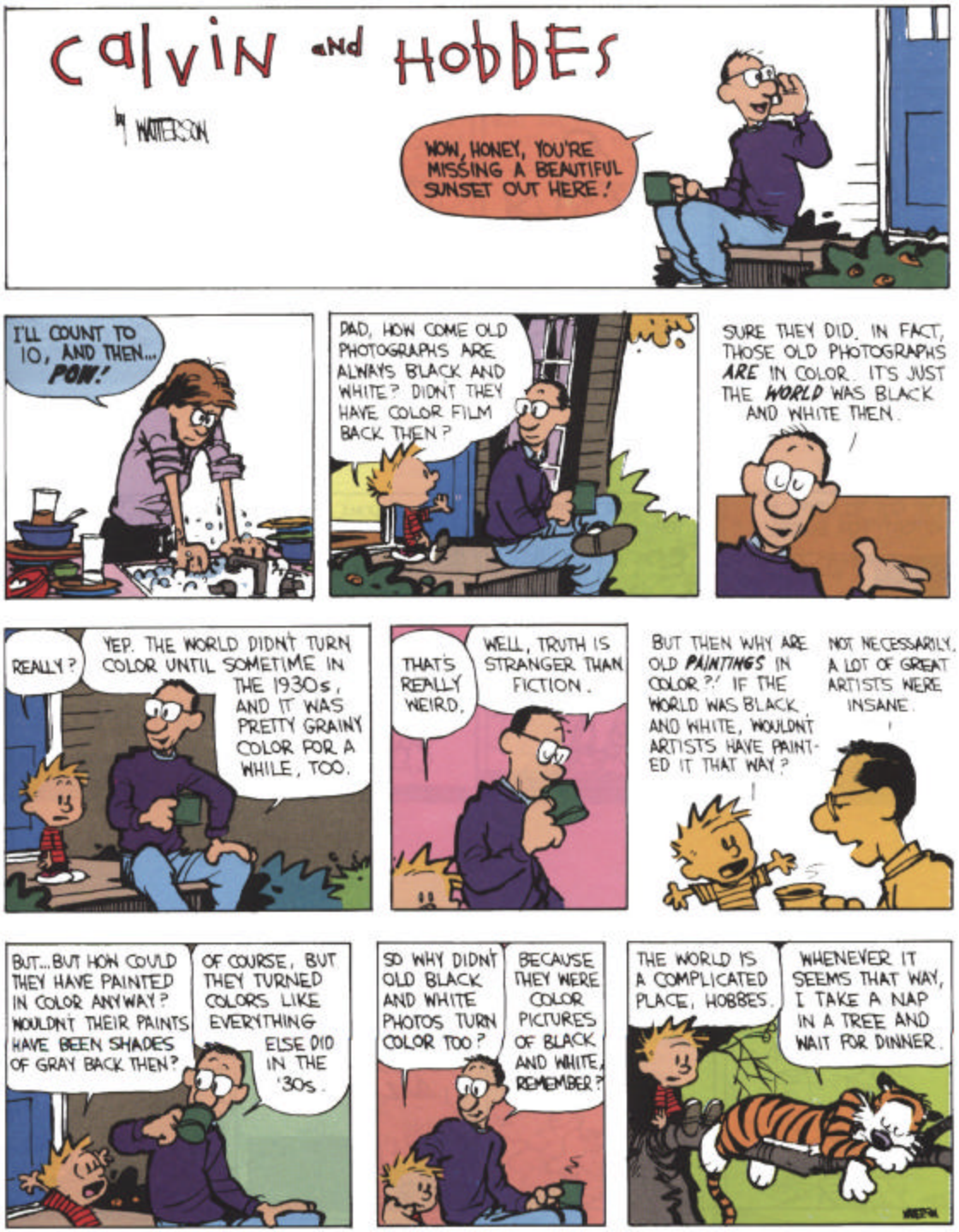
The Art and Science of Depiction

Color

Fredo Durand
MIT- Lab for Computer Science

Color


CALVIN AND HOBBES
BY WATTERSON
WOW, HONEY, YOU'RE MISSING A BEAUTIFUL SUNSET OUT HERE!
I'LL COUNT TO 10, AND THEN... POW!
DAD, HOW COME OLD PHOTOGRAPHS ARE ALWAYS BLACK AND WHITE? DIDN'T THEY HAVE COLOR FILM BACK THEN?
SURE THEY DID. IN FACT, THOSE OLD PHOTOGRAPHS ARE IN COLOR. IT'S JUST THE WORLD WAS BLACK AND WHITE THEN.
REALLY?
YEP. THE WORLD DIDN'T TURN COLOR UNTIL SOMETIME IN THE 1930s, AND IT WAS PRETTY GRAINY COLOR FOR A WHILE, TOO.
THAT'S REALLY WEIRD.
WELL, TRUTH IS STRANGER THAN FICTION.
BUT THEN WHY ARE OLD PAINTINGS IN COLOR?! IF THE WORLD WAS BLACK AND WHITE, WOULDN'T ARTISTS HAVE PAINTED IT THAT WAY?
NOT NECESSARILY. A LOT OF GREAT ARTISTS WERE INSANE.
BUT... BUT HOW COULD THEY HAVE PAINTED IN COLOR ANYWAY? WOULDN'T THEIR PAINTS HAVE BEEN SHADES OF GRAY BACK THEN?
OF COURSE, BUT THEY TURNED COLORS LIKE EVERYTHING ELSE DID IN THE '30s.
SO WHY DIDN'T OLD BLACK AND WHITE PHOTOS TURN COLOR TOO?
BECAUSE THEY WERE COLOR PICTURES OF BLACK AND WHITE, REMEMBER?
THE WORLD IS A COMPLICATED PLACE, HOBBES.
WHENEVER IT SEEMS THAT WAY, I TAKE A NAP IN A TREE AND WAIT FOR DINNER.

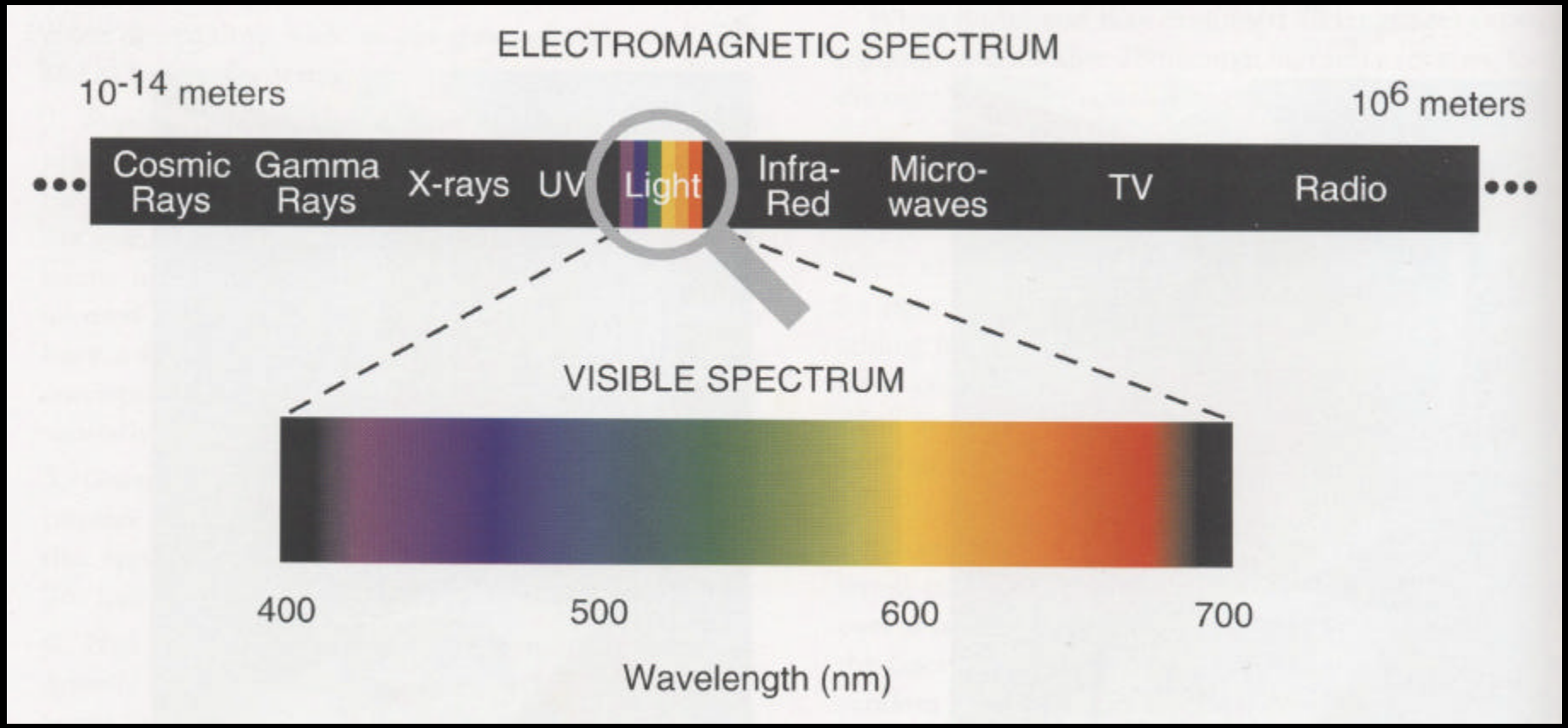
Talks

- Abstract
- Issues

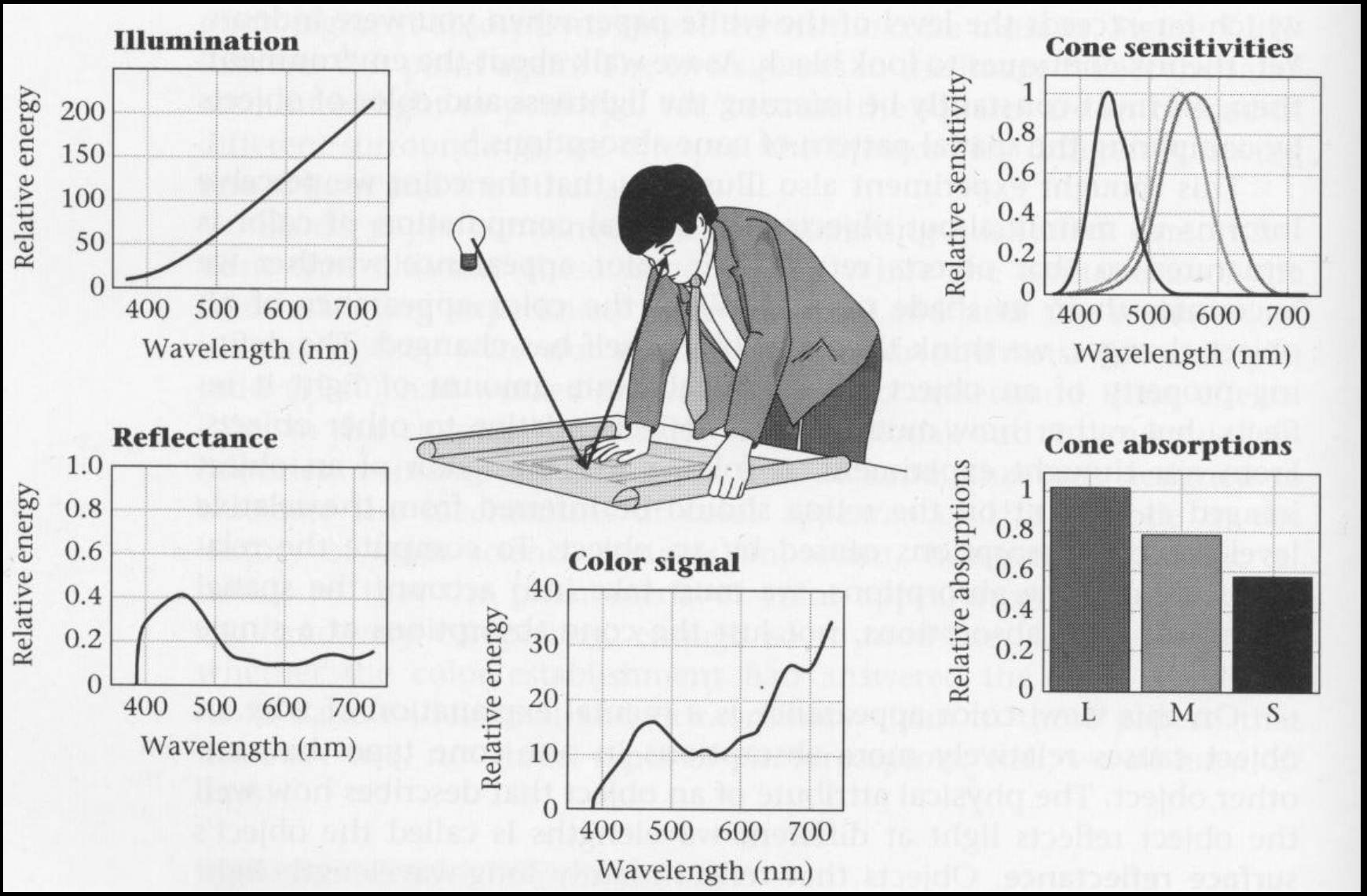
Plan

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

Physical spectrum

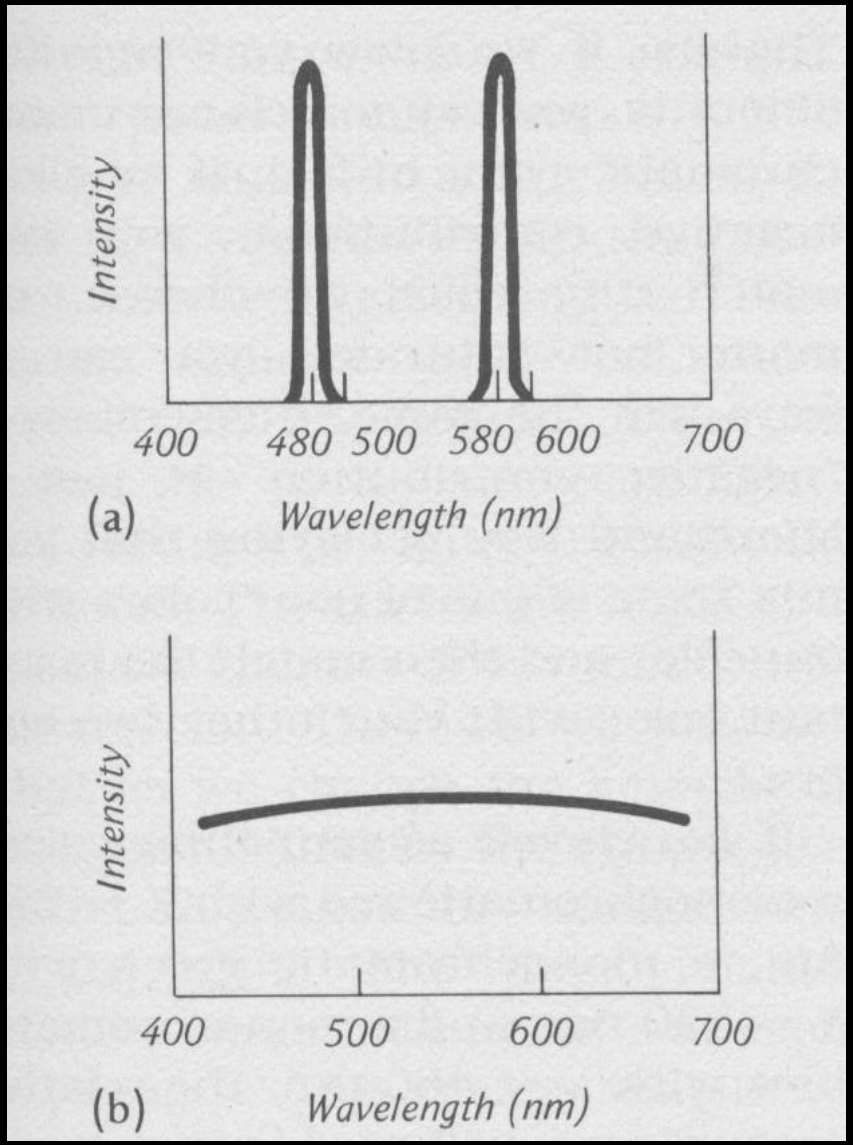


Summary


Illumination
Relative energy
200
150
100
50
0
400 500 600 700
Wavelength (nm)
Cone sensitivities
Relative sensitivity
1
0.8
0.6
0.4
0.2
0
400 500 600 700
Wavelength (nm)
Reflectance
Relative energy
1.0
0.8
0.6
0.4
0.2
0
400 500 600 700
Wavelength (nm)
Color signal
Relative energy
40
30
20
10
0
400 500 600 700
Wavelength (nm)
Cone absorptions
Relative absorptions
1
0.8
0.6
0.4
0.2
0
L
M
S

