



Computer Graphics (Graphische Datenverarbeitung)

- HDR & Tone Mapping-

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WS 2021/2022



Corona

- Regular random lookup of the 3G certificates
- Contact tracing: We need to know who is in the class room
 - New ILIAS group for every lecture slot
 - Register via ILIAS or this QR code (only if you are present in this room)

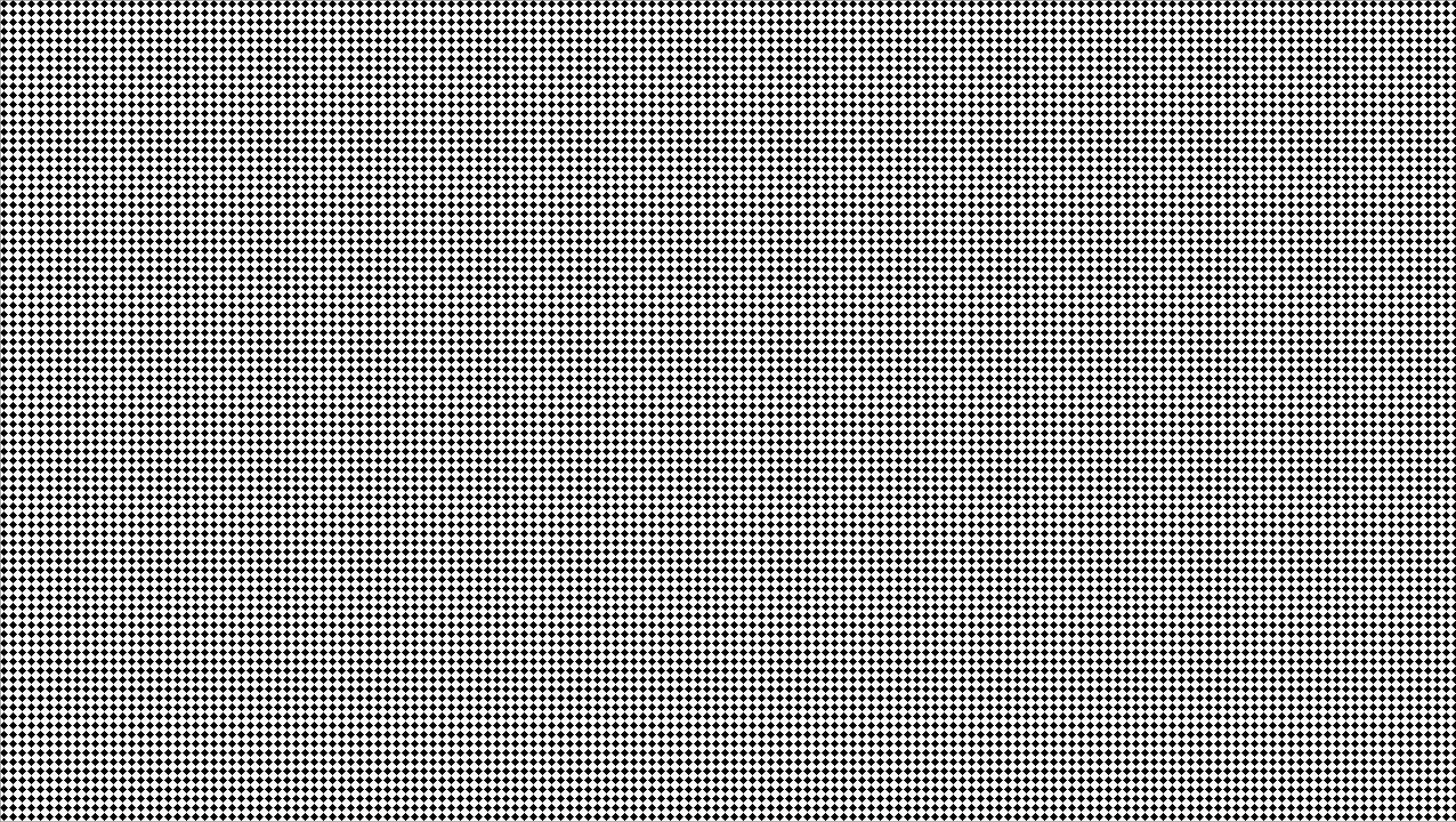




Overview

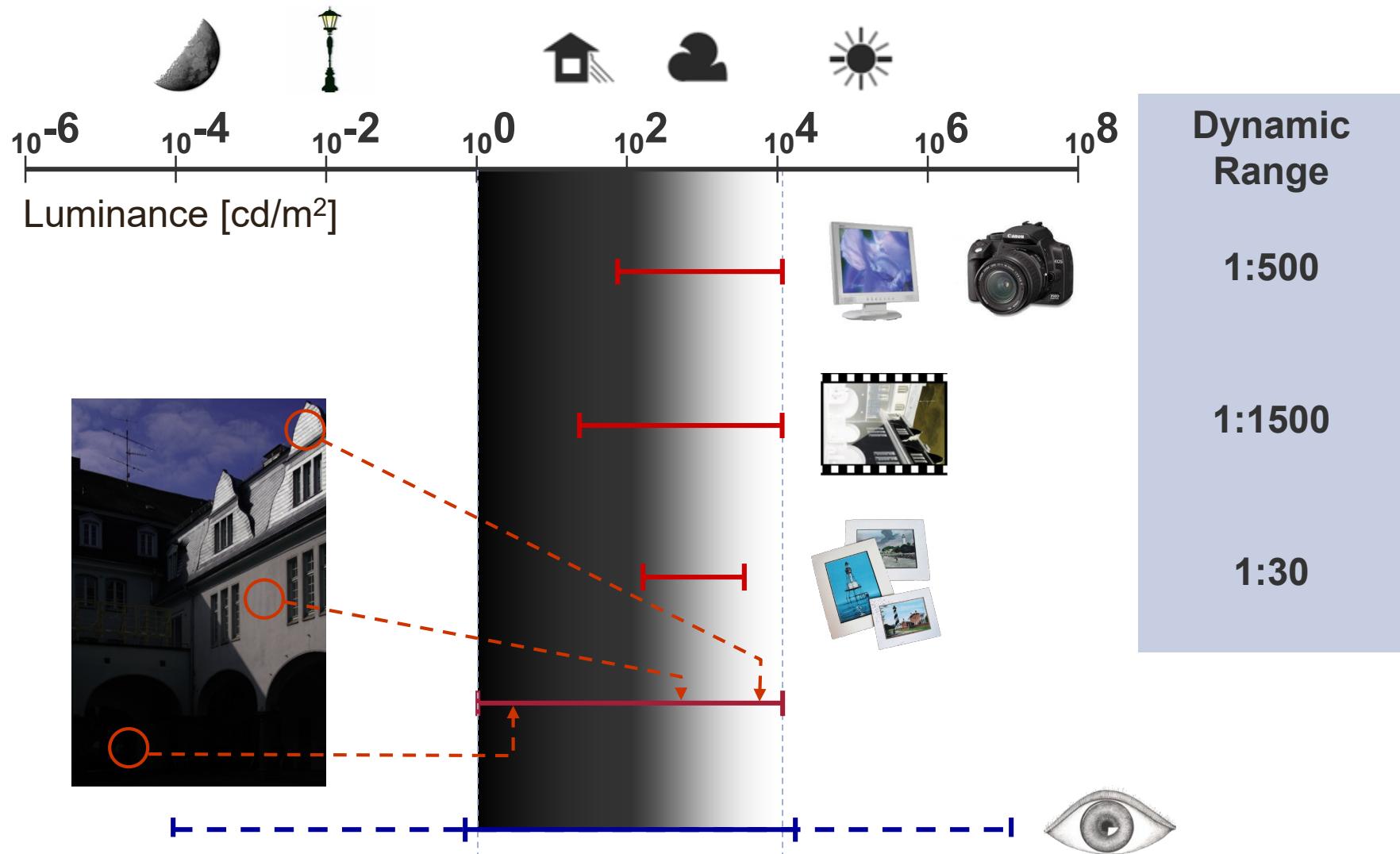
- Last time
 - Gamma Correction
 - Color spaces
- Today
 - Terms and Definitions
 - Tone Mapping
- Next lecture
 - Transformations







Dynamic Range





Acquisition and Display of HDR

- Luminance in real-world scenes -> HDR
- Can be easily simulated
- Acquisition with LDR cameras
- Display on LDR monitors
- HDR displays



Exposure Bracketing



- capture additional over and underexposed images



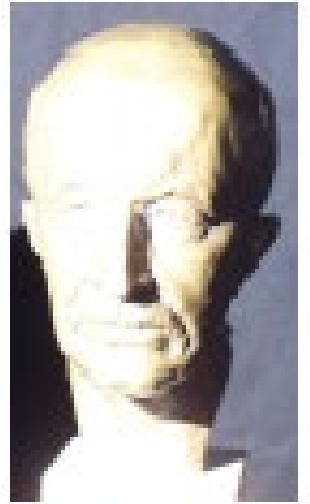
Exposure Bracketing



- capture additional over and underexposed images



Exposure Bracketing



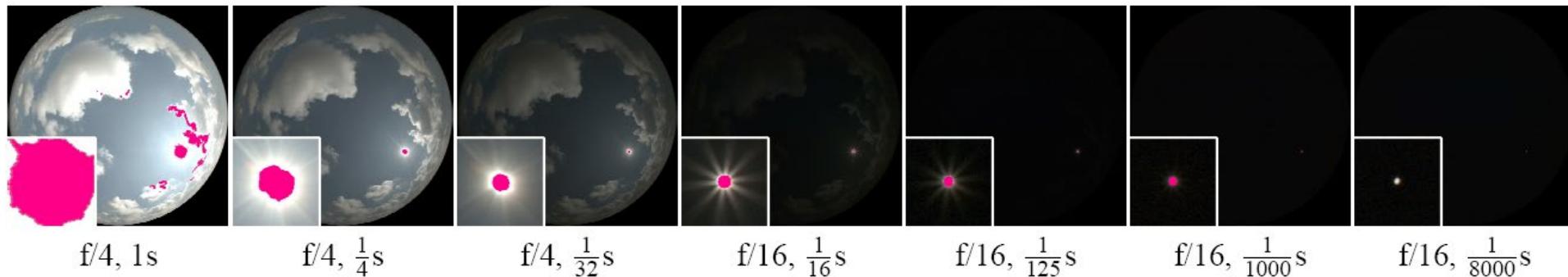
- capture additional over and underexposed images
- how much variation?
- how to combine?



Dynamic Range in Real World Images

- natural scenes: 18 stops (2^{18})
- human: 17 stops
(after adaptation 30 stops $\sim 1:1,000,000,000$)
- camera: 10-16 stops

[Stumpfel et al. 00]





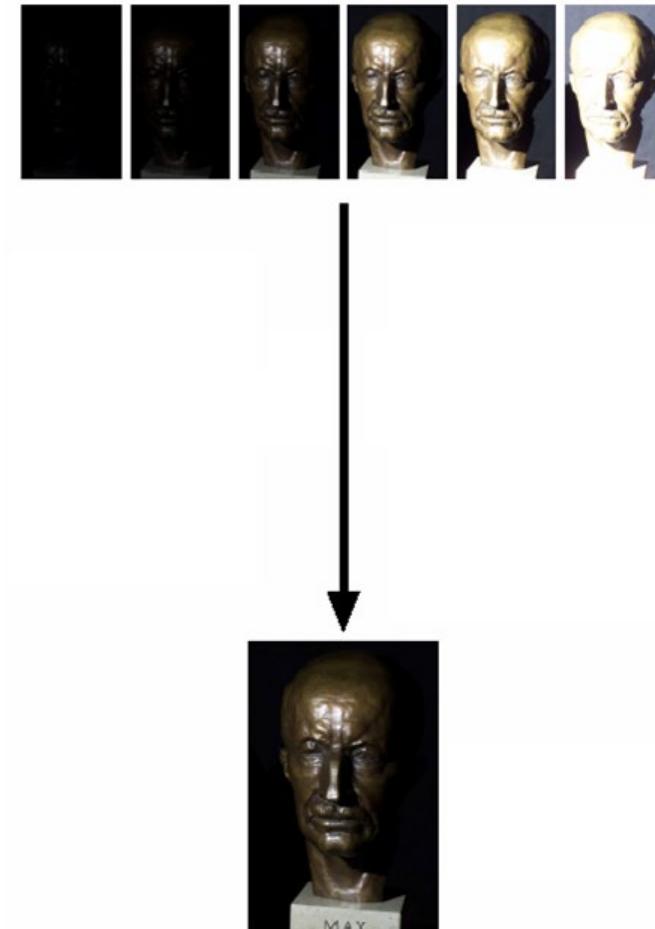
Dynamic Range of Cameras

- example: photographic camera with standard CCD sensor
 - dynamic range of sensor
 - exposure variation (handheld camera/non-static scene): $1/60^{\text{th}}$ s – $1/6000^{\text{th}}$ s exposure time
 - varying aperture f/2.0 – f/22.0
 - exposure bias/varying “sensitivity”
 - total (sequential)
 - simultaneous dynamic range still only 1:1000
 - similar situation for analog cameras
- | | |
|---------------|--|
| 1:1000 | |
| 1:100 | |
| ~1:100 | |
| 1:10 | |
| <hr/> | |
| 1:100,000,000 | |



High Dynamic Range (HDR) Imaging

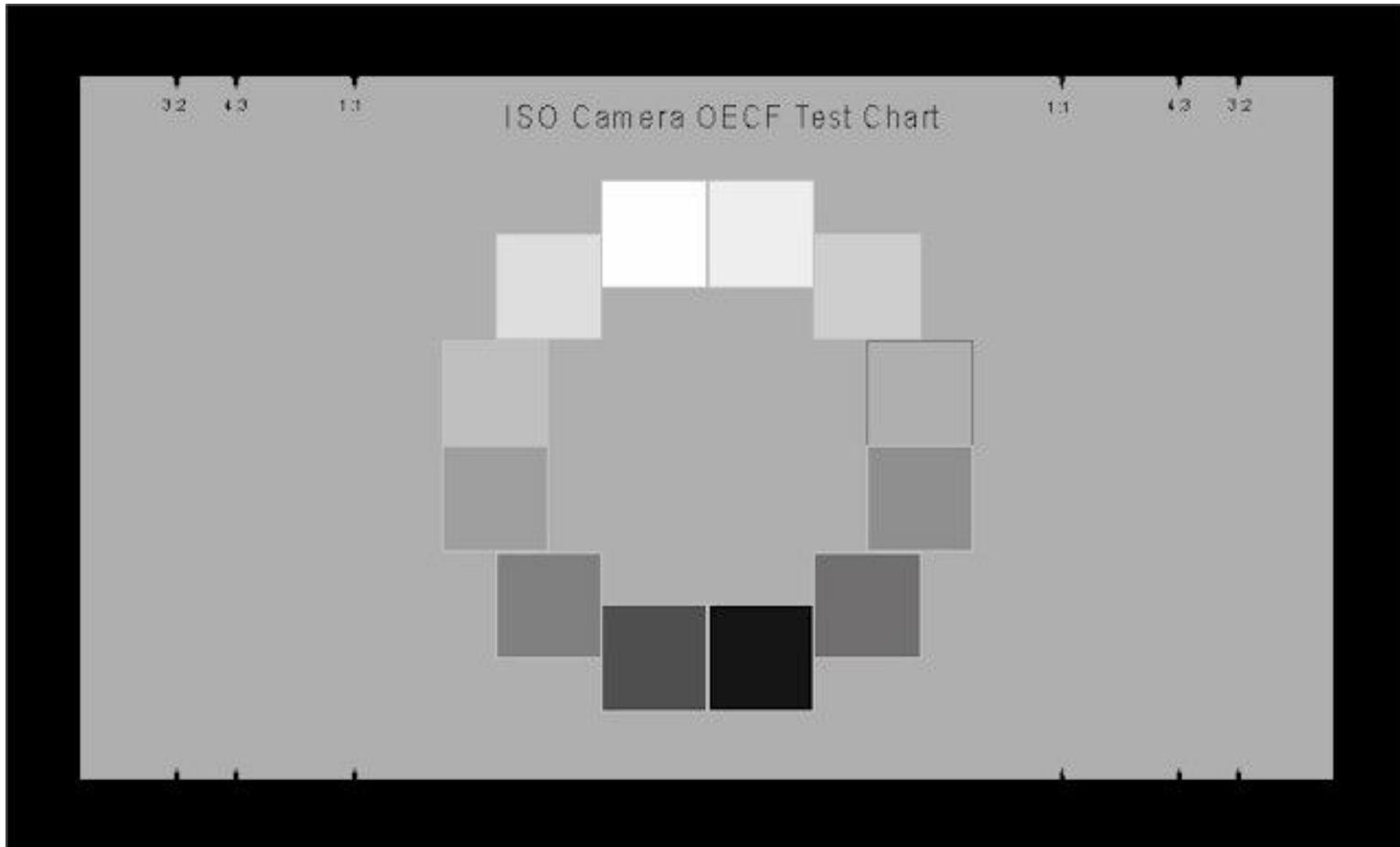
- basic idea of multi-exposure techniques:
 - combine multiple images with different exposure settings
 - makes use of available sequential dynamic range
- other techniques available (e.g. HDR video)





OECF Test Chart

- absolute calibration





High Dynamic Range Imaging

- limited dynamic range of cameras is a problem
 - shadows are underexposed
 - bright areas are overexposed
 - sampling density is not sufficient
- some modern CMOS imagers have a higher and often sufficient dynamic range than most CCD imagers

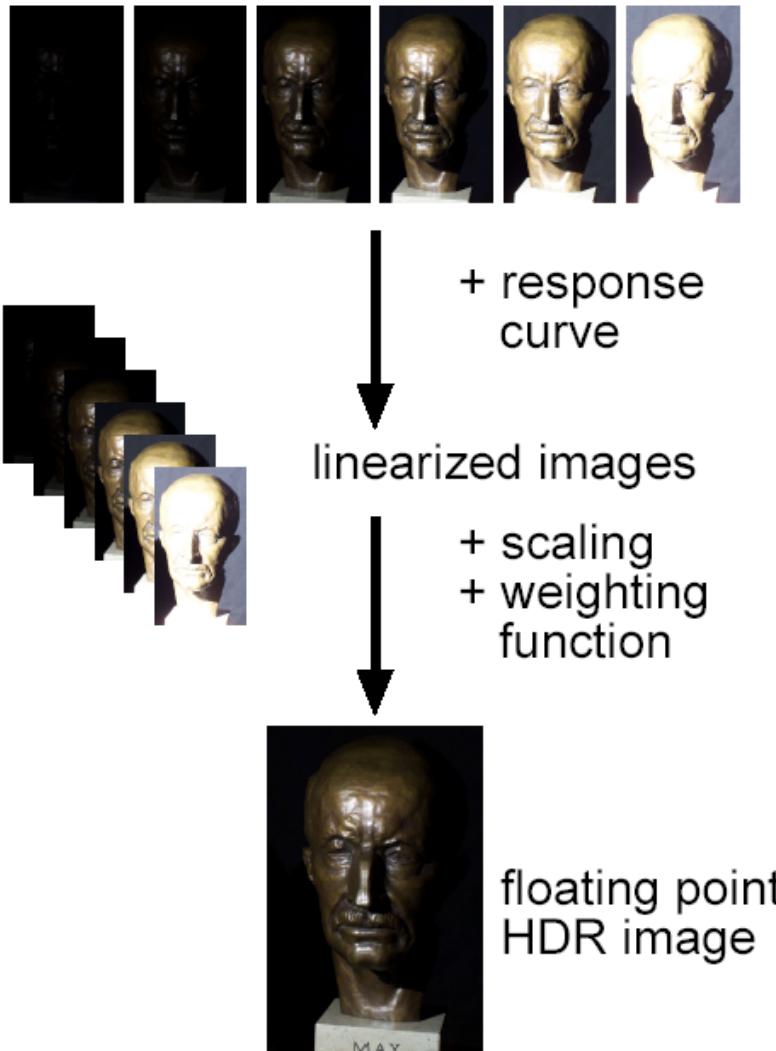


High Dynamic Range Imaging

- general idea of High Dynamic Range (HDR) imaging:
- combine multiple images with different exposure times
 - pick for each pixel a well exposed image
 - response curve needs to be known
 - don't change aperture due to different depth-of-field



High Dynamic Range Imaging





HDR Imaging [Robertson et al.99]

- Principle of this approach:
 - calculate a HDR image using the response curve
 - find a better response curve using the HDR image
 - (to be iterated until convergence)



