# HDR Capture and Tone Mapping

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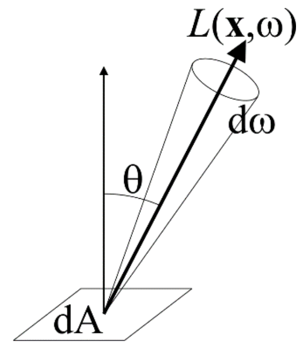
# LDR vs HDR – Comparison

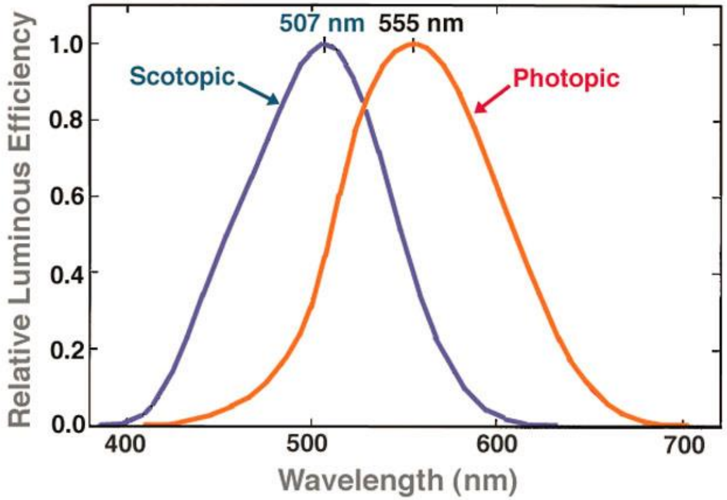
| Standard Dynamic Range | | High Dynamic Range |
|---|---|---|
|  | QUALITY OF CONTRAST & COLOR |  |
| 50 dB | Camera Dynamic Range | 120 dB |
| 1:200 | Display Contrast | 1:15.000 |
| limited | Color Gamut | vivid and saturated colors |
| display-referred | Image Representation | scene-referred |
| display limited | Fidelity | as good as the eye can see |

# Luminance

– Physically:




$$L_v = \frac{d^2\Phi_v}{dA\, d\Omega \cos\theta}$$ [nit=cd/m²]




  - luminous power [lm] per unit solid angle per unit area
  - analogous to “what we see with our eyes”
  - photometric analog of radiance (weighted by luminous efficiency function)

– In color science: weighted sum of **linear** RGB

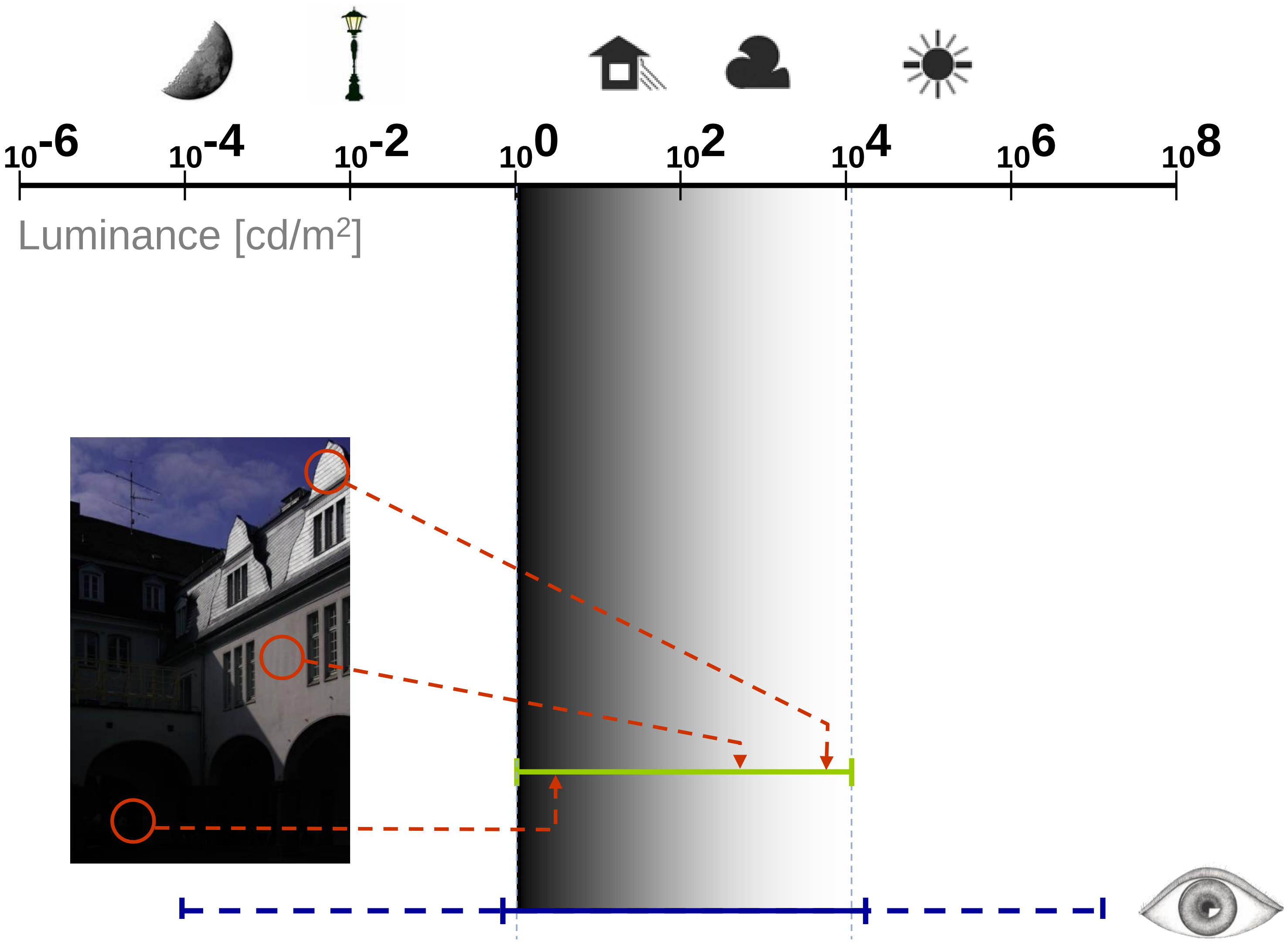
  - Y = 0.2126 R + 0.7152 G + 0.0722 B

- Luma

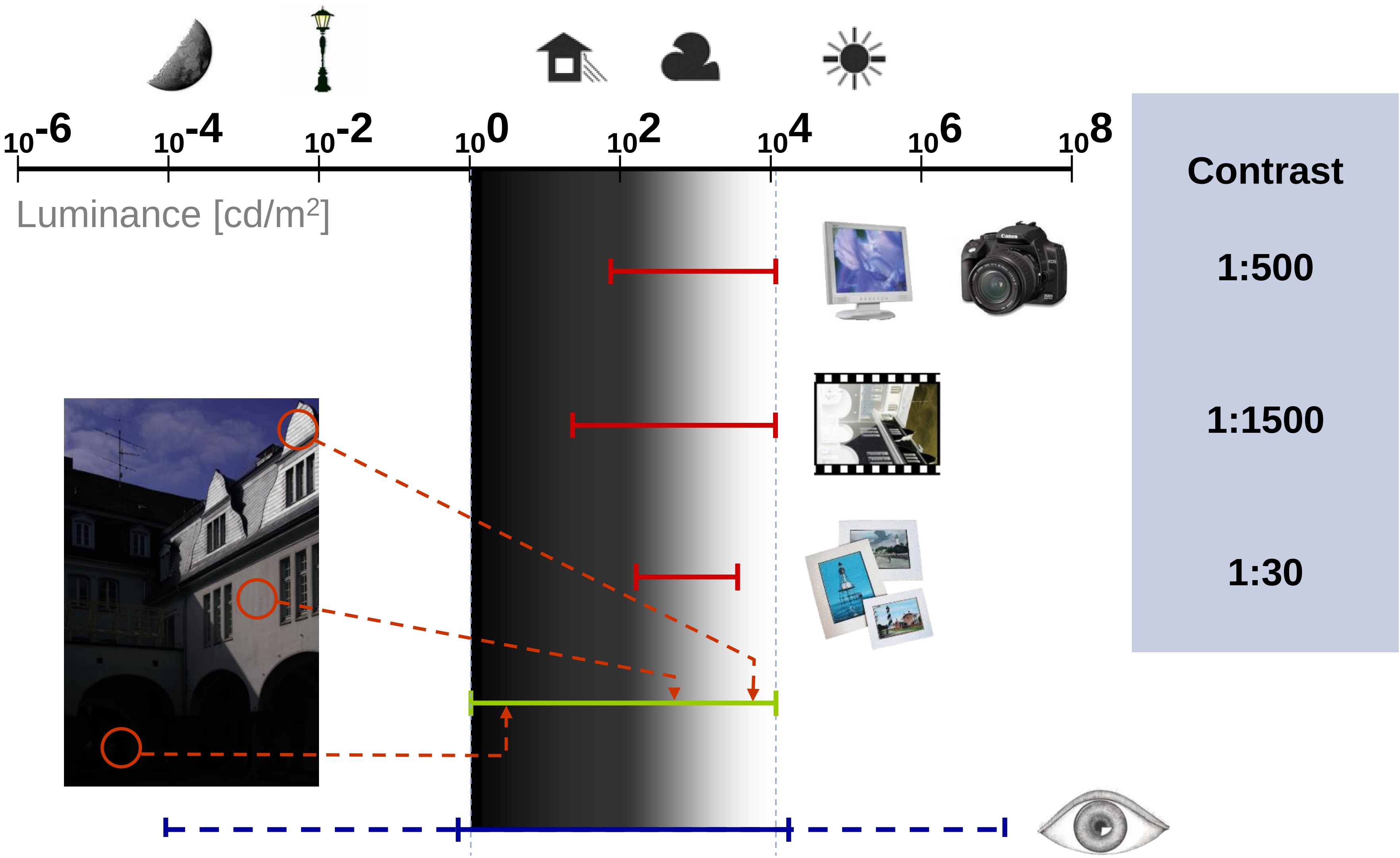
– Weighted sum of **gamma corrected** (nonlinear) RGB

  - Y' = 0.2126 R' + 0.7152 G' + 0.0722 B'

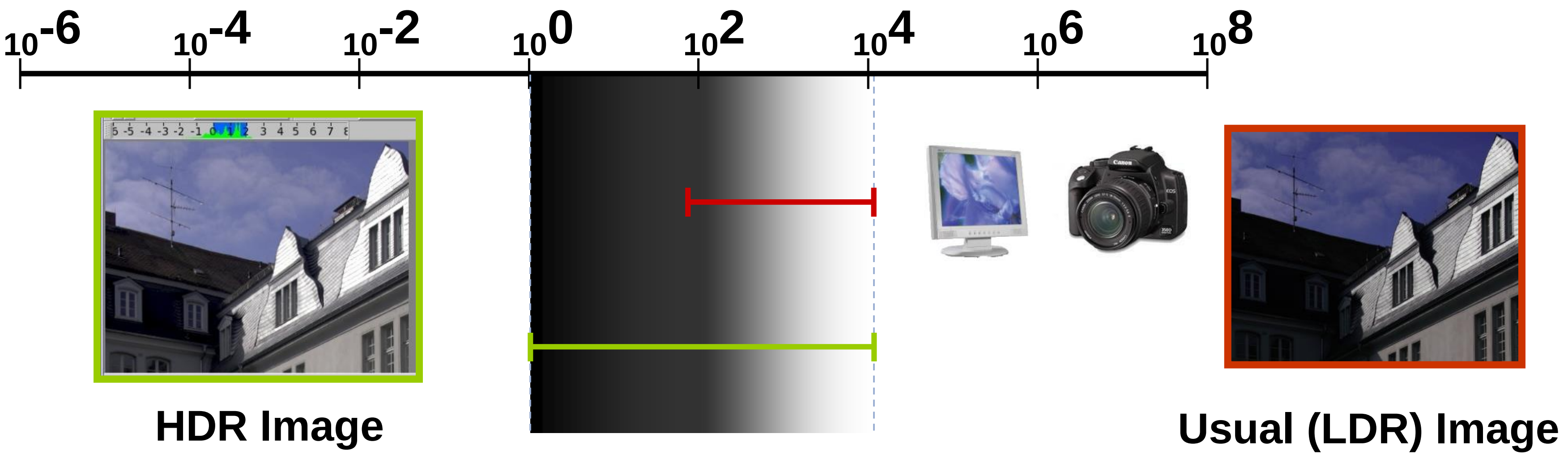
# Various Dynamic Ranges (1)



# Various Dynamic Ranges (2)



# High Dynamic Range



# Measures of Dynamic Range

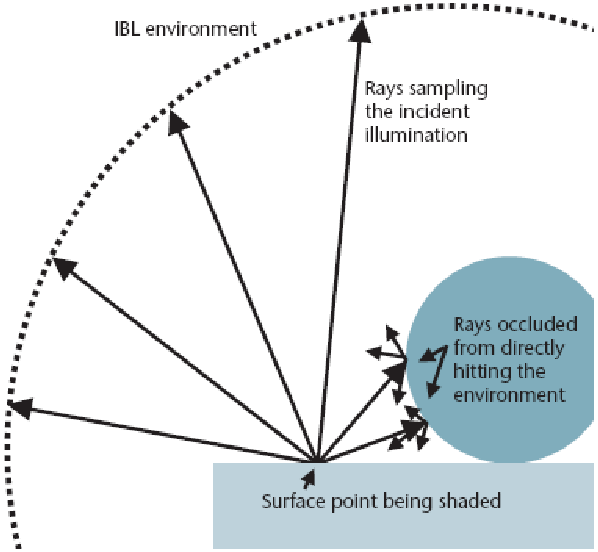
| | | |
|---|---|---|
| Contrast ratio | $\mathbf{CR = 1 : (Y_{peak}/Y_{noise})}$ | displays<br>(e.g., 1:500 ) |
| Orders of magnitude | $\mathbf{M = \log_{10}(Y_{peak})\text{-}\log_{10}(Y_{noise})}$ | HDR imaging<br>(= 2.7 orders) |
| Exposure latitude (f-stops) | $\mathbf{L = \log_{2}(Y_{peak})\text{-}\log_{2}(Y_{noise})}$ | photography<br>(= 9 f-stops) |
| Signal to noise ratio (SNR) | $\mathbf{SNR = 20*\log_{10}(A_{peak}/A_{noise})}$ | digital cameras<br>(= 53 [dB]) |

# Motivation

- real world is HDR!
- physically-based rendering outputs
- photography
- digital cinema
- games (explosions are really HDR ☺), video [1:04]
- ...

# HDR Applications

- Image-Based Lighting
  - [Debevec 98]
  - using HDR radiance maps to objects
  - RNL – **video1**, **video2**




# HDR Applications

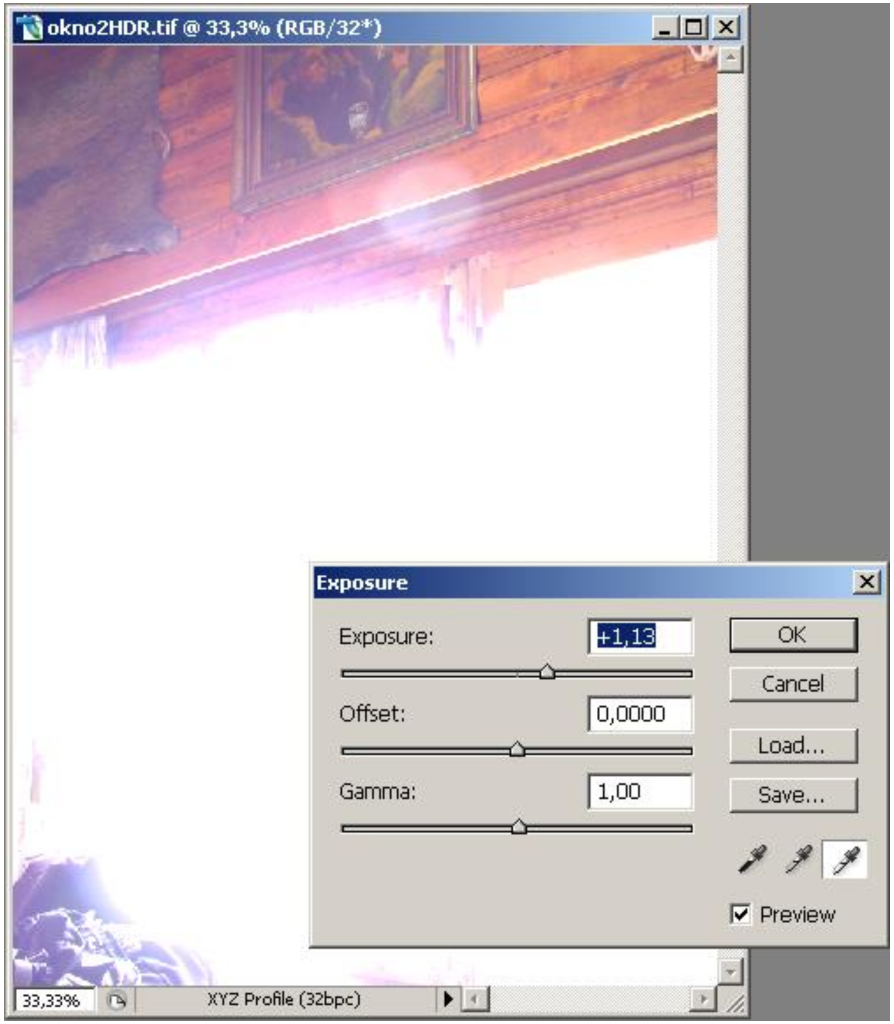
- physically-based rendering (global illumination)
- image-based rendering and modeling
- HDR panoramic imaging
- visualization (i.e. medical imaging)
- computer vision (algorithms may perform better)
- human vision simulation and psychophysics

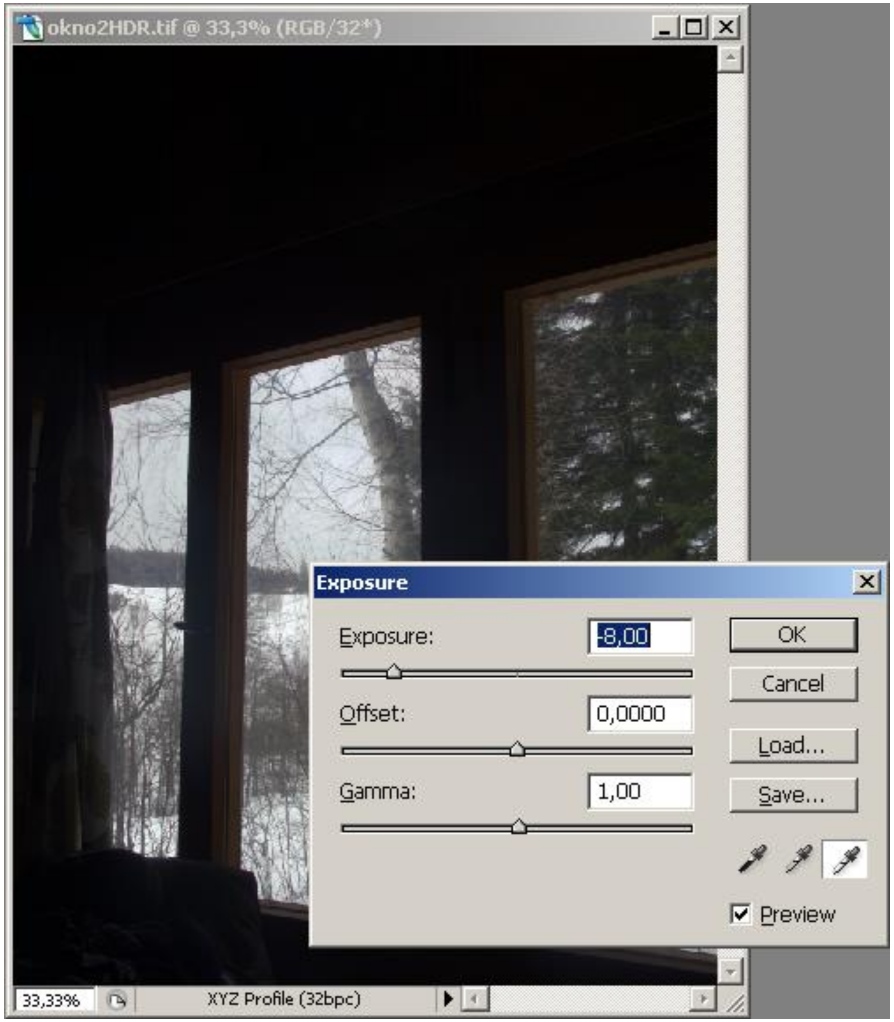
# HDR Applications

- digital photography in PS
  - HDR first in version: 9.0 (CS2)
  - 32 bits-per-channel HDR images
  - Merge To HDR command
  - Photoshop (PSD, PSB), Radiance (HDR), Portable Float Map (PFM), OpenEXR, TIFF (LogLuv just reads)

