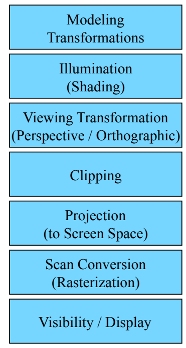
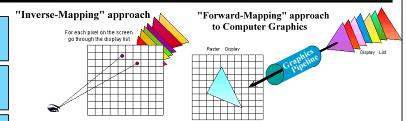
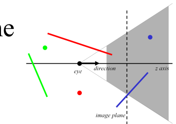
Programmable GPUS

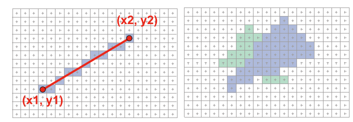
Last Time:





- Graphics Pipeline
- Clipping
- Rasterization



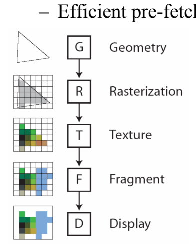


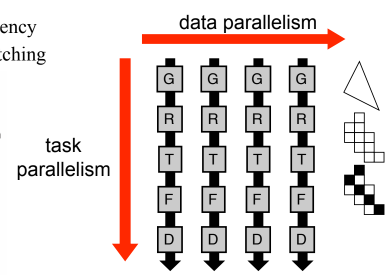
Today

- Modern Graphics Hardware
- Cg Programming Language
- Gouraud Shading vs. Phong Normal Interpolation
- Bump, Displacement, & Environment Mapping

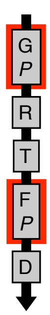
Modern Graphics Hardware

- High performance through
  - Parallelism
  - Specialization
  - No data dependency
  - Efficient pre-fetching

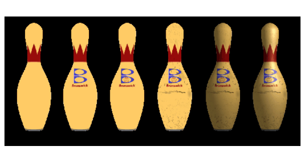




Programmable Graphics Hardware



- Geometry and pixel (fragment) stage become programmable
  - Elaborate appearance
  - More and more general-purpose computation (GPU hacking)



Modern Graphics Hardware

- 2005
  - About 4-6 geometry units
  - About 16 fragment units
  - Deep pipeline (~800 stages)
  - 600 million vertices/second
  - 6 billion texels/second

- NVIDIA GeForce 9 (Feb 2008)
  - ~1 TFLOPS
  - 32/64 stream processors
  - 512 MB/1GB memory
- ATI Radeon R700 (2008?)
  - 480 stream processing units

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Emerging Languages

- Inspired by Shade Trees [Cook 1984] & Renderman Shading Language:
  - RTSL [Stanford 2001] – real-time shading language
  - Cg [NVIDIA 2003] – C for graphics
  - HLSL [Microsoft 2003] – Direct X
  - GLSL [OpenGL ARB 2004] – OpenGL 2.0
- CUDA [NVIDIA 2007] – language for general purpose GPU computing

Cg Design Goals

"Cg: A system for programming graphics hardware in a C-like language"
Mark et al. SIGGRAPH 2003

- Ease of programming
- Portability
- Complete support for hardware functionality
- Performance
- Minimal interference with application data
- Ease of adoption
- Extensibility for future hardware
- Support for non-shading uses of the GPU

Cg Design

- Cg was designed as a "hardware-focused general-purpose language rather than a domain-specific shading language"
- Multi-program model for Cg to match hardware:

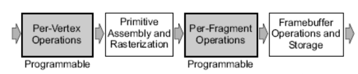

Figure 2: *Current graphics architectures* (DX9-class architectures) *include programmable floating-point vertex and fragment processors.*

"Cg: A system for programming graphics hardware in a C-like language"
Mark et al. SIGGRAPH 2003

Cg Design

- Hardware is changing rapidly… no single standard
- Specify "profile" for each hardware
  - May omit support of some language capabilities (e.g., texture lookup in vertex processor)
- Use hardware virtualization or emulation?
  - "Performance would be so poor it would be worthless for most applications"
  - Well, it might be ok for general purpose programming (not real-time graphics)

Cg compiler vs. GPU assembly

- Can inspect the assembly language produced by Cg compiler and perform additional optimizations by hand
  - Generally once development is complete (& output is correct)
  - Using Cg is easier than writing GPU assembly from scratch

