CMT107 Visual Computing

v.1 Texture Mapping

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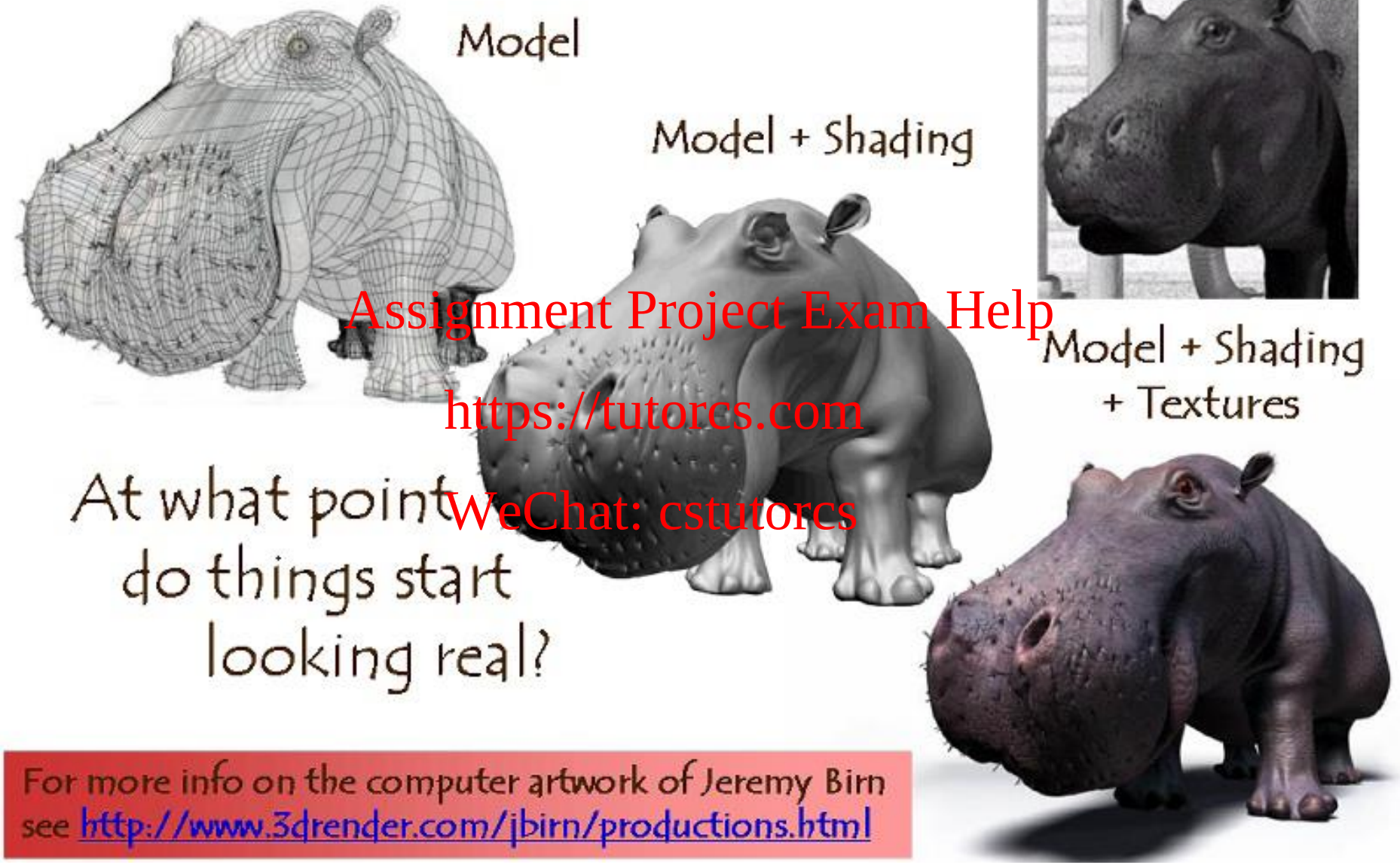
Overview

