

THE NEW DIGITAL MANTRA: RESOLUTION, RESOLUTION, RESOLUTION!

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By far, the most misunderstood concept that has caused more problems and frustration than anything else is **resolution**. People talk about resolution when they are choosing a digital camera, when they are using a scanner, when they are scaling their images for 1:1 output, when they are enhancing their images, or when they are purchasing a printer. No wonder they’re confused!

Don’t get me wrong, image quality, image authenticity and image enhancement processes are critical issues to consider when you are presenting digital images in the courtroom. Resolution can affect these issues adversely as well!

In fact, resolution affects every single facet of digital imaging from choosing the appropriate digital camera to choosing the proper image format to determining how much you can zoom in on the displayed image to choosing the appropriate output device.

In the beginning, I was amused by some of the misconceptions of resolution; now I am simply amazed at the misunderstandings of resolution. I have found that there are a vast number of people, both technical and non-technical, who do not know the difference between a pixel and a dot. Some people will even tell you that you can use the terms “dot” and “pixel” interchangeably. A word of advice: “Don’t do it!” The terms dot and pixel have very different and distinct meanings, and these terms guide every step we take in the world of digital imaging.

Resolution is a fairly basic concept that has been used since computer images began to be displayed as artwork as far back as 1965.

However, there are several recent technical innovations that affect image quality even though they are not resolution-specific. The paper you choose, the inks you use, and even the printer settings you select significantly impact the quality of your digital image even though those issues have nothing to do with the actual resolution of the original image. Failing to understand these issues can cause you to degrade the image quality during the printing process, even when you are printing a high resolution digital image.

I also find it amazing that law enforcement agencies spend thousands of dollars on high resolution digital cameras, but then print their images using “inexpensive” inkjet printers on “inexpensive” paper. Then they complain about the poor quality of their digital images.

For those agencies that are cost-conscious, I would like to point out that the cost to produce an 8 by 10-inch glossy print on Premium Glossy Photo Paper is approximately \$1.25 (both ink and paper cost).¹ This is significantly less than the costs associated with traditional film processing and printing.

What I find most frightening is the number of agencies that buy “inexpensive” (cheap) digital cameras just because they are affordable, and use the argument that they are “good enough.” The reason for my concerns is that image quality degradation has a serious side effect in a forensic environment. You should ask yourself how well can you defend image quality and image integrity in the court room because of color interpolation and image compression? Defense attorneys are learning to challenge the integrity of digital images because the image format used at the point of capture creates artifacts within the final image. Therefore, resolution must be considered throughout the entire imaging process.

Let’s start by defining two crucial elements: image resolution and printer resolution. “Image resolution” refers to the actual number of pixels within a digital photograph — this is the actual number of pixels captured by the digital camera or the scanner. “Printer resolution” refers to the way ink is placed on the paper — typical desktop inkjet printers can place 1440 dots within each inch of the final printed image regardless of how many pixels are contained in the actual captured image. In other words, a seven-inch wide image could be captured with a sensor resolution of 1904 pixels that would be represented by 10,080 dots across the width of the image when it is printed.

Confused? It is easy to understand why people get confused when you start applying numbers to the process because the numbers don’t always seem to make sense. (And we’re not talking new math here!) Taking a closer look at these two definitions will help you understand why there are so many issues to consider when capturing, storing and printing digital images.

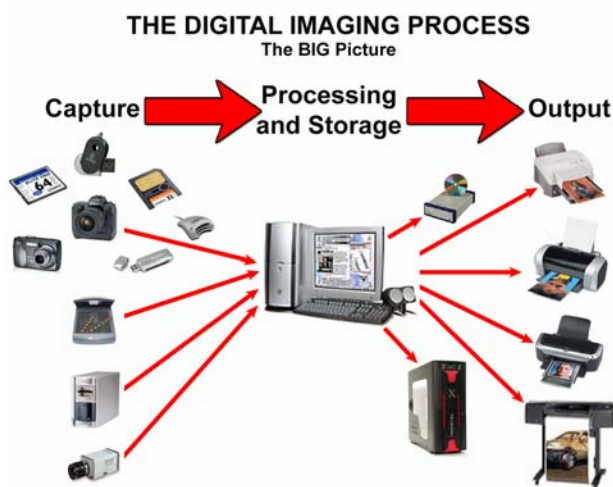


Figure 1. By looking at the different components within the imaging process, it is easy to understand why so much confusion exists!

