Shadow Algorithms

CPSC 314

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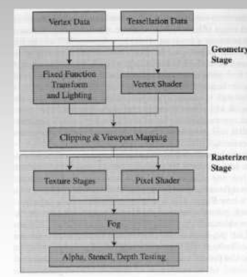
Last Lecture: Modern GPU Architectures

Vertex shader

- Replaces model/view, lighting, and perspective
- Have to implement these yourself
- But can also implement much more

Fragment/pixel shader

- Replaces texture mapping
- Fragment shader must do texturing
- But can do other things



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Vertex Program Properties

Run for every vertex, independently

- Access to all per-vertex properties
  - *Position, color, normal, texture coords, other custom properties*
- Access to read/write registers for temporary results
  - *Value is reset for every vertex*
  - *I.e. cannot pass information from one vertex to the next*
- Access to read-only registers
  - *Global variables, like ligt position, transformation matrices*
- Write output to a specific register for the resulting color

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Vertex Shaders/Programs

Concept:

- Programmable pipeline stage
  - *Floating-point operations on 4 vectors*
    - Points, vectors, and colors!
- Replace all of
  - *Model/View Transformation*
  - *Lighting*
  - *Perspective projection*

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Vertex Programs – Instruction Set

Arithmetic Operations on 4-vectors:

- ADD, MUL, MAD, MIN, MAX, DP3, DP4

Operations on Scalars

- RCP (1/x), RSQ (1/√x), EXP, LOG

Specialty Instructions

- DST (distance: computes length of vector)
- LIT (quadratic falloff term for lighting)

Very latest generation:

- Loops and conditional jumps

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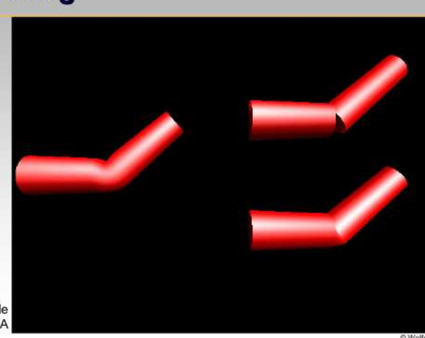
Skinning



Example by NVIDIA

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Fragment Shaders

- *Fragment shaders* operate on fragments in place of the texturing hardware
  - *After rasterization, before any fragment tests or blending*
- Input: The fragment, with screen position, depth, color, and a set of texture coordinates
- Access to textures and some constant data and registers
- Compute RGBA values for the fragment, and depth
  - *Can also "kill "a fragment, that is throw it away*
- Two types of fragment shaders: register combiners (GeForce4) and fully programmable (GeForceFX, Radeon 9700)

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High Level Shading Languages e.g. Cg

Cg is a high-level language developed by NVIDIA

- It looks like C or C++
- Actually a language and a runtime environment
  - *Can compile ahead of time, or compile on the fly*
  - *Why compile on the fly?*
- What it can do is tightly tied to the hardware
  - *How does it know which hardware, and how to use it?*

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Vertex Program Example

```
void C5E2v_fragmentLighting(float4 position : POSITION,
                            float3 normal   : NORMAL,

                        out float4 oPosition : POSITION,
                        out float3 objectPos : TEXCOORD0,
                        out float3 oNormal   : TEXCOORD1,

                    uniform float4x4 modelViewProj)
{
  oPosition = mul(modelViewProj, position);
  objectPos = position.xyz;
  oNormal = normal;
}
```

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Pixel Program Example

```
void C5E3f_basicLight(float4 position : TEXCOORD0,
                      float3 normal   : TEXCOORD1,

                  out float4 color    : COLOR,

              uniform float3 globalAmbient,
              uniform float3 lightColor,
              uniform float3 lightPosition,
              uniform float3 eyePosition,
              uniform float3 Ke,
              uniform float3 Ka,
              uniform float3 Kd,
              uniform float3 Ks,
              uniform float  shininess)
{
  float3 P = position.xyz;
  float3 N = normalize(normal);

  // Compute the emissive term
  float3 emissive = Ke;

  // Compute the ambient term
  float3 ambient = Ka * globalAmbient;

  // Compute the diffuse term
  float3 L = normalize(lightPosition - P);
  float diffuseLight = max(dot(N, L), 0);
  float3 diffuse = Kd * lightColor * diffuseLight;

  // Compute the specular term
  float3 V = normalize(eyePosition - P);
  float3 H = normalize(L + V);
  float specularLight = pow(max(dot(N, H), 0),
                            shininess);
  if (diffuseLight <= 0) specularLight = 0;
  float3 specular = Ks * lightColor * specularLight;

  color.xyz = emissive + ambient + diffuse + specular;
  color.w = 1;
}
```

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Shadow Algorithms

CPSC 314

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Shadows

Types of light sources

- Point, directional
- Area lights and generally shaped lights
  - *Not considered here*
  - *Later: ray-tracing for such light sources*

Problem statement

- A shadow algorithm for point and directional lights determines which scene points are
  - *Visible from the light source (I.e. illuminated)*
  - *Invisible from the light source (I.e. in shadow)*
- Thus: shadow casting is a visibility problem!

