Digital Photography

Hand Out 01

Digital Cameras and Color Management

OVERVIEW

(This handout is based on the books: *Photoshop 6 Color Companion* by Jim Rich, *Photoshop 7 Artistry* by Barry Haynes and Wendy Crumpler, *The Digital Photography Manual* by Philip Andrews, "Understanding Image Sensors" by Michael Guncheon from the September/ October issue of Digital Photo Pro, Connected Photographer Website under the article What the Heck is a Megapixel by David Gewitz, Adobe Photoshop CS2 user guide and *Adobe Photoshop CS2 for Photographers* by Martin Evening.)

Like all machines, digital cameras are designed around ideas established by past inventions and theories. I believe it's important to understand how these concepts govern the design and function of the digital camera as well as the software designed with it. This handout is short discussion of major theories and functions of the digital camera.

COLOR MANAGEMENT TERMS

Color Space and Color Modes

Image modes, color space, and color modes are synonymous terms and are used to define, display, and print images from a computer.

Mode of an image defines the color space that supports the pixels of the image so it can be displayed and printed. Three major color spaces for reproduction are RGB, CMYK, and LAB color.

Modes and Channels

High quality 8 bit gray scale images are capable of having 256 levels of gray (values 0 – 255) and 16 bit can reproduce 65,536 levels of gray (2 to the 16 power). One gray scale image has one channel. Each color is represented in a gray scale and that gray scale representation is called a color channel. RGB and LAB color have 3 channels of color and CMYK has 4 channels. Each color mode or color space is made up of channels of numerical values that represent on the scale of 0-255 (256 values) the intensity or brightness of that color in the channel.

Bit Depth

16 bit and 8 bit per pixel refer to the amount of information in each channel. Most users of Adobe Photoshop work in 8 bit because it can use the whole range of Photoshop tools (like filters and layers- although Photoshop CS2 gives opportunities to do more in 16 bit). The disadvantage to working in 8 bit is the less information held in each channel. The more you manipulate an image in 8 bit the more the image will be corrupted. This corruption occurs each time the pixels are manipulated (like using the stamp tool, or excessive color selection) because the pixels are recalculated in whole numbers not in fractions. This will eventually manifest itself in fuzzy images and heavy banding of gradients. Many cameras capture only in 8 bit and its not recommended to up size images to 16 bit because it creates other kinds of

corruption, such as noise and color fragments. Higher bit depth isn't always the best option because it takes up more memory in your computer and thus harder to work with. Balance out your quality needs and performance of your computer.

RGB Color mode/space

RGB color space is based on additive color theory. This theory divides color into primary colors of light R(ed), G(reen), and B(lue) and secondary or complimentary colors of the primary colors C(yan), M(agenta), and Y(ellow). The same color theory is used in color photography; negative film captures the Red, Green, and Blue spectrum and the enlarger has filters with Cyan, Magenta, and Yellow to print the positive image. On the computer RGB color space can represent 16 million colors and each color is represented by a channel, thus RGB has 3 color channels. The drawback of this color space is different ranges of color that can be represented in this space depending on the RGB profile you use. Common color profiles in this color mode are sRGB, Adobe RGB 1998, and Color Match RGB. The color range or value range that is represented by each color profile is called a gamut. For instance, Adobe RGB 1998 can represent a wide range of colors, and so it is considered a color profile with a large gamut. A shorter gamut profile is sRGB which represents a shorter range of values. RGB is considered device dependent because of this discrepancy of color range. Each device you use can have a different range of representing the RGB color space. RGB color profiles help keep the devices consistent.

CMYK Color mode/space

CMYK color mode is a subtractive color model that defines C(yan), M(agenta), Y(ellow), and blac(K). This mode represents the four common inks used to produce color in printing. The range of color is defined by the percentage of ink on the paper from 0% (white) to 100% ink (black). CMYK is also device dependent because each printer device represents color differently and inks vary in color purity. Color profiles are important when using this color mode as well. A common color profile is U.S. Web Coated (SWOP) v2. Color profiles in CMYK color space create a way to define CMYK output device that works with the RGB working space of your monitor.