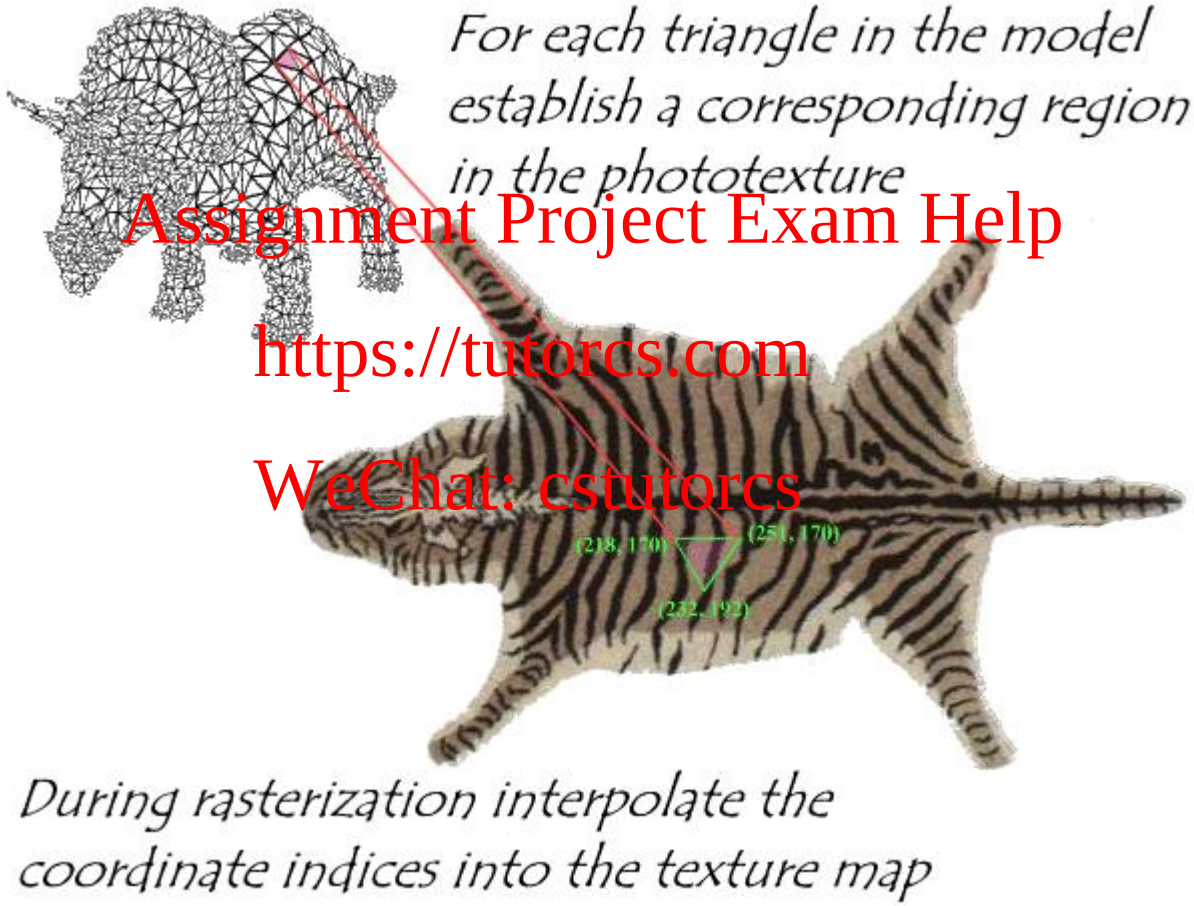
- Texture mapping
  - Texture coordinates
  - Aliasing effects and MIP mapping
- Bump mapping
- Displacement mapping
- Light maps
- Shadow maps
- Texture Mapping in OpenGL

From Shading to Texture



Texture

- Visual appearance of objects can be enhanced by textures
- The concept is simple



Texture Coordinates

- For each vertex specify *texture coordinates* $(s,t) \in [0,1]^2$
  - Canonical position of pixel in texture for vertex
  - For each point p on the 3D polygon, corresponding texture coordinates (s,t) are required

  → *Bilinearly interpolate* texture coordinates in 3D

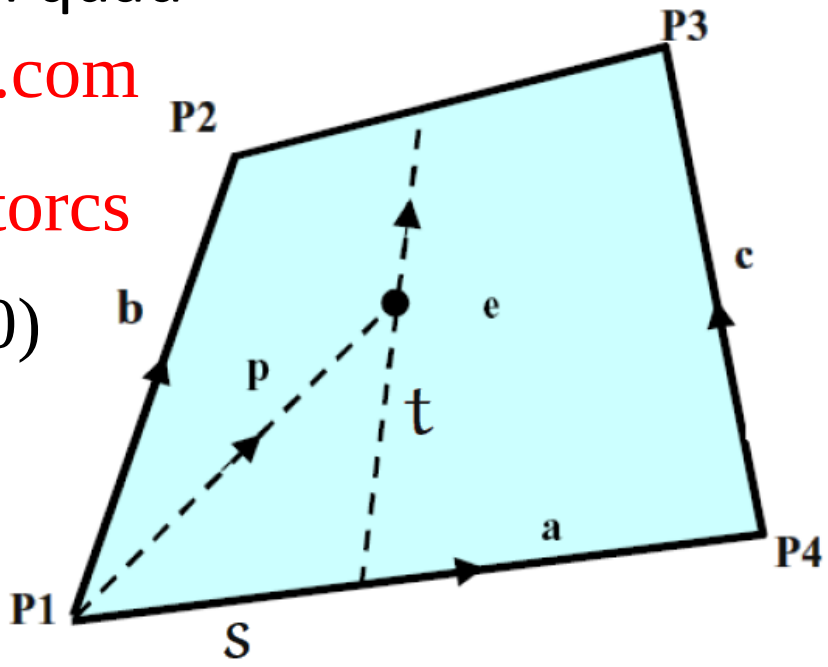
- Texture coordinates for point on quad

$p = sa + te$

$e = b + s(c - b)$

$p = sa + tb + st(c - b)$

→ Solve for (s,t) (assuming $(0,0)$ is texture coordinate of P_1)



Alias Effects

- One major problem of texture: *alias effects*
  - Caused by *undersampling*; results in *unreal artefacts*

