Objective Color Metrics
For Single-Stream High Dynamic Range, Wide Color Gamut and Standard Dynamic Range
This presentation covers how NBCUniversal assures that we preserve the original artistic intent during broadcast transmission.
Verifying Our Mappings

...and asks.... How can we use similar tools for testing ICC Mappings?
NBCUniversal UHD HDR Experiences

2015: NYC July 4th Fireworks
2016: RIO Olympics Opening Ceremonies
2018: Pyeongchang Winter Olympics, Men’s FIFA
2018-2021: Notre Dame Football Seasons
2020 US Open Golf
2021 Chicago Basketball, Baseball
2021 Tokyo Olympics
2022 Beijing Olympics
Single-Stream Workflow Conversions

- Determine Conversion Points
- Determine conversion goals (i.e. - where is graphics white, what are the anchor points between formats)
- Make conversions from one format to another without changing perceptual representation (“original artistic intent”).
NBCU’s Single Stream Recommendation

NBCU, in collaboration with Cromorama, and building on ITU working group discussions for HDR operational practices involving Dolby, BBC and Philips, has developed techniques to enable “single-stream” production that feeds both UHD HDR and SDR transmission simultaneously.

The NBCU LUTs developed for this workflow enable single-stream production whereby the HDR and SDR products are consistent to the point where the benefits of HDR are realized making a unified production possible. Subsequently we’re sharing these efforts with the broadcast community for continued collaboration and use in production and distribution.

The NBCU LUTS include both HLG and PQ LUTs following similar HDR/SDR conversion methodology and color science.

NBCU has a commitment to industry collaboration and would like to encourage consistent media exchange, therefore we are willing to provide the NBCU LUTs freely. The NBCU LUTs are provided on an “as is” basis with no warranties.

The package of NBCU LUTs with additional documentation are available at the following link:


Chris Seeger and Michael Drazin are happy to answer questions pertaining to this effort and provide further insight into workflow.

Chris Seeger  
Chris.Seeger@nbcuni.com

Michael Drazin  
michael.drazin@nbcuni.com

We ask that manufactures include an acknowledgment in their license to their customers that the LUTs were “developed by NBCUniversal Media, LLC.”
New Video Formats

In A Typical Broadcast Workflow
There Are Now Several Possible Video Formats
UHD Broadcasting: Today and Tomorrow

* Per ITU-R, HLG reference display normalized at 1k cd/m²
HDR and WCG have a much larger color volume
Compared to SDR
What can possibly go wrong?
ICC Profiles
Will Provide New Capabilities For Explicit Mapping of Broadcast Video For Still Graphics Files Using MPEG CICP
Explicit Mappings

Define a specific mathematical rendering of broadcast video from images to desktop displays.
Example: SDR Content Into HDR Without Proper Conversion

HDR into HDR Display

Correct

SDR into HDR Display – without LUT conversion

Content Clips, and over-saturated
Example: HDR Content Into SDR Without Proper Conversion

SDR into SDR Display

Correct

HDR Into SDR Display – Without LUT Conversion

Dim and under-saturated
HDR to SDR Conversion - Saturation Preservation

- SDR RED matches HDR
- "Mid-tone" light levels
HDR to SDR Conversion - Saturation Clipping

Red turns Orange

“Mid-tone” light levels
SDR->HLG->SDR (Light-Level Anchor Points)

- SDR Peak White 100000 nits @ 100% Signal Level
- HLG Normalized Peak White 10000 nits @ 100% Signal Level
- SDR Peak White 100000 nits @ 100% Signal Level

HLG Native Highlights preserved within SDR
HLG→PQ (Light-Level Anchor Points)
WaveForms: HDR to SDR Tone-Mapping is hard!

Compressing HDR Highlights to SDR Require Good LUT Interpolation or Accurate Mathematical Conversions
Subjective assessments of conversions yielded inconsistent results.
Be Objective!!!

