Visualization. Perception

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Outline

- Introduction
- Preattentive Processing
- Perception Laws
- Applying Perception to Visualization

Outline

- **Introduction**
- Preattentive Processing
- Perception Laws
- Applying Perception to Visualization

Introduction. Recap

From Shneiderman, 1996

Information visualization tasks

- Overview
- Zoom
- Filter
- Details-on-demand
- Relate
- History
- Extract

Data Types

- 1-D Linear (document lens, SeeSoft, IM)
- 2-D Map (GIS, ThemeScape)
- 3-D World (CAD, Visible Human)
- Temporal (Perspective Wall, LifeLines)
- Multi-dimensional (SpotFire, HomeFinder)
- Tree (Cone trees, Hyperbolic trees)
- Network (Netmap, SemNet)
- Documents (Digital Library)

Introduction. Recap

- High-level tasks

From 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

Introduction. Recap

- Data types

From Shneiderman, 1996

1	1-dimensional	alphabetic lists, source code, text/documents
2	2-dimensional	planar or map data, photos
3	3-dimensional	molecules, human body, buildings
4	temporal	{start, finish}, e.g., medical records, project management, historical presentations
5	multi-dimensional	n attribute => points in n-dimensional space, e.g., relational DB
6	tree	Hierarchies or tree structured, e.g., file directories, business organizations
7	network	connected as graph(s), e.g., telecommunications network, www

Introduction

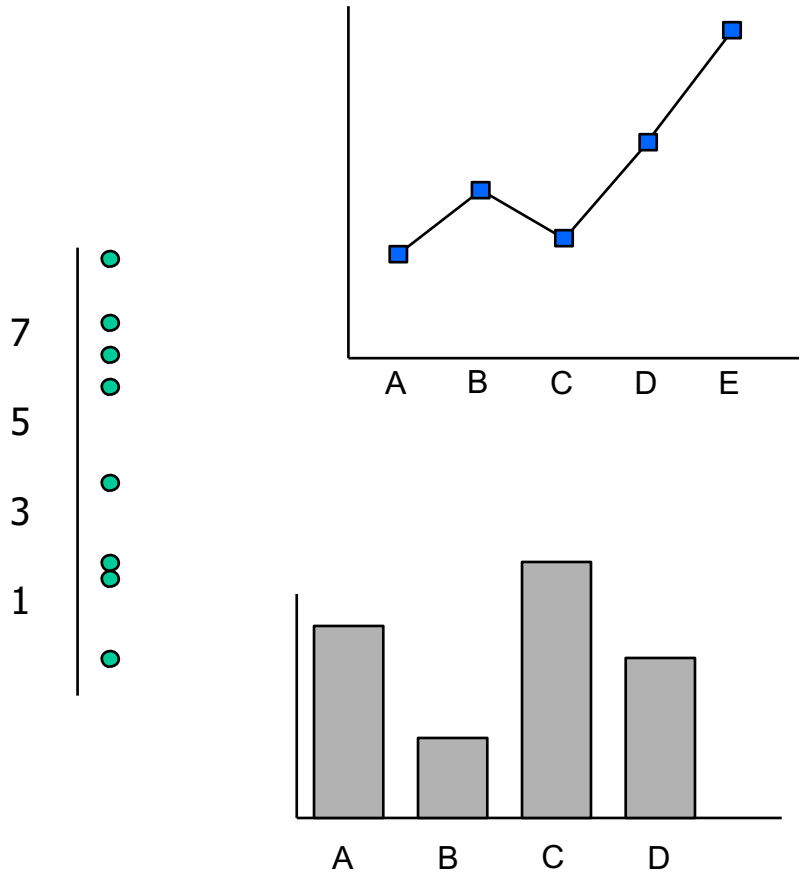
- Low number of dimensions → “easy”

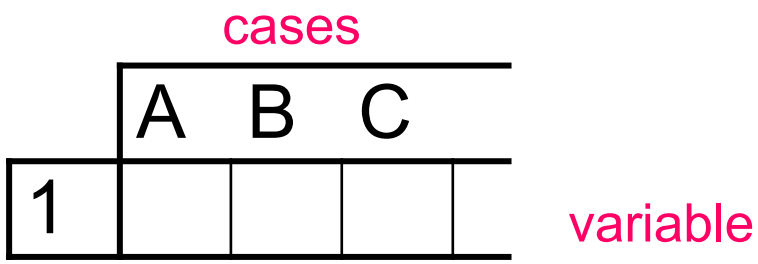
- High number of dimensions → hard

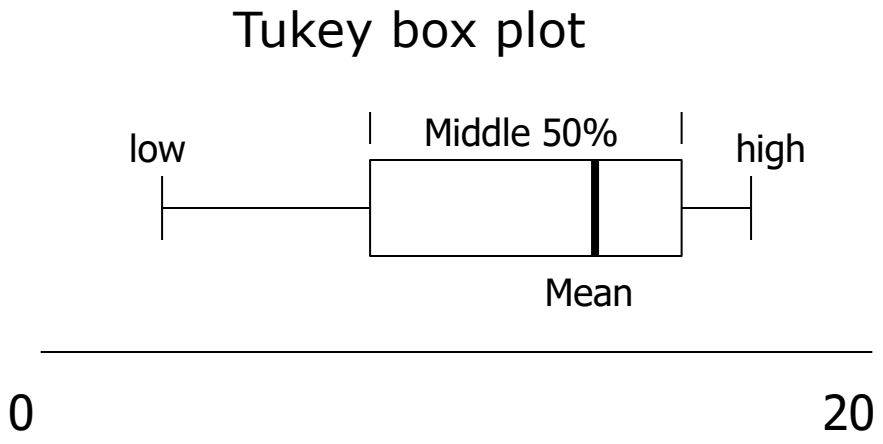
Introduction

From Mackinlay, 2000

- Univariate data





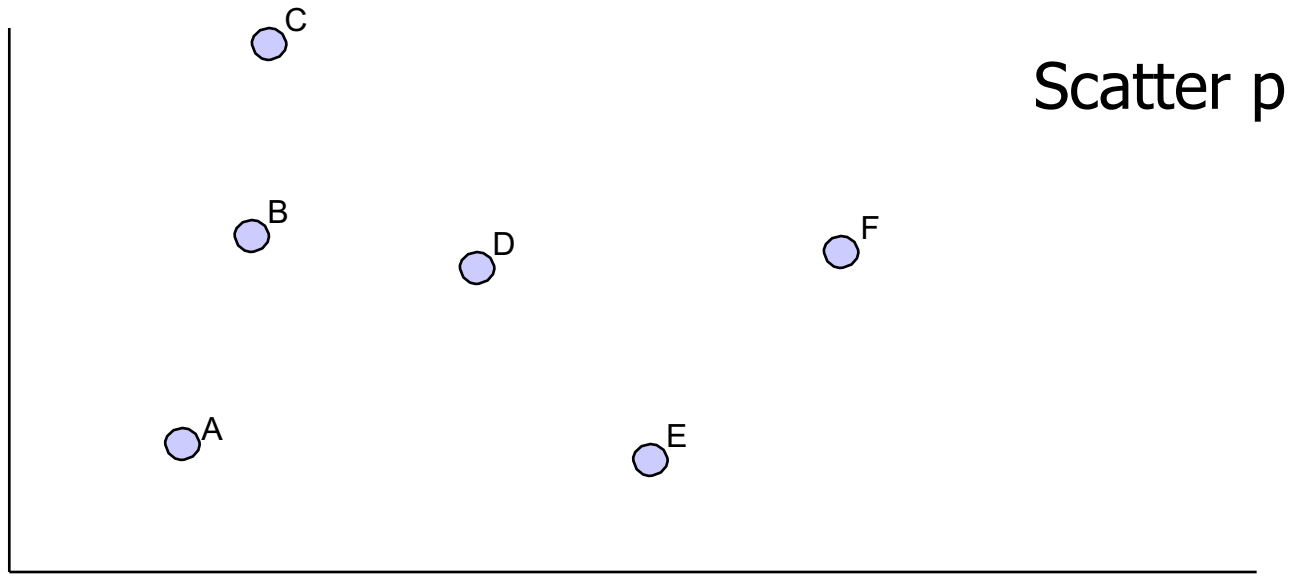


Introduction

From Mackinlay, 2000

- Bivariate data

	A	B	C	
1				
2				



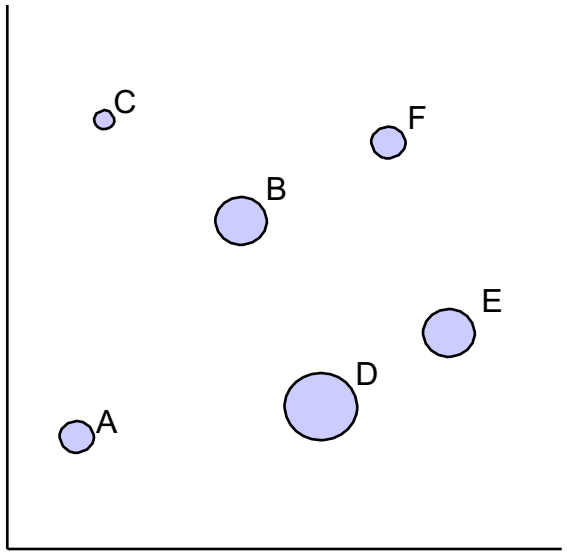
Scatter plot is common

Introduction

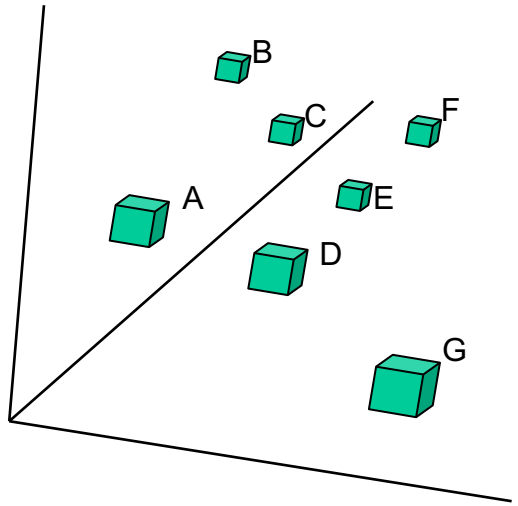
From Mackinlay, 2000

- Trivariate data

	A	B	C	
1				
2				
3				



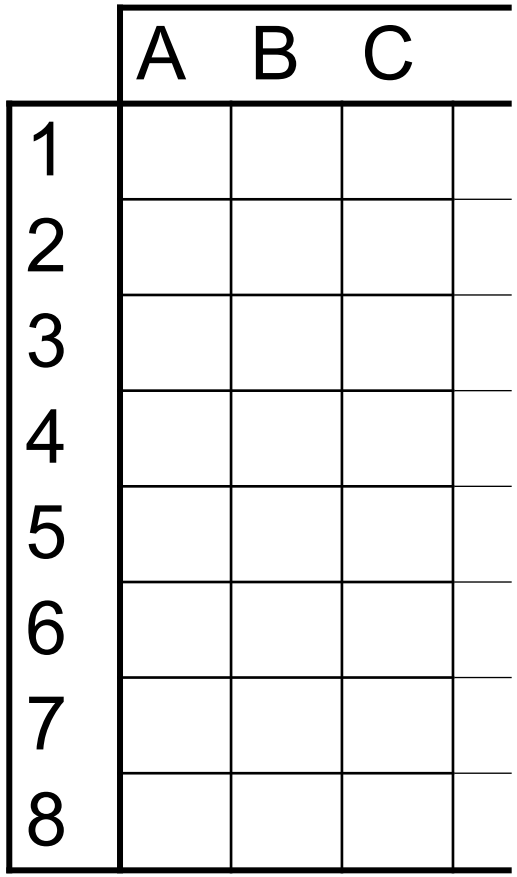
3D scatter plot is possible



Introduction

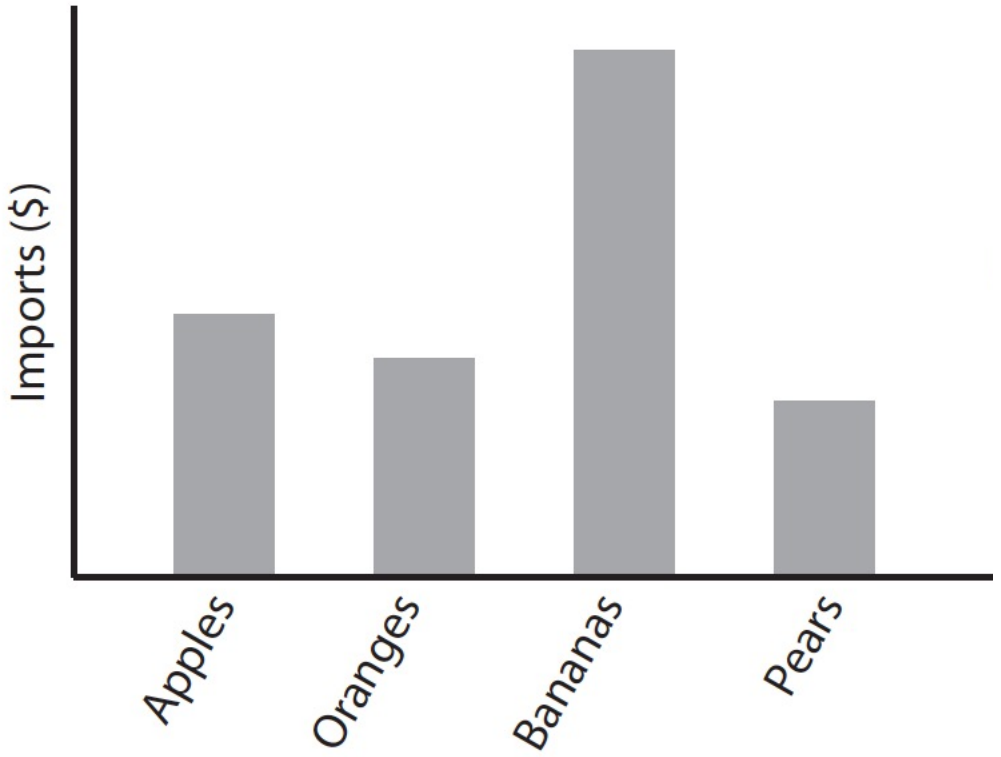
From Mackinlay, 2000

- Multivariant
  - How many dimensions?
  - Which visual encodings?



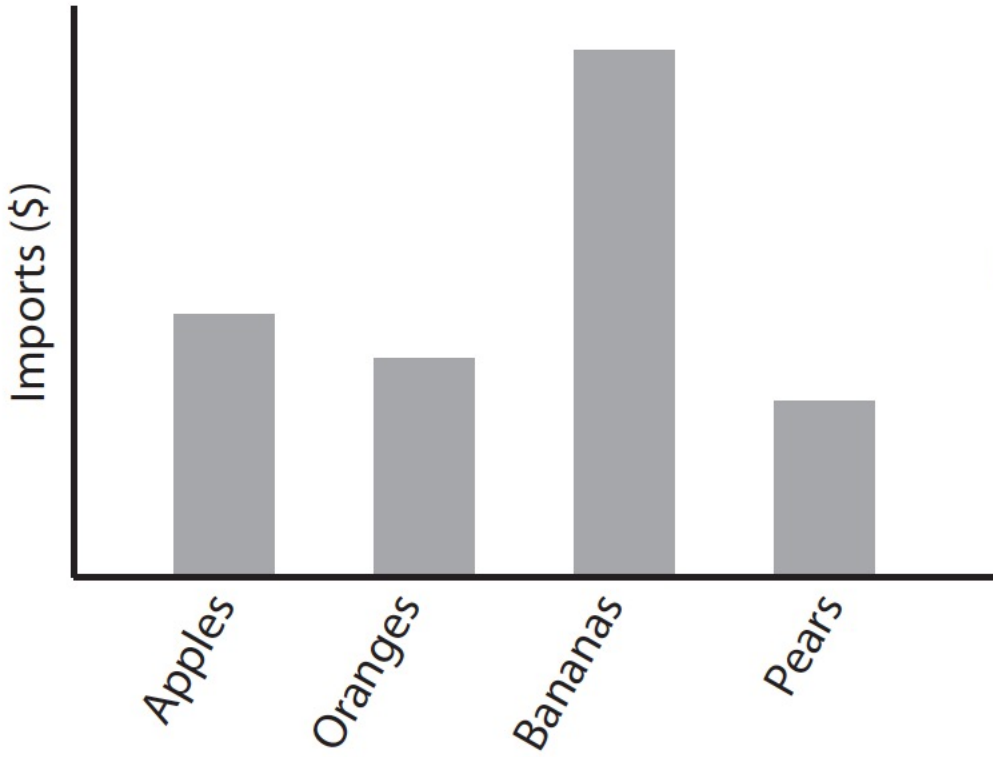
Introduction

- Visual search: Find out which kind of fruit import is the largest by dollar value



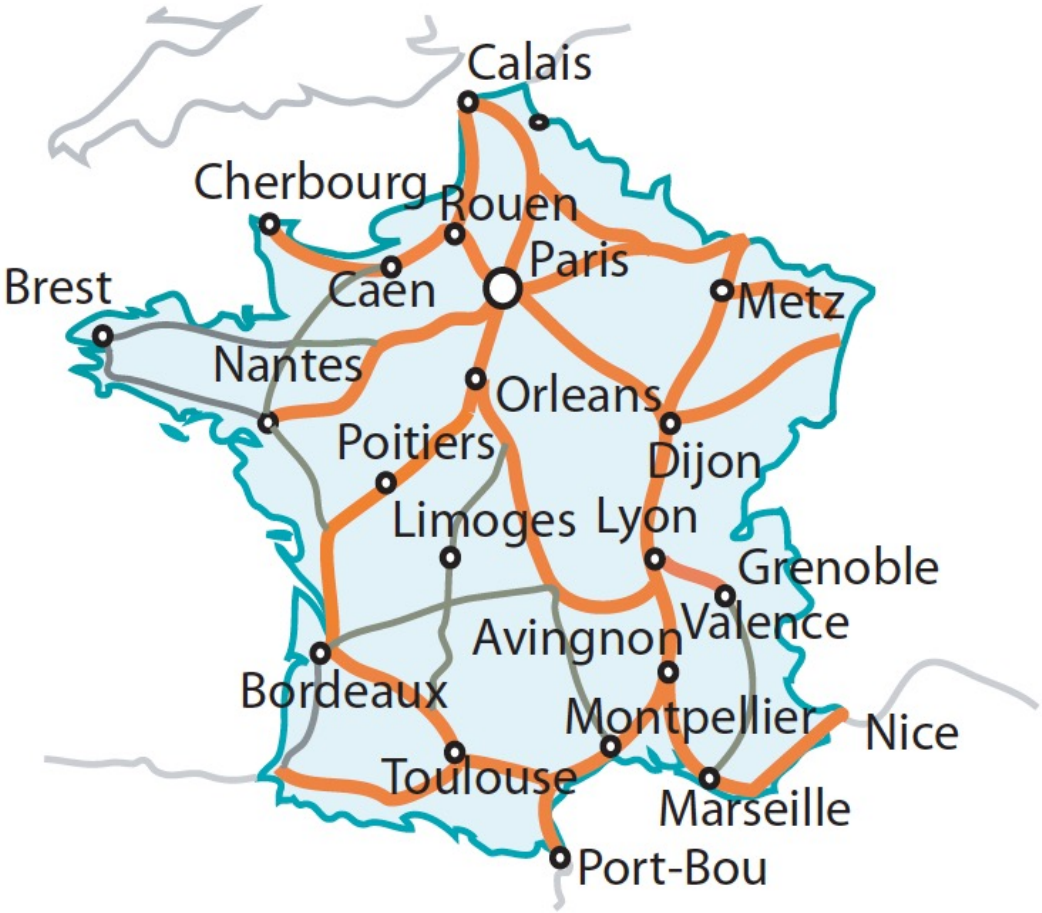
Introduction

- Visual search: Find out which kind of fruit import is the largest by dollar value
  - Visual process:
    - Find the tallest bar
    - Then find and read the label beneath



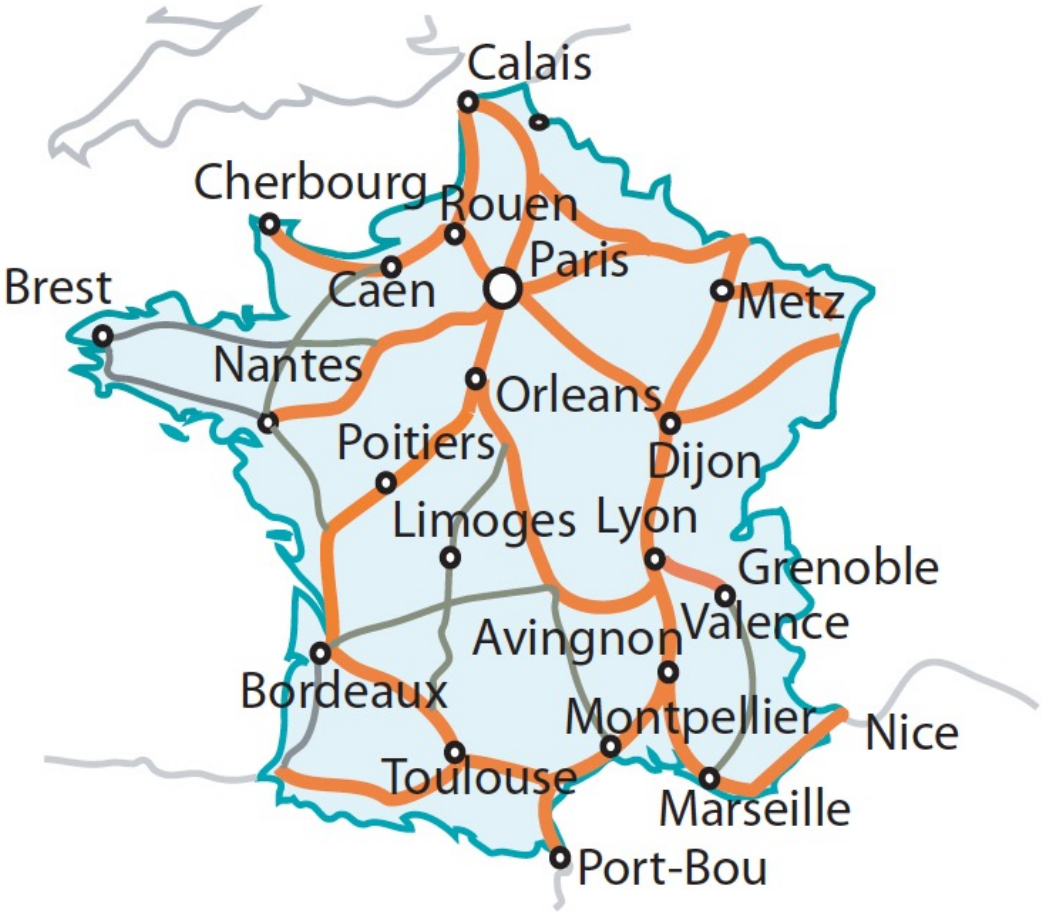
Introduction

- Visual search: Find a fast route



Introduction

- Visual search: Find a fast route
  - Visual process:
    - Make visual queries to find the starting and ending cities
    - Then we make queries to find a connected red line, indicative of fast roads, between those points



Outline

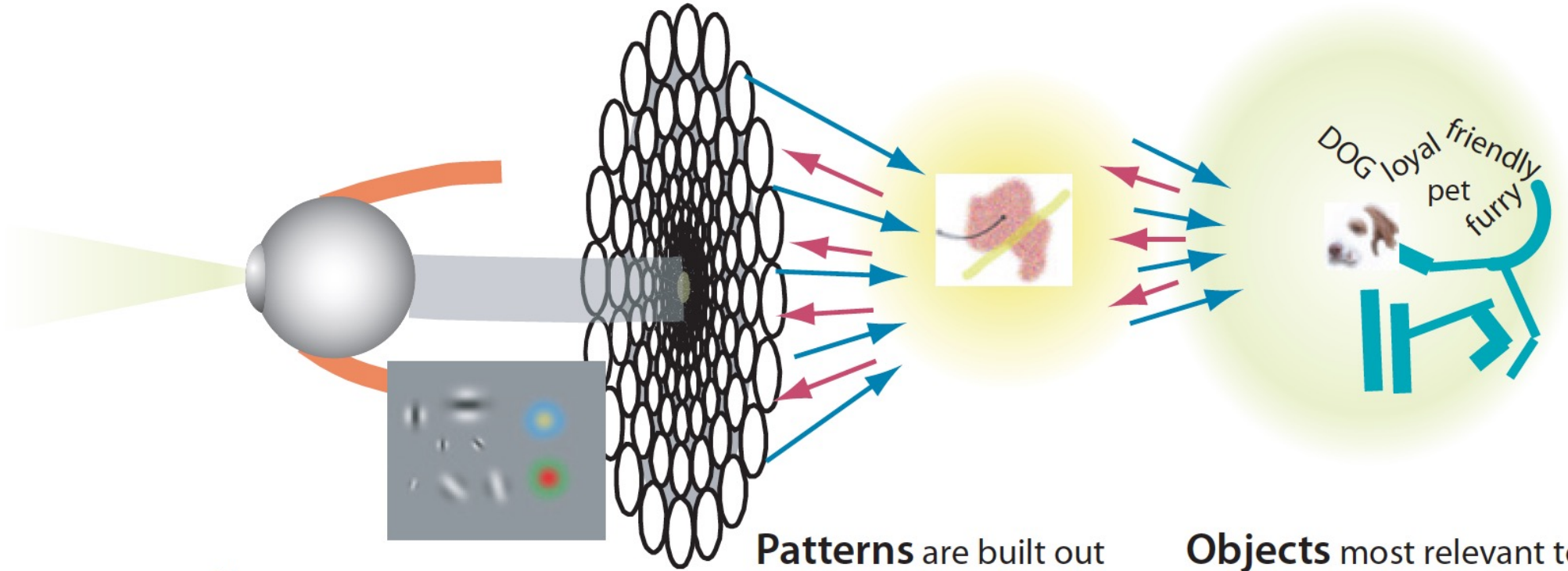
- *Introduction*
- **Preattentive Processing**
- Perception Laws
- Applying Perception to Visualization

Preattentive processing

- Design visual information to be efficiently perceivable – quick, unambiguous
- Need to understand how human visual perception and information processing works
- Perception science related to:
  - Physiology: study the physical, biochemical and information processing functions of living organisms
  - Cognitive psychology: studying internal mental processes
    - how do people learn, understand, solve problems with regard to sensory information?

Preattentive processing

- Many perceptual processing models exist
- Simplified 3-stage model:
  - Stage 1: rapid parallel processing to extract low-level properties
  - Stage 2: pull out structures via pattern perception
  - Stage 3: sequential goal-directed processing



Features are processed in parallel from every part of the visual field. Millions of features are processed simultaneously.

Patterns are built out of features depending on attentional demands. Attentional tuning reinforces those most relevant.

Objects most relevant to the task at hand are held in Visual Working Memory. Only between one and three are held at any instant. Objects have both non-visual and visual attributes.

Bottom-up information drives pattern building

Top-down attentional processes reinforce relevant information

Preattentive processing. 3-stage model

- Stage 1: rapid parallel processing to extract low-level properties
  - Detection of shape, spatial attributes, orientation, color, texture, movement
  - Billions of Neurons work in parallel, extracting information simultaneously
  - Occurs automatically, independent of (cognitive) focus
  - Information is transitory (though briefly held in a short- lived visual buffer)
  - Often called “preattentive” processing

Preattentive processing. 3-stage model

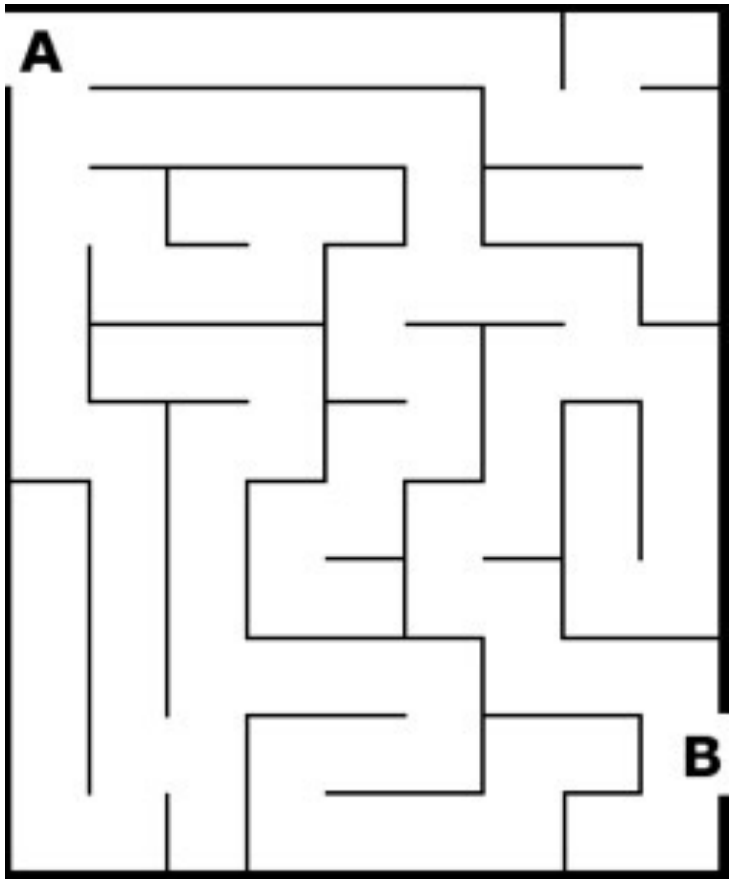
- Stage 2: pull out structures via pattern perception
  - Visual field is divided in simple patterns: e.g. continuous contours, regions of the same color / texture
  - Object recognition
  - Slower serial processing

Preattentive processing. 3-stage model

- Stage 3: sequential goal-directed processing
  - Information is further reduced to a few objects held in visual working memory
  - Used to answer and construct visual queries
  - Attention-driven – forms the basis for visual thinking
  - Interfaces to other subsystems:
    - Verbal linguistic: connection of words and images
    - Perception-for-action: motor system to control muscle movement

Preattentive processing. 3-stage model

- Example. Route between the two letters?
  - Stage 1: automatic parallel extraction of colors, shapes, position, etc.
  - Stage 2: Pattern finding of black contours (lines) between two symbols (letters)
  - Stage 3:
    - Few objects are held in working memory at a time
    - Identify path sequentially (formulate new visual query)



Will mainly talk about stages 1 & 2

Preattentive processing

- A limited set of basic visual properties are processed ***preattentively***
  - Information that "pops out"
  - Parallel processing by the low-level visual system (Stage 1 in the model)
  - Occurs prior to conscious attention
  - Important for designing effective visualizations
    - What features can be perceived rapidly?
    - Which properties are good discriminators?
    - What can mislead viewers?
    - How to design information such that it pops out?

Preattentive processing

- Example: Find the 3s

1424164963575984759217659684748917284822859588198294509685048506958476121240440746748989851714959691245676596080208606083654164964575906439804792485769607812859607999187128452681014959691245677818742416496457576596081495969124567012859607999187128452681014959691245678196079916496457512787991871284529849691223591649645759588198250963576596080596

Preattentive processing

- Example: Find the 3s

142416496357598475921765968474891728482
285958819829450968504850695847612124044
074674898985171495969124567659608020860
608365416496457590643980479248576960781
285960799918712845268101495969124567781
874241649645757659608149596912456701285
960799164964575127879918712845298496912
223591649645759588198250963576596080596

Preattentive processing

- How to find out if a visual attribute is preattentive?
  1. Measure response time for tasks
  2. Check whether time is smaller than a certain threshold

- Different **tasks** are possible
  - Detection of a target among distractors – Is the target present?
  - Boundary detection – Do items form two groups?
  - Counting – How many targets are there?

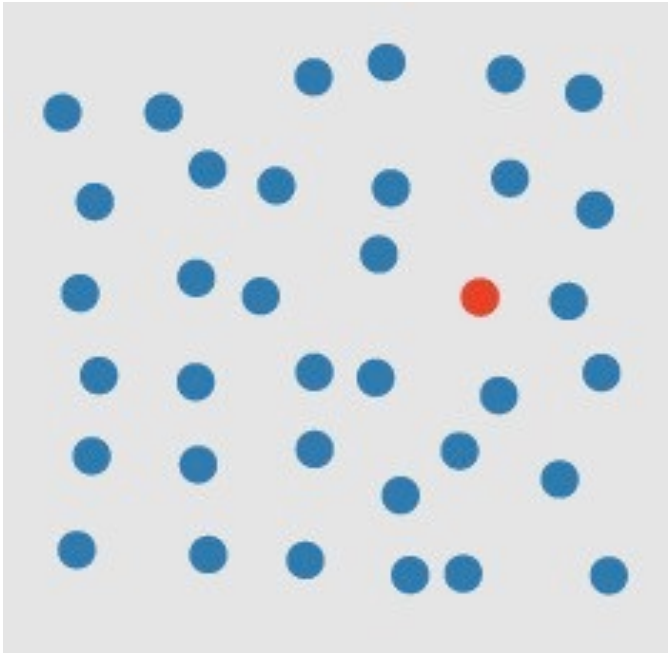
Preattentive processing

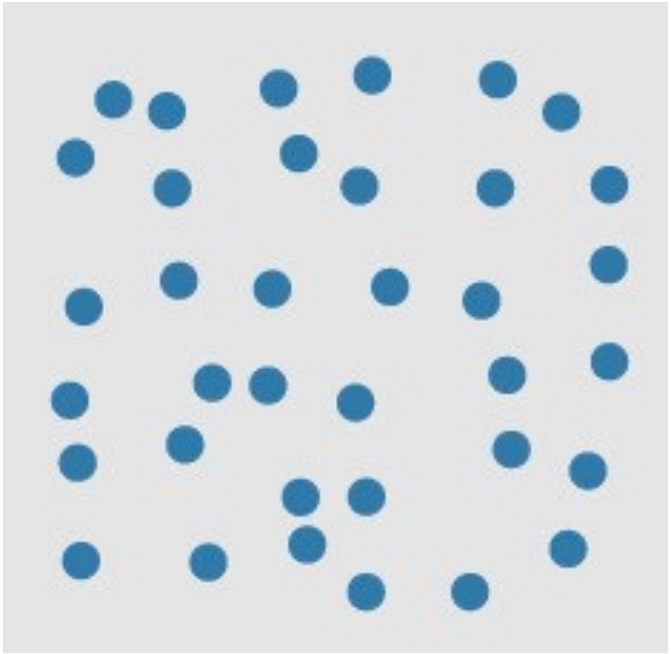
- **Time** threshold:
  - Detection of targets on a large multi-element display
    - Times < 200 to 250 ms are considered preattentive
  - Eye movement takes at least 200 ms to initiate

- Example: is there a red target present in the images?

Preattentive processing

- Is there a red circle present in the image?

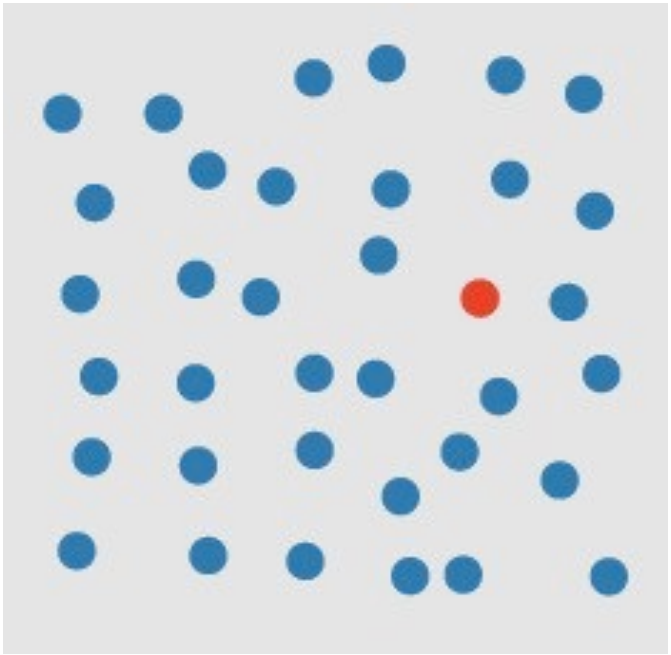


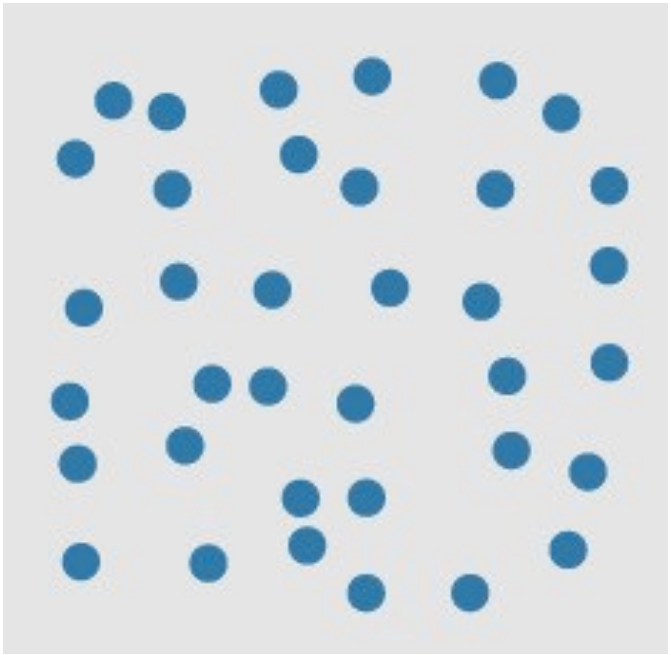


Images taken from http://www.csc.ncsu.edu/faculty/healey/PP/index.html

Preattentive processing

- Is there a red circle present in the image?



