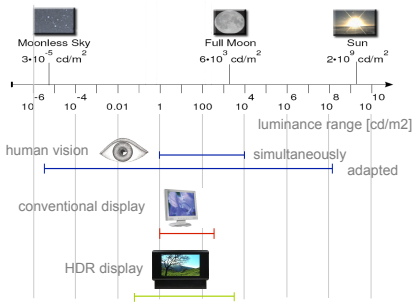
Displaying High Dynamic Range

Rafal Mantiuk
Bangor University, North Wales, UK

Outline

- Tone mapping
  - in painting
  - in photography
  - reflectance & illumination decomposition
  - visual models for tone mapping
  - display adaptive tone mapping
  - subjective aspect of tone mapping
- HDR display technologies
  - Spatially modulated backlight
  - OLED
  - Projecting light on prints

Tone mapping



Tone mapping

Reduce image contrast so that it can be shown on a particular display medium.

Tone mapping in painting

- Renaissance artist started to use non-uniform, highly varying illumination in painting
- Paint pigments can produce relative low contrast (50:1)
- Yet the painters could convey the impression of very high contrast

1620 Gerrit van Honthorst
The childhood of Christs

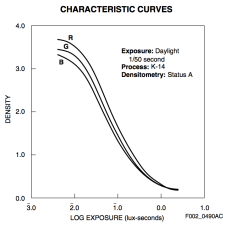
Tone mapping in photography

- The first photographic films could capture very low dynamic range
- In 1858 H.P. Robinson used 5 exposures to capture a high dynamic range scene
- The dynamic range of film negatives improved significantly over the years

1858 Robson *Fading away*
(combined 5 negatives)

Tone mapping in photography

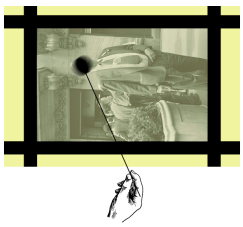
- Film response curve
  - Designed to boost contrast
  - Smooth round-off for high and low tones



KODACHROME 64 Film
From: http://www.kodak.com/global/en/consumer/products/pdf/e88.pdf

Tone mapping in photography

- Dodging and burning
  - Darken on brighten image parts by occluding photographic paper during exposure
  - Ansel Adams, *The print*, 1995
  - Photoshop tool



- In computer graphics
  - Reinhard et al., *Photographic tone reproduction for digital images*. SIGGRAPH 2002

Tone mapping – illumination & reflectance

Image = Illumination x Reflectance

- Visual system tries to discount illumination
  - Less important, can be distorted (compressed)
- Reflectance & illumination separation cannot be solved
  - But good approximations exist: bilateral filter, gradient domain processing, Retinex
- But illumination IS important
  - One of the greatest achievements of Renaissance artists was to convey illumination

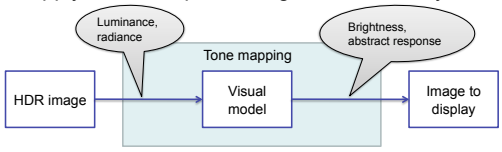
Example of Retinex from: McCann, HVEI, 2007

Tone mapping – illumination & reflectance

- Operators
  - Durand F, Dorsey J. Fast bilateral filtering for the display of high-dynamic-range images. SIGGRAPH'02
  - Tumblin J, Turk G. LCIS: A boundary hierarchy for detail-preserving contrast reduction. SIGGRAPH'03
  - Meylan L, Susstrunk S. High dynamic range image rendering with a Retinex-based adaptive filter. IEEE Transactions on Image Processing. 2006

Tone-mapping – forward visual models

- Apply the same processing as the visual system



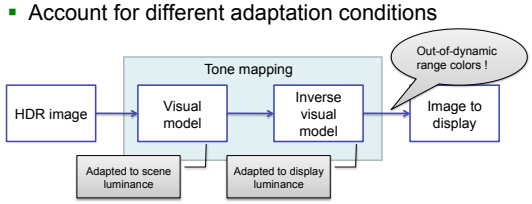
- The neural response of Ganglion cells has limited dynamic range
  - But, unlike camera, the eye can scan the scene
- Problem: The eye senses light (luminance) and not abstract response

