Make an impression!

7 Texture Mapping

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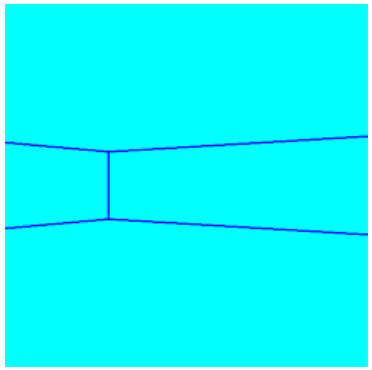
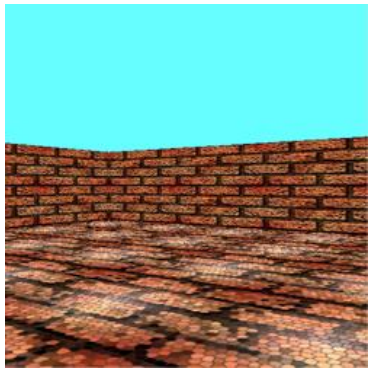
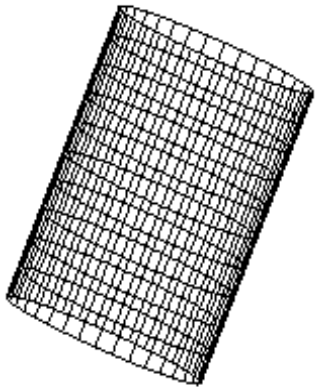
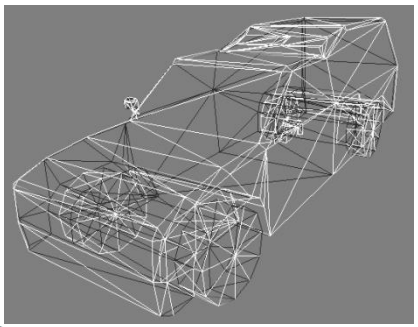
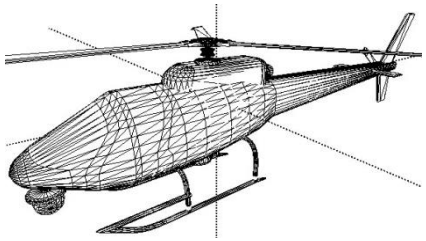
Basic Texture Mapping

- Basic texture mapping refers to the process of applying an image or a set of images to an object or a primitive.
  - Adds colour based surface features to polygons
  - Makes objects and scenes appear more realistic

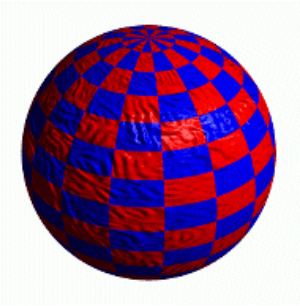



Advanced Applications

- Environment Mapping: Simulates reflections in an object that suggest the “world” surrounding that object.

- Billboarding: View oriented texture mapped polygons commonly used in place of models of trees.

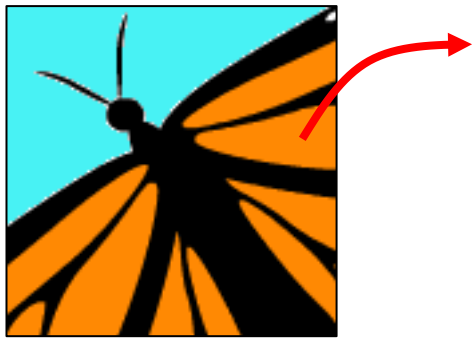
- Bump Mapping: Simulates surface displacements without modifying the geometry, to create the appearance of bumps and wrinkles.

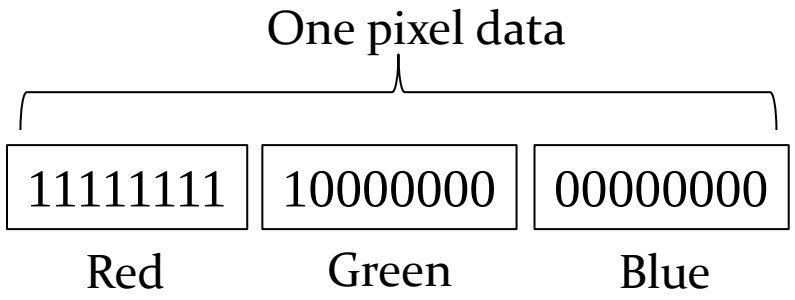


Textures

- For most texture mapping applications, we require images.
- Depending on the image type, we require a *loader* to parse the data contained in the image file, and to load the image data to texture memory.
- An image is a consecutive array of byte values. Each pixel in the image may be represented by 1, 3 or 4 bytes.

3-byte representation:

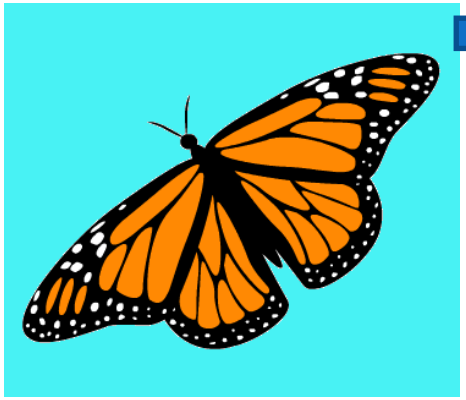




100x100 image $\Rightarrow$ 100x100x3 bytes

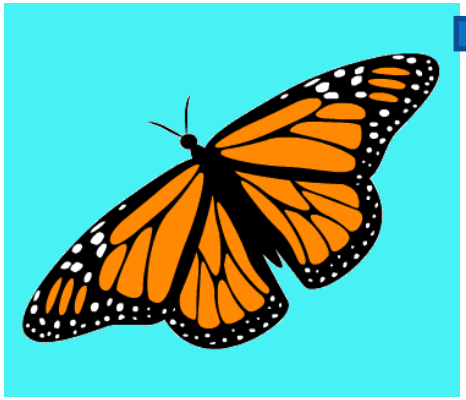
- Grey-scale image
- 1 byte per pixel
- Pixel depth (bpp): 8
- GL_LUMINANCE

