Applications

Frédo Durand
MIT CSAIL

Overview

- Denoising

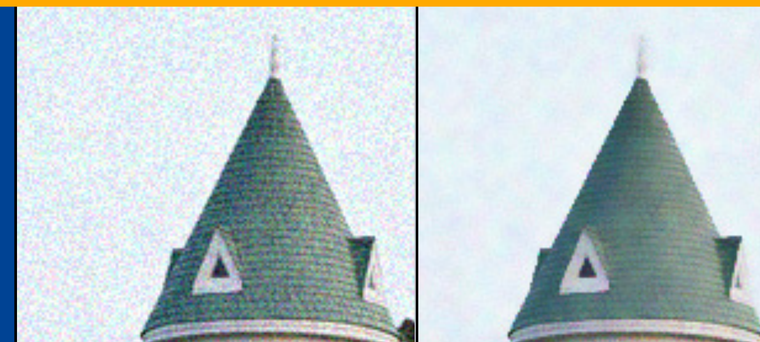
- Tone mapping

- Relighting & texture editing

Overview

- **Denoising**

  Not most powerful application
  Not best denoising, but good & simple



- Tone mapping

- Relighting & texture editing

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 sigma

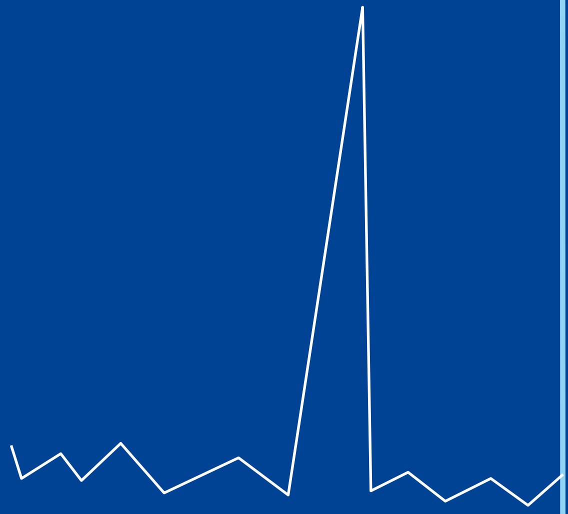
Basic denoising

Bilateral filter

Bilateral filter – higher sigma

Impulse noise

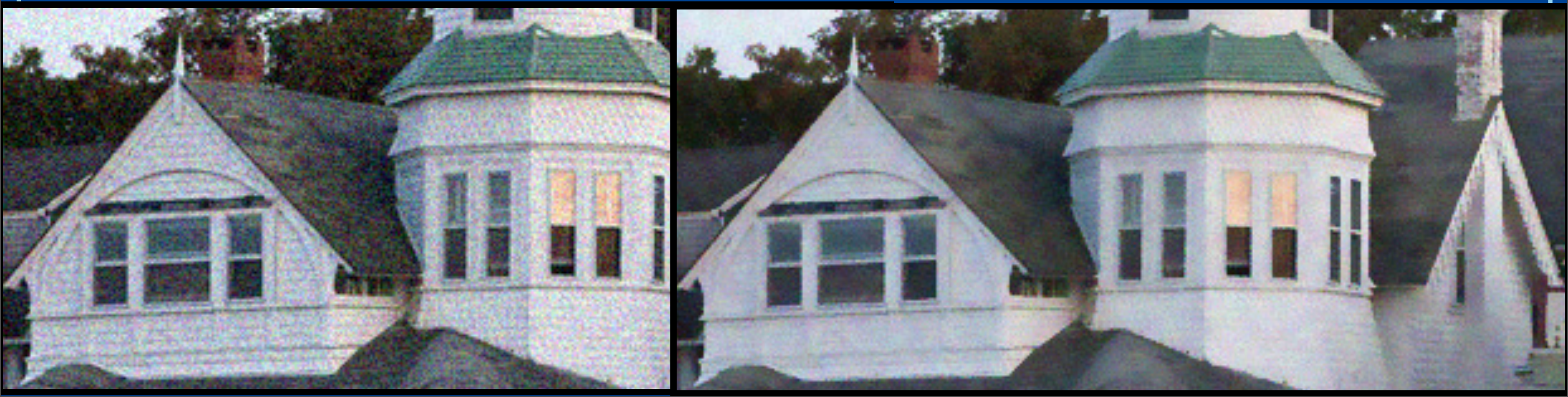
- High amplitude noise at few pixels
- Outlier rejection of bilateral filter works too well
  – the noise is treated as a strong edge
- Solution:
  – Pre-filter with median filter
  – Use median-filtered image M as reference for range Gaussians



$$BF[I]_{\mathbf{p}} = \frac{1}{W_{\mathbf{p}}} \sum_{\mathbf{q} \in S} G_{\sigma_s}(\| \mathbf{p} - \mathbf{q} \|) \, G_{\sigma_r}(| \mathbf{M}_{\mathbf{p}} - I_{\mathbf{q}} |) \, I_{\mathbf{q}}$$

Denoising

- Small spatial sigma (e.g. 7x7 window)
- Adapt range sigma to noise level
- Maybe not best denoising method, but best simplicity/quality tradeoff
  - No need for acceleration (small kernel)
  - But the denoising feature in e.g. Photoshop is better
- Pre-filter with median for impulse noise