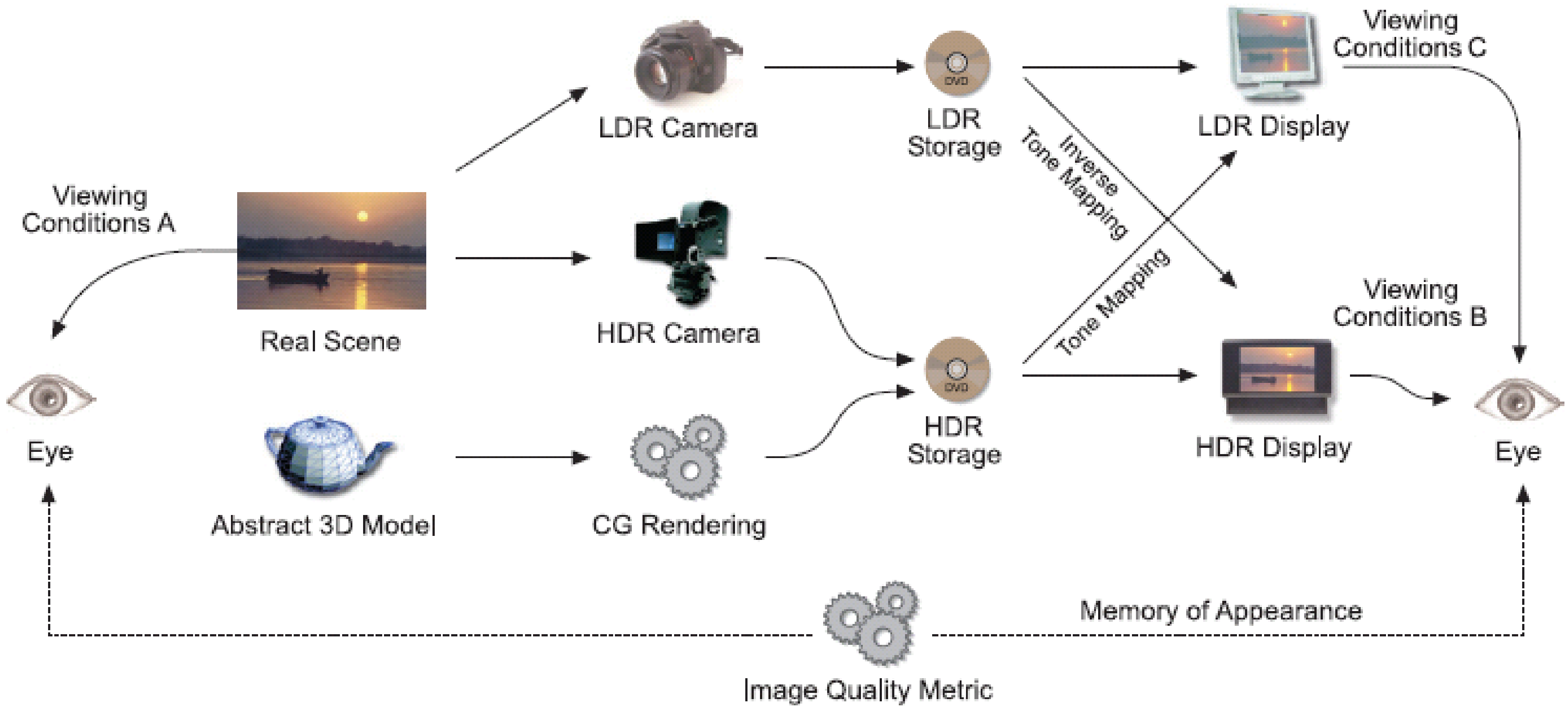
# HDR Applications

Adobe® Photoshop®



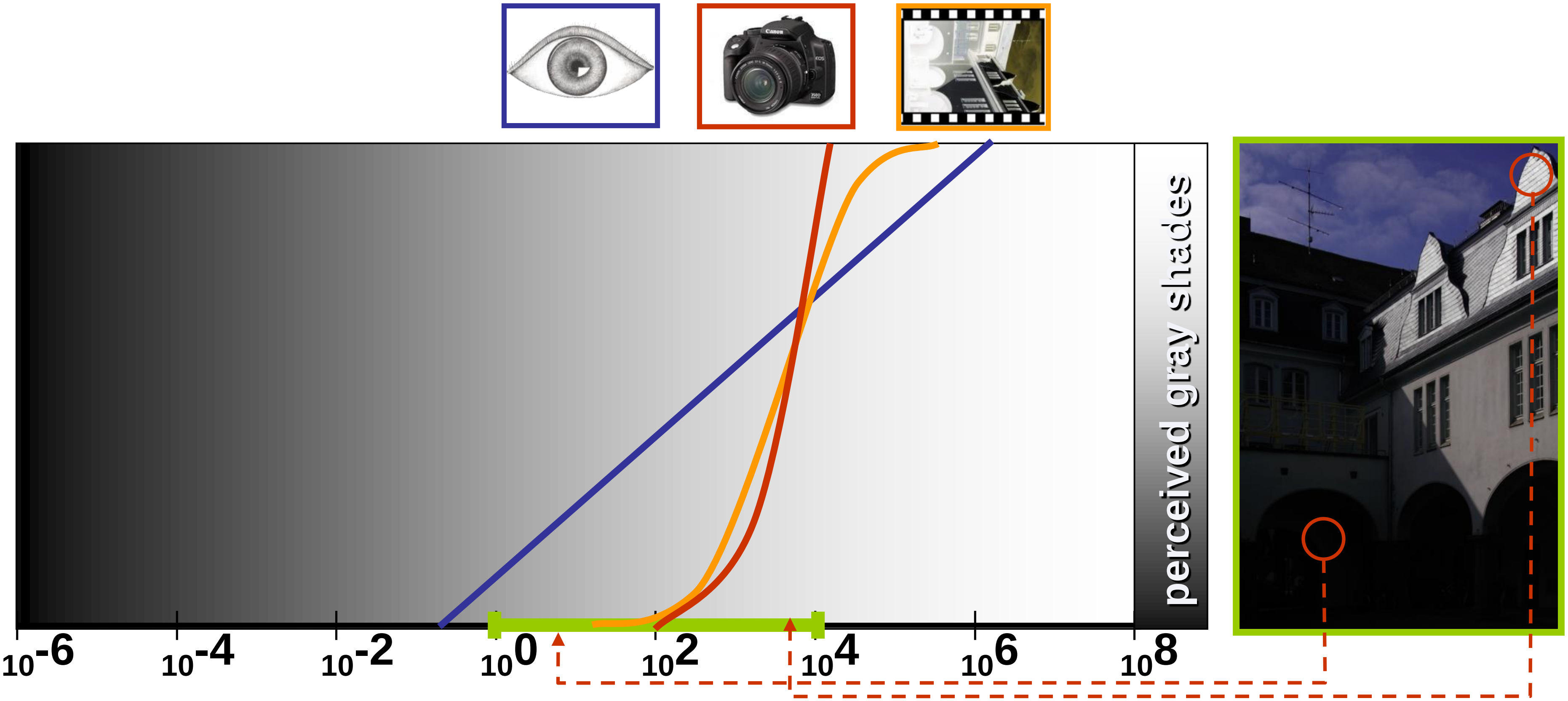
# HDR Pipeline



# Lecture Overview

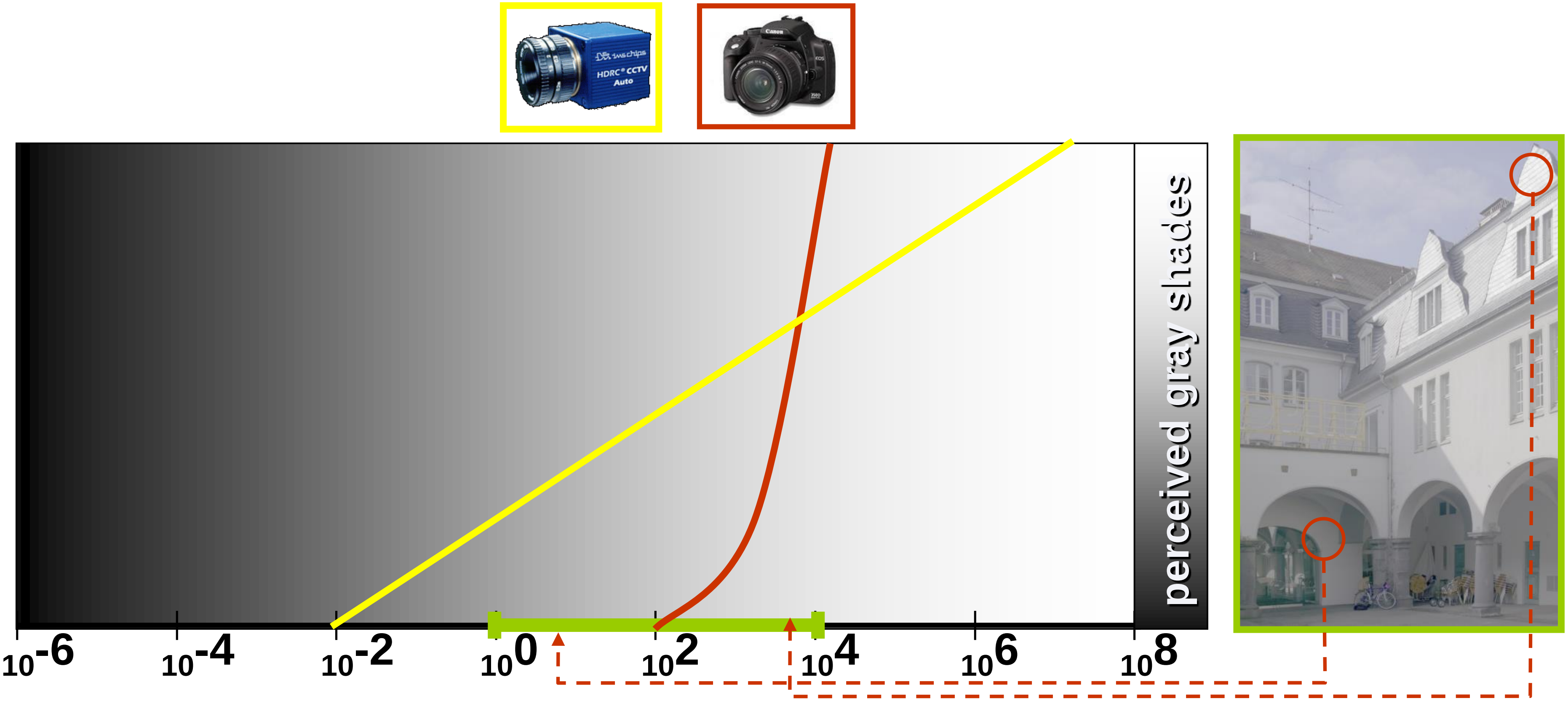
- Capture of HDR images and video
  - HDR sensors
  - Multi-exposure techniques
  - Photometric calibration
- Tone Mapping of HDR images and video
  - Early ideas for reducing contrast range
  - Image processing – fixing problems
  - Alternative approaches
  - Perceptual effects in tone mapping
- Summary

# HDR: a normal camera can't…




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

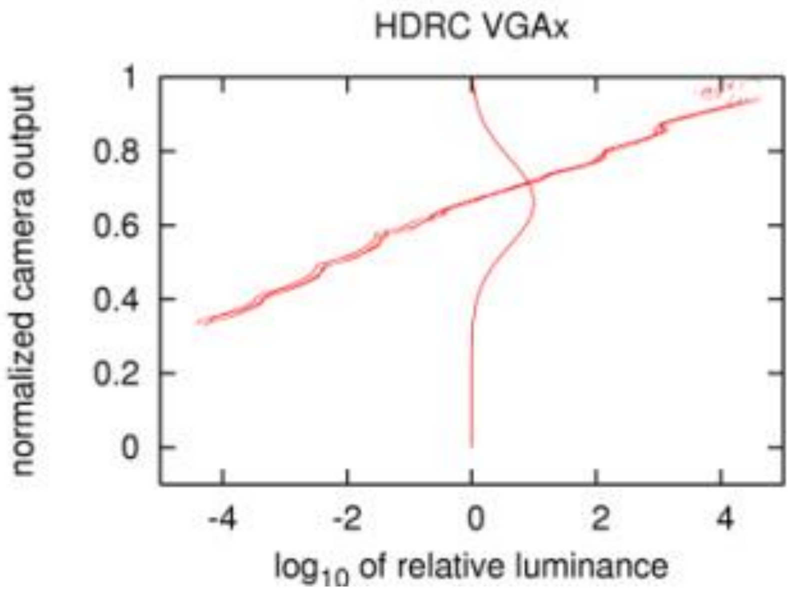
# HDR Sensors




- logarithmic response
- locally auto-adaptive
- hybrid sensors (linear-logarithmic)

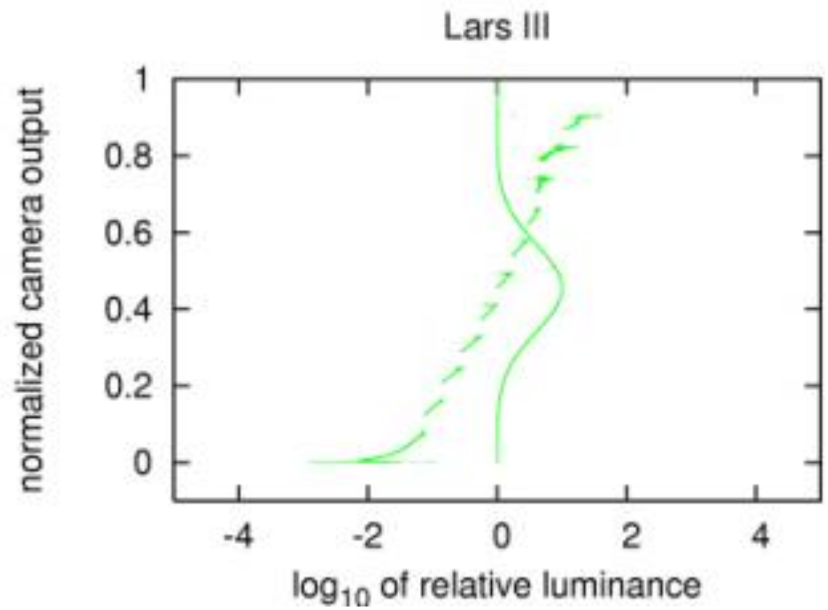
# Logarithmic HDR Sensor

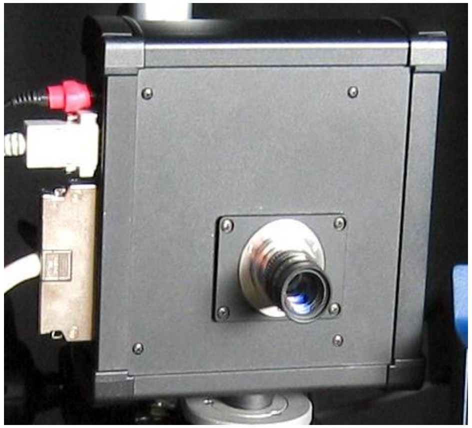
- CMOS sensor (10bit)
- Transforms collected charge to logarithmic voltage (analog circuit)
- Dynamic range at the cost of quantization
- Very high saturation level
- High noise floor
- Non-linear noise
- Slow response at low luminance levels
- **Lin-log variants of sensor**
  - better quantization
  - lower noise floor




# Locally Auto-adaptive Sensor

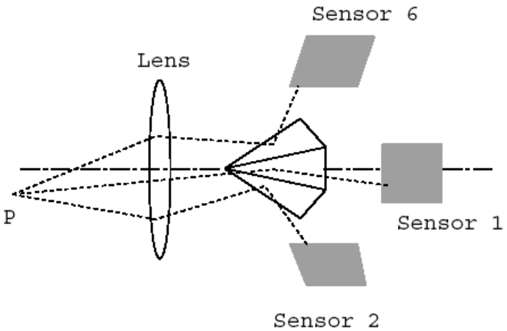
- Individual integration time for each pixel
- 16bit sensor
  - collected charge (8bit)
  - integration time (8bit)
- Irradiance from time and charge
- Complicated noise model
- Fine quantization over a wide range
- Non-continuous output!
- Difficult implementation

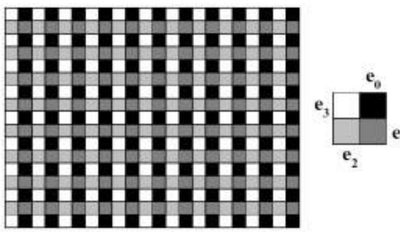


# HDR Using Multiple Sensors

- semi-transparent mirror /prism
  - multimple sensors with different sensitivity
- or sacrifice resolution
- Panoscan Mark3, SpheronVR (scanning panoramic cameras), HDR video, HDR-Cam, etc.

