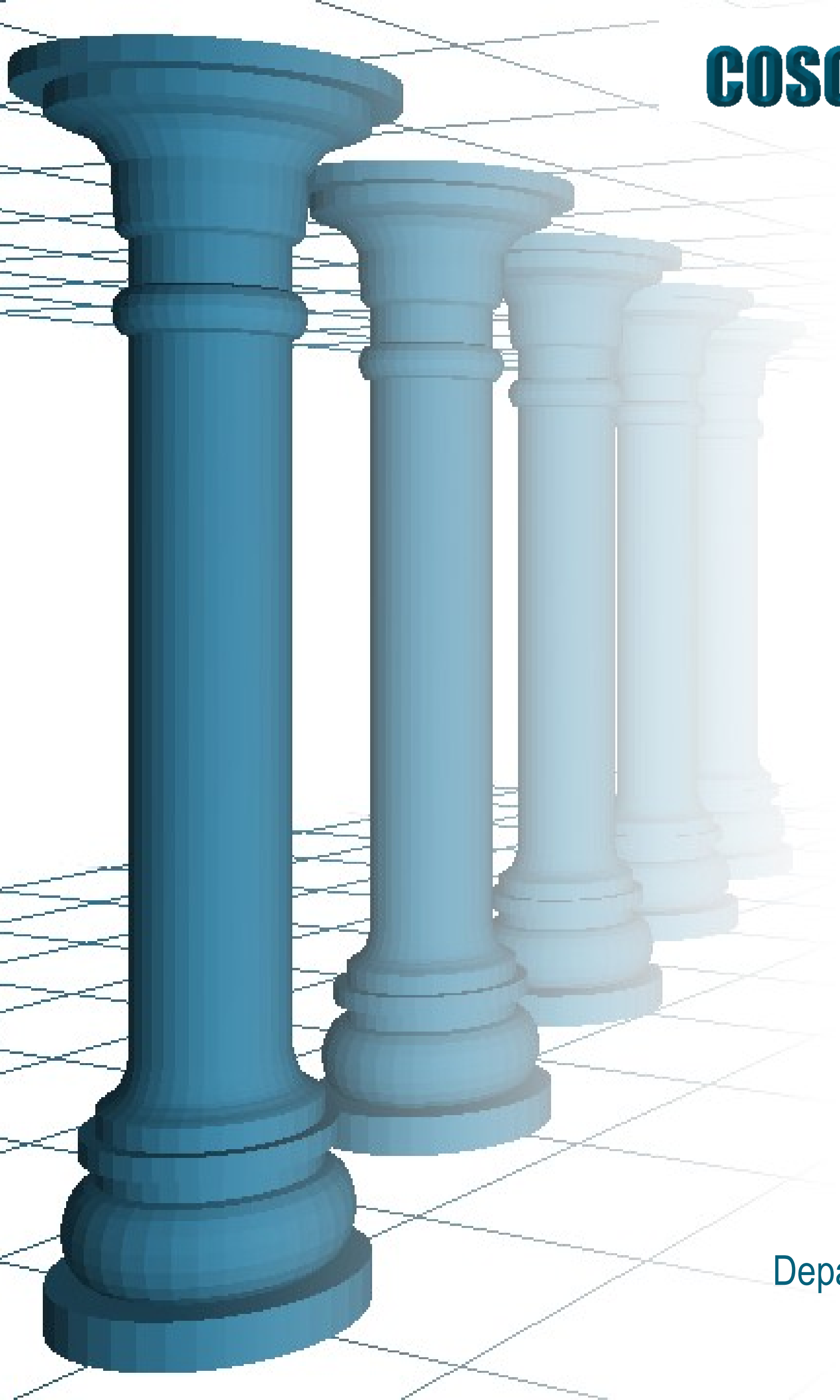

COSC363 Computer Graphics

4

Texture Mapping

Make an impression!

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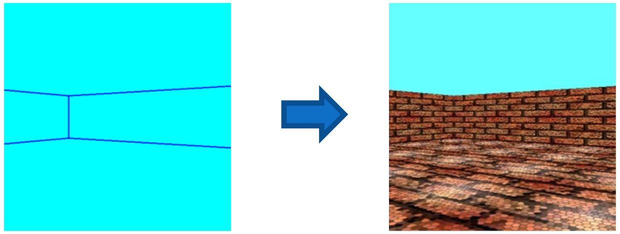
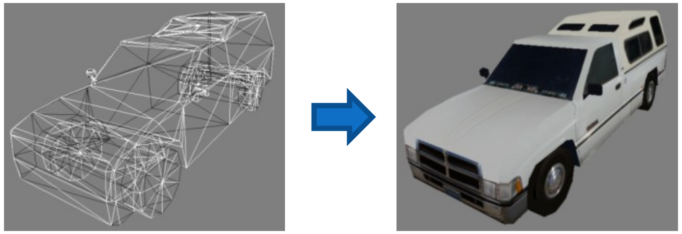
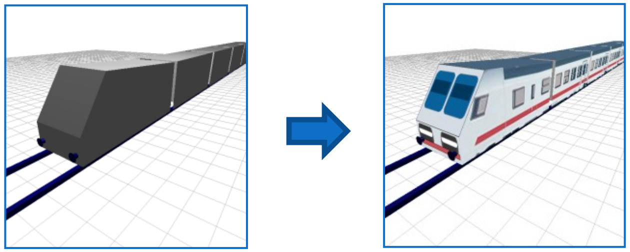
Basic Texture Mapping

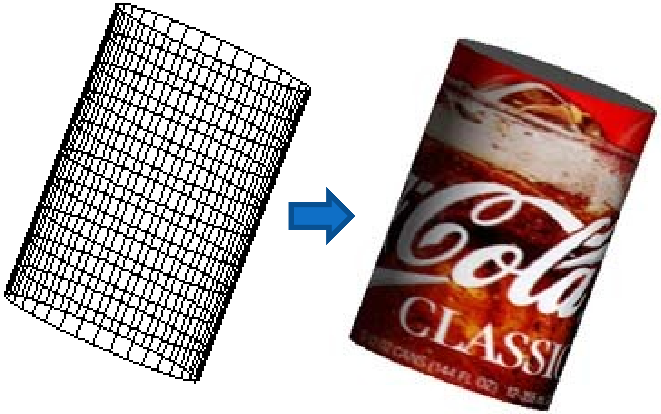
Basic texture mapping refers to the process of applying an image or a set of images to an object or a primitive.

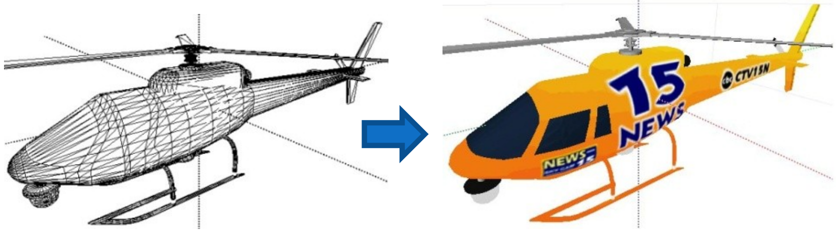
- Adds colour based surface features to polygons
- Makes objects and scenes appear more realistic











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.

