CPSC 453

Textures and Images

Demos 3 and 4

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HW2

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Demo 3

Game of Life

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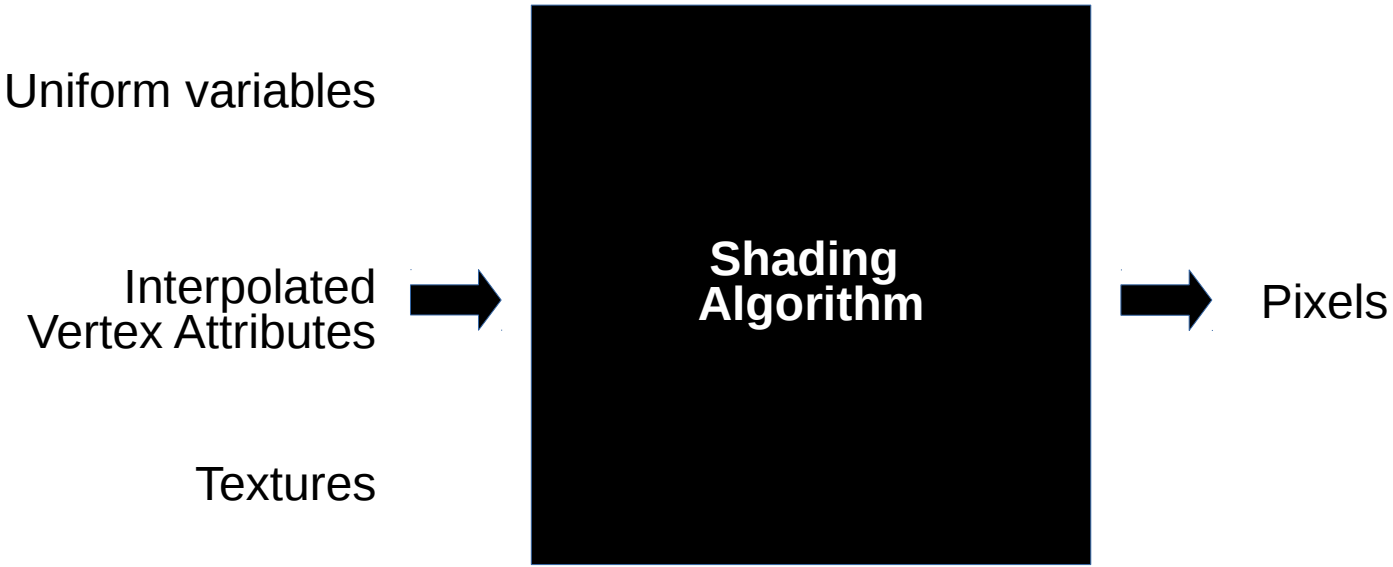
Fragment Shader



