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

1974
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
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 → Camera → Perspective → Raster Operations → Image Storage → Display

User Input
Phong Model: Variations of Specular Exponent
Reflectance Three Approximate Components

- Ideal diffuse (Lambertian)
- Ideal specular
- Directional diffuse
Cook-Torrance Renderings 1979

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 Only
Global Illumination
Radiosity
1990s
Rendering Framework 1997

Local Reflection
emission
goniometric geometry comparison
BRDF

Transport Simulation
radiometric values
goniometric error metric

Visual Display
perceptual displayed error metric
image

Display Observer
Example: Automobile Pipeline

Automobile takes 8 minutes to make, but the assembly line makes a car every two minutes.
Graphics Hardware circa 1970

• System used to generate Phong goblet
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!)
• Added Z-Buffer
• Added Double Frame Buffer
• Rasterization and visible surface computations performed in hardware
Graphics Hardware 1999

- 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.
• 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
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

- 6144 processor cores (rumor)
- 20 nm
- Q4 2014
• 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
ELITE AMD A-SERIES /
CODENAMED “RICHLAND”

42%
GPU*
AMD – Integrated Graphics

• “Kaveri”
• 28 nm
• 47% GPU

47% GPU
Mobile GPU market share 2013

All GPU Suppliers

- Qualcomm: 33%
- Imagination: 50.10%
- ARM: 2.60%
- Vivante: 4.80%
- DMP: 3.30%
- Takumi: 2.70%
- Broadcom: 0.20%
- ZiiLabs: 0.10%
- NVIDIA: 3%

All GPU IP Suppliers

- Imagination: 78.80%
- ARM: 4.20%
- DMP: 5.20%
- Takumi: 4.30%
- Vivante: 7.50%

End...