Is Your

# COLOR SPACE

## 4:2:2 Or 20/20

Color space is a term you'll often hear thrown around, but what exactly does it constitute? By C.R. Caillouet

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**Color space is** a popular term used to refer to many aspects of color-reproduction quality, but a color space is actually the range of colors available to a device, as determined by its reference colors. The color space of a reproduction system is limited by the capabilities of the display(s) in use, the capture device(s) that translate the scene values and the representation(s) of the colors between the devices.

For simplicity, I'll limit the discussion to cameras and monitors, although the same logic applies to scanners, projectors and printers, which may have more or fewer elements.

> *"Most video cameras use red, green and blue sensors for color detection. The placement of these sensor colors (in the space of all possible colors) limits the identifiable colors to combinations of red, green and blue."*

The accuracy of a color reproduction depends on a lot more than just the color space of a camera. Assuming a transparent transmission system, color reproduction is affected by the color of the scene illumination, the color of the subject, the color space of the camera, the mapping of colors interpreted by the camera into a numeric representation, the limitations of that representation, the mapping of the colors back to those of the display, the display color space and the viewing conditions. Whew!

### COLOR REPRESENTATIONS

Most video cameras use red, green and blue sensors for color detection. The placement of these sensor colors (in the space of all possible colors) limits the identifiable colors to combinations of red, green and blue.

Narrowing of the spectral response of each color sensor limits the sensitivity of the camera and affects the range of "in-between" colors that can be discriminated.

Increasing the range of each sensor makes it difficult to distinguish between colors and reduces the saturation. Consequently, colors outside the range of the camera may overload one or more sensors, or may fall outside the sensor response and not be detected as color at all. So the color space of the camera definitely has a limiting impact on the reproduction.

In the red, green and blue (RGB) tri-color system, cameras capture and measure positive color values from black (no color) to peak white (maximum amounts of all three colors). In television distribution systems, however, it's often useful to process color information (chroma) separately from brightness information (luma).

### TRANSCODING EQUATIONS

A set of three equations can be used to convert from RGB to the separate luma/chroma form known as color-difference signals, or from one color-difference representation to another.

The luma signal is created by combining portions of the red, green and blue signals in a way that corresponds to the response of the human visual system. The term "color difference" comes from the method of creating the chroma signal, which is a process of subtracting the luma information from each of the red and blue color signals, thereby generating two chroma signals that are (theoretically) independent of the luma signal.

Once the chroma information is contained in color-difference signals, positive and negative adjustments can be made to the colors to further alter the colorimetry of the system by modifying the translation of the camera colors to represented colors. These may be referred to as user-matrix or color-correction adjustments.

Color shifts can occur when the encoding and decoding equations don't match, even if the sizes of the color spaces are not significantly different. Shifts can show up when a general-purpose device is used for both HD and SD operations, and different equations are used at one end or the other in the translation process.