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Types of Shadow Algorithms

Object Space

- Like object space visibility algorithms, the method computes in object space which polygon parts that are illuminated and which are in shadow
  - *Individuyal parts are then drawn with different intensity*
- Typically slow, O(n^2), not for dynamic scenes

Image Space

- Determine visibility per pixel in the final image
  - *Sort of like depth buffer*
  - *Shadow maps*
  - *Shadow volumes*

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Credits

- The following shadow mapping slides are taken from Mark Kilgard's OpenGL course at Siggraph 2002.

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Shadow Mapping Concept (1)

Depth testing from the light's point-of-view

- Two pass algorithm
- First, render depth buffer from the light's point-of-view
  - The result is a "depth map" or "shadow map"
  - Essentially a 2D function indicating the depth of the closest pixels to the light
- This depth map is used in the second pass

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Shadow Mapping Concept (2)

Shadow determination with the depth map

- Second, render scene from the eye's point-of-view
- For each rasterized fragment
  - Determine fragment's XYZ position relative to the light
  - This light position should be setup to match the frustum used to create the depth map
  - Compare the depth value at light position XY in the depth map to fragment's light position Z

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The Shadow Mapping Concept (3)

The Shadow Map Comparison

- Two values
  - A = Z value from depth map at fragment's light XY position
  - B = Z value of fragment's XYZ light position
- If B is greater than A, then there must be something closer to the light than the fragment
  - Then the fragment is shadowed
- If A and B are approximately equal, the fragment is lit

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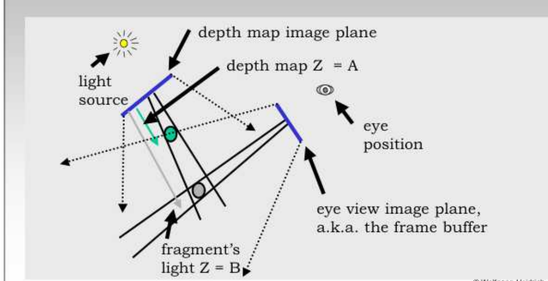
Shadow Mapping with a Picture in 2D (1)

The A < B shadowed fragment case



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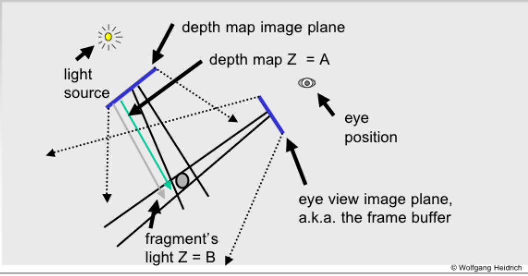
Shadow Mapping with a Picture in 2D (2)

The A ≈ B unshadowed fragment case



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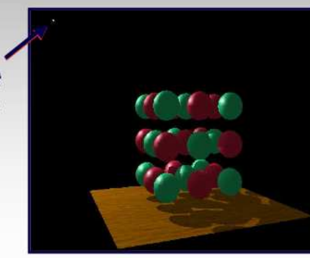
Visualizing the Shadow Mapping Technique (1)

A scene with fairly complex shadows

the point light source



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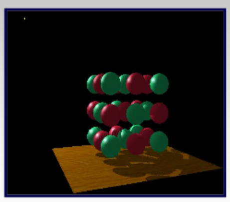
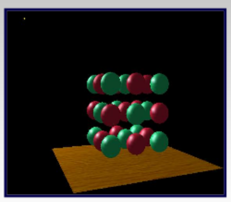
Visualizing the Shadow Mapping Technique (2)

Compare with and without shadows



with shadows



without shadows

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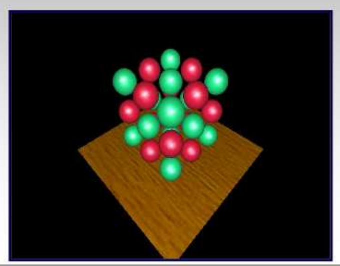
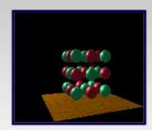
Visualizing the Shadow Mapping Technique (3)

