Visual perception

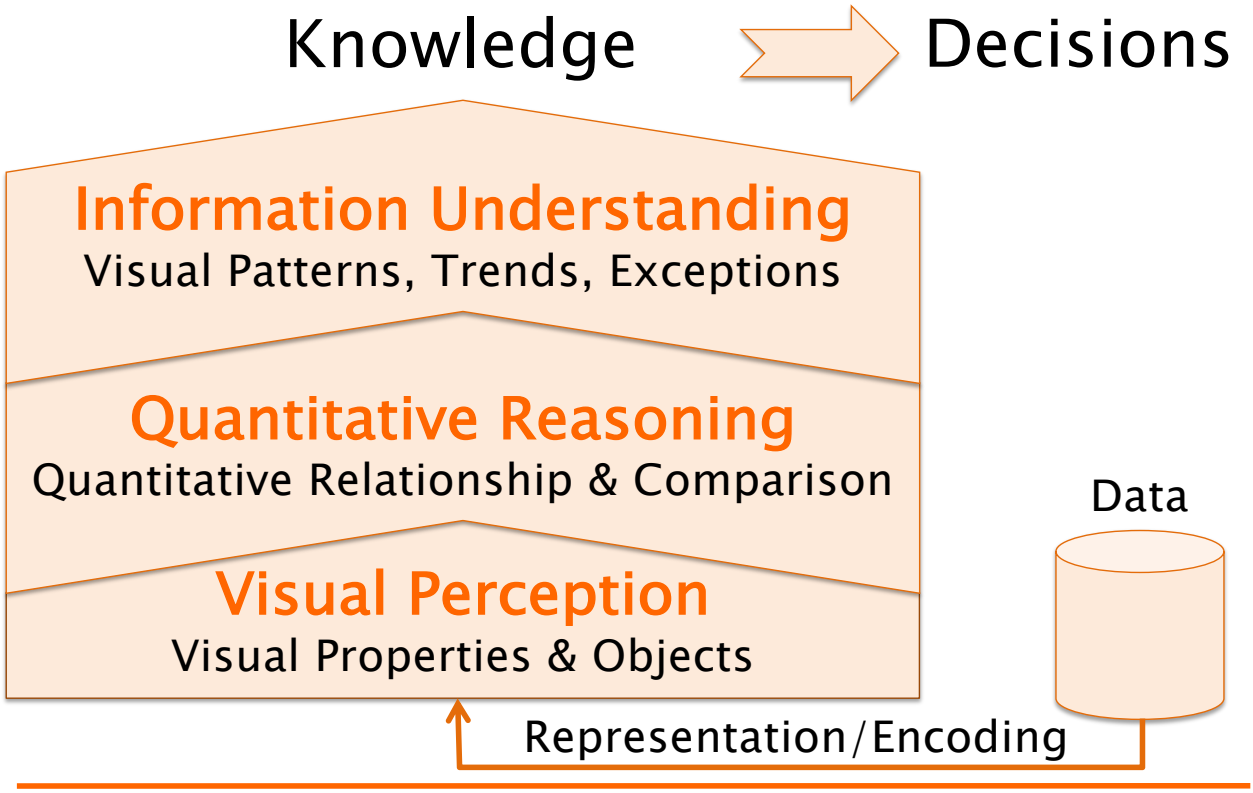
Visualizzazione dell'Informazione Quantitativa

http://softeng.polito.it/courses/VIQ

SOftEng
http://softeng.polito.it

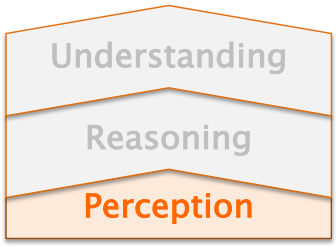
VISUALIZATION PIPELINE

Visualization Pipeline



Visual Perception

- Any variable (measure) must be visually encoded, i.e. we need to identify:
  - Visual object to represent entity
  - Visual attribute to represent the measure



Example

Votes received by four candidates in recent elections

Candidate	Votes	Proportion
Sergio	197800	50.09%
Alberto	140545	35.59%
Giorgio	53748	13.61%
Valter	2759	0.70%

http://www.comune.torino.it/elezioni/2019/regionali/presidente/citta/

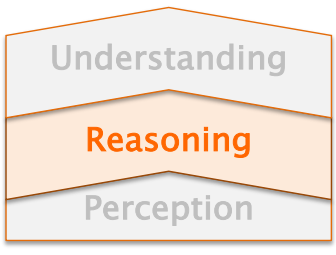
Encoding

- Visual object: line
- Visual attribute: length

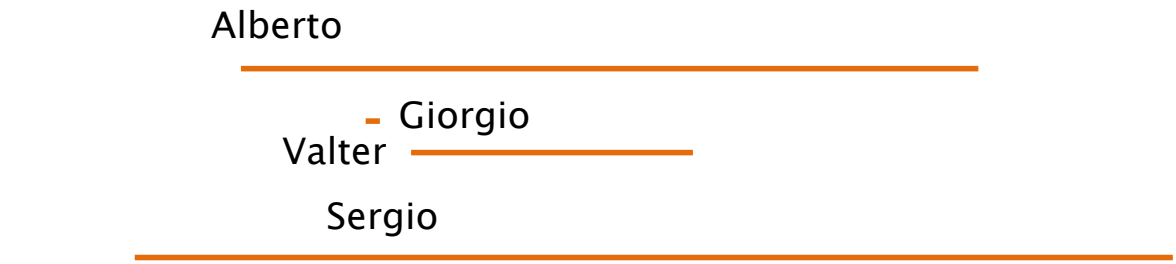
Visual Reasoning

Layout and visual attributes allow:

- Discrimination
  - Distinguish visual objects or group of –
- Comparison
  - Place visual objects in order
- Magnitude assessment
  - Evaluate the (relative) magnitude of visual objects



Reasoning



Reasoning

- Discrimination

Reasoning

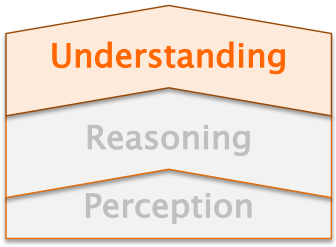
- Comparison

Reasoning

- Assessment

Understanding

- Variation within quantitative measures
  - Distribution
  - Deviation
  - Correlation
- Variation within category
  - Ranking
  - Part-to-whole
  - Time
  - Space
- Multivariate



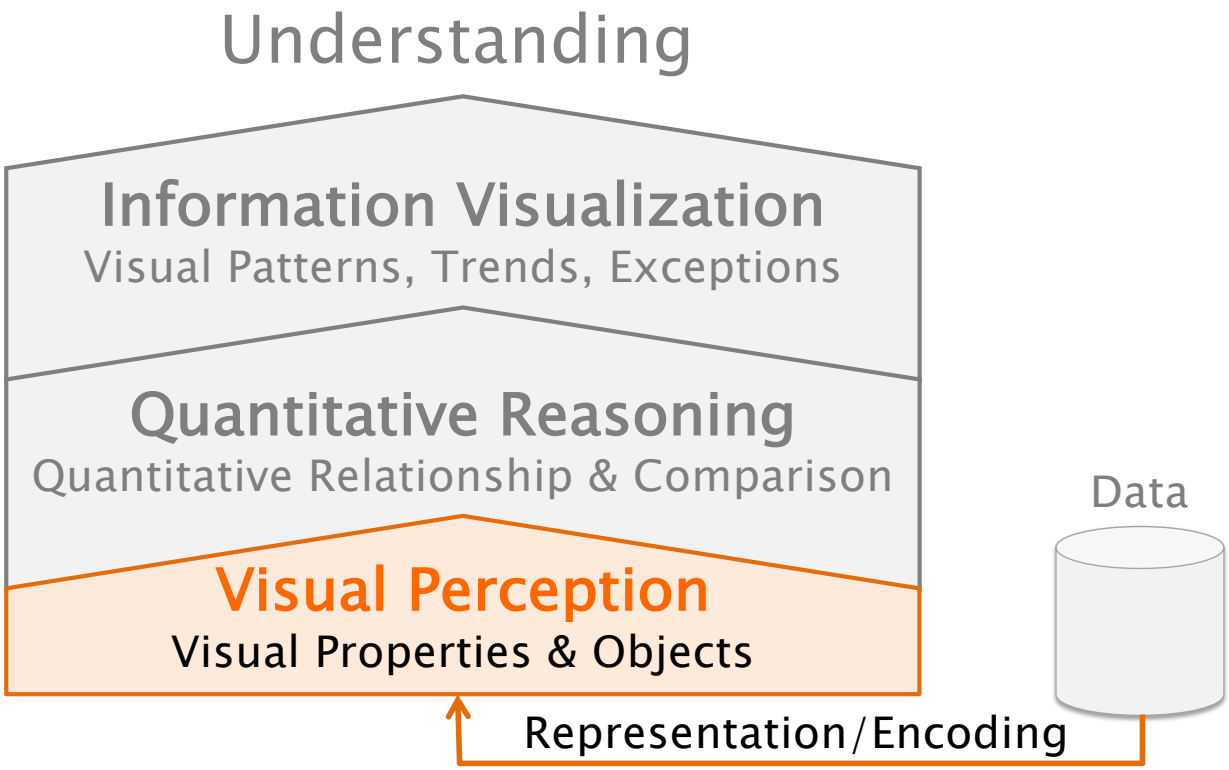
Understanding

Understanding

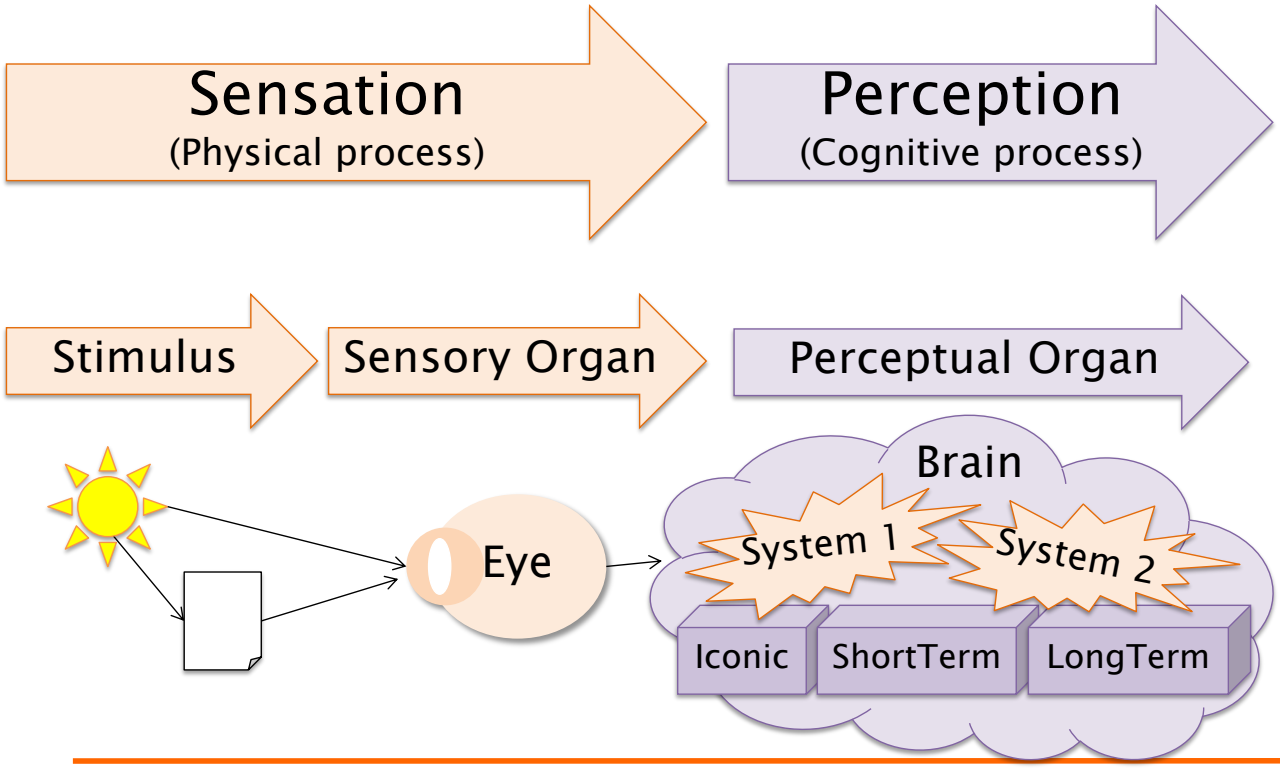
- Ranking

VISUAL PERCEPTION

Data Visualization



Visual perception



Memory Hierarchy

- Iconic memory (visual sensory register)
  - Pre-attentive processing
  - Detects a limited number of attributes
- Short-term memory (working memory)
  - Store visual chunks
  - Limited number
- Long-term memory
  - Store high-level knowledge

Simplified Model

- The three levels of memory represent a simplified model
  - does not correspond to “real” physical structure
- Useful to explain a few phenomena
  - The 7 ± 2 rule
  - Change blindness

Change blindness

http://www2.psych.ubc.ca/~rensink/flicker/download/index.html

Pre-Attentive Attributes

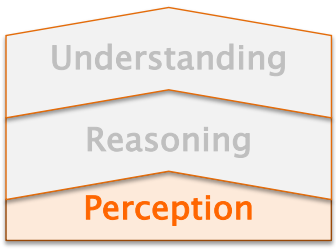
5 7 8 4 9 8 3 1 1 0 6 8 8 2 1 1 5 2 6 6 5
9 5 1 8 4 6 8 4 9 3 0 4 5 3 4 9 2 5 8 5 8
5 0 5 4 6 2 6 5 7 3 7 8 6 5 3 7 2 6 3 1 5
5 8 6 6 8 3 7 6 5 0 9 6 3 4 6 1 9 5 6 6 4
1 6 7 3 9 9 2 8 3 4 0 3 5 1 6 3 5 3 9 3 4
8 6 9 7 5 4 2 4 7 4 9 5 8 5 3 0 7 6 0 6 7
0 3 1 5 3 2 3 5 6 7 2 8 9 8 5 3 7 8 8 2 4
5 5 3 4 8 1 5 6 2 3 5 5 1 2 1 0 8 7 2 6 3
7 4 3 8 4 8 2 6 7 9 5 6 2 3 6 7 8 0 8 3 6
4 9 5 6 7 2 2 2 8 3 1 1 0 1 8 6 2 6 2 1 4

