COMP5048
Visual Analytics

Week 8:
Perception, Color

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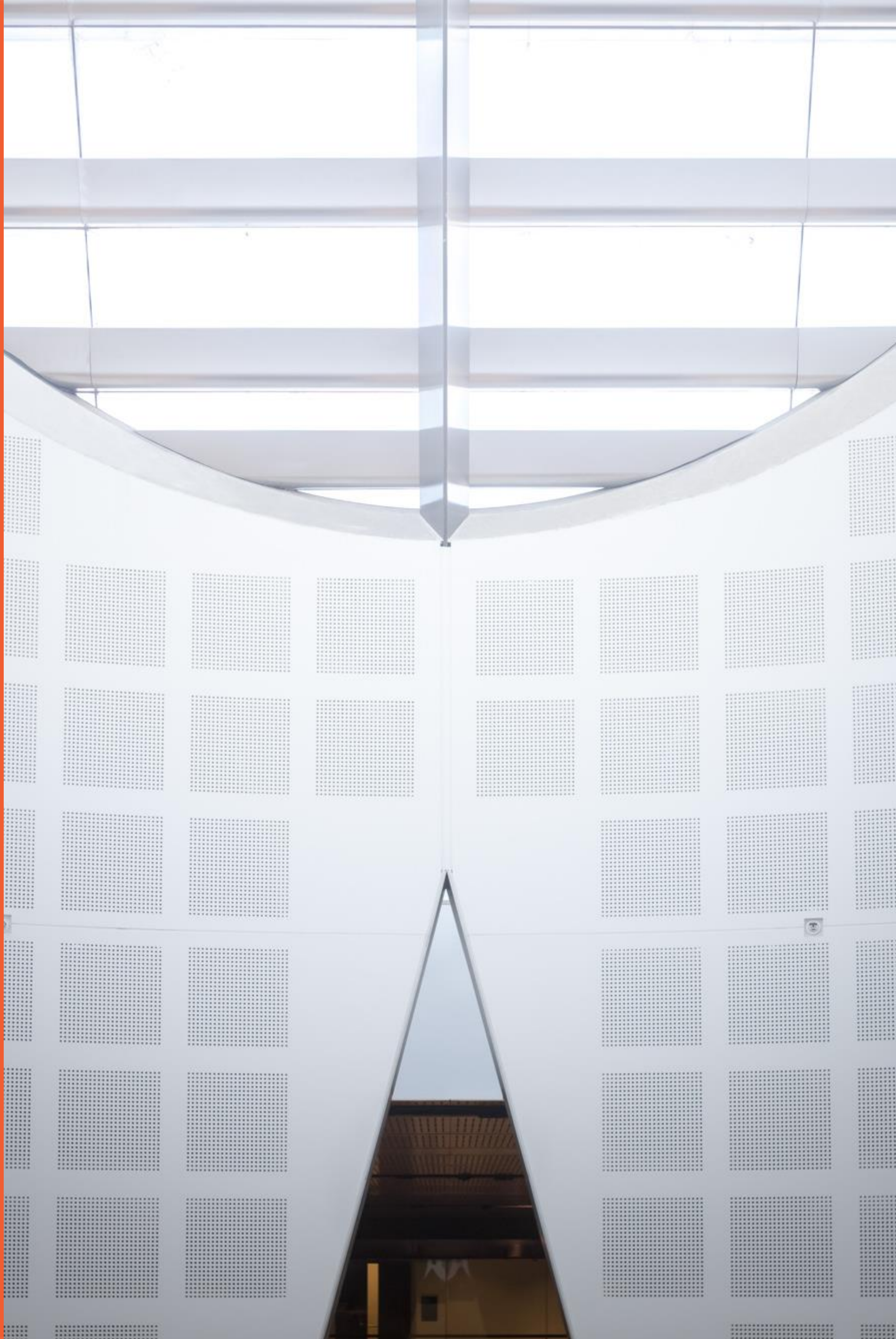
THE UNIVERSITY OF SYDNEY



Copyright warning

Outline

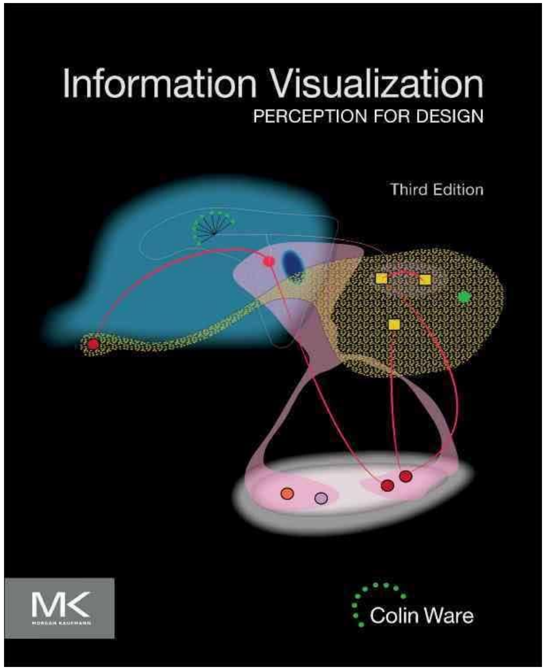
1. Human Perception
2. Gestalt principles
3. Color
4. Rules of Thumb

(1) How Human Understand Visualization

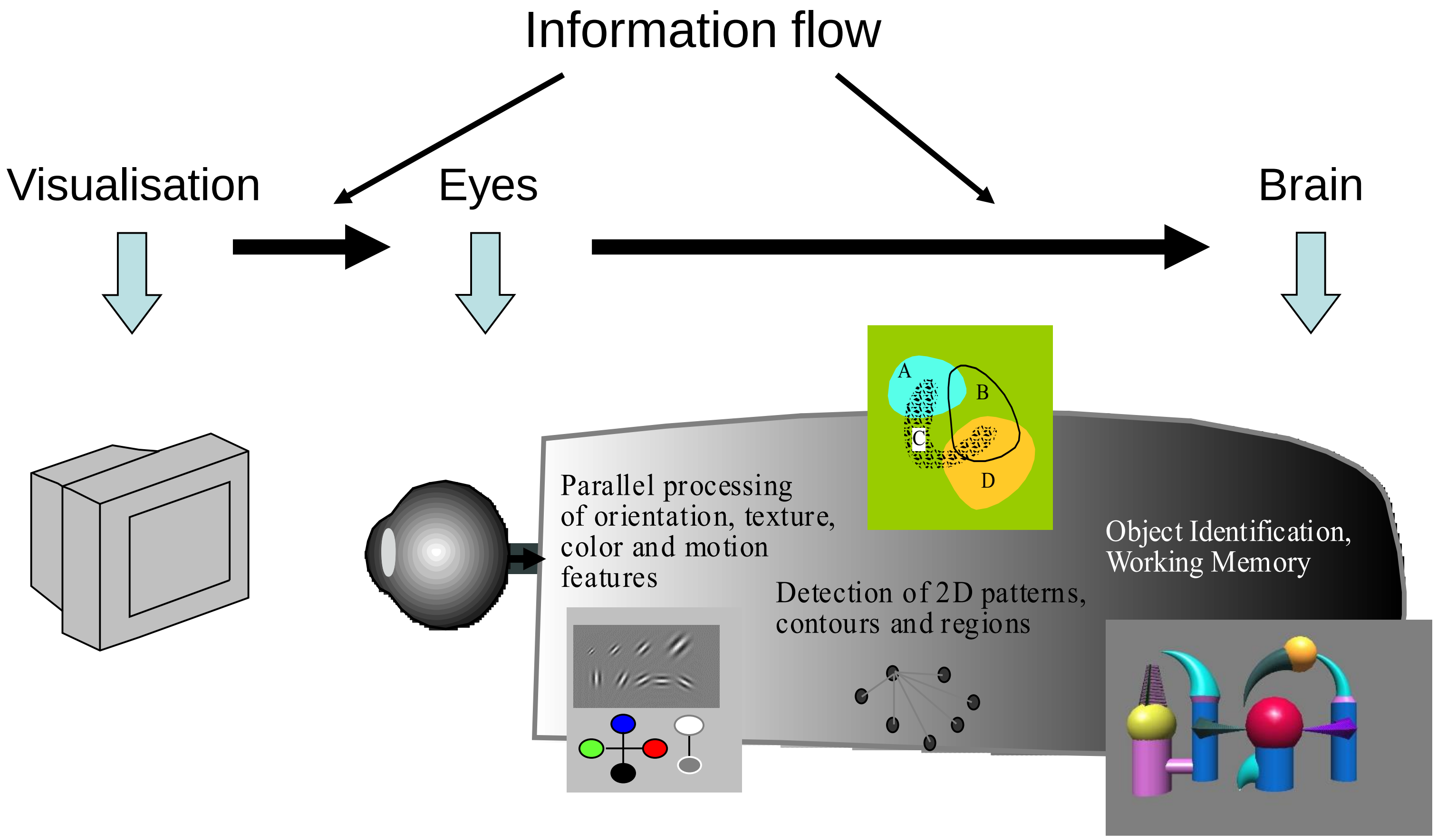
“Information Visualization – Perception for Design”

Colin Ware

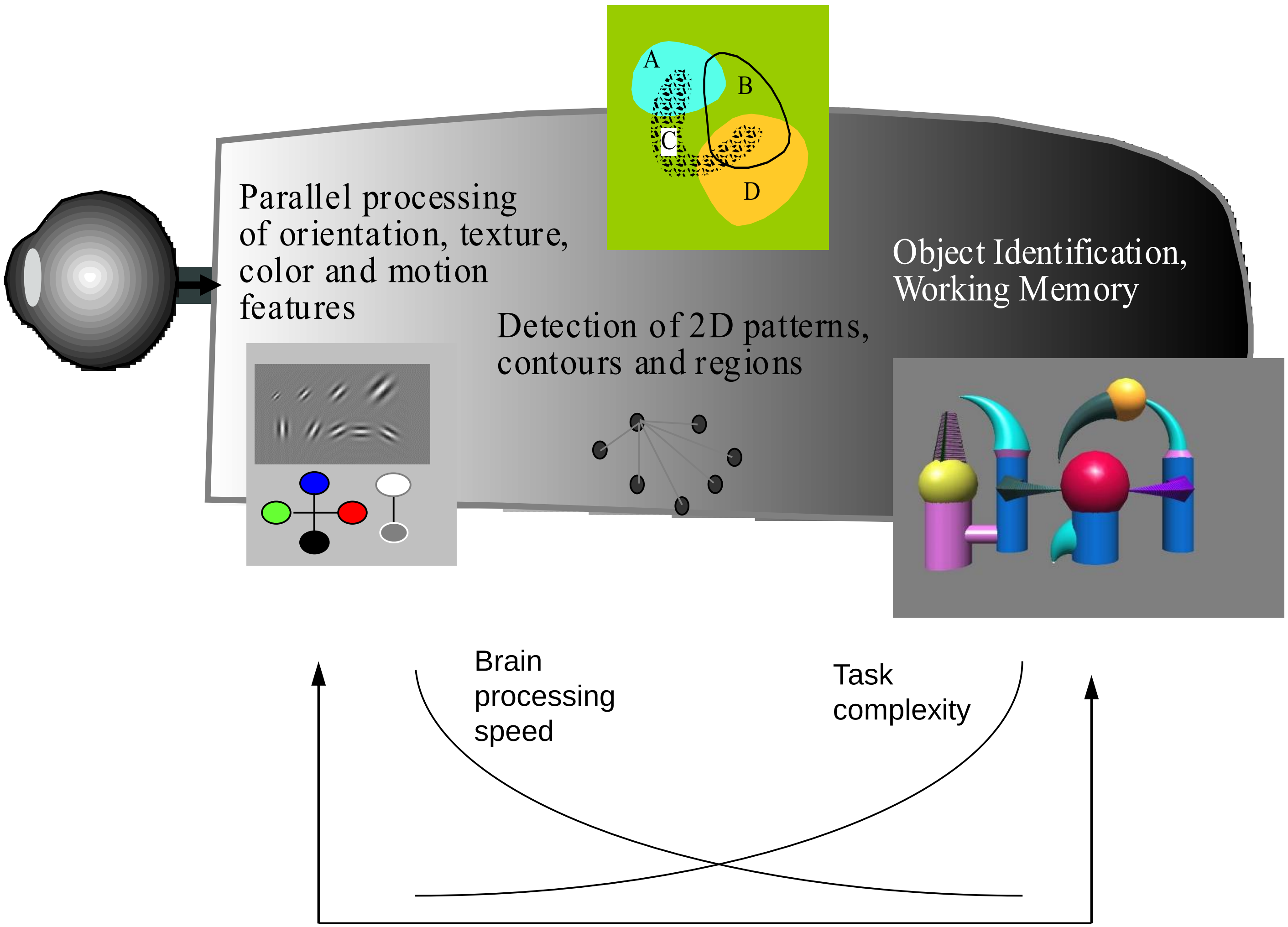
Chapter 1, Chapter 5



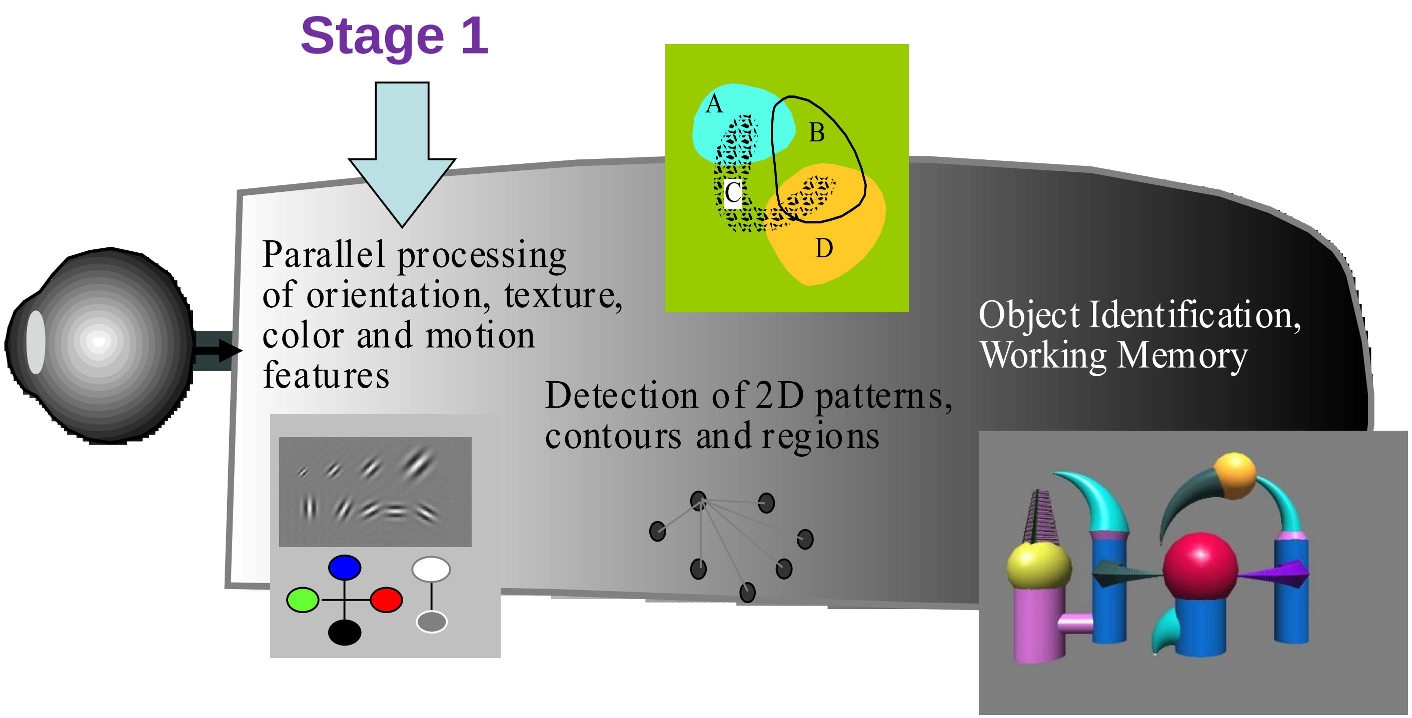
1. Visual Perception System



Model for Visual Information Processing

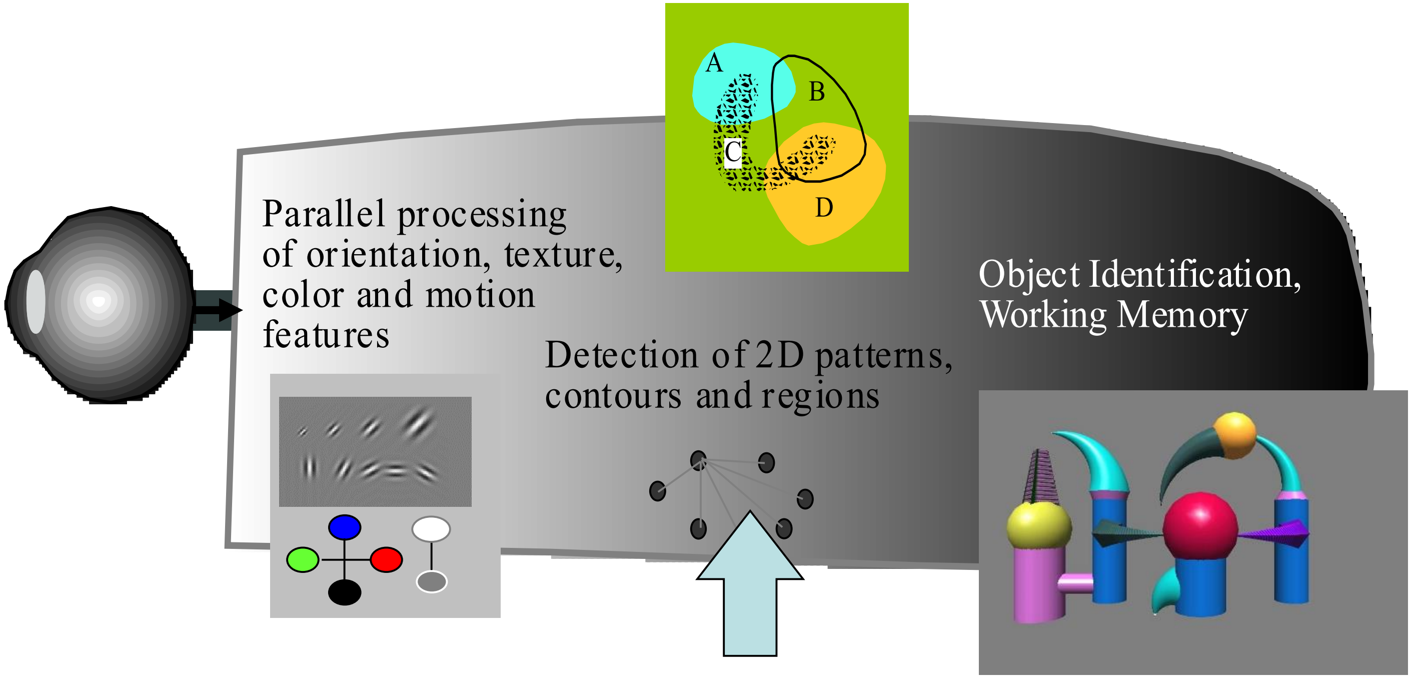


Visual Perception System: Stage 1



- Rapid parallel processing: billions of neurons;
- Extraction of orientation, texture, color, and motion features.

