

# Visual Perception



CS 7450 - Information Visualization  
September 7, 2016  
John Stasko

## Learning Objectives



- Describe the visual processing pipeline
- Define pre-attentive processing
  - Identify visual features that are and are not pre-attentive
- Describe Gestalt principles and their application to visualization
- Explain how luminance and brightness relate
- Learn about and use principles of color in visualization
- Understand integral versus separable visual components
- Explain which perception factors best encode different communication goals
- Define change blindness
- Describe key limitations of visual channel
  
- Ultimately, critique and apply perception principles to designs

# Semiotics



- The study of symbols and how they convey meaning
- Classic book:
  - J. Bertin, 1983, *The Semiology of Graphics*

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# Related Disciplines



- Psychophysics
  - Applying methods of physics to measuring human perceptual systems
    - How fast must light flicker until we perceive it as constant?
    - What change in brightness can we perceive?
- Cognitive psychology
  - Understanding how people think, here, how it relates to perception

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# Perceptual Processing



- Seek to better understand visual perception and visual information processing
  - Multiple theories or models exist
  - Need to understand physiology and cognitive psychology

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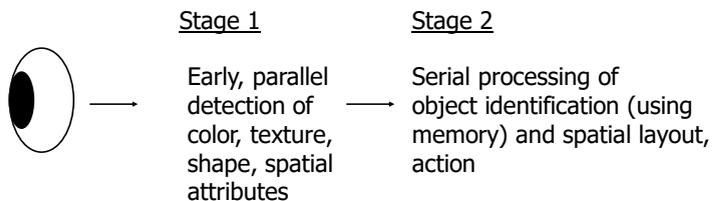
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## One (simple) Model



- Two stage process
  - Parallel extraction of low-level properties of scene
  - Sequential goal-directed processing



Ware 2000

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## Stage 1 - Low-level, Parallel



- Neurons in eye & brain responsible for different kinds of information
  - Orientation, color, texture, movement, etc.
- Arrays of neurons work in parallel
- Occurs “automatically”
- Rapid
- Information is transitory, briefly held in iconic store
- Bottom-up data-driven model of processing
- Often called “pre-attentive” processing

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## Stage 2 - Sequential, Goal-Directed



- Splits into subsystems for object recognition and for interacting with environment
- Increasing evidence supports independence of systems for symbolic object manipulation and for locomotion & action
- First subsystem then interfaces to verbal linguistic portion of brain, second interfaces to motor systems that control muscle movements

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## Stage 2 Attributes



- Slow serial processing
- Involves working and long-term memory
- More emphasis on arbitrary aspects of symbols
- Top-down processing

## Preattentive Processing



- How does human visual system analyze images?
  - Some things seem to be done preattentively, without the need for focused attention
  - Generally less than 200-250 msec (eye movements take 200 msec)
  - Seems to be done in parallel by low-level vision system

Drawn from  
C. Healey web article

# How Many 3's?



1281768756138976546984506985604982826762  
9809858458224509856458945098450980943585  
9091030209905959595772564675050678904567  
8845789809821677654876364908560912949686

# How Many 3's?



12817687561**3**8976546984506985604982826762  
980985845822450985645894509845098094**3**585  
90910**3**0209905959595772564675050678904567  
8845789809821677654876**3**64908560912949686

# What Kinds of Tasks?



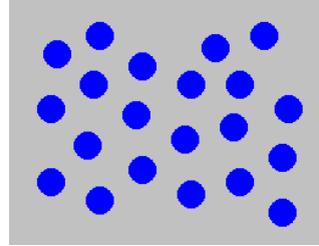
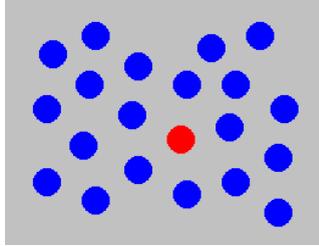
- Target detection
  - Is something there?
- Boundary detection
  - Can the elements be grouped?
- Counting
  - How many elements of a certain type are present?

