CSCI 420 Computer Graphics
Lecture 11

Texture Mapping

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

Jernej Barbic
University of Southern California

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

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 !

Map textures to surfaces

an image

texture map

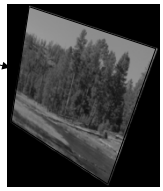


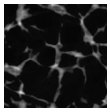
image mapped to a 3D polygon

The polygon can have arbitrary size, shape and 3D position

The texture

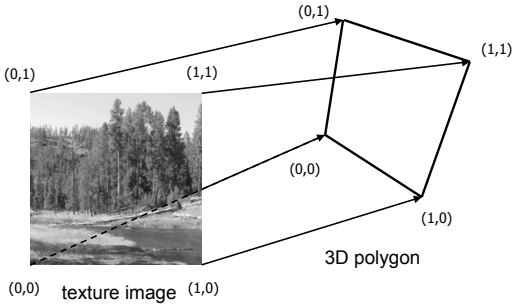
- Texture is a bitmap image
  - Can use an image library to load image into memory
  - Or can create images yourself within the program

- 2D array:
  unsigned char texture[height][width][4]
- Or unrolled into 1D array:
  unsigned char texture[4*height*width]

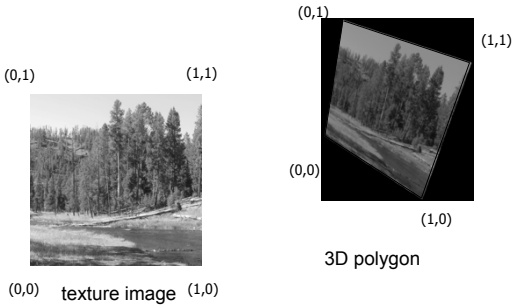


- Pixels of the texture are called *texels*
- Texel coordinates (s,t) scaled to [0,1] range

Texture map

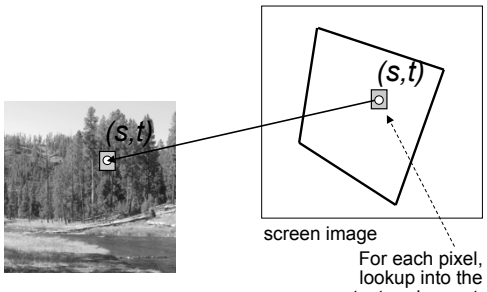


Texture map



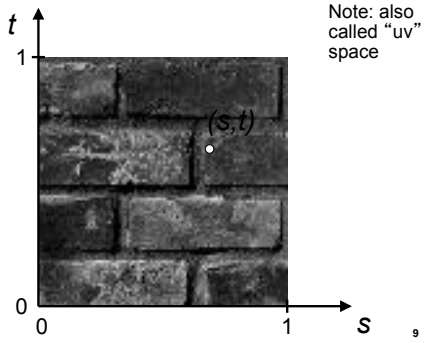
7

Inverse texture map



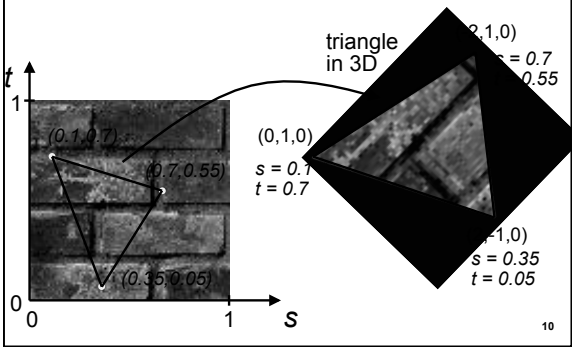
8

The "st" coordinate system



9

Texture mapping: key slide

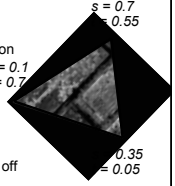


10

Specifying texture coordinates in OpenGL

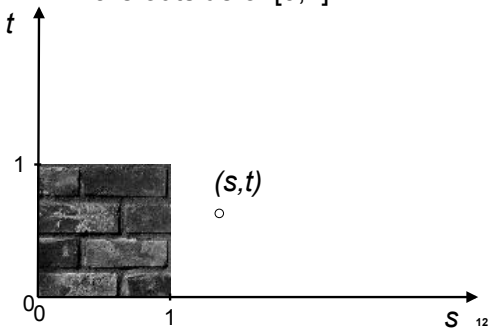
- Use glTexCoord2f(s,t)
- State machine: Texture coordinates remain valid until you change them
- Example (from previous slide) :

```
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
```



11

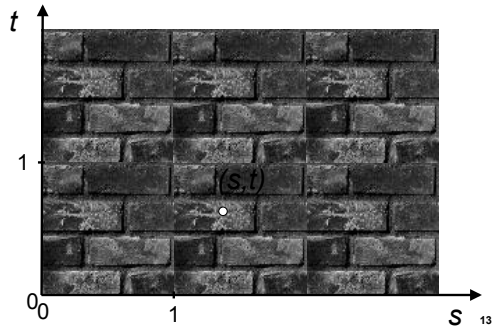
What if texture coordinates are outside of [0,1] ?



