2. Visual Perception

Optimizing Information Visualization regarding the human visual system

Dr. Thorsten Büring, 25. Oktober 2007, Vorlesung Wintersemester 2007/08

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Outline

- Perception Definition & Context
- Preattentive processing
- Gestalt Laws
- Change Blindness
- Data encoding – glyphs
- Data encoding – color
- Characteristics of Visual Properties

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Perceptual 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?

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Model of Perceptual Processing

- Numerous other models exist
- Simplified 3-stage model: many subsystems involved in human vision
- **Stage 1** – rapid parallel processing to extract low-level properties of a visual scene
  - Detection of shape, spatial attributes, orientation, color, texture, movement
  - Billions of Neurons work in parallel, extracting information simultaneously
  - Occurs automatically, independent of focus
  - Information is transitory (though briefly held in a short-lived visual buffer)
  - Often called "**preattentive**" processing

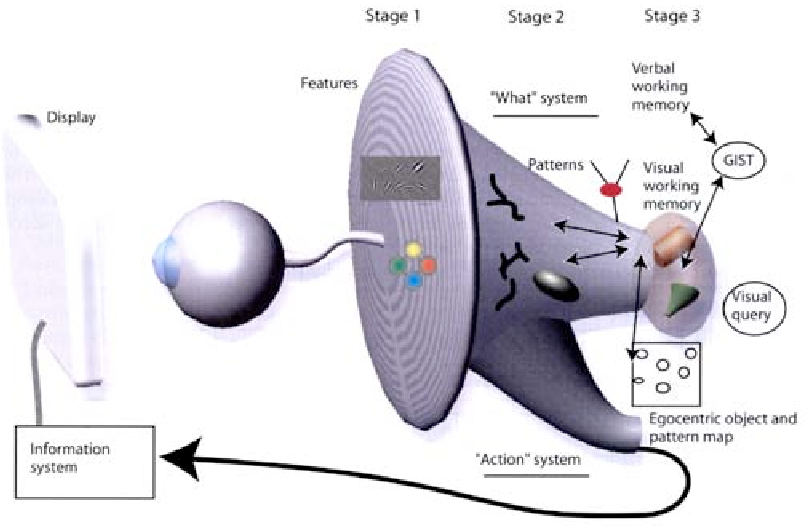

Image taken from Ware 2001

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Model of Perceptual Processing

- 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
- 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

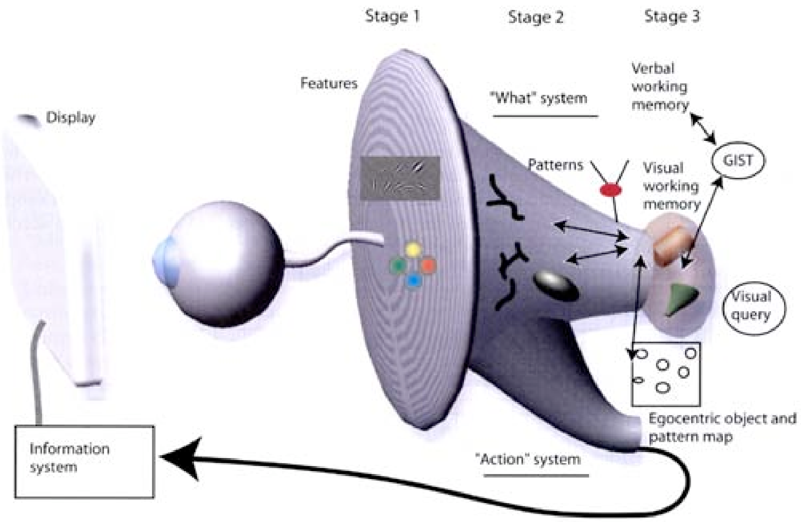
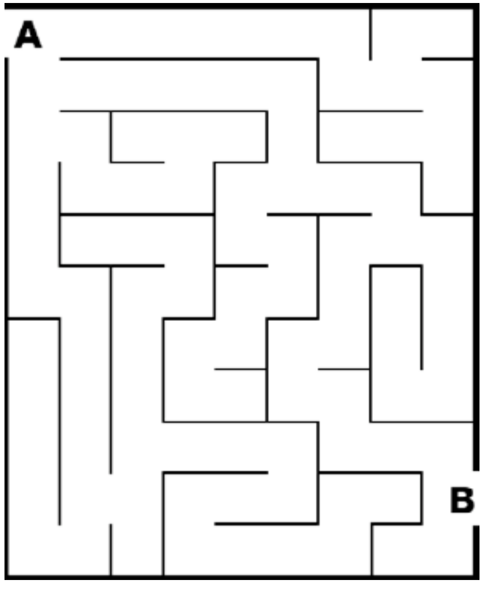


Image taken from Ware 2001

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)
- In this lecture we will focus on aspects related to stage 1 & 2 of the model



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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?

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Example: Find the 3s

1424164963575984759217659684748917284822859588198294

5096850485069584761212404407467489898517149596912456

7659608020860608365416496457590643980479248576960781

2859607999187128452681014959691245677818742416496457

5765960814959691245670128596079916496457512787991871

2845298496912223591649645759588198250963576596080596

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2859607999187128452681014959691245677818742416496457

5765960814959691245670128596079916496457512787991871

2845298496912223591649645759588198250963576596080596

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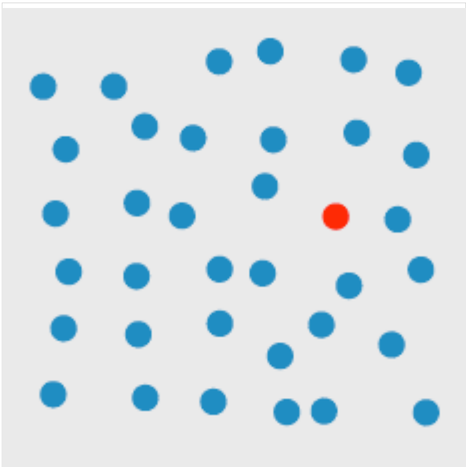
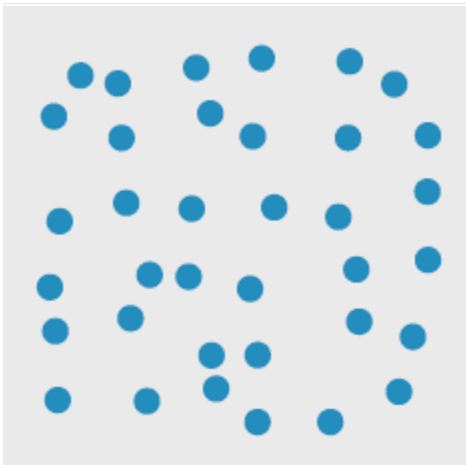
Preattentive Processing

- How to find out if a visual attribute is preattentive?
- Measure response time for tasks
  - Detection of a target among distractors – Is the target present?
  - Boundary detection – Do items form two groups?
  - Counting – How many targets are there?
- Detection of targets on a large multi-element display (Healey)
  - < 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?

Color

- Is there a red circle present in the image?

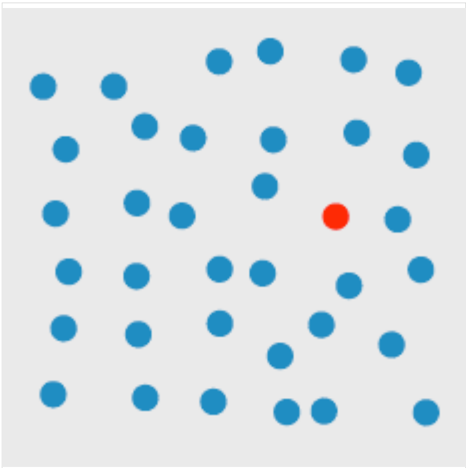


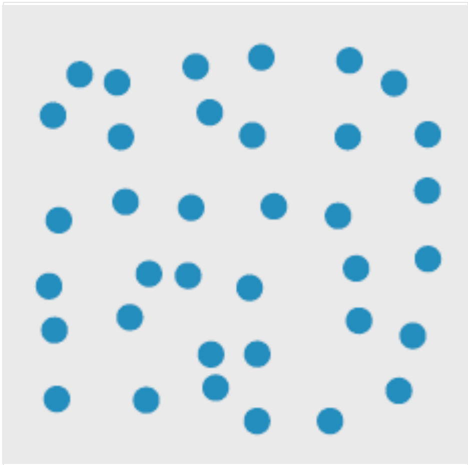


Images taken from http://www.csc.ncsu.edu/faculty/healey/PP/index.html

Color

- Is there a red circle present in the image?



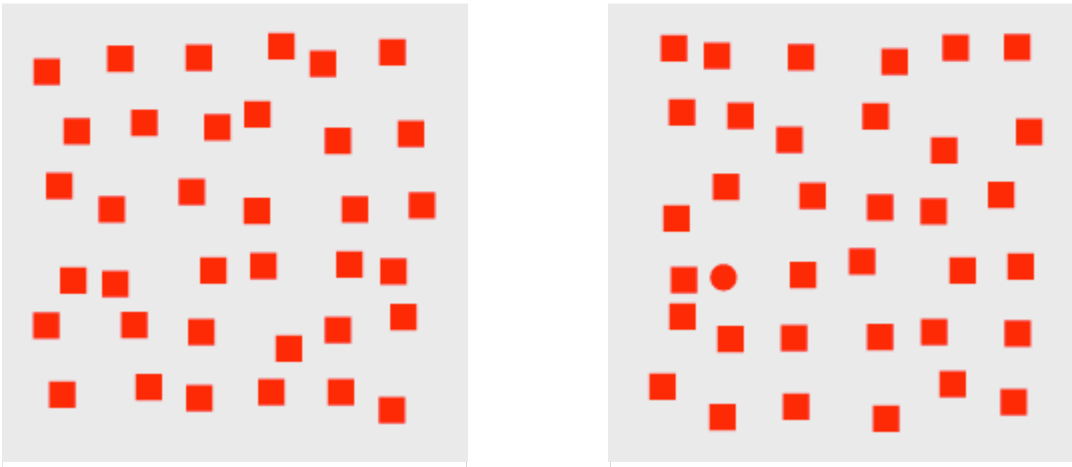


Color is preattentively processed!

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

Shape

- Is there a red circle present in the image?



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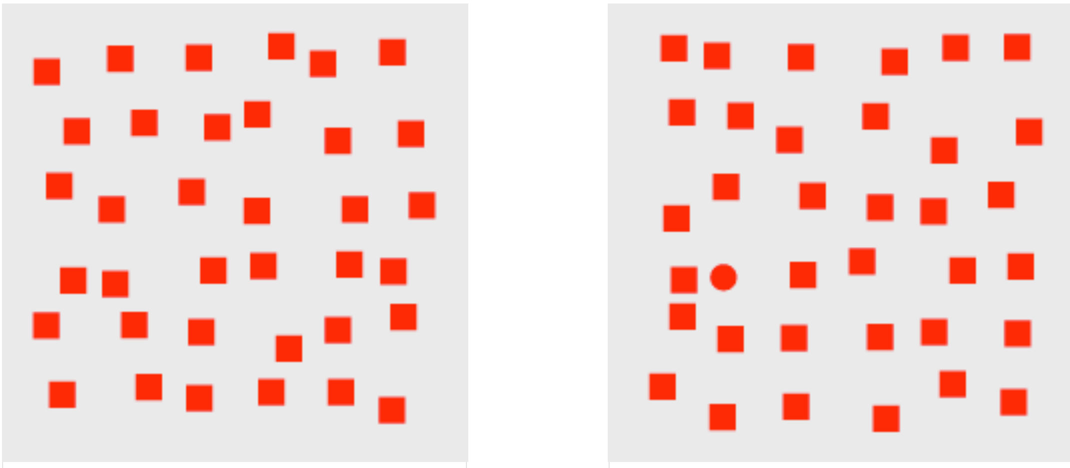

Shape is preattentively processed!