## Example



- Determine if a red circle is present
- (2 sides of the room)

# Hue



Can be done rapidly (preattentively) by people  
Surrounding objects called "distractors"

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# Example



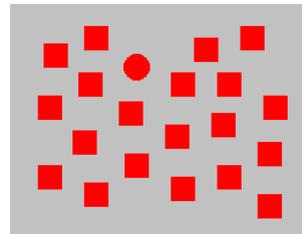
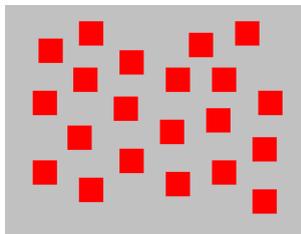
- Determine if a red circle is present

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# Shape



Can be done preattentively by people

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# Example



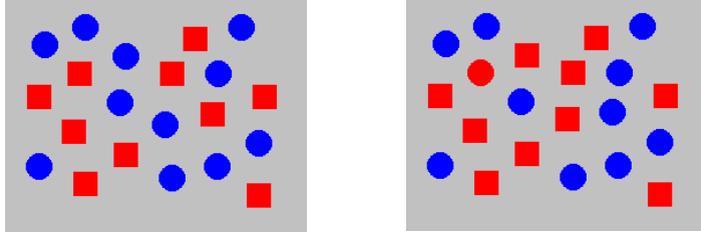
- Determine if a red circle is present

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# Hue and Shape



- Cannot be done preattentively
- Must perform a sequential search
- Conjunction of features (shape and hue) causes it

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# Example



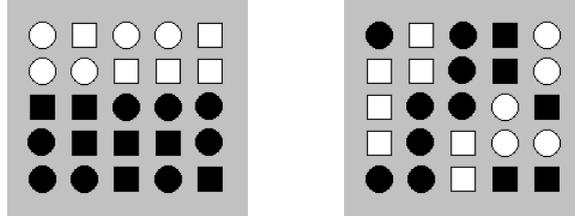
- Is there a boundary in the display?

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# Fill and Shape



- Left can be done preattentively since each group contains one unique feature
- Right cannot (there is a boundary!) since the two features are mixed (fill and shape)

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# Example



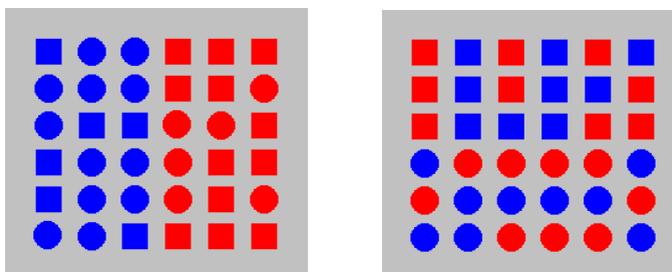
- Is there a boundary in the display?

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# Hue versus Shape



Left: Boundary detected preattentively based on hue regardless of shape

Right: Cannot do mixed color shapes preattentively

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## Example



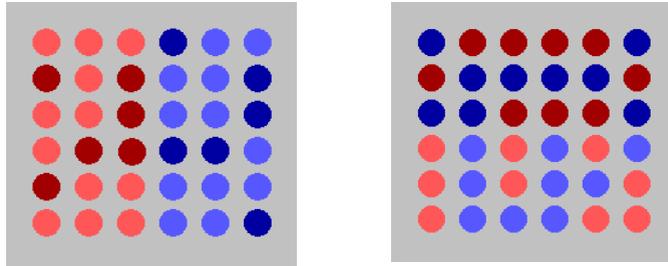
- Is there a boundary?