To begin the digital imaging process, you must first identify the effective resolution of the sensor in the camera. Generally speaking, image quality improves when you use a digital camera that captures more pixels. But then again, the perceived image quality depends upon what

¹ Based on cost information provided by Epson America, Inc. using the Epson Stylus Photo 2200.

you are going to do with the image. Are you going to send the image across the internet? Are you going to print it? If so, how big are you going to print it?

In addition to knowing how many pixels you need to capture, you must identify the actual size of the sensor itself. They always say bigger is better, and in this case it is certainly true! The size of the sensor and the number of pixels on that sensor can also be affected by the optics of the camera, including factors such as how much you zoom in on an area. Equally important is your understanding the camera settings because these settings affect how image data is interpolated, not only in terms of brightness and contrast but more importantly how color is processed based upon the resolution and physical size of the sensor. More simply stated, it is extremely difficult to capture an incredibly sharp image using a small sensor.

Both Canon and Kodak have sensors that are approximately the same size as a standard 35MM frame. These larger sensors allow you to use different lenses, which allow you to capture both smaller and larger areas more accurately. Using a macro lens, you can capture a fingerprint, blood spatter, hair and fibers, and so forth with a very high resolution. With a wide angle lens and the same sensor, you can capture a palm print, shoeprint, or tire tread with a resolution that is still sufficient to provide a high level of detail.

You must bear in mind, however, that resolution is an inverse function: the smaller the area captured, the higher the image resolution. The larger the area captured, the lower the image resolution. Using a macro lens, the area “captured” by the sensor might be one and a half inch by two inches; using a wide angle lens to capture a shoeprint, the area captured by the sensor might be 12 inches by 7 inches. Both images would have exactly the same number of pixels within the image, but the final “image resolution” would vary anywhere from approximately 2300 PPI (2300 sensor pixels to capture a one inch area) for the fingerprint to approximately 650 PPI (650 sensor pixels to capture a one inch area) for the shoeprint. In either event, the larger the sensor and the more pixels there are on the sensor, the clearer and sharper the image will be rendered.

In terms of output resolution, most printer manufacturers recommend using a capture device that captures images with a final resolution from 240 PPI to 300 PPI in the printed image. (Some printer manufacturers state that having more than 300 PPI in the final image will actually degrade the image quality when the image is passed to the printer driver from the imaging application. They state that pixels are discarded using a simple averaging algorithm, which can cause blurring of fine image detail.) Following those basic guidelines, the image file size should be approximately:

<i>FILE SIZE</i>	<i>FINAL PRINT SIZE</i>
4 – 5 MB	4 inches by 6 inches
7 – 10 MB	5 inches by 7 inches
13 – 20 MB	8 inches by 10 inches

To understand why this is so important, let's discuss the resolution required to capture two straight lines. To fully understand this example, you must understand one crucial feature of a pixel: a pixel can have only one color value! This means that you cannot split a pixel and make it half black or half white. Therefore, to maintain the separation of the two straight lines, you must have a minimum of 5 pixels in a single row.

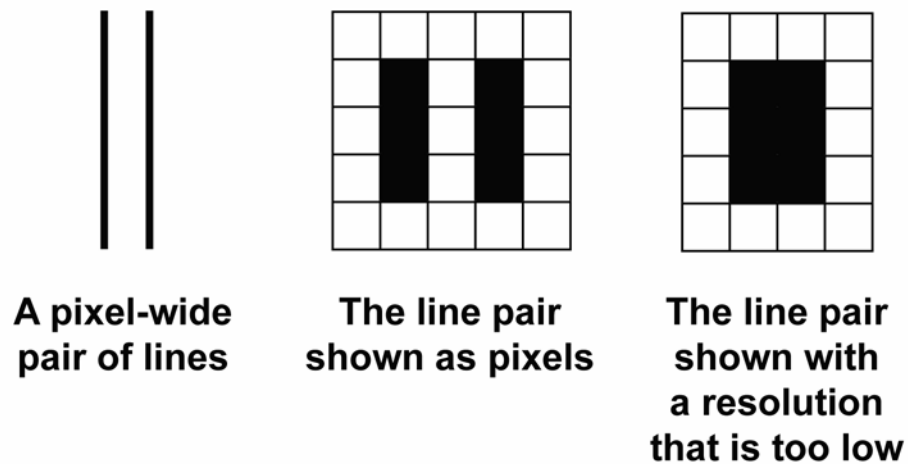


Figure 2. A simple line pair illustrates what happens when you don't have sufficient resolution to distinguish between the individual lines.

