Buffers and Fragment Tests

CS 432 Interactive Computer Graphics
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Buffers
Define a buffer by its spatial resolution \((n \times m)\) and its depth (or precision) \(k\), the number of bits/pixel.
WebGL Frame Buffer

![Diagram of WebGL Frame Buffer]

- Stencil buffer
- Depth buffer
- Back buffer
- Front buffer

\[ \text{Color buffers} \]
Where are the Buffers?

• HTML5 Canvas
  - Default front and back color buffers
  - Under control of local window system
  - Physically on graphics card
• Depth buffer also on graphics card
• Stencil buffer
  - Holds masks
• Most RGBA buffers 8 bits per component
• Latest are floating point (IEEE)
Other Buffers

- Desktop OpenGL supported other buffers
  - auxiliary color buffers
  - accumulation buffer
  - these were on application side
  - now deprecated

- GPUs have their own or attached memory
  - texture buffers
  - off-screen buffers
    - not under control of window system
    - may be floating point
Images

• Framebuffer contents are unformatted
  - usually RGB or RGBA
  - one byte per component
  - no compression

• Standard Web Image Formats
  - jpeg, gif, png

• WebGL has no conversion functions
  - Understands standard Web formats for texture images
Writing into Buffers

• WebGL does not contain a function for writing bits into frame buffer
  - Use texture functions instead

• We can use the fragment shader to do bit level operations on graphics memory

• Bit Block Transfer (BitBlt) operations act on blocks of bits with a single instruction
BitBlt

- Conceptually, we can consider all of memory as a large two-dimensional array of pixels.
- We read and write rectangular block of pixels:
  - Bit block transfer (bitblt) operations
- The frame buffer is part of this memory.

![Diagram showing bitblt operations](image-url)
The (Old) Pixel Pipeline

• OpenGL has a separate pipeline for pixels
  - Writing pixels involves
    • Moving pixels from processor memory to the frame buffer
    • Format conversions
    • Mapping, Lookups, Tests
  - Reading pixels
    • Format conversion

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Packing and Unpacking

- Compressed or uncompressed
- Indexed or RGB
- Bit Format
  - little or big endian
- WebGL (and shader-based OpenGL) lacks most functions for packing and unpacking
  - use texture functions instead
  - can implement desired functionality in fragment shaders
Buffer Reading

• WebGL can read pixels from the current framebuffer with gl.readPixels
• Returns 8 bit or integer RGBA values
• In general, the format of pixels in the frame buffer is different from that of processor memory and these two types of memory reside in different places
  - Need packing and unpacking
  - Reading can be slow
• Drawing through texture functions and off-screen memory (frame buffer objects)
WebGL Pixel Function

```javascript
var myimage[512*512*4];

gl.readPixels(0,0, 512, 512, gl.RGBA,
             gl.UNSIGNED_BYTE, myimage);
```
• gl.RGBA
• gl.RGB
• gl.ALPHA
• gl.RED
• gl.RG
• gl.RED_INTEGER
• gl.RG_INTEGER
• gl.RGB_INTEGER
• gl.RGBA_INTEGER

• gl.UNSIGNED_BYTE
• gl.BYTE
• gl.FLOAT
• gl.HALF_FLOAT
• gl.SHORT
• gl.UNSIGNED_SHORT
• gl.INT
• gl.UNSIGNED_INT
Clearing Buffers

• A clear (default) value may be set for each buffer
  - `gl.clearColor()`
  - `gl.clearDepth()`
  - `gl.clearStencil()`

• `gl.clear(Glbitfield mask)`

• Clears the specified buffer
  - `gl.COLOR_BUFFER_BIT, gl.DEPTH_BUFFER_BIT, gl.STENCIL_BUFFER_BIT`
  - Can be or’ed together in one `clear()` call
A buffer may be *masked*, i.e. enabled or disabled

- `gl.colorMask(red, green, blue, alpha)`
  - Arguments are booleans
- `gl.depthMask(flag)`
- `gl.stencilMask(mask)`
- `gl.stencilMaskSeparate(face, mask)`
  - Stencil specific sides (front & back) of triangles
• GPUs now include a large amount of texture memory that we can write into
• Advantage: fast (not under control of window system)
• Using frame buffer objects (FBOs) we can render into texture memory instead of the frame buffer and then read from this memory
  - Image processing
  - GPGPU
Framebuffer Objects
Objectives