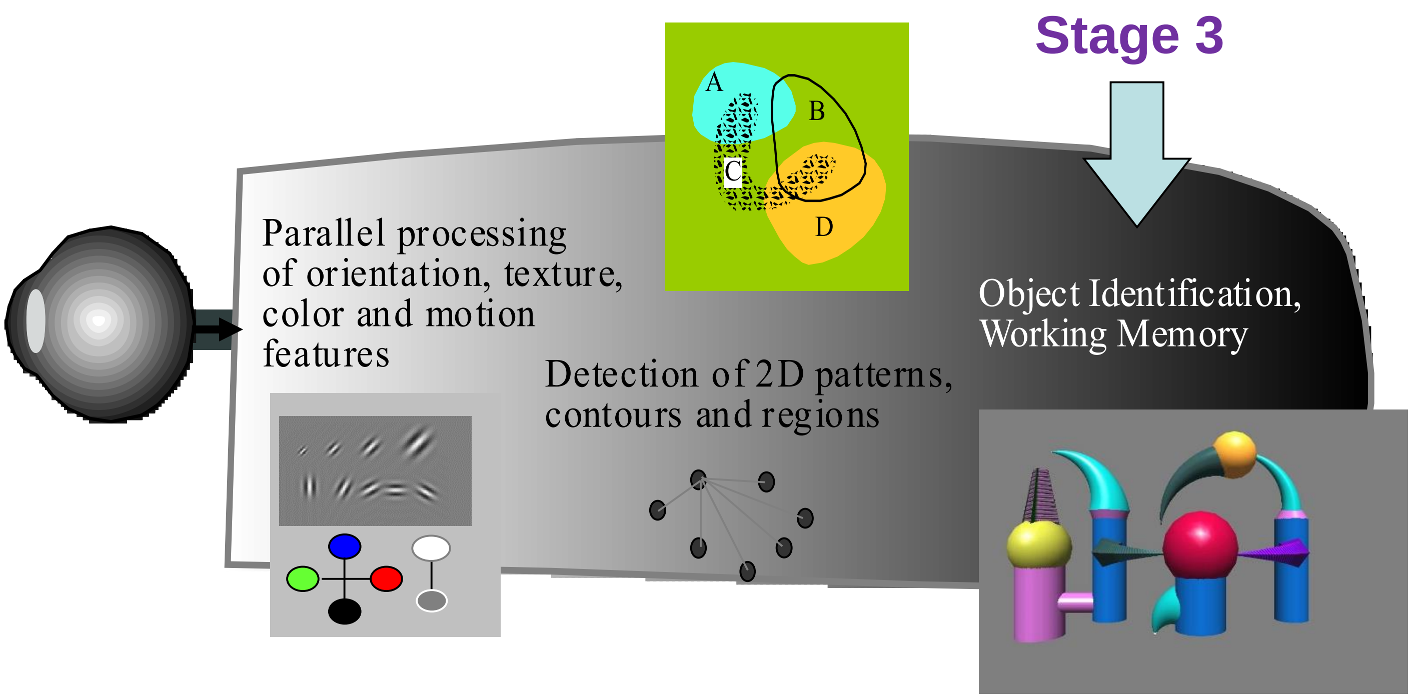
Visual Perception System; Stage 2



Stage 2

- Slower processing than stage 1;
- Detection of 2D patterns, contours and regions.

Visual Perception System: Stage 3



- Slow serial processing;
- Involve both working and long-term memory;
- Object identification and eye-hand coordination.

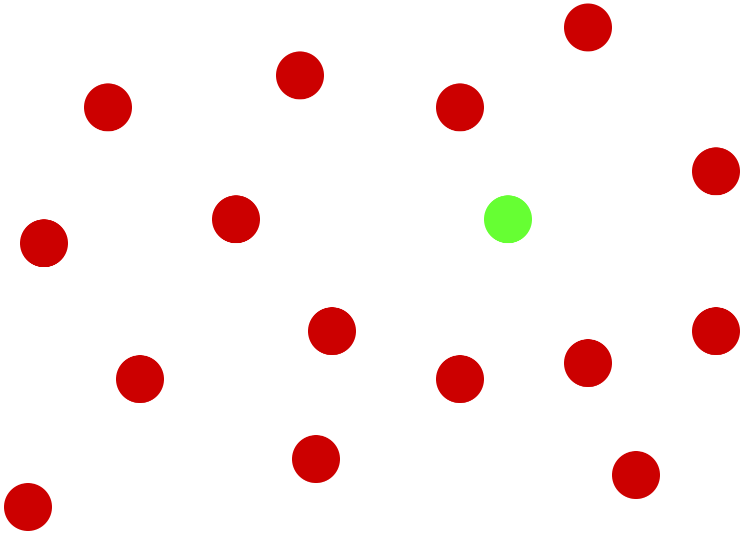
2. Visual Attention and Pre-Attentive Patterns

- In the stage 1 of perception system, the whole visual field is processed in parallel and very fast;

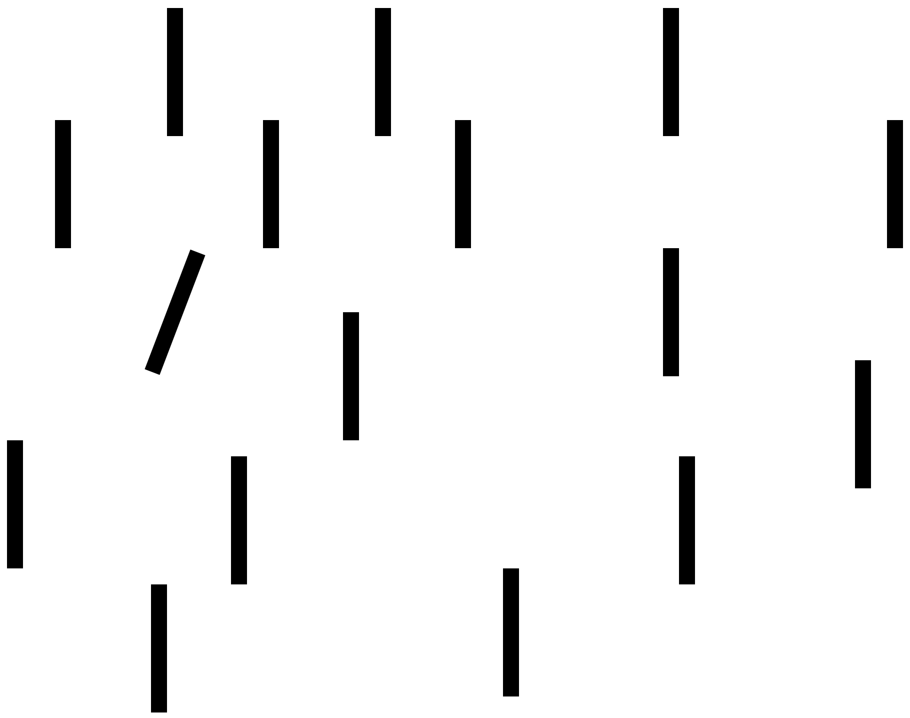
- The information that can be captured in this stage are easily distinguished.

- Pre-attentive patterns (pop-out effects).
- Should be considered when designing visualisation.

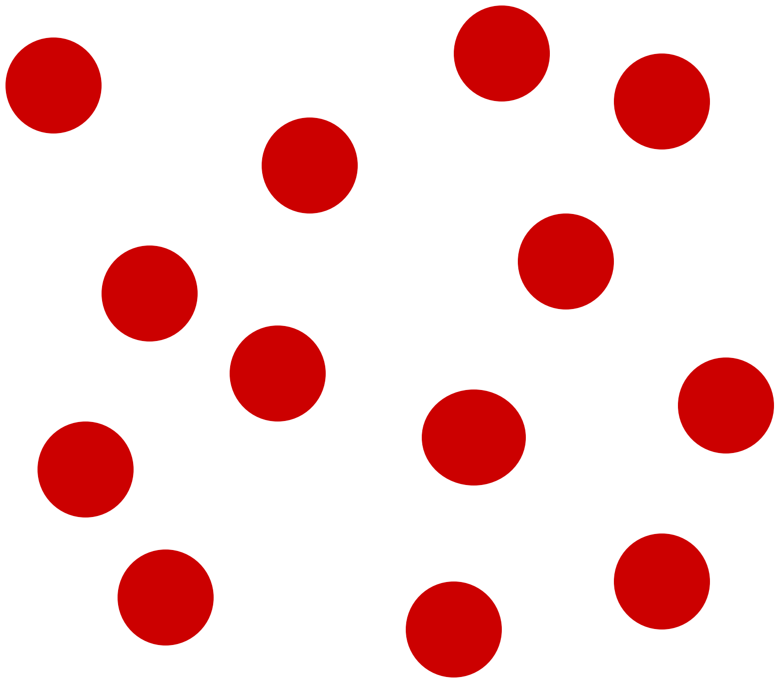
Color



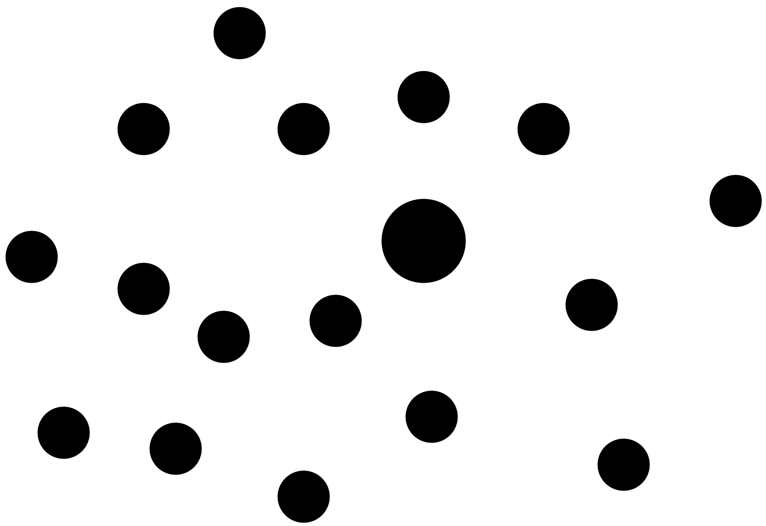
Orientation



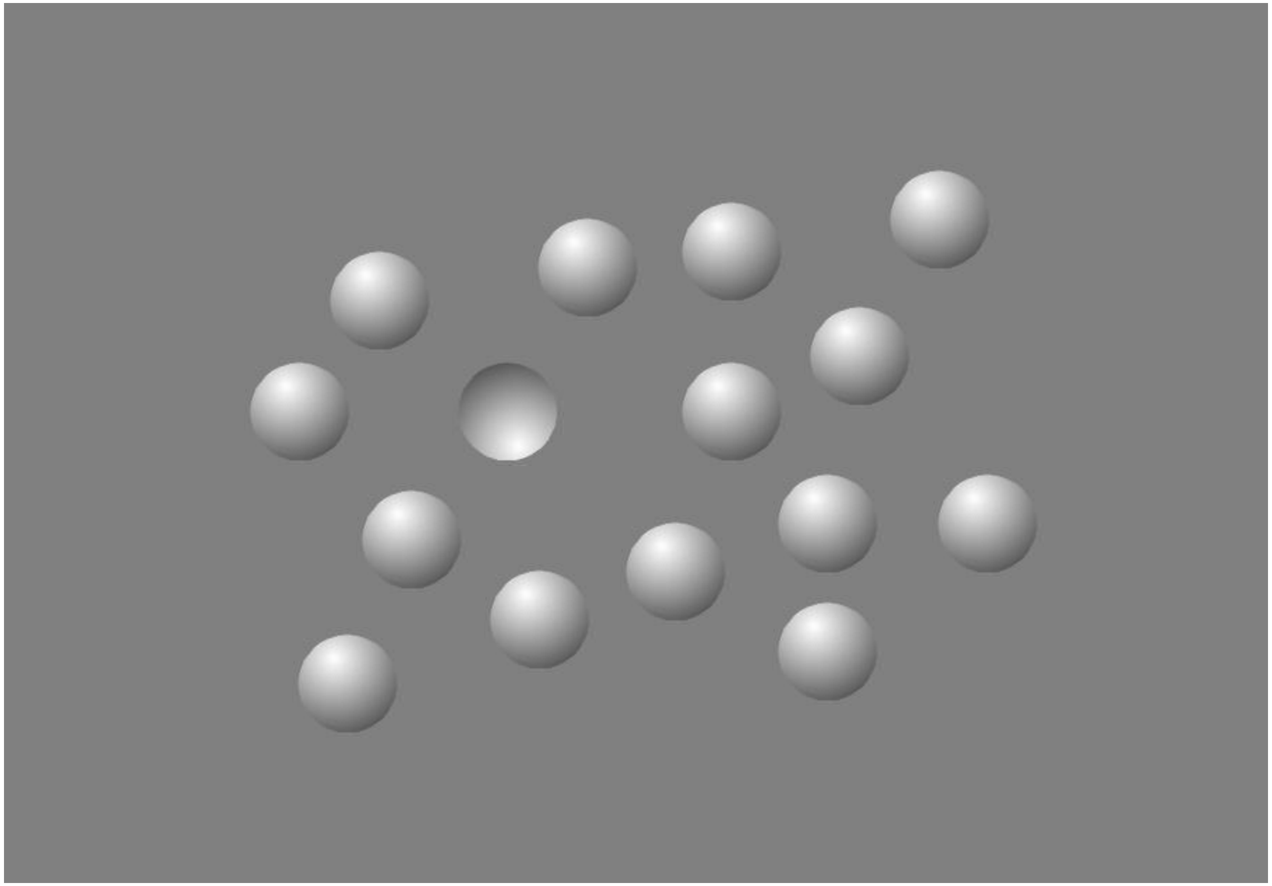
Motion



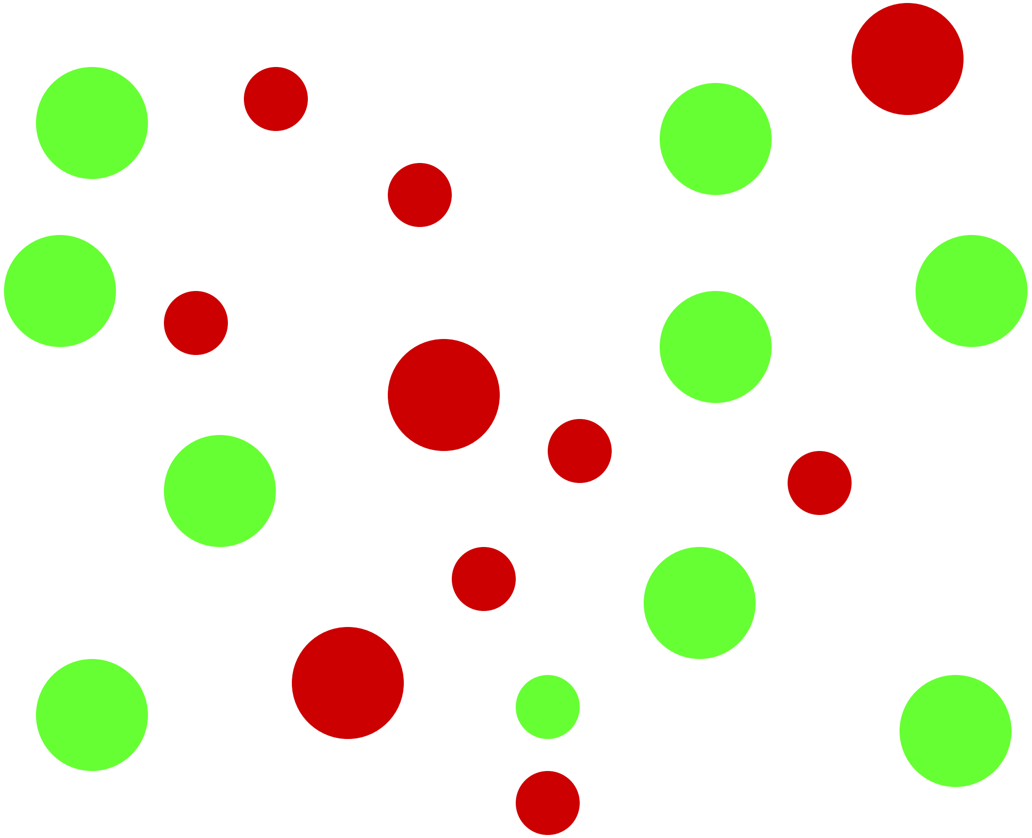
Size



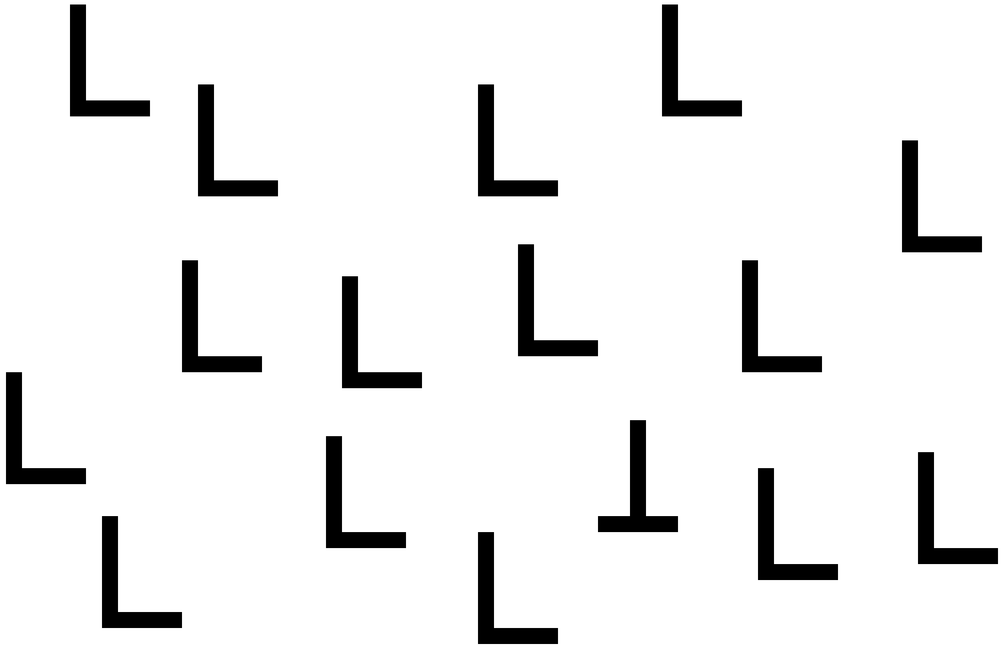
Simple shading



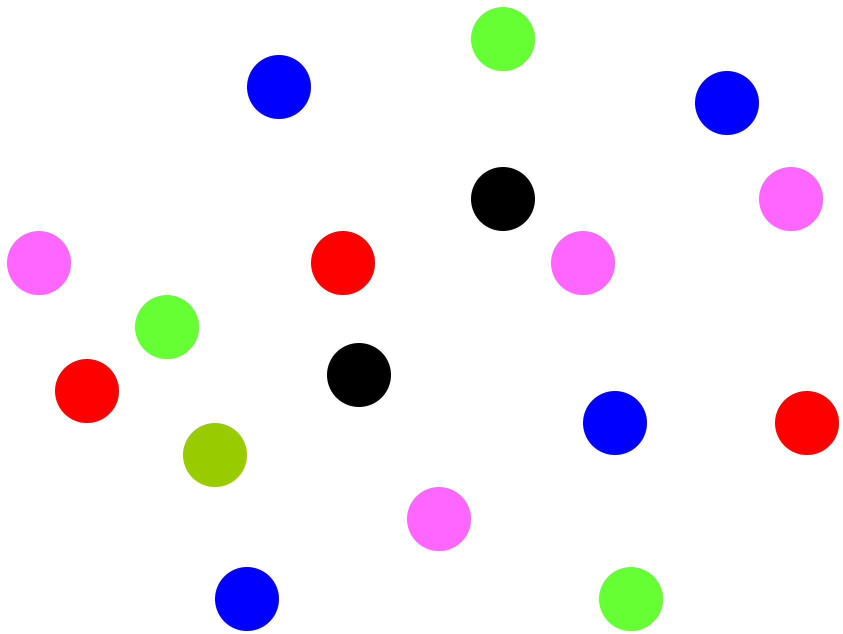
Conjunction (does not pop out)



Compound features (do not pop out)



Surrounded colors do not pop out



Laws of pre attentive display

- Must stand out on some simple dimension
  - color,
  - simple shape = orientation, size
  - motion,
  - depth

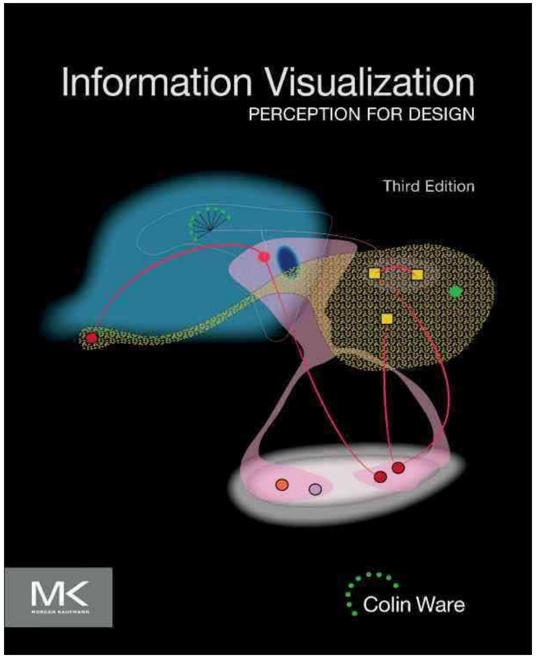
- Conjunctions of pre-attentive dimensions do not always work.

