
# Introduction to Computer Graphics with WebGL

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# Framebuffer Objects

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# 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 have already seen 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 shade
- 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 renderbuffer for texture image
- Bind FBO
- Render scene
- Detach renderbuffer
- 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


# Frame Buffer Object

```
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);
// Attach color buffer
gl.framebufferTexture2D(gl.FRAMEBUFFER, gl.COLOR_ATTACHMENT0,
        gl.TEXTURE_2D, texture1, 0);
//gl.framebufferRenderbuffer(gl.FRAMEBUFFER, gl.DEPTH_ATTACHMENT,
        gl.RENDERBUFFER, renderbuffer);
// check for completeness
  var status = gl.checkFramebufferStatus(gl.FRAMEBUFFER);
  if(status != gl.FRAMEBUFFER_COMPLETE) alert('Frame Buffer Not Complete');
```


# 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


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# Render to Texture

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# 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


# Program Object 1 Shaders

pass through vertex shader:

```
attribute  vec4 vPosition;
void main()
 {
    gl_Position = vPosition;
}
```

fragment shader to get a red triangle:

```
precision mediump float;
void main()
{
    gl_FragColor = vec4(1.0, 0.0, 0.0, 1.0);
}
```


# Program Object 2 Shaders

```
// vertex shader

attribute vec4 vPosition;
attribute vec2 vTexCoord;
varying vec2 fTexCoord;
void main()
{
gl_Position = vPosition;
fTexCoord = vTexCoord;
}
```

```
// fragment shader

precision mediump float;

varying  vec2 fTexCoord;
uniform sampler2D texture;
void main()
{
    gl_FragColor = texture2D( texture,
                fTexCoord);
}
```


# First Render (to Texture)

```
gl.useProgram( program1 );
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 vPosition = gl.getAttribLocation( program1, "vPosition" );
gl.vertexAttribPointer( vPosition, 2, gl.FLOAT, false, 0, 0 );
gl.enableVertexAttribArray( vPosition );

// Render one triangle
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

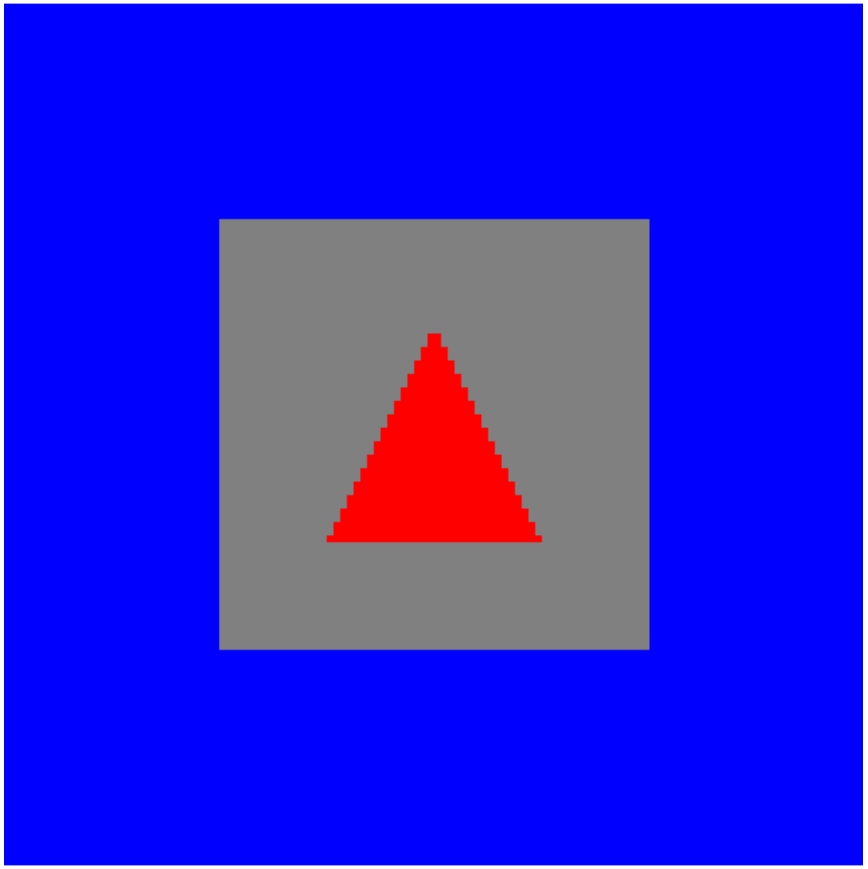
```
// Bind to default window system framebuffer