• Look at methods that use memory on the graphics card
• Introduce off screen rendering
• Learn how to create framebuffer objects
  - Create a renderbuffer
  - Attach resources
Discrete Processing in WebGL

- Recent GPUs contain large amounts of memory
  - Texture memory
  - Framebuffer
  - Floating point

- Fragment shaders support discrete operations at the pixel level

- Separate pixel (texel) pipeline
Accessing the Framebuffer

• Pre 3.1 OpenGL had functions that allowed access to the framebuffer and other OpenGL buffers
  - Draw Pixels
  - Read Pixels
  - Copy Pixels
  - BitBlt
  - Accumulation Buffer functions
• All deprecated
Going between CPU and GPU

• We will see that we can write pixels as texels to texture memory
• Texture objects reduce transfers between CPU and GPU
• Transfer of pixel data back to CPU slow
• Want to manipulate pixels without going back to CPU
  - Image processing
  - GPGPU
Framebuffer Objects

- Framebuffer Objects (FBOs) are buffers that are created by the application
  - Not under control of window system
  - Cannot be displayed
  - Can attach a renderbuffer to a FBO and can render off screen into the attached buffer
  - Attached buffer can then be detached and used as a texture map for an on-screen render to the default frame buffer
Render to Texture

- Textures are shared by all instances of the fragment shader
- If we render to a texture attachment we can create a new texture image that can be used in subsequent renderings
- Use a double buffering strategy for operations such as convolution
Steps

- Create an Empty Texture Object
- Create a FBO
- Attach renderbuffers to create and store texture image
- Bind FBO
- Render scene
- Detach renderbuffer
- Bind window system frame buffer
- Bind texture
- Render with new texture
Empty Texture Object

texture1 = gl.createTexture();
gl.activeTexture( gl.TEXTURE0 );
gl.bindTexture( gl.TEXTURE_2D, texture1 );

gl.texImage2D(gl.TEXTURE_2D, 0, gl.RGBA, 512, 512, 0, gl.RGBA,
gl.UNSIGNED_BYTE, null);

gl.generateMipmap(gl.TEXTURE_2D);
gl.texParameteri( gl.TEXTURE_2D, gl.TEXTURE_MIN_FILTER,
gl.NEAREST_MIPMAP_LINEAR );
gl.texParameteri( gl.TEXTURE_2D, gl.TEXTURE_MAG_FILTER,
gl.NEAREST );
Creating a FBO

• We create a framebuffer object in a similar manner to other objects
• Creating an FBO creates an empty FBO
• Must add needed resources
  - Can add a renderbuffer to render into
  - Can add a texture which can also be rendered into
  - For hidden surface removal we must add a depth buffer attachment to the renderbuffer
  - Can also add a stencil buffer to FBO
Frame Buffer Object

```javascript
var framebuffer = gl.createFramebuffer();
gl.bindFramebuffer(gl.FRAMEBUFFER, framebuffer);
framebuffer.width = 512;
framebuffer.height = 512;
renderbuffer = gl.createRenderbuffer();
gl.bindRenderbuffer(gl.RENDERBUFFER, renderbuffer);
gl.renderbufferStorage(gl.RENDERBUFFER,
    gl.DEPTH_COMPONENT16, 512, 512);
gl.framebufferRenderbuffer(gl.FRAMEBUFFER, gl.DEPTH_ATTACHMENT, gl.RENDERBUFFER, renderbuffer);

// Attach color buffer
gl.framebufferTexture2D(gl.FRAMEBUFFER, gl.COLOR_ATTACHMENT0, gl.TEXTURE_2D, texture1, 0);

// check for completeness
var status = gl.checkFramebufferStatus(gl.FRAMEBUFFER);
if (status != gl.FRAMEBUFFER_COMPLETE) alert('Frame Buffer Not Complete');
```

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Rest of Initialization

• Same as previous examples
  - Allocate VAO
  - Fill VAO with data for render to texture

• Initialize two program objects with different shaders
  - First for render to texture
  - Second for rendering with created texture
Render to Texture
Objectives

• Examples of render-to-texture
• Render a triangle to texture, then use this texture on a rectangle
• Introduce buffer pingponging
Program Objects and Shaders

• For most applications of render-to-texture we need multiple program objects and shaders
  - One set for creating a texture
  - Second set for rendering with that texture