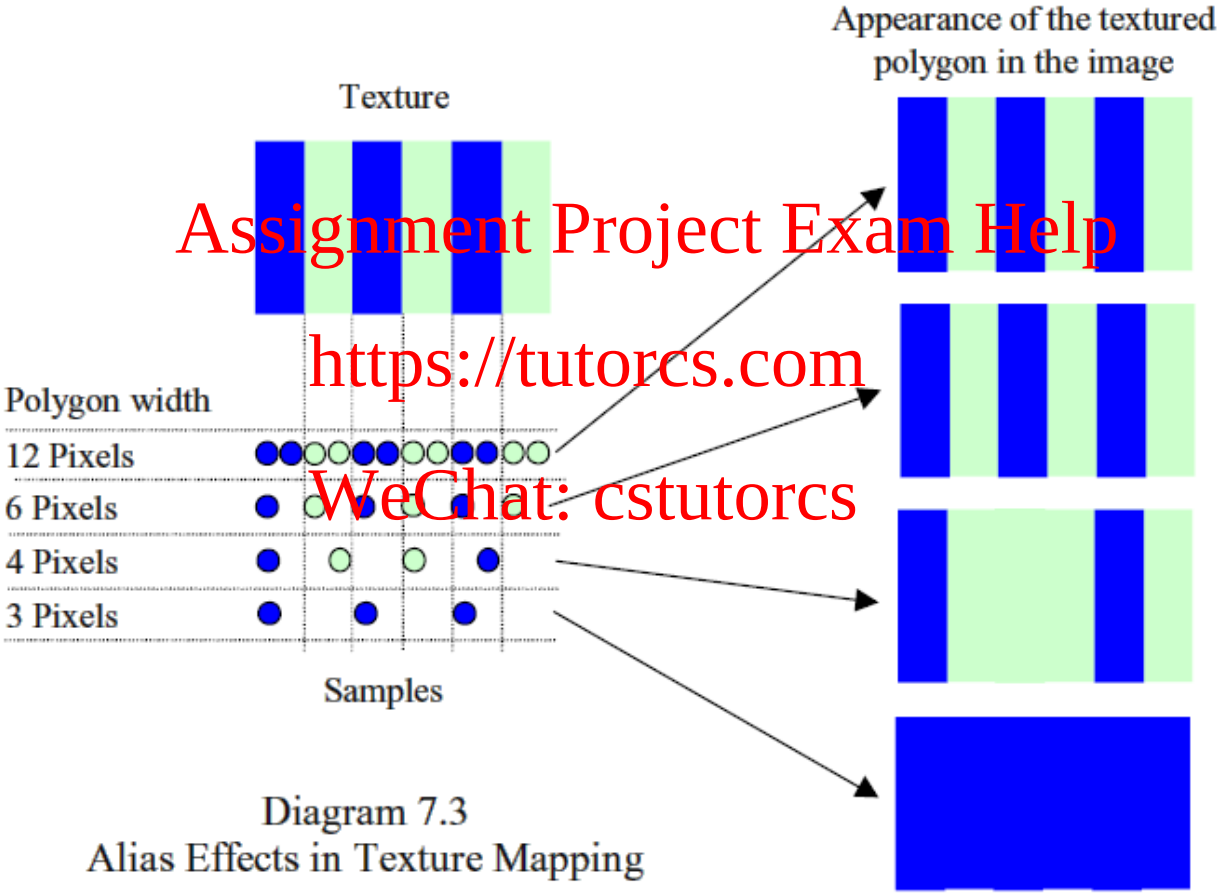


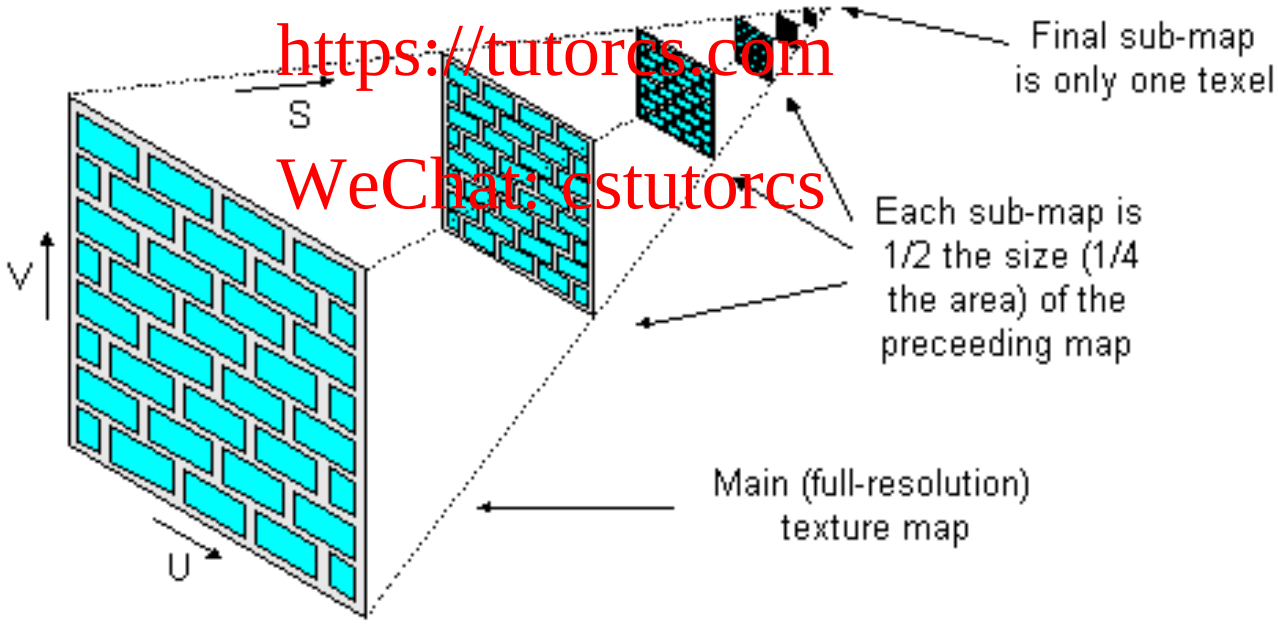
Diagram 7.3
Alias Effects in Texture Mapping