    gl.bindFramebuffer(gl.FRAMEBUFFER, null);
    gl.disableVertexAttribArray(vPosition);
    gl.useProgram(program2);

// Assume we have already set up a texture object with null texture image

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

// set up vertex attribute arrays for texture coordinates and rectangle as usual
```


# Data for Second Render

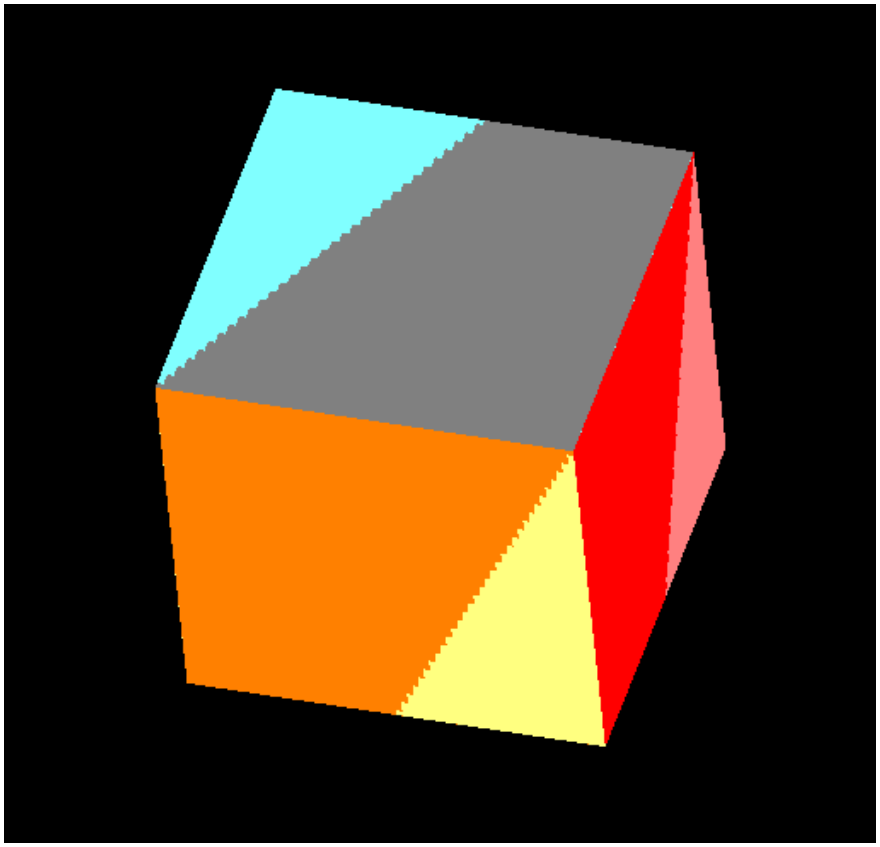
```
var buffer2 = gl.createBuffer();
gl.bindBuffer( gl.ARRAY_BUFFER, buffer2);
gl.bufferData(gl.ARRAY_BUFFER,   new flatten(vertices),
            gl.STATIC_DRAW);

