Tone mapping

Digital Visual Effects, Spring 2007

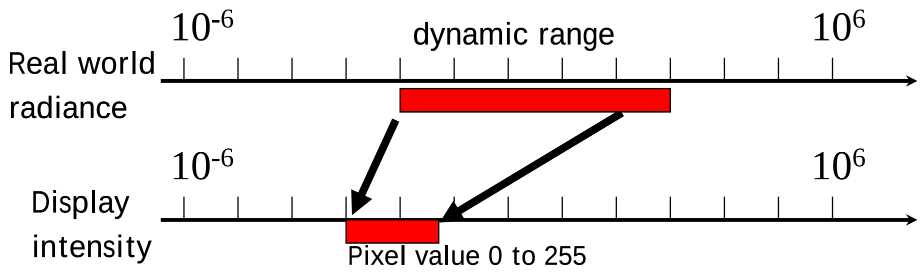
Yung-Yu Chuang

2007/3/13

with slides by Fredo Durand, and Alexei Efros

Tone mapping

- How can we display it?
  Linear scaling?, thresholding?



CRT has 300:1 dynamic range

Preliminaries

- For color images

$$\begin{bmatrix} R_d \\ G_d \\ B_d \end{bmatrix} = \begin{bmatrix} L_d \frac{R_w}{L_w} \\ L_d \frac{G_w}{L_w} \\ L_d \frac{B_w}{L_w} \end{bmatrix}$$

- Log domain is usually preferred.
- Gaussian filter. Sampling issues. Efficiency issues.

Eye is not a photometer!

- *"Every light is a shade, compared to the higher lights, till you come to the sun; and every shade is a light, compared to the deeper shades, till you come to the night."*

— John Ruskin, 1879

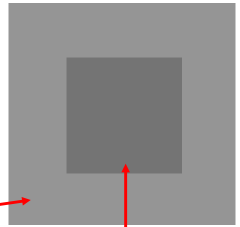
We are more sensitive to contrast

- Weber's law

Just-noticeable Difference (JND)

$$\frac{\Delta I_b}{I_b} \sim 1\%$$

background intensity



flash

Global operator (Reinhart et al)

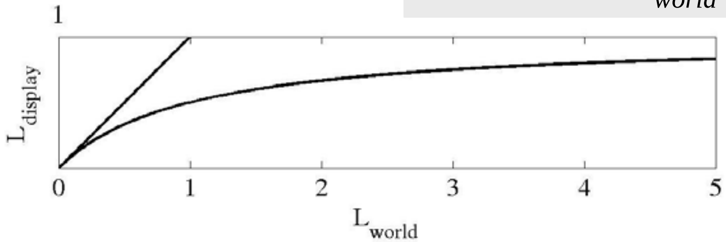
$$\bar{L} = \exp\left(\frac{1}{N}\sum_{x,y}\log(\delta + L(x,y))\right)$$

Approximation of scene's key (how light or dark it is). Map to 18% of display range for average-key scene

User-specified; high key or low key

$$L_w(x,y) = \frac{a}{\bar{L}} L(x,y)$$

$$L_{display} = \frac{L_{world}}{1 + L_{world}}$$



low key (0.18) high key (0.5)

Frequency domain

- First proposed by Oppenheim in 1968!
- Under simplified assumptions,

image = illuminance * reflectance

illuminance: low-frequency, attenuate more

reflectance: high-frequency, attenuate less

Oppenheim

- Taking the logarithm to form density image
- Perform FFT on the density image
- Apply frequency-dependent attenuation filter

$$s(f) = (1-c) + c\frac{kf}{1+kf}$$

- Perform inverse FFT
- Take exponential to form the final image

Fast Bilateral Filtering for the Display of High-Dynamic-Range Images

Frédo Durand & Julie Dorsey
Laboratory for Computer Science
Massachusetts Institute of Technology