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# Hue versus brightness



Left: Varying brightness seems to interfere  
Right: Boundary based on brightness can be done preattentively

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## Example Applet



- Nice on-line tutorial and example applet
  - <http://www.csc.ncsu.edu/faculty/healey/PP/index.html>
  - Chris Healey, NC State
  - Prior pictures taken from site

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# Preattentive Features



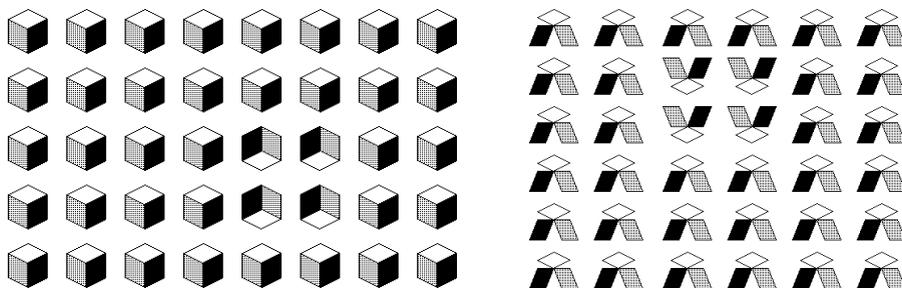
- Certain visual forms lend themselves to preattentive processing
- Variety of forms seem to work

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# 3-D Figures



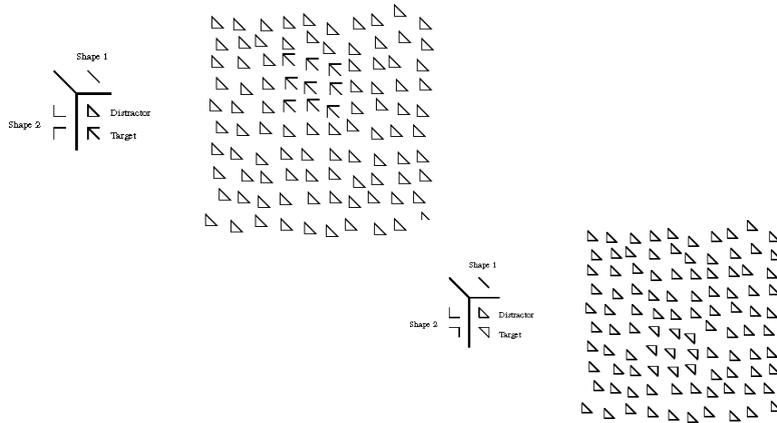
3-D visual reality has an influence

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# Emergent Features



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# Potential PA Features



- |              |                     |
|--------------|---------------------|
| length       | hue                 |
| width        | intensity           |
| size         | flicker             |
| curvature    | direction of motion |
| number       | binocular lustre    |
| terminators  | stereoscopic depth  |
| intersection | 3-D depth cues      |
| closure      | lighting direction  |

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## Discussion



- What role does/should preattentive processing play in information visualization?

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## Gestalt Laws



- Background
  - German psychologists, early 1900's
  - Attempt to understand pattern perception
  - Founded Gestalt school of psychology
  - Provided clear descriptions of many basic perceptual phenomena
    - Gestalt Laws of Pattern Perception

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# Gestalt Laws



- Proximity
  - Things close together are perceptually grouped together
- Similarity
  - Similar elements get grouped together
- Connectedness
  - Connecting different objects by lines unifies them
- Continuity
  - More likely to construct visual entities out of smooth, continuous visual elements

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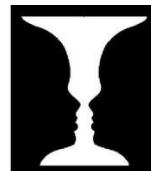
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# Gestalt Laws



- Symmetry
  - Symmetrical patterns are perceived more as a whole
- Closure
  - A closed contour is seen as an object
- Relative Size
  - Smaller components of a pattern as perceived as objects
- Figure & Ground
  - Figure is foreground, ground is behind



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# Key Perceptual Properties



- Brightness
- Color
- Texture
- Shape

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# Luminance/Brightness



- Luminance
  - Measured amount of light coming from some place
- Brightness
  - *Perceived* amount of light coming from source

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# Brightness



- Perceived brightness is non-linear function of amount of light emitted by source
  - Typically a power function
  - $S = aI^n$ 
    - S - sensation
    - I - intensity
- Very different on screen versus paper

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# Grayscale



- Probably not best way to encode data because of contrast issues
  - Surface orientation and surroundings matter a great deal
  - Luminance channel of visual system is so fundamental to so much of perception
    - We can get by without color discrimination, but not luminance

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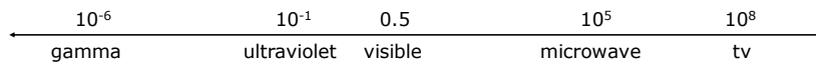
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# Color