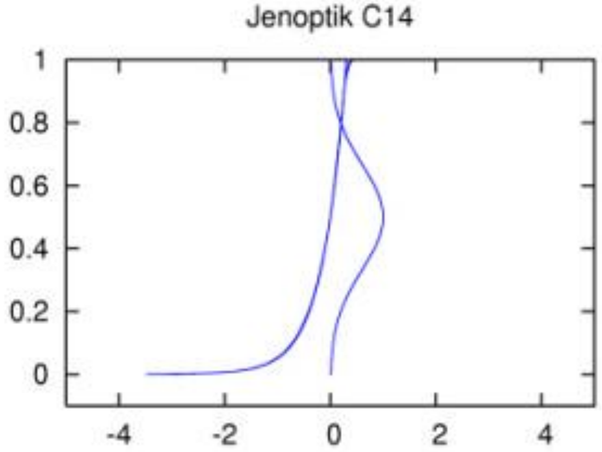


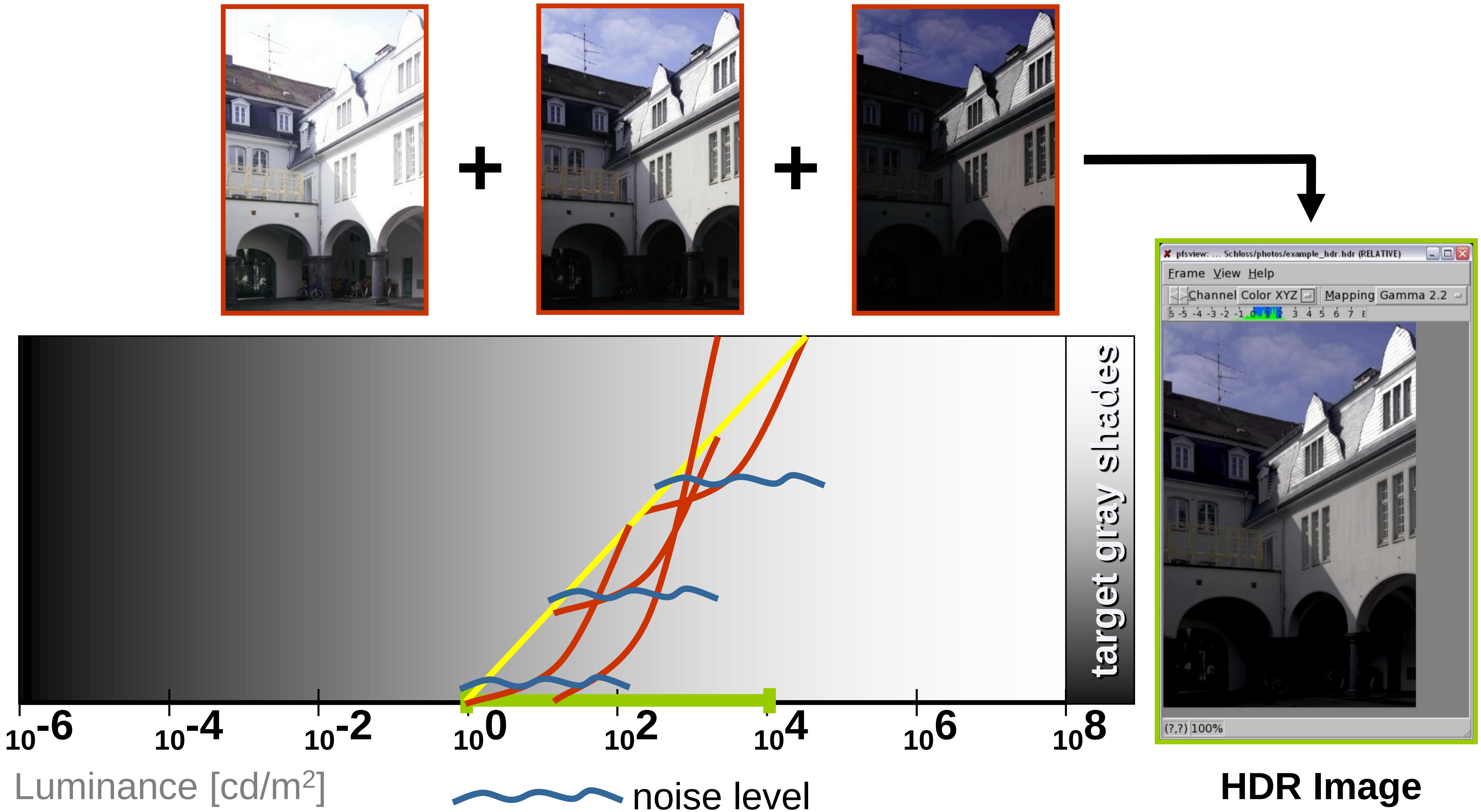
# HDR with a normal camera

| | |
|---|---|
| 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)

# Multi-exposure Technique (3)

f/8, 1/1000s

f/5.6, 1/250s

f/5.6, 1/30s

f/5.6, 1/4s

f/5.6, 2s

f/5.6, 8s

# Algorithm (1/3)

### Merge to HDR

- Linearize input images and normalize by exposure time

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

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

- Weighted average of images (weights from certainty model)

$$x_{uv} = \frac{\sum_i w_{iuv} x_{iuv}}{\sum_i w_{iuv}}$$

### Optimize Camera Response

- Camera response

$$I^{-1}(y_{iuv}) = t_i x_{uv}$$

assume $\boldsymbol{x_{uv}}$ is correct

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

$$E_m = \{(i,u,v) : y_{iuv} = m\}$$

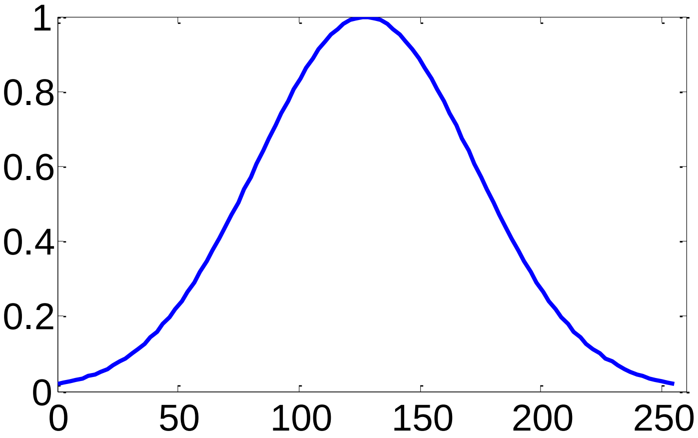
$$I^{-1}(m) = \frac{1}{\mathrm{Card}(E_m)} \sum_{i,u,v \in E_m} t_i x_{uv}$$

| | |
|---|---|
| $t_i$ | exposure time of image $\boldsymbol{i}$ |
| $y_{iuv}$ | pixel of input image $\boldsymbol{i}$ at position $\boldsymbol{uv}$ |
| $I$ | camera response |
| $x_{uv}$ | HDR image at position $\boldsymbol{uv}$ |
| $w$ | weight from certainty model |
| $m$ | camera output value |

# Algorithm (2/3)

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

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




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

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

# Algorithm (3/3)

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

$$x_{uv} = \frac{\sum_i w(y_{iuv}) t_i^2 \cdot \frac{I^{-1}(y_{iuv})}{t_i}}{\sum_i w(y_{iuv}) t_i^2}$$

3. Refine camera response

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

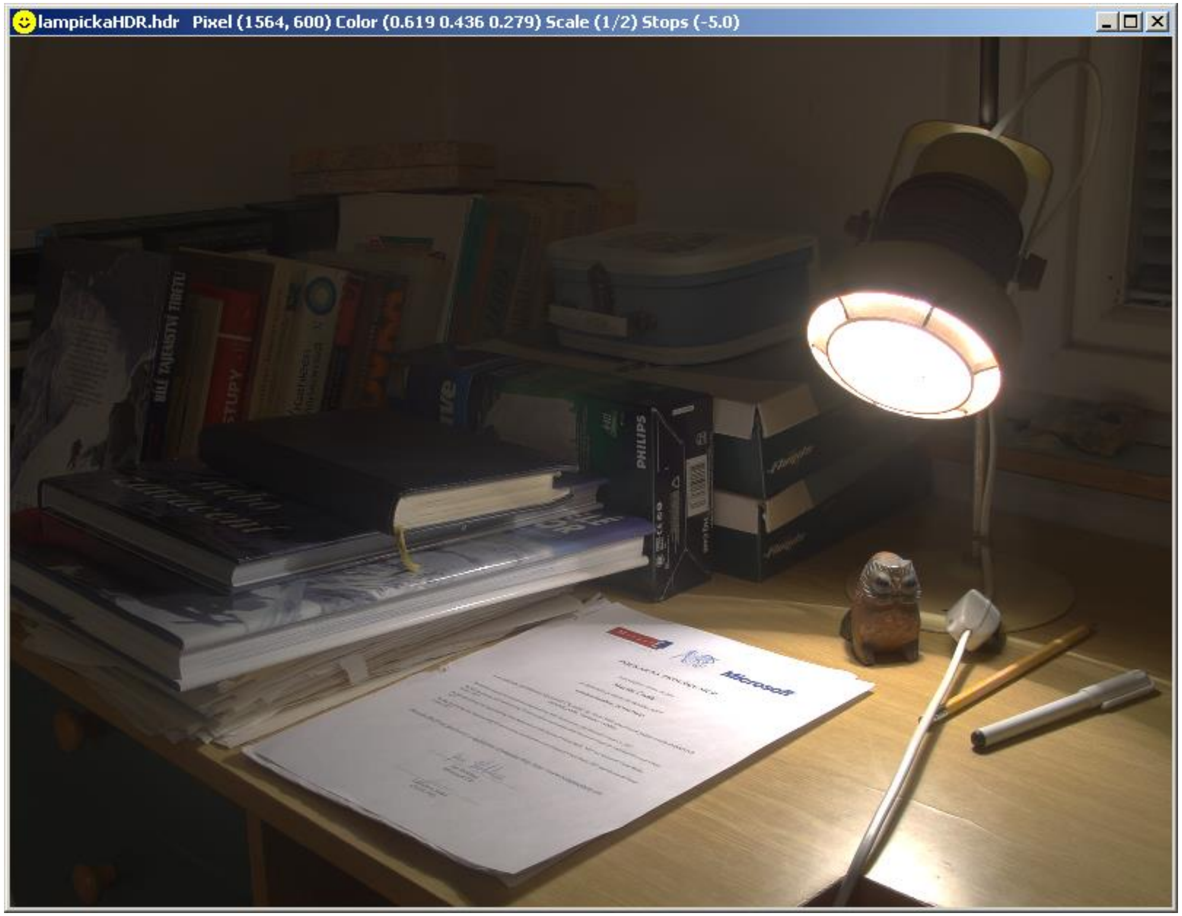
$$I^{-1}(m) = \frac{1}{\mathrm{Card}(E_m)} \sum_{i,u,v \in E_m} t_i x_{uv}$$

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

$$O = \sum_{i,u,v} w(y_{iuv})(I^{-1}(y_{iuv}) - t_i x_{uv})^2$$

# HDR Image

– [sample]



# Issues with Multi-exposures

- How many source images?
  - First expose for shadows: all output values above 128 (for 8bit image)
  - 2 f-stops spacing (factor of 4) between images
  - one or two images with 1/3 f-stop increase will improve quantization in HDR image
  - Last exposure: no pixel in image with maximum value
- Alignment
  - Shoot from tripod
  - Otherwise use panorama stitching techniques to align images
- Ghosting
  - Moving objects between exposures leave “ghosts”
  - Statistical method to prevent such artifacts
- Practical only for images!
  - Multi-exposure video projects exist, but not very successful

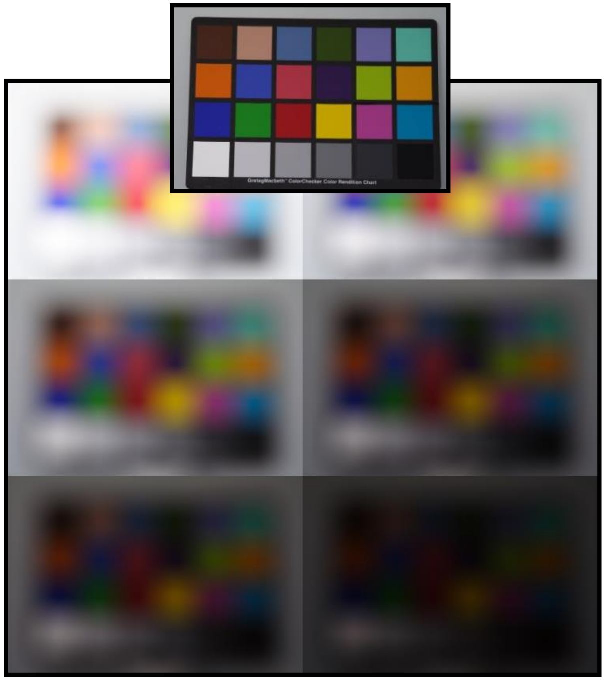
# Other Algorithms

- [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

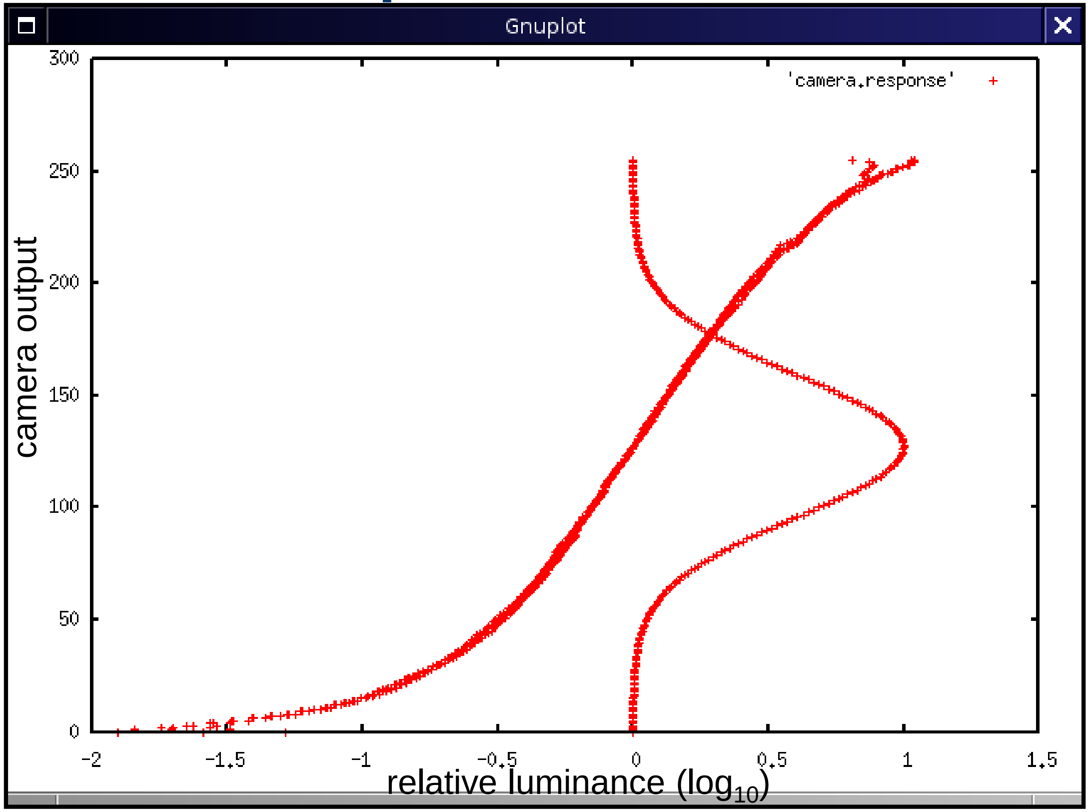
# Calibration (Response Recovery)

- Camera response can be reused
  - for the same camera
  - for the same picture style settings (eg. contrast)
- Good calibration target
  - Neutral target (e.g. Gray Card)
    - Minimize impact of color processing in camera
  - Smooth illumination
    - Uniform histogram of input values
  - Out-of-focus
    - No interference with edge aliasing and sharpening

# Recovered Camera Response



multiple exposures
of out-of-focus
color chart

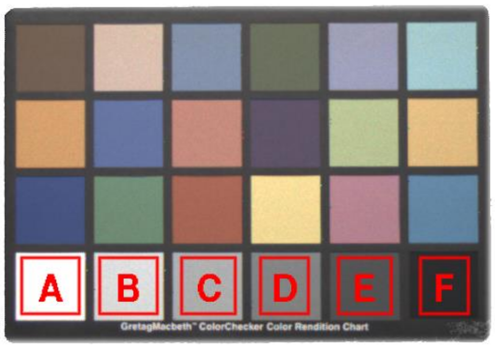




recovered camera response
(for each RGB channel separately)

# Photometric Calibration

- Converts camera output to luminance
  - requires camera response,
  - and a reference measurement for known exposure settings
- Applications
  - predictive rendering
  - simulation of human vision response to light
  - common output in systems combining different cameras

# Photometric Calibration (cntd.)

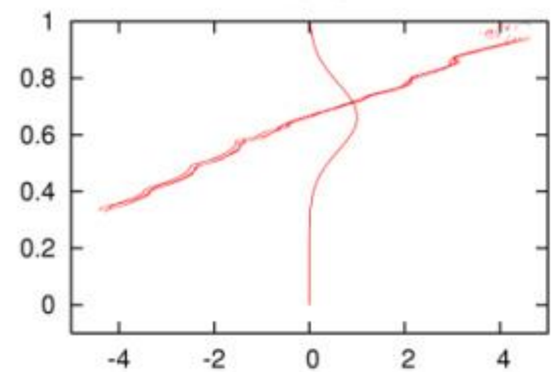



**acquire target**


**camera output values**

**measure luminance**

**luminance values**

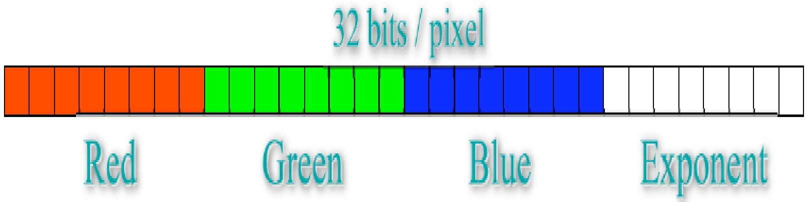



**camera response**

# HDR Image File Formats

- Raw Binary Floating Point (`.raw,.cr2,.nef,etc.`)
  - cameras, manufacturer-specific
  - not really HDR

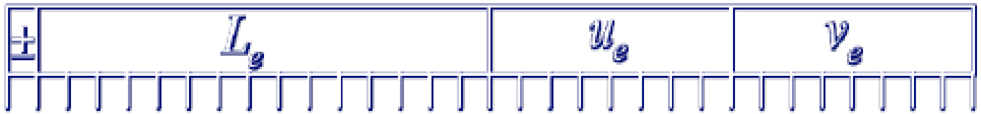
- we need **FLOATS** (at least) (`.pfm`)
  - precision, dynamic range
  - typically 4B == 3.4 E+/- 38
  - the image file is **4x bigger** (96b/pixel vs. 24b/pixel) than usual!



