CSE 332
Introduction to Visualization

Visual Design & Aesthetics

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Lecture	Topic	Projects
1	Intro, schedule, and logistics	
2	Applications of visual analytics, data, and basic tasks	
3	Data preparation and reduction	Project 1 out
4	Data preparation and reduction	
5	Data reduction and similarity metrics	
6	Dimension reduction	
7	Introduction to D3	
8	Bias in visualization	Project 2 out
9	Perception and cognition	
10	Visual design and aesthetics	
11	Cluster and pattern analysis	
12	High-Dimensional data visualization: linear methods	
13	High-D data vis.: non-linear methods, categorical data	Project 3 out
14	Computer graphics and volume rendering	
15	Techniques to visualize spatial (3D) data	
16	Scientific and medical visualization	
17	Scientific and medical visualization	
18	Non-photorealistic rendering	Project 4 out
19	Midterm	
20	Principles of interaction	
21	Visual analytics and the visual sense making process	
22	Visualization of graphs and hierarchies	
23	Visualization of text data	Project 5 out
24	Visualization of time-varying and time-series data	
25	Memorable visualizations, visual embellishments	
26	Evaluation and user studies	
27	Narrative visualization and storytelling	
28	Data journalism	

Three Key Visual Representations

Gestalt Principles:

- the tendency to perceive elements as belonging to a group, based on certain visual properties (top-down attention)

Saliency Map:

- pay attention to interesting detail first and then integrate these features into a scene (bottom-up attention)

Pre-attentiveness:

- certain low level visual aspects are recognized before conscious awareness

Visual variables:

- the different visual aspects that can be used to encode information

Gestalt

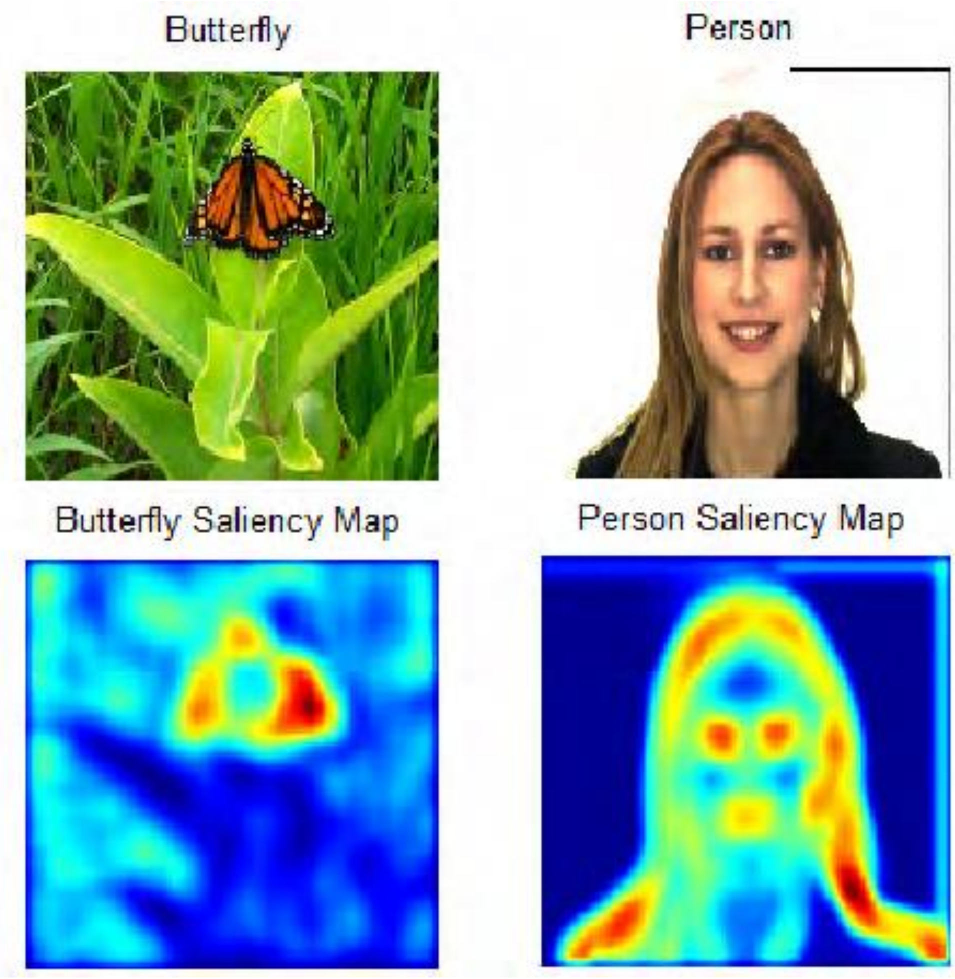
Concept of totality

- you grasp the "totality" of something before worrying about the details

saliency Map

Red: high saliency

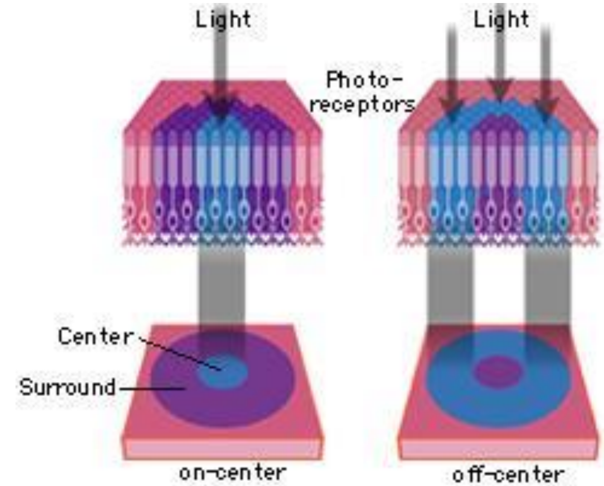
Blue: low saliency



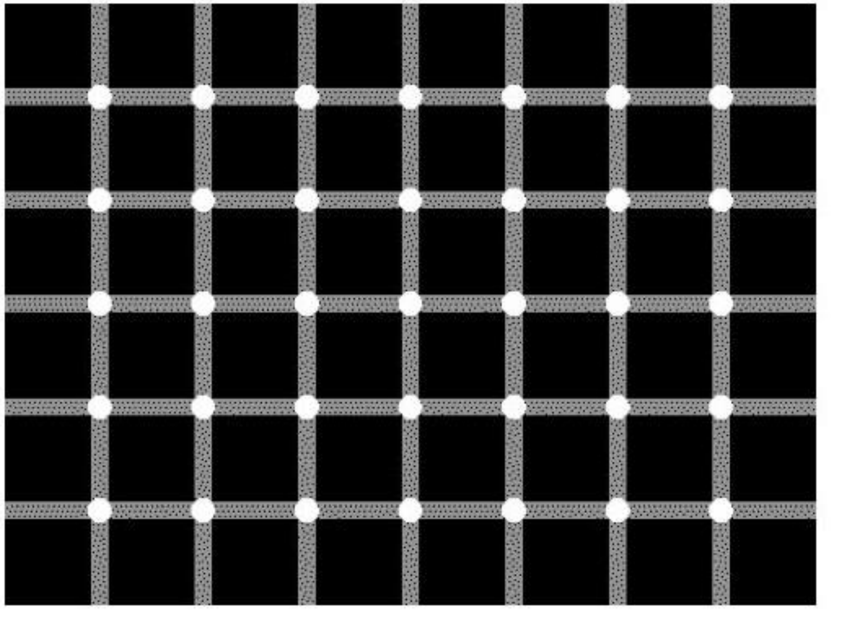
Center-Surround Detection

Center-surround receptive fields

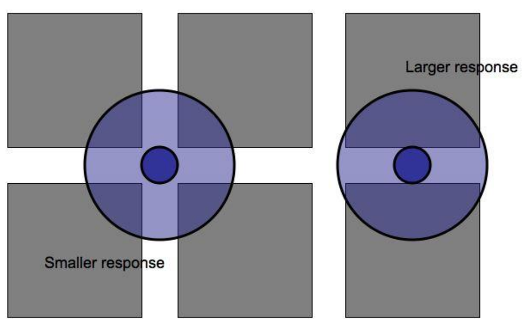
- a pool of photoreceptors
- surround has an inhibitory effect



