Hue-Preserving Color Transforms for LED Wall Virtual Production Workflows

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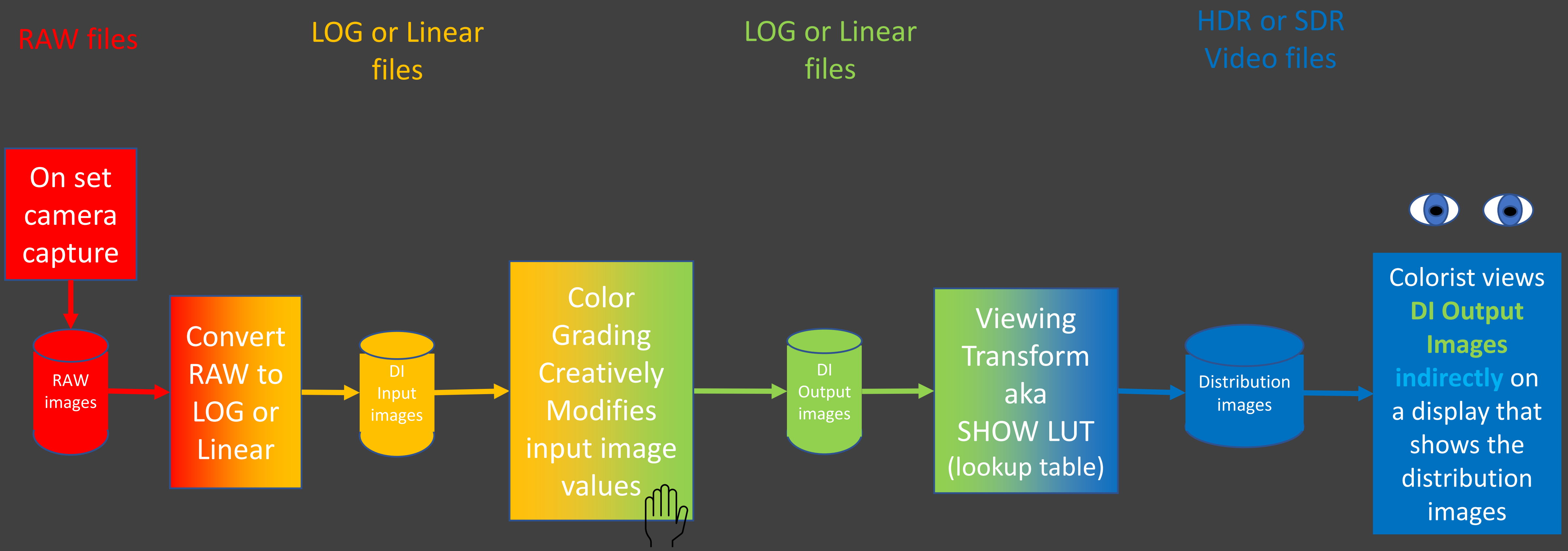
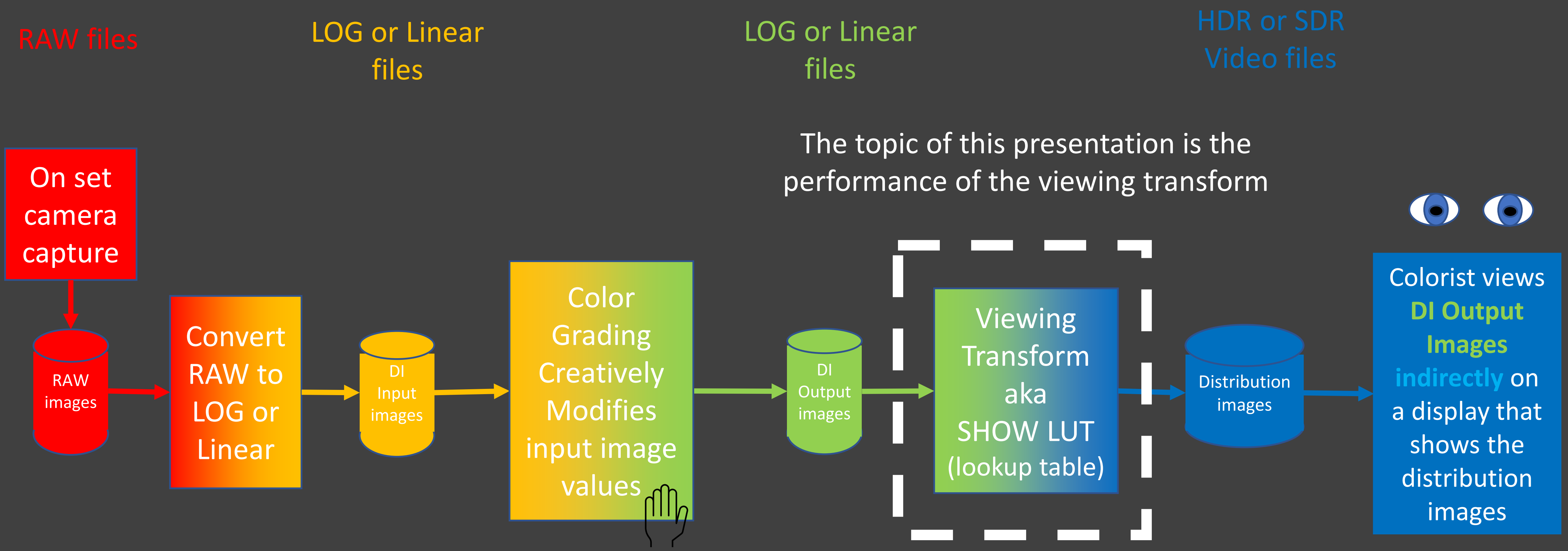
Overview

