High Dynamic Range Imaging

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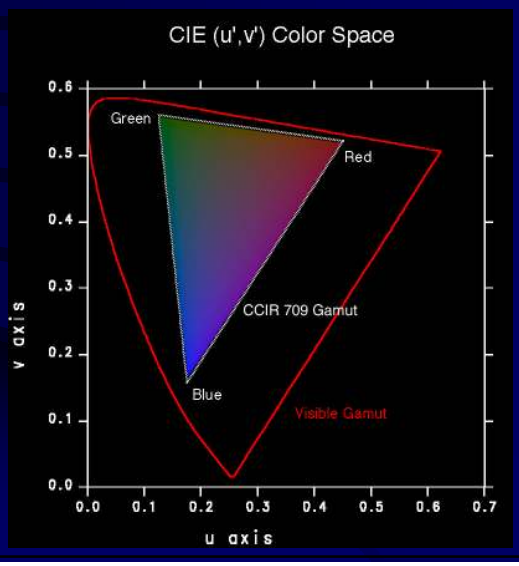
Observations

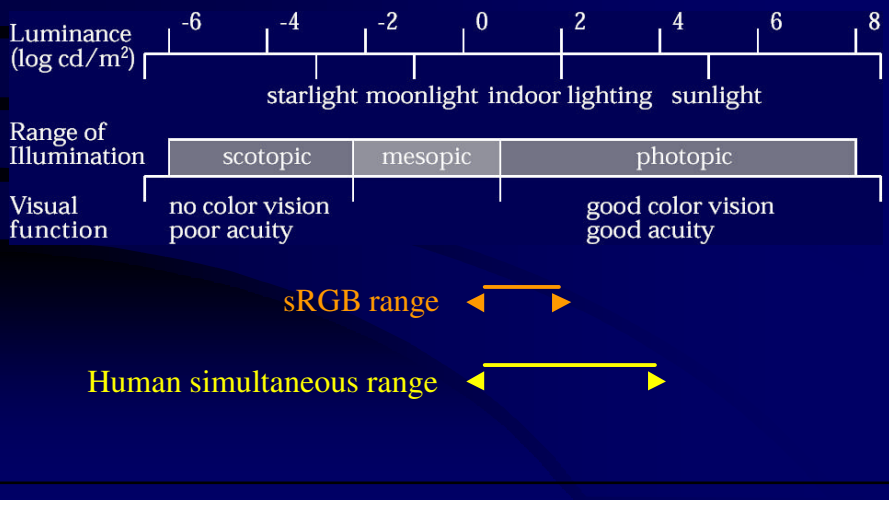
- Human visiual abilities are known
- Future display technologies are unknown
- Display-based imaging is contemporary
- Human-based imaging is archival

CCIR-709 (sRGB) Color Space



Dynamic Range

From Ferwerda et al, SIGGRAPH '96



HDR Imaging Approach

- Render into floating-point color space
- Store entire perceivable gamut (at least)
- Post-process in extended color space
- Apply tone-mapping for specific display

HDR Tone-mapping

Linear tone-mapping

Non-linear tone-mapping

Post-production Possibilities

Simulated glare

Low vision

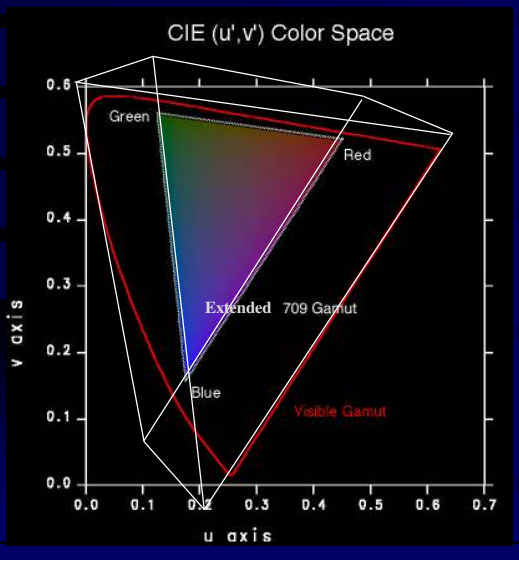
Talk Outline

I. Image Creation
II. HDR Encoding
III. HDR Post-production
IV. Tone-mapping and Display
Conclusion

I. Image Creation

- Render into gamut-less floating point color
  - Extended RGB space
  - CIE XYZ
  - Any other linear color space, incl. spectral
- Don't worry about levels or dynamic range
  - Focus on contrast
- Use non-linear filtering to avoid glitter

