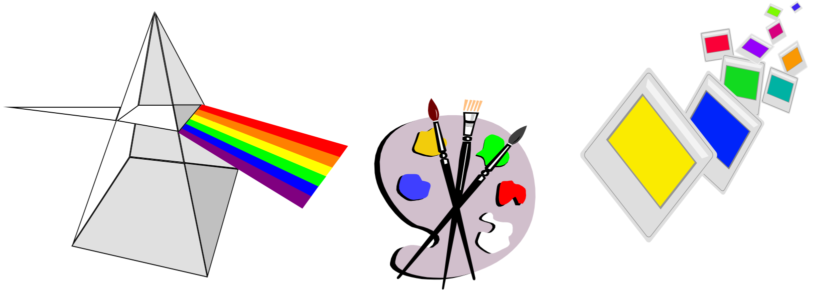
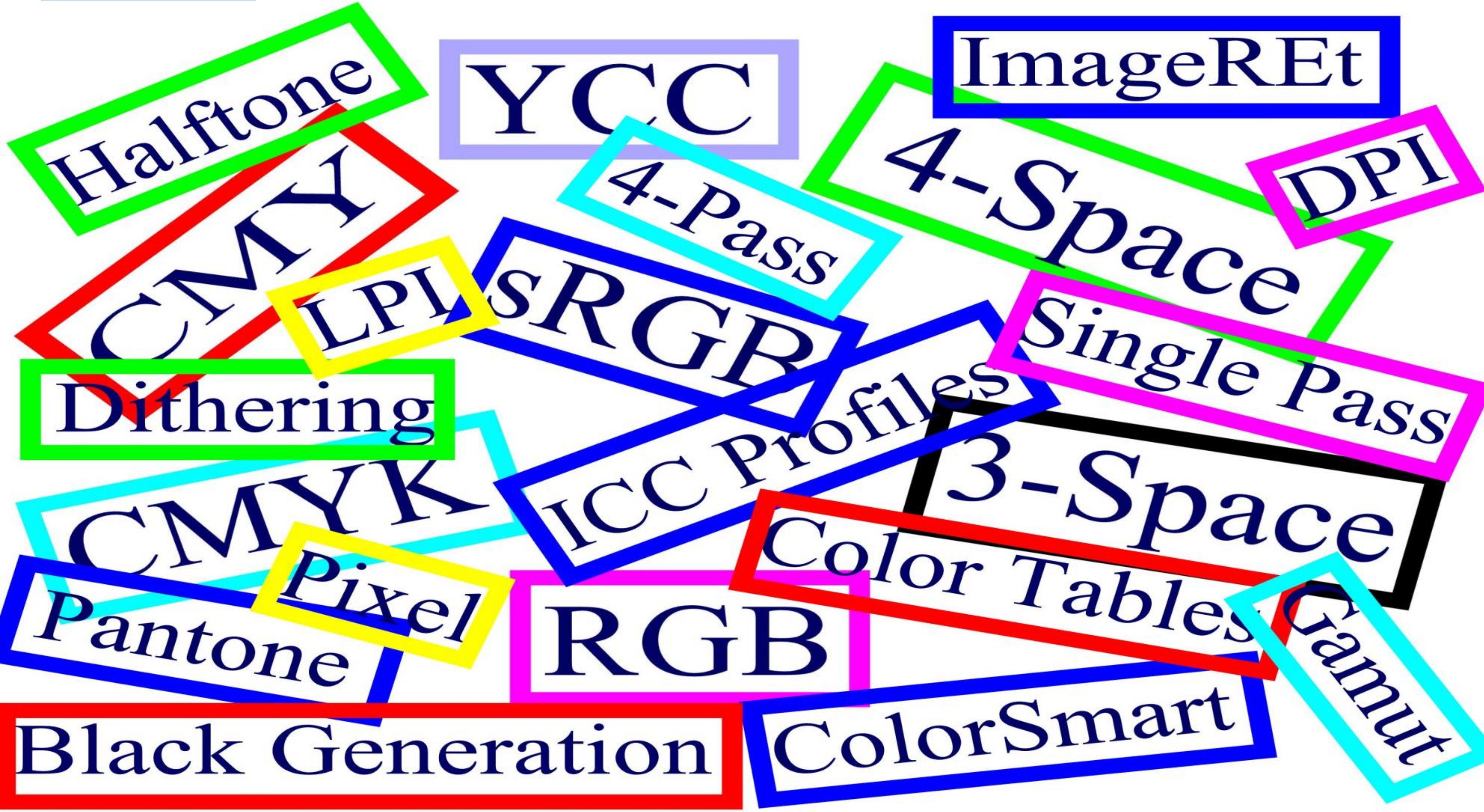
Color Concepts 101



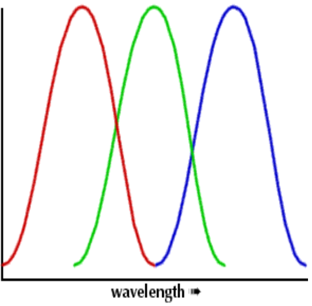
April 2001

Color is Simple: Right?



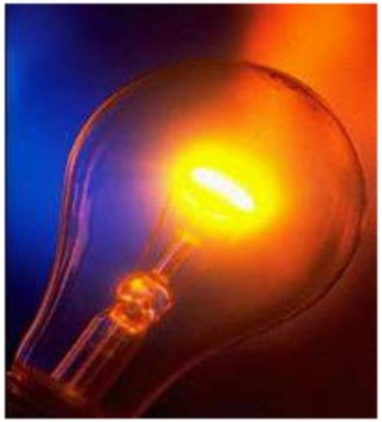
Color Concepts 101

What is Color?

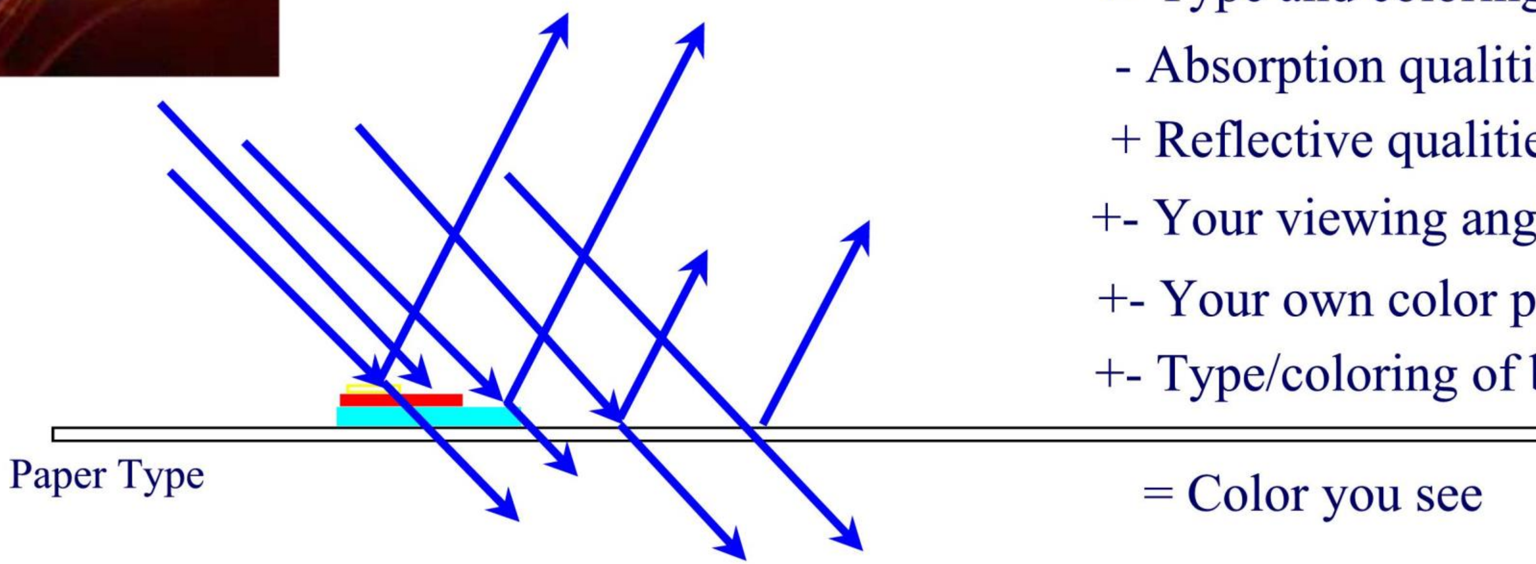


- Color is the perception of the different wavelengths of light.