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Color & Shape

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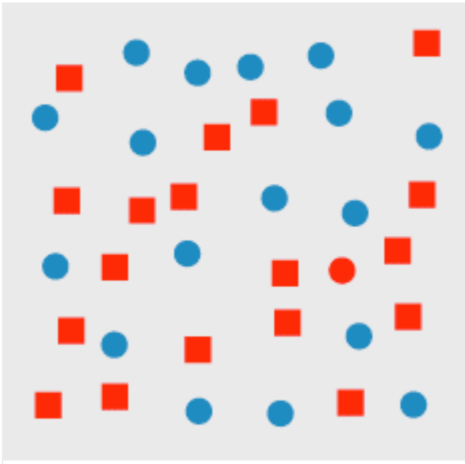

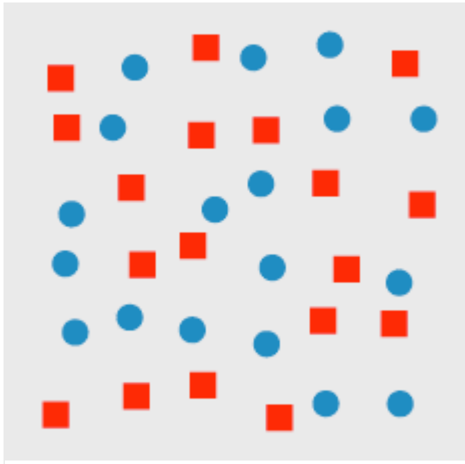

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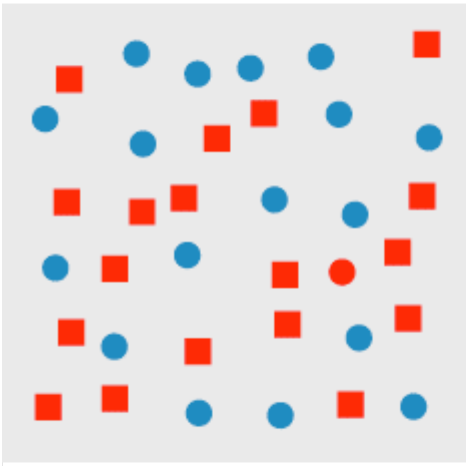

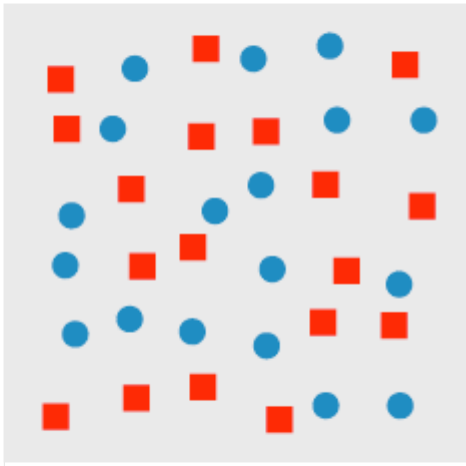

Conjunction search is usually not preattentive!

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

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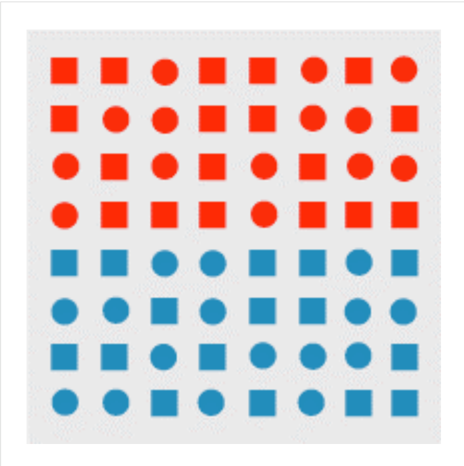
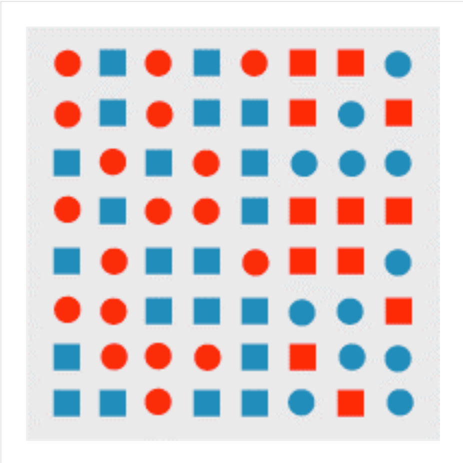
Boundary Detection

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





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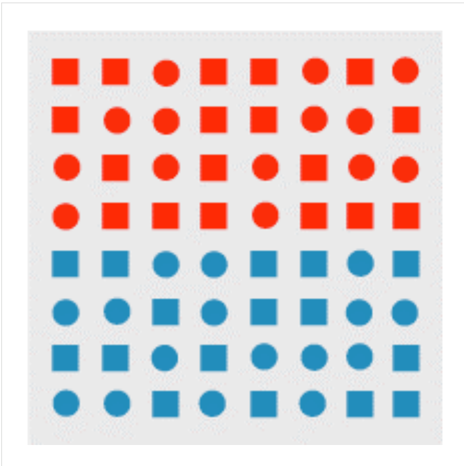
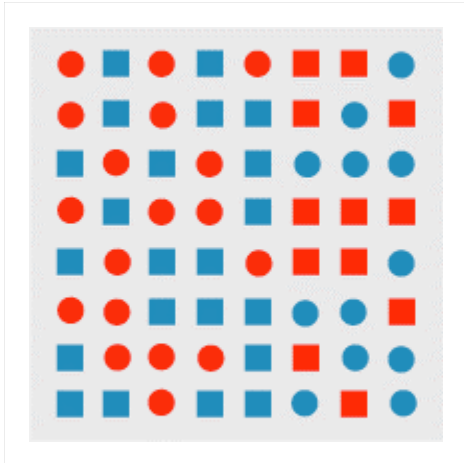


Preattentive: grouping by hue

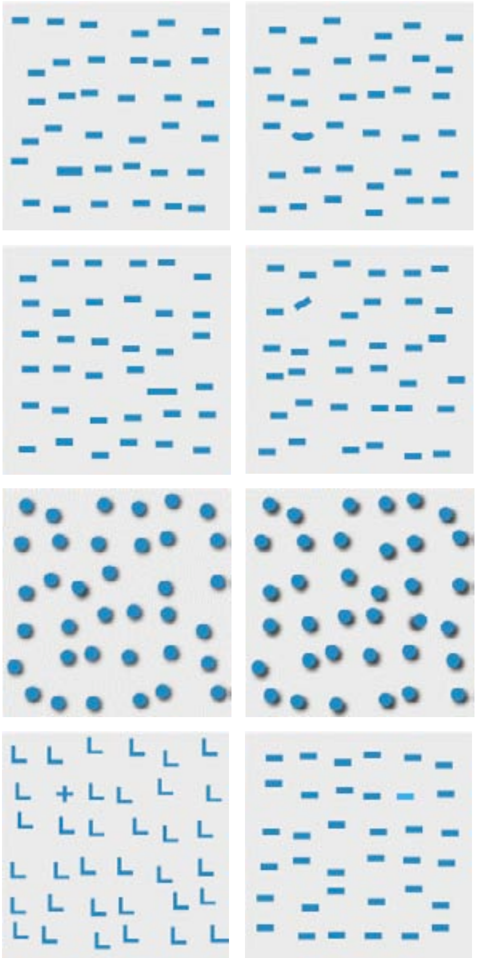


Conjunction search: grouping by hue and shape

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

Common Preattentive Properties

- Form
  - Line orientation
  - Line length
  - Line width
  - Size
  - Curvature
  - Shape
  - Spatial grouping
  - Bur
- Color
  - Hue
  - Intensity
- Motion
  - Flicker
  - Direction of motion
- Spatial Position
  - 2D position
  - Stereoscopic depth
  - Convexity / Concavity



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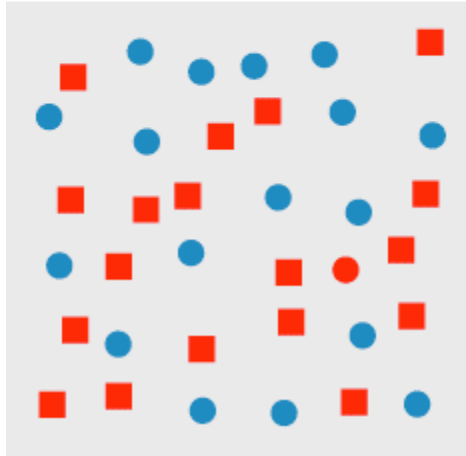
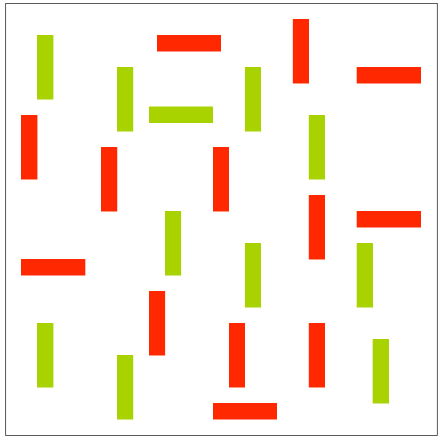
Conjunction Search

- 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 cricular item: is it red?
- Exception: preattentive conjunctions involving:
  - Motion
  - Depth
  - Color
  - orientation





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Cognition and Gestalt Laws

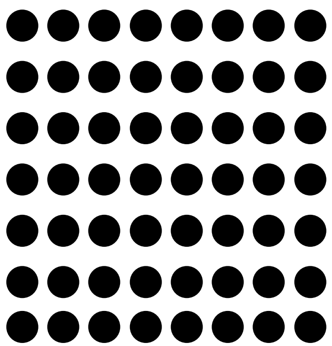
- Recap: step 2 of the visual information processing model – pattern and object recognition using the raw data collected in step 1
- Based on which visual properties to we structure the data?
- Gestalt school of psychology founded in 1912 formulated Gestalt laws
- "The whole is greater than the sum of parts" (Koffka 1935)
- Laws still useful today, but not the neural mechanisms proposed
- Perception: An introduction to the Gestalt-theorie (Kurt Koffka, 1922): http://psychclassics.yorku.ca/Koffka/Perception/perception.htm

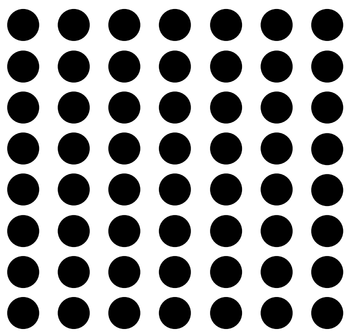
What do you see?