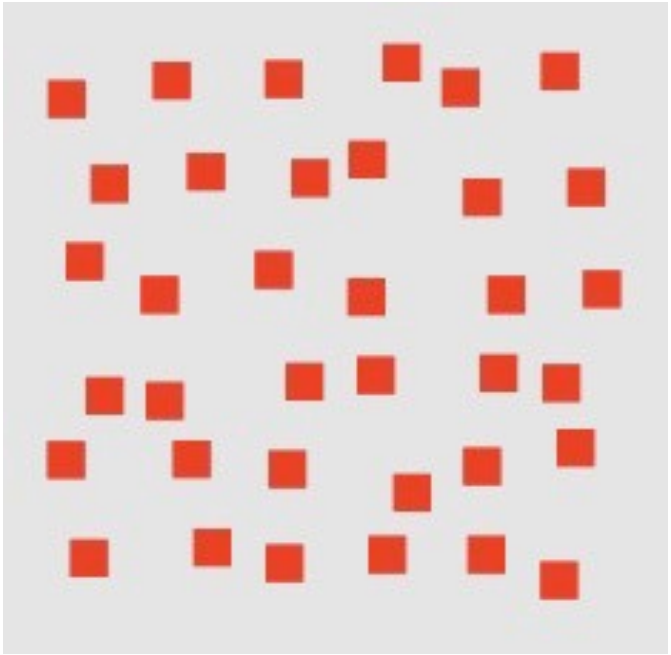


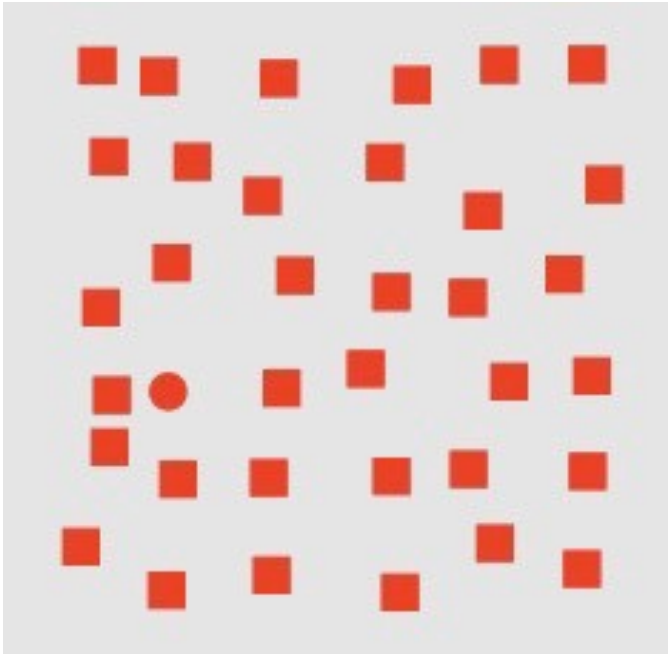
Color is preattentively processed!

Images taken from http://www.csc.ncsu.edu/faculty/healey/PP/index.html

Preattentive processing

- Is there a red circle present in the image?





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Preattentive processing

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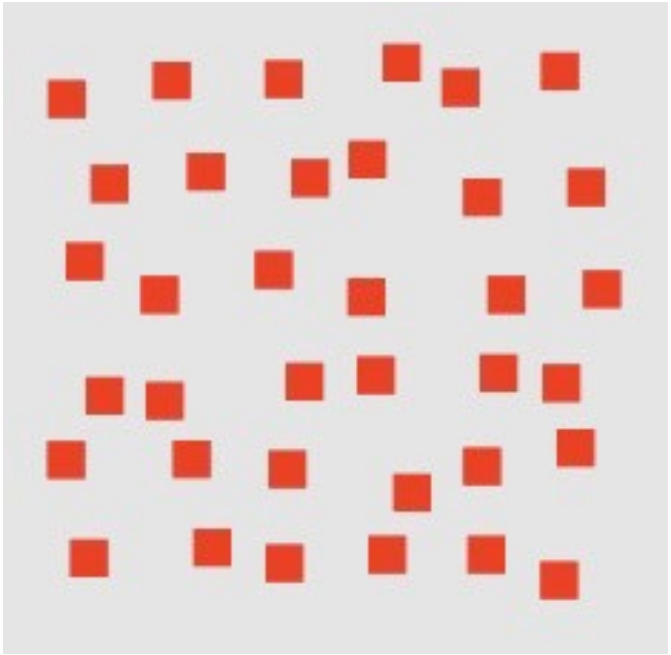
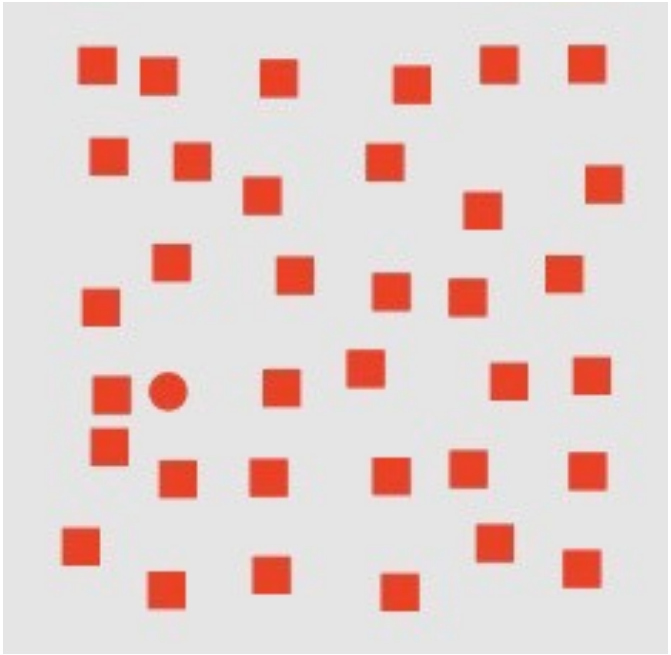


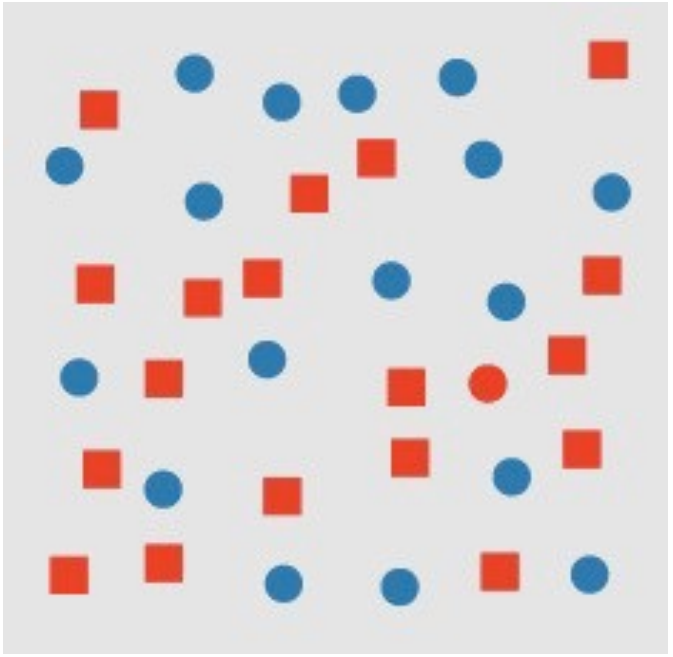


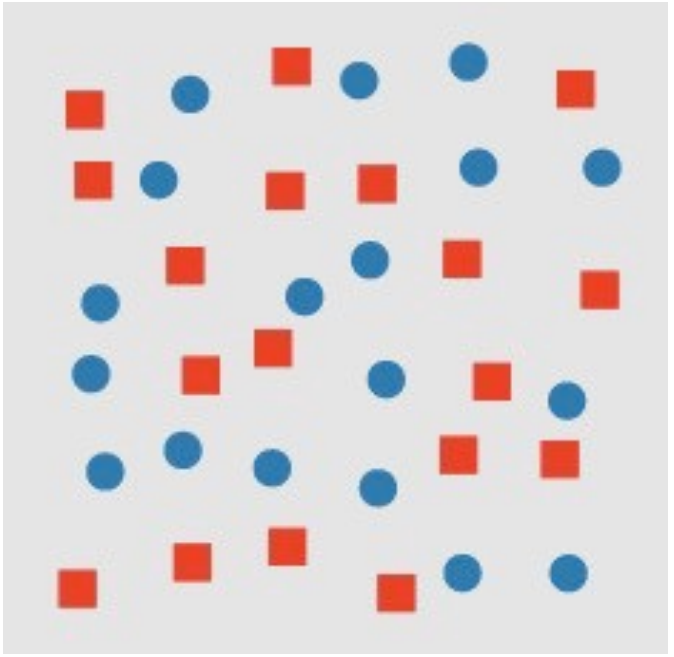
Shape is preattentively processed!

Images taken from http://www.csc.ncsu.edu/faculty/healey/PP/index.html

Preattentive processing

- Is there a red circle present in the image?





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Preattentive processing

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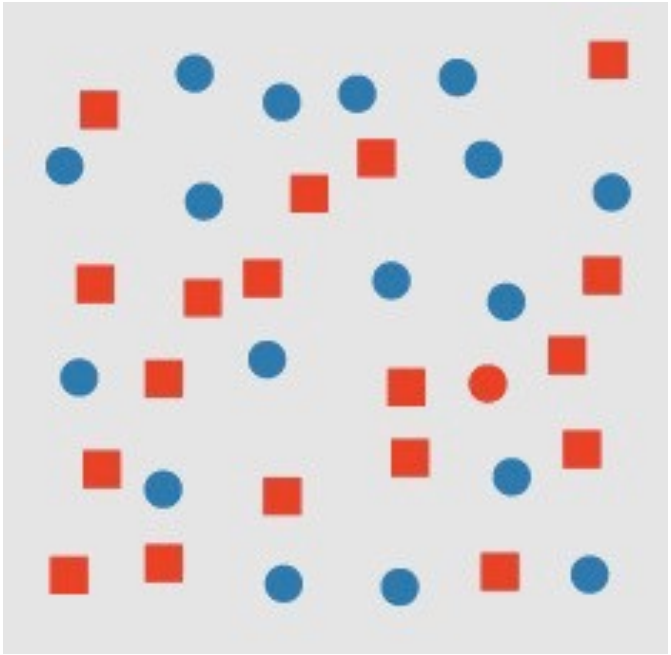
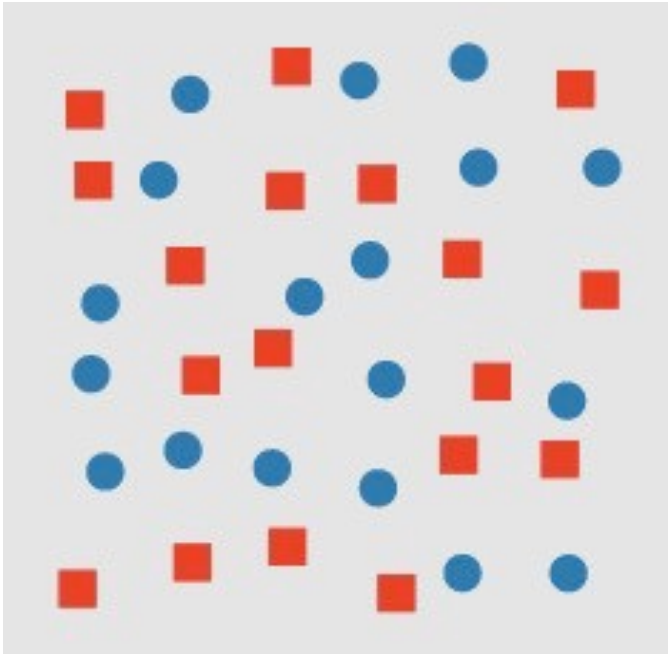


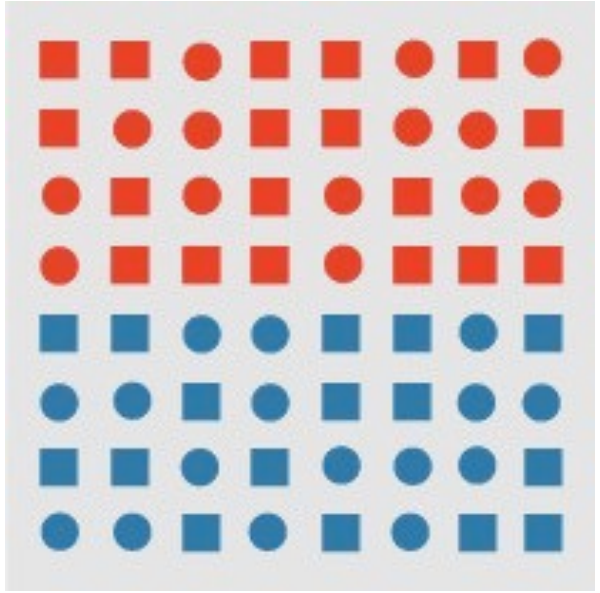


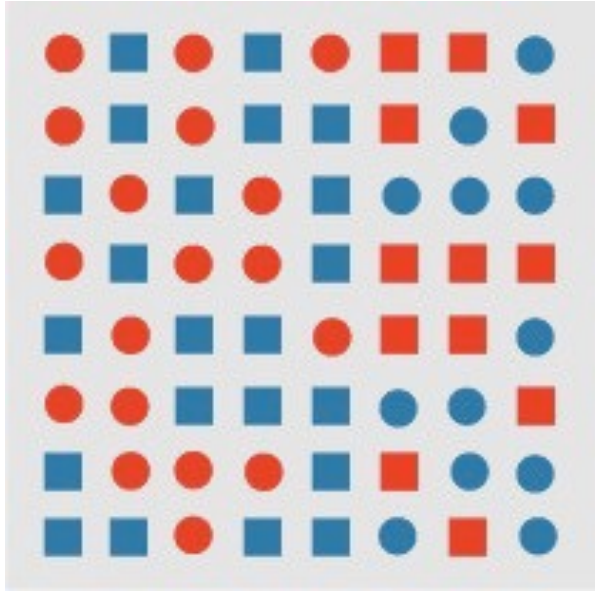
Conjunction of 2 properties is usually not preattentive

Images taken from http://www.csc.ncsu.edu/faculty/healey/PP/index.html

Preattentive processing

- Do items form a boundary? If yes, based on which attribute(s)?





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Preattentive processing

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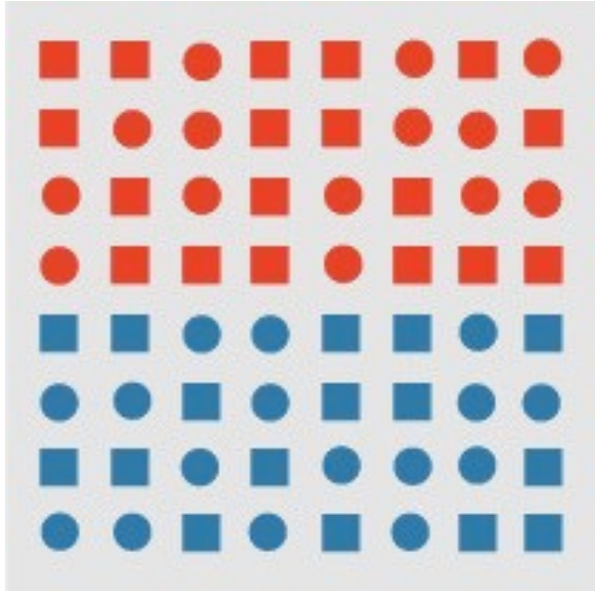
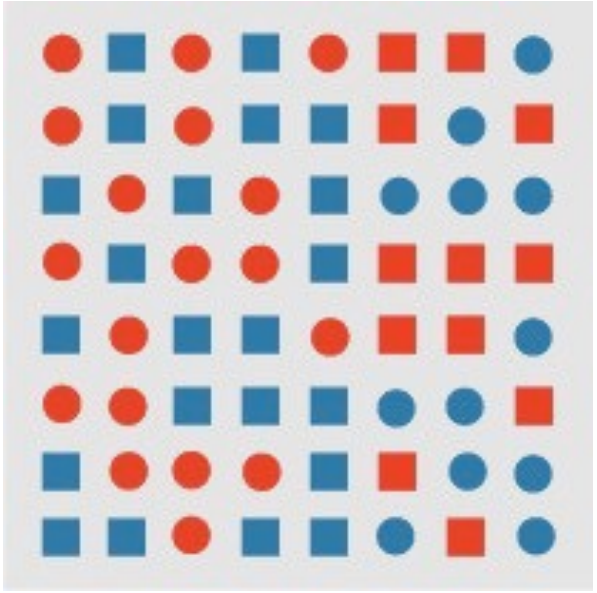


Preattentive: grouping by hue

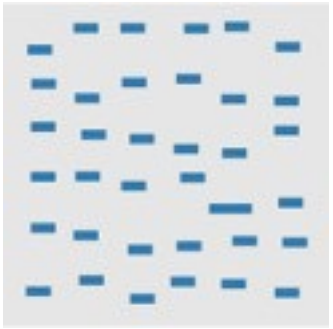
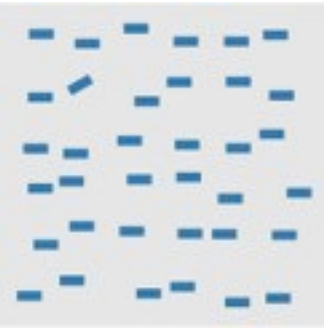


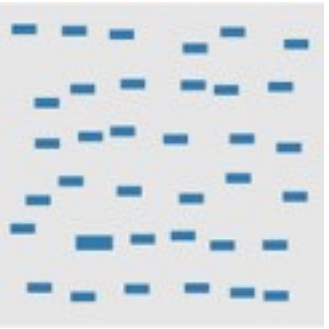
Conjunction search: grouping by hue and shape

Images taken from http://www.csc.ncsu.edu/faculty/healey/PP/index.html

Preattentive processing

- Common Preattentive Properties
  - Form
    - Line orientation
    - Line length
    - Line width
    - Size
    - Curvature
    - Shape
    - Spatial grouping

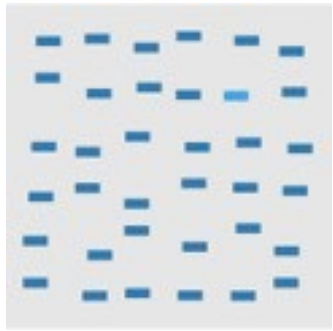



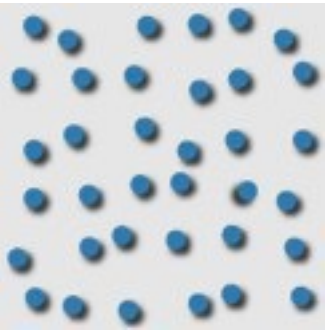


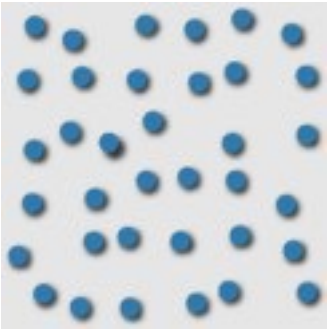
Images taken from http://www.csc.ncsu.edu/faculty/healey/PP/index.html

Preattentive processing

- Common Preattentive Properties
  - Color
    - Hue
    - Intensity
    - Motion
    - Flicker
    - Direction of motion
    - Spatial Position
    - 2D position
    - Stereoscopic depth
    - Convexity / Concavity



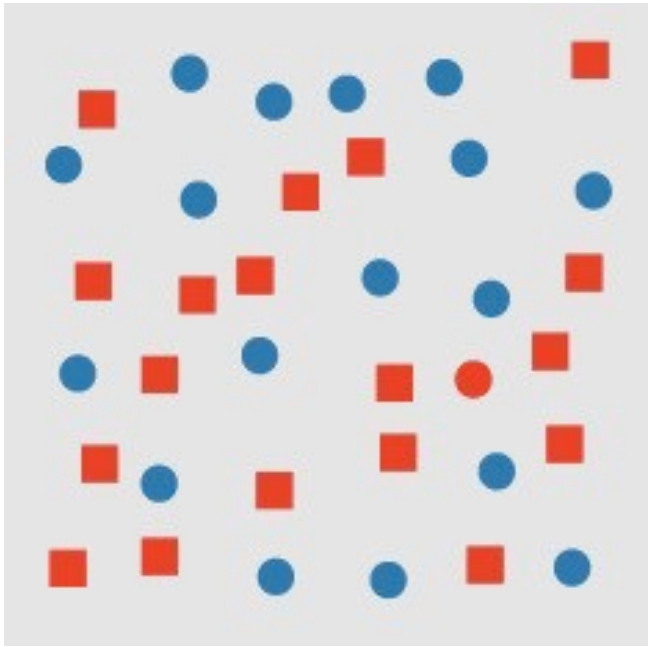




Images taken from http://www.csc.ncsu.edu/faculty/healey/PP/index.html

Preattentive processing

- Conjunction Search
  - A target with a unique visual property (e.g., shape OR color) "pops out"
- Conjunction target is made up of non-unique features
  - Requires a time-consuming serial search, e.g.
    - For every red colored item: is it a circle?
    - For every circular item: is it red?



Images taken from http://www.csc.ncsu.edu/faculty/healey/PP/index.html

Preattentive processing

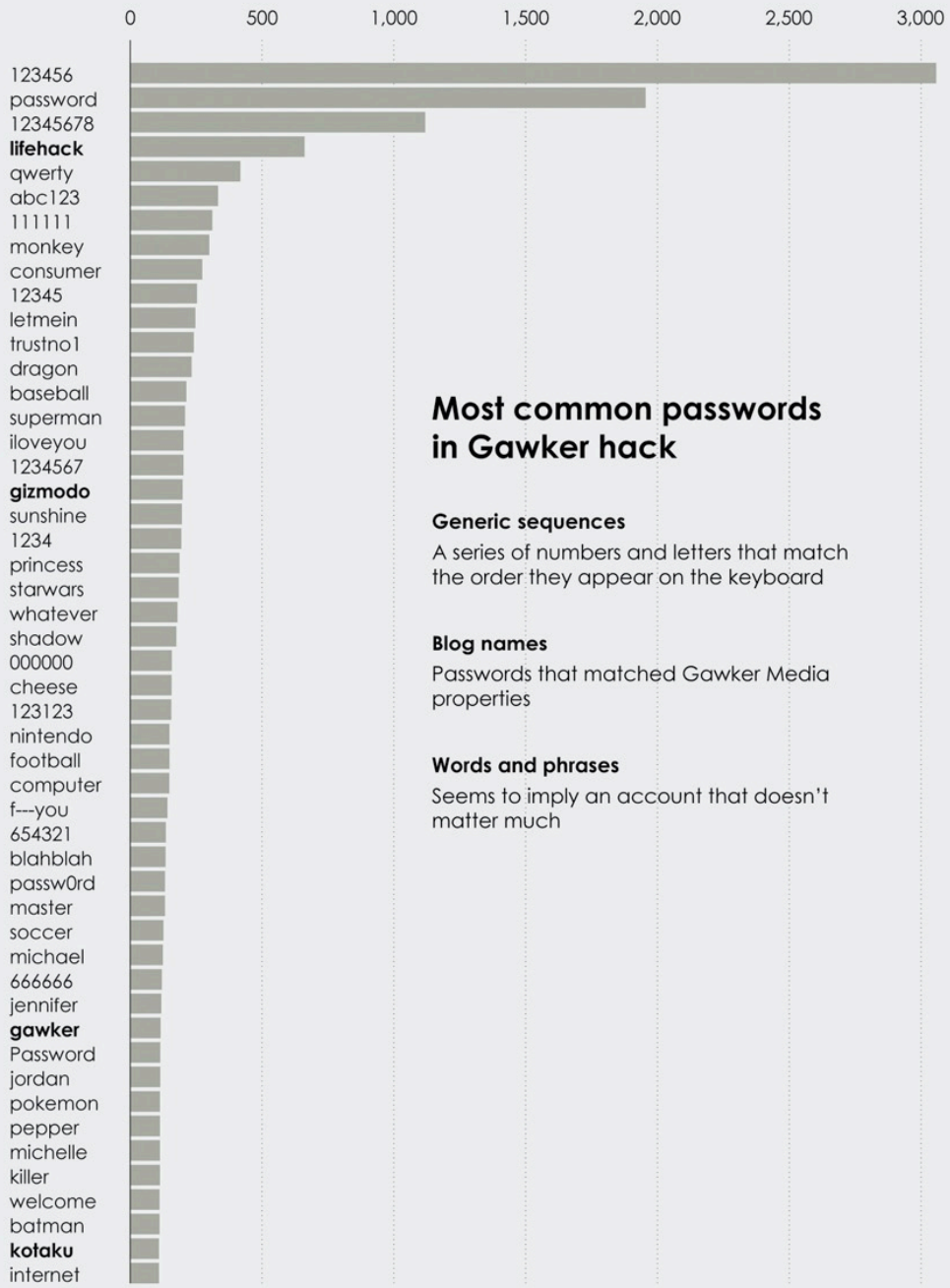
- Preattentive Perception theories
  - Try to understand **how** the human brain works
    - Not necessarily the biological or anatomical aspects (not why)
  - Some "explain" certain behavior
    - But not others…

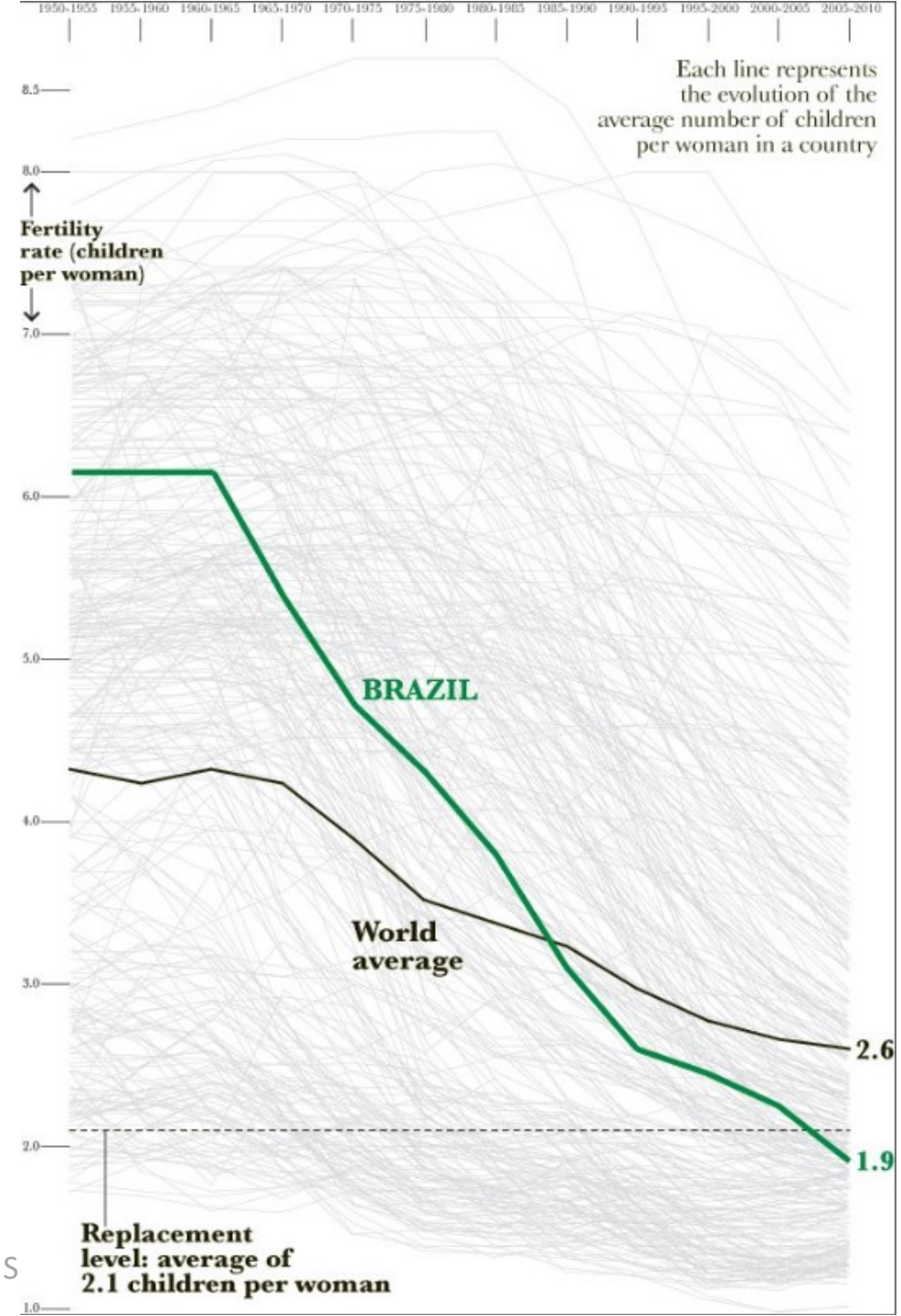
Preattentive processing

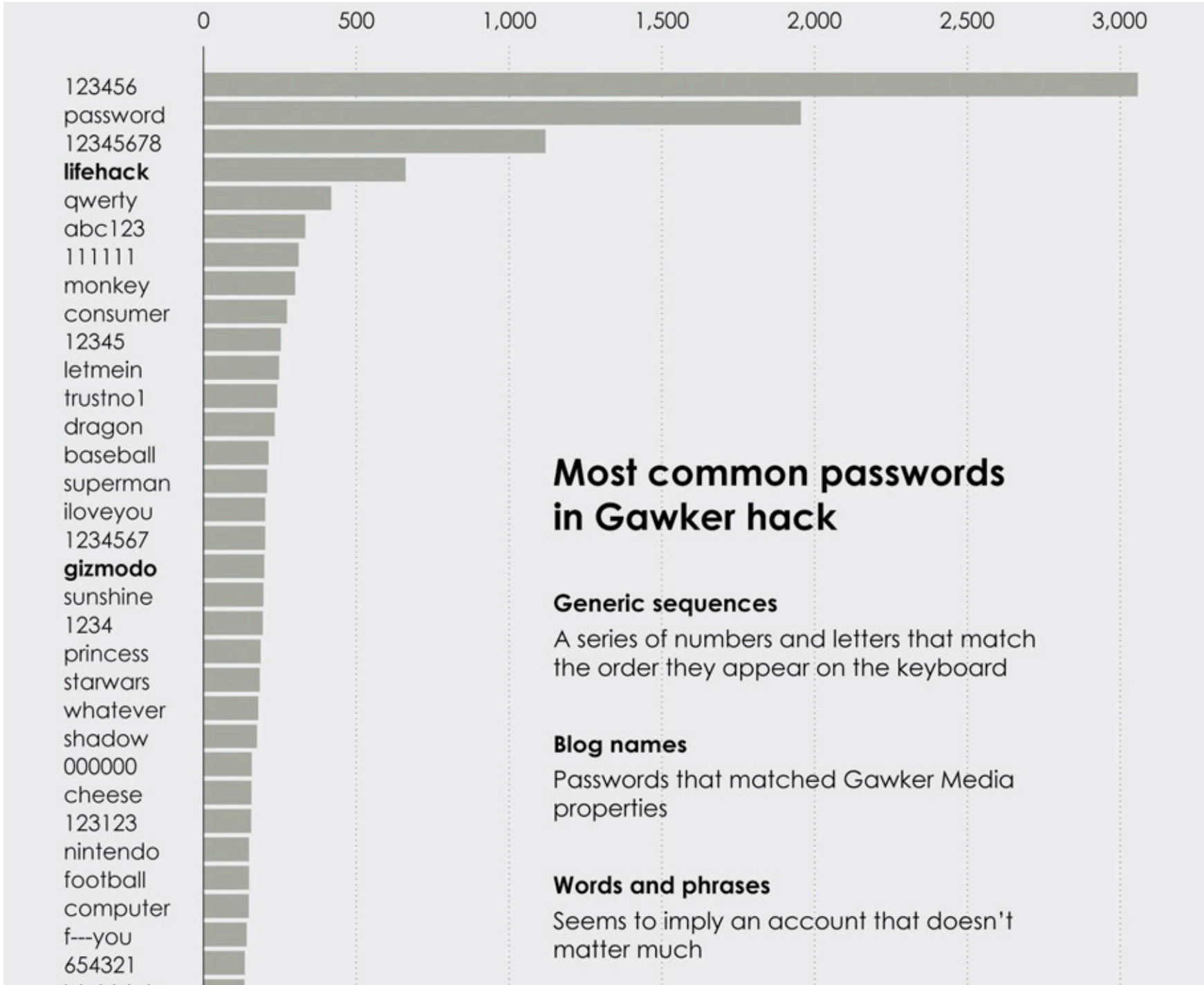
- Feature Integration Theory
- Texton Theory
- Similarity Theory
- Guided Theory
- Boolean Theory

Preattentive processing

- Use of preattentive features in visualization. Some tips:
  - Remember preattentive features are asymmetric
    - E.g., a sloped line in a sea of vertical lines can be detected preattentively, but the opposite is not true
  - Consider the effect of background distractors with the target feature
  - Avoid use of conjunction targets


0
500
1,000
1,500
2,000
2,500
3,000
123456
password
12345678
lifehack
qwerty
abc123
111111
monkey
consumer
12345
letmein
trustno1
dragon
baseball
superman
iloveyou
1234567
gizmodo
sunshine
1234
princess
starwars
whatever
shadow
000000
cheese
123123
nintendo
football
computer
f---you
654321
blahblah
passw0rd
master
soccer
michael
666666
jennifer
gawker
Password
jordan
pokemon
pepper
michelle
killer
welcome
batman
kotaku
internet
Most common passwords in Gawker hack
Generic sequences
A series of numbers and letters that match the order they appear on the keyboard
Blog names
Passwords that matched Gawker Media properties
Words and phrases
Seems to imply an account that doesn't matter much