Lessons for Information Visualisation

- Can be used for individual symbols or areas;
- Avoid possible negative effect:
  - Do not use large areas of strong color.
- Orthogonality: use a different channel for a different type of information.
- Example: Mapping high dimensional data to display variables.
  - Position
  - Orientation
  - Size
  - Motion
  - Color
  - …

(2) Gestalt Principles of Visual Perception

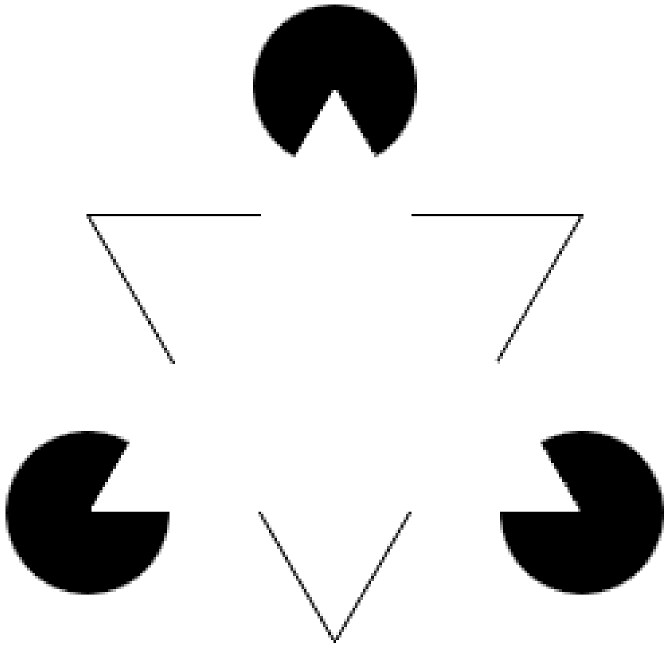
“Information Visualization – Perception for Design”
Colin Ware
Chapter 6



Visual Perception

W.E. Hill, 1915

Illusory Contours



The Kanisza triangle as figure-ground illusory contours

Gestalt Laws/Principles

- **Gestalt**: German word for "*pattern*" or "*whole*" – refers an organized whole
- Our tendency to bring pieces of info into *meaningful wholes*.
- We perceive objects as *well-organized patterns* rather than separate components.
- Based on the concept of "grouping".

- Three Main Principles:
  - **Figure/ground relationships**
  - **Grouping (Proximity, Similarity, Continuity, Closure)**
  - **Goodness of figures**

1. Figure/Ground

- ✓ Elements are perceived as either figures (objects) or ground (the background or landscape on which the figures rest).
- ✓ **Figure** – perceived as the <u>foreground</u>
- ✓ **Ground** – lies behind the Figure
- ✓ Contours – “belong” to the figure

Reversible Figure/Ground relationship:

A vase or two faces?

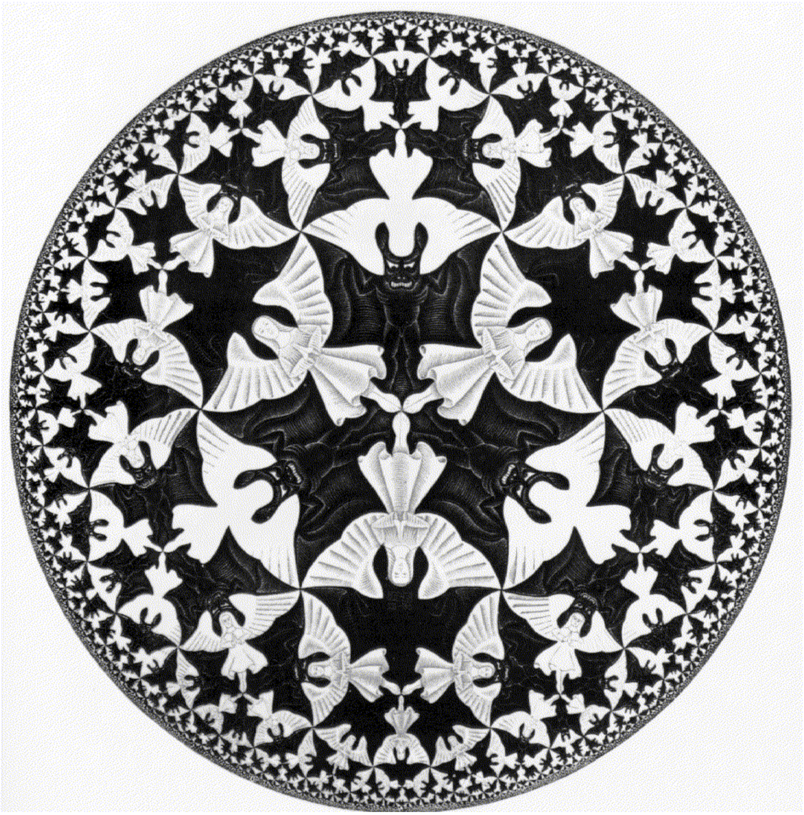
Figure/Ground

Reversible Figure/Ground Relationship:

- Tessellation – interlocking figure/ground

- M.C. Escher

Figure/Ground

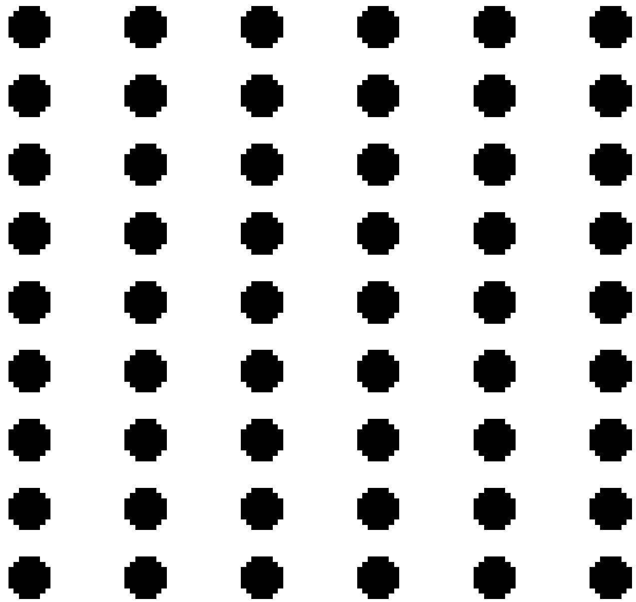


- M.C. Escher

Reversible Figure/Ground Relationship:

- Figure and background are not seen simultaneously
- When looking at this image our eyes have to switch their focus between black fish and white fish

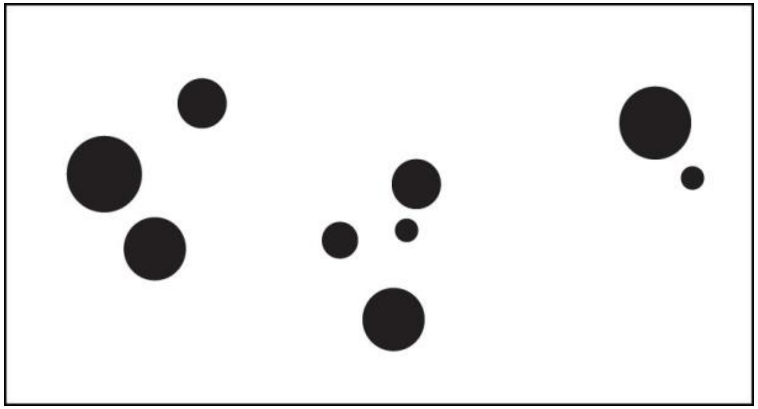
2. Proximity



Grouping: Law of Proximity

Things that are **<u>close</u>** together are perceptually **<u>group</u>**ed together

Proximity

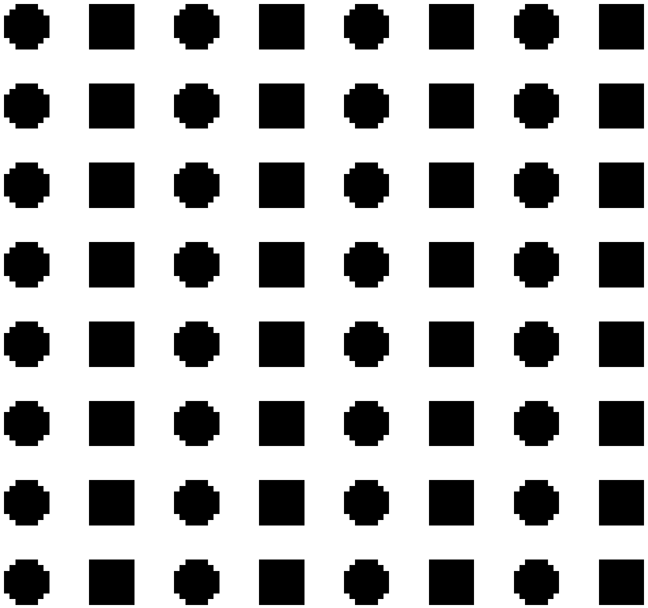


- Items that are located **near** each other are perceived ***more related***.
- The **closer items** are the more likely they are perceived as ***a group***.
- Rather than counting the circles we see three “groups”.

Proximity

• Instead of seeing black spots, we group the black spots together and see them as the figure of a Dalmatian

3. Similarity

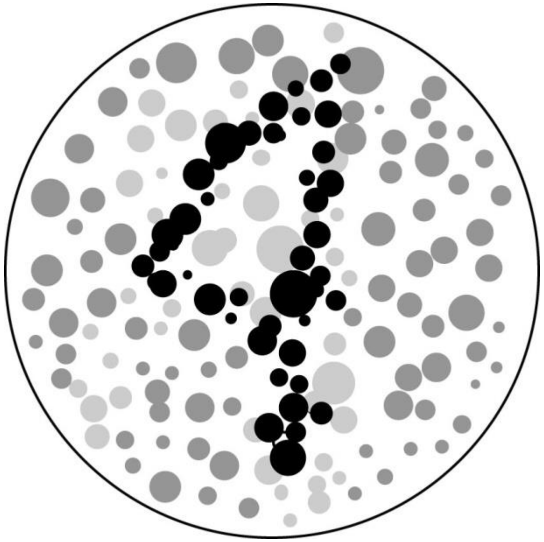


Grouping: Law of Similarity

Similar elements are grouped together

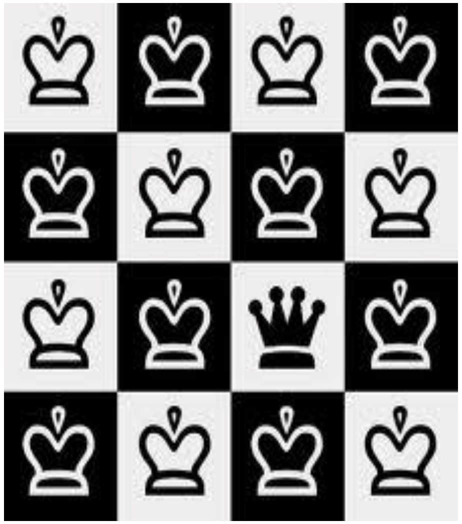
Similarity

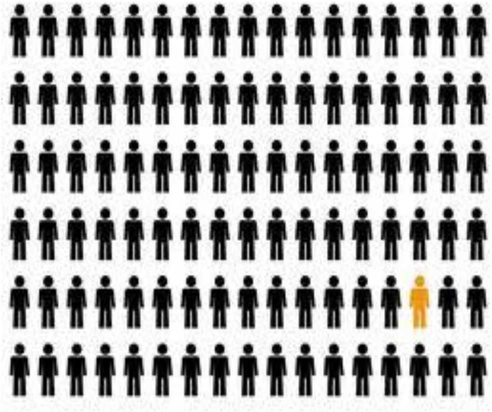
- Grouping: Law of Similarity
  - Visual elements similar in ***shape, size, color, proximity, motion, and direction*** are perceived as part of a group.



We seek patterns, easily grouping the black dots into a number 4.

Similarity





Are there 3 groups
in the above chessboard?

We see two groups:
little black people are seen as one group,
and the yellow is another.

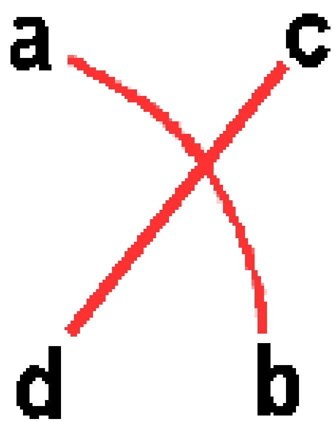
Similarity

Grouping: Law of Similarity: Shape, Color

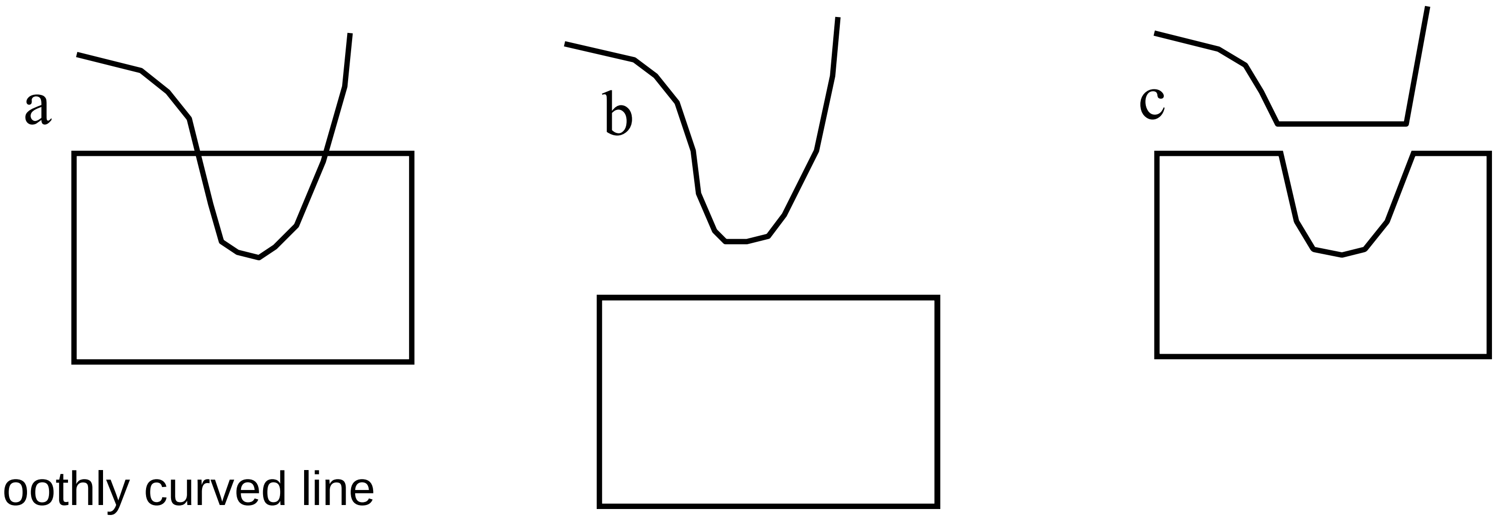
4. Continuity

Law of Good Continuation, or Continuity

- People tend to see things as **smooth and continuous**, rather than ones that contain abrupt changes.
- Objects arranged in either a *straight line or a smooth curve* tend to be seen as a unit.

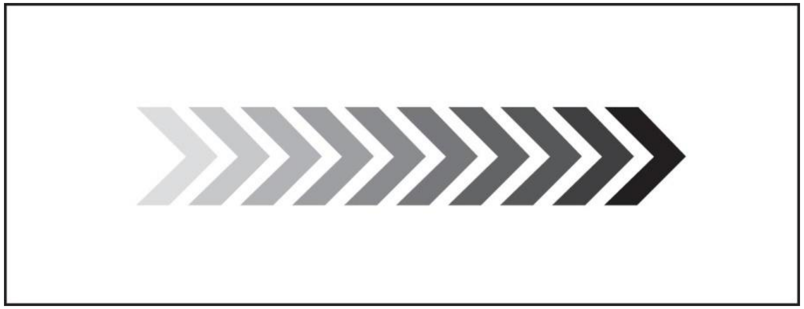


Continuity



Smoothly curved line
overlapping a rectangle

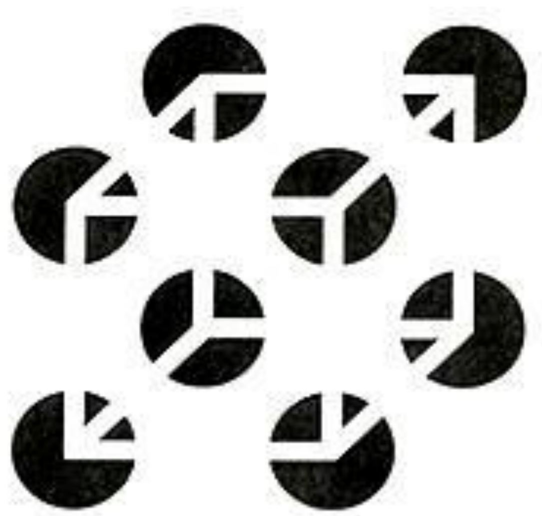
Continuity



- The eye follows along a **line, curve, or sequence of shapes** identifying visual relationships.
- We seek relationships between shapes, especially repeating shapes.