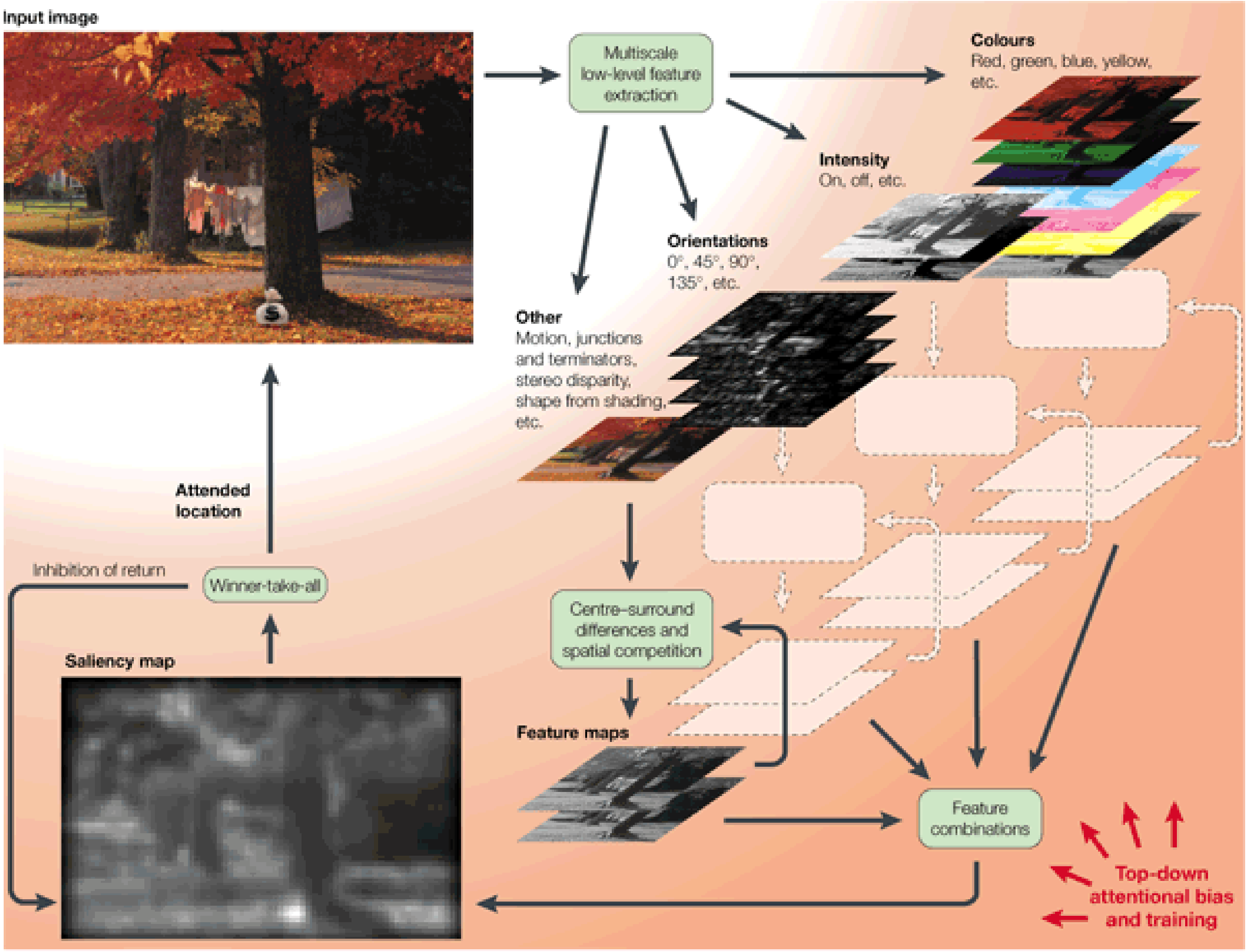
Stronger variant of the Hermann grid



Explanation of Hermann grid



Bottom-Up Visual Attention



Nature Reviews | Neuroscience

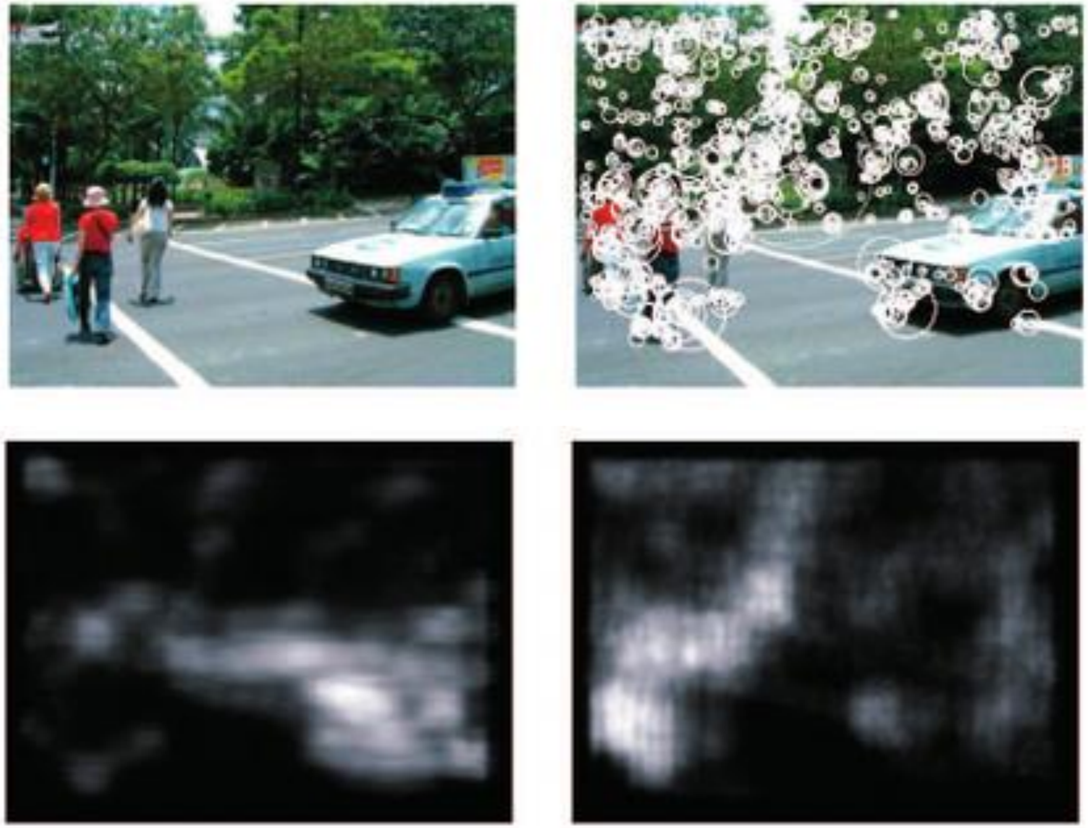
Bottom-Up and Top-Down

Probably occur in conjunction for scene recognition

top-down bottom-up

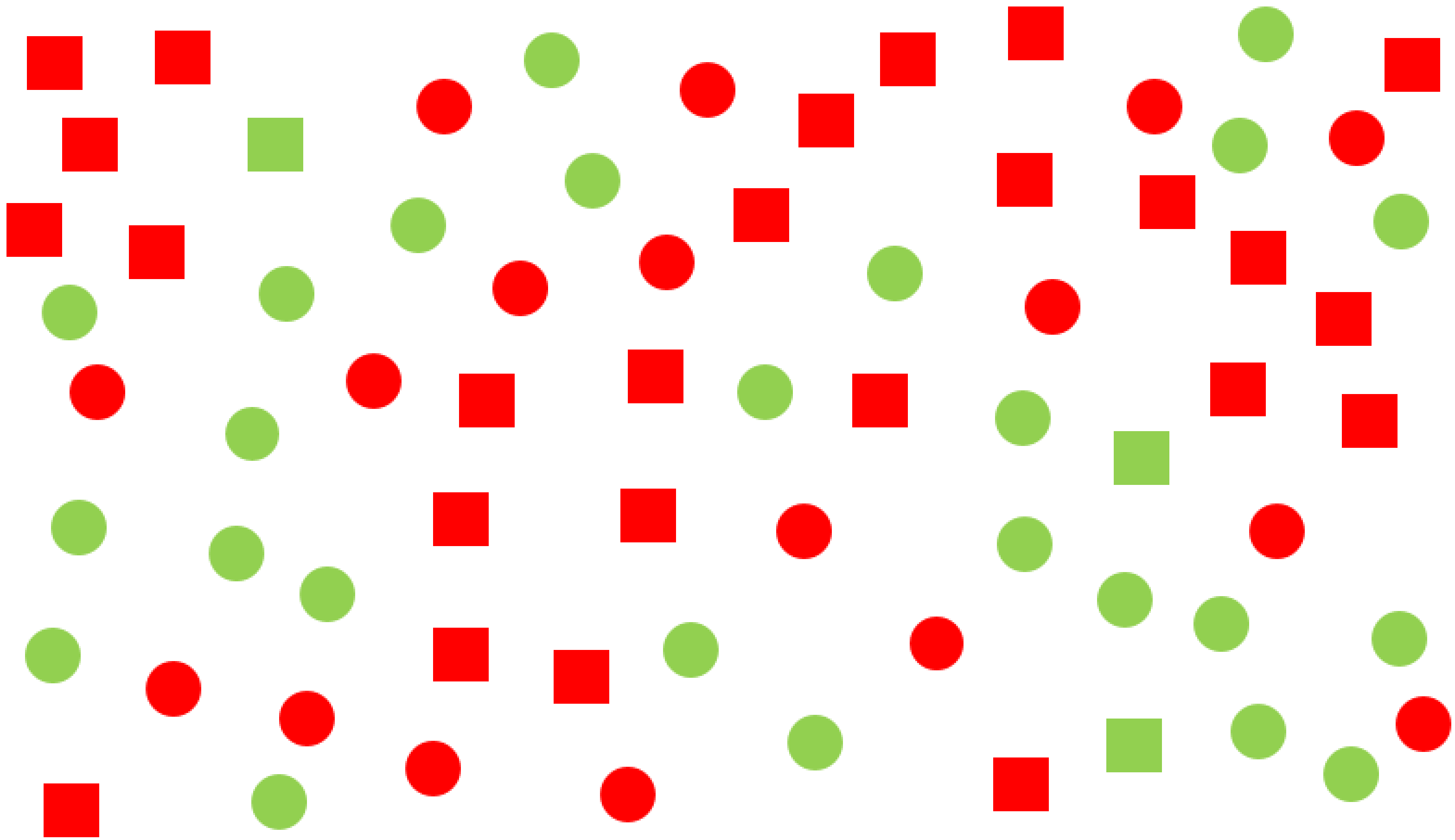
Filters

Saliency map



Pre-Attentiveness

Also called pop-out (multiple conjunctions shown here):



Which Popped-out Faster

Color (red vs. green)

Shape (circle vs. square)

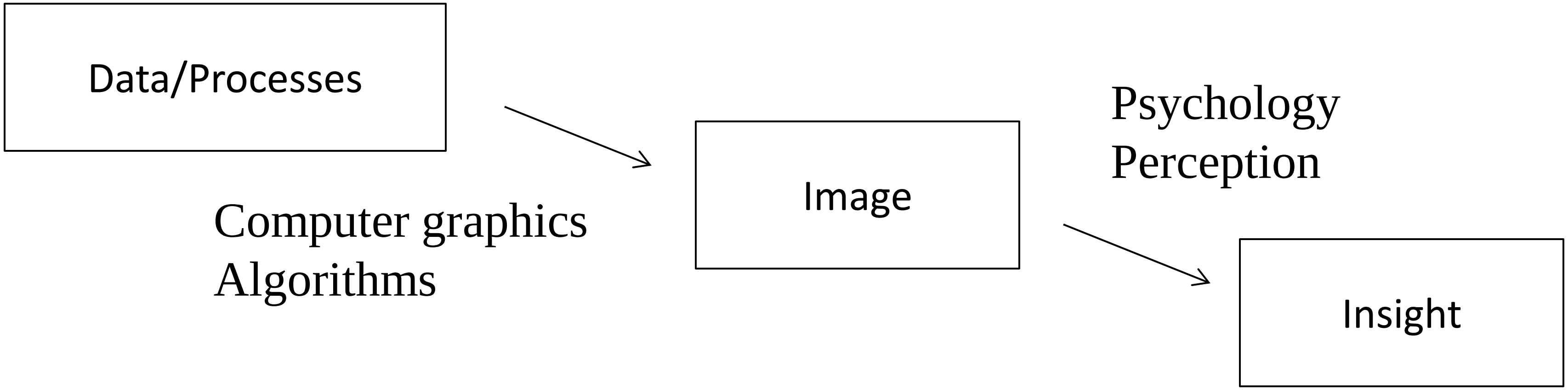
popup

Visual Variables

Formal theory linking perception to visualization

Established by Jacques Bertin (1967)

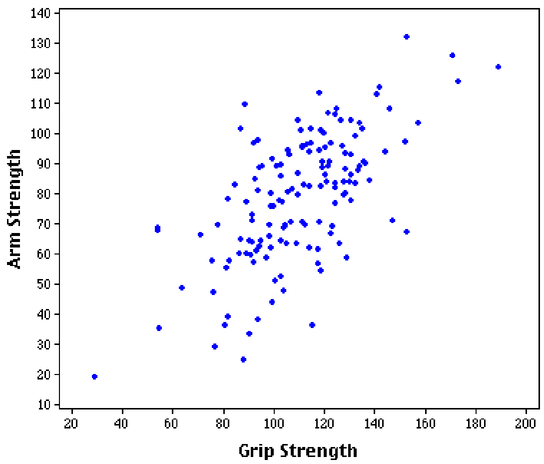
- he called it ‘Image Theory’
- original book in French (*Sémiologie Graphique*) translated into English by W. Berg (1983)
- not formally linked to vision research more based on intuition
- but has been shown later by M. Green to be quite accurate



Visual Variables

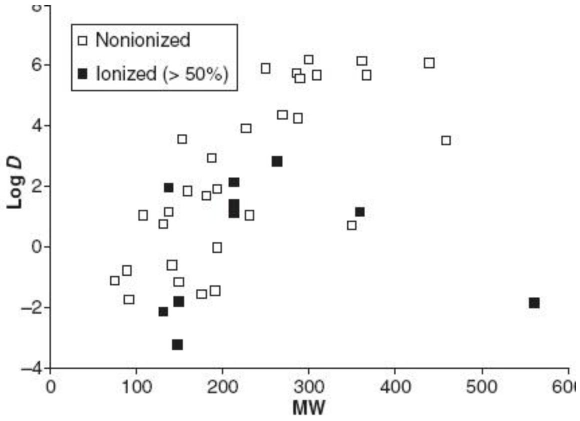
Two planar variables

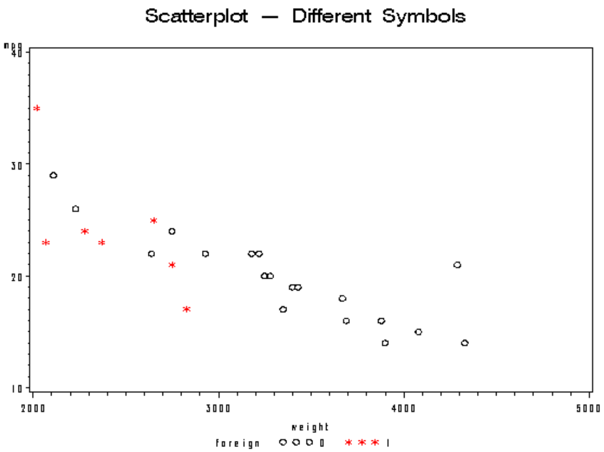
- spatial dimensions
- map (arm, grip) to (x,y)



Six retinal variables

- size
- color
- shape
- orientation
- texture
- brightness





Retinal variables allow for one more variable to be encoded

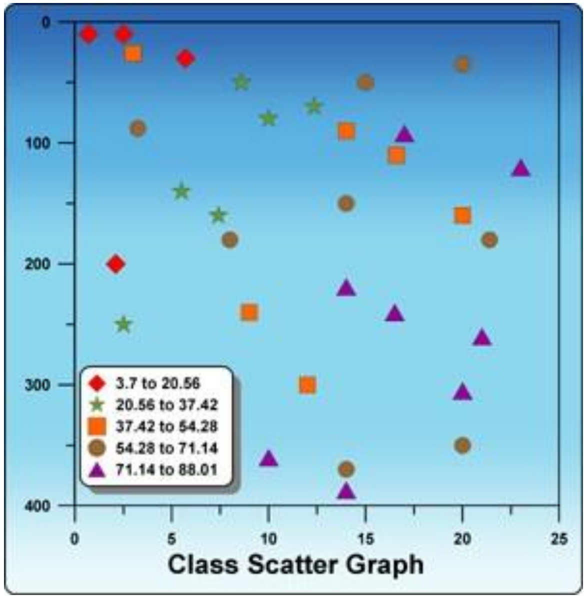
- more than three variables will hamper efficient visual search
- recall low decoding speed of conjunctions

Associative vs. Selective

Both are nominal qualities

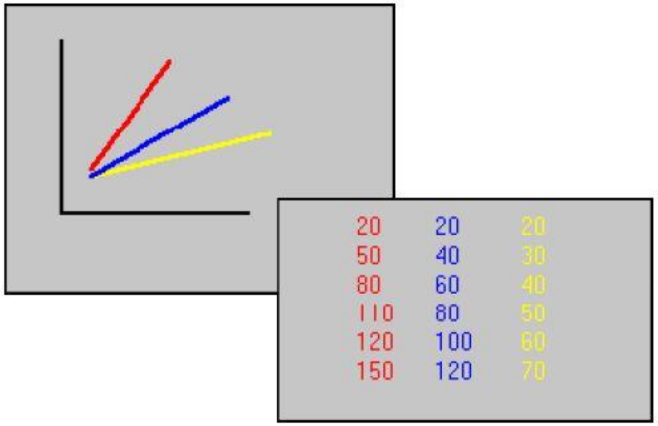
Associative

- lowest organizational level
- enables **visual grouping** of all elements of a variable



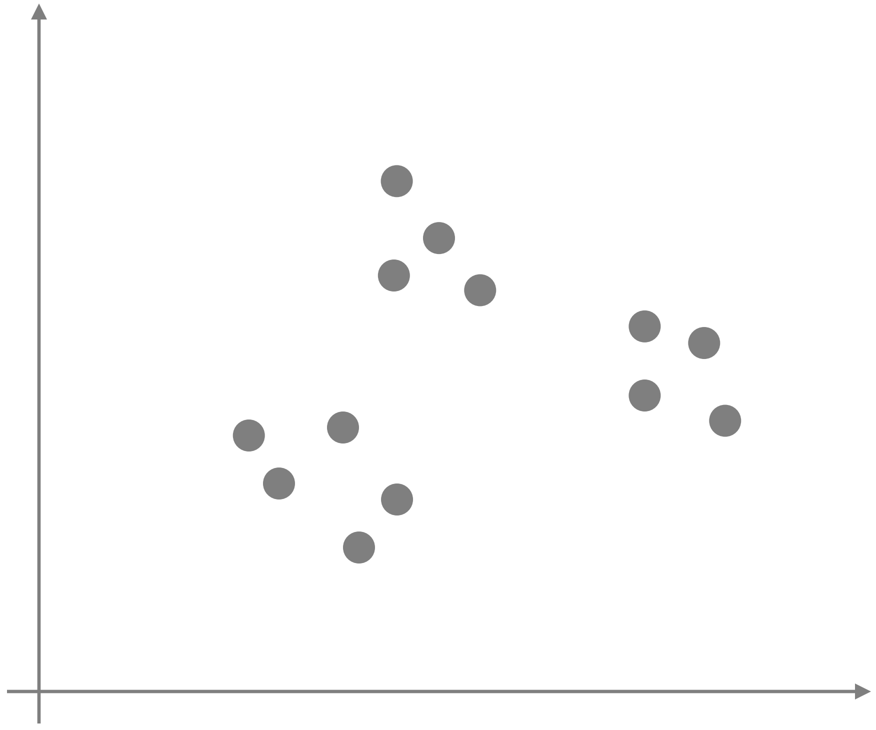
Selective

- next lowest level
- enables viewer to **isolate encoded data** and ignore others