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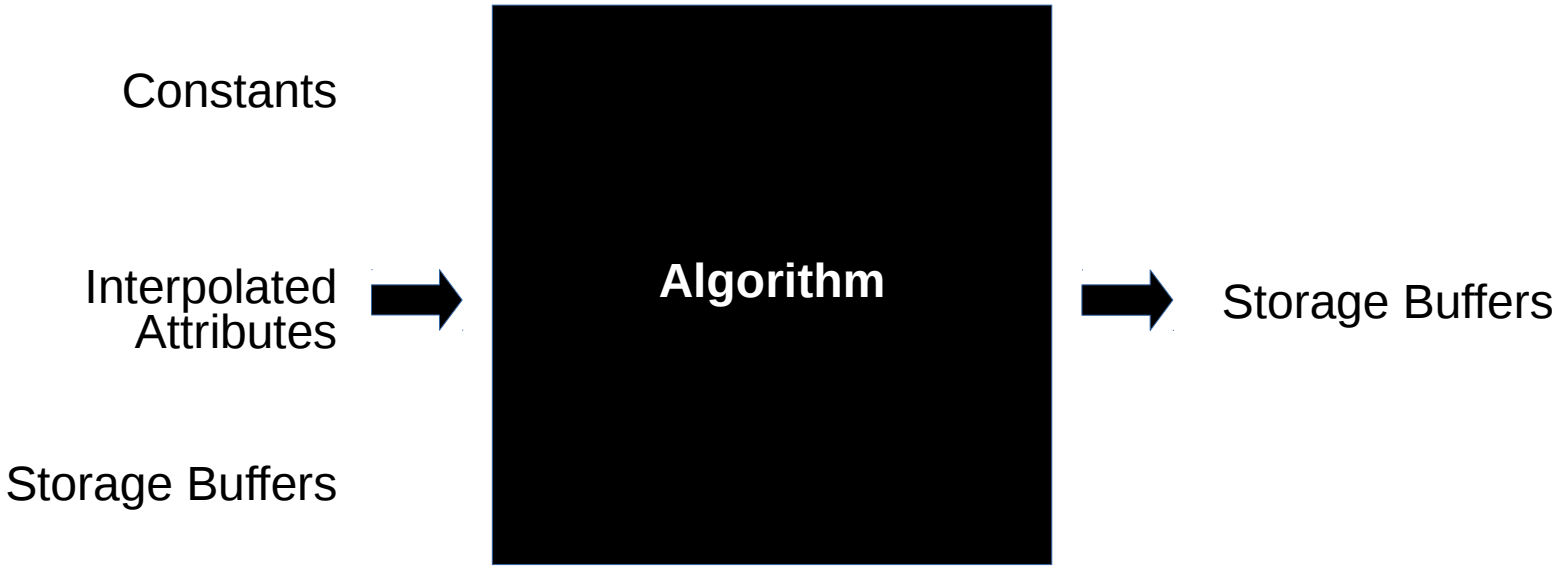
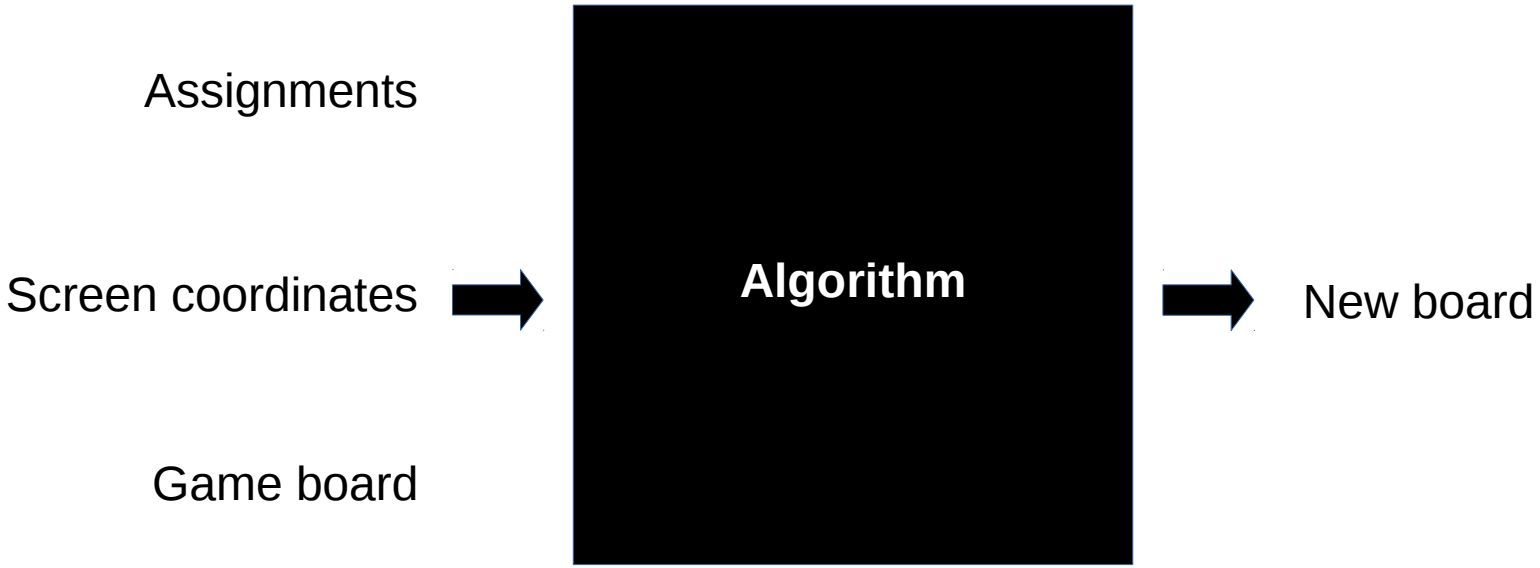
Fragment Shader



Game of Life


Assignments
Screen coordinates
Game board
Algorithm
New board

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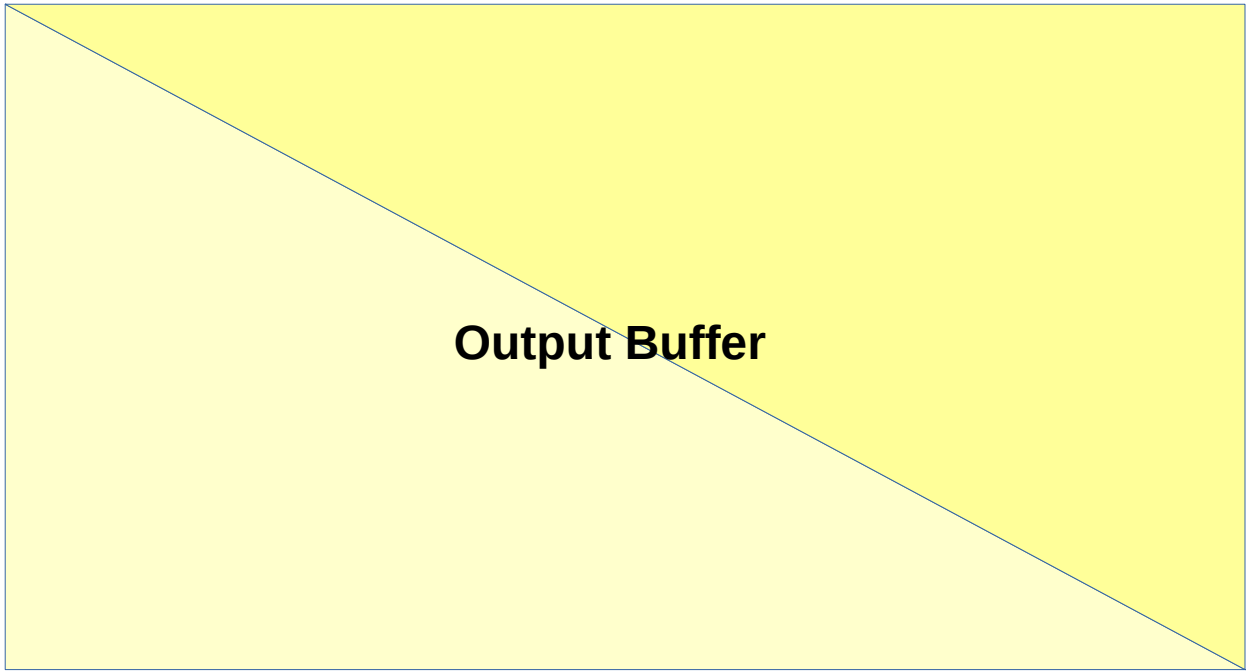
Hacking the Fragment Shader



