HDR imaging and the Bilateral Filter

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Leica discussion

- **Photographers discuss what features they want in future Leica cameras**
  - http://luminous-landscape.com/essays/leica-open-letter.shtml
  - http://luminous-landscape.com/essays/leica-different-view.shtml
  - http://luminous-landscape.com/essays/hogan-leica.shtml
- **Inspiring for class projects on focusing & metering**

From
http://luminous-landscape.com/essays/leica-open-letter.shtml

The dynamic range problem

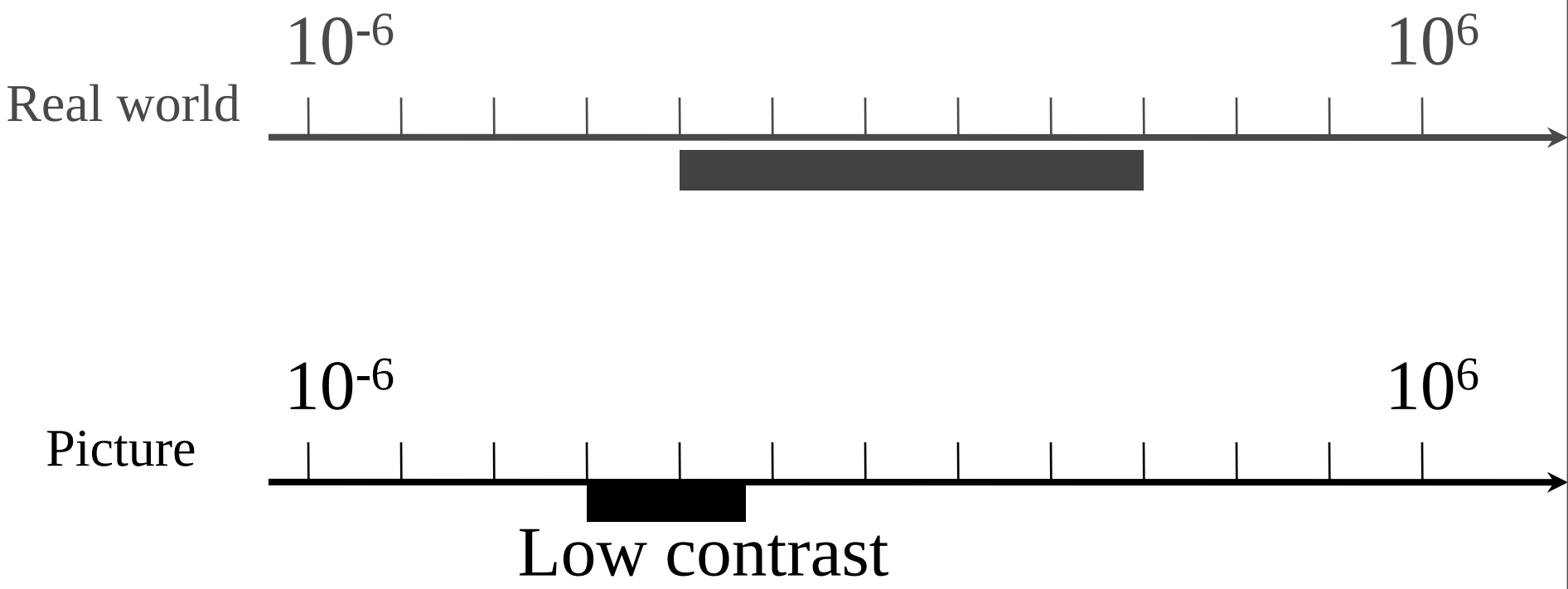
- media (approximate and debatable)

10:1	photographic print (higher for glossy paper)
20:1	artist's paints
200:1	slide film
500:1	negative film
1000:1	LCD display
2000:1	digital SLR (~11 bits)

- challenges
  - choosing which 6-12 bits of the world to include in your photograph (cell phone to professional SLR, respectively)
  - metering the world to help you make this decision, since the world has more dynamic range than any light meter
  - compressing 12 bits into 4 bits for print, or 10 for LCD
    - this is the *tone mapping* problem

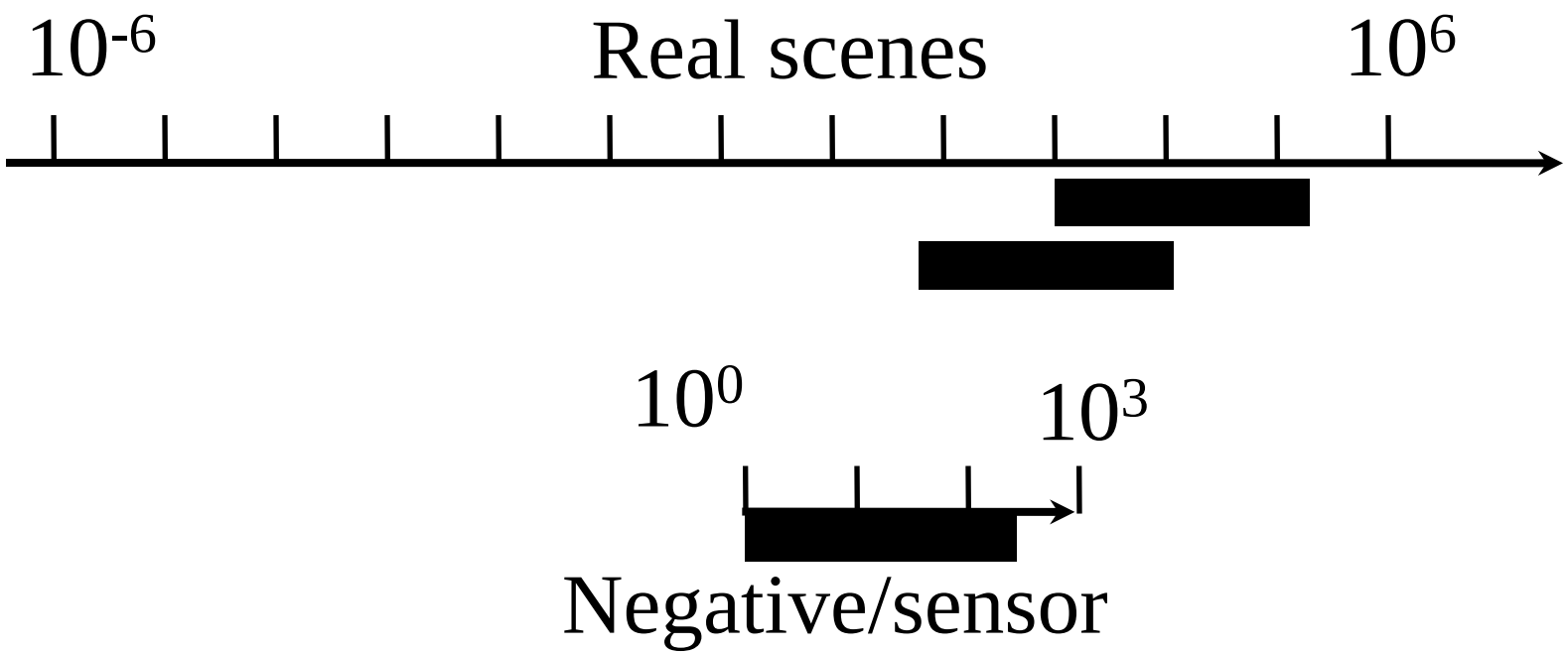
Picture dynamic range

- **Typically 1: 20 or 1:50**
  - Black  is ~ 50x darker than white



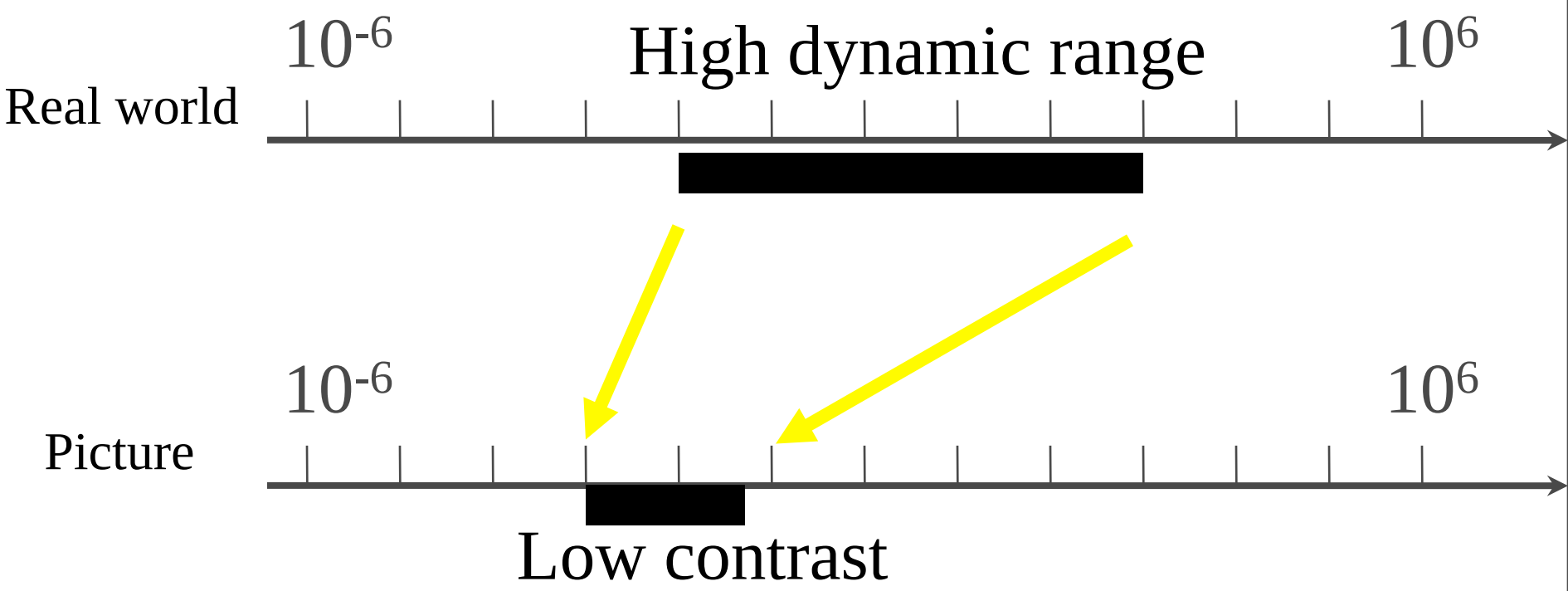
Problem 1: record the information

- **The range of illumination levels that we encounter is 10 to 12 orders of magnitudes**
- **Negatives/sensors can record 2 to 3 orders of magnitude**



Problem 2: Display the information

- **Match limited contrast of the medium**
- **Preserve details**



Without HDR & tone mapping

With HDR & tone mapping

Can be extreme

- **By Anthony Wong, http://abduzeedo.com/20-beautiful-hdr-pictures-part-3**

Not always cheesy

By Alexandre Buisse

http://luminous-landscape.com/essays/hdr-plea.shtml

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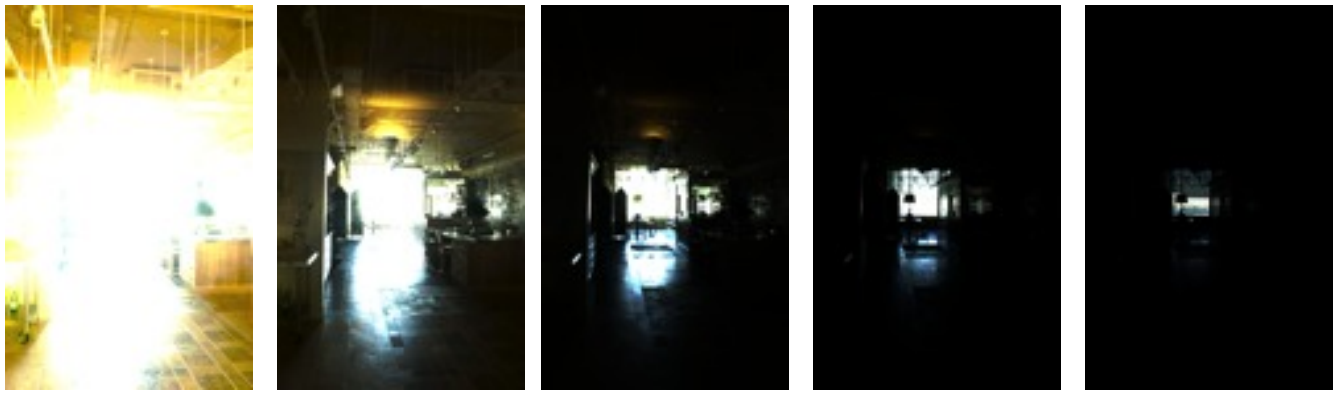
Today

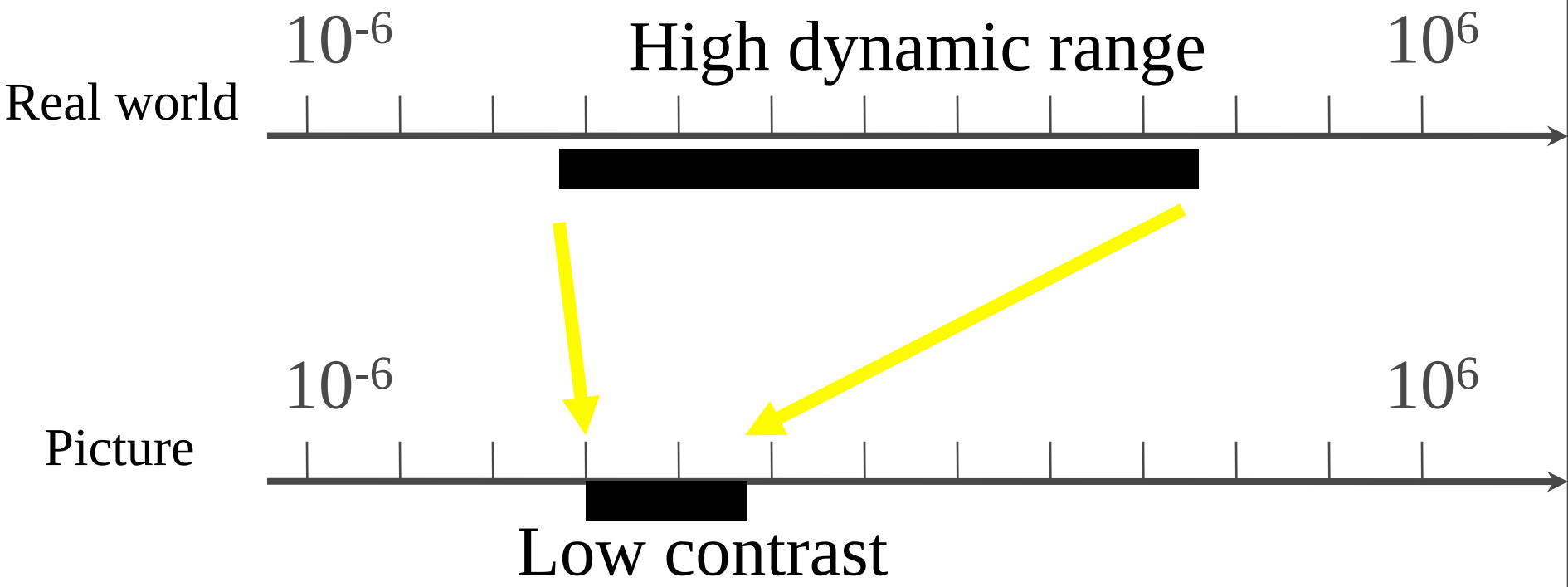
- **Multiple-exposure High-Dynamic-Range imaging**



- **Tone mapping using the bilateral filter**

Multiple exposure photography

- **Sequentially measure all segments of the range**



Multiple exposure photography

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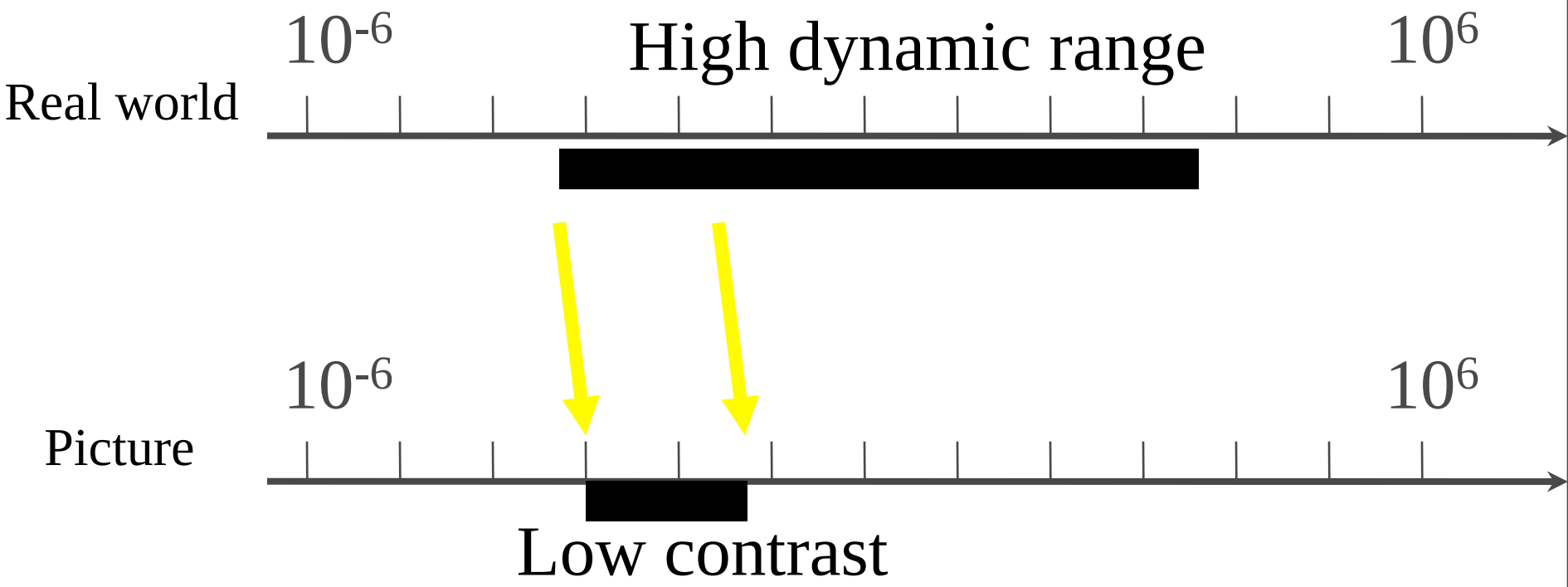

Multiple exposure photography

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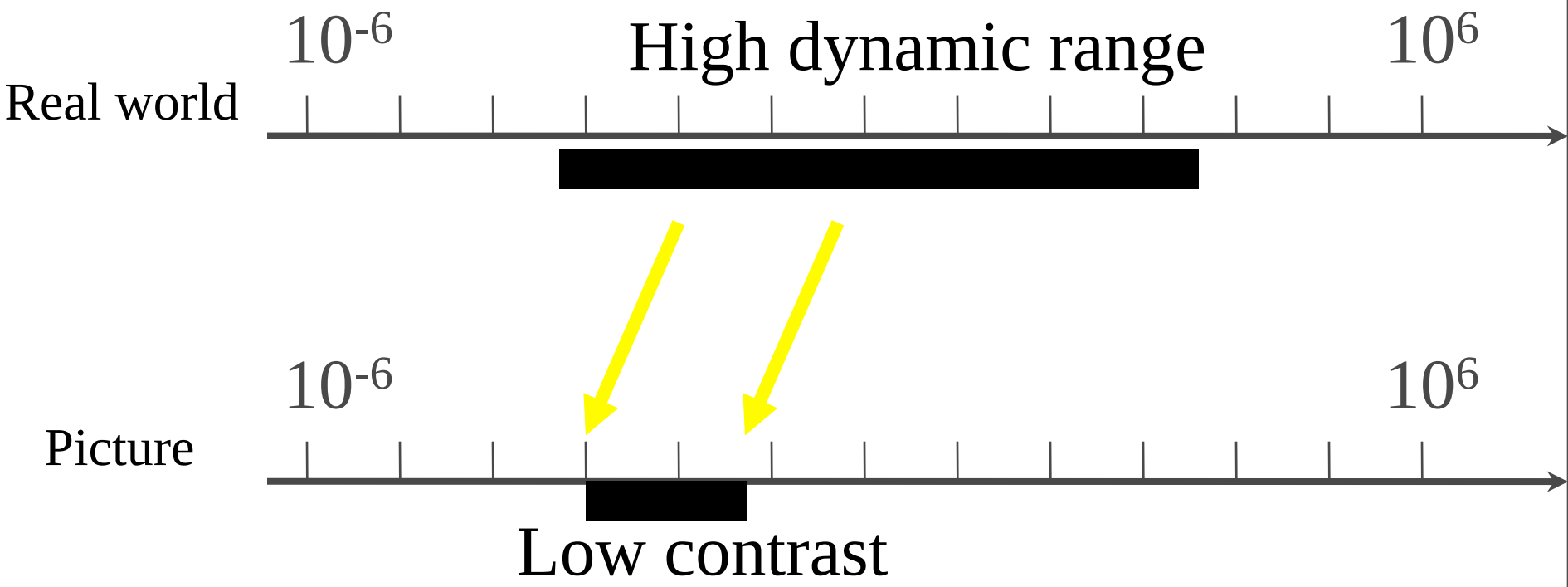

