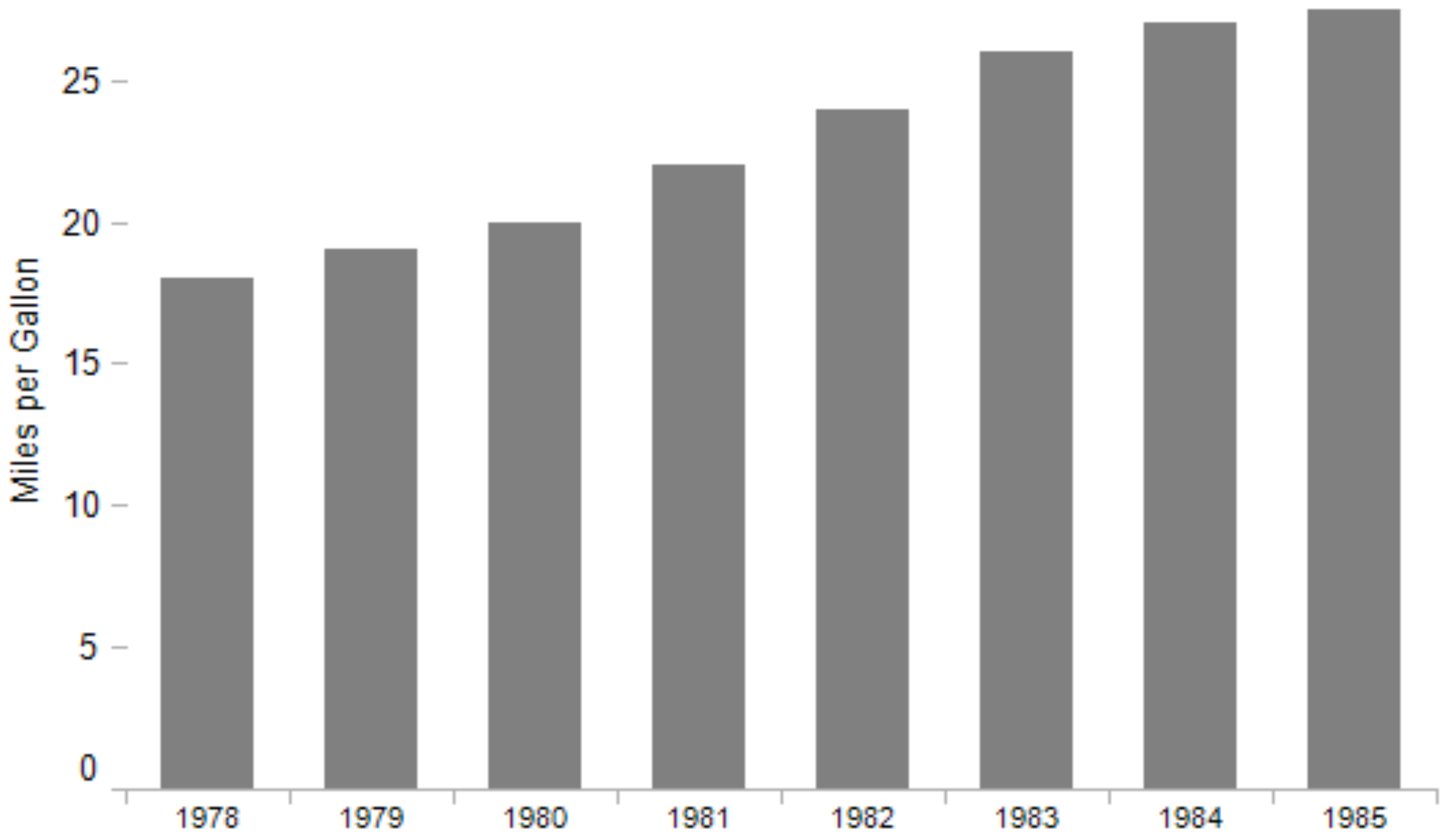
$$\frac{27.5-18.0}{18.0} * 100\% = 53\%$$

$$\text{The Lie Factor} = \frac{\text{size of effect shown in graphics}}{\text{size of effect in data}}$$

$$= \frac{783}{53} = 14.8$$

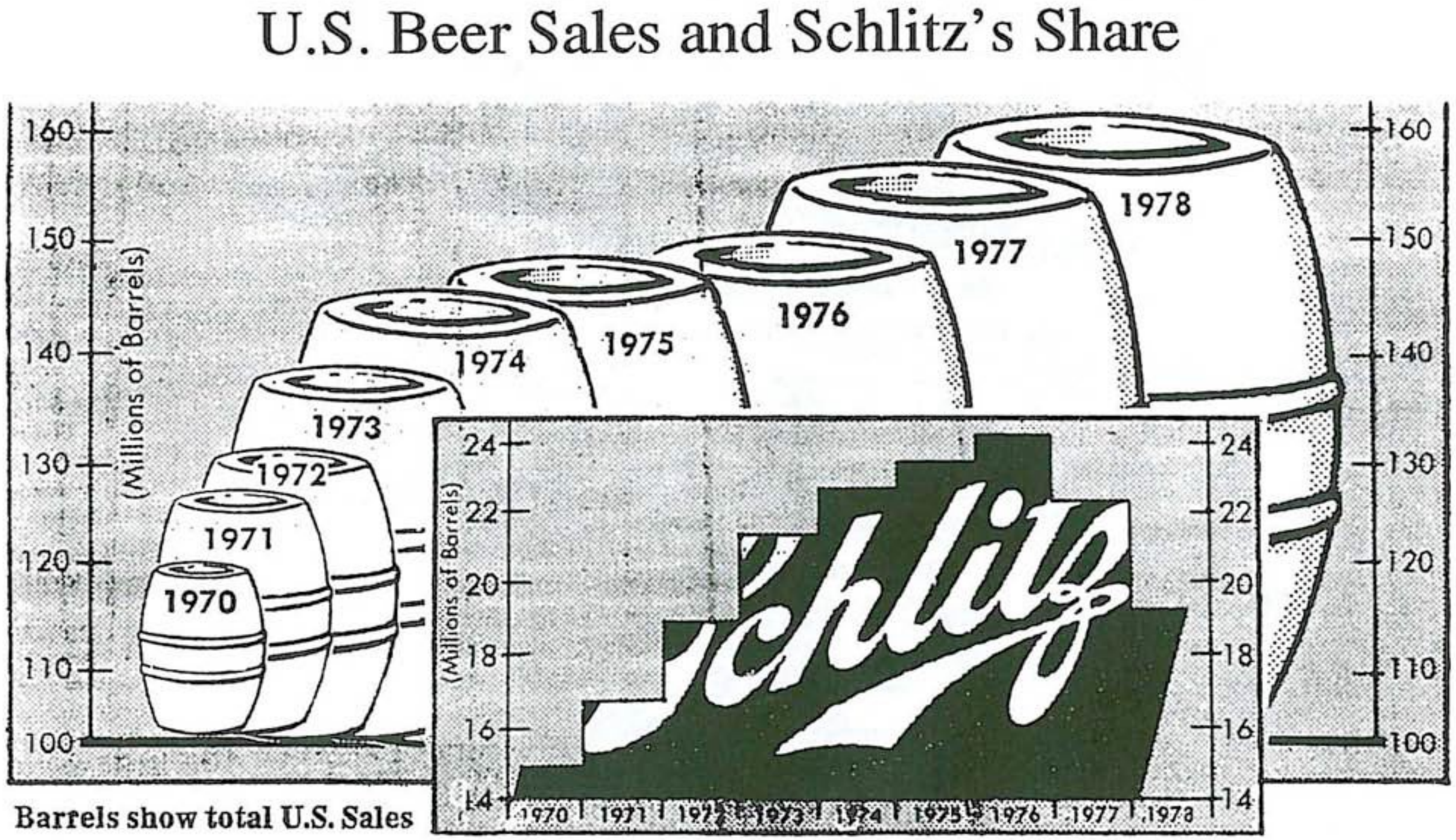
APPLYING PERCEPTION IN VISUALIZATION. EXAMPLES