Overview

- Denoising

- **Tone mapping**

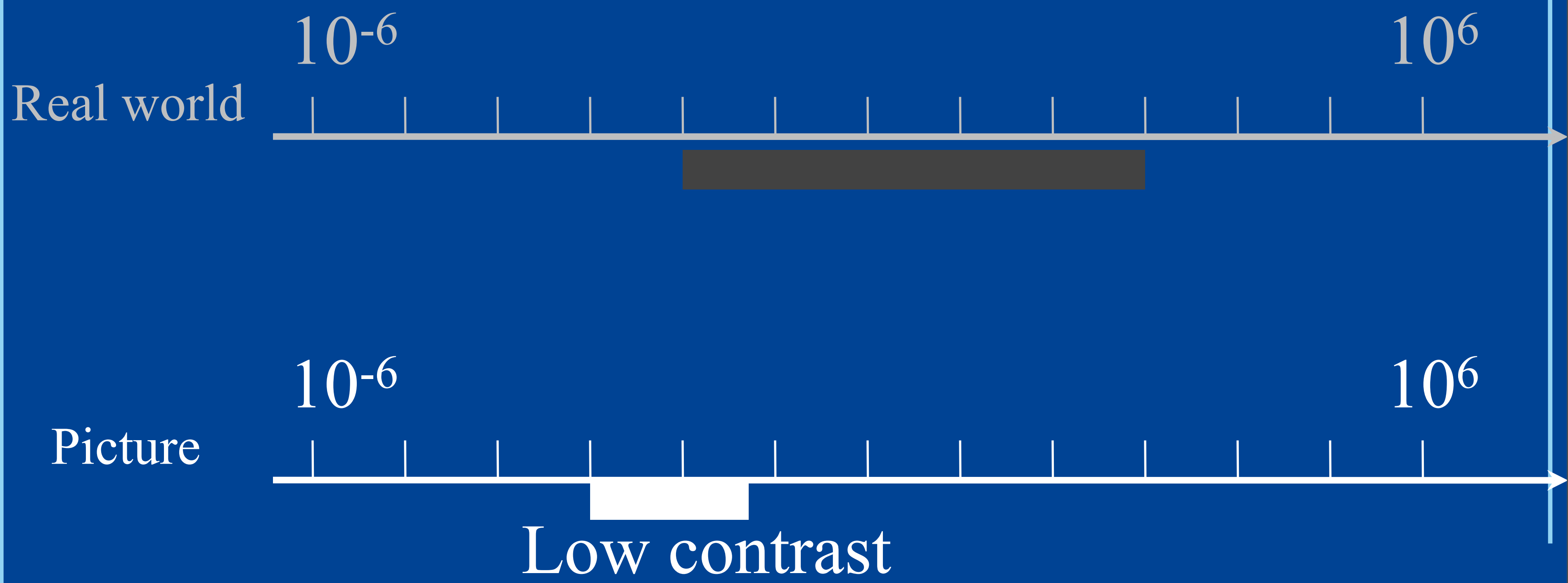
- Relighting & texture editing

Real world dynamic range

- Eye can adapt from ~ 10^{-6} to 10^{6} cd/m^2
- Often 1 : 10,000 in a scene

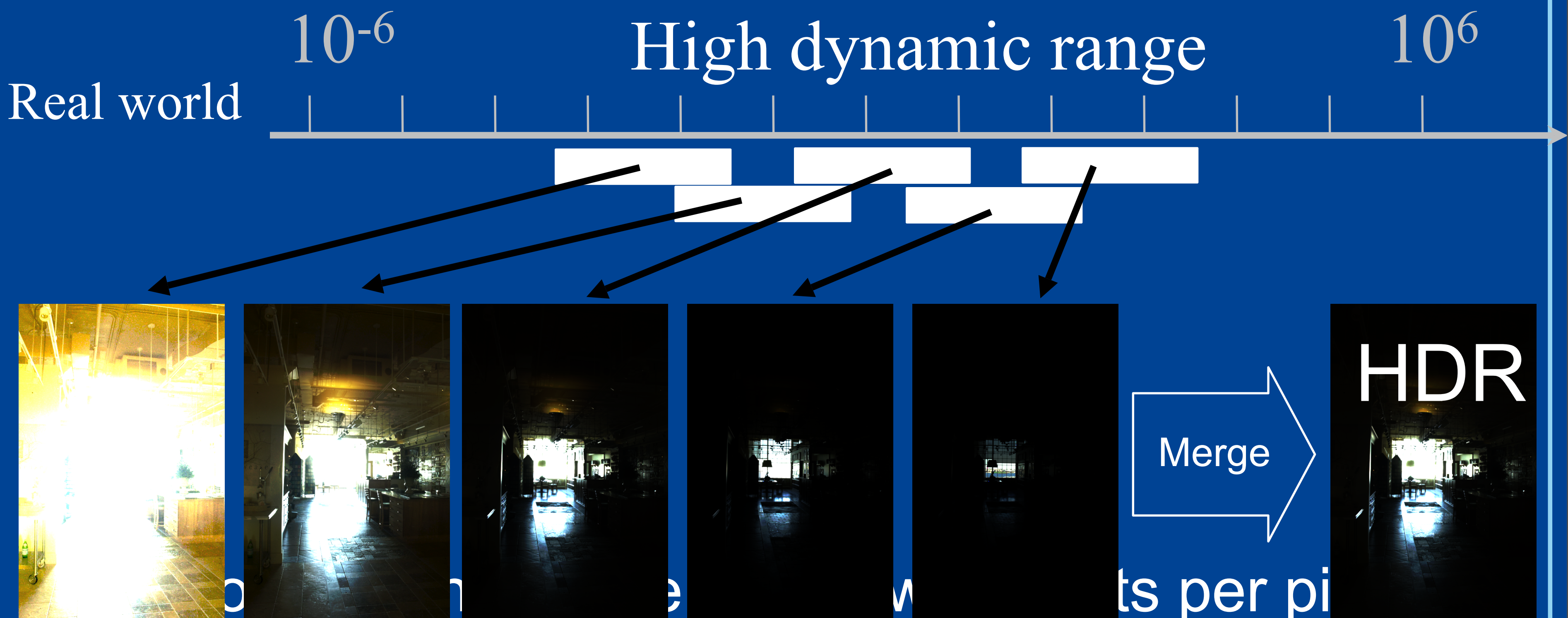
Picture dynamic range

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



Multiple exposure photography

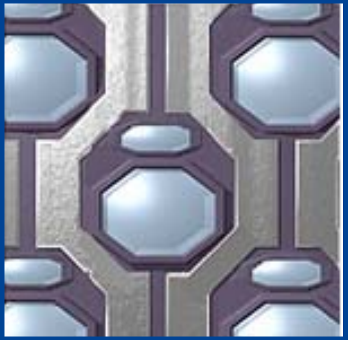
- Merge multiple exposure to cover full range



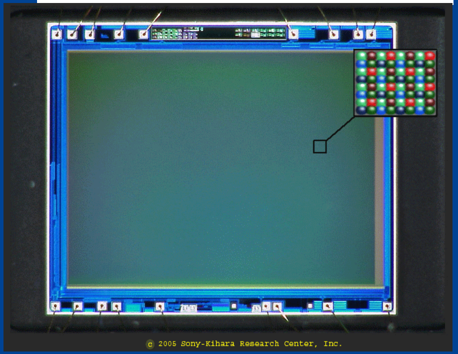
  – But we still can't display it

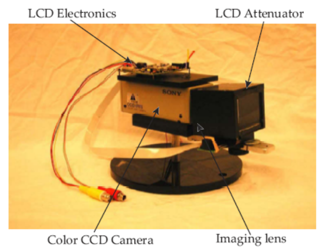
The future: HDR Cameras

- HDR sensors using CMOS
  - Use a log response curve
  - e.g. SMaL,
- Assorted pixels
  - Fuji
  - Nayar et al.
- Per-pixel exposure
  - Filter
  - Integration time
- Multiple cameras using beam splitters
- Other computational photography tricks



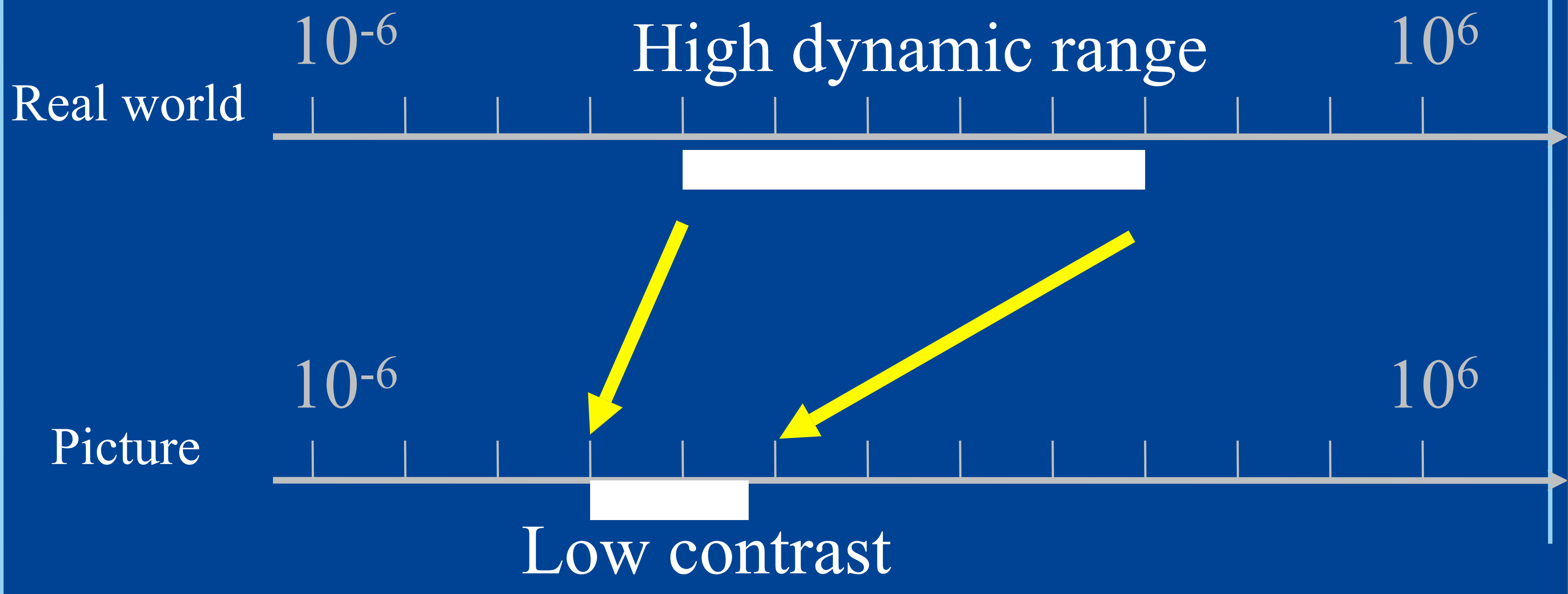
Fuji SuperCCD





Problem: Contrast reduction

- Match limited contrast of the medium
- Preserve details



Tone mapping

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

Naïve technique

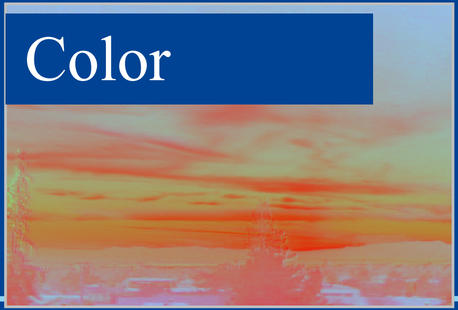
- Scene has *1:10,000* contrast, display has *1:100*
- Simplest contrast reduction?