- Colour image
- 3 bytes per pixel
- Pixel depth (bpp): 24
- GL_RGB



Red Green Blue

- Colour image
  + alpha
- 4 bytes per pixel
- Pixel depth (bpp): 32
- GL_RGBA



Red Green Blue Alpha

Texture Mapping: Step 1

- Generate texture Ids (also referred to as texture names).
  - A texture Id is an unsigned integer value (or values) obtained by calling the function `glGenTextures`.
  - The texture Ids are then used in the function `glBindTexture` to specify the texture in use.

Example: 1 Texture

```
Gluint texId;
glGenTextures(1, &texId);
glBindTexture(GL_TEXTURE_2D, texId);
...
```

Example: 3 Textures

```
Gluint texId[3];
glGenTextures(3, texId);
glBindTexture(GL_TEXTURE_2D, texId[0]);
...
glBindTexture(GL_TEXTURE_2D, texId[1]);
...
glBindTexture(GL_TEXTURE_2D, texId[2]);
...
```

Texture Mapping: Step 2

- Load a texture by calling the function:

```
glTexImage2D (GL_TEXTURE_2D, 0,
  n,   //No. of colour components(1, 3, 4)
  wid, //Image width,  a power of 2
  hgt, //Image height, a power of 2
  0,   //Border
  format, //GL_LUMINANCE,GL_RGB or GL_RGBA
  type,   //GL_UNSIGNED_BYTE
  imgData // Pointer to image data
 );
```

Loading Textures

Scene.tga
256x256
24 bpp
Uncompressed

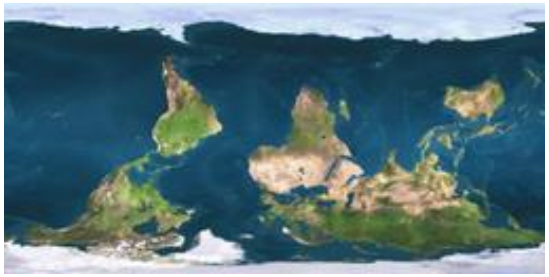
loadTGA.h

loadTGA("Scene.tga"); calls glTexImage2D(...)

Example:

```
#include "loadTGA.h"
...
Gluint texId;
glGenTextures(1, &texId);
glBindTexture(GL_TEXTURE_2D, texId);
loadTGA("Scene.tga");
...
```

Loading Textures



Earth.raw
256x128
24 bpp
Interleaved
"flipped vertically"

loadRAW.h

Must specify image size

loadRAW("Earth.raw", 256, 128);

calls

glTexImage2D(...)

Example:

```
#include "loadRAW.h"
...
Gluint texId;
glGenTextures(1, &texId);
glBindTexture(GL_TEXTURE_2D, texId);
loadRAW("Earth.raw", 256, 128);
...
```

Texture Mapping: Step 3

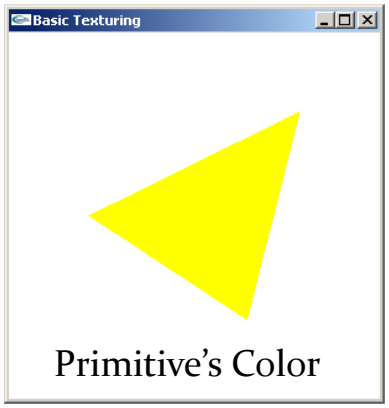
- Set texture sampling parameters:
  - Minification and magnification filters (discussed later)
  - Wrapping mode.

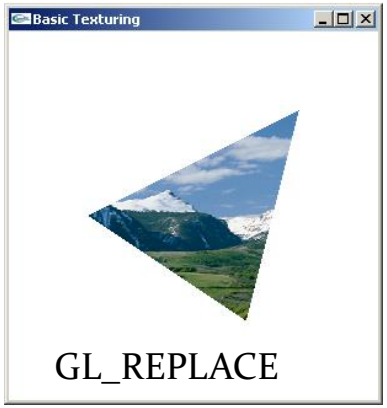
Example:

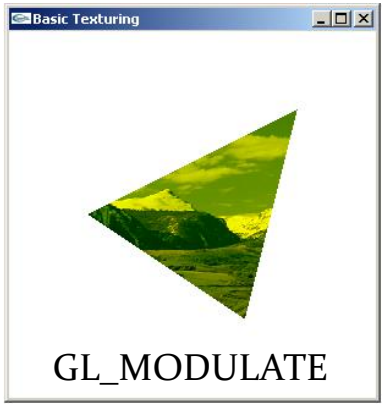
```
#include "loadTGA.h"
...
Gluint texId;
glGenTextures(1, &texId);
glBindTexture(GL_TEXTURE_2D, texId);
loadTGA("Scene.tga");
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_LINEAR);
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MAG_FILTER, GL_LINEAR);
...
```

Texture Mapping: Step 4

- Set texture environment parameters
  - GL_REPLACE: Texture colour replaces the fragment's colour
  - GL_MODULATE: Texture colour is multiplied by fragment's colour



