Color Enhancement and Rendering in Film and Game Production: Color Management

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Three layers

- **layer 1: color management**
  - metadata, without which color is ambiguous
  - transforms, without which color is locked to a particular representation


Image credit: Joseph Goldstone
Three layers

- **layer 1: color management**
- **layer 2: color rendering**
  - default transformation of scene colors to display colors
  - uniform across all parts of each frame
Three layers

- layer 1: color management
- layer 2: color rendering
- layer 3: color enhancement
  - can be frame/region-specific
  - unique, distinguishing ‘look’
Three take-home points today

• Make critical color judgments in the image consumer’s viewing conditions
• Understand your color encodings
• Use ‘motion imaging’ color management
Make critical judgments in the image consumer’s viewing conditions

• This excludes any color stimulus from window light, neighboring cubicles, overheads...

• Same color appearance factors as consumers
  – absolute luminance affects contrast and colorfulness
  – black-curtain surround affects contrast and sharpness
  – angular subtense affects perceived color
  – most color appearance models excel with isolated spot colors, not colors assembled into images
Understand your color encodings

- color image encoding
  - color space encoding
    - thing being represented
    - equations of measurement
    - color channels
    - encoding transforms
    - storage layout
    - image state
    - reference viewing environment

Image credit: VES
Image credit: Joseph Goldstone
Understand your color encodings: example

Adobe RGB color image encoding

Adobe RGB color space encoding

physically measurable colorimetry
measure CIE XYZ and matrix to Adobe RGB
RGB
8-,16-bit unsigned integer
output-referred
rounding of power function
47 ft-L, 288:1 contrast

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### Colorimetric vs. densitometric encodings

<table>
<thead>
<tr>
<th>Colorimetric</th>
<th>Densitometric</th>
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</thead>
<tbody>
<tr>
<td>What hits the eye</td>
<td>What hits the densitometer</td>
</tr>
<tr>
<td>What is</td>
<td>What is (Status M), or what will be (various printing density metrics)</td>
</tr>
<tr>
<td>Crosstalk-free</td>
<td>Crosstalk-laden</td>
</tr>
</tbody>
</table>
Example colorimetric encodings

• ITU-R BT.709 (‘Rec. 709’): color space encoding
• sRGB: color image encoding
• Adobe RGB: color image encoding
• Academy Color Encoding Specification (ACES): color image encoding
Example densitometric encodings

- Cineon (née Cinéon): color space encoding
- Printing density defined by spectral condition given in SMPTE RP-180; often found as DPX payload: color space encoding
- Academy Densitometric Encoding (ADX): color image encoding

- ISO Status M, ISO Status A and SMPTE RP-180 are not color space encodings, they are spectral conditions defining density, independent of storage layout or encoding equations.
Underlying spectral conditions compared

- Spectral condition defining Cineon Printing Density (CPD) not shown, since never published; this is a big reason a service bureau’s Cineon scans may not match those of another service bureau.

Image credit: Joseph Goldstone
3D LUTs for DI: predicting colorimetry for projected densitometric images

• How to use an optoelectronic display to preview the results of a densitometrically-defined imaging chain

• Output-referred approach
  – measure densitometric chain (recorder, film, projector)
  – measure colorimetric display device (e.g. DLP)
  – compute emulation transform
Start and end of the emulation process

• Start with the scans and ignore their fidelity to the real-world scene (mandatory, since with CGI there might not be a real-world scene)
• End with output-referred evaluation as butterfly
  – equal proximity to surround
  – avoids vignetting issues
  – abstract image limits imagination
Measure densitometric chain

- aggregate 8 steps into two measurable steps

DPX to spectral transmission

Reflected open gate spectral power distribution

- film recorder
- lab negative development
- latent image
- release printer
- latent image
- lab positive development
- projector lamp & reflector
- projection screen
Measure densitometric chain

- Then, measure it
  - 1,728 element, $12^3$ RGB sample (1 sample = 1 frame)
  - measure sample frames’ spectral transmission
  - measure open-gate projection spectral reflection
  - multiply the spectra and compute 1,728 CIE XYZs
  - convert to CIE LAB as perceptually uniform space
  - assemble into 3D LUT
Assemble 3D LUT (RGB->CIE LAB->RGB)

- **Film: RGB to CIE LAB**
  - divide source lattice into tetrahedra
  - barycentric weights for source RGB values
  - apply weights to get corresponding CIE LAB values

