Understanding pixels – what is a digital image and how does it compare to film?

Electronic Imaging Consulting

To understand pixels, let's start with discussing how photography captures the patterns of lightness, darkness and varied colors that the eye sees.

Traditional black and white photography uses a clear plastic film base covered with a layer of chemicals – the emulsion –, which contains some combination of silver halide crystals in a random orientation. These silver halide crystals may be silver chloride (AgCl), silver iodide (AgI) or silver bromide (AgBr) and when referred to in general, are called "AgX" crystals.

In a camera, when light from the scene hits these silver halide particles, a latent image composed of very small metallic silver specks is formed. Chemical development of this latent image results in a negative image of the scene made up of larger and smaller metallic silver grain clumps. Areas of the scene that were bright produce larger, denser silver clumps while darker areas produce very small or no silver clumps. These silver particles of various sizes are arranged to form the image.

Digital imaging sensors carry out the image capture job in a fundamentally different way. Digital images are referred to as being "sampled", and they are sampled in two ways: in space and in brightness.

"Sampled in space" means that image sensors are composed of a number of light sensitive areas arranged in a fixed, regular pattern, like a checkerboard and not a random pattern like the light sensitive silver halide particles in film. The total number of these light sensitive areas – which are called PIXELS, short for picture elements – is important to image quality. The more pixels on the sensor, the higher quality (details and sharpness) your image will be. Because the pixels are arranged in a regular pattern, they can be fooled by a subject that contains a regular pattern of fine detail (like stripes on a shirt). Two or more stripes may fall on the same pixel and end up as one stripe in the digital image. This is called "aliasing" and results in high frequency information (fine detail) being converted (or aliased) into incorrect, low frequency information (course detail). In a picture of the striped shirt, you might see bands of broad stripes running across the shirt instead of fine stripes.

"Sampled in brightness" means each pixel can have only one value that represents the total light hitting the pixel – if the light hitting a pixel is half black and half white, the pixel would report that as gray. In addition, the one value can only be selected from a limited number of values determined by the number of "bits" (binary digits) the pixel can capture. A binary digit can be either 0 or 1. Combining binary digits into groups (called bits) produces all the decimal numbers. The more bits captured by a pixel, the better the image will be because it has more brightness levels. In general, about 8 bits, which gives 256 brightness levels, is sufficient for most uses. See table.

More bits per pixel can be useful if you are working with professional images in something like Photoshop, but that's a topic for another article.

Color photography "is the same as black and white but different". Our eyes see a variety of colors in a scene because sensors in our eyes (called cones) are sensitive to red or green or blue light. What we see as sharpness is a mix of the three colors, but is really mostly due to the green light (About 30% is due to red, about 60% is due to green, and only about 10% is due to blue.)

There are two different color systems – additive and subtractive. Additive color mixes red, green and blue light. An equal amount of all three produces white light. Projection television sets use the additive system and so does your computer monitor. Subtractive color removes red, green and blue from white light, and color photography using film is based on subtractive color.

Color film has three layers – a red sensitive layer that produces cyan dye (cyan is blue-green), a green sensitive layer that produces magenta dye (magenta is red-yellow), and a blue sensitive layer that produces yellow dye. Cyan dye removes red light, magenta light removes green light, and yellow dye removes blue light.

With color reversal (slide) film, red light exposes the AgX in the cyan layer. In the development process, reversal film is first subjected to a black and white developer that converts the AgX in the exposed layer to metallic silver leaving the AgX in the other two layers unaffected. The film is then "reversed" – either by exposure to light or with chemicals – making the AgX in the other two layers developable. A special color developer is then used in which the developing agent used to convert the AgX to silver then combines with a chemical (called a dye coupler) to form a colored dye. In the case of this red exposure, the color developer will form magenta and yellow dye in the two layers not originally exposed by red light, but will not form any cyan dye. When we pass white light through the developed reversal film, the magenta dye will remove green light and the yellow dye will remove blue light – this leaves only red light, which is what we want. All other combination of colors are formed in a similar way.

With color digital photography, most digital sensors use a colored filter mosaic dye pattern superimposed on the sensor, so that any given pixel sees only red or green or blue light. Since green light is the most important component of sharpness, typical dye patterns will have two pixels of green for every pixel of red and blue.

Note that each pixel captures only one of the three colors. To create a full color image, software in your camera (or computer) must "guess" at the missing two colors. Originally, the image reconstruction process just averaged the values of the nearest neighbors of the same color. This could result in some pretty poor "guesses" and resulted in a lot of colored "confetti" artifacts appearing in images. Over the last 12 years, it's been possible to put a lot more computing power in digital cameras. This makes it possible for the image reconstruction calculations to be a lot smarter. In the digital cameras available today, this smarter color processing and many more pixels means that noticeable image artifacts are now rare.

