Perceptual Effects in Real-time Tone Mapping

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High Dynamic Range (HDR)

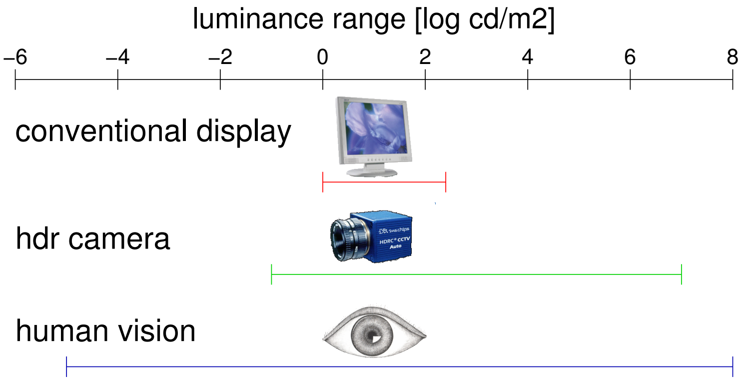


Figure: Various dynamic ranges

Sample HDR Frame

Figure: Sample frame from the HDR movie player [Mantiuk et al. 2004]

[Mantiuk et al. 2004] *Perception-motivated high dynamic range video encoding*, Proc. of SIGGRAPH 2004

Display of HDR content (1)

Figure: Gamma corrected mapping to the displayable range

Display of HDR content (2)

Figure: Adaptive logarithmic mapping (global operator)

[Drago et al. 2003] *Adaptive Logarithmic Mapping For Displaying High Contrast Scenes*, Proc. of Eurographics 2003

Display of HDR content (3)

Figure: Photographic tone reproduction (local operator)

[Reinhard et al. 2002] *Photographic Tone Reproduction for Digital Images*, Proc. of Siggraph 2002

Perceptual Effects: Night Vision

Figure: Lack of color vision and loss of visual acuity in night scenes, comparing to daylight vision.

Perceptual Effects: Veiling Luminance (Glare)

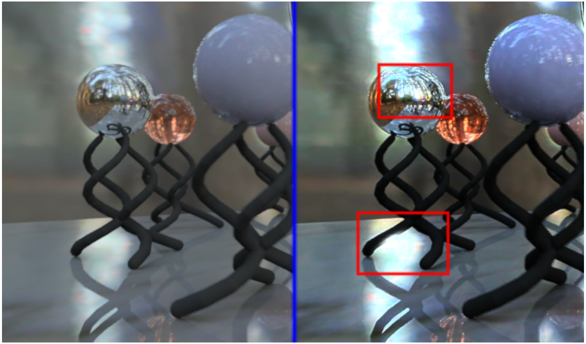


Figure: Sample frame from the RNL demo [1] illustrating the veiling luminance effect (glare).

[1] Debevec et al. *Rendering with Natural Light Demo*, www.debevec.org

Statement

Objectives for the display of HDR content:

- contrast reduction
- good local details visibility
- perceptual effects to convey realistic impression
  - scotopic vision (no color perception)
  - visual acuity
  - veiling luminance

Assumption: HDR data calibrated to $\frac{cd}{m^2}$ units.

Previous Work

Majority of tone mapping algorithms neglect perceptual effects.

Perceptual effects addressed solely:

- night vision [Ferwerda02]
- veiling luminance [Spencer95]

Perceptual effects in offline TM [Ferwerda96, Ward97, Durand00],
→ but each effect approached separately.
Effects applied globally to increase performance.

GPU implementation of TM without perceptual effects:

- global tone mapping [Drago03] (real-time)
- local tone mapping [Goodnight03] (interactive)

Contribution

Real-time implementation
of local tone mapping with perceptual effects.

Contribution:

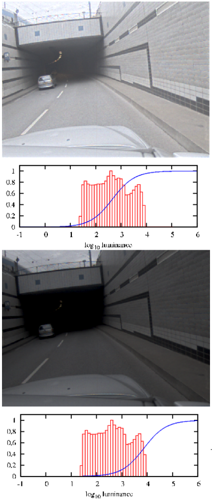
- real-time tone mapping with perceptual effects
- efficient way to combine these effects
- effects applied in correct domain: local/global
- tone mapping embedded in a stand-alone module

Methods Overview

Following methods contribute to the final result:

- tone mapping
  - global mapping curve
  - local detail preservation
  - temporal adaptation
- night vision
  - scotopic vision (lack of color discrimination)
  - loss of visual acuity
- veiling luminance (glare)

