Lecture 12 of 41

Surface Detail 3 of 5: Mappings
OpenGL Textures

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KSOL course pages: http://bit.ly/hGvXlH / http://bit.ly/eVizrE
Public mirror web site: http://www.kddresearch.org/Courses/CIS636
Instructor home page: http://www.cis.ksu.edu/~bhsu

Readings:
Today: Sections 20.5 – 20.13, Eberly 2e – see http://bit.ly/ieUq45
Next class: Section 3.1, Eberly 2e
Brown CS123 slides on Polygons/Texture Mapping – http://bit.ly/h2VZn8
Wayback Machine archive of Brown CS123 slides: http://bit.ly/gAhJbh
Gröller & Jeschke slides on Texturing – http://bit.ly/dJFYq9

Lecture Outline

- Reading for Last Class: §2.6.3, 20.3 – 20.4, Eberly 2e
- Reading for Today: §20.5 – 20.13, Eberly 2e (Many Mappings)
- Reading for Next Class: §3.1, Eberly 2e
- Last Time: Texture Mapping Explained
  - Definitions and design principles
  - Enclosing volumes: cylinder, sphere, box
  - Mapping methods
    - reflected ray – bounce ray off object *O*
    - object normal – ray from face normal of object (polygon mesh)
    - object center – ray from center of object
    - intermediate surface normal – ray from inside of enclosing *S*
- Today: Mappings, OpenGL Texturing
  - Shadow, reflection/environment, transparency, bump, displacement
  - Other mappings: gloss, volumetric fog, skins, rainbows, water
  - OpenGL texture mapping how-to

Where We Are

Lecture	Topic	Primary Source(s)
0	Course Overview	Chapter 1, Eberly 2e
1	**CG Basics: Transformation Matrices; Lab 0**	**Sections (§) 2.1, 2.2**
2	Viewing 1: Overview, Projections	§ 2.2.3 – 2.2.4, 2.8
3	Viewing 2: Viewing Transformation	§ 2.3 esp. 2.3.4; FVFH slides
4	**Lab 1a: Flash & OpenGL Basics**	**Ch. 2, 16[1], Angel *Primer***
5	Viewing 3: Graphics Pipeline	§ 2.3 esp. 2.3.7; 2.6, 2.7
6	Scan Conversion 1: Lines, Midpoint Algorithm	§ 2.5.1, 3.1; FVFH slides
7	**Viewing 4: Clipping & Culling; Lab 1b**	**§ 2.3.5, 2.4, 3.1.3**
8	Scan Conversion 2: Polygons, Clipping Intro	§ 2.4, 2.5 esp. 2.5.4, 3.1.6
9	Surface Detail 1: Illumination & Shading	§ 2.5, 2.6.1 – 2.6.2, 4.3.2, 20.2
10	**Lab 2a: Direct3D / DirectX Intro**	**§ 2.7, Direct3D handout**
11	Surface Detail 2: Textures; OpenGL Shading	§ 2.6.3, 20.3 – 20.4, *Primer*
12	Surface Detail 3: Mappings; OpenGL Textures	§ 20.5 – 20.13
13	**Surface Detail 4: Pixel/Vertex Shad.; Lab 2b**	**§ 3.1**
14	Surface Detail 5: Direct3D Shading; OGLSL	§ 3.2 – 3.4, Direct3D handout
15	Demos 1: CGA, Fun; Scene Graphs: State	§ 4.1 – 4.3, **CGA handout**
16	**Lab 3a: Shading & Transparency**	**§ 2.6, 20.1, *Primer***
17	**Animation 1: Basics, Keyframes; HW/Exam**	**§ 5.1 – 5.2**
	Exam 1 review; Hour Exam 1 (evening)	**Chapters 1 – 4, 20**
18	**Scene Graphs: Rendering; Lab 3b: Shader**	**§ 4.4 – 4.7**
19	**Demos 2: SFX; Skinning, Morphing**	**§ 5.3 – 5.5, CGA handout**
20	Demos 3: Surfaces; B-reps/Volume Graphics	§ 10.4, 12.7, **Mesh handout**

Lightly-shaded entries denote the due date of a written problem set; heavily-shaded entries, that of a machine problem (programming assignment); blue-shaded entries, that of a paper review; and the green-shaded entry, that of the term project.

Green, **blue** and **red** letters denote **exam review**, **exam**, and **exam solution review** dates.

