Rethinking the Color Space Representation

Submitted By Bob Davis
To Digital Cinema DC28.2 Mastering Study Group

Why Consider Changing Color per ITU-R BT.709.2

The current color space reference is ITU-R BT.709.2. This recommended practice is based on historic television and has evolved for HDTV program interchange purposes. We are claiming conformance to elements 1.1, 1.2, 1.3 and 1.4 of that document, the rest is not relevant to the Digital Cinema task.

This system continues the Television technology founded on a set of phosphors that could be driven hard to create a bright color image and has continued through raised color temperature. NTSC is the first and worst example of this.

BT.709.2 makes the assumption of gamma=0.45 and includes video sync signaling within the available color values. This recommendation is for color television based on current CRT design and is in the mature stage of its life.

The eye is sensitive to much more than the RGB display area. The CIE diagram attempted to show this but cannot be printed properly as the CMYK color space is not wide enough. Only a spectral definition will work. We should be able to display more accurately than can be printed.

Major Change is Needed

We need to change to a more measurable standard that can be measured by a spectrometer and is independent of the technologies currently available. The ability to get to absolute SI values makes the image element measurable and hence require conformance to.

The FUTURE Starts HERE

I am not trying to be theatrical here, that's someone else's job, but - what we do here is fundamental to the future of Digital Cinema and sets the precedence for future color representation and conformance issues. This change in image representation removes the previous constraints and requires a basic, not radical, change to be made. There is no installed base to protect - yet.

What Are We Representing and How is it Measured

The Color Space issue here is the database that will be used in many ways. It is a set of images, or frames, that are displayed, singularly or in sequence, to create an impression on the viewer. The job here is to define a content representation that can be accurately measured, a prerequisite to conformance requirements. Spectral content is the ultimate definition that has no bias.

If the captured image is not modified by the Director, or other creative input, the spectra of the display should match the spectra of the original scene, measurably.

Digital Data Base

Images that will be shipped to theaters and other consuming points such as TV and secondary distribution methods are shipped as a data base of frames, audio and metadata as needed to support the images.
This image will NEVER be displayed directly. It will always be converted to another format for presentation. The gamut of the presentation environment can never be known.

Digital Image Representation

Our concern and specifications need to consider the shape and spectral content of each pixel.
Shape should be defined as square or a rectangular ratio so that it can be properly mapped into the display device. Any lens selection or mapping protocols require this information.
Each pixel may have a variable dimension to support center weighting of the image and support better compression.

Pixel Content

This must be measurable. A Spectrometer is used to match the display system back to the database. The feedback from the display mechanism is measured and compared with the basic database image for correctness. This leaves no room for excuses.
Each pixel will be converted FROM the input source and TO some display via a mechanism that will be required to maintain the spectral characteristics.

The Spectral Characteristics of each pixel

We must consider encoding each pixel as a set of spectral lines with the wavelength, or wavelength bands to be defined, and the intensity of each line, or band, measured in a SI defined quantity such as Lux or photons per second.
Characteristics common to each pixel can be carried in the frame header as a pointer to the descriptor file. If each of the frames is the same the descriptor, it can be the one pointed to in the first frame or database descriptor.
Element depth needs agreement. We should make this larger than any known or planned conversion capabilities. 12 bit linear converters are now available and 16 bit A/D's at the appropriate speeds are just a matter of time. Is 16 bits enough? – how about 24? If specified large enough and made variable, unused bit can be truncated with no information loss and still be within format as in audio.
A separate, but related, issue is the use of floating point vs linear representation. 16 - 24 bits linear or 16 – 24 bits of floating point representation. Pick ONE please.
Keeping the elements on byte boundaries is useful as that is the amount of storage that will be allocated.

Default array would look like RGB 4:4:4 data stream

The obvious initial representation is for a Red band, a Blue band and a Green band, which is a three element array that we currently use. Future mechanisms can then expand the number of spectral units as sensor and computer technology improve.
Only the descriptor files would define which spectral content is included in the Red spectral band, the Green spectral band and the Blue spectral band.

