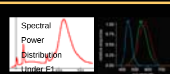
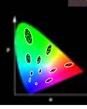
Color

Review of last week

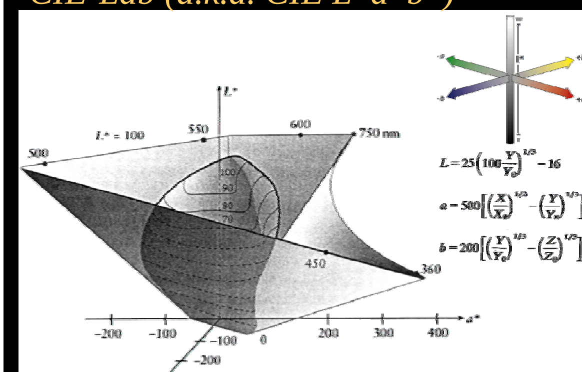
Review of color

- Spectrum
- Cone sensitivity function
- Metamers
  - same color, different spectrum
- Opponent
  - black-white, blue-yellow, red-green
- Color spaces
  - Linear algebra
  - Problem with negative values
  - Standard: CIE XYZ
- Perceptually uniform color space
  - CIE Lab (non-linear wrt XYZ)





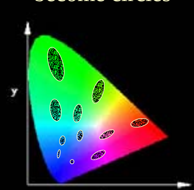
CIE-Lab (a.k.a. CIE L*a*b*)

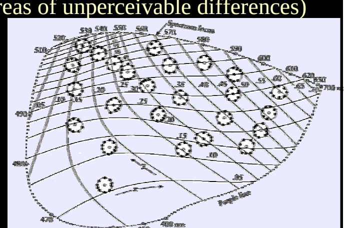


Source: [Wyszecki and Stiles '82]

Perceptually Uniform Space: MacAdam

- In color space CIE-XYZ, the perceived distance between colors is not equal everywhere
- In perceptually uniform color space, Euclidean distances reflect perceived differences between colors
- MacAdam ellipses (areas of unperceivable differences) become circles

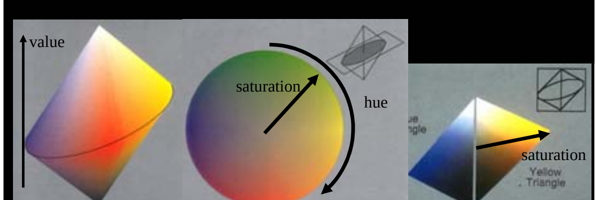




Source: [Wyszecki and Stiles '82]

Hue Saturation Value

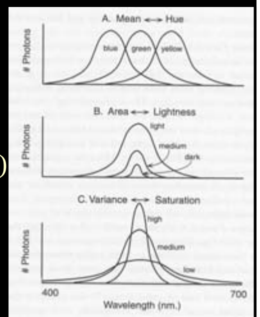
- Value: from black to white
- Hue: dominant color (red, orange, etc)
- Saturation: from gray to vivid color
- HSV double cone



Hue Saturation Value

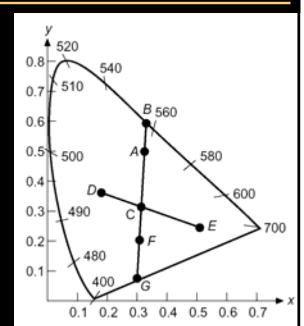
- One interpretation in spectrum space
- Not the only one because of metamerism

- Dominant wavelength (hue)
- Intensity
- Purity (saturation)



CIE color space

- Match color at some point A
- A is mix of white C, spectral B!
- What is dominant wavelength of A?
- What is excitation purity (%) of A?
  - Move along AC/BC



Plan

- Color Vision
- Color spaces
- Color effects
  - Definitions
  - Spatial sensitivity
  - Color illusion and color appearance
- Producing color

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.