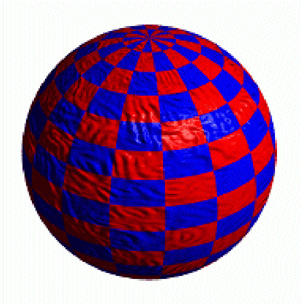
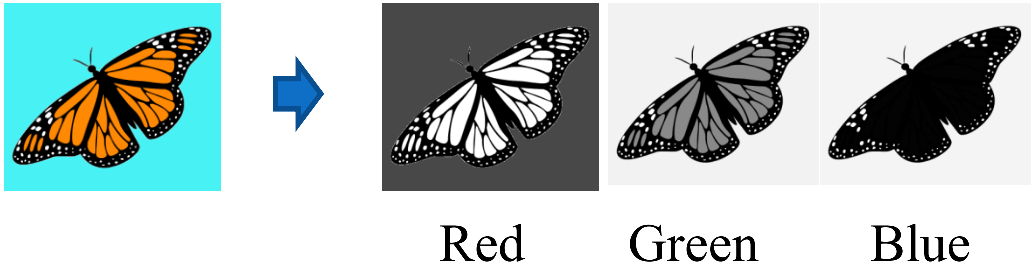


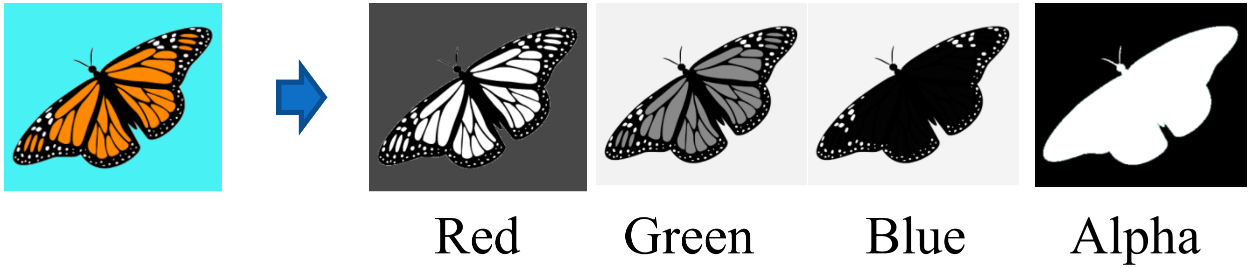
Image Types

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

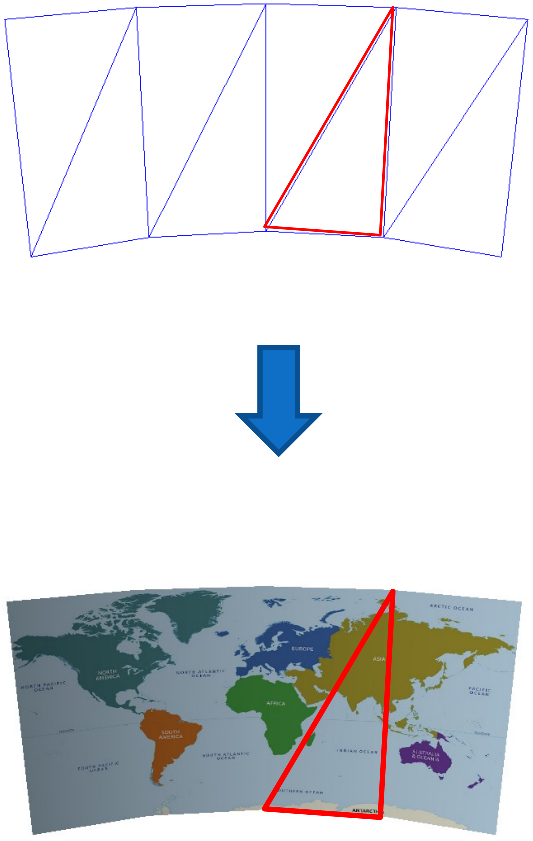


Colour image
+ alpha
4 bytes per pixel
Pixel depth (bpp): 32
GL_RGBA

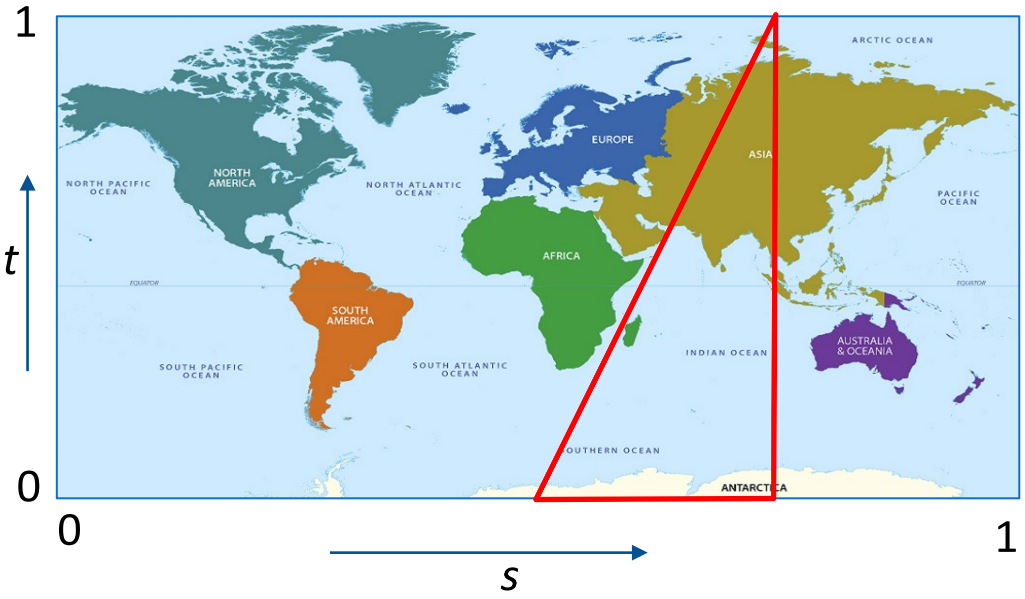


Texture Mapping

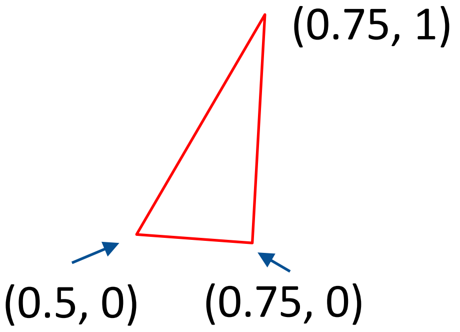
3D Object



Texture



Texture coordinates = (*s*, *t*)



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

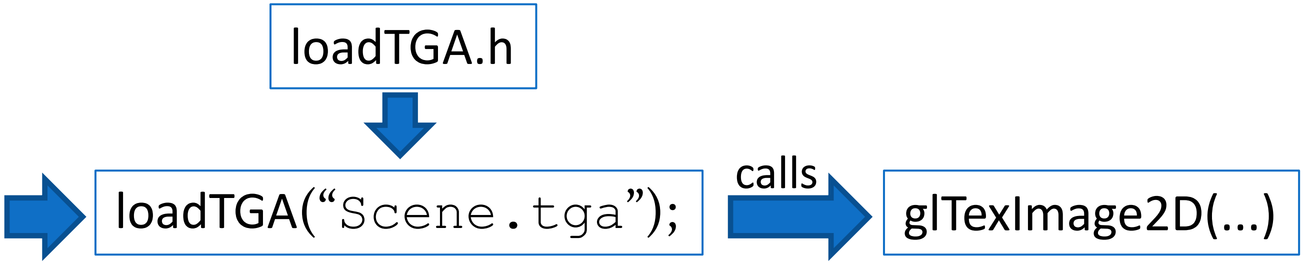
Load a texture by calling the function:

```
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
  );
```

Examples of image sizes: 256x256,   1024x512

Loading Textures

Scene.tga
256x256
24 bpp
Uncompressed



loadTGA.h

loadTGA(“Scene.tga”);

calls

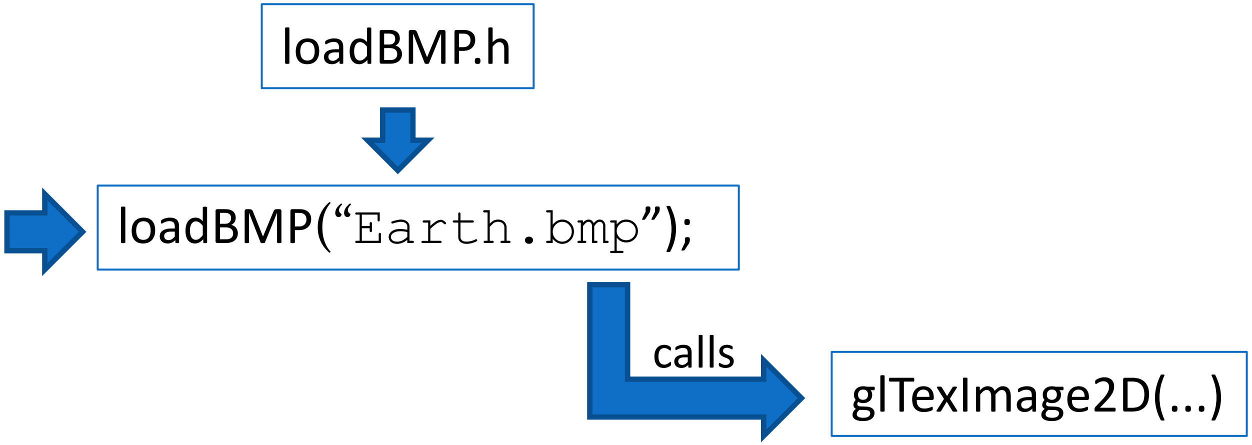
glTexImage2D(...)

