Single Master HDR Architecture

Gary Demos, *Image Essence LLC*

HPA

Feb 2017

HDR Landscape

- Cameras have ever-widening range and ever-lowering noise floor
- Displays have also greatly expanded bright range, and some display technologies have greatly expanded dark range
- Some test scenes being shown at tradeshows, especially in the 400nit to 1000nit range, are great to look at
- Some test scenes being shown at tradeshows, mostly above 1500nits, appear harsh and difficult to watch (although also fascinating)
- Gaining control of the aesthetics of HDR content is a primary goal
- Reproduction of the appearance of the HDR master is also a primary goal

Dangers of "Grading to Glass" to Master HDR

- If using PQ, pixel brightness above the mastering display's range will not be visible (e.g. 1000nit and 2000nit pixels side-by-side look identical on a 1000nit display)

- Color outside P3 gamut with 2020 container has a similar issue, (e.g. a pixel outside P3 and at the P3 boundary can look identical on a P3 display)

- Only one surround is typically utilized during mastering (e.g. dark surround, 5nits, 20nits, ?nits). Presentation may differ in the consumer home.

- Masters created this way should be "inverted" into a neutral form which is independent of the specific display and surround in order to be utilized on displays having different bright or dark range, and/or different gamut, and/or different surround.

- Such inversion may not always be possible, or may be flawed

For these reasons, display-referred HDR masters are problematic

- A “neutral form” is required for the HDR master
- My preference is scene-referred linear light
- The single master HDR system’s goal is to work out the mechanisms that provide a consistent appearance, corresponding to the creative intent for the mastered appearance
- This must be done without being (strictly) display referred

Strawman Requirement for HDR/Single-Master System Architectures:

Must AT LEAST be able to reproduce mastered appearance over 150nit-1200nit (three stops) range and P3 gamut

Everything else is “extra” capability

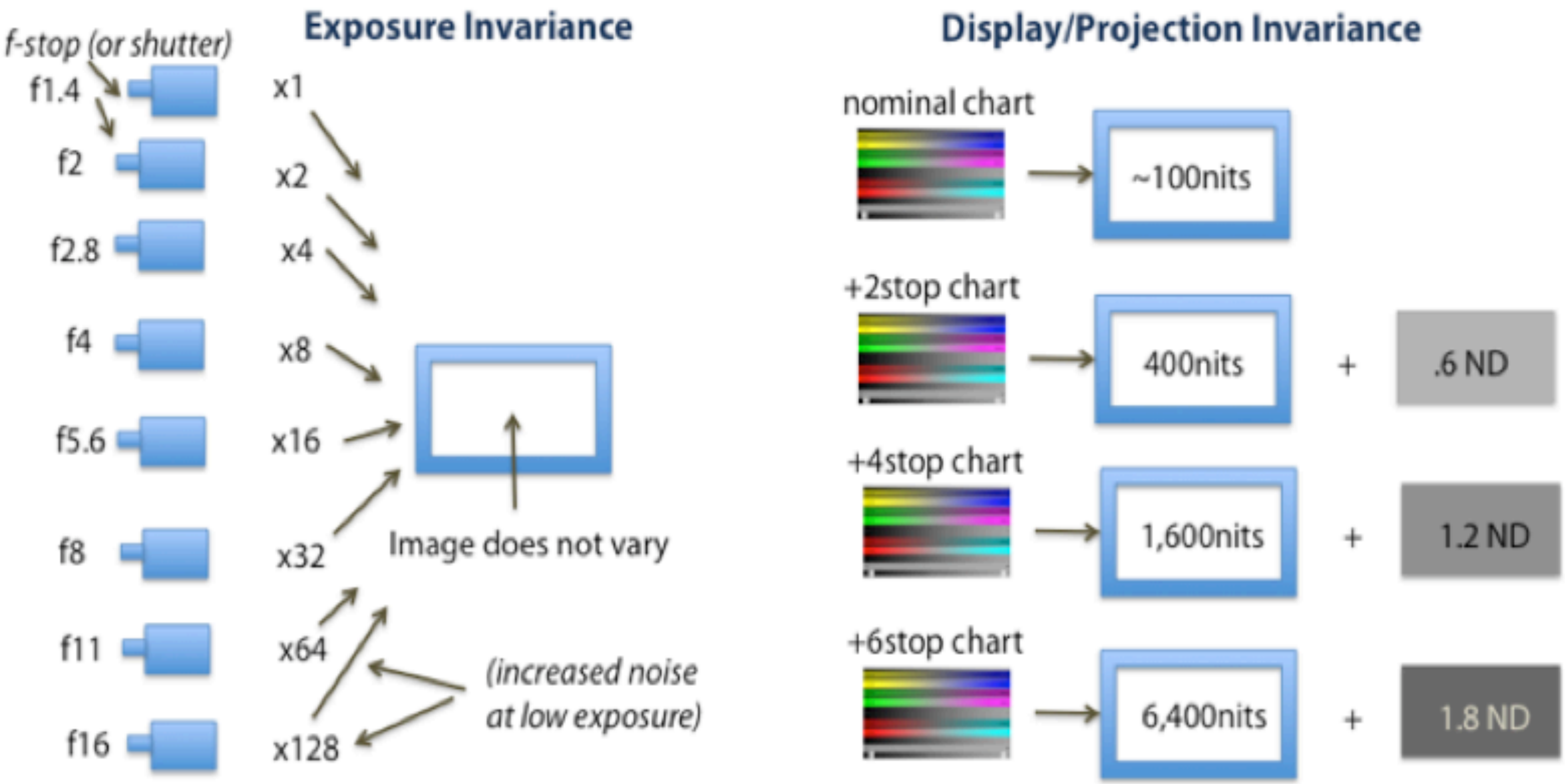
The SDR end of things:

- May be possible to go to lower brightness with a single HDR master, but that remains an open issue.

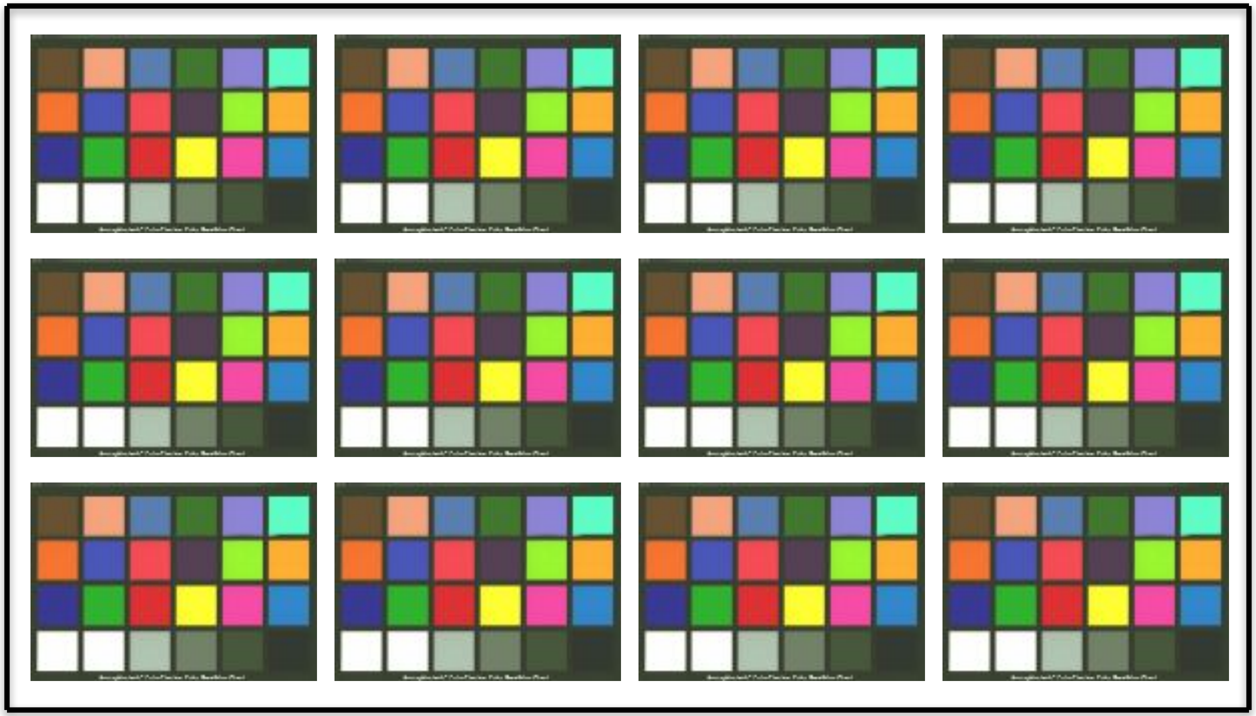
- The assumption is that 50nits (e.g. DCinema) and 100nits (e.g. Rec709) probably require a separate grade for optimum results (e.g. using “power windows”).

- The demonstration here at HPA 2017 goes down to 150nits.