- Sensory response to electromagnetic radiation in the spectrum between wavelengths 0.4 - 0.7 micrometers



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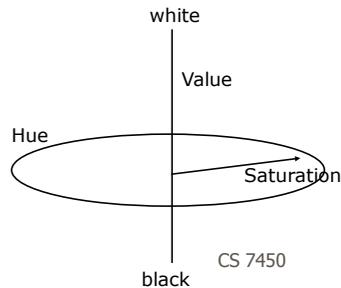
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# Color Models



- HVS model
  - Hue - what people think of color
  - Value - light/dark, ranges black $\leftrightarrow$ white
  - Saturation - intensity, ranges hue $\leftrightarrow$ gray



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# How Not to Use Color



<http://www.cc.com/video-clips/w066sz/the-daily-show-with-jon-stewart-full-color-coverage>

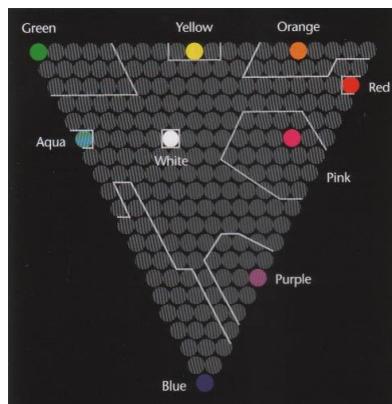
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# Color Categories

- Are there certain canonical colors?
  - Post & Greene '86 had people name different colors on a monitor
  - Pictured are ones with > 75% commonality



From Ware '04

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# Maybe Not All the Same?



<http://www.boreme.com/posting.php?id=30670>



Himba tribe

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## Luminance



- Important for fg-bg colors to differ in brightness

Hello, here is some text. Can you read what it says?  
Hello, here is some text. Can you read what it says?  
Hello, here is some text. Can you read what it says?  
Hello, here is some text. Can you read what it says?  
Hello, here is some text. Can you read what it says?  
Hello, here is some text. Can you read what it says?  
Hello, here is some text. Can you read what it says?

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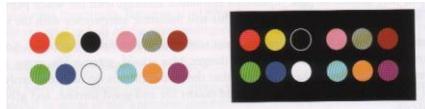
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# Color for Categories



- Can different colors be used for categorical variables?
  - Yes (with care)
  - Ware’s suggestion: 12 colors  
red, green, yellow, blue, black, white, pink, cyan,  
gray, orange, brown, purple



From Ware '04

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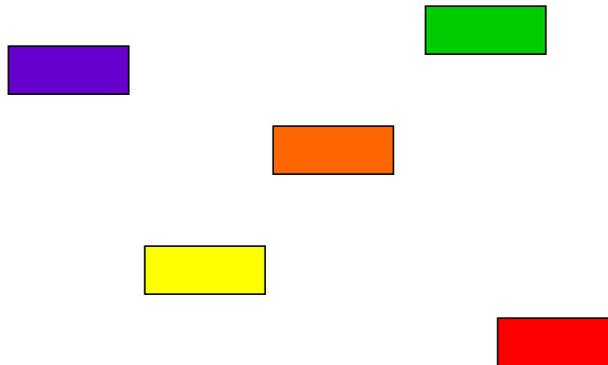
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# Color for Sequences



Can you order these (low->hi)