Example:

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

Loading Textures

Earth.bmp
256 x 128
24 bpp
Windows Bitmap



loadBMP.h

loadBMP(“Earth.bmp”);

calls

glTexImage2D(...)

Example:

```
#include “loadBMP.h”
...
Gluint texId;
glGenTextures(1, &texId);
glBindTexture(GL_TEXTURE_2D, texId);
loadBMP(“Earth.bmp”);
...
```

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

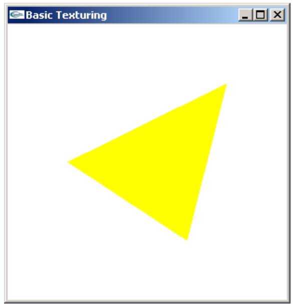
Required

Optional

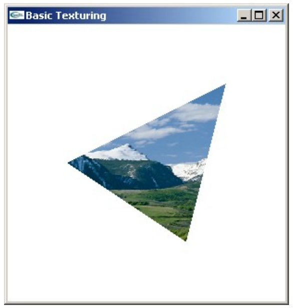
Texture Mapping: Step 4

Set texture environment parameters

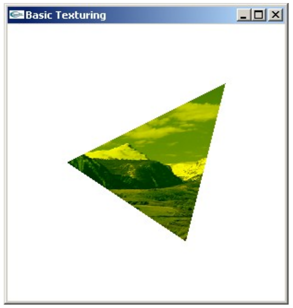
- GL_REPLACE: Texture colour replaces the fragment’s colour
- GL_MODULATE: Texture colour is multiplied by fragment’s colour



Primitive’s Color



GL_REPLACE



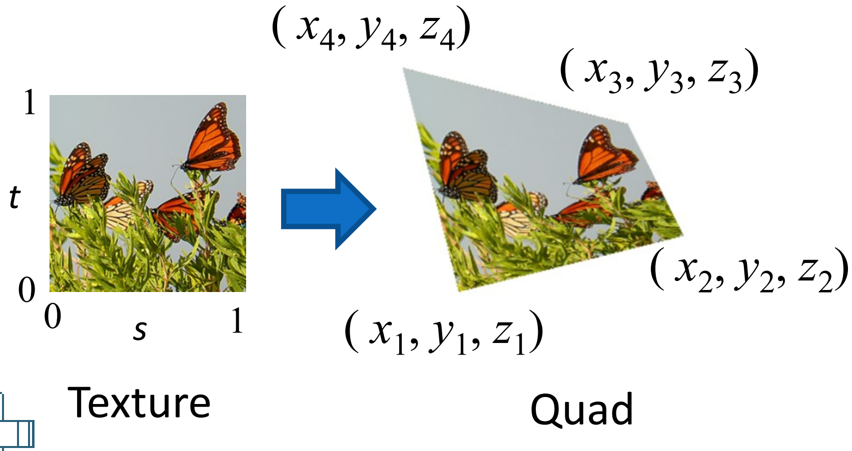
GL_MODULATE

```
#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);
```

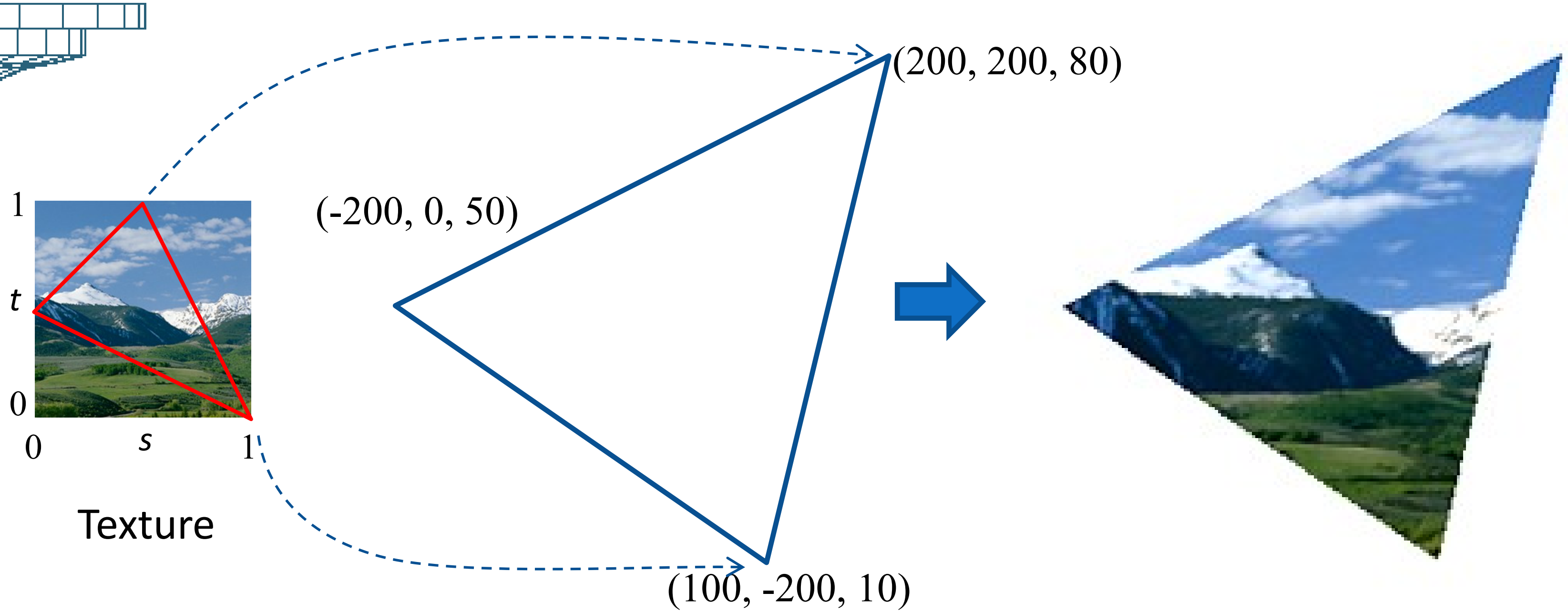
Texture Mapping: Step 5

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, <u>independent of image size</u>.
- The user specifies the image region to be mapped to a primitive by associating a pair of texture coordinates with each vertex.



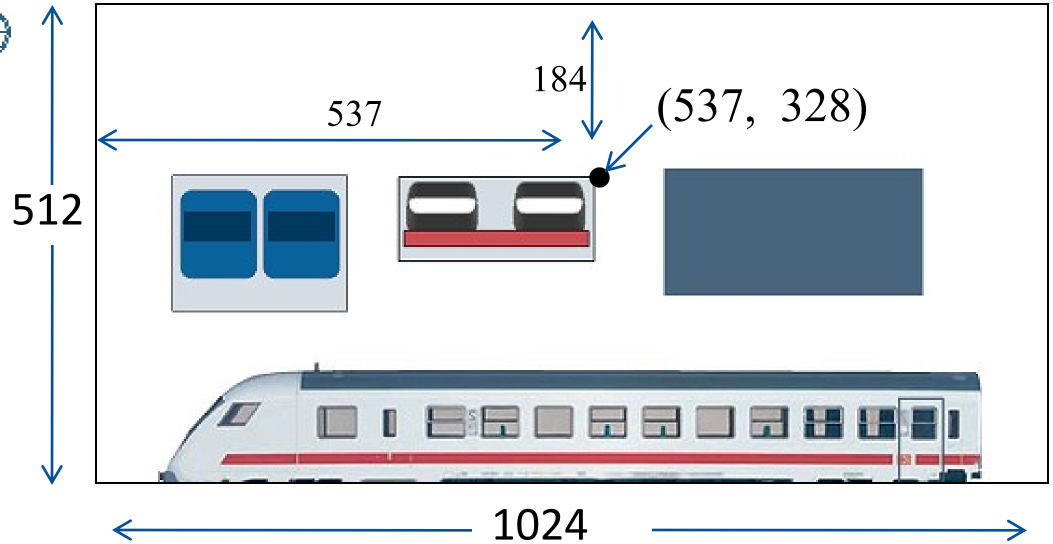
```
glEnable(GL_TEXTURE_2D);
glBindTexture(GL_TEXTURE_2D, texId);

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();
```

