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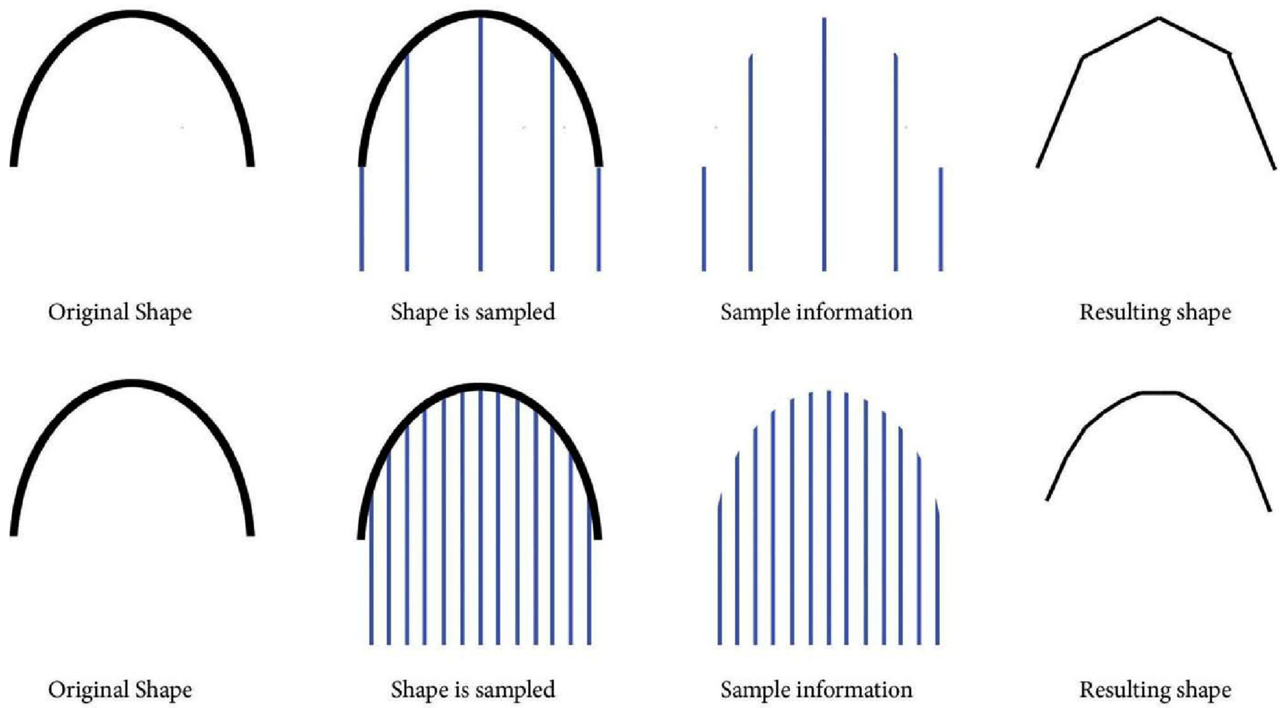
DETAILED DEFINITION

Evolution of the Term “Resolution”