Naïve: Gamma compression

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

Gamma compression on intensity

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

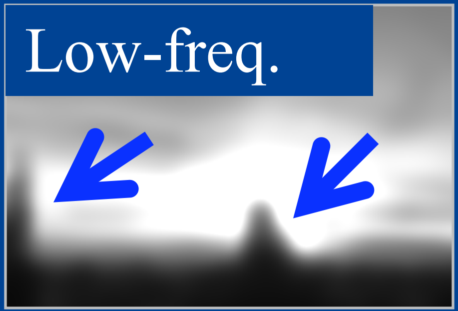


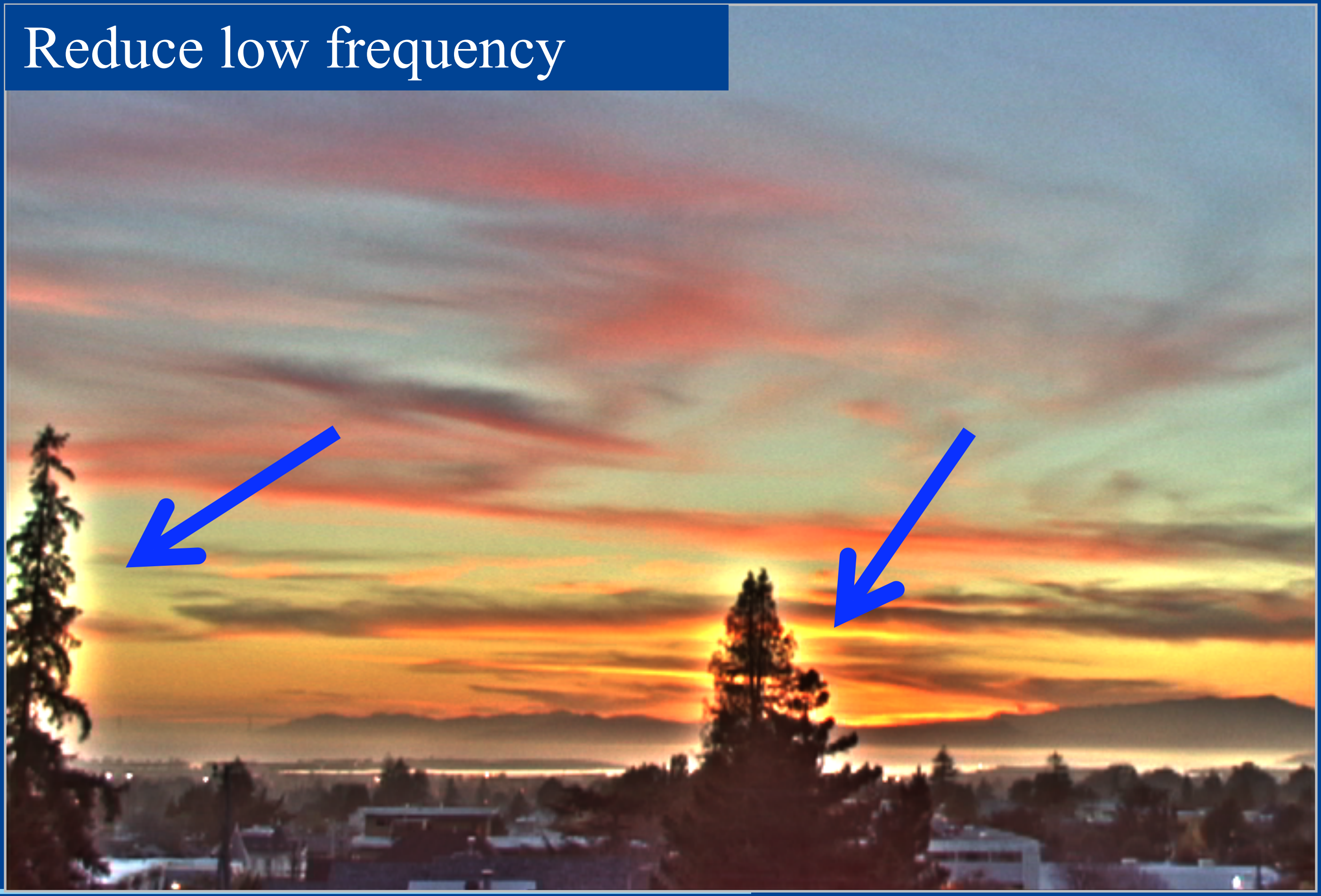
Oppenheim 1968, Chiu et al. 1993

- Reduce contrast of low-frequencies (log domain)
- Keep high frequencies

The halo nightmare

- For strong edges
- Because they contain high frequency

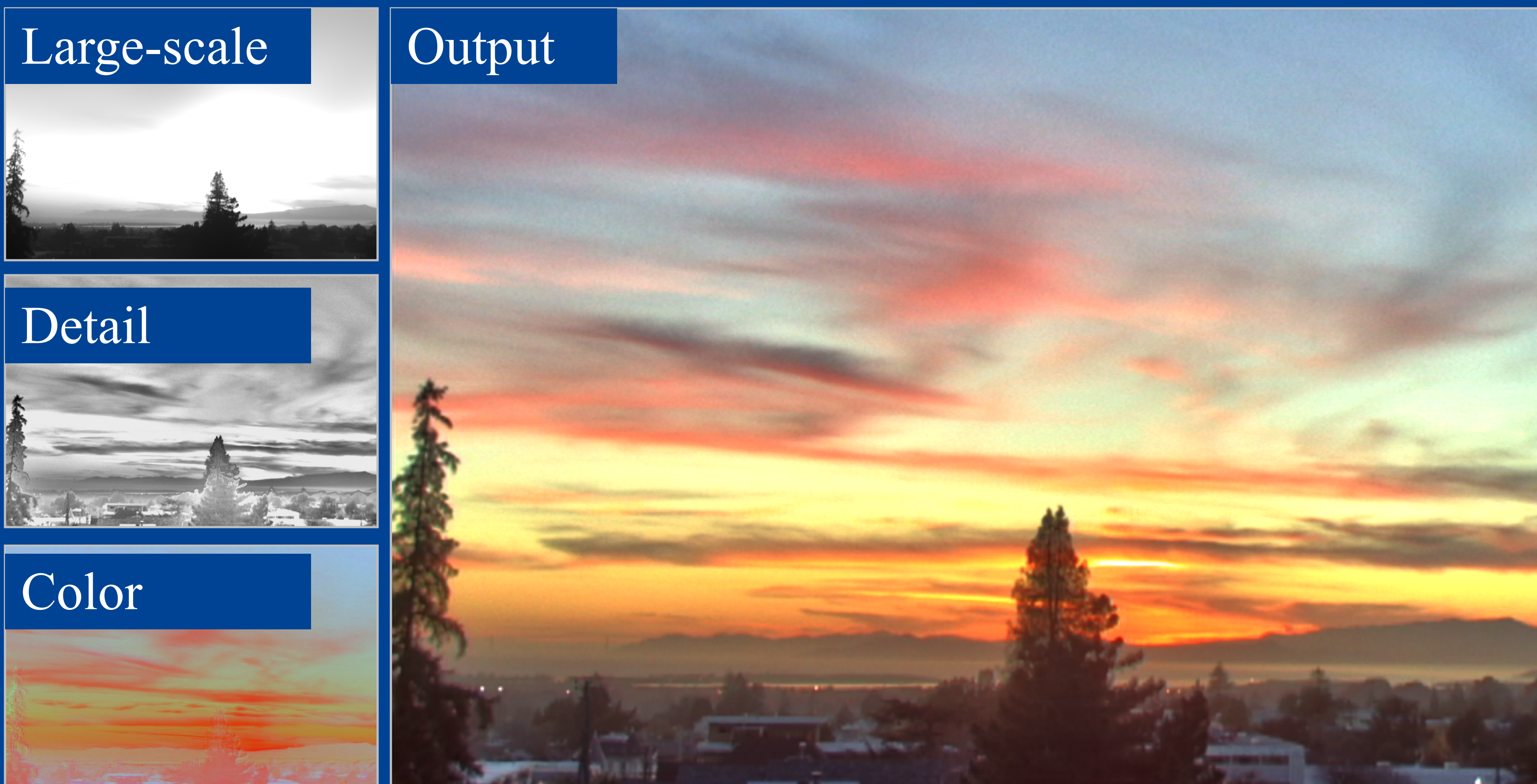




Bilateral filtering to the rescue

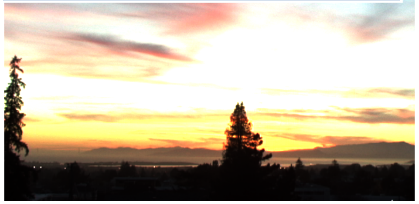
- Large scale = bilateral (log intensity)
- Detail = residual

[Durand & Dorsey 2002]



Contrast reduction

Input HDR image

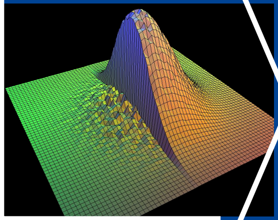


Contrast
too high!

Contrast reduction

Input HDR image

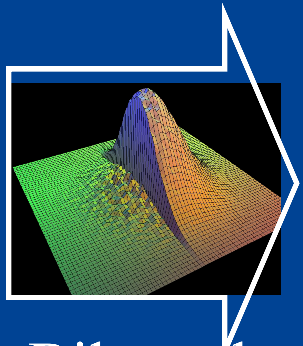
Contrast reduction



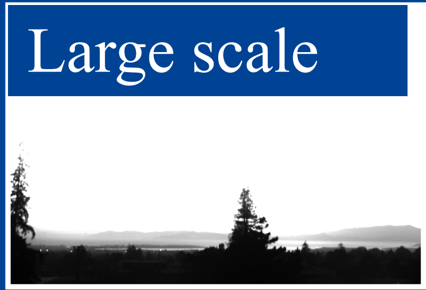
Bilateral
Filter
(in log domain!)