• Applications that we consider later such as buffer pingponging may require additional program objects
pass through vertex shader:

```cpp
in vec4 aPosition;
void main()
{
    gl_Position = aPosition;
}
```

fragment shader to get a red triangle:

```cpp
precision mediump float;
out vec4 fColor;
void main()
{
    fColor = vec4(1.0, 0.0, 0.0, 1.0);
}
```
Program Object 2 Shaders

// vertex shader

in vec4 aPosition;
in vec2 aTexCoord;
out vec2 vTexCoord;
void main()
{
  gl_Position = aPosition;
  vTexCoord = aTexCoord;
}

// fragment shader

precision mediump float;
in vec2 vTexCoord;
out vec4 fColor;
uniform sampler2D texture;
void main()
{
  fColor = texture2D(texture, vTexCoord);
}
First Render (to Texture)

```javascript
gl.useProgram( program1 );  // Outputs a constant color
var buffer1 = gl.createBuffer();
gl.bindBuffer( gl.ARRAY_BUFFER, buffer1 );
gl.bufferData( gl.ARRAY_BUFFER, flatten(pointsArray), gl.STATIC_DRAW );

// Initialize the vertex position attribute from the vertex shader
var aPosition = gl.getAttribLocation( program1, "aPosition" );
gl.vertexAttribPointer( aPosition, 2, gl.FLOAT, false, 0, 0 );
gl.enableVertexAttribArray( aPosition );

// Render one triangle to an FBO

gl.viewport(0, 0, 64, 64);
gl clearColor(0.5, 0.5, 0.5, 1.0);
gl.clear(gl.COLOR_BUFFER_BIT);
gl.drawArrays(gl.TRIANGLES, 0, 3);
```
Set Up Second Render

// Bind to default window system framebuffer using null argument

```javascript
    gl.bindFramebuffer(gl.FRAMEBUFFER, null);
    gl.bindRenderbuffer(gl.RENDERBUFFER, null);
    gl.disableVertexAttribArray(aPosition);
    gl.useProgram(program2); // Outputs colors from texture map
```

// We have already set up a texture object with null texture image
// texture1 was written into by the previous drawArrays command

```javascript
    gl.activeTexture(gl.TEXTURE0);
    gl.bindTexture(gl.TEXTURE_2D, texture1);
```

// set up vertex attribute arrays for texture coordinates and rectangle as usual
var buffer2 = gl.createBuffer();
gl.bindBuffer( gl.ARRAY_BUFFER, buffer2);
gl.bufferData( gl.ARRAY_BUFFER, flatten(vertices), gl.STATIC_DRAW);

var aPosition = gl.getAttribLocation( program2, "aPosition" );
gl.vertexAttribPointer( aPosition, 2, gl.FLOAT, false, 0, 0 );
gl.enableVertexAttribArray( aPosition );

var buffer3 = gl.createBuffer();
gl.bindBuffer( gl.ARRAY_BUFFER, buffer3);
gl.bufferData( gl.ARRAY_BUFFER, flatten(texCoord), gl.STATIC_DRAW);

var aTexCoord = gl.getAttribLocation( program2, "aTexCoord" );
gl.vertexAttribPointer( aTexCoord, 2, gl.FLOAT, false, 0, 0 );
gl.enableVertexAttribArray( aTexCoord );
Render a Quad with Texture

```gl
gl.uniform1i(gl.getUniformLocation(program2, "texture"), 0);

gl.viewport(0, 0, 512, 512);
gl clearColor(0.0, 0.0, 1.0, 1.0);
gl.clear(gl.COLOR_BUFFER_BIT);

gl.drawArrays(gl.TRIANGLES, 0, 6);
```
Buffer Ping-pong

• Iterative calculations can be accomplished using multiple render buffers
• Original data in texture buffer 1
• Render to texture buffer 2
• Swap buffers and rerender to texture
Picking by Color
Objectives

• Use off-screen rendering for picking
• Example: rotating cube with shading
  - indicate which face is clicked on with mouse
  - normal rendering uses vertex colors that are interpolated across each face
  - Vertex colors could be determined by lighting calculation or just assigned
  - use console log to indicate which face (or background) was clicked
Algorithm

- Assign a unique color to each object
- When the mouse is clicked:
  - Do an off-screen render using these colors and no lighting
  - use gl.readPixels to obtain the color of the pixel where the mouse is located
  - map the color to the object id
  - do a normal render to the display
Shaders

