Visual Perception

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Includes slides adapted from John Stasko (Georgia Tech),
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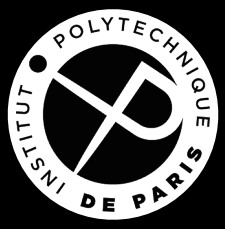

Updated: May 2020

Agenda

Visual Search & Saliency

- Pre-attentive Processing & Selective Attention

Color

Choosing & Combining Visual Variables

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

Semiotics

- The study of symbols and how they convey meaning

- Classic book:
  - J. Bertin, *Sémiologie Graphique,* 1967
  - (In English: J. Bertin, *The Semiology of Graphics,* 1983)

Perceptual Processing

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

One (simple) Model

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

Stage 1

Early, parallel detection of color, texture, shape, spatial attributes

Stage 2

Serial processing of object identification (using memory) and spatial layout, action

[Ware 2000]

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

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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 msecs (eye movements take 200 msecs)
  - Seems to be done in parallel by low-level vision system

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How Many 3's?

12817687561389765469845069856049828267629809858458224509856458945098450980943585909103020990595959577256467505067890456788457898098216776548763649085609129496869

How Many 3's?

128176875613897654698450698560498282676298098584582245098564589450984509809435859091030209905959595772564675050678904567884578980982167765487636490856091294968 6

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

Hue

[Healey 2009]

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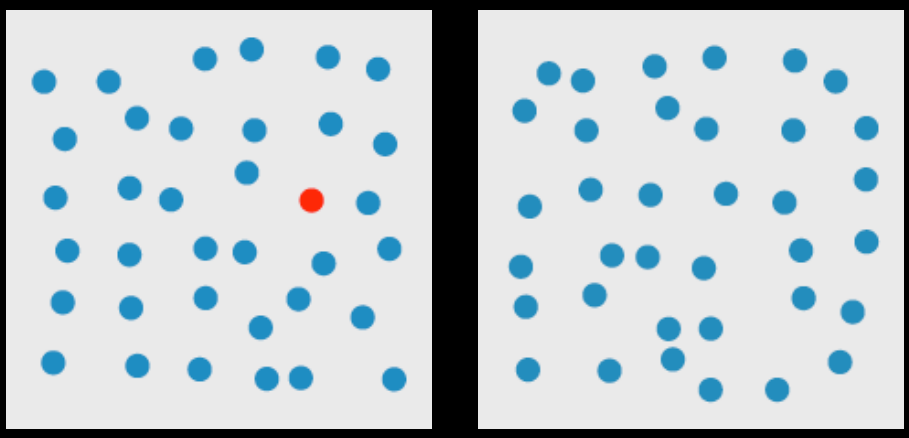
Hue



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

[Healey 2009]

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Example

Determine if a red circle is present

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Shape

[Healey 2009]

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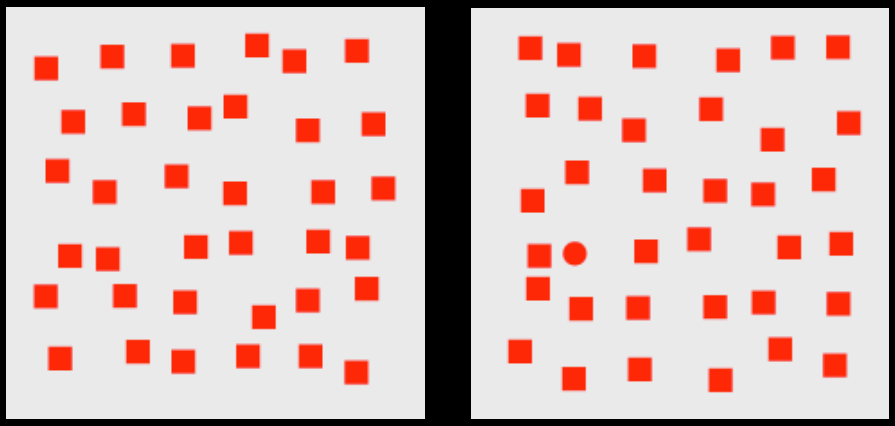
Shape



Can be done preattentively by people

[Healey 2009]

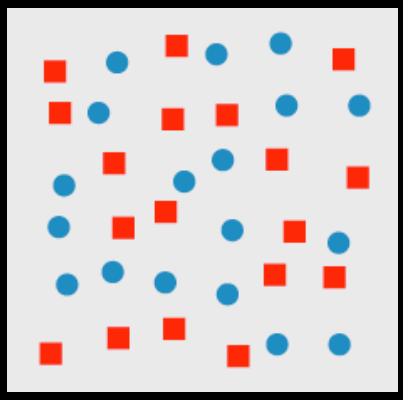
Example

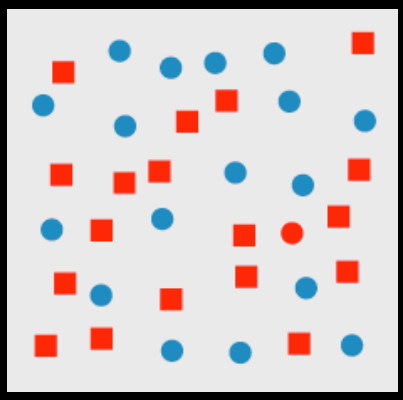
Determine if a red circle is present

Hue & Shape

[Healey 2009]

Hue & Shape





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

[Healey 2009]

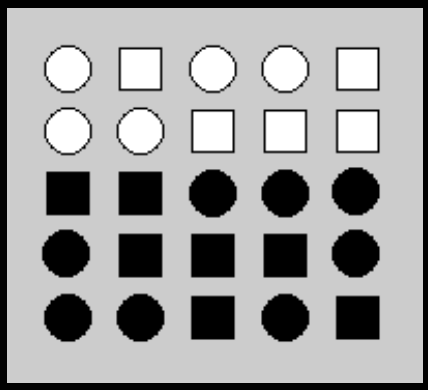
Example

Is there a boundary in the display?

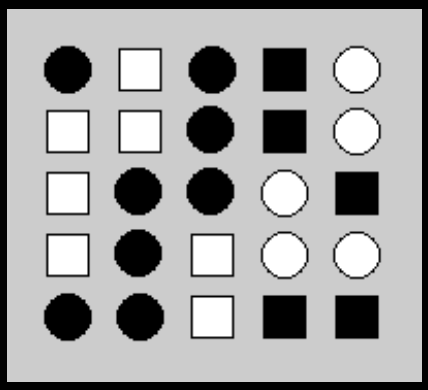
Fill & Shape

[Healey 2009]

Fill & Shape



Can be done preattentively since each group contains one unique feature



Cannot (there is a boundary!) since the two features are mixed (fill and shape)

[Healey 2009]

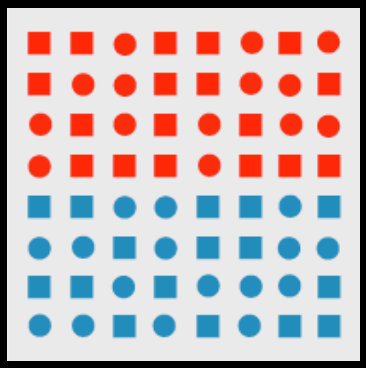
Example

Is there a boundary in the display?

