6.815 Digital and Computational Photography
6.865 Advanced Computational Photography

HDR imaging and the Bilateral Filter

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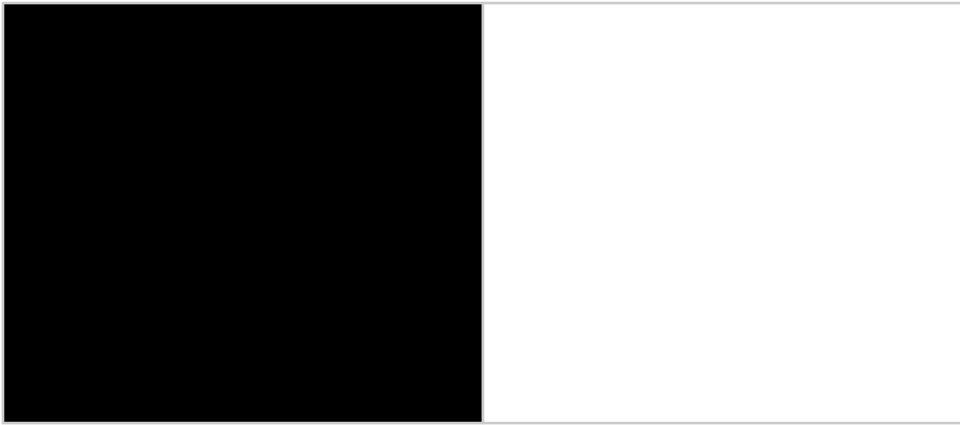
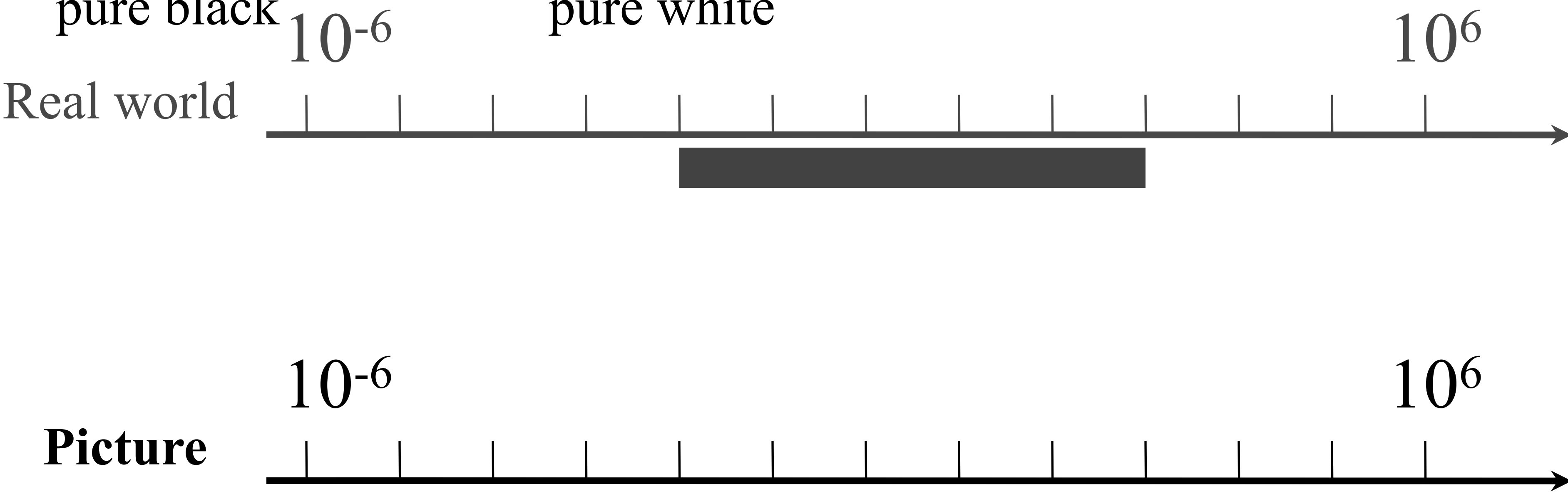
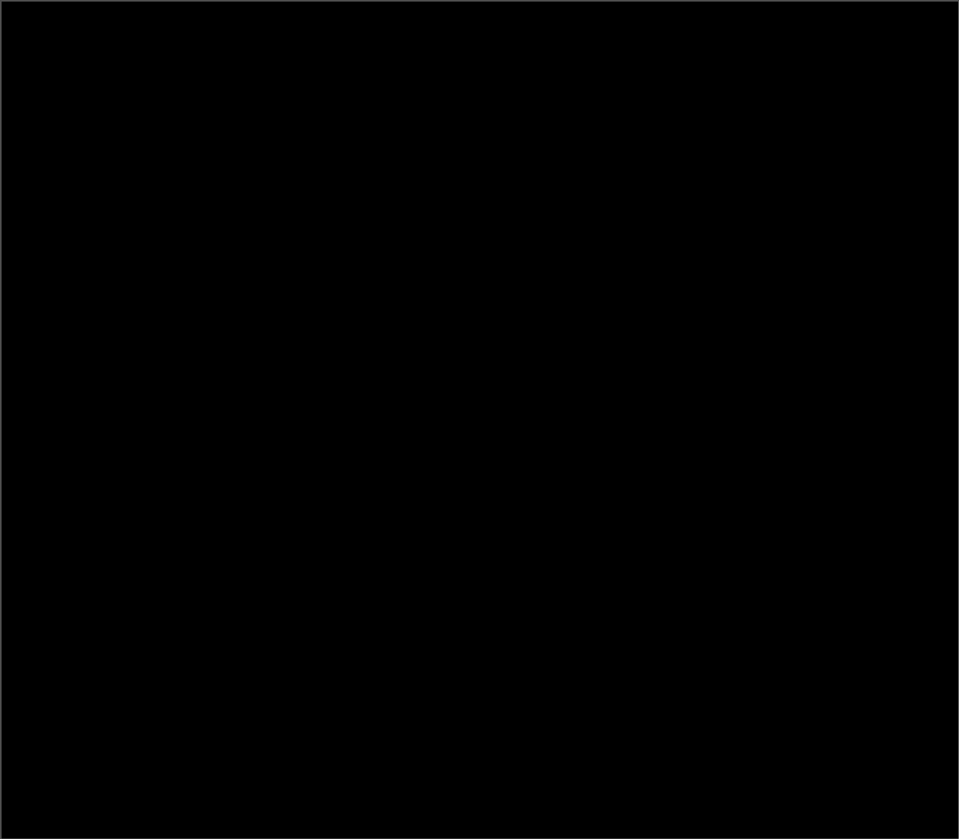
Picture dynamic range: Guess!



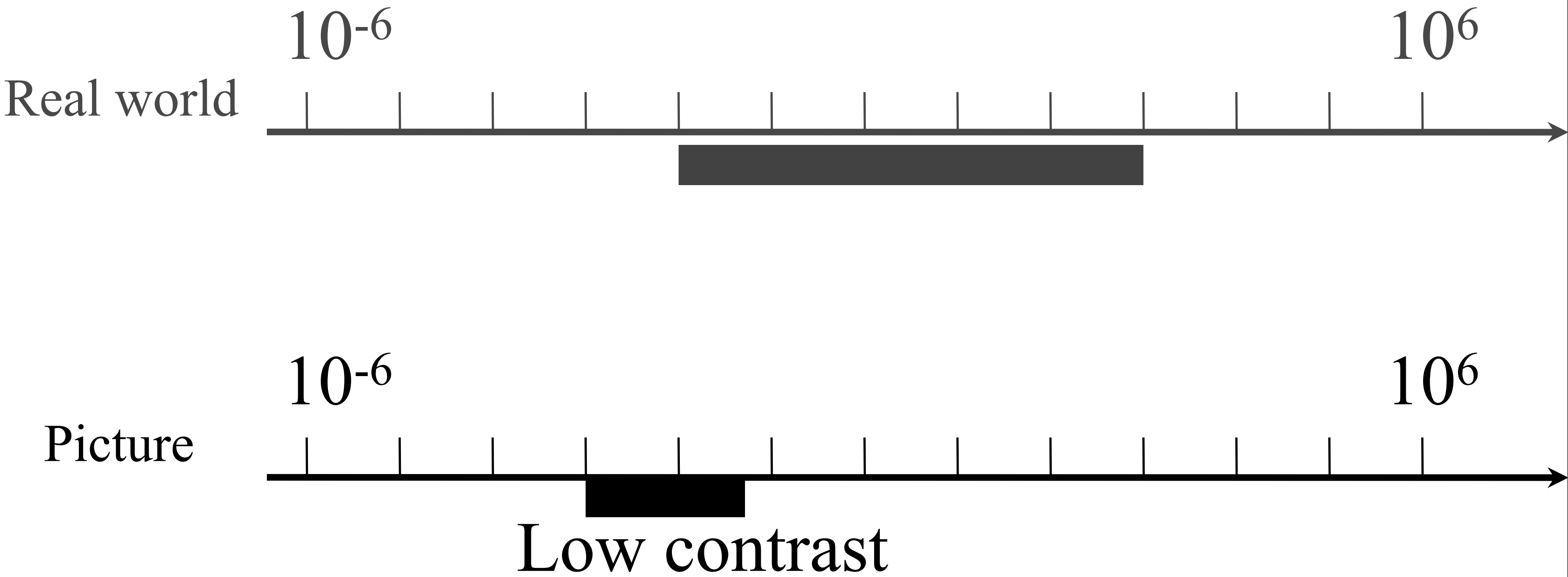




Picture dynamic range

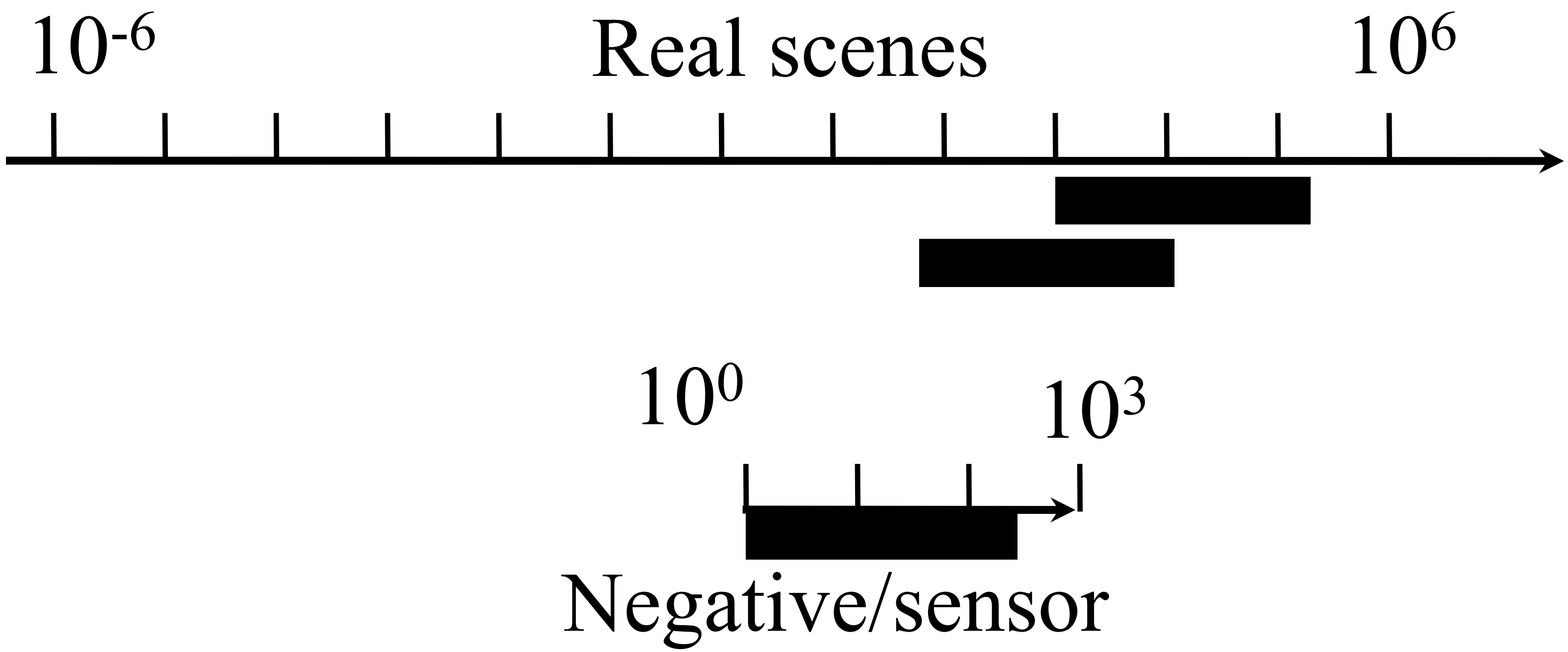
- **Typically 1: 20 or 1:50**
  - Black is ~ 50x darker than white

- **Max 1:500**



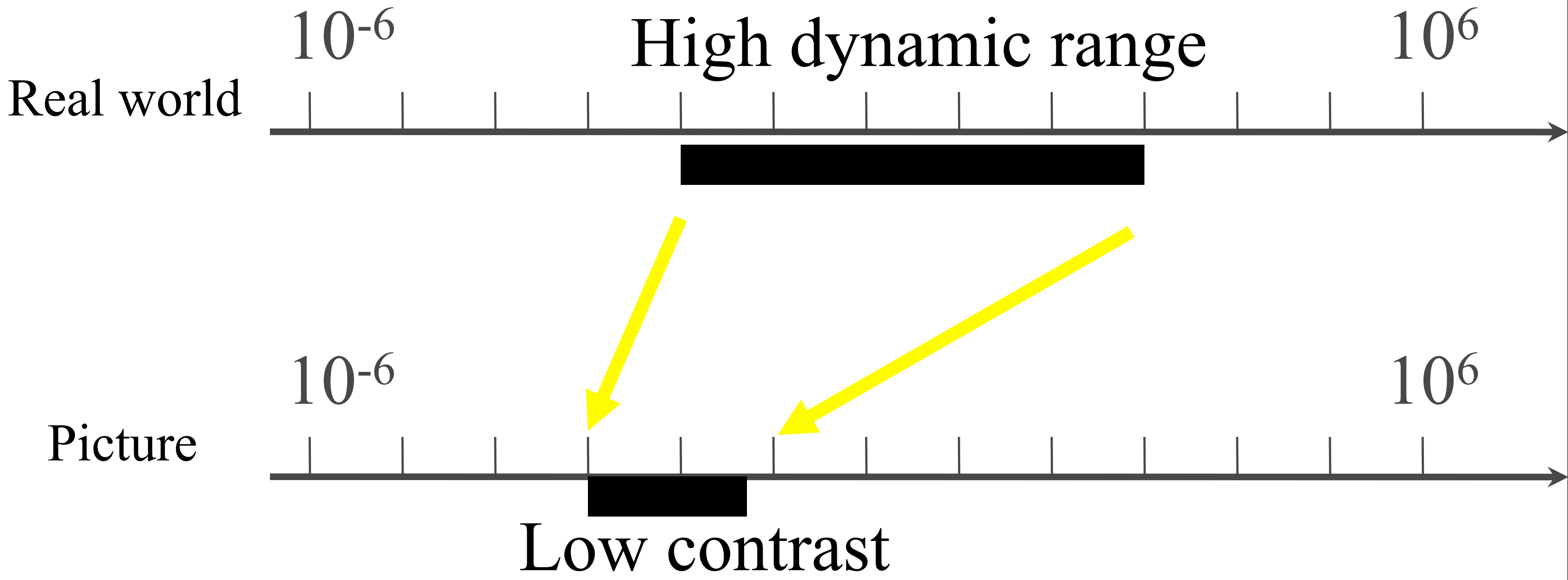
Problem 1: record the information

- **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**



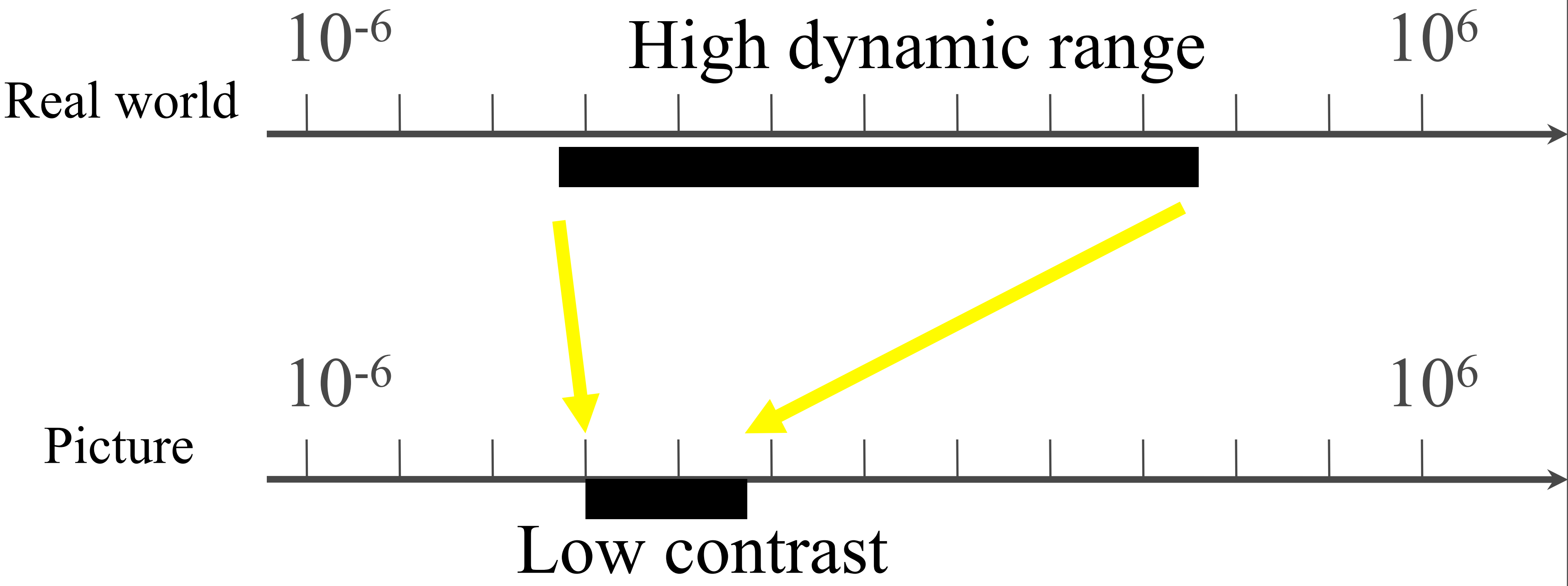
Problem 2: Display the infromation

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



Multiple exposure photography

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



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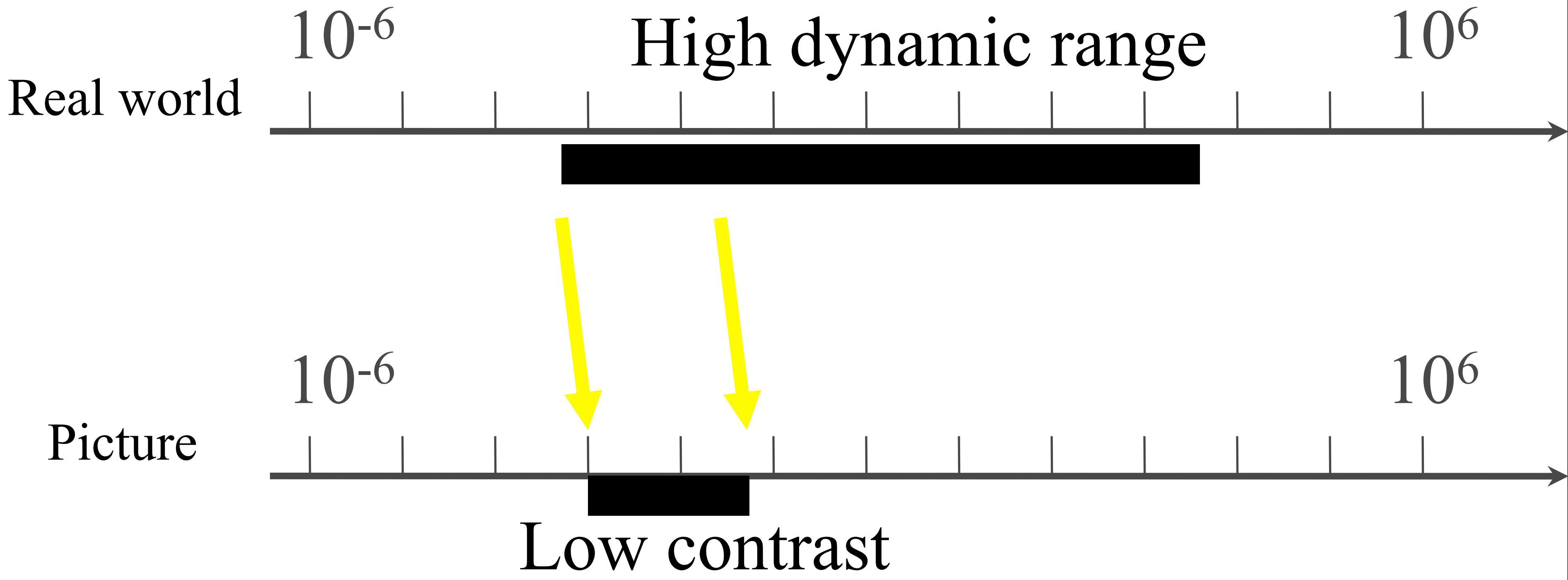