LAB Color mode/space

LAB color space describes colors numerically. By using LAB it is possible to measure the same color with the same LAB values and have a visual match. In 1931, the Commission International de L'Eclairage defined a color model that provides a standardized mathematical approach to viewing and defining color. The CIE System is universal because of it's ability to standardize color data from different sources. It is also possible to represent all visually perceptible color spaces. Adobe Photoshop, as well as many other modern color management systems, use CIE or LAB as part of it's underlying calibration system. In fact when you convert color from one color space to another Photoshop first converts the image to LAB and then to the destination space to keep accurate representation of the color of the image. The three variables (or channels) of LAB space are L (luminance) which are the values of grays between 100 = white and 0 = black. This channel carries most of the image details. The "a" channel encompasses Redness (positive) to Greenness (negative), while the “b” component encompasses Yellow (positive) to Blueness (negative). The positive and negative values of the channels range from +128 to –128. The “a” and “b” channels influence the color of the image. This color space can be used in both 8 bit and 16 bit images. Lab is also used to create measurements for ICC profiles.

Color Gamut
Color Gamut is defined as a range of color. A wide gamut means working with a color space that has a large color variation in values. A short gamut has little range of values. Out of gamut refers to colors that cannot be reproduced or represented by a color space.

COLOR CAPTURING AND REPRESENTATION, WITH DIGITAL MEDIA

Additive Color theory:
This theory divides white light into 3 colors, RED, GREEN, and BLUE. Adding all colors at full intensity creates white light. Two primary colors make a secondary color (or complementary colors), they are: Cyan (made of Blue and Green and the opposite of Red), Magenta (made of Blue and Red and the opposite of Green), and Yellow (made of Red and Green and the opposite of Blue). Because this color star is created by light, it differs from the traditional color wheel created by pigment.

Film and film development are based on Additive Color Theory. If you are familiar with color printing you will recognize the concept. Color film captures images with three layers of silver sensitive filters (the orange cast of color film). There is one layer for each of the primary colors of the light color Star. The light rays pass through the aperture and strike the film. Only the light waves of Red pass the through the Red filtration while Blue and Green are absorbed. Only Green light waves pass through the Green filter and the Red and Blue are absorbed and so on with the Blue filtration. When printing from a negative you use the secondary colors of Cyan, Magenta, and Yellow to create color photographs. This is how one creates a color balanced photograph. For example, if an image is too Red than you add Cyan to take the Red out of the image.

This same theory governs how the camera captures images with photo- cells of the digital camera. Colored filters over the photo- cells capture the Red, Green, and Blue spectrum of white light. The current created by light (light after all is also heat and energy) is converted with aid of the computer chip into the final image displayed on the LCD and computer. Viewing images on the monitor is also based on the additive light theory. A monitor displays combinations of Red, Green, and Blue pulses to create color.

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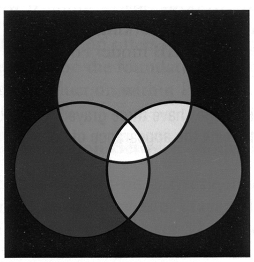
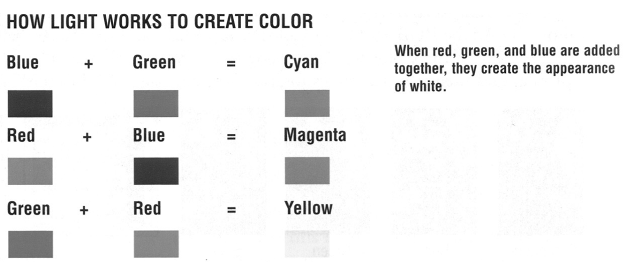
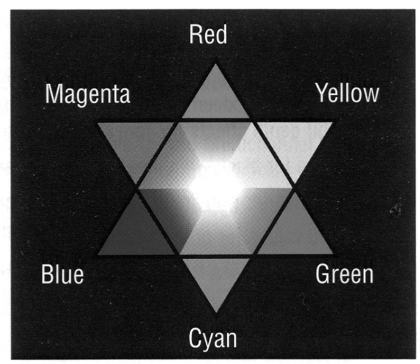
Subtractive Color Theory:

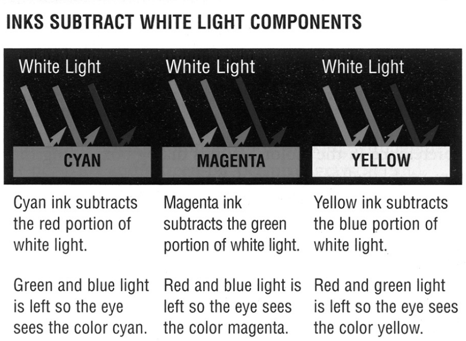
Cyan, Magenta, and Yellow pigments subtract components of white light to create colors reflected off a white piece of paper. The ink (composed of the secondary colors of the color star) acts as a filter that absorbs part of the color spectrum, which reflects the remainder of the colors into the eye to simulate color.