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

Contrast reduction

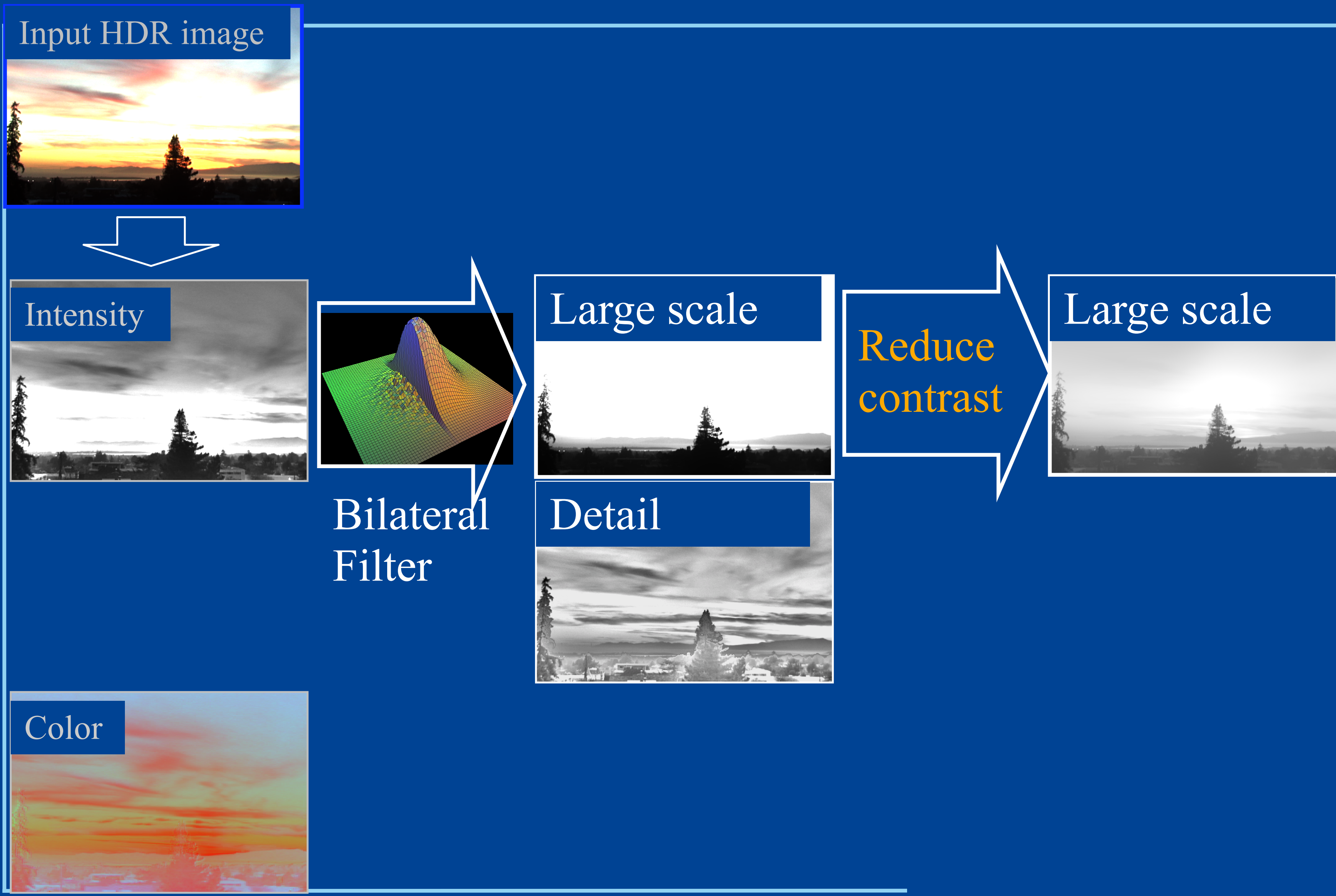


Bilateral Filter

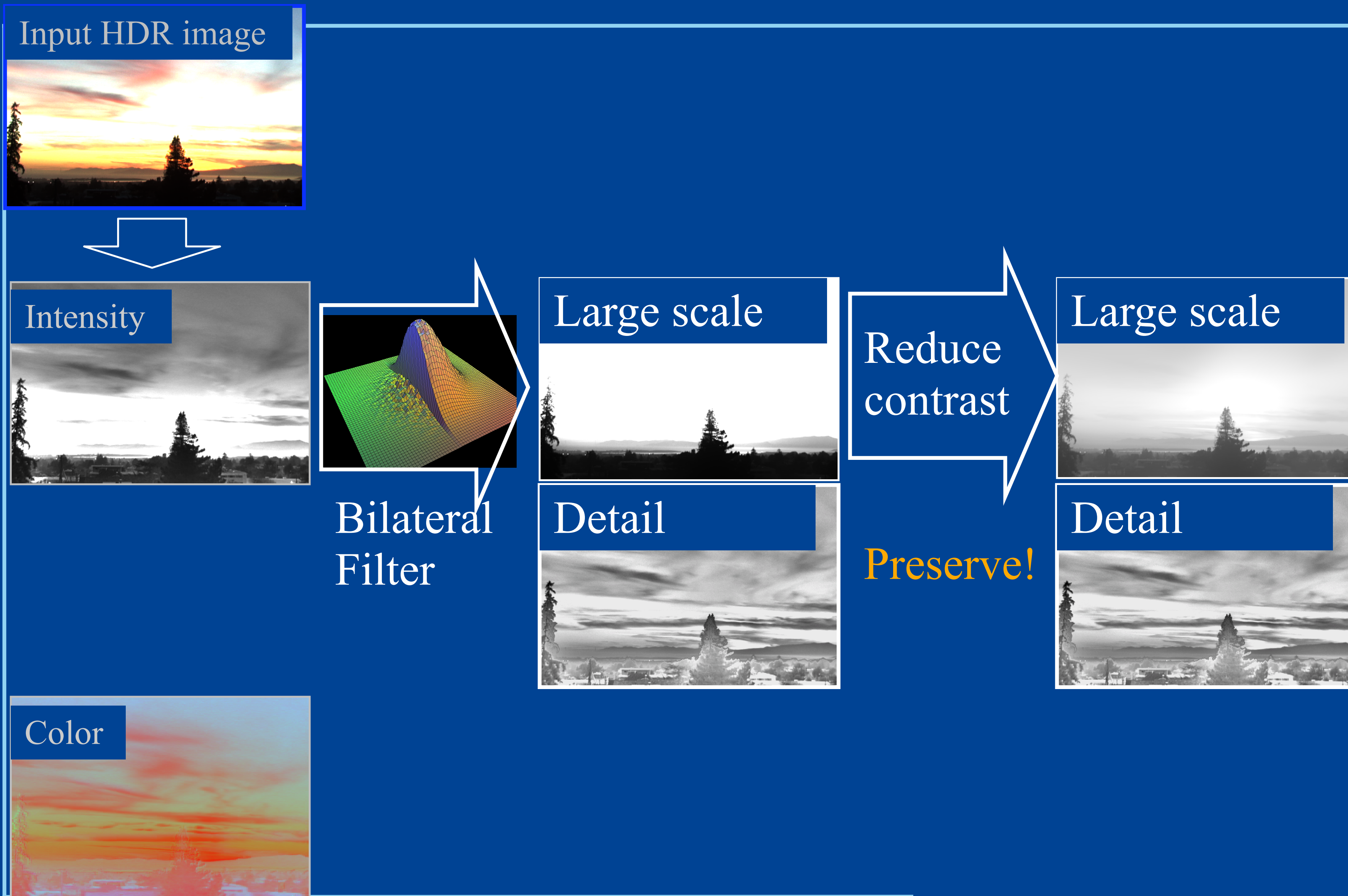


Detail = log intensity –large scale (residual)