Plan

- Color Vision
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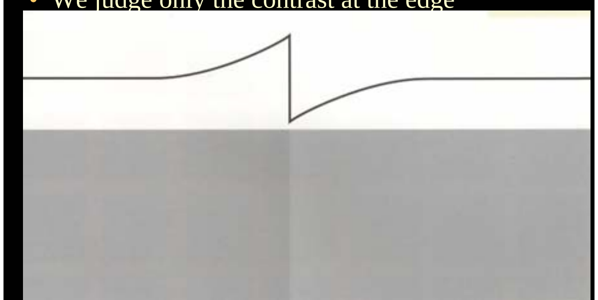
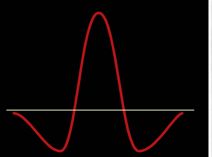
Cornsweet illusion

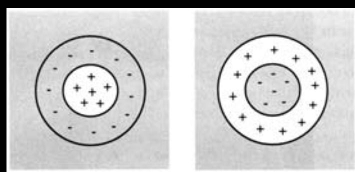
- Two opposite gradients
- We judge only the contrast at the edge



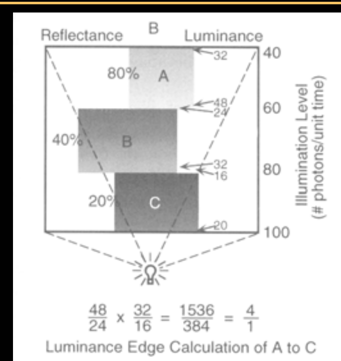
Contrast processing

- Receptors are wired to other neurons
- Center-surround organization
- Sensitive mostly to local contrast



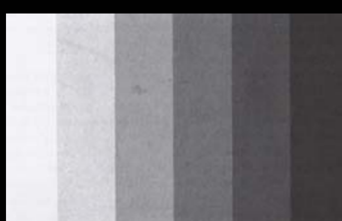


Land Retinex and local contrast



Mach Bands

- Contrast is enhanced at region boundaries



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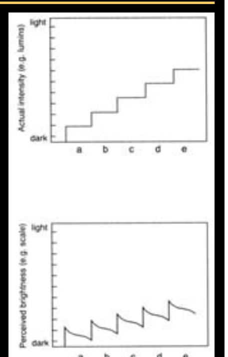
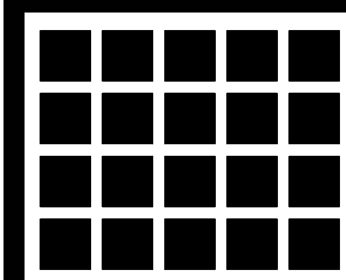
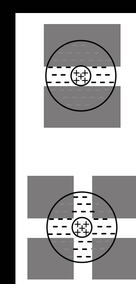
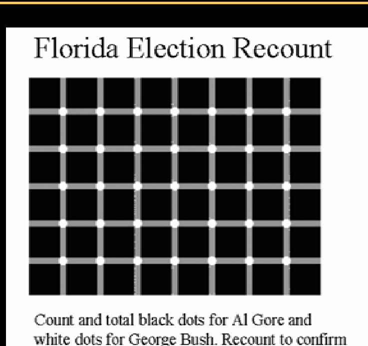


Hermann Grid



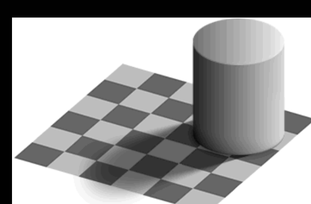


Hermann Grid



Brightness vs. lightness

- Brightness: subjective amount of light
- Lightness: how "white"



The white cells in shadow are as dark as the black illuminated cells

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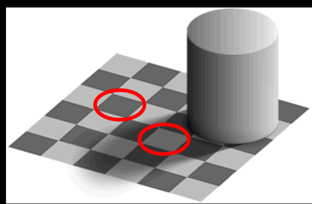

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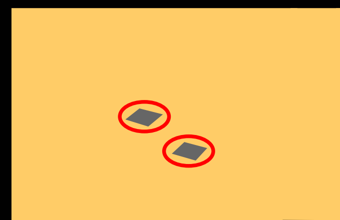
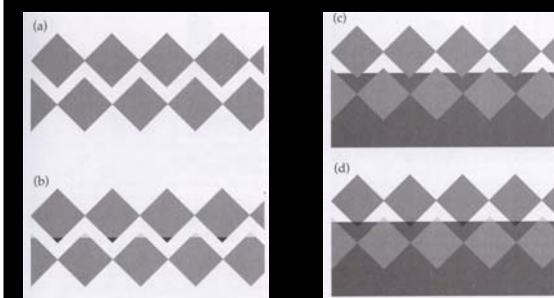


The white cells in shadow are as dark as the black illuminated cells

Lightness and transparency

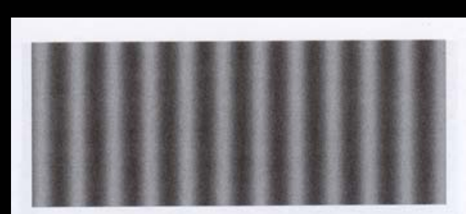


Opponents and image compression

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

Contrast Sensitivity

- Sine Wave grating
- What contrast is necessary to make the grating visible?