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

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

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


# Render a Quad with Texture

```
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);
```




# Dynamic 3D Example



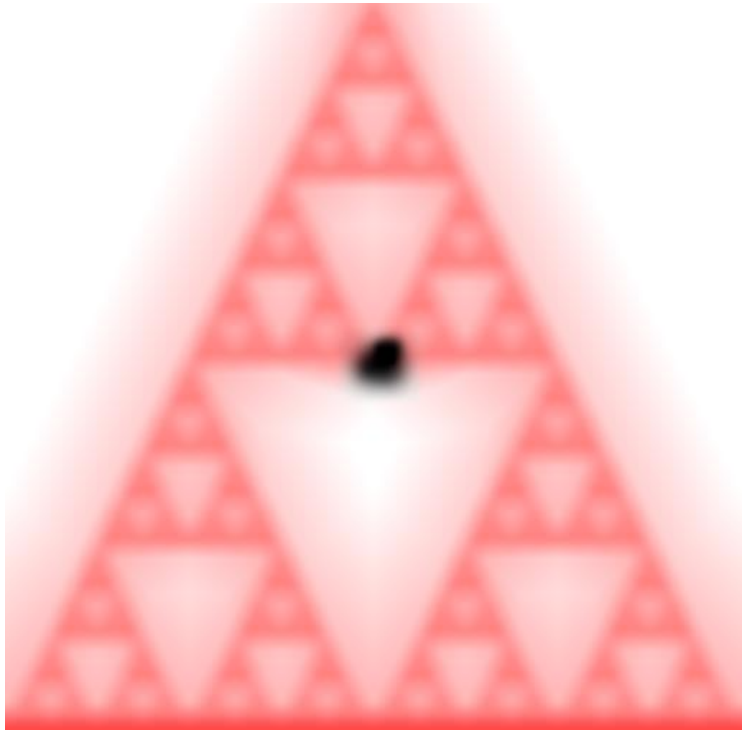

# Buffer Ping-ponging

- 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


# Particle System Example

- Random motion of a particle
  - Render as a point
  - Diffuse rendered image to create motion blur effect
  - Insert particle again in new position
- Example use Sierpinski gasket as initial background
- Uses three program objects


# Screen Shots

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# Agent Based Models

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# Objectives

- Introduce a powerful form of simulation
- Use render-to-texture for dynamic simulations using agent-based models
- Example of diffusion


# Agent Based Models (ABMs)

- Consider a particle system in which particle can be programmed with individual behaviors and properties
  - different colors
  - different geometry
  - different rules
- Agents can interact with each other and with the environment


# Simulating Ant Behavior

- Consider ants searching for food
- At the beginning, an ant moves randomly around the terrain searching for food
  - The ant can leave a chemical marker called a pheromone to indicate the spot was visited
  - Once food is found, other ants can trace the path by following the pheromone trail
- Model each ant as a point moving over a surface
- Render each point with arbitrary geometry


# Diffusion Example I

- Two types of agents
  - no interaction with environment
  - differ only in color
- All move randomly
- Leave position information
  - need render-to-texture
- Diffuse position information
  - need buffer pingponging