A typical photo

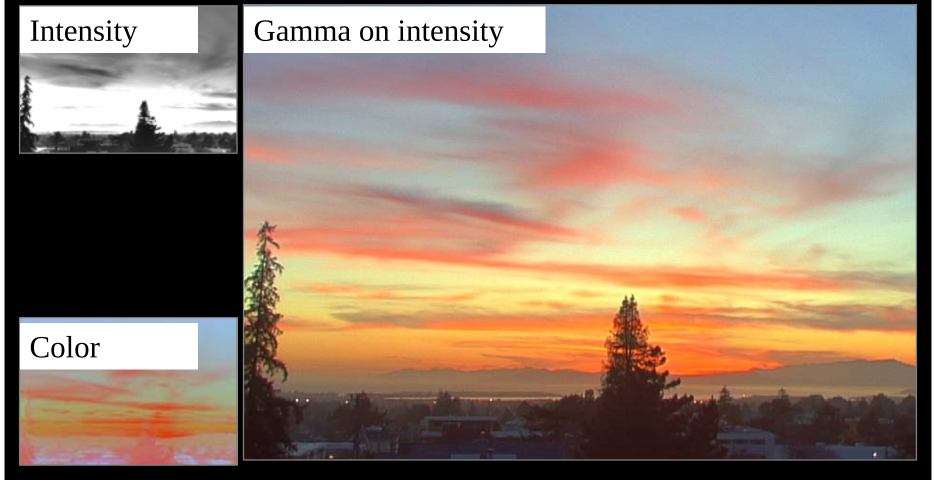
- Sun is overexposed
- Foreground is underexposed