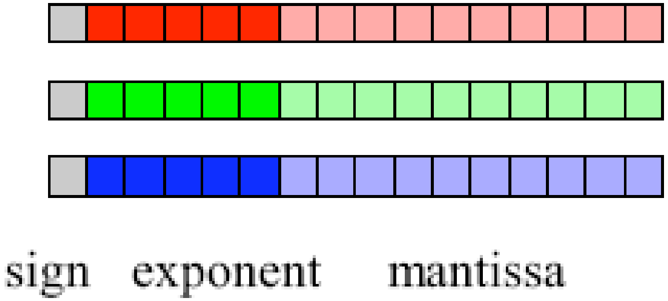

- Radiance RGBE (`.pic,.hdr`)
  - [Ward92]
  - 32b/pixel
  - 3x 8b mantissa + 1x exponent
  - $10^{+/-38}$ (too much, $10^{+9/-7}$ would be enough), 1% relative accuracy

# HDR Image File Formats

- SGI LogLuv TIFF (`.tif`)
  - [Ward 98]
  - human perception based:
    log encoding of luminance, $10^{+/-38}$, 0.3% relative accuracy
    CIE (u, v) encoding for chroma, errors under visible threshold
  - 3 variants: 24b/pixel, 30b/pixel, 32b/pixel




- OpenEXR (`.exr`)
  - Industrial Light and Magic [2003]
  - 16b float (Half data type)
  - 48 or 96b/pixel + lossless compression
  - multiresolution
  - supported by graphics hardware (NVidia, ATI frame buffers)

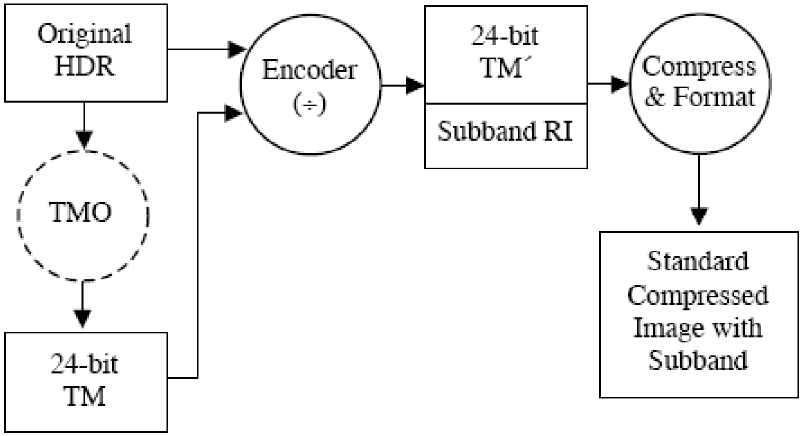


# HDR Image File Formats

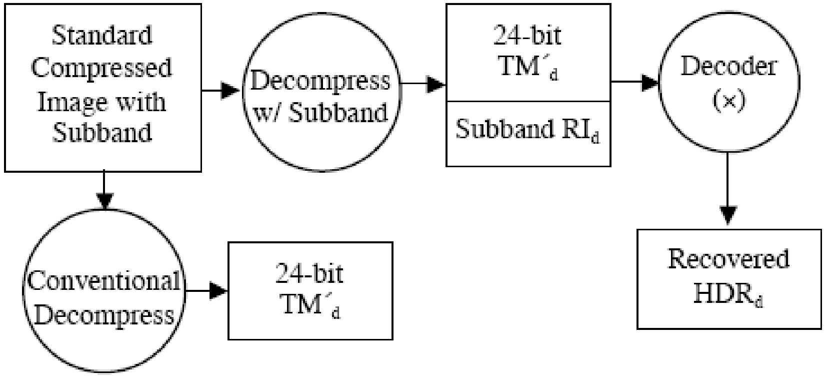
- JPEG HDR - Subband Encoding (`.jpeg`) [Ward and Simmons 04]
  - Tone-mapped version
    + Ratio image (subband – metadata JFIF)
  - Ratio Image:
  - allows lossy compression
  - naive software = tone mapped version, specialized software = HDR

$$RI(x,y) = \frac{L(HDR(x,y))}{L(TM(x,y))}$$

## Encoding pipeline

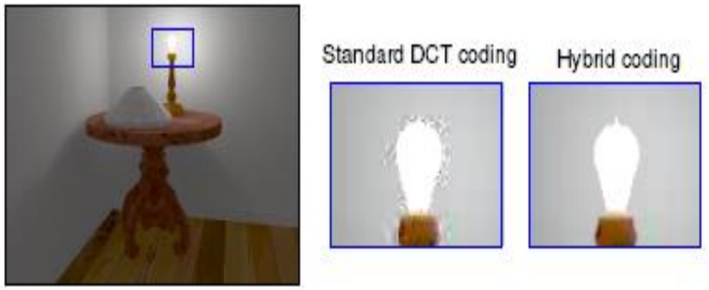


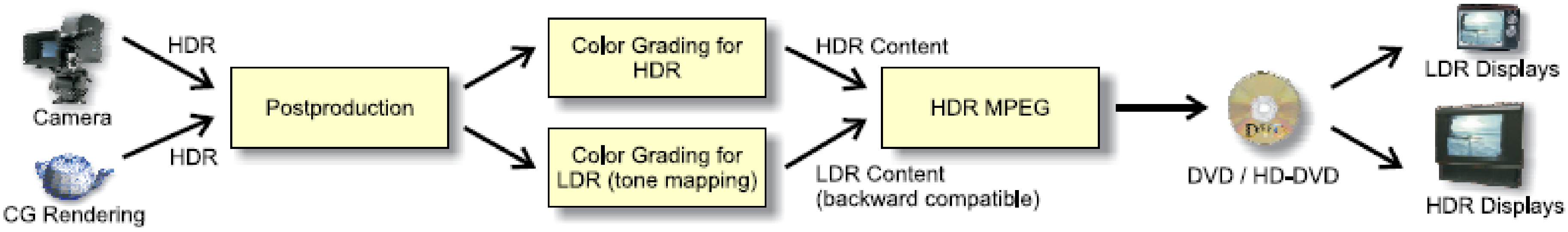

## Alternate decoding paths



# HDR Video

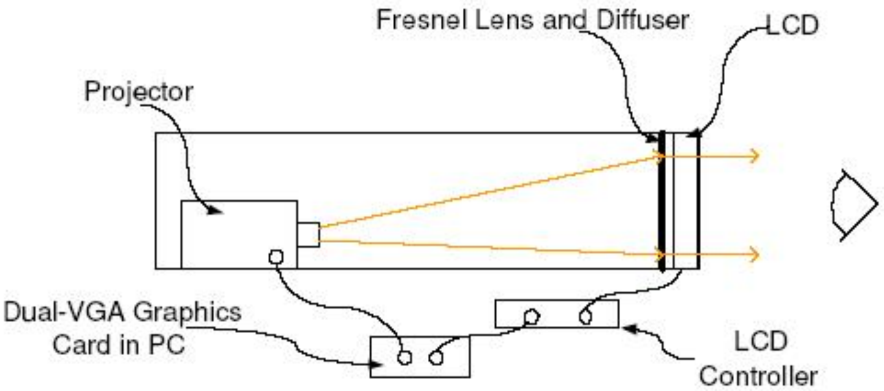
- HDRV – perception-motivated [Mantiuk et al. 04]
  - perceptual Luminance quantization
  - 11b for Luminance + 2x 8b for chrominance
  - based on MPEG-4
  - no LDR (pure HDR video)
- HDR MPEG [Mantiuk et al. 06]
  - backward-compatible MPEG
  - residual stream + standard LDR stream

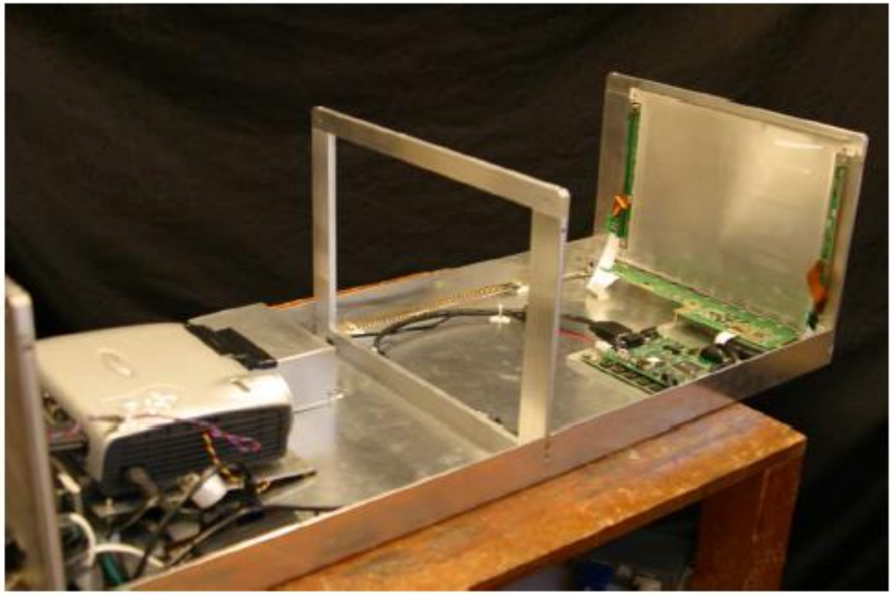


# HDR Display Systems

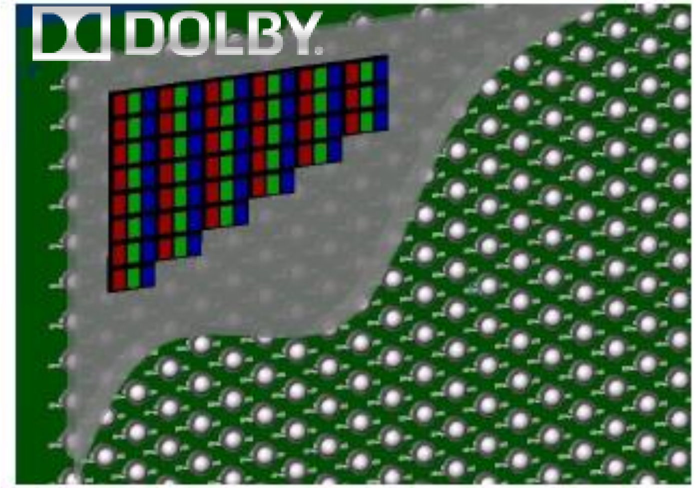
- [Seetzen et al.]
  - LCD panel + projector
  - LCD panel + LED panel
  - applications:
    - HDR image viewer
    - interactive photorealistic rendering
    - volume rendering
    - medical image viewer

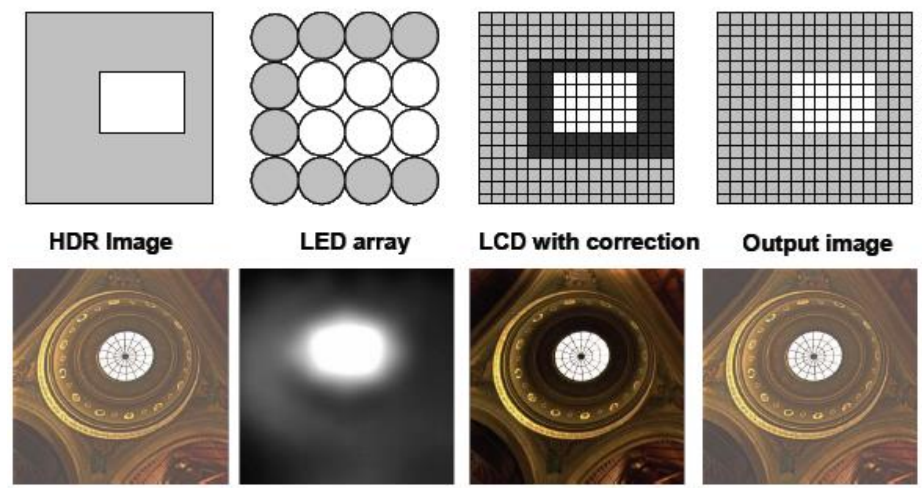


# HDR Display Systems

- ordinary LCD
  - 300:1 to 1000:1
  - black=0.1 to 1 cd/m$^2$
  - peak=300 to 500 cd/m$^2$
- [brightsidetech.com]
  - HDR LCD
  - individually modulated LEDs (not uniform backlight)
  - 200 000:1
  - black=0 cd/m$^2$
  - peak=4000 cd/m$^2$
  - HDR from LDR

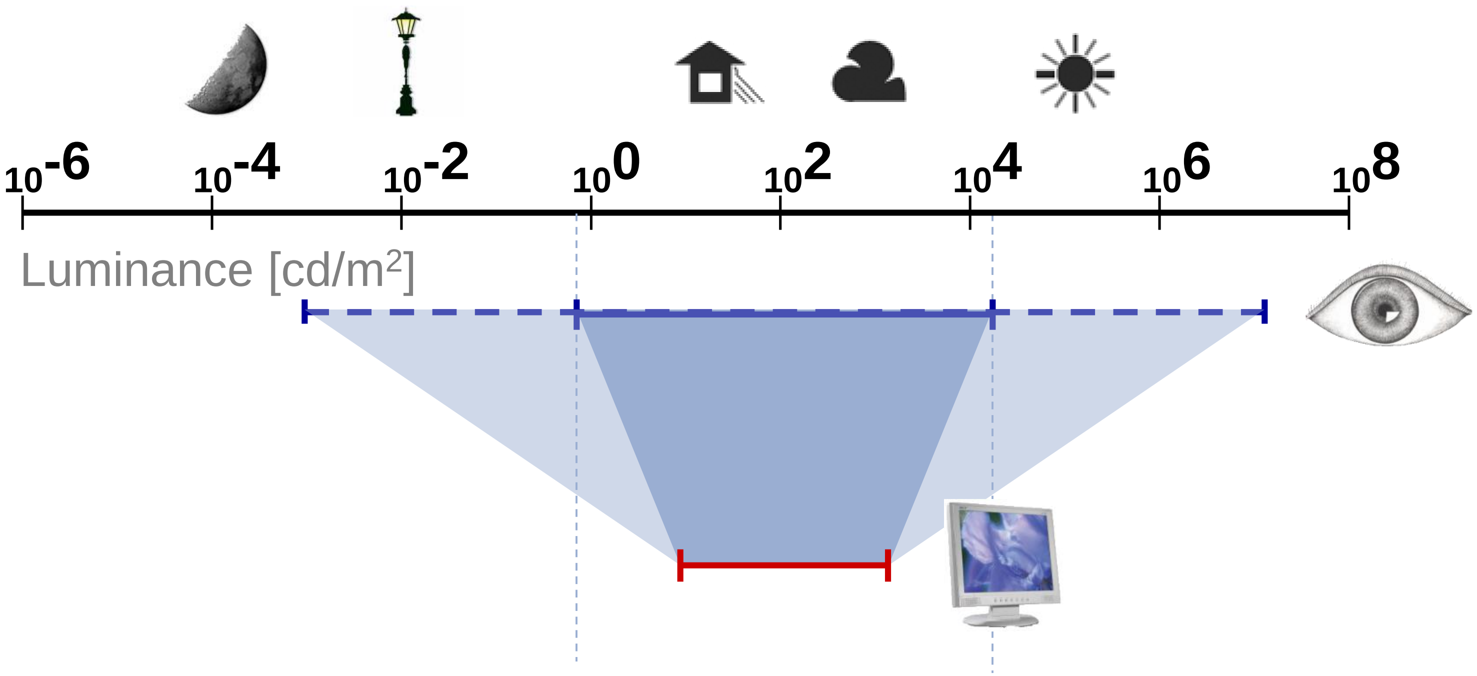


# Lecture Overview

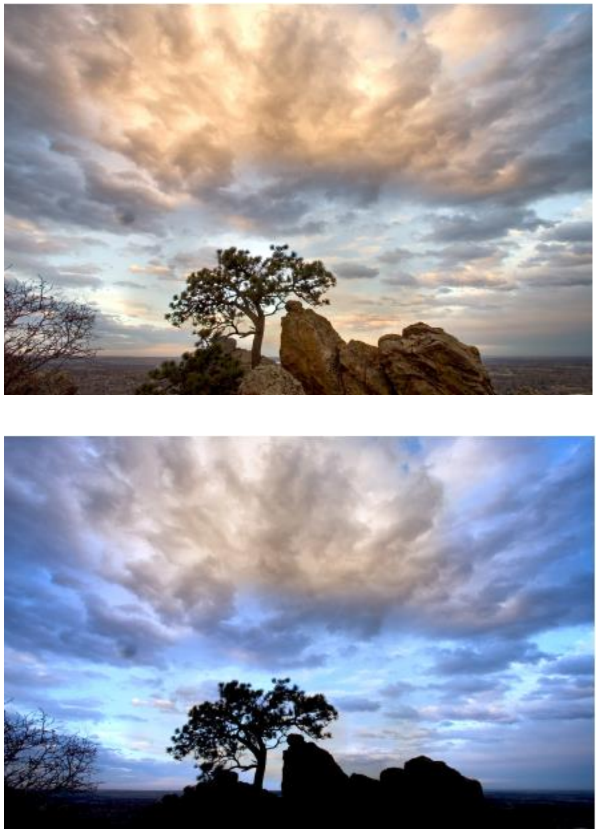
- Capture of HDR images and video
  - HDR sensors
  - Multi-exposure techniques
  - Photometric calibration
- Tone Mapping of HDR images and video
  - Early ideas for reducing contrast range
  - Image processing – fixing problems
  - Alternative approaches
  - Perceptual effects in tone mapping
- Summary

# HDR Tone Mapping

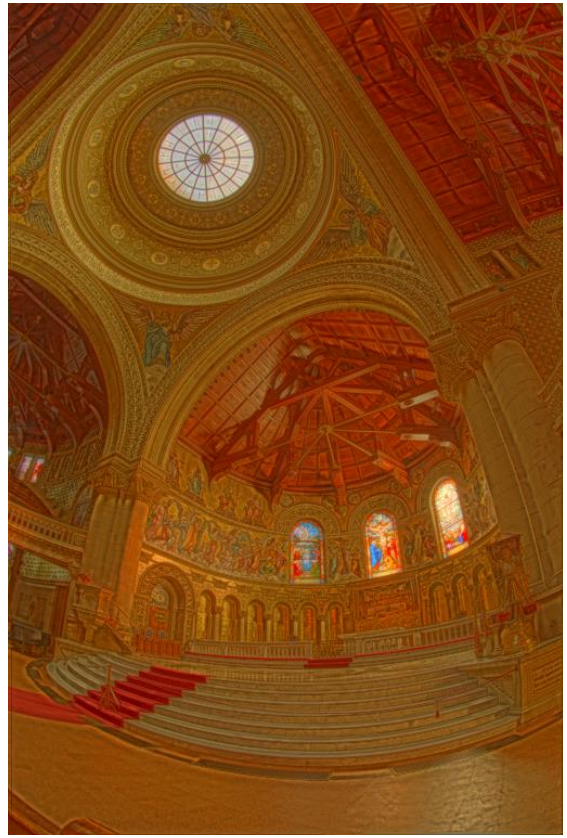



- Many objectives of tone mapping
  - nice looking images
  - perceptual brightness match
  - good detail visibility
  - equivalent object detection performance
  - really application dependent…