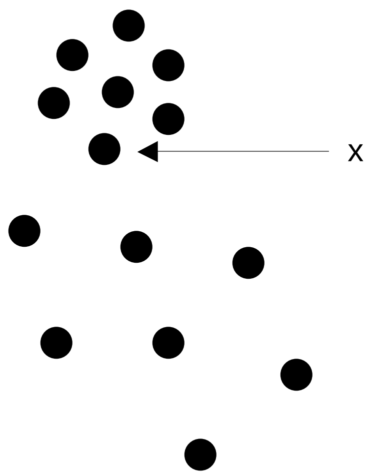
- Can you find the dog?
- Dalmatinian exploring a leave covered forest floor
- Once you have found it, try to think of the picture as a simple pattern of black and white again
- Does it work?
- Mind tries to detect anything meaningful by identifying patterns
- Different tools are tried sequentially
-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

GL: 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!
- Spatial concentration principle: we group regions of similar element density (Slocum1983)







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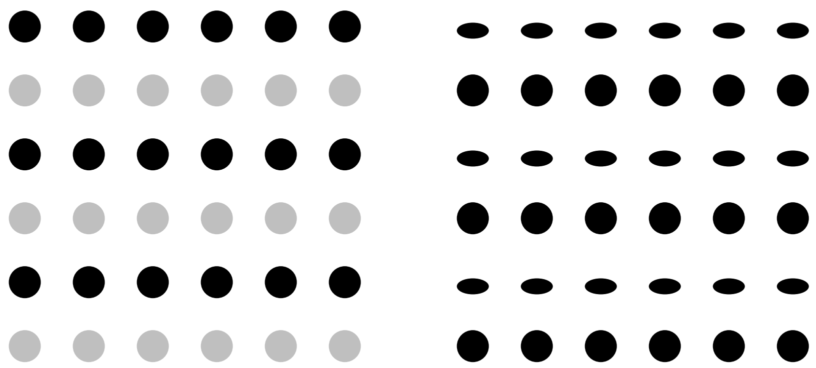
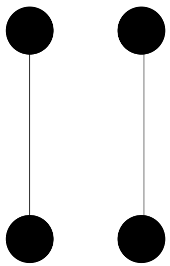
GL: Similarity

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

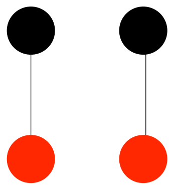


GL: Connectedness

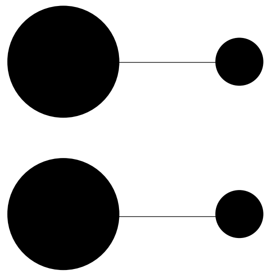
- Palmer & Rock 1994
- Potentially more powerful organizing principle than proximity, color, size, shape



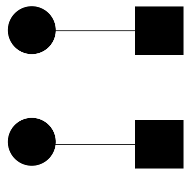
proximity



color



size



shape

Example: node-link diagram

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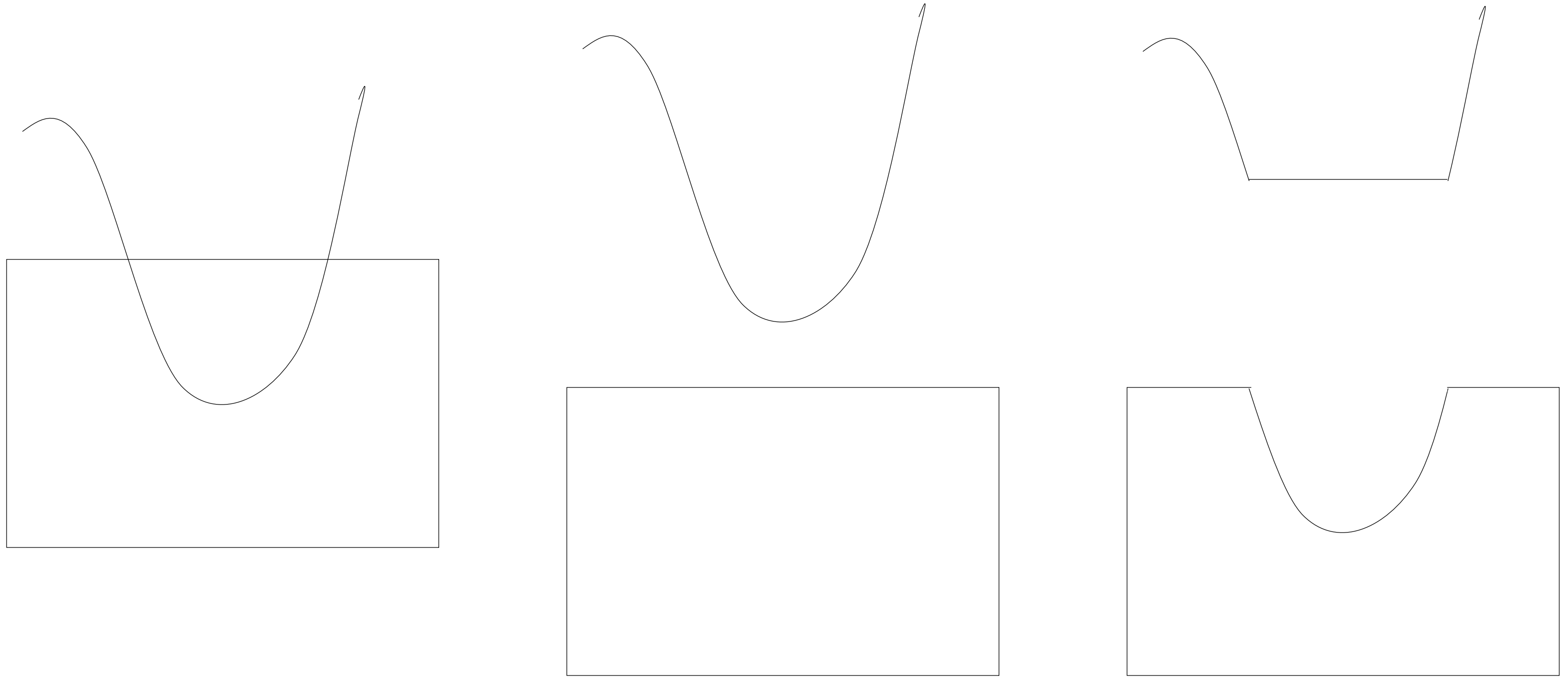
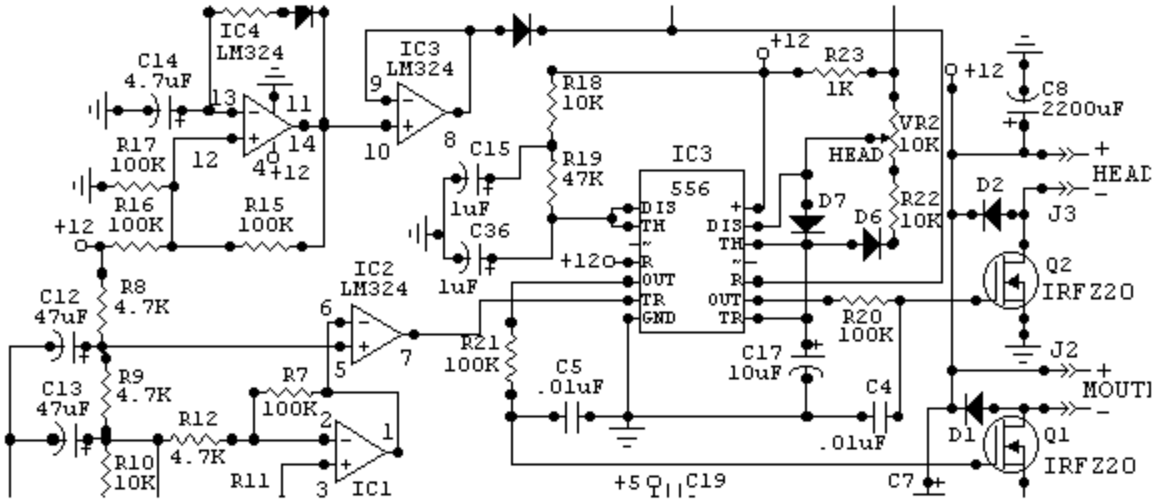
GL: Continuity

- Smooth and continuous visual elements are likely to be perceived as an entity
- Abrupt changes in direction create the opposite effect
- What are the two shapes the figure is assembled from?



GL: Continuity

- Example circuit design – understanding how components are connected



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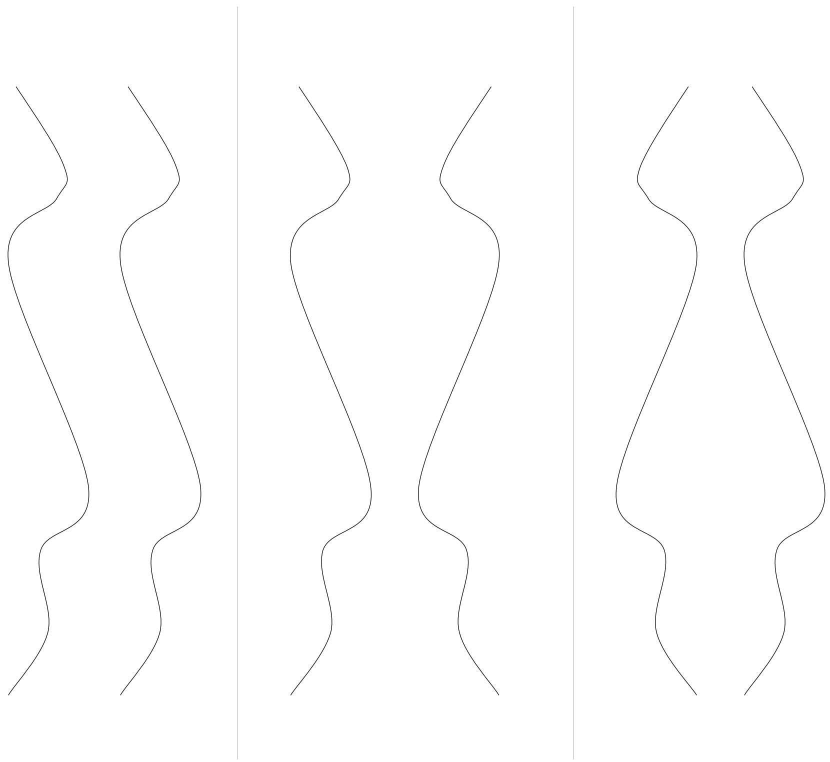
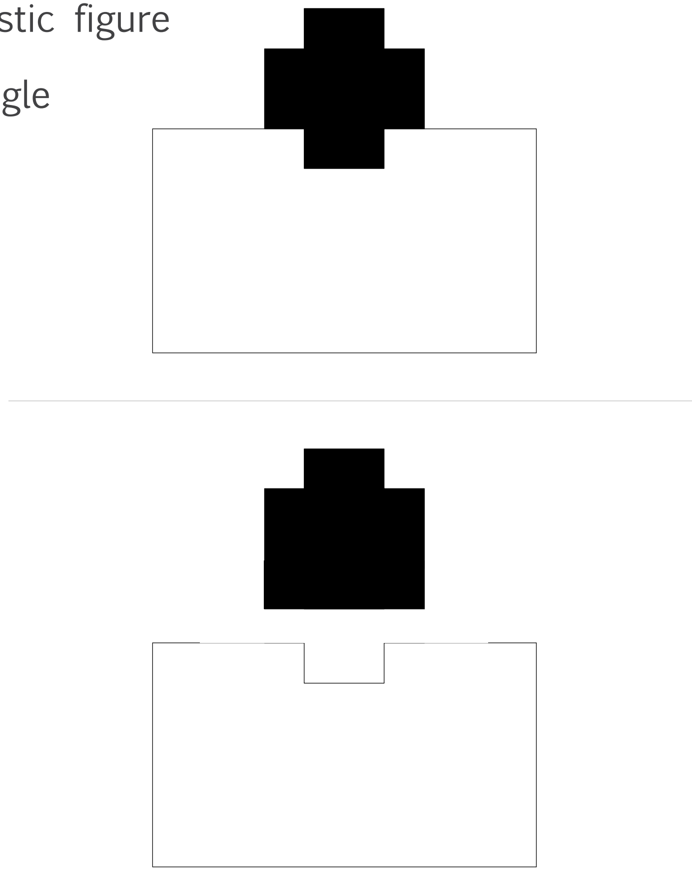
GL: Symmetry

- Symmetric forms are perceived much more as a holistic figure
- Symmetry makes us see a cross in front of a rectangle





GL: 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)