- Common Color Rendering Pipeline
- Viewing Transforms
- How is Hue altered in Viewing Transforms ?
- Algorithm review of two Viewing Transforms under study
- Virtual Production LED Wall imagery using two viewing transforms
- Conclusions

Common Color Rendering Pipeline



Common Color Rendering Pipeline



Viewing Transforms

- Typically used to convert LOG or Linear images to Video
- Each camera manufacturer provides a default viewing transform.
  - ARRI provides LogC to Video LUTs
  - SONY provides SLog to Video LUTs
  - Red, Canon, Panasonic, BlackMagic, etc. also provide Viewing LUTs

Viewing Transforms

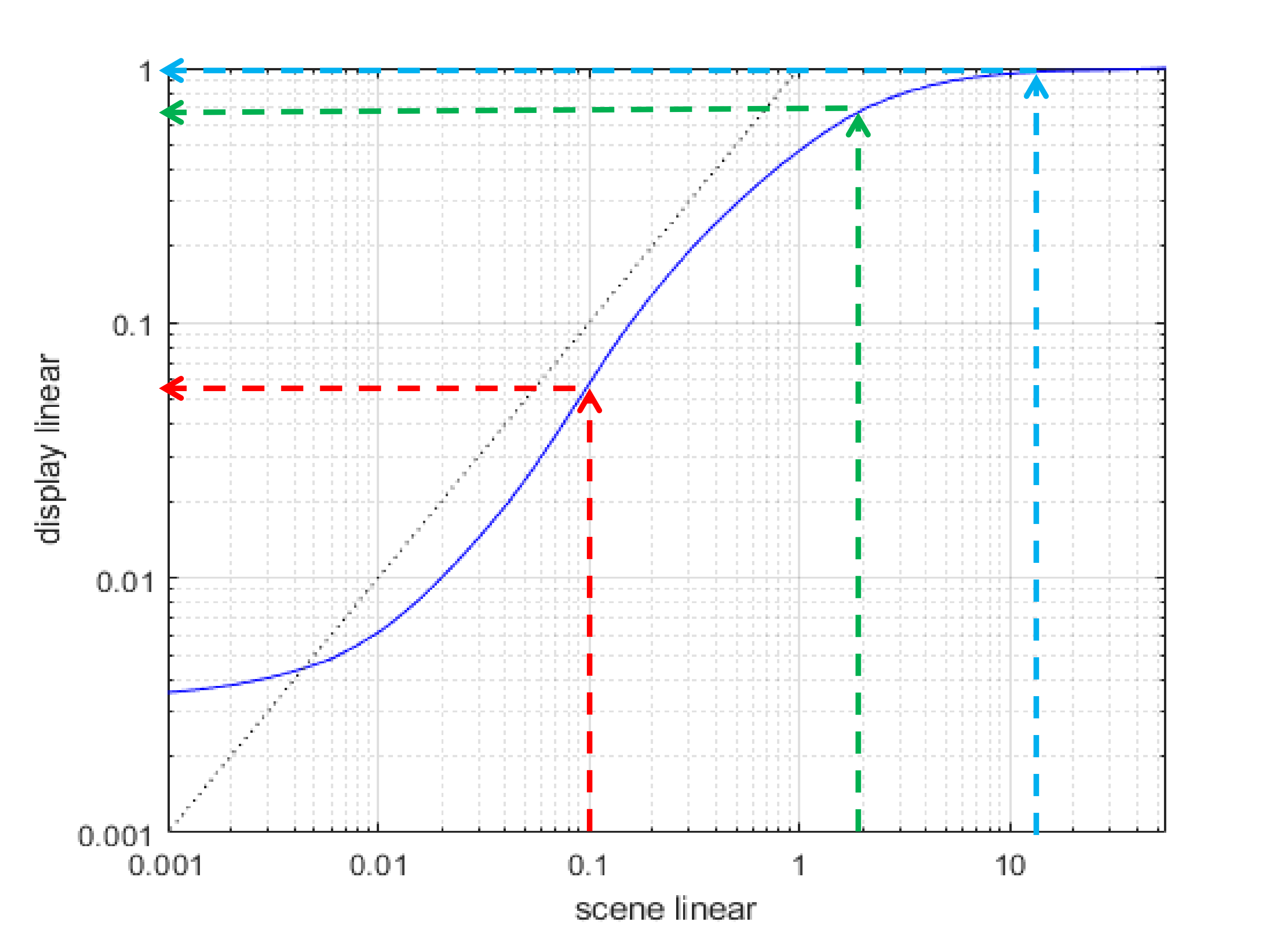
- Sometimes an individual production's creative team creates a unique SHOW LUT that may be a modified version of the manufacturer's default viewing transform or something entirely different.
- ACES provides default viewing transforms in addition to a workflow step called the Look Modification Transform that is placed before the default viewing transforms to make creative changes to the result.

Viewing Transforms

- Components:
  - Creative Look – global adjustments to scene-referred imagery to achieve creative goals, like changes to saturation, contrast, gain, etc.
  - Rendering – scene-referred to display-referred conversion
    - tone curve processing
  - Display Transform
    - Encoding Primary conversion (rendering primaries to display encoding primaries) examples AWG to BT709, ACES AP1 to BT709, SGamut.Cine to BT2020
    - Formatting for video-interface or distribution-file
      - inverse-EOTF aka “gamma-correction”
      - Full-to-legal-range conversion

How is Hue altered in Viewing Transforms ?

- Answer #1 - Rendering Tone curve applied independently to R, G, B channels can result in a hue shift.
- Example:
  - input color is bright blue (R,G,B) = (0.1, 2.0, 12.0)
  - output color is cyan (R,G,B) = (0.06, 0.70, 0.96)
  - RGB ratio, rg-chromaticity is altered
    - (r,g) = (R / R+G+B, G / R+G+B)
    - Input (r,g) = (0.007, 0.142)
    - Output (r,g) = (0.035, 0.407)



How is Hue altered in Viewing Transforms ?

