

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



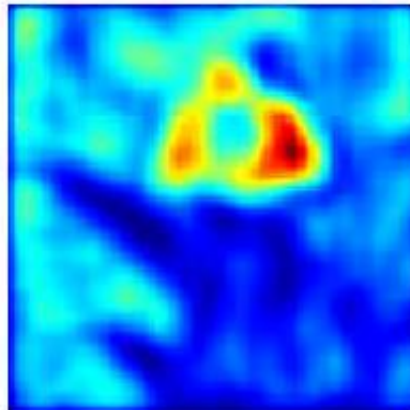
# SALIENCY MAP

Red: high saliency  
Blue: low saliency

Butterfly



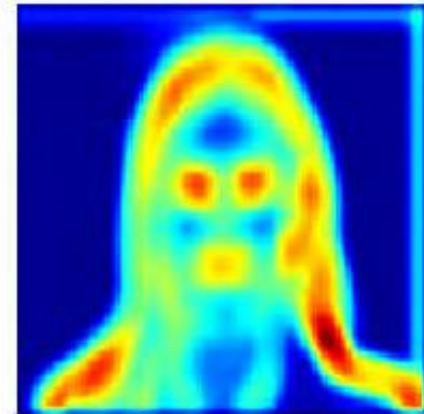
Butterfly Saliency Map



Person



Person Saliency Map

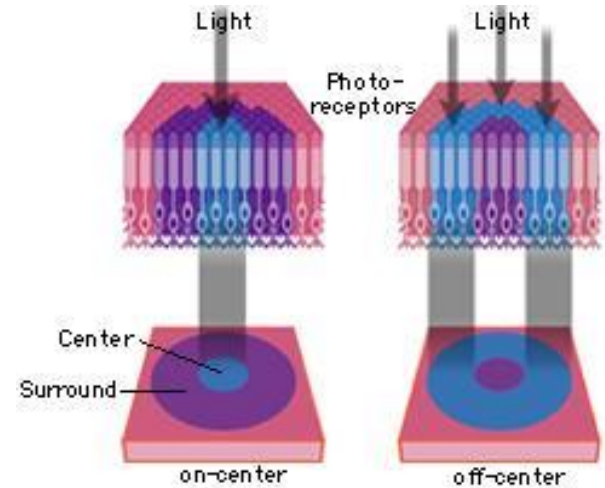
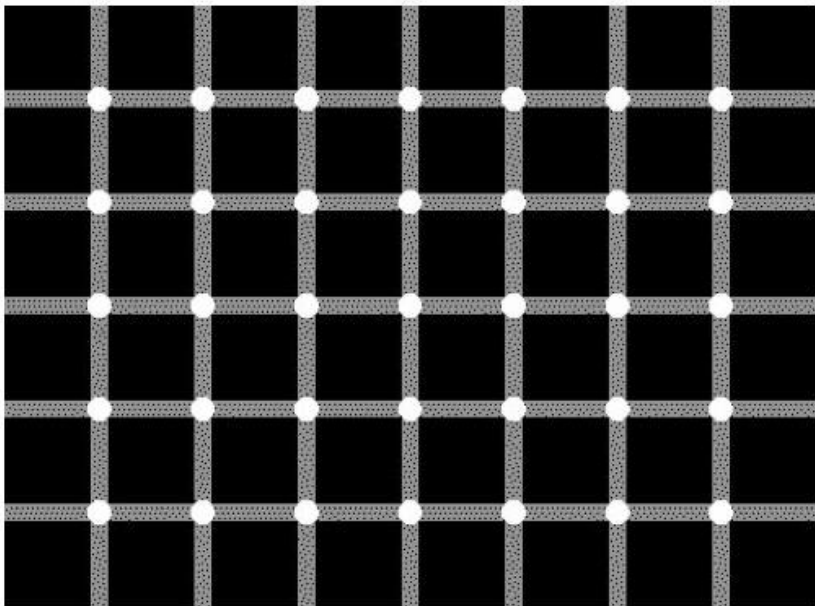


# CENTER-SURROUND DETECTION

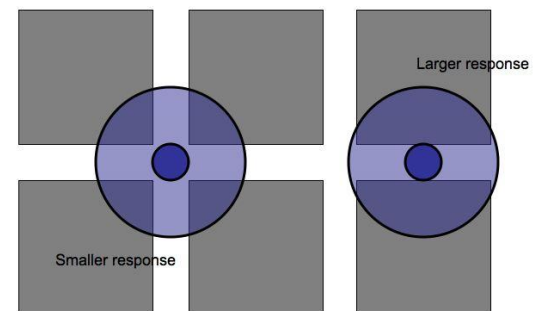
## Center-surround receptive fields

- a pool of photoreceptors
- surround has an inhibitory effect

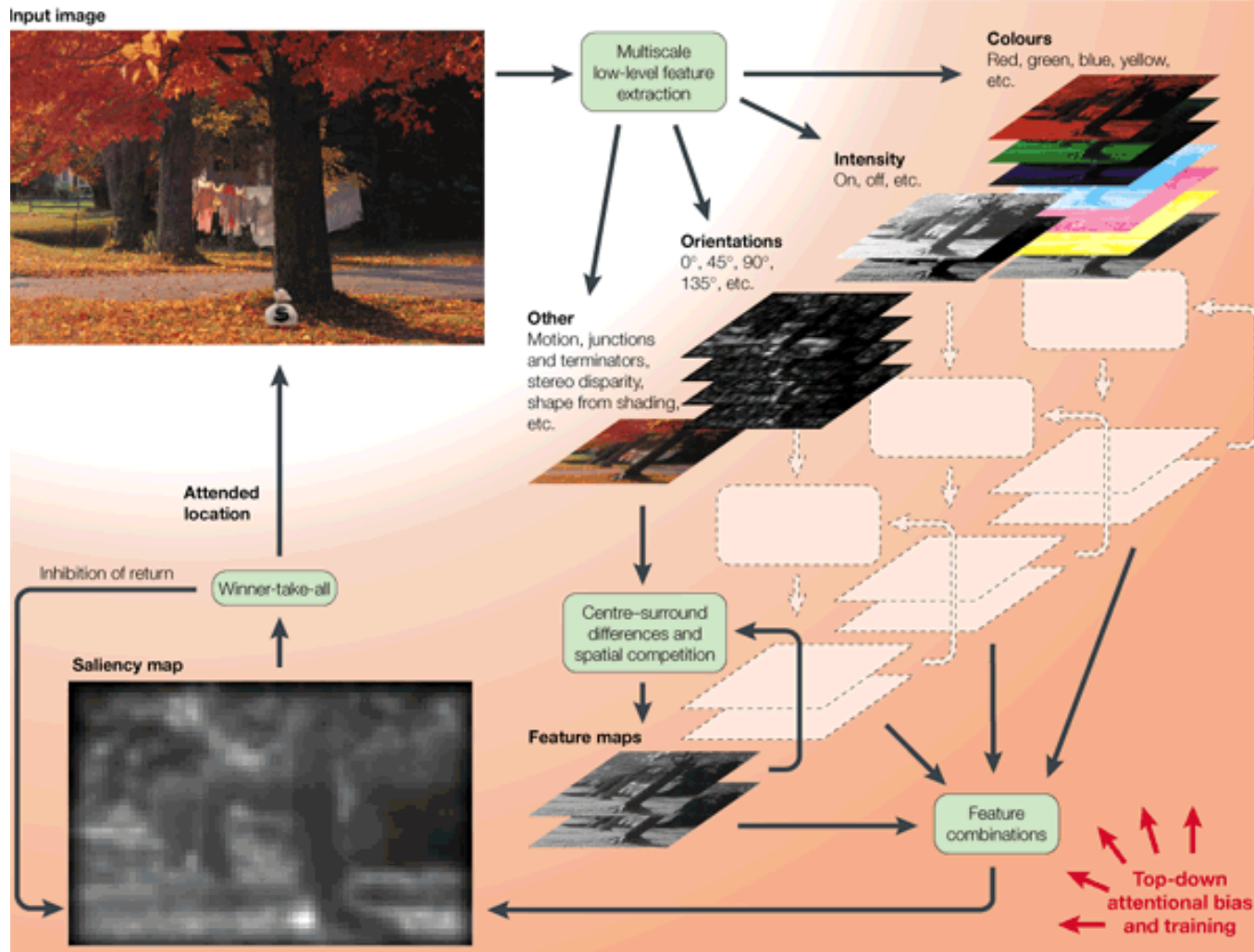
## Stronger variant of the Hermann grid



## Explanation of Hermann grid



# BOTTOM-UP VISUAL ATTENTION





# BOTTOM-UP AND TOP-DOWN

Probably occur in conjunction for scene recognition

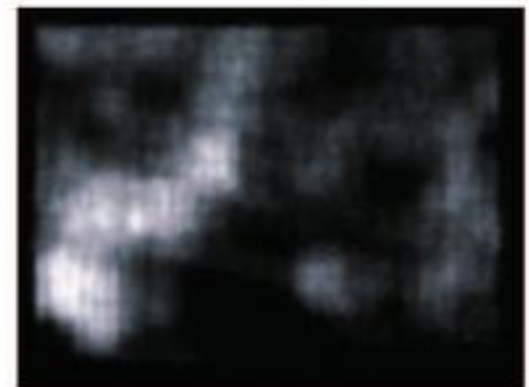
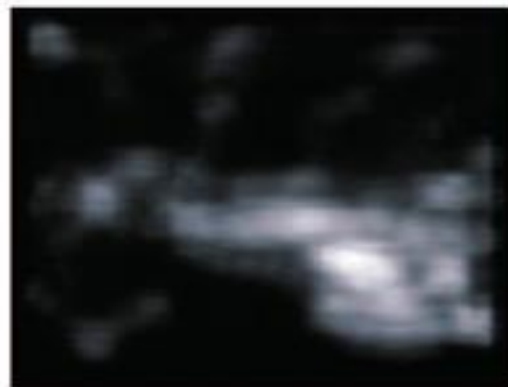
top-down

bottom-up

Filters



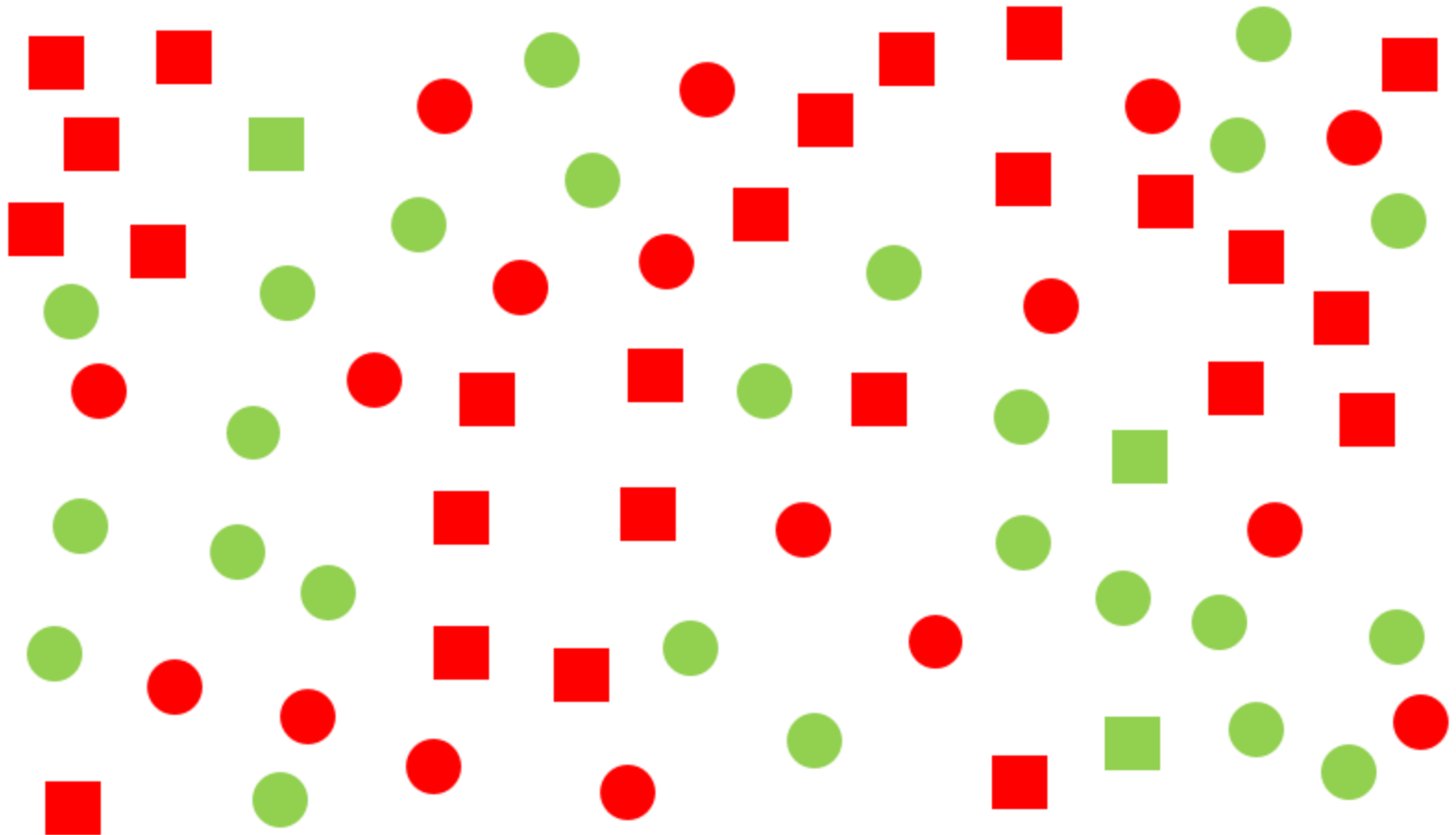
Saliency map





# PRE-ATTENTIVENESS

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



# WHICH POPPED-OUT FASTER

Color (red vs. green)

