15-462 Computer Graphics

Lecture 10

Texture Mapping

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Administrativia

- Countdown:
  - About 1 week until Assignment 3 is due
- Assignment 2 handback, comments
- Questions on Assignment 3?

Itinerary

- Introduction to Texture Mapping
- Aliasing and How to Fight It
- Texture Mapping in OpenGL
- Applications of Texture Mapping

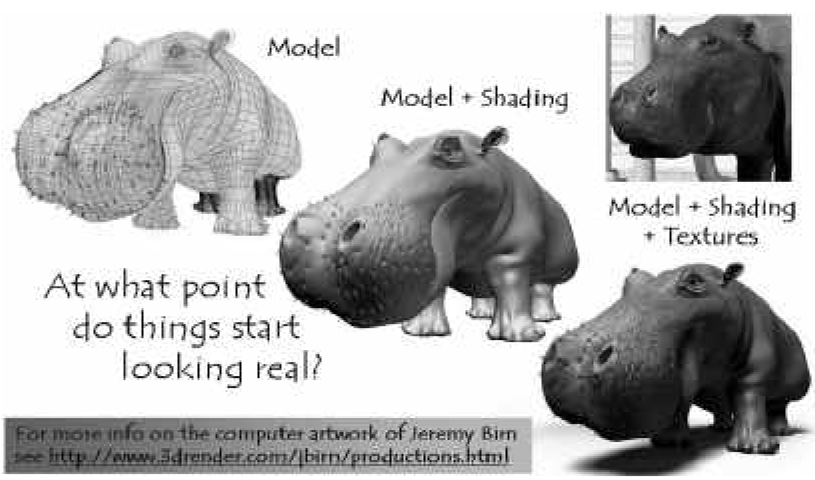
Motivation for Texture Mapping

- Phong illumination model coupled with a single color across a broad surface
  - Produces boring objects
  - Very limited
- Options to make things interesting:
  - No simple surfaces—use many tiny polygons
    - Expensive! Too much geometry.
  - Apply textures across the polygons
    - Less geometry, and the image looks almost as good!

Definitions

- Texture—the appearance and feel of a surface
- Texture—an image used to define the characteristics of a surface
- Texture—a multidimensional image which is mapped to a multidimensional space.

Texture mapping sample



Basic Concept

- "Slap an image on a model."
- How do we map a two-dimensional image to a surface in three dimensions?
- Texture coordinates
  - 2D coordinate (s,t) which maps to a location on the image (typically s and t are over [0,1])
- Assign a texture coordinate to each vertex
  - Coordinates are determined by some function which maps a texture location to a vertex on the model in three dimensions

Basic Concept

- Once a point on the surface of the model has been mapped to a value in the texture, change its RGB value (or something else!) accordingly
- This is called *parametric texture mapping*
- A single point in the texture is called a *texel*

Something else?

- The first known use of texture in graphics was the modulation of surface color values, (diffuse coefficients) by Catmull in 1974.
- A texture does not have to indicate color!
- Bump mapping was developed in 1978 by Blinn
- Transparency maps in 1985 by Gardner

What is a texture map?

- Practical: “A way to slap an image on a model.”
- Better: “A mapping from any function onto a surface in three dimensions.”
- Most general: “The mapping of any image into multidimensional space.”

Overview

(u, v)

Texture Space (2D)

parameterization

Object Space (3D)

World Space (3D)

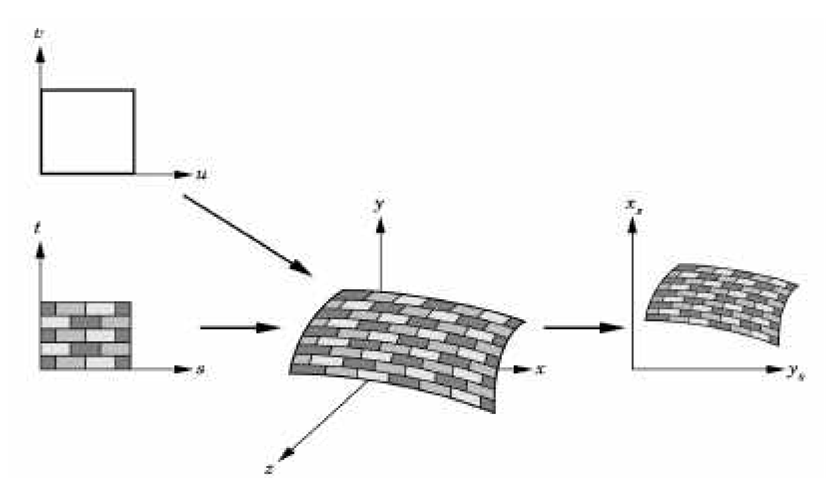
projection

(x, y)

