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High Dynamic Range Video: Issues Related to Moving Image Preservation

The technology and materials of moving image production, distribution, and display have changed and evolved considerably since their invention—from celluloid to magnetic tape to born-digital files, from standard definition to high definition and beyond, from VHS to DVD to streaming, from movie theatre screens to smart phone displays, and so on. As science and technology continues to evolve, moving images will be reshaped again and again, as will the material nature of what moving image archivists work to preserve. The latest interrelated series of changes in digital moving image capture and display technology focus on increasing resolution, dynamic range, frame rate, and color volume. With the community of digital moving image preservationists in mind, this paper seeks to introduce some of these new developments with a focus on High Dynamic Range (HDR) video. This writing will include some history and context, as well as sections on production and capture, distribution and available content, and finally preservation. While HDR video will be the main focus, it is useful to understand the advances in resolution and color as these are often mentioned side-by-side in the literature, standards, and specifications for HDR video, and these will also be explored.

The human eye is able to perceive a broad range of luminance; however, imaging technology has always been much more restricted. HDR aims to increase the range of luminance that cameras are able to capture and that displays are able to reproduce. Some experts believe that HDR video has the potential to be the “biggest qualitative change in TV quality since color.”[1] For the preservation of today’s media production using this advanced technology, it is imperative for digital moving image archivists–

[1] *High Dynamic Range Video: Concepts, Technologies, and Applications*. Alan Chalmers, et al. eds. Academic Press, 2017. XV.

whether in memory institutions, public broadcasting, Hollywood studios, or elsewhere–to be aware of and think critically about this potentially significant shift in moving image capture, distribution, and display technology.

HDR: Some Definitions

Dynamic range is simply defined as the "ratio of the maximum light intensity to the minimum light intensity" in any scene.[2] This range is measured by the unit, f-stop, with the values divided into the following categories for imaging:

- Standard dynamic range (SDR) is ≤ 10 f-stops;
- Enhanced dynamic range (EDR) is > 10 f-stops and ≤ 16 f-stops;
- High dynamic range (HDR) is > 16 f-stops.[3]

To contextualize these numbers, it should be noted that motion picture film stock can capture up to 15 f-stops, and a special black and white motion picture film (specifically developed in the 1960s to capture high dynamic range scenes, such as like nuclear detonations or rocket launches) captured 26 f-stops—a staggering number, much higher than any currently available digital cameras are capable of capturing.[4]

Nits, another related unit, is used to measure luminance and is also helpful when discussing HDR video. While SDR video has a range of 0.05 to 100 nits (candela per square meter or cd/m²), HDR aims to increase this range dramatically to encompass nit values between 0.0005 to 10,000.[5] However, even the best reference monitors today are only capable of rendering a luminance range of 0,005 to 4,000 nits.[6]

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[2] *High Dynamic Range Video: Concepts, Technologies, and Applications*. XVII.
[3] Ibid. XIX.
[4] Chalmers, Alan, and Kurt Debattista. "HDR video past, present and future: A perspective." *Signal Processing: Image Communication*, Volume 54, 2017, 49-55. 49. https://doi.org/10.1016/j.image.2017.02.003.
[5] Deutsche TV-Plattform. "High Dynamic Range (HDR)." http://www.tv-plattform.de/en/high-dynamic-range-2
[6] ARRI Corporation. "High Dynamic Range FAQ." http://www.arri.com/camera/alexa/learn/hdr_faq/

Background and Production

The first literature on HDR appears in the early 1990s.[7] According to Dufaux et al., the first instance of combining multiple digital images of the same scene with different exposures to create a still HDR image occurred in 1993.[8] The first HDR video displays were made in 2004 and the first video cameras in 2009.[9] While HDR video was initially confined to capturing multiple exposures of a scene and combining them to form one frame, this method would result in visible ghosting artifacts during playback of scenes with motion.[10] Today, there are multiple methods of creating HDR video, including multiple-exposure as well as simultaneous capture, which is employed in professional cameras with sensors that are able to capture an increased dynamic range in a single exposure.[11] This was made possible by improved camera sensors that can be exposed to an incredible amount of light without incurring damage.[12]

Some professional cameras, such as the ARRI Alexa, RED Epic, and Sony F65, are capable of capturing HDR video in a range that displays are not yet capable of showing–indeed, these cameras have been capturing video in these ranges even before HDR video became the buzz-word and marketing vehicle that it has over the last few of years.[13] Aside from real life capture, HDR video can also be created through mastering SDR video to HDR in post-production. Today, many projects require videos to be produced and delivered in HDR for TV or cinema distribution with some studios, such as 20th Century