1950-1955
1955-1960
1960-1965
1965-1970
1970-1975
1975-1980
1980-1985
1985-1990
1990-1995
1995-2000
2000-2005
2005-2010
Each line represents the evolution of the average number of children per woman in a country
8.5
8.0
Fertility rate (children per woman)
7.0
6.0
5.0
4.0
3.0
2.0
1.0
BRAZIL
World average
2.6
1.9
Replacement level: average of 2.1 children per woman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12345678
lifehack
qwerty
abc123
111111
monkey
consumer
12345
letmein
trustno1
dragon
baseball
superman
iloveyou
1234567
gizmodo
sunshine
1234
princess
starwars
whatever
shadow
000000
cheese
123123
nintendo
football
computer
f---you
654321
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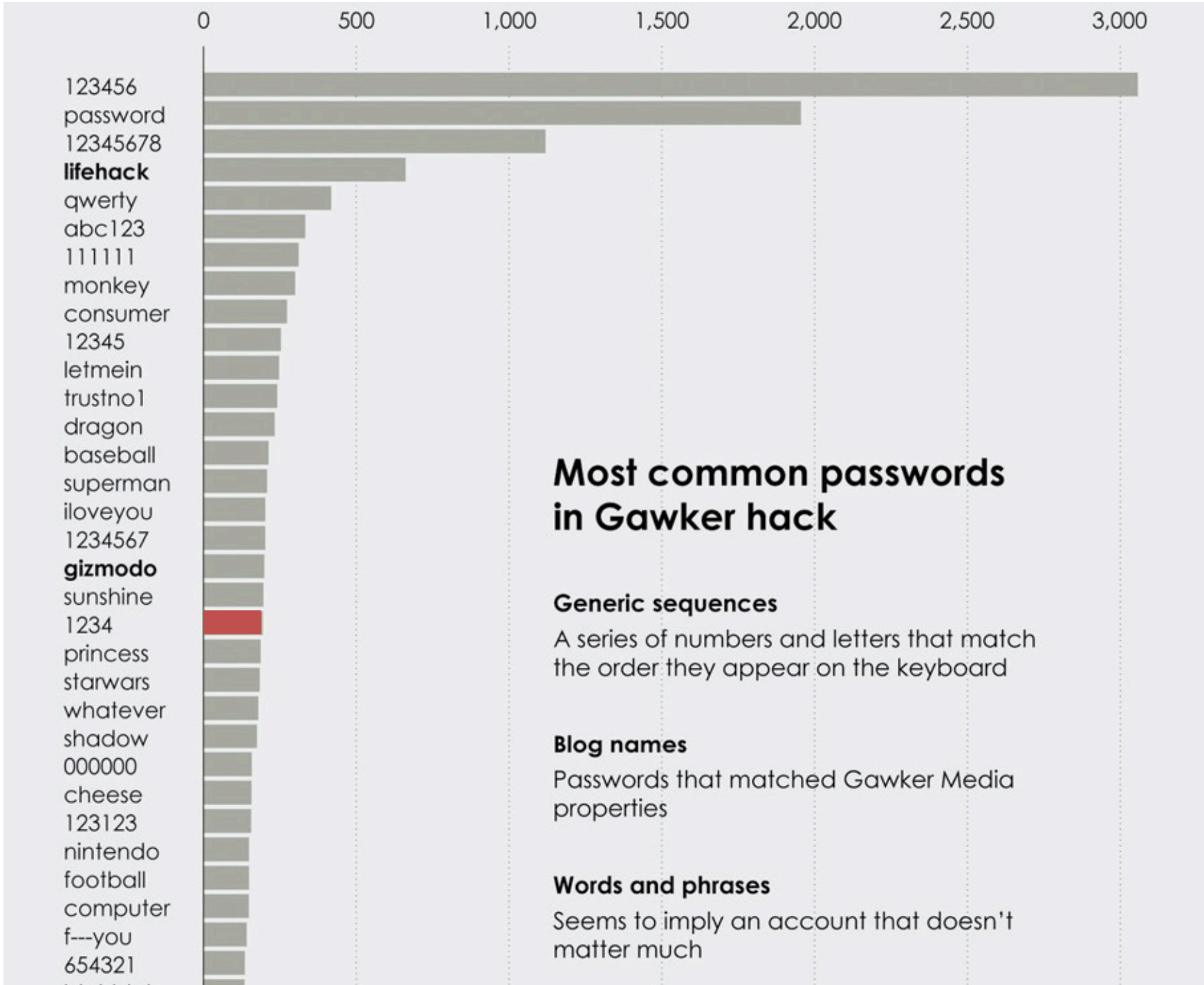
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abc123
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monkey
consumer
12345
letmein
trustno1
dragon
baseball
superman
iloveyou
1234567
gizmodo
sunshine
1234
princess
starwars
whatever
shadow
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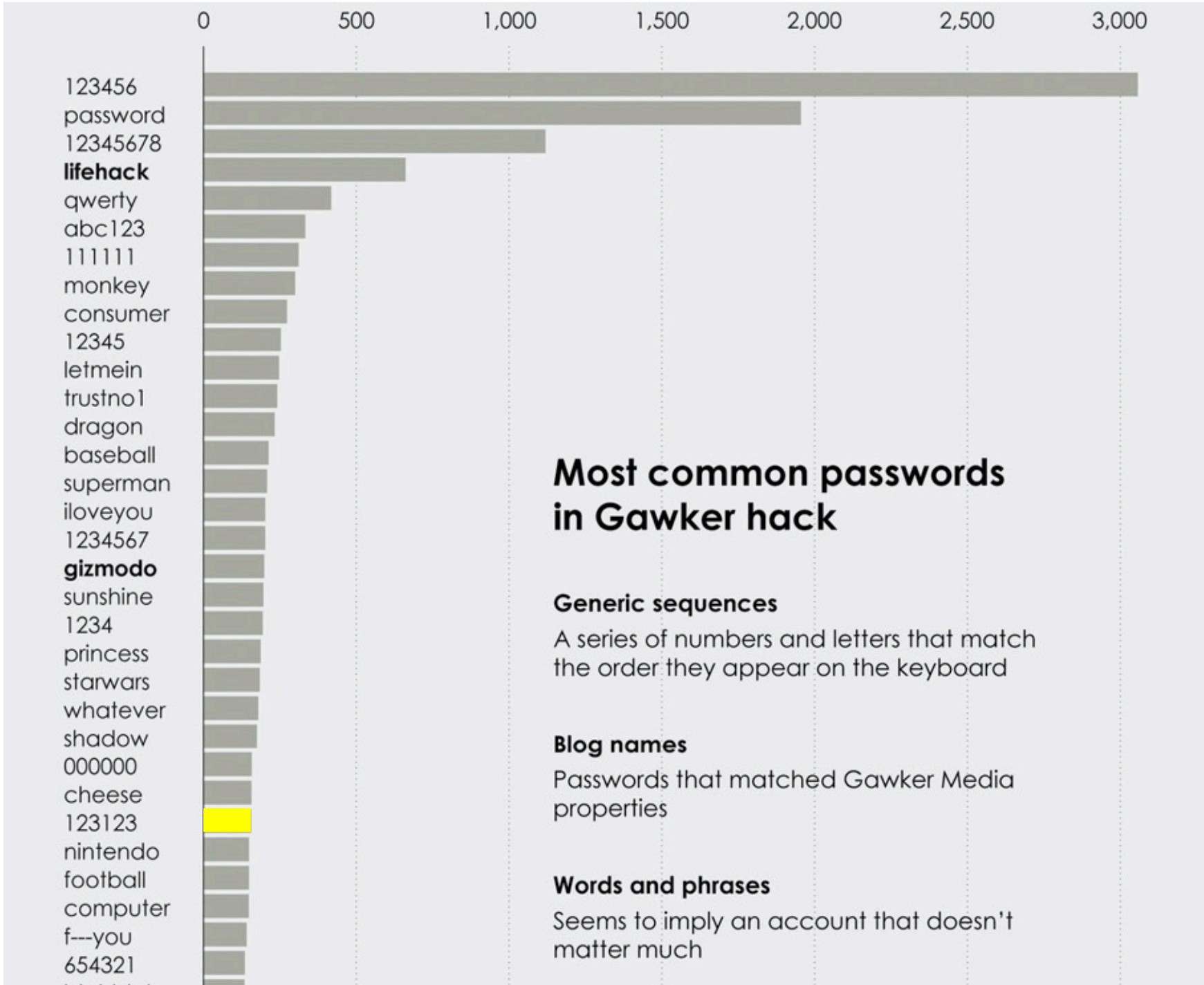
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monkey
consumer
12345
letmein
trustno1
dragon
baseball
superman
iloveyou
1234567
gizmodo
sunshine
1234
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starwars
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Preattentive processing. Conclusions

- Preattentive processing **works when we know what we are looking for**
  - The brain lets the cells sensitive to the element searched for to have more relevant paper
    - While the other are partially silenced
  - Very sensitive to the distractors
  - Training does not have any influence

Preattentive processing. Conclusions

- Preattentive processing **works when we know what we are looking for**
  - Otherwise, most stimuli pass undetected

Preattentive processing. Conclusions

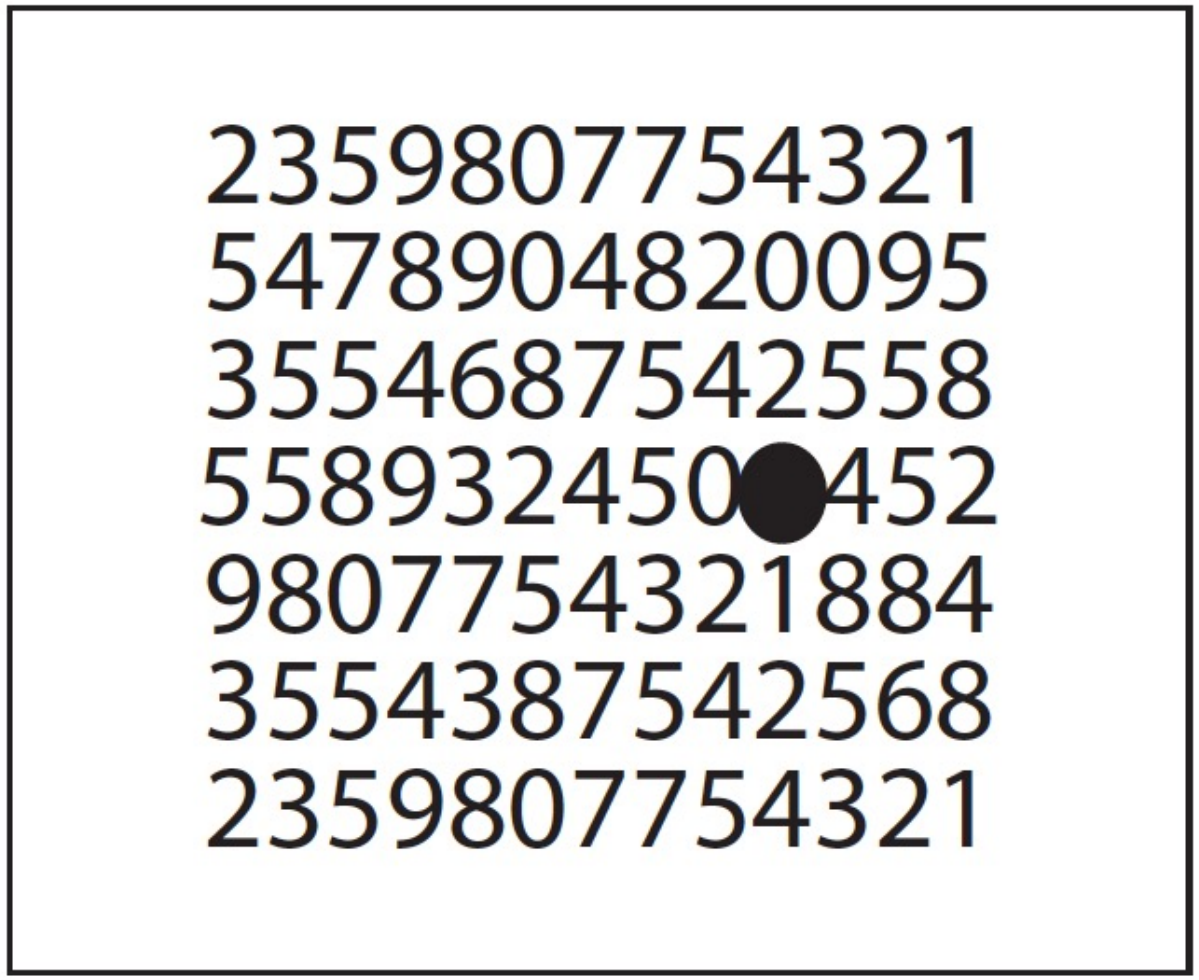
- Preattentive processing **works when we know what we are looking for**

- Movement ALWAYS attracts our attention
  - Moving elements in webpages, flickering text or banners, are highly distracting!

Preattentive processing. Conclusions

6
difficult

easy

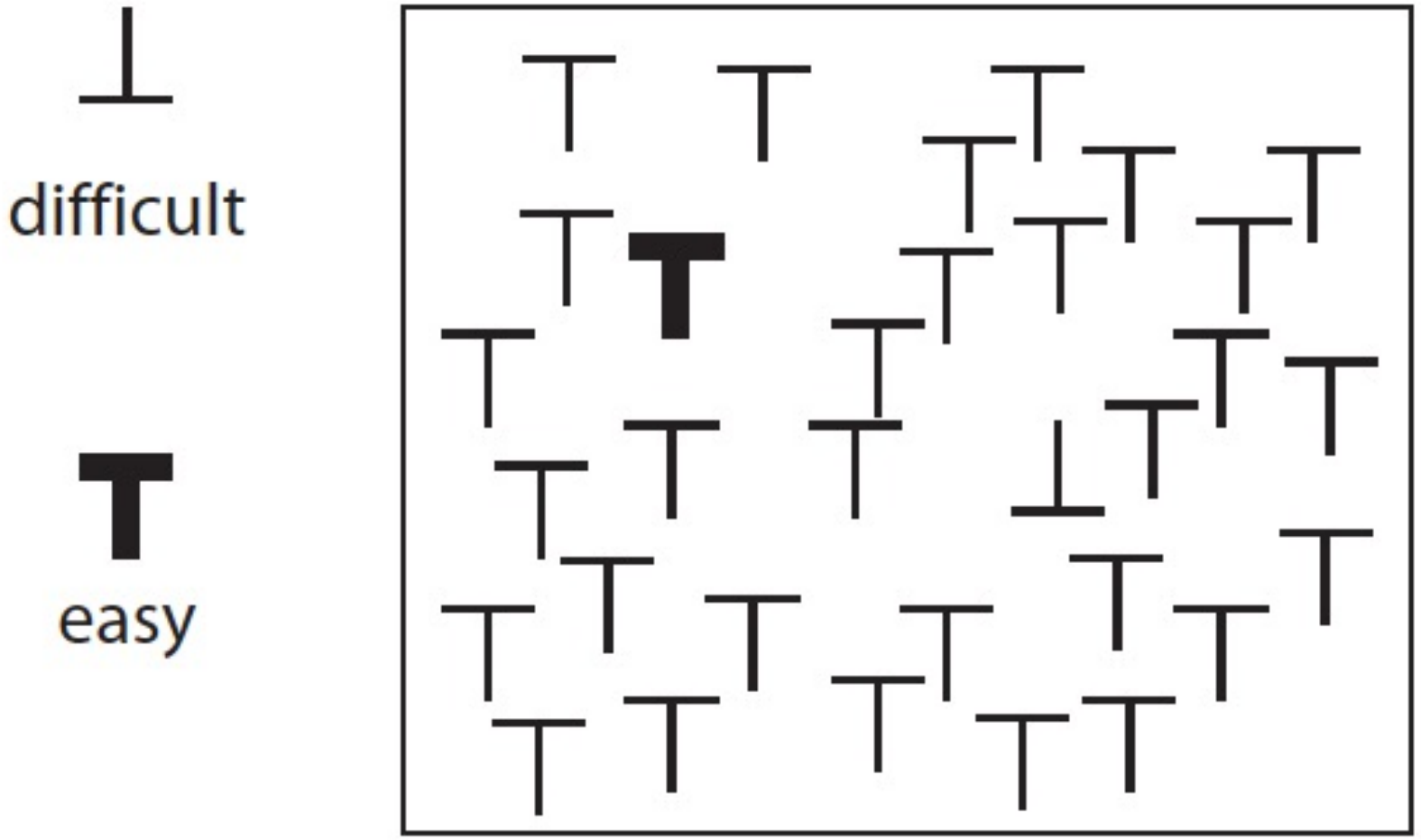


Preattentive processing. Conclusions

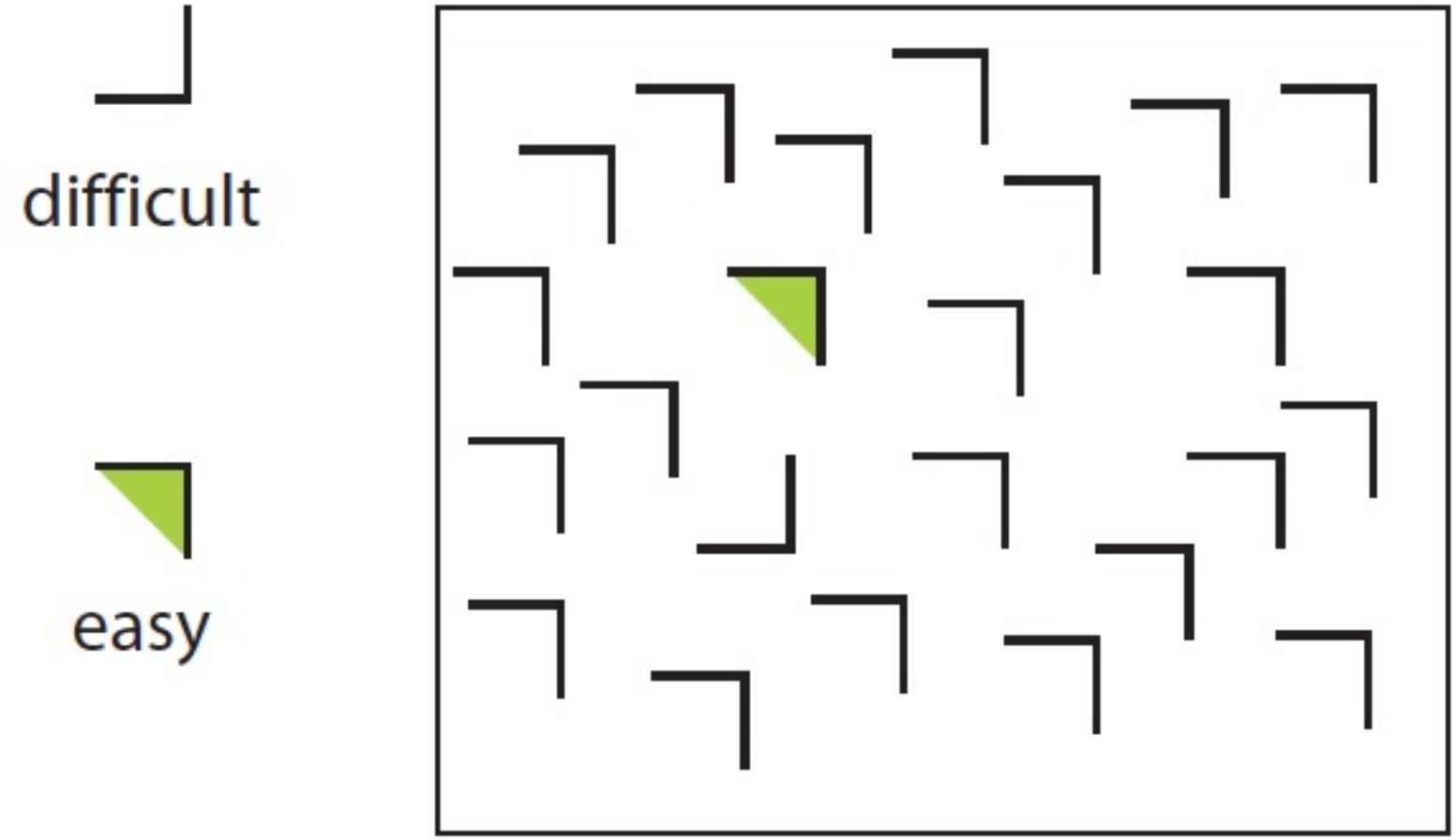
difficult

easy

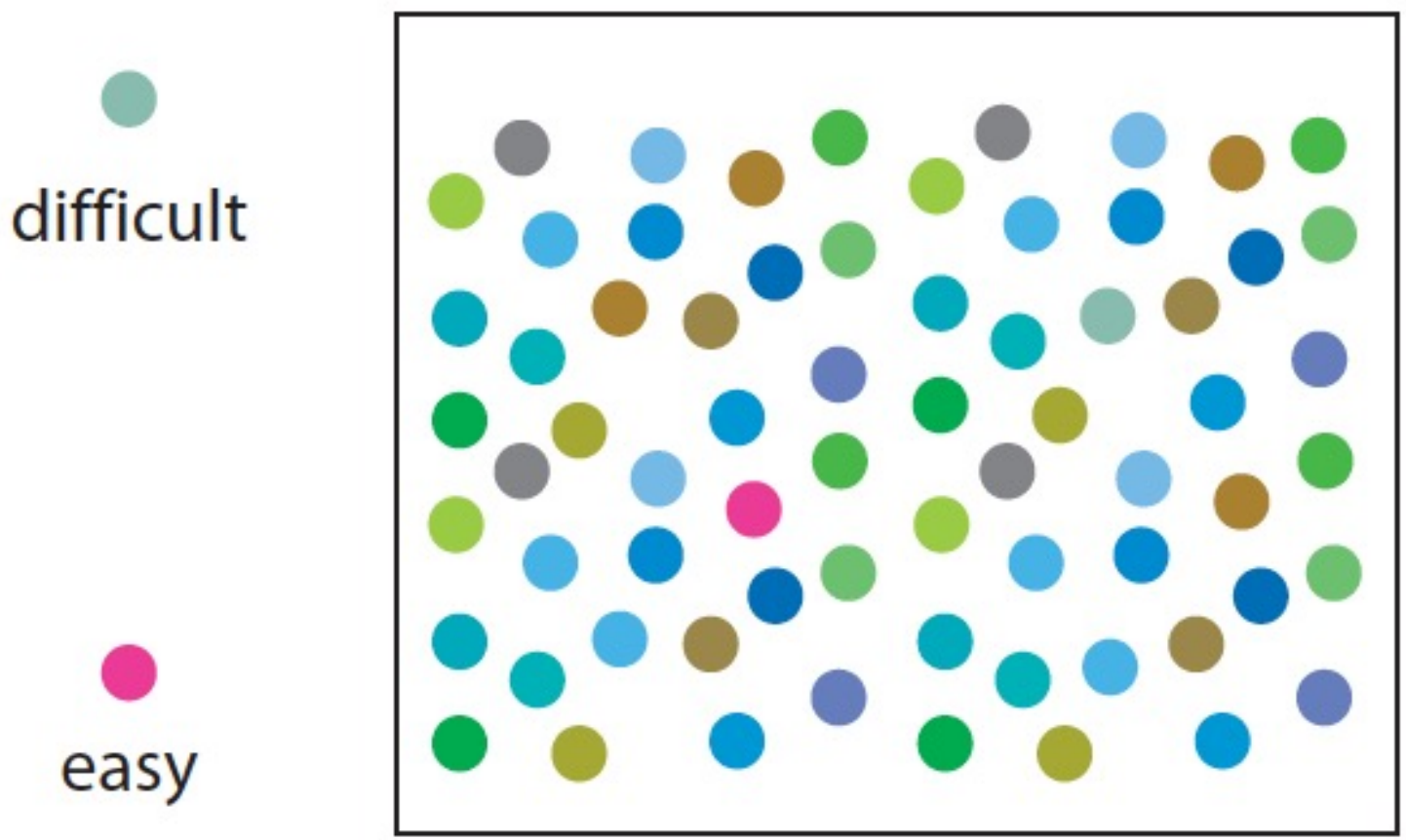
Preattentive processing. Conclusions



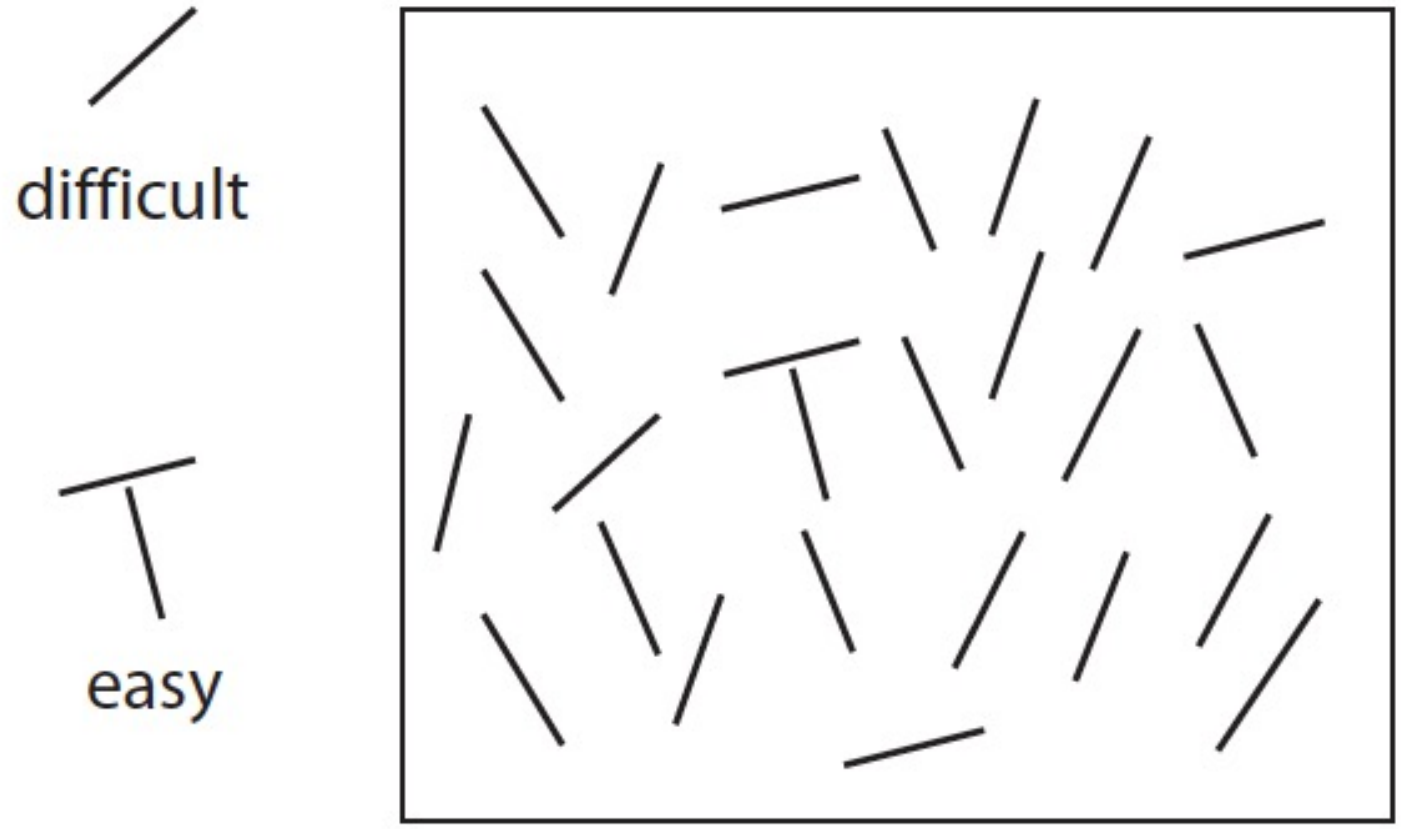
Preattentive processing. Conclusions



Preattentive processing. Conclusions



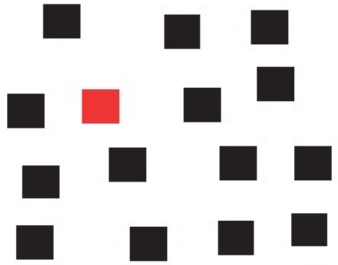
Preattentive processing. Conclusions



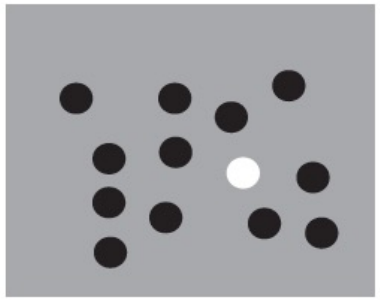
Preattentive processing. Basic pop-out channels

Color

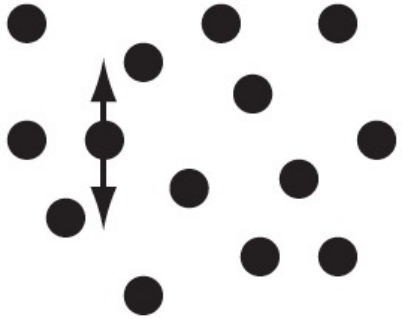
hue



lightness



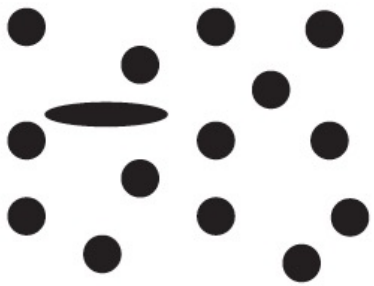
Motion



Elementary shape

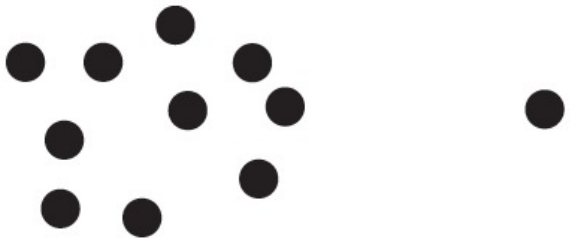
size

elongation



orientation

Spatial grouping



Outline

- *Introduction*
- *Preattentive Processing*
- **Perception Laws**
- Applying Perception to Visualization

Perception Laws in Design

Perception Laws in Design

- Can you find the dog?
  - Dalmatinian exploring a leave covered forest floor
    - Once you have found it, try to think of the picture as a simple pattern of black and white again

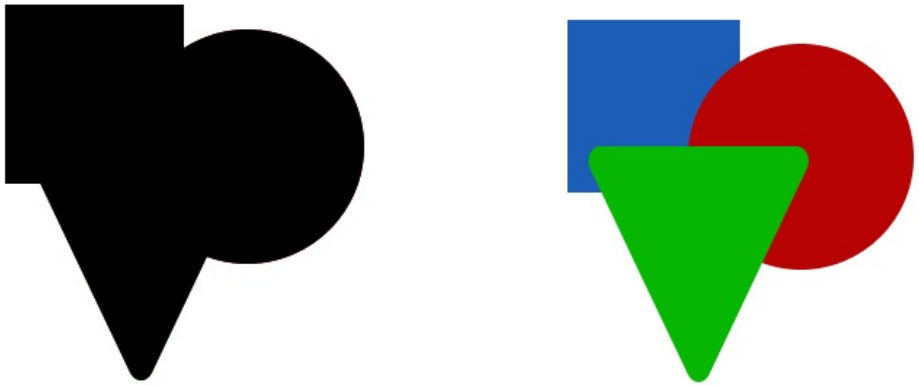
Perception Laws in Design

Perception Laws in Design

- Can you find the dog?
  - Dalmatinian exploring a leave covered forest floor
    - Once you have found it, try to think of the picture as a simple pattern of black and white again
  - Does it work?
    - Mind tries to detect anything meaningful by identifying patterns
    - Different tools are tried sequentially
- Perceptual organization is a powerful mechanism

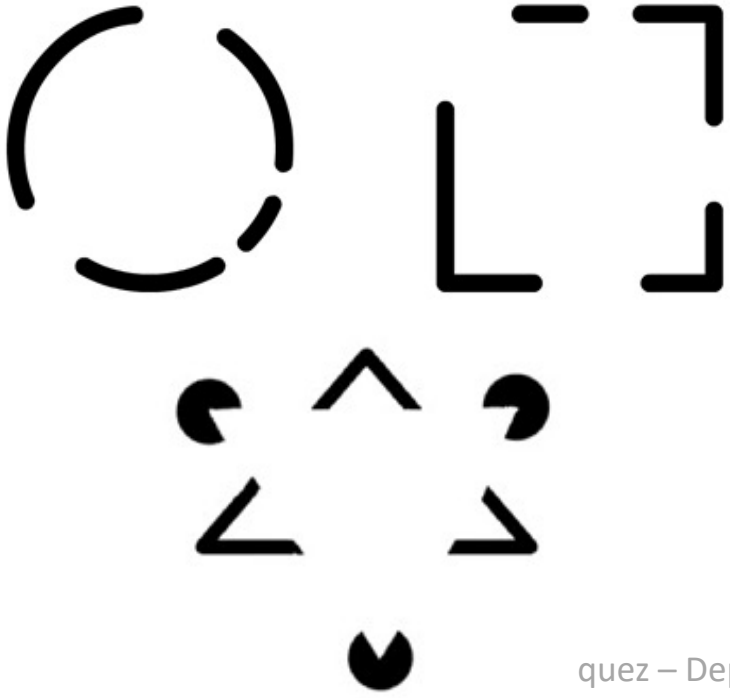
Perception Laws in Design

- Pragnänz Law: Law of good figure, simplicity: We tend to perceive simpler shapes



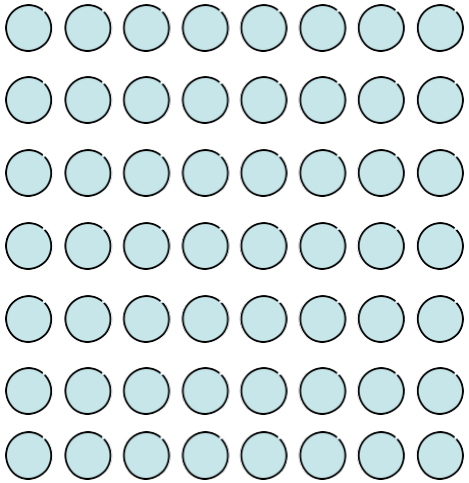
Perception Laws in Design

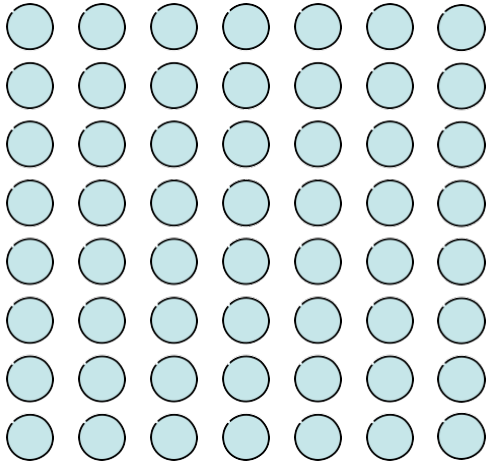
- The law of closure: The mind may experience elements it does not perceive through sensation, in order to complete a regular figure



Perception Laws in Design

- Grouping by spatial proximity
  - Columns or rows?



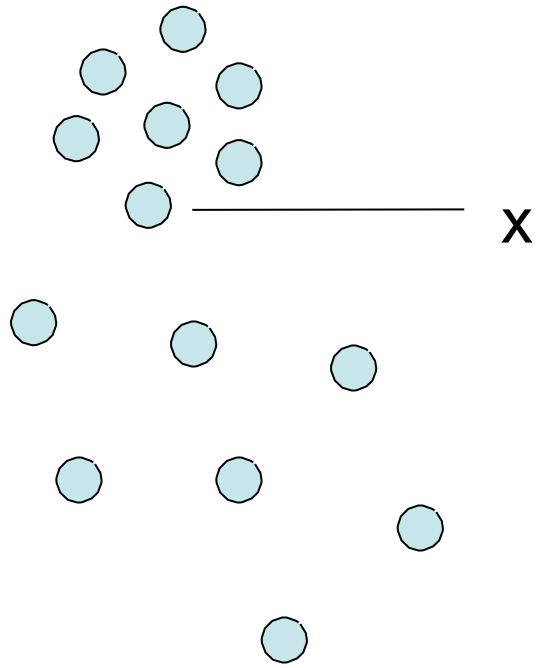


Perception Laws in Design

- Grouping by spatial proximity. Columns or rows?
  - Small difference in spacing causes change in perception
  - Use proximity to emphasize between display items
  - To which group (top / bottom) does the x dot belong? Spacing is equal for both groups!

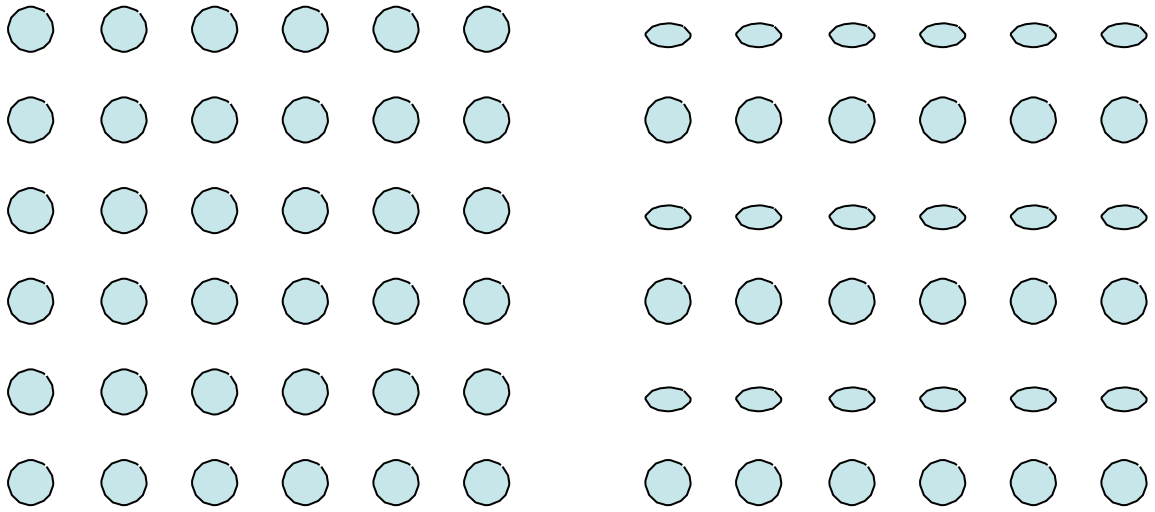
Perception Laws in Design

- Grouping by spatial proximity
  - Spatial concentration principle: we group regions of similar element density (Slocum1983)



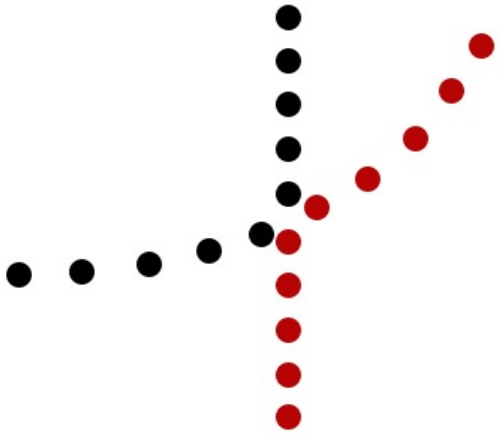
Perception Laws in Design

- Similarity
  - Rows or columns?
  - Similar elements tend to be grouped together



Perception Laws in Design

- The law of continuity: The mind continues visual, auditory, and kinetic patterns.
  - Elements on a line/curve may be perceived as more related than elements not on the line/curve.

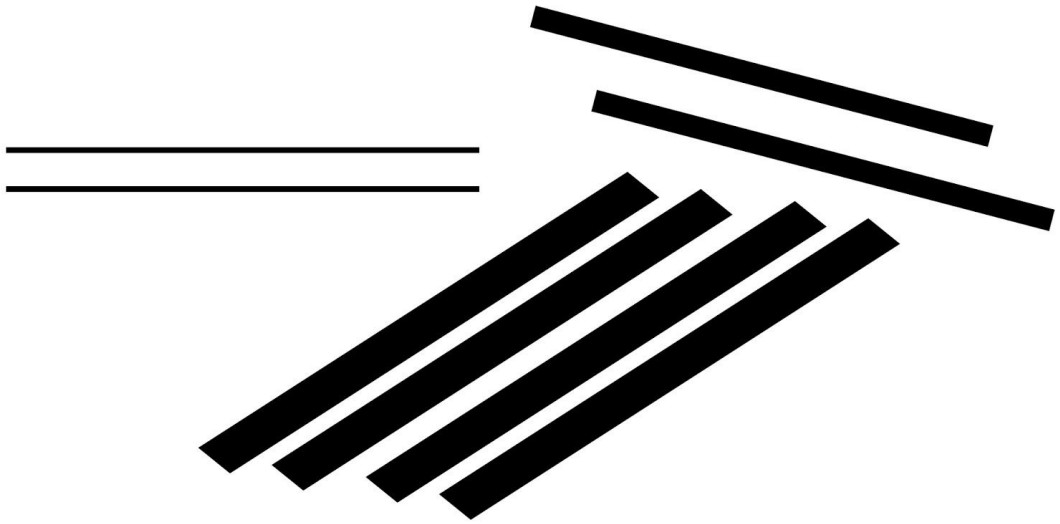


Perception Laws in Design

- The law of common fate: Elements with the same moving direction are perceived as a collective or unit.