Extended CCIR-709 Color Space

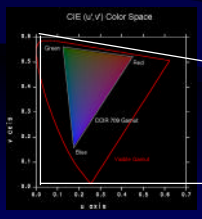


Extend Red, Green, and Blue channels to include values outside [0,1] range, thus encompassing the entire visible gamut

CIE XYZ Color Space

CIE XYZ color space uses imaginary primaries such that values between 0 and 1 cover the visible gamut

Values much greater than 1 should also be accommodated to include the desired dynamic range

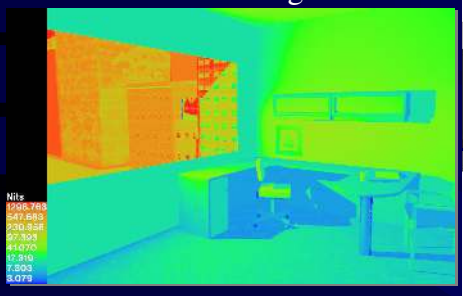


CIE XYZ Gamut

(u',v')=(0,4)

Real-world Dynamic Range

False color showing luminance

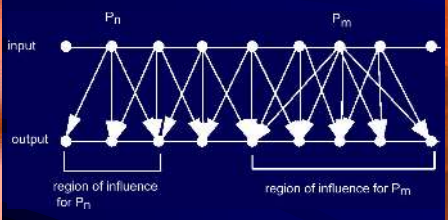


Short exposure

Long exposure

Energy-preserving Non-linear Filters

From Rushmeier & Ward, SIGGRAPH '94



II. HDR Encoding

- Current high dynamic-range formats
  - – *Radiance* 32-bit RGBE and XYZE pictures
  - – Pixar 33-bit Log TIFF
  - – SGI 24-bit and 32-bit LogLuv TIFF
- HDR potential in JPEG 2000

Radiance RGBE and XYZE

- Simple format with free source code
- 8 bits each for 3 mantissas and 1 exponent
- 76 orders of magnitude in 1% steps
- Run-length encoding (20% avg. compr.)
- RGBE format does not cover visible gamut
- Dynamic range at expense of accuracy
- Color quantization not perceptually uniform

Pixar Log TIFF Codec

- Implemented in Sam Leffler's TIFF library
- 11 bits each of log red, green, and blue
- 3.8 orders of magnitude in 0.4% steps
- ZIP lossless entropy compression
- Does not cover visible gamut
- Dynamic range marginal for tone-mapping

SGI 24-bit LogLuv TIFF Codec

- Implemented in Leffler's TIFF library
- 10-bit LogL + 14-bit CIE (u',v') lookup
- 4.8 orders of magnitude in 1.1% steps
- Just covers visible gamut and range
- No compression

SGI 32-bit LogLuv TIFF Codec

- Implemented in Leffler's TIFF library
- 16-bit LogL + 8 bits each for CIE (u',v')
- 38 orders of magnitude in 0.3% steps
- Run-length encoding (30% avg. compr.)
- Allows negative luminance values

32-bit LogLuv Pixel

From Larson, JGT '98

$$L_e = \lfloor 256(\log_2 L + 64) \rfloor$$

$$u_e = \lfloor 410u' \rfloor \qquad u' = \frac{4x}{-2x+12y+3}$$

$$v_e = \lfloor 410v' \rfloor \qquad v' = \frac{9y}{-2x+12y+3}$$

JPEG 2000

- Advanced Wavelet (lossy) compression
- Variable sample widths and rates
  - Amenable to LogLuv encoding
- Could be boon for digital photography
- Extensions to MPEG?