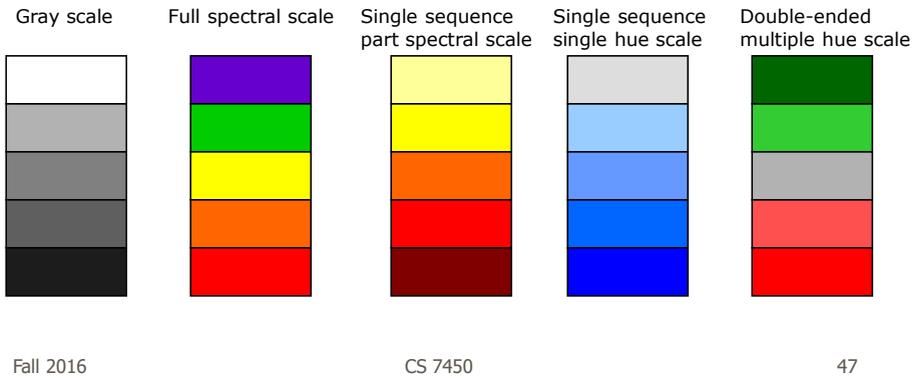


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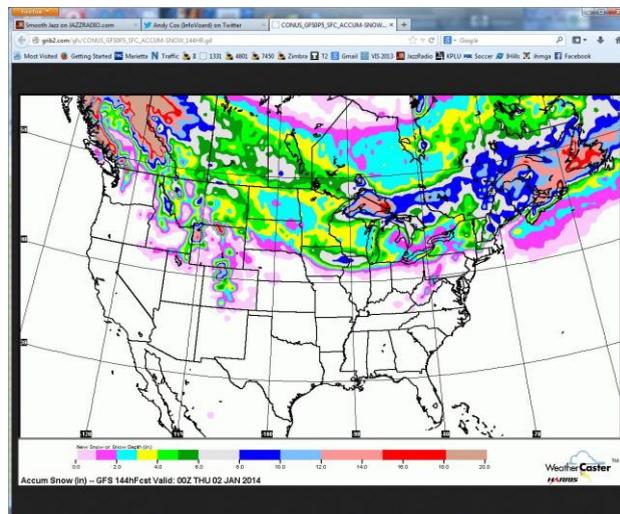
# Possible Color Sequences



# Advice



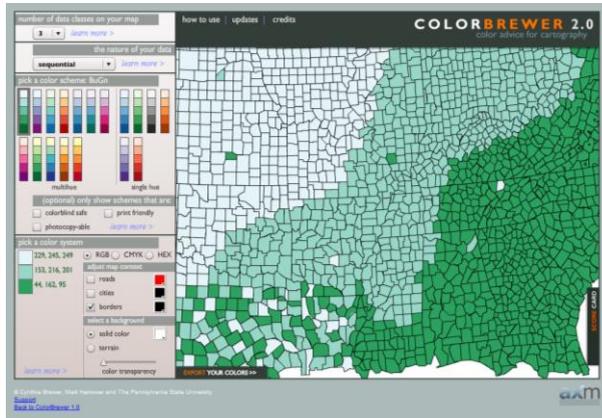
Don't use the rainbow color scale for quantitative data



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# ColorBrewer



Help with selecting colors for maps

<http://colorbrewer2.org/>

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## Color Purposes



- Call attention to specific data
- Increase appeal, memorability
- Increase number of dimensions for encoding data
  - Example, Ware and Beatty '88
    - x,y - variables 1 & 2
    - amount of r,g,b - variables 3, 4, & 5

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# Using Color



- Modesty! Less is more
- Use blue in large regions, not thin lines
- Use red and green in the center of the field of view (edges of retina not sensitive to these)
- Use black, white, yellow in periphery
- Use adjacent colors that vary in hue & value

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# Using Color

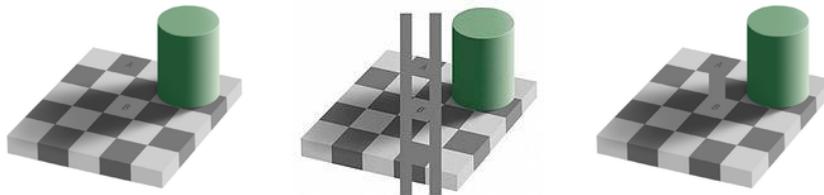


- For large regions, don't use highly saturated colors (pastels a good choice)
- Do not use adjacent colors that vary in amount of blue
- Don't use high saturation, spectrally extreme colors together (causes after images)
- Use color for grouping and search
- Beware effects from adjacent color regions (my old house - example)