Anti-aliasing

- Similar to untextured images use *anti-aliasing* technique
- Most successful approach: *supersampling*
  - Compute picture at a *higher resolution*
  - *Average* the supersamples to find pixel colour
  - This blurs boundaries, but leaves coherent areas of colour unchanged
  - Works well for polygons, but requires a lot of computations and does not work for line drawings
- Other approaches: convolution filtering (see image processing)

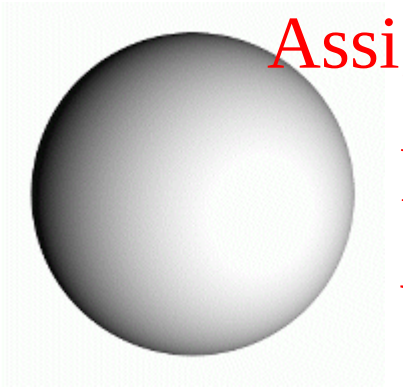
MIP Mapping

- Popular technique of precomputing / prefiltering to address alias effects (MIP = multum in parvo; much in little)
- Basic idea: construct a *pyramid of images* for *different* texture sizes (prefiltered and resampled)
  - Pick texture image suitable for size or interpolate between texture images

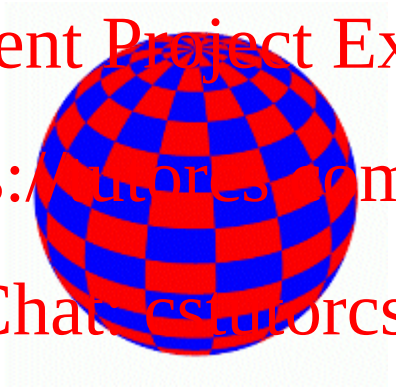


Generalising Texture Mapping

- So far: texture is a *label* (colour) for each pixel
- Can use it to modify other things
  - E.g. use it for *illumination* to adjust material properties (all light types or only some of them)



Material

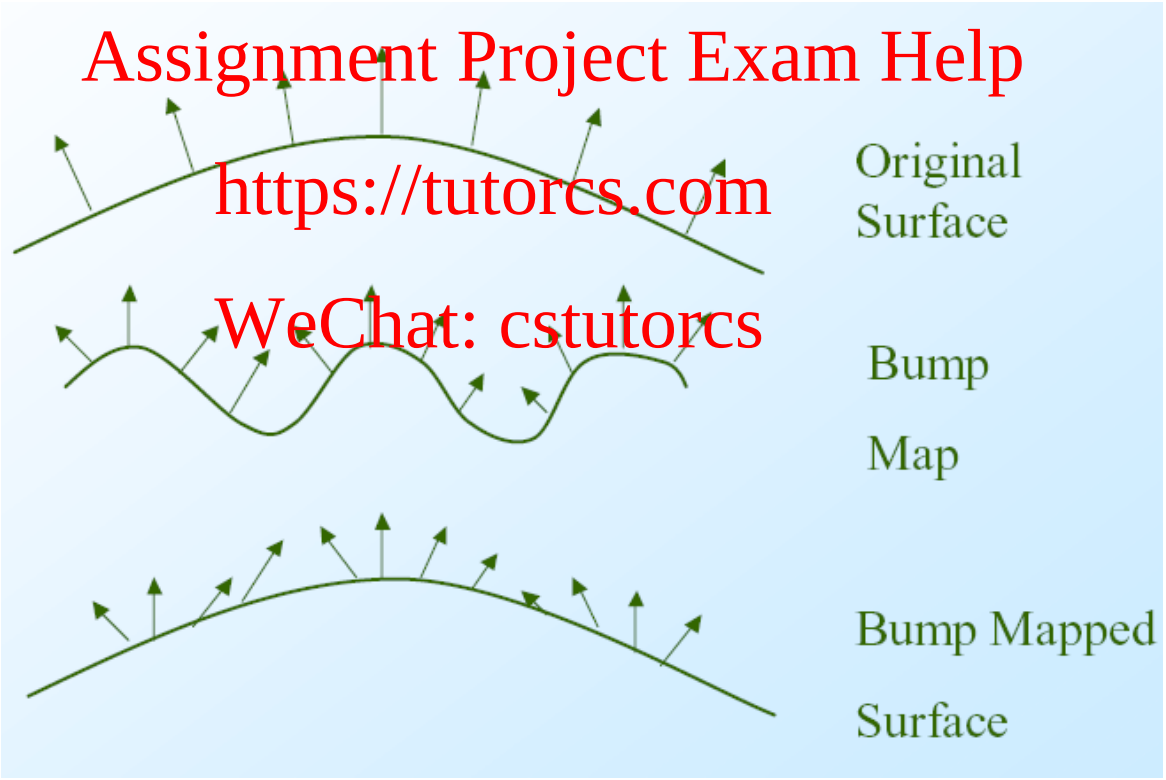


Texture as label

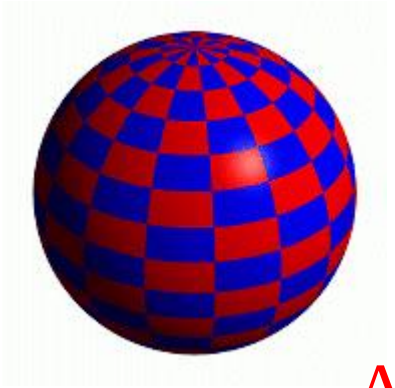
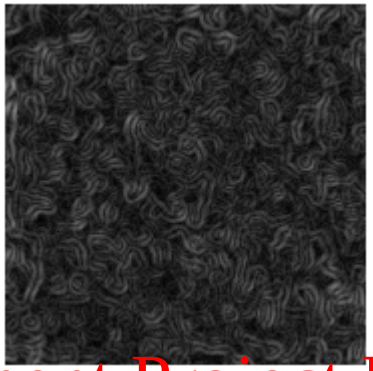
Texture as material