Insufficient resolution will cause the lines to appear blurred or will cause them to run together creating the appearance of a single line instead of maintaining their separation as two separate, distinct lines.

But wait! Resolution by itself does not indicate image sharpness or size. The same number of pixels can be spread over a small area or a large area on your monitor or your printout. What this means is that if you have a low resolution image, the perceived sharpness of the image falls as the pixels are spread over a larger area. Conversely, if the pixels are squeezed into a smaller area, the perceived sharpness increases. That is why images on a monitor appear sharper than they are when printed, because the available pixels are displayed in a much smaller area and you can't see the intricate detail when the image is viewed on the monitor at a normal viewing distance.

However, if you zoom into the image you will begin noticing the loss of detail in a low resolution image. Using our line example, if you start off with two separate lines when

you capture the image, you can lose separation of the lines if the image is displayed too small on your screen.

The quality of the output device can also cause problems such as blurring the lines or making them “appear” indistinguishable because of the difference between the image resolution and the printer resolution.

During the printing process, you not only need sufficient resolution to keep the lines separate, but you must also print it large enough to show the level of detail. If the image is printed too small, too much resampling occurs, which reduces the image resolution causing the lines to blur together. If the image is printed too large, sharpness will begin to fade and the image will appear pixilated even though you can identify two separate lines. (OK, Goldilocks! When is it “just right?”)

If you remember nothing else about digital imaging, you should always remember that the final size and the quality of the image depends upon both the resolution of the original image as well as the resolution of the output device whether that output device is a monitor or a printer.

In addition to printer resolution, we need to understand a technique called halftoning — a process that defines how many pixels can be printed using a set number of dots. This is also where a great deal of confusion is created by the terms pixels per inch (PPI) and dots per inch (DPI).

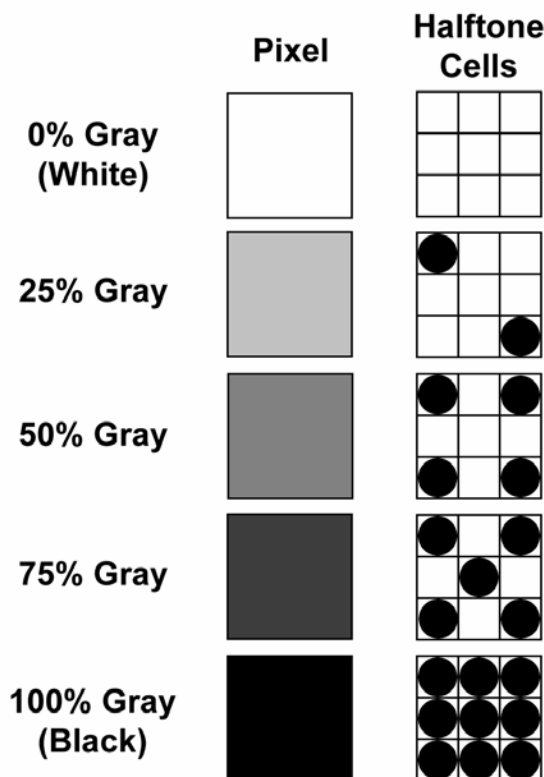


Figure 3. When a pixel is printed using a laser printer or an ink jet printer, each pixel is converted into a series of cells. In the case of a black and white laser printer, each cell is filled a black dot, or the cell is left blank.

In the case of a color laser or color inkjet, each cell is filled with a specific color dot: Cyan, Magenta, Yellow or Black. Many new printers, such as Epson, HP, Canon and so forth, use multiple ink colors, such as Cyan, Light Cyan, Magenta, Light Magenta, Yellow, Light Yellow, Black and Light Black. These color variations help provide greater contrast and improve image quality.