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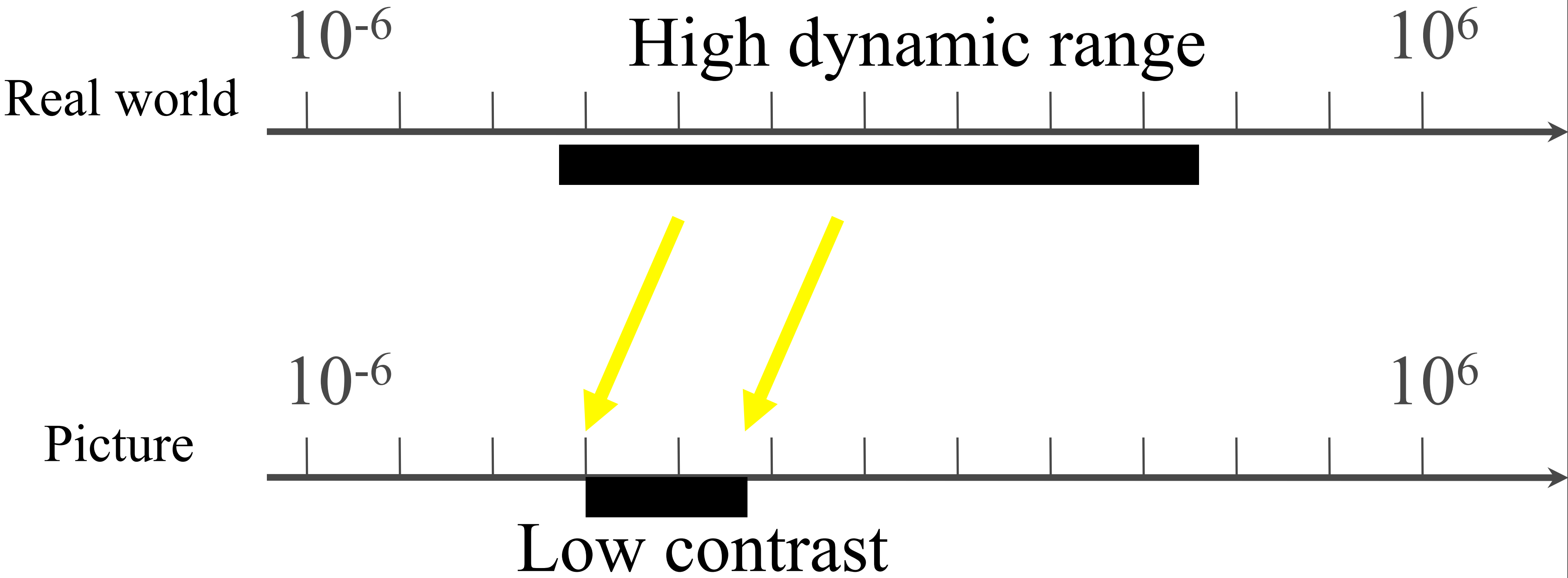

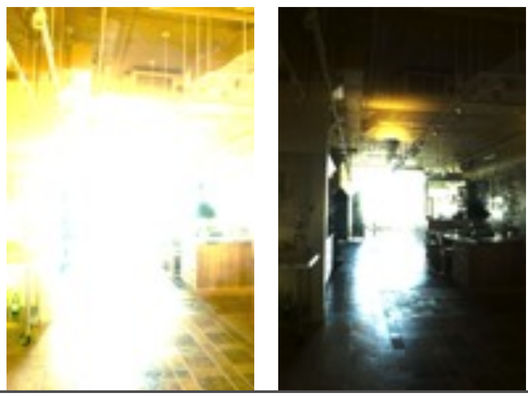

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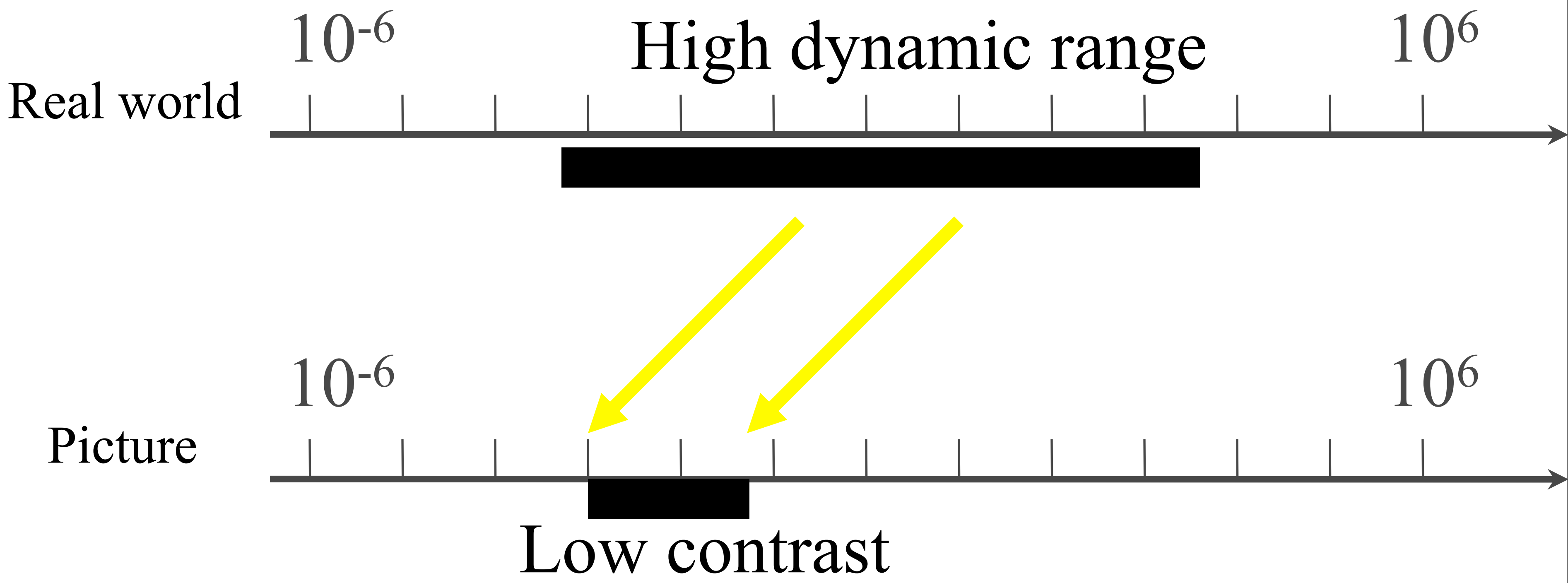

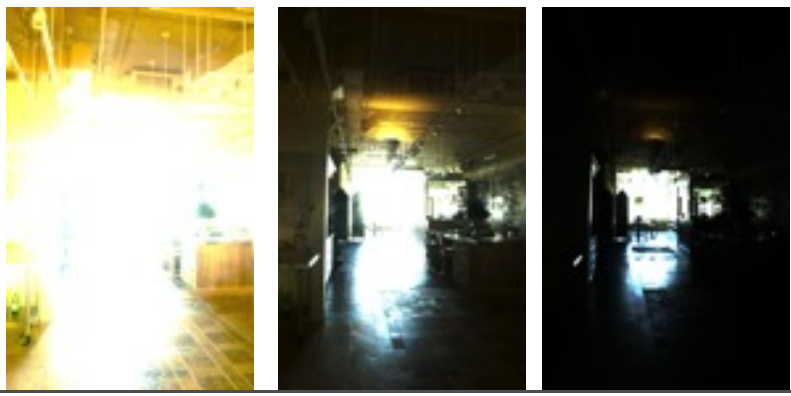

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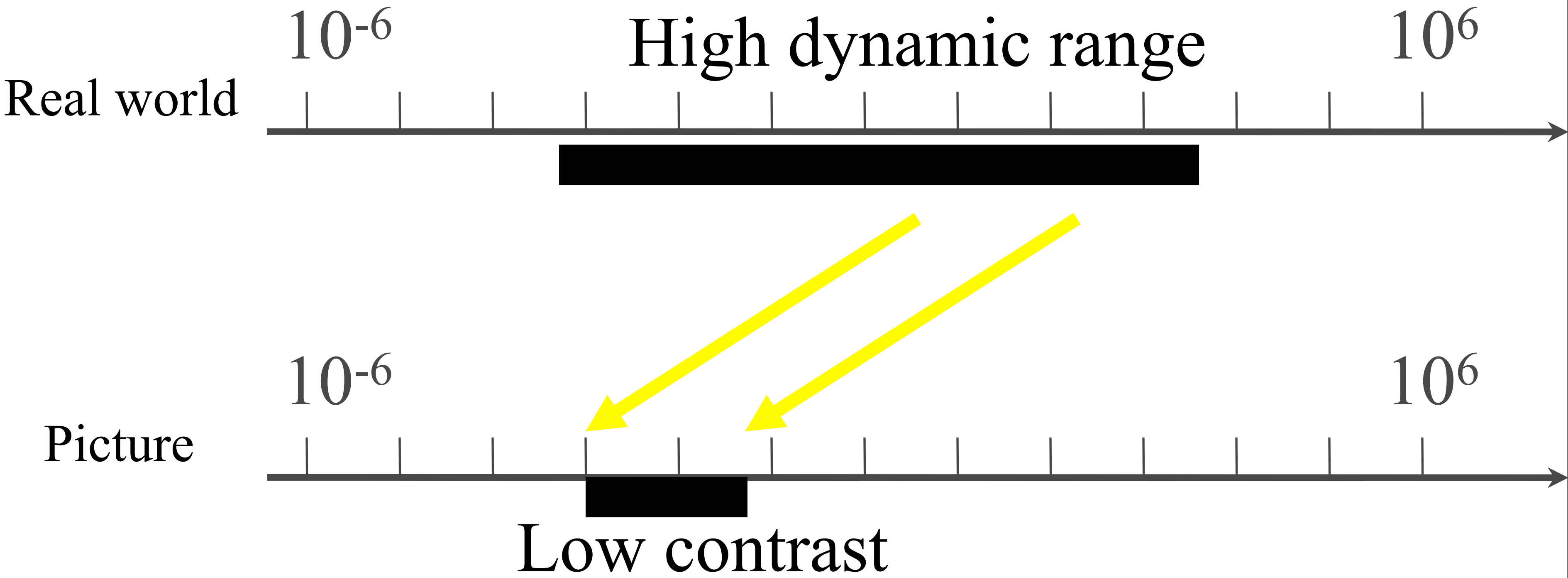

Multiple exposure photography

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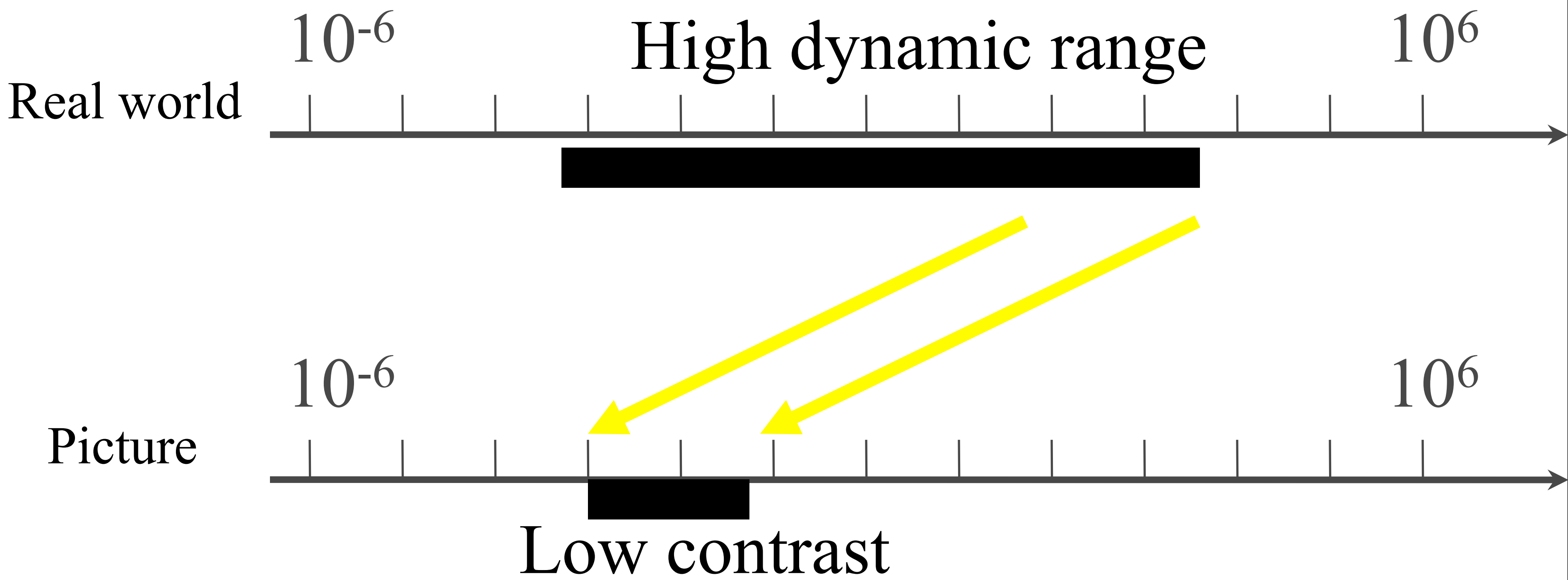
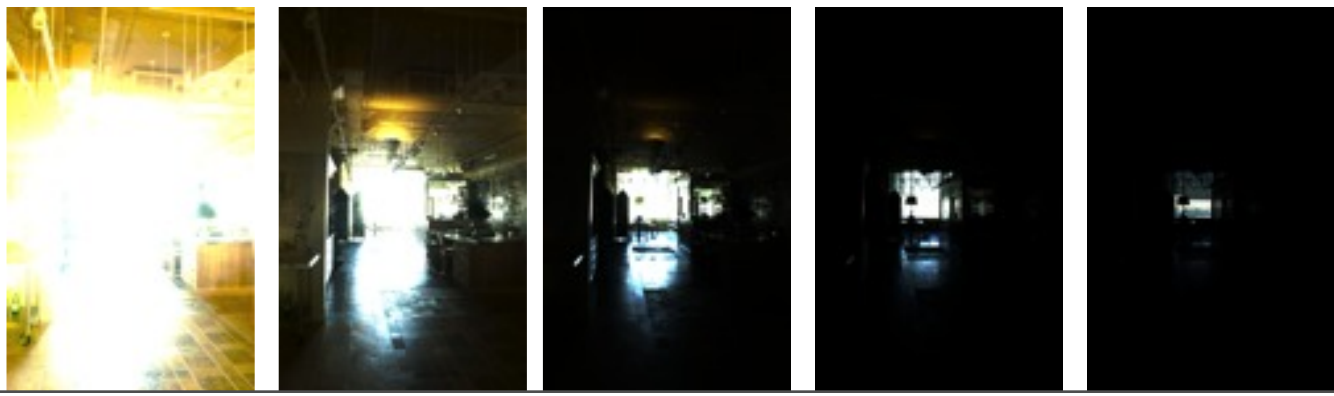
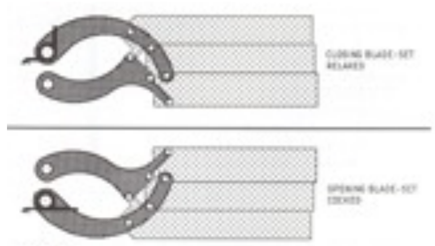




How do we vary exposure?

- **Options:**
  - Shutter speed



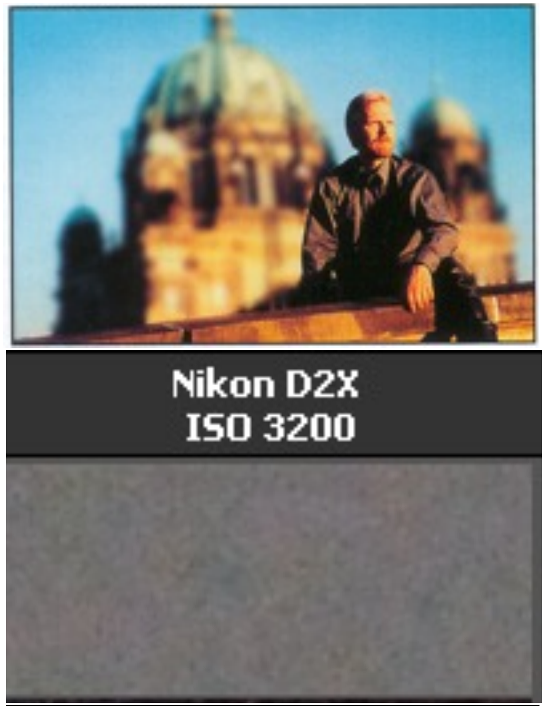
  - Aperture

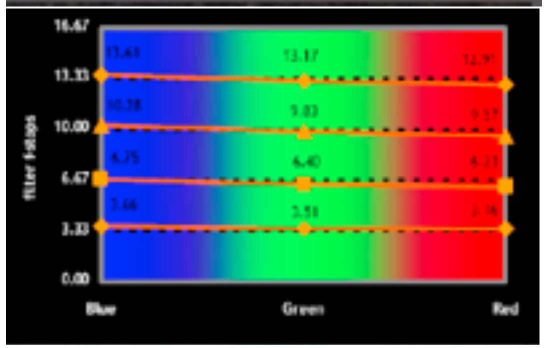
  - ISO
  - Neutral density filter

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





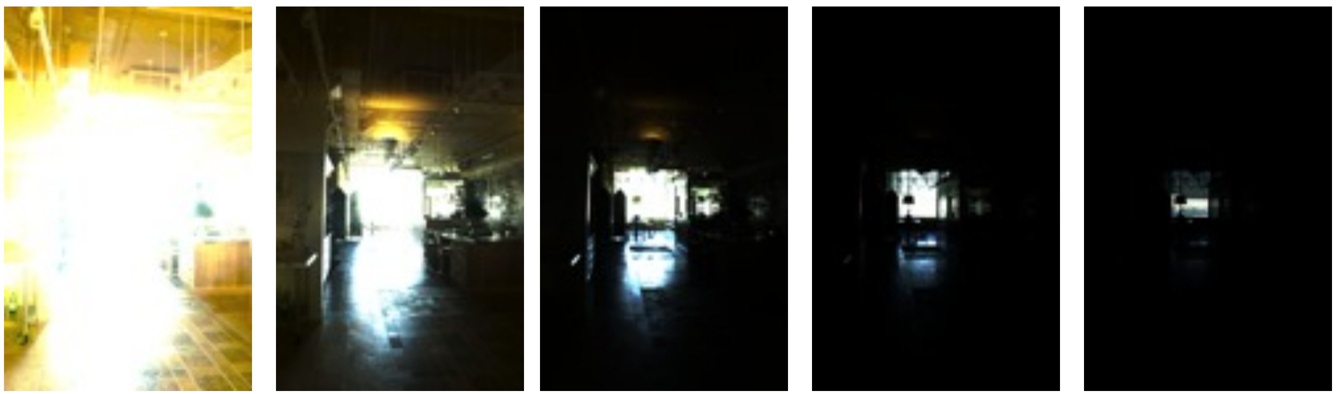
Slide after Siggraph 2005 course on HDR

Questions?