# Tone Mapping Goals



Aesthetical

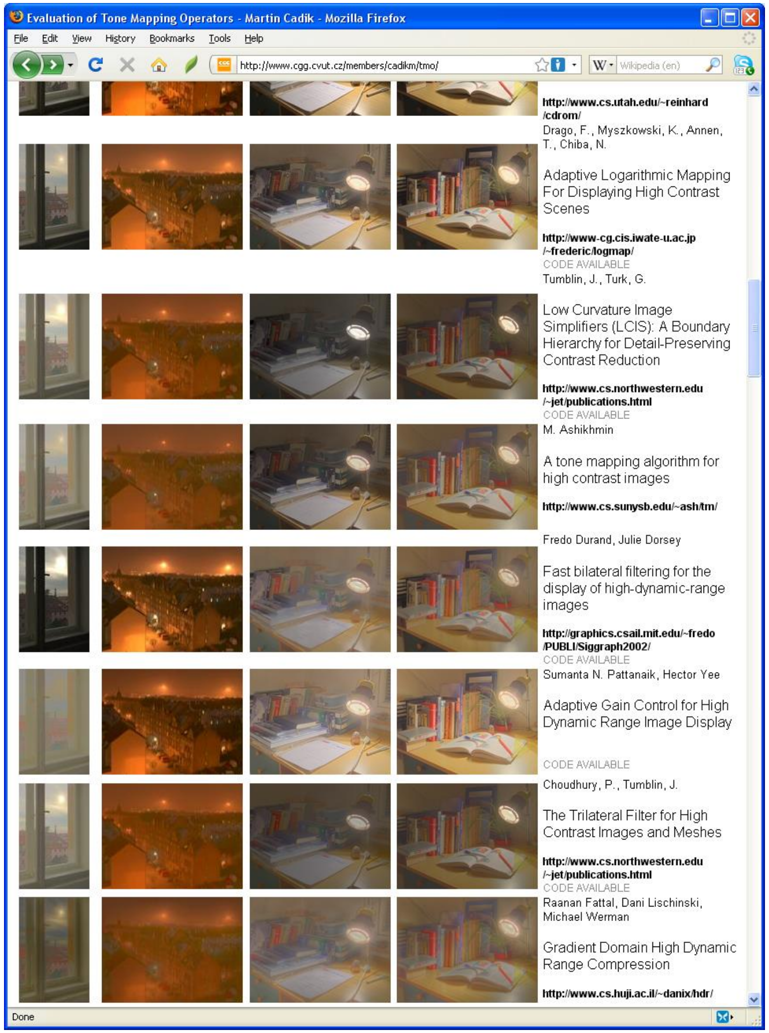


Cognitive

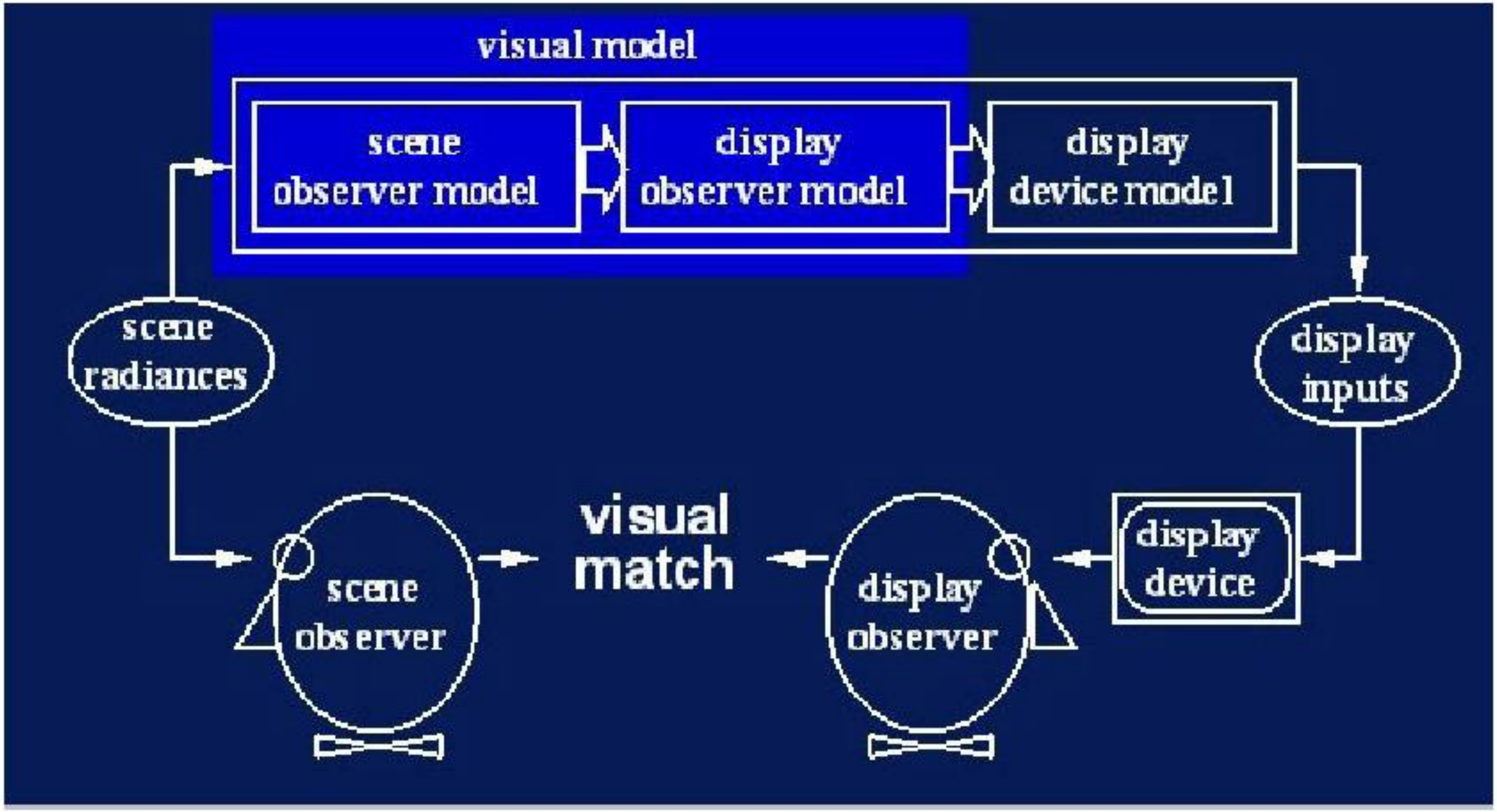

Perceptual

[Čadík et al. 06]

# (Over)abundance of Methods



# Perceptual: General Principle




[Tumblin and Rushmeier 1993]

# General Ideas

- 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
- Colors
  - most algorithms work on luminance
    - use RGB to Yxy color space transform
    - inverse transform using tone mapped luminance
  - otherwise each RGB channel processed independently

# General Problems

- Constraint observation conditions
  - limited contrast
  - quantization
  - different ambient illumination
  - different luminance levels
  - adaptation level often incorrect for the scene
  - narrow field of view
- Appearance may not always be matched

# Transfer Functions

- Linear mapping (naïve approach)
  - like taking an usual digital photo
- Log 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
- 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
  - like using gray card or auto-exposure in photography
  - goal of adaptation processes in human vision
- Adapting luminance exists in many TM algorithms

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

# Logarithmic Tone Mapping

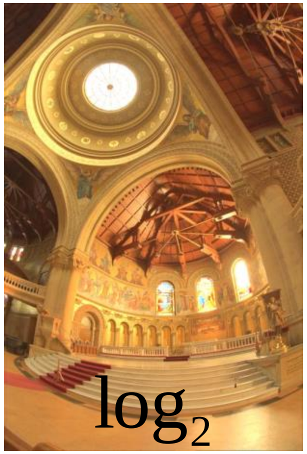
- Logarithm is a crude approximation of brightness
- Change of base for varied contrast mapping in bright and dark areas
  - $\log_{10}$ maps better for bright areas
  - $\log_2$ maps better for dark areas
- Mapping parameter *bias* in range 0.1:1

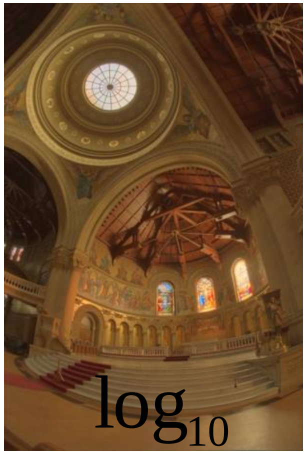
[Drago et al. 03]

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

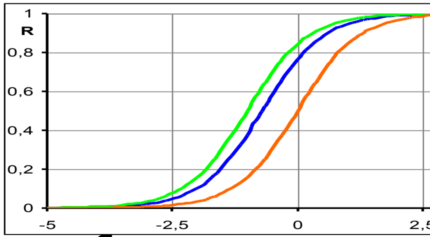
$$L = L_{\max} \cdot \frac{\log_{base(Y)}(Y'+1)}{\log_{10}(\max(Y')+1)}$$

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



# Sigmoid Response




- Model of photoreceptor

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

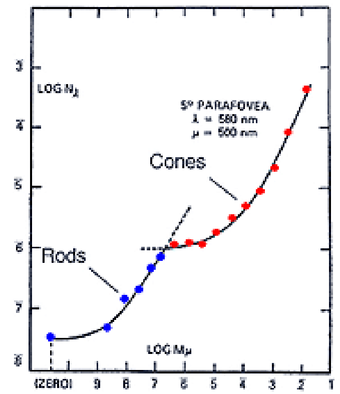
- Brightness parameter $\boldsymbol{f}$
- Contrast parameter $\boldsymbol{m}$
- Adapting luminance $\boldsymbol{Y_A}$
  - average in an image
  - measured pixel (equal to $\boldsymbol{Y}$)

logarithmic mapping

sigmoid mapping

# Histogram Equalization (1)

- 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)

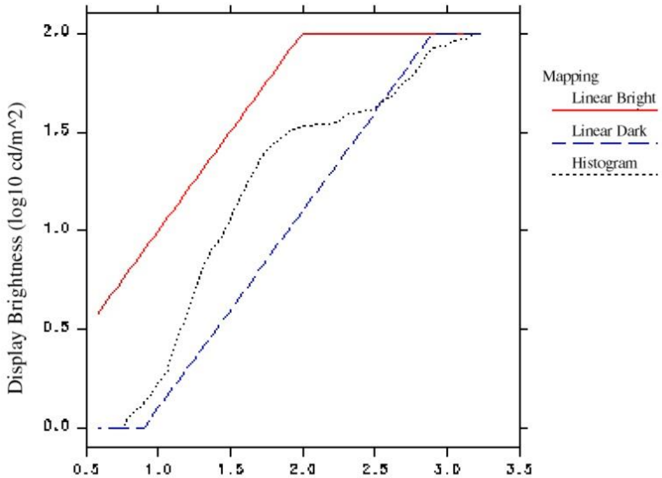
      TVI gives visible luminance difference for adapting luminance
- “Optimal” transfer function
- Not efficient when large uniform areas are present in the image

# Histogram Equalization (2)

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

Greg Ward

World to Display Luminance Mapping




Greg Ward

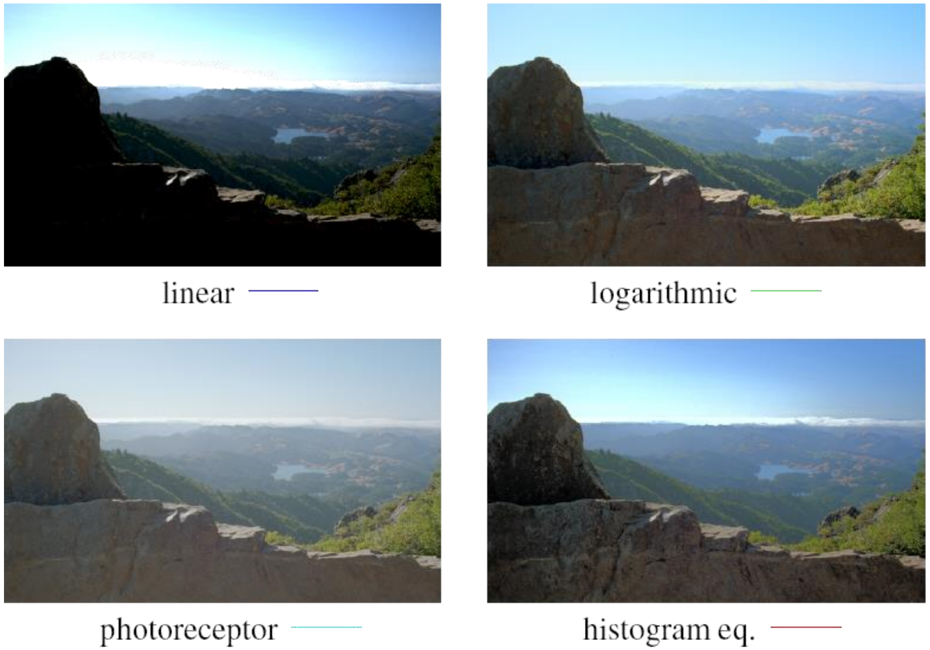
A linear mapping of the luminances that underexposes the view of the interior.

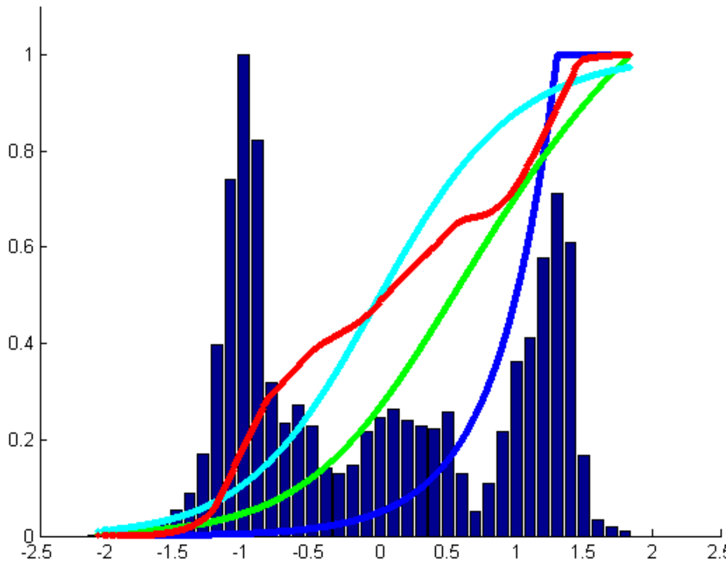
Greg Ward

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

[Ward et al. 97]

# Transfer Functions Compared




- 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

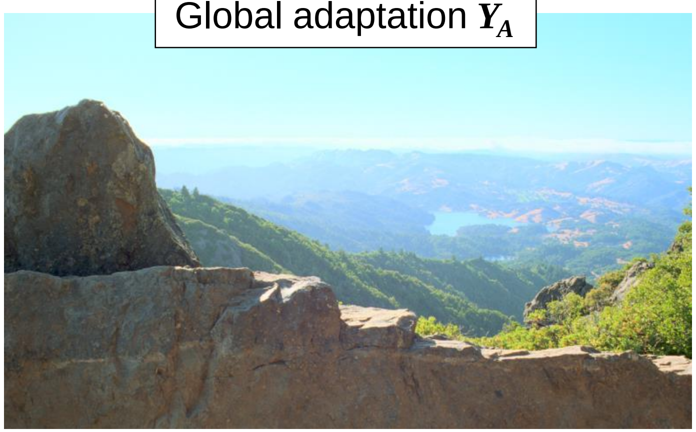
# Introducing Local Adaptation

- Eye adapts locally to observed area

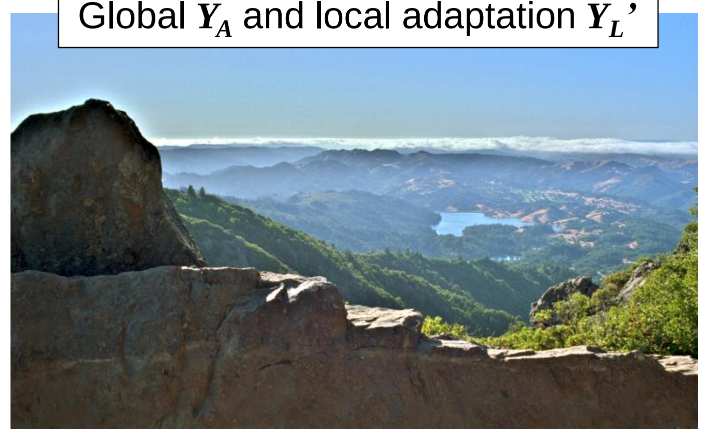
$$L = \frac{Y'}{Y'+1} \qquad Y' = \frac{Y}{Y_A} \qquad L = \frac{Y'}{Y_L'+1}$$

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

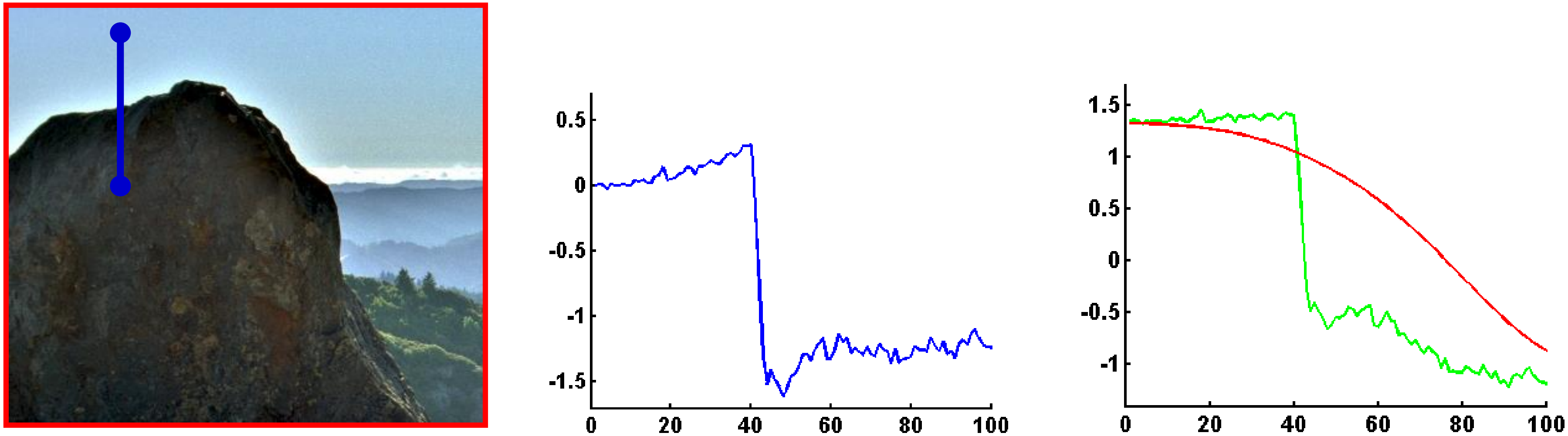
Global adaptation $Y_A$



Global $Y_A$ and local adaptation $Y_L'$



# The Halo Artifact



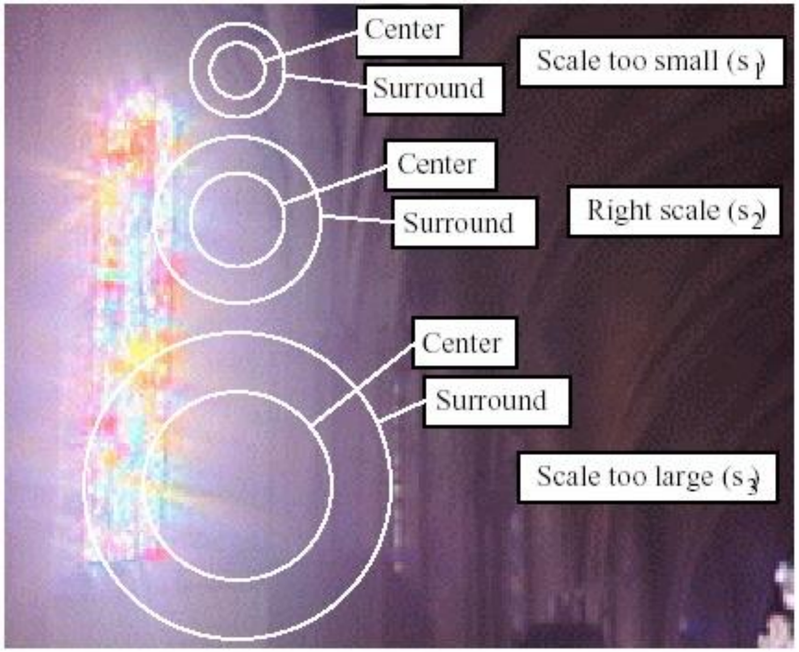

- Scan line example:
  - Gaussian blur under- (over-) estimates local adaptation near a high contrast edge
  - tone mapped image gets too bright (too dark) closer to such an edge
- Smaller blur kernel reduces the artifact (but then no details)
- Larger blur kernel spreads the artifact on larger area

