Colour and Brightness

HIGH DYNAMIC RANGE VIDEO

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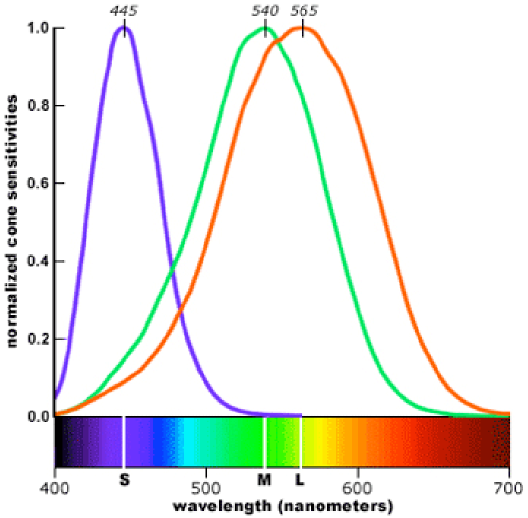
R, G, B are just different wavelengts of light

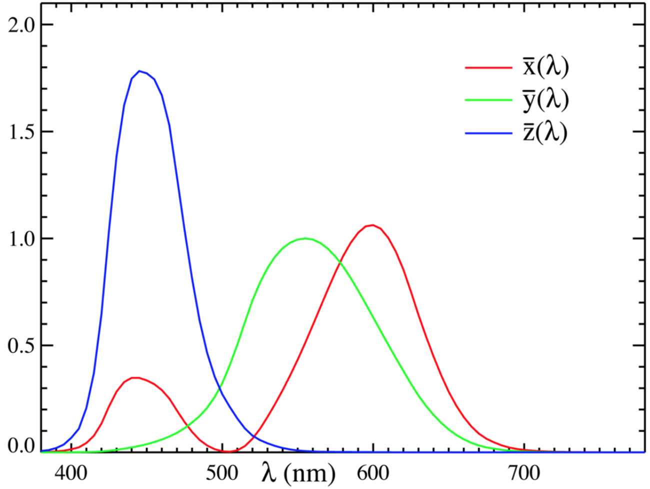
So far been loosely talking about color “R”, “G”, “B”.

Spectral sensitivity of human eye

$$R = \int_0^\infty M(\lambda)\,\overline{r}(\lambda)\,d\lambda$$
$$G = \int_0^\infty M(\lambda)\,\overline{g}(\lambda)\,d\lambda$$
$$B = \int_0^\infty M(\lambda)\,\overline{b}(\lambda)\,d\lambda$$



CIE 1931 XYZ spectral sensitivity



Many colour standards

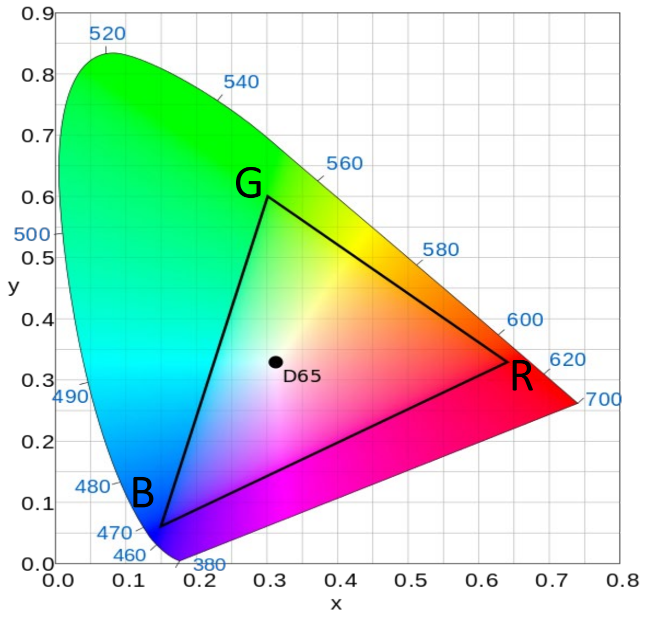
Colour standardization requires standardization of the bandwidths of each R, G, B primary … hence defining a "colour space"

CCIR 1931 / BT601 : Standard Definition Digital Video // YUV
BT709 : 720p (1280 x 720), 1080p (1920 x 1080)
BT2020 : UHD 2160p 4K , 8K etc
sRGB, REDLog (Used in post production)
XYZ perceptually uniform colour space
Pipeline : Measure -> Quantise -> Encode -> Send -> Decode -> Recontruct -> Display

"Gamut" Defined by Color Primaries

$$M^{bt709}_{rgb \to xyz} = \begin{bmatrix} 0.412 & 0.357 & 0.180 \\ 0.212 & 0.715 & 0.072 \\ 0.019 & 0.119 & 0.950 \end{bmatrix}$$

To display a picture we must produce the same perceived colour at every pixel site. Which means synthesising the R, G, B wavelengths in the right ratio. Here we show where all the legal RGB values map to in the XYZ space (a decorrelated colour space.) We also show the BT.709 (sRGB) legal space and its associated primaries.



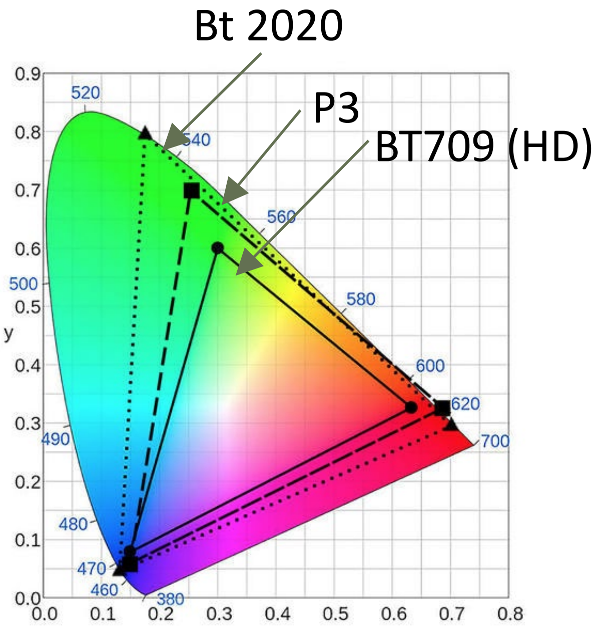
UHDTV Alliance: Wide Color Gamut (WCG)

