Development of a High Dynamic Range (HDR) Ecosystem

June 21, 2019
Dolby Background

- Dolby develops ecosystems for improved multimedia experiences
  - Professional Audio
  - Theatrical Audio
  - Consumer Audio
  - Theatrical Imaging
  - Consumer Imaging
  - Teleconferencing
Audio Noise Reduction

Dolby A
Professional Noise Reduction.
Matrix Surround Sound
Discreet Surround Sound
Discreet Surround Sound
Early facilities were only AES pairs.
A new paradigm (ATMOS)

Multi-track audio is flattened to 5.1 or 7.1
A new paradigm (ATMOS)

All tracks sent as objects. Sound layout is sent as metadata.
Dolby Activity in HDR – a 14 Year Journey

• First findings
  – Pictures stretched to high brightness don’t look good
  – Complete E-E ecosystem needed, production, delivery, display

• Research needed
  – How bright and how dark?
  – Baseband signal format
  – Optimization for various displays

• Technology developed
  – PQ curve, local dimming for LCD, quantum dot films, ICₜCcₚ color, content/display mapping
  – Displays: SIM2, 20k nit research display, Pulsar, Maui, Dolby Vision Projector
The Real World

- 133,000 nits
- 170,000 nits
- 6000 nits
- 300,000 nits
- 6000 nits
- 185 nits
- 15 nits
- 10,000 nits
- 185 nits
- 6000 nits
- 300 nits
- 77 nits
- 0.5 nits
- 15 nits
- 0.25 nits
- 15 nits
- 15 nits
- 3 nits
- 0.5 nits
- 15 nits

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HDR Luminance Range

- Previous HDR studies lacked a high dynamic range and high contrast ratio display.
- Dolby built a prototype HDR P3 display which could create very deep black levels - 0.004 nits and up to 20,000 peak nits while maintaining a contrast of 5 Million:1.
- 3 preference studies were conducted to determine the preferences for:
  - The Black level
  - The Diffuse White maximum
  - For the Highlights
HDR Study (small screen)
Real World

- Real World
  - >15 orders of magnitude

- The eye
  - 4 orders of magnitude
  - But adaptive

- Current TV
  - 3 orders of magnitude
Barten Formula for Contrast Sensitivity Function

\[
CSF = \frac{1}{m_t} = \frac{M_{\text{opt}}(u)/k}{\sqrt{T \left( \frac{1}{X_0^2} + \frac{1}{X_{\text{max}}^2} + \frac{u^2}{N_{\text{max}}^2} \right) \left( \frac{1}{\eta p E} + \frac{\Phi_0}{1 - e^{-(u/u_0)^2}} \right)}}
\]

\[
M_{\text{opt}}(u) = e^{-2\pi^2 \sigma^2 u^2}
\]

\[
\sigma = \sqrt{\sigma_0^2 + (C_{ab} d)^2}
\]

\[
d = 5 - 3 \tanh \left( 0.4 \log \left( L X_0^2 / 40^2 \right) \right)
\]

\[
E = \frac{\pi d^2}{4} L \left( 1 - (d/9.7)^2 + (d/12.4)^4 \right)
\]

\[
k = 3.0
\]

\[
\sigma_0 = 0.5 \text{ arcmin}
\]

\[
C_{ab} = 0.08 \text{ arcmin/mm}
\]

\[
T = 0.1 \text{ sec}
\]

\[
X_0 = 40^\circ
\]

\[
X_{\text{max}} = 12^\circ
\]

\[
N_{\text{max}} = 15 \text{ cycles}
\]

\[
\eta = 0.03
\]

\[
\Phi_0 = 3 \times 10^{-8} \text{ sec deg}^2
\]

\[
u_0 = 7 \text{ cycles/deg}
\]

\[
p = 1.25 \times 10^6 \text{ photons/sec/deg}^2/Td
\]

