Chapter 3: Visual Encoding Principles
(this time: first 25 pages, Sec 3.1-3.4)
(next time: last 11 pages, Sec 3.5)

Further Reading


Further Reading

Stone. Color In Information Display. IEEE Visualization 2006
Course Notes. http://www.stonesc.com/Vis06


Tufte, Envisioning Information. Chapter 5: Color and Information

Ware, Information Visualization: Perception for Design:
Ch 3: Lightness, Brightness, Contrast, and Constancy
Ch 4: Color
Ch 5: Visual Attention and Information That Pops Out
Ch 6: Static and Moving Patterns
Ch 8: Space Perception and the Display of Data in Space
Relative vs Absolute Perception: Length

- Weber’s Law: relative judgements
  - ratio of increment threshold to background intensity is constant
  \[
  \frac{\Delta I}{I} = K
  \]
  - filled rectangles vs white rectangles

\[\text{unframed unaligned}\]
\[\text{framed unaligned}\]
\[\text{unframed aligned}\]
Relative vs Absolute Perception: Lightness

Relative vs Absolute Perception: Color

[Purves. http://www.purveslab.net/seeforyourself/]
Relative vs Absolute Perception: Color

[Purves. http://www.purveslab.net/seeforyourself/]
Image Theory

- marks: geometric primitives
  - points
  - lines
  - areas

- visual channels: control appearance of marks
  - position
    - horizontal
    - vertical
    - both
  - color
  - tilt
  - size
  - shape
Visual Encoding

- analyze as combination of marks and channels showing abstract data dimensions

1: vertical position
2: vertical position, horizontal position
3: vertical position, horizontal position, color
4: vertical position, horizontal position, color, size

mark: line  mark: point    mark: point  mark: point
Visual Channel Types and Rankings

what / where

How much
Visual Channel Types and Rankings

what/where
- planar position
- color hue
- shape
- stipple pattern

how much
Visual Channel Types and Rankings

**What/Where**
- Planar position
- Color hue
- Shape
- Stipple pattern

**How much**
- Position on common scale
- Position on unaligned scale
- Length (2D size)
- Tilt, angle
- Area (2D size)
- Curvature
- Volume (3D size)
- Lightness (black/white)
- Color saturation
- Stipple density
Visual Channel Types and Rankings

Categorical
what/where

- planar position
- color hue
- shape
- stipple pattern

How much

- position on common scale
- position on unaligned scale
- length (1D size)
- tilt, angle
- area (2D size)
- curvature
- volume (3D size)
- lightness black/white
- color saturation
- stipple density
Visual Channel Types and Rankings

**Categorical**
- what/where
  - planar position
  - color hue
  - shape (△, □, ○, △, □)
  - stipple pattern (□, □, □)

**Ordered: Ordinal/Quantitative**
- how much
  - position on common scale
  - position on unaligned scale
  - length (2D size)
  - tilt, angle
  - area (2D size)
  - curvature
  - volume (3D size)
  - lightness (black/white)
  - color saturation
  - stipple density (□, □, □, □)
Visual Channel Types and Rankings

**Categorical**

*what/where*

- planar position
- color hue
- shape
- stipple pattern

**Ordered: Ordinal/Quantitative**

*how much*

- position on common scale
- position on unaligned scale
- length (1D size)
- tilt, angle
- area (2D size)
- curvature
- volume (3D size)
- lightness (black/white)
- color saturation
- stipple density

**Grouping**

- containment (2D)
- connection (1D)
- similarity (other channels)
- proximity (position)
Visual Channel Types and Rankings

**Categorical**
- What/where
  - planar position
  - color hue
  - shape
  - stipple pattern

**Relational, Same Category Grouping**
- Containment (2D)
- Connection (1D)
- Similarity (other channels)
- Proximity (position)

**Ordered: Ordinal/Quantitative**
- How much
  - position on common scale
  - position on unaligned scale
  - length (1D size)
  - tilt, angle
  - area (2D size)
  - curvature
  - volume (3D size)
  - lightness black/white
  - color saturation
  - stipple density
Only Planar Position Works For All!

Categorical
what/where
- planar position
- color hue
- shape
- stipple pattern

Relation, Same Category
Grouping
- containment (2D)
- connection (1D)
- similarity (other channels)
- proximity (position)

Ordered: Ordinal/Quantitative
how much
- position on common scale
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- tilt, angle
- area (2D size)
- curvature
- volume (3D size)
- lightness black/white
- color saturation stipple density
Ranking Differs For All Other Channels

Categorical
what/where
- planar position
- color hue
- shape
- stipple pattern

Ordered: Ordinal/Quantitative
how much
- position on common scale
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- area (2D size)
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- volume (3D size)
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- color saturation
- stipple density

Relationship, Same Category
Grouping
- Containment (2D)
- Connection (1D)
- Similarity (other channels)
- Proximity (position)
Grouping Channels

- a) proximity
- b) similarity (color)
- c) connection
- d) containment
Expressiveness and Effectiveness

- expressiveness principle
  - pick visual channel to express all of and only information in dataset

- effectiveness principle
  - ranking of channel should match importance of attribute

- what criteria determine channel ranks?
  - accuracy, discriminability, separability, popout
  - grouping precedence
Accuracy

Stevens' Psychophysical Power Law

\[ S = I^n \]

- Electric Current \( n = 3.5 \)
- Color Saturation \( n = 1.3 \)
- Blk Lightness \( n = 1.2 \)
- Length \( n = 1.0 \)
- Area \( n = 0.7 \)
- Loudness \( n = 0.67 \)
- Brightness \( n = 0.5 \)
Discriminability

- limits on available dynamic range
Separability vs. Integrality
Separability vs. Integrality

- position
- hue (color)