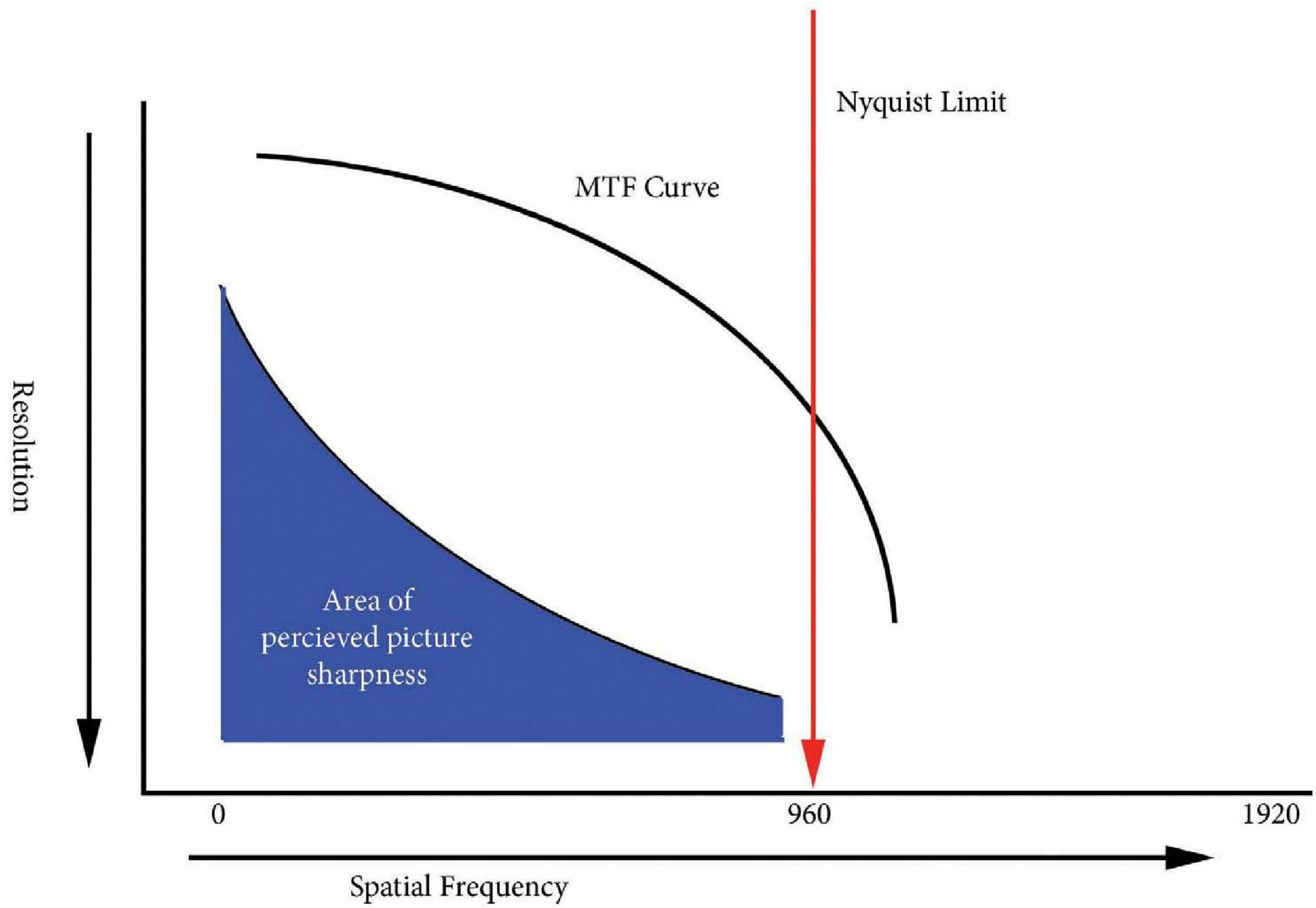
The higher the number of samples taken, the more accurate the digital representation of the original subject.

Resolution is a term that is thrown around with reckless abandon like mashed potatoes at a food fight. Unfortunately, it’s a term that is rarely used properly.

While many people refer to resolution as the pixel count in the final display image or as the number of photosites on a camera’s sensor, neither of these measurements is actually resolution. 1920 x 1080 is not resolution; it’s merely the number of pixels in an image. Likewise, the RED EPIC may have 5120 x 2700 active photosites on its sensor, but that is not a definition of resolution either.

Resolution is reliant on, yet independent of, the number of photosites on a sensor and the final number of pixels within the display image.