- Tell the truth about the data. Fuel economy redesign:



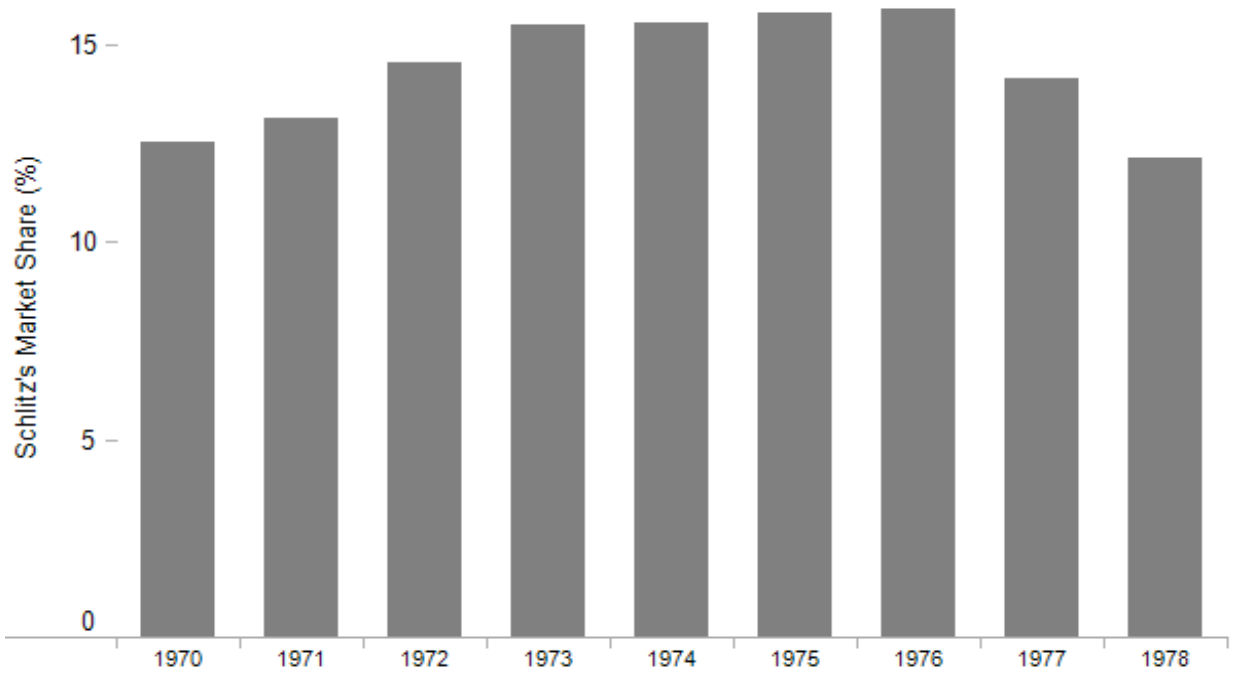
APPLYING PERCEPTION IN VISUALIZATION. EXAMPLES

- Tell the truth about the data. Beer sales example:



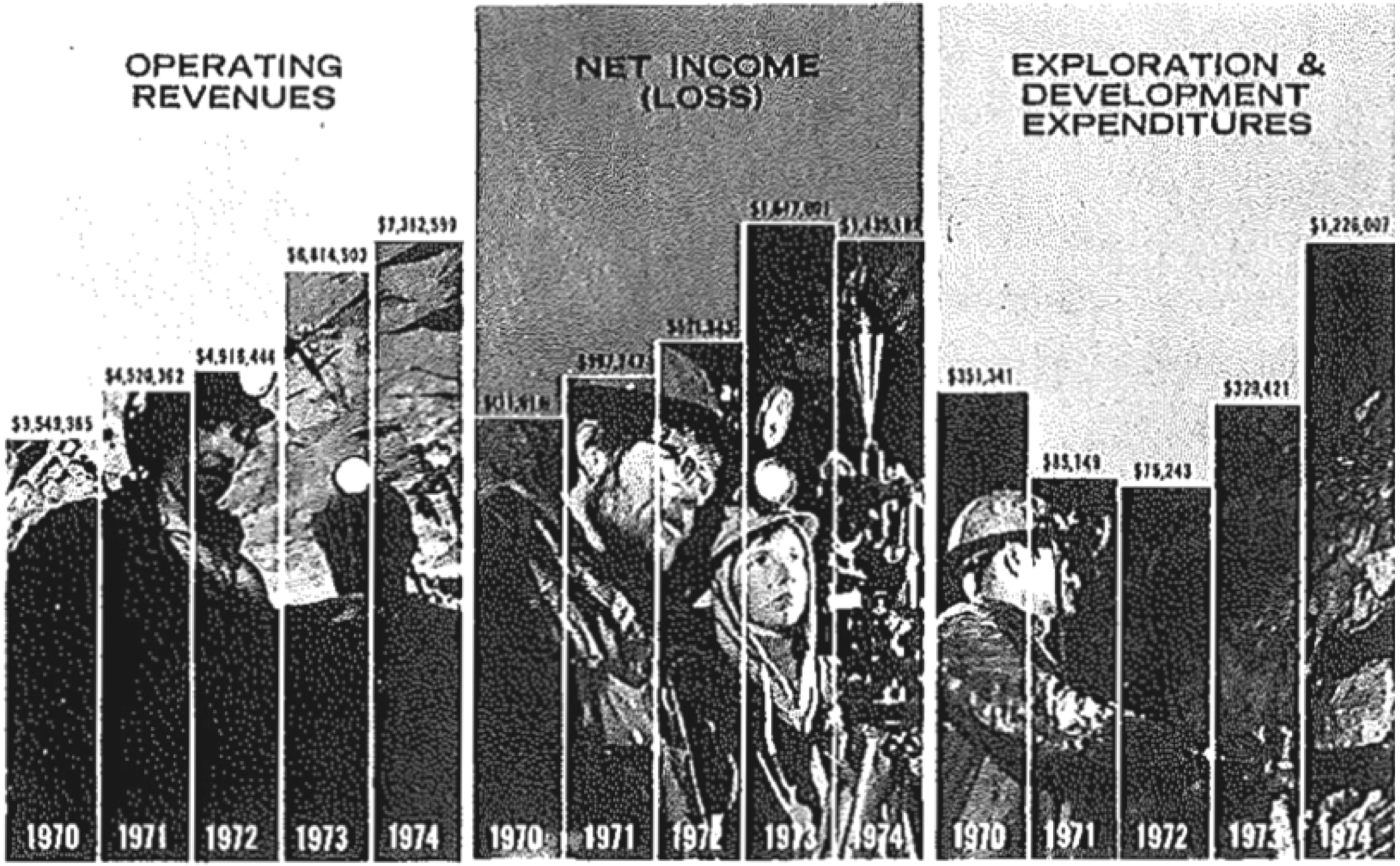
APPLYING PERCEPTION IN VISUALIZATION. EXAMPLES