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[7] Deutsche TV-Plattform.
[8] Dufaux, Frederic, et al. editors. *High Dynamic Range Video: From Acquisition to Display and Applications*. Academic Press, 2017. 5.
[9] Chalmers, Alan, and Kurt Debattista. "HDR video past, present and future: A perspective." *Signal Processing: Image Communication*, Volume 54, 2017, 49-55. https://doi.org/10.1016/j.image.2017.02.003. 49.
[10] Ibid. 50.
[11] Akyüz, A.O., et al. "Ghosting in HDR Video." *High Dynamic Range Video: Concepts, Technologies, and Applications*. Chalmers, Alan, et al. editors. Academic Press, 2017. 3.
[12] *High Dynamic Range Video: From Acquisition to Display and Applications*. 3.
[13] *High Dynamic Range Video: Concepts, Technologies, and Applications*. 216.

Fox, mastering all their 4K content in HDR.[14] HDR monitors to judge images on a production set are also becoming common as more productions aim to master and distribute content in HDR.

After raw camera files have been exported, they are color corrected and encoded for distribution and display. This encoding process can occur in a couple different ways, and this distinguishes the different formats of HDR for display monitors. The key element is the transfer function, or EOTF (electro-optical transfer function), which is "the description of how to convert the signal's carrier (analog voltage, film density, or digital code values) to optical energy."[15] The formula that is used to perform this translation of digital code to the luminance that you see on screen determines what HDR standard or transfer function was used to create and now play back the digital video.

Although new developments in this area are unfolding rapidly, as of this writing there are two main HDR video transfer functions: Perceptual Quantizer (PQ) and Hybrid Log Gama (HLG). Specifications for both HLG and PQ are standardized in several documents including BT.2100 by the International Telecommunication Union (ITU) in July 2016.[16] HLG was developed by the British and Japanese public broadcasting companies BBC and NHK and designed to be backwards compatible with SDR displays.[17] HLG has also been standardized for broadcasting in Japan by the Association of Radio Industries and Businesses (ARIB) in the document ARIB STD-B67 which sets out its scope as applying to "video equipment for programme production of the extended image dynamic range television."[18] HLG is

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[14] ARRI Corporation.

[15] Miller, Scott, et al. "Perceptual Signal Coding for More Efficient Usage of Bit Codes." SMPTE Motion Imaging Journal, May/June 2013, 52-59. 52.

[16] ITU. *Recommendation ITU-R BT.2100-1 (06/2017) Image parameter values for high dynamic range television for use in production and international programme exchange.* July 2017.

[17] ITU. *Report ITU-R BT.2390-3 (10/2017): High dynamic range television for production and international programme exchange.* October 2017. 23.

[18] Association of Radio Industries and Businesses (ARIB). *ARIB ST.B67 Version 1: Essential Parameter Values for the Extended Image Dynamic Range Television (EIDRTV) System for Programme Production*. July 3, 2015. https://www.arib.or.jp/english/html/overview/doc/2-STD-B67v1_0.pdf. 1.

also an open, royalty-free standard that, unlike PQ, does not require production metadata in order to display properly, making it an ideal candidate for over-the-air broadcasting.[19]

The PQ transfer function, more widely adopted in the United States, was developed by Dolby Laboratories and subsequently adopted by the Society of Motion Picture and Television Engineers (SMPTE) in SMPTE ST 2084.[20] This standard requires that video files carry either static or dynamic HDR metadata in order to be displayed properly. This is another important concept related to HDR Video: mastering metadata. This is used by some HDR formats to adjust video during playback to look as the creators intended at the end of post-production. There are two types of mastering metadata: static metadata is transmitted to the display once for the entire digital video file at the beginning of playback, whereas dynamic metadata adjustments are done on a scene by scene, or even frame by frame, basis throughout playback.

