Charles Poynton
tel +1 416 535 7187
charles @ poynton.com
www.poynton.com

SpectraCal

POYNTON'S VECTOR 17

Linearity and the *-nesses*

Two recent incidents prompt me to write this month about terminology. Many people find discussion of terminology to be boring. However, according to a Zen master that I once met, the path to wisdom begins with calling things by their proper names.

The first incident concerns my scanning the glossary of a newly issued book about VFX and CGI – the second edition, nonetheless! The book shall remain nameless. I encountered this definition:

> **Linear color space:** A color space in which the relationship between a pixel's digital value and its visual brightness remains constant (linear) across the full gamut of black to white.

This passage is confused. First, it's self-referential: The definition of *linear* includes the word *linear.* Second, the concept of *linear* (as used in imaging) has only a tangential connection to *gamut.* Third, if it's a *pixel*, it must be digital: Pixels are by definition discrete; there are no analog pixels. Most seriously, "visual brightness" is a dangerously imprecise component of this definition. What really characterizes *linear* in digital imaging is that a pixel component value (typically *R, G,* or *B*) is proportional to *physical light power.* Vision has nothing whatsoever to do with it.

ENGLEDRUM, PETER G. (2000), *Psychometric Scaling* (Winchester, Mass.: Imcotek Press).

The word *brightness* in the definition above is an example of what my colleague Peter Engledrum calls a *-ness word.* According to Peter, *-ness* words are invariably related to perceptual quantities, none of which can be directly measured. Seeing the suffix *-ness* is a tip-off that the quantity being discussed isn't physical. But the whole *raison d'être* of a linear colour space is to form a direct connection to the physics of the imaging situation. For example, a scene-linear workflow has been introduced by Florian Kainz and his colleagues at ILM, and is being further developed by the Academy as the Image Interchange Framework (IIF) for digital cinema production.

www.oscars.org/science-technology/council/projects/iif.html

My definition has twelve more characters, but one fewer word:

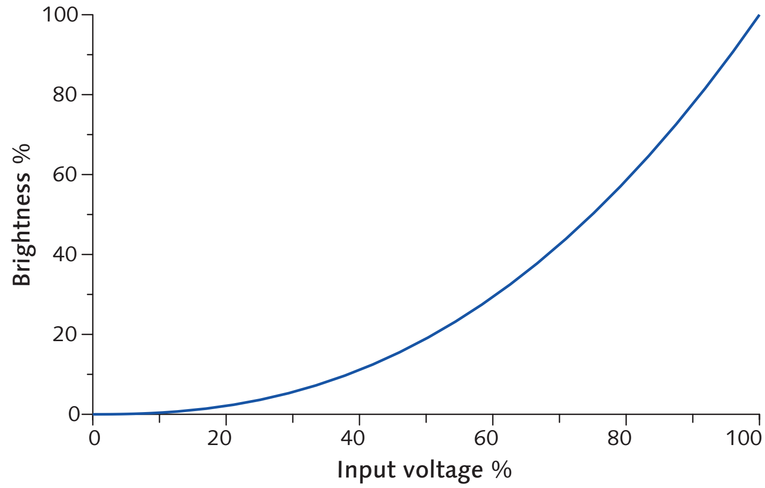
> **Linear colour space:** Colour data wherein each component value, over most of its range, is proportional to light power – that is, proportional to radiance, intensity, luminance, or tristimulus value.

The qualifier "over most of its range" is necessary because linearity fails when component values below zero or above maximum are clipped.

To be complete, *linearity* accommodates an additive offset (bias) term as well as the (multiplicative) proportionality factor.

The second incident relates to my attending a recent 3-day video calibration course – level 2! The organization and presenter shall remain anonymous. A graph similar to Figure 17.1 was presented:

Figure 17.1 **Putative relationship** in a video display takes an input voltage and produces "brightness."

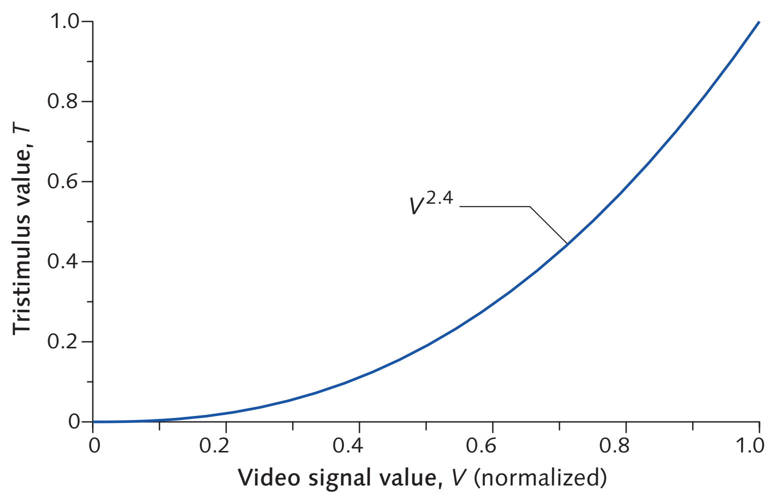


In another video calibration class that I attended, the presenter called the video signal *stimulus*. This is wrong. *Stimulus* is properly the stimulus to perception, not the input to a display system.

What's wrong? The *x*-axis is labelled *Input voltage*, but modern displays are driven by digital values. More seriously, the *y*-axis is labelled *brightness*, but the display produces a physical quantity, tristimulus or luminance: It is the viewer's visual system – not graphed here! – that converts the physical light stimulus to a percept, a *-ness.*

The graph is corrected simply by relabelling the axes (Figure 17.2):

Figure 17.2 **Display EOCF** takes an R', G', or B' video signal component value – here in the range 0 to 1 – and produces the corresponding R, G, or B tristimulus value (relative, by definition). The luminance of each tristimulus value can be measured individually. The recently adopted ITU-R BT.1886 calls for a 2.4-power relationship for studio HD.



These graphs present the *electro-optical conversion function* (EOCF) of a display. A historical CRT's light output is approximately the 2.4-power of voltage. (Modern displays incorporate signal processing to mimic CRTs.) Human vision perceives tristimuli or luminance nonlinearly: The perceptual response is approximately the tristimulus value raised to an exponent of 0.42. It is an amazing coincidence that a CRT exhibits the inverse of the characteristic of human vision! Video decoding with a CRT is a near-perfect match to vision. A video signal of 0.5 produces half the lightness. This fact is central to the design of video systems. This vital insight only emerges if you use the correct terminology.

Eq 17.1

$$0.42 \approx \frac{1}{2.4}$$

$$0.5^{2.4} \approx 0.189;\ 0.189^{0.42} \approx 0.5$$

Wisdom arises from referring to things using their proper names!