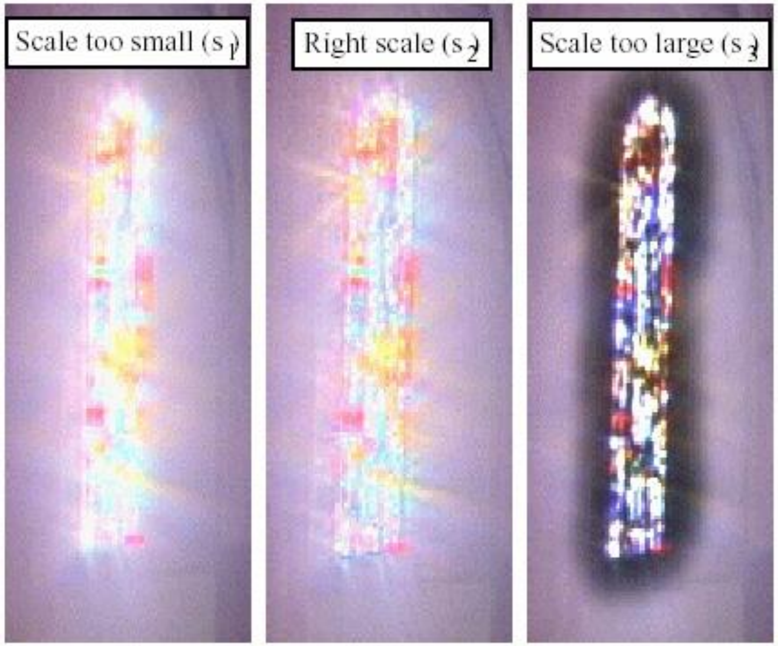
# Adjusting Gaussian Blur

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

[Reinhard et al. 02]

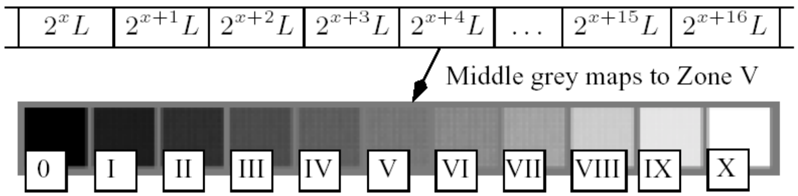
$$\left|Y_L(x,y,\sigma_i) - Y_L(x,y,\sigma_{i+1})\right| < \varepsilon$$



# Photographic Tone Reproduction

- Map luminance using Zone System




Print zones: Zone V 18% reflectance

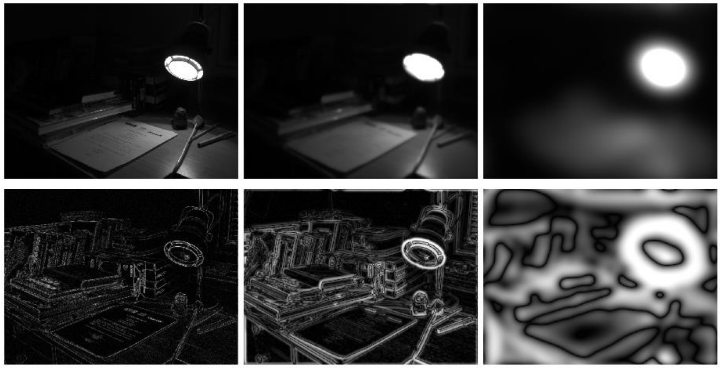
$$Y' = \frac{Y}{Y_A}, \quad Y_A = \exp\left(\frac{\sum \log(Y)}{N}\right)$$

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

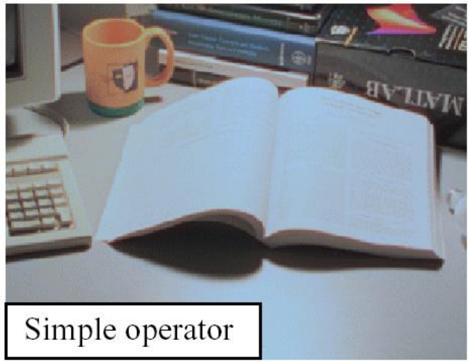
$$\left|Y_L'(x,y,\sigma_i) - Y_L'(x,y,\sigma_{i+1})\right| < \varepsilon$$

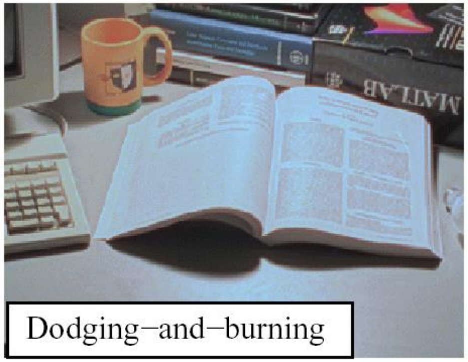
- Tone map using sigmoid function
  - different blur levels from Gaussian pyramid

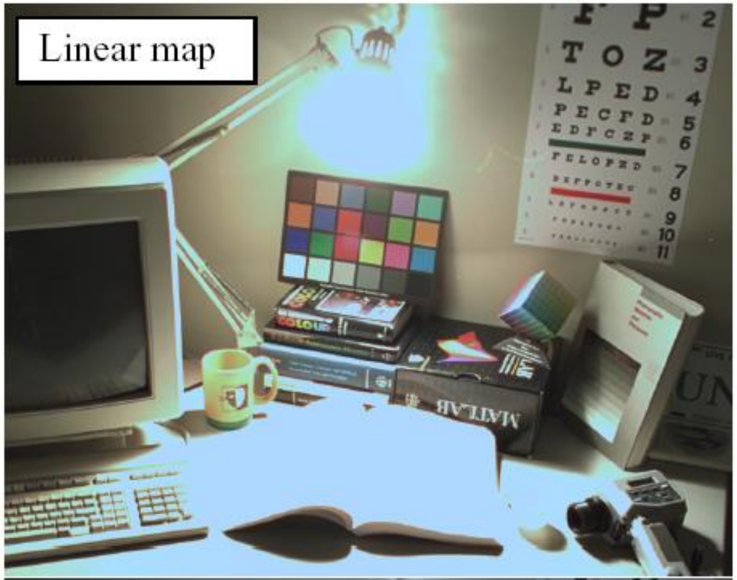
$$L(x,y) = \frac{Y'(x,y)}{Y_L'(x,y,\sigma_{x,y}) + 1}$$

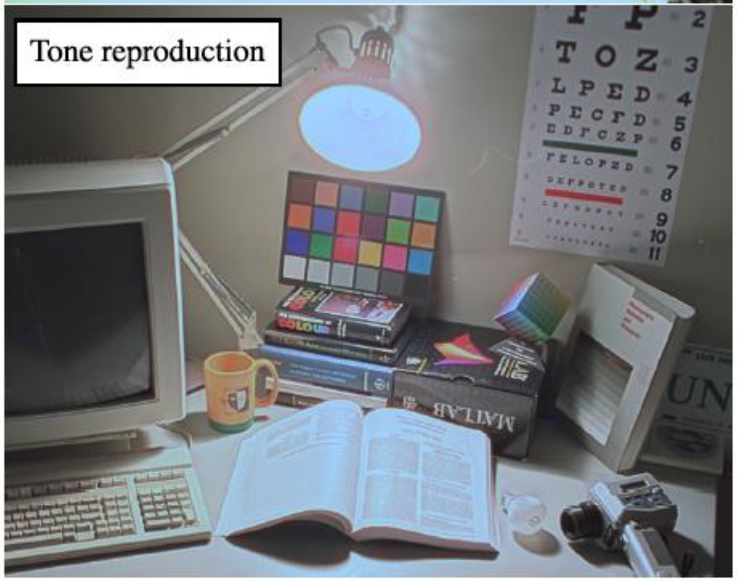


# Photographic Tone Reproduction




**dodge** luminance of pixels in bright regions is significantly decreased

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

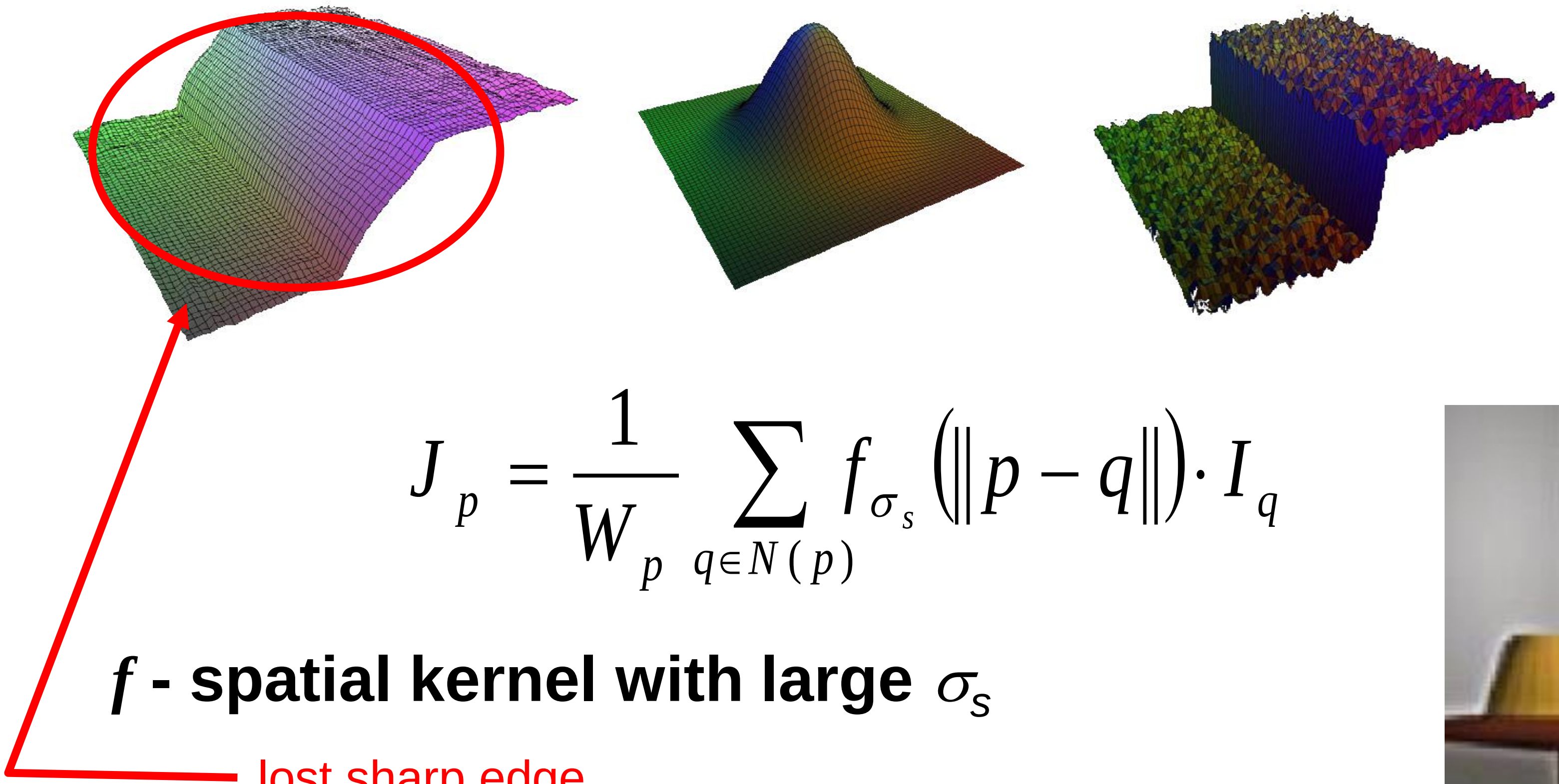
Automatic dodging-and-burning technique is more effective in preserving local details (notice the print in the book).

# 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

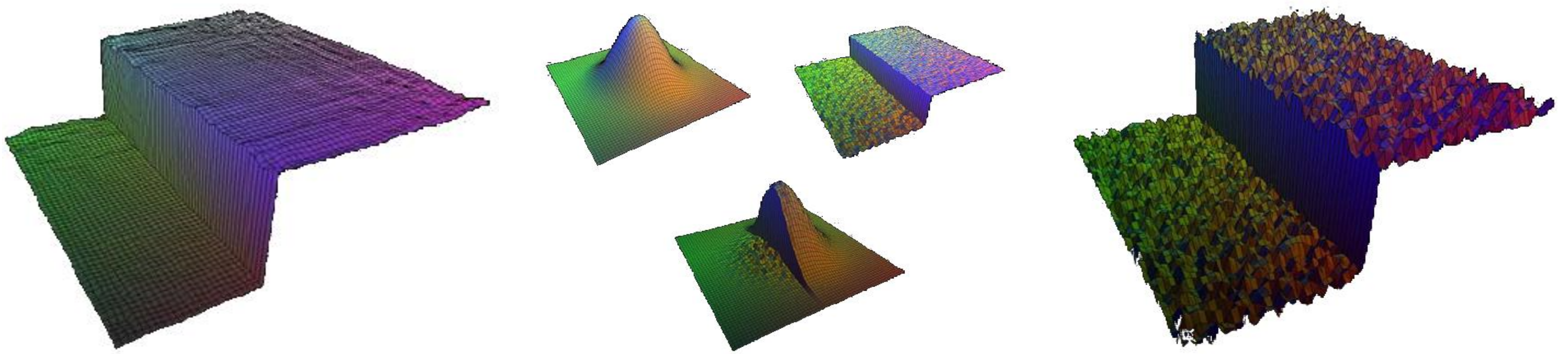



$$J_p = \frac{1}{W_p} \sum_{q \in N(p)} f_{\sigma_s}\left(\|p-q\|\right) \cdot I_q$$

***f*** **- spatial kernel with large** $\sigma_s$

# Illumination Layer (2)

- Edge preserving filter – no halo artifacts

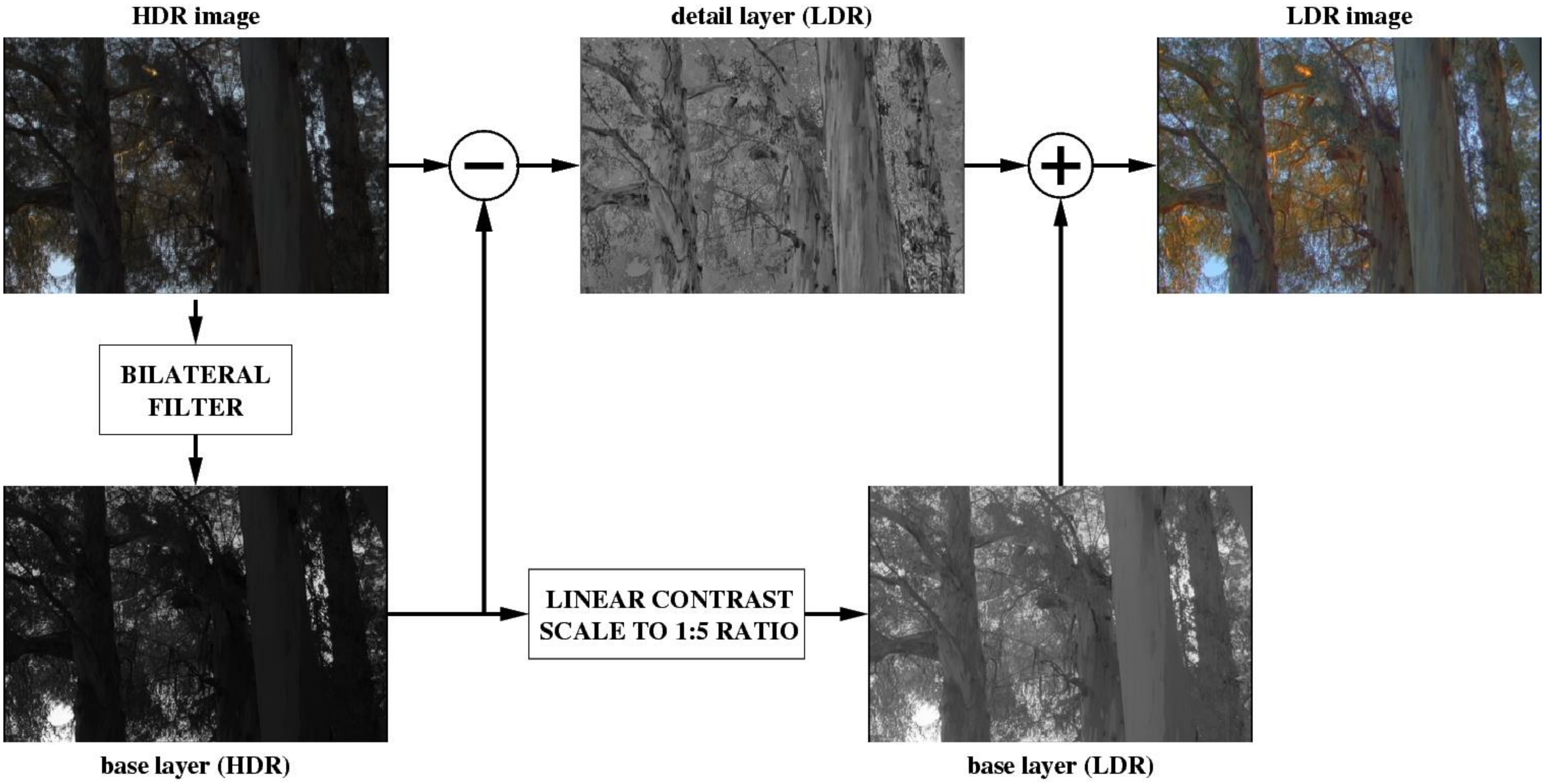


$$J_p = \frac{1}{W_p} \sum_{q \in N(p)} f_{\sigma_s}(\|p-q\|) \cdot g_{\sigma_r}(|I_p - I_q|) \cdot I_q$$

***f*** **- spatial kernel with large** $\sigma_s$

***g*** **- range kernel with very small** $\sigma_r$

# Tone Mapping Algorithm




Luminance in logarithmic domain.