- Answer #2 - Encoding Primary conversion and the handling of out-of-gamut colors can lead to hue-shifts.
- Clamping out-of-gamut colors to [0,1] after primary conversion matrix can lead to hue-shifts.
- Example:
  - example AWG to BT709 primary conversion matrix (approximated):

    Rout = 1.62 * R + -0.54 * G + -0.08 * B

    Gout = -0.07 * R + 1.33 * G + -0.26 * B

    Bout = -0.02 * R + -0.23 * G + 1.25 * B
  - example orange input color (R,G,B) = (0.85, 0.50, 0.03)

    Processed by AWG-to-BT709 conversion results (Rout,Gout,Bout) = (1.10, 0.60, -0.09)

    leads to values outside of range [0,1] this means the input AWG color is out-of-gamut in BT.709

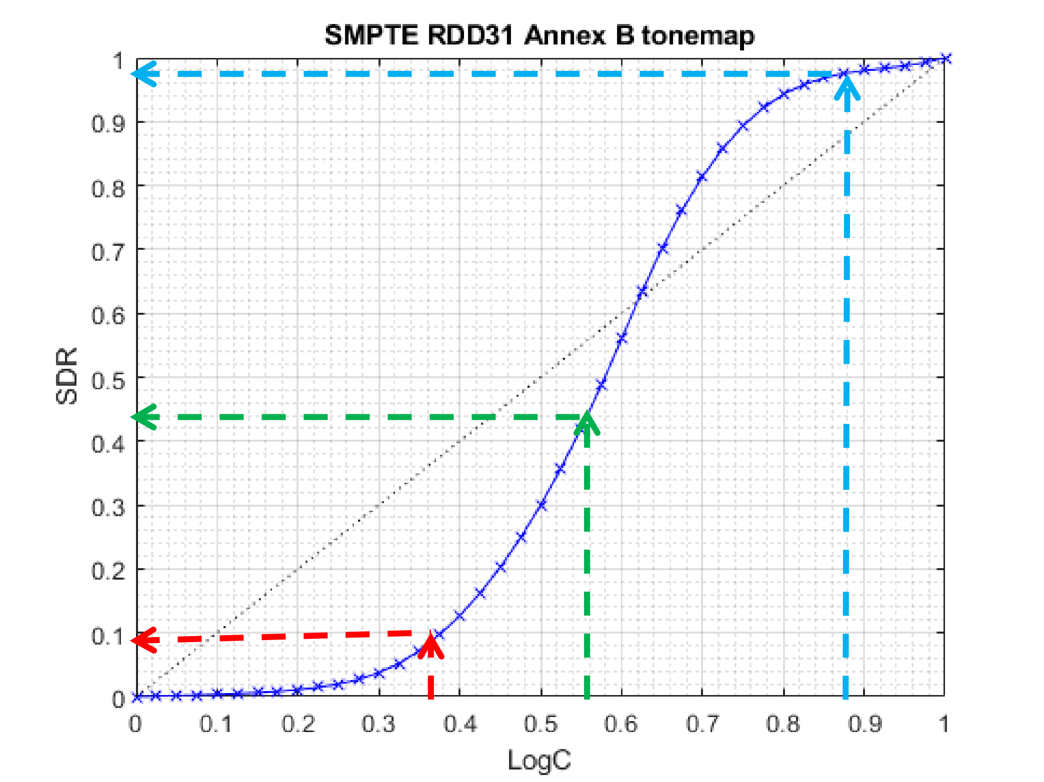
    Common simple technique is to clamp the output to range [0,1] to force the result to gamut boundary of BT.709

    clamp(Rout,Gout,Bout) = clamp(1.10, 0.60, -0.09) = (1.0, 0.60, 0.00)
  - RGB ratio, rg-chromaticity is altered by clamp()
    - (r,g) = (R / [abs(R)+abs(G)+abs(B)], G / [abs(R)+abs(G)+abs(B)])
    - BT709 output unclamped (r,g) = (0.615, 0.335)
    - BT709 output clamped (r,g) = (0.625, 0.375)

ARRI default Viewing Transforms

- ARRI documented their default LogC to SDR video viewing transform in SMPTE RDD 31, it has 3 easy steps…

1. Rendering - Apply Sigmodal Tone Curve independently to each R, G and B to ARRI Wide Gamut (AWG) LogC components.
2. Display Transform - Apply 3x3 matrix to convert AWG primaries to BT.709 primaries with some additional desaturation. Additional desaturation could be considered a creative look adjustment or a gamut mapping technique.
3. Display Transform - Apply inverse-EOTF (“gamma-correction”) to convert BT.709 display linear to BT.709 non-linear video.