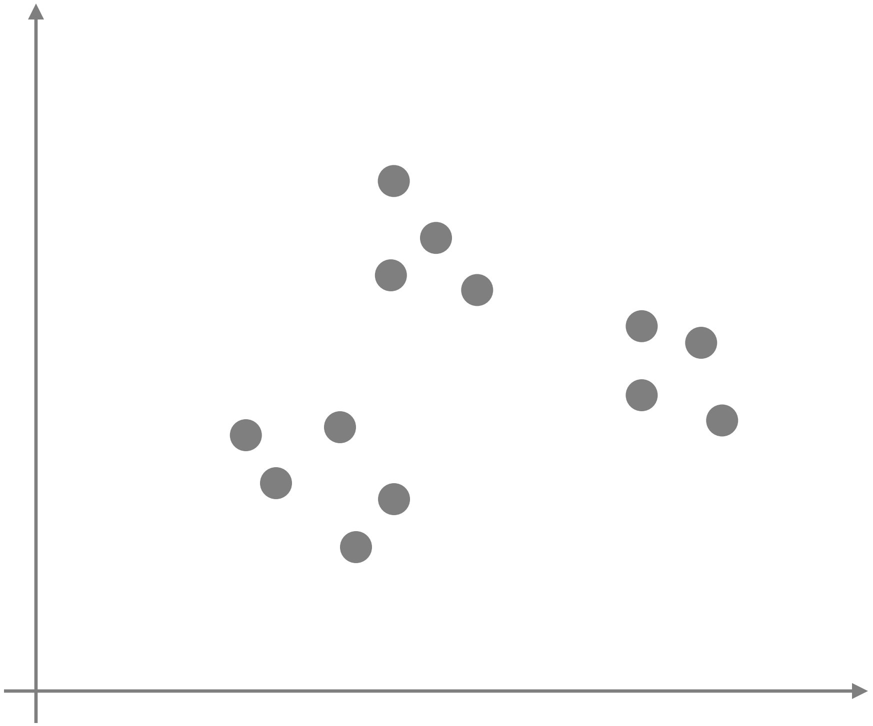
Visual variable #1 – Planar

Visual property	Can convey
Associative	
Selective	
Ordered	
Quantitative	



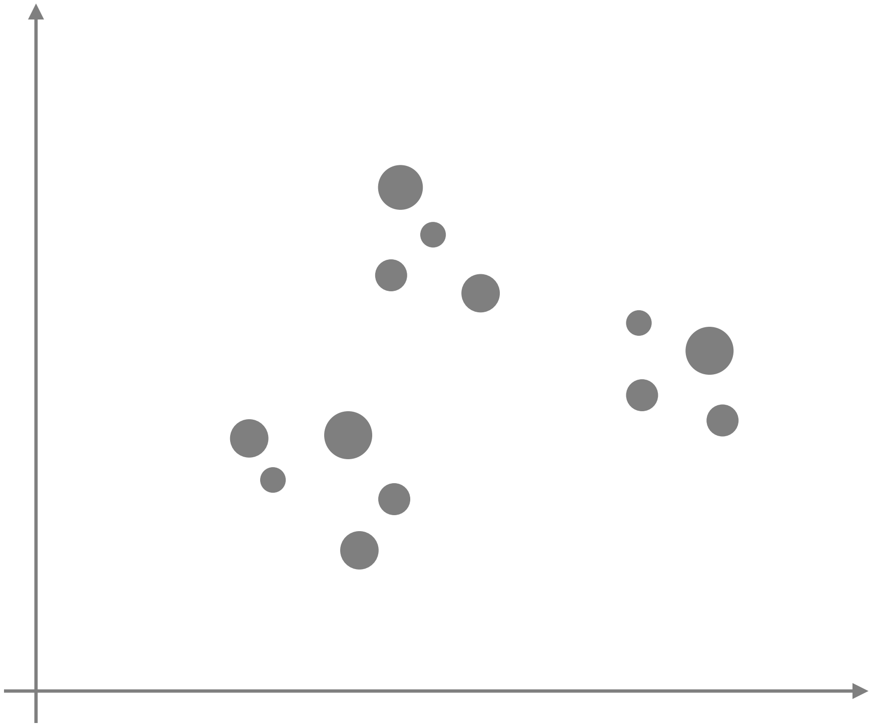
Visual variable #1 – Planar

Visual property	Can convey
Associative	Y
Selective	Y
Ordered	Y
Quantitative	Y



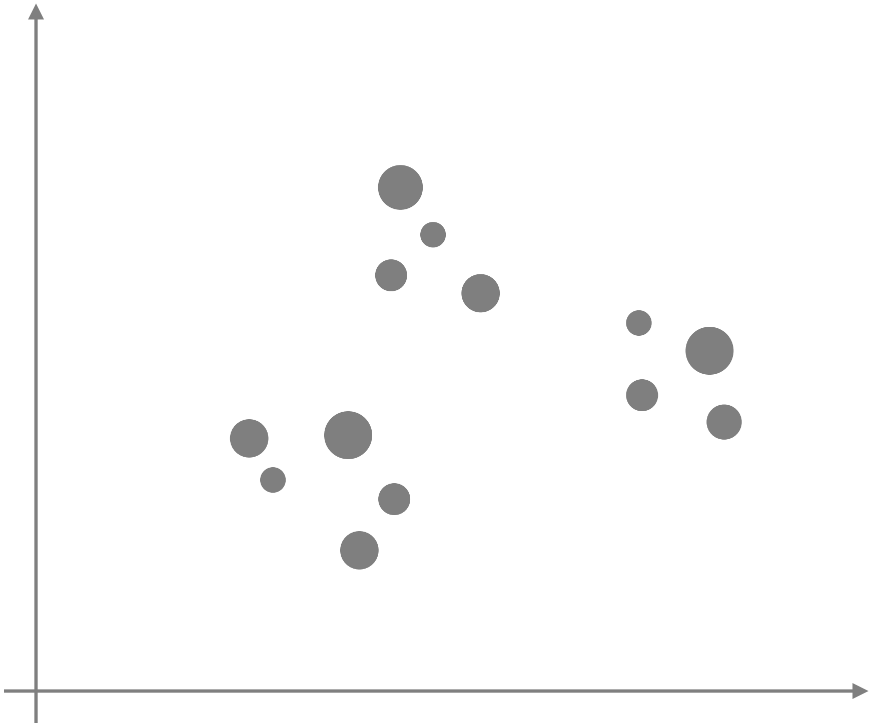
Visual variable #2 – Size

Visual property	Can convey
Associative	
Selective	
Ordered	
Quantitative	



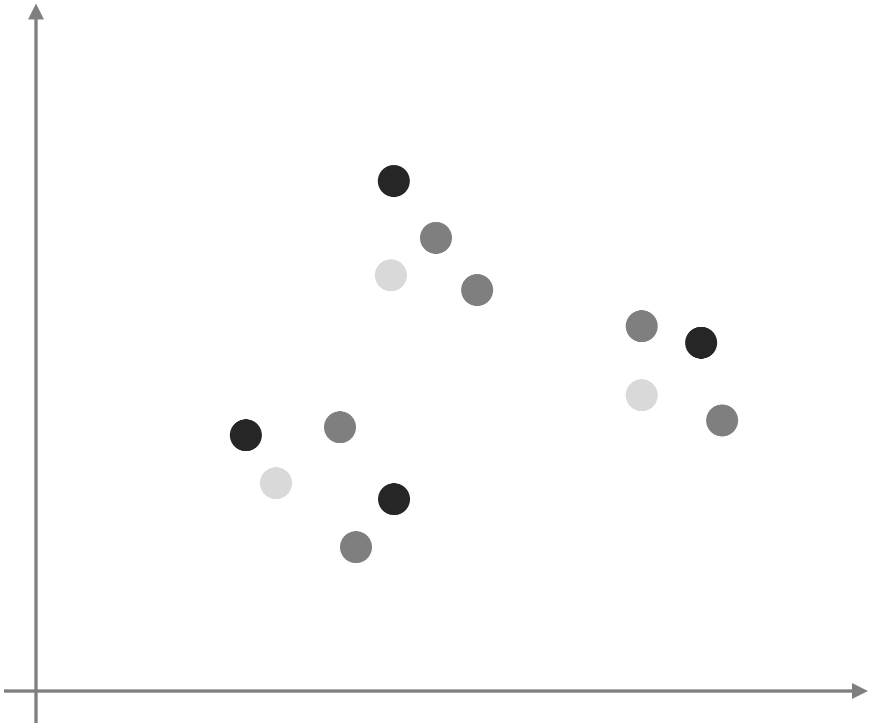
Visual variable #2 – Size

Visual property	Can convey
Associative	Y
Selective	Y
Ordered	Y
Quantitative	(Y)