[Durand and Dorsey 02]

# Illumination & Reflectance

# Alternative Approaches to TM

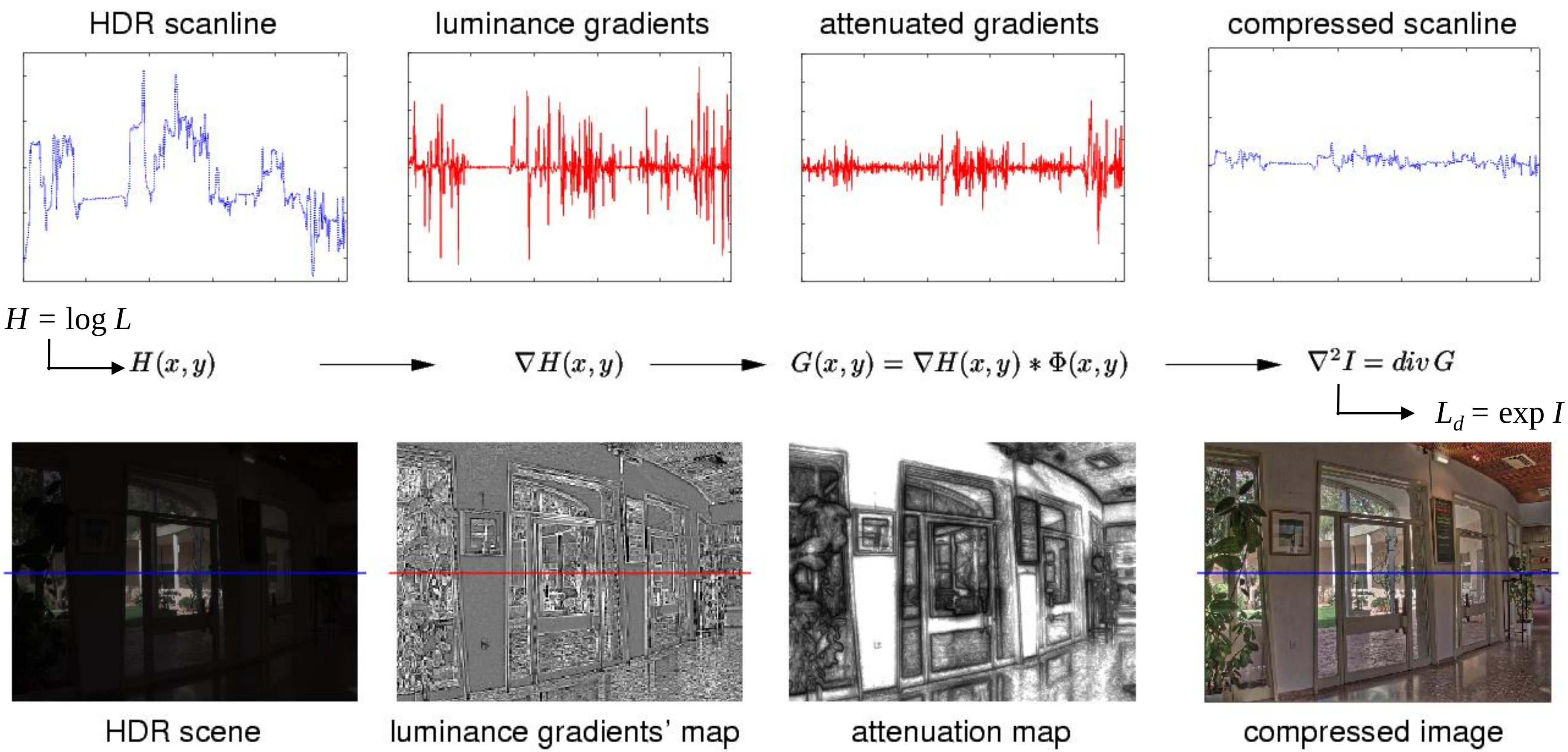
- Gradient domain tone mapping
  - transfer function for contrasts (not luminance)



- Segmentation for tone Mapping
  - based on perception theory and Gestalt assumptions
  - fuzzy segmentation based on illumination
  - simple tone mapping within segments

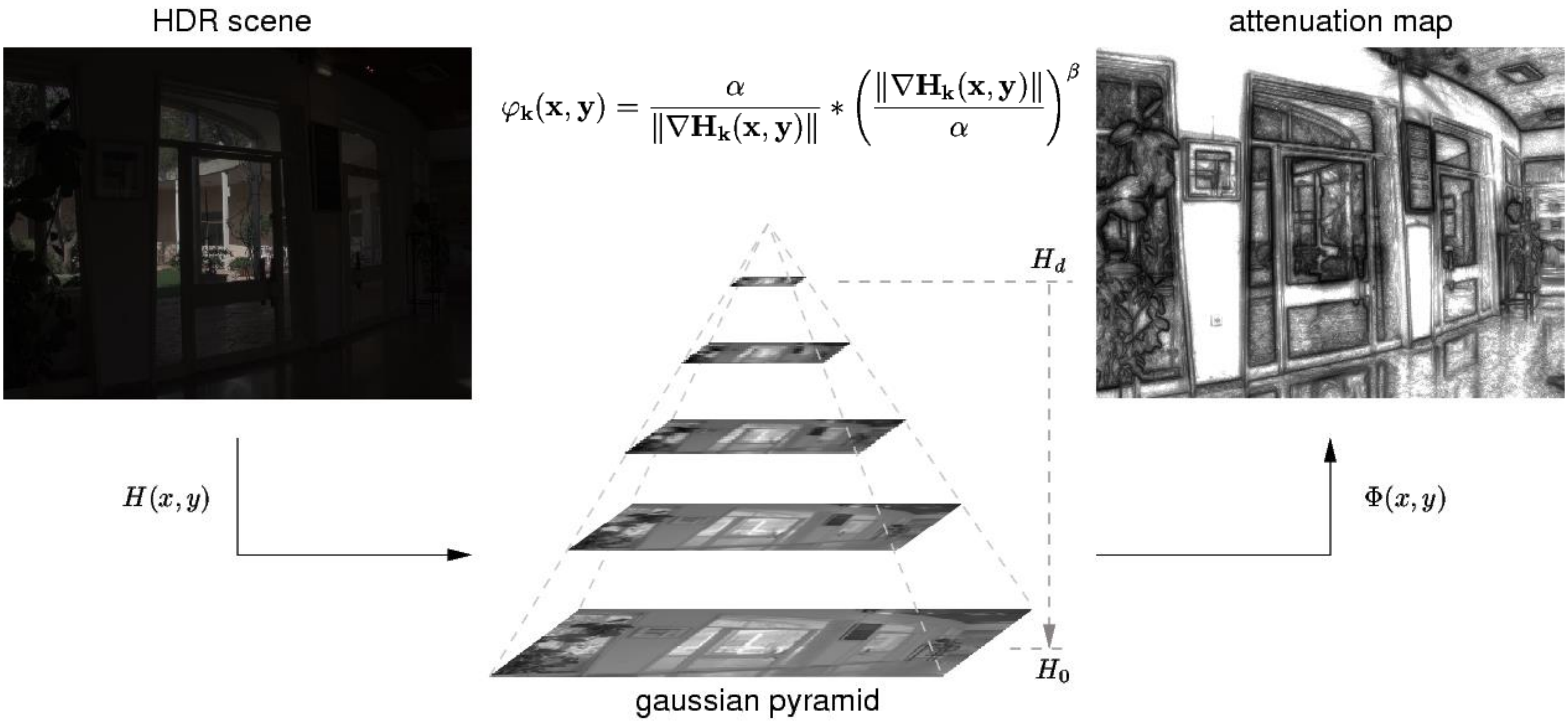
# Gradient Compression Algorithm

[Fattal et al. 02]




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

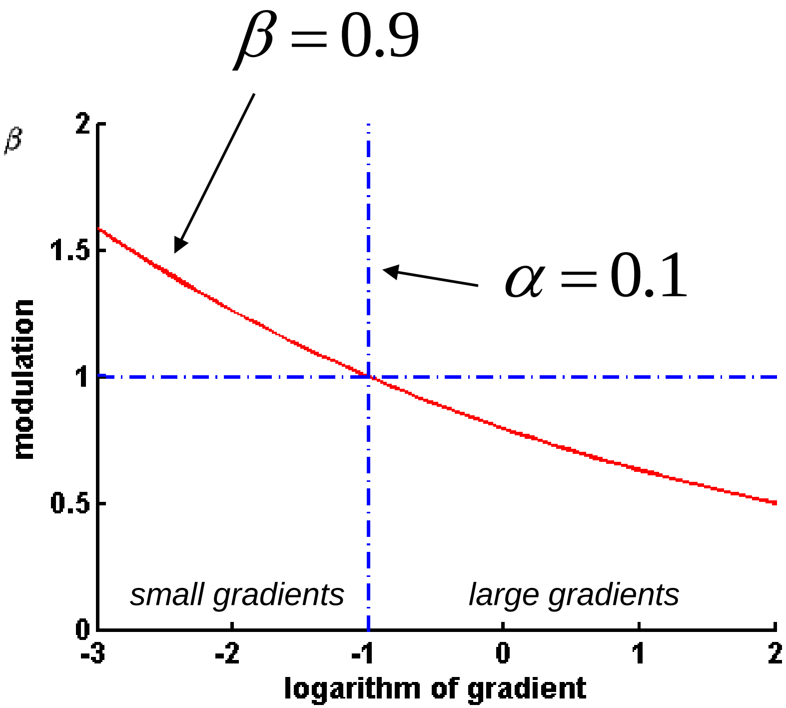
# Attenuation Map




1. Create Gaussian pyramid
2. Calculate gradients on levels
3. Calculate attenuation on levels - $\varphi_k$
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

- Loss of overall contrast
- Loss of texture details
- Short execution time
- Simple hardware implementation

Gradient Domain Compression

- Impression of high contrast
- Good preservation of fine details
- Takes time
- Complicated hardware implementation

# Alternative Approaches to TM

- Gradient domain tone mapping
  - transfer function for contrasts not luminance
  - basic idea today
  - contrast processing framework on the next lecture
- Segmentation for Tone Mapping
  - based on perception theory and Gestalt assumptions
  - fuzzy segmentation based on illumination
  - simple tone mapping within segments

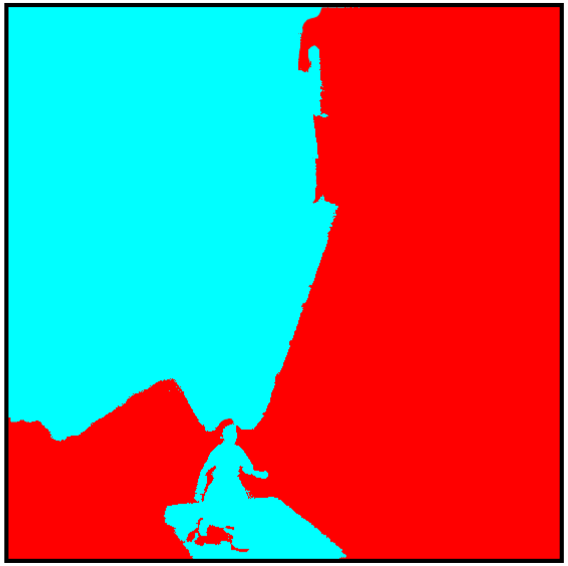
# Lightness Perception

- Lightness depends strongly on the context
  (according to “Anchoring Theory of Lightness Perception”)
- And does not depend on:
  - absolute luminance
  - its relation with background
    (this is against contrast theories)
- Fuzzy segmentation for tone mapping
  - to find spatial contexts
  - to tone map within such contexts

[Krawczyk et al. 06]

# Estimation of Lightness

Image copyrights: Magnum Photos.



- Constant lightness within certain image areas

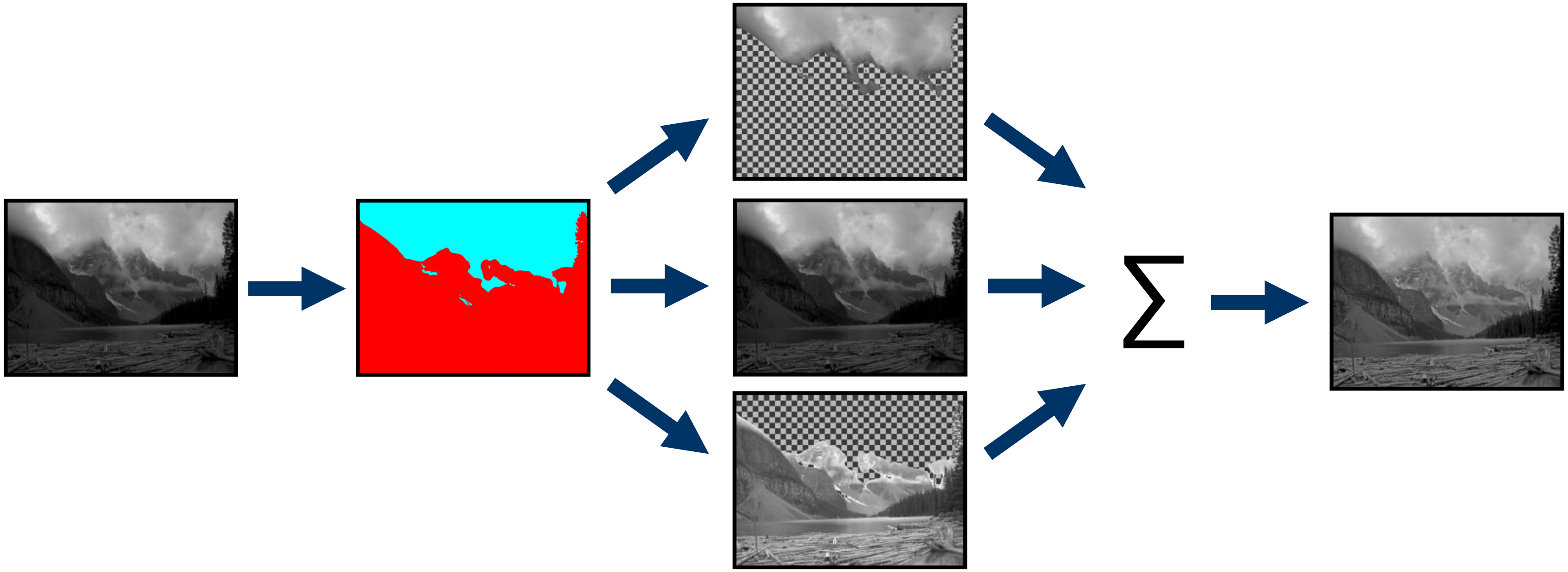
# The Theory

"An Anchoring Theory of Lightness Perception"

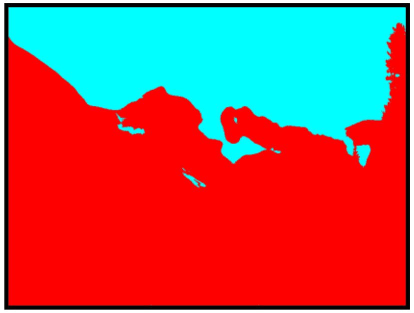
developed by Gilchrist et al. 1999

Key concepts:

- Frameworks – areas of common illumination
- Anchoring – luminance → lightness mapping



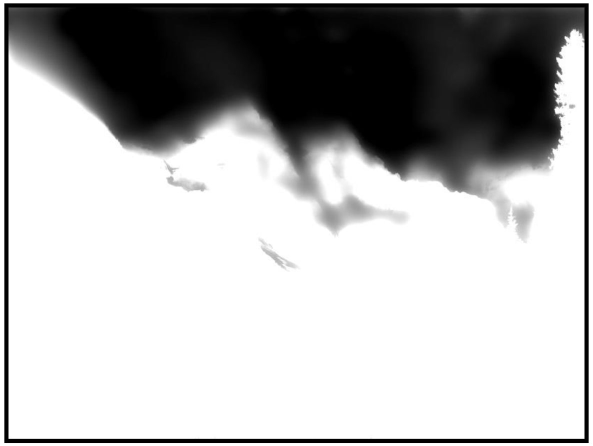
# Fuzzy Segmentation



Perceptual organization:

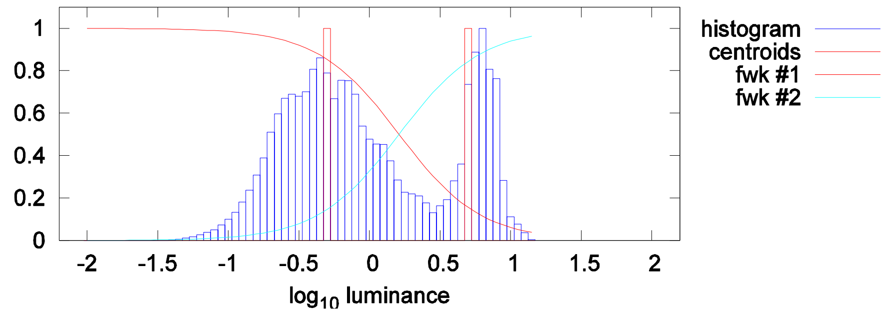
- semantic grouping
- good continuation
- grouping of illumination
- proximity

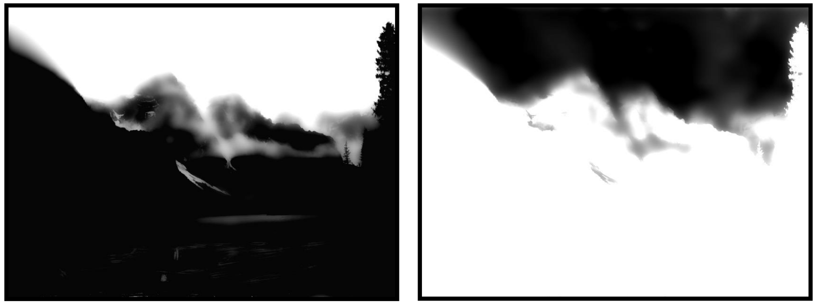
Probability maps define segments



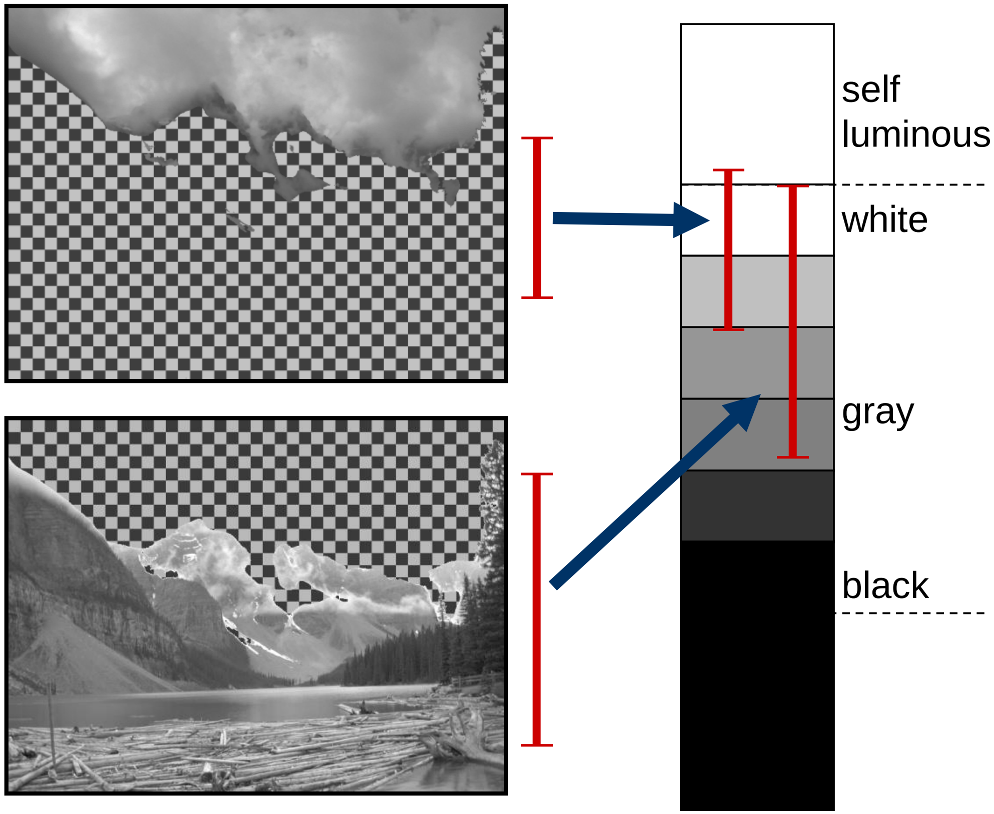
# Computational Model for Frameworks

1. Identify frameworks by luminance
   - grouping of illumination
   - customized K-means
     *constraints imposed by the theory*
   - probability distr. defined by centroids
2. Refine fuzzy frameworks
   - proximity
   - edge preserving spatial filtering of probabilities