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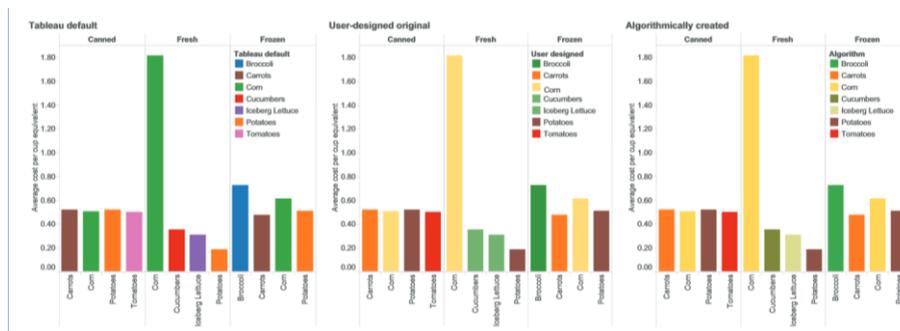
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Are regions A and B the same color?

## Tableau's Colors



Provides "default" colors for legend items  
Use NLP, Google n-grams & images

Setlur & Stone  
*TVCG (InfoVis) '15*

# More Choices

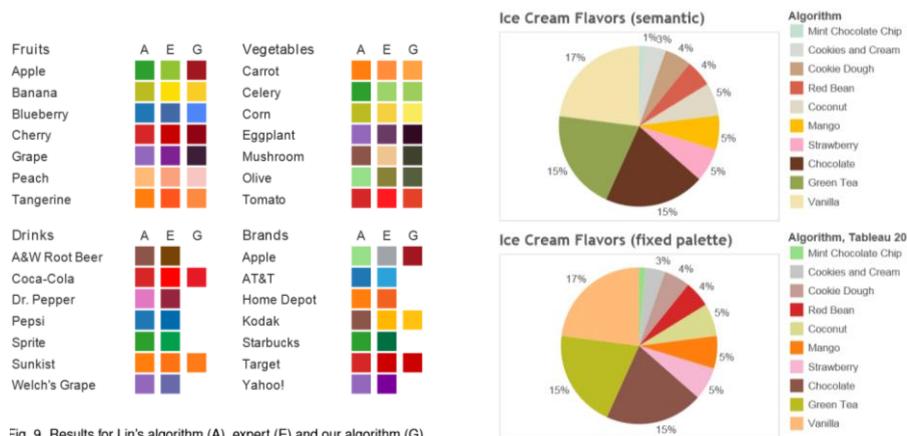


Fig. 9. Results for Lin's algorithm (A), expert (E) and our algorithm (G).

# Color Challenge



Test your color abilities

# Good Color Advice



Maureen Stone's website  
Many references and links  
She frequently offers  
tutorials about color at  
conferences

<http://www.stonesc.com>

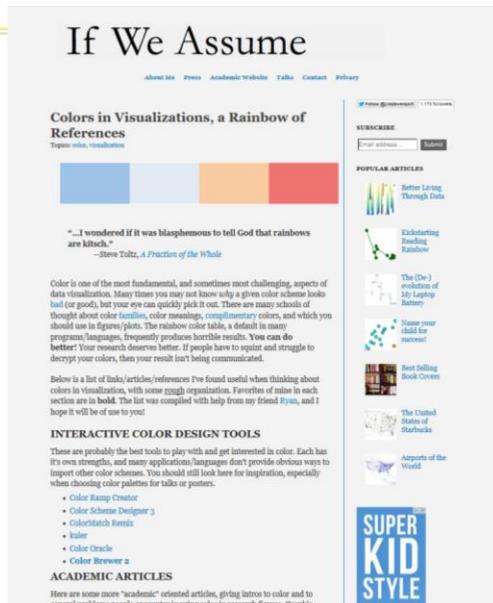
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<http://www.ifweassume.com/2012/12/colors-in-visualizations-rainbow-of.html>

# Color Resources



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# Texture



- Appears to be combination of
  - orientation
  - scale
  - contrast
- Complex attribute to analyze

# Shape, Symbol



- Can you develop a set of unique symbols that can be placed on a display and be rapidly perceived and differentiated?
- Application for maps, military, etc.
- Want to look at different preattentive aspects