At the same time that HDR specifications emerged,

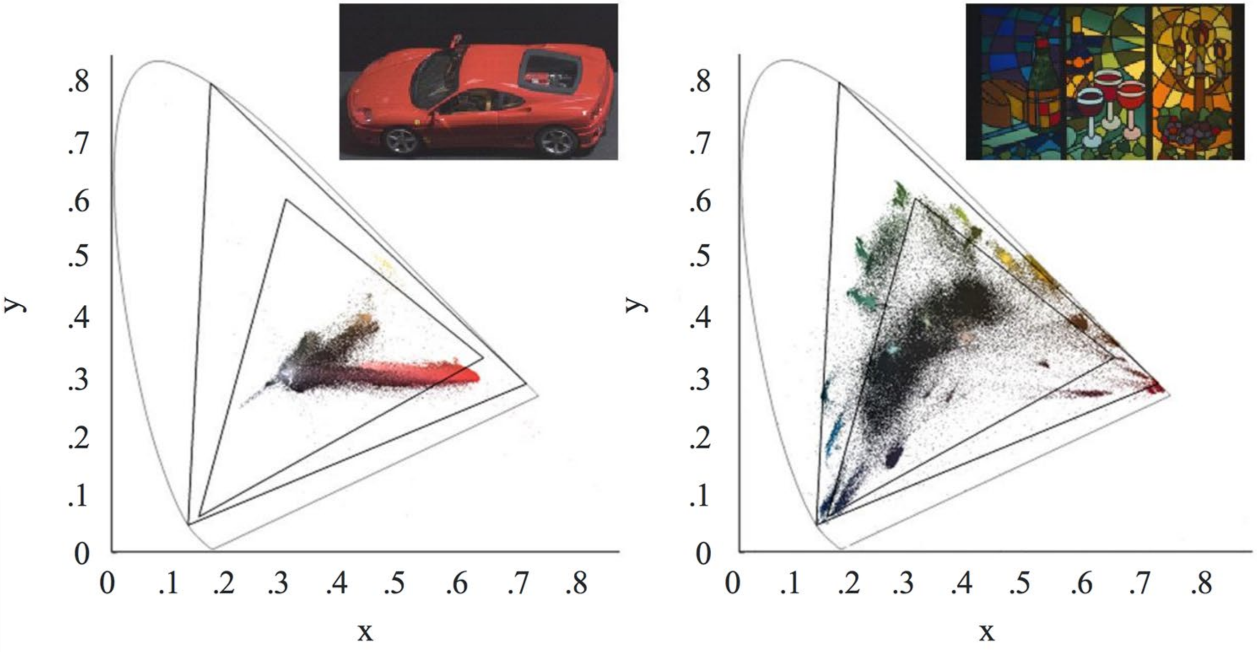
Color bit depth: 10-bit signal

Signal Input: BT.2020 color representation

Display Reproduction: more than 90% of P3 colors



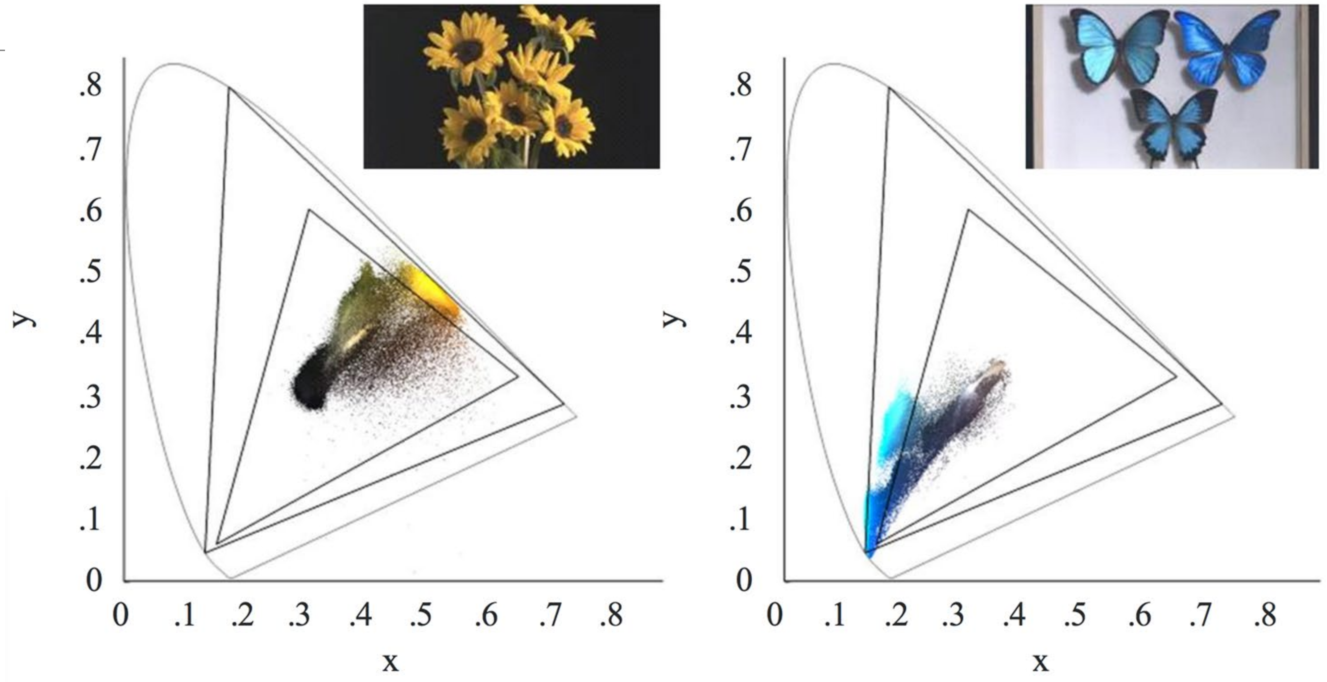
Color distribution of real examples



(e) Model car (f) Stained glass

Examples from https://www.itu.int/dms_pub/itu-r/opb/rep/R-REP-BT.2246-5-2015-PDF-E.pdf

Color distribution of real examples



c) Sunflower (d) Butterfly

Examples from https://www.itu.int/dms_pub/itu-r/opb/rep/R-REP-BT.2246-5-2015-PDF-E.pdf

HDR : High Dynamic Range (brightness)
WCG : Wide Colour Gamut (colour)