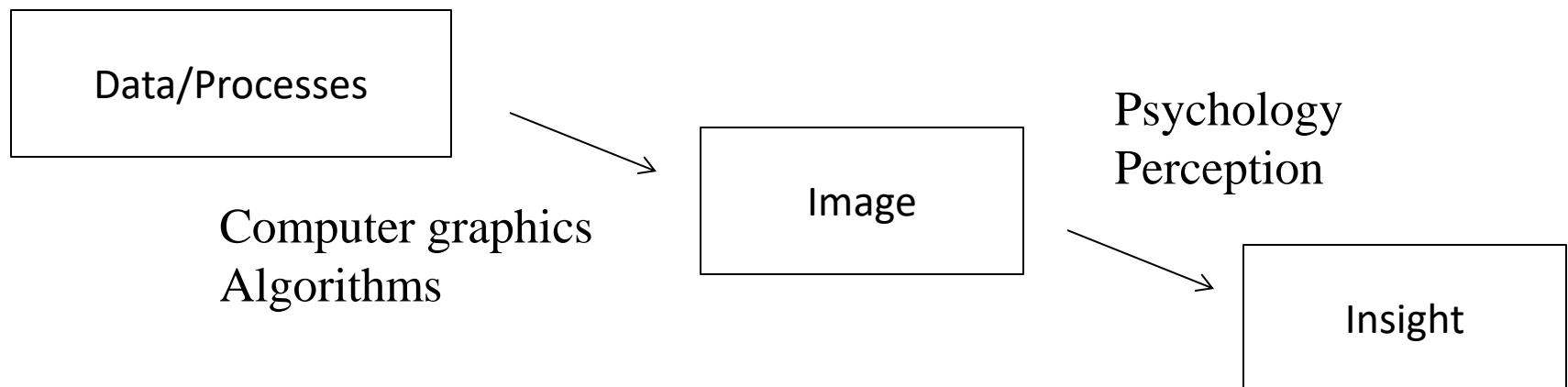
Shape (circle vs. square)

# VISUAL VARIABLES

Formal theory linking perception to visualization

Established by Jacques Bertin (1967)

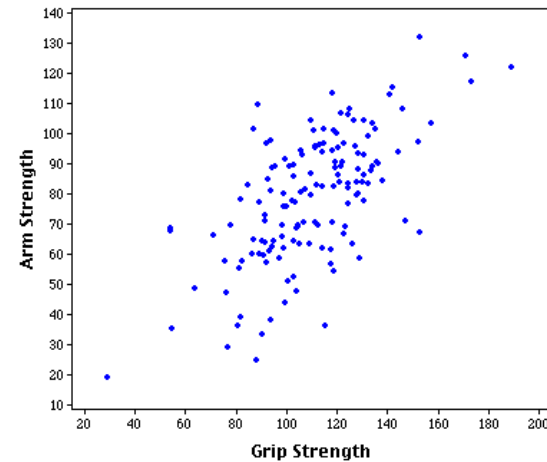
- he called it 'Image Theory'
- original book in French (*Sémiologie Graphique*) translated into English by W. Berg (1983)
- not formally linked to vision research more based on intuition
- but has been shown later by M. Green to be quite accurate



# VISUAL VARIABLES

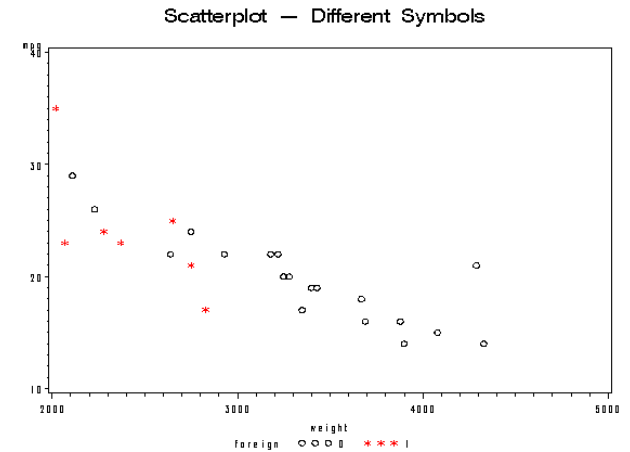
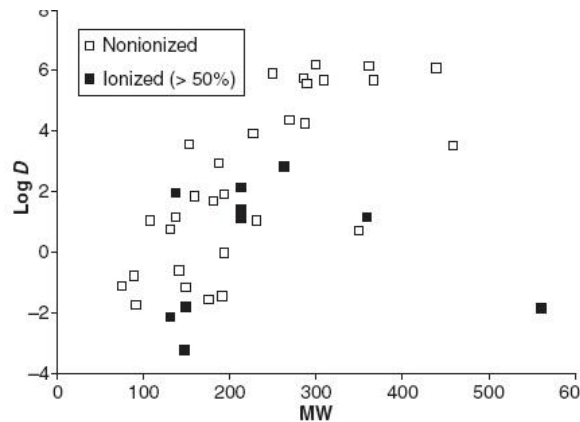
## Two planar variables

- 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

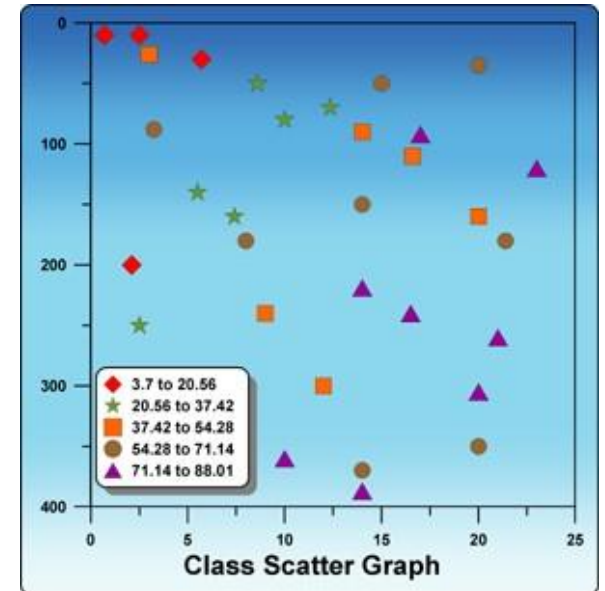
- more than three variables will hamper efficient visual search
- recall low decoding speed of conjunctions