Light Energy Linearity



Exposure Invariance **Display/Projector Invariance**



Linear Scene-Referred Light *Linear Display/Projector-Referred Light*

(both can be read directly with a Spectral Radiometer)

Scene Light → **Display/Projector Light**

Linear Scene-Referred Light

Linear Display/Projector-Referred Light

(both can be read directly with a Spectral Radiometer)

This is the Fundamental Transform

(aka "OOTF", Optical to Optical Transfer Function)

- **BT.2100 and ACES pursue the definition of an "OOTF"**
- **The OOTF is the key to all forms of "color science"**
- **The centerpiece of the OOTF is also known as "color rendering"**

History

- In search of linearized system architecture
- prototype ACES-like versions:
- In the lineage of “Uchida Tune” RRTs, using the DC22 look reference
- These ACES versions brighten and darken while retaining fixed chromaticities

Uchida-san

ACES Oct2012 Emmy

Back rows LtoR: ?(Fuji?), George Joblove, M. Uchida, Scott Dyer, Alex Forsythe, Harald Brendel, Joseph Goldstone, Floiran Kainz, Lars Borg, Gary Demos

Front Row: Jack Holm, Jim Houston, Ray Feeney, Andy Maltz

A dozen other ACES contributors not shown here, such as Doug Walker, Iwaki-san, John McElvain

Modular ACES-like version

- “gd10” developed as a prototype ACES-like version in 2013

  - modular

  - rendering tone curve down through zero, to negative values

  - rendering “nugget”, in output portion of split color rendering module

  - new theory, “one size fits all” may not be workable for rendering appearance

  - one favored rendered appearance module, “full” with two bright behaviors:
    - bright end opened up and saturation-preserving

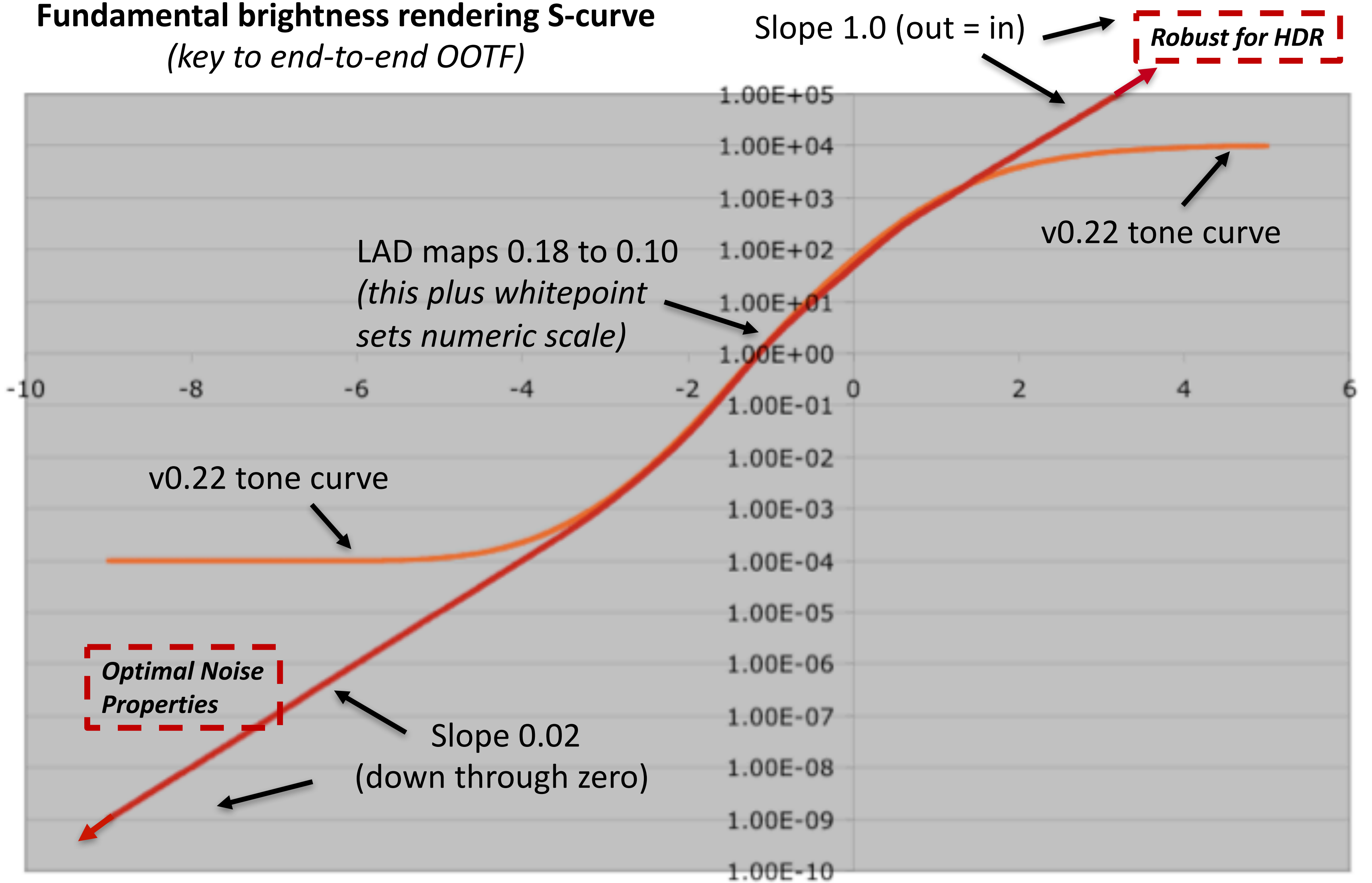
    vs.

    - bright end rolled off with desaturation (best for faces)

  - “full” appearance based on ACES non-HDR “DC22” look reference
    (note: ACES v0.1x, v0.2x, and v0.7x all used the DC22 look reference)

Fundamental brightness rendering S-curve

(key to end-to-end OOTF)



2015 ASC work on the HDR_System

- Radiometric capabilities are new in HDR Single-Master System, as are room ambient compensation, and for “colorfulness” compensation (the Hunt effect)

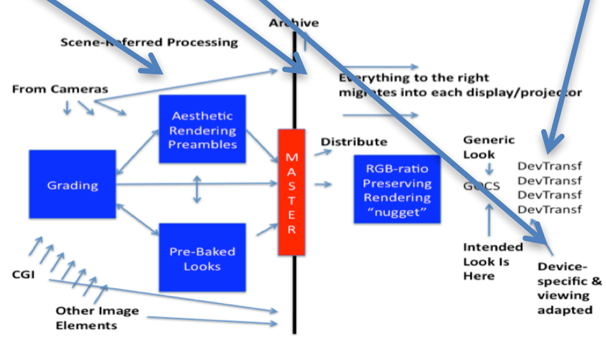
- Emphasis on MDR/HDR (and not on 50nit/100nit DCinema/Rec709)

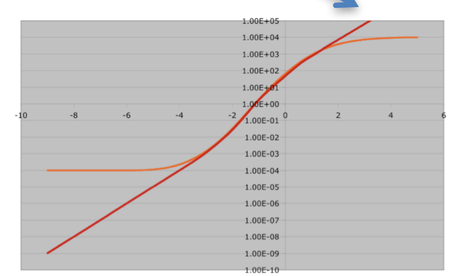
- rendering split into optional aesthetic rendering preamble(s), and nugget

- display-type transform split into display/projector appearance attributes, and “coding on the wire” attributes (which have no affect on appearance)