Metamerism

- Different spectrum
- Same response



Puzzles

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

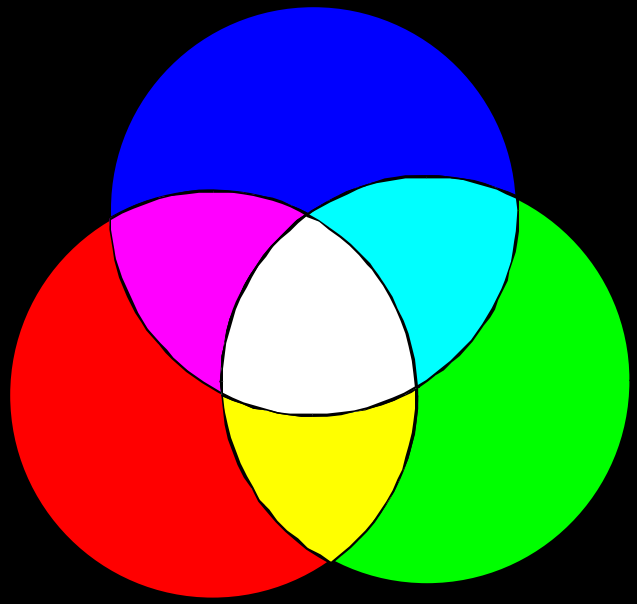
Why color is complex

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

Color synthesis

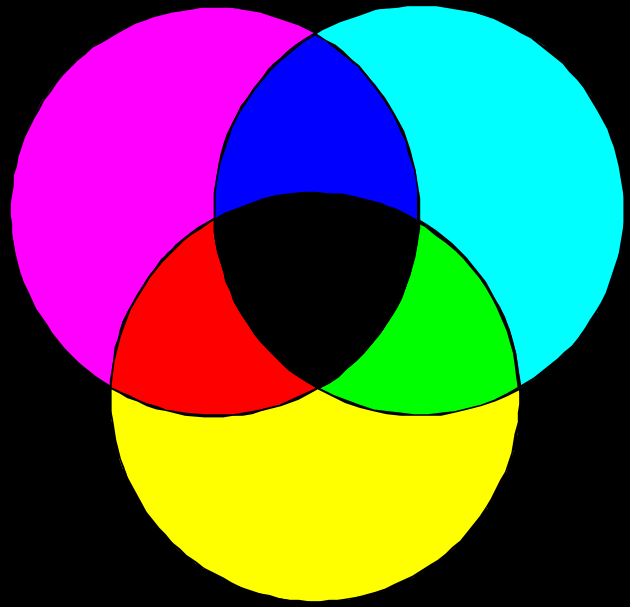
Additive

red, green, blue



Subtractive

cyan, magenta, yellow



Color synthesis: a wrong example

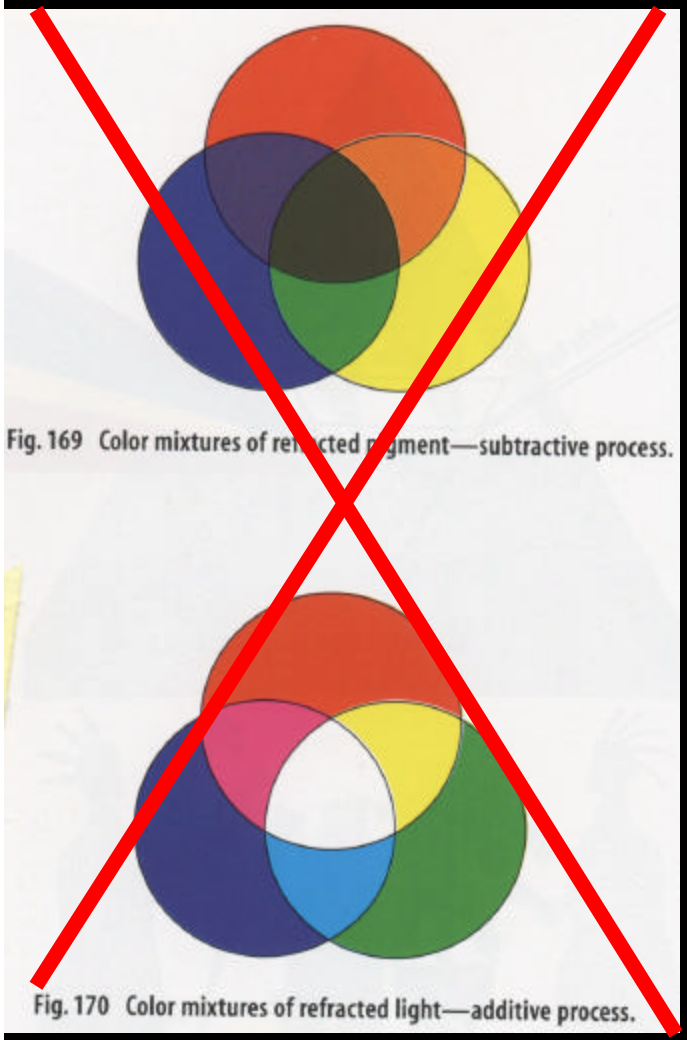


Fig. 169 Color mixtures of refracted pigment—subtractive process.

Fig. 170 Color mixtures of refracted light—additive process.