# ASSOCIATIVE VS. SELECTIVE

Both are nominal qualities

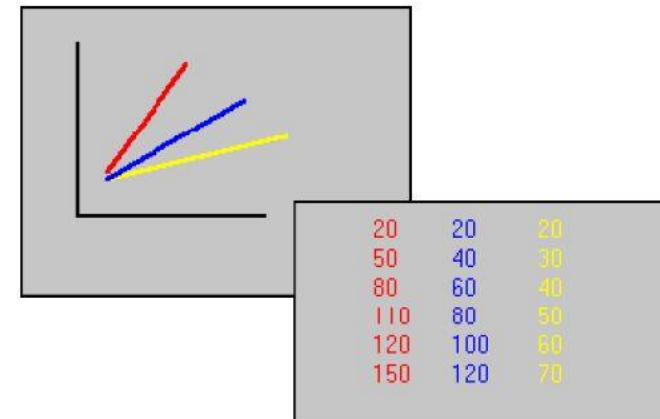
## Associative

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



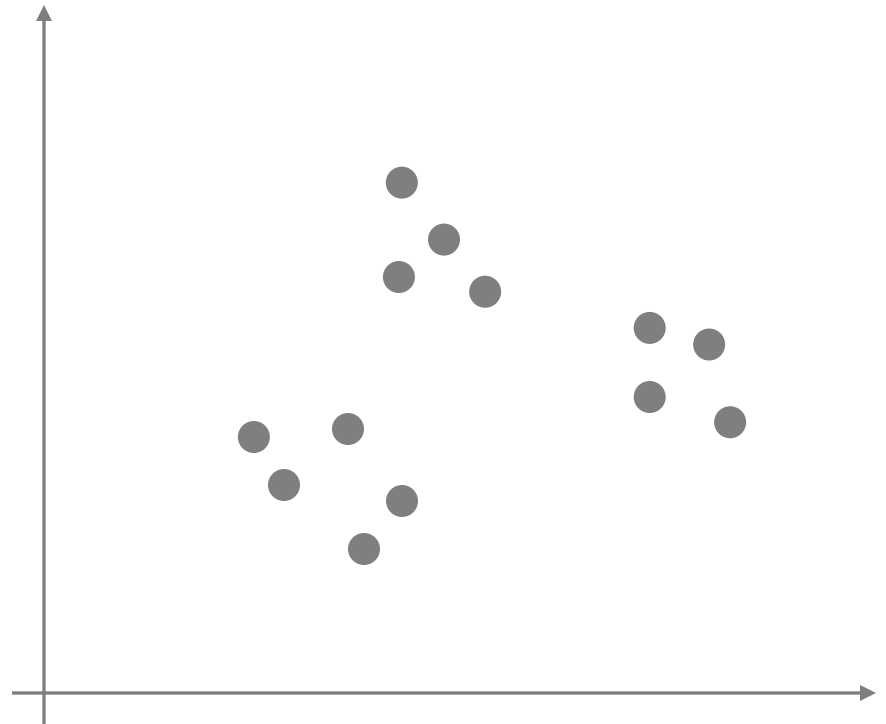
## Selective

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



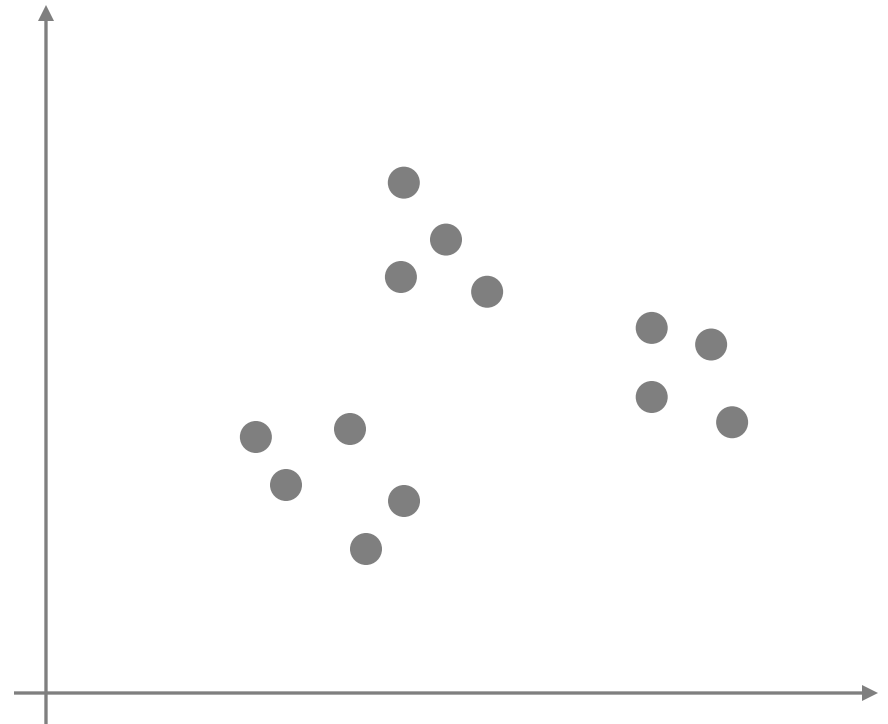
# VISUAL VARIABLE #1 – PLANAR

Visual property	Can convey
Associative	
Selective	
Ordered	
Quantitative	



# VISUAL VARIABLE #1 – PLANAR

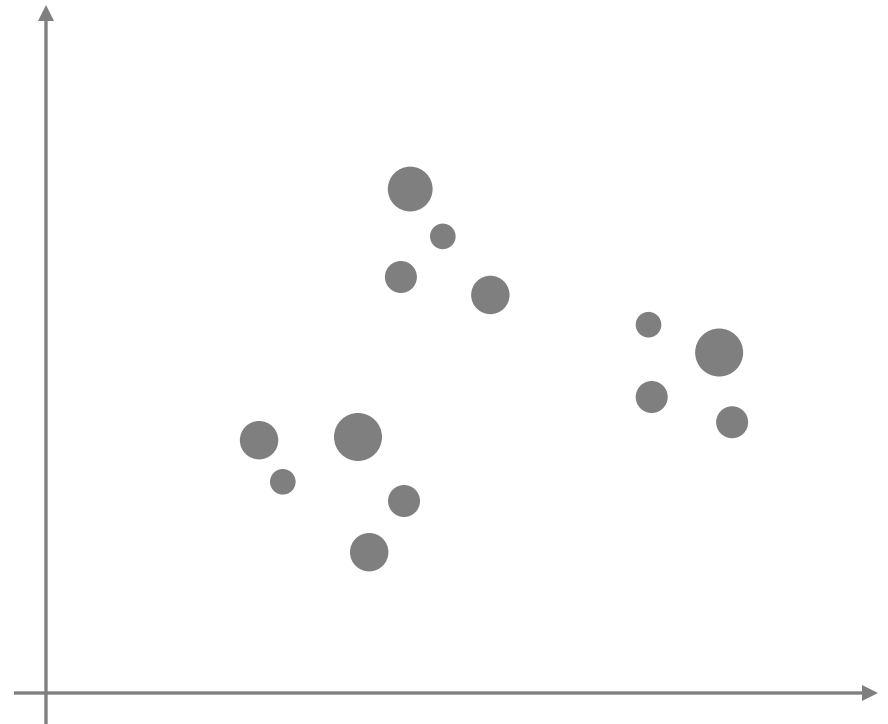
Visual property	Can convey
Associative	Y
Selective	Y
Ordered	Y
Quantitative	Y