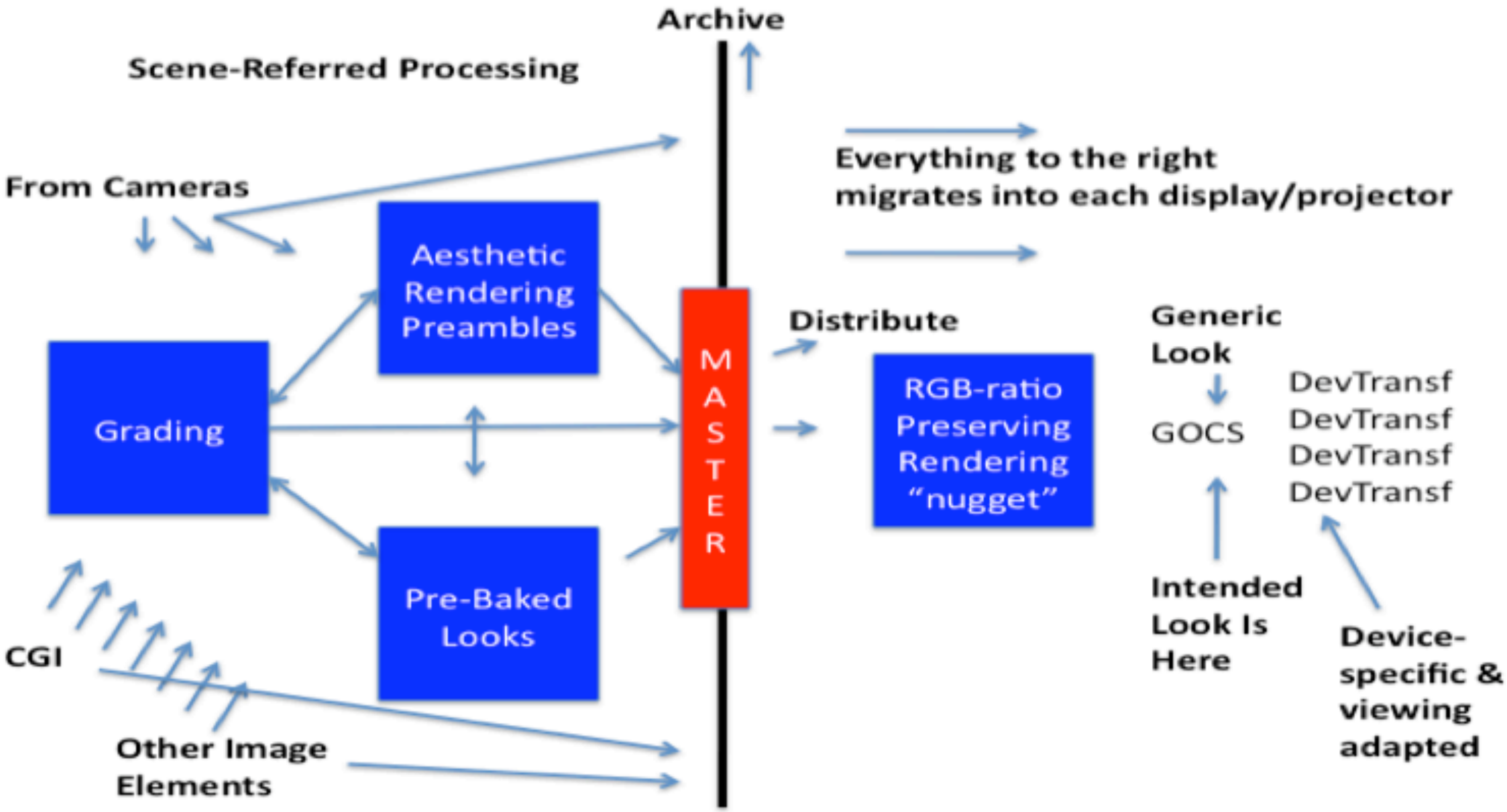
- Top end of rendering tone curve opened up to unity slope (out = in)

- Top end reduction and desaturation moved into optional preambles

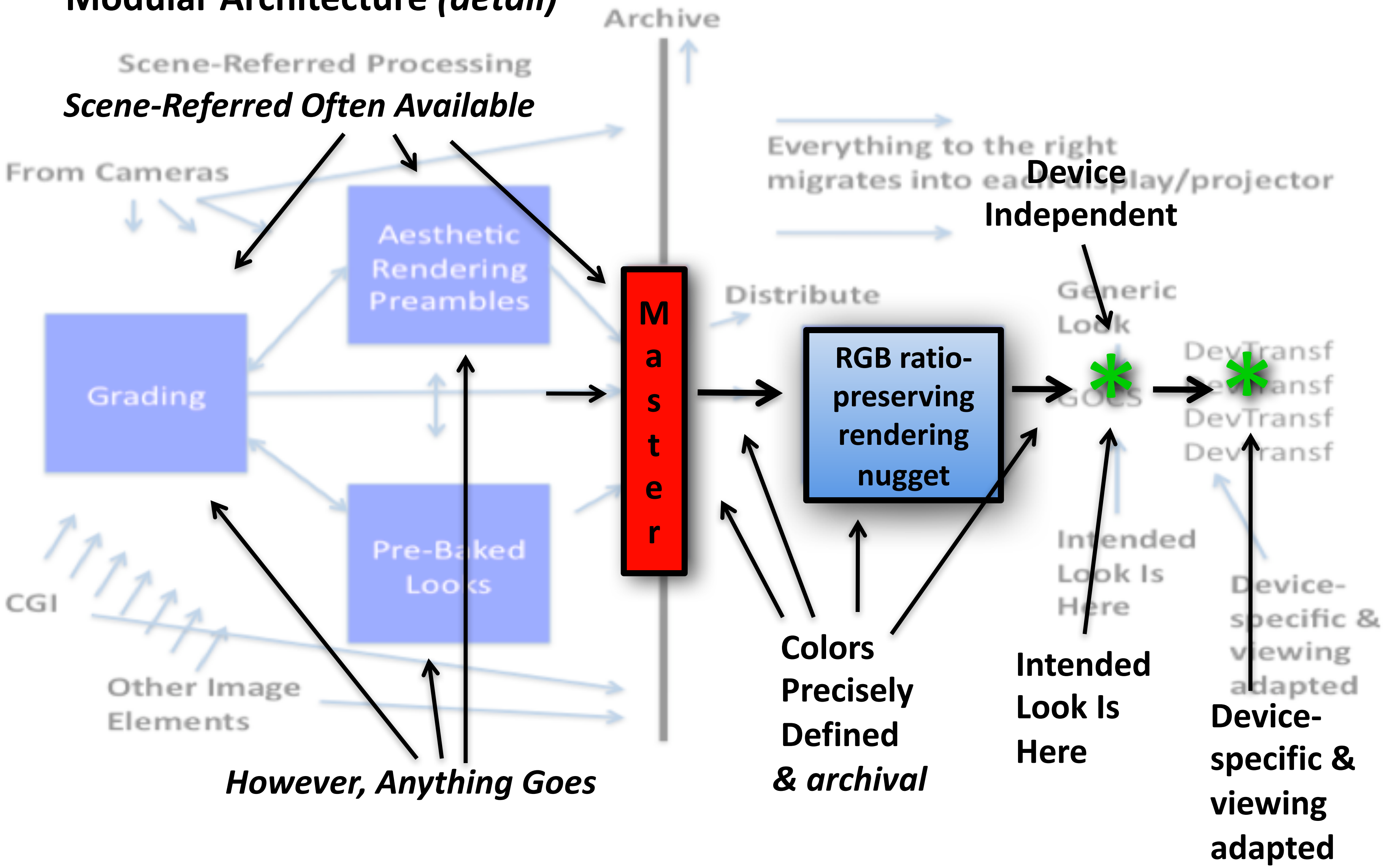




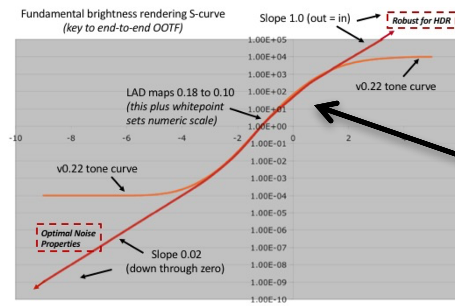
Modular Architecture



Modular Architecture *(detail)*



Modular Architecture *(detail)*



curve applied to Norm(R,G,B)

Archive

scene-referred

Scene Physics (real and/or artificial)

(needs appearance module, e.g. "full")

