COLOR MANAGEMENT FOR DIGITAL PUBLISHING

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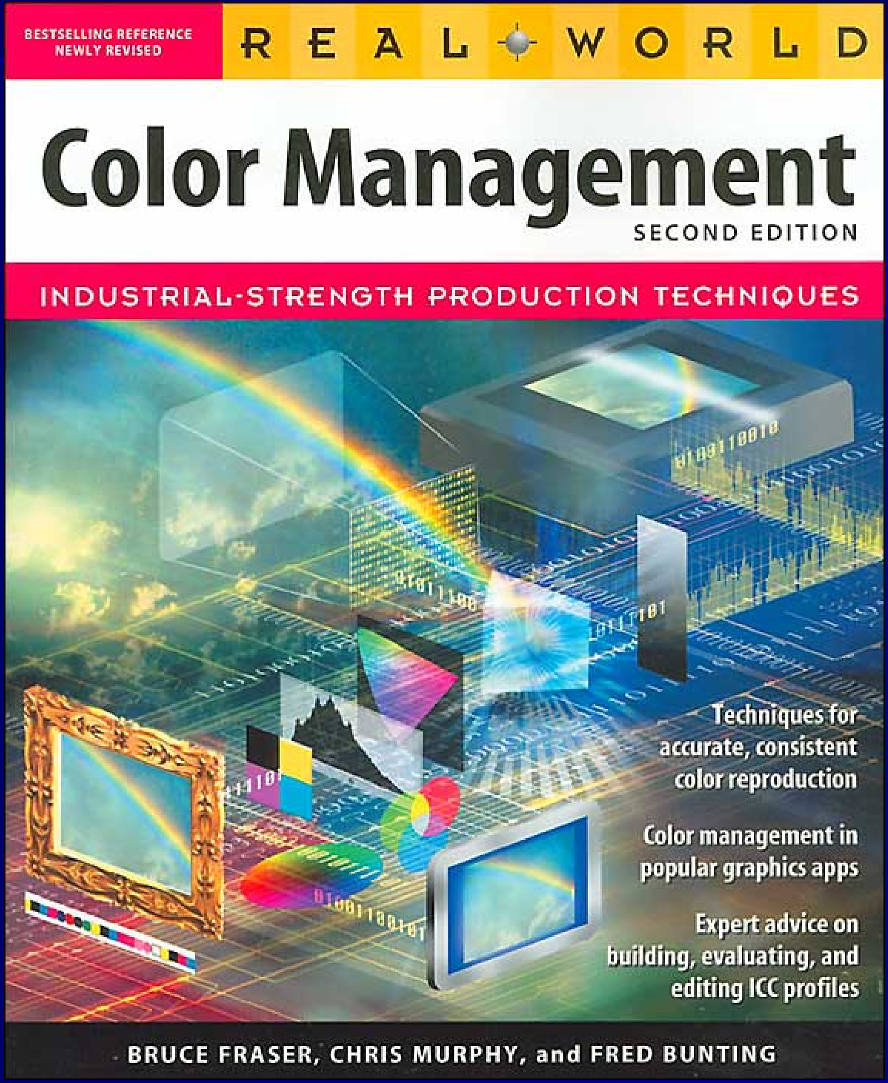
Or...

A million reasons why none of this may work!

You must read...



Color Management

- What is color?
- Color theory and models
- How devices interpret color
- Device and color space profiles
- Color management in software
- Profile and calibrate your monitor
- Calibrate your RGB proofer

Color Management

- Almost a contradiction in terms
- More an art than a science
- Cannot be absolutely controlled
- Can be improved; not perfected
- Technology is a confusing moving target

- Yes it can be improved!

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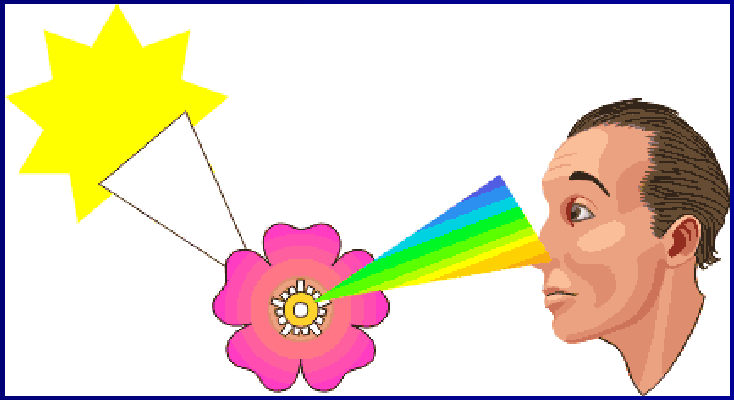
What is color?

- Color is a property of objects
- Color is a property of light
- Color happens in the observer
- Color always has 3 participants
  - Light source
  - Object
  - Observer



Light source can change

- Morning light, noon, evening light
- Inside lighting
- Fluorescent
- Incandescent
- Halogen incandescent
- Controlled lighting booth

Why you
can't
control color

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Object can change

- Different papers
- Different inks, dyes, toners
- Different printer devices
- Different temp/humidity
- Different finish coatings

Why you
can't
control color

Fluorescence issues

Why you can't control color

- Absorbing one wavelength and re-emitting another lower wavelength
- Scanners, cameras, film may be affected
- Lighting may have less UV than daylight
- Inks or toners or paper may have fluorescent properties that make it unpredictable depending on the light source used to view it

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User issues

Why you can't control color

- You can't understand the software
- You can't figure out the dialogs
- The software might not feel well today
- Your monitor is not calibrated
- Print RIPs are flawed

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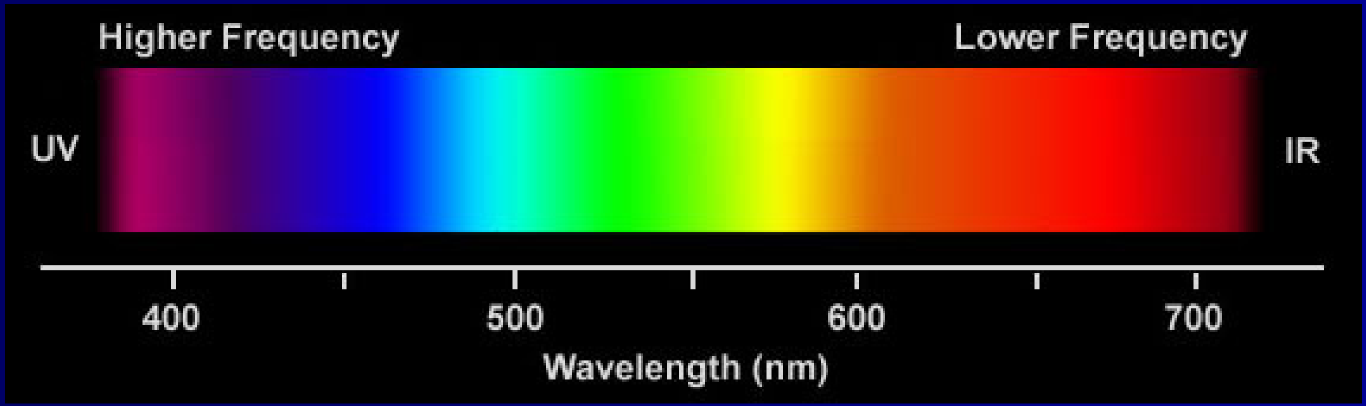
What is light?

- Acts like particles; acts like waves
- Called a photon—a pulsating packet of energy traveling thru space
- Energy levels equal wavelength
- We perceive wavelengths between 380 nm (violet) and 700 nm (red)
- The visible spectrum of wavelengths

What is light?

- You always see a blend of wavelengths
- The blend of waves is the spectral energy
- White light has equal amounts of all
- Laser light is monochromatic light



Light sources

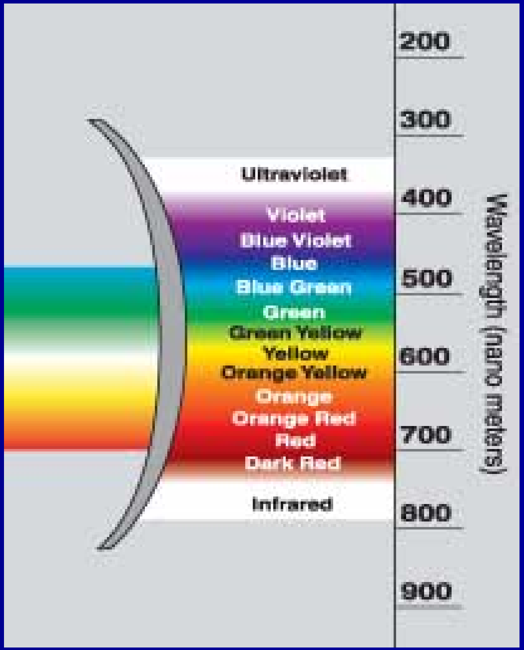
- Any emitter of visible spectrum photons
- Blackbody radiators such as stars and lightbulbs
- Electric discharge lamps (fluorescents)
- Computer monitors
- Daylight

Illuminants

- A light source that has been measured or specified formally in terms of spectral energy by the CIE (Commission Internationale de l'Eclairage or International Commission on Illumination)

The color of white

- We describe color of light by temperature
- Measured in Kelvins
- Long wavelength = low energy
- Low, infrared is heat
- Higher temperatures is light
- 2000K = red hot
- 3000-4000K = orange to yellow
- 5000-7000K = neutral white
- 9000K = blue



Objects and light

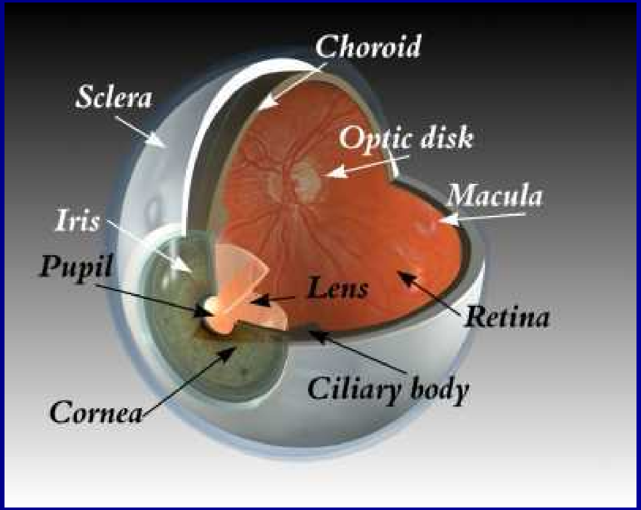
- Photons enter the surface of an object
- Some are absorbed
- Some wavelengths are re-emitted or reflected
- Objects have spectral reflectance
- Objects can be transmissive
- Objects can be fluorescent

Your amazing eye

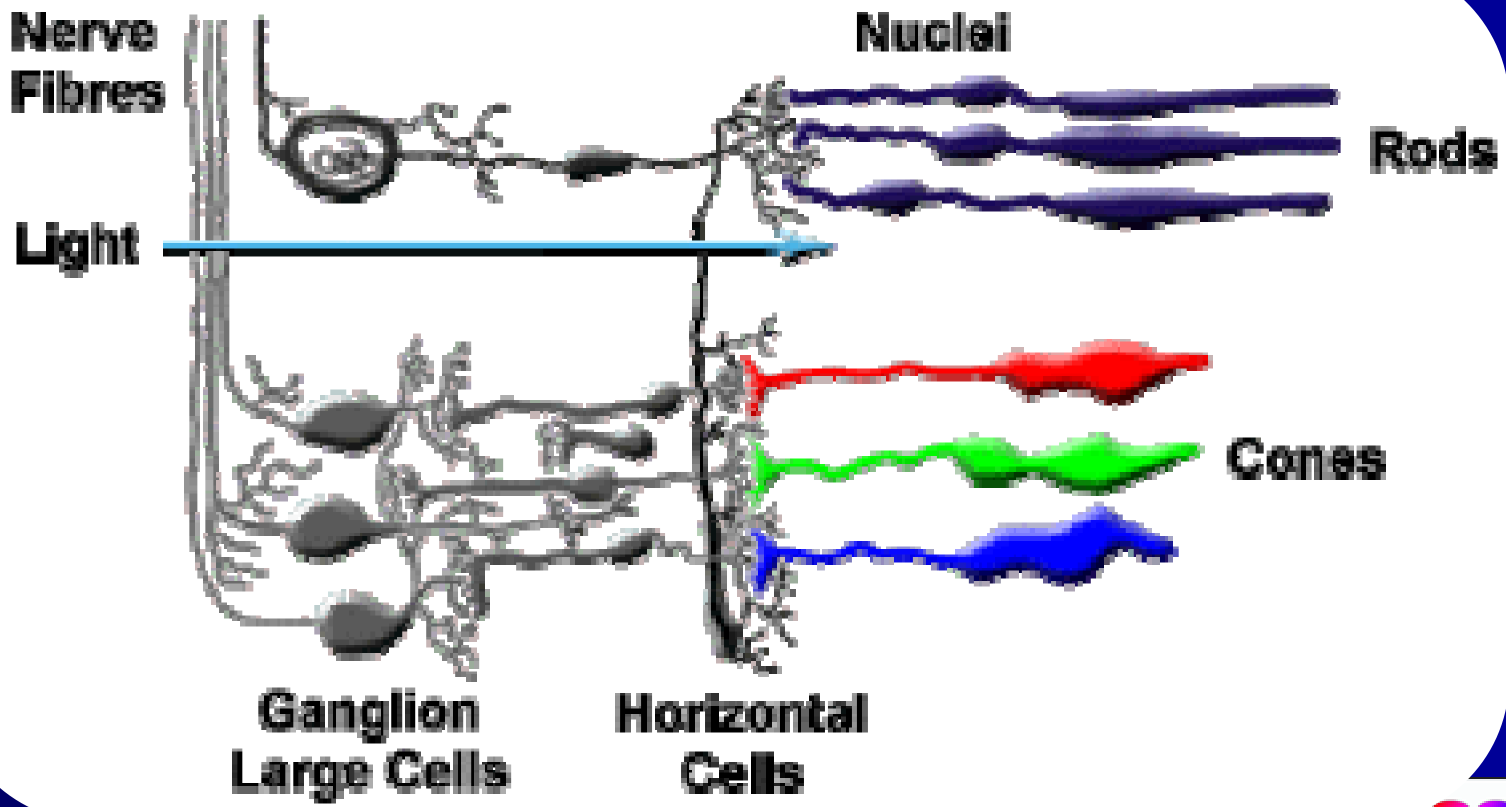
- Your eye and brain are a wonderful visual system
- The fundamental basis for all color reproduction is the 3-channel design of the human retina
- Color is perceived in the brain

Structure of the eye

- Light focuses thru the cornea onto the retina
- Retina contains two types of photoreceptor nerve cells that respond to light
- Rods for low light
- Cones for bright light

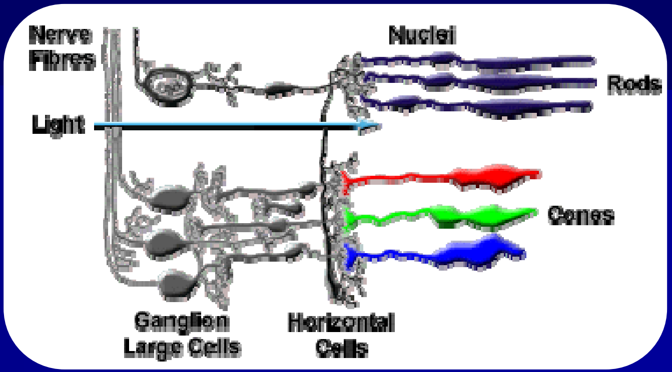


Cones and rods



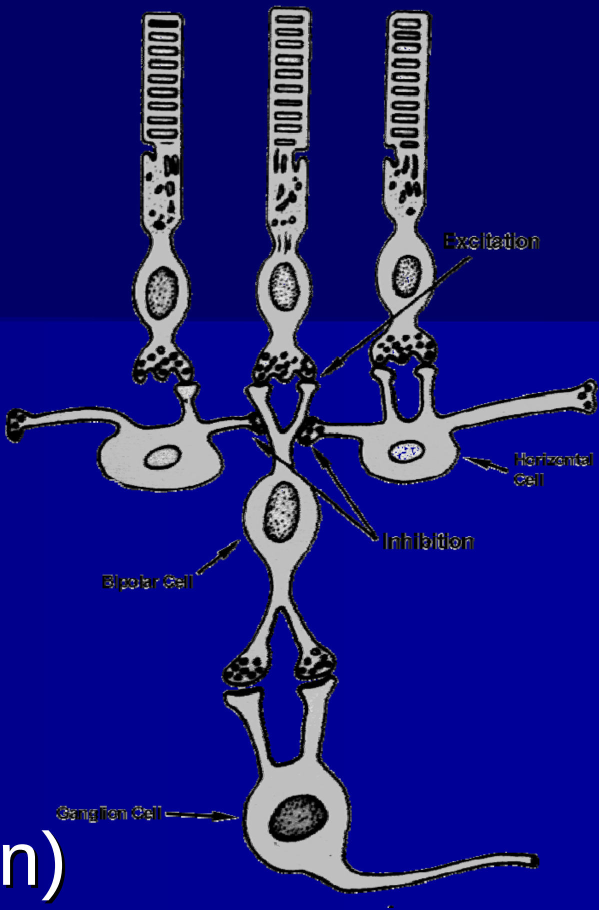
Structure of the eye

- Far more rods (low light) than cones (bright light)
- Except in center of retina, called fovea, where cones (bright light) outnumber rods
- Highest density also here in center fovea for acuity



Rods and cones

- Rods are for night vision
- Cones are for bright light
- 3 types of cones
  - Long wavelength (red)
  - Medium wavelength (green)
  - Short wavelength (blue)



How does sight work? (1)

- When light first strikes the retina, a photon interacts with a molecule called 11-cis-retinal, which rearranges within picoseconds to trans-retinal.
- The change in the shape of the retinal molecule forces a change in the shape of the protein, rhodopsin, to which the retinal is tightly bound. The protein's metamorphosis alters its behavior. Now called metarhodopsin II, the protein sticks to another protein, called transducin.
- Before bumping into metarhodopsin II, transducin had tightly bound a small molecule called GDP. But when transducin interacts with metarhodopsin II, the GDP falls off, and a molecule called GTP binds to transducin.
- GTP-transducin-metarhodopsin II now binds to a protein called phosphodiesterase, located in the inner membrane of the cell.

Vision is complex (2)

- When attached to metarhodopsin II and its entourage, the phosphodesterase acquires the chemical ability to cut a molecule called cGMP (a chemical relative of both GDP and GTP). Initially, there are a lot of cGMP molecules in the cell, but the phosphodiesterase lowers its concentration, just as a pulled plug lowers the water level in a bathtub.
- Another membrane protein that binds cGMP is called an ion channel. It acts as a gateway that regulates the number of sodium ions in the cell.
- Normally, the ion channel allows sodium ions to flow into the cell, while a separate protein actively pumps them out again. The dual action of the ion channel and pump keeps the level of sodium ions in the cell within a narrow range.
- When the amound of cGMP is reduced because of cleavage by the phosphodiesterase, the ion channel closes, causing the cellular concentration of positively charged sodium ions to be reduced.

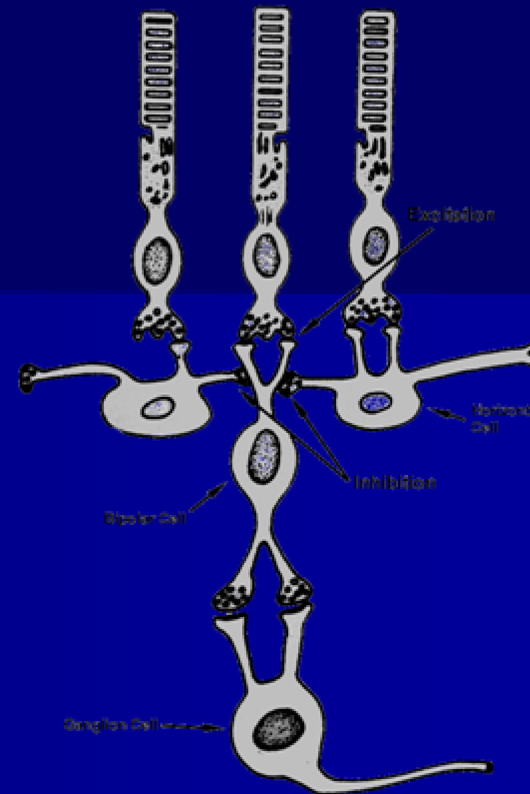
Vision is very complex (3)

- This causes an imbalance of charge across the cell membrane that, finally, causes a current to be transmitted down the optic nerve to the brain.
- The result, when interpreted by the brain, is vision.
- If the reactions mentioned above were the only ones that operated in the cell, the supply of 11-cis-retinal, cGMP, and sodium ions would quickly be depleted. Something has to turn off the proteins that were turned on and restore the cell to its original state. Several mechanisms do this:
- First, in the dark the ion channel (in addition to sodium ions) also lets calcium ions into the cell.
- The calcium is pumped back out by a different protein so that a constant calcium contration is maintained.
- When cGMP levels fall, shutting down the ion channel, caocium ion concentration decreases, too. The phosphodiesterase enzyme, which destroys cGMP, slows down at lower calcium concentration.

Vision is way complex (4)

- Second, a protein called guanylate cyclase begins to resynthesize cGMP when calcium levels start to fall.
- Third, while all of this is going on, metarhodopsin II is chemically modified by an enzyme called rhodopsin kinase. The modified rhodopsin then binds to a protein known as arrestin, which prevents the rhodopsin from activating more transducin. So the cell contains mechanisms to limit the amplified signal started by a single photon.
- Trans-retinal eventually falls off rhodopsin and must be reconverted to 11-cis-retinal and again bound by rhodopsin to get back to the starting point for another visual cycle.
- To accomplish this, trans-retinal is first chemically modified by an enzyme to trans-retinol—a form containing tow more hydrogen atoms.
- A second enzyme then converts the molecule to 11-cis-retinol. Finally, a third enzyme removes the previously added hydrogen atoms to form 11-cis-retinal, a cycle is complete.

Glad you asked!

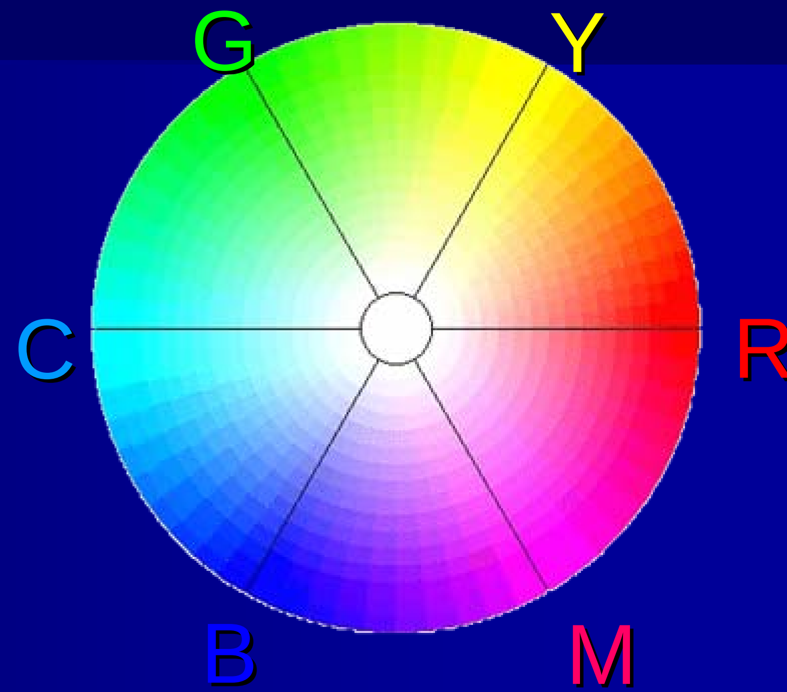


Trichromacy

- The three component theory says we have three receptors for color
- Tristimulus refers to experiments and measurements involving human vision
- We can simulate almost any color by using just three primary colors of light
- Additive primary colors: RGB
- Subtractive primaries: CMY

Color spectrum

- Listed in increasing wavelength: ROYGBIV
- Divided roughly in thirds: RGB
- Subtractives written as opposite counterparts to the additives: CMY
- Color space is 3D



Other trichromats

- Your eye, of course, and ...
- Scanners
- Film cameras
- Digital cameras
- Colorimeters

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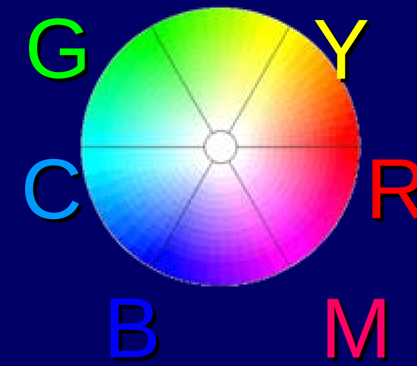
Opponency theory



- Much about why color vision happens is completely unknown and mysterious
- Receptors seem to work in opponent pairs
  - Red and green make yellow color
  - Blue and yellow make green color
  - Black and white are opponent pairs

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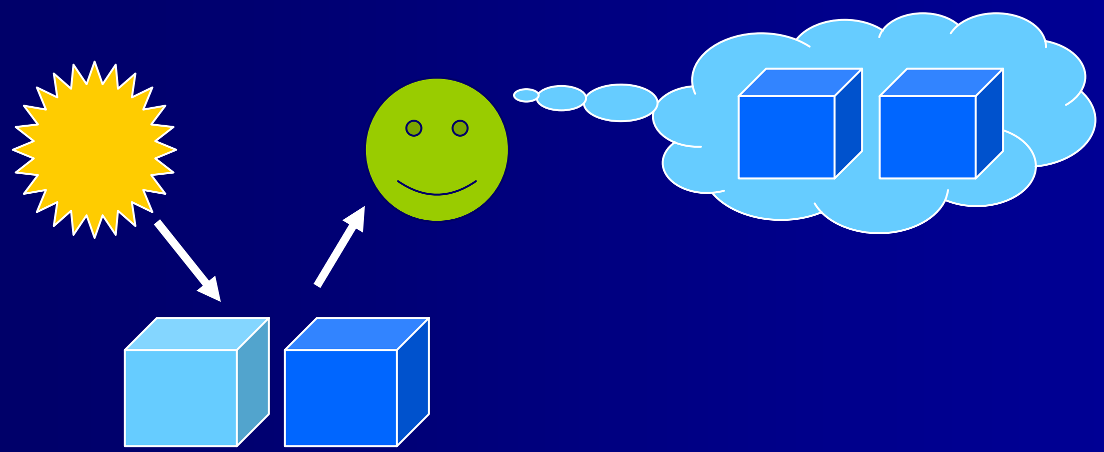
Metamerism

- The phenomenon where two different color samples produce the same sensation of color
- But with different lighting, or different observers, the two may not match



Metamers

- Two spectrally different color samples that produce the same color sensation
- Usually it is the lighting
- Occurs because the eye divides all incoming spectra into the three cone responses to decipher wavelength in the mind

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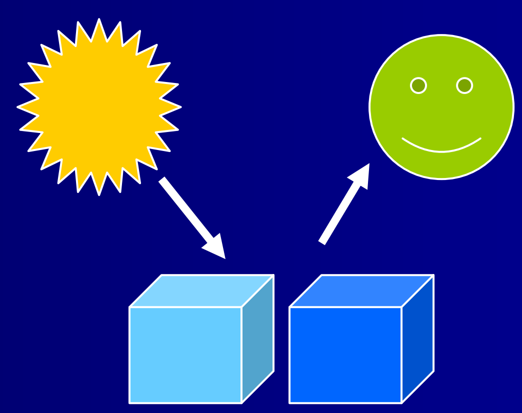
Metamerism

- The basis for all color reproduction; i.e., allowing you to reproduce green without green ink
- Camera and scanner metamerism can pose problems



Describing color

- Hue
- Saturation
- Brightness

Hue, Sat. & Brightness

- An achromatic component of color
- Brightness is the quantity of light from dim to bright with no limits;
  ...a subjective sensation
- Hue and saturation are quality of light
- Lightness is relative brightness and is measurable from dark to light

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Hue and Saturation

- Attribute of color that gives its name
- Attribute of color that is its dominant wavelength
- The wavelength that "appears" most prevalent in a color sample is its hue
- IOW, the same cone response, or a metameric match

Hue and Saturation

- Saturation is the purity of color; how far away from neutral gray
- The extent to which that dominant wavelength seems contaminated by other wavelengths
- More monochromatic equals more saturated

Non-linearity of color

- Intensity of light is non-linear response
- To perceive something about twice as bright, we multiply the intensity about nine times
- Our senses have a non-linear response
- Our senses can operate over a wide range without quickly overloading

Measuring color

- We can't measure color; only light
- Gadgets we use:
  - Densitometers measure density; the degree to which light is absorbed; the ratio between reflectance and transmittance
  - Colorimeters measure numbers that model our visual response
  - Spectrophotometers measure spectral properties; how much light is reflected or transmitted

Colorimetry

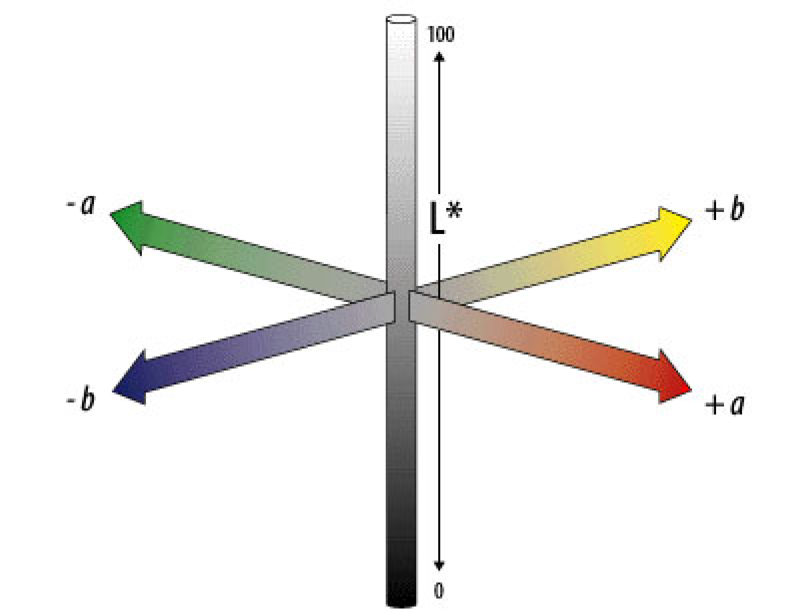
- The science of predicting color matches as human vision would see them
- A numeric model that can predict when metamerism does or doesn't occur
- CIELab numbers represent colors
- Color difference is predictable by number difference

CIE colorimetric system

- Standard illuminants
- Standard observer
- CIE XYZ primary system
- CIE xyY
- Uniform color spaces (Lab, Luv)
- Color difference calculations (delta E)
  - (p. 41-42)

CIE Lab

- As close to a perfectly unambiguous color model that has been developed yet



Spectrophotometry

- The science of measuring spectral reflectance
- Ratio between the intensity of each wavelength of light shown versus reflected back to the detector
- Spectrophotometers can also be used as a densitometer and a colorimeter

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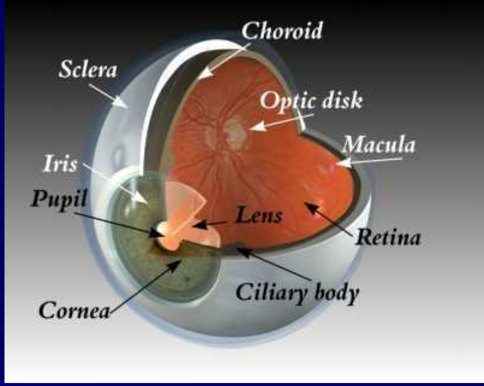
Color constancy



- The tendency to perceive objects as having a constant color, even if the lighting conditions change
- A complex capacity of the brain causing the eye to discount the illuminant
- This is both good and bad for CM
- Scanners and cameras don’t have color constancy

Color constancy

Color constancy

- Devices don't know color constancy, but the important thing is to preserve color relationships
  - Perceptual preserves color relationships
  - Colorimetric preserves white point first, then more of the original colors
- It takes practice to ignore the eye's color constancy and see the cast
- D50 ? D65 is preferred

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Psychological factors

- If the color is off enough to trigger the use of a different color name, people notice the shift more readily
- Colors we are familiar with by memory, familiarity, or cultural expectation are more important to get right
- Emotion influences visual perception

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Lessons for color mgt

- Lighting is important, yet the eye adjusts
- Metamerism is the basis of color mgt
- Look out for fluorescent papers or inks
- Train yourself to see your RGB response
- Train yourself to think opponencies
- Colors have psychological factors
- Colorimetry isn't perception

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Computers and Color

Color expressed indirectly
by numbers

Encoding colors

- Colors are comprised of channels
  - RGB equals 3 channels
- Channels are subdivided into tone levels
  - 2^8 power = 256 tone levels
- The eye needs about 200 to perceive smooth continuous tone, so 256 is plenty
- Computer storage is organized in 8-bits or 256—a perfect coincidence

RGB and CMYK models

- Analog in origin; ambiguous; representing amounts of colorants
- File contains, not color, but a recipe for color that each device interprets
- Not designed as an accurate math description of color
- They are control signals sent to devices
- Device dependent; bad for CM

A major thought:

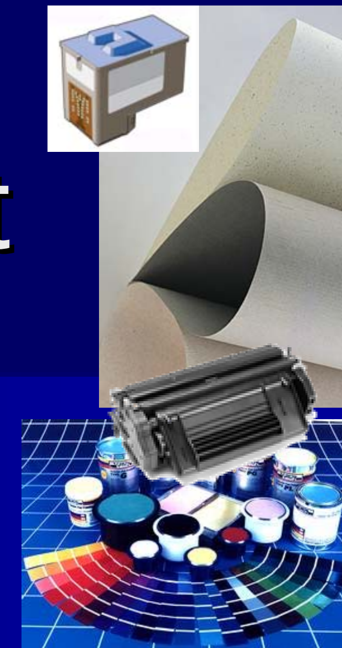
- Colorants are not color!
- Graphic artists are manipulating colorants; not color

Why are they ambiguous?

- Variations in colorants (primaries)
- Variations in white and black point
- Variations in tone reproduction characteristics
- Variations in paper
- Variations in environment like temp, light, humidity

Why you
can't
control color

Colorants are all different



- Process inks, toners, dyes
  - Influenced by paper substrates
- Phosphor pixels on monitor
- Camera and scanner CCD filters
- Colorants define the possible gamut or range of reproducible colors

Why you **can't** control color

White and black point

- The color of white is the most important factor because the eye adjusts to it
  - Called white point adaptation, an instant and involuntary task performed by the eye
- The density of black
- Represent the extremes of gamut
- These two make the dynamic range
- Greater range means more detail
- Large part of color management

Device dependent problems

- Different colors on different devices
- Need to change the numbers to devices
- Need to take out the ambiguity
- Need a numerical model that is based on human perception; not on device colorants, such as CIELAB

Why you
can't
control color

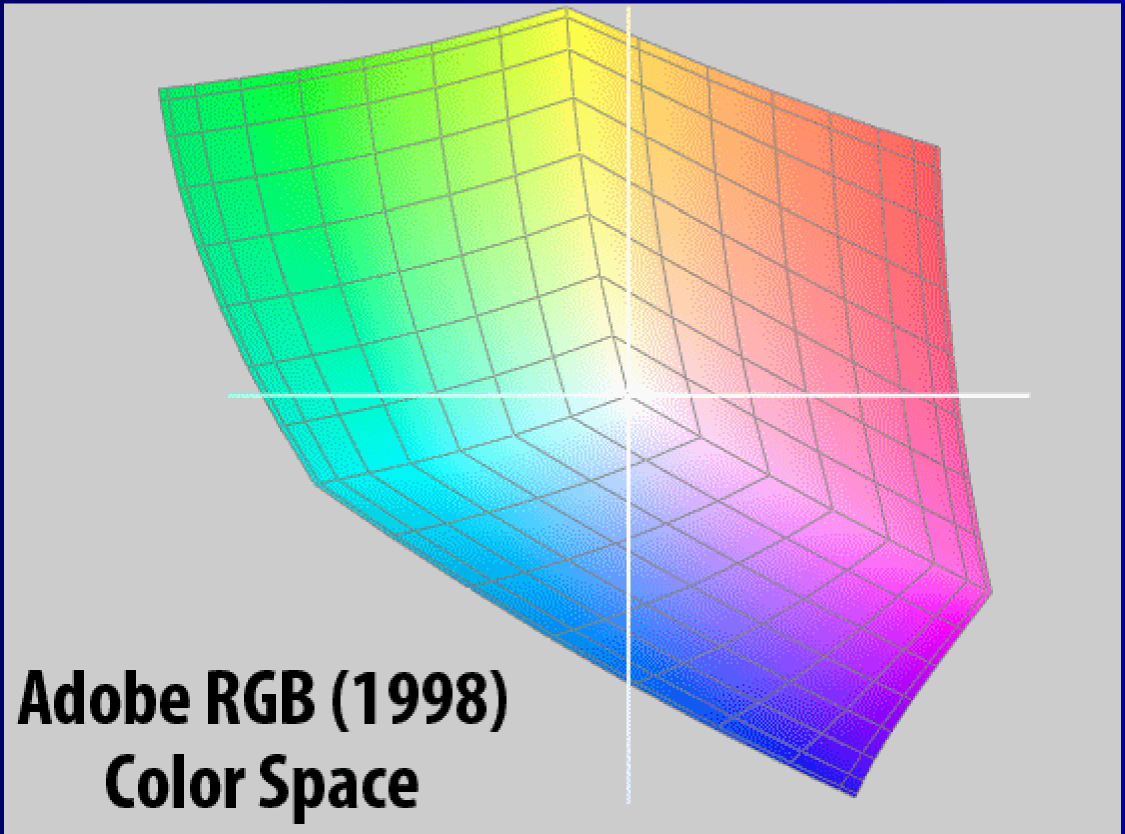
CIEXYZ and CIELAB

- Device independent color model that mimics human visual perception
- RGB only tells how much colorant to use
- CIE models the specific color we see
- LAB is perceptually based
- We need to use both in color mgt to express unambiguously the meaning of colors we want

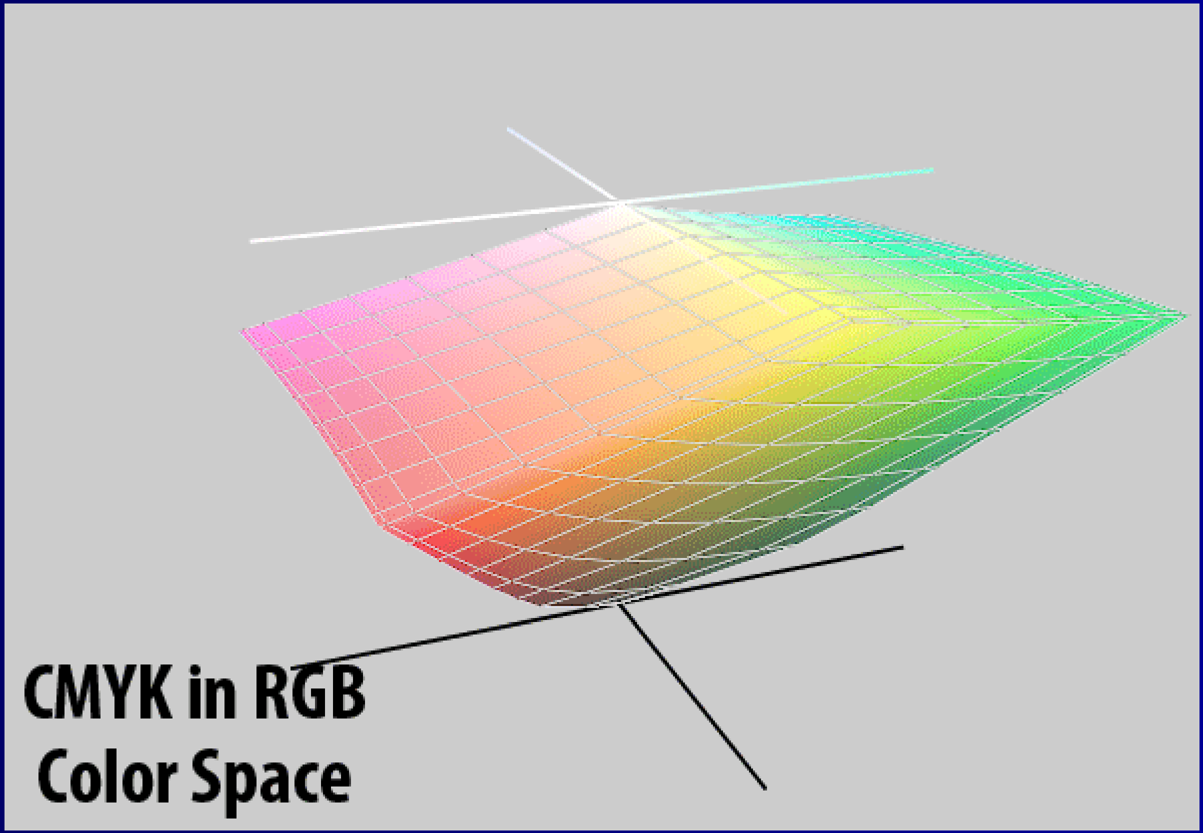
Dynamic range and space

- The range of brightness differences a device can reproduce
- Input devices usually have wider dynamic range than output devices
- Input devices frequently see beyond our vision into infrared and ultraviolet
- Gamut represents the limit edges
- Space represents the 3D volume

Colorspace is 3D



RGB and CMYK



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Color Management Systems

Color management module

- Figure out what colors our RGB and CMYK numbers represent
- Must keep those colors consistent from device to device
- They attach color meaning to numbers
- They change the numbers for different devices to make the same color

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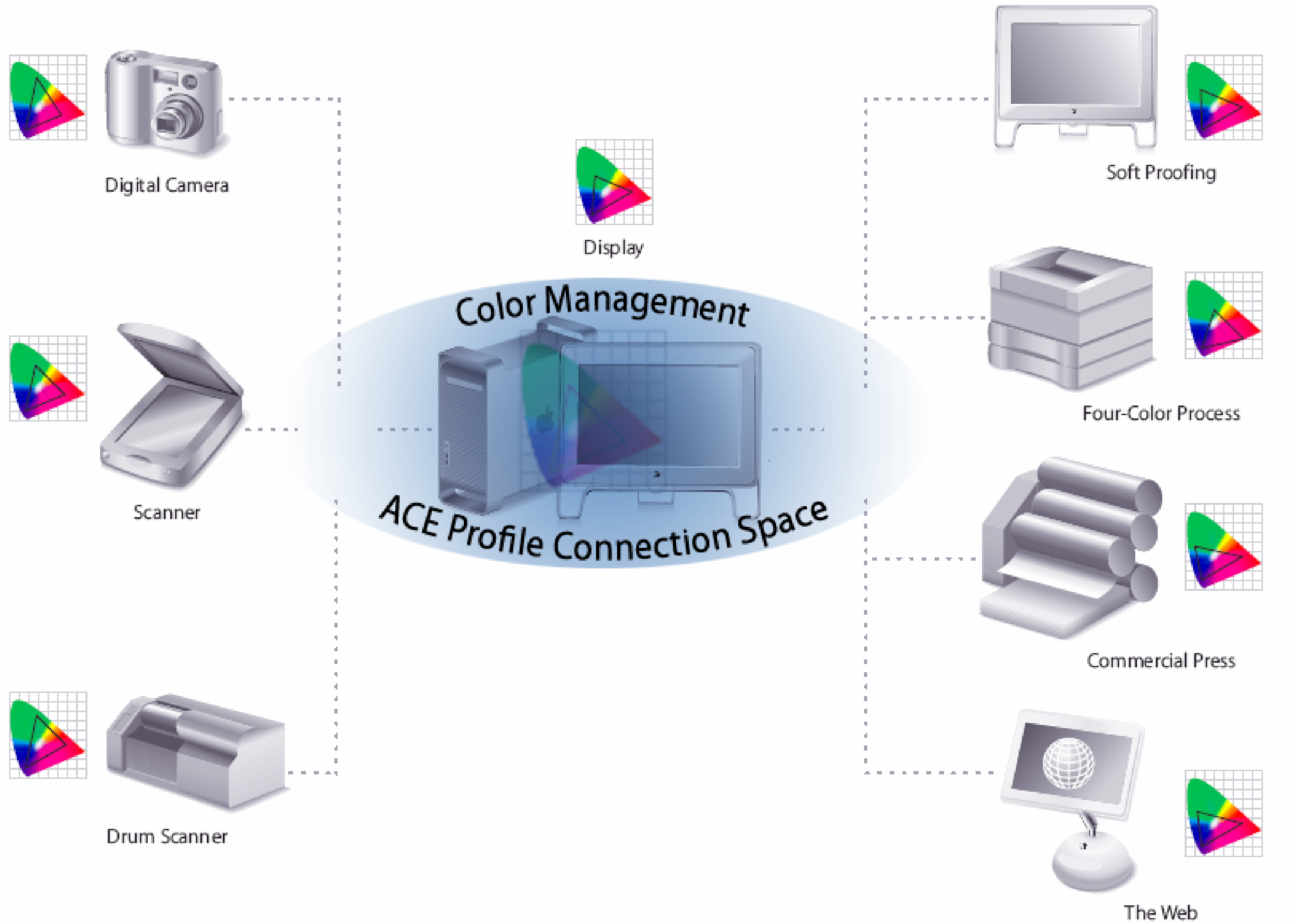
4 Components of CM

- PCS is like a hub of an airline
- Profiles connect device with the PCS, usually CIELAB or CIEXYZ
- CMM engine is the software doing the translating
- Rendering intents are four ways of dealing with out-of-gamut colors

Profiles give color meaning

- A computer monitor
- A digital scanner
- A digital camera
- A desktop printer/proofer
- A printing press
- Abstract color space (Adobe RGB 1998)
- Are lookup tables translating the device numbers to perceptual colors

Profiles translate to profiles



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Converting profiles

- Requires four ingredients:
  - The CMM to translate using
    - The source profile
    - The destination profile
    - A rendering intent

Rendering intents

- 4 ways to handle out-of-gamut colors:
  - Perceptual preserves overall color appearance
  - Saturation tries to produce vivid colors
  - Relative colorimetric adapts white point
  - Absolute colorimetric doesn't map source white to destination white

    (p. 89)

Profiles' purpose

- Source profiles tell the CMS where the color came from; input device space
- Destination profiles tell the CMS where the color is going to; output device space

Converting profiles

- Doesn’t change the color appearance; but is intended to keep the appearance the same
- Actually changes the RGB or CMYK numbers to hold onto the appearance

Embedding profiles

- Lets you transfer documents between apps or computer systems without losing the color meaning of the number values
- Assigning and embedding a profile in a document doesn't change the numbers: the CMS changes the numbers to translate the color the same

CMMs

- ACE (Adobe Color Engine)
  - PS, AI, INDD, PDF
- ColorSync on Mac OS X
- ICM on Microsoft Windows
- Heidelberg
- Other manufacturers

Color-managed Apps

- Does color manage:
  - Photoshop
  - Illustrator
  - InDesign
  - Acrobat
- Doesn't fully color manage:
  - QuarkXPress
  - PageMaker
  - Freehand
  - CorelDraw

Color Management summary

- An assigned or embedded profile describes the actual colors represented by RGB or CMYK numbers
- A conversion from one profile to another keeps those actual colors consistent by changing the numbers that get sent to the output

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All About Profiles

Describing Devices

Classes of profiles

- Input profiles (1-way)
  - Scanners and digital cameras
- Display profiles (2-way)
  - Monitors and LCD displays
- Output profiles (2-way)
  - Printers and presses

Profiles defined

- Tagging means associating a source profile with an image file
- Assigning means tagging a document
- Embedding means saving a document with the source profile included
- Assuming means how an application behaves toward an untagged file

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Controlling the Process

Measurement, calibration, testing

Control all the variables

- Software settings
- Paper, inks, toners, dyes, waxes
- Hardware settings like the monitor
- Account for variability in your various devices, starting with the monitor
- You are working on shifting sand!

Maybe
it will work

Process control

- The art and science of tracking and compensating for variability
- Calibration is the act of changing a device’s behavior
- Profiling or characterization is the process of recording a device’s behavior into a profile

Maybe
it will work

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Display profiling

- You are adjusting these:
  - Luminance of monitor white
  - Color temperature of monitor white
  - Tone response curve gamma value
  - Luminance of monitor black

Calibrate monitor monthly

- Warm up for 1 hour
- Settled on resolution and refresh rate
- Clean the screen—no solvents! No paper!
- Set contrast, brightness, color temp
- Run the device software
- Save and apply the new profile
- Useful life 3 years?

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Before calibration

- Analog controls for white luminance at around 85-95 cd/m^2; or
  24 and 28 foot lamberts
- Analog brightness control sets black level
- Color temperature set to 6500 K or the next preset higher, like 7500 K

Calibrate your monitor

- Calibrate to a white point of 6500 K
  - Close to daylight color
  - Not too yellow like 5000 K
  - Anyway, the eye sees color relationships within the image or page
- Choose a gamma of 2.2
  - Smoother gradients; less banding than 1.8
  - Mac gamma 1.8 was for matching the dot-gain curve of the old LaserWriter

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Where is the display profile?

- Mac OS X: /Library/ColorSync/Profiles/Displays
- Win XP, 2K, ME: WinNT/System/Spool/Drivers/Color

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Where is the Adobe Color Settings File?

- Mac
  - Library/Application Support/Adobe/Color/Settings/Recommended
- Win XP
  - Documents and Settings/User/Application Data/Adobe/Color/Settings
  - Program Files/Common Files/Adobe/Color/Settings

Where is the printer profile?

- Mac OS X:
  /Library/ColorSync/Profiles/
- Mac OS 9:
  System Folder:ColorSync Profiles
- Win XP:
  \Windows\system32\spool\drivers\color
- Win 2K:
  \WinNT\system32\spool\drivers\color

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2 printer technologies

- Inkjets are piezo-electric devices
  - Less variable in nature
  - They hold calibration well
  - Usually slower devices
- Lasers are electrophotostatic devices
  - Far more variable in nature
  - They don’t hold calibration well
  - Usually faster at printing

Before profiling RGB inkjets

- Know the software settings
- Allow printout to dry completely
- Ink and paper will often change

Profile an inkjet printer

- Work with pre-canned profiles
- Send printout thru scanner device
- Settle on same recipe of settings

Media settings in an inkjet

- Paper type choices affect amount of ink, black generation, and screening algorithm—a huge impact on print
- Experiment until you find the best paper type and setting combination
- Don’t expect perfection. Linearity is often sacrificed for larger gamut. Shadows will block up

Color settings in an inkjet

- Photorealistic? Vivid?
  Look for “No Color Adjustment”
  or some other raw setting
- Or try a manufacturer setting if it works well
- Decide on a compromise and always use this setup; then profile it

Profiling CMYK laser printers

- Paper humidity is stable
- Toner cartridge has a changing state
- Ink limiting set in profile or RIP; not both

CMYK laser parameters

- For color lasers and copiers with built-in ink limiting:
  - Total Ink Limit: 400%
  - Black Ink Limit: 100%
  - Black generation or GCR: maximum
  - Black Start/Onset: 5-10%

CMYK laser parameters

- For color lasers and copiers without built-in ink limiting:
  - Total Ink Limit: 260%
  - Black Ink Limit: 100%
  - Black generation or GCR: maximum
  - Black Start/Onset: 5-10%

CMYK inkjet parameters

- For color inkjets with built-in ink limiting:
  - Total Ink Limit: 400%
  - Black Ink Limit: 100%
  - Black generation or GCR: med to heavy
  - Black Start/Onset: 30%

CMYK inkjet parameters

- For color inkjets without built-in ink limiting:
  - Total Ink Limit: 260%
  - Black Ink Limit: 100%
  - Black generation or GCR: heavy
  - Black Start/Onset: 30%

Black generation

- Under Color Removal (UCR)
  use black only in the neutral and near-neutral areas; often used on newsprint
- Gray Component Replacement (GCR)
  use more black ink relative to colors; aggressively replacing the amount of CMY that would make a neutral

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Viewing printed samples

- Viewing room painted neutral gray
- Matte white is OK
- No strong colors intruding into view
- Filtered daylight ambient light is OK
- Use a monitor hood
- Illumination booth with D50 ideally
- Use a viewing light checker

Viewing printed samples

- Try to match brightness; not temperature
- Put the monitor and light box in separate field of views so eyes can adjust

Evaluate monitor calibration

- View > Proof Setup > Monitor RGB
- Black point check (p. 216)
  - Between 1 and 7 is good
    If no change within 12 levels, recalibrate requesting a slightly higher black point
- Gamma check (p. 216)
  - Make crossover gradients and look for banding in shadows and color in midtones

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Class activities

- Setup color management software
- Calibrate and prep a monitor
- Setup a viewing booth
- Subjective monitor test
- Calibrate a printer

In summary:

- You are up against a lot of variables
- You must calibrate that monitor
- The software is imperfect
- CM settings are complex
- The print/PDF dialog boxes are complex
- Workflow depends on profiles
- You can improve color accuracy

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Color Management

Thanks for attending

Call me for Adobe CS2 training:

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