HDR : High Dynamic Range

Definitions / background ; Contrast sensitivity

HDR transfer functions

- Perceptual quantizer
- Hybrid log gamma

Example pipeline

State of ecosystem

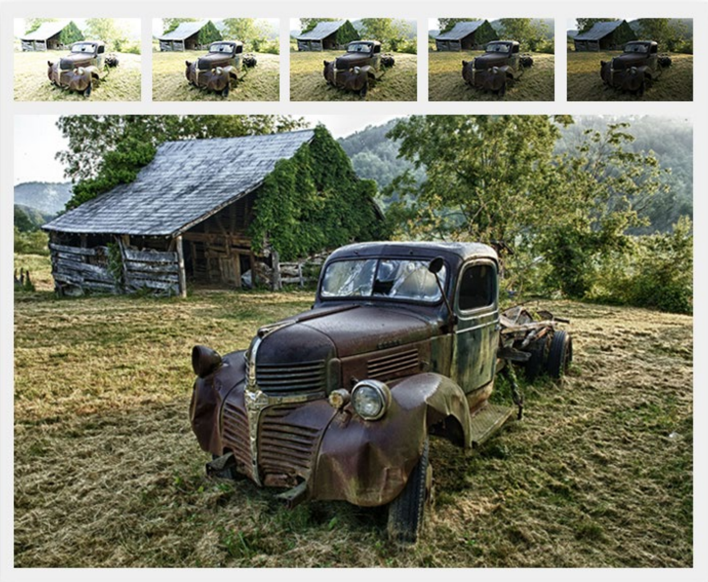
HDR Video is not HDR Photos

HDR Photography well known for over a decade.

-Multiple exposures (e.g., different shutter speed)

-Local tone mapping achieve 8-bit picture that looks good on low contrast display

HDR video is about better use of bigger dynamic range of better displays

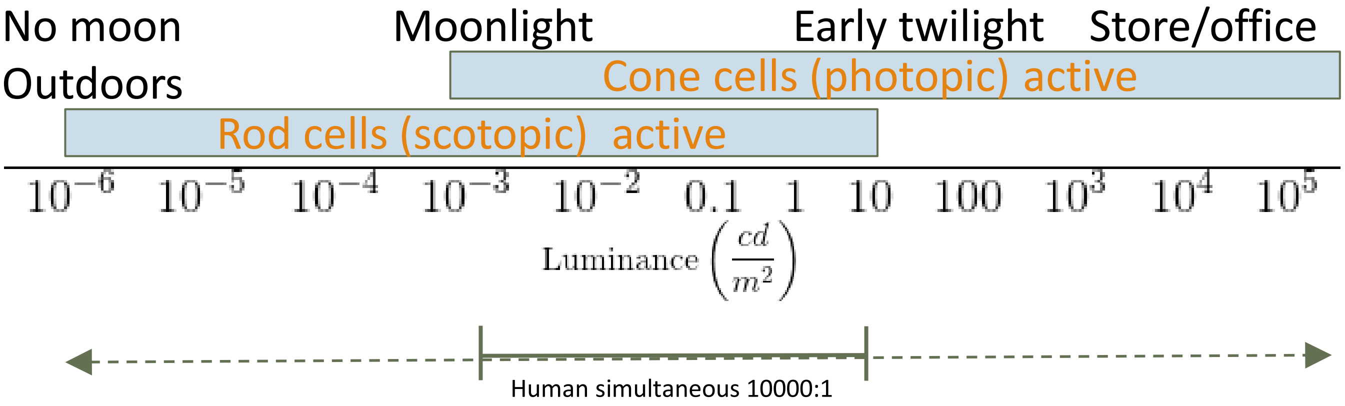


How bright is bright?

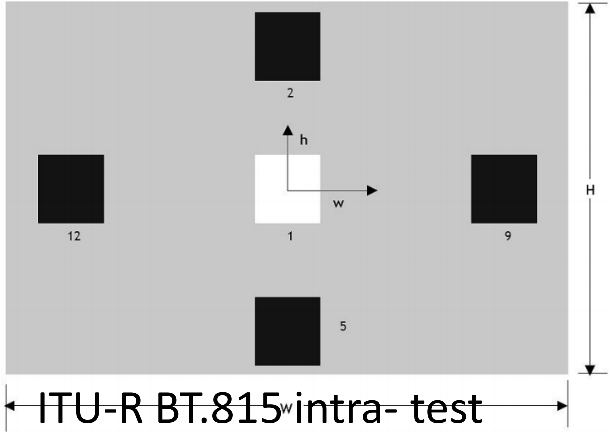
Luminance: measure of luminous intensity emitted/reflected from a surface (cd/m^2 or nits)

Direct sunlight 1.6*10^9 nits, fluorescent lamp 10000 nits

Common human environments …. Human contrast sensitiviy is $\frac{10^5}{10^{-6}} = 1 \times 10^{11}$



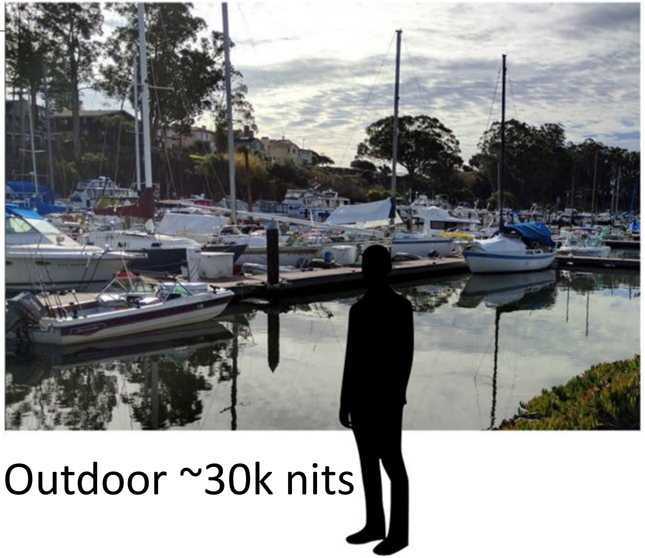
Traditional display technology



ITU-R BT.815 intra- test pattern

	Max (nits)	Min (nits)	Typical Inter-image (CR)	Typical Intra-image (CR)
Cinema	48	0.01-0.03	1000:1	100:1
HD, studio	120	0.005-0.01	10000:1	1000:1
HD, home	200	0.1	1000:1	400:1
Office(sRGB)	300	0.1	100:1 - 1000:1	100:1
Dolby vision reference monitor	4000	0.002	2 million : 1	--