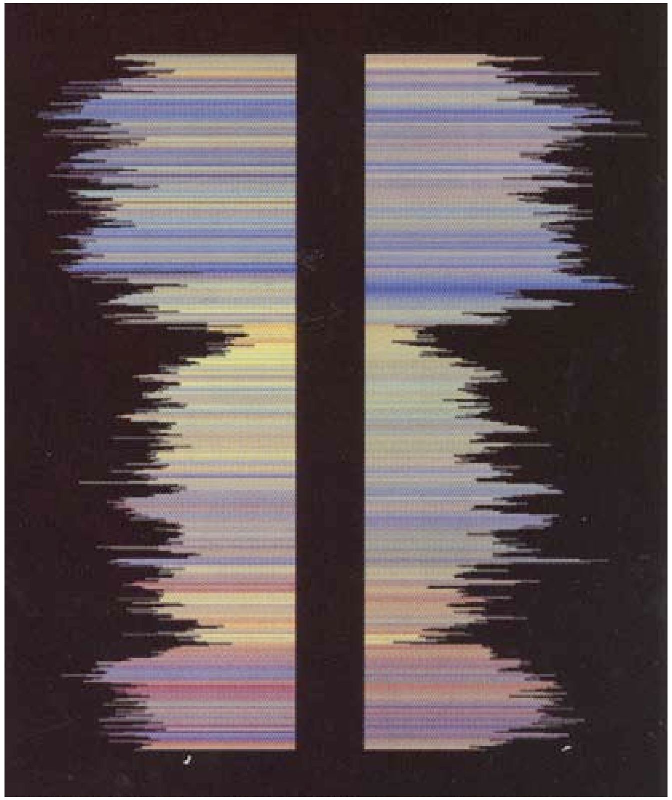
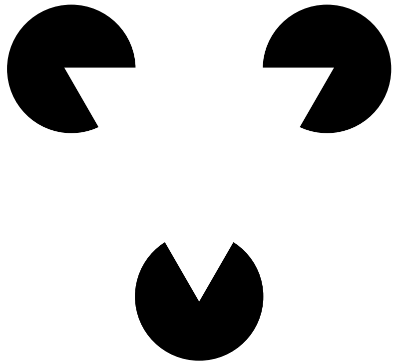
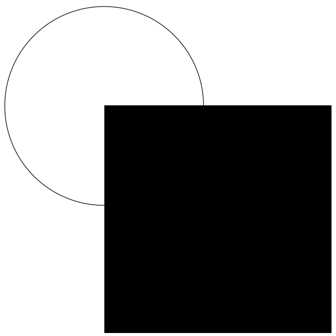


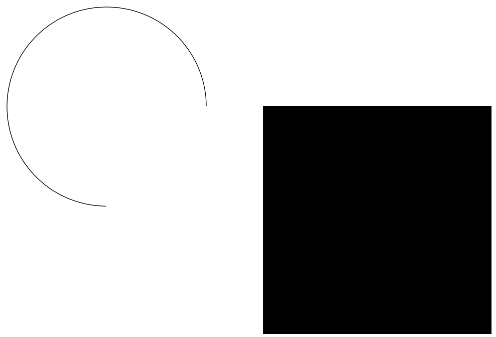
Image taken from Ware 2001

GL: Closure

- We see a closed contour as an object
- Tendency to close contours that have gaps
- Mind reacts to patterns that are familiar
- Illusory contours

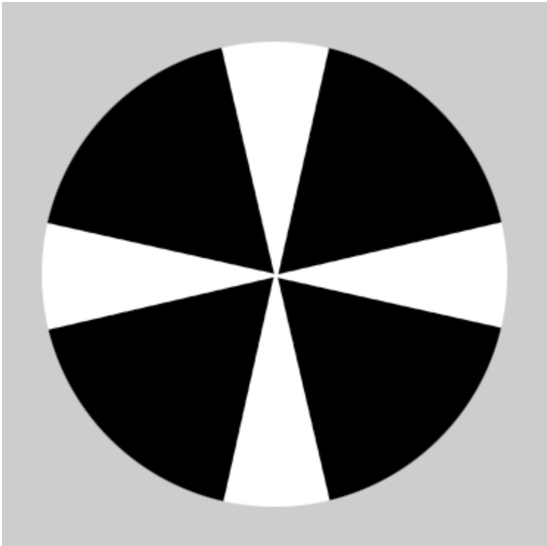


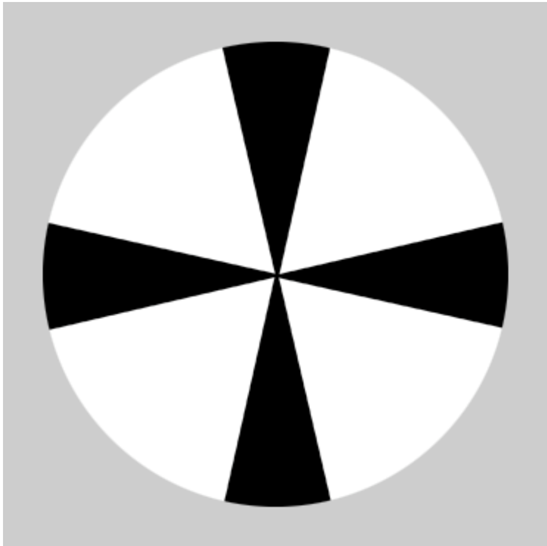




GL: Area

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





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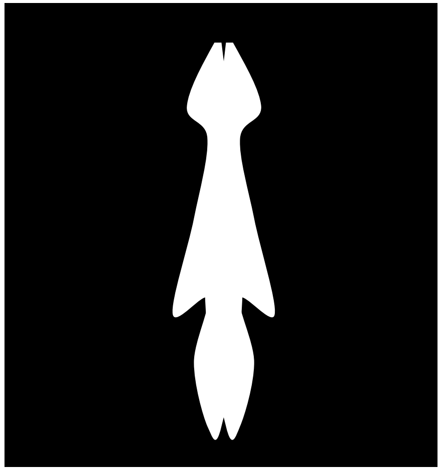
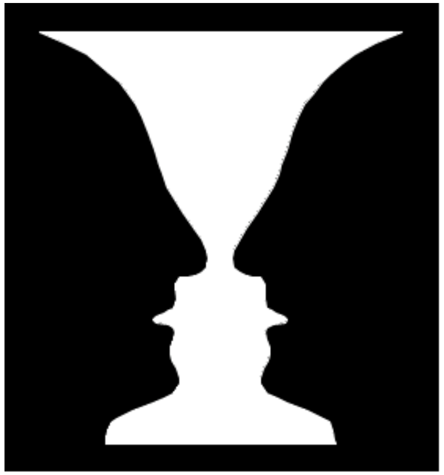
GL: Figure & Ground

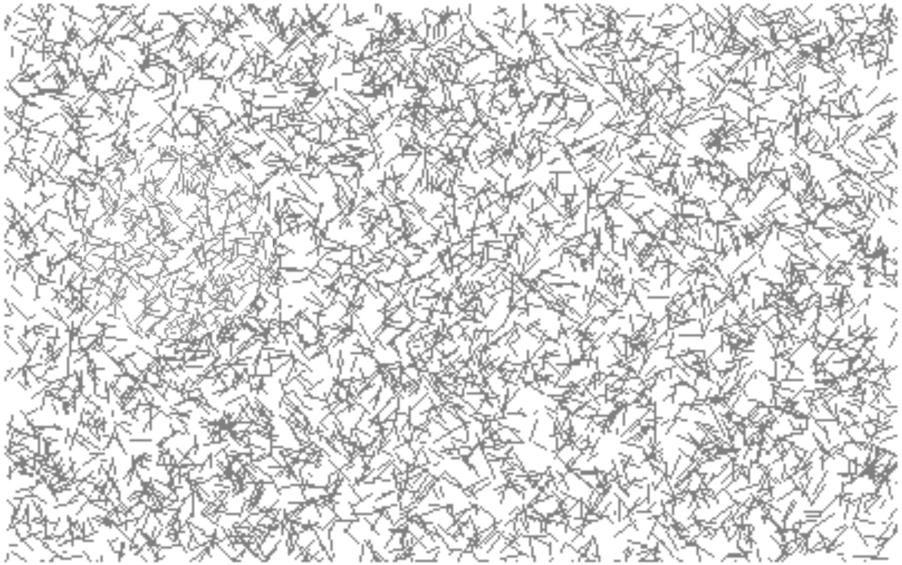


- Figure: something object-like that is perceived being in the foreground
- Ground: whatever lies behind the figure
- Fundamental perceptual act of identifying objects
- All Gestalt laws contribute, e.g. in upper image: closed contour, symmetry, area
- Equally balanced cues for figure and ground can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



GL: Common Fate

- Objects moving in the same direction are perceived as an entity
- Example taken from: http://tepserver.ucsd.edu/~jlevin/gp/time-example-common-fate/



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Change Blindness (CB)

- Example: old style aircraft altimeter
  - Thinnest hand indicates number of tens of thousands of feet
  - Next larger hand number of thousands of feet
  - Quick glance after interruption results in misinterpretation if the change in the display is not noticed
  - Difference of ten thousand feet
- Phenomenon: inability to detect changes in visual scenes
  - mid-eye movement
  - mid-blink
  - Flicker (short blanking of screen)
  - Gradual change

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Change Blindness (CB)

- Participants of a study were found unable to detect a change from one person to another in midconversation (Simson & Levin 1998)
- Sample principle: insensitivity to changes of objects in movie scenes interrupted my a cut (Levin & Simons 1997)
- Various examples: http://viscog.beckman.uiuc.edu/djs_lab/demos.html
- Problem related to the short-lived visual buffer and the very limited capacity of our visual working memory
- Need to emphasize changes
- In some applications changes may be distracting, e.g. ambient information visualization -> utilize CB

Levin & Simons 1997

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CB: Flicker Example 1

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

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CB: Flicker Example 2

CB: Gradual Change Example

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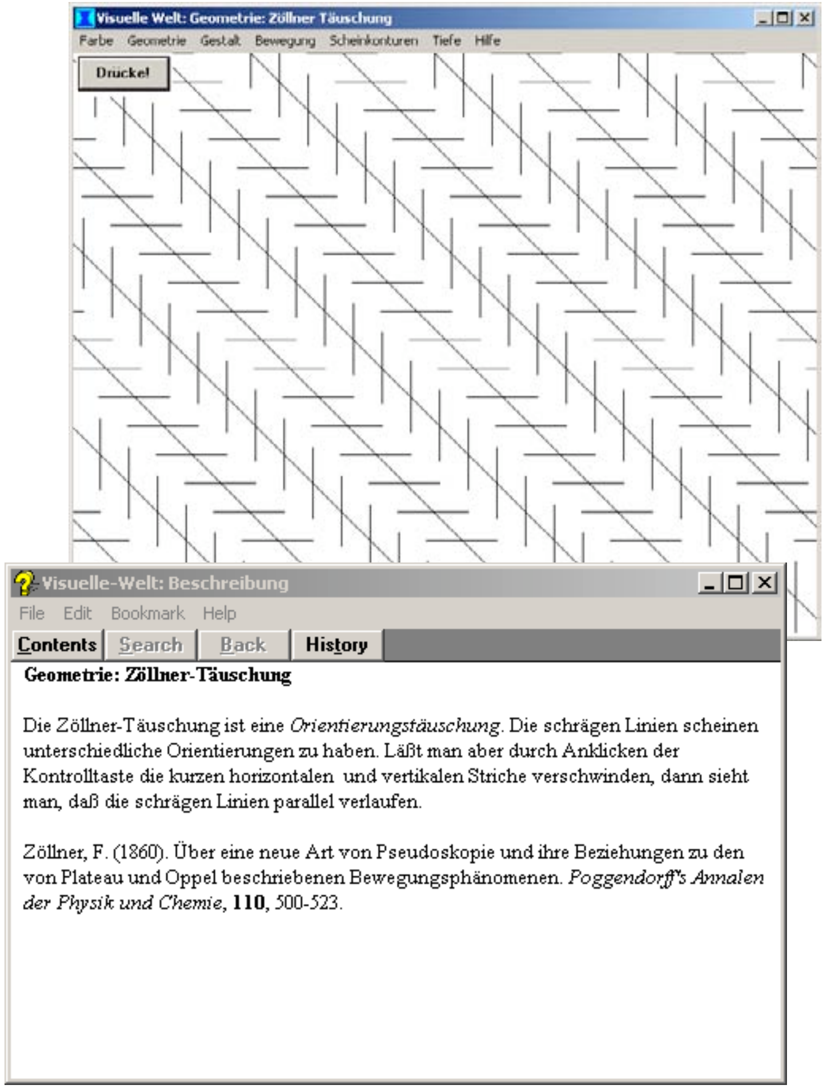
CB Resources

