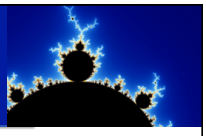
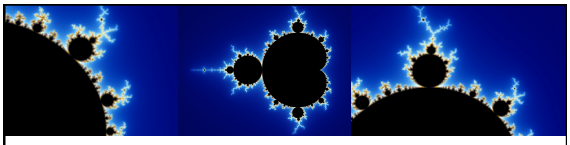
Computer Graphics



Interactivity

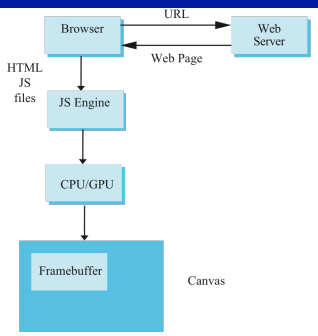


Animation

Callbacks

- Programming interface for event-driven input uses *callback functions* or *event listeners*
  - Define a callback for each event the graphics system recognizes
  - Browsers enters an event loop and responds to those events for which it has callbacks registered
  - The callback function is executed when the event occurs

Execution in a Browser



Execution in a Browser

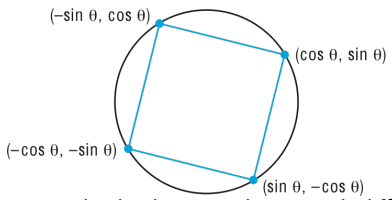
- Start with HTML file
  - Describes the page
  - May contain the shaders
  - Loads files
- Files are loaded asynchronously and JS code is executed
- Then what?
- Browser is in an event loop and waits for an event

onload Event

- What happens with our JS file containing the graphics part of our application?
  - All the "action" is within functions such as init() and render()
  - Consequently these functions are never executed and we see nothing
- Solution: use the onload window event to initiate execution of the init function
  - onload event occurs when all files read
  - window.onload = init;

Rotating Square

- Consider the four points



Animate display by rerendering with different values of θ

Simple but Slow Method

```
for(var theta = 0.0; theta <thetaMax; theta += dtheta; {

    vertices[0] = vec2(Math.sin(theta), Math.cos(theta));
    vertices[1] = vec2(Math.sin(theta), -Math.cos(theta));
    vertices[2] = vec2(-Math.sin(theta), -Math.cos(theta));
    vertices[3] = vec2(-Math.sin(theta), Math.cos(theta));

    gl.bufferSubData(……

    render();
}
```


Better Way

- Send original vertices to vertex shader
- Send θ to shader as a uniform variable
- Compute vertices in vertex shader
- Render recursively

Render Function

```
var thetaLoc = gl.getUniformLocation(program, "theta");

function render()
{
    gl.clear(gl.COLOR_BUFFER_BIT);
    theta += 0.1;
    gl.uniform1f(thetaLoc, theta);
    gl.drawArrays(gl.TRIANGLE_STRIP, 0, 4);

    render();
}
```


Vertex Shader

```
attribute vec4 vPosition;
uniform float theta;

void main()
{
    gl_Position.x = -sin(theta) * vPosition.x + cos(theta) * vPosition.y;
    gl_Position.y = sin(theta) * vPosition.y + cos(theta) * vPosition.x;
    gl_Position.z = 0.0;
    gl_Position.w = 1.0;
}
```


Double Buffering

- Although we are rendering the square, it always renders into a buffer that is not displayed
- Browser uses double buffering
  - Always display front buffer
  - Rendering into back buffer
  - Need a buffer swap
- Prevents display of a partial rendering

Triggering a Buffer Swap

- Browsers refresh the display at ~60 Hz
  - redisplay of front buffer
  - not a buffer swap
- Trigger a buffer swap though an event
- Two options for rotating square
  - Interval timer
  - requestAnimFrame

Interval Timer

- Executes a function after a specified number of milliseconds
  - Also generates a buffer swap

```
setInterval(render, interval);
```

  - May not be smooth animation
- Note an interval of 0 generates buffer swaps as fast as possible

requestAnimFrame

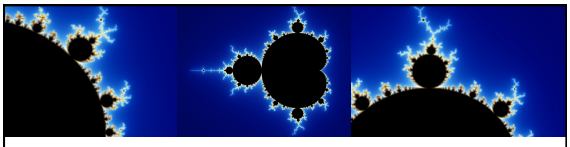
- Requests the browser to display the rendering the next time it wants to refresh the display and then call the render function recursively.

```
function render {

    gl.clear(gl.COLOR_BUFFER_BIT);
    theta += 0.1;
    gl.uniform1f(thetaLoc, theta);
    gl.drawArrays(gl.TRIANGLE_STRIP, 0, 4);

    window.requestAnimFrame(render);
}
```


Add an Interval

- After the buffer in browser is ready for displaying the rendering, display it. Then, wait for 100 ms before calling the render function again.

```
function render() {
  setTimeout(
            function() {
                requestAnimFrame(render);
                gl.clear(gl.COLOR_BUFFER_BIT);
                theta += 0.1;
                gl.uniform1f(thetaLoc, theta);
                gl.drawArrays(gl.TRIANGLE_STRIP, 0, 4);
            },
            100
    );
}
```

Event Driven Interaction

Objectives

- Introduce the basic input devices
  - Physical Devices
  - Logical Devices
  - Input Modes
- Event-driven input
- Programming event input with WebGL

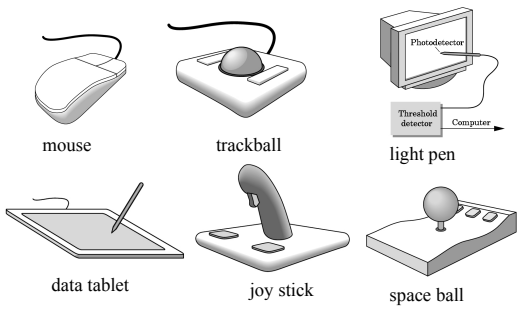
Project Sketchpad

- Ivan Sutherland (MIT 1963) established the basic interactive paradigm that characterizes interactive computer graphics:
  - User sees an *object* on the display
  - User points to (*picks*) the object with an input device (light pen, mouse, trackball)
  - Object changes (moves, rotates, morphs)
  - Repeat

Graphical Input

- Devices can be described either by
  - Physical properties
    - Mouse
    - Keyboard
    - Trackball
  - Logical Properties
    