The Art and Science of Depiction

Photorealism
vs. Non-Photorealism
in Computer Graphics

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Global illumination

• How to take into account all light inter-reflections
The Rendering equation

• Light leaving one point in one direction
  – Integral of incoming light from every direction
  – Multiplied by BRDF (reflectance)
Radiosity

- E.g. Lightscape
- Assume surfaces diffuse (independent of direction)
Radiosity

- Subdivide the scene into discrete elements
Radiosity

- Subdivide the scene into discrete elements
- Each element is assumed to have constant radiosity
Radiosity

- Form-factor between 2 elements: ratio of light leaving one element that reaches the other
Radiosity

- Form-factor between 2 elements: ratio of light leaving one element that reaches the other
  - Taking visibility into account
Radiosity

- Iterative solution
- Shoot light from the most luminous source
Radiosity

- Iterative solution
- Shoot from element with the most unshot radiosity
Radiosity

- Iterative solution
- Shoot from element with the most unshot radiosity
Radiosity

• Smoothing and other gimmicks
Radiosity

• Pros
  – View independent

• Cons
  – Meshing is costly
    • Memory
    • Mostly limited to polyhedra
  – Aliasing (jagged shadow boundary)
  – Diffuse assumption (can be sort of alleviated)
Discontinuity meshing

- Subdivide along shadow boundary
- But costly and complex (not in commercial soft)
Discontinuity meshing

• Limits of umbra and penumbra
Discontinuity meshing
Comparison

With skeleton
10 minutes 23 seconds

[Gibson 96]
1 hour 57 minutes

Photorealism vs. NPR
Hierarchical approach

- Group elements when the light exchange is not important
  - Control non trivial
Lightscape

Rendered using the Lightscape Visualization System.
Courtesy of and copyright (c) 1996 Design Visualization Partners (Santa Monica, CA).
Lightscape
Lightscape

Rendered using Lightscape®
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Lightscape

Rendered using the Lightscape Visualization System. Courtesy of and copyright (c) 1994 A.J. Diamond, Donald Schmitt and Company (Toronto, ON)

Photorealism vs. NPR
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Rendered using the Lightscape Visualization System
Courtesy of Isao Nagaoka and Joe Henke. Copyright (c) 1995 Digital Architecture (New York, NY).

Photorealism vs. NPR
Monte-Carlo ray-tracing

- E.g. Radiance (by Greg Ward-Larson), Mental Ray
- Probabilistic sampling approach
Monte-Carlo computation of $\pi$

- Take a square
- Take a random point $(x, y)$ in the square
- Test if it is inside the $\frac{1}{4}$ disc ($x^2 + y^2 < 1$)
- The probability is $\frac{\pi}{4}$
Monte-Carlo computation of $\pi$

- The probability is $\pi/4$
- Count the inside ratio $n = \# \text{inside} / \text{total} \# \text{trials}$
- $\pi \approx n * 4$
- The error depends on the number of trials
Monte-Carlo

- Cast a ray from the eye through each pixel
Monte-Carlo

- Cast a ray from the eye through each pixel
- Cast random rays from the visible point
Monte-Carlo

- Cast a ray from the eye through each pixel
- Cast random rays from the visible point
- Recurse
Monte-Carlo

- Cast a ray from the eye through each pixel
- Cast random rays from the visible point
- Recurse
Monte-Carlo

- Systematically sample primary light
Monte-Carlo

• Take BRD into account
  – Multiply incoming light
  – Sampling density
Monte-Carlo

- Bi-directional
- Cast rays from the eye and from light
Monte-Carlo

- Bi-directional
- Cast rays from the eye and from light
- Join
Radiance cache

- Store the indirect illumination
Radiance cache

• Store the indirect illumination
Radiance cache

- Store the indirect illumination
- Interpolate existing cached values
- Always sample direct lighting
Monte-Carlo & Radiance

• Pros
  – Can treat any scene and any BRDF
  – The Radiance system is free!