HDR image using multiple exposure

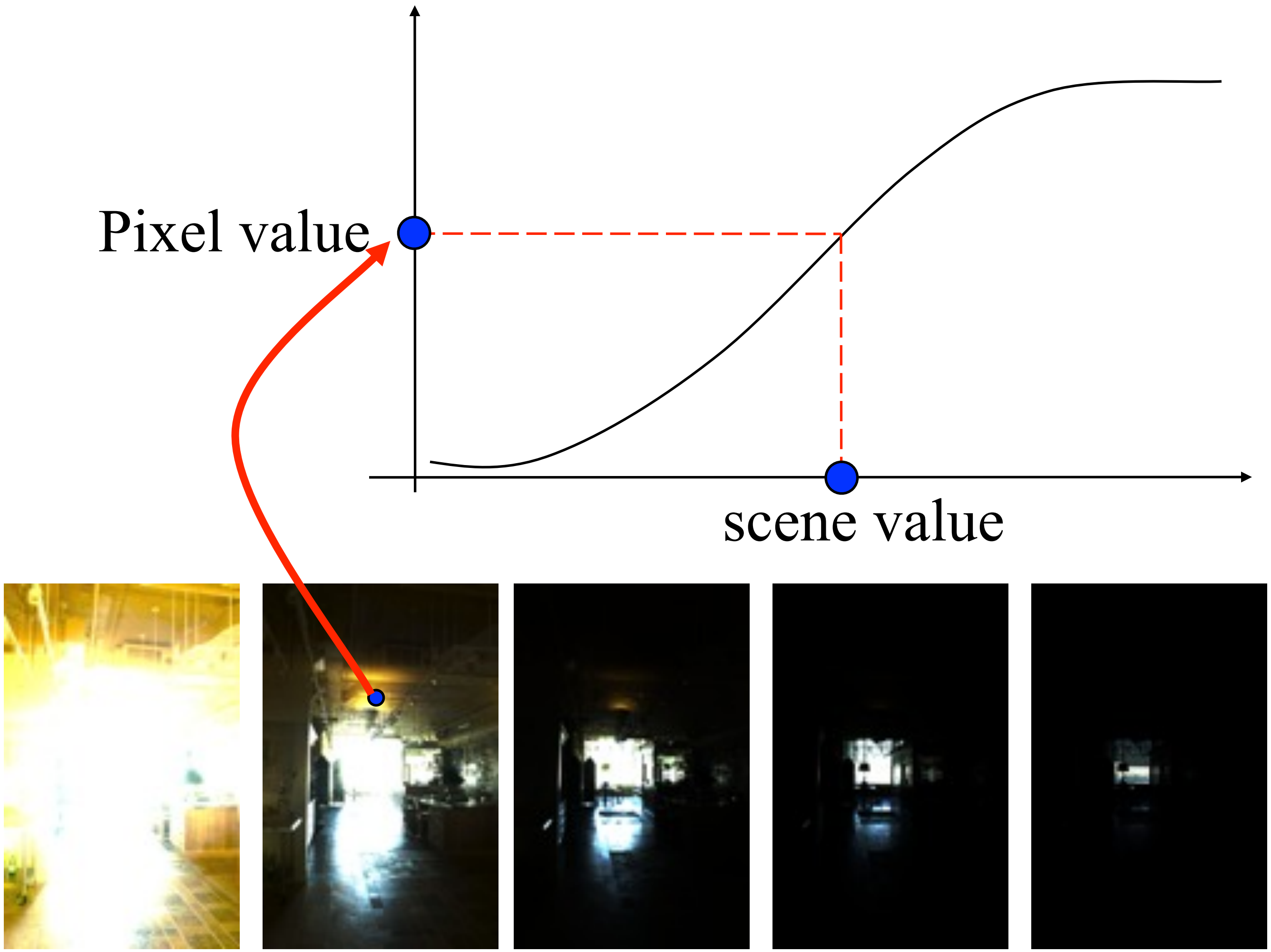
- **Given N photos at different exposure**
- **Recover a HDR color for each pixel**

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



If we know the response curve

- **Just look up the inverse of the response curve**
- **But how do we get the curve?**



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

CSAIL

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

$$\text{Exposure} = \text{Radiance} \times \Delta t$$

$$\log \text{Exposure} = \log \text{Radiance} + \log \Delta t$$

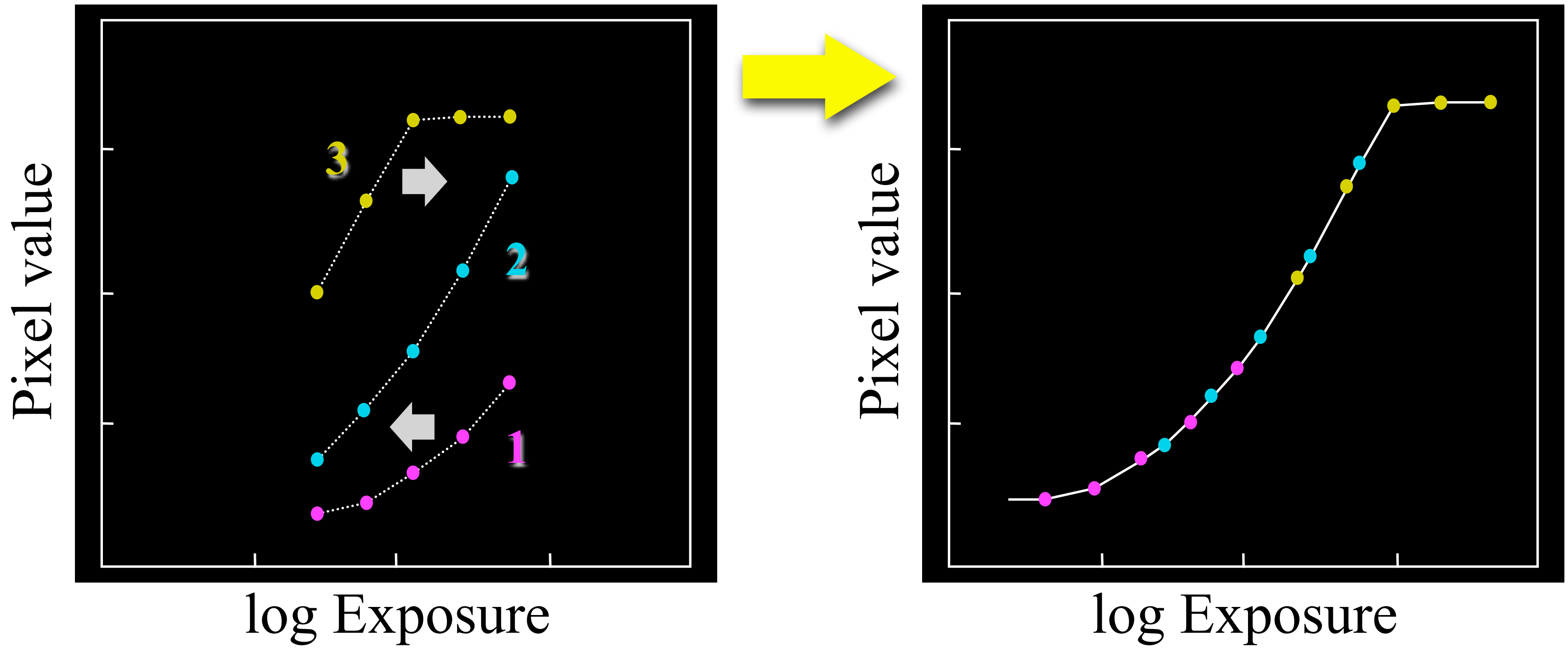
Slide adapted from Alyosha Efros who borrowed it from Paul Debevec
Δ t don't really correspond to pictures. Oh well.

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



Slide stolen from Alyosha Efros who stole it from Paul Debevec

The math

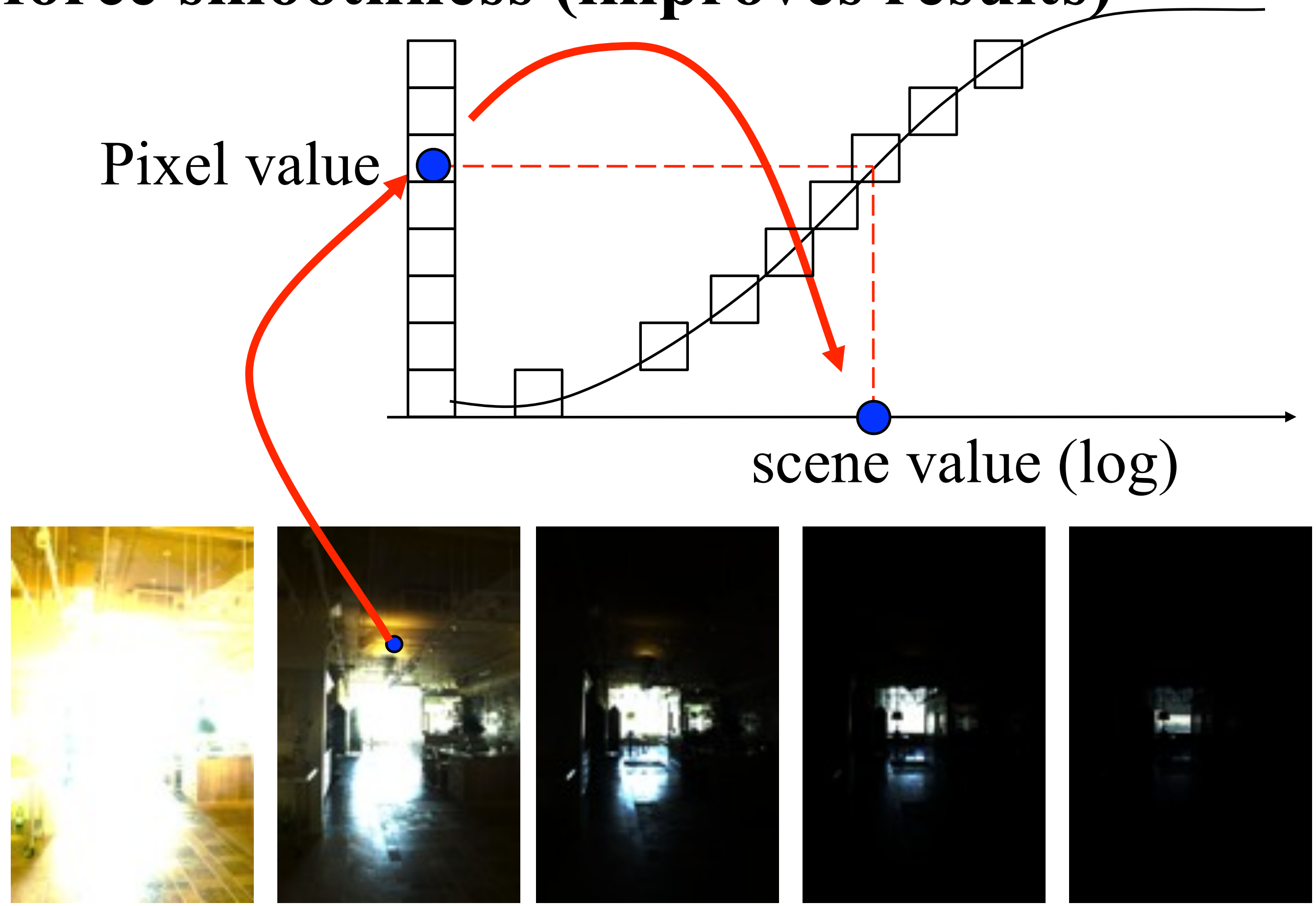
- **unknowns: response curve f and radiance of pixels**
- **for each pixel i and image j**
  - Pixel Value $Z_{ij}=f(Exposure_{i,j})$
  - log Exposure = log $Radiance_i$ + log Δt_j
- **Easier to deal with inverse function (in log) $g=\log(f^{-1})$**

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

- **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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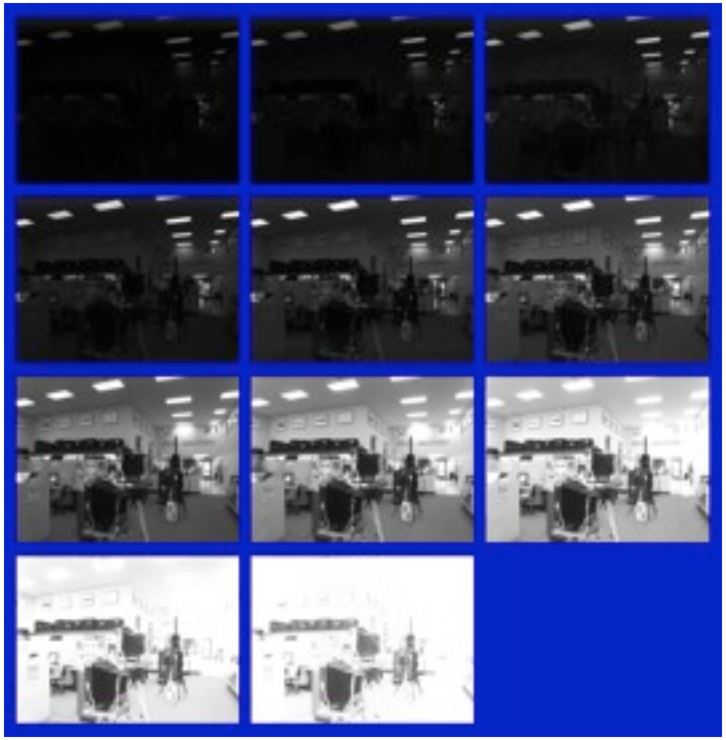
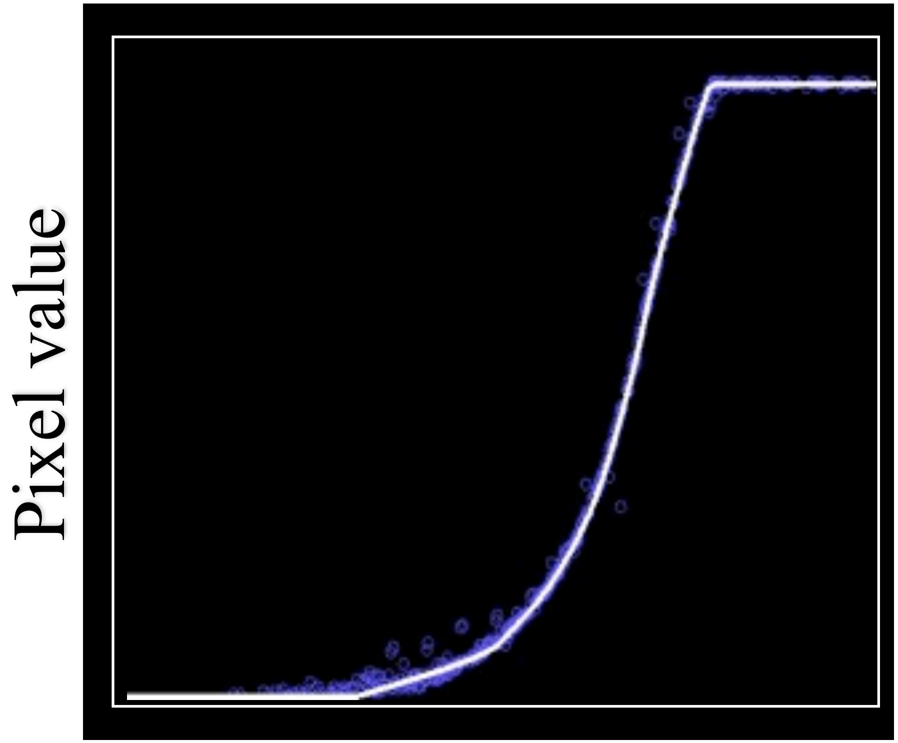
Result: digital camera

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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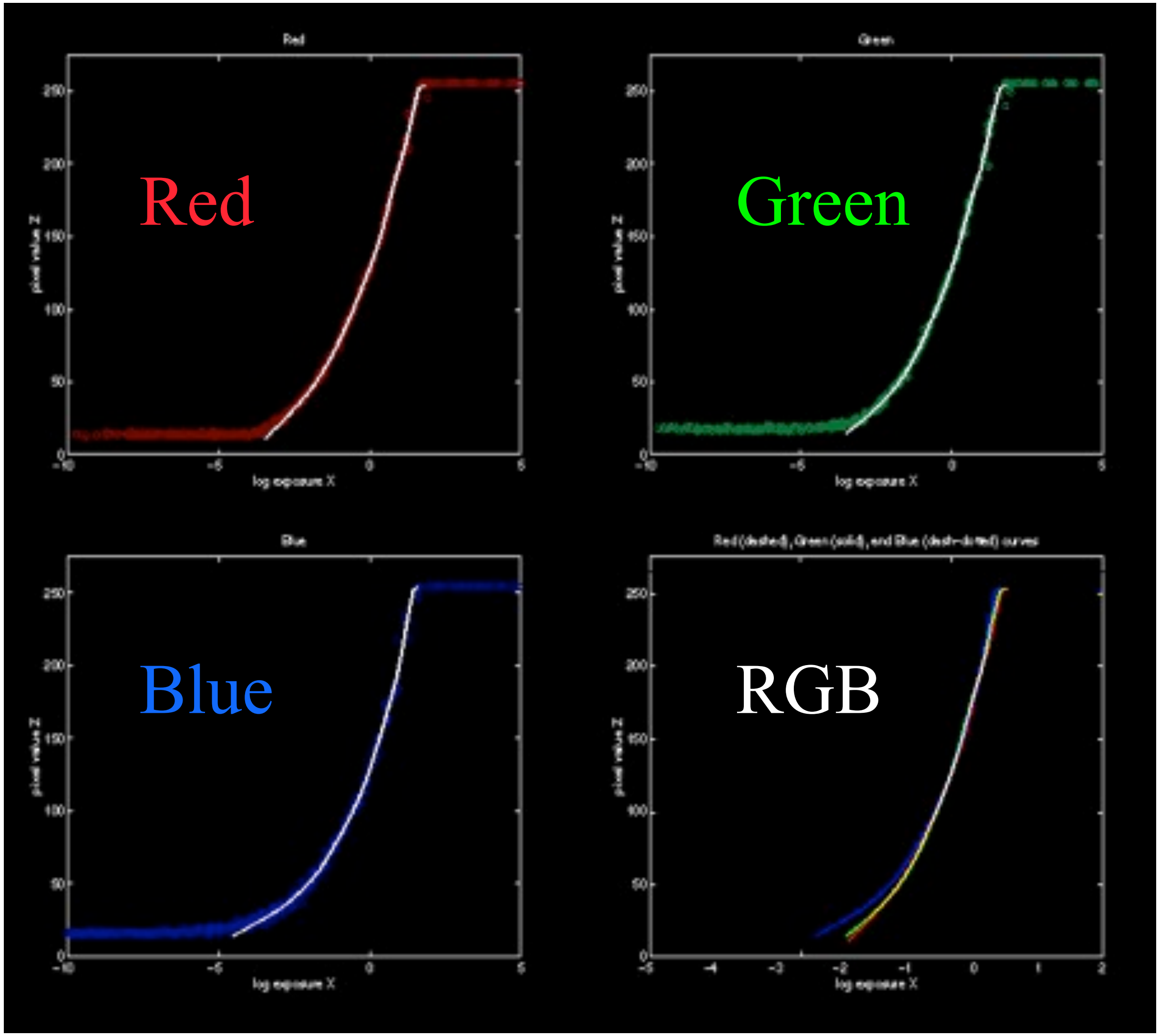
Recovered response curves



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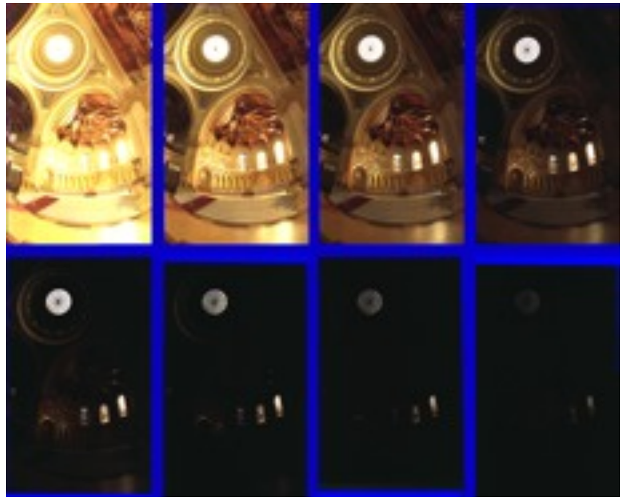
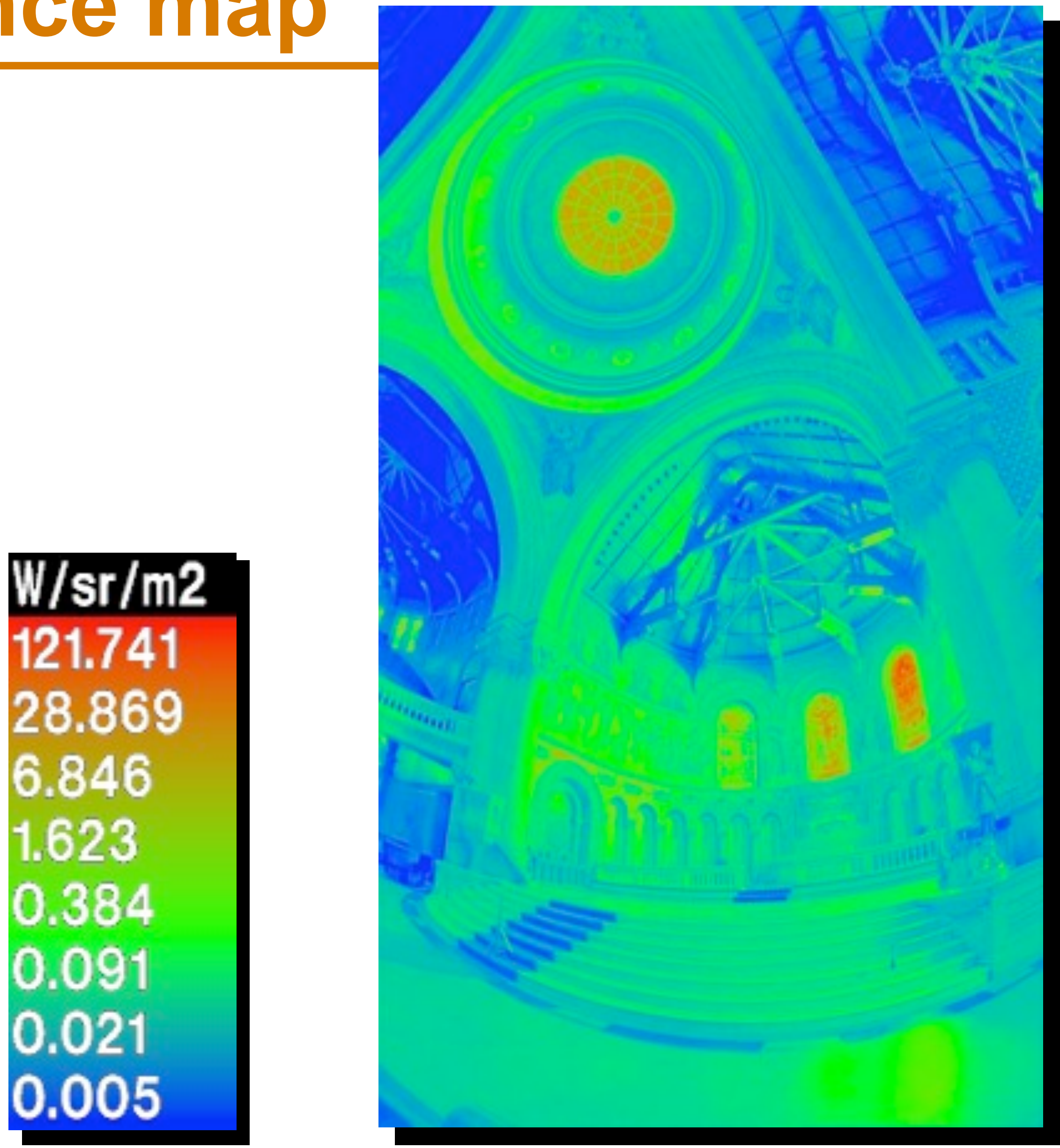
Recap