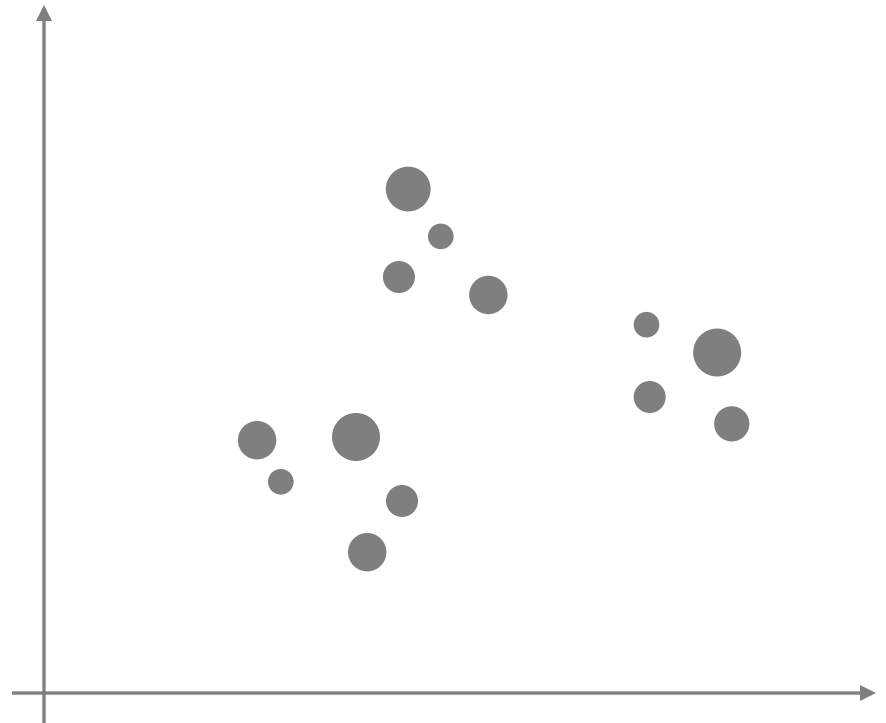
# VISUAL VARIABLE #2 – SIZE

Visual property	Can convey
Associative	
Selective	
Ordered	
Quantitative	



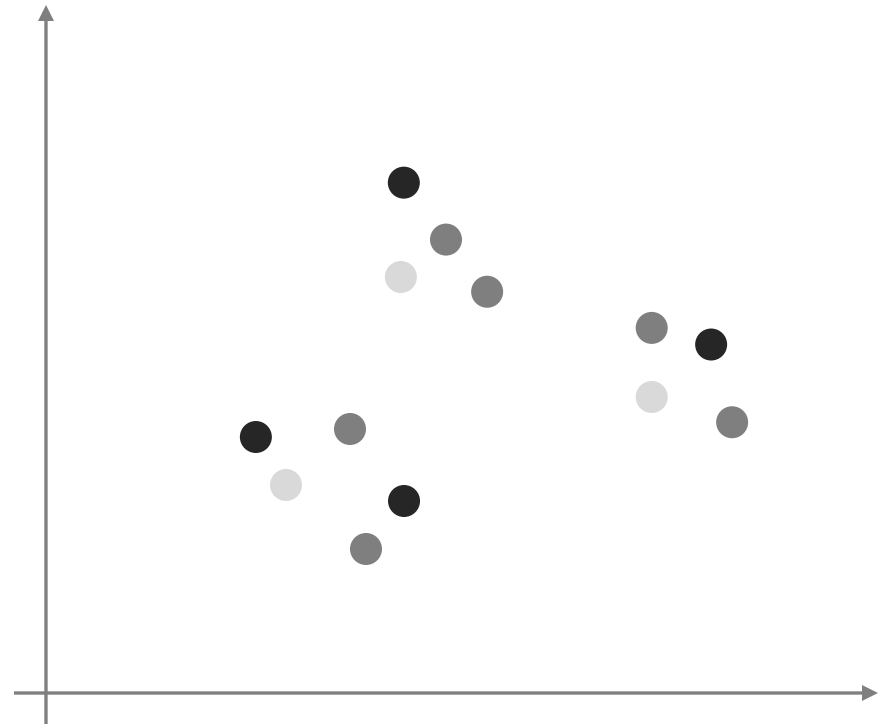
# VISUAL VARIABLE #2 – SIZE

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



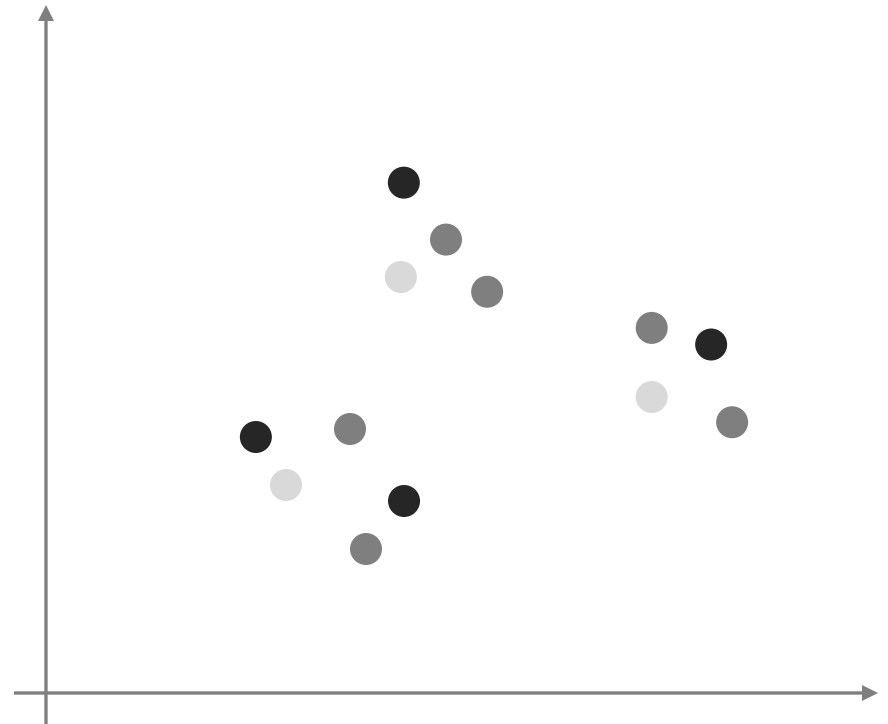
# VISUAL VARIABLE #3 – BRIGHTNESS

Visual property	Can convey
Associative	
Selective	
Ordered	
Quantitative	



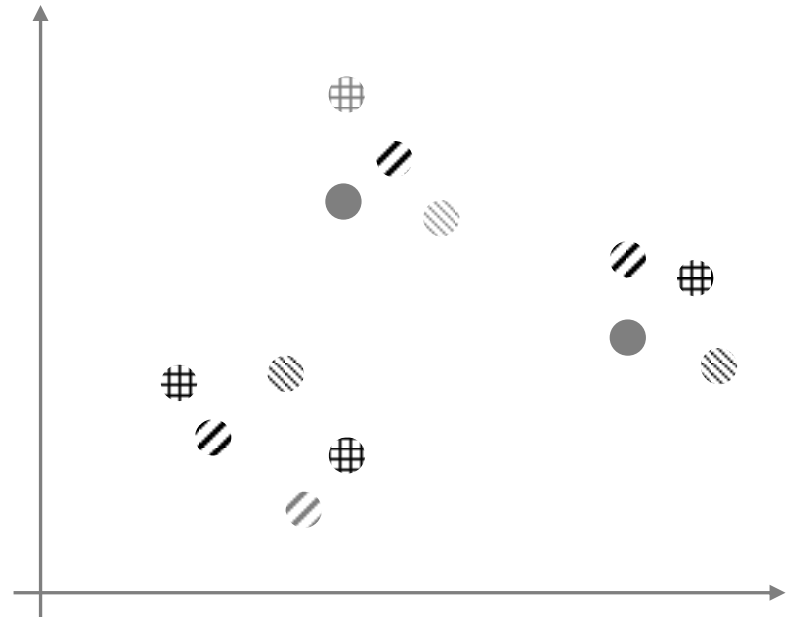
# VISUAL VARIABLE #3 – BRIGHTNESS

Visual property	Can convey
Associative	Y
Selective	Y
Ordered	Y
Quantitative	



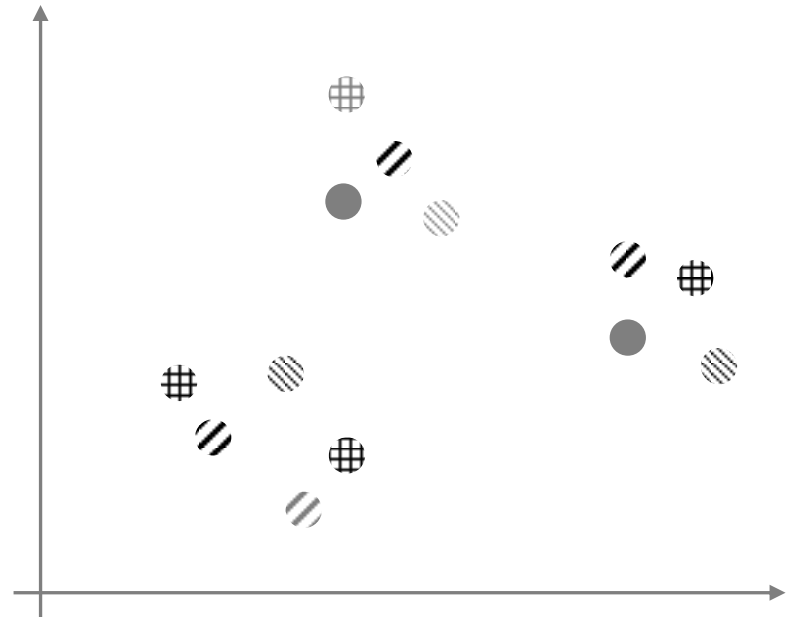
# VISUAL VARIABLE #4 – TEXTURE

Visual property	Can convey
Associative	
Selective	
Ordered	
Quantitative	



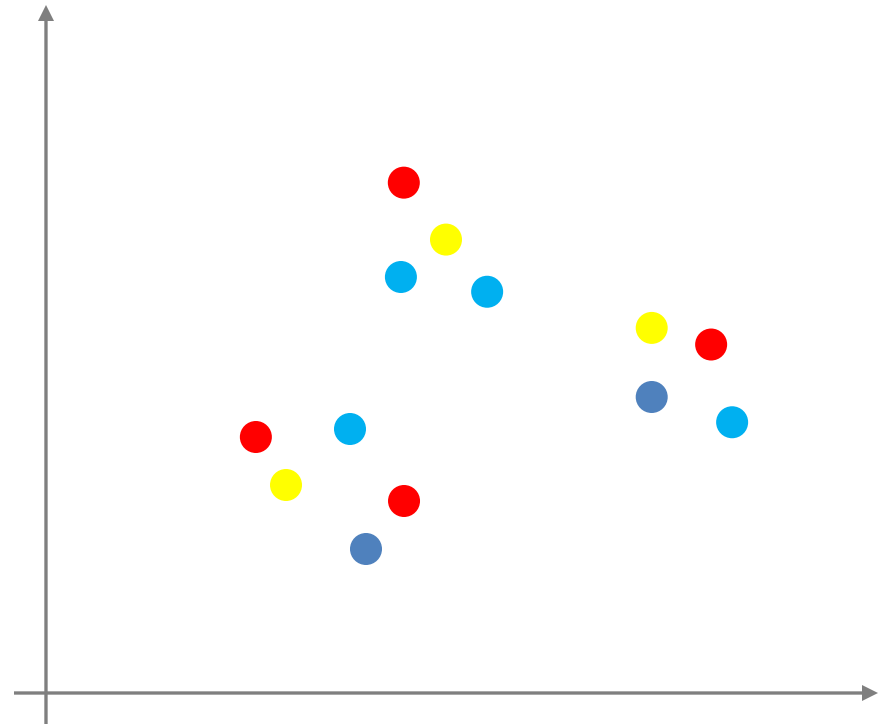
# VISUAL VARIABLE #4 – TEXTURE

Visual property	Can convey
Associative	Y
Selective	Y
Ordered	
Quantitative	



# VISUAL VARIABLE #4 – COLOR

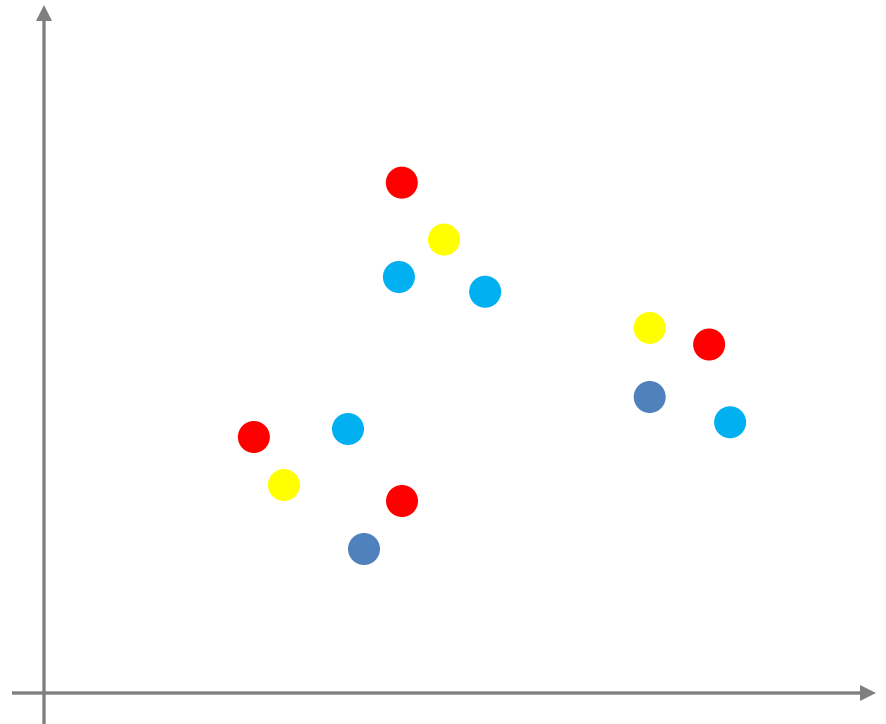
Visual property	Can convey
Associative	
Selective	
Ordered	
Quantitative	





# 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	



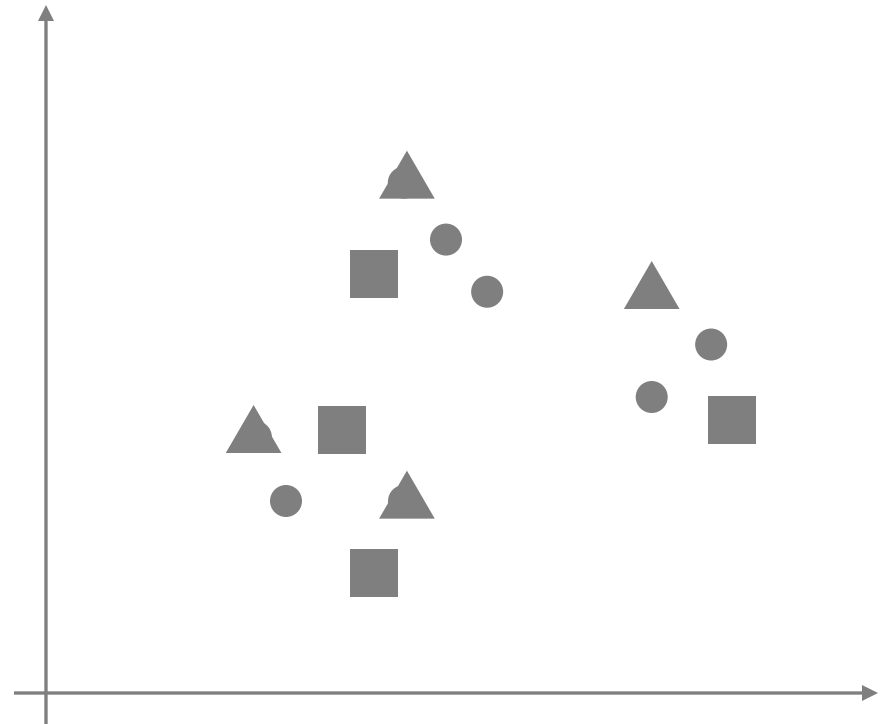
# VISUAL VARIABLE #5 – ORIENTATION

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



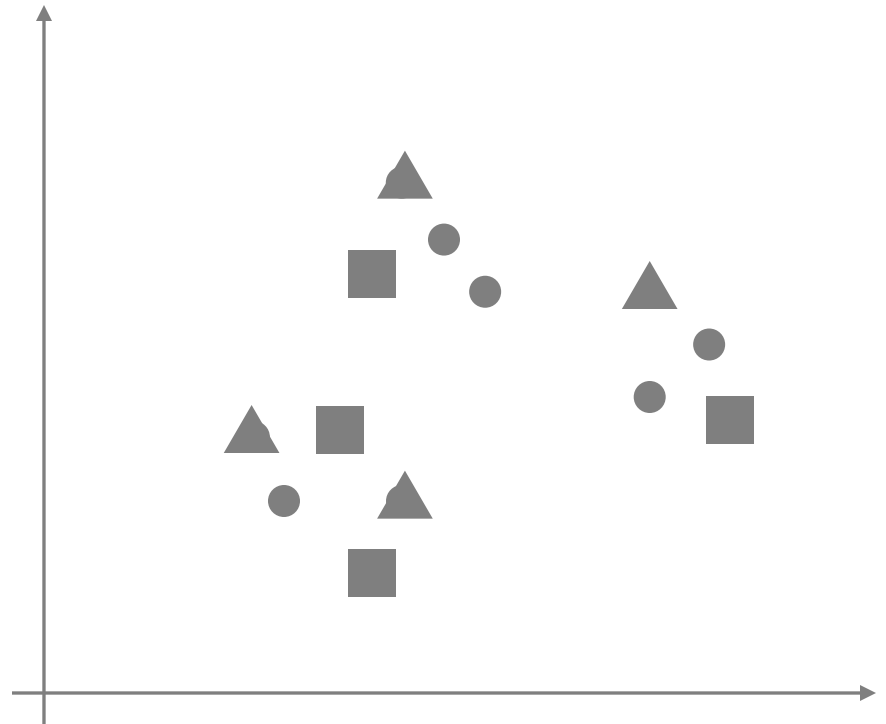
# VISUAL VARIABLE #6 – SHAPE

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

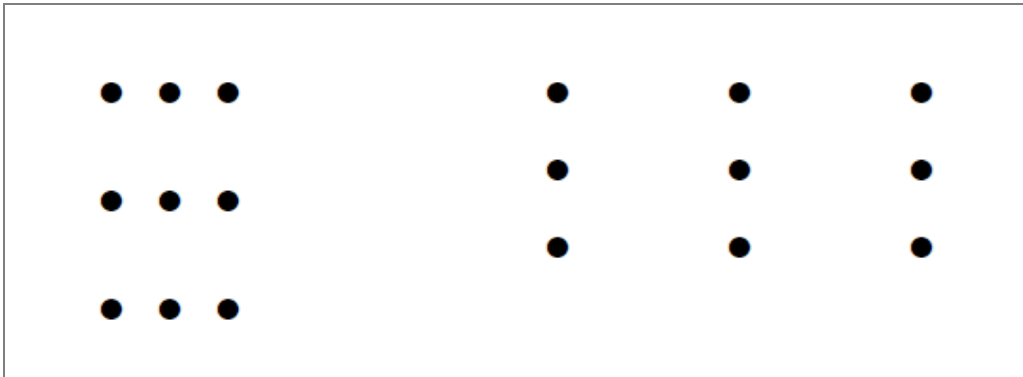
Visual variables differ in what data properties they can convey

	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



**TYPICAL WEB FORM**

**Personal Information**

First Name

Last Name

**Contact Information**

Address

City

Country

Post Code  Country

| [Cancel](#)

PRIMARY ACTION | SECONDARY ACTION



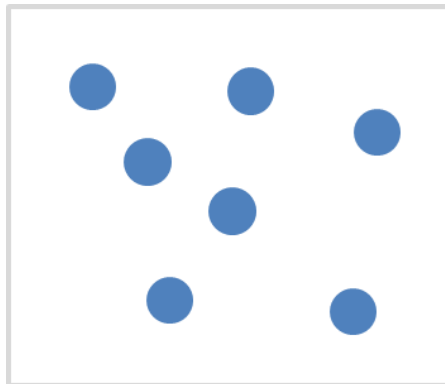
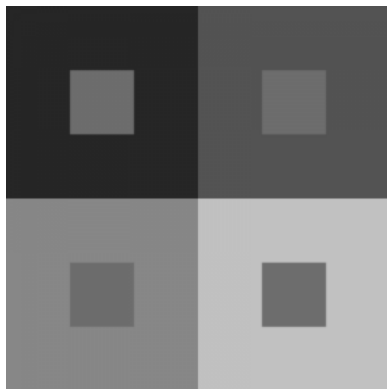
# TAKE-AWAYS (2)

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

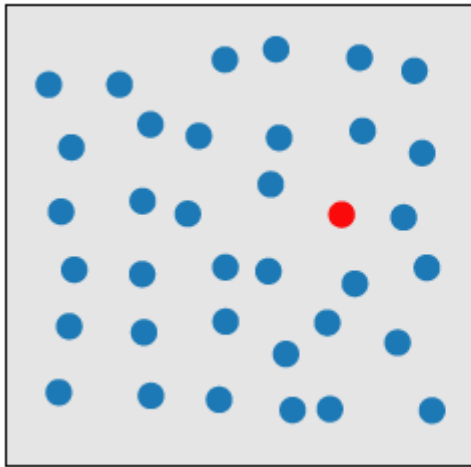
- + brightness does not consume extra space (bigger disks do)
- brightness depends on environmental lighting (size does not)  
where do you view the visualization (office, outdoors, night or day?)