• Cons
  – View-dependent
  – Costly
  – Can be noisy (because of sampling)
Radiance

Photorealism vs. NPR
Radiance

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Radiance

Photorealism vs. NPR
Radiance
Monte-Carlo ray-tracing
Non Photorealistic Rendering

- Stanislaw Ulam
  - The study of non-linear physics is like the study of non-elephant biology
  - (quoted by Craig Reynolds)
Painting with numbers

- [Haeberli 1990]
- Reference photo for color
- Interactive painting with brushes
Painting with numbers

- [Haeberli 1990]
- Reference photo for color
- Interactive painting with brushes
Painting with numbers

- Direction control

Figure 6. Using a second image to control brush stroke direction.
Painting with numbers

- Direction control using gradient
Painting with numbers

- From 3D geometry
Painting with number

- Automatic optimization of brush placement
Line drawing

- [Markosian et al. 97]
Line drawing

- [Hertzman and Zorin 2000]
Line drawing

- [Hertzman and Zorin 2000]

Figure 8: Direction fields on the Venus. (a) Silhouettes alone do not convey the interior shape of the surface. (b) Raw principle curvature directions produce an overly-complex hatching pattern. (c) Smooth cross field produced by optimization. Reliable principal curvature directions are left unchanged. Optimization is initialized by the principal curvatures. (d) Hatching with the smooth cross field. (e) Very smooth cross field produced by optimizing all directions. (f) Hatching from the very smooth field.
Watercolor

- [Curtis et al. 1997]
- Physical simulation of watercolor-paper interaction

Figure 3 The three-layer fluid model for a watercolor wash.
Watercolor

- [Curtis et al. 1997]
- Physical simulation of watercolor-paper interaction
- Very costly (not interactive)

Figure 2  Simulated watercolor effects created using our system.
Watercolor

Photorealism vs. NPR
Watercolor

Figure 10 An automatic watercolorization (left) of a low resolution image captured using a poor-quality video camera (above). The finished painting consists of 11 glazes, using a total of 2750 iterations of the simulator, rendered at a resolution of 640 by 480 pixels in 7 hours on a 133 MHz SGI R4600 processor.
Painterly animation

- [Meier 1996]
Painterly animation

Particle Placer

Particles in World Space

Geometry

Reference Pictures

Shaders

Camera Transform

Painterly Renderer

Color

Orientation

Size

Brush Image

Output Image

Photorealism vs. NPR
Painterly animation

- Different styles

Photorealism vs. NPR
Painterly animation

• Use of different layers
Brushes of multiple sizes

- [Hertzman 1998]
Brushes of multiple sizes

- Different styles depending on parameters

“Impressionist”

“Expressionist”
**Brushes of multiple sizes**

- Different styles depending on parameters

  "Impressionist"

  "Expressionist"

Photorealism vs. NPR
Style and soul

- Icon painting, Expressionism
Interactive assisted drawing

- [Durand, Ostromoukhov et al.]
Interactive assisted drawing

• Thresholding
Interactive assisted drawing

- Smudging
Interactive assisted drawing

Photorealism vs. NPR
Interactive assisted drawing
Interactive assisted drawing
NPR: fuzzy issues

- No systematic classification of techniques
  - Mainly by medium and interactive/full 3D
- No clear issues
  - What are we trying to solve?
- No inter-operability of techniques
  - No clear input and output
- Mainly out-of-the-blue full systems with overlap
Some issues in NPR

- Medium simulation
- Animation and coherence
- Line drawing, hatching
- Shading
- Style
- Perspective
- User interface
Can visual art and psychology help?

- Understand underlying and “universal” pictorial issues
  - Limitations and compensation
  - Different modes
    - Texture, color, shape
  - Composition, color harmony
- Coarse-grain classification of issues in picture-making
  - Drawing
  - Denotation
  - Tone and Color
  - Physical realization through marks
A one-way pipeline

- Mechanical and deterministic projection from 3D to 2D
- Input is purely 3D (world space)

3D geometry
Material attributes
Light sources
viewpoint

Light simulation
Projection
Rasterization, etc.

Image
A one-way pipeline

- Mechanical and deterministic projection from 3D to 2D
- Input is purely 3D (world space)

3D geometry
Material attributes
Light sources
Light simulation
Projection
Rasterization, etc.
Image
viewpoint
Human feedback
**Mixed 2D/3D specification**

- We should be able to specify "properties" and constraints directly in 2D
  - E.g. color harmony, composition, style
- Still edit the image after rendering
  - E.g. shadows, lighting, colors, compensations
Pictures for dummy

• Help non-artists produce nice images
• The “gorgeous image” button in your CAD software
• The “digital photo beautifier”
• Realistic or Non-Photorealistic
• Digital assistant that finds problems
**Style**

- **Coarse-grain style**
  - Different categories of drawing, denotation, tone
- **Finer-grain**
- **Local style**
- **Parameterization**
- **Capture**
  - Automatically deduce style from 3D renderings
  - (semi)-Automatically capture style from image(s)
Convergence of games and movies

- Game industry is now as big as movie industry
- Graphics accelerator permit stunning 3D graphics
- Cinema quality is not far
- However, games are interactive, “unpredictable”
- How can we transform the art and craft of cinema into algorithmic games

- E.g. Lighting, camera control, editing