Decomposing color
• first rule of color: do not JUST talk about color!
  – color is confusing if treated as monolithic:

HSL decomposition
• decompose into three channels
  – ordered can show magnitude
  – luminance: how bright
  – saturation: how colourful
  – categorical can show identity
  – hue: what color

channels have different properties
– what they convey directly to perceptual system
– how much they can convey how many discriminable bins can we use?

Perceptual colorspace: L*a*b*
• perceptual processing before optic nerve
  – one achromatic luminance channel (L*)

CIE LAB
– perceptually uniform
– great for interpolating
– complex shape
– poor for encoding

Color Channels in Visualization

Categorical vs ordered color
• human perception built on relative comparisons
  – great if color contiguous
  – surprisingly bad for absolute comparisons

Categorical color: limited number of discriminable bins

Many color spaces
• RGB: good for display hardware
  – poor for encoding & interpolation
• Luminance (L*), hue (H), saturation (S)
  – good for encoding
  – but not standard colorspace, few tools

Corners of the RGB color cube
L from HLS
All the same
Luminance values
L* values

Attributes
• Chroma information
• Identity
• Spatial region
• Volume (3D size)
• Curvature
• Depth (3D position)
• Length (1D size)
• Position on unaligned scale
• Position on common scale
Ordered color: Rainbow is poor default
• problems
– perceptually unordered
– perceptually nonlinear
• benefits
– fine-grained structure visible and nameable
• alternatives
– large-scale structure fewer hues

Interaction with other channels: integral/separable
• color channel interactions
– hue heavily affects saturation
– small regions need high saturation
– large regions need low saturation
– saturation & luminance:
– rest separable from each other
– rest not separable from transparency
– fine tuned colors (f small, separate regions)
– ramp (clear with saturation regions)

Viridis / Magma
• monotonically increasing luminance, perceptually uniform
• colorful, colorblind-safe
– R, python, D3

Color palettes: univariate
• Categorical

Color palettes: univariate
• Ordered
• Sequential
• Diverging

Color maps: bivariate
• Binary
• Categorical
• Diverging
• Sequential
Opponent color and color deficiency
• perceptual processing before optic nerve
  – edge detection through luminance contrast
  – 2 chroma channels
  – red-green (a*) & yellow-blue axis (b*)

Opponent color and color deficiency
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“colorblind”: degraded acuity, one axis
  – 8% of men are red/green color deficient
  – blue/yellow is rare

Designing for color deficiency: Check with simulator
• redundantly encode
  – vary luminance
  – change shape
  • change luminance of marks depending on background
  • change shape

Designing for color deficiency: Avoid encoding by hue alone
• colorblind simulations
  – Deuteranope
  – Protanope
  – Tritanope
  – Normal

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
• change shape

Interaction with the background: tweaking yellow for visibility

Color Contrast & Naming
The difference between foreground and background color determines test legibility.

Color/Lightness constancy: Illumination conditions
Image courtesy of John McCann via Maureen Stone
Color/Lightness constancy: Illumination conditions

Image courtesy of John McCann via Maureen Stone

Contrast with background

Black and blue? White and gold?

Bezold Effect: Outlines matter

Contrast with background

Color Appearance

• given L, a*, b*, can we tell what color it is?
  – no, it depends
  • chromatic adaptation
  • luminance adaptation
  • simultaneous contrast
  • spatial effects
  • viewing angle
  • ...

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
  – ...

Tools and Libraries in Practice

ColorBrewer

• limited customization: 2 parameters
  • saturation and area example: size affects salience!

Adobe Color Picker

• for general design purpose, not particularly for vis

Colorgorical

• highly customized: #colors, perceptual distance, name uniqueness, hue, lightness range...

Color management in D3

• D3-color
  – https://github.com/d3/d3-color
  – Conversion to/from different color spaces
  – Low-level computations

• D3-scale
  – https://github.com/d3/d3-scale
  – Customizable color scale using d3.scaleSequential() and d3.scaleOrdinal()
  – Use case: generate color schemes using the web tools mentioned before, then use d3-scale to implement it

• D3-scale-chromatic
  – https://github.com/d3/d3-scale-chromatic
  – Implementation of the colormap
  – Lots of good color schemes and scales
  – High-level, ready-to-use for most vis
  – Use this for your project