Image acquisition, transmission display (review)



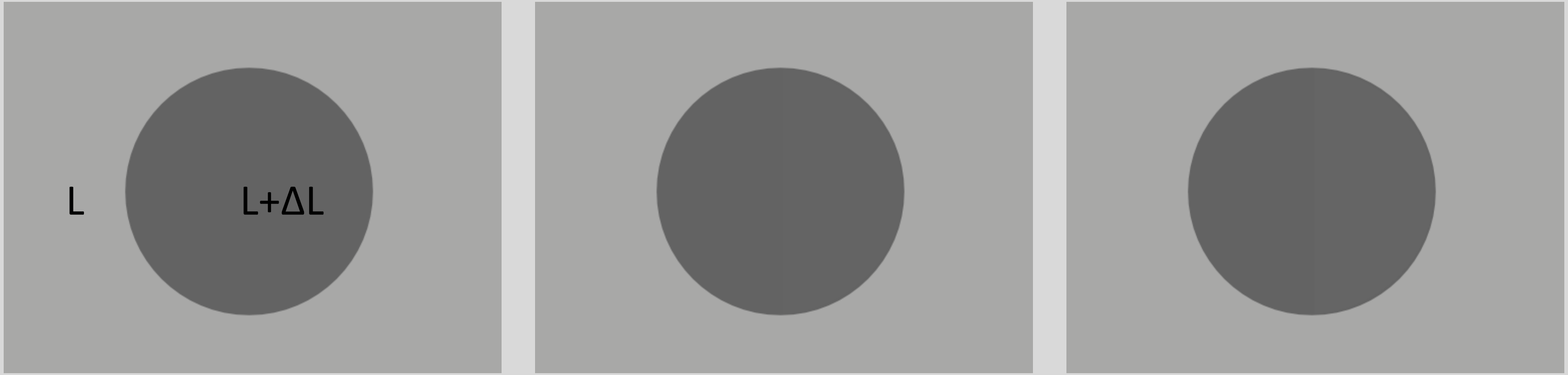
Outdoor ~30k nits

Display ~200 nits
But since 2015 displays > 300 nits, now 1200 nits normal

Surround is different, eye adaptation different, mapping necessary.

Contrast Sensitivity / Perceptual Uniformity

Weber law says: $\frac{\Delta L}{L} \approx \mathrm{k}$



So we can get away with coarser quantisation at high brightness (larger step size) and use more of our bits at the lower brightness end

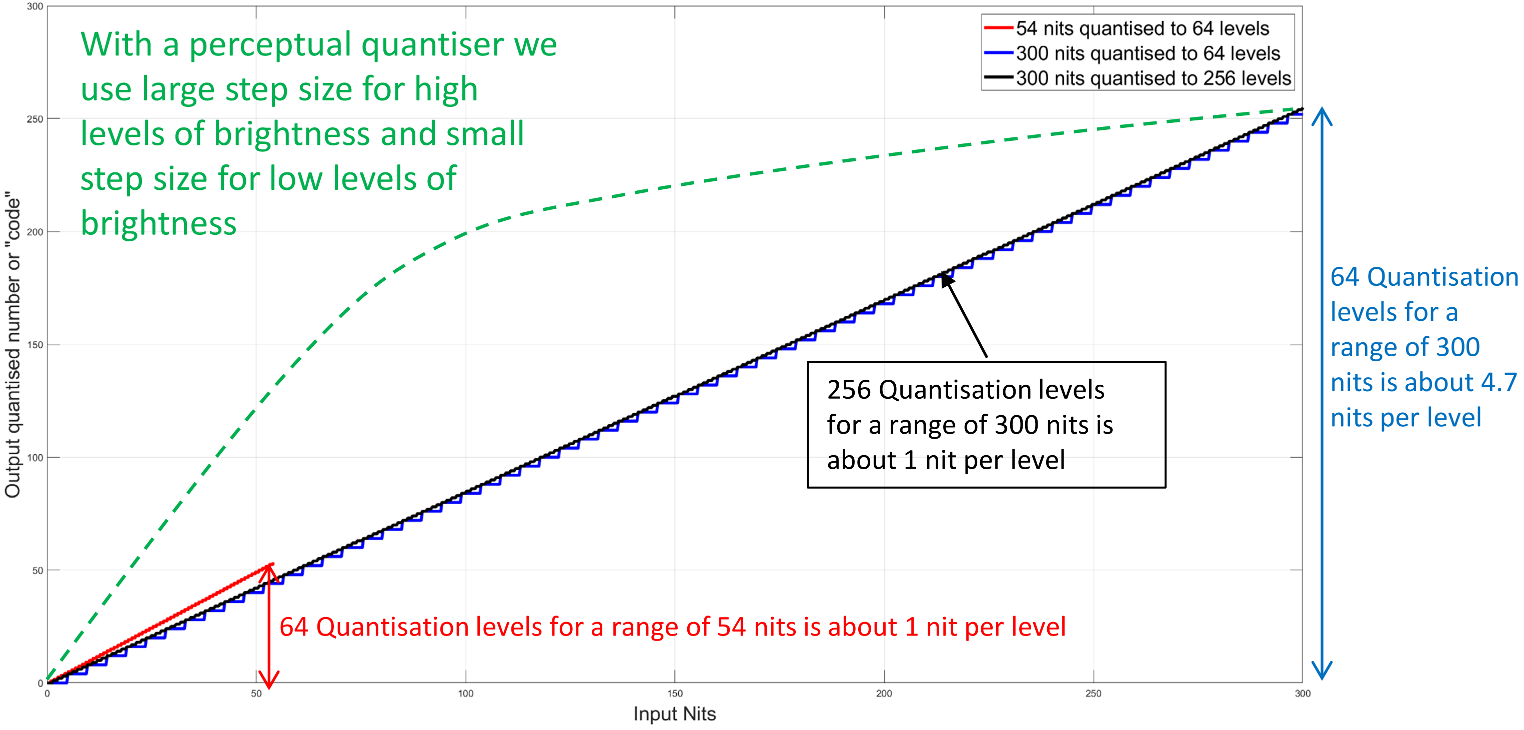
Brightness 54 nits quantised with 6 bits (64 levels)

With this linear quantiser we are ok to use 64 levels of quantisation for low brightness


