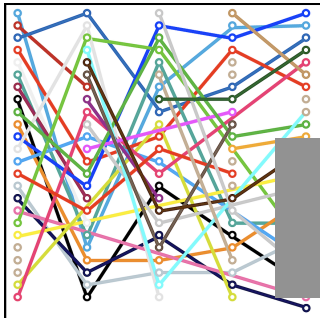

VU 188.305 – VO: 2 hrs. / 3 ECTS

Information Visualization

Visual Perception, Cognition & Visual Encoding

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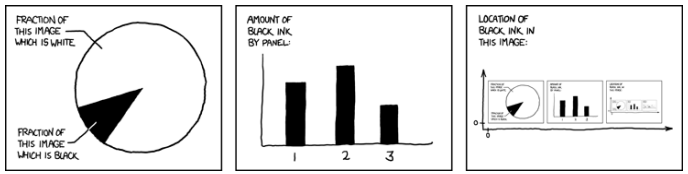
TU WIEN FAKULTÄT FÜR INFORMATIK Faculty of Informatics | CVAST Centre for Visual Analytics Science & Technology | ISIS. | ieg information engineering group



[http://xkcd.com/688/]

Contents

What is perception
Anatomy of the visual system
Visual processing
Color perception
Preattentive processing
Gestalt principles
Cognitive models
Visual encoding & graphical excellence

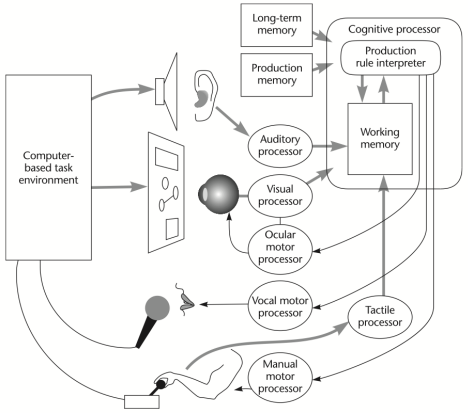
Perception

Perception deals with the human senses that generate signals from the environment through sight, hearing, touch, smell and taste.

[…] the process of recognizing (being aware of), organizing (gathering and storing), and interpreting (binding to knowledge) sensory information

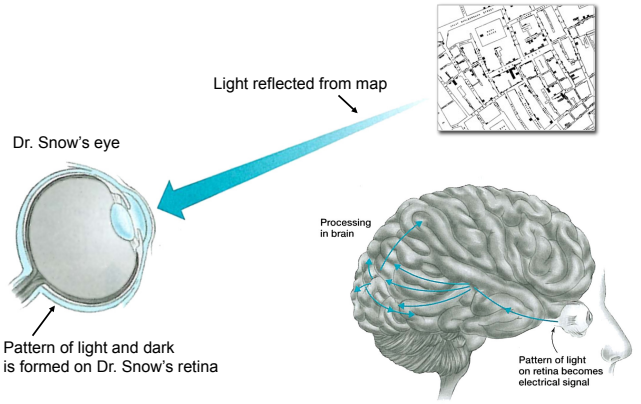
[Ward et al., 2010]

Perception



[Ware, 2004, Kieras and Meyer, 1997]

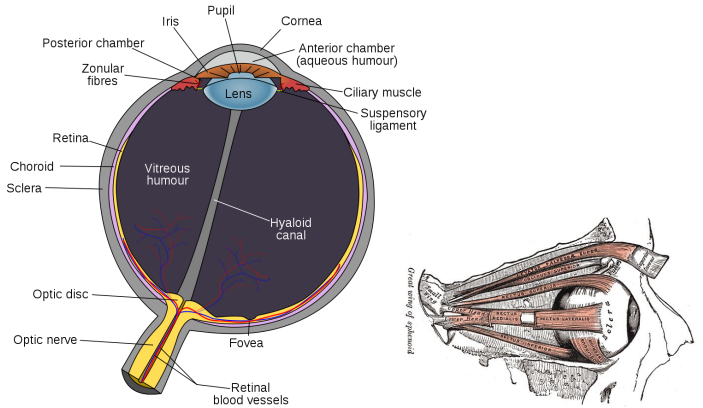
Visual Perception



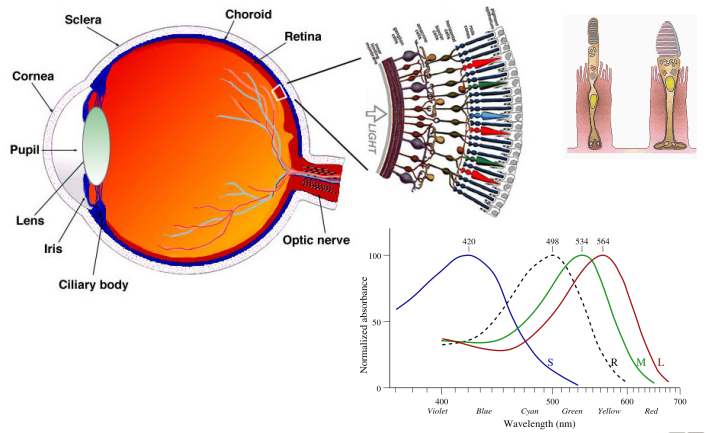
[Goldstein, 2005]

ANATOMY OF THE VISUAL SYSTEM

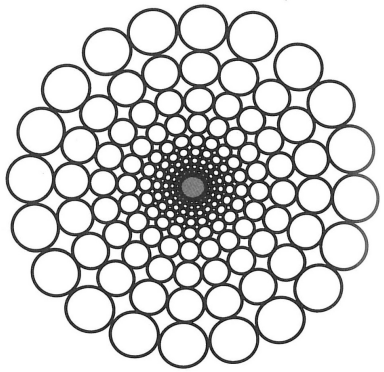
Eye



Retina



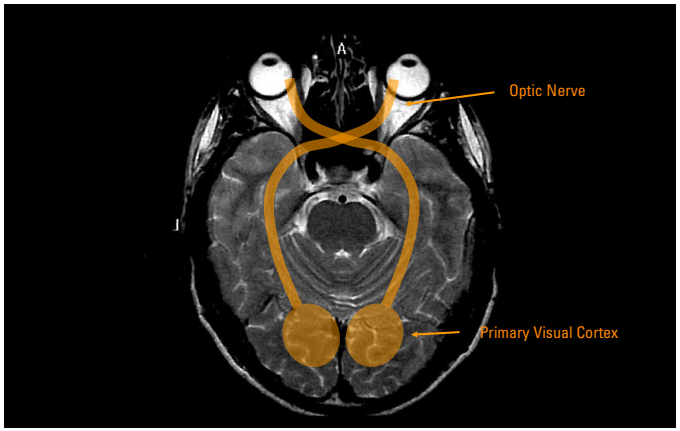
Brain Pixel



[Ware, 2008]