- **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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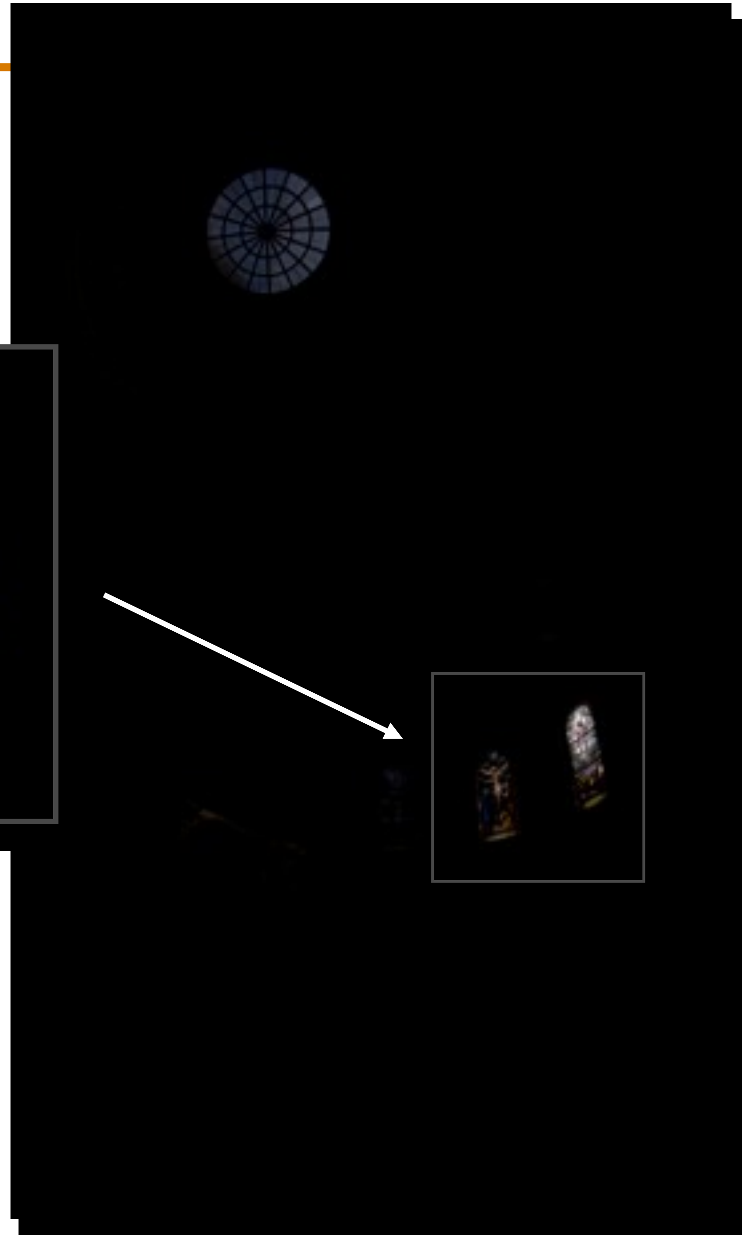
The Radiance map



Linearly scaled to display device

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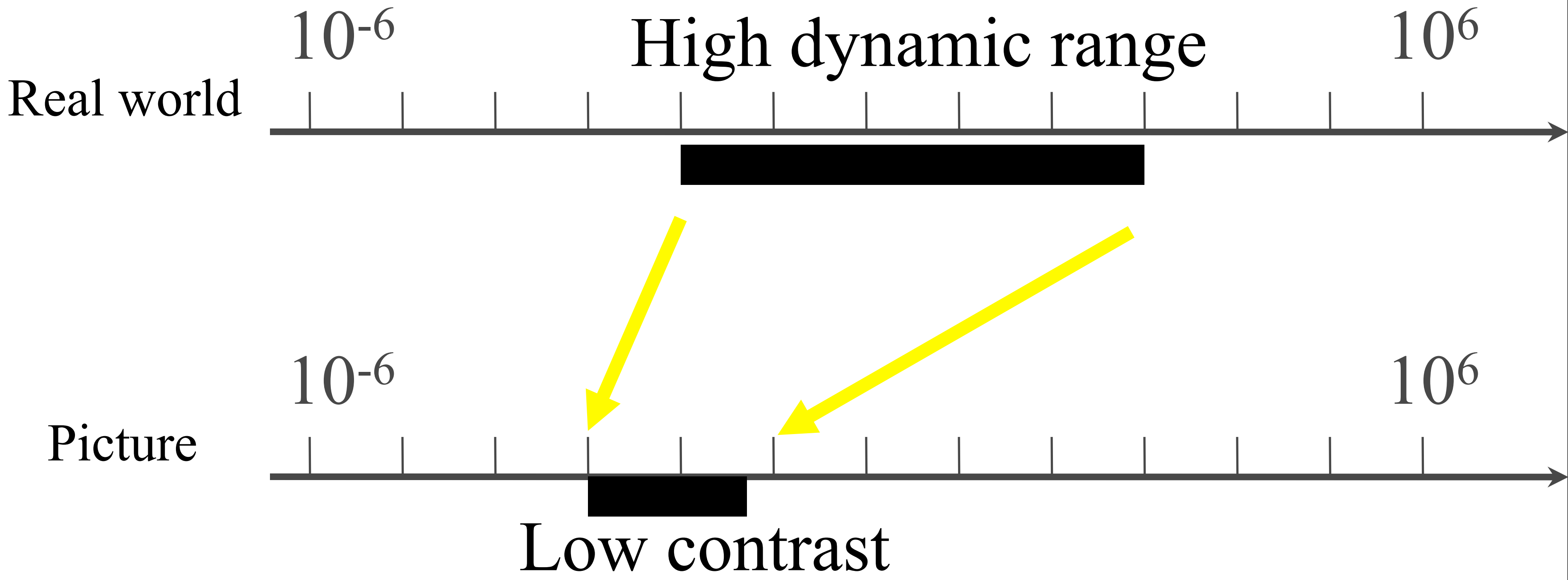
Questions?

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)

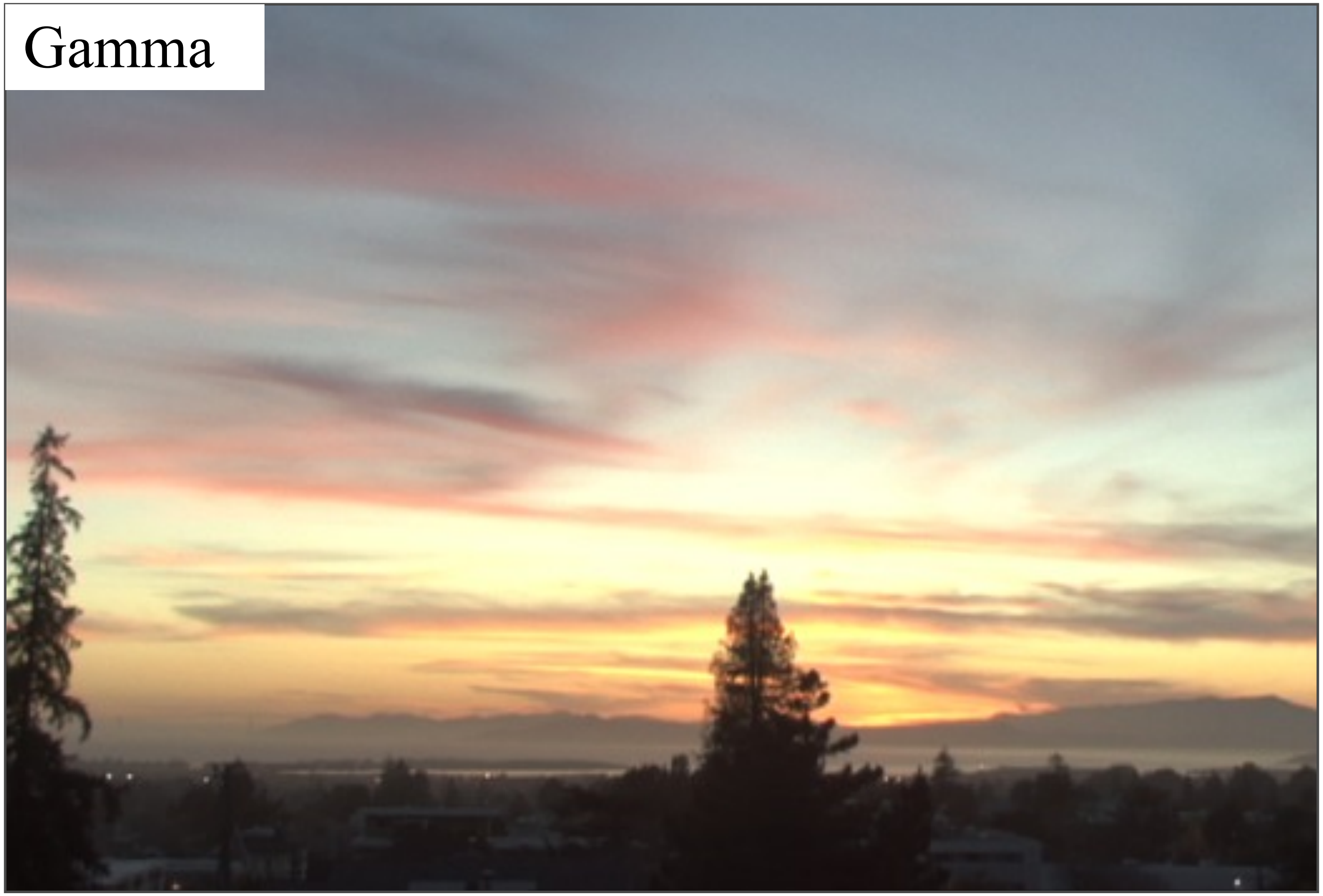
Naïve technique

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

Naïve: Gamma compression

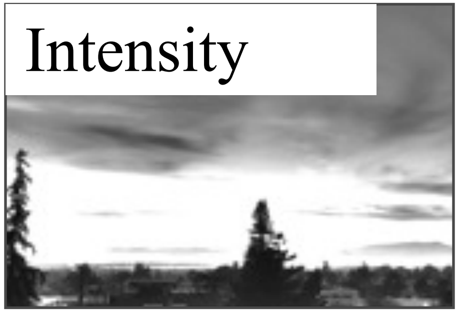
- **$X \rightarrow X^{\gamma}$ (where γ=0.5 in our case)**
- **But… colors are washed-out. Why?**

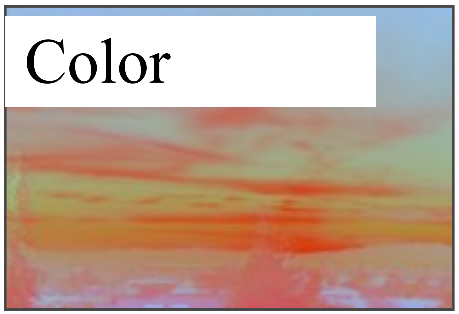
applied independently on R, G & B

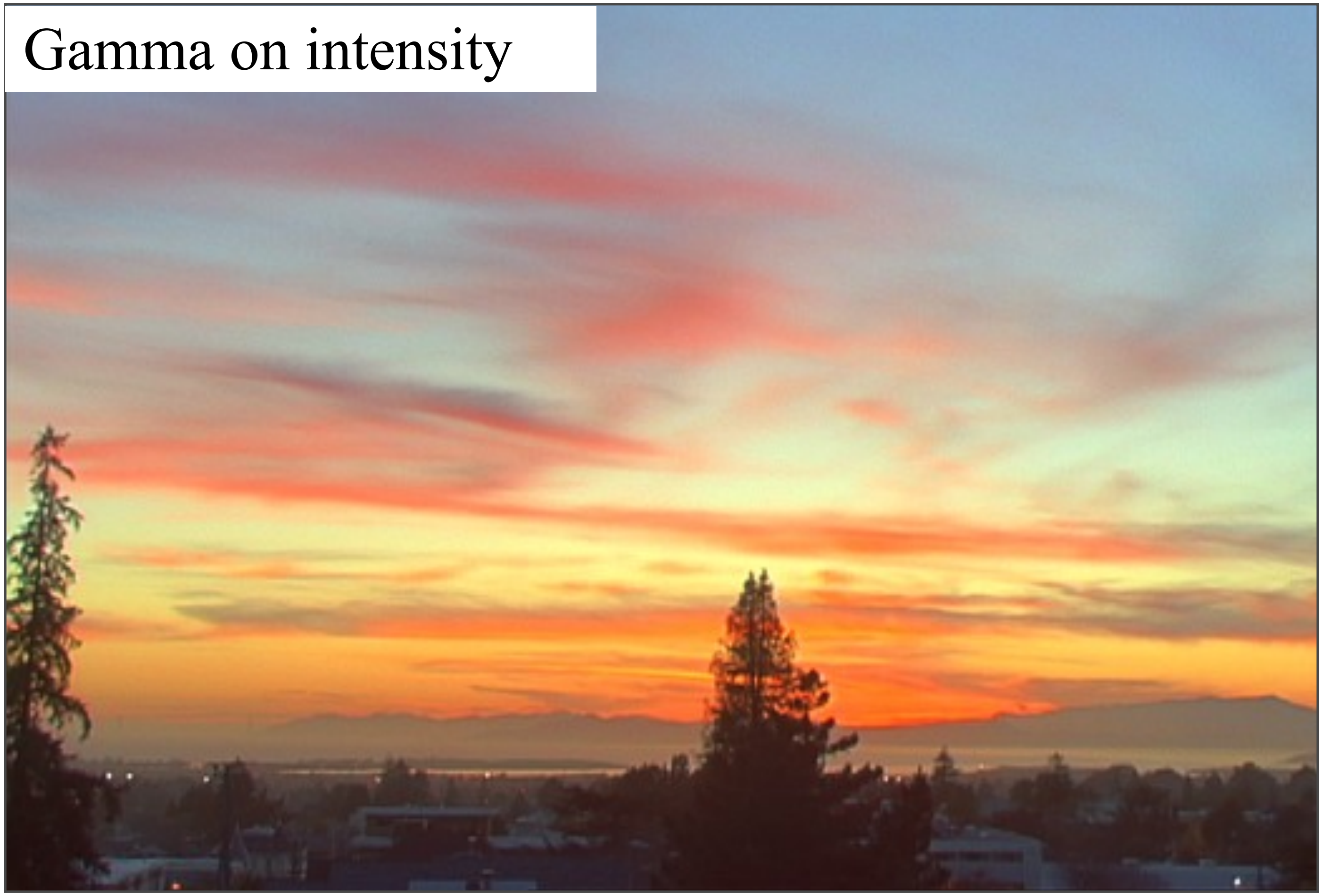


Gamma compression on intensity

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

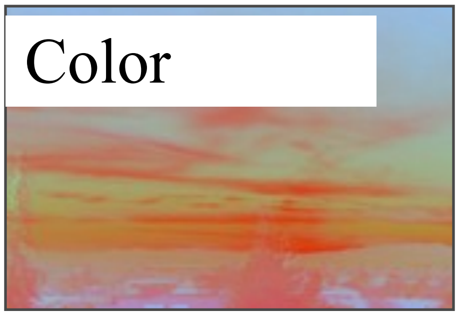

Intensity


Color


Gamma on intensity

Oppenheim 1968, Chiu et al. 1993

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



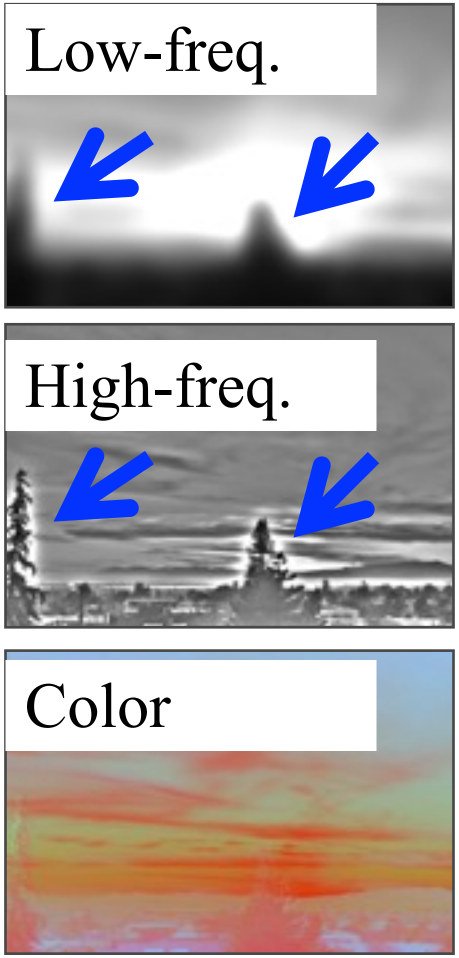
Homomorphic filtering

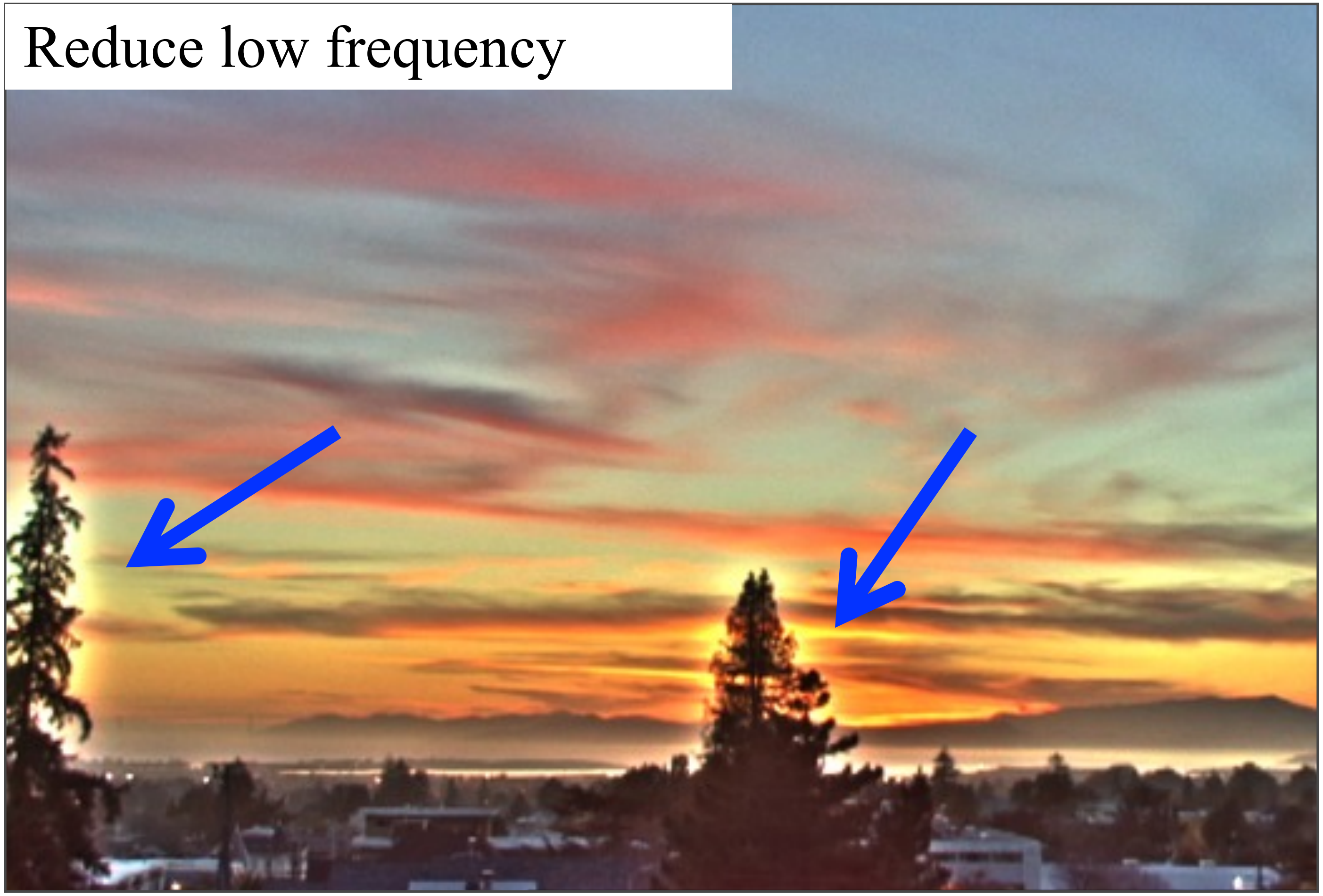
- **Oppenhein, in the sixties**
- **Images are the *product* of illumination and albedo**
  - Similarly, many sounds are the *product* of an envelope and a modulation
- **Illumination is usually slow-varying**
- **Perform albedo-illumination using low-pass filtering of the log image**

