Realistic Image Synthesis

- HDR Imaging & Tone Mapping -

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Overview

- **LDR vs. HDR imaging**
- **HDR image capturing**
- **Tone mapping intents**
- **Display model**
- **Tone mapping**
  - Global TMO
  - Local TMOs: photographic, bilateral, gradient domain,
  - Perceptual effects in TMO
- **Apparent contrast enhancement**
  - Unsharp masking, Cornsweet illusion

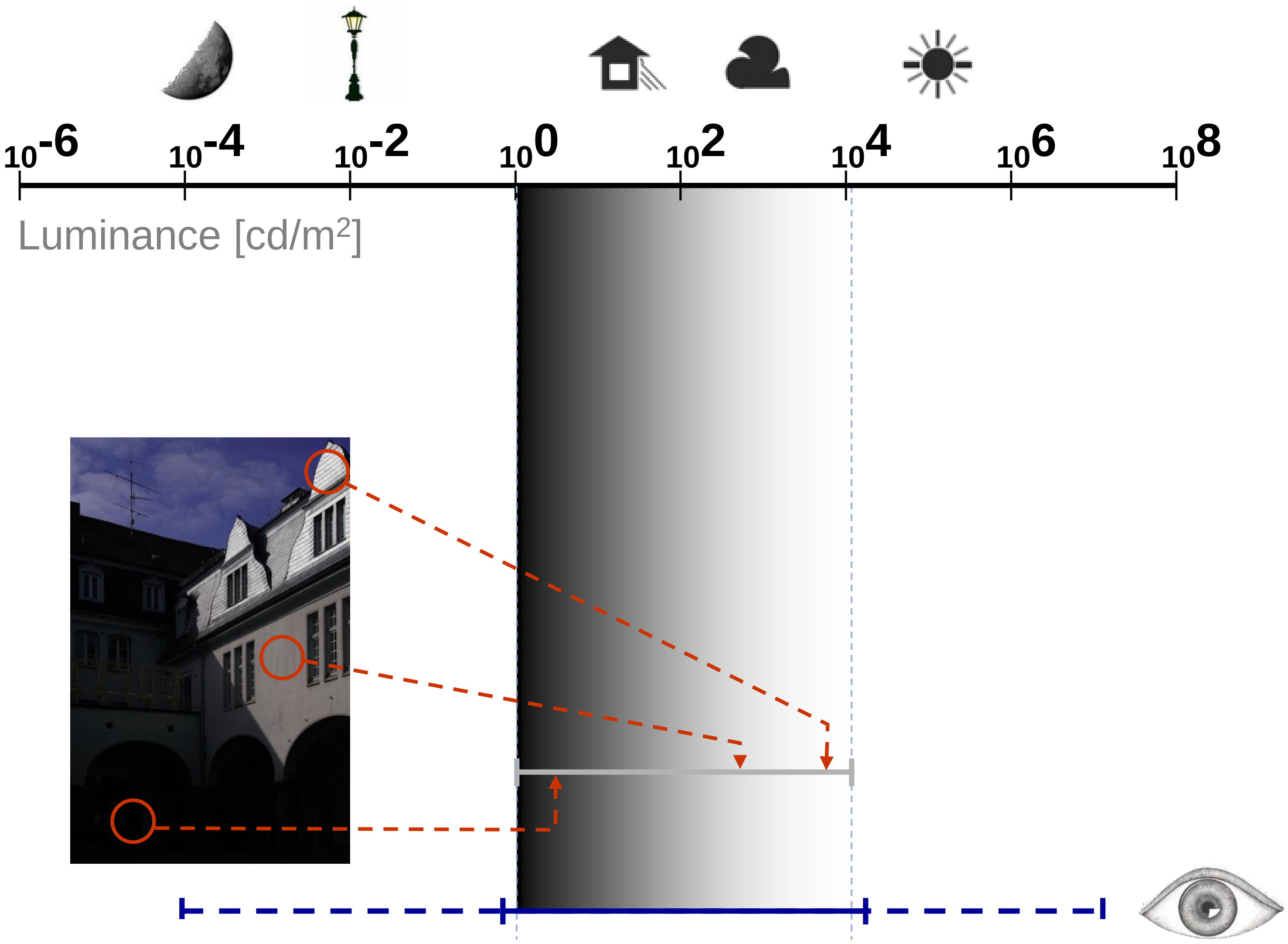
LDR vs. HDR – Comparison

Standard (Low) Dynamic Range

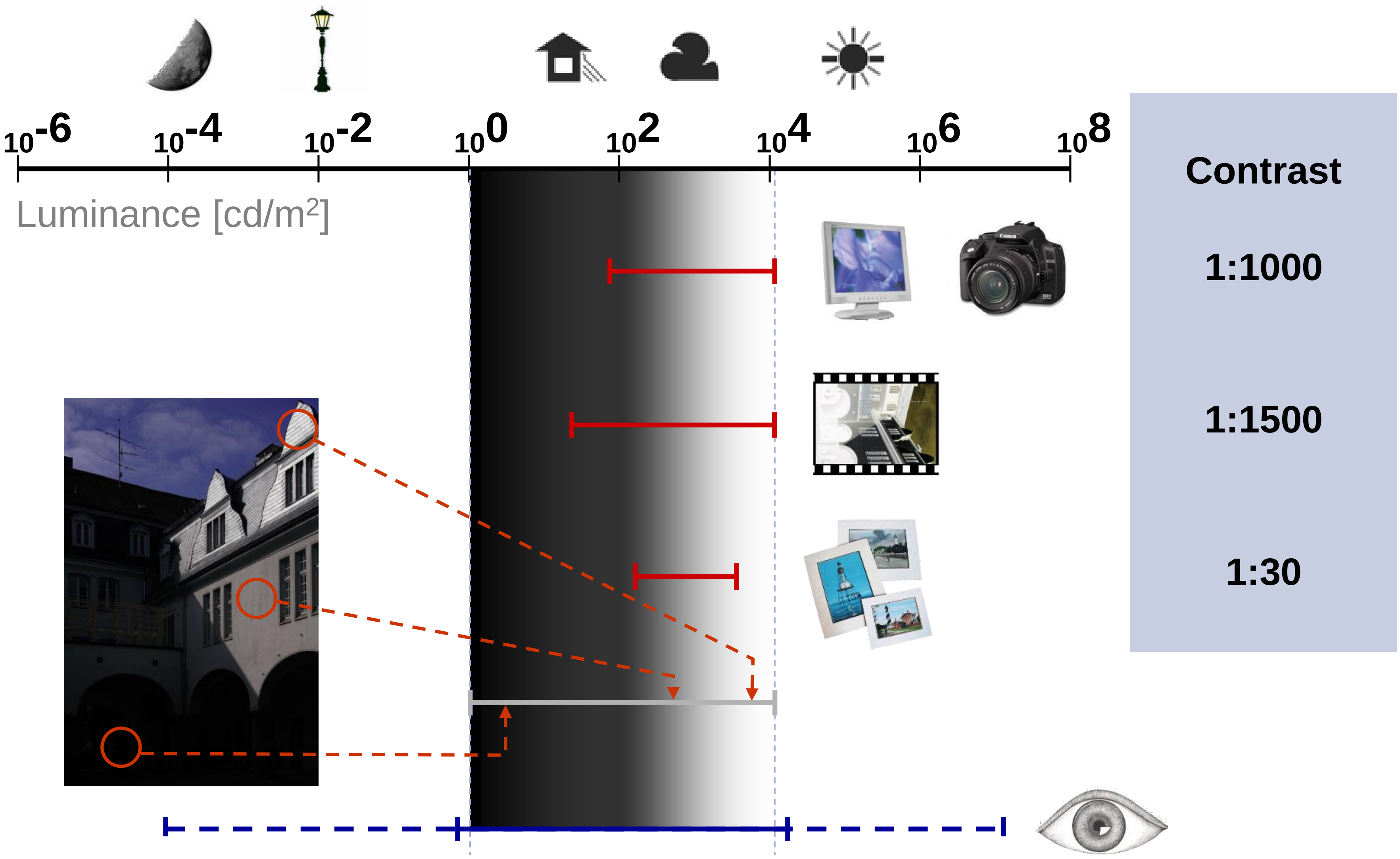
High Dynamic Range

up to 500 cd/m^2	peak brightness	2 000-10 000 cd/m^2
50 dB	camera dynamic range	120 dB
1:1 000	display contrast	1:1 000 000
from 8 to 16 bit	quantization	floating point or variable
display-referred	image representation	scene-referred
display-limited	fidelity	as good as the eye can see

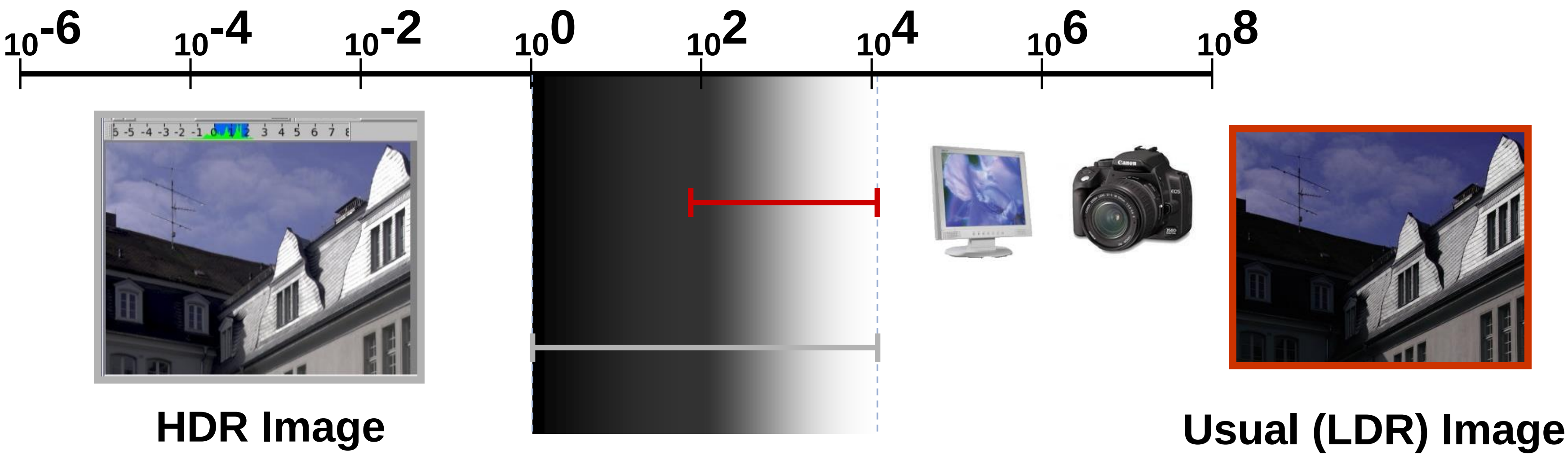
Various Dynamic Ranges (1)



Various Dynamic Ranges (2)



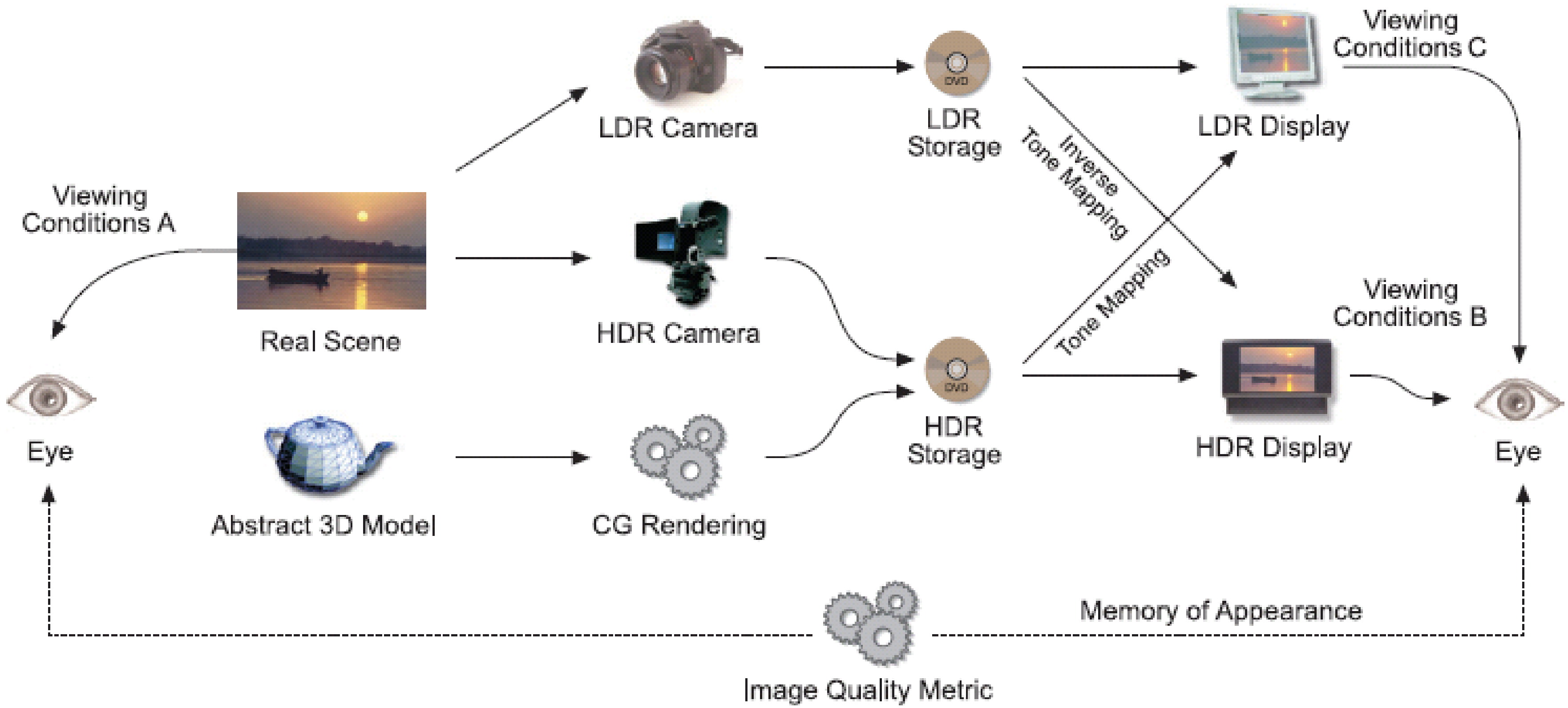
High Dynamic Range



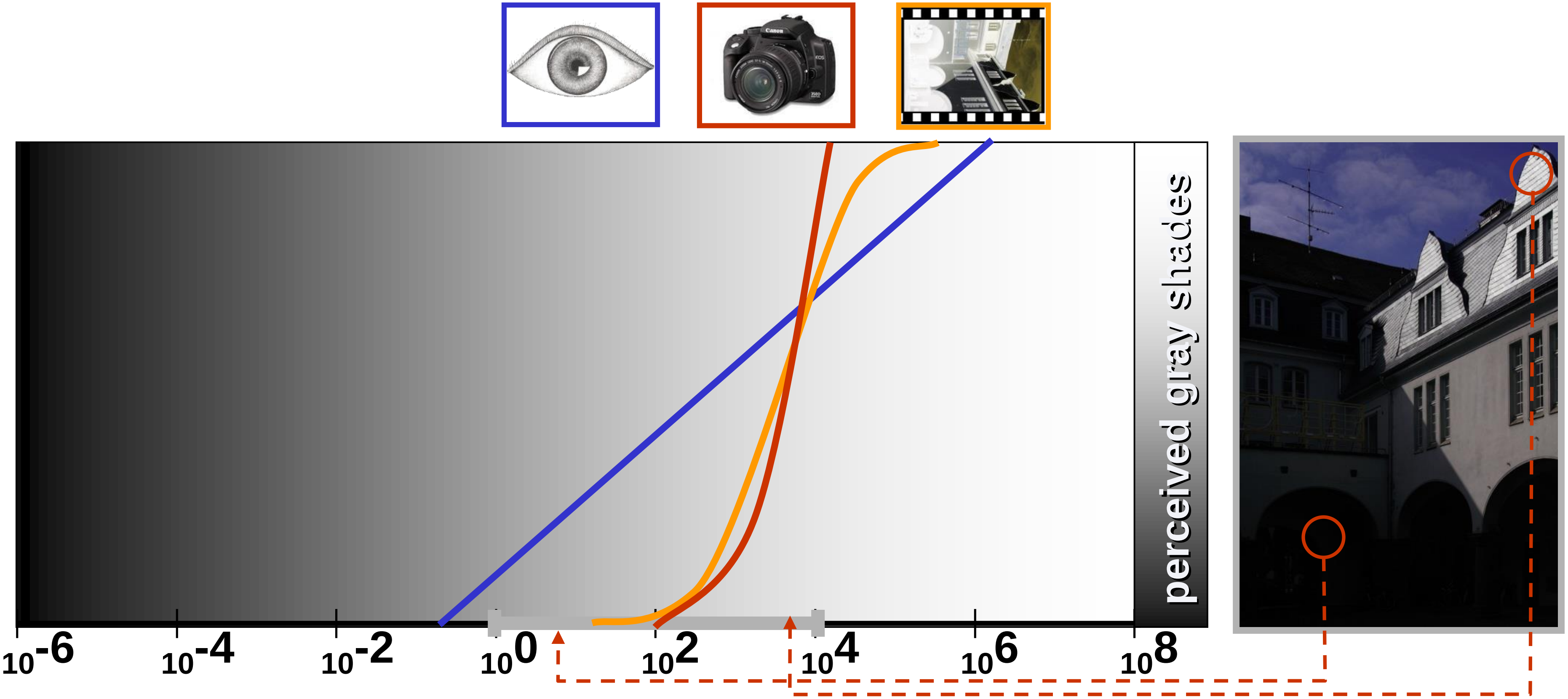
Measures of Dynamic Range

Contrast ratio	**$CR = 1 : (Y_{peak}/Y_{noise})$**	displays (1:500)
Orders of magnitude	**$M = \log_{10}(Y_{peak}) - \log_{10}(Y_{noise})$**	HDR imaging (2.7 orders)
Exposure latitude (f-stops)	**$L = \log_2(Y_{peak}) - \log_2(Y_{noise})$**	photography (9 f-stops)
Signal to noise ratio (SNR)	**$SNR = 20 * \log_{10}(A_{peak}/A_{noise})$**	digital cameras (53 [dB])

HDR Pipeline

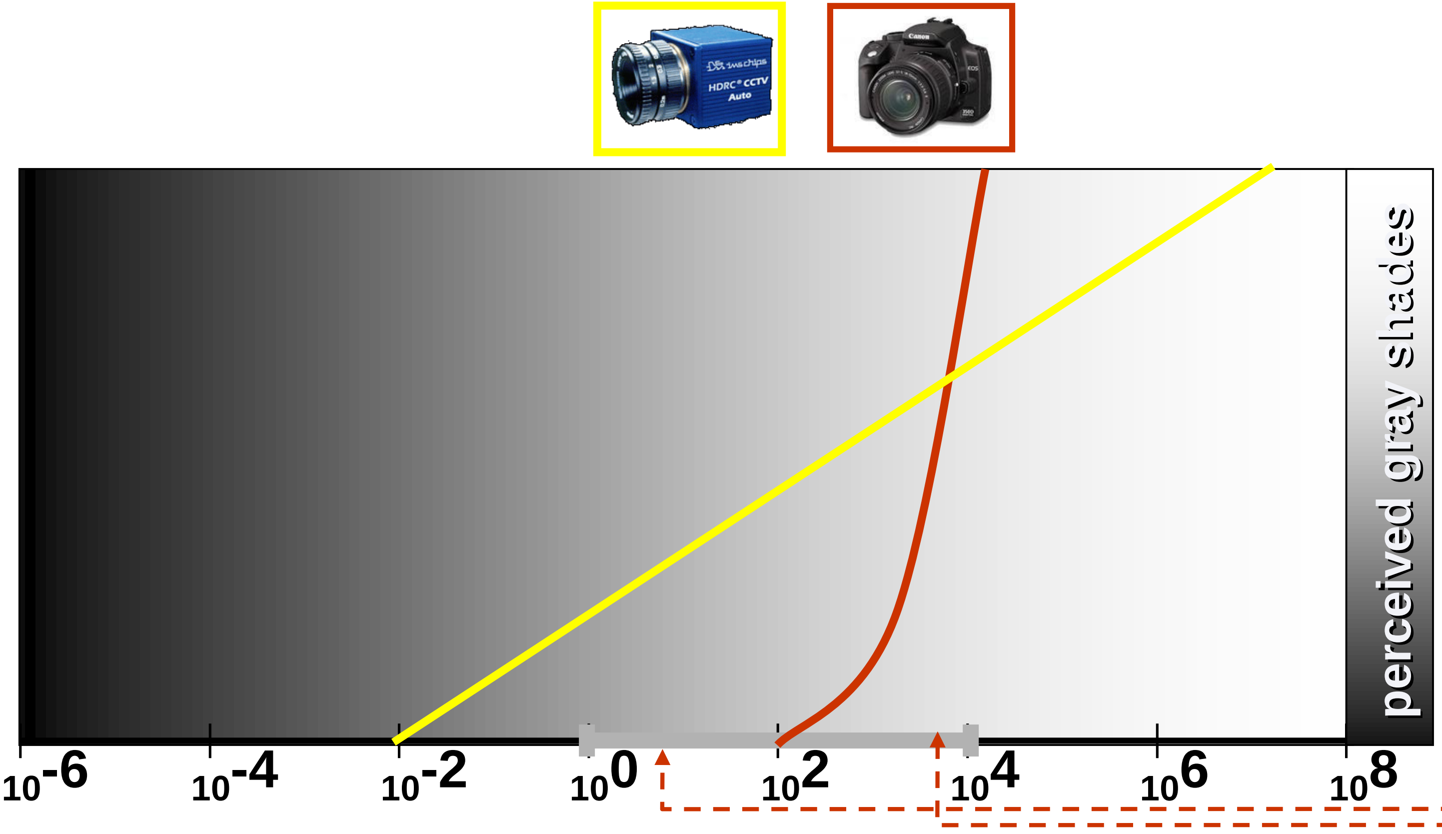


HDR: a normal camera can't…



- linearity of the CCD sensor
- bound to 8-14bit processors
- saved in an 8bit gamma corrected image