Pre-Attentive Attributes

5 7 8 4 9 8 3 1 1 0 6 8 8 2 1 1 5 2 6 6 5
9 5 1 8 4 6 8 4 9 3 0 4 5 3 4 9 2 5 8 5 8
5 0 5 4 6 2 6 5 7 3 7 8 6 5 3 7 2 6 3 1 5
5 8 6 6 8 3 7 6 5 0 9 6 3 4 6 1 9 5 6 6 4
1 6 7 3 9 9 2 8 3 4 0 3 5 1 6 3 5 3 9 3 4
8 6 9 7 5 4 2 4 7 4 9 5 8 5 3 0 7 6 0 6 7
0 3 1 5 3 2 3 5 6 7 2 8 9 8 5 3 7 8 8 2 4
5 5 3 4 8 1 5 6 2 3 5 5 1 2 1 0 8 7 2 6 3
7 4 3 8 4 8 2 6 7 9 5 6 2 3 6 7 8 0 8 3 6
4 9 5 6 7 2 2 2 8 3 1 1 0 1 8 6 2 6 2 1 4

Encoding

- Encoding is the key to enable visual perception
  - Visual object to represent entity
  - Visual attribute to represent the measure
- Two main types
  - Quantitative (different properties)
  - Categorical (ordinal or not)



Pre-Attentive attributes

Category	Attribute
Form	Orientation Length/distance Line width Size Shape Curvature Added marks Enclosure
Color	Hue Intensity
Spatial position	2-D position
Motion	Flicker Direction Speed

Perception task

Visual attributes allow:

- Discrimination
  - Distinguish visual objects
- Comparison
  - Place visual objects in order
- Magnitude assessment
  - Evaluate the (relative) magnitude of visual objects

Just noticeable difference

- Given a phisical dimension (length, brightness, etc.) xx
- *d* is the just noticeable difference if:
  - difference between *x* and *x+d* is perceivable
  - but not smaller differences
- *d* depends on many factors:
  - Subject
  - Environment
  - Physical dimension

Weber's law

- Just noticeable difference *d* is:

$$d_p(x) = k_p \cdot x$$

- Where
  - x: dimension
  - $d_p(x)$: just noticeable difference
  - k_p: constant
    - Subjective
    - Environmental

Consequences of Weber's law

- It is easier to compare lengths that differ by a large percentage
- The same difference is easier to notice between smaller measures
  - More likely to be larger than just noticeable difference

$$x < y \implies d_p(x) < d_p(y)$$

Non-aligned objects lengths

Non-aligned objects lengths

- Additional references my help comparison
  - They provide alternative possible comparisons
- If lengths range between 0 and a maximum (L), e.g. percentages
- Comparing l_1 and l_2 (close to L) that differ by a small amount d
  - Difference $L-l_1$ vs. $L-l_2$ easier to notice than l_1 vs. l_2

Stevens's law

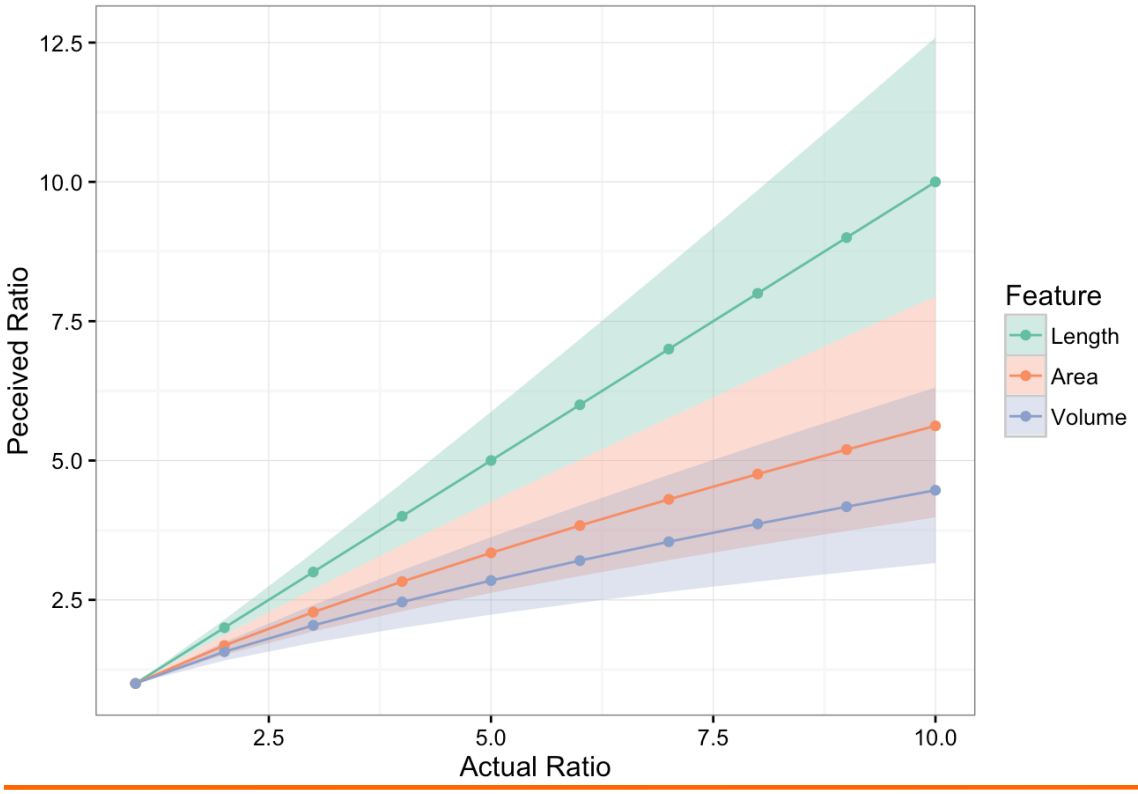
- Perceive scale (magnitude ratio)

$$p(x) = c \cdot x^{\beta}$$

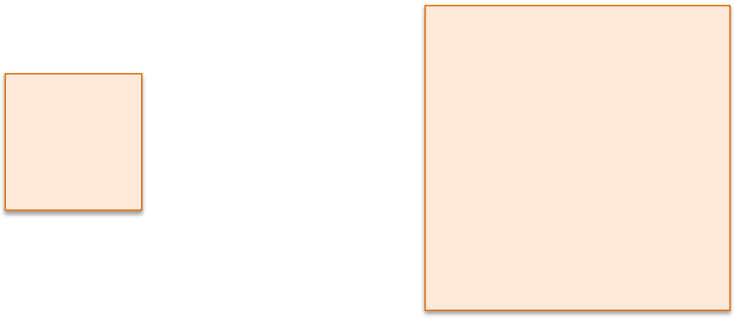
- Where β depends on spatial dimension
  - 1D: Length → β in [0.9, 1.1]
  - 2D: Area → β in [0.6, 0.9]
  - 3D: Volume → β in [0.5, 0.8]

Stevens S. S. (1975). Psychophysics, John Wiley & Sons.

Steven's law



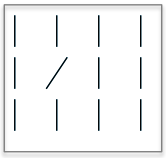
Steven's law

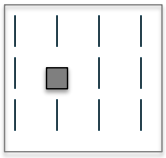


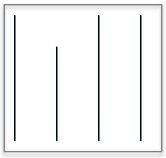
Consequences

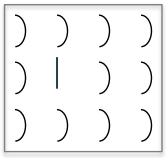
- Prefer comparing lengths
- Avoid comparison between areas
  - Except for ordinal measures
- Never-ever make volume comparisons

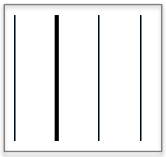
Attributes of form

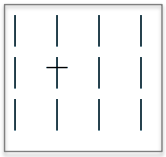
Orientation 

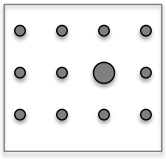
Shape 

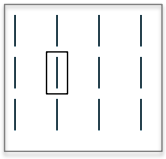
Line Length 

Curvature 

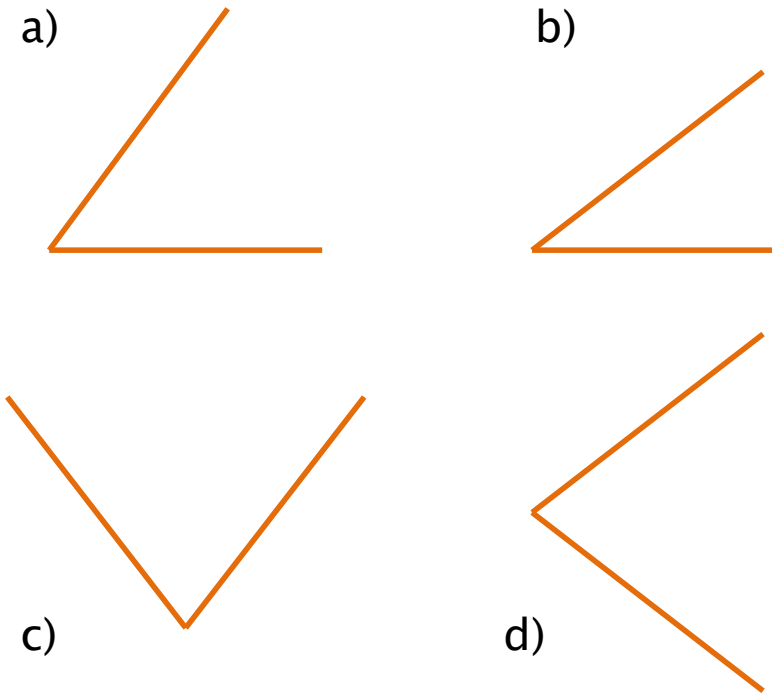
Line Width 

Added mark 

Size 

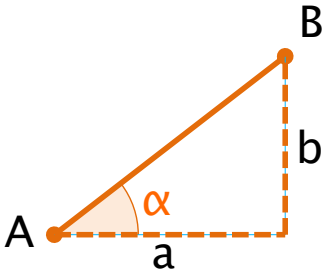
Enclosure 

Orientation (angle or slope)



Angle vs. Slope

- Slope of A–B is b/a
  - tan(α)
- Slope judgment typically falls back to an angle judgment
  - Given an error ϵ in the angle judgment
  - It is reflected in a slope error

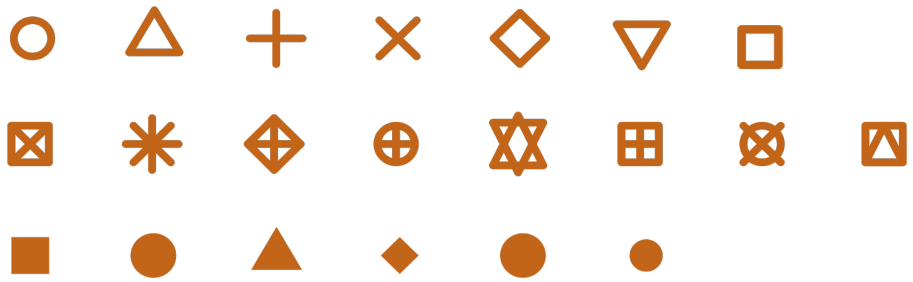


$$tan(\alpha+\epsilon) - tan(\alpha) = \epsilon \cdot tan'(\alpha) = \frac{\epsilon}{cos^2(\alpha)}$$

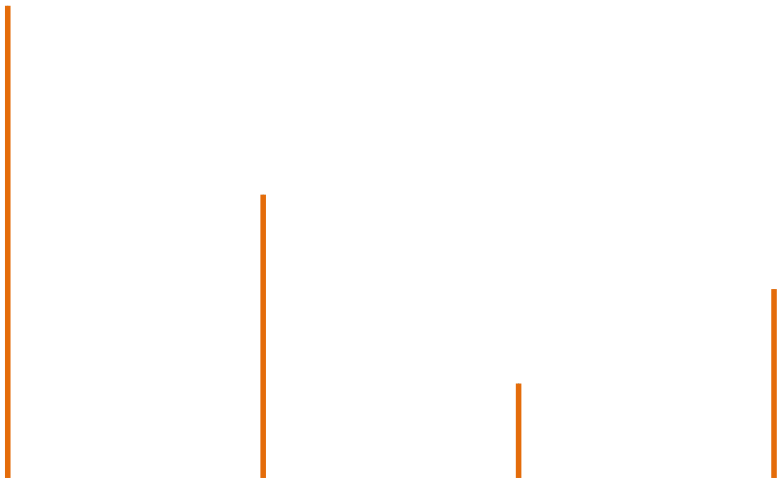
– Getting infinite as α approaches to π/2

Shape

- There is no common quantitative semantics for the shapes
  - Unless they are characters…
  - Fill textures are shapes too