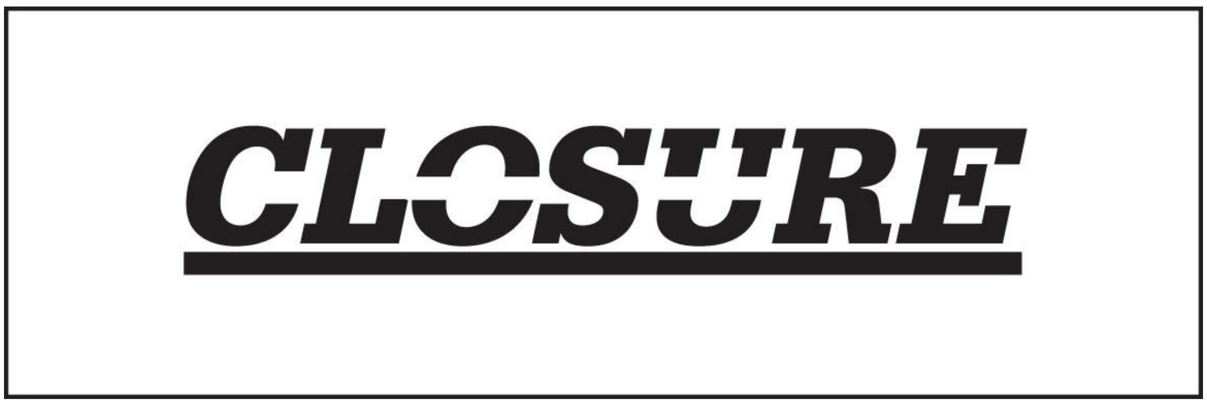
5. Closure

- Law of Closure (Common Region)
  - People tend to first look for a single, recognizable pattern.
  - We have a tendency to **visually close gaps** in a form.
  - The **more familiar** the form the faster we visually close the gap.
  - Closure occurs because we seek to make the forms stable.

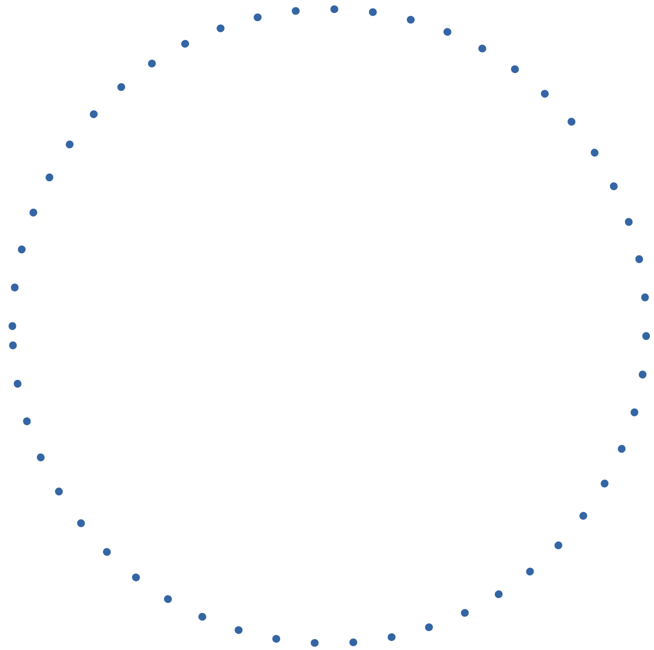


Closure

- We visually close forms.
- The O and the U are easily read as letters despite missing parts.



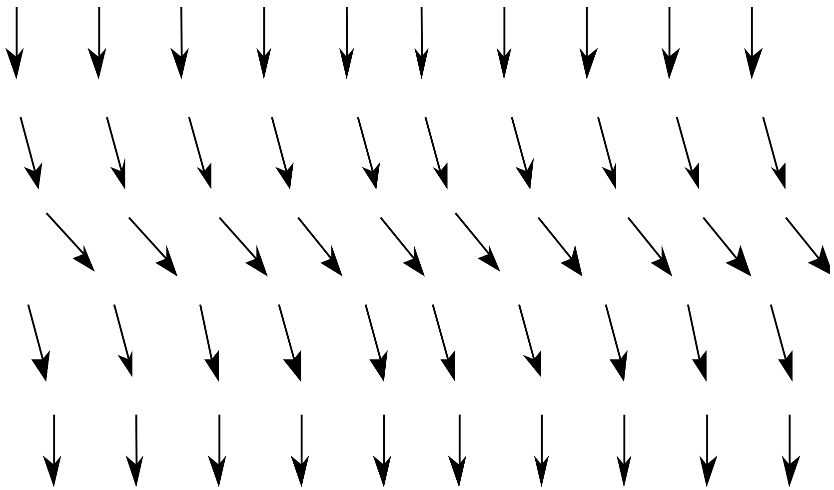
Closure



- We perceive this as an image of a circle.

6. Common Fate

- Law of Common Fate
  - Objects that **move together** are seen as **related**

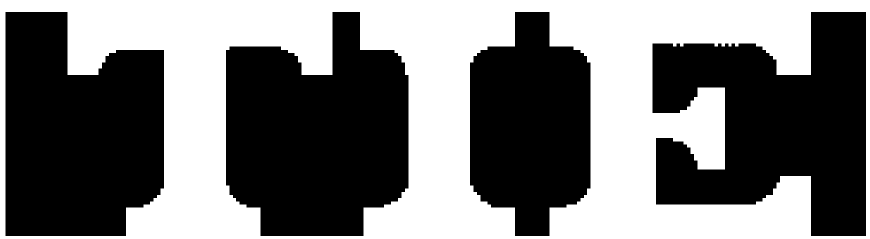


Common Fate

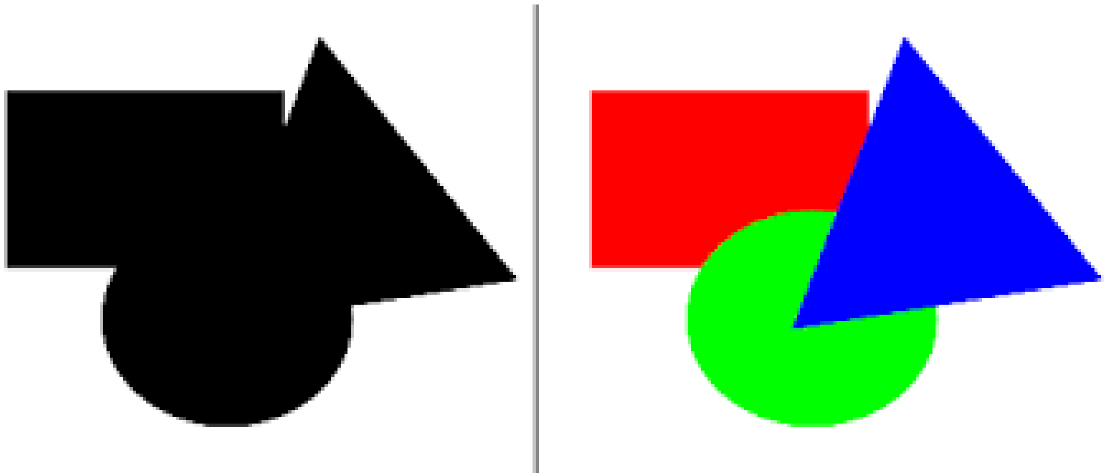
- People see the cars moving in two opposite directions

7. Goodness of Figure

- Goodness of Figure, or the Law of Pragnanz
  - Humans tend to interpret ambiguous or complex images as ***simple and complete***.
  - People tend to **perceive** things based on the simplest and most stable or complete interpretation



Goodness of Figure (2)



Summary: Gestalt Principles

- ***Figure/ground relationships***
- ***Grouping***
  - ***Proximity***
  - ***Similarity***
  - ***Continuity***
  - ***Closure***
- ***Goodness of figures*** (or the Law of Pragnanz)

- Figure/Ground relationships define *important parts* of the scene
- Grouping organize the visual scene into units
- Goodness of Figure creates the simplest most meaningful pattern

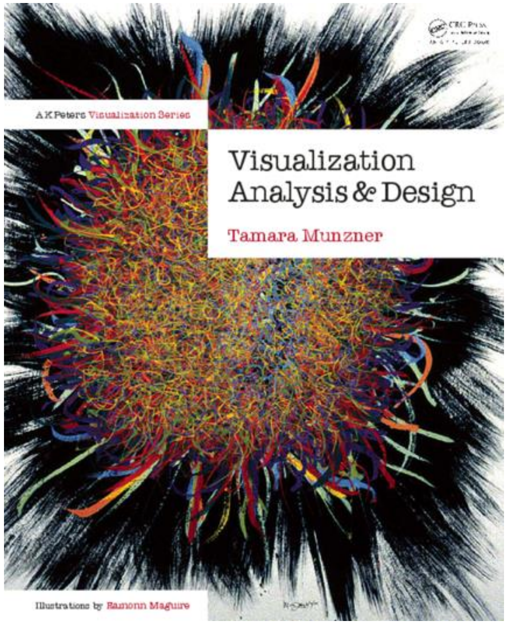
References and Further readings

use materials from the slides:

https://webspace.ringling.edu/~ccjones/curricula/07-08/seqdesign/Gestalt.ppt
https://www.cs.auckland.ac.nz/courses/compsci345s1c/lectures/2009/Lecture_11_Principles_of_Interaction_Design%202.ppt
https://www.cs.ubc.ca/~tmm/courses/cpsc533c-03-spr/0113.kendeeter.ppt
https://soma.sbcc.edu/users/ajarabo/intro_Multimedia/flash_video/JenifferBrooks_gestalt A/JenifferBrooks_gestalt_files/JenifferBrooks_gestalt.pptx
https://www.wsfcs.k12.nc.us/cms/lib/NC01001395/Centricity/Domain/152/Perception.ppt
https://www.cs.cmu.edu/afs/cs/academic/class/15494-s07/lectures/gestalt.pdf
www.wsfcs.k12.nc.us/cms/lib/NC01001395/Centricity/Domain/152/Perception.ppt

(3) Color

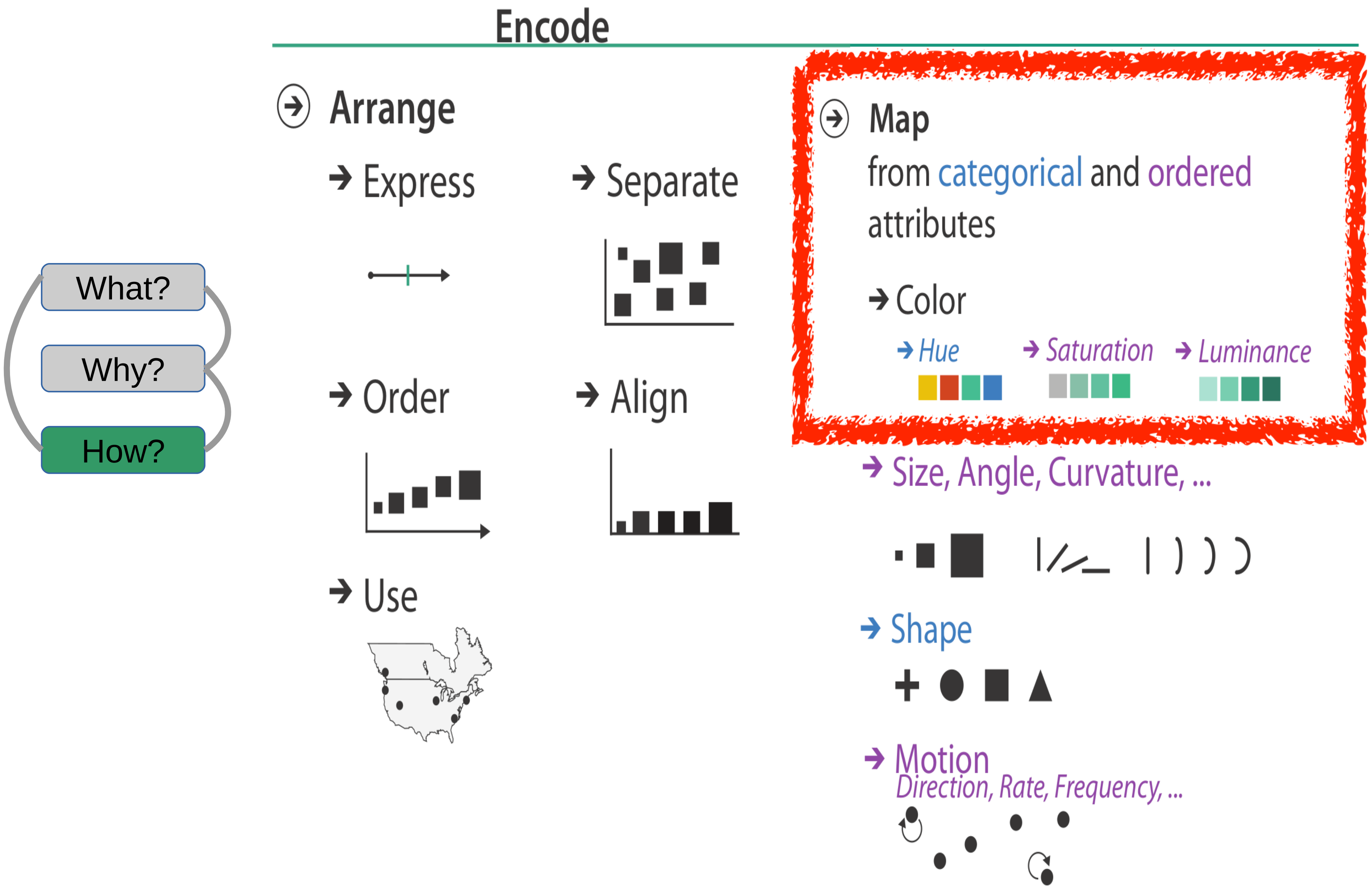
Tamara Munzner
Visualization Analysis and Design, 2014, Chapter 10



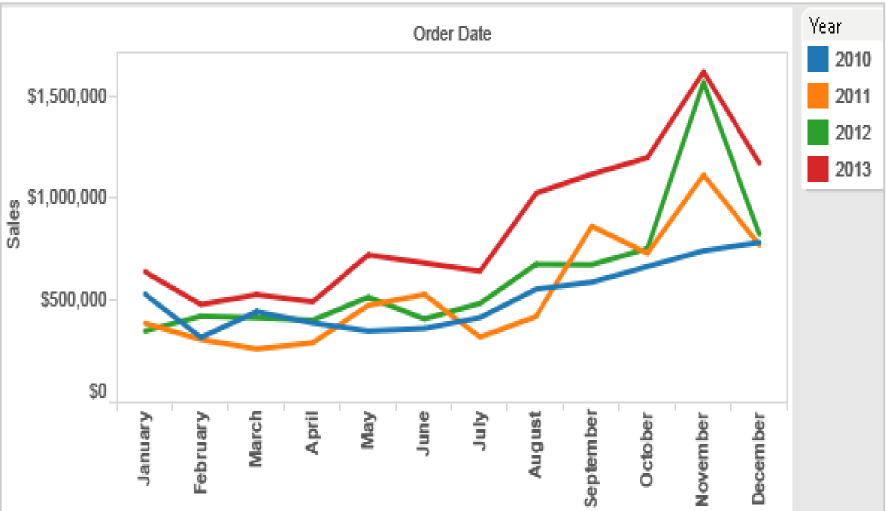
Outline: Color

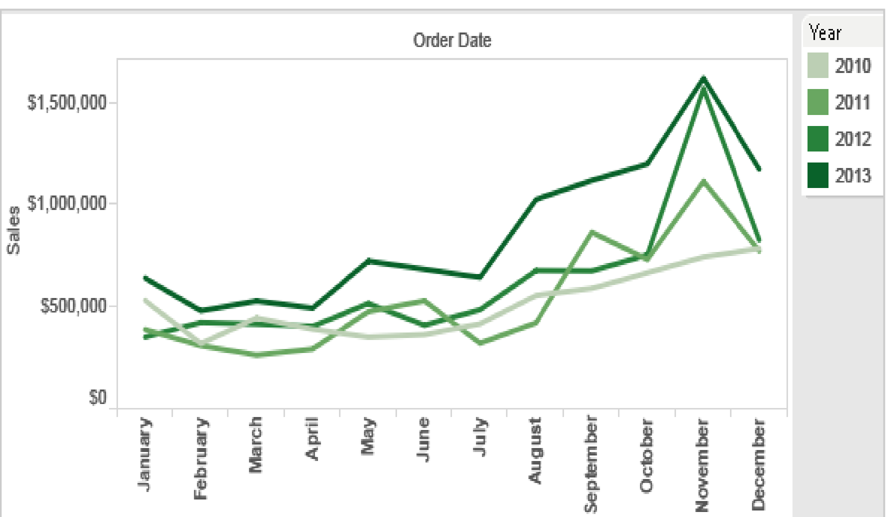
- Categorical vs Ordered color
- Luminance, Saturation, Hue
- Color deficiency
- Colormaps

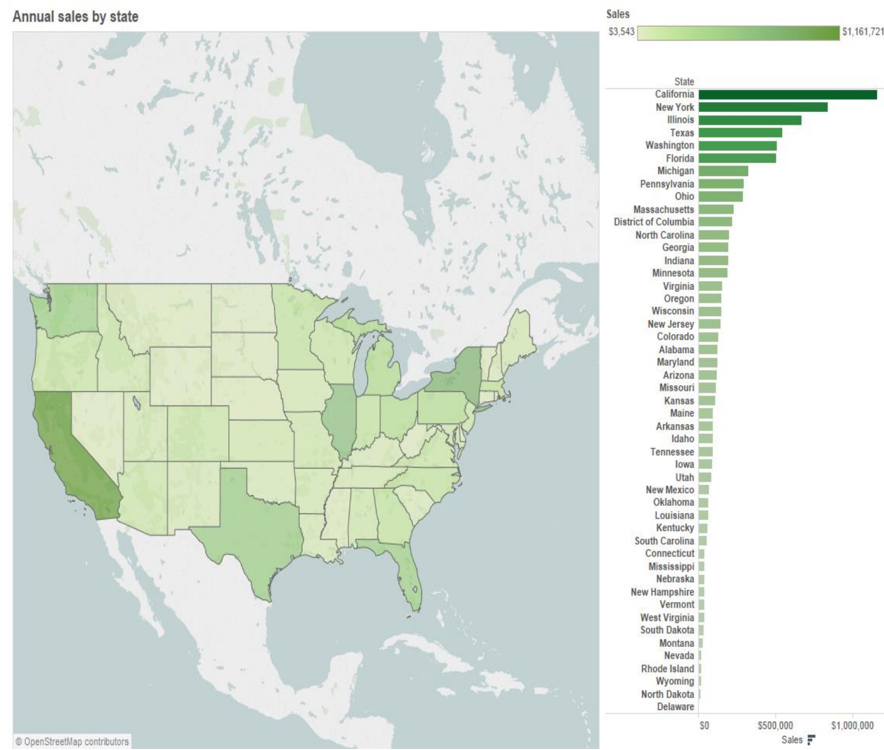
design choices: Encode (Color)



Categorical vs Ordered color





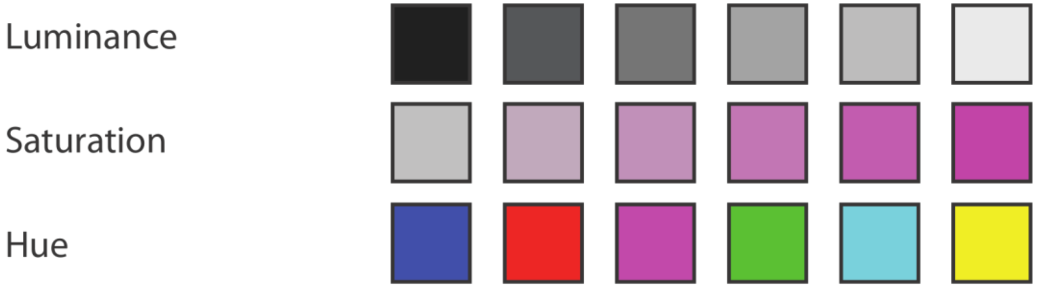


[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]

