A Brief History of High Dynamic Range Imaging

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Anyhere Software

Talk Outline

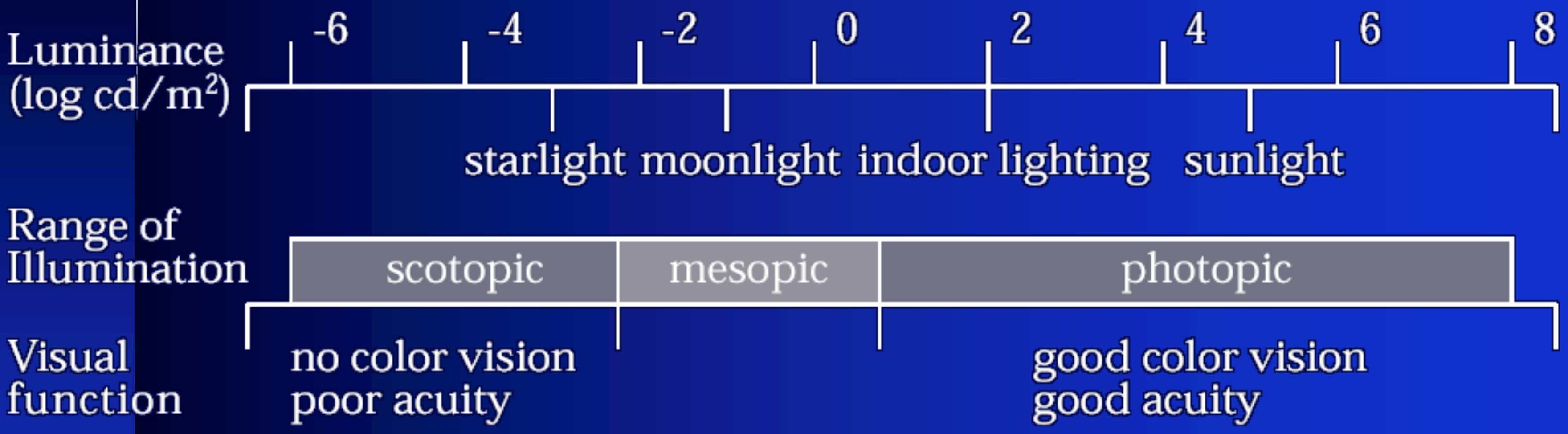
I. Origins of High Dynamic Range Imaging
II. Film and Digital HDR Capture
III. HDR Representation / Tone-Mapping
IV. Image-Based Lighting (IBL)
V. HDR Display
VI. New Developments

I. HDR Origins

- B&W negative film offers ~4 orders of magnitude (10000:1) dynamic range
- Computer graphics rendering can produce floating-point images
  - First saved as *Radiance* RGBE circa 1986
- Digital tone-mapping first considered by Tumblin & Rushmeier in 1993
- Image-based lighting [Debevec et al. 1998] led to widespread use in special effects

Visible Dynamic Range

From Ferwerda et al, SIGGRAPH '96

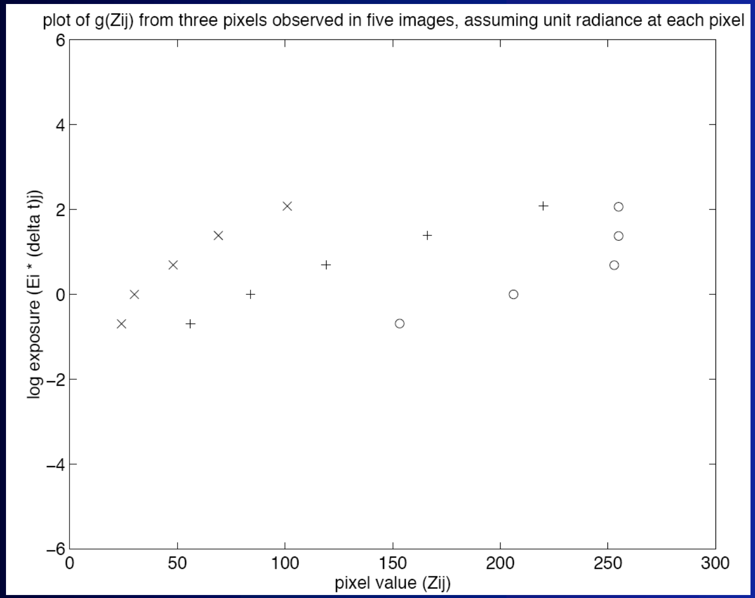


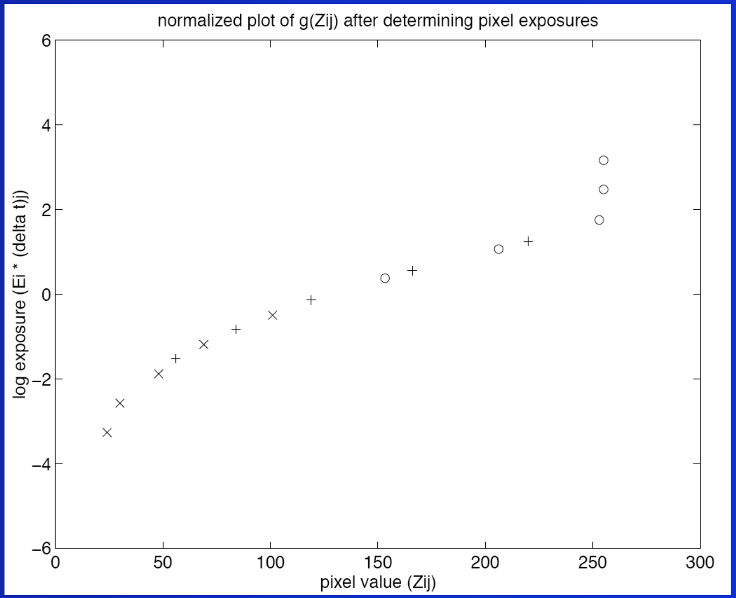
sRGB range

Human ≈ film simultaneous range

II. HDR Capture: Recovering Camera Response Function

Debevec, P. & Malik, J., “Recovering High Dynamic Range Radiance Maps from Photographs.” SIGGRAPH 1997.

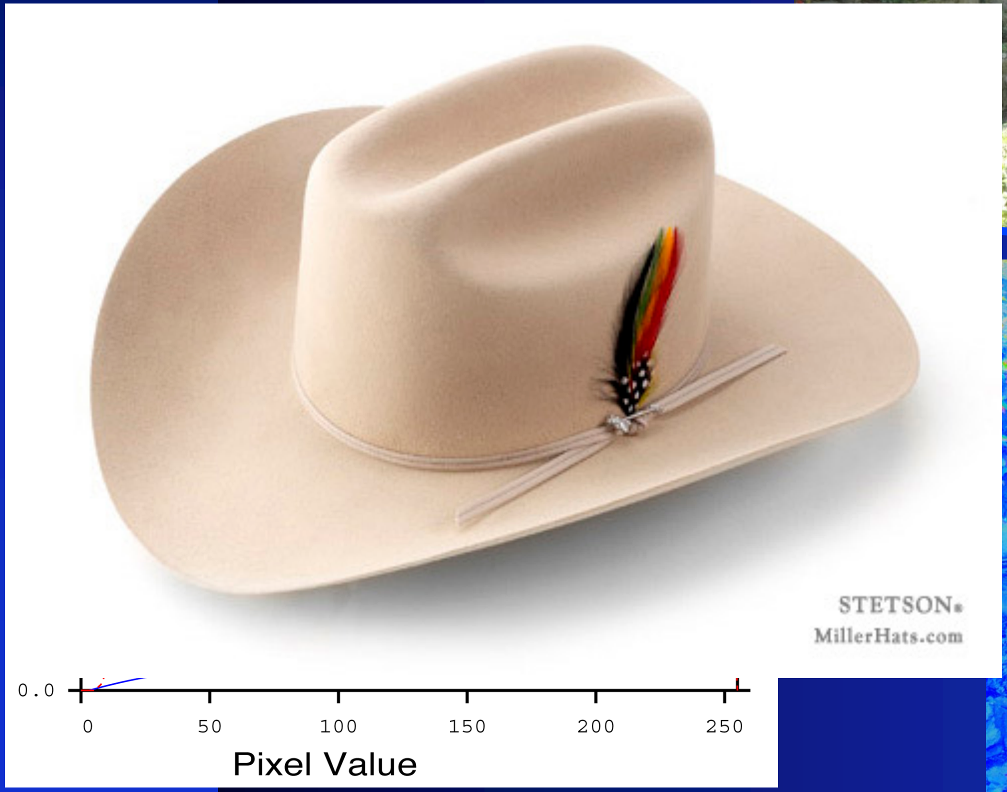


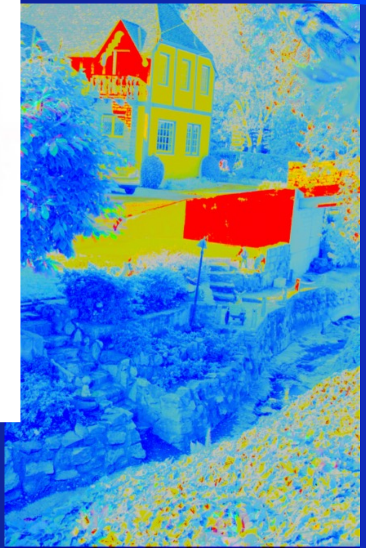


HDR from Multiple Exposures

Input exposures:

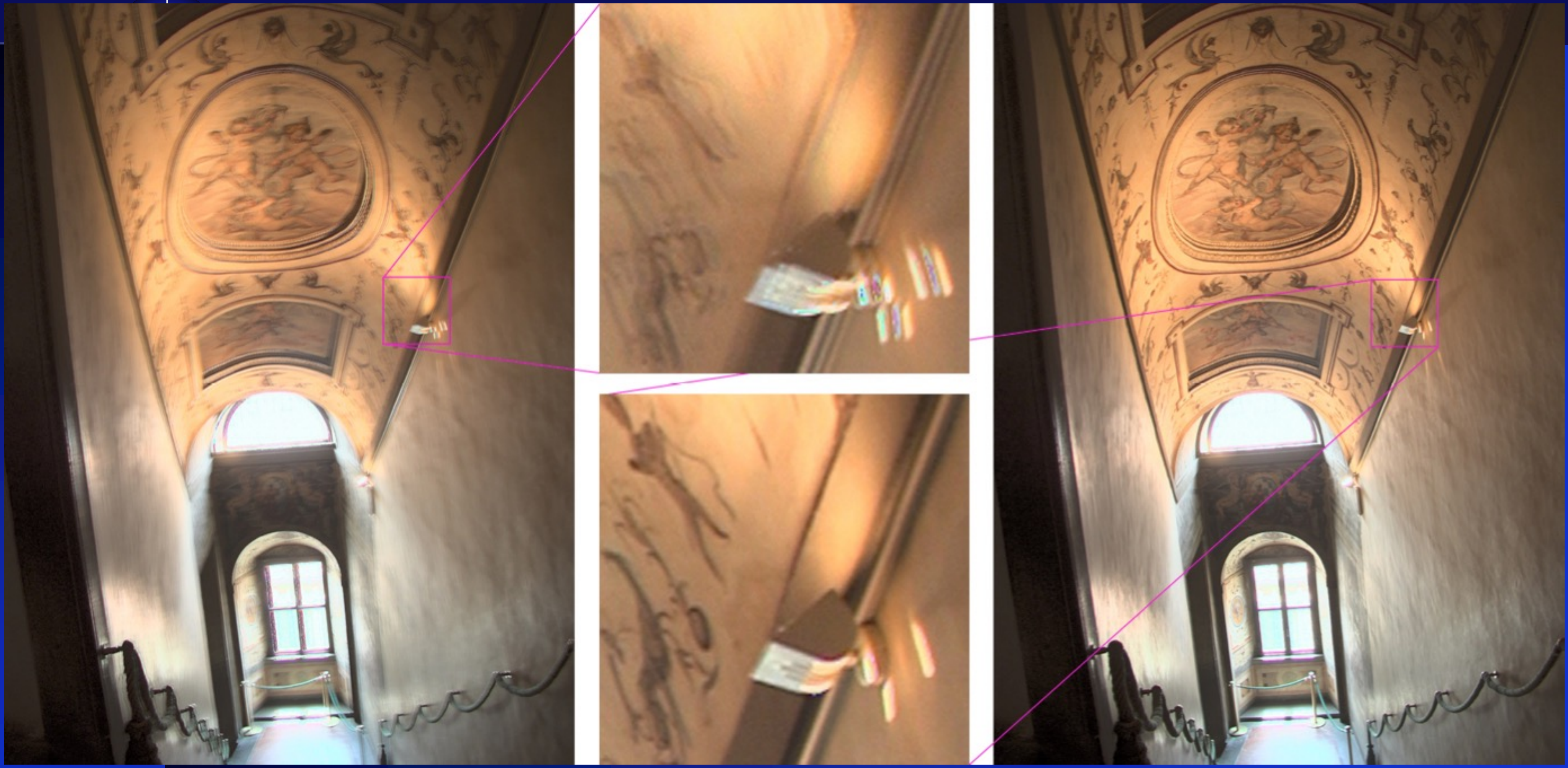
Camera response & weighting functions





Tone-mapped result

X-Y Exposure Alignment

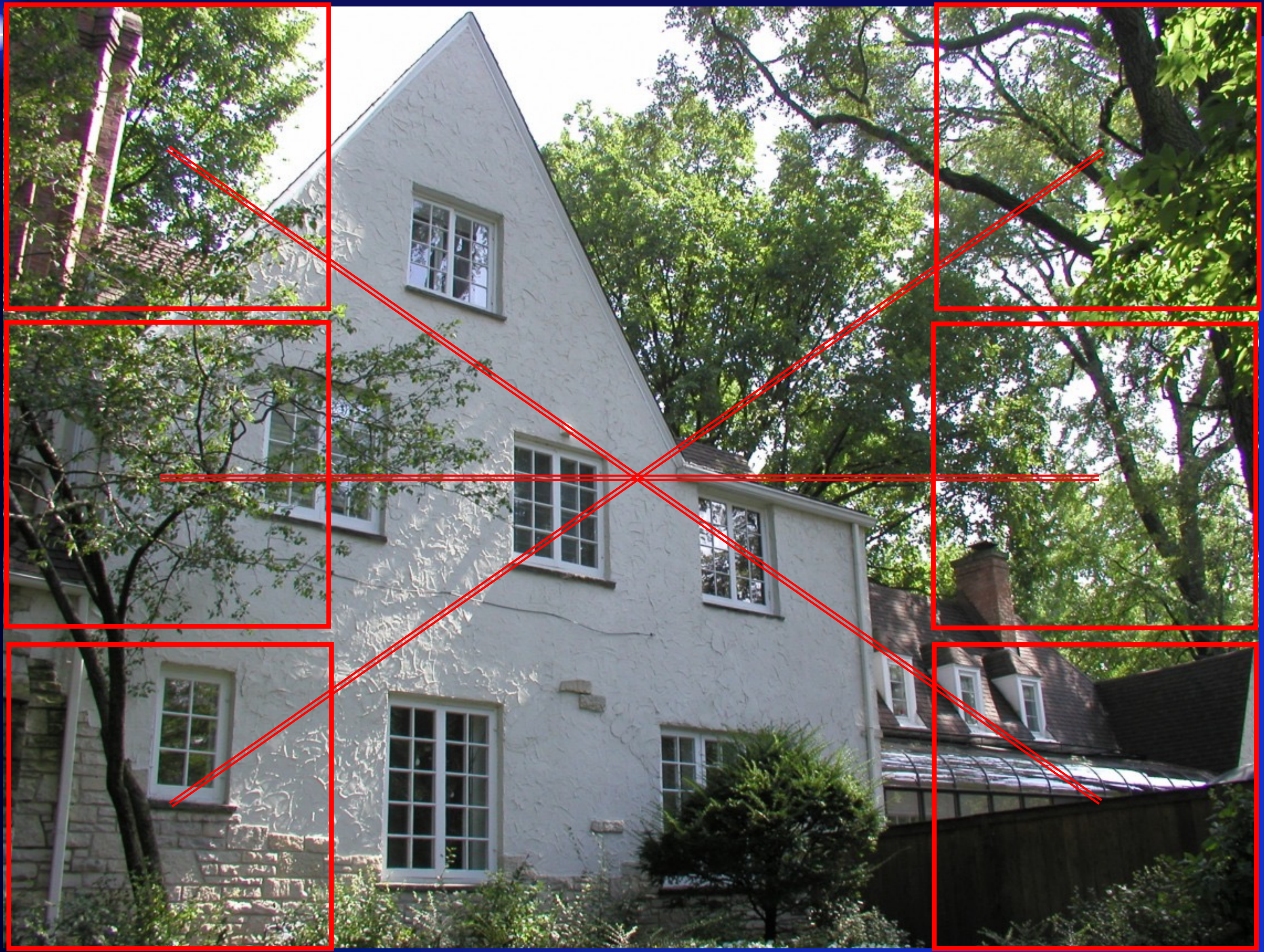


5 unaligned exposures   Close-up detail   MTB alignment

Fast alignment with mean threshold bitmaps and XOR

Rotational Alignment (1)

"Barbell" Rotation Regions



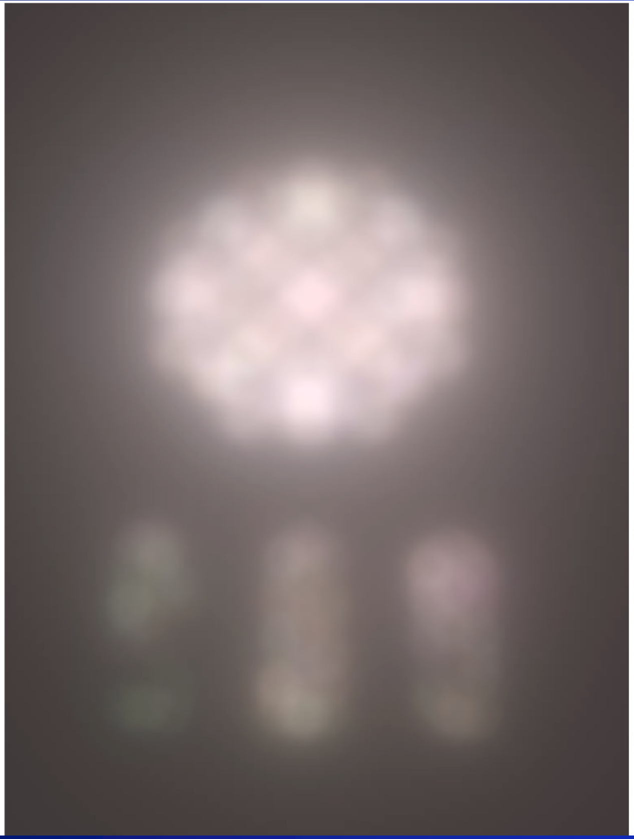
Rotational Alignment (2)

Old Translational Alignment

Rotational Alignment (3)