VISUAL PROCESSING

Visual Perception



Perceptual processing

intrinsic and uncontrolled (preattentive)

fast and is performed in parallel, often within 250ms

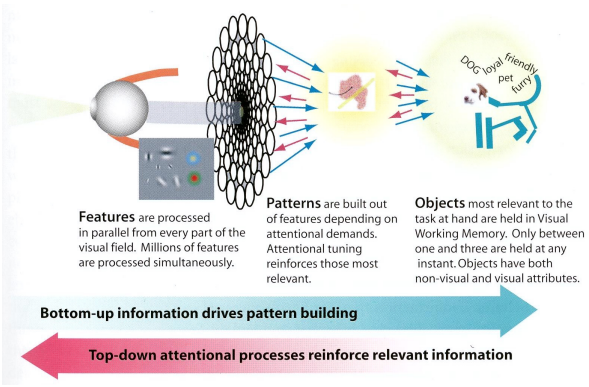
limited set of visual properties that are detected very rapidly and accurately by the low-level visual system

controlled (attentive)

slower and uses short-term memory

[Ward et al., 2010]

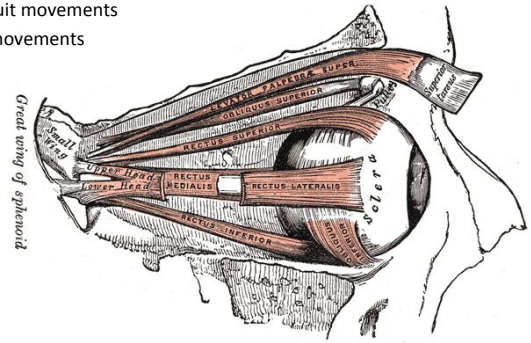
Model of visual processing



[Ware, 2008]

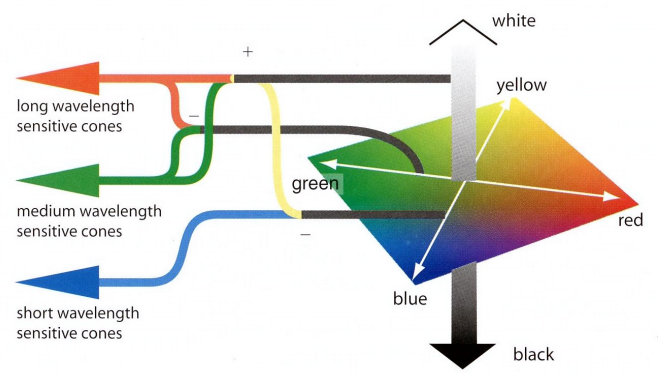
Eye movements

Saccadic movements
Smooth-pursuit movements
Convergent movements



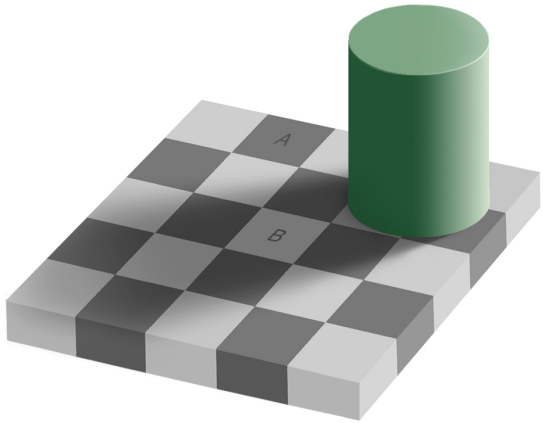
COLOR PERCEPTION

Opponent process theory

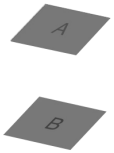


[Ware, 2008]

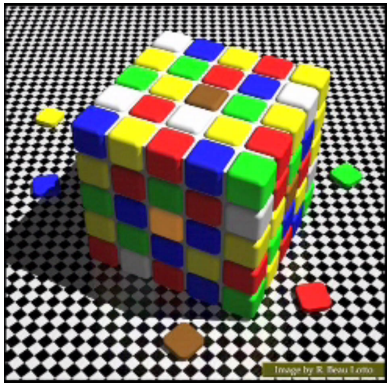
Contrast



Contrast

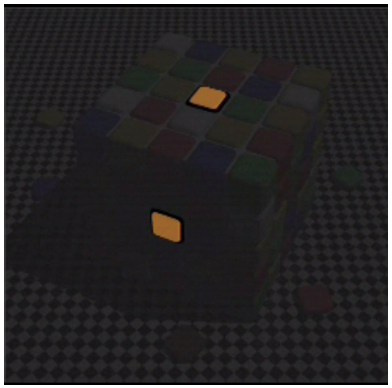


Contrast



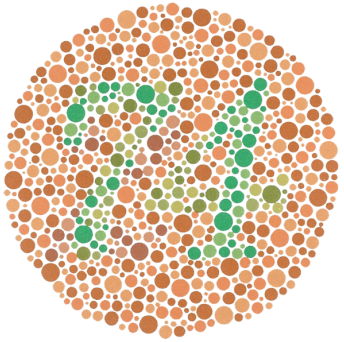
[Beau Lotto]

Contrast

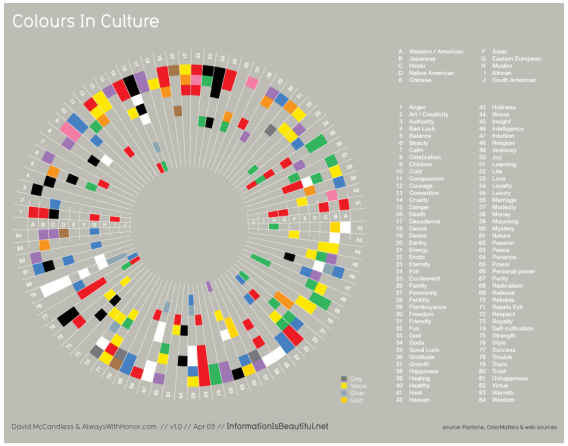


[Beau Lotto]