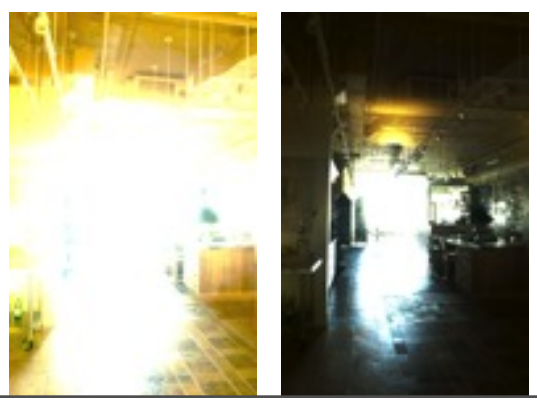

Multiple exposure photography

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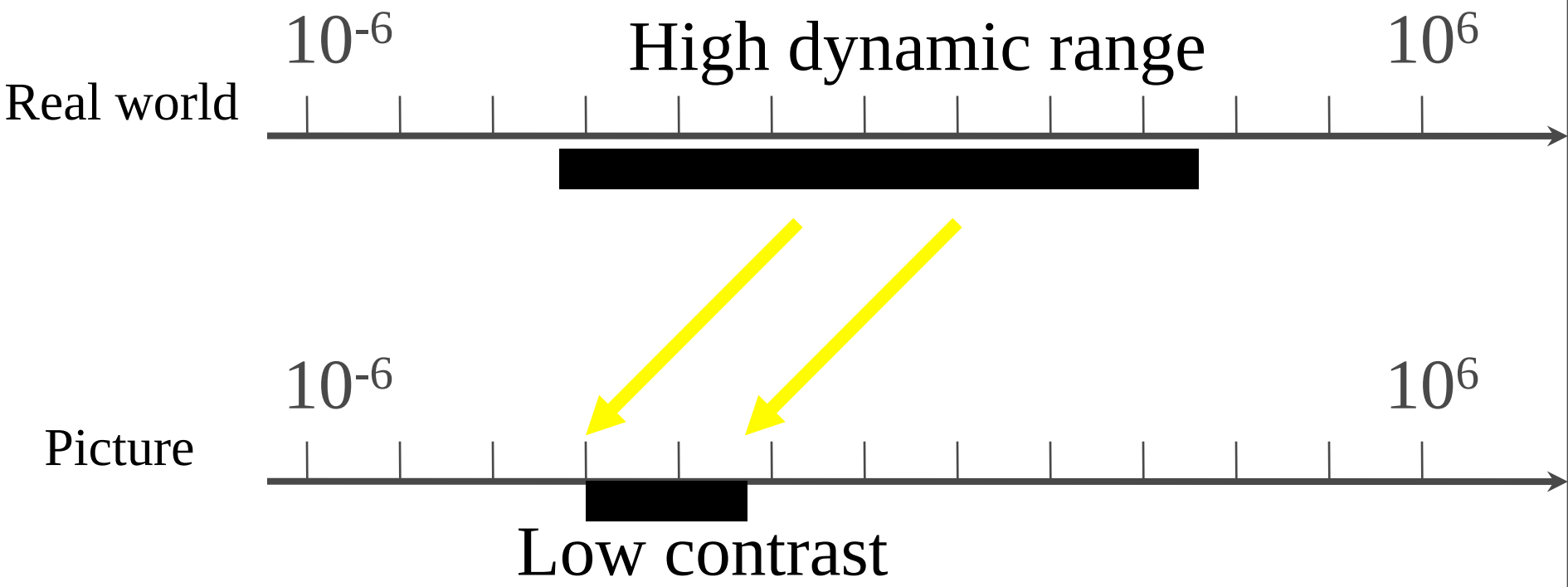

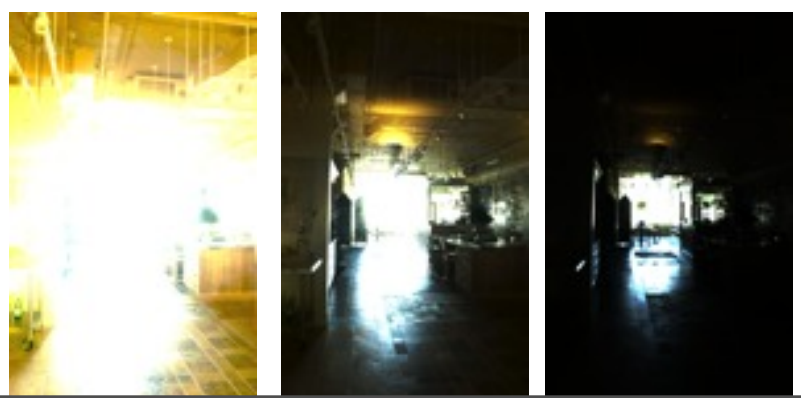

Multiple exposure photography

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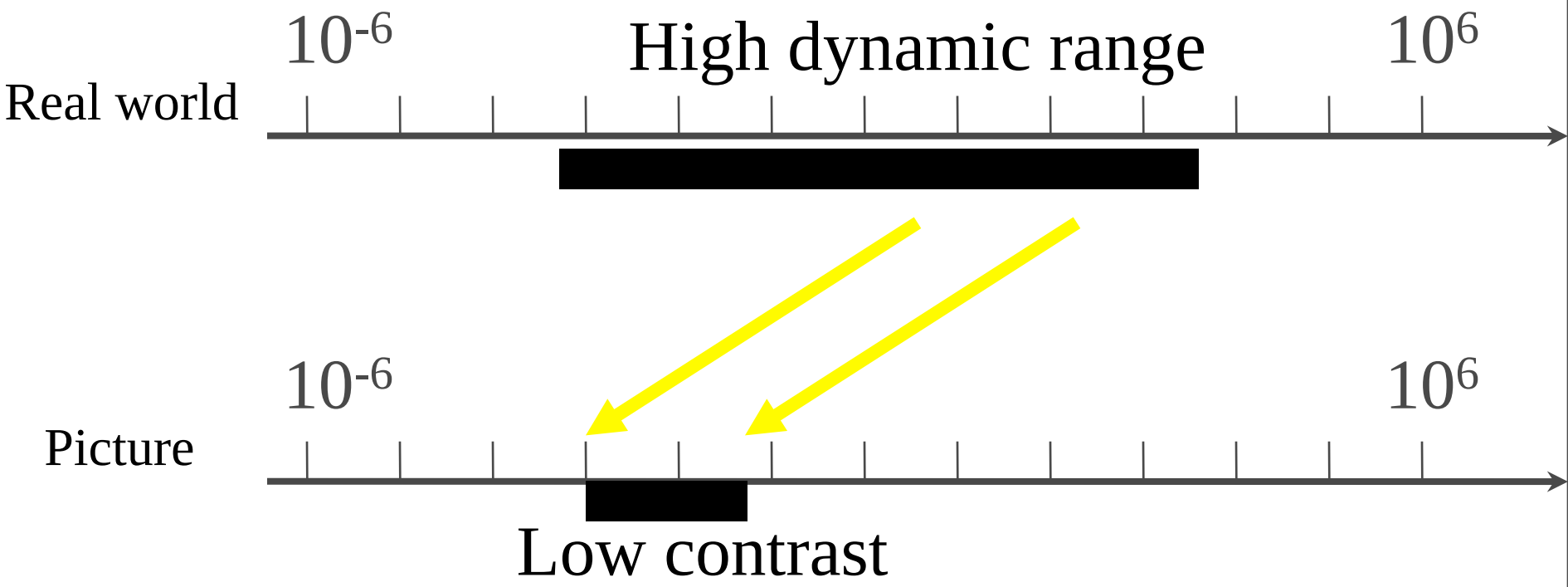

Multiple exposure photography

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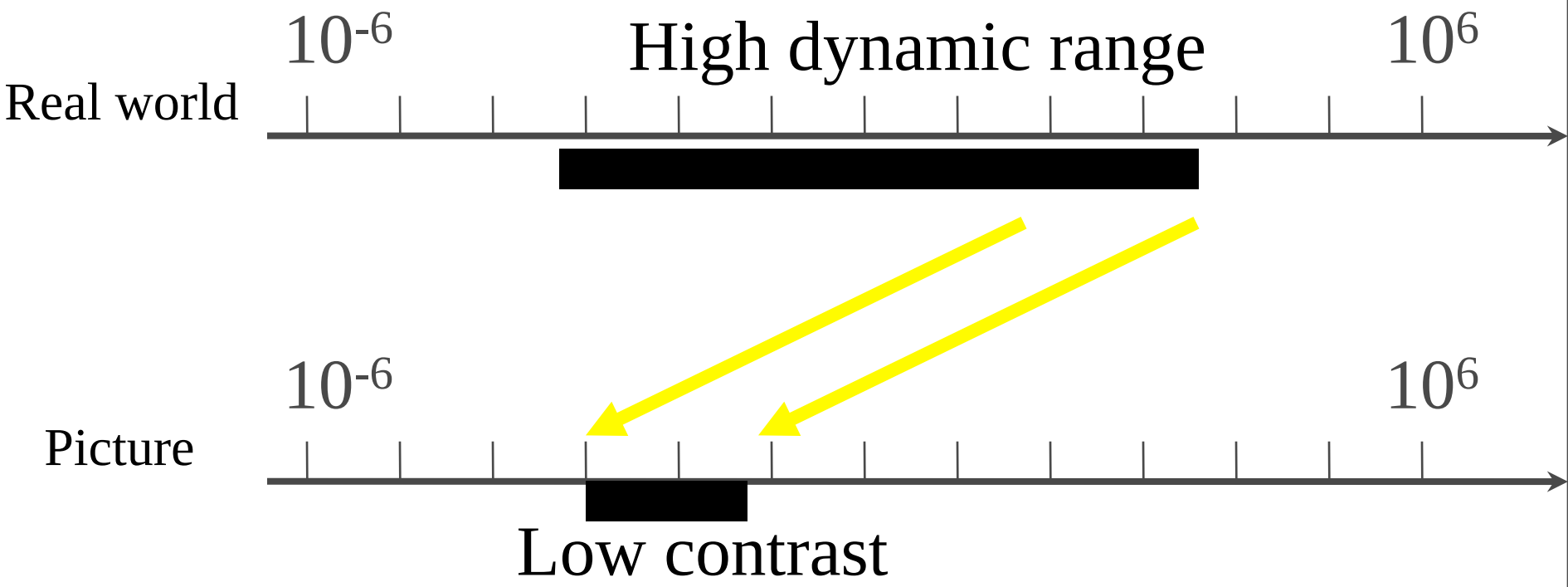
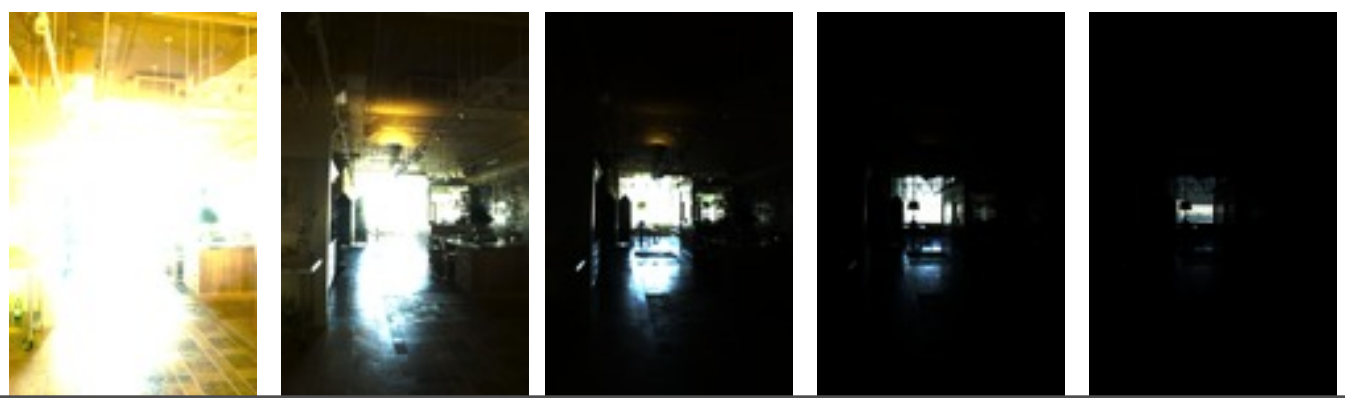
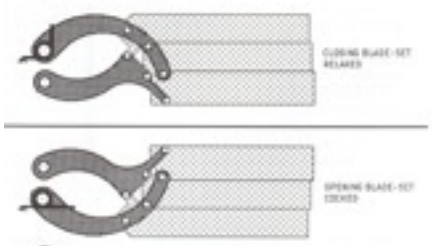




How do we vary exposure?

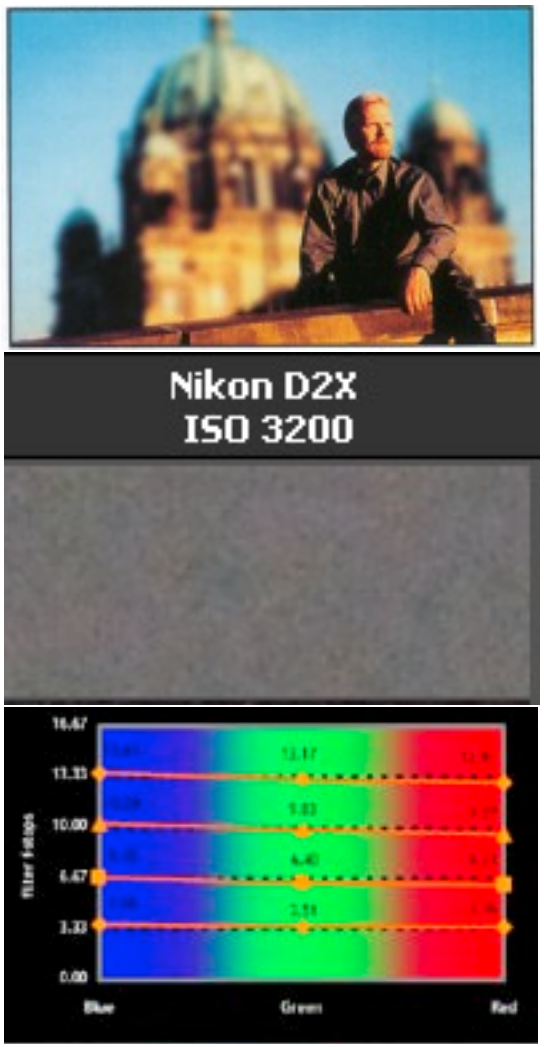
- **Options:**
  - Shutter speed
  - Aperture
  - ISO
  - Neutral density filter



Slide inspired by Siggraph 2005 course on HDR

Tradeoffs

- **Shutter speed**
  - Range: ~30 sec to 1/4000sec (6 orders of magnitude)
  - Pros: reliable, linear
  - Cons: sometimes noise for long exposure
- **Aperture**
  - Range: ~f/1.4 to f/22 (2.5 orders of magnitude)
  - Cons: changes depth of field
  - Useful when desperate
- **ISO**
  - Range: ~100 to 1600 (1.5 orders of magnitude)
  - Cons: noise
  - Useful when desperate
- **Neutral density filter**
  - Range: up to 4 densities (4 orders of magnitude) & can be stacked
  - Cons: not perfectly neutral (color shift), not very precise, need to touch camera (shake)
  - Pros: works with strobe/flash, good complement when desperate



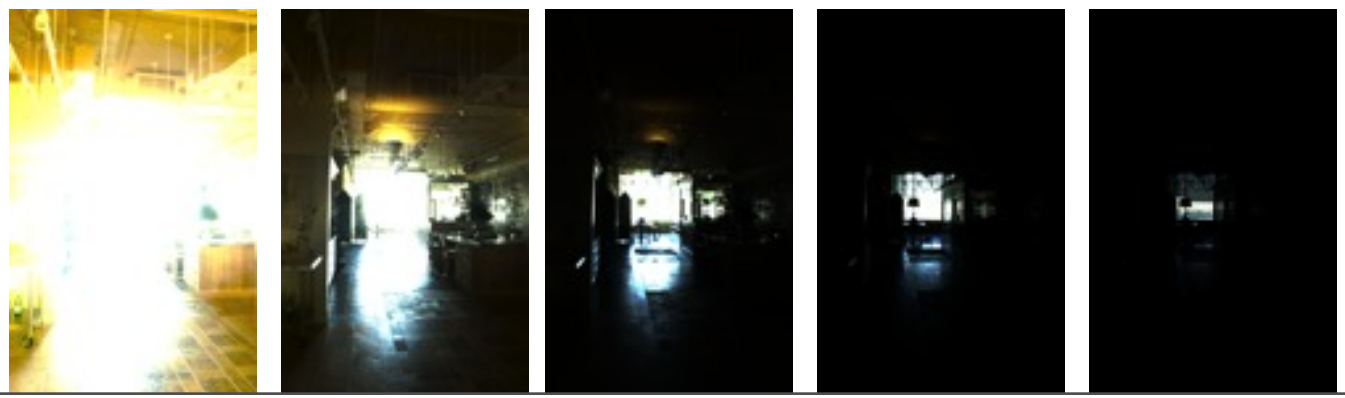
Slide after Siggraph 2005 course on HDR

Questions?

HDR image using multiple exposure

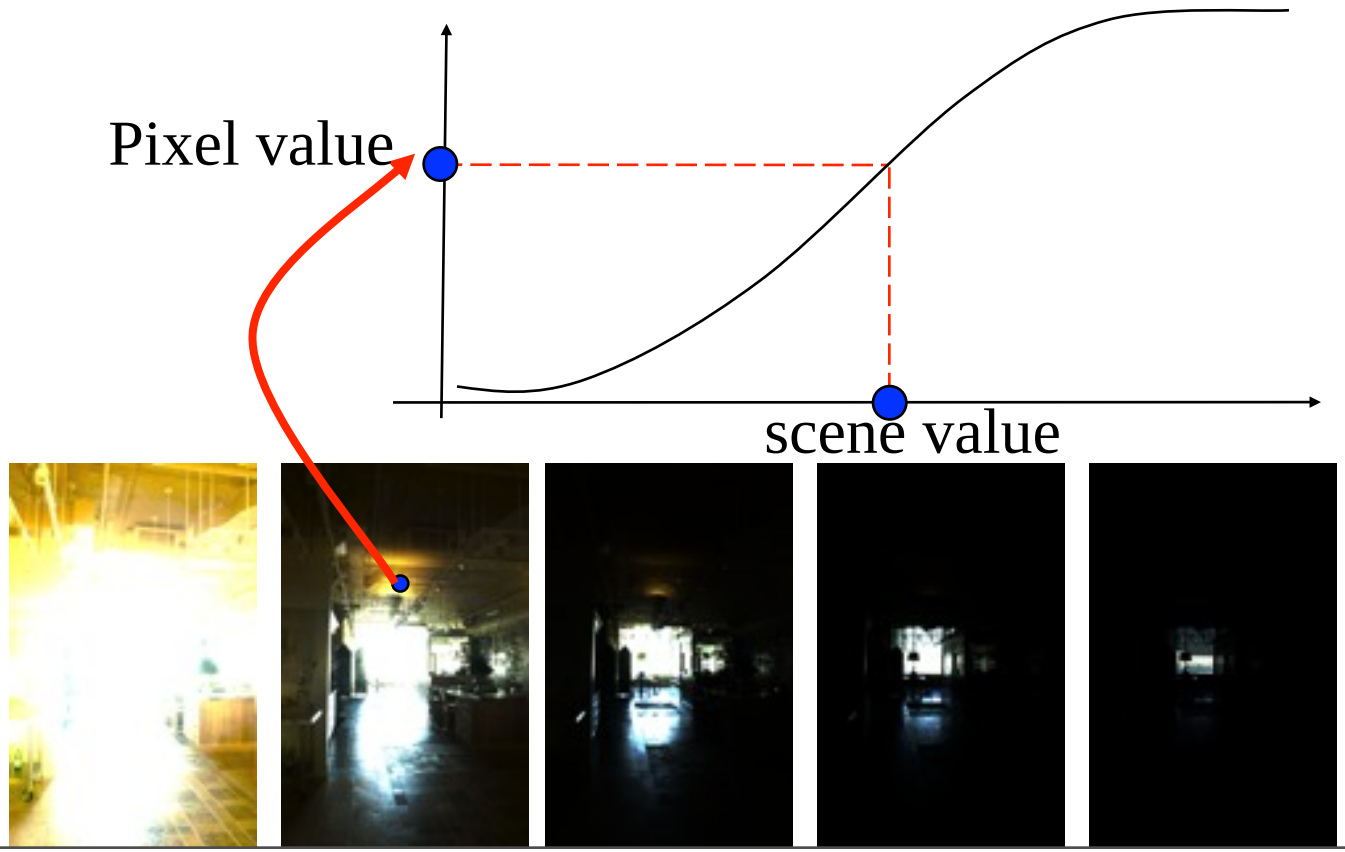
- **Given N photos at different exposure**
- **Recover a HDR color for each pixel**

- **We'll study Debevec and Malik's 97 algorithm**
  - http://www.debevec.org/Research/HDR/



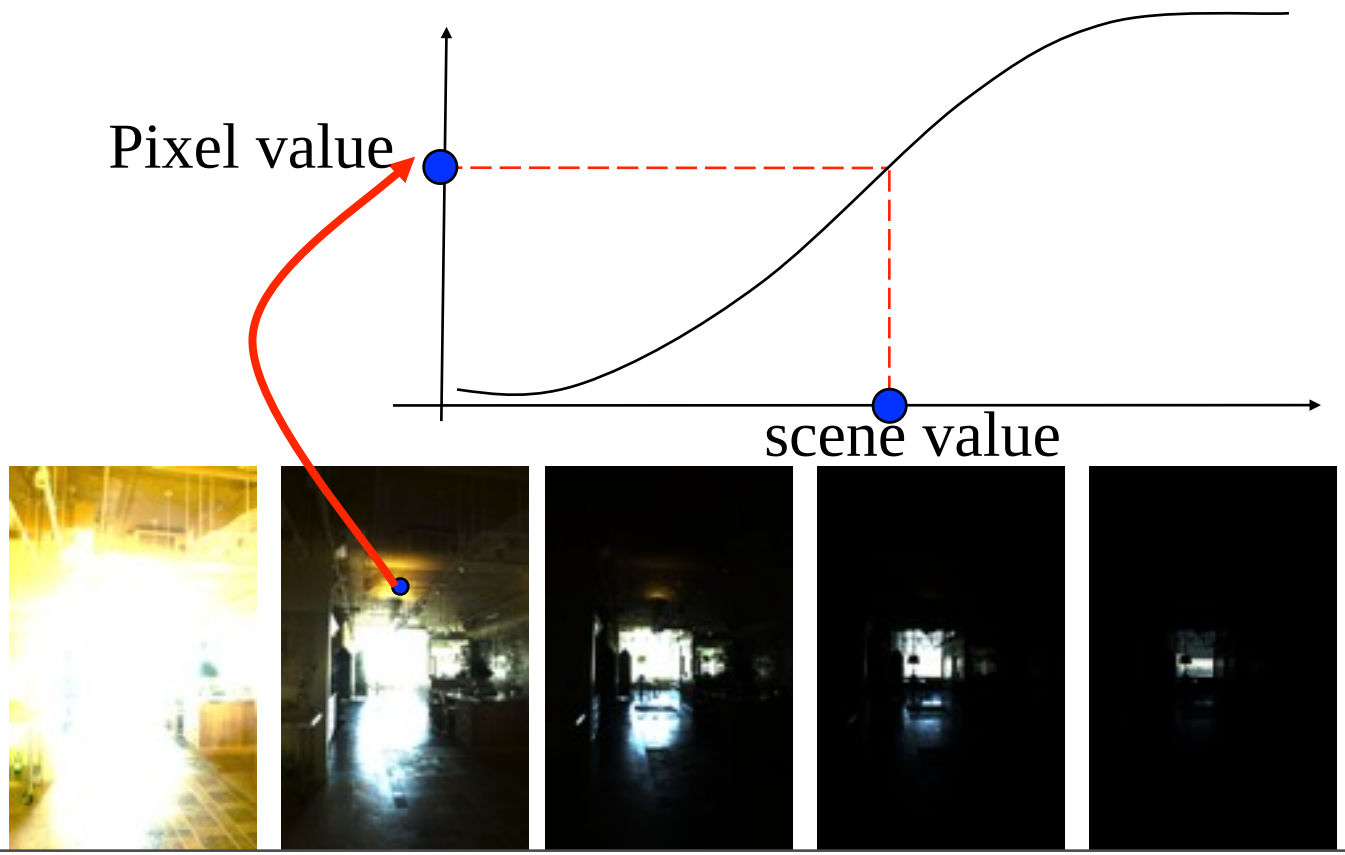
If we know the response curve

- **For each pixel**
  - for each frame
    - if not black & not saturated, convert to absolute luminance
  - Take average if well-exposed in multiple frames



But how do we get the curve?