Brightness 300 nits quantised with 6 bits (64 levels)
When the brightness increases we no longer have enough levels to avoid seeing the bands

Brightness 300 nits quantised with 8 bits (256 levels)

With this linear quantiser we are wasting quantisation levels here because we can’t see difference in levels well when the brightness is high

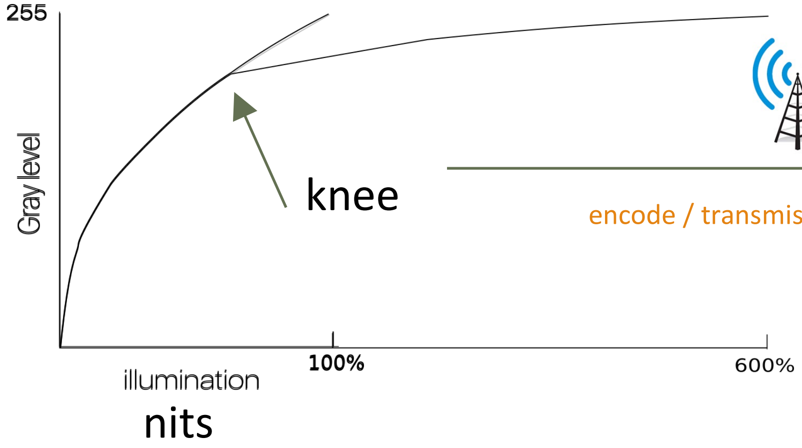


With a perceptual quantiser we use large step size for high levels of brightness and small step size for low levels of brightness
54 nits quantised to 64 levels
300 nits quantised to 64 levels
300 nits quantised to 256 levels
64 Quantisation levels for a range of 300 nits is about 4.7 nits per level
256 Quantisation levels for a range of 300 nits is about 1 nit per level
64 Quantisation levels for a range of 54 nits is about 1 nit per level
Output quantised number or "code"
Input Nits
0
50
100
150
200
250
300

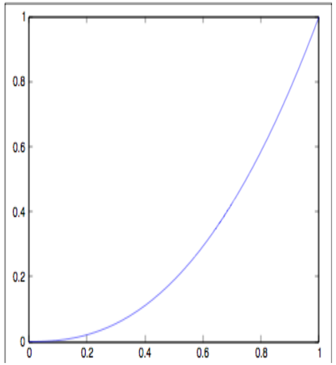
The display pipeline

OETF: opto-electronic transfer function

EOTF: electro-optic transfer function



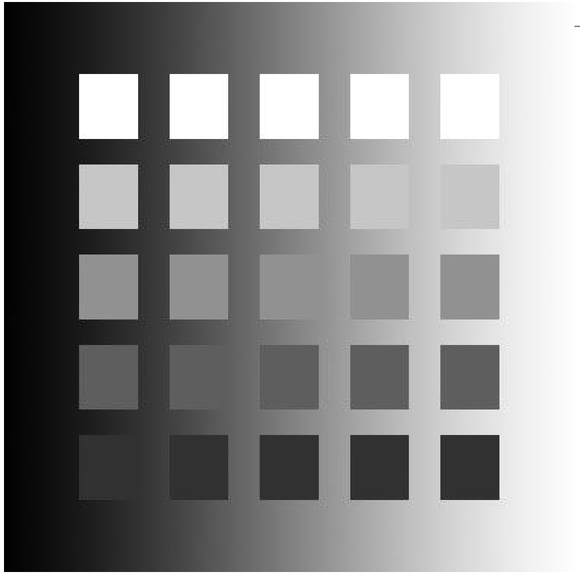
encode / transmission / decode



$L = V^{\gamma},$

$\gamma = 2.4$

Surround Effect : Human vision adapts to surroundings



Displayed images will usually not be as bright as the orginal scene hence will lack contrast and will not be as colorful

So we fake it by "boosting" the signal at the end of the chain

System gamma (OETF != inv(EOTF)):

$$EOTF(OETF(L)) = (L^{\gamma_{\text{enc}}})^{\gamma_{\text{dec}}} = L^{\gamma_{\text{enc}}\gamma_{\text{dec}}} = L^{\gamma_{\text{sys}}}$$

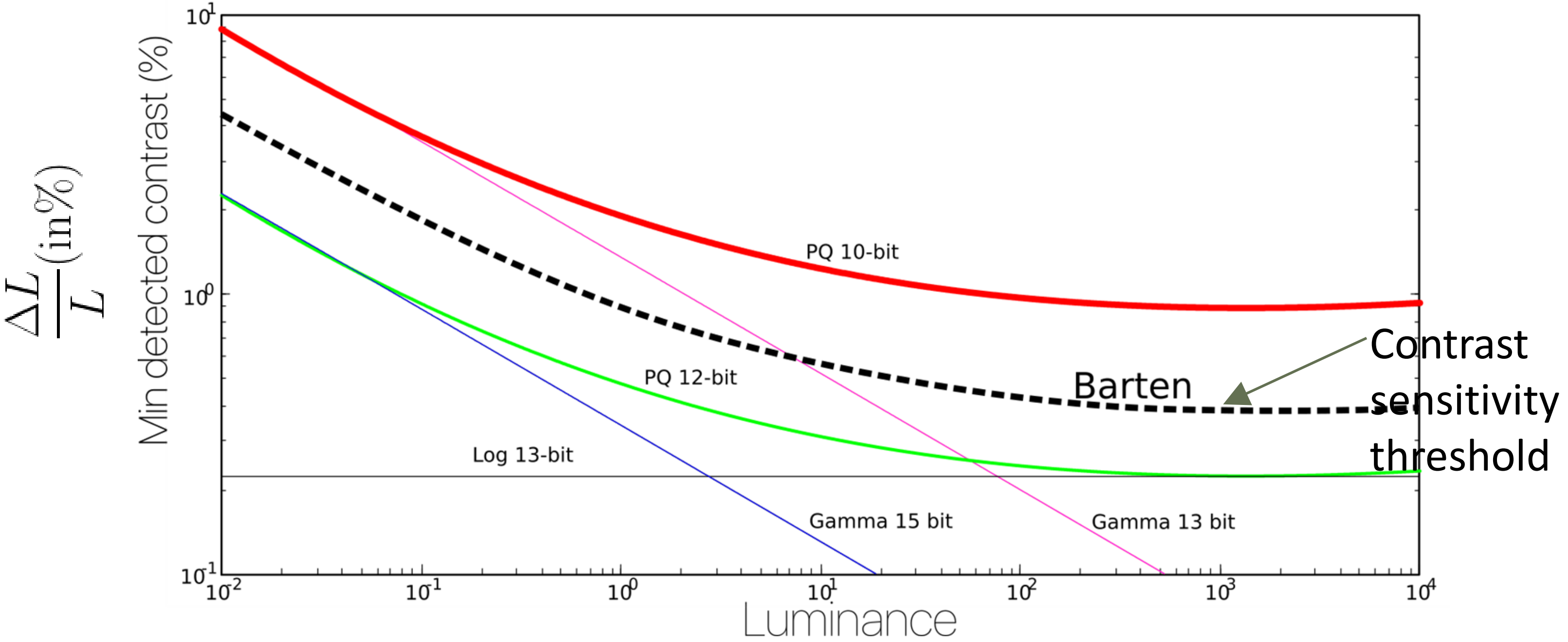
System	Encoding exponent	Decoding exponent	Surround	System Gamma
Cinema	0.6	2.5	Dark	1.5
HD studio	0.5	2.4	Very dim	1.2
HD living room	0.5	2.4	Dim	1.2
Office (sRGB)	0.45	2.2	Avg	1.1