*Peter G. J. Barten, “Formula for the contrast sensitivity of the human eye”  
Proc. SPIE-IS&T Vol. 5294:231-238, Jan 2004
Contrast Sensitivity

This HDR EOTF is defined in SMPTE Standard ST 2084 and ITU BT.2100

- 12 bit PQ shows no visible contouring
- 10bit PQ is above the Barten threshold
  - Contouring can occur
  - Can be masked by sensor noise
Color Gamut
Dolby Contributions to HDR

PQ
• Transfer function requires no compromises: can represent deepest blacks to brightest highlights, with detail visible (and no contouring) across the entire range from black to 10k nits (no need to limit highlights)

ICtCp
• The YCbCr limitations become apparent with HDR and WCG.
• ICtCp is a color representation with attributes of constant luminance and constant hue

Optional ST 2094-10 metadata to assist display adaption
• Allows receivers to optimize image display based on actual display capabilities
• Metadata can be generated live at encode
Dolby Participation in the Industry

• “Dolby Vision” ecosystem has launched for services where standards are not required
  – Branded: content, delivery, display
  – OTT: Warner, Sony, MGM, Universal, Vudu, Netflix, Amazon; Vizio, LG, TCL
  – Cinema: Dolby Premium Cinemas

• Broadcast needs standards so Dolby is leading standards development
  – JPEG-HDR (ISO/IEC 18477-2) for richer still photography
  – SMPTE ST 2084 (PQ), ST 2086 (static metadata), ST 2094-10 (dynamic metadata)
  – ITU-R Report BT.2390, ITU-R Recommendation BT.2100
  – MPEG-HEVC Development, Enable and Improve for HDR
  – ATSC A/341 Annex E
  – ETSI TS 103 572 (DVB)
Dolby and Standards

Dolby has been a leader in HDR standards development

Chairs or leads Standards efforts in:

- ITU-R
- SMPTE
- MPEG
- ETSI
- DVB
Display Adaptation

Color Volume Mapping

- Typical UHDA HDR Display e.g. OLED/LCD
- Legacy SDR 709 Display
- Future HDR Display
Display Adaptation

• With the advent of HDR, mastering displays can and will be different than consumer displays

• Display Adaptation (aka Dynamic Metadata) adjusts content in the display device based on:
  • Target display (brights, darks and color volume)
  • Target viewing environment
  • Keeps the creative intent on the target display
Types of metadata

Descriptive Metadata

• Content is parameterized
• Unique solution is created for each display at the point of display based on:
  • Content
  • Display
  • Environment
  • Trims (creative)

Prescriptive Metadata

• Curve(s) are created upstream
• Either many curves are transmitted or a small set
  • Many curves gives better interpolation but raises bit rate
  • Small set of curve(s) means most solutions are interpolated or extrapolated
  • Creative intent is limited
What is in Dolby Vision Metadata?

<table>
<thead>
<tr>
<th>Metadata Level</th>
<th>SMPTE ST 2094-10</th>
<th>A/341 Annex E / TS 103 572</th>
</tr>
</thead>
<tbody>
<tr>
<td>L0</td>
<td>N/A – see ST 2086</td>
<td>MDCV SEI (ST 2086)</td>
</tr>
<tr>
<td>L1</td>
<td>Min/mid/max luminance of scene</td>
<td>Min/mid/max luminance of scene</td>
</tr>
<tr>
<td>L2</td>
<td>Display Specific Trims (Creative)</td>
<td>Display Specific Trims (Creative)</td>
</tr>
<tr>
<td>L3</td>
<td>L1 offset – in SMPTE, HDMI; (Creative)</td>
<td></td>
</tr>
<tr>
<td>L4</td>
<td>Not defined in 2094-10</td>
<td></td>
</tr>
<tr>
<td>L5</td>
<td>Processing window</td>
<td>Active area (Letterbox)</td>
</tr>
<tr>
<td>Other Levels</td>
<td>Not defined in 2094-10</td>
<td>Structure is extensible</td>
</tr>
</tbody>
</table>
Backward Compatibility with HDR10 and PQ10