- **Easy when shooting raw (linear)**
- **Need calibration otherwise**



Calibrating the response curve

- **Two basic solutions**
  - Vary scene luminance and see pixel values
    - Assumes we control and know scene luminance
  - Vary exposure and see pixel value for one scene luminance
    - But note that we can usually not vary exposure more finely than by 1/3 stop
- **Best of both:**
  - Vary exposure
  - Exploit the large number of pixels

The Algorithm

Image series

$\Delta t =$ **10 sec**

$\Delta t =$ **1 sec**

$\Delta t =$ **1/10 sec**

$\Delta t =$ **1/100 sec**

$\Delta t =$ **1/1000 sec**

Pixel Value Z = f(Exposure)

exposure: essentially # photons

Exposure = Radiance × Δt

log Exposure = log Radiance + log Δt

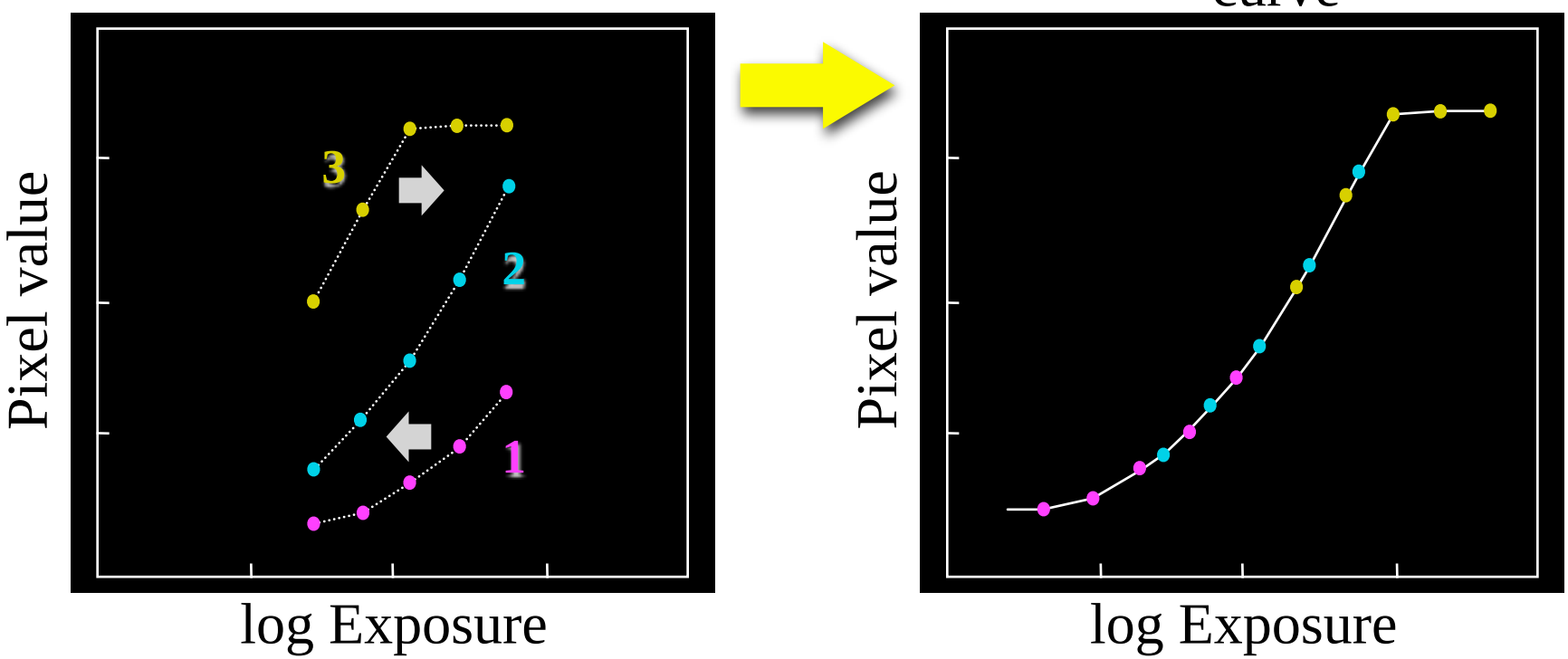
Slide adapted from Alyosha Efros who borrowed it from Paul Debevec
Δ t don't really correspond to pictures. Oh well.

Response curve

- **Exposure is unknown, fit to find a smooth curve**

Assuming unit radiance for each pixel

After adjusting radiances to obtain a smooth response curve



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The math

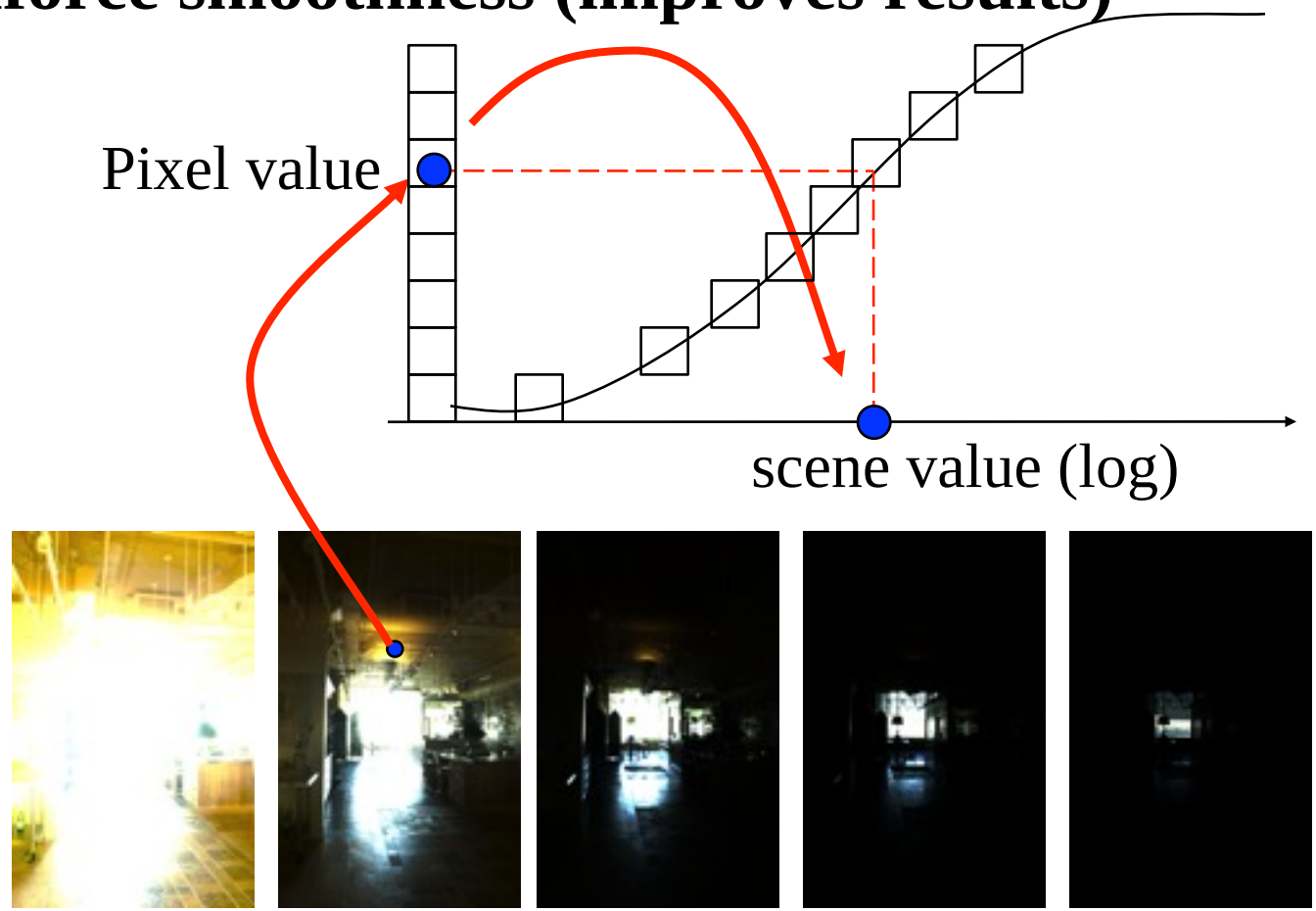
- **unknowns: response curve f and radiance of pixels**
- **for each pixel i and image j**
  - Pixel Value $Z_{ij}=f(\text{Exposure}_{i,j})$
  - $\log \text{Exposure} = \log \text{Radiance}_i + \log \Delta t_j$
- **Easier to deal with inverse function (in log) $g=\log(f^{-1})$**

$$\log \text{Radiance}_i + \log \Delta t_j = g(Z_{ij})$$

- **We have #pixels * #images equations**

Inverse response curve g

- **Discretize pixel values**
  - but ignore saturated black and white pixels
- **Enforce smoothness (improves results)**



The Math

- **For each pixel site *i* in each image *j*, want:**

$$\log Radiance_i + \log \Delta t_j = g(Z_{ij})$$

- **Solve the overdetermined linear system:**

$$\sum_{i=1}^{N} \sum_{j=1}^{P} \left[\log Radiance_i + \log \Delta t_j - g(Z_{ij}) \right]^2 + \lambda \sum_{z=Z_{min}}^{Z_{max}} g''(z)^2$$

fitting term

smoothness term

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Matlab code

```
function [g,lE]=gsolve(Z,B,l,w)

n = 256;
A = zeros(size(Z,1)*size(Z,2)+n+1,n+size(Z,1));
b = zeros(size(A,1),1);

k = 1;                  %% Include the data-fitting equations
for i=1:size(Z,1)
  for j=1:size(Z,2)
    wij = w(Z(i,j)+1);
    A(k,Z(i,j)+1) = wij; A(k,n+i) = -wij; b(k,1) = wij * B(i,j);
    k=k+1;
  end
end

A(k,129) = 1;           %% Fix the curve by setting its middle value to 0
k=k+1;

for i=1:n-2             %% Include the smoothness equations
  A(k,i)=l*w(i+1); A(k,i+1)=-2*l*w(i+1); A(k,i+2)=l*w(i+1);
  k=k+1;
end

x = A\b;                %% Solve the system using SVD
```

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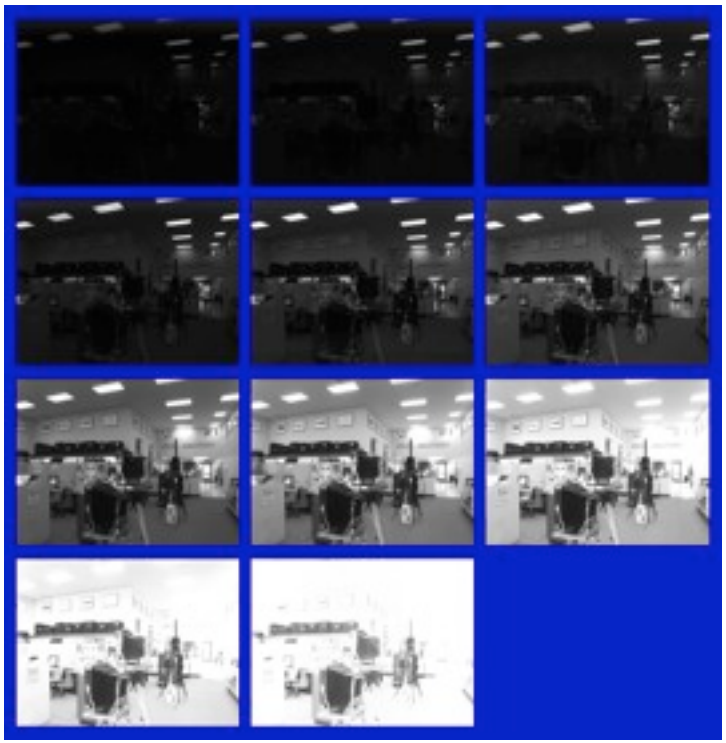
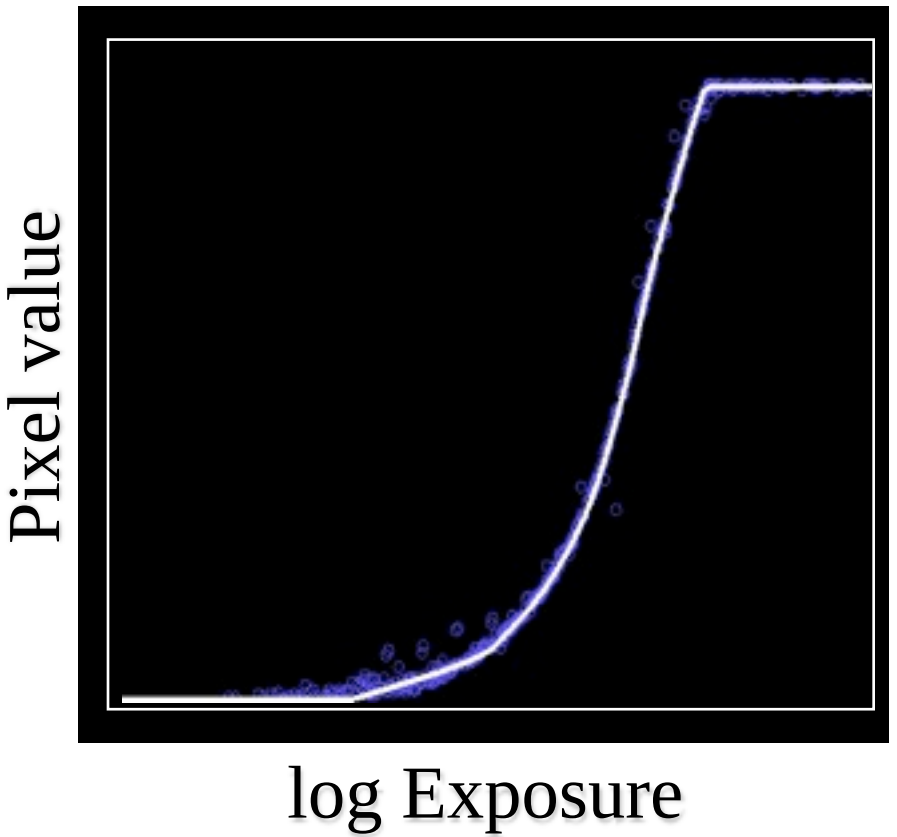
Result: digital camera

Kodak DCS460
1/30 to 30 sec



Recovered response curve



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Reconstructed radiance map

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Result: color film

- **Kodak Gold ASA 100, PhotoCD**

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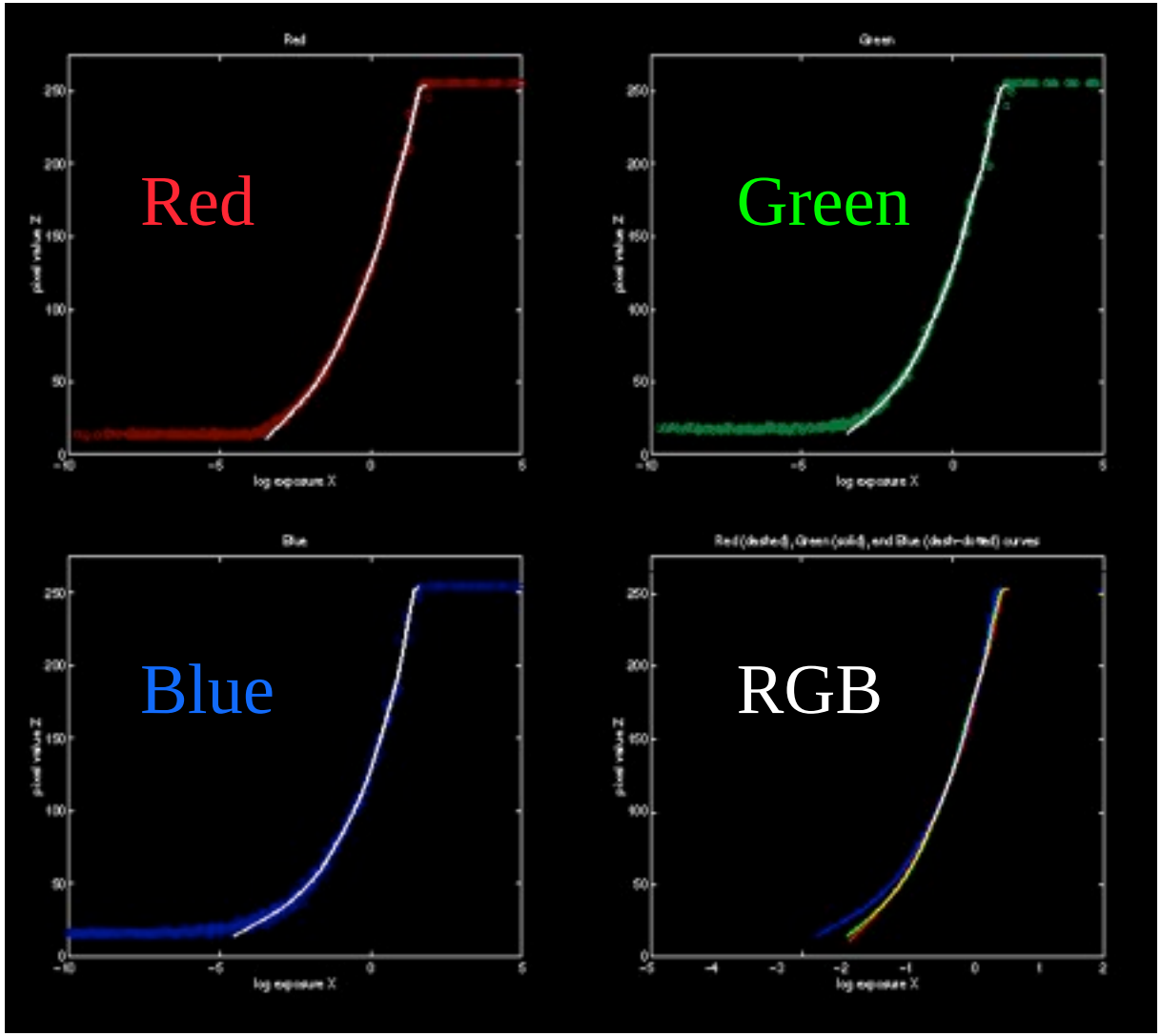
Recovered response curves



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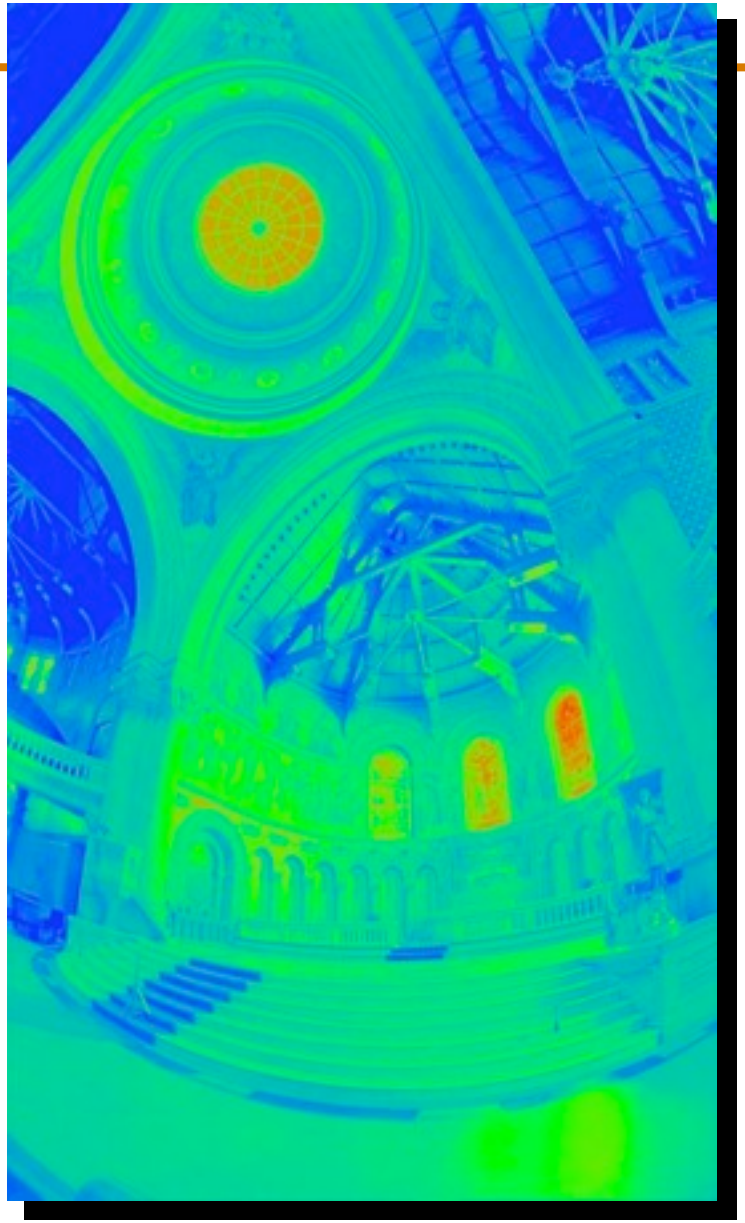
Recap

- **Curve calibration**
  - Take many images of static scene (1/3 stop)
  - Solve optimization problem
- **HDR multiple-exposure merging**
  - Take multiple exposures (e.g. every 2 stops)
  - (optional) align images
  - for each pixel, use picture(s) where properly exposed
    - use inverse response curve and exposure time
  - Output: one image where each pixel has full dynamic range, stored e.g. in float aka radiance map