Global Tone Mapping



Tone mapping by [Reinhard et al. 2002]

- relate luminance to middle gray

$$Y_r = \frac{\alpha \cdot Y}{\bar{Y}}$$

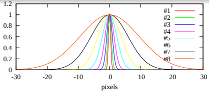
- global mapping function

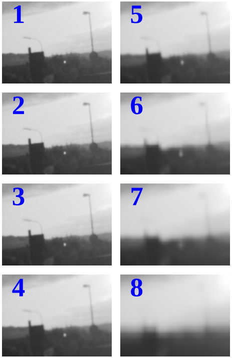
$$L = \frac{Y_r}{1 + Y_r}$$

α key value, Y HDR luminance,
$\bar{Y}$ adapting luminance, Y_r relative luminance,
L displayable pixel intensities

[Reinhard et al. 2002] *Photographic Tone Reproduction for Digital Images*, Proc. of Siggraph 2002

Local Tone Mapping





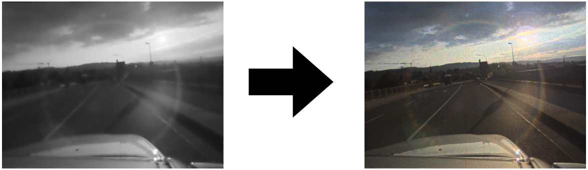
Gaussian Pyramid

Preserve local details using

spatially variant adaptation map V.

$$L(x,y) = \frac{Y_r(x,y)}{1 + V(x,y)}$$

Adaptation map used for local tone mapping:



[Reinhard et al. 2002] *Photographic Tone Reproduction for Digital Images*, Proc. of Siggraph 2002

Temporal Luminance Adaptation

Temporal adaptation compensates changes in illumination.

Simulated by smoothing
adapting luminance over time.

$$\bar{Y}_a^{new} = \bar{Y}_a + (\bar{Y} - \bar{Y}_a) \cdot (1 - e^{-\frac{T}{\tau}})$$

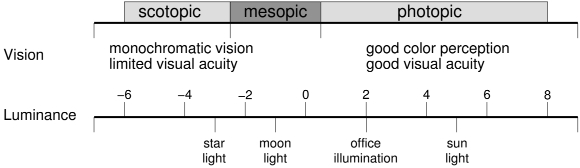
$$\tau_{rods} = 0.4\text{sec} \quad \tau_{cones} = 0.1\text{sec}$$

$\bar{Y}$ actual adapting luminance,
$\bar{Y}_a$ filtered $\bar{Y}$ according to the adaptation processes,
τ speed of the adaptation,
T discrete time step between frames

[Durand and Dorsey 2002] *Interactive Tone Mapping*,
Rendering Techniques 2000: 11th Eurographics Workshop on Rendering

Night Vision: Lack of Color Perception

Human vision operates in three distinct adaptation conditions:



Night Vision: Visual Acuity

Perception of spatial details is
limited with decreasing illumination level.

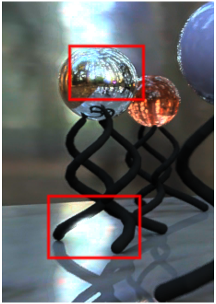
The highest resolvable spatial frequency for adapting luminance:

$$RF(Y) = 17.25 \cdot \arctan(1.4 \log_{10} Y + 0.35) + 25.72$$

Details removed by the convolution with the Gaussian kernel.

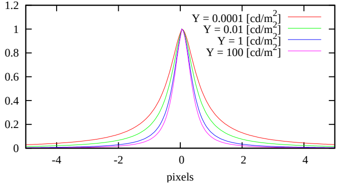
Veiling Luminance (Glare)

Scattering of light in the optical system of the eye causes the decrease of contrast in the vicinity of relatively strong light sources.



$$OTF(\rho, d(\bar{Y})) = \exp\left(-\frac{\rho}{20.9 - 2.1 \cdot d}^{1.3 - 0.07 \cdot d}\right)$$

ρ spatial frequency, d pupil aperture



[Deeley at al. 1991] *A simple parametric model of the human ocular modulation transfer function*, Ophthalmology and Physiological Optics 1991

Implementation Requirements

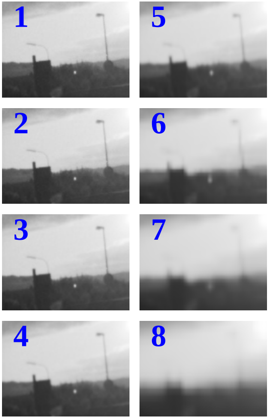
Real-time implementation
of local tone mapping with perceptual effects.