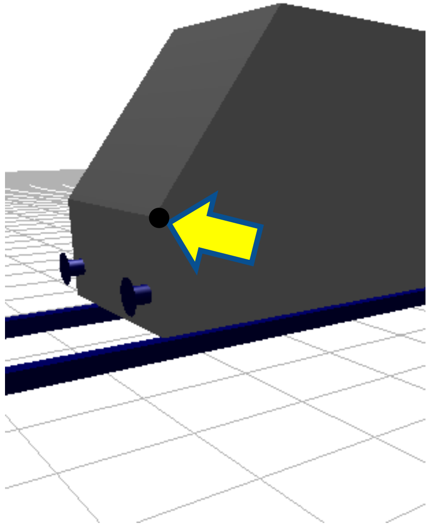


```
glEnable(GL_TEXTURE_2D);
glBindTexture(GL_TEXTURE_2D, texId);
...
glBegin(GL_TRIANGLES);
  glTexCoord2f(0.0, 0.5);
  glVertex3f(-200, 0, 50);
  glTexCoord2f(1.0, 0.0);
  glVertex3f(100, -200, 10);
  glTexCoord2f(0.5, 1.0);
  glVertex3f(200, 200, 80);
glEnd();
```

Another Example

A single texture containing several sections





$$(537,\ 328)$$
$$\Rightarrow (537/1024,\ 328/512)$$
$$\Rightarrow \mathbf{(0.5244,\ 0.6406)}$$

```
glBegin(GL_QUADS);
 ...
glNormal3f(0, 0, 1);   //Lights
glTexCoord2f(0.3212, 0.4628);
glVertex3f(-6.5, 0, 22.5);
glTexCoord2f(0.5244, 0.4628);
glVertex3f(6.5, 0, 22.5);
glTexCoord2f(0.5244, 0.6406);
glVertex3f(6.5, 6., 22.5);
glTexCoord2f(0.3212, 0.6406);
glVertex3f(-6.5, 6., 22.5);
```

Texture Image Types

- Bitmap (.bmp) :
  - 24 bits per pixel, Windows bitmap.
  - Use loadBMP() function included in loadBMP.h
- Targa (.tga):
  - 24 bits per pixel, Uncompressed.
  - Use loadTGA() function included in loadTGA.h
- Other formats (.PNG, .JPG etc)
  - Option 1: Convert to .bmp or .tga using an image editor (e.g., GIMP)
  - Option 2: Use the image loader in

    http://openil.sourceforge.net/tuts/tut_10/index.htm

    Sample code given in Lab04.

A full featured cross-platform image library.

Texture Image Sizes

- Width and height must be a power of 2. You may crop or resize an image using an image editor (e.g., GIMP)

- Please use low resolution images (1024x1024 or lower). 4K and 8K resolutions are required only for UHD display devices.

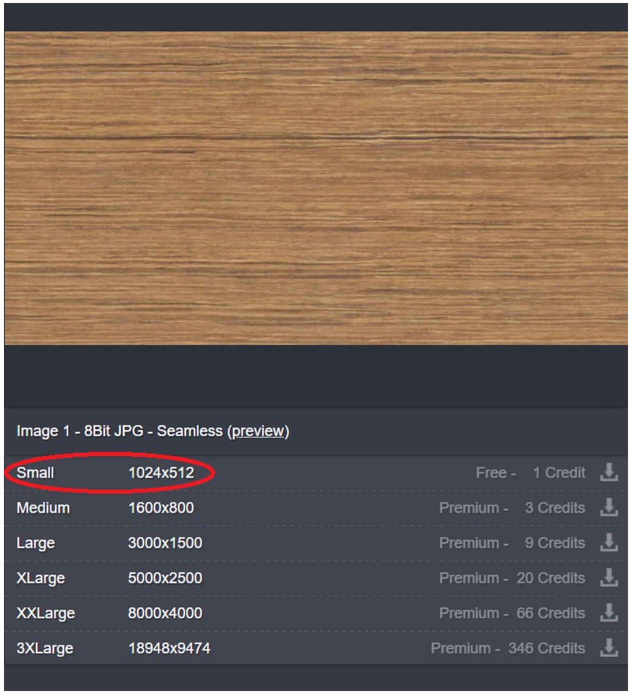


Image 1 - 8Bit JPG - Seamless (preview)

Small	1024x512	Free -	1 Credit
Medium	1600x800	Premium -	3 Credits
Large	3000x1500	Premium -	9 Credits
XLarge	5000x2500	Premium -	20 Credits
XXLarge	8000x4000	Premium -	66 Credits
3XLarge	18948x9474	Premium -	346 Credits

https://www.textures.com/

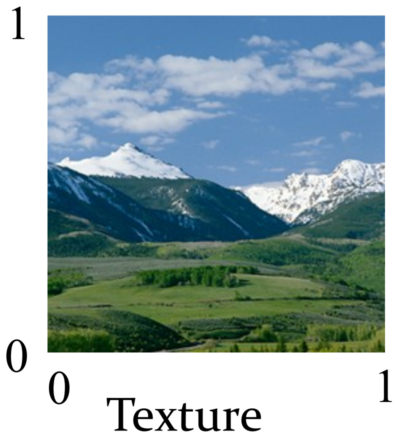
Trivia Quiz

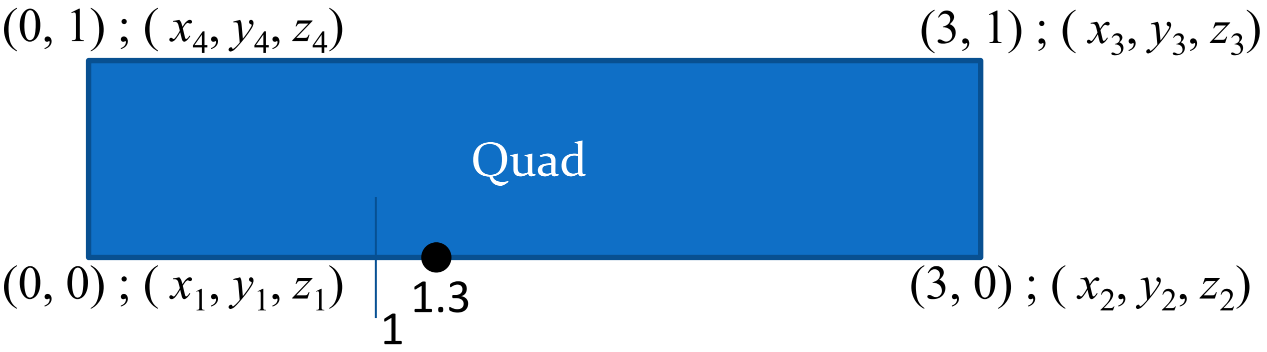
Texture Tiling

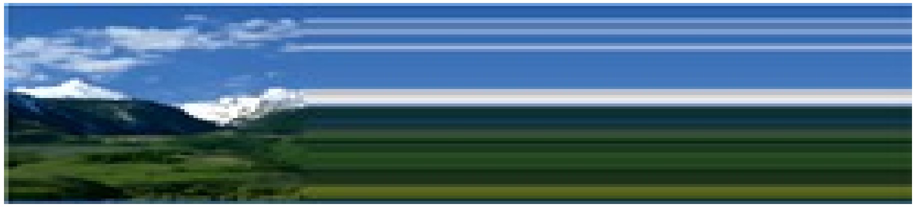
If the wrap parameter for a texture axis is set to GL_CLAMP, then the coordinate value is clamped to the range [0, 1].

(E.g., a texture coordinate value 1.3 is treated as 1).

