**CS 4731: Computer Graphics**
**Lecture 17: Texturing**

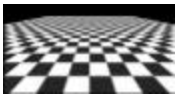
Emmanuel Agu

## Announcement

- Help session for project 4 today
- FL 320, 5-6pm

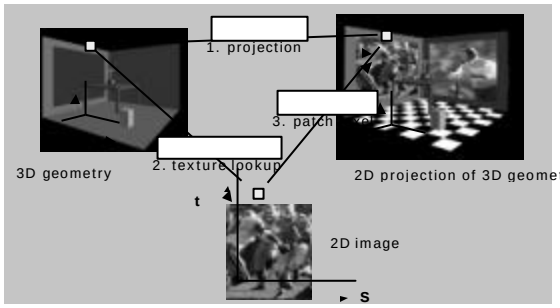
## Texture Mapping

- A way of adding surface details
- Two ways can achieve the goal:
  - Surface detail polygons: create extra polygons to model object details
    - Add scene complexity and thus slow down the graphics rendering speed
    - Some fine features are hard to model!
  - ✓ Map a texture to the surface (a more popular approach)



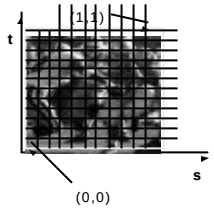
Complexity of images does
Not affect the complexity
Of geometry processing
(transformation, clipping…)

## Texture Mapping



## Texture Representation

- ✓ Bitmap (pixel map) textures (supported by OpenGL)
- Procedural textures (used in advanced rendering programs)

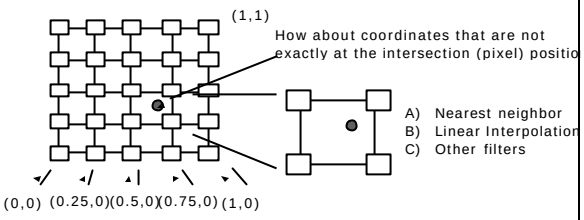



Bitmap texture :

- A 2D image - represented by 2D array texture[height][width]
- Each pixel (or called **texel**) by a unique pair texture coordinate (s, t)
- The s and t are usually normalized to a [0,1] range
- For any given (s,t) in the normalized ran there is also a unique image value (i.e., a unique [red, green, blue] set )

## Texture Value Lookup

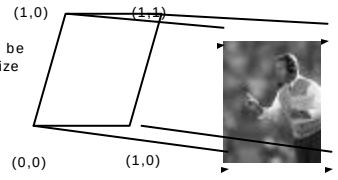
- For given texture coordinates (s,t), we can find a unique image value from the texture map




## Map textures to surfaces

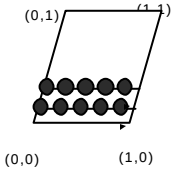
- Establish mapping from texture to surfaces (polygons):
  - Application program needs to specify texture coordinates for each corner of the polygon

The polygon can be in an arbitrary size




## Map textures to surfaces

- Texture mapping is performed in rasterization




- For each pixel that is to be painted, its texture coordinates (s, t) are determined (interpolated) based on the corners' texture coordinates (why not just interpolate the color?)
- The interpolated texture coordinates are then used to perform texture lookup

## OpenGL texture mapping

- Texturing steps in your program
  1) Specify texture
     - read or generate image
     - Assign to texture
  2) Specify texture mapping parameters
     - Wrapping, filtering, etc.
  3) Enable GL texture mapping (GL_TEXTURE_2D)
  4) Assign texture coordinates to vertices
  5) Disable GL texture mapping (if you don't need to perform texture mapping any more)

## Specify textures

- Load the texture map from main memory to texture memory
  - glTexImage2D(Glenum target, Glint level, Glint iformat, int width, int height, Glenum format, Glenum type, Glvoid* img)
- Example:
  - glTeximage2D(GL_TEXTURE_2D, 0, GL_RGB, 64, 64, GL_RGB, GL_UNSIGNED_BYTE, myImage);
    (myImage is a 2D array: GLuByte myImage[64][64][3];)
- The dimensions of texture images must be powers of 2