So how are dot values translated to represent the color value of a single pixel? Using a traditional 8-bit process, a linear array of 1200 dots within an inch provides an equivalent of 150 pixels within that one inch (1200 dots divided by 8 dots per pixel (the dot width of a pixel) equals 150 pixels).

The dichotomy? Many law enforcement agencies require images that are to be used for comparison, such as latent prints, blood spatter, questioned documents, DNA samples and so forth be captured with a high resolution. To comply with FBI IAFIS requirements, a latent print must be captured with a minimum resolution of 1000 PPI, but must also be printed as life size. Unfortunately very few people understand why that requirement exists or worse, they don't understand the implications of printing the image at life size or as an enlarged image.

Simply stated, latent prints must have a minimum of 1000 pixels along each side of the area containing the print, where the area containing the print must measure one inch on each side. In other words, you must account for both the two dimensional physical size (width and height) as well as the number of pixels contained within those measurements.

If the comparison is performed on screen, this high resolution requirement pays off. If, however, the image is to be printed as life size, the unused pixels are actually discarded during the printing process. (As discussed previously, most desktop printers print from 240 pixels per inch to 300 pixels per inch depending upon the printer being used, the number of inks used by the device, and the type of paper used.) Only when the images are enlarged during the printing process will you "see" the value of the 1000 PPI resolution.

How large can you print it? If you capture an image with a 3.7 MegaPixel (MP) camera (resolution of 2240 x 1680 pixels), the output device and the quality of paper determines how large you can print the image without interpolation – the process of creating additional pixels using an averaging technique to fill in missing pixels.

For instance, using a dye sublimation printer (such as the Kodak 8500 Digital Photo Printer or the Olympus P440 Digital Photo Printer that prints 314 pixels per inch) to print a 5 by 7 inch picture, you would need to have a minimum of 1570 pixels by 2198 pixels in the original image resolution. The 3.7 MP camera described above will capture a sufficient number of pixels to accurately print a 5 by 7 with pixels left over. If you wanted to print an 8 by 10 of the same image, you would require 2512 pixels by 3140 pixels. In this case, you would have to create 748,800 pixels, which is an increase of the 3.7 MP resolution by 832 pixels by 900 pixels.

In the past few years, printer manufacturers have worked diligently to improve digital output quality using bidirectional printing, multi-pass droplet offsetting as well as dot layering, and additional ink colors beyond the traditional CMYK. You don't have to be a rocket scientist to figure out why there is so much confusion about resolution when manufacturers start touting their increased dot per inch capabilities, nozzle size, and

dithering capabilities. And the latest term to confuse the end user is a term called “addressable printer resolution.” Due to the limited space in this article, we aren’t even going to go there!

As the quality of the output improves – based on the quality of paper, number of inks, quality of output device, and so forth – the number of pixels required increases. Failure to have a sufficient number of pixels to print the appropriate sized image will result in “pixilation.” Pixilation can be defined as a slight blurring around text to significant blurring around text, and from minor color gradation changes to considerable color gradation changes, resulting in the appearance of artifacts. The more pixilated an image, the more blurry and stair-stepped the image appears.

Simply rotating (using arbitrary degree rotations other than 90 degree movements) an image can also cause a whole multitude of resolution problems, primarily pixilation, color manipulation, and aspect ratio manipulation.