There are three main versions of HDR developed using the PQ transfer function: HDR10, HDR10+, and Dolby Vision. HDR10 uses static metadata to control the how the video is rendered on displays, while HDR10+ is a newer variant that uses dynamic metadata that has the potential to control the rendering of every frame of video.[21] For displays to be considered HDR-compatible, at a minimum they have to be able to render video with static HDR metadata.[22] Dynamic metadata for HDR video is standardized in SMPTE ST 2094 which also defines the third PQ variant, Dolby Vision. While HDR10 and HDR10+ are open standards, Dolby Vision is Dolby's proprietary HDR technology and requires licensing

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[19] ITU. *Report ITU-R BT.2390-3 (10/2017)*. 23.
[20] SpectraCal, Inc. *Understanding HDR: What the New Viewing Experience Means for Color Calibration*. May 2015. 1. http://www.spectracal.com/Documents/Understanding-HDR.pdf
[21] Giovara, Vittorio. "Color Me Intrigued: A Jaunt Through Color Technology in Video." 2017. https://vimeo.com/blog/post/luminous-colors-stunning-high-quality-hdr-arrived.
[22] Advanced Television Systems Committee, Inc. "CES 2017 Preview: TV Has Come a Long Way in 50 Years Since First CES." https://www.atsc.org/newsletter/ces-2017-preview-tv-come-long-way-50-years-since-first-ces/

fees to be used by camera and display manufacturers, content producers, and distributors. [23] Dolby Vision, like HDR10+, will use dynamic metadata created during production or post-production to adjust displays to accurate luminance levels and dynamic range on a frame by frame basis during playback.[24] This type of metadata helps to preserve the correct way to display video as creators intended across the various distribution platforms.

Related Advances in Color

Another major area of evolution in digital video is color, and it is useful to look at two different concepts when talking about these advances: bit-depth and color gamut. Bit-depth is an indication of how many bits are used to describe the color of any individual pixel, so the higher the bit depth the higher the number of distinct colors can be displayed. Where color bit-depth is concerned, there is a shift from the 8-bit color depth world of 1080p to the higher 10 or 12-bit depth of 4K and HDR video. Color gamut is a different concept that defines the range of colors that each of those bits can be chosen from. The color standard for HDTV has remained Rec.709 for years. The newer Rec.2020 specification outlines a color space that is meant to capture a much higher range of colors that the human eye can percieve.[25] While Rec.709 is defined to encompass 36% of the visible color spectrum to humans, the intermediate P3 color space encompasses 62% of this range. Meanwhile, the Rec.2020 includes 76%. It is noteworthy that the Rec.2020 specification currently exceeds the gamut of any actual monitors that can be manufactured. While both PQ and HLG specifications mandate the use of the Rec.2020 color space, the standards differ when it comes to bit-depth–with Dolby Vision defined as having 12-bit color depth while all others (HLG, HDR, HDR10+) use a 10-bit color depth.

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[23] Greenwald, Will. "What Is HDR (High Dynamic Range) for TVs?" October 13, 2017. https://www.pcmag.com/article2/0,2817,2490643,00.asp
[24] Dent, Steve. "Samsung and Amazon counter Dolby Vision HDR with HDR10+" https://www.engadget.com/2017/04/20/samsung-and-amazon-counter-dolby-vision-hdr-with-hdr10/
[25] Advanced Television Systems Committee, Inc. "High Dynamic Range Planned for ATSC 3.0." https://www.atsc.org/newsletter/high-dynamic-range-planned-for-atsc-3-0/

Display Technology and Distribution

With production technology rapidly advancing, distributors and display manufacturers are also entering the HDR world, albeit slowly. While many 4K displays manufactured today are HDR capable, this technology will be used in rendering only content that is encoded in Dolby Vision, HDR10, or HLG which is not yet widely available (HDR10+ content is still in development and not available at all). When it comes to various companies that produce and distribute HDR content, there is also a format war underway with regards to the transfer function reminiscent of VHS vs. Betamax and Blu-ray vs. HD-DVD. Some studios, such as Universal, Sony Pictures, Warner Bros and Lionsgate, have announced support for Dolby Vision,[26] while all studios support HDR10. Most 4K media streaming devices currently offer support for some type of HDR video: Roku supports only HDR10 while Apple TV and Google Chromecast also support Dolby Vision. HDR video content today can also be found on 4K Blu-Ray discs as well as on most of the major streaming platforms. Platforms that currently support HDR video for some of their 4K content include: Netflix, Amazon, iTunes, Vudu, Vimeo and YouTube.

While flat-screen TVs with HDR displays have become popular in the last couple of years, HDR displays are now also becoming the norm on the latest smartphones. LG was the first company to have an HDR display on a mobile device with their LG6.[27] Apple, Sony, Samsung, and LG have all released HDR compatible displays on various devices in 2017.[28] However, while all the smartphone displays support HDR10, only Apple and LG support Dolby Vision at the moment. The UHD Alliance[29] has established a

[26] Hall, Chris, and Elyse Betters. "What is HDR, what TVs and devices support HDR, and what HDR content can I watch?" September 11, 2017. https://www.pocket-lint.com/tv/news/137367-what-is-hdr-what-tvs-and-devices-support-hdr-and-what-hdr-content-can-i-watch

[27] Hall, Chris, and Mike Lowe. "Mobile HDR: Dolby Vision, HDR10 and Mobile HDR Premium explained." November 3, 2017. https://www.pocket-lint.com/phones/news/dolby/138387-mobile-hdr-dolby-vision-hdr10-and-mobile-hdr-premium-explained

[28] Ibid.