Color Perception



Source of the light
+- Angle of the light source
+- Quality of light
+- Amount of light
- Color frequencies absorbed
+ Color frequencies reflected
+- Type and coloring of media
- Absorption qualities of media
+ Reflective qualities of media
+- Your viewing angle
+- Your own color perceptions
+- Type/coloring of background



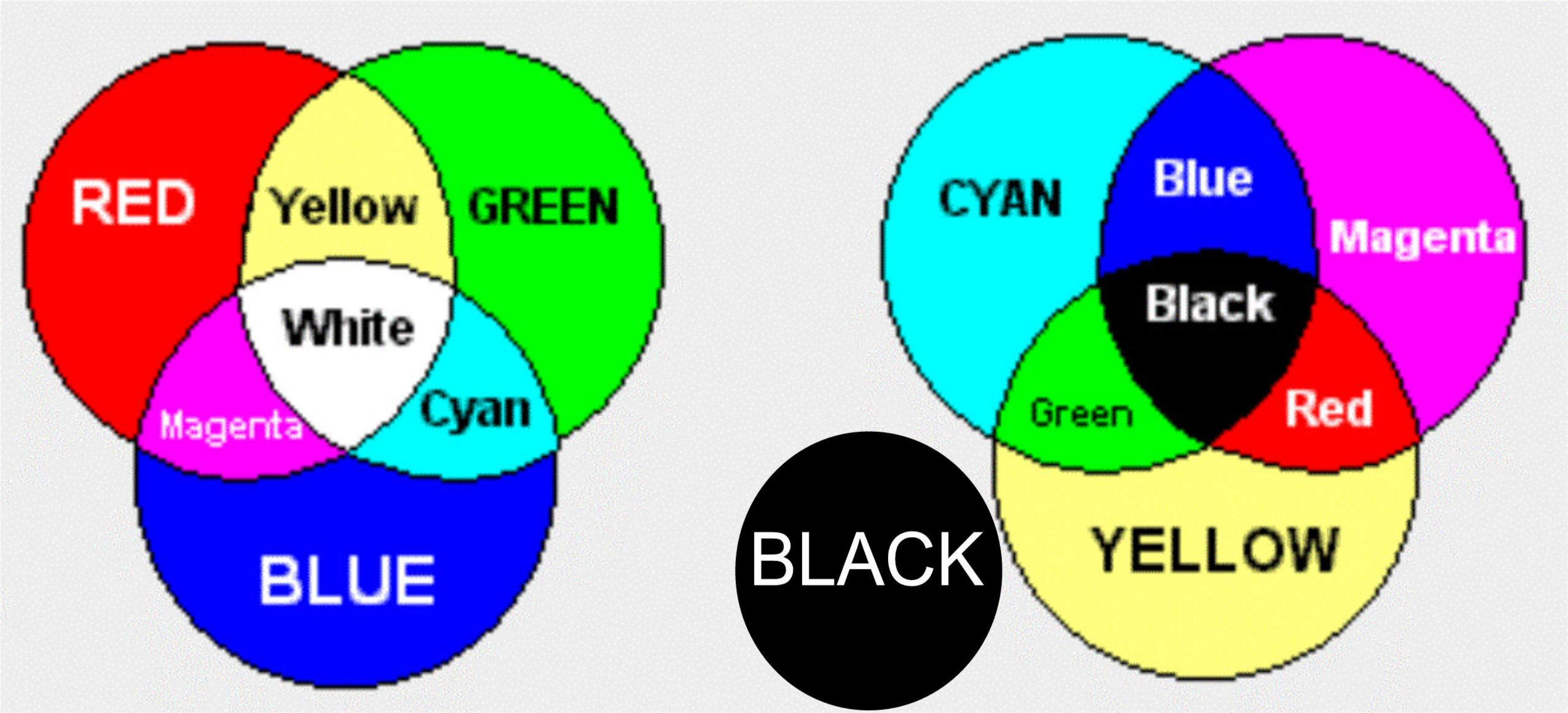
= Color you see

Color Spaces

- Almost all visible colors can be created using two systems of primary colors.
  - Transmitted colors using red, green and blue (RGB) -- colors are added to create white.
  - Reflected colors using cyan (light blue), magenta (purplish-red), yellow and black (CMYK) -- colors are subtracted to create white.

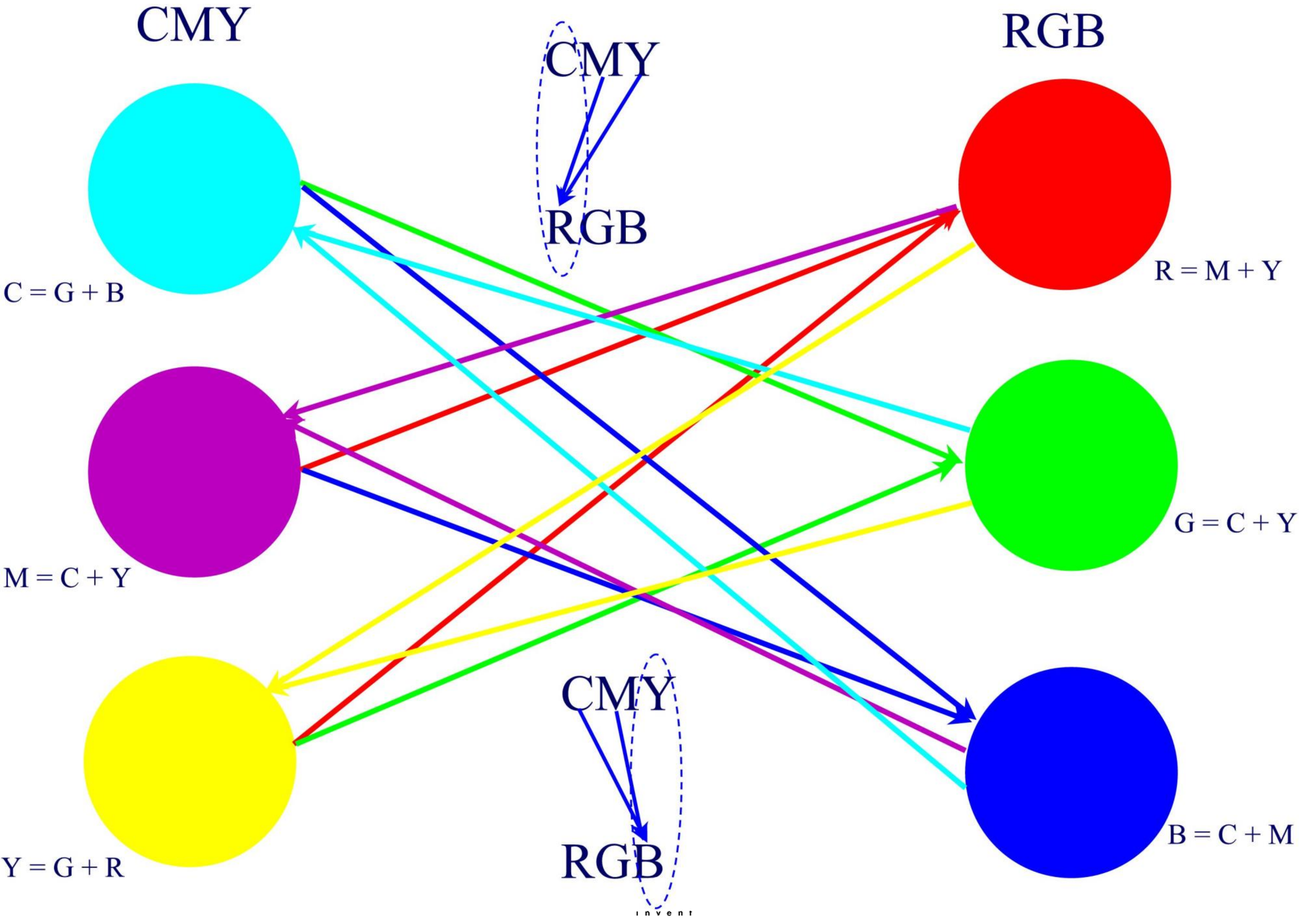
Color Spaces

RGB (Transmitted Colors) CMYK (Printed Colors)



Why so many Color Spaces?

- Color spaces are focused at specific color requirements, uses or areas:
  - RGB is a three-dimensional model that corresponds to the way the human eye sees color, that is, with red, green, and blue "cones.“
  - CMYK is a four-dimensional model that corresponds to the way the printer produces color.
  - Converting a color from RGB to CMY (or CMY to RGB) is fairly straight forward, enabling you to move between models.

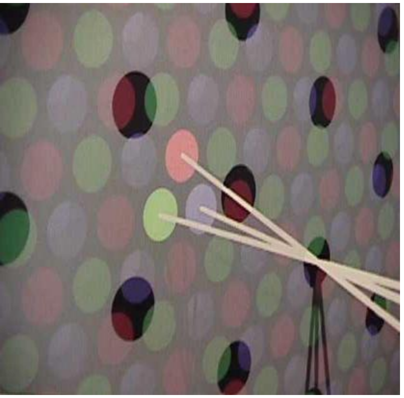

CMY
CMY
RGB
RGB
C = G + B
R = M + Y
M = C + Y
G = C + Y
CMY
RGB
Y = G + R
B = C + M
invent

Why so many Color Spaces?

- HSB closely resembles our everyday experience of color (hue -- the name of the color, saturation – how deep or vibrant a color is, brightness – adding or removing white from a color).
- CIE XYZ which is based on color information gathered with a spectrophotometer, which measures colors to a standard object, illuminant, and observer.
- YCC was designed to enable greater compression for Photo CDs.

RGB

- Uses red, green and blue (primary colors) to create transmitted colors.



