Rendering to a Texture

and

Rendering to an Offscreen Framebuffer

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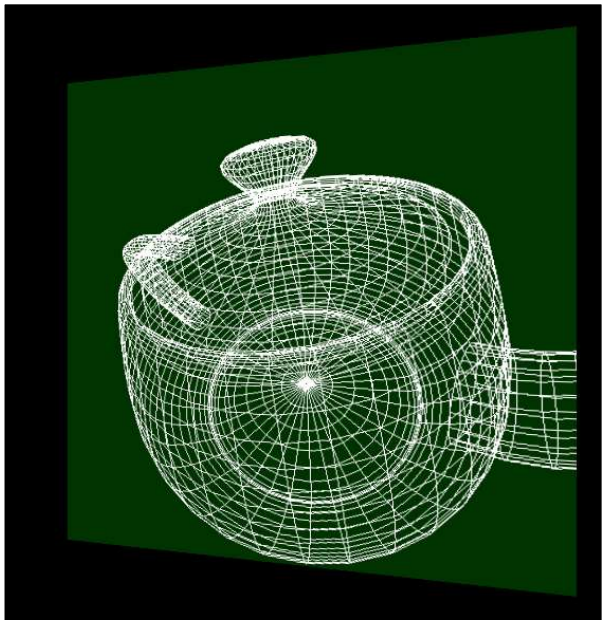
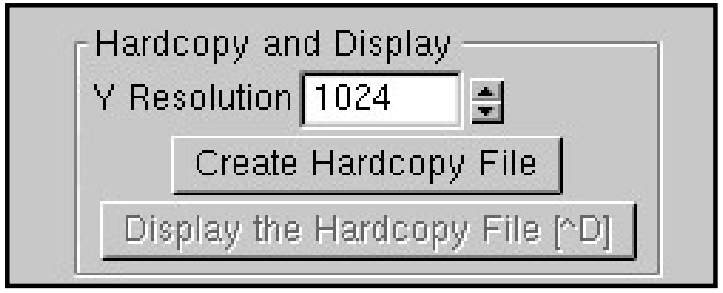
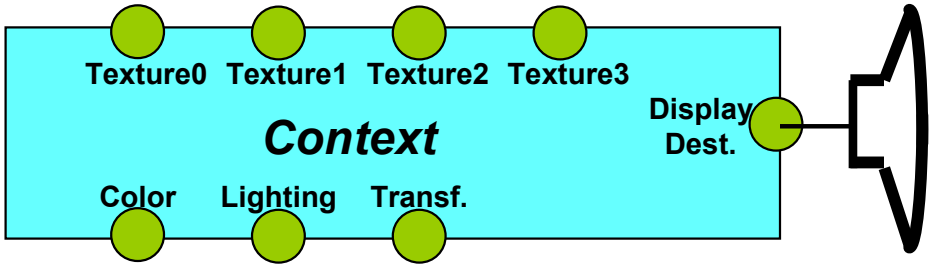




Preliminary Background – the OpenGL *Rendering Context*

The OpenGL Rendering Context contains all the characteristic information necessary to produce an image from geometry. This includes transformations, colors, lighting, textures, where to send the display, etc.



Some of these characteristics have a default value (e.g., lines are white, the display goes to the screen) and some have nothing (e.g., no textures exist)

More Background – What is an OpenGL "Object"?

An OpenGL Object is pretty much the same as a C, C++, C#, or Java object: it encapsulates a group of data items and allows you to treat them as a single whole. For example, a Texture Object could be created in C++ by:

```
class TextureObject
{
    enum minFilter, maxFilter;
    enum storageType;
    int numComponents;
    int numDimensions;
    int numS, numT, numR;
    void *image;
};
```

Then, you could create any number of Texture Object instances, each with its own characteristics encapsulated within it. When you want to make that combination current, you just need to bring in ("bind") that entire object. You don't need to deal with the information one piece of information at a time.

More Background – How do you Create an OpenGL "Object"?

In C/C++, objects are pointed to by their address.

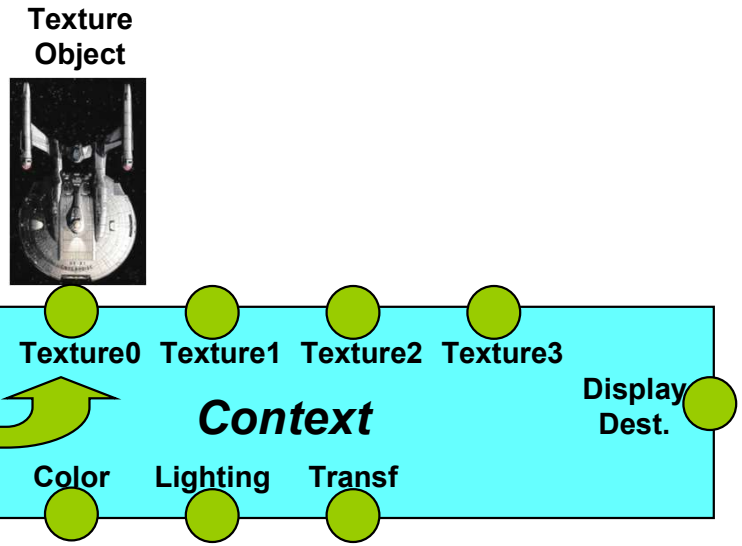
In OpenGL, objects are pointed to by an unsigned integer handle. You can assign a value for this handle yourself (not recommended), or have OpenGL generate one for you that is guaranteed to be unique. For example:

```
GLuint texA;

glGenTextures( 1, &texA );
```