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Hacking the Fragment Shader

```
in vec2 coordinate;
out vec4 colour;

void main() {

    // do things with coordinates

    colour = something;
    }
```

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Hacking the Fragment Shader

```
in vec2 coordinate;      // [-1:1]
out vec4 colour;

void main() {

    vec2 address = coordinate + /* pixel offset */

    // do things with coordinates

    colour = something;
    }
```

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Hacking the Fragment Shader

```
out vec4 colour;

void main() {

    vec2 coordinates = gl_FragCoord.xy; // pixels

    // do things with coordinates

    colour = something;
    }
```

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Hacking the Fragment Shader

```
layout(binding=0) uniform sampler2D source;   // old board
out vec4 colour;

void main() {

     vec2 address = gl_FragCoord.xy;

     int sum = texture2D( source, address );

     // grab more old values

     if ( /* condition */ )
          colour = something;

     }
```

Hacking the Fragment Shader

```
layout(binding=0) uniform sampler2D source;
out vec4 colour;

void main() {

     vec2 address = /* pixel coordinates */;

     int sum = texture2D( source, /* unit square */ );

     // grab more old values

     if ( /* condition */ )
          colour = something;

     }
```

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Hacking the Fragment Shader

```
layout(binding=0) uniform sampler2D source;
out vec4 colour;
uniform vec2 scalar;        // vec2( 1/width, 1/height );

void main() {

     vec2 address = gl_FragCoord.xy * scalar;

     int sum = texture2D( source, address );

     // grab more old values

     if ( /* condition */ )
          colour = something;

     }
```

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Hacking the Fragment Shader

```
layout(binding=0) uniform sampler2D source;
out vec4 colour;
uniform vec2 scalar;

void main() {

     vec2 address = gl_FragCoord.xy * scalar;

     int sum = texture2D( source, address );

     address = (gl_FragCoord.xy + vec2( 1.0, 1.0 )) * scalar;

     sum += texture2D( source, address );
     // etc...

     if ( /* condition */ )
          colour = something;

     }
```

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Hacking the Fragment Shader

```
layout(binding=0) uniform sampler2D source;
out vec4 colour;
uniform vec2 scalar;

void main() {

     vec2 address = gl_FragCoord.xy * scalar;

     /* int */ = /* vec4 */

     address = (gl_FragCoord.xy + vec2( 1.0, 1.0 )) * scalar;

     /* int */ += /* vec4 */
     // etc...

     if ( /* condition */ )
          colour = something;

     }
```

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Hacking the Fragment Shader

```
layout(binding=0) uniform sampler2D source;
out vec4 colour;
uniform vec2 scalar;

int grab( vec2 offset ) {

      vec2 address = (gl_FragCoord.xy + offset) * scalar;
      vec4 value = texture2D( source, address );
      if ( value.r > 0.5 )
            return 1;
      else
            return 0;
      }

void main() {

      int sum = grab( vec2( -1.0, 1.0 ) );
      sum += grab( vec2( 0.0, 1.0 ) );
      sum += grab( vec2( 1.0, 1.0 ) );
      // etc...

      if ( /* condition */ )
            colour = something;

      }
```

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Hacking the Fragment Shader

```
layout(binding=0) uniform sampler2D source;
out vec4 colour;              // we just want one channel
uniform vec2 scalar;

int grab( vec2 offset ) {

      vec2 address = (gl_FragCoord.xy + offset) * scalar;
      vec4 value = texture2D( source, address );     // we just want one channel
      if ( value.r > 0.5 )
            return 1;
      else
            return 0;
      }

void main() {

      int sum = grab( vec2( -1.0, 1.0 ) );
      sum += grab( vec2( 0.0, 1.0 ) );
      sum += grab( vec2( 1.0, 1.0 ) );
      // etc...

      if ( /* condition */ )
            colour = something;

      }
```