Gamma compression

- X –> X^{γ}
- Colors are washed-out

Gamma compression on intensity

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

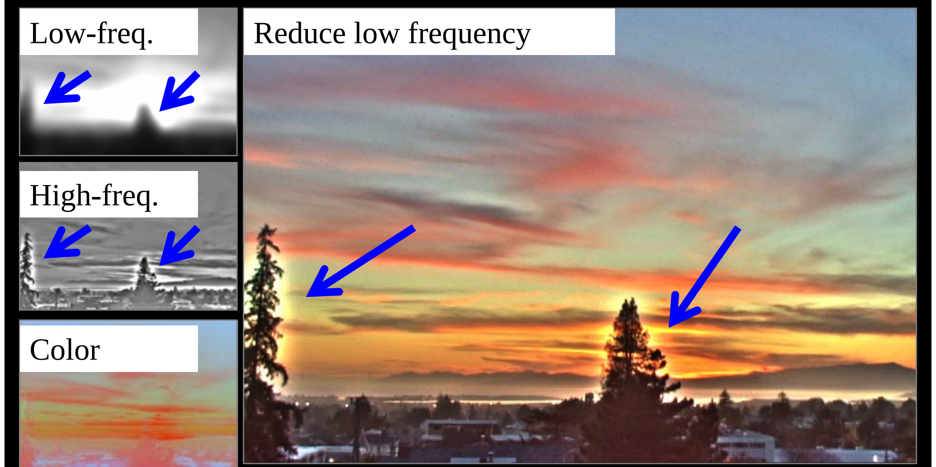


Chiu et al. 1993

- Reduce contrast of low-frequencies
- Keep high frequencies

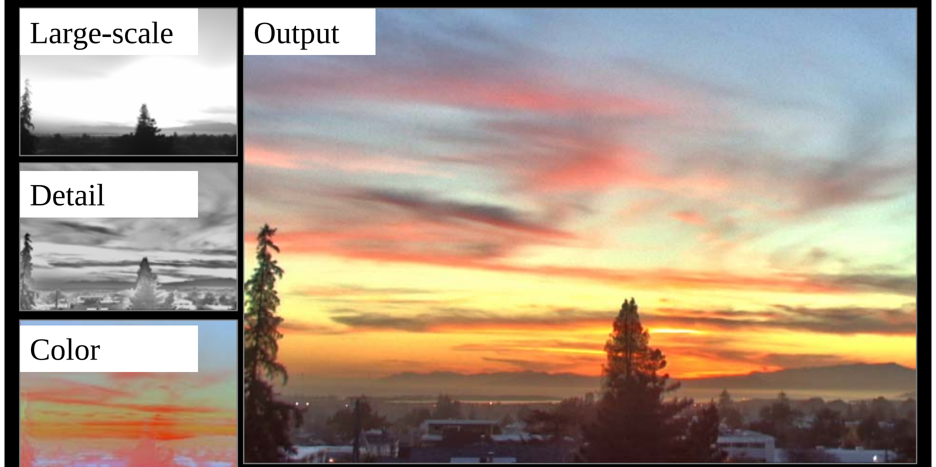
The halo nightmare

- For strong edges
- Because they contain high frequency



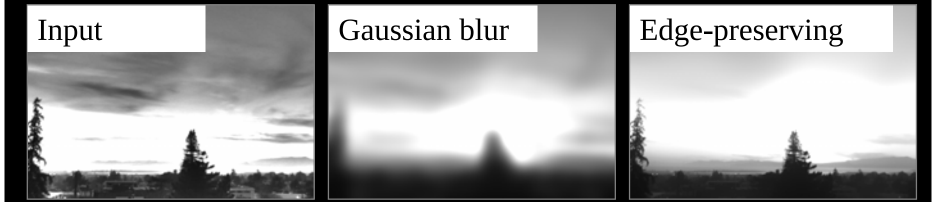
Durand and Dorsey

- Do not blur across edges
- Non-linear filtering



Edge-preserving filtering

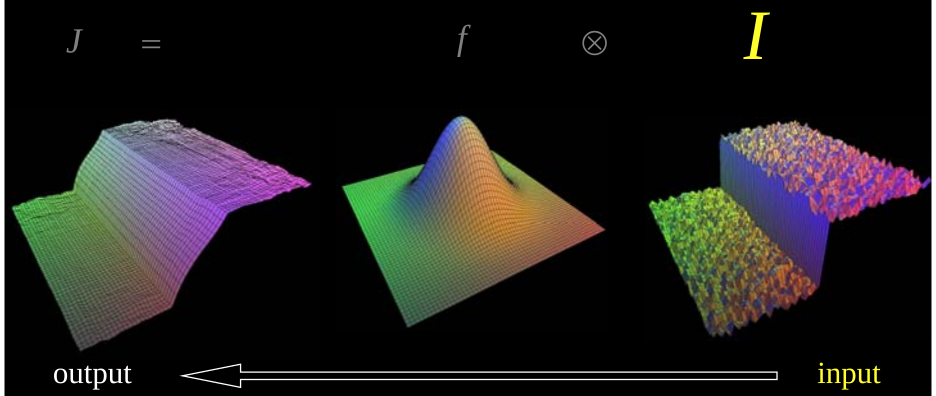
- Blur, but not across edges



- Anisotropic diffusion [Perona & Malik 90]
  - Blurring as heat flow
  - LCIS [Tumblin & Turk]
- Bilateral filtering [Tomasi & Manduci, 98]