This doesn't actually allocate memory for the texture object yet, it just acquires a unique handle. To allocate memory, you need to bind this handle to the Context.

More Background -- "Binding" to the Context

The OpenGL term "binding" refers to "docking" (a Star Trek-ish metaphor which I find to be more visually pleasing) an OpenGL object to the Context. You can then assign characteristics, and they will "flow" through the Context into the object.

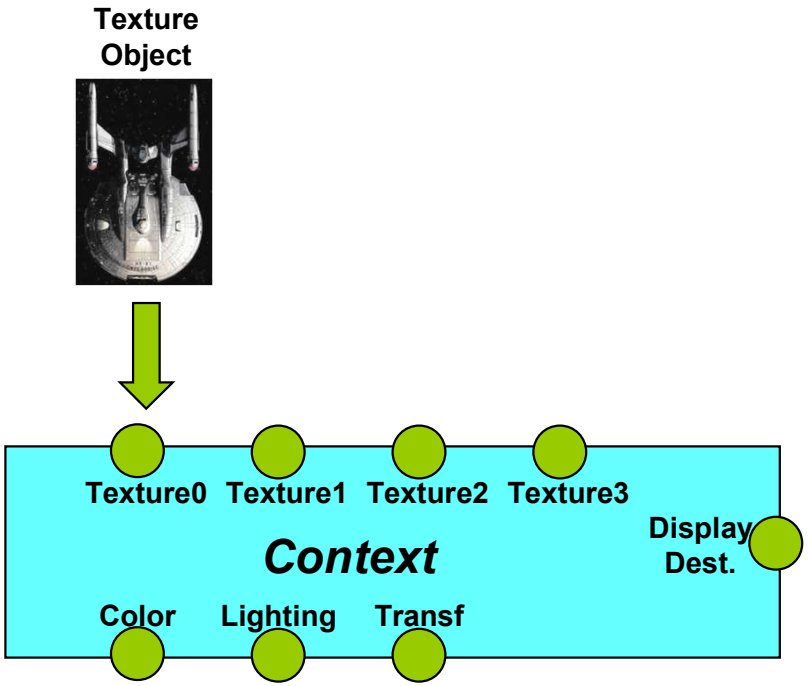



```
glBindTexture( GL_TEXTURE_2D, texA );
glTexParameterf( GL_TEXTURE_2D, GL_TEXTURE_WRAP_S, GL_REPEAT );
glTexParameterf( GL_TEXTURE_2D, GL_TEXTURE_WRAP_T, GL_REPEAT );
glTexParameterf( GL_TEXTURE_2D, GL_TEXTURE_MAG_FILTER, GL_LINEAR );
glTexParameterf( GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_LINEAR );
glTexImage2D( GL_TEXTURE_2D, 0, GL_RGBA, dimS, dimT, 0, GL_RGBA,
              GL_UNSIGNED_BYTE, image );
```

Memory for the object is allocated the first time the handle goes through the bind process.

More Background -- "Binding" to the Context

When you want to use that Texture Object, just bind it again. All of the characteristics will then be active, just as if you had specified them again.




```
glActiveTexture( GL_TEXTURE0 );
glBindTexture( GL_TEXTURE_2D, texA );
```

The Overall Render-to-Texture Process

1 You will be changing the Display Destination. Generate a handle for a Framebuffer Object. Generate handles for one (depth) Renderbuffer Object and for one (color) Texture Object. (These will later be attached to the Framebuffer Object)

2 Bind the Framebuffer Object to the Context, thus un-binding the display monitor

3 Bind the Depth Renderbuffer Object to the Context
Assign storage attributes to it
Attach it to the Framebuffer Object

4 Bind the Color Texture Object to the Context
Assign storage attributes to it
Assign texture parameters to it
Attach it to the Framebuffer Object