Hacking the Fragment Shader

```
layout(binding=0) uniform sampler2D source;
out float colour;             // expand if output is RGBA
uniform vec2 scalar;

int grab( vec2 offset ) {

      vec2 address = (gl_FragCoord.xy + offset) * scalar;
      float value = texture2D( source, address ).r;  // don't bother expanding out
      if ( value > 0.5 )
            return 1;
      else
            return 0;
      }

void main() {

      int sum = grab( vec2( -1.0, 1.0 ) );
      sum += grab( vec2( 0.0, 1.0 ) );
      sum += grab( vec2( 1.0, 1.0 ) );
      // etc...

      if ( /* condition */ )
            colour = something;

      }
```

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Hacking the Fragment Shader

```
layout(binding=0) uniform sampler2D source;
out float colour;
uniform vec2 scalar;

uniform float dead = 0.0;          // can be changed
uniform float reborn = 1.0;
uniform float old = 0.51;

int grab( vec2 offset ) { /* etc. */ }

void main() {

      int centre = grab( vec2( 0.0, 0.0 ) );

      int sum = grab( vec2( -1.0, 1.0 ) );
      sum += grab( vec2( 0.0, 1.0 ) );
      sum += grab( vec2( 1.0, 1.0 ) );
      // etc...

      if ( /* condition */ )
            colour = dead;
      }
```

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Hacking the Fragment Shader

```
/* etc. */

int grab( vec2 offset ) { /* etc. */ }

void main() {

      int centre = grab( vec2( 0.0, 0.0 ) );

      int sum = grab( vec2( -1.0, 1.0 ) );
      sum += grab( vec2( 0.0, 1.0 ) );
      sum += grab( vec2( 1.0, 1.0 ) );
      // etc...

      if ( (sum > 3) || (sum < 2) )
            colour = dead;

      else if ( centre == 1 )
            colour = old;

      else if ( sum == 3 )
            colour = reborn;

      else
            colour = dead;

      }
```

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Hacking the Fragment Shader

```
/* etc. */

int grab( vec2 offset ) { /* etc. */ }

void main() {

      int centre = grab( vec2( 0.0, 0.0 ) );

      int sum = grab( vec2( -1.0, 1.0 ) );
      sum += grab( vec2( 0.0, 1.0 ) );
      sum += grab( vec2( 1.0, 1.0 ) );
      // etc...

      if ( (sum > 3) || (sum < 2) )            // if statements?!?!?!
            colour = dead;

      else if ( centre == 1 )
            colour = old;

      else if ( sum == 3 )
            colour = reborn;

      else
            colour = dead;

      }
```

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Hacking the Fragment Shader

```
/* etc. */

int grab( vec2 offset ) { /* etc. */ }

void main() {

      int centre = grab( vec2( 0.0, 0.0 ) );    // tonnes of memory access

      int sum = grab( vec2( -1.0, 1.0 ) );
      sum += grab( vec2( 0.0, 1.0 ) );
      sum += grab( vec2( 1.0, 1.0 ) );
      // etc...

      if ( (sum > 3) || (sum < 2) )
            colour = dead;                      // short code paths

      else if ( centre == 1 )
            colour = old;

      else if ( sum == 3 )
            colour = reborn;

      else
            colour = dead;

      } // function ends
```

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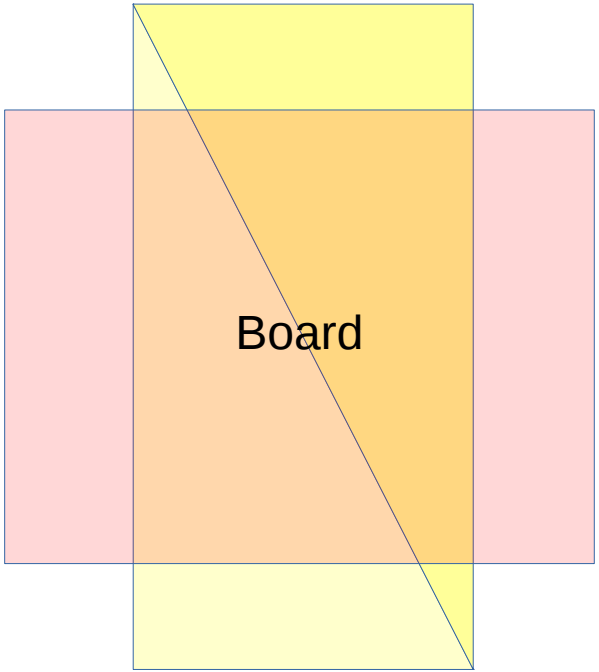
Hacking the Fragment Shader