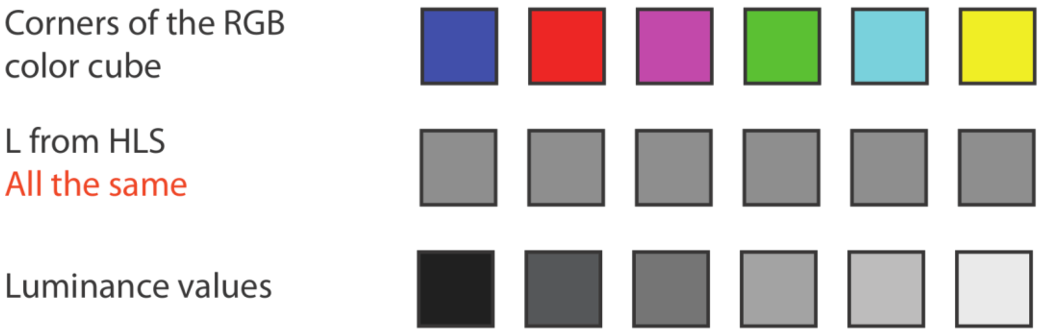
Luminance, Saturation, Hue

- identity for **<u>Categorical</u>**
  - ✓ **Hue**: pure color
- magnitude for **<u>Ordered</u>**
  - ✓ **Saturation**: amount of White mixed with pure color
  - ✓ **Lightness**: amount of Black mixed with a color
  - ✓ **Luminance**

HSL colorpicker design

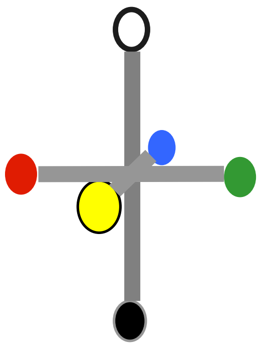


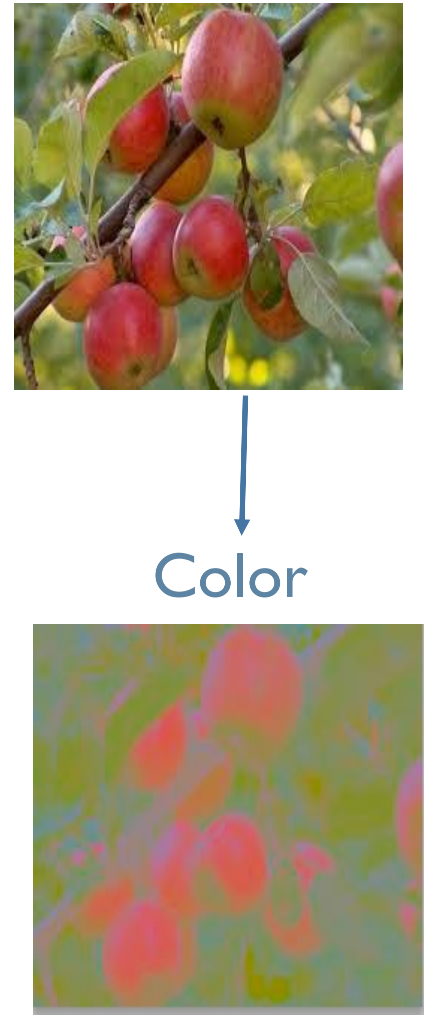
- **RGB** system: popular, but poor for encoding
- **HSL** system: better alternative
- **Luminance**: better match with perception than Lightness



Opponent color and Color deficiency

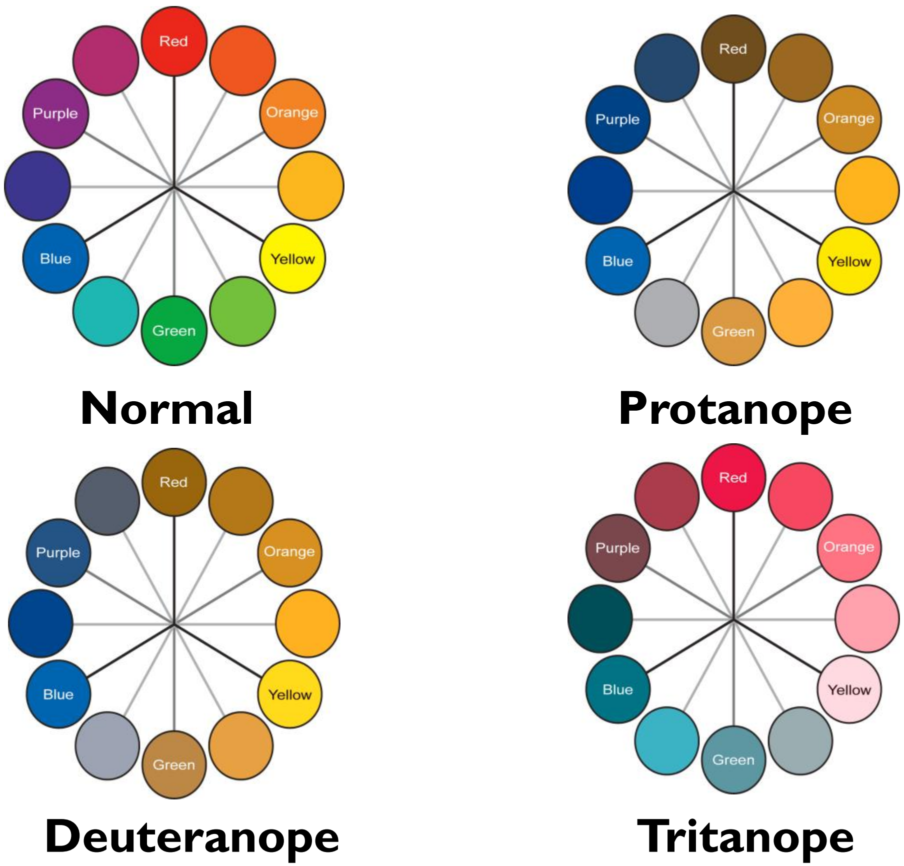
- two chroma channels: R-G and Y-B axis
- "color blind" if one axis has degraded acuity
  - 8% of men are red/green color deficient
  - blue/yellow is rare





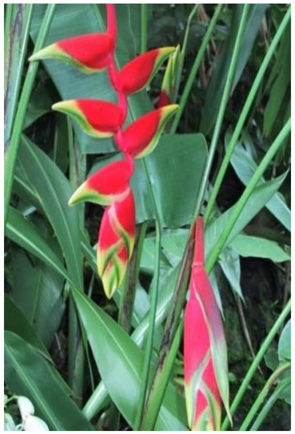
[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]

Color deficiency: Reduces color to 2 dimensions



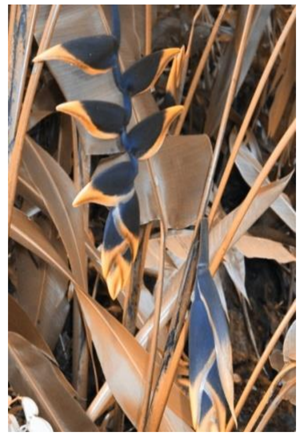
[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]

Designing for color deficiency: Check with simulator



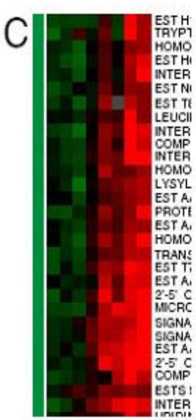
Normal vision

Deuteranope



Protanope

Tritanope

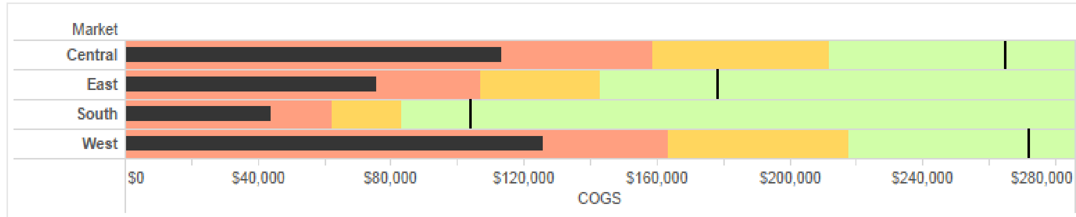


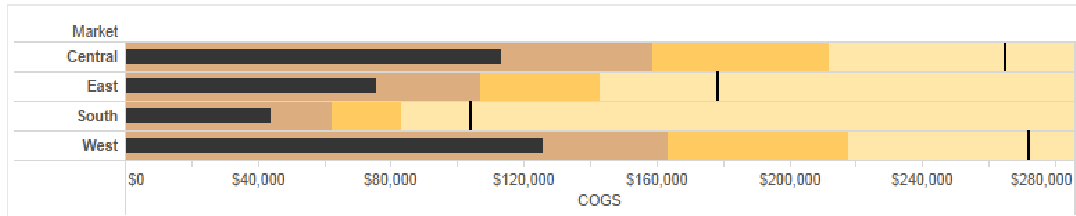
http://rehue.net

[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]

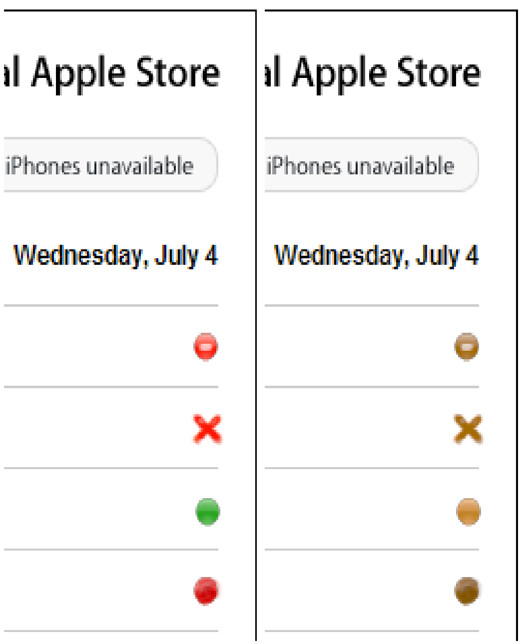
Designing for color deficiency: Avoid encoding by hue alone

- redundantly encode
  - ***vary luminance***
  - ***change shape***





Deuteranope simulation

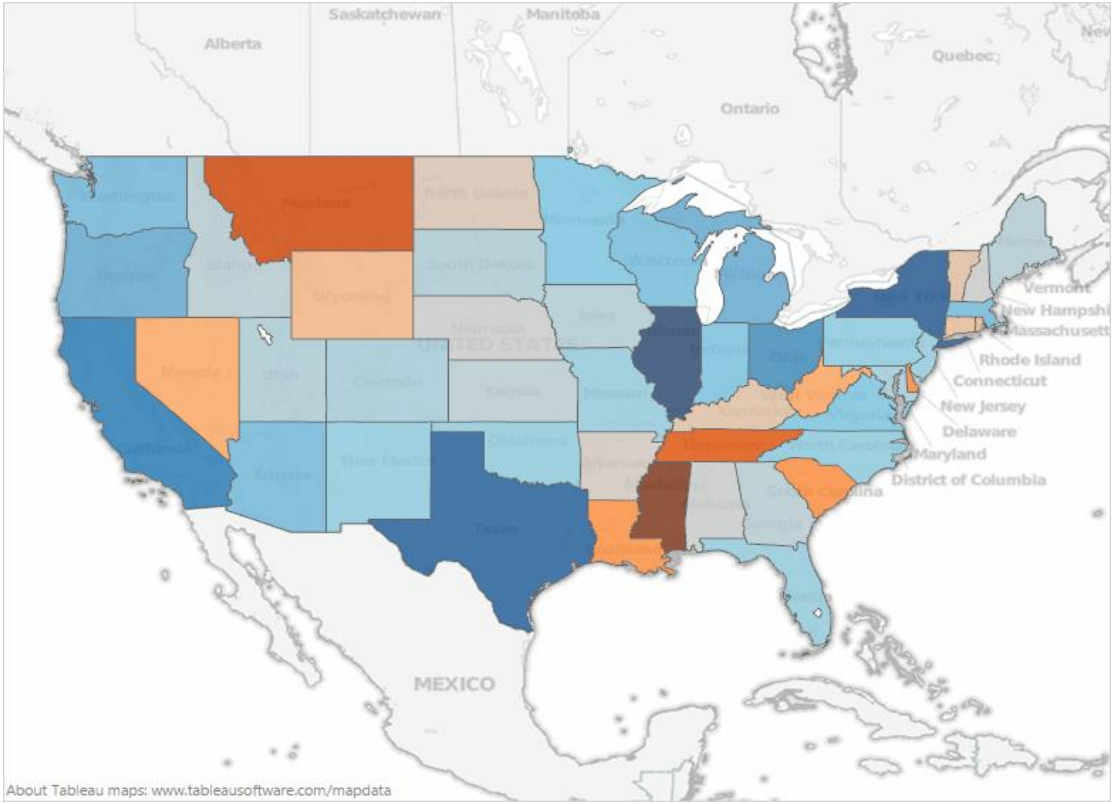


Change the shape

Vary luminance

[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]

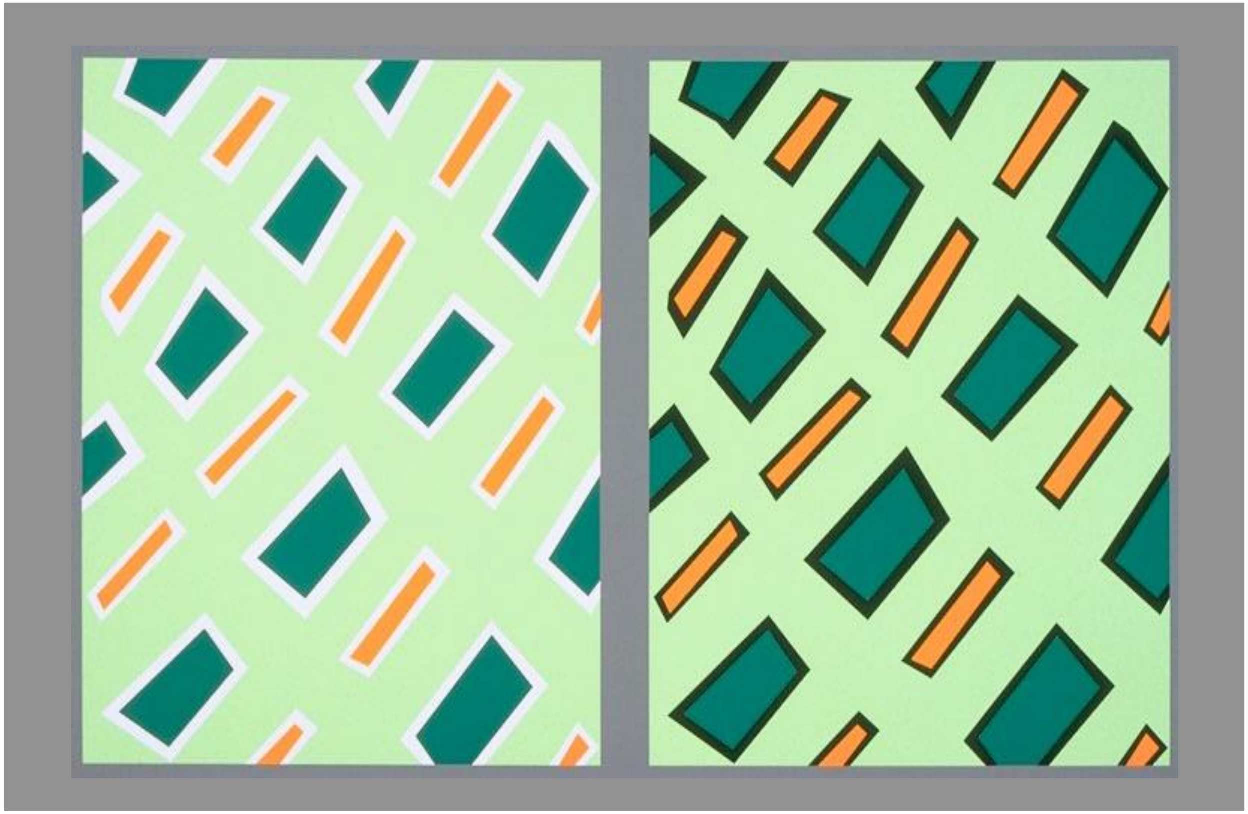
Designing for color deficiency: Blue-Orange is safe



[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]

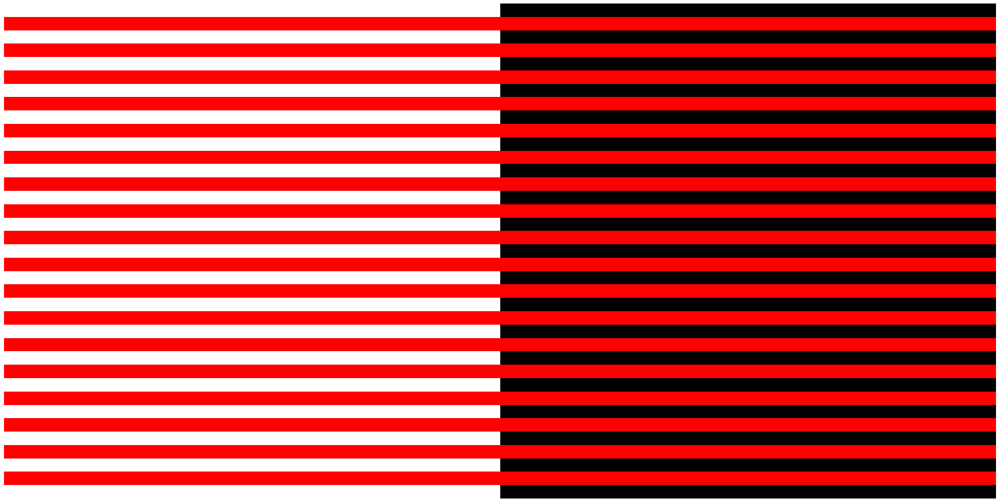
Bezold Effect: Outlines matter

- color constancy: simultaneous contrast effect
  - human perceives color of objects remains relatively constant under varying illumination conditions.



[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]

Bezold Effect: Outlines matter

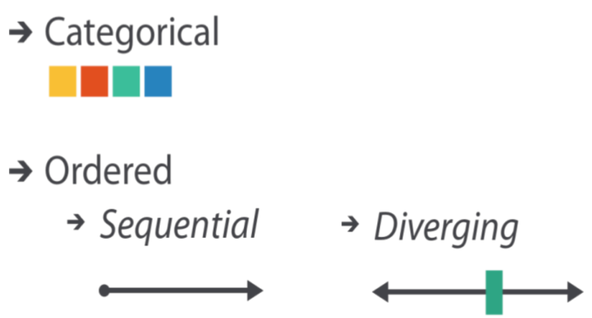


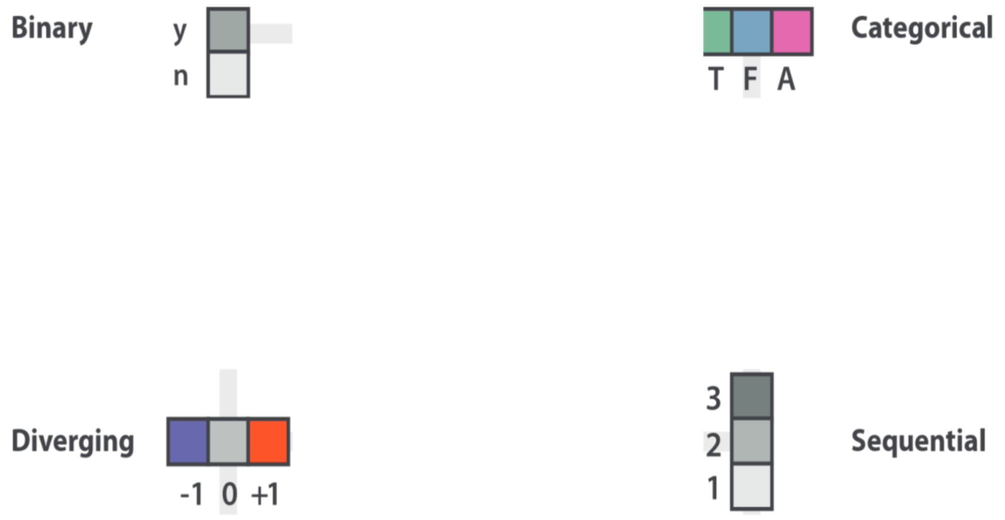
- A color may *appear* <u>*different*</u> depending on *adjacent* colors.