Bump Mapping

- Texture can be used to alter *surface normals* of an object
  - Does not change shape, but illumination computation
  - Changes in texture (partial derivatives) tell how to change the "height" of the normals



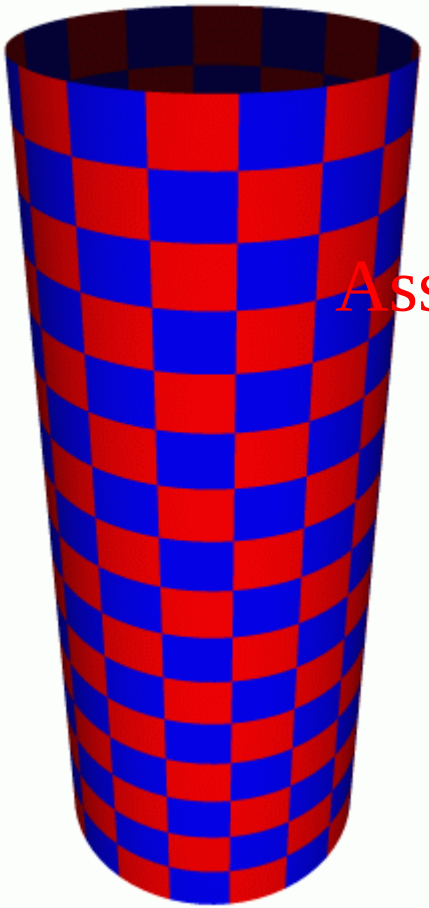
Bump Map Example


Sphere w/Texture Bump Map Bumpy Sphere

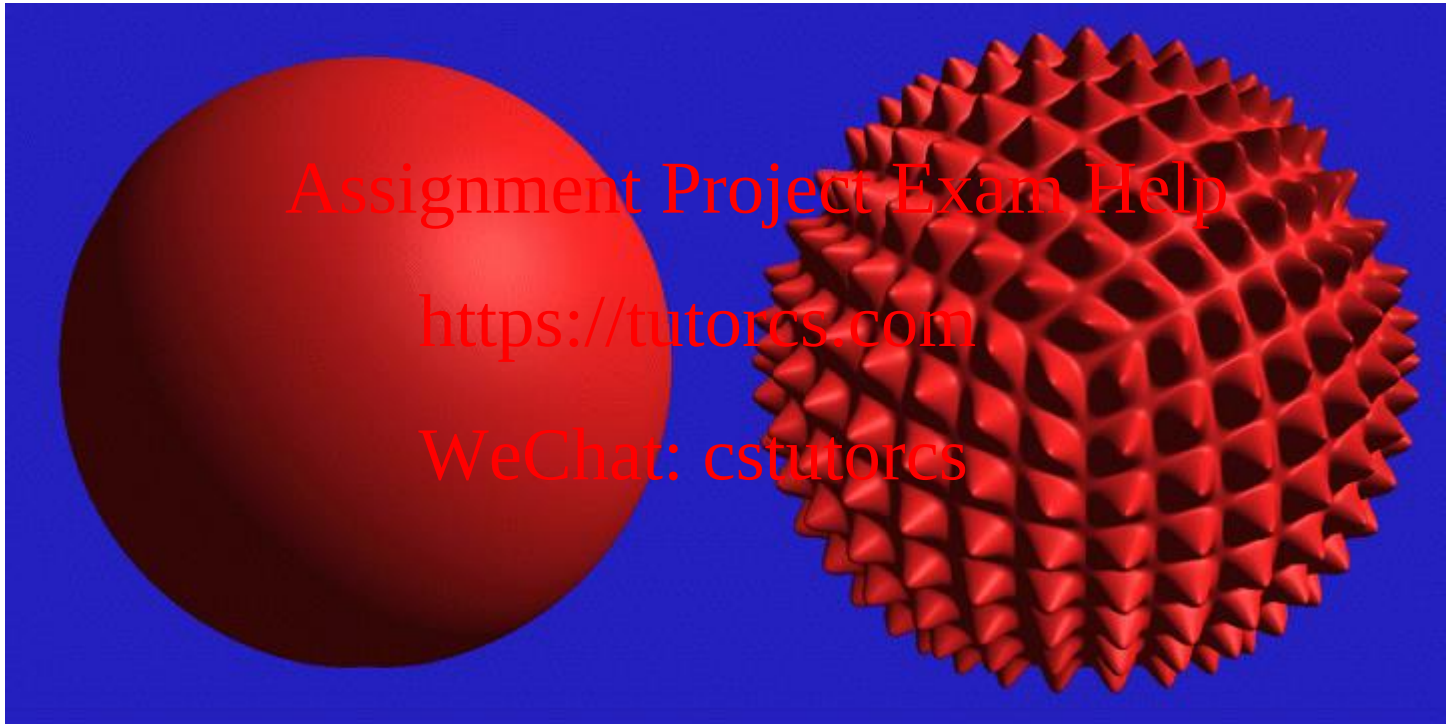
- As we do not change the shape, the silhouette does not change
  - Use only for small bumps
  - Requires illumination computation for each pixel (Phong shading, ray tracing, . . .)

