

Texture Mapping

Texture Mapping + Shading
Filtering and Mipmaps
Non-color Texture Maps
[Angel Ch. 8.7-8.8]

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Texture Mapping

- A way of adding surface details
- Two ways can achieve the goal:
 - Model the surface with more polygons
 - » Slows down rendering speed
 - » Hard to model fine features
 - Map a texture to the surface
 - » This lecture
 - » Image complexity does not affect complexity of processing
- Efficiently supported in hardware



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Trompe L' Oeil (“Deceive the Eye”)

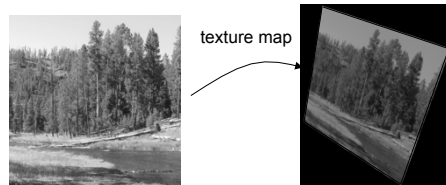


Jesuit Church, Vienna, Austria

- Windows and columns in the dome are painted, not a real 3D object
- Similar idea with texture mapping:
Rather than modeling the intricate 3D geometry, replace it with an image !

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Map textures to surfaces



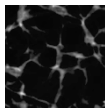
an image

image mapped to a 3D polygon
The polygon can have arbitrary size, shape and 3D position

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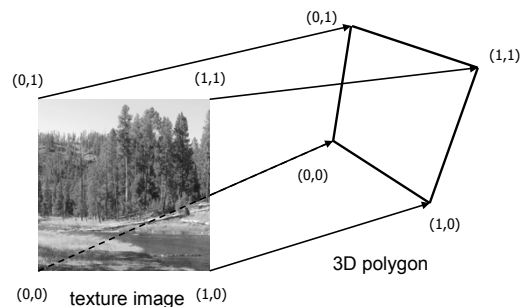
The texture

- Texture is a bitmap image
 - Can use an image library to load image into memory
 - Or can create images yourself within the program
- 2D array:
unsigned char texture[height][width][4]
- Or unrolled into 1D array:
unsigned char texture[4*height*width]
- Pixels of the texture are called *texels*
- Texel coordinates (s,t) scaled to [0,1] range

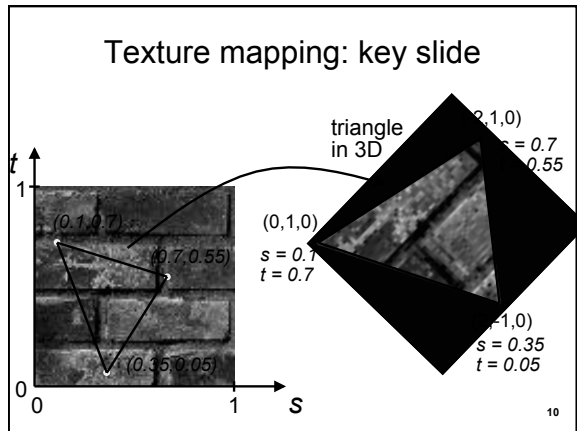
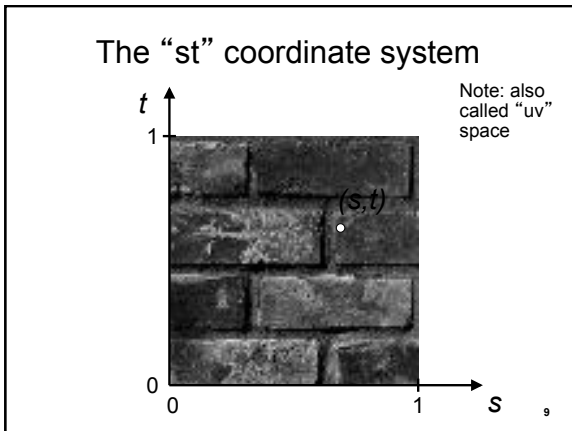
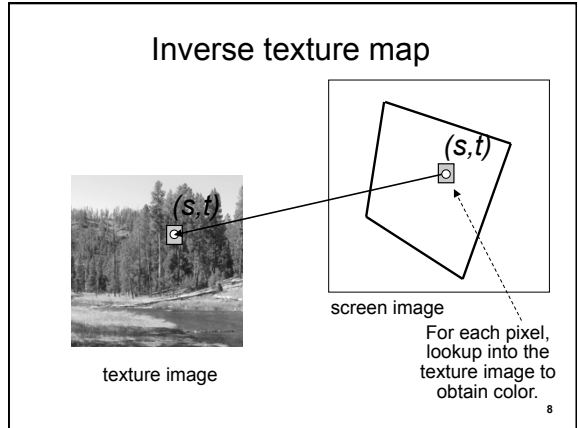
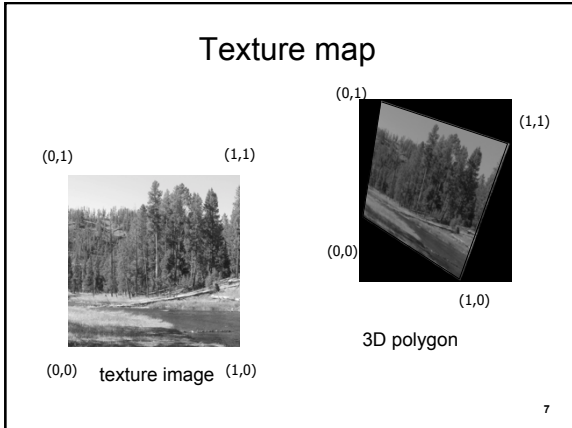