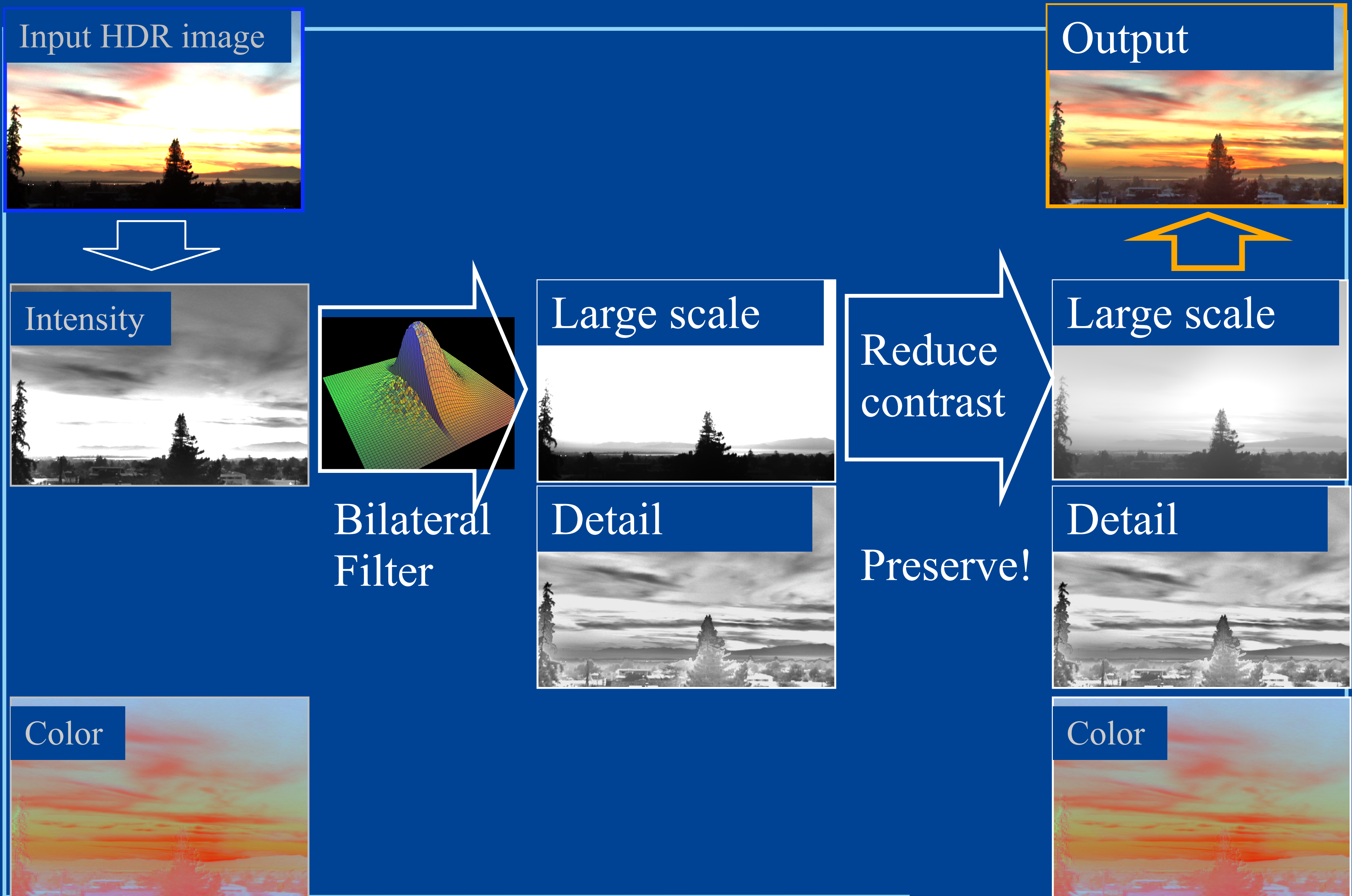
Contrast reduction



Contrast reduction



Contrast reduction



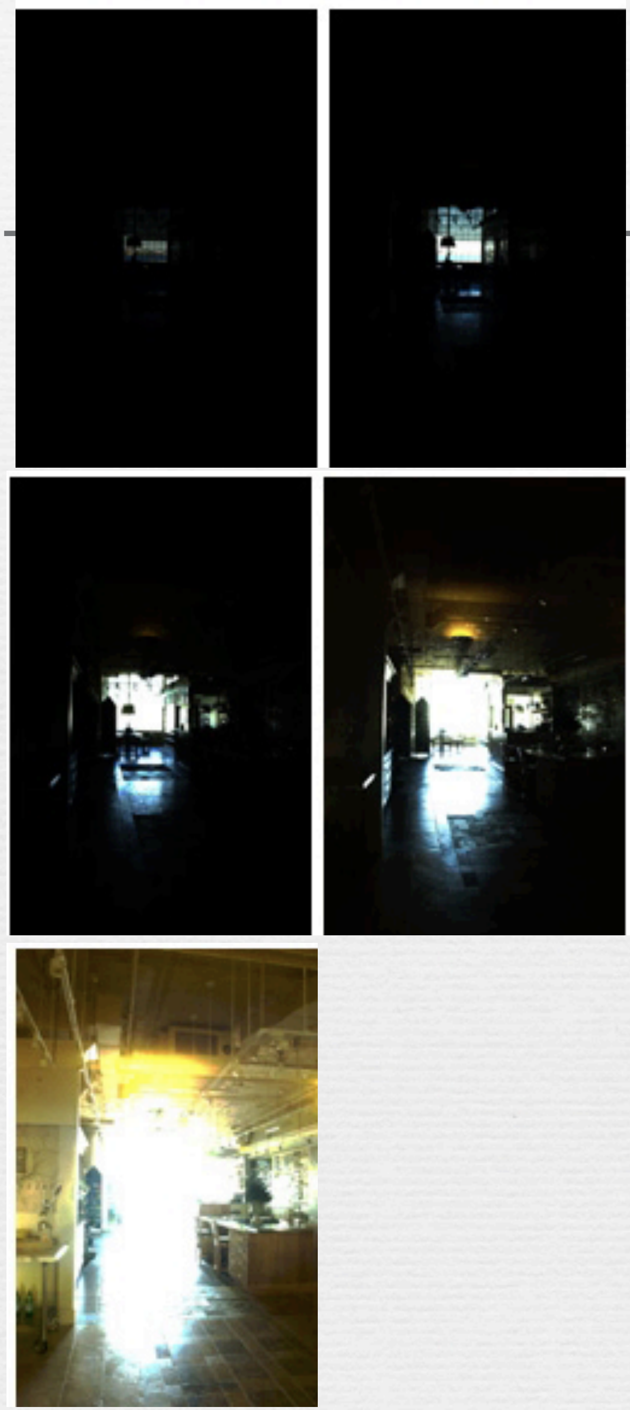
Contrast reduction in log domain

- 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

$$\text{outLog} = \text{inLogDetail} + \text{inLogLarge} * k - \max(\text{inLogLarge})$$

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

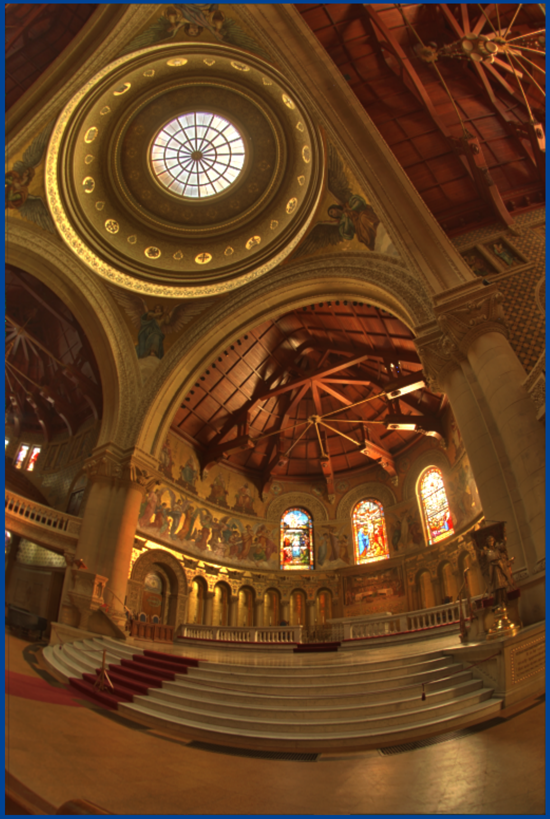


Denoising vs. tone mapping

- Denoising:
  - decompose into noise+signal
  - Throw away noise, keep signal
  - Small kernel
- Tone mapping
  - Decompose into large scale + detail
  - Preserve detail, reduce large scale
    - Opposite of denoising!
  - Large kernel
    - because detail=high+medium frequency
    - ➔computation challenge

Crossing lines

- The bilateral filter is influenced by pixels across thin line
- Good for tone mapping

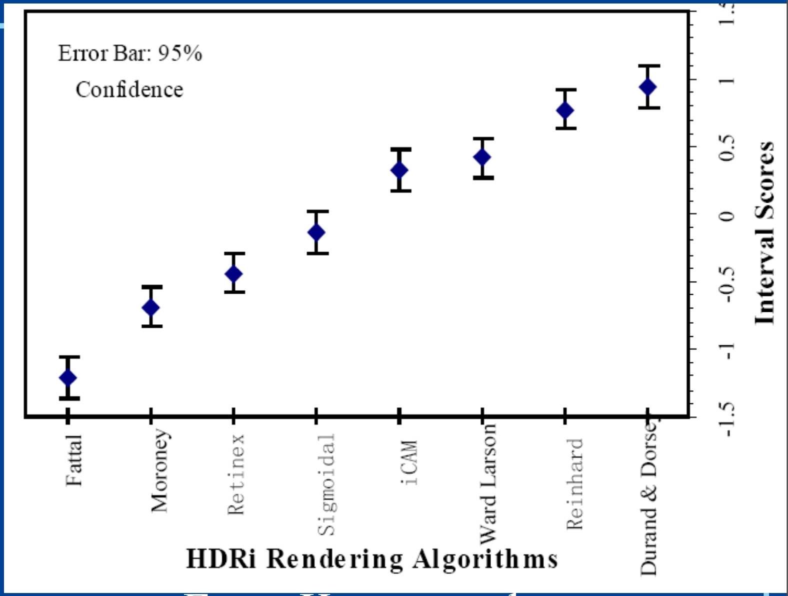



What matters

- 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

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.

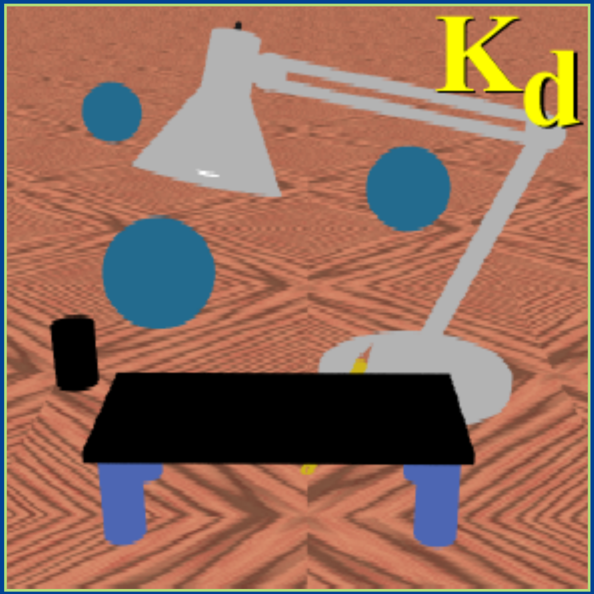
	1st	2nd	3rd	4th	5th	6th
Scene 1	P	B	A	H	I	L
Scene 2	I	P	H	A	B	L
Scene 3	P	I	A	H	L	B
Scene 4	P	L	I	A	H	B
Scene 5	I	H	A	P	L	B
Scene 6	I	H	A	P	L	B
Scene 7	I	A	P	H	B	L
Scene 8	I	P	A	H	L	B
Scene 9	P	A	L	H	B	I

Adapted from Ledda et al.