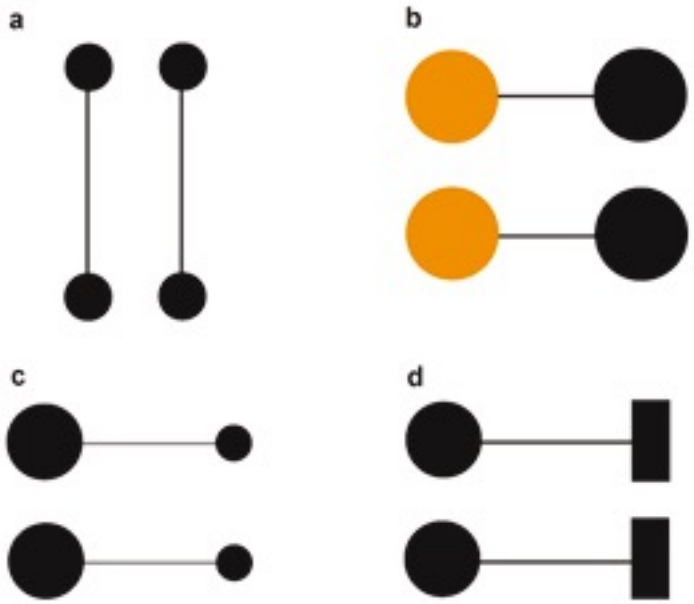
Perception Laws in Design

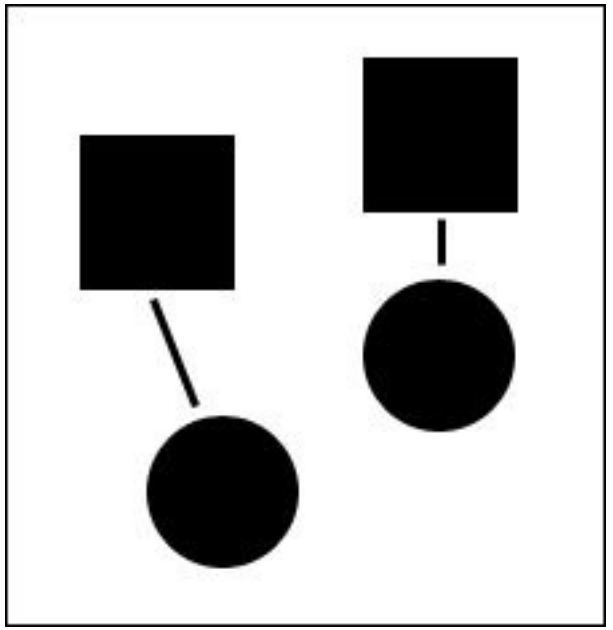
- Principle of parallelism: Parallel elements tend to be perceived as a group
  - Similar to principle of common fate since element are seen as pointing in the same direction



Perception Laws in Design

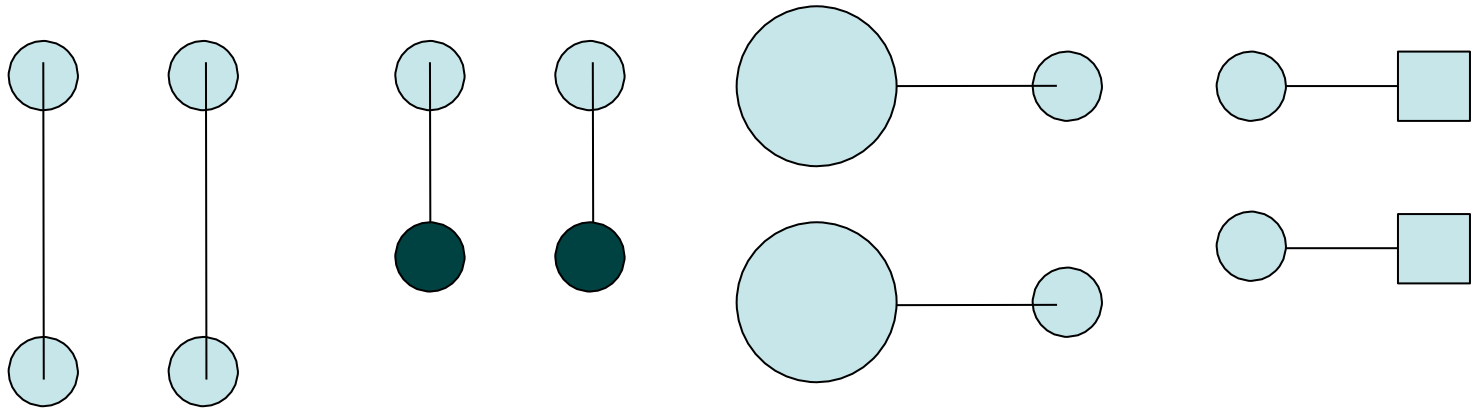
- Principle of connectedness
  - Elements being visually connected are perceived as more related than unconnected elements



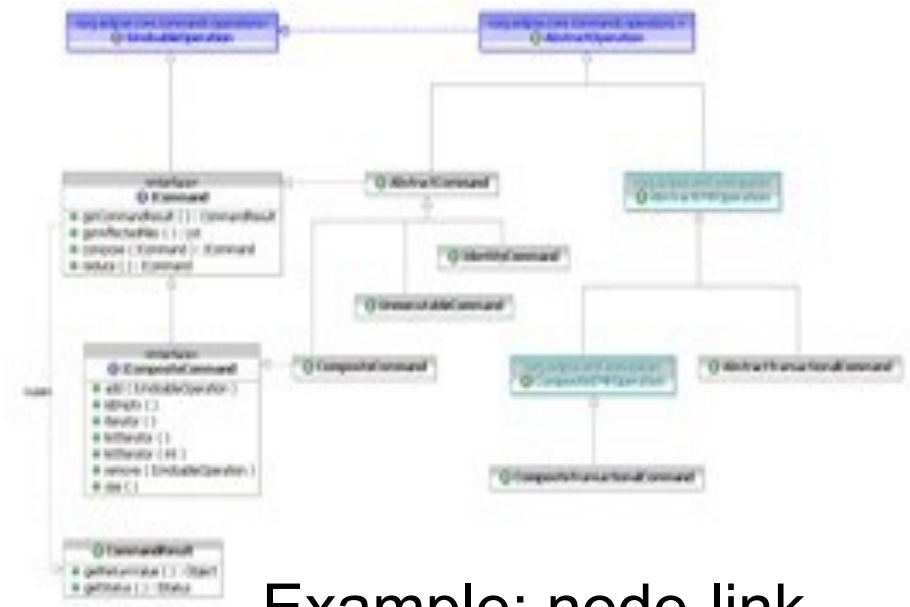


Perception Laws in Design

- Connectedness
  - Palmer & Rock 1994
  - Potentially more powerful organizing principle than proximity, color, size, shape



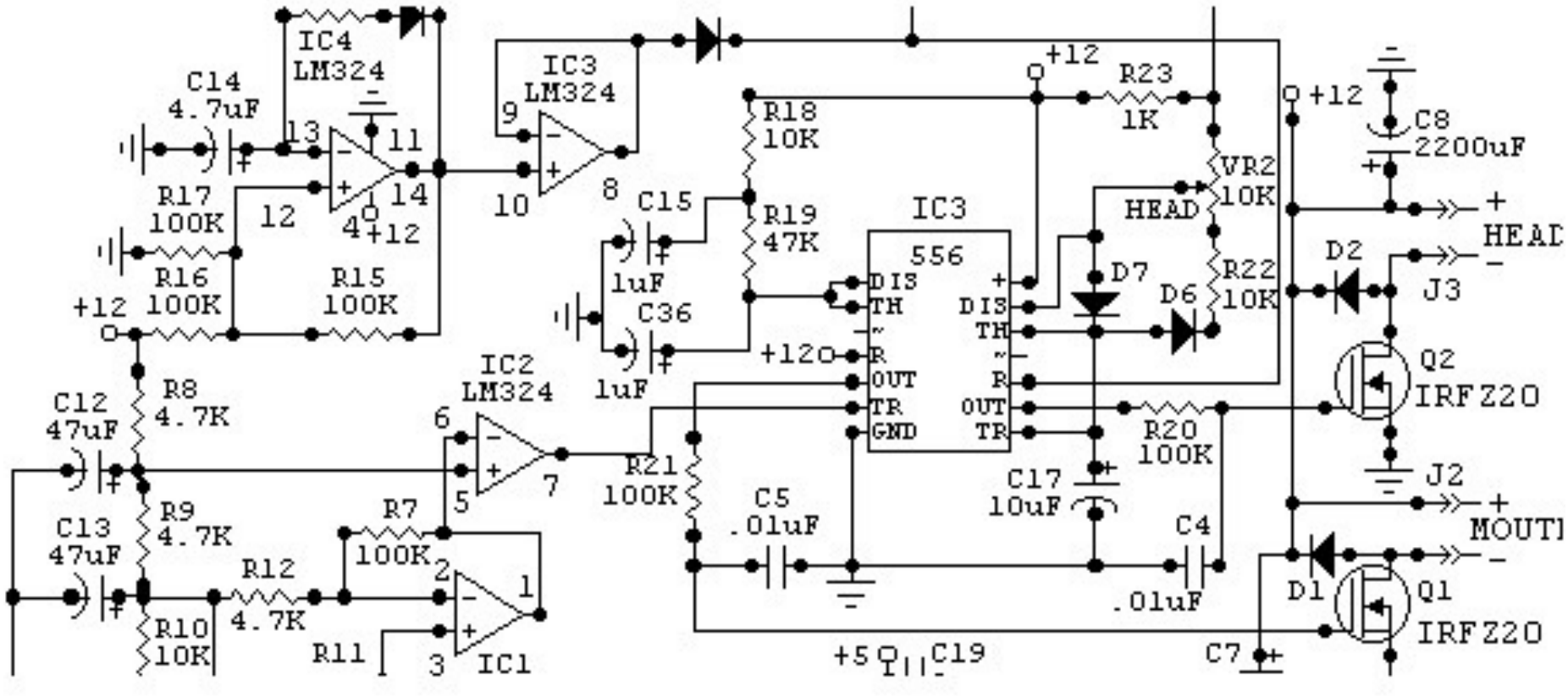
proximity color size shape



Example: node-link diagram

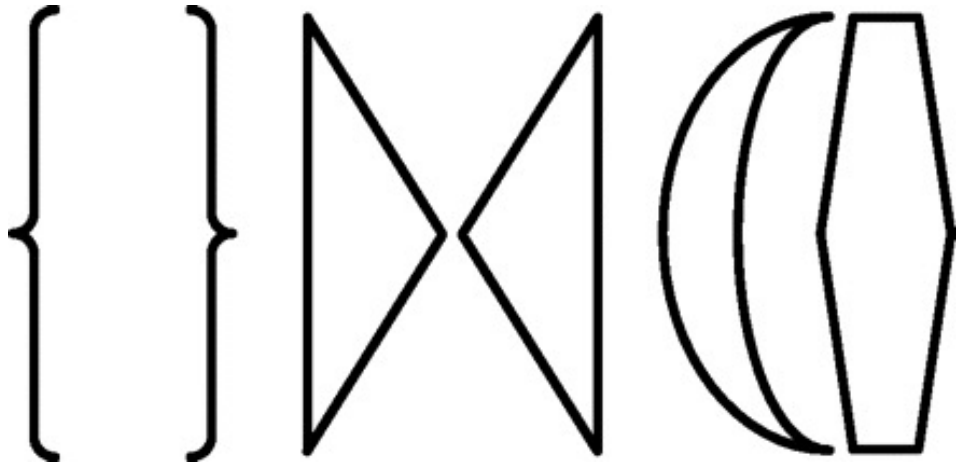
Perception Laws in Design

- Connectedness & continuity, example:
  - Circuit design – understanding how components are connected



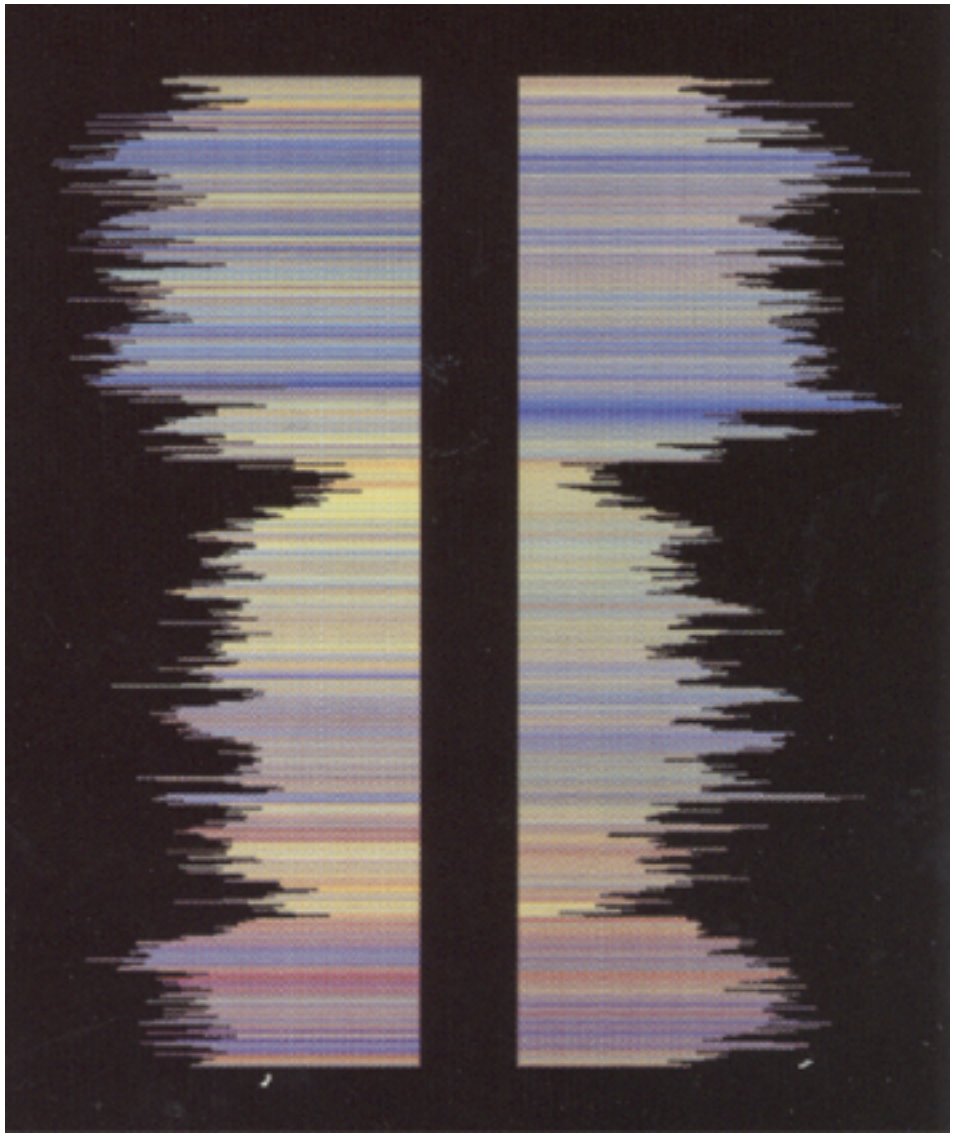
Perception Laws in Design

- The law of symmetry: Symmetrical images are perceived collectively, even in spite of distance.



Perception Laws in Design

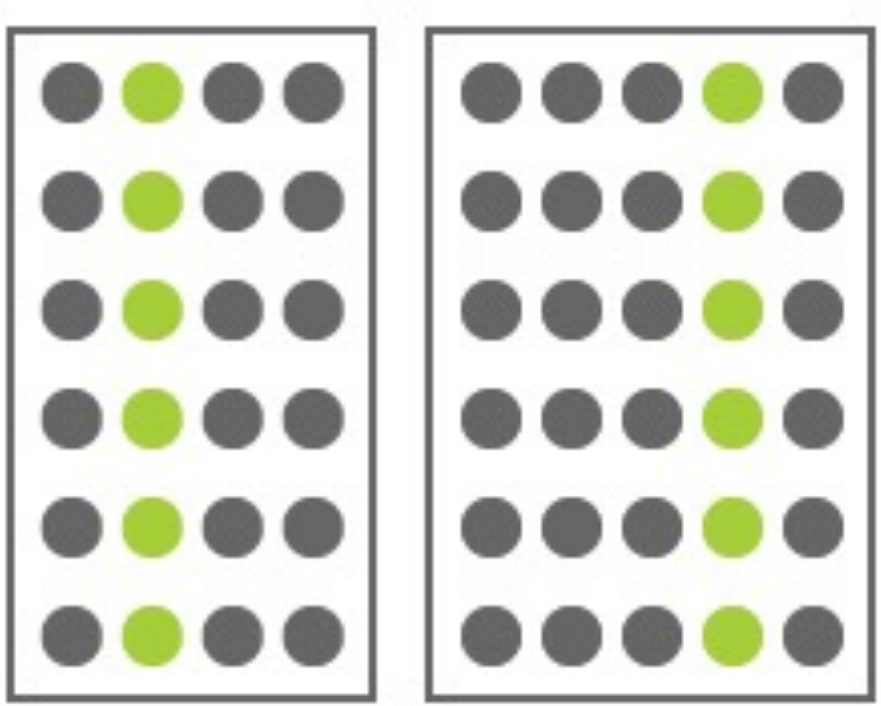
- Symmetry
  - Example of how symmetry detection may be exploited for visual data mining
  - Support the search for similar patterns in time-series plots (measurements of deep ocean drilling cores)



From Ware, 2001

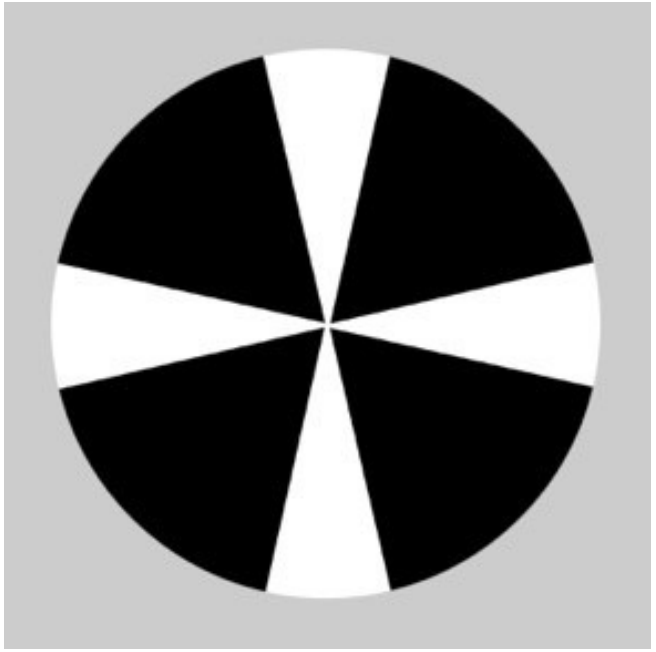
Perception Laws in Design

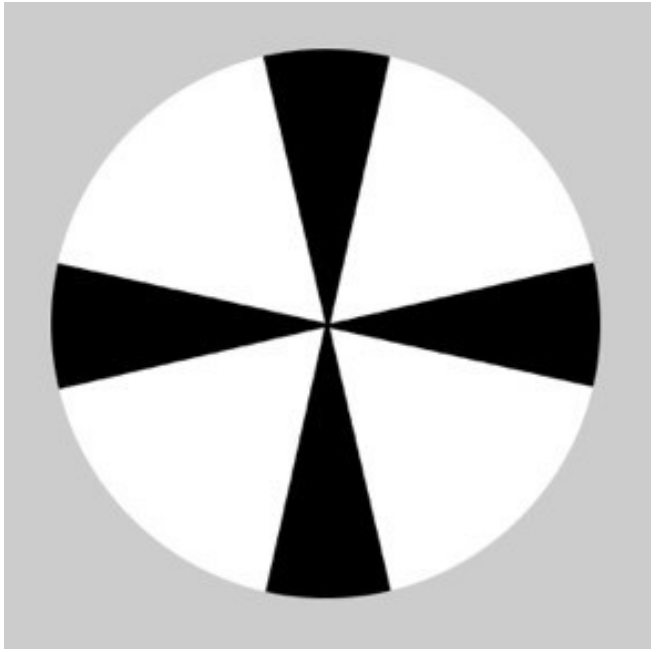
- Principle of common region: Elements located in the same closed region are perceived as a group (*containment*)



Perception Laws in Design

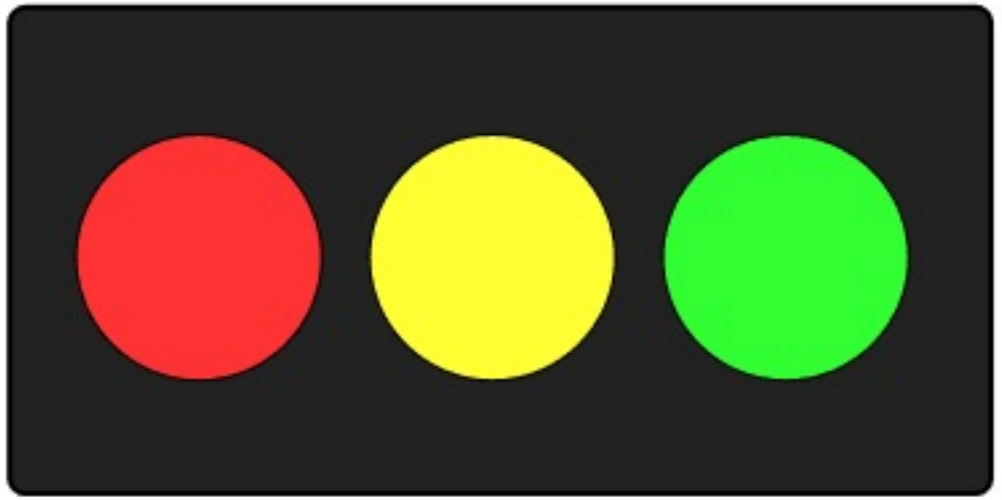
- Area: Smaller components of a pattern tend to be perceived as an object
  - White propeller and black propeller





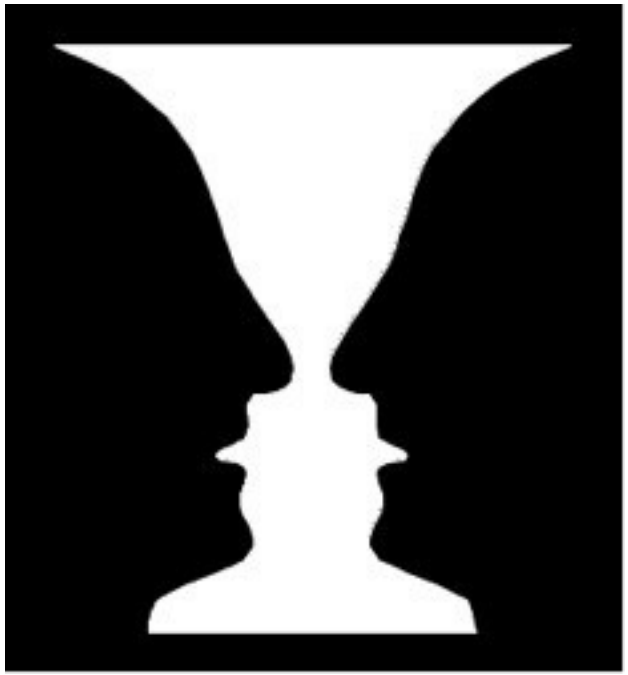
Perception Laws in Design

- Principle of past experience: People's experience influences their perception
  - Experience is unique to the individual but some experiences are shared, e.g., in a cultural circle



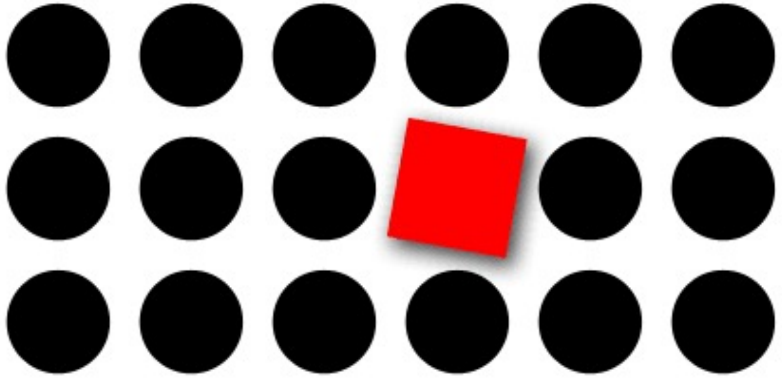
Perception Laws in Design

- Figure & ground
  - Figure: something object-like that is perceived being in the foreground
  - Ground: whatever lies behind the figure
  - Fundamental perceptual act of identifying objects
  - All Gestalt laws contribute, e.g., closed contour, symmetry, area
  - Equally balanced cues for figure and ground can result in bistable perception



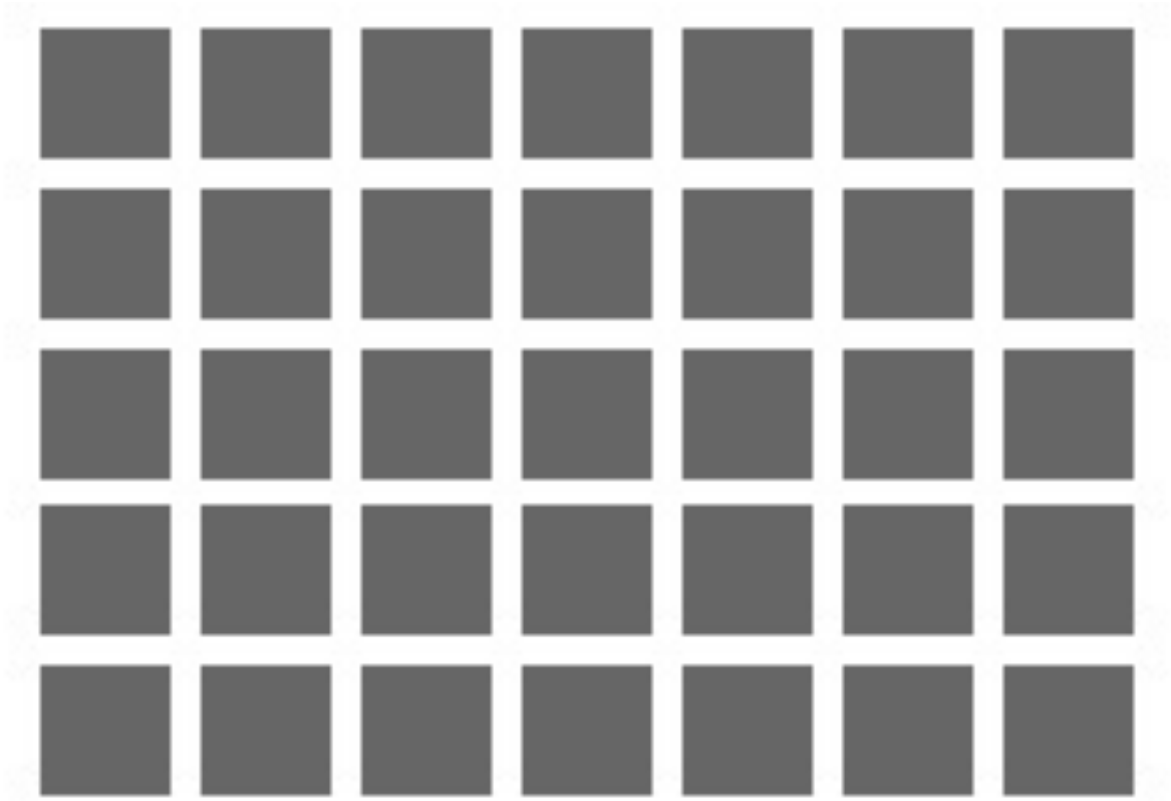
Perception Laws in Design

- Principle of focal point: Among elements, a point of interest, emphasis, or difference will capture the viewer's attention
  - Serve as an entry point into visualization



Perception Laws in Design

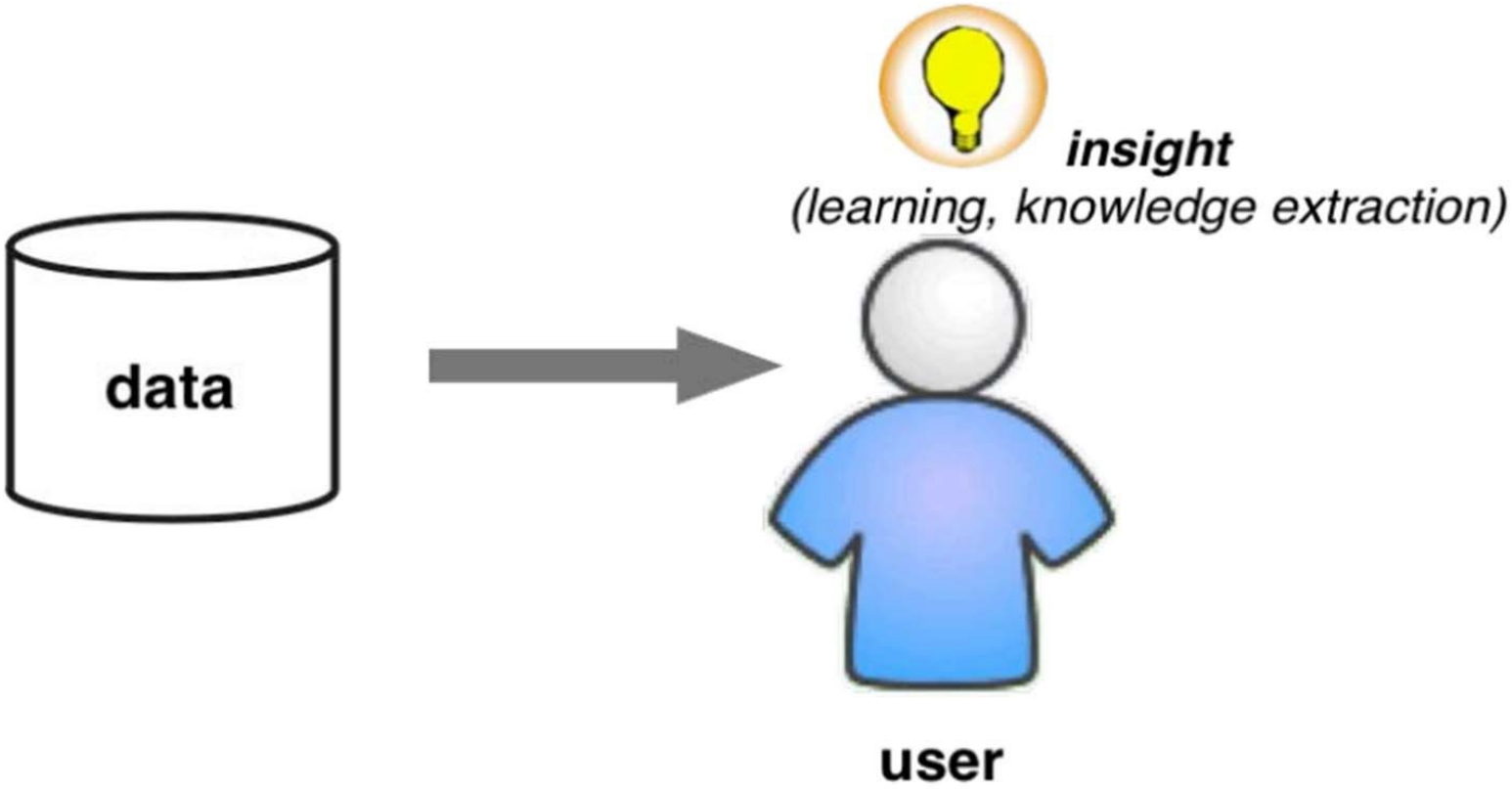
- 1+1 = 3 effect



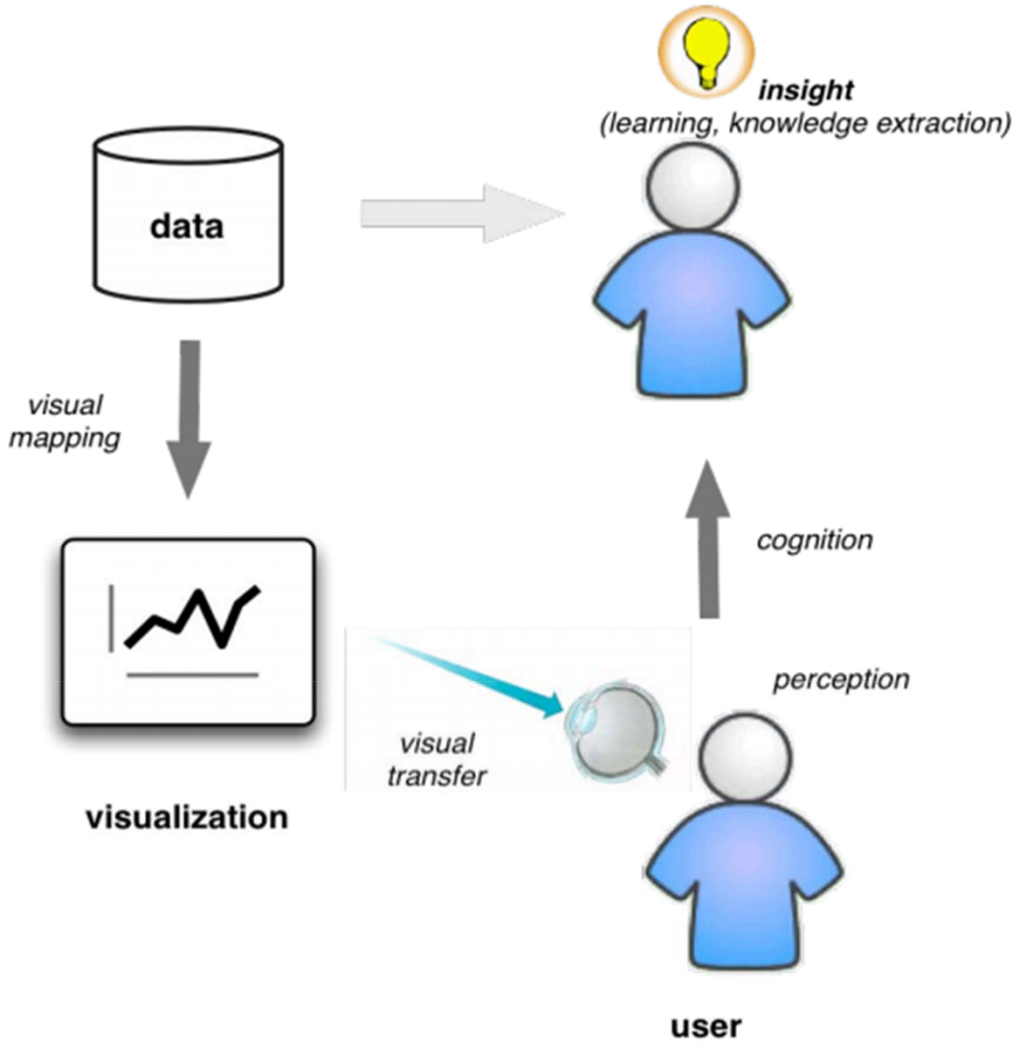
Outline

- *Introduction*
- *Preattentive Processing*
- *Perception Laws*
- **Applying Perception to Visualization**