Backward Compatibility

This is a required element of this new methodology. Conversion to and from current color spaces is required.
To RGB - If higher spectral content is available the conversion would be by summing, with weighting factors, the area under the response curve for the chosen Red Green and Blue sensor curves. To convert from old RGB, including 4:2:2 YCrCb space, by scaling to go from 0 to 1.
To CIE(1931) - This would use the current conversion formulas.

Where Is Image/Frame Database USED

This database is used to display and present the work.
The first place of use is for the Director to release the work. The display that is used to prove the database to his liking must be measurable in absolute terms. This must be capable of maintaining the same color space with a CRT, transmission or reflective devices, and film technology.

Now – Today's technology

These technologies are here today and will have improved long before our color space comes to market. The life expectancy, before improvement, of these devices is a matter of months, not years.
CRT Display - Old technology, will be with us for some time to come but is being replaced as other devices become less expensive. This device has the true fixed phosphor triads with specific qualities defined in the gamma of 0.45 prescribed in 709 documentation and SMPTE 274.
Digital Mirror Device - This TI device is one of the initial new projection devices of choice and will continue to improve. DMD has no specific spectral content and is projected through filters for this effect. Currently implementations range from one device and a color wheel to many devices with appropriate mapping.
LED Displays - JumboTron and similar devices are pixel accurate emitting surfaces used in dark or bright environments. As these devices are multiple emitters per pixel the ability to broaden the range of spectral display is not limited.
Light Valve – JVC/Hughes - A Light Transmission device. Each light valve depends on the light transmitted through it and the filters used with the same limitation and growth potential of the DMD device.
Laser Display Devices - Dye lasers are available in almost any color. This is a scanning projection technology with a wide range of capabilities.
LCD panels and systems of panels can be made into large systems. The technology is transmission through switched filters with a light source needed. This technology is becoming dominant in the computer industry with that money fueling its development.
Silicon Light Machines – GLV technology - Exciting new development with wavelength selective reflection capability. Could obviously be modified to extend the spectral content of the displayed image.
Film - Balancing the director's approved display coloration requires care in the filtering and dye control in the film.

I would assume that the film exposed is the direct display film and not an intermediate negative for best color control.
The film stock will need to be developed and measured against the data base to determine the quality of the transfer to film.

Future – all bets are off

All projections of the future development of this equipment will probably fall way short of the actual development. This is extremely promising for pulling more people into the theaters. The growth will be in resolution, better color projection, and into revival of stereo at high levels, without flicker. Competition will drive the improvements into a replacement market. Without the limitations of film, the display market will improve quickly in quality and performance
We cannot predict what device the databases developed today will be displayed on.

Where Does It Come FROM

The Digital Cinema Distribution Master Database is derived form the Digital Master "Thingie" which is not characterized and is studio dependent.

Current Sources

Film - Each batch of film is different as the dies are not perfect. Film is also non-linear with respect to exposure. This must be made linear for processing.
CCD Cameras – CCD's have a spectral response from about 300nm through about 1100nm more if stretched. The current production is 1920x1080 x 30 frames per second with 12 bit A/D converters.
Computer Graphics - Rendering time is the current limit on resolution of the generated images. Pixar claimed that they are only limited by the display technology. Rendering to higher spectral content should not be a problem except for computational time.

Future

More and better sources, from known and unknown technology, is just a matter of time.

Summary

We should define a color space database representation that is measured with a spectrometer. All input images will be converted to this format and all displays will be converted from this format. Direct correlation, via spectral measurement, must be possible from any input to any output.
This is our opportunity, and our charge. Do it correctly NOW. We will live with this decision as NTSC has lived with its initial choices, built around convenience at the time, and propagated until now.

Respectfully Submitted
Bob Davis