Linear Response Curve



1/8s

1/4s

1/2s

1s

2s

4s

HDR

□ .0125

.025

.05

.1

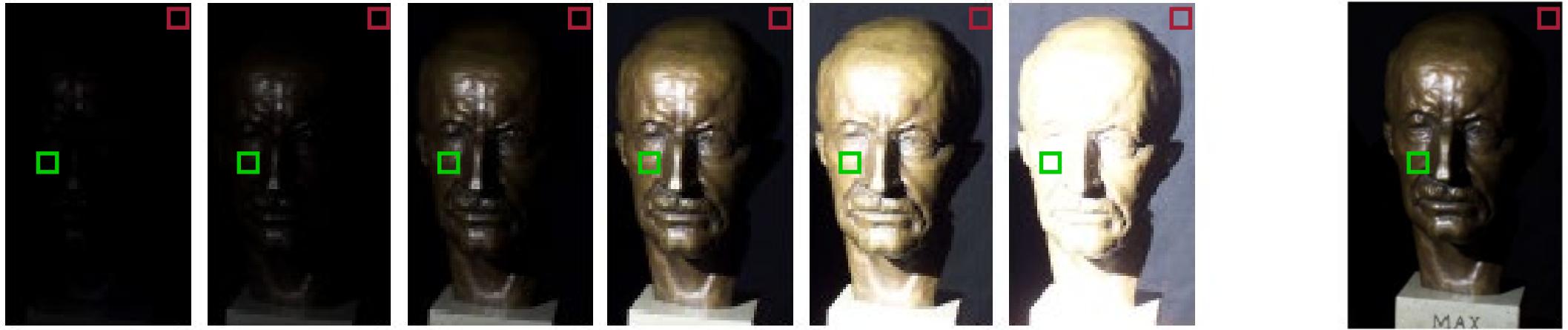
.2

.4

0.1



Linear Response Curve



1/8s

1/4s

1/2s

1s

2s

4s

HDR

□ .0125

.025

.05

.1

.2

.4

0.1

□ .0675

.125

.25

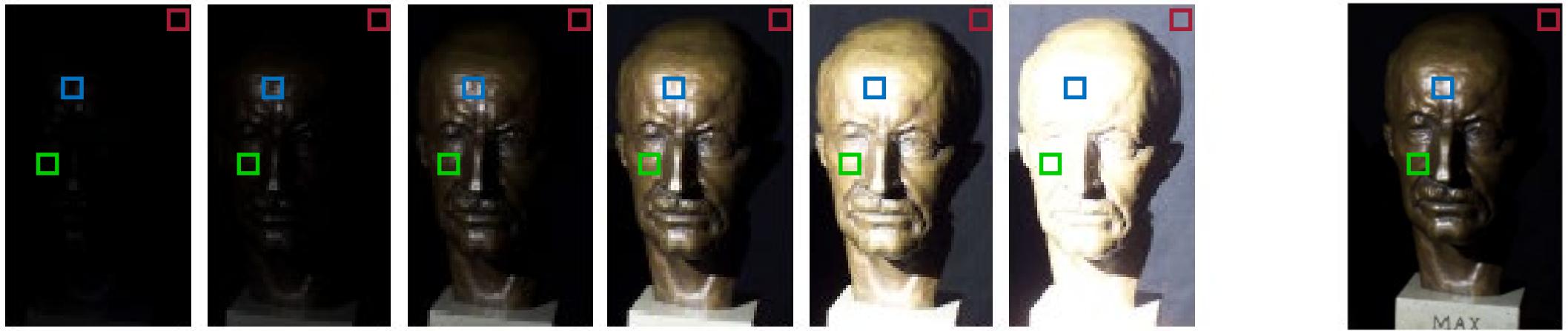
.5

1

2

0.5

Linear Response Curve



1/8s

1/4s

1/2s

1s

2s

4s

HDR

□ .0125

□ .025

□ .05

□ .1

□ .2

□ .4

□ 0.1

□ .0675

□ .125

□ .25

□ .5

□ 1

□ 0.5

□ .125

□ .25

□ .5

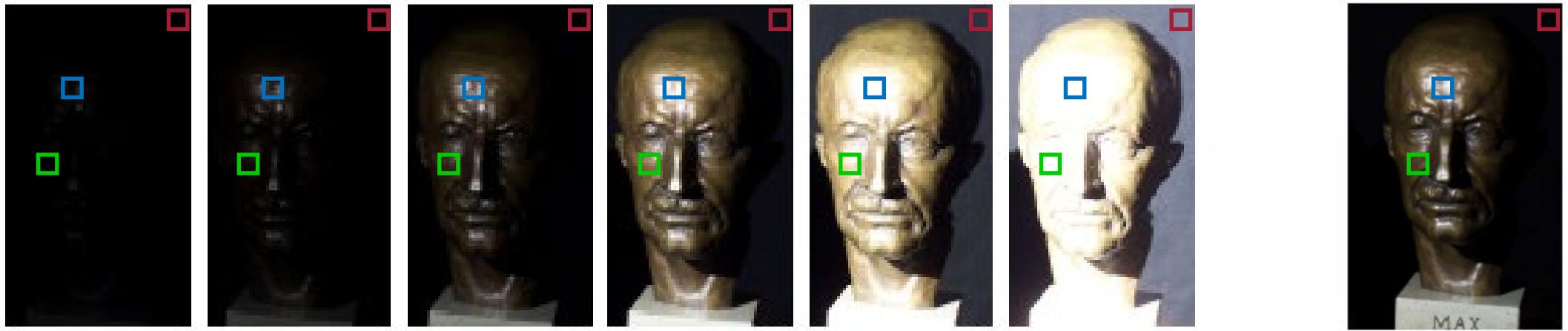
□ 1

□ 2

□ 4

□ 1

Linear Response Curve



1/8s

1/4s

1/2s

1s

2s

4s

HDR

□ .0125

.025

.05

.1

.2

.4

0.1

□ .0675

.125

.25

.5

1

1

0.5

□ .125

.25

.5

1

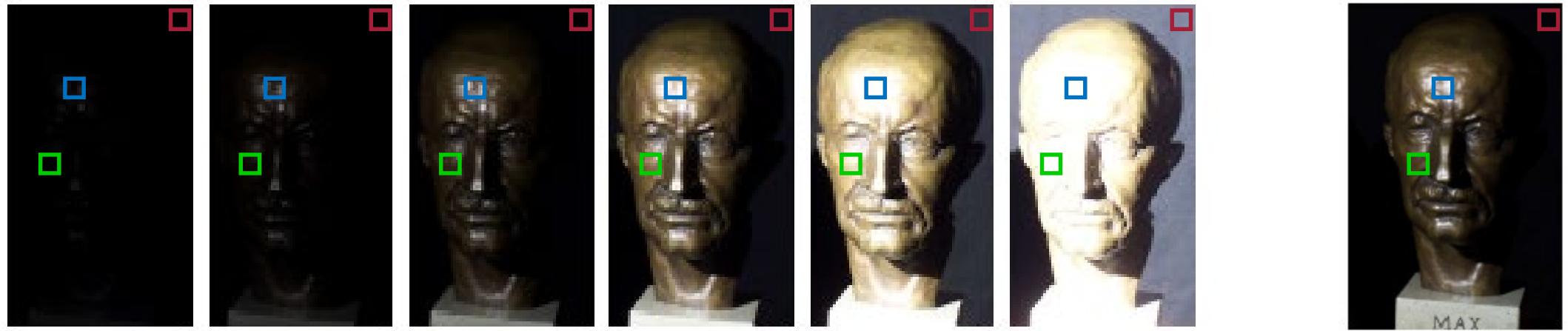
1

1

1

- overexposed – saturation

Linear Response Curve



1/8s

1/4s

1/2s

1s

2s

4s

HDR

□	0	0	0	.1	.2	.4	0.1
□	0	.125	.25	.5	1	1	0.5
□	.125	.25	.5	1	1	1	1

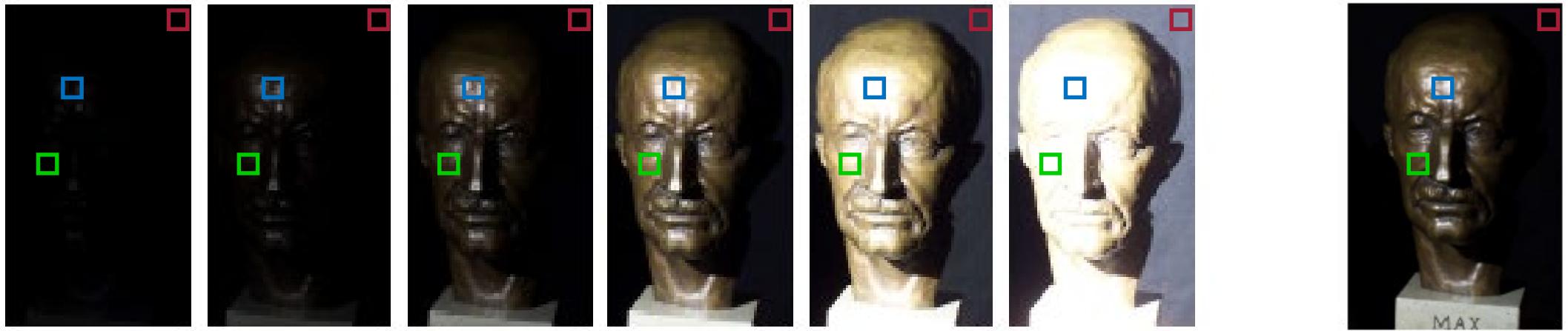
- overexposed – saturation
- underexposed – quantization (lost in noise)

Non-linear Response Curve – e.g. \sqrt{x}



- overexposed – saturation
- underexposed – quantization (lost in noise)

Unknown Response Curve



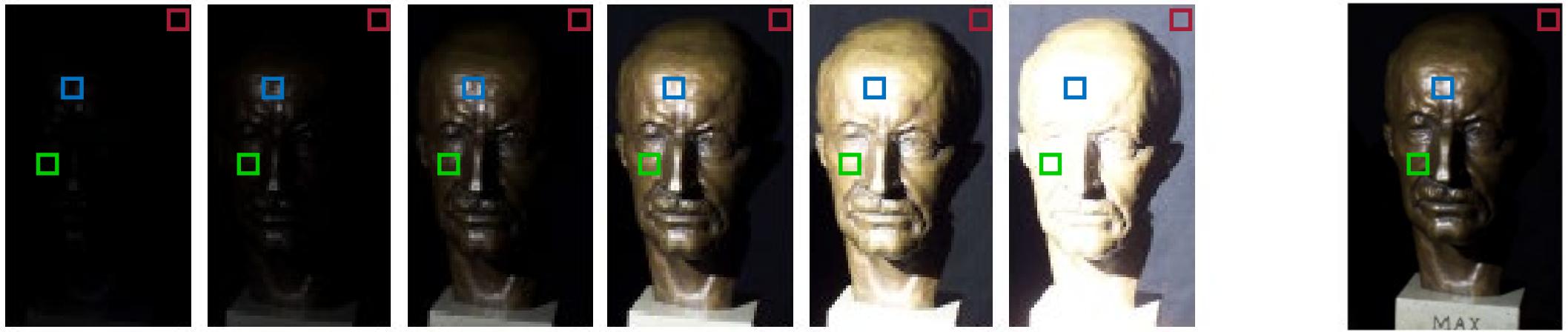
1/8s 1/4s 1/2s 1s 2s 4s HDR

□	0	0	0	.316	.447	.634
□	0	.353	.5	.707	1	1
□	.353	.5	.707	1	1	1

- Reconstruct HDR image assuming linear response curve

$$x_j = \sum_i \frac{f^{-1}(y_{ij})}{t_i} = \sum_i \frac{y_{ij}}{t_i}$$

Unknown Response Curve



1/8s

1/4s

1/2s

1s

2s

4s

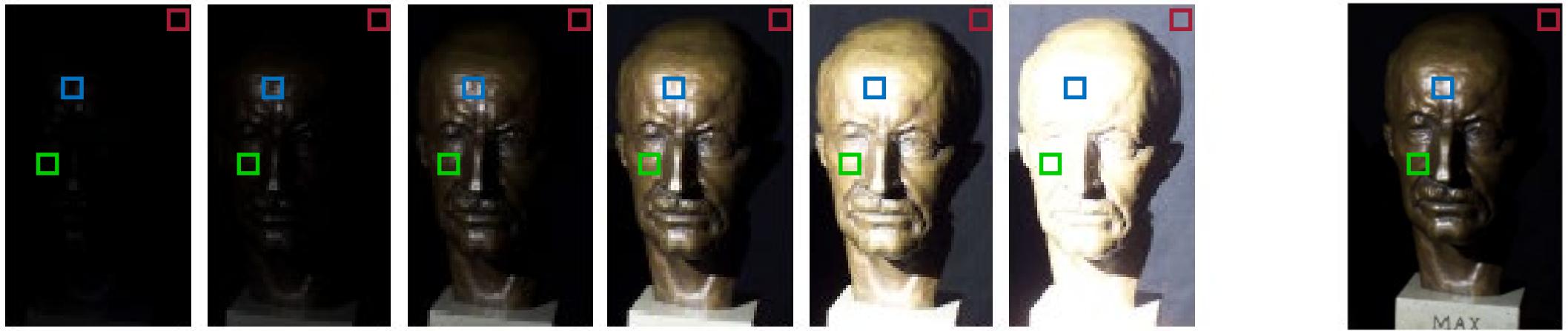
HDR

□	0	0	0	$.316_{/1}$	$+ .447_{/2}$	$+ .634_{/4} =$	0.233
□	0	.353	.5	.707	1	1	
□	.353	.5	.707	1	1	1	

- Reconstruct HDR image assuming linear response curve

$$x_j = \frac{1}{N} \sum_i \frac{f^{-1}(y_{ij})}{t_i}$$

Unknown Response Curve



1/8s

1/4s

1/2s

1s

2s

4s

HDR

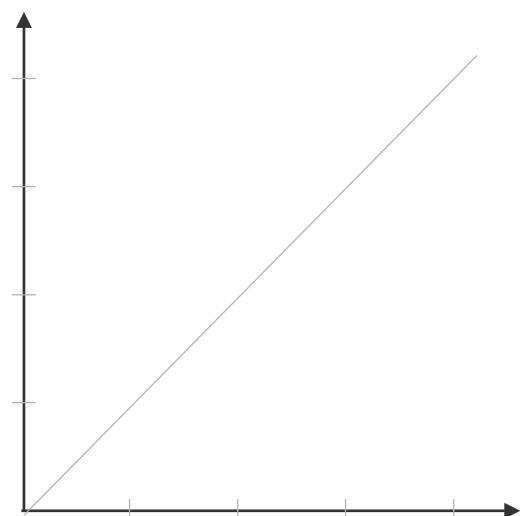
□	0	0	0	.316	.447	.634	0.233	0.1
□	0	.353	.5	.707	1	1	0.905	0.5
□	.353	.5	.707	1	1	1	1.934	1

- Reconstruct HDR image assuming linear response curve

$$x_j = \frac{1}{N} \sum_i \frac{f^{-1}(y_{ij})}{t_i}$$

Recover Response Curve

	1/8s	1/4s	1/2s	1s	2s	4s	HDR	
■	0	0	0	.316	.447	.634	0.233	0.1
□	0	.353	.5	.707	1	1	0.905	0.5
□	.353	.5	.707	1	1	1	1.934	1

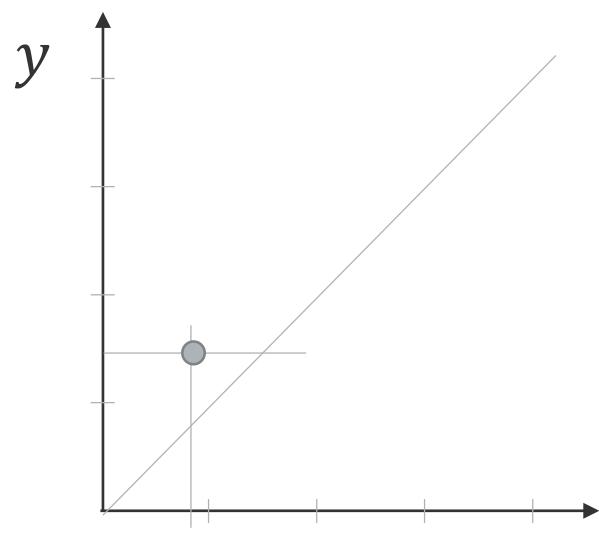


- Find all pixels with the same y ; average

$$f^{-1}(y) = \frac{1}{N} \sum_i t_i x_i$$

Recover Response Curve

	1/8s	1/4s	1/2s	1s	2s	4s	HDR	
■	0	0	0	.316	.447	.634	0.233	0.1
□	0	.353	.5	.707	1	1	0.905 ₄	0.5
□	.353	.5	.707	1	1	1	$\frac{.353 + 1.934}{2} = .688$	1

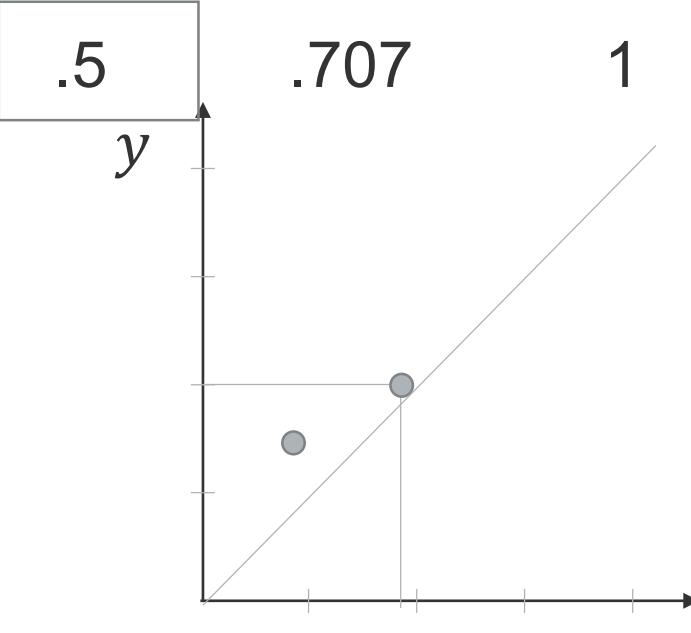


- find all pixels with the same y ; assume known HDR
- average exposure

$$f^{-1}(y) = \frac{1}{N} \sum_i t_i x_i$$

Recover Response Curve

	1/8s	1/4s	1/2s	1s	2s	4s	HDR	
■	0	0	0	.316	.447	.634	0.233	0.1
□	0	.353	.5	.707	1	1	0.905/2	0.5
□	.353	.5	.707	1	1	1	$\frac{.936}{2} = .468$	1

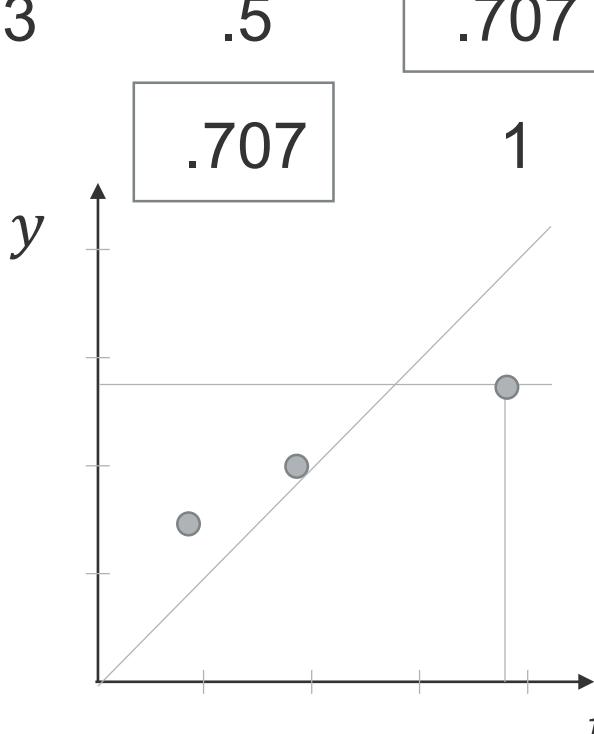


- find all pixels with the same y ; assume known HDR
- average exposure

$$f^{-1}(y) = \frac{1}{N} \sum_i t_i x_i$$

Recover Response Curve

	1/8s	1/4s	1/2s	1s	2s	4s	HDR	
■	0	0	0	.316	.447	.634	0.233	0.1
□	0	.353	.5	.707	1	1	0.905 _{/1}	0.5
□	.353	.5	.707	1	1	1	$\frac{+}{=} 1.934_{/2}$	1