- Tell the truth about the data. Beer sales redesign:



APPLYING PERCEPTION IN VISUALIZATION. EXAMPLES

- If measured, you’ll find that baseline is at -4200$. If labeled, this would be visible




Always label your axes
LIGHT
HEAVY
DOUBLE

APPLYING PERCEPTION IN VISUALIZATION

- Make sure that the graph is complete
- All axes must be labelled
- There should be a title on the graph
    - For explanatory visualization, consider including a takeaway message in the title

APPLYING PERCEPTION IN VISUALIZATION

- Signal to noise ratio: Measure used in science and engineering that compares the level of a desired signal to the level of background noise.
  - A ratio higher than 1:1 indicates more signal than noise
  - The goal of communication is maximizing signal and minimizing noise
- Converting the measure to visualization: Data-to-ink ratio (Data-to-pixel)
  - Keep the design simple => enhance perception
  - We can enhance information by using redundant coding and highlighting
  - Remove noise by eliminating unnecessary elements

APPLYING PERCEPTION IN VISUALIZATION

- Data-Ink ratio:

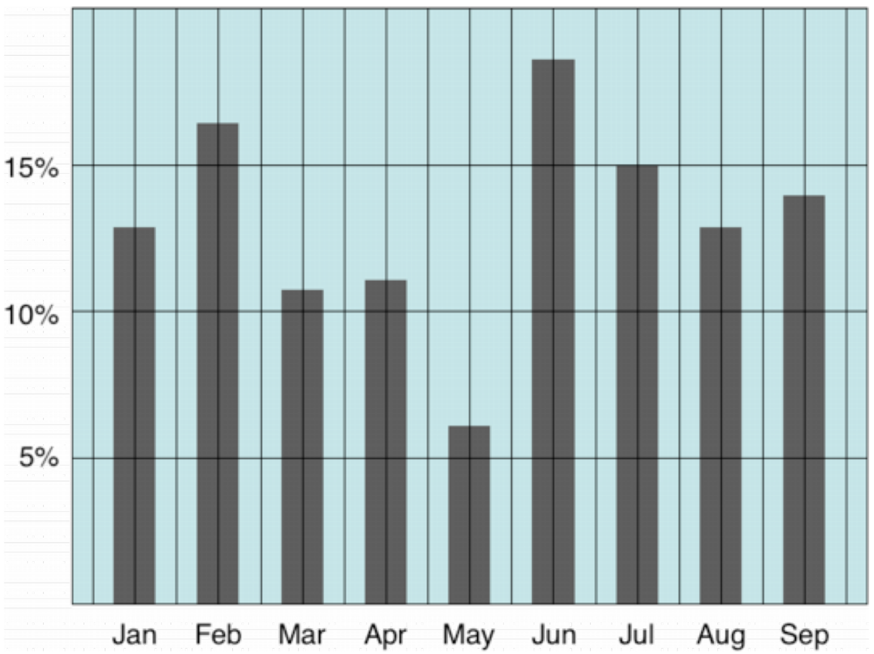
$$\textbf{Data-ink ratio} = \frac{\textbf{Data-ink}}{\textbf{Total ink used to print the graphic}}$$

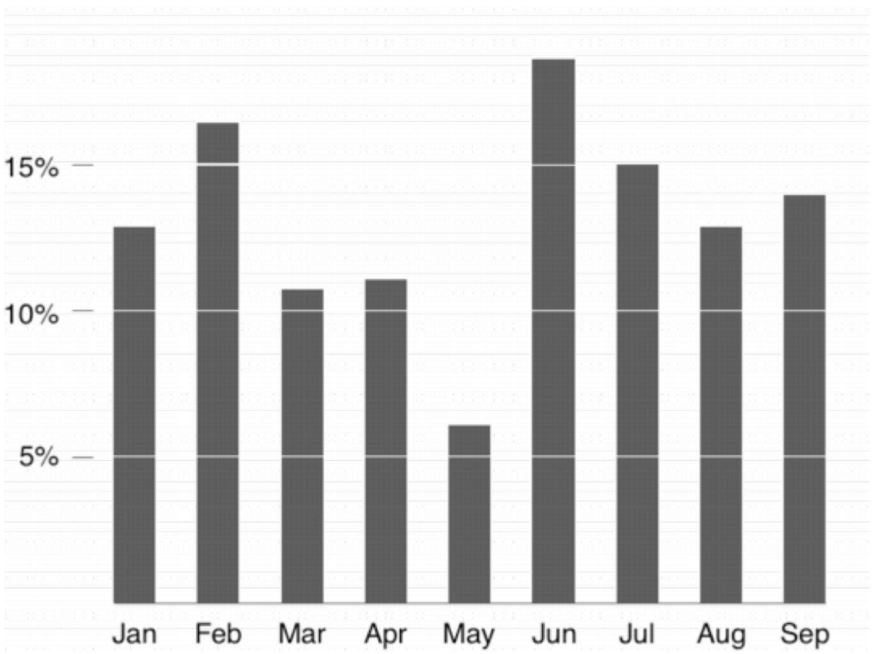
$$= \textbf{proportion of a graphic's ink devoted to the non-redundant display of data-information}$$

$$= \textbf{1.0 - proportion of a graphic that can be erased}$$

APPLYING PERCEPTION IN VISUALIZATION

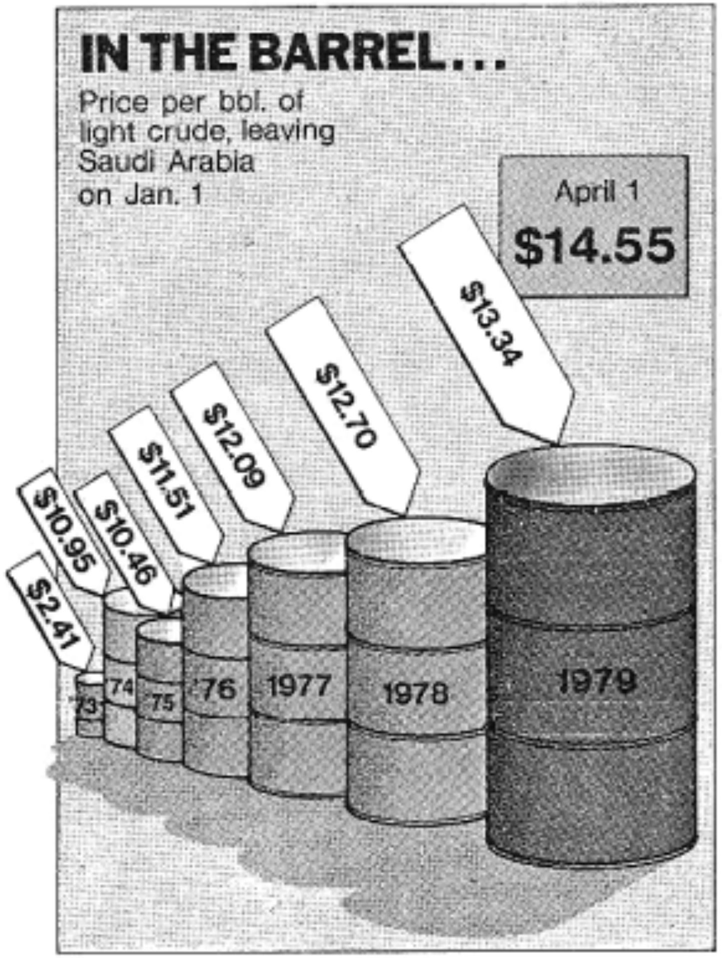
- Data-Ink ratio:





APPLYING PERCEPTION IN VISUALIZATION

- Not all examples are good
  - Be fair!!!
  - Tufte has plenty of examples…



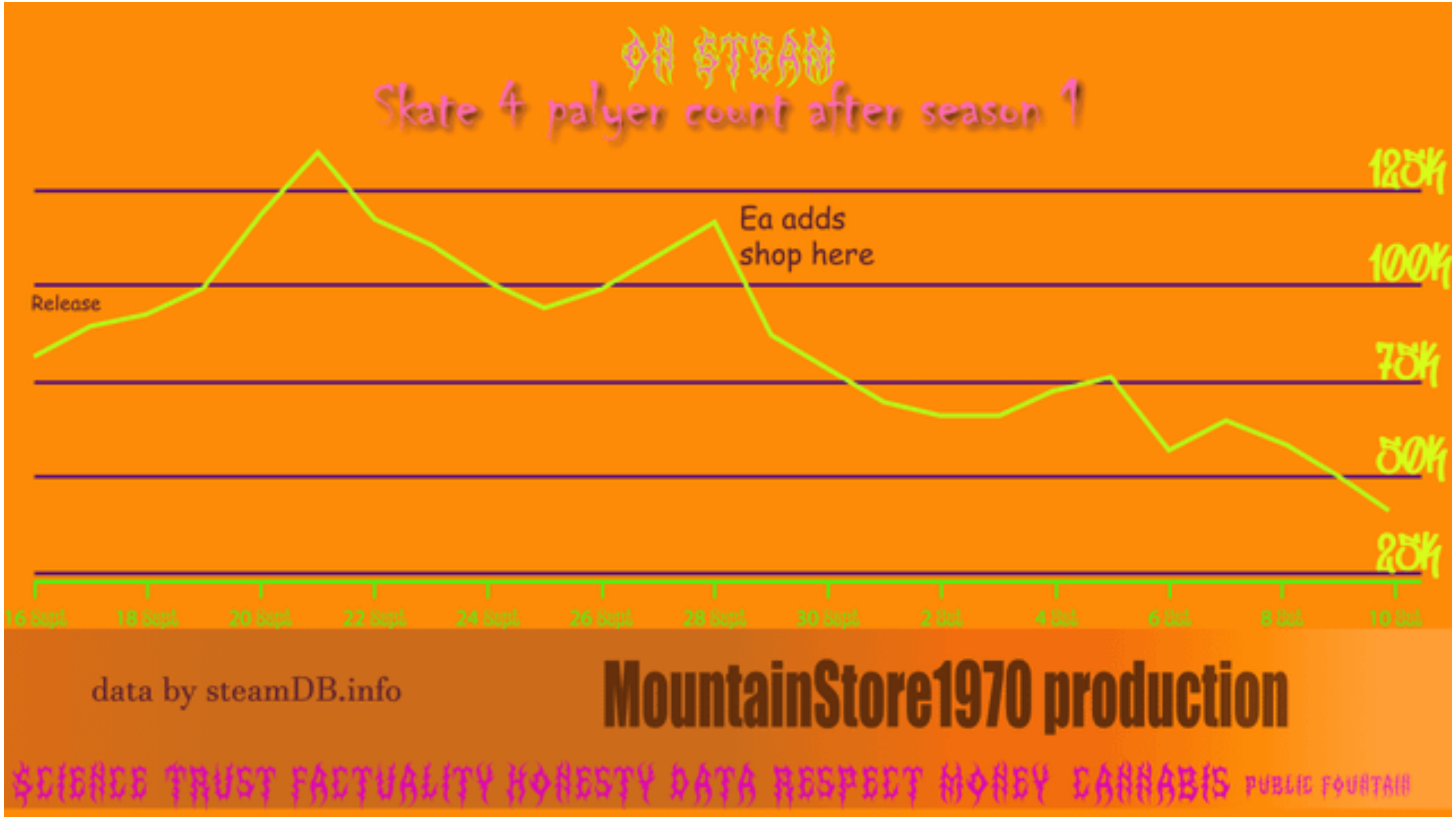
SOURCES OF INFORMATION

- Information Visualization: Perception for Design, 3rd edition, Colin Ware, Morgan Kaufmann, 2013
- Color Basics for Creating Visualizations. Theresa-Marie Rhyne: https://www.youtube.com/watch?v=RiG1Rn0Acn0
- Perception in Vision web page with demos, Christopher Healey
- Attention and Visual Memory in Visualization and Computer Graphics, Christopher G. Healey and James T. Enns, IEEE TVCG 18(7):1170-1188 2012
- Mazza, R.: Introduction to Information Visualization, Springer-Verlag, London, 2009