...so... we rely on Objective Measurements Based on ITU-R BT.2124

Which allow us to preserve the original artistic intent

And Preserve The Presentation of Our Beautiful Pictures
ITU-R BT.2124 OBJECTIVE METRICS DETERMINE ACCURATE CONVERSIONS

HOW DO WE USE ITP TO COMPARE DIFFERENT VIDEO FORMATS
- PQ, HLG or SDR are converted to a large enough container for all the video formats (ITP-PQ-BT.2020)
- We use the container for plotting all formats together for simplified analysis
- Normalized video colors can be compared in a 2D X/Y (or in this case T/P) plot for hue consistency
- We can compare multiple video sources objectively for perceptual color volume differences of color and light using formulas defined in BT.2124 (ΔE-ITP)

Use T/P color component plots to find hue shifts between multiple images

Use ΔE-ITP to check color volume differences between 2 images. A unit of “1” or above indicates a “Just-Noticeable Difference.”
A Newer Color Representation: $\text{IC}_T\text{C}_P$ and it’s sister ITP

“L”, “M”, “S” each element captures different wavelengths representing specific color ranges

“I” represents brightness(intensity) while “T/P” represent chroma components (tritan/protan)
Vooya: A Tool for Color Metric Measurement & Plotting

**Vooya Color Volume Measurement Plug-In**

- NBCU commissioned a plug-in for Vooya which makes it easier to plot video within ITP
- User-supplied X/Y pixel positions allows Vooya to grab YC_B_C_R code values from test patterns and convert them to “I-T-P” or “u’v’” for measurement
- Visualize hue consistency thru plots of T/P for (left) or export to a spreadsheet for more sophisticated analysis
- By applying a specific formulas we can compare a source vs the output using specific test patterns.

*This Plot Compares Sources vs Conversion*

- Source = HLG BT.2020 Reference Pattern (BLUE)
- Conversion = HLG to PQ Conversion NBCU LUT7 (RED)
Delta-E ITP: Examining Color and Light Differences Easily

- Color Volume Difference
- Chroma Difference
- Intensity Difference
- Input/Output Intensity Plot
- Constant Intensity and Chroma Difference
- Visualizing Hue Shifts: Blue (Input) Vs Red (Output)
Why do we see differences in specific colors?

UHD Video is sometimes broken up into QUADS. These are the colors that are affected.

A frame-sync was processing a single quad differently.
Delta-E ITP: Examining Color and Light Differences Easily

Any # above one(1) is a “Just Noticeable Difference” (JND)

Red (output) that drifts from the blue (source) in this T/P plot identifies a hue shift.
Open CSV ITP results (see example below) into any plotting software including Apple Numbers or MS Excel as a “line graph”.