- **PQ10** – defined in ITU-R BT.2100-0, and ITU-R
  - SMPTE 2084 “Perceptual Quantizer”
  - Rec BT.2100, and 10 bits per color channel

- **HDR10** – defined by UHDA, and used in UHD Blu-ray, OTT, ATSC and SCTE
  - Similar to PQ10, but requires metadata:
    - ST.2086 mastering display metadata; MaxFALL and MaxCLL values

- **Dolby Vision** – deployed in OTT and UHD Blu-ray
  - In ATSC 3.0 and DVB
  - PQ at 12-bits per color channel
  - ST.2094-10 dynamic metadata to characterize content
Offline Production

- Cinema Grading
- Video Grading
- Dolby Cinema (Laser)

- Video target
  - 4000 nit
  - 2100 nit
  - 1000 nit
  - P3
  - 100 nit
  - 709

- Cinema trims

Descriptive metadata with target trims
Signaling is a mix of network, local and syndicated content. Metadata can be generated at emissions when missing.
Live Production

BT.2408
HLG -> PQ

PQ or
PQ derived from SLog3

Metadata or
Metadata + trims

HPU or
Encoder with HPU

PQ
Affiliate and/or O&O

Signals are ingested from a variety of sources
May or may not have embedded metadata

- Network
- Advertisements
- Local News Feed
- SDR Feed
- 3D LUT
- SDR-HDR mapper

Master Control

Metadata driven for best quality

- HDR to SDR downmapping
- ATSC 1.0
- ATSC 3.0
- MVPD
- A/341 Annex E

Encoder with HPU

Metadata driven for best quality

- DASH
- HLS
- CTA WAVE
- Internet Delivery

Metadata driven for best quality

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If Display Metadata exists, pass it through; Otherwise generate the metadata.
Curves are created at the display device

Content is optimized to the display at the point of rendering
ATSC 3.0 Over-The-Air (OTA) Demonstration
WJW Transmitter Setup

Server with “Lowriders” (4000 nit) content

A/341 Annex E Full Range

MP4 Packets with SEI Messages

Triveni

DASH/ROUTE Packets

Enensys Gates Air

600 KW ERP
2000 ft HAAT
WJW Receiver Setup

Received RF with ST 2094-10 SEI → Stream with SEI Message → PC modelling a STB → HDMI with Dolby Vision → Current model LG HDR TV purchased locally at Best Buy plays Dolby Vision.

Prototype LG ATSC 3.0 TV without Dolby Vision in RF path displays HDR10.
Types of Standards

Fundamental Standards

Foundational Standards

Applications Standards
Distribution Partners

- VUDU
- LG
- ULTRA HD
- Blu-ray
- NETFLIX
- VIZIO
- deluxe digital STUDIOS
- DOLBY CINEMA
- amc prime
- Amazon
- iTunes
- SONY
- TCL
Content

300+ movies completed and approved
100’s of hours of episodic television
Multiple production facilities
SL-HDR1

Prescriptive Metadata

Base is SDR BT.2020 10 bit

HDR is carried by stretching the SDR signal

Added to ATSC 3.0 as an amendment

No broadcasts announced
SL-HDR2

Prescriptive Metadata
Base is HDR10
Display Adaptation
Added to DVB
HDR10+

Prescriptive Metadata
Single curve sent – 350 cd/m²
Tone curves are interpolated
Standards still being developed
Samsung, Fox, Panasonic
Amazon announced
Key Points

Dolby develops ecosystems for improved multimedia presentation

Final rendering is moving toward the presentation devices

HDR was developed as an end-to-end ecosystem

All aspects of the content chain have need considered

Dolby vision is now in Cinema, Blu-ray, OTT and Broadcast
Questions?