EXERCISES

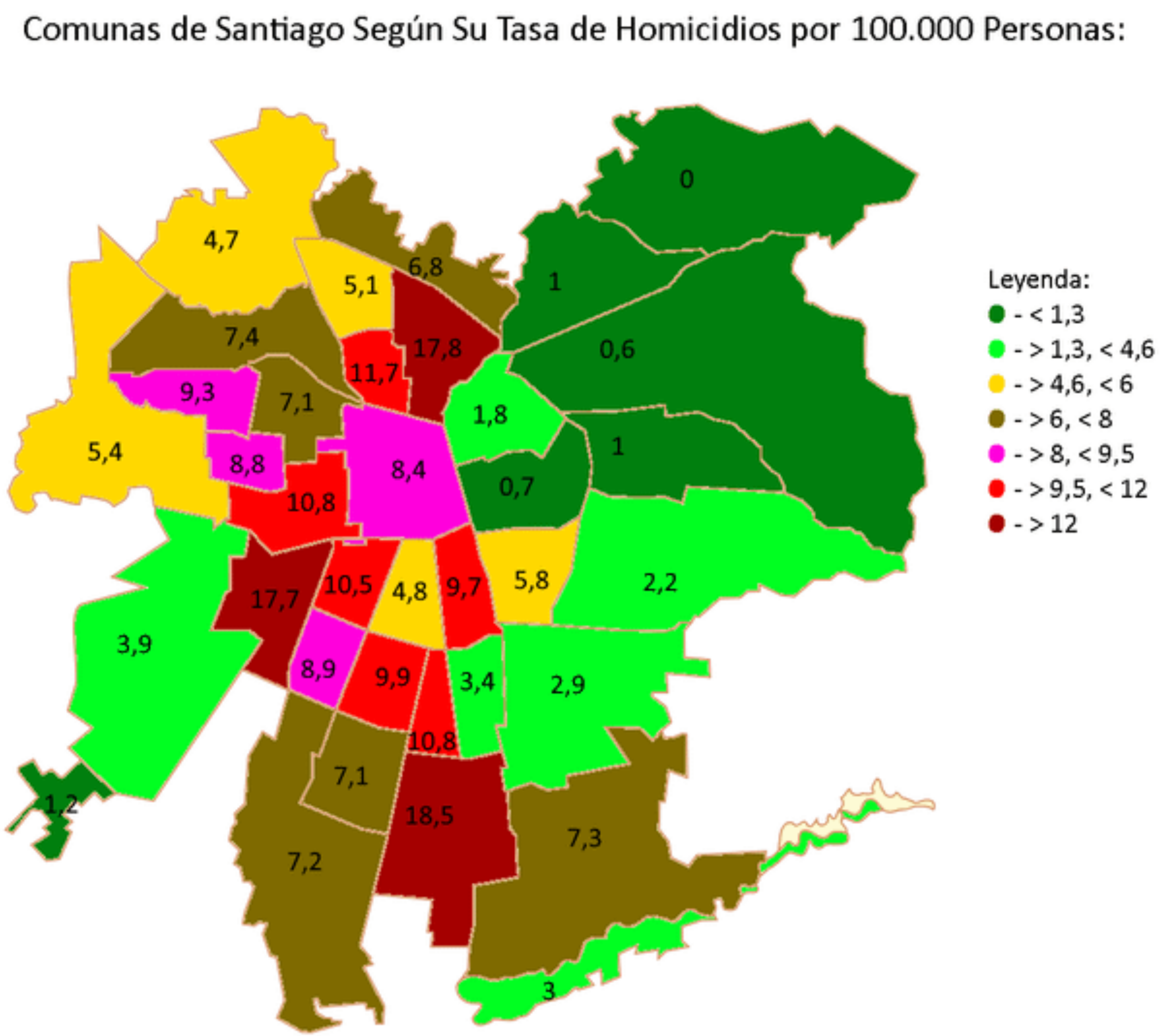
PERE-PAU VÁZQUEZ – VIRVIG GROUP – UPC

EXERCISES



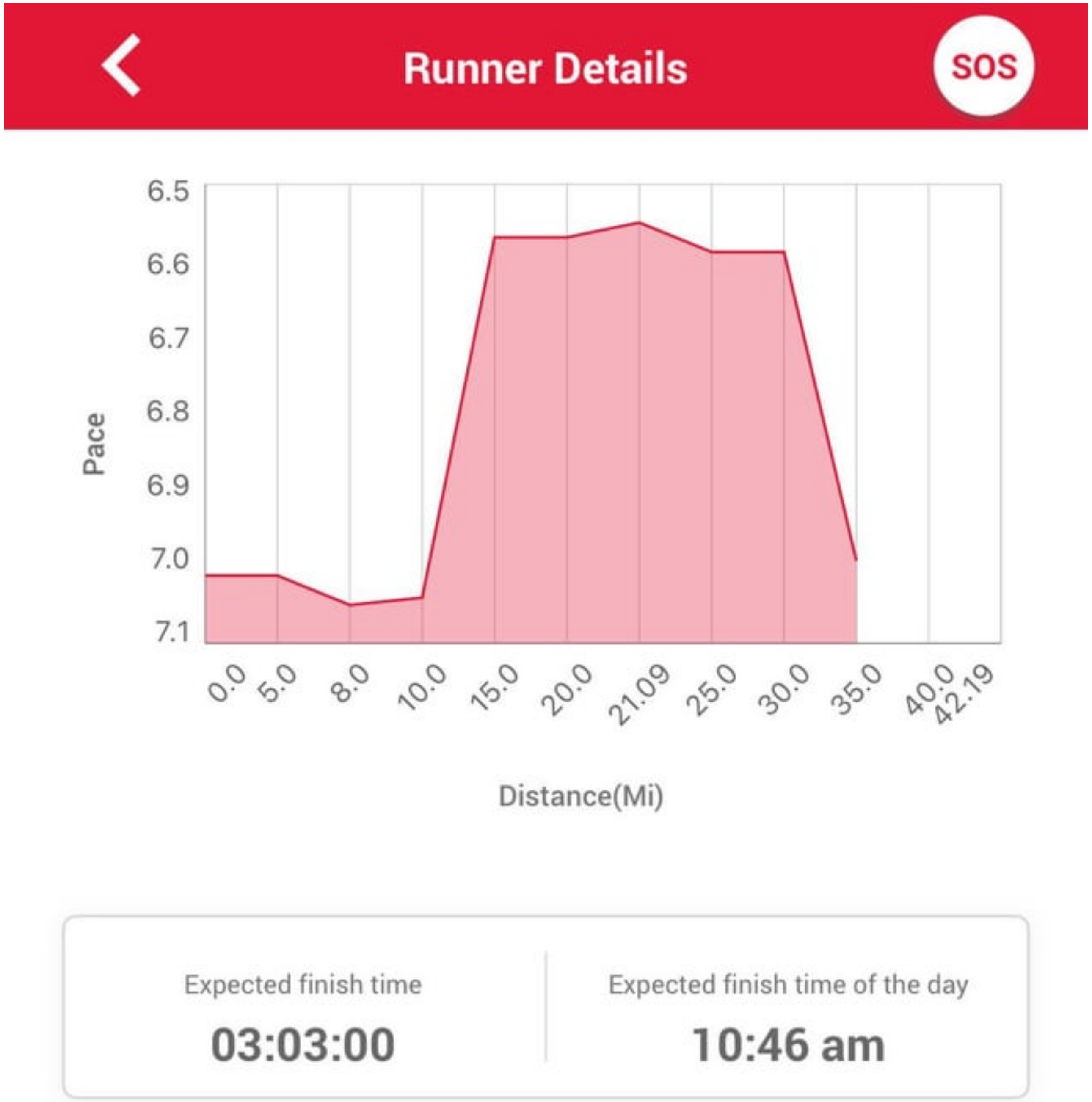
ON STEAM
Skate 4 palyer count after season 1
125K
100K
75K
50K
25K
Release
Ea adds
shop here
16 Sept
18 Sept
20 Sept
22 Sept
24 Sept
26 Sept
28 Sept
30 Sept
2 Oct
4 Oct
6 Oct
8 Oct
10 Oct
data by steamDB.info
MountainStore1970 production
SCIENCE TRUST FACTUALITY HONESTY DATA RESPECT MONEY CANNABIS
PUBLIC FOUNTAIN