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



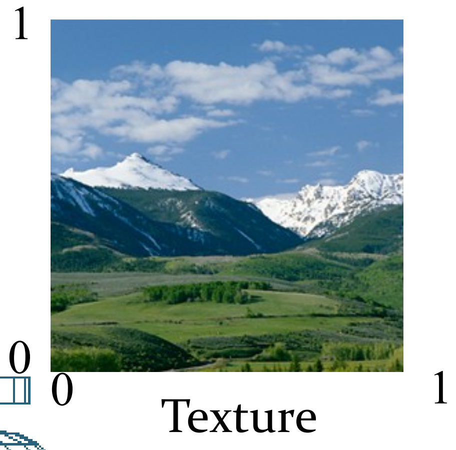

(0, 1) ; (x_4, y_4, z_4)
(3, 1) ; (x_3, y_3, z_3)
Quad
(0, 0) ; (x_1, y_1, z_1)
1
1.3
(3, 0) ; (x_2, y_2, z_2)



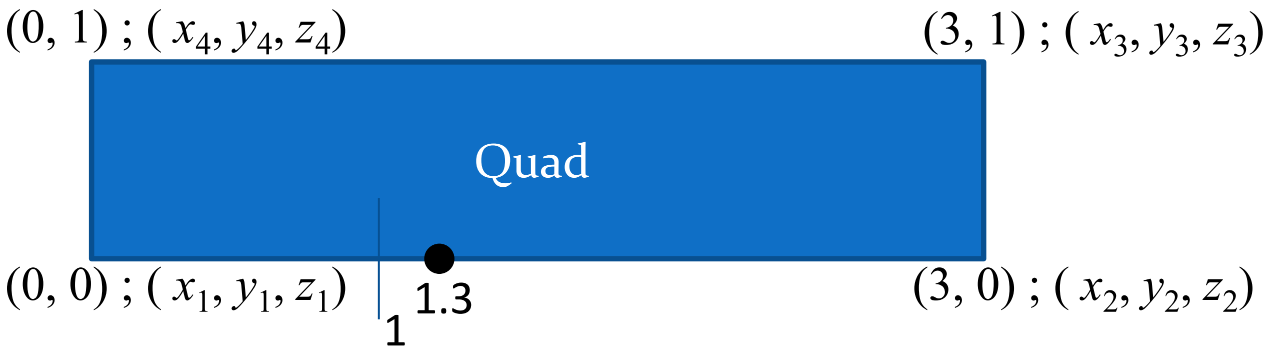
Texture Tiling

- 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


(0, 1) ; (x_4, y_4, z_4)

(3, 1) ; (x_3, y_3, z_3)

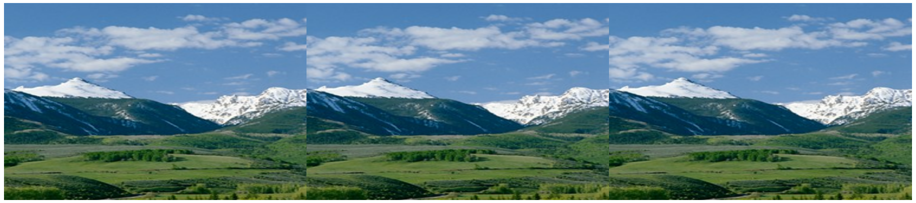
Quad

(0, 0) ; (x_1, y_1, z_1)

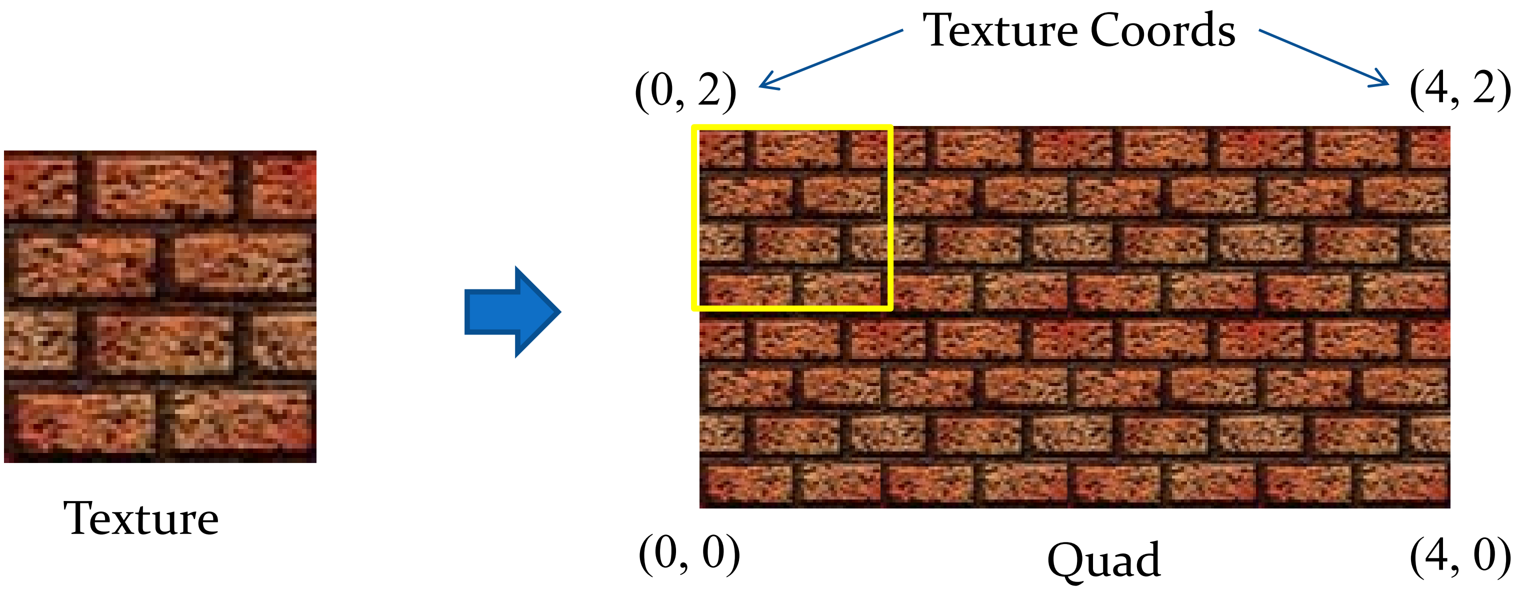
1

1.3

(3, 0) ; (x_2, y_2, z_2)



Seamlessly Tileable Textures

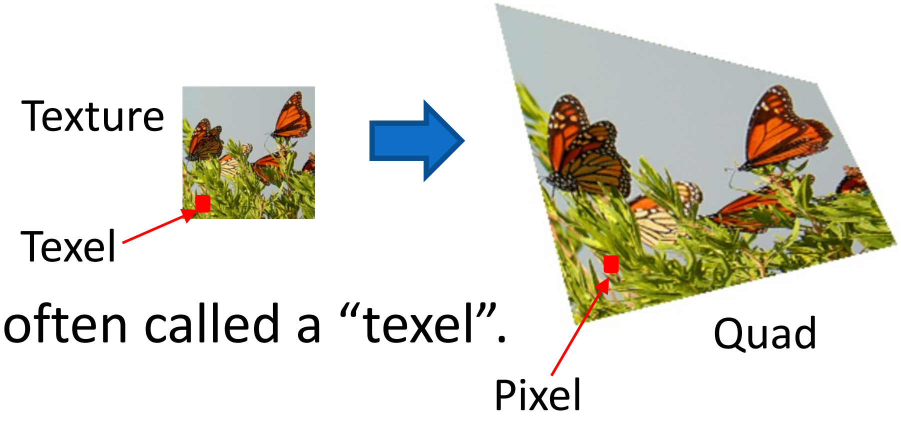


https://www.textures.com/

Texture Sampling

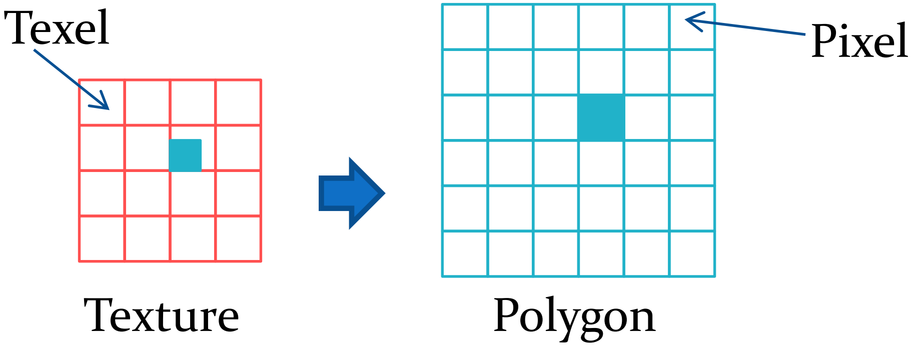
```
glTexParameteri(GL_TEXTURE_2D,GL_TEXTURE_MAG_FILTER, ⎛GL_NEAREST)⎞
                                                     ⎝GL_LINEAR  ⎠

glTexParameteri(GL_TEXTURE_2D,GL_TEXTURE_MIN_FILTER, ⎛GL_NEAREST ⎞
                                                     ⎝GL_LINEAR  ⎠
```