- Only need one program object
- Vertex shader: same as in previous cube examples
  - includes rotation matrices
  - gets angle as uniform variable
- Fragment shader
  - Stores face colors for picking
  - Gets vertex color for normal render from rasterizer
- Send uniform integer to fragment shader as index for desired color
Fragment Shader

precision mediump float;

uniform int uColorIndex;
in vec4 vColor;
out vec4 fColor;
void main()
{
  vec4 c[7];
c[0] = vColor;
c[1] = vec4(1.0, 0.0, 0.0, 1.0);
c[2] = vec4(0.0, 1.0, 0.0, 1.0);
c[3] = vec4(0.0, 0.0, 1.0, 1.0);
c[4] = vec4(1.0, 1.0, 0.0, 1.0);
c[5] = vec4(0.0, 1.0, 1.0, 1.0);
c[6] = vec4(1.0, 0.0, 1.0, 1.0);

  fColor = c[uColorIndex];
}
Setup

// Allocate a frame buffer object
framebuffer = gl.createFramebuffer();
gl.bindFramebuffer( gl.FRAMEBUFFER, framebuffer );

// Attach color buffer
// Must first define empty texture object “texture”
gl.framebufferTexture2D( gl.FRAMEBUFFER,
    gl.COLOR_ATTACHMENT0, gl.TEXTURE_2D, texture, 0 );

// Bind screen frame buffer
gl.bindFramebuffer( gl.FRAMEBUFFER, null );
Event Listener

canvas.addEventListener("mousedown", function() {
    gl.bindFramebuffer(gl.FRAMEBUFFER, framebuffer);
    gl.clear( gl.COLOR_BUFFER_BIT);
    for(var i=0; i<6; i++) {
        gl.uniform1i(gl.getUniformLocation(program, "uColorIndex"), i+1);
        gl.drawArrays( gl.TRIANGLES, 6*i, 6 );
    }
    var x = event.clientX;
    var y = canvas.height - event.clientY; // Flipping y !!!!
    gl.readPixels(x, y, 1, 1, gl.RGBA, gl.UNSIGNED_BYTE, color);
});
if(color[0] == 255)
    if(color[1] == 255) console.log("yellow");
    else if(color[2] == 255) console.log("magenta");
    else console.log("red");

else if(color[1] == 255)
    if(color[2] == 255) console.log("cyan");
    else console.log("green");

else if(color[2] == 255) console.log("blue");
    else console.log("background");
// return to default framebuffer
   gl.bindFramebuffer(gl.FRAMEBUFFER, null);
// send index 0 to fragment shader
   gl.uniform1i(gl.getUniformLocation(program, "uColorIndex " ), 0);

// normal render
   gl.clear( gl.COLOR_BUFFER_BIT );
   gl.drawArrays(gl.TRIANGLES, 0, 36);
Picking by Selection

- Possible with render-to-texture
- When mouse clicked do an off-screen rendering with new viewing conditions that render only a small area around mouse
- Or render full scene and just sample off-screen image at mouse click position
- Keep track of what gets rendered to this off-screen buffer
- Know what was picked by returned color
Fragment Tests
Objectives

• Introduce fragment tests and operations
• Learn to use blending
• Introduce additional WebGL buffers
• Reading and writing buffers
• Buffers and Images
After the fragment shader is executed, a series of tests and operations are performed on the fragment.

Determine how and whether a fragment color is drawn into the frame buffer.
Fragment Tests and Operations

- Determine how and whether a fragment color is drawn into the frame buffer

- This is where the depth test is being performed
Fragment Tests and Operations

• Tests and operations are performed in the following order
  - Scissor test
  - Stencil test
  - Depth test
  - Blending
  - Dithering

• On/off `gl.enable()`, `gl.disable()`
Pixel Tests

• Scissor
  - Only draw in a rectangular portion of screen
    - `gl.scissor()` – Specify rectangle
  - Default rectangle matches window

• Depth
  - Draw based on depth value and comparison function
    - `gl.depthFunc()` – Specify comparison function
  - Default is `gl.LESS`
Pixel Tests

• Stencil
  - Draw based on values in stencil buffer, if available and enabled
  - Used for drawing into an irregular region of color buffer
    - `gl.stencilFunc()` – Specifies comparison function, reference value and mask
    - `gl.stencilOp()` – Specifies how fragments can modify stencil buffer
  - Used for reflections, capping and stippling
Dithering

- Dithering may be enabled (gl.DITHER) on some systems with limited color resolution
- System/hardware-dependent
Opacity and Transparency using Blending