Color blindness



Semantics of color



[McCandless, 2009]

PREATTENTIVE PROCESSING

Preattentive Processing

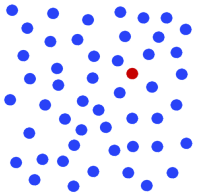
15613212036584130765103746274
17312752732759273299070974217
03707774179527931749270973401
97432179093709451792794l7

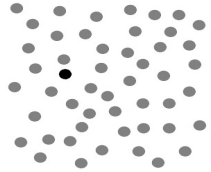
15613212036584130765103746274
17312752732759273299070974217
03707774179527931749270973401
97432179093709451792794l7

Color

Hue

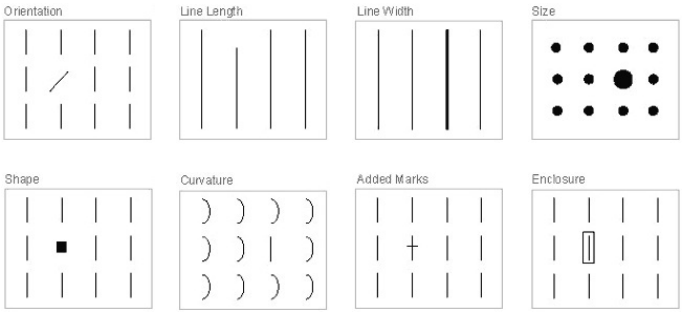
Intensity





[Dürsteler, 2006]

Form

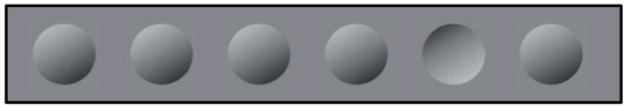


Applet:
http://www.csc.ncsu.edu/faculty/healey/PP/index.html

[Few, 2004]

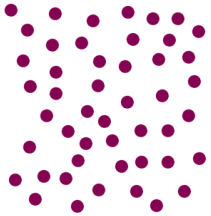
Spatial position

2D position
Stereoscopic depth
Concavity convexity

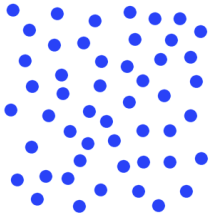


Movement

(Direction of) motion



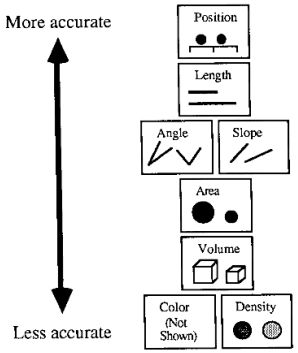
Flicker



[Dürsteler, 2006]

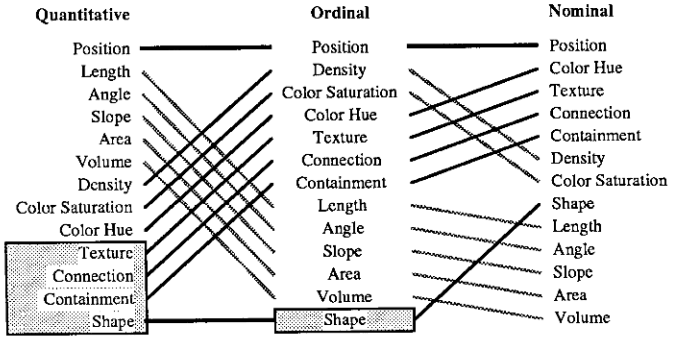
ELEMENTARY GRAPHICAL PERCEPTION TASKS

Visual variables



[Cleveland & McGill, 1984]

Visual variables & data types



[Mackinlay, 1987]

LAWS

Relative judgements

Which of the two bars is longer?

[Cleveland and McGill, 1984]

Weber's Law

the likelihood of detecting a change is proportional to the relative change, not the absolute change, of a graphical attribute

[Ward et al., 2010]

Steven's Law

As the dimension of an attribute increases, the degree at which we underestimate it increases

[Ward et al., 2010]

GESTALT PRINCIPLES

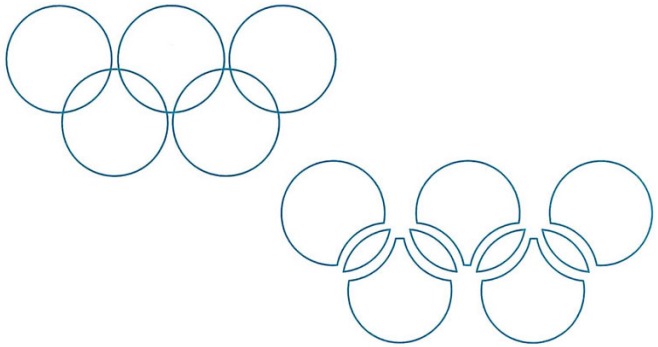
Proximity

[Winkler, 2005]

Similarity

[Winkler, 2005]

Prägnanz



[Goldstein, 2005]

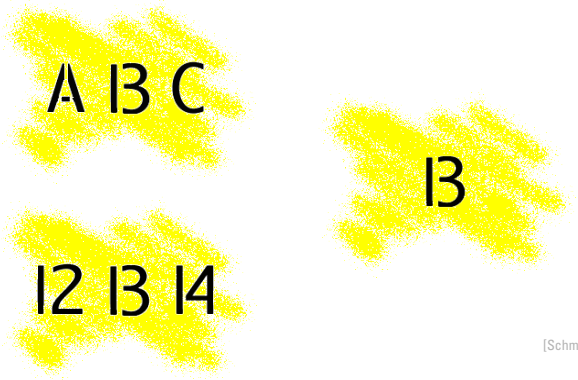
Good Continuation

[Winkler, 2005]

Common Fate

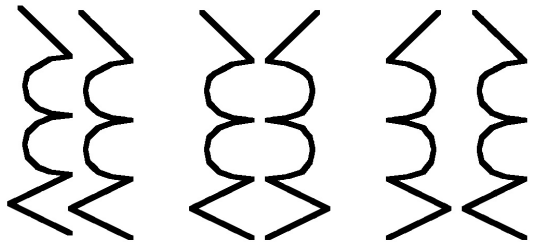
[Pedroza, 2005]