5 Render as normal

6 Un-bind the Framebuffer Object from the Context, thus re-binding the display monitor

Code for the Render-to-Texture Process

In InitGraphics( ), generate a FrameBuffer handle, a RenderBuffer handle, and a Texture handle:

```
GLuint FrameBuffer;
GLuint DepthBuffer;
GLuint Texture;

glGenFramebuffers(  1, &FrameBuffer );
glGenRenderBuffers( 1, &DepthBuffer );
glGenTextures(          1, &Texture );
```

Setup the size you want the texture rendering to be (this can be larger than the display window or even the display monitor):

```
int sizeS = 2048;
int sizeT = 2048;
```

Bind the offscreen framebuffer to be the current output display:

```
glBindFramebuffer(  GL_FRAMEBUFFER,  FrameBuffer );
```

Bind the Depth Buffer to the context, allocate its storage, and attach it to the current Framebuffer:

```
glBindRenderbuffer(             GL_RENDERBUFFER, DepthBuffer );
glRenderbufferStorage(        GL_RENDERBUFFER, GL_DEPTH_COMPONENT, sizeS, sizeT );
glFramebufferRenderbuffer( GL_FRAMEBUFFER, GL_DEPTH_ATTACHMENT,   GL_RENDERBUFFER, DepthBuffer );
```

Code for the Render-to-Texture Process

Bind the Texture to the Context:

```
glBindTexture(  GL_TEXTURE_2D,  Texture );
```

Setup a NULL texture of the size you want to render into and set its properties:

```
glTexImage2D(    GL_TEXTURE_2D, 0, 4, sizeS, sizeT, 0, GL_RGBA, GL_UNSIGNED_BYTE, NULL );
glTexParameteri( GL_TEXTURE_2D, GL_TEXTURE_WRAP_S, GL_CLAMP );
glTexParameteri( GL_TEXTURE_2D, GL_TEXTURE_WRAP_T, GL_CLAMP );
glTexParameteri( GL_TEXTURE_2D, GL_TEXTURE_MAG_FILTER, GL_LINEAR );
glTexParameteri( GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_LINEAR);
```

Tell OpenGL that you are going to render into the color planes of the Texture (we've already done this to the depth buffer):

```
glFramebufferTexture2D( GL_FRAMEBUFFER, GL_COLOR_ATTACHMENT0, GL_TEXTURE_2D, Texture, 0 );
```

Check to see if OpenGL thinks the framebuffer is complete enough to use:

```
GLenum status = glCheckFramebufferStatus( GL_FRAMEBUFFER );
if( status != GL_FRAMEBUFFER_COMPLETE )
        fprintf( stderr, "FrameBuffer is not complete.\n" );
```

Code for the Render-to-Texture Process

Now, render as you normally would. Be sure to set the viewport to match the size of the color and depth buffers:

```
glClearColor( 0., 0., 0., 1. );
glClear( GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT );
glEnable( GL_DEPTH_TEST );
glShadeModel( GL_SMOOTH );
glViewport( 0, 0, sizeS, sizeT );

glMatrixMode( GL_PROJECTION );
glLoadIdentity( );
gluPerspective( 90., 1., 0.1, 1000. );

glMatrixMode( GL_MODELVIEW );
glLoadIdentity( );
gluLookAt( 0., 0., 3.,     0., 0., 0.,     0., 1., 0. );

glRotatef( RotY, 0., 1., 0. );
glRotatef( RotX, 1., 0., 0. );
glScalef( Scale, Scale, Scale );
glColor3f( 1., 1., 1. );

glutWireTeapot( 1. );
```

Tell OpenGL to go back to rendering to the display monitor:

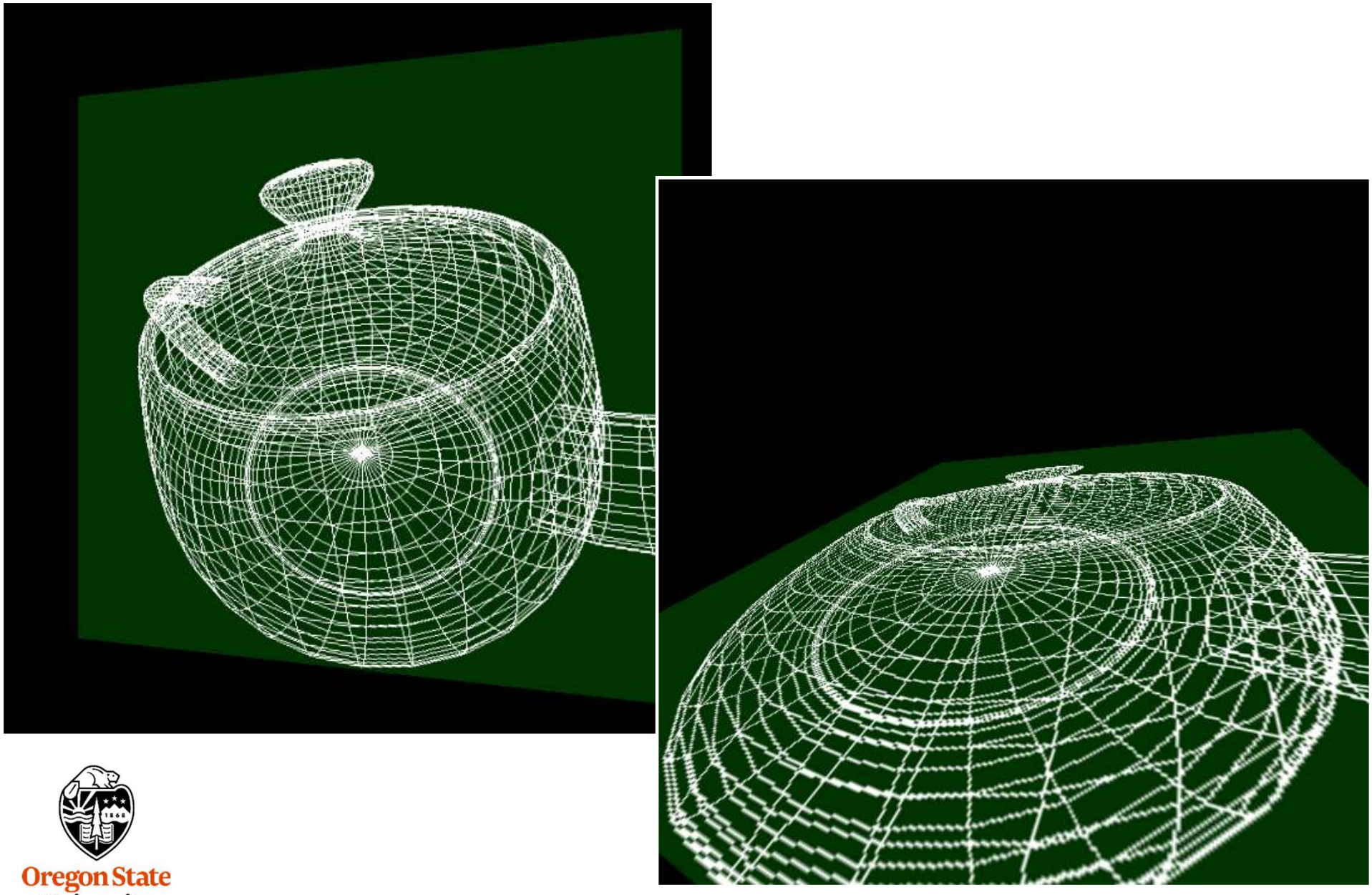
```
glBindFramebuffer( GL_FRAMEBUFFER, 0 );
```

Code for the Render-to-Texture Process

Now, render the second pass of the scene as normal, mapping the Texture onto a quadrilateral:

```
glClearColor( 0., 0., 0., 1. );
glClear( GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT );
glEnable( GL_DEPTH_TEST );
glShadeModel( GL_FLAT );
glViewport( 0, 0,  v, v );

glMatrixMode( GL_PROJECTION );
glLoadIdentity( );
gluOrtho2D( -1., 1.,   -1., 1. );

glMatrixMode( GL_MODELVIEW );
glLoadIdentity( );

glEnable( GL_TEXTURE_2D );
glBindTexture( GL_TEXTURE_2D, Texture );
glBegin( GL_QUADS );
        glTexCoord2f( 0., 0. );
        glVertex2f( -1., -1. );
        glTexCoord2f( 1., 0. );
        glVertex2f(  1., -1. );
        glTexCoord2f( 1., 1. );
        glVertex2f(  1.,  1. );
        glTexCoord2f( 0., 1. );
        glVertex2f( -1.,  1. );
glEnd();

glDisable( GL_TEXTURE_2D );

. . .
```