HDR Sensors



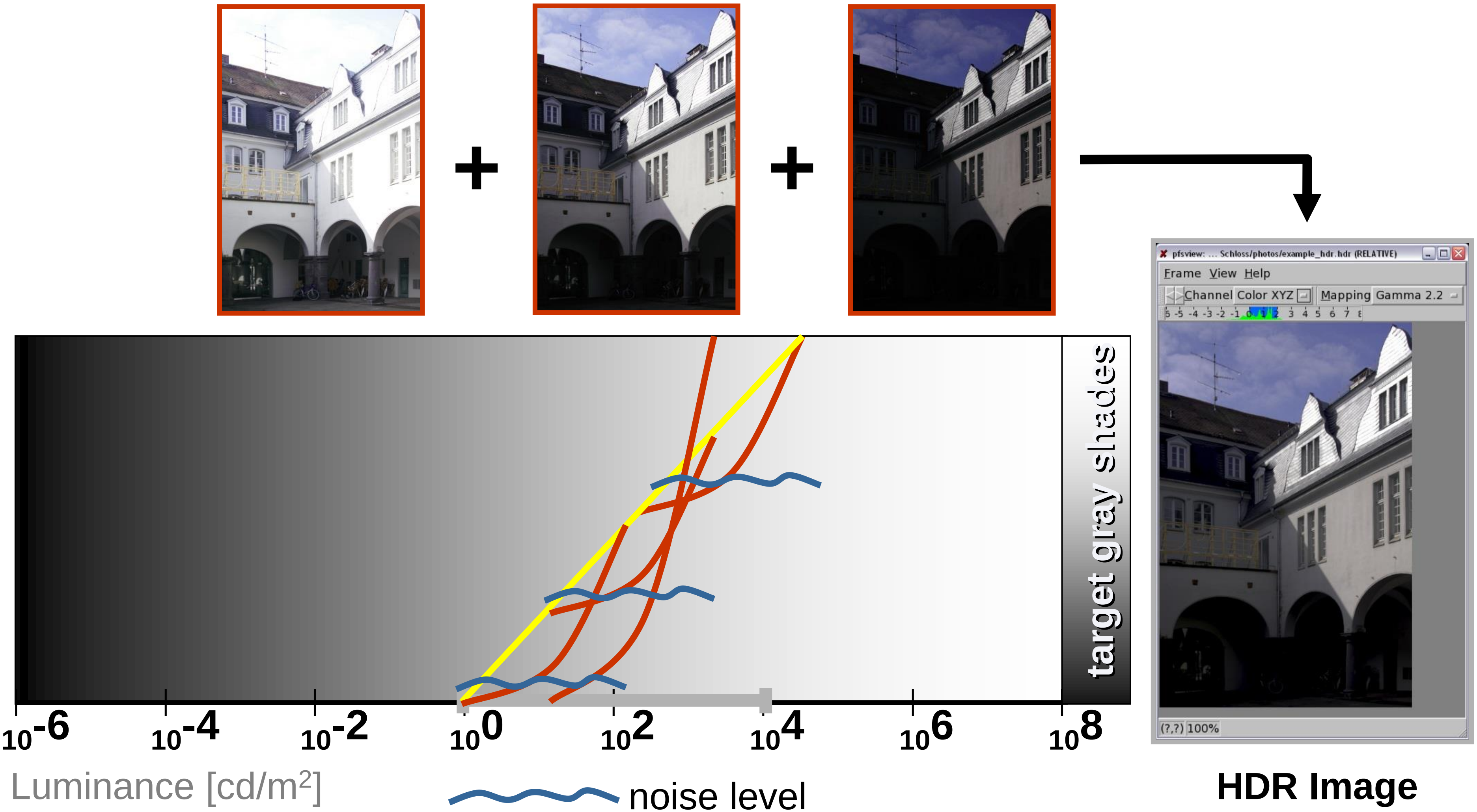
- logarithmic response
- locally auto-adaptive
- hybrid sensors (linear-logarithmic)
- multi-exposure (programmable) sensors: dual, quad-bayer, etc.

HDR with a normal camera

Dynamic range of a typical CCD	**1:1000**	
Exposure variation ($^1/60$: $^1/6000$)	1:100	
Aperture variation (f/2.0 : f/22.0)	~1:100	
Sensitivity variation (ISO 50 : 800)	~1:10	
Total operational range	**1:100,000,000**	**High Dynamic Range!**

Dynamic range of a single capture only **1:1000**

Multi-exposure Technique (1)



Multi-exposure Technique (2)

- **Input**
  - images captured with varying exposure
    - change exposure time, sensitivity (ISO), ND filters
    - same aperture!
    - exactly the same scene!
- **Unknowns**
  - camera response curve (can be given as input)
  - HDR image
- **Process**
  - recovery of camera response curve (if not given as input)
  - linearization of input images (to account for camera response)
  - normalization by exposure level
  - suppression of noise
  - estimation of HDR image (linear combination of input images)

Algorithm (1/3)

Camera Response

$$y_{ij} = I(x_{ij} \cdot t_i)$$

Merge to HDR

- **Linearize input images and normalize by exposure time**

$$x_{ij} = \frac{I^{-1}(y_{ij})}{t_i}$$

assume $\boldsymbol{I}$ is correct (initial guess)

- **Weighted average of images (weights from certainty model)**

$$x_j = \frac{\sum_i w_{ij} x_{ij}}{\sum_i w_{ij}}$$

Optimize Camera Response

- **Camera response**

$$I^{-1}(y_{ij}) = t_i x_j$$

assume $\boldsymbol{x_j}$ is correct

- **Refine initial guess on response**
  - linear eq. (Gauss-Seidel method)

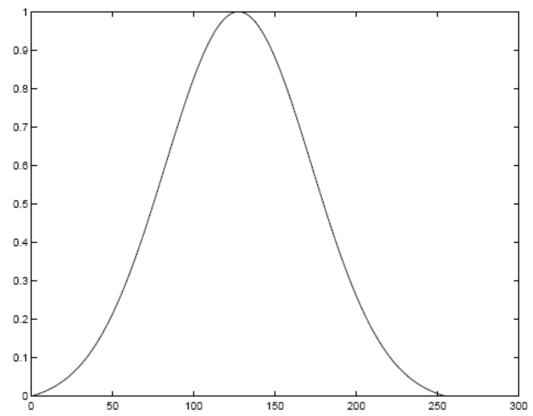
$$E_m = \{(i, j) : y_{ij} = m\}$$

$$I^{-1}(m) = \frac{1}{\mathrm{Card}(E_m)} \sum_{i,j \in E_m} t_i x_j$$

$\boldsymbol{t_i}$ exposure time of image $\boldsymbol{i}$
$\boldsymbol{y_{ij}}$ pixel of input image $\boldsymbol{i}$ at position $\boldsymbol{j}$
$\boldsymbol{I}$ camera response
$\boldsymbol{x_j}$ HDR image at position $\boldsymbol{j}$
$\boldsymbol{w}$ weight from certainty model
$\boldsymbol{m}$ camera output value

Algorithm (2/3)

- **Certainty model (for 8bit image)**
  - High confidence in middle output range
  - Dequantization uncertainty term
  - Noise level



$$w(y_{ij}) = \exp\left(-4\frac{(y_{ij}-127.5)^2}{127.5^2}\right)$$

- **Longer exposures are favored t_i^2**
  - Less random noise
- **Weights**

$$w_{ij} = w(y_{ij})t_i^2$$

Algorithm (/3)

1. **Assume initial camera response I (linear)**
2. **Merge input images to HDR**

$$x_j = \frac{\sum_i w(y_{ij}) t_i^2 \cdot \frac{I^{-1}(y_{ij})}{t_i}}{\sum_i w(y_{ij}) t_i^2}$$

3. **Refine camera response**

$$E_m = \{(i, j) : y_{ij} = m\}$$

$$I^{-1}(m) = \frac{1}{\mathrm{Card}(E_m)} \sum_{i,j \in E_m} t_i x_j$$

4. **Normalize camera response by middle value: $I^{-1}(m)/I^{-1}(m_{med})$**
5. **Repeat 2,3,4 until the objective function is acceptable**

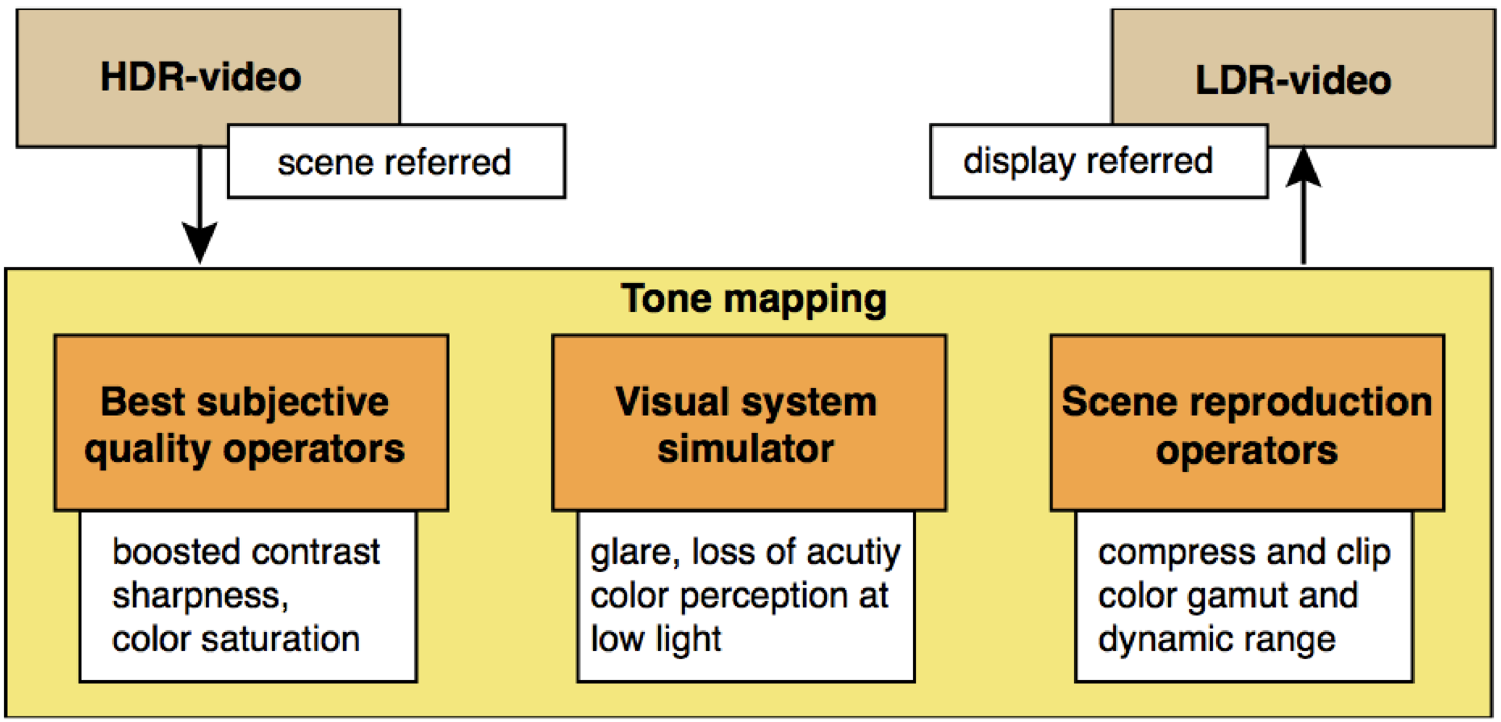
$$O = \sum_{i,j} w(y_{ij}) (I^{-1}(y_{ij}) - t_i x_j)^2$$

Other Algorithms

- **[Debevec & Malik 1997]**
  - in log space
  - assumptions on the camera response
    - monotonic
    - continuous
  - a lot to compute for >8bit
- **[Mitsunaga & Nayar 1999]**
  - camera response approximated with a polynomial
  - very fast
- **Both are more robust but less general**
  - not possible to calibrate non-standard sensors

Three intents of tone-mapping

1. **Best subjective quality**
2. **Visual system simulator**
3. **Scene reproduction operator**



Intent #1: Best Subjective Quality

- **Tools**
  - Photoshop
  - Lightroom
  - Photomatix
- **Techniques**
  - Color-grading
- **Often artistic intent**

Intent #2: Visual System Simulator

The eye adapted to the display viewing conditions

Real-world

The eye adapted to the real-world viewing conditions

Display

Goal: match color appearance

Possible Appearance Match

Perceptual dimension	Real world observation	Display observation
Hue	yellow	yellow
Brightness	high	low
Lightness	high	high
Colorfulness	high	low
Chroma (color purity)	high	high

Imagine viewing a yellow school bus outside on a sunny day.

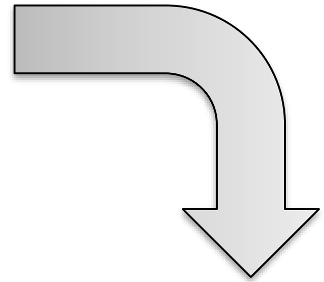
A photo cannot match reality in brightness and colorfulness, because the energy reflected of the print cannot match that reflected of the real object.

Hue usually remains constant.

It's important to reproduce lightness and chroma.