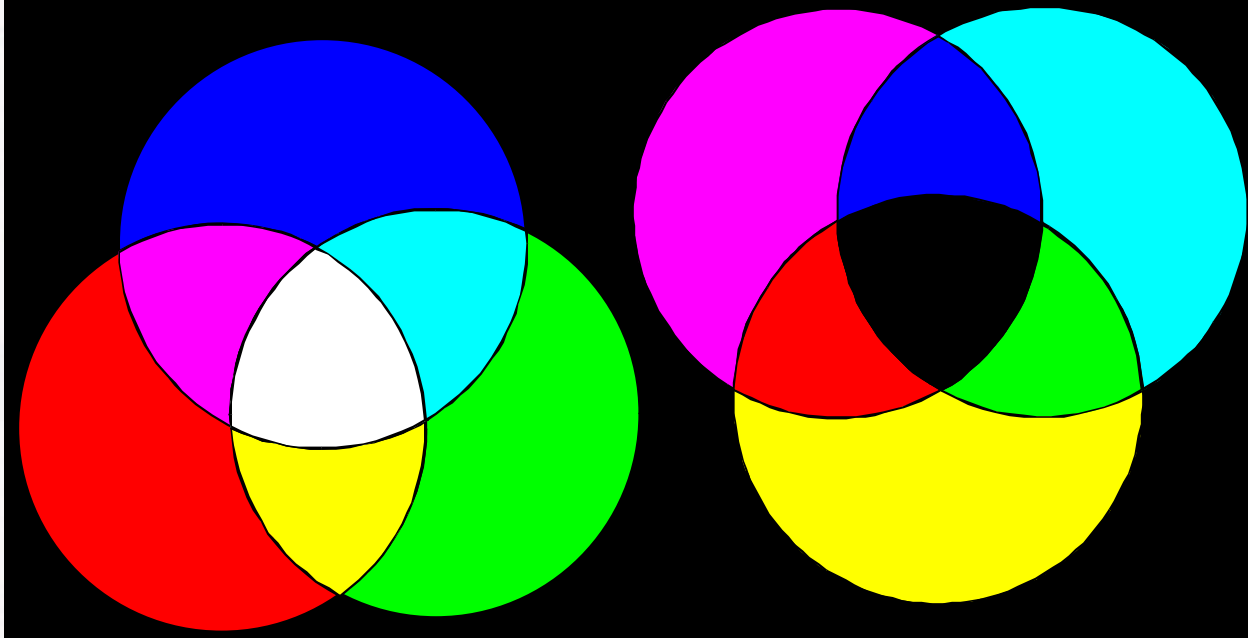
WRONG

Additive

red, green, blue

Subtractive

cyan, magenta, yellow



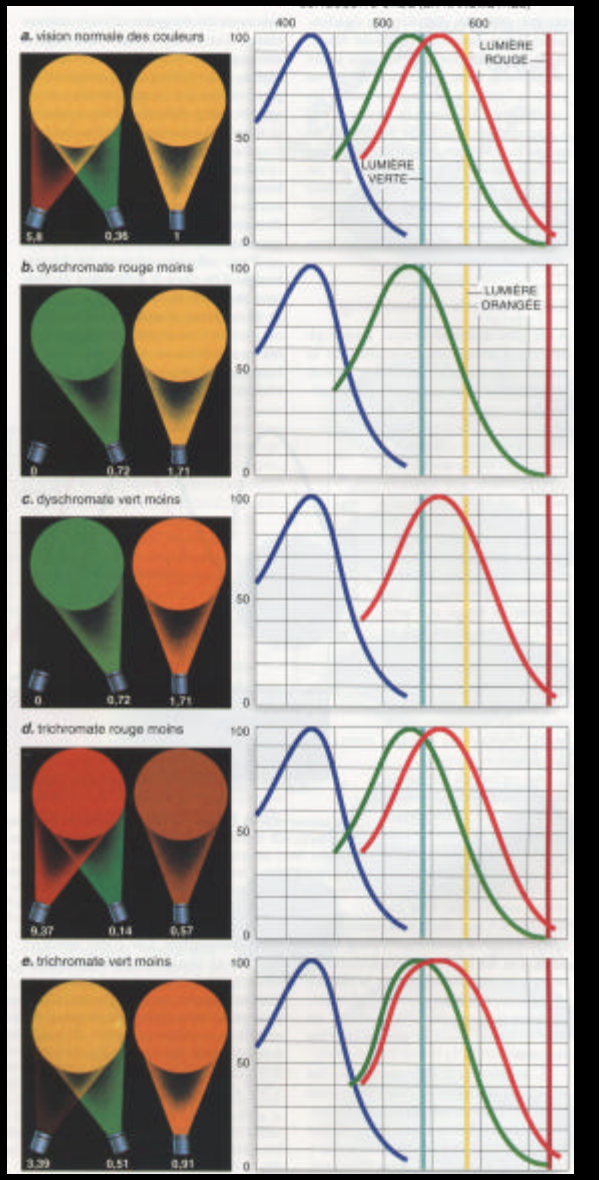
RIGHT

Plan

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

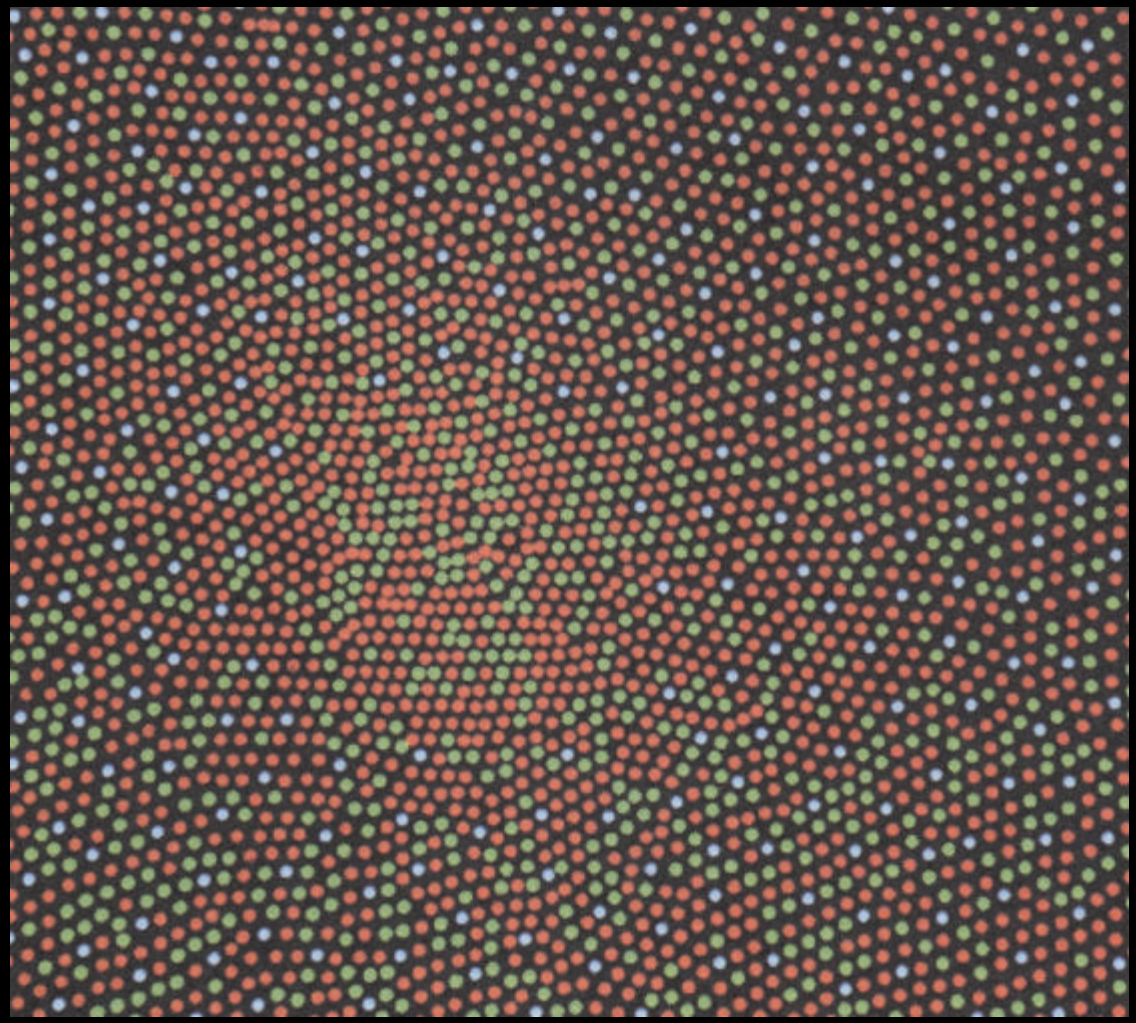
Color blindness

- 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

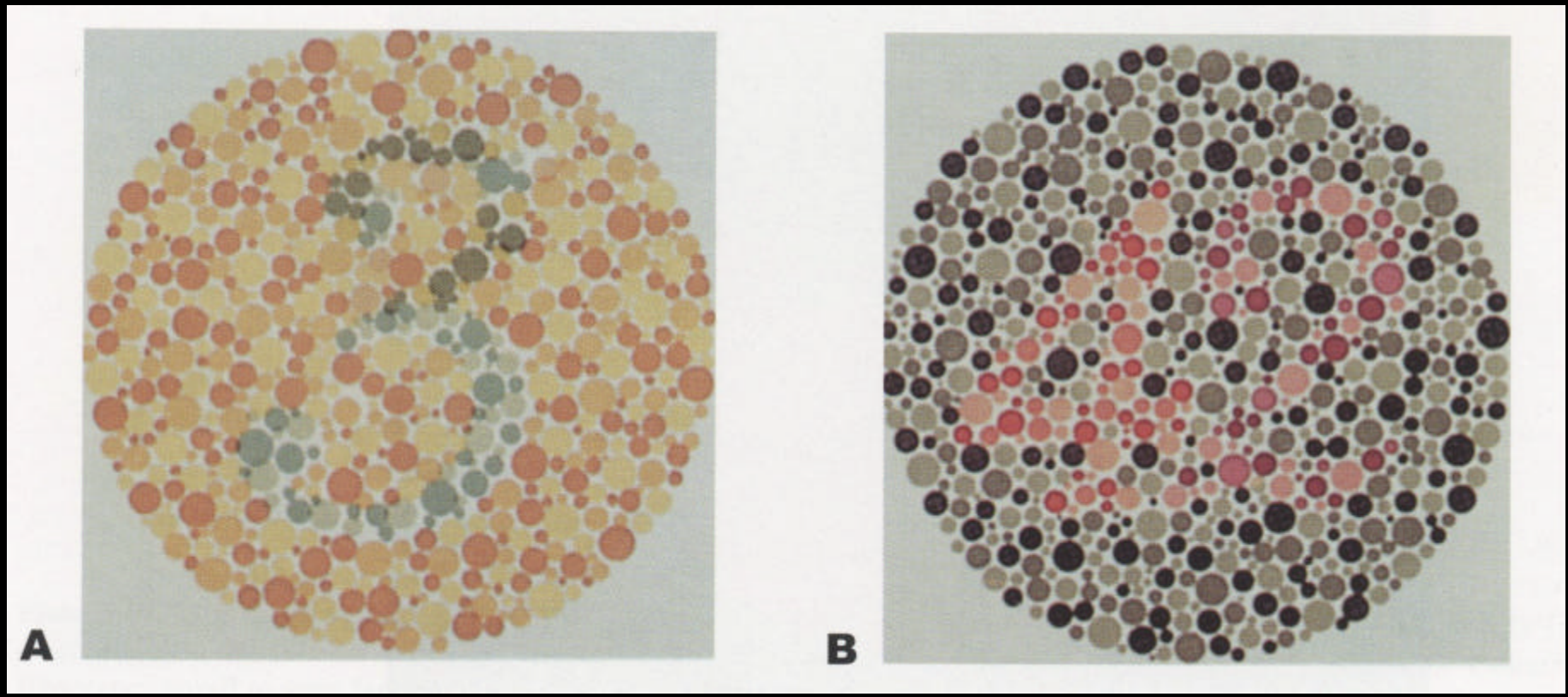


We are all color blind

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

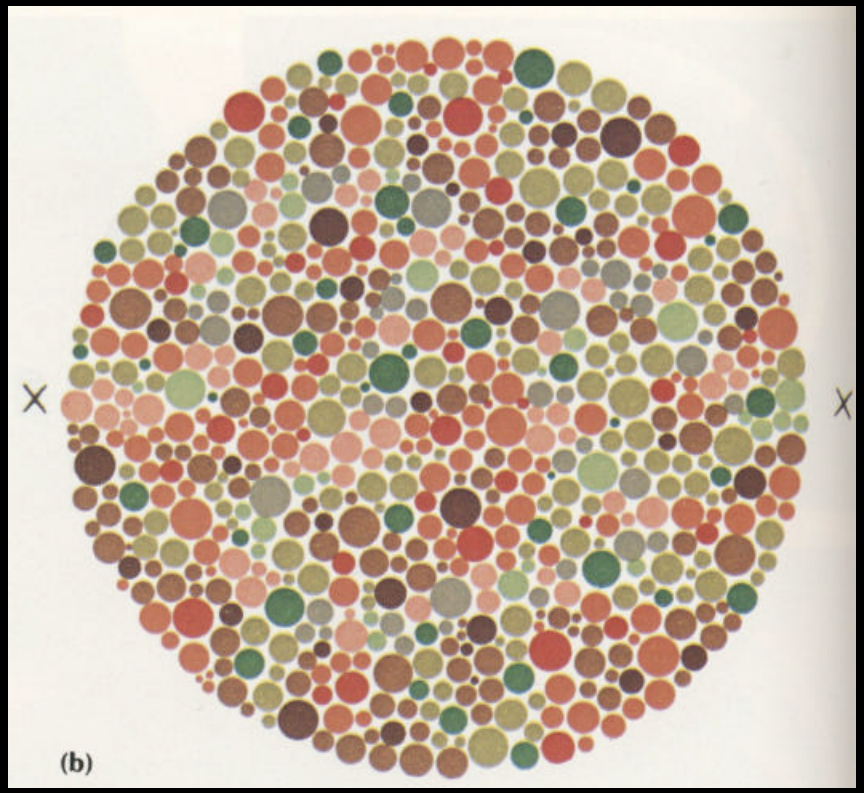


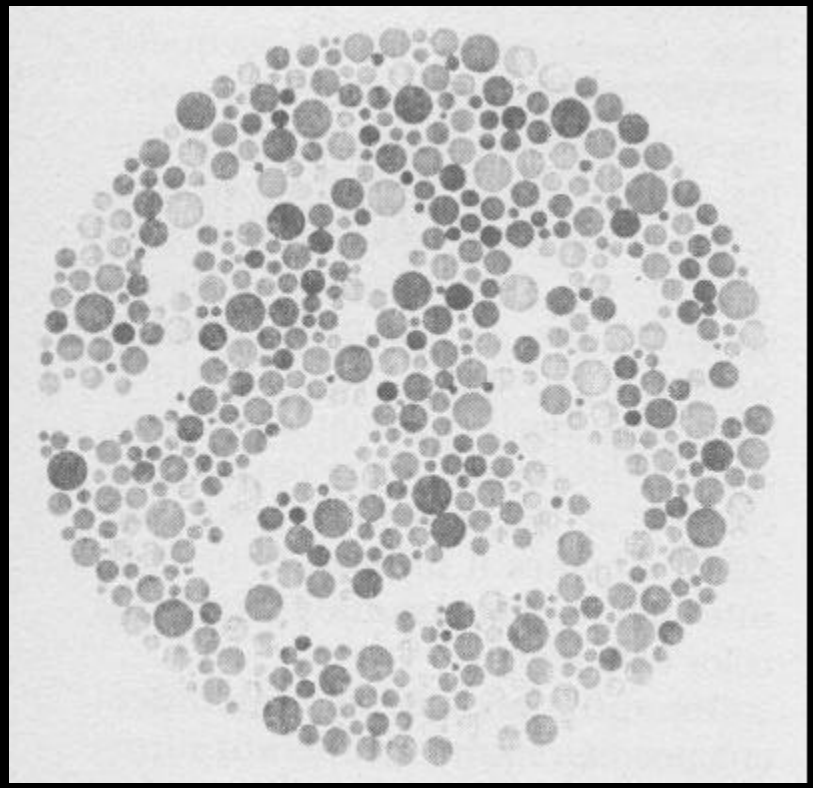
Color blindness test



Color blindness test

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





Color blindness correction

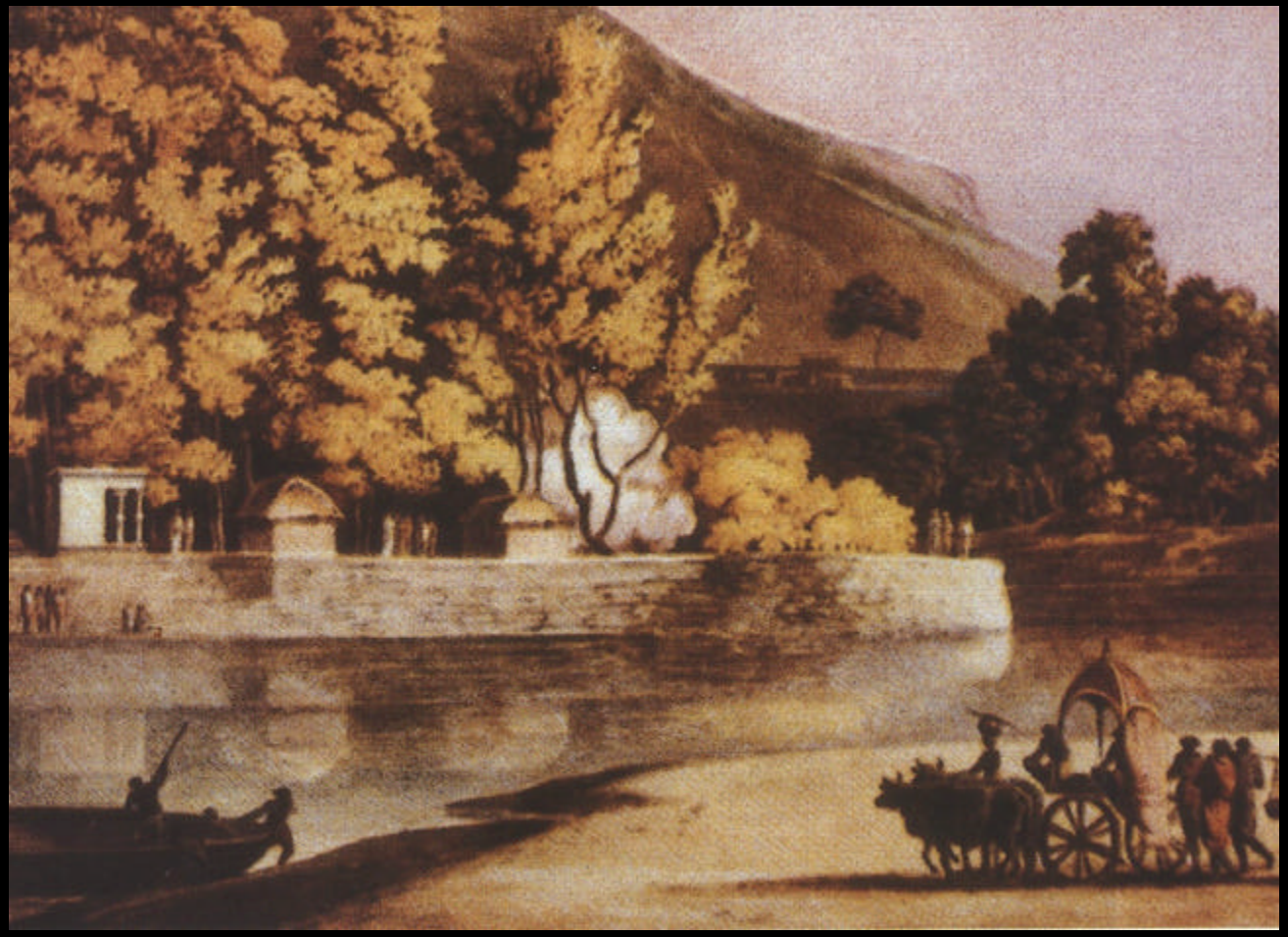
- Filter
  - On one eye
  - Set of filters (case of electronics)

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*

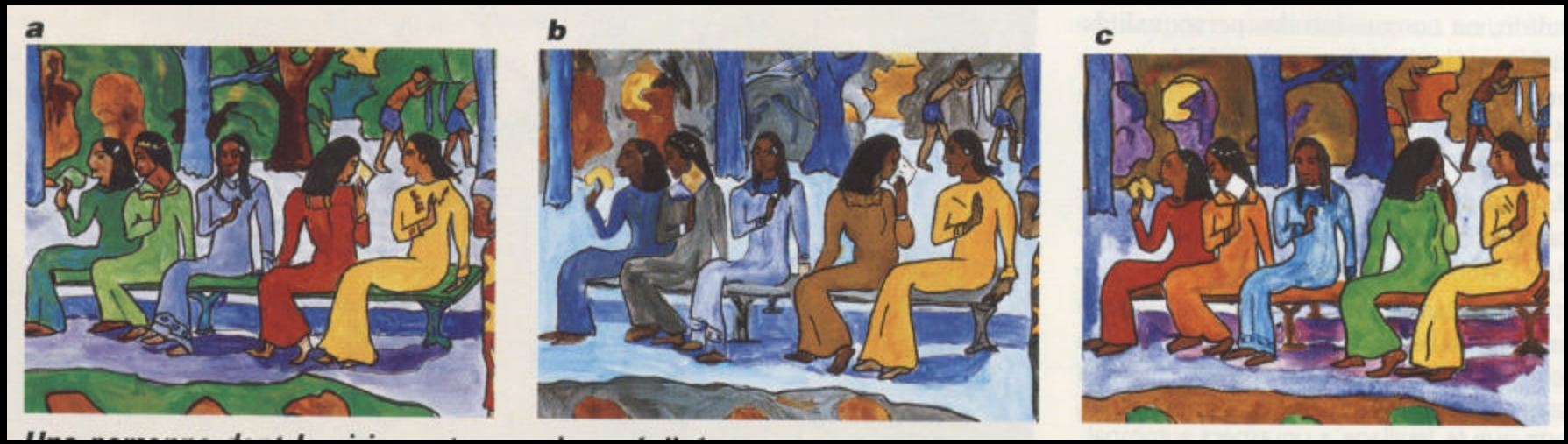
Color blindness & Painting

- Restricted to blue-yellow

J. J.

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

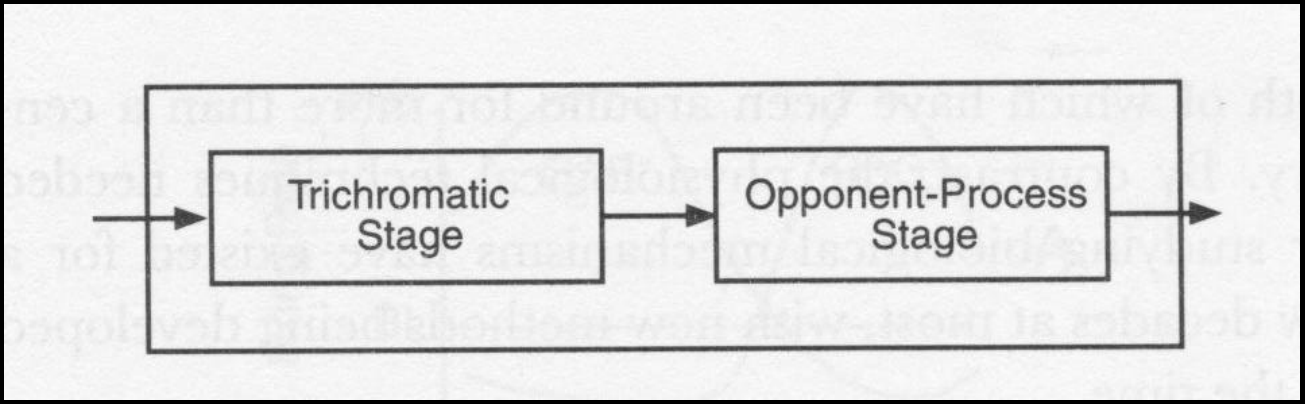
- Color blindness
- Color Opponents, Hue-Saturation Value
- Perceptual color effects
- Color categories and culture