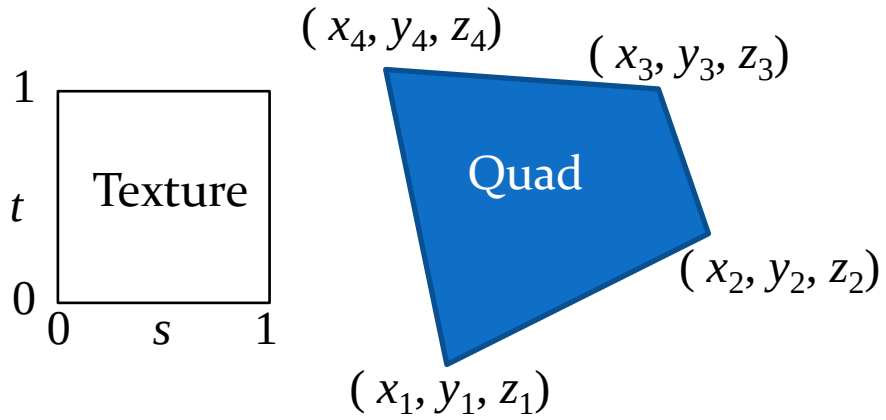




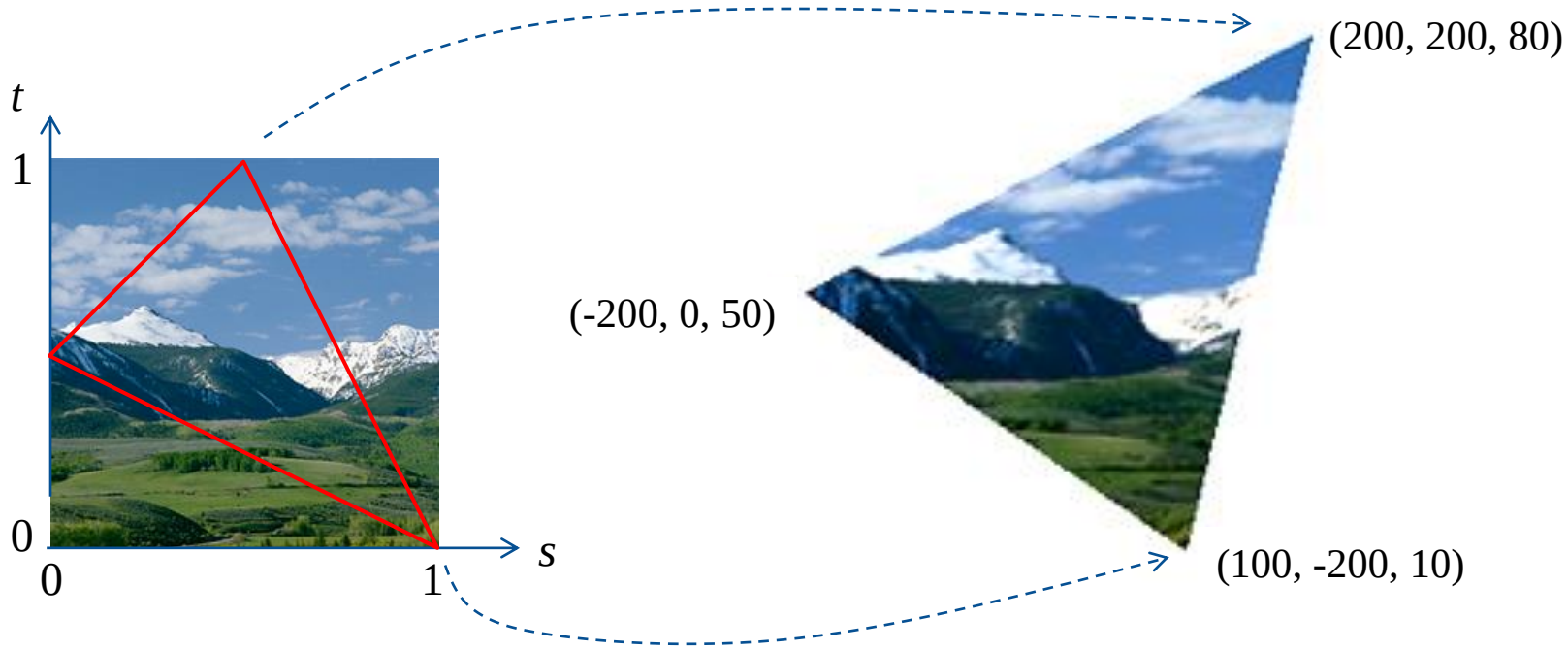

```
#include "loadTGA.h"
...
Gluint texId;
glGenTextures(1, &texId);
glBindTexture(GL_TEXTURE_2D, texId);
loadTGA("Scene.tga");
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_LINEAR);
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MAG_FILTER, GL_LINEAR);
glTexEnvi(GL_TEXTURE_ENV, GL_TEXTURE_ENV_MODE, GL_REPLACE);
```

Texture Mapping: Step 5

- Enable texturing and assign texture coordinates to vertices.
  - Texture coordinates (*s*, *t*) are defined in the image space with the origin at the bottom-left corner of the image, and a value 1 at image extremities, independent of image size.
  - The user specifies the image region to be mapped to a primitive by associating a pair of texture coordinates with each vertex.




```
glEnable(GL_TEXTURE_2D);
...
glBegin(GL_QUADS);
  glTexCoord2f(0., 0.);
  glVertex3f(x1, y1, z1);
  glTexCoord2f(1., 0.);
  glVertex3f(x2, y2, z2);
  glTexCoord2f(1., 1.);
  glVertex3f(x3, y3, z3);
  glTexCoord2f(0., 1.);
  glVertex3f(x4, y4, z4);
glEnd();
```