Intent #3: Scene Reproduction Problem

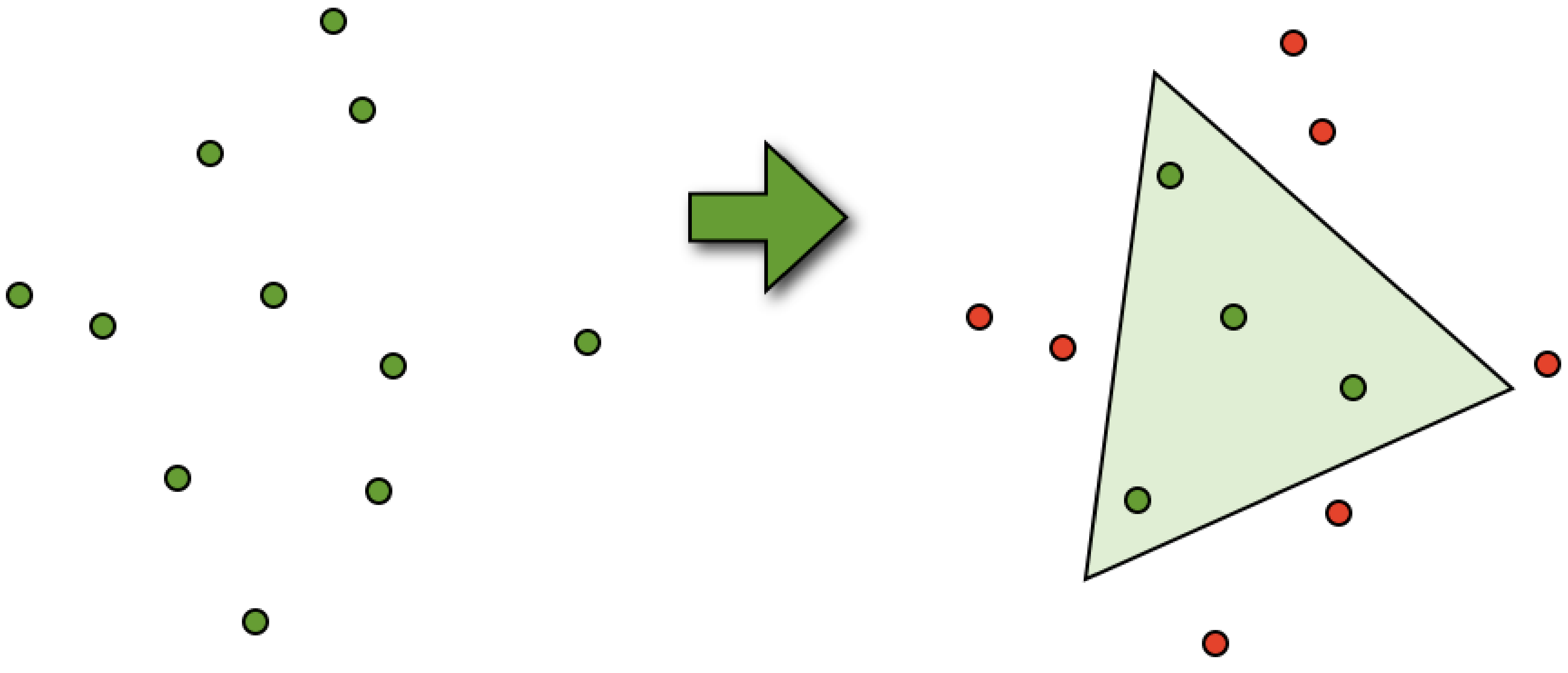
Real-world



Display

Goal: map colors to a restricted color space

Mapping Problem

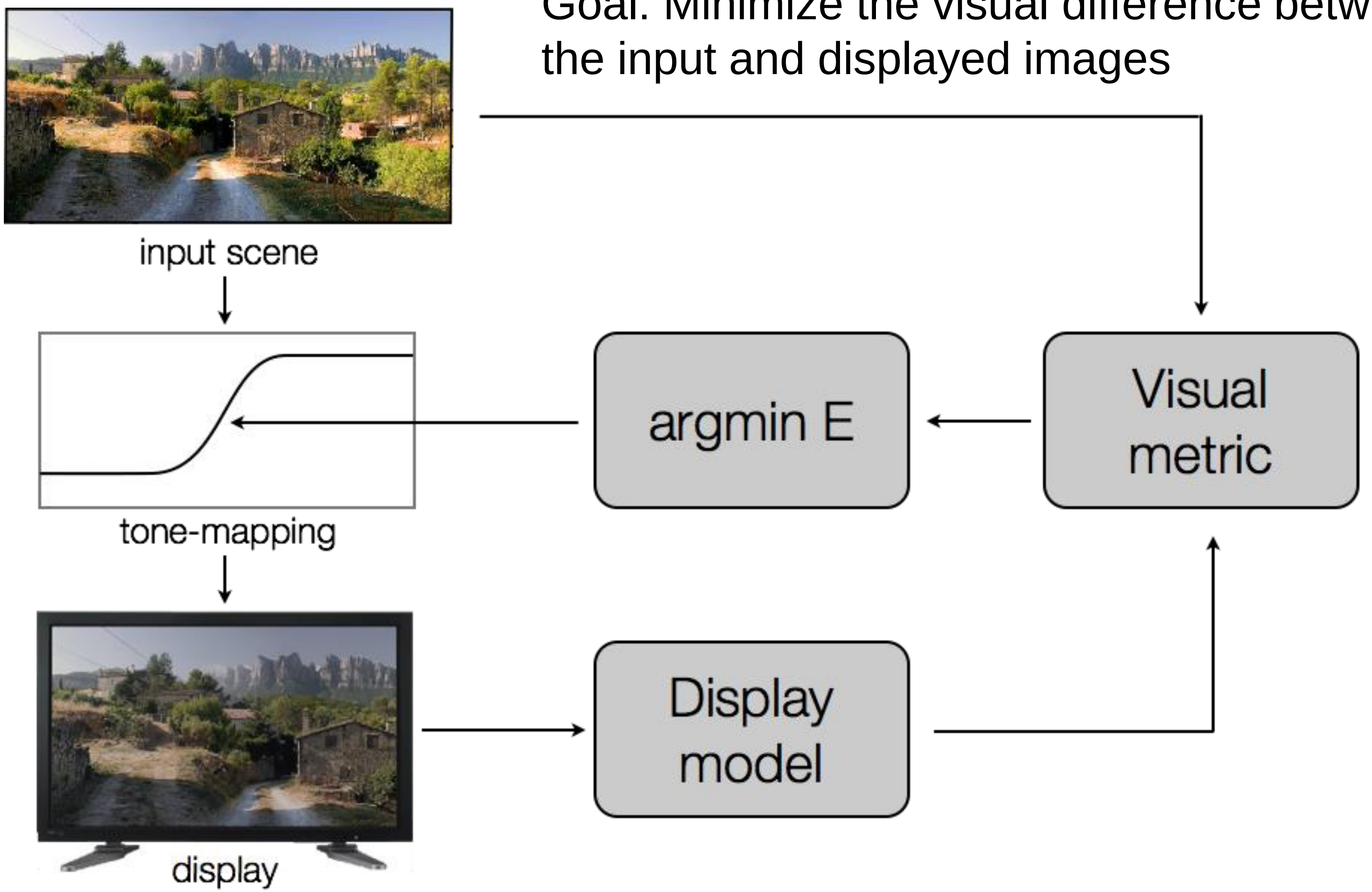


Real-world

Display

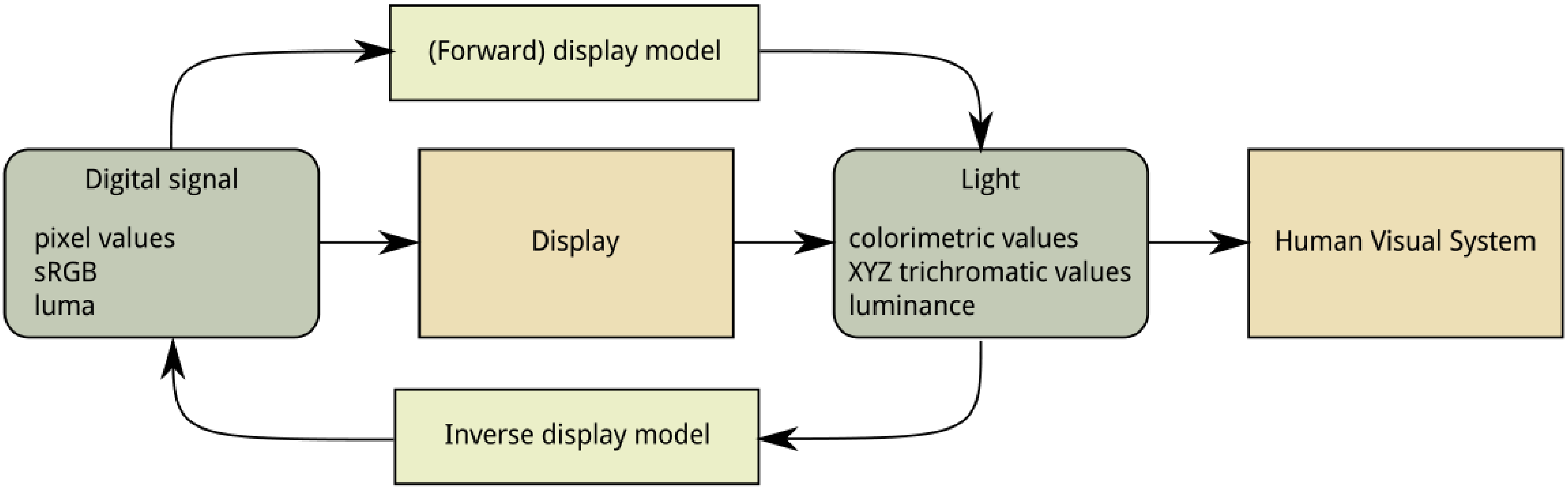
Display Adaptive Tone-mapping

Goal: Minimize the visual difference between the input and displayed images



[Mantiuk et al., SIGGRAPH 2008]

Forward and Inverse Display Model



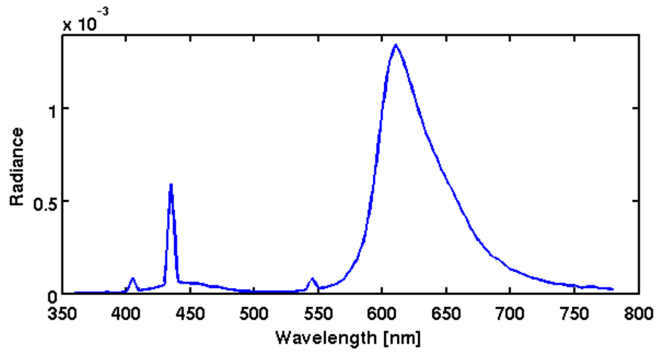
Luminance

- **Luminance – perceived brightness of light, adjusted for the sensitivity of the visual system to wavelengths**

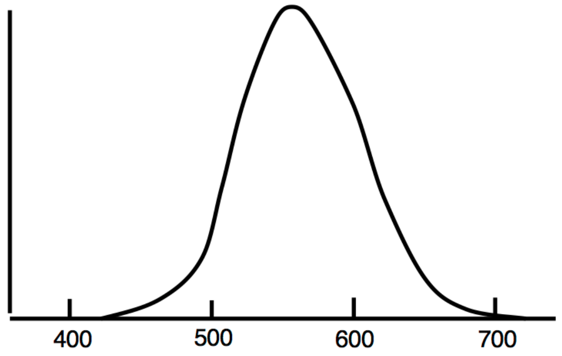
Luminance

$$L_V = \int_0^\infty L(\lambda) \cdot V(\lambda) d\lambda$$

Light spectrum (radiance)



Luminous efficiency function (weighting)

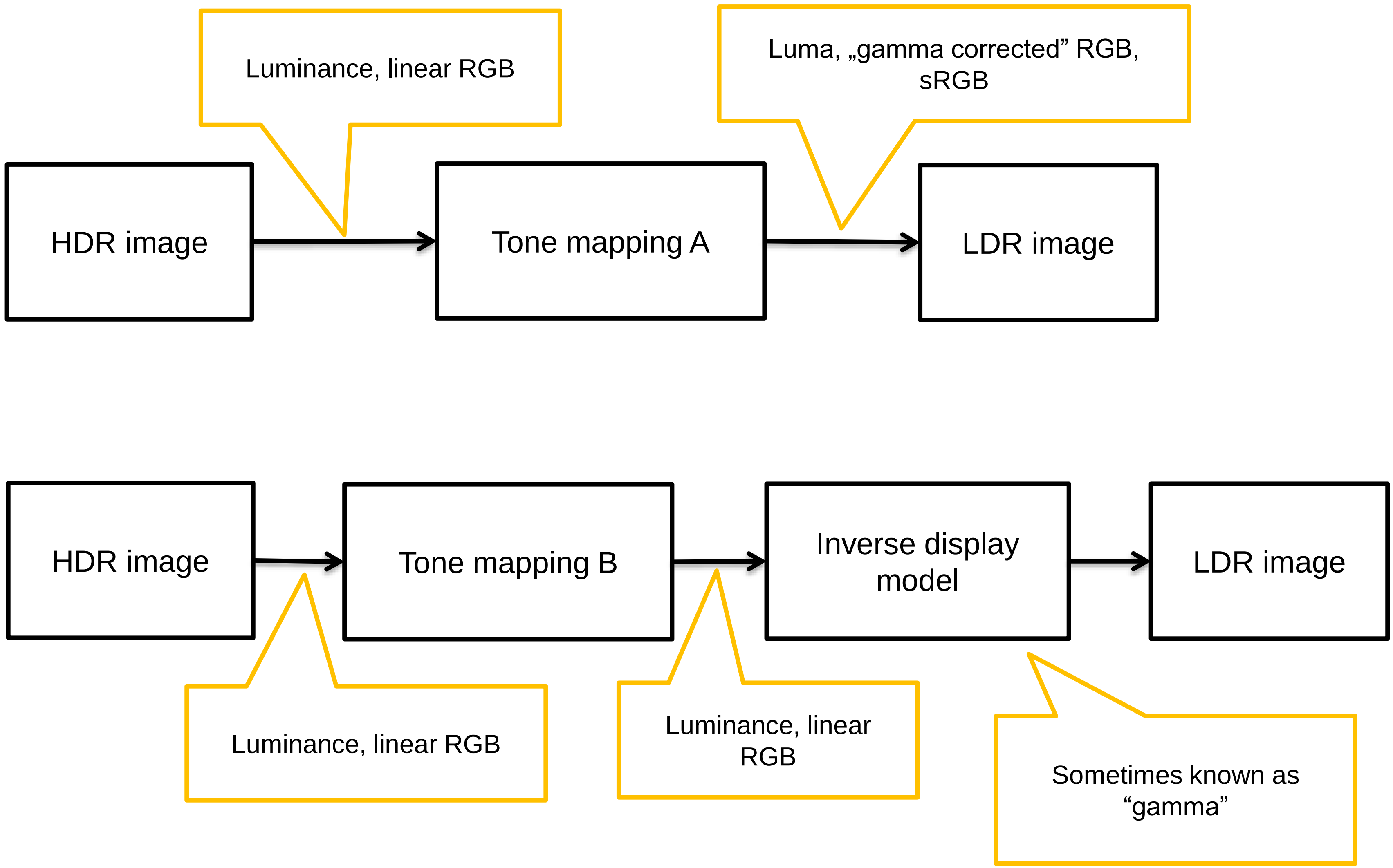


Luminance and Luma

- **Luma**
  - Gray-scale value computed from LDR (gamma corrected) image
- **Y = 0.2126 R’ + 0.7152 G’ + 0.0722 B’**
- **Unitless**

- **Luminance**
  - Photometric quantity defined by the spectral luminous efficiency function
- **L ≈ 0.2126 R + 0.7152 G + 0.0722 B**
- **Units: cd/m^2**

Two Ways to do Tone-mapping



(Forward) Display Model

- **GOG: Gain-Gamma-Offset**

$$L = (L_{peak} - L_{black}) V^{\gamma} + L_{black} + L_{refl}$$

- Luminance: L
- Peak luminance: L_{peak}
- Gamma: γ
- Display black level: L_{black}
- Screen reflections: L_{refl}
- Gain: $(L_{peak} - L_{black})$
- Pixel value 0-1: V
- Offset: $L_{black} + L_{refl}$

$$L_{refl} = \frac{k}{2\pi} E_{amb}$$

- Reflectance factor (0.01): k
- Ambient illumination (in lux): E_{amb}

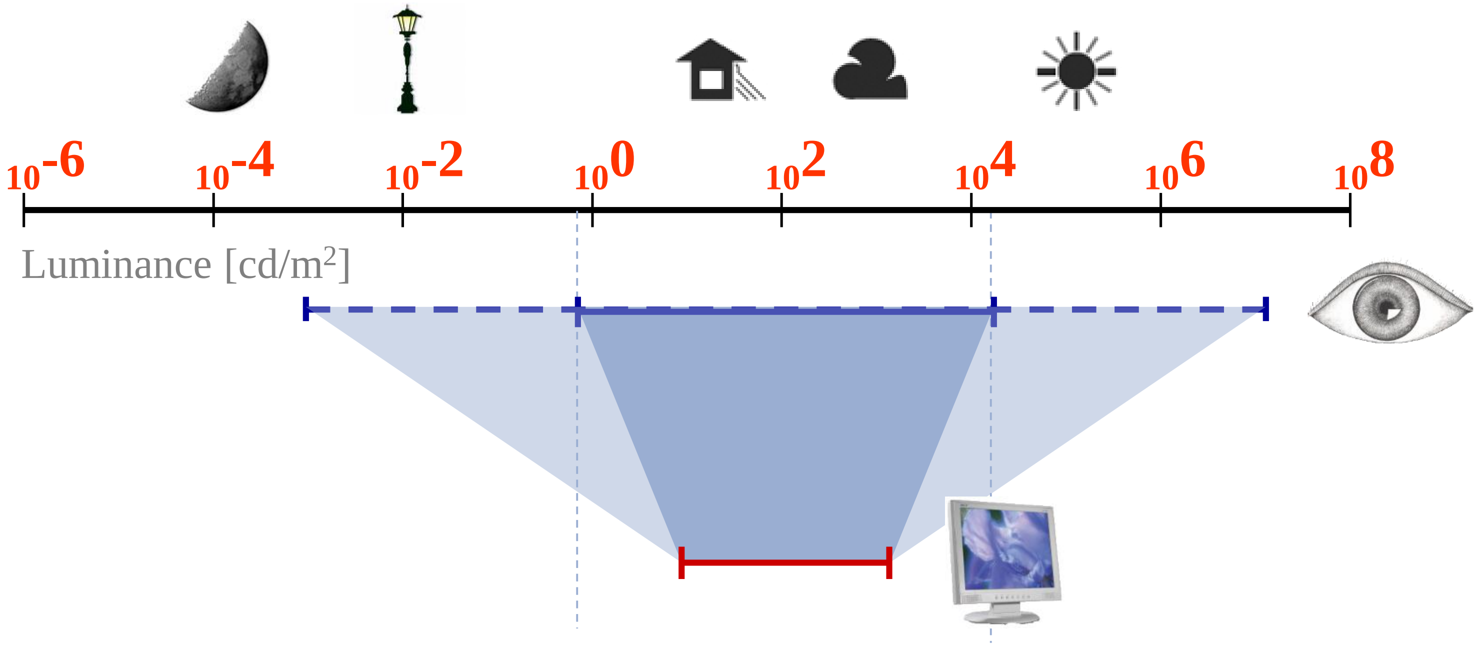
Inverse Display Model

Symbols are the same as for the forward display model

$$V = \left(\frac{L - L_{black} - L_{refl}}{L_{peak} - L_{black}} \right)^{(1/\gamma)}$$

Note: This display model does not address any color issues. The same equation is applied to red, green and blue color channels. The assumption is that the display primaries are the same as for the sRGB color space.

Typically Luminance Mapping



Color Processing

- **Most algorithms work on luminance**
  - use RGB to Yxy color space transform
  - inverse transform using tone mapped luminance:

$$C_{out} = \left(\frac{C_{in}}{L_{in}} \right)^{s} \cdot L_{out}$$

Output color channel

Saturation parameter

Resulting luminance

  - select value ‘s’ manually
  - for an automatic solution refer to:
    - Mantiuk et al. “Color correction for tone mapping”. Computer Graphics Forum. 2009;28(2):193–202.
- **Otherwise each RGB channel processed independently**

General Idea

- **Luminance as an input**
  - absolute luminance
  - relative luminance (luminance factor)
- **Transfer function**
  - maps luminance to a certain pixel intensity
  - may be the same for all pixels (**global operators**)
  - may depend on spatially local neighbors (**local operators**)
  - dynamic range is reduced to a specified range
- **Pixel intensity as output**
  - often requires gamma correction

Tone Mapping Arithmetic

Multiplication —
brightness change

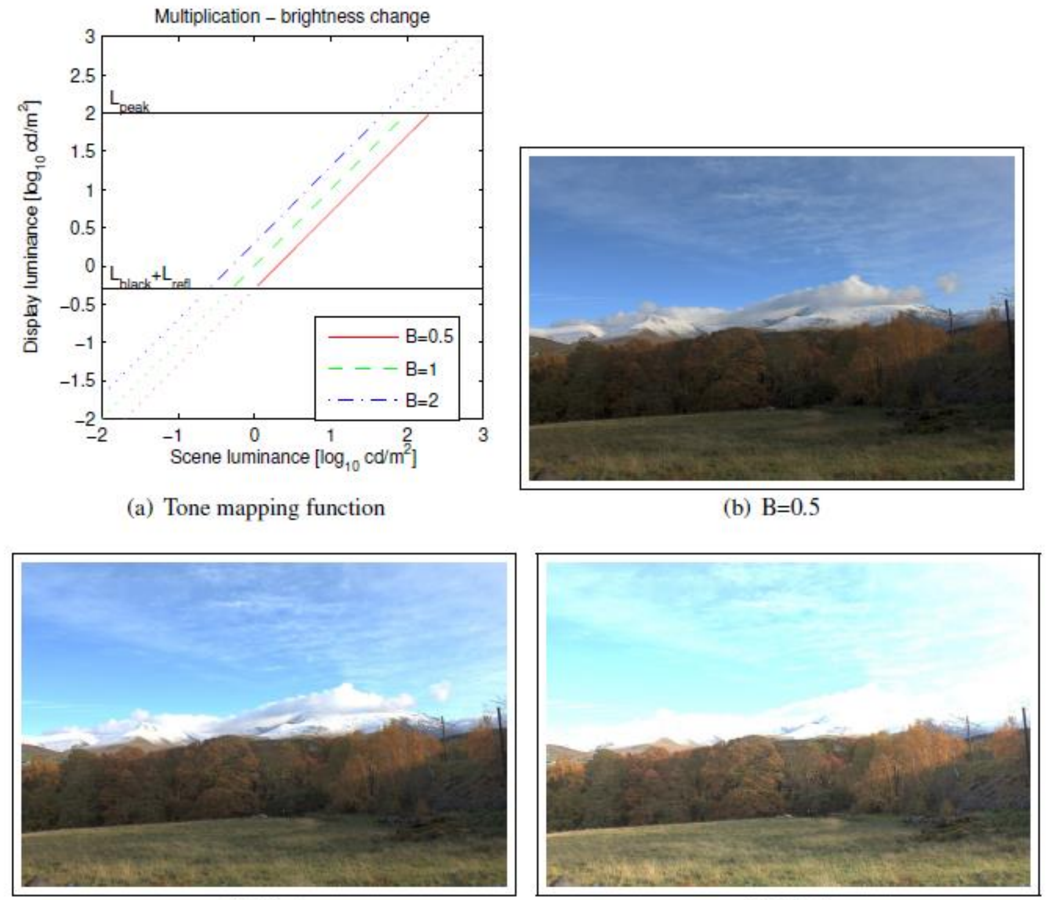
$$T(L_p) = BL_p$$

in logarithmic domain:

$$t(l_p) = b + l_p$$

where

$$b = \log_{10} B$$
$$l_p = \log_{10} l_p$$



(a) Tone mapping function (b) B=0.5 (c) B=1 (d) B=2

Figure 18: Multiplication performed on the HDR pixel values. The operation adjusts image brightness. The horizontal lines in (a) represent minimum and maximum luminance shown on a display. The luminance values corresponding to the dotted parts of the curves will not be reproduced on a display.