The Radiance map



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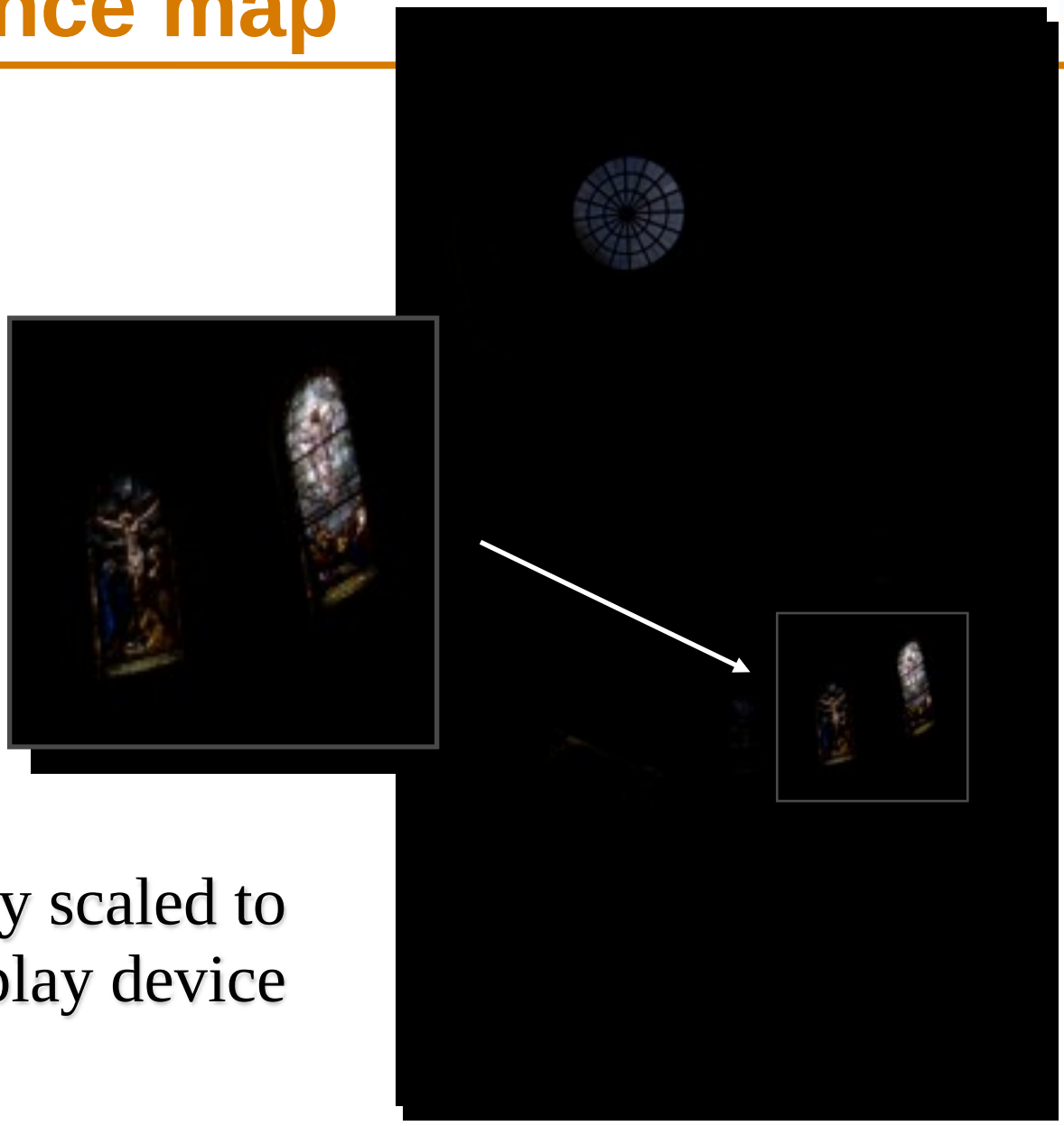
The Radiance map



Linearly scaled to display device

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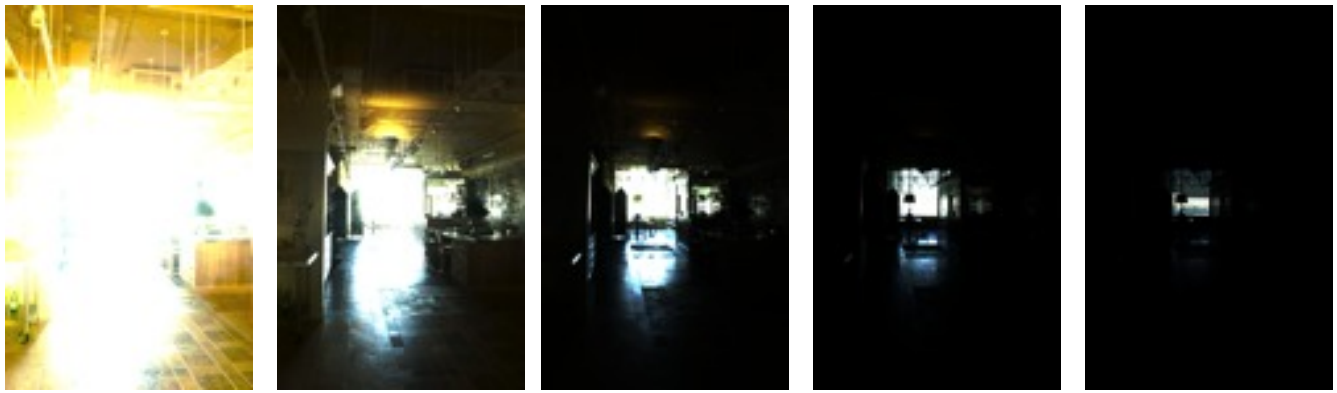
Questions?

Today

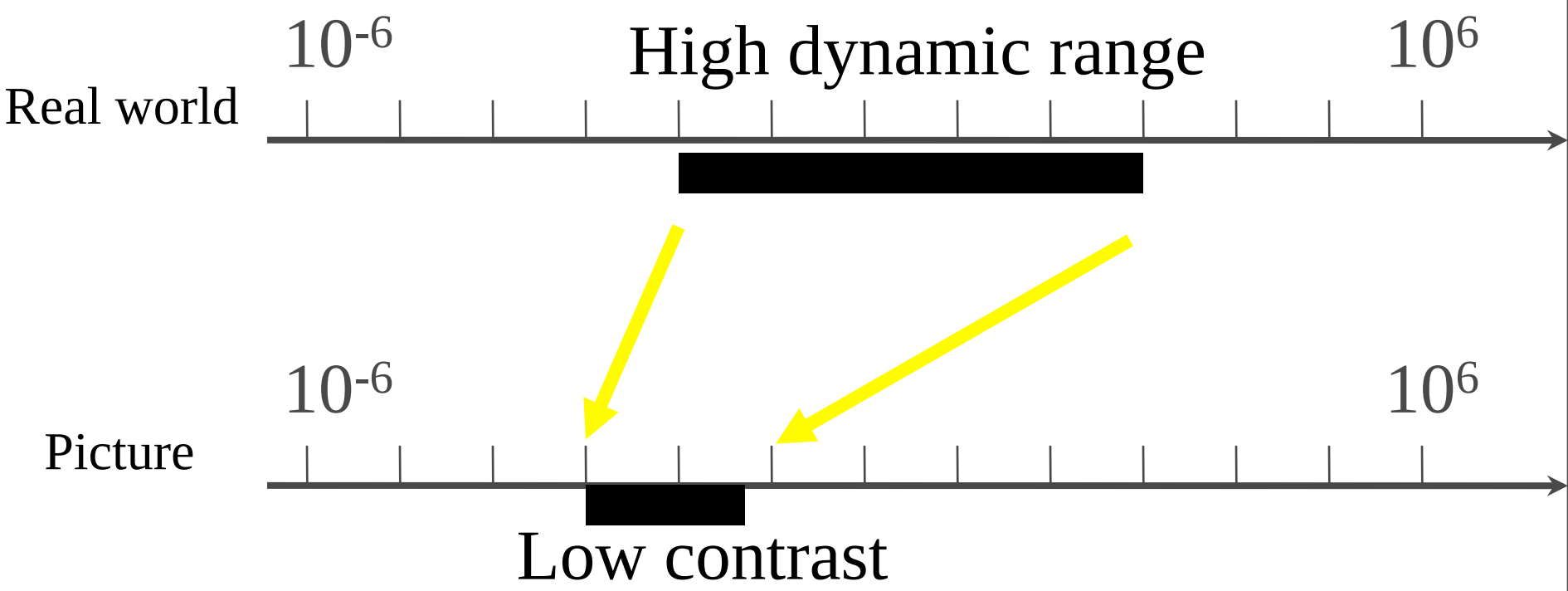
- **Multiple-exposure High-Dynamic-Range imaging**



- **Tone mapping using the bilateral filter**

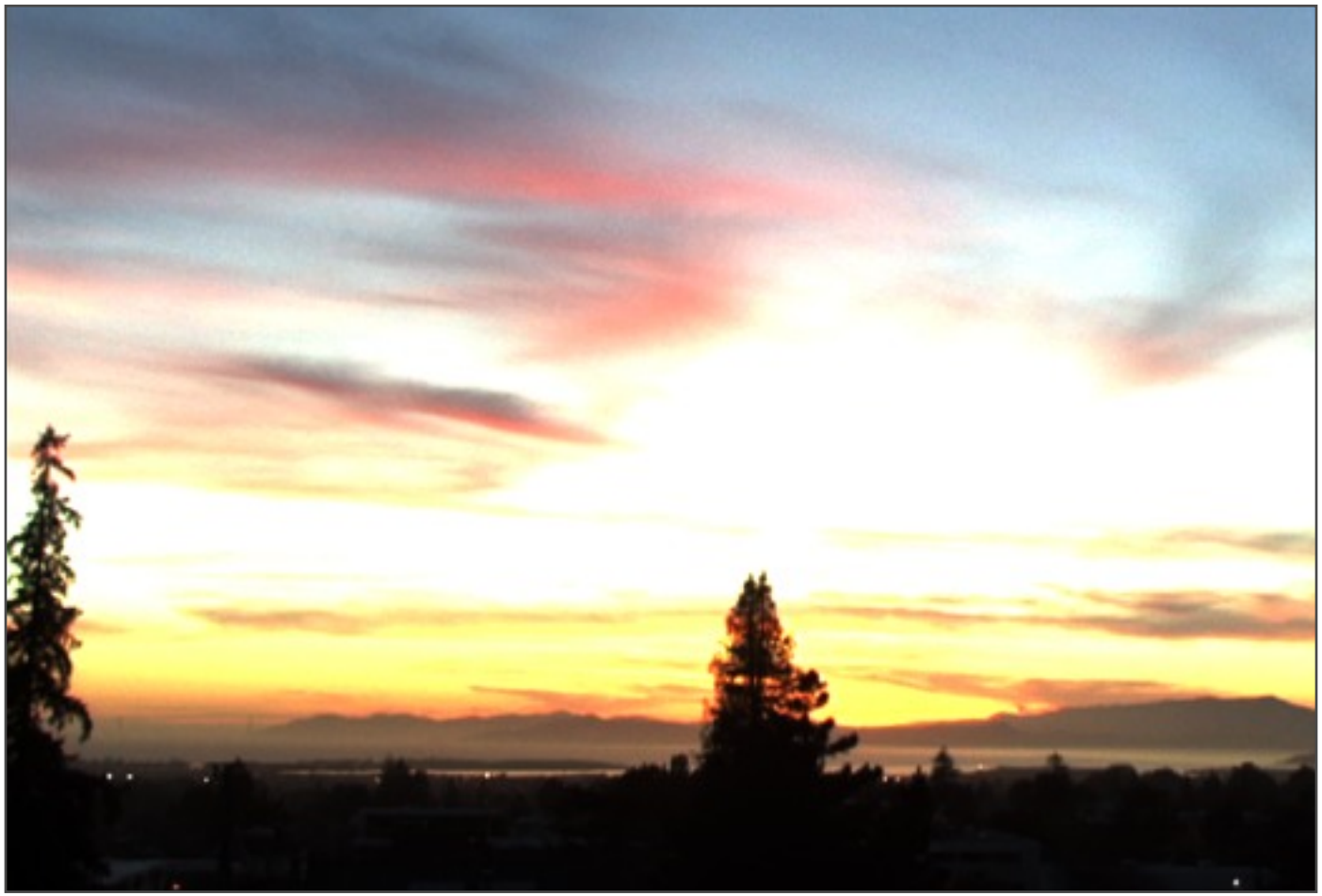
Problem 2: Display the infromation

- **Match limited contrast of the medium**
- **Preserve details**



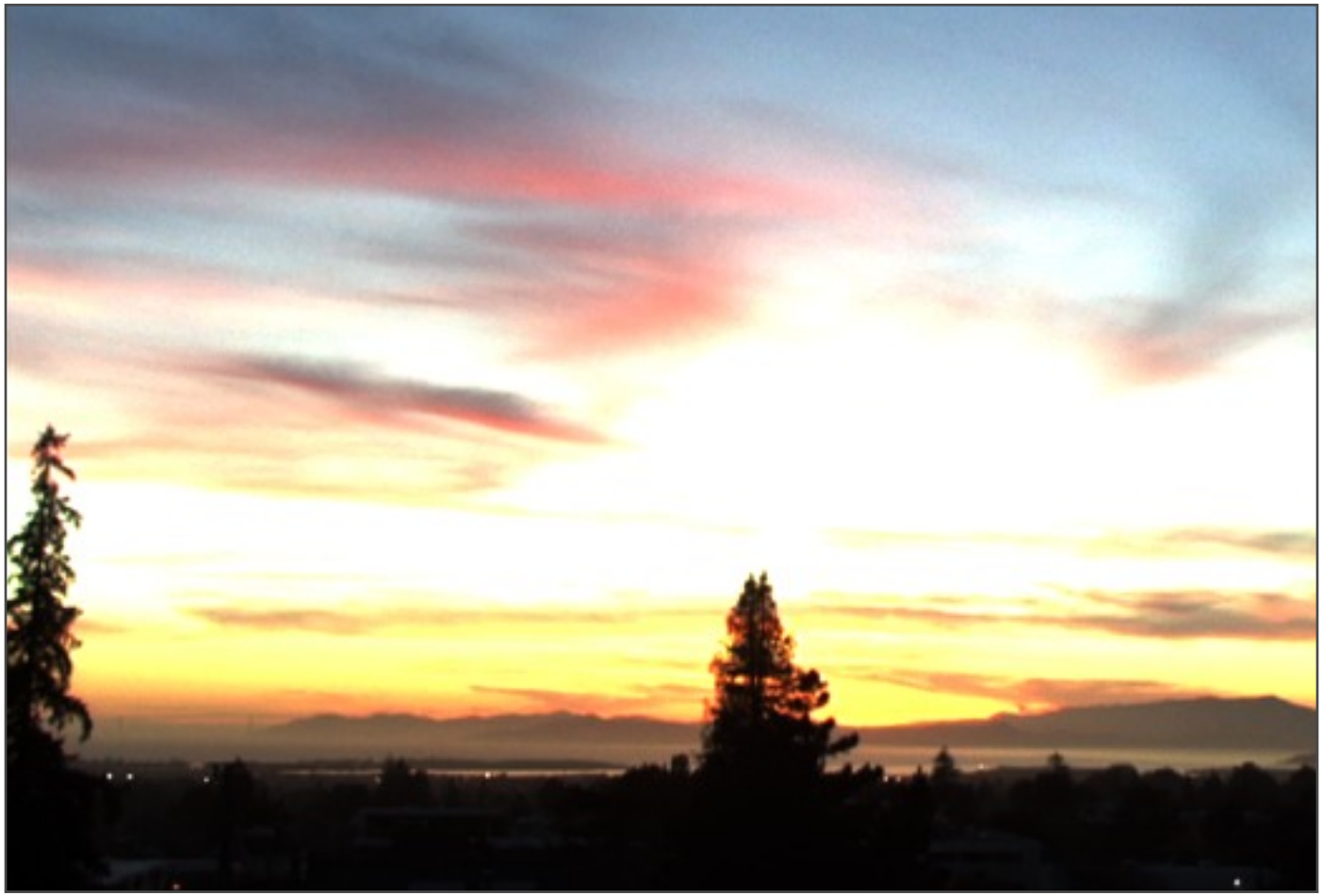
The second half: contrast reduction

- **Input: high-dynamic-range image**
  - (floating point per pixel)



Naïve technique

- **Scene has *1:10,000* contrast, display has *1:100***
- **Simplest contrast reduction?**



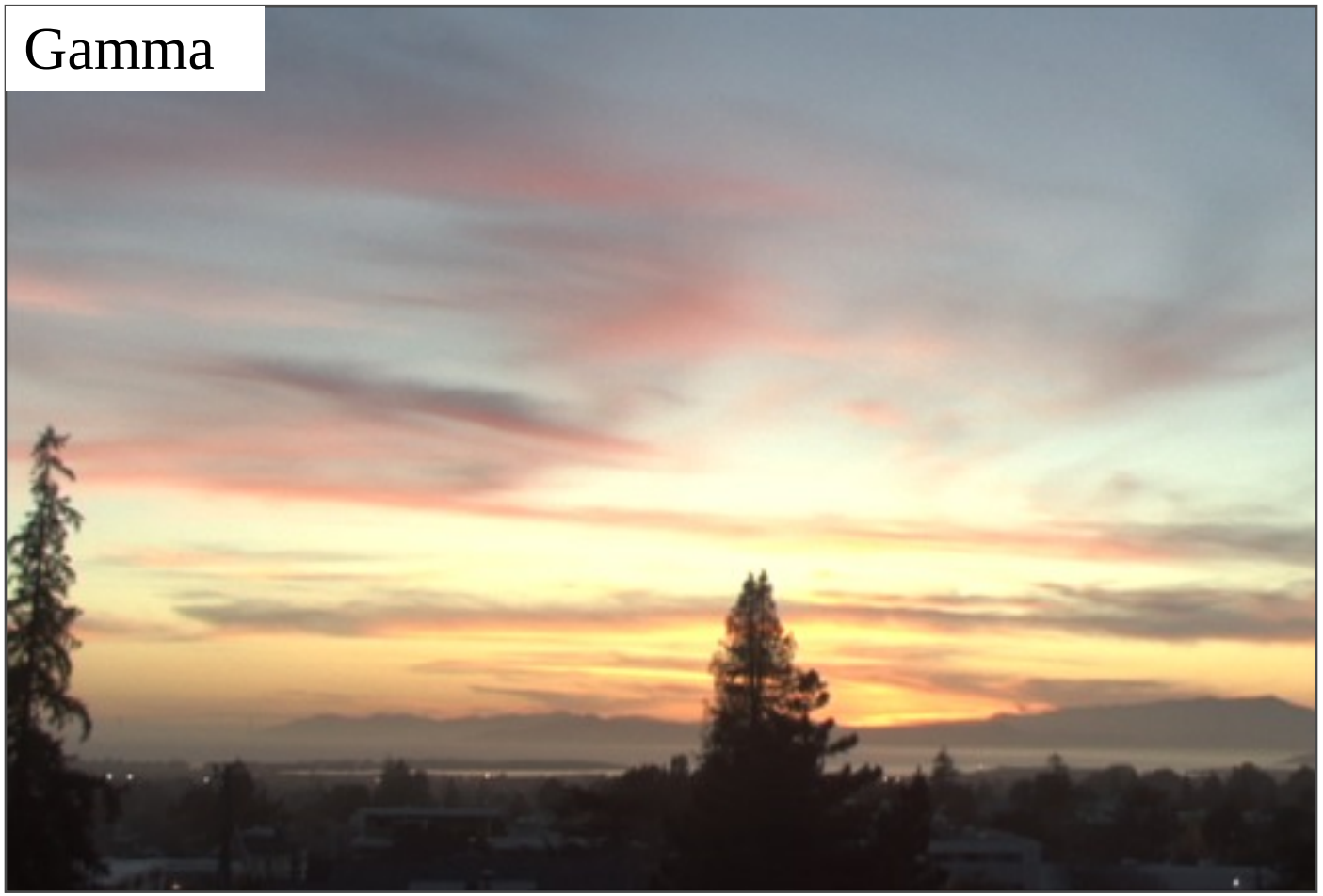
Naïve: Gamma compression

- **$X \rightarrow X^{\gamma}$ (where γ=0.5 in our case)**
- **But… colors are washed-out. Why?**