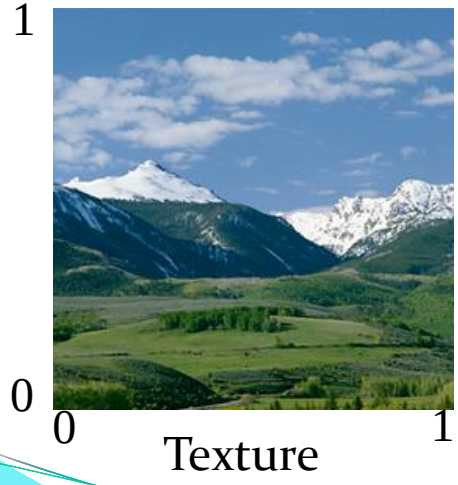


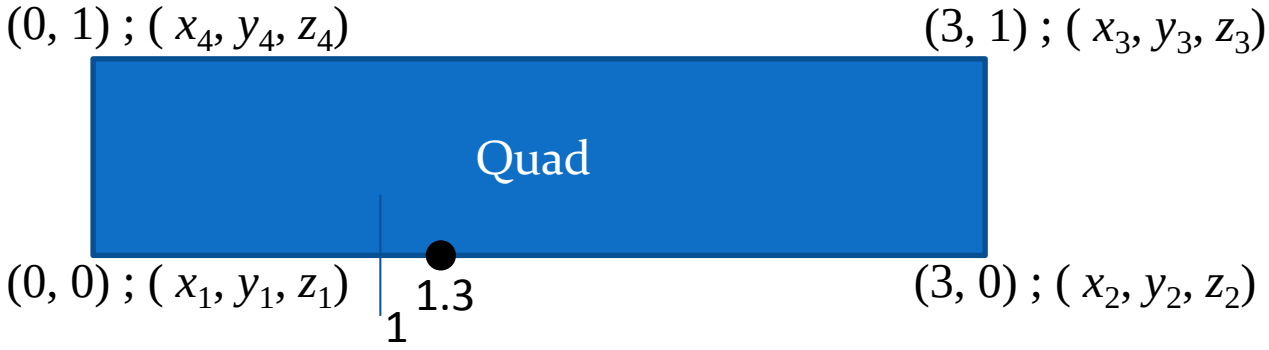

```
glEnable(GL_TEXTURE_2D);
glBindTexture(GL_TEXTURE_2D, texId);
...
glBegin(GL_TRIANGLES);
  glTexCoord2f(0.0, 0.5);  glVertex3i(-200, 0, 50);
  glTexCoord2f(1.0, 0.0);  glVertex3i(100, -200, 10);
  glTexCoord2f(0.5, 1.0);  glVertex3i(200, 200, 80);
glEnd();
```

Texture Tiling

- Texture coordinates assigned to a vertex can have values greater than 1. Such values can be used for tiling.
  - If the wrap parameter for a texture axis is set to GL_REPEAT, then the integer part of the texture coordinate along that axis is ignored. (eg. A value 1.3 is treated as 0.3). This results in the tiling of the image along that axis. [Default]

glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_S, **GL_REPEAT**);

