DELIVERING THE ULTRA-HD IMMERSIVE VIEWING EXPERIENCE (MASTER CLASS)

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WHAT IS 4K ULTRA-HD?

› Commonly called 4K UHDTV or 4K TV
› “4K” resolution (3840 x 2160) – 4x more spatial resolution than 1080i HD
› p50/59.94 frame rates – 2x the temporal definition than 1080i*
› But otherwise the same as today – Dynamic range, colorspace, sample bit depth** as HD broadcast today
› Together this makes UHD-1 Phase 1

* p24/25/30 are allowed but not popular
** 10-bit is allowed but not mandated
HUMAN VISUAL SYSTEM

Fovea Centralis
Central 2-3° of vision
< 0.5 arc minute resolution

Central Field of Vision
Approx. 90°
Objects are recognized

Total Field of Vision
Approx. 180°
Objects can be seen if critical
VISUAL PERCEPTION - RESOLUTION

1 arc minute*

*limit of Fovea Centralis 0.5 arc minute
PROPER VIEWING DISTANCE (D)
HD ~ 3H
4K UHD ~ 1.5H

D = (W/2)/tan(x)
Screen size = √(H^2+W^2)

HDTV field-of-view ~30°
4K UHDTV field-of-view ~60°
HD SPATIAL RESOLUTION

Human central field of vision 90-100°
UHD-1 SPATIAL RESOLUTION (4xHD)

3840 x 2160 UHD

Human central field of vision 90-100°
SCREEN SIZE VS. VIEWING DISTANCE

You will not see a difference compared to 1080p

4k Ultra HD Worth It

So, UHDTV-1 = 2x horizontal & 2x vertical resolution of HDTV, but spatial resolution is not the entire story …
HIGH FRAME RATE (HFR)

Conventional Frame Rate

High Frame Rate

› Wider viewing angle = more immersive
  - Increased motion sensitivity = increased perceived motion artifacts

› Higher frame rates needed to compensate:
  50/60 fps minimum (100/120 fps being vetted)
If the camera and subject are static or moving slowly, HFR doesn’t do anything and 24 /25/30 fps is acceptable. However this is less temporal resolution than SD or HD TV today. Note: Almost all films are shot at (or around) 24 fps.

For most content, 50 or 60 fps are needed to reduce motion artifacts. As progressive formats, these also give better temporal resolution than interlace. Note: A few films are now being shot at 48 fps HFR.

As motion increases further, 100 or 120 fps can further reduce motion artifacts but at correspondingly greater cost than 50/60 fps. Note: Frame rates of 240 fps or above may be needed to eliminate artifacts.
COLOR GAMUT

Expanded color space for more realistic representation

› UHDTV can offer more realism via color
  - But, we need technology with the right color space

› Quantization of levels
  - With more colors to represent, higher bit sample depth (10-bit) becomes important (more on this later)

UHD color space per Rec. ITU-R BT.2020
HD color space per Rec. ITU-R BT.709
WIDE COLOR GAMUT (WCG)
CAPTURE MORE OF REALITY – RICHER COLORS

From Report
ITU-R BT.2246-3
Inner triangle: HDTV primaries
Outer triangle: UHDTV primaries
THE SAME OR NOT THE SAME?
WE “MAKE” COLOR
WE DON’T “SEE” COLOR
HIGH DYNAMIC RANGE (HDR)

› HDR immersion not limited to strict viewing distance
  – Benefits large screens (including HD) and tablets and phones

› From transmit side, HDR is potentially more economically viable to deploy than 4K UHDTV

› Once you have seen HDR, you realize how much better than current TV it is

› Cameras can capture HDR now, but we can’t see it at home

Pictures are richer, more lifelike and sharper with HDR. Seeing is believing.
RESOLUTION AS A CONSTRUCT

› The Human Visual System (HVS) builds resolution through a complex mechanism
  – The eye is relatively low resolution so we sample an image

› Saccadic motion combines with eye tracking
  – This is important for UHD production - viewers need time to take in the picture

› Humans also detect sharpness as a function of contrast

› These inputs are combined with internal reference models based on memory
WHY HDR LOOKS “SHARPER”

Low contrast image looks ‘softer’ as some detail is harder to see. More dynamic range can reveals more detail especially edges and looks sharper (although the pixel resolution is the same).

Which one is sharper?
TV Today:
Low dynamic range means subtle contrast differences in the original content (which many cameras capture) are not maintained – detail is missing

HDR TV:
High dynamic range means subtle contrast differences in the original content can be captured and transmitted to the consumers, revealing previously hidden detail
DYNAMIC RANGE AND THE HVS
DYNAMIC RANGE AND THE HVS

Light Grey?