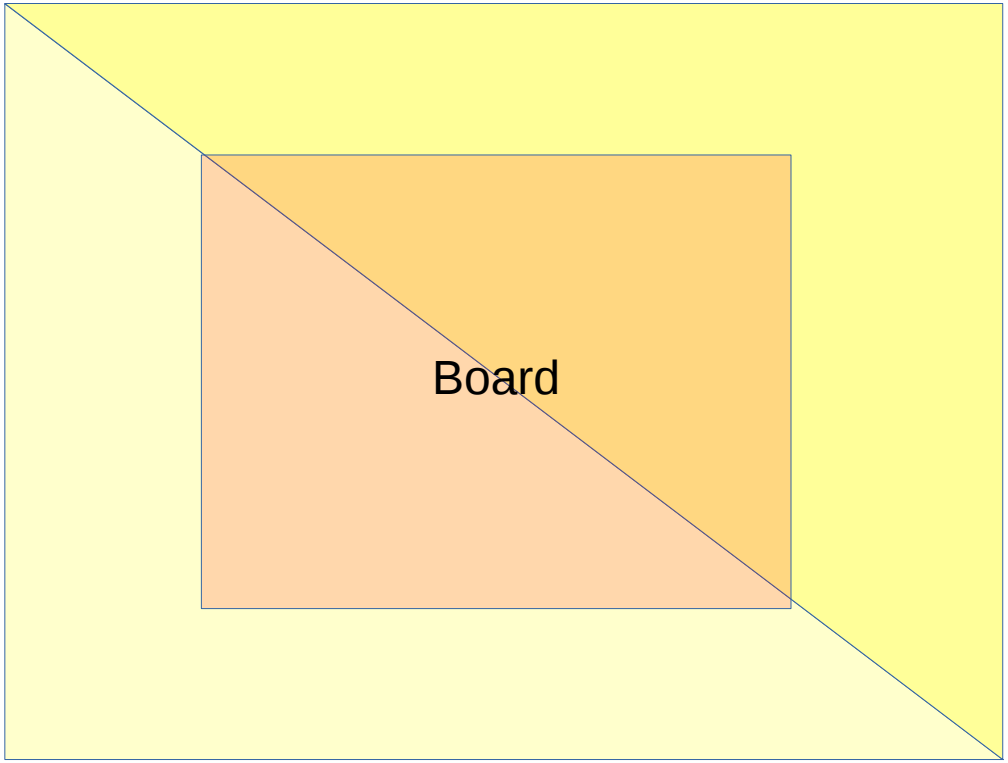
```
/* etc. */

int grab( vec2 offset ) { /* etc. */ }

void main() {

      int centre = grab( vec2( 0.0, 0.0 ) );

      int sum = grab( vec2( -1.0, 1.0 ) );
      sum += grab( vec2( 0.0, 1.0 ) );
      sum += grab( vec2( 1.0, 1.0 ) );

      sum += grab( vec2( -1.0, 0.0 ) );
      sum += grab( vec2( 1.0, 0.0 ) );

      if ( sum > 3 ) {                          // save precious bandwidth

            colour = dead;
            return;
            }

      sum += grab( vec2( -1.0, -1.0 ) );
      sum += grab( vec2( 0.0, -1.0 ) );
      sum += grab( vec2( 1.0, -1.0 ) );

      // etc...
```

Drawing the Board

```
layout(binding=0) uniform sampler2D source;
in vec2 coordinate;    // [-1:1]
out vec4 colour;

void main() {

    colour = texture2D( source, coordinate*.5 + .5 );

    }
```

Drawing the Board





Pixels must be 1:1

Drawing the Board

```
layout(binding=0) uniform sampler2D source;
out vec4 colour;
uniform vec2 scalar;      // figure this out CPU-side
uniform vec2 offset;

void main() {

    vec2 address = (gl_FragCoord.xy * scalar) + offset; // MAD
    colour = texture2D( source, address );

    }
```

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Drawing the Board

```
layout(binding=0) uniform sampler2D source;
out vec4 colour;
uniform vec2 scalar;
uniform vec2 offset;

void main() {

    vec2 address = (gl_FragCoord.xy * scalar) + offset;
    colour = texture2D( source, address );    // float -> vec4

    }
```

Drawing the Board

```
layout(binding=0) uniform sampler2D source;
out vec4 colour;
uniform vec2 scalar;
uniform vec2 offset;

uniform vec4 alive = vec4( 1.0, 1.0, 0.9, 1.0 );  // flexibility
uniform vec4 dead = vec4( 0.0, 0.0, 0.1, 1.0 );

void main() {

     vec2 address = (gl_FragCoord.xy * scalar) + offset;
     float value = texture2D( source, address ).r;

     colour = mix( dead, alive, value );

     }
```

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Drawing the Board

```
layout(binding=0) uniform sampler2D source;
out vec4 colour;
uniform vec2 scalar;
uniform vec2 offset;

uniform vec4 alive = vec4( 1.0, 1.0, 0.9, 1.0 );
uniform vec4 dead = vec4( 0.0, 0.0, 0.1, 1.0 );

void main() {

    vec2 address = (gl_FragCoord.xy * scalar) + offset;
    float value = texture2D( source, address ).r;     // OOB = OK!

    colour = mix( dead, alive, value );

    }
```

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How to load Textures?

Render to Texture?

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How to load Textures?

