Textures

The Basic Idea

Texture mapping is a computer graphics operation in which a separate image, referred to as the texture, is stretched onto a piece of 3D geometry and follows it however it is transformed. This image is also known as a texture map. This can be most any image. At one time, some graphics hardware required the image's pixel dimensions to be a power of two. This restriction has been lifted on most (all?) graphics cards, but just to be safe... The X and Y dimensions did not need to be the same power of two, just a power of two. So, a 128x512 image would have been OK, a 129x511 image might not have.

Also, to prevent confusion, the texture pixels are not called pixels. A pixel is a dot in the final screen image. A dot in the texture image is called a texture element, or texel. Similarly, to avoid terminology confusion, a texture's width and height dimensions are not called X and Y. They are called S and T. A texture map is not generally indexed by its actual resolution coordinates. Instead, it is indexed by a coordinate system that is resolution-independent. The left side is always $S=0$, the right side is $S=1$, the bottom is $T=0$, and the top is $T=1$. Thus, you do not need to be aware of the texture’s resolution when you are specifying coordinates that point into it. Think of S and T as a measure of what fraction of the way you are into the texture.

Enable texture mapping:
```plaintext
glEnable( GL_TEXTURE_2D );
```

Draw your polygons, specifying s and t at each vertex:
```plaintext
glBegin( GL_POLYGON );
glTexCoord2f( s0, t0 );
glNormal3f( nx0, ny0, nz0 );
glVertex3f( x0, y0, z0 );
glTexCoord2f( s1, t1 );
glNormal3f( nx1, ny1, nz1 );
glVertex3f( x1, y1, z1 );
. . .
glEnd( );
```

Disable texture mapping:
```plaintext
DISABLE( GL_TEXTURE_2D );
```

In OpenGL terms: assigning an (s,t) to each vertex

The easiest way to figure out what s and t are at a particular vertex is to figure out what fraction across the object the vertex is living at. For a plane,

\[
\begin{align*}
S &= \frac{x - X_{\text{min}}}{X_{\text{max}} - X_{\text{min}}} \\
T &= \frac{y - Y_{\text{min}}}{Y_{\text{max}} - Y_{\text{min}}}
\end{align*}
\]

Using a Texture: How do you know what (s,t) to assign to each vertex?

You specify an (s,t) pair at each vertex, along with the vertex coordinate. At the same time that the rasterizer is interpolating the coordinates, colors, etc. inside the polygon, it is also interpolating the (s,t) coordinates. Then, when it goes to draw each pixel, it uses that pixel’s interpolated (s,t) to lookup a color in the texture image.

Triangles in an Array of Structures

Triangles in an Array of Structures
Using a Texture: How do you know what \((s,t)\) to assign to each vertex?

Or, for a sphere,

\[
s = \frac{\theta - (-\pi)}{2\pi} \quad t = \frac{\phi - (-\frac{\pi}{2})}{\pi}
\]

From the Sphere code:

\[
s = \frac{\text{lng} + \text{M}_{\pi}}{2 \times \text{M}_{\pi}}; \quad t = \frac{\text{lat} + \text{M}_{\pi/2}}{\text{M}_{\pi}};
\]

You really are at the mercy of whoever did the modeling...

Be careful where \(s\) abruptly transitions from 1. back to 0.

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Memory Types

Texture RGBA Data Values

Texture Sampler

Combined Image Sampler
Imagine an object rendered with that texture as ending up all white. Consider a texture that consists of one red texel and all the rest white. It is easy to understand why having never been included in the final image. The solution is to create lower resolutions of the same texture so that the red texel gets included somehow in all resolution-level textures.

As an object gets farther away and covers a smaller and smaller part of the screen, the texel-to-pixel ratio used in the coverage becomes larger and larger. This means that there are pieces of the texture leftover in between the pixels that are being drawn into, so that some of the texture image is not being taken into account in the final image. This means that the texture is being undersampled and could end up producing artifacts in the rendered image.

Textures’ Undersampling Artifacts

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Texture Mip-mapping

As an object gets farther away and covers a smaller and smaller part of the screen, the texel-to-pixel ratio used in the coverage becomes larger and larger. This means that there are pieces of the texture leftover in between the pixels that are being drawn into, so that some of the texture image is not being taken into account in the final image. This means that the texture is being undersampled and could end up producing artifacts in the rendered image.
```c
// transition the texture buffer layout:
VkMemoryAllocateInfo vmai;
{
    VkDeviceMemory vdm;
}
vkGetImageMemoryRequirements(
    LogicalDevice, IN &vici, PALLOCATOR, OUT &textureImage); // allocated, but not filled
vkCreateImage(LogicalDevice, IN &vici, PALLOCATOR, OUT &textureImage); // allocated, but not filled

// transition the staging buffer layout:
vkCmdCopyImage(TextureCommandBuffer, IN &vcbbi);

// copy pixels from the staging image to the texture:

// 0 and 0 = offset and memory map flags
memcpy(
    gpuMemory,
    (void *)texture,
    (size_t)textureSize);
```
Reading in a Texture from a BMP File

```c
typedef struct MyTexture {
    uint32_t                        width;
    uint32_t                        height;
    VkImage texImage;
    VkImageView texImageView;
    VkSampler texSampler;
    VkDeviceMemory vdm;
} MyTexture;

MyTexture MyPuppyTexture;
```

This function can be found in the `sample.cpp` file. The BMP file needs to be created by something that writes uncompressed 24-bit color BMP files, or was converted to the uncompressed BMP format by a tool such as ImageMagick’s `convert`, Adobe Photoshop, or GNU’s `GIMP`.

Anisotropic Texture Filtering

```c
https://en.wikipedia.org/wiki/Anisotropic_filtering
```