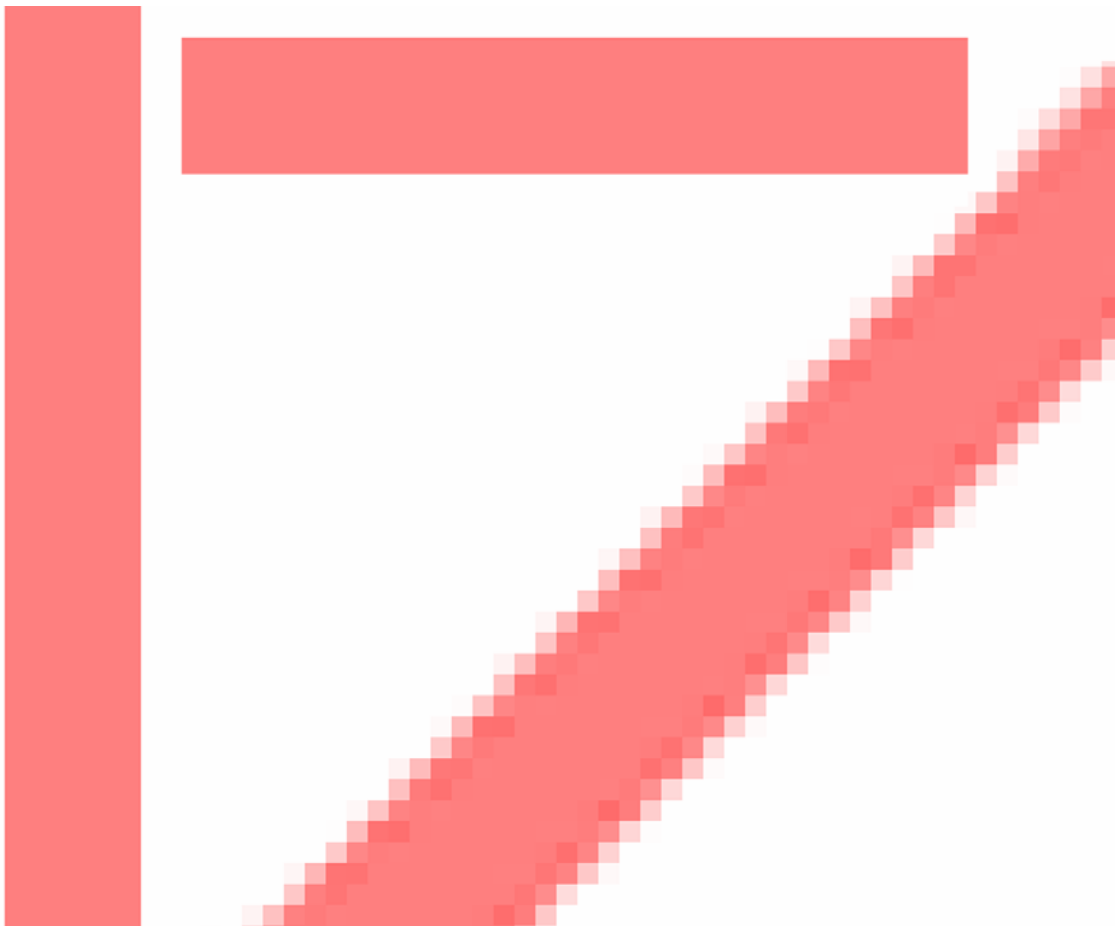


Figure 4. Rotating an image can have some very serious side effects.

While output quality varies with the make and model of the various printers, the final image quality is actually affected more by the quality of the paper you use. I am

endlessly amazed at how many law enforcement agencies are using an “inexpensive printer” with a poor grade of “copy” paper in their printers, and then are disappointed and frustrated because the image quality does not meet their expectations. (I am also shocked by the number of people who don’t know how to change the printer settings for their printers!)

Image quality is lost with inexpensive grades of paper because these papers are very porous. When the ink is sprayed onto the paper, the ink is absorbed into the paper, which causes the ink to spread. The higher the quality of paper, the less the ink is absorbed, and the more accurately the ink is controlled.

Now that we have looked at resolution for both ends of the process, let’s look at what happens in the middle, from the time you press the shutter release button on your camera until to you get to see the final printout.

As we have already discussed, image quality (resolution) is first defined by the number of pixels on the sensor in the camera. This resolution is then “adjusted” based upon the format used when the image is stored during the capture process. Many cameras use JPG as the most popular method for storing digital images in a camera. The concept behind this format is that a lower resolution, hence smaller file, is an acceptable tradeoff for the loss of image quality.

The argument is that the loss of image quality isn’t “significantly” noticeable unless you are using a low image quality setting. But in the case of most forensic imaging applications, any image quality degradation affects how clearly you can see fingerprint details, the directional flow of blood spatter, the shape of an identifying artifact in a shoeprint, etc.

Most people understand that JPG is a lossy compression routine. They also understand that higher resolution provides better image quality, so they buy high resolution cameras. But image storage is often limited because of the memory device used in the camera, so they use a low resolution JPG format so they can store more images in the camera.