- http://www.cs.sfu.ca/~stella/papers/blairthesis/main/node33.html
- **See also Koenderink "Image processing done right"** http://www.springerlink.com/(l1bpumaapconcbjngteojwqv)/app/home/contribution.asp?referrer=parent&backto=issue,11,53;journal,1538,3333;linkingpublicationresults,1:105633,1

The halo nightmare

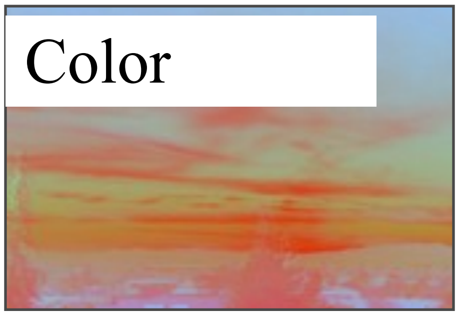
- For strong edges
- Because they contain high frequency

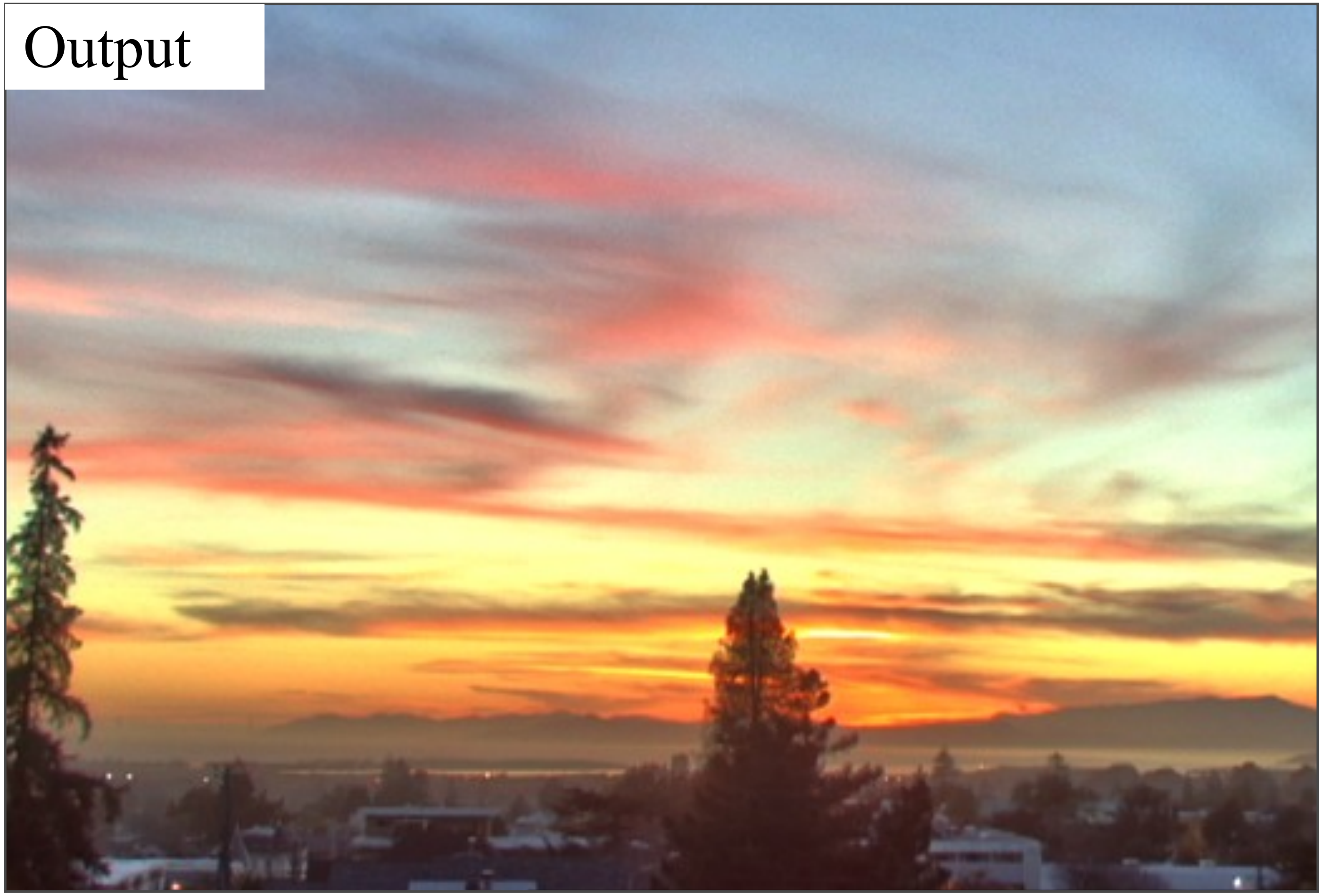




Our approach

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





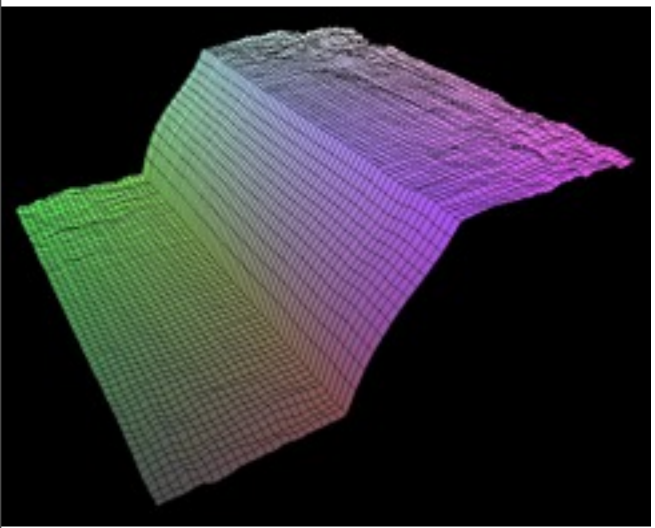
Bilateral filter

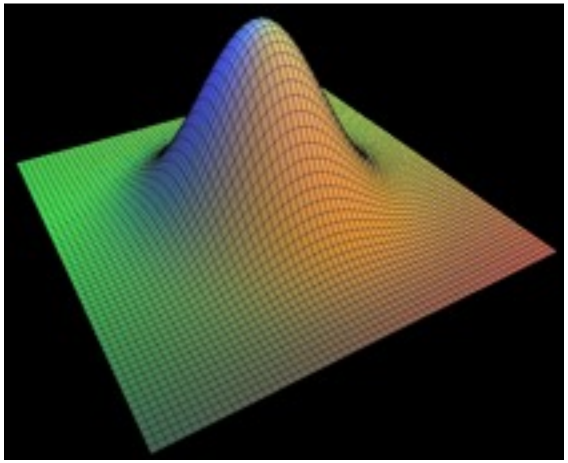
- **Tomasi and Manduci 1998** **http://www.cse.ucsc.edu/~manduchi/Papers/ICCV98.pdf**
- **Related to**
  - SUSAN filter
    [Smith and Brady 95] http://citeseer.ist.psu.edu/smith95susan.html
  - Digital-TV [Chan, Osher and Chen 2001] http://citeseer.ist.psu.edu/chan01digital.html
  - sigma filter http://www.geogr.ku.dk/CHIPS/Manual/f187.htm

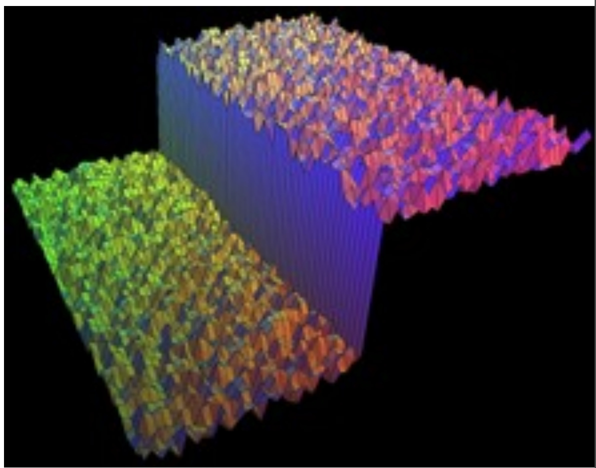
Start with Gaussian filtering

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

$$J = f \otimes I$$







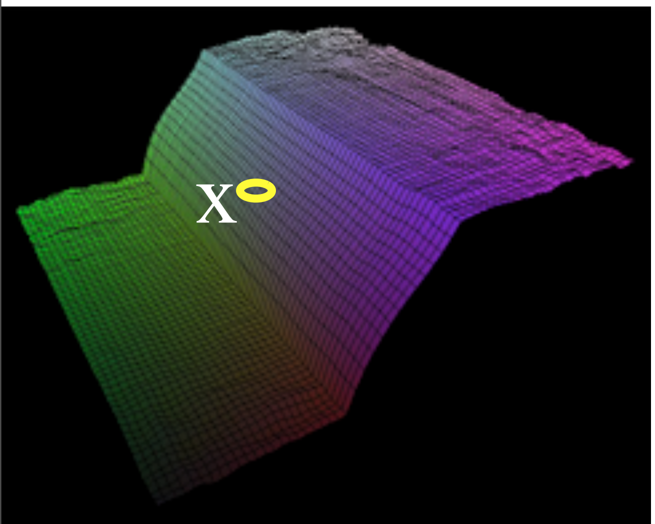
output

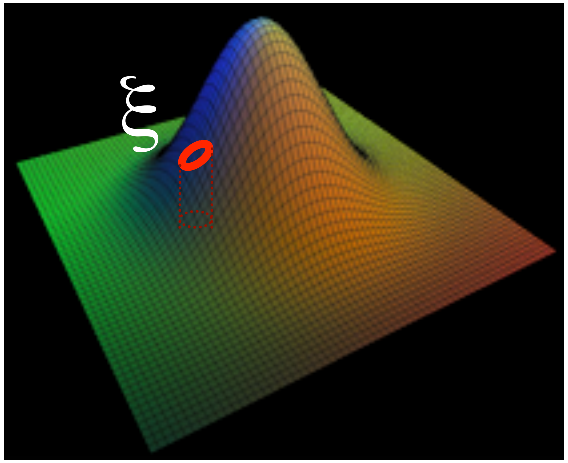
input

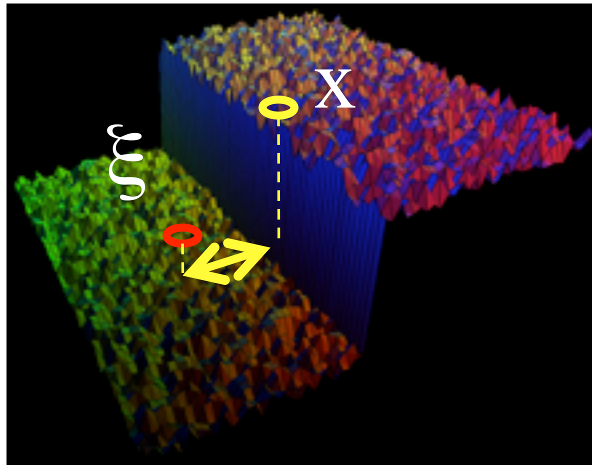
Gaussian filter as weighted average

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

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





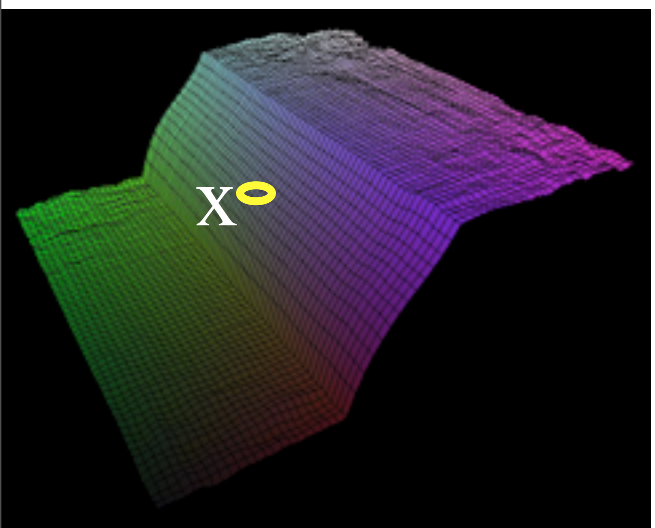


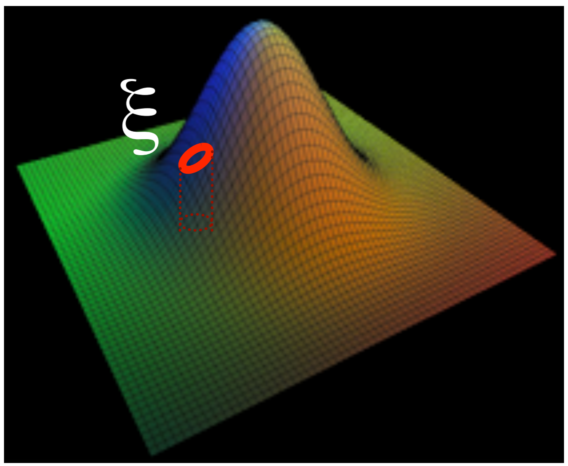
output ⟵ input

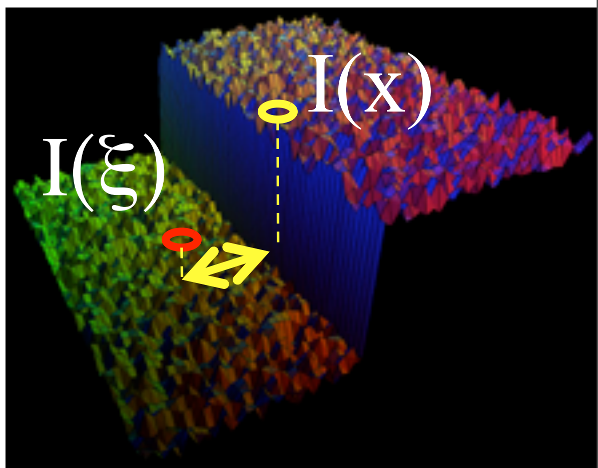
The problem of edges

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

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







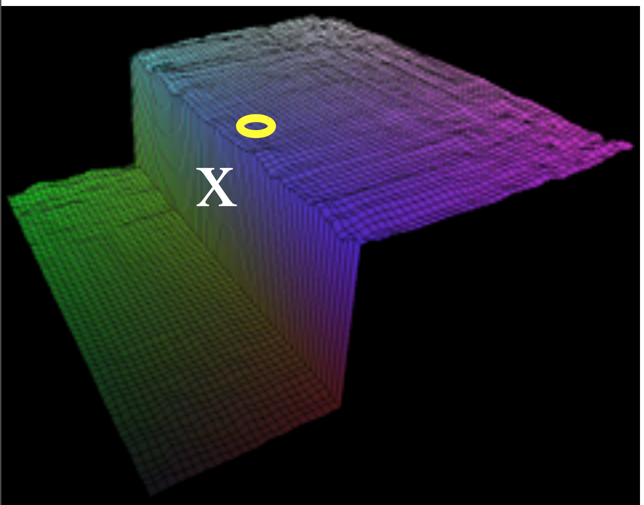
output ⟵ input

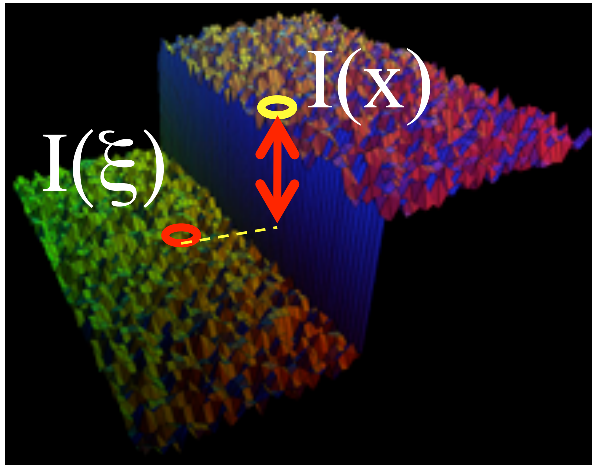
Principle of Bilateral filtering

[Tomasi and Manduchi 1998]

- **Penalty g on the intensity difference**

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





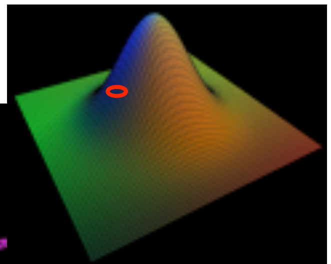
output ⟵ input

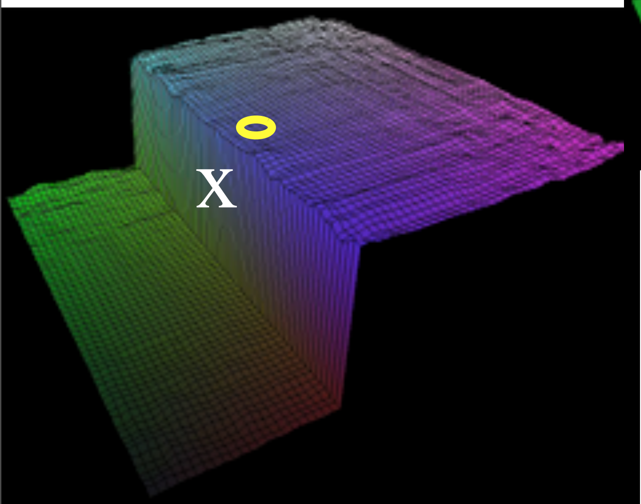
Bilateral filtering

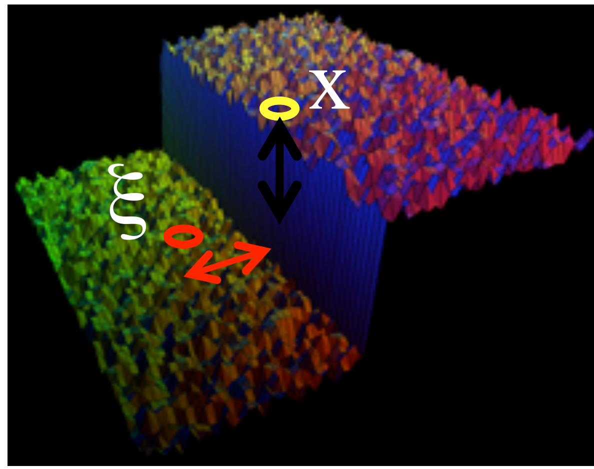
[Tomasi and Manduchi 1998]

- **Spatial Gaussian f**

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







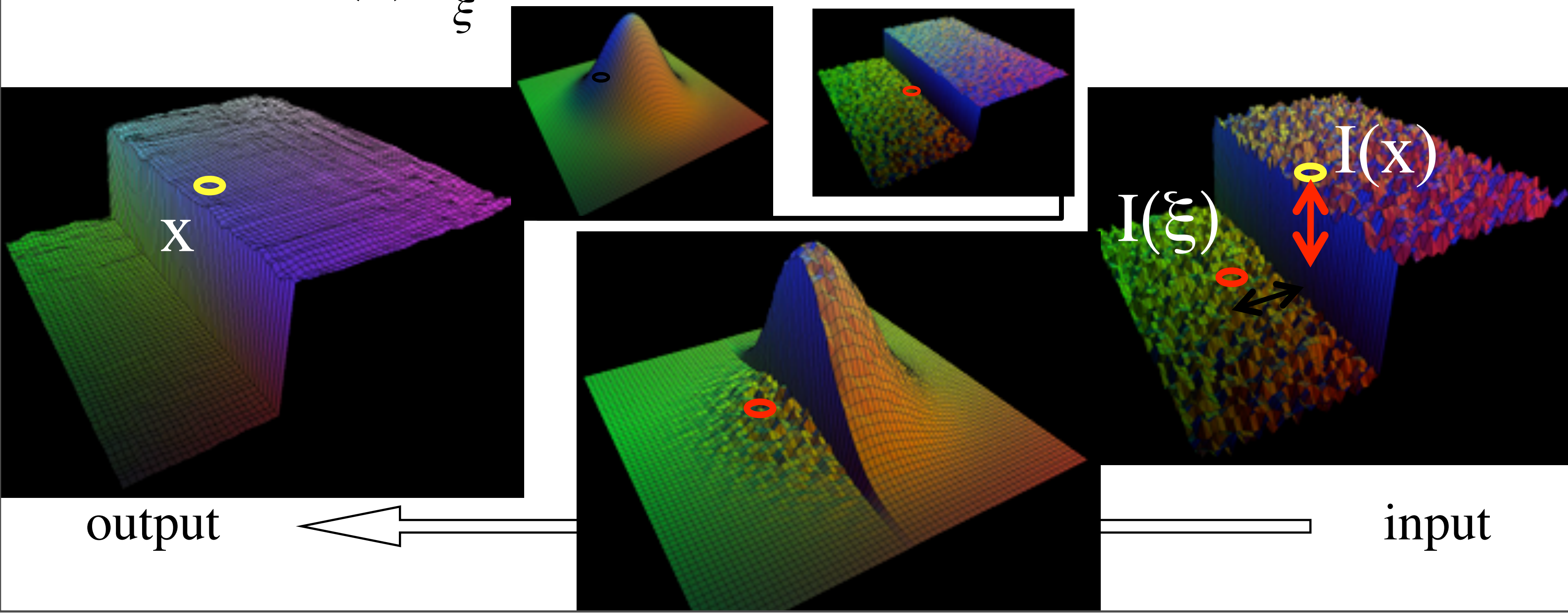
output ⟵ input

Bilateral filtering

[Tomasi and Manduchi 1998]