  - The transmitted quality of RGB is best exemplified by a color monitor, which creates color when white light strikes the red, green, and blue phosphors on the screen.
- An additive system that combines light to create millions of colors.

RGB

- **RGB values are described using numbers where (0,0,0) is black**
- Equal amounts of all three produce white light (255,255,255).
- When any two of the RGB colors combine, they create one of the secondary colors that make up the CMK color model (Cyan, Magenta, and Yellow).

Color Concepts 101

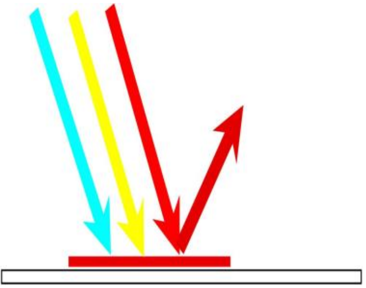
CMY

Converting a color from RGB to CMY (or CMY to RGB) is fairly straight forward.

- Uses cyan, magenta and yellow (primaries) to create printed colors.
- **CMY values are described as percentages where (100,100,100) represents black**
- A subtractive system that works by taking color away from white light.
- When all color has been removed from light, what's left is black.

CMY

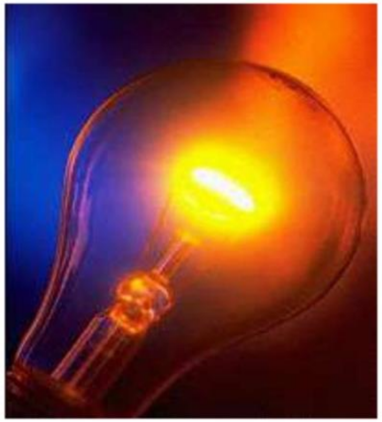
- The color of any part of a CMY image results from:
  - The frequency of light it reflects
  - The light-absorbing properties of the toner (or inks) and media.
- Example: When a light source strikes an area of printed magenta toner (ink), all colors are absorbed except the magenta wavelength, which is reflected to the viewer's eye.



CMY

- A white surface reflects all wavelengths of visible light.
- A black surface (100% of CMY) absorbs all of them.
- A green surface (combination of Cyan and Yellow) absorbs (subtracts) all but the green wavelengths.

Color Perception



Source of the light
+- Angle of the light source
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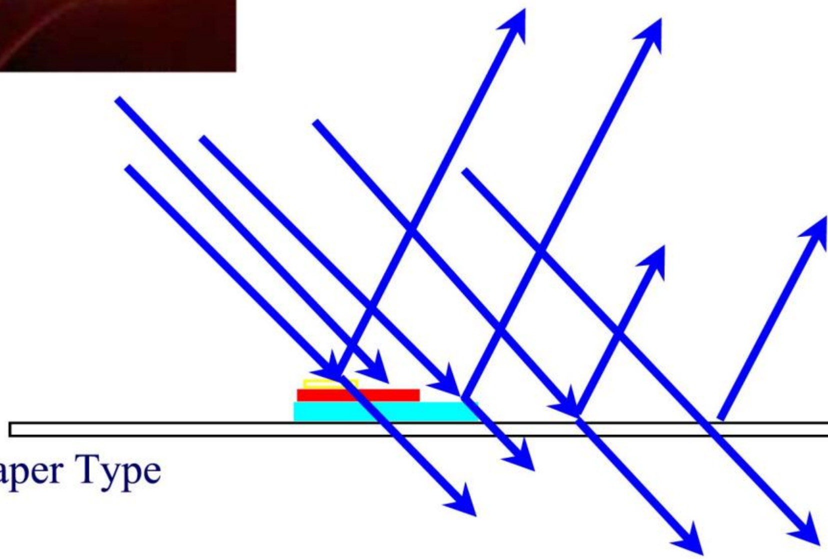


= Color you see

CMYK

"K" is used for black to avoid confusion with Blue and because the black component is the "Key" for a set of color separations.

- In theory, the combination of CMY at 100% (100,100,100) creates black,
- In practice it creates a muddy brown due to limitations of toner (and ink) secondaries.
- To resolve this, a pure blacK fourth toner is added in order to produce black on a printed page.

CMYK

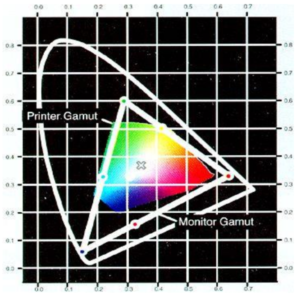
- This results in sharper text and lines using black only.
- Better overall contrast within photographs.
- Better detail and depth in shadow tones.
- The ability to replace three color toners with black when printing black only text and images.

CMYK versus RGB: Gamut

- Unfortunately, due to the colorants commonly used today,
- a CMYK (four-dimensional model) has a more limited gamut (or range of colors)
- compared to RGB,
- with a range of only tens of thousands of colors.

Color Concepts 101

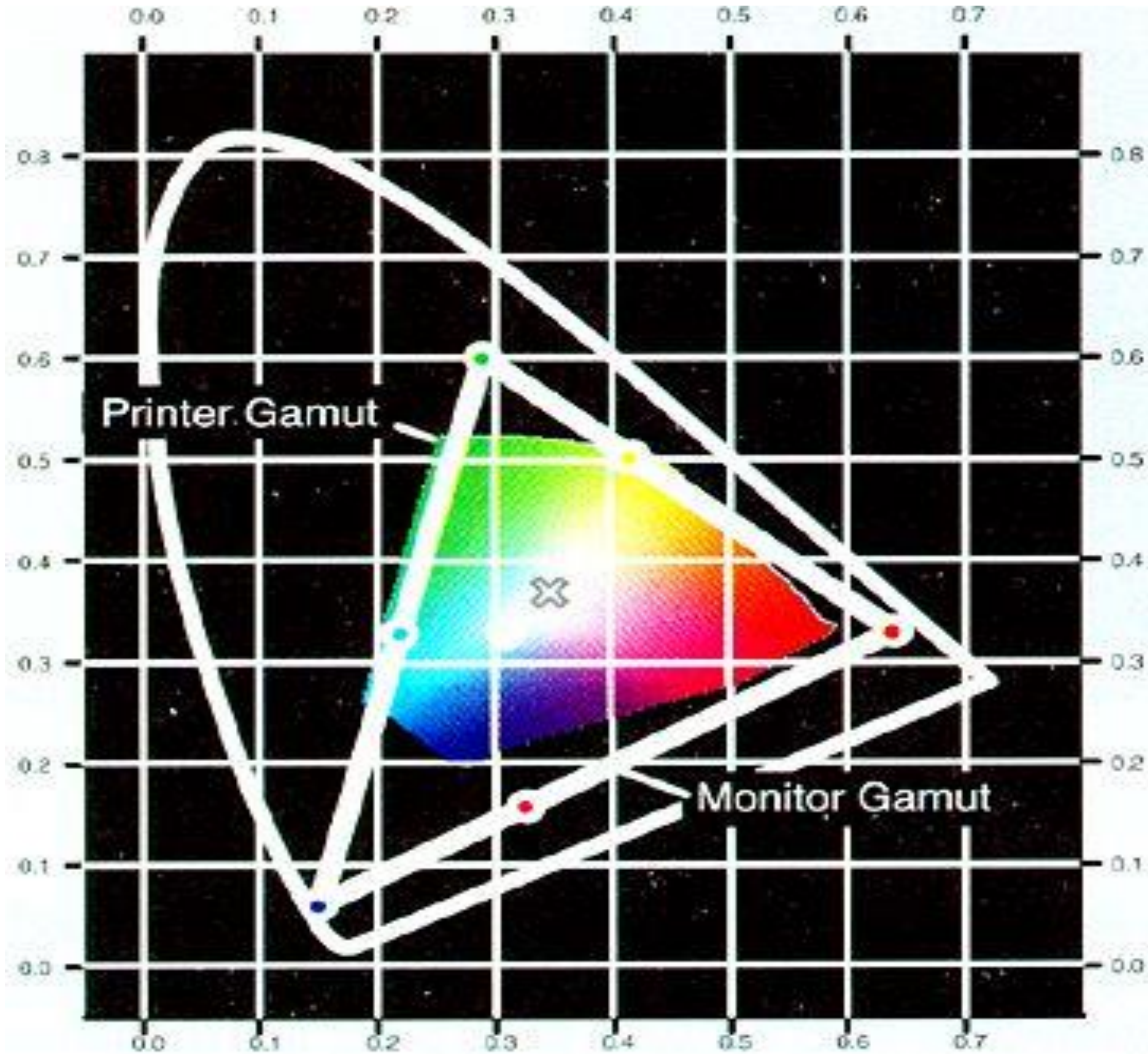
Color Gamut



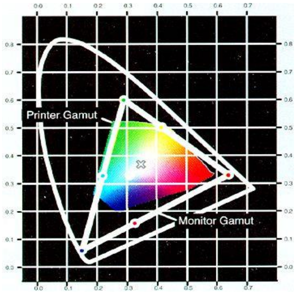
- The following graphic compares the color gamut across devices.
- The outermost area within the boundaries of the horseshoe shape represents all the colors perceivable by the human visual system.
- The triangle represents the range of colors available on a color monitor
- The innermost color area represents the gamut of a color printer.