Applying Perception to Visualization

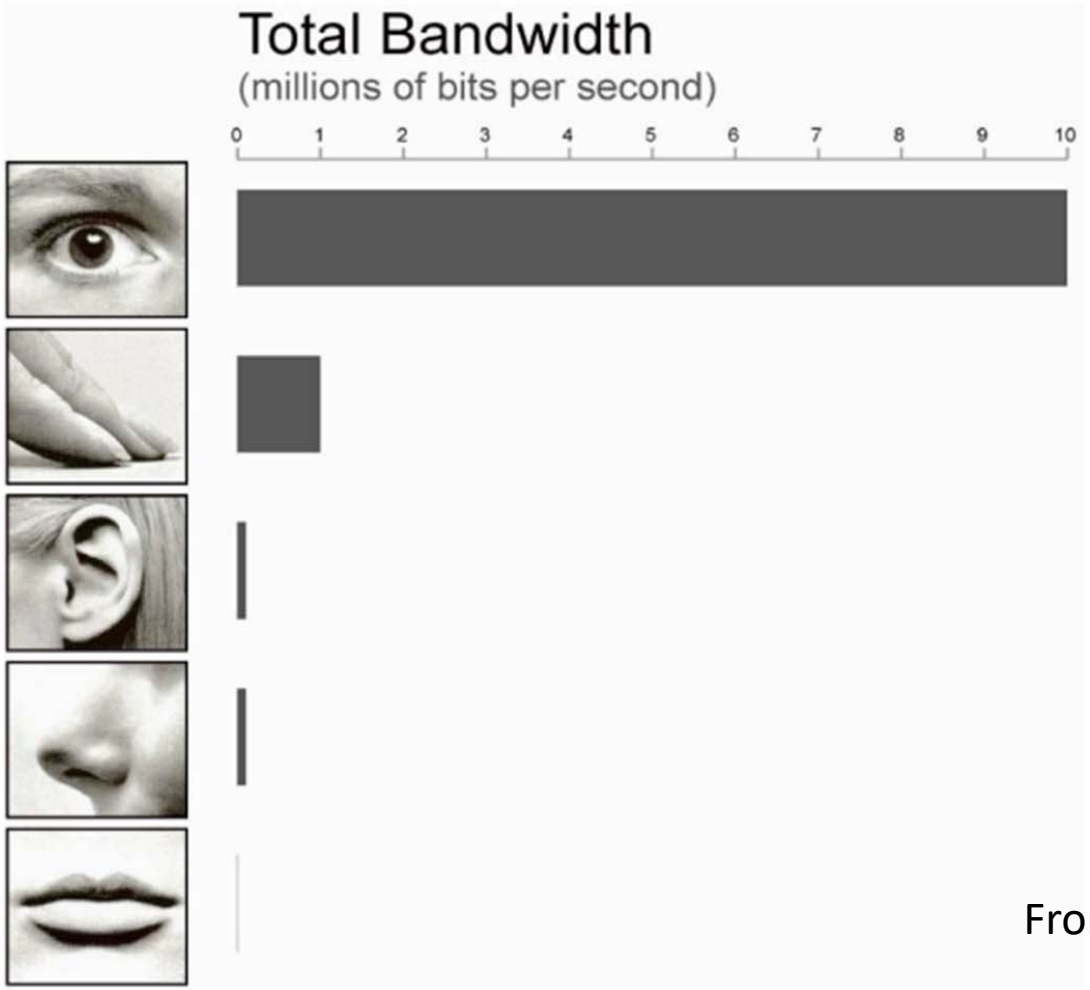


Applying Perception to Visualization



Applying Perception to Visualization

- Need of visualization



From Few, 2006

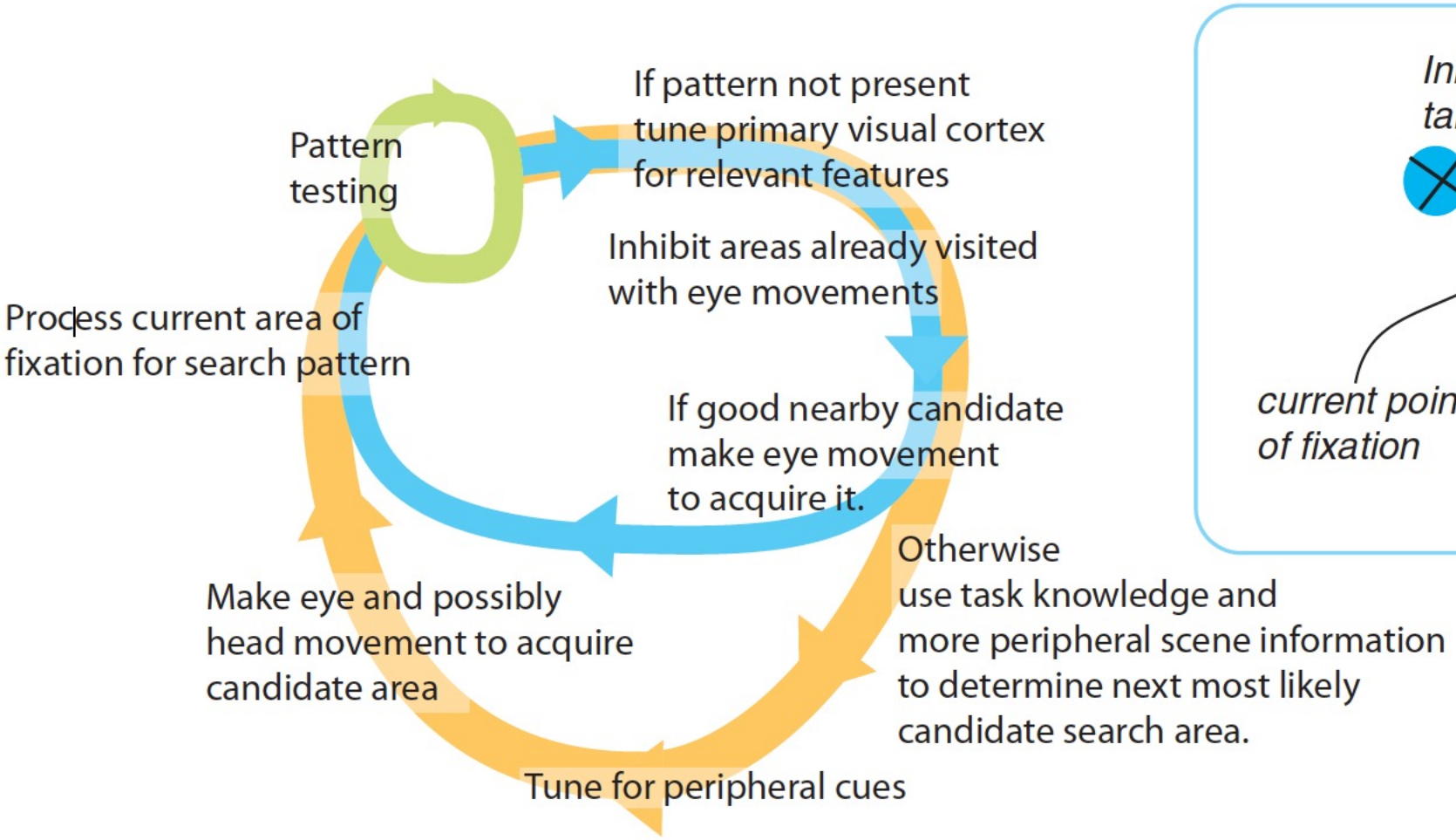
Applying Perception to Visualization

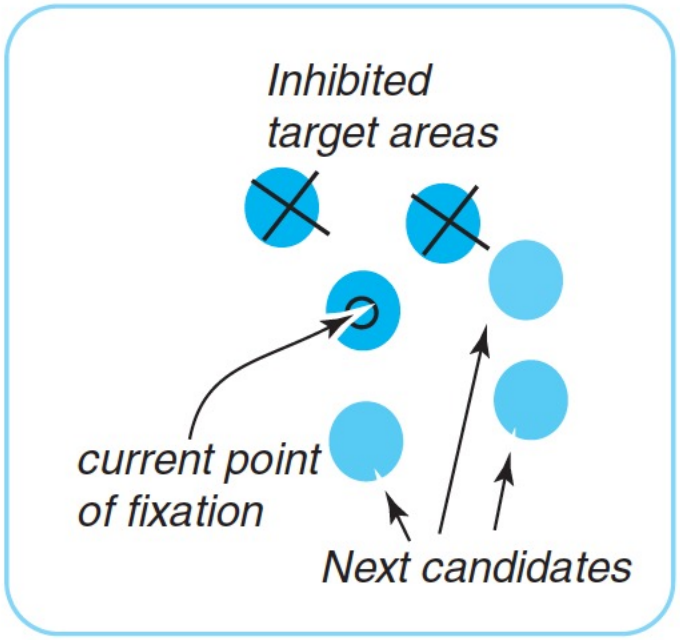
- Feature hierarchy
  - Assign different visual features to different data attributes
  - For certain tasks, the visual system seems to favor one type of visual feature over another

Applying Perception to 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 to Visualization





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

Applying Perception to 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 to Visualization

- Applying feature hierarchy in visualization
  - Organize the layout from large to small
    - Keep structure at each level
  - Makes search much more efficient

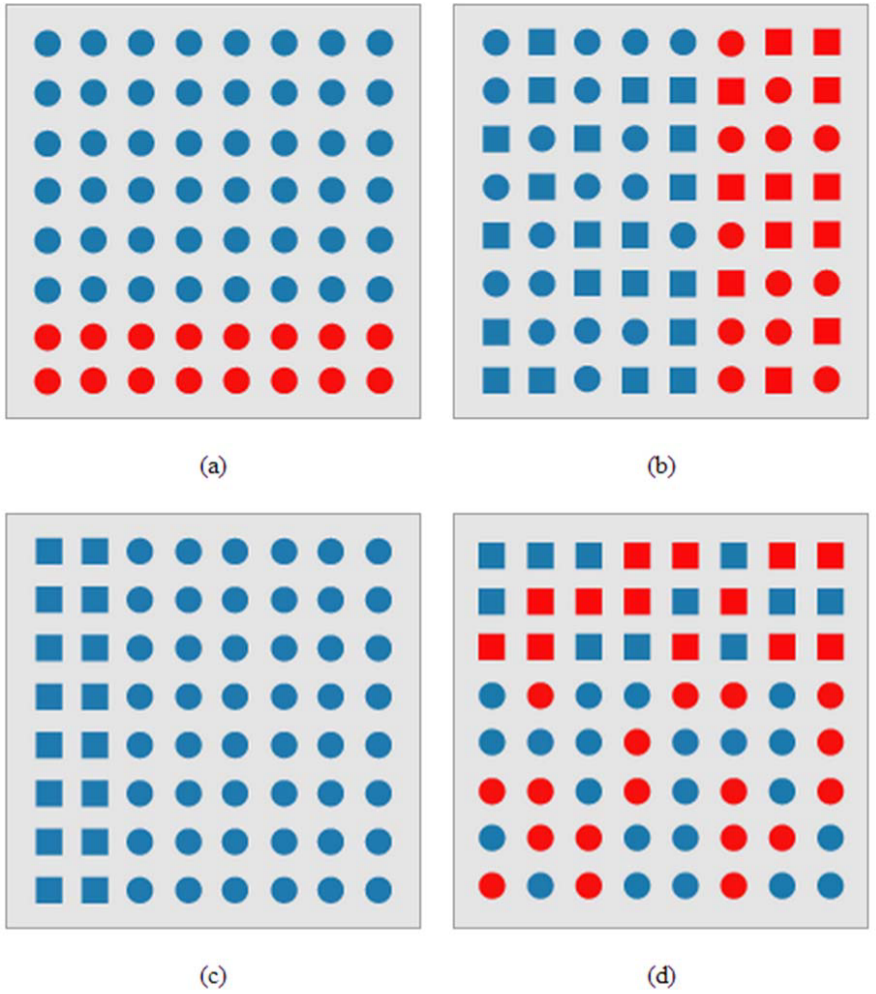
Applying Perception to Visualization

- Applying feature hierarchy in visualization
  - 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 to Visualization

- Feature hierarchy

Hue vs. Shapes

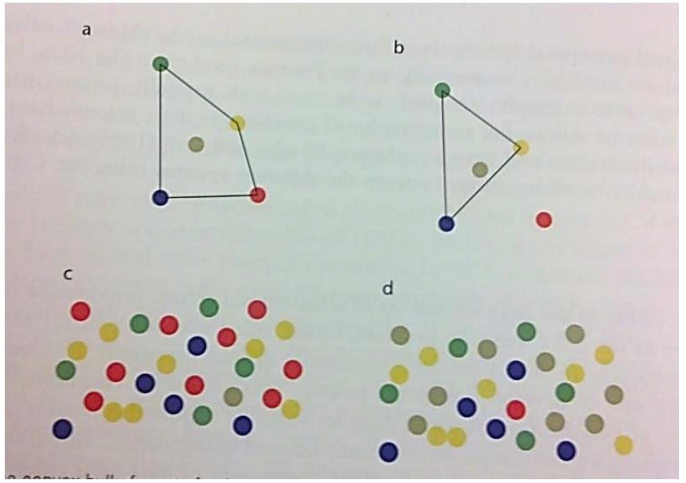


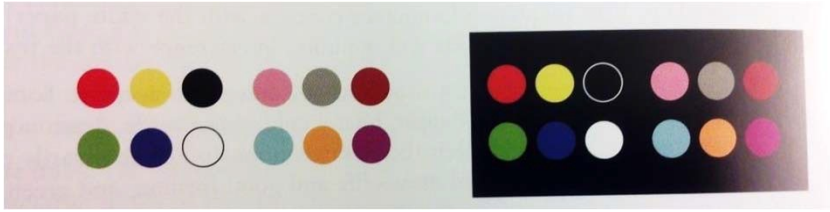
Applying Perception to Visualization

- 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 to Visualization

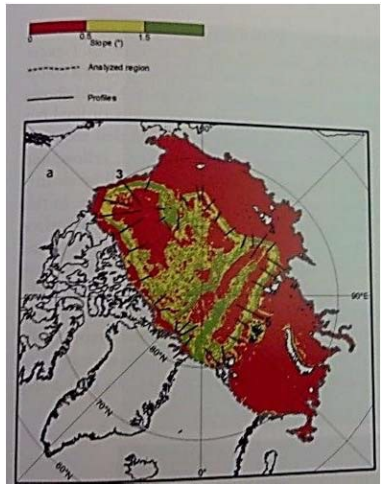
- Color choice. Factors to consider
  - Distinctness
  - Unique hues
  - Contrast with background
  - Number -> Difference
  - Field Size
  - Color blindness, Conventions





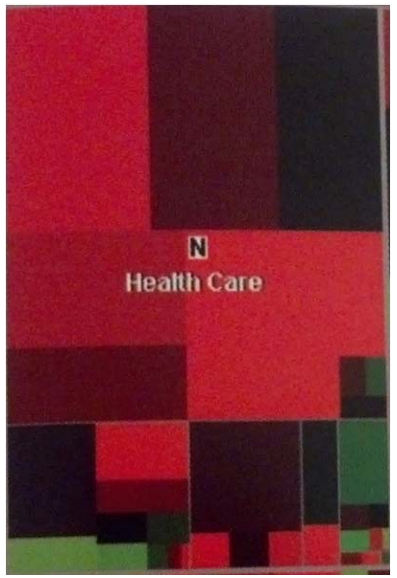
Applying Perception to Visualization

- Pseudocoloring: Representing continuously varying map values using a sequence of colors
  - Astronomical Radiation charts, medical imaging

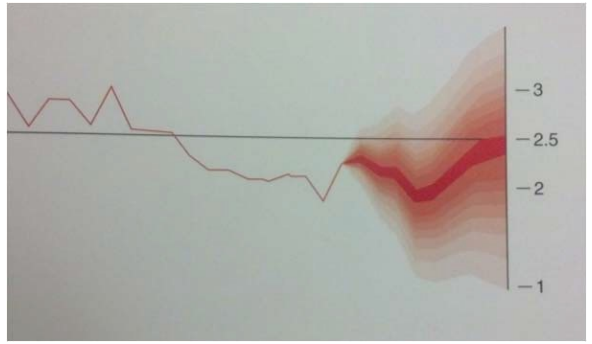


Nominal: Rapid Classification, No order

Ordinal: Monotonic Ordering, Continuous



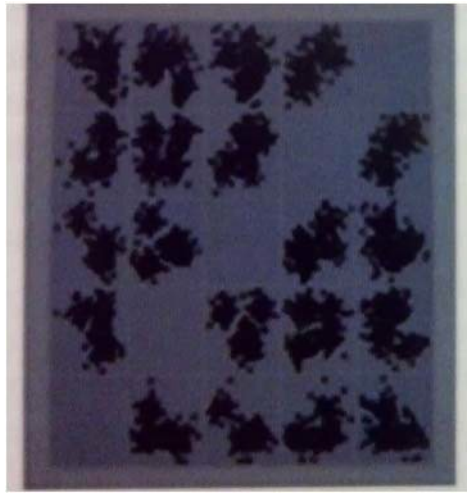
Ratio: Sign of the value, true zero



Interval each step = equal change in magnitude

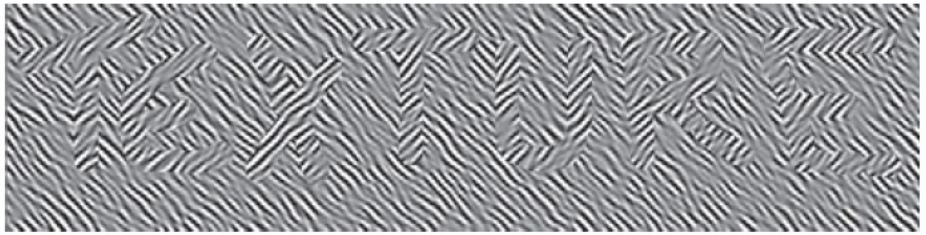
Applying Perception to Visualization

- Color for exploring multidimensional discrete data
  - Plot the data, look for pattern and interpret the findings
    - Critical for discovery -> act of perception
  - Problem with plotting data beyond 3D
    - Solution 1: generalized drafter's plot
      - Display scatter plot pairs of data
      - Disadvantage: difficult to see patterns in >2 dimensions
    - Solution 2: color-mapped scatter plot
      - var1 = x, var2 = y, var3 = amount of red, var4 = amount of green, var5 = amount of blue



Applying Perception to 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

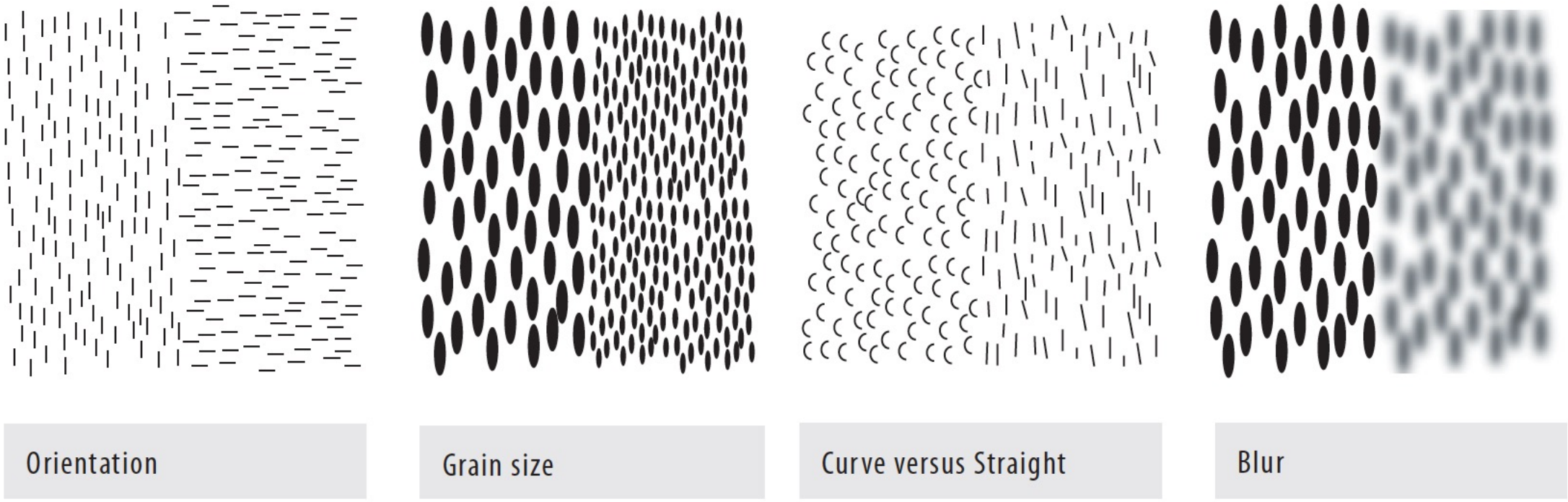
Orientation + spatial frequency

Contrast

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

Applying Perception to Visualization

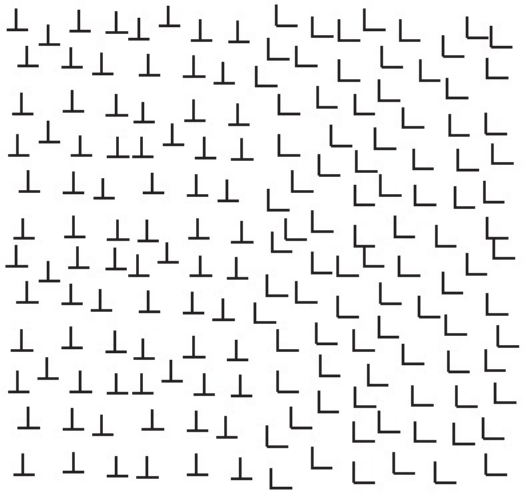
- Texture



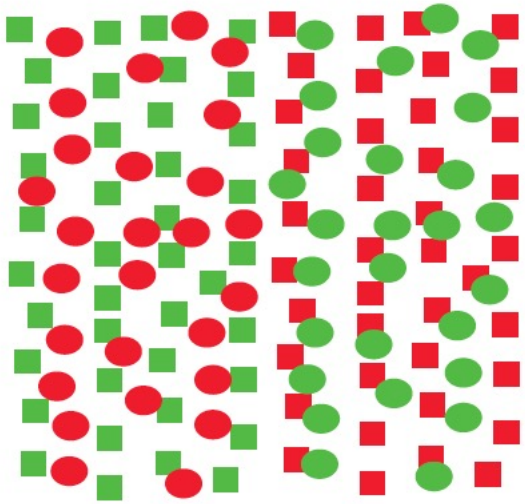
From Ware's Information Visualization. Perception for Design, 2012

Applying Perception to Visualization

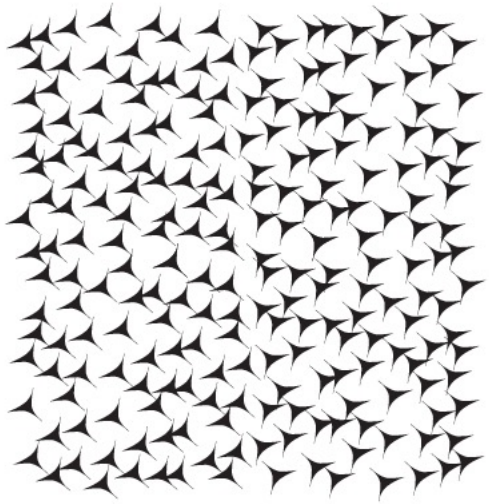
- Texture



Ts and Ls have the same line components.



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

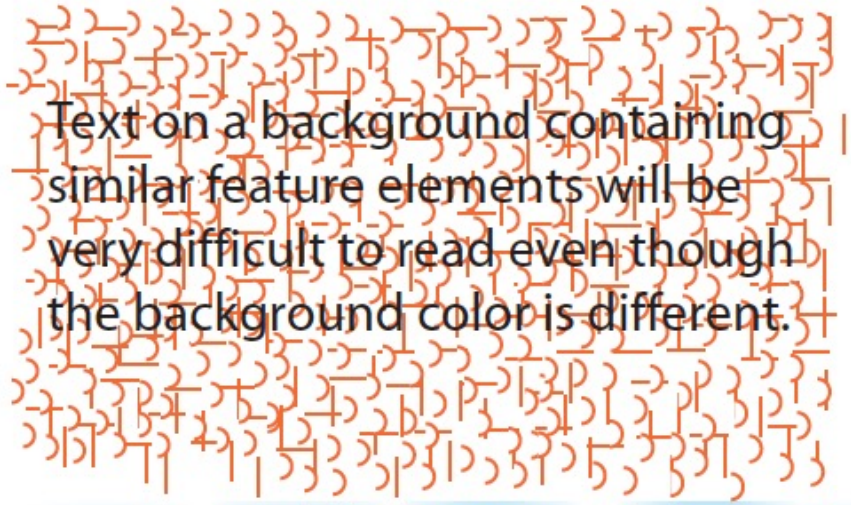


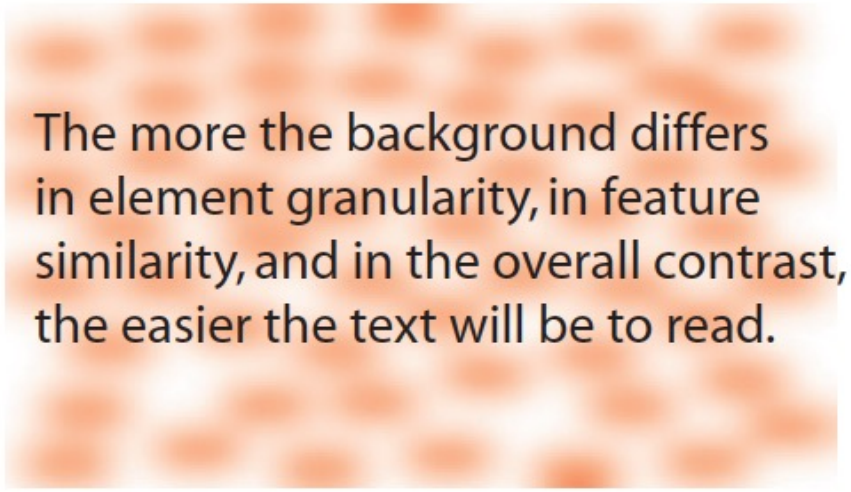
The spikes are oriented differently; the field of orientations is the same.

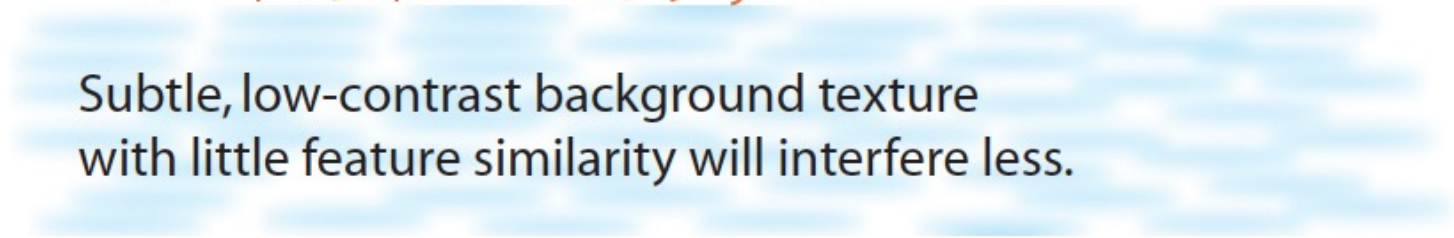
From Ware's Information Visualization. Perception for Design, 2012

Applying Perception to Visualization

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



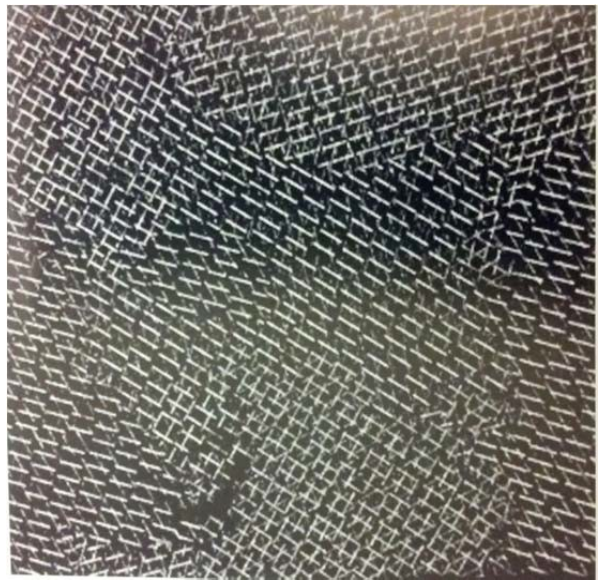




Applying Perception to Visualization

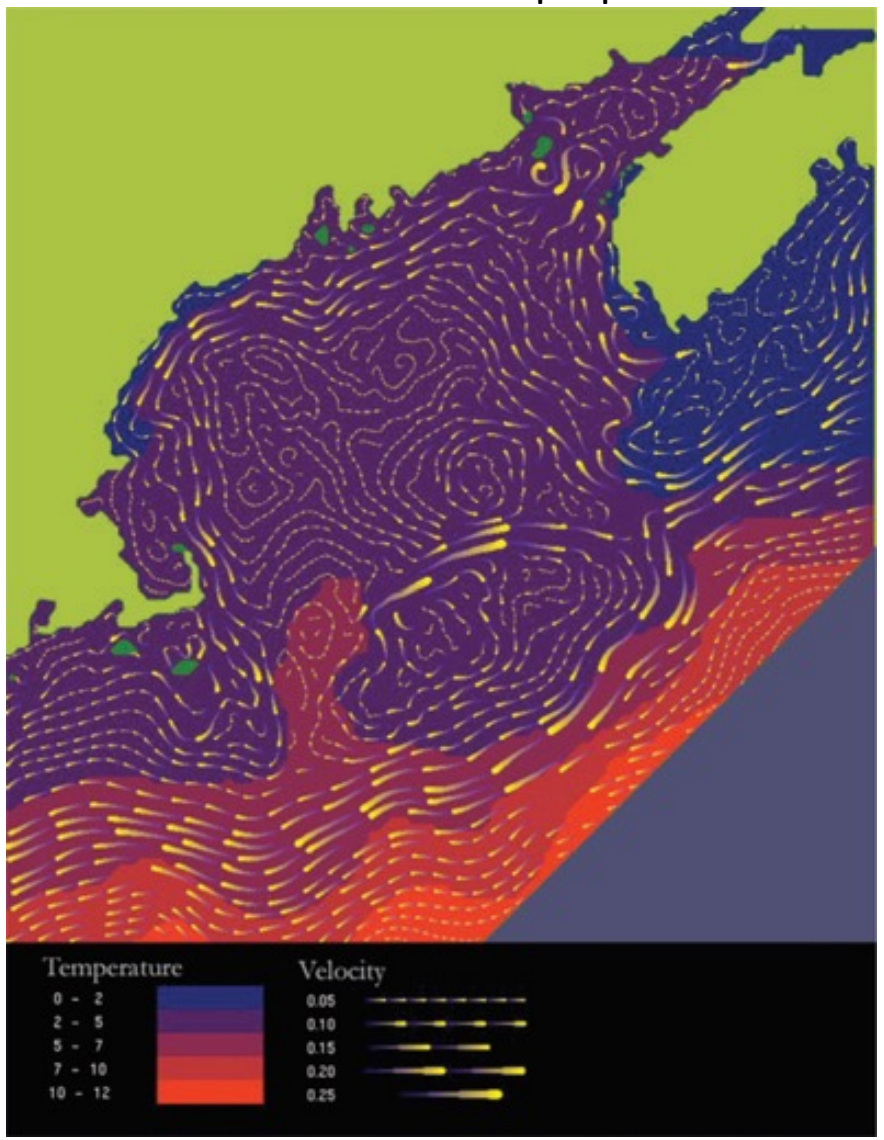
- Texture

Sliver plot with 3 orientations, color for 4th variable



Sliver plot with 8 orientations

Combination of properties



Applying Perception to Visualization

- Glyphs and multivariate discrete 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 to 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 to 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 to Visualization

- Speeded classification task:
  - Users are asked to quickly classify objects according to one of the visual attributes
    - Helps us understand how they interfere: integral dimensions interfere a lot, separable dimensions interfere less

Applying Perception to Visualization

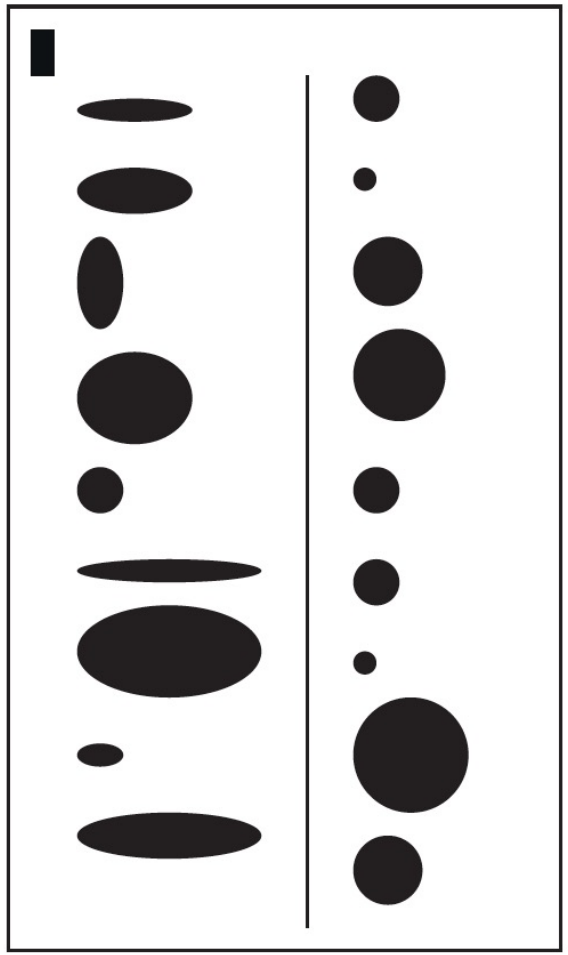
Width interferes with height

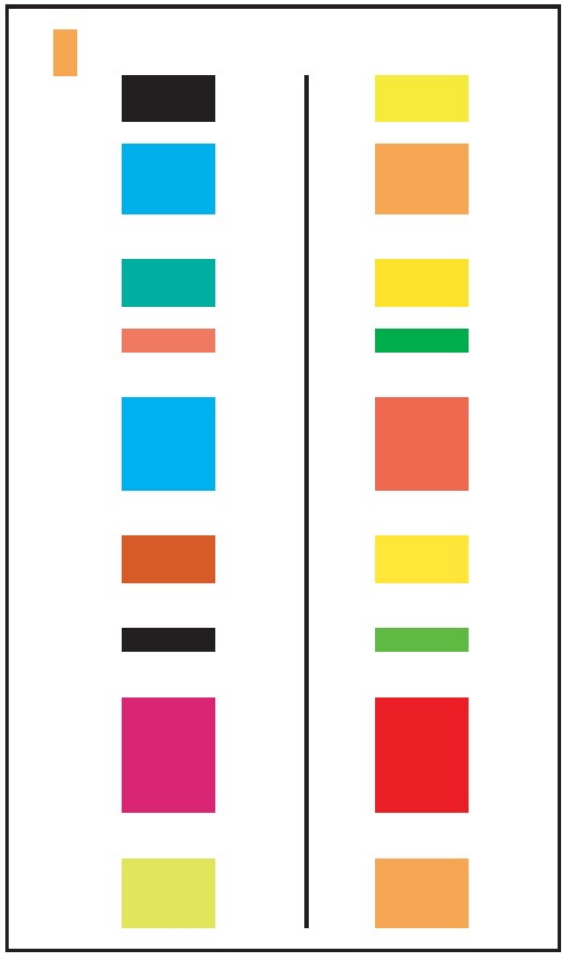
Redundant size speeds up classification

Color does not interfere

Redundant color does not help

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





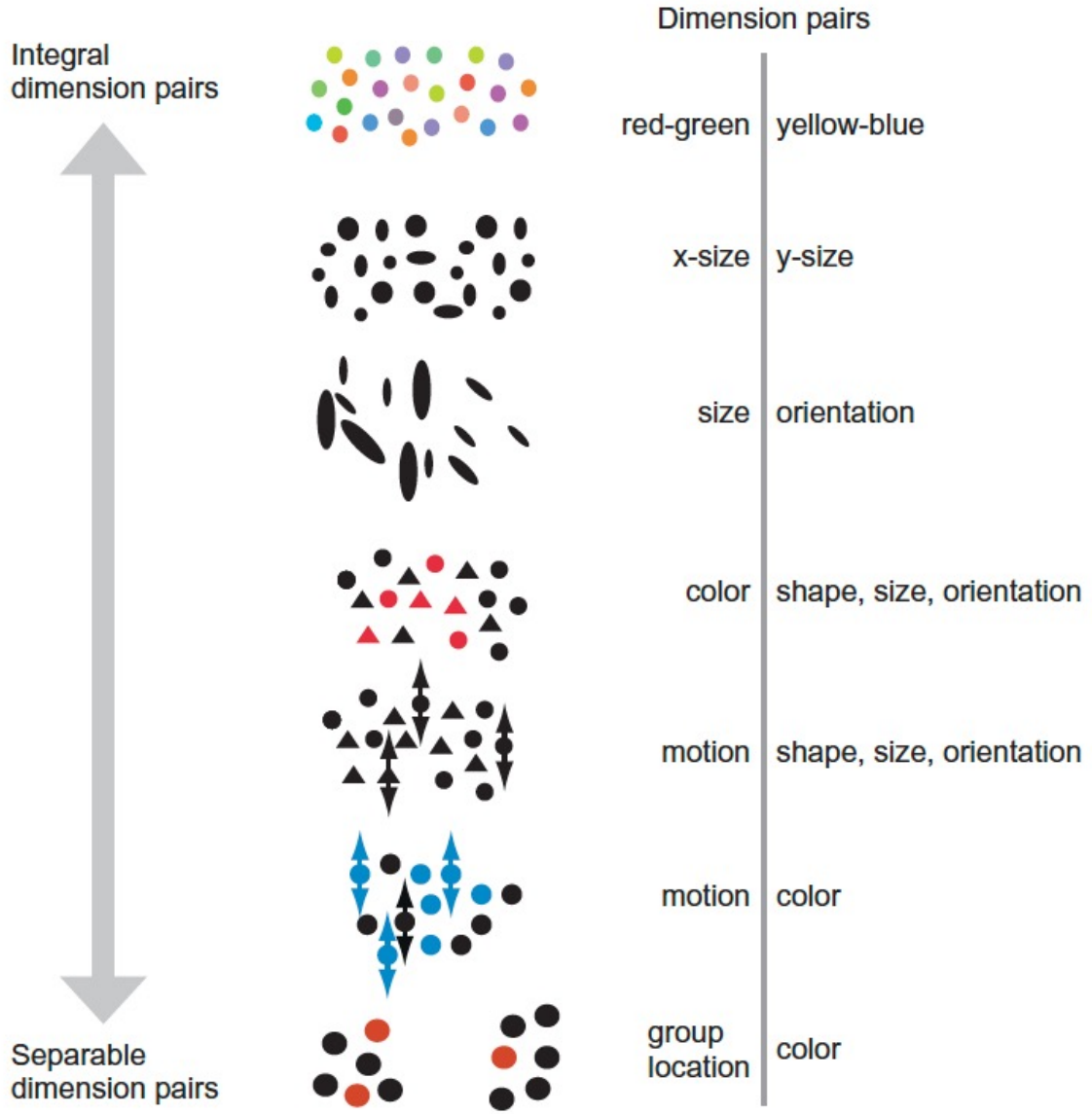
Integral dimensions

Separable dimensions

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

Applying Perception to Visualization

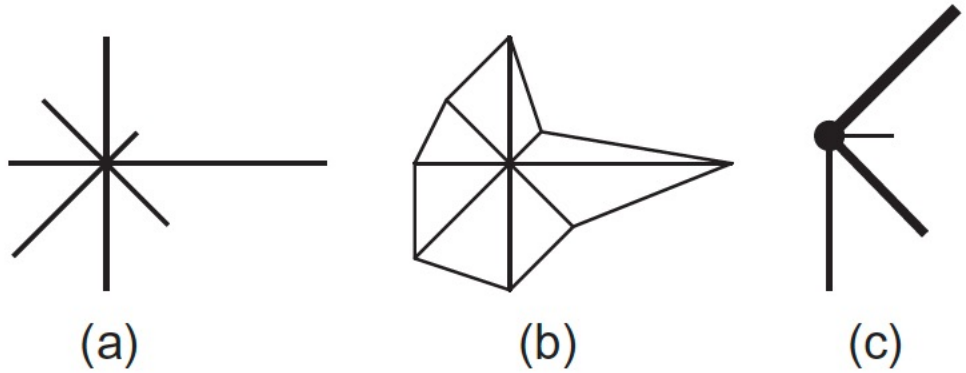
- Dimensions. Key points
  - If we want users to respond **holistically**, use integral dimensions
  - If we want users to respond **analytically**, understanding one variable at a time, use separable dimensions
    - Consider color blindness