[29] The UHD Alliance works to set standards for consumer TVs that will communicate to consumers whether a TV is HDR-capable or not; the first UHD Alliance certified TVs became available for consumer purchase in 2016.

standard called Mobile HDR Premium that certifies displays on smartphones, tablets, and laptops up to these particular HDR standards:

- Dynamic range: .0005-550nits
- Color space: 90 per cent of the P3 color gamut
- Bit depth: 10[30]

Broadcast signals is another area in which HDR content may become available in the near future in the United States–other countries, such as Japan and Korea, are ahead of the US in this regard. Broadcast technology in the United States still relies on the ATSC 1.0 standard which was adopted for HDTV's in the early 2000s.[31] Currently, the outdated MPEG-2 video compression codec is used in ATS 1.0 broadcasting standard for digital TV.[32] This has changed over the last few months, with the H.265 HEVC (High Efficiency Video Coding) Main 10 Profile being adopted by the ATSC for their new ATSC 3.0 broadcasting standard that will allow the broadcast of 4K and HDR video over the air.[33] Alan Stein who works on HDR standardization for the new broadcasting standard, notes that the "live production environment, regional opt-outs and interstitial advertising" are particular challenges for broadcasting HDR content that offline distribution such as streaming and discs do not face.[34]

The adoption of ATSC 3.0 was further solidified on November 16, 2017 when the Federal Communications Commission (FCC) announced that companies can now broadcast 4K video using the Next Generation TV broadcast standard (ATSC 3.0) using the 6MHZ channels reserved for digital TV broadcasting.[35] While wide-spread adoption by broadcasters is likely a few years away, Phoenix, AZ will

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[30] Hall, Chris, and Mike Lowe.
[31] Siegler, Dave. "Why ATSC 3.0? Opportunity!" 2017. https://www.atsc.org/newsletter/why-atsc-3-0-opportunity/
[32] Ibid.
[33] Advanced Television Systems Committee, Inc. "High Dynamic Range Planned for ATSC 3.0."
[34] Ibid.
[35] Lumb, David. "FCC paves way for 4K over-the-air TV broadcasting." November 16, 2017. https://www.engadget.com/2017/11/16/fcc-paves-way-for-4k-over-the-air-tv-broadcasting/

be a test-site that will start broadcasting over-the-air using the ATSC 3.0 standard as early as Spring 2018.[36] HDR and 4K broadcasting in Japan has already been standardized by the ARIB, using the HLG standard for HDR.[37] Even as nescient as HDR and 4K capture and display technologies are, there are already plans to broadcast the 2020 Tokyo Olympics live in 8K HDR.[38] In Germany, the Sky channel has already performed test transmissions of HDR in the summer of 2015, airing a live soccer game in UHD/HDR via satellite.[39]

Considerations for Preservation

Separate from the transfer function used to master and display HDR video (PQ or HLG), the video stream still has to be encoded using the various available video codecs. Currently, VP9 and HEVC are two video codecs widely used for HDR video.[40] HDR10+ has also been integrated with HEVC, which is the codec used by 4K Blu-Ray discs and Netflix for streaming. This information about HDR video files could be determined by using a metadata extraction tool such as MediaInfo. Various tests were performed for this project using the software to determine whether it could be used to identify HDR video files. This was done by downloading sample HDR files from the website 4kmedia.org and comparing their metadata to SDR 4K files.[41]

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[36] Williams, Martyn. "The FCC gives 4K, next-gen TV the green light." November 16, 2017. https://www.techhive.com/article/3237744/consumer-electronics/the-fcc-gives-4k-next-gen-tv-the-green-light.html

[37] Rohde & Schwarz. "What are the main competing HDR standards for broadcast?" https://www.rohde-schwarz.com/nl/solutions/broadcast-media/always-on-blog/posts/9-17-hdr-wp_231572.html?rusprivacypolicy=0

[38] Pino, Nick. "First 8K broadcast coincides with the Olympics, but only one company will have it." August 2, 2016. http://www.techradar.com/news/television/first-8k-broadcast-coincides-with-the-olympics-but-only-one-company-will-have-it-1325926

[39] Rhode and Schwarz. "Color Explosion on the Scree – HDMI 2.0a Transmits HDR Video." 2017. https://cdn.rohde-schwarz.com/pws/dl_downloads/dl_common_library/dl_news_from_rs/214/NEWS_214_HDMI-20a_English.pdf

[40] Giovara, Vittorio.