- fully separable

- 2 groups each
Separability vs. Integrality

- **Position**
  - Hue (color)
  - Fully separable
  - 2 groups each

- **Size**
  - Hue (color)
  - Some interference
  - Difficult to discriminate small items
  - 2 groups each
Separability vs. Integrality

- **position**
  - hue (color)
  - fully separable
  - 2 groups each

- **size**
  - hue (color)
  - some interference
  - difficult to discriminate small items
  - 2 groups each

- **size: width**
  - size: height
  - some/significant interference
  - integral percept: area (planar size)
  - 3 groups
Separability vs. Integrality

- **Position hue (color)**: fully separable, difficult to discriminate small items, 2 groups each
- **Size hue (color)**: some interference, integral percept: area (planar size), 2 groups each
- **Size: Width, Size: Height**: some/significant interference, integral percept: color/hue, 3 groups
- **Red, Green**: major interference, 4 groups

Legend:
- Red
- Green
Separability vs. Integrality

- **Position hue (color)**: 2 groups each
- **Size hue (color)**: some interference
- **Size: width**: some/significant interference
difficult to discriminate small items
- **Size: height**: integral percept: area (planar size)
- **Red green**: major interference

- **Integrality**:
  - 2 groups each
  - 3 groups
  - 4 groups
Separability vs. Integrality

- **Separability**
  - Position hue (color)
  - Size hue (color)
  - Fully separable
  - 2 groups each

- **Integrality**
  - Size width
  - Size height
  - 3 groups

- **Interference**
  - Some interference
  - Some/significant interference
  - Major interference

- **Perception**
  - Integral percept: area (planar size)
  - Integral percept: color/hue

- **Groups**
  - 2 groups each
  - 4 groups
Visual Popout
Visual Popout

[Image with two diagrams showing visual popout]
Visual Popout

- parallelism: independent of distractor count
Visual Popout

speed depends on: which channel, difference from surroundings
‘sufficiently different’ is context dependent
Visual Popout

- Speed depends on: which channel, difference from surroundings
  - ’sufficiently different’ is context dependent
Popout Channels: Many But Not All

- Most channels operate in parallel, allowing sufficiently different items to be noticed immediately, independent of distractor count.
- Some channels require serial search, indicating they are not as effective for popout.
- combination searches are serial
  - exception: a few pairs
Visual Channel Types and Rankings

**Categorical**
what/where

- planar position
- color hue
- shape
- stipple pattern

**Relational, Same Category**

Grouping

- containment (2D)
- connection (1D)
- similarity (other channels)
- proximity (position)

**Ordered: Ordinal/Quantitative**
how much

- position on common scale
- position on unaligned scale
- length (1D size)
- tilt, angle
- area (2D size)
- curvature
- volume (3D size)
- lightness black/white
- color saturation
- stipple density
Grouping: Precedence Not Effectiveness

- all channels effective; rank is order of precedence

proximity  similarity (color)  sim (size)  sim (shape)
Grouping: Precedence Not Effectiveness

- all channels effective; rank is order of precedence

proximity    similarity (color)    sim (size)    sim (shape)

containment overrides connection
Power of Planar Position

Categorical
what/where
- planar position
  - color hue
- shape
- stipple pattern

Relational, Same Category
Grouping
- containment (2D)
- connection (1D)
- similarity (other channels)

Proximity (position)

Ordered: Ordinal/Quantitative
How much
- position on common scale
- position on unaligned scale
- length (1D size)
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- volume (3D size)
- lightness
- black/white
- color saturation
- stipple density
Color Vision Process

- rods
  - B/W info in low-light conditions
  - not discussed further
- 3 cone types
  - sensors: RGB
- 3 opponent color channels
  - one luminance: black/white
  - two “color”: red/green, blue/yellow
- color deficiency
  - one hue channel collapsed
  - sex-linked mutation: 8% of men, .5% of women
Luminance, Saturation, Hue

- luminance: how much
- saturation: how much
- hue: what

[Stone, Representing Color As Three Numbers, CG&A 25(4):78-85]
Ordered: Lum/Sat, Unordered: Hue

- luminance: how much
- saturation: how much
- hue: what

Unique black and white
Uniform differences
Perception & design

[Stone, Representing Color As Three Numbers, CG&A 25(4):78-85]
Discriminability: Categorical Color

- noncontiguous small regions: 6-12 bins

Other Channels

- size: how much
  - small sizes interfere with many other channels
- tilt/angle: both
- shape: what
- stipple: how much
  - interferes with luminance
- motion: how much
  - grabs attention, difficult to attend to other channels
Color As Three Numbers

Stone
Representing Color As Three Numbers, CG&A 25(4):78-85
Trichromacy

- different cone responses area function of wavelength
- for a given spectrum
  - multiply by response curve
  - integrate to get response

Metamerism

- brain sees only cone response
- different spectra appear the same

Metamerism Demo

by Jeff Beall, Adam Doppelt and John F. Hughes
(c) 1995 Brown University and the NSF Graphics and Visualization Center

[www.cs.brown.edu/exploratories/freeSoftware/repository/edu/brown/cs/exploratories/applets/spectrum/metamers_java_browser.html]
Color Matching Experiments

Color Matching Functions

Stiles-Burch, negative lobe

CIE standard, all positive

Color Spaces

- RGB: convenient for machines
  - these three channels **not** separable
- CIE XYZ: from color matching functions
  - perceptually based
- L*a*b*: from XYZ + reference whitepoint
  - perceptually linear, safe to interpolate
- HLS: simple transformation of RGB
  - good: separates out lightness, hue, saturation channels
  - bad: lightness **not** true luminance
  - careful: only *pseudo*-perceptual!
Lightness vs Luminance

Corners of the RGB color cube

Luminance values

L* values

L from HLS
All the same

Spectral Sensitivity