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

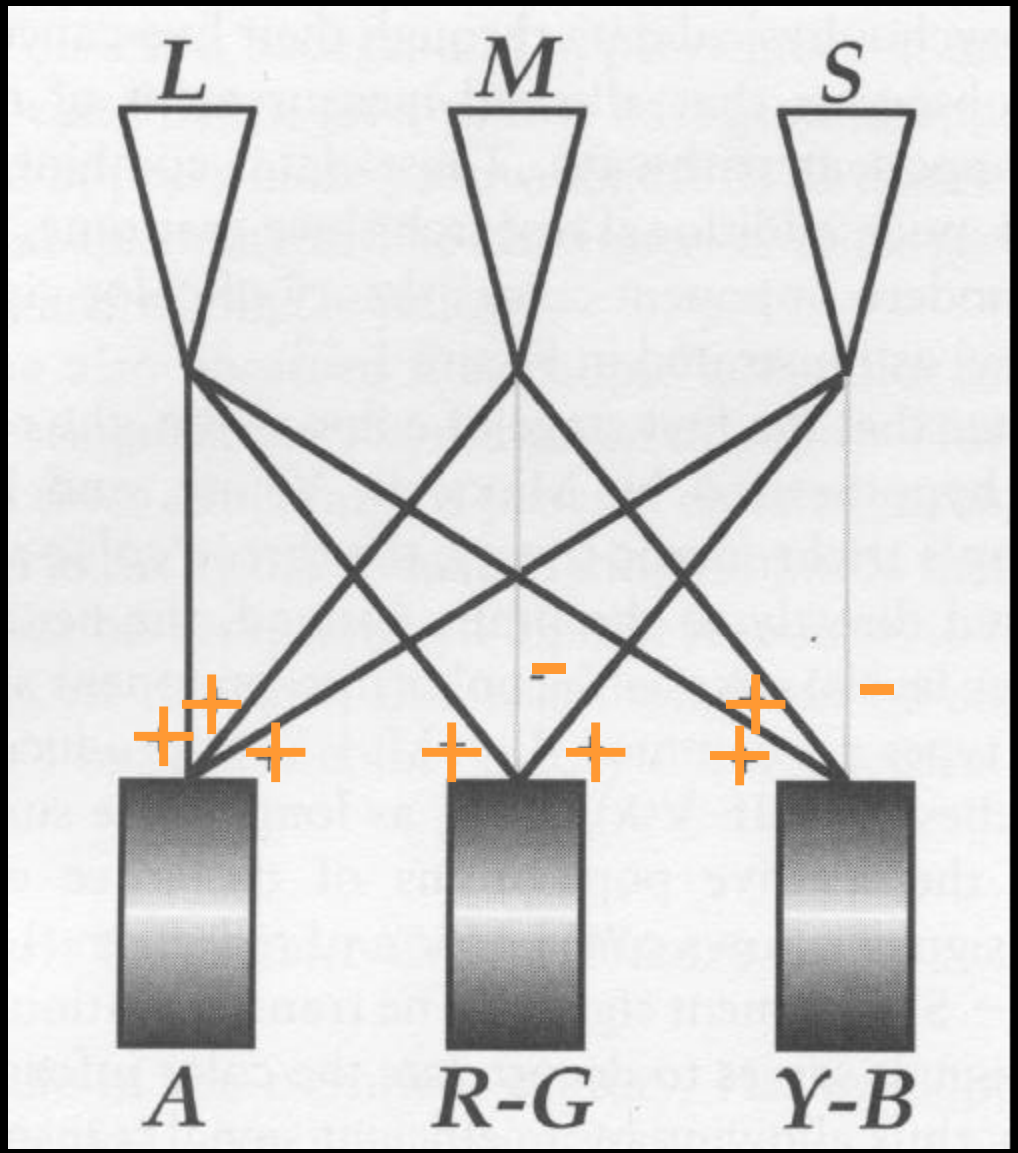
Color reparameterization

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



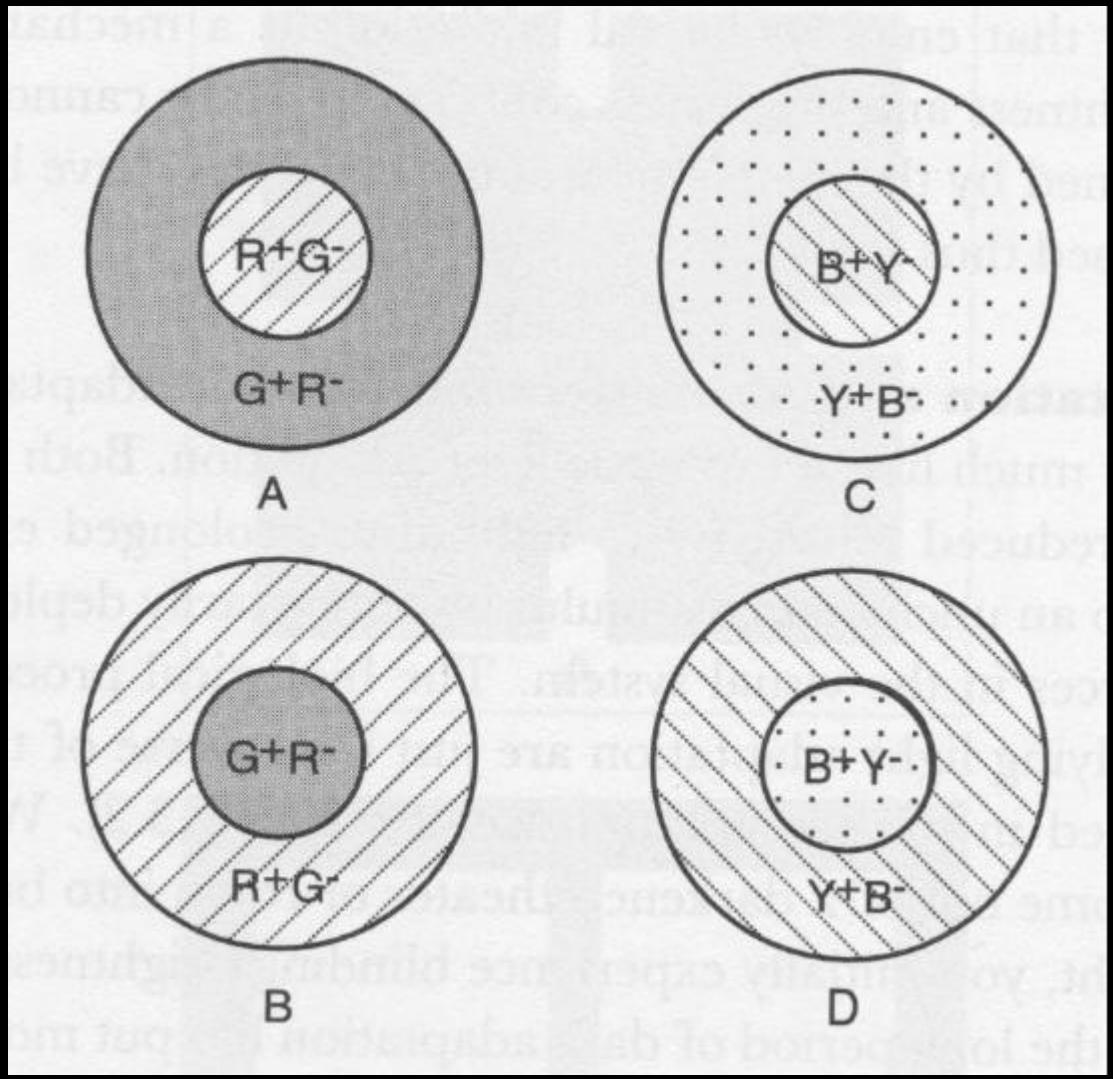
Color opponents wiring

- Sums for brightness
- Differences for color opponents



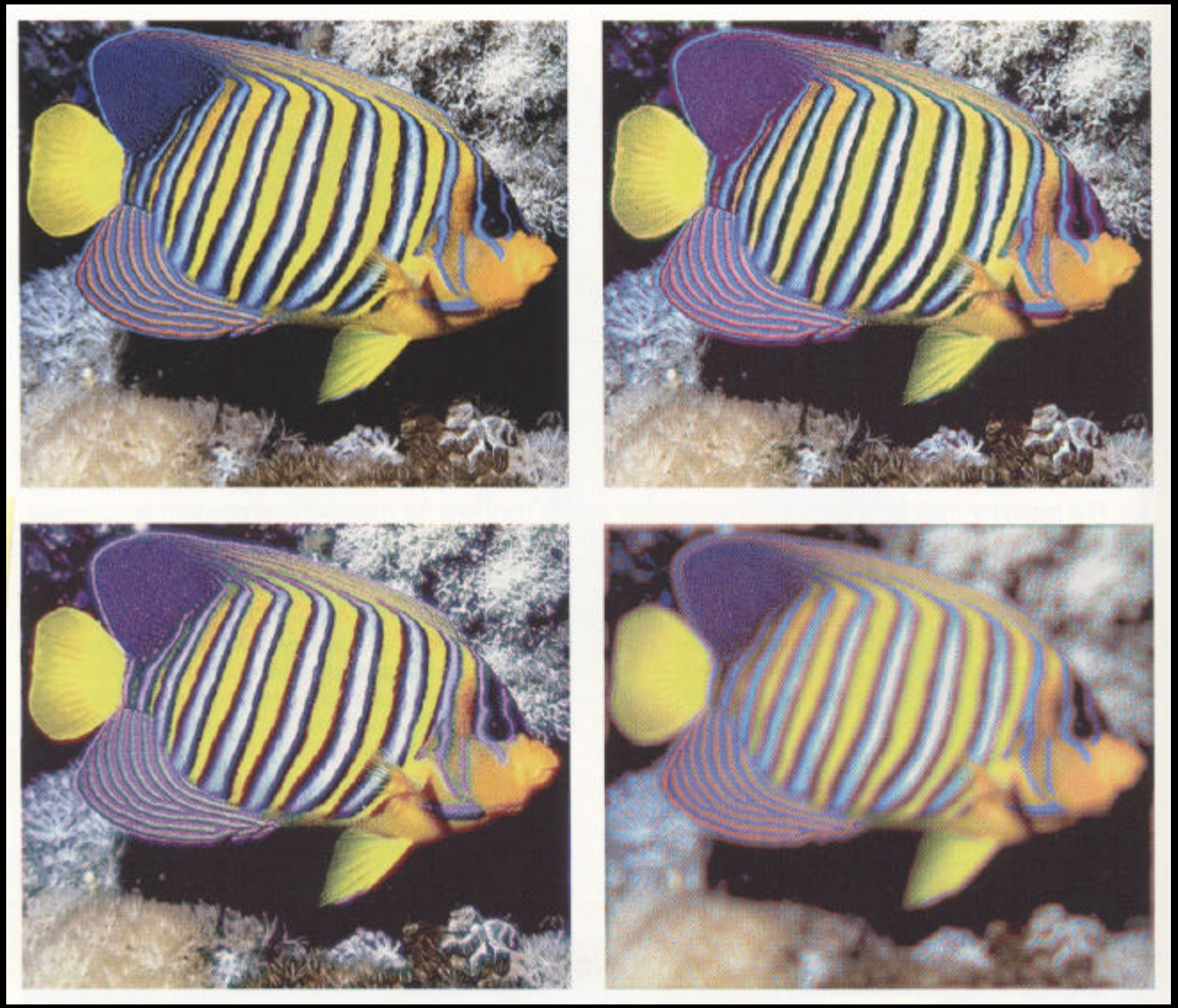
Double center surround opponents

- Center-surround
- Color opponents



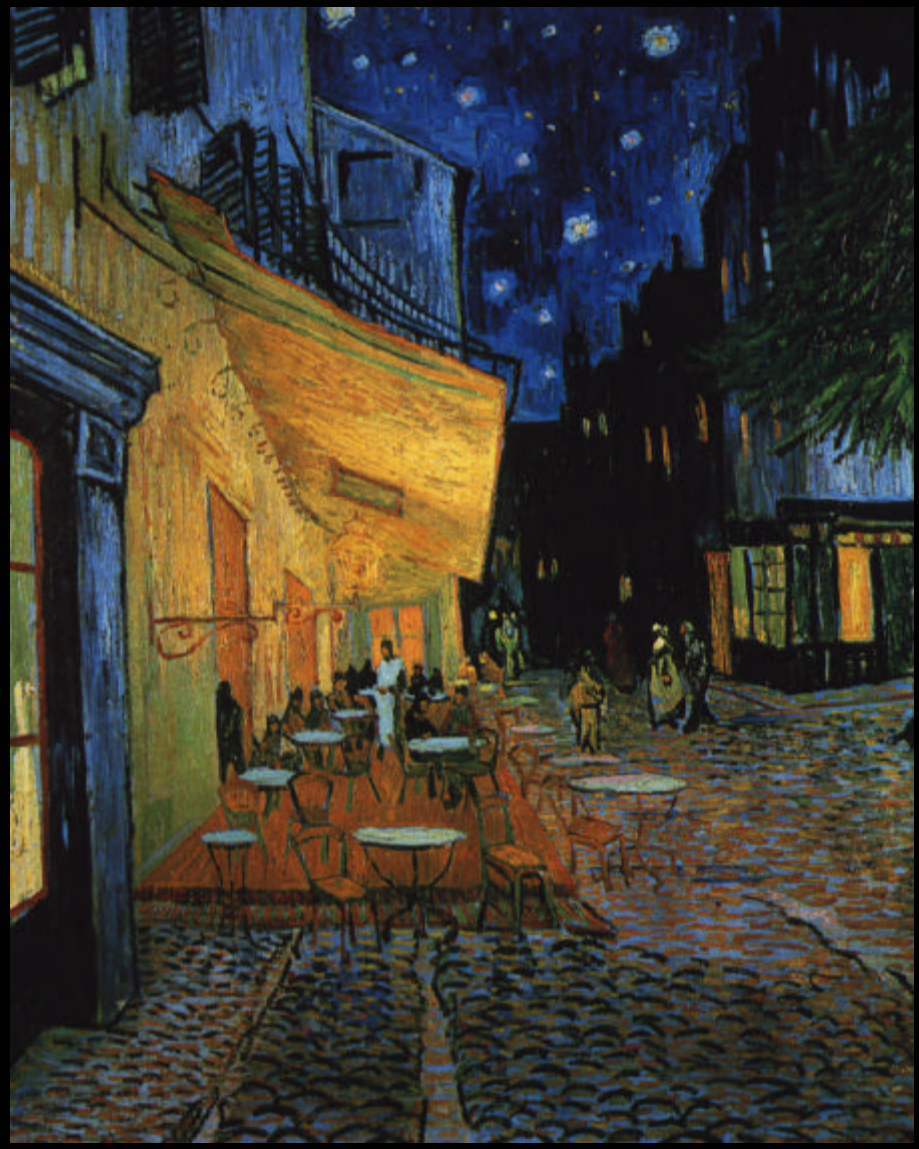
Opponents and image compression

- JPG, MPG
- Color opponents instead of RGB
- Compress color more than luminance



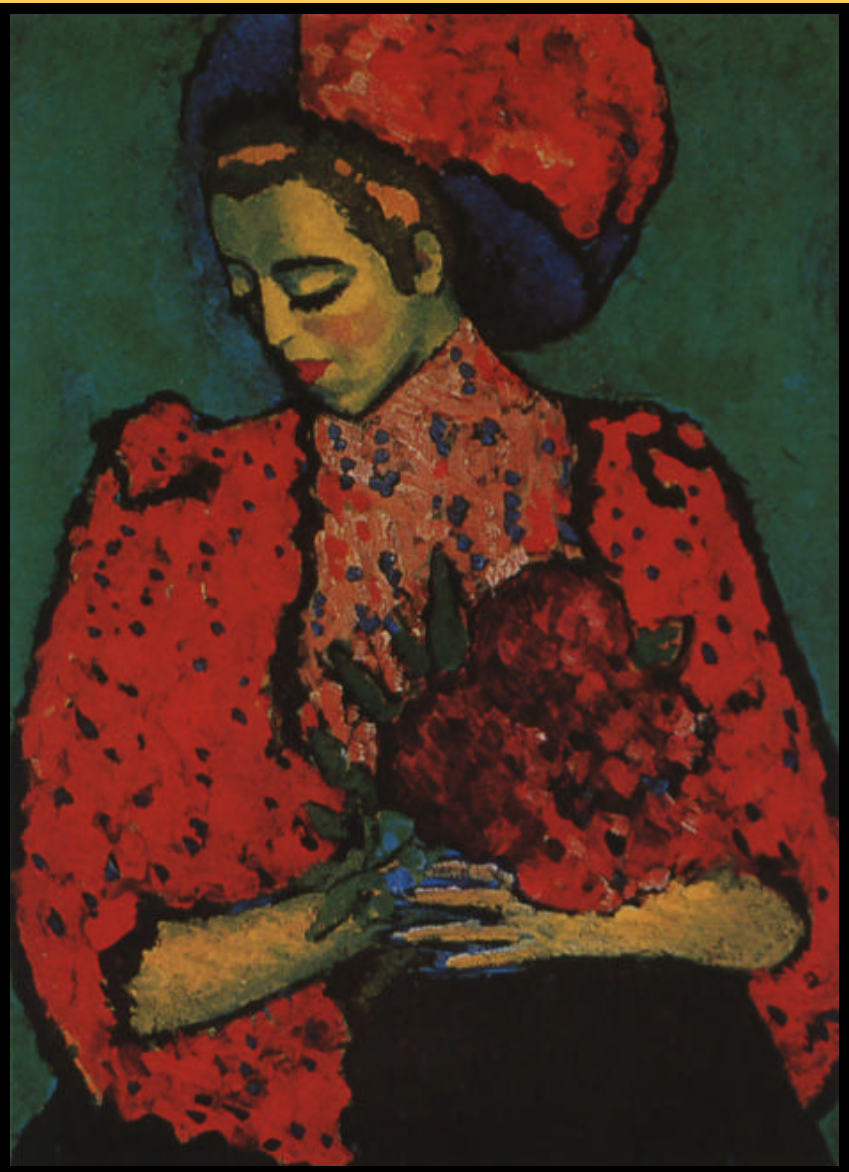
Blue-yellow opponent and painting