applied independently on R, G & B

Input

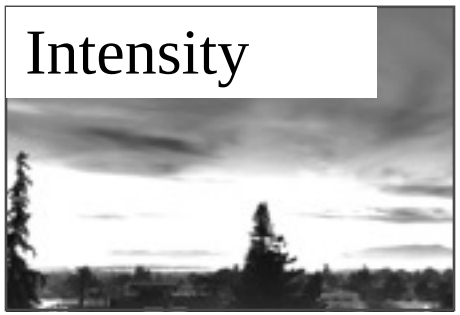
Gamma



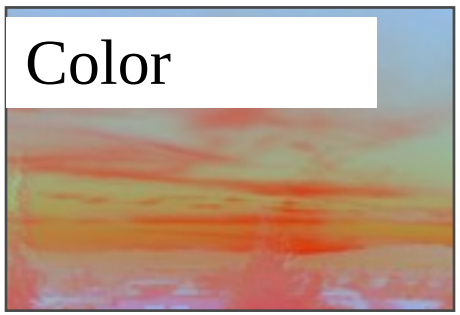
Gamma compression on intensity

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

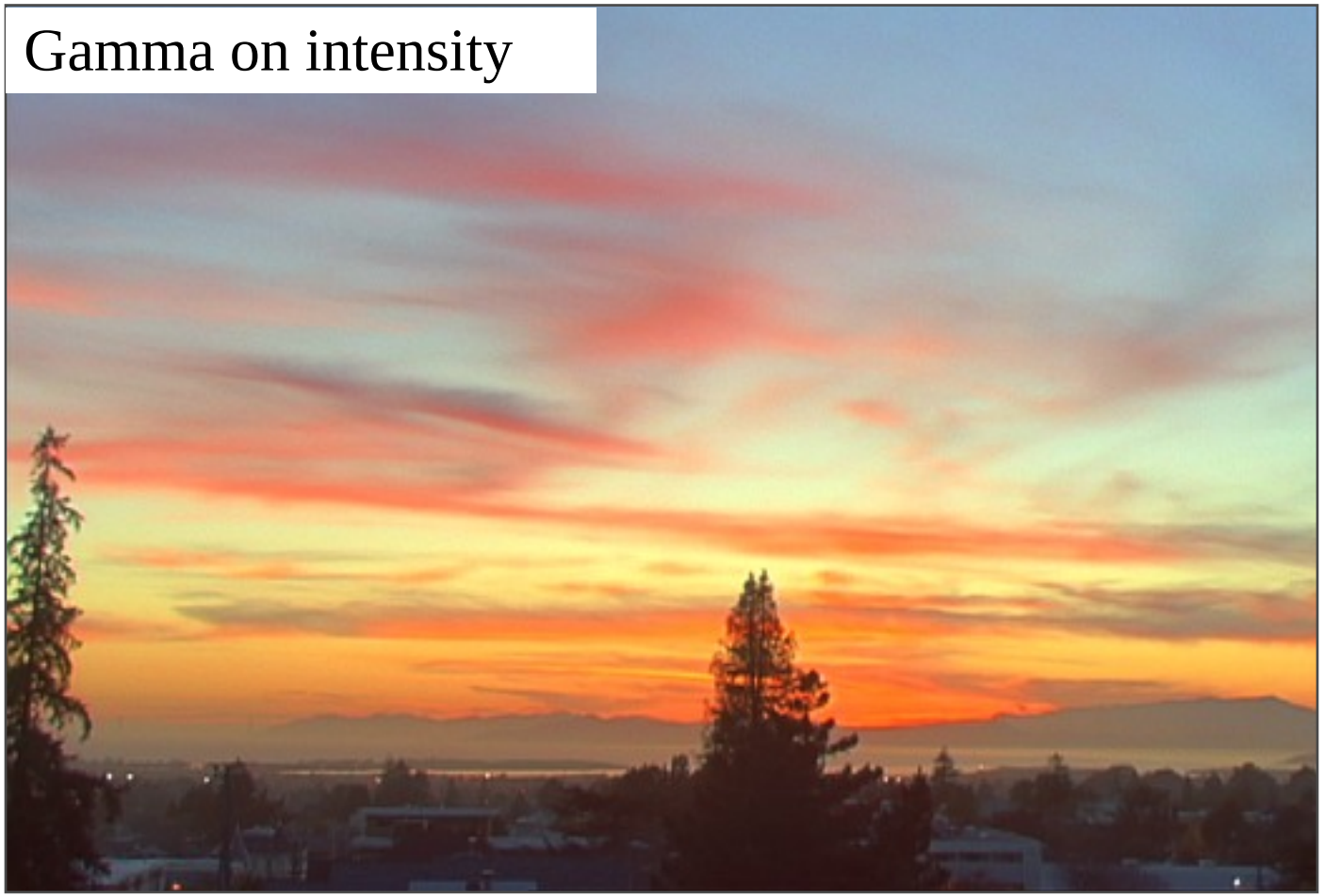
Intensity



Color

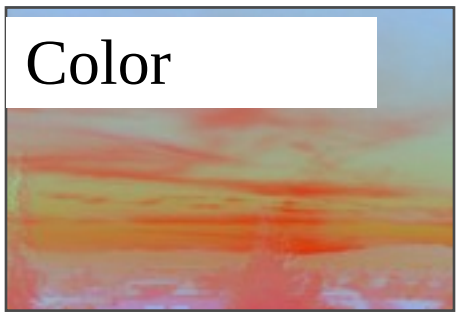


Gamma on intensity



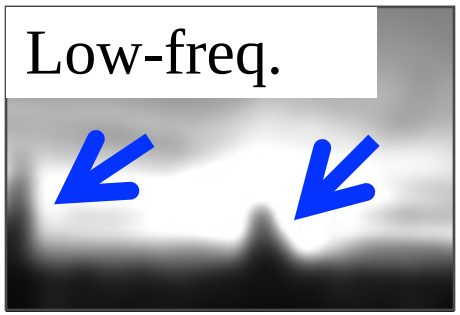
Oppenheim 1968, Chiu et al. 1993

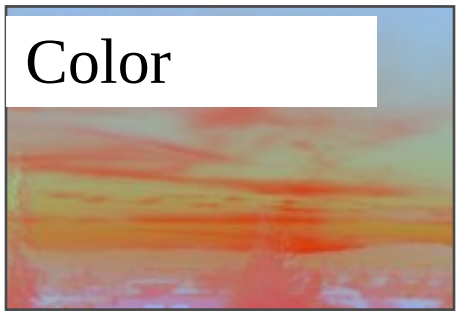
- **Reduce contrast of low-frequencies**
- **Keep high frequencies**

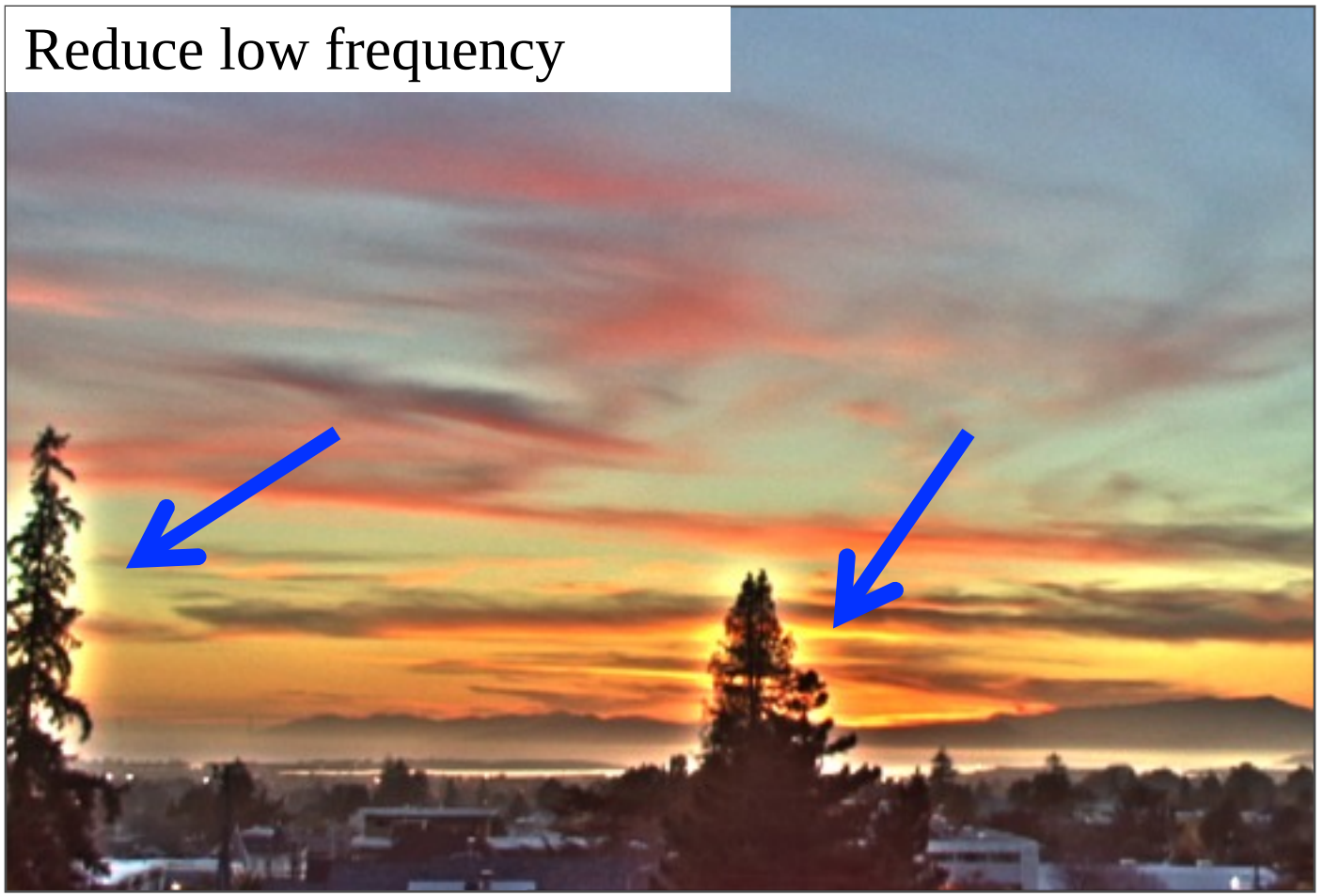


The halo nightmare

- **For strong edges**
- **Because they contain high frequency**







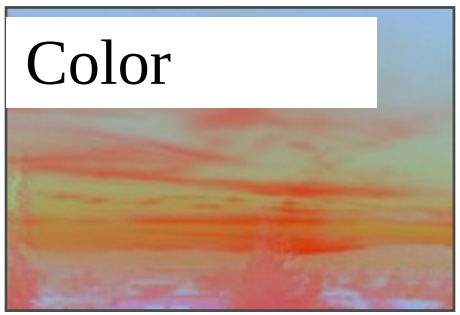
Our approach

- **Do not blur across edges**
- **Non-linear filtering**

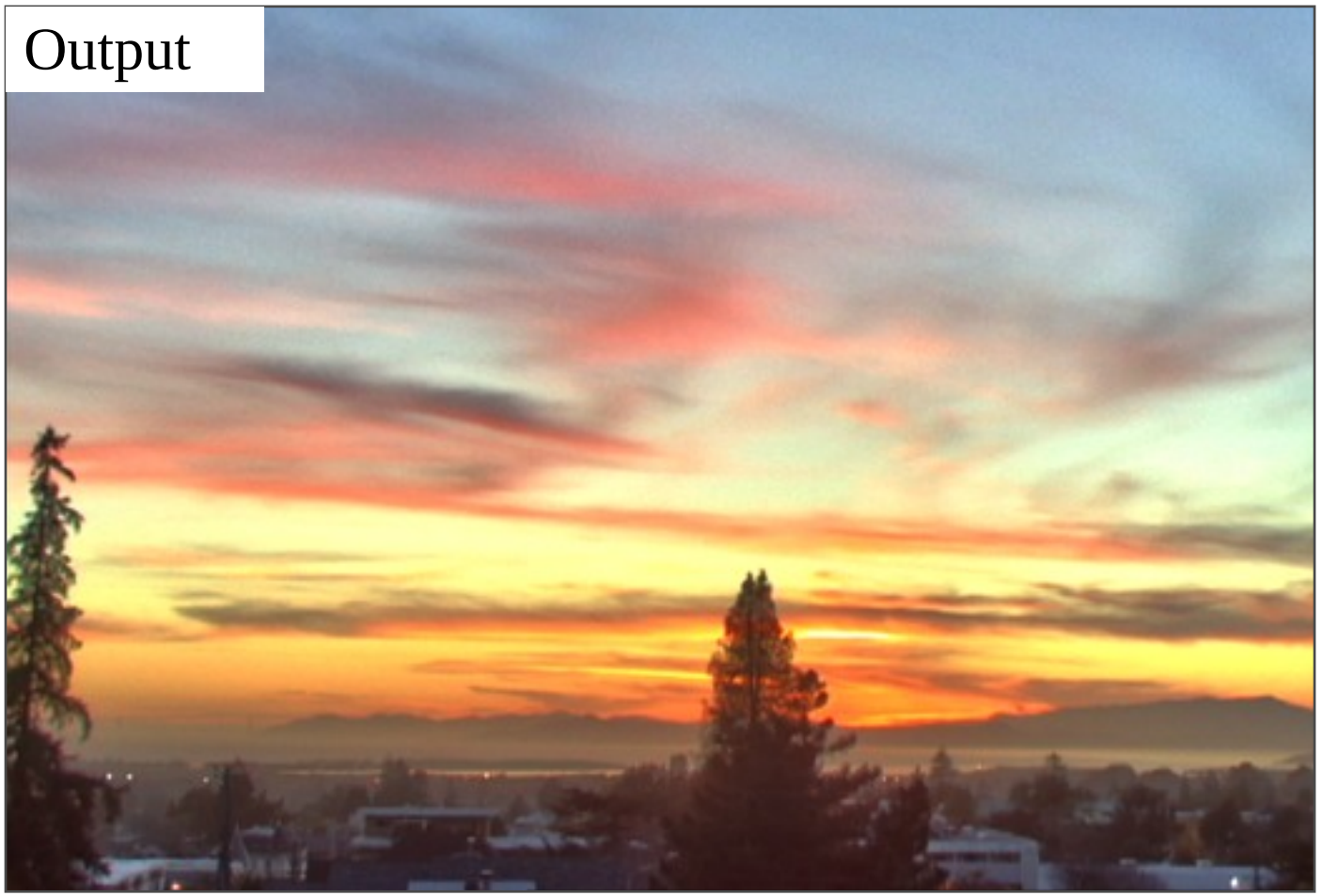
Large-scale

Detail

Color



Output



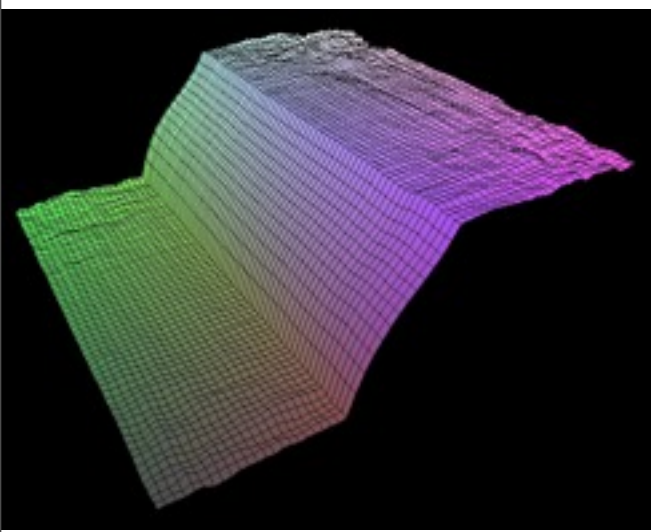
Bilateral filter

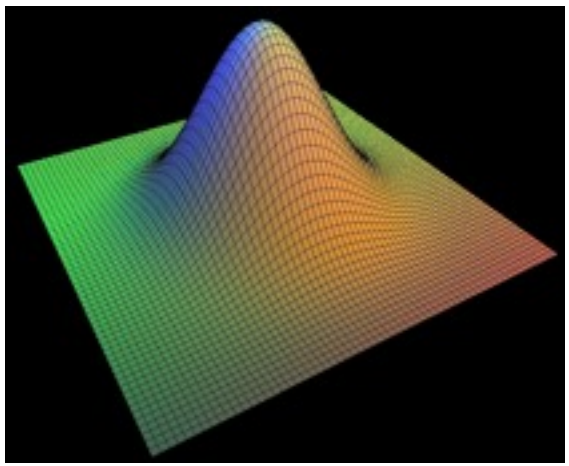
- **Tomasi and Manduci 1998]**
  - http://www.cse.ucsc.edu/~manduchi/Papers/ICCV98.pdf
- **Discussed for denoising in previous lecture**
- **Related to**
  - SUSAN filter [Smith and Brady 95] http://citeseer.ist.psu.edu/smith95susan.html
  - Digital-TV [Chan, Osher and Chen 2001] http://citeseer.ist.psu.edu/chan01digital.html
  - sigma filter http://www.geogr.ku.dk/CHIPS/Manual/f187.htm
- **Full survey: http://people.csail.mit.edu/sparis/publi/2009/fntcgv/Paris_09_Bilateral_filtering.pdf**

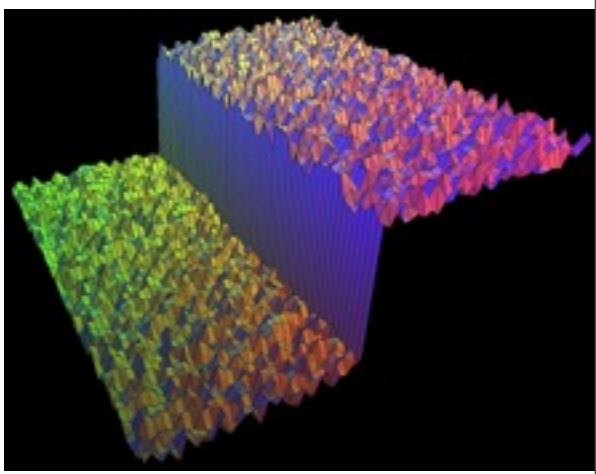
Start with Gaussian filtering

- **Here, input is a step function + noise**

$$J = f \otimes I$$





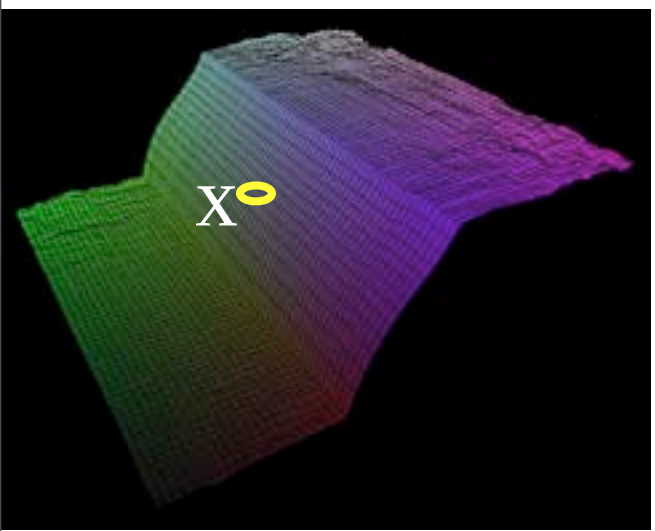


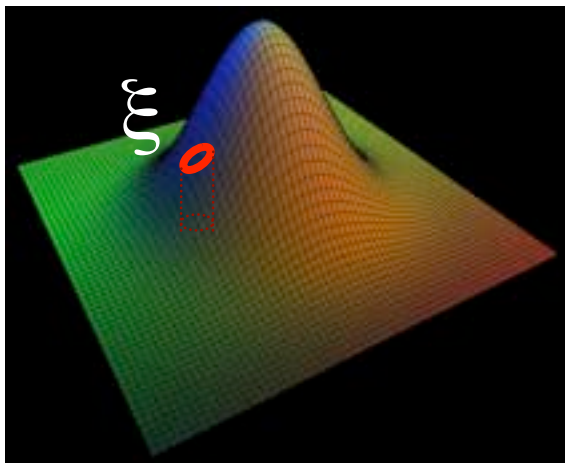
output ⟵ input

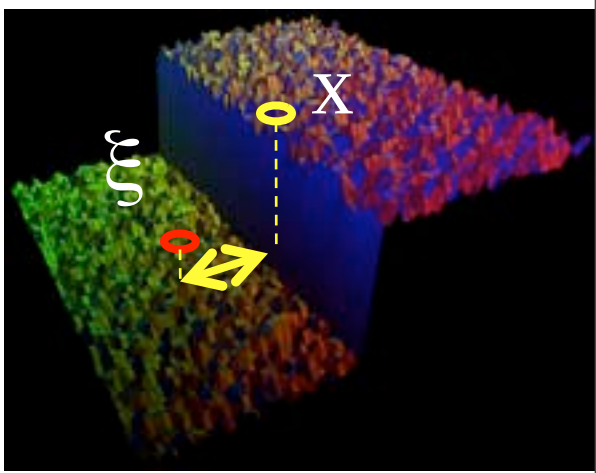
Gaussian filter as weighted average

- **Weight of ξ depends on distance to x**

$$J(x) = \sum_{\xi} f(x,\xi)\, I(\xi)$$





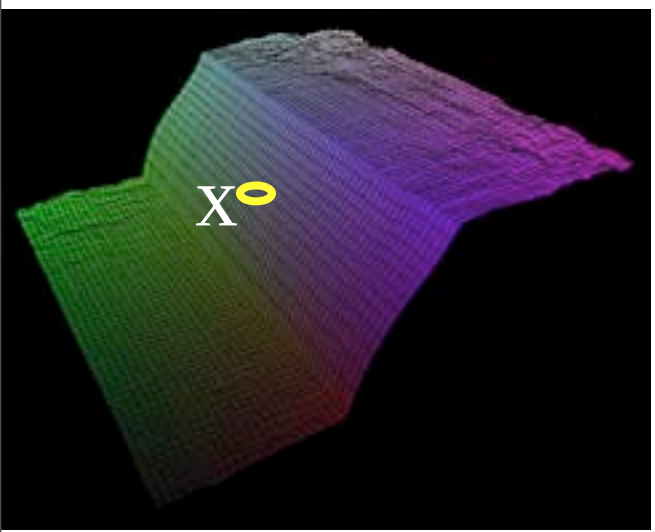


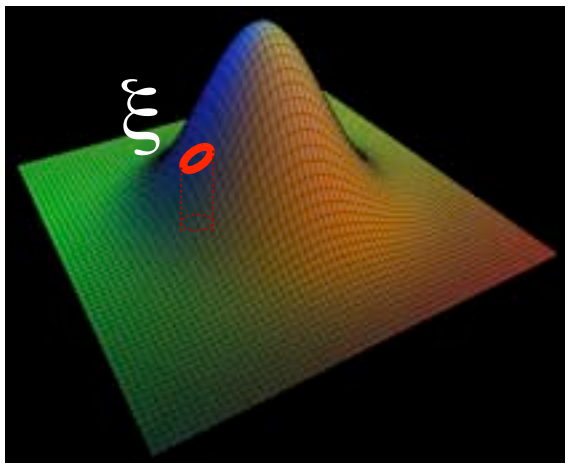
output ⟵ input

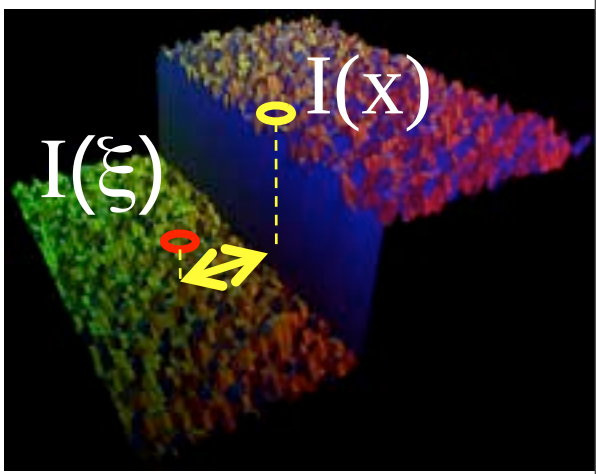
The problem of edges

- **Here, $I(\xi)$ "pollutes" our estimate J(x)**
- **It is too different**

$$J(x) = \sum_{\xi} f(x,\xi)\, I(\xi)$$







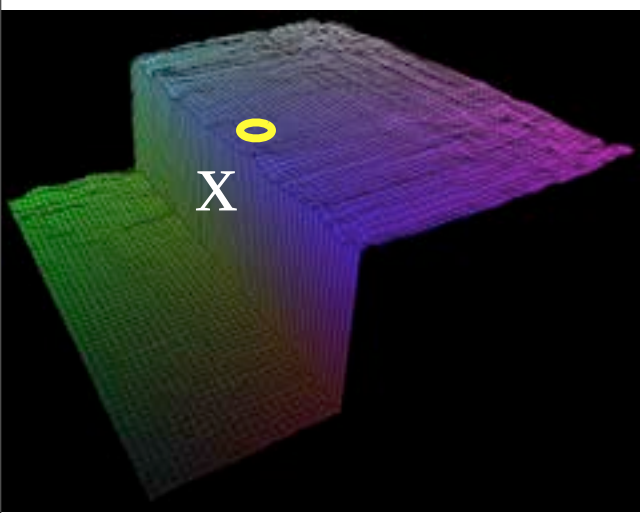
output ⟵ input

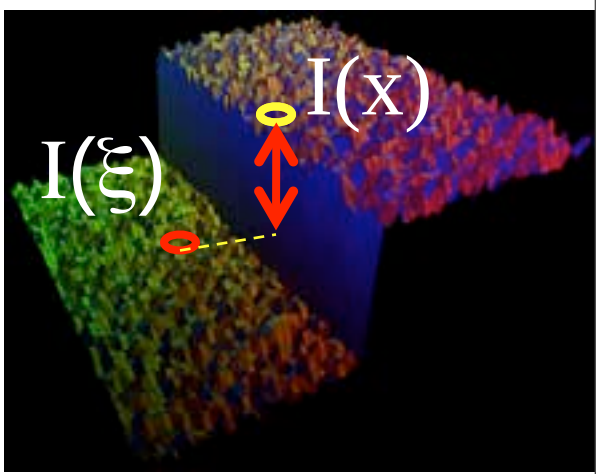
Principle of Bilateral filtering

[Tomasi and Manduchi 1998]