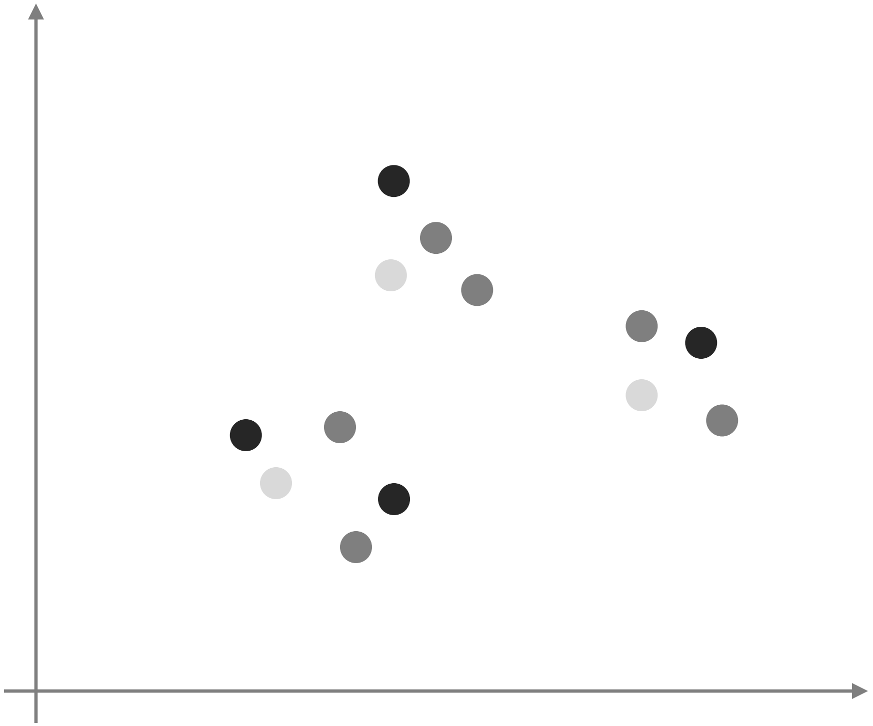
Visual variable #3 – Brightness

Visual property	Can convey
Associative	
Selective	
Ordered	
Quantitative	



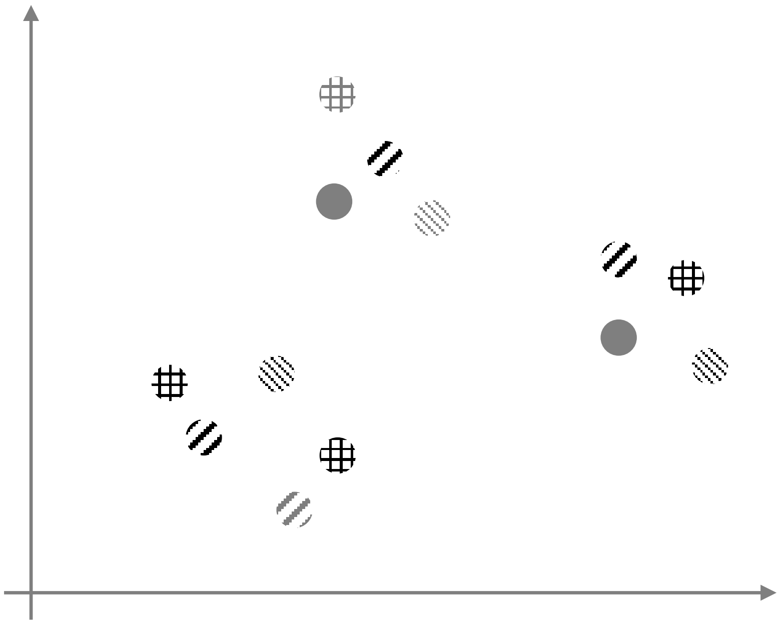
Visual variable #3 – Brightness

Visual property	Can convey
Associative	Y
Selective	Y
Ordered	Y
Quantitative	



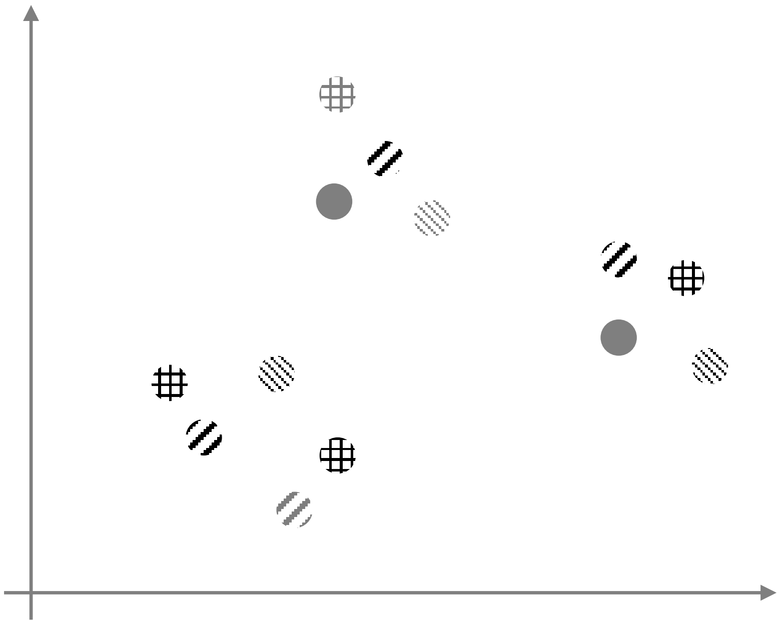
Visual variable #4 – Texture

Visual property	Can convey
Associative	
Selective	
Ordered	
Quantitative	



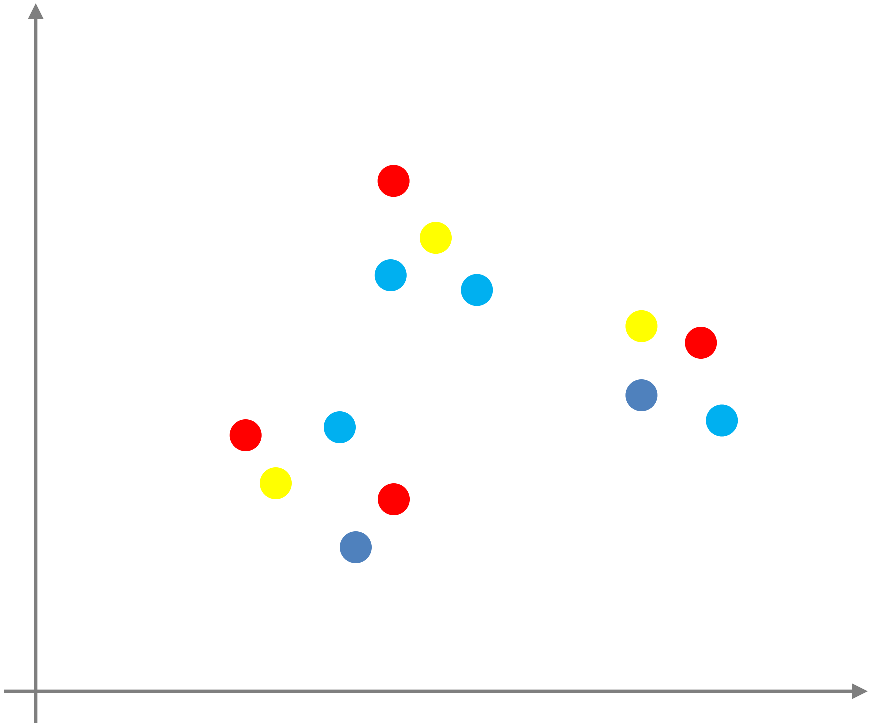
Visual variable #4 – Texture

Visual property	Can convey
Associative	Y
Selective	Y
Ordered	
Quantitative	



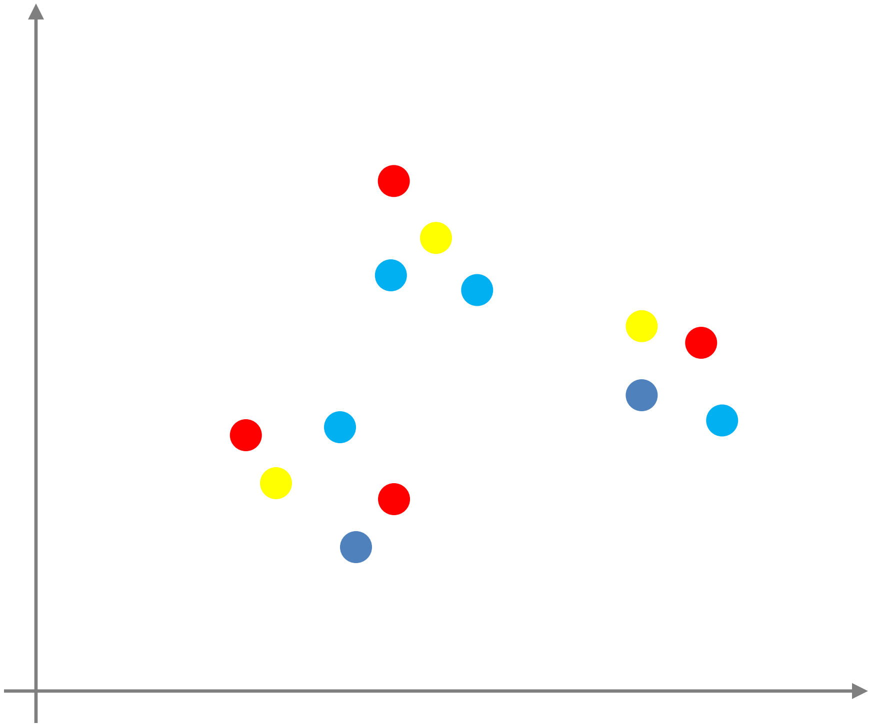
Visual variable #4 – Color

Visual property	Can convey
Associative	
Selective	
Ordered	
Quantitative	



Visual variable #4 – Color

Visual property	Can convey
Associative	Y
Selective	Y
Ordered	
Quantitative	



Visual variable #5 – Orientation

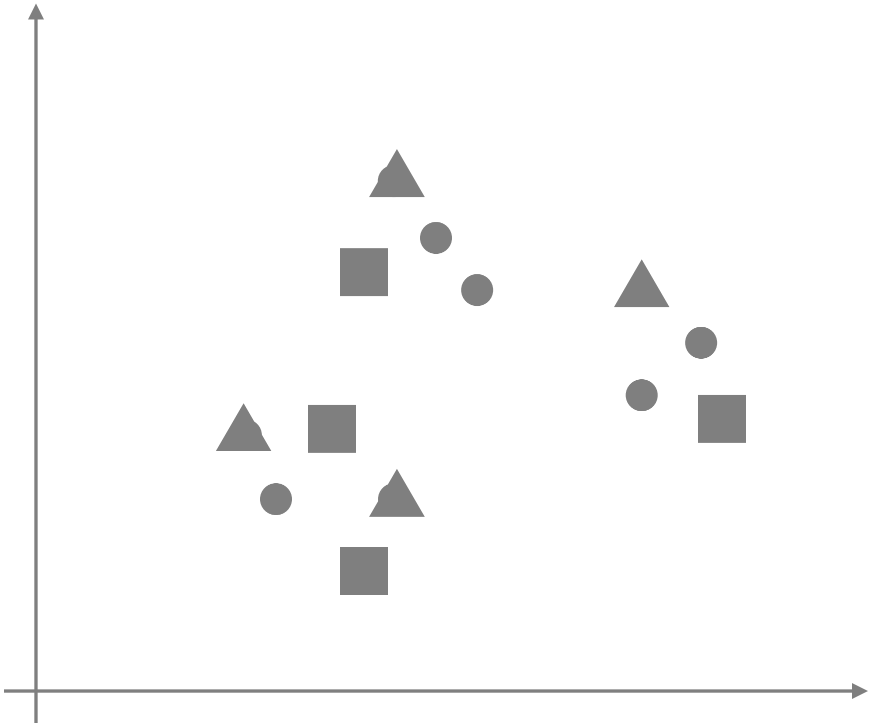
Visual property	Can convey
Associative	
Selective	
Ordered	
Quantitative	

Visual variable #5 – Orientation

Visual property	Can convey
Associative	(Y)
Selective	(Y)
Ordered	
Quantitative	

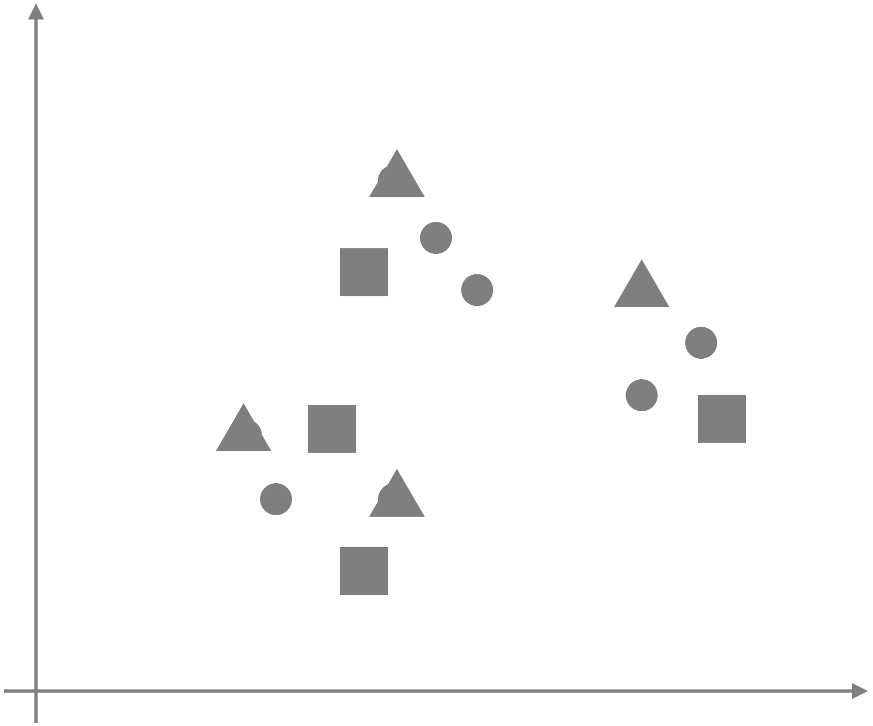
Visual variable #6 – Shape

Visual property	Can convey
Associative	
Selective	
Ordered	
Quantitative	



Visual variable #6 – Shape

Visual property	Can convey
Associative	(Y)
Selective	(Y)
Ordered	
Quantitative	



Levels of Organization

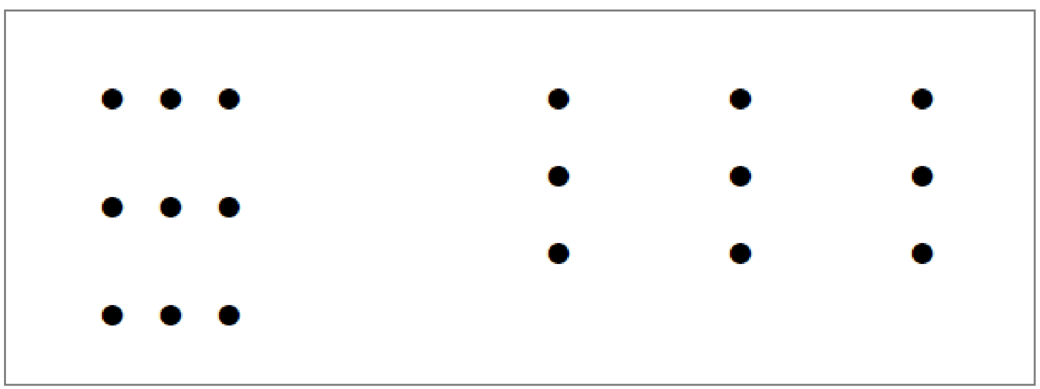
Visual variables differ in what data properties they can convey

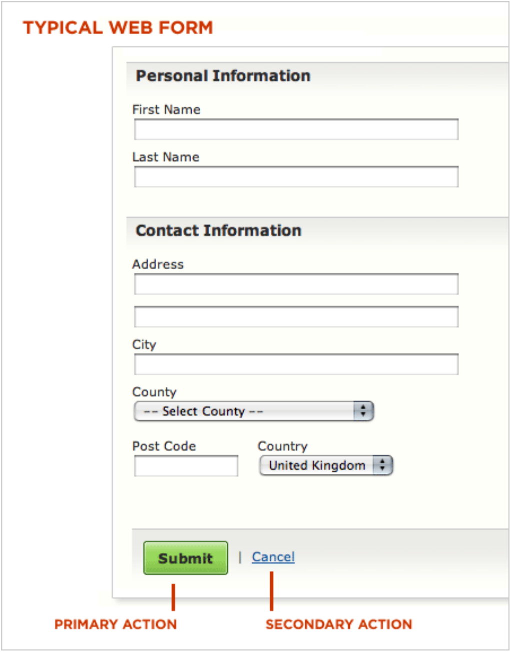
	Associative	Selective	Ordered	Quantitative
Planar	yes	yes	yes	yes
Size	yes	yes	yes	(yes)
Brightness (Value)	yes	yes	yes	
Texture	yes	yes		
Color (Hue)	yes	yes		
Orientation	(yes)	(yes)		
Shape	(yes)	(yes)		

Take-Aways (1)

Planar variable is the single most strongest visual variable

- maps to proximity
- provides an intuitive organization of information
- things close together are perceptually grouped together





Take-Aways (2)

Size and brightness are good secondary visual variables to encode *relative* magnitude

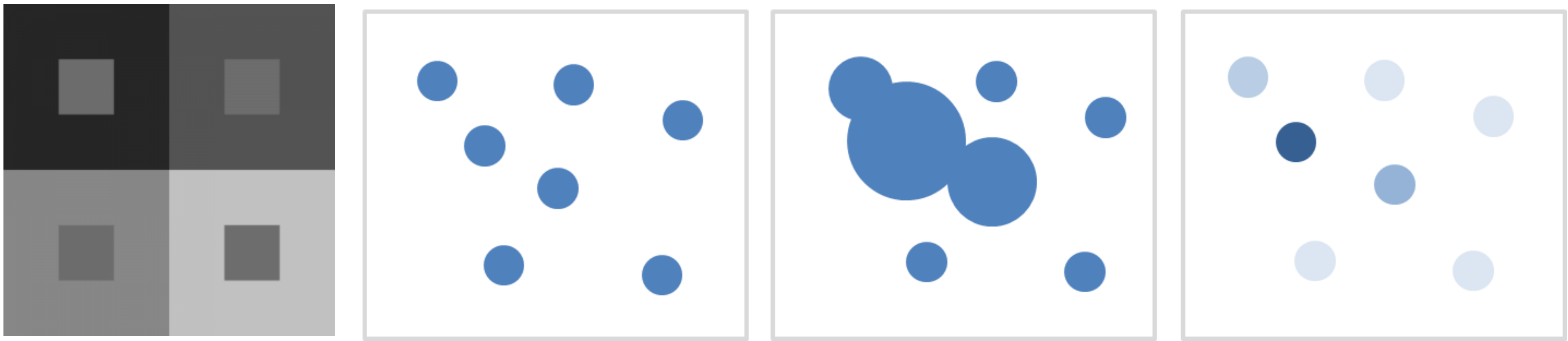
- size appeals to spatial perceptive channels

What are the advantages and disadvantages of brightness

+ brightness does not consume extra space (bigger disks do)

- brightness depends on environmental lighting (size does not)

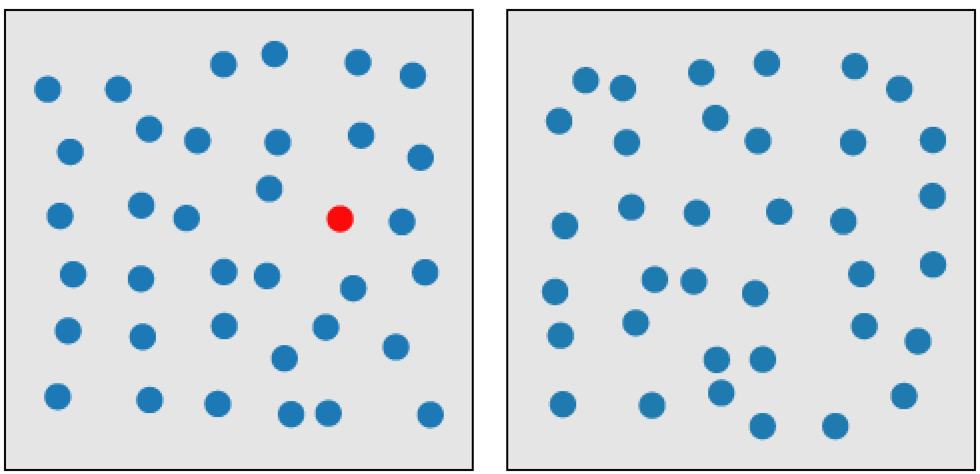
where do you view the visualization (office, outdoors, night or day?)