(Typical) Language Design Issues

- Parameter binding
- Call by reference vs. call by value
- Data types: 32 bit float, 16 bit float, 12 bit fixed & type-promotion (aim for performance)
- Specialized arrays or general-purpose arrays
  - `float4 x` vs. `float x[4]`
- Indirect addressing/pointers (not allowed…)
- Recursion (not allowed…)

Data flow in Cg

- Sample vertex program:

input/output through vertex position & texture coordinates

infrequently changing state variables

```
void simpleTransform(float4 objectPosition : POSITION,
                     float4 color          : COLOR,
                     float4 decalCoord     : TEXCOORD0,
                 out float4 clipPosition   : POSITION,
                 out float4 oColor         : COLOR,
                 out float4 oDecalCoord    : TEXCOORD0,
             uniform float  brightness,
             uniform float4x4 modelViewProjection)
{
  clipPosition = mul(modelViewProjection, objectPosition);
  oColor = brightness * color;
  oDecalCoord = decalCoord;
}
```

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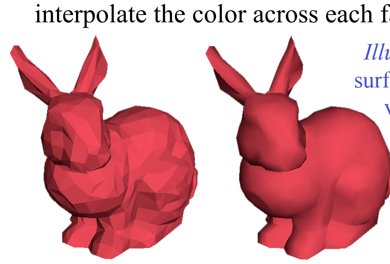
Remember Gouraud Shading?

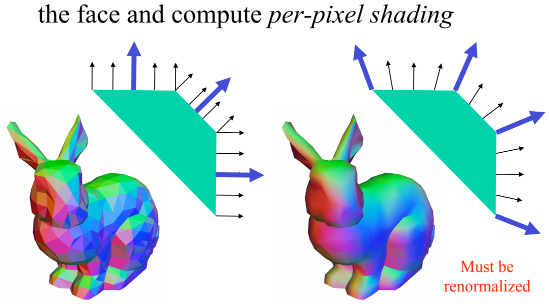
- Instead of shading with the normal of the triangle, shade the vertices with the *average normal* and interpolate the color across each face



Illusion of a smooth surface with smoothly varying normals

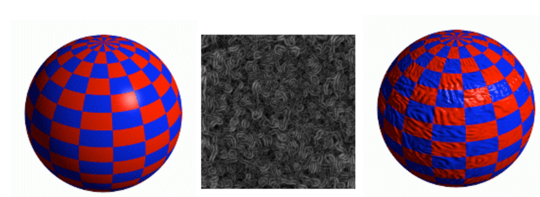
Phong Normal Interpolation (Not Phong *Shading*)

- Interpolate the average vertex normals across the face and compute *per-pixel shading*



Bump Mapping

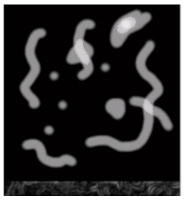
- Use textures to alter the surface normal
  - Does not change the actual shape of the surface
  - Just shaded as if it were a different shape

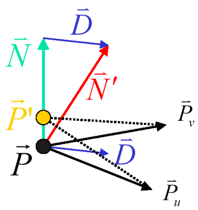


Sphere w/Diffuse Texture — Swirly Bump Map — Sphere w/Diffuse Texture & Bump Map

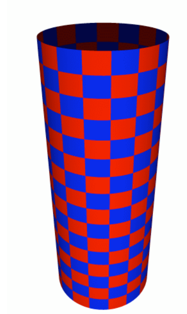
Bump Mapping

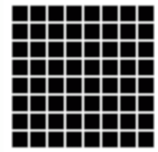
- Treat the texture as a single-valued height function
- Compute the normal from the partial derivatives in the texture

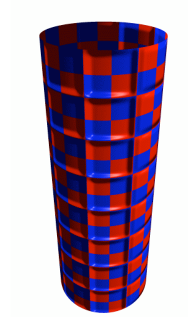




Another Bump Map Example

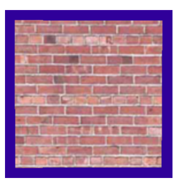

Cylinder w/Diffuse Texture Map

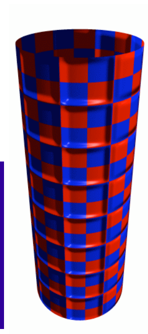

Bump Map


Cylinder w/Texture Map & Bump Map

What's Missing?