Tone-mapping – forward visual models

- Operators
  - Land EH, McCann JJ. Lightness and Retinex theory. Journal of the Optical society of America, 1971
  - Ashikhmin M. A tone mapping algorithm for high contrast images. EGSR' 02
  - Spitzer H, Karasik Y, Einav S. Biological Gain control for High Dynamic Range Compression. In: Proc. SID Color Imaging Conference, 2003
  - Ledda P, Santos LP, Chalmers A. A local model of eye adaptation for high dynamic range images. In: Proc. of AFRIGRAPH, 2004
  - Reinhard E, Devlin K. Dynamic range reduction inspired by photoreceptor physiology. IEEE Trans. Vis. Comput. Graph. 2005
  - Krawczyk G, Myszkowski K, Seidel HP. Lightness perception in tone reproduction for high dynamic range images. Eurographic'05
  - Meylan L, Susstrunk S. High dynamic range image rendering with a Retinex-based adaptive filter. IEEE Transactions on Image Processing. 2006

Tone-mapping – forward and inverse visual models

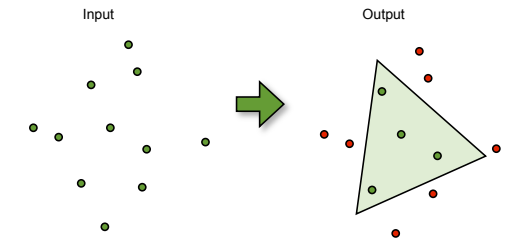
- Make images appear as in real-world
- Account for different adaptation conditions



Tone-mapping – forward & inverse visual models

- Operators
  - Stockham Jr T. Image processing in the context of a visual model. In: Proceedings of the IEEE.Vol 60.; 1972
  - Tumblin J, Rushmeier H. Tone reproduction for realistic images. IEEE Computer Graphics and Applications. 1993
  - Pattanaik et al. A multiscale model of adaptation and spatial vision for realistic image display. SIGGRAPH'98
  - Pattanaik SN, Tumblin J, Yee H, Greenberg DP. Time-dependent visual adaptation for fast realistic image display. SIGGRAPH'02
  - Kuang J, Johnson GM, Fairchild MD. iCAM06: A refined image appearance model for HDR image rendering. Journal of Visual Communication and Image Representation. 2007

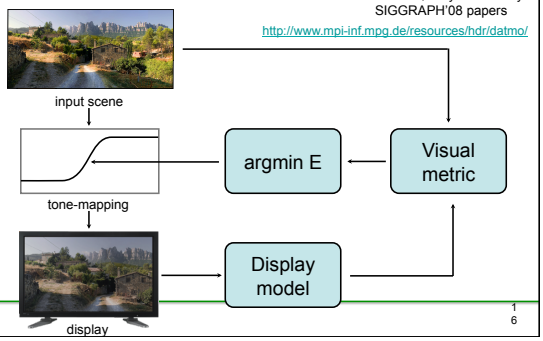
Mapping problem



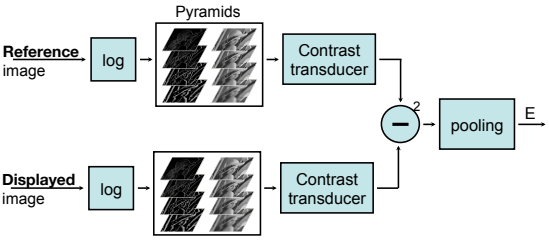
Goal: Least damage to the input values

Display-adaptive tone mapping

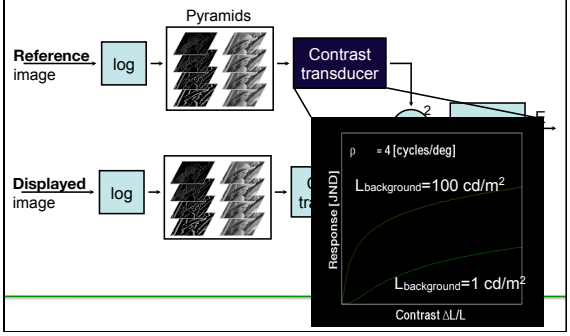
Mantiuk, Daly & Kerofsky SIGGRAPH'08 papers
http://www.mpi-inf.mpg.de/resources/hdr/datmo/



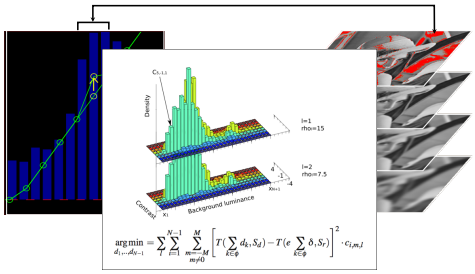
Visual metric



Visual metric



How to compute a visual metric fast?