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



Red-green opponent and painting

- Jawlensky

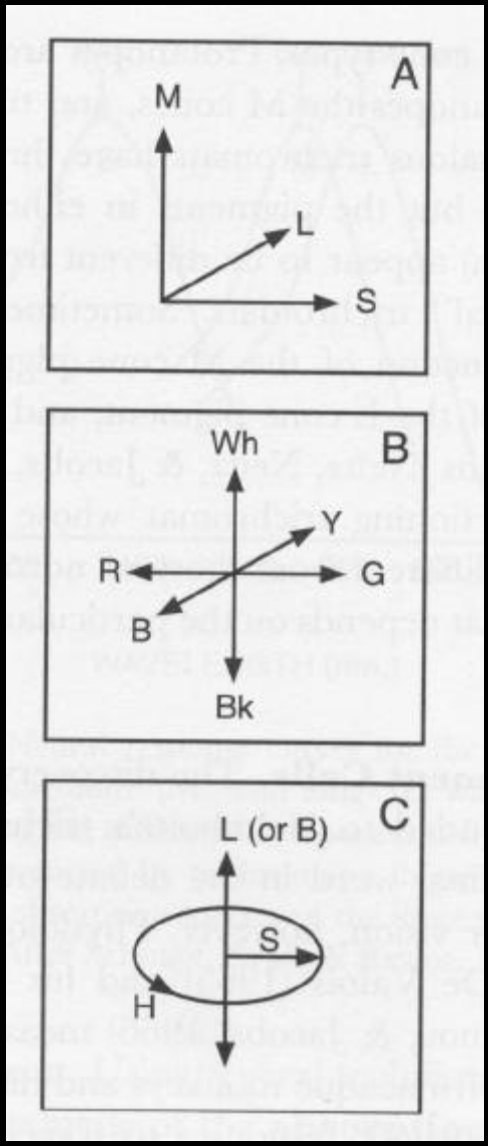


Opponent and painting

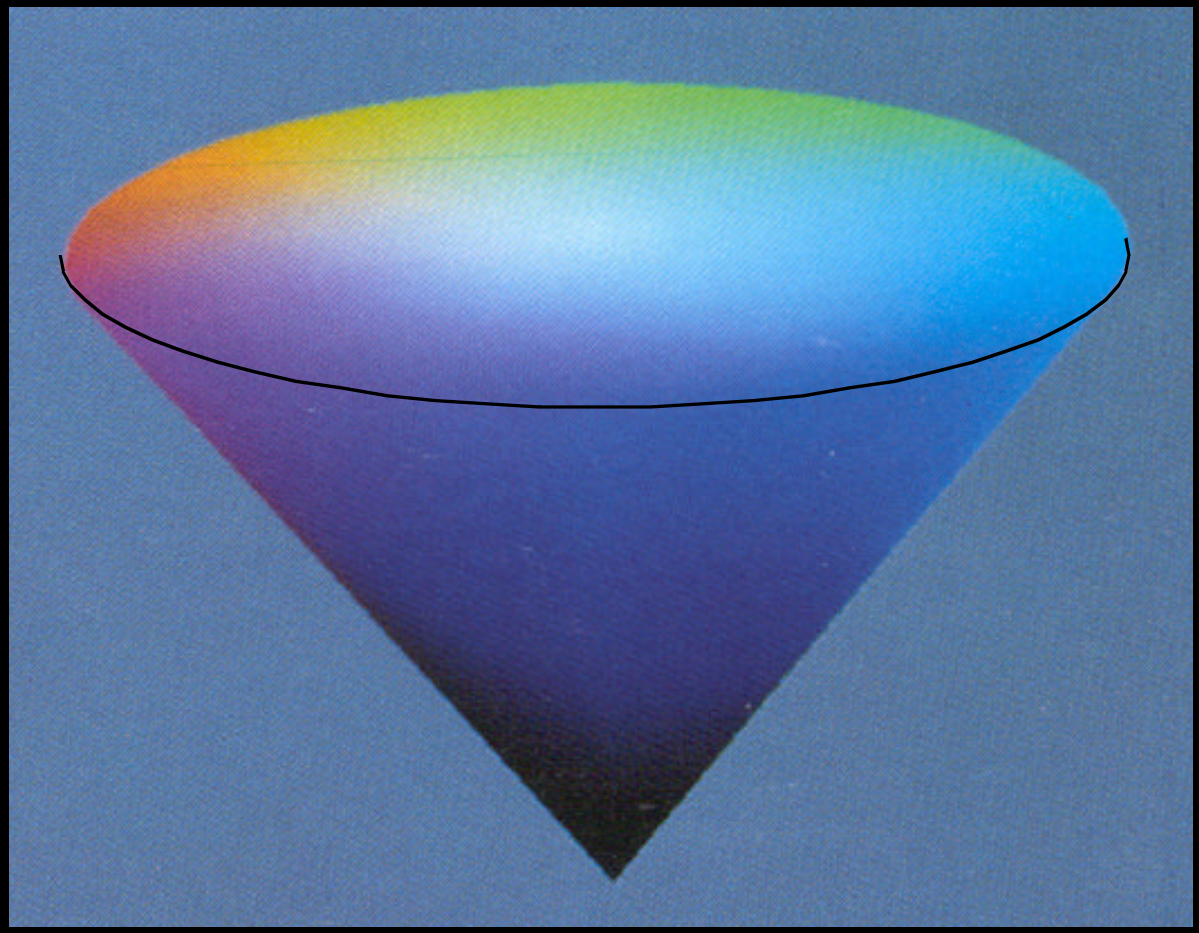
- Degas

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

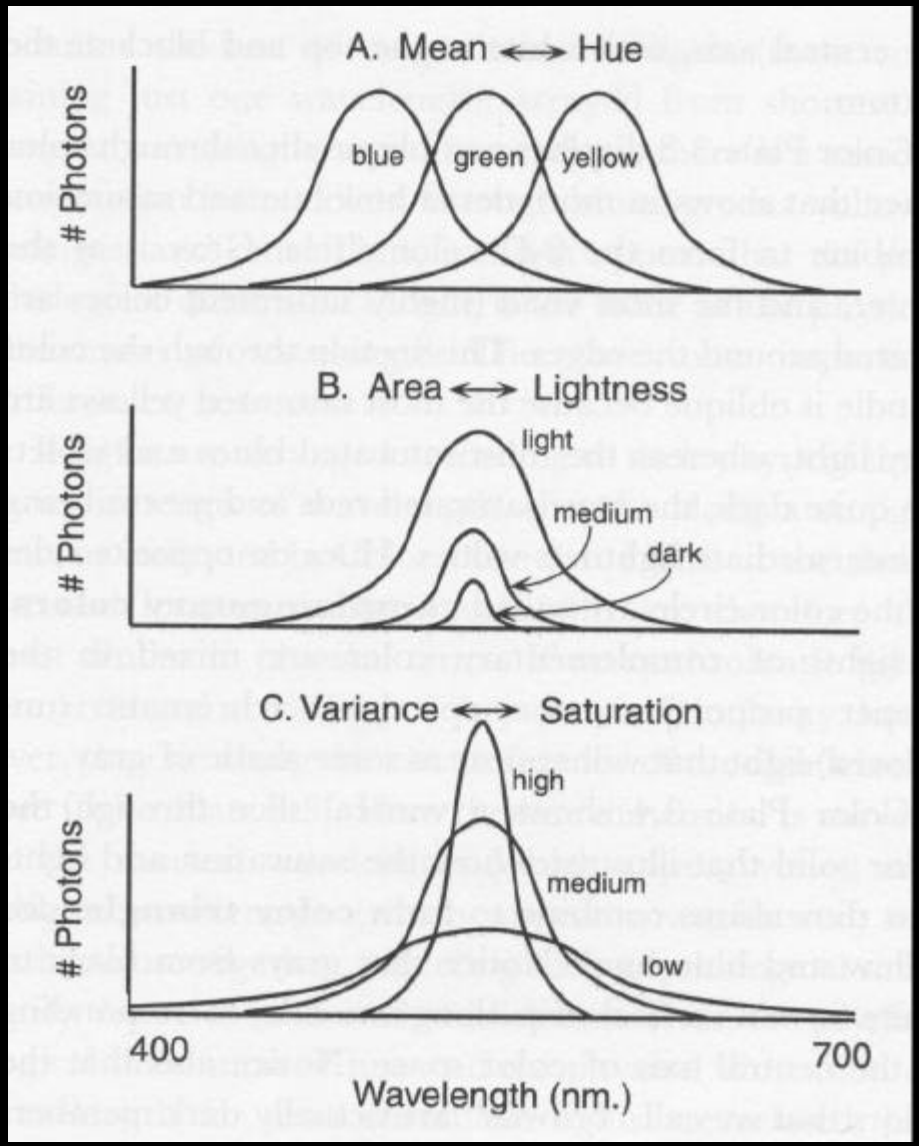


Hue Saturation Value



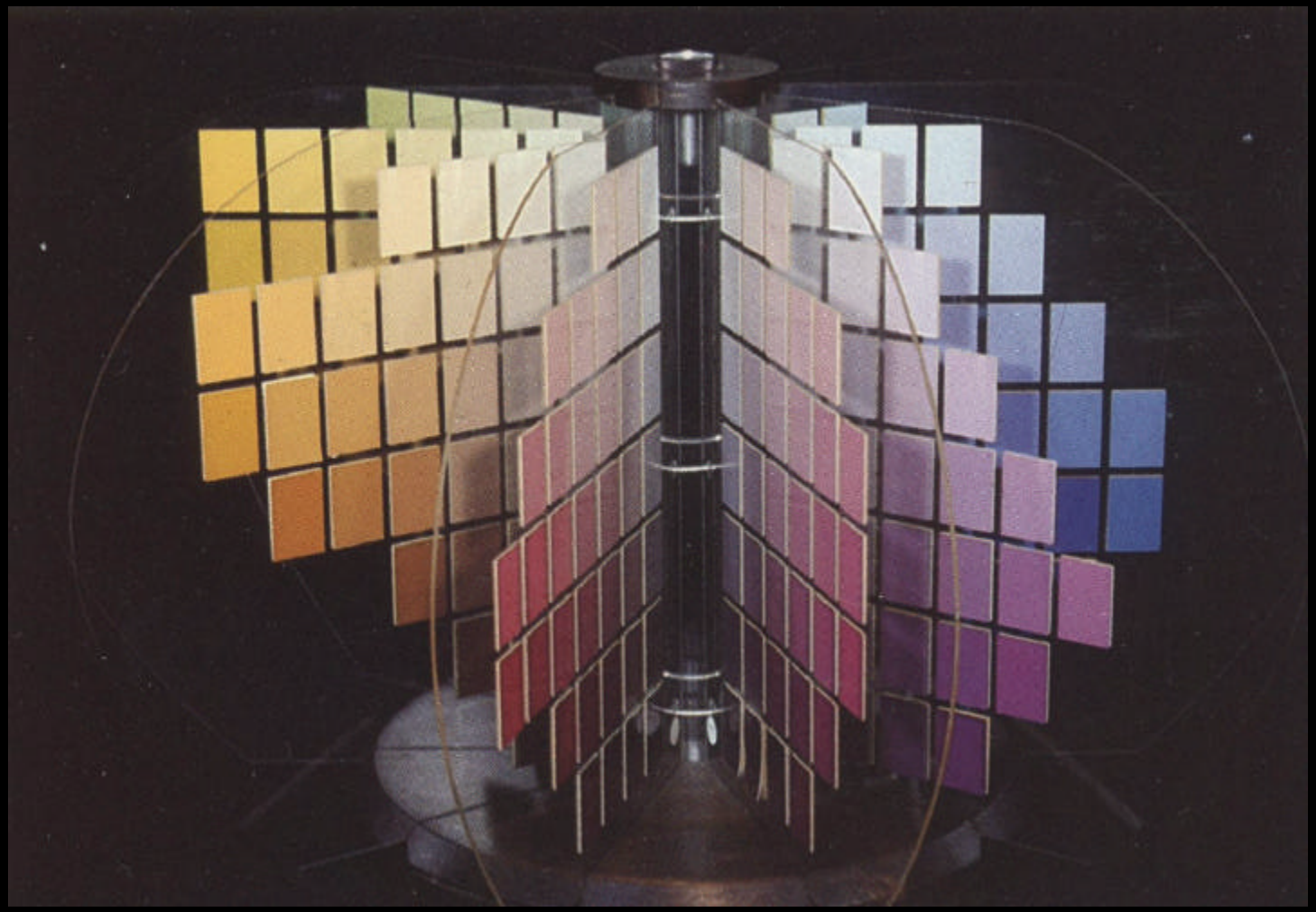
Hue Saturation Value

- 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

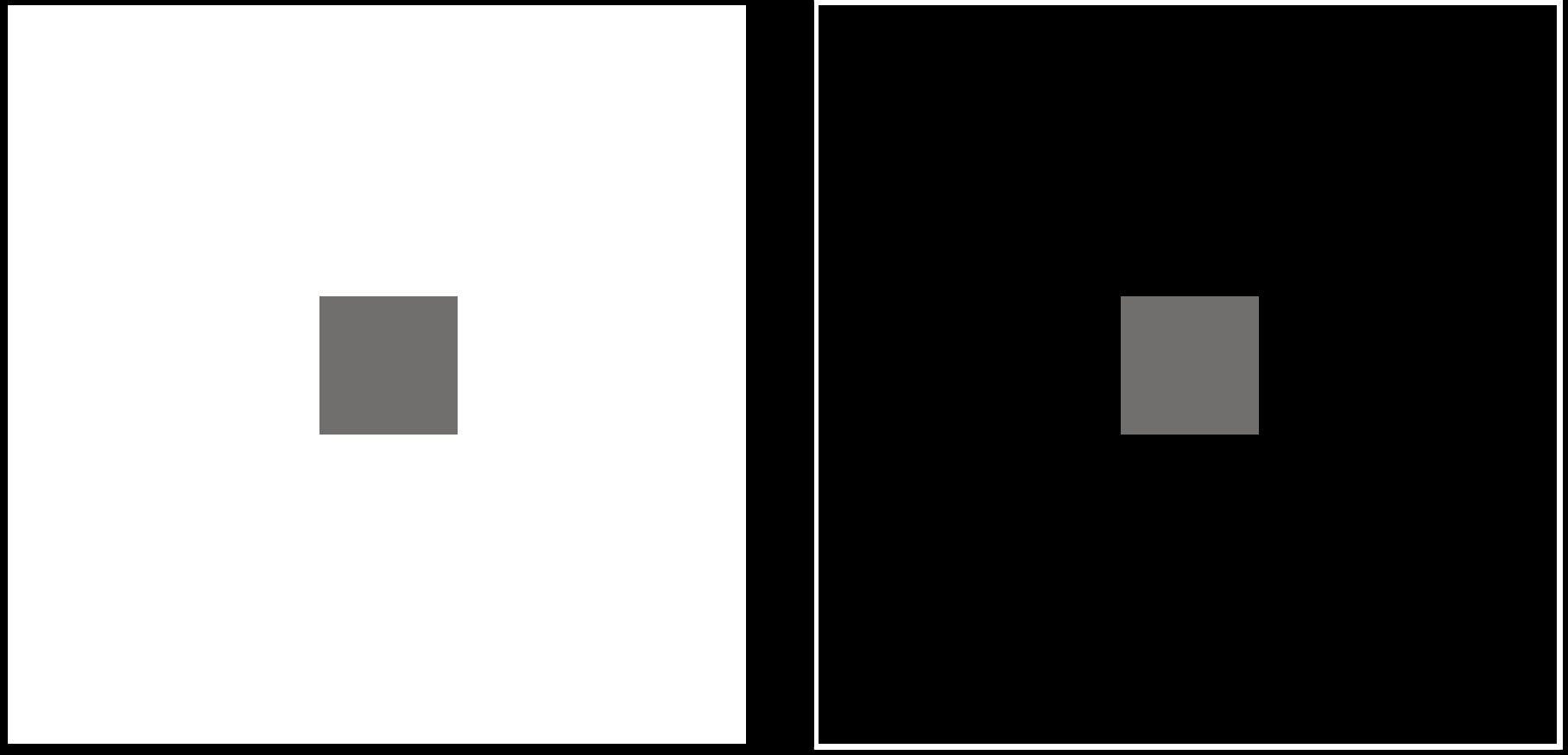
- Color blindness
- Color Opponents, Hue-Saturation Value
- Perceptual color effects
- Color categories and culture