~~Render to Texture?~~

Texture Types

```
class SimpleTexture {

      // ...

        private:
        GLuint id = 0;          // named texture
        uint width;             // dimensions
        uint height;

                                // how to handle sampling
        GLenum upsampling       = GL_LINEAR;
        GLenum downsampling     = GL_LINEAR_MIPMAP_LINEAR;
        GLenum wrapping         = GL_REPEAT;
        GLuint sampler = 0;     // the named reference

        GLenum format;          // pixel format
                                // what type of texture? 1D, 2D, RECTANGLE, ...
        GLenum type = GL_TEXTURE_2D;

      // ...
```

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Texture Types

There are a number of different types of textures. These are:

- `GL_TEXTURE_1D`: Images in this texture all are 1-dimensional. They have width, but no height or depth.
- `GL_TEXTURE_2D`: Images in this texture all are 2-dimensional. They have width and height, but no depth.
- `GL_TEXTURE_3D`: Images in this texture all are 3-dimensional. They have width, height, and depth.
- `GL_TEXTURE_RECTANGLE`: The image in this texture (only one image. No mipmapping) is 2-dimensional. Texture coordinates used for these textures are not normalized.
- `GL_TEXTURE_BUFFER`: The image in this texture (only one image. No mipmapping) is 1-dimensional. The storage for this data comes from a Buffer Object.
- `GL_TEXTURE_CUBE_MAP`: There are exactly 6 distinct sets of 2D images, all of the same size. They act as 6 faces of a cube.
- `GL_TEXTURE_1D_ARRAY`: Images in this texture all are 1-dimensional. However, it contains multiple sets of 1-dimensional images, all within one texture. The array length is part of the texture's size.
- `GL_TEXTURE_2D_ARRAY`: Images in this texture all are 2-dimensional. However, it contains multiple sets of 2-dimensional images, all within one texture. The array length is part of the texture's size.
- `GL_TEXTURE_CUBE_MAP_ARRAY`: Images in this texture are all cube maps. It contains multiple sets of cube maps, all within one texture. The array length * 6 (number of cube faces) is part of the texture size.
- `GL_TEXTURE_2D_MULTISAMPLE`: The image in this texture (only one image. No mipmapping) is 2-dimensional. Each pixel in these images contains multiple samples instead of just one value.
- `GL_TEXTURE_2D_MULTISAMPLE_ARRAY`: Combines 2D array and 2D multisample types. No mipmapping.

https://www.khronos.org/opengl/wiki/Texture

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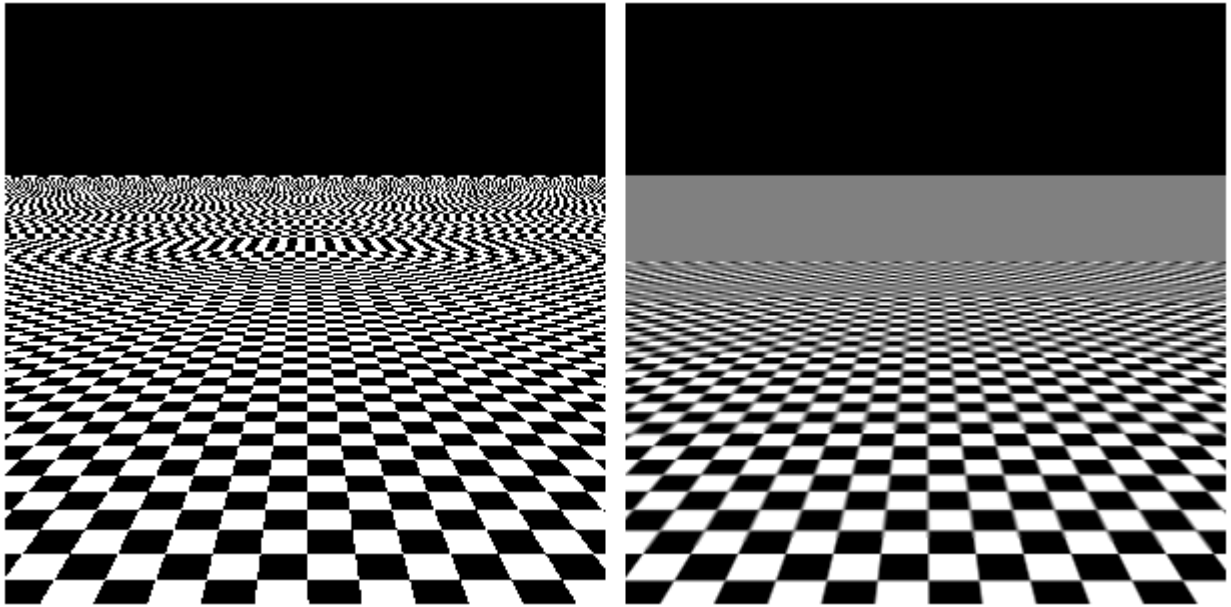
Aliasing / Moire Patterns



https://textureingraphics.wordpress.com/what-is-texture-mapping/anti-aliasing-problem-and-mipmapping/

Mipmaps

http://www.tomshardware.com/reviews/ati,819-2.html

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Mipmaps

http://www.tomshardware.com/reviews/ati,819-2.html

Creating Textures

```
SimpleTexture::SimpleTexture( uint w, uint h, GLenum f ) {

        glGenTextures( 1, &id );        // generate the texture and sampler
        glGenSamplers( 1, &sampler );

// ...

        format = f;

        switch (f) {                    // how many channels do we have?

                case GL_R8:
                case GL_R16:
                case GL_R16F:
                case GL_R32F:
                        perPixelChan = 1;
                        break;

                case GL_RGB8:
                        perPixelChan = 3;
                        break;

                case GL_RGBA8:
                case GL_RGBA16F:
                case GL_RGBA32F:
                        perPixelChan = 4;
                        break;

// ...
```