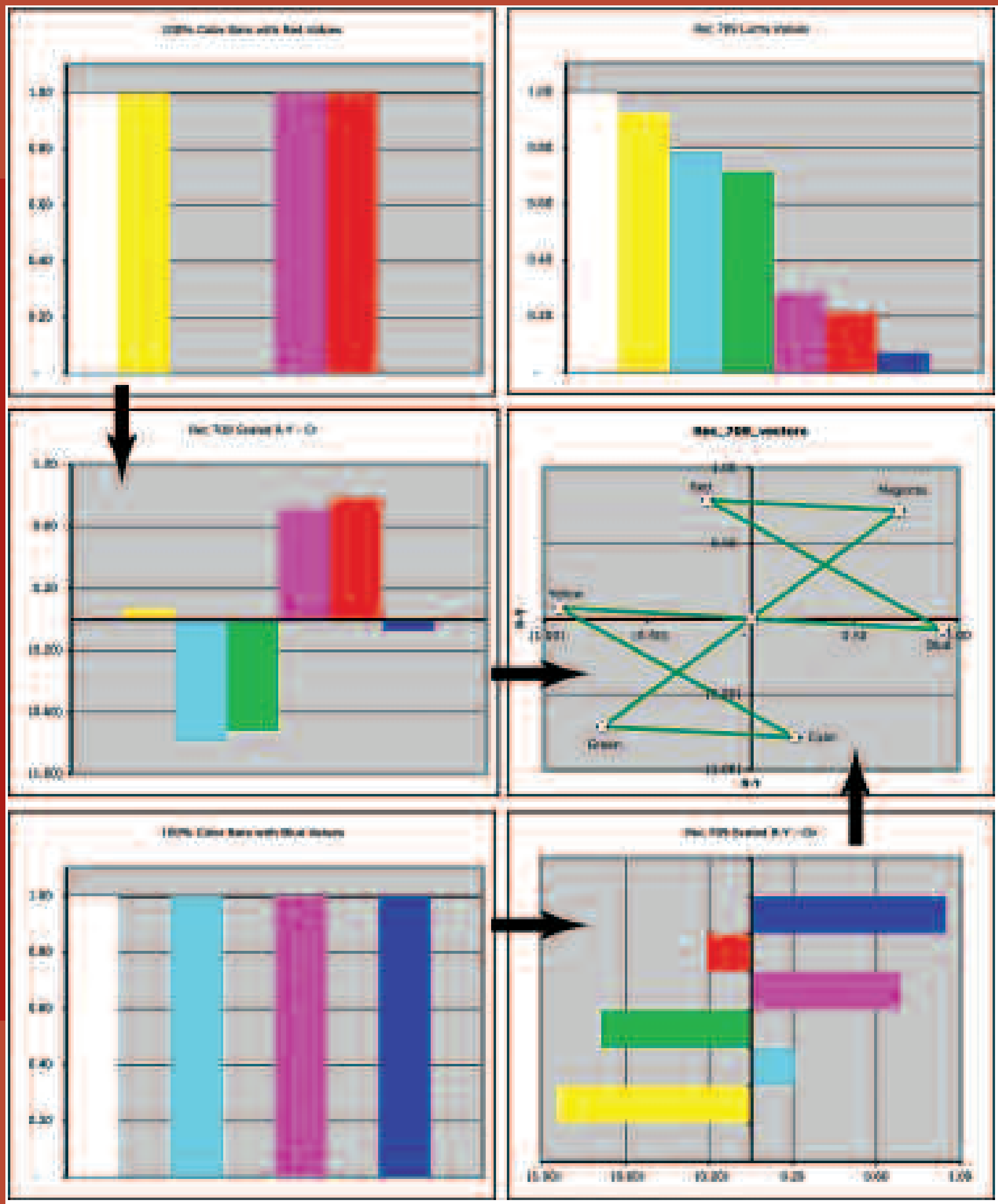
HD does have a slightly bigger color space than does SD—but not as much as we are led to believe, and most color errors are caused by the use of the wrong encoding or decoding equations or by intentional changes made in the production process.

### THE DISPLAY

On the display side, the representation has to be mapped into the color space of the display. Display colors outside the camera color space can only be approximated because they can't be captured reliably. If the primaries of the display correspond to those of the camera, then a credible job of reproducing the colors within the color space can be done by using the proper decoding equations. An inverse set of equations to those in the camera is applied to re-create RGB signals for projection or direct display.

### EYEBALLS AND ADAPTATION

Because of color adaptation, humans tend to interpret the dominant illuminating color in any area as neutral, and the



"Higher overall image resolution allows more color detail, which contributes to better color contrast and detail saturation"

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interpretation of specific colors within that area are affected by that reference. So, it's possible to convince human viewers that a scene and its reproduction are different in color by presenting the reproduction within a viewing environment that doesn't correspond to that of the display. Such a condition often exists when a daylight-balanced monitor is viewed on a tungsten-illuminated set.

## WHAT ABOUT 4:2:2?

The familiar three-number designation (separated by colons and usually starting with a four) doesn't tell you anything about color space. Instead, it describes the relative horizontal resolution of the luma (the first digit) and the chroma channels (the last two digits).

For historic reasons, the four implies full resolution in whatever format is in use, and the other digits designate a proportionate reduction in the resolution of each color-difference signal (Cb or Cr).

So 4:2:2 describes a system with half resolution in each color signal, compared to luma, and 4:1:1 describes one-quarter chroma resolution. In both cases, vertical resolution of luma and chroma are the same.

A zero in the third position is a special symbol indicating that both color channels are reduced in resolution in the horizontal and vertical directions by the value of the other digit. 4:2:0 would be half chroma resolution in both H and V.

Other color parameters affect the quality of color in ways that many people assume are caused by a larger color space. Higher overall image resolution allows more color detail, which contributes to better color contrast and detail saturation. Better camera and lens quality produces clearer initial images; digital processing and transmission maintain image quality without the blurring and/or streaking of marginal analog circuits' and greater bit depth in each component reduces image contouring in smoothly shaded areas.

This discussion just scratched the surface of color issues. If you want more information on the details of color representations in video, you should get the latest edition of Charles Poynton's book, *Digital Video and HDTV Algorithms and Interfaces*, Morgan Kaufmann, 2003. HDVP