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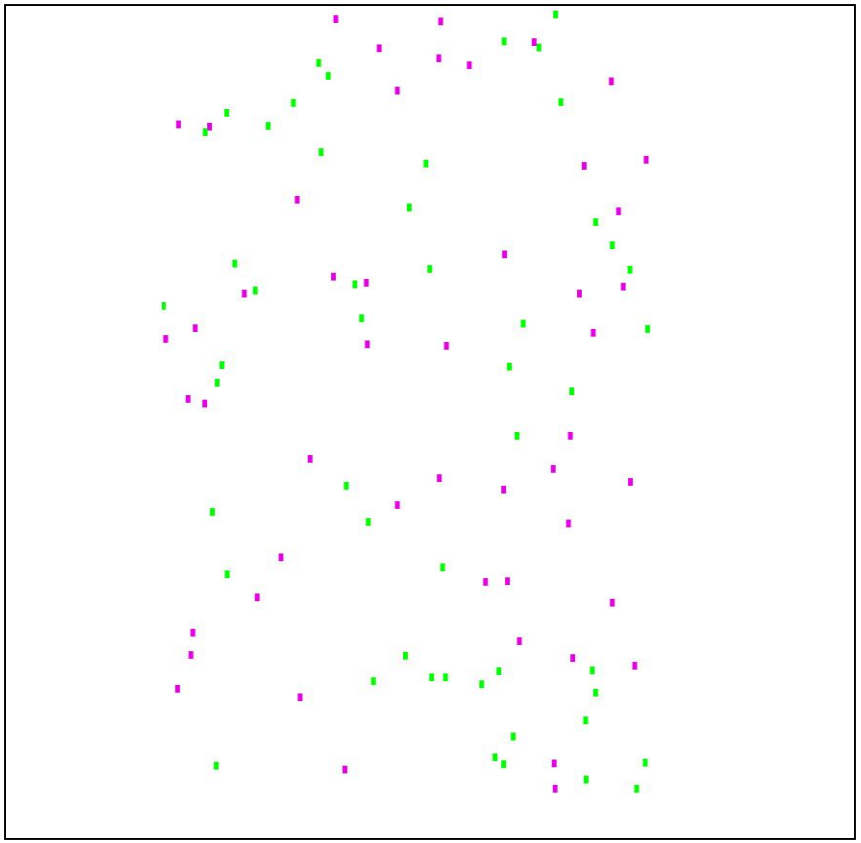
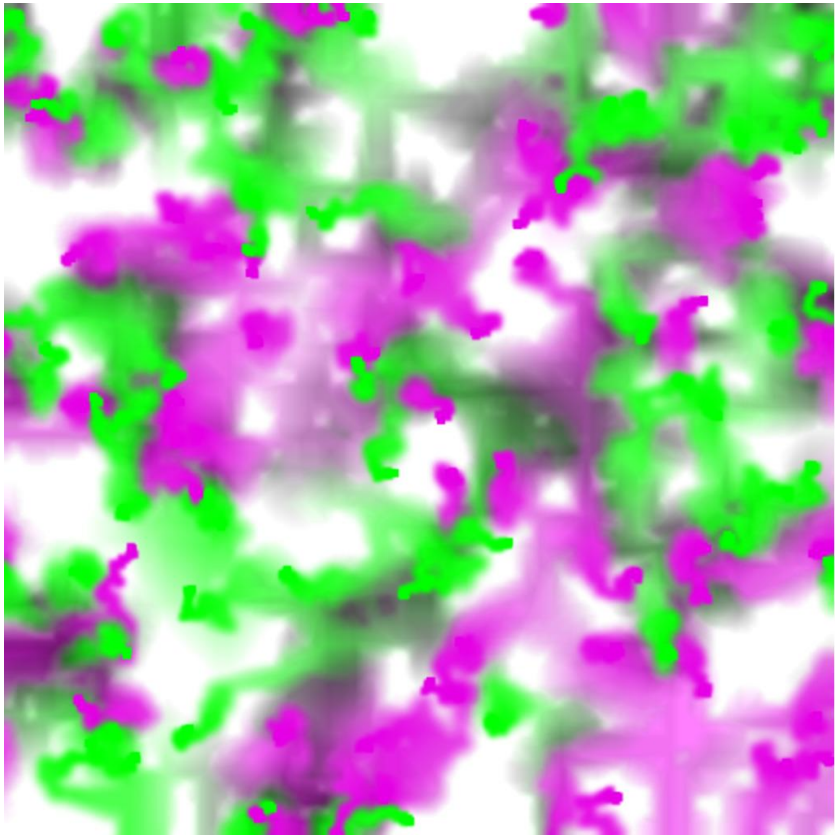
# Snapshots






# Initialization

- We need two program objects
  - One for rendering points in new positions
  - One for diffusing texture map
- Initialization is standard otherwise
  - setup texture objects
  - setup framebuffer object
  - distribute particles in random locations


# Vertex Shader 1

```
attribute vec4 vPosition1;
attribute vec2 vTexCoord;
varying vec2 fTexCoord;
void main()
{
    gl_Position = vPosition1;
    fTexCoord = vTexCoord;
}
```