Quadratic programming problem - 30-40 variables

DLP projector image: dark room

Non-adaptive TMO | Display adaptive TMO

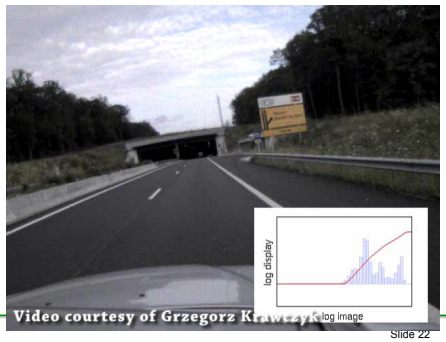
<1 lux

DLP projector image: bright room

Non-adaptive TMO | Display adaptive TMO

400 lux

Results: Video



Video courtesy of Grzegorz Krawczyk

Slide 22

Visual illusions for tone mapping

Trick visual system into seeing something more

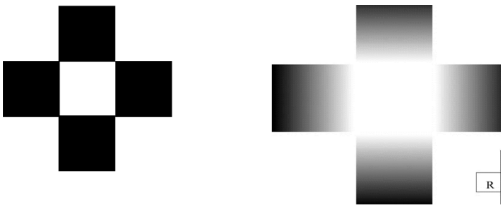
- Glare
- Cornsweet / countershading

Glare

Slide 24

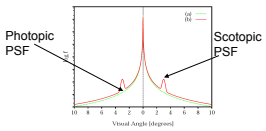
Apparent self-luminosity

- [Zavagno 1999] [Zavagno and Caputo 2001]
  - Measured self-luminous of glare.



Spencer et al.'s Model

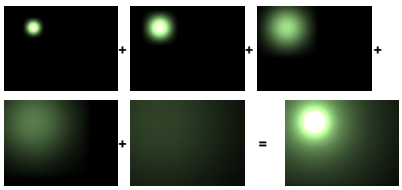
- *Physically-Based Glare Effects for Digital Images*, SIGGRAPH, 1995.



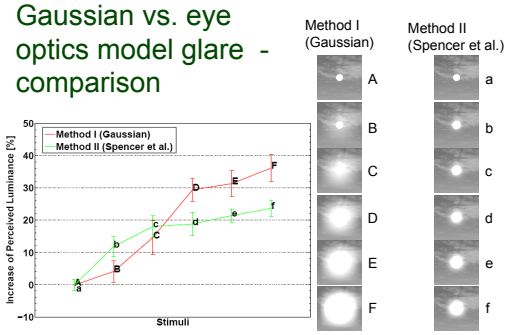
- Based on physical mechanisms of human eyes and physiological causes.

Glare in Games

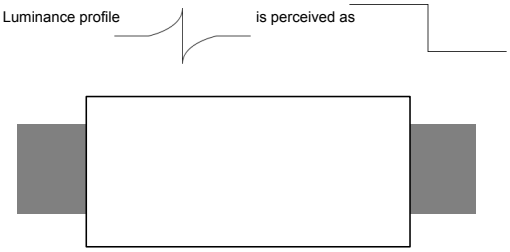
- Kawase, *Practical Implementation of High Dynamic Range Rendering*, GDC, 2004.



Gaussian vs. eye optics model glare - comparison



Cornsweet illusion



Adaptive counter-shading

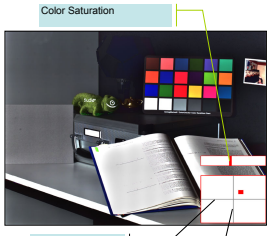
G. Krawczyk, K. Myszkowski, H.-P. Seidel. Contrast restoration by adaptive counter-shading. In: Proc. of Eurographics'07

Tone Mapping?

- HDR ?
- or something else?