- The texture has a fixed size, but the projected size of the polygon on the screen may vary based on distance from camera.
- Texture parameters determine how a texture is sampled to obtain a colour value at each pixel of a polygon. Commonly used filter parameters are:
  - GL_NEAREST
  - GL_LINEAR

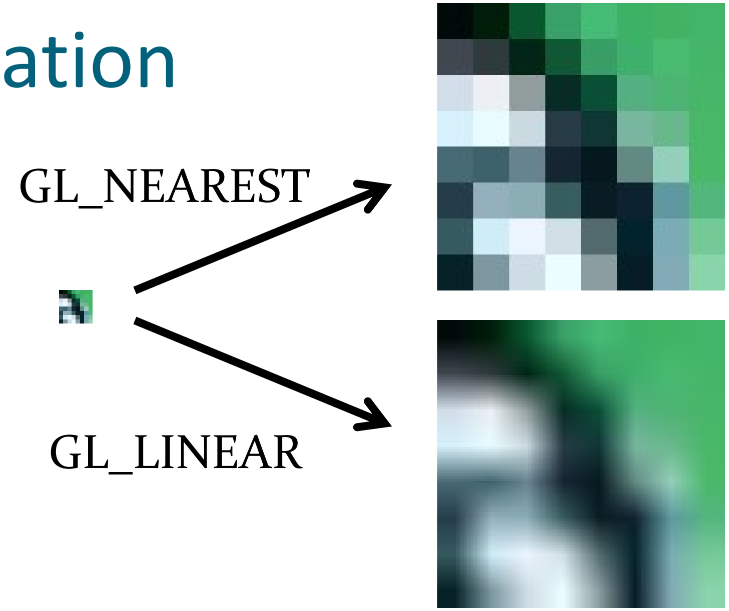


The pixel value of a texture is often called a “texel”.

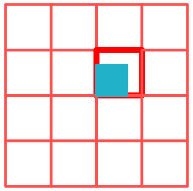
Texture Magnification



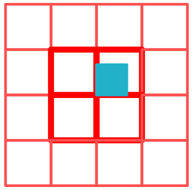
A small texture mapped to a large polygon



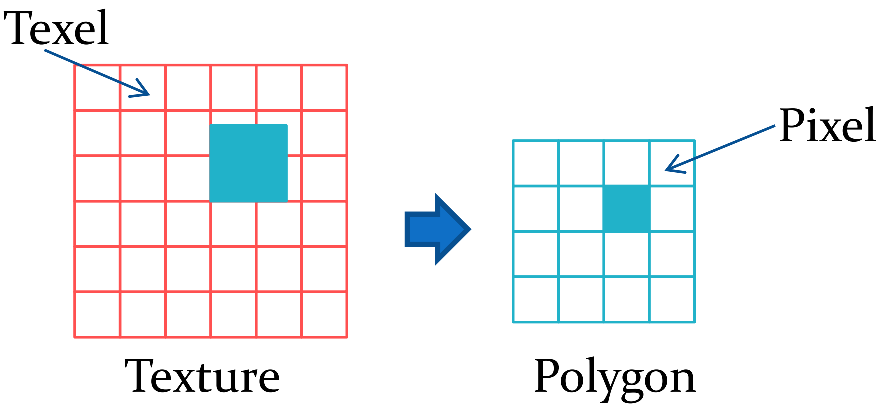
GL_NEAREST: The pixel gets the colour of the texel value nearest to the centre of the pixel.



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

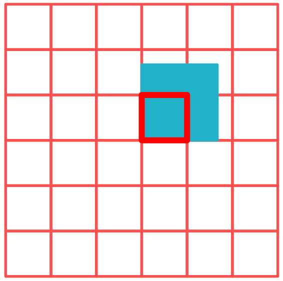


Texture Minification

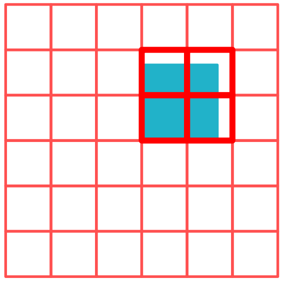


A large texture mapped to a small polygon

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

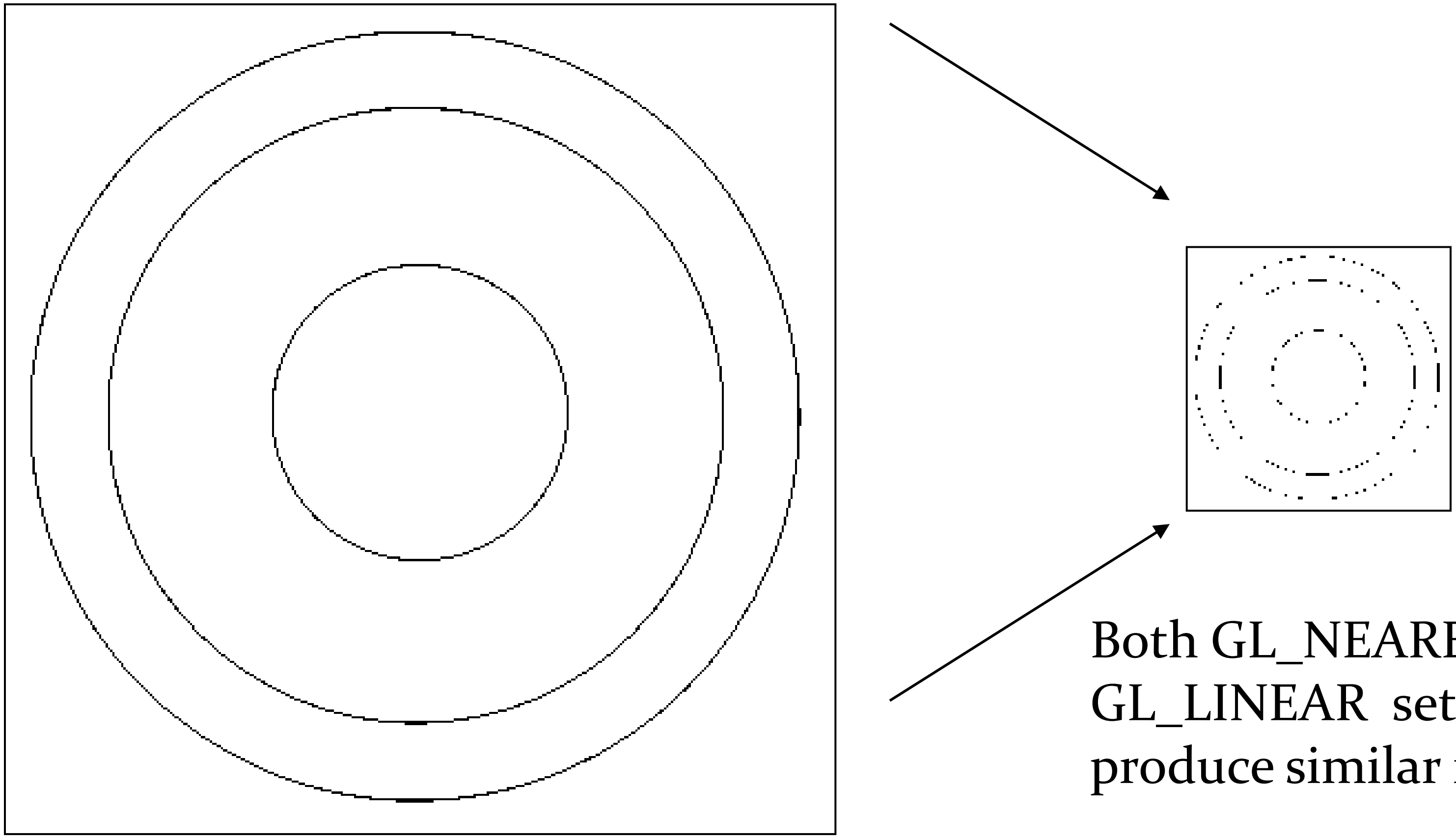


GL_LINEAR: The pixel gets the weighted average of four texel values closest to the centre of the pixel.