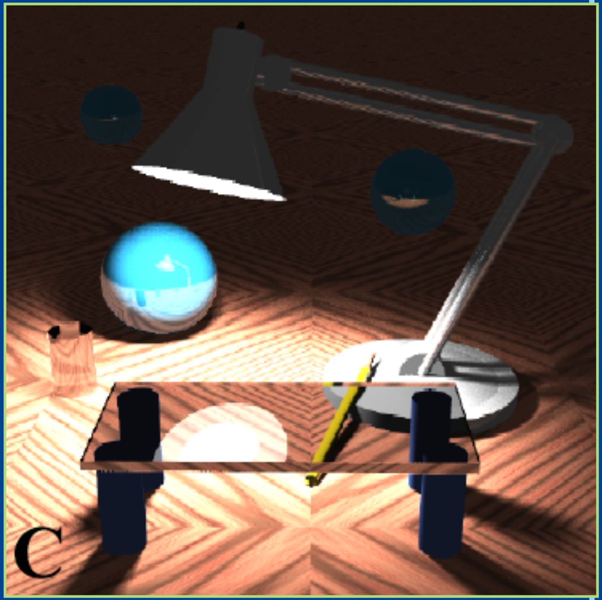
Alternative explanation

- 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

Overview

- Denoising

- Tone mapping

- **Relighting & texture editing**

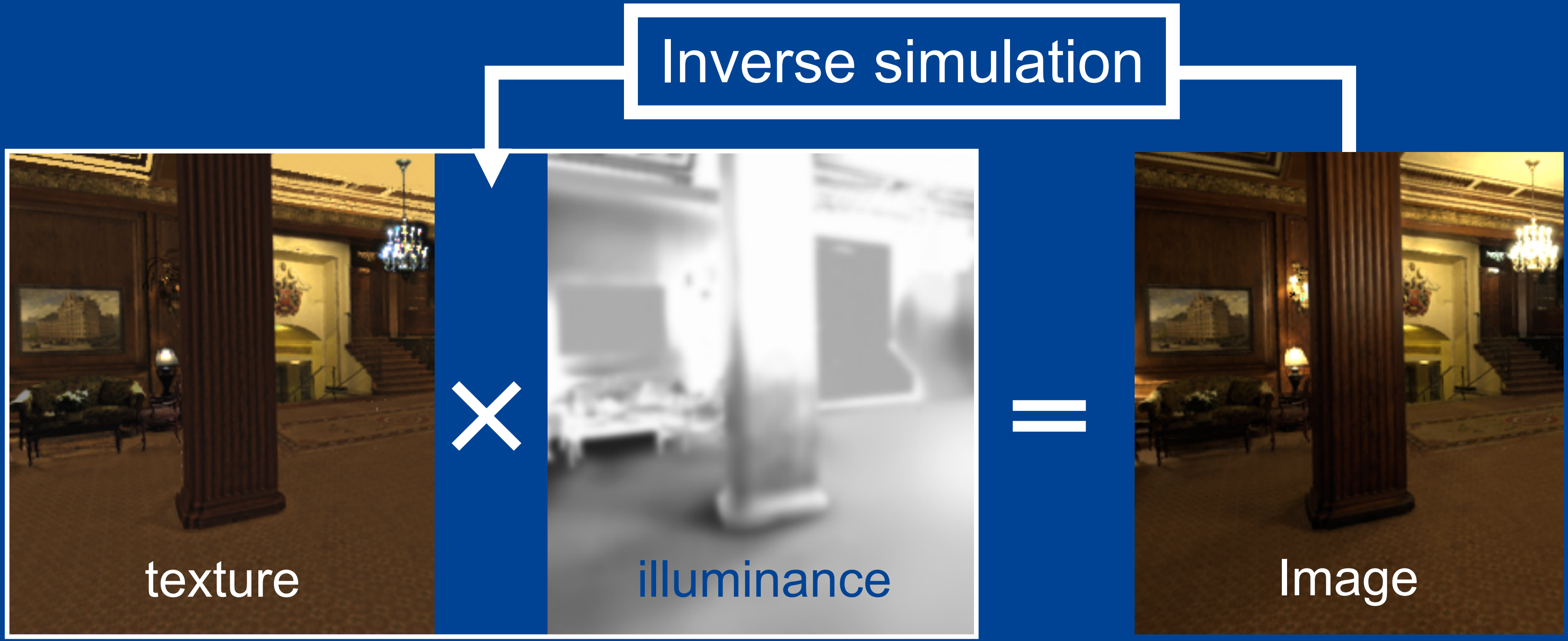
Discounting Existing Lighting

- Motivation
  - Relighting
  - Image manipulation (e.g. clone brush, texture synthesis)
- Context:
  - The following slides are from a project dealing with images +depth

Inverse Lighting Simulation

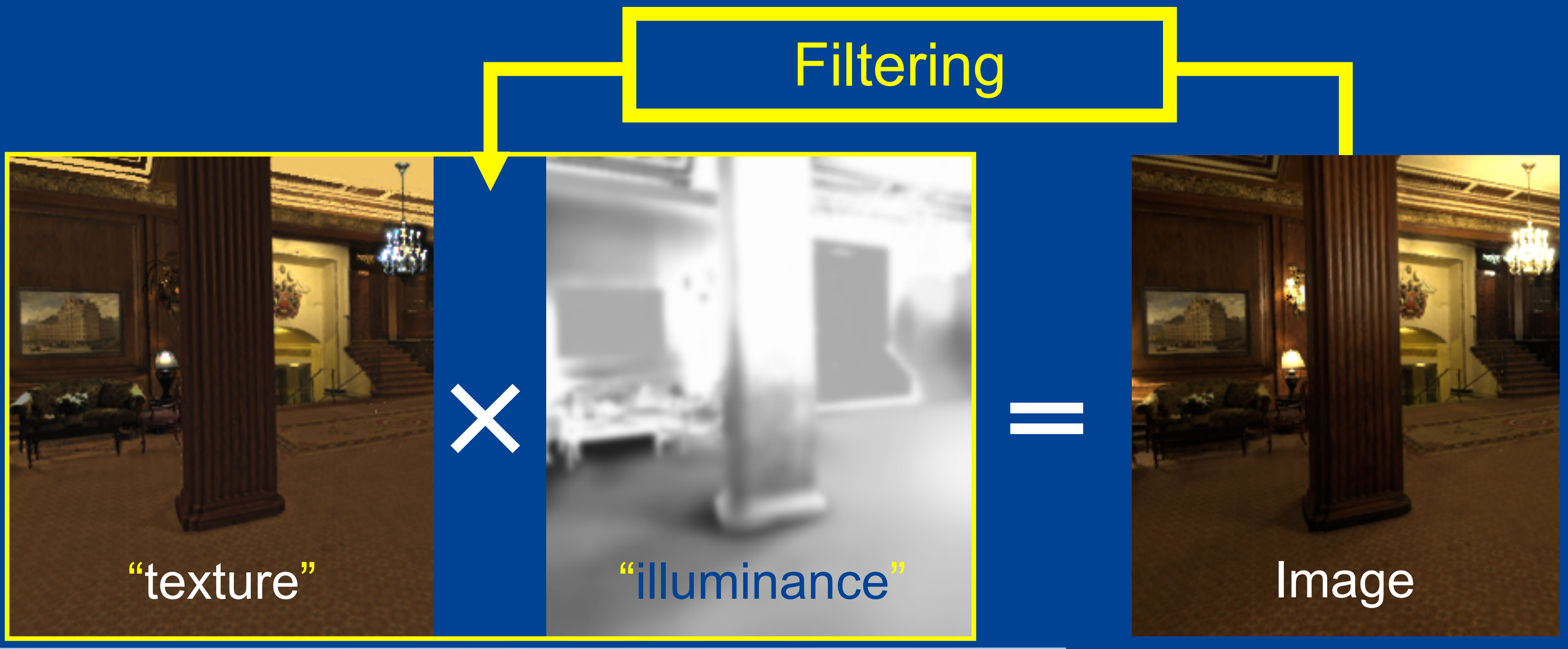
- Physically-based approaches

  e.g. [Fournier et al.93, Drettakis et al.97, Debevec.98, Yu et al.99, Loscos et al. 99, Loscos et al.00]



Texture-Illuminance Decoupling

- Not physically based
  - Our “texture” and “illuminance” are reasonable estimates