- Various theories about CB, see for instance http://cvcl.mit.edu/IAP05/Simons_2000a.pdf
- http://viscog.beckman.uiuc.edu/djs_lab/demos.html
- http://viscog.beckman.uiuc.edu/change/demolinks.shtml
- Visual Perception Phenomena
  - Demonstrator tool: Visuelle Welt, Prof. Dr. Ronald Hübner
  - http://www.uni-konstanz.de/psychologie/ag-kog/viwog.htm



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Encoding Data with Glyphs

- Glyph: graphical object designed to convey multiple data values
- Multidimensional discrete data, e.g. a collection of cars with several attributes each, e.g. horsepower, weight, acceleration etc.
- What visual properties can be mapped to the attributes?
- FilmFinder example
  - Color to film genre
  - X-position to year of release
  - Y-position to popularity
- Additional properties
  - Lightness
  - Shape
  - Orientation
  - Texture
  - Motion
  - Blinking

FilmFinder (www.cs.umd.edu/)

Encoding Data with Glyphs

- Limitations of low-level graphical attributes for glyph design
- Easily resolvable steps of a visual property
  - 12 colors (for preattentive processing only 8 colors)
  - About 4 orientation steps
  - At most 4 size steps
  - Binary blink coding (on / off)
  - Texture unknown
  - Shape unkown
- Mixing visual properties
  - Properties are not independent from each other, e.g. blink coding interferes with motion coding
  - Conjunctions are usually non-preattentive
  - Some dimensions are **integral**
  - Best to restrict the mapping to color, shape, spatial position (and motion)
- Denotes the need for interaction to enable dynamic glyph encoding

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Integral & Separable Dimensions

- Problem when designing glyphs: perceptual dependency of visual properties
- Example:
  - Does color interfere with shape when representing two variables?
- Concept of integral vs. separable dimensions (Garner 1974)
  - Integral dimensions: two or more properties of a visual object are perceived holistically (dependency), e.g. width and height of a rectangle
  - Separable dimensions: properties are perceived as independent, allows for separate judgment of the properties, e.g. size and color
- How to classify visual properties?
- Evaluation via restricted classification tasks

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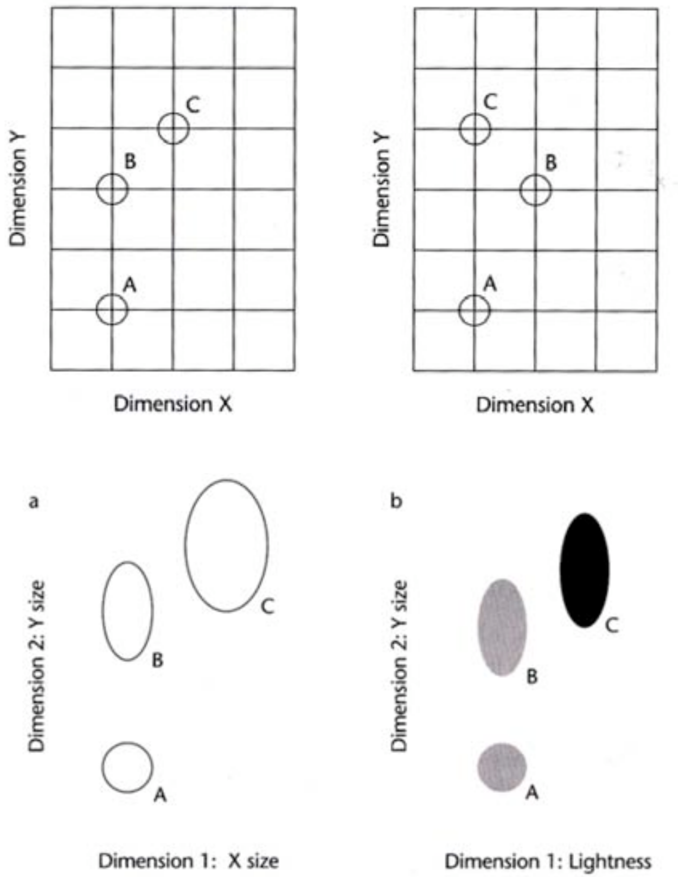
Restricted Classification Task

- Sets of thee glyphs
- Two of the glyphs are identical on one variable (A and B)
- Third glyph C is closer to B in feature space, buth is different to the other glyphs in both dimensions
- Evaluation task: group by similarity
- Integral dimensions: B and C are grouped together (closer in feature space)
- Separable dimensions: A and B are grouped together (identical values for one dimension)



Ware 2004

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Integral & Separable Dimensions

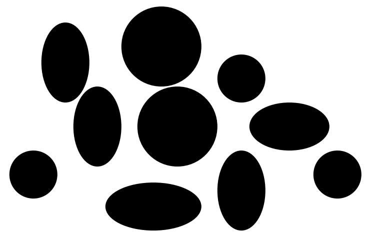
- Visual properties are never fully separable
- Concept nevertheless provides a useful and simple design guideline
- List pairs of visual properties ordered in an integral-separable continuum

Integral dimension pairs

Red-green	Yellow-blue
Red-green	Black-white
Shape height	Shape width
Shape	Size
Color	Size
Direction of motion	Shape
Color	Shape
Color	Direction of motion
XY position	Size, shape, or color

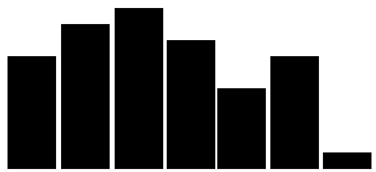
Separable dimension pairs

Examples:



X-size | Y-size

Color | Shape



X-position | Height
=
bar chart

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Outline

- Perception Definition & Context
- Preattentive processing
- Gestalt Laws
- Change Blindness
- Data encoding – glyphs
- Data encoding – color
- Characteristics of Visual Properties

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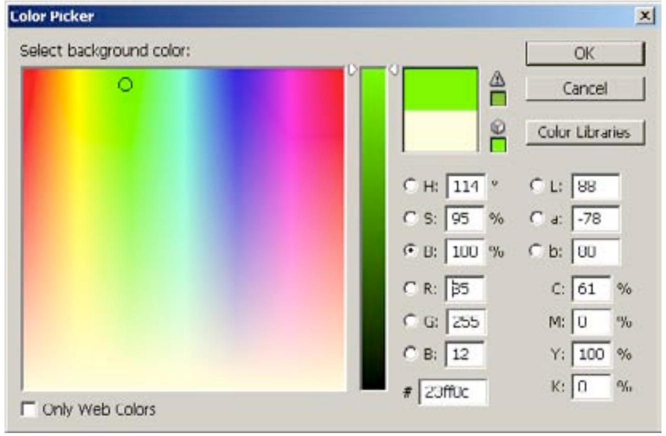
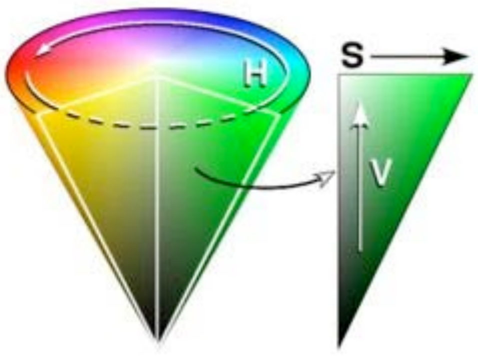
Color Vision & Model

- Human color vision
  - Sensory response to electromagnetic radiation in the spectrum 0.4 – 0.7 micrometers
  - Based on three dimensions (three different types of color receptors in human retina)
- Powerful encoding potential: compared to gray scales the number of just noticeable differences is much higher
- About 10% of the male and 1% of the female population are color-blind
- Color Model HSV (aka HSB)
  - Hue - blue, green, etc. (X axis)
  - Saturation – intensity of color (Y axis)
  - Value – light/dark (slider)



HSV 2D color picker



HSV cone representation

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Color Scales

- Definition: pictorial representation of a set of distinct categorical or numerical values, where each value is assigned its own color (Levkovitz 1996)
- Desired properties of perception
  - Preserve the order of the data values, if any
  - Uniform distance between adjacent values (i.e. equally spaced numerical steps are perceived as equally spaced perceptual steps)
  - No artificial boundaries that do not exist in the data (i.e. continuously present continuous values)

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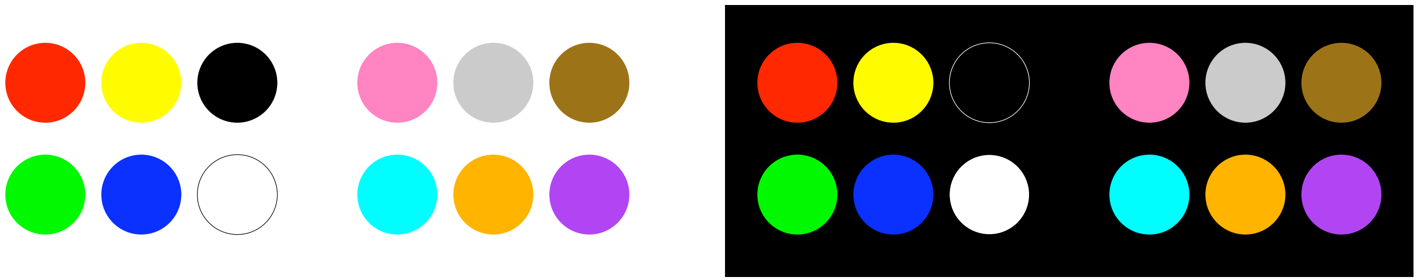
Color Rules I

- Always ensure a reasonable luminance contrast between foreground and background color – chromatic variation may not enough!
- Always ensure a reasonable luminance contrast between foreground and background color – chromatic variation may not enough!
- Black and white borders around colored symbols can reduce contrast effects
- Canonical colors (close to an ideal) are easier to remember
- Only a small set of basic colors should be used for nominal (distinct) labeling
  - At most 12 colors: red, green, yellow, blue, black, white, pink, cyan, gray, orange, brown, purple
  - The first four colors are "hard-wired" into the human brain – should be used with priority



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Grayscale

- Usually not considered a color scale, but very common
- Provides simple and natural sense of order
- Disadvantages
  - Limited number of just-noticeable-differences (JNDs) of about 60 to 90
  - Contrast effects can significantly reduce accuracy
  - Luminance channel is fundamental to much of perception – grayscale encoding may be considered *"a waste of perceptual resources"* (Ware, 2000)
- Rather not use

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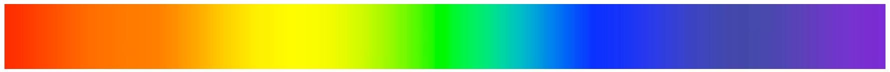
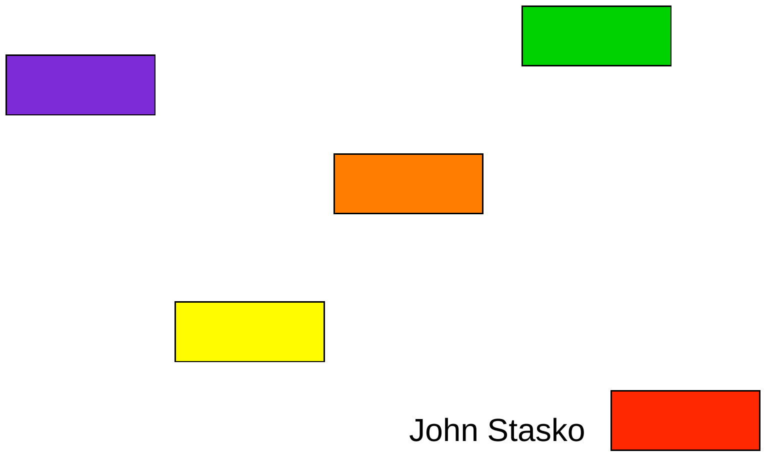
Rainbow for Ordering Data?