Familiarity



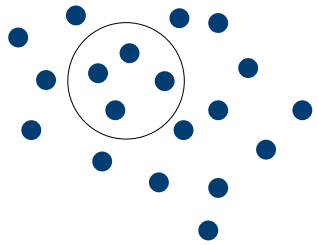
[Schmidt, 2005]

Symmetry

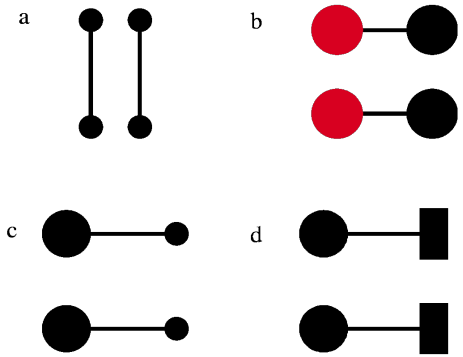


[Ware, 2004]

Enclosure

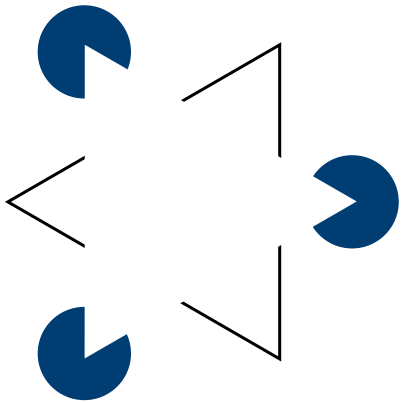


Connection



[Ware, 2004]

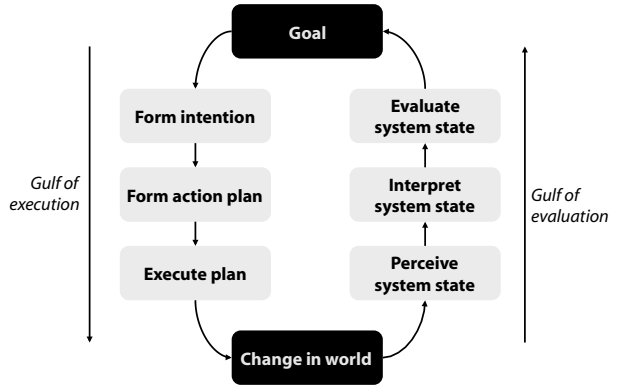
Closure



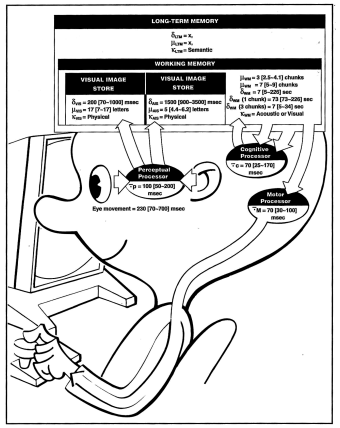
COGNITIVE MODELS

Norman's execution-evaluation cycle

[Norman, 1988]



Model Human Processor (MHP)



[Card et al. 1983, p. 26]

Mental models & visual reasoning

What is a mental model?
- Internal representation of real-world phenomenon
- Logical reasoning based on formal logic
- Functional
- Structural
- → functional, analogue representation to an external interactive visualisation system

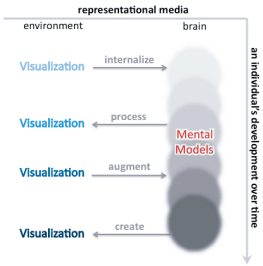
Where are mental models situated?
- created in working memory (limited capacity)
- High relationship between mental models and external visualisation

What are mental models used for?
- Reasoning
- Constructing, simulating and manipulating mental models and external visualisations
- Theories for design, evaluation and theory of development

[Liu and Stasko, 2010]

Dynamics between mental models and external visualisations

Dynamics are:
- Internalisation
- Processing
- Augmenting
- Creation

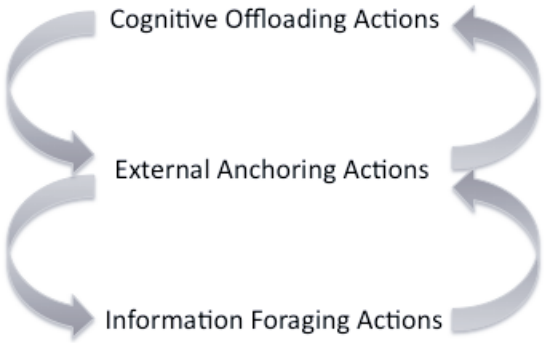


Dynamics are basis for information visualisation

External processes are involved in reasoning

[Liu and Stasko, 2010]

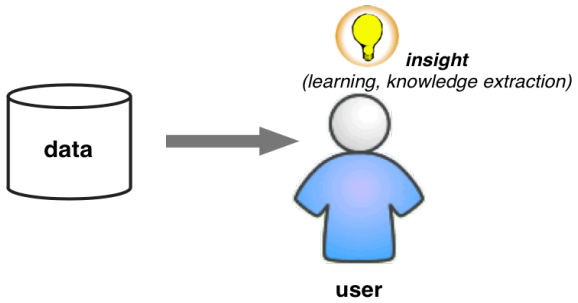
Interaction



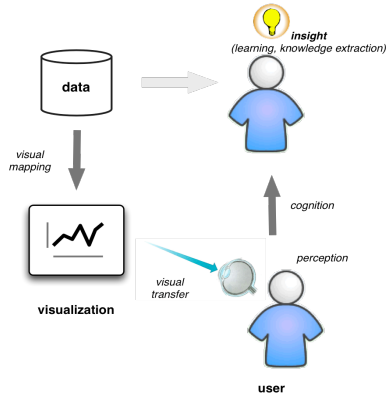
[Liu and Stasko, 2010]