Another Bump Map Example



Displacement Mapping

- Use texture map to *move* surface points



Light Maps

- In Quake *texture* and *light maps* are used
  - Light map contains precomputed illumination at low resolution
  - Multiply light map with texture map at run-time (and cache it)

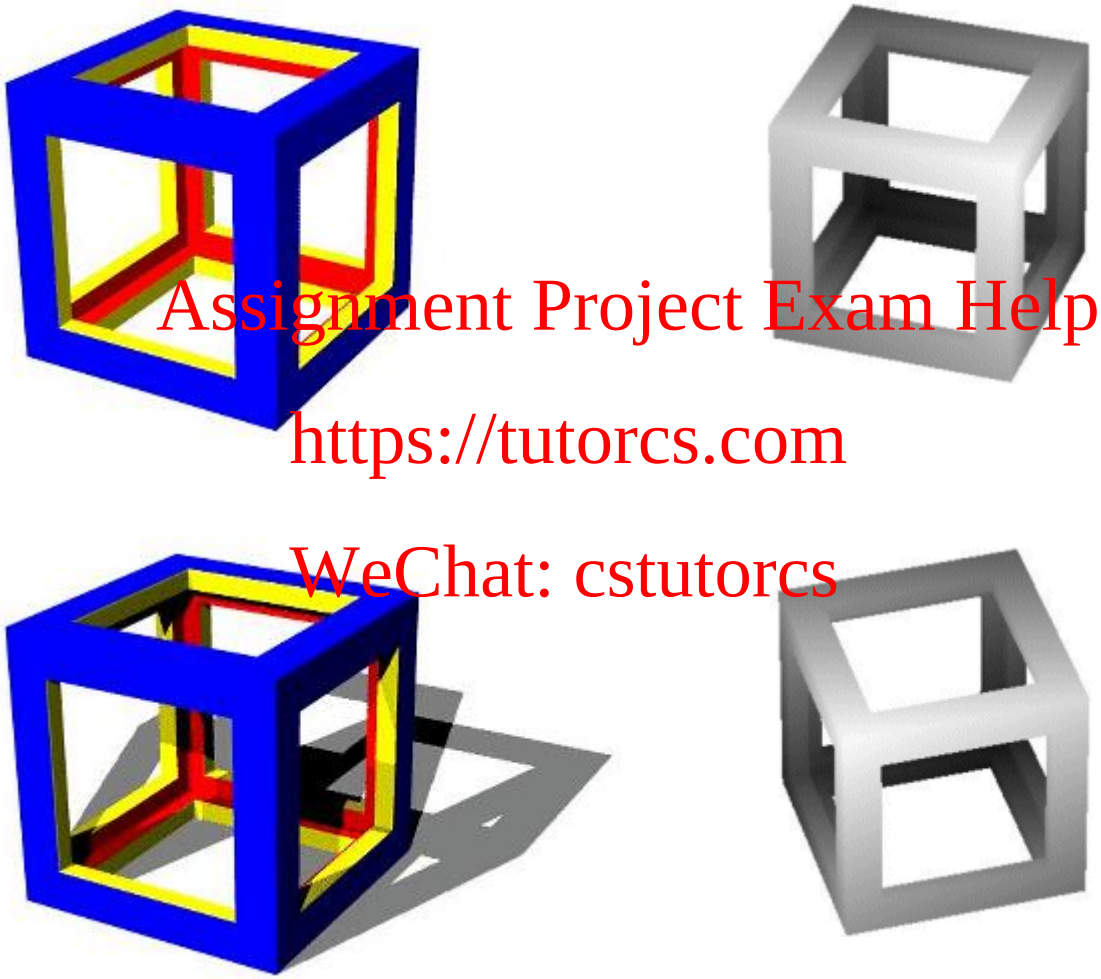
Only Texture Map

Texture and Light Map

Shadow Maps

- Generate *shadows* using texture maps
  - Render scene from the *viewpoint of each light source* and only keep *depth buffer* values in *shadow buffers*
  - When shading each pixel (illumination computation per pixel):
    - Compute vector *L* from visible point to light source (needed for illumination computation)
    - Compute the length of *L*
    - *Compare* this length with corresponding value in the *shadow buffers*
    - If the shadow buffer value is *less*, then the point is in the shadow and we can ignore the light source

Shadow Map Example



Texture Mapping in OpenGL

- Use Texture and TextureIO to apply a texture
  1. Create a texture object using TextureIO
     - TextureIO.newTexture(File, boolean);
  2. Indicate how the texture is to be applied to each pixel
     - Texture.setTexParameteri (…)
  3. Draw the scene, supplying both texture and geometric coordinates; send the coordinates to vertex shader, and send texture sampler to fragment shader
     - Texture.getImageTexCoords().top() …

Texture Mapping in OpenGL

- Using OpenGL Core functions to apply a texture
  1. Create a texture object and specify a texture for that object
     - glGenTextures(…)
     - glBindTexture(…)
     - glTexImage2D(…)
  2. Indicate how the texture is to be applied to each pixel
     - glTexParameteri(…)
  3. Enable texture mapping
     - glEnable(GL_TEXTURE_2D)
  4. Draw the scene, supplying both texture and geometric coordinates; send the coordinates to vertex shader, and send texture sampler to fragment shader

