Applications

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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

\[
BF[I]_p = \frac{1}{W_p} \sum_{q \in S} G_{\sigma_s}(\| p - q \|) G_{\sigma_r}(\| M_p - I_q \|) I_q
\]
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 $\sim 10^{-6}$ to $10^6$ cd/m$^2$
- Often 1 : 10,000 in a scene

Real world

$10^{-6}$

$10^6$

High dynamic range
Picture dynamic range

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

Real world

<table>
<thead>
<tr>
<th>10^{-6}</th>
<th>10^6</th>
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Picture

<table>
<thead>
<tr>
<th>10^{-6}</th>
<th>10^6</th>
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</table>

Low contrast
Multiple exposure photography

- Merge multiple exposure to cover full range

10^{-6}  High dynamic range  10^{6}

Real world

- 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
Problem: Contrast reduction

- Match limited contrast of the medium
- Preserve details

Real world: 10^{-6} to 10^6 (High dynamic range)

Picture: 10^{-6} to 10^6 (Low contrast)
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 $\gamma=0.5$ 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

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
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

Intensity

Color
Contrast reduction

Input HDR image

Intensity

Bilateral Filter (in log domain!)

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

Large scale

Color
Contrast reduction

Input HDR image

Intensity

Bilateral Filter

Large scale

Detail

Detail = log intensity – large scale (residual)
Contrast reduction

Input HDR image

Intensity

Bilateral Filter

Detail

Large scale

Reduce contrast

Large scale

Color
Contrast reduction

Input HDR image

Intensity

Bilateral Filter

Large scale

Detail

Reduce contrast

Preserve!

Large scale

Detail
Contrast reduction

Input HDR image

Bilateral Filter

Intensity

Large scale

Detail

Color

Reduce contrast

Preserve!

Output

Large scale

Detail

Color
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:
  - $\text{largeRange} = \max(\text{inLogLarge}) - \min(\text{inLogLarge})$
- Scale factor $k = \log_{10}(10) / \text{largeRange}$
- Normalize so that the biggest value is 0 in log

\[
\text{outLog} = \text{inLogDetail} + \text{inLogLarge} \times k - \max(\text{inLogLarge})
\]
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
      - \(\rightarrow\) 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

• 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

Adapted from Ledda et al. and Kuang 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
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

Filtering

“texture” \times “illuminance” = Image
Texture-Illuminance Decoupling

- Not physically based: Filtering
- Assumptions:
  - Small-scale features $\rightarrow$ “texture”
  - Large-scale features $\rightarrow$ “illuminance”
General Idea

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

“illuminance”

Image
General Idea

- Extract texture from illuminance and input image
Edge-Preserving Filter

<table>
<thead>
<tr>
<th></th>
<th>texture</th>
<th>illuminance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Naïve</td>
<td><img src="image1" alt="Naïve Texture" /></td>
<td><img src="image2" alt="Naïve Illuminance" /></td>
</tr>
<tr>
<td>Bilateral + foreshortening</td>
<td><img src="image3" alt="Bilateral Texture" /></td>
<td><img src="image4" alt="Bilateral Illuminance" /></td>
</tr>
</tbody>
</table>
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!)

- Fit smooth function to illumination

- Use texture synthesis

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![Image](c.png)

![Image](f.png)

![Image](e.png)

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![Diagram](g.png)

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![Diagram](h.png)
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