Render-to-Texture
A Rotating 3D Teapot Displayed on a Rotating Plane

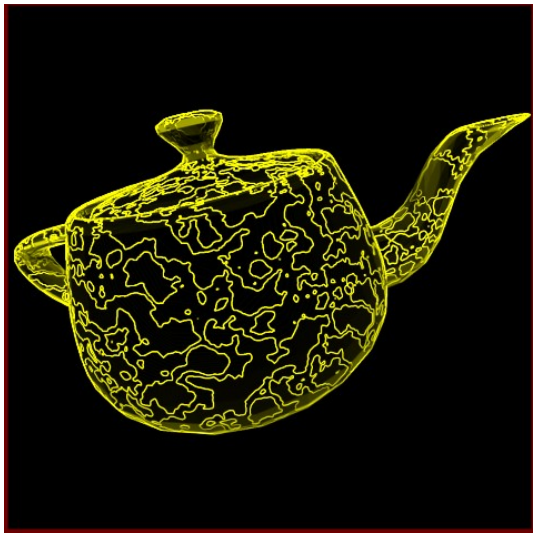


Render-to-Texture : An Image-filtered 3D Noisy-Ovaled Teapot

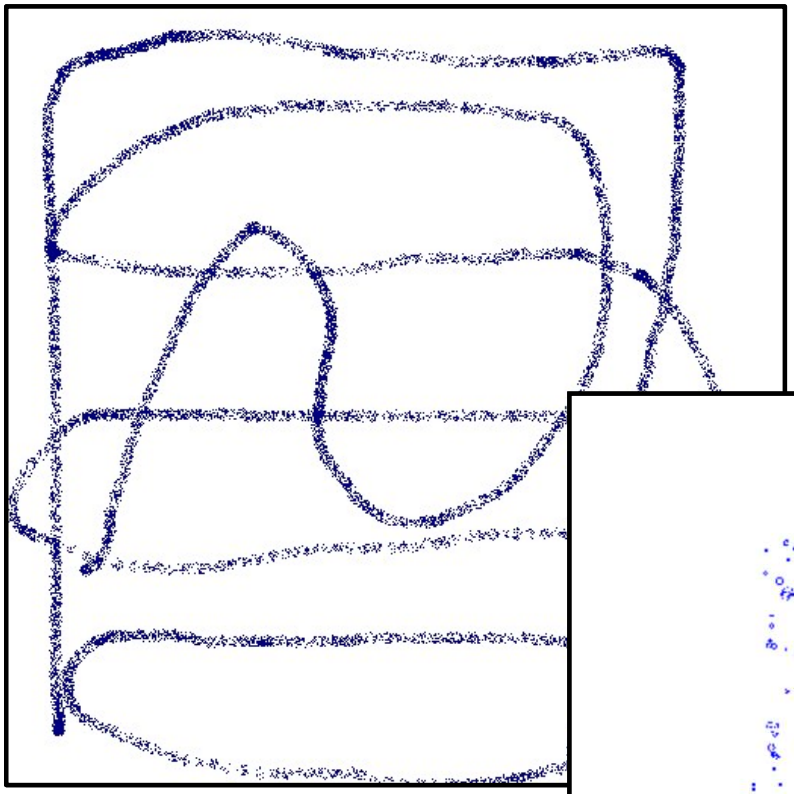
twopass.glib

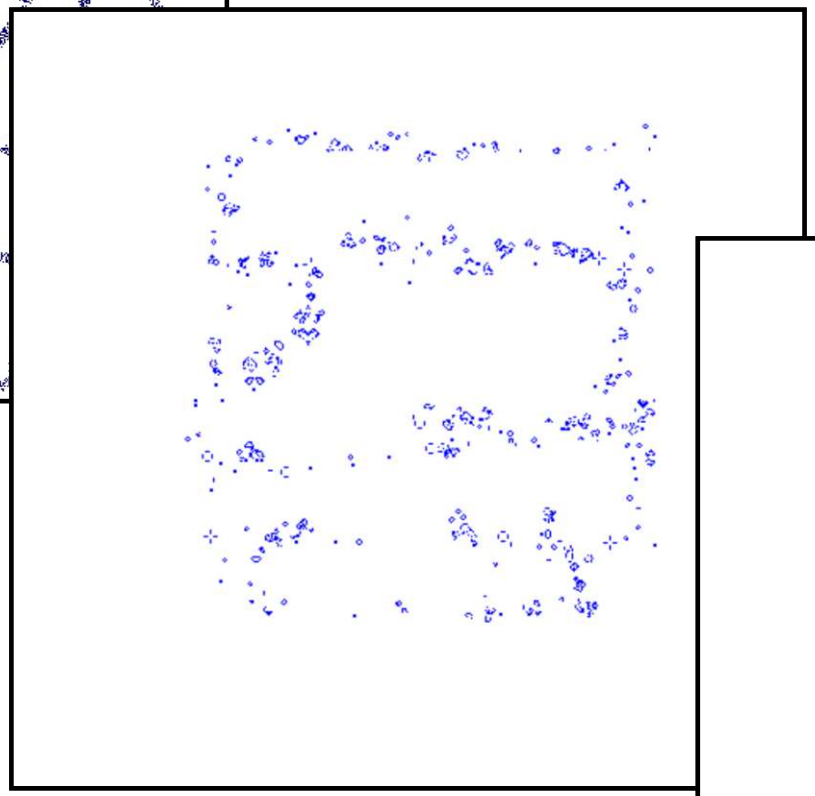
```
##OpenGL GLIB
Perspective 90

Texture2D   6  1024 1024                # a 1024x1024 NULL texture
RenderToTexture  6                      # render to texture unit 6
Background  0. 0. 0.
Clear
LookAt  0. 0. 3.   0. 0. 0.   0. 1. 0.

Vertex       ovals.vert
Fragment   ovals.frag
Program    Ovals                                                \
               uAd <.01 .2 .5>  uBd <.01 .2 .5>                 \
               uNoiseAmp <0. 0. 1.>  uNoiseFreq <0. 1. 2.>      \
               uTol <0. 0. 1.>

Teapot

RenderToTexture                         # render to the display monitor
Background 0. 0. 0.
Clear
LookAt  0. 0. 3.   0. 0. 0.   0. 1. 0.

Vertex       image.vert
Fragment  image.frag
Program    Filter           uTexUnit 6                           \
                            uEdgeDetect <true>                   \
                            uTedge   <0. 0. 1.>                  \
                            uTSharp <-3. 1. 10.>

Con QuadXY .2  2.
```