- **Penalty g on the intensity difference**

$$J(x) = \frac{1}{k(x)} \sum_{\xi} f(x,\xi) \quad g(I(\xi) - I(x)) \quad I(\xi)$$





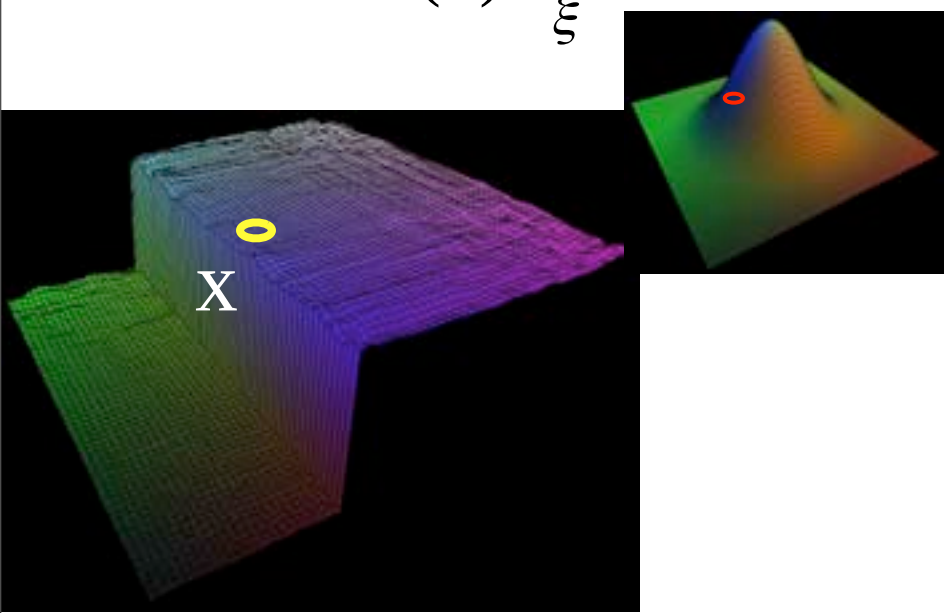
output ⟵ input

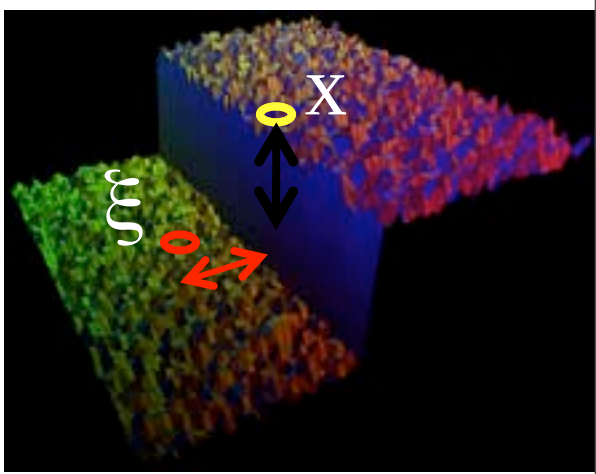
Bilateral filtering

[Tomasi and Manduchi 1998]

- **Spatial Gaussian f**

$$J(x) = \frac{1}{k(x)} \sum_{\xi} f(x,\xi) g(I(\xi) - I(x)) \quad I(\xi)$$





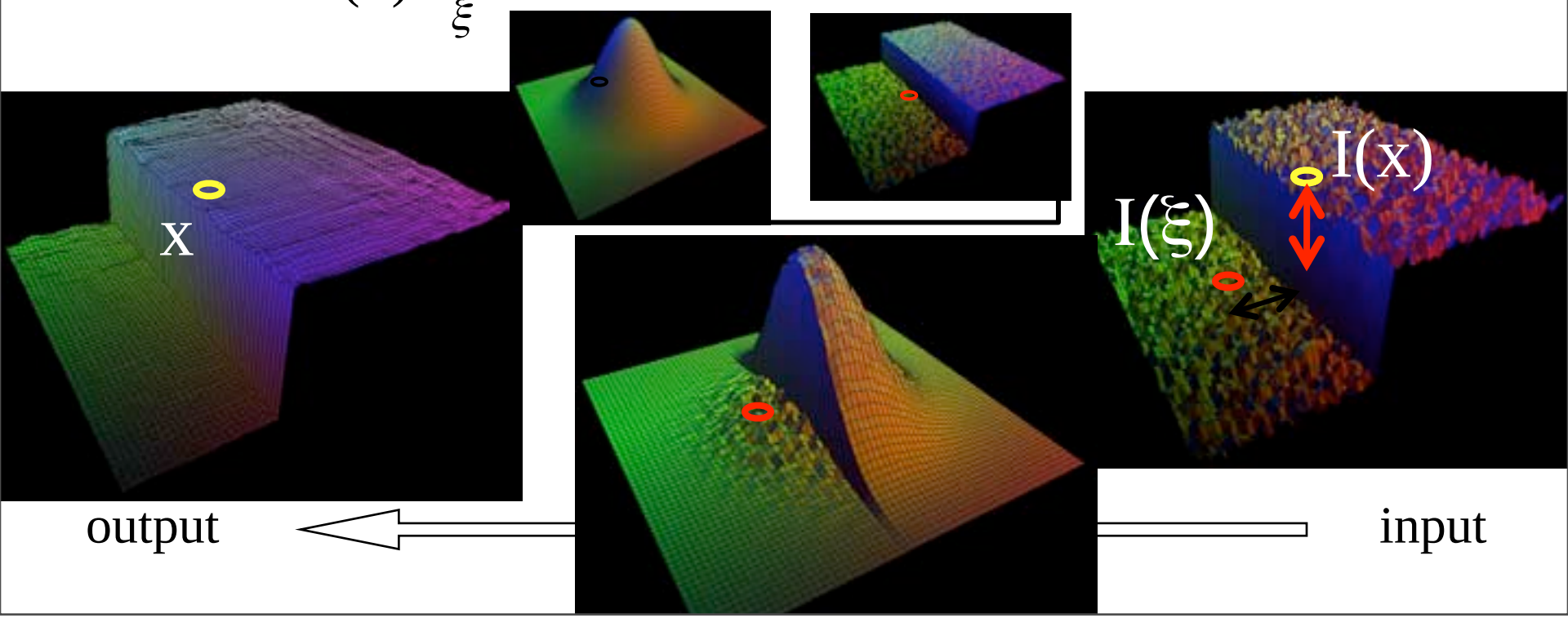
output ⟵ input

Bilateral filtering

[Tomasi and Manduchi 1998]

- **Spatial Gaussian f**
- **Gaussian g on the intensity difference**

$$J(x) = \frac{1}{k(x)} \sum_{\xi} f(x,\xi)\, g(I(\xi) - I(x))\, I(\xi)$$

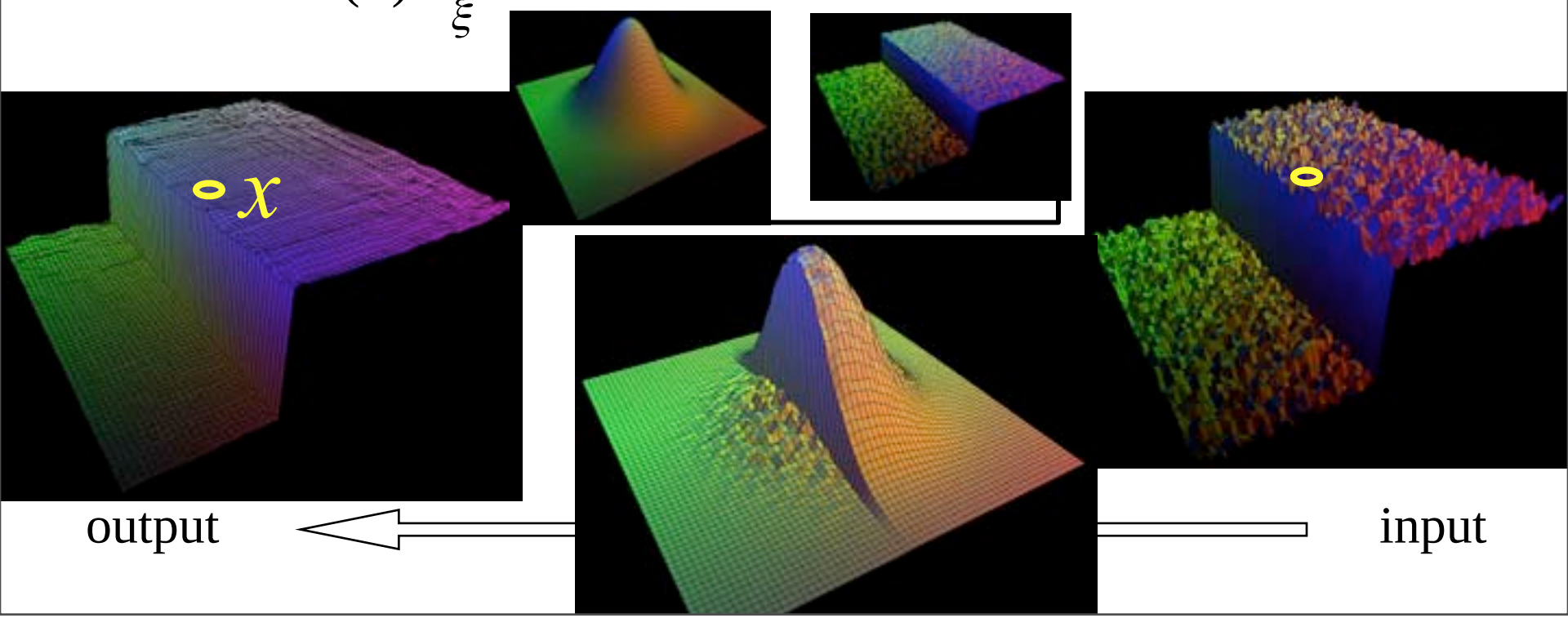


Normalization factor

[Tomasi and Manduchi 1998]

- **k(x)=** $\sum_{\xi} f(x,\xi) \quad g(I(\xi) - I(x))$

$$J(x) = \frac{1}{k(x)} \sum_{\xi} f(x,\xi) \quad g(I(\xi) - I(x)) \quad I(\xi)$$

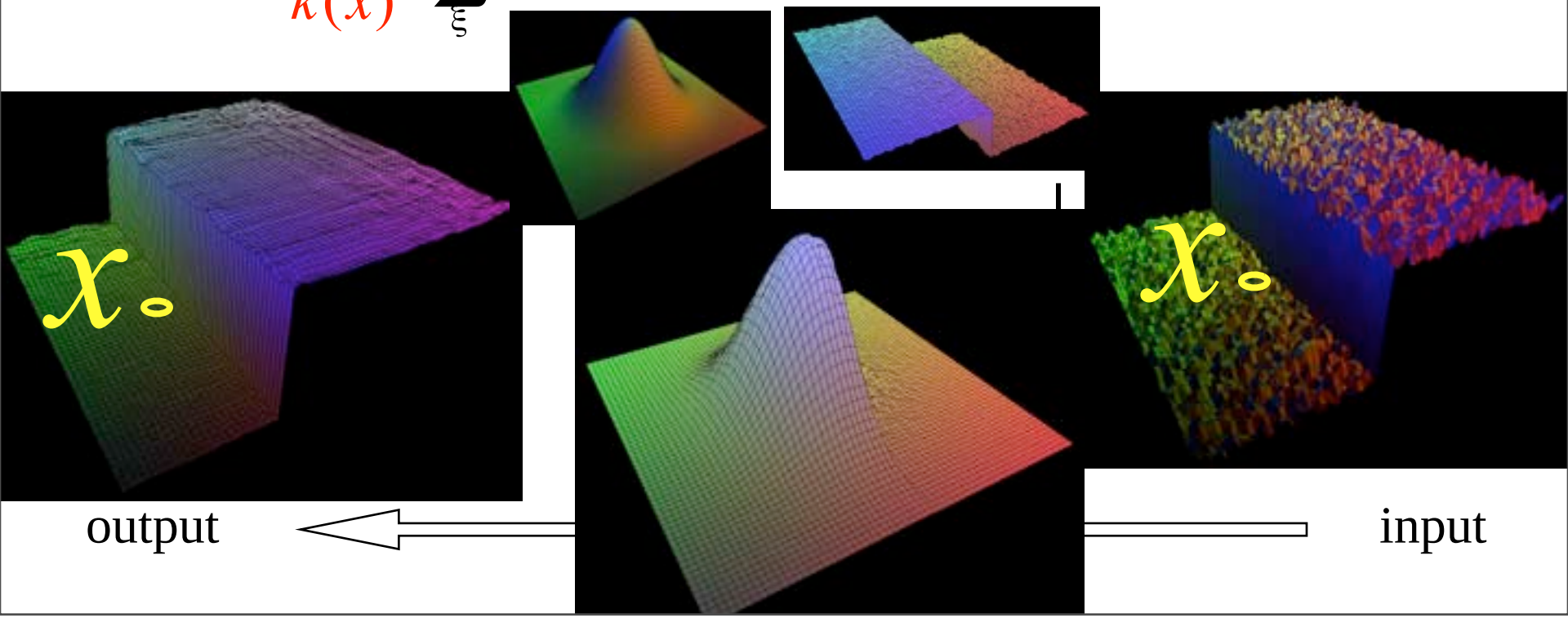


Bilateral filtering is non-linear

[Tomasi and Manduchi 1998]

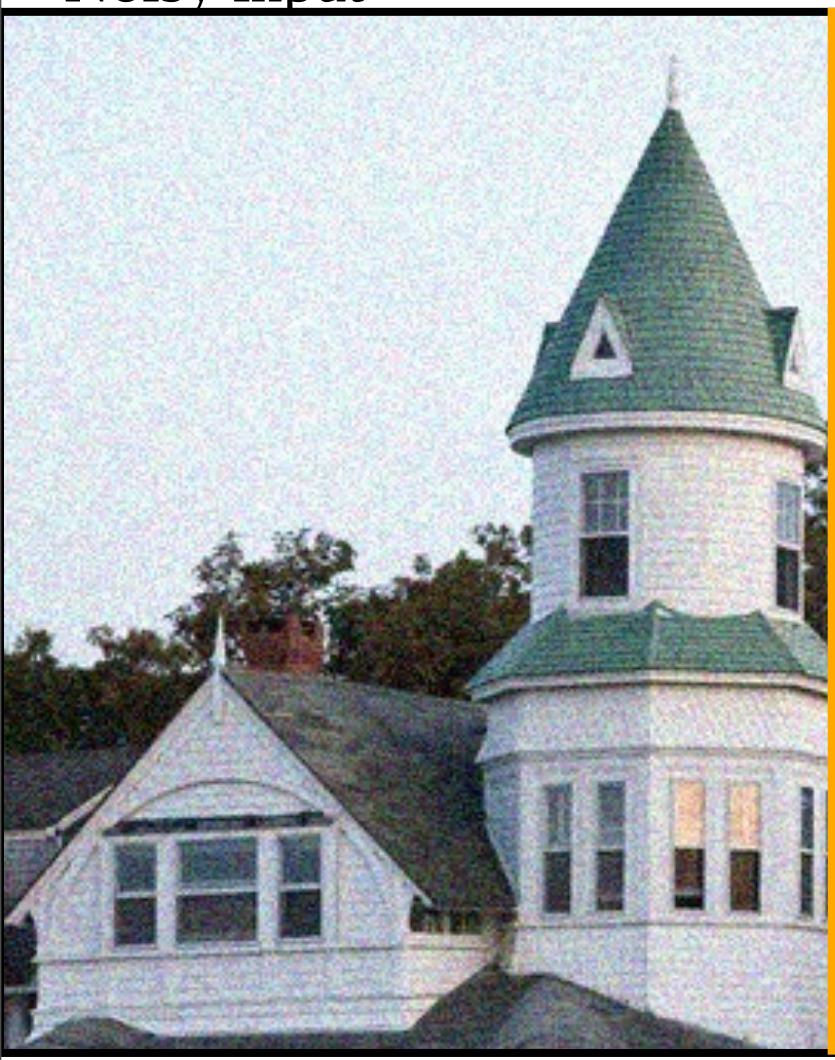
- **The weights are different for each output pixel**

