15-462 Computer Graphics
Lecture 10

Texture Mapping

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M. Ian Graham
Carnegie Mellon University

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

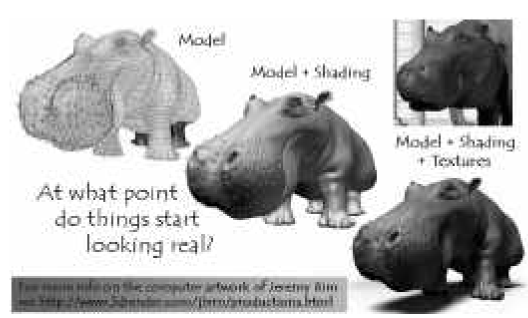
Motivation for Texture Mapping

- 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)

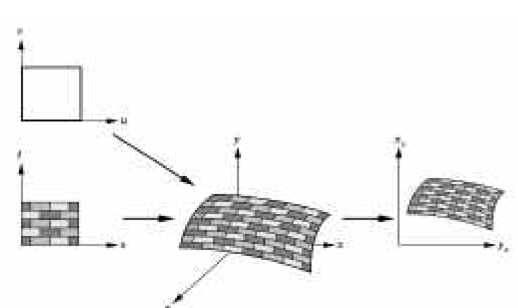
World Space (3D)

projection

Screen Space (3D) (z buffer)

`(x, y)` Screen Space (2D)

Visual Overview

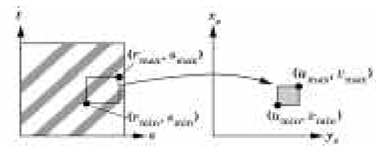


Hardware Notes

- 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?")

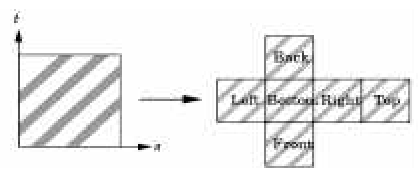
Linear Texture Mapping

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



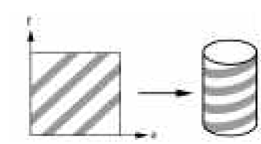
Cube Mapping

- "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

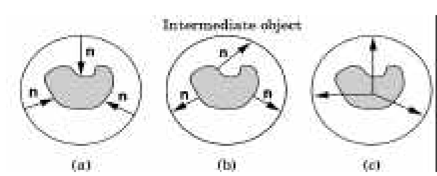


Two-part Mapping

- 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

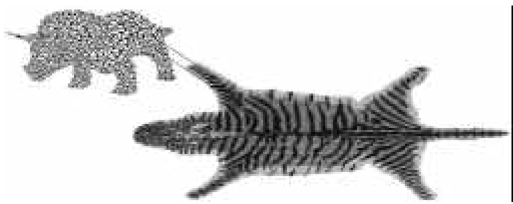
Intermediate Object to Model

- 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

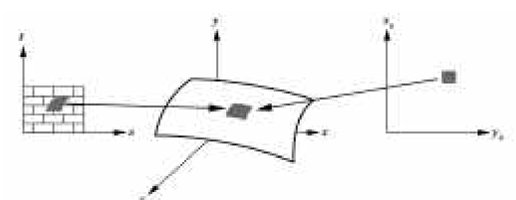


Itinerary

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

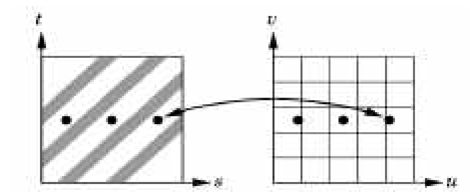
What is aliasing?

- Interested in mapping from screen to texture coordinates

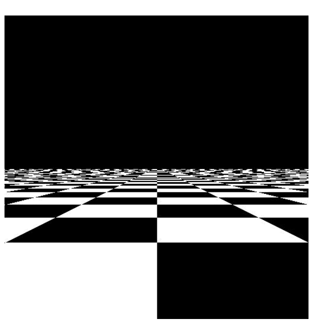


What is aliasing?