Tone Mapping Arithmetic

Power function — contrast change

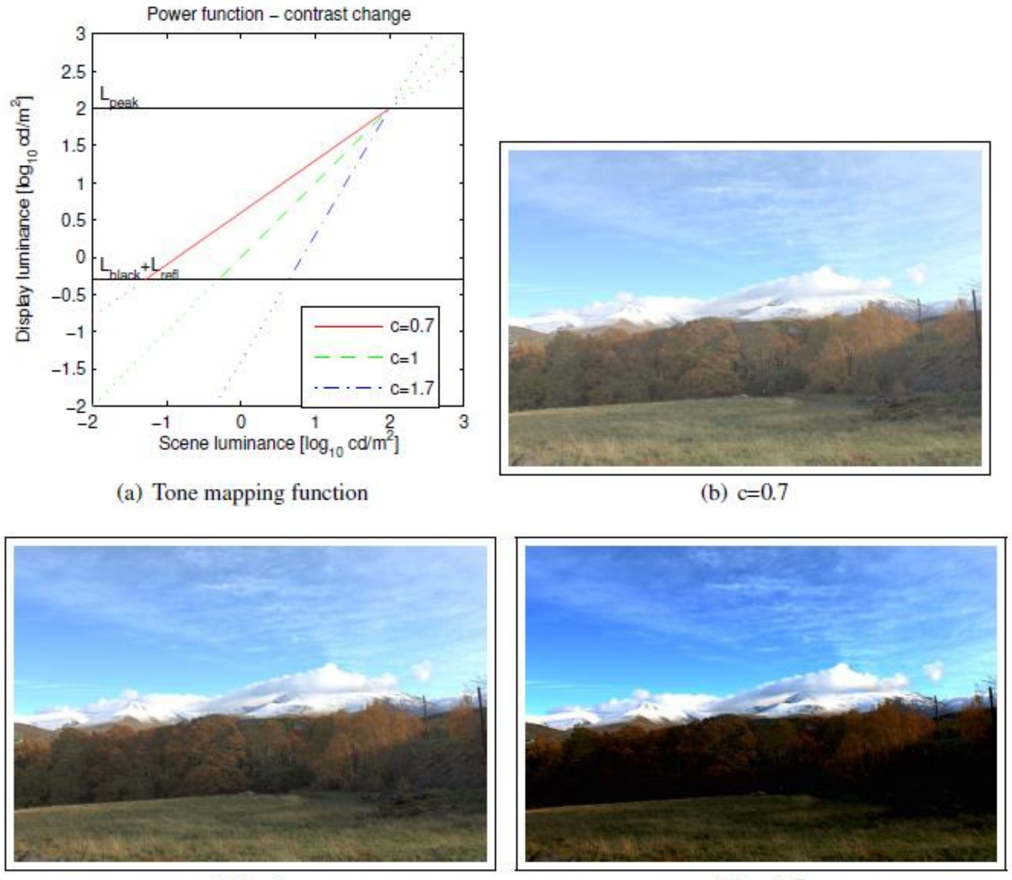
$$\mathrm{T}(L_p) = \left(\frac{L_p}{L_{white}}\right)^{c}$$

in logarithmic domain:

$$\mathrm{t}(l_p) = c\left(l_p - l_{white}\right)$$

where

$$l_p = \log_{10} l_p$$
$$l_{white} = \log_{10} l_{white}$$



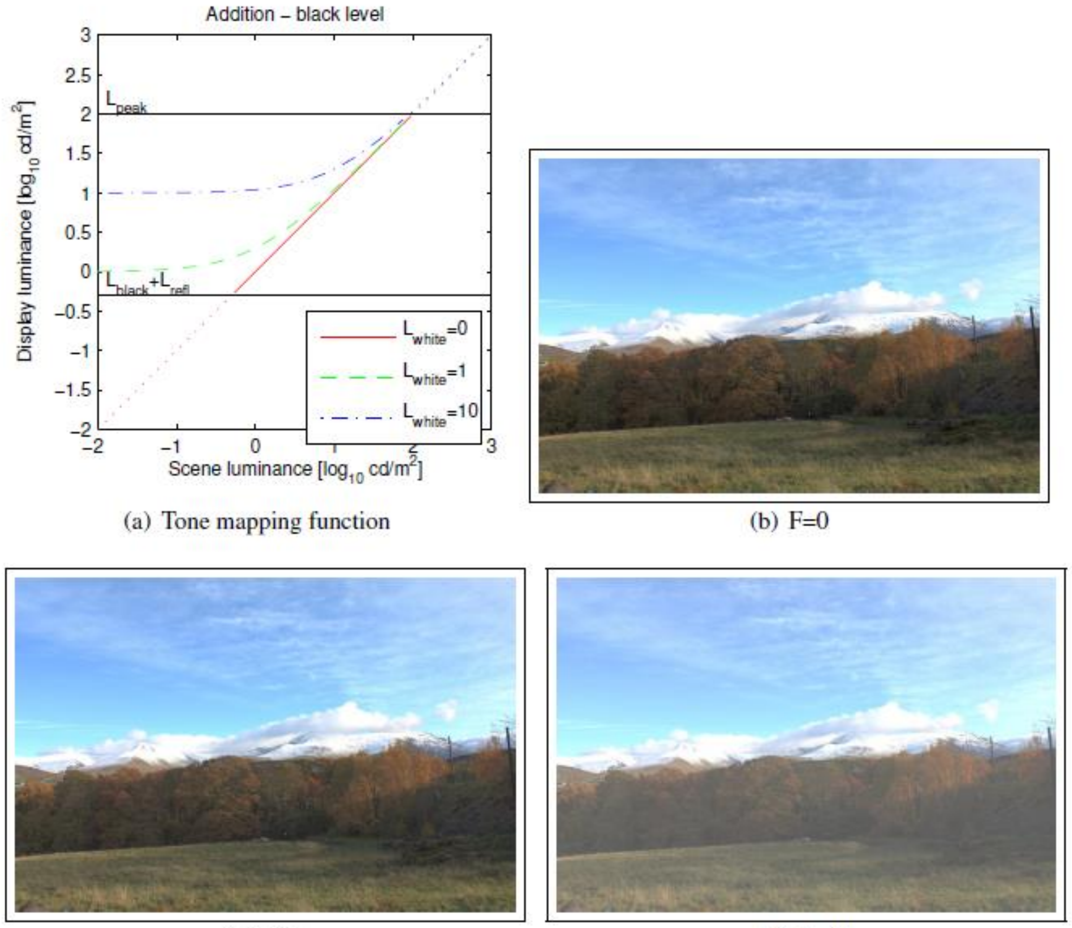
(a) Tone mapping function (b) c=0.7 (c) c=1 (d) c=1.7

Figure 19: Power function applied to the HDR pixel values. The operation adjusts image contrast.

Tone Mapping Arithmetic

Addition —
black level, fog

$$T(L_p) = L_p + F$$



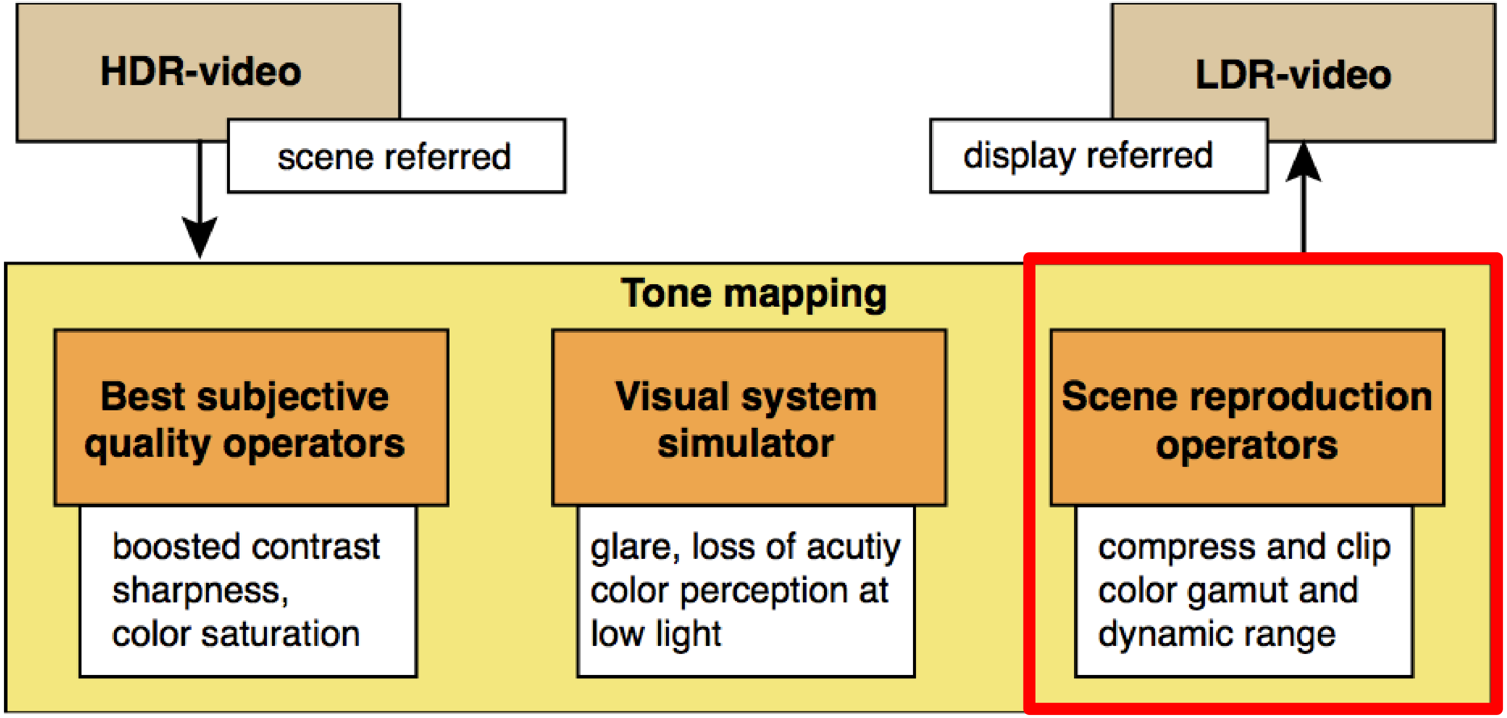
(a) Tone mapping function (b) F=0

(c) F=1 (d) F=10

Figure 20: Constant value added to the HDR pixel values. The operation elevates black level or introduces fog to an image. It will also affect contrast of the lower tones in an image.

Three Intents of Tone-mapping

1. **Scene reproduction operator**
2. **Visual system simulator**
3. **Best subjective quality**



Transfer Functions

- **Linear mapping (naïve approach)**
  - like taking a usual photo
- **Brightness function**
- **Sigmoid responses**
  - simulate our photoreceptors
  - simulate response of photographic film
- **Histogram equalization**
  - standard image processing
  - requires detection threshold limit to prevent contouring

Adapting Luminance

- **Maps luminance on a scale of gray shades**
- **Task is to match gray levels**
  - average luminance in the scene is perceived as a gray shade of medium brightness
  - such luminance is mapped on medium brightness of a display
  - the rest is mapped proportionally
- **Practically adjusts brightness**
  - sort of like using gray card or auto-exposure in photography
  - goal of adaptation processes in human vision
- **Adapting luminance used in many TM algorithms**

$$Y_A = \exp\left(\frac{\sum \log(Y + \varepsilon)}{N} - \varepsilon \right)$$

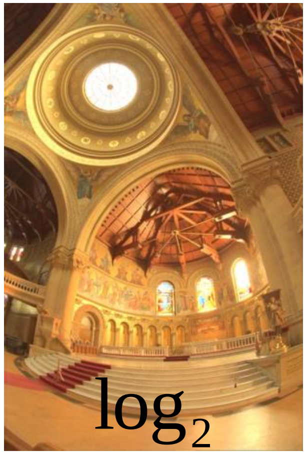
Logarithmic Tone Mapping

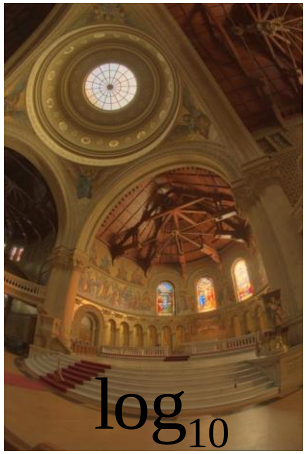
- **Logarithm is a crude approximation of brightness**
- **Change of base for varied contrast mapping in bright and dark areas**
  - $\log_{10}$ maps better for bright areas
  - $\log_2$ maps better for dark areas
- **Mapping parameter *bias* in the range 0.1:1**

$$Y' = \frac{Y}{Y_A}$$

$$L = L_{\max} \cdot \frac{\log_{base(Y)}(Y'+1)}{\log_{10}(\max(Y')+1)}$$

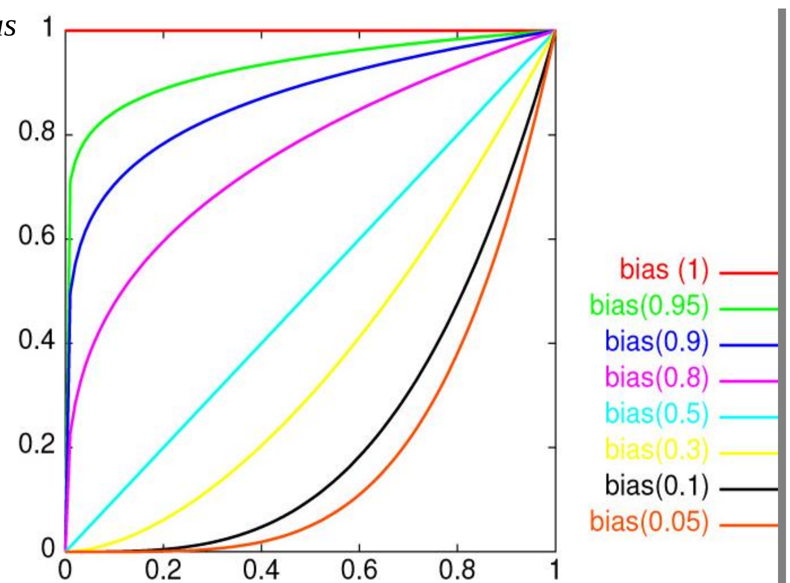
$$base(Y') = 2 + 8 \cdot \left(\frac{Y'}{\max(Y')} \right)^{\log_{0.5} bias}$$





Logarithmic Tone Mapping

$$\left(\frac{Y'}{\max(Y')}\right)^{\log_{0.5} bias}$$



- These images illustrate how high luminance values are clamped to the maximum displayable values using different bias parameter values.
- The scene dynamic range is 1:11,751,307.

$$\left(\frac{Y'}{\max(Y')}\right)$$

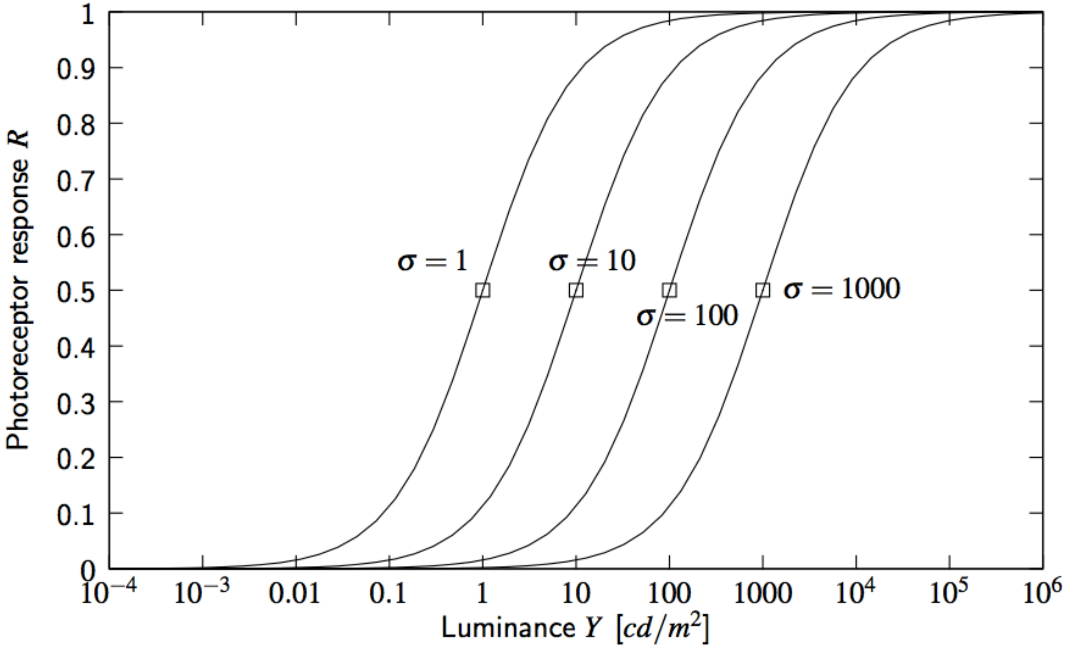
Sigmoid Response

- **Model of photoreceptor**

$$L = \frac{Y}{Y + (f \cdot Y_A)^m} L_{\max}$$

$$\sigma = f \cdot Y_A$$

- Brightness parameter $\boldsymbol{f}$
- Contrast parameter $\boldsymbol{m}$
- Adapting luminance $\boldsymbol{Y_A}$
  - average in an image
  - measured pixel (equal to $\boldsymbol{Y}$)



Sigmoid Response

- **Model of photoreceptor**

$$L = \frac{Y}{Y + (f \cdot Y_A)^m} L_{\max}$$

- Brightness parameter $\boldsymbol{f}$
- Contrast parameter $\boldsymbol{m}$
- Adapting luminance $\boldsymbol{Y_A}$
  - average in an image
  - measured pixel (equal to $\boldsymbol{Y}$)

logarithmic mapping

sigmoid mapping

Histogram Equalization

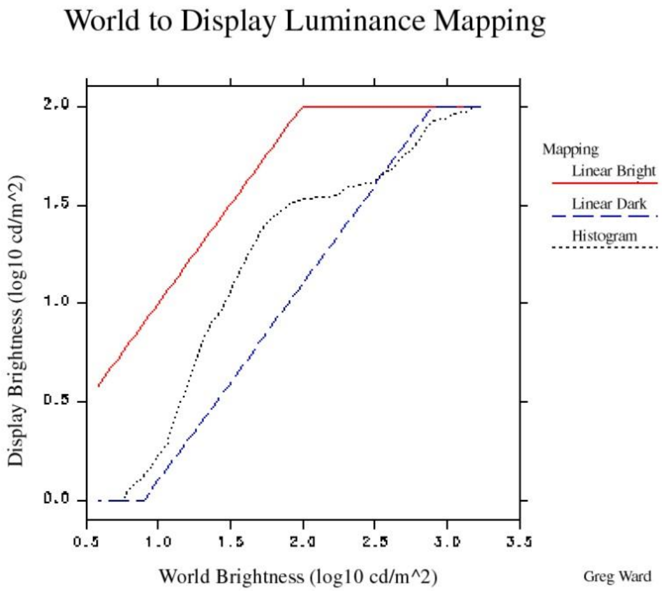
- **Adapts transfer function to distribution of luminance in the image**
- **Algorithm:**
  - compute histogram
  - compute transfer function (cumulative distribution)
  - limit slope of transfer function to prevent contouring
    - contouring – visible difference between 1 quantization step
    - use threshold versus intensity function (TVI)

      TVI gives visible luminance difference for adapting luminance
- **Most optimal transfer function**
- **Not efficient when large uniform areas are present in the image**

Histogram Equalization

A linear mapping of the luminances that overexposes the view through the window.

Greg Ward



A linear mapping of the luminances that underexposes the view of the interior.

Greg Ward

The luminances mapped to preserve the visibility of both indoor and outdoor features.

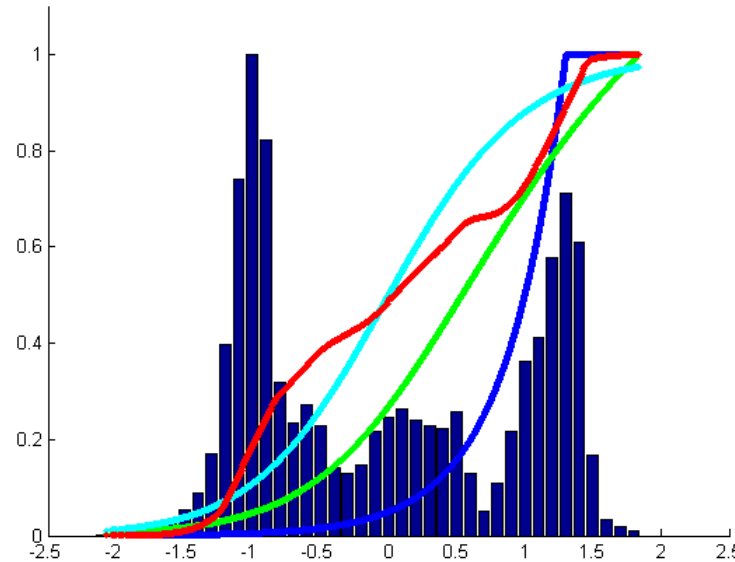
Transfer Functions Compared

linear

logarithmic

photoreceptor

histogram eq.



- **Interpretation**
  - steepness of slope is contrast
  - luminance for which output is ~0 and ~1 is not transferred
- **Usually low contrast for dark and bright areas!**

Problem with Details

- **Strong compression of contrast puts micro-contrasts (details) below quantization level**

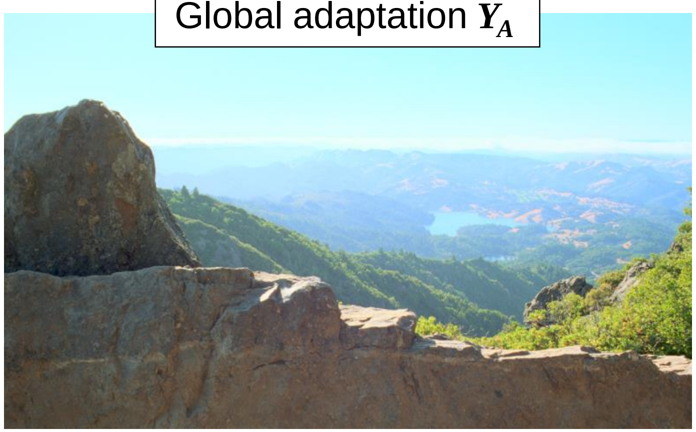
Introducing Local Adaptation

- **Eye adapts locally to observed area**

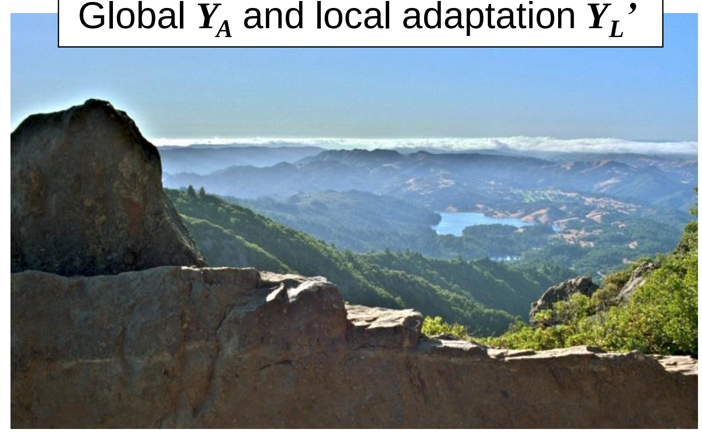
$$L = \frac{Y'}{Y'+1} \qquad Y' = \frac{Y}{Y_A} \qquad L = \frac{Y'}{Y_L'+1}$$

Gaussian blur of HDR image, $\boldsymbol{\sigma}$ ~ 1deg of visual angle.