Resolution, by definition, is the ability of a camera (or lens, compression algorithm or display) to resolve detail within a scene. It is measured by resolving fine detail between high-contrast elements—namely fine black and white lines next to each other. Modulation transfer function, as I discussed in my September 2012 DV101 column, is a method of measuring the resolving power (resolution) of a lens or optical system. It is tested by photographing high-contrast black and white lines of increasing spatial frequency—meaning they’re getting narrower and narrower, with more and more of them fitting into the same space so that the frequency of alternating lines increases within the given space. A lens that can resolve detail from a high spatial frequency image is said to have high resolution.



Otto H. Schade found that what humans experience as appearing sharp from a normal viewing distance is equal to the square of the area under the MTF curve.

In the digital world, resolution is also dependent on the number of samples that are taken from a given scene. The more samples taken, the more accurately the original image can be reproduced in the digital picture.

An example: if we take the basic shape of an ellipse and sample that shape at five points, we have a very small sample size and the resulting digital shape will not accurately represent the original form. If we increase the number of samples, we can record more of the gradual curve of the ellipse and the resulting digital image will more accurately reflect the original.

Each photosite on a digital sensor can be thought of as a device that takes a single sample of an image. It would stand to reason, then, that the higher the number of samples, the more potential resolution we have. This is where photosite and pixel counts relate to but do not define a camera or system's resolution.

As it turns out, we need twice the number of samples to reproduce a given resolution without introducing artifacting or aliasing. This idea is the basis of the Nyquist theorem.

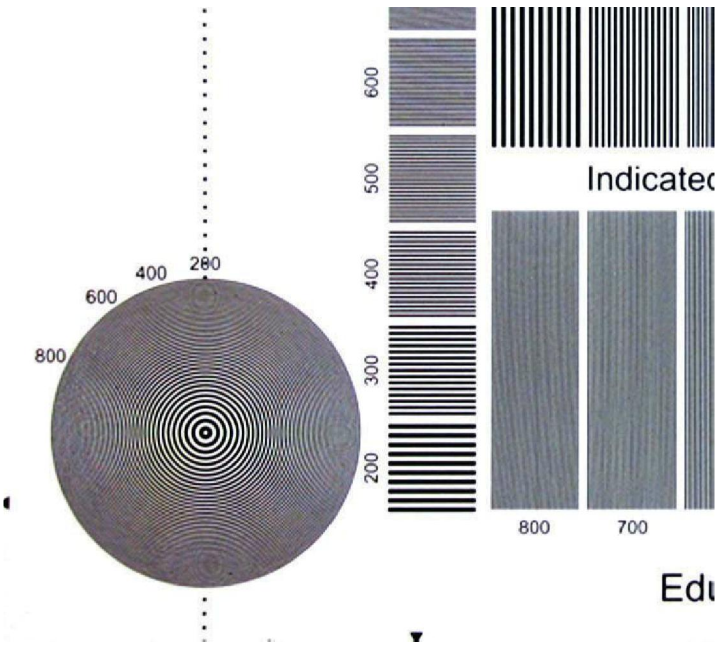
Harry Nyquist was an engineer at AT&T's (which later became Bell Telephone Labs) Department of Development and Research from 1917 to 1934. He is most famous for his Nyquist sampling theorem, which postulated that any sampling rate must be at least twice the highest frequency present in order to reconstruct the original signal.

In other words, for X samples, we can resolve only X/2 resolution without interference.

