

Linearity and gamma are terms often used in digital imaging and color management, but what do they mean?

Linearity and gamma

Last month I mentioned that Epson print drivers can produce highly non-linear output depending on the settings. **Linearity** and the related term **gamma** are often used in digital imaging, color management and photography, but what do they mean?

The simplest way to define the linear behavior of a process is to use an example in which input and output values are identical throughout the process. With an output device like a display, the input value is the voltage it receives and the output value is the amount of light it emits. If one unit of voltage produces one unit of light output, two units in produces two units out, and so forth, that's linear behavior. Few devices are linear—something gets lost in the translation.

To fully define the linearity of a device, it's necessary to look at the entire range of its input-output relationship. If you plotted these values on a graph, the pattern would look like

Figure 1, or the familiar Curves dialog in Photoshop, which plots input and output values. Its default is a straight line; if you pull a point up or down, the input and output values change because you're changing the input-output relationship and making it non-linear.

In Photoshop, this relationship represents the input and output values of pixels; altering the relationship alters tone or color. When you open an image in Photoshop, the Curves dialog defaults to a straight line so you can begin to alter this input-output relationship from a standard starting point. (It doesn't mean that the image you opened is linear.)

A few processes do behave in a linear fashion, such as the sensor on your digital camera. The sensor is a photon counter that makes a linear record of the light striking it. Each level recorded produces an equal level of corresponding data in the RAW file. If one photon strikes the sensor, representing the first dark tone that can be recorded, the result is level one in the digital file. If 4,096 photons strike the sensor, representing the brightest value it can record, the result is level

4,096 in the digital file. This is one reason why it's recommended that you "expose to the right," meaning for the highlights.

In an image with 4,096 tones and six stops of tonal data from black to white, the first stop of highlight values contains 2,048 steps, or half the data (see **Figure 2**). The last stop has only 64 bits of data, so without proper exposure, that last stop of shadow detail will contain far more noise than usable data.

With a 10-stop range, the last stop would have only 4 bits of data with which to define the first stop of the captured dark tones. The human visual system is not linear. Imagine you're in a pitch-black room and you turn on a 60-watt bulb. Now the room has a fixed illumination level. If you turn on a second 60-watt bulb, you double the amount of light. The room looks brighter, but not twice as bright, even though it is, and would appear so if viewed linearly. If our visual system *were* linear, emerging from the dark into full sunlight would be a painful experience. In fact, many human sensations aren't linear, which shields us from serious sensory overload.

GAMMA

In color management, the display gamma is often defined as a calibration target value. If the input and output values were linear, you could plot a straight-line curve, and better,

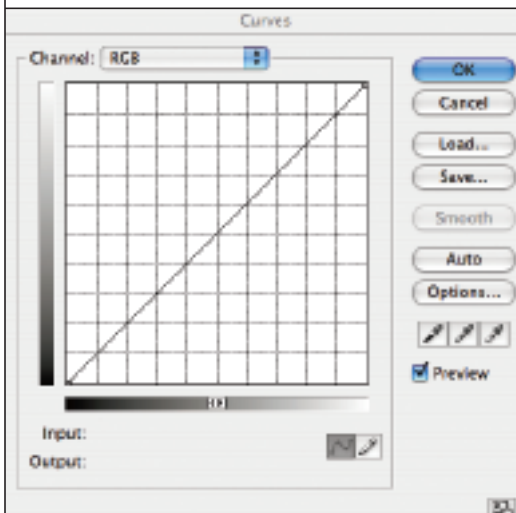


Figure 1. The Photoshop Curves dialog opens by default as a linear curve.

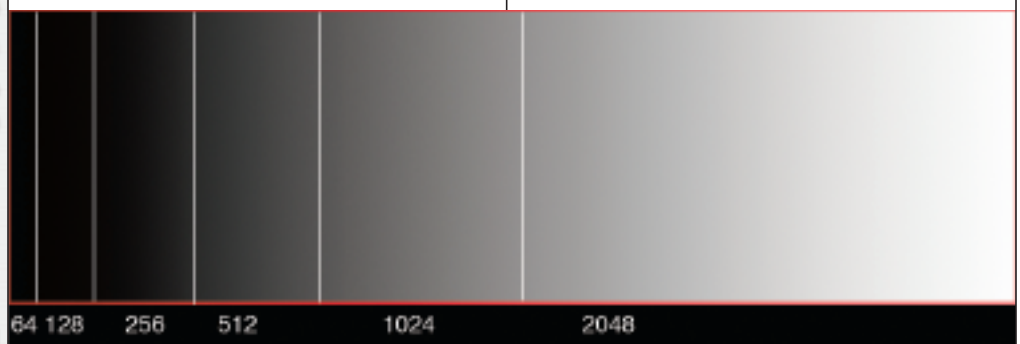


Figure 2. The linear nature of a RAW file exhibits 6 stops of tonal range and 4,096 bits from black (1) to white (4,096). The first stop of data contains half of all the captured tones.