Length



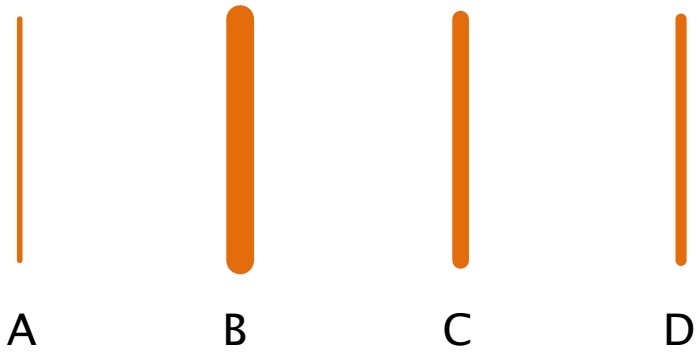
Effect of context

Curvature

- There is no common magnitude assessment for the curvature

Width

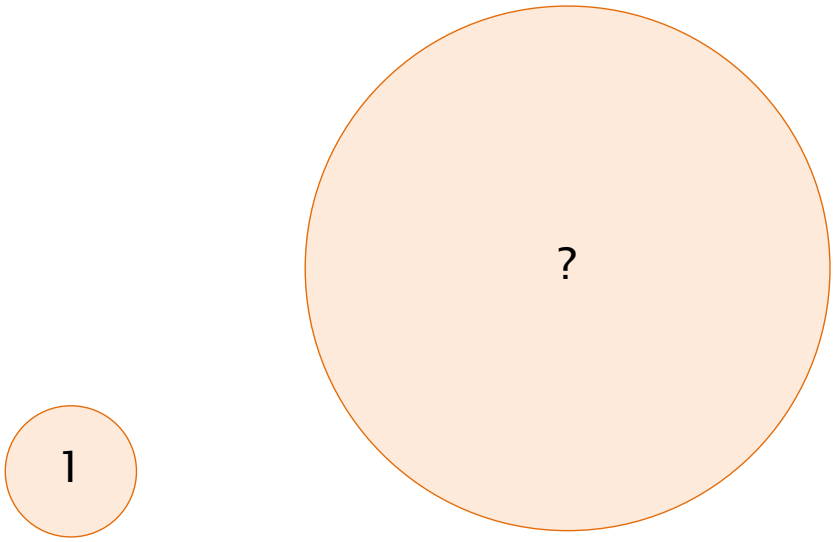
- Order can be identified
  - Difficult to appreciate actual magnitude



Mark

- No common quantitative semantics of marks
- Number of marks could encode a natural number
  - Harder to read than a cipher

Size / Area

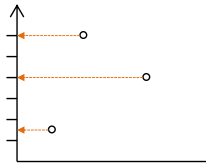


Enclosure

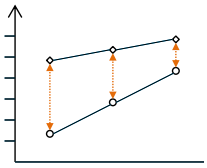
- No common quantitative semantics for enclosure
  - Except counting items enclosed

Spatial Position

- Position along axis
  - Common scale
  - Distinct identical scales
    - Possibly un-aligned

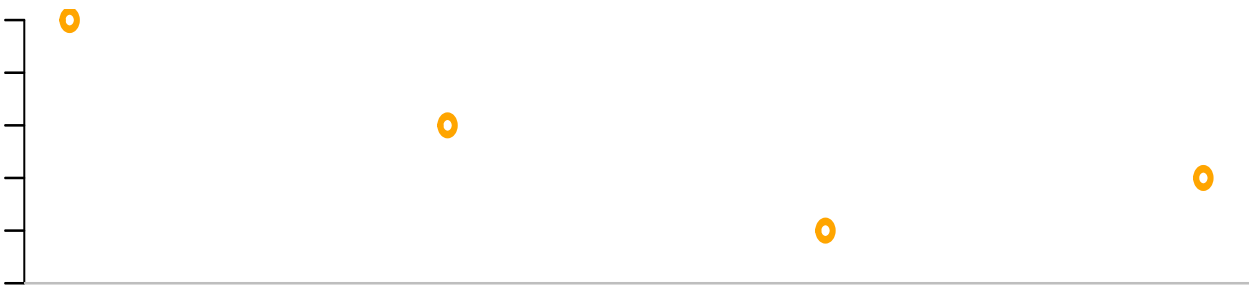


- Distance

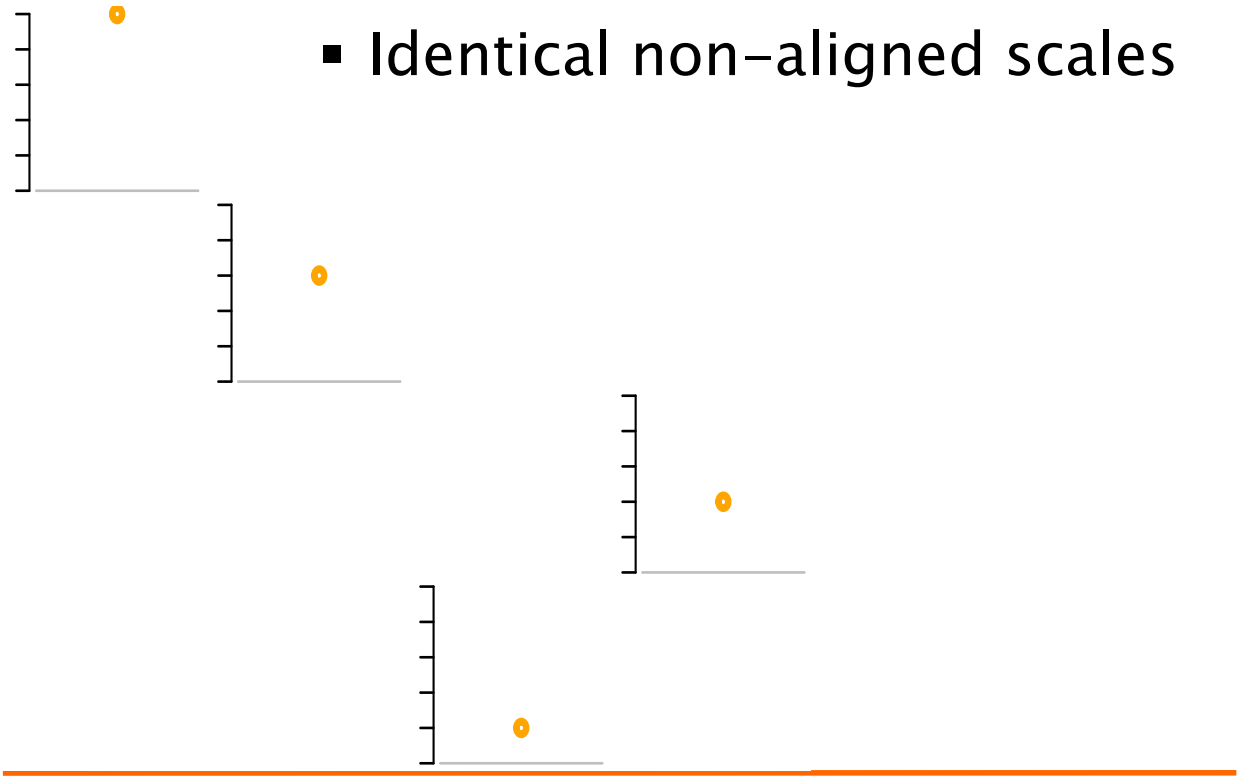


Position

- A common scale



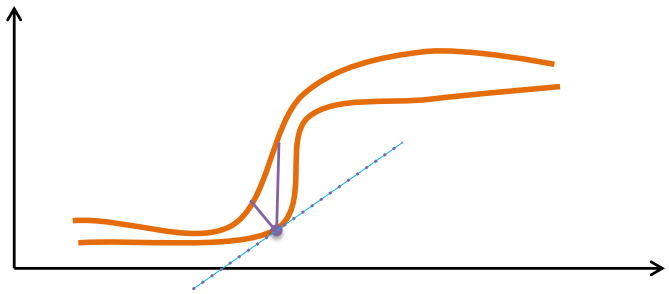
Position



- Identical non-aligned scales

Distance

- Points
  - Use length of imaginary connecting lines
- Lines
  - Distance orthogonal to tangent
    - Not what is meant in xy plots



Detection and Separation

Comparison is affected by:

- Detection
  - The capability to visually identify the objects that represent the data to be compared
- Separation
  - The distance between the objects to be compared
    - affects negatively the accuracy

Attributes of color

- Hue

- Saturation

- Intensity

  - Luminance
  - Value

Hue

- There is no common ordering semantics for hues
  - High spatial frequencies are perceived through intensity changes
  - Often perceived as separated into bands of almost constant hue, with sharp transitions between hues
- Nominal values can be represented by suitably spaced values

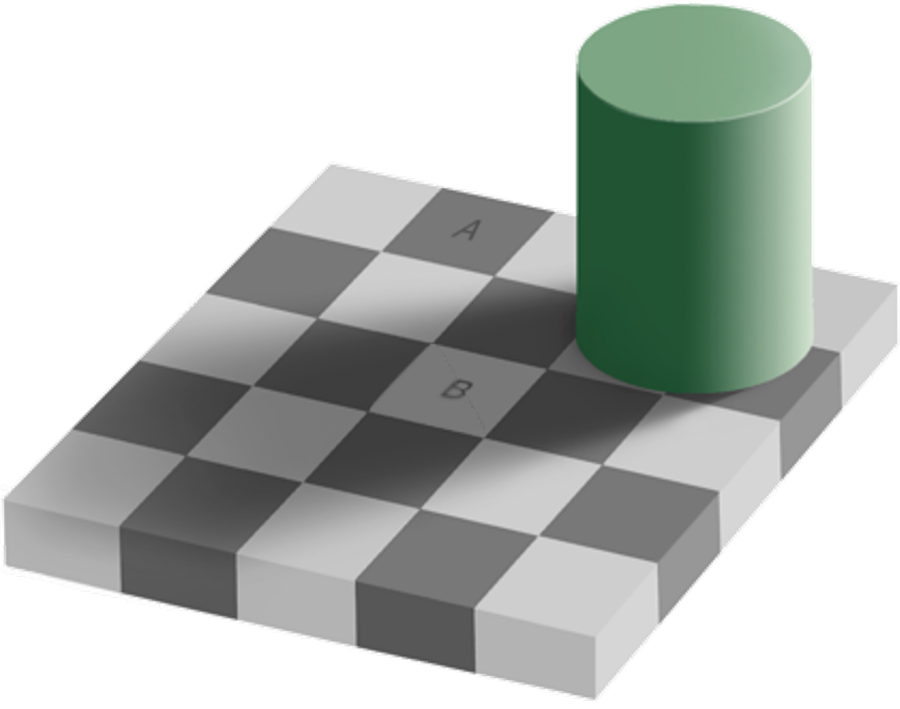
Intensity

  - a.k.a. Luminance, Value
- Provides a perceptually unambiguous ordering
  - Context can affect accuracy

Saturation

- Perceptually difficult to associate an ordered semantics
  - Can be combined with hue to increase discrimination

Effect of Context



Effect of Context

- Use uniform background
  - To make distinct visual objects for the same feature look the same
- Use a background color that is contrasting enough with the visual objects' color
  - To make visual objects easily seen
- Avoid non-uniform background

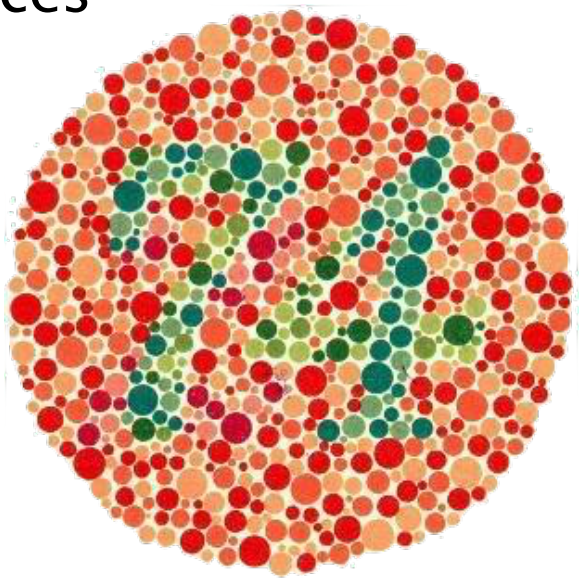
Color usage

- Ordinal measure should be mapped to increasing saturation and intensity
  - Avoid rainbow palette
- Use sequential or diverging palette
  - E.g.

– http://colorbrewer2.org/

Color Blindness

- Inability so see colors or perceive color differences



http://www.color-blindness.com

Pre-Attentive attributes

Category	Attribute	Quantitative
Form	Orientation	Partly
	Length	Yes
	Line width	No
	Size	Partly
	Shape	No
	Curvature	No
	Added marks	No
	Enclosure	No
Color	Hue	No
	Intensity	Limited
Spatial position	2-D position	Yes
Motion	Flicker	No
	Direction	No

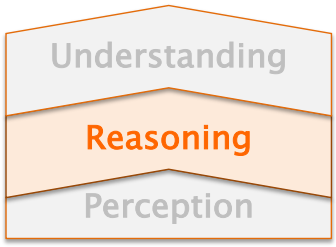
Visual Encoding: Quantitative

Object	Attribute
Point	Position (w.r.t. axis/axes)
Line	Length Position (w.r.t. axis/axes) Slope
Bar	Length
Shape	Size (area) Count

Visual Encoding: Categorical

Attribute		
Position		Ordinal
Size		Ordinal
Color	Intensity	Ordinal
	Saturation	Ordinal
	Hue	Categorical
Shape		Categorical
Fill pattern		Categorical
Line style		Categorical

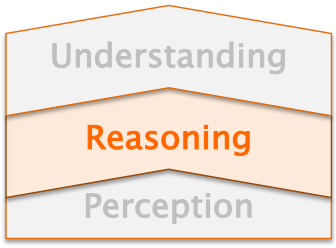
VISUAL REASONING



Graph layout

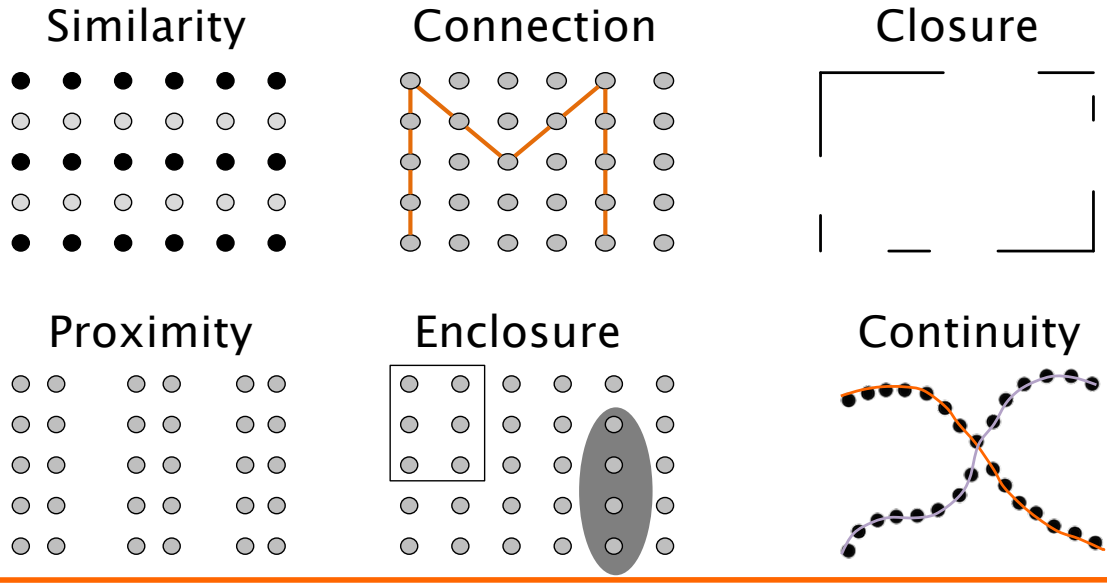
Layout + visual attributes should allow:

- Discrimination
  - Distinguish visual objects or group of –
- Comparison
  - Place visual objects in order
- Magnitude assessment
  - Evaluate the (relative) magnitude of visual objects



Gestalt principles

- Visual features that lead the viewer to group visual objects together



Gestalt principles

- Visual patterns that lead observers to perceive objects together or separate
  - Proximity
  - Similarity
  - Enclosure
  - Closure
  - Continuity
  - Connection

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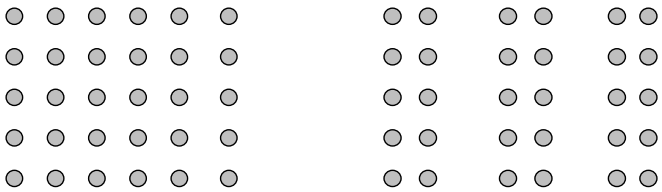

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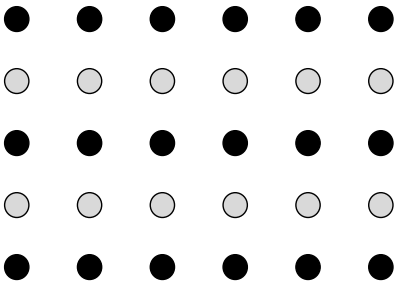

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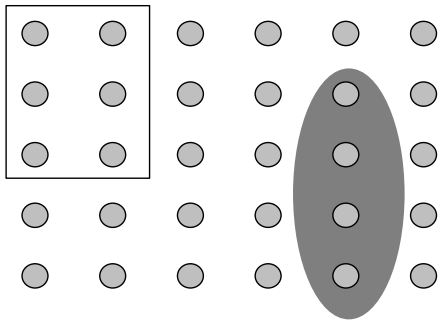

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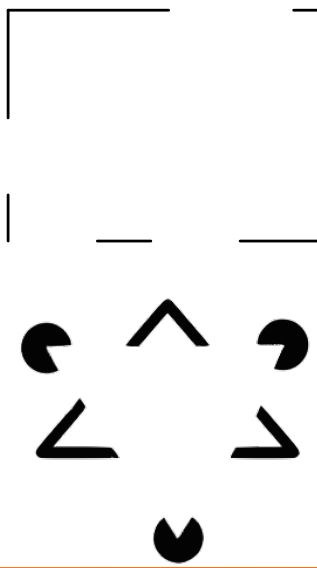

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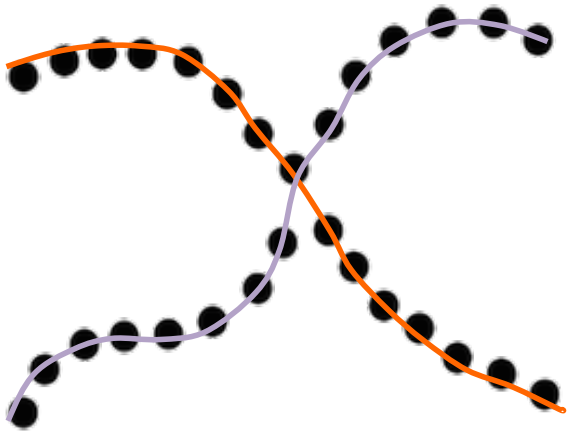
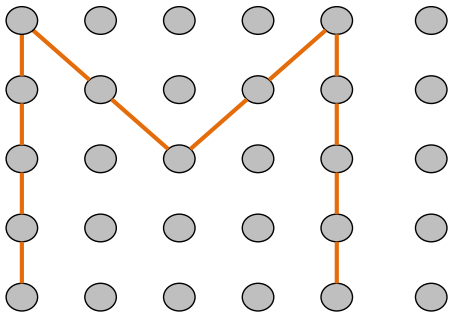
  - Closure
  - **Continuity**
  - Connection

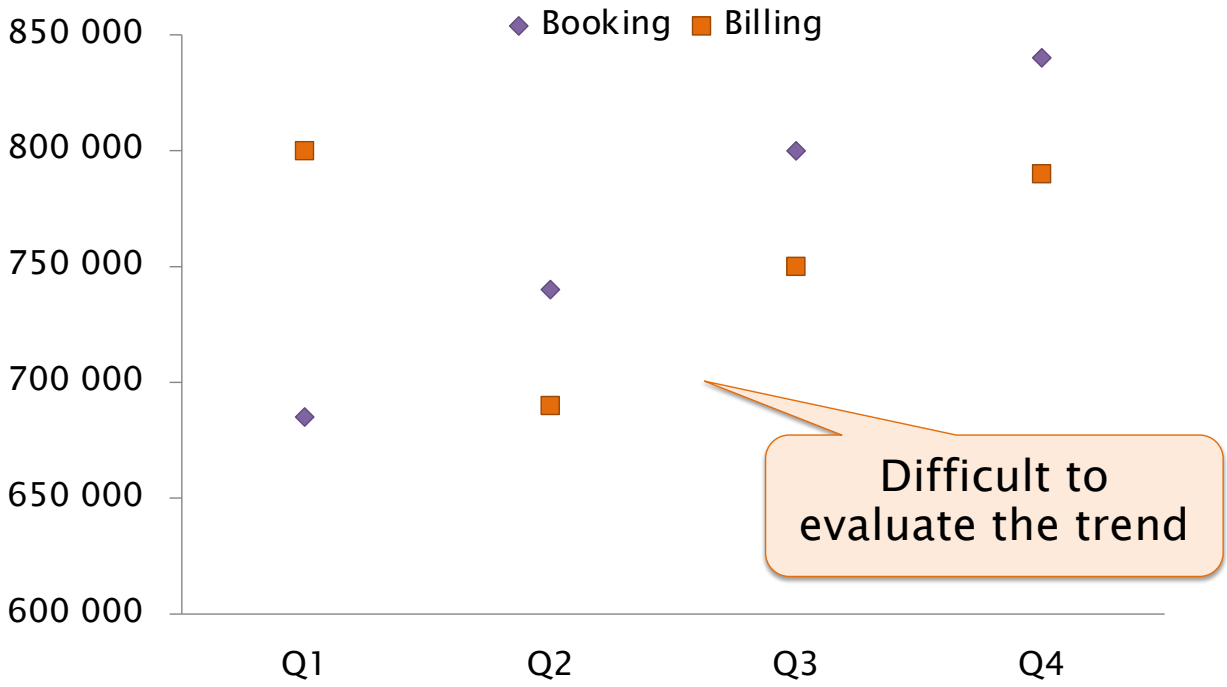


Gestalt principles

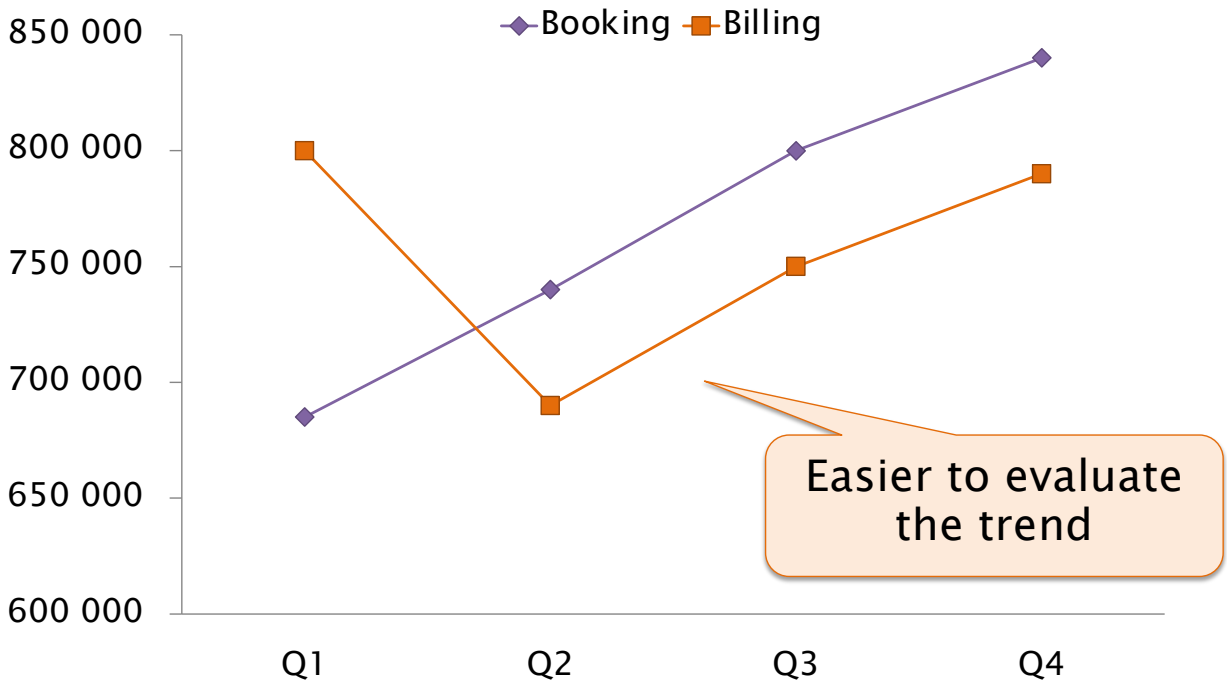
- Visual patterns that lead observers to perceive objects together or separate
  - Proximity
  - Similarity
  - Enclosure
  - Closure
  - Continuity
  - **Connection**