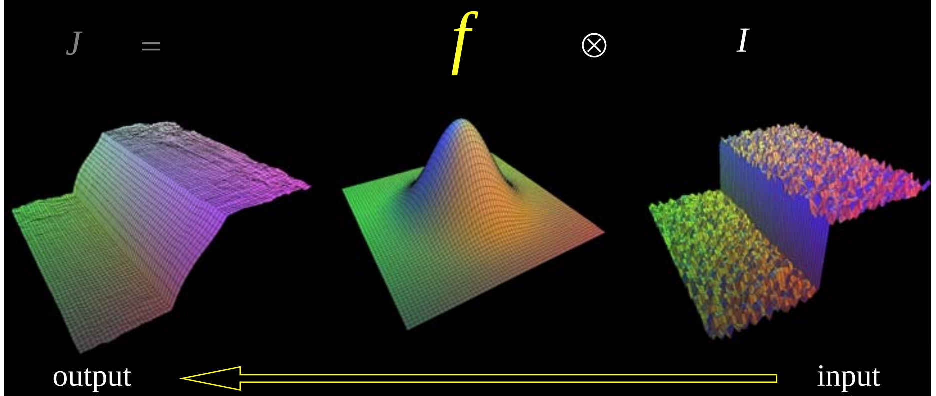
Start with Gaussian filtering

- Here, input is a step function + noise



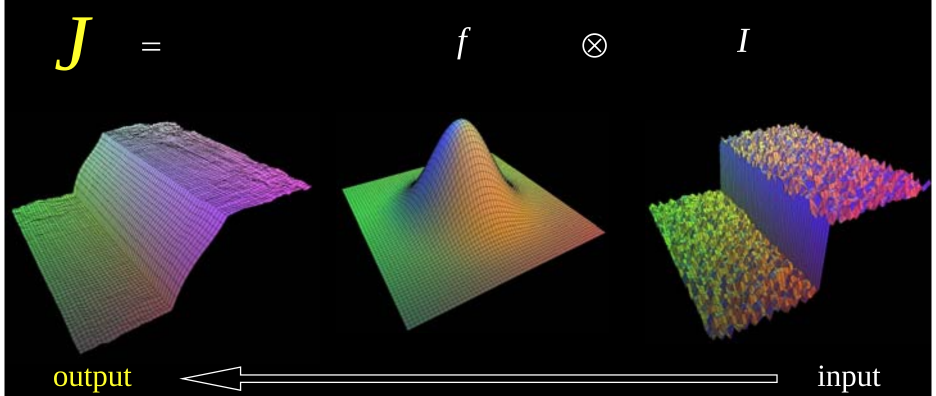
Start with Gaussian filtering

- Spatial Gaussian f



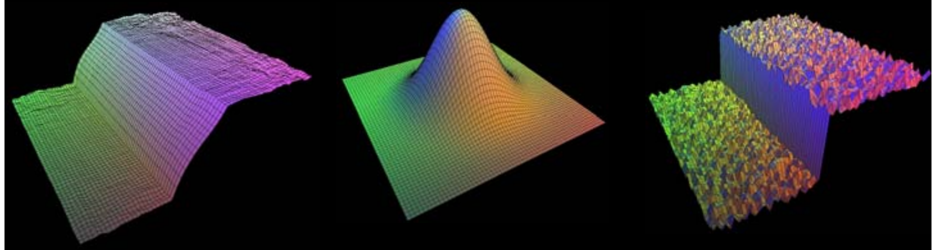
Start with Gaussian filtering

- Output is blurred



Gaussian filter as weighted average

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

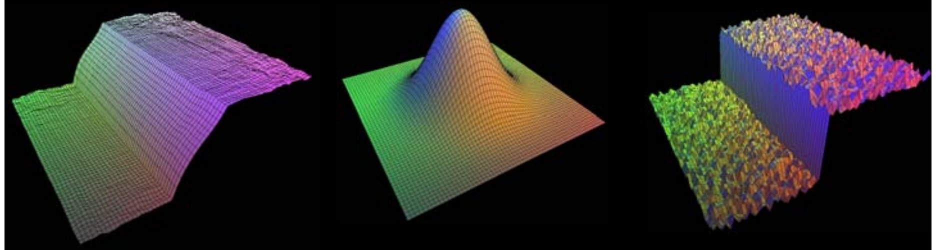


output ⟵ input

The problem of edges

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

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

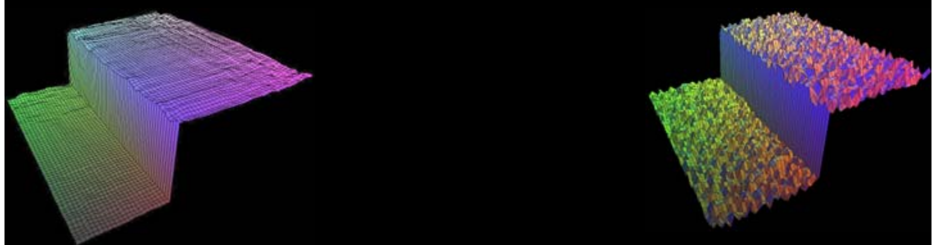


output ⟵ input

Principle of Bilateral filtering

- [Tomasi and Manduchi 1998]
- Penalty g on the intensity difference