Review: OpenGL Shading (Overview)

Frank Pfenning
Professor of Computer Science
School of Computer Science
Carnegie Mellon University
http://www.cs.cmu.edu/~fp/

See also: *OpenGL: A Primer, 3e* (Angel)
http://bit.ly/hVcVWN

- **Set Up Point Light Sources**
  - Directional light given by "position" vector
```
GLfloat light_position[] = {-1.0, 1.0, -1.0, 0.0};
glLightfv(GL_LIGHT0, GL_POSITION, light_position);
```
  - Point source given by "position" point
```
GLfloat light_position[] = {-1.0, 1.0, -1.0, 1.0};
glLightfv(GL_LIGHT0, GL_POSITION, light_position);
```
- **Set Up Materials, Turn Lights On**
```
GLfloat mat_specular[]={0.0, 0.0, 0.0, 1.0};
GLfloat mat_diffuse[]={0.8, 0.6, 0.4, 1.0};
GLfloat mat_ambient[]={0.8, 0.6, 0.4, 1.0};
GLfloat mat_shininess={20.0};
glMaterialfv(GL_FRONT, GL_SPECULAR, mat_specular);
glMaterialfv(GL_FRONT, GL_AMBIENT, mat_ambient);
glMaterialfv(GL_FRONT, GL_DIFFUSE, mat_diffuse);
glMaterialf(GL_FRONT, GL_SHININESS, mat_shininess);

glShadeModel(GL_SMOOTH); /*enable smooth shading */
glEnable(GL_LIGHTING); /* enable lighting */
glEnable(GL_LIGHT0);  /* enable light 0 */
```
- **Start Drawing (`glBegin` … `glEnd`)**

Adapted from slides © 2003 F. Pfenning, Carnegie Mellon University
http://bit.ly/g1J2nj

Acknowledgements: Many Mappings

Stefan Jeschke
Research Assistant
http://bit.ly/hUUM94

Eduard Gröller
Associate Professor
Director, Visualization Working Group
http://bit.ly/hUUM94

Institute of Computer Graphics and Algorithms
Technical University of Vienna

TECHNISCHE UNIVERSITÄT WIEN
Institut für Computergraphik und Algorithmen
Arbeitsbereich Computergraphik

Texturing material from slides © 2002 E. Gröller & S. Jeschke, Vienna University of Technology
http://bit.ly/dJFYq9

Mapping material from slides © 1995 – 2009 P. Hanrahan, Stanford University
http://bit.ly/hZfsjZ (CS 348B, Computer Graphics: Image Synthesis Techniques)

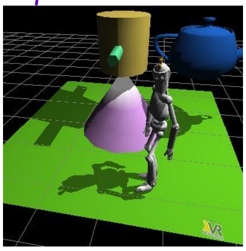
Overview of Mappings: Eberly 2e Chapter 20 Sections

- Fine Surface Detail: Bump (§20.5 Eberly 2e)
- Material Effects: Gloss (§20.6)
- Enclosing Volumes
  - Sphere (§20.7)
  - Cube (§20.8)
- Light
  - Refraction for Transparency (§20.9)
  - Reflection *aka* Environment (§20.10)
- Shadow
  - Shadow Maps (§20.11, 20.13)
  - Projective Textures (§20.12)
- More Special Effects (SFX)
  - Fog (§20.14)
  - Skinning (§20.15)
  - Iridescence (§20.16), Water (§20.17)

Babylon 5

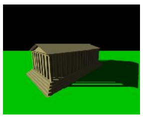
Shadow Mapping [1]: Basic Concept

- Process for Adding Shadows in 3-D CG
- Compatible with Local Illumination
  - Global method: shadow rays
  - Not needed here as in raytracing
  - Instead, use decaling
- Decals
  - "Paste" surface detail onto model
  - Semi-transparent: alpha blending
  - Can simulate many attributes



Shadow Mapping © 2007 XVR Wiki
http://wiki.vrmedia.it/index.php?title=Shadow_Mapping

Without shadow map

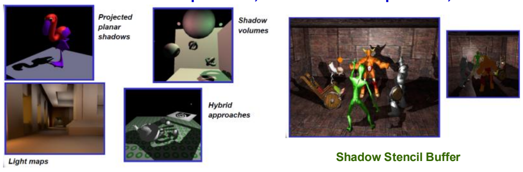


With shadow map

Shadow Mapping © 2005 Wikipedia
http://en.wikipedia.org/wiki/Shadow_mapping

Shadow Mapping [2]: Techniques

- Ways to Handle Shadows
  - Projected planar shadows: works well on flat surfaces only
  - Shadow stencil buffer: powerful, excellent results possible; hard!