HDR 8-bit Banding

Here we have shown an image with 600 nits max illumination using 255 levels of brightness and the usual gamma OETF/EOTF

Result is banding

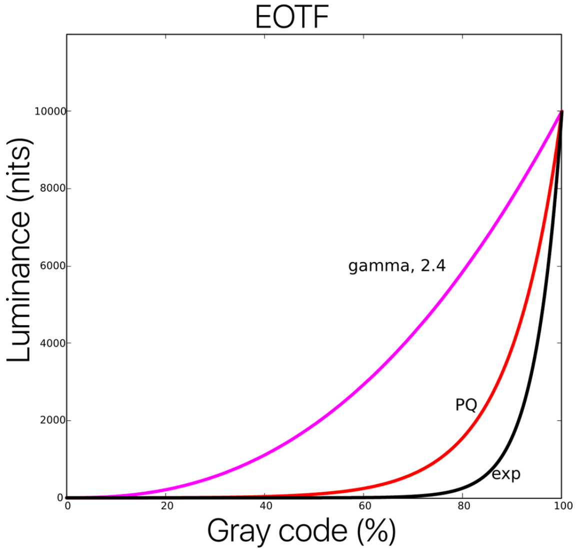
Dolby was the first to propose a new quantiser curve : Perceptual Quantiser (PQ)



EOTFs for HDR : Perceptual Quantizer (PQ)

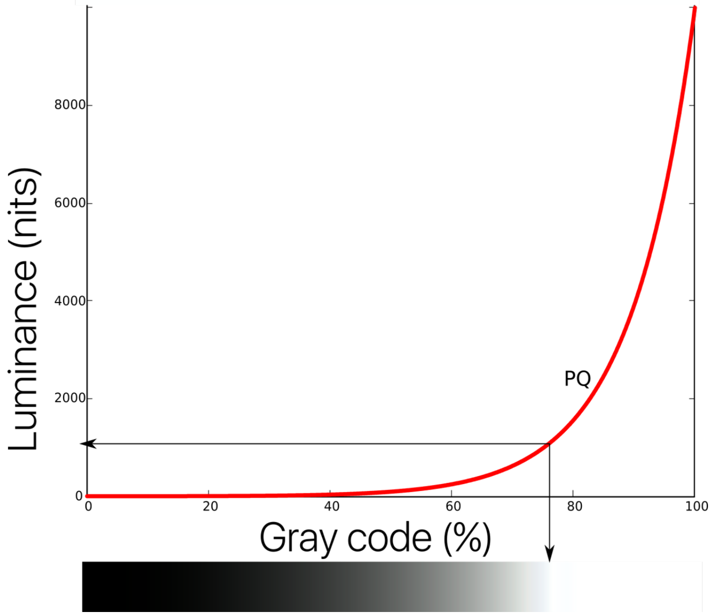
For HDR brighter display, gamma not good approximation of perceptual quality

Hence SMPTE 2084, Perceptual quantizer (PQ) EOTF

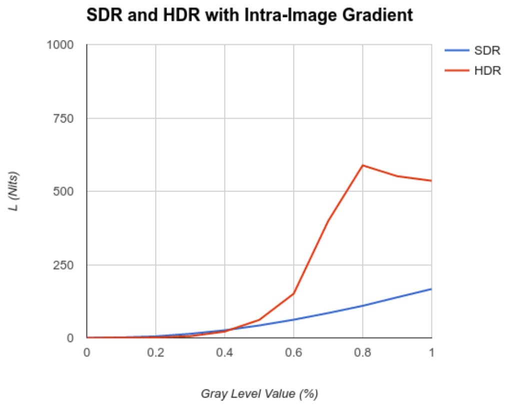


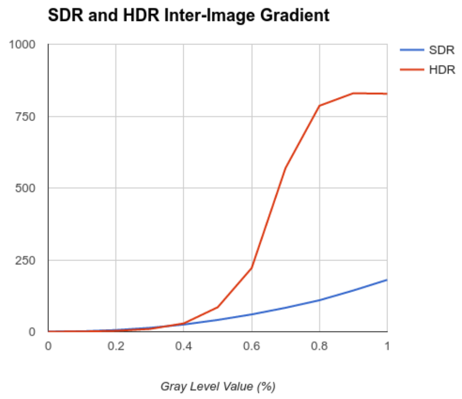
PQ EOTF

PQ Transfer function defined on absolute scale (up to 10000 nits)



Actual measurements from Samsung





Consumer Devices & Outlook

UHDTV Alliance High dynamic range requirements

SMPTE ST2084 EOTF (Dolby PQ)