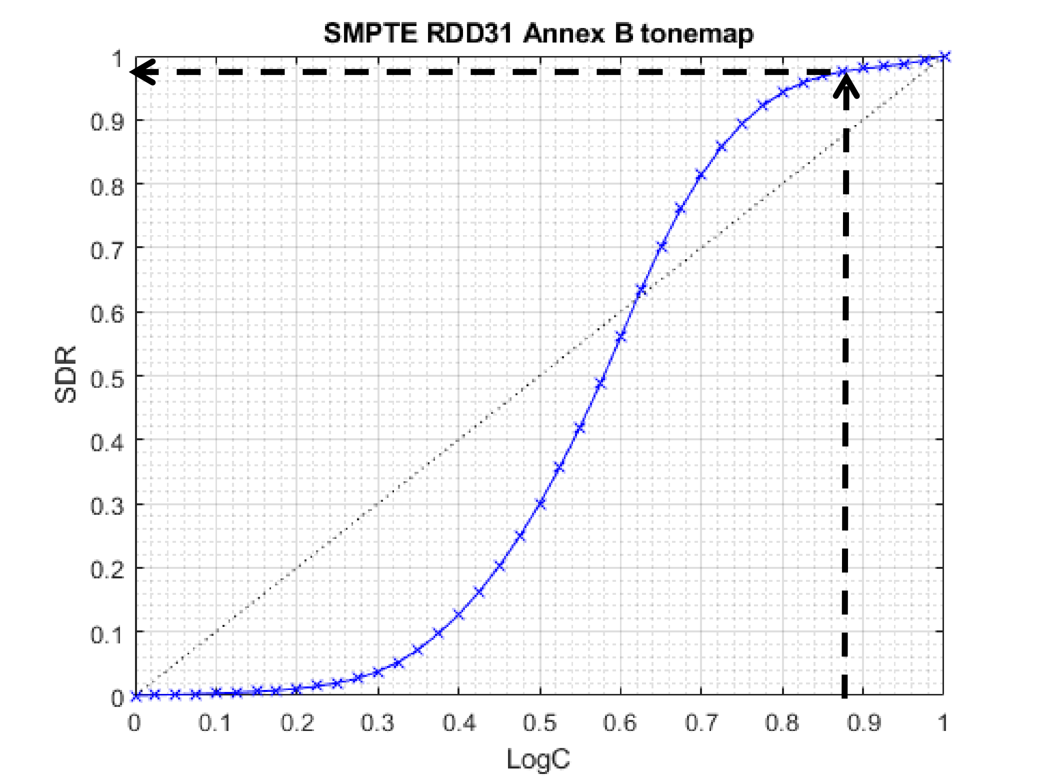


Hue-Preserving Viewing Transform based on SMPTE RDD 31

1. Compute norm
   maxRGB_LogC = max(R_LogC, G_LogC, B_LogC)
2. Apply Sigmodal Tone Curve to norm maxRGB_LogC
3. Compute Scaling Factor =
   scaling_factor = maxRGB_display_linear_AWG / linearize(maxRGB_LogC)

   where linearize() converts from LogC to scene-linear, equation is in section 5.6 of RDD 31
4. Apply Scaling factor to linearized AWG RGB values

   RGB_display_linear =
   scaling_factor * linearize(R_LogC, G_LogC, B_LogC)
5. Apply 3x3 matrix to convert AWG primaries to BT.709 primaries with some additional desaturation
6. Apply inverse-EOTF ("gamma-correction") to convert BT.709 display linear to BT.709 non-linear video