Color appearance effects

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

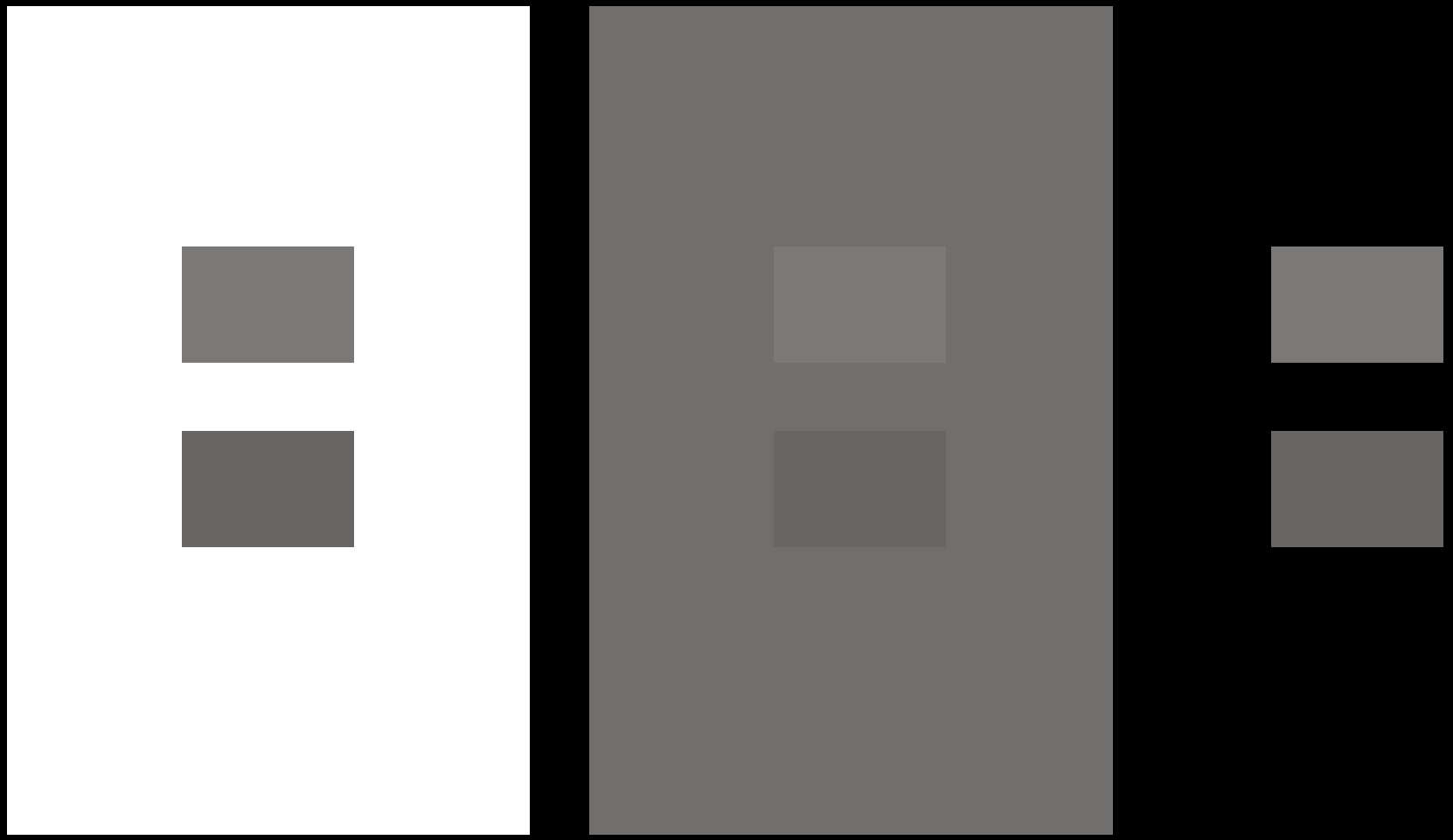
Simultaneous contrast

- Chevreul
- In color opponent direction



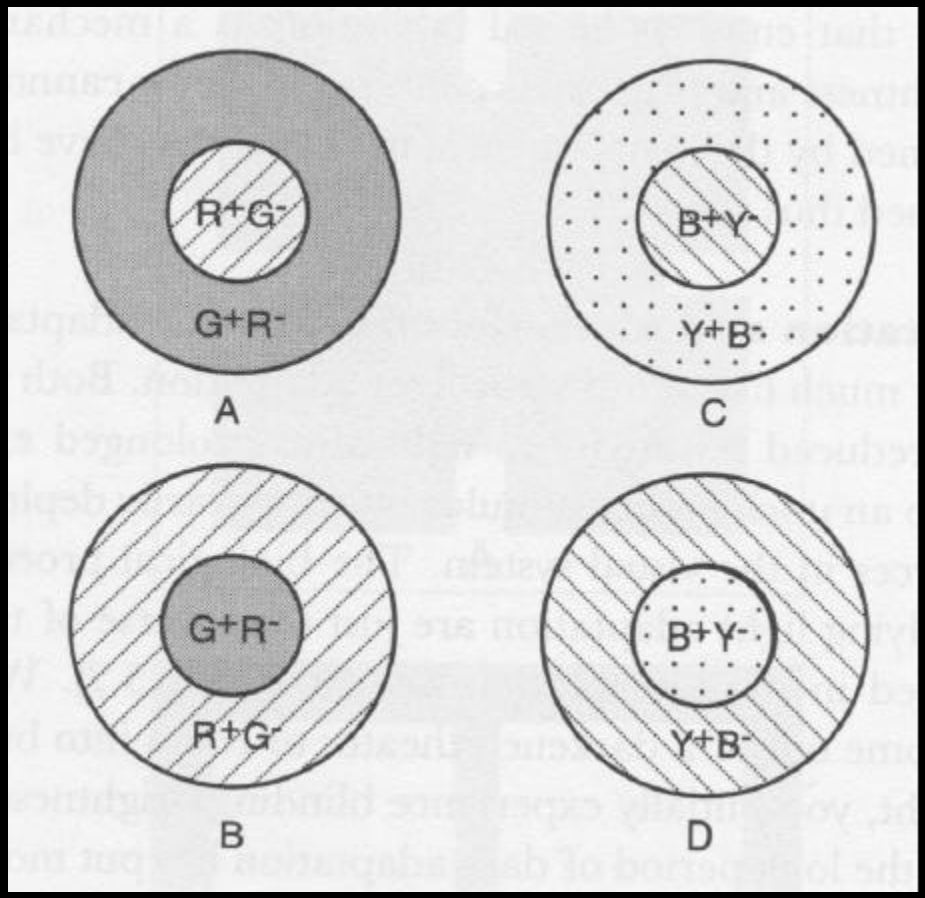
Crispening

- Increased sensitivity

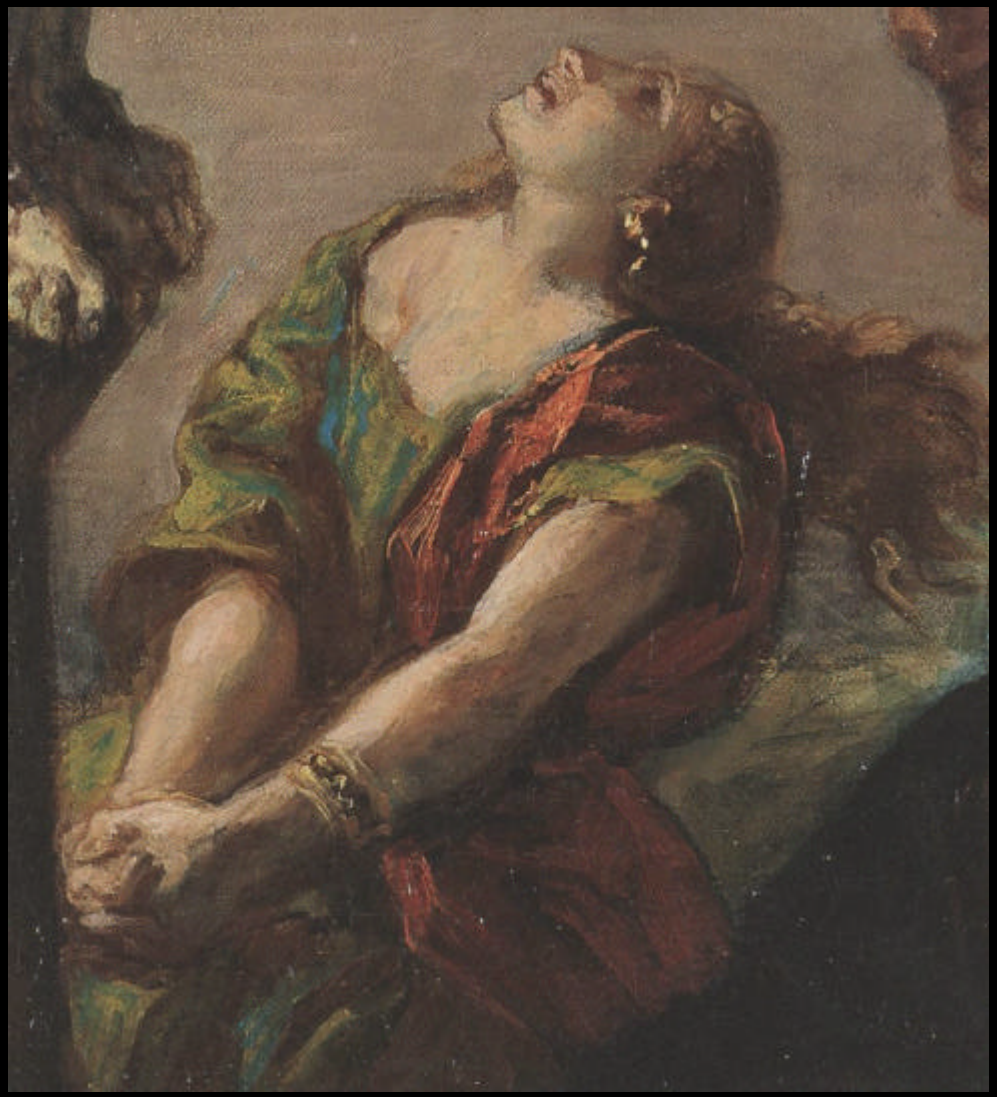


Simultaneous contrast

- In color opponent direction
- Center-surround



Eugène Delacroix



Eugène Delacroix

Impressionism

- Claude Monet

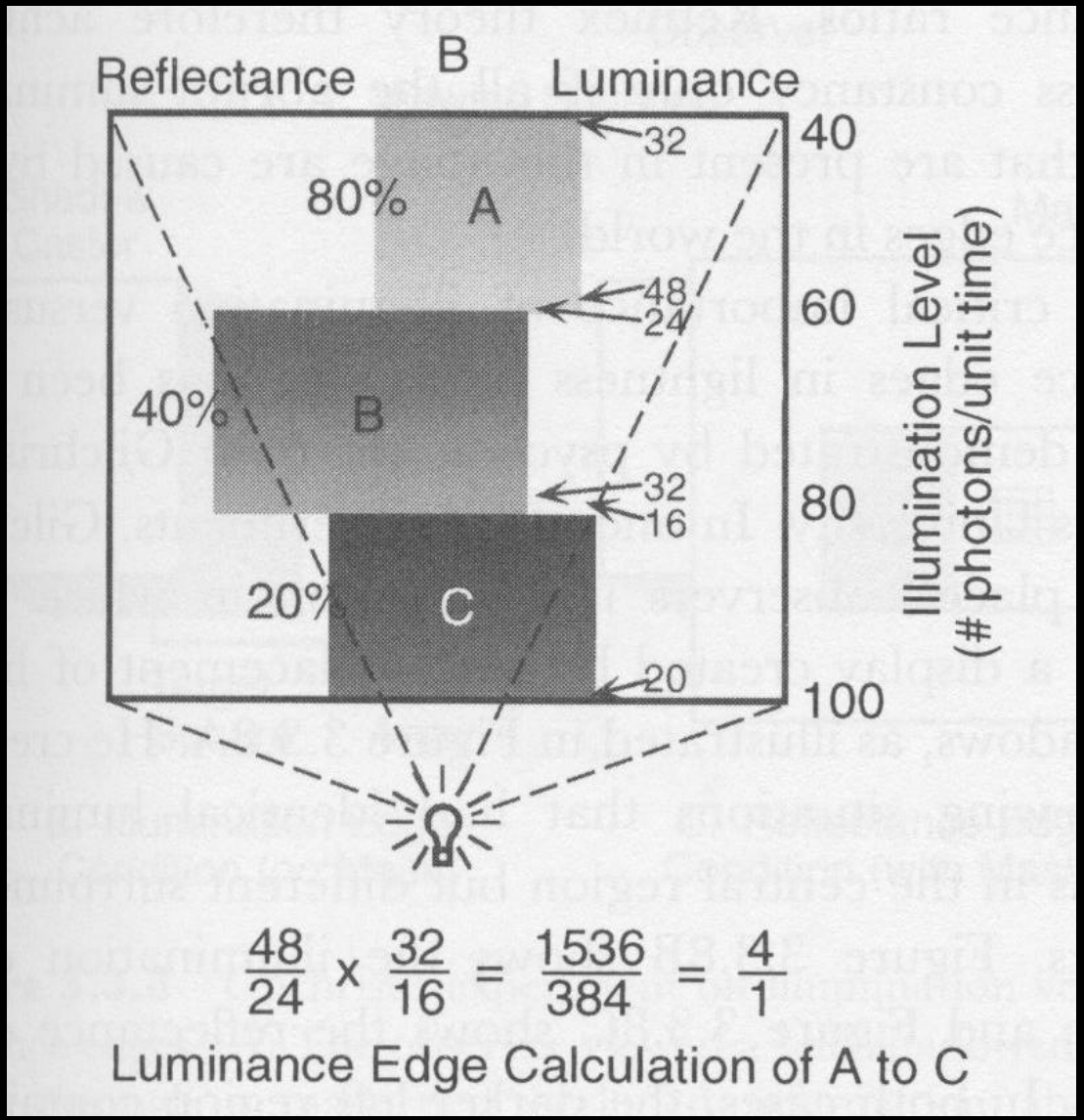
Post-Impressionism

- Van Gogh

Post-Impressionism

- Van Gogh

Land Retinex

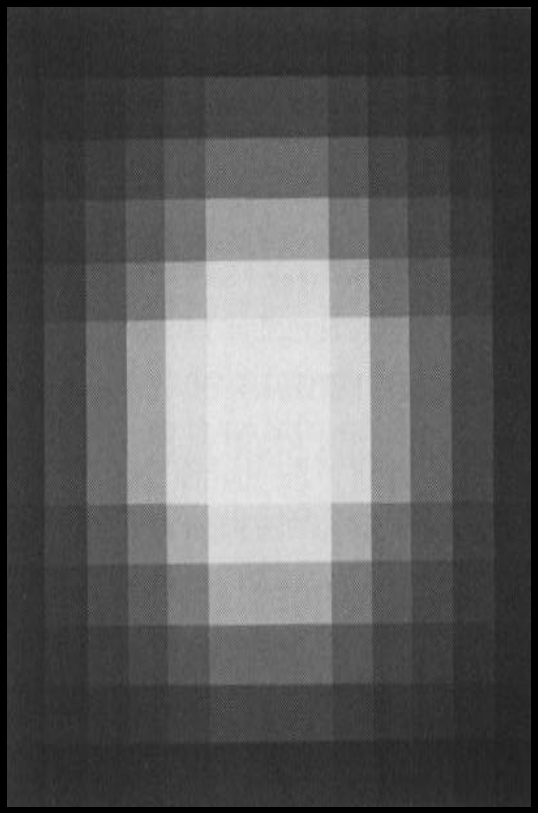


Haloing, local contrast

- Seurat, *Bathers at Asnières*, 1884

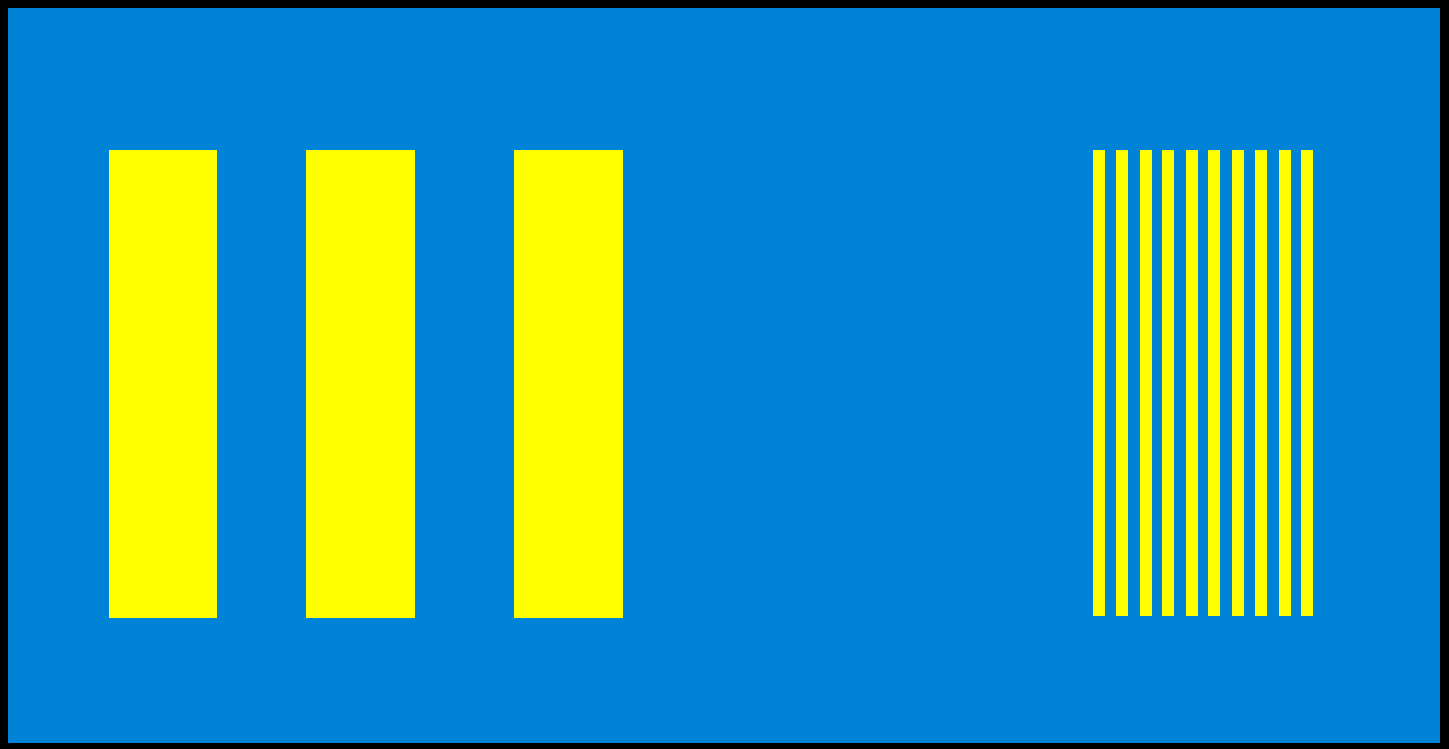
Edge burning

- Ansel Adams


Spreading

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



Pointillism

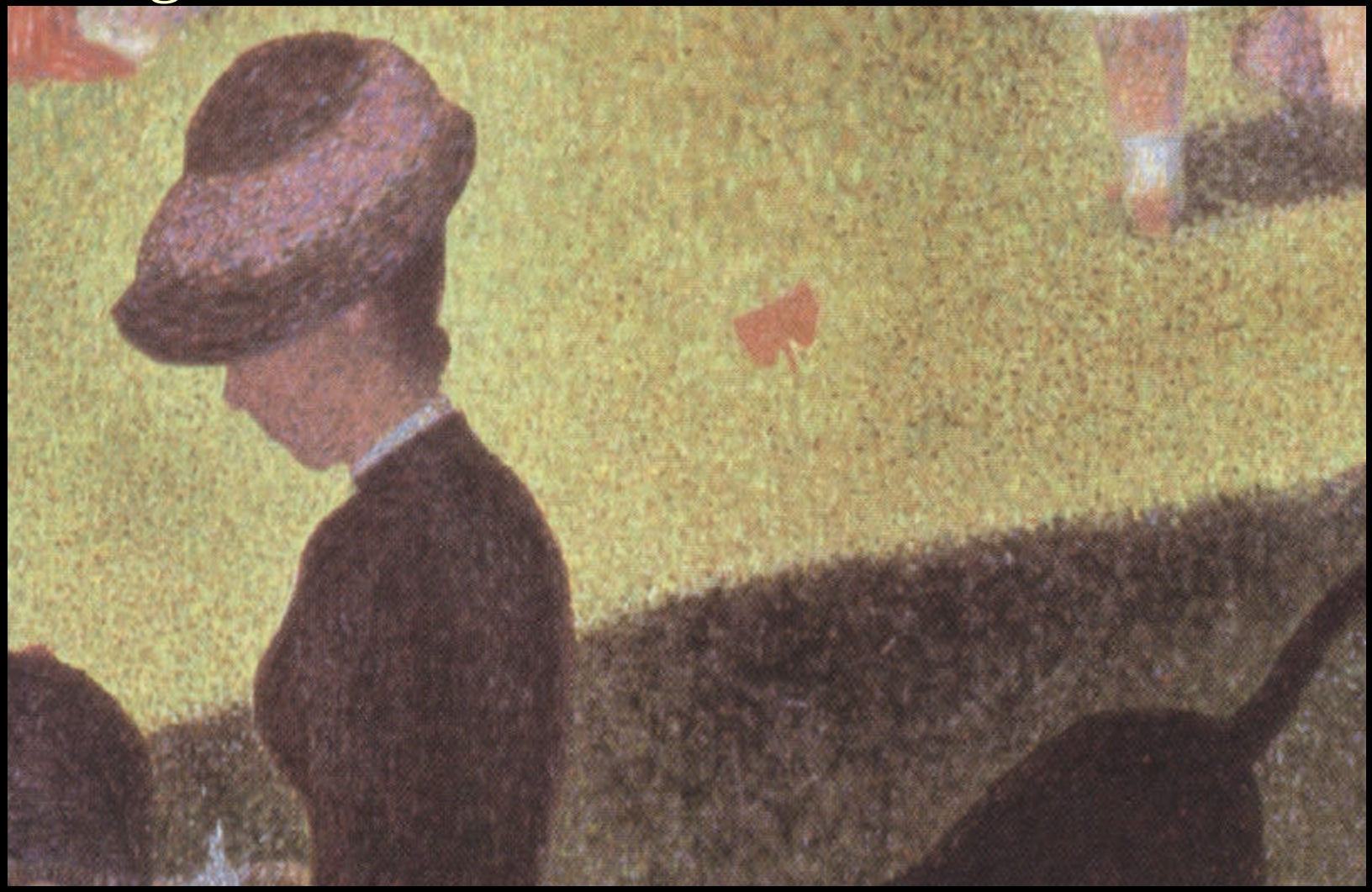
- George Seurat, *The Channel of Gravelines, Grand Fort-Philippe*, 1890