VISUAL ENCODING & GRAPHICAL EXCELLENCE

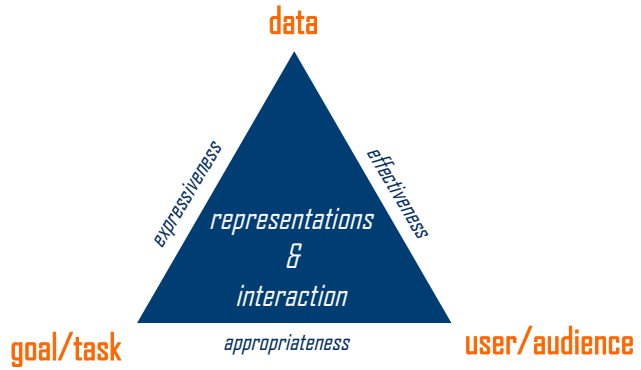
Goal



Method



Visualization Design



Data

cmp. [Shneiderman, 1996]

Variables –
Scale of measurement
- nominal
- ordinal
- quantitative
  - discrete
  - continuous
- (binary)

Data Type -
Structure
- univariate
- multivariate
- hierarchy / tree
- graph / network
- time-oriented
- text/document

- (2D map)
- (3D world)

Data: Example

FilmID	230	105	540	…
Title	Goldfinger	Ben Hur	Ben Hur	…
Director	Hamilton	Wyler	Niblo	…
Actor	Connery	Heston	Novarro	…
Actress	Blackman	Harareet	McAvoy	…
Year	1964	1959	1926	…
Length	112	212	133	…
Popularity	7.7	8.2	7.4	…
Rating	PG	G	G	…
Film Type	Action	Action	Drama	…

Data: Example

Nominal Ordinal Quantitative

FilmID	230	105	540	…
Title	Goldfinger	Ben Hur	Ben Hur	…
Director	Hamilton	Wyler	Niblo	…
Actor	Connery	Heston	Novarro	…
Actress	Blackman	Harareet	McAvoy	…
Year	1964	1959	1926	…
Length	112	212	133	…
Popularity	7.7	8.2	7.4	…
Rating	PG	G	G	…
Film Type	Action	Action	Drama	…

Data type / structure: multivariate

Tasks

[Shneiderman, 1996]

1	overview	gain an overview of the entire set of data
2	zoom	adjust the size of items of interest
3	filter	remove uninteresting items
4	details-on-demand	select one or more items and get details
5	relate	identify relationships between items
6	history	keep a history of actions to support undo/redo
7	extract	extract subsets of items for separate analysis

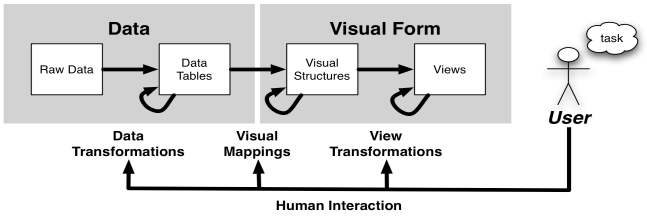
Visual Information Seeking Mantra

[Shneiderman, 1996]

overview first, zoom and filter, then details-on-demand
overview first, zoom and filter, then details-on-demand
overview first, zoom and filter, then details-on-demand
overview first, zoom and filter, then details-on-demand
overview first, zoom and filter, then details-on-demand
overview first, zoom and filter, then details-on-demand

InfoVis Reference Model

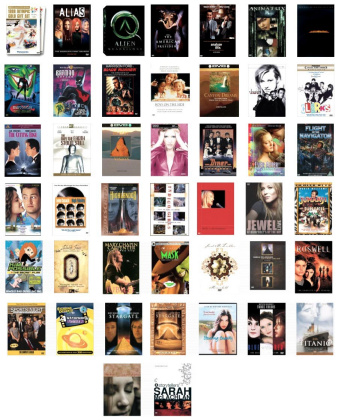
[Card et al., 1999]



Raw Data: idiosyncratic formats
Data Transformations: Mapping raw data into an organization appropriate for visualization
Data Tables: relations (cases by variables) + metadata
Visual Mappings: Encoding abstract data into a visual representation
Visual Structures: spatial substrates + marks + graphical properties
View Transformations: Changing the view or perspective onto the visual presentation
Views: graphical parameters (position, scaling, clipping, ...)
Human Interaction: User influence at any level

User interaction can feed back into any level

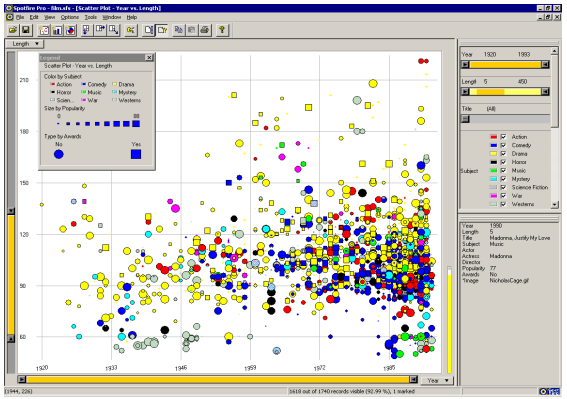
Data



year
length
popularity
subject
award?

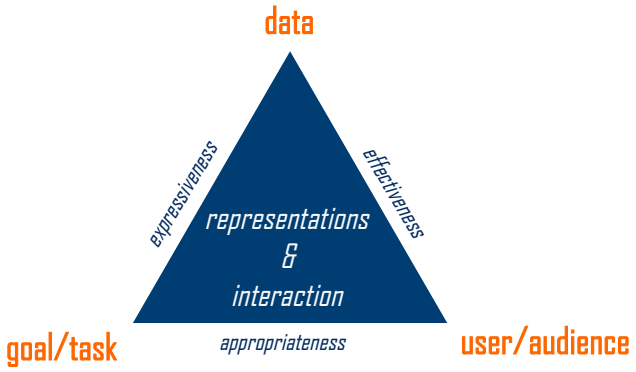
[garysaid.com]

Visual Mapping



[Spotfire]

Visualization Design



Expressiveness

A visualization is considered to be **expressive** if the relevant information of a dataset (and only this) is expressed by the visualization. The term "relevant" implies that expressiveness of a visualization 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]

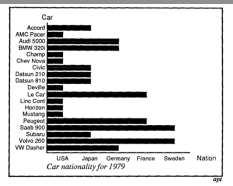


Fig. 11. Incorrect use of a bar chart for the *Nation* relation. The lengths of the bars suggest an ordering on the vertical axis, as if the USA cars were longer or better than the other cars, which is not true for the *Nation* relation.