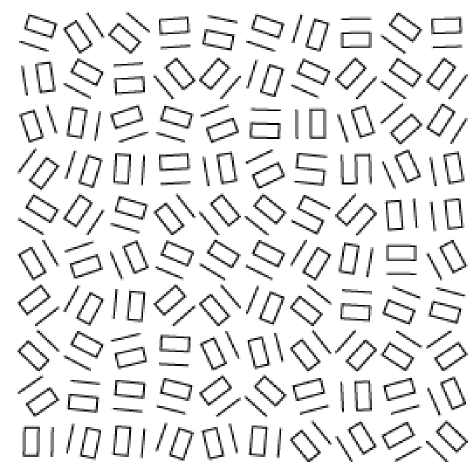
Take-Aways (3)

Color is a good visual variable for labeling

- texture can do this as well, but it does not support pop-out much



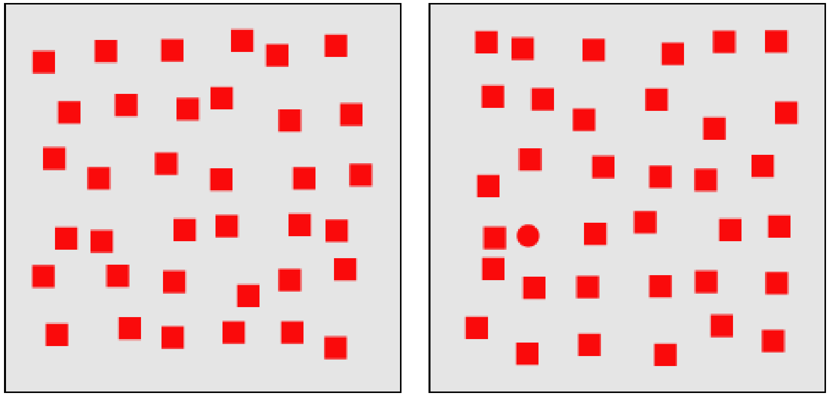
color pop-out



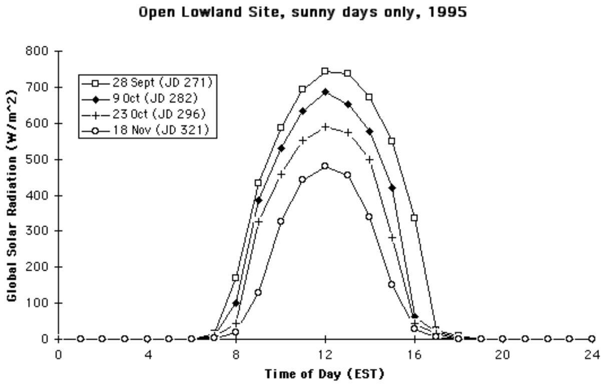
texture pop-out?

TAKE AWAYS (4)

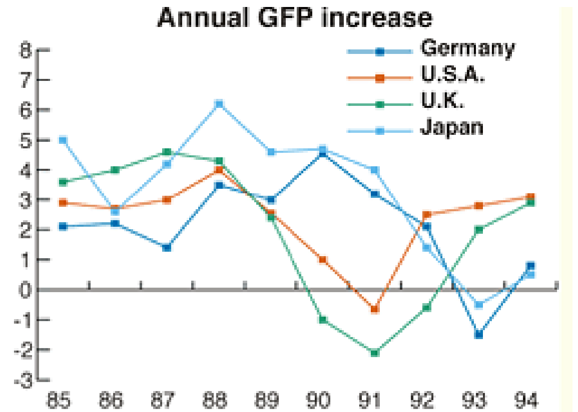
Shape provides only limited pop-out



- compare with color pop-out on the previous slide
- another example: coloring of graphs



vs.



Color and Contrast

Background with same-colored object at the same brightness

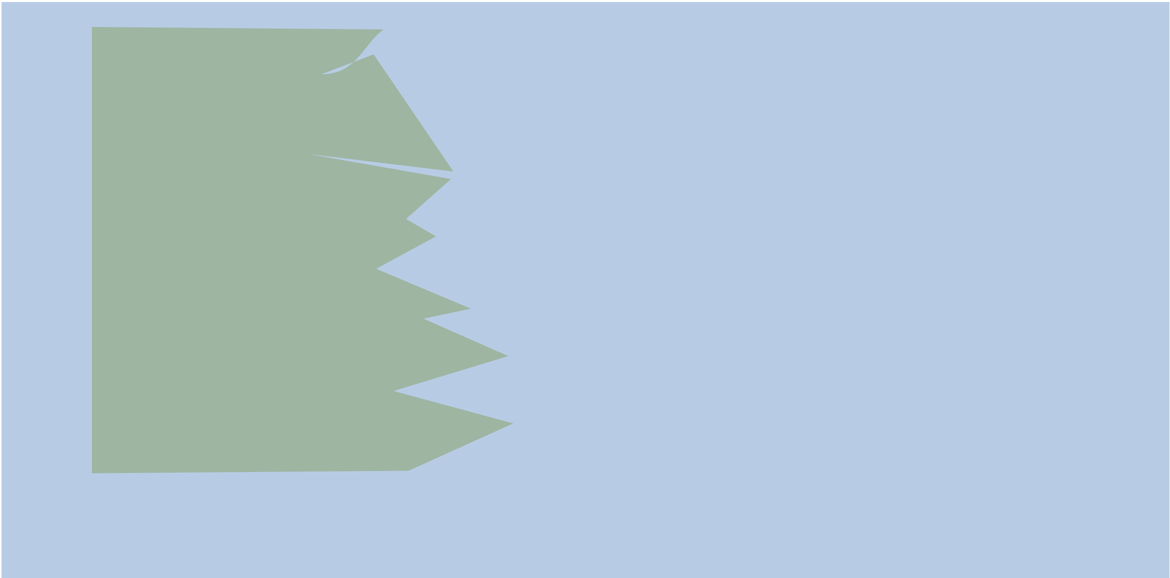
- can you see the shape?
- can you count the number of gaps?

Color and Contrast

Background with different-colored object at similar brightness

- can you see the shape?
- can you count the number of gaps?

Color and Contrast



Background with different-colored object at lower brightness

- can you see the shape?
- can you count the number of gaps?

Color and Contrast

Background with different-colored object at higher brightness

- can you see the shape?
- can you count the number of gaps?

What Did we Learn from that Experiment?

Color is for …

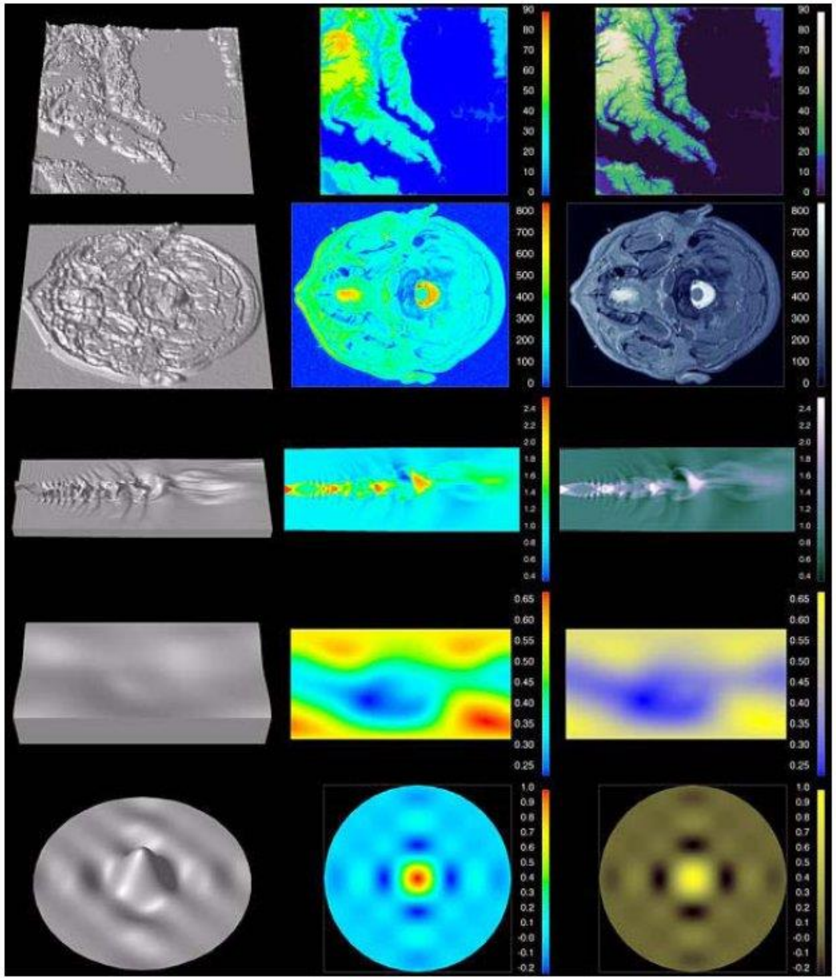
Brightness (intensity, luminance) is for …

What Did we Learn from that Experiment?

Color is for … labeling

Brightness (intensity, luminance) is for … fine detail contrast

Luminance and Hue

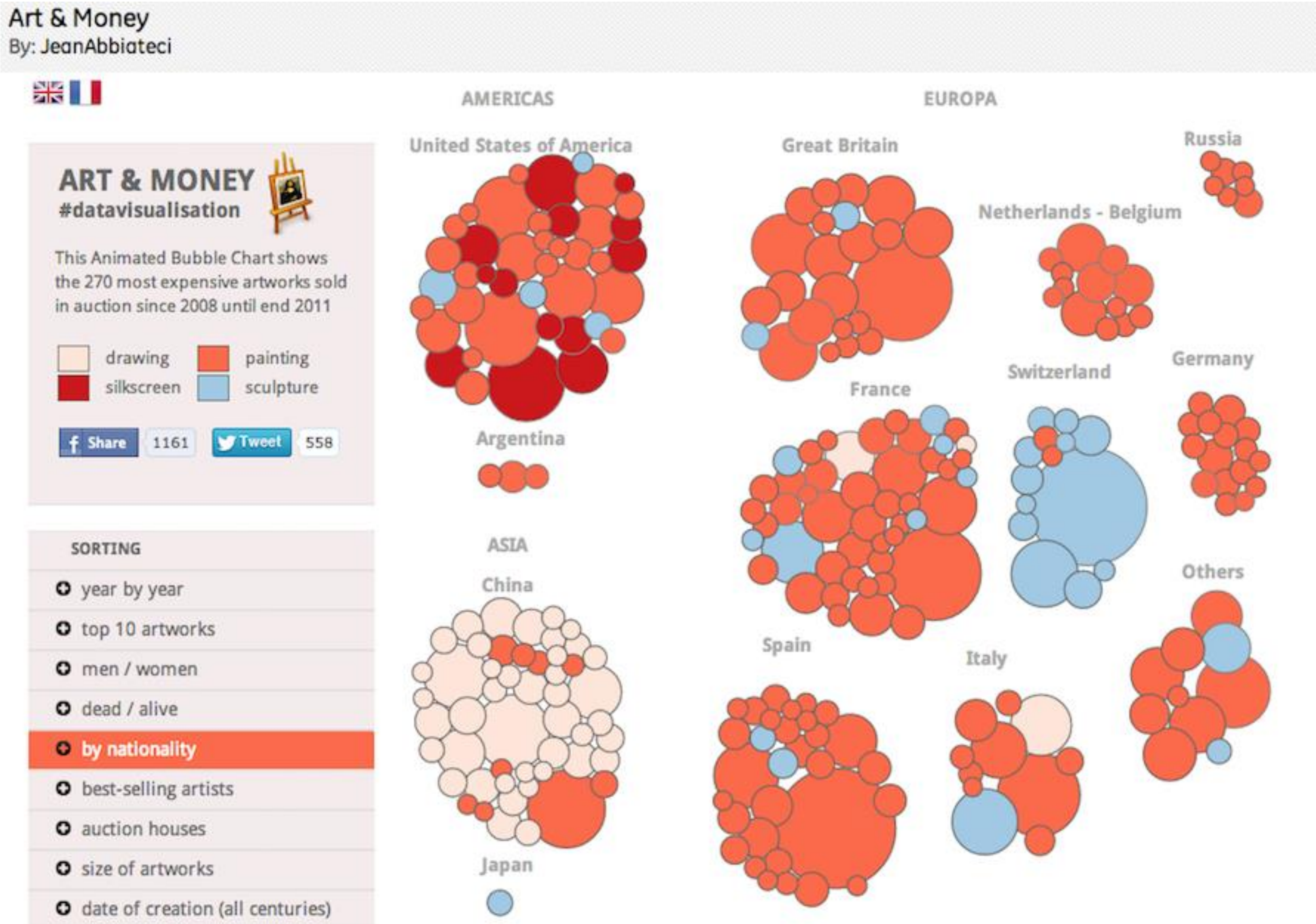


luminance mapped to height — just hue — hue and luminance

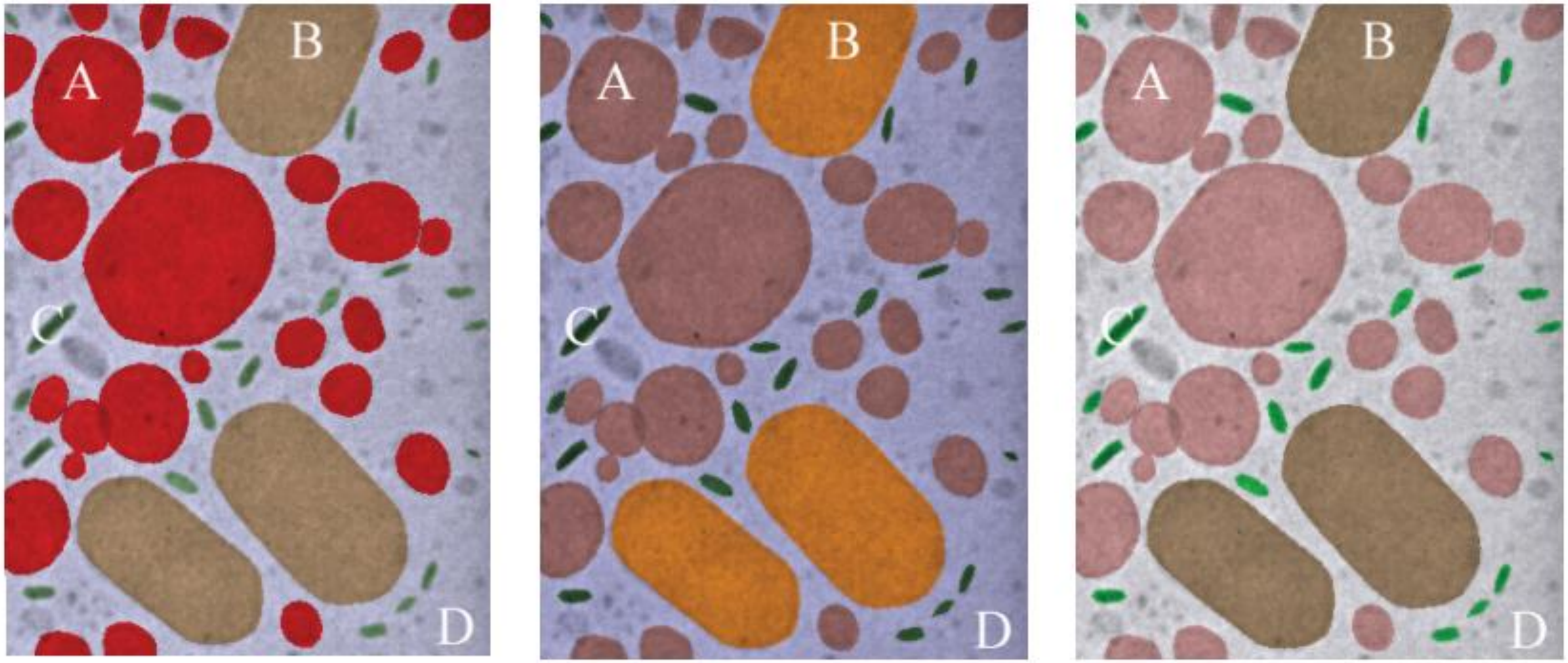
encode high frequency information by L

from Bergman/Rogowitz/Treinish Vis'95

Role of Saturation



Color Tagging for Importance

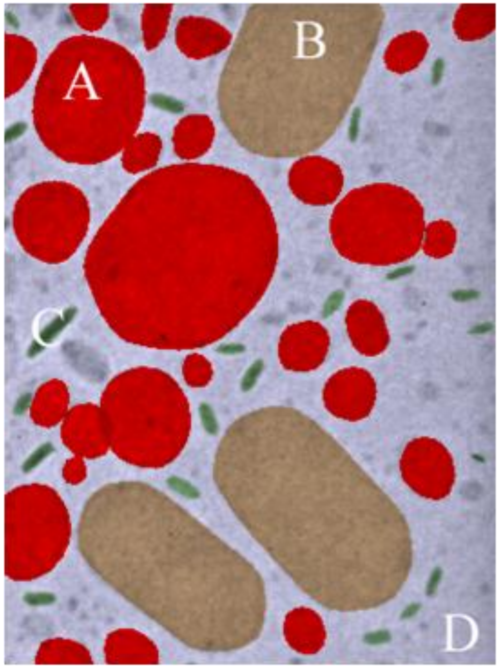


Which is the most important structure in each (as intended by the author)