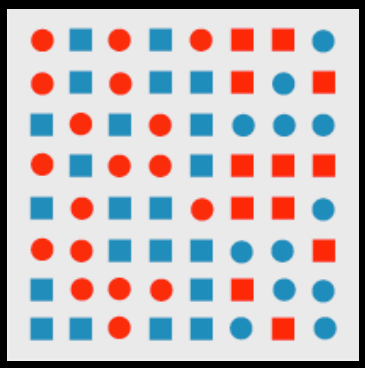
Hue & Shape

[Healey 2009]

Hue & Shape



Boundary detected preattentively based on hue regardless of shape



Cannot do mixed color shapes preattentively

[Healey 2009]

Preattentive Features

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

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Potentially Preattentive Features

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

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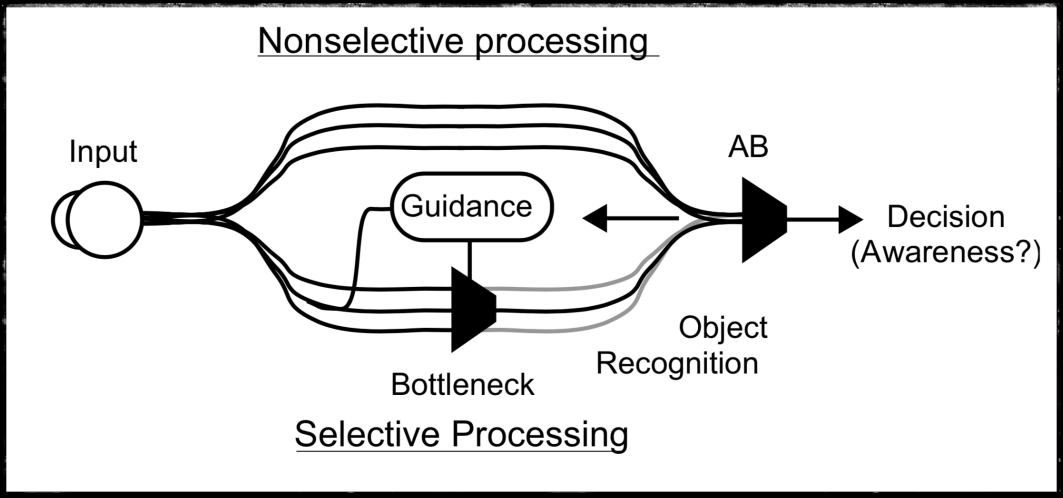
Guided Search



[J. Wolfe in W. Gray '07, Oxford University Press]

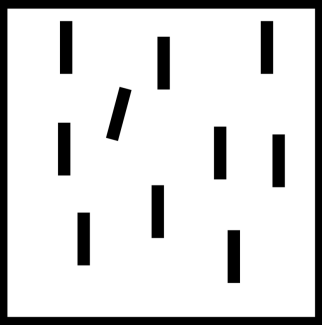
Basic Principles

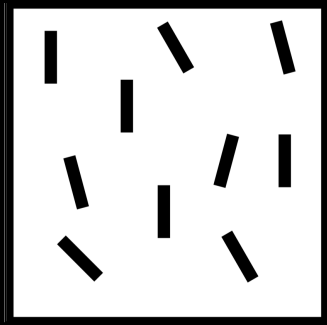
Set size
more distracters → longer *t*

Presence
absent target → longer *t*

Target similarity
larger difference → smaller *t*

Distractor heterogeneity:
different distractors → harder search





[J. Wolfe in W. Gray '07, Oxford University Press]

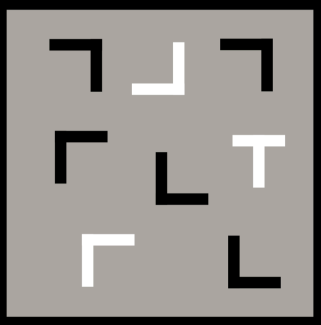
Basic Principles

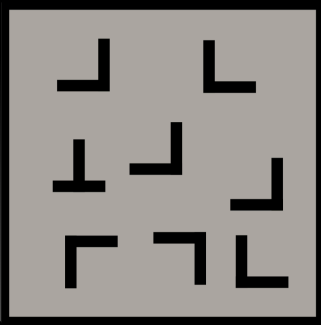
Flanking
flanking target → longer t

Asymmetry
search for a in b ≠ b in a

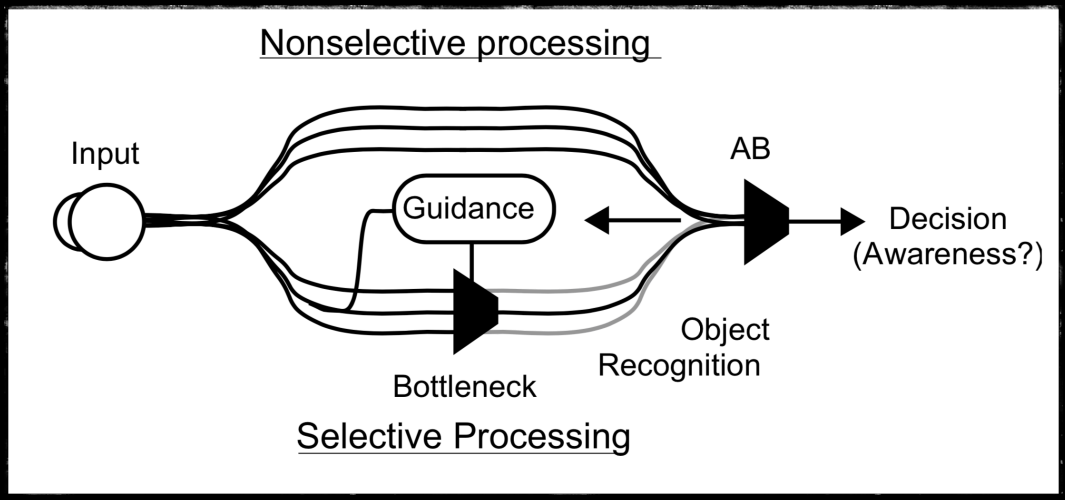
Categorical processing
easier to find target when unique

Guidance:
visual cues to orient attention





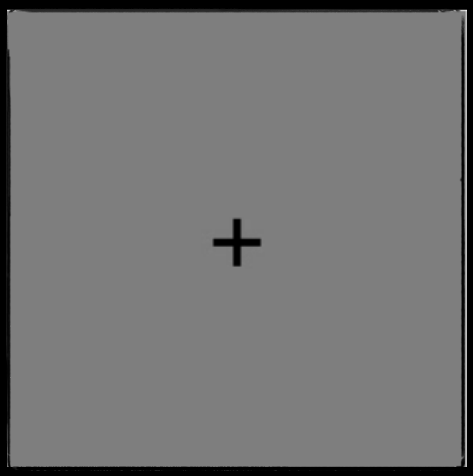
Guided Search



[J. Wolfe in W. Gray '07, Oxford University Press]

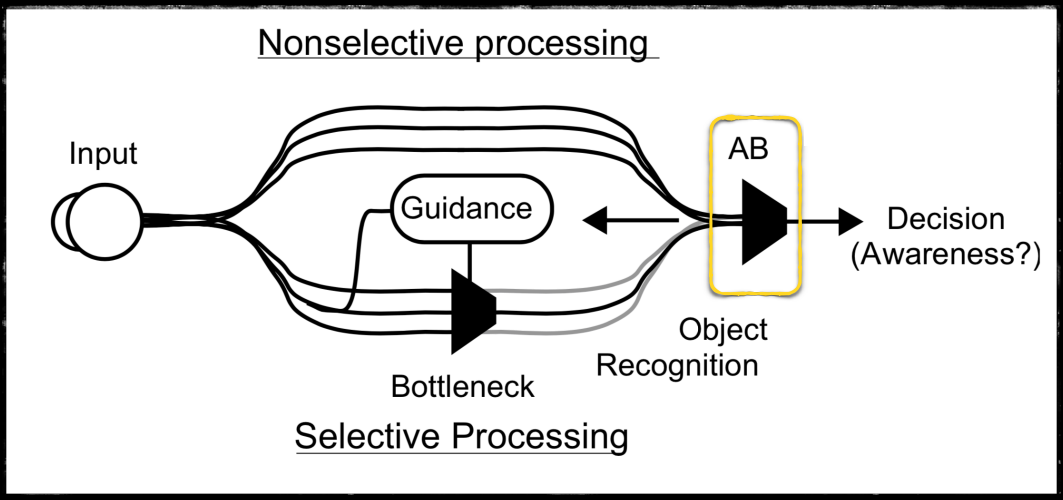
Change-Blindness

- Under what circumstances will the viewer not perceive differences?
  - Really many phenomena
  - Often related to “stage 1/stage 2” processing
  - Understand how to avoid or exploit