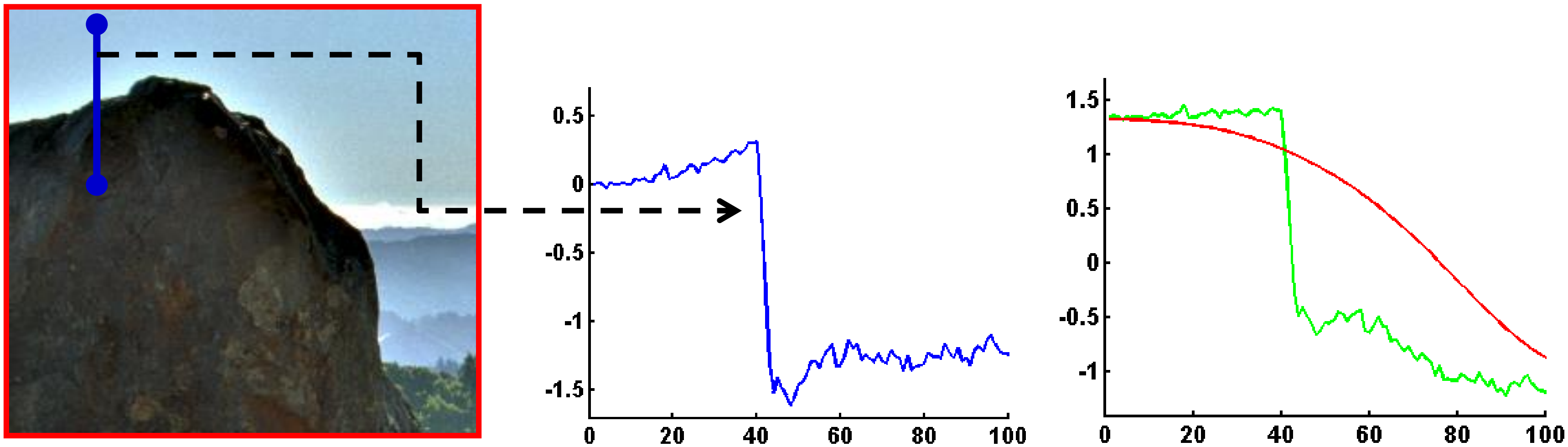
Global adaptation $\boldsymbol{Y_A}$



Global $\boldsymbol{Y_A}$ and local adaptation $\boldsymbol{Y_L'}$



The Halo Artifact

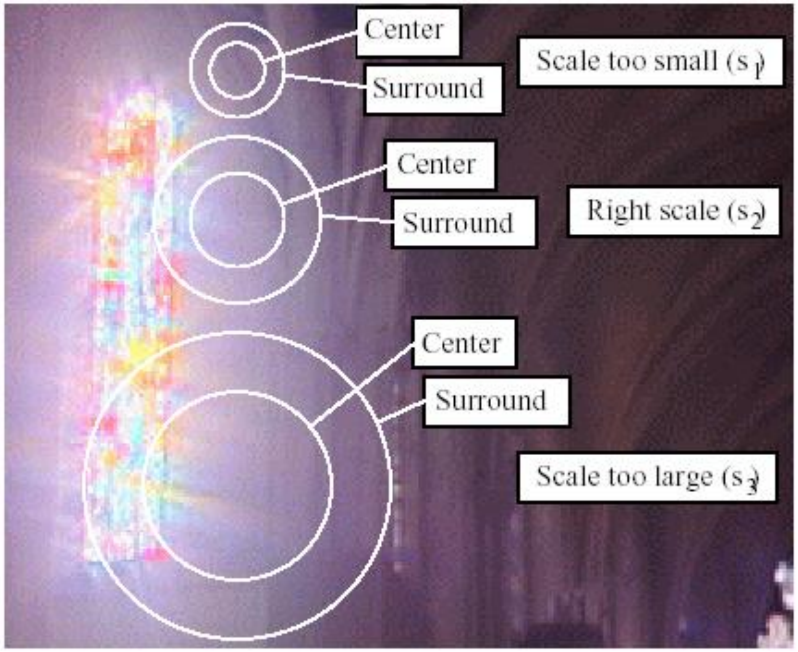


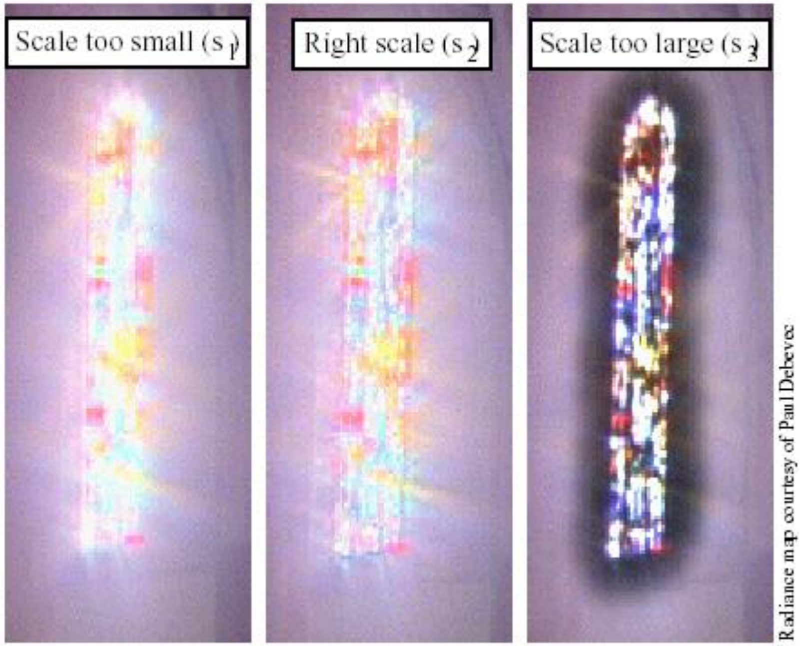
- **Scan line example:**
  - Gaussian blur under- (over-) estimates local adaptation near a high contrast edge
  - tone mapped image gets too bright (too dark) closer to such an edge
- **Smaller blur kernel reduces the artifact (but then no details)**
- **Larger blur kernel spreads the artifact on larger area**

Adjusting Gaussian Blur

- **So called: Automatic Dodging and Burning**
  - for each pixel, test increasing blur size σ_i
  - choose the largest blur which does not show halo artifact

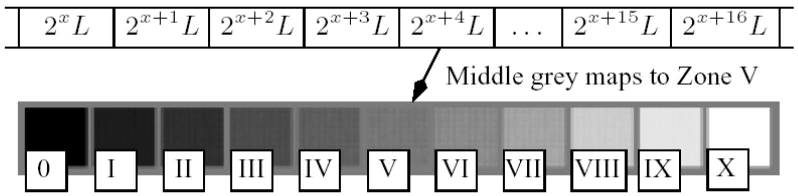
$$\left| Y_L(x, y, \sigma_i) - Y_L(x, y, \sigma_{i+1}) \right| < \varepsilon$$





Photographic Tone Reproduction

- **Map luminance using Zone System**



Print zones: Zone V 18% reflectance

$$Y' = \frac{Y}{Y_A}, \quad Y_A = \exp\left(\frac{\sum \log(Y)}{N}\right)$$

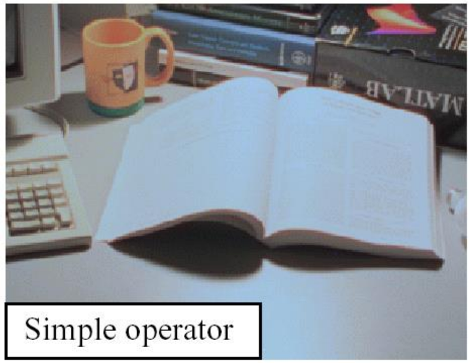
- **Find local adaptation for each pixel**
  - appropriate size of Gaussian (automatic dodging & burning)

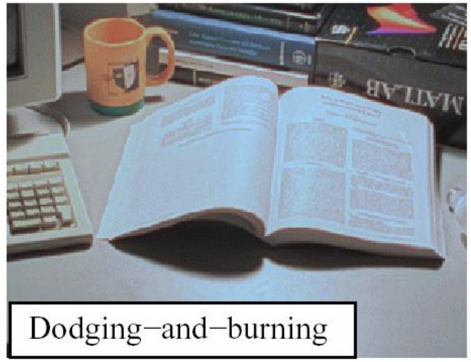
$$\left| Y_L'(x, y, \sigma_i) - Y_L'(x, y, \sigma_{i+1}) \right| < \varepsilon$$

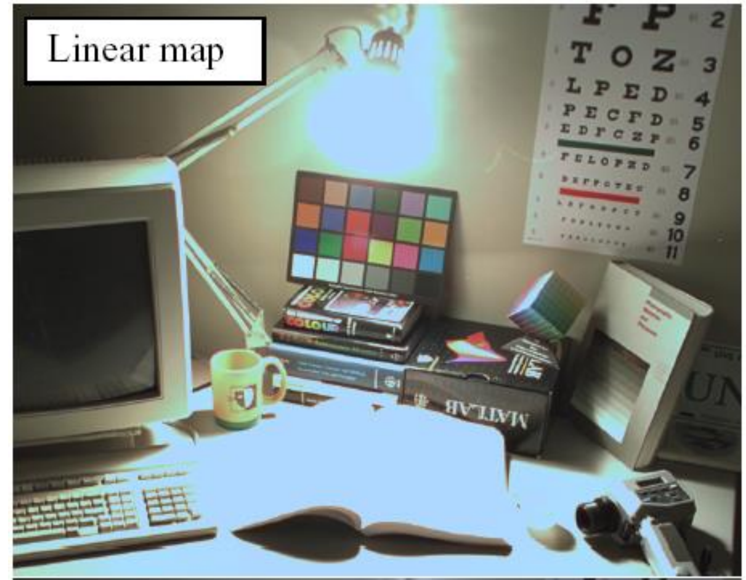
- **Tone map using sigmoid function**
  - different blur levels from Gaussian pyramid

$$L(x, y) = \frac{Y'(x, y)}{Y_L'(x, y, \sigma_{x,y}) + 1}$$

Photographic Tone Reproduction







burn luminance of pixels in bright regions is significantly decreased

dodge pixels in dark regions are compressed less, so their relative intensity increases

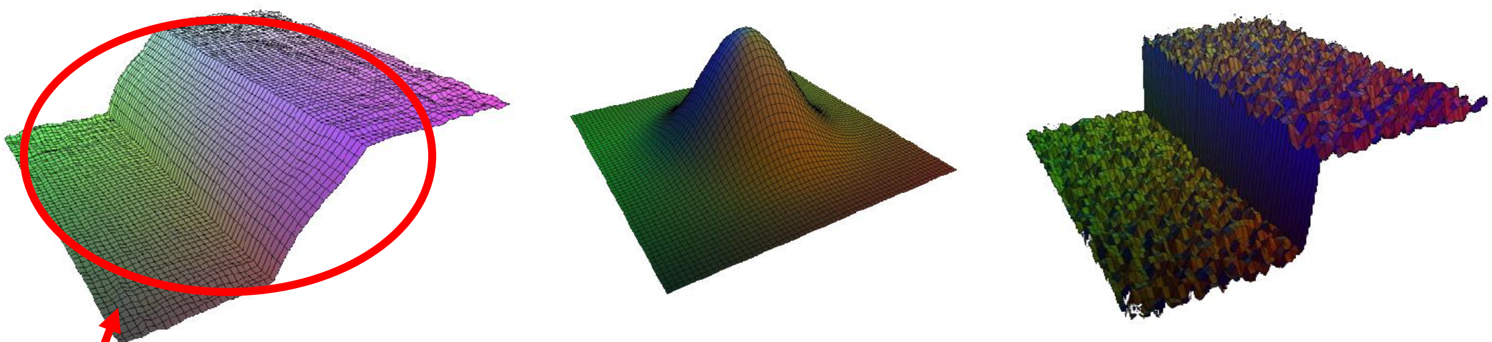
Automatic dodging-and-burning technique is more effective in preserving local details (notice the print in the book).

Bilateral Filtering

- **Edge preserving Gaussian filter to prevent halo**
- **Conceptually based on intrinsic image models:**
  - decoupling of illumination and reflectance layers
    - very simple task in CG
    - complicated for real-world scenes
  - compress range of illumination layer
  - preserve reflectance layer (details)
- **Bilateral filter separates:**
  - texture details (high frequencies, low amplitudes)
  - illumination (low frequencies, high contrast edges)

Illumination Layer (1)

- **Identify low frequencies in the scene**
  – Gaussian filtering leads to halo artifacts



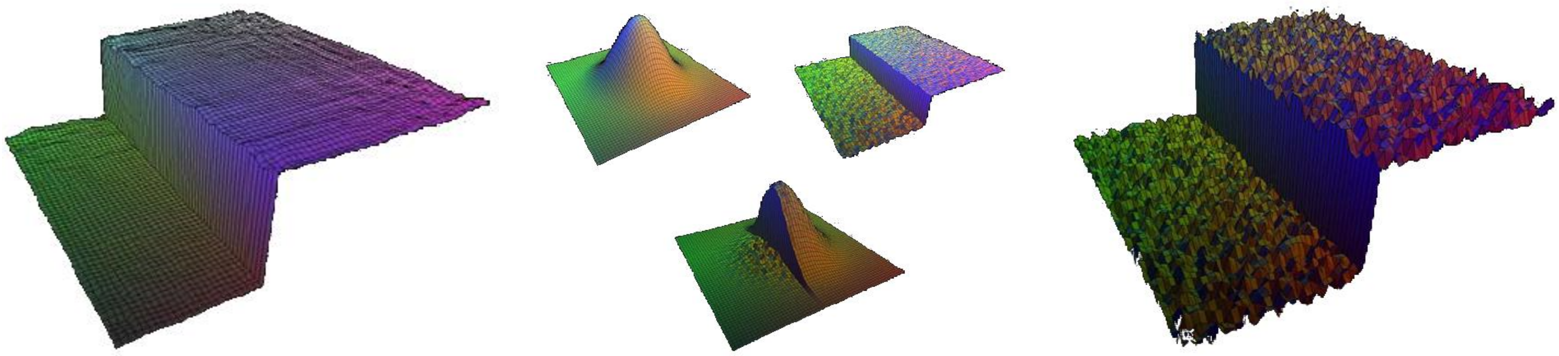
$$J_p = \frac{1}{W_p} \sum_{q \in N(p)} f_{\sigma_s}\left(\|p-q\|\right) \cdot I_q$$

f **spatial kernel with large** σ_s

lost sharp edge

Illumination Layer (2)

- **Edge preserving filter – no halo artifacts**

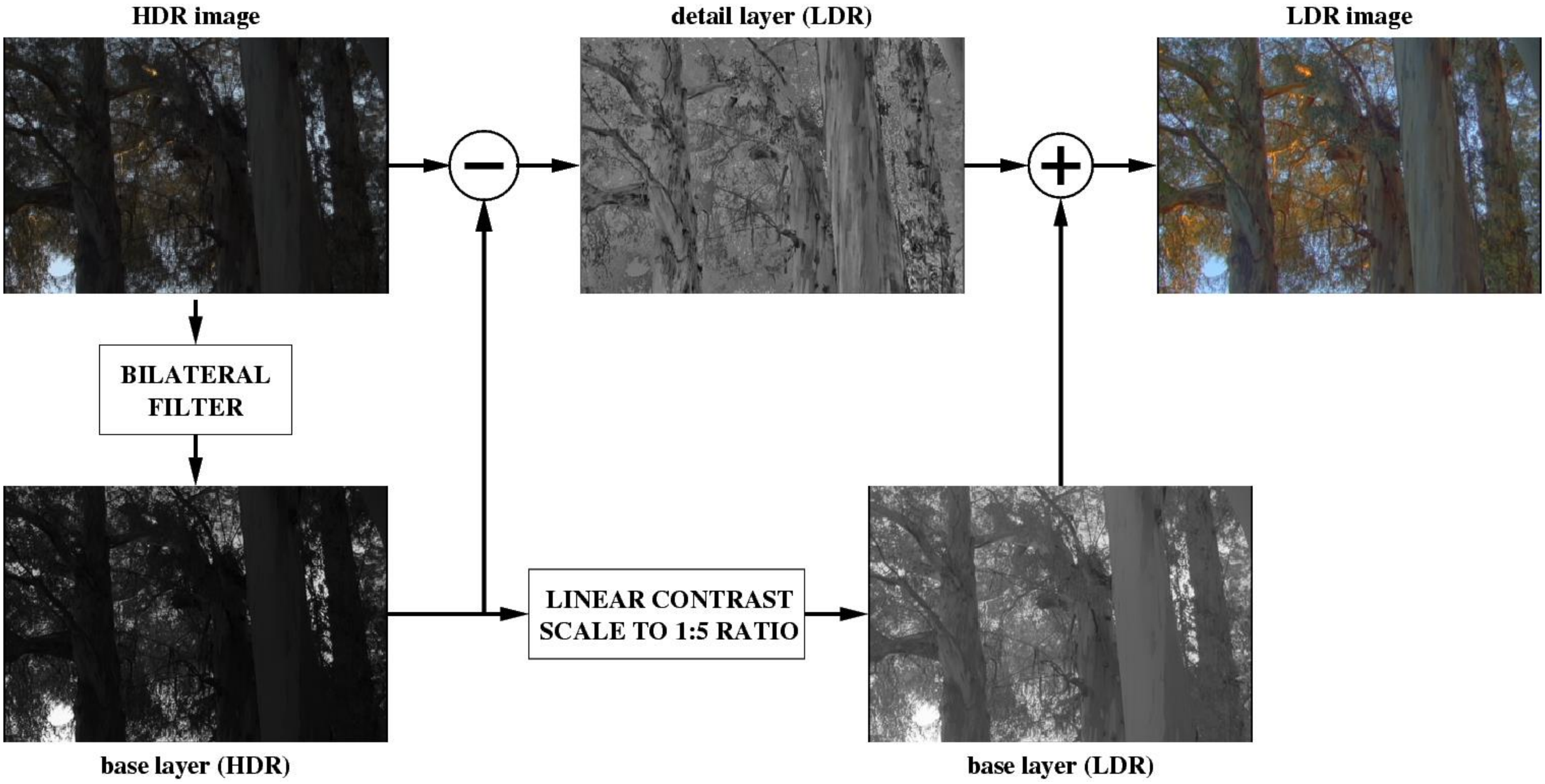


$$J_p = \frac{1}{W_p} \sum_{q \in N(p)} f_{\sigma_s}\left(\|p-q\|\right) \cdot g_{\sigma_r}\left(\left|I_p - I_q\right|\right) \cdot I_q$$

f **spatial kernel with large** σ_s

g **range kernel with very small** σ_r

Bilateral Filtering TMO



Luminance in logarithmic domain.