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

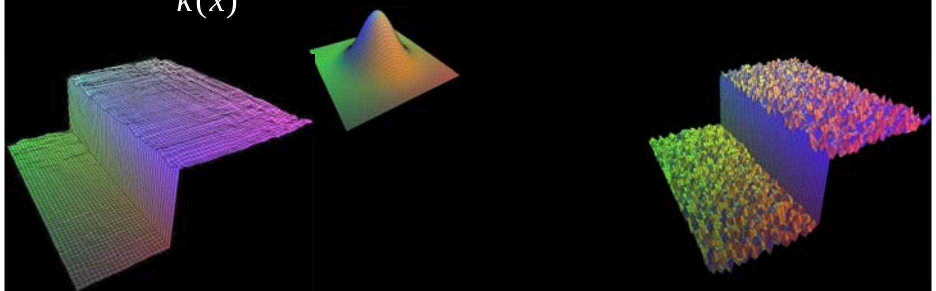


output ⟵ input

Bilateral filtering

- [Tomasi and Manduchi 1998]
- Spatial Gaussian f

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

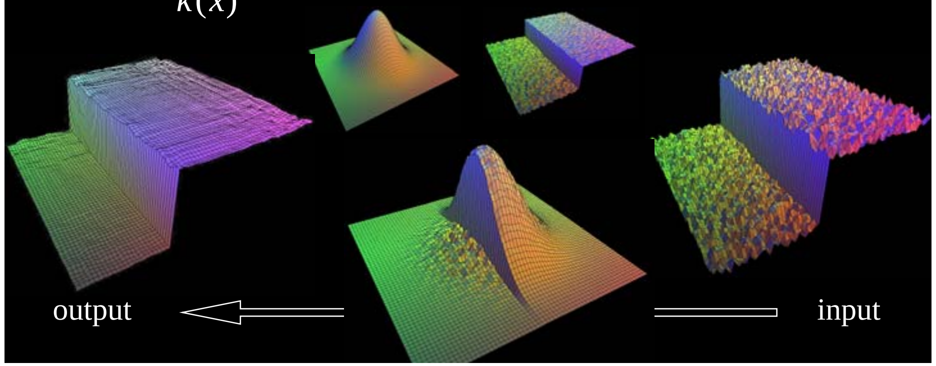


output ⟵ input

Bilateral filtering

- [Tomasi and Manduchi 1998]
- Spatial Gaussian f
- Gaussian g on the intensity difference

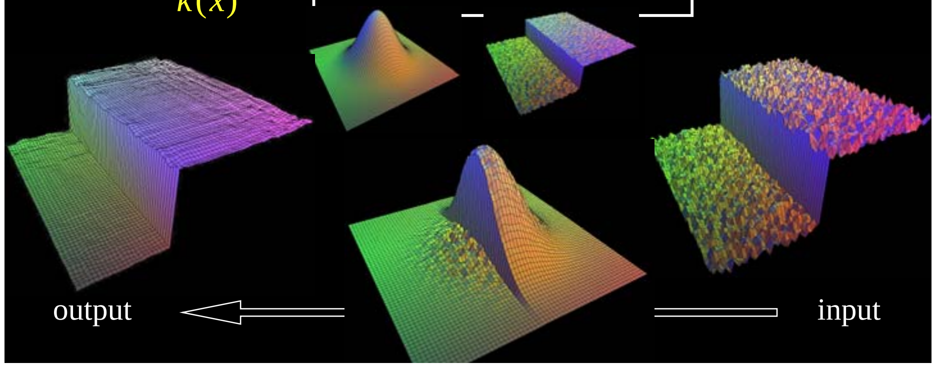
$$J(x) \quad \frac{1}{k(x)} \quad f(x,\xi) \quad g(I(\xi)-I(x)) \quad I(\xi)$$



Normalization factor

- [Tomasi and Manduchi 1998]
- k(x)= $\sum_{\xi} f(x,\xi) \quad g(I(\xi)-I(x))$

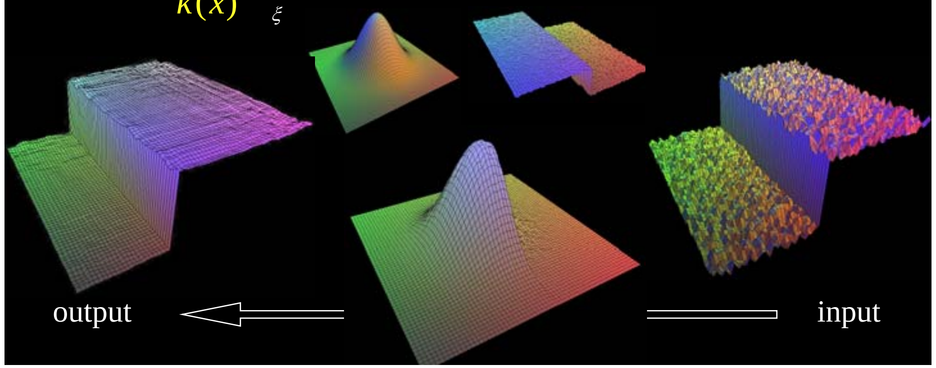
$$J(x) \quad \frac{1}{k(x)} \quad f(x,\xi) \quad g(I(\xi)-I(x)) \quad I(\xi)$$