# Glyph Construction



- Suppose that we use two different visual properties to encode two different variables in a discrete data set
  - color, size, shape, lightness
- Will the two different properties interact so that they are more/less difficult to untangle?
  - Integral - two properties are viewed holistically
  - Separable - Judge each dimension independently

# Integral-Separable



- Not one or other, but along an axis



Ware '04

# Encodings



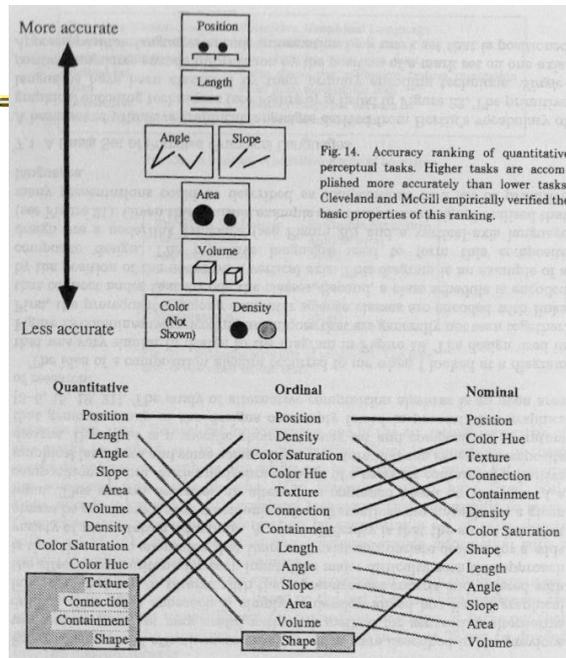
- When you want to communicate one type of variable, which visual property should you use?

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Accuracy ranking of quantitative perceptual tasks



Ranking of perceptual tasks

From Jock Mackinlay's 1986 thesis

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# Change Blindness



- Is the viewer able to perceive changes between two scenes?
  - If so, may be distracting
  - Can do things to minimize noticing changes
- Fun examples
  - Static pictures (Ron Rensink, UBC)  
<http://www.psych.ubc.ca/~rensink/flicker/download/>
  - Videos (Dan Simons, Illinois)  
<http://www.simonslab.com/videos.html>

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# Optical Illusions



The screenshot shows a web browser window displaying a page titled "53 Optical Illusions & Visual Phenomena (Visual Illusion - Optische Täuschungen)" by Michael Bach. The page includes a navigation menu, a list of 53 optical illusions, and a grid of images illustrating these illusions. The text on the page explains that optical illusions are not malfunctions of the visual system but rather adaptations to standard viewing situations. It also mentions that the page is available in German and English.

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## Stage 2



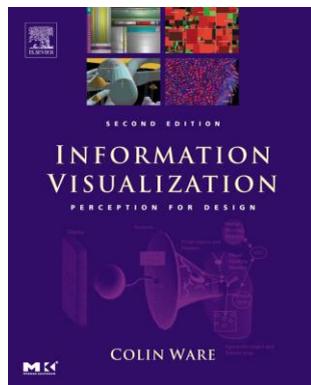
- Missing here!
- Object recognition and locomotion/action
- Maybe in the future... :^)

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## Great Book



*Information Visualization  
Perception for Design*  
2<sup>nd</sup> edition

Colin Ware  
Morgan Kaufmann

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- Learn about and use principles of color in visualization
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- Explain which perception factors best encode different communication goals
- Define change blindness
- Describe key limitations of visual channel
  
- Ultimately, critique and apply perception principles to designs

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# HW 1 Return



- Observations

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## VotD



- Instructions in t-square – Resources page
- Connect to tumblr
- Follow instructions!
- Find your day

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## Project



- Teams paired up
- Topic proposal due next Weds.
- Good project ideas in t-square

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## Reading



- M. Stone, "Choosing colors for data visualization"
- Browse colorbrewer website
- Do first perception test on  
<http://www.simonslab.com/videos.html>

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## Upcoming



- Vis programming tutorial
  - D3, etc.
- Multivariate visual representations 1

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# Sources Used



Healey website and article

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

Marti Hearst SIMS 247 lectures

C. Ware, *Information Visualization*