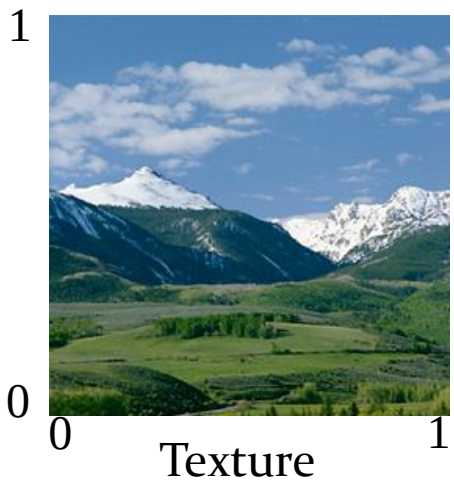


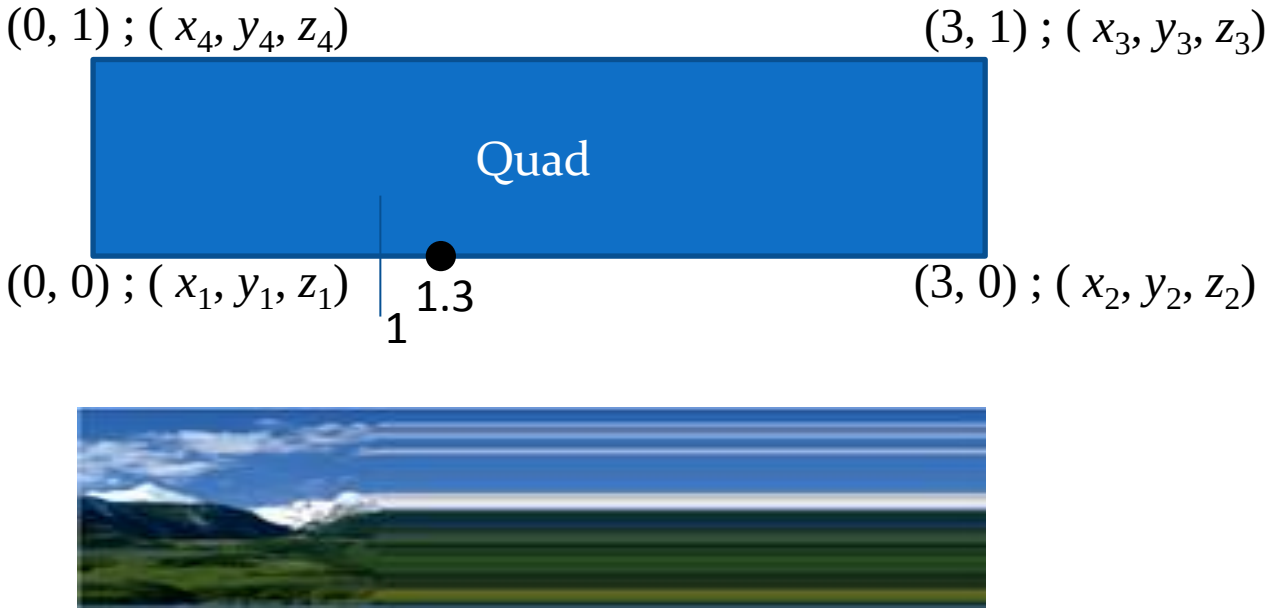


Texture Tiling

- If the wrap parameter for a texture axis is set to GL_CLAMP, then the coordinate value is clamped to the range [0, 1]. (eg. A value 1.3 is treated as 1).

glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_S**, GL_CLAMP**);



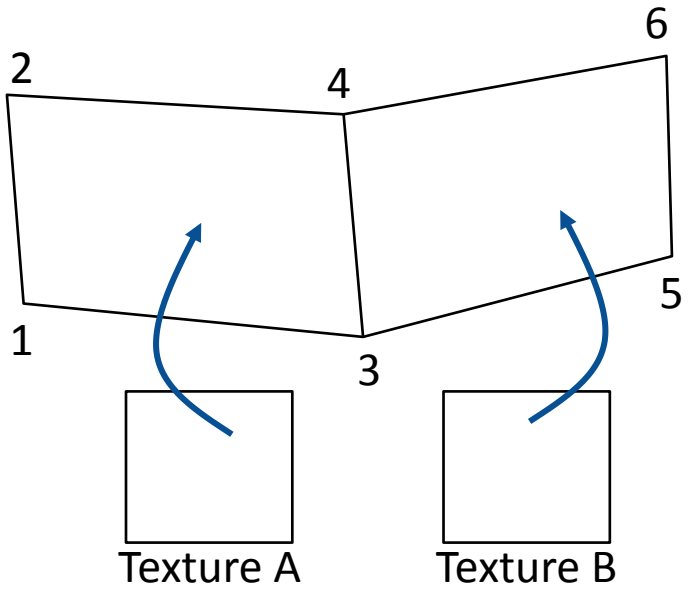


Texturing Quad Strips: Problem

- Consider a quad strip defined using six vertices:

```
glEnable(GL_TEXTURE_2D);
glBindTexture(GL_TEXTURE_2D, texId[0]);

glBegin(GL_QUAD_STRIP);
  glTexCoord2f(0., 0.);
  glVertex3f(x1, y1, z1);
  glTexCoord2f(0., 1.);
  glVertex3f(x2, y2, z2);
  glTexCoord2f(1., 0.);
  glVertex3f(x3, y3, z3);
  glTexCoord2f(1., 1.);
  glVertex3f(x4, y4, z4);
  glVertex3f(x5, y5, z5);
  glVertex3f(x6, y6, z6);
glEnd();
```

← ?

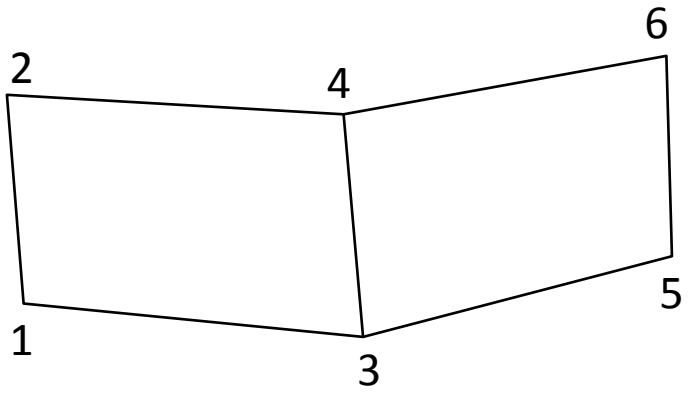


- glBindTexture(...) cannot be called inside a glBegin-glEnd block.

Texturing Quad Strips: Solution

- Create a combined texture

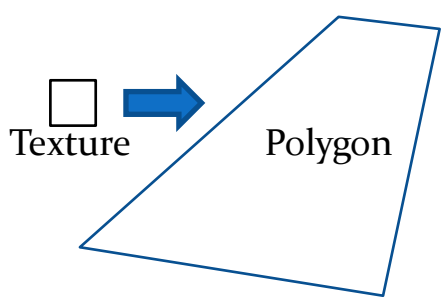
```
glEnable(GL_TEXTURE_2D);
glBindTexture(GL_TEXTURE_2D, texId);

glBegin(GL_QUAD_STRIP);
  glTexCoord2f(0., 0.);
  glVertex3f(x1, y1, z1);
  glTexCoord2f(0., 1.);
  glVertex3f(x2, y2, z2);
  glTexCoord2f(0.5, 0.);
  glVertex3f(x3, y3, z3);
  glTexCoord2f(0.5, 1.);
  glVertex3f(x4, y4, z4);
  glTexCoord2f(1., 0.);
  glVertex3f(x5, y5, z5);
  glTexCoord2f(1., 1.);
  glVertex3f(x6, y6, z6);
glEnd();
```



