Tone mapping

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with slides by Fredo Durand, and Alexei Efros

Tone mapping

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

Global operator (Reinhart et al)

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

\[ L_{\text{display}} = \frac{L_{\text{world}}}{1 + L_{\text{world}}} \]

Global operator results

Real world radiance

Display intensity

CRT has 300:1 dynamic range

Pixel value 0 to 255

Dynamic range

Pixel value 0 to 255

CRT has 300:1 dynamic range
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

Compressing dynamic range

A typical photo

- Sun is overexposed
- Foreground is underexposed

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

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**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

**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

**Input**  
**Gaussian blur**  
**Edge-preserving**

- 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

\[ J = f \otimes I \]

**Start with Gaussian filtering**

- Spatial Gaussian f

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

- Output is blurred

\[ J = f \otimes I \]

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

- \([\text{Tomasi and Manduchi 1998}]\)
- Penalty \( g \) on the intensity difference

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

- [Tomasi and Manduchi 1998]
- Spatial Gaussian $f$

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

Normalization factor

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

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

Bilateral filtering is non-linear

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

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

Input HDR image

Contrast too high!

Input HDR image

Intensity

Color

Large scale

Fast Bilateral Filter

Contrast reduction

Input HDR image

Intensity

Color

Large scale

Fast Bilateral Filter

Detail