12

Solution 1: Repeat texture

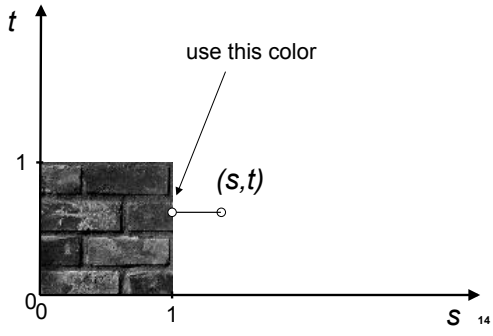
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_S, GL_REPEAT)
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_T, GL_REPEAT)



13

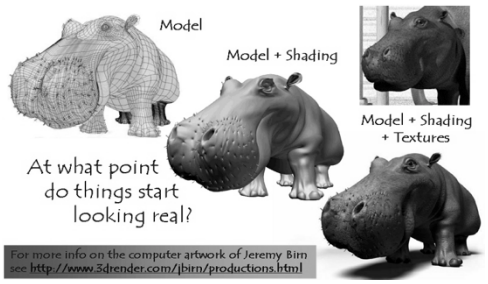
Solution 2: Clamp to [0,1]

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



14

Combining texture mapping and shading



15

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);
```

16

Outline

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

17

Texture mapping in OpenGL

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

18

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

19

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 convertes the data to internalFormat
- Data: pointer to the image buffer

20

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

21

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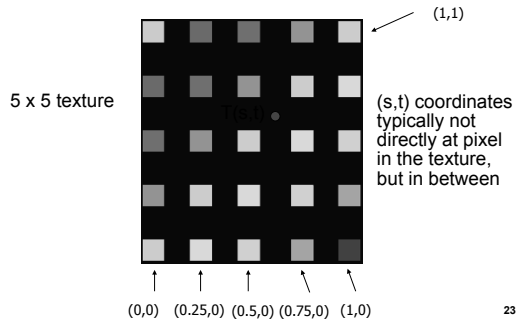
22

Texture interpolation



23

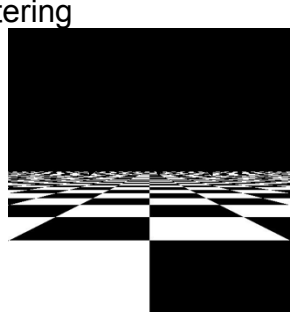
Texture interpolation

- (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)

24

Filtering

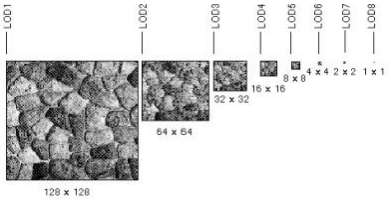
- Texture image is shrunk in distant parts of the image
- This leads to aliasing
- Can be fixed with *filtering*
  - bilinear in space
  - trilinear in space and level of detail (mipmapping)



25

Mipmapping

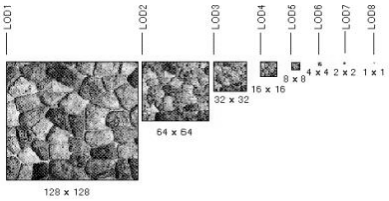
- Pre-calculate how the texture should look at various distances, then use the appropriate texture at each distance
- Reduces / fixes the aliasing problem



26

Mipmapping

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



27

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

28

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29

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)
```

30

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()
```


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)
```


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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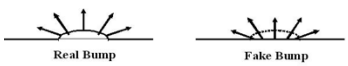
Textures do not have to represent color

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

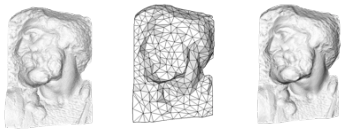
Bump mapping

- 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



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?

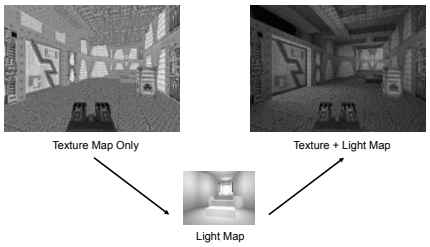


Original model (5M) | Simplified (500) | Simple model with bump map

37

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

38

Summary

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39