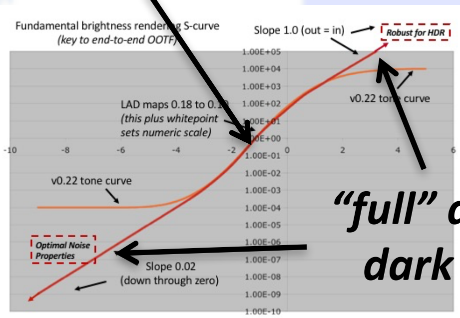
Master

RGB ratio-preserving rendering nugget

Device Independent

*****

"full" is active mid-curve, at mid-saturation

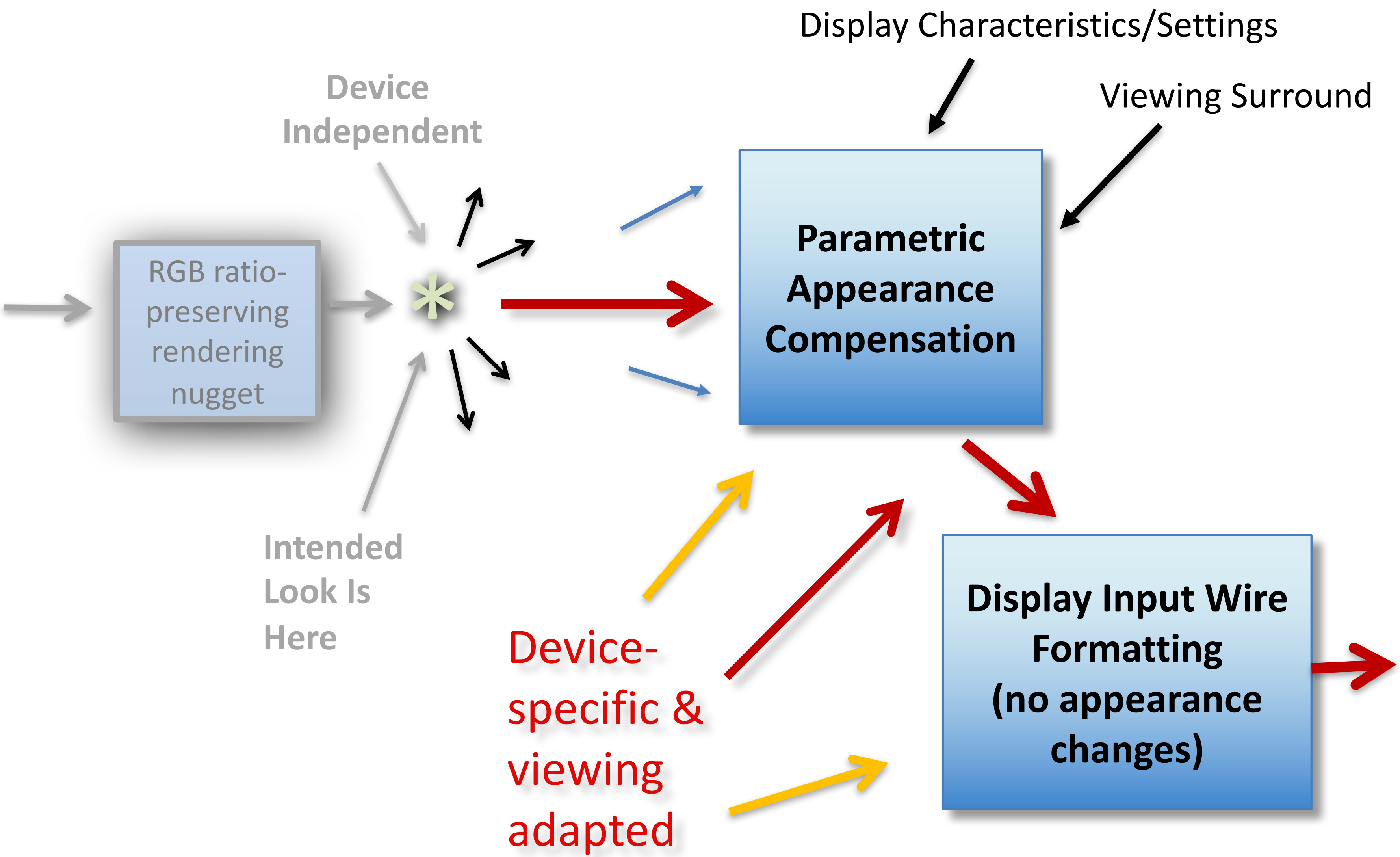


"full" dials-out for dark and bright

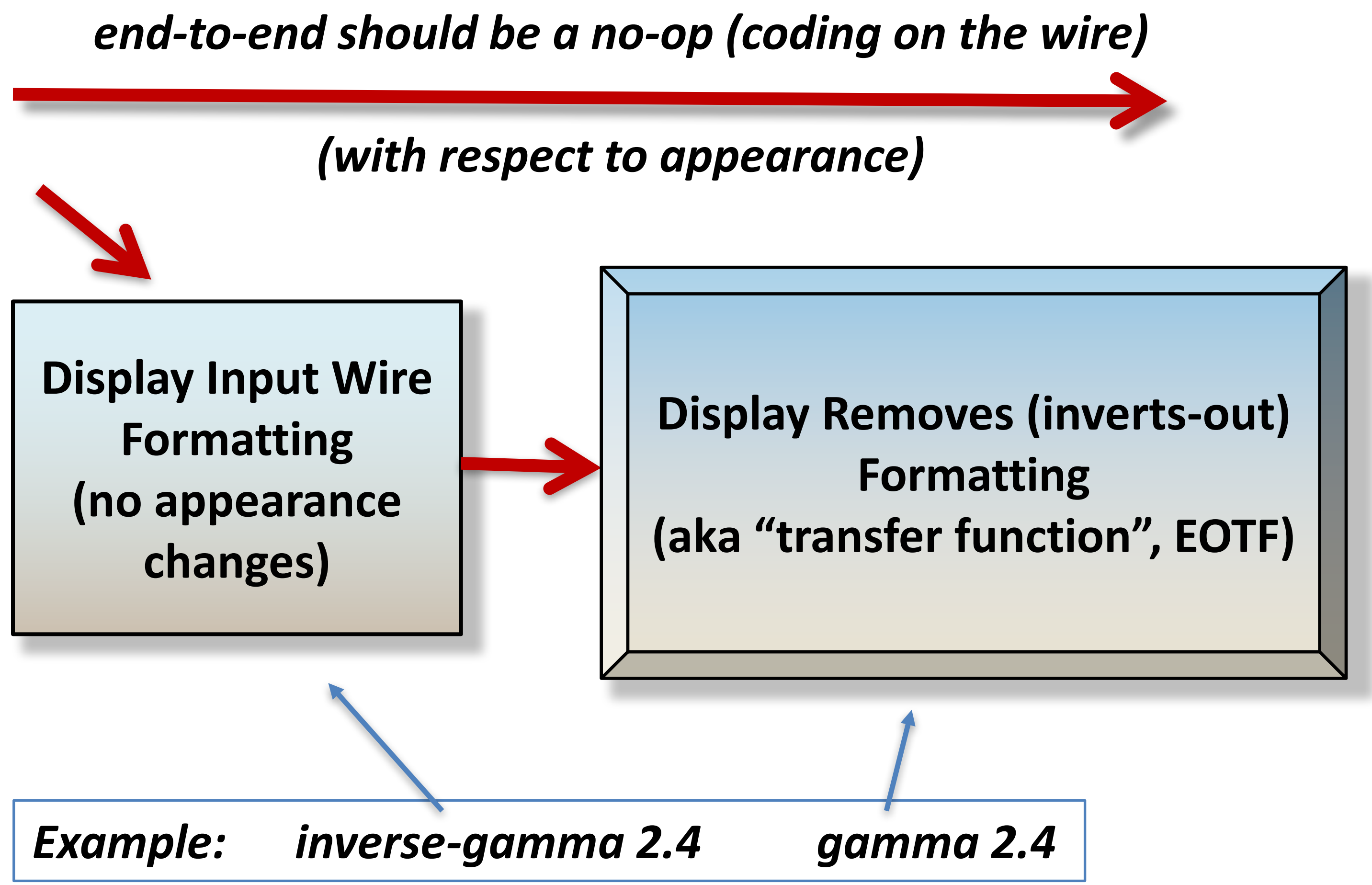
Colors Precisely Defined *& archival*

Intended Look Is Here

Modular Architecture *(detail)*



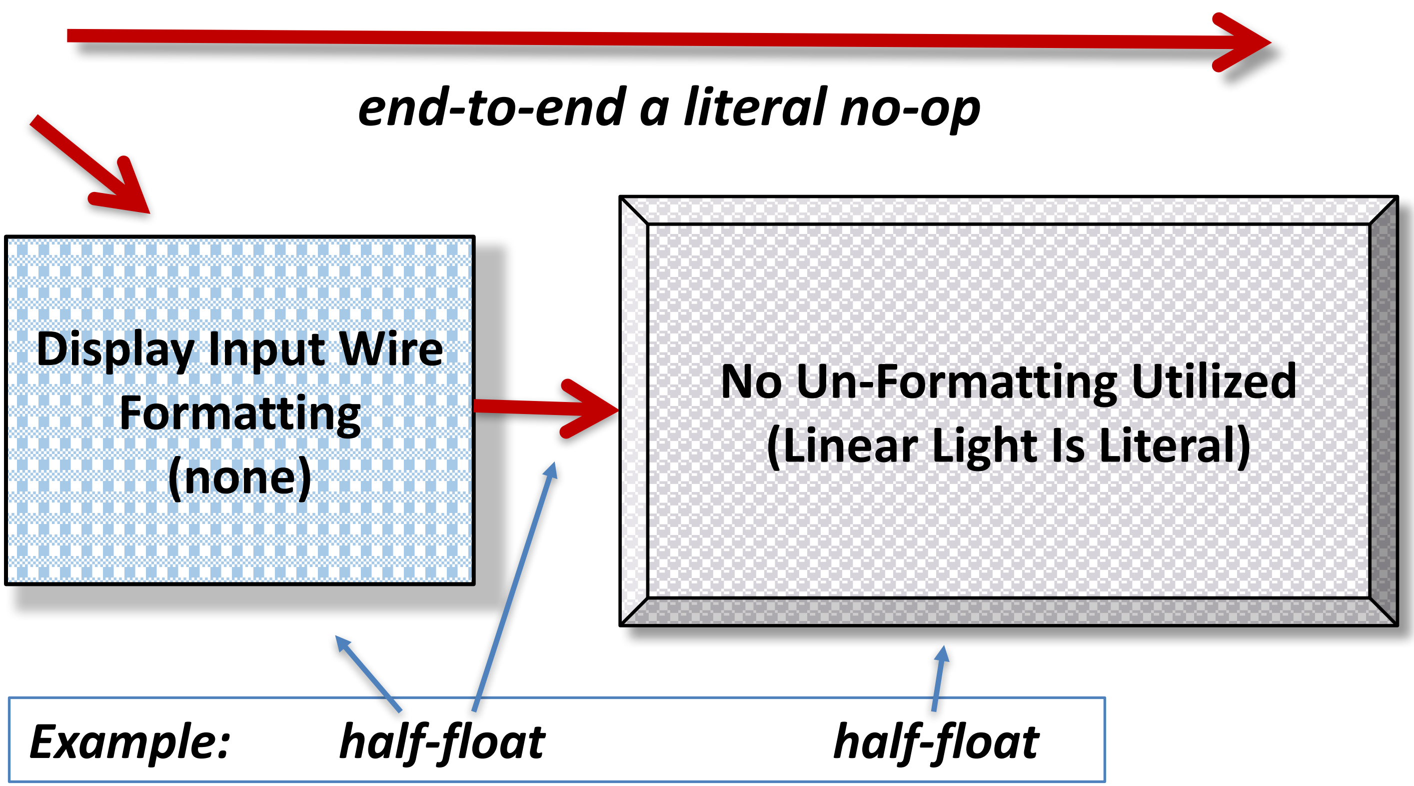
Modular Architecture *(detail)*



<u>Caveats:</u>

- *Top end of PQ may be difficult*
- *Gamut boundary soft-clip (if present)*
- *Bit depth <-> perceptual threshold*
- *Dark behavior (near black)*
- *Larger bright area darkening*
- *Function <-> perceptual threshold*