Arri LogC to BT.709
SMPTE RDD31 Annex B

MaxRGB LogC to BT.709
RGB ratio hue-preserving LUT

SRC Fm: 1896749

A004C002_210804_R26L.[1896677-1897337].dpx

Arri LogC to BT.709
SMPTE RDD31 Annex B

MaxRGB LogC to BT.709
RGB ratio hue-preserving LUT

SRC Fm: 1898338

A004C003_210804_R26L.[1898300-1898842].dpx

Arri LogC to BT.709
SMPTE RDD31 Annex B

Notice the difference between the color of the shadows and the background light source

MaxRGB LogC to BT.709
RGB ratio hue-preserving LUT

SRC Fm: 1860944
A003C012_210804_R26L.[1860804-1861294].dpx

Arri LogC to BT.709
SMPTE RDD31 Annex B

MaxRGB LogC to BT.709
RGB ratio hue-preserving LUT

SRC Fm: 1900741

A004C005_210804_R26L.[1900723-1901207].dpx

Arri LogC to BT.709
SMPTE RDD31 Annex B

MaxRGB LogC to BT.709
RGB ratio hue-preserving LUT

SRC Fm: 1899526

A004C004_210804_R26L.[1899501-1899979].dpx

Arri LogC to BT.709
SMPTE RDD31 Annex B

MaxRGB LogC to BT.709
RGB ratio hue-preserving LUT

SRC Fm: 1901865
A004C006_210804_R26L.[1901842-1902392].dpx

Arri LogC to BT.709
SMPTE RDD31 Annex B

MaxRGB LogC to BT.709
RGB ratio hue-preserving LUT

SRC Fm: 1894797

A004C001_210804_R26L.[1894618-1895321].dpx

Arri LogC to BT.709
SMPTE RDD31 Annex B

Notice the halos of out-of-focus bokeh are different colors than the background

MaxRGB LogC to BT.709
RGB ratio hue-preserving LUT

SRC Fm: 1897187
A004C002_210804_R26L.[1896677-1897337].dpx

Arri LogC to BT.709
SMPTE RDD31 Annex B

MaxRGB LogC to BT.709
RGB ratio hue-preserving LUT

SRC Fm: 1898665

A004C003_210804_R26L.[1898300-1898842].dpx

Arri LogC to BT.709
SMPTE RDD31 Annex B

MaxRGB LogC to BT.709
RGB ratio hue-preserving LUT

SRC Fm: 1861129
A003C012_210804_R26L.[1860804-1861294].dpx

Arri LogC to BT.709
SMPTE RDD31 Annex B

MaxRGB LogC to BT.709
RGB ratio hue-preserving LUT

SRC Fm: 1901089
A004C005_210804_R26L.[1900723-1901207].dpx

Arri LogC to BT.709
SMPTE RDD31 Annex B

MaxRGB LogC to BT.709
RGB ratio hue-preserving LUT

SRC Fm: 1899844

A004C004_210804_R26L.[1899501-1899979].dpx

Arri LogC to BT.709
SMPTE RDD31 Annex B

MaxRGB LogC to BT.709
RGB ratio hue-preserving LUT

SRC Fm: 1902225
A004C006_210804_R26L.[1901842-1902392].dpx

Arri LogC to BT.709
SMPTE RDD31 Annex B

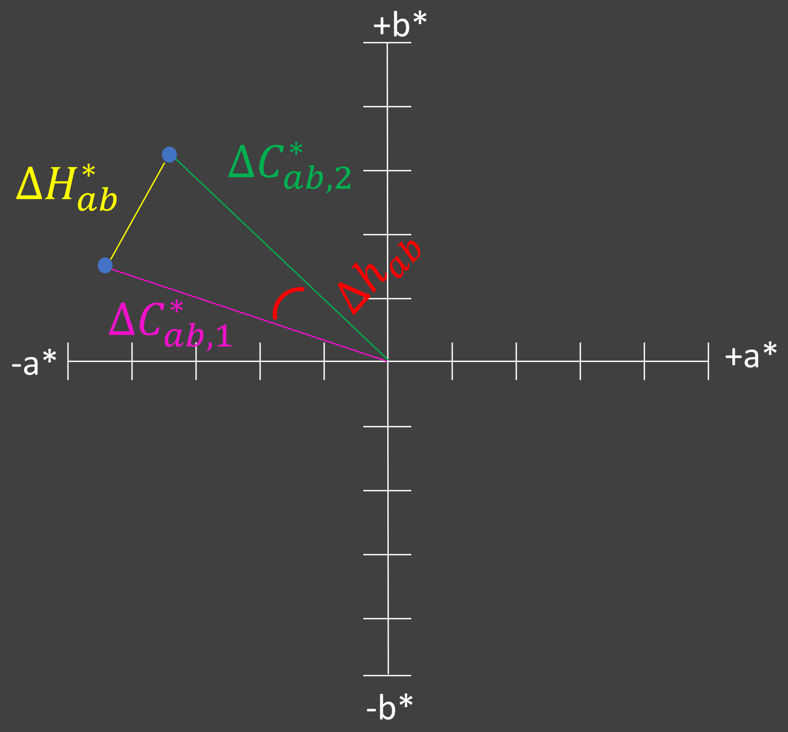
MaxRGB LogC to BT.709
RGB ratio hue-preserving LUT

SRC Fm: 1895109
A004C001_210804_R26L.[1894618-1895321].dpx

Measuring Hue Difference in Color Science

- Measuring Hue Difference is described in Color Science texts, Berns Principles of Color Technology 4th Ed pages 87-88:
- "The difference in hue angle is scaled by the geometric mean chroma of the color-difference pair"

$$\Delta H^*_{ab} = 2\sqrt{C^*_{ab,1} C^*_{ab,2}} \cdot \sin\left(\frac{\pi}{180} \cdot \frac{\Delta h_{ab}}{2}\right)$$



Hue-Preservation, Virtual Production and LED Wall

- Unlike most real physical background scenes, an LED wall can produce bright and saturated backgrounds over large areas.
  - Bright saturated colors can have a larger differences between MaxRGB and MinRGB, leading to larger changes in RGB ratios when independent R,G,B tone-curve is used for rendering.
  - Bright saturated colors have high chroma values, which leads to more visible Hue Difference for the same hue-angle difference.
- LED walls are also used for lighting and reflections in Virtual Production. Preserving hue between background and objects lit with colored light from LED wall helps reduce discrepancies that break the consistency between visual effects and photography of real objects.
- More predictable “what you see is what you get” experience for everyone on set.

Other Hue Preserving techniques

- Use a different Norm, instead of MaxRGB
  - Luminance
  - Power Norms (cubes over squares, 5ths over 4ths, …)
  - Weighted Power Norms that have different scaling weights on R, G and B.
  - Others?
- Hue restoration algorithm like ***hue_restore_dw3()*** from ACES v0.71
- Can tone-curve mapping be performed in a more perceptual space like CIE 1976 or ITP instead of RGB or norm(RGB)?
- Use more advanced gamut mapping to avoid hue-shifts due to clamp()

Conclusions

- Simple to modify existing viewing transforms to be hue-preserving.
- Camera manufacturers could offer alternative LUTs that are hue-preserving for filming LED wall backgrounds.
- Workflows in use today support using alternative viewing transforms with custom LUT files, like SHOW LUTs that vary by title, which allows easy experimentation.
- HD-SDI LUT boxes like BlackMagic Teranex Mini can load custom LUTs could be used to monitor the camera output using a hue-preserving LUT in real time on set.
- Some downsides to using hue-preserving norm-based tone-curve are
  - potential noise amplification if the noise level is not equal in R, G, and B channels.
  - most photography has historically used independent R, G, B tonescale processing, so viewers are already familiar with its associated hue-shifts like blown-out skies or sunsets, fire that turns yellow or white, etc. Will viewers be distracted from the story if they see the accurate hue of a lightbulb filament when they are used to seeing lightbulb filaments clipped to white?