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

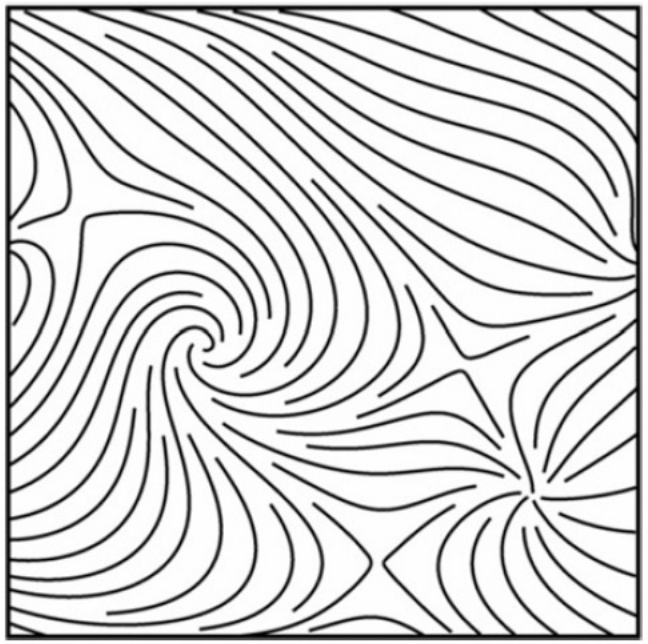
Applying Perception to Visualization

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

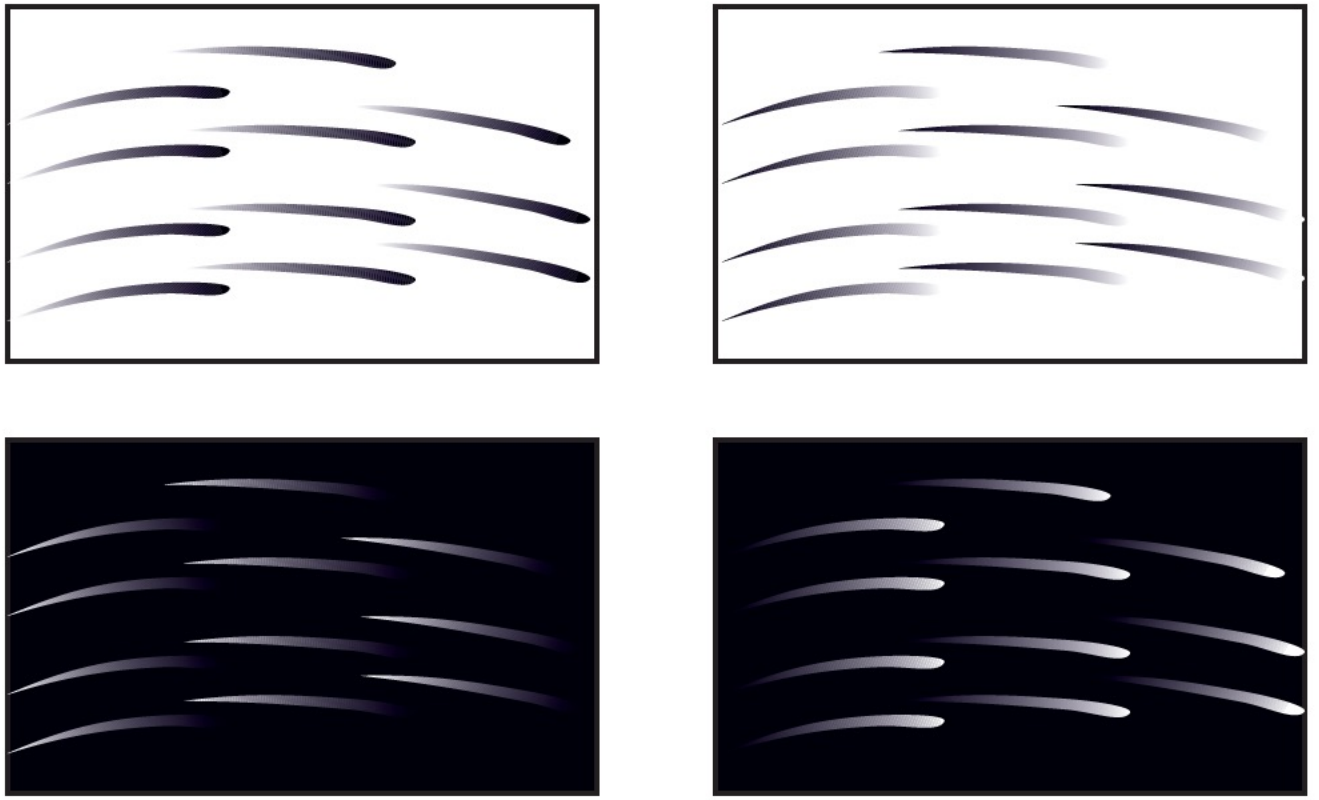


Applying Perception to Visualization

- Perceiving directions



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

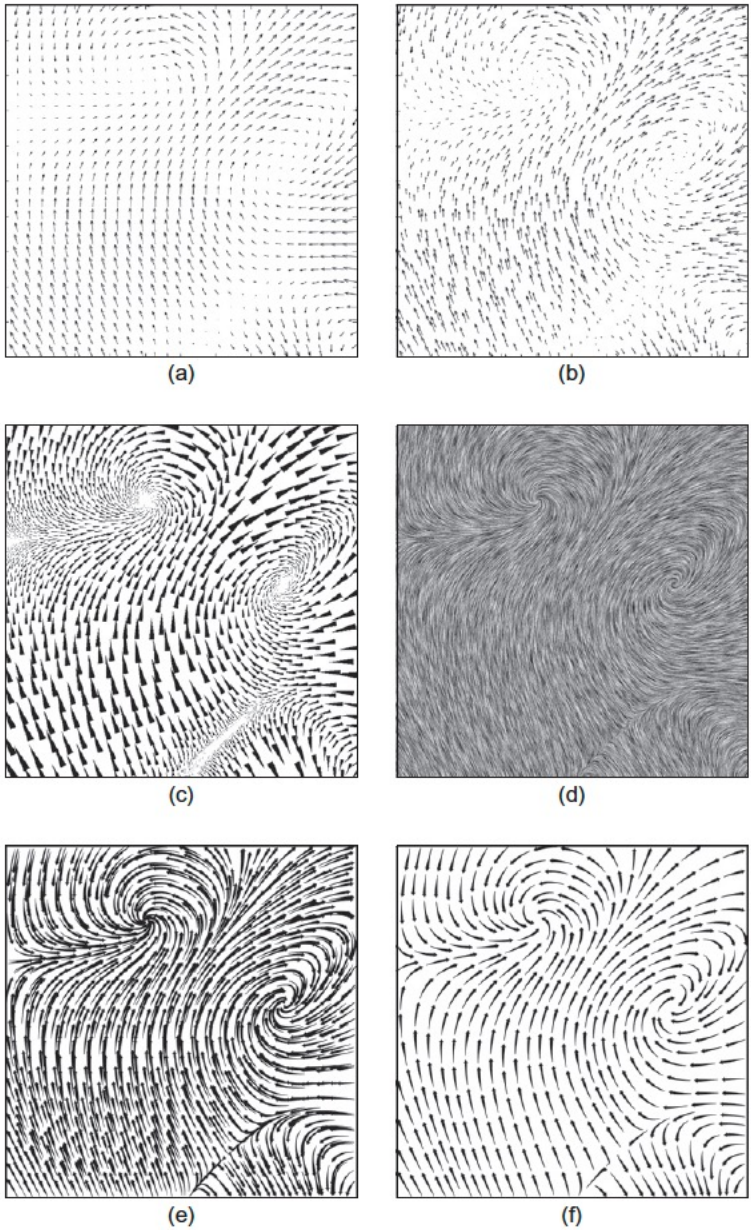


Vector direction w.r.t background
(orientation weakened)

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

Applying Perception to 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 to 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 to 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.

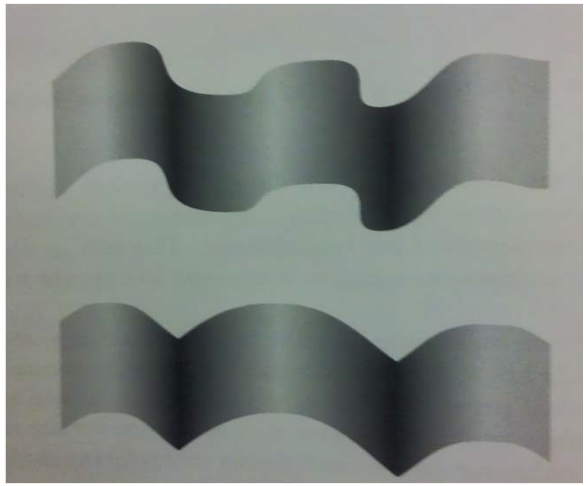
From Ware's Information Visualization. Perception for Design, 2012

Applying Perception to Visualization

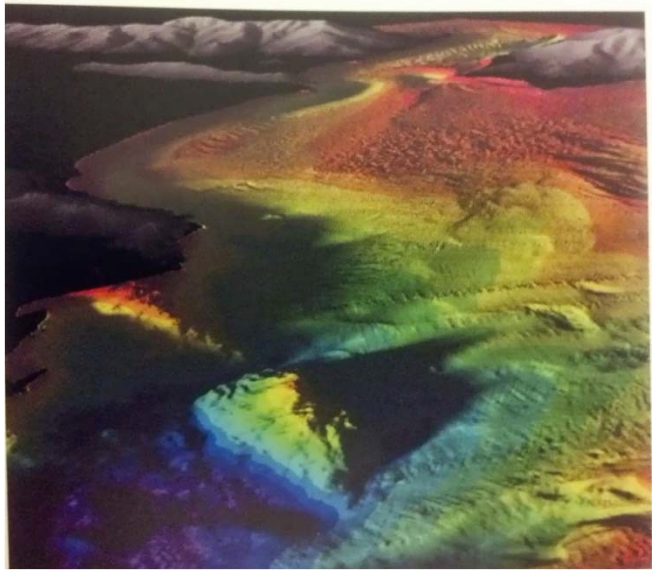
- Pattern learning
  - Use the fact that people observe patterns in data to present relations
  - Some people may take time to “learn” but then it will be easy
  - **Familiarity:** Can make use of patterns that are familiar to people (example: lines between points)
    - Use patterns familiar to skills/research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

Applying Perception to Visualization

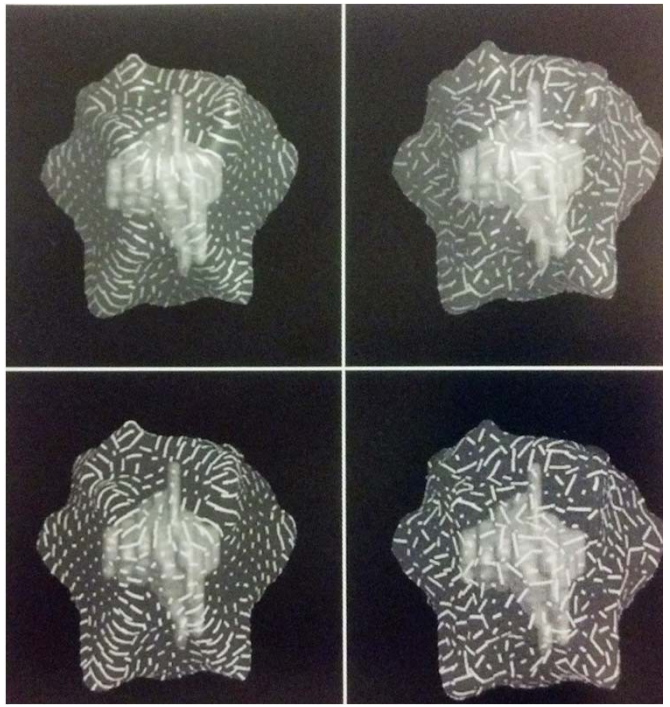
- Perceiving surface shapes
  - Some spatial cues are effective



Shading and contours



Shading models - Lighting



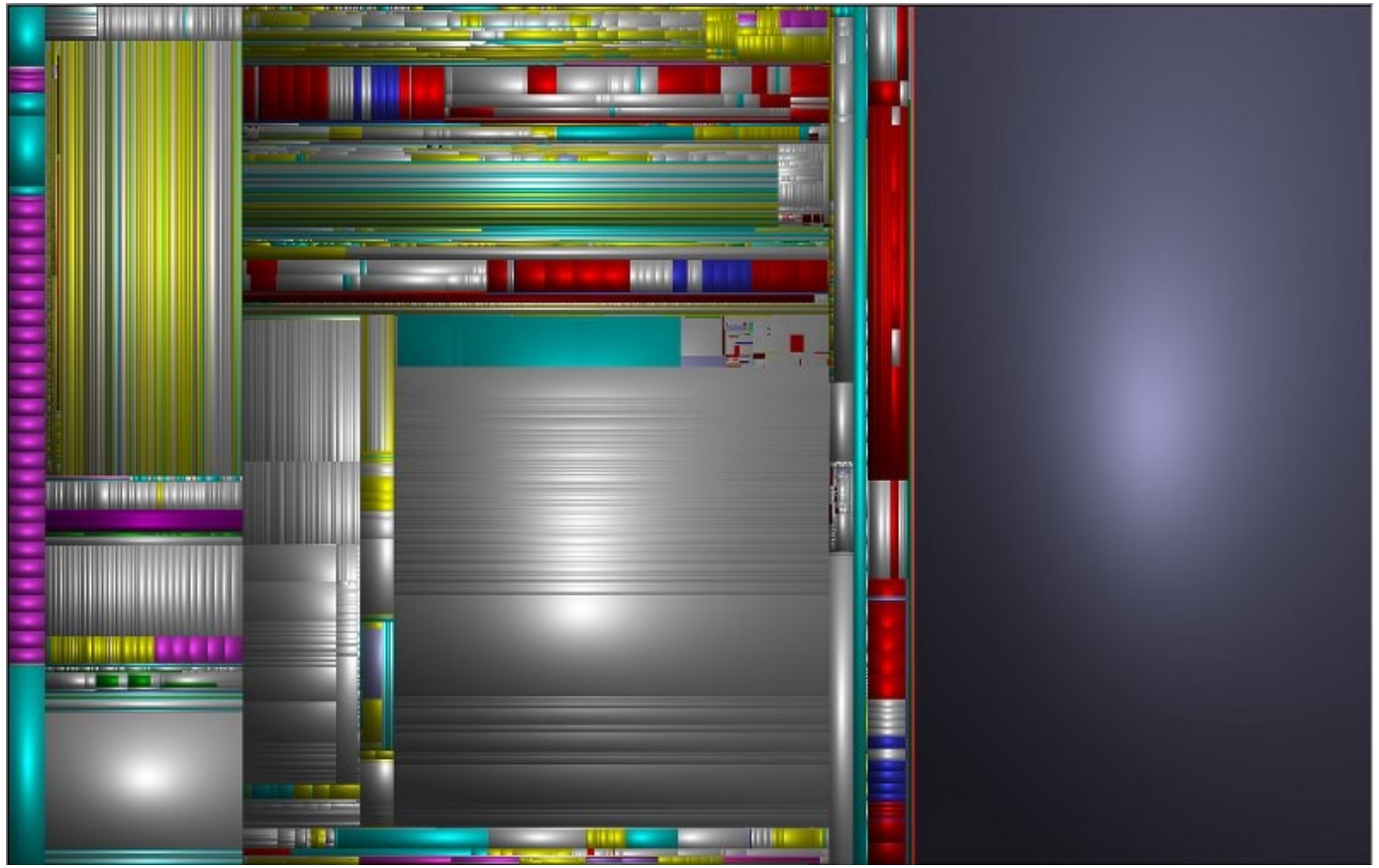
Surface Texture - Lacing

Applying Perception to 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

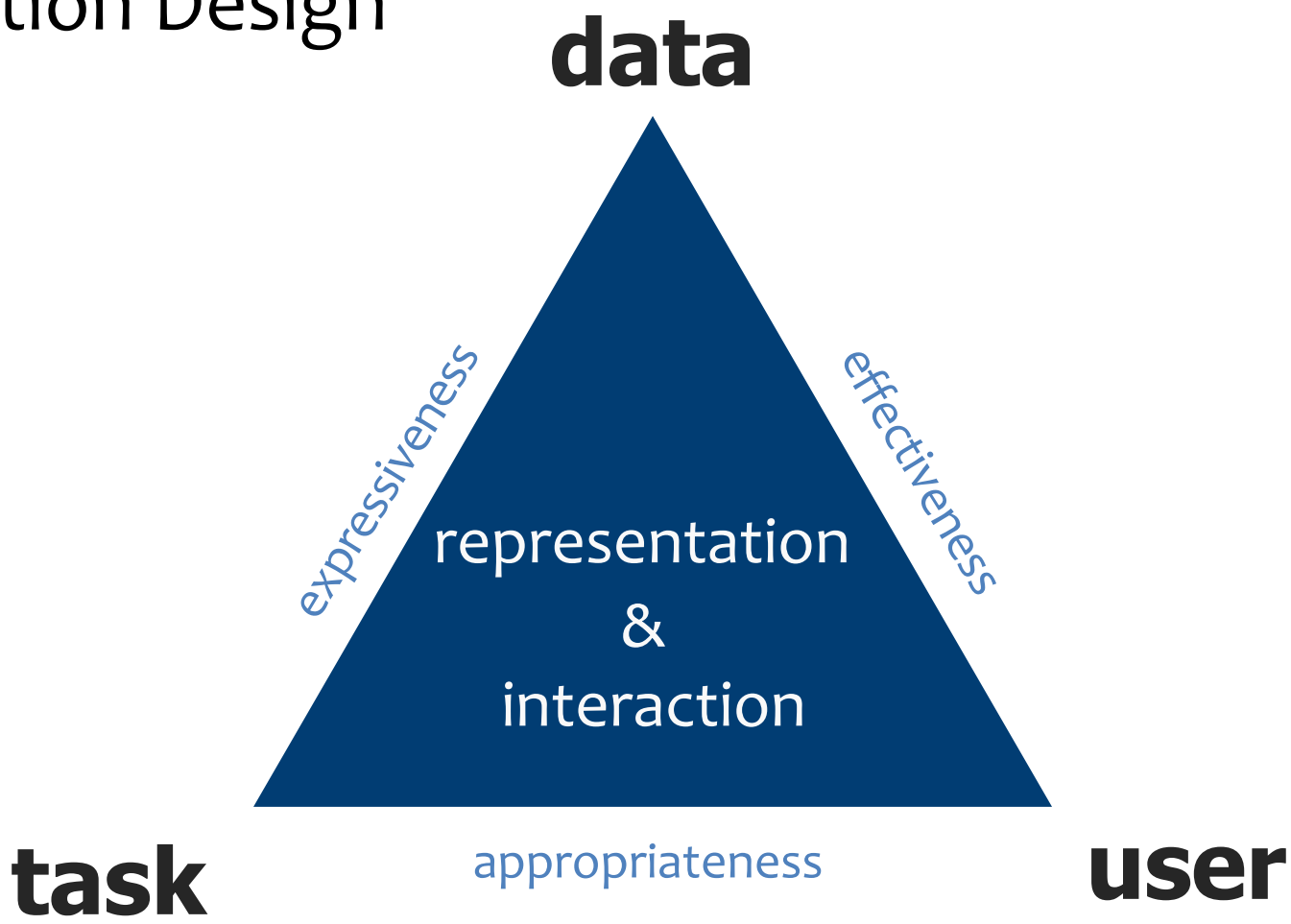
Applying Perception to Visualization

- Perceiving surface shapes. Cushion treemap



Applying Perception to Visualization

- Visualization Design



Applying Perception to Visualization

- 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]

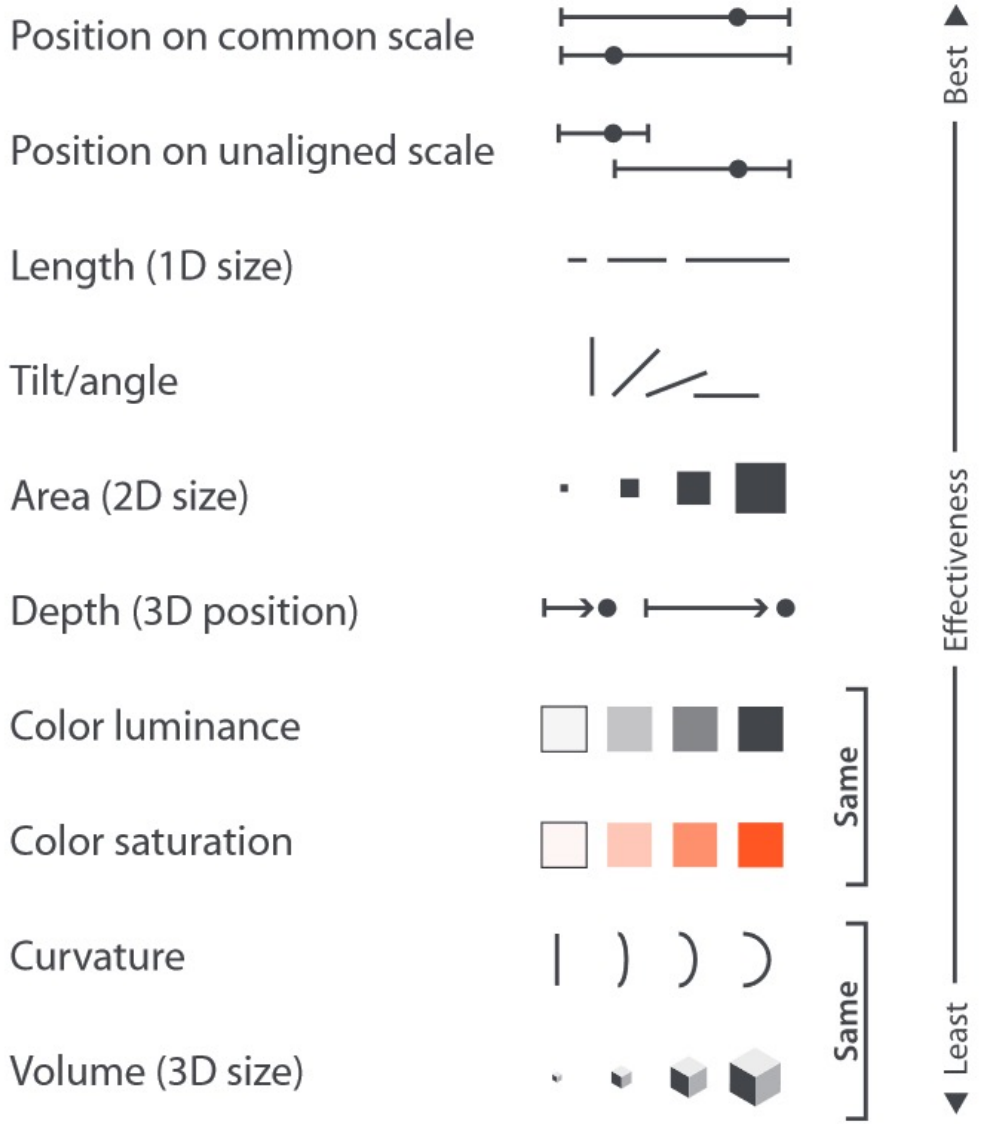
Applying Perception to Visualization

- 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.

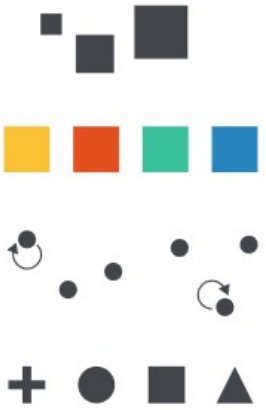
  - *"Effectiveness criteria identify which of these graphical languages [that are expressive], in a **given situation**, is the most effective at **exploiting the capabilities** of the output **medium** and the **human visual system**."* [Mackinlay, 1986]

Applying Perception to Visualization

Magnitude Channels: Ordered Attributes



Identity Channels: Categorical Attributes



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

Applying Perception to Visualization

Magnitude Channels: Ordered Attributes

- Position on common scale
- Position on unaligned scale
- Length (1D size)
- Tilt/angle
- Area (2D size)
- Depth (3D position)
- Color luminance
- Color saturation
- Curvature
- Volume (3D size)

Same

Same

Best ▲

Effectiveness

▼ Least

Identity Channels: Categorical Attributes

- Spatial region
- Color hue
- Motion
- Shape

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

Applying Perception to Visualization

Magnitude Channels: Ordered Attributes

- Position on common scale
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Same

Same

Best ▲

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▼ Least

Identity Channels: Categorical Attributes

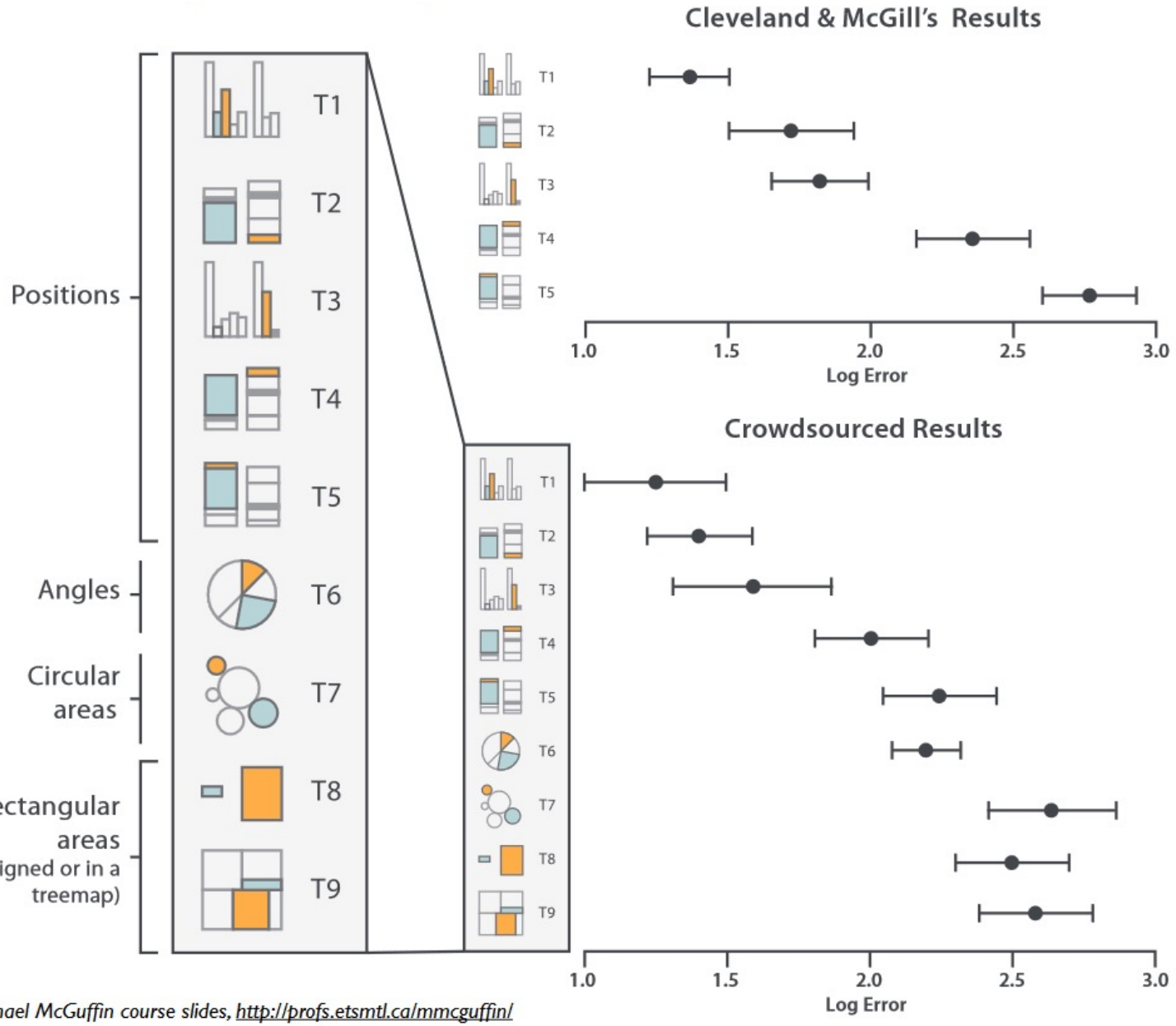
- Spatial region
- Color hue
- Motion
- Shape

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

Applying Perception to 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 to Visualization

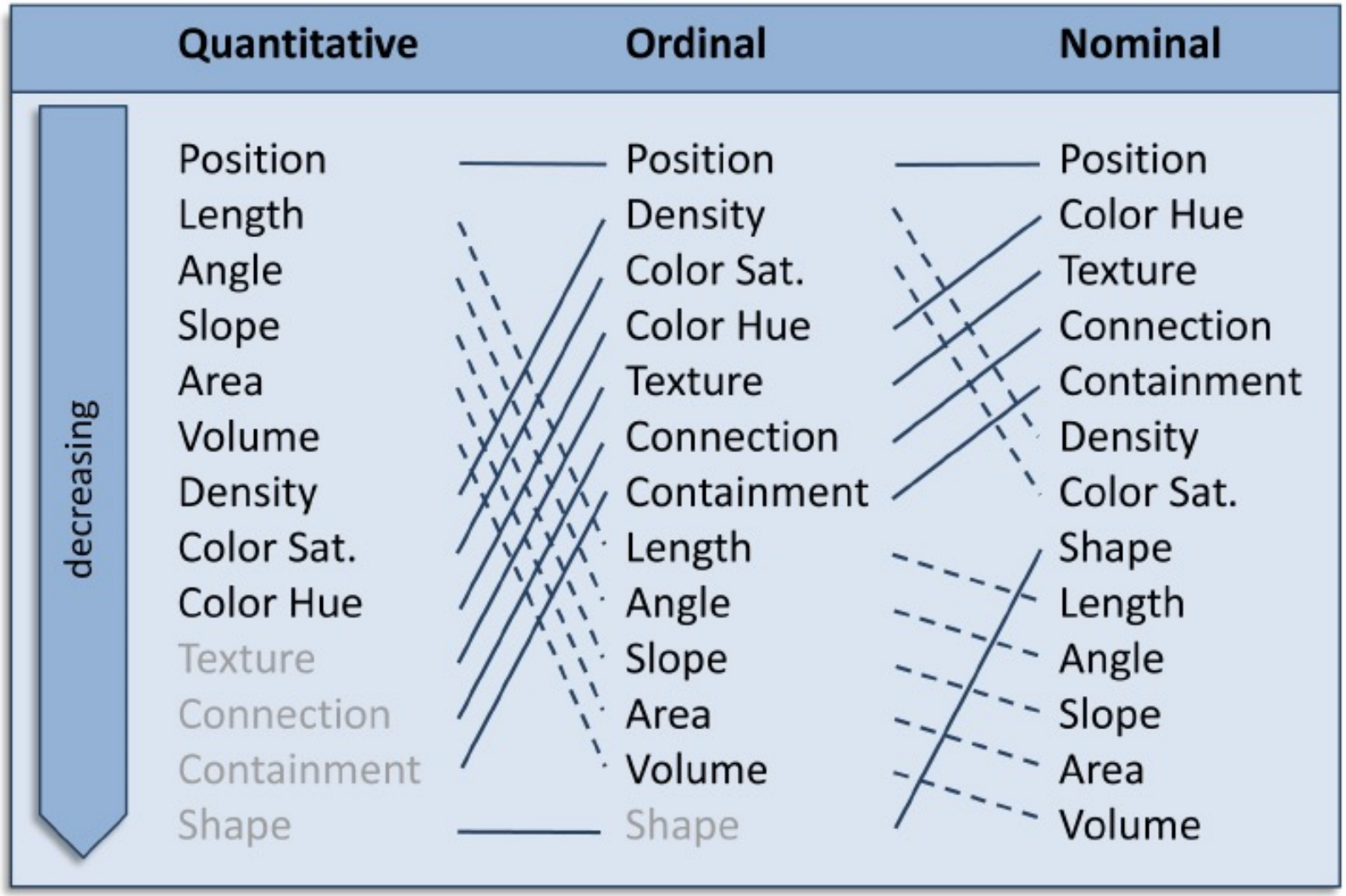


[Crowdsourcing Graphical Perception: Using Mechanical Turk to Assess Visualization Design. Heer and Bostock. Proc ACM Conf. Human Factors in Computing Systems (CHI) 2010, p. 203–212.]