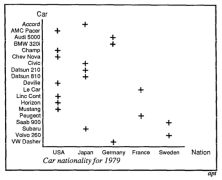


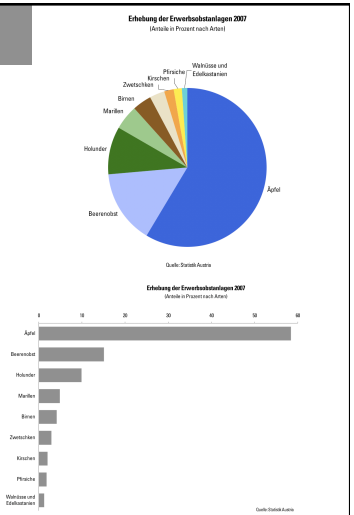
Fig. 12. Correct use of a plot chart for the *Nation* relation. Since bar charts encode ordered domain sets, plot charts are conventionally used to encode nominal domain sets. The ordering of the labels on the axes is ignored.

[Mackinlay, 1986]

Effectiveness

A visualization is effective if it **addresses the capabilities of the human visual system**. Since perception, and hence the mental image of a visual representation, varies among users, 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]



Appropriateness

[Schumann and Müller, 2000]

Appropriateness regards the tradeoff between efforts required for creating the visual representation and the benefits yielded by it. If this tradeoff is balanced, the visualization is considered to be appropriate.

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(ΔK) ... Value of acquired knowledge ΔK = K(T) - K(0)

Total costs:

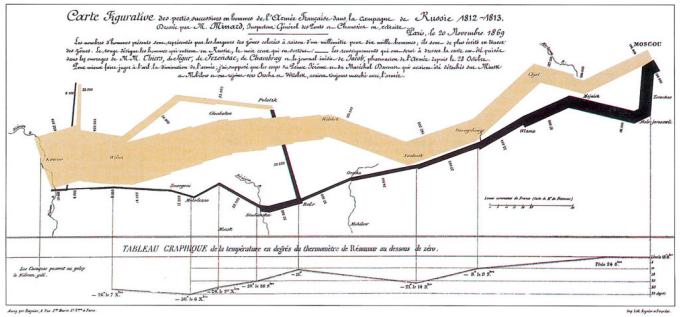
$$C = C_i + n*C_u + n*m*C_s + n*m*k*C_e$$

Overall profit:

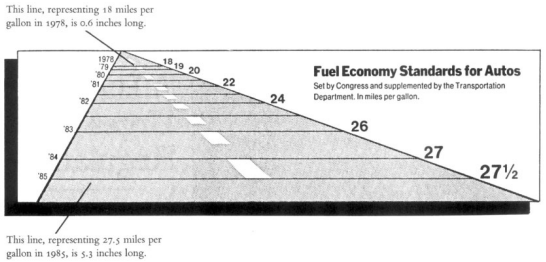
$$F = n*m*(W(\Delta K) - C_s - k*C_e) - C_i - n*C_u$$

[Van Wijk, 2006]

Graphical Excellence



Tell the truth about the data

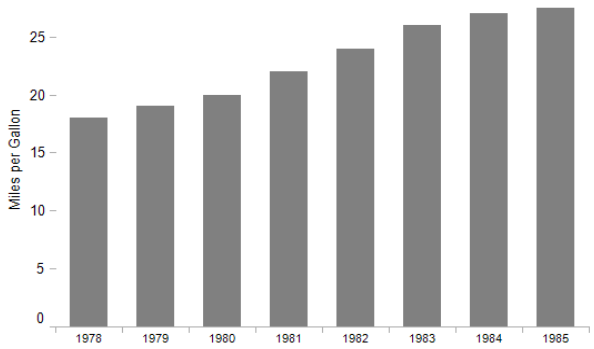


$$\text{Data Effect} = \frac{27.5 - 18}{18} = 0.53, \qquad \text{Graph Effect} = \frac{5.3 - .6}{.6} = 7.83,$$

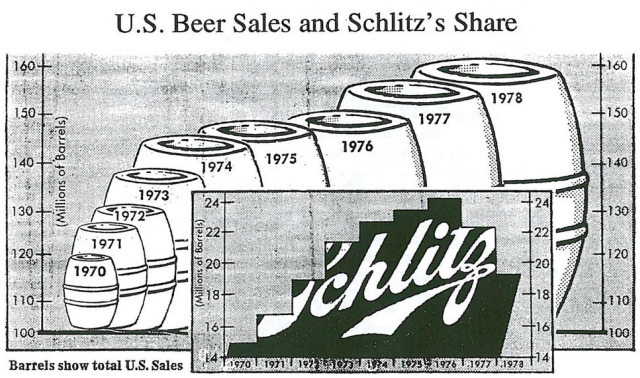
$$\text{Lie Factor} = 14.8$$

[Tufte, 1983]

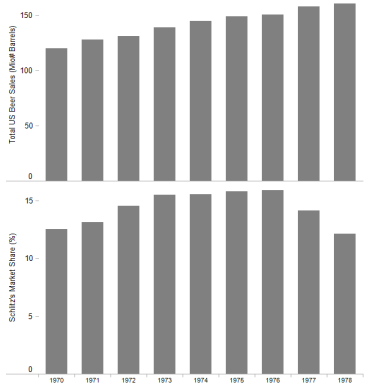
Fuel Economy Standard Redesign



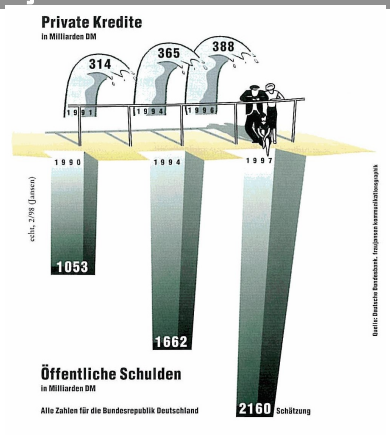
Lie Factor



Beer Sales Redesign



Avoid Chartjunk



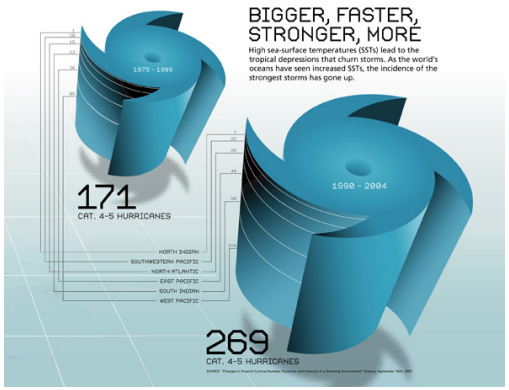
[Jansen & Scharfe, 1999]

Tufte Design Principles

1. Above all else show the data.
2. Maximize the data-ink ratio.
3. Erase non-data-ink.
4. Erase redundant data-ink.
5. Revise and edit.