Color Concepts 101

Values on the chart represent x and y chromaticities (a measure of the combination of both hue and saturation in color produced by lights).

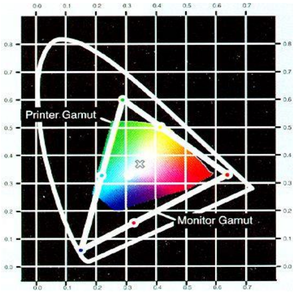


Color Gamut



- The gamut shows the entire range of colors available on a particular device such as a monitor or printer.
- Starting from the colors in real life, the color gamut decreases as it moves to analog film to a digital scanner to a printer.
- No one system can reproduce all possible colors in the spectrum.

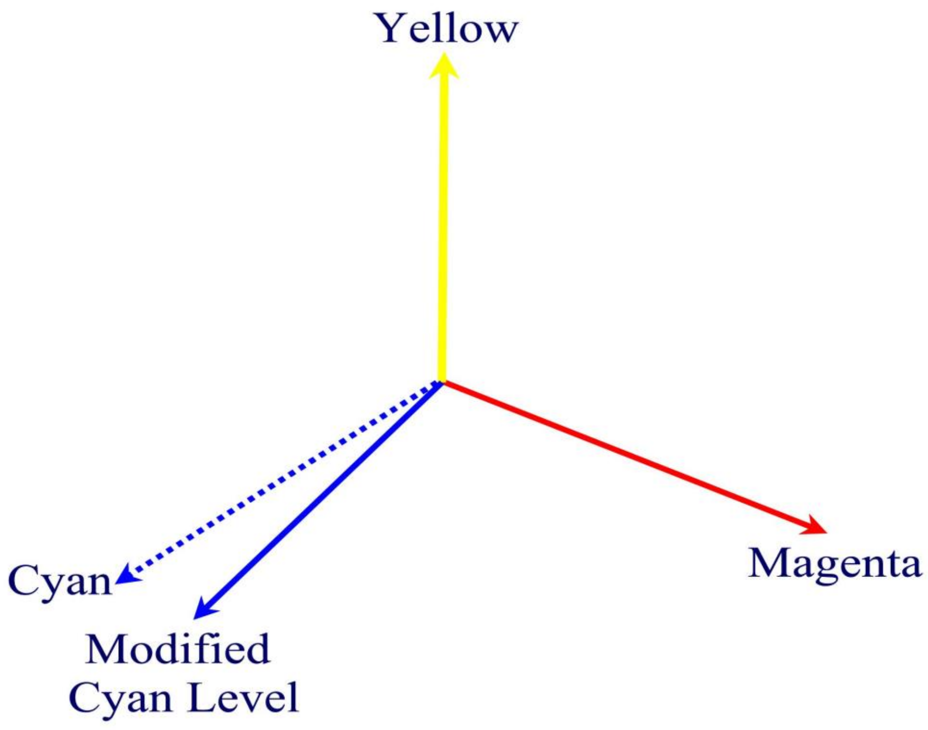
Color Gamut



- Factors that limit gamut
  - Subtractive versus additive qualities of CMY versus RGB
  - Opaqueness of toner
  - Number of process colors
  - Hue, lightness, and chroma (relative colorfulness) in pigments of primary
  - Primary color selections.

Color Gamut

To produce better colors in the business arena, some printers also modify the Cyan base value.



Black Generation

- When converting an RGB or CMY image to CMYK color mode (or vice versa),
- Black generation refers to the values that are generated for the black toner
- Which replaces certain amounts of the cyan, magenta, and yellow toners.
  - A night scene in a city will require more black to keep the shadows dark and crisp.
  - A bright and colorful image will need little or no black to avoid neutralizing the colors.

Black Generation

Converting CMYK to CMK or RGB for the formatter, then back to CMYK for the engine raises concerns for quality and conversion time.

- A specific shade of purple may contain anywhere from 10% to 40% black, with the other process colors adjusted accordingly.
- To manage this, algorithms are developed for the HP Color LaserJet printers to convert from RGB or CMY to CMYK.
- In addition, the emulation of different CMYK print ink standards are provided to get more accurate color in specific environments.

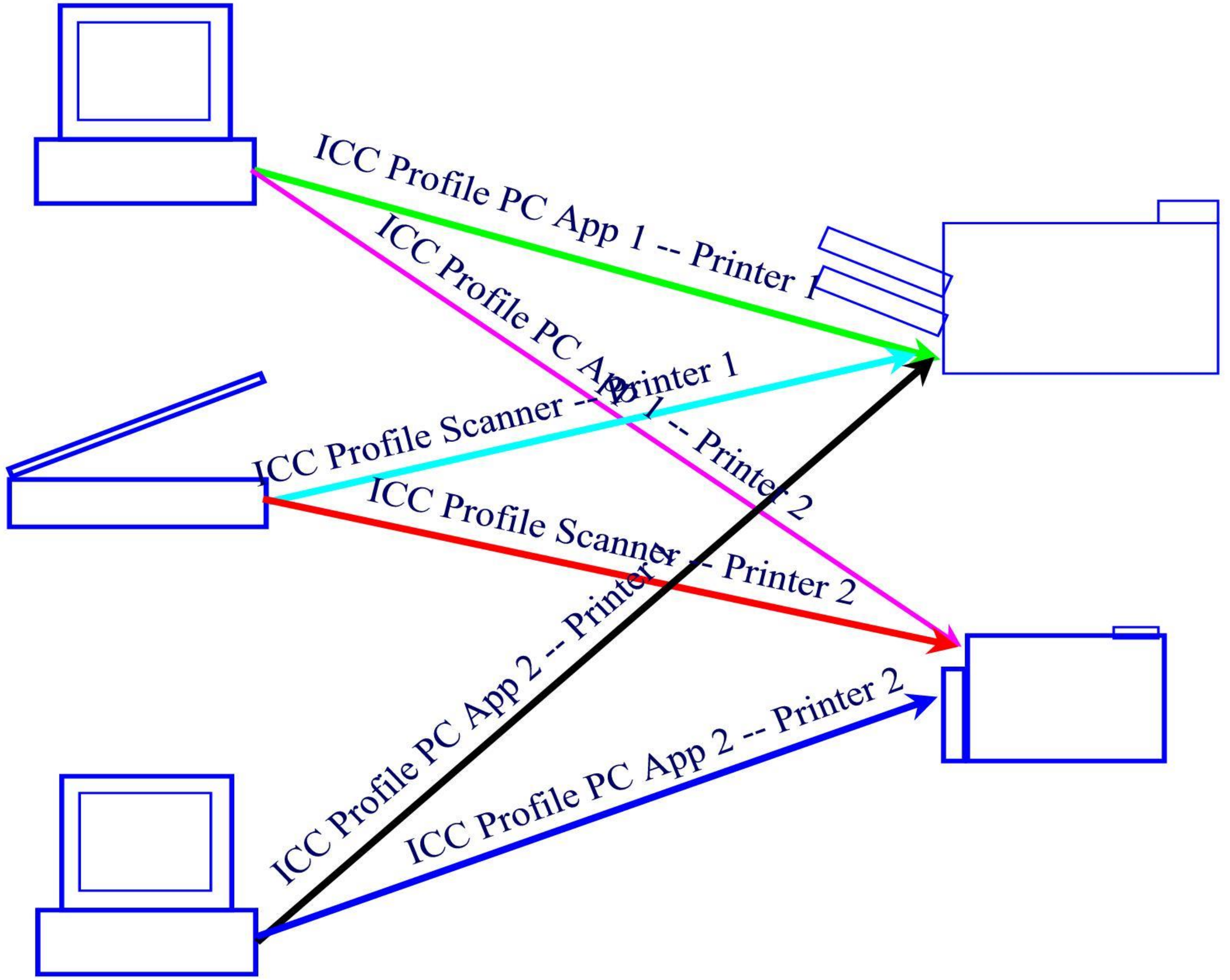
ICC Profiles
(International Color Consortium)

- Specifies the attributes of imaging devices such as scanners, digital cameras, monitors, and printers
- Provides a closed loop color system providing the most accurate and predictable output.
- A profile is embedded into the image itself.

ICC Profiles
(International Color Consortium)

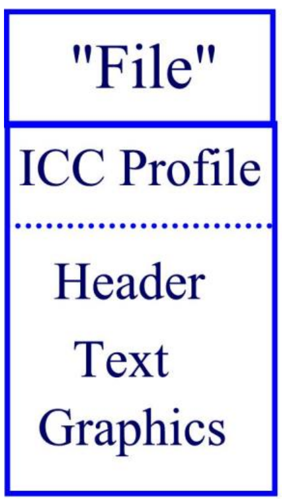
- Industry standard format for describing device specific color to color management systems.
- The color of an image remains true from source to destination.
- Individual ICC profiles are provided for each HP Color LaserJet printers.