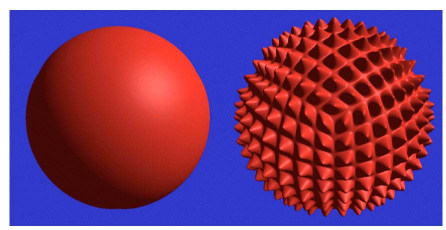
- There are no bumps on the silhouette of a bump-mapped object
- Bump maps don't allow self-occlusion or self-shadowing





Displacement Mapping

- Use the texture map to actually move the surface point
- The geometry must be displaced before visibility is determined



Displacement Mapping

Image from:

Geometry Caching for Ray-Tracing Displacement Maps EGRW 1996 Matt Pharr and Pat Hanrahan

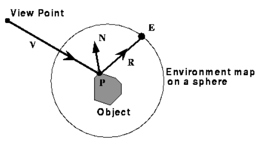
note the detailed shadows cast by the stones

Displacement Mapping

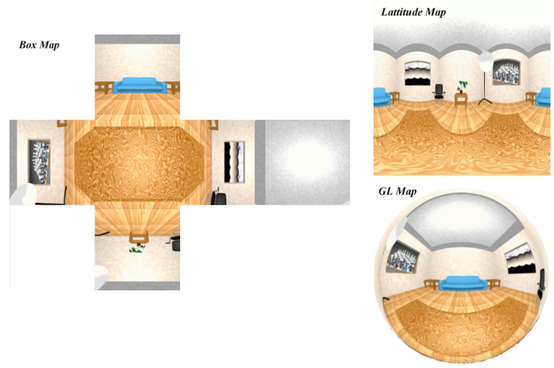

Ken Musgrave

Environment Maps

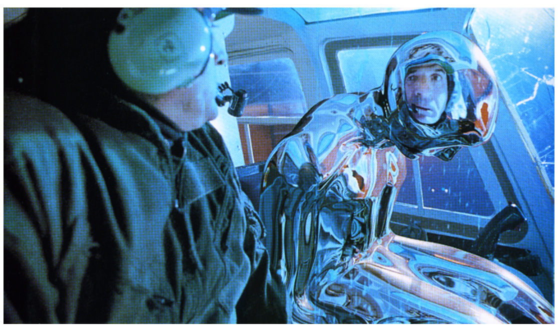
- We can simulate reflections by using the direction of the reflected ray to index a spherical texture map at "infinity".
- Assumes that all reflected rays begin from the same point.



What's the Best Chart?



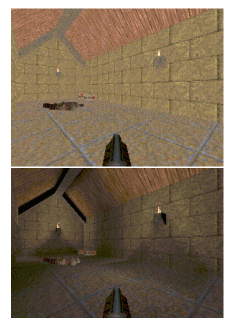
Environment Mapping Example



Terminator II

Texture Maps for Illumination

- Also called "Light Maps"



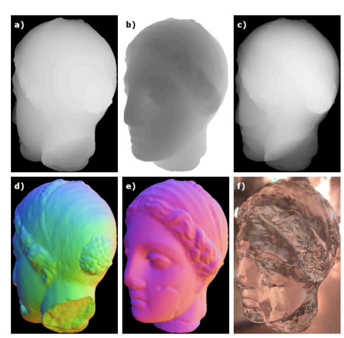
Quake

Questions?

Image by Henrik Wann Jensen
Environment map by Paul Debevec

Reading for Today:

- Chris Wyman, "An Approximate Image-Space Approach for Interactive Refraction", SIGGRAPH 2005

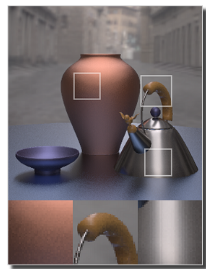


Reading for Tuesday (3/24)

"Efficient BRDF Importance Sampling Using a Factored Representation"
Lawrence, Rusinkiewicz, & Ramamoorthi, SIGGRAPH 2004

1200
Samples/Pixel

Traditional importance function



Lawrence et al.