Lens Flare Removal

Original



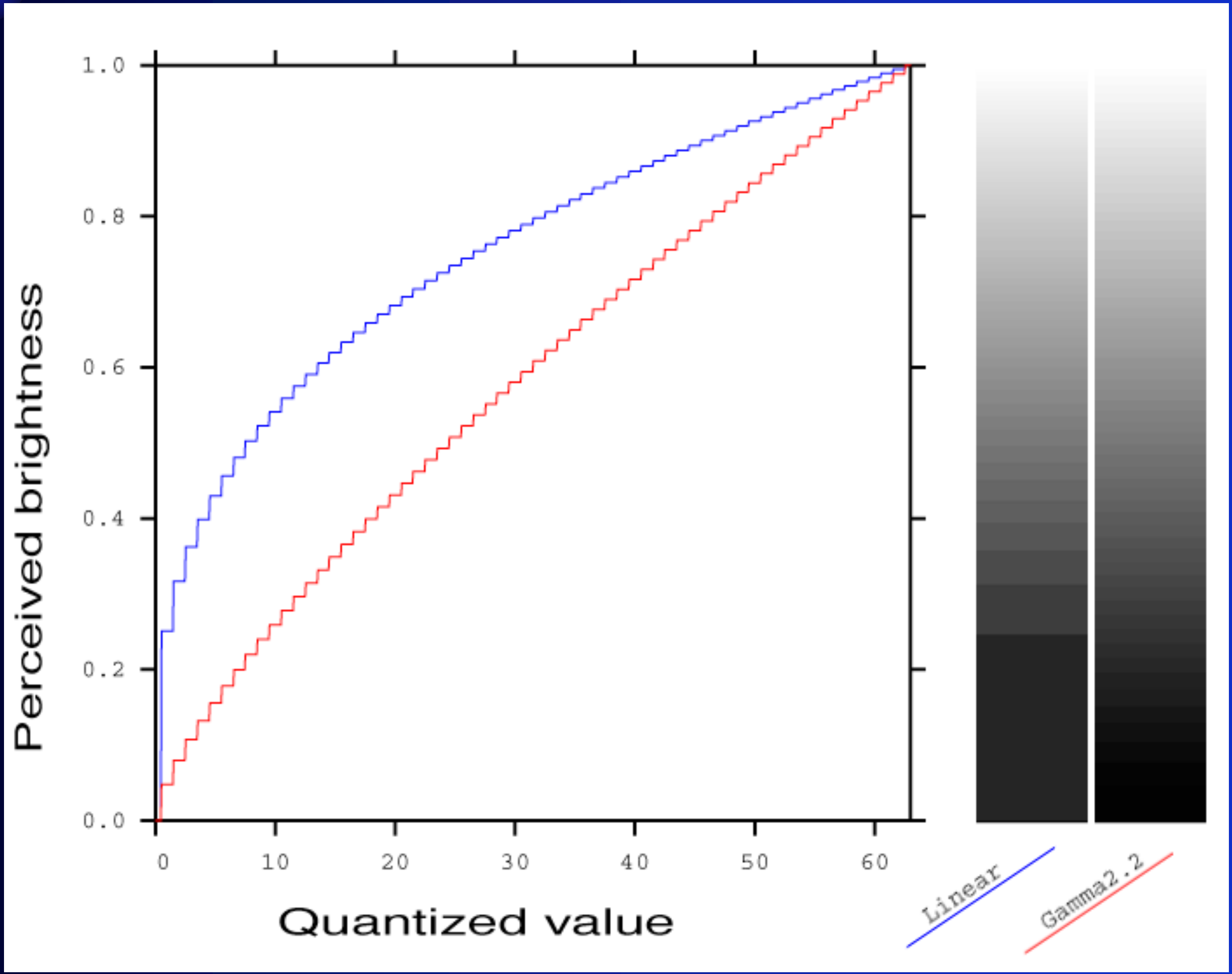
Flare

Subtracted

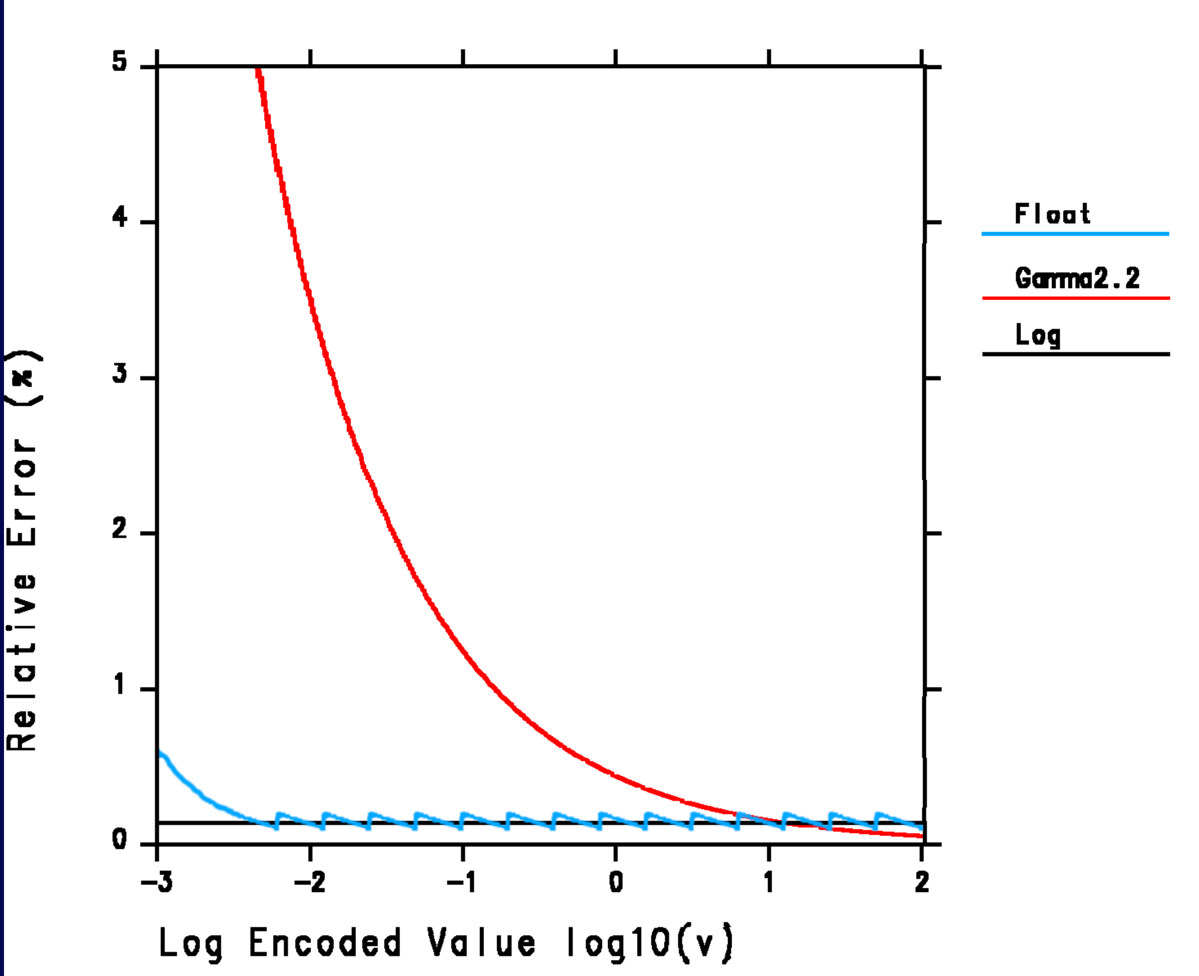
III. Luminance Encoding

- Linear quantization
- Gamma function (e.g., CRT curve)
- Logarithmic encoding
- Floating point
- Perceptual