Shadow Stencil Buffer

- OpenGL Shadow Mapping Tutorials
  - Beginner/Intermediate (Baker, 2003): http://bit.ly/e1LA2N
  - Advanced (Octavian *et al.*, 2000): http://bit.ly/f1iRYB (old NeHe #27)

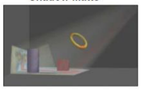
Adapted from "Shadow Mapping" © 2001 C. Everitt, nVidia
http://developer.nvidia.com/object/shadow_mapping.html

Shadow Mapping [3]: Advanced Methods & Research

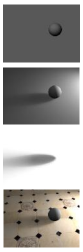
- Shadow Mattes (Hanrahan)

Projected Texture

Shadow Matte



```
UberLight( )
{
  Clip to near/far planes
  Clip to shape boundary
  foreach superelliptical blocker
      atten *= …
  foreach cookie texture
      atten *= …
  foreach slide texture
      color *= …
  foreach noise texture
      atten, color *= …
  foreach shadow map
      atten, color *= …
  Calculate intensity fall-off
  Calculate beam distribution
}
```



© 2010 M. Gryka
http://bit.ly/hJlfps

- Can Be Layered (See Maya 2011 Tutorial by Maciek Gryka)

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http://bit.ly/hZfsjZ (CS 348B)

Reflection/Environment Mapping [1]: Basic Concept

- Reflection Maps (Special Type) ~ Environment Maps (General Case)
  - For a given viewing direction
    - For each normal direction
      - For each incoming direction (hemispherical integral)
        - Evaluate reflection equation
- Idea: Take Picture of Scene Faced by Object, Apply as Map to Object
- Requirements: Need to Take Account of Projective Distortions

Ray Traced — Environment Map

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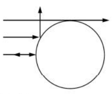
Reflection/Environment Mapping [2]: Techniques

- Gazing Ball (Mirrorball)

Photo © 2009 K. Turkowski



Note:
- Photograph of reflective ball
- Reflection indexed by normal
- Maps entire field of view to circle
- Resolution function of orientation; maximum head-on
- Fish eye camera lens similar

- Reflection Functions
  - Diffuse: irradiance map
  - Glossy: radiance map
  - Anisotropic: for each tangent direction
  - Mirror: reflection map (related to environment map)
- Illumination Functions: Environment Map or Procedural Light Sources

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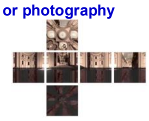
http://bit.ly/hZfsjZ (CS 348B)

Reflection/Environment Mapping [3]: Advanced Methods & Research

- How To Create Direction Maps
  - Latitude-Longitude (Map Projections) - paint
  - Gazing Ball - photograph reflective sphere
  - Fisheye Lens - standard (wide-angle) camera lens
  - Cubical Environment Map - rendering program or photography
    - Easy to produce
    - "Uniform" resolution
    - Simple texture coordinates calculation



- Old NeHe OpenGL Mapping Tutorials (2000)
  - #6 (texture map onto cube) – Beginner (Molofee): http://bit.ly/gKj2Nb
  - #23 (sphere) – Intermediate (Schmick & Molofee): http://bit.ly/e3Zb8h
- nVidia Tutorial: OpenGL Cube Map (1999): http://bit.ly/eJEdAM
- Issues: Non-Linear Mapping, Area Distortion, Converting Between Maps

Adapted from slides © 1995 – 2009 P. Hanrahan, Stanford University
http://bit.ly/hZfsjZ (CS 348B)

Transparency Mapping [1]: Basic Concept

- Transparency: One Term for Many Techniques

Tom Porter's Bowling Pin

Source: RenderMan Companion, Pls. 12 & 13

- Goal: "See Through" Objects (Could Be Real Decals)
- Ideas: Render Background Object, Then Foreground Object or Material
  - Blend in color of (semi-)transparent/translucent foreground object
  - Simulate little holes in foreground material (screen door)

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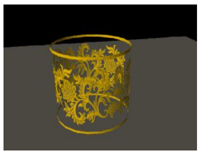
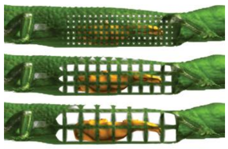
http://bit.ly/hZfsjZ (CS 348B)

