Tone mapping / bilateral filter

Flickr user mapgoblin
Recap from previous lecture

• Real world scenes have radiance dynamic ranges beyond the capture capabilities of most cameras.
• How to combine multiple exposures into a single high-dynamic range image.
• How to compress the HDR image into a displayable dynamic range with global operators.
Project 5

• Recover high dynamic range radiance map from multiple uncalibrated images with known exposure time (previous lecture)

• Compress high dynamic range image into low dynamic range visualization using bilateral filter based decomposition.
Fast Bilateral Filtering for the Display of High-Dynamic-Range Images

Frédo Durand & Julie Dorsey
Laboratory for Computer Science
Massachusetts Institute of Technology
SIGGRAPH 2002
Contributions

- Contrast reduction for HDR images
  - Local tone mapping
  - Preserves details
  - Fewer halos than naïve filtering
  - Fast with optimized implementation of bilateral filter
    (otherwise sort of slow)
High-dynamic-range (HDR) images

- CG Images

- Multiple exposure photo [Debevec & Malik 1997]

- HDR sensors

Recover response curve
HDR value for each pixel
Contrast reduction

- Match limited contrast of the medium
- Preserve details
A typical photo

- Sun is overexposed
- Foreground is underexposed
Gamma compression

- $X \rightarrow X^\gamma$
- Colors are washed-out
Gamma compression on intensity

- Colors are OK, but details (intensity high-frequency) are blurred.
Chiu et al. 1993

• Reduce contrast of low-frequencies
• Keep high frequencies

Low-freq.  |  Reduce low frequency
High-freq. |  Color
The halo nightmare

- For strong edges
- Because they contain high frequency

Reduce low frequency

Low-freq.

High-freq.

Color
Our approach

- Do not blur across edges
- Non-linear filtering
Start with Gaussian filtering

- Here, input is a step function + noise

\[ J = f \times I \]
Start with Gaussian filtering

- Spatial Gaussian f

\[ J = f \ast I \]

output \[ \Rightarrow \] \[ \ast \] \[ \Rightarrow \] \[ I \] \[ \text{input} \]
Start with Gaussian filtering

- Output is blurred

\[
J = f \ast I
\]
Gaussian filter as weighted average

- Weight of $\xi$ depends on distance to $x$

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

output $\xrightarrow{\text{arrow}}$ input
The problem of edges

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

\[
J(x) = \sum_{\xi} f(x, \xi) I(\xi)
\]
Principle of Bilateral filtering

[Tomasi and Manduchi 1998]

- Penalty $g$ on the intensity difference

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

[Tomasi and Manduchi 1998]

- Spatial Gaussian filter

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

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

\[
J(x) = \frac{1}{k(x)} \sum_{\xi} f(x, \xi) g(I(\xi) - I(x)) I(\xi)
\]
Bilateral filtering is non-linear

[Tomasi and Manduchi 1998]

- The weights are different for each output pixel

\[ J(x) = \frac{1}{k(x)} \sum_{\xi} f(x, \xi) g(I(\xi) - I(x)) I(\xi) \]
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
Contrast reduction

Input HDR image

Contrast too high!
Contrast reduction

Input HDR image

Intensity

Color
Contrast reduction

Input HDR image

Intensity

Fast Bilateral Filter

Color

Large scale
Contrast reduction

Input HDR image

Intensity

Fast Bilateral Filter

Color

Large scale

Detail
Contrast reduction

Input HDR image

Intensity

Fast Bilateral Filter

Large scale

Detail

Reduce contrast

Large scale

Color
Contrast reduction

Input HDR image

Intensity

Fast Bilateral Filter

Large scale

Detail

Reduce contrast

Preserve!

Large scale

Detail

Color
Contrast reduction

Input HDR image

Intensity

Fast Bilateral Filter

Large scale

Detail

Reduce contrast

Preserve!

Output

Large scale

Detail

Color
Informal comparison

Gradient-space  [Fattal et al.]
Bilateral            [Durand et al.]
Photographic  [Reinhard et al.]
Informal comparison

Gradient-space [Fattal et al.]

Bilateral [Durand et al.]

Photographic [Reinhard et al.]
Next Monday

• Guest Speaker Sylvain Paris of Adobe Research will discuss the bilateral filter, and how to create a simple yet reasonably efficient implementation of it.