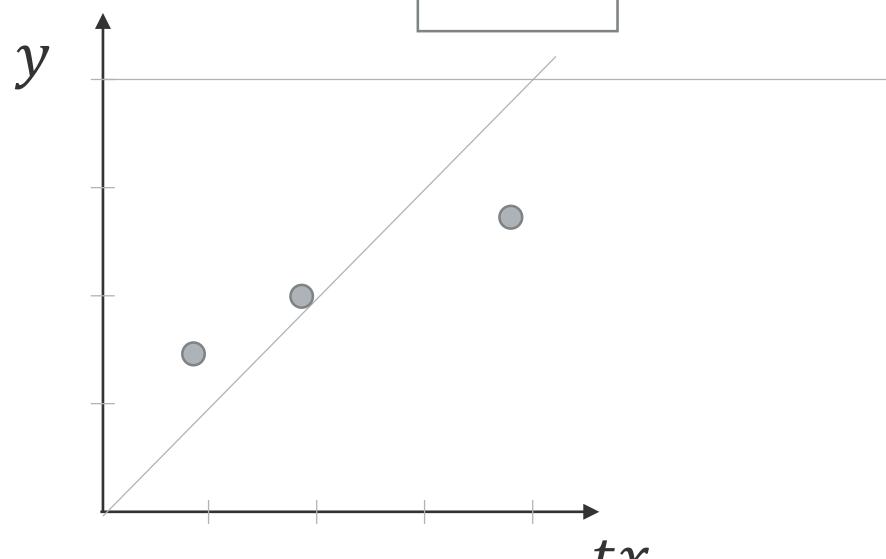


- find all pixels with the same y ; assume known HDR
- average exposure

$$f^{-1}(y) = \frac{1}{N} \sum_i t_i x_i$$

Recover Response Curve

	1/8s	1/4s	1/2s	1s	2s	4s	HDR	
■	0	0	0	.316	.447	.634	0.233	0.1
□	0	.353	.5	.707	1	1	0.905/.5	0.5
□	.353	.5	.707	1	1	1	+ 1.934/1 =	1

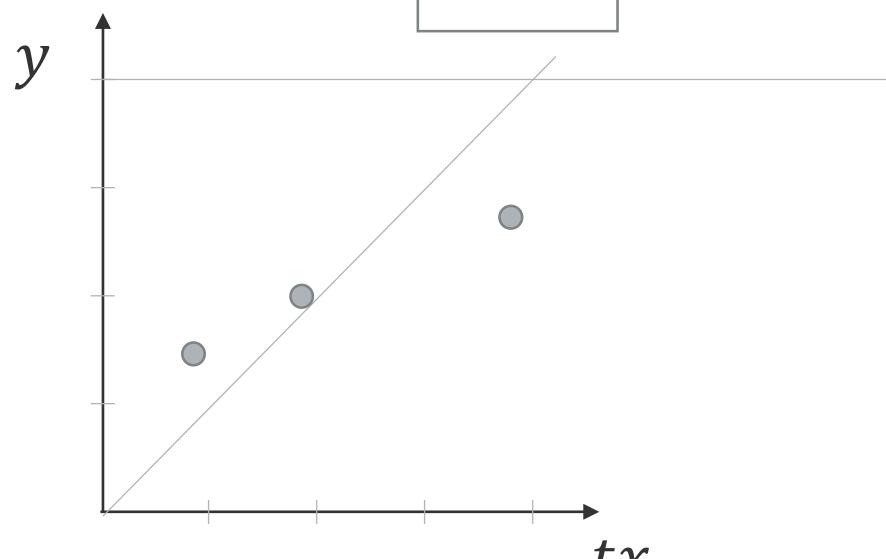


- find all pixels with the same y ; assume known HDR
- average exposure

$$f^{-1}(y) = \frac{1}{N} \sum_i t_i x_i$$

Recover Response Curve

	1/8s	1/4s	1/2s	1s	2s	4s	HDR	
■	0	0	0	.316	.447	.634	0.233	0.1
□	0	.353	.5	.707	1	1	0.905/.5	0.5
□	.353	.5	.707	1	1	1	+ 1.934/1 =	1

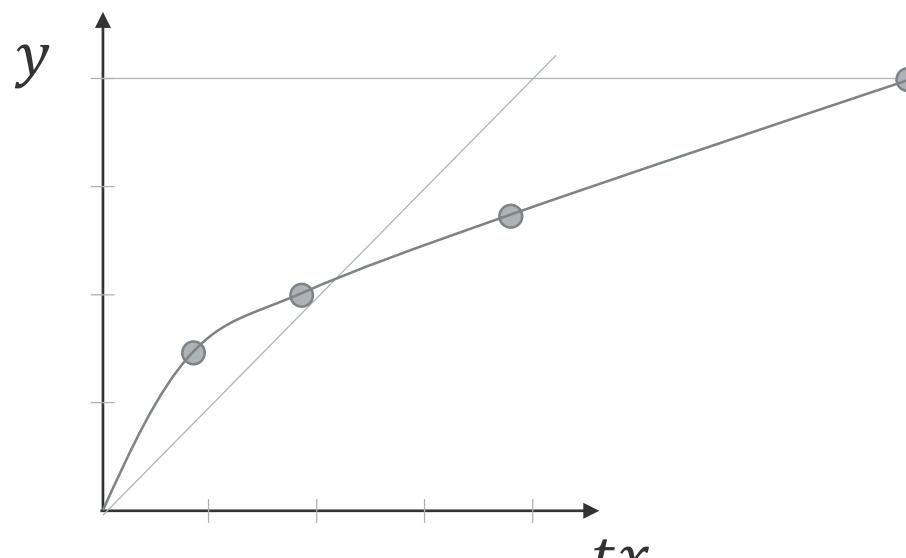


- find all pixels with the same y ; assume known HDR
- average exposure

$$f^{-1}(y) = \frac{1}{N} \sum_i t_i x_i$$

Recover Response Curve

	1/8s	1/4s	1/2s	1s	2s	4s	HDR	
■	0	0	0	.316	.447	.634	0.233	0.1
□	0	.353	.5	.707	1	1	0.905	0.5
□	.353	.5	.707	1	1	1	1.934	1

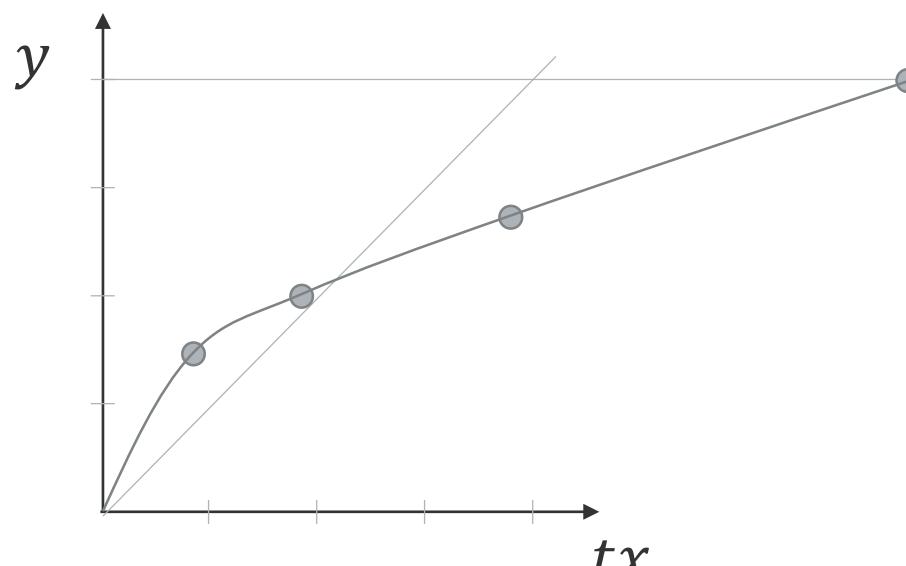


- find all pixels with the same y ; assume known HDR
- average exposure

$$f^{-1}(y) = \frac{1}{N} \sum_i t_i x_i$$

Recover Response Curve

	1/8s	1/4s	1/2s	1s	2s	4s	HDR	
■	0	0	0	.316	.447	.634	0.233	0.1
□	0	.353	.5	.707	1	1	0.905	0.5
□	.353	.5	.707	1	1	1	1.934	1

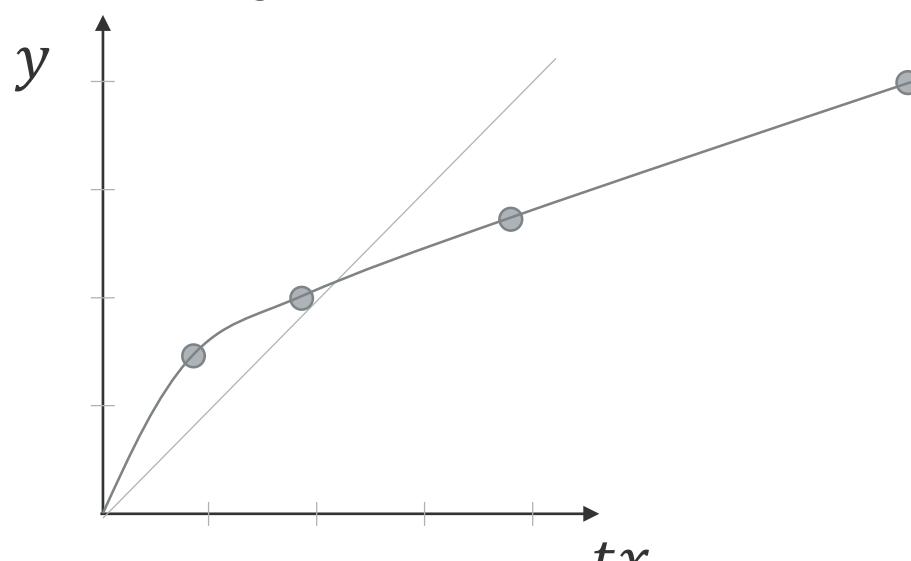


- Reconstruct HDR image (with current curve)

$$x_j = \frac{1}{N} \sum_i \frac{f^{-1}(y_{ij})}{t_i}$$

Calculating new HDR image

$f^{-1}(y)$	1/8s	1/4s	1/2s	1s	2s	4s	HDR	
■	0	0	0	.316	.447	.634	0.233	0.1
□	0	.353	.5	.707	1	1	0.905	0.5
□	.353	.5	.707	1	1	1	1.934	1

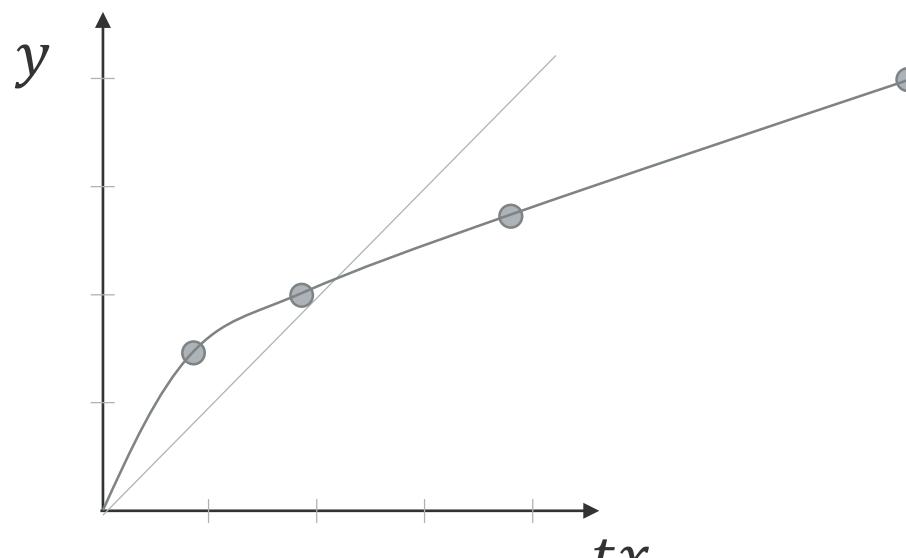


- Reconstruct HDR image (with current curve)

$$x_j = \frac{1}{N} \sum_i \frac{f^{-1}(y_{ij})}{t_i}$$

Calculating new HDR image

$f^{-1}(y)$	1/8s	1/4s	1/2s	1s	2s	4s	HDR	
■	0	0	0	.18	.31	.75	0.233	0.1
□	0	.21	.5	.97	1.87	1	0.905	0.5
□	.21	.5	.97	1.87	1	1	1.934	1

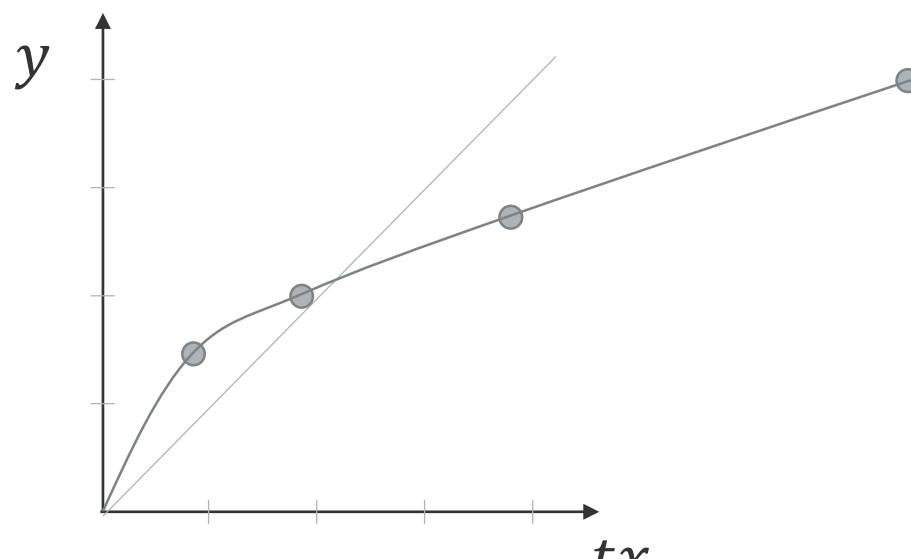


- Reconstruct HDR image (with current curve)

$$x_j = \frac{1}{N} \sum_i \frac{f^{-1}(y_{ij})}{t_i}$$

Calculating new HDR image

$f^{-1}(y)$	1/8s	1/4s	1/2s	1s	2s	4s	HDR	
■	0	0	0	.18	.31	.75	0.174	0.1
□	0	.21	.5	.97	1.87	1	0.936	0.5
□	.21	.5	.97	1.87	1	1	1.87	1



- Reconstruct HDR image (with current curve)
- ... calculate updated curve ... reconstruct HDR

$$x_j = \frac{1}{N} \sum_i \frac{f^{-1}(y_{ij})}{t_i}$$



HDR Imaging [Robertson et al.99]

input:

- series of i images with exposure times t_i
- and pixel values y_{ij}

$$y_{ij} = f(t_i x_j)$$

task:

- find irradiance (luminance) x_j
- recover response curve

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



HDR Imaging [Robertson et al.99]

input:

- series of i images with exposure times t_i and pixel values y_{ij}
- a weighting function $w_{ij} = w(y_{ij})$ (bell shaped curve)
- a camera response curve
 - initial assumption: linear response
- calculate HDR values x_j from images using $f^{-1}(y_{ij})$

$$x_j = \frac{\sum_i w_{ij} t_i f^{-1}(y_{ij})}{\sum_i w_{ij} t_i^2}$$

HDR Imaging [Robertson et al.99]

- optimizing the response curve $f^{-1}(y_{ij})$ resp. $f^{-1}(m)$:
- minimization of objective function O

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

using Gauss-Seidel relaxation yields

$$I_m = \frac{1}{\text{Card}(E_m)} \sum_{i,j \in E_m} t_i x_j$$

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

- Normalization, e.g. normalize $f^{-1}(y_{ij})$ so that $f^{-1}(128) = 1.0$

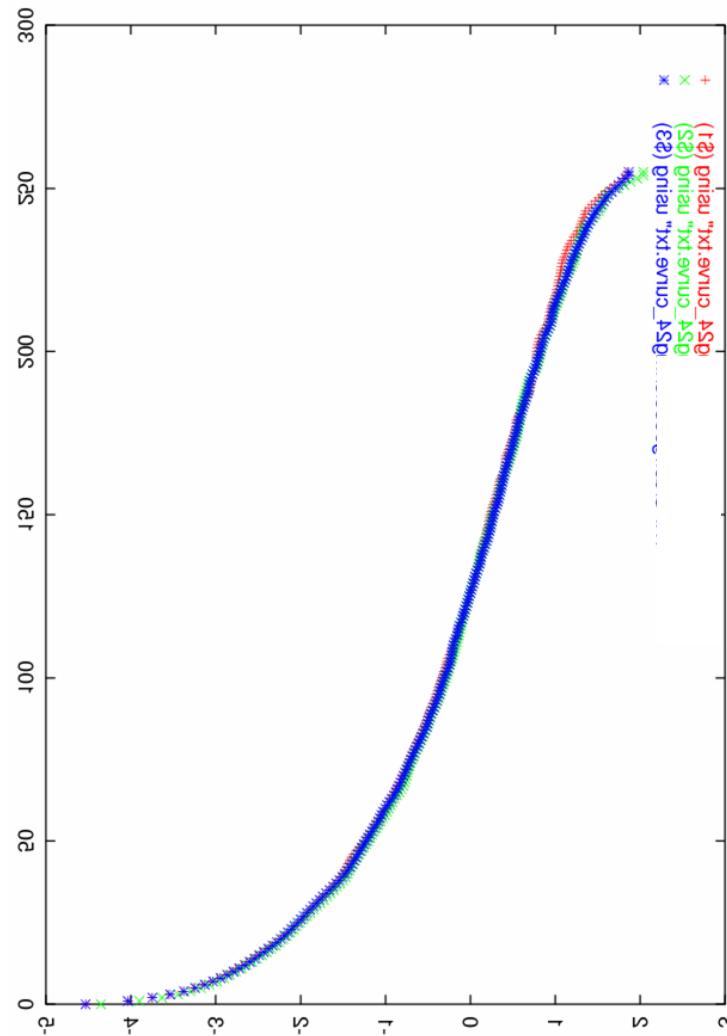
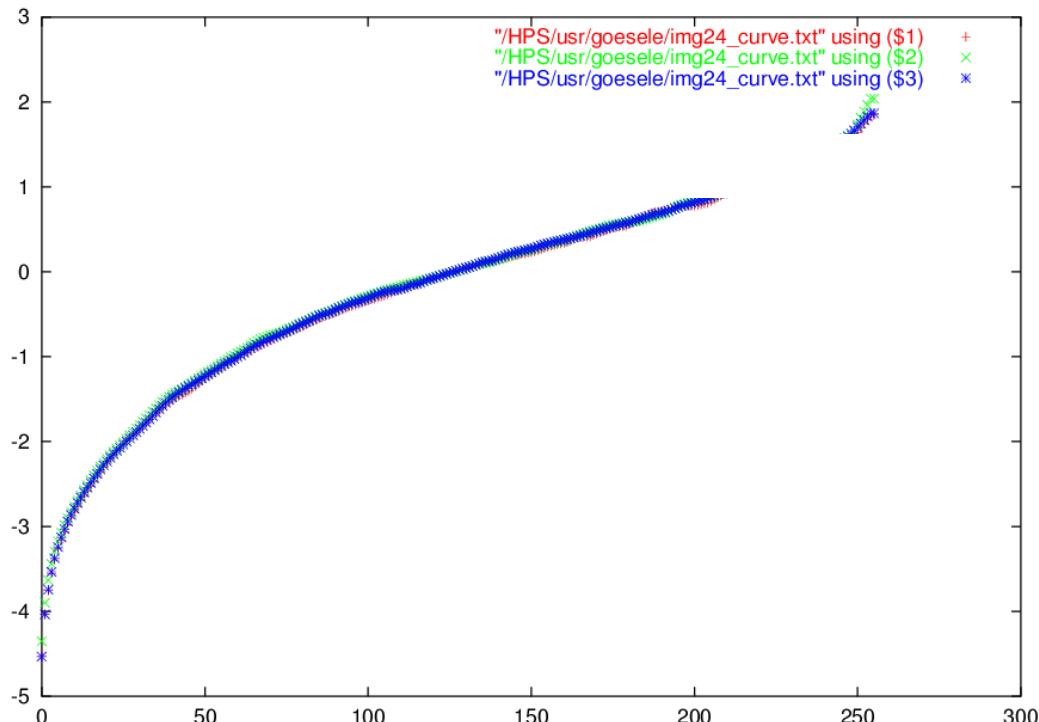


HDR Imaging [Robertson et al. 99]

- both steps
- calculation of a HDR image using $f^{-1}(y_{ij})$
- optimization of $f^{-1}(y_{ij})$ using the HDR image
- are now iterated until convergence
 - criterion: decrease of O below some threshold
 - usually about 5 iterations



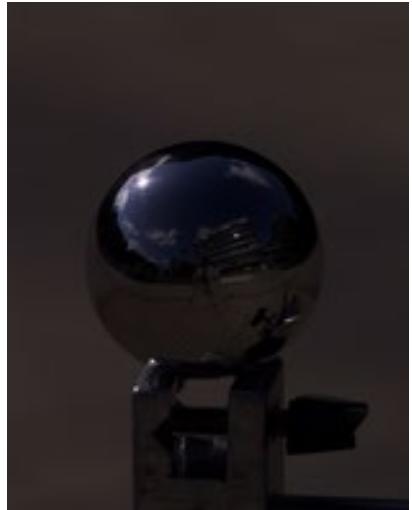
HDR Imaging [Robertson et al.99]



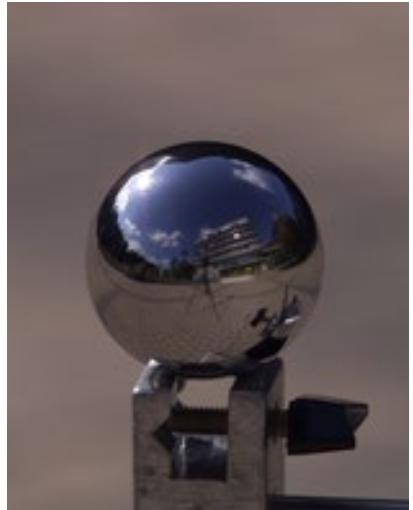
$$\log(f^{-1}(y_{ij}))$$



Capturing Environment Maps



1/2000s



1/500s



1/125s



1/30s

1/8s

series of input images



Capturing Environment Maps





Weighting Function

- [Robertson et al.99]

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

- clip to zero in under and over exposed regions
- choice of weighting function $w(y_{ij})$ for response recovery
 - for 8 bit images
 - possible correction at both ends (over/underexposure)
 - motivated by general noise model



Algorithm of Robertson et al.