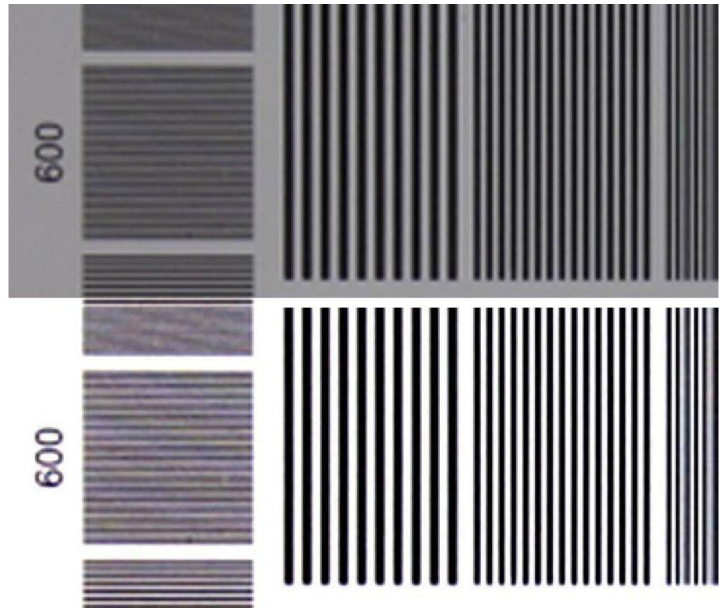
Let's take a closer look at this concept. Resolution is defined as a system's ability to differentiate detail between high-contrast elements. So if we have black and white lines, we need two of them—one black and one white—in order to tell the distinction between them and define resolution. The smallest single element in a digital image is the size of a pixel. So if we have a 1920 x 1080 image, the smallest area that we can get details in is 1920 pixels or lines across the screen and 1080 down. For 1,920 lines, we need one black line and one white line in order to define resolution via contrast, so we have—at maximum—960 line pairs (1920/2 = 960).

That's the Nyquist limit. For 1,920 samples, we can resolve only 960 lines of resolution. Beyond that point, the detail is too fine for the camera or display to discern and we begin to get artifacting like aliasing and moiré.

Moiré is a common problem with digital images; it happens when the frequency of detail within the scene is higher than the system's ability to



When the spatial frequency of the image being captured exceeds the Nyquist limit, we see artifacting. Instead of clean concentric circles, we see odd, anomalous patterns that are a result of the sensor's inability to resolve the detail in the image.



The top and bottom parts of this image are identical except for contrast. The bottom area received a significant contrast increase, which, in turn, increases the apparent sharpness.

resolve. With an HD image, if any element in the image has greater detail than 960 line pairs per picture width, then that element will display moiré artifacting.

It stands to reason, then, that the higher the sampling rate, the greater the resolution—and this is true. The more photosites we have on a camera's sensor, the higher the frequency of digital samples of an image and the greater our Nyquist limit. If we increase the number of photosites on our sensor to 4096, we can now resolve 2048 lines of resolution in an image. This is the theoretical maximum, however—not necessarily the actual resolution.

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Just like MTF, every component of an imaging system has its own resolution limit. The lens, the digital recording format and the display all have their own resolution limitations, and the highest resolution possible in a given system is determined by the maximum of the lowest resolution component in the chain.

Further, there's a very interesting distinction to be made between resolution—the system's ability to reproduce fine details—and *perceived sharpness* as seen by the human eye.

This is where Otto H. Schade comes in. Schade, an engineer at RCA, performed extensive studies on perceived picture sharpness. He found that what humans experience as appearing sharp from a normal viewing distance is equal to the square of the area under the MTF curve.

So if our MTF curve—which, remember, is the product of the MTF of the lens, the digital format and the display—allows us to represent a certain resolution, which maxes out at half the total sample rate, then the *perceived* image sharpness, as seen by the human eye, will be even lower—in the square under that curve. This means that what we see as sharp is really defined by the low spatial frequency resolution elements of an image.

Just like camera lenses, human eyes are more sensitive toward lower spatial frequencies, so we see larger elements as defining the sharpness of an image. Additionally, human eyes will perceive higher contrast as sharper than actual detail in a lower-contrast image. You can have all the detail in the world, but if there isn't significant contrast in the image, the image will appear to lack sharpness. Ever play with sharpening filters in a program like Adobe Photoshop? What you're actually doing is increasing the contrast in high-contrast lines in the image. By increasing that contrast, the apparent sharpness of the image is increased.

What is the lesson to be learned here? Resolution is not just the pixel count in an image, but it is dependent on pixels and can be only a maximum of half of the pixels in an image. Even if we have a high-resolution image, if there isn't sufficient contrast in low spatial frequency areas of the image, it will generally not be perceived as sharp to the human eye. **dv**