# Lightness in Frameworks




## Anchoring to white:

- highest luminance appears white
- highest luminance may appear self-luminous

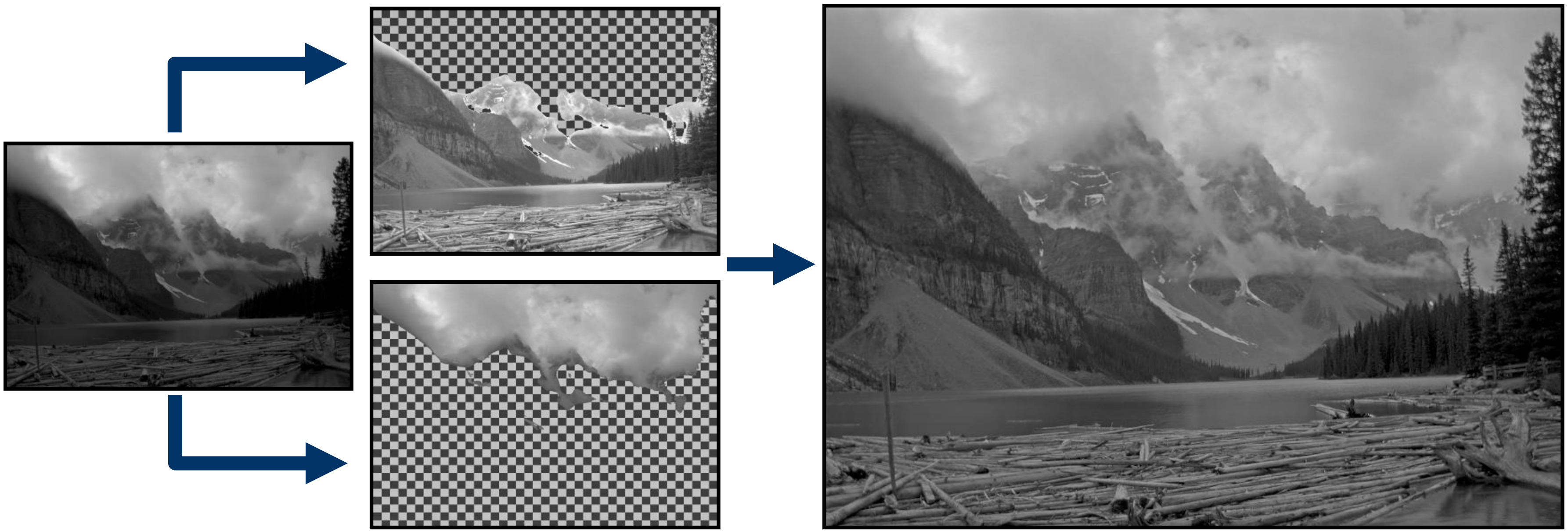
## Our approach:

- filter framework area to eliminate highlights
- highest luminance in framework becomes an anchor

# Net Lightness

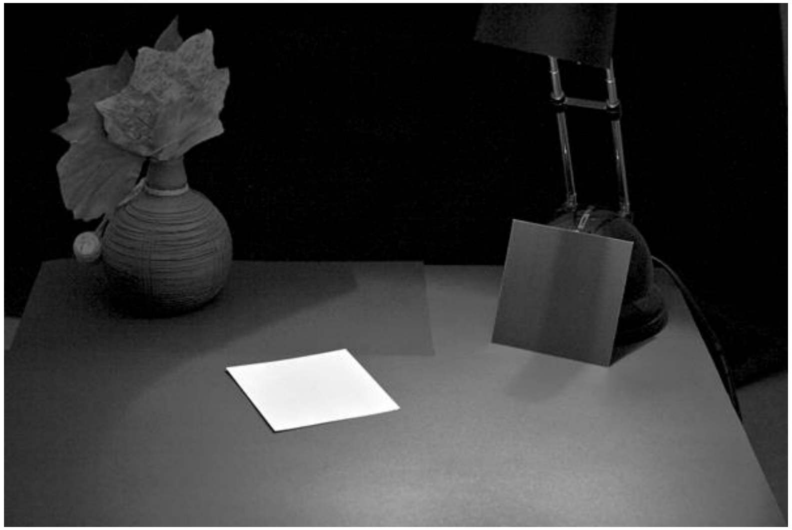
## Shift original luminance $Y(x,y)$

- according to local lightness (framework's local anchor $W_i$)
- proportionally to probabilities $P_i(x,y)$ and framework articulation $D_i$
- constant influence of the global framework (global anchor $W_0$)

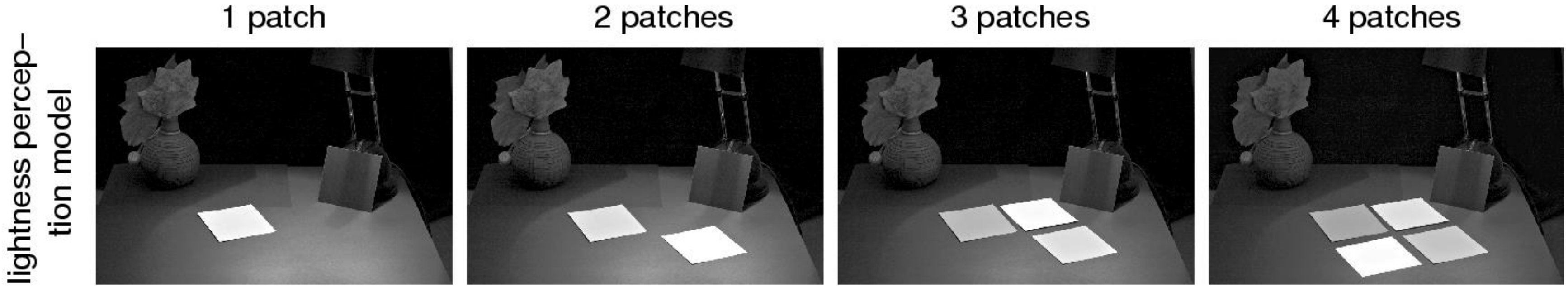


$$L(x,y) = 70\% \cdot \sum_i \frac{(Y - W_i)}{D_i} \cdot P_i(x,y) + 30\% \cdot (Y - W_0)$$

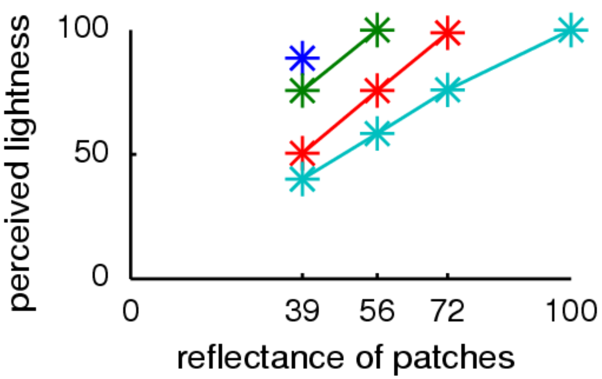
# Testing: Advanced Lightness Estimation

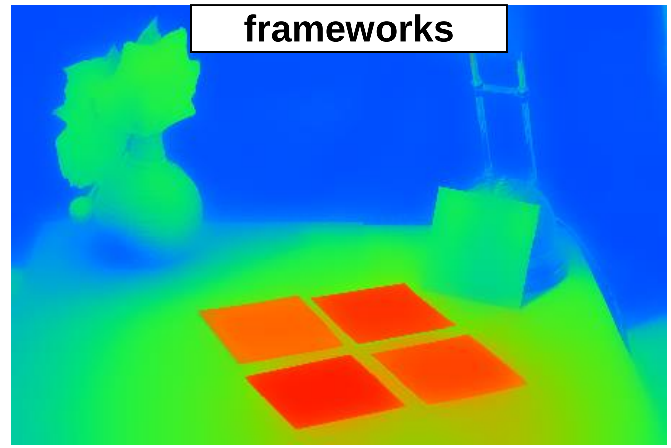


Tone mapping of the Gelb illusion

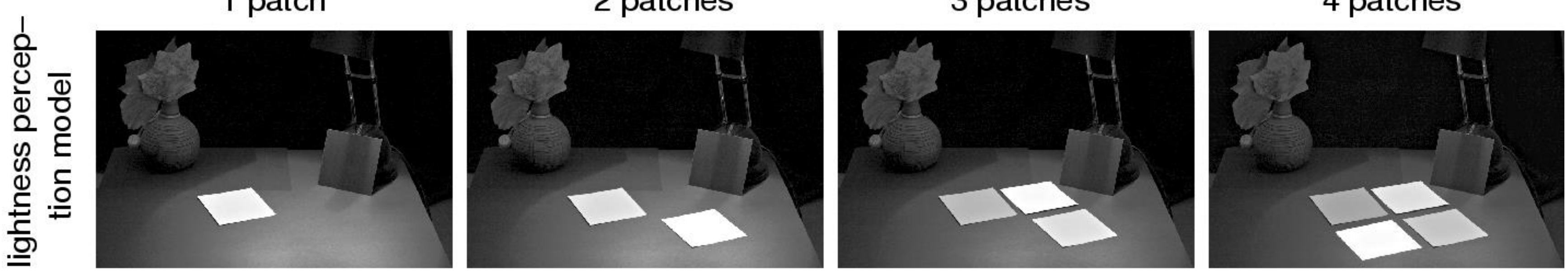


# Analysis of Gelb Illusion



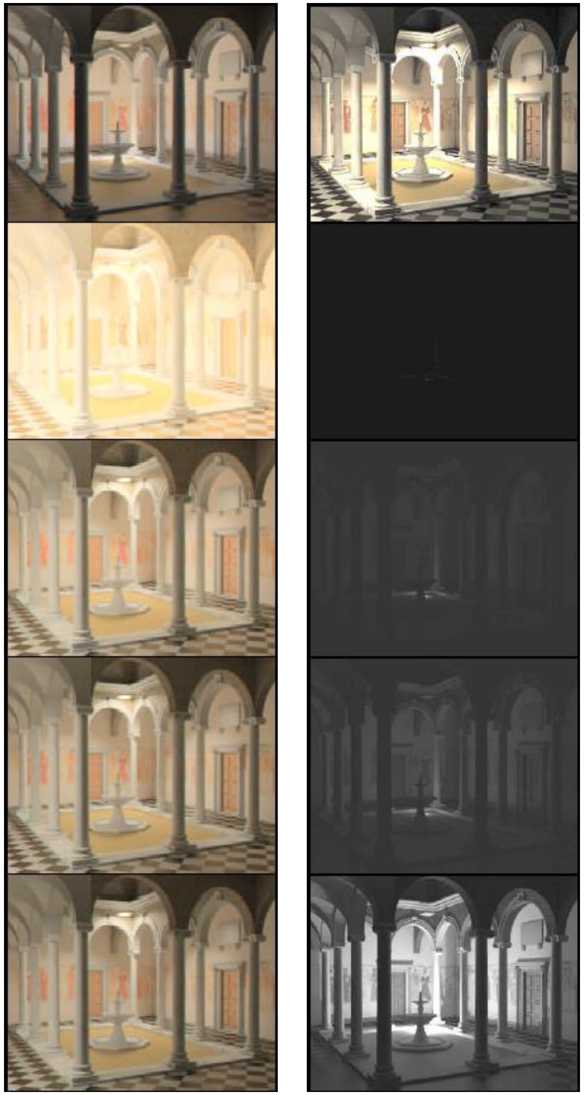

1 patch visible
2 patches visible
3 patches visible
4 patches visible



# 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

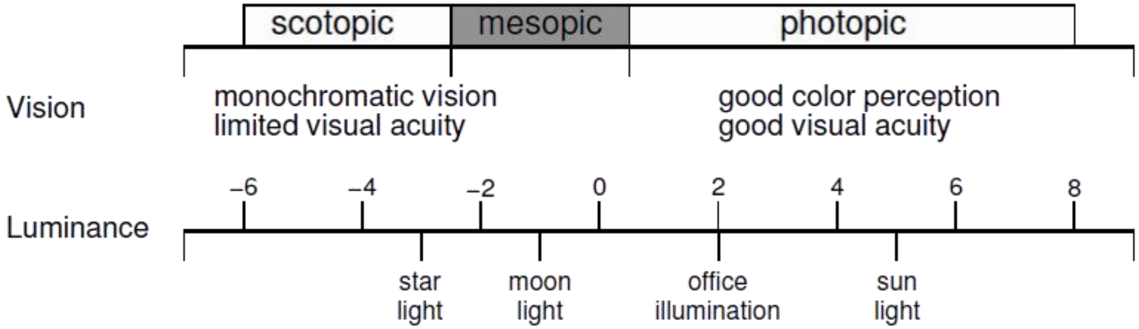
# Temporal Luminance Adaptation



- Compensates changes in illumination
- Simulated by smoothing adapting luminance in tone mapping equation
- Different speed of adaptation to light and to darkness

# 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:

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

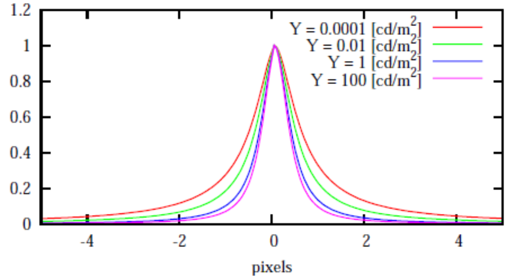
# Veiling Luminance (Glare)

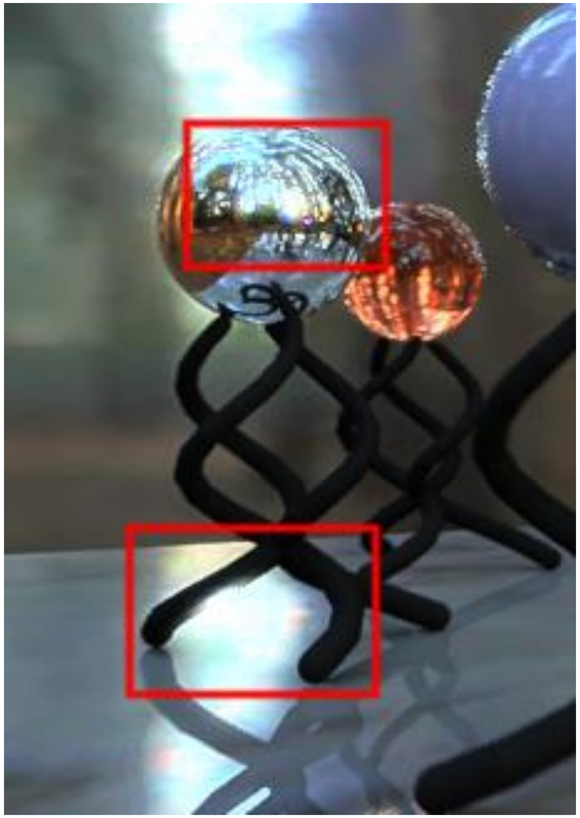
- Decrease of contrast and visibility due to light scattering in the optical system of the eye

- Described by the optical transfer function:

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

$\rho$ spatial frequency, $d$ pupil aperture



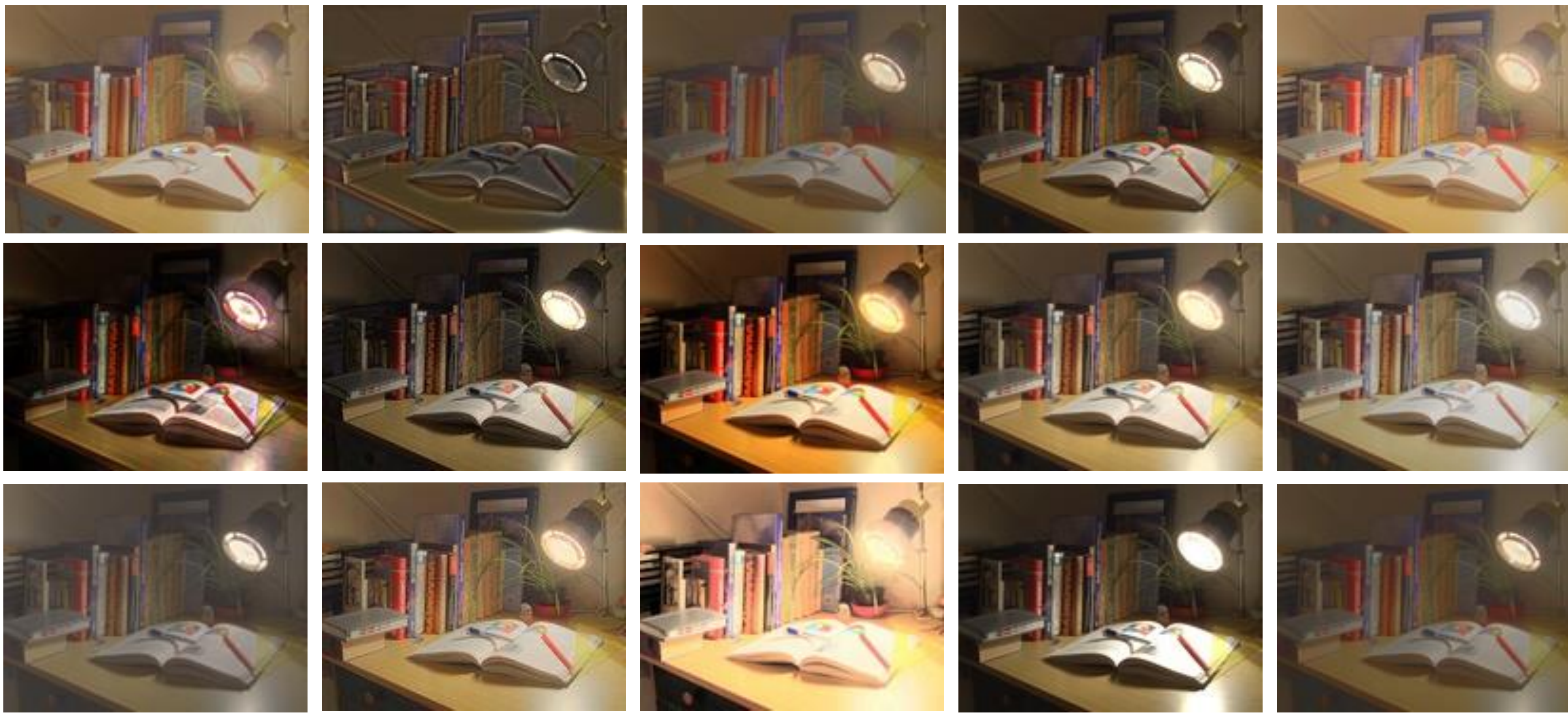
# Fast TM on GPU

- Simple transfer function is very fast
- What about those advanced algorithms
  - bilateral: fast approximate algorithms available
  - gradient domain: GPU needs ~100ms per 1MPx
- Real-time?
  - automatic dodging & burning
  - Gaussian pyramid can be built fast on GPU
  - the pyramid can be used to add perceptual effects at no additional cost!

# HDR Video Player with Perceptual Effects

# Thank You

- cadik@fit.vutbr.cz
- Many thanks to Karol Myszkowski and MPII Saarbrücken HDRI crowd



# Papers about Calibration

- Estimation-Theoretic Approach to Dynamic Range Improvement Using Multiple Exposures
  - M. Robertson, S. Borman, and R. Stevenson
  - In: Journal of Electronic Imaging, vol. 12(2), April 2003.
- Recovering High Dynamic Range Radiance Maps from Photographs
  - Paul E. Debevec and Jitendra Malik
  - In: SIGGRAPH 97
- Radiometric Self Calibration
  - T. Mitsunaga and S.K. Nayar
  - In: Computer Vision and Pattern Recognition (CVPR), 1999.
- High Dynamic Range from Multiple Images: Which Exposures to Combine?
  - M.D. Grossberg and S.K. Nayar
  - In: ICCV Workshop on Color and Photometric Methods in Computer Vision (CPMCV), 2003.

# Papers about Tone Mapping

- 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
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