# Fragment Shader 1

```
precision mediump float;
uniform sampler2D texture;
uniform float d;
uniform float s;
varying vec2 fTexCoord;
void main()
 {
   float x = fTexCoord.x;
   float y = fTexCoord.y;
   gl_FragColor = (texture2D( texture, vec2(x+d, y))
                +texture2D( texture, vec2(x, y+d))
                +texture2D( texture, vec2(x-d, y))
                +texture2D( texture, vec2(x, y-d)))/s;
 }
```


# Vertex Shader 2

```
attribute  vec4 vPosition2;
uniform float pointSize;
void main()
 {
    gl_PointSize = pointSize;
    gl_Position = vPosition2;
}
```


# Fragment Shader 2

```
precision mediump float;
uniform vec4 color;
void main()
{
    gl_FragColor = color;
}
```


# Rendering Loop I

```
var render = function(){
   // render to texture
   // first a rectangle that is texture mapped
    gl.useProgram(program1);
    gl.bindFramebuffer( gl.FRAMEBUFFER, framebuffer);
    if(flag) {
        gl.bindTexture(gl.TEXTURE_2D, texture1);
        gl.framebufferTexture2D(gl.FRAMEBUFFER,
        gl.COLOR_ATTACHMENT0, gl.TEXTURE_2D, texture2, 0);
    }
    else {
        gl.bindTexture(gl.TEXTURE_2D, texture2);
        gl.framebufferTexture2D(gl.FRAMEBUFFER,
           gl.COLOR_ATTACHMENT0, gl.TEXTURE_2D, texture1, 0);
    }
   gl.drawArrays( gl.TRIANGLE_STRIP, 0, 4 );
```


# Rendering Loop II

```
// render points
    gl.useProgram(program2);
    gl.vertexAttribPointer( vPosition2, 2, gl.FLOAT, false, 0, 0);
    gl.uniform4f( gl.getUniformLocation(program2, "color"), 0.9, 0.0, 0.9, 1.0);
     gl.drawArrays(gl.POINTS, 4, numPoints/2);
    gl.uniform4f( gl.getUniformLocation(program2, "color"), 0.0, 9.0, 0.0, 1.0);
    gl.drawArrays(gl.POINTS, 4+numPoints/2, numPoints/2);
 // render to display
    gl.useProgram(program1);
    gl.vertexAttribPointer( texLoc, 2, gl.FLOAT, false, 0, 32+8*numPoints);
    gl.generateMipmap(gl.TEXTURE_2D);
    gl.bindFramebuffer(gl.FRAMEBUFFER, null);
// pick texture
    if(flag) gl.bindTexture(gl.TEXTURE_2D, texture2);
    else gl.bindTexture(gl.TEXTURE_2D, texture1);
```


# Rendering Loop III

```
    var r = 1024/texSize;
    gl.viewport(0, 0, r*texSize, r*texSize);
    gl.clear( gl.COLOR_BUFFER_BIT );
    gl.drawArrays( gl.TRIANGLE_STRIP, 0, 4 );
    gl.viewport(0, 0, texSize, texSize);
    gl.useProgram(program2);
// move particles in a random direction with wrap around
    for(var i=0; i<numPoints; i++) {
        vertices[4+i][0] += 0.01*(2.0*Math.random()-1.0);
       vertices[4+i][1] += 0.01*(2.0*Math.random()-1.0);
       if(vertices[4+i][0]>1.0) vertices[4+i][0]-= 2.0;
       if(vertices[4+i][0]<-1.0) vertices[4+i][0]+= 2.0;
       if(vertices[4+i][1]>1.0) vertices[4+i][1]-= 2.0;
       if(vertices[4+i][1]<-1.0) vertices[4+i][1]+= 2.0;
}
gl.bufferSubData(gl.ARRAY_BUFFER,  0, flatten(vertices));
```