Colormaps

Mapping between colors and data values:

- ***Categorical vs Ordered (sequential, diverging)***
- Continuous vs segmented





[after [Color Use Guidelines for Mapping and Visualization. Brewer, 1994. http://www.personal.psu.edu/faculty/c/a/cab38/ColorSch/Schemes.html]](http://www.personal.psu.edu/faculty/c/a/cab38/ColorSch/Schemes.html)

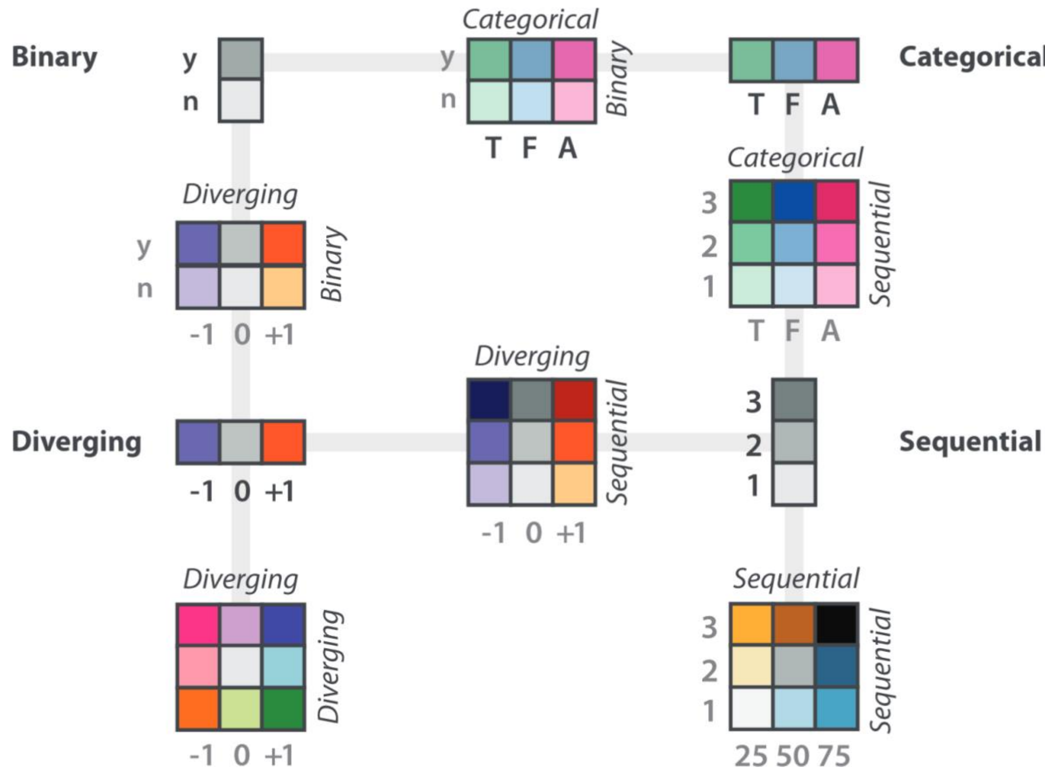
Colormaps

- Categorical

- Ordered
  - *Sequential*

  - *Diverging*

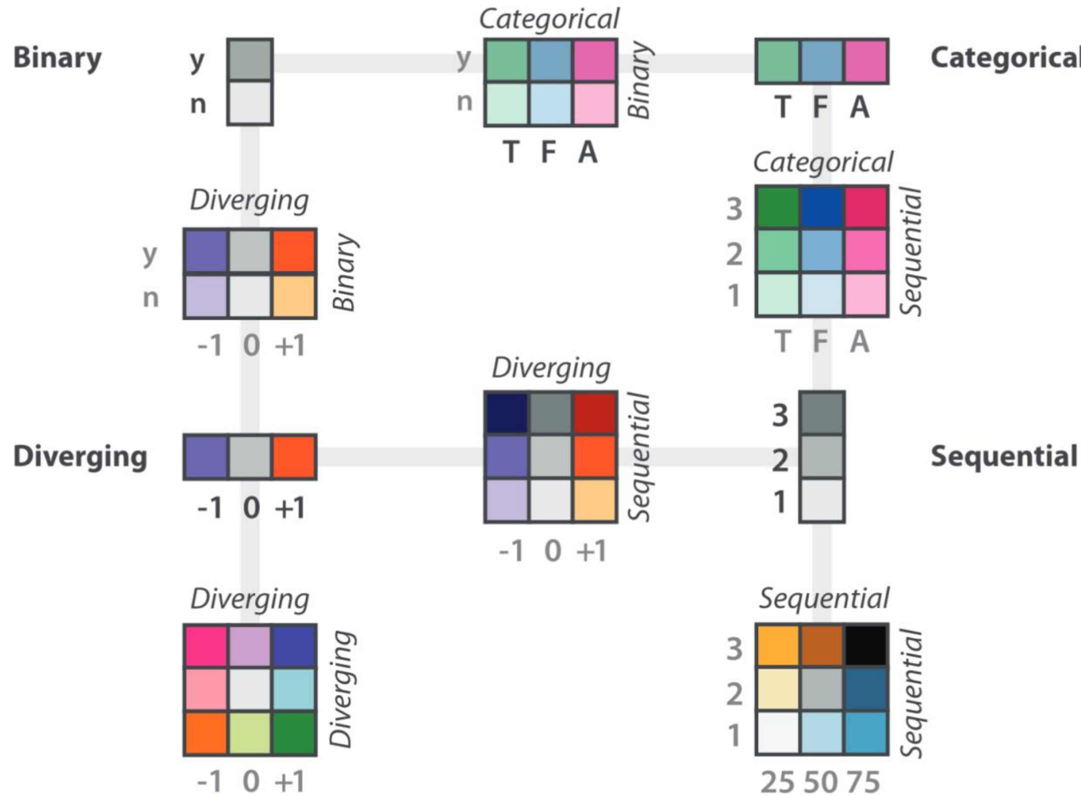
- Bivariate

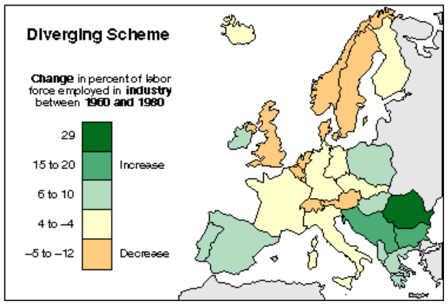


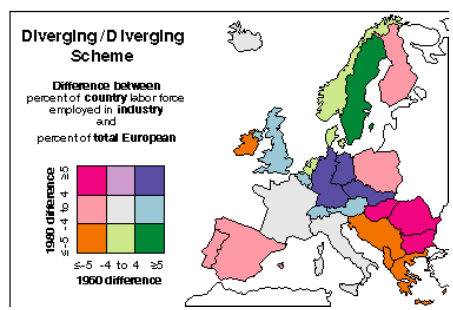
- color channel interactions
  - **size** heavily affects salience
    - small regions need **high** saturation
    - large need **low** saturation
  - saturation & luminance: 3-4 color bins max

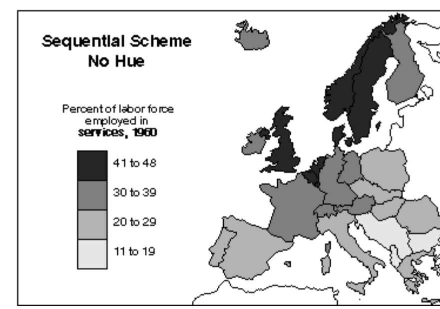
[after [Color Use Guidelines for Mapping and Visualization. Brewer, 1994. http://www.personal.psu.edu/faculty/c/a/cab38/ColorSch/Schemes.html]](http://www.personal.psu.edu/faculty/c/a/cab38/ColorSch/Schemes.html)

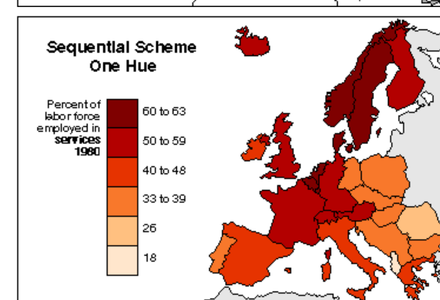
Colormap Examples







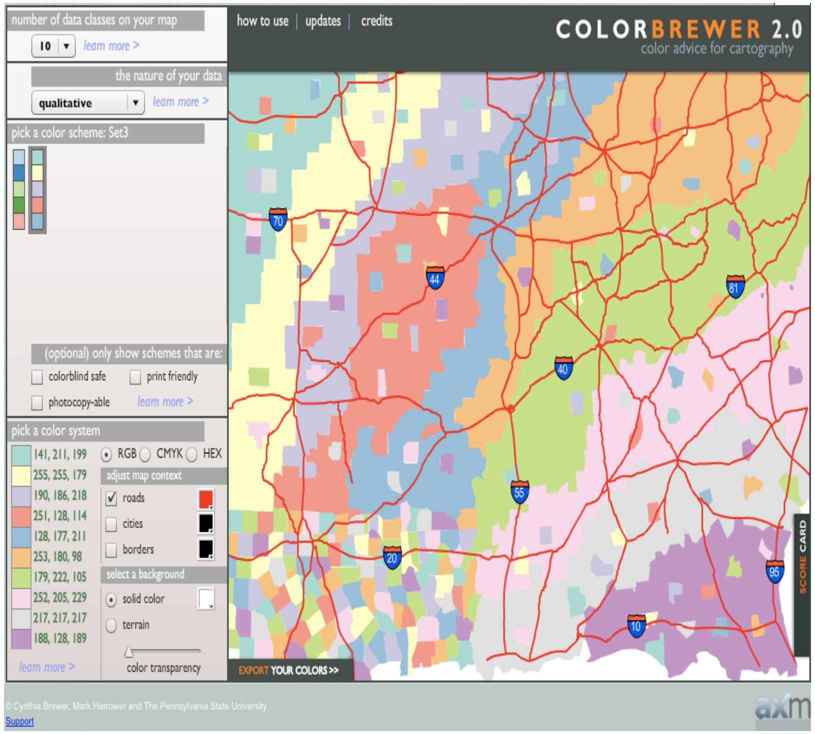


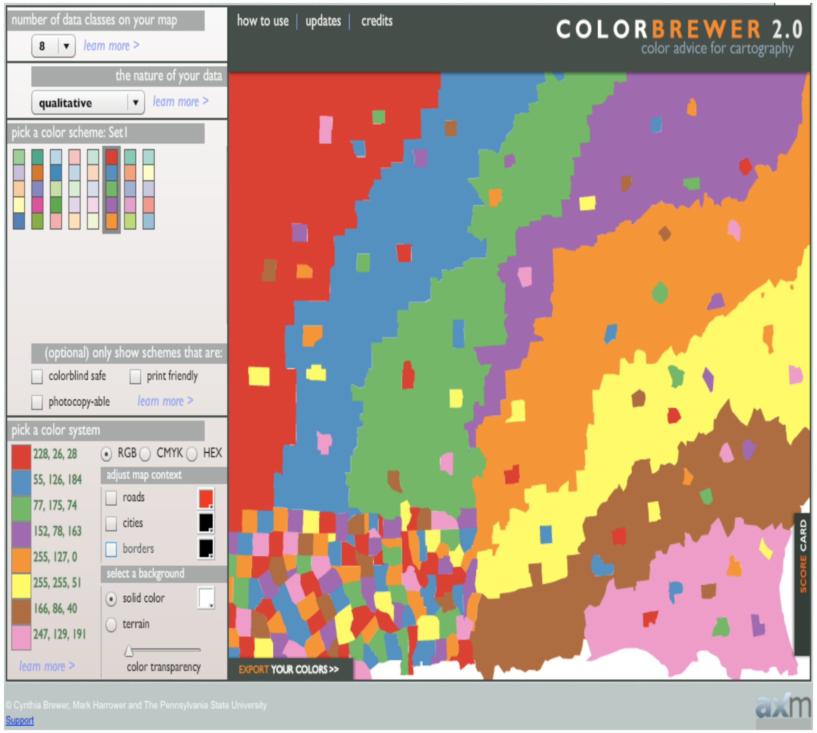


Color Use Guidelines for Mapping and Visualization
https://web.natur.cuni.cz/~langhamr/lectures/vtfg1/mapinfo_2/barvy/colors.html

ColorBrewer

- http://www.colorbrewer2.org
- **saturation** and **area**: size affects salience!
  - Low-saturation map works well with large areas
  - High saturation map would be better suited for small areas



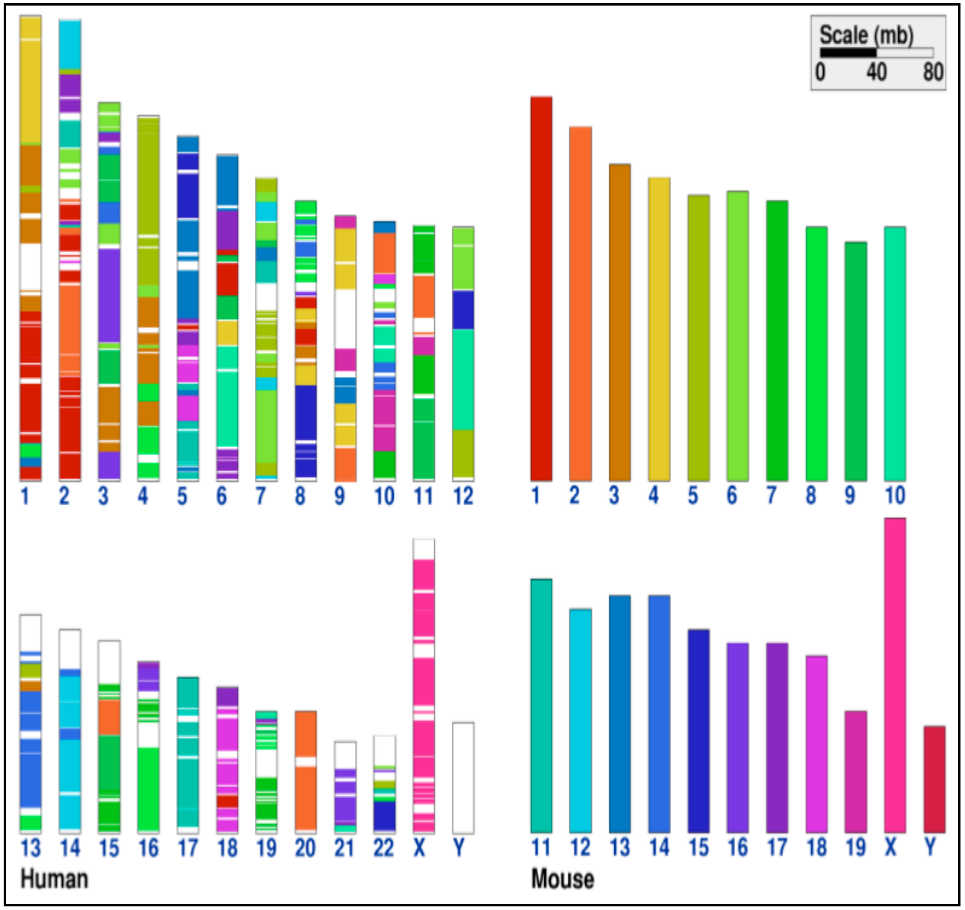


Categorical color: Discriminability constraints

Ineffective categorical color map: ***noncontiguous small regions*** of color

- Reduce # of colors
- Use other visual encoding

Noncontiguous small regions of color

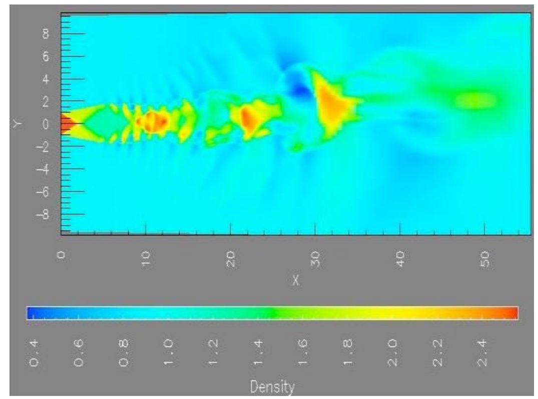


One color per 21 chromosomes in the mouse: Large regions

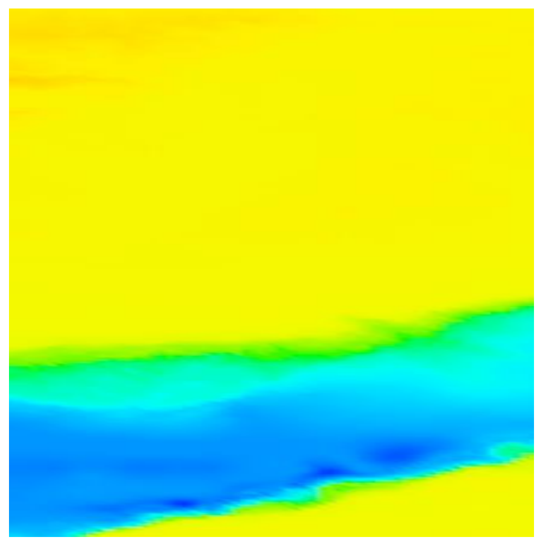
[Cinteny: flexible analysis and visualization of synteny and genome rearrangements in multiple organisms. Sinha and Meller. BMC Bioinformatics, 8:82, 2007.]

Ordered color: Rainbow is poor default

- **<u>problems</u>**
  - perceptually unordered
  - perceptually nonlinear
- **<u>benefits</u>**
  - fine-grained structure visible and nameable



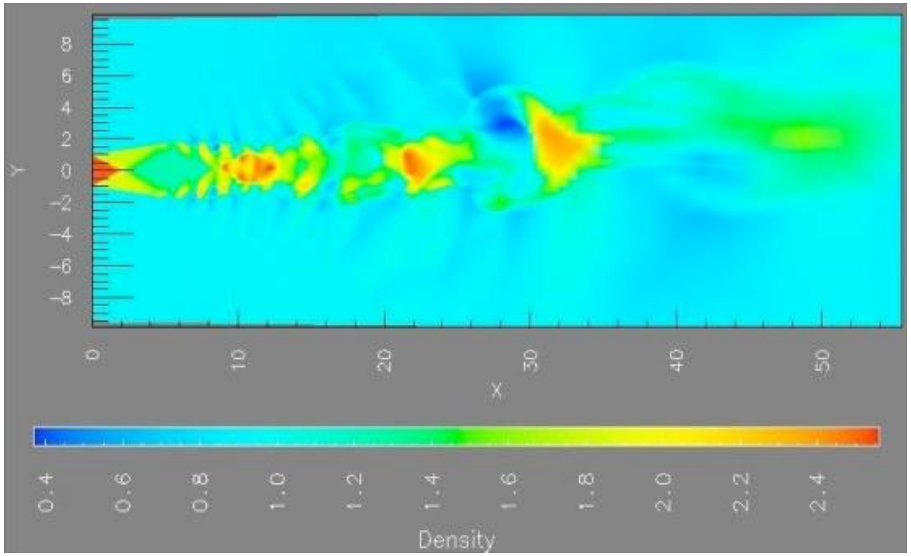
[A Rule-based Tool for Assisting Colormap Selection. Bergman,. Rogowitz, and. Treinish. Proc. IEEE Visualization (Vis), pp. 118–125, 1995.]