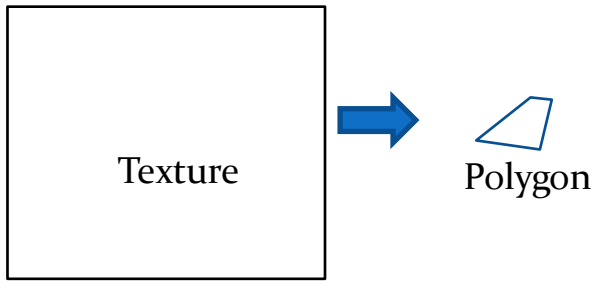
A single texture image

Texture Sampling

- In general, the number of pixels in a texture is not equal to number of pixels in the polygon to which the texture is mapped.
- Various forms of sampling error can arise (e.g. aliasing)
- Texture magnification occurs when a small texture is mapped onto a large polygonal surface.
- Texture minification occurs when a large texture is mapped to a small polygonal area.



Texture Magnification



Texture Minification

Texture Parameters GL_NEAREST, GL_LINEAR

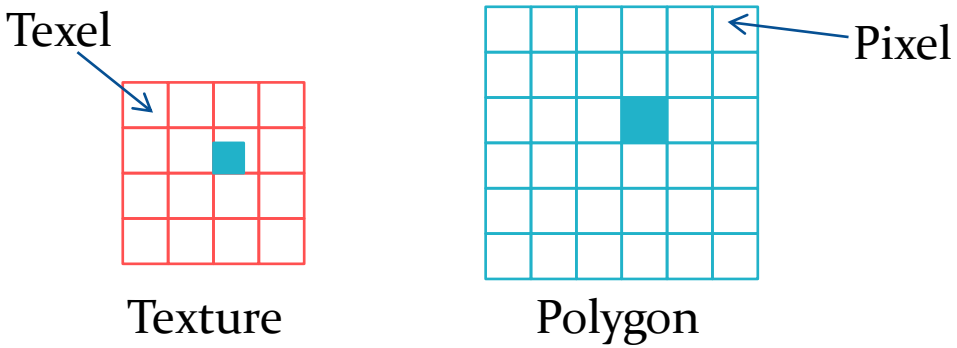
```
glTexParameteri(GL_TEXTURE_2D,GL_TEXTURE_MAG_FILTER, GL_NEAREST )
                                                     GL_LINEAR

glTexParameteri(GL_TEXTURE_2D,GL_TEXTURE_MIN_FILTER, GL_NEAREST )
                                                     GL_LINEAR
                                                        ...
```

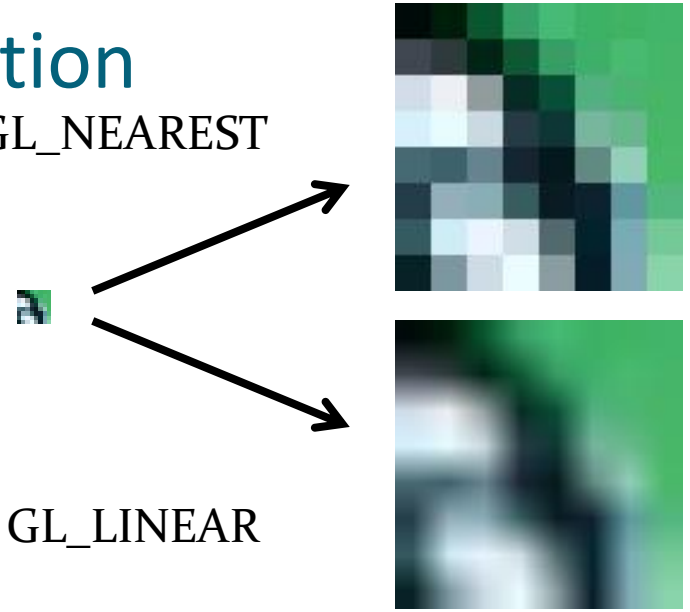
- GL_NEAREST: Returns the texel value nearest to the centre of the pixel.
- GL_LINEAR: Returns the weighted average of four texel values closest to the centre of the pixel.

Note:

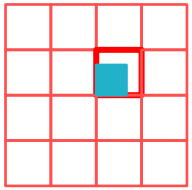
The pixel value of a texture is often called a “texel”.

Texture Magnification

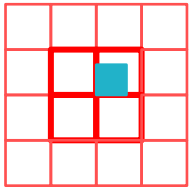




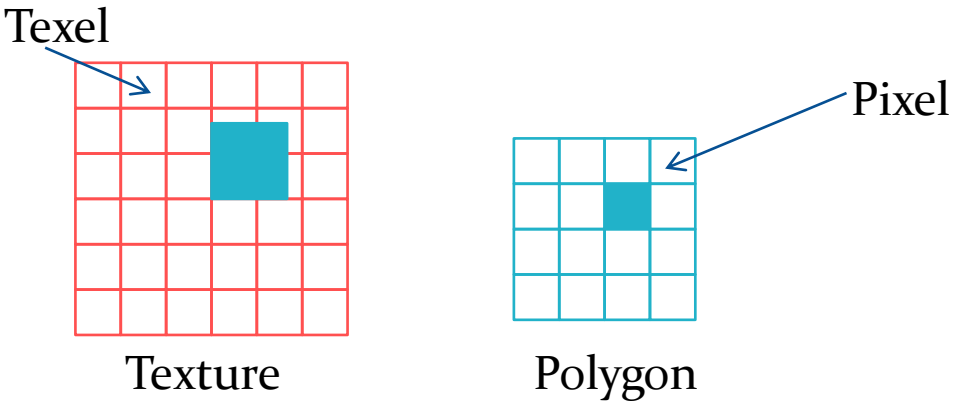
GL_NEAREST: The pixel gets the colour of the texel value nearest to the centre of the pixel.



