Recommended Readings for Lecture 6

Why Is It Important?

• 99% of our information intake is pictorial through our eyes
• Educational Modules
• Entertainment
• Games
• Advertising
• Medical
• Computer Aided Design
• Data Visualization
Ivan Sutherland  1963
Cornell in Perspective Film

1972
Each polygon is shaded based on a single normal.

Gouraud Thesis
Each pixel is shaded by interpolating intensities computed in each of the polygon’s vertices.
Phong Shading
Model

- Environment
  - Geometry & topology
  - Material properties
    - Color, reflectance, textures
    - (Cost, strength, thermal properties)

- Lighting
  - Geometry & position
  - Intensity, spectral distribution
  - Direction, spatial distribution
Camera

- Viewer Position
- Viewer direction
- Field of view
  - Wide angle
  - Telephoto
- Depth of focus
  - Near
  - Far

Model
Camera
Perspective
Raster Operations
Image Storage
Display
Perspective Transformation

- Perspective transformation
  Matrix multiplication (4 x 4)

- Clipping objects outside of the field of view

- Culling back-facing surfaces
Hidden Line Algorithm
Hidden Line Algorithm
Raster Operations

- Conversion from polygons to pixels
- Color computation
- Hidden surface removal (z-buffer)
Image Storage

- Typical frame buffer
  - 1280 x 1024 pixels
  - 3 channels (red, green, blue)
  - 1 byte/channel
- Total memory
  - 3 3/4 megabytes - single buffer
  - 7 1/2 megabytes - double buffer
**Display**

- Digital to analog conversion
  - 1280 x 1024 resolution
  - 60 frames per second
- Total data rate
  - 1 1/4 million pixels
  - x 3 bytes/pixel
  - x 60 frames/second
  - = 225 megabytes/second
  - = 1.8 gigabits/second
Direct Illumination

Model

Perspective

Raster Operations

Image Storage

Display

User Input

Camera
Phong Model: Variations of Specular Exponent

![Phong Model Diagram](image)

Roy Hall
Reflectance

Three Approximate Components

Ideal diffuse (Lambertian)
Ideal specular
Directional diffuse
Cook-Torrance Renderings

Carbon  Red Rubber  Obsidian  Lunar Dust  Olive Drab  Rust
Bronze  Tungsten  Copper  Tin  Nickel  Stainless Steel
The geometry of scattering from a layered surface
Direct Lighting and Indirect Lighting
Direct Lighting Only
Global Illumination
Radiosity
1984

49 patches per side
linear interpolation RGB plot
Radiosity
1990s
Example: Automobile Pipeline

Automobile takes 8 minutes to make, but the assembly line makes a car every two minutes.

Stage 1
Stage 2
Stage 3
Stage 4

Time (minutes)
Graphics Hardware circa 1970

- System used to generate Phong goblet
Graphics Hardware circa 1980

- Model
- P-xform Clipping
- Lighting
- Rasterize
- Frame Buffer

CPU

Display

Graphics Hardware

Cost of Memory was Prohibitive

- 512x480x8 bit frame buffer cost $80,000!
- No z-buffer (at 24 or 32 bits/pixel, it requires even more memory than FB)
- Only single frame buffer
- All work done in CPU until frame buffer(slow!)
Graphics Hardware circa 1986

- Added Z-Buffer
- Added Double Frame Buffer
- Rasterization and visible surface computations performed in hardware
• Addition of texture mapping units
• With texturing, high resolution detail is possible with relatively simple geometry
Multipass Example: Light Maps

- Two separate textures, one for the material’s composition, one for the lighting

J.L. Mitchell, M. Tatro, and I. Bullard
Castle’s Geometry

Agata & Andrzej Wojaczek, Advanced Graphics Applications Inc.
Reflection Example - Castle

Agata & Andrzej Wojaczek, Advanced Graphics Applications Inc.
Graphics Hardware 2000

- Vertex buffer (model data) added to reduce bandwidth requirements between CPU and graphics board
Graphics Pipeline - 1980’s

M — Model
L — Lighting
P — Perspective/Clipping
S — Scan Conversion/Z-buffer
D — Display Storage
V — Video

© Donald P. Greenberg - Cornell Program of Computer Graphics
Graphics Pipeline - 2000 +

M — Model
L — Lighting
P — Perspective/Clipping
T — Texturing
S — Scan Conversion/Z-buffer
D — Display Storage
V — Video
• Early GPU’s performed lighting and clipping operations on locally stored model
Faster than Moore’s Law

Graph courtesy of Professor John Poulton (from Eric Haines)
nVidia’s Kepler Chip  2012
NVIDIA’s new Maxwell Chip 2014

- 6144 processor cores (rumor)
- 20 nm
- Q4 2014
<table>
<thead>
<tr>
<th>Processor</th>
<th>Transistor count</th>
<th>Date of introduction</th>
<th>Manufacturer</th>
<th>Process</th>
<th>Area</th>
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<td>AMD</td>
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Moore’s Law – GPU Transistor Counts

http://en.wikipedia.org/wiki/Transistor_count
• nVidia has designed a series of rackable Tesla servers for very fast computation using parallel sets of their GPU hardware

• They developed a novel programming language (CUDA) to take advantage of their unique hardware architectures. This can be used for many other disciplines

• They now offer a product called Iray which computes photorealistic imagery on a cloud
Intel – Integrated Graphics

<table>
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<th>“SANDY BRIDGE”</th>
<th>“IVY BRIDGE”</th>
<th>“HASWELL” Estimated</th>
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<td>17% GPU*</td>
<td>27% GPU*</td>
<td>31% GPU*</td>
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2013
ELITE AMD A-SERIES / CODENAMED "RICHLAND"

42% GPU*
• “Kaveri”
• 28 nm
• 47% GPU
Mobile GPU market share 2013

End...