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Sampler Preparation

```
// handle sampler settings
bool SimpleTexture::setDownsampler( GLenum value ) {

        // check for validity
        switch (value) {

                case GL_NEAREST:
                case GL_LINEAR:
                case GL_NEAREST_MIPMAP_NEAREST:
                case GL_LINEAR_MIPMAP_NEAREST:
                case GL_NEAREST_MIPMAP_LINEAR:
                case GL_LINEAR_MIPMAP_LINEAR:

                        downsampling = value;
// ...
        }

bool SimpleTexture::setWrapping( GLenum value ) {

        // check for validity
        switch (value) {

                case GL_CLAMP_TO_BORDER:
                case GL_CLAMP_TO_EDGE:
                case GL_MIRRORED_REPEAT:
                case GL_MIRROR_CLAMP_TO_EDGE:
                case GL_REPEAT:

                        wrapping = value;
// ...
        }
```

Allocating Blank Textures

```
// allocate blank storage, if possible
bool SimpleTexture::load() {

       // ...

         glBindTexture( type, id );
         if ( OpenGL::error( "glBindTexture" ) )
                 return false;

         glTexStorage2D( type, 1, format, width, height );
         if ( OpenGL::error( "glTexStorage2D" ) )
                 return false;

         glBindTexture( type, 0 );                        // unbind and mark as ready to go

       // ...
         }
```

Allocating Existing Textures

```
// stuff some values into the texture
bool SimpleTexture::load( vector<float> data ) {

        // ...

         // determine the proper format
         GLenum components;
         switch (perPixelChan) {

                 case 1:
                         components = GL_RED;
                         break;
                 case 3:
                         components = GL_RGB;
                         break;
                 case 4:
                         components = GL_RGBA;
                         break;
              // ...
                 }

         glBindTexture( type, id );
         if ( OpenGL::error( "glBindTexture" ) )
                 return false;

         glTexImage2D( type, 0, format, width, height, 0, components, GL_FLOAT,
                         data.data() );
         if ( OpenGL::error( "glTexImage2D" ) )
                 return false;

         glBindTexture( type, 0 );                       // unbind and mark as ready to go
        // ...
        }
```

Binding the Texture to the Shader

```
// associate a texture with an input
bool ShaderProgram::setTexture( string variable, shared_ptr<SimpleTexture> tex ) {

        // ...

        // grab the texture's location, if possible
        GLint location = glGetUniformLocation( id, variable.c_str() );
        if ( location < 0 )
                return false;

        // textures require a bit more work
        glUniform1i(            location, textureSlot );

        glActiveTexture(        GL_TEXTURE0 + textureSlot );
        if ( OpenGL::error( "glActiveTexture" ) )
                return false;

        glBindTexture(          tex->type, tex->id );
        if ( OpenGL::error( "glBindTexture" ) )
                return false;

        if ( tex->loadSampler( textureSlot ) ) {

                textureSlot++;          // only increment on success
                return true;
                }
        else
                return false;

        }
```

Setting Sampler Settings

```
// load the sampler settings
bool SimpleTexture::loadSampler( GLuint unit ) {

        // bind the sampler first
        glBindSampler( unit, sampler );
        if ( OpenGL::error( "glBindSampler" ) )
                return false;

        // set up the parameters
        glSamplerParameteri( sampler, GL_TEXTURE_MIN_FILTER, downsampling );
        glSamplerParameteri( sampler, GL_TEXTURE_MAG_FILTER, upsampling );
        glSamplerParameteri( sampler, GL_TEXTURE_WRAP_S, wrapping );
        glSamplerParameteri( sampler, GL_TEXTURE_WRAP_T, wrapping );
        glSamplerParameteri( sampler, GL_TEXTURE_WRAP_R, wrapping );

        // cheat a bit and only error check here
        return !OpenGL::error( "glSamplerParameter" );

        }
```

Deleting Textures

```
// just trash the texture
SimpleTexture::~SimpleTexture() {       glDeleteTextures( 1 , &id ); }
```

Summary

Preparation

- Generate name for texture
- Generate name for sampler (optional)
- Allocate storage for texture