What they fail to realize is that during JPG compression, **actual pixel data is discarded.** However, the image quality (the actual number of pixels used to capture the image) is recorded as part of the metadata within the file. Based upon the camera that you are using, this image quality can either be an interpolated value, where additional pixel values are made up using existing pixel values within the image; or it can be a compressed value, where the actual pixel information is discarded before the image is saved.

When the file is displayed, the discarded pixels are recreated using a sampling technique. The lower the image quality setting, the more information that is recreated. The common symptoms of low image quality settings (also known as JPG artifacts) are less sharpness, poor color gradations, weak contrast and blocky details. These artifacts are typically

most noticeable in areas where there are only slight color gradations, such as in the sky, water, and so forth.



Figure 5. The affects of JPG compression/decompression can be very harmful. The more it is compressed, the more “blocky” it becomes when it is viewed at full resolution.

The solution for “blocky” details is to set the digital camera to the highest quality setting even though that means larger file sizes. For optimum results, you should choose a digital camera that provides either RAW or TIF image file format settings. From a purely technical point of view, a TIF image is *“the truest interpretation of an image.”*

If you have a camera that produces a RAW image, you must remember that only a few imaging programs provide a conversion function to display RAW image files. Most of those programs apply a tone (color) mapping that is specific to that specific program profile, and only the final image is stored and a lot of color information can be lost. The worst part about dealing with RAW image files is that once an image is mapped for a particular application, it might not be the optimum solution for another application, including the printer. To minimize these problems, the original RAW image must be stored so that mapping can be done for each particular imaging application or device.

Using a JPG format, compression is not only based on a simple algorithm for discarding pixel values but color values also play a significant role in the compression process.

Have you ever wondered why the file size of your images varies from picture to picture even though you are using the same digital camera with the same exact settings? I have a Nikon Coolpix 880 digital camera that I use for taking personal pictures to share with friends. Using the Fine image quality setting, the file sizes of my images vary from 803 KB to 472 KB. When displayed, the decompressed image has a resolution of 2048 by 1536 pixels; as an RGB image, the decompressed file size is 9.01 MB! Just by considering this difference between the stored (compressed) file size and the displayed (decompressed) file should give you a pretty good idea about the harmful effects of JPG formats! (Could you testify about the changes that resulted in the image as a result of the JPG compression?)

The image quality of a JPG image can be even further degraded if the image is enhanced, because new pixel values are created and then saved, and when the image is decompressed again, the “new” pixel values are used to recreate the discarded pixel values. As you go through a series of saves, the image becomes more and more degraded. Therefore it is recommended that JPG format ***not*** be used as a working format during image processing. You should save your image in a loss-free format, such as TIF, before initiating any enhancement process.

Image resolution also affects image quality during the enhancement process. If the image is compressed too much, background colors will bleed together, thus making it difficult, if not altogether impossible, to remove backgrounds when enhancing fingerprints or trying to visualize rifling characteristics, blood spatter, bruising and so forth.

During the enhancement process, image clarity can be your greatest challenge if the image has a lot of fine, diagonal or curved lines with slight changes in color gradation. The level of difficulty increases by a level of magnitude equivalent to the compression ratio.

The bottom line is that the printer is the lowest common denominator in ANY digital imaging system. But it is equally important to remember that the printer resolution isn't the only thing that you need to be concerned with. You should make a ***resolution*** that you will understand how ***resolution*** affects you throughout the entire imaging process: capture, storage, enhancement, and output.

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David Witzke, better known as Ski, has more than 14 years of experience with forensic digital imaging and AFIS technologies. His extensive background covers all facets of software development, user and technical documentation development, systems integration and installation, technical support, and training. Ski has been conducting forensic digital imaging training programs for law enforcement agencies at all levels (local, state and federal) throughout the United States, Canada and England for more than eight years. He has an established

reputation in forensic image processing and is frequently a guest speaker at regional and international conferences in the United States and abroad. He has also been teaching forensic digital image processing for the Latent Print Program at the FBI Academy in Quantico, Virginia as well as at the British Columbia Institute of Technology in Vancouver, British Columbia, Canada.