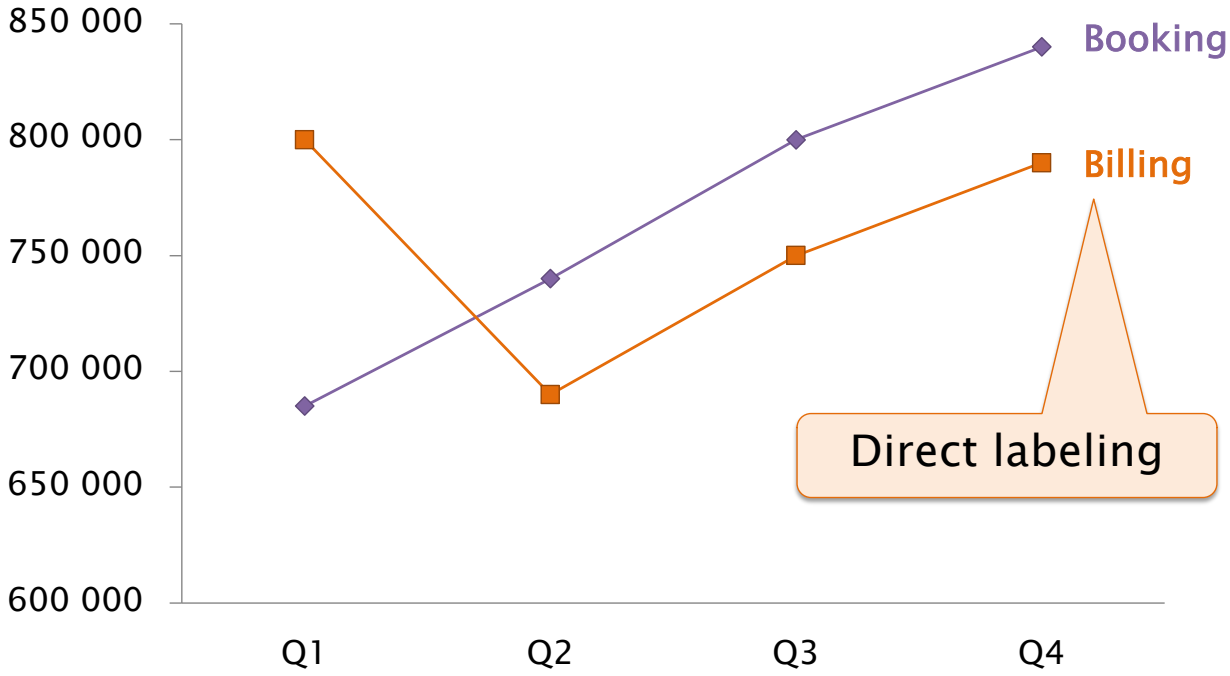
Similarity in Shape & Color



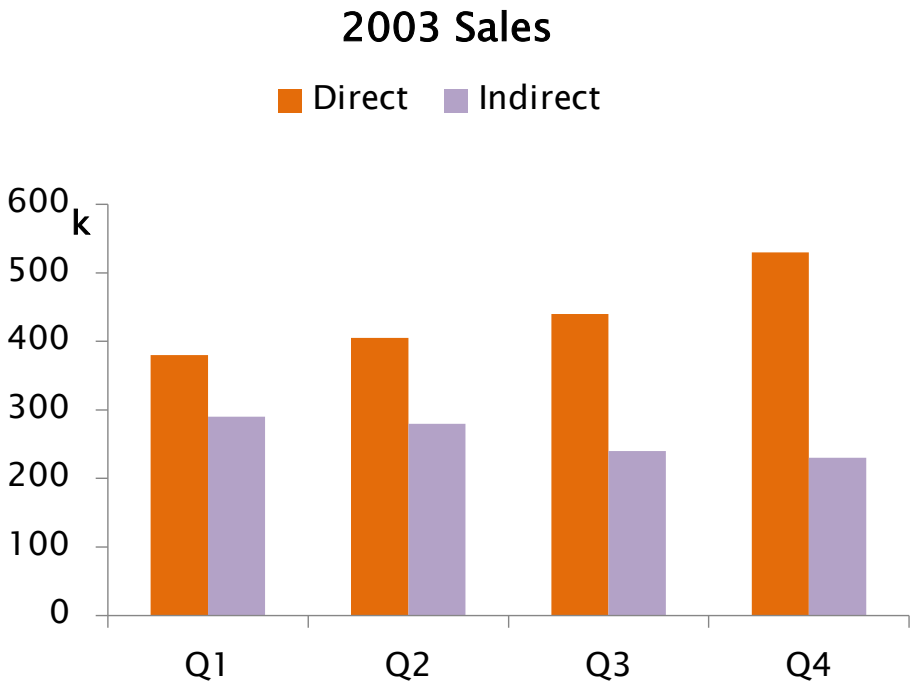
Similarity+Connection



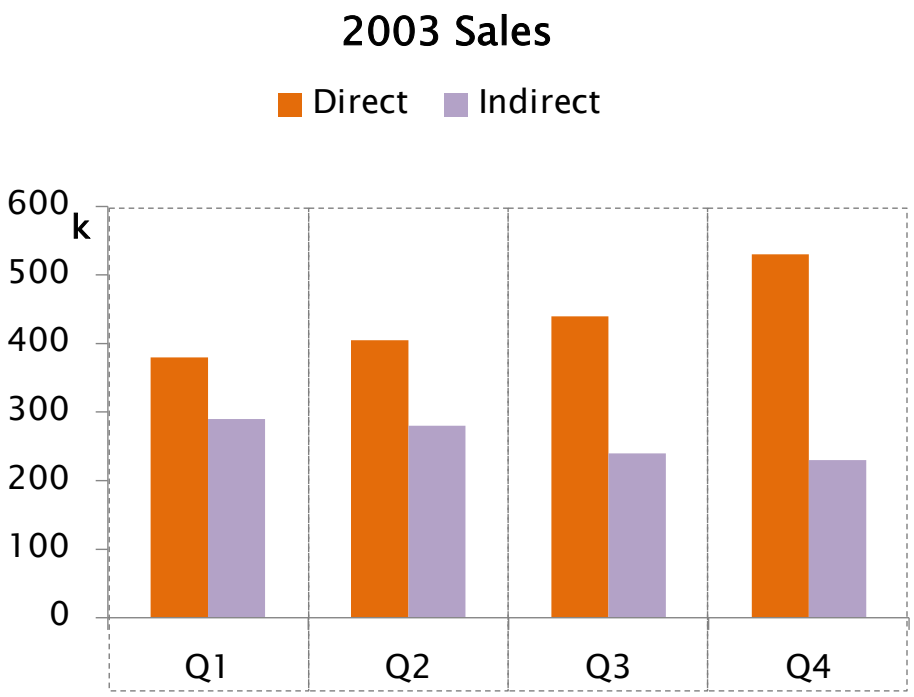
Similarity+Connection+Proximity



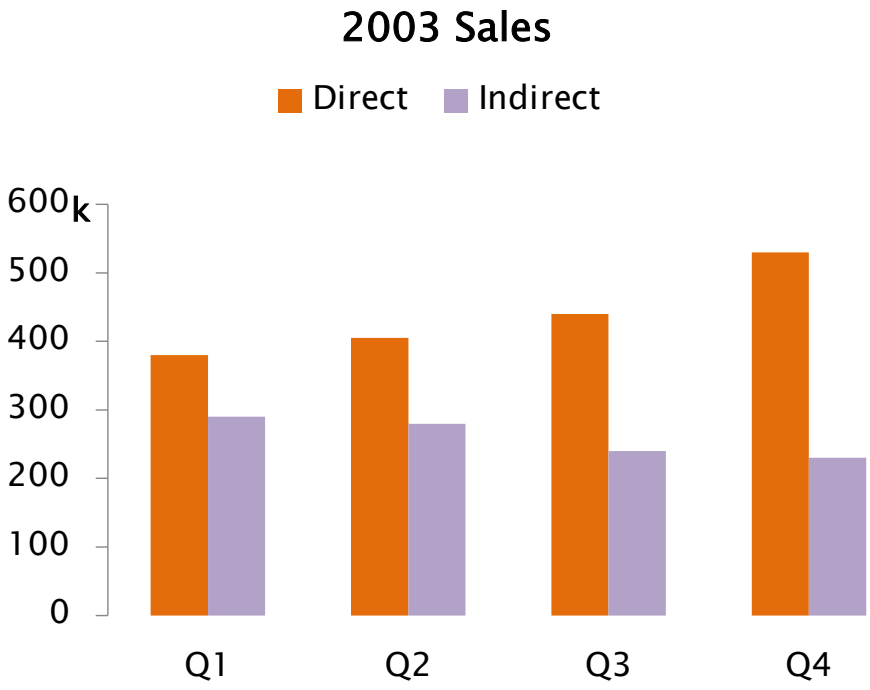
Similarity × Proximity



Similarity × Proximity & Enclosure



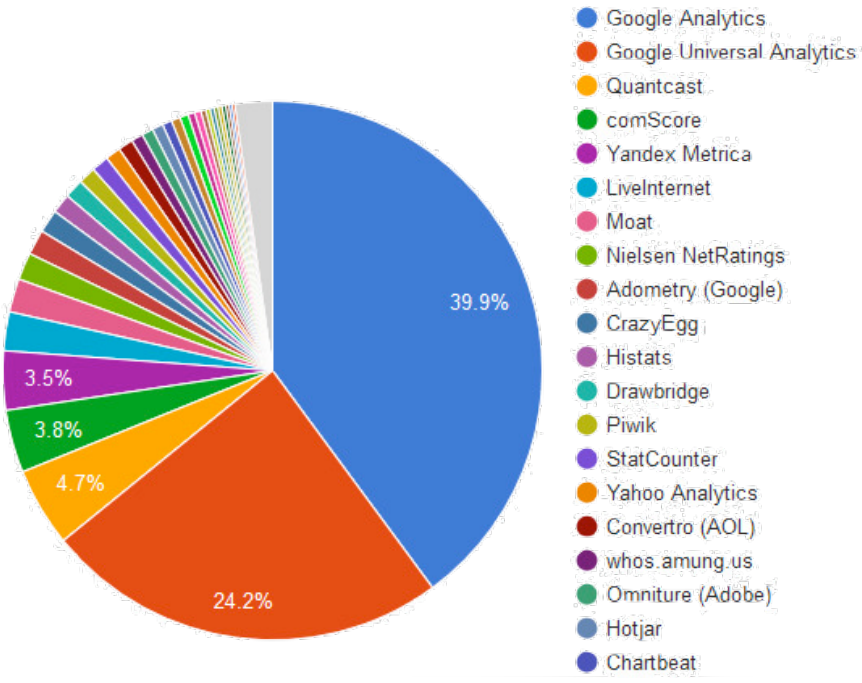
Continuity replaces axis



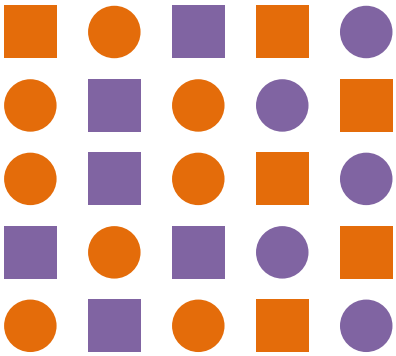
Distinct perceptions

- The immediacy of any pre-attentive cue declines as the variety of alternative patterns increases
  - Even if all the distracting patterns are individually distinct from the target
  - For each single attribute no more than four distinct levels are immediately discernible
  - This limit affects the similarity principle

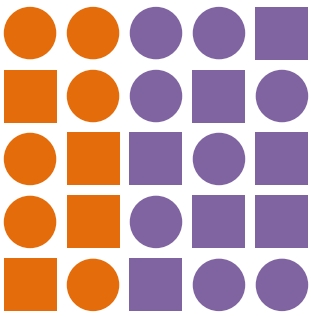
Rainbow Pies

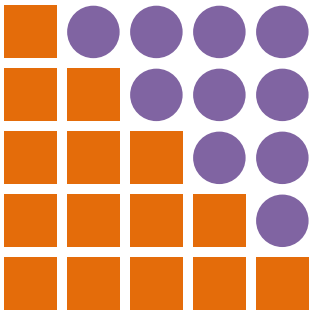


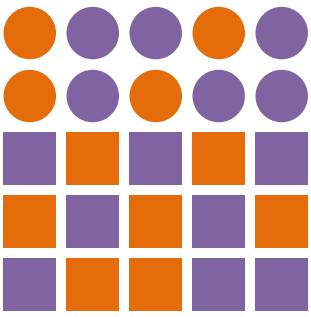
Attribute Interference

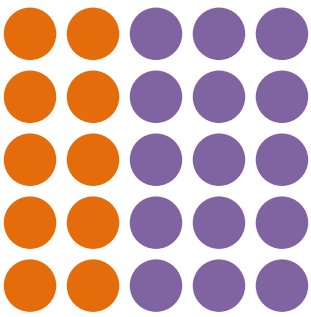


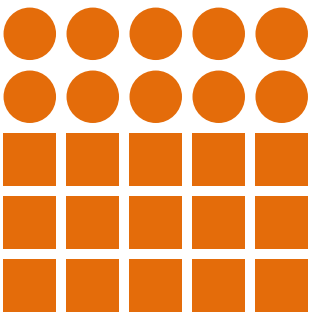
Attribute Interference











Cultural conventions

- Reading proceed from left to right and from top to bottom
  - At least in western culture
- What is at the top (on the left) precedes what is at the bottom (on the right) in terms of
  - Importance
  - Ordering
  - Time

Emphasis

Attribute	Tables	Graphs
Line width	Boldface text	Thicker lines
Size	Bigger tables Larger fonts	Bigger graphs Wider bars Bigger symbols
Color intensity	Darker or brighter colors	
2-D position	Positioned at the top Positioned at the left Positioned in the center	

Visualizzazione dell'Informazione Quantitativa

VISUAL INTEGRITY

Principles of integrity

PUC

- Proportionality
  - Representation as physical quantities should be proportional to the represented numbers
- Utility
  - Graphical element should convey useful information
- Clarity
  - Labeling should counter graphical distortion and ambiguity

Proportionality

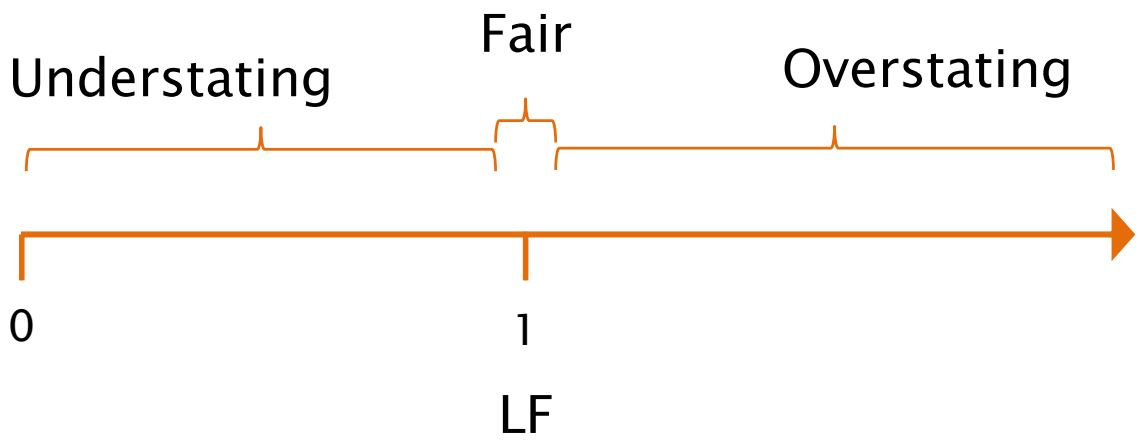
PUC

- The magnitude of visual attributes should represent faithfully the magnitude of measures
- They should allow
  - Discrimination: are they different?
  - Comparison: which is larger?
  - Magnitude Assessment: how much larger?