- Most common: rainbow scale for ordinal and quantitative (spectral colors)
  - Continuous spectrum 
  - Common arbitrary division in 8 or less named colors (red, orange, yellow, green, cyan, blue, indigo, violet)
- Problems with rainbow scale
  - Can you order the color blocks from low to high?
  - Yellow (in the middle of the scale) may draw too much attention, when users are seeking for extreme values
  - Perception of non-existing boundaries



John Stasko

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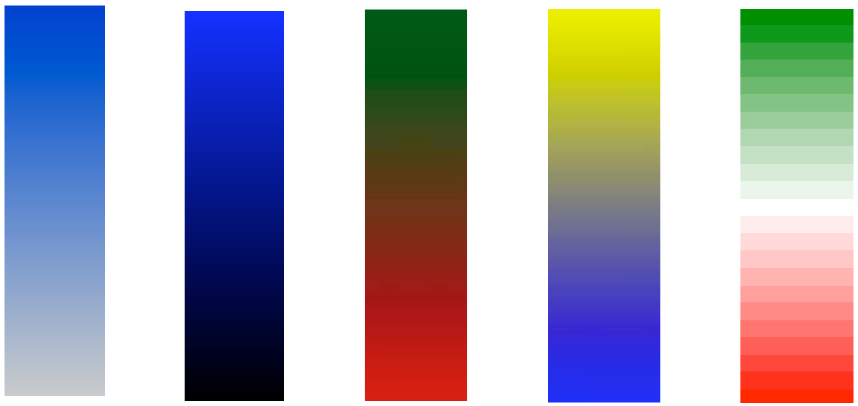
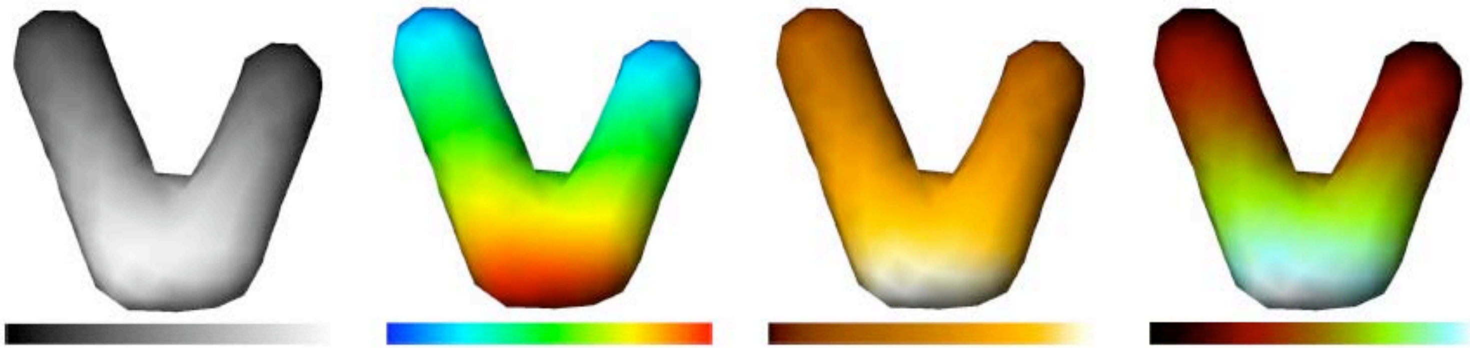
Recommended Color Scales

- Ordinal data
  - Low saturation to high saturation (single hue) - also very limited JNDs
  - Dark to light (single hue)
  - Red to green, yellow to blue, red to blue
- Ratio (hardly feasible) / diverging data
  - Neutral value (e.g. white) to represent zero
  - Increases in saturation toward distinct colors for positive and negative values (double-ended multiple hue)



Redundant Color Scales

- Use multiple color properties to redundantly represent data
- Visual reinforcement of steps
- Overcome visual deficiencies
- Redundant model components: data values are mapped to both hue and brightness
- Heated-object scale
  - Going from black to white passing through orange and yellow
  - Monotonic increase in brightness provides more natural ordering than rainbow scale
- Linearized optimal color scale
  - Scale maximizing the number of JNDs while preserving a (more or less) natural order



Silva et al. 2007

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Color Scale

- US presidential elections - Bush & RNC's campaign funding

http://fundrace.huffingtonpost.com/moneymap.php?cand=Bush&zoom=County

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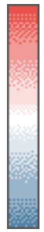
Color Scale

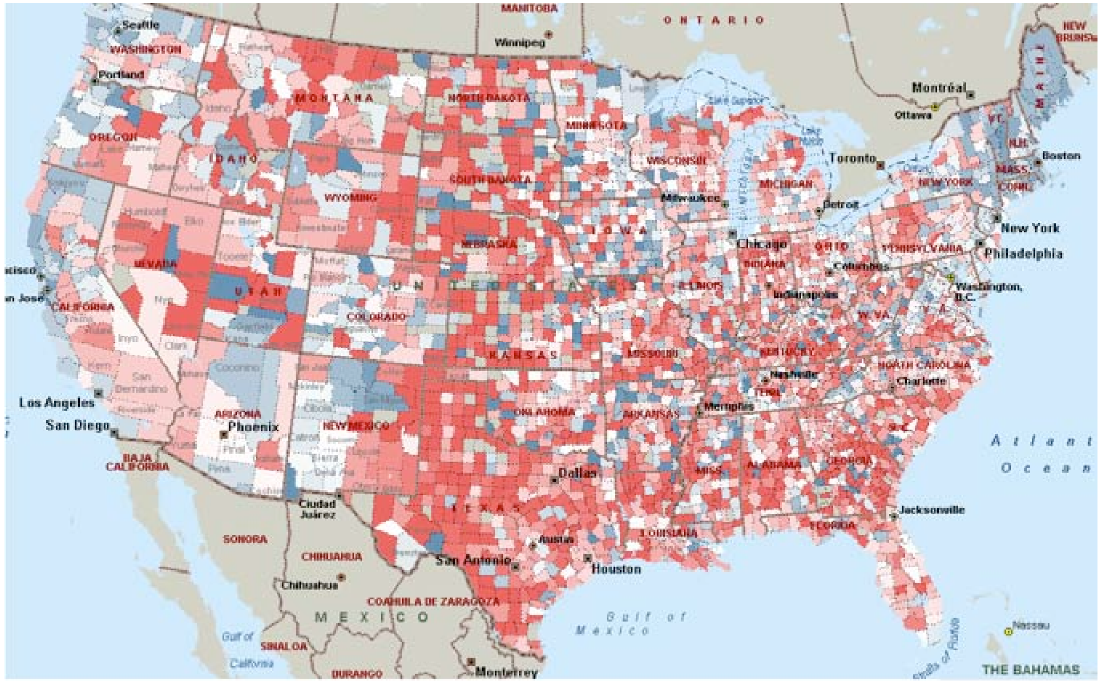
- Vote distribution of 2004 US presidential election - the darker the color, the more of a landslide it was for the winning party



Republican

Neutral

Democrat



http://fundrace.huffingtonpost.com/moneymap.php

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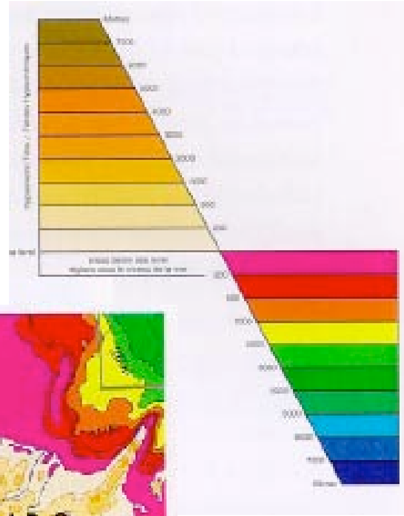
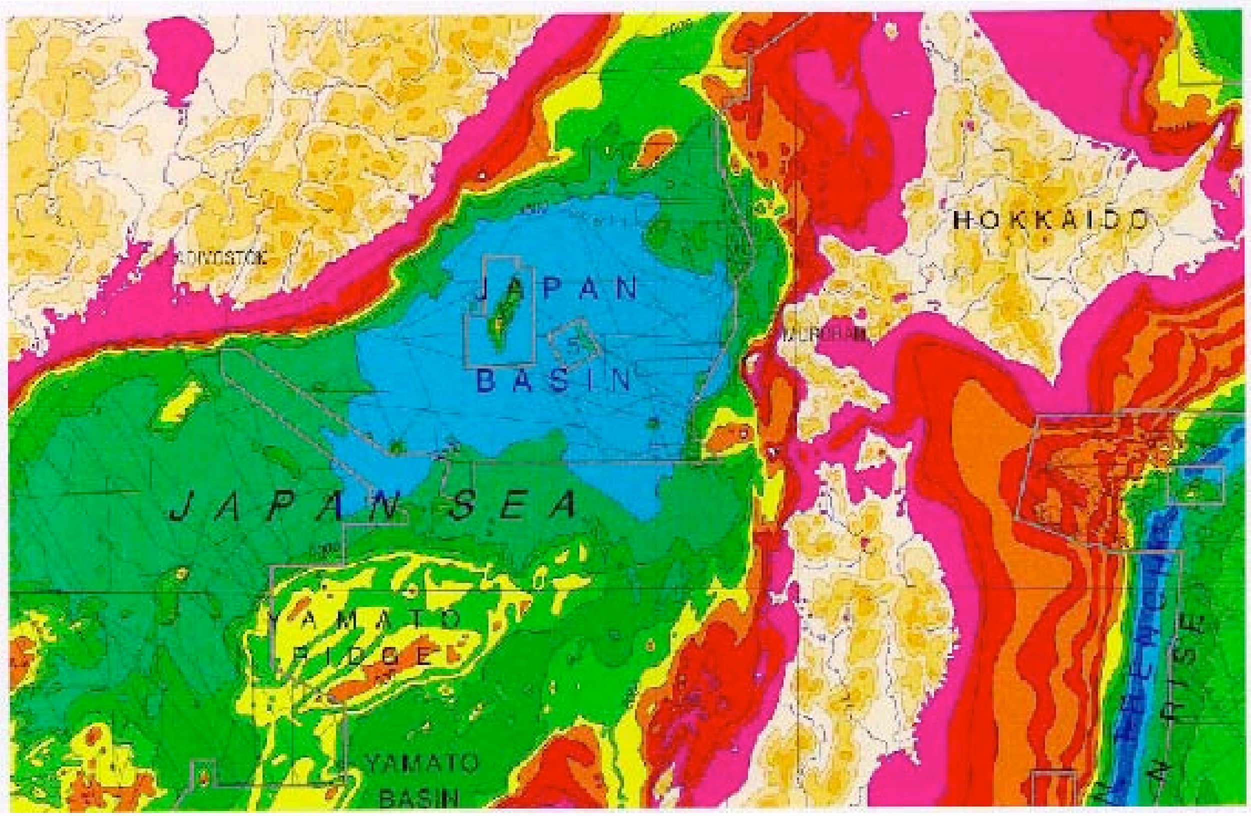
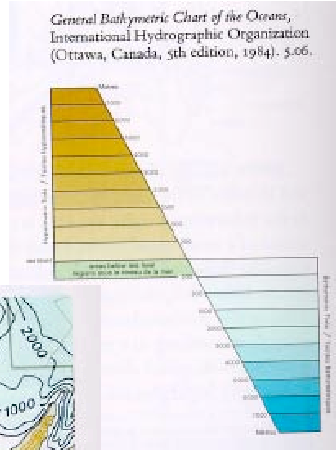
Color Scale