EXERCISES

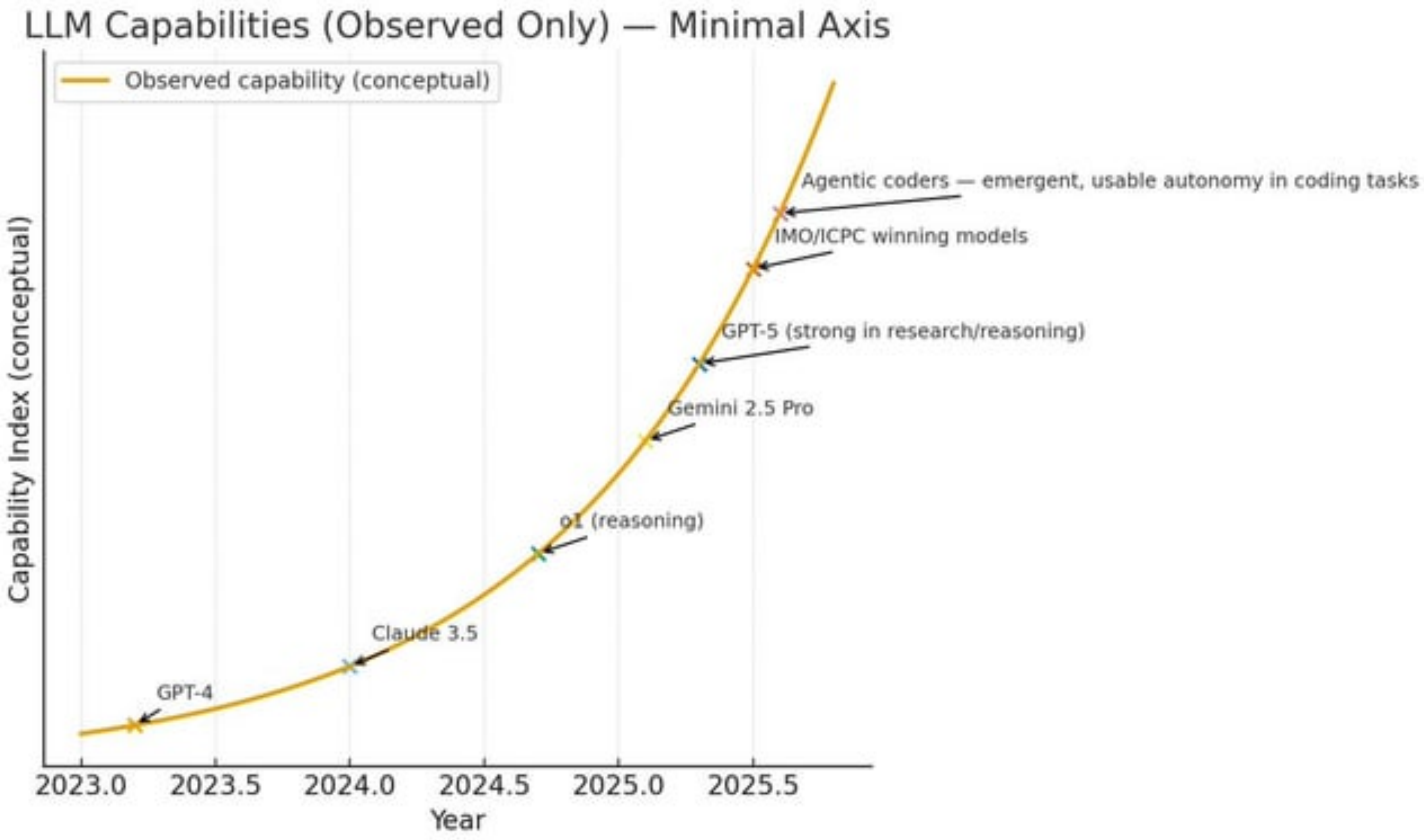


Comunas de Santiago Según Su Tasa de Homicidios por 100.000 Personas:
0
4,7
6,8
1
5,1
17,8
7,4
0,6
11,7
9,3
7,1
1,8
1
5,4
8,8
8,4
0,7
10,8
10,5
4,8
9,7
5,8
2,2
17,7
3,9
8,9
9,9
3,4
2,9
10,8
7,1
1,2
18,5
7,3
7,2
3
Leyenda:
- < 1,3
- > 1,3, < 4,6
- > 4,6, < 6
- > 6, < 8
- > 8, < 9,5
- > 9,5, < 12
- > 12

EXERCISES

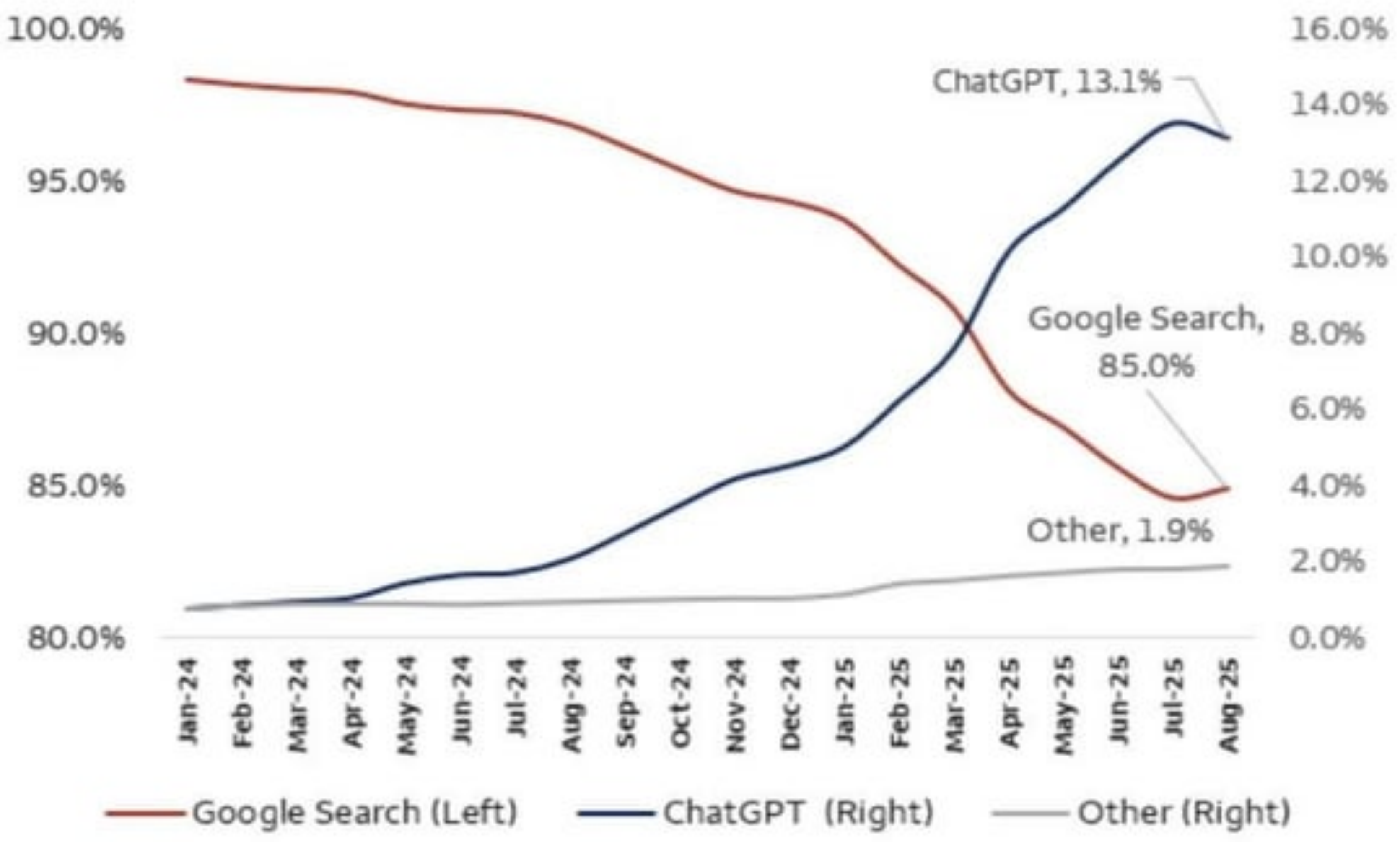

Runner Details
SOS
6.5
6.6
6.7
6.8
6.9
7.0
7.1
Pace
0.0
5.0
8.0
10.0
15.0
20.0
21.09
25.0
30.0
35.0
40.0
42.19
Distance(Mi)
Expected finish time
03:03:00
Expected finish time of the day
10:46 am