Bilateral filtering is non-linear

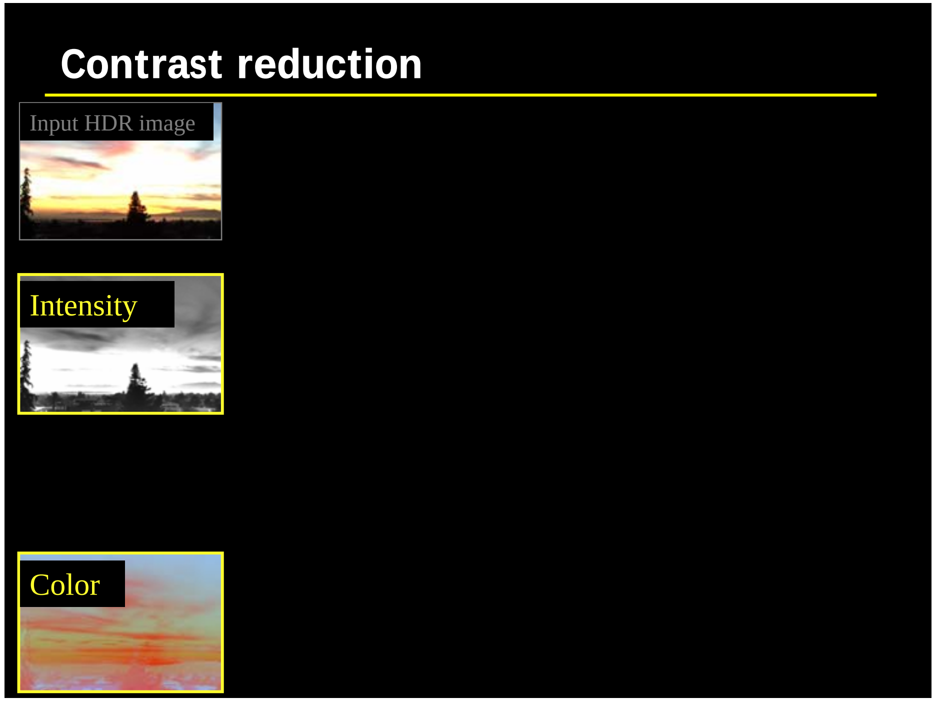
- [Tomasi and Manduchi 1998]
- The weights are different for each output pixel

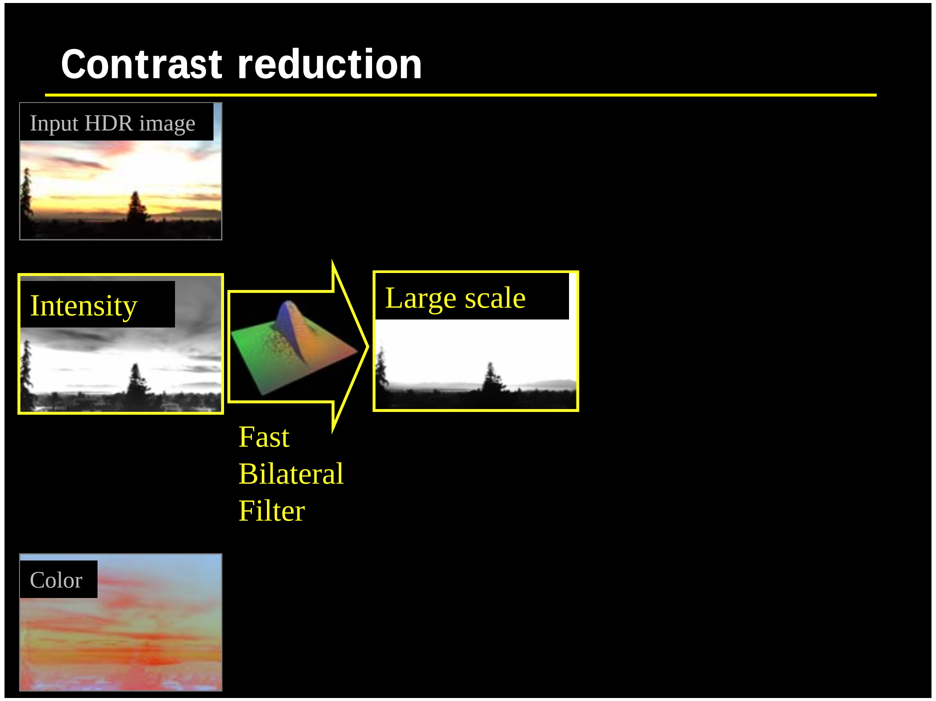
$$J(x) \quad \frac{1}{k(x)} \sum_{\xi} f(x,\xi) \quad g(I(\xi)-I(x)) \quad I(\xi)$$

