Applied Perception in Graphics

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Computer Graphics

- Produce computer generated imagery that cannot be distinguished from real scenes
- Do this in real-time
Trends in Computer Graphics

- Greater realism
  - Scene complexity
  - Lighting simulations

- Faster rendering
  - Faster hardware
  - Better algorithms

- Together: still too slow and unrealistic
Algorithm design

- Largely opportunistic
- Computer graphics is a maturing field
- Hence, a more directed approach is needed
Long Term Strategy

• Understand the differences between natural and computer generated scenes

• Understand the Human Visual System and how it perceives images

• Apply this knowledge to motivate graphics algorithms
This Presentation (1)

Introduction

The Human Visual System is evolved to look at natural images.
Human Visual System
Retina
Color Processing

Rod and Cone pigments

After Bowmaker & Dartnall, 1980
Color Processing

- Cone output is logarithmic
- Color opponent space
Ruderman’s work on color statistics:

- Principal Components Analysis (PCA) on colors of natural image ensembles
- Axes have meaning: color opponents (luminance, red-green and yellow-blue)
Color Processing Summary

- Human Visual System expects images with natural characteristics (not just color)
- Color opponent space has decorrelated axes
- Color space is logarithmic (compact and symmetrical data representation)
- Independent processing along each axis should be possible → Application
Color Transfer

• Make one image look like another

• For both images:
  – Transfer to new color space
  – Compute mean and standard deviation along each color axis

• Shift and scale target image to have same statistics as the source image
Lαβ Color Space

Convert RGB triplets to LMS cone space

Take logarithm

Rotate axes
Why not use RGB space?

Input images

Output images

RGB

Lαβ
Color Transfer Example
Color Transfer Example
Color Transfer Example
Color Processing Summary

- Changing the statistics along each axis independently allows one image to resemble a second image.

- If the composition of the images is very unequal, an approach using small swatches may be used successfully.
Global vs. Local

• Global
  – Scale each pixel according to a fixed curve
  – Key issue: shape of curve

• Local
  – Scale each pixel by a local average
  – Key issue: size of local neighborhood
Global Operators

Ward

Tumblin

Ferwerda
Global Operators

Ward

Tumblin

Ferwerda
Local Operator

Pattanaik
Spatial Processing

- Light reaches the retina and is detected by rods and cones.
- The number of rods and cones is much larger than the number of nerves leaving the eye.
- Hence, data reduction occurs in the retina.
Spatial Processing

- Certain aspects of natural images are more important than others.

- For example, contrast edges need to be detected with accuracy, whereas slow gradients do not need to be perceived at high resolution.
Spatial Processing

- Circularly symmetric receptive fields
- Centre-surround mechanisms
  - Laplacian of Gaussian
  - Difference of Gaussians
  - Blommaert
- Scale space model
Scale Space
(Histogram Equalized Images)
Tone Reproduction Idea

- Modify existing global operator to be a local operator, e.g. Greg Ward’s
- Use spatial processing to determine a local adaptation level for each pixel
Blommaert Brightness Model

\[ R_i = \frac{1}{k_i^2 s^2 \pi} e^{\frac{-r^2}{k_i^2 s^2}} \]

\[ V_i(x, y, s) = L(u, v) \otimes R_i \]

\[ V(x, y, s) = W(s) \frac{V_1(x, y, s) - V_2(x, y, s)}{2^\phi \sqrt{s^2} + V_1(x, y, s)} \]

\[ B(x, y) = \sum_{s_0}^{s_n} V(x, y, s) \]
Brightness

\[ B(x, y) = \sum_{s_0}^{s_n} V(x, y, s) \]
How large should a local neighborhood be?

- Mean value

\[ B(x, y) = \frac{V(x, y, s_m(x, y))}{s_n - s_0} \]

- Thresholded

\[ s_m : |V(x, y, s_m(x, y))| < \varepsilon \]
Mean Value

\[ B(x, y) = \frac{V(x, y, s_m(x, y))}{s_n - s_0} \]
Thresholded

\[ s_m : |V(x, y, s_m)| < \varepsilon \]
Local adaptation

Greg Ward’s tone-mapping with local adaptation

\[ L_a(x, y) = V_1(x, y, s_m(x, y)) \]

\[ L_{output} = \frac{L(x, y)}{L_{d\ max}} \times \left[ \frac{1.219 + \left( \frac{L_{d\ max}}{2} \right)^{0.4}}{1.219 + L_a(x, y)^{0.4}} \right]^{2.5} \]
Results

• Good results, but something odd about scale selection:

• For most pixels, a large scale was selected

• Implication: a simpler algorithm should be possible
Greg Ward’s tone-mapping with local adaptation

Simplify

Fix overall lightness of image

\[
L_{output} = \frac{L(x, y)}{L_{d_{max}}} \left[ \frac{1.219 + \left( \frac{L_{d_{max}}}{2} \right)^{0.4}}{1.219 + L_a(x, y)^{0.4}} \right]^{2.5}
\]

\[
L_{output} \approx \frac{L(x, y)}{1 + L(x, y)}
\]

\[
L(x, y) = \frac{a}{L_w} L_w(x, y)
\]
Global Operator Results

Our method

Ward
Global Operator Results

Our method

Ward
Global $\rightarrow$ Local

Global operator

Local operator

\[
L_{\text{output}} = \frac{L(x, y)}{1 + L(x, y)}
\]

\[
L_{\text{output}} = \frac{L(x, y)}{1 + V_1(x, y, s_m(x, y))}
\]
Local Operator Results

Global

Local
Local Operator Results

Global  Local  Pattanaik
Summary

- Knowledge of the Human Visual System can help solve engineering problems
- Color and spatial processing investigated
- Direct applications shown
Ongoing Research

• Natural Image Statistics

• Applications:
  – Reconstruction filters
  – Perlin noise
  – Fractal terrains
Ongoing Research

Impoverished environments
Future Work

This presentation
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