Dark Grey?
ANOTHER EXAMPLE

Is ‘A’ or ‘B’ lighter?
ANOTHER EXAMPLE

They are the same
HVS: LUMINOUS INTENSITY

Cinema: 55 cd/m² in dark viewing environment
Reference white: 100 cd/m² (ITU-R BT.1886)
Based on 1930s CRT

HDR TVs, now to future: 1,000 to 4,000 cd/m²

Candela per square meter (cd/m²) or “nit”
COMPARING SDR TO HDR

Standard Dynamic Range, Lowlight Exposure

Standard Dynamic Range, Highlight Exposure

High Dynamic Range, (simulated by tone mapping)

Images source: K. McCoy. Licensed under CC BY-SA 3.0 via Wikimedia Commons
HDR: SPECULAR LIGHT IMPACT

Images courtesy of Dolby Laboratories

Clipping at 40% Luminance reduction

Displayed at 100% luminance
EOTF / GAMMA

› Electro-Optical Transfer Function

› TVs
  - Do not linearly convert voltage to display intensity
  - \( L = V^\gamma \)
    > Where \( \gamma = 2.35 \) (HDTV spec, Rec. ITU-R BT.709 color space)

› Cameras
  - Must apply the reverse function \( \rightarrow \) OETF, Opto-Electrical Transfer Function
  - “Voltage” is equivalent to numerical sample value
 › Not all levels are useful for entertainment
    - Region between shaded areas is useful
 › Color grading should map levels to only the useful range

 › Ambient light reflection
    - \( L_{\text{refl}} = \left( \frac{k}{\pi} \right) E_{\text{amb}} \)
      - LCD screens: \( \sim 1\% \) (low reflectance)
      - \( E_{\text{amb}} \sim 300 \text{ lux for a dim room} \)
    - So \( L_{\text{refl}} \geq 0.1 \text{ cd/m}^2 \)
    - Lower levels unlikely to be seen …

Step size / Luminance (dL/L) is the measure of visibility.

Levels below the dashed curve (Barten model) are very hard for human visual system to resolve.

Mapping signal levels to display luminance is known as the *gamma* curve.

8-bit gamma-coded has large, visible steps across the range.

10-bit gamma-coded reduces that dramatically.
VISUAL QUALITY: 10-BIT SAMPLE DEPTH

› Not just for wider color gamut and extended/high dynamic range …

› Banding (posterization) with 8b, especially in plain areas
  – Sky, backgrounds, graphics, logo
  – Very noticeable with slow changes, such as fades

› Significantly improved image quality with 10-bit sample depth

› No bandwidth cost in the compressed domain

Visible banding
OETF FOR HDR

› Gamma comes from a desire to simplify analog TV electronics
  - Based a typical CRT’s range

› Two candidate alternatives:
  › Both offer HDR with 10-bits
    - SMPTE ST 2084
    - BBC WHP283
  - Pros & Cons for each
    › Consequences for the production chain

10-bit levels over range wider range
BROADCAST CHAIN IMPLICATIONS

› HDR and other new features of UHD-1 Phase 2 may mean a change to all equipment

› Open standardization is good
  - MPEG to issue Call for Evidence for HDR (for HEVC)
  - SMPTE and ITU-R studying HDR (“EIDR TV”)
  - CEA, BDA, HDMI Forum, etc.
HDR “BACKWARD COMPATIBILITY”

› Q1: Are we trying to make an HDR signal that also can be viewed on any SDR TV or other display device? If so, is it single or dual layer?

Or

› Q2: Are we trying to make a signal that can be converted by an intermediate step to be shown on any SDR TV or other display device, e.g. by metadata?

Or

› Q3: Are we planning to simulcast, as we do today with HD/SD and are planning to do with UHD/HD?