Brightness & contrast preference on HDR display

- 25 Images
- 15 Subjects
- 18” HDR display

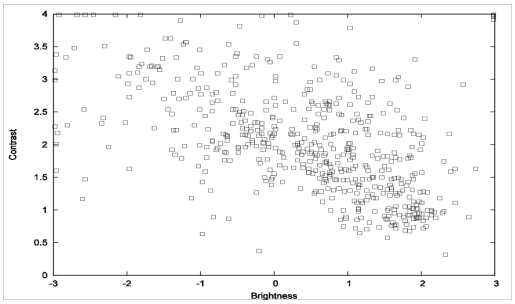


Yoshida, Mantiuk, Myszkowski, Seidel EUROGRAPHICS’06

http://www.mpi-inf.mpg.de/resources/hdr/subtmo.html

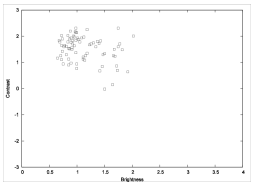
32

Experimental results - overall

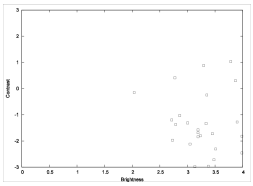


33

Experimental results



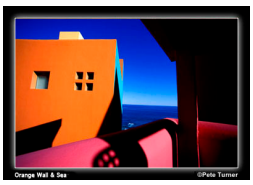
Subject #2



Subject #6

34

Tone editing - question of style



Photography by Pete Turner

Photography by Ansel Adams

35

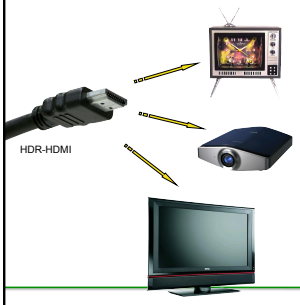
Photoshop post-processing

- relighting
- contrast enhancement
- attract attention to important scene regions

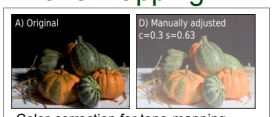
36

Tone mapping in a display

- Now:
  - tone mapping in cameras
- Future:
  - HDR file formats
  - Processing done in HDR, HDR send to a display
  - Tone-mapping in displays to adapt to display gamut and ambient light conditions



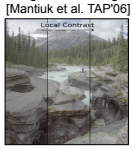
Tone mapping

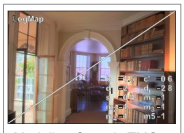


Color-correction for tone-mapping
[Mantiuk et al., Eurographics 2009]

Display Adaptive Tone Mapping
[Mantiuk et al., SIGGRAPH'08]

Contrast Domain Image Processing
[Mantiuk et al. TAP'06]

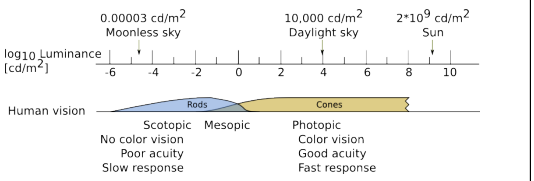




Modeling Generic TMO
[Mantiuk & Seidel, EUROGRAPHICS'08]

Enhancement of Bright Video Features
[Didyk, Mantiuk, Hein, Seidel, EGSR'08]

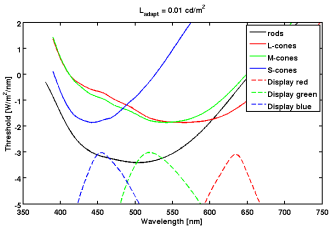
Perception across the luminance range



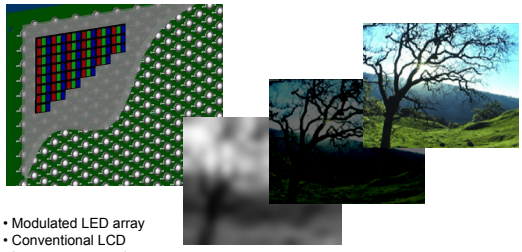
Display considerations for dark-viewing

[Rempel et al., APGV'09]

- Long wavelengths are visible by L-cones
  - but not rods
- Less glare, less fatigue
- Applications
  - Mobile phones
  - E-book readers



HDR Display



- Modulated LED array
- Conventional LCD
- Image compensation

Low resolution LED Array x High resolution Colour Image = High Dynamic Range Display

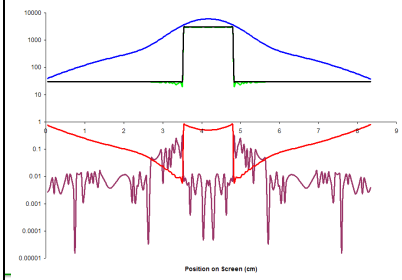
HDR Display

- Idea: Replace constant backlight of LCD panels w/ array of LEDs
  - Very few (about 1000) LEDs sufficient
  - Every LED intensity can be set individually
  - Very flat form factor (fits in standard LCD housing)

HDR Display

- Results:
  - Intensity: up to 8,500 cd/m2, contrast >150,000:1
- Issue:
  - LEDs larger than LCD pixels
  - This limits maximum local contrast
    - Is this a problem?