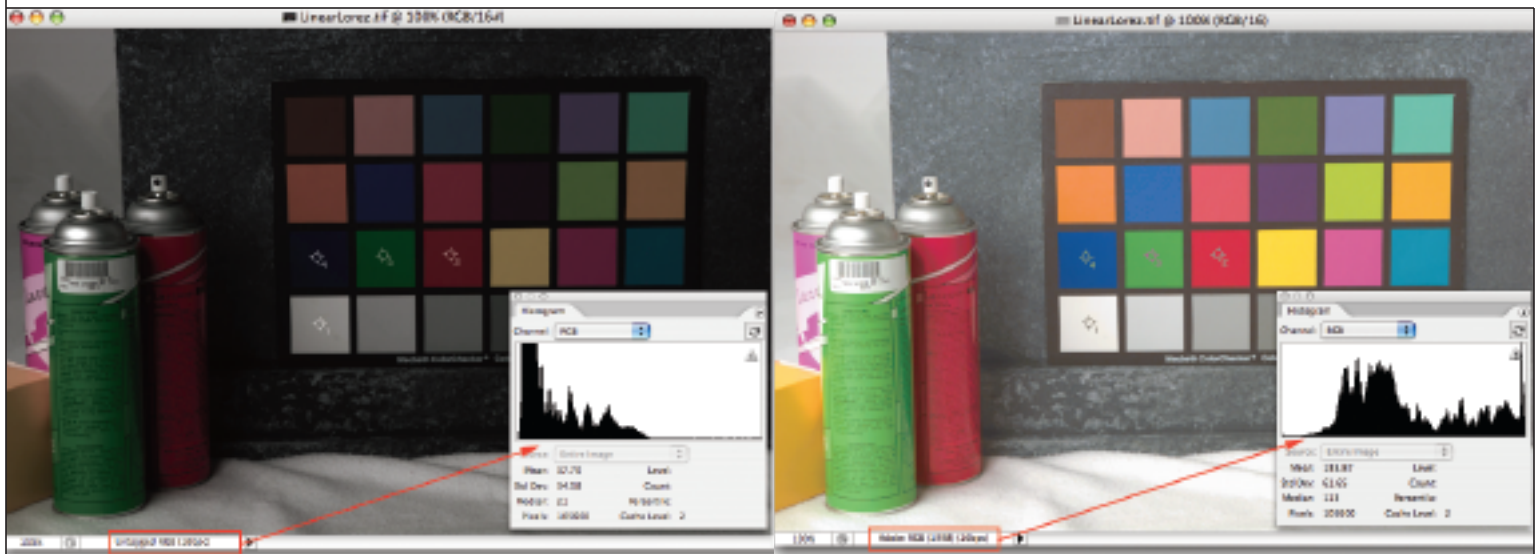


Figure 3. Left: The histogram of a RAW file rendered and encoded into a linear 1.0 gamma color space. Right: The remapping of the tones after conversion to Adobe RGB (1998), which has a gamma of 2.2.

assign a numeric value based on the **gamma formula**. With this formula, a flat linear gamma curve has a value of 1.0. The values increase as the curve becomes steeper. Most displays have an input-output relationship that follows a simple gamma curve of 2.0 to 2.2.

Displays are among the few devices that exhibit input-output behavior based on the gamma formula. Technically, it's incorrect to use a gamma value to define other devices. The input and output values of a scanner or printer produce complex curves, which are better described as **tone response curves** when discussing the devices' input-output relationship. In other words, a nonlinear tone response curve may or may not follow the gamma formula.

In analog photography, it's common to see the effect of nonlinearity in film, paper and similar light-sensitive materials. Perhaps you recall the S-shaped H&D (Hurter-Driffield) curves, also known as the characteristic curve. When light strikes film, the resulting density is not linear. Film's response is less sensitive in shadows and more sensitive in highlights with a linear response between both areas of these two curve points. Digital

images can have a linear or nonlinear tone curve as well.

RAW format images have a linear encoded gamma of 1.0. If viewed on a display that doesn't compensate for this with an embedded profile, the images look quite dark and the histograms look like the left example in **Figure 3**. Some RAW converters allow images to be rendered in this encoded linear color space. When you convert the files to an RGB working space, which has a specified tone response curve, the histogram will be remapped, like the example on the right in **Figure 3**. Images, color spaces and devices all have tone response curves. Some are simple enough to follow the gamma formula, others are not.

If you create a file in Photoshop with equal density range from black to white in, say, 21 steps, then output the file to an Epson using the No Color Adjustment setting, the first three to five steps in the darker tones would come out nearly black. If the behavior were linear, the output would match the input, and each step would have equal separation. Because the behavior is far from linear, the result is blocked up tones.

When someone has "linearized" a printer, he has output a linearization file with equal density range, measured the output, and attempted to alter the device to produce a more linear behavior. This is ideal when possible. Since a device profile only describes the behavior of a device and does not alter it, there is only so much it can do to aid optimal output. Linearization is a process, much like calibration, in which the device is placed in the best possible behavior prior to building a profile. ■

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