Texture Minification

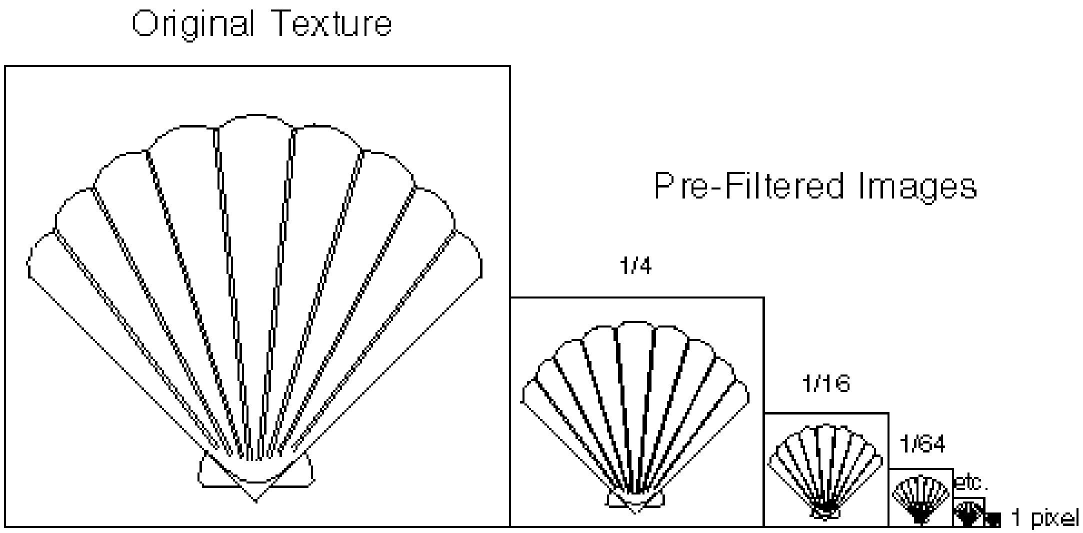
Thin lines often disappear when a texture is mapped to a region containing fewer pixels.



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)
- The problem of disappearing lines when a texture is mapped to a small region can be solved by using a mipmap.
- 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)
```

Texturing a Quadric Surface

- Quadric surfaces have a two-dimensional parametric representation which can be used to get a mapping to the texture coordinate space (*s*, *t*).
- 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 );
```

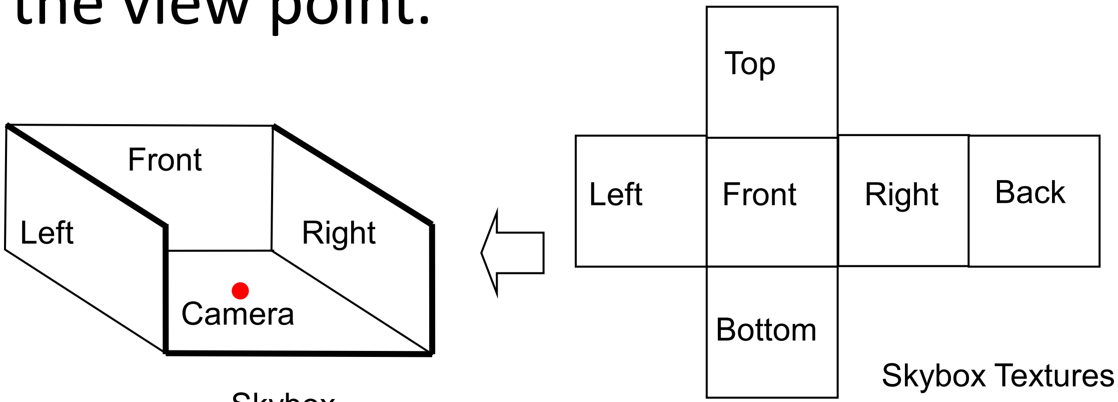
Texturing and Lighting

- 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);
```

Sky Boxes

- The surrounding environment is displayed as textures on the faces of a large cube, and the cube is rendered centered around the view point.

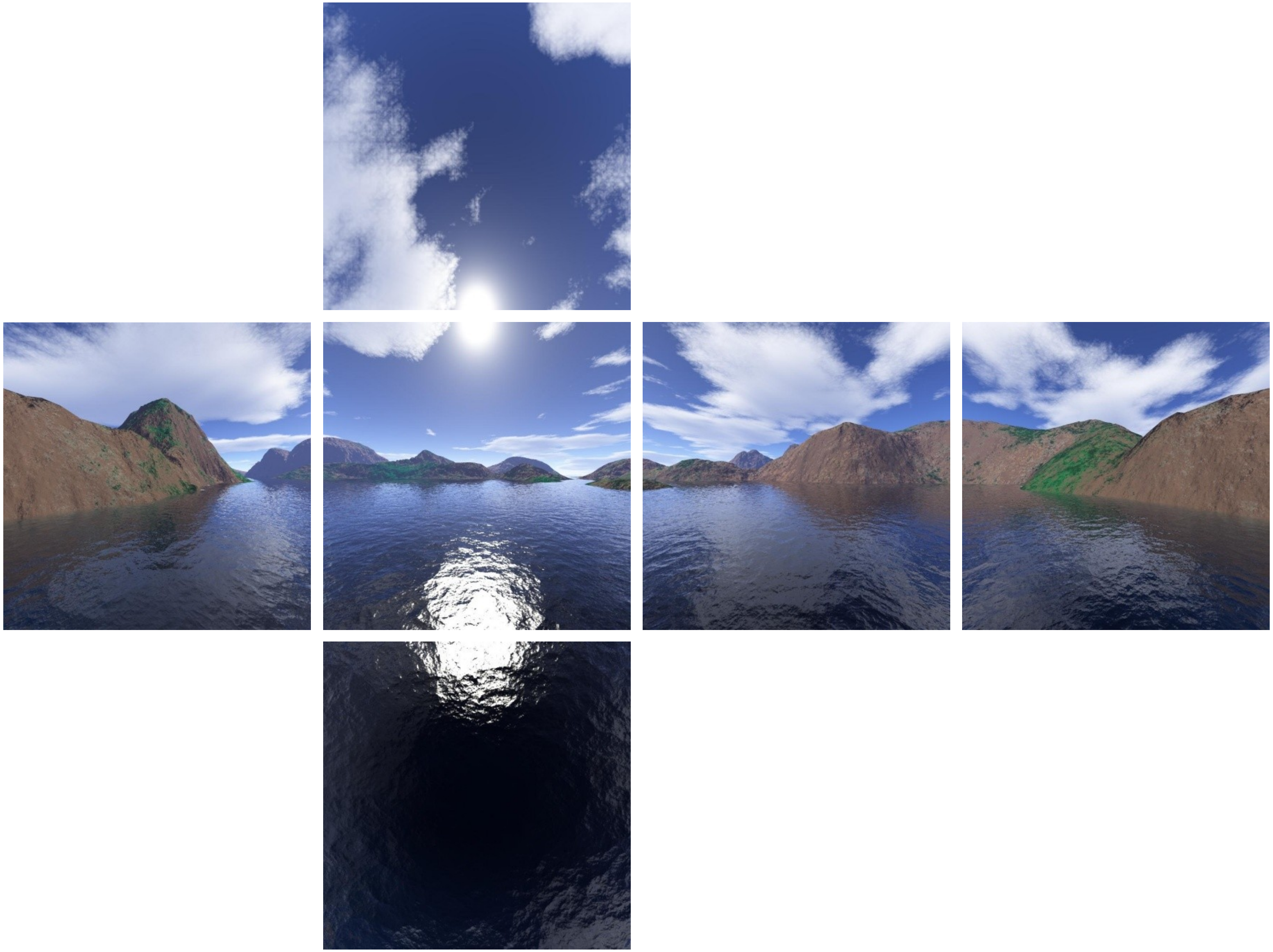


Skybox

Skybox Textures

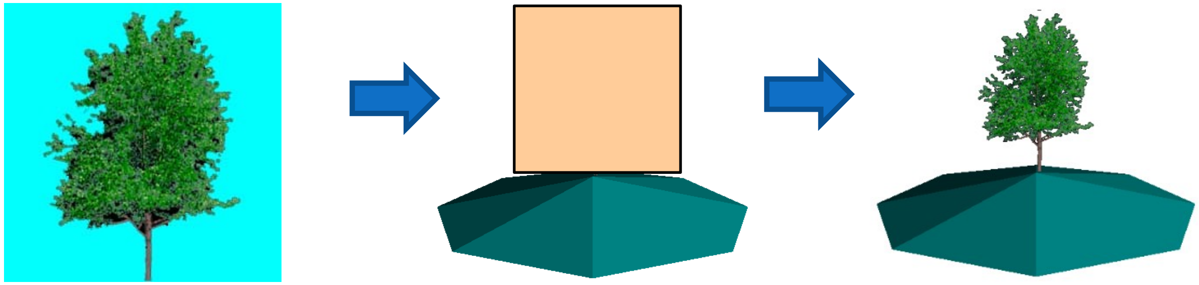
- Try to minimise perspective distortions by
  - Adjusting the focal length (“near” value in gluPerspective) and the field of view (“fov” value in gluPerspective)
  - Adjusting the size of the cube used for texture mapping
  - Not moving the camera very close to the four sides of the cube

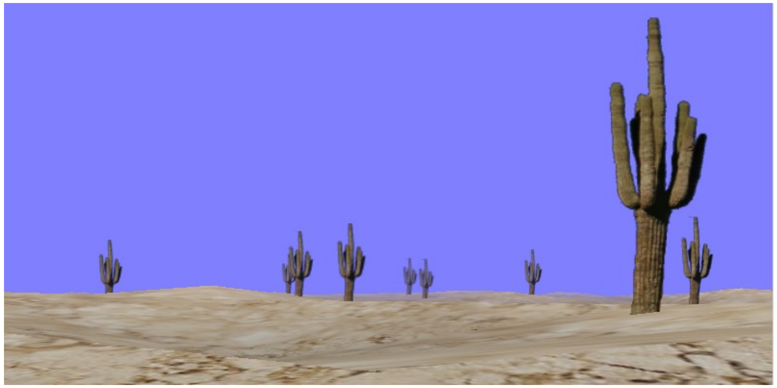
Sky Box Textures



Billboarding

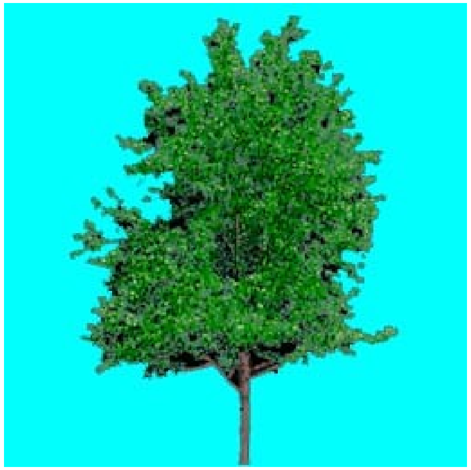
- Billboarding is a technique that changes the orientation of texture mapped quads in a 3D environment based on view direction.
- When a texture is mapped to a quad, only those pixels belonging to the object are rendered. The background of the texture is removed using alpha texturing (next slide)





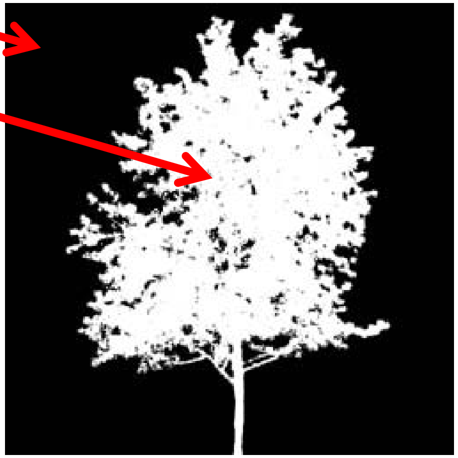
Alpha Texturing