## Fix texture size

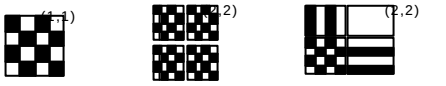
- If the dimensions of the texture map are not power of 2, you can
  1) Pad zeros 2) use gluScaleImage()


Ask OpenGL to filter the data for you to the right size – you can specify the output resolution that you want

Remember to adjust the texture coordinates for your polygon corners – you don't want to include black texels in your final picture

## Texture mapping parameters

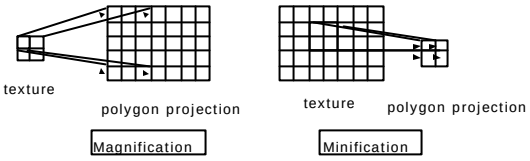
- What happen if the given texture coordinates (s,t) are outside [0,1] range?




- E.g: glTexParameteri(GL_TEXTAURE_2D, GL_TEXTURE_WRAP_S, GL_CLAMP)

## Texture mapping parameters

- Since a polygon can get transformed to arbitrary screen size, texels in the texture map can get magnified or minified.




- Filtering: interpolate a texel value from its neighbors or combine multiple texel values into a single one

## Texture mapping parameters

- OpenGL texture filtering:

1) Nearest Neighbor (lower image quality)

**glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_NEAREST);**

2) Linear interpolate the neighbors (better quality, slower)

**glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_LINEAR)**

Or GL_TEXTURE_MAX_FILTER

## Texture color blending

- Determine how to combine the texel color and the object color
  - GL_MODULATE – multiply texture and object color
  - GL_BLEND – linear combination of texture and object color
  - GL_REPLACE – use texture color to replace object color
- E.g: glTexEnvf(GL_TEXTURE_ENV, GL_TEXTURE_ENV_MODE, GL_REPLACE);

## Enable (Disable) Textures

- Enable texture – glEnable(GL_TEXTURE_2D)
- Disable texture – glDisable(GL_TEXTURE_2D)
- Remember to disable texture mapping when you draw non-textured polygons

## Specify texture coordinates

- Give texture coordinates before defining each vertex

```
glBegin(GL_QUADS);
  glTexCoord2D(0,0);
 glVertex3f(-0.5, 0, 0.5);
 ...
glEnd();
```

## Transform texture coordinates

- All the texture coordinates are multiplied by Gl_TEXTURE matrix before in use
- To transform texture coordinates, you do:
  - glMatrixMode(Gl_TEXTURE);
  - Apply regular transformation functions
  - Then you can draw the textured objects

## Put it all together

```
...
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_S, GL_REPEAT);
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_T, GL_REPEAT);
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MAG_FILTER, GL_NEAREST);
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_NEAREST);
glTexEnvf(GL_TEXTURE_ENV, GL_TEXTURE_ENV_MODE, GL_REPLACE);
...
glEnable(GL_TEXTURE_2D);
glTeximage2D(GL_TEXTURE_2D, 0, GL_RGB, 64, 64, 0, GL_RGB,
    GL_UNSIGNED_BYTE, mytexture);

Draw_picture1(); // define texture coordinates and vertices in the function
...
```

## Other Stuff

- Wrapping texture onto curved surfaces. E.g. cylinder, can, etc

$$s = \frac{q - q_a}{q_b - q_a} \qquad t = \frac{z - z_a}{z_b - z_a}$$

- Wrapping texture onto sphere

$$s = \frac{q - q_a}{q_b - q_a} \qquad s = \frac{f - f_a}{f_b - f_a}$$

- Bump mapping: perturb surface normal by a quantity proportional to texture

## References

- Hill, 8.5