ICC Profiles
Application and Output Device Specific



ICC Profiles: Issues

- Device dependent color focus
  - Gamut mapping issues between devices
- More overhead
  - Additional software processes, support requirements, increased file sizes, must consciously configure
- Incompatibility between profiles -- Kodak to HP, newer profiles to older profiles



sRGB

- “standardized Red, Green and Blue" color space.
  - Ensures consistency of presentation & color definition across devices
- Device independent color
  - Devices conform to a standard versus configuring profiles between source and destination
  - **Color definition controlled in the background**

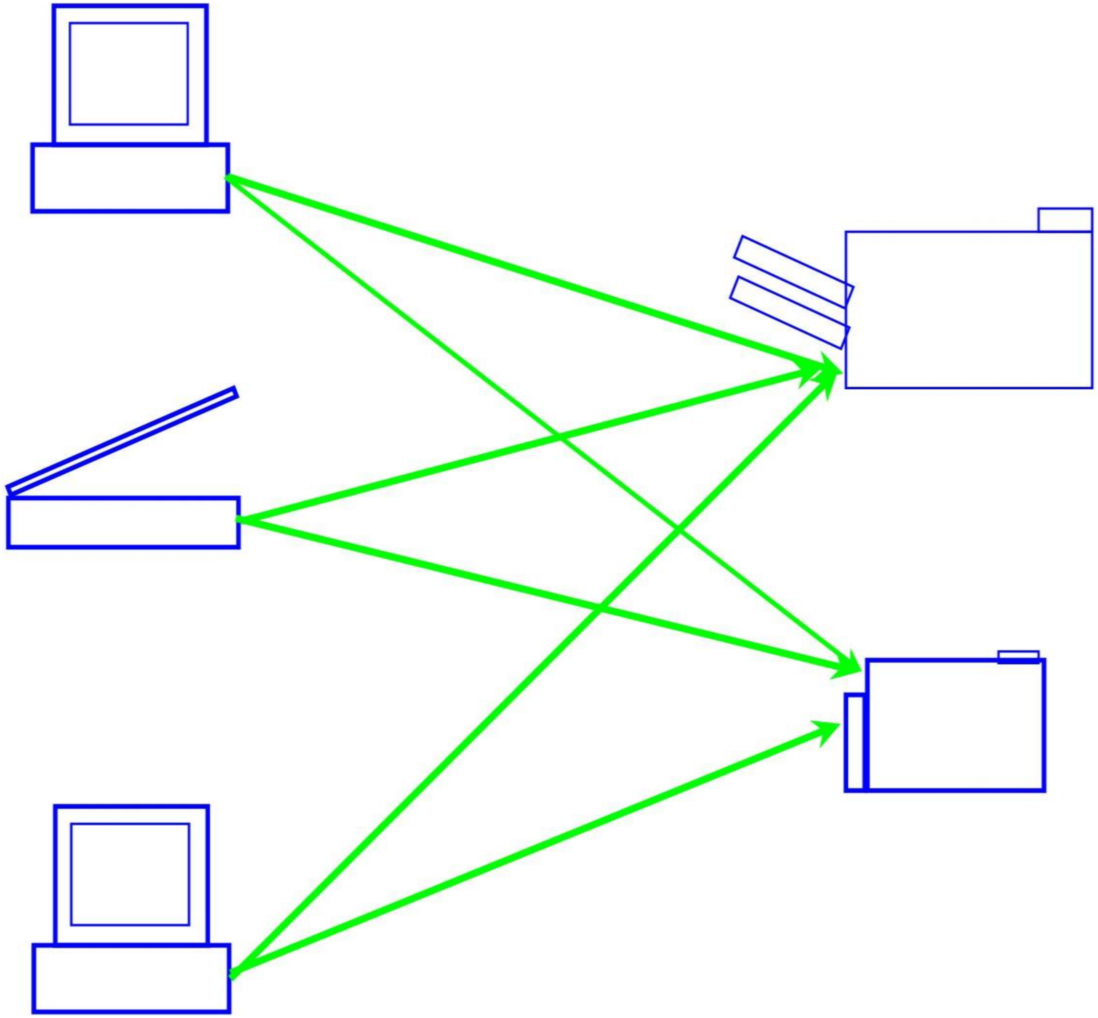
sRGB

- Industry standard developed and proposed by HP and Microsoft for use in monitors, input devices (scanners, digital cameras) and output devices (inkjet printers, laser printers, plotters).
- Combined with improved HP technology -- Simplifies PCL command set

sRGB

- Maintains advantage of a clear relationship with ICC color management systems
- Minimizes software processes, support requirements, & file sizes.
- Default Standard for Microsoft Operating Systems, the Worldwide Web, HDTV, HP Color Printers, and over 80% of office software.

sRGB
Common Profile across Applications and Devices



Pixel (**PIX** [picture] **El**ement)

- Basic building block of all digital images
- Monochrome uses one bit per pixel (on/off -- 1/0).
- Gray scale and color typically use from 4 to 24 bits per pixel, providing from 16 to 16 million colors.

Pixel

- The higher the pixel resolution (the more rows and columns of pixels), the more information that can be displayed.
- The greater the ”bit depth," the more shades or colors that can be represented.

Color Depth

- Number of bits used to hold a pixel.
- Color depth determines the number of colors that can be displayed at one time.
- Also called ”bit depth" and "pixel depth."

Color Depth

Color depth	Number of colors
4-bits	16
8-bits	256
15-bits	32,768
16-bits	65,536
24-bits	16,777,216
32-bits	16,777,216 + alpha channel

- Note: Digital video requires at least 15 bits, while 24 bits produces photorealistic colors.

Color Concepts 101

CMYK versus CMY or RGB:File Size

- Assuming 8 bits per primary (0 to 256)
- 600 dpi (600 x 600)
- Letter-size Media
- ¼-inch margins on sides, top, and bottom
- CMY or RGB File Size = (**3** x 8 x 600 x 600 x 8 x 10.5)/8 = **90.27 Mbytes**
- CMYK = (**4** x 8 x 600 x 600 x 8 x 10.5)/8 = **120.96 Mbytes**

Halftone, Dither, and LPI

- Basically:
  - Halftone is binary, referring to turning dots on and off to represent colors
  - Dithering refers to the random pattern used to group halftone dots
  - LPI refers to the frequency at which you repeat the halftone/dither pattern on the page.

Halftone/Dithering

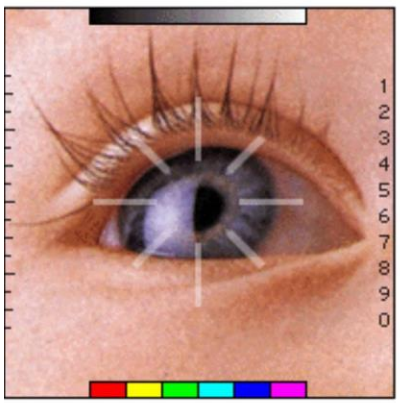
- Halftone refers to a pattern of dots of varying sizes that are applied to an image to simulate the varying tones or tints of color.
- In printing, a continuous tone image, such as a photograph, is converted into a series of dots to enable a printer to reproduce the photograph.

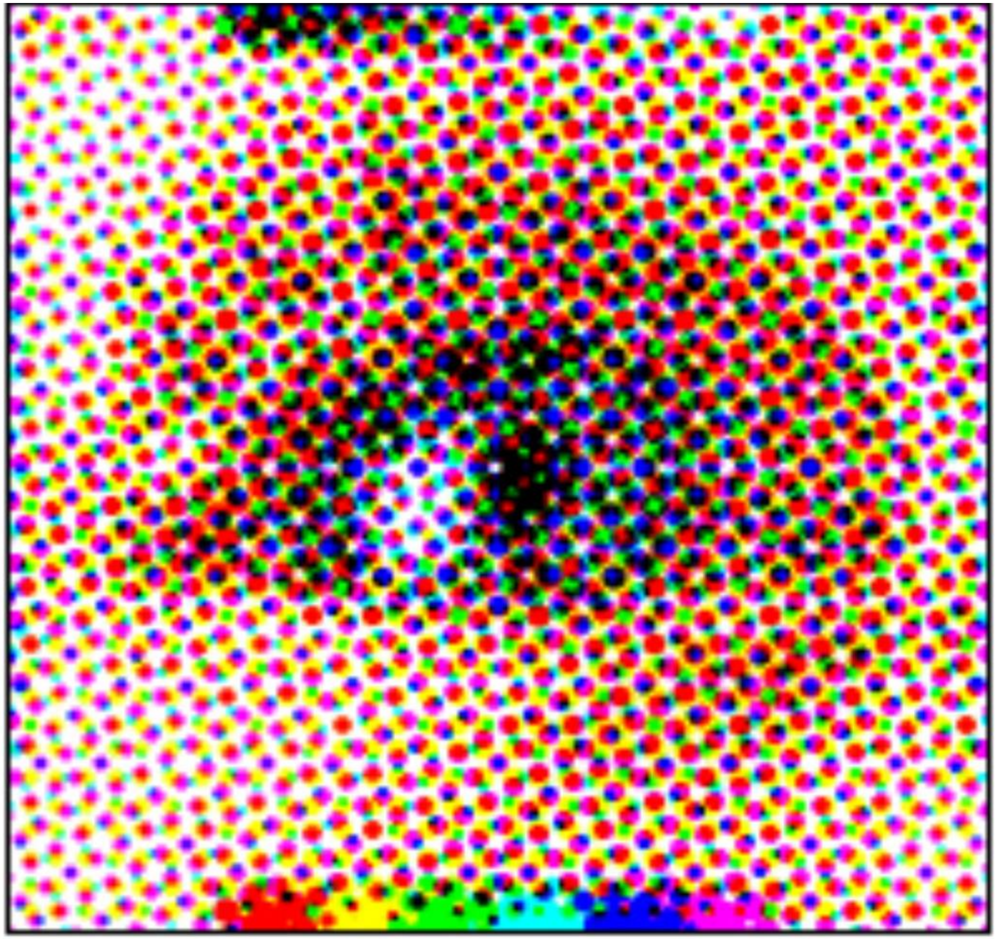
Halftone/Dithering

- Halftones are created through a process called dithering, in which the density and pattern of dots are varied to simulate different shades of gray or tints of color.
  - Smaller dots used for lighter areas
  - Larger dots used for darker areas
  - The more dots printed in the cell, the darker the area.
  - Hues are produced by varying primaries