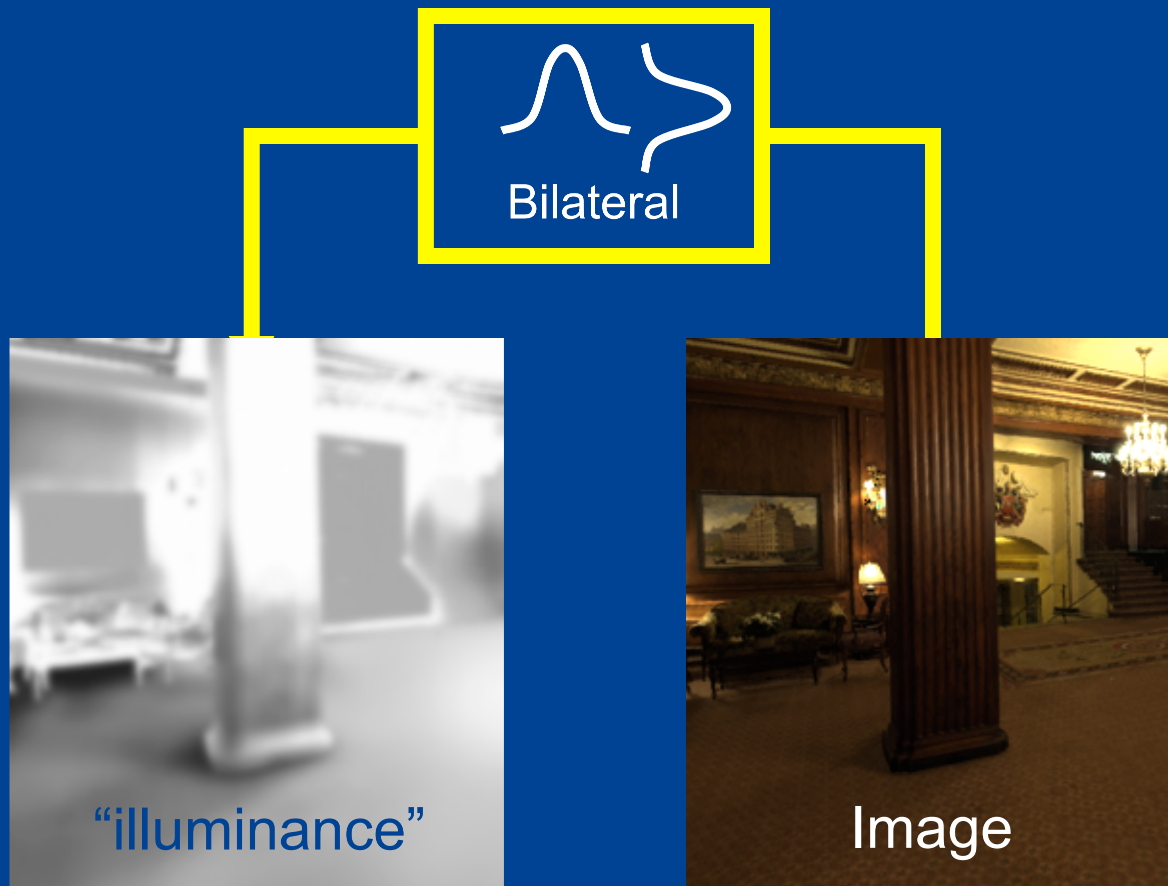


Texture-Illuminance Decoupling

- Not physically based: Filtering
- Assumptions:
  - Small-scale features → “texture”
  - Large-scale features → “illuminance”

General Idea

- Large-scale features using low-pass filter
  - Color is assumed to be from texture



General Idea

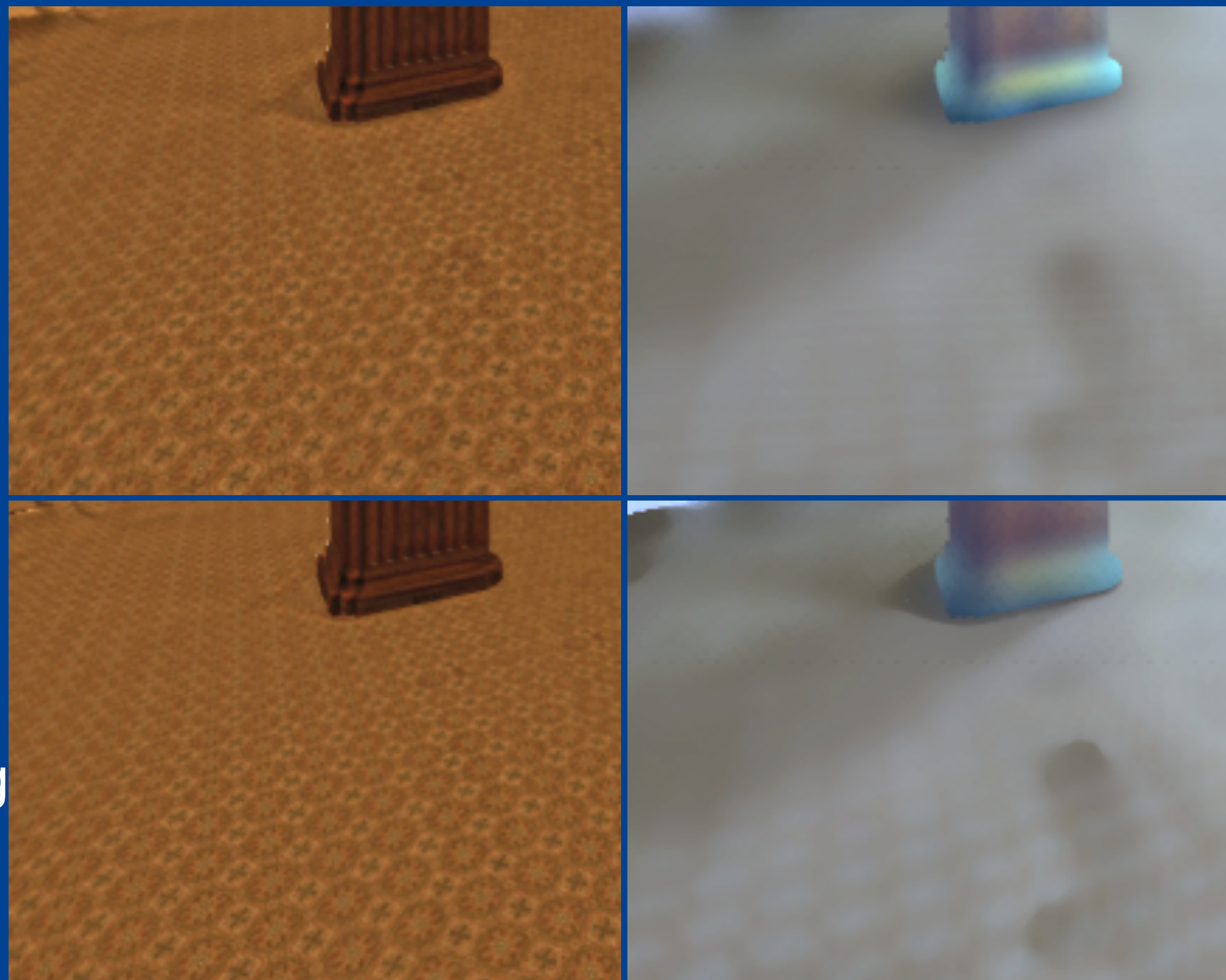
- Extract texture from illuminance and input image