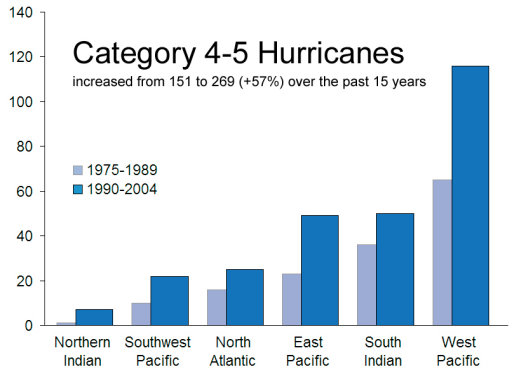
[Tufte, 1983]

Example



[Seed, 2006] Edit Staff, State of the Planet - Bigger, Faster, Stronger, More, Seed - seedmagazine.com, Created at: April 20, 2006, Retrieved at: June 21, 2006. http://www.seedmagazine.com/news/2006/04/state_of_the_planet.php

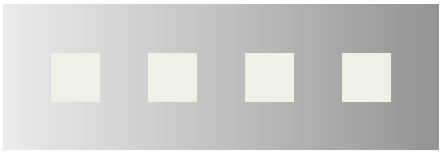
Redesign



[Weber et al., 2006] Sonja Weber, Christof Kopfer, Matteo Savio, Nicole Brosch, Category 4-5 Hurricances, Created at: November 14, 2006, Retrieved at: November 3, 2009. http://www.infovis-wiki.net/index.php?title=Image:Verbessert3.jpg

Using Color

Color Context



Rule #1: If you want different objects of the same color in a table or graph to look the same, make sure that the background--the color that surrounds them--is consistent.

Rule #2: If you want objects in a table or graph to be easily seen, use a background color that contrasts sufficiently with the object.

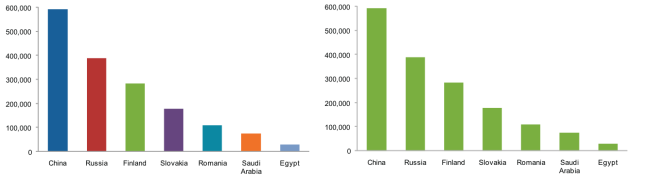
[Few, 2008]

Color Usage

Rule #3: Use color only when needed to serve a particular communication goal.

Rule #4: Use different colors only when they correspond to differences of meaning in the data.

- To highlight particular data
- To group items
- To encode quantitative values



[Few, 2008]

Color Usage

Rule #5: Use soft, natural colors to display most information and bright and/or dark colors to highlight information that requires greater attention.

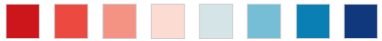
[Few, 2008]

Palette Types

Categorical

Sequential

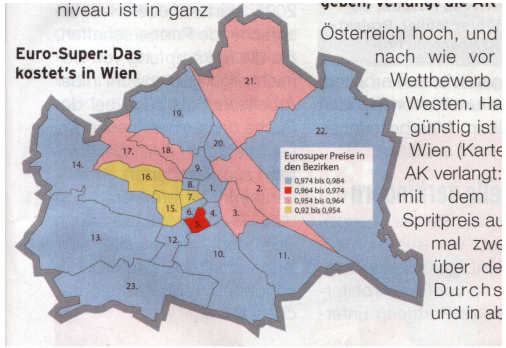
Diverging



Rule #6: When using color to encode a sequential range of quantitative values, stick with a single hue (or a small set of closely related hues) and vary intensity from pale colors for low values to increasingly darker and brighter colors for high values.

[Few, 2008]

Example



Quelle: AK Für Sie, Mitgliederzeitschrift der AK Wien,

De-emphasize non-data components

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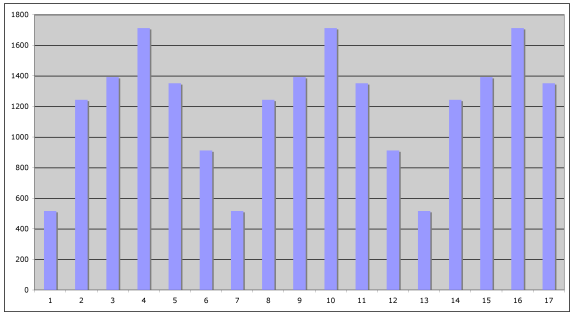

[Few, 2008]

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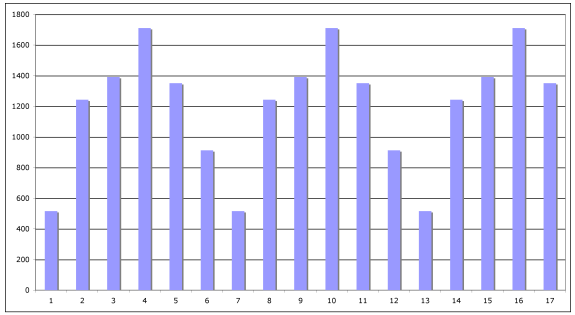

[Few, 2008]

WOLFGANG AIGNER perception and visualization

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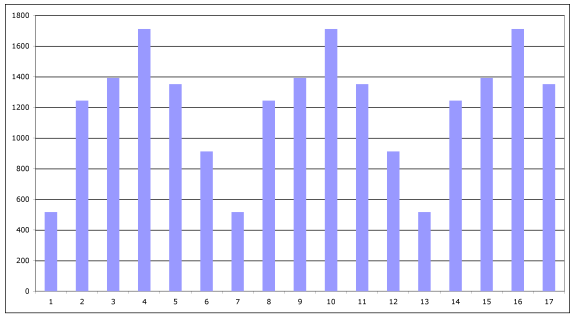