Lie Factor

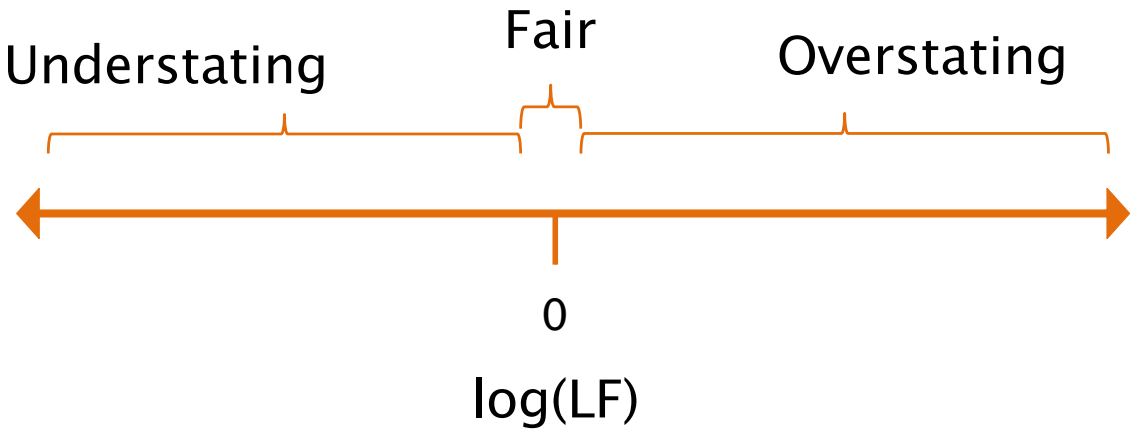
PUC

$$LF = \frac{\text{size of effect shown in graphic}}{\text{size of effect in data}}$$



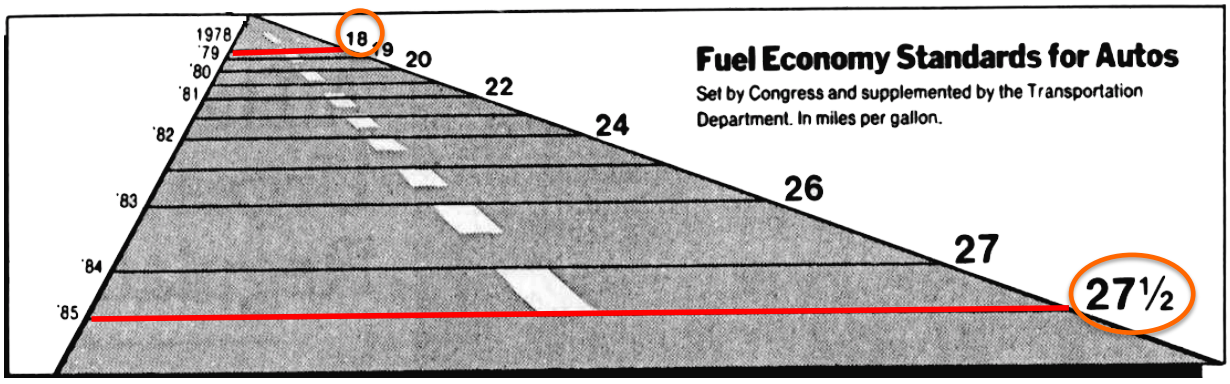
Lie Factor

$$LF = \frac{\text{size of effect shown in graphic}}{\text{size of effect in data}}$$