Discussion

- method very easy
- doesn't make assumptions about response curve shape
- converges fast
- takes all available input data into account
- can be extended to >8 bit color depth
- 16bit should be followed by smoothing



Input Images for Response Recovery

- Image set should cover full range of radiance values
 - grey card, out of focus, smooth illumination gradient
- Advantages
 - uniform histogram of values
 - no color processing or sharpening interfering with the result
- How many images are necessary to get good HDR images?
 - depends on scene dynamic range and on quality requirements
 - most often a difference of two stops (factor of 4) between exposures is sufficient
 - [Grossberg & Nayar 2003]



HDR-Video

- LDR [Bennett & McMillan 2005]
- HDR image formats [OpenExr, HDR JPEG]
- HDR MPEG Encoding [Mantiuk et al. 2004]
- HDR + motion compensation [Kang et al. 2003]



...



...

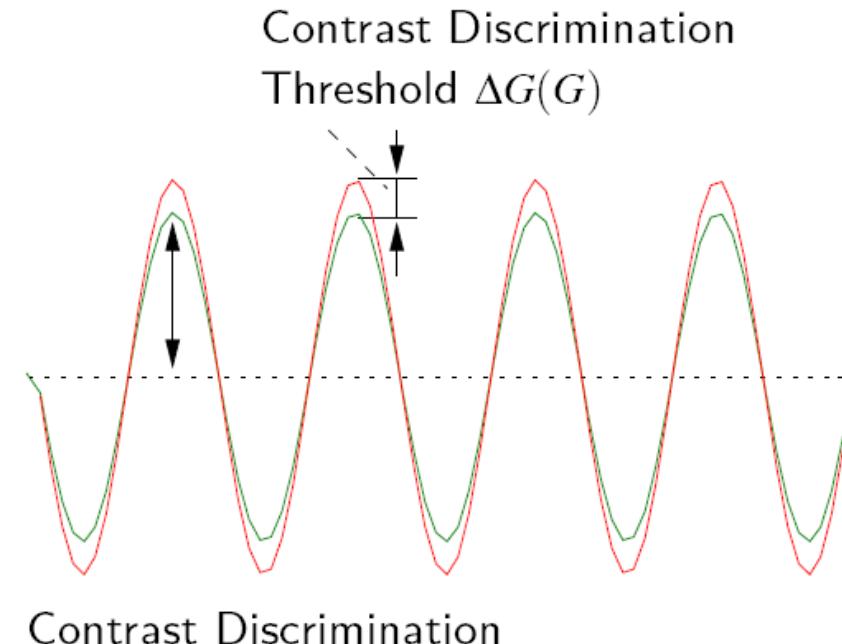
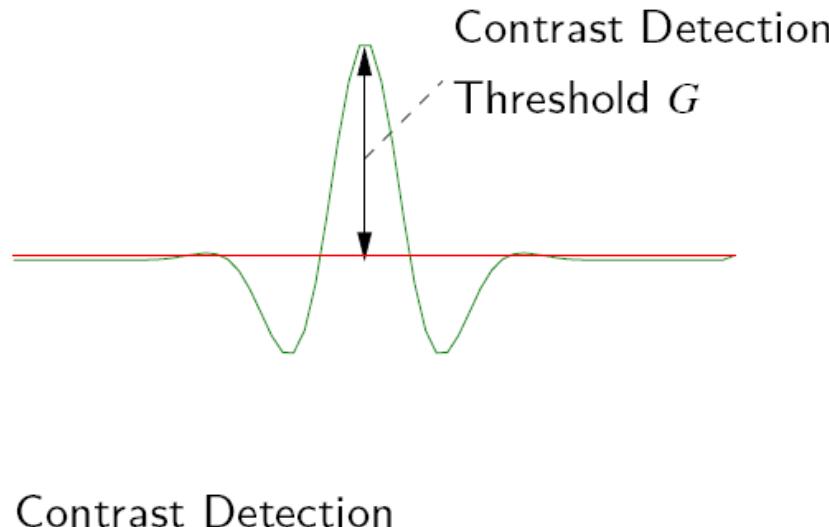


Tone Mapping



Contrast Measurement

- Contrast Detection Threshold
 - Smallest detectable contrast in a uniform field of view
- Contrast Discrimination Threshold
 - Smallest visible difference between two similar signals
 - Works in the suprathreshold domain (signals above threshold)
 - Often sinusoidal or square wave pattern



Terms and Definitions

- Dynamic Range
 - Factor between the highest and the smallest representable value
 - Two strategies
 - Make white brighter
 - Make black darker
- Contrast
 - Simple contrast
 - Weber fraction (step fct.)
 - Michelson contrast (sinusoidal fct.)
 - Logarithmic ratio
 - Signal to noise ratio (SNR)
 - Best for HVS: CW and CL

$$C_S = \frac{L_{max}}{L_{min}}$$

$$C_W = \frac{\Delta L}{L_{min}}$$

$$C_M = \frac{|L_{max} - L_{min}|}{L_{max} + L_{min}}$$

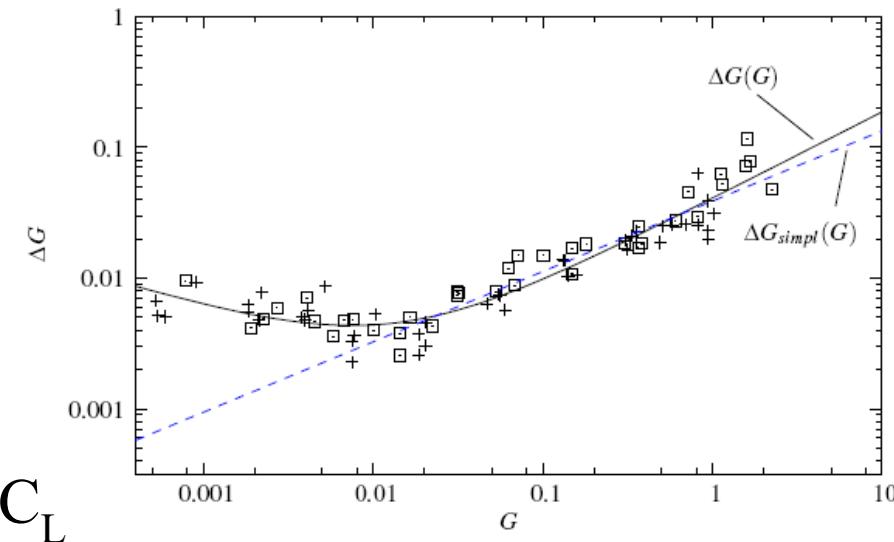
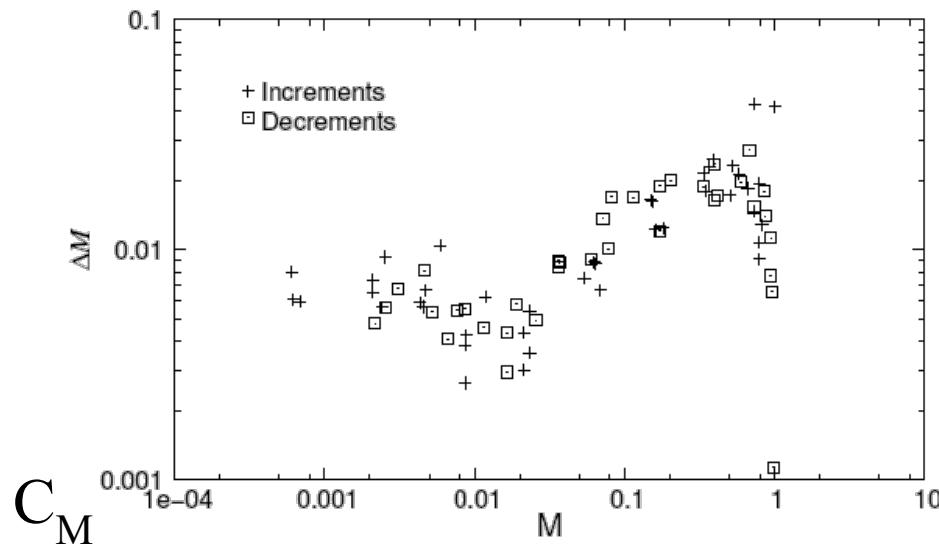
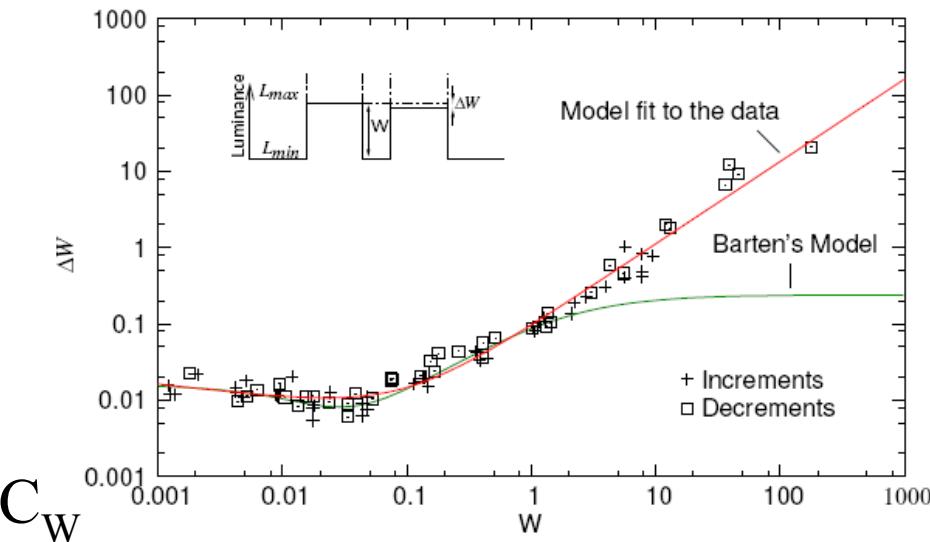
$$C_L = \log_{10} \left(\frac{L_{max}}{L_{min}} \right)$$

$$C_{SNR} = 20 \cdot \log_{10} \left(\frac{L_{max}}{L_{min}} \right)$$



Contrast Discrimination

- Experiments [Whittle 1986]
 - Including high contrast
 - Michelson does not work too well
 - Particularly for high contrast
 - Good fits for C_W and C_L
 - Simplified linear model for CL
 - $\Delta C_{L,simpl}(C_L) = 0.038737 * C_L^{0.537756}$
 - [Mantiuk et al., 2006]



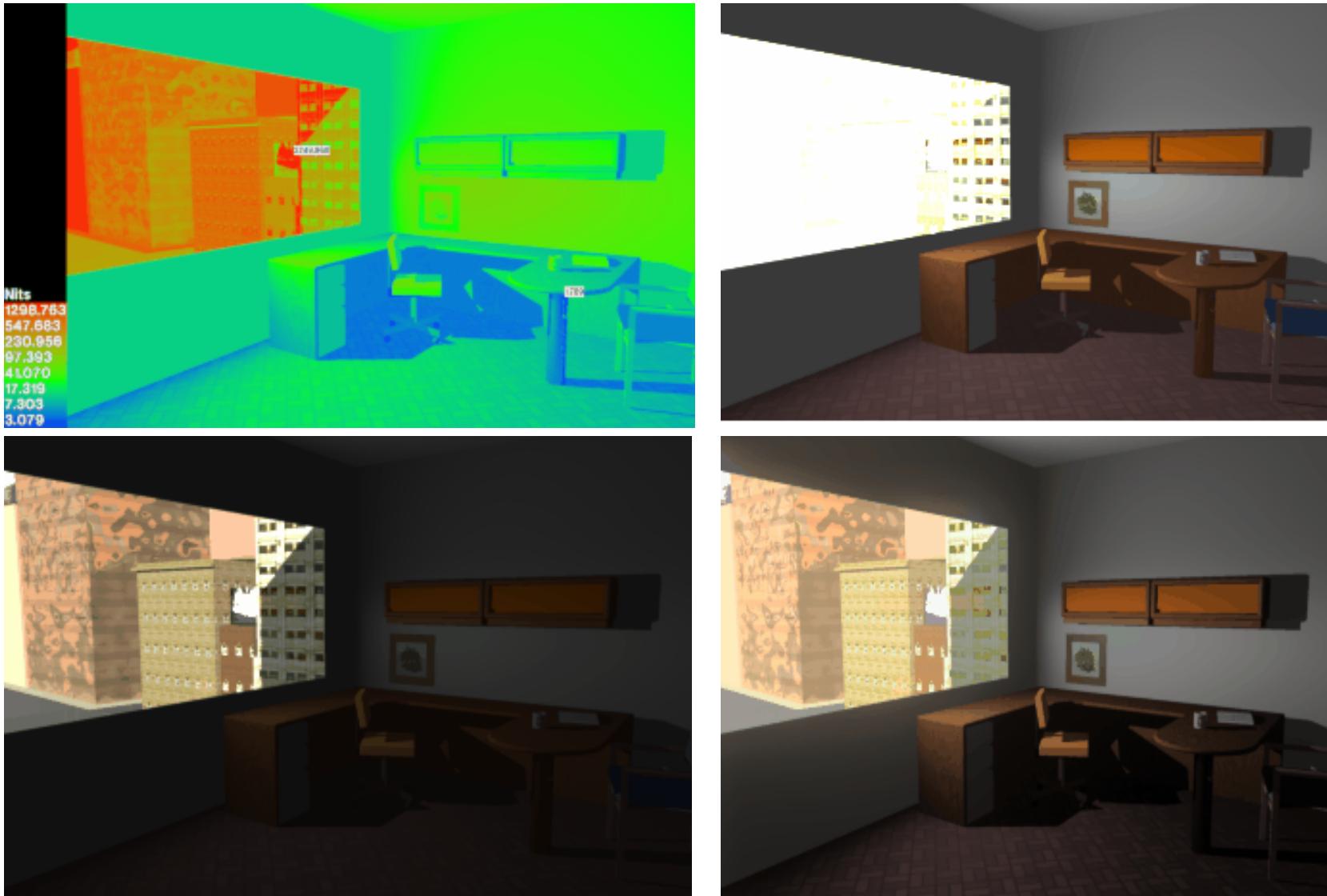


Why Tone-Mapping?

- Mapping radiance to pixel values?
 - Luminance of typical desktop displays:
 - Up to a few 100 cd/m^2
 - Luminance range for human visual perception
 - Min 10^{-5} cd/m^2 Shadows under starlight
 - Max 10^5 cd/m^2 Snow in direct sun light
- Goal
 - Compress the dynamic range of an input image
 - Reproduce human perception to closely match that of the real scene
 - Brightness and contrast
 - Adaptation of the eye to environment
 - Other issues (glare, color perception, resolution)



Example





Heuristic Approaches

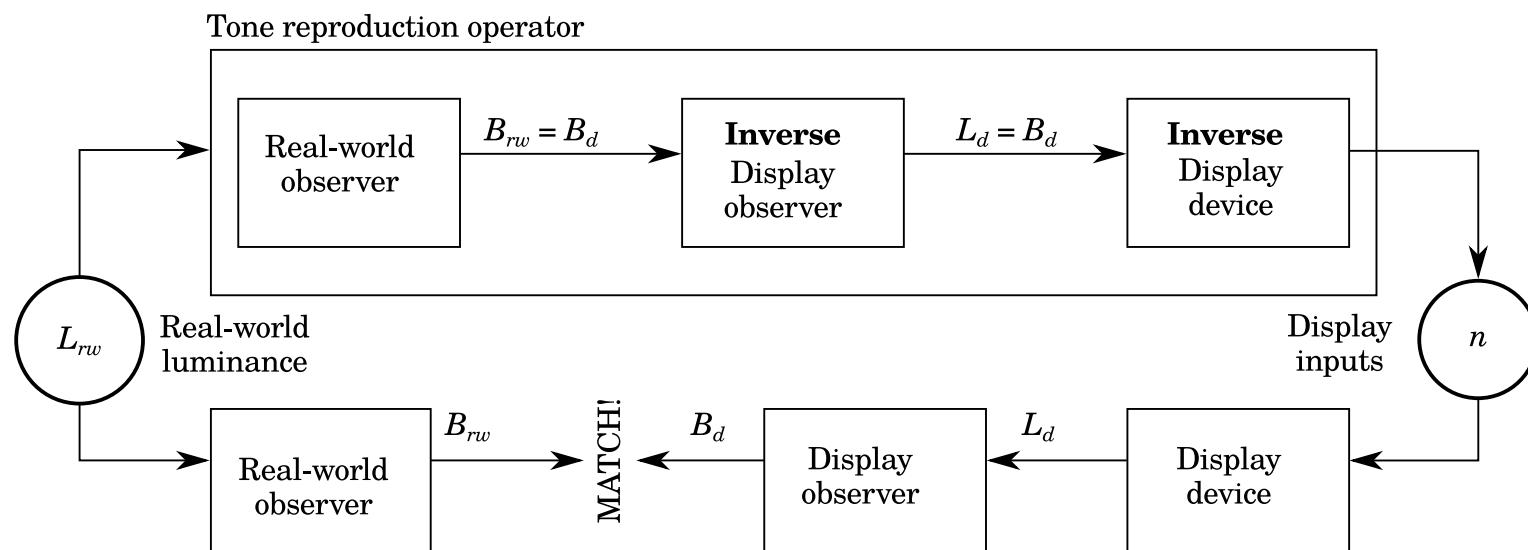
- Scaling brightest value to 1 (in gray value)
 - Problem: light sources are often several orders of magnitude brighter than the rest
→ Rest will be black
- Scaling of brightest non-light-source value
 - Scaling to a value slightly below 1
 - Capping light source values to 1
- General problem of simple scaling
 - Absolute brightness gets lost:
 - Dimming of light sources will have no effect
- Much better: Logarithmic domain
 - Linear scaling in the logarithmic domain
 - Much closer to human perception
 - Typically using \log_{10}





General Principle

- Approach [Tumblin/Rushmeier]
 - Create model of the observer
 - Requirement:
 - Observer should perceive same image from real and virtual display
 - Compute Tone-Mapping using concatenation and inversion of operators
 - Model usually operates only on luminance (no color)

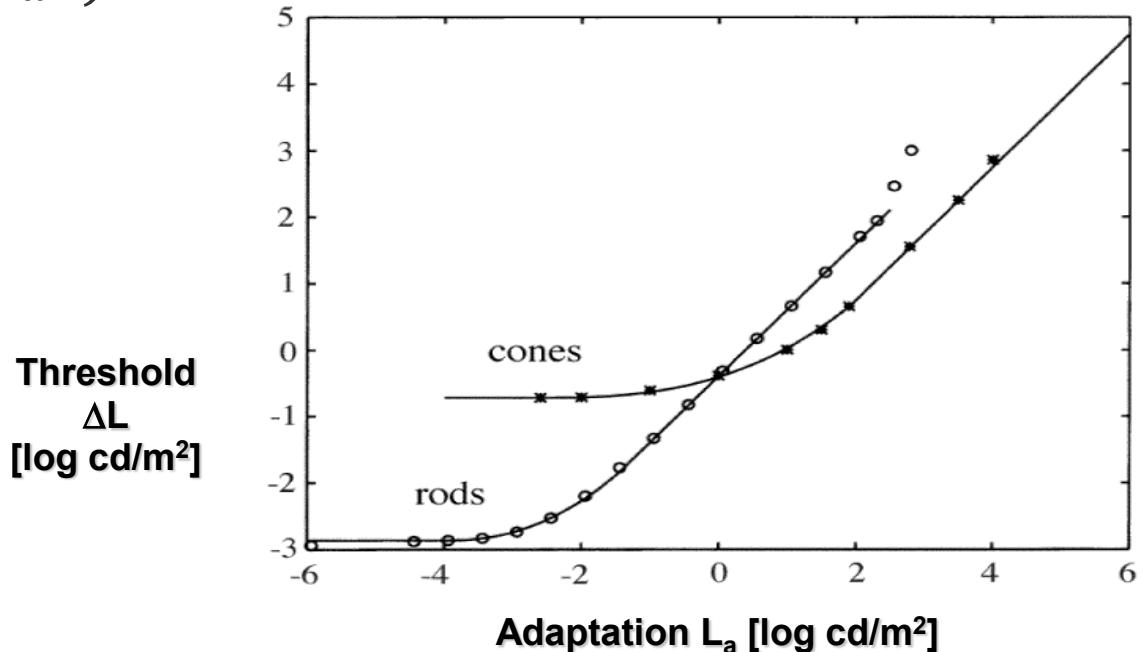


Maintaining Contrast

- Contrast-based Scaling Factor [Ward '94]
 - Maintain visible contrast differences in the image
 - Using Weber contrast
 - Just noticeable contrast according to Blackwell [CIE'81] (subjective measurements)

$$\Delta L(L_a) = 0.0594(1.219 + L_a^{0.4})^{2.5}$$

- L_a : Adaptation level of eye (luminance)
- Goal: linear scaling factor $m(L_a)$
 - $L_d = m(L_a)L_w$
 - L_d : display luminance
 - L_w : world luminance