Color Concepts 101

Halftone/Dithering





Halftone/Dithering

- An algorithm is used to produce the appearance of a random distribution of dots.
  - Good for graphic images and photos.
- Uniformly distributing the dots sometimes produces noticeable geometric patterns.
  - Used for free-hand images, clip art, complex graphics, desktop publishing images, and color text.

Dithering a Color Image

- When there aren't enough colors in a display system to render an image properly, an infinite palette can be created by dithering.
- Quite often, a 24-bit color image is dithered to 256 colors.
- The right side is a magnification of the white box on the left.

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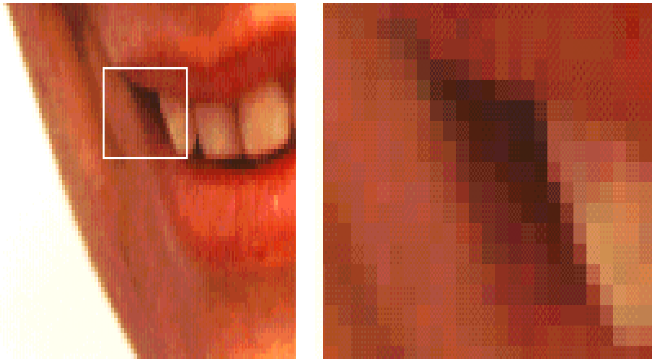


Dithering Text

When dithering is performed against the edges of an image, it is called "anti-aliasing."

- Notice how much softer the word DATABASE is at the top of this example, compared with the undithered word below it.
- The magnified view shows where lighter blue pixels filled in for the curves.

Halftone versus Continuous Tone

- Continuous-tone images, such as photographs and television images, have a virtually unlimited range of color or shades of grays.
- Halftone is generally binary referring to turning dots on or off to represent colors in an image.

Color Concepts 101

Halftone versus Continuous Tone

- To approach continuous-tone quality, an HP laser printer:
  - **Varies the dot size**,
  - Uses the laser to **modulate the dots**, versus just on or off, producing multiple levels or shades of dots (lightness and darkness)
  - Dithers the image
- Producing photographic-like output.

Halftone versus Continuous Tone

- Although continuous-tone (**Contone**) printers are not true continuous-tone due to the limited level of shades
- There are enough shades (256 or more)
- So that the difference between one shade and the next is imperceptible to the human eye.

Gray Scale

- A series of shades from white to black.
- The more shades, or levels, the more realistic an image can be recorded and displayed, especially a scanned photo.
- Scanners differentiate typically from 16 to 256 gray levels.
- Converting a black-and-white continuous-tone image into a computer image is known as gray scaling.

DPI versus LPI

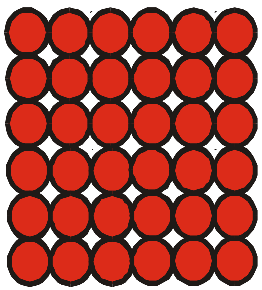
- DPI – the measurement of the resolution of displays and printers.
- LPI – the *screen frequency,* measured in lines per inch, which determines how many dots are used to make each spot of gray.
- A compromise must be made between printer resolution (dots per inch -- dpi) and screen frequency (lines per inch -- lpi).

DPI versus LPI

- In theory, the higher the screen frequency (the more lines per inch), the more accurate the halftone will be.
  - Increasing screen frequency (more cells per inch) increases the detail.
  - Higher screen frequencies create smaller, more tightly packed dots.
  - Resulting in less room for dots in each cell.
  - Reducing the number of shades of gray or color that can be generated.
  - And the number of rows of halftone cells per inch or lines per inch.

Color Concepts 101

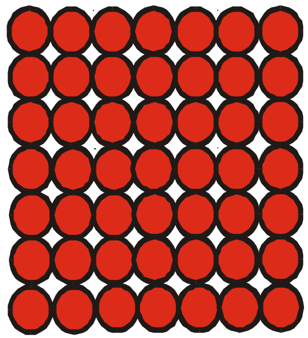
DPI versus LPI



6 x 6 Cell

$$\frac{600\ \text{dpi}}{6} = 100\ \text{LPI}$$

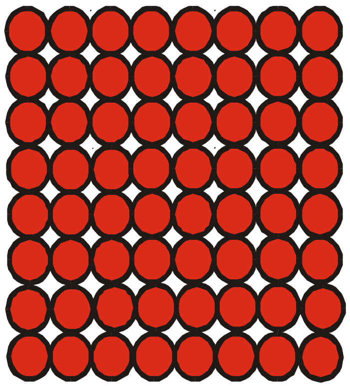
36 shades of gray or color



7 x 7 Cell

$$\frac{600\ \text{dpi}}{7} = 85\ \text{LPI}$$

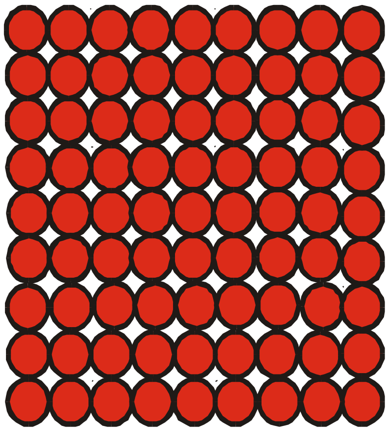
49 shades of gray or color



8 x 8 Cell

$$\frac{600\ \text{dpi}}{8} = 75\ \text{LPI}$$

64 shades of gray or color



10 x 10 Cell

$$\frac{600\ \text{dpi}}{10} = 60\ \text{LPI}$$

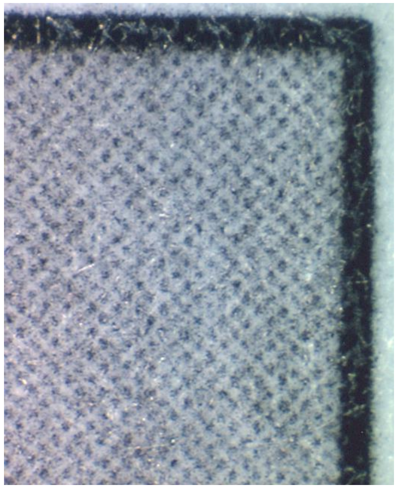
100 shades of gray or color

Halftone cell (printer pixel) is the smallest increment used to represent a tonal image.

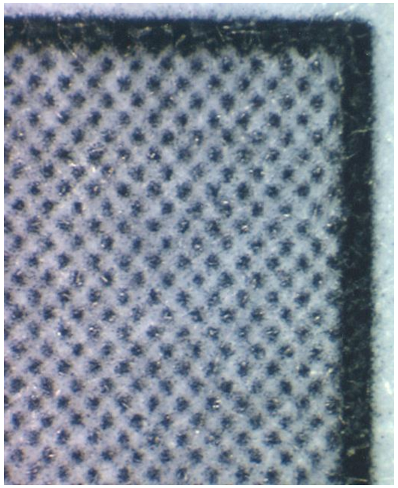
Color Concepts 101

DPI versus LPI

212 LPI



155 LPI



Newspapers are printed at 65 to 85 lpi, magazines at 200 lpi.

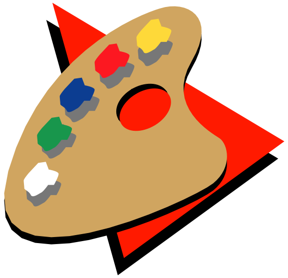
DPI versus LPI

- In color printing only a limited number of line frequencies are available because of the **complexity of registering the four individual color planes** on top of one another.
    - Typical line frequencies (LPI) for Color LaserJet printers are 155 LPI, 200 LPI and 212 LPI.