• Opaque surfaces permit no light to pass through
• Transparent surfaces permit all light to pass
• Translucent surfaces pass some light

translucency = 1 – opacity (α)

opaque surface $\alpha = 1$
Physical Models

• Dealing with translucency in a physically correct manner is difficult due to
  - the complexity of the internal interactions of light and matter
  - Using a pipeline renderer
Writing Model for Blending

• Use A component of RGBA (or RGB\(\alpha\)) color to store opacity

• During rendering we can expand our writing model to use RGBA values

\[
\text{source blending factor} \rightarrow \text{blend} \rightarrow \text{destination component}
\]

\[
\text{source component} \rightarrow \text{destination blending factor} \rightarrow \text{Color Buffer}
\]
Blending Equation

- We can define source and destination blending factors for each RGBA component

\[
\mathbf{s} = [s_r, s_g, s_b, s_\alpha]
\]
\[
\mathbf{d} = [d_r, d_g, d_b, d_\alpha]
\]

Suppose that the source and destination colors are

\[
\mathbf{b} = [b_r, b_g, b_b, b_\alpha]
\]
\[
\mathbf{c} = [c_r, c_g, c_b, c_\alpha]
\]

Blend as

\[
\mathbf{c'} = \mathbf{s} \odot \mathbf{b} + \mathbf{d} \odot \mathbf{c}
\]

\[
\mathbf{c'} = [b_r s_r + c_r d_r, b_g s_g + c_g d_g, b_b s_b + c_b d_b, b_\alpha s_\alpha + c_\alpha d_\alpha]
\]
WebGL Blending

- Must enable blending and set source and destination factors
  
  ```javascript
  gl.enable(gl.BLEND)
  gl.blendFunc(source_factor, destination_factor)
  ```

- Only certain factors supported
  
  - `gl.ZERO, gl.ONE`
  - `gl.SRC_ALPHA, gl.ONE_MINUS_SRC_ALPHA`
  - `gl.DST_ALPHA, gl.ONE_MINUS_DST_ALPHA`
  
  - See WebGL spec for complete list
Example

• Suppose that we start with the opaque background color \((R_0, G_0, B_0, 1)\)
  - This color becomes the initial destination color
• We now want to blend in a translucent polygon with color \((R_1, G_1, B_1, \alpha_1)\)
• Select `gl_SRC_ALPHA` and `gl_ONE_MINUS_SRC_ALPHA` as the source and destination blending factors
  \[
  R'_0 = \alpha_1 R_1 + (1 - \alpha_1) R_0,
  \]
• Note this formula is correct if polygon is either opaque or transparent
Clamping and Accuracy

• All the components (RGBA) are clamped and stay in the range (0,1)
• However, in a typical system, RGBA values are only stored to 8 bits
  - Can easily lose accuracy if we add many components together
  - Example: add together n images
    • Divide all color components by n to avoid clamping
    • Blend with source factor = 1, destination factor = 1
    • But division by n loses bits
Order Dependency

• Is this image correct?
  - Probably not
  - Polygons are rendered in the order they pass down the pipeline
  - Blending functions are order dependent
Opaque and Translucent Polygons

- Suppose that we have a group of polygons some of which are opaque and some translucent.
- How do we use hidden-surface removal?
- Opaque polygons block all polygons behind them and affect the depth buffer.
- Translucent polygons should not affect depth buffer.
  - Render with `gl.depthMask(false)` which makes depth buffer read-only.
- Sort polygons first to remove order dependency!
- Draw back to front.
Blending and HTML

• In desktop OpenGL, the A component has no effect unless blending is enabled.
• In WebGL, an A other than 1.0 has an effect because WebGL works with the HTML5 Canvas element.
• A = 0.5 will cut the RGB values by ½ when the pixel is displayed.
• Allows other applications to be blended into the canvas along with the graphics.
Fragment Tests and Operations

• Tests and operations are performed in the following order
  - Scissor test
  - Stencil test
  - Depth test
  - Blending
  - Dithering

• On/off gl.enable(), gl.disable()
Other Buffer Applications
Anti-aliasing

• Aliasing – artifacts produced from inadequate sampling
  - Jagged edges
  - Missing thin objects/features

• Anti-aliasing – removing artifacts via super-sampling, filtering, blurring, smoothing

• OpenGL offers a number of ways to perform anti-aliasing

• More limited in WebGL
Line Aliasing

• Ideal raster line is one pixel wide
• All line segments, other than vertical and horizontal segments, partially cover pixels
• Simple algorithms color only whole pixels
• Lead to the “jaggies” or aliasing
• Similar issue for polygons
Antialiasing