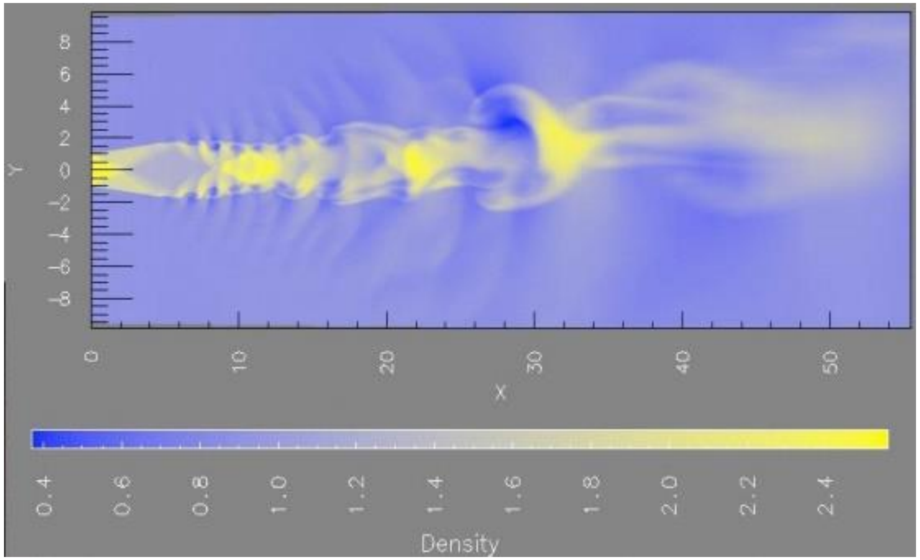


[Why Should Engineers Be Worried About Color? Treinish and Rogowitz 1998. http://www.research.ibm.com/people/l/lloydt/color/color.HTM]

Ordered color: Rainbow vs Two-hue Continuous

- **<u>Alternatives</u>**
  - **large-scale structure: fewer hues**

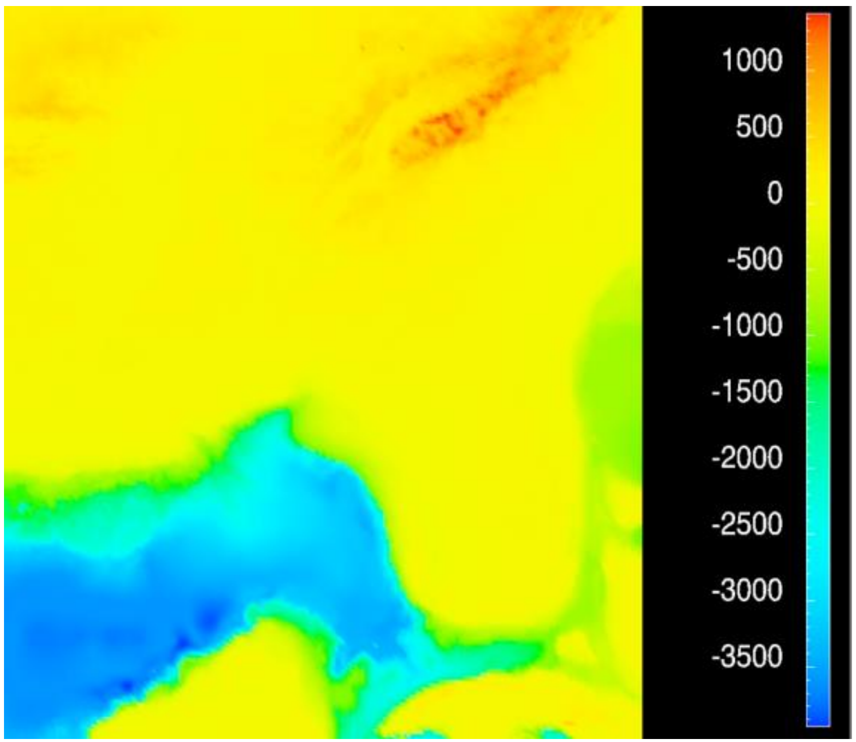


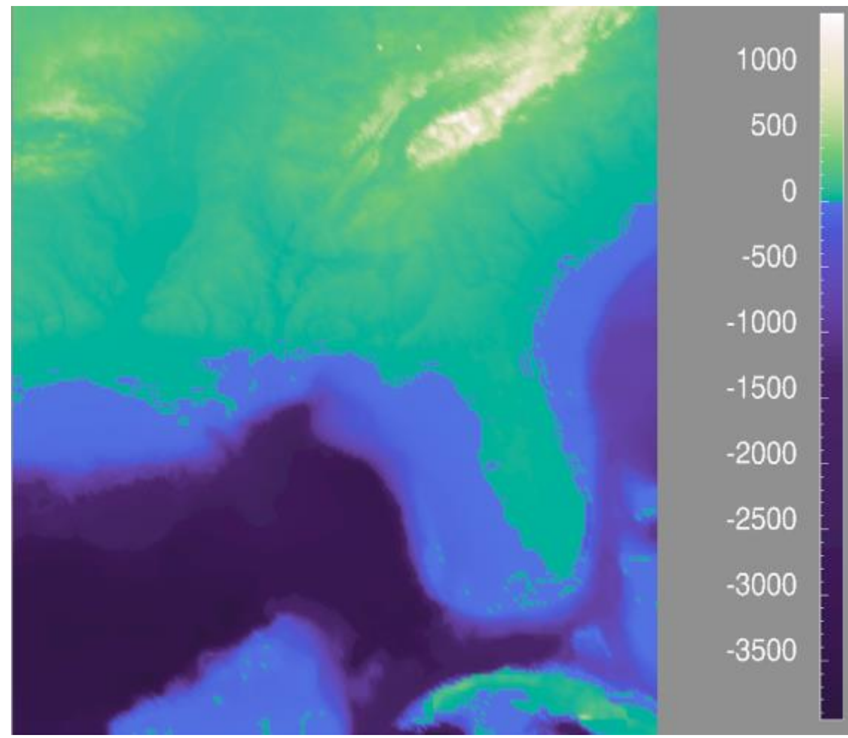


[A Rule-based Tool for Assisting Colormap Selection. Bergman,. Rogowitz, and. Treinish. Proc. IEEE Visualization (Vis), pp. 118–125, 1995.]

Ordered color: Rainbow vs Multi-hue Continuous

- **<u>Alternatives</u>**
  - large-scale structure: fewer hues
  - **fine structure: multiple hues with monotonically increasing luminance**



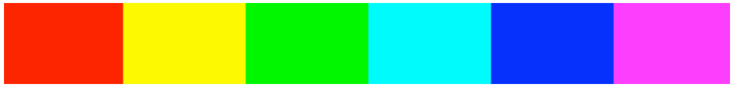


[Why Should Engineers Be Worried About Color? Treinish and Rogowitz 1998. http://www.research.ibm.com/people/l/lloydt/color/color.HTM]

Segmented Rainbow: Categorical data

- **Alternatives**
  - large-scale structure: fewer hues
  - fine structure: multiple hues with monotonically increasing luminance

  - **segmented rainbows** for **categorical data**



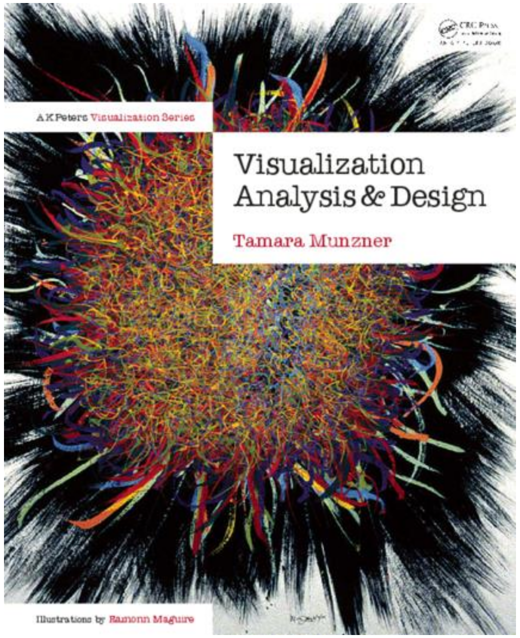
Summary: Color

- **Categorical vs ordered color**
- **Luminance, Saturation, Hue**
- **Color deficiency**
- **Colormaps**

- **References:**
  - http://www.cs.ubc.ca/~tmm/talks.html#minicourse
  - Chapter 10, Visualization Analysis and Design. Tamara Munzner, 2014.

(4) Rules of Thumb

Tamara Munzner
Visualization Analysis and Design, 2014.
Chapter 6

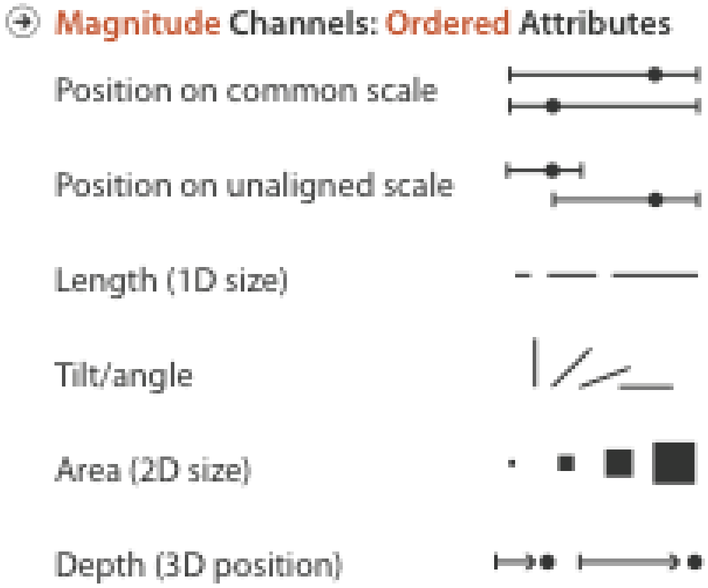


Rules of Thumb [Munzner]

1. No unjustified 3D
    - Power of the plane
    - Disparity of depth
    - Occlusion hides information
    - Perspective distortion dangers
    - Tilted text isn't legible
2. No unjustified 2D
3. Eyes beat memory
4. Resolution over immersion
5. Overview first, zoom and filter, details on demand
6. Responsiveness is required
7. Function first, form next

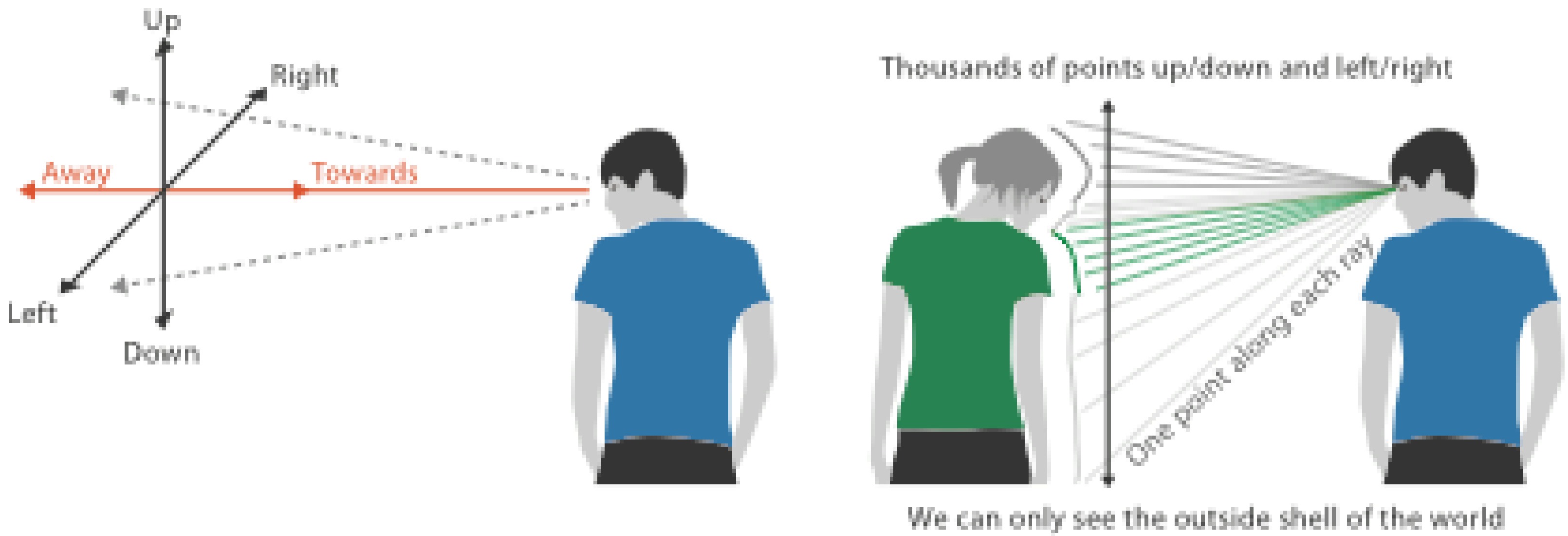
1. No unjustified 3D: Power of the plane

- high-ranked spatial position channels: planar spatial position
  - not depth!



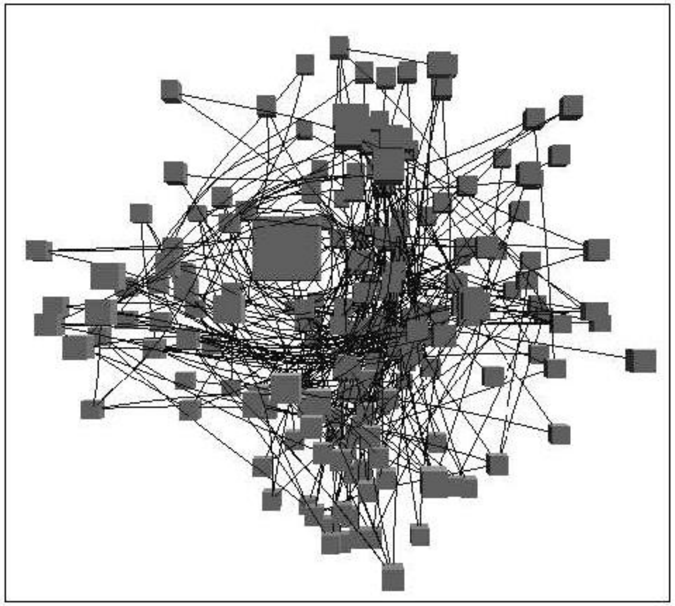
No unjustified 3D: Danger of depth

- we don't really live in 3D: we *see* in 2.05D
  - –acquire more info on image plane quickly from eye movements
  - –acquire more info for depth slower, from head/body motion



Occlusion hides information

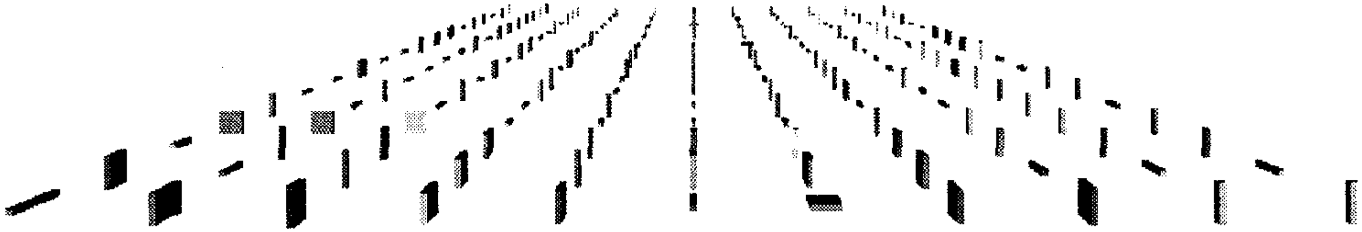
- occlusion
- interaction complexity



[Distortion Viewing Techniques for 3D Data. Carpendale et al. InfoVis1996.]

Perspective distortion loses information

- perspective distortion
  - –interferes with all size channel encodings
  - –power of the plane is lost!

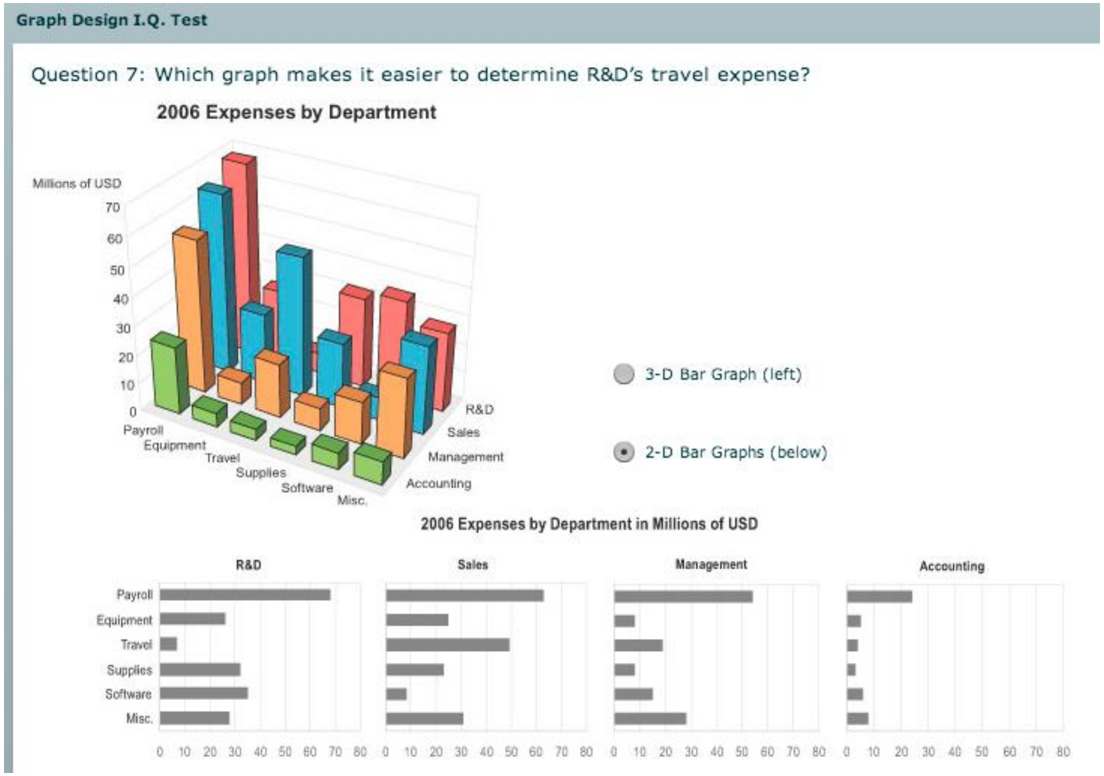


[Visualizing the Results of Multimedia Web Search Engines. Mukherjea, Hirata, and Hara. InfoVis 96]

3D vs 2D bar charts

3D bars never a good idea!