# Rendering Loop IV

```
// swap textures
    flag = !flag;
    requestAnimFrame(render);
}
```


# Add Agent Behavior

- Move randomly
- Check color where particle is located
- If green particle sees a green component over 128 move to (0.5, 0.5)
- If magenta particle sees a red component over 128 move to (-0.5, -0.5)


# Diffusion Code

```
var color = new Uint8(4);
for(var i=0; i<numPoints/2; i++) {
        var x = Math.floor(511*(vertices[4+i][0]));
        var y = Math.floor(511*(vertices[4+i][1]));
        gl.readPixels(x, y, 1, 1, gl.RGBA, gl.UNSIGNED_BYTE, color);
       if(color[0]>128) {
             vertices[4+i][0] = 0.5;
             vertices[4+i][1] = 0.5;
    }
    for(var i=numPoints/2; i<numPoints; i++) {
        var x = Math.floor(511*(vertices[4+i][0]));
        var y = Math.floor(511*(vertices[4+i][1]));
        gl.readPixels(x, y, 1, 1, gl.RGBA, gl.UNSIGNED_BYTE, color);
        if(color[1]>128) {
            vertices[4+i][0] = -0.5;
            vertices[4+i][1] = -0.5;
    }
```

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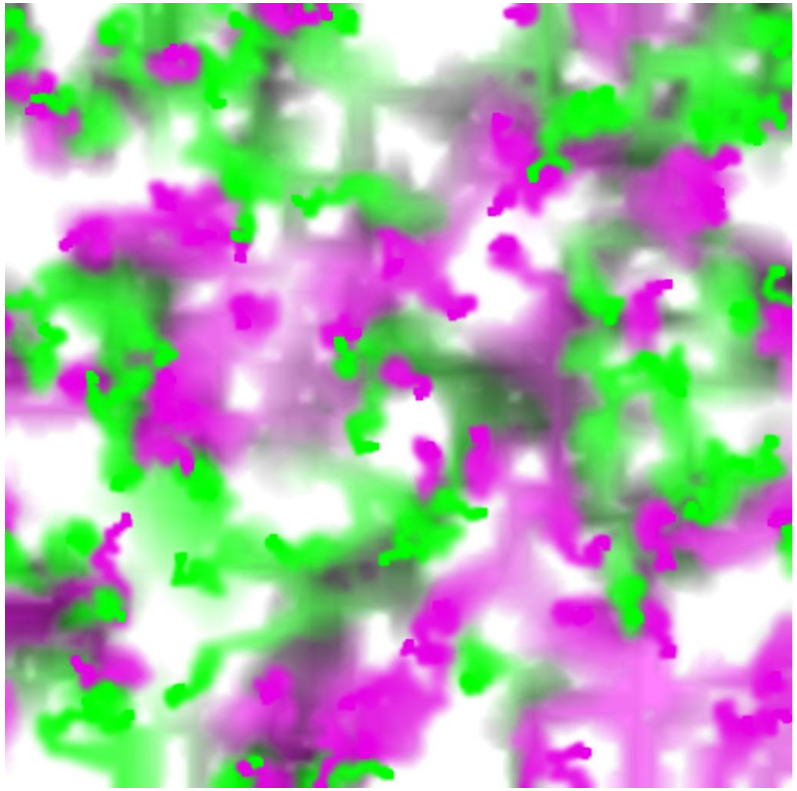
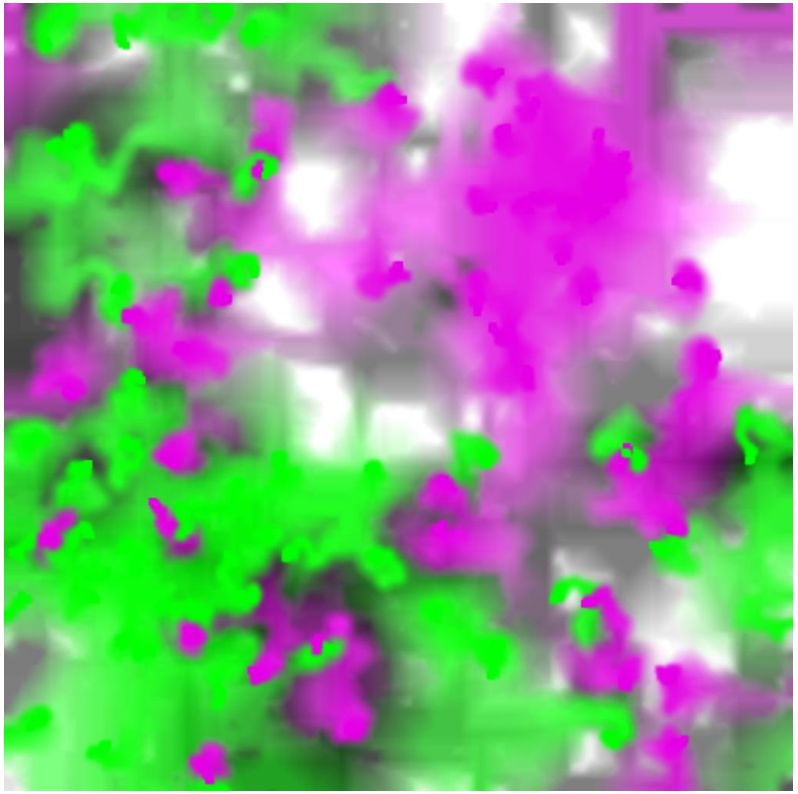
# Snapshots