Color digital photography uses both additive and subtractive color – additive when images are displayed on a computer monitor and subtractive when images are printed. Conversion between the two systems is just a matter of simple subtraction.

The new RAW file format that is becoming popular in prosumer cameras is basically just the raw data captured by the sensor. Instead of this data being converted to a full color image in the camera, a RAW file allows you to do the image reconstruction in your computer. This offers you complete control of the process – much like printing a color negative in your darkroom.

I should mention that a company called Foveon has developed new X3 sensor technology that doesn't use a color filter on the sensor. Instead, it relies on the fact that red, green and blue light penetrate the sensor's silicone to different depths, making it possible to capture all three colors of light at each pixel location. This sensor is being used in the Sigma SD10 digital camera.

One question that always came up when I was making presentations on digital imaging for Kodak was "how many pixels does 35mm film capture?"

There really is no universally accepted way to convert an AgX image into its 'PIXEL' equivalent, but I've always approximated the pixel equivalent in the following way:

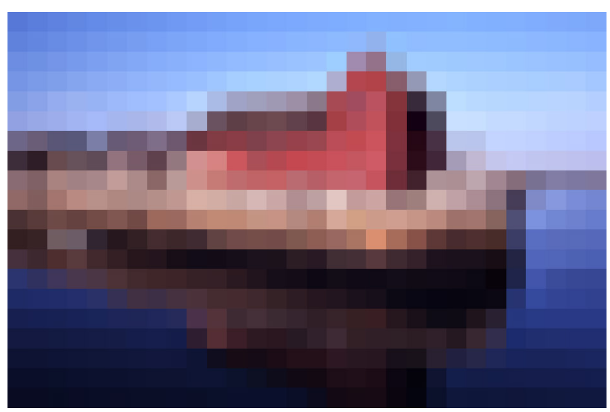
The resolving power of typical 100-speed color negative film at medium contrast is around 65-line pairs/mm. Remember that a line pair represents a BLACK line and a WHITE line - so a line pair represents two pixels. This means this film has around 130 pixels/mm. For a 24 X 36 mm 35mm frame this gives 14.6 million pixels.

Lots of things like camera shake, dirt on the camera lens and misfocus can greatly reduce the actual number of equivalent pixels. When Kodak developed the PhotoCD product line about 12 years ago, they decided that the typical amateur 35mm frame only contained about 6 megapixels worth of data.

I'm always looking for possible digital imaging topics to write about so if you have any digital imaging questions of general interest, please email them to me at fshippey@mac.com.

Figures:

motif1
Fishing wharf in Rockport, Massachusetts, USA. Often photographed and painted and known as "Motif #1". 1500 pixels wide by 1000 pixels high. 8-bits per color which can reproduce 16.78 million colors.



motif1_20x30
"Sampled in space." Original image reduced to 30 pixels wide by 20 pixels high. Still 8-bits per

color but notice that each pixel is just a single color.

motif_3l
"Sampled in brightness." Original image (1500x1000 pixels) reduced to 3-bits per color. 3-bits per color can reproduce only 512 colors.

motif1_g_comp
The Green channel of the original image as a grayscale image. The left half has 256 levels (8-bits) while the right half has 8 levels (3-bits).

Table:

Bits	Number of Grays	Number of Colors
1	2	8
2	4	64
3	8	512
4	16	4096
5	32	32768
6	64	262144
7	128	2097152
8	256	16777216
9	512	134217728
10	1024	1073741824

In black and white photography, if we have just 1-bit of data, we can have 2 possible gray levels (black and white). In color photography, with 1-bit per color we can have 2 levels of red times 2 levels of green times 2 levels of blue or 8 different colors (2x2x2=8).

In black and white photography, if we have 2-bits of data, we can have 2x2 or 4 possible gray levels. In color photography, with 2-bits per color we can have 4 levels of red times 4 levels of green times 4 levels of blue or 64 different colors (4x4x4=64).

And so on.

8-bits per red, green and blue channel will reproduce about 16.78 million colors which are plenty for most of our digital photography needs. However, some professional cameras capture 14 or 16 bits per color allowing more control when carrying out image enhancement procedures.

Sidebar:

The way digital images are sampled in space and brightness makes it possible to transform them from the spatial domain that we see to something called the frequency domain and back again using a form of math called Fourier transforms. Open any book on digital image processing and you'll see lots of Fourier math. It may sound like magic to most of us, but this mathematical magic makes it possible to performs all kinds of digital image processing tricks using programs like Photoshop. Luckily, someone else has worked out all the mathematics and we can just enjoy the results.