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

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

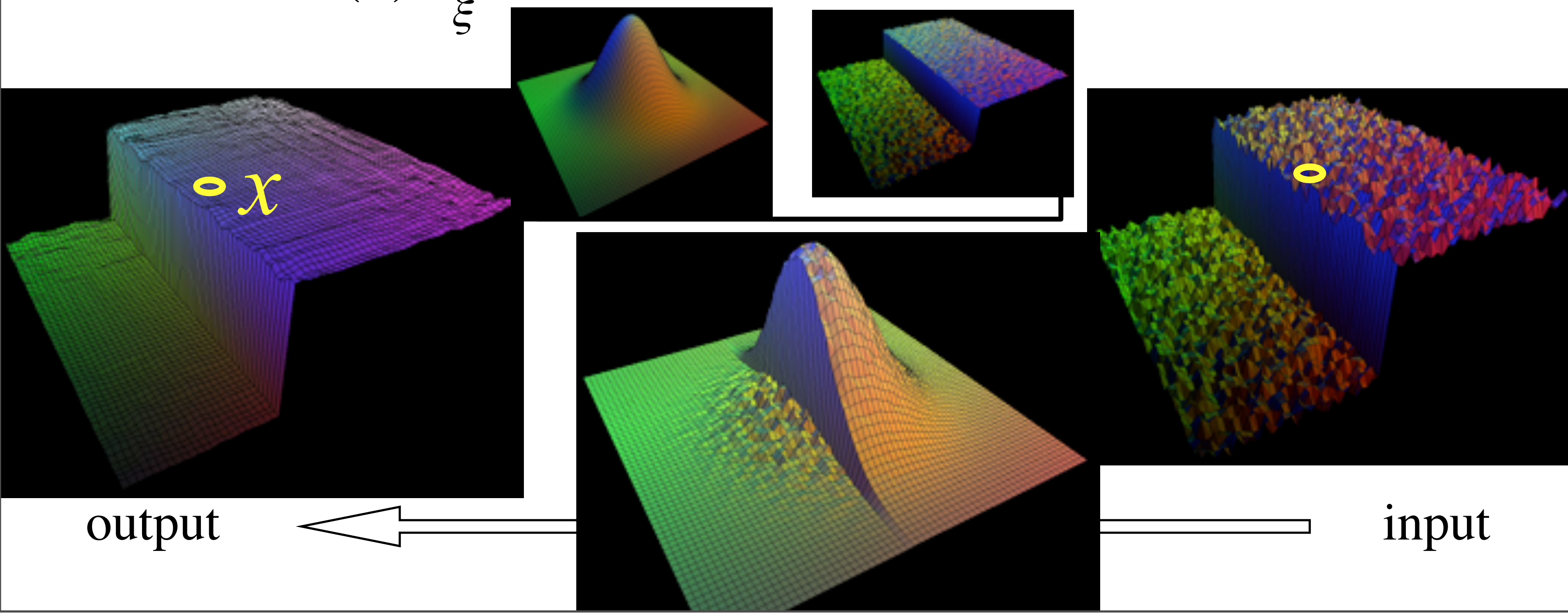


Normalization factor

[Tomasi and Manduchi 1998]

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

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

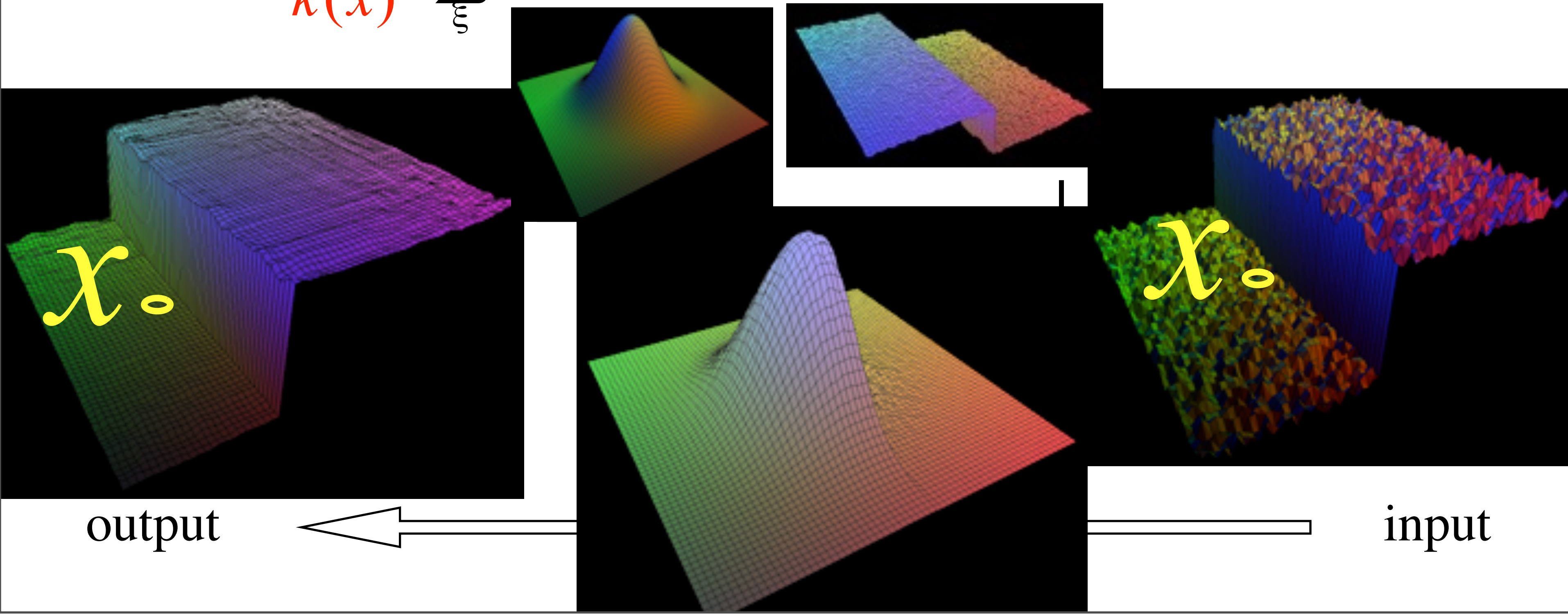


Bilateral filtering is non-linear

[Tomasi and Manduchi 1998]

- The weights are different for each output pixel

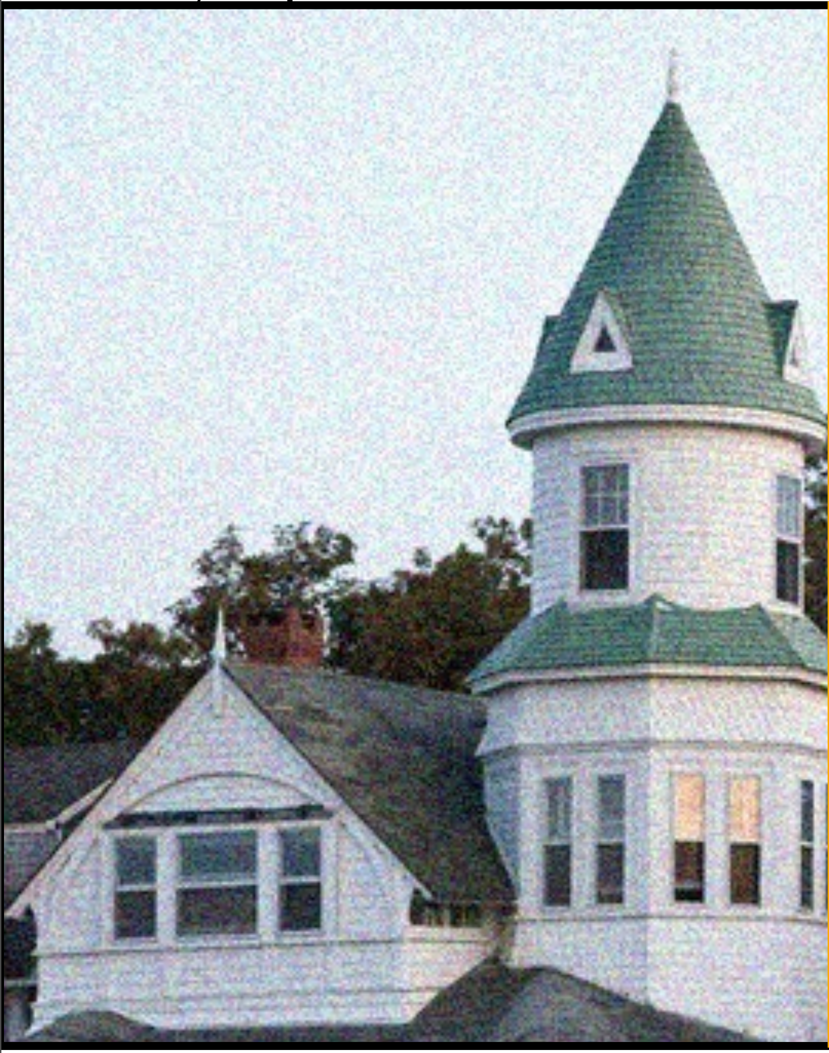
$$J(x) = \frac{1}{k(x)} \sum_{\xi} f(x,\xi) \quad g(I(\xi)-I(x)) \quad I(\xi)$$



- **NEEDS WORK TO MAKE GAUSSIAN DETAILS CLEARER**
- **SHOW EFFECT OF SIGMAS**

Basic denoising

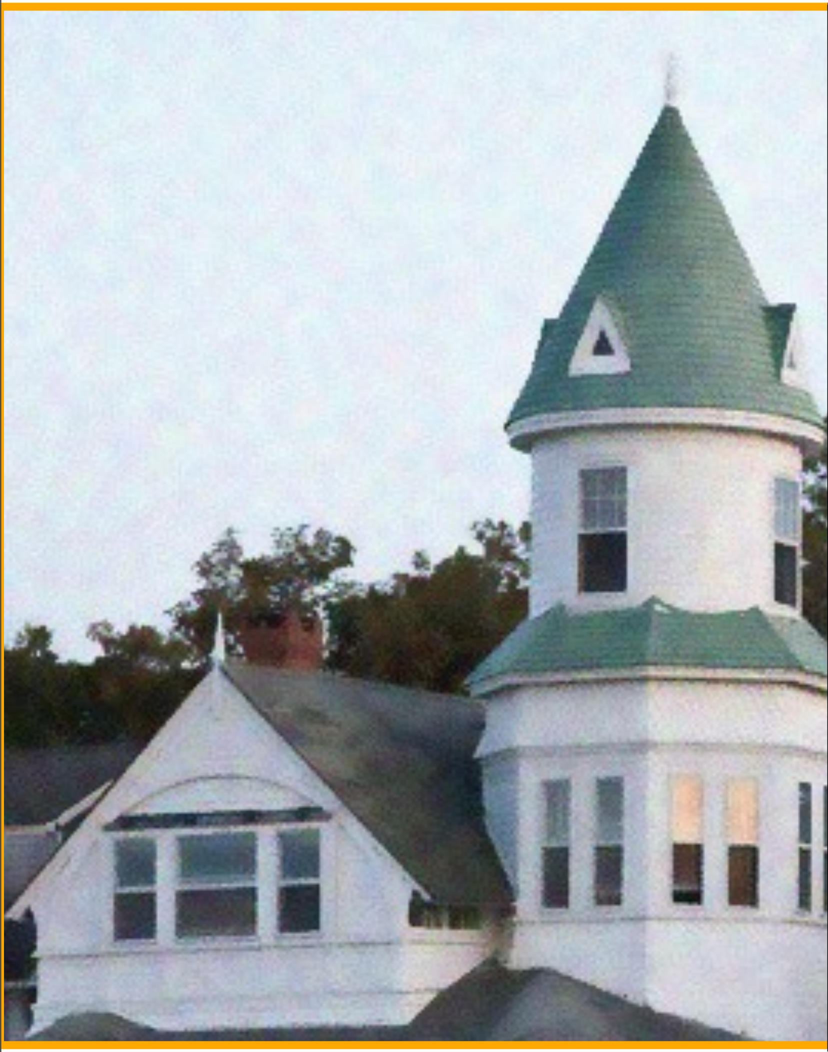
Noisy input



Bilateral filter 7x7 window

Basic denoising

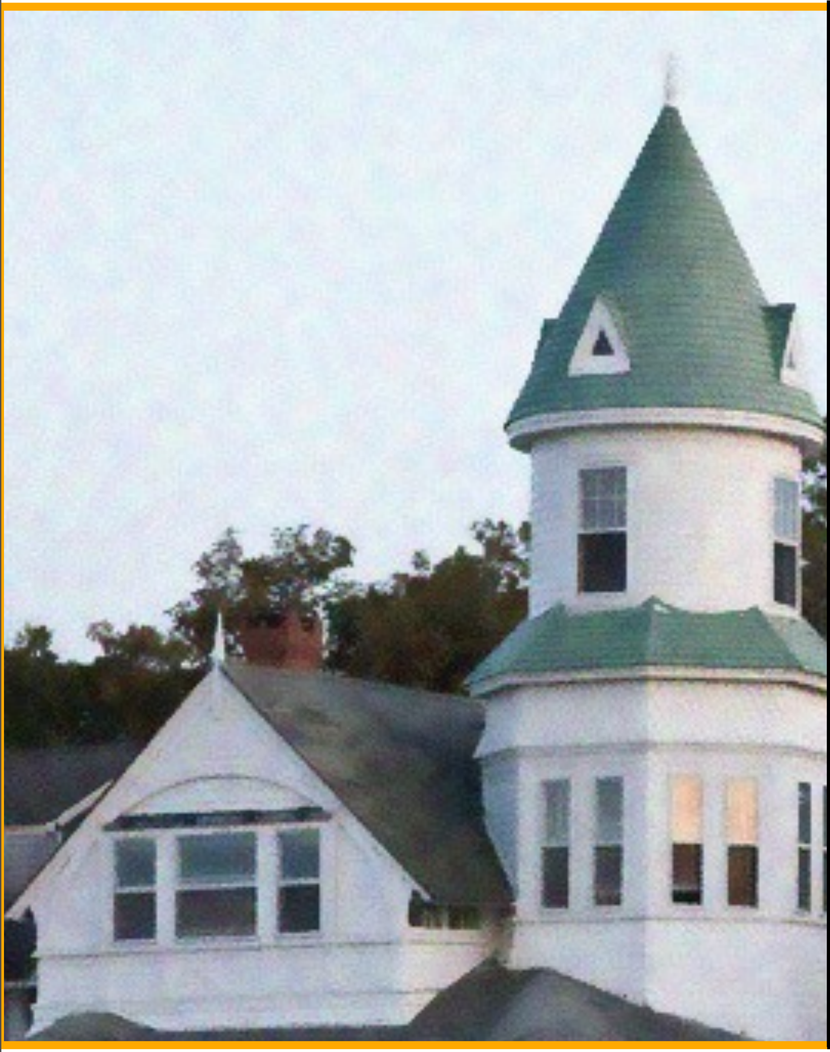
Bilateral filter



Median 3x3

Basic denoising

Bilateral filter



Median 5x5

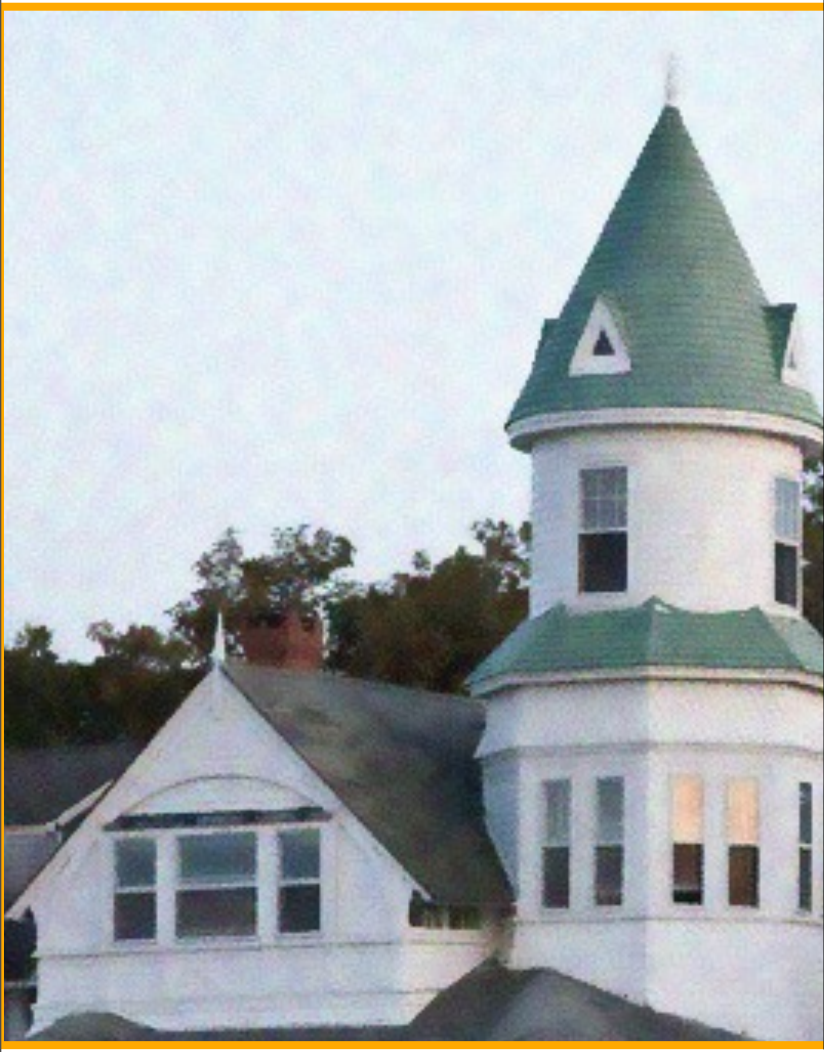
Basic denoising

Bilateral filter

Bilateral filter – lower

Basic denoising

Bilateral filter

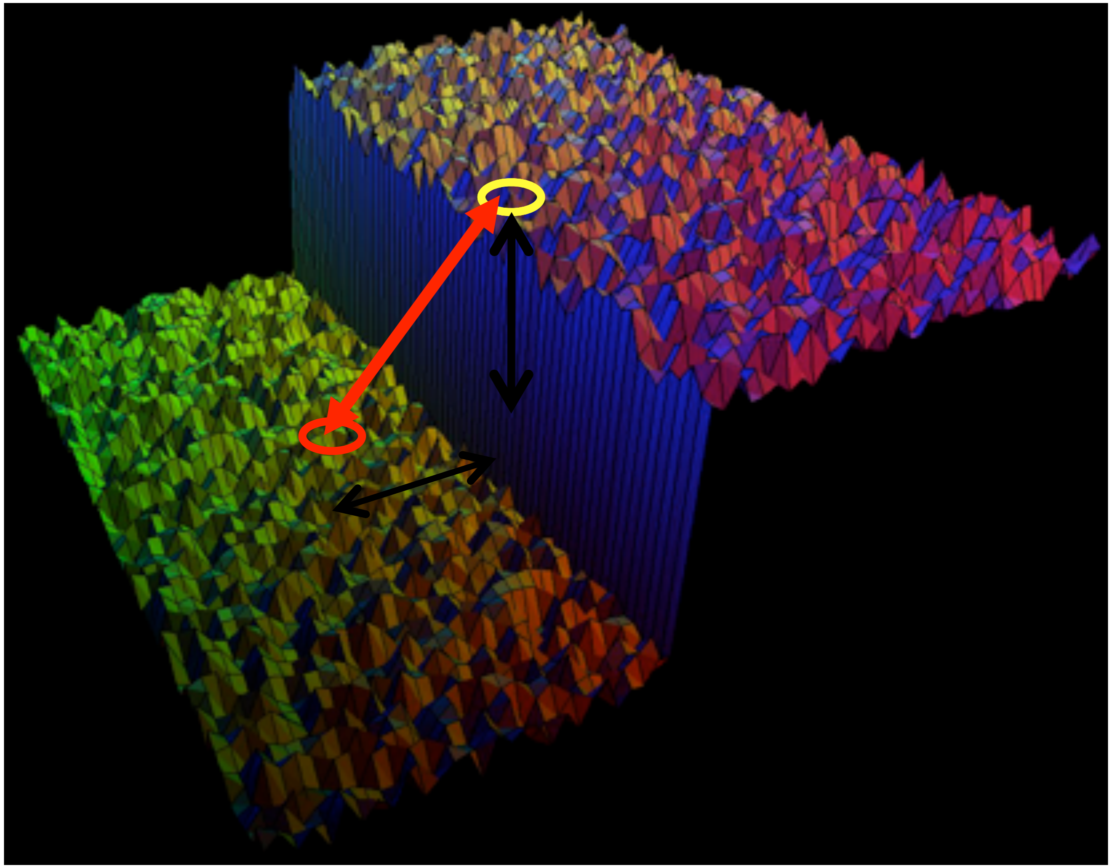


Bilateral filter – higher

Questions?