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

Applying Perception to Visualization

Ranking of visual variables

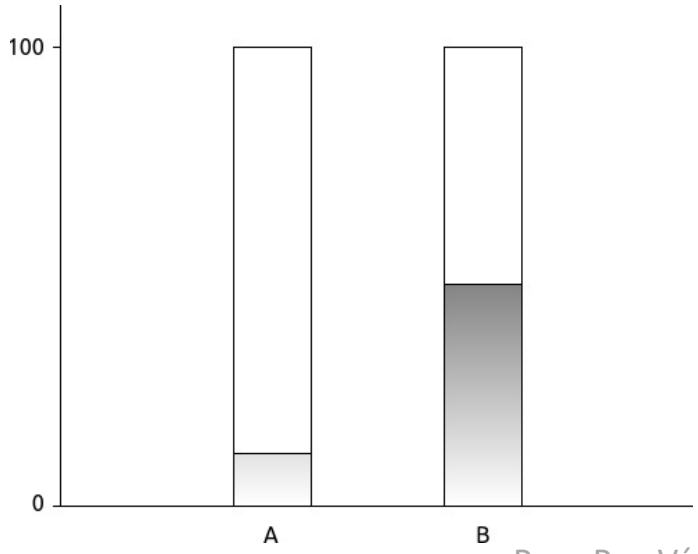


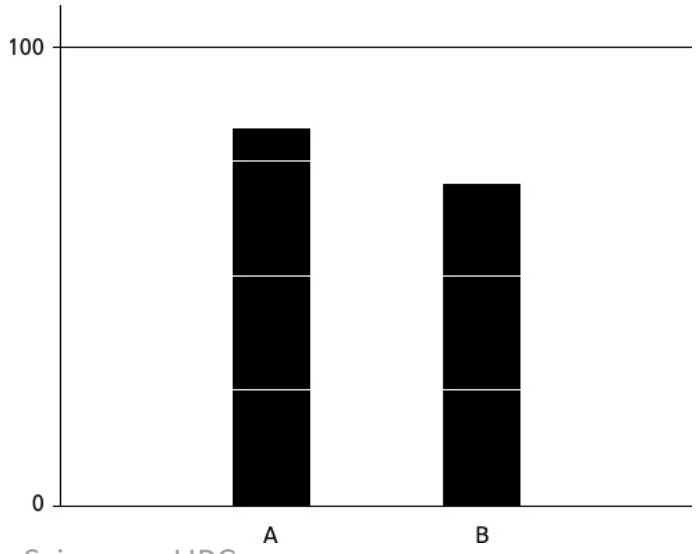
Applying Perception to Visualization

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

Applying Perception to Visualization

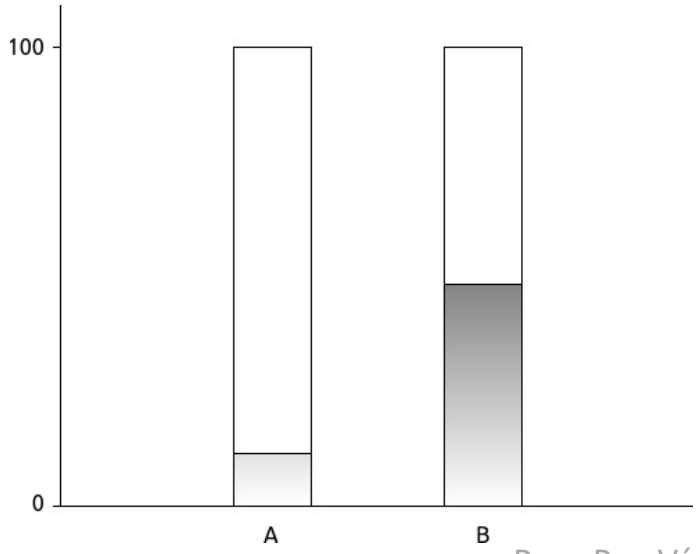
- Relative judgments
  - Relative position
    - Aligned, one in top of the other…
  - Presence of references: top line, inner marks…

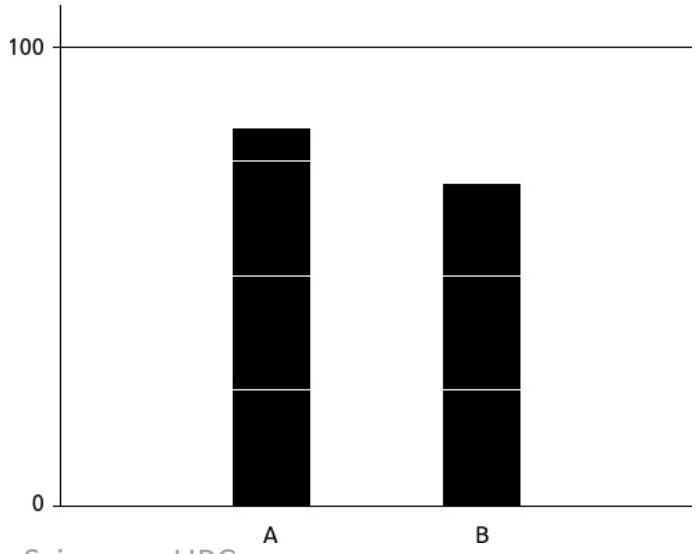




Applying Perception to Visualization

- Absolute judgments
  - Presence of references: top line, inner marks…

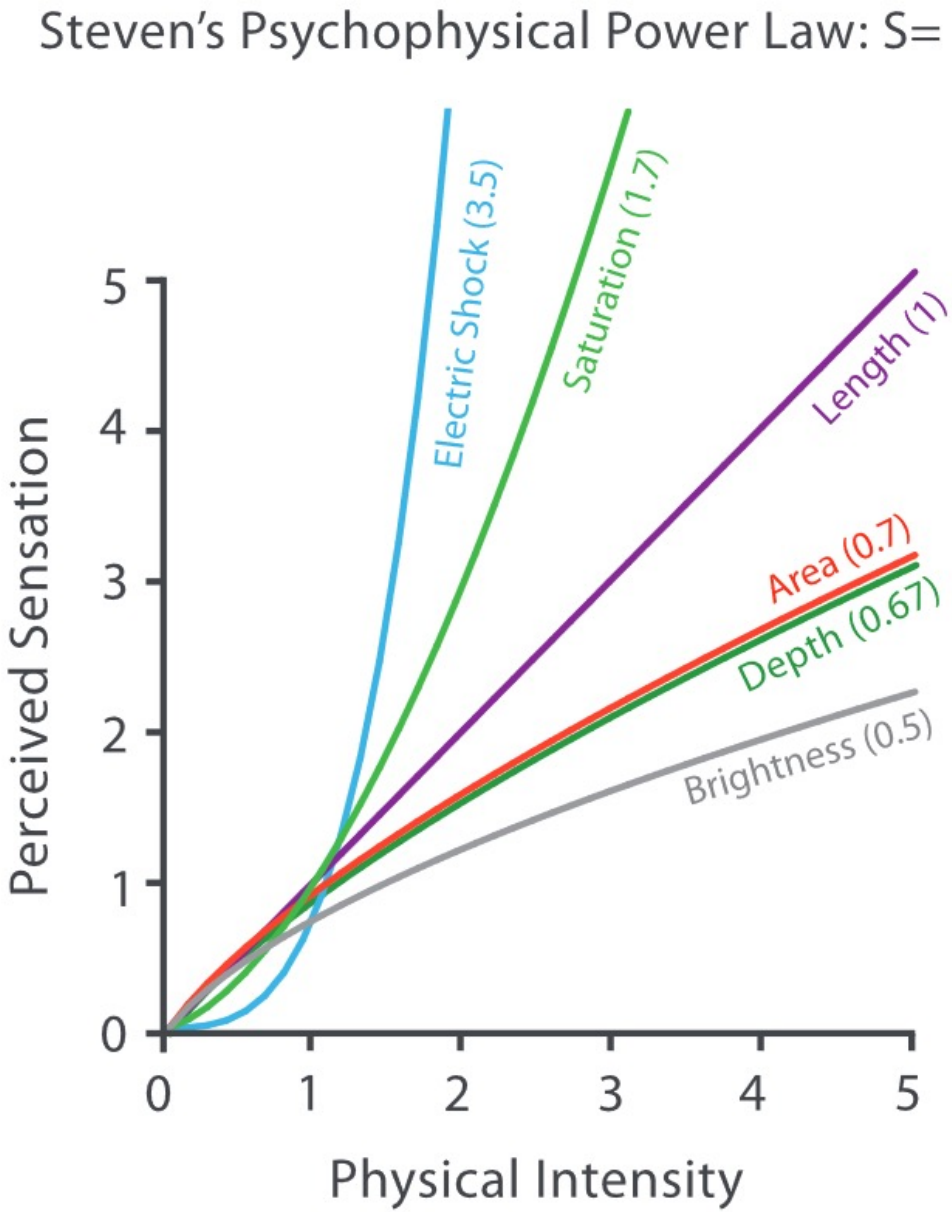




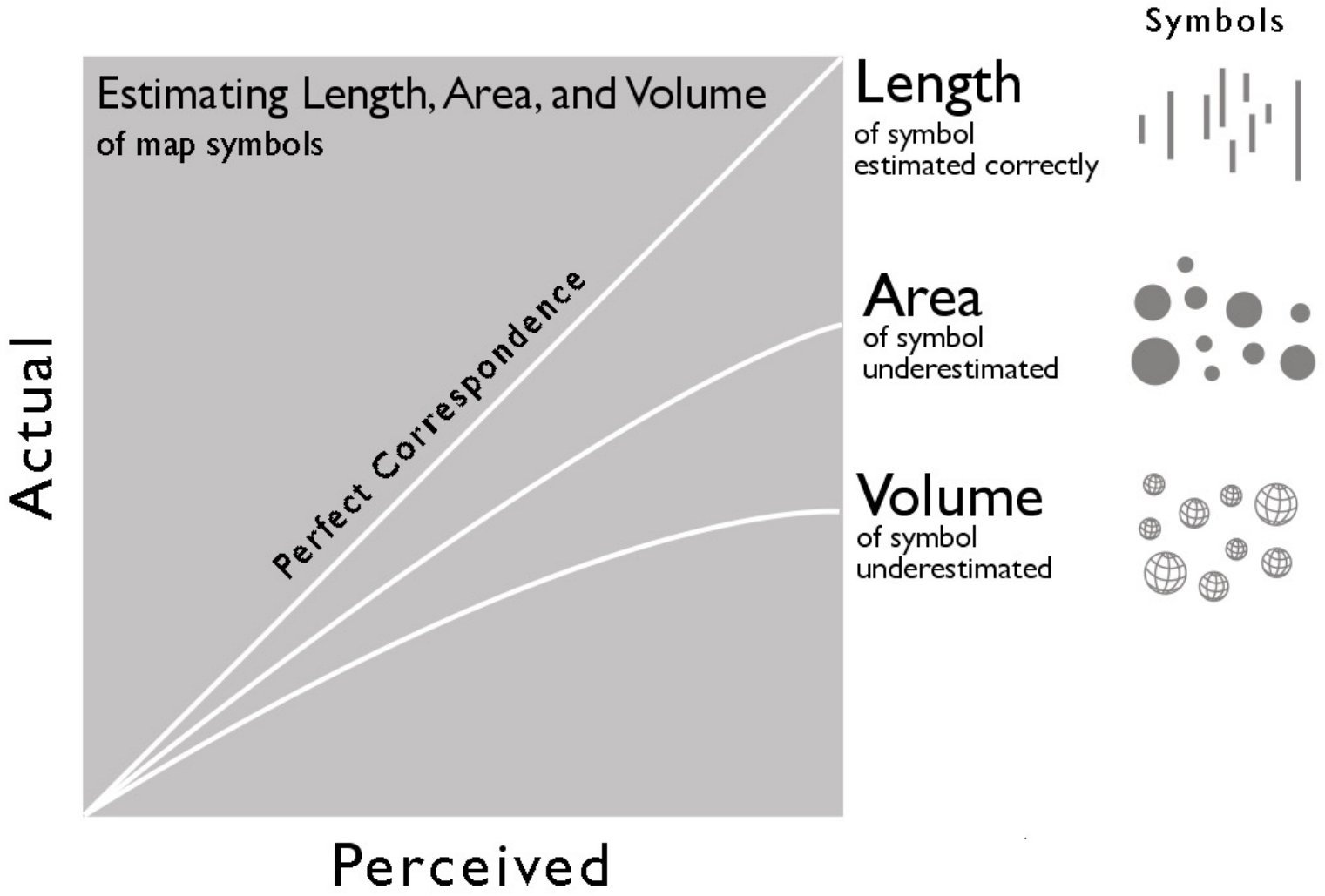
Applying Perception to Visualization

- Dimensions affect judgments:
  - Steven's Law: As the dimension of an attribute increases, the degree at which we underestimate it increases

Applying Perception to Visualization



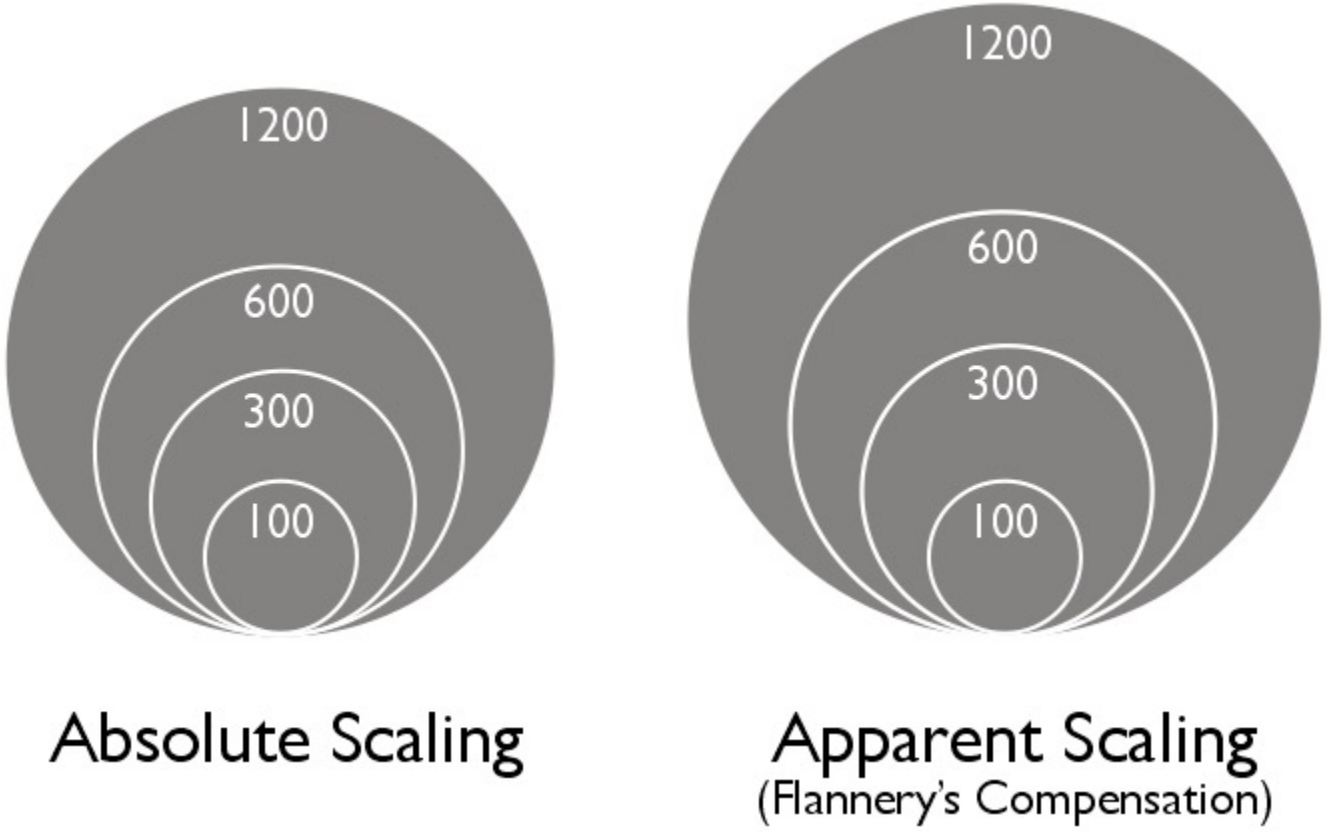
Applying Perception to Visualization



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

Applying Perception to Visualization

- Flannery's compensation



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

Applying Perception to Visualization

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

Applying Perception to Visualization

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

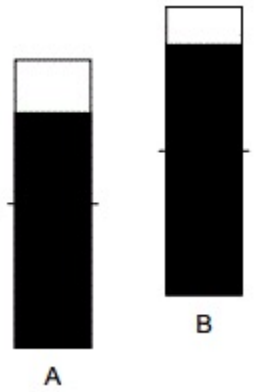
Small difference in stimulus (bar length)

Applying Perception to 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 to 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 to Visualization

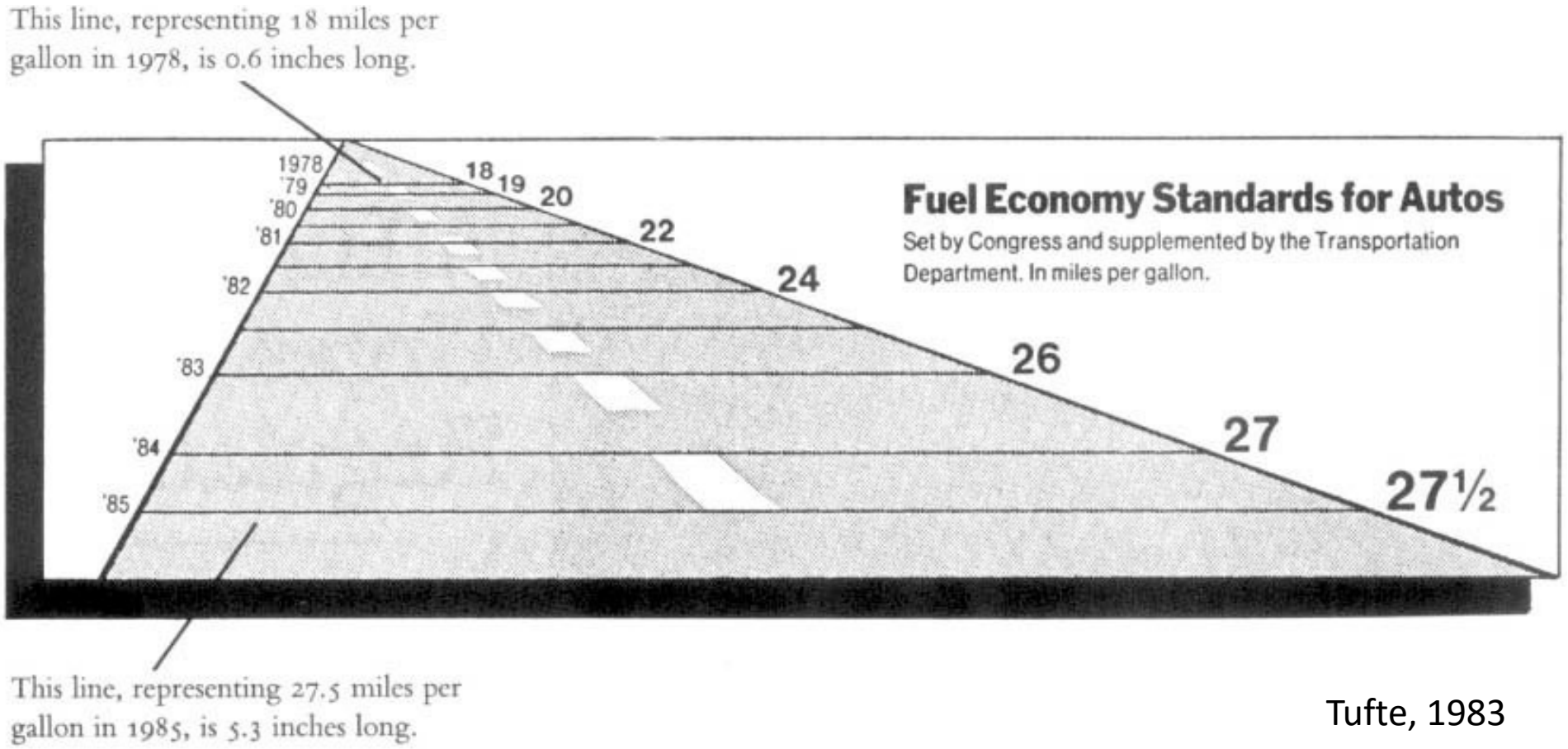
- Appropriateness. Model of Van Wijk:
  - *n* users use visualization *V* to visualize a data set m times each where each session takes *k* exploratory steps and time *T*
  - C_i ... Initial development costs
  - C_u ... Initial costs per user (e.g., selection, acquisition, learning, tailoring) Cs ... 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)

Applying Perception to 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 to Visualization

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

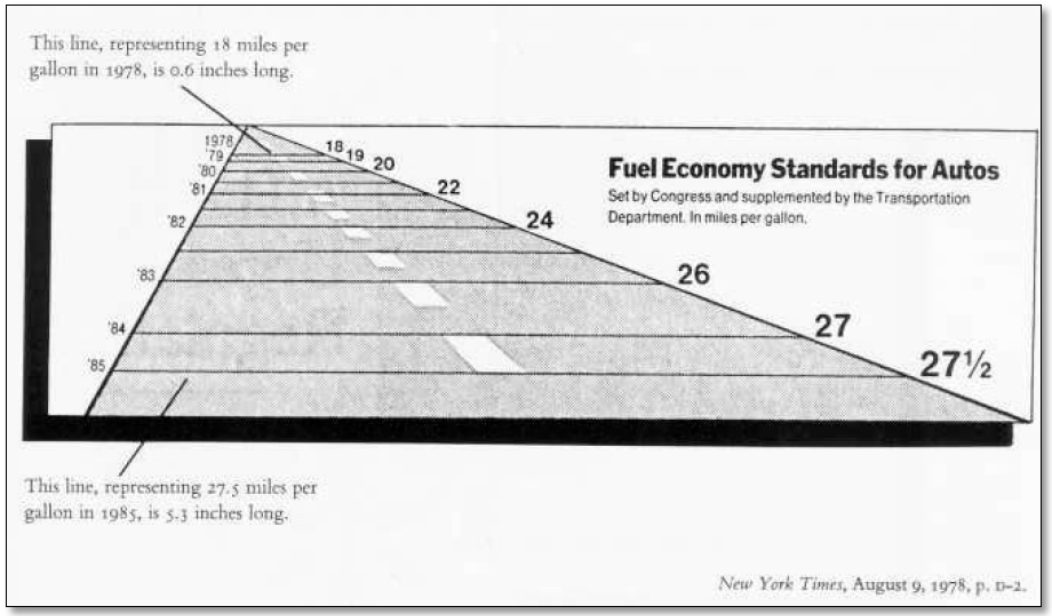


Tufte, 1983

Applying Perception to Visualization

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

Applying Perception to Visualization



Discussed in [Tufte01]

Graphic

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

Data

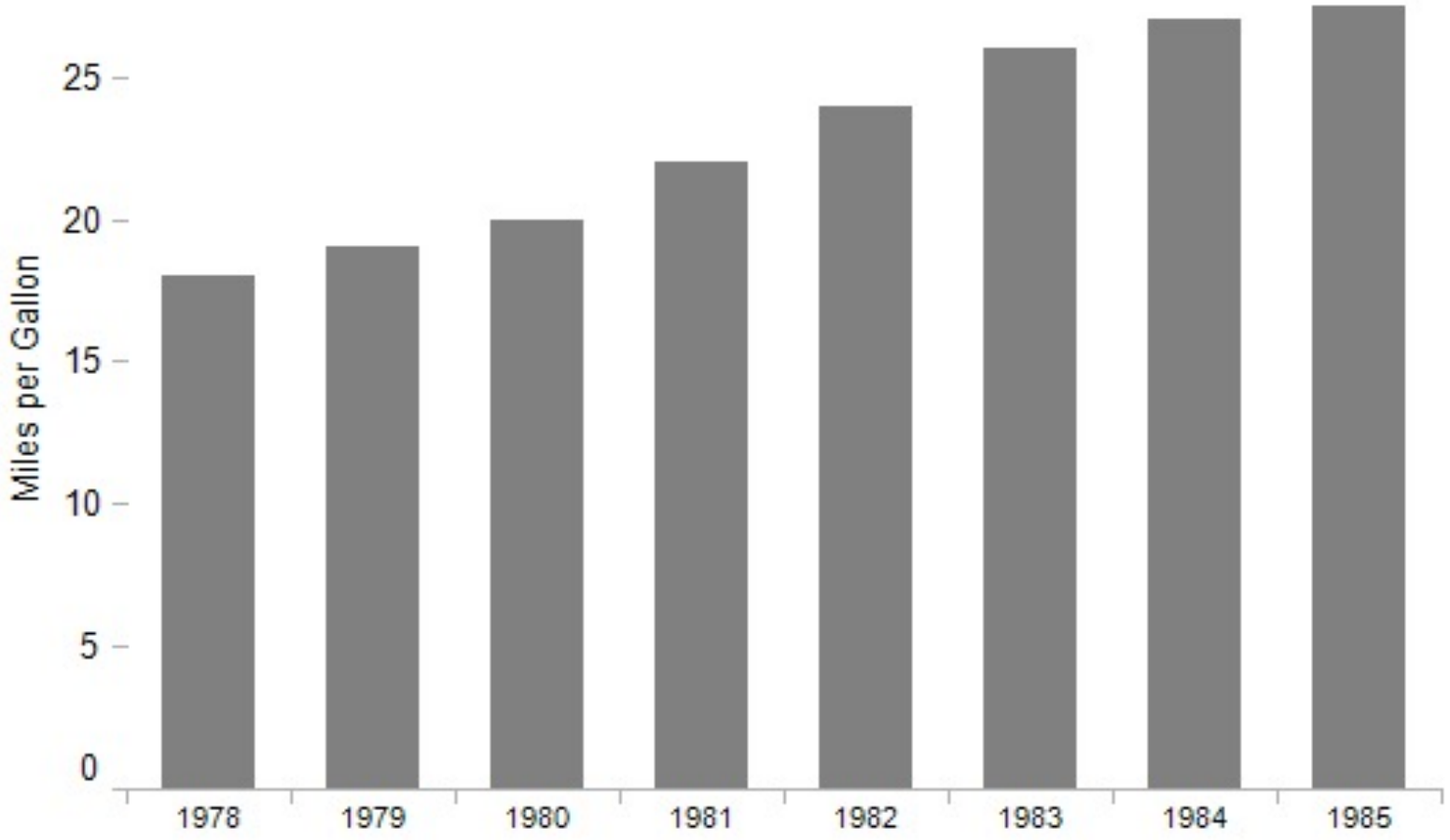
$$\frac{27.5-18.0}{18.0}*100\% = 53\%$$

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

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

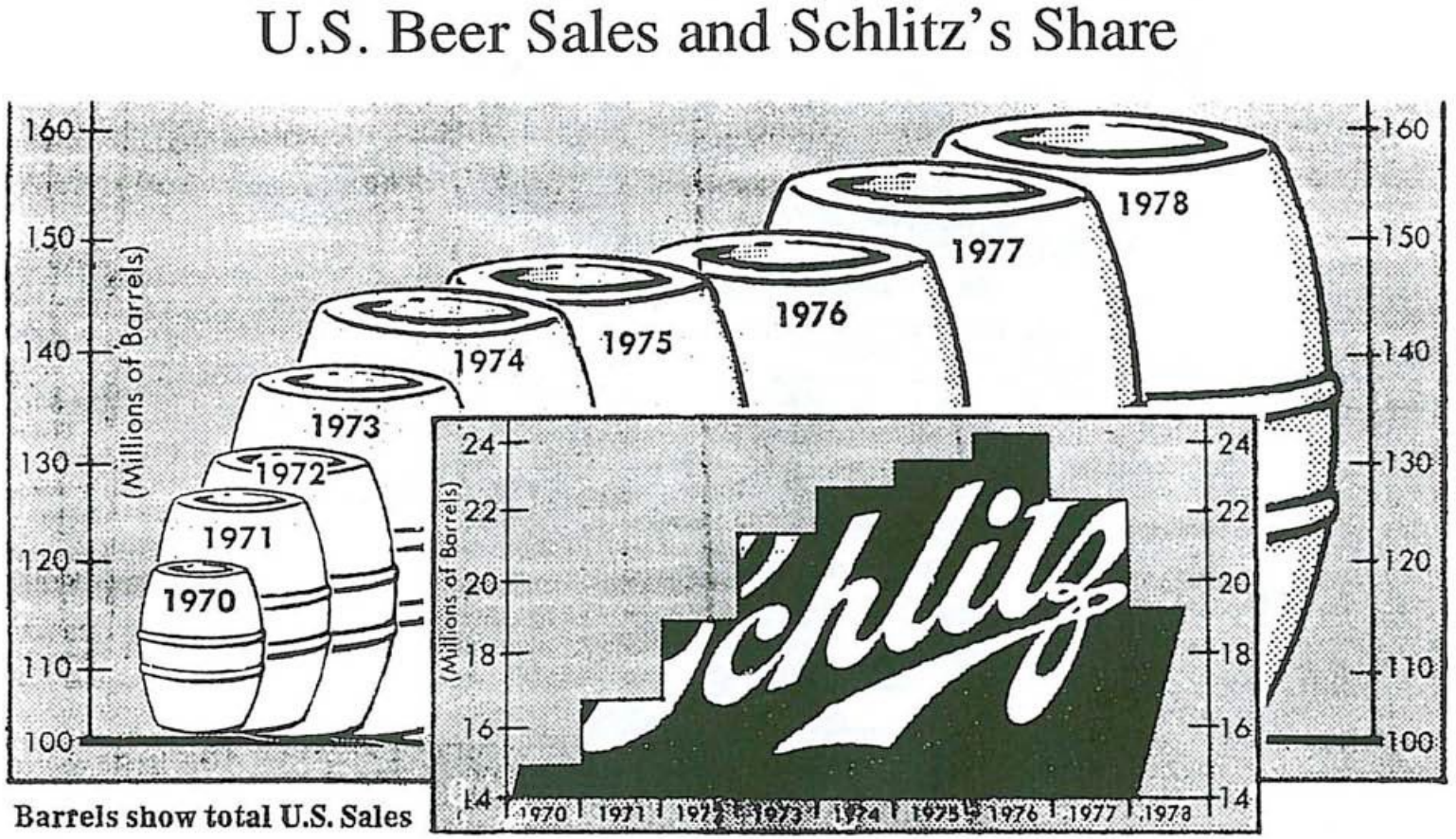
Applying Perception to Visualization

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



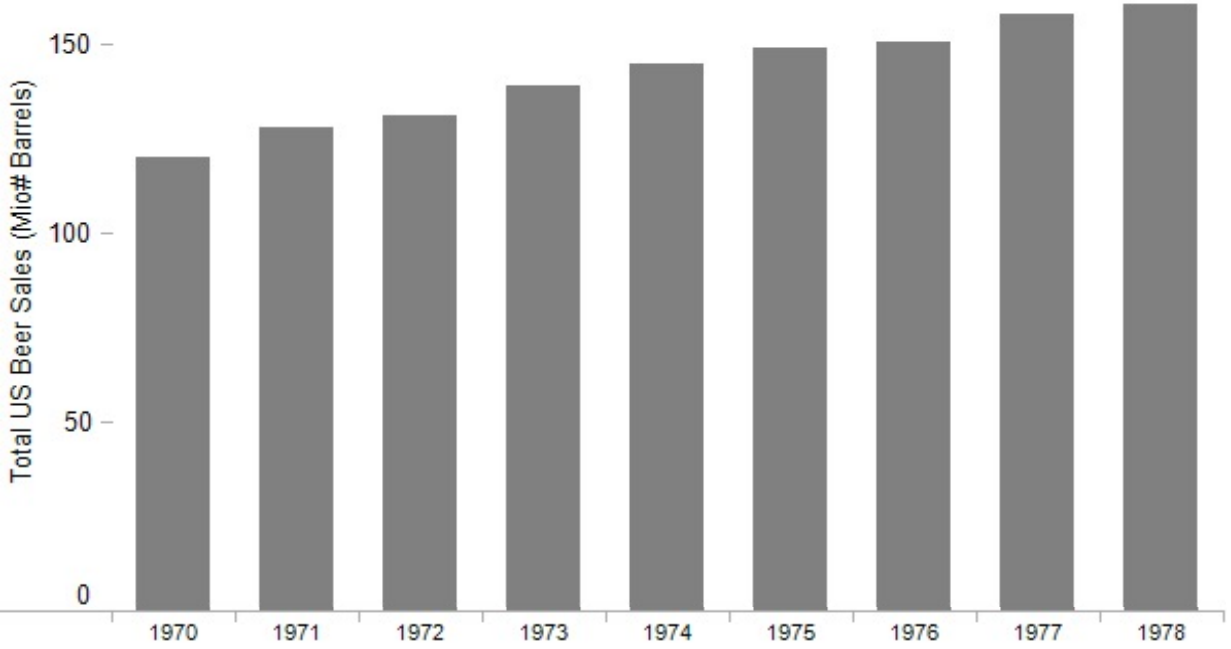
Applying Perception to Visualization

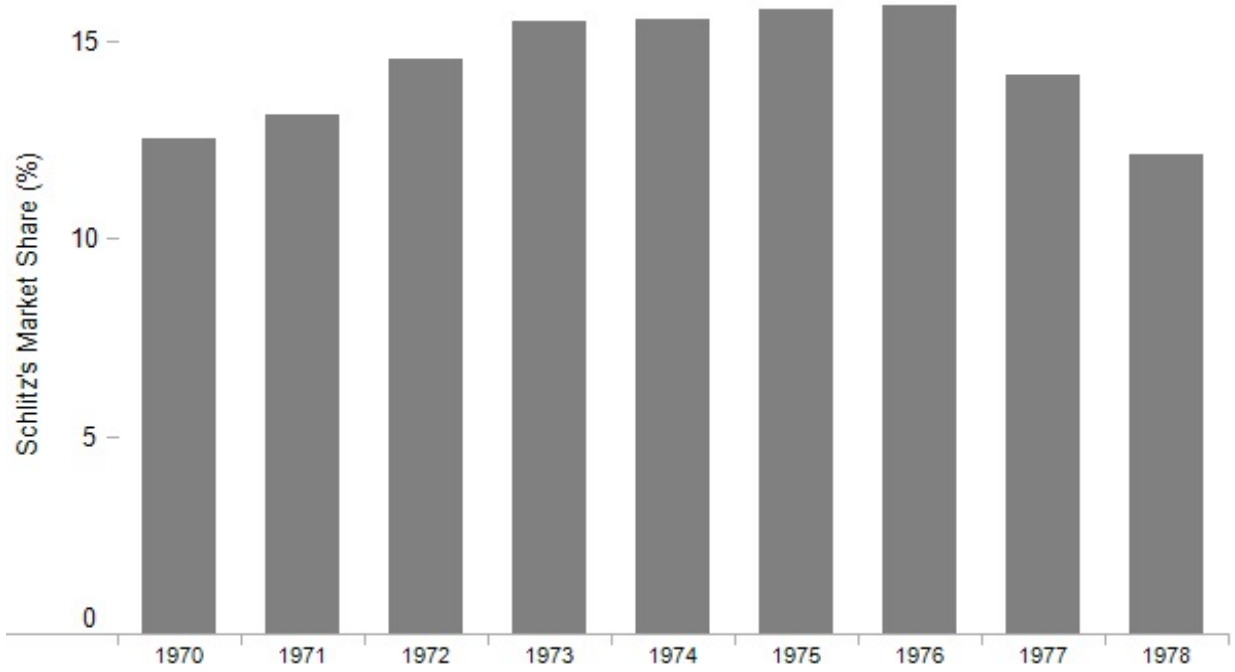
- Tell the truth about the data. Beer sales example:



Applying Perception to Visualization

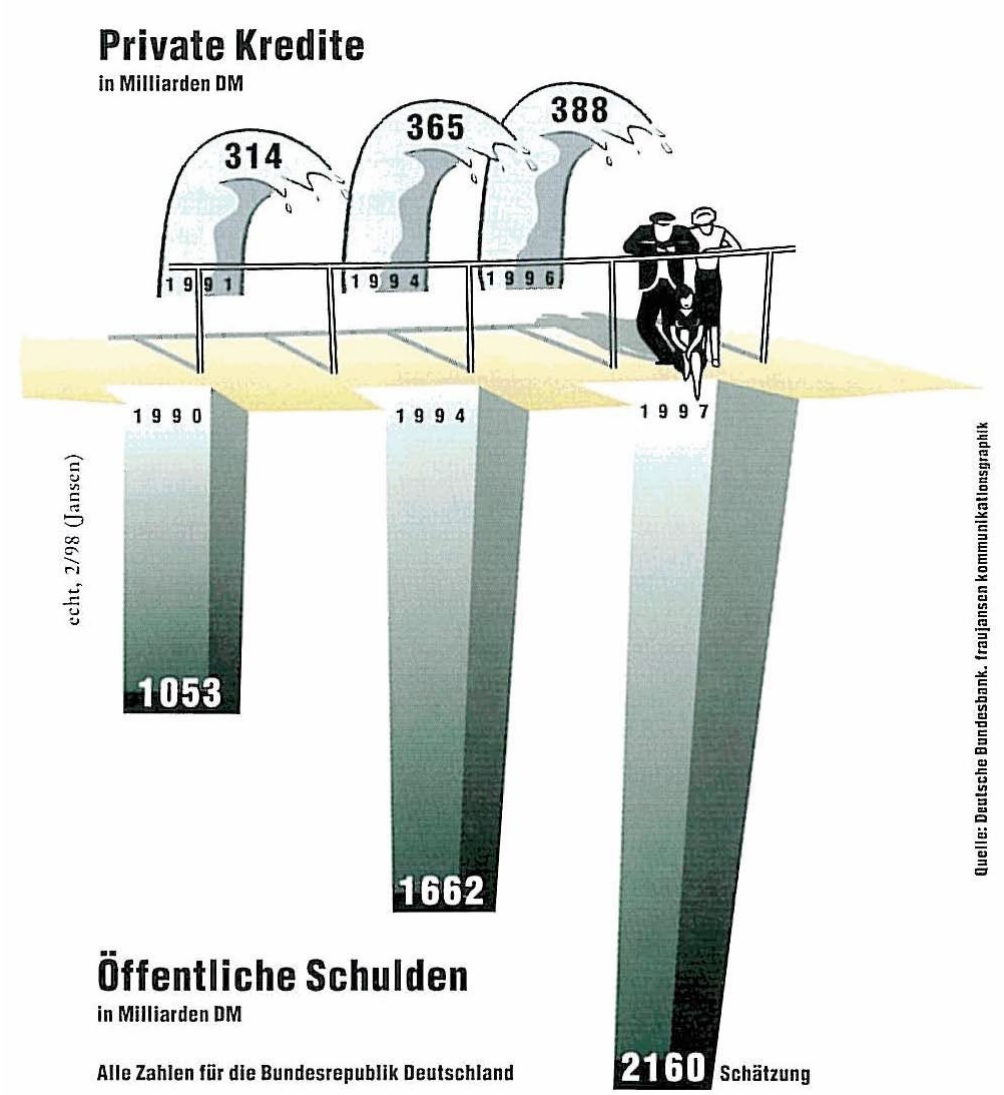
- Tell the truth about the data. Beer sales redesign:





Applying Perception to Visualization

- Avoid chartjunk



Jansen & Scharfe, 1999

Applying Perception to Visualization

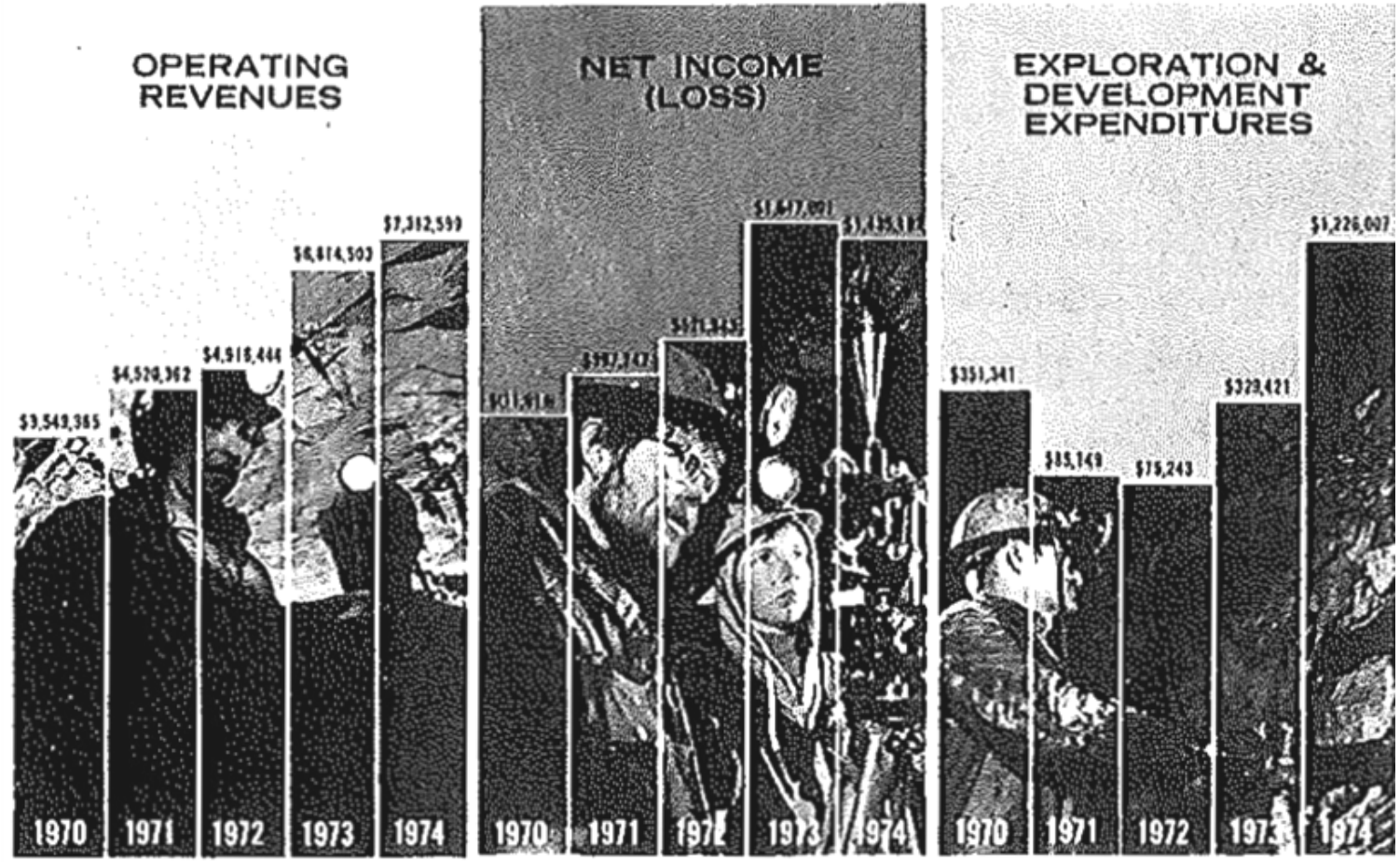
- Tufte's Design Principles:
  - Tell the truth about your data
  - Show the entire scale and show the context
  - Scale visual attribute values proportional to differences in represented numerical quantities
  - Label important events in the data and add explanations to defeat graphical distortion and ambiguity
  - Show data variation not variation in design