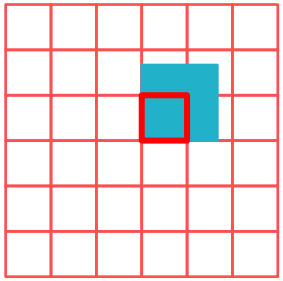
GL_LINEAR: The pixel gets the weighted average of four texel values closest to the centre of the pixel.



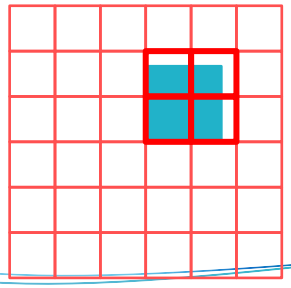
Texture Minification



GL_NEAREST: The pixel gets the colour of the texel value nearest to the centre of the pixel.

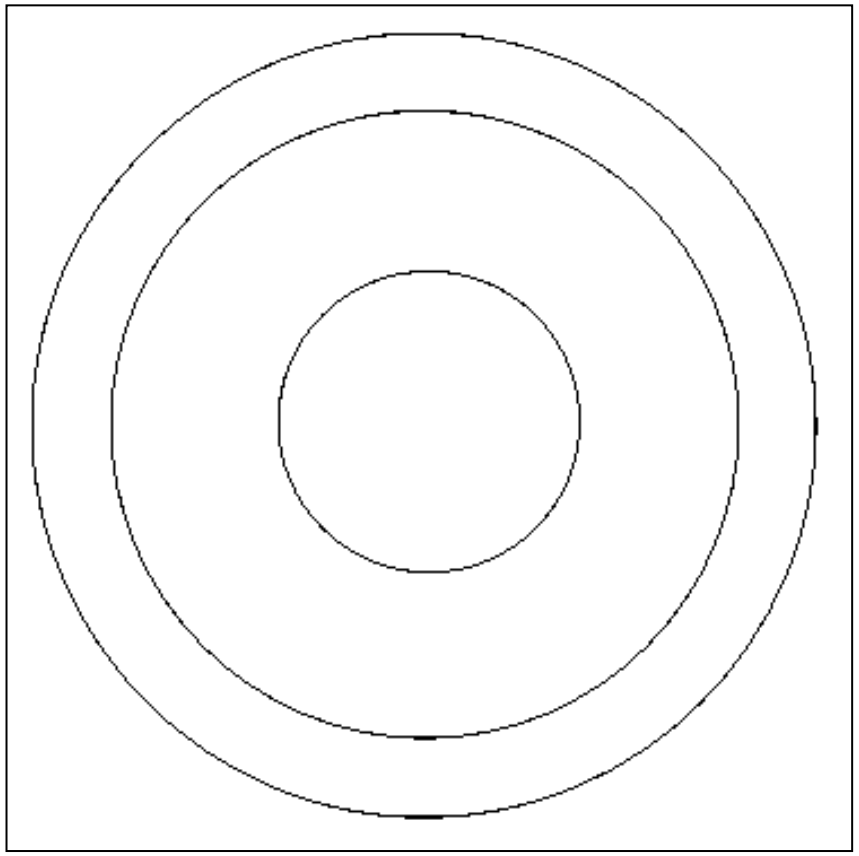


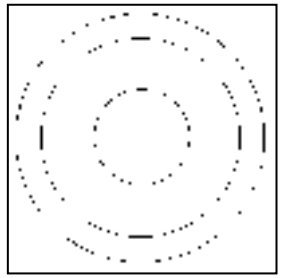
GL_LINEAR: The pixel gets the weighted average of four texel values closest to the centre of the pixel.



Texture Minification

- Thin lines often disappear when a texture is mapped to a region containing fewer pixels.





Both GL_NEAREST and GL_LINEAR settings produce similar images

Texture Mipmaps

- MIP = Multum In Parvo = “Much in a small place”
- A mipmap is a set of prefiltered versions of the same image at different scales (resolutions)





…

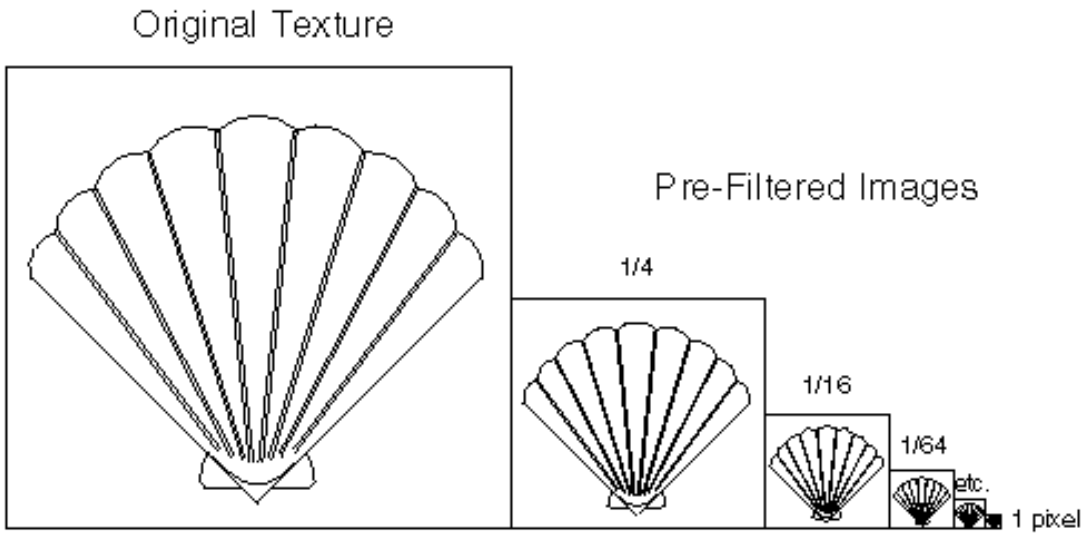
Last image is a single texel.
Average of all original texels.