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

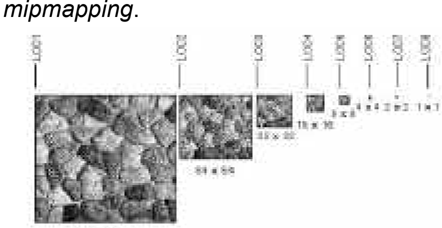


Example



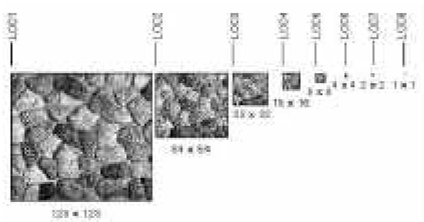
The Beginnings of a Solution

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

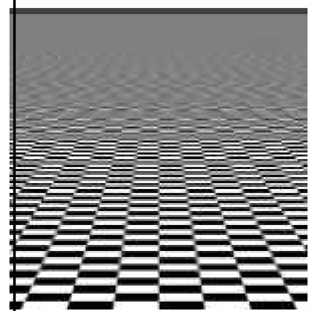


The Beginnings of a Solution

- 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!

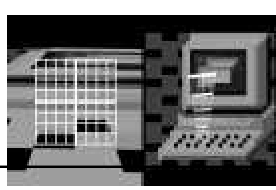
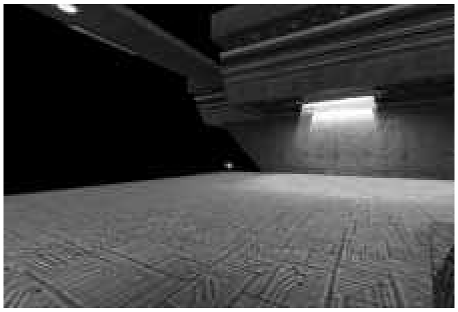


Image courtesy of nVidia

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

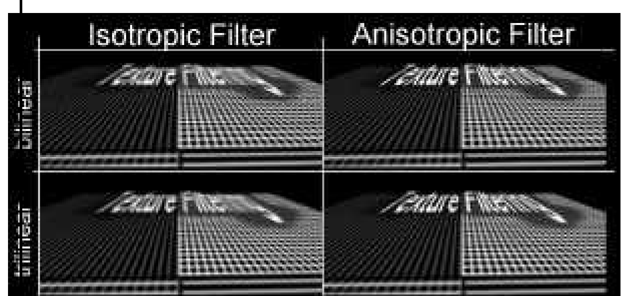
Trilinear Filtering

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…*

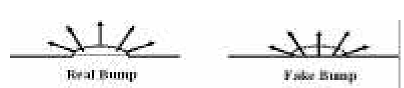
- Textures do not have to represent color values.
- Using texture information to modify other aspects of a model can yield much more realistic results

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)

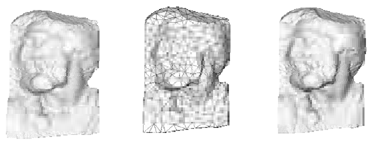
Bump Mapping

- 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



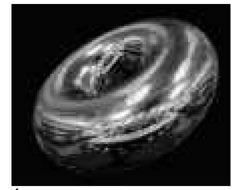
Bump Mapping

- 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

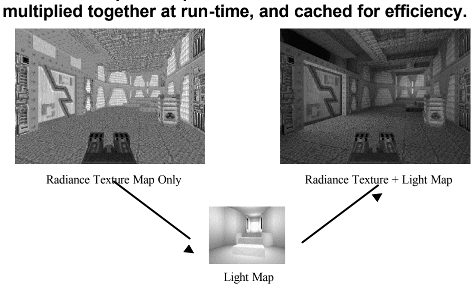
Environment Mapping



- 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.**



Summary

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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/