- Perspective distortion
- occlusion

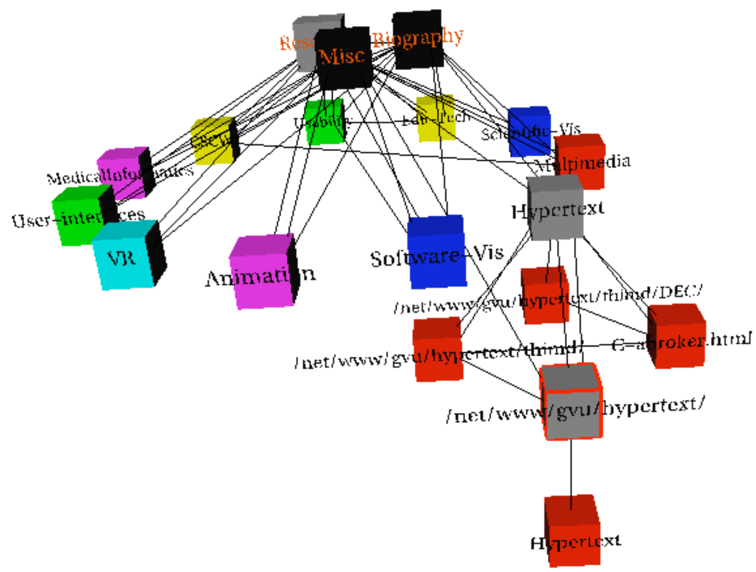


[http://perceptualedge.com/files/GraphDesignIQ.html]

Tilted text isn't legible

- text legibility
  - –far worse when tilted from image plane

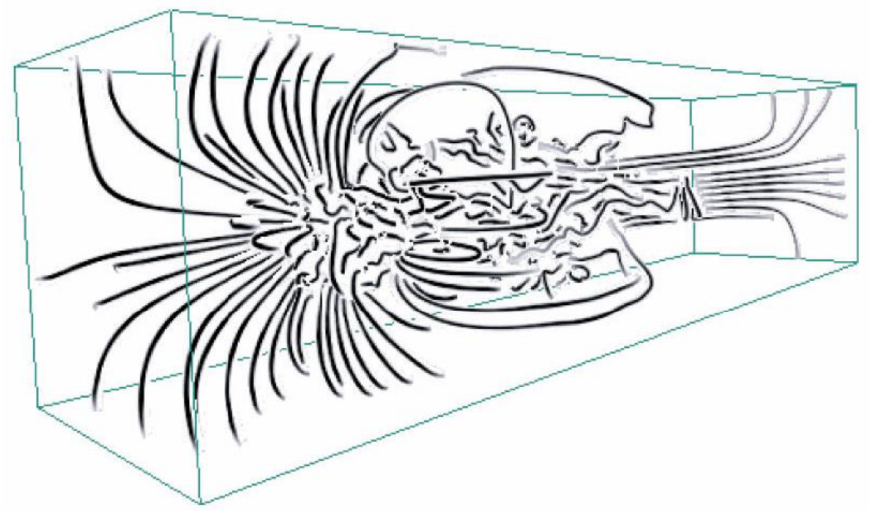
- further reading
  [Exploring and Reducing the Effects of Orientation on Text Readability in Volumetric Displays. Grossman et al. CHI 2007]



[*Visualizing the World-Wide Web with the Navigational View Builder. Mukherjea and Foley. Computer Networks and ISDN Systems, 1995.]*

Justified 3D: shape perception

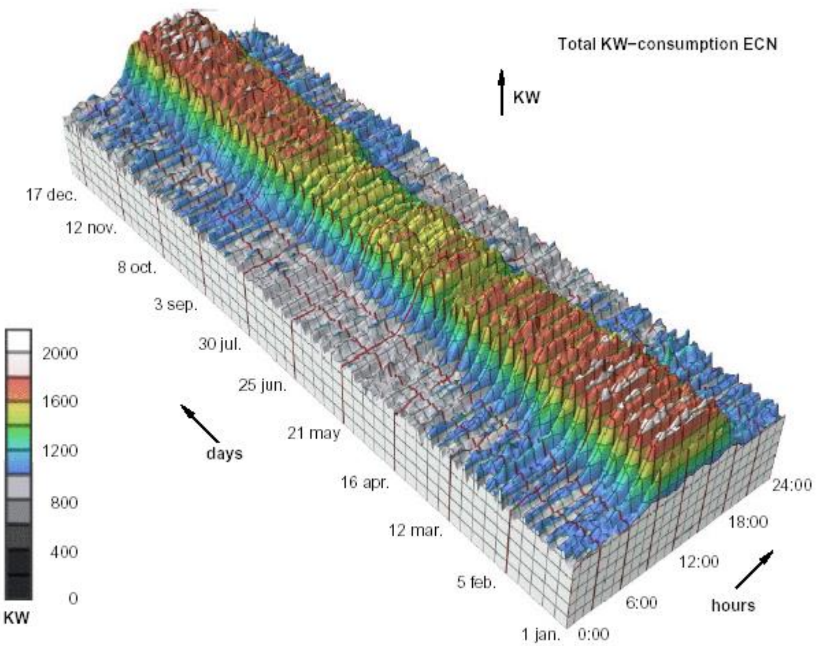
- benefits outweigh costs when task is shape perception for 3D spatial data
  - interactive navigation supports synthesis across many viewpoints

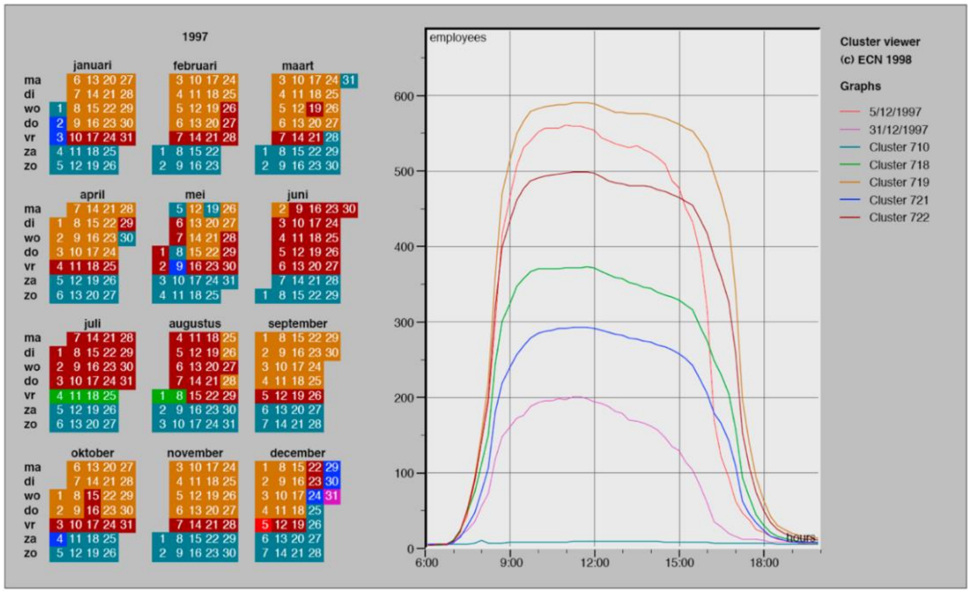


[Image-Based Streamline Generation and Rendering. Li and Shen. IEEE Trans. Visualization and Computer Graphics (TVCG) 13:3 (2007), 630–640.]

Example: 3D vs 2D (Time-series data)

- 3D: extruded curves (detailed comparisons impossible)
- 2D derived data: cluster hierarchy
- juxtapose multiple views: calendar, superimposed 2D curves

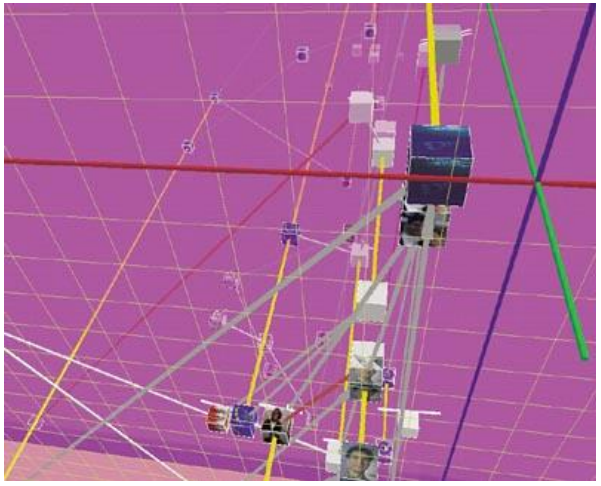




[Cluster and Calendar based Visualization of Time Series Data. van Wijk and van Selow, Proc. InfoVis 99.]

No unjustified 3D

- 3D legitimate for true 3D spatial data
- 3D needs very careful justification for abstract data
  - enthusiasm in 1990s, but now skepticism
  - be especially careful with 3D for point clouds or networks

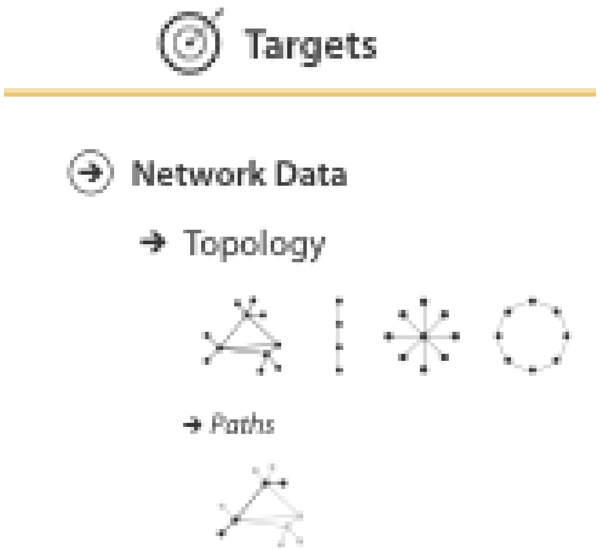


[WEBPATH-a three dimensional Web history. Frecon and Smith. Proc. InfoVis 1999]

2. No unjustified 2D

- consider whether network data requires 2D spatial layout
  - –especially if reading text is central to task!
  - –arranging as network means lower information density and harder label lookup compared to text lists

- benefits outweigh costs when topological structure/context important for task
  - –be especially careful for search results, document collections, ontologies



3. Eyes beat memory

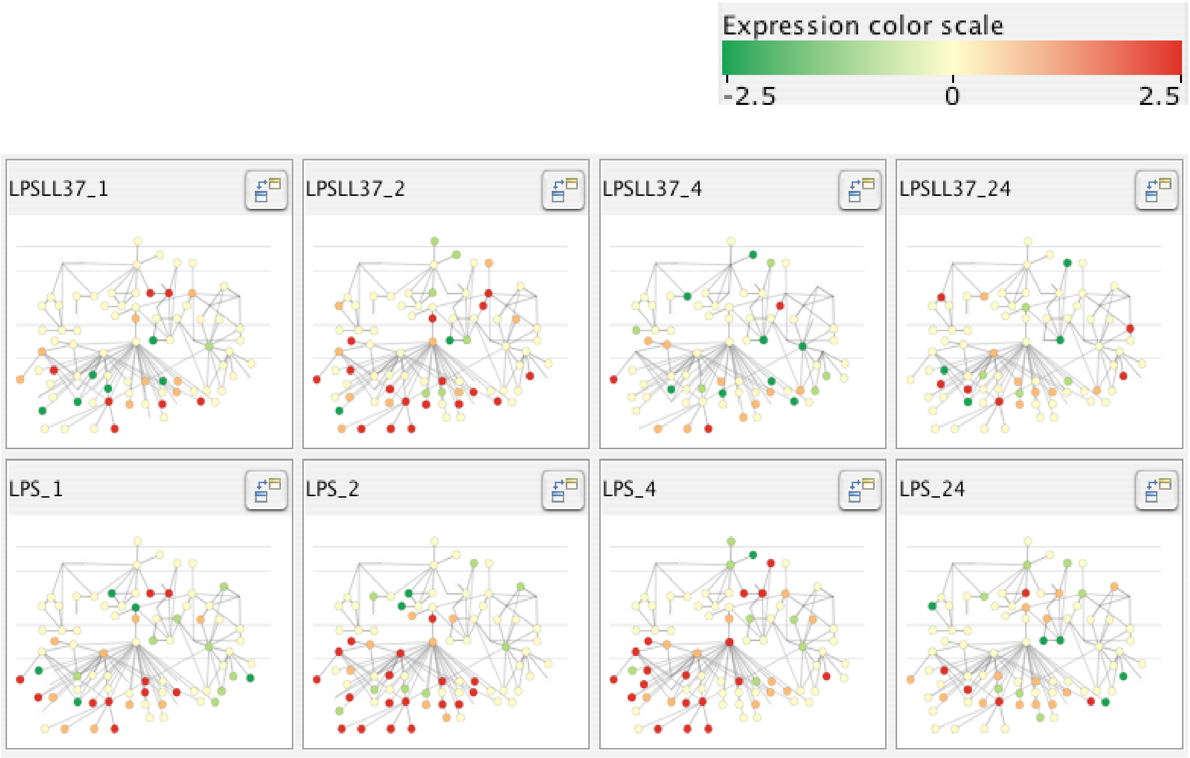
- principle: external ***cognition*** vs. internal ***memory***
  - –easy to compare by moving eyes between side-by-side views
  - –harder to compare visible item to memory of what you saw

- implications for **animation**
  - –great for choreographed storytelling
  - –great for transitions between two states
  - –poor for many states with changes everywhere
    - consider **small multiples** instead

literal	abstract
animation	**small multiples**
show time with time	show time with space

Eyes beat memory example: Cerebral

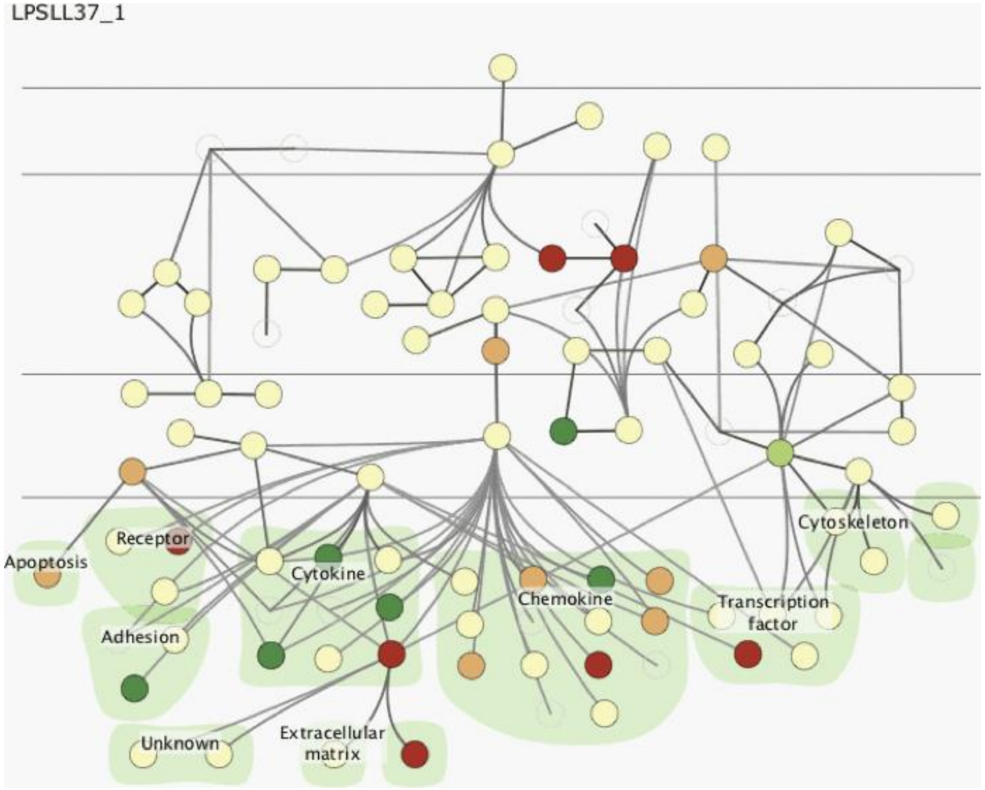
- small multiples: one graph instance per experimental condition
  - –same spatial layout
  - –color differently, by condition



[Cerebral: Visualizing Multiple Experimental Conditions on a Graph with Biological Context. Barsky, Munzner, Gardy, and Kincaid. IEEE Trans. Visualization and Computer Graphics (Proc. InfoVis 2008) 14:6 (2008), 1253–1260.]

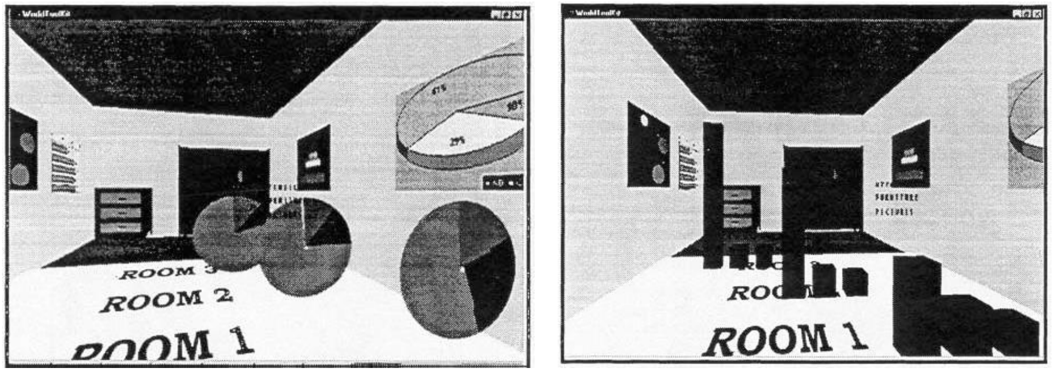
Why not animation?

- disparate frames and regions: comparison difficult
  - –vs contiguous frames
  - –vs small region
  - –vs coherent motion of group
- safe special case
  - –animated transitions



4. Resolution beats immersion

- immersion typically not helpful for abstract data
  - –do not need sense of presence or stereoscopic 3D
- ***resolution*** much more important
  - –pixels are the scarcest resource
  - –desktop also better for workflow integration
- virtual reality for abstract data very difficult to justify



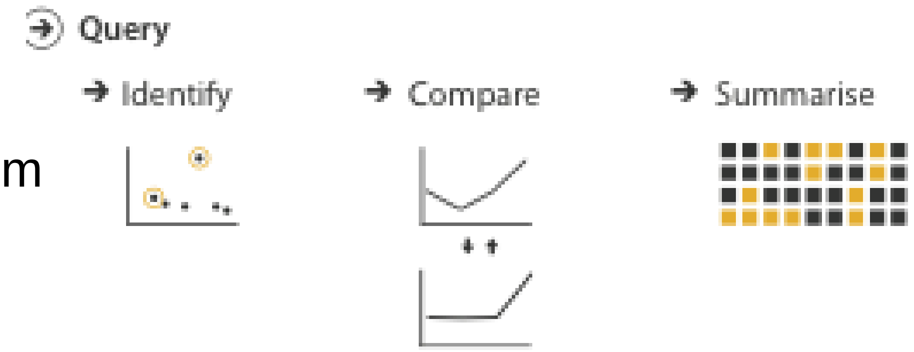
[Development of an information visualization tool using virtual reality. Kirner and Martins. Proc. Symp. Applied Computing 2000]

5. Overview first, zoom and filter, details on demand

- influential mantra from Shneiderman

[The Eyes Have It: A Task by Data Type Taxonomy for Information Visualizations. Shneiderman. Proc. IEEE Visual Languages, pp. 336–343, 1996.]

- overview = summary
  - –microcosm of full vis design problem



6. Responsiveness is required

- ***Latency*** of interaction: how much time it takes for the system to respond to the user action

- three major categories
  - 0.1 seconds: perceptual processing
  - 1 second: immediate response
  - 10 seconds: brief tasks

- importance of visual feedback

7. Function first, form next

- start with focus on functionality (effective)
  - straightforward to improve aesthetics later on, as refinement
  - if no expertise in-house, find good graphic designer to work with
- dangerous to start with aesthetics (beautiful)
  - usually impossible to add function retroactively

Summary: Rules of Thumb

1. No unjustified 3D
2. No unjustified 2D
3. Eyes beat memory
4. Resolution over immersion
5. Overview first, zoom and filter, details on demand
6. Responsiveness is required
7. Function first, form next

Summary

1. **Human Perception**
2. **Gestalt Principles**
3. **Color**
4. **Rules of Thumb**