Maintaining Contrast

- Approach using „Just noticeable difference (JND)“
 - Assume JND for real and virtual image are the same
 - JND of real world: $\Delta L(L_{wa})$
 - JND of display: $\Delta L(L_{da})$

$$\Delta L(L_{da}) = m(L_{wa}) \Delta L(L_{wa})$$

- Substitution results in

$$m(L_{wa}) = \left[\frac{1.219 + L_{da}^{0.4}}{1.219 + L_{wa}^{0.4}} \right]^{2.5}$$

- With $L_{da} = L_{dmax}/2$ and scaling factor sf in [0..1]

$$sf = \frac{1}{L_{dmax}} \left[\frac{1.219 + \left(\frac{L_{dmax}}{2} \right)^{0.4}}{1.219 + L_{wa}^{0.4}} \right]^{2.5}$$



Maintaining Contrast

- Deriving L_{wa}
 - Depends on light distribution in field of view of observer
 - Simple approximation using a single value
 - Eyes try to adjust to average brightness
 - Brightness B:
 $\log_{10}(B) = a(L_{in}) \log_{10}(L_{in}) + b(L_{in})$ Power-Law [Stevens'61]
 - Comfortable brightness
 $\log_{10}(L_{wa}) = E\{\log_{10}(L_{in})\} + 0.84$
- Problems of this Approach
 - Single factor for entire image
 - Different adaptation for different locations in image
 - We do not perceive absolute differences in luminance
 - Adaptation mainly acts on the 1 degree fov (fovea)
 - Results in clamping for too bright regions

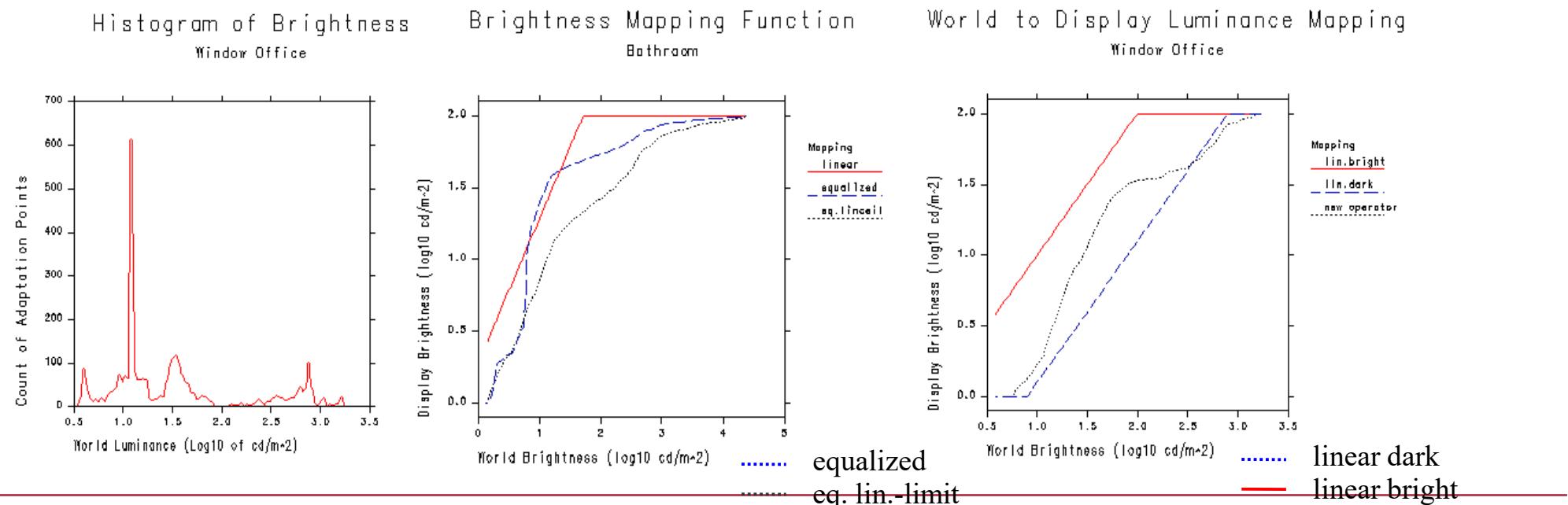


Histogram-based Global Tone Mapping



Histogram-Adjustment

- Optimal Mapping of the Dynamic Range [Ward'97]
 - Computing an adjustment image
 - Averaging over 1 degree regions and reducing the resolution
 - Computing the histogram of the image
 - Binning of luminance values
 - Adjusting the histogram based on restrictions of human visual system
 - Limiting contrast enhancement





Histogram-Adjustment

- Computing the Adjustment Image
 - Assumes known view point
 - Average image
 - Filtering non-overlapping regions covering 1 degree fov
 - Reference uses simple box filter

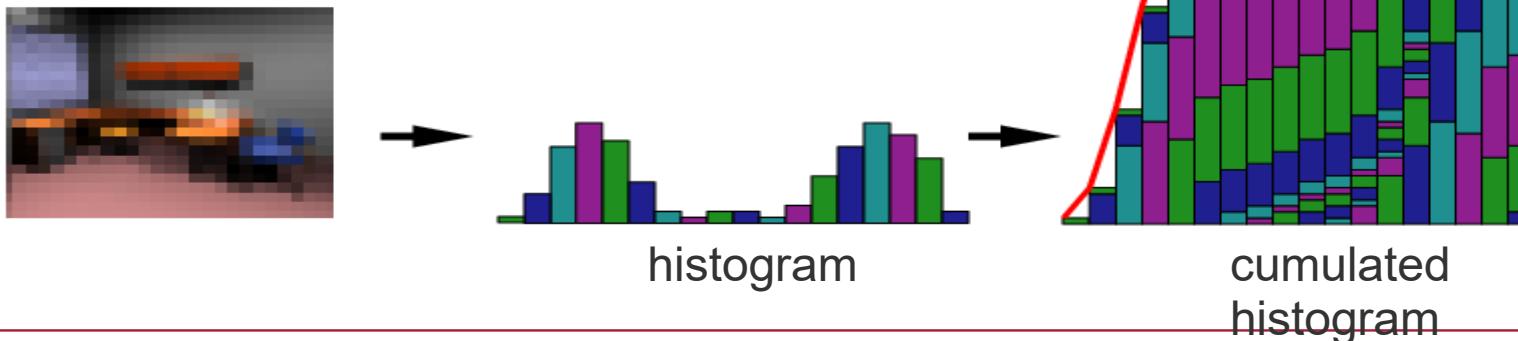


Histogram-Adjustment

- Naïve Histogram Adjustment (Equalization)

- $f(B_w)$: Number of sample per bin
- $P(B_w)$: Accumulated probability (sum of sample counts)
- T : Sum over all $f(B_w)$
- Mapping

$$B_d = \log(L_{d\min}) + [\log(L_{d\max}) - \log(L_{d\min})]P(B_w)$$



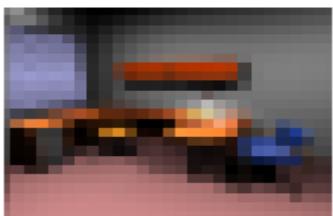


Histogram-Adjustment

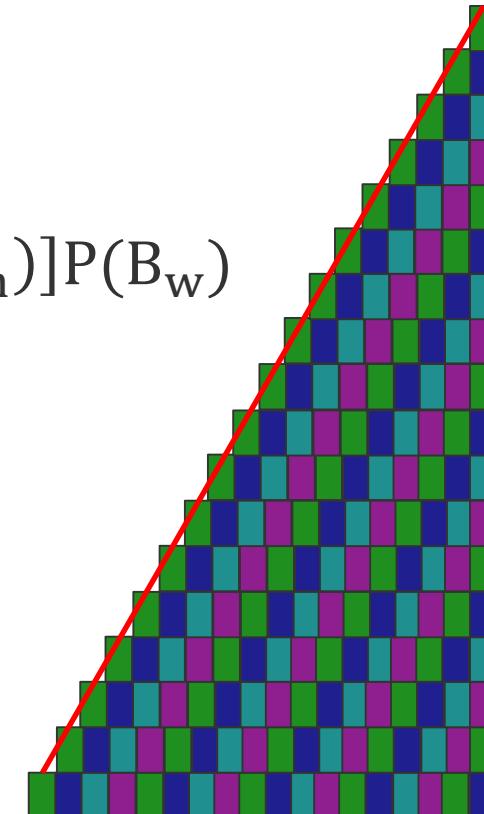
- Naïve Histogram Adjustment (Equalization)

- $f(B_w)$: Number of sample per bin
- $P(B_w)$: Accumulated probability (sum of sample counts)
- T : Sum over all $f(B_w)$
- Mapping

$$B_d = \log(L_{d\min}) + [\log(L_{d\max}) - \log(L_{d\min})]P(B_w)$$



equalized histogram

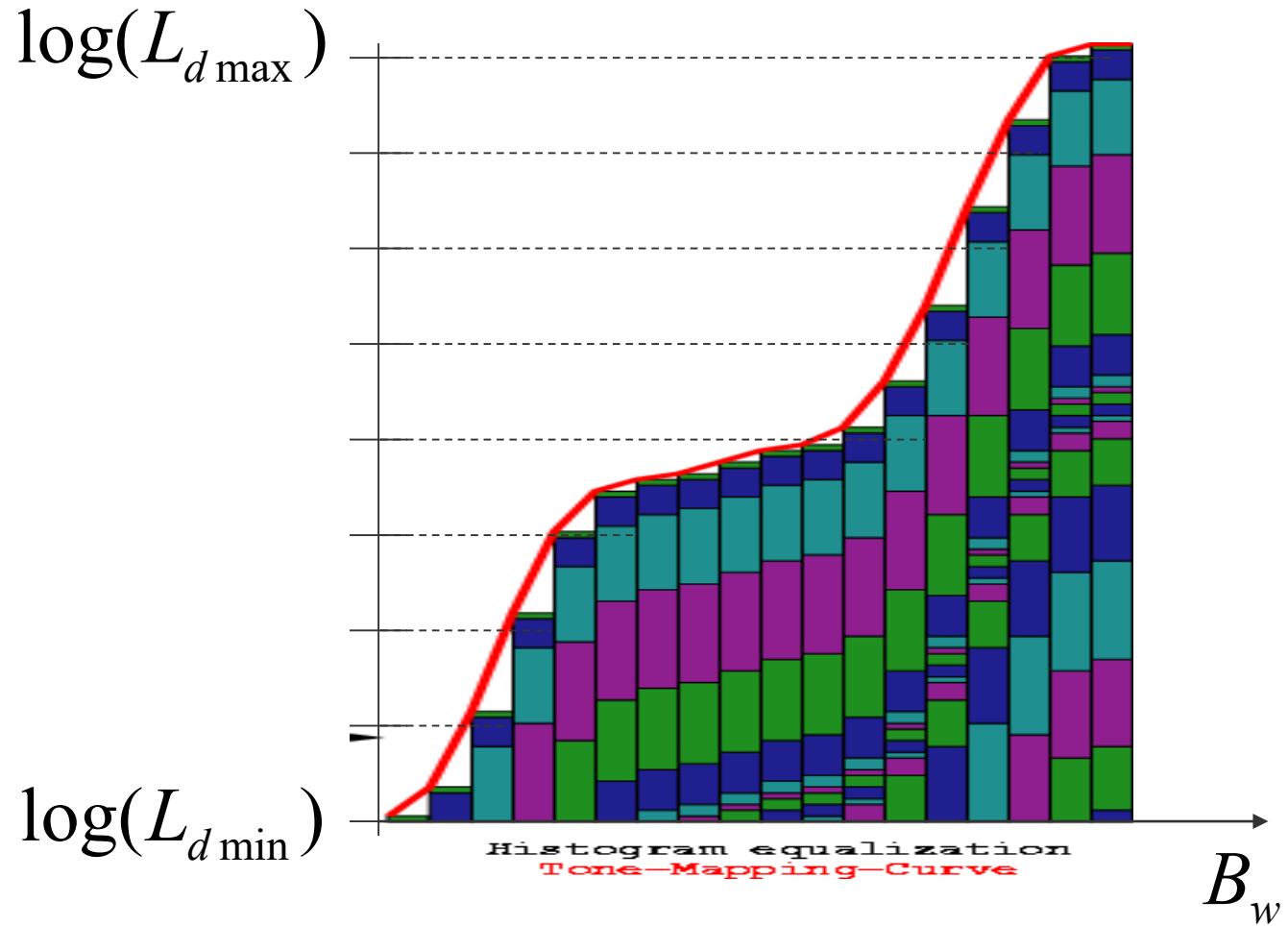


cumulated histogram



Histogram-Adjustment

- Tone-mapping-curve follows cumulated histogram





Histogram-Adjustment



Linear Mapping



Naïve
Histogram-Adjustment



Histogram-Adjustment
considering the human
visual system



Example: Darkening a Room



Bright Bathroom



**Dark Bathroom (1/100)
with reduced contrast**

Extensions: Glare

- Considering Glare
 - Bright light sources result in veiling (German: Schleier)
 - Due to scattering of strong illumination in the eye
 - Results in correction to adaptation level
- Approach
 - Moderate illumination in periphery does not contribute to adaptation
 - Depend exclusively on foveal region
 - But: glare in the periphery does change the adaptation
 - Scattered light is added even in foveal region
 - Compute a veiled image by filtering over peripheral region
 - Added to normal adaptation luminance L_f [Moon and Spencer, '45]

$$L_a = 0.913L_f + \frac{K}{\pi} \iint_{\theta > \theta_f} \frac{L(\theta, \varphi)}{\theta^2} \cos(\theta) \sin(\theta) d\theta d\varphi$$



