The Art and Science of Depiction

Color

Fredo Durand
MIT- Lab for Computer Science
Color

Color Vision
Talks

- Abstract
- Issues
Plan

- Color blindness
- Color Opponents, Hue-Saturation Value
- Perceptual color effects
- Color categories and culture
Physical spectrum

ELECTROMAGNETIC SPECTRUM

VISIBLE SPECTRUM

Wavelength (nm)

400 500 600 700

Color Vision
Metamerism

- Different spectrum
- Same response
Puzzles

- Why is violet “close” to red
- Primaries
  - Cyan and magenta are not “spontaneous” primaries
- Color mixing
Why color is complex

- 3 dimensional
- Difference spectrum-color
- Additive-subtractive
- LMS-opponents-Hue Saturation Value
- Color constancy
- Color appearance effects
- Cultural
- Preferred colors, memory
Color synthesis

Additive
red, green, blue

Subtractive
cyan, magenta, yellow
**Color synthesis: a wrong example**

**Additive**
- red, green, blue

**Subtractive**
- cyan, magenta, yellow

**WRONG**

Color Vision
Plan

- Color blindness
- Color Opponents, Hue-Saturation Value
- Perceptual color effects
- Color categories and culture
Color blindness

- Dalton
- 8% male, 0.6% female
- Genetic
- Dichromate (2% male)
  - One type of cone missing
  - L (protanope), M (deuteranope), S (tritanope)
- Anomalous trichromat
  - Shifted sensitivity
We are all color blind

- Center of retina
- No S (blue)
- We compensate via gaze movement
- Not well understood
Color blindness test
**Color blindness test**

- Maze in subtle intensity contrast
- Visible only to color blinds
- Color contrast overrides intensity otherwise
Color blindness correction

• Filter
  – On one eye
  – Set of filters (case of electronics)
Color blind impressions

- A normal scene
- B protanope L
- C deuteranope M
- D tritanope S
Color blindness & Painting

- Restricted to blue-yellow

Goethe after a color-blind
Color blindness & Painting

• Restricted to blue-yellow

Meryon, *Le Vaisseau Fantôme*
Color blindness & Painting

- Restricted to blue-yellow
Color blindness & Painting

• Image reproduction (after Gauguin)
• Different strategies

Normal color vision  Color blind (perceived)  Color blind (confusion)
Color vision variability

- Color blindness
- Mutations
- Gender, racial
- Cultural differences
Preferred colors

- Caucasian skin
  - More tanned
- Grass
  - Greener
- Sky
  - Bluer
Plan

- Color blindness
- Color Opponents, Hue-Saturation Value
- Perceptual color effects
- Color categories and culture
Color Opponents

• Hering
• A color can be “blue-green”, “yellow-red”, “yellow-green”, etc
• But never “yellow-blue” or “red-green”
• Suspected two opponents:
  – Blue-yellow axis
  – Red-Green axis
Color reparameterization

- The input is LMS
- The output has a different parameterization:
  - Light-dark
  - Blue-yellow
  - Red-green
Color opponents wiring

- Sums for brightness
- Differences for color opponents
Double center surround opponents

- Center-surround
- Color opponents
Opponents and image compression

- JPG, MPG
- Color opponents instead of RGB
- Compress color more than luminance
Blue-yellow opponent and painting

- Often used to depict night
- (S cones share properties with rods…)
- Van Gogh
  Café at Night
Red-green opponent and painting

- Jawlensky
Opponent and painting

- Degas
Color reparameterization

- The input is LMS
- The output has a different parameterization:
  - Light-dark
  - Blue-yellow
  - Red-green
- A later stage may reparameterize:
  - Brightness or Luminance or Value
  - Hue
  - Saturation
Hue Saturation Value
**Hue Saturation Value**

- One interpretation in spectrum space
- Not the only one because of metamerism
Munsell book of colors

- Perceptually uniform
History of color theories

• Aristotle & followers
• Scale from black to white
  – Blue, red, yellow
  – Position of green varies
• Nicolas Poussin
  Ecstasy of Saint Paul
  1650
Plan

- Color blindness
- Color Opponents, Hue-Saturation Value
- Perceptual color effects
- Color categories and culture
Color appearance effects

- ... 
- Goethe, 19th century
  - Importance of subjective experience
- Chevreul, 19th century
  - Law of simultaneous contrast, optical mix
- Modern theories
  - Measured effects
Simultaneous contrast

- Chevreul
- In color opponent direction
Crispening

- Increased sensitivity
Simultaneous contrast

- In color opponent direction
- Center-surround
Eugène Delacroix
Eugène Delacroix
Impressionism