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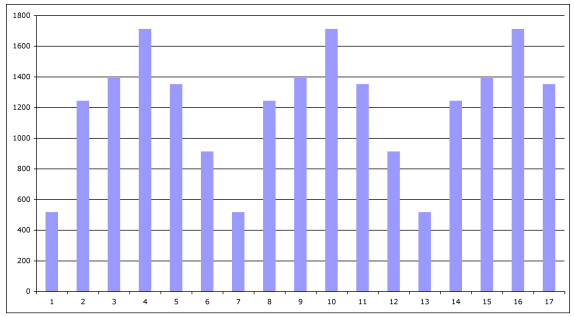

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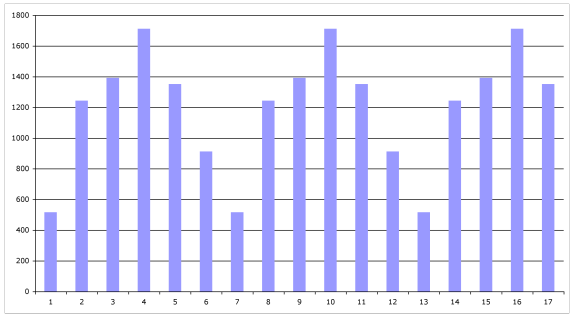

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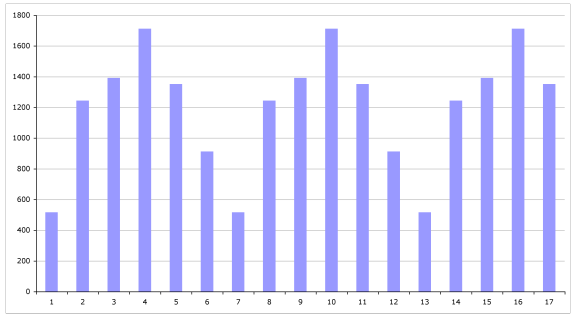

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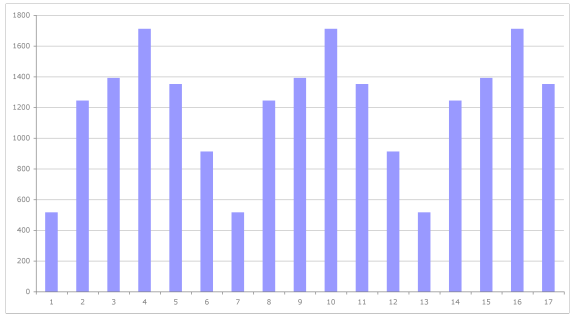

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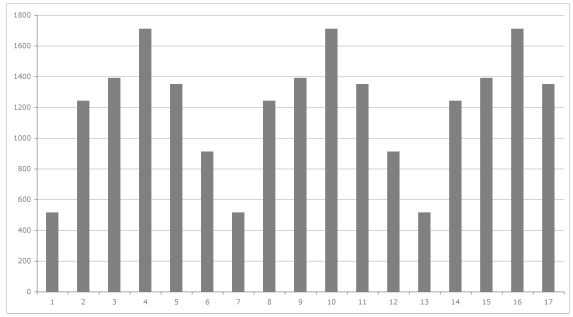

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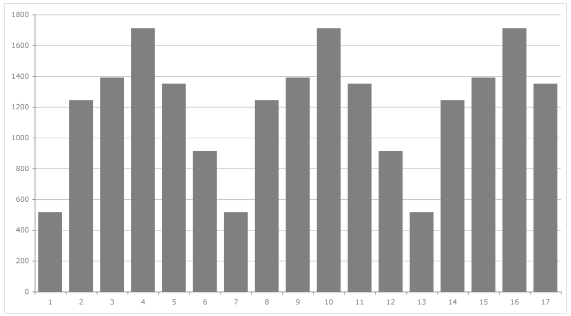

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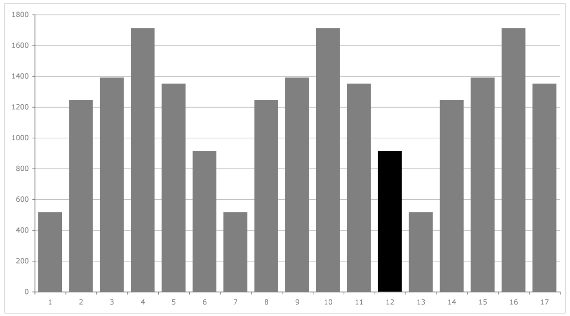

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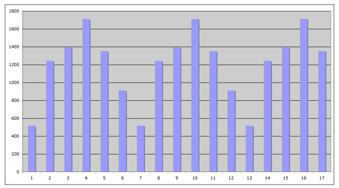
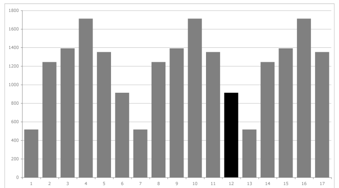
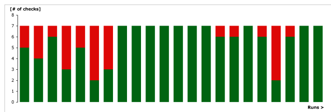


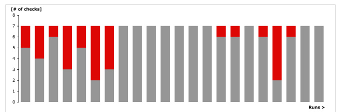


[Few, 2008]

Avoid Red-Green

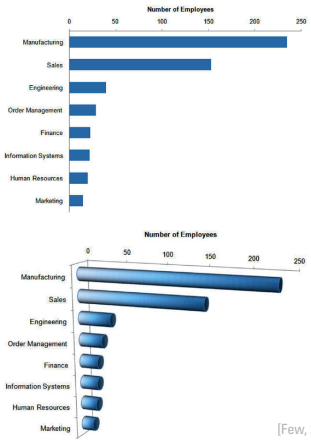
Rule #8: To guarantee that most people who are colorblind can distinguish groups of data that are color coded, avoid using a combination of red and green in the same display.





[Few, 2008]

Rule #9: Avoid using visual effects in graphs.



[Few, 2008]

Summary: InfoVis...

- ... is a very complex task
- ... can help to get insight into data more quickly
- ... requires preparation and sensible handling of the information
- ... should make use of the properties of human visual perception
- ... requires sensible handling, relative to the task
- ... is a big challenge, if you want to do it good

»Die Umwelt, so wie wir sie wahrnehmen, ist unsere Erfindung.«

Heinz von Foerster

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