Screen Space (2D)

Screen Space (3D) (z buffer)

Visual Overview

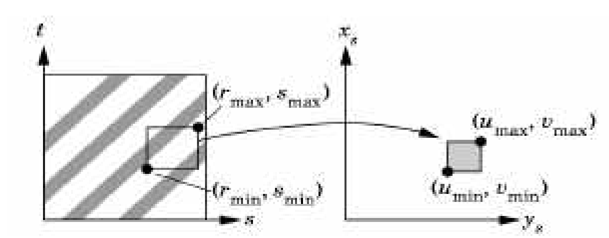


Hardware Notes

- Texture-mapping is supported in all modern graphics hardware since the introduction of the Voodoo 3Dfx—it's therefore cheap and easy
- Though the mapping is conceptualized in the order texture -> object -> screen, it is determined in reverse order in hardware, during scan conversion ("To which texel does this pixel map?")

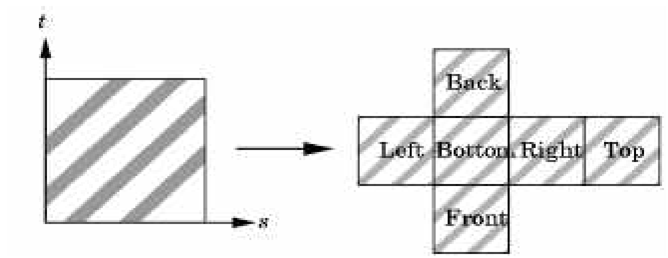
Linear Texture Mapping

- Do a direct mapping of a block of texture to a surface patch



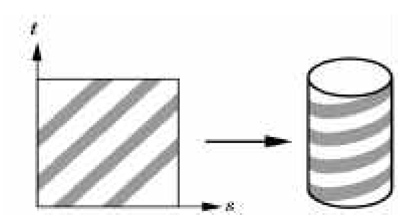
Cube Mapping

- “Unwrap” cube and map texture over the cube



Cylinder Mapping

- Wrap texture along outside of cylinder, not top and bottom
  - This stops texture from being distorted

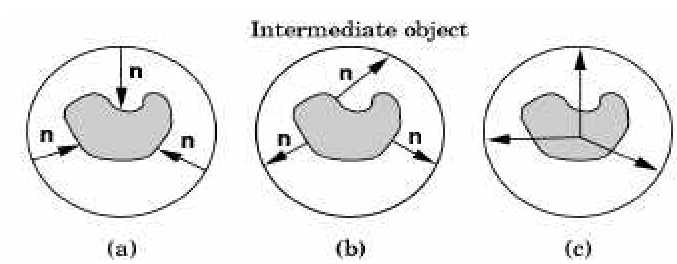


Two-part Mapping

- To simplify the problem of mapping from an image to an arbitrary model, use an object we already have a map for as an intermediary!
- Texture -> Intermediate object -> Final model
- Common intermediate objects:
  - Cylinder
  - Cube
  - Sphere

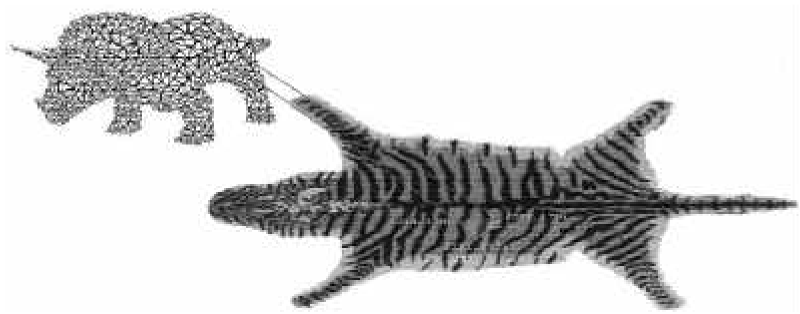
Intermediate Object to Model

- This step can be done in many ways
  - Normal from intermediate surface
  - Normal from object surface
  - Use center of object



Still tough!