My Preference:

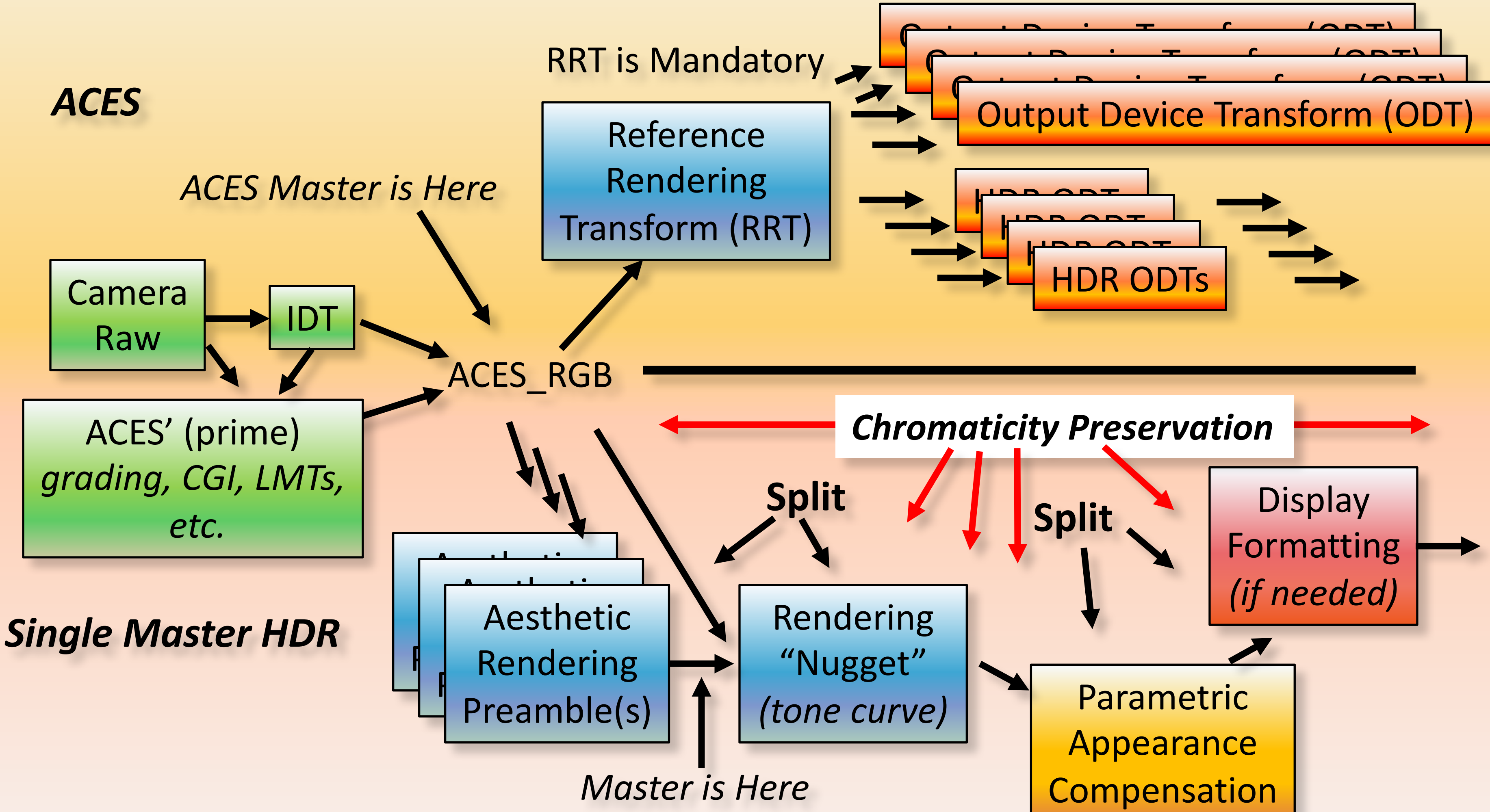


another viewpoint: <u>this all disappears</u>!

<u>Configuration:</u>

- *Gamut in signal matches display gamut (e.g. P3)*
- *1.0 is display maximum for each of R, G, B, and W*
- *Linear light represented as half-float (aka "FP16"), will be below perceptual threshold*
- *Every different value in the 0.0 to 1.0 range for R, G, and B are visually distinct*

Single Master HDR Architecture Comparison vs ACES



Color Rendering is Modular
Only Nugget is Mandatory

Single Master HDR_System approach

• Aesthetic rendering preambles, and grading, are not normative.
The result of these is embodied in the radiometric HDR_System master.

• The use and meaning of the HDR_System master is normative

• The entire normative processing for the HDR_System can move into display/projector electronics, if the HDR master is directly distributed (e.g. using a floating point codec). This is a migration path.

• The HDR_System master maintains the linear light characteristics of the master, even through grading (as demonstrated by the Lustre grading tests). No limitations on future use of such a linear light ("aces-prime") graded master.

• This enables the HDR_System to support single-master HDR (within the HDR_System's range and gamut).

• The resulting HDR_System master obtains radiometric integrity, which includes long-term defined meaning of an HDR master

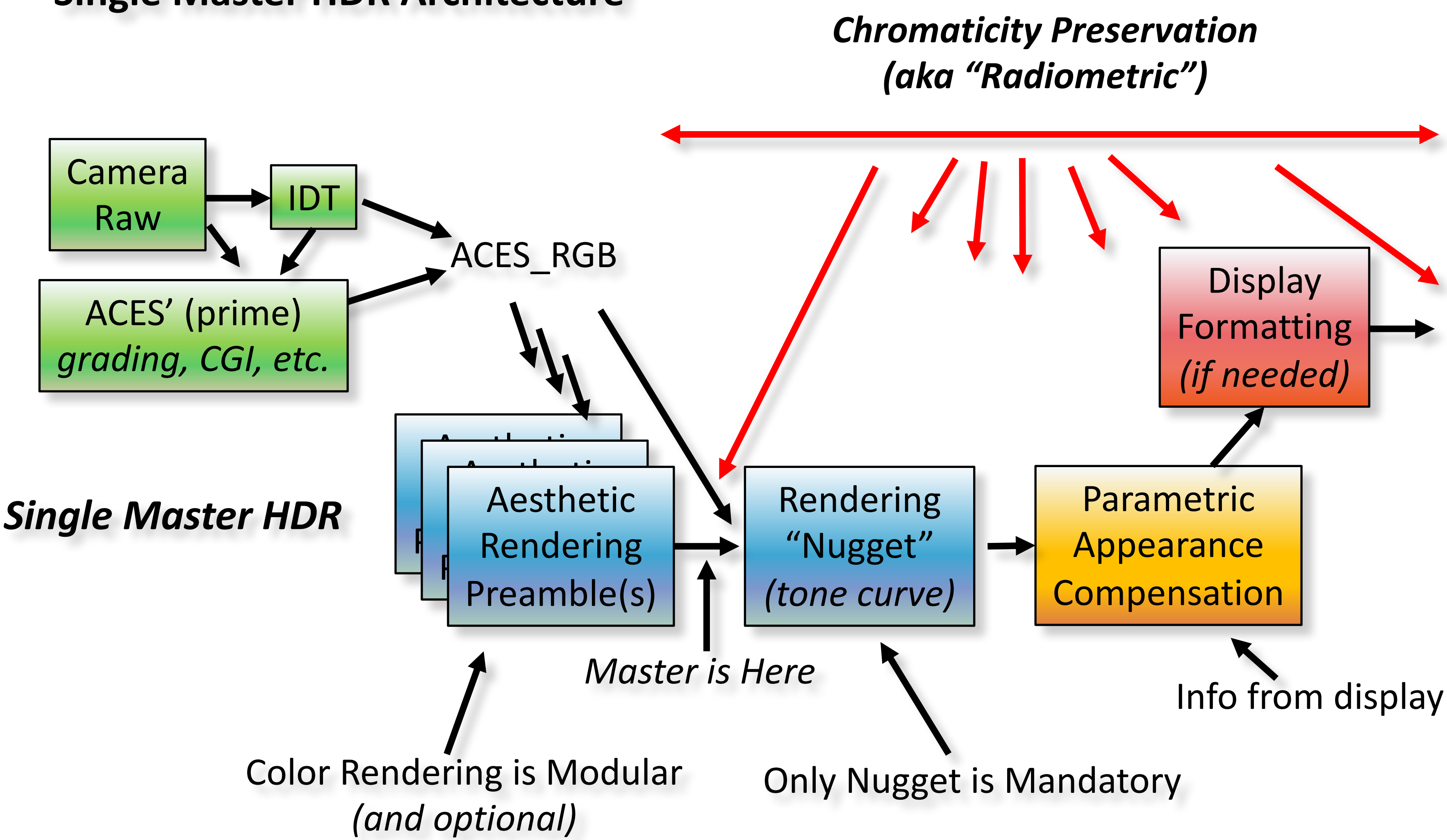
Basis of the Single Master HDR System

Key design principle for the correct presentation ***appearance*** for the HDR_System master:

- ***Brightness moves***
- ***Chromaticity does not****

** (except for Hunt effect saturation compensation on high brightness displays)*

Single Master HDR Architecture



Discovery During Lustre v0.7 grade vs. original ICAS

-original and grade look the same except for intentional adjustments

- the graded image is thus in **linear scene-referred light**

- no loss of high-end color saturation

- no noise build up in dark areas (nor at any brightness nor color)

- an HDR master in this form is unassailable
  cannot be questioned regarding "gradeability"

  - *Similar to film negative/digital-film-density intermediate*
  - *Full camera range and gamut preserved (if desired)*
  - *Creative adjustments in grading process are not tied to specific displays (neither at mastering nor at distribution/presentation)*

Architectural Implications of this Single-Master HDR Architecture

- **No use of metadata** in this example architecture (for now)

- **Masters can be created in full range and gamut like camera originals** (similar to film negative being a master, but having even more range)

- **Scene light linear physics is then fundamental** to the definition/specification of the archival master
  - defined using D60 or D65 whitepoint, and LAD
  - full gamut (e.g. ACES RGB or XYZ, adding spectral info if available)

- **Each distribution display should have a mechanism to compensate** for its own inherent properties:
  - Brightness (including large area brightness dimming)
  - Gamut
  - Ambient surround
  - Bit depth (dithering down from higher bit depth source(s), when avail.)

- **Independent of "coding on the wire"** attributes (e.g. EOTF nulled out)

Appearance Compensation

Pixel-independent (not regional) appearance effects:

*** Abney: Constant hue vs. saturation goes along curved lines**

*** Stevens: Constrast increases with luminance**

*** Hunt: Colorfulness increases with luminance**

x Bezold-Brucke: Hue changes with luminance

x Helmholtz-Kohlrausch: Brightness increases with color saturation

*** *modeled and compensated***

x *to be explored*

Appearance Compensation *(continued)*

Regional and time-sensitive appearance effects:

*** Bartleson-Breneman: Contrast increases with surround luminance**

x Appearance effect involving contrast changing with subtended angle?

- Surround white adaptation when different from displayed white

- Color and brightness persistence effects (including cone-bleaching)

- Regional optical illusions (often related to localized surround adaptation)

*** *modeled and compensated***

x *to be explored*

- *not sure what can be done*

LAD Must Move!

- LAD (Laboratory Aim Density, mid-grey)
  - LAD was the main brightness anchor for SDR film

- LAD needs to vary somewhere in-between absolute nits (e.g. PQ) and percent of max (e.g. SDR LAD is set at 10% of Max)

- ***LAD (mid-grey) would be 1000nits (10% of Max) if scaling up SDR to max 10,000!***

- ***LAD would be deep 0.1% black if held at SDR's 10nits vs PQ max 10,000!***

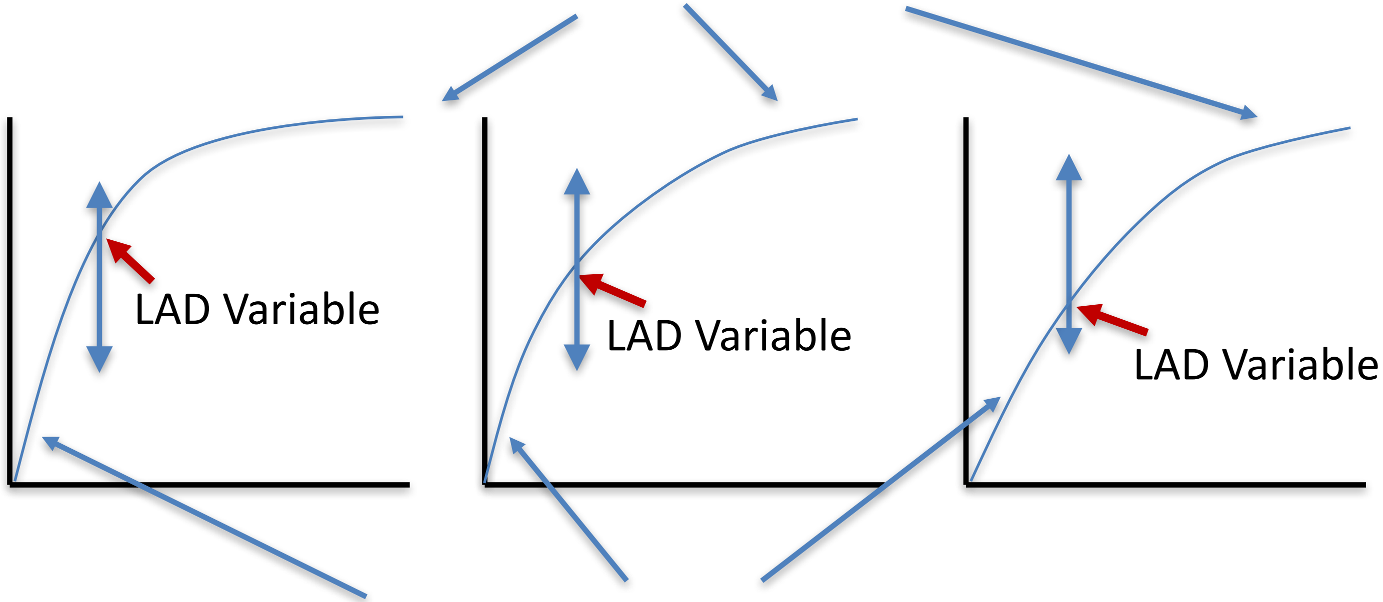
- There is a vast region between 0.1% of peak and 10% of peak
  - 0.1% to 10% is 100-to-1 range!
  - LAD (mid-grey) belongs somewhere in this range
  - However, LAD should not be fixed as percentage of Max, nor absolute nits

- LAD needs to move with respect to display maximum, and ambient surround

Brightness Compensation

Appearance Brightness Compensation Built On Variable Asymptote (thus, LAD Moves):

High End of Curve Asymptotic to Display Maximum (using norm)



Low Portion is Straight Line To Zero

- *no s-curve at bottom*
- *lifted display black compensation requires better than crude Lb*
- *dark appearance and compensation is an open topic*

Diffuse White vs. Lights and Highlights

- Diffuse white (e.g. a white shirt in the scene) needs to move similar to LAD

- Lights and Highlights can vary in brightness
  - but not too much
  - must think about the 3stop max range we are considering:
    - 150nits to 1200nits
    - consider 100nit diffuse white is 1% of 10,000nits!
    - 1% black in SDR is mid-black (between ½% black and 2% high black)
  - need to balance max bright capability with natural appearance
  - the ambient surround level also is a factor

- When mastering, need to specify allowed variability for diffuse white, lights, and highlights
  - Lock down the diffuse white allowed variability when making the master
  - Lock down the shiny reflective highlight behavior also
  - Lock down the behavior of white and colorful (e.g. neon) lights
  - Enforce consistent bright regions between different composite elements
  - Manage brightness of highlight glints on the eyes of actors in close-ups

Bright and Too Colorful

Hunt Effect (colorfulness):

- Function of absolute brightness
- Applies equally to saturated and desaturated colors
- Applies more to brighter parts within a frame
- Compensation via desat needs to follow constant-hue curves and applies luminance brightness adjustment (e.g. desat blue darkens)
- Seems to affect colorfulness over very large dark to bright range

Colorfulness questions to explore:

- Do people partially adapt to saturation levels at higher brightnesses?
- If so, is such adaptation affected by the surround appearance?
- Is it useful to darken bright saturated colors?
  - HLG asserts this
  - Should desaturation and darkening of bright colors be combined?
- Is a simple overall (all brightnesses for a given peak) desaturation sometimes adequate? Over what range if so?

Summary

- Scene referred

- Built on “radiometric” (chromaticity-preserving) spine

  This enables:
  - colorfulness compensation
  - ambient surround compensation
  - unambiguous masters
  - end-to-end calibration
  - appearance attributes created into master, reproducible subsequently over MDR/HDR range and gamut

- Master, after appearance module/grading defined by linear scene light, LAD, and D60 (or D65)

- Work not complete, but reasonably far along

View Demonstration in the Innovation Zone

(This Architecture Works!)