- Claude Monet

![Impressionist painting by Claude Monet](image-url)
Post-Impressionism

• Van Gogh
Post-Impressionism

• Van Gogh
Land Retinex

\[
\frac{48}{24} \times \frac{32}{16} = \frac{1536}{384} = \frac{4}{1}
\]

Luminance Edge Calculation of A to C
Haloing, local contrast

- Seurat, *Bathers at Asnières*, 1884
Edge burning

- Ansel Adams
**Spreading**

- Optical mix when spatial frequency increases
- But before fusion frequency
- Additive mix! (opposed to pigment mix)
Pointillism

• George Seurat, *The Channel of Gravelines, Grand Fort-Philippe*, 1890
Pointillism

• George Seurat, *La Grande Jatte*, 1886
Pointillism

- George Seurat, *La Grande Jatte*, 1886
Divisionism

- Paul Signac, *The Mills at Overschie*, 1905
“Layered” pointillism

Artistic Half toning

- Ostromoukhov 1999
Other effects

- Problems for color reproduction
- Problem in design and production
Hunt and Stevens effect

- Stevens effect
  - Contrast increases with luminance

- Bartleson-Breneman effect
  - Image contrast changes with surround
  - A dark surround decreases contrast
    (make the black of the image look less deep)

- Hunt effect
  - Colorfulness increases with luminance

- Hence the need for gamma correction
**Bezold-Brücke Hue Shift**

- Monochromatic stimulus
- Perceived hue changes when luminance varies

Wavelength shift necessary to keep the same hue when luminance is decreased by a factor of 10
Abney Effect

- Hue changes with the addition of pure white
Color appearance models

- Predict the appearance of a color depending on
  - Objective stimulus
  - Surrounding, context
Plan

- Color blindness
- Color Opponents, Hue-Saturation Value
- Perceptual color effects
- Color categories and culture
Color categories

- Prototypes
- Harder to classify colors at boundaries
Color and culture

- Ancient Greeks
  - Same term for blue-green-dark
- Berinmo
Lexical study of basic color terms

- Berlin and Kay 1969-78
- 20+78 languages
- Monolexemic
  - Not compound, e.g. not “blue-green”
- Primary chromatic reference
  - Not material, e.g. not “gold”
  - But allow “orange”
- General purpose
  - No specific field, e.g. not “blond”, “roan”
- High frequency
  - E.g. not “mauve”, “taupe”, “puce”
Lexical study of basic color terms

• 20+78 languages
• 16 basic color terms
  – 11 in English
    • Red, green, blue, yellow, black, white, gray, orange, purple, brown, pink
  – light-blue
  – 4 that encompass more than one color
    • Warm, cool, light-warm, dark-cool
Lexical study of basic color terms

- Common pattern
- There are exceptions
Visual Perception

- Very complex
- Different stages
- Different pathways for different elements
- Can explain some pictorial techniques/styles
- Can be helped of challenged
Discussion

- Piranesi
**Discussion**

- Perception and images
- Does it help the analysis
- Does it dazzle?
- Does it refrain creativity?
Color terms *(Fairchild 1998)*

- Color
- Hue
- Brightness vs. lightness
- Colorfulness and Chroma
- Saturation
- Unrelated and related colors
Color

- chromatic and achromatic content. This attribute can be described by chromatic color names such as yellow, orange, brown, red, pink, green, blue, purple, etc., or by achromatic color names such as white, gray, black, etc., and qualified by bright, dim, light, dark, etc., or by combinations of such names.

- Note: Perceived color depends on the spectral distribution of the color stimulus, on the size, shape, structure, and surround of the stimulus area, on the state of adaptation of the observer's visual system, and on the observer's experience of the prevailing and similar situations of observations.
Related and Unrelated Colors

• **Unrelated Color**
  – Color perceived to belong to an area or object seen in isolation from other colors.

• **Related Color**
  – Color perceived to belong to an area or object seen in relation to other colors.
Hue

• Hue
  – Attribute of a visual sensation according to which an area appears be similar to one of the perceived colors: red, yellow, green, and blue, or to a combination of two of them.

• Achromatic Color
  – Perceived color devoid of hue.

• Chromatic Color
  – Perceived color possessing a hue.
**Brightness vs. Lightness**

- **Brightness**
  - Attribute of a visual sensation according to which an area appears to emit more or less light.

- **Lightness**:
  - The brightness of an area judged relative to the brightness of a similarly illuminated area that appears to be white or highly transmitting.
Colorfulness & Chroma

• Colorfulness
  – Attribute of a visual sensation according to which the perceived color of an area appears to be more or less chromatic.

• Chroma:
  – Colorfulness of an area judged as a proportion of the brightness of a similarly illuminated area that appears white or highly transmitting.
Saturation

- Colorfulness of an area judged in proportion to its brightness.