[Scholarpedia]

Attentional Blink



[J. Wolfe in W. Gray '07, Oxford University Press]

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Selective attention

[Simons & Chabris, Perception '99 ; Youtube]

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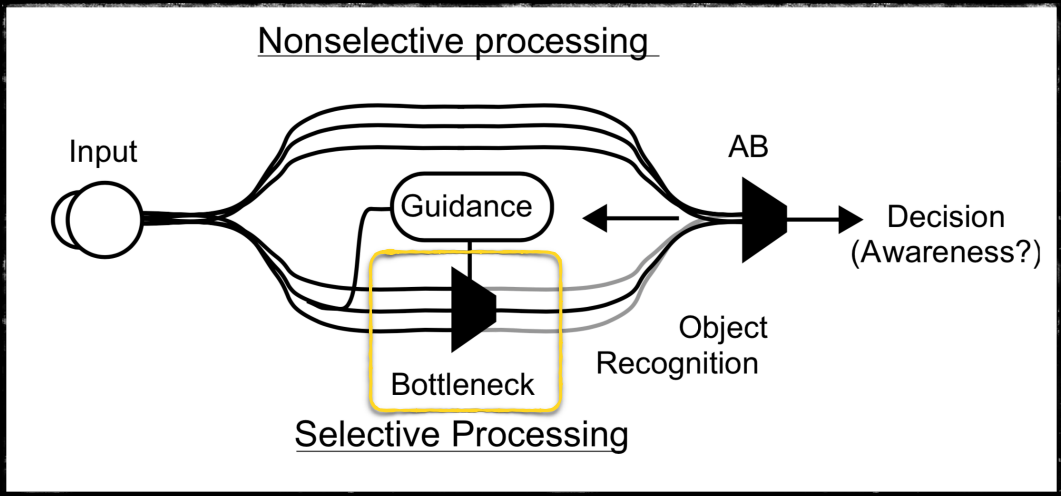
Guided Search



[J. Wolfe in W. Gray '07, Oxford University Press]

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Simplified Model

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

Stage 1

Early, parallel detection of color, texture, shape, spatial attributes

Stage 2

Serial processing of object identification (using memory) and spatial layout, action

[Ware 2000]

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Change Blindness Demos









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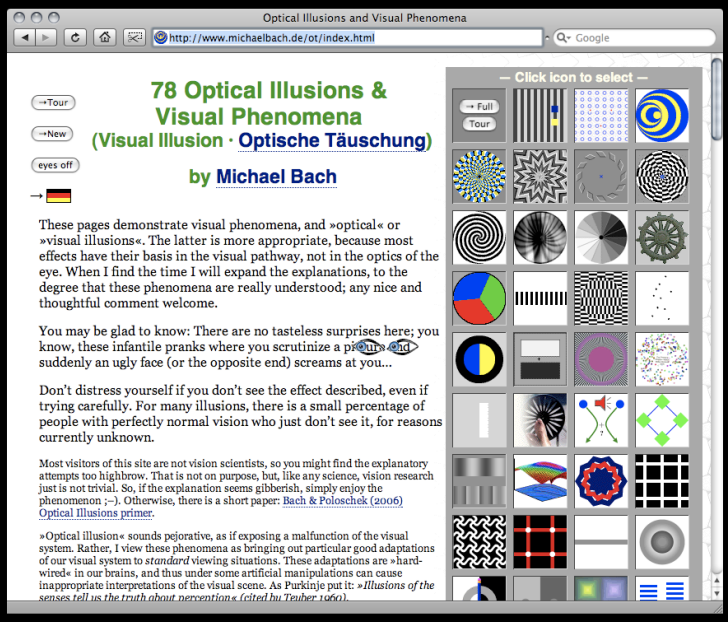
Optical Illusions



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Back to Visualization

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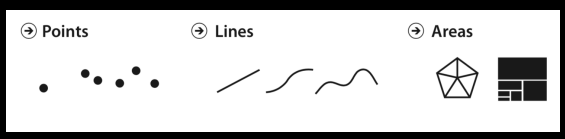
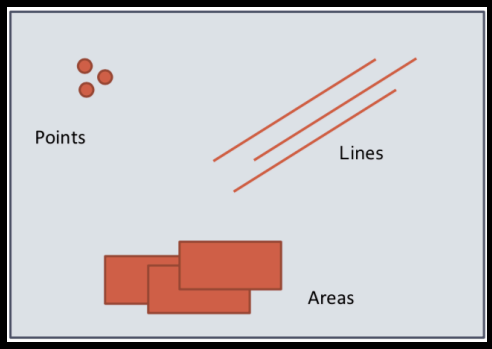
Visualization components

- Space
- Marks
- Implantation
- Visual variables

Marks



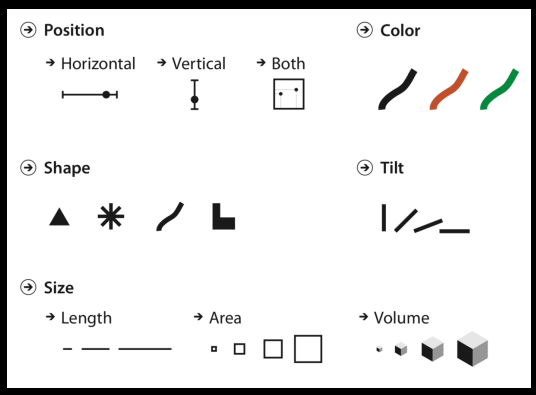
- Points
- Lines
- Areas



[Bertin, Semiology of Graphics, 1967 ; Nadia Boukhelifa ; Munzner, ch. 5]

Visual Variables

- Position
- Color
- Length
- Area
- Angle
- etc.
- Which ones to use? **When?**



[Munzner, ch. 5]

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Key Perceptual Properties

Position

Size

Shape

Brightness

Color

Texture

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Key Perceptual Properties

Position	Brightness
Size	Color
Shape	Texture

Luminance/Brightness

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

Brightness

- Nonlinear function of the amount of light emitted by a source
  - Typically a power function
  - $S = aI^n$
    - S = sensation
    - I = intensity
- Very different on screen versus paper

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Greyscale

- 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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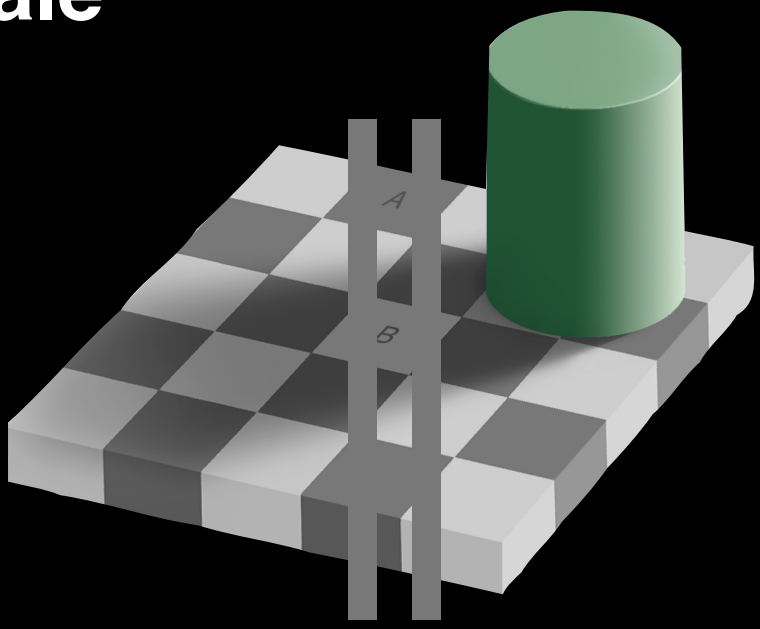
Greyscale