Note: appendices follow, FYI

Also check out:

SMPTE (smpte.org):
education -> on-demand-webinars -> 23April2015 “HDR Intermediate”

garyd@alumni.caltech.edu

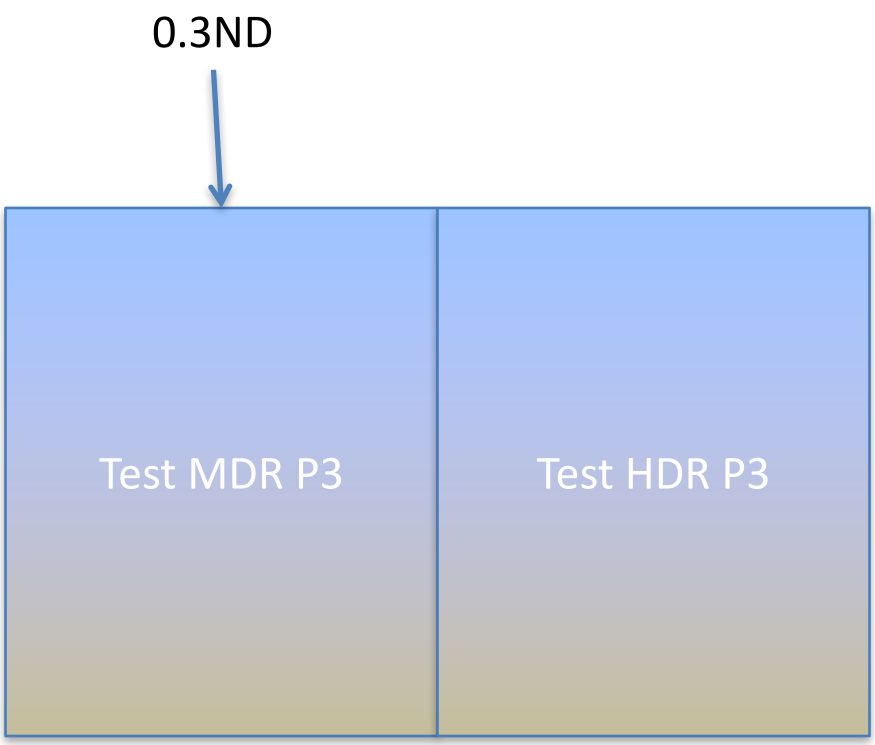
Appendices:

- ***Demonstration Descriptions***
- ***Further Investigations***
- ***Tips for HDR Mastering***
- ***Avoiding Structural Limitations***
- ***The Film Density Model***
- ***Pixel Meanings***
- ***Meaning of "Color"***

Demonstrations

Demonstration of MDR and HDR matching (150nit to 1200nits)

- Left image(s) covered with 0.3 ND Filter (one stop)
- Display brightness compensation
- “colorfulness compensation” for the Hunt effect



Demonstrations *(continued)*

- Side-by-side 0.7 Lustre grade of ICAS vs. F65 camera-native (via Sony Raw Viewer)

- Face highlight desaturation demonstration

- Bright region desat for Hunt Effect compensation, along constant-hue curves

- Near 60fps realtime 10bit UHD decoding with 257-cubed 3D LUT in GPU

- 24fps realtime 12bit 4k decoding running “full” algorithms in GPU

- MacPro Laptop, 500nits, P3 gamut, w/ companion LG 5k 27” Thunderbolt-3 display

- On-screen graduated neutral surround for D60 and D65
  (for use when HDR mastering)

- Behind-screen adjustable ambient surround

Demonstrations *(continued)*

- Radiometric rendering
  - No preamble, nugget only
  - Chromaticity-preserving appearance compensation only
  - Brightening and darkening as a function of hue:
    - *Red and Yellow brighter*
    - *Green, Cyan, Blue, and Magenta darker*
  - End-to-end chromaticity preserving (i.e. hue and saturation preserving)
  - No Colorfulness compensation (but could be added using HLG-style darkening)
- Not fully aesthetic (e.g. not DC-2.2 look), but not bad (have a look)

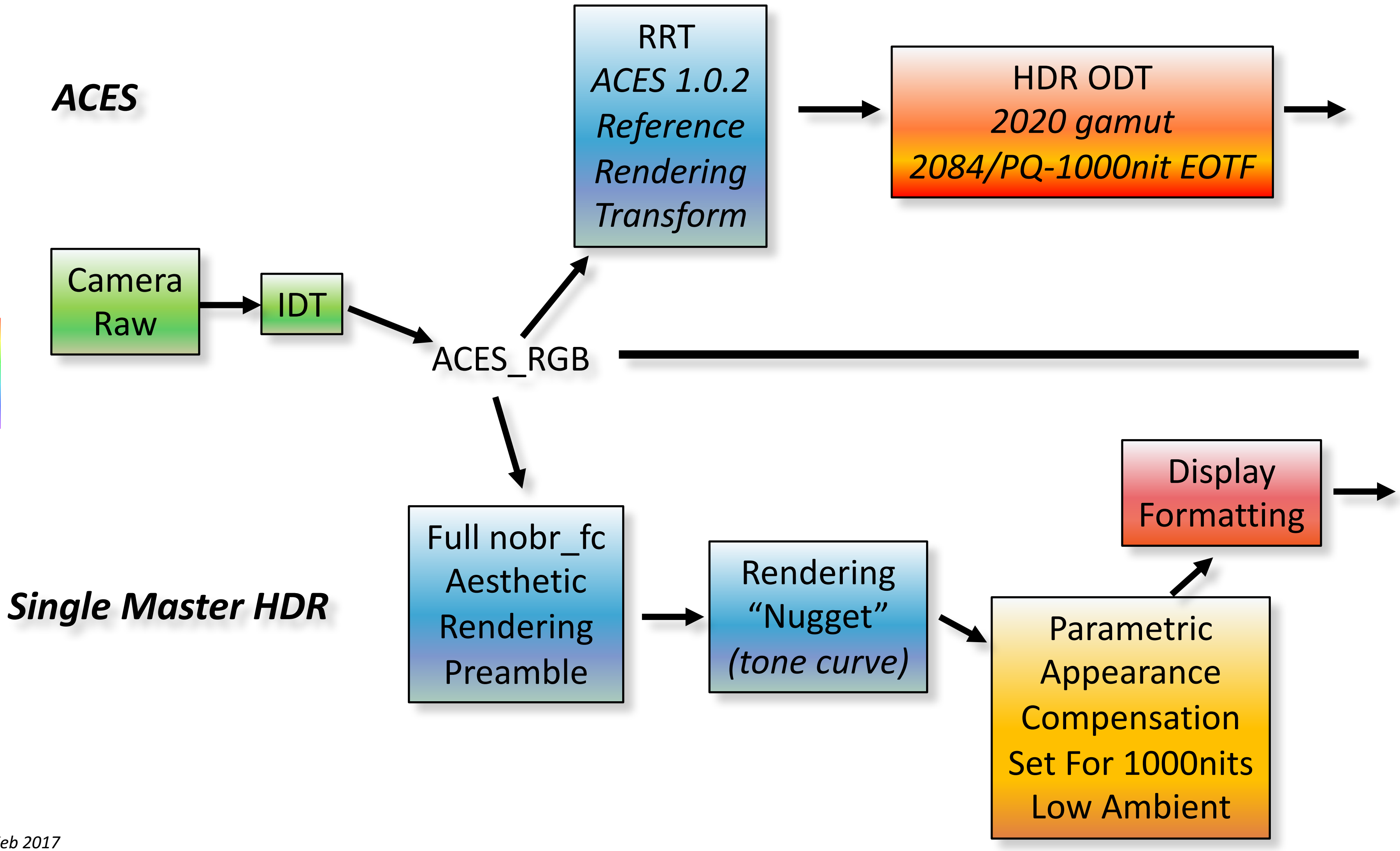
Demonstrations *(continued)*

Comparison of Appearance vs. ACES 1.0.2

- Comparison of “Full_nobr_fc” aesthetic rendering preamble vs. ACES 1.0.2 RRT with 2020gamut/2084PQ_1000nit_EOTF HDR ODT

- ACES 1.0.2 RRT and HDR ODT from BlackMagic DaVinci Resolve

Single Master HDR Appearance Comparison vs ACES 1.0.2



Further Investigations

Investigations and Verifications of Current Version:

- Yellow-biased norm

- Tone curve section fit refinement
    - low linear, .02 slope, down through 0.0
    - mid tries to hit LAD (.18 maps to .10)
    - high linear, in = out

- Matrix from ACES RGB to P3 RGB gamut reduction issues
    - matrix has ~2.0 red-to-red term
    - negative terms can take all positive input to negative output
    - input currently limited to all positive
    - how to soft-clip gamut top and bottom on hue curves/luminance?