III. HDR Post-production

- Operators
  - Contrast & brightness
  - Color balance
  - Low vision
  - Glare
  - Motion blur
  - Lens flare
- Compositing
  - 16-bit log alpha
  - Post-prod. shading?

From Debevec & Malik, SIGGRAPH '97

Example HDR Post-processing

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(LF gray)^(2/3)

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High dynamic-range + extended gamut = lots of cool tricks

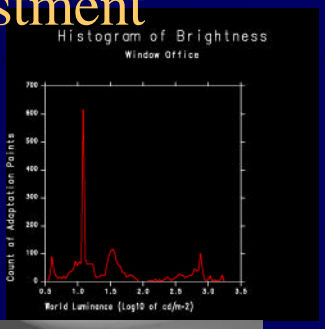
IV. Tone-mapping and Display

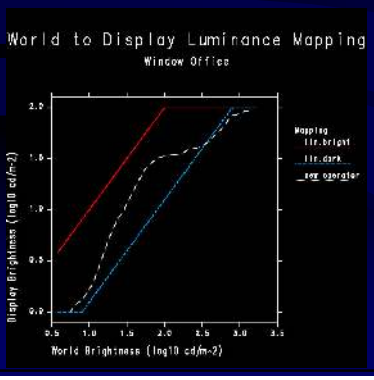
- A renderer is like an "ideal" camera
- TM is medium-specific and goal-specific
- Need to consider:
  - Display gamut, dynamic range, and surround
  - What do we wish to simulate?
    - Cinematic camera and film?
    - Human visual abilities and disabilities?
- Emerging display technologies

One Tone-mapping Approach

- Generate histogram of log luminance
- Redistribute luminance to fit output range
- Optionally simulate human visibility
  - match contrast sensitivity
  - scotopic and mesopic color sensitivity
  - disability (veiling) glare
  - loss of visual acuity in dim environments

Histogram Adjustment

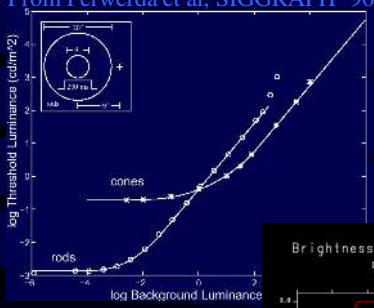


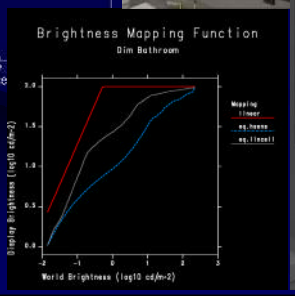


Result

Contrast & Color Sensitivity

From Ferwerda et al, SIGGRAPH '96





From Larson et al, TVCG '97

$$f(R_a) \le \frac{\Delta L_t(L_a)}{\Delta L_a(L_a)} \cdot \frac{T\Delta bL_a}{\left[\log(L_{a\max}) - \log(L_{a\min})\right]L_a}$$

Veiling Glare Simulation

Emerging Display Technologies

- TI Micro-mirror Device
  - Good dynamic range, tunable gamut
  - Widely used for still projection systems
  - Already in trials for digital cinema
- Silicon Light Machines Grating Light Valve
  - Amazing dynamic range, widest gamut
  - Still in development
  - Promising for digital cinema

Conclusion

- HDR Imaging preserves work for posterity
- Provides opportunities in post-production
- Modest computation and storage costs
- May simplify lighting stage

Further Reference

- http://positron.cs.berkeley.edu/gwlarson
  - publication list with online links
  - LogLuv TIFF pages and images
- http://www.debevec.org
  - publication list with online links
  - *Radiance* RGBE images and light probes
- http://radsite.lbl.gov/radiance
  - *Radiance* rendering software and links