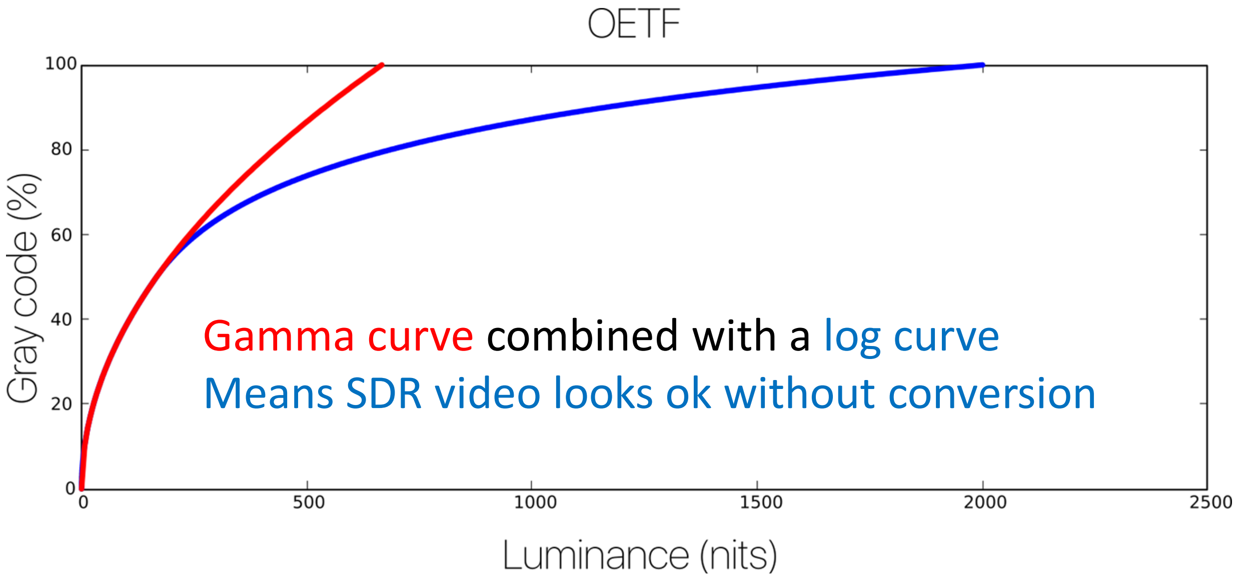
A combination of peak brightness and black level **either**:

- More than 1000 nits peak brightness and less than 0.05 nits black level
- (OR) More than 540 nits peak brightness and less than 0.0005 nits black level

Dolby vision : Subjective experiments suggest up to 10000 nits, black level of 0.002 nits

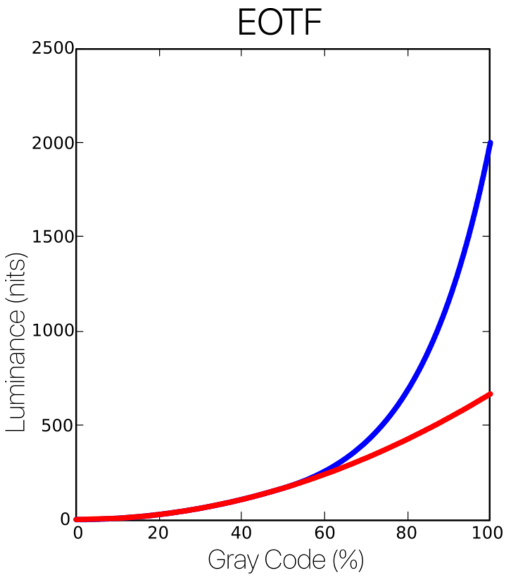
Hybrid log-gamma (HLG)

BBC solution is display independent i.e. relative scale : doesn’t require a statement of what is the max luminance in the bitstream



Gamma curve combined with a log curve

Means SDR video looks ok without conversion



PQ / HLG Interpreted as Gamma

so you see the "raw data"

PQ

HLG

SDR Tone mapped

To show these images properly you have to apply the correct EOTF in your display. Powerpoint can't do that yet. So for the PQ and HLG images no special transfer function is applied i.e. the display will interpret it as if it were a normal EOTF using "gamma". For the SDR tone mapped image, the true EOTF is compensated for so that after gamma inversion (gamma EOTF) you see the correct brightness. But the quantisation is sill 8 bit. That means you may still see banding. We do not discuss this tone mapping of HDR->SDR here.

What about Color (again)?

So far been loosely talking about color “R”, “G”, “B”.

Spectral sensitivity of human eye

$$R = \int_0^\infty M(\lambda)\,\overline{r}(\lambda)\,d\lambda$$
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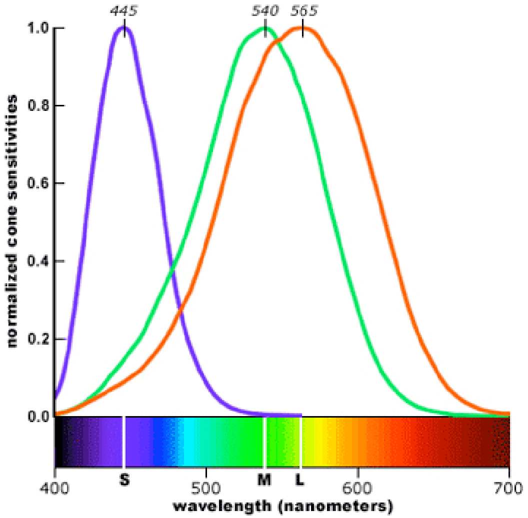

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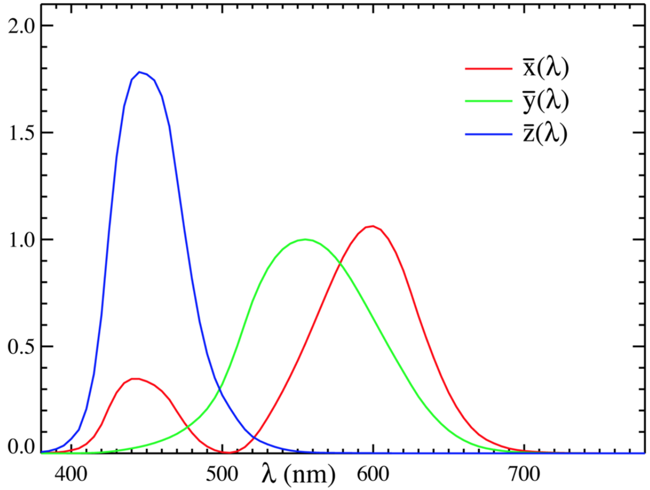