[Edward H. Adelson]

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Visual Operations

Selective
Can we select targets based on this visual attribute

Associative
Can we group targets based on this visual attribute

Quantitative
Can we read a numerical value from this visual attribute

Orderable
Can we perceive an ordering based on this visual attribute

Discriminable
How many nuances of this visual attribute can we recognize

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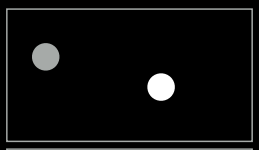
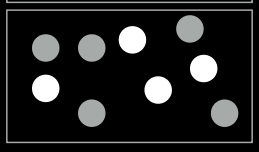
Greyscale

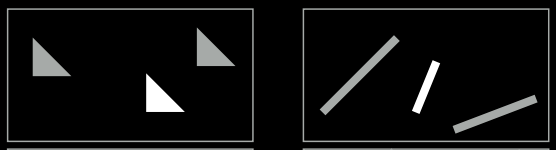
Selective



Associative



Quantitative



Orderable

Discriminable (Up to around 10 shades)

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Color

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

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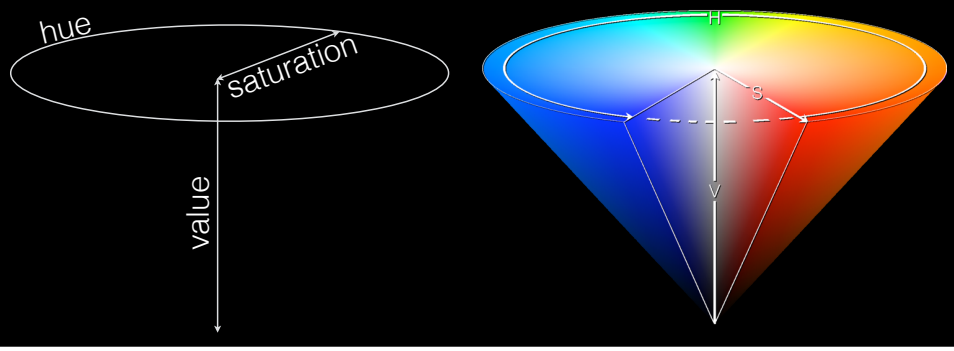
Color Models

- HSV model
  - Hue — what people think of color
  - Saturation — intensity, ranges hue↔gray
  - Value — light/dark, ranges black↔white



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Luminance

- Important for foreground/background colors to differ in brightness.

Bonjour, voici un peu de texte. Can you read it?
Bonjour, voici un peu de texte. Can you read it?
Bonjour, voici un peu de texte. Can you read it?
Bonjour, voici un peu de texte. Can you read it?
Bonjour, voici un peu de texte. Can you read it?
Bonjour, voici un peu de texte. Can you read it?
Bonjour, voici un peu de texte. Can you read it?

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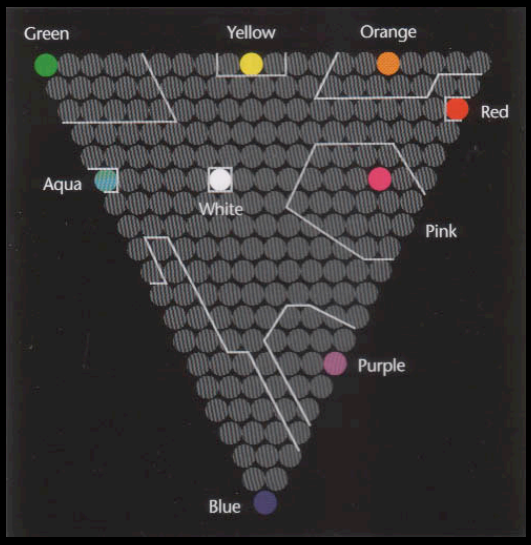
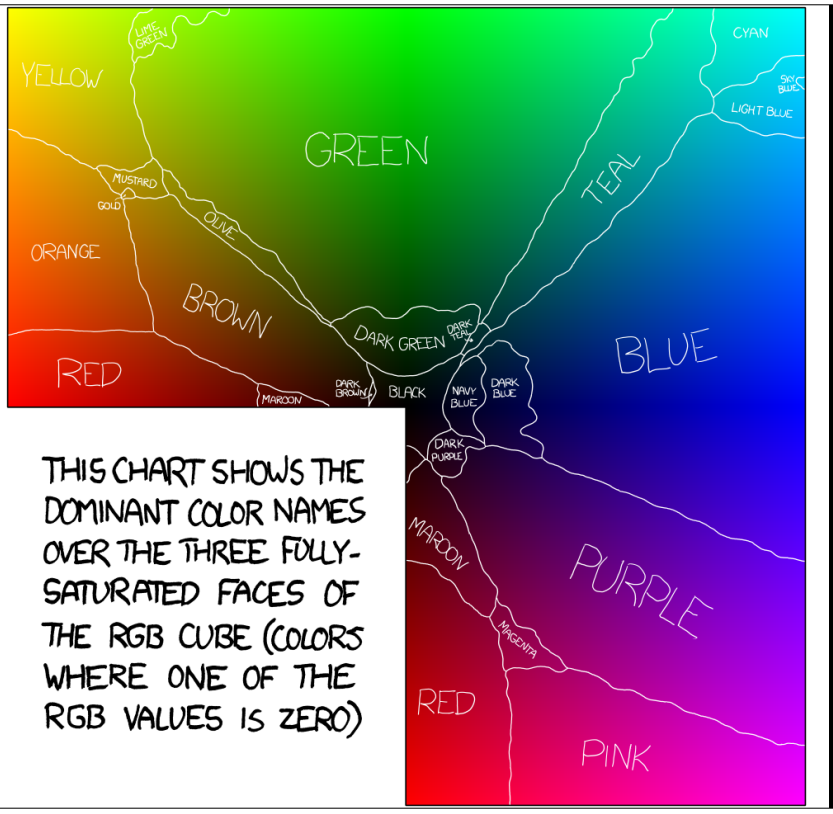
Color Categories

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



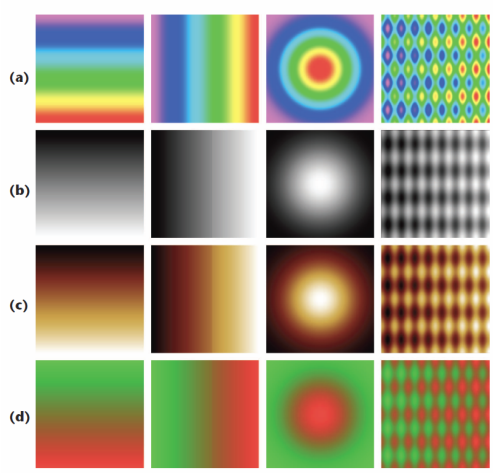
[Ware 2004]



[xkcd]

Color Scale Transitions

- Rainbow color scale
  - appears separated into bands of almost constant hue
  - sharp transitions between hues are perceived as sharp transitions in the data



rainbow color scale

gray scale

heated color scale

isoluminant green-red scale

From: Rainbow Color Map (Still) Considered Harmful, CG&A 07

[Slide courtesy of Petra Isenberg, INRIA]

Using 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

D3 10

Google 10

[Ware 2004]