Transparency Mapping [2]: Techniques

- Alpha Compositing *aka* Alpha Blending
  - Combine colors of transparent foreground, opaque background
  - Uses alpha channel *A* of (*R*, *G*, *B*, *A*) – think "% transparency"
  - Wikipedia: http://bit.ly/ePpwoh (see also RGBA, http://bit.ly/ePpwoh)



Alpha blending: Lim (2010), http://bit.ly/6TsJrb
Goon Creative, Maya Transparency Tutorial



Screen door: Viola *et al.* (2004), http://bit.ly/dVEa7I
Technical University of Vienna, IEEE Vis 2004

- Screen Door Transparency
  - Simulate little holes in foreground material (screen door)
  - Result: visual effect of being able to see through foreground

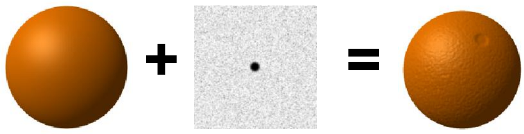
Transparency Mapping [3]: Advanced Methods & Research

- OpenGL Transparency How-To at OpenGL.org: http://bit.ly/hRaQgk
- Screen Door Transparency
  - Use `glPolygonStipple()`, `glEnable(GL_POLYGON_STIPPLE)`
  - See http://bit.ly/g1hQpJ
- Glass-Like Transparency using Alpha Blending
  - Use `glEnable(GL_BLEND)`, `glBlendFunc(…)`
  - See http://bit.ly/hs82Za

Viola *et al.* (2004), http://bit.ly/dVEa7I
Technical University of Vienna, IEEE Vis 2004

Bump Mapping [1]: Basic Concept

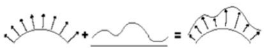
- Goal: Create Illusion of Textured Surface



Bump Mapping © 2010 Wikipedia
http://en.wikipedia.org/wiki/Bump_mapping

- Idea
  - Start with regular smooth object
  - Make height map (by hand and/or using program, *i.e.*, procedurally)
  - Use map to perturb surface normals
  - Plug new normals into illumination equation
- Will This Look Realistic? Why/Why Not?

Bump Mapping [2]: Techniques



$\mathbf{P}(u,v)$

$\mathbf{S}(u,v)=\dfrac{\partial \mathbf{P}(u,v)}{\partial u} \qquad \mathbf{T}(u,v)=\dfrac{\partial \mathbf{P}(u,v)}{\partial v}$

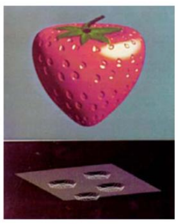
$\mathbf{N}(u,v)=\mathbf{S}\times\mathbf{T}$

- Displacement

$\mathbf{P}'(u,v)=\mathbf{P}(u,v)+h(u,v)\mathbf{N}(u,v)$

- Perturbed normal

$$\mathbf{N}'(u,v)=\mathbf{P}'_u\times\mathbf{P}'_v = \mathbf{N}+h_u(\mathbf{T}\times\mathbf{N})+h_v(\mathbf{S}\times\mathbf{N})$$

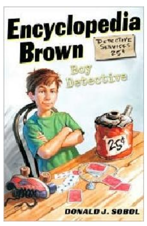


From Blinn 1976

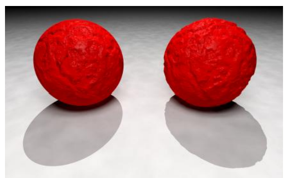
Adapted from slides © 1995 – 2009 P. Hanrahan, Stanford University
http://bit.ly/hZfsjZ (CS 348B)

Bump Mapping [3]: Advanced Methods & Research

- Bump Mapping Tutorial for OpenGL (Baker, 2003): http://bit.ly/fun4a5



Hey, wait a minute!

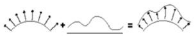


… what's wrong with the one on the left?

- Right Ball (Displacement Mapped) Casts *Rough* Shadow
- Left Ball (Bump Mapped) Casts *Smooth* Shadow – Why?
- Bump Mapping Only Perturbs Normals (Surface Only!)

Displacement Mapping [1]: Basic Concept

- Remember What We Did to Perform Bump Mapping?