- Mapping onto complicated objects is difficult
  - Even simple objects can be hard—spheres always distort the texture

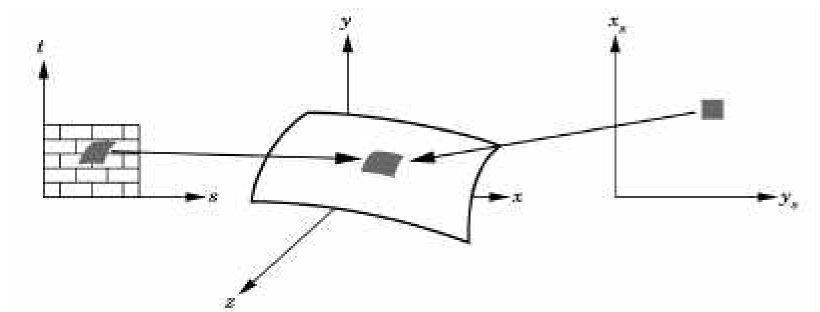


Itinerary

- Introduction to Texture Mapping
- Aliasing and How to Fight It
- Texture Mapping in OpenGL
- Applications of Texture Mapping

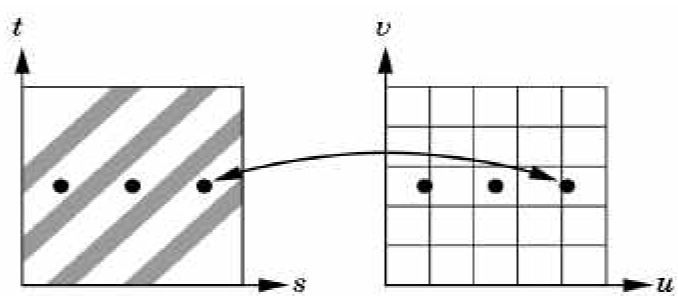
What is aliasing?

- Interested in mapping from screen to texture coordinates

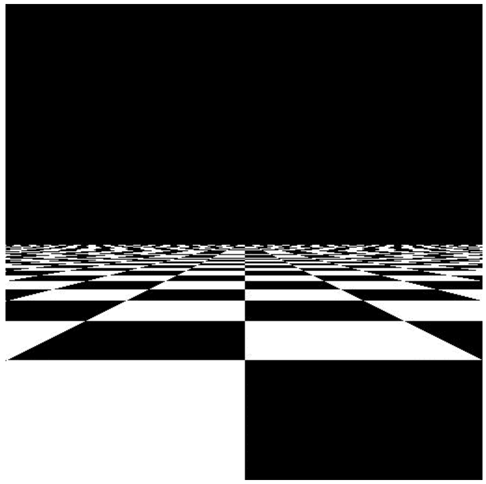


What is aliasing?

- An on-screen pixel does not always map neatly to a texel. Particularly severe problems in regular textures