Requirements:

- efficient implementation of expensive spatial processing
- prevent redundancy of computations
  $\longrightarrow$ reuse spatially processed data
- a stand-alone rendering module in GPU

Similarities in Spatial Processing

Gaussian pyramid from local tone mapping can be reused to compute visual acuity and estimate veiling luminance.



Gaussian Pyramid

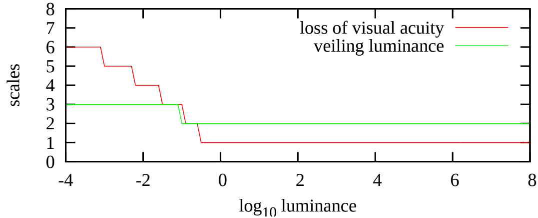


Figure: Which scale from local tone mapping corresponds to which convolution for visual acuity and veiling luminance (glare).

Visual Acuity in Monochromatic Vision

Lack of visual acuity is noticable in scotopic vision
$\longrightarrow$ spatial processing of luminance is sufficient.

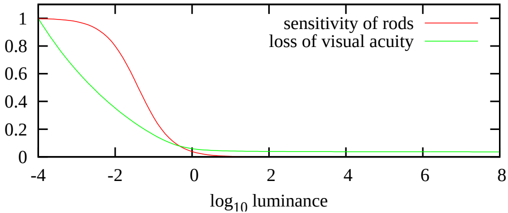
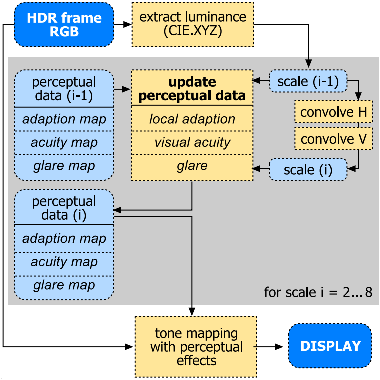


Figure: Correlation between scotopic sensitivity and visual acuity

Framework Design



Rendering passes:

1. extract luminance
2. calculate perceptual data (Gaussian Pyramid)
   - render new scale
     2 pass convolution
   - update adaptation map
     by comparing scales
   - update visual acuity
     choosing right scale per pixel
   - update glare map
     choosing right scale per image
3. tone mapping
   with perceptual effects

Approximate Convolution

Convolving with large kernels:

down-sample $\longrightarrow$ convolve H $\longrightarrow$ convolve V $\longrightarrow$ up-sample

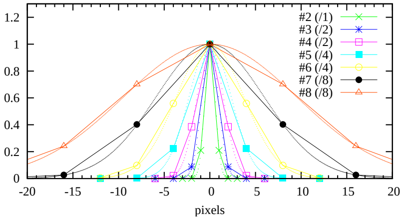


Figure: Effective Gaussian kernel due to down-sampling.

Final Tone Mapping Equations

Tone mapping equation:

$$L(x,y) = \frac{Y_{acuity}(x,y) + Y_{glare}(x,y)}{1 + V(x,y)}$$

Recovering color information:

$$\begin{bmatrix} R_L \\ G_L \\ B_L \end{bmatrix} = \underbrace{\frac{1}{Y} \cdot \begin{bmatrix} R \\ G \\ B \end{bmatrix} \cdot L \cdot (1 - \sigma(Y))}_{\text{photopic}} + \underbrace{\begin{bmatrix} 1.05 \\ 0.97 \\ 1.27 \end{bmatrix} \cdot L \cdot \sigma(Y)}_{\text{scotopic}}$$

$\{R, G, B\}$ original HDR values, $\{R_L, G_L, B_L\}$ displayable values
σ rods sensitivity, V adaptation map,
Y HDR luminance, L tone mapped luminance

Performance

	320x240	640x480	1024x768
8 scales	8ms (58fps)	25ms (27fps)	80ms (10fps)
6 scales	7ms (62fps)	21ms (30fps)	66ms (12fps)
4 scales	6ms (62fps)	16ms (30fps)	51ms (14fps)

Table: Time-slice required for the display of an HDR frame using perceptual tone mapping.