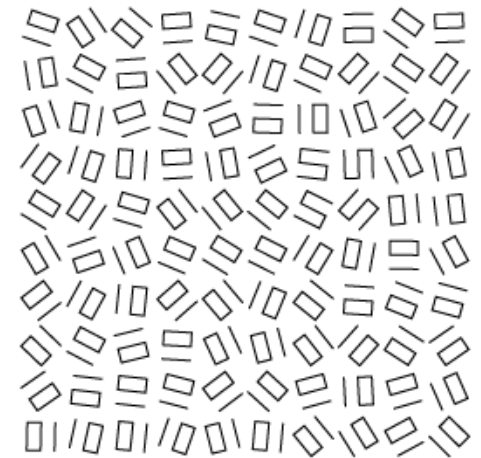
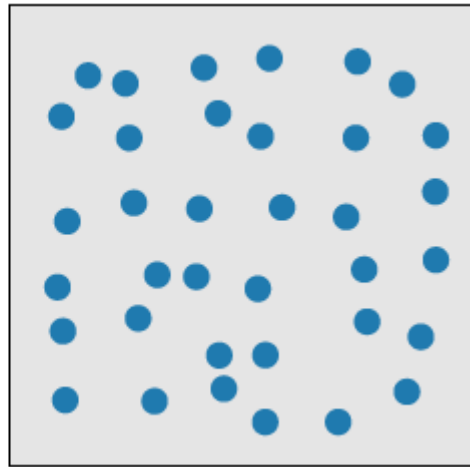
# TAKE-AWAYS (3)

Color is a good visual variable for labeling

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



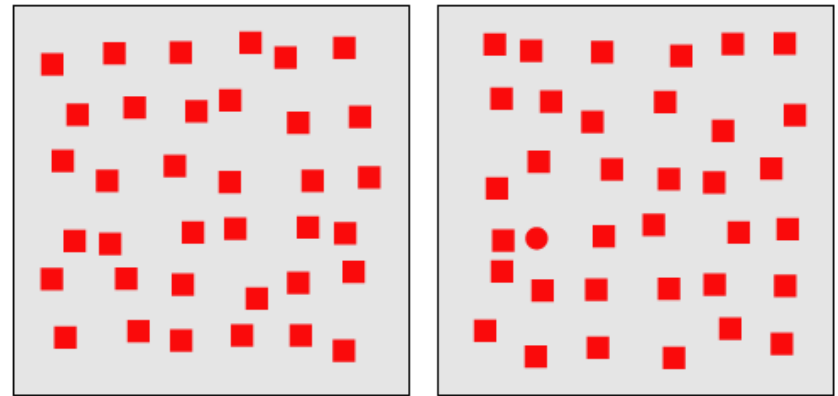
color pop-out



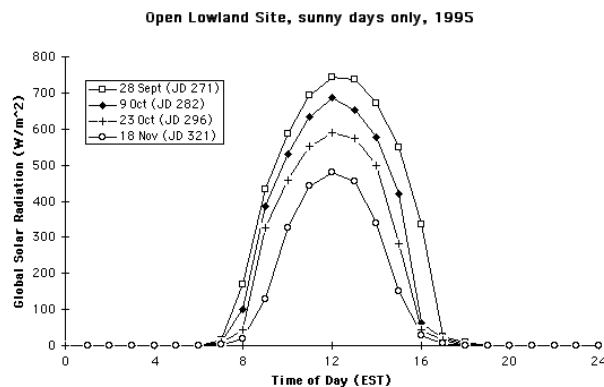
texture pop-out?

# TAKE AWAYS (4)

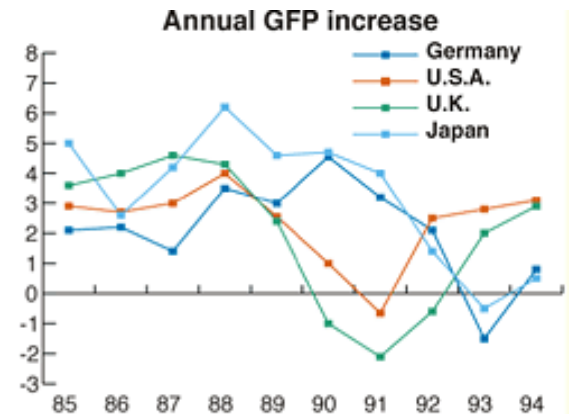
*Shape* provides only limited pop-out



- 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 ...

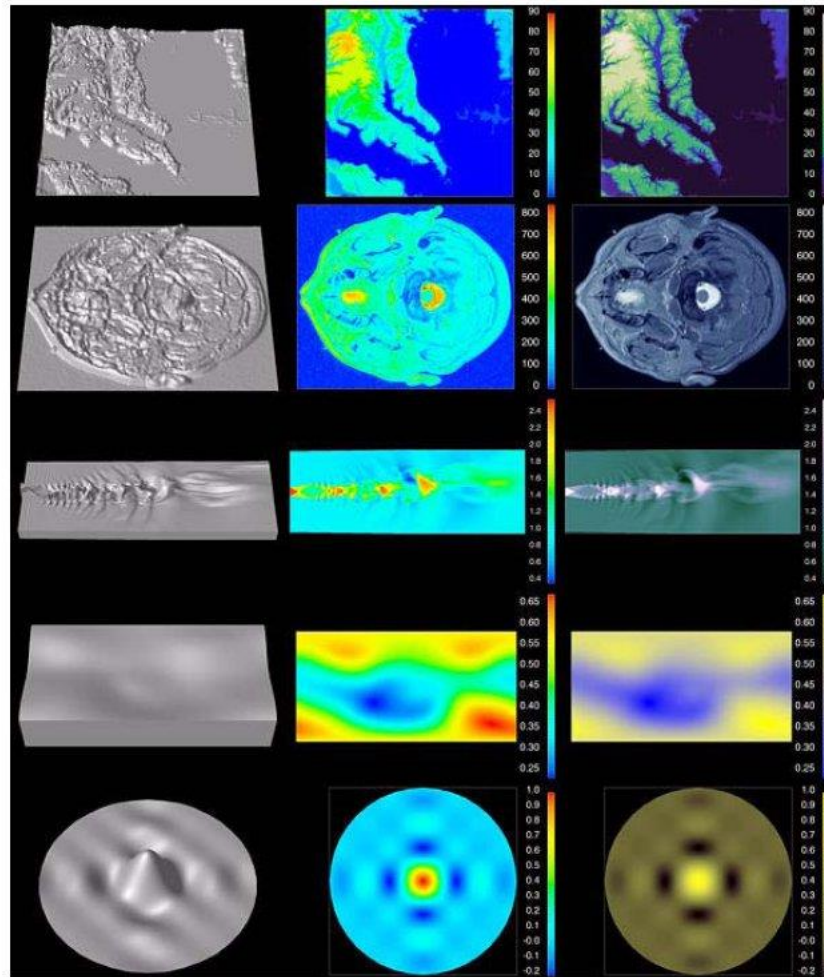


# WHAT DID WE LEARN FROM THAT EXPERIMENT?

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

# ROLE OF SATURATION

## Art & Money

By: JeanAbbateci



### ART & MONEY

#datavisualisation



This Animated Bubble Chart shows the 270 most expensive artworks sold in auction since 2008 until end 2011

drawing painting  
 silkscreen sculpture

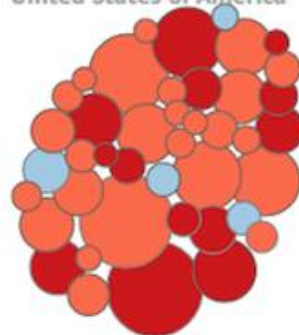
Share 1161 Tweet 558

#### SORTING

- year by year
- top 10 artworks
- men / women
- dead / alive
- by nationality**
- best-selling artists
- auction houses
- size of artworks
- date of creation (all centuries)

#### AMERICAS

United States of America

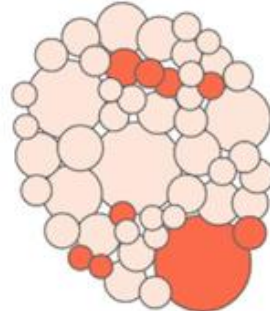


Argentina



#### ASIA

China

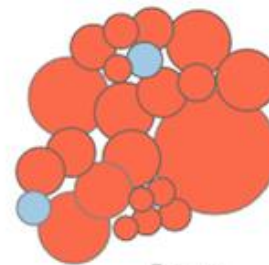


Japan

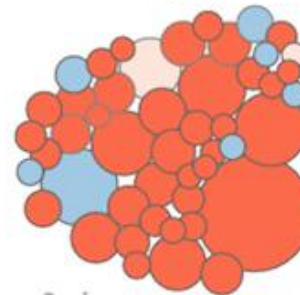


#### EUROPA

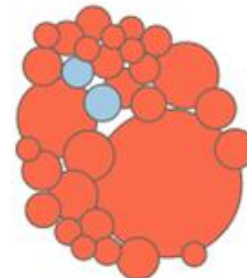
Great Britain



France



Spain



Italy



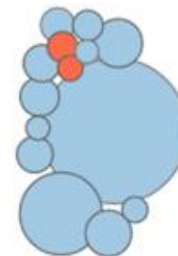
Russia



Netherlands - Belgium



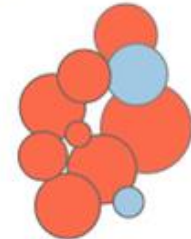
Switzerland



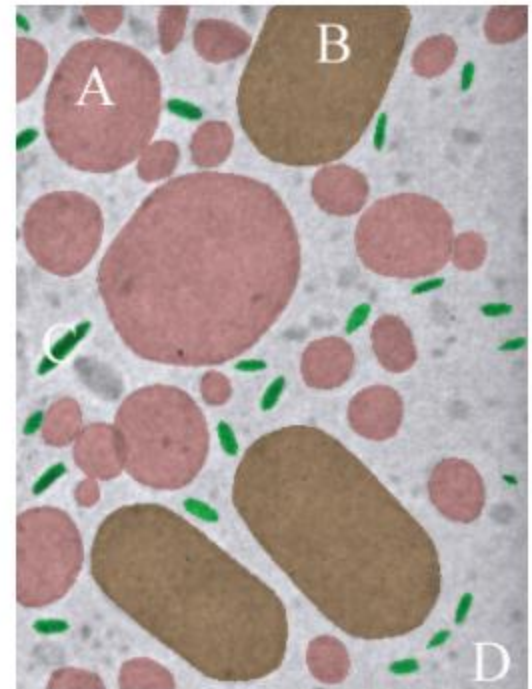
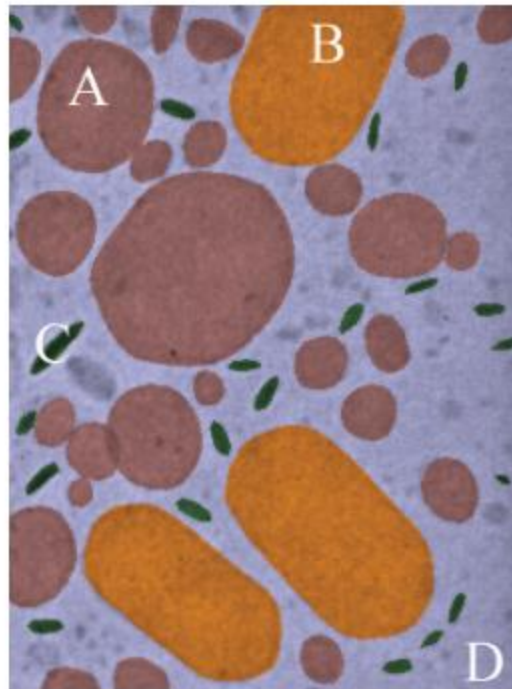
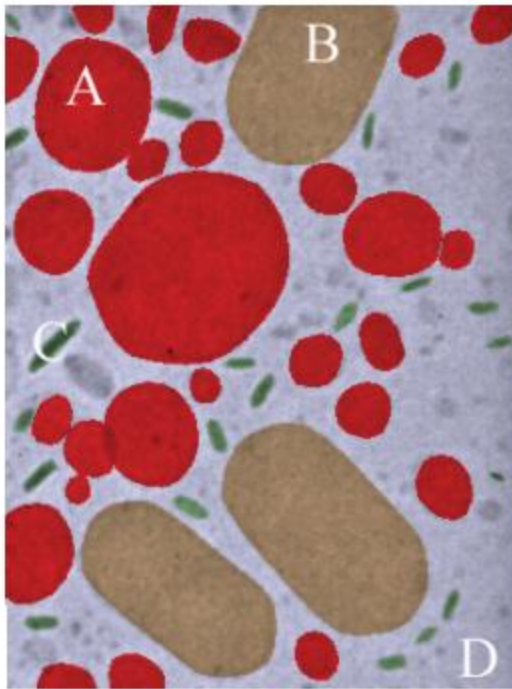
Germany



Others



# COLOR TAGGING FOR IMPORTANCE



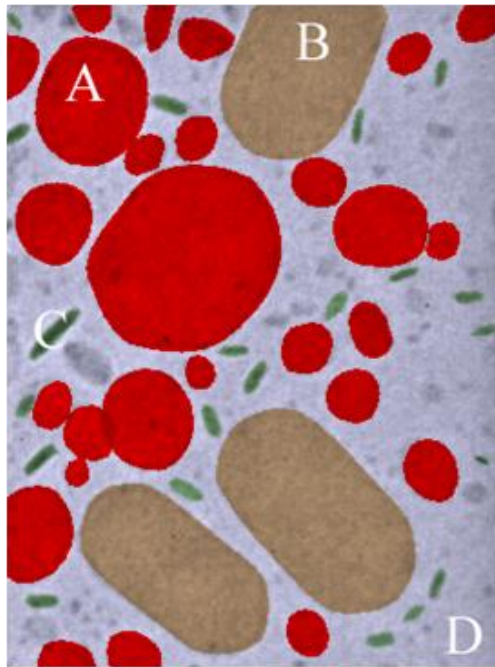
Which is the most important structure in each (as intended by the author)



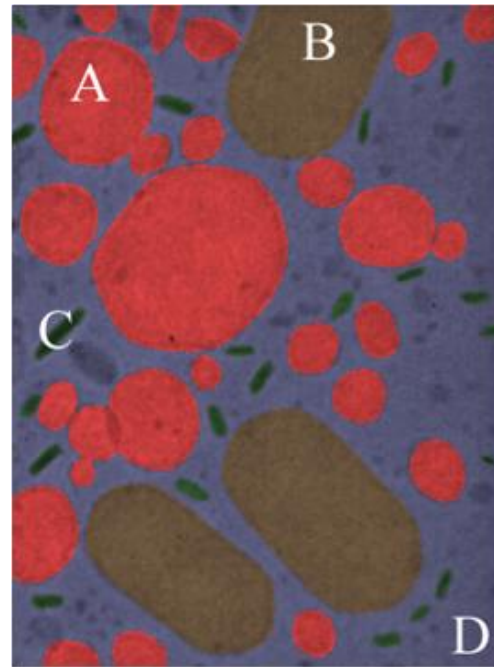
# HOW ABOUT AESTHETICS?