```
glEnable(GL_TEXTURE_2D);
glEnable(GL_ALPHA_TEST);
glAlphaFunc(GL_GREATER,0);
glBindTexture(GL_TEXTURE_2D, texId);
drawBillboard();
glDisable(GL_TEXTURE_2D);
glDisable(GL_ALPHA_TEST);
```



RGB

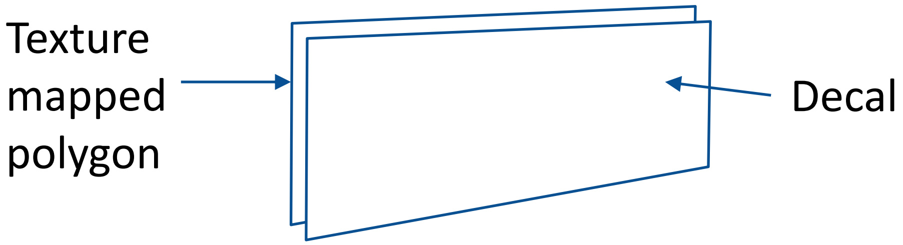
- Requires an RGBA image.
- Background pixels have alpha value 0.
- Foreground pixels have alpha value 1.
- By enabling alpha testing, we can selectively map only those pixels where the alpha value greater than zero.



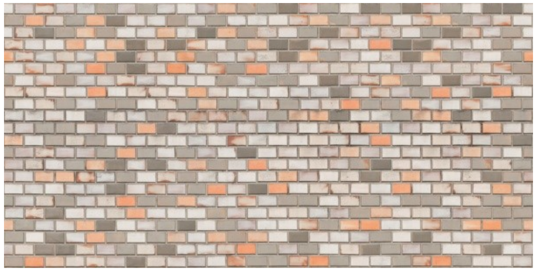
Alpha

Decals

- Decals are used to overlay certain surface features such as dirt, rust etc., on top of a texture mapped polygon
- Decals are also alpha textures.
  - Alpha = 0: Background
  - Alpha > 0: Foreground. Alpha may take a range of values greater than 0, and less than 1. By using a non-zero threshold for the alpha test, we can adjust the degree of mapping of the decal on another texture.
- We cannot map multiple textures on to the same polygon using OpenGL-2 functions. The decal is therefore displayed on another quad placed in front of the textured polygon.



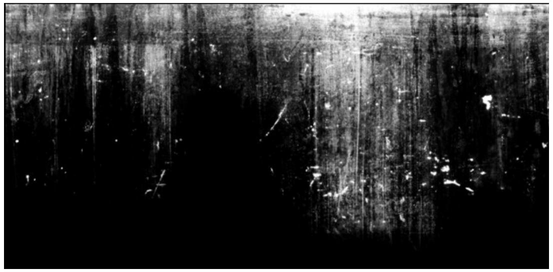
Decals



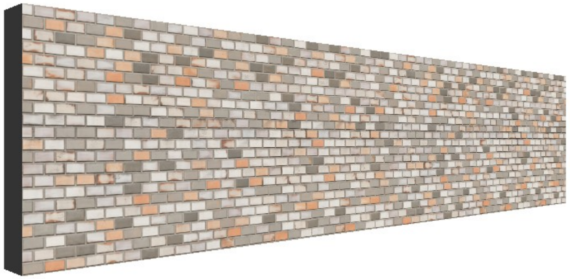
Texture

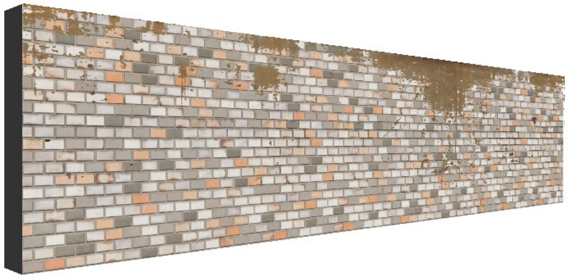
RGB

Alpha

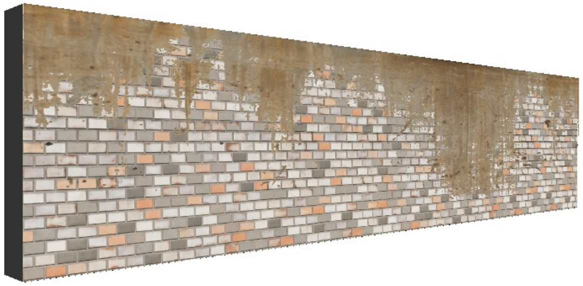


Decal





```
glAlphaFunc(GL_GREATER,0.5);
```



```
glAlphaFunc(GL_GREATER,0.2);
```