[41] http://4kmedia.org/

The results of these comparisons indicate that the following fields from MediaInfo could be used to identify information that may be unique to HDR video files.[42]

- *Video Color Primaries*
    - This field was consistently *BT.2020 non-constant* for HDR videos but *BT.709* for SDR 4K videos.
- *Video Format*
    - While *HEVC* does not guarantee a file to be HDR, many of the HDR videos tested were found to be encoded in this format.
- *Video Codec ID*
    - While this field was blank for the majority of the videos (even those who had a *Video Format* listed as *HEVC*) the codec id for some *HEVC* files was written as both *hev1* and *hvc1*.
- *Video Bit Depth*
    - This field was consistently *10 bit* for HDR videos although this is not unique to HDR videos.
- *Video Transfer Characteristics*
    - This is referred to as *PQ* or *HLG* for some HDR files and for HDR files only. *PQ* is in fact one of the main transfer functions outlined in this paper, along with *HLG*. This field, if containing these two values, is the clearest indicator that a video is HDR.
- *Video Matrix Coefficients*
    - *BT.2020 non-constant* was displayed for some HDR files, referring to the BT.2020 color space. This was not determined to be unique to HDR files.

[42] The results of this comparison are attached in an excel spreadsheet titled "17f_1807_Dowlatshahi_b"

One concern for the archiving and preservation of HDR video in the short term may be the massive amount of storage needed to store the uncompressed version of these files. Although it is difficult to find access to an uncompressed HDR video file to perform tests, according to one source, one frame of uncompressed HDR video at a 4K resolution is 95 MB, making one minute of this content at 30 fps approximately 167 GB.[43] However, it is likely that storage costs for digital content will continue declining, making storage less of a concern.

To conclude this research project, 4 audio-visual archives that work within a production environment or with contemporary digital AV material, were contacted with the following set of questions:

- Do any of your productions produce HDR videos? If so, how recent of a practice is this and what cameras are used? Are there particular HDR standards that are used?
- Has there been any conversation between the archive and production teams, or within the organization at large, regarding HDR video preservation? Are there particular challenges in the preservation HDR video for the archive?
- If there is HDR video in the archive, are there particular metadata extraction software used to verify this? If so, what fields of metadata are looked at?
- As HDR displays and monitors become more available and affordable, has your organization considered this technology for the playback of HDR footage?

Responses were received from two of the four recipients and are summarized below:

Audio-visual archivist Dave Rice at CUNY TV was contacted with questions regarding the institution's use of HDR. Rice contends that although he is not certain if any productions at CUNY TV use HDR capture technology, he is doubtful. He points out that the archive has not instituted any test to see if

[43] Chalmers, Alan and Kurt Debattista. 50.

incoming content is HDR video and that there has been no conversation between the archive and production teams regarding HDR video. Rice thinks that there is too large gap between when technologies become common in the production sector and when they are discussed in the digital preservation community and that archivists should participate more in standards creation. He also points out that there has been a shift recently in which more digital AV archivists are becoming involved in “communities like demuxed, fosdem, vdd, and ffmpeg.” [44]

Nicole Martin from Human Rights Watch (HRW) also works in digital audiovisual archiving and preservation in a production environment, albeit one much different than CUNY TV. While 4K video is occasionally handled by HRW and workstations use 4K monitors, Martin notes that HDR video has not infiltrated the archive or production workflows as of yet. Martin contends that although this technology is currently beyond the technical scope of their distribution platform (1080i), the archive may consider using HDR displays once “Apple upgrades all of its Retina displays so that they are HDR-capable, and television is broadcast in 4K/HDR.”[45]

It is likely that much of the moving image material encountered by audio-visual archivists trained in the Moving Image Archiving and Preservation Program (MIAP) at New York University will not be HDR video. It is also possible that this technology will become the dominant form in which moving images are produced and distributed in the 21st century. With this paper, I aim to initiate a conversation within the field of moving image preservation about HDR video, since the earlier archivists engage in new developments in digital video, the higher the chances of successfully foreseeing and addressing challenges in their digital preservation.

[44] Rice, David. Email communication with author. December 2, 2017.
[45] Martin, Nicole. Email communication with author. December 4, 2017.

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