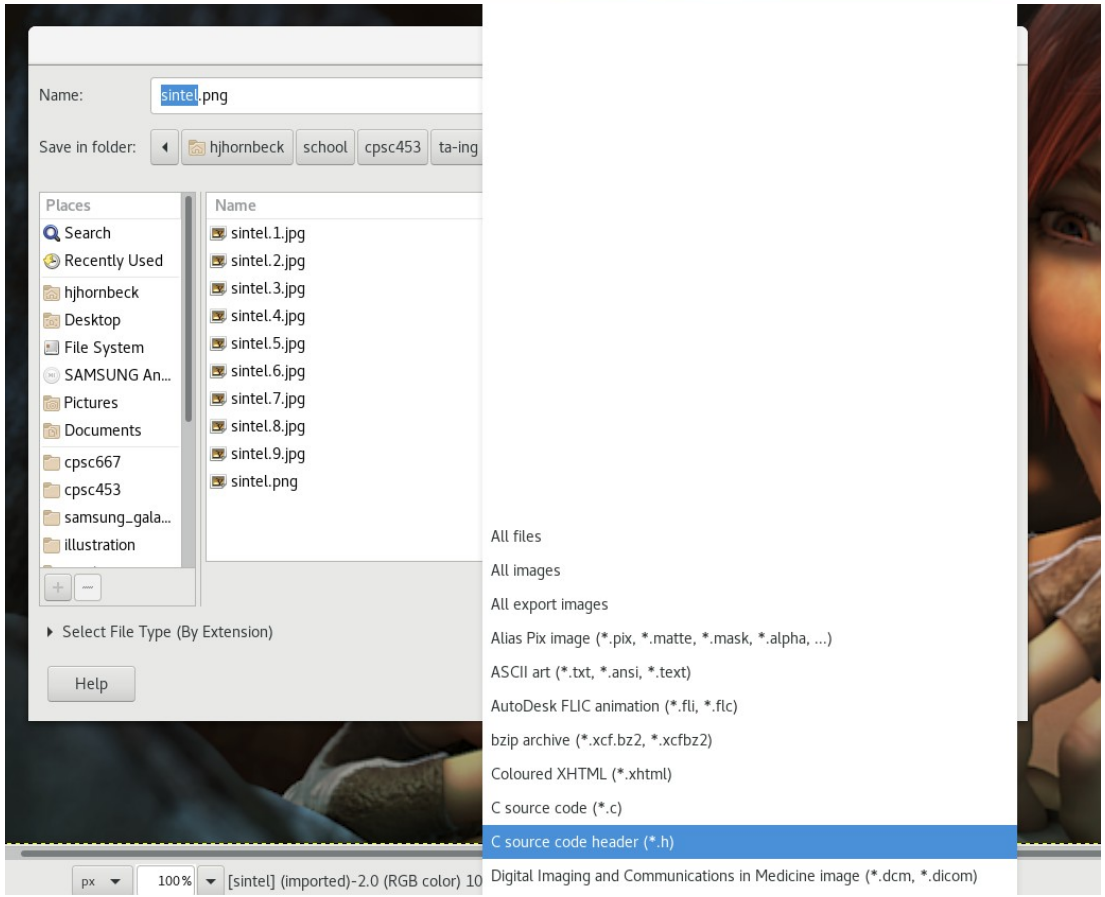
Rendering

- Attach the texture to a shader texture slot
- Bind the texture, bind the sampler, configure it (optional)
- Draw

Allocating Existing Textures

```
// stuff some values into the texture
bool SimpleTexture::load( vector<float> data ) {

        // ...

        // determine the proper format
        GLenum components;
        switch (perPixelChan) {

                case 1:
                        components = GL_RED;
                        break;
                case 3:
                        components = GL_RGB;
                        break;
                case 4:
                        components = GL_RGBA;
                        break;
             // ...
                }

        glBindTexture( type, id );
        if ( OpenGL::error( "glBindTexture" ) )
                return false;

        glTexImage2D( type, 0, format, width, height, 0, components, GL_FLOAT,
                        data.data() );
        if ( OpenGL::error( "glTexImage2D" ) )
                return false;

        glBindTexture( type, 0 );                       // unbind and mark as ready to go
        // ...
        }
```

GIMP


Name:
sintel.png
Save in folder:
hjhornbeck
school
cpsc453
ta-ing
Places
Search
Recently Used
hjhornbeck
Desktop
File System
SAMSUNG An...
Pictures
Documents
cpsc667
cpsc453
samsung_gala...
illustration
Name
sintel.1.jpg
sintel.2.jpg
sintel.3.jpg
sintel.4.jpg
sintel.5.jpg
sintel.6.jpg
sintel.7.jpg
sintel.8.jpg
sintel.9.jpg
sintel.png
Select File Type (By Extension)
Help
All files
All images
All export images
Alias Pix image (*.pix, *.matte, *.mask, *.alpha, ...)
ASCII art (*.txt, *.ansi, *.text)
AutoDesk FLIC animation (*.fli, *.flc)
bzip archive (*.xcf.bz2, *.xcfbz2)
Coloured XHTML (*.xhtml)
C source code (*.c)
C source code header (*.h)
Digital Imaging and Communications in Medicine image (*.dcm, *.dicom)
px
100%
[sintel] (imported)-2.0 (RGB color) 10

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Demo 4

Difference

STB Library

```
// in a C/C++ source file!

#define STB_IMAGE_IMPLEMENTATION
#include "stb_image.h"


void Difference::loadImage( const char* file, uint index ) {

        // ...

        // call STB
        int width, height, channels;

        float* pixels = stbi_loadf(file, &width, &height, &channels, 0);
        // unsigned char* out = stbi_load( /* ... */ );

        // ...

        // free up the buffer
        stbi_image_free( pixels );
```

https://github.com/nothings/stb/blob/master/stb_image.h