- **DI projector: CIE LAB to RGB**
  - divide transported RGB lattice into tetrahedra
  - barycentric weights for CIE LAB values
  - apply weights to get corresponding RGB values
Anatomy of a measuring device

- light conduit
- stabilized illuminator
- film transport
- spectroradiometer
- film print

Image credit: Joseph Goldstone
Anatomy of a measuring device (closeup)

- light conduit
- stabilized illuminator
- film transport
- film print
- spectroradiometer
- punchout frame (for transmission reference)
- normal frame (full-frame color)

Image credit: Joseph Goldstone
Measure colorimetric chain

• Early on, automated measurement of DLP cube over a weekend (17 x 17 x 17 = 4,913 patches)
  – extremely good fit to model of internal DLP pipeline
  – use DLP simulator to free up DI suite on weekends
Comparison of film and DLP gamuts

Comparison is in CIELAB space; white point is DLP’s

Image credit: Joseph Goldstone
Evaluate with butterfly test

Recorder output projection

Digital projection

Unmodified image credit: Kodak
Use ‘motion imaging’ color management

• Two widely used systems: Truelight & Cinespace
  – Truelight and Cinespace documentation and support are couched in motion imaging terminology
  – may or may not be appropriate for games
  – ICC less well used; renders to a reference medium which is a graphic arts paper print in a viewing booth
• One new system: Academy Image Interchange Framework (IIF)
Truelight in one minute or less

- Output-referred, or perhaps put another way, scene-agnostic
- Used at desktop and in DI
- Considerable ability to tune for various color appearance factors (surround, flare, absolute brightness)
- [http://www.tinyurl.com/2er84wb](http://www.tinyurl.com/2er84wb), then choose *Truelight Software Library*
Cinespace in one minute or less

• More of a closed architecture than Truelight
  – whereas TL is lists or formulae, Cinespace is XML, and processing more of a black-box procedure

• Provides a lower-fidelity color management path by bashing 3 independent graphic card 1D LUTs
  – cannot model film crosstalk this way
  – neutral system menus can take on tint
IIF in five minutes or less

**Key points**
- HDR & wide-gamut from the start
- Exchange scene data, not color-rendered data, supporting later manipulation
- ACES images unambiguous even if metadata destroyed because of fixed RRT

Image credit: Joseph Goldstone
Colorimetric encoding: ACES

• Academy Colorimetric Encoding Specification (ACES) color image encoding
  – wide-gamut, encloses all colors
  – high-dynamic-range, allowing negative amounts
  – intended for exchange, not necessarily as working space, although some positive results there
Input Device Transforms (IDTs) for RAW

- Spectral response from narrow-band stimuli

Image credits: Deitmar Wüller, Image Engineering

- [http://image-engineering-shop.de/](http://image-engineering-shop.de/)

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Reference Rendering Transform (RRT)

- embodies all the design decisions reasonably common to any output device
- turns out to be very close to print film emulation
Output Device Transforms (ODTs)

• map full tone scale and gamut of RRT’s output to limited tone scale and gamut of output device

• Incorporates assumptions about output device’s viewing context
  – good colorists and VFX supervisors optimize for best viewing conditions
  – really good ones verify tolerability in awful conditions
Why the IIF is good for CG artists

• result of applying IDT is scene-referred ACES data, which plays very well with CGI
  – radiometrically linear
  – rigorously defined and well documented
• See S-2008-001, Academy Color Encoding Specification (ACES), at the Academy IIF site (http://tinyurl.com/2452q2p)
• Also see S-2008-002, Academy Density Exchange Encoding (ADX) and the Spectral Responsivies Defining Academy Printing Density (APD), ibid.
Why the IIF is good for producers

- Well-defined scanner setup means matched scans from different service bureaus
- Scene data means better CGI integration
- Open sourced reference implementation means investment isn’t vulnerable to vendor collapse
- No need to reinvent the wheel each time
-
Why the IIF is good for colorists

- Well-defined ACES encoding and fixed RRT means no more guess-the-encoding game
- HDR and wide-gamut all the way to DI preserves tonal and chromatic latitude for later changes
- Should be easier to match shots from different sources if both went through camera IDTs
So to sum up

• Judge color in your paying audience’s venue.
• Understanding your color encoding is the key to really using it well
• Go with ‘motion imaging’ color management and check out the Academy’s IIF
  – TinyURL previously mentioned: [http://tinyurl.com/2452q2p](http://tinyurl.com/2452q2p)
• Questions? Speak up, or email joseph@LP.com