Pointillism

- George Seurat, *La Grande Jatte*, 1886

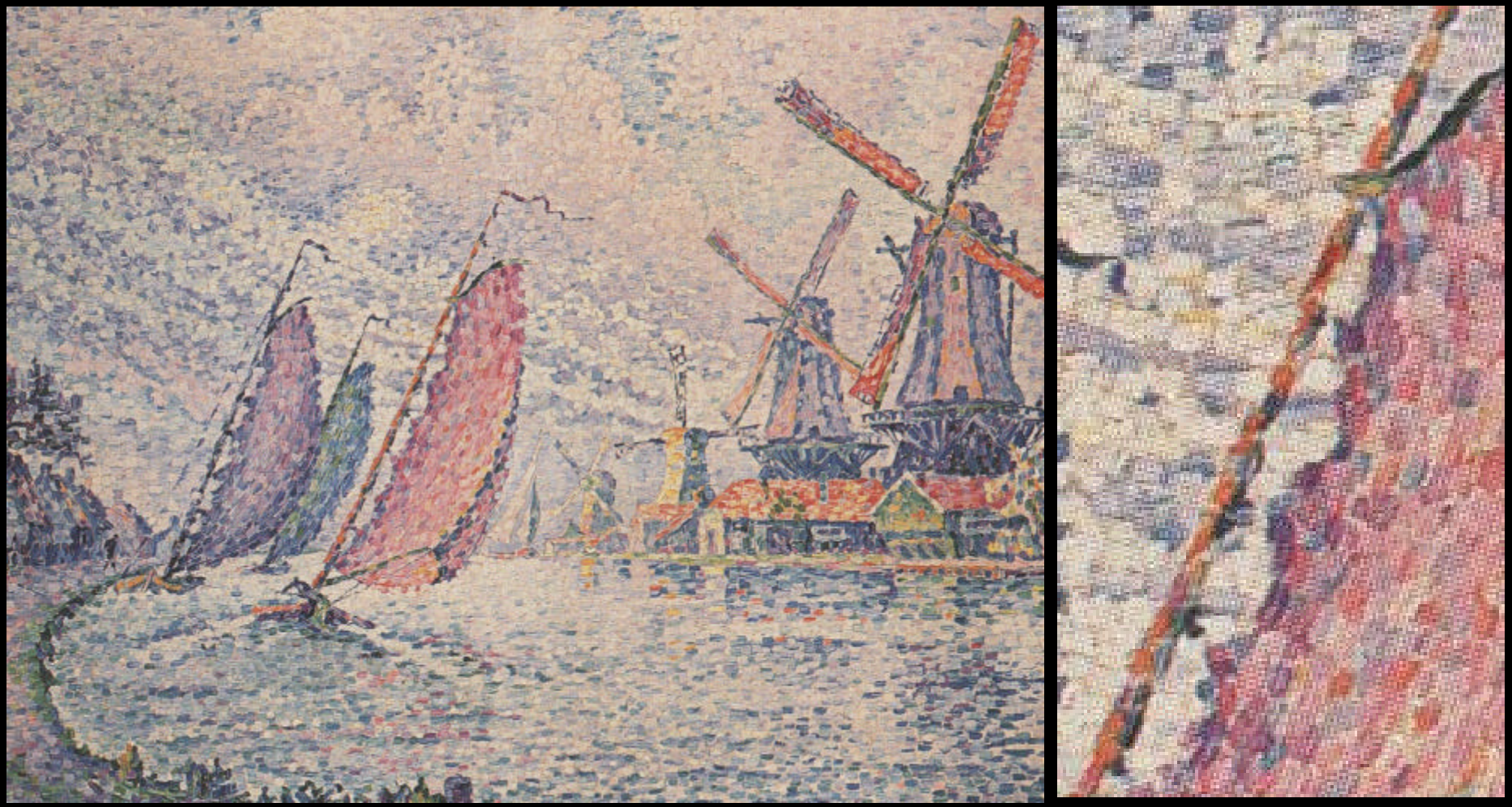
Pointillism

- George Seurat, *La Grande Jatte*, 1886



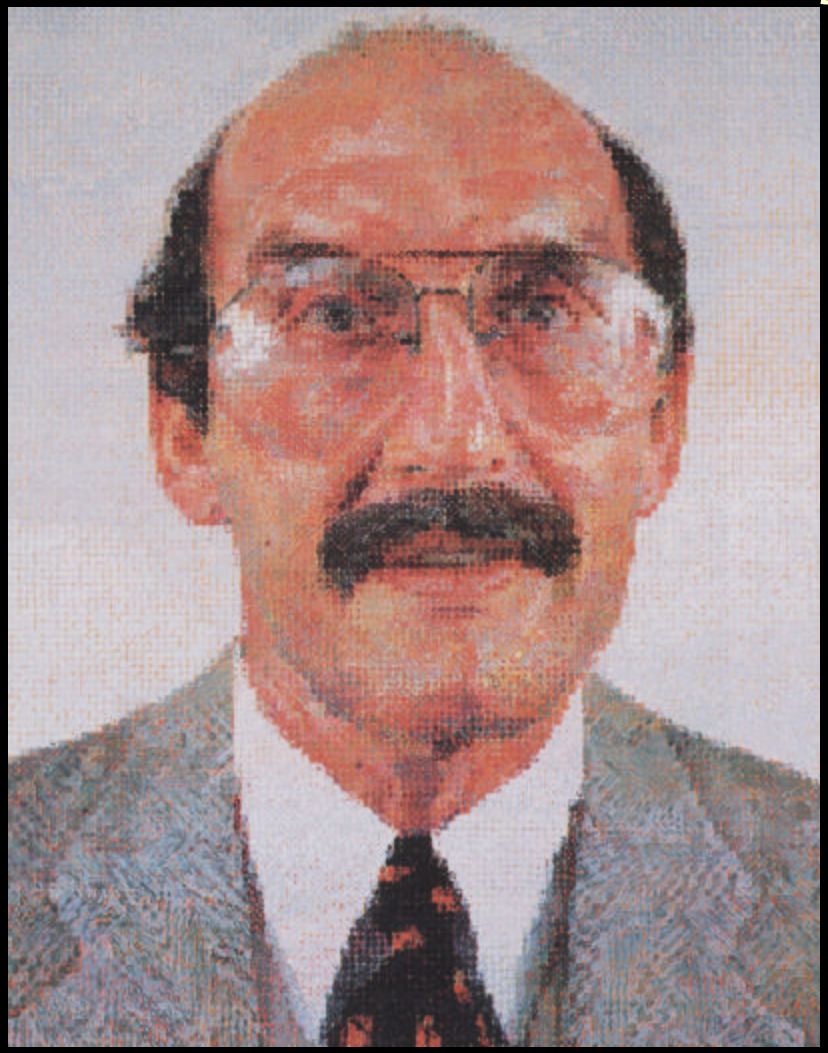
Divisionism

- Paul Signac, *The Mills at Overschie*, 1905



"Layered" pointillism

- Chuck Close, *Stanley*, 1980-81



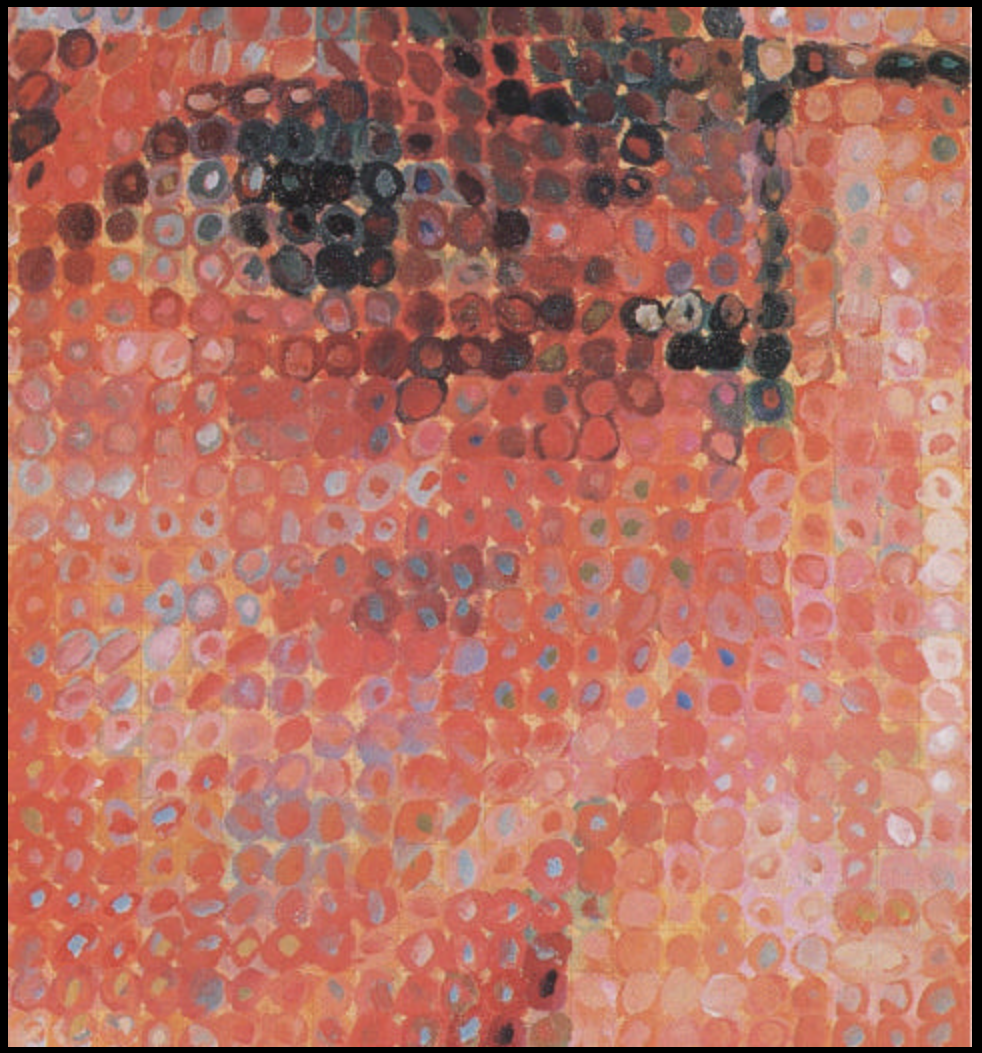
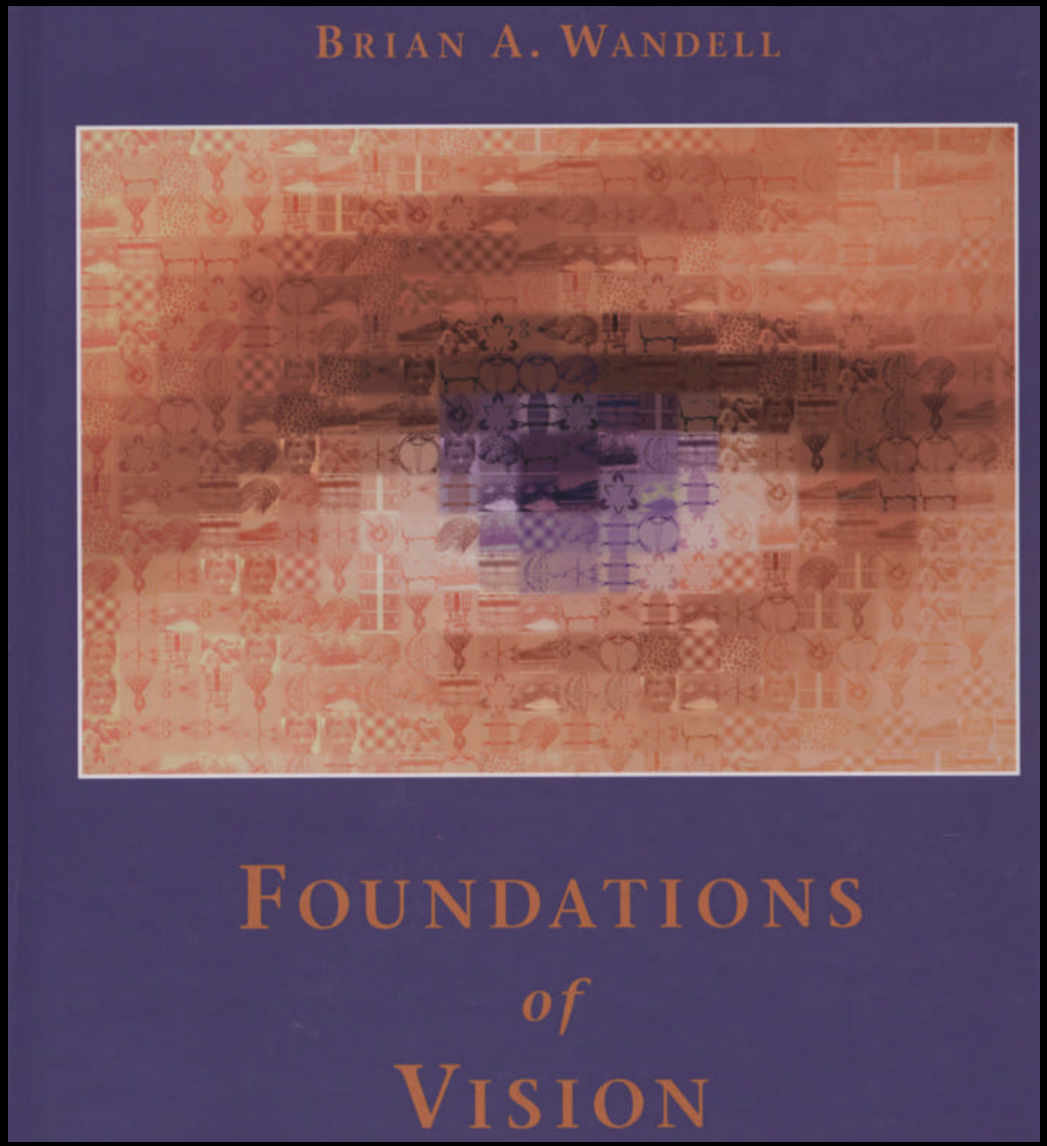
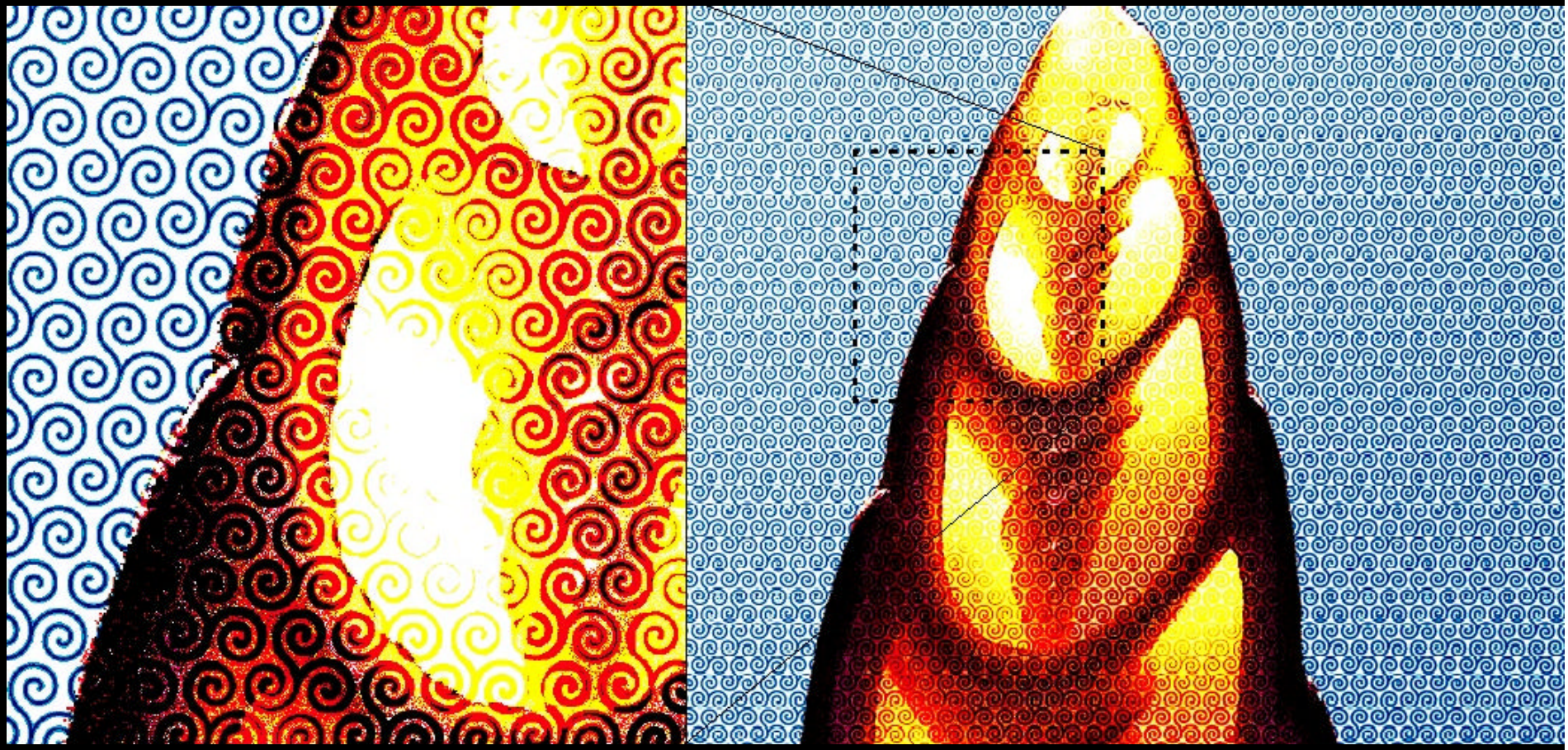


Photo-Mosaics



Artistic Half toning

- Ostromoukhov 1999



Other effects

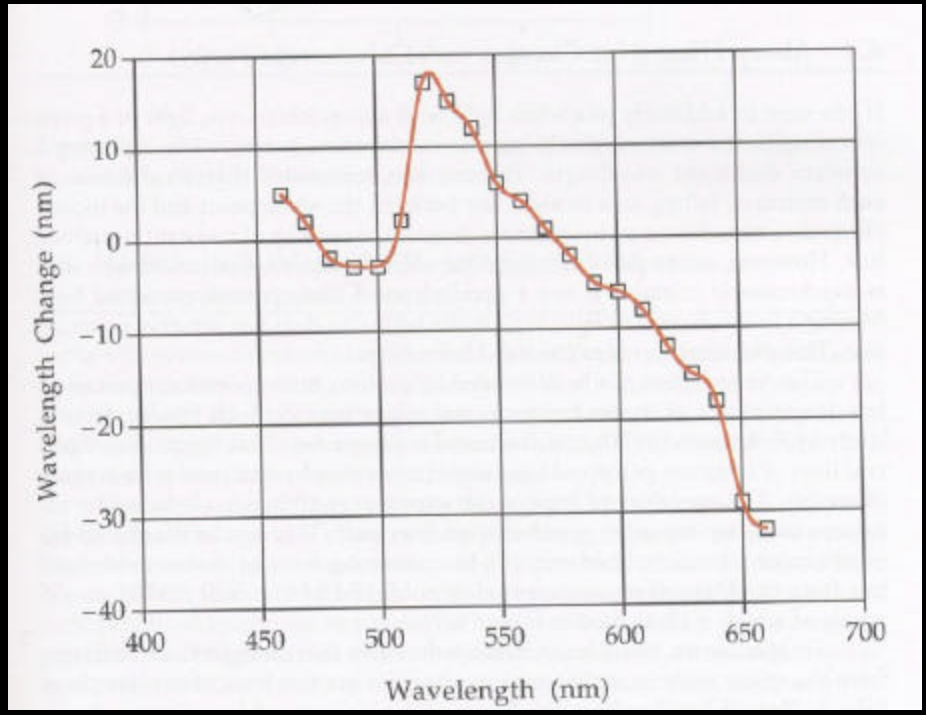
- Problems for color reproduction
- Problem in design and production