Using Color for Sequences

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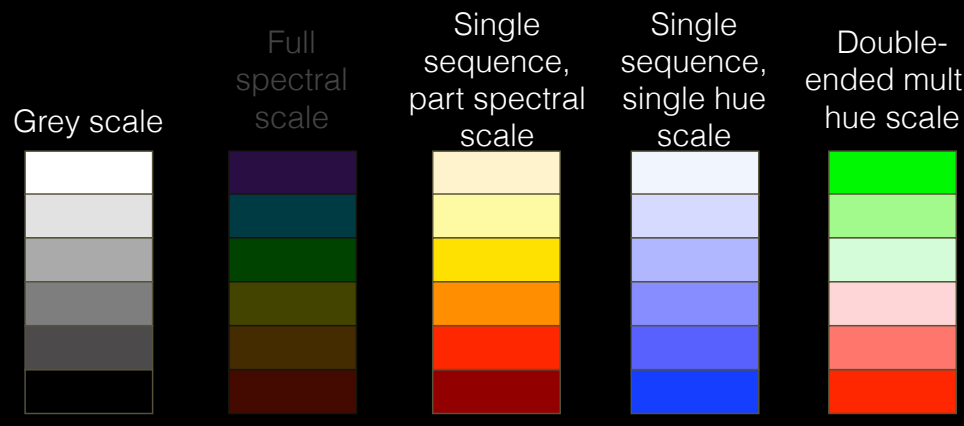
Possible Color Sequences



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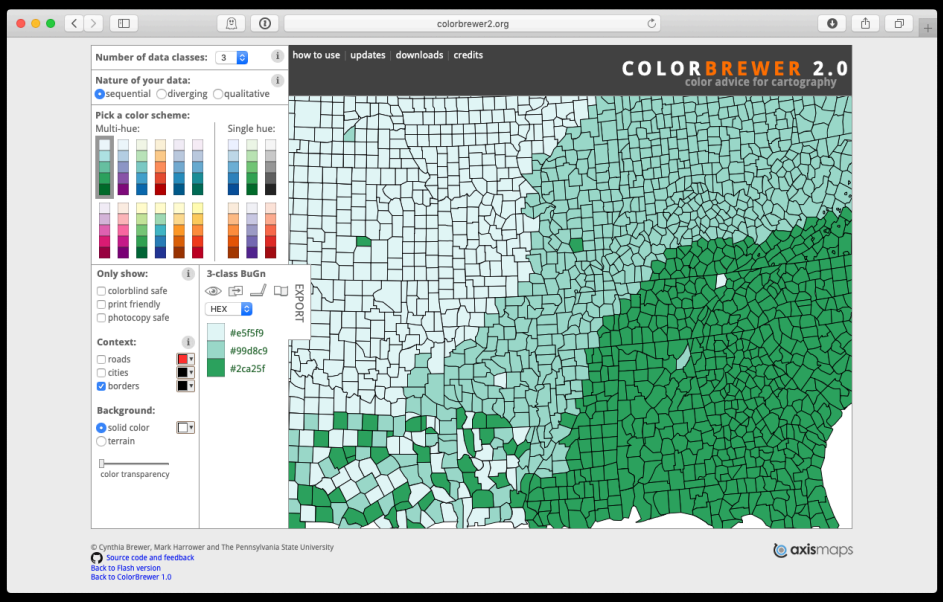
ColorBrewer

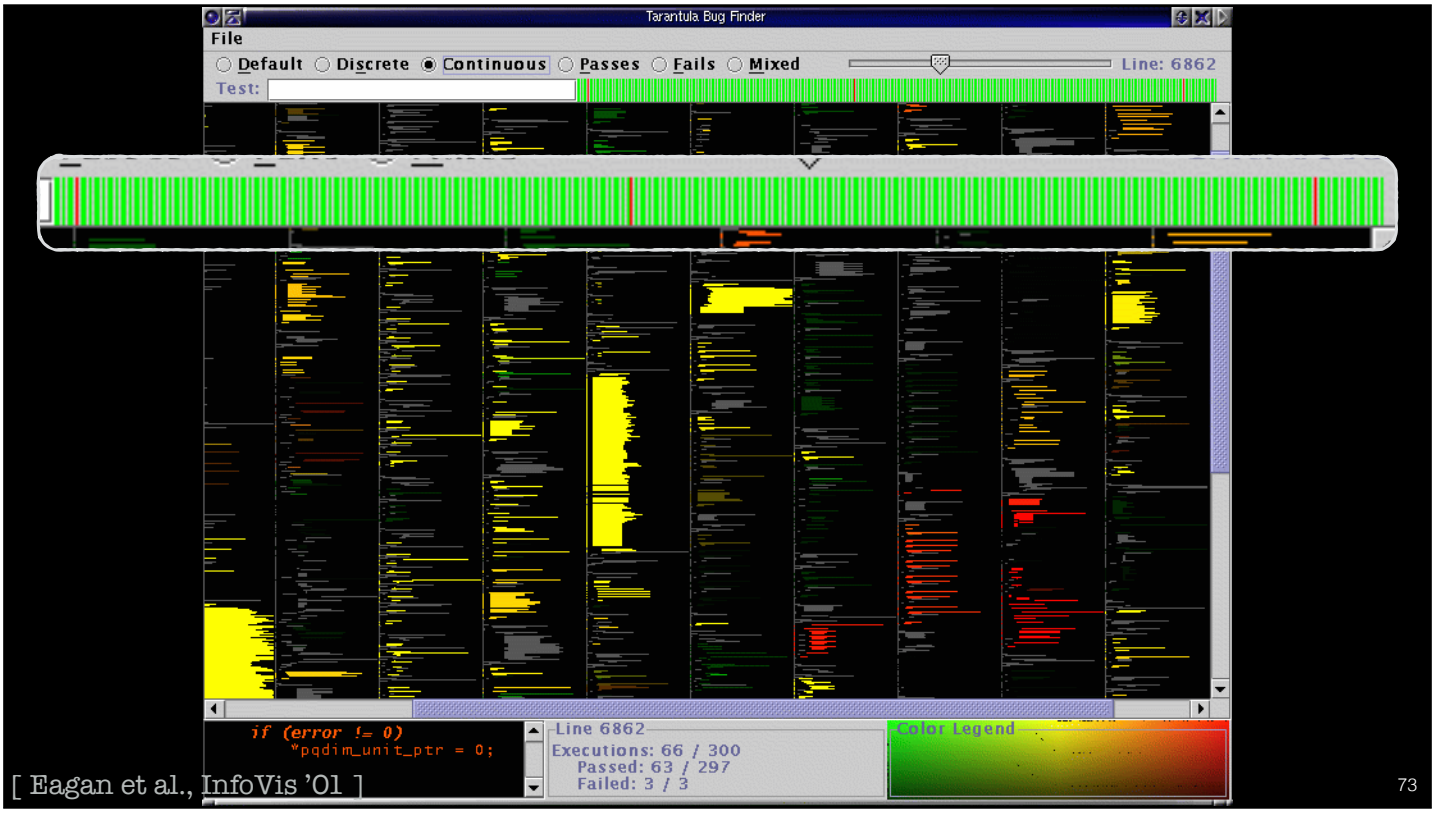


[colorbrewer2.org, Cynthia Brewer, Penn State University]

Using Color

- Always have high luminance contrast between foreground and background
- Use only few distinct colors
- Red, green, yellow, blue are hard-wired into the brain. Use them first.
- For large areas use muted colors

[Ware, Information Visualization]