$\mathbf{P}(u,v)$

$\mathbf{S}(u,v) = \frac{\partial \mathbf{P}(u,v)}{\partial u} \quad \mathbf{T}(u,v) = \frac{\partial \mathbf{P}(u,v)}{\partial v}$

$\mathbf{N}(u,v) = \mathbf{S} \times \mathbf{T}$

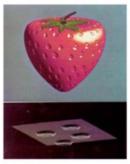
- Displacement

$\mathbf{P}'(u,v) = \mathbf{P}(u,v) + h(u,v)\mathbf{N}(u,v)$

- Perturbed normal

$\mathbf{N}'(u,v) = \mathbf{P}'_u \times \mathbf{P}'_v$

$= \mathbf{N} + h_u(\mathbf{T} \times \mathbf{N}) + h_v(\mathbf{S} \times \mathbf{N})$



From Blinn 1976

- Q: Can We Make This *Permanent*? How?
- A: Sure! Let Perturbed Normals Define New Surface; Save Out Vertices

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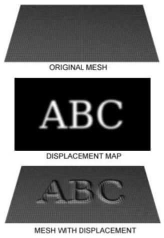
http://bit.ly/hZfsjZ (CS 348B)

Displacement Mapping [2]: Techniques

- Displacement Map: Similar to Bump Map – Contains Delta Values



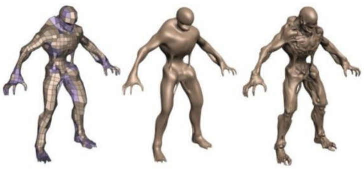
Displacement Mapping © 2005 Wikipedia
http://en.wikipedia.org/wiki/Displacement_mapping

Displacement Mapping: For Real!

- Displacement Mapping: Uses Open GL Shading Language (GLSL)
- Tutorial using GLSL (Guinot, 2006): http://bit.ly/dWXNya

Displacement Mapping [3]: Advanced Methods & Research

- When To Consider Using Displacement Mapping
  - Very "deep" texture effect: veins, ridges, *etc.*
  - Shadows expected



The "Imp" © Kenneth Scott, id Software 2008

The "Imp" © 2008 K. Scott, id Software
Bjorn3D, http://bit.ly/i78SiP

Like Many Mappings and Other Effects, Wanted In Hardware!

Acknowledgements: Texture Mapping Slides

Andy van Dam
T. J. Watson University Professor of Technology and Education &
Professor of Computer Science
Brown University
http://www.cs.brown.edu/~avd/

Texture Mapping

Beautification of Surfaces

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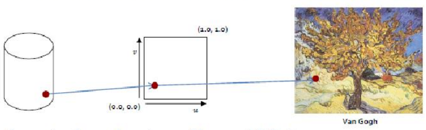
Texture Mapping Technique [1]

- Texture mapping is the process of mapping a geometric point in space to a value (color, normal, other...) in a texture
  - Our goal is to map any arbitrary geometry to a texture of any dimension
  - This is done in two steps:
    - Map a point on the geometry to a point on the unit square
    - Map the unit square point to point on the texture



  - Second mapping is much easier, we'll present it first.

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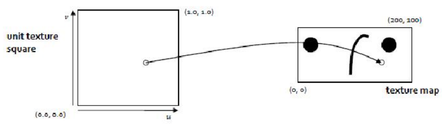
Texture Mapping Technique [2]

- Mapping a point in the unit u, v square to a texture of arbitrary dimension:
  - In general, any point (u, v) on the unit square, the corresponding point on the texture of length l pixels and height h pixels is $(u * l, v * h)$.



  - Above: (0.0, 0.0) -> (0, 0); (1.0, 1.0) -> (200, 100); (.7, .45) -> (140, 45)
  - Once we have coordinates for the texture, we just need to look up the color of the texture at these coordinates
  - Coordinates not always a discrete point on texture as they come from continuous space. May need to average neighboring texture pixels (i.e. filter)

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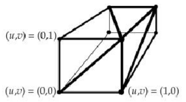
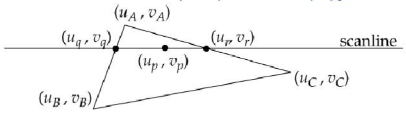
Texture Mapping Technique [3]

- Texture mapping polygons
  - (u, v) texture coordinates are pre-calculated and specified per vertex
  - Vertices may have different texture coordinates for different faces



  - Texture coordinates are linearly interpolated across polygon



Interpolation Trick: Barycentric Coordinates

- Consider interpolating between two values along a line
  - Given two colors C_a and C_b, you can compute any value along the "line" between the two colors by evaluating:

$$C(t) = (1-t)C_a + tC_b \quad 0 \le t \le 1$$

  - This equation can be written as:

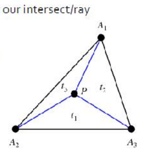
$$C(s,t) = sC_a + tC_b \qquad s + t = 1 \qquad s, t \ge 0$$

  - s and t are the Barycentric Coordinates of the line segment between C_a and C_b
  - The EQ of the line is a convex linear combination of its endpoints. We've seen this before (splines, color theory)
- Barycentric coordinates can be generalized to triangles

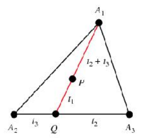
$$C(s,t,u) = sC_a + tC_b + uC_c \qquad s + t + u = 1 \qquad s, t, u \ge 0$$

Applying Barycentric Coordinates

- When you intersect a ray with a polyhedral object (not needed for our intersect/ray projects):
  - return the vertex data of the triangle intesected
  - return the Barycentric coordinates (t_1, t_2, t_3) of the intersection point
  - These coordinates can be used to interpolate between vertex colors, normals, texture coordinates, or other data
  - What weights do we hang on each vertex such that the triangle would be perfectly balanced on a pin at point P
  - Alternatively, think of a mobile suspended from P with 2 arms A_1Q and A_2A_3.



  - Compute Q as intersection of line through A_1 and P and line through A_2 and A_3
  - $t_3' = |Q - A_2|$
  - $t_2' = |Q - A_3|$
  - $t_1' = |P - Q|$
  - $(t_1, t_2, t_3) = (t_1', t_2', t_3')/(t_1 + t_2 + t_3)$



  - Another way of thinking about this is by triangle area. The weight at A_1 should be proportional to the area of the triangle P, A_2, A_3, and so on...

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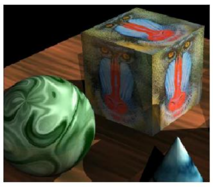
Texture Mapping Technique [4]: Map Point to Object on (u, v) Square

- Texture mapping in "Ray": mapping solids
  - Using ray tracing, we obtain an intersection point (x, y, z) in object space
  - We need to map this point to a point on the (u, v) unit square, so we can map that to a texture value
  - Three easy cases: planes, cylinders, and spheres
  - Easiest to compute the mapping from (x, y, z) coordinates in **object space** to (u, v)

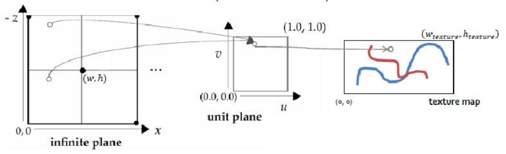


  - Can cause unwanted texture scaling
  - Texture filtering is an option in most graphics libraries
  - OpenGL allows you to choose filtering method. (GL_NEAREST, GL_LINEAR, etc...)

Texture Mapping Technique [5]

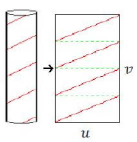
- Texture mapping large quads:
  - How to map a point on a very large quad to a point on the unit square?
  - Tiling: texture is repeated over and over across infinite plane
  - Given coordinates (x, y) of a point on an arbitrarily large quad that we want to tile with quads of size (w, h), the (u, v) coordinates on the unit square representing a texture with arbitrary dimensions are:

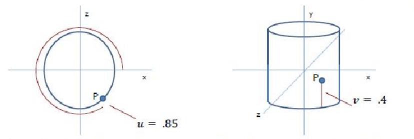
$$(u, v) = \left(\frac{(x \,\%\, w)}{w}, \frac{(y \,\%\, h)}{h}\right)$$



Texture Mapping Technique [6]

- How to texture map cylinders and cones:
  - Given a point P on the surface:
    - If it's on one of the caps, map as though the cap is a plane
    - If it's on the curved surface:
      - Use the position of the point around the perimeter to determine u
      - Use the height of the point to determine v

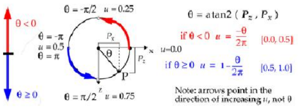




  - Mapping v is trivial, [-.5, .5] gets mapped to [0.0, 1.0] just by adding .5

Texture Mapping Technique [7]

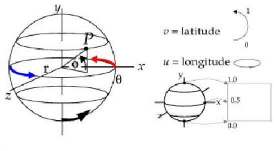
- Computing the u coordinate for cones and cylinders:
  - We need to map all the points on the perimeter of the object to [0, 1].
  - The easiest way is to say $u = \frac{\theta}{2\pi}$, but computing θ can be tricky



  - Standard atan function computes a result for θ but its always between 0 and π and it maps two positions on the perimeter to the same θ value.
    - Example: atan(1, 1) = atan(-1, -1) = $\frac{\pi}{2}$
  - atan2(x, y) yields values between $-\pi$ and π, but isn't continuous. See above diagram.