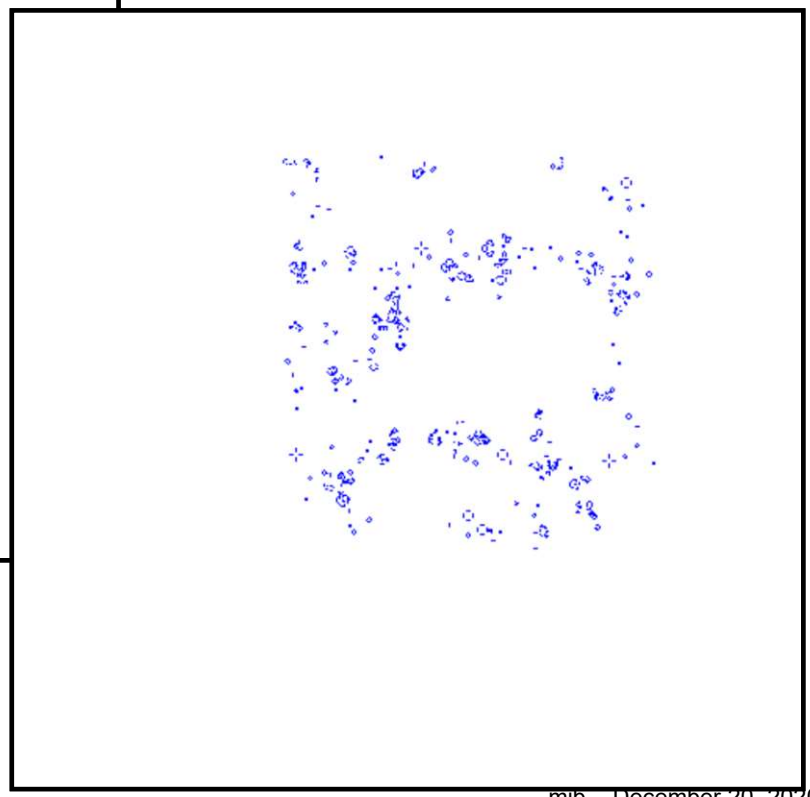
Multipass Algorithm to Render and then Image Process

	Original	Sharpened	Edge Detected
No Noise			
Noise			

Multipass Algorithm to Implement Conway's Game of Life







Ping-pong between two different textures. One texture is being read from (the previous state) and the other is being written into (the next state).

life.glib

```
##OpenGL GLIB
Perspective 70

# setup the 2 textures:
Texture2D  5  paint0.bmp
Texture2D  6  512  512

# execute the first iteration:
RenderToTexture 6
Background 0. 0. 0.
Clear
Vertex        life.vert
Fragment    life.frag
Program    GameOfLife1     uTexUnit 5
TextureMatrix
Translate 0. 0. -3.08
QuadXY .2 2.

# render it so we can see it:
RenderToTexture
Background 0. .2 0.
Clear
Vertex         texture.vert
Fragment     texture.frag
Program Texture1     uTexUnit 6
ModelViewMatrix
Translate 0. 0. -3.08
QuadXY .2 2.
SwapBuffers
```

```
# execute the second iteration:
RenderToTexture 5
Background 0. 0. 0.
Clear
Vertex         life.vert
Fragment     life.frag
Program GameOfLife2   uTexUnit  6
QuadXY .2 2.

# render it so we can see it:
RenderToTexture
Background .2 0. 0.
Clear
Vertex         texture.vert
Fragment    texture.frag
Program Texture     uTexUnit 5
QuadXY .2 2.

# repeat:
animate
```

