Interaction between channels: Not fully separable

- color channel interactions
  - can heavily affect each other
  - small region need high saturation
  - large region need low saturation

- saturation & luminance:
  - not separable from each other
  - also not separable from transparency

Categorical color: limited number of discriminable bins

- human perception built on relative comparisons
  - great if color contiguous
  - surprisingly bad for absolute comparisons

- noncontiguous small regions of color:
  - fewer bins than you want
  - rule of thumbs 6-12 bins, including background and highlights

Ordered color: Rainbow is poor default

- problems
  - perceptually unordered
  - perceptually nonlinear

- benefits
  - fine-grained structure visible and nameable

Viridis / Magma: sequential colormaps

- monotonically increasing luminance, perceptually uniform
- colorful, colorblind-safe
- R, python, D3

Interaction between channels: Not fully separable

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  - can heavily affects each other
  - small region need high saturation
  - large region need low saturation

- saturation & luminance:
  - not separable from each other
  - also not separable from transparency
### Diverging

• perceptual processing before optic nerve
  – one achromatic luminance channel ... information


### Opponent color and color deficiency

- perceptual processing before optic nerve
  - one achromatic luminance channel • use neutral color for midpoint • white, yellow, grey • use saturated colors for endpoints
  - sequential • ramp luminance or saturation • if multi-hue, good to order by luminance

### Saturated colors for endpoints

• use saturated colors for endpoints

### Use neutral color for midpoint

• use neutral color for midpoint

### Diverging or sequential or cyclic?

• divergence • useful when data has meaningful "midpoints" • ramp luminance or saturation • if multi-hue, good to order by luminance

### Luminance values

- need luminance for edge detection
  - fine-grained detail only visible through luminance contrast

### Opponent color and color deficiency

- perceptual processing before optic nerve

### Categorical

- one achromatic luminance channel

### Sequential

- use neutral color for midpoint

### Binary

- binary in one of the directions

### Categorical can show identity

- hue when color

### Opponent color and color deficiency

• perceptual processing before optic nerve

- one achromatic luminance channel

### Categorical color

- ordered can show magnitude

### Sequential color

- luminance how bright (B)

### Categorical color

- saturation how colourful

### Binary

- binary is one of the directions

### Categorical can show identity

- hue when color

### Luminance information

- need luminance for edge detection

### Color Deficiency

- colorblind safe?

### Luminance

- need luminance for edge detection

- fine-grained detail only visible through luminance contrast

- legend text requires luminance contrast!

### Opponent color and color deficiency

- perceptual processing before optic nerve

### Continuous

- one achromatic luminance channel

### Categorical

- one achromatic luminance channel

### Sequential

- edge detection through luminance contrast

- 2 chroma channels

### Segmenting

- red-green (a*) & yellow-blue axis (b*)

### Color palettes: univariate

- categorical

### Color palettes: bivariate

- bivariate can be very difficult to interpret

- when multiple levels in each direction

### Designing for color deficiency

- Check with simulator

### Deuteranope simulation

- green-weak

### Protanope

- red-weak

### Tritanope

- blue-weak

### Color encoding

- perceptually linear?

- continuous

### Color palette design considerations

- univariate

### Color palettes: multivariate

- categorical

### Color palettes: continuous

- sequential

### Color palettes: cyclic

- segmented or continuous

### Color palettes: sequential

- single-hue or two-hue or multi-hue

### Categorical

- perceptually linear!

### encoded by hue alone

- redundancy encode

- Vary luminance

- Vary shape
Many color spaces
• Luminance (L*), hue (H), saturation (S)
– good for encoding
– but not standard graphics/tools colorspace
• RGB: good for display hardware

Perceptual color space: L*a*b*
• perceptual processing before optic nerve
  – one achromatic luminance channel (L*)
  – edge detection through luminance contrast
  – 2 chroma channels
  – red-green (a*) & yellow-blue axis (b*)
• CIE LAB
  – perceptually uniform
  – good for interpolating

HSL/HSV
• somewhat better for encoding
  – hue/saturation wheel intuitive
  – saturation
  – in HSL (double-cone) desaturated = white
  – in HLS (single-cone) desaturated = grey
HSL/HSV
• HSL/HSV: somewhat better for encoding
  • hue/saturation wheel intuitive
• saturation
  • in HSV (single-cone) desaturated = white
  • in HSL (double-cone) desaturated = grey
• luminance vs saturation
  • channels not very separable
  • typically not crucial to distinguish between these with encoding/decoding
  • key point is hue vs luminance/saturation

Many color spaces
• Luminance (L*), hue (H), saturation (S)
  • good for encoding
  • but not standard graphics/tools colorspace
• RGB: good for display hardware
  • poor for encoding & interpolation
• CIE LAB (L*a*b*): good for interpolation
  • hard to interpret, poor for encoding
  • HSL/HSV somewhat better for encoding
    • hue/saturation wheel intuitive
    • beware: only pseudo-perceptual!
    • lightness (L) or value (V) ≠ luminance (L*)

Interaction with the background
• marks with high luminance on a background with low luminance
• marks with medium luminance on a background with high luminance
• change luminance of marks depending on background

Color/Lightness constancy: Illumination conditions

Bezold Effect: Outlines matter

Contrast with background

Color naming
Color naming
- nameability affects
  - communication
  - memorability
- can integrate into color models
  - in addition to perceptual considerations

Color is just part of vision system
- Does not help perceive
  - Position
  - Shape
  - Motion
  - ...

Map Other Channels

Spectral sensitivity to luminance

Angle / tilt / orientation channel
- different mappings depending on range used
  - high exact horizontal, vertical, diagonal (0, 45, 90 degrees)
  - lower: other orientations (e.g., 37 vs. 38 degrees)

Map other channels
- size
  - aligned length best
  - length accurate
  - 2D area ok
  - 3D volume poor
- shape
  - complex combination of lower-level primitives
  - many bins
- motion
  - highly separable against static
  - great for highlighting (binary)
  - use with care to avoid irritation

Map other channels
- size
  - aligned length best
  - length accurate
  - 2D area ok
  - 3D volume poor
- shape
  - complex combination of lower-level primitives
  - many bins
- motion
  - Direction, Rate, Frequency