Lie Factor – Example

PUC



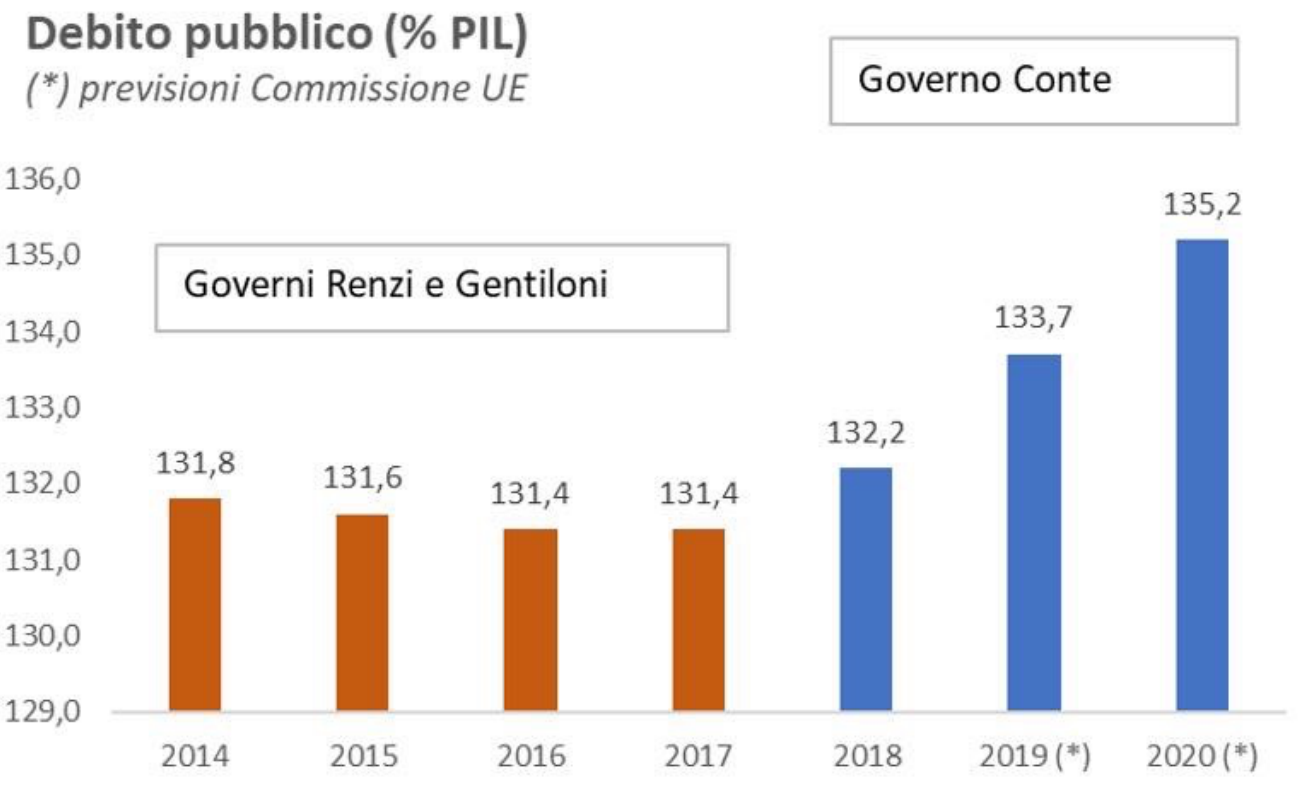
$\frac{18.7}{2.2}$ = 8.5 on graphic

$\frac{27.5}{18}$ = 1.52 in data

LF = 8.5 / 1.52 = 5.59

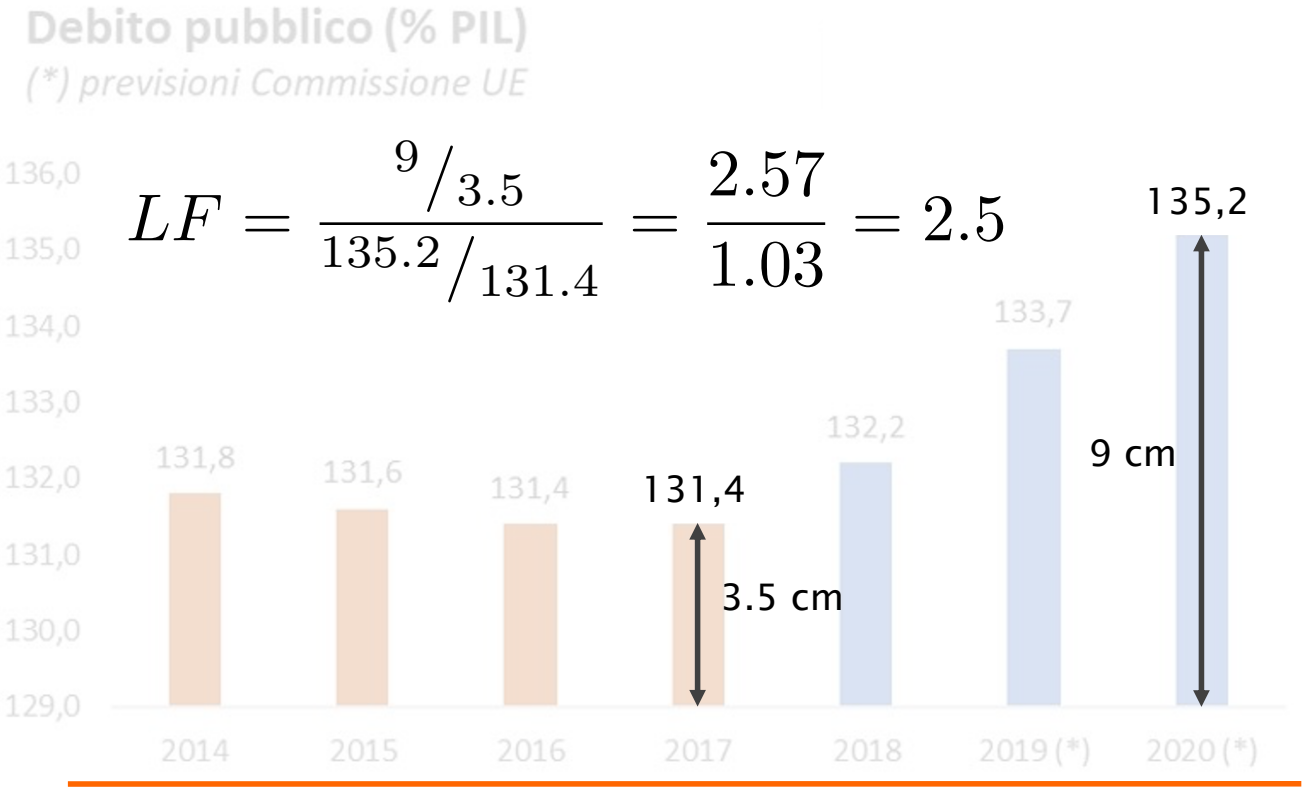
Lie Factor – Example

PUC



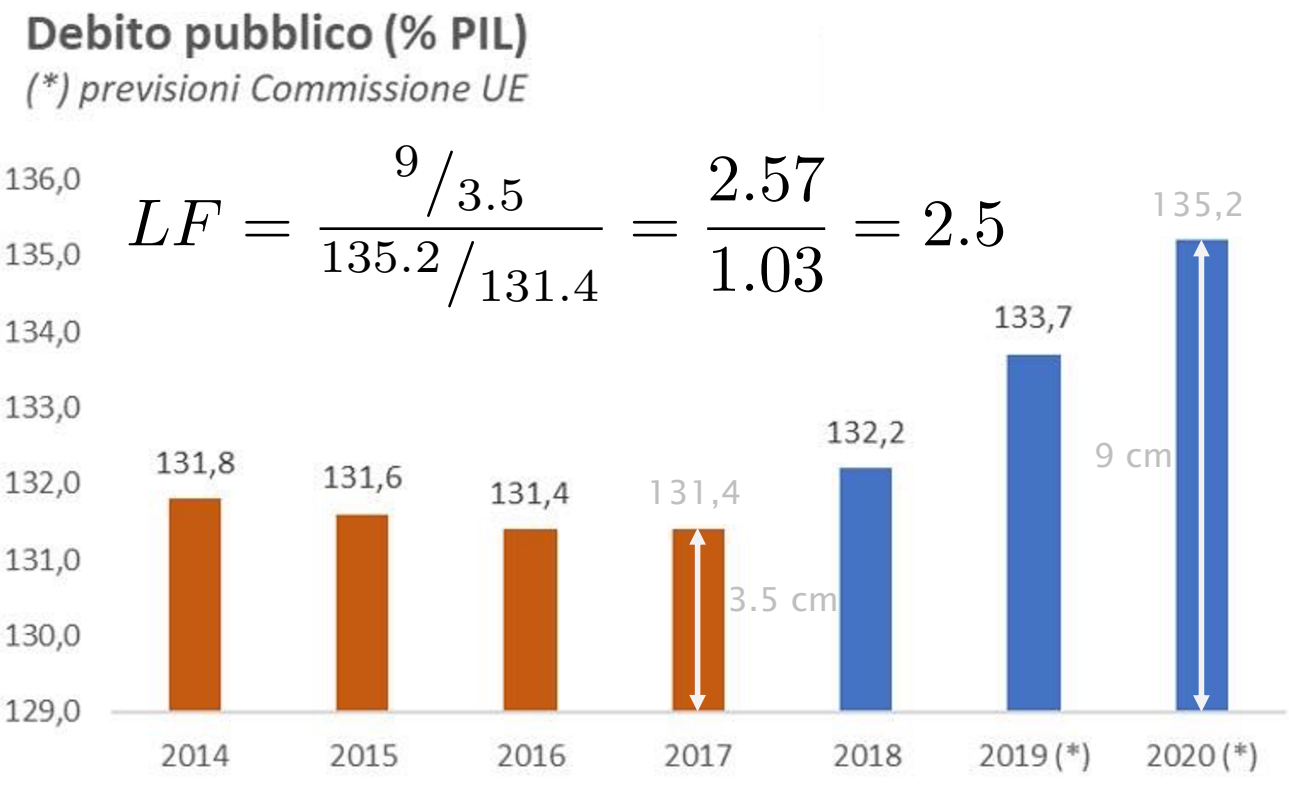
Lie Factor – Example

PUC



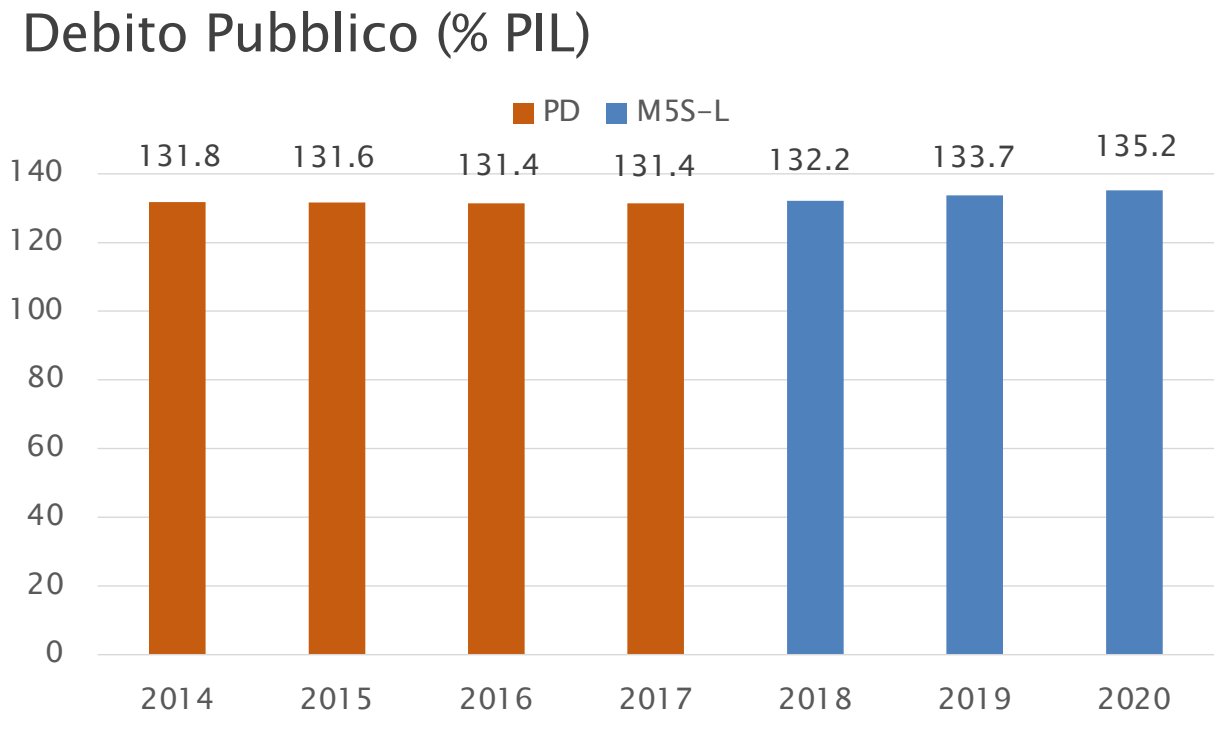
Lie Factor – Example

PUC



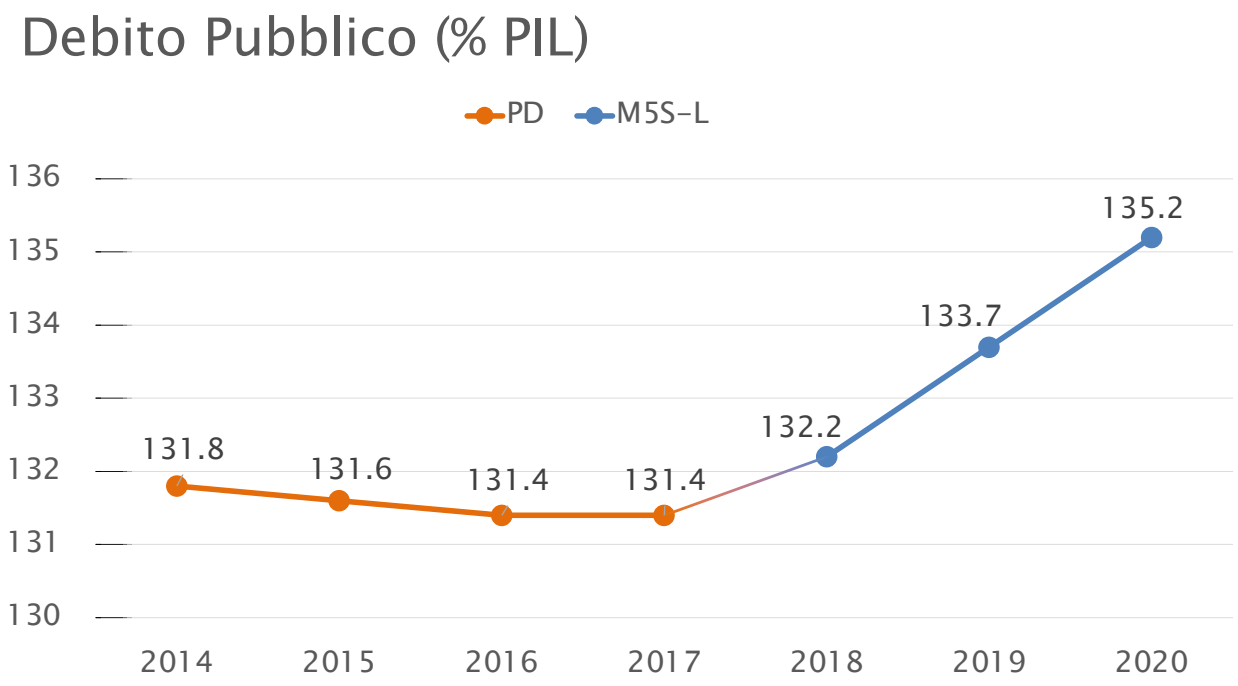
Lie Factor –Redesign

PUC



Lie Factor – Redesign

PUC



Guidelines for design

- Keep the physical Lie Factor = 1
- Limit the perceptual Lie Factor as much as possible
  - Per Steven's law, avoid area comparisons

Utility

PUC

- Every element should convey useful information
- Unnecessary visual objects or attributes distract from the message
  - Different attributes trigger a search for a rationale (e.g. random colors)

Data-ink

PUC

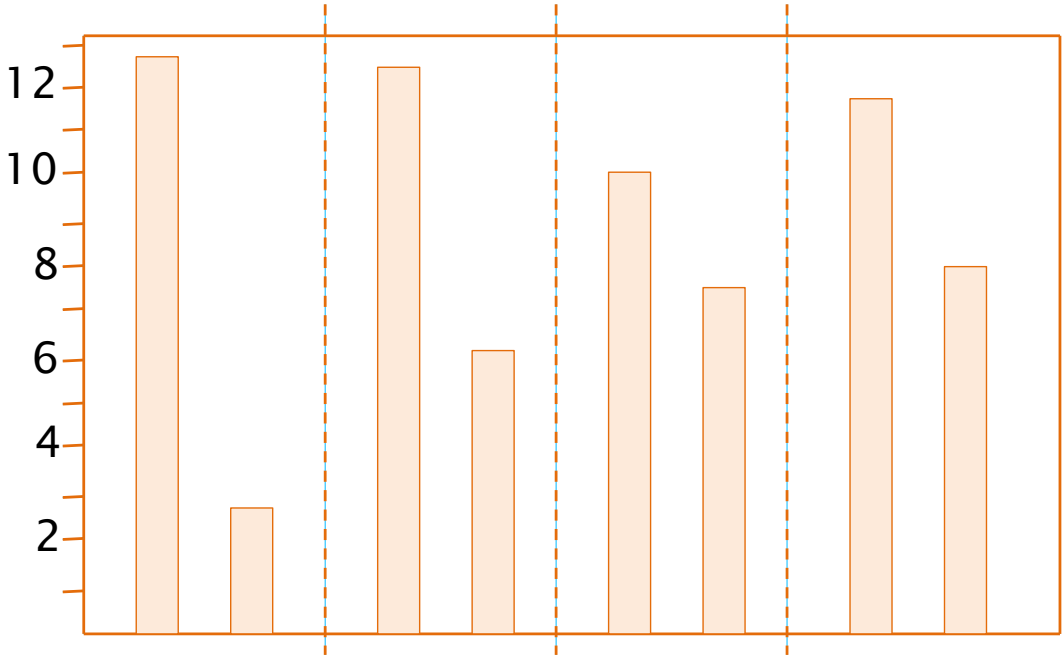
$$\text{Data-ink ratio} = \frac{\text{data ink}}{\text{total ink used to print the graphic}}$$

- Proportion of a graphic's ink devoted to the non-redundant display of data information
  - Or:

$$1 - \frac{\text{ink that can be erased without loss of information}}{\text{total ink used to print the graphic}}$$

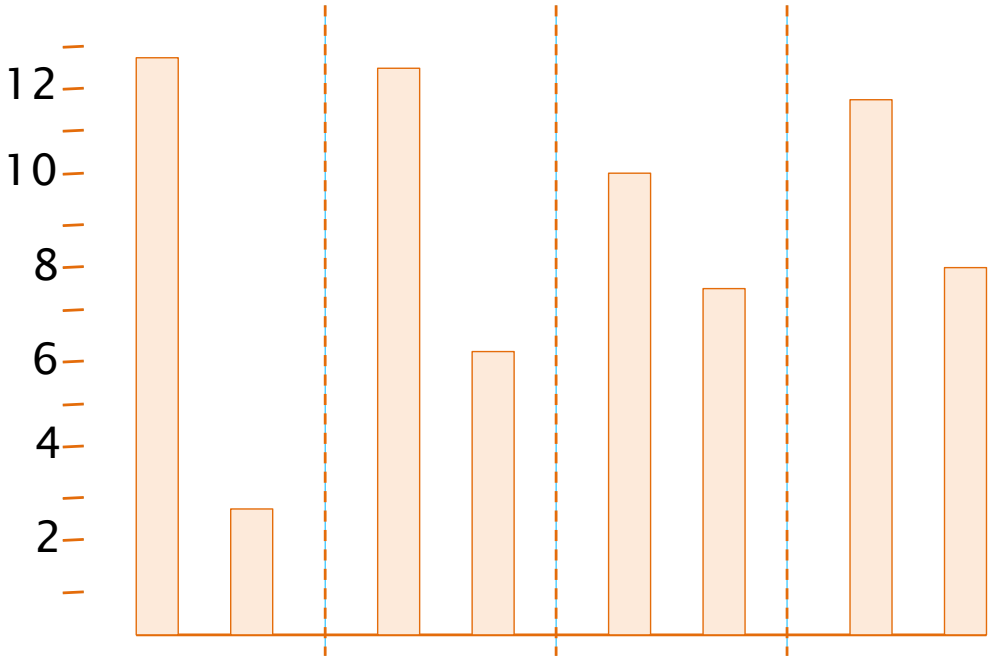
Data-ink

PUC



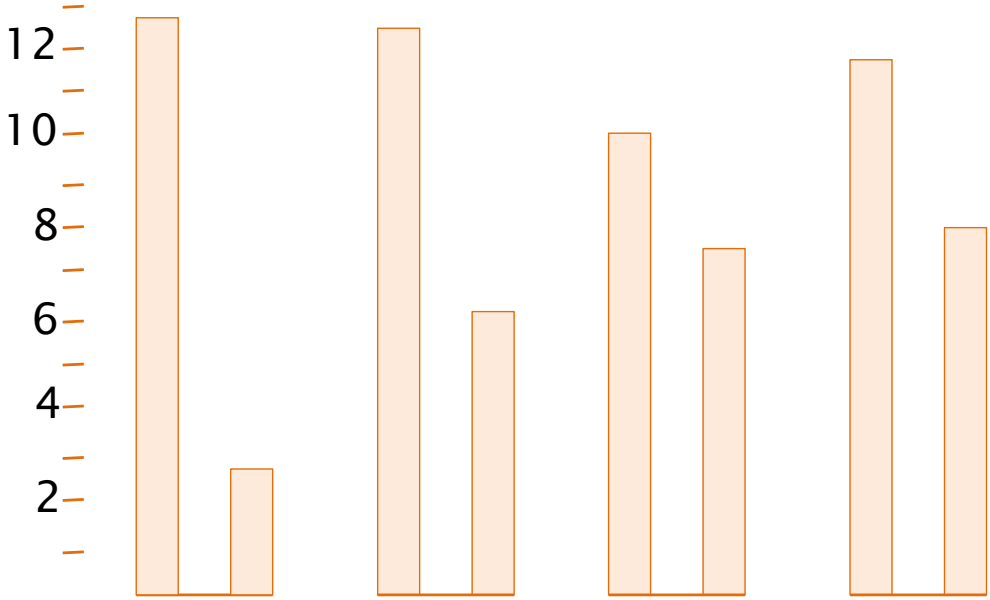
Data-ink

PUC



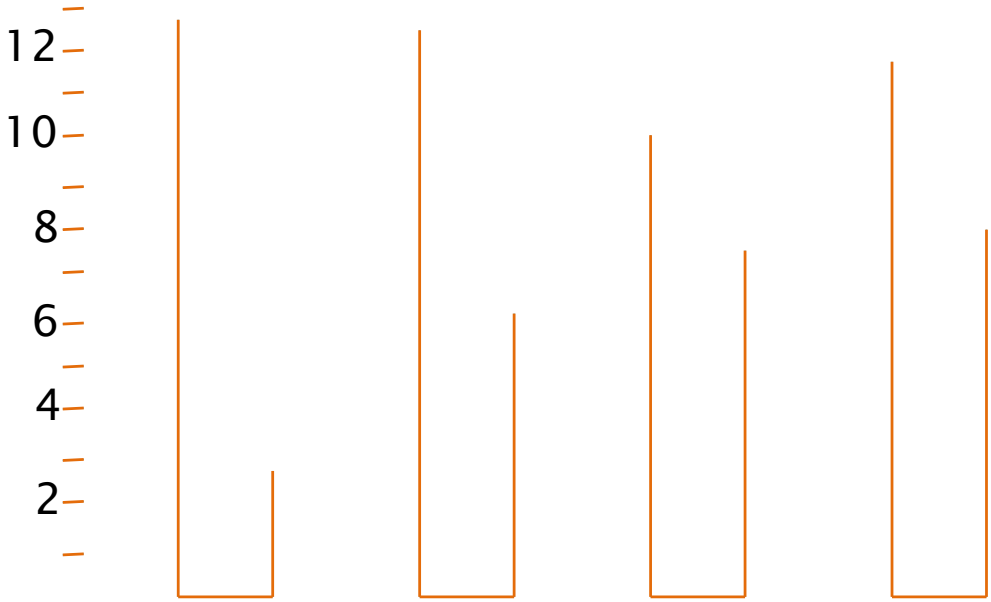
Data-ink

PUC



Data-ink

PUC



Tufte's proposed redesign

Guidelines for design

PUC

- Maximize data-ink ratio
  - Erase non-data-ink
  - Erase redundant data-ink
- "Within reason"

Above all else show the data

E. Tufte

Use of contrast

PUC

- Include differences corresponding to actual differences
- Effective when one item is different in a context of other items that are the same
  - Bright saturated color among mid colors