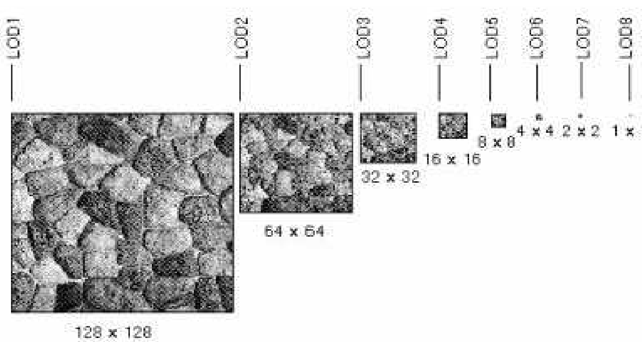


Example



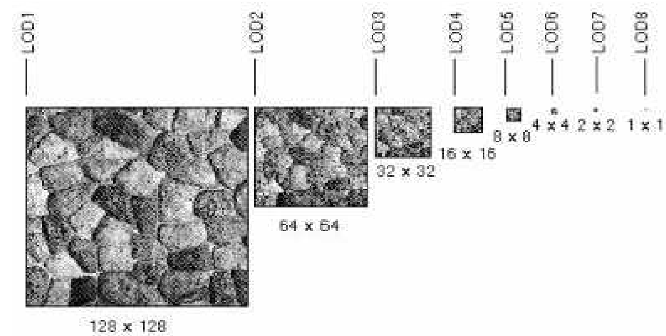
The Beginnings of a Solution

- Pre-calculate how the texture should look at various distances, then use the appropriate texture at each distance. This is called *mipmapping*.

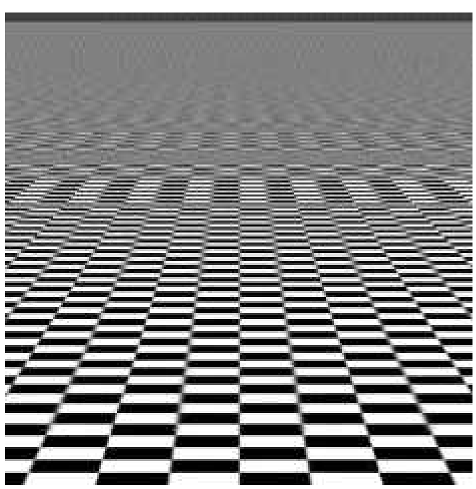


The Beginnings of a Solution

- Each mipmap (each image below) represents a level of depth (LOD).
- Powers of 2 make things much easier.



The Beginnings of a Solution



- Problem: Clear divisions between different levels of depth!
- Mipmapping alone is unsatisfactory.

Another Component: Filtering

- Take the average of multiple texels to obtain the final RGB value
- Typically used along with mipmapping
- *Bilinear filtering*
  - Average the four surrounding texels
  - Cheap, and eliminates some aliasing, but does not help with visible LOD divisions

(demonstration movies)

Another Component: Filtering

- *Trilinear filtering*
  - Interpolate between two LODs
  - Final RGB value is between the result of a bilinear filter at one LOD and a second bilinear filter at the next LOD
  - Eliminates “seams” between LODs
  - At least twice as expensive as bilinear filtering

Another Component: Filtering

- *Anisotropic filtering*
  - Basic filtering methods assume that a pixel on-screen maps to a square (isotropic) region of the texture
  - For surfaces tilted away from the viewer, this is not the case!

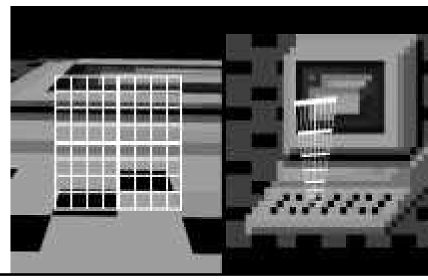
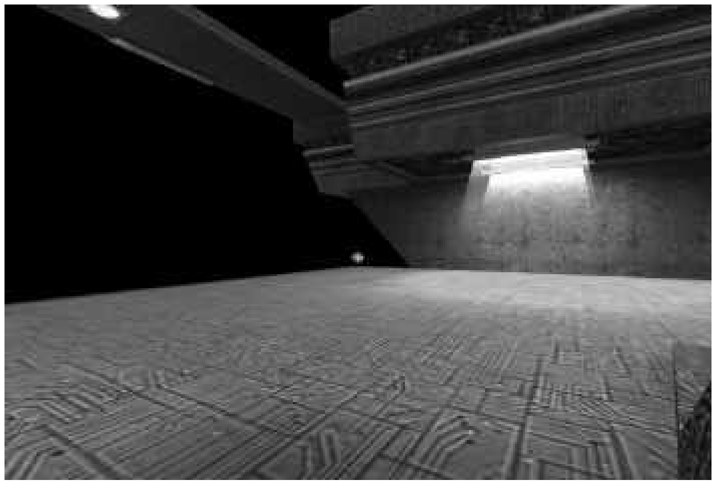