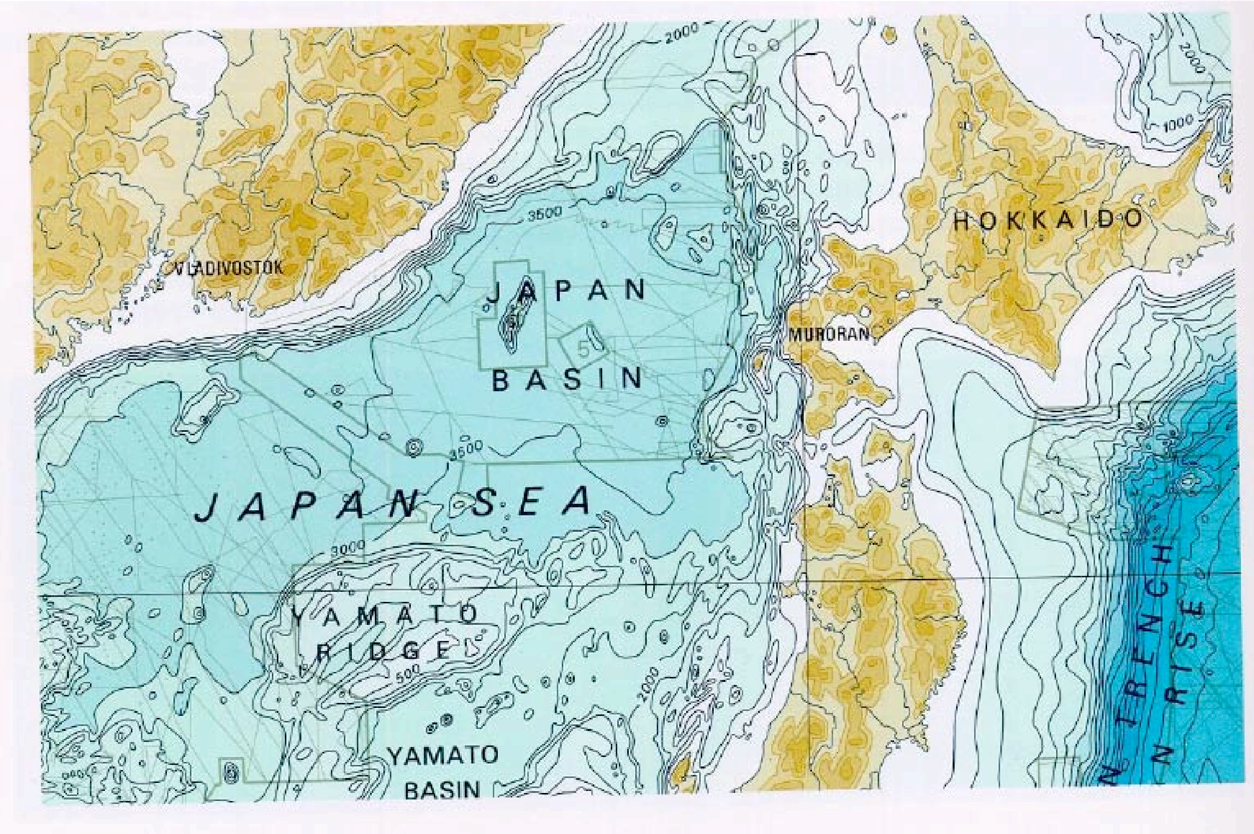




Sheelagh Carpendale

Color Scale





Sheelagh Carpendale

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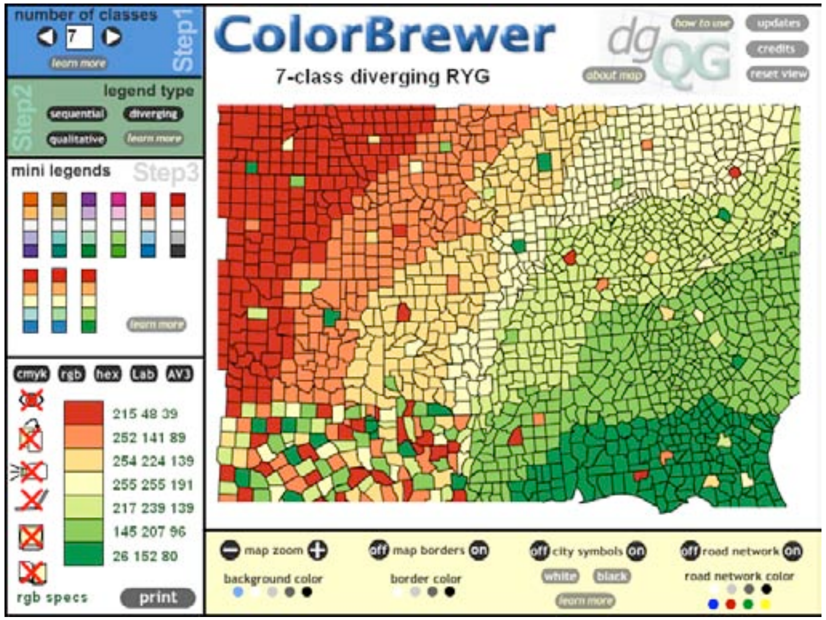
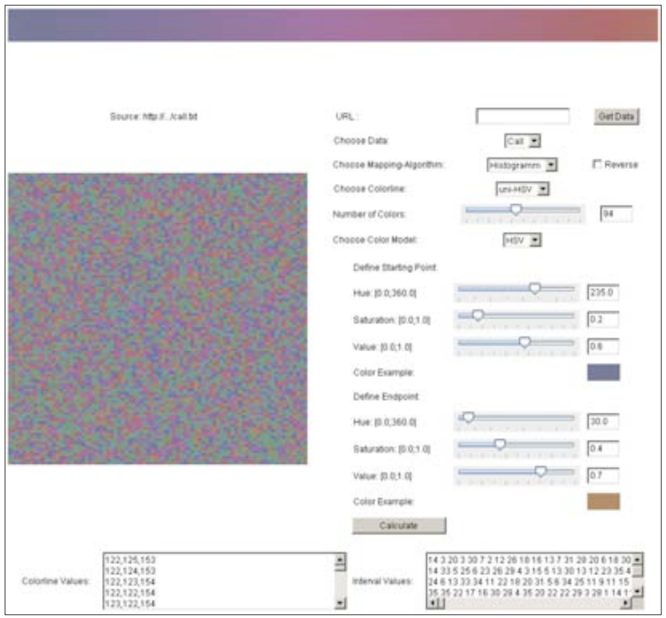
Color Tools

- ColorBrewer: generates color palettes based on data type and number of classes
- http://www.personal.psu.edu/cab38/ColorBrewer/ColorBrewer.html
- More complex tool: ColorMap applet: http://infovis.uni-konstanz.de/tools/colormap/index.html





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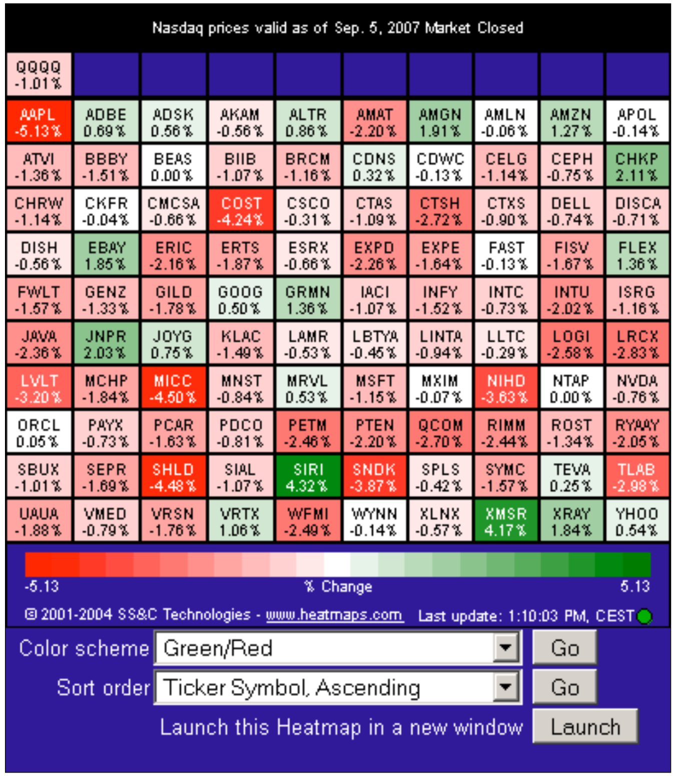
Application example

- Nasdaq - diverging data encoded by color: http://screening.nasdaq.com/heatmaps/heatmap_100.asp
- Price of companies in the NASDAQ-100 Index at a glance
- Green means stock price is up
- Red means stock price is down
- The more saturated a color is, the bigger the move
- Red-green sequence has been found most effective (Spence & Efendor, 2001)



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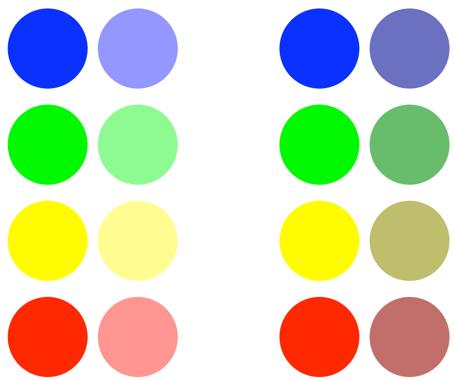
Color Rules II

- For larger areas on a white background use low-saturation light colors
- Small color-coded objects should be given high saturation
- Use red and green in the center of the field of view (edges of retina not sensitive for these)
- Use black, white, yellow in periphery
- Use color for grouping and search
- Color Blindness Simulator: http://www.etre.com/tools/colourblindsimulator/
- Generation of color families
  - Use canonical colors
  - Family members should differ by saturation
  - Better: saturation and lightness



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Bivariate Color Coding

- Recap: color is three-dimensional
- Two data dimensions may be mapped to different color dimensions (e.g. hue and saturation, hue and lightness)
- Problem: bivariate color coding has been found notoriously difficult to read (Wainer & Francolini, 1980)
- The same applies to multidimensional color coding
  - E.g. amount of red, amount of green, amount of blue for coding colored dots in scatterplot (Ware & Beatty 1988)
  - Clusters could be easily identified by the participants of a user test
  - Precise decoding of the color components difficult

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Example: Bivariate Color Coding