Illumination & Reflectance

base layer

detail layer

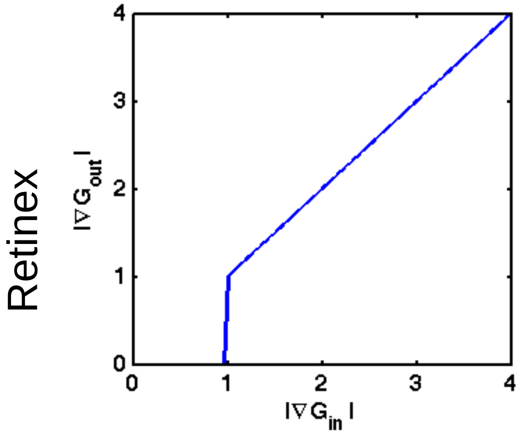
Alternative Approaches to TM

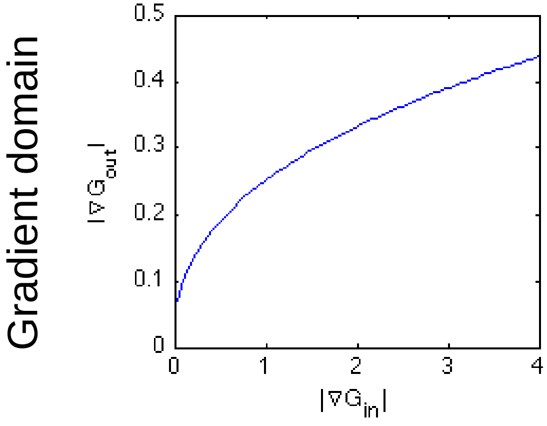
- **Gradient domain tone mapping**
  - transfer function for contrasts (not luminance)

Gradient Domain HDR Compression

[Fattal et al., SIGGRAPH 2002]

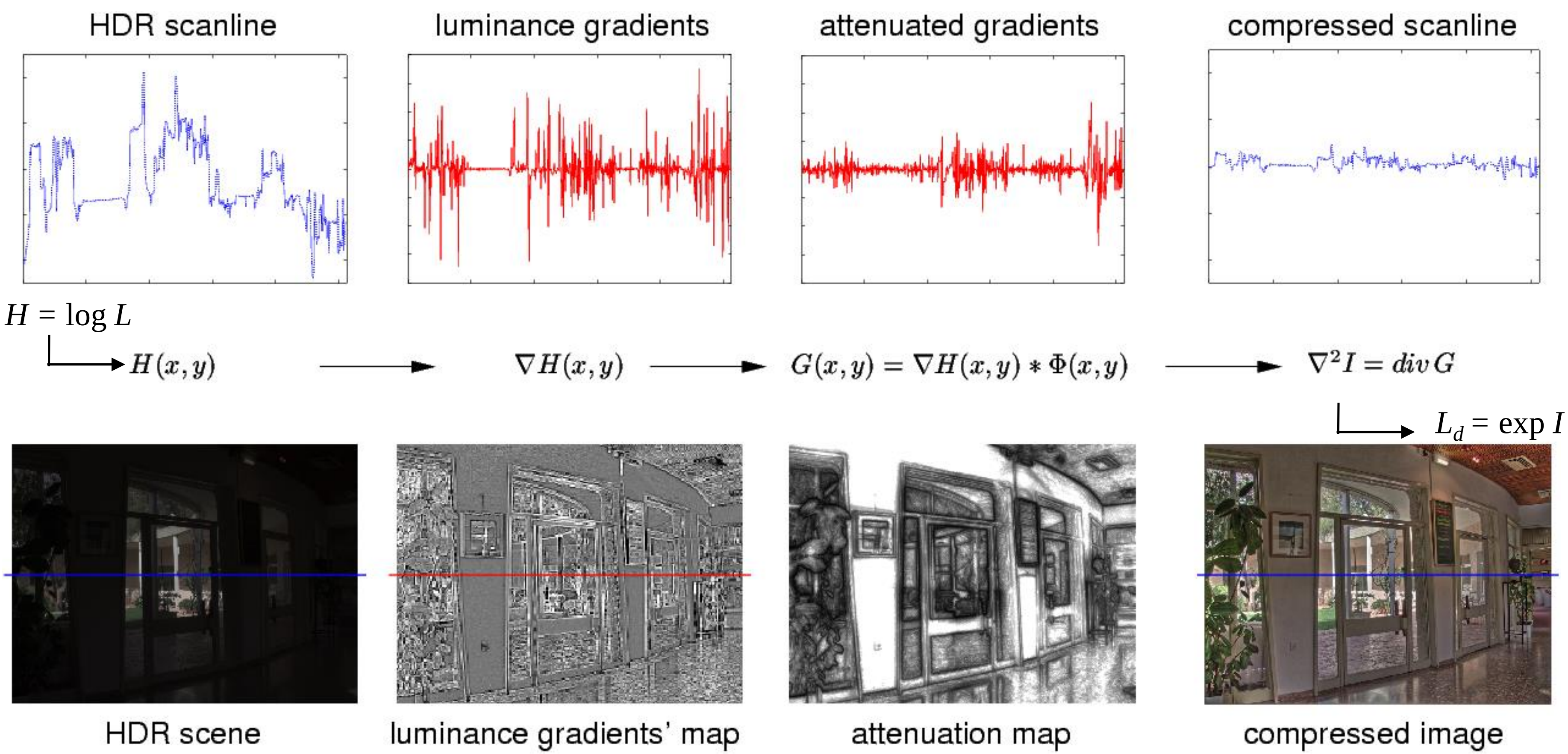
- Similarly to Retinex, it operates on log-gradients
- But the function amplifies small contrast instead of removing it





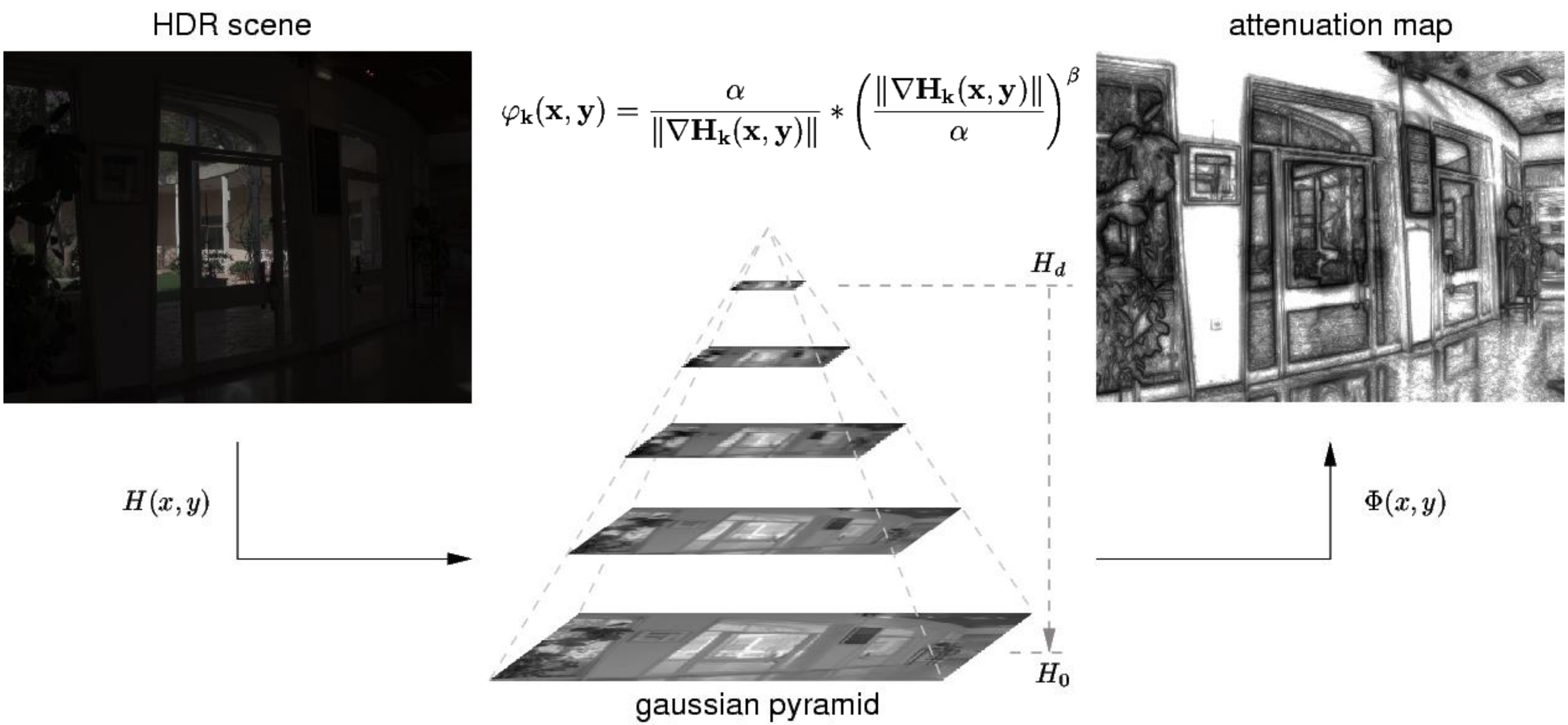
- **Contrast compression achieved by global contrast reduction**
- **Enhance reflectance, then compress everything**

Gradient Compression Algorithm



1. Calculate gradients map of image
2. Calculate attenuation map
3. Attenuate gradients
4. Solve Poisson equation to recover image

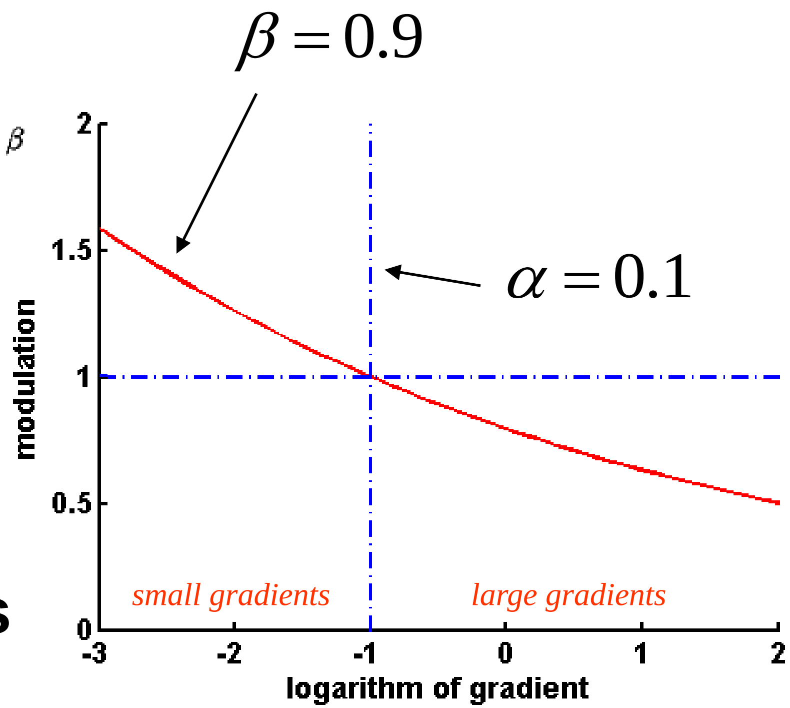
Attenuation Map



1. Create Gaussian pyramid
2. Calculate gradients on levels
3. Calculate attenuation on levels - φ_k
4. Propagate levels to full resolution

Transfer Function for Contrasts

$$\varphi_{\mathbf{k}}(\mathbf{x},\mathbf{y}) = \frac{\alpha}{\|\nabla \mathbf{H}_{\mathbf{k}}(\mathbf{x},\mathbf{y})\|} * \left(\frac{\|\nabla \mathbf{H}_{\mathbf{k}}(\mathbf{x},\mathbf{y})\|}{\alpha}\right)^{\beta}$$



- **Attenuate large gradients**
  - presumably illumination
- **Amplify small gradients**
  - hopefully texture details
  - but also noise

Global vs. Local Compression

Adaptive Logarithmic Mapping

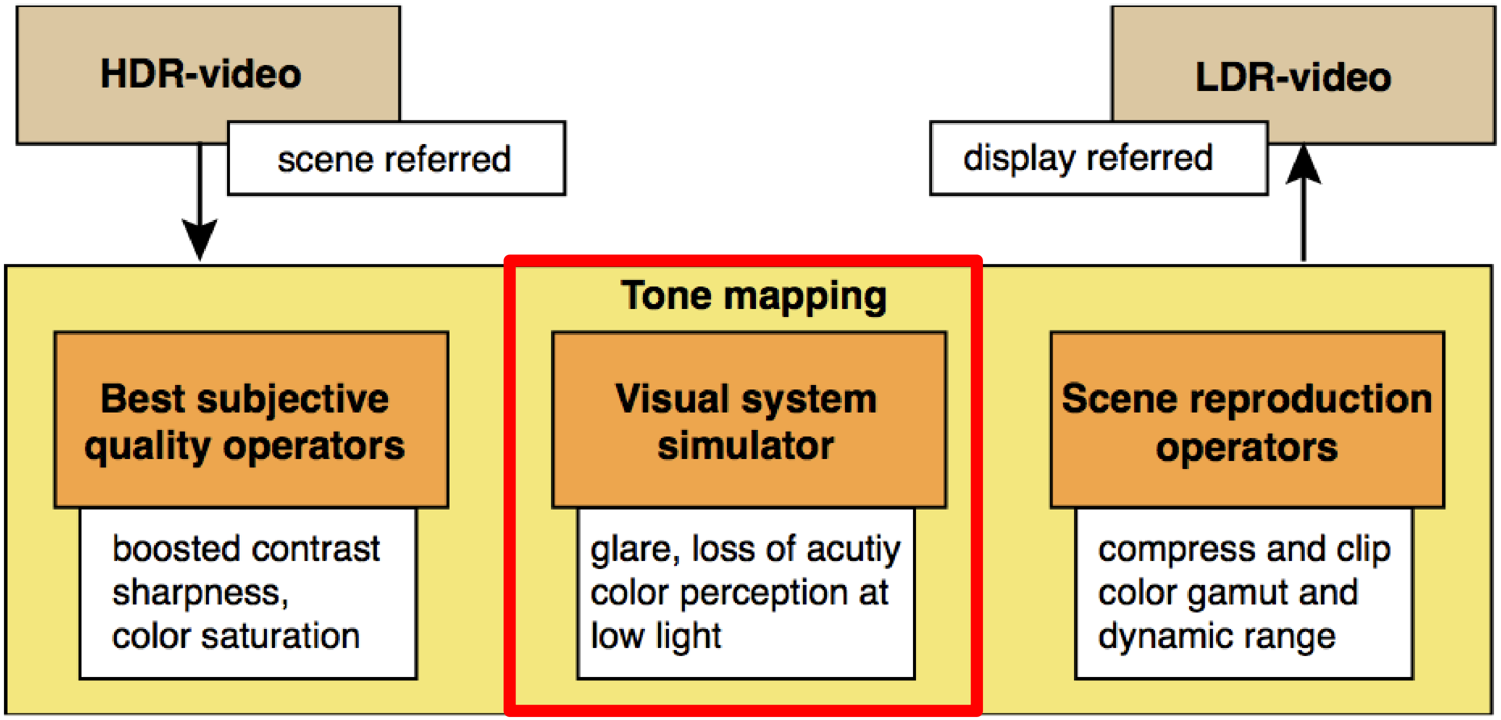
Gradient Domain Compression

- Loss of overall contrast
- Loss of texture details
- Real-time even on CPU
- Simple GPU implementation

- Impression of high contrast
- Good preservation of fine details
- Solving Poisson equation takes time
- On GPU ~10fps still possible

Three Intents of Tone-mapping

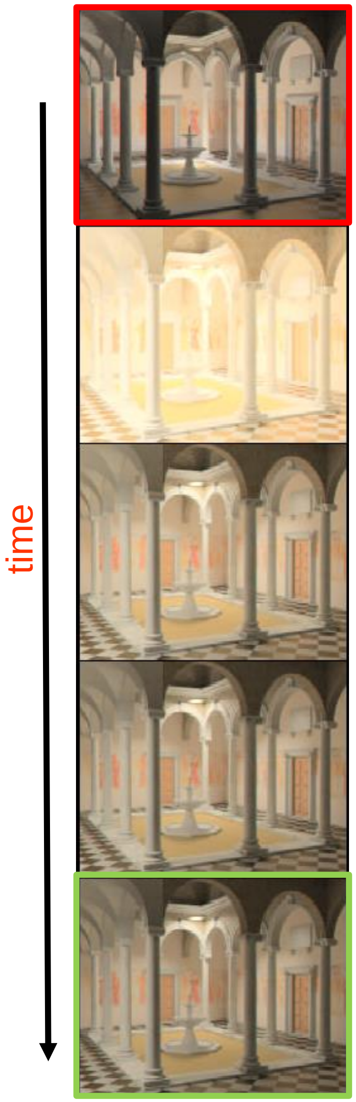
1. **Scene reproduction operator**
2. **Visual system simulator**
3. **Best subjective quality**



Perceptual Effects in TM

- **Simulate effects that do not appear on a screen but are typically observed in real-world scenes**
  – veiling glare
  – night vision
  – temporal adaptation to light
- **Increase believability of results, because we associate such effects with luminance conditions**

Temporal Luminance Adaptation

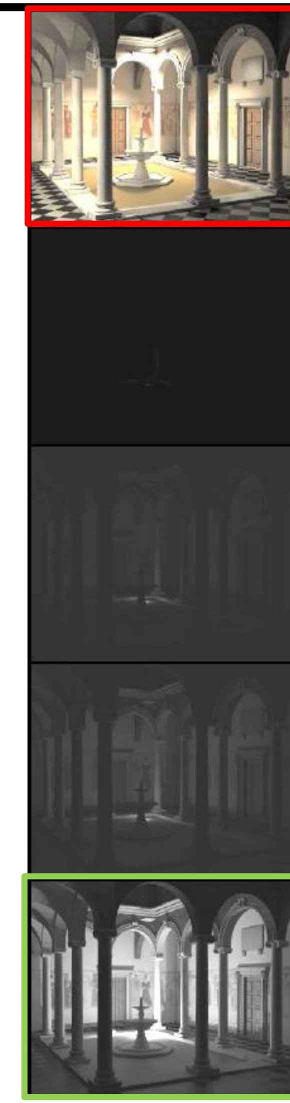


fully adapted

- **Compensates changes in illumination**
- **Simulated by smoothing adapting luminance in tone mapping equation**
- **Different speed of adaptation**

  ← to light (seconds)

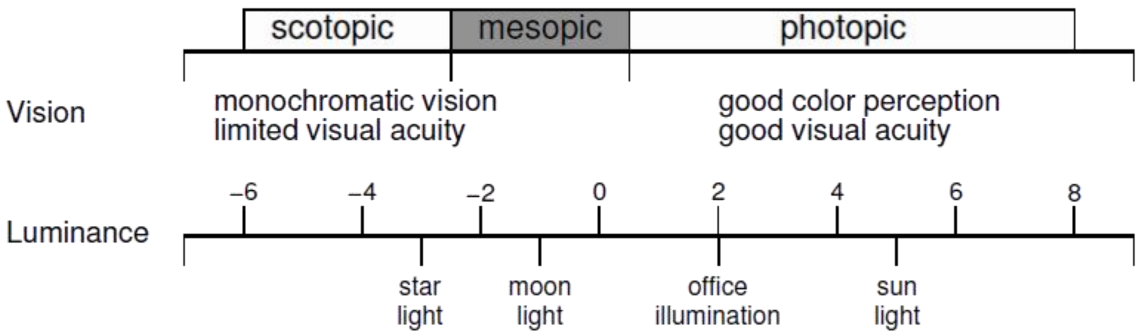
  to darkness (minutes) →



fully adapted

Night Vision

- **Human Vision operates in three distinct adaptation conditions:**

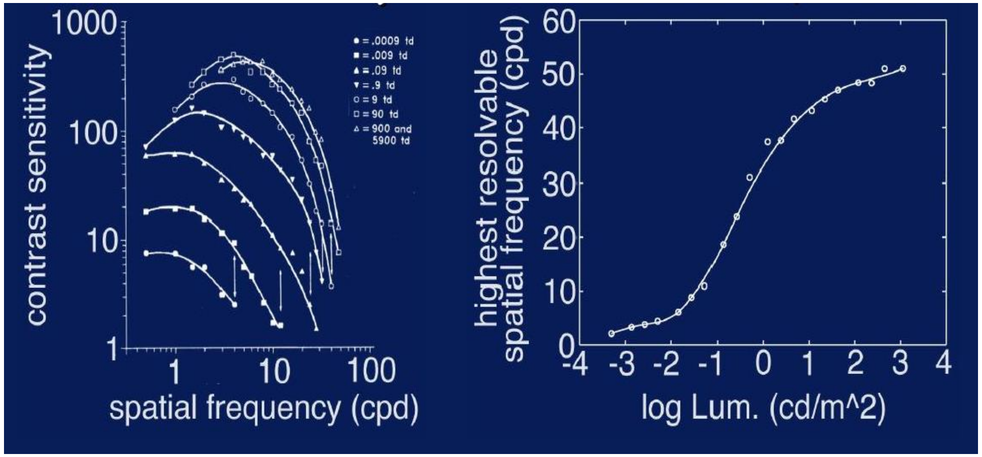


Visual Acuity

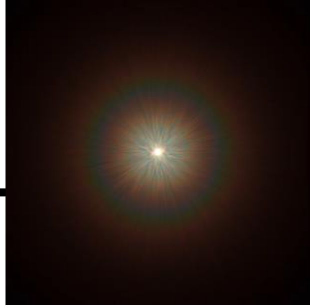
- **Perception of spatial details is limited with decreasing illumination level**