Veiling Luminance



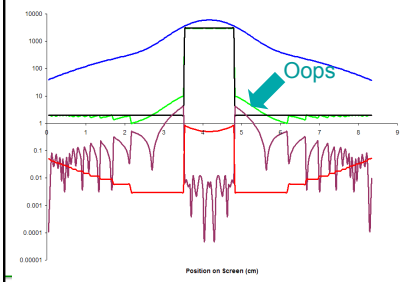
Receive Image

Drive LED

Divide Image by LED light field to obtain LCD values

Output Luminance is the product of LED light field and LCD transmission (modest error)

Veiling Luminance



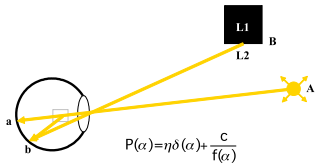
Receive Image

Drive LED

Divide Image by LED light field to obtain LCD values

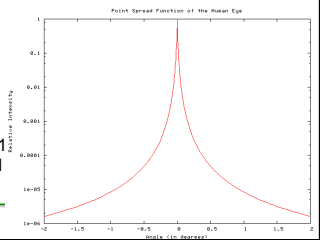
Output Luminance is the product of LED light field and LCD transmission (Problematic error)

Veiling Luminance



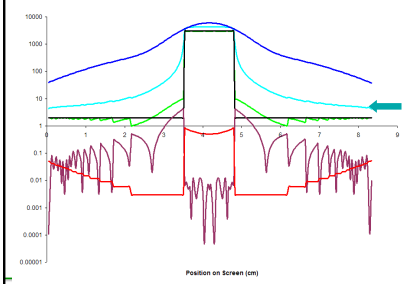
Veiling Luminance

- Maximum perceivable contrast
  - Globally very high (5-6 orders of magnitude)
    - That is why we create these displays!
  - Locally pretty low: 150:1
    - Point-spread function of human eye
    - Consequence: High contrast edges above 150:1 are not seen at full contrast



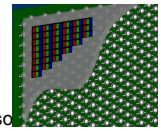
Veiling Glare (Camera)

Veiling Luminance

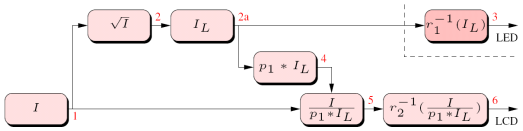


Software Issues

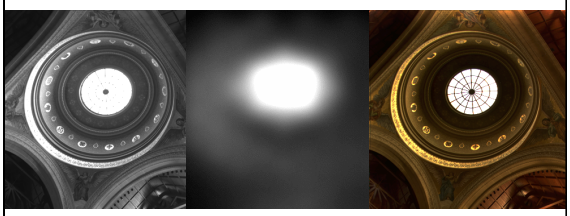
- Rendering:
  - Have to split floating point image into
    - LED array contribution
    - LCD panel contribution
  - Have to compensate for the lower reso LED array
  - Many ways to do this, since LED and LCD values are not independent!



Rendering Algorithm

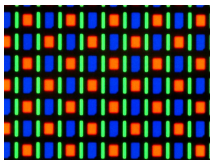


Rendering Algorithm

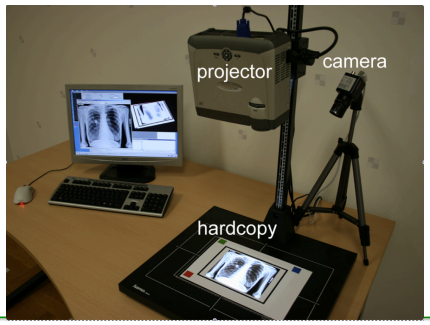


Active matrix OLED

- Commonly used in mobile phones (AMOLED)
- Very good contrast
  - But the screen more affected by glare than LCD
- But limited brightness
  - The brighter is OLED, the shorter is its live-span



Superimposing HDR images



Summary

- Tone mapping
  - in painting
  - in photography
  - reflectance & illumination decomposition
  - visual models for tone mapping
  - display adaptive tone mapping
  - subjective aspect of tone mapping
- HDR display technologies
  - Spatially modulated backlight
  - OLED
  - Projecting light on prints