256 x 256 128 x 128 64 x 64 etc

Mipmap Level: 0 1 2 3 4 ..

Texture Mipmaps

- The problem of disappearing lines when a texture is mapped to a small region can be solved by using a mipmap containing pre-filtered images.
- Mipmapping requires additional processing, and 33% extra texture storage space.



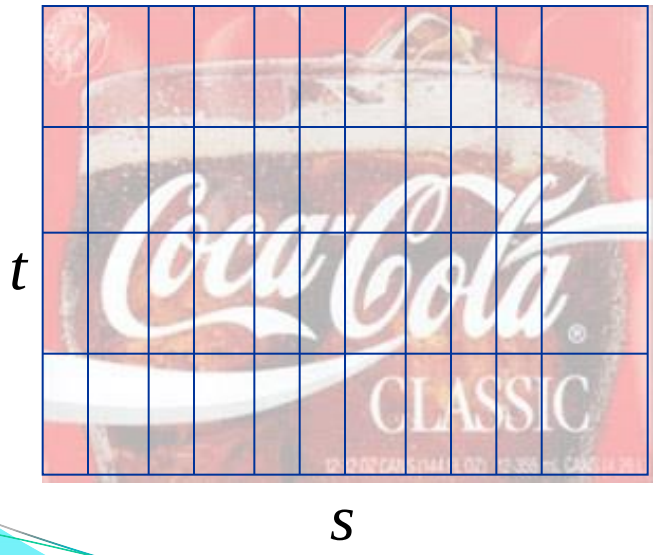
Texture Mipmaps

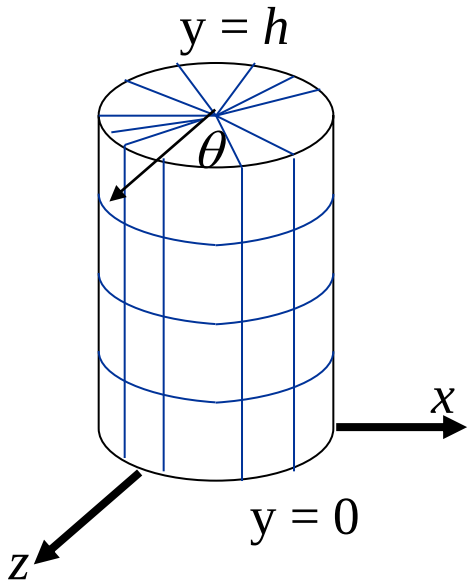
```
glTexParameteri(GL_TEXTURE_2D,
                GL_TEXTURE_MIN_FILTER,
                GL_LINEAR_MIPMAP_LINEAR)

glTexImage2D(GL_TEXTURE_2D, 0, 3, 64,64, 0, GL_RGB,
GL_UNSIGNED_BYTE, img1)
glTexImage2D(GL_TEXTURE_2D, 1, 3, 32,32, 0, GL_RGB,
GL_UNSIGNED_BYTE, img2)
glTexImage2D(GL_TEXTURE_2D, 2, 3, 16,16, 0, GL_RGB,
GL_UNSIGNED_BYTE, img3)
...
glTexImage2D(GL_TEXTURE_2D, 6, 3, 1,1, 0, GL_RGB,
GL_UNSIGNED_BYTE, img7)
```

GL_LINEAR_MIPMAP_LINEAR uses *trilinear* interpolation. Finds nearest two mipmap images given the minification factor, bilinear interpolates in each one as for GL_LINEAR, then interpolates between the two selected mipmaps.

Texture Coordinates from Parameterization

- If a surface has a parametric representation using two parameters (*u*, *v*, say), then we can easily obtain a linear mapping from (*s*, *t*) to (*u*, *v*).
- Surfaces like sphere, cylinder, torus etc have such a parametric representation.





Vertices:

$$x = R\sin(\theta)$$

$$y$$

$$z = R\cos(\theta)$$

Texture Coords:

$$s = \theta / 360$$

$$t = y / h$$

Texturing a Quadric Surface

- Using GLU library, the texture coordinates can be automatically generated for a quadric surface:

```
GLUquadric *q = gluNewQuadric();
gluQuadricDrawStyle ( q, GLU_FILL );
gluQuadricNormals( q, GLU_SMOOTH );
 gluQuadricTexture( q, GL_TRUE );
gluSphere ( q, 3.0, 18, 12 );
```

Texturing and Lighting

- Lighting computation is a per-vertex operation, whereas texturing is done later at the fragment processing stage.
- If GL_REPLACE is used as the texturing environment (See slide 11), the colour values got from lighting computation would be replaced with texture colours.
- In order to see the variation of diffuse reflections from the surface, the texture values must be modulated with the already computed fragment colour (GL_MODULATE)
- Modulation will reduce the effect of specular highlights. To get a strong specular highlight on a textured surface, select the following light model:

```
glLightModeli(GL_LIGHT_MODEL_COLOR_CONTROL,
                    GL_SEPARATE_SPECULAR_COLOR);
```