Linear vs. Gamma Encoding

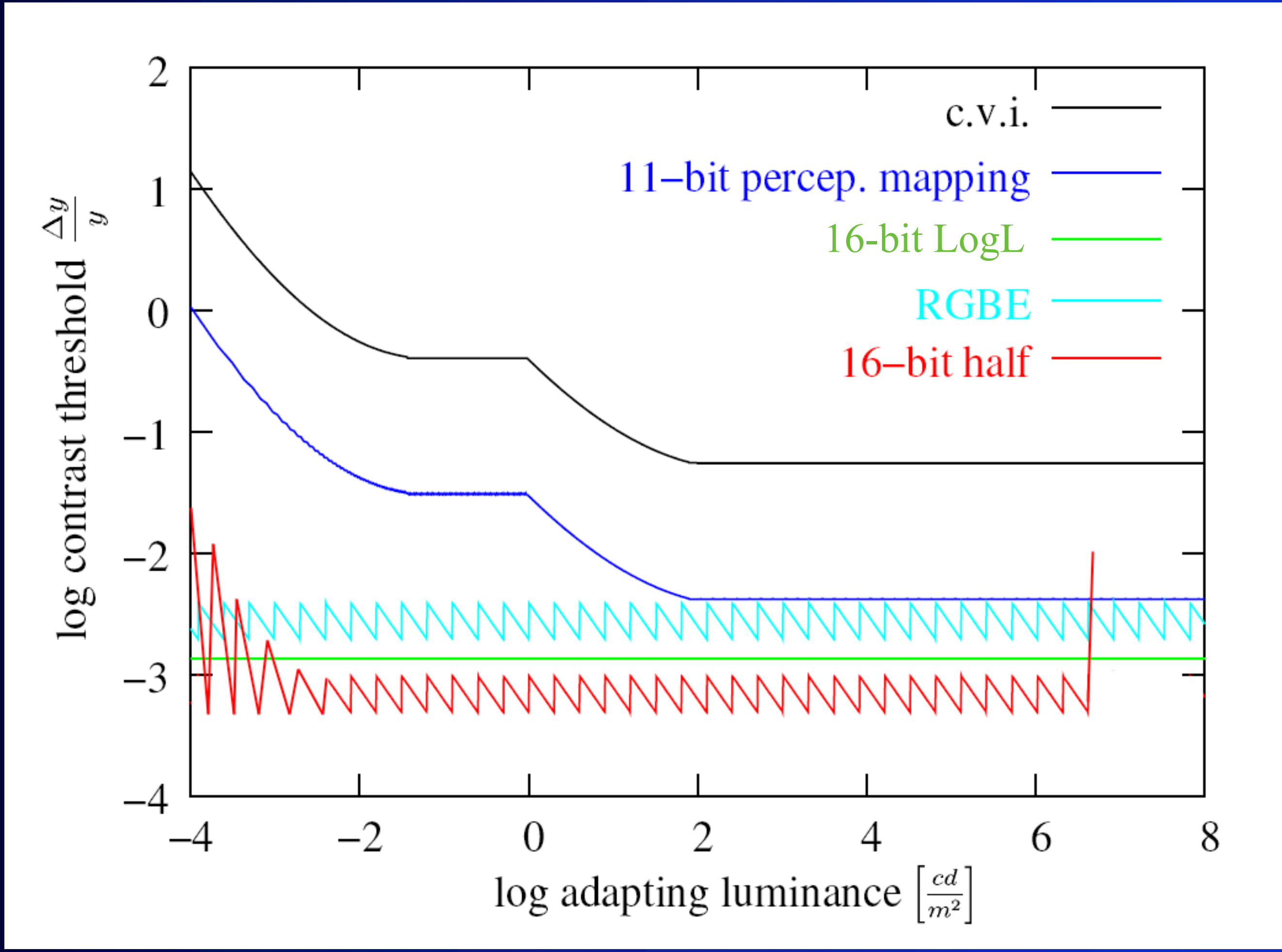


Logarithmic vs. Floating Point



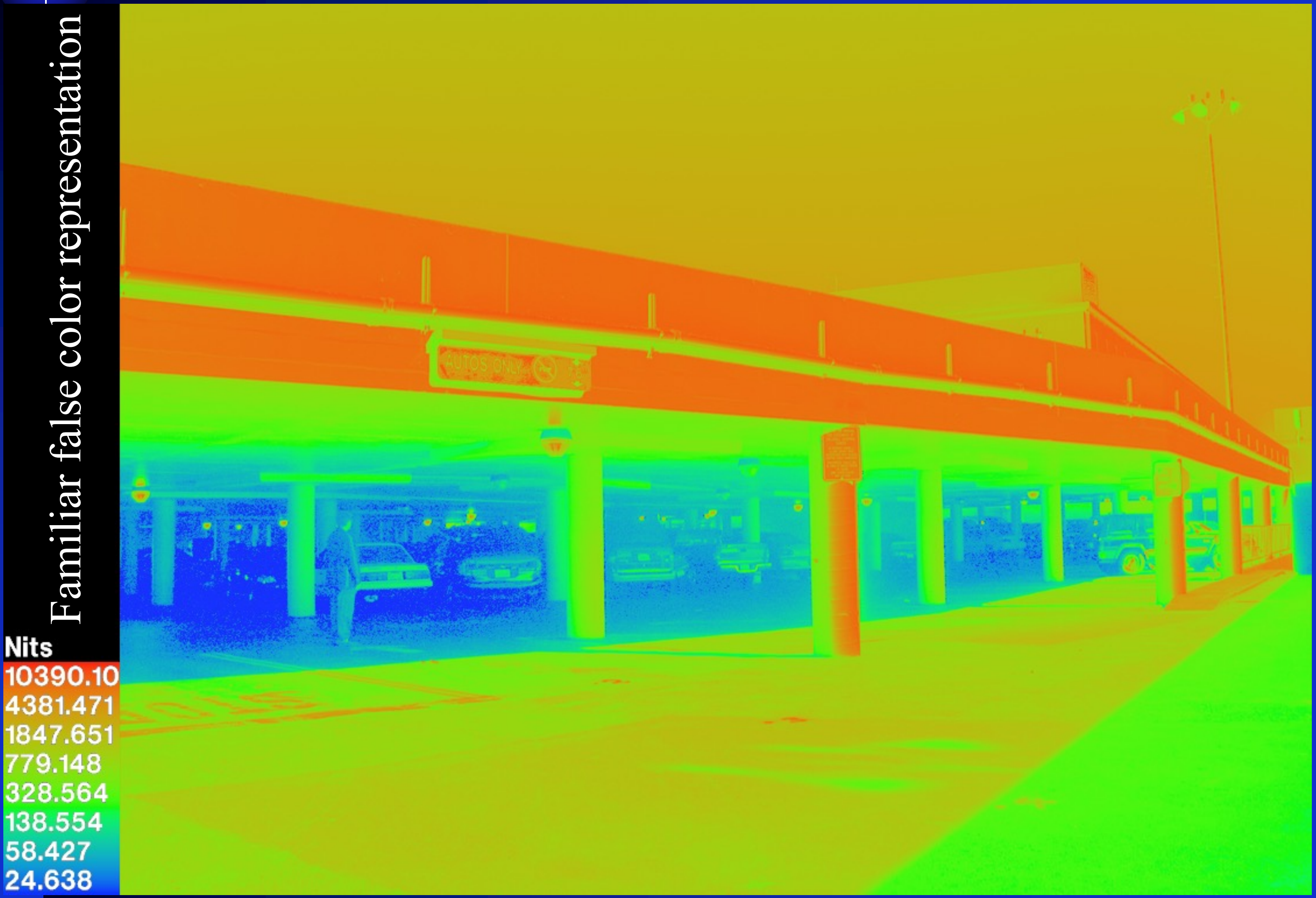
Fictitious 12-bit encoding

Perceptual Encoding



Mantiuk et al., SIGGRAPH 2004

HDR Image Processing and Tone-Mapping

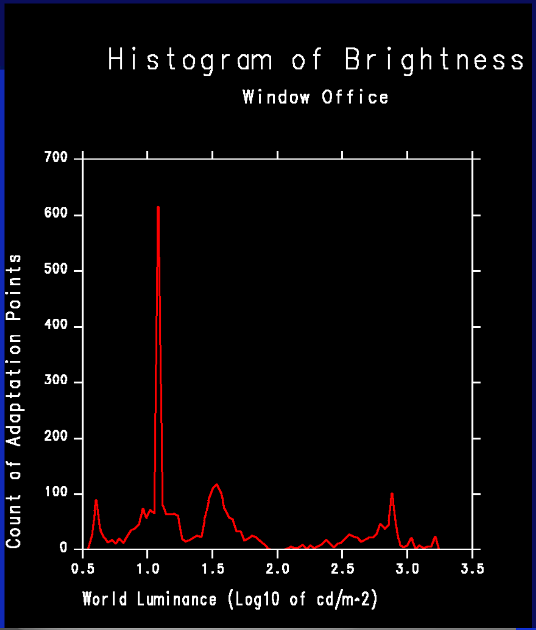


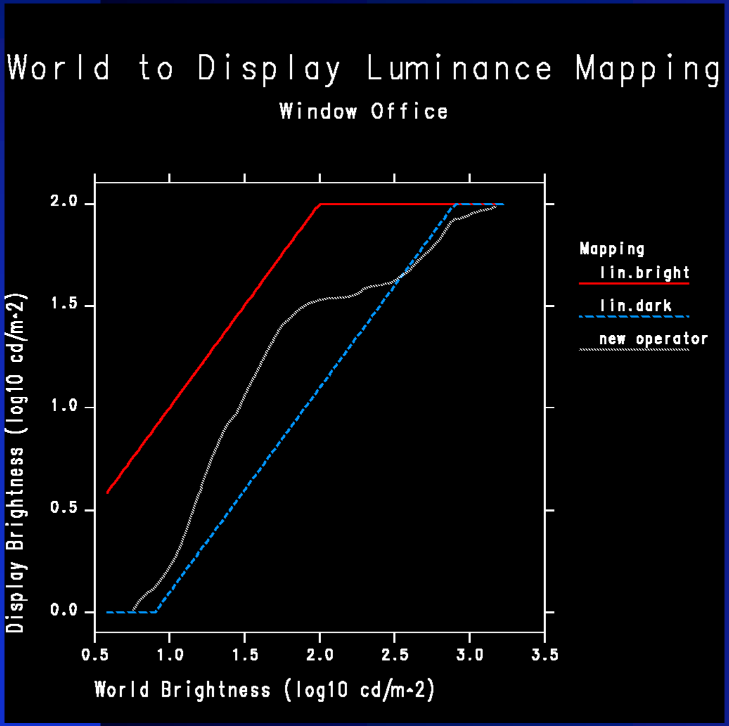
Visibility Simulation

Visibility-Preserving TMO

- 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

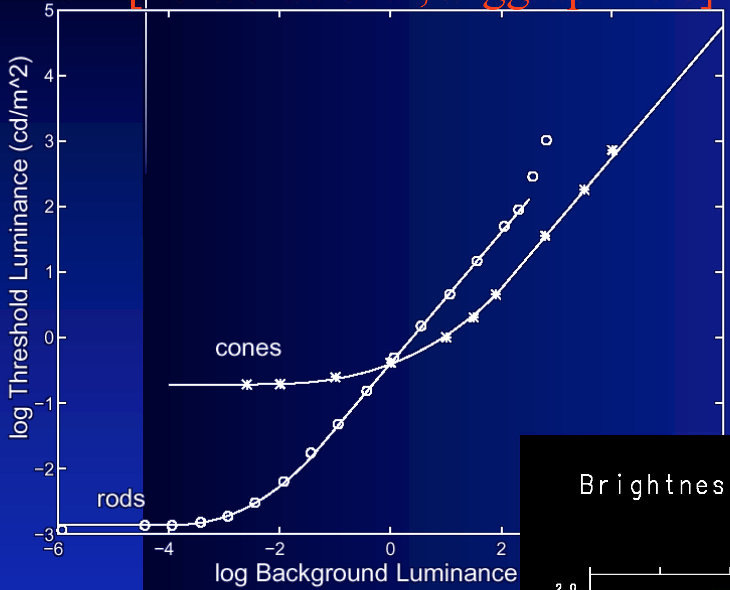


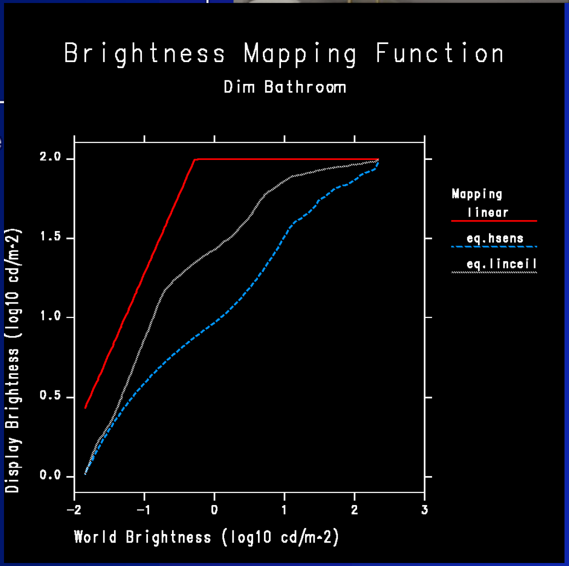


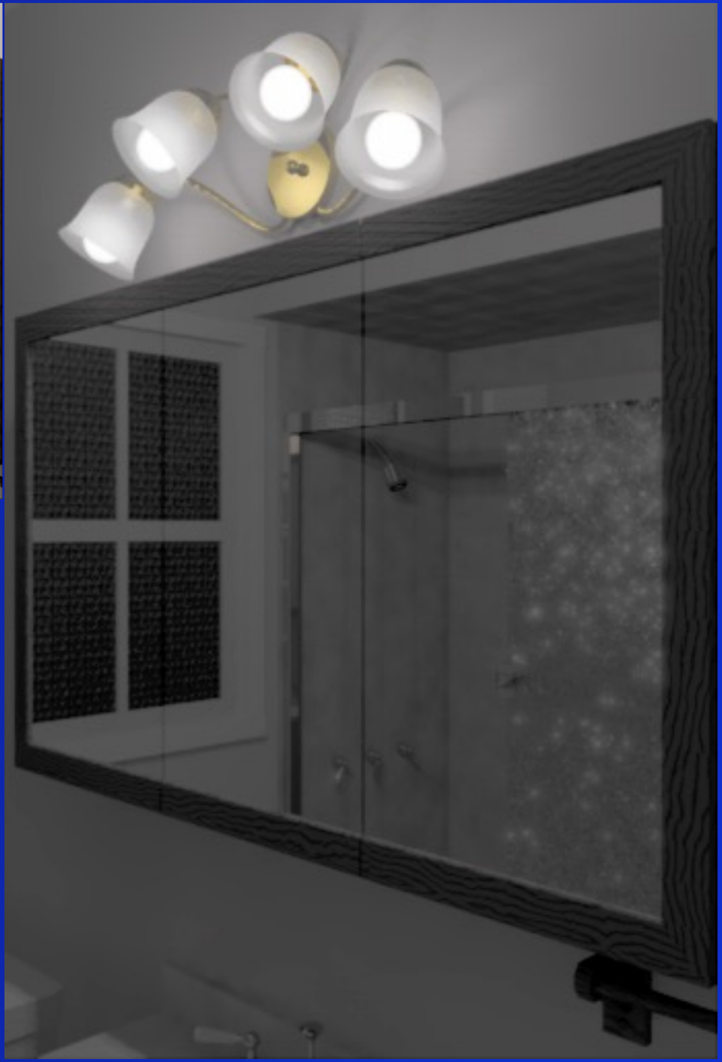
Result

Contrast & Color Sensitivity

From [Ferwerda et al, Siggraph '96]