Which one do people like better?

- perceived importance level of red object is the same



Vis 1

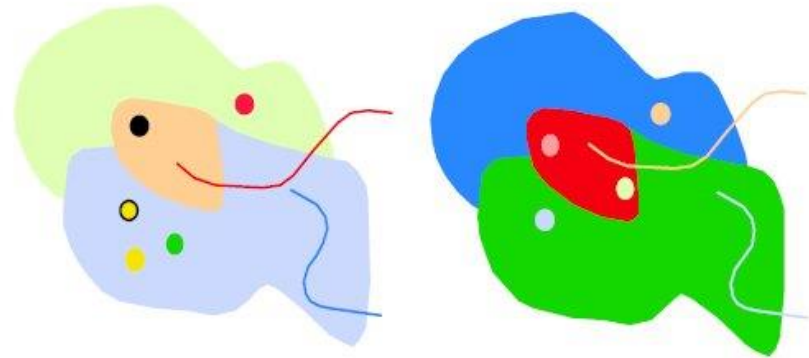


Vis 2



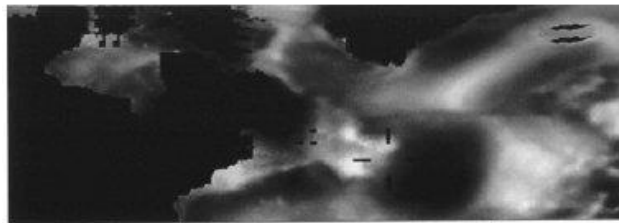
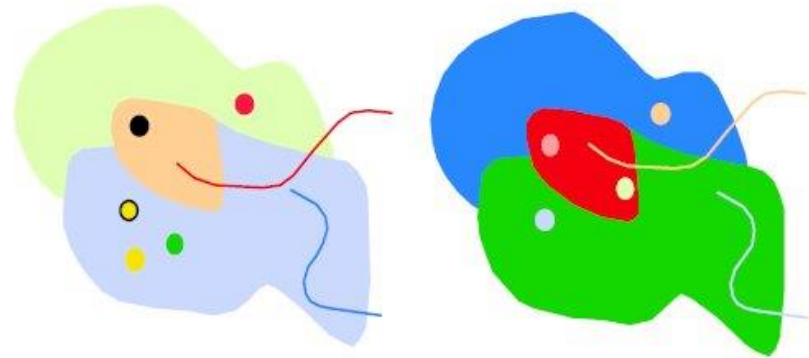
# COLOR CODING AND COLORMAPS

- 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

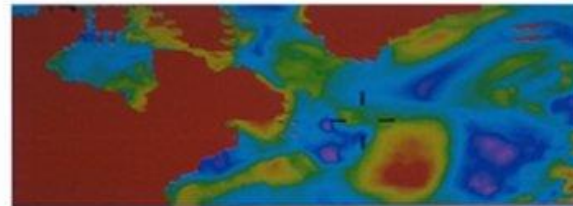


# COLOR CODING AND COLORMAPS

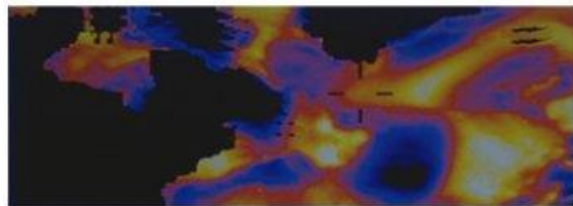
- Color coding
  - large areas: low saturation
  - small areas: high saturation
  - maintain luminance contrast
  - break iso-luminances with borders
- Pseudo-coloring: assign colors to grey levels by indexing the grey levels into a color map



original greylevel map



simple spectrum sequence  
with iso-luminance

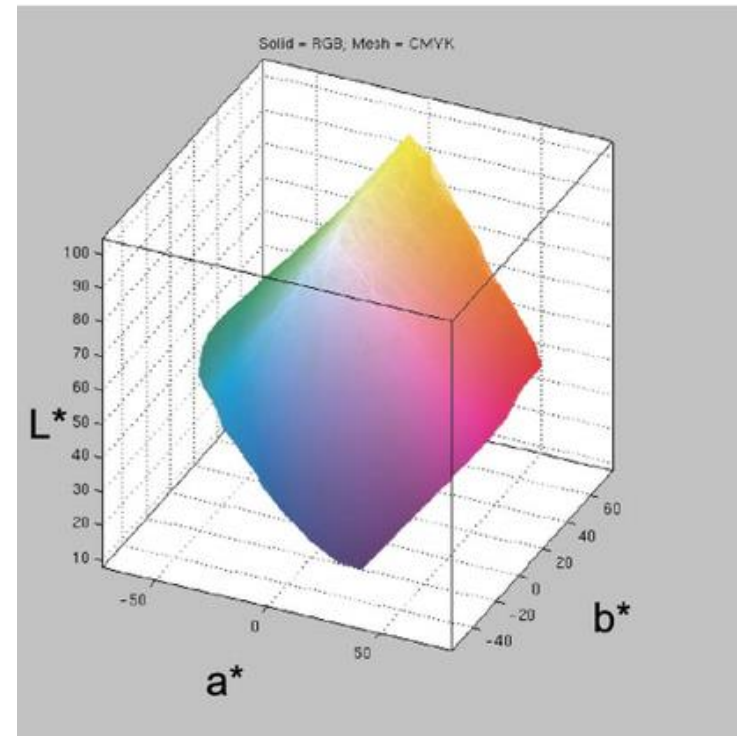
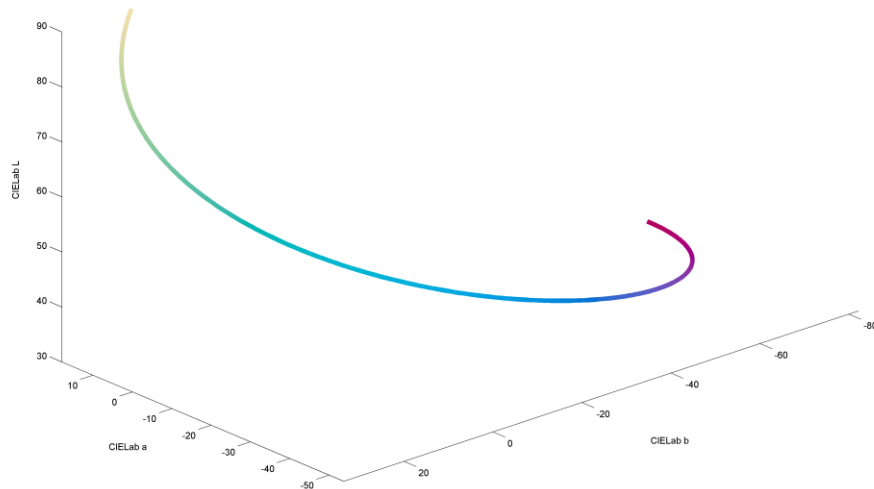


more effective:  
spiral sequence through  
color space  
luminance increases with  
hue

# 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

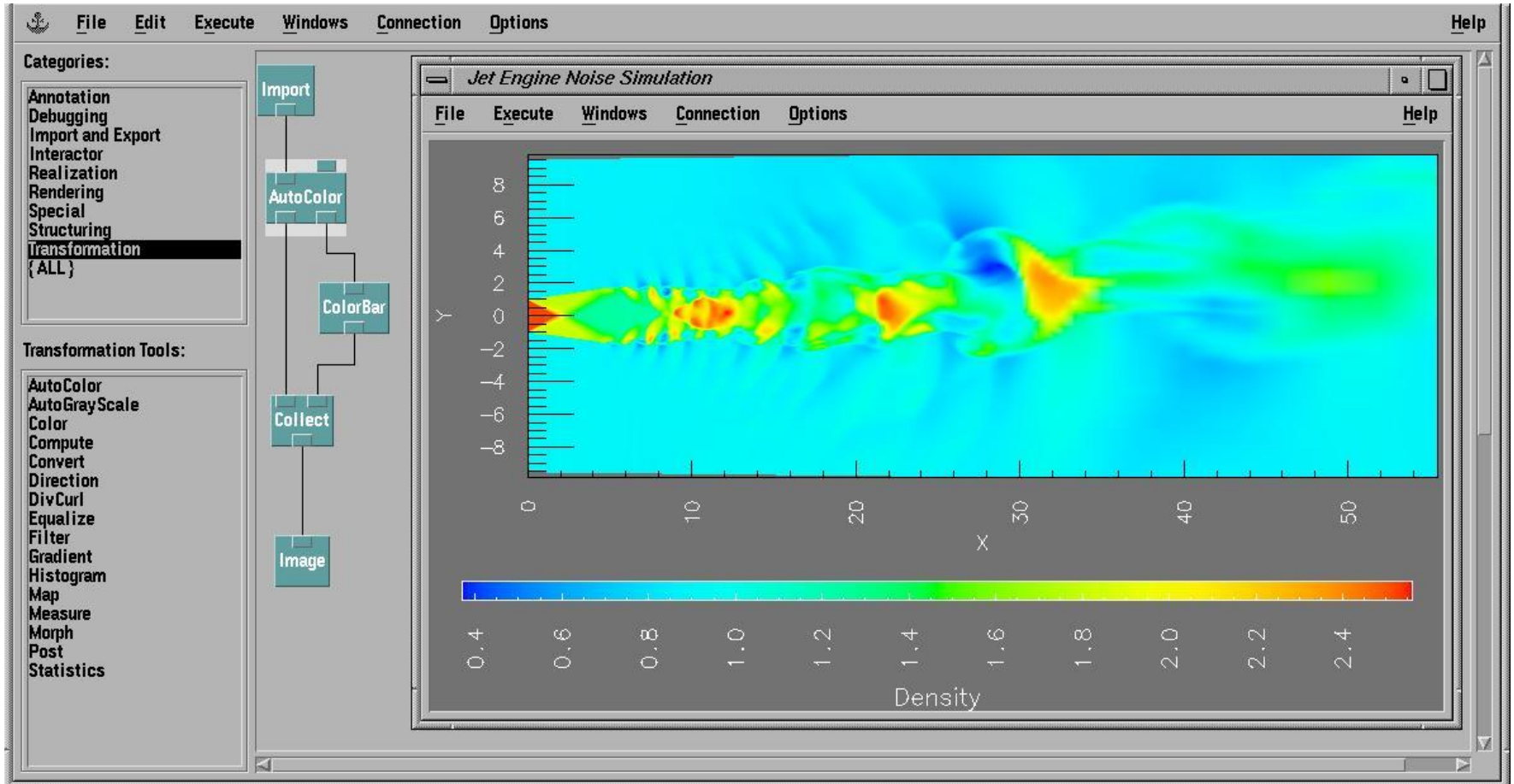
Solution 1:

- map to hue → the rainbow colormap



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

# AVOID RAINBOW COLORMAPS



# BETTER: LINEAR HUE

The image displays a software interface for "Jet Engine Noise Simulation". The main window shows a 2D density plot with a color scale ranging from 0.4 to 2.4. The plot is titled "Jet Engine Noise Simulation" and has a menu bar with "File", "Execute", "Windows", "Connection", "Options", and "Help". The plot shows a complex, elongated structure with a central core and surrounding regions of varying density. The X-axis ranges from 0 to 50, and the Y-axis ranges from -8 to 8. A color bar below the plot indicates the density values, with a scale from 0.4 to 2.4. The color bar is labeled "Density".