UHDTV Alliance: Wide Color Gamut

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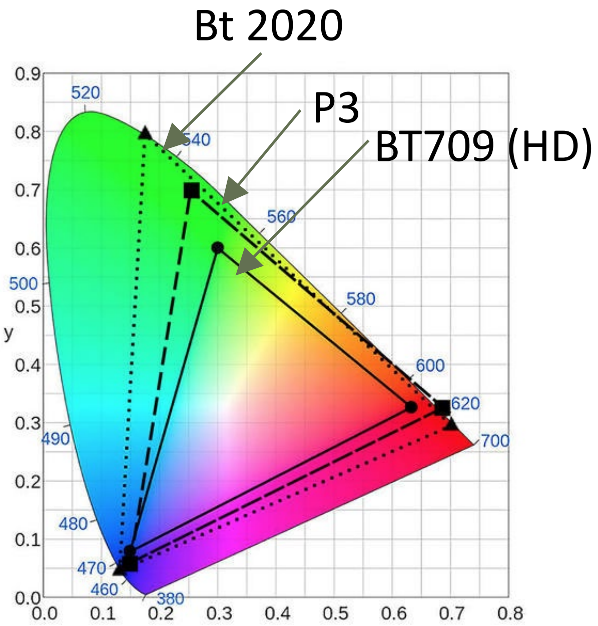
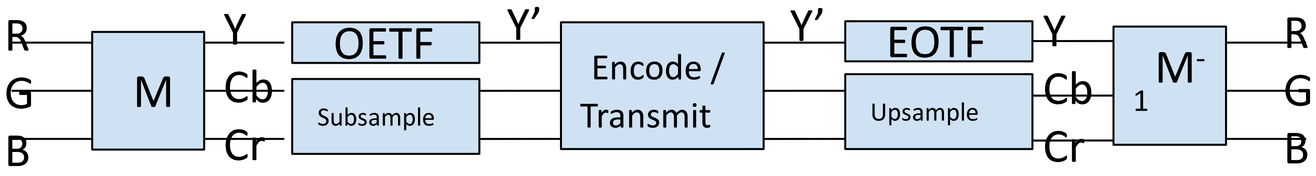
Display Reproduction: more than 90% of P3 colors

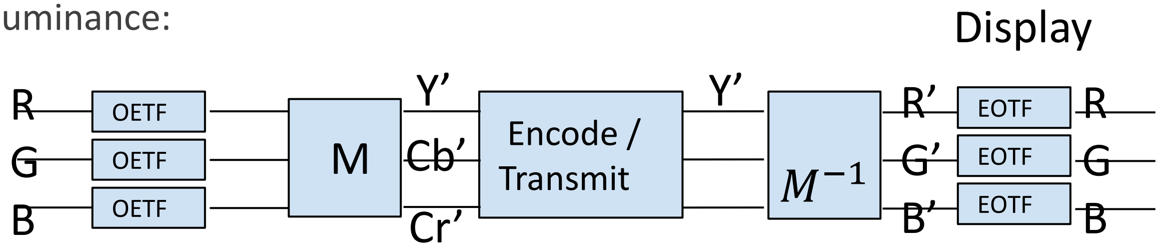


OETF/EOTF & Color Matrix Coefficients

Constant luminance (Y is computed from linear components):



Non-constant luminance:



HDR File signaling

Because of the different ways of expressing HDR we need to tell devices what “standard” we are using

Three main things:

- Color matrix coefficients (conversion between R’G’B’ and YCbCr in coding)
- Color primaries (meaning of red, green, and blue) in device independent
- Transfer function: gamma, perceptual quantizer PQ (smpte 2084), HLG

Additional metadata used by display (conversion SDR) to get closer approximation to artistic intent

- Mastering display metadata (capabilities of reference display)
- Statistics of the image data

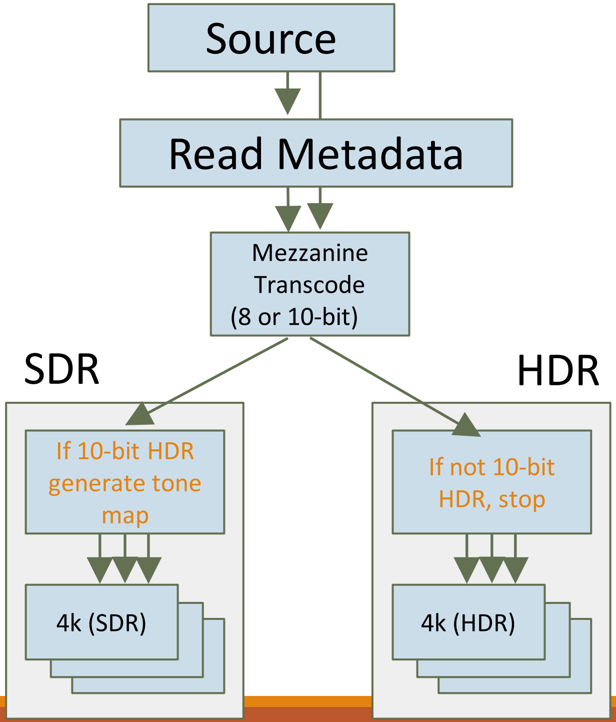
HDR is STABLE since 2017

Physical interconnect signalling : HDMI (HDR data, metadata, transfer function, via Info Frame)
Bitstream signalling : Coding independent code points (CICP) (ISO/IEC 23001-8:2013)
HEVC supports Transfer Functions (PQ, HLG) (via VUI, and mastering via SEI)
H264: enum values for primaries, etc. are same as CICP
MKV / WEBM spec finalized
MOV / MP4 (colr atom, ISO/IEC 14496-12:2012)

Cameras: E.g., Canon EOS C300, Arri Alexa, Red EPIC/Scarlet

HDR Streaming Pipeline

With HDR and SDR content being broadcast, our pipelines are now more complicated. Both the broadcaster and the display must read the file metadata to make sure that “artistic intent” is preserved. Tone mapping from HDR->SDR is perhaps more important than SDR->HDR



HDR Streaming Media Pipeline

- Subjective quality: Is PSNR meaningful for HDR video?
- Should noise reduction, edge enhancement, image scaling be done in linear light?
- In professional world, mastering (grading) should be done for SDR and HDR
- HDR -> SDR can't be fully automated (two streams or dynamic metadata will be required here to do the tone mapping on a scene-by-scene basis)
- Bitrate increase required?
  - "Dolby Vision" suggests 25% increase in their two -layer approach

HDR & WCG Means Better, More Realistic Pictures

References

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Miller's SMPTE PQ Talk
BBC's Hybrid log gamma whitepaper
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