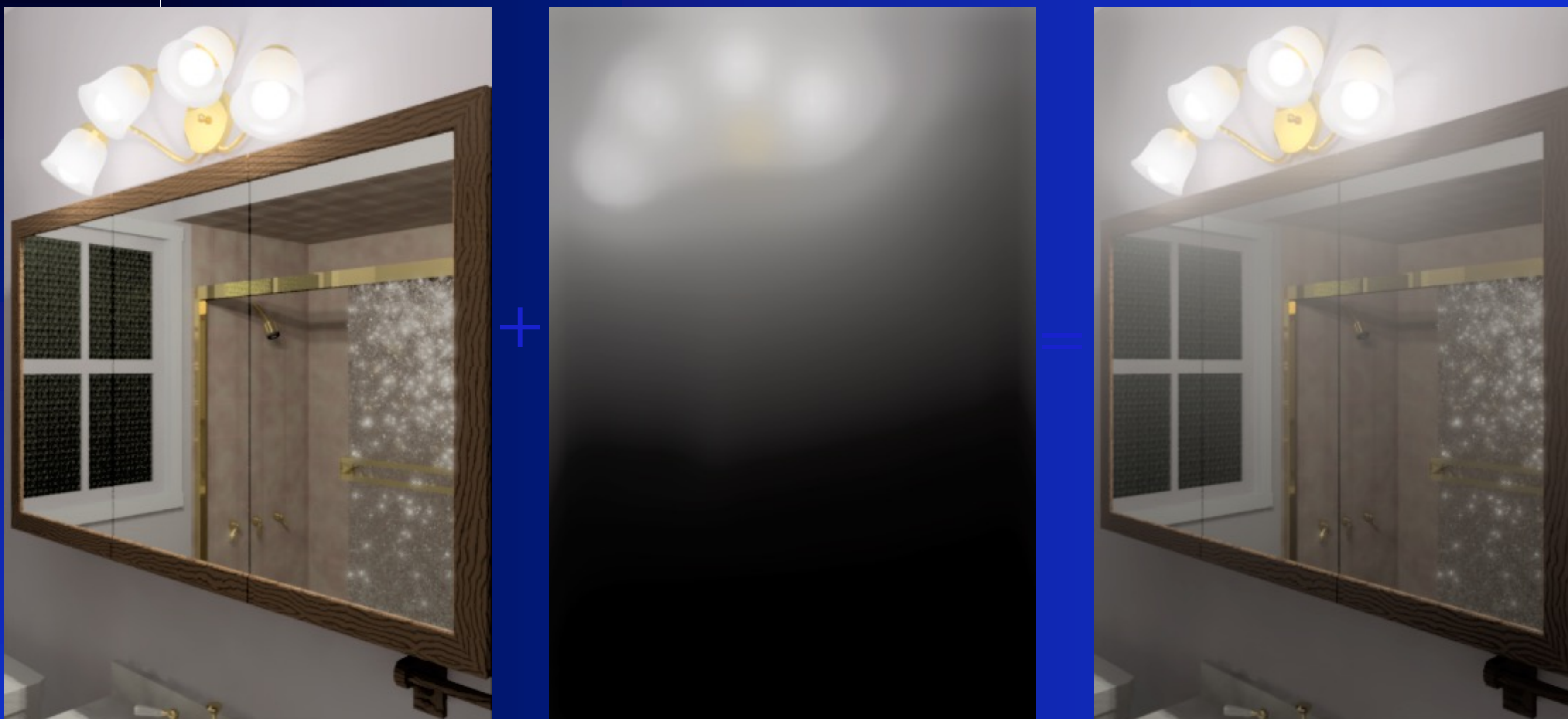






From [Larson et al, TVCG '97]

Veiling Glare Simulation

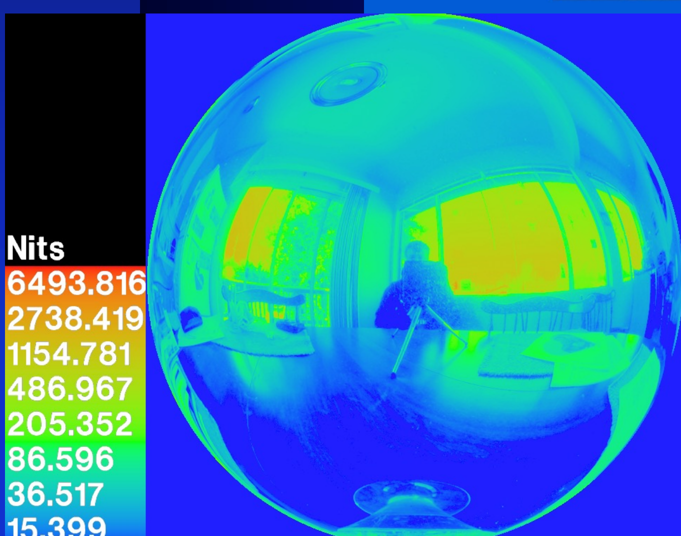


Similar to adding in lens flare, but corresponds to human perception

Other Tone Mapping Methods

- Retinex-based [Jobson et al. IEEE TIP July ‘97]
- Psychophysical [Pattanaik et al. Siggraph ‘98]
- Local Contrast [Ashikhmin, EGWR ‘02]
- Photographic [Reinhard et al. Siggraph ‘02]
- Bilateral Filtering [Durand & Dorsey, Siggraph ‘02]
- Gradient Domain [Fattal et al. Siggraph ‘02]
- Others…

IV. Image-based Lighting



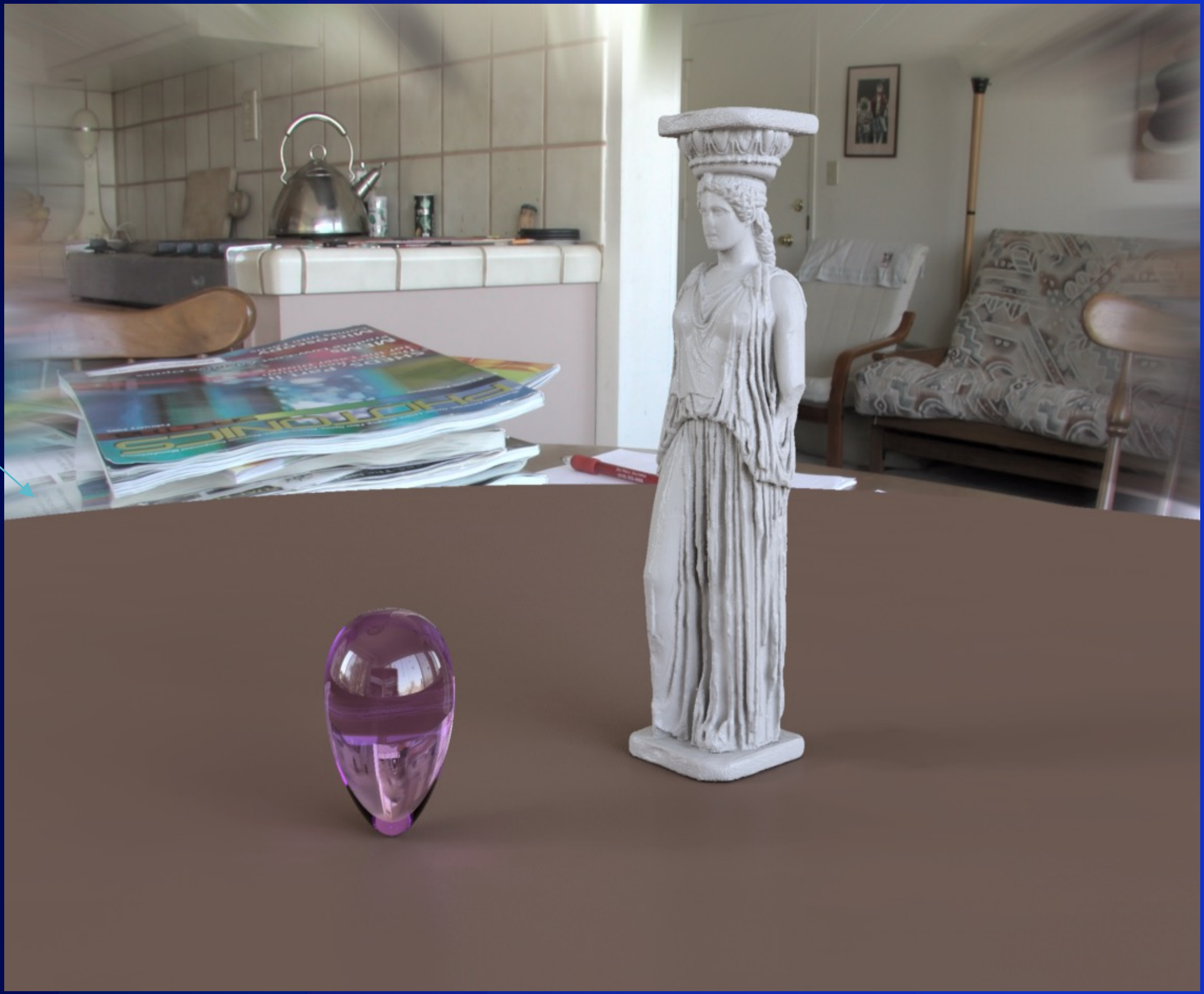
A sequence is captured and merged into an HDR image that we may use to illuminate synthetic objects

IBL: Rendering of Environment

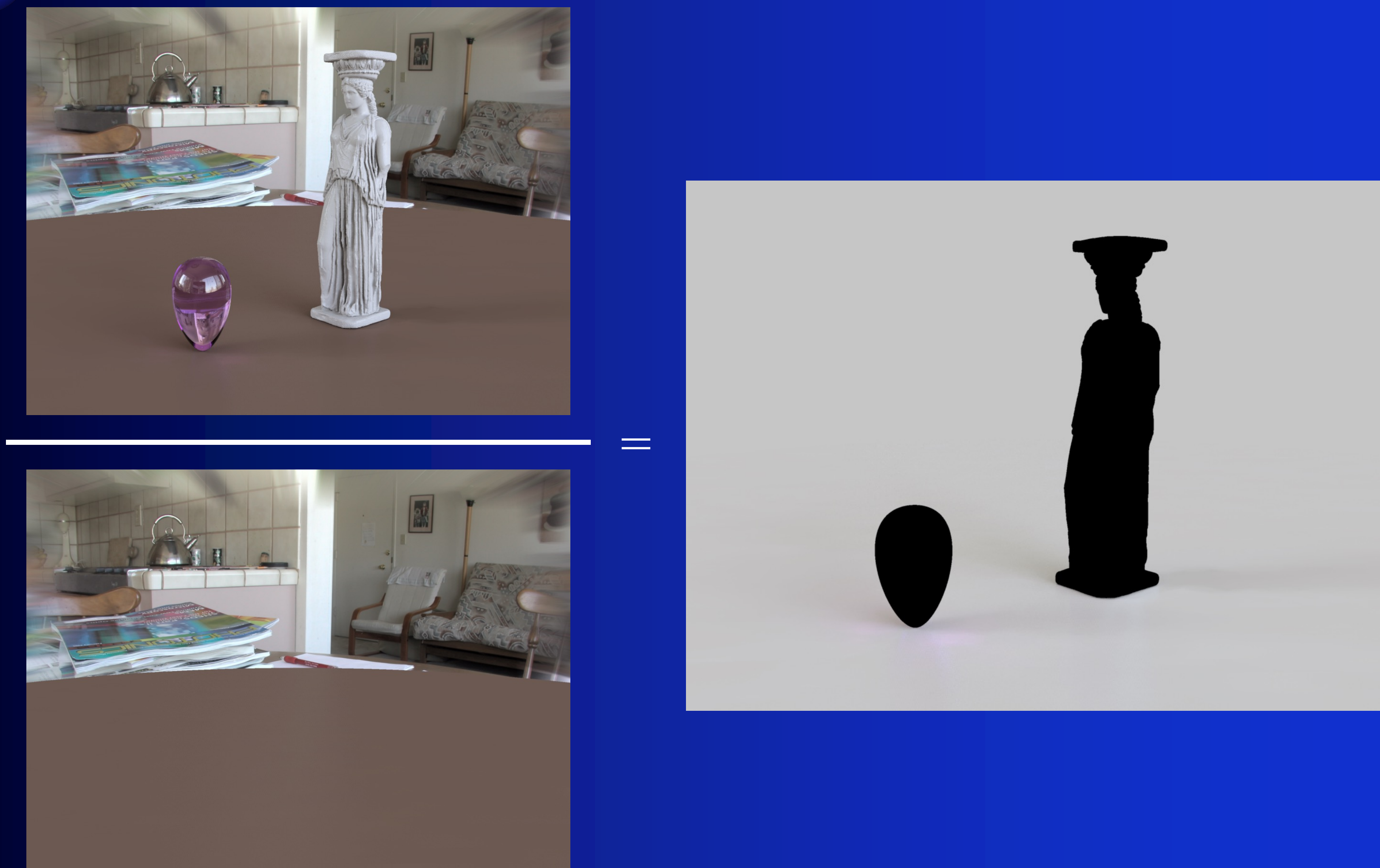
Information behind mirrored ball is missing, so replace it with HDR background plate