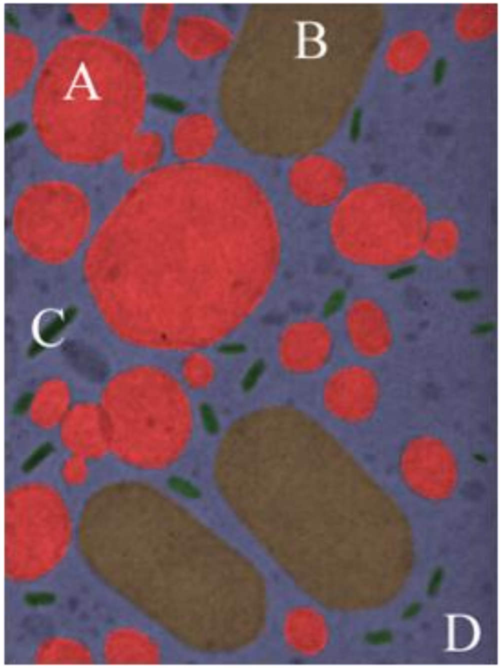
How About Aesthetics?

Which one do people like better?

- perceived importance level of red object is the same

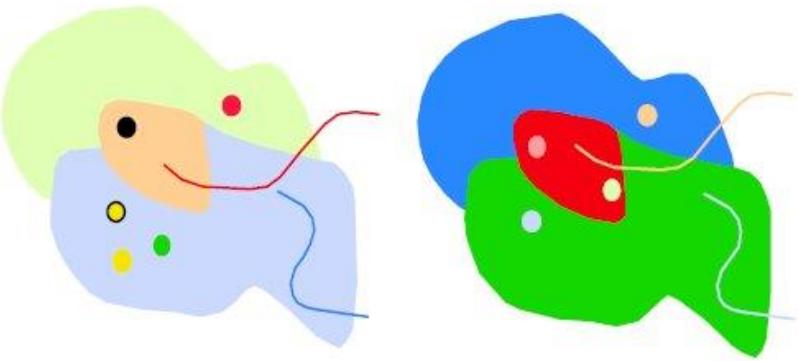


Vis 1



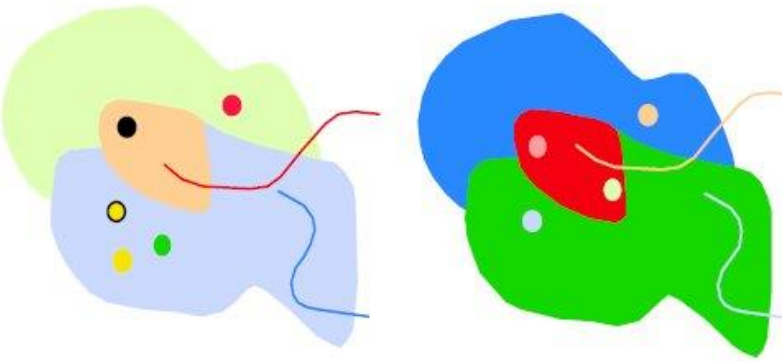
Vis 2

Color Coding and Colormaps



- Color coding
  - large areas: low saturation
  - small areas: high saturation
  - maintain luminance contrast
  - break iso-luminances with borders
- Pseudo-coloring: assign colors to grey levels by indexing the grey levels into a color map

Color Coding and Colormaps



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  - large areas: low saturation
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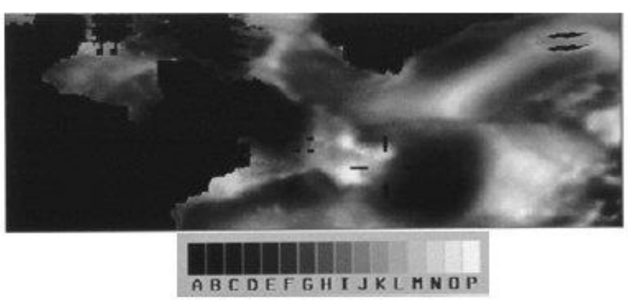
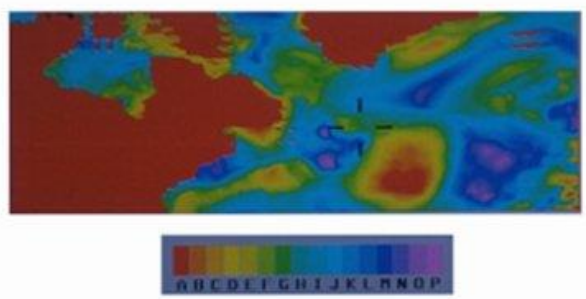
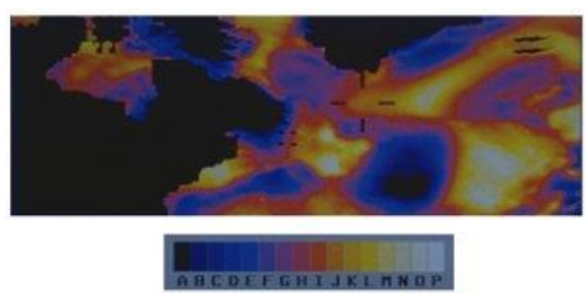


original greylevel map



simple spectrum sequence with iso-luminance



more effective:

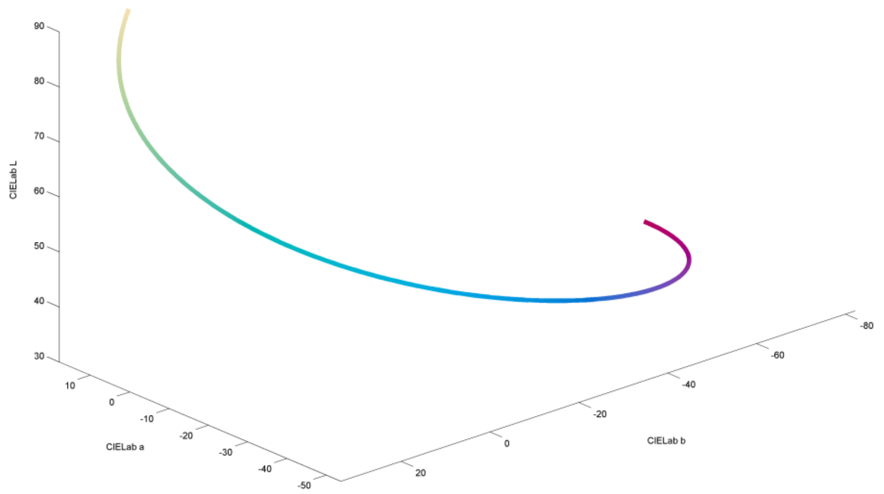
spiral sequence through color space

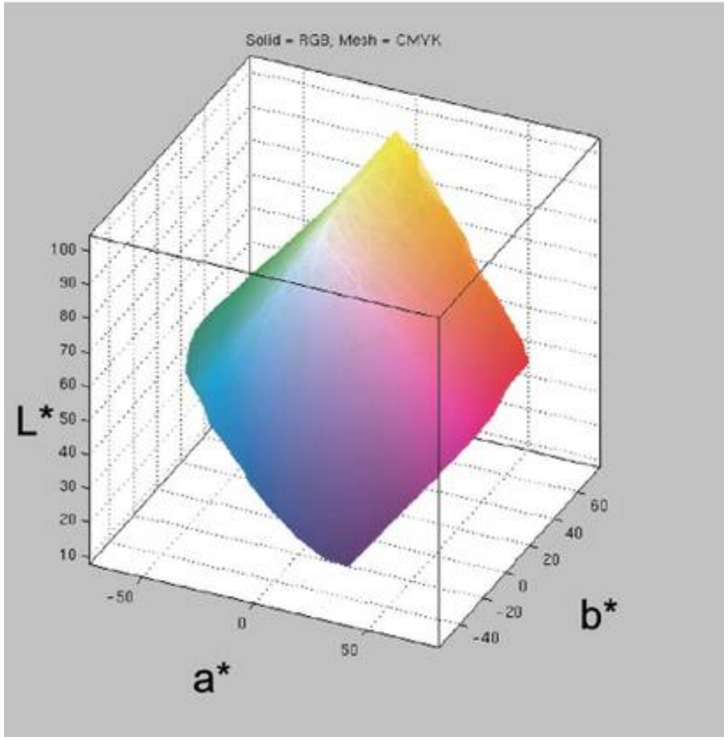
luminance increases with hue

Spiral Through Color Space

Varies hue and intensity at the same time

- shown here: CIE Lab color space





The Rainbow Colormap

As we saw, colors can add detail information to a visualization

- instead of 256 levels get 256^3 = 16,777,216

Oftentimes you have a visualization with just one variable

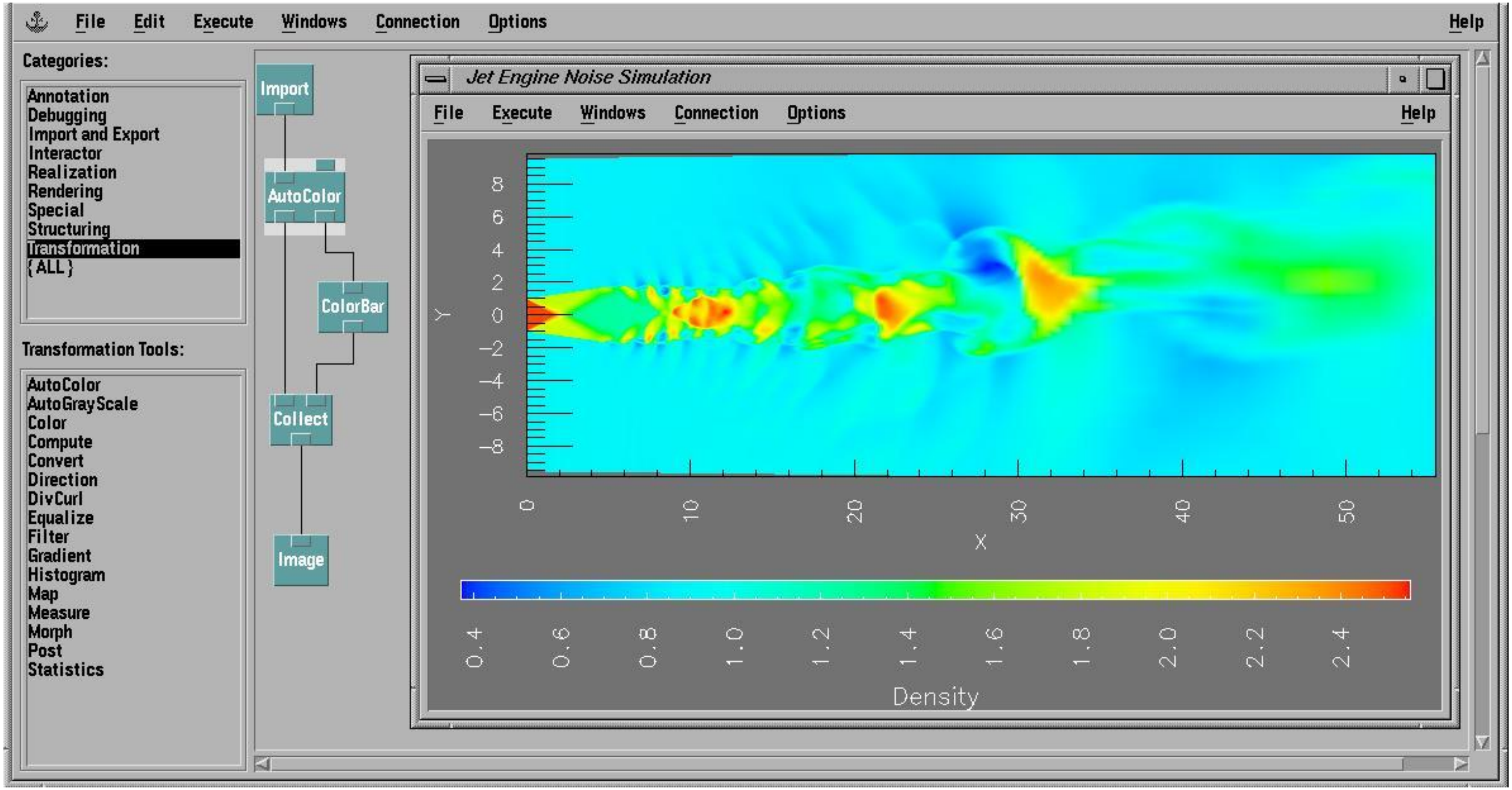
- this would give you a grey level image
- how to turn this into a color image for better detail

Solution 1:

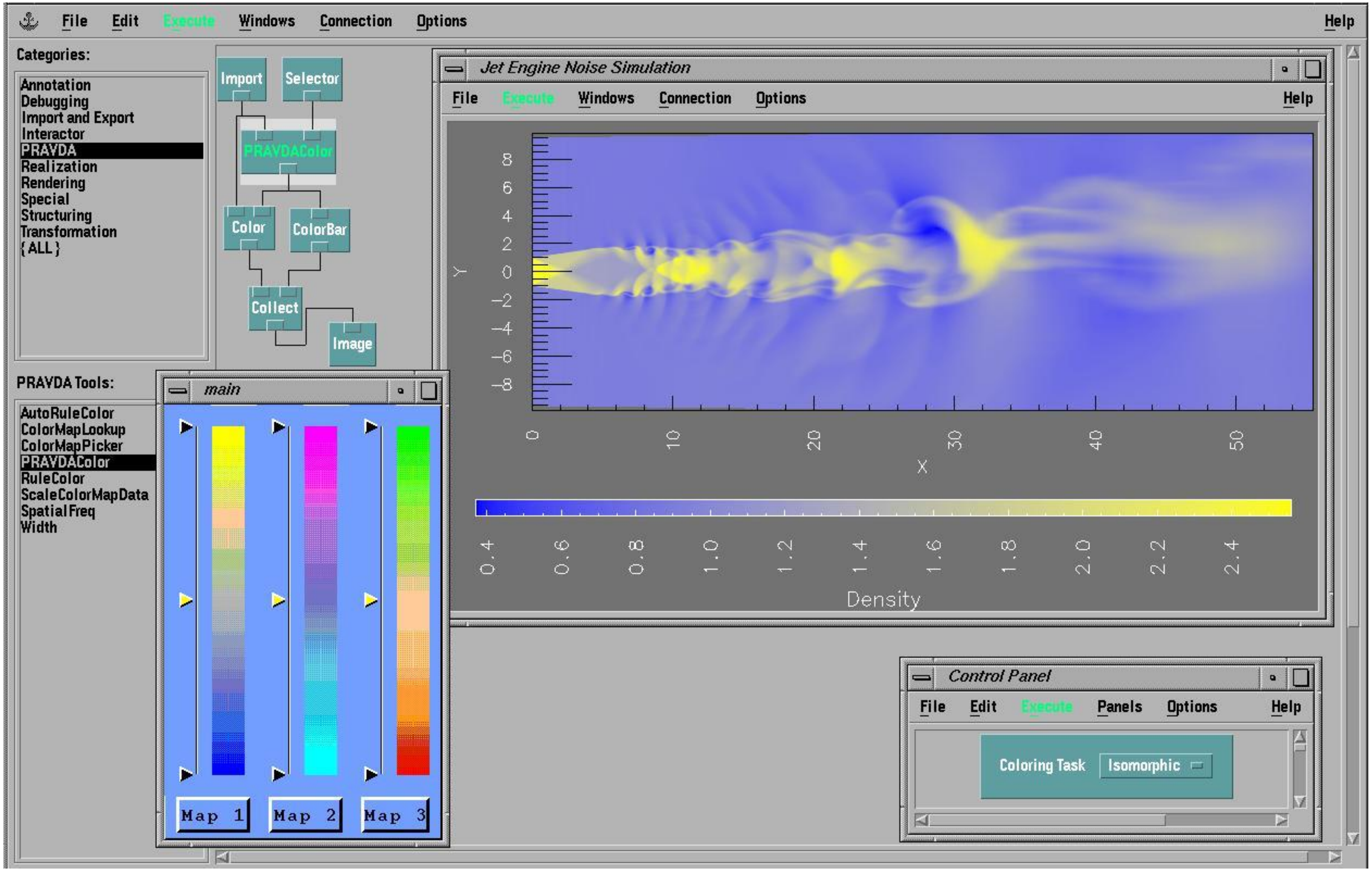
- map to hue → the rainbow colormap

- can you see all adjacent colors at the same contrast?

Avoid rainbow Colormaps



Better: Linear Hue



Effective Use of Rainbow Color maps

Wait, did I not tell you that rainbow color maps are bad?

- actually, they can be useful if the intervals are carefully chosen

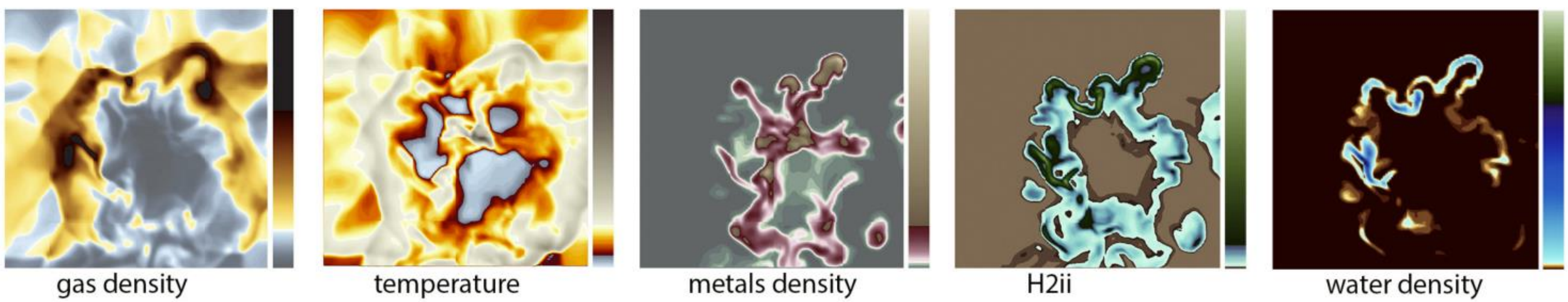
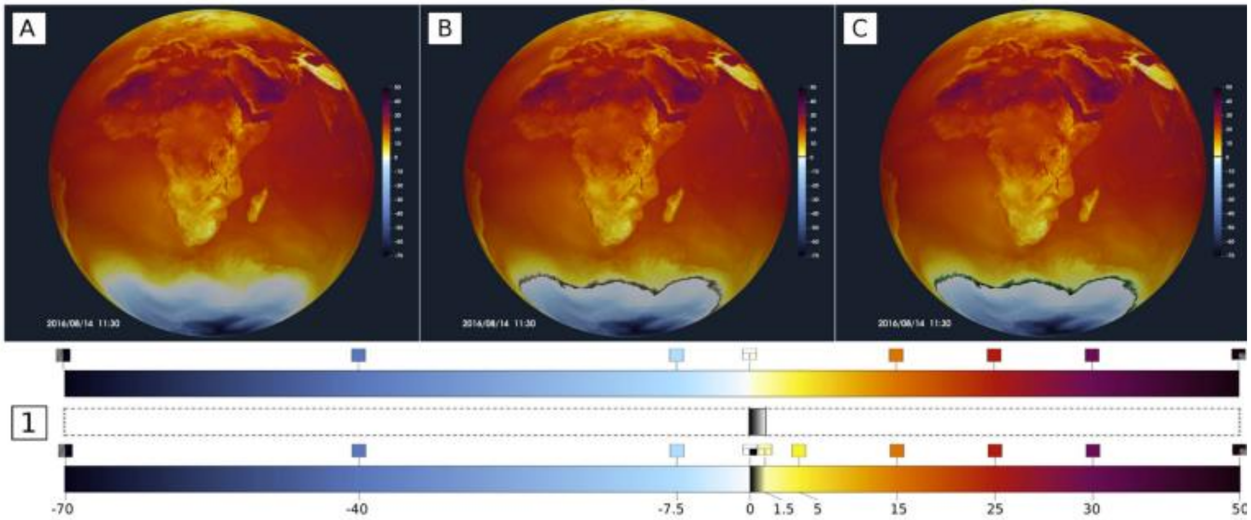
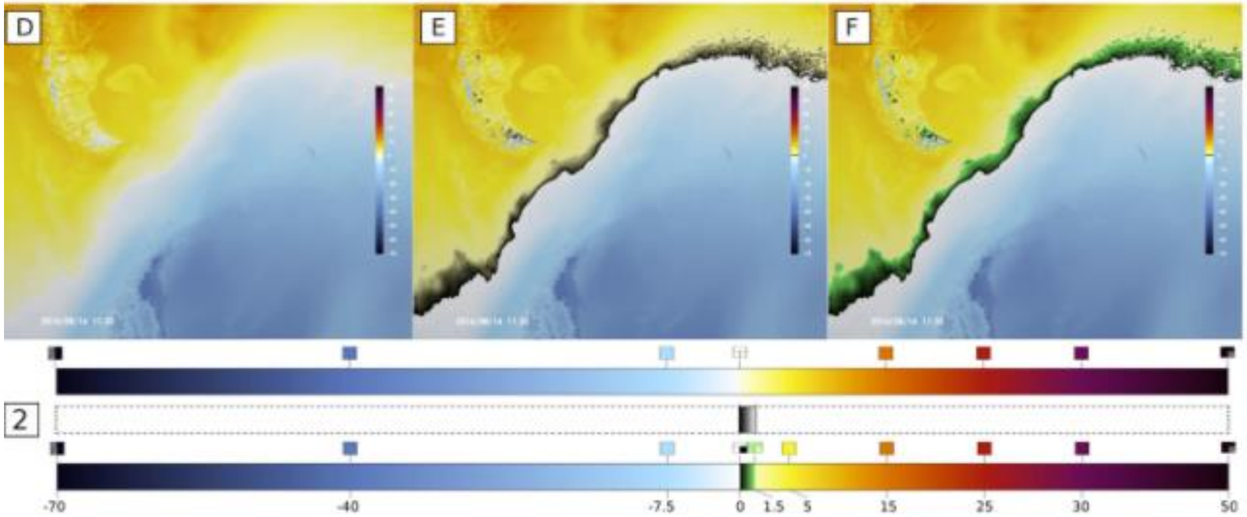


Fig. 15. Scientists examine multiple variables in order to gain an understanding into the locations and quantities where ancient water was likely to have formed. CCC-Tool color bar locations are crafted to highlight the data ranges for each variable that is conducive to water formation, enabling scientists to easily recognize and compare the locations over multiple variables and time steps.

Nardini et al. “The Making of Continuous Colormaps” IEEE TVCG, VOL. 27, NO. 6, 2021

More Purposeful Rainbow Colormaps





also Nardini et al.

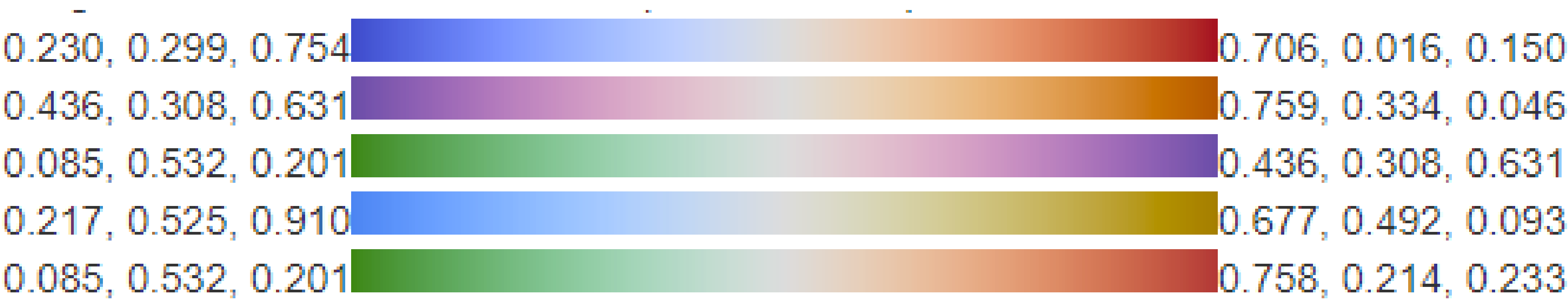
Explanation for Last Slide

At the example of the 2m-temperature of a high resolution simulation with the global atmosphere model ICON, the figure illustrates the use of probes to inspect small sub-ranges of the global data range. The rendering on the left (A) shows the the global temperature distribution with colormapping using a CMS (inset 1, top) that was designed to resolve the data range from -70 to 50C. However, within small sub-regions, as shown in a close-up (D), only a small section of the CMS is used and local structures are hardly visible. In order to probe the temperature range 0 - 1.5C in more detail, we added single probe at 0C to compose a CMS (1, bottom) that creates an isoline-like-structure to highlight the freezing point and the data range above. The images (B) and (E) show the result for a One-Sided-Transparent-Probe. The according colormap composition is shown in inset (1). Similarly, (C) and (F) show the according renderings for One-Sided-Probe according to the definition shown in inset (2, middle). (1: Top: Divergent CMS for the 2m-temperature. Middle: one sided transparent probe for the range 0 - 1.5C. Bottom: resulting colormap. 2: One sided probe without transparency.)

Moreland's Diverging Colormaps

Algorithmically generated

- all have the same midpoint value (0.865, 0.865, 0.865)
- begin and end point listed here