$$J(x) = \frac{1}{k(x)} \sum_{\xi} f(x,\xi)\; g(I(\xi) - I(x))\; I(\xi)$$



Basic denoising

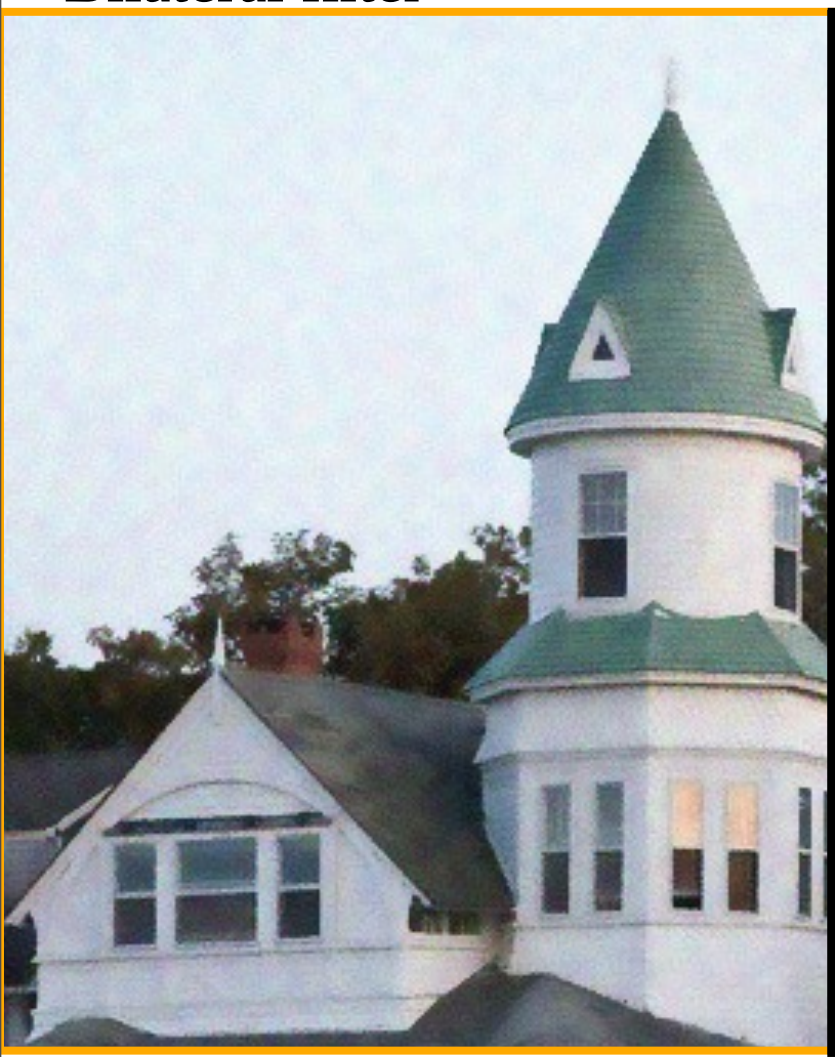
Noisy input



Bilateral filter 7x7 window

Basic denoising

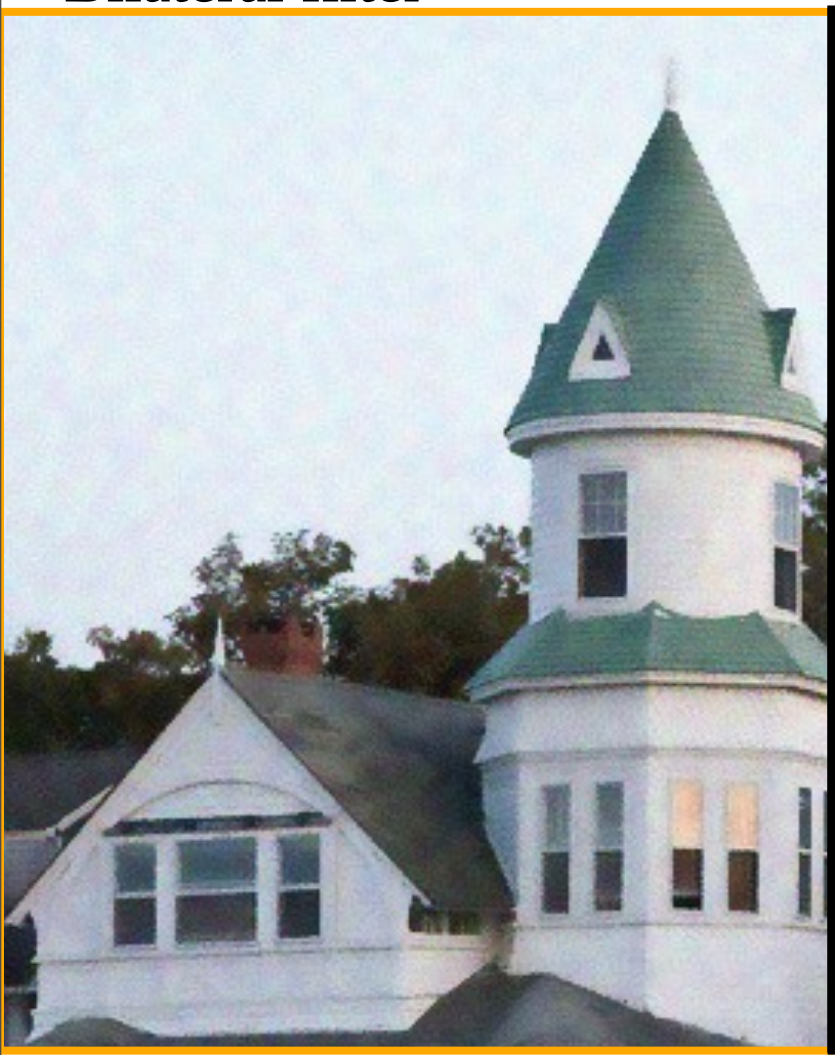
Bilateral filter



Median 3x3

Basic denoising

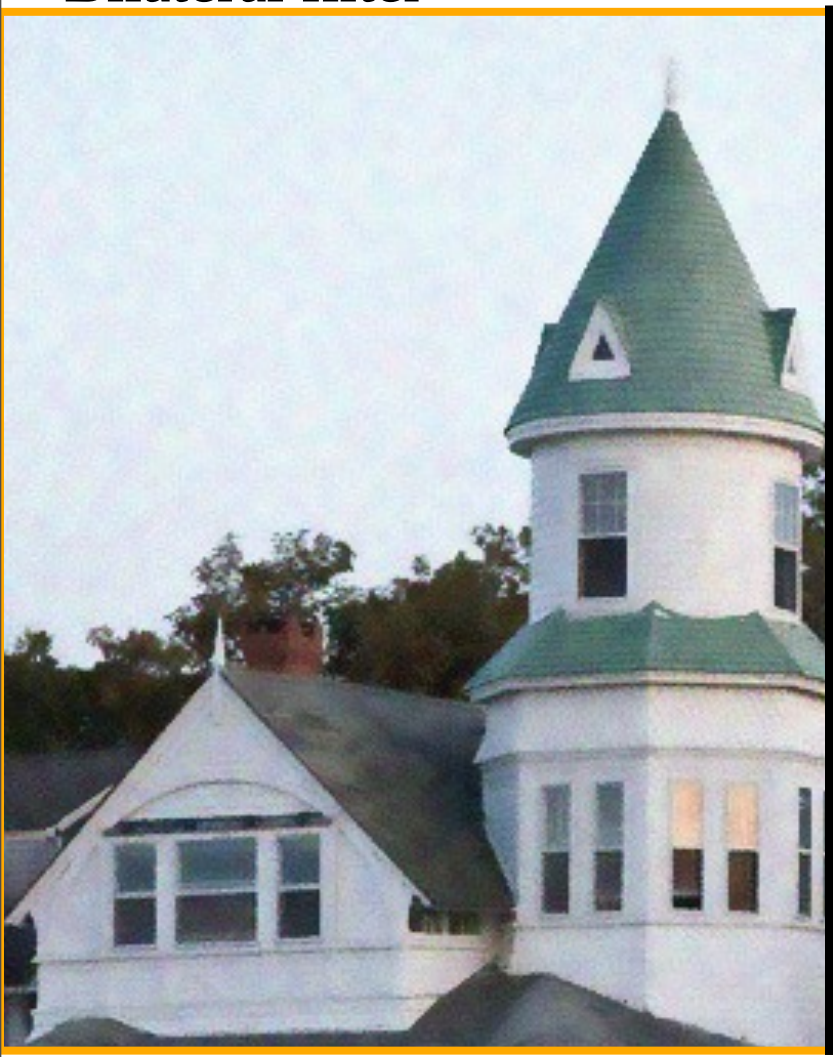
Bilateral filter



Median 5x5

Basic denoising

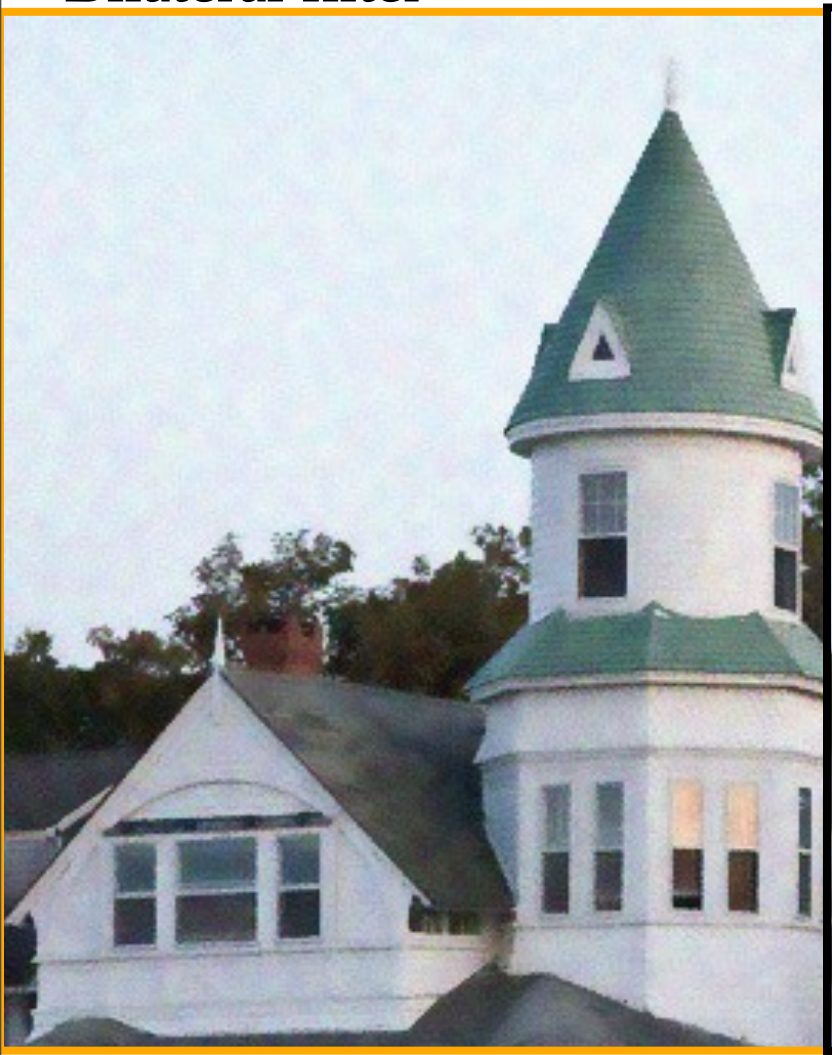
Bilateral filter



Bilateral filter – lower

Basic denoising

Bilateral filter



Bilateral filter – higher

Questions?

Questions?

Contrast reduction

Input HDR image

Contrast
too high!

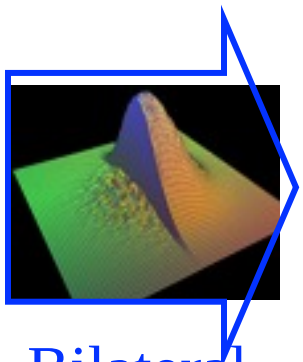
Contrast reduction

Input HDR image

Intensity

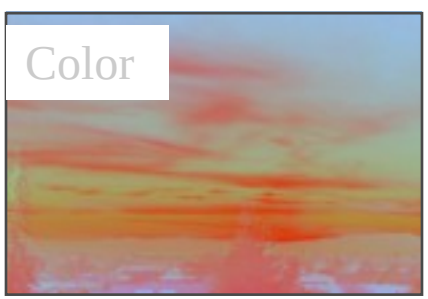
Color

Contrast reduction



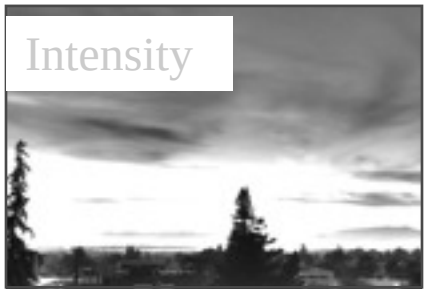
Bilateral Filter

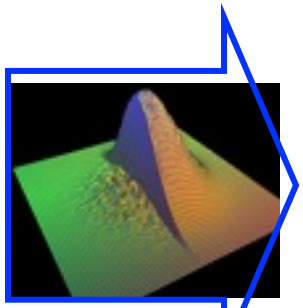
in log



Spatial sigma: 2 to 5% image size
Range sigma: 0.4 (in log 10)

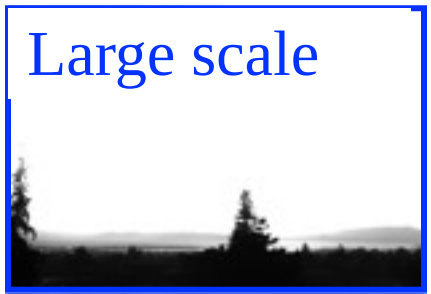
Contrast reduction

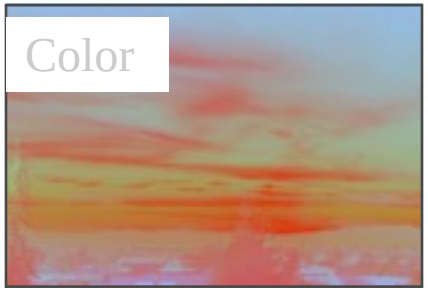




Bilateral Filter

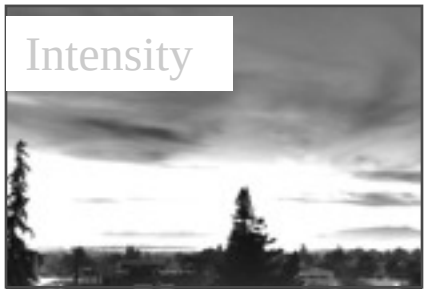
in log

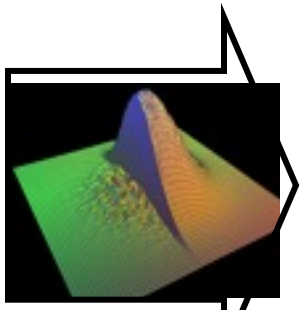




Detail = log intensity - large scale (residual)

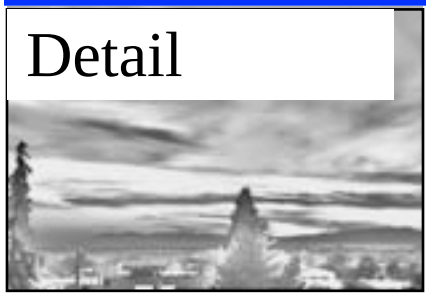
Contrast reduction



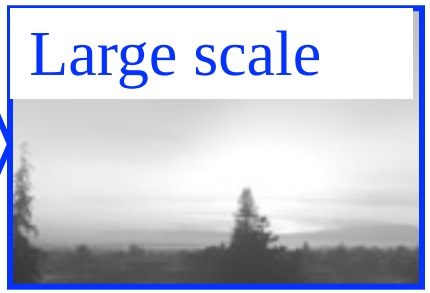


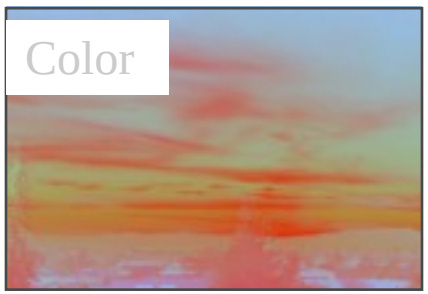
Bilateral Filter

in log

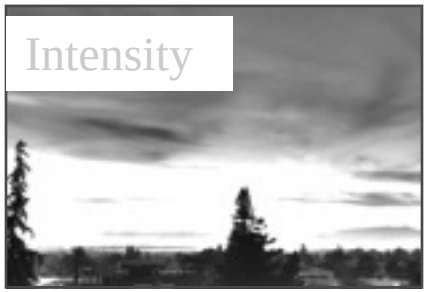


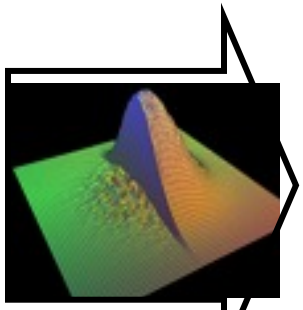
Reduce contrast





Contrast reduction

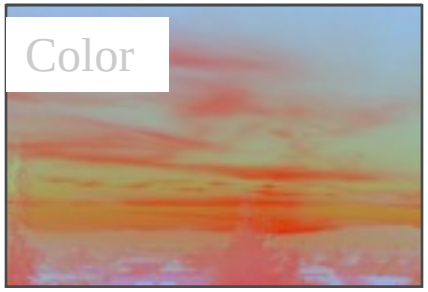




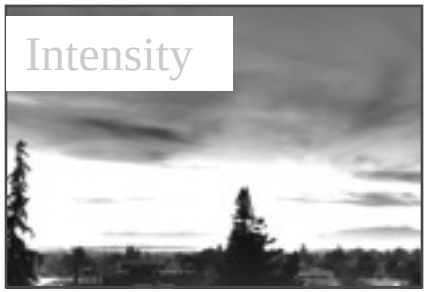
Fast Bilateral Filter

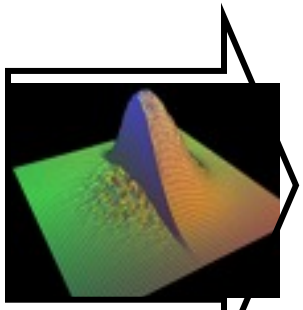
Reduce contrast

Preserve!



Contrast reduction

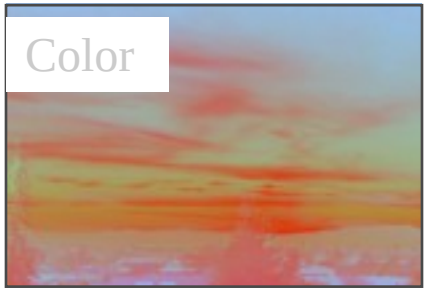


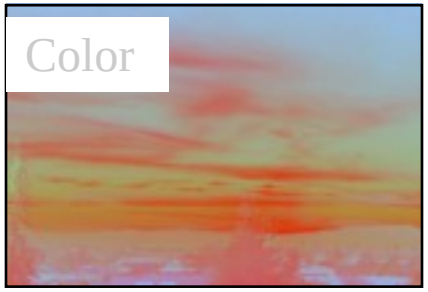


Fast Bilateral Filter

Reduce contrast

Preserve!





Reduction

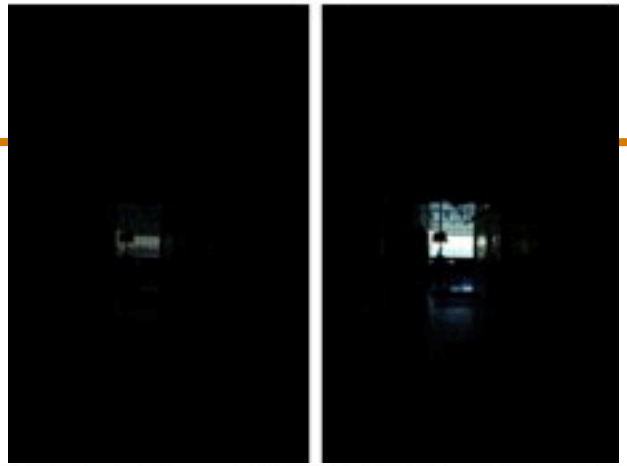
- **To reduce contrast of base layer**
  - scale in the log domain
  - ➔ γ exponent in linear space
- **Set a target range: $\log_{10}$ (5)**
- **Compute range in the base (log) layer: (max-min)**
- **Deduce γ using an elaborate operation known as *division***
- **You finally need to normalize so that the biggest value in the (linear) base is 1 (0 in log):**
  - Offset the compressed based by its max

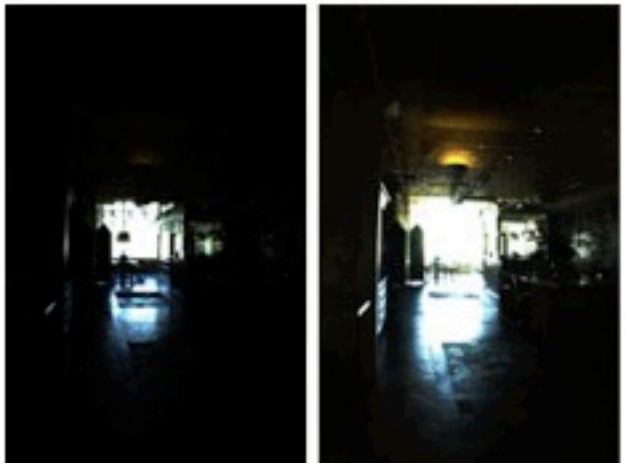
Contrast reduction in log domain

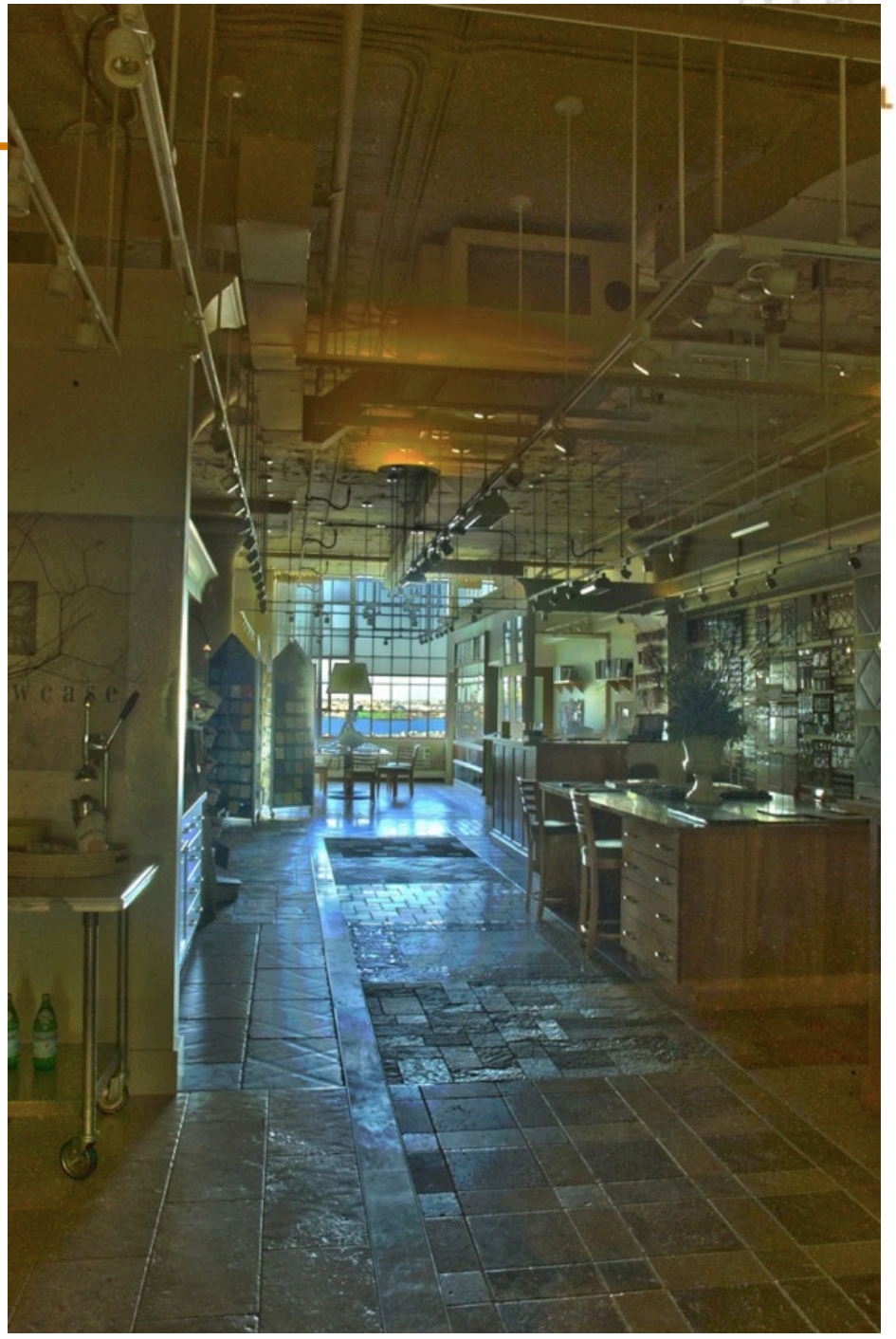
- **Set target large-scale contrast (e.g. $\log_{10}$ 10)**
  - In **linear** output, we want 1:10 contrast for large scale
- **Compute range of input large scale layer:**
  - largeRange = max(inLogLarge) – min (inLogLarge)
- **Scale factor *k*= $\log_{10}$ (10) / largeRange**
- **Normalize so that the biggest value is 0 in log**

outLog= inLogDetail +

inLogLarge * *k* – max(inLogLarge)







What matters

- **Spatial sigma: not very important**
- **Range sigma: quite important**
- **Use of the log domain for range: critical**
  - Because HDR and because perception sensitive to multiplicative contrast
  - CIELab might be better for other applications
- **Luminance computation**
  - Not critical, but has influence
  - see our Flash/no-flash paper [Eisemann 2004] for smarter function

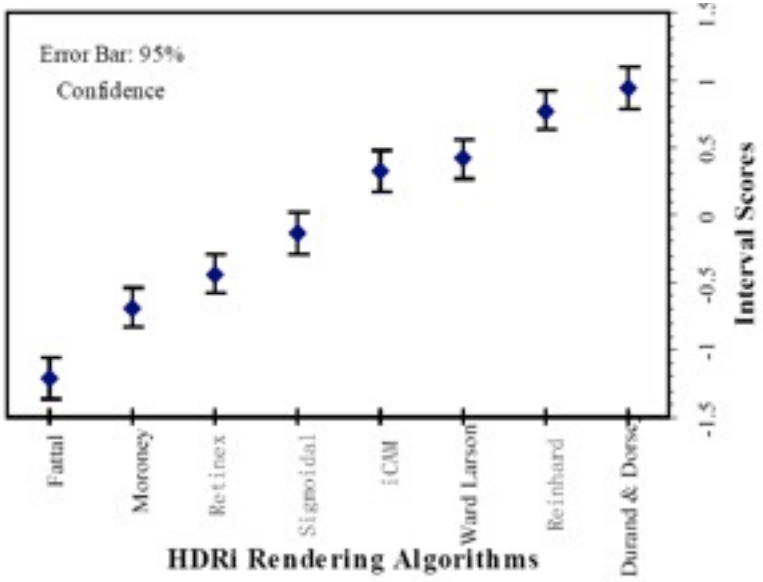
Speed

- **Direct bilateral filtering is slow (minutes)**

- **Fast algorithm: bilateral grid**
  - http://groups.csail.mit.edu/graphics/bilagrid/
  - http://people.csail.mit.edu/sparis/publi/2009/ijcv/Paris_09_Fast_Approximation.pdf
  - http://graphics.stanford.edu/papers/gkdtrees/

Tone mapping evaluation

- **User experiments to evaluate competing tone mapping**
  - Ledda et al. 2005 http://www.cs.bris.ac.uk/Publications/Papers/2000255.pdf
  - Kuang et al. 2004 http://www.cis.rit.edu/fairchild/PDFs/PRO22.pdf
- **Interestingly, the former concludes bilateral is the worst, the latter that it is the best!**
  - They choose to test a different criterion: fidelity vs. preference
- **More importantly, they focus on algorithm and ignore parameters**



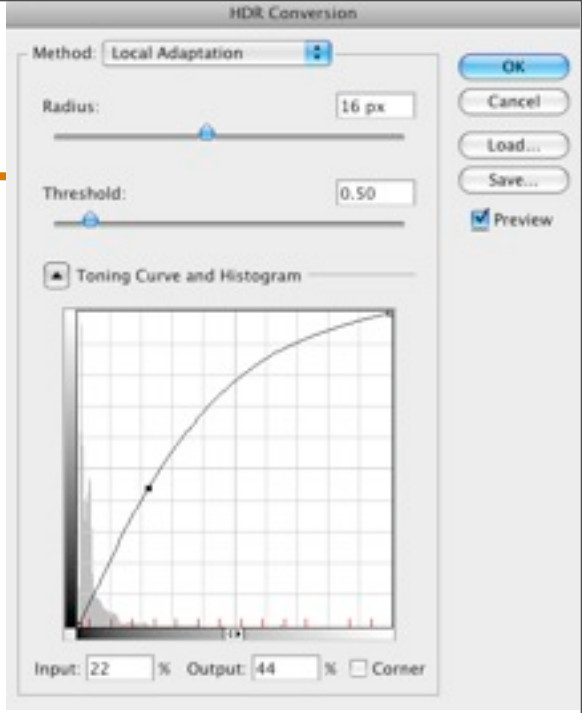
From Kuang et al.