life.frag, I

```
uniform sampler2D uTexUnit;
in  vec2    vST;

const vec3  DEAD  =  vec3( 1., 1., 1. );
const vec3  ALIVE =  vec3( 0., 0., 1. );

const float TB = 0.20;        // color threshold
const float TR = 0.20;        // color threshold
const int T1 = 1;             // critical # of neighbors
const int T3 = 3;             // critical # of neighbors
const int T4 = 4;             // critical # of neighbors

void main( )
{
        ivec2 isize = textureSize( uTexUnit, 0 );
        vec2 st = vST;
        ivec2 ist      = ivec2( st.s*float(isize.s-1) , st.t*float(isize.t-1) );          // 0 -> dimension-1
        ivec2 istp0  = ivec2( 1, 0 );
        ivec2 ist0p  = ivec2( 0, 1 );
        ivec2 istpp  = ivec2( 1, 1 );
        ivec2 istpm = ivec2( 1, -1 );

        vec3 i00      =  texelFetch( uTexUnit, ist, 0 ).rgb;         // index using integer indices
        vec3 im10    =  texelFetch( uTexUnit, ist-istp0, 0 ).rgb;
        vec3 i0m1    =  texelFetch( uTexUnit, ist-ist0p, 0 ).rgb;
        vec3 ip10    =  texelFetch( uTexUnit, ist+istp0, 0 ).rgb;
        vec3 i0p1    =  texelFetch( uTexUnit, ist+ist0p, 0 ).rgb;
        vec3 im1m1 =  texelFetch( uTexUnit, ist-istpp, 0 ).rgb;
        vec3 ip1p1   =  texelFetch( uTexUnit, ist+istpp, 0 ).rgb;
        vec3 im1p1  =  texelFetch( uTexUnit, ist-istpm, 0 ).rgb;
        vec3 ip1m1  =  texelFetch( uTexUnit, ist+istpm, 0 ).rgb;
```

life.frag, II

```
		int sum = 0;
		if( im10.b   > TB  &&  im10.r    < TR )   sum++;
		if( i0m1.b   > TB  &&  i0m1.r    < TR )   sum++;
		if( ip10.b   > TB  &&  ip10.r    < TR )   sum++;
		if( i0p1.b   > TB  &&  i0p1.r    < TR )   sum++;
		if( im1m1.b > TB  &&  im1m1.r < TR )   sum++;
		if( ip1p1.b  > TB  &&  ip1p1.r   < TR )   sum++;
		if( im1p1.b  > TB  &&  im1p1.r  < TR )   sum++;
		if( ip1m1.b  > TB  &&  ip1m1.r  < TR )   sum++;

		vec3 newcolor = i00;
		if( sum == T3 )
		{
			newcolor = ALIVE;
		}
		else if( sum <= T1  ||  sum >= T4 )
		{
			newcolor = DEAD;
		}

		gl_FragColor = vec4( newcolor, 1. );
}
```

A Slight Variation: Render-to-Offscreen-Framebuffer Memory

1	You will be changing the Display Destination. Generate a handle for a Framebuffer Object. Generate handles for two (color+depth) Renderbuffer Objects. (These will later be attached to the Framebuffer Object)
2	Bind the Framebuffer Object to the Context
3	Bind the Depth Renderbuffer Object to the Context Assign storage attributes to it Attach it to the Framebuffer Object
4	Bind the Color Renderbuffer Object to the Context Assign storage attributes to it Attach it to the Framebuffer Object
5	Render as Normal
6	Un-bind the Framebuffer Object from the Context

Code for the Render-to-Offscreen-Framebuffer Process

In InitGraphics( ), generate Framebuffer and Renderbuffer handles:

```
GLuint FrameBuffer;
GLuint ColorBuffer;
GLuint DepthBuffer;

glGenFramebuffers(  1, &FrameBuffer );
glGenRenderbuffers( 1, &ColorBuffer );
glGenRenderbuffers( 1, &DepthBuffer );
```

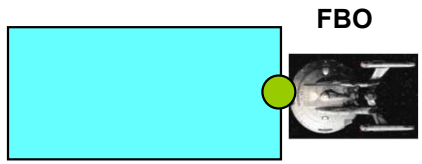
Setup the size you want the off-screen rendering to be :

```
int sizeS = 2048;
int sizeT = 2048;
```

You will reference these sizes a few times, so it is a good idea to use variables for the sizes and not hardcode them as numbers in function calls !

Bind the offscreen framebuffer to be the current output display:

```
glBindFramebuffer(  GL_FRAMEBUFFER,  FrameBuffer );
```