- **Details can be removed using convolution with a Gaussian kernel**
- **Highest resolvable spatial frequency:**

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



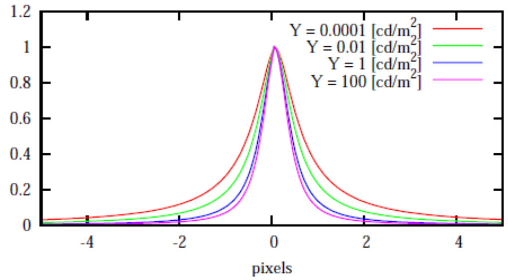
Veiling Luminance (Glare)

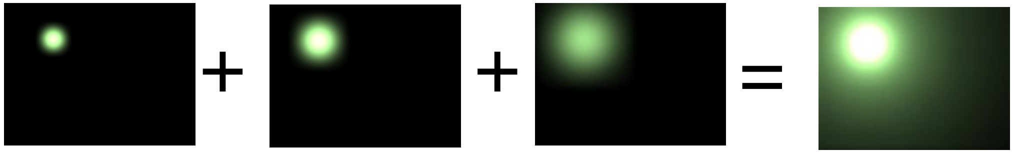


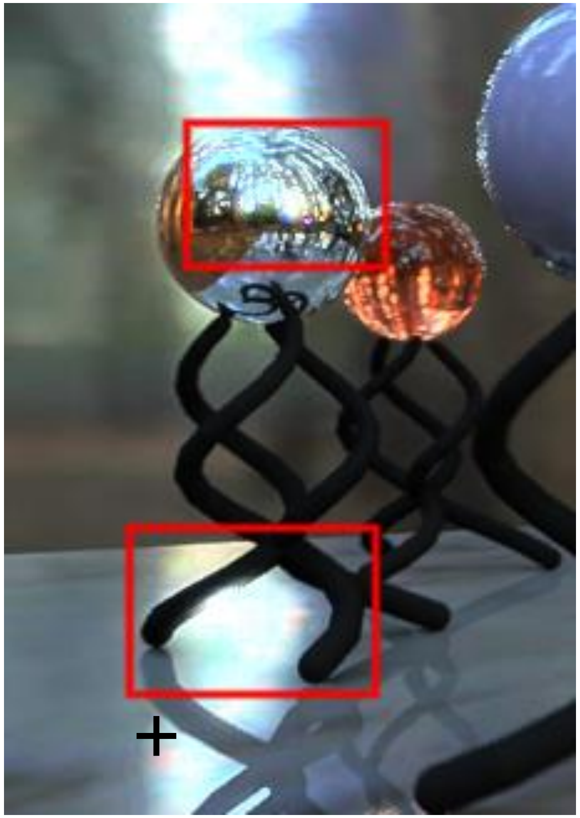
- **Decrease of contrast and visibility due to light scattering in the optical system of the eye**
- **Described by the optical transfer function:**

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

ρ spatial frequency, d pupil aperture

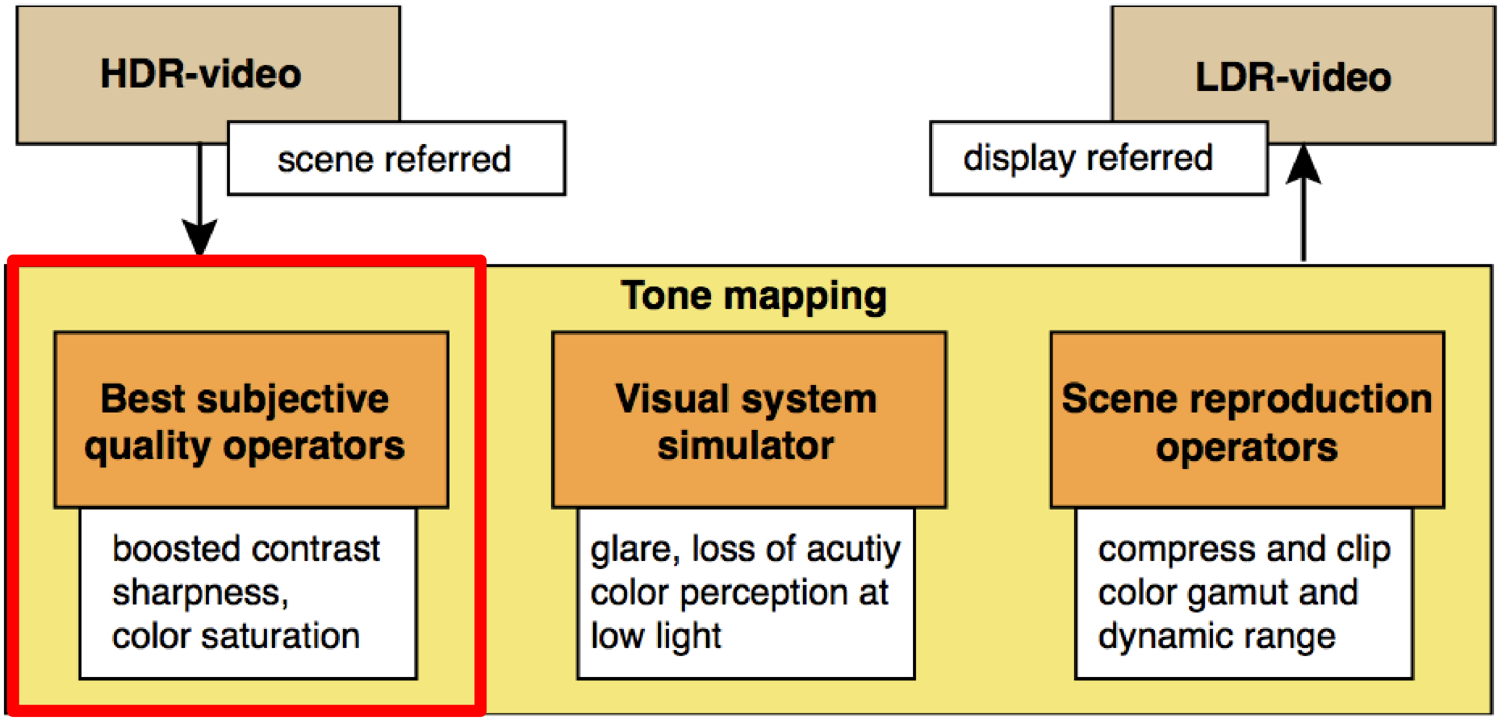




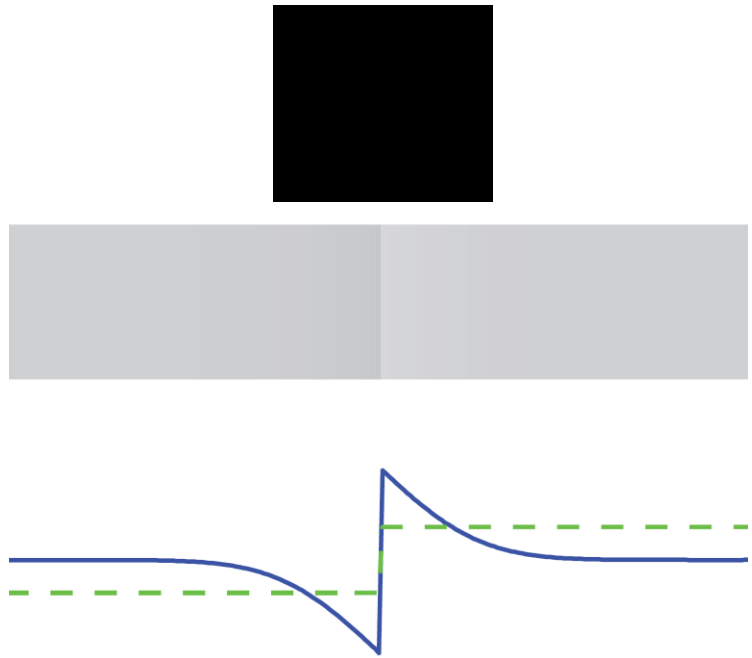


Three Intents of Tone-mapping

1. **Scene reproduction operator**
2. **Visual system simulator**
3. **Best subjective quality**

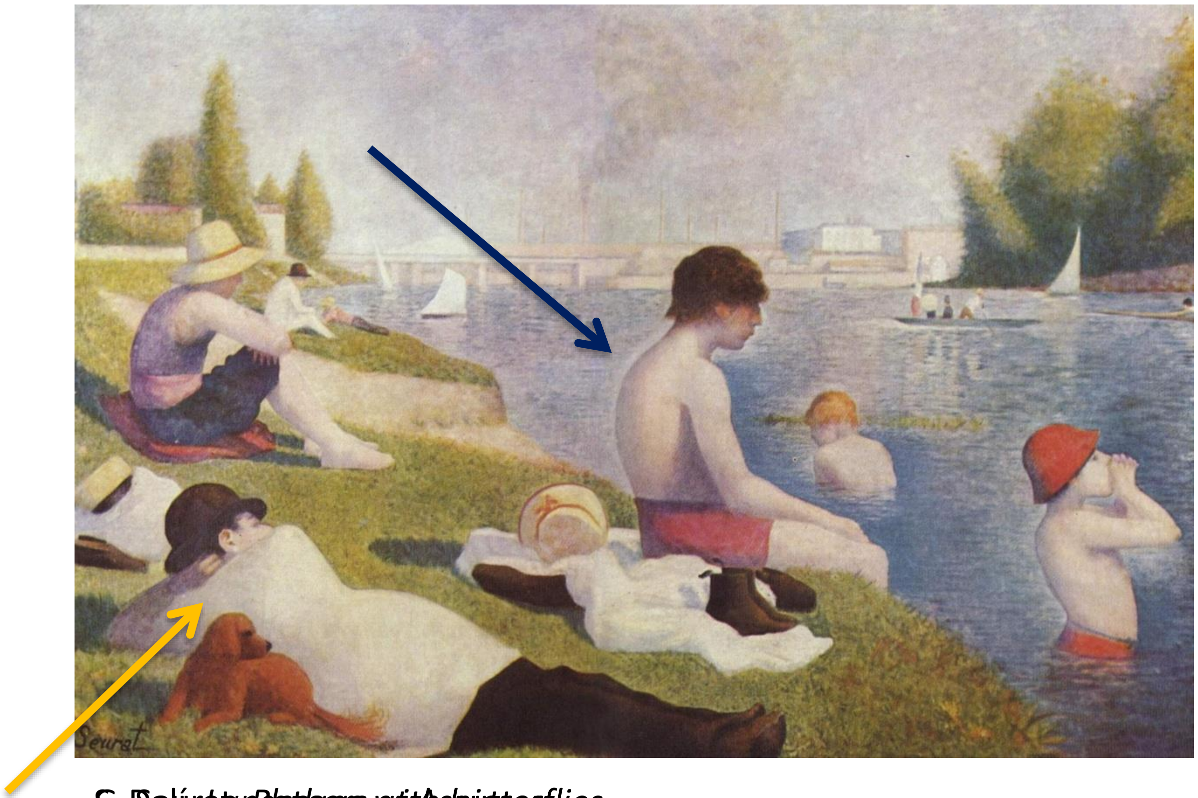


Cornsweet Illusion: Revisited



Apparent Contrast Enhancement

Usage Examples From Art



G. Seurat, *Bathers at Asnières*
S. Dalí, *Landscape with butterflies*

Contrast Enhancement: Motivation

HDR image (reference real world contrast)

restore missing contrast

tone mapping result (displayed image)

- **Usual contrast enhancement techniques**
  - either enhance everything
  - require manual intervention
  - change image appearance
- **Tone mapping often gives numerically optimal solution**
  - no dynamic range left for enhancement

Krawczyk et al. EG2007

Contrast Enhancement: Overview

Reference HDR Image

Measure Lost Contrast at Several Feature Scales

Tone Mapped Image

Enhance Lost Contrast in Tone Mapped Image

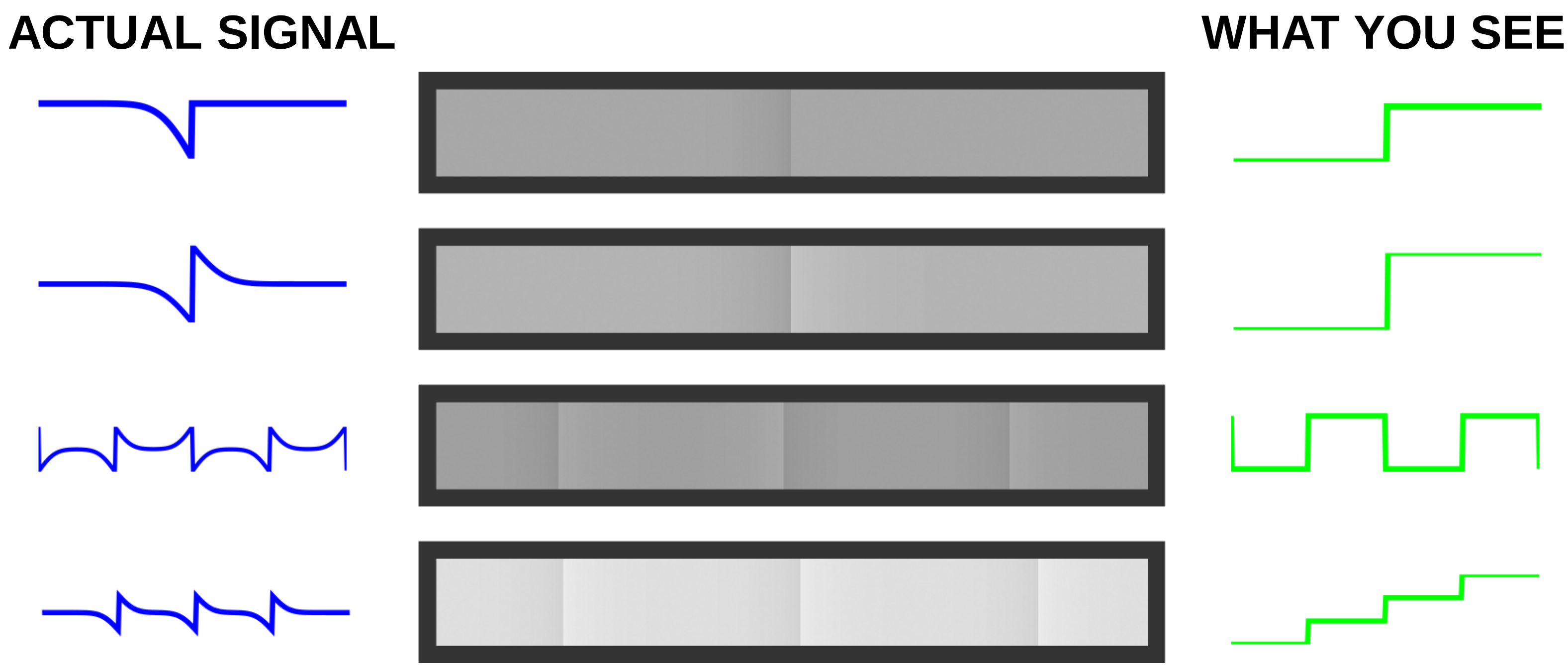
Enhanced TM Image

communicate lost image contents

maintain image appearance

Krawczyk et al. EG2007

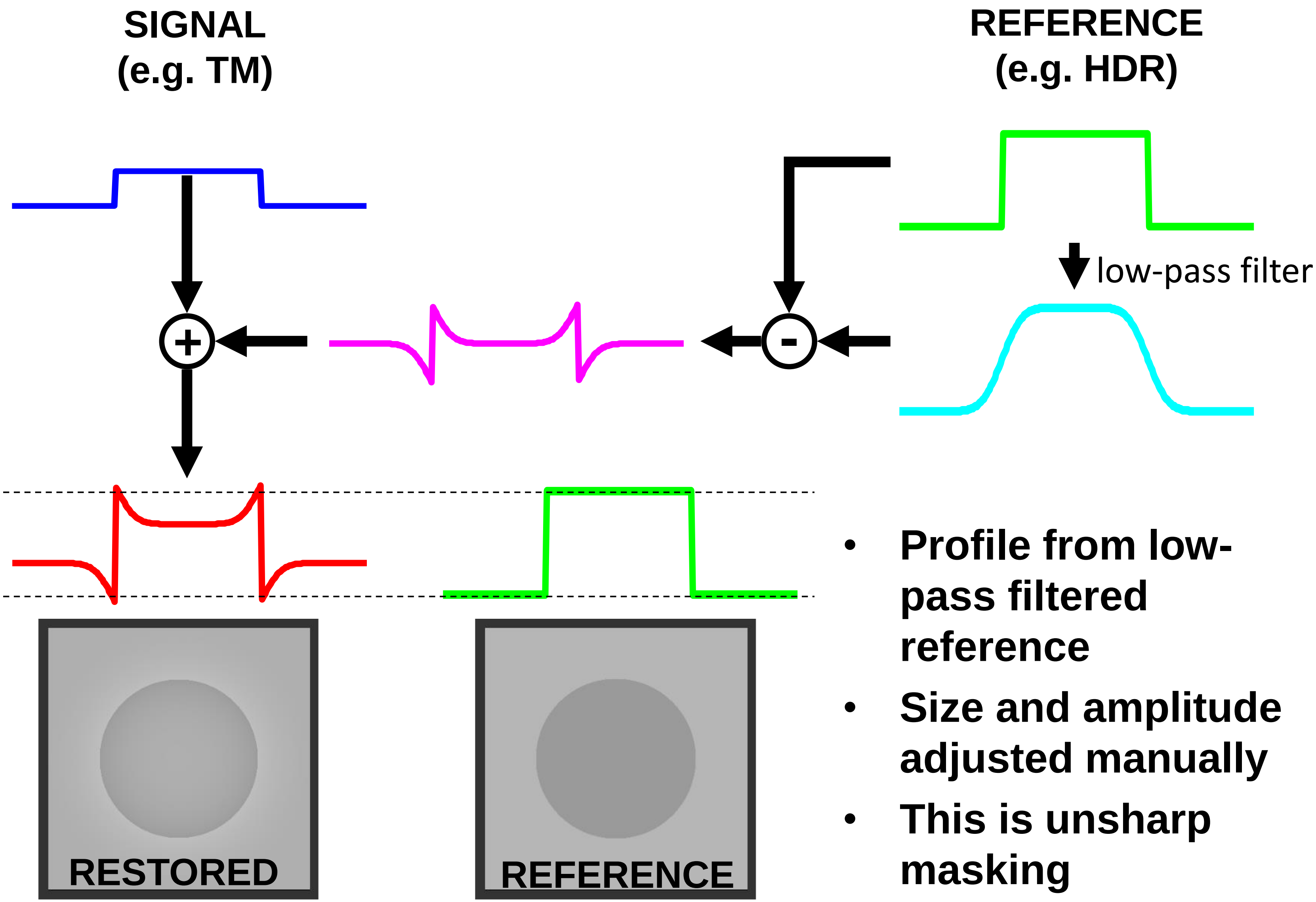
Details of Contrast Illusion



1. **Contrast between areas caused by luminance profiles**
2. **Properties:**
   - shape of the profile matches the shape of the enhanced feature
   - amplitude of the profile defines the perceived contrast
   - noise (texture) does not cancel the illusion
   - profiles should not be look objectionable