- D60 (ACES whitepoint) vs. D65 (HLG/BT.2100 and PQ/BT.2020 whitepoints)

- On-screen ambient and/or behind-screen ambient during mastering

Investigations and Verifications of Current Version (cont.):

- Specific function of max brightness
- Specific function of ambient surround
- Currently max and surround are combined in a single adjustment
- Active preambles:
  - Null (radiometric)
  - Full
  - Full rolled-off-desaturated brights
  - gd9 desaturated brights
  - gd9 rolled-off-desaturated brights

Reproduces desired appearance based upon scene light energy

- Inactive preambles:
  - gamma_and_mat, simple, moderate, double, some "looks"
- Feasible preamble: ACES 1.0 (may not be orthogonal to all 1.0 ODTs)

Tips for Using the HDR Mastering Display

Helpful procedures for HDR display during mastering:

- Test various surround levels (e.g. adjusting onscreen appearance vs. surround brightness, using the methods described here)
- Lift darks by two or three stops to inspect
- Drop brights by two or three stops to inspect
- Inspect HDR composites lifted, darkened, desaturated, and at reduced contrast
- Attempt to inspect every mastered pixel value within display's range/gamut
- Alternatively, put mastering display into a mode where every pixel value is visibly distinct, and limit the master to that range/gamut

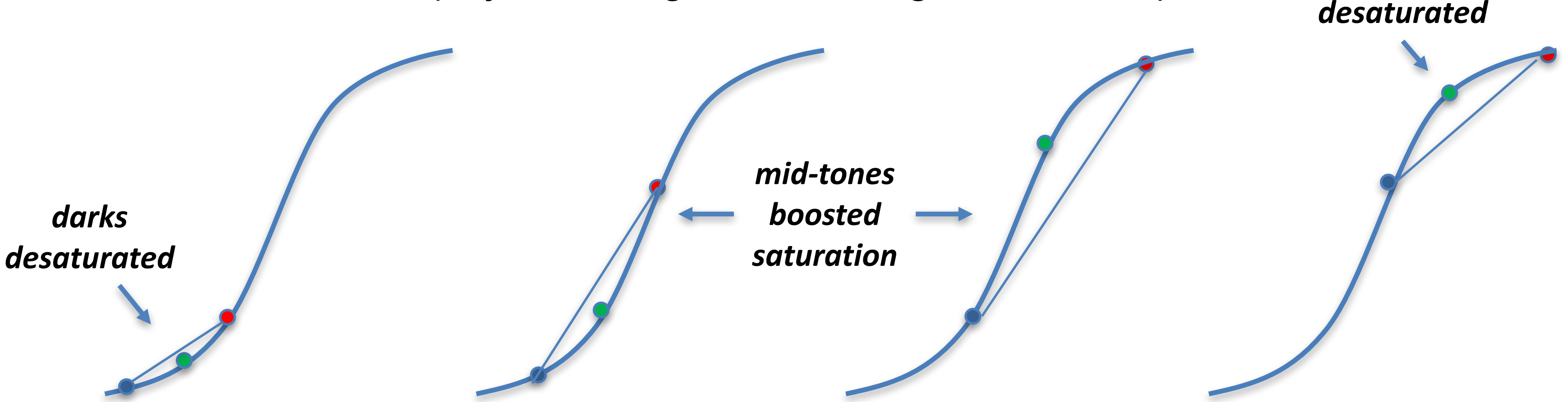
  - e.g. P3 gamut 10/12bit gamma 2.6 w/small range/gamut edge margin

  - Not sure how to obtain a neutral form (e.g. scene-referred) doing this

Avoiding Structural Limitations

When R, G, and B independently "ride" an S-Curve

Hue and Saturation Vary With Brightness
(objects change color as brightness varies)



*Orange **Desaturated***
*Hue Pushed **Toward Red***

*Orange **Boosted Saturation***
*Hue Pushed **Toward Red***

*Orange **Boosted Saturation***
*Hue Pushed **Toward Yellow***

*Orange **Desaturated***
*Hue Pushed **Toward Yellow***

This is OK for an optional "Look", but creates difficulty when mandatory ---

Inherently challenging to attempt building a single-master HDR system from this

Avoiding Structural Limitations

What the mandatory parts of this HDR architecture do NOT do:

- R, G, and B do <u>not</u> ride the tone curve independently (yielding hue and saturation varying as a function of brightness)

- No Lb (black offset, e.g. BT1886) crude processing

- No rendered-in display appearance compensation processing

- No mandatory modification of hue and saturation

- No mandatory desaturation of darks

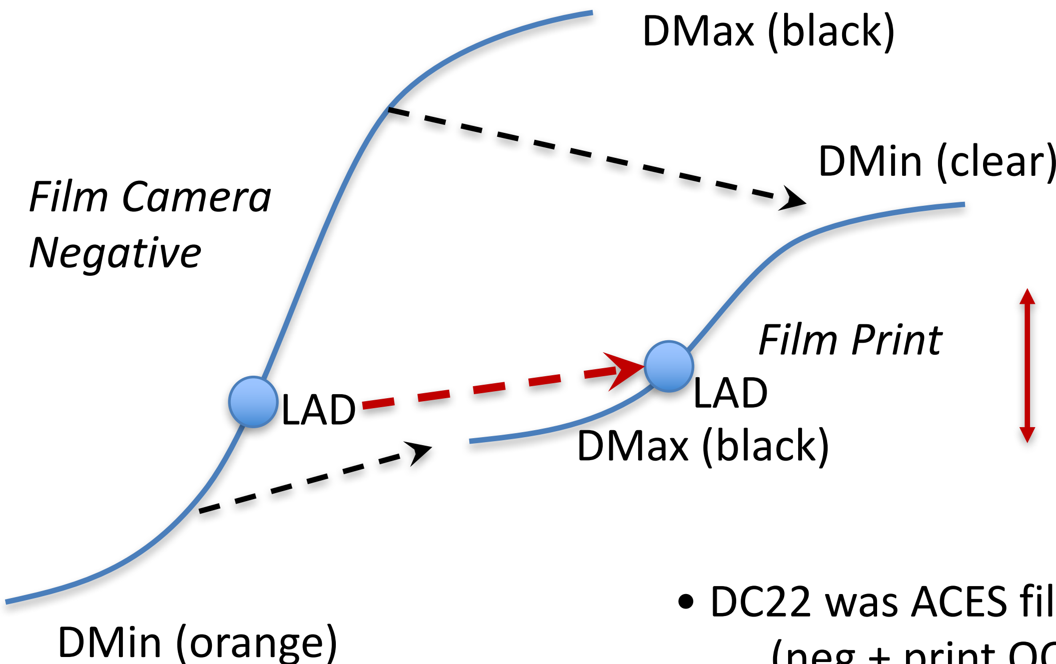
- No mandatory desaturation of brights

- No fixing to absolute nits (cd/m^2)

No!

The Film Density Model

Film Density



LAD Moves, RGB shifts, when “timing” Neg to Print (default OOTF .18->.10)

- DC22 was ACES film-density model
  (neg + print OOTF)
- Print DMin (clear) limited to 14fl Lamp/Lens
- Not High Dynamic Range
- Darks and lights desaturate
- Everything is nonlinear (straightest near LAD)

Pixel Meanings

Pixel Linear and Nonlinear Meanings and their Properties

- Gamma 2.22 + linear black toe (Rec709, BT1886), OETF
- Gamma 2.4 +/- Lb (BT1886), EOTF (Lb is crude black offset)
- Mis-use of “linear”, meaning either or both of the above
- Gamma 2.6 (DCinema/DCI/DC-28), EOTF, no black compensation
- Correct use of “linear”, gamma 1.0
    - Scene referred linear is the radiometry physics of the scene
    - Display referred linear is the radiometry physics of the display
- Perceptual Quantizer (BT.2084), EOTF, HLG (BT.2100), OOTF+
- Film Density (a measure of negative density)
- Various quasi-logs optimized for cameras (S-Log, Log-C, Filmstream, etc.)

Pixel Representation Properties (cont.)

- Pixel ”coverage” is inherently linear (anti-aliasing), but may interact via sub-pixel specific orientations
- Pixel ”transparency” and density is inherently logarithmic (.3ND + .3ND = .6ND in logarithmic density = 0.5 x 0.5 = .25 linear
- All non-linear formats will alias during processing and compositing
- Increasing resolution helps (less prominent aliasing artifacts)
- Increasing dynamic range hurts (more prominent aliasing artifacts)
- Aliasing and cross-talk issues are inherent in “Non-Constant-Luminance”
- 4:2:0 is usually applied in non-linear spaces, e.g. HEVC Main-10

Meaning of "Color"

Multiple Meanings of "Color"

- As perceived (appeareance)

- As a measurable "chromaticity"

- Chromaticities imply color matching functions ("CMF's)

- There are multiple relevant CMF's (e.g. 1931 2deg, 1964 10deg, 170-1)

- As linear weights of sensing or emissive spectra, measurable with a spectral radiometer

- As the combined meaning of illuminating light spectra together with surface spectral absorption/reflectance

- As surface spectral absorption itself

- Emissive color lights (e.g. neon), etc.

<end>