Contrast Sensitivity Function (CSF)

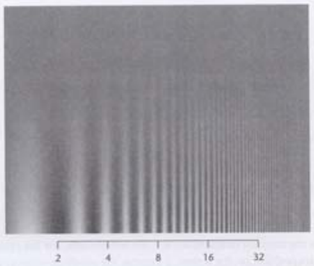


Figure 2.21 This grating pattern changes frequency exponentially from left to right and varies in contrast in a vertical direction. The highest frequency you can resolve depends on the distance from which you view the pattern. The scale gives the spatial frequency if it is viewed from 2.3 m.

Contrast Sensitivity Function (CSF)

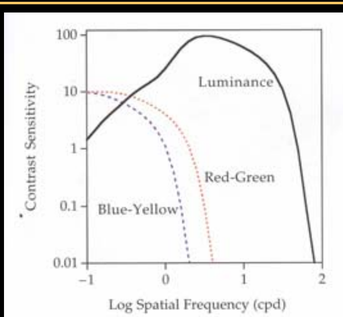


Figure 1-18. Spatial contrast sensitivity functions for luminance and chromatic contrast.

JPEG Compression

- Perform DCT to work in frequency space
  - Local DCT, 8x8 blocks
- Use CSF for quantization (more bits for sensitivity with more contrast)
- Other usual coding tricks

Question?

"Well, that's an interesting bit of trivia — I guess I *do* only dream in black and white."

Plan

- Color Vision
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  - Definitions
  - Spatial sensitivity
  - Color illusion and color appearance
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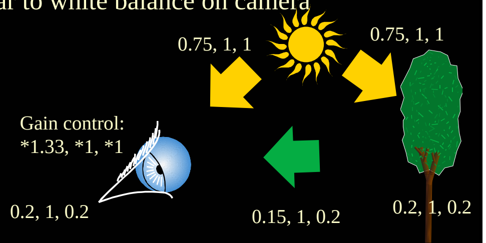
Color constancy

- Chromaticity of light sources vary
- Chromatic adaptation
  - Similar to white balance on camera
  - Different films, filters

Objective colors under neon lighting — With chromatic adaptation

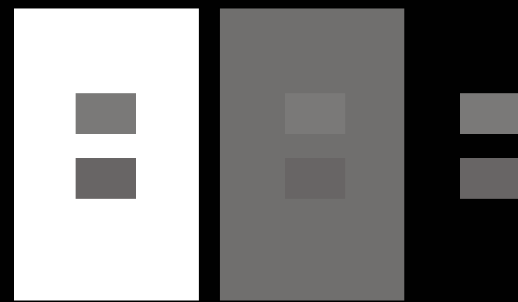
Chromatic adaptation

- Von Kries adaptation
- Different gain control on L, M, S
- Similar to white balance on camera



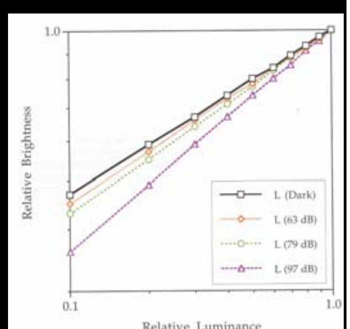
Crispening

- Increased sensitivity



Stevens effect

- Stevens effect
  - Perceived contrast increases with luminance

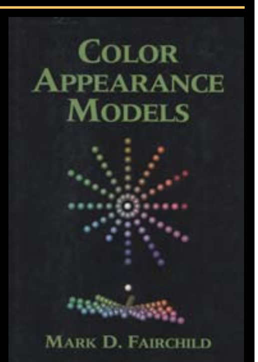


Hunt and Stevens effect

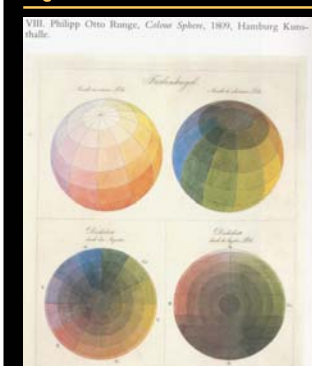
- Stevens effect
  - Perceived contrast increases with luminance
- Bartleson-Breneman effect
  - Image contrast changes with surround
  - A dark surround decreases contrast (make the black of the image look less deep)
  - Important for movies
- Hunt effect
  - Colorfulness increases with luminance
- Hence the need for gamma correction (see later)

Color appearance models

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



Questions?