Texture Mapping Technique [8]

- Texture mapping spheres:
  - Find (u, v) coordinates for P
  - We compute u the same we do for cylinders and cones
  - If $v = 0$ or $v = 1$, there is a singularity. Set u to some predefined value. (.5 is good)
  - v is a function of the latitude of P



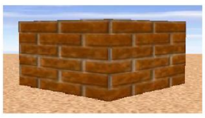
$$\phi = \sin^{-1}\frac{P_y}{r} \qquad -\frac{\pi}{2} \le \phi < \frac{\pi}{2} \qquad r = \text{radius}$$

$$v = \frac{\phi}{\pi} + .5$$

Texture Mapping Style [1]: Tiling

- We want to create a brick wall with a brick pattern texture
  - A brick pattern is very repetitive, we can use a small texture and "tile" it across the wall


Texture


Without Tiling

  - Tiling allows you to scale repetitive textures to make texture elements just the right size.


With Tiling

Texture Mapping Style [2]: Stretching

- With non-repetitive textures, we have less flexibility
  - Have to fill an arbitrarily large object with a texture of finite size
  - Can't tile, have to stretch
  - Example, creating a sky backdrop:


Texture


Applied with stretching

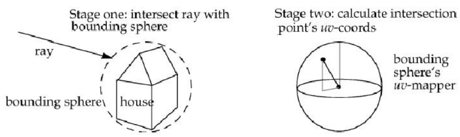
Texture Mapping Complex Geometry [1]

- Sometimes, reducing objects to primitives for texture mapping doesn't achieve the right result.
  - Consider a simple house shape as an example
  - If we texture map it by our old methods, we get discontinuities at some edges.

  - Solution: Pretend object is a sphere and texture map using the sphere (u, v) map

Texture Mapping Complex Geometry [2]

- Intuitive approach: Place a bounding sphere around the complex object
  - Find ray's object space intersection with bounding sphere
  - Convert to (u, v) coordinates



- We actually don't need a bounding sphere!
  - Once we have the intersection point with the object, we just treat it as though it were on the sphere. Same results, but be careful with radii.

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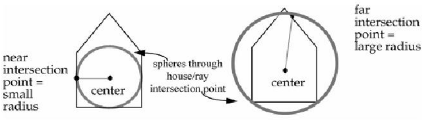
Texture Mapping
Complex Geometry [3]

- When we treat the object intersection point as a point on a sphere, our "sphere" won't always have the same radius



- What radius to use?
  - Compute the radius as the distance from the center of the complex object to the intersection point. Use that as the radius for the (u, v) mapping.

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Texture Mapping
Complex Geometry [4]

- Results of spherical (u, v) mapping:

- You can use cylindrical or planar mappings for complex objects as well
  - Each has drawbacks
    - Spherical: warping at the "poles" of the object
    - Cylindrical: discontinuities at the caps
    - Planar: one dimension must be ignored

sphere mapped with spherical projection

sphere mapped with planar projection

- For best overall results, mapping techniques can be swapped

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OpenGL Texturing [1]:
Steps

- Create and specify a texture object
  - Create a texture object
  - Specify the texture image
  - Specify how texture has to be applied for each pixel
- Enable texture mapping
- Draw the textured polygons
  - Identify the active texture
  - Specify texture coordinates with vertices

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OpenGL Texturing [2]:
Specify 2-D Texture Object

- ***glTexImage2D(GLenum target, GLint level, GLint internalformat, GLsizei width, GLsizei height, GLint border, GLenum format, GLenum type, const GLVoid *texels);***
  - Eg: ***glTexImage2D(GL_TEXTURE_2D, 0, GL_RGBA, 128, 128, 0, GL_RGBA, GL_UNSIGNED_BYTE, image);***
  - ***format*** and ***type*** used to specify the way the texels are stored
  - ***internalFormat*** specifies how OpenGL should store the data internally
  - ***width*** and ***height*** have to be powers of 2; you can use ***gluScaleImage( )*** to scale