Applying Perception to Visualization

- Tufte's Design Principles. Application to design:
  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

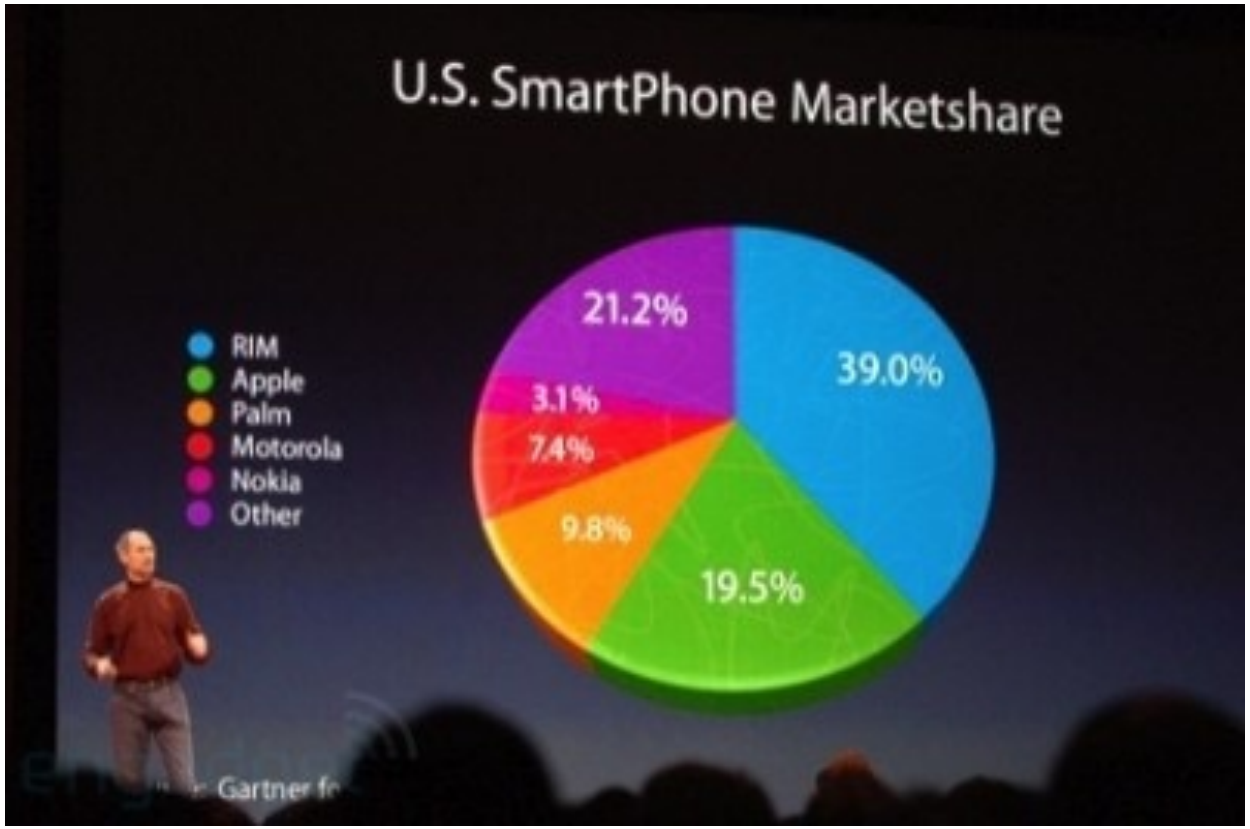
Applying Perception to Visualization

- If measured, you'll find that baseline is at -4200$



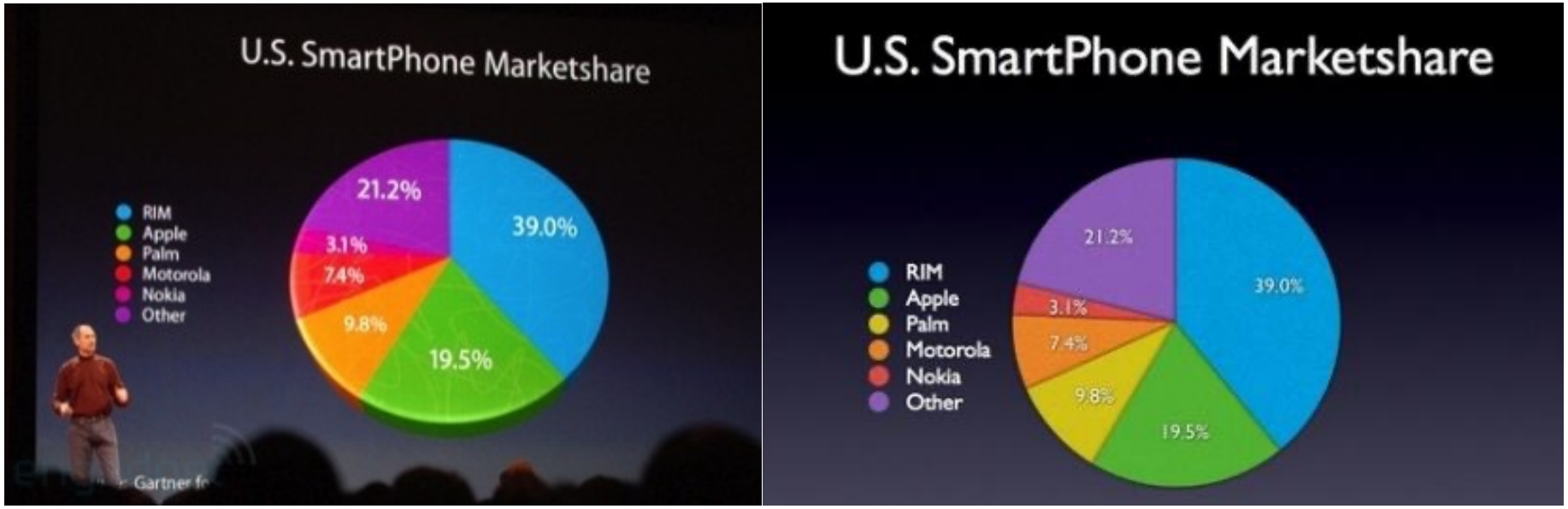
Applying Perception to Visualization

- Data distortion

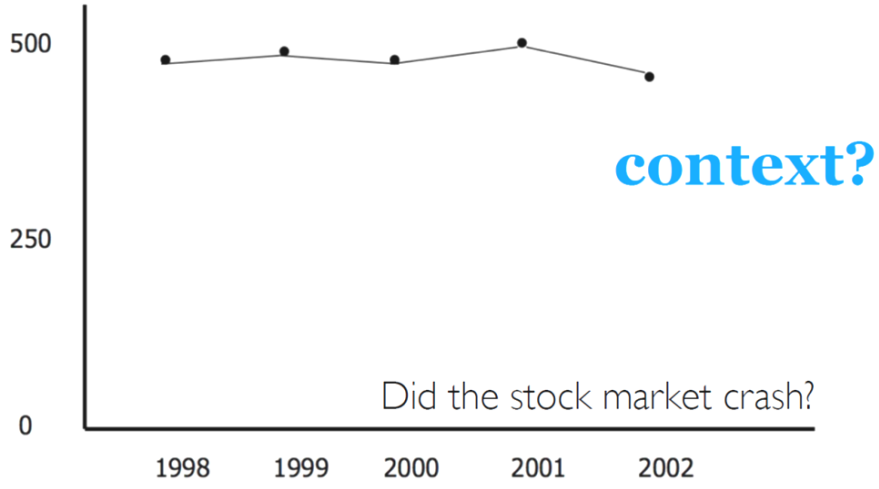


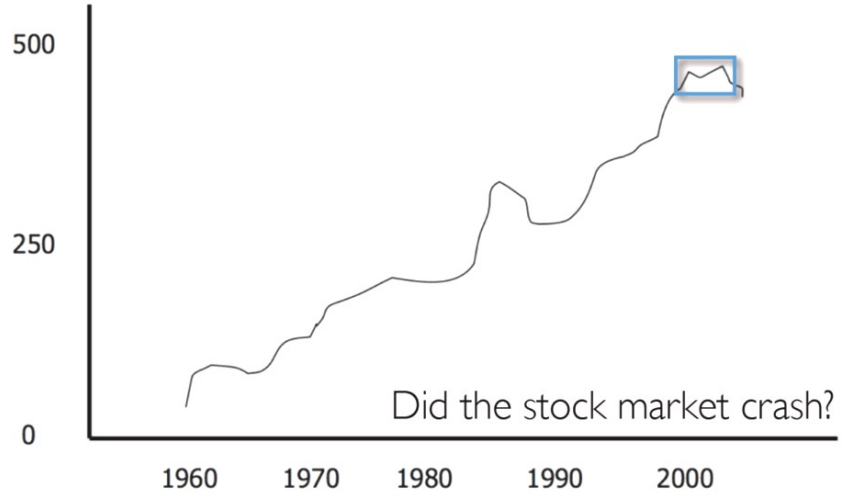
Applying Perception to Visualization

- Data distortion



Applying Perception to Visualization





Applying Perception to Visualization

- Make sure that the graph is complete. All axes must be labelled. There should be a title on the graph

Applying Perception to 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
  - Keep the design simple => enhance perception
  - We can enhance information by using redundant coding and highlighting
  - Remove noise by eliminating unnecessary elements

Applying Perception to Visualization

- Data-Ink ratio:

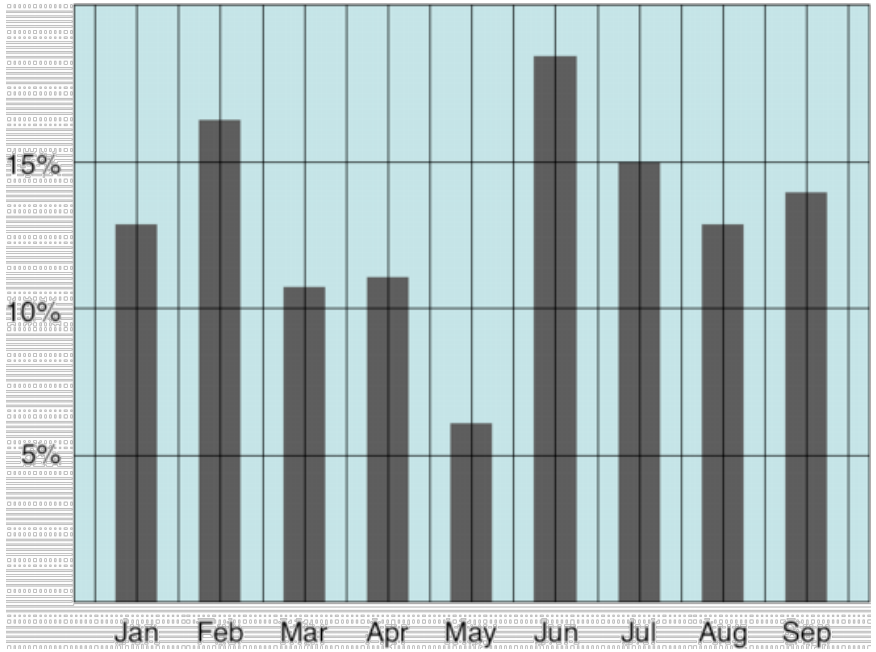
$$\text{Data-ink ratio} = \frac{\text{Data-ink}}{\text{Total ink used to print the graphic}}$$

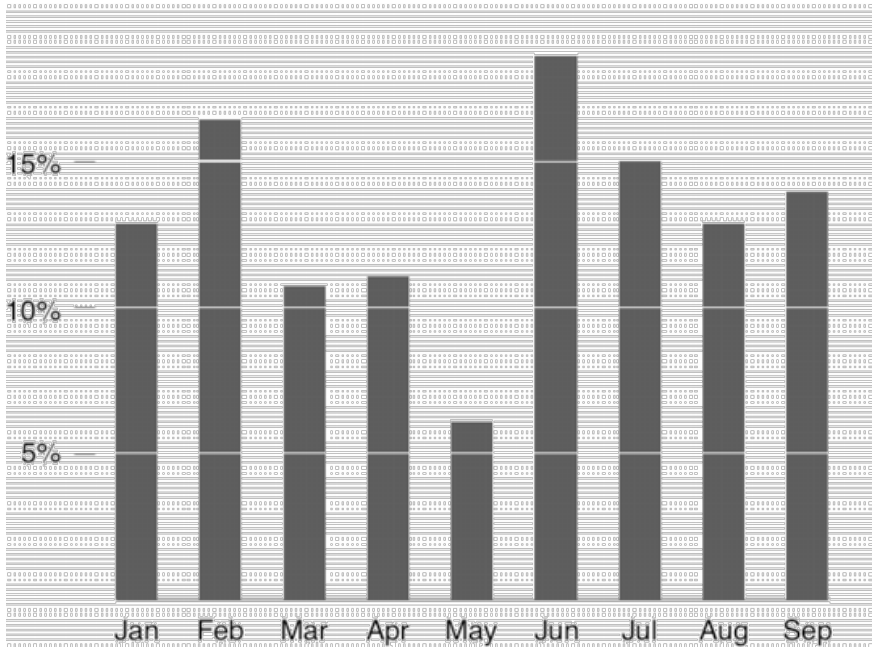
$$= \text{proportion of a graphic's ink devoted to the non-redundant display of data-information}$$

$$= \text{1.0 – proportion of a graphic that can be erased}$$

Applying Perception to Visualization

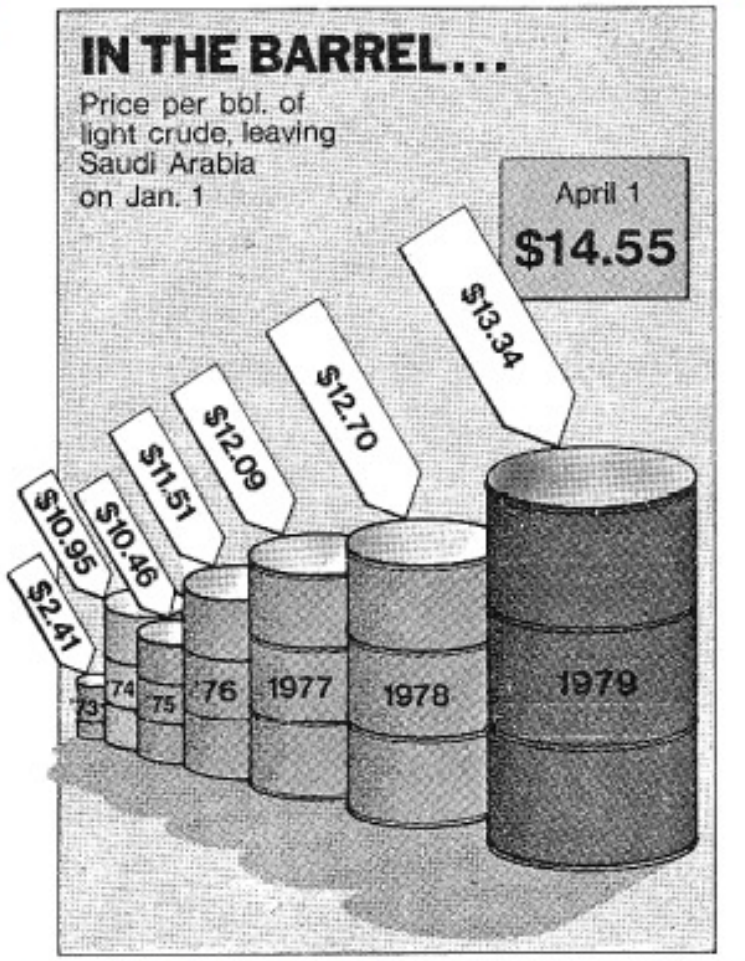
- Data-Ink ratio:





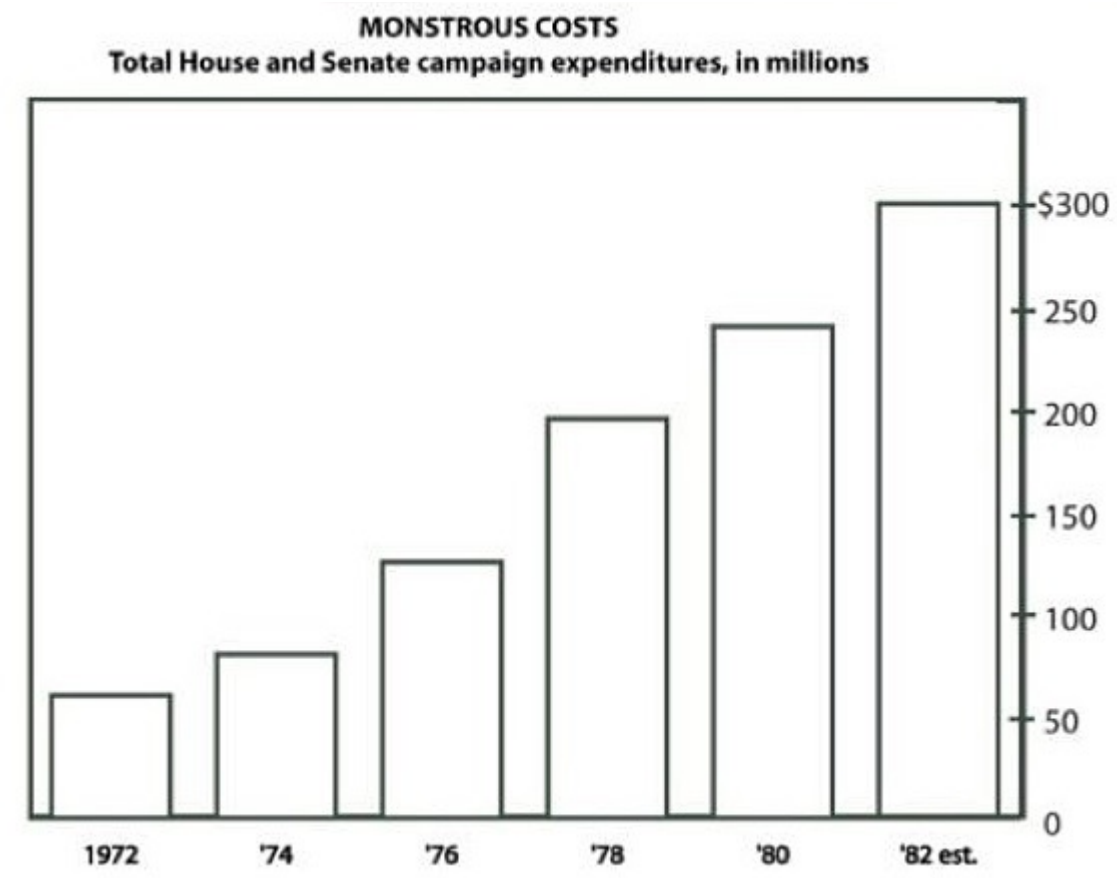
Applying Perception to Visualization

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



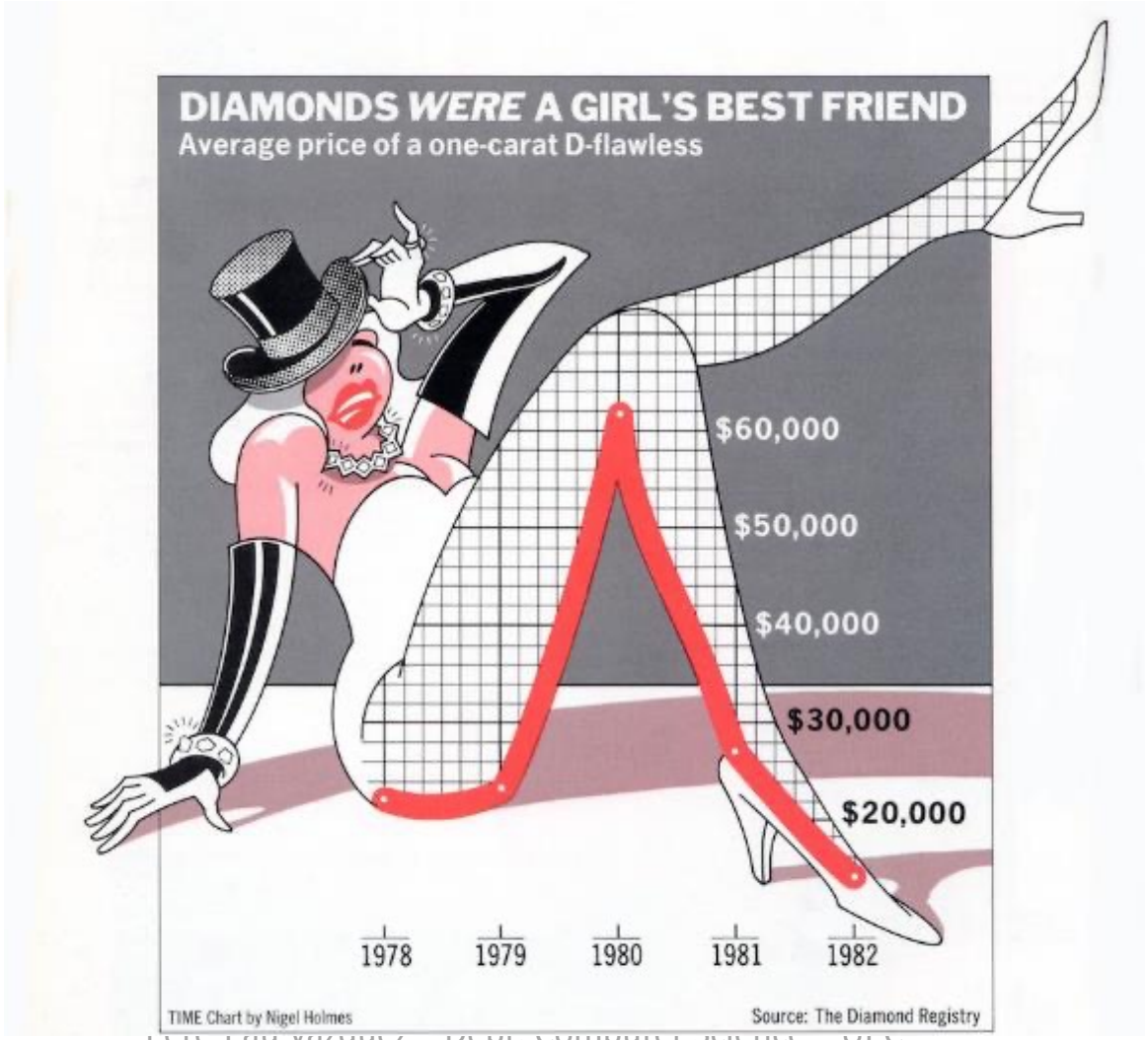
Applying Perception to Visualization

Applying Perception to Visualization



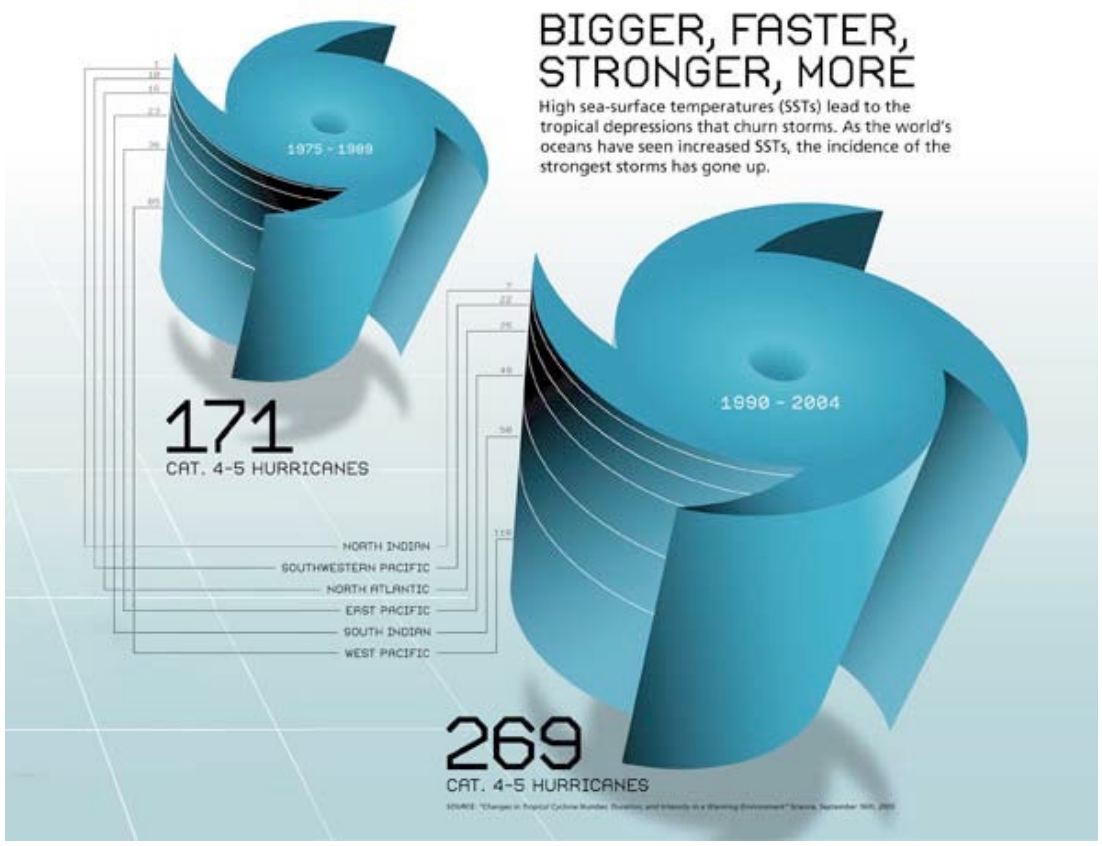
PC

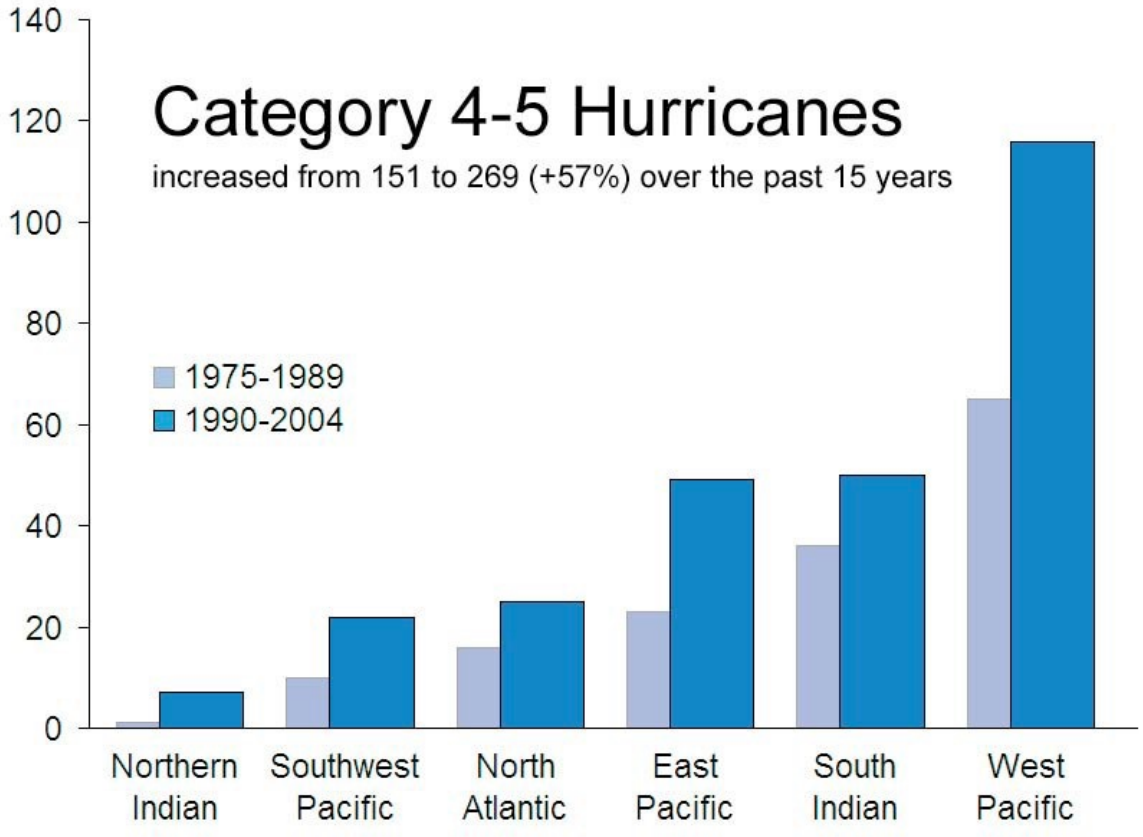
Applying Perception to Visualization



Applying Perception to Visualization

- Example:





Sources of information

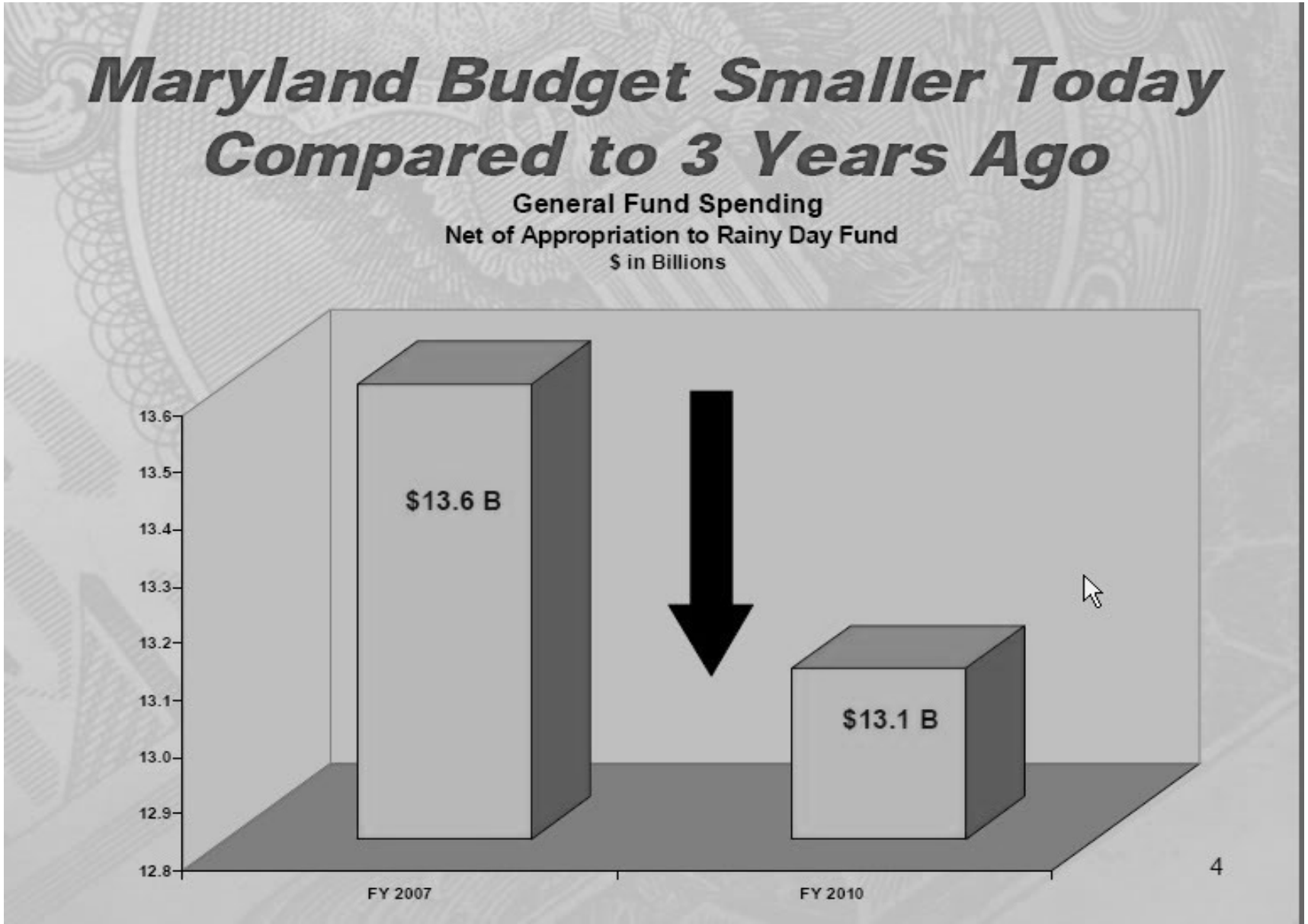
- Information Visualization: Perception for Design, 3rd edition, Colin Ware, Morgan Kaufmann, 2013.
- Perception in Vision web page with demos, Christopher Healey.
- Attention and Visual Memory in Visualization and Computer Graphics, Christopher G. Healey and James T. Enns, IEEE TVCG 18(7):1170-1188 2012.
- Mazza, R.: Introduction to Information Visualization, Springer-Verlag, London, 2009.
- Slides from: Silvia Miksch, Wolfgang Aigner, Theresia Gschwandtner, Martin Krzywinski, Christopher G. Healey, Andreas Butz, Thorsten Büring

Visualization. Perception

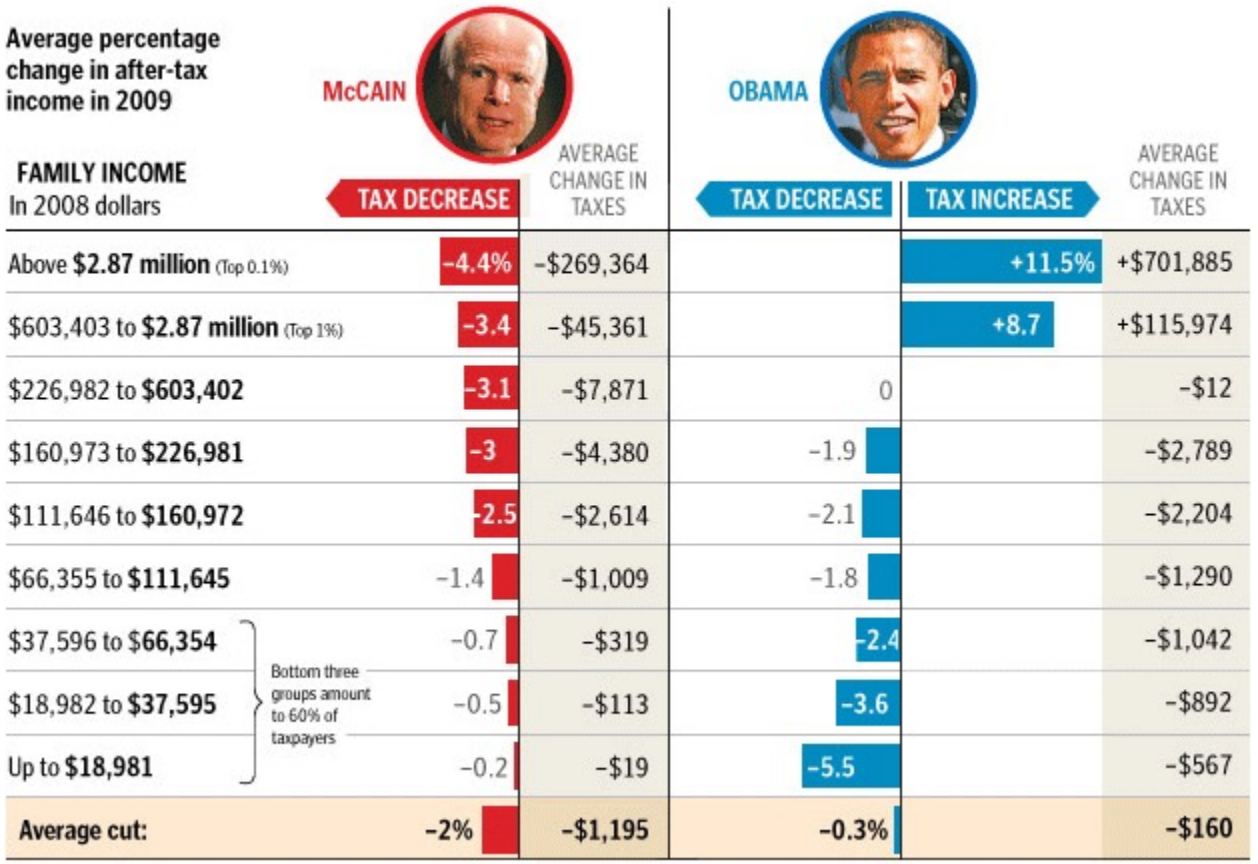
Pere-Pau Vázquez

Dept. Computer Science – UPC

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
4

Chartjunk



Average percentage change in after-tax income in 2009

FAMILY INCOME In 2008 dollars	McCAIN TAX DECREASE	McCAIN AVERAGE CHANGE IN TAXES	OBAMA TAX DECREASE	OBAMA TAX INCREASE	OBAMA AVERAGE CHANGE IN TAXES
Above **$2.87 million** (Top 0.1%)	-4.4%	-$269,364		+11.5%	+$701,885
$603,403 to **$2.87 million** (Top 1%)	-3.4	-$45,361		+8.7	+$115,974
$226,982 to **$603,402**	-3.1	-$7,871	0		-$12
$160,973 to **$226,981**	-3	-$4,380	-1.9		-$2,789
$111,646 to **$160,972**	-2.5	-$2,614	-2.1		-$2,204
$66,355 to **$111,645**	-1.4	-$1,009	-1.8		-$1,290
$37,596 to $66,354 (Bottom three groups amount to 60% of taxpayers)	-0.7	-$319	-2.4		-$1,042
$18,982 to **$37,595**	-0.5	-$113	-3.6		-$892
Up to **$18,981**	-0.2	-$19	-5.5		-$567
Average cut:	**-2%**	**-$1,195**	**-0.3%**		**-$160**