IBL: Render Synthetic Objects

Approximate local geometry



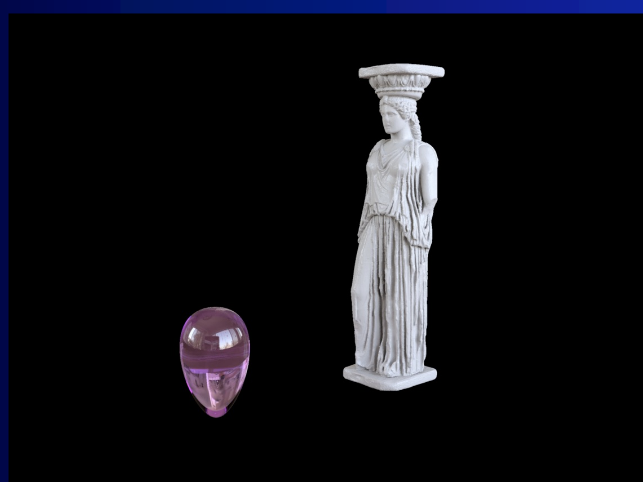
IBL: Compositing of Shadows



IBL: Compositing

*

+



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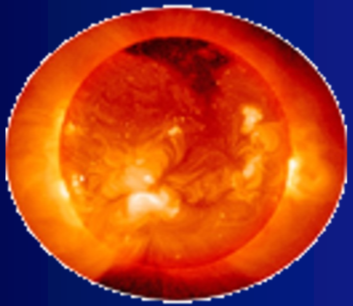
Debevec, P. 1998. "Rendering Synthetic Objects Into Real Scenes: Bridging Traditional and Image-based Graphics with Global Illumination and High Dynamic Range Photography." In *Proceedings of SIGGRAPH 98*, Computer Graphics Proceedings, Annual Conference Series, 189-198.

IBL: Final Composite Result

More generally, IBL may be used for daylight simulation

Photosphere Demo

- HDRI Browsing & Cataloging Application
  - Also builds HDRI's from bracketed exposures
- Available from www.anyhere.com
  - Mac OS X app., Linux command-line tool



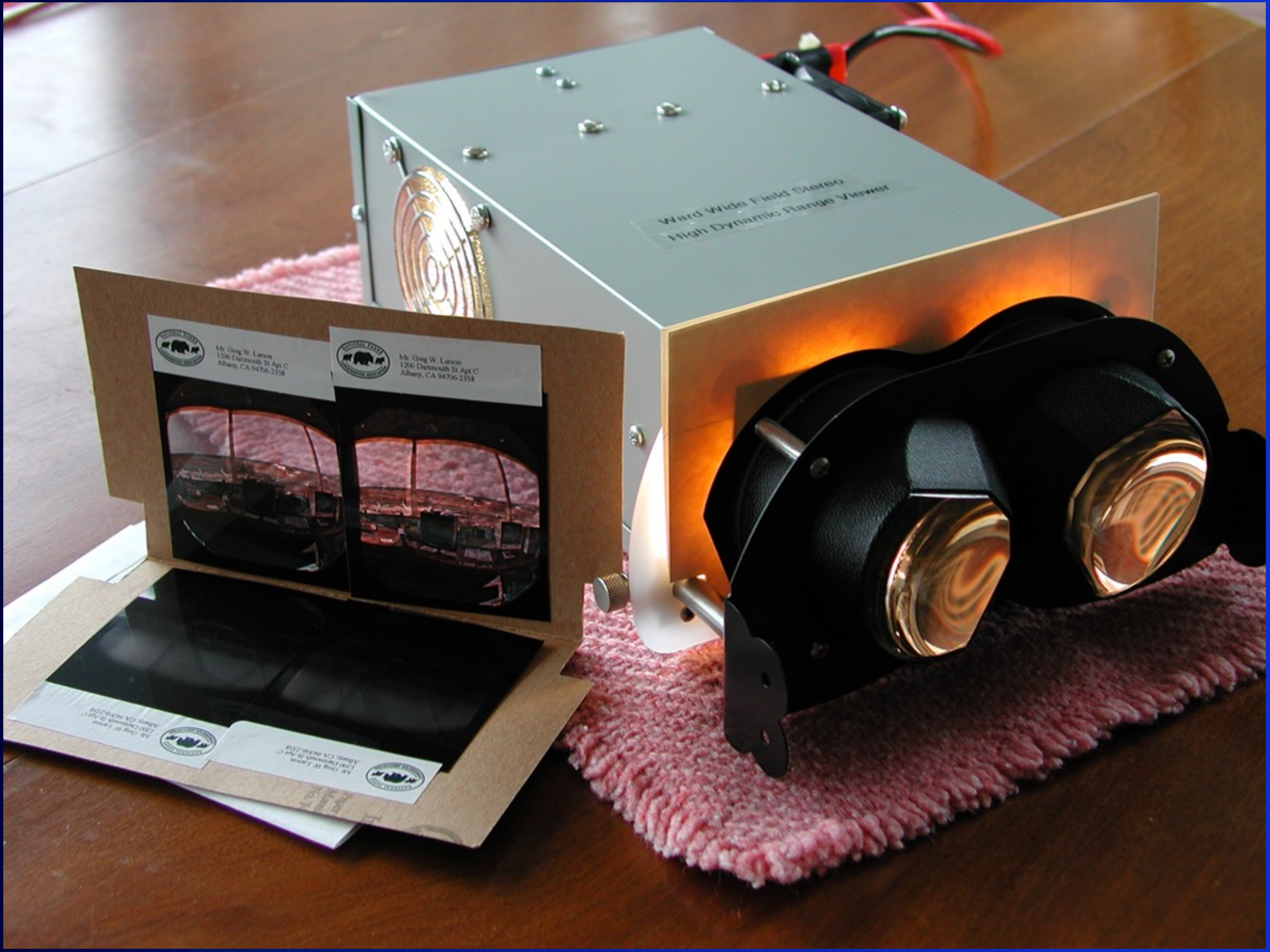
Launch Photosphere

Needs updating for latest macOS

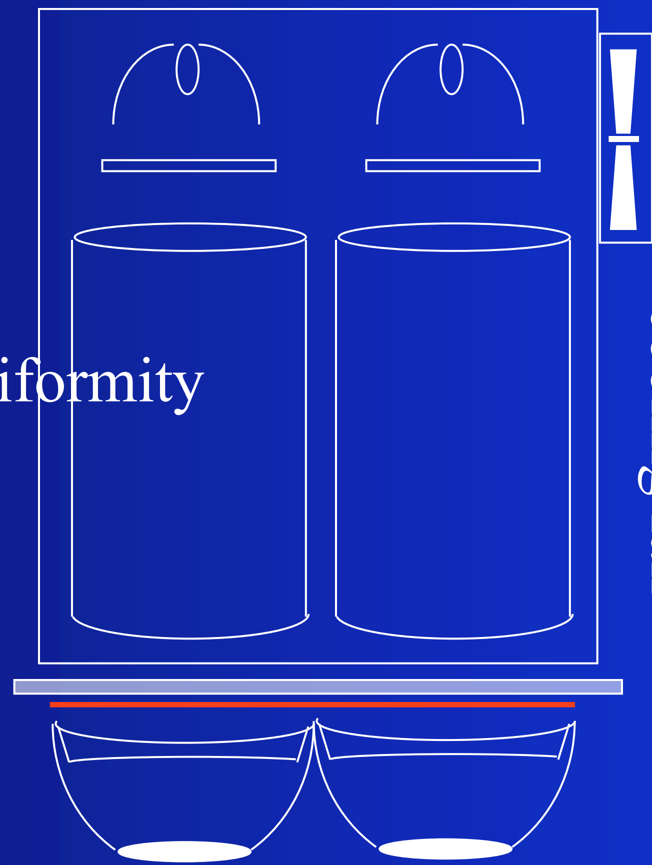
V. HDR Display

- Early 2000's
  - Canadian university group spun up BrightSide Technologies, which developed the first commercial HDR display
- Circa 2005
  - Dolby Labs bought BrightSide, developing the technology further and implementing Dolby Vision™ pipeline for movies / streaming
- Circa 2020
  - Apple implemented dual-modulation displays in HDR monitors, laptops, tablets