Image courtesy of nVidia

Another Component: Filtering

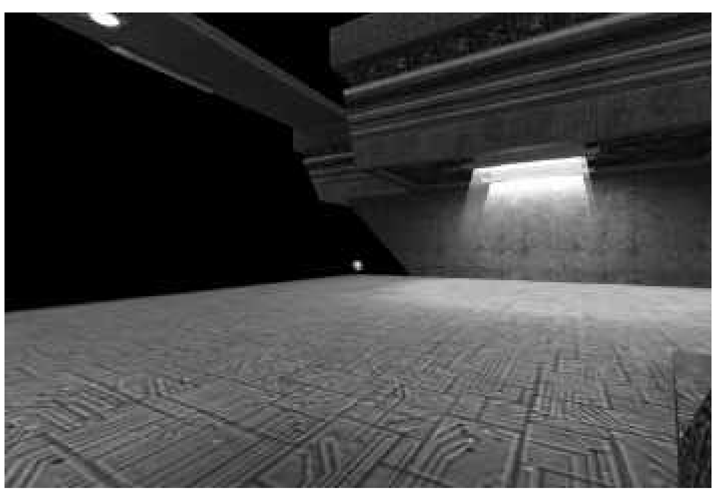
- *Anisotropic filtering*
  - A pixel may map to a rectangular or trapezoidal section of texels—shape filters accordingly and use either bilinear or trilinear filtering
  - Complicated, but produces very nice results