	1st	2nd	3rd	4th	5th	6th
Scene 1	P	B	A	H	I	L
Scene 2	I	P	H	A	B	L
Scene 3	P	I	A	H	L	B
Scene 4	P	L	I	A	H	B
Scene 5	I	H	A	P	L	B
Scene 6	I	H	A	P	L	B
Scene 7	I	A	P	H	B	L
Scene 8	I	P	A	H	L	B
Scene 9	P	A	L	H	B	I

Adapted from Ledda et al.

Related tools

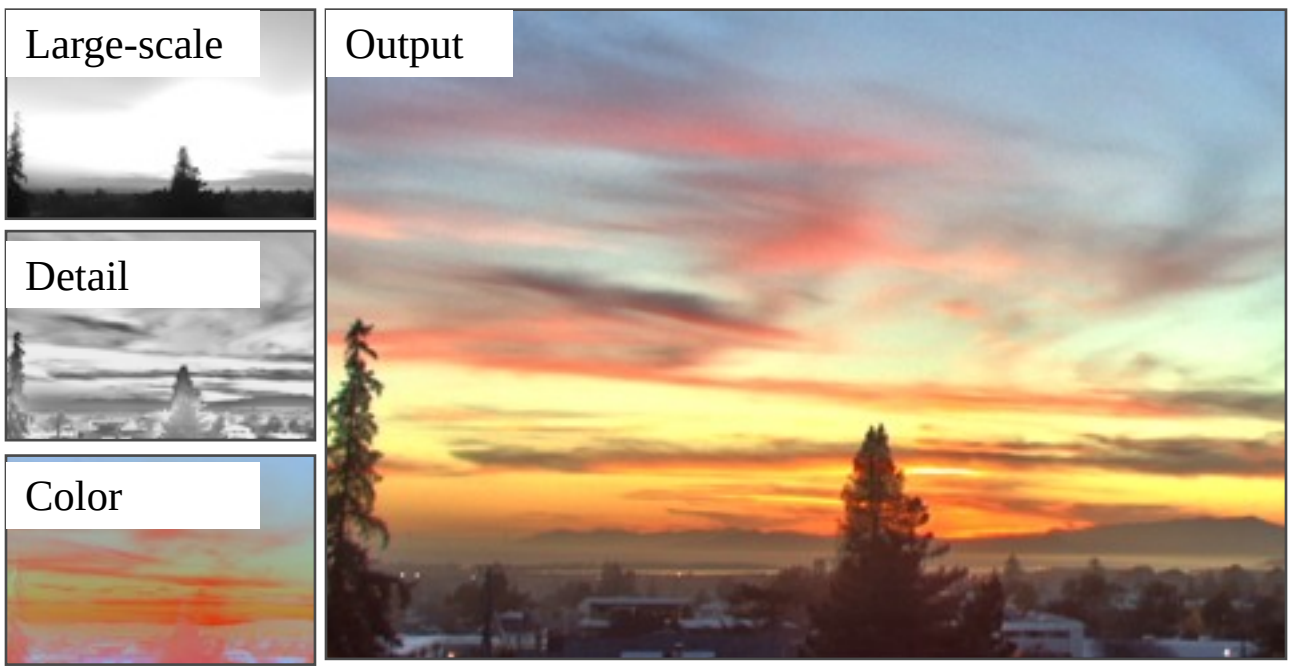
- **Photoshop “Local adaptation”**
- **Lightroom Fill Light**
- **Lightzone Relight**



Questions?

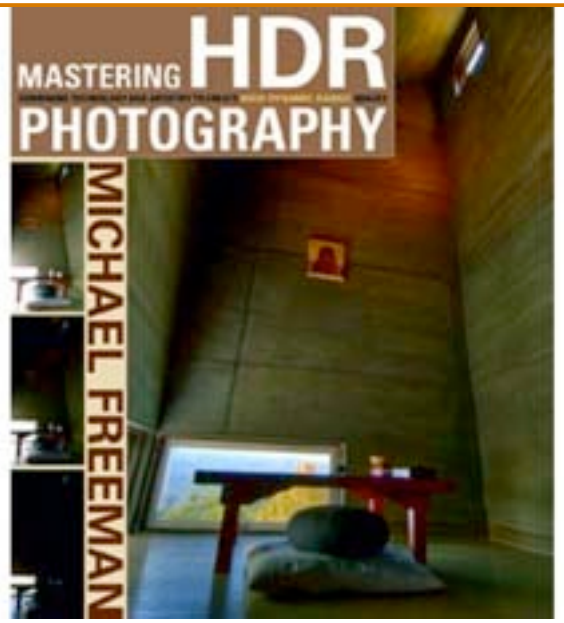
What have we learnt?

- **Log is good**
- **Luminance is different from chrominance**
- **Separate components:**
  - Low and high frequencies
- **Strong edges are important**

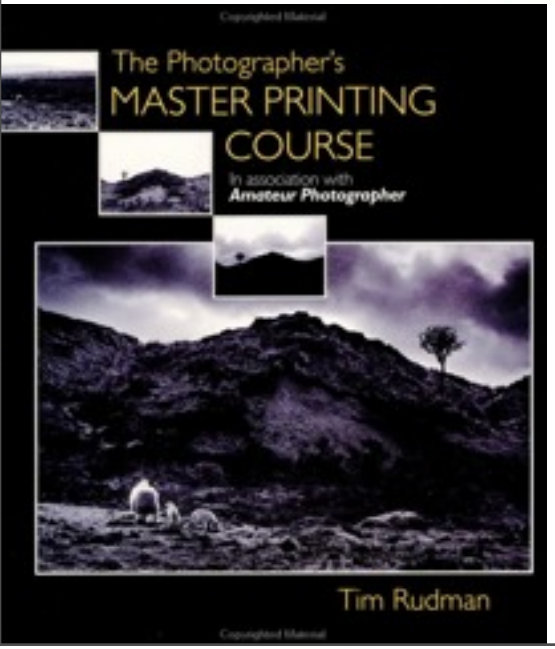


References


HIGH DYNAMIC
RANGE IMAGING
ACQUISITION, DISPLAY AND IMAGE-BASED LIGHTING


MASTERING HDR
PHOTOGRAPHY
MICHAEL FREEMAN


Bernd Hoefflinger
Editor
High-Dynamic-Range
(HDR) Vision
Springer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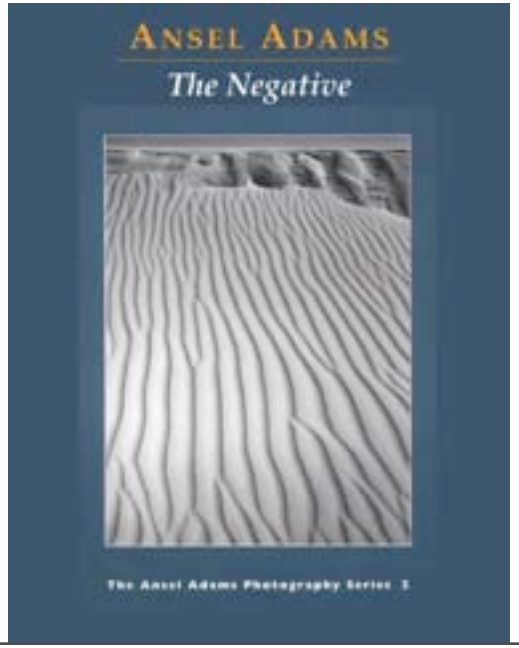
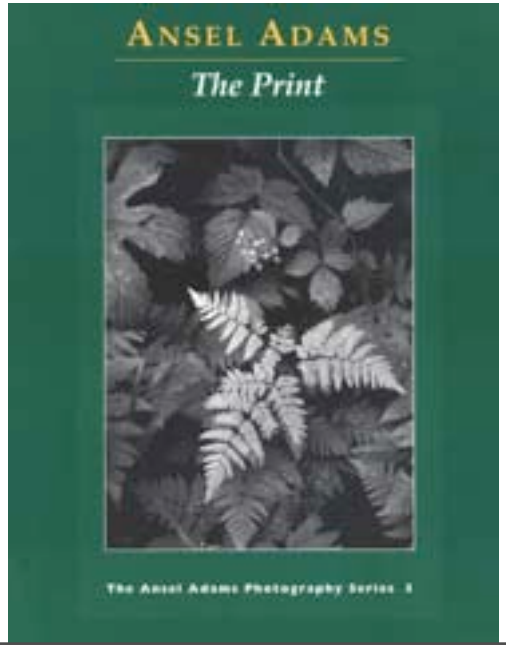
COURSE
In association with
Amateur Photographer
Tim Rudman


ANSEL ADAMS
The Negative


ANSEL ADAMS
The Print

Other tone mapping references

- **J. DiCarlo and B. Wandell, Rendering High Dynamic Range Images** http://www-isl.stanford.edu/%7Eabbas/group/papers_and_pub/spie00_jeff.pdf
- **Choudhury, P., Tumblin, J., "The Trilateral Filter for High Contrast Images and Meshes". http://www.cs.northwestern.edu/~jet/publications.html**
- **Tumblin, J., Turk, G., "Low Curvature Image Simplifiers (LCIS): A Boundary Hierarchy for Detail-Preserving Contrast Reduction." http://www.cs.northwestern.edu/~jet/publications.html**
- **Tumblin, J., "Three Methods For Detail-Preserving Contrast Reduction For Displayed Images" http://www.cs.northwestern.edu/~jet/publications.html**
- **Photographic Tone Reproduction for Digital Images Erik Reinhard, Mike Stark, Peter Shirley and Jim Ferwerda http://www.cs.utah.edu/%7Ereinhard/cdrom/**
- **Ashikhmin, M. ``A Tone Mapping Algorithm for High Contrast Images'' http://www.cs.sunysb.edu/~ash/tm.pdf**
- **Retinex at Nasa http://dragon.larc.nasa.gov/retinex/background/retpubs.html**
- **Gradient Domain High Dynamic Range Compression Raanan Fattal, Dani Lischinski, Michael Werman http://www.cs.huji.ac.il/~danix/hdr/**
- **Li et al. : Wavelets and activity maps http://web.mit.edu/yzli/www/hdr_companding.htm**

Tone mapping code

- http://www.mpi-sb.mpg.de/resources/pfstools/
- http://scanline.ca/exrtools/
- http://www.cs.utah.edu/~reinhard/cdrom/source.html
- http://www.cis.rit.edu/mcsl/icam/hdr/

Refs

http://people.csail.mit.edu/sparis/bf_course/

http://people.csail.mit.edu/fredo/PUBLI/Siggraph2002/

http://www.hdrsoft.com/resources/dri.html

http://www.clarkvision.com/imagedetail/dynamicrange2/

http://www.debevec.org/HDRI2004/

http://www.luminous-landscape.com/tutorials/hdr.shtml

http://www.anyhere.com/gward/hdrenc/

http://www.debevec.org/IBL2001/NOTES/42-gward-cic98.pdf

http://www.openexr.com/

http://gl.ict.usc.edu/HDRShop/

http://www.dpreview.com/learn/?/Glossary/Digital_Imaging/Dynamic_Range_01.htm

http://www.normankoren.com/digital_tonality.html

http://www.anyhere.com/

http://www.cybergrain.com/tech/hdr/

Available in HDRShop

Slide from Siggraph 2005 course on HDR

HDR combination papers

- **Steve Mann http://genesis.eecg.toronto.edu/wyckoff/index.html**
- **Paul Debevec http://www.debevec.org/Research/HDR/**
- **Mitsunaga, Nayar , Grossberg http://www1.cs.columbia.edu/CAVE/projects/rad_cal/rad_cal.php**

Questions?

Smarter HDR capture

Ward, Journal of Graphics Tools, 2003

http://www.anyhere.com/gward/papers/jgtpap2.pdf

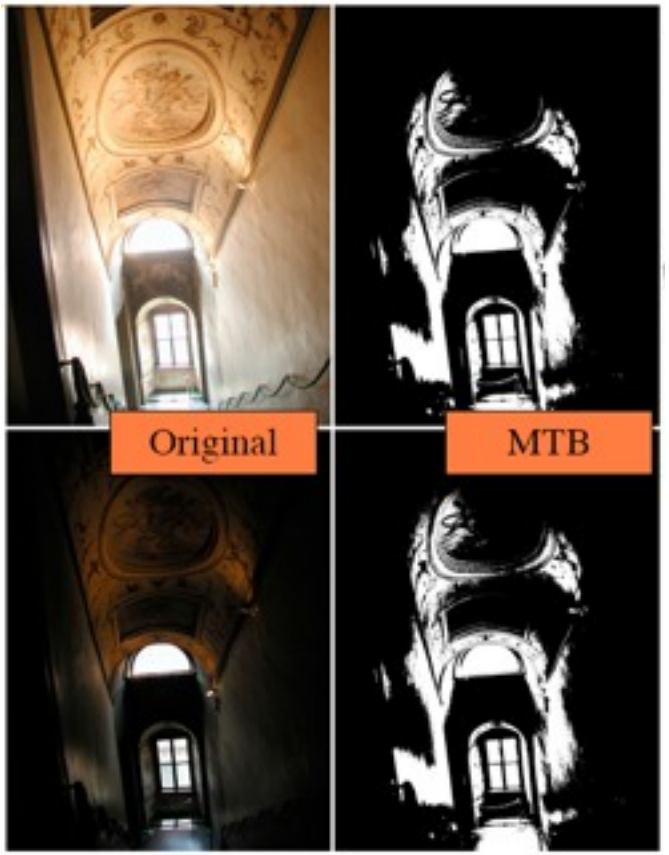
Implemented in Photosphere http://www.anyhere.com/

- **Image registration (no need for tripod)**
- **Lens flare removal**
- **Ghost removal**

Images Greg Ward

Image registration

- **How to robustly compare images of different exposure?**
- **Use a black and white version of the image thresholded at the median**
  - Median-Threshold Bitmap (MTB)
- **Find the translation that minimizes difference**
- **Accelerate using pyramid**



Alignment Results

5 unaligned exposures | Close-up detail | MTB alignment

Time: About .2 second/exposure for 3 MPixel image

Slide from Siggraph 2005 course on HDR

Automatic “Ghost” Removal

SIGGRAPH2005

Before

After

Slide from Siggraph 2005 course on HDR

Variance-based Detection

Slide from Siggraph 2005 course on HDR

Region Masking

Slide from Siggraph 2005 course on HDR

Best Exposure in Each Region

SIGGRAPH2005

Slide from Siggraph 2005 course on HDR

Lens Flare Removal

SIGGRAPH2005

Before

After

Slide from Siggraph 2005 course on HDR

Extension: HDR video

- **Kang et al. Siggraph 2003 http://portal.acm.org/citation.cfm?id=882262.882270**

Figure 1: High dynamic range video of a driving scene. *Top row: Input video with alternating short and long exposures. Bottom row: High dynamic range video (tonemapped).*

Extension: HDR video

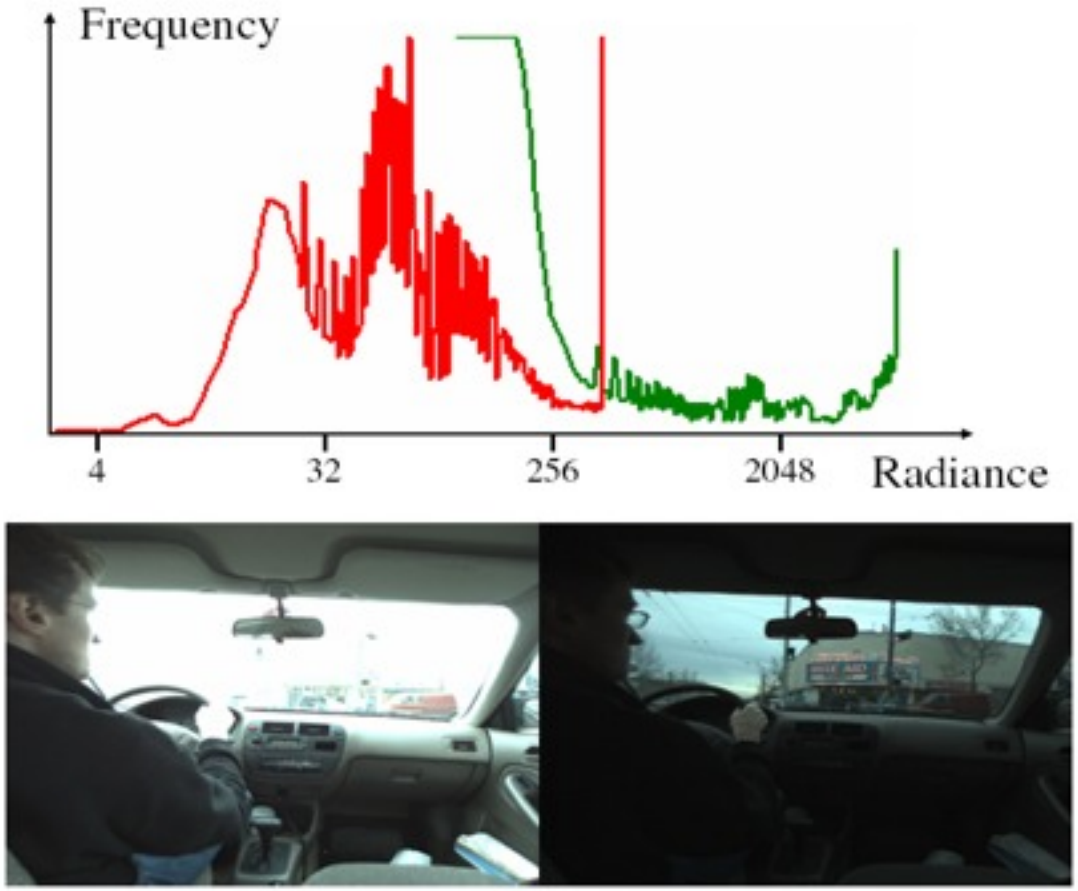


Figure 3: Two input exposures from the driving video. *The radiance histogram is shown on top. The red graph goes with the long exposure frame (bottom left), while the green graph goes with the short exposure frame (bottom right). Notice that the combination of these graphs spans a radiance range greater than a single exposure can capture.*

Questions?

HDR encoding

- **Most formats are lossless**
- **Adobe DNG (digital negative)**
  - Specific for RAW files, avoid proprietary formats
- **RGBE**
  - 24 bits/pixels as usual, plus 8 bit of common exponent
  - Introduced by Greg Ward for Radiance (light simulation)
  - Enormous dynamic range
- **OpenEXR**
  - By Industrial Light + Magic, also standard in graphics hardware
  - 16bit per channel (48 bits per pixel) 10 mantissa, sign, 5 exponent
  - Fine quantization (because 10 bit mantissa), only 9.6 orders of magnitude
- **JPEG 2000**
  - Has a 16 bit mode, lossy

HDR formats

- **Summary of all HDR encoding formats (Greg Ward): http://www.anyhere.com/gward/hdrenc/hdr_encodings.html**
- **Greg's notes: http://www.anyhere.com/gward/pickup/CIC13course.pdf**
- **http://www.openexr.com/**
- **High Dynamic Range Video Encoding**

(MPI) http://www.mpi-sb.mpg.de/resources/hdrvideo/

HDR code

- **HDRShop http://gl.ict.usc.edu/HDRShop/ (v1 is free)**
- **Columbia's camera calibration and HDR combination with source code Mitsunaga, Nayar , Grossberg http://www1.cs.columbia.edu/CAVE/projects/rad_cal/rad_cal.php**
- **Greg Ward Phososphere HDR browser and image combination with regsitration (Macintosh, command-line version under Linux) with source code http://www.anyhere.com/**
- **Photoshop CS2**
- **Idruna http://www.idruna.com/photogenicshdr.html**
- **MPI PFScalibration (includes source code) http://www.mpii.mpg.de/resources/hdr/calibration/pfs.html**
- **EXR tools http://scanline.ca/exrtools/**
- **HDR Image Editor http://www.acm.uiuc.edu/siggraph/HDRIE/**
- **CinePaint http://www.cinepaint.org/**
- **Photomatix http://www.hdrsoft.com/**
- **EasyHDR http://www.astro.leszno.net/easyHDR.php**
- **Artizen HDR http://www.supportingcomputers.net/Applications/Artizen/Artizen.htm**
- ***Automated High Dynamic Range Imaging Software & Images*** **http://www2.cs.uh.edu/~somalley/hdri_images.html**
- **Optipix http://www.imaging-resource.com/SOFT/OPT/OPT.HTM**

HDR images

- http://www.debevec.org/Research/HDR/
- http://www.mpi-sb.mpg.de/resources/hdr/gallery.html
- http://people.csail.mit.edu/fredo/PUBLI/Siggraph2002/
- http://www.openexr.com/samples.html
- http://www.flickr.com/groups/hdr/
- http://www2.cs.uh.edu/~somalley/hdri_images.html#hdr_others
- http://www.anyhere.com/gward/hdrenc/pages/originals.html
- http://www.cis.rit.edu/mcsl/icam/hdr/rit_hdr/
- http://www.cs.utah.edu/%7Ereinhard/cdrom/hdr.html
- http://www.sachform.de/download_EN.html
- http://lcavwww.epfl.ch/%7Elmeylan/HdrImages/February06/February06.html
- **http://lcavwww.epfl.ch/%7Elmeylan/HdrImages/April04/april04.html**
- **http://books.elsevier.com/companions/0125852630/hdri/html/images.html**

HDR photography

- **http://luminous-landscape.com/essays/hdr-plea.shtml**
- **http://en.wikipedia.org/wiki/High_dynamic_range_imaging**
- **http://www.cambridgeincolour.com/tutorials/high-dynamic-range.htm**
- **http://www.luminous-landscape.com/tutorials/hdr.shtml**
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