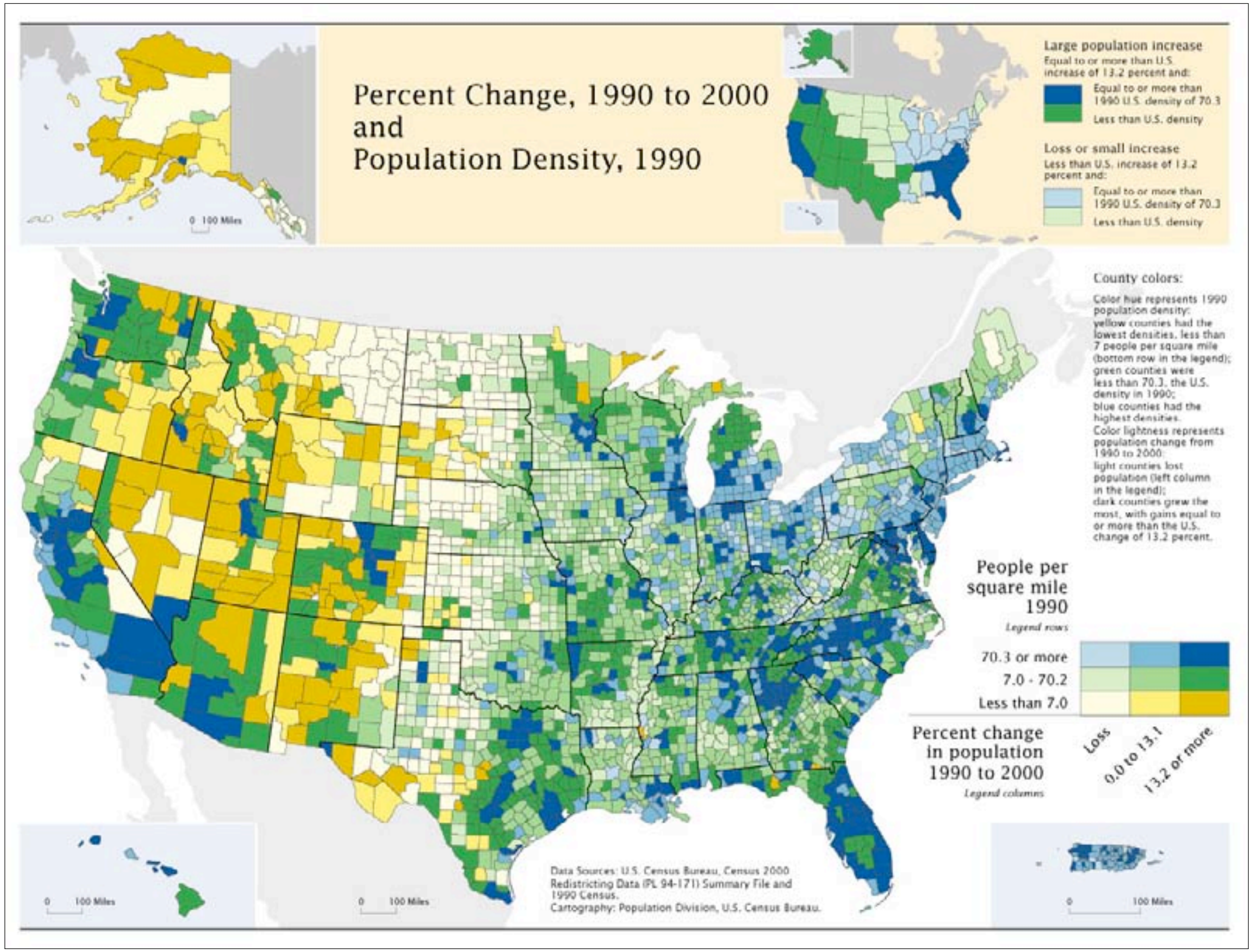

Image by Cynthia Brewer, http://www.psu.edu/ur/2003/MapColorphotos.html

Outline

- Perception Definition & Context
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- Data encoding – glyphs
- Data encoding – color
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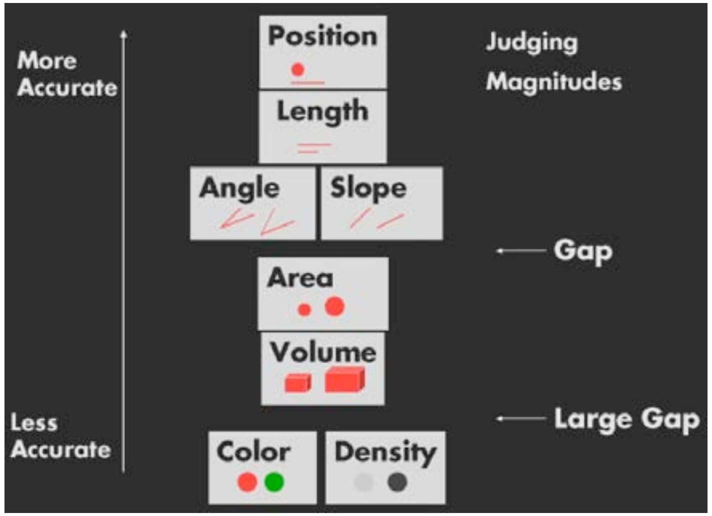
Characteristics of Visual Properties

- Some properties possess intrinsic meaning
  - Density with Grayscale: the darker the more
  - Size / Length / Area: the larger the more
  - Position: depending on culture, in Europe the leftmost / topmost are first
  - Color: depending on culture, e.g. white associated with death in Japan
- Accuracy of representations for quantitative measures (empirically verified by Cleveland & McGill, 1985)



(Mackinlay, 1988)

(Few, 2004)

Attribute	Quantitative	Qualitative
Line length	x	
2D position	x	
Orientation		x
Line width		x
Size		x
Shape		x
Curvature		x
Enclosure		x
Hue		x
Intensity		x

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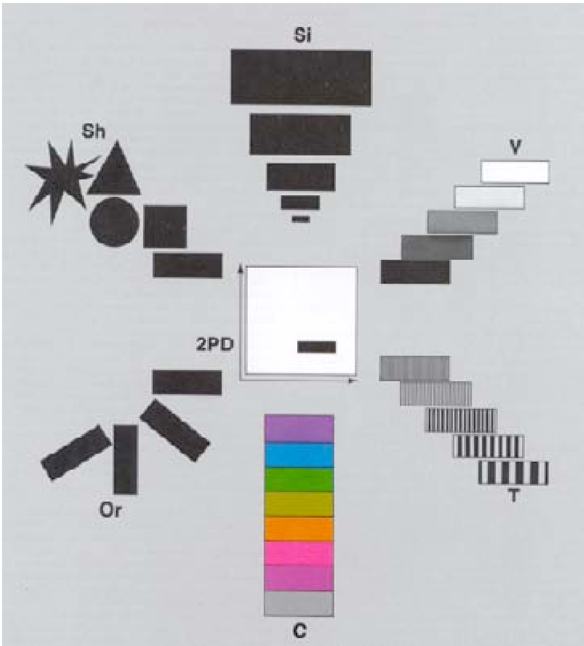
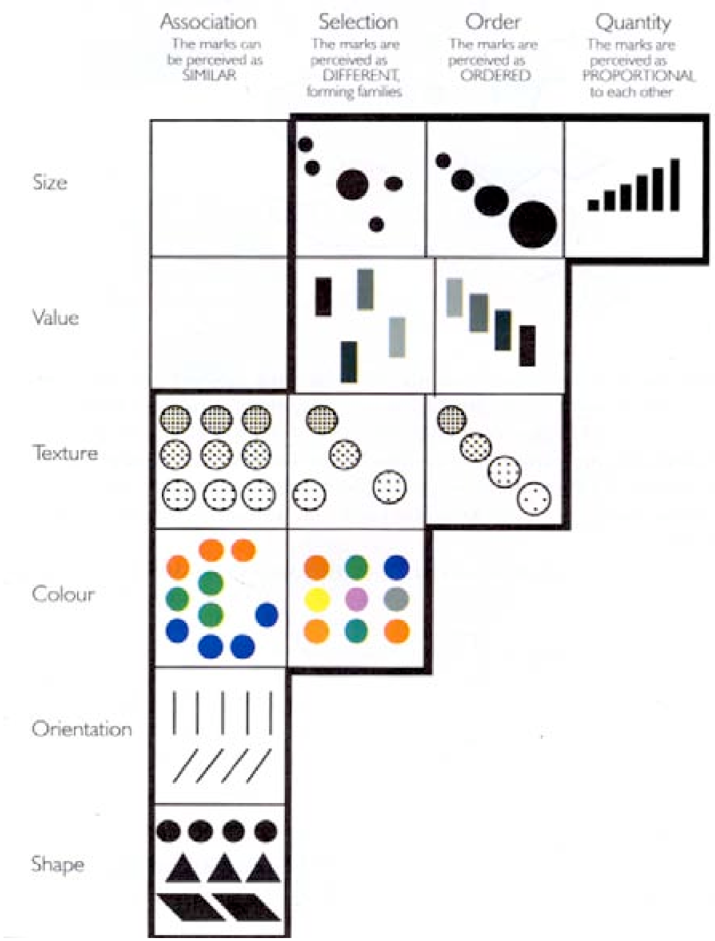
Characteristics of Visual Properties

- Jaques Bertin: Semiology of Graphics, 1983 (english translation)
- Guidance on retinal variables (encoding mechanisms) and measurement properties

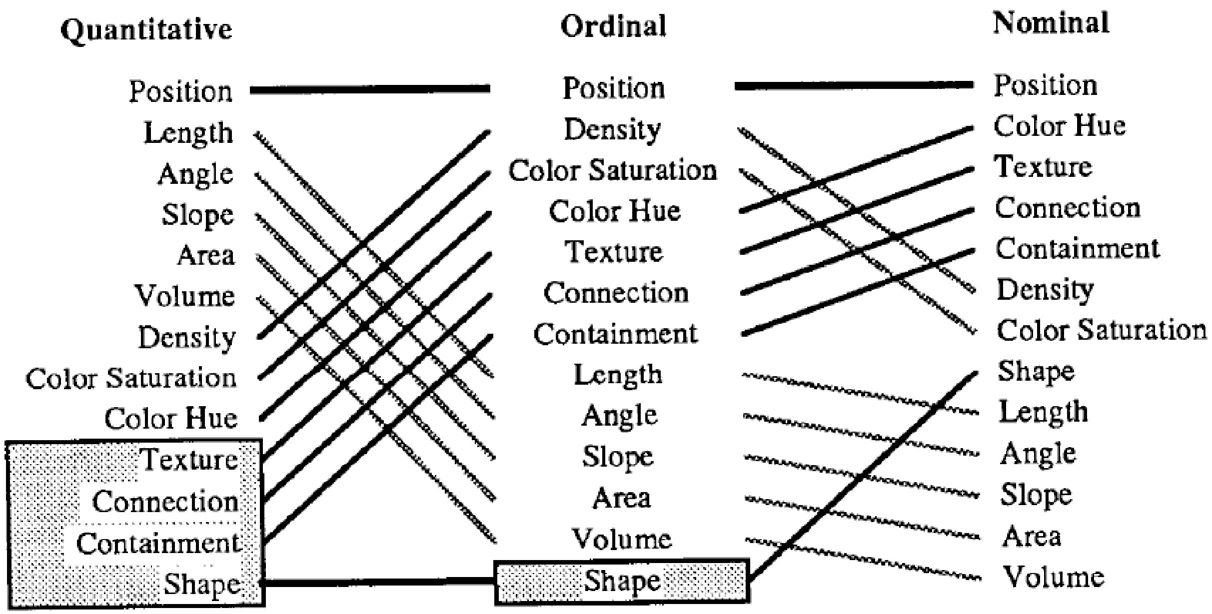




Reproduction of Bertin's diagram by Spence 2004

Characteristics of Visual Properties

- Ranking of perceptual tasks by Mackinlay 1986 (estimation, not empirically verified)
- Tasks in gray boxes are not relevant to these types of data



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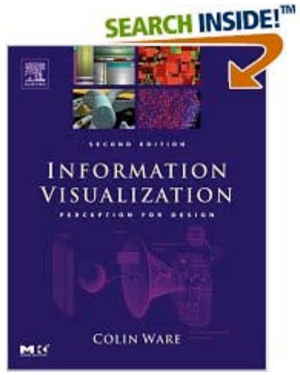
Sources & Literature



- Obligatory paper to read and summarize:

  C. Healey: "Perception in Visualization" - http://www.csc.ncsu.edu/faculty/healey/PP/index.html

- C. Ware: "Information Visualization. Perception for Design", 2. Auflage, 2004.
- J. Mackinlay: "Automating the design of graphical presentations of relational information", ACM Transactions on Graphics, Volume 5, Issue 2, p. 110-141, 1986.
- Perception: An introduction to the Gestalt-theorie (Kurt Koffka, 1922): http://psychclassics.yorku.ca/Koffka/Perception/perception.htm
- Lecture material, John Stasko