On the left side, there is a "Categories" panel with a list of categories: Annotation, Debugging, Import and Export, Interactor, PRAYDA (highlighted), Realization, Rendering, Special, Structuring, Transformation, and { ALL }. Below this is a "PRAYDA Tools" panel with a list of tools: AutoRuleColor, ColorMapLookup, ColorMapPicker, PRAYDAColor (highlighted), RuleColor, ScaleColorMapData, SpatialFreq, and Width. The "PRAYDA Tools" panel also contains three color maps labeled "Map 1", "Map 2", and "Map 3".

At the bottom right, there is a "Control Panel" window with a menu bar: "File", "Edit", "Execute", "Panels", "Options", and "Help". It contains a "Coloring Task" section with a dropdown menu set to "Isomorphic".

The interface also features a "PRAYDAColor" tool window with a menu bar: "Import", "Selector", "Color", "ColorBar", "Collect", and "Image".

# 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

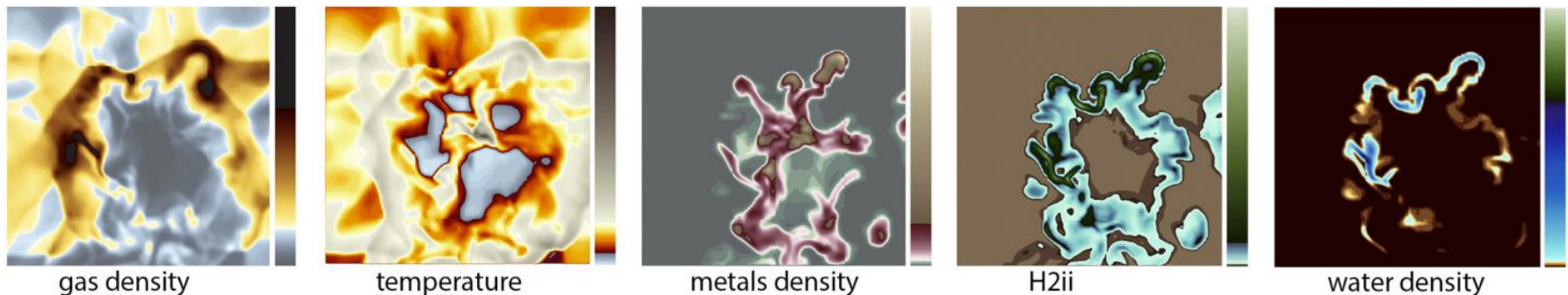
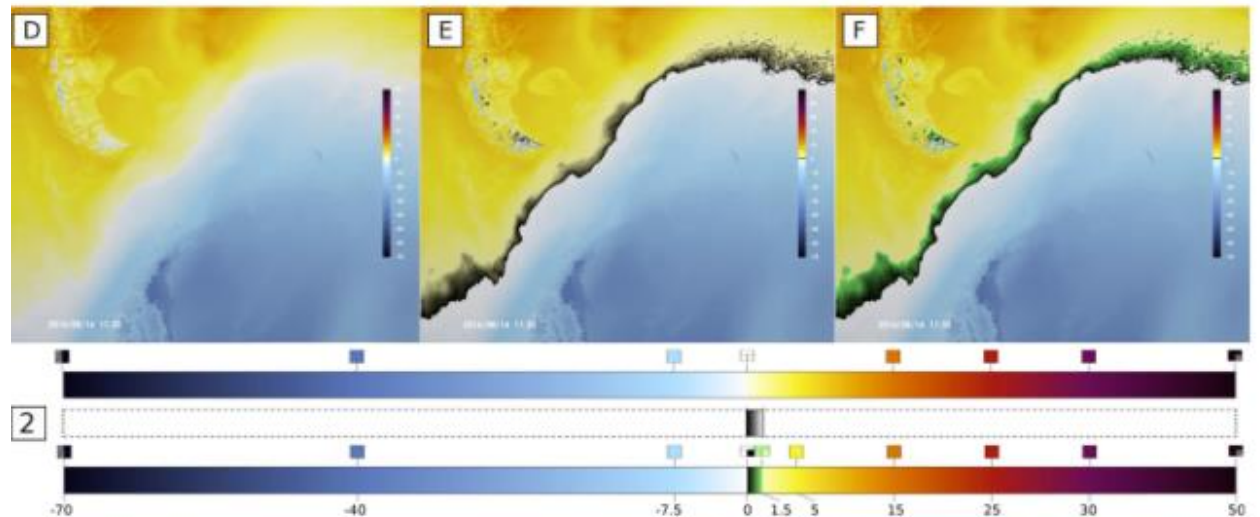
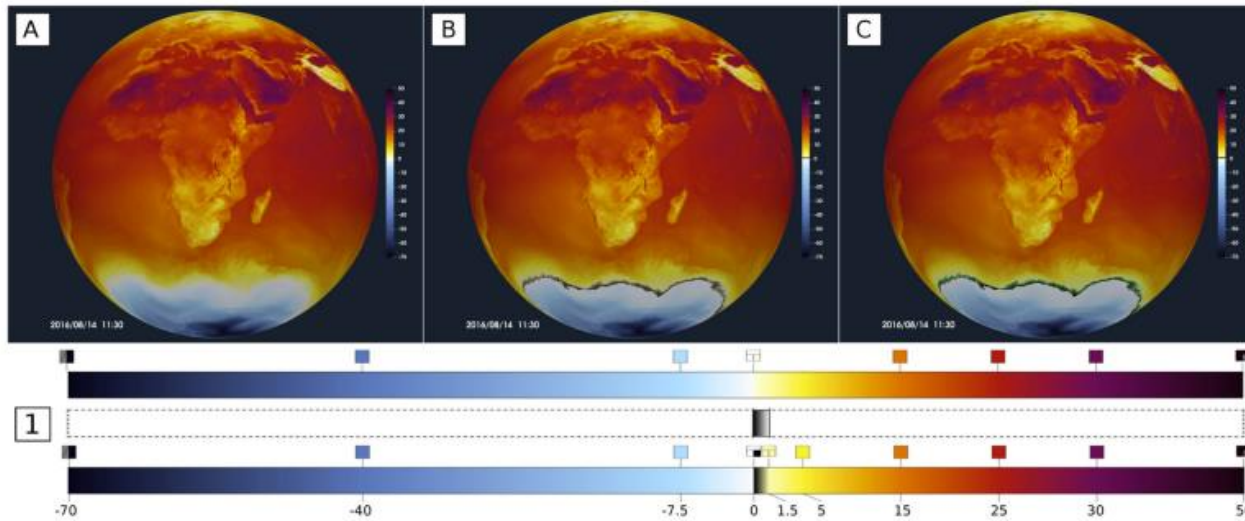


Fig. 15. Scientists examine multiple variables in order to gain an understanding into the locations and quantities where ancient water was likely to have formed. CCC-Tool color bar locations are crafted to highlight the data ranges for each variable that is conducive to water formation, enabling scientists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



# MORE PURPOSEFUL RAINBOW COLOREMAPS



also Nardini et al.

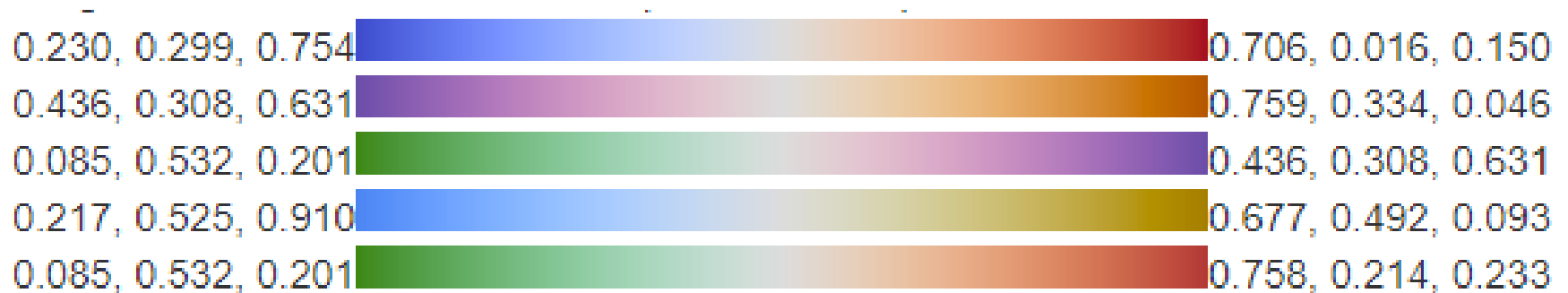
# EXPLANATION FOR LAST SLIDE

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

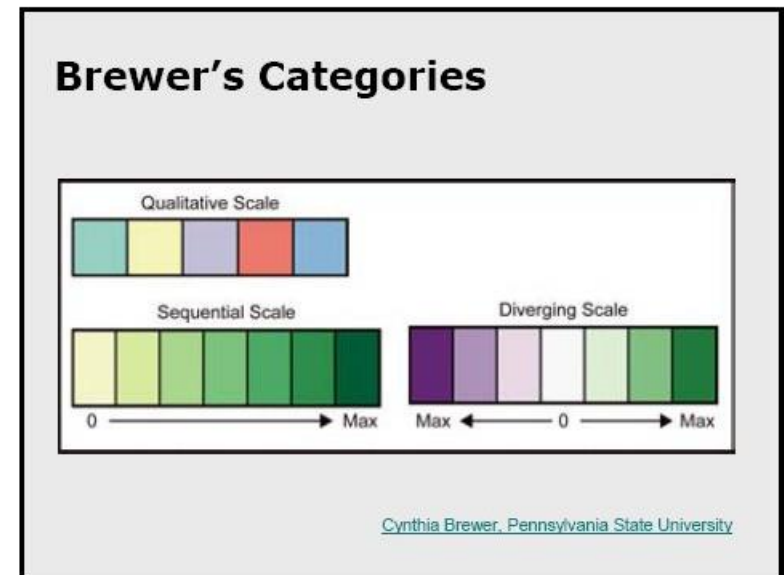
## Sequential scales

- vary in lightness and saturation
- vary slightly in hue

<http://colorbrewer2.org/>

## Diverging scale

- complementary sequential scales
- neutral at "zero"



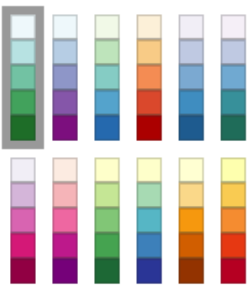


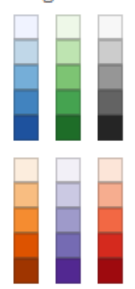
# COLOR BREWER

Number of data classes: 3 i [how to use](#) [updates](#) [downloads](#) [credits](#)

Nature of your data: i  
 sequential  diverging  qualitative

Pick a color scheme:

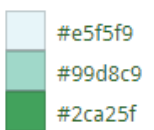
Multi-hue: 

Single hue: 