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Texture map



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Specifying texture coordinates in OpenGL

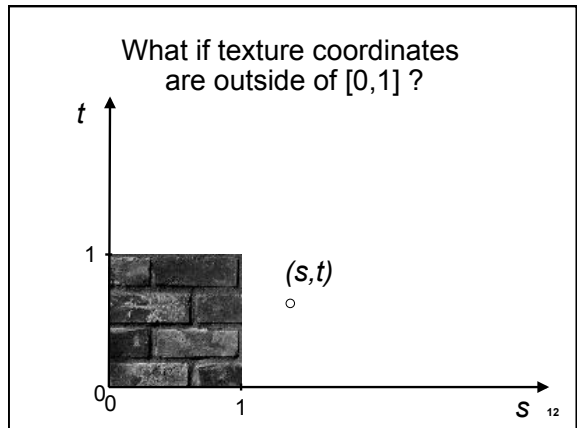
- Use `glTexCoord2f(s,t)`
- State machine: Texture coordinates remain valid until you change them
- Example (from previous slide) :

```

glEnable(GL_TEXTURE_2D); // turn texture mapping on
glBegin(GL_TRIANGLES);
glTexCoord2f(0.35,0.05); glVertex3f(2.0,-1.0,0.0);
glTexCoord2f(0.7,0.55); glVertex3f(-2.0,1.0,0.0);
glTexCoord2f(0.1,0.7); glVertex3f(0.0,1.0,0.0);
glEnd();
glDisable(GL_TEXTURE_2D); // turn texture mapping off

```

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Solution 1: Repeat texture

```
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_S, GL_REPEAT)
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_T, GL_REPEAT)
```

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Solution 2: Clamp to [0,1]

```
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_S, GL_CLAMP)
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_T, GL_CLAMP)
```

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Combining texture mapping and shading

At what point do things start looking real?

For more info on the computer artwork of Jeremy Birn see <http://www.3drender.com/jbirn/productions.html>

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Combining texture mapping and shading

- Final pixel color = a combination of texture color and color under standard OpenGL Phong lighting
- GL_MODULATE: multiply texture and Phong lighting color
- GL_BLEND: linear combination of texture and Phong lighting color
- GL_REPLACE: use texture color only (ignore Phong lighting)
- Example:


```
glTexEnvf(GL_TEXTURE_ENV, GL_TEXTURE_ENV_MODE, GL_REPLACE);
```

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Outline

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- Texture mapping in OpenGL
- Filtering and Mipmaps
- Example
- Non-color texture maps

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Texture mapping in OpenGL

- During your initialization:
 - Read texture image from file into an array in memory, or generate the image using your program
 - Specify texture mapping parameters
 - » Wrapping, filtering, etc.
 - Initialize and activate the texture
- In display():
 - Enable OpenGL texture mapping
 - Draw objects: Assign texture coordinates to vertices
 - Disable OpenGL texture mapping

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Initializing the texture

- Do once during initialization, for each texture image in the scene, by calling `glTexImage2D`
- The dimensions of texture images must be powers of 2
 - if not, rescale image or pad with zero
 - or can use OpenGL extensions
- Can load textures dynamically if GPU memory is scarce

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glTexImage2D

- `glTexImage2D(GL_TEXTURE_2D, level, internalFormat, width, height, border, format, type, data)`
- `GL_TEXTURE_2D`: specifies that it is a 2D texture
- `Level`: used for specifying levels of detail for mipmapping (default: 0)
- `internalFormat`
 - Often: `GL_RGB` or `GL_RGBA`
 - Determines how the texture is stored internally
- `Width, Height`
 - The size of the texture must be powers of 2
- `Border` (often set to 0)
- `Format, Type`
 - Specifies what the input data is (`GL_RGB`, `GL_RGBA`, ...)
 - Specifies the input data type (`GL_UNSIGNED_BYTE`, `GL_BYTE`, ...)
 - Regardless of `Format` and `Type`, OpenGL converts the data to `internalFormat`
- `Data`: pointer to the image buffer

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Enable/disable texture mode

- Must be done before rendering any primitives that are to be texture-mapped
- `glEnable(GL_TEXTURE_2D)`
- `glDisable(GL_TEXTURE_2D)`
- Successively enable/disable texture mode to switch between drawing textured/non-textured polygons
- Changing textures:
 - Only one texture is active at any given time (with OpenGL extensions, more than one can be used simultaneously; this is called *multitexturing*)
 - Use `glBindTexture` to select the active texture