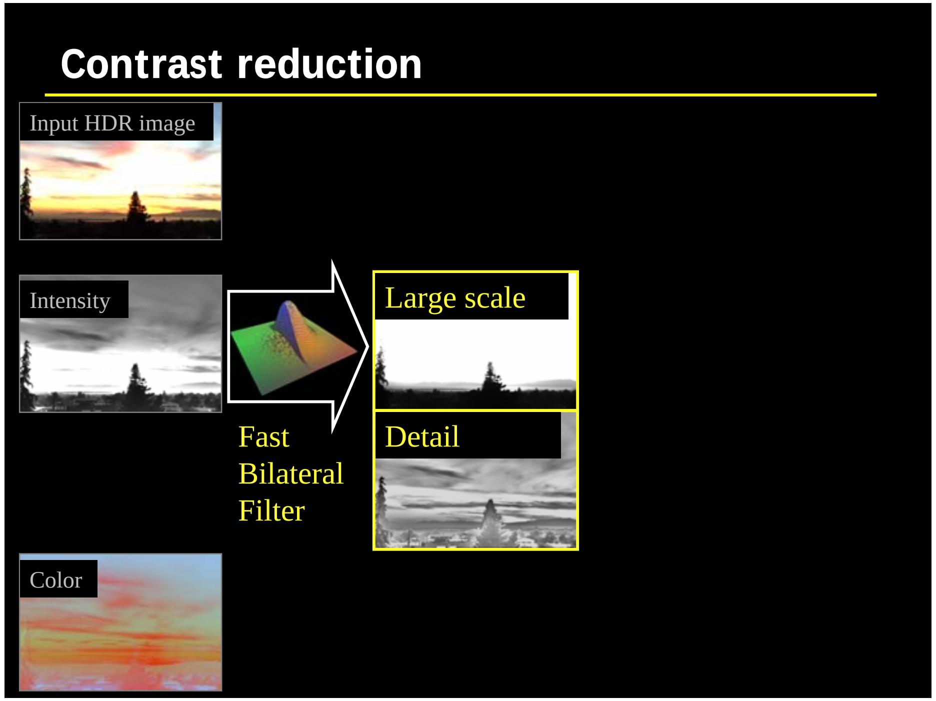


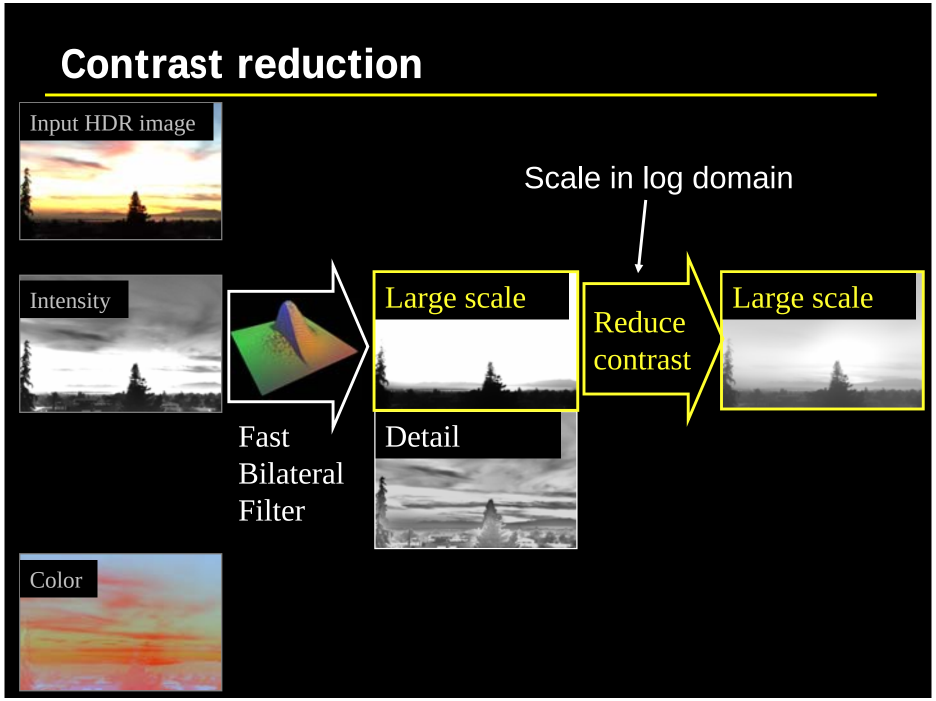
Contrast reduction

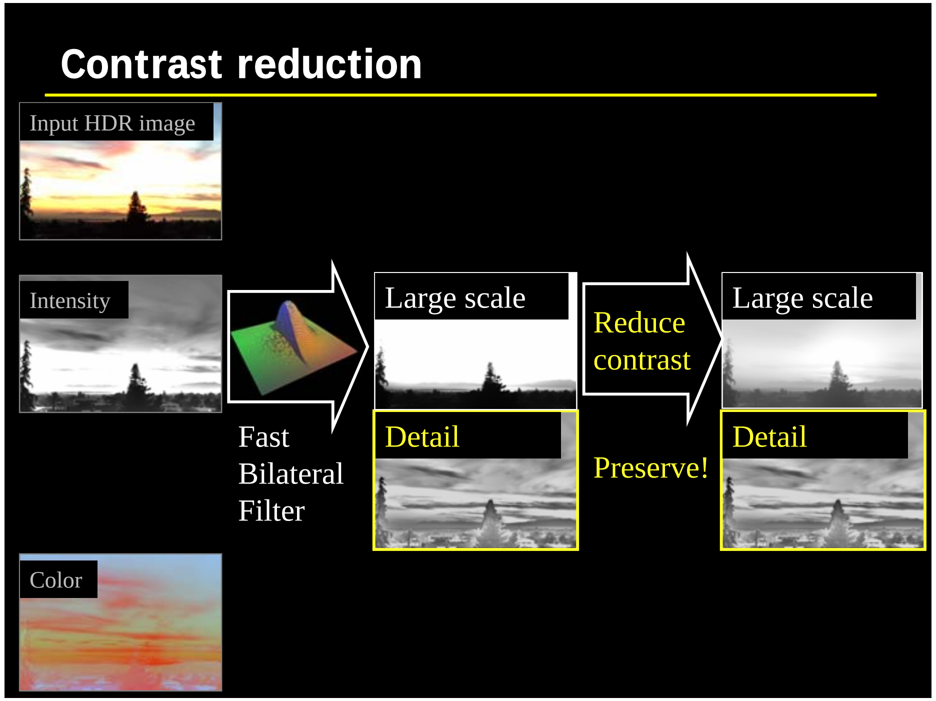
Contrast
too high!

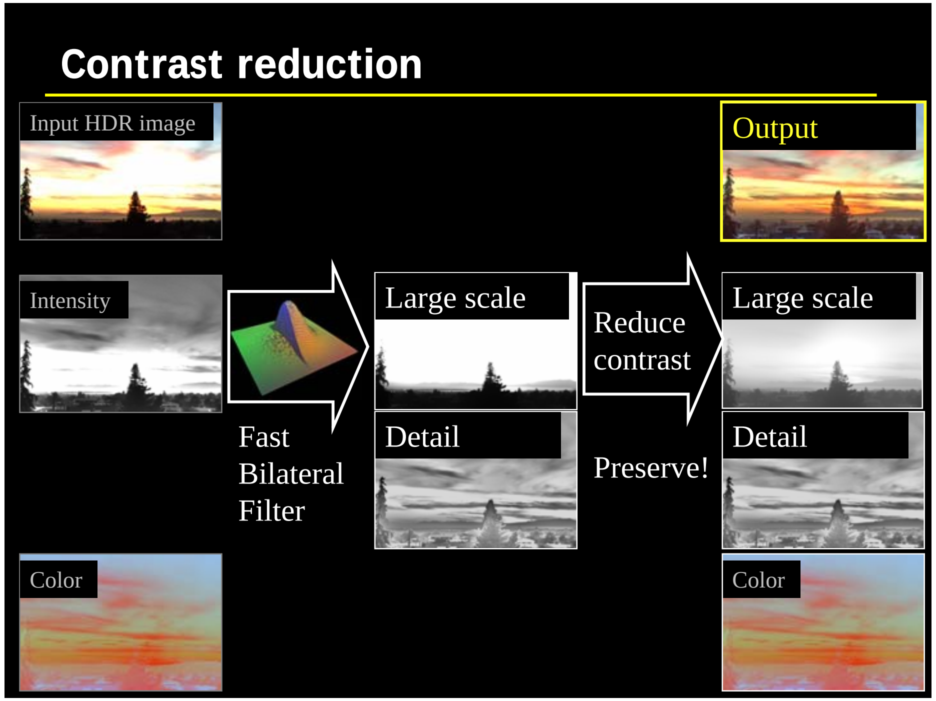

Contrast reduction
Input HDR image
Intensity
Color


Contrast reduction
Input HDR image
Intensity
Large scale
Fast
Bilateral
Filter
Color


Contrast reduction
Input HDR image
Intensity
Large scale
Detail
Fast
Bilateral
Filter
Color


Contrast reduction
Input HDR image
Scale in log domain
Intensity
Large scale
Reduce
contrast
Large scale
Fast
Bilateral
Filter
Detail
Color





Oppenheim bilateral