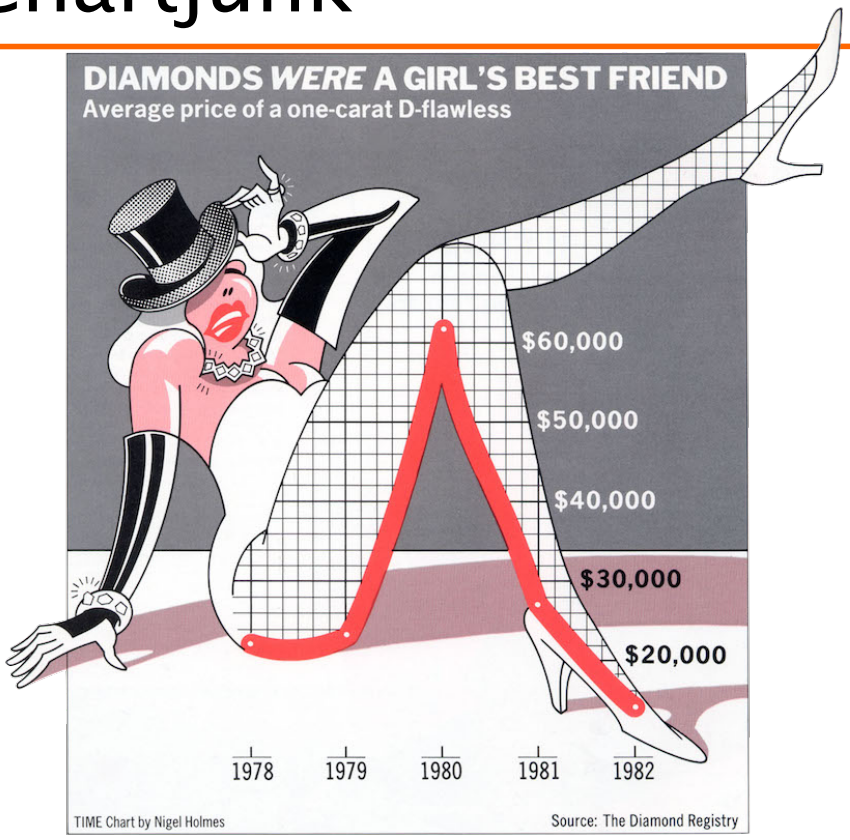
Chartjunk

PUC

- The presence of unnecessary elements that distract or hide the message conveyed by the diagram

Chartjunk

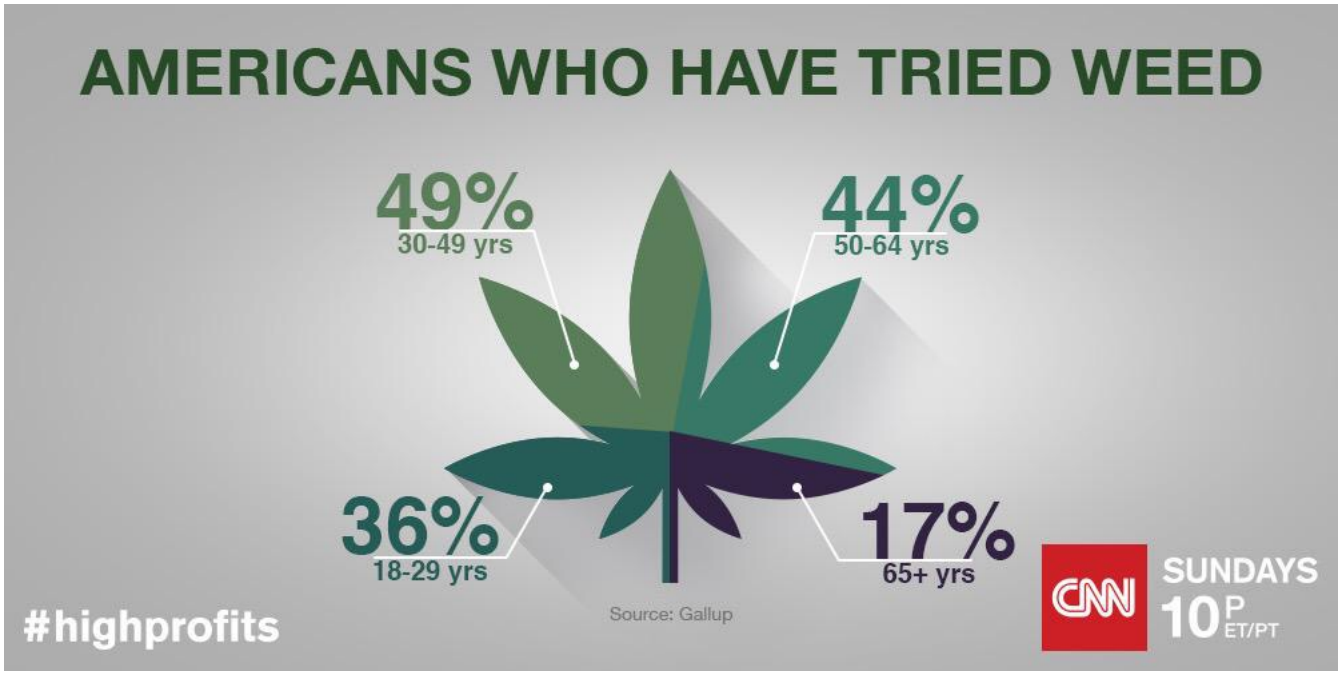
PUC



Nigel Holmes:
http://nigelholmes.com

Chartjunk

PUC



Clarity

PUC

- Visual encoding and layout should make perception tasks easy and effortless
- Textual and support elements should provide effective support to understanding the information
- Any variation in the graph should represent useful information otherwise it is noise obfuscating the message

Clarity

PUC

- Textual elements should provide effective support to understanding
  - Hierarchical
    - Size and position reflects importance
  - Readable
    - Large enough
  - Horizontal
  - Close to data (avoid legends)
- Always label the axes

Colors

PUC

- Get it right in black and white
- Use medium hues or pastels
  - Bright colors distract and tire out
- Use color only when needed to serve a particular communication goal

Cognitive Dissonance

Detection and Separation

PUC

Efficiency and efficacy of perception tasks is affected by:

- Detection

  The capability to visually identify the objects that represent the data to be compared

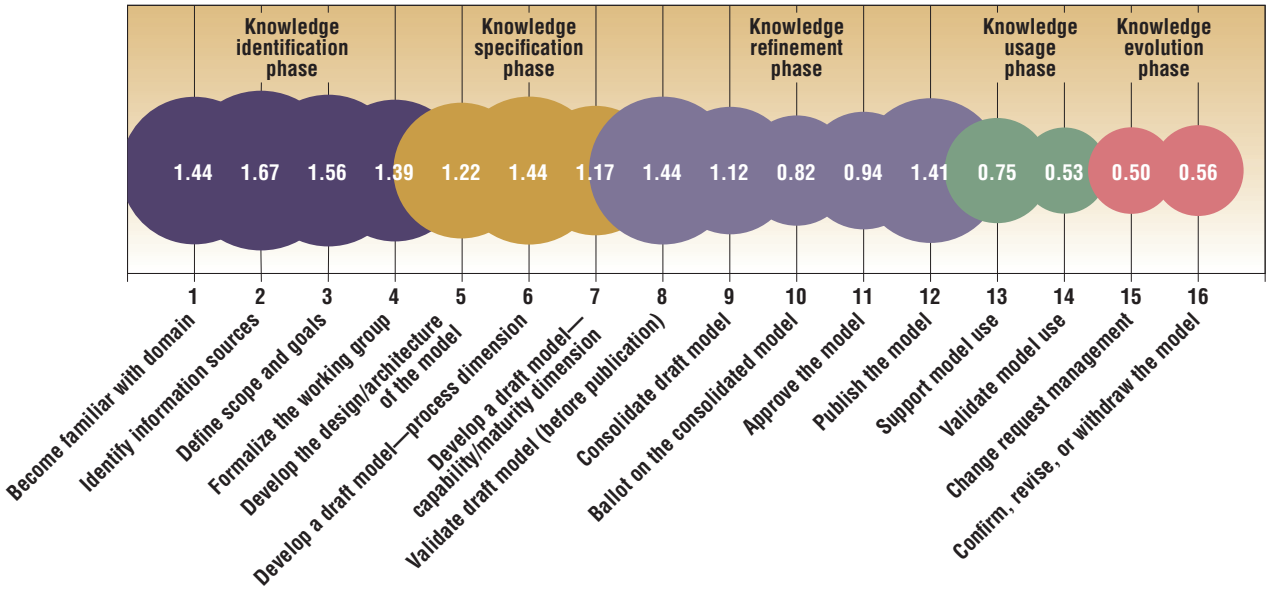
- Separation

  The distance between the objects to be compared

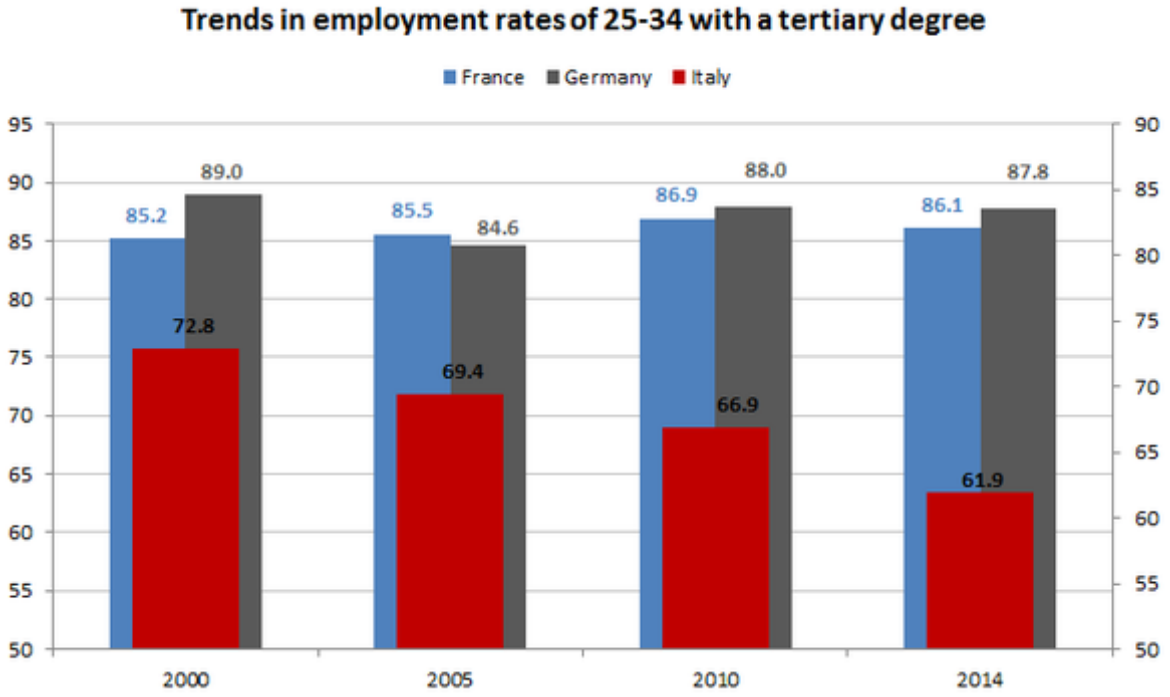
  - affects negatively the accuracy

Clarity

PUC



Example



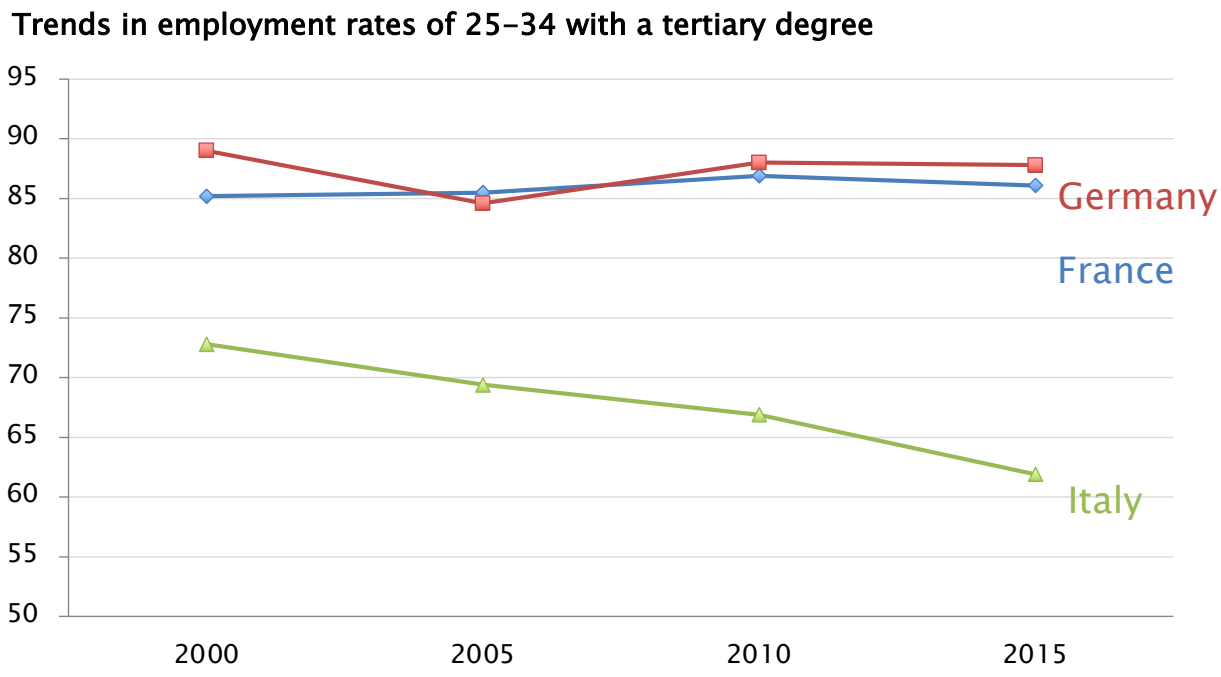
Analysis

- Proportionality
  - Due to non-zero base bars, it has a large lie factor (2.2):
    - ratio of real values: 87.8 : 61.9
    - ratio on graph: 37.8 : 11.9
- Utility
  - Most elements appear useful
  - X-axis ticks can be removed
  - Y grid could be made less prominent

Analysis

- Clarity
  - It uses a dual scale that confuses and makes very hard a visual comparison of the values and further distorting the compared values.
  - The dual scale is not mentioned anywhere and it is not clear which values refer to which scale.
  - In general the usage of bars is not the most appropriate visual representation if the goal is to show a trend or evolution in time.

Redesign



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