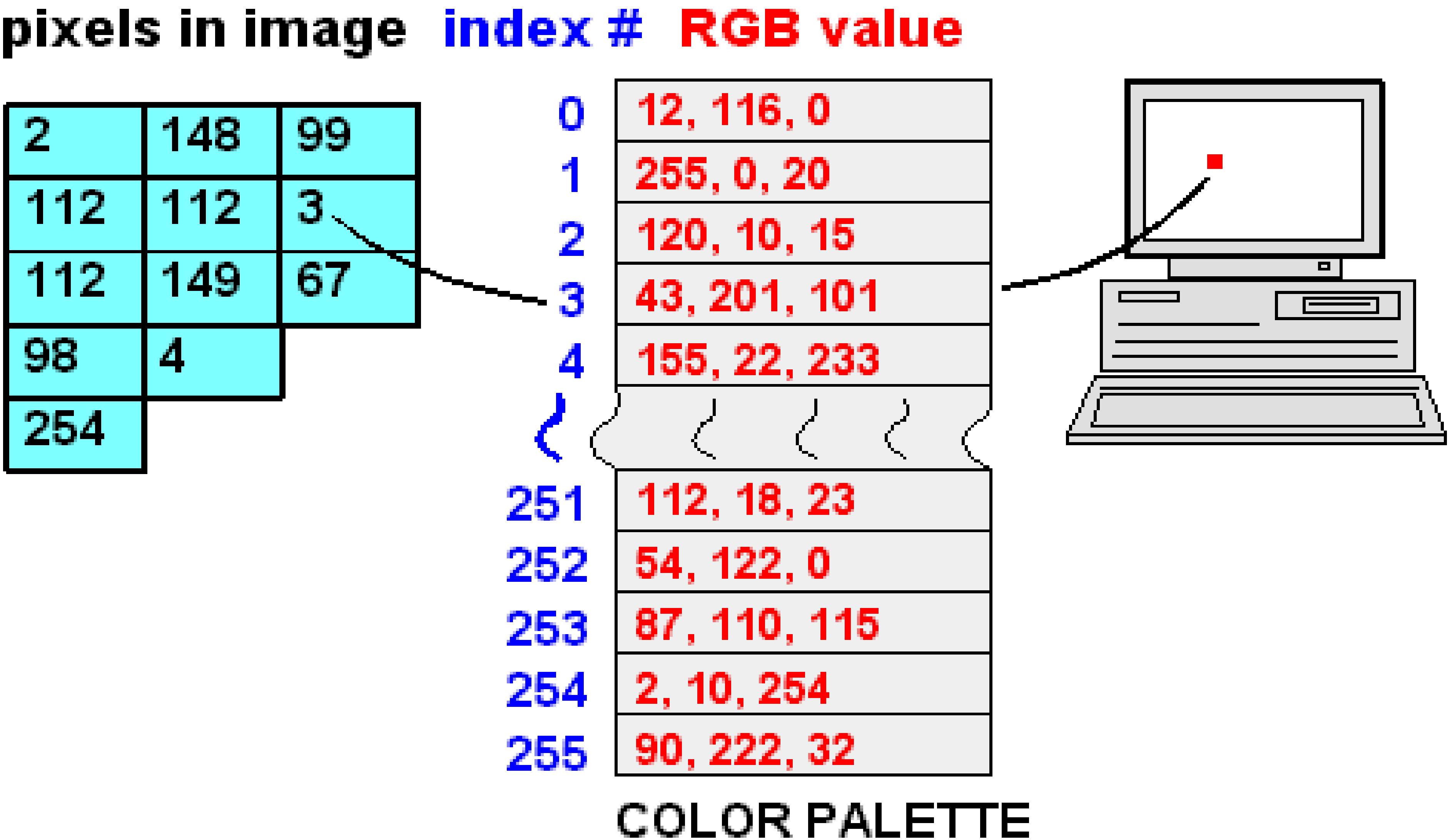
Color Palette

- When people think of a palette, they often think of an artist's paint palette.
- Basically, the color palette for a printer is the same thing -- the set of available colors.
- An artist mixes colors of paint to get different colors.
- A printer mixes combinations of cyan, yellow, magenta, and black toner dots to get different colors.

Color Palettes



- More specifically, in a printer, it is a collection of color specifications which can be selected using index numbers.
- Instead of each pixel containing its own red, green and blue values, which would require 24 bits…
- Each pixel holds an 8-bit value, which is an index number into the color palette.


pixels in image
index #
RGB value
2
148
99
112
112
3
112
149
67
98
4
254
0
12, 116, 0
1
255, 0, 20
2
120, 10, 15
3
43, 201, 101
4
155, 22, 233
251
112, 18, 23
252
54, 122, 0
253
87, 110, 115
254
2, 10, 254
255
90, 222, 32
COLOR PALETTE

Color Palette

- The color palette contains 256 predefined RGB values from 0 to 255.
- Each entry associates an index number with three primary color components
- Also called a "color lookup table," "lookup table," "index map," "color table" or "color map," it is a commonly-used method for saving file space when creating 8-bit color images.

Data Compression

Increases in importance due to increased file sizes with color

- Encoding data to take up less storage space.
  - Digital data compressed by finding repeatable patterns of binary 0s and 1s -- more patterns found, greater the compression.
- Graphics files can be compressed from 20% to 90% of original size.
  - PCL 5c does not support text compression

Data Compression

- Lossless compression -- no loss -- decompressed file and original are identical.
- Lossy compression -- minimal loss (no perceptual loss), but provides higher degrees of compression and smaller files.
- Business data requires lossless compression.

Data Compression

- Audio and video applications can tolerate some loss, which may not be very noticeable.
- Compression has increased importance with color due to increased amount of data required for color.

Lossless versus Color Depth

- Saving a 24 bit color file as GIF (Lossless)
  - **Results in greater data loss from converting the file to 8 bit GIF format**
  - Than from using lossy compression such as JPEG with a reasonable quality setting.

Pantone Matching System (PMS)

Pantone requires a precise ink formula for accurate reproduction.

- A color matching system that has a number assigned to over 500 different colors and shades.
- Standard for the printing industry
- Built into many graphics and desktop publishing programs to ensure color accuracy.
- Pantone developed its color matching system from 14 inks.

Why Pantone Certification is Important?

- Established brand name in the color community that is heavily associated with color quality.
- For a printer to be Pantone certified means its print quality meets a perceivable high quality standard.
- Customers use Pantone certification as a yardstick for measuring print quality.
- The printer industry uses it as a measure of quality, including HP.

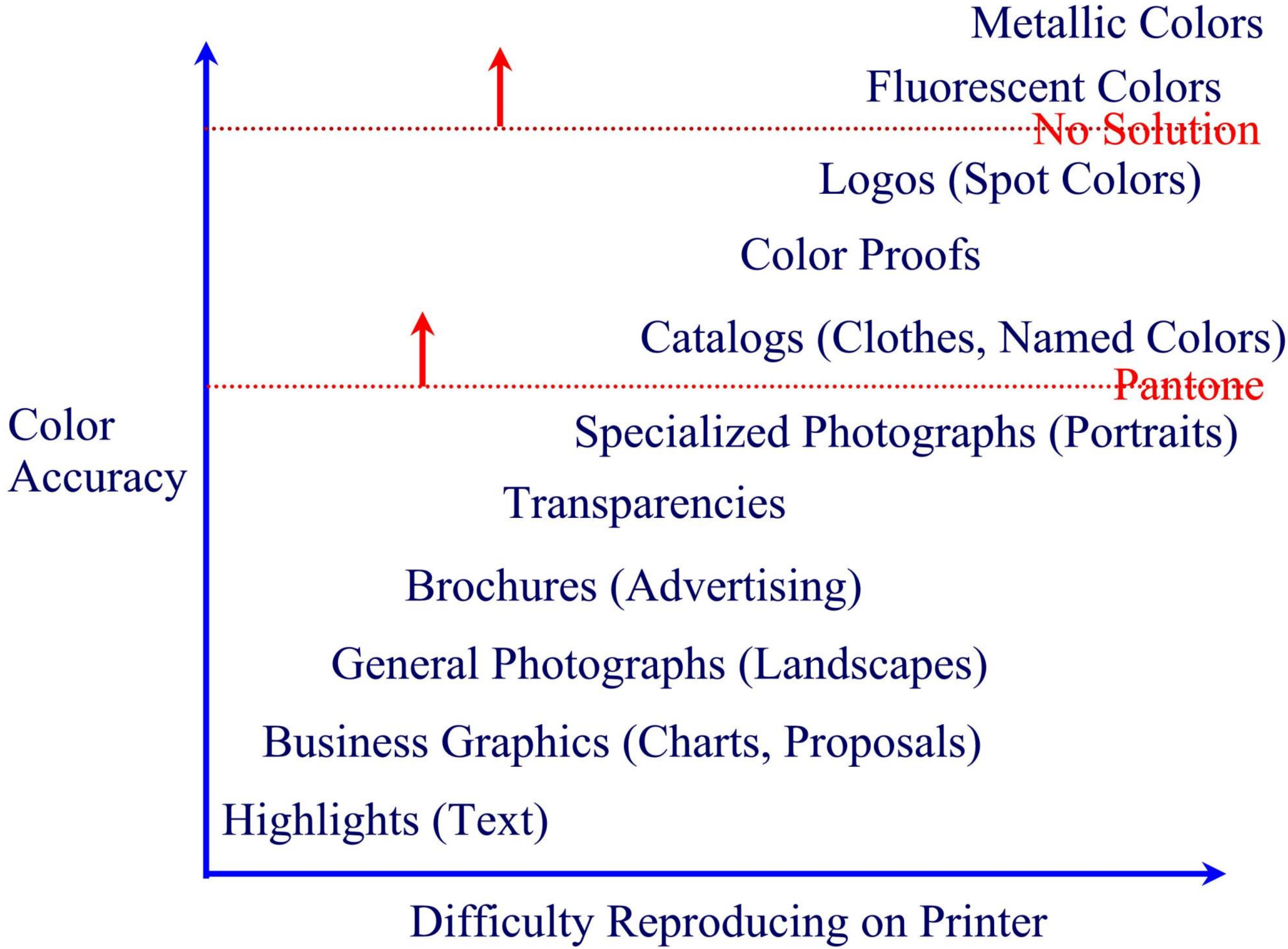
Pantone versus CMYK

Printers can only simulate, NOT duplicate Pantone colors.