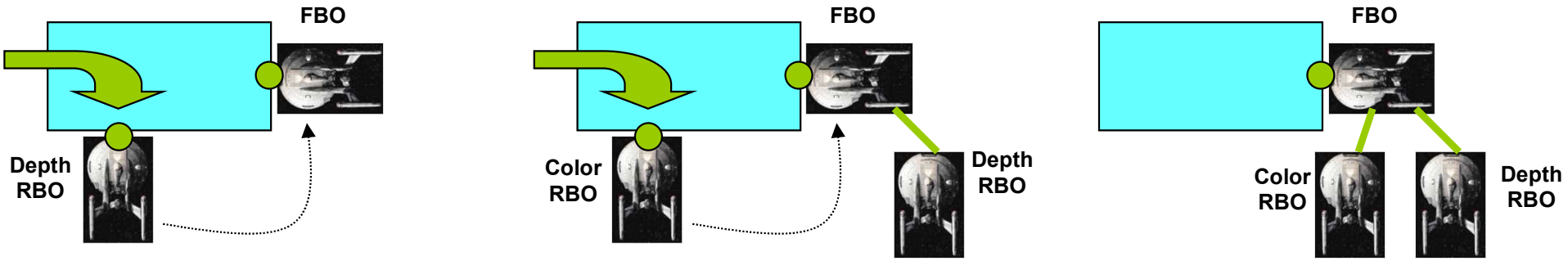
Code for the Render-to-Offscreen-Framebuffer Process

Bind the Depth Buffer to the context, allocate its storage, and attach it to the Framebuffer:

```
glBindRenderbuffer( GL_RENDERBUFFER, DepthBuffer );
glRenderbufferStorage( GL_RENDERBUFFER, GL_DEPTH_COMPONENT, sizeS, sizeT );
glFramebufferRenderbuffer( GL_FRAMEBUFFER, GL_DEPTH_ATTACHMENT,  GL_RENDERBUFFER, DepthBuffer );
```

Bind the Color Buffer to the context, allocate its storage, and attach it to the Framebuffer:

```
glBindRenderbuffer( GL_RENDERBUFFER, ColorBuffer );
glRenderbufferStorage( GL_RENDERBUFFER, GL_RGBA, sizeS, sizeT );
glFramebufferRenderbuffer( GL_FRAMEBUFFER, GL_COLOR_ATTACHMENT0,
                GL_RENDERBUFFER, ColorBuffer );
```



Check to see if OpenGL thinks the framebuffer is complete enough to use:

```
GLenum status = glCheckFramebufferStatus( GL_FRAMEBUFFER );
if( status != GL_FRAMEBUFFER_COMPLETE )
        fprintf( stderr, "FrameBuffer is not complete.\n" );
```

Code for the Render-to-Offscreen-Framebuffer Process

Now, render as you normally would. Be sure to set the viewport to match the size of the color and depth buffers:

```
glClearColor( 0.0, 0.2, 0.0, 1. );
glClear( GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT );
glEnable( GL_DEPTH_TEST );
glShadeModel( GL_FLAT );
glViewport( 0, 0, sizeS, sizeT );

glMatrixMode( GL_PROJECTION );
glLoadIdentity( );
gluPerspective( 90., 1.,0.1, 1000. );

glMatrixMode( GL_MODELVIEW );
glLoadIdentity();
gluLookAt( 0., 0., 3.,     0., 0., 0.,     0., 1., 0. );

glTranslatef( TransXYZ[0], TransXYZ[1], TransXYZ[2] );
glMultMatrixf( RotMatrix );
glScalef( scale, scale, scale );
glColor3f( 1., 1., 1. );

glutWireTeapot( 1. );
```

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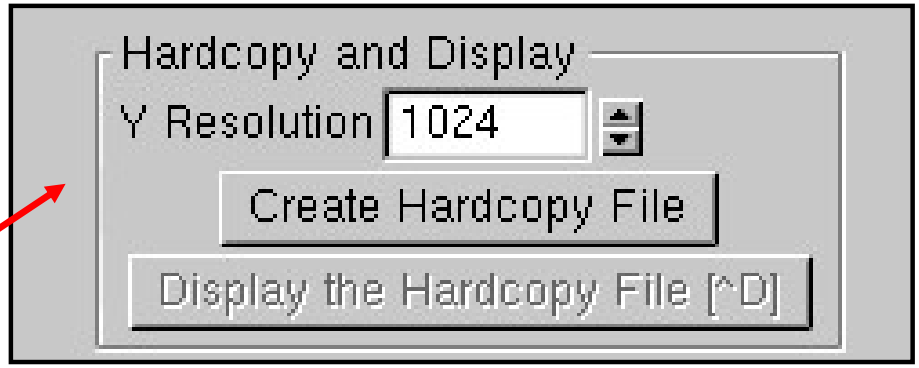
Code for the Render-to-Offscreen-Framebuffer Process

Read the pixels back and do something with them (such as writing an image file):

```
unsigned char *image = new unsigned char [ 3*sizeS*sizeT ];
glPixelStorei( GL_PACK_ALIGNMENT, 1 );
glReadPixels( 0, 0, sizeS, sizeT, GL_RGB, GL_UNSIGNED_BYTE, image );
. . .
```

Tell OpenGL to go back to rendering to the display monitor:

```
glBindFramebuffer( GL_FRAMEBUFFER, 0 );
```



Render-to-Framebuffer is *great* for creating arbitrary-resolution hardcopy!