https://www.kennethmoreland.com/color-maps/

Brewer Scales

Nominal scales

- distinct hues, but similar emphasis

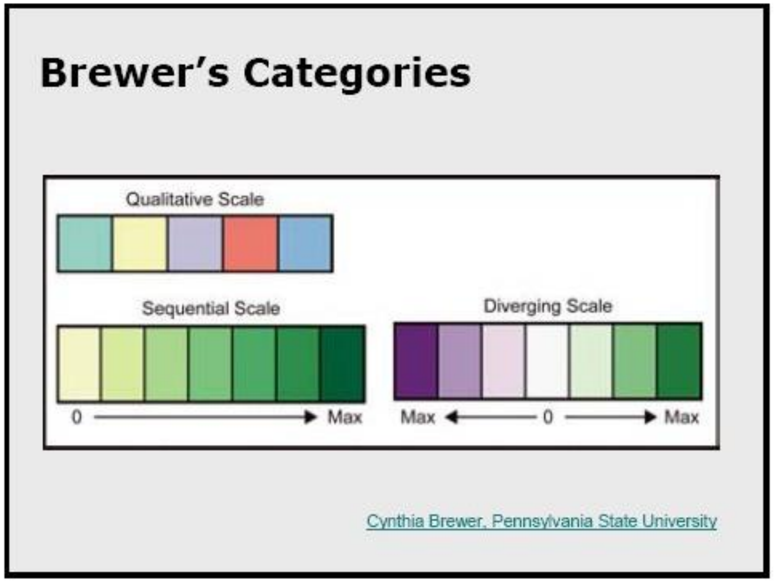
Sequential scales

- vary in lightness and saturation
- vary slightly in hue

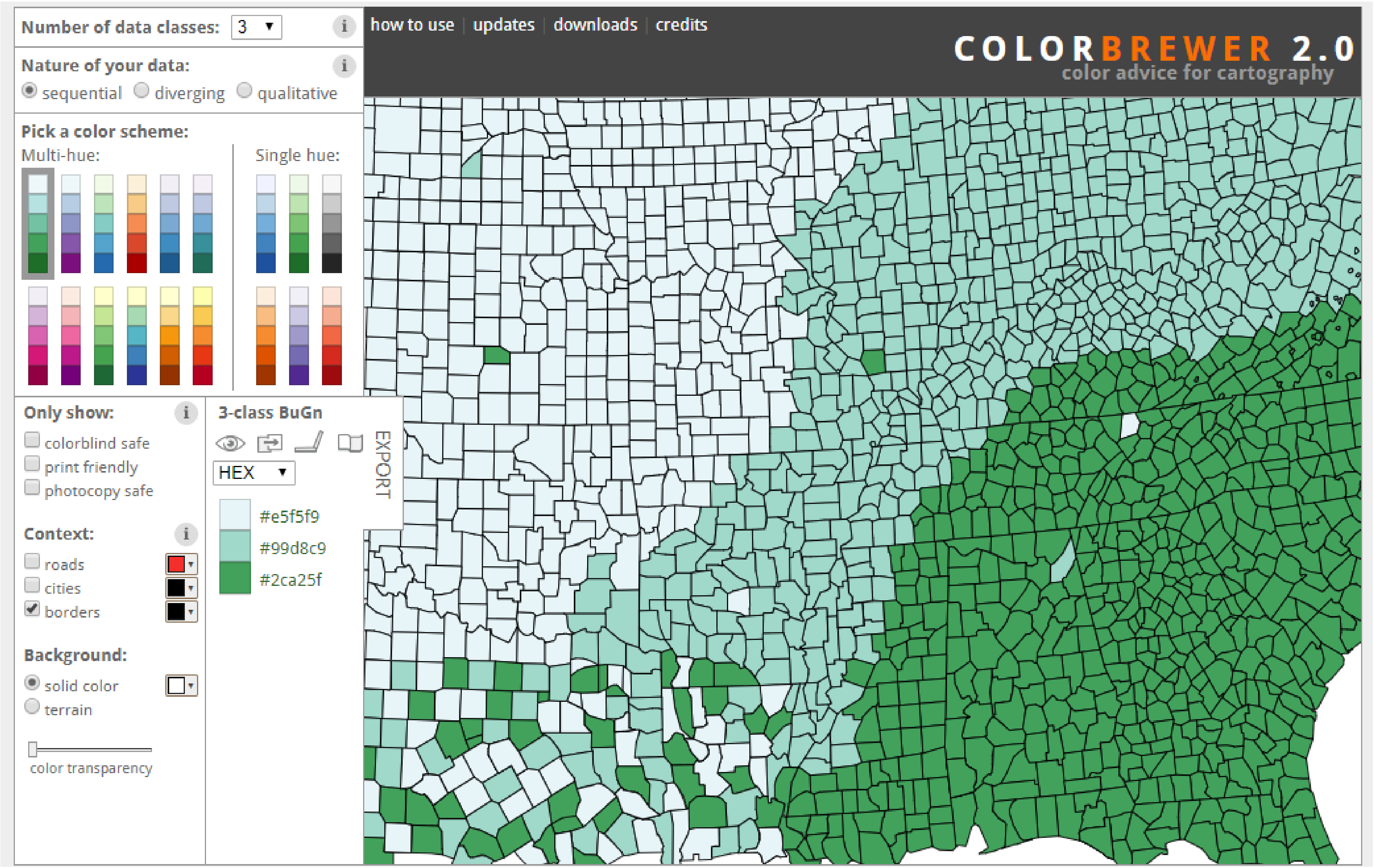
Diverging scale

- complementary sequential scales
- neutral at "zero"

http://colorbrewer2.org/



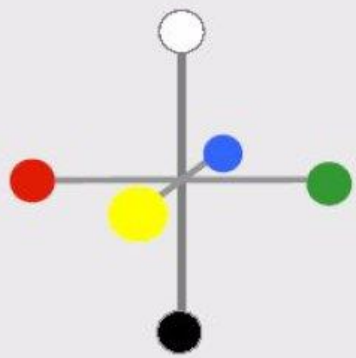
Color Brewer



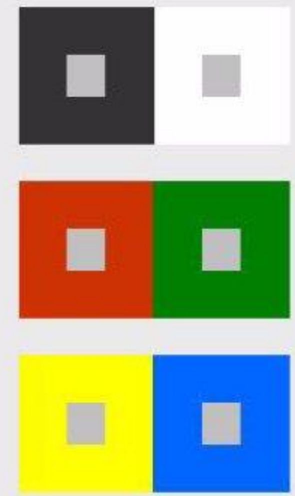
Opponent Color

Definition
- Achromatic axis
- R-G and Y-B axis
- Separate lightness from chroma channels

First level encoding
- Linear combination of LMS
- Before optic nerve
- Basis for perception
- Defines "color blindness"

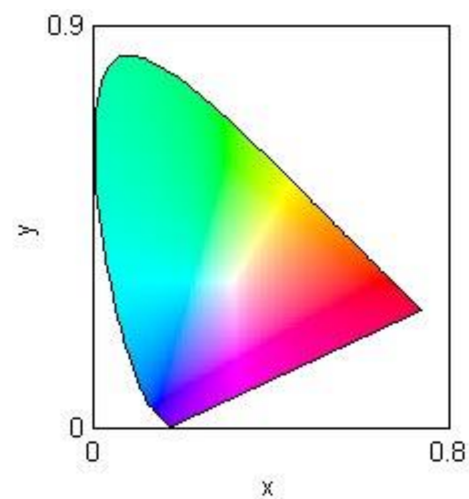


Add Opponent Color
- Dark adds light
- Red adds green
- Blue adds yellow

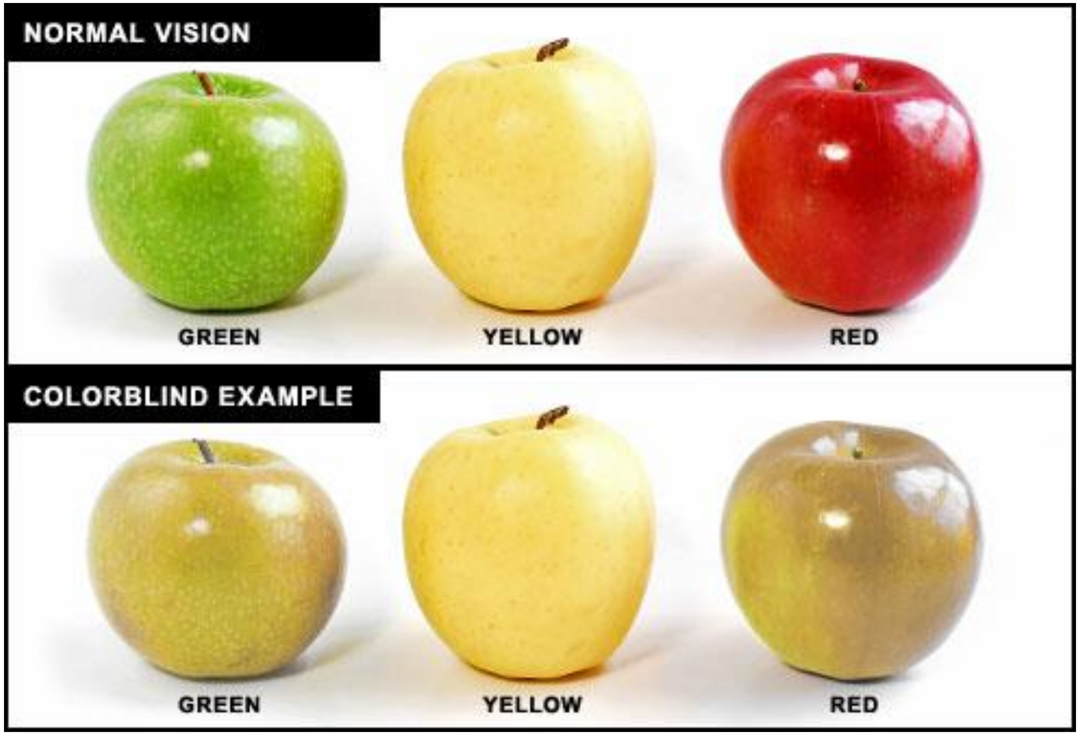


These samples will have both light/dark and hue contrast

Opponent colors do not mix
- can only see one of the opponents
- there is no blueish yellow
- there is no reddish green



Color Blindness



Most common is deficiency in distinguishing red and green

Forms of Color Blindness

normal

The colors of the rainbow as viewed by a person with no color vision deficiencies.

The colors of the rainbow as viewed by a person with deuteranopia.

green missing

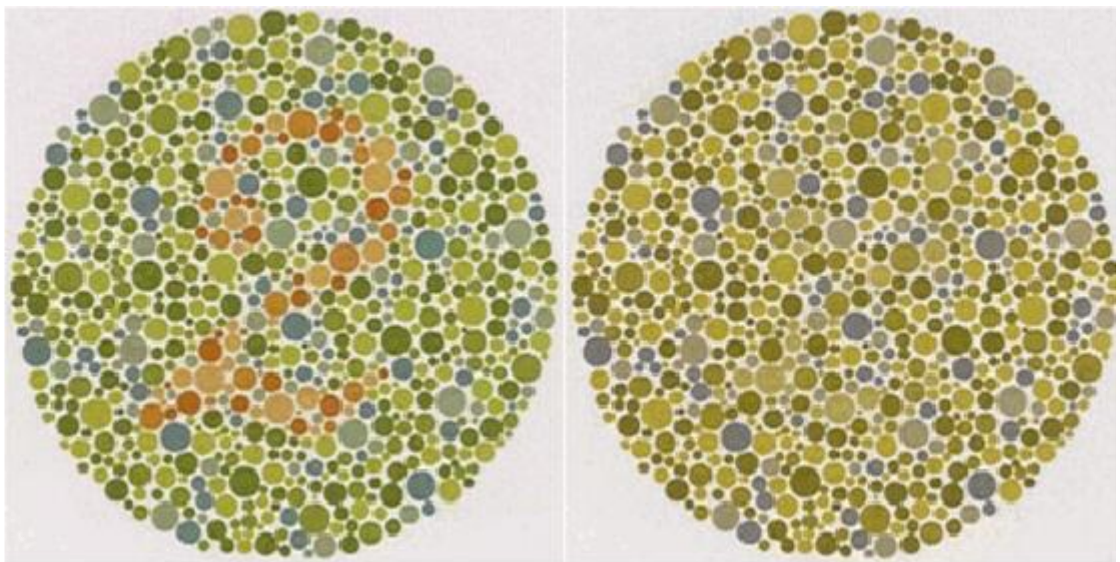
red missing

The colors of the rainbow as viewed by a person with protanopia.

The colors of the rainbow as viewed by a person with tritanopia.

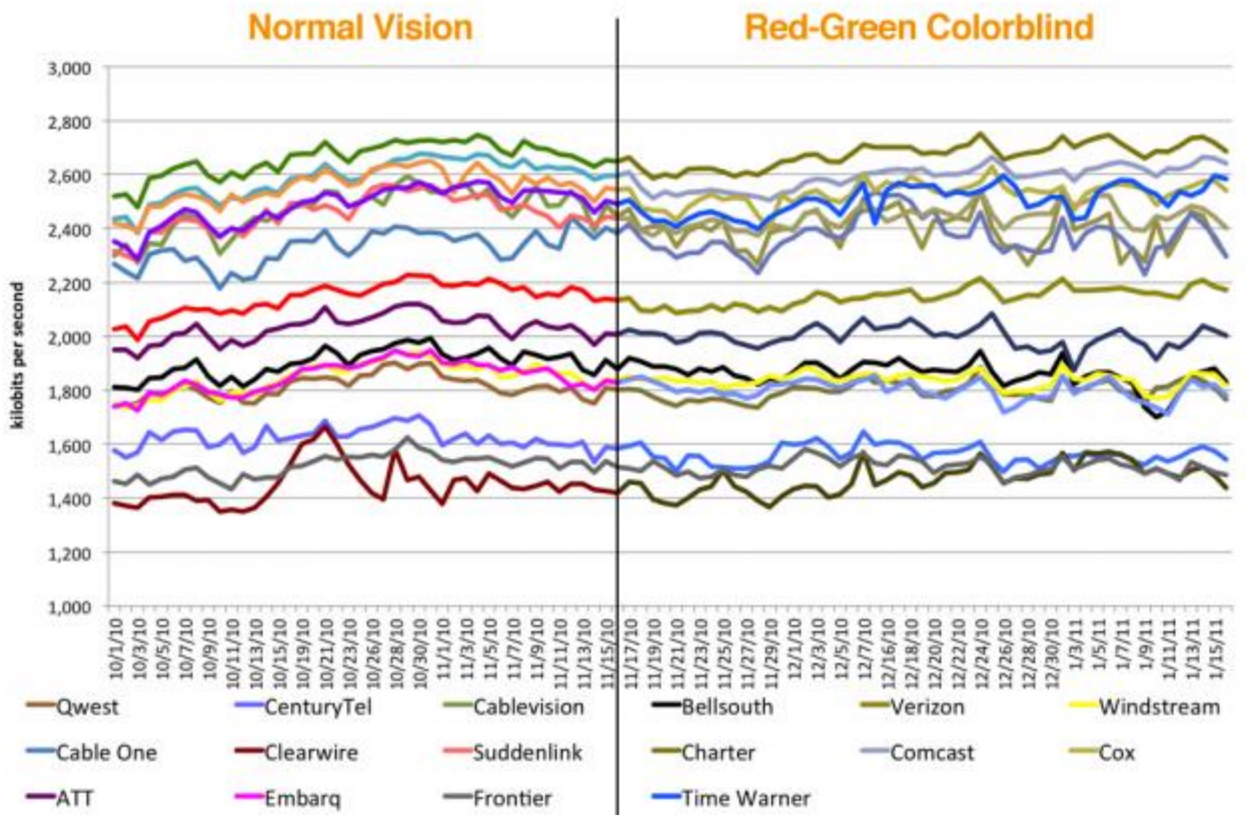
blue missing (rare)

Ishihara Test



normal protanopia

Line Charts



Normal Vision
Red-Green Colorblind
kilobits per second
3,000
2,800
2,600
2,400
2,200
2,000
1,800
1,600
1,400
1,200
1,000
Qwest
CenturyTel
Cablevision
Bellsouth
Verizon
Windstream
Cable One
Clearwire
Suddenlink
Charter
Comcast
Cox
ATT
Embarq
Frontier
Time Warner

Designing For Color Deficient Users

8% (0.5%) of US males (females) are color deficient

- so be careful when designing visualizations

What to do?

- use different intensities for red-green (e.g. light green, dark red)
- space red and green colored colors dots far apart or make large
- add symbols to line charts or vary line style
- avoid using gradient colors to indicate data value

Summing Up

Use Luminance for detail, shape, and form

Use color for coding – few colors

Use strong colors for small areas

Use subtle colors to code large areas

Visualization artistry:

- Use of luminance to indicate direction