Edge-Preserving Filter

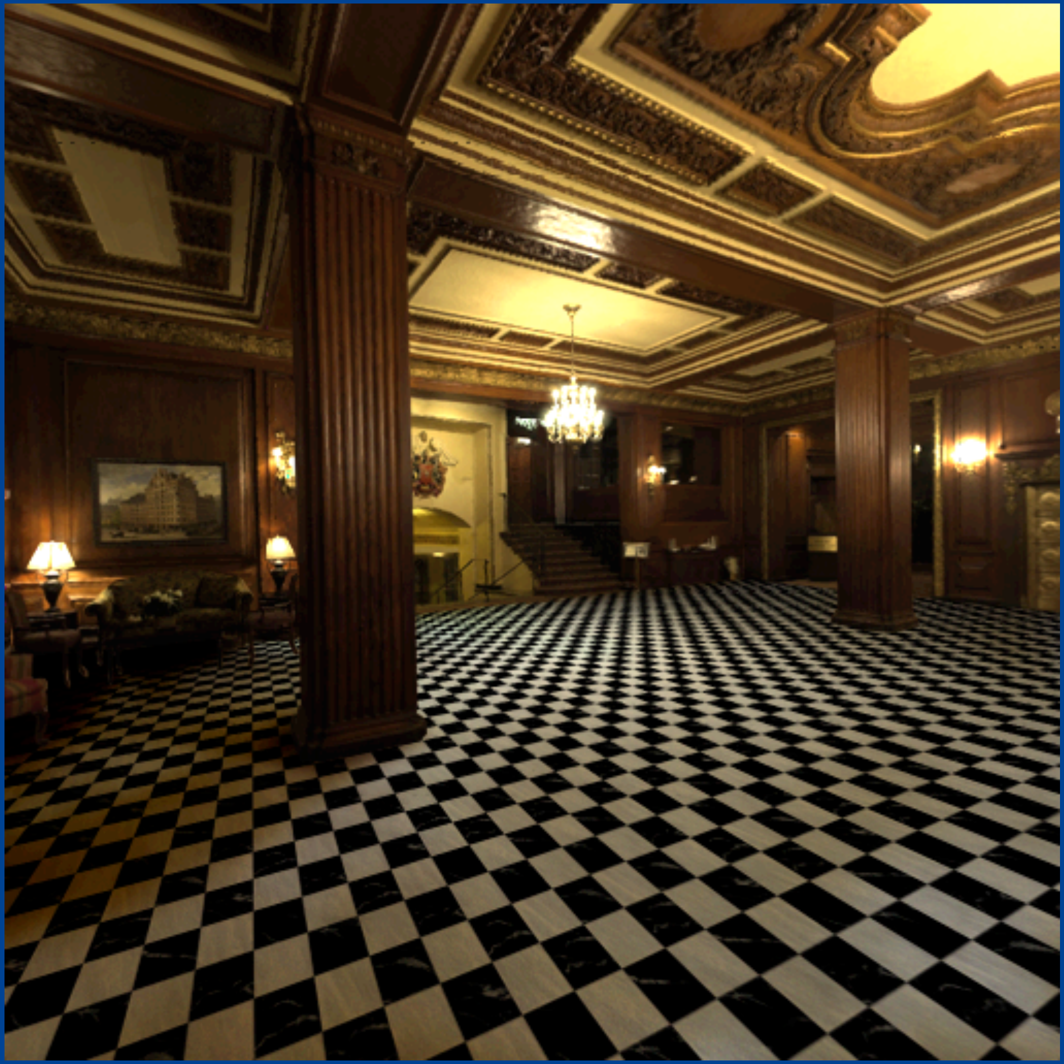
texture | illuminance

Naïve

Bilateral + foreshortening

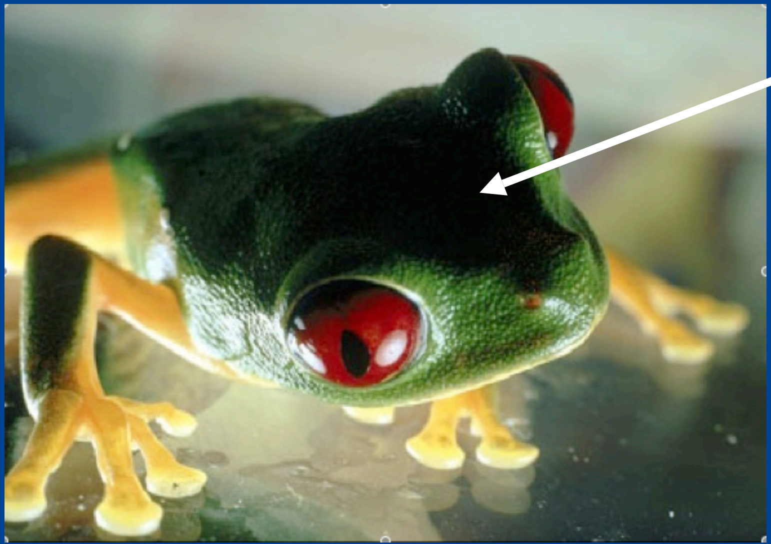


Examples



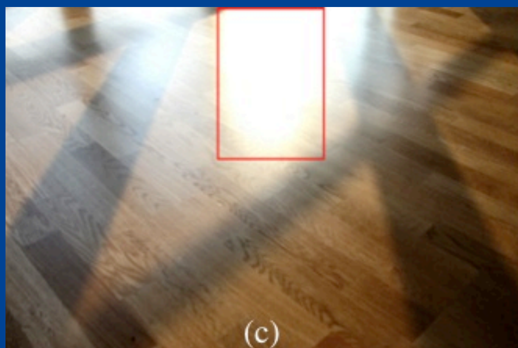
HDR hallucination

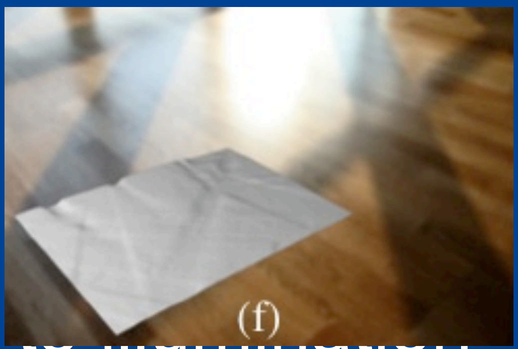
- *[Lvdi Wang, Liyi Wei, Kun Zhou, Baining Guo, Heung-Yeung Shum, EGSR 2007]*
- Low-dynamic-range images have under- and over-exposed parts
  - Information missing

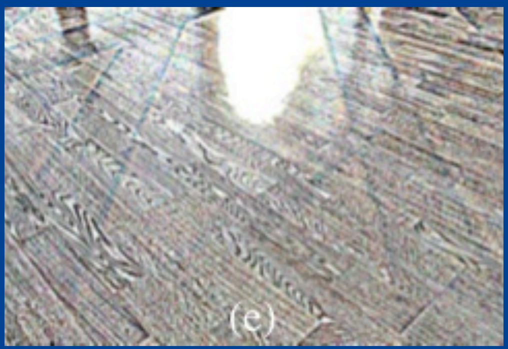


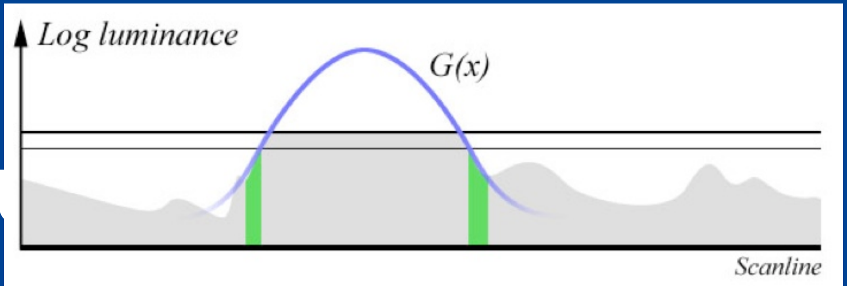
HDR hallucination

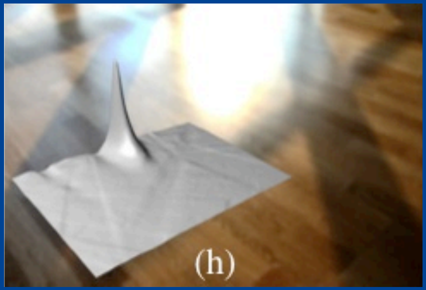
- Separate illumination and texture (Bilateral!)

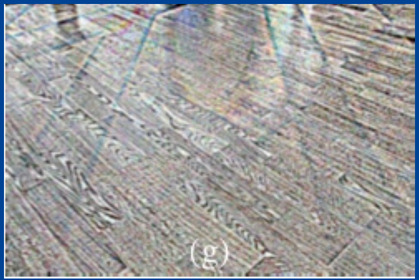






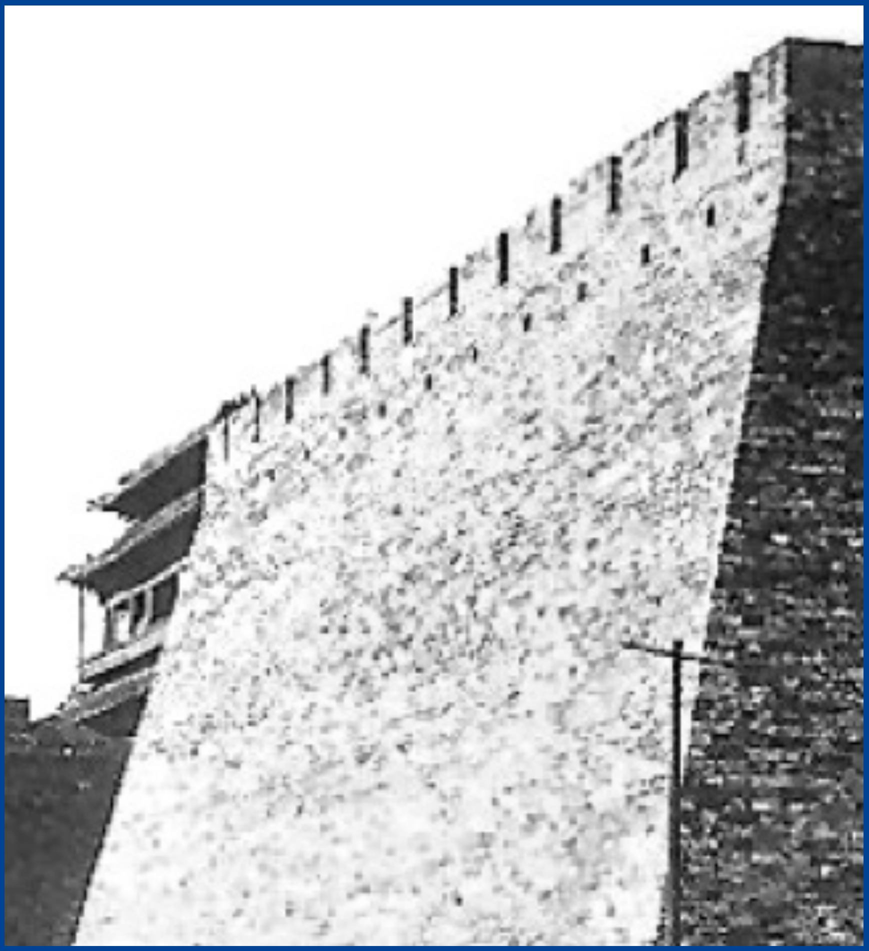






HDR hallucination

input



output

HDR hallucination

input

output

Recap

- Decompose into
  - Large scale (with bilateral filter)
  - Detail (residual: medium+high frequencies)
    - Use big kernels
- Use appropriate domain (log for HDR)
- Manipulate/process independently
- Tone mapping
- Relighting, HDR hallucination
- HDR hallucination