- Step 0: Read in texture image

Texture Object

- Texture objects store texture data and keep it readily available for usage. Many texture objects can be generated.
- Generate identifiers for texture objects first

  int texids[n];

  glGenTextures(n, texids)
  - `n`: the number of texture objects identifiers to generate
  - `texids`: an array of unsigned integers to hold texture object identifiers
- Bind a texture object as the current texture

  glBindTexture(target, identifier)
  - target: can be GL_TEXTURE_1D, GL_TEXTURE_2D, or GL_TEXTURE_3D
  - identifier: a texture object identifier
- Specify texture image

  glTexImage2D(target, level, internalFormat,
  width, height, border, format, type, data);

Texture Object Example Code

```
int texids[] = new int[1];
ByteBuffer texImg = readImage("textures/Day.png");

glGenTextures(1, texids, 0);
glBindTexture(GL_TEXTURE_2D, texids[0]);
glTexImage2D(GL_TEXTURE_2D, 0, GL_RGB,
             texWidth, texHeight,0, GL_BGR,
             GL_UNSIGNED_BYTE, texImg);
```

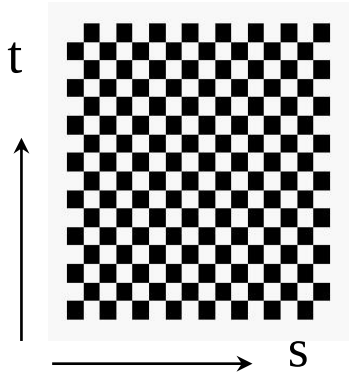
Texture Parameters

- OpenGL has a variety of parameters that determine how texture is applied.
  - Wrapping parameters determine what happens if s and t are outside the (0,1) range
  - Filter modes allow us to use area averaging instead of point samples
  - Environment parameters determine how texture mapping interacts with shading
  - Mipmapping allows us to use textures at multiple resolutions
- OpenGL Command

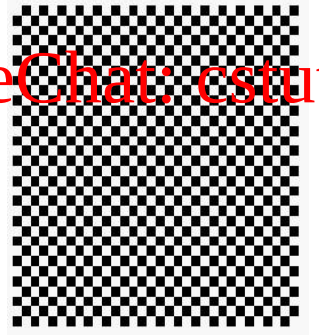
  glTexParameterf(target, pname, param);
  - target: Specifies the target texture
  - pname: Specifies the symbolic name of a single-valued texture parameter
  - param: Specifies the value of pname.

Wrapping Modes

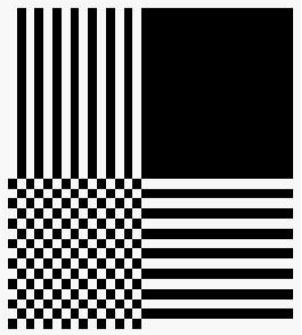
- Repeat: use s,t modulo 1
- Clamp: if s,t > 1 use 1, if s,t <0 use 0
  - glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_S, GL_REPEAT)
  - glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_T, GL_CLAMP_TO_EDGE)
  - GL_CLAMP_TO_BORDER, GL_MIRRORED_REPEAT…



texture



GL_REPEAT wrapping



GL_CLAMP_TO_EDGE wrapping

Texture Filtering

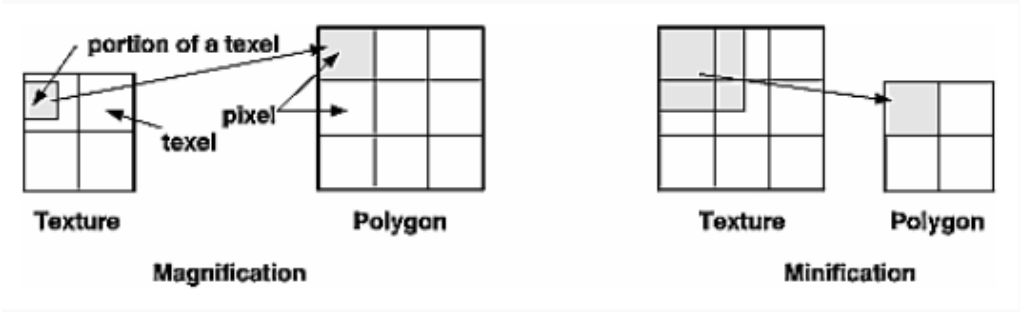
- A pixel may be mapped to a small portion of a texel or a collection of texels from the texture map. How to determine the color of the pixel?
- Magnification: when a pixel mapped to a small portion of a texel

```
glTexParameteri(GL_TEXTURE_2D,
                GL_TEXTURE_MAG_FILTER, type);
```

  - type: GL_NEAREST or GL_LINEAR
- Minification: when a pixel mapped to many texels

```
glTexParameteri(GL_TEXTURE_2D,
                GL_TEXTURE_MIN_FILTER, type);
```

  - type: GL_NEAREST, GL_LINEAR, GL_NEAREST_MIPMAP_LINEAR, GL_LINEAR_MIPMAP_LINEAR, …



Shading and Texture Interaction

- You can specify how the texture-map colors are used to modify the pixel colors by setting environment parameters in old version of OpenGL

  glTexEnvi(GL_TEXTURE_ENV,GL_TEXTURE_ENV_MODE, mode);