EXERCISES

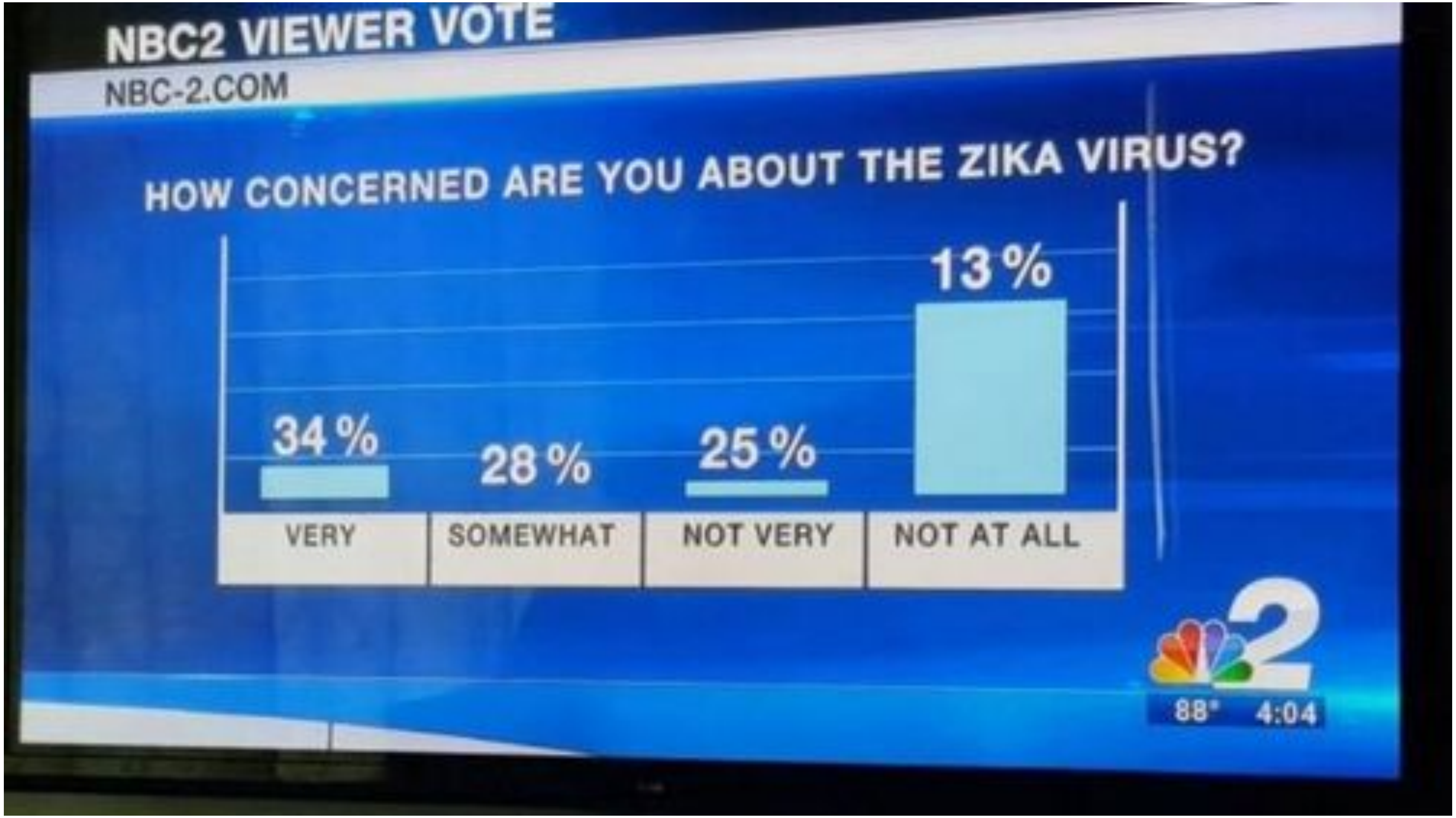

LLM Capabilities (Observed Only) — Minimal Axis
Observed capability (conceptual)
Agentic coders — emergent, usable autonomy in coding tasks
IMO/ICPC winning models
GPT-5 (strong in research/reasoning)
Gemini 2.5 Pro
o1 (reasoning)
Claude 3.5
GPT-4
Capability Index (conceptual)
2023.0
2023.5
2024.0
2024.5
2025.0
2025.5
Year