Other view

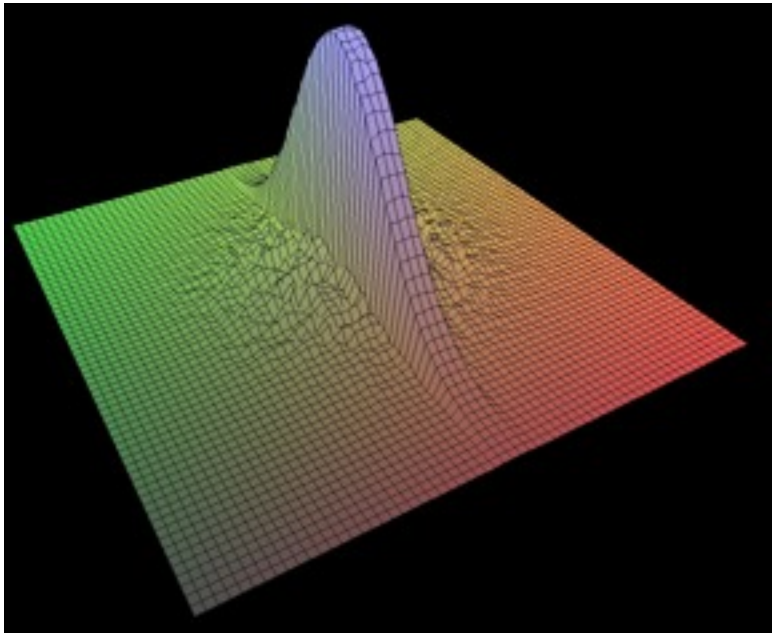
- **The bilateral filter uses the 3D distance**



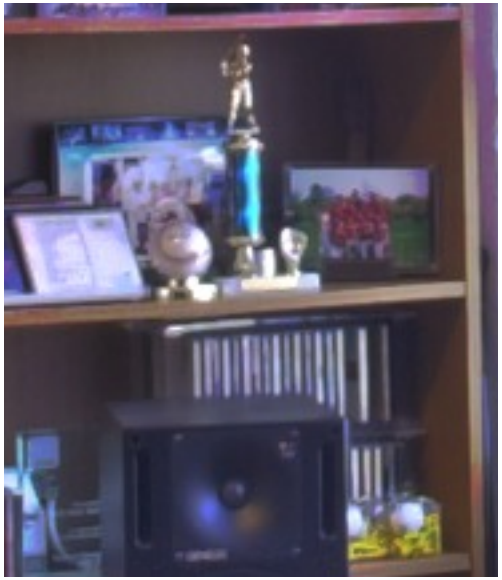
Questions?

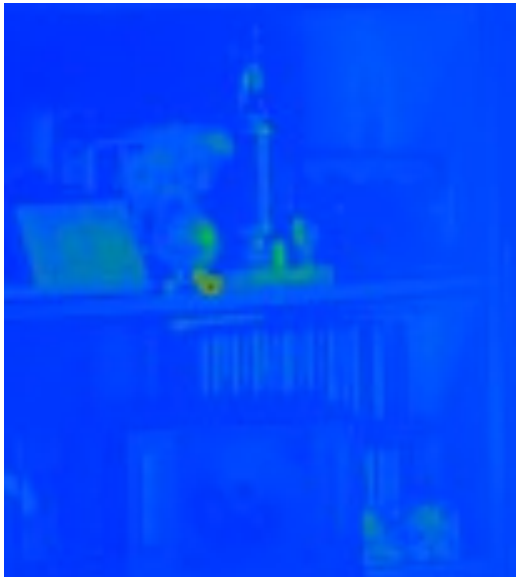
Handling uncertainty

- Sometimes, not enough "similar" pixels
- Happens for specular highlights
- Can be detected using normalization k(x)
- Simple fix (average with output of neighbors)



Weights with high uncertainty





Uncertainty

Questions?

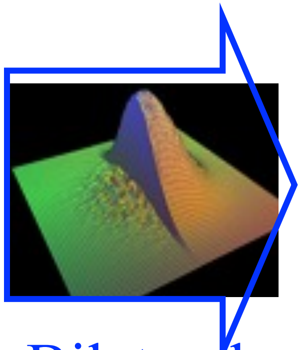
Contrast reduction

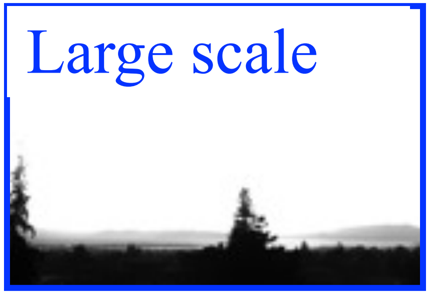
Input HDR image

Contrast
too high!

Contrast reduction

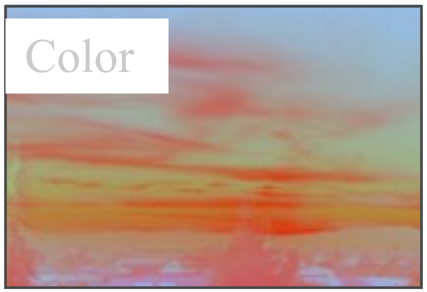
Contrast reduction





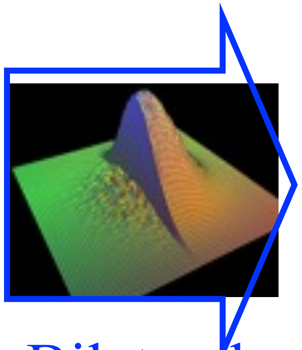
Bilateral
Filter

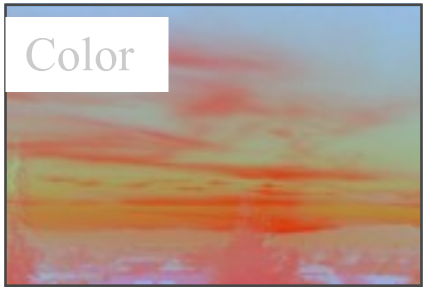
in log



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

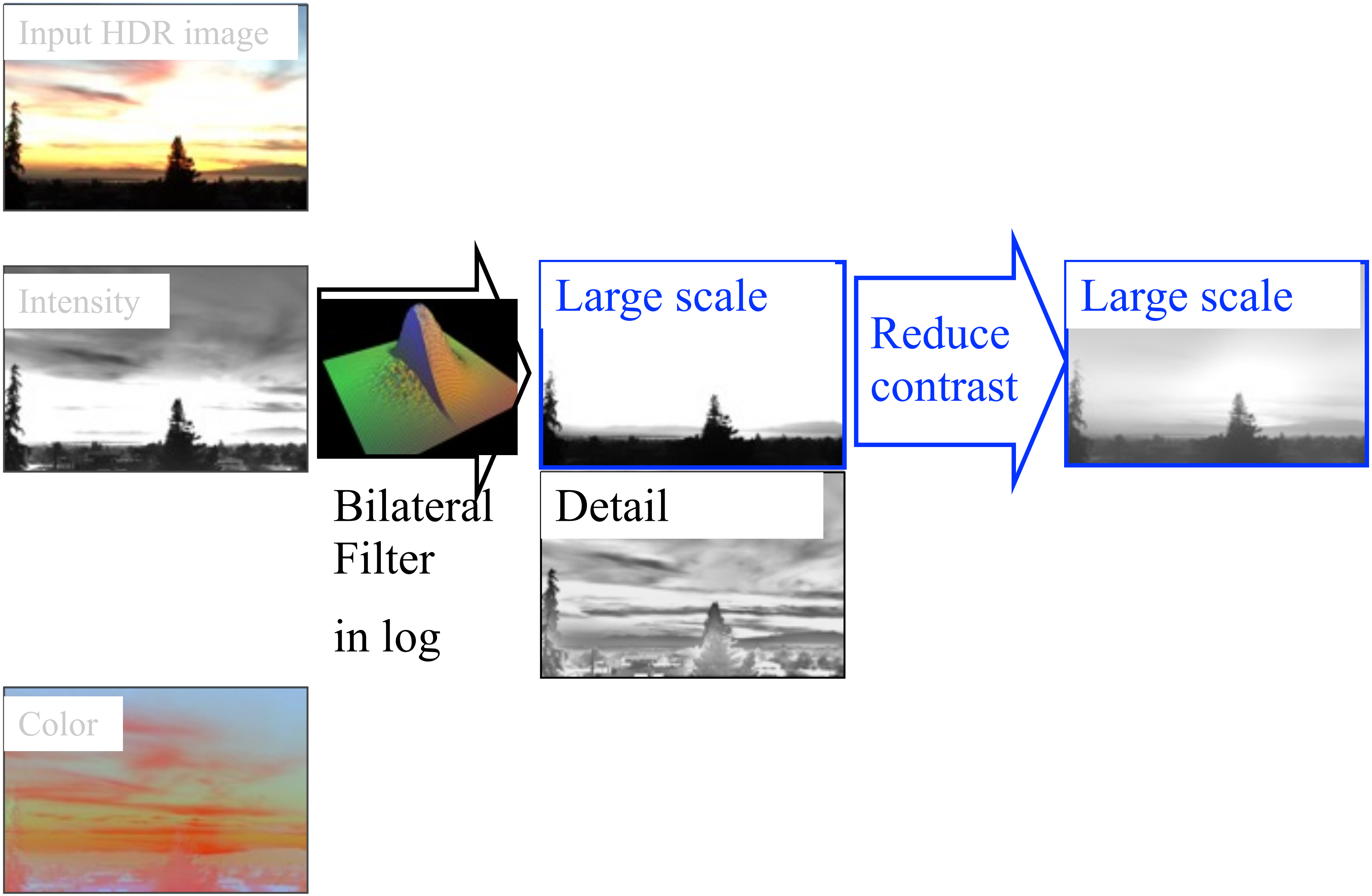
Contrast reduction



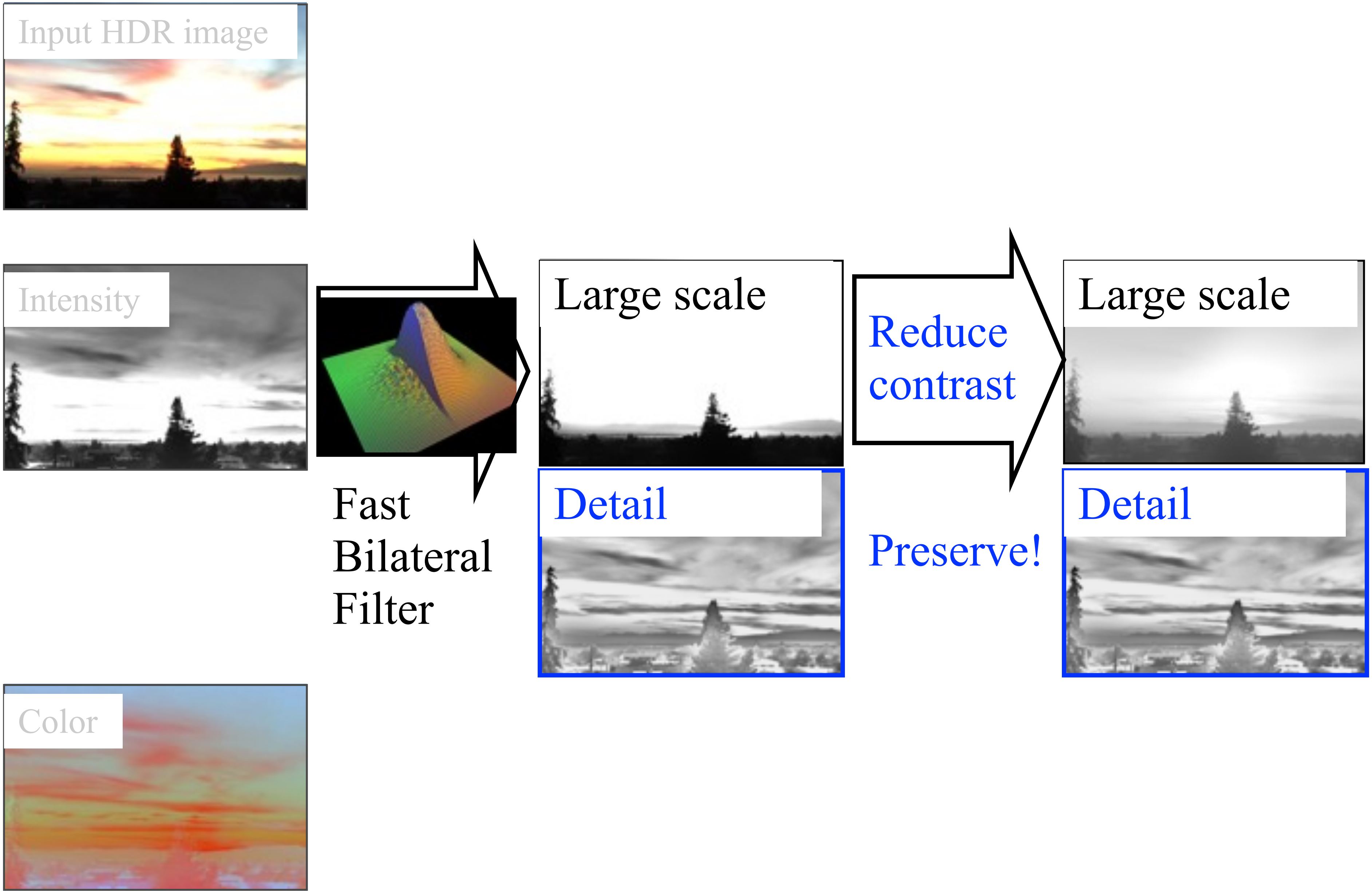


Detail = log intensity - large scale (residual)

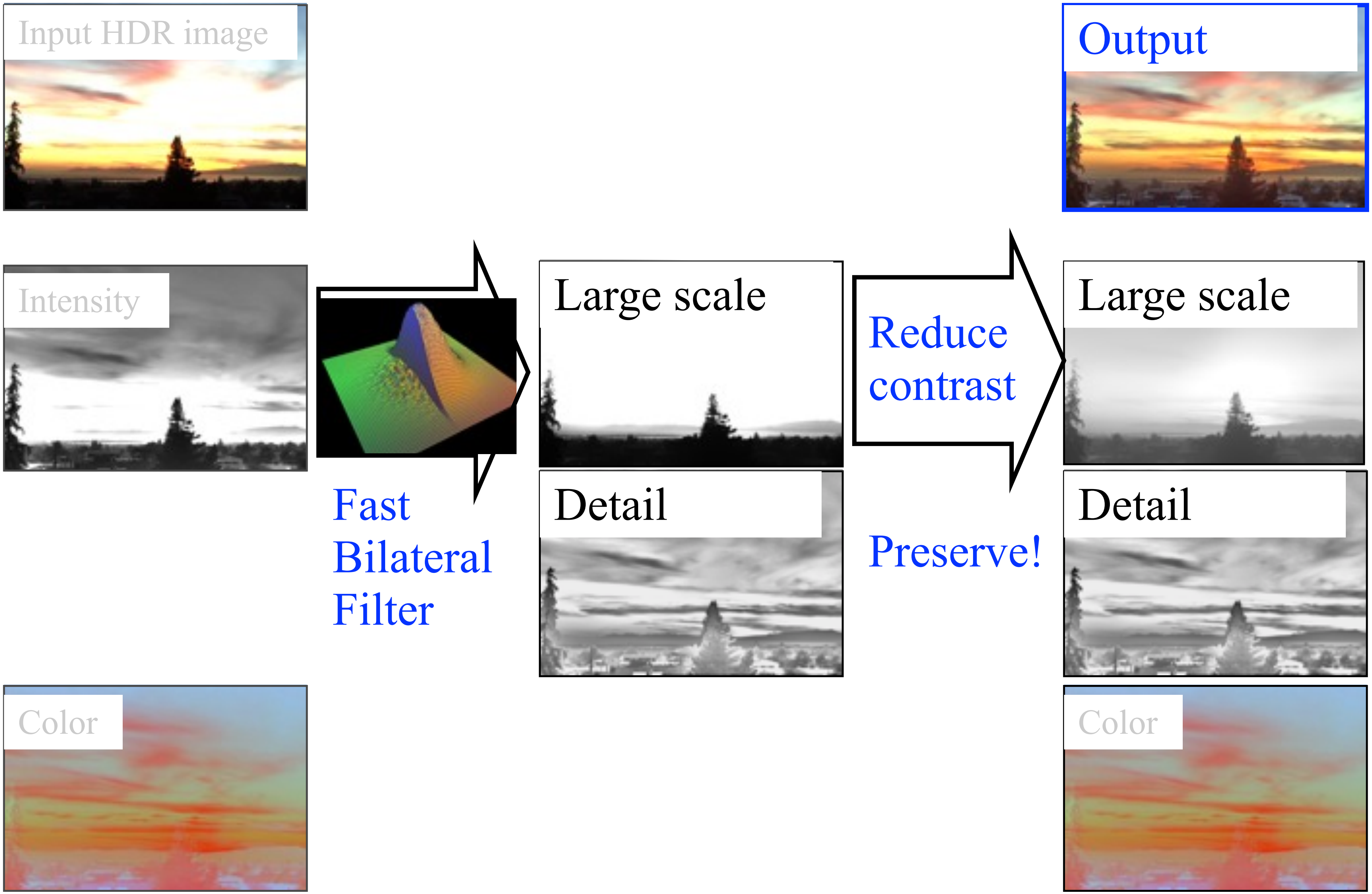
Contrast reduction



Contrast reduction



Contrast reduction



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

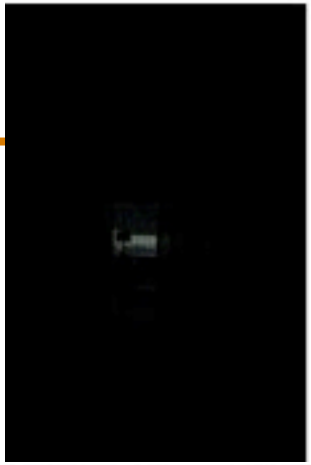
Contrast reduction in log domain

- **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)

Alternative explanation

- **Explanation 1 (previous slides):**
  - outLog =*k* inLogLarge + inLogDetail (ignoring offset)
- **Explanation 2**
  - outLog = *k* inLogIntensity + (1-*k*) detail
  - Reduce contrast of full intensity layer
  - Add back some detail
- **Same final effect since**
  - inLogDetail+inLogLarge scale = inLogIntensity
  - But different philosophy: decomposition vs. add back detail






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

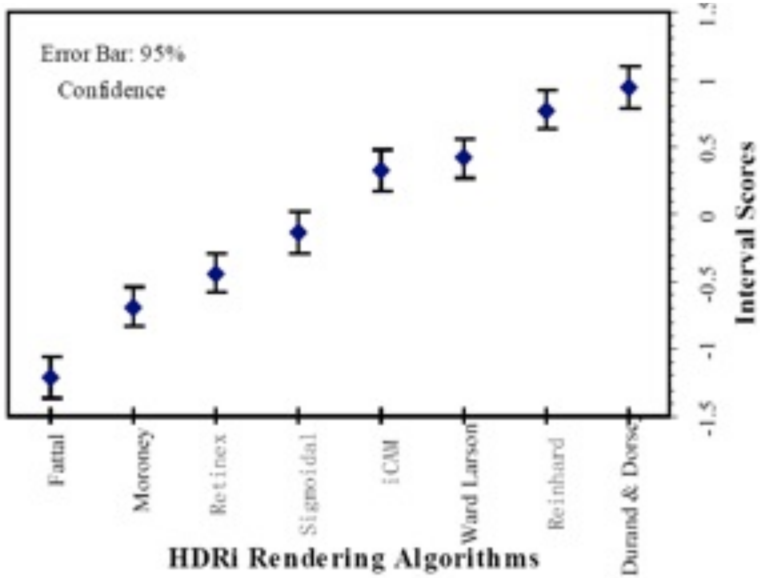
Speed

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

- **Next time: acceleration**

Tone mapping evaluation

- **Recent 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.

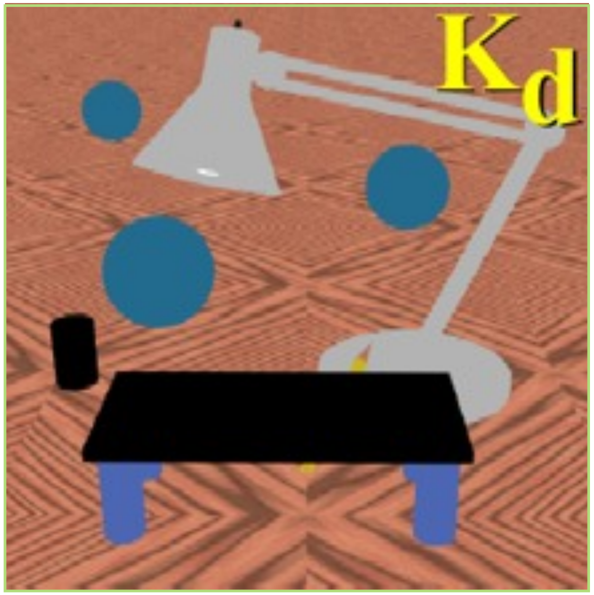
	1st	2nd	3rd	4th	5th	6th
Scene 1	P	B	A	H	I	L
Scene 2	I	P	H	A	B	L
Scene 3	P	I	A	H	L	B
Scene 4	P	L	I	A	H	B
Scene 5	I	H	A	P	L	B
Scene 6	I	H	A	P	L	B
Scene 7	I	A	P	H	B	L
Scene 8	I	P	A	H	L	B
Scene 9	P	A	L	H	B	I

Adapted from Ledda et al.