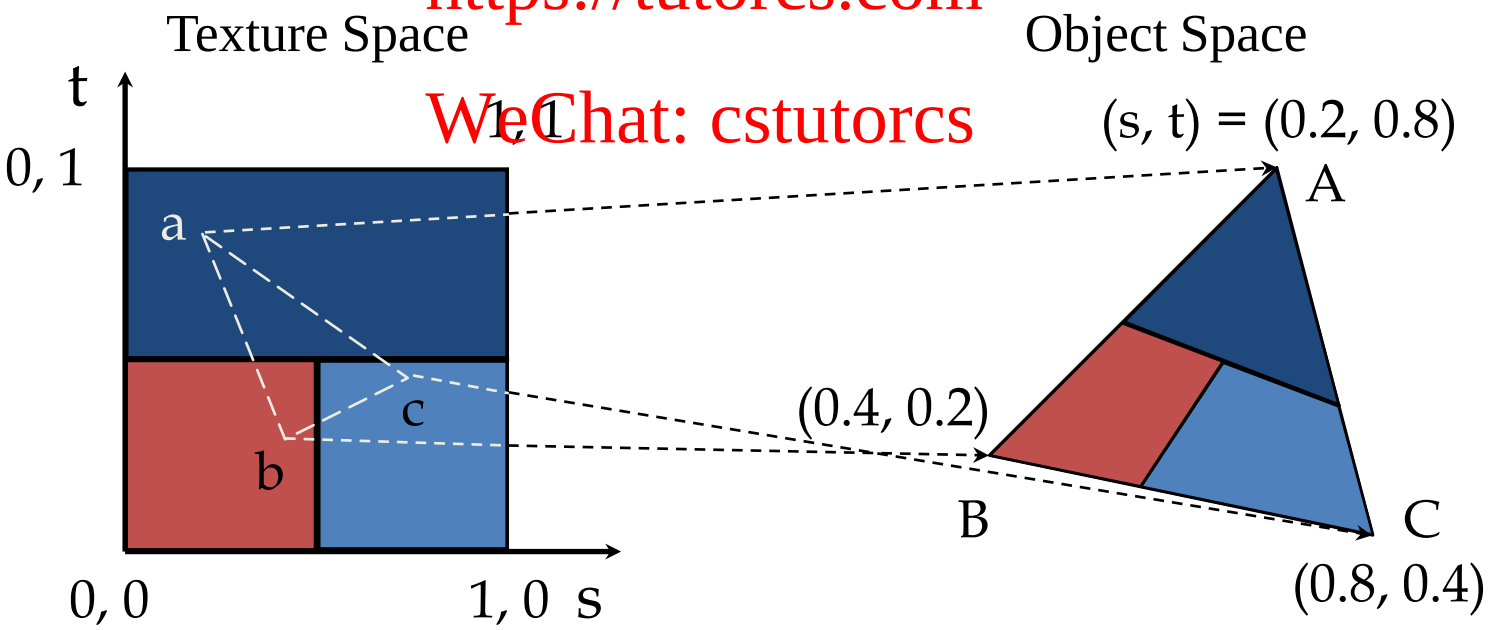
  mode values:

  - GL_REPLACE : replace pixel color with texture color
  - GL_BLEND : $C = C_f(1-C_t) + C_cC_t$,
    - C_f is the pixel color, C_t is the texture color, and C_c is some constant color
  - GL_MODULATE : $C = C_fC_t$ (Default)
  - More on OpenGL programming guide

- In the shader version of OpenGL, the interaction should be implemented in the fragment shader.

Assign Texture Coordinates

- Every point on a surface should have a texture coordinate (s, t) in texture mapping
- We often specify texture coordinates to polygon vertices and interpolate texture coordinates with the polygon
- Texture.getImageTexCoords() can be used to retrieve texture coordinates



Typical Code in Main Program

```
// Set the texture to be used
try {
        texture = TextureIO.newTexture(new File("WelshDragon.jpg"), false);
    }   catch (IOException ex) {
        Logger.getLogger(getClass().getName()).log(Level.SEVERE, null, ex);
    }

    // Set texture coordinates
    float[] texCoord ={…};
    FloatBuffer textures = FloatBuffer.wrap(texCoord); gl.glGenBuffers(…);
    gl.glBindBuffer(…);
    gl.glBufferData(…);
    gl.glBufferSubData(…);

    // Send texture coordinates to vertex shader
    vTexCoord = gl.glGetAttribLocation( program, "vTexCoord" );
    gl.glEnableVertexAttribArray( vTexCoord );
    gl.glVertexAttribPointer( vTexCoord, 2, GL_FLOAT, false, 0, offsetSize);

    // Set the fragment shader texture sampler variable
    gl.glUniform1i( gl.glGetUniformLocation(program, "tex"), 0 );
```

Vertex Shader

```
#version 330 core

layout(location = 0) in vec4 vPosition;
layout(location = 1) in vec3 vColour;
layout(location = 2) in vec2 vTexCoord;

out vec4 color;
out vec2 texCoord;

uniform mat4 ModelView;
uniform mat4 Projection;

void main()
{
    gl_Position = Projection * ModelView * vPosition;
    texCoord    = vTexCoord;

    color.rgb = vColour;
    color.a = 1.0;
}
```

Fragment Shader

```
#version 330 core

in  vec4 color;
in  vec2 texCoord;

out vec4 fColor;

uniform sampler2D tex;

void main()
{
    fColor = color* texture( tex, texCoord );
}
```


More details in the Labs...

Summary

- Describe the principle of texture maps. What are texture coordinates and how are they related to 3D coordinates?
- What options do exist to generalise texture maps? For what other effects are they useful and what are the advantages and disadvantages of these techniques?
- How to program texture mapping in OpenGL?