Tarantula Bug Finder
File
Default
Discrete
Continuous
Passes
Fails
Mixed
Line: 6862
Test:
if (error != 0)
*pqdim_unit_ptr = 0;
Line 6862
Executions: 66 / 300
Passed: 63 / 297
Failed: 3 / 3
Color Legend
[Eagan et al., InfoVis '01]
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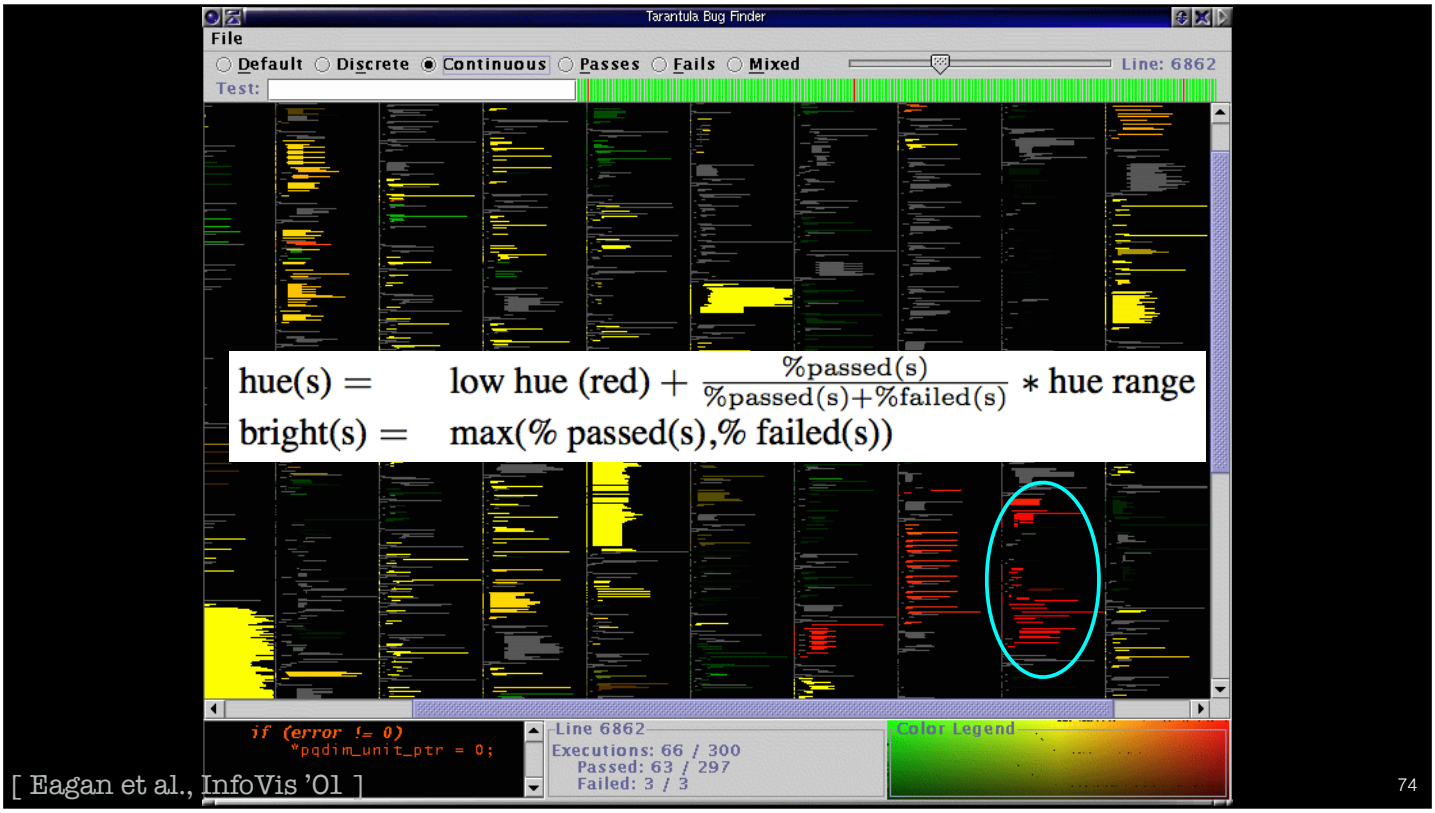
Tarantula Bug Finder
File
Default
Discrete
Continuous
Passes
Fails
Mixed
Line: 6862
Test:
hue(s) = low hue (red) + %passed(s) / (%passed(s)+%failed(s)) * hue range
bright(s) = max(% passed(s),% failed(s))
if (error != 0)
*pqdim_unit_ptr = 0;
Line 6862
Executions: 66 / 300
Passed: 63 / 297
Failed: 3 / 3
Color Legend
[Eagan et al., InfoVis '01]
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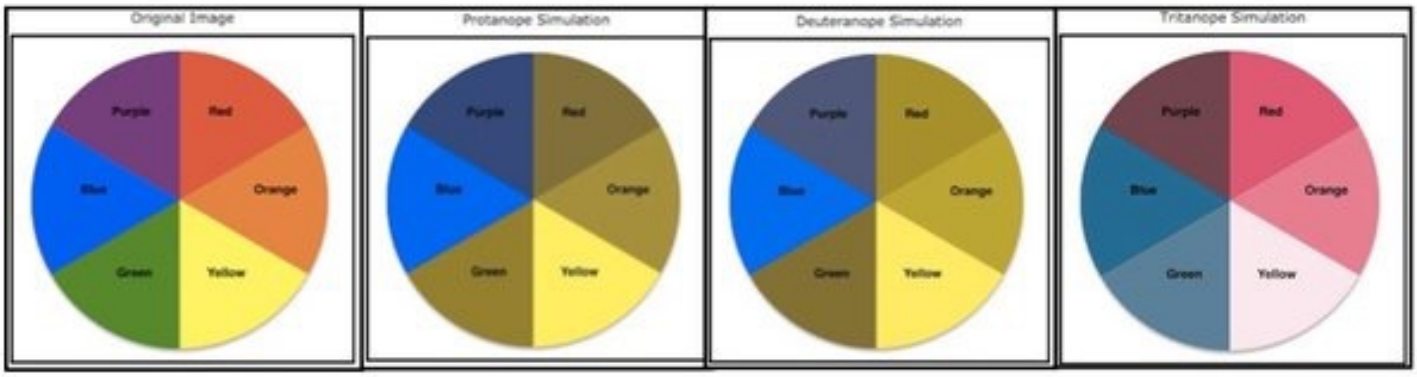
Red, Yellow & Blue primary and secondary color wheel with color deficiency tests.