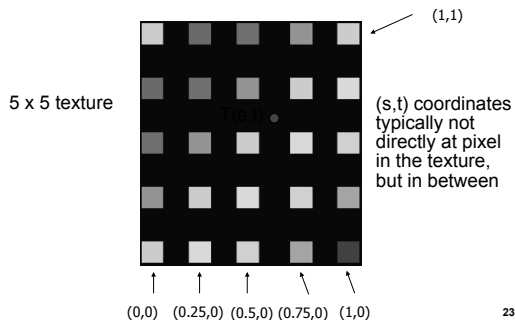
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Texture interpolation



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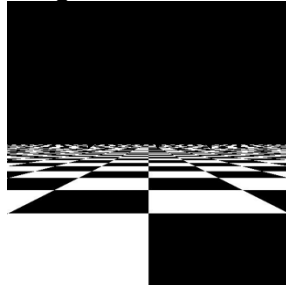
Texture interpolation

- (s,t) coordinates typically not directly at pixel in the texture, but in between
- Solutions:
 - Use the nearest neighbor to determine color
 - » Faster, but worse quality
 - » `glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_NEAREST);`
 - Linear interpolation
 - » Incorporate colors of several neighbors to determine color
 - » Slower, better quality
 - » `glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_LINEAR);`

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Filtering

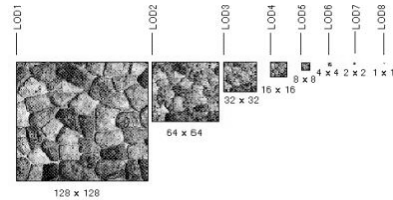
- Texture image is shrunk in distant parts of the image
- This leads to aliasing
- Can be fixed with *filtering*
 - bilinear in space
 - trilinear in space and level of detail (mipmapping)



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Mipmapping

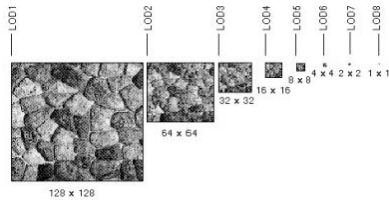
- Pre-calculate how the texture should look at various distances, then use the appropriate texture at each distance
- Reduces / fixes the aliasing problem



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Mipmapping

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



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Mipmapping in OpenGL

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

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Complete example

```
void initTexture()
{
    load image into memory; // can use libjpeg, libtiff, or other image library
    // image should be stored as a sequence of bytes, usually 3 bytes per
    // pixel (RGB), or 4 bytes (RGBA); image size is 4 * 256 * 256 bytes in
    // this example
    // we assume that the image data location is stored in pointer
    "pointerToImage"

    // create placeholder for texture
    glGenTextures(1, &texName); // must declare a global variable in
    // program header: GLuint texName
    glBindTexture(GL_TEXTURE_2D, texName); // make texture
    "texName" the currently active texture

    (continues on next page)
```

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Complete example (part 2)

```
// specify texture parameters (they affect whatever texture is active)
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_S,
GL_REPEAT); // repeat pattern in s
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_T,
GL_REPEAT); // repeat pattern in t

// use linear filter both for magnification and minification
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MAG_FILTER,
GL_LINEAR);
glTexParameterf(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER,
GL_LINEAR);

// load image data stored at pointer "pointerToImage" into the currently
active texture ("texName")
glTexImage2D(GL_TEXTURE_2D, 0, GL_RGBA, 256, 256, 0,
GL_RGBA, GL_UNSIGNED_BYTE, pointerToImage);

} // end init()
```

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Complete example (part 3)

```
void display()
{
...
// no modulation of texture color with lighting; use texture color directly
glTexEnvf(GL_TEXTURE_ENV, GL_TEXTURE_ENV_MODE,
GL_REPLACE);

// turn on texture mapping (this disables standard OpenGL lighting,
unless in GL_MODULATE mode)
glEnable(GL_TEXTURE_2D);

(continues on next page)
```

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Complete example (part 4)

```
glBegin(GL_QUADS); // draw a textured quad
glTexCoord2f(0.0,0.0); glVertex3f(-2.0,-1.0,0.0);
glTexCoord2f(0.0,1.0); glVertex3f(-2.0,1.0,0.0);
glTexCoord2f(1.0,0.0); glVertex3f(0.0,1.0,0.0);
glTexCoord2f(1.0,1.0); glVertex3f(0.0,-1.0,0.0);
glEnd();

// turn off texture mapping
glDisable(GL_TEXTURE_2D);

// draw some non-texture mapped objects
(standard OpenGL lighting will be used if it is enabled)
...
// switch back to texture mode, etc.
...
} // end display()
```

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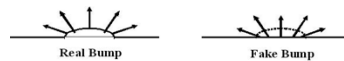
Textures do not have to represent color

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

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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



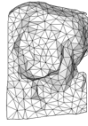
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Bump mapping

- 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)

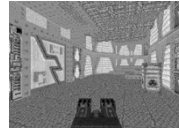


Simple model with
bump map

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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.



Texture Map Only



Texture + Light Map



Light Map

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