Bilinear Filtering



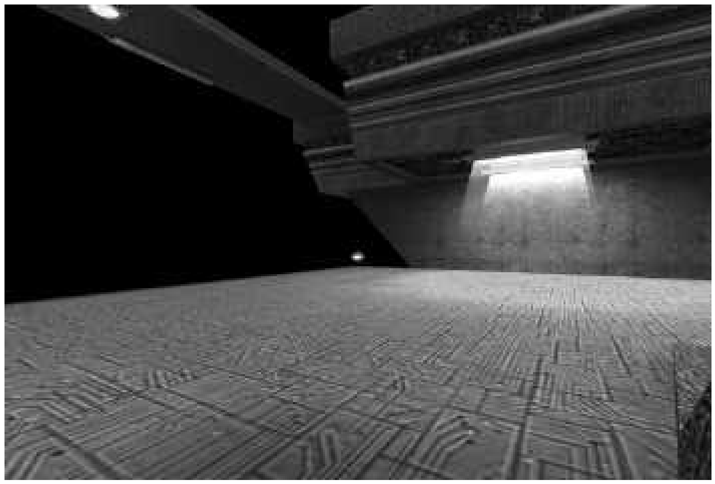
ID Software

Trilinear Filtering



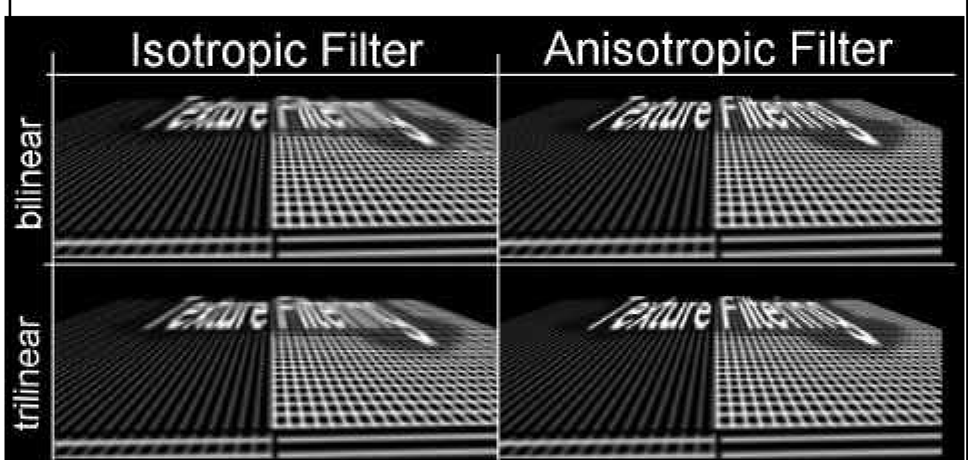
ID Software

Anisotropic Filtering



ID Software

Side-by-Side Comparison



nVidia

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glTexImage2D

- glTexImage2D(GL_TEXTURE_2D, level, components, width, height, border, format, type, tarray)
- GL_TEXTURE_2D
  - Specify that it is a 2D texture
- Level
  - Used for specifying levels of detail for mipmapping (more on this later)
- Components
  - Generally is 0 which means GL_RGB
  - Represents components and resolution of components
- Width, Height
  - The size of the texture must be powers of 2
- Border
- Format, Type
  - Specify what the data is (GL_RGB, GL_RGBA, …)
  - Specify data type (GL_UNSIGNED_BYTE, GL_BYTE, …)

glTexCoord2f

```
glEnable(GL_TEXTURE_2D);
glTexImage2D(GL_TEXTURE_2D, 0, 3, texture->nx, texture->ny, 0, GL_RGB,
             GL_UNSIGNED_BYTE, texture->pix);

glBegin(GL_POLYGON);

  glTexCoord2f(1.0, 1.0);
  glVertex3f(1.0, 0.0, 1.0);

  glTexCoord2f(1.0, -1.0);
  glVertex3f(1.0, 0.0, -1.0);

  glTexCoord2f(-1.0, -1.0);
  glVertex3f(-1.0, 0.0, -1.0);

  glTexCoord2f(-1.0, 1.0);
  glVertex3f(-1.0, 0.0, 1.0);

glEnd();
```


Other Texture Parameters

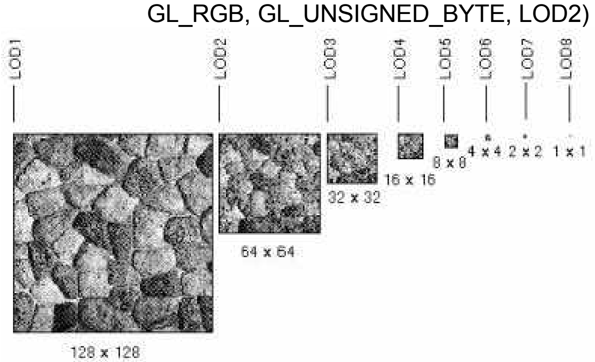
- glTexParameterf()
  - Use this function to set how textures repeat
    - glTexParameterf(GL_TEXTURE_WRAP_S, GL_REPEAT)
    - glTexParameterf(GL_TEXTURE_WRAP_S, GL_CLAMP)
  - Which spot on texture to pick
    - glTexParameterf(GL_TEXTURE_2D,
      GL_TEXTURE_MAG_FILTER, GL_NEAREST)
    - glTexParameterf(GL_TEXTURE_2D,
      GL_TEXTURE_MIN_FILTER, GL_NEAREST)

Mipmapping in OpenGL

- gluBuild2DMipmaps(GL_TEXTURE_2D, components, width, height, format, type, data)
- This will generate all the mipmaps using gluScaleImage
- glTexParameterf(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_NEAREST_MIPMAP_NEAREST)
  - This will tell GL to use the mipmaps for the texture

Mipmapping in OpenGL

- If you design the mipmaps yourself
  - glTexImage2D(GL_TEXTURE_2D, 0, GL_RGB, 128, 128, 0, GL_RGB, GL_UNSIGNED_BYTE, LOD1)
  - glTexImage2D(GL_TEXTURE_2D, 1, GL_RGB, 64, 64, 0, GL_RGB, GL_UNSIGNED_BYTE, LOD2)



Other Texturing Issues

- glTexEnvi(GL_TEX_ENV, GL_TEX_ENV_MODE, GL_MODULATE)
  - Will balance between shade color and texture color
- glTexEnvi(GL_TEX_ENV, GL_TEX_ENV_MODE, GL_DECAL)
  - Will replace shade color with texture color
- glHint(GL_PERSPECTIVE_CORRECTION, GL_NICEST)
  - OpenGL does linear interpolation of textures
    - Works fine for orthographic projections
  - Allows for OpenGL to correct textures for perspective projection
    - There is a performance hit
- Texture objects
  - Maintain texture in memory so that it will not have to be loaded constantly