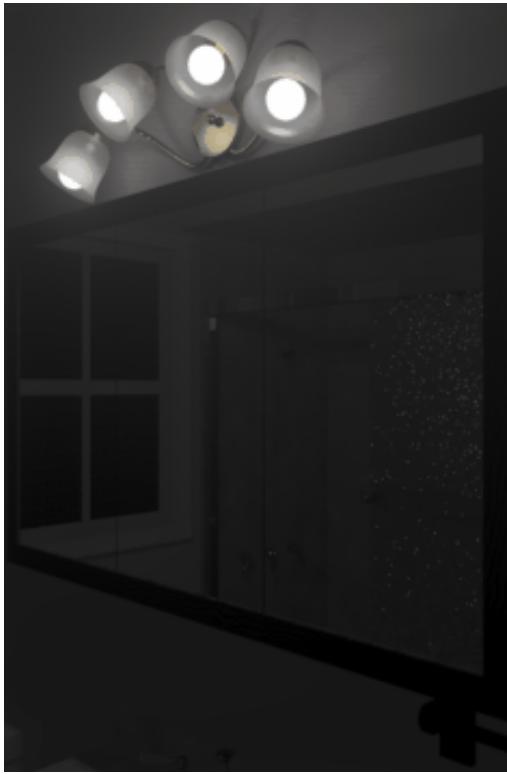
Example: Veiling due to Glare





Extensions

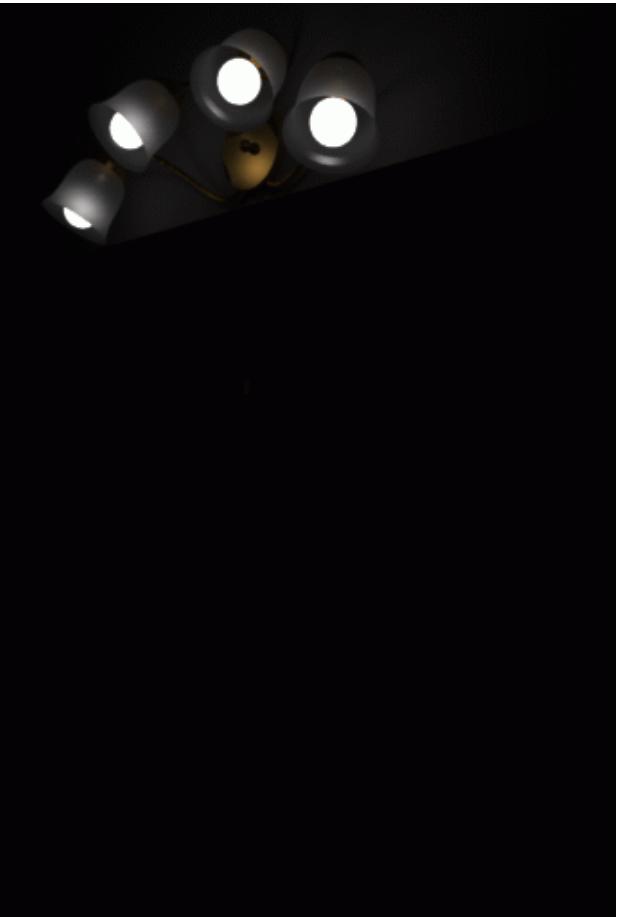
- Loss of color vision in dark areas



- Loss of visual resolution in dark areas
 - Simple blur filter



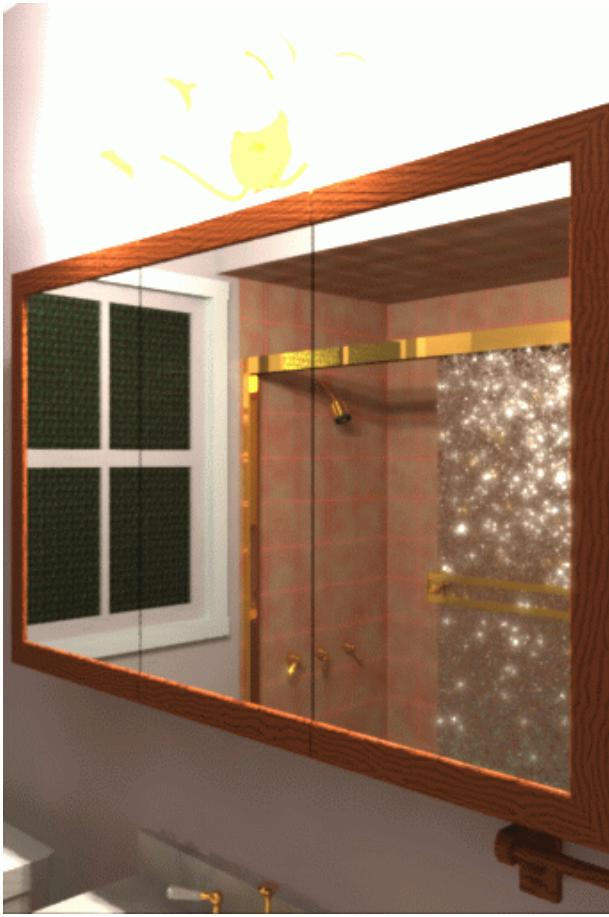
Comparison



Maximum
Tone-Mapping



Tumblin/Rushmeier
Tone-Mapping



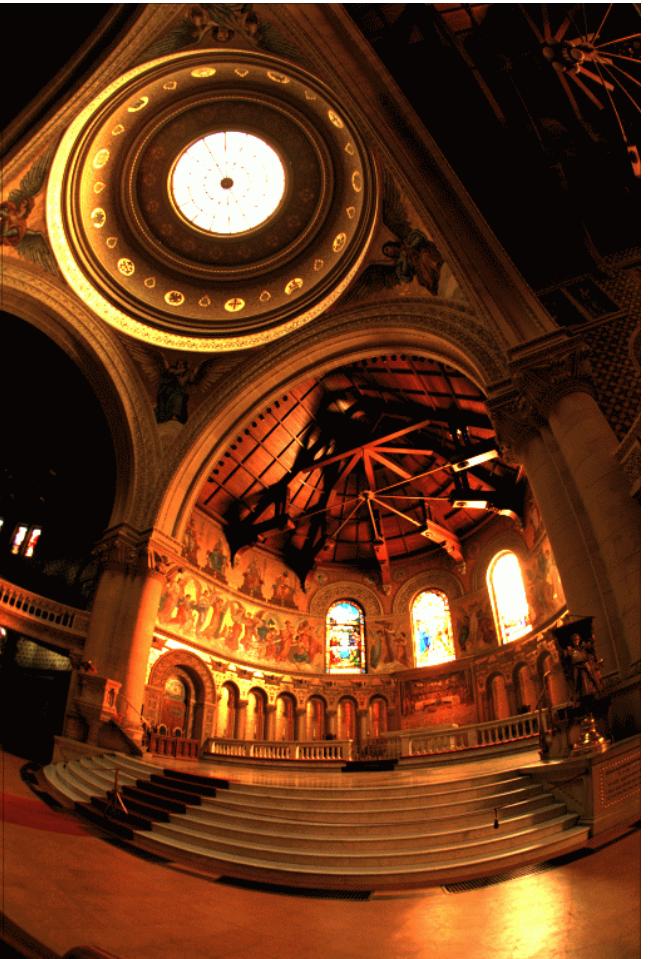
Ward`94
Tone-Mapping



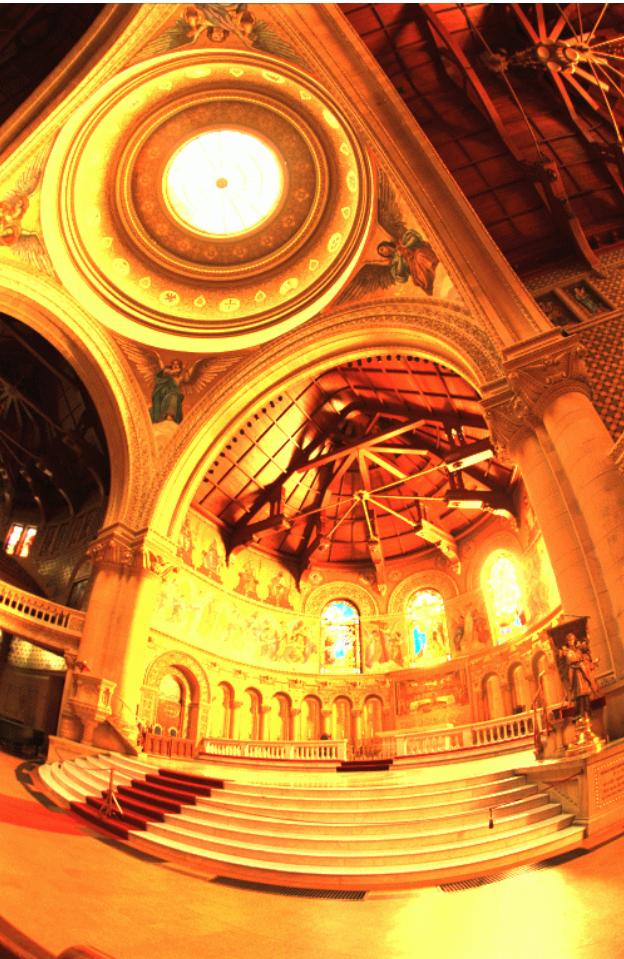
Ward`97
Tone-Mapping



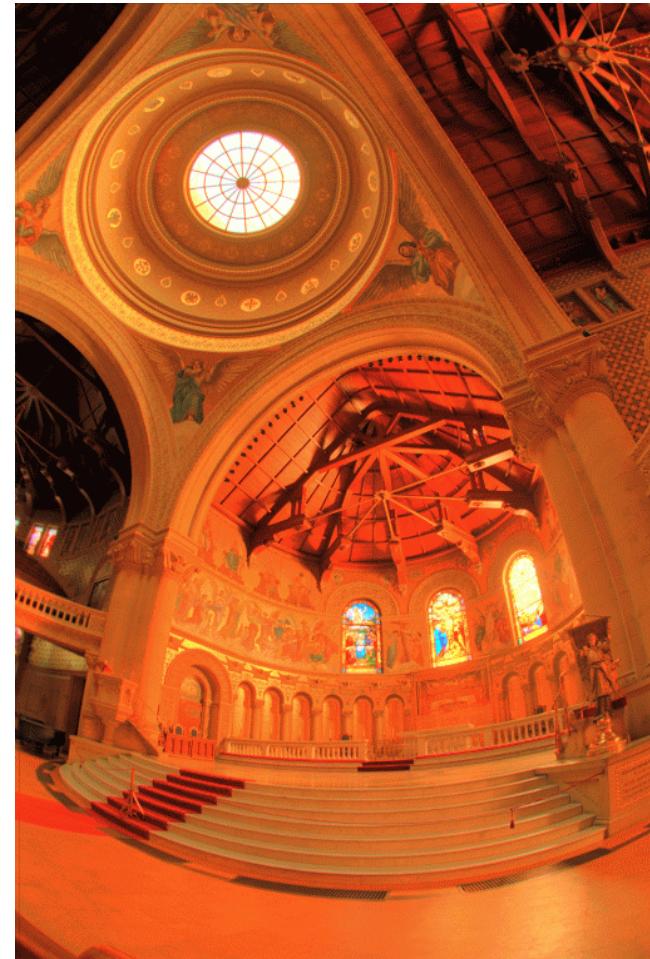
Comparison



Tumblin/Rushmeier
Tone-Mapping



Ward`94
Tone-Mapping



Ward`97
Tone-Mapping



Comparison: Tumblin/Rushmeier





Comparison: Ward`94





Comparison: Ward`97





Partially Local Tone Mapping Bilateral Filtering



A typical photo

- Sun is overexposed
- Foreground is underexposed

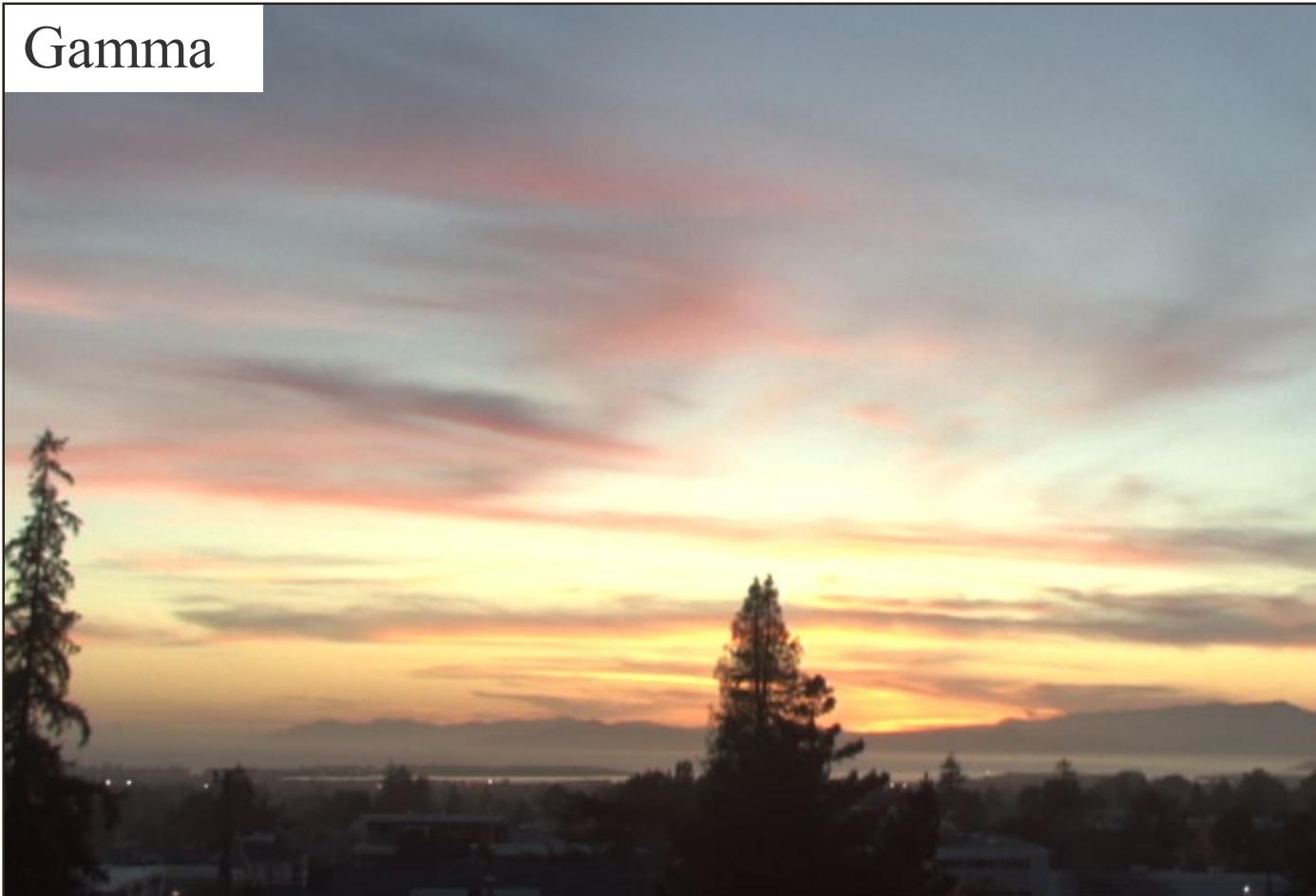
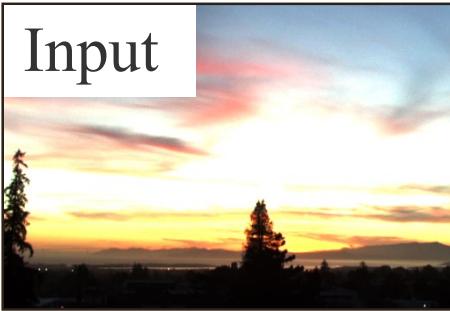
[slides from Durand&Dorsey 2002
„Fast Bilateral Filtering for the Display of High-Dynamic-Range
Images”]





Gamma compression

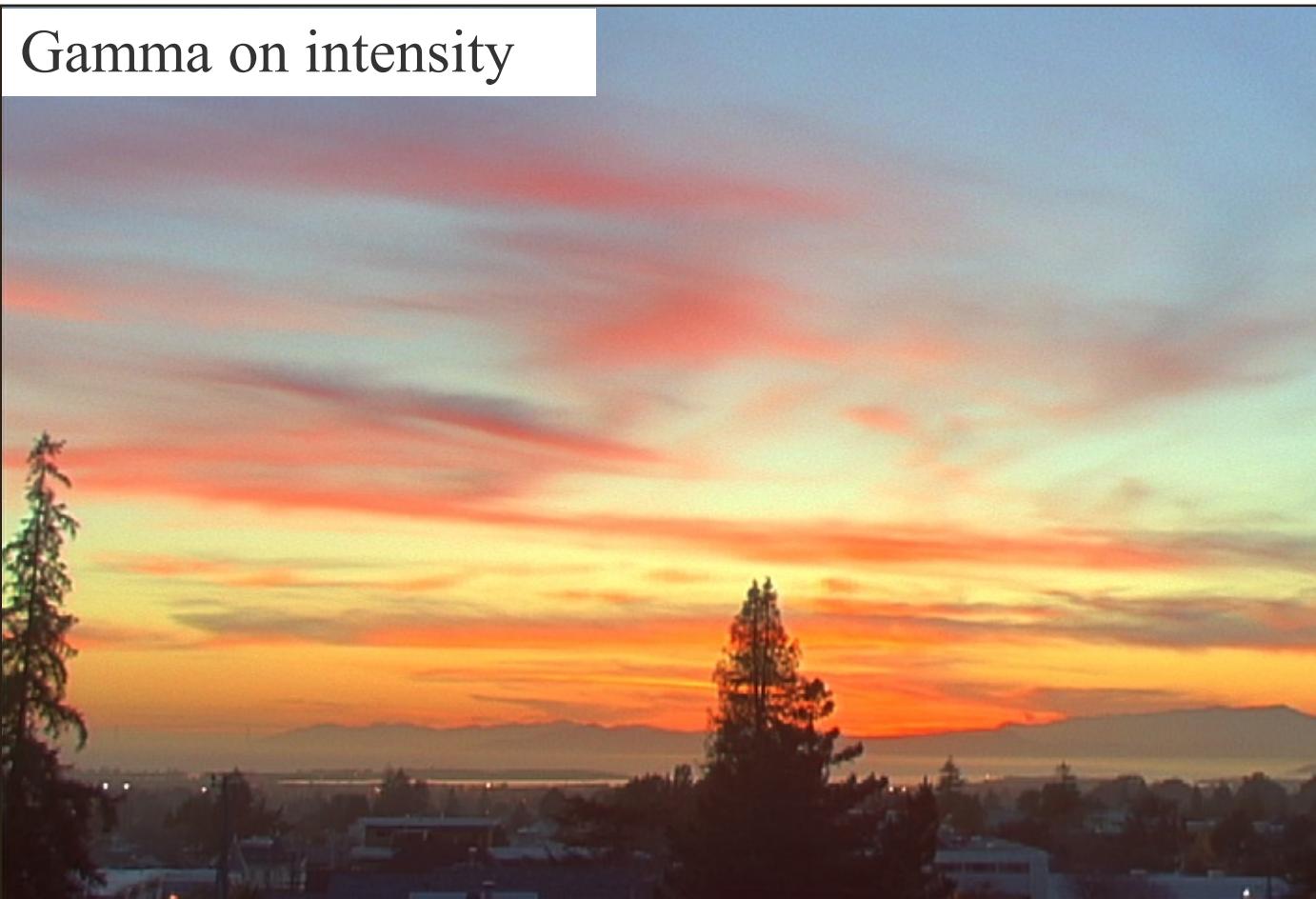
- $X \rightarrow X^\gamma$
- Colors are washed-out





Gamma compression on intensity

- Colors are OK,
but details (intensity high-frequency) are blurred





Chiu et al. 1993

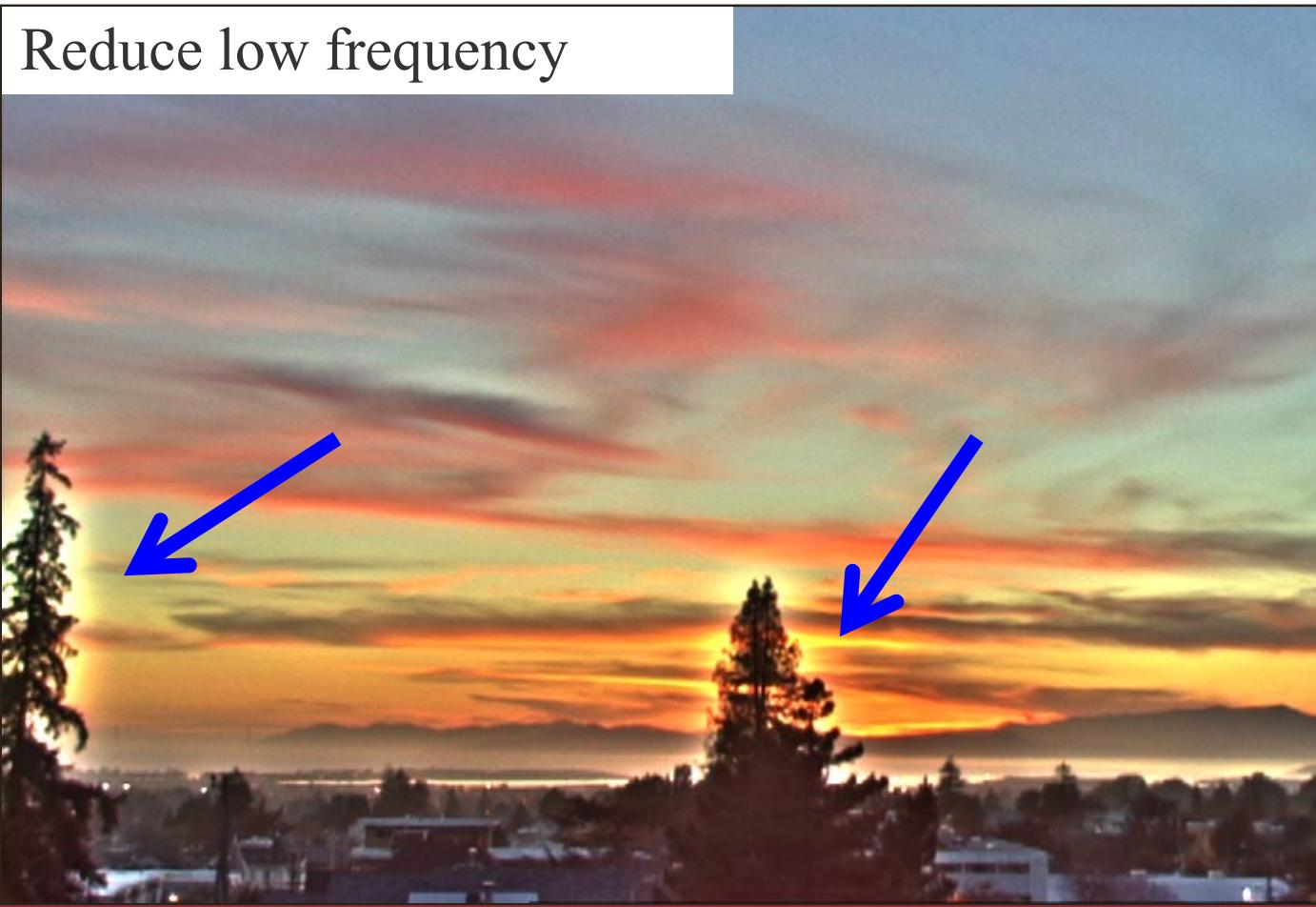
- Reduce contrast of low-frequencies
- Keep high frequencies





The halo nightmare

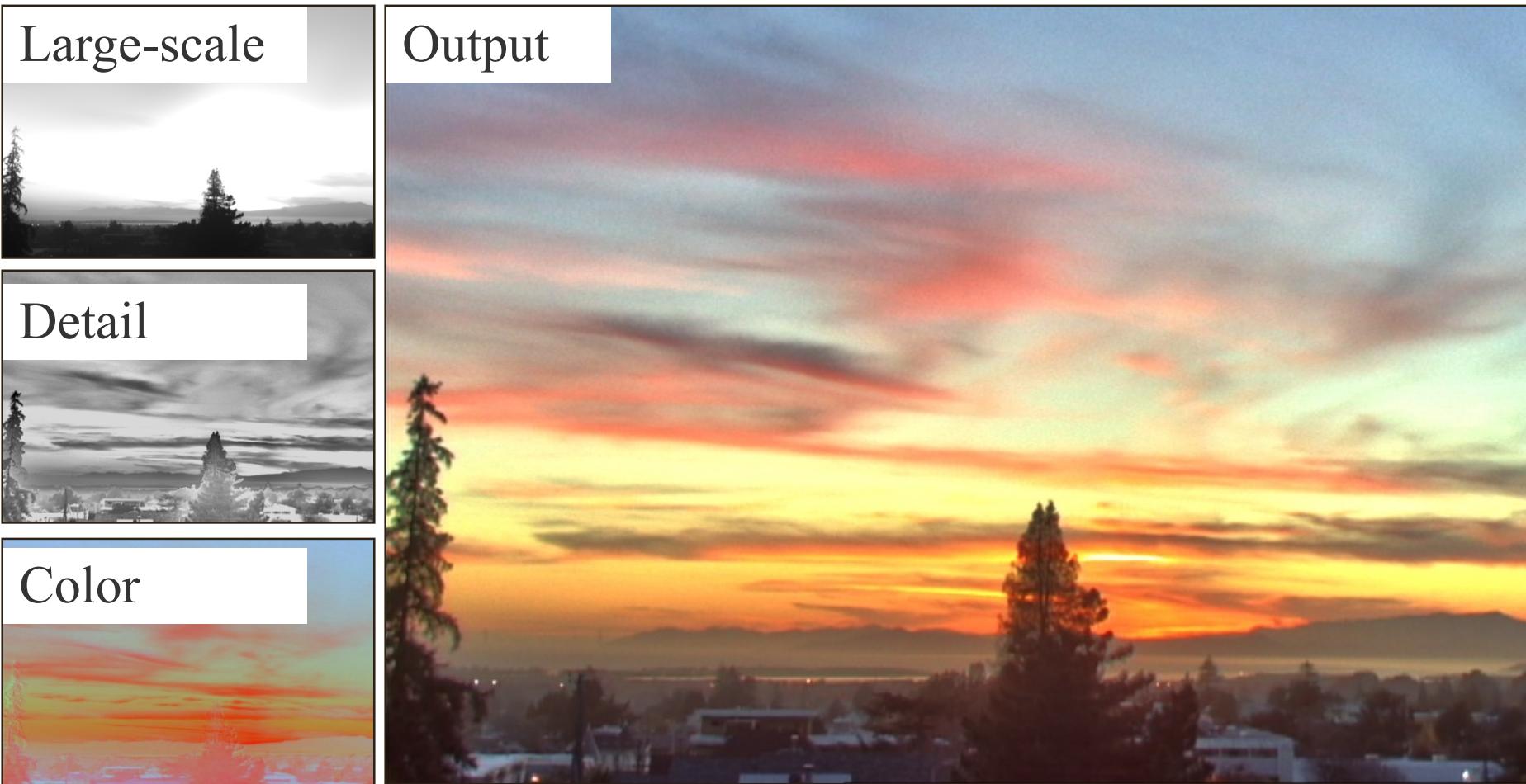
- For strong edges
- Because they contain high frequency





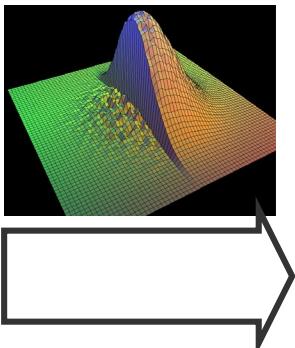
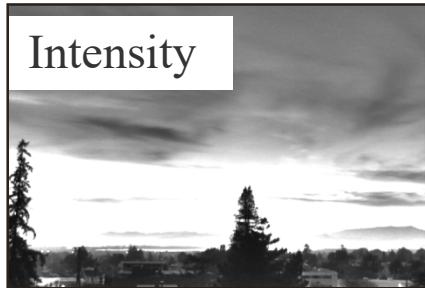
Bilateral Filter for Tone Mapping

- Do not blur across edges
- Non-linear filtering

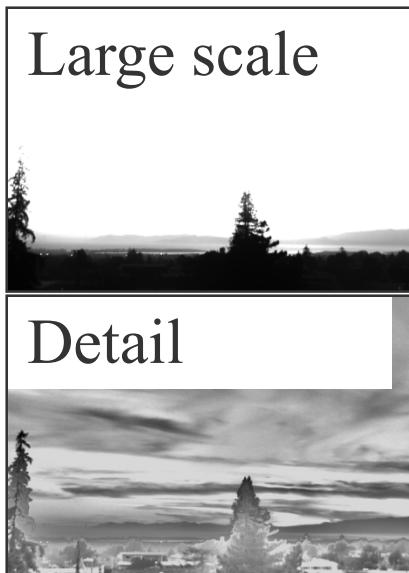




Bilateral Filter for Contrast Reduction



Fast
Bilateral
Filter



Reduce
contrast

Preserve!