• Color a pixel by adding in a fraction of the fragment’s color
  - Fraction depends on percentage of pixel covered by object
  - Fraction depends on whether there is overlap

no overlap

overlap
Area Averaging

- Use average area $\alpha_1 + \alpha_2 - \alpha_1 \alpha_2$ as blending factor
Area Averaging

OpenGL Antialiasing

• Not (yet) supported in WebGL
• Can enable separately for points, lines, or polygons

```c
// Compute fractional alpha values along edges
// Based on pixel coverage
glEnable(GL_POINT_SMOOTH);
glEnable(GL_LINE_SMOOTH);
glEnable(GL_POLYGON_SMOOTH);

glEnable(GL_BLEND);
glBlendFunc(GL_SRC_ALPHA, GL_ONE_MINUS_SRC_ALPHA);
```

• Note most hardware will automatically antialias

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WebGL Antialiasing

- Full-screen antialiasing
- Multiple renderings with texture ping-pong
- Jitter view
- Average several jittered images together
Fog

• We can blend with a fixed color and have the blending factors depend on depth
  - Simulates a fog effect
• Blend source color $C_s$ and fog color $C_f$ by
  
  $$C_s' = f C_s + (1-f) C_f$$

• $f$ is the *fog factor* based on depth
  - Exponential
  - Gaussian
  - Linear (depth cueing)
• Hard-coded fog deprecated but can recreate
Fog Functions

\[ e^{-z^2}, \quad 1 - 0.5z \]

Distance

Attenuation

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Fog Effect

http://www.engin.swarthmore.edu/~jshin1
Interactive Depth-of-Field

• Jitter camera
• Each frustum has common plane “in focus”
• Accumulate & blend images
Interactive Depth-of-Field

[+/-] focus: 176.00
[j] jitter: 2.00
press F to show the focal plane.

http://www.cs.stevens.edu/~quynh
Reflections

• One of the most noticeable effects of inter-object lighting
• Direct calculation of the physics (ray tracing) is too expensive
• Our focus is to capture the most significant reflection while minimizing the overhead via rendering the “virtual object”
Image vs. Object Space Methods

• Image space methods: create a texture from a view of the reflected objects and apply it to the reflector
  - Advantage: does not depend on the object geometry
  - Disadvantage: sampling issue and also only an approximation (environment mapping as an example)

• Object space methods: create the actual geometry of the object to be reflected and render it to the reflector
  - Disadvantage: Limited to planar reflections
  - Advantage: more accurate reflection (for nearby objects)

• Both methods need to create the virtual objects
Planar Reflections

• The most common reflection – flat mirror, floor, wall, etc

• Creating virtual objects (or reflected objects) is much easier

• A view independent operation – only consider the relative position of the object and the reflector

• The virtual object is created by transforming the object across the reflector plane
Planar Reflections

Figure 54. Mirror Reflection of the Viewpoint

Figure 55. Mirror Reflection of the Scene
Render the Reflected Geometry

• An important task: clip the reflected geometry so it is only visible on the reflector surface
  - Beyond the reflector boundaries and in front of reflector
Clipping using the stencil

• The key is you only want the reflected geometry to appear on the reflector surface

• Use stencil buffer:
  - Clear the stencil buffer
  - Render the reflector and set the stencil
  - Render the reflected geometry only where the stencil pixels have been set

• The above algorithm uses the stencil buffer to control where to **draw** the reflection
Clipping using the stencil

• Another method: render the reflected object first, and then render the reflector to set the stencil buffer, then clear the color buffer everywhere except where the stencil is set.

• This method is to use the stencil buffer to control where to erase the incorrect reflection.

• Advantage: when it is faster to use stencil to control clearing the scene than drawing the entire scene with stencil tests.
The stencil erase algorithm

Figure 57. Stencil Reflection Steps
Reflection Effect

http://www.canny.org.uk
Motion Effects
HW9 Suggestions

• Create an off-screen frame buffer
  - With color(texture) and depth buffers

• Draw your three objects to this frame buffer, with each object having a unique, constant color
  - This color will act as the object’s ID

• Draw normally to on-screen frame buffer

• Allow user to click in the graphics window
HW9 Suggestions

- Read color at click point out of the off-screen frame buffer
- The color will tell you if an object was selected and which one
- Randomly change the diffuse color of the picked object
- Your EventListener should draw to both the off-screen and on-screen buffers