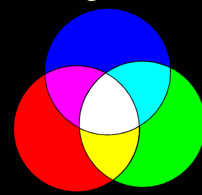


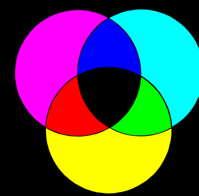
Plan

- Color Vision
- Color spaces
- Color effects
- Producing color

Color synthesis

Additive	Subtractive
red, green, blue	cyan, magenta, yellow





Add light
(CRT, video projector)

Remove light (e.g. filter)
printer, photos

Color synthesis: a ***wrong*** *example*

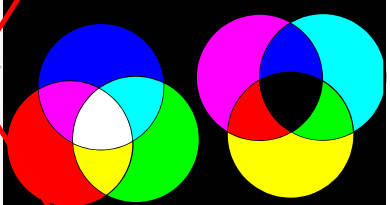
WRONG

Additive

red, green, blue

Subtractive

cyan, magenta, yellow



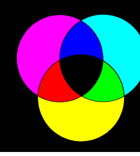
RIGHT

Device Color Models (Subtractive)

Start with white, remove energy (e.g., w/ ink, filters)

Example: CMY color printer

- Cyan ink absorbs red light
- Magenta ink absorbs green light
- Yellow ink absorbs blue light
- C+M+Y absorbs all light: Black!



RGB => CMY conversion

$$\begin{pmatrix} C \\ M \\ Y \end{pmatrix} = \begin{pmatrix} 1 \\ 1 \\ 1 \end{pmatrix} - \begin{pmatrix} R \\ G \\ B \end{pmatrix}$$

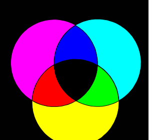
Some digital cameras use CMY

CMYK

CMY model plus black ink (K)

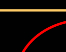
- Saves ink
- Higher-quality black
  - Increases gamut

Conversion not completely trivial



The infamous gamma curve

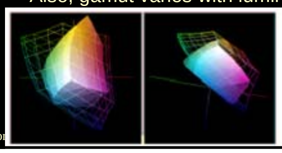
A gamma curve x->x^{γ} is used for many reasons:

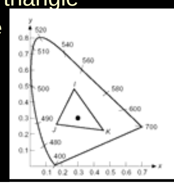


- CRT response
  - The relation between voltage and intensity is non-linear
- Color quantization
  - We do not want a linear color resolution
  - More resolution for darker tones
  - Because we are sensitive to intensity ratios
- Perceptual effect
  - We perceive colors in darker environment less vivid
  - Hunt and Stevens effect
- Contrast reduction
  - Keep some contrast in the highlights

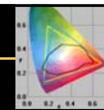
Gamut

- Every device with three primaries can produce only colors inside some (approx.) triangle
  - Convexity!
- This set is called a color gamut
  - (Why can't RGB can't give all visible colors?)
- Usually, nonlinearities warp the triangle
  - Also, gamut varies with luminance





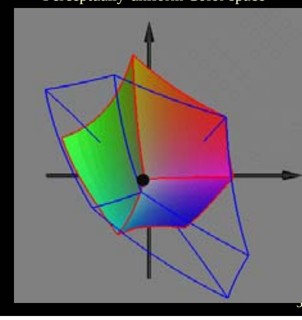
Gamut Mapping



- Color gamut of different processes may be different (e.g. CRT display and 4-color printing process)
- Need to map one 3D color space into another

CIE-Lab

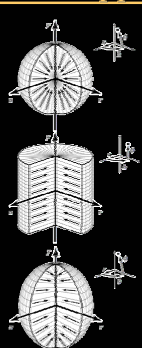
Perceptually-uniform Color space



Typical CRT gamut

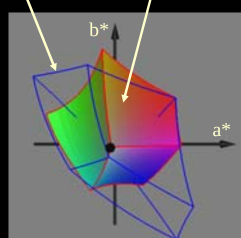
4-color printing gamut

Gamut Mapping



Typical CRT gamut

4-color CMYK printing gamut



Gamut mapping is a morphing of 3D color space according to adopted scheme

ICC standard

- Every device has a different color response (gamut, spectrum)
- Picture file should store this color profile
- ICC standard
- Unfortunately not spread enough

http://www.color.org/

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760 pages (May 7, 1999)

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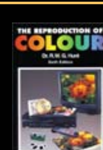

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Questions?
Van Gogh
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Color Vision
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