<table>
<thead>
<tr>
<th>Frame</th>
<th>Pixel Nr.</th>
<th>x</th>
<th>y</th>
<th>Y</th>
<th>Cb</th>
<th>Cr</th>
<th>I</th>
<th>Ct</th>
<th>Cp</th>
<th>I</th>
<th>T</th>
<th>V'</th>
<th>u'</th>
<th>v'</th>
<th>min_nits</th>
<th>max_nits</th>
<th>Input</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>1620</td>
<td>103</td>
<td>851</td>
<td>485</td>
<td>0.4691691952331</td>
<td>-0.276285906140</td>
<td>0.468191952331</td>
<td>-0.276285906140</td>
<td>0.1428485890</td>
<td>-0.276285906140</td>
<td>0.1428485890</td>
<td>-0.276285906140</td>
<td>0.1428485890</td>
<td>-0.276285906140</td>
<td>0.1428485890</td>
<td>-0.276285906140</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>1580</td>
<td>103</td>
<td>849</td>
<td>485</td>
<td>0.4691691952331</td>
<td>-0.276285906140</td>
<td>0.468191952331</td>
<td>-0.276285906140</td>
<td>0.1428485890</td>
<td>-0.276285906140</td>
<td>0.1428485890</td>
<td>-0.276285906140</td>
<td>0.1428485890</td>
<td>-0.276285906140</td>
<td>0.1428485890</td>
<td>-0.276285906140</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>1540</td>
<td>101</td>
<td>832</td>
<td>485</td>
<td>0.4691691952331</td>
<td>-0.276285906140</td>
<td>0.468191952331</td>
<td>-0.276285906140</td>
<td>0.1428485890</td>
<td>-0.276285906140</td>
<td>0.1428485890</td>
<td>-0.276285906140</td>
<td>0.1428485890</td>
<td>-0.276285906140</td>
<td>0.1428485890</td>
<td>-0.276285906140</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>1000</td>
<td>100</td>
<td>821</td>
<td>487</td>
<td>0.4691691952331</td>
<td>-0.276285906140</td>
<td>0.468191952331</td>
<td>-0.276285906140</td>
<td>0.1428485890</td>
<td>-0.276285906140</td>
<td>0.1428485890</td>
<td>-0.276285906140</td>
<td>0.1428485890</td>
<td>-0.276285906140</td>
<td>0.1428485890</td>
<td>-0.276285906140</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>1460</td>
<td>99</td>
<td>808</td>
<td>486</td>
<td>0.4691691952331</td>
<td>-0.276285906140</td>
<td>0.468191952331</td>
<td>-0.276285906140</td>
<td>0.1428485890</td>
<td>-0.276285906140</td>
<td>0.1428485890</td>
<td>-0.276285906140</td>
<td>0.1428485890</td>
<td>-0.276285906140</td>
<td>0.1428485890</td>
<td>-0.276285906140</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>1420</td>
<td>97</td>
<td>795</td>
<td>489</td>
<td>0.4691691952331</td>
<td>-0.276285906140</td>
<td>0.468191952331</td>
<td>-0.276285906140</td>
<td>0.1428485890</td>
<td>-0.276285906140</td>
<td>0.1428485890</td>
<td>-0.276285906140</td>
<td>0.1428485890</td>
<td>-0.276285906140</td>
<td>0.1428485890</td>
<td>-0.276285906140</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>1380</td>
<td>95</td>
<td>781</td>
<td>490</td>
<td>0.4691691952331</td>
<td>-0.276285906140</td>
<td>0.468191952331</td>
<td>-0.276285906140</td>
<td>0.1428485890</td>
<td>-0.276285906140</td>
<td>0.1428485890</td>
<td>-0.276285906140</td>
<td>0.1428485890</td>
<td>-0.276285906140</td>
<td>0.1428485890</td>
<td>-0.276285906140</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>1340</td>
<td>94</td>
<td>759</td>
<td>491</td>
<td>0.4691691952331</td>
<td>-0.276285906140</td>
<td>0.468191952331</td>
<td>-0.276285906140</td>
<td>0.1428485890</td>
<td>-0.276285906140</td>
<td>0.1428485890</td>
<td>-0.276285906140</td>
<td>0.1428485890</td>
<td>-0.276285906140</td>
<td>0.1428485890</td>
<td>-0.276285906140</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>1300</td>
<td>92</td>
<td>756</td>
<td>492</td>
<td>0.4691691952331</td>
<td>-0.276285906140</td>
<td>0.468191952331</td>
<td>-0.276285906140</td>
<td>0.1428485890</td>
<td>-0.276285906140</td>
<td>0.1428485890</td>
<td>-0.276285906140</td>
<td>0.1428485890</td>
<td>-0.276285906140</td>
<td>0.1428485890</td>
<td>-0.276285906140</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>1260</td>
<td>91</td>
<td>743</td>
<td>493</td>
<td>0.4691691952331</td>
<td>-0.276285906140</td>
<td>0.468191952331</td>
<td>-0.276285906140</td>
<td>0.1428485890</td>
<td>-0.276285906140</td>
<td>0.1428485890</td>
<td>-0.276285906140</td>
<td>0.1428485890</td>
<td>-0.276285906140</td>
<td>0.1428485890</td>
<td>-0.276285906140</td>
</tr>
</tbody>
</table>
Line Plotting using Vooya ITP Output

Each sampled ITP Value is multiplied by 720 times the Square Root of the sum of squares of the differences of corresponding values in two arrays.

This produces each $\Delta E$-ITP Value.