without reading color

with reading color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# Picking by Color

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# 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 i;
varying vec4 fColor;
void main()
{
    vec4 c[7];
    c[0] = fColor;
    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);
```


# Fragment Shader

```
// no case statement in GLSL

   if(i==0) gl_FragColor = c[0];
   else if(i==1) gl_FragColor = c[1];
   else if(i==2) gl_FragColor = c[2];
   else if(i==3) gl_FragColor = c[3];
   else if(i==4) gl_FragColor = c[4];
   else if(i==5) gl_FragColor = c[5];
   else if(i==6) gl_FragColor = c[6];
}
```


# Setup

```
// Allocate a frame buffer object
   framebuffer = gl.createFramebuffer();
   gl.bindFramebuffer( gl.FRAMEBUFFER, framebuffer);
// Attach color buffer
   gl.framebufferTexture2D(gl.FRAMEBUFFER,
 gl.COLOR_ATTACHMENT0, gl.TEXTURE_2D, texture, 0);
 gl.bindFramebuffer(gl.FRAMEBUFFER, null);
```


# Event Listener

```
canvas.addEventListener("mousedown", function(){
        gl.bindFramebuffer(gl.FRAMEBUFFER, framebuffer);
    gl.clear( gl.COLOR_BUFFER_BIT);
    gl.uniform3fv(thetaLoc, theta);
    for(var i=0; i<6; i++) {
       gl.uniform1i(gl.getUniformLocation(program, "i"), i+1);
       gl.drawArrays( gl.TRIANGLES, 6*i, 6 );
    }
    var x = event.clientX;
    var y = canvas.height -event.clientY;
    gl.readPixels(x, y, 1, 1, gl.RGBA,
          gl.UNSIGNED_BYTE, color);
```


# Event Listener

```
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");
```


# Event Listener

```
 // return to default framebuffer
        gl.bindFramebuffer(gl.FRAMEBUFFER, null);
//send index 0 to fragment shader
        gl.uniform1i(gl.getUniformLocation(program, "i"), 0);
//normal render
        gl.clear( gl.COLOR_BUFFER_BIT );
        gl.uniform3fv(thetaLoc, theta);
        gl.drawArrays(gl.TRIANGLES, 0, 36);
    });
```


# Picking by Selection

- Possible with render-to-texture
- When mouse clicked do a off screen rendering with new viewing conditions that render only a small area around mouse
- Keep track of what gets rendered to this off screen buffer