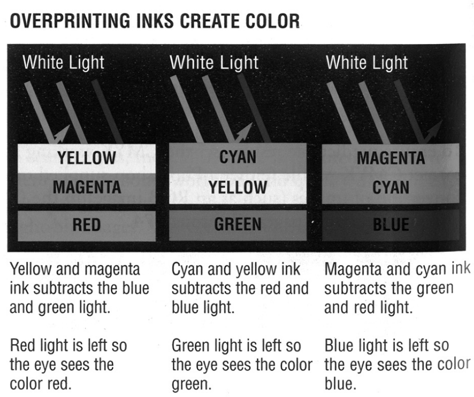
In contrast to the way color is captured and displayed with digital media, the Subtractive Color Theory is based on four-color screen-printing techniques. This theory governs how your ink-jet printer out-puts your images. The theory still uses the idea that white light is created by three primary colors, but this time the primary colors are reflected off a white surface which in return reflects the color into the eye. For example, white light is all three primary colors combined. So to create the color blue, the secondary colors of Cyan (which will absorb the Red spectrum of the light), and Magenta (which will absorb the green spectrum of the light), must be printed on the paper to reflect the remaining Blue primary color into the eye.











Rich, Jim. <u>Photoshop 6 Color Companion</u>. Pittsburgh: GATF press, 2001.

Design of the Digital Camera

The Digital Camera is similar to the design of a film camera. Any camera is basically a black box with a lens on one end that focuses the light onto a light sensitive material. The three basic factors of exposure remain in digital photography. The aperture controls the amount of light focused on the image area and the depth of field of the image captured. The shutter speed controls the time for the exposure from the aperture. The final factor is the sensitivity of the image-capturing device. Film is a light sensitive material made up of silver bromide that reacts to the intensity of the reflected light of objects directly in front of the camera lens. This captured image is then chemically changed into a negative and can be eventually printed as a positive image. Instead of film, a digital camera has a grid of light sensitive photo-cells that react to the intensity of reflected light. The ISO setting of the digital camera is mimicking the sensitivity scale of film types from ISO 50 to usually ISO 1600. The higher the ISO number the more sensitive to light the photo-cells are. In film, the grain is larger on higher speed films and not densely packed, this is combined with a higher chemical sensitivity to light. The results of this formula create very grainy and diffused images, but also the ability to capture images in low light without long shutter times or small depth of field. Digital sensitivity is similar, but not exactly the same. The sensors do not change size with the higher ISO setting; instead the electronic charge from light is artificially amplified to create a higher sensitivity to light. This creates certain problems that relate exclusively to digital photography.

Presently there are two types of image capturing devices used in digital photography. The most common is called a CCD or Coupled Charged Device, and the other is called a CMOS or Complementary Metal Oxide Semiconductor. CCD refers to the design of the chip while CMOS refers to the chips manufacturing process. Both are designed to convert light into an electronic charge.

As mentioned before, CCD's are made of a photo-cell grid and a storage area to hold the charge made from light striking it. This charge is moved from the holding area to a transfer register one row after another to the register. This process is termed coupling, and that is how this sensor gets it's name by coupling the rows of the photon charge one row at a time. From the transfer it is converted into digital information at another processor chip inside the camera called an ADC or analog (the electronic charge) to digital converter (in this case digital means bits and bytes or zeroes and ones) and is positioned into a grid based on the pattern of the CCD. In order to create a color image the photo-cell grid is comprised of interlacing color filters in a mosaic pattern (the primary colors of the color star Red, Green, and Blue) that cover the cell grid. Each cell captures one color and then an algorithm interpolates the full color spectrum for the image.