The scene from the light's point-of-view





FYI: from the eye's point-of-view again

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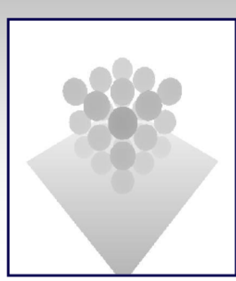
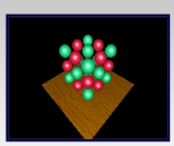
Visualizing the Shadow Mapping Technique (4)

The depth buffer from the light's point-of-view





FYI: from the light's point-of-view again

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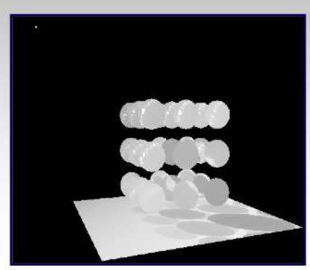
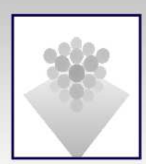
Visualizing the Shadow Mapping Technique (5)

Projecting the depth map onto the eye's view





FYI: depth map for light's point-of-view again

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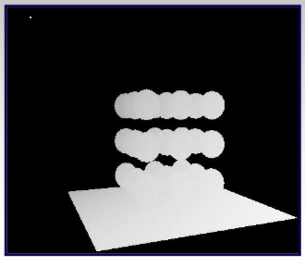
Visualizing the Shadow Mapping Technique (6)

Projecting light's planar distance onto eye's view



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Visualizing the Shadow Mapping Technique (6)

Comparing light distance to light depth map

Green is where the light planar distance and the light depth map are approximately equal

Non-green is where shadows should be

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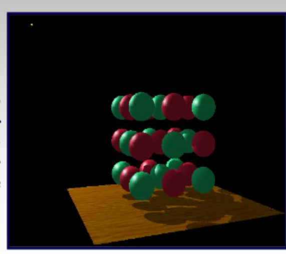
Visualizing the Shadow Mapping Technique (7)

Complete scene with shadows

Notice how specular highlights never appear in shadows



Notice how curved surfaces cast shadows on each other

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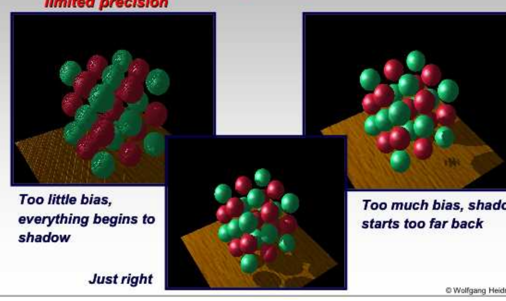
In Practice: Depth Map Precision Issues

Have to add a little offset to depth map values to account for limited precision



Too little bias, everything begins to shadow

Just right

Too much bias, shadow starts too far back

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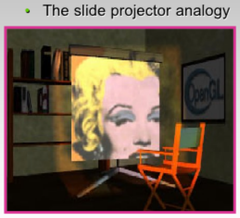
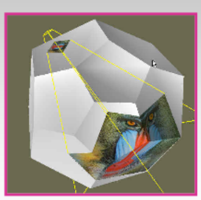
What is Projective Texturing?

An intuition for projective texturing

- The slide projector analogy





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About Projective Texturing (1)

First, what is perspective-correct texturing?

- Normal 2D texture mapping uses (s, t) coordinates
- 2D perspective-correct texture mapping
  - Means (s, t) should be interpolated linearly in eye-space
  - So compute per-vertex s/w, t/w, and 1/w
  - Linearly interpolated these three parameters over polygon
  - Per-fragment compute s' = (s/w) / (1/w) and t' = (t/w) / (1/w)
  - Results in per-fragment perspective correct (s', t')

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About Projective Texturing (2)

So what is projective texturing?

- Now consider homogeneous texture coordinates
  - (s, t, r, q) --> (s/q, t/q, r/q)
  - Similar to homogeneous clip coordinates where (x, y, z, w) = (x/w, y/w, z/w)
- Idea is to have (s/q, t/q, r/q) be projected per-fragment

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Back to the Shadow Mapping Discussion . . .