Processor: Pentium4 2GHz
System: CygWIN under WindowsXP
Graphics card: NVIDIA GeForce 6800GT
Implementation: C++ / OpenGL / Cg

Demo

Real-time HDR Video playback with perceptual effects

Bottlenecks and Trade-offs

Performance issues:

- context switching due to multi-pass rendering
- large or high resolution displays may require more scales

Constraints:

- not every tone mapping method can be implemented in framework
- limited choice of PSF models for veiling luminance

Conclusions

Increasing application of HDR images and video raises the issue of displaying them on typical display devices

Summary:

- real-time local tone mapping with perceptual effects
- efficient way to combine these effects
- effects applied in correct domain: local/global
- a plug-able stand-alone framework
- implementation in graphics hardware

Thank You

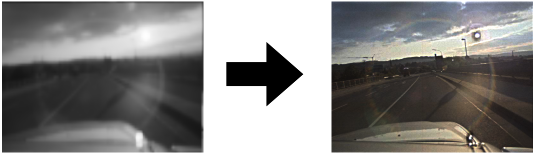
Local Tone Mapping

Global tone mapping function may lead to the loss of fine details.

Local details can be preserved using spatially variant adaptation map V.

$$L(x,y) = \frac{Y_r(x,y)}{1 + V(x,y)}$$

Local adaptation map could be a low-pass filtered HDR image, but it leads to halo artifacts.



[Reinhard et al. 2002] *Photographic Tone Reproduction for Digital Images*, Proc. of Siggraph 2002

Local Adaptation Map

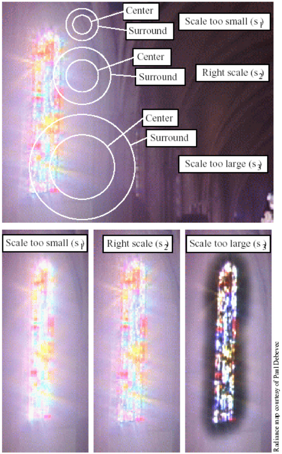


Figure from paper [Reinhard et al. 2002]

Finding appropriate adaptation area

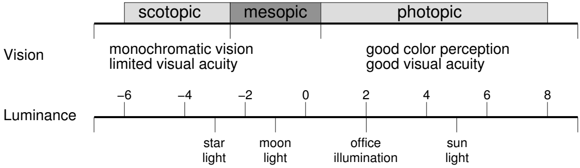
1. build a Gaussian Pyramid
2. find the largest scale s, which does not cause high variation of local luminance V between scales

$$|V_s(x,y) - V_{s-1}(x,y)| < \epsilon$$

[Reinhard et al. 2002] *Photographic Tone Reproduction for Digital Images*, Proc. of Siggraph 2002

Scotopic Vision

Human vision operates in three distinct adaptation conditions:



Sensitivity of rods σ can be modelled after [Hunt 1995]:

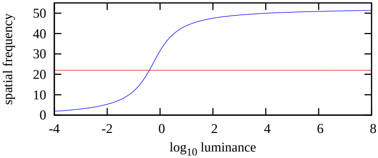
$$\sigma(Y) = \frac{0.04}{0.04 + Y}$$

Visual Acuity (1)

Perception of spatial details in human vision becomes limited with decreasing illumination level.

The highest resolvable spatial frequency for given adapting luminance:

$$RF(Y) = 17.25 \cdot \arctan(1.4 \log_{10} Y + 0.35) + 25.72$$



On typical displays simulation possible for luminance below $0.5 \frac{cd}{m^2}$

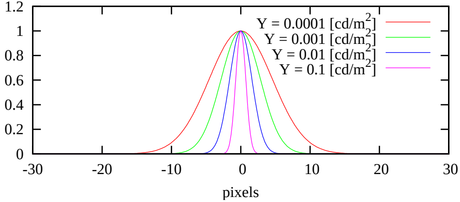
[Shaler 1937] *The Relation Between Visual Acuity and Illumination*, Journal of General Psychology 1937
[Ward at al. 1997] *A Visibility Matching Tone Reproduction Operator for High Dynamic Range Scenes*, IEEE TVCG 1997

Visual Acuity (2)

Details can be removed from an image by the convolution with the Gaussian kernel.

Effect dependent on local illumination.

$$s_{acuity}(Y) = \frac{width}{fov} \cdot \frac{1}{1.86 \cdot RF(Y)} \qquad \frac{width}{fov} \approx 45$$



width frame width in pixels,

fov horizontal field of view in visual degrees

[Ward at al. 1997] *A Visibility Matching Tone Reproduction Operator for High Dynamic Range Scenes*, IEEE TVCG 1997