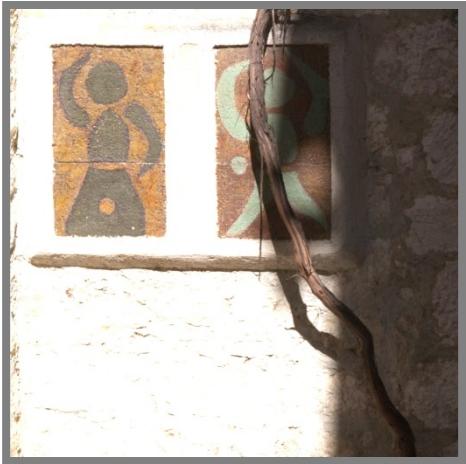




Local Tone Mapping



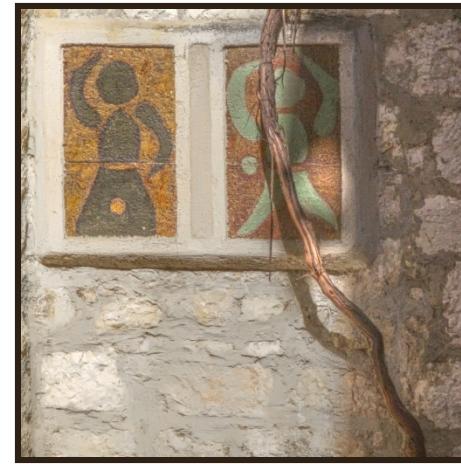
Local Tone mapping



**HDR image
(reference)**



restore
missing
contrast

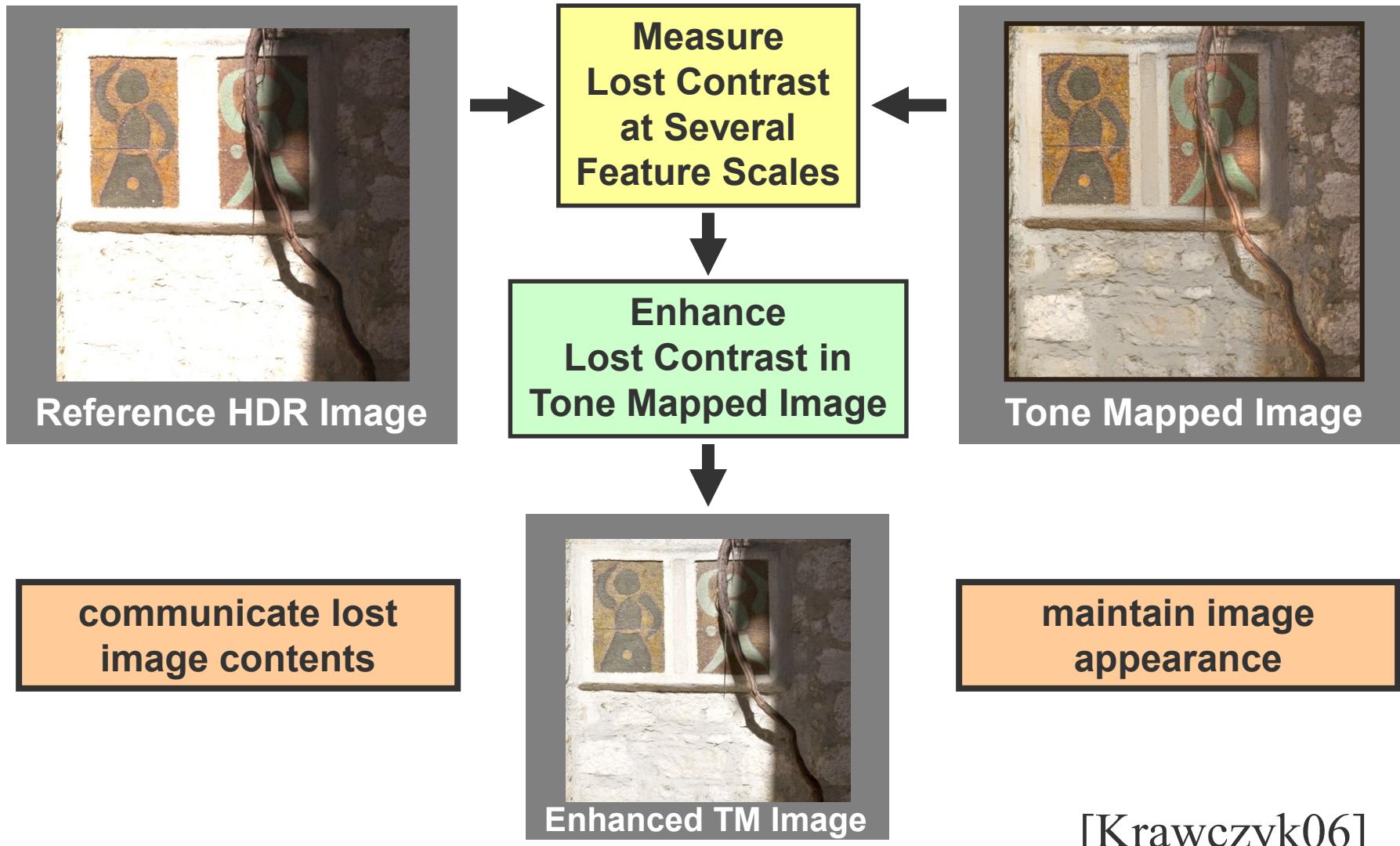


tone mapping result

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

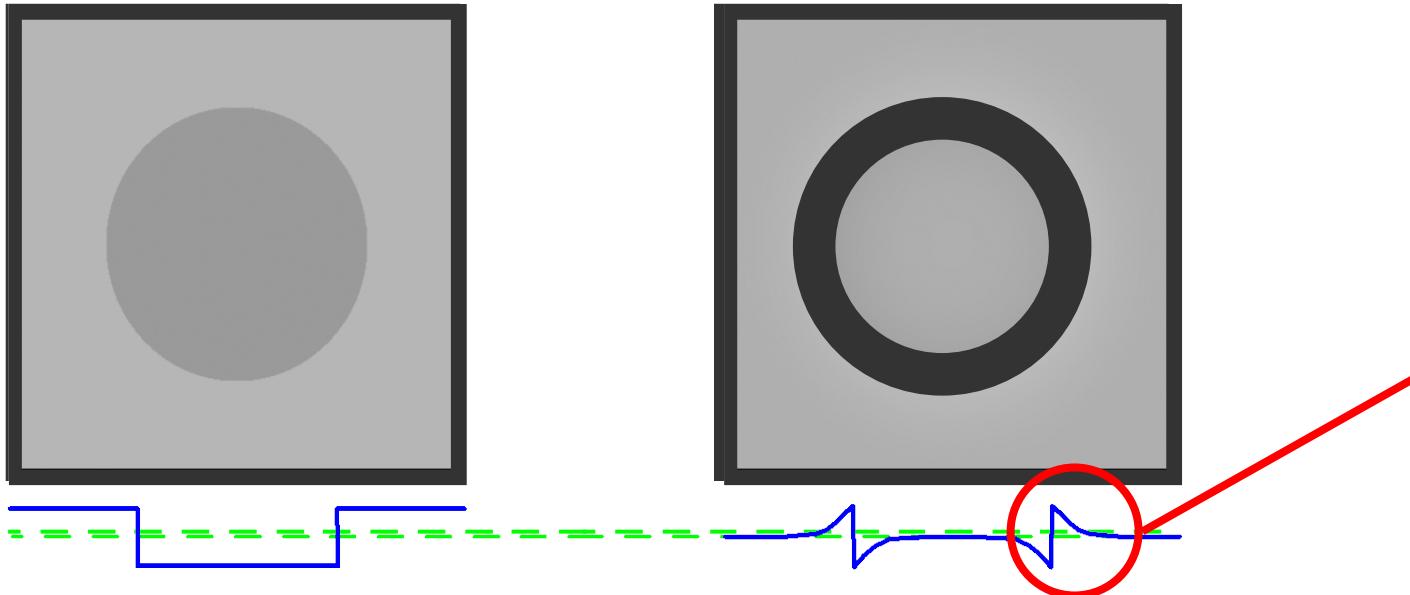


Idea: Enhance Local Contrast





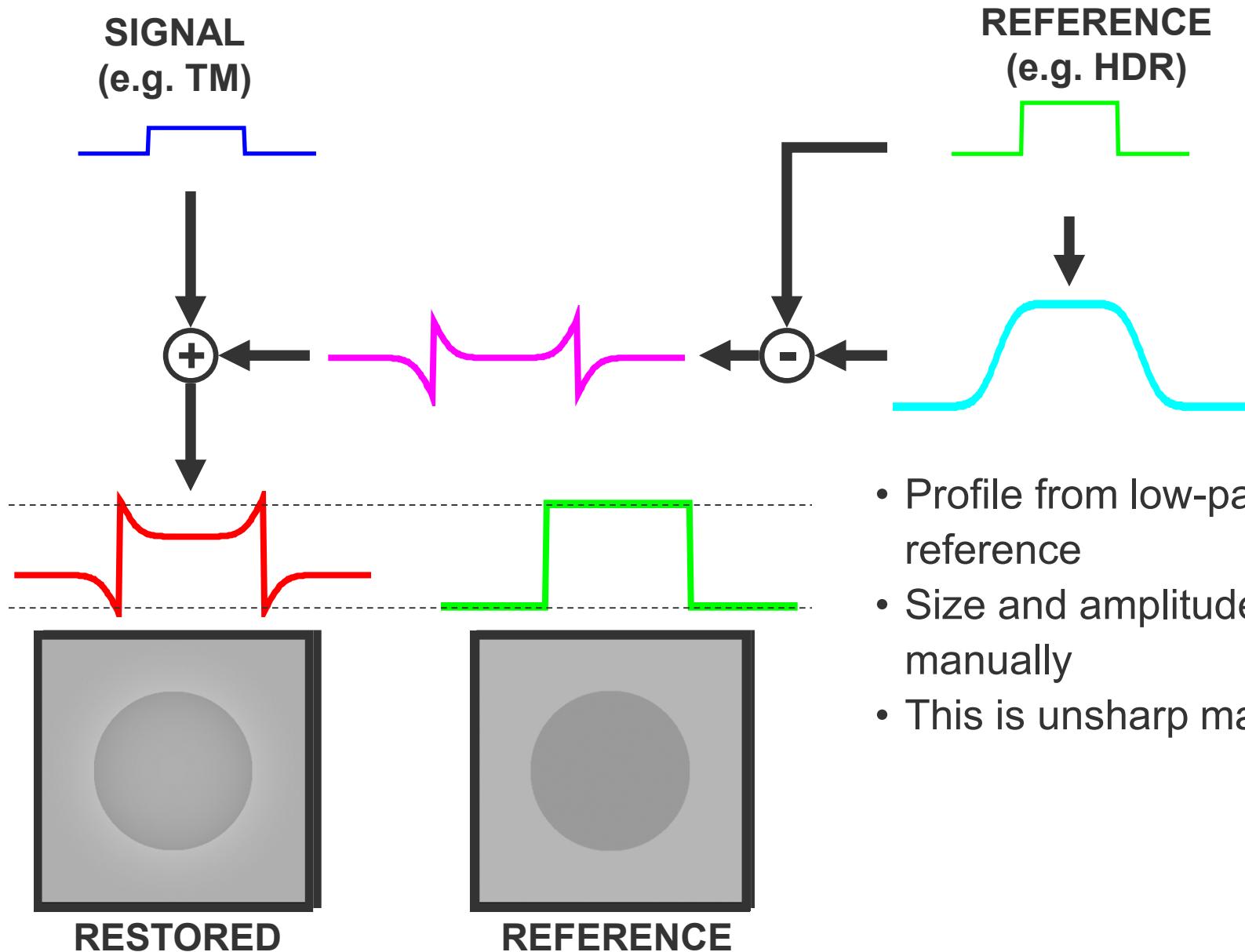
Method: Adaptive Countershading



- Create apparent contrast based on Cornsweet illusion
- Countershading
 - gradual darkening / brightening towards a contrasting edge
 - contrast appears with 'economic' use of dynamic range

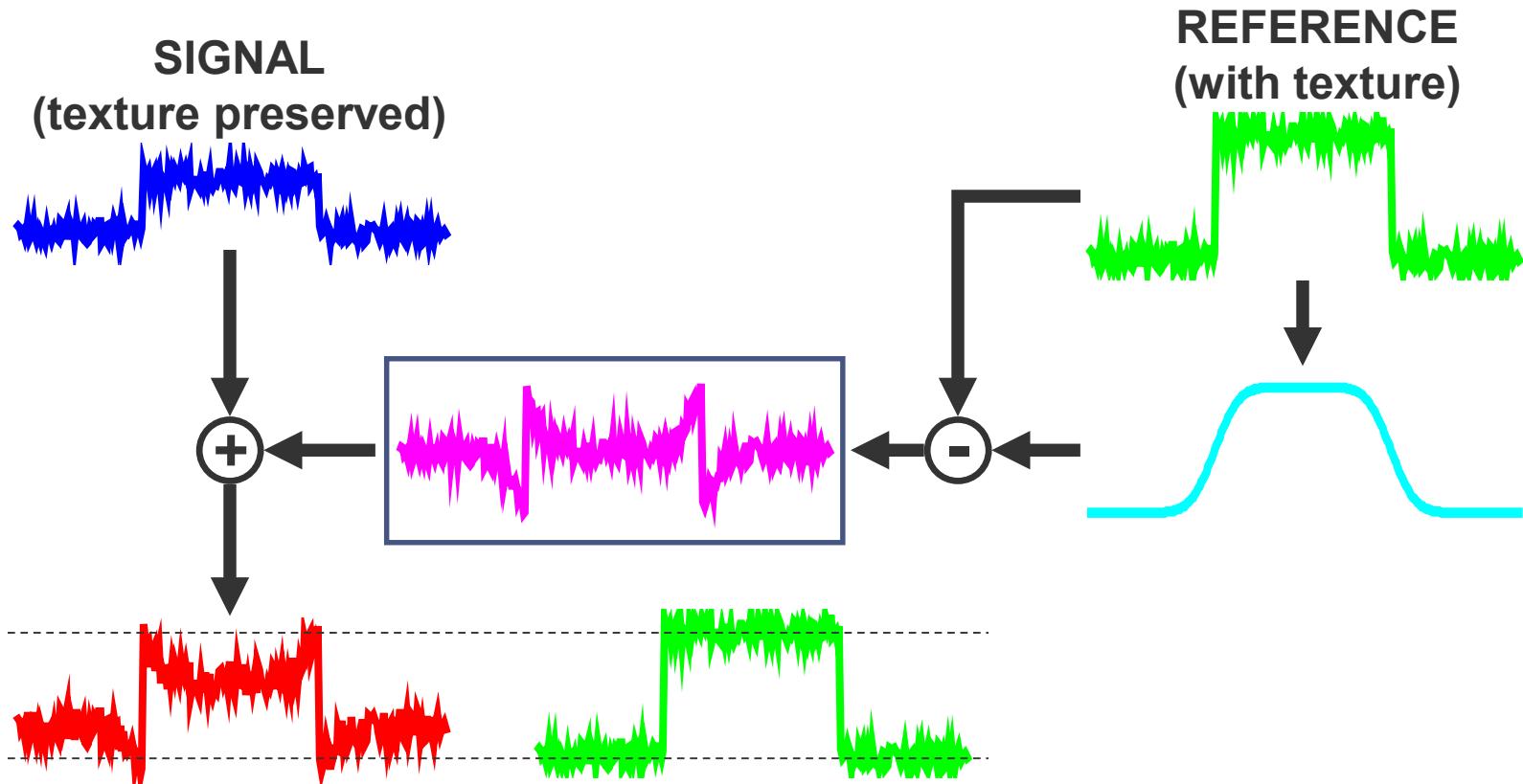


Construction of Simple Profile (1/2)





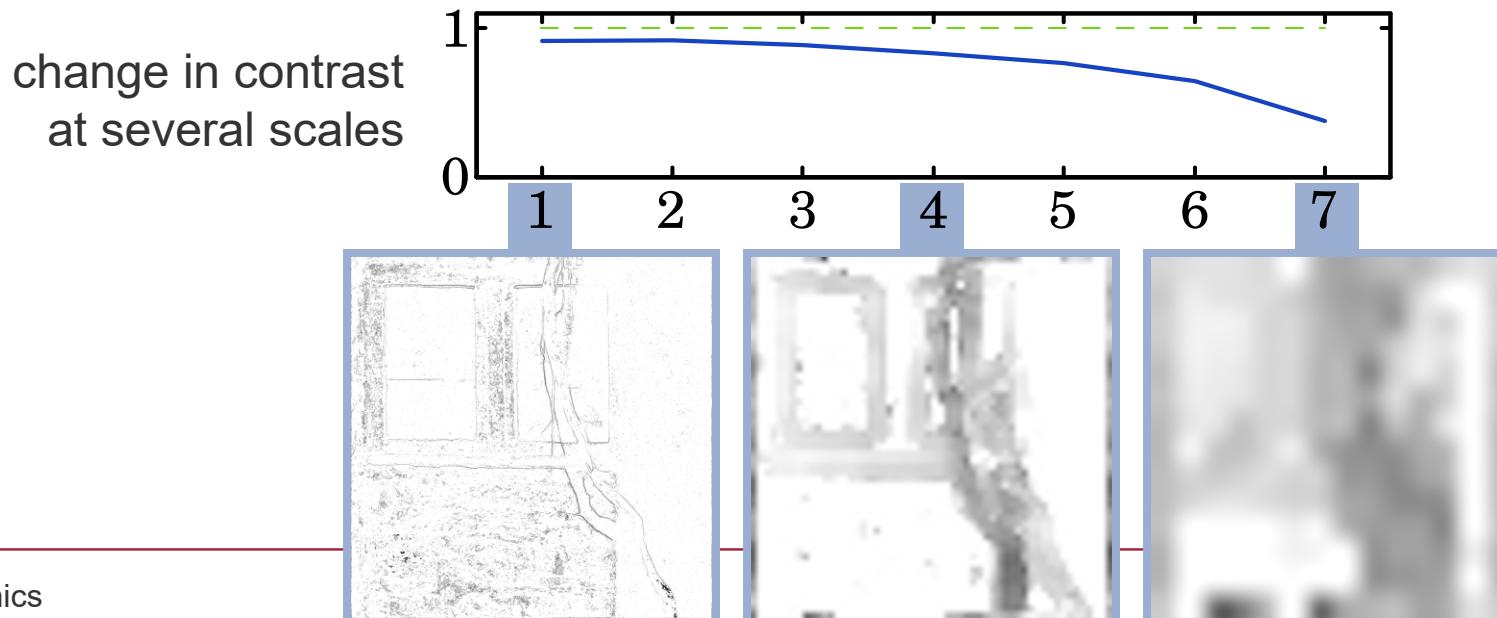
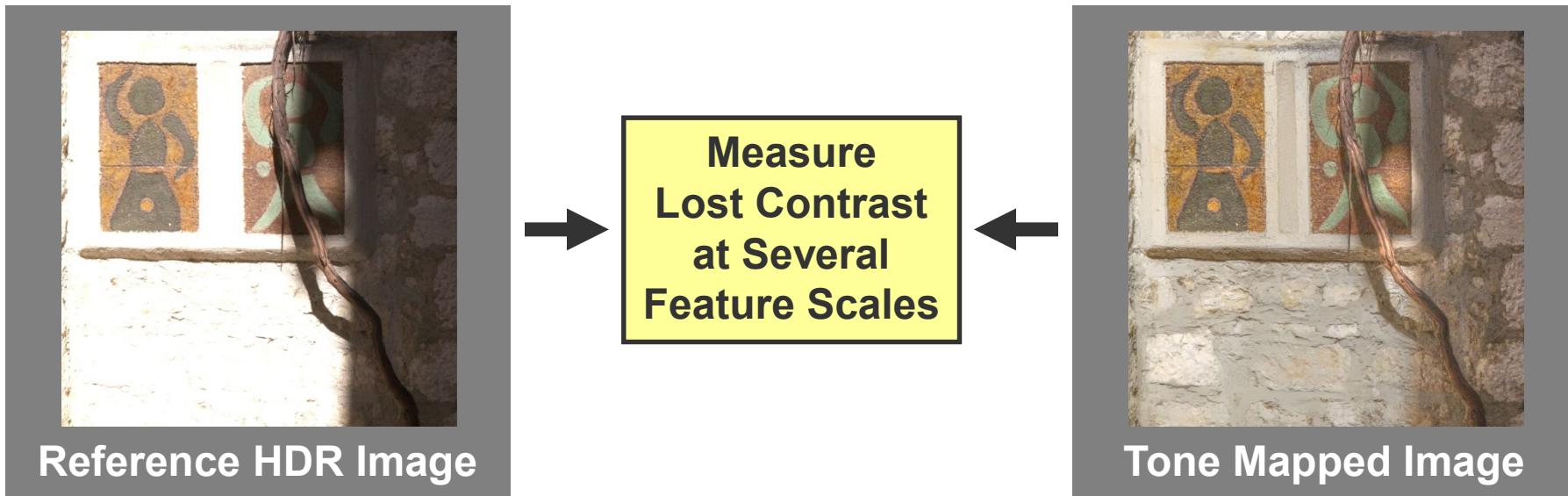
Construction of Simple Profile (2/2)