Assign light-space texture coordinates to polygon vertices

- Transform eye-space (x, y, z, w) coordinates to the light's view frustum (match how the light's depth map is generated)
- Further transform these coordinates to map directly into the light view's depth map
  - *Expressible as a projective transform*
- (s/q, t/q) will map to light's depth map texture

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Shadow Map Operation

Next Step:

- Compare depth map value to distance of fragment from light source
- Different GPU generations support different means of implementing this
  - *Today's GPUs: pixel shader!*
  - *Earlier: special hardware for implmenting this feature (e.g. SGI), or just using alpha blending [Heidrich'99]*

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Issues with Shadow Mapping (1)

Not without its problems

- Prone to aliasing artifacts
  - "percentage closer" filtering helps this
  - normal color filtering does **not** work well
- Depth bias is not completely foolproof
- Requires extra shadow map rendering pass and texture loading
- Higher resolution shadow map reduces blockiness
  - but also increase texture copying expense

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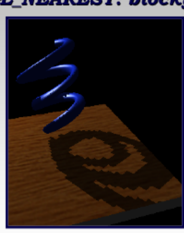
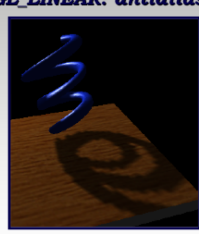
Hardware Shadow Map Filtering Example

GL_NEAREST: blocky



GL_LINEAR: antialiased edges



Low shadow map resolution used to heightens filtering artifacts

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Issues with Shadow Mapping (2)

Not without its problems

- Shadows are limited to view frustums
  - could use six view frustums for omni-directional light
- Objects outside or crossing the near and far clip planes are not properly accounted for by shadowing
  - move near plane in as close as possible
  - but too close throws away valuable depth map precision when using a projective frustum

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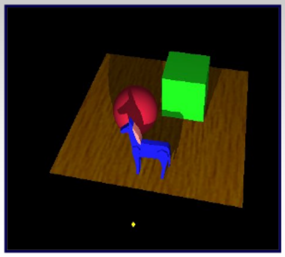
More Examples

Complex objects all shadow



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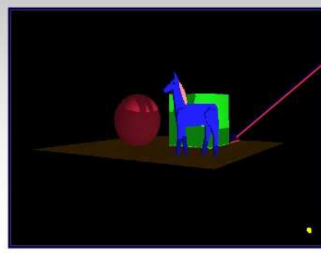
More Examples

Even the floor casts shadow



Note shadow leakage due to infinitely thin floor

Could be fixed by giving floor thickness

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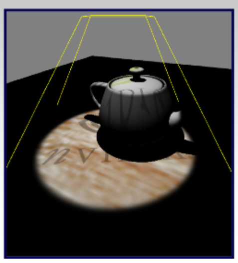
Combining Projective Texturing for Spotlights

Use a spotlight-style projected texture to give shadow maps a spotlight falloff



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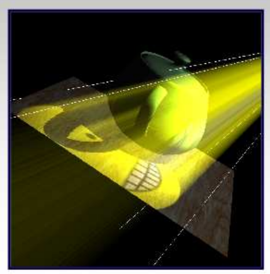
Combining Shadows with Atmospherics

Shadows in a dusty room



Simulate atmospheric effects such as suspended dust

1) *Construct shadow map*
2) *Draw scene with shadow map*
3) *Modulate projected texture image with projected shadow map*
4) *Blend back-to-front shadowed slicing planes also modulated by projected texture image*

Credit: Cass Everitt

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Shadow Maps

Approach for shadows from point light sources

- Surface point is in shadow if it is not visible from the light source
- Use depth buffer to test visibility:
  - *Render scene from the point light source*
  - *Store resulting depth buffer as texture map*
  - *For every fragment generated while rendering from the camera position, project the fragment into the depth texture taken from the camera, and check if it passes the depth test.*

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Shadow Volumes

Use new buffer: stencil buffer

- Just another channel of the framebuffer
- Can count how often a pixel is drawn

Algorithm (1):

- Generate silhouette polygons for all objects
  - *Polygons starting at silhouette edges of object*
  - *Extending away from light source towards infinity*
  - *These can be computed in vertex programs*

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Shadow Volumes

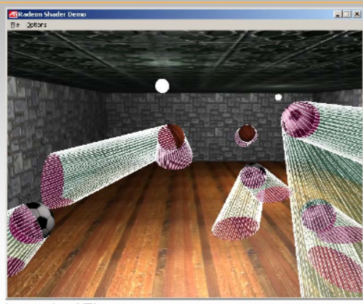

Image by ATI

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Shadow Volumes

Algorithm (2):

- Render all original geometry into the depth buffer
  - *I.e. do not draw any colors (or only draw ambient illumination term)*
- Render <u>front-facing</u> silhouette polygons while <u>incrementing</u> the stencil buffer for every rendered fragment
- Render <u>back-facing</u> silhouette polygons while <u>decrementing</u> the stencil buffer for every rendered fragment
- Draw illuminated geometry where the stencil buffer is 0, shadow elsewhere

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Shadow Volumes

Image by ATI

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Shadow Volumes

Discussion:

- Object space method therefore no precision issues
- Lots of large polygons: can be slow
  - *High geometry count*
  - *Large number of pixels rendered*

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Coming Up…

Tuesday:

- Color

Thursday:

- Ray-tracing

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