1991 HDR Still Viewer



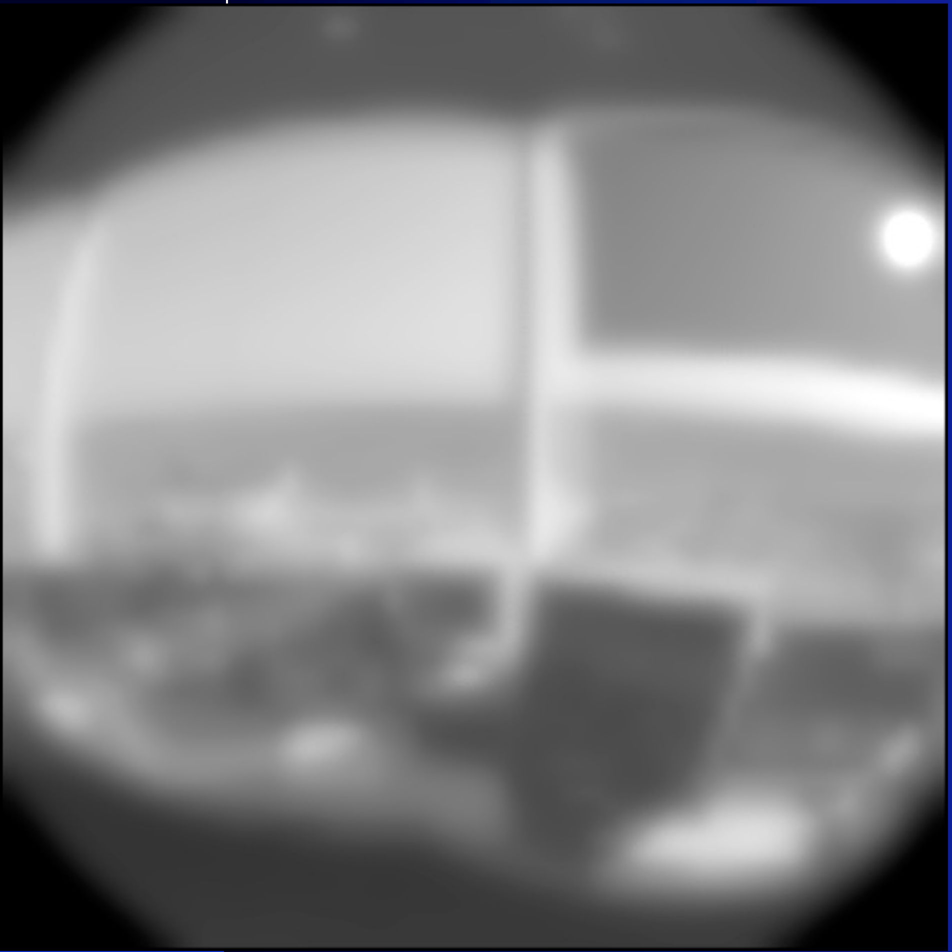
HDR Viewer Schematic



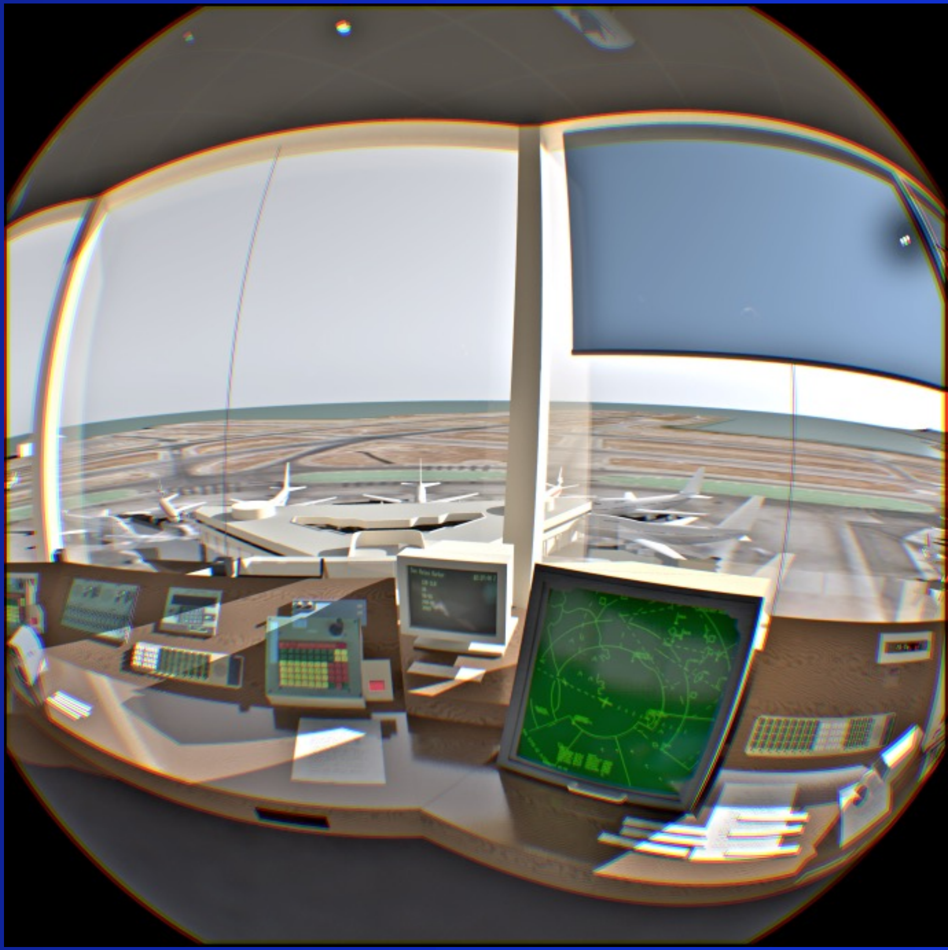
HDR Transparency Preparation

- Two transparency layers yield $1{:}10^4$ range
  - B&W “scaling” layer
  - Color “detail” layer
- Resolution difference avoids registration (alignment) problems
- 120º hemispherical fisheye perspective
- Correction for chromatic aberration

Example Image Layers



Scaling Layer

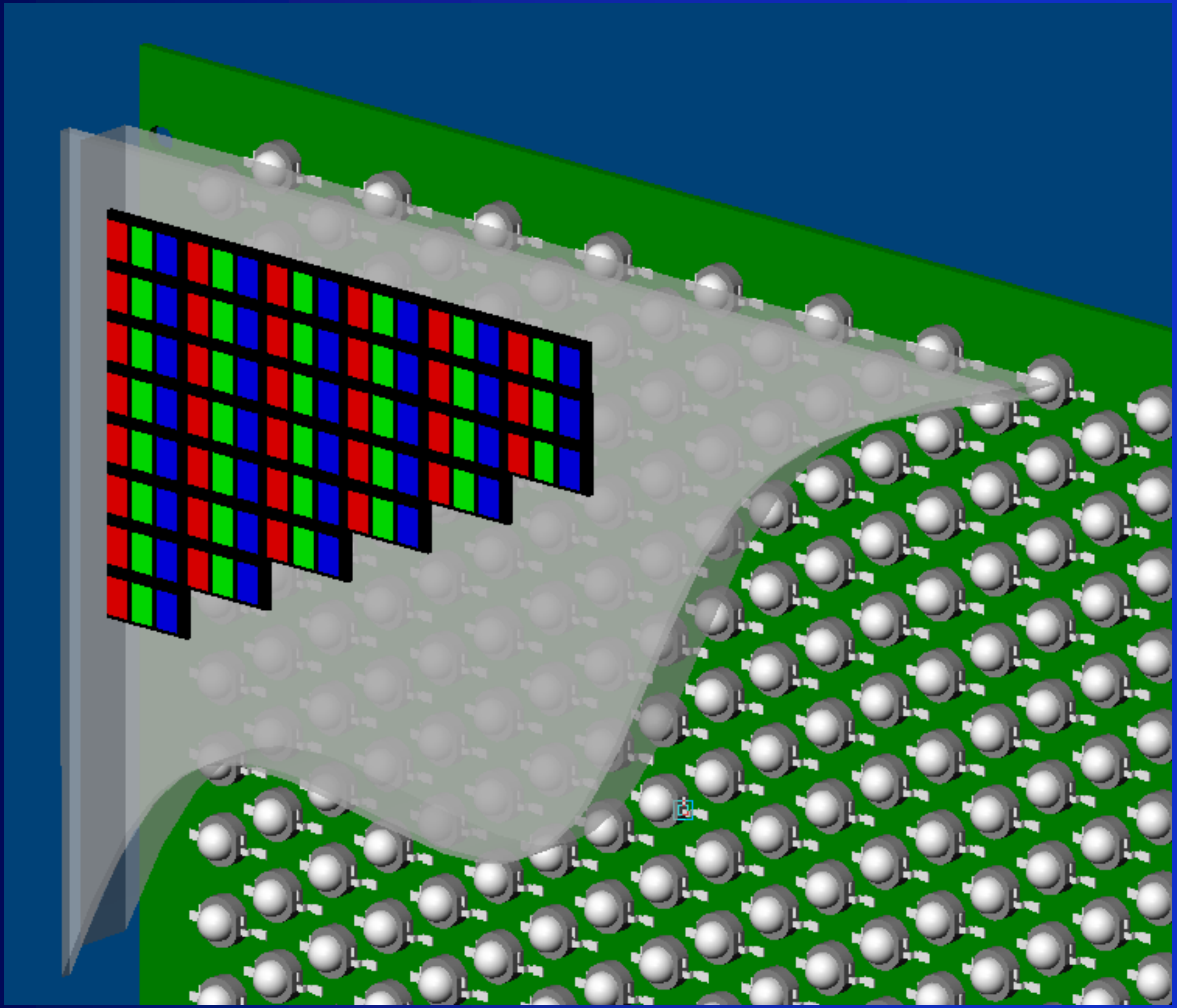


Detail Layer

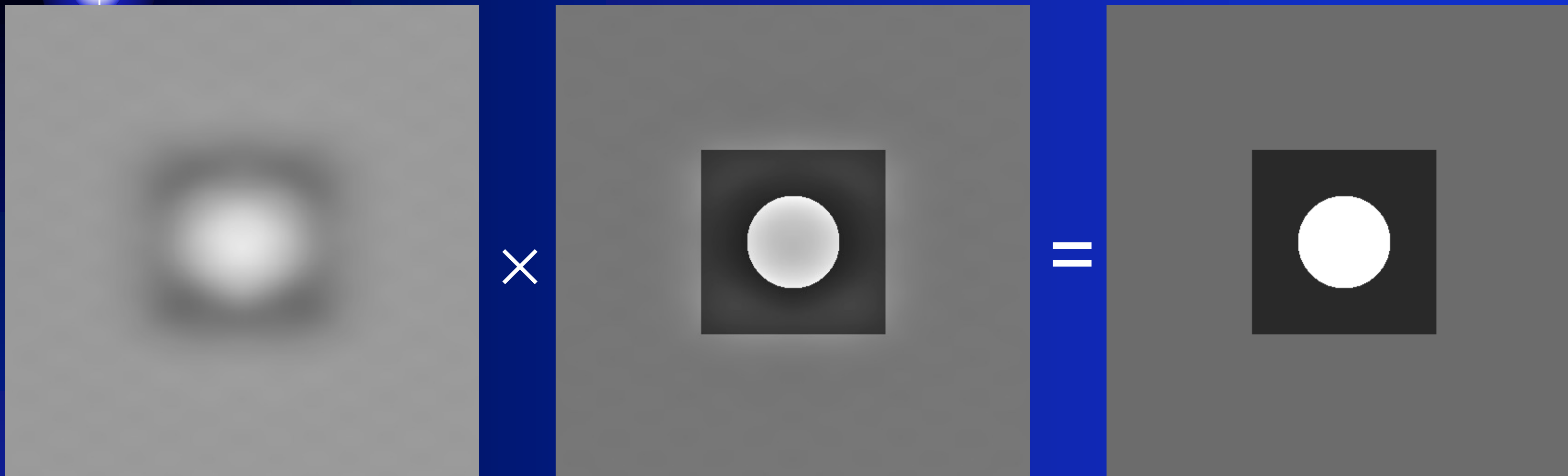
BrightSide/Dolby Monitor

- Use bright source + two 8-bit modulators
  - Transmission multiplies together
  - Over 10,000:1 dynamic range