EXERC

Exhibit 3 - Share Mix - AI Agent vs. Traditional Search Usage Instance

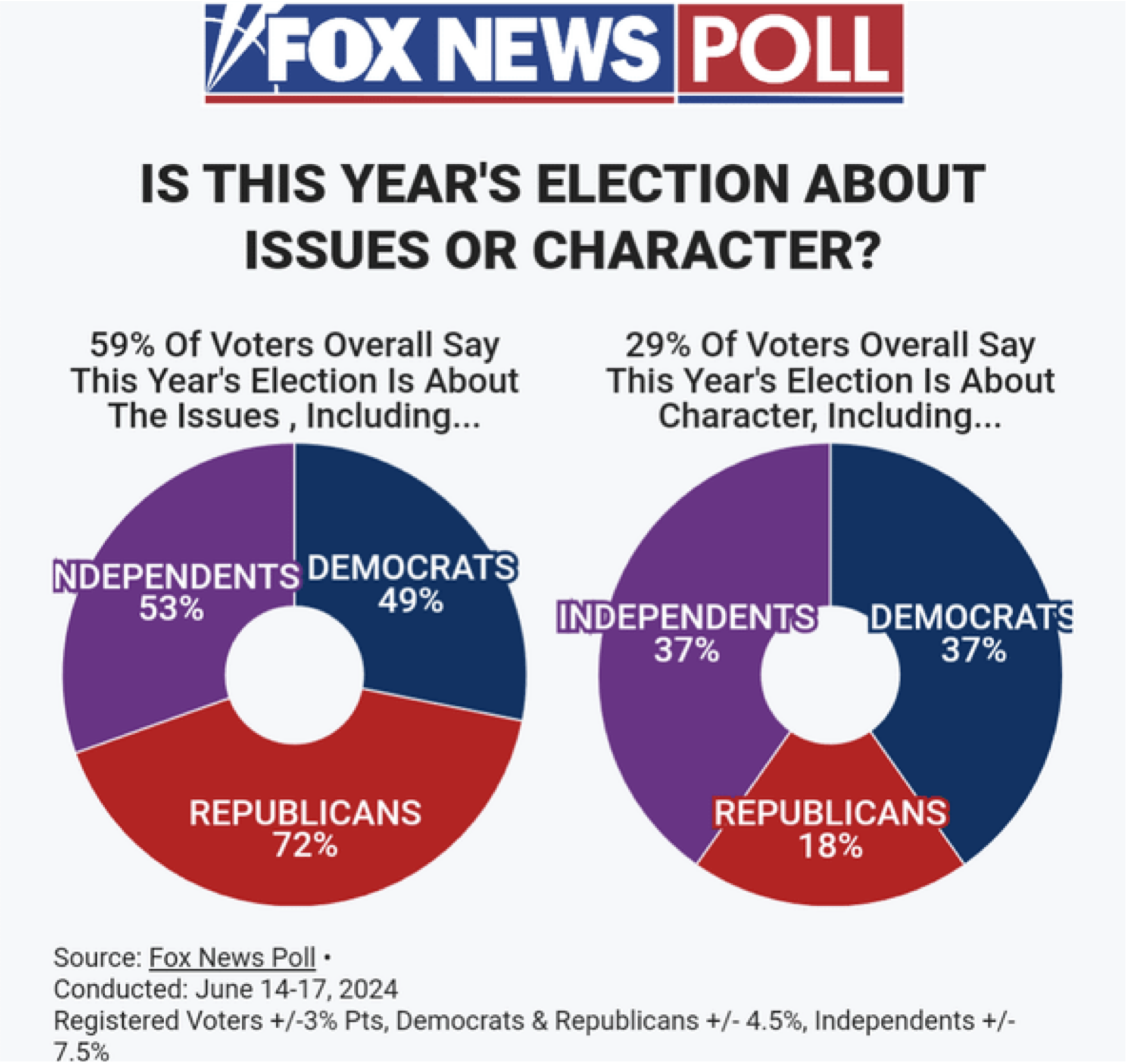


EXERCISES



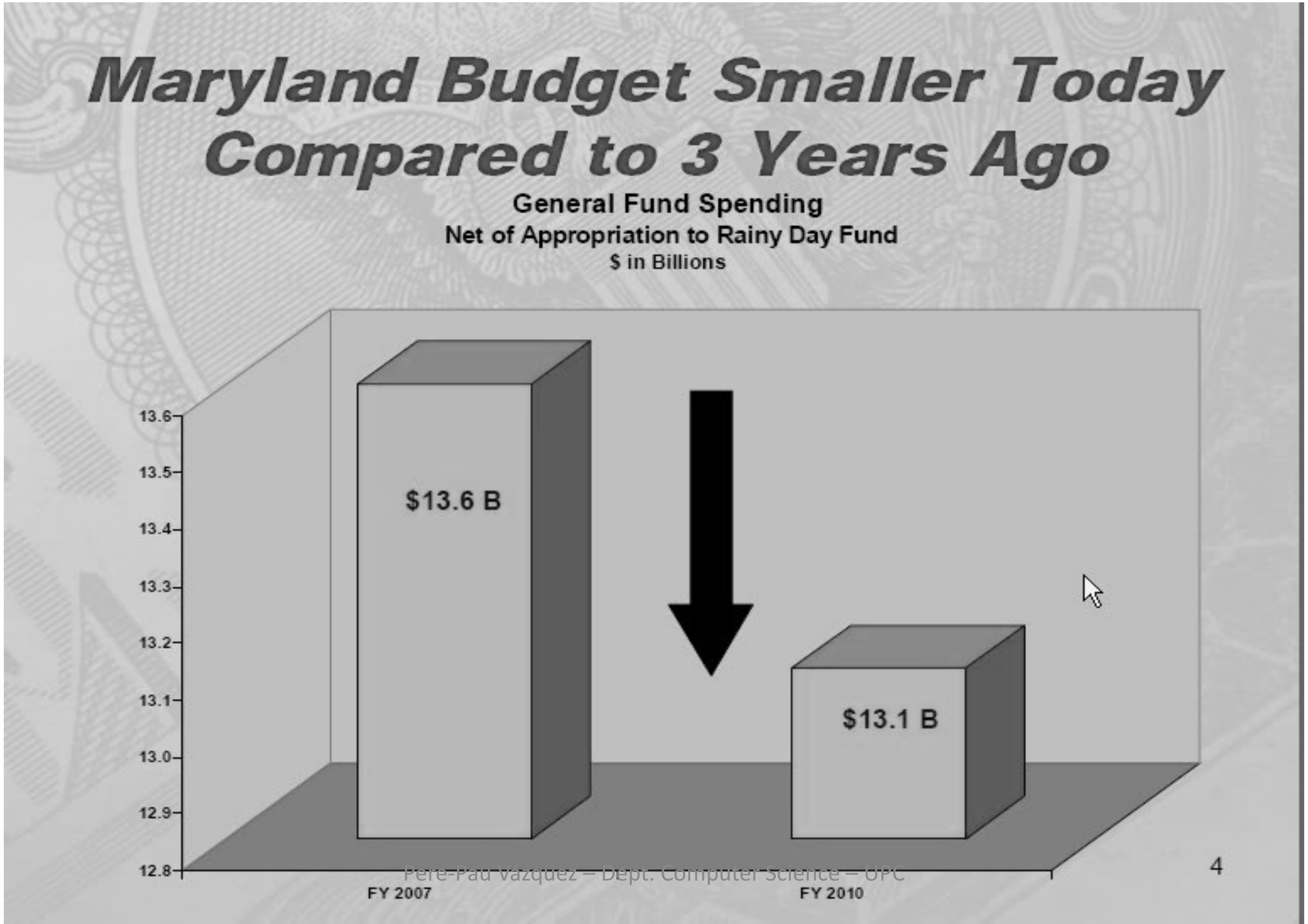
NBC2 VIEWER VOTE
NBC-2.COM
HOW CONCERNED ARE YOU ABOUT THE ZIKA VIRUS?
34 %
28 %
25 %
13 %
VERY
SOMEWHAT
NOT VERY
NOT AT ALL
88°
4:04

EXERCISES



FOX NEWS POLL
IS THIS YEAR'S ELECTION ABOUT ISSUES OR CHARACTER?
59% Of Voters Overall Say This Year's Election Is About The Issues , Including...
NDEPENDENTS 53%
DEMOCRATS 49%
REPUBLICANS 72%
29% Of Voters Overall Say This Year's Election Is About Character, Including...
INDEPENDENTS 37%
DEMOCRATS 37%
REPUBLICANS 18%
Source: Fox News Poll •
Conducted: June 14-17, 2024
Registered Voters +/-3% Pts, Democrats & Republicans +/- 4.5%, Independents +/- 7.5%

EXERCISE


Maryland Budget Smaller Today Compared to 3 Years Ago
General Fund Spending
Net of Appropriation to Rainy Day Fund
$ in Billions
13.6
13.5
13.4
13.3
13.2
13.1
13.0
12.9
12.8
$13.6 B
$13.1 B
FY 2007
FY 2010

PERCEPTION IN VIS

PERE-PAU VÁZQUEZ – VIRVIG GROUP – UPC