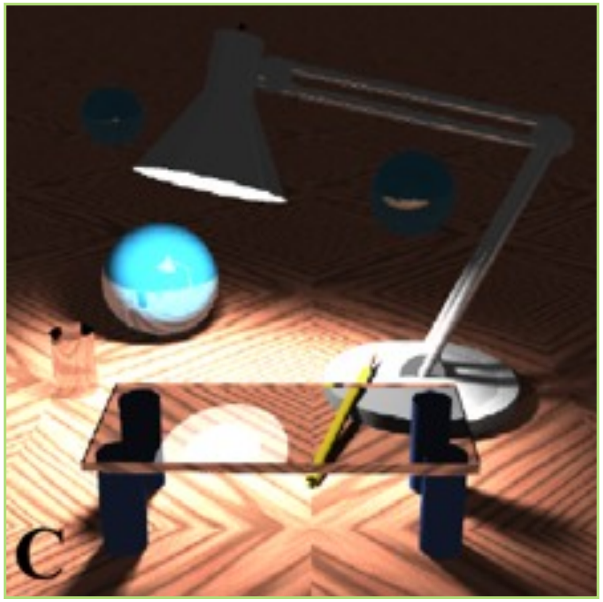
Alternative explanation

- Contrast reduction w/ intrinsic layers [Tumblin et al. 1999]
- For 3D scenes: Reduce only illumination layer

Illumination layer
Compressed



Reflectance layer



Output

Dirty vision for cool graphics

Three wrongs make one right

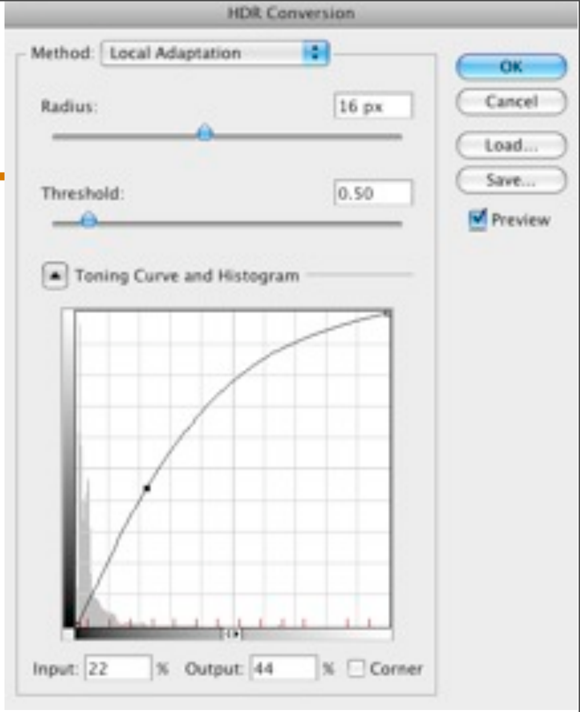
- **Analyze image**
  - Intrinsic image: albedo & illumination
  - Simple bilateral filter

- **Modify**
  - In our case, reduce contrast of large-scale (illumination)

- **Recombine**
  - Get final image

Related tools

- Photoshop “Local adaptation”



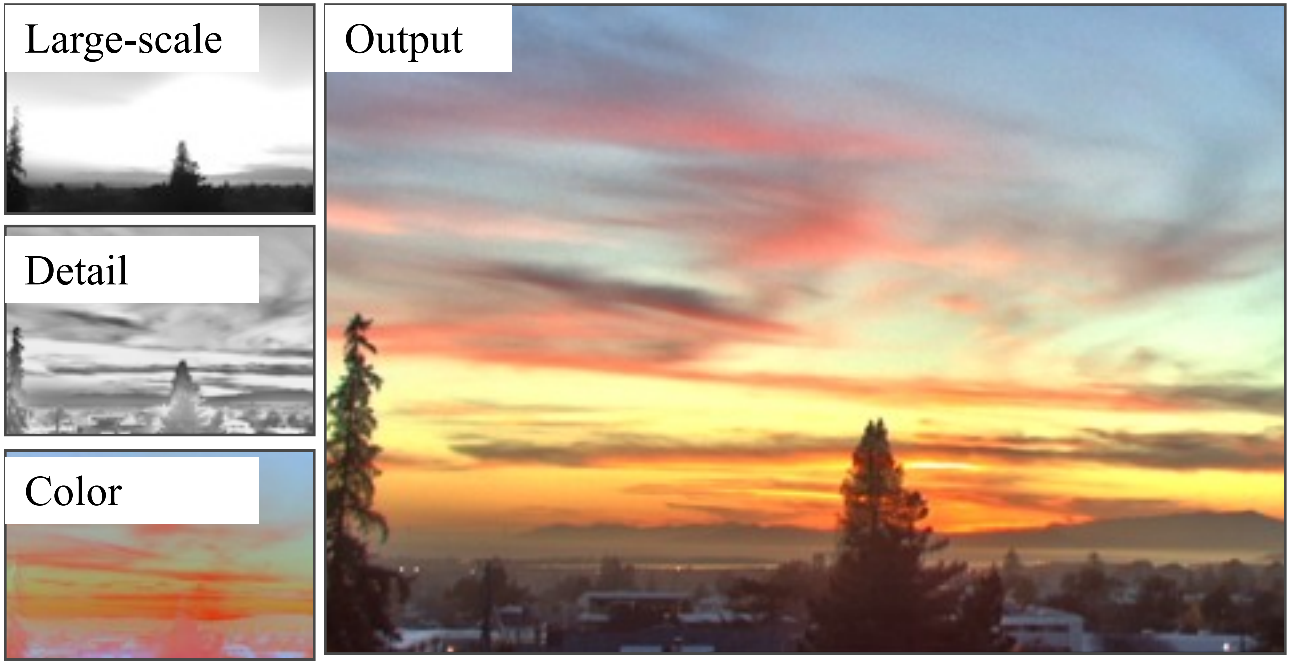
- Lightroom Fill Light

- Lightzone Relight

Questions?

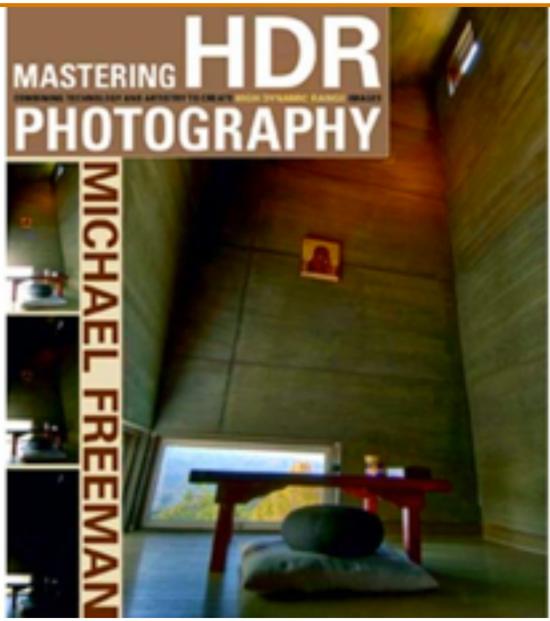
What have we learnt?

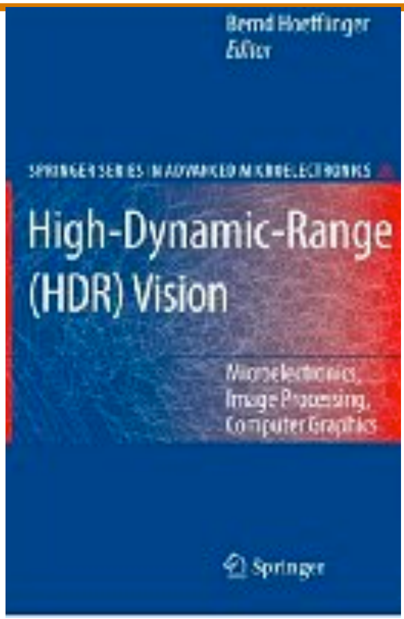
- **Log is good**
- **Luminance is different from chrominance**
- **Separate components:**
  - Low and high frequencies
- **Strong edges are important**

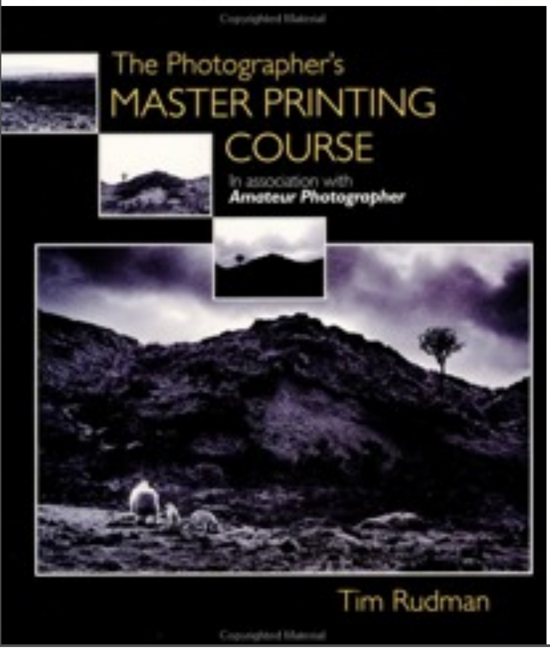


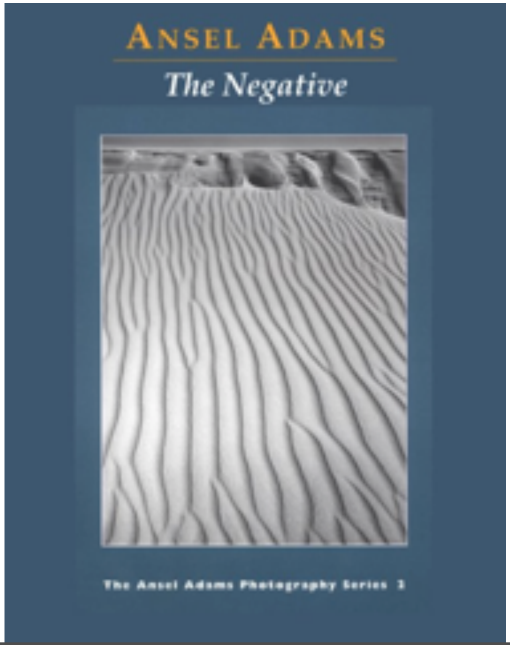
References

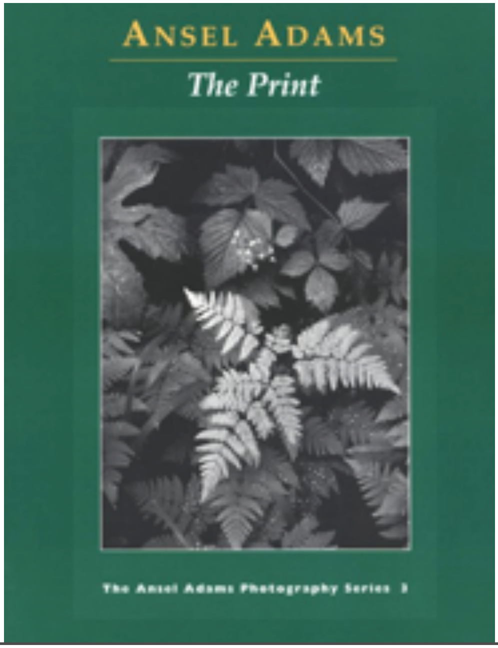

HIGH DYNAMIC
RANGE IMAGING
ACQUISITION, DISPLAY AND IMAGE-BASED LIGHTING


MASTERING HDR
PHOTOGRAPHY
MICHAEL FREEMAN


Bernd Hoefflinger
Editor
High-Dynamic-Range
(HDR) Vision
Springer


The Photographer's
MASTER PRINTING
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

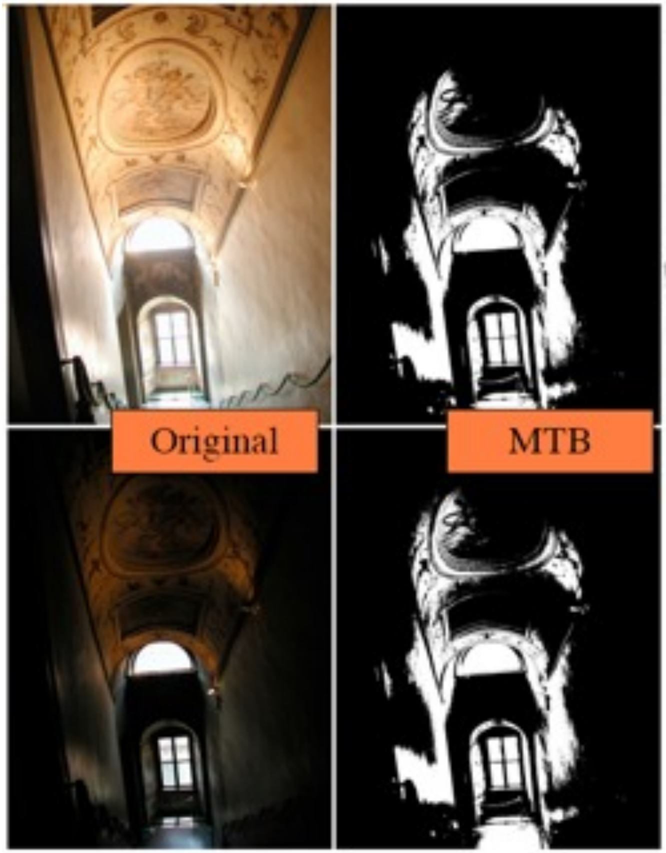
Implemented in Photosphere http://www.anyhere.com/

- 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

SIGGRAPH2005

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

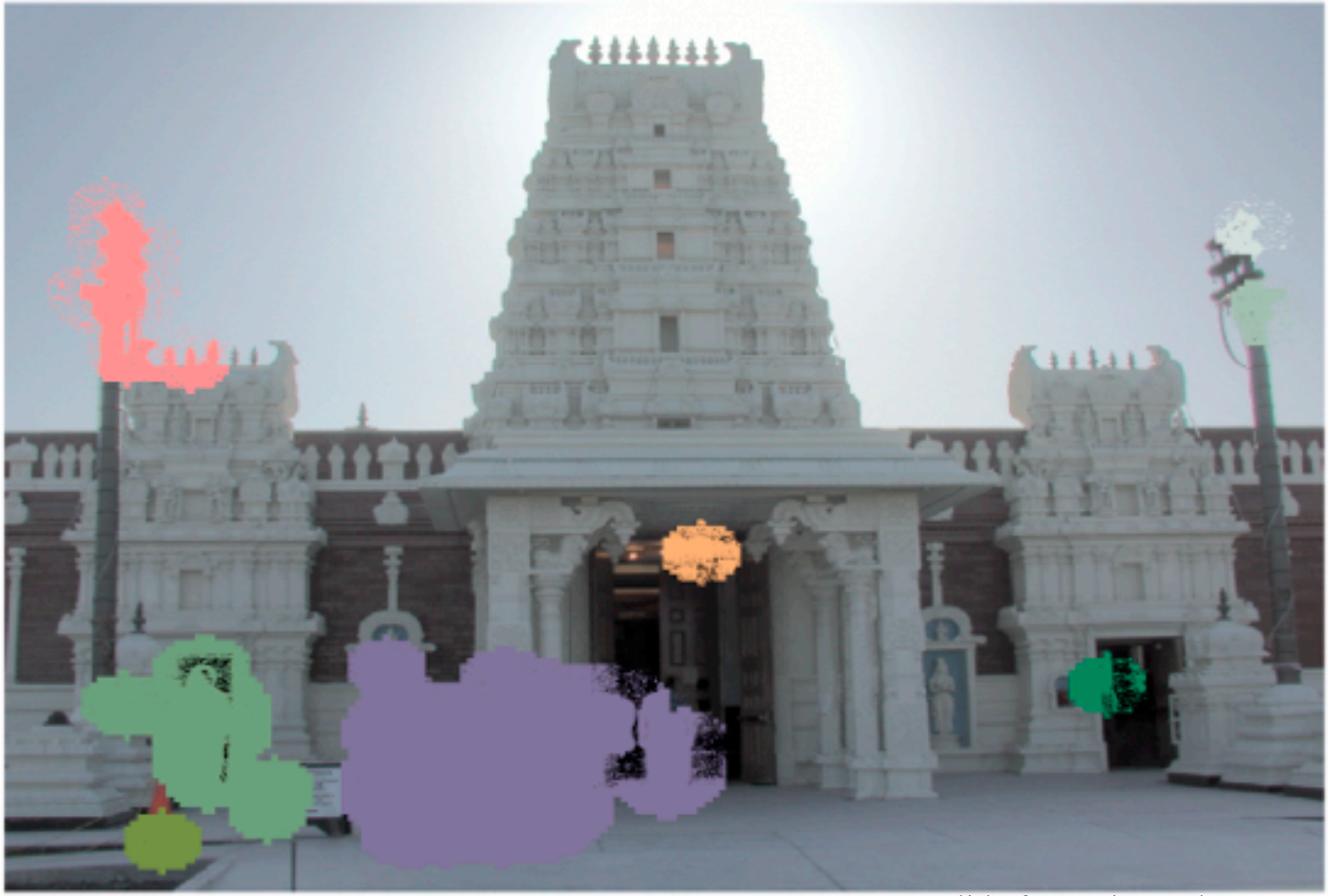
Variance-based Detection

SIGGRAPH2005

Slide from Siggraph 2005 course on HDR

Region Masking

SIGGRAPH2005



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

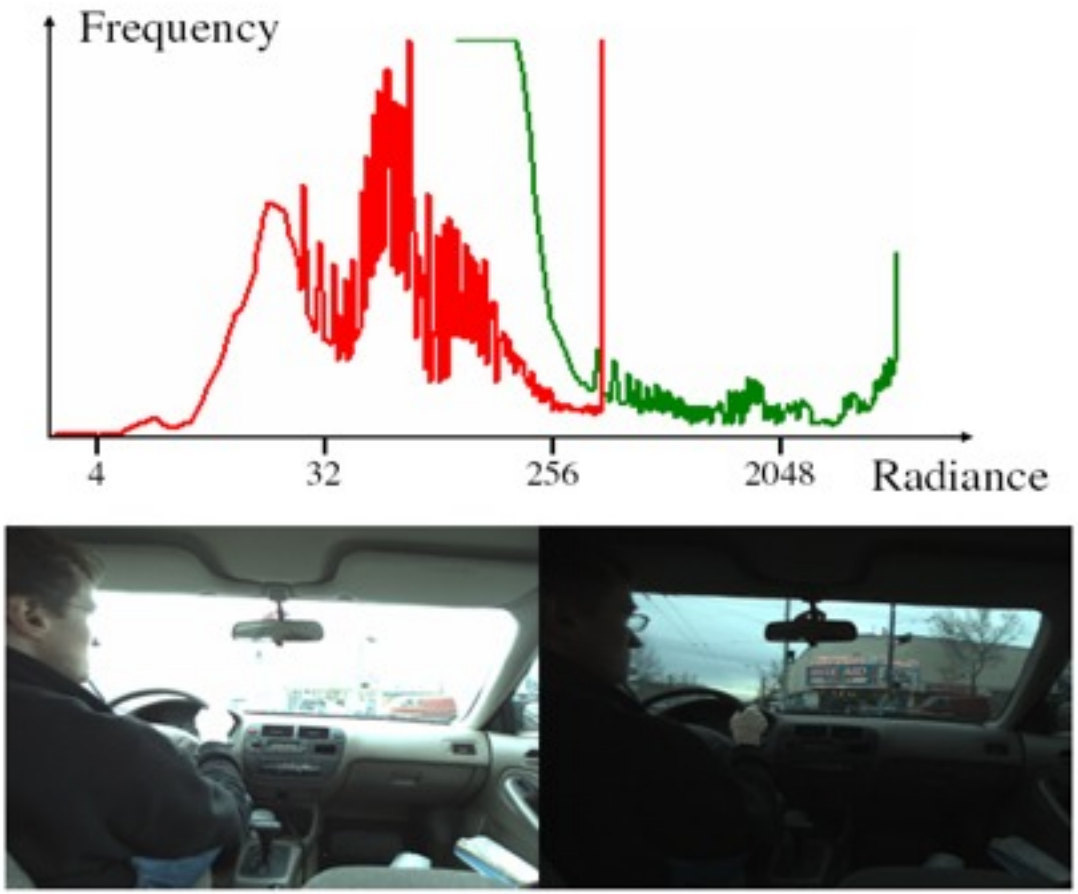


Figure 3: Two input exposures from the driving video. *The radiance histogram is shown on top. The red graph goes with the long exposure frame (bottom left), while the green graph goes with the short exposure frame (bottom right). Notice that the combination of these graphs spans a radiance range greater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