One of the problems with digital photography is the irregularity of color captured in the image. This is usually called noise. Noise is created by two factors. The first factor is the design of the CCD. It takes time and battery power to accomplish the processing of photons of light into digital information. Heat is created from this process and is amplified by the transfer of electrons as well as the heat released from the battery to power this process. The higher the ISO setting of the camera the more that electron signal is boosted and the more heat is created from the battery. The CCD photo-cells cannot distinguish between the light (remember light is also energy released as heat) radiating from the image in front of the camera and the heat generating from the camera itself. The CCD records this energy on the image area as color variations. The other factor to noise is infrared light. The photo-sensors capture light monochromatically. Colored gels over the cells capture a specific part of the spectrum of light. Because colored gels cannot distinguish a drastic difference between red spectrum of white light and infrared wavelengths of light, the sensor dedicated to reading red also records infrared information, which again increases the noise, or extra color information recorded to digital files. The infrared capture also allows the camera capture images in low light settings. This is also the reason why digital images that are not color corrected look pink or magenta in certain tones (for instance skin tones-especially if the subject is flushed).

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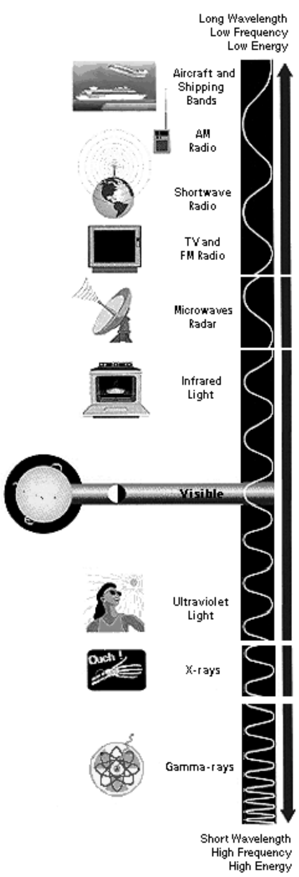
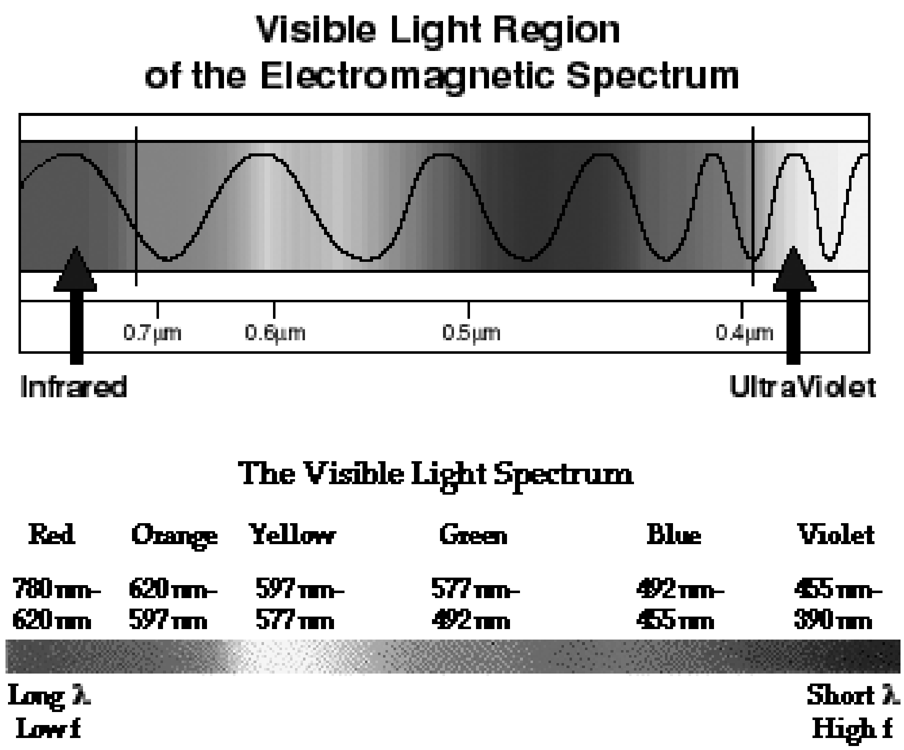
CMOS is also composed in a grid pattern. The difference is that the photons of light are partly converted to analog at the photo-cell itself and not transferred to anther holding area and then transferred again to be processed. The grid is still interpolated and finally converted, but it is not read out row by row like the CCD. For the most part CMOS chips (actually processors) use the same interlacing colored gel mosaic over the photo-cells to create color images. Foveon is the only manufacturer that uses a CMOS processor with it's photo-cells and does not use the mosaic grid. Instead it has one filter over the whole photo-cell grid comprising of the three layers of colored gels that filter primary colors of white light. This method is mimicking how color film records color (the Sigma SD D-SLR uses this technology). Because the CMOS converts the energy of light partly at the photo- cell it is more efficient with battery power, but this does not translate into less image noise. Since energy conversion is at the photo-cell and each conversion works at different efficiencies, this process creates heat and this energy release is read as light to the sensor. In fact, you may have more noise with a CMOS than with a CCD. However, you gain in faster transfer rates of information and longer battery life when you have CMOS processing chip.