Only show: i  
 colorblind safe  
 print friendly  
 photocopy safe

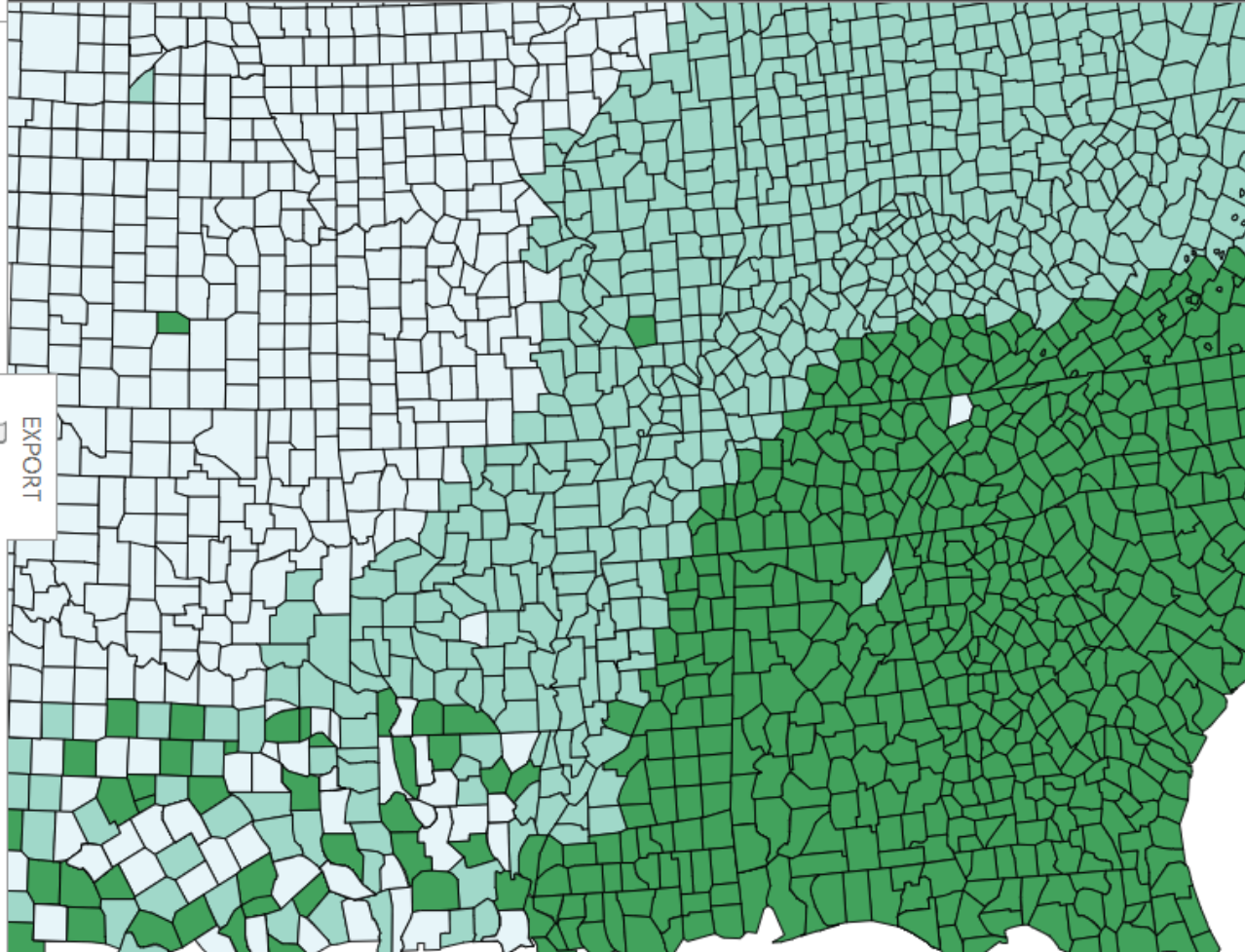
Context: i  
 roads  
 cities  
 borders

Background:  
 solid color i  
 terrain  
 color transparency

3-class BuGn  
  
HEX v

EXPORT

**COLORBREWER 2.0**  
color advice for cartography



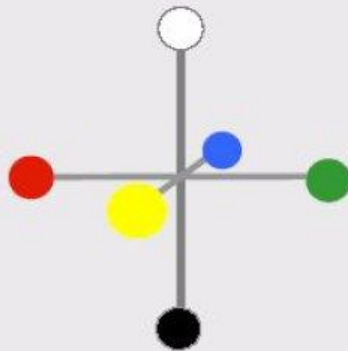
# OPPONENT COLOR

## Definition

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

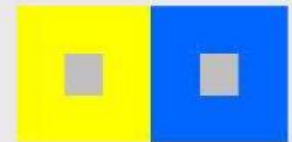
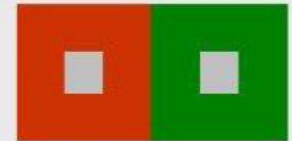
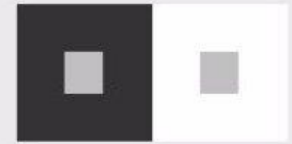
## First level encoding

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



## Add Opponent Color

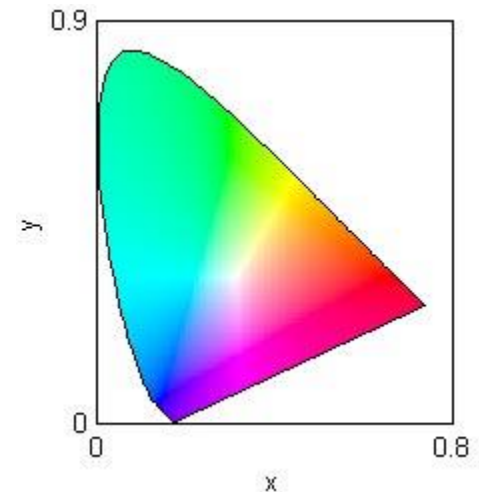
- Dark adds light
- Red adds green
- Blue adds yellow



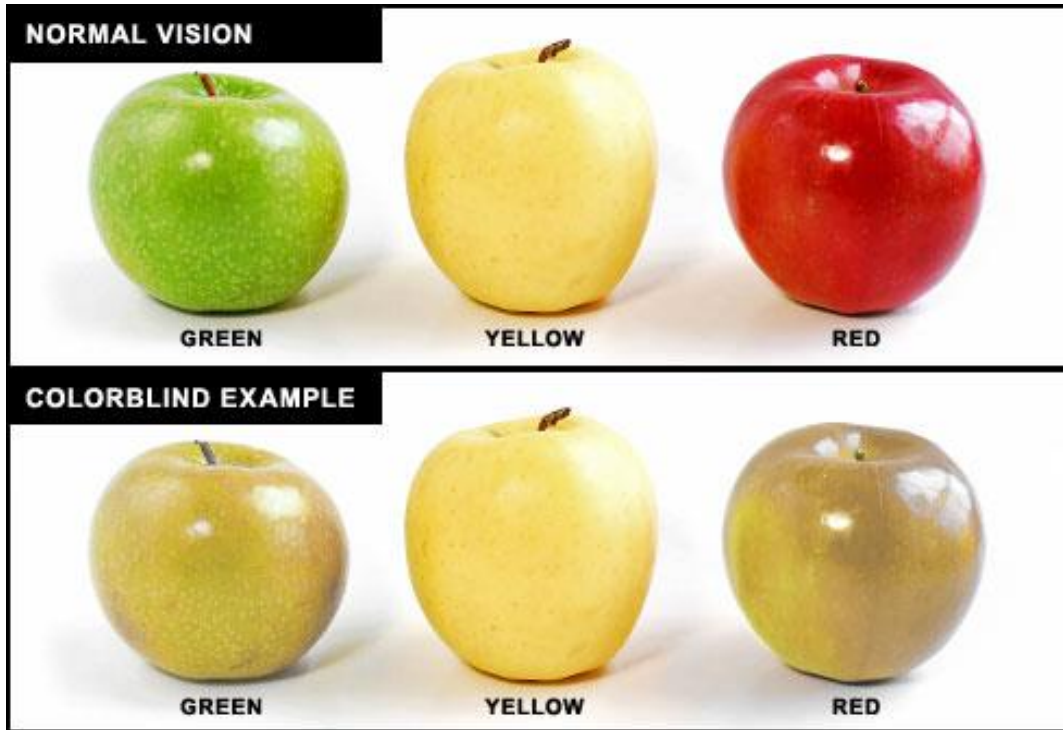
These samples will have both light/dark and hue contrast

## 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.

green missing



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

red missing



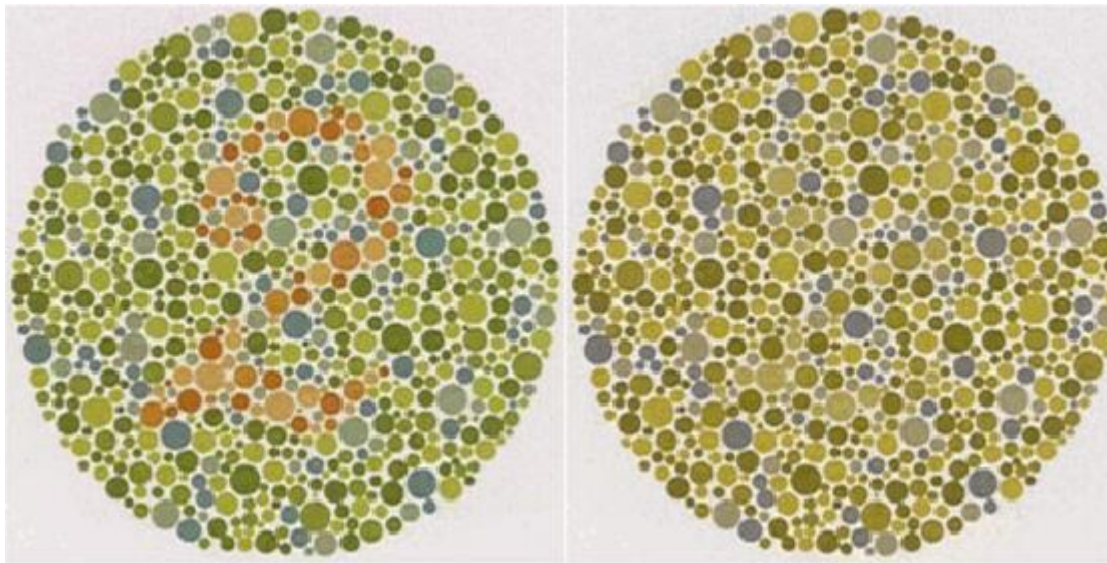
The colors of the rainbow as viewed by a person with protanopia.

blue missing  
(rare)



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

# ISHIHARA TEST

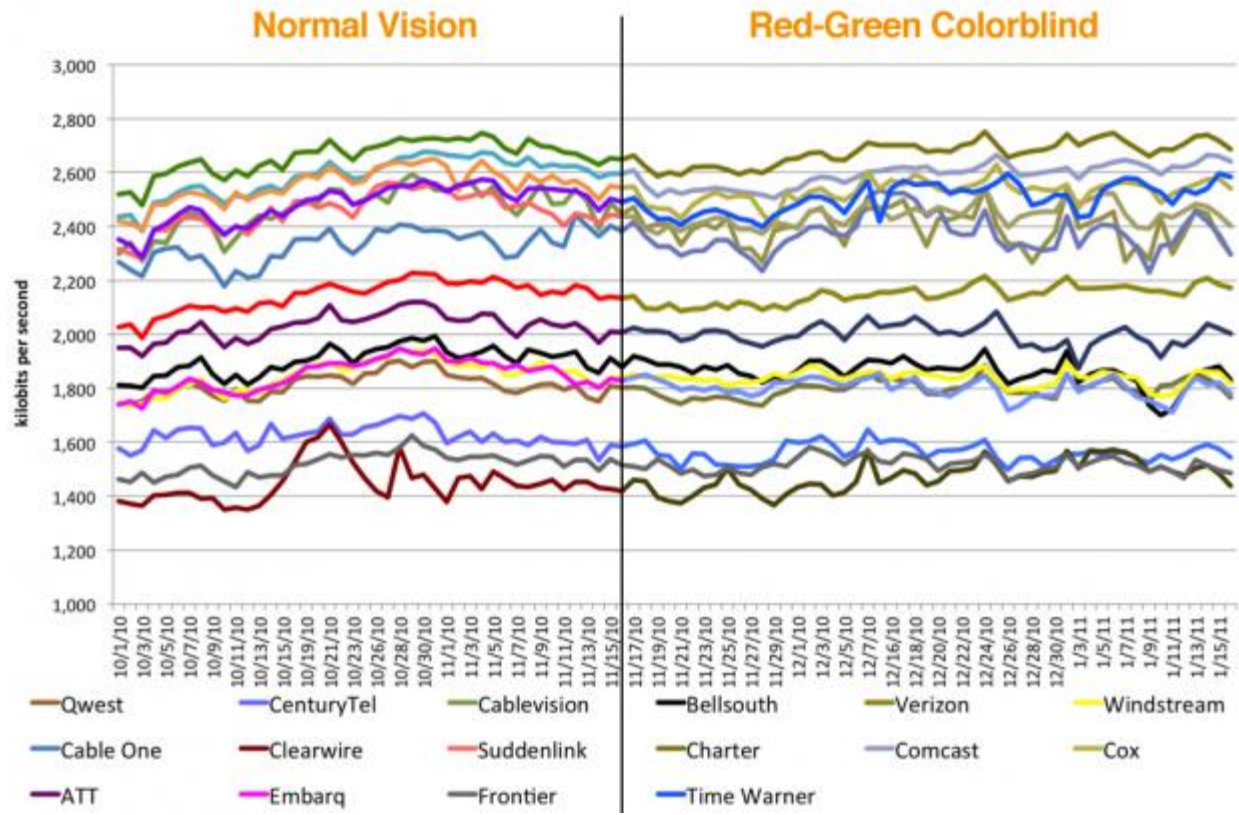


normal

protanopia



# LINE CHARTS



# 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