Krawczyk et al. EG2007

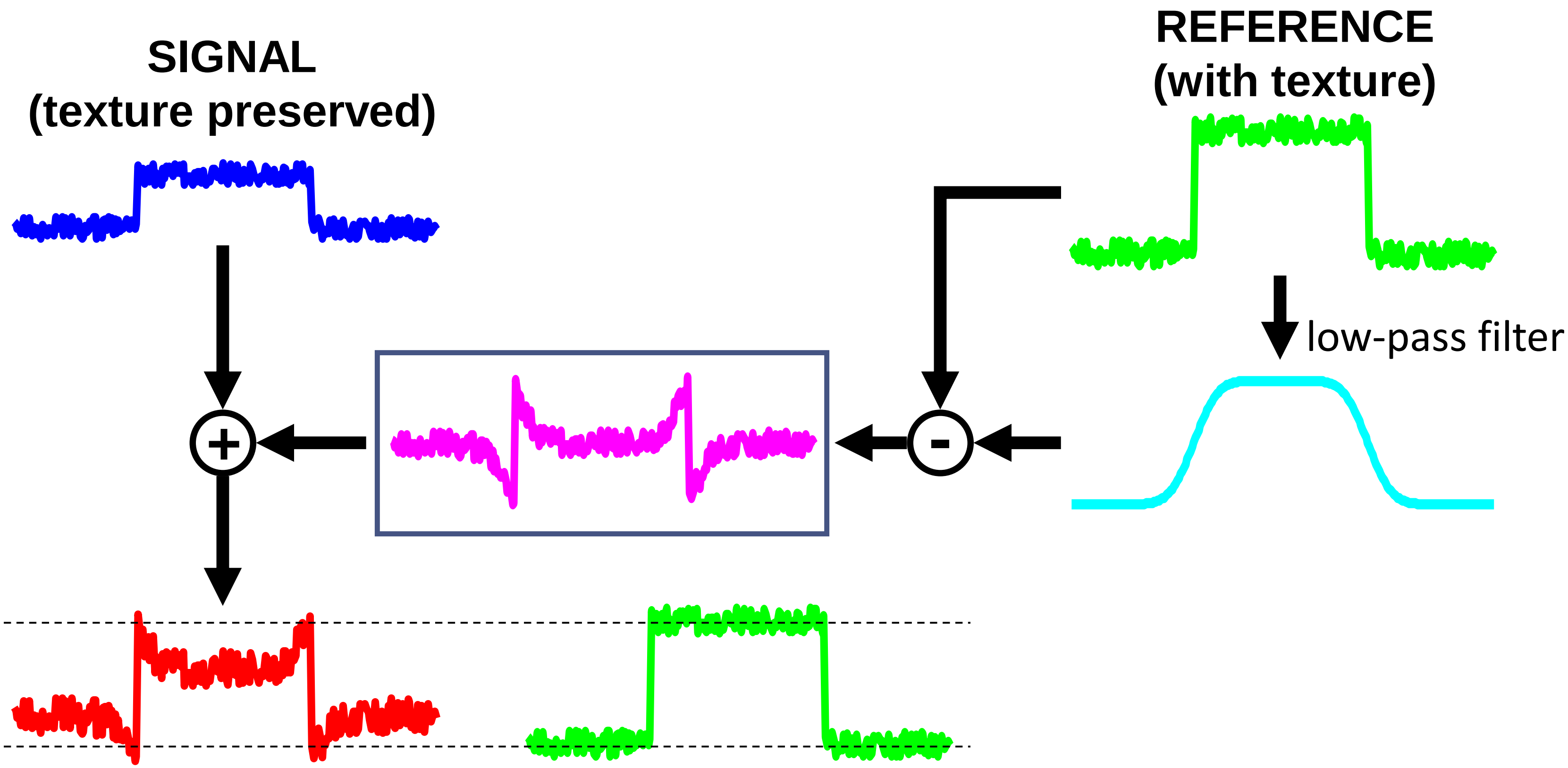
Construction of Simple Profile (1/2)



- **Profile from low-pass filtered reference**
- **Size and amplitude adjusted manually**
- **This is unsharp masking**

Krawczyk et al. EG2007

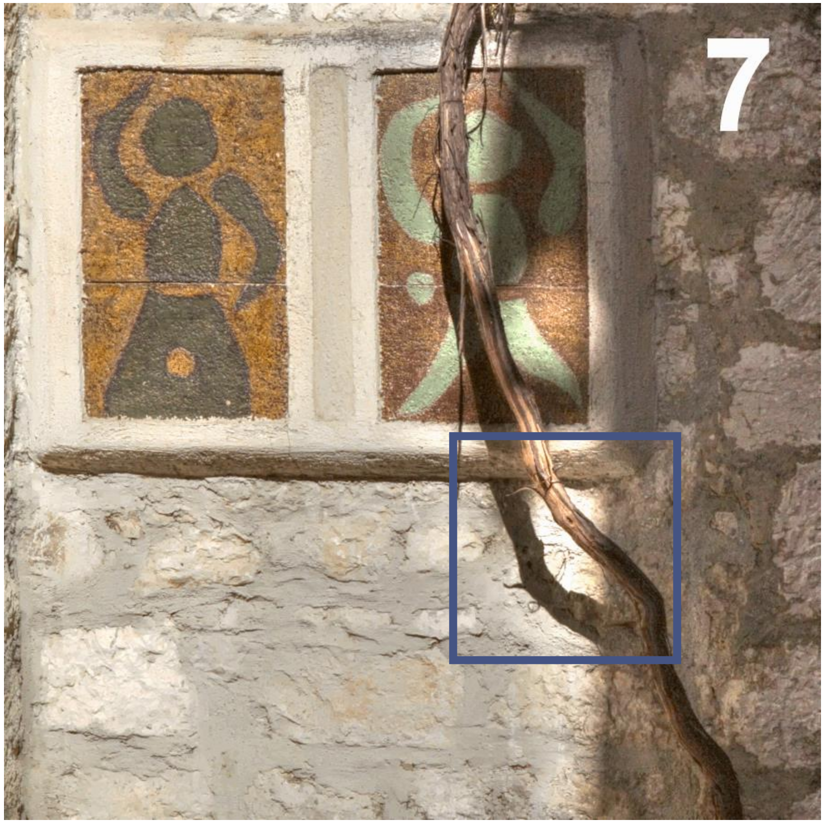
Construction of Simple Profile (2/2)



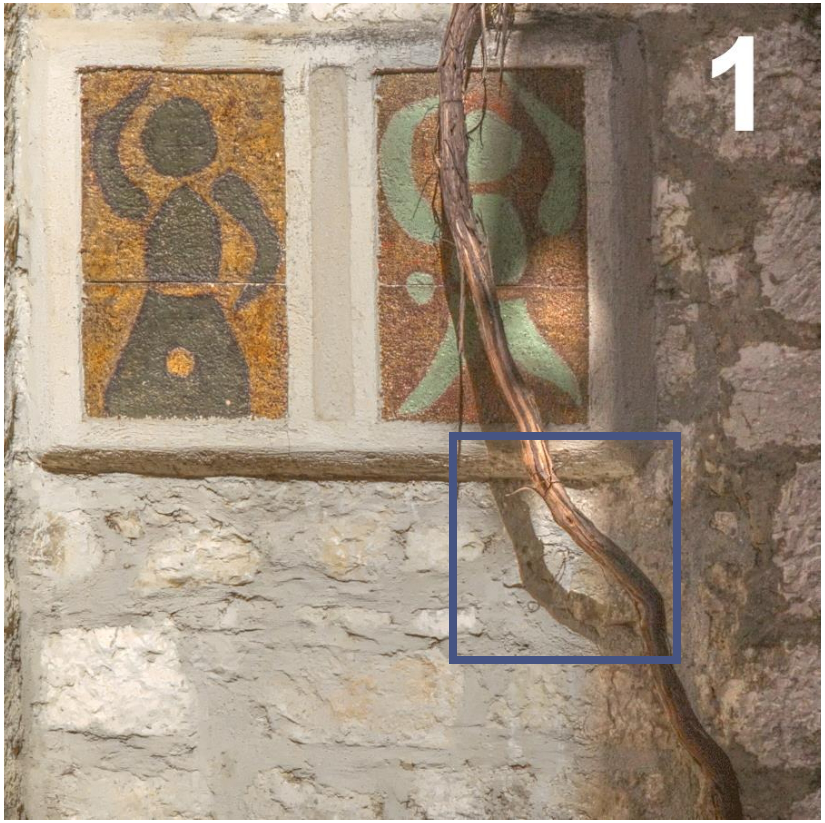
Well preserved signal is exaggerated by unsharp masking

Krawczyk et al. EG2007

Adaptive Countershading



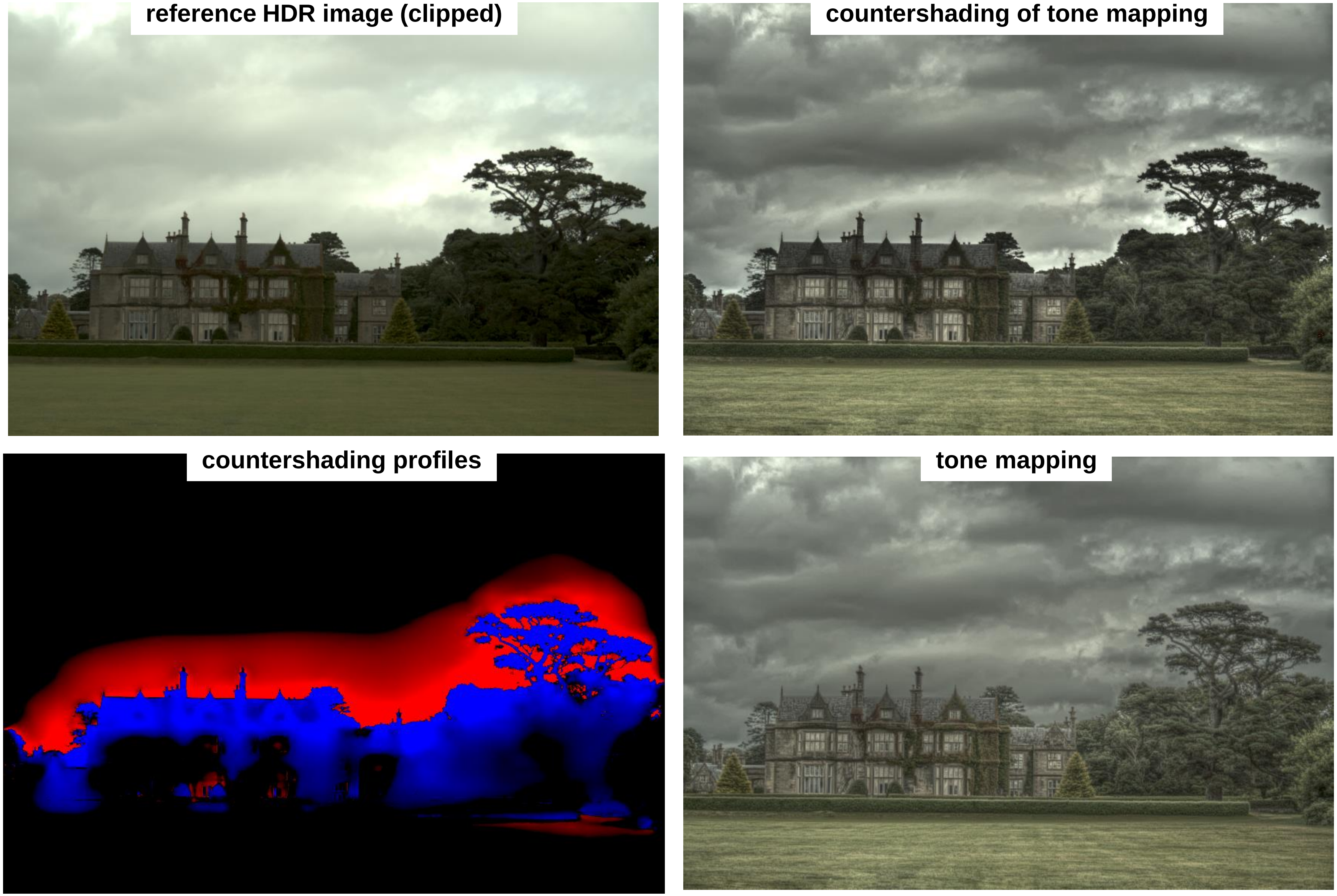
final contrast restoration



progress of restoration

Objectionable visibility of countershading profiles

Restoration of TM Images



C-shading vs. Unsharp Mask

adaptive countershading

unsharp masking

tone mapping

Krawczyk et al. EG2007

Enhanced Text Contrast in the Shadow

3D unsharp masking

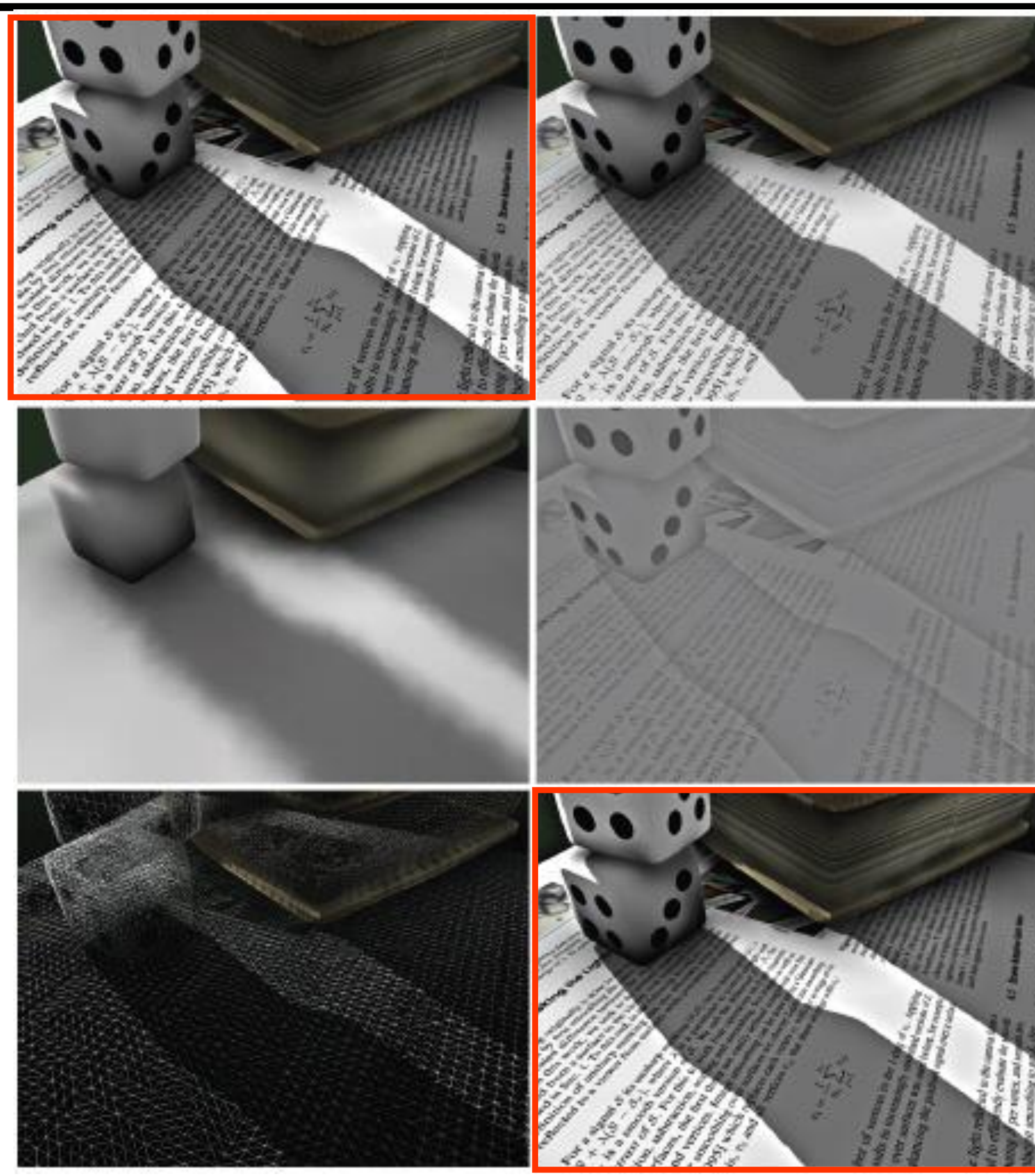
Original image

3D blurred signal

Enhancement signal

Mesh

2D unsharp masking



Ritschel et al. SIG2008

Unsharp Masking, Countershading and Haloes: Enhancements or Artifacts?

- **Same countershading operation is perceived differently, depending on parameter choice**
- **Some parameters increase sharpness or contrast**
- **But other choices can introduce haloes**

Sharpeness

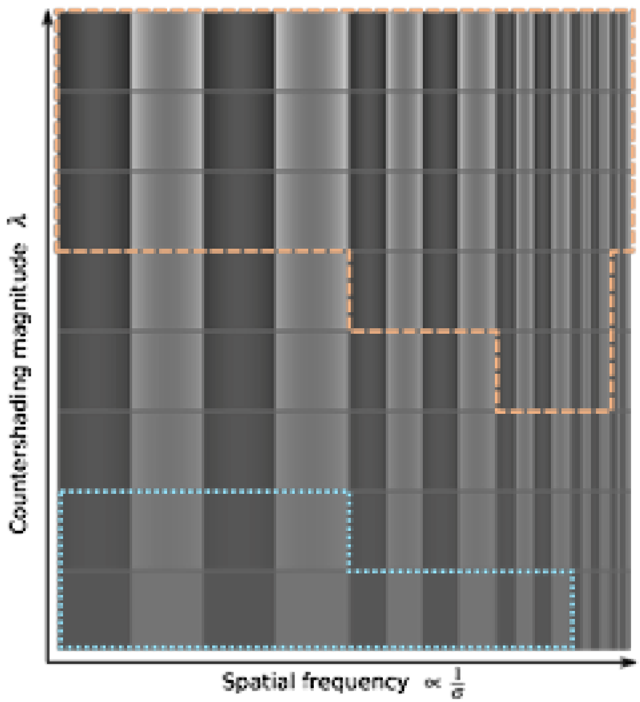
Contrast

Haloes

Trentacoste et al. EG2012

Model of Acceptable Countershading

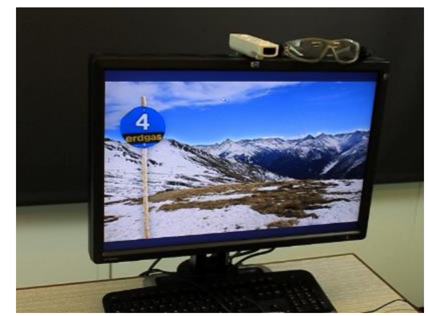
Objectionable countershading (halos)



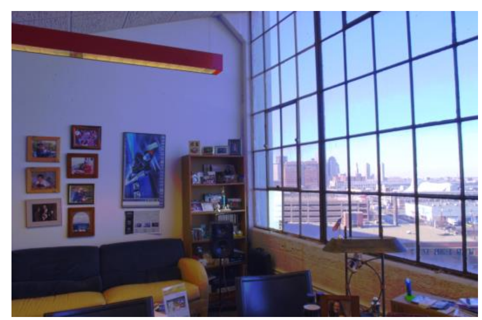
Indistinguishable countershading (halos)

Applications

Image resizing



Viewer-adaptive display



Tone mapping

Papers on Tone Mapping/Enhancements

Wiley Encyclopedia of Electrical and Electronics Engineering

- **High Dynamic Range Imaging; http://www.cl.cam.ac.uk/~rkm38/hdri_book.html**
  - R.K. Mantiuk, K. Myszkowski and H.-P. Seidel

Articles:

- **Adaptive Logarithmic Mapping for Displaying High Contrast Scenes**
  - F. Drago, K. Myszkowski, T. Annen, and N. Chiba
  - In: Eurographics 2003
- **Photographic Tone Reproduction for Digital Images**
  - E. Reinhard, M. Stark, P. Shirley, and J. Ferwerda
  - In: SIGGRAPH 2002 (ACM Transactions on Graphics)
- **Fast Bilateral Filtering for the Display of High-Dynamic-Range Images**
  - F. Durand and J. Dorsey
  - In: SIGGRAPH 2002 (ACM Transactions on Graphics)
- **Gradient Domain High Dynamic Range Compression**
  - R. Fattal, D. Lischinski, and M. Werman
  - In: SIGGRAPH 2002 (ACM Transactions on Graphics)
- **Dynamic Range Reduction Inspired by Photoreceptor Physiology**
  - E. Reinhard and K. Devlin
  - In IEEE Transactions on Visualization and Computer Graphics, 2005
- **Time-Dependent Visual Adaptation for Realistic Image Display**
  - S.N. Pattanaik, J. Tumblin, H. Yee, and D.P. Greenberg
  - In: Proceedings of ACM SIGGRAPH 2000
- **Lightness Perception in Tone Reproduction for High Dynamic Range Images**
  - G. Krawczyk, K. Myszkowski, H.-P. Seidel
  - In: Eurographics 2005

Papers on Tone Mapping/Enhancements

- **Perceptual Effects in Real-time Tone Mapping**
  - G. Krawczyk, K. Myszkowski, H.-P. Seidel
  - In: Spring Conference on Computer Graphics, 2005
- **Contrast Restoration by Adaptive Countershading**
  - Grzegorz Krawczyk, Karol Myszkowski, Hans-Peter Seidel,
  - In: EUROGRAPHICS 2007
- **3D Unsharp Masking for Scene Coherent Enhancement**
  - Tobias Ritschel, Kaleigh Smith, Matthias Ihrke, Thorsten Grosch, Karol Myszkowski, Hans-Peter Seidel:
  - In: SIGGRAPH 2008 (ACM Transactions on Graphics)