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

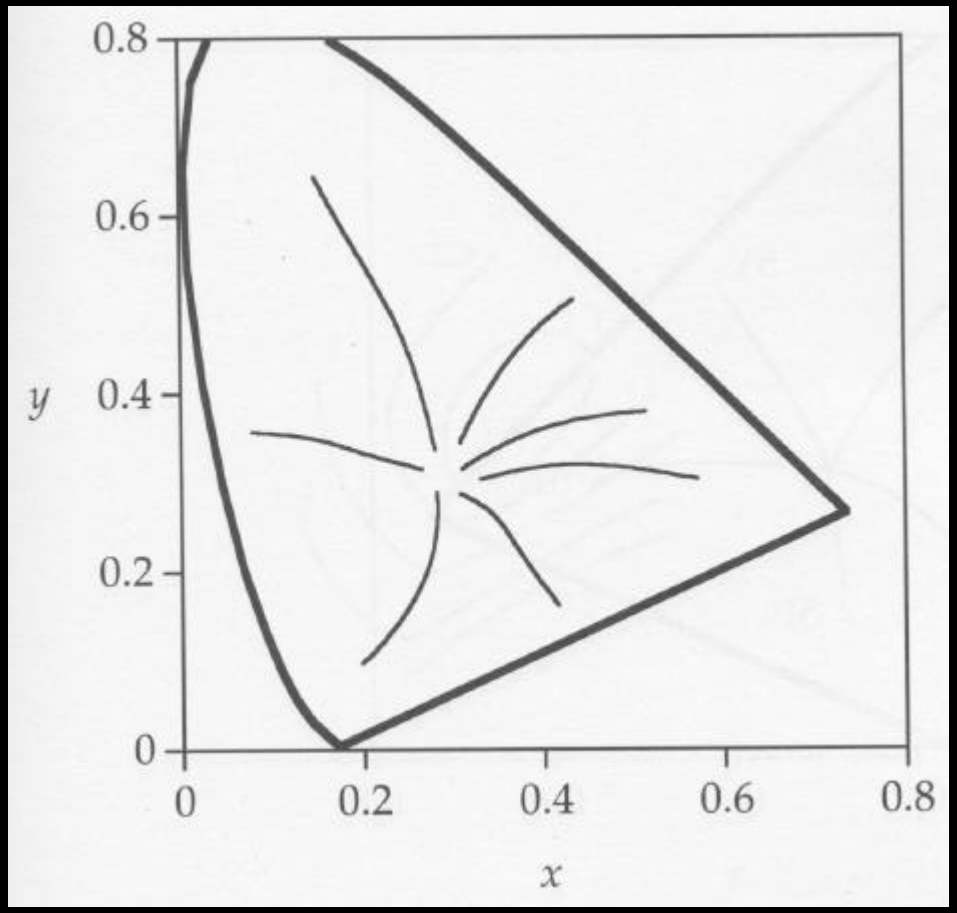
- Monochromatic stimulus
- Perceived hue changes when luminance varies



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

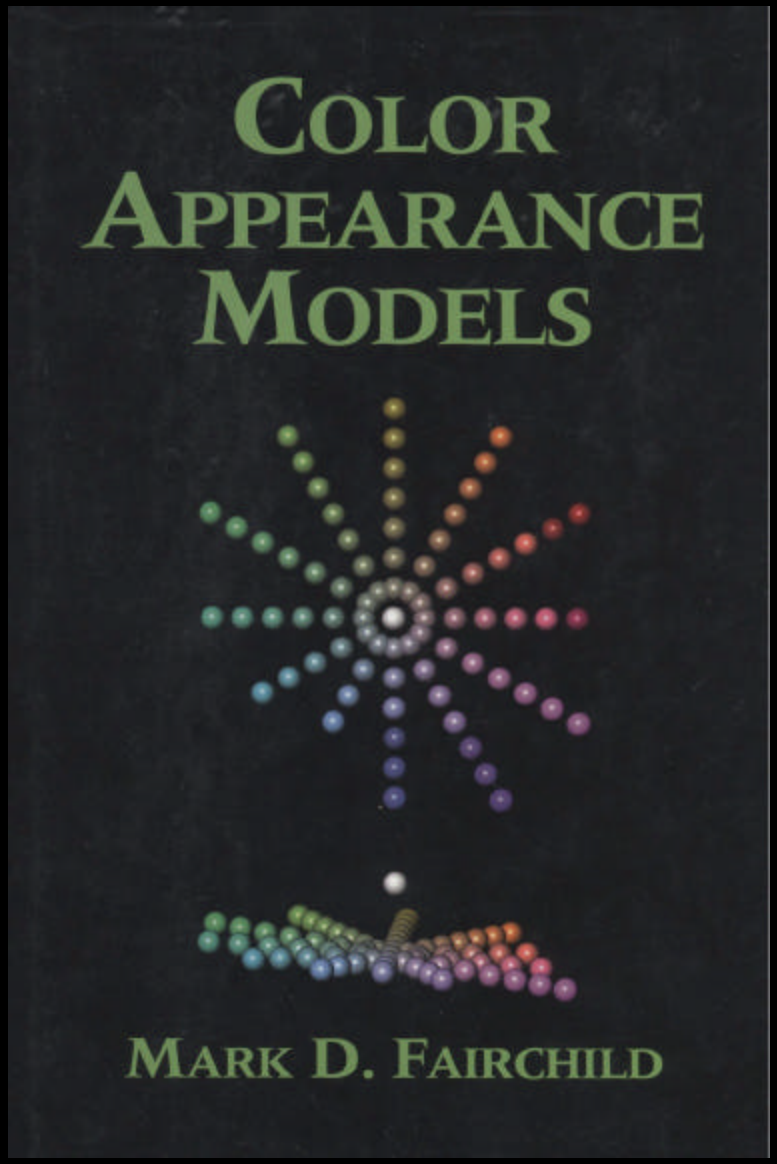
Abney Effect

- Hue changes with the addition of pure white



Color appearance models

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

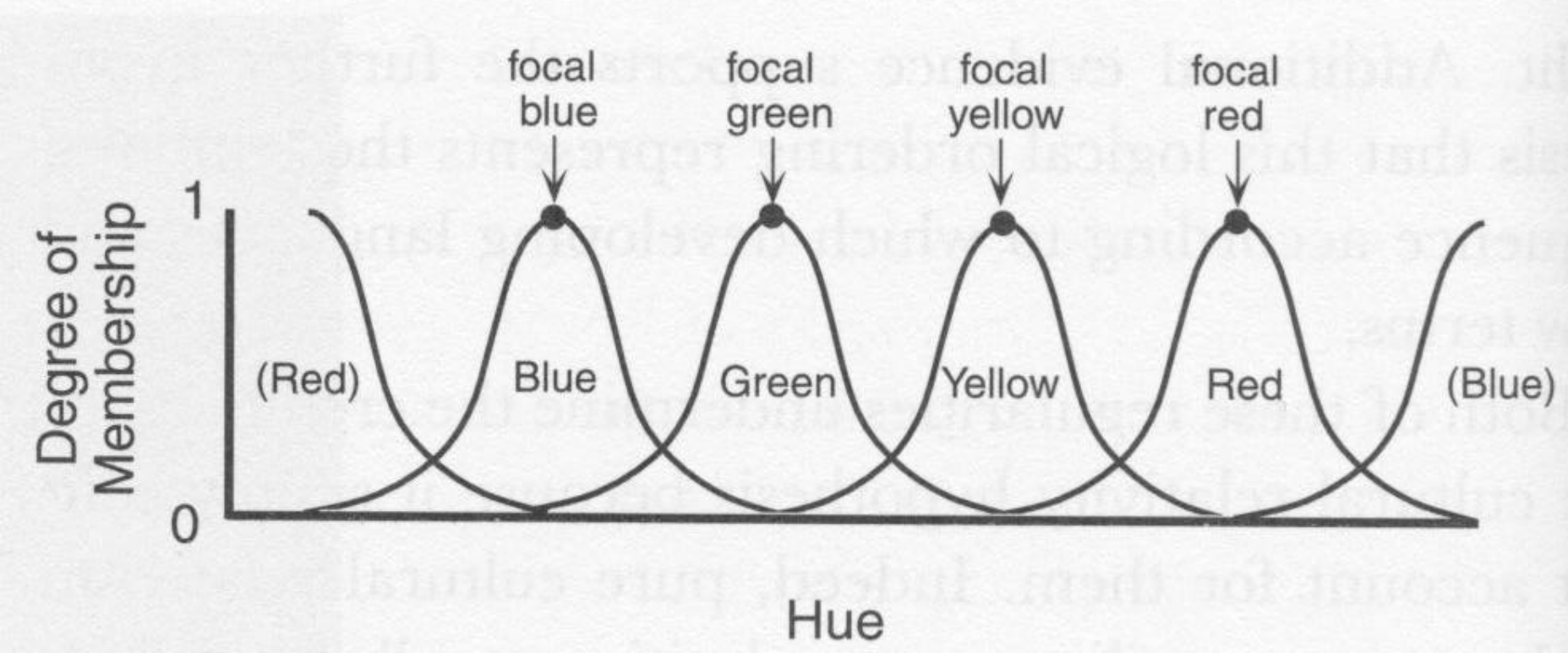


Plan

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

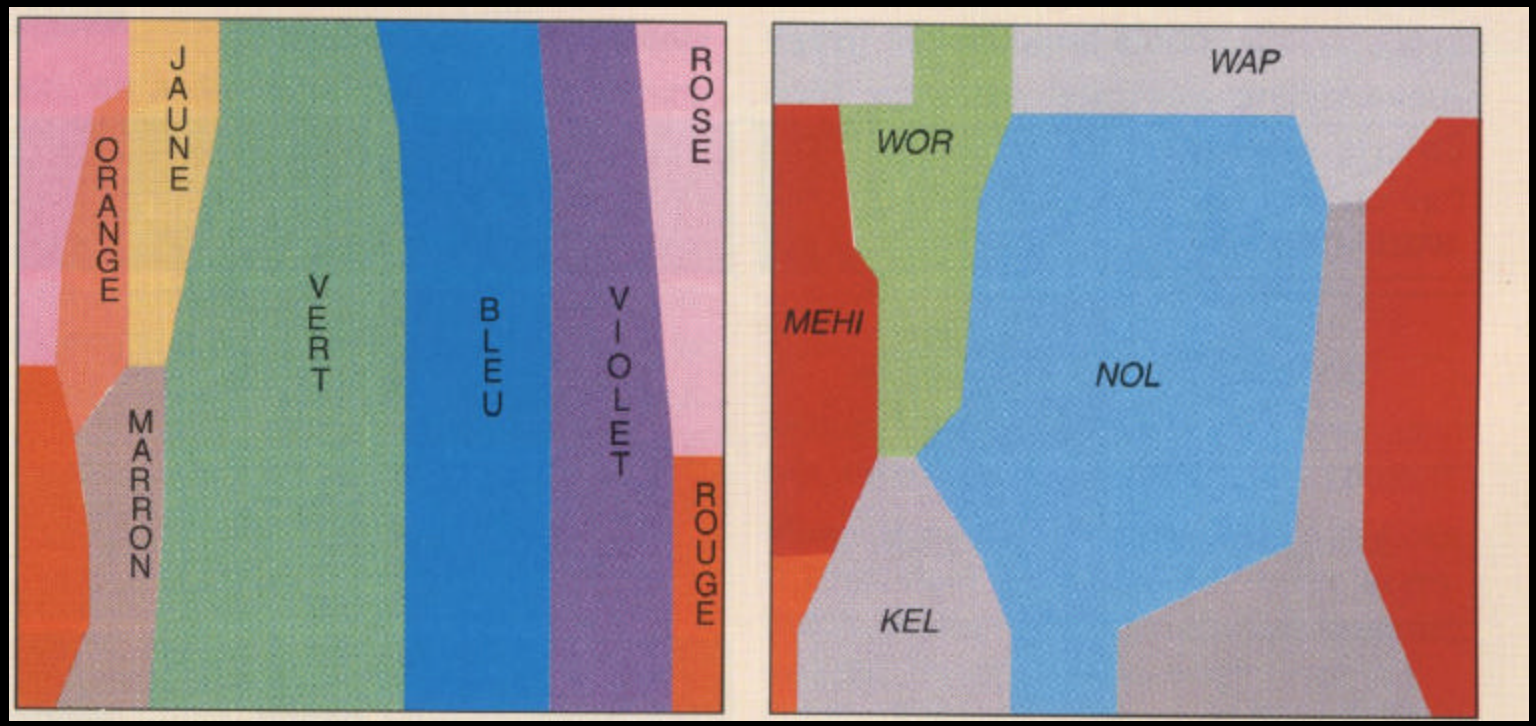
Color categories

- 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

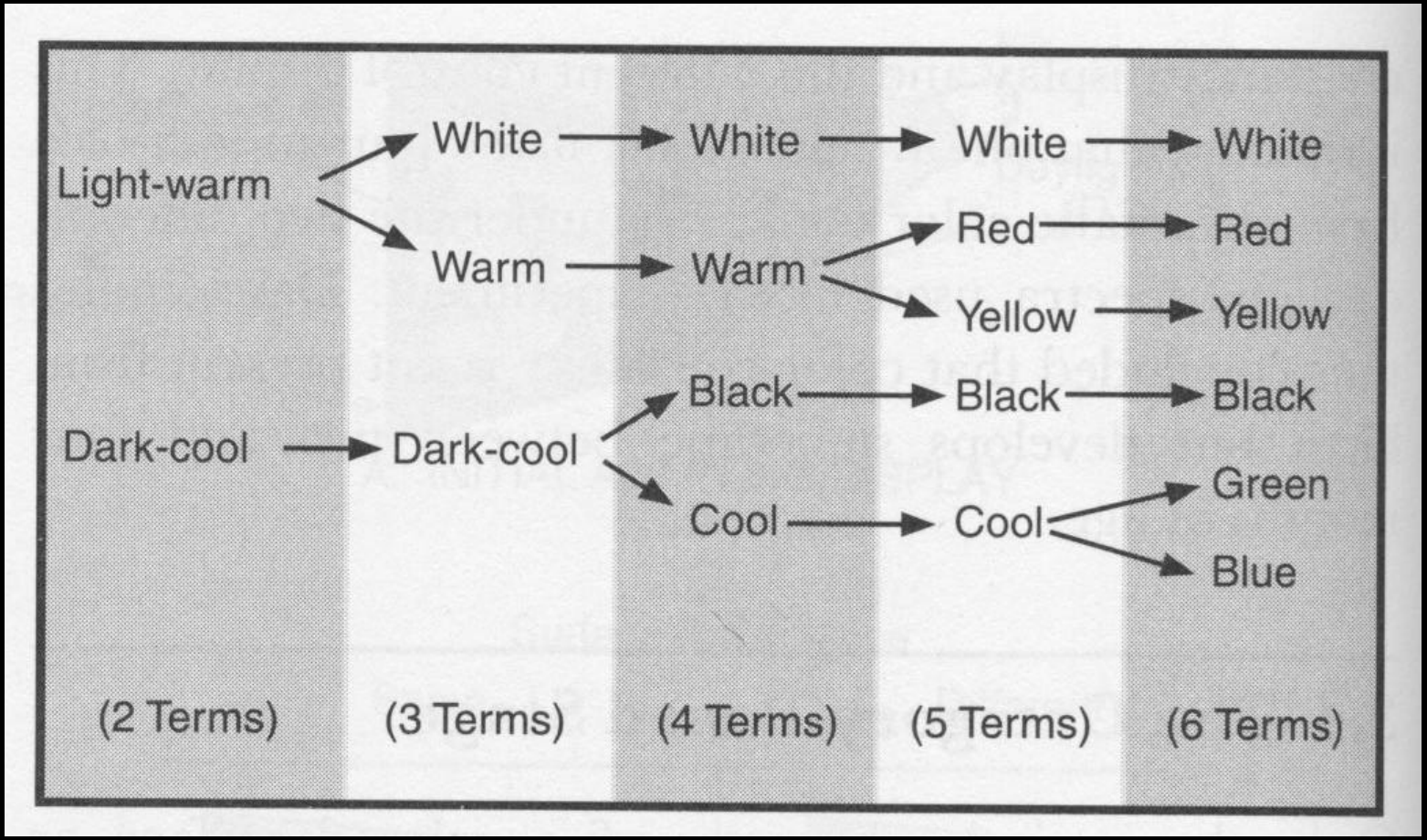
- Berlin and Kay 1969-78
- 20+78 languages
- Monolexemic
  - Not compound, e.g. not “blue-green”
- Primary chromatic reference
  - Not material, e.g. not “gold”
  - But allow “orange”
- General purpose
  - No specific field, e.g. not “blond”, “roan”
- High frequency
  - E.g. not “mauve”, “taupe”, “puce”

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.