OpenGL texturing code

This code assumes that it's an RGB texture map

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Non-2D Texture Mapping

- The domain of a texture mapping function may be any number of dimensions
  - 1D might be used to represent rock strata
  - 2D is used most often
  - 3D can be used to represent interesting physical phenomena
  - Animated textures are a cheap extra dimension—further dimensions are somewhat harder to conceptualize

3D Texture Mapping

- Almost the same as 2D texture mapping
  - Texture is a “block” which objects fit into
  - Texture coordinates are 3D coordinates which equal some value inside the texture block

RGB values *or*…

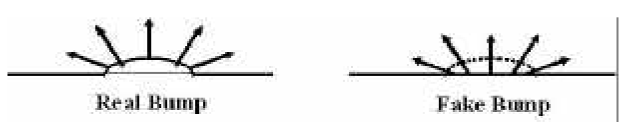
- Textures do not have to represent color values.
- Using texture information to modify other aspects of a model can yield much more realistic results

RGB values *or*…

- Specularity (patches of shininess)
- Transparency (patches of clearness)
- Normal vector changes (bump maps)
- Reflected light (environment maps)
- Shadows
- Changes in surface height (displacement maps)

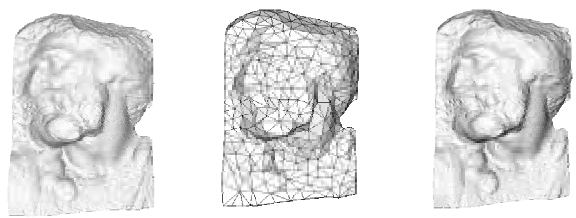
Bump Mapping

- How do you make a surface look *rough*?
  - Option 1: model the surface with many small polygons
  - Option 2: perturb the normal vectors before the shading calculation
    - Fakes small displacements above or below the true surface
    - The surface doesn't actually change, but shading makes it look like there are irregularities!
    - A texture stores information about the "fake" height of the surface
    - For the math behind it all look at Angel 7.8



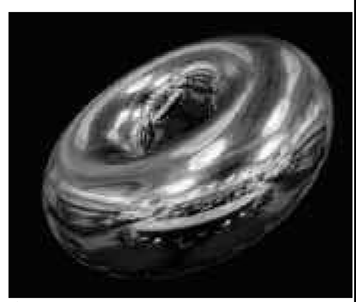
Bump Mapping

- We can perturb the normal vector without having to make any actual change to the shape.
- This illusion can be seen through—how?



Original model (5M) | Simplified (500) | Simple model with bump map

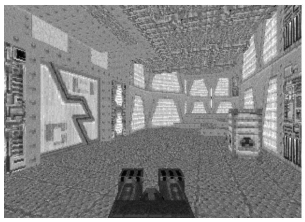
Environment Mapping



- Allows for world to be reflected on an object without modeling the physics
- Map the world surrounding an object onto a cube
- Project that cube onto the object
- During the shading calculation:
  - Bounce a ray from the viewer off the object (at point P)
  - Intersect the ray with the environment map (the cube), at point E
  - Get the environment map's color at E and illuminate P as if there were a light source at position E
  - Produces an image of the environment reflected on shiny surfaces

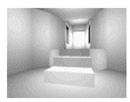
Light Mapping

- ***Quake* uses *light maps* in addition to texture maps. Texture maps are used to add detail to surfaces, and light maps are used to store pre-computed illumination. The two are multiplied together at run-time, and cached for efficiency.**



Radiance Texture Map Only

Radiance Texture + Light Map



Light Map

Summary

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- Aliasing and How to Fight It
- Texture Mapping in OpenGL
- Applications of Texture Mapping

Acknowledgements/Resources

- Frank Pfenning and Shayan Sharkar

  (last year's instance of this course)
- Paul Heckbert
  - http://www.cs.cmu.edu/~ph
- UNC (filter demonstration movies)
  - http://www.cs.unc.edu/~sud/courses/comp235/a6/