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Camera Resolution: Megapixels and Megabytes

The definition of a Pixel is a picture element. One million pixels equals a megapixel. Each photo-cell of your camera will capture a certain amount of pixels, this depends on the size of the sensor grid and how densely packed the sensors are on the grid. The quality of your camera is not necessary in the amount of megapixels it can capture but the size of the sensor combined with amount of megapixels it can capture. For example, a 6 megapixel camera that has CCD that measures one inch by half inch does not have the same quality as a 6 megapixel camera that is one and half inches by inch. The more surface area there is to capture an image the greater the quality of the image represented. Thus an older camera that is a 3.3 megapixel camera but has a large image sensor could have greater image detail than a newer 6 megapixel camera that is super compact.

The digital camera is a small computer. Computers process data in binary code called a bit. A bit is the smallest unit data and can either be a one or a zero. Eight bits equals one byte and 1,000 bits equals 1 kilobyte or K for short and 1,000,000 bits equals one meagabyte or M. (These numbers are rounded for easy addition. Actually a kilobyte is 1,024 bits and a megabyte is 1,048,576 bits, or 2^10 and 2^20 respectively) For example a file size or 12 megabytes would be represented as 12M. This may seem academic, but understanding this basic architecture will help in determining your file size for printing.

Images are broken down into Red, Green, and Blue. Each color of the image is in it's own channel. Channels can have either 8 bit depth or 16 bit depth. The most common bit depth of an image is 8. To understand how that translates to image detail, lets do some math. A bit has a factor of two (remember a bit can be one or zero). Two to the power of 8 (8 bit depth = 2x2x2x2x2x2x2x2) will equal 256 value variations. So each pixel can represent a value from 0 to 255. One pixel is in essence one byte of information (8 bits = a byte and a pixel has a bit depth of 8). Each channel can represent 256 shades or colors.

Now lets take this information and translate it into file size. When printers talk about resolution of an image they talk about the size in Dots Per Inch or DPI. Cameras will sometimes call the same resolution PPI or pixels per inch. The terms DPI and PPI are interchangeable in terms of resolution. For example, a 300 DPI image means that in every square inch is made up of 300 dots (or pixels).

Applying this to picture making takes more math. First lets figure out how many megabytes are in a one square inch at 300 DPI. A square inch at 300x300= 90,000 pixels per inch. 90,000 pixels divided by 1 megabyte (or 1,000,000 bytes ((again one byte = one pixel)) equals .09 M. An 8x10 image at 300 DPI will equal 7.2 megabytes (8x10 = 80 square inches multiply that by .09 = 7.2 megabytes). At the beginning of this discussion on megapixels and megabytes I mentioned that each image is made up of 3 channels. We now have to factor the other two channels of information into file size. 7.2 megabytes would be the file size of a black and white image (one color = one channel). For a full color image with 3 channels (Red, Green, and Blue) the file size will be 21.6M.

Lets work at this from a different direction. Let's say you would like to have a digital camera that can make 8x10 prints at 300 DPI. What size megapixel camera will you need to purchase? 8 multiplied by 300 = 2400. 10 x 300 = 3000. 3000 x 2400 = 7,200,000. 7,200,000 ÷ 1,000,000 (1 megapixel) = 7.2 megapixel camera. Now from what we know from the previous calculations that is not the file size of the image. 7.2 megapixels is the camera you would need to make an 8x10 photograph, but that means that camera captures 7.2 megapixels for each channel of color. So the actual size of a 7.2 megapixel camera file would be 7.2x3 = 21.6 megabytes of information for one image at 300 DPI.

Lets take this further. You have a media storage card that is 512M. How many images can you store on it? A six megapixel image is actually 6 x 3= 18M. 512 ÷ 18 = 28 digital photographs at full resolution.

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LECTURE NOTES