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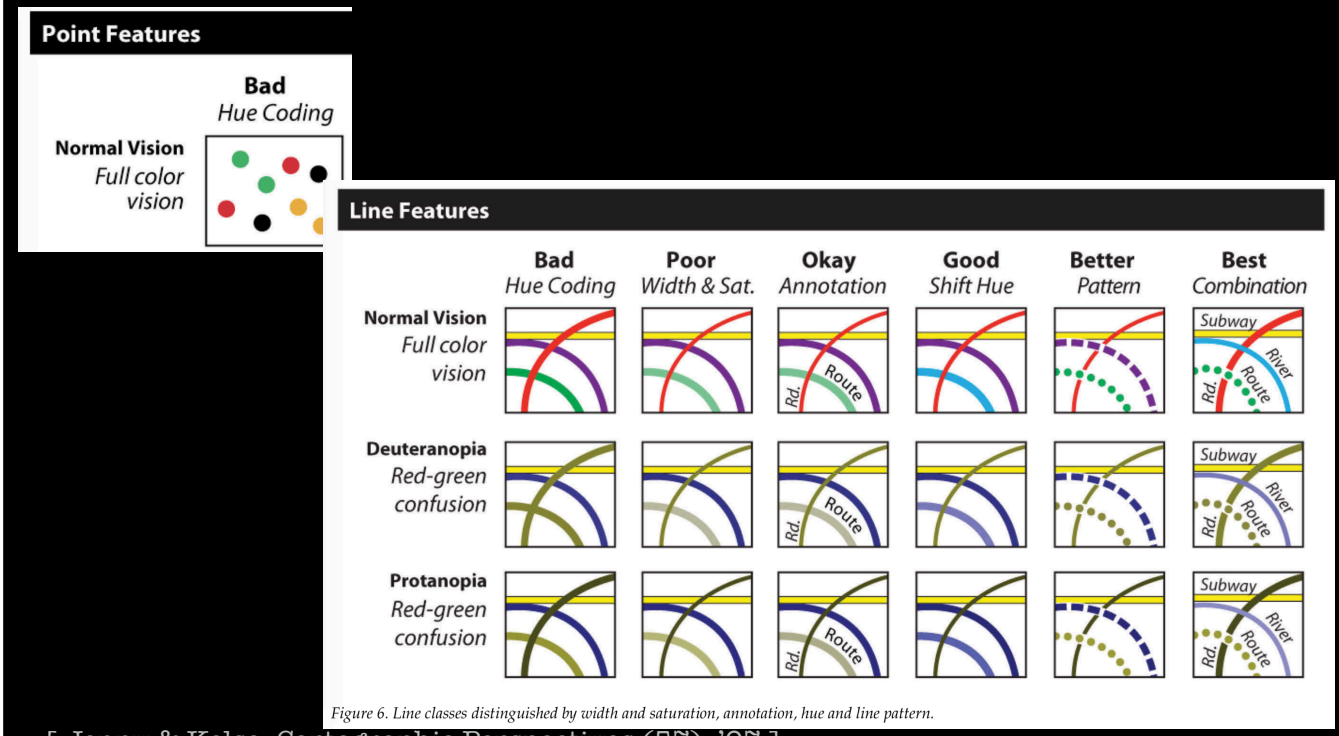
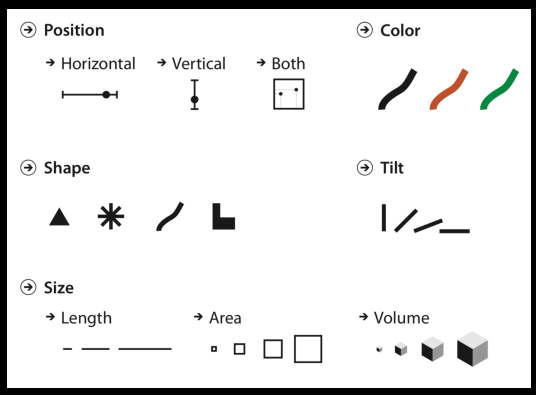


Figure 6. Line classes distinguished by width and saturation, annotation, hue and line pattern.

[Jenny & Kelso, Cartographic Perspectives (57), '07]

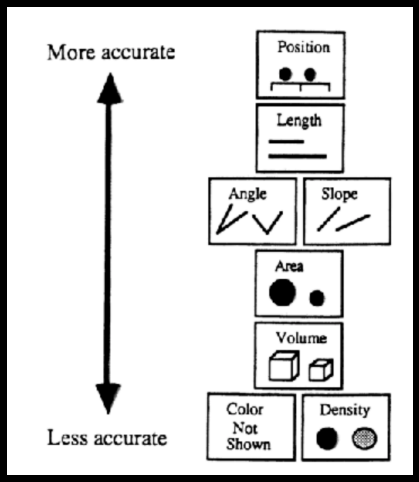
Combining Visual Variables

Which ones to use? **When?**



[Munzner, ch. 5]

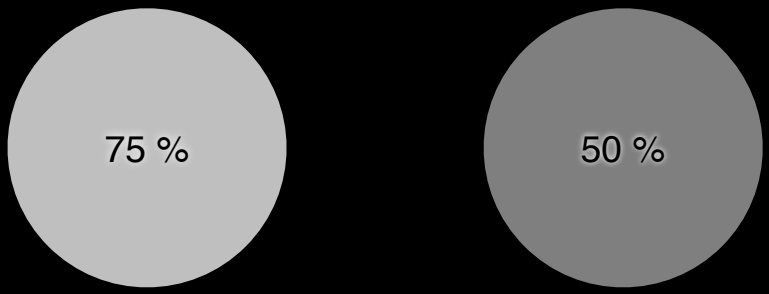
Perception of Visual Variables



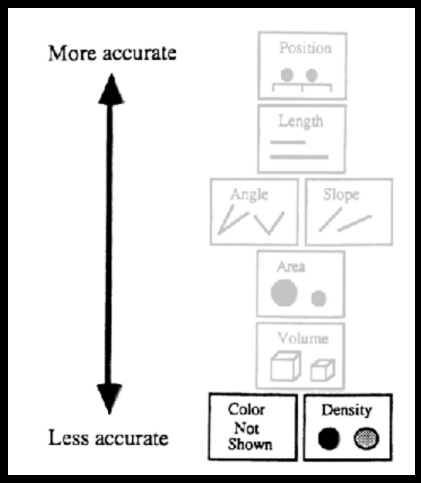
[Cleveland & McGill, '84, '85, '86, ...]

Accuracy: Value (Greyscale)

- What is the value of the right relative to the left?



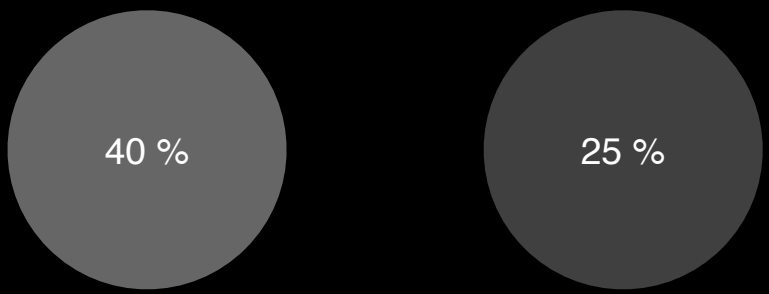
67 %



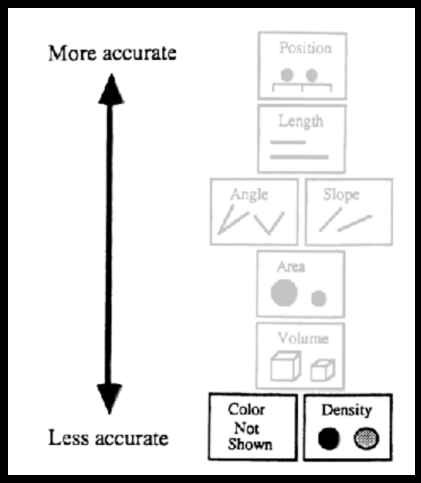
79

Accuracy: Value (Greyscale)

- What is the value of the right relative to the left?



63 %

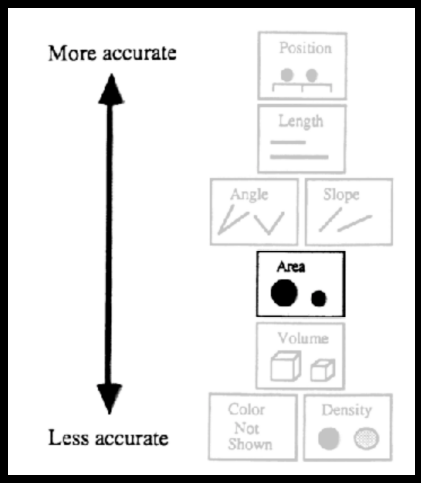


80

Accuracy: Area

- What is the size of the right relative to the left?

25 %

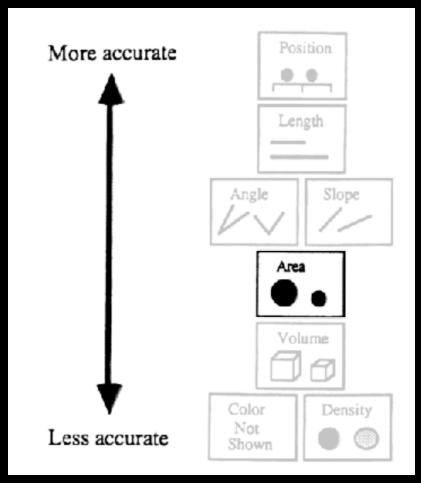


81

Accuracy: Area

- What is the size of the right relative to the left?