Historical note: Prior to HD being launched, backward compatibility was a big topic – after launch it went away
CARRYING TRUE 4K UHDTV

12 Gbps

Acquisition – Production – Exchange – Distribution

? Mbps
BANDWIDTH EFFICIENCY TRENDS

- 1994 MPEG-2 VIDEO
- 2003 AVC
- 2013 HEVC

50% bitrate saving – Direct-to-home
30% bitrate saving – Contribution
HEVC POTENTIAL - DIRECT-TO-HOME FOR SIMILAR PICTURE QUALITY

<table>
<thead>
<tr>
<th></th>
<th>MPEG-2 Video</th>
<th>AVC</th>
<th>HEVC</th>
</tr>
</thead>
<tbody>
<tr>
<td>SD</td>
<td>3 - 5 Mbps</td>
<td>1.8 - 3 Mbps</td>
<td>1 - 1.8 Mbps</td>
</tr>
<tr>
<td>HD</td>
<td>10 - 18 Mbps</td>
<td>5 - 9 Mbps</td>
<td>2.5 - 4.5 Mbps</td>
</tr>
<tr>
<td>4K UHDTV (2160p60 10b)</td>
<td>N/A</td>
<td>N/A</td>
<td>8 – 15 Mbps*  15 – 25 Mbps**</td>
</tr>
</tbody>
</table>

*For typical PQ comparisons
**For higher PQ expectations

As with all bitrate projections, these ranges are subject to PQ expectations & content complexity
# HEVC Potential - Contribution for Similar Picture Quality

<table>
<thead>
<tr>
<th></th>
<th>MPEG-2 Video 4:2:2 8b</th>
<th>AVC 4:2:2 10b</th>
<th>HEVC 4:2:2 10b</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>HD</strong></td>
<td>35 - 60 Mbps</td>
<td>23 - 40 Mbps</td>
<td>17 - 30 Mbps**</td>
</tr>
<tr>
<td><strong>4K UHDTV (2160p60)</strong></td>
<td>N/A</td>
<td>100 - 160 Mbps*</td>
<td>55 - 100 Mbps**</td>
</tr>
</tbody>
</table>

*4 x 1080p60

**Estimated; HEVC Range Extension Main 4:2:2 10 Profile still under evaluation

As with all bitrate projections, these ranges are subject to PQ expectations & content complexity.
## COSTS VS. CONSUMER EXPERIENCE

<table>
<thead>
<tr>
<th>Enhancement</th>
<th>Baseband Network Costs</th>
<th>Baseband Storage Costs</th>
<th>Small Screen Benefit</th>
<th>Large Screen Benefit</th>
<th>Content Dependency</th>
<th>Legacy Content Enhancement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wide Color Gamut</td>
<td>Cheap</td>
<td>Cheap</td>
<td>Not known yet</td>
<td>Yes</td>
<td>Most content benefits</td>
<td>Yes</td>
</tr>
<tr>
<td>High Frame Rate (100/120 fps)</td>
<td>Expensive (HD)</td>
<td>Expensive (HD)</td>
<td>Yes</td>
<td>Yes</td>
<td>Mostly limited to sports</td>
<td>No</td>
</tr>
<tr>
<td>High Dynamic Range</td>
<td>Cheap</td>
<td>Cheap</td>
<td>Yes</td>
<td>Yes</td>
<td>Most content benefits</td>
<td>Yes</td>
</tr>
<tr>
<td>4K UHD resolution</td>
<td>Expensive</td>
<td>Expensive</td>
<td>No/some</td>
<td>Yes</td>
<td>Most content benefits</td>
<td>Some</td>
</tr>
</tbody>
</table>
UHD ROADMAP: UNCERTAINTIES

› UHDTV is all about the consumer experience
  - But only UHD-1 Phase 1 defined:
    **Does not include many immersive technologies!**

› UHD-1 Phase 2 in development
  - Not clear how technologies will be defined

Source: DVB CM-UHDTV
AND SO SOME PRESS IS NEGATIVE

Why Ultra HD 4K TVs are still stupid

The flood of TVs with higher resolution than 1080p is inevitable, but at typical TV sizes, quadruple the pixels makes no difference in picture quality and are not worth the extra price.

by Geoffrey Morrison @TechWriterGeoff / January 28, 2013 5:32 PM PST
SUMMARY

› Will “4K” or UHD-1 services be successful?
  - Depends on how we in the industry present it!
  - *Can be transformative if the experience is immersive*

› Not all touted “4K” or UHD solutions are “full” or “true” 4K UHDTV
  - For an immersive viewing experience,
    › 50-60 fps required for sports and other complex motion content
    › 10-bit depth data values required for all content
    › *High dynamic range may end up being the single most important factor*
      - *So, service providers should seriously consider 1080p60 HD HDR!*

› Much work effort still to be done for UHD-1 Phase 2 (2017+)
  - Standardization of technologies: HDR, WCG, sample bit depth, HFR, etc.
  - Standardization of interfaces: from production to consumer
  - Standardization/recommendations for workflows (interoperability)