- Well preserved signal is exaggerated by unsharp masking

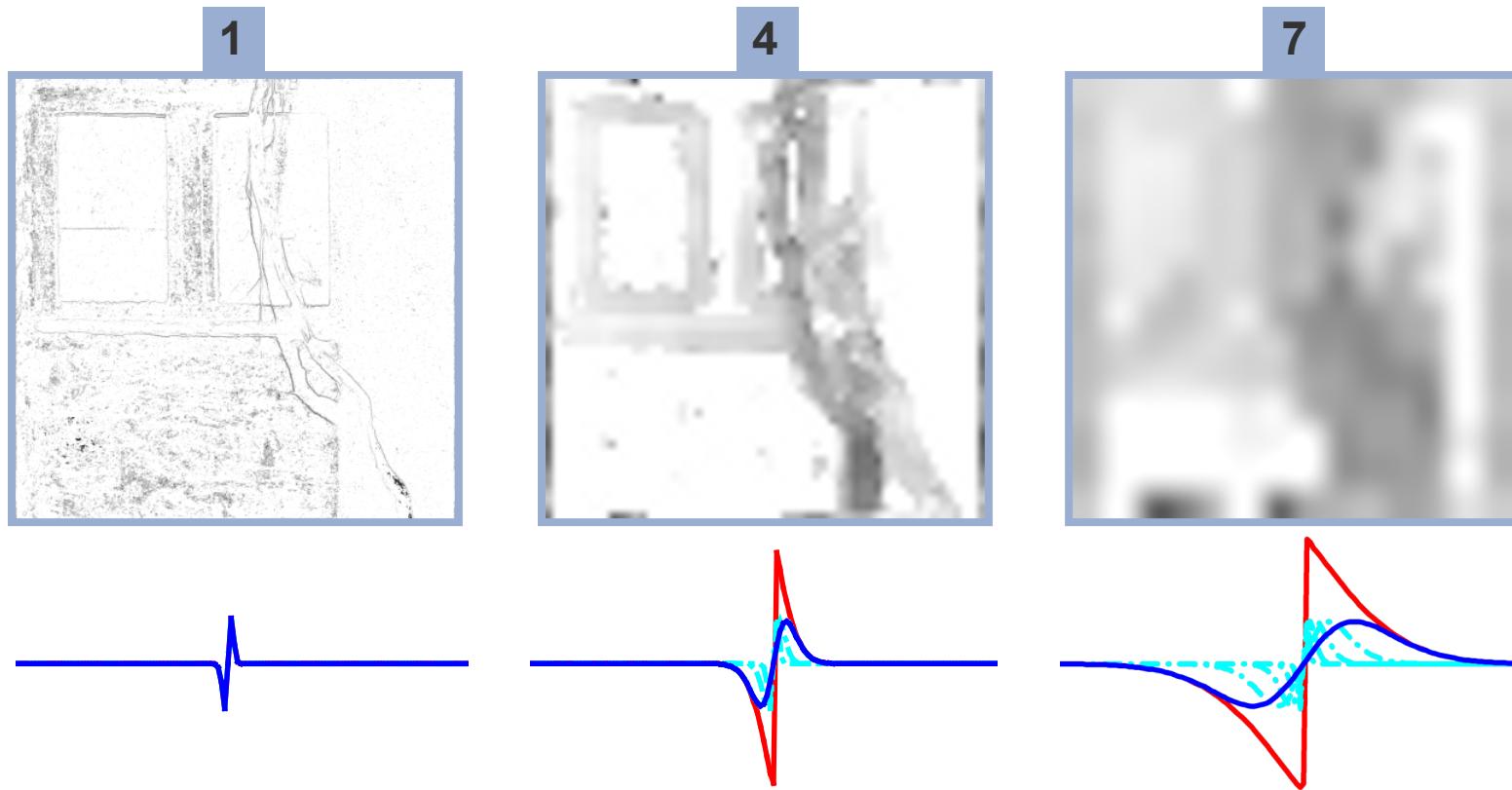


Where to Insert Profiles?





How to Construct Profiles?



- Scale of contrast measure defines the profile size
- Contrast ratio at each scale defines the sub-band amplitude (blue)
- Contrast for larger scales appears also on smaller scales
 - the full profile is always reconstructed (red)



Subtle Correction of Details

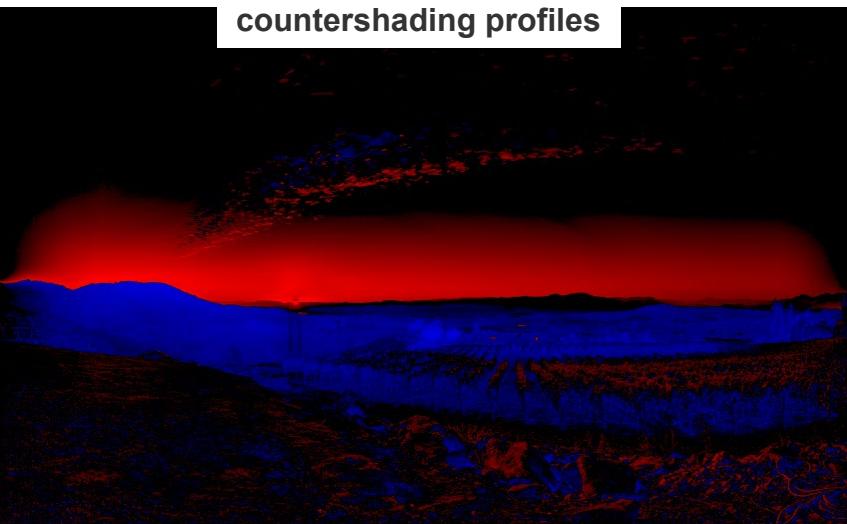
reference HDR image (clipped)



countershading of tone mapping



countershading profiles

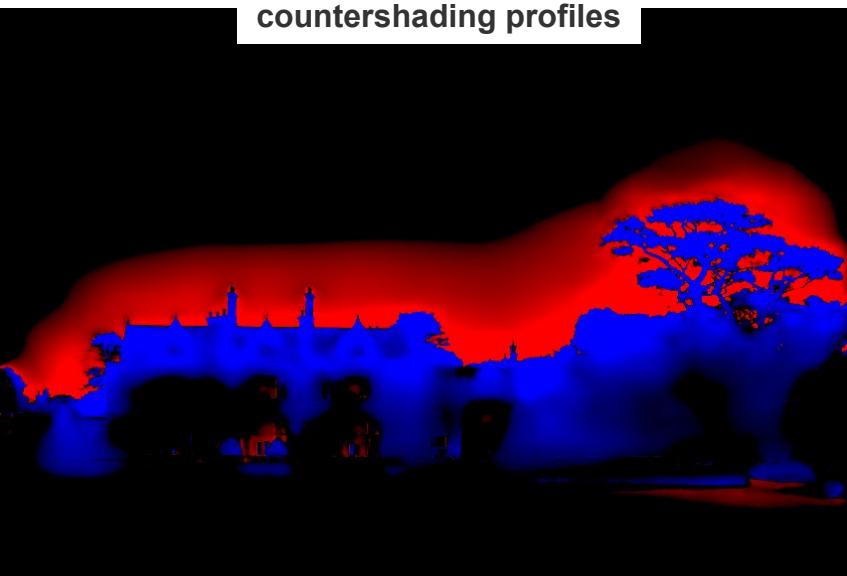


tone mapping





Improved Separation





Counter Shading vs. Unsharp Masking





HDR Displays

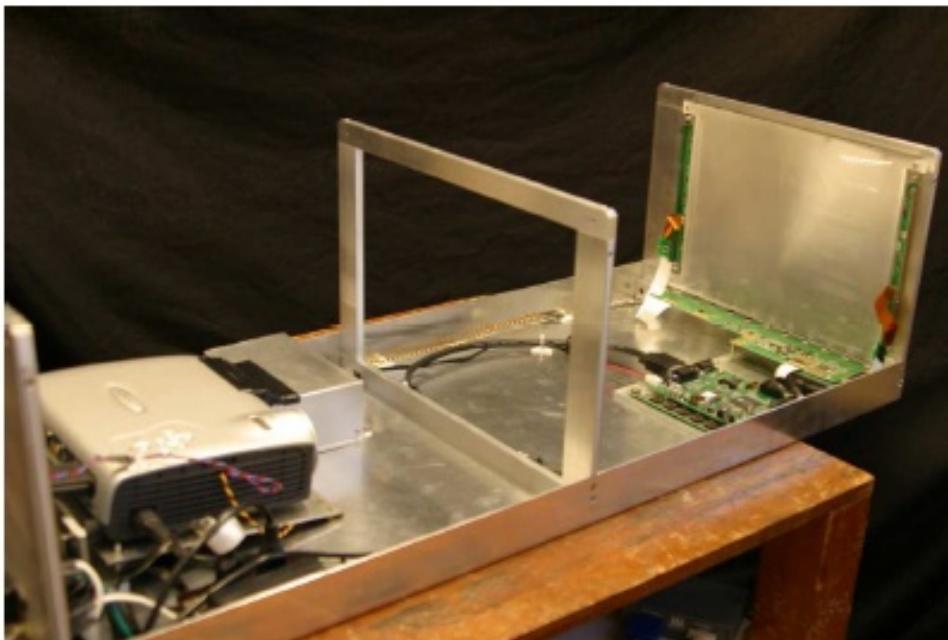
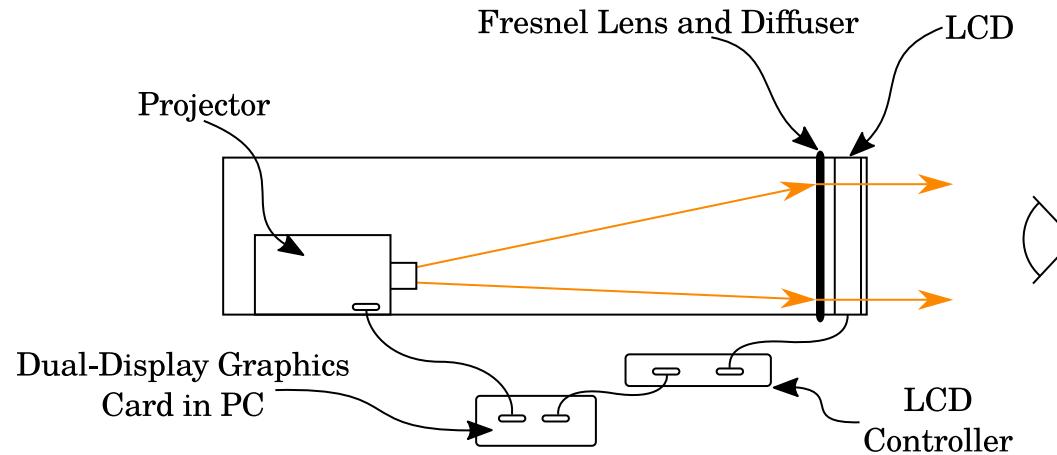


Alternative: HDR Display

- Human Visual System
 - Sensitive to contrast, insensitive to absolute luminance difference
 - Mach bands: reduced resolution at discontinuities
 - “Very high contrast, although important on a global scale, cannot be perceived by humans at high spatial frequencies”
- Idea [Heidrich et al., Siggraph 2004]
 - High-resolution transparency filter to modulate high-intensity (low-resolution) image from a second display
 - Transparency filter: LCD screen
 - High intensity image: video projector, array of superluminous LEDs
 - dynamic range: >50,000:1
 - maximum intensity: 2700 cd/m², 8500 cd/m²



Setup





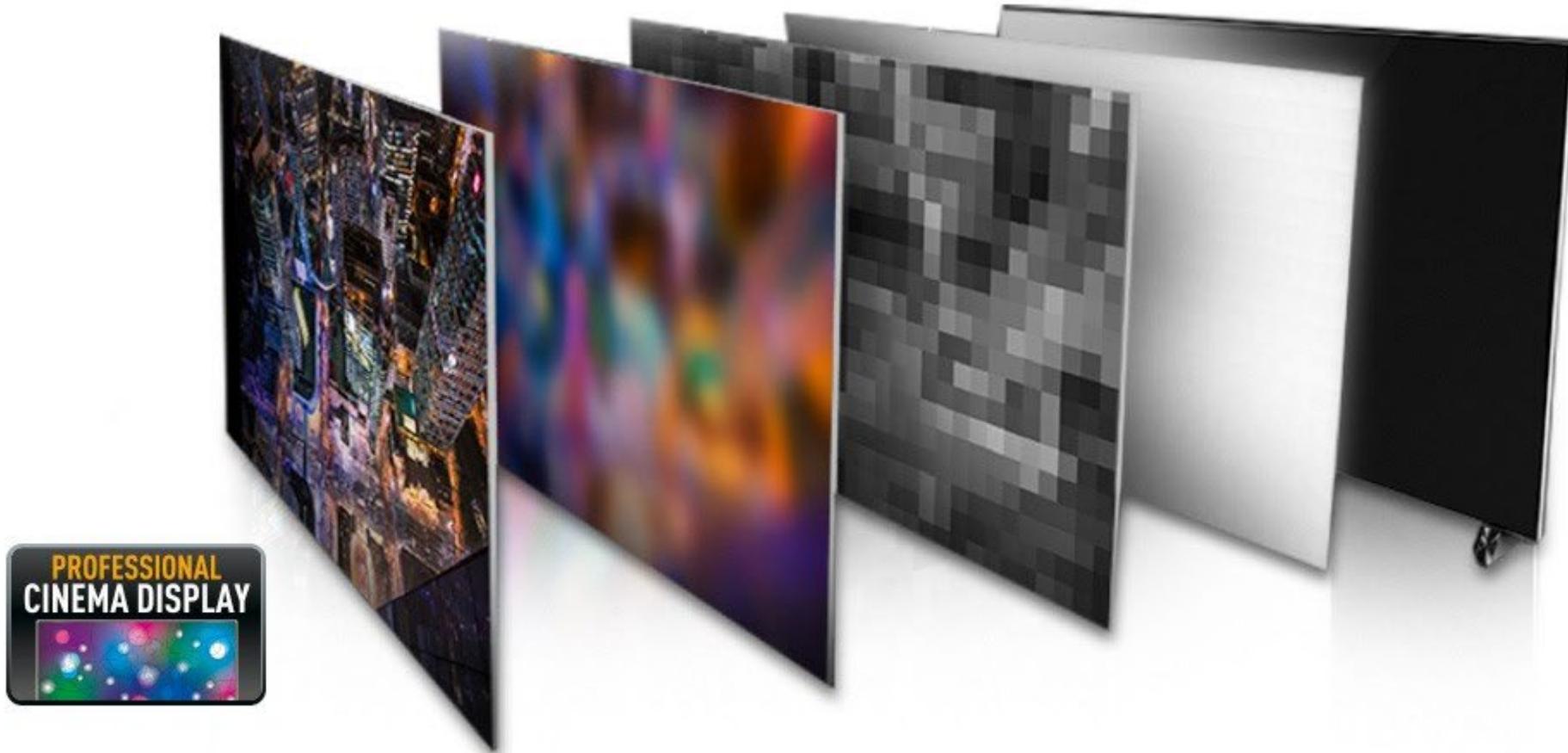
Of-Screen Captured Photographs

- 4 aperture stops difference





Current HDR – TV set

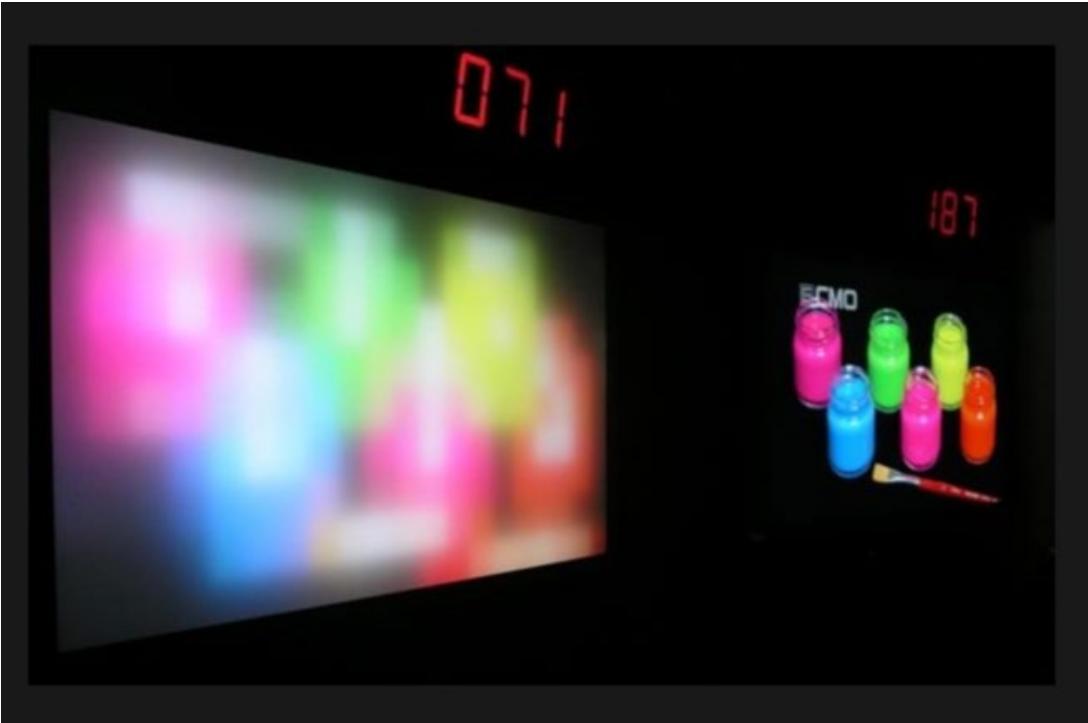
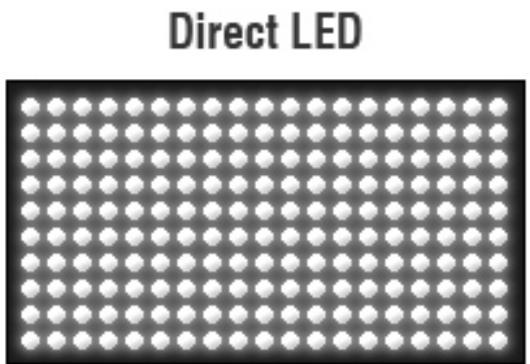


[panasonic]



Backlight for HDR Displays

- Control intensity and color for led grid
- Multiplicative effect of LCD * backlight modulation
- Backlight has way lower resolution





Wrap-up

- HDR acquisition
- Tone mapping necessary due to dynamic range
- Reduction of dynamic range
- Histogram equalization
- Just noticeable difference
- Local tone mapping
- HDR displays