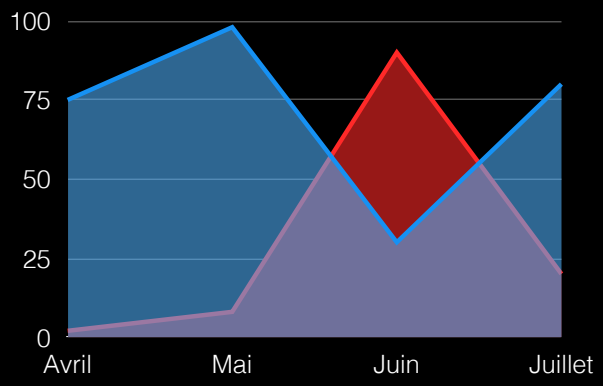
33 %



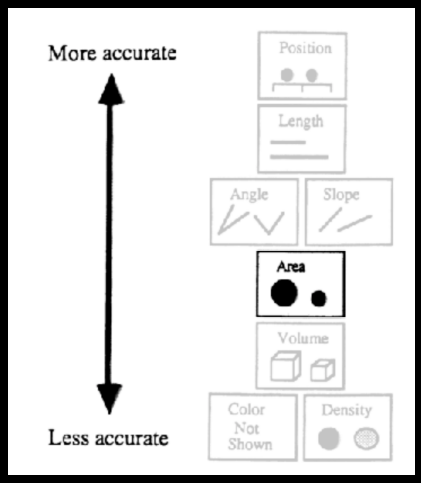
82

Accuracy: Area

- What is the area of the red relative to the blue?



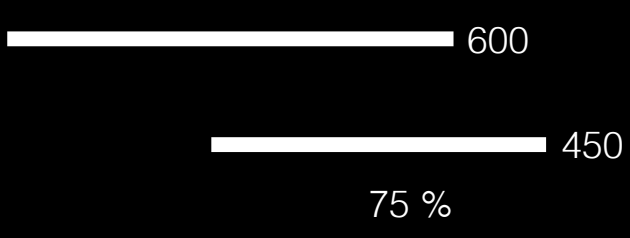
This is very hard!



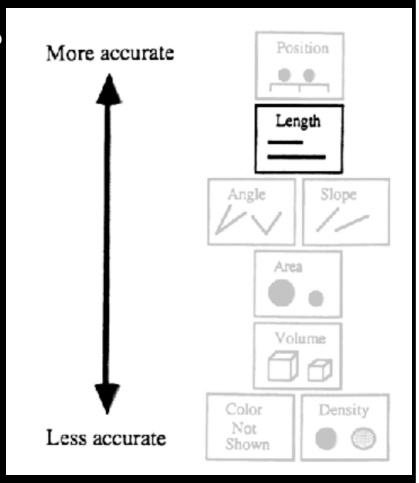
83

Accuracy: Area

- What is the length of the bottom relative to the top?



75 %

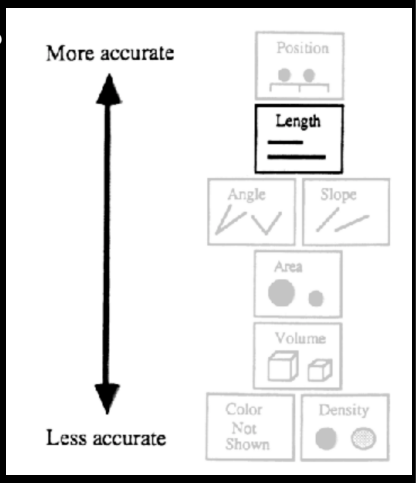


84

Accuracy: Area (aligned)

- What is the length of the bottom relative to the top?

25 %

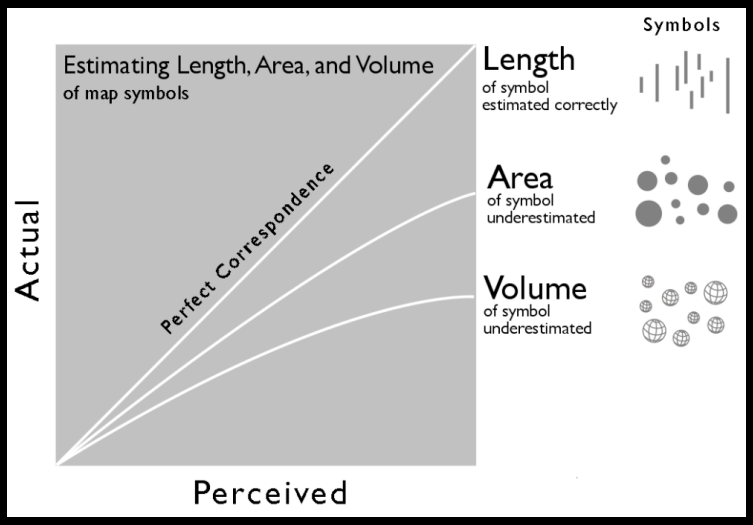


85

Visual Perception Accuracy

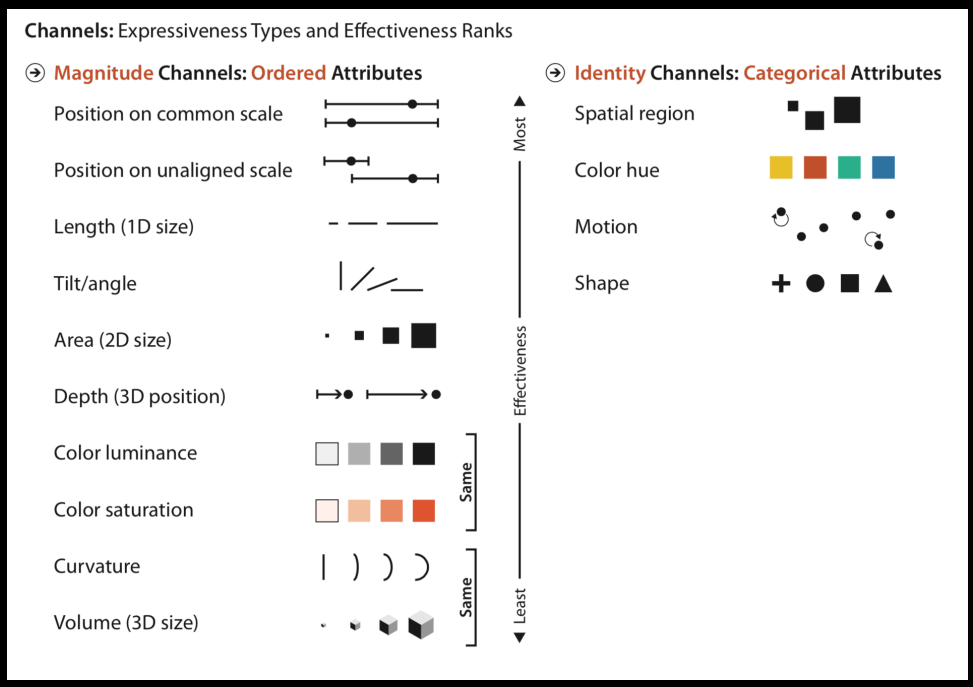
People tend to correctly estimate lengths

They tend to underestimate areas and volumes



[John Krygier, 2007 (via Nadia Boukhelifa)]

86



[Munzner, ch. 5]

Combining Visual Variables

- Not an either-or; more of a spectrum

INTEGRAL

red-green	yellow-blue
red-green	black-white
shape height	shape width
shape	size
color	size
direction motion	shape
color	shape
color	direction motion
x,y position	size, shape, color

SEPARABLE

[Ware 2004]

Summary

- The visual system is better at picking out some properties than others
- These characteristics influence how data will be perceived
- These characteristics are not independent

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