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OpenGL Texturing [3]:
Specify How Texture Is Applied

- ***glTexParameter{if}(GLenum target, GLenum pname, TYPE param)***
- ***target*** can be: *GL_TEXTURE_1D, GL_TEXTURE_2D, …*

pname	***param***
GL_TEXTURE_WRAP_S	*GL_CLAMP, GL_REPEAT*
GL_TEXTURE_WRAP_T	*GL_CLAMP, GL_REPEAT*
GL_TEXTURE_MAG_FILTER	*GL_NEAREST, GL_LINEAR*
GL_TEXTURE_MIN_FILTER	*GL_NEAREST, GL_LINEAR*

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OpenGL Texturing [4]:
Enable Texture and Draw

- ***glEnable****(GL_TEXTURE_2D)*
  – Enable 2D texturing
- ***glTexCoord2f****(GL_FLOAT u, GL_FLOAT v)*
  – Specify texture coordinates per vertex (just as normals, color, etc).

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OpenGL Texturing [5]: Create Texture Object

- *glGenTextures(GLsizei n, GLuint* textureIDs);*
  - Returns *n* currently unused texture ID in *textureIDs*
  - Each texture ID is an integer greater than 0
- *glBindTexture(GLenum target, Gluint textureID);*
  - *target* is GL_TEXTURE_1D, GL_TEXTURE_2D, or GL_TEXTURE_3D
  - if *textureID* is being used for the first time a new texture object is created and assigned the ID = *textureID*
  - if *textureID* has been used before, the texture object with ID = *textureID* becomes active

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OpenGL Texturing [6]: Putting It All Together

In initialization:

```
glGenTextures(...);
glBindTexture( ... );
glTexParameteri(...); glTexParameteri(...); ...
glTexImage2D(...);
glEnable(GL_TEXTURE_2D);
```

In display:

```
glBindTexture( ... ); // Activate the texture defined in initialization
glBegin(GL_TRIANGLES);
 glTexCoord2f(...); glVertex3f(...);
glTexCoord2f(...); glVertex3f(...);
glTexCoord2f(...); glVertex3f(...);
glEnd( );
```

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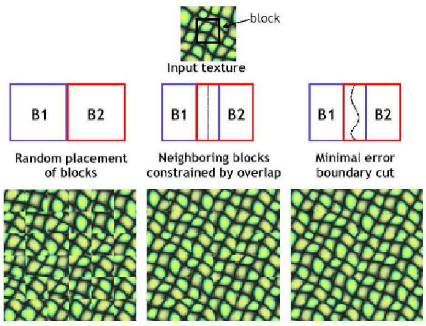
Preview: Texturing with Blocks



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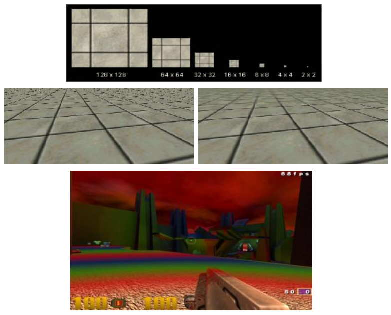
Preview: Mipmapping



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Summary

- Last Time: Texture Mapping Explained
  - Definitions and design principles
  - Enclosing volumes: cylinder, sphere, box
  - Mapping methods
    - reflected ray
    - object normal
    - object center
    - intermediate surface normal

The Lord of the Rings: The Fellowship of the Ring
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- Today: Mappings, OpenGL Texturing
  - Idea: define "texture" to simulate surface detail
  - Shadow, reflection/environment, transparency, bump, displacement
  - Other mappings: gloss, volumetric fog, skins, rainbows, water
  - OpenGL texture mapping how-to

Terminology

- Texture Mapping - Adding Detail, Raster Image, Color, *etc.* to CG Model
  - Planar projection: apply flat texture to flat surface(s)
  - Enclosing volumes: cylinder, sphere, box
  - Mapping methods
    - reflected ray – bounce ray off object *O*
    - object normal – ray from face normal of object (polygon mesh)
    - object center – ray from center of object
    - intermediate surface normal – ray from inside of enclosing *S*
- Mappings: Apply Image or Simulated Surface Detail to Object
  - Shadow: cast planar projective shadows or calculate volume
  - Reflection/environment: take picture of scene from "inside" object
  - Transparency: take picture of scene "behind" object; refract
  - Bump: perturb color based on height map
  - Displacement: perturb face normals, recalculate lighting