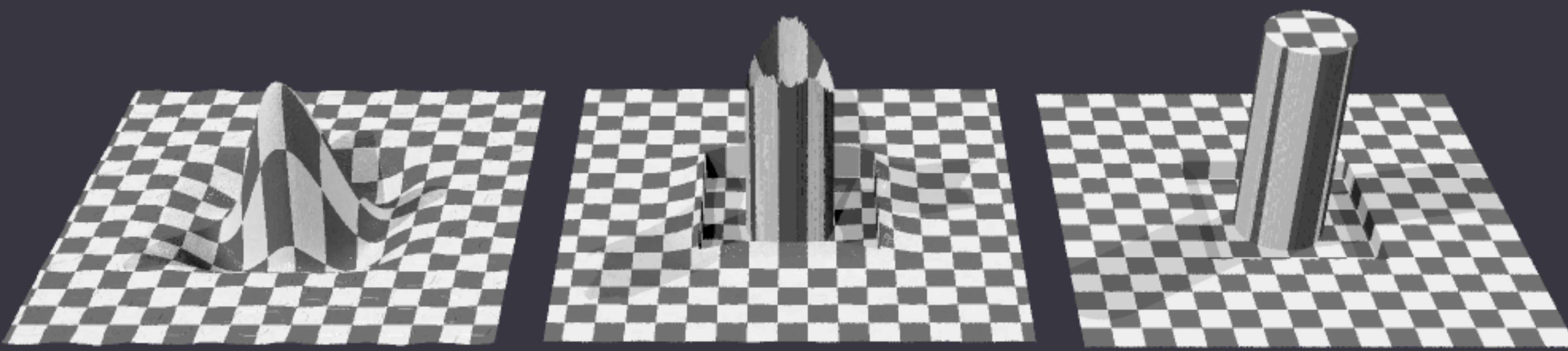
LED-Based Display



How It Works

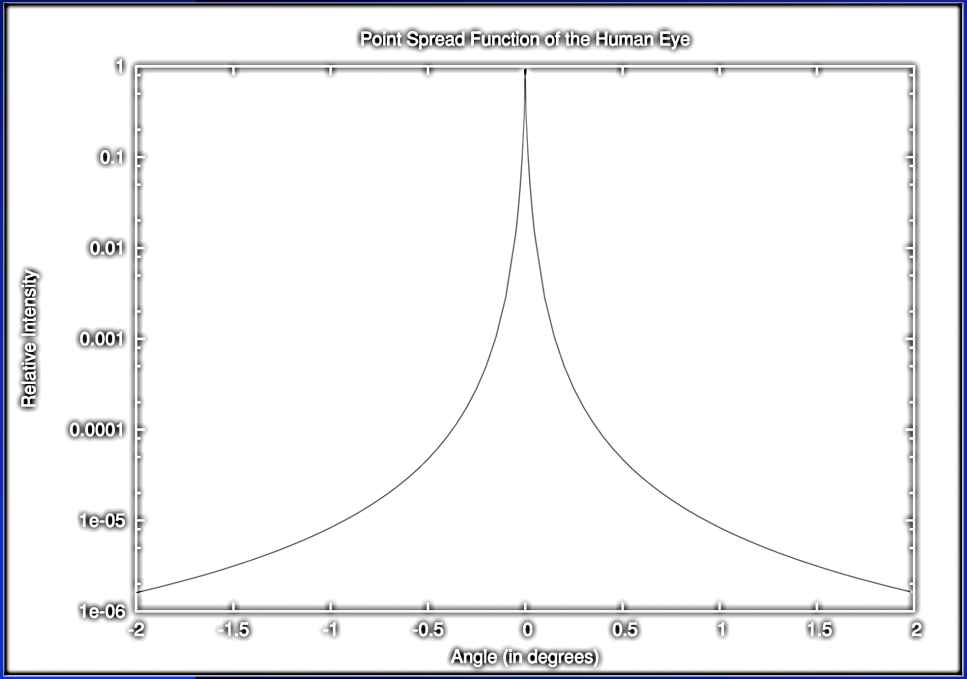


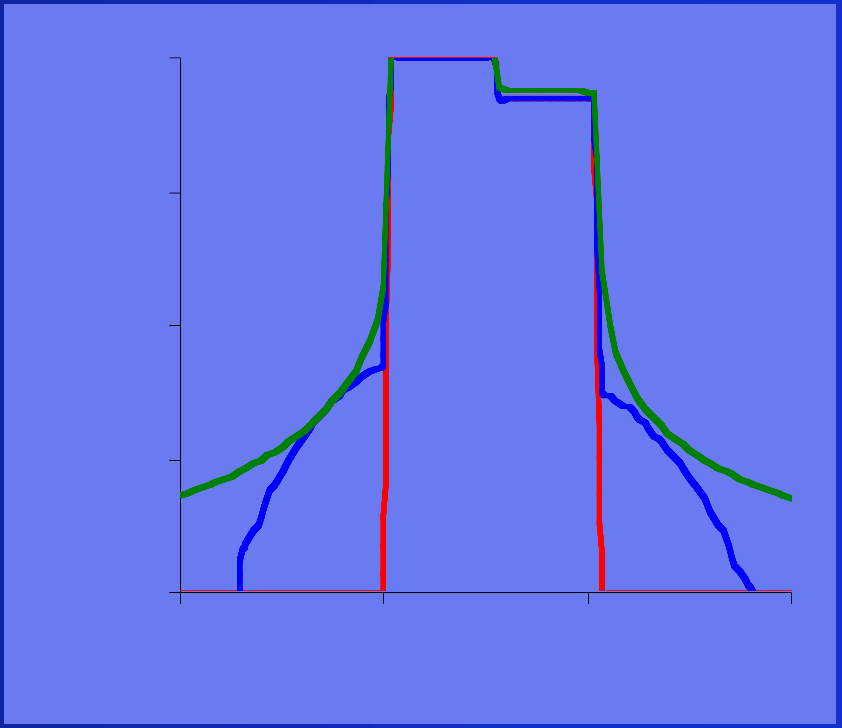
LED Backlight × LCD Screen = Combined Result



What If Edge Contrast Exceeds LCD Range?

Observers cannot tell when this happens because the eye has limited local contrast capacity due to scattering

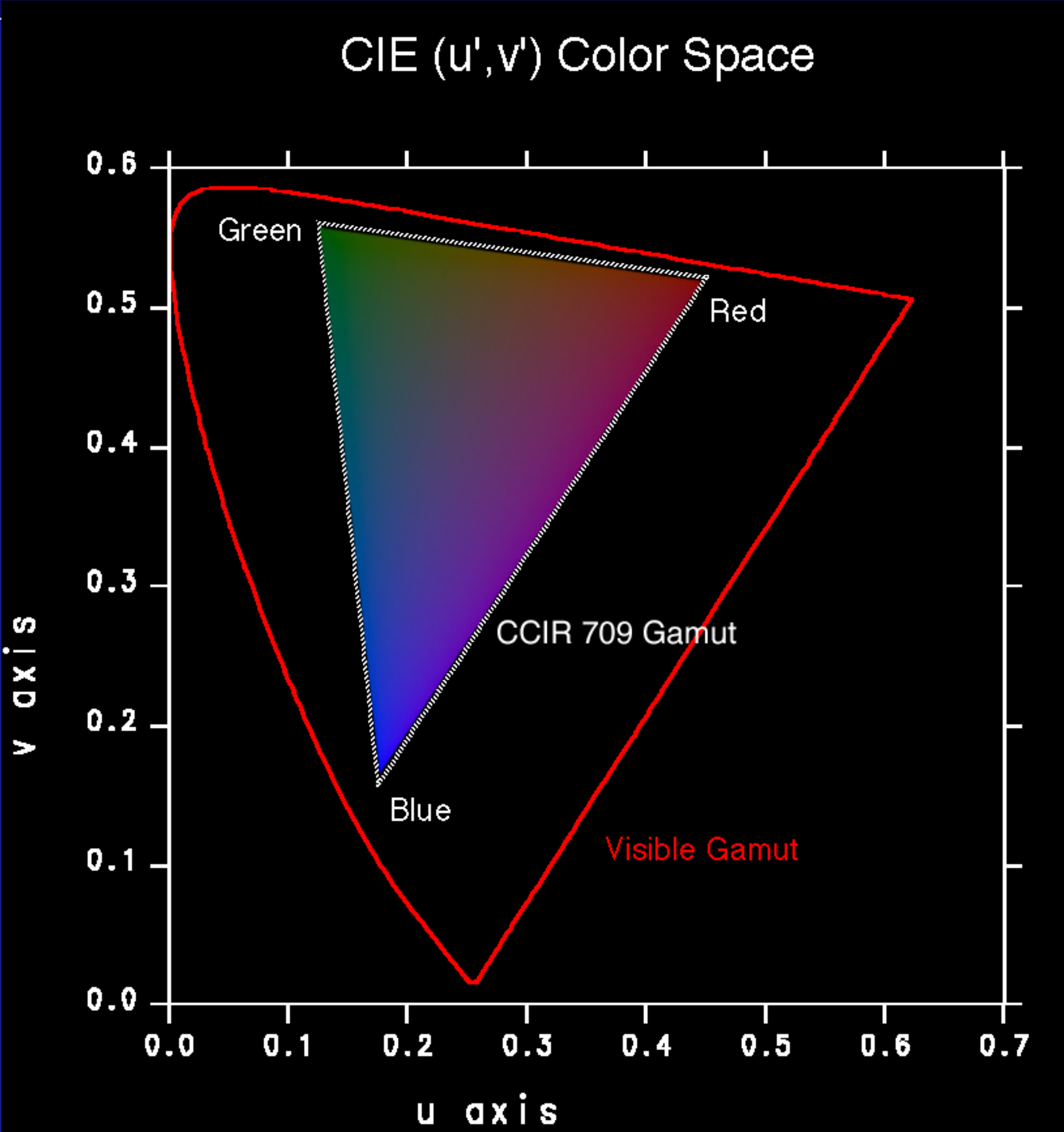




See Seetzen et al., SIGGRAPH 2004

CCIR-709 Color Space

- Human visible gamut is much larger than standard display’s
- Saturated blues, greens, and purples are lost in sRGB
- Many HDR image formats also cover a larger color gamut



Gamut Is a Volume!

- HDR can represent brighter colors
- This *delays* saturation near white
- Result is much larger color volume

← Comparison of standard LCD display to BrightSide HDR display

VI. New Developments

- Dolby Cinema projector uses dual-modulation with laser light sources
- Some OLED TVs in market are true HDR
- Inorganic LED displays are coming
  - HDR for Extended Reality (XR) headsets
- Open source release of *Pancine* C/C++ library for HDR image processing
  - originally developed for **Photospere**
  - includes tools such as **hdrgen** and **hdrcvt**

Additional Resources

www.openexr.com

www.debevec.org

www.anyhere.com

discourse.radiance-online.org/c/hdri

www.radiance-online.org