- The Pantone Matching System is fundamentally different from the CMYK color model.
- Pantone colors are recipes for mixing standard printing inks (or toners) of various colors.
- CMYK colors are proportional, screened percentages of coverage using only CMYK primary colors.

Pantone: Issues

- HP's printers are Pantone certified.
- Printers can only simulate, NOT duplicate Pantone colors.
- Most printers can reproduce only 40% of Pantone colors, but the majority of these colors are not those frequently used.
- Most printers are unable to meet the commonly required Pantone color quality 80% of the time.


Metallic Colors
Fluorescent Colors
No Solution
Logos (Spot Colors)
Color Proofs
Catalogs (Clothes, Named Colors)
Pantone
Specialized Photographs (Portraits)
Transparencies
Brochures (Advertising)
General Photographs (Landscapes)
Business Graphics (Charts, Proposals)
Highlights (Text)
Color Accuracy
Difficulty Reproducing on Printer

Spot Colors versus Process Colors

- Spot color printing is used for precise color, such as a corporate logo, and is based on pre-mixing ink of the desired color prior to printing.
- Process color printing is based on creating the appearance of a multitude of colors by combining percentages of cyan, magenta, yellow and black (CMYK) inks or toners to produce full color reproduction.

HP ColorSmart

- HP ColorSmart uses object tagging and sRGB color technologies.
- Object tagging allows optimal color and halftone settings to be used for different objects on a page (text, graphics, and photos).
- The printer analyzes the page (what objects it contains), and then uses the halftone and color settings that provide the best print quality for each object.

HP ColorSmart Process

- The "objects" or page elements are tagged automatically by ColorSmart.
- This information (tagging of objects) is then used to decide which color controls to request the printer to use for the various objects.
- This process applies the capability of the particular printer technology to the hierarchy of user needs for different color objects.

HP ColorSmart Process

Goal: Great color right out of the box every time

- For a page that consists of one object--pie chart, for example--ColorSmart selects the color map that delivers vivid, clear output for business graphics.
- For a photograph, it selects a color map that embraces color matching and photo-realism, as well as vibrancy and clarity.
- For a page containing text, graphics and a scanned photograph, ColorSmart is able to assign multiple color maps so that each object on the page is rendered optimally.

ImageREt

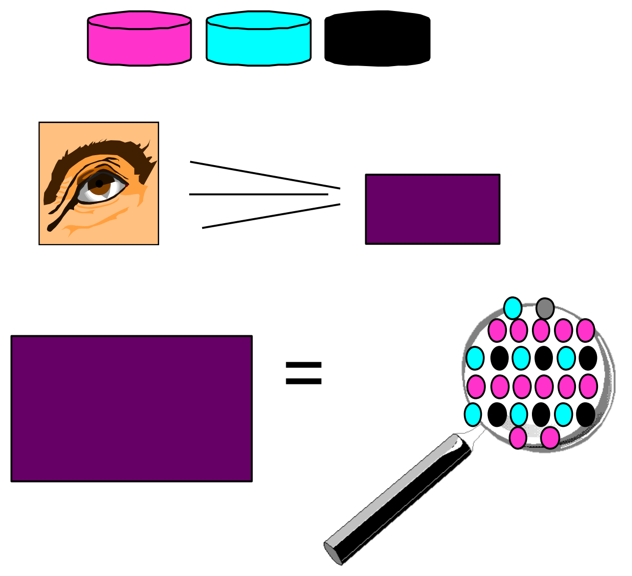
- Most color lasers create the illusion of color by combining cyan, magenta, yellow, and black toner in groups of dots (halftone cells) in patterns that the eye perceives as additional colors (*dithering*).
- Through this process thousands of dithered colors can be created.

ImageREt

- The number of dots in the halftone cell is directly proportional to the number of colors that may be generated.
- Larger halftone cells are required to create more colors:
  - Requiring more area on the printed page
  - Resulting in reduced edge sharpness and detail, as well as a visible dot structure.
- In the following example, magenta dots are being placed next to cyan dots to create a dither pattern that creates the illusion to the eye of purple.

Color Concepts 101

Single Level Color Laser Printing



Eight solid colors

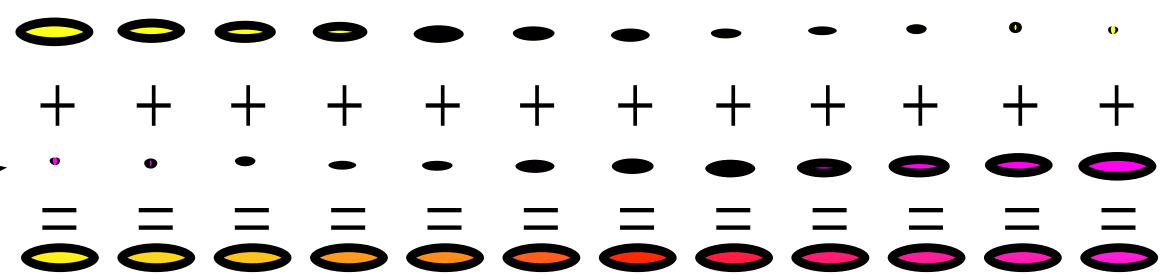
Millions of dithered color patterns

ImageREt

- ImageREt uses complex algorithms to allow the printer to **blend** up to four toner colors together **within** the space of a single dot (or pixel).
- The printer can vary the amount of toner blended to produce the exact shade desired.
- In the following example, by varying the amounts of yellow and magenta toner, you can combine the two to produce multiple shades.

ImageREt

Various Amounts of Yellow



Various Amounts of Magenta

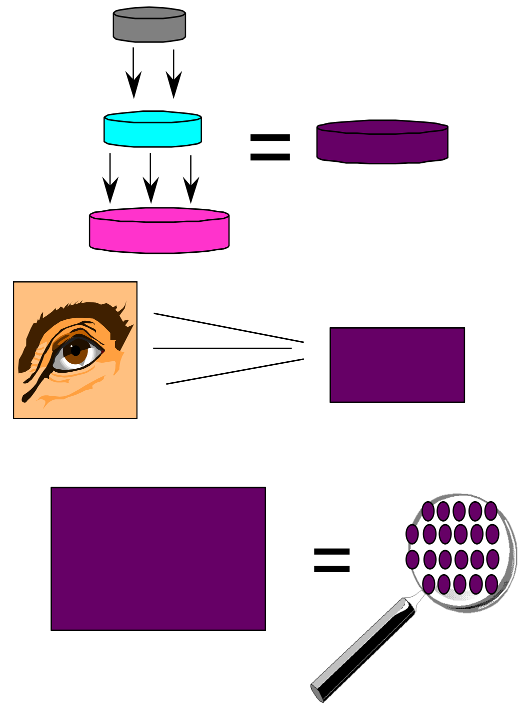
Various Shades that were previously only RED.

ImageREt

- In the following example, ImageREt combines in one dot area, or pixel, a tiny amount of black toner, a larger amount of cyan toner and an even greater amount of magenta toner to create dark purple.
- No dithering of multiple dots is required to create the dark purple dot.

Color Concepts 101

ImageREt 2400 - Multi-level Printing



Millions of solid colors

ImageREt

- Using this process, the HP Color LaserJet printers can, within a few pixel spaces, create millions of solid colors with exceptionally smooth gradient fills and sharp details.
- As a result, the very large halftone cells required to produce these colors in other color laser printers are no longer needed.

Color Concepts 101

ImageREt

HP Image REt 2400 has a dramatic impact on print quality.

- In the following illustration, the left photo is from a printer with a 600-dpi engine, but without HP Image REt 2400.
- The middle photo is from a 2400-dpi color laser class printer.
- Note the graininess and loss of detail.
- You can also see a loss of colors, which are not as true to the photo as the Image REt 2400 sample on the right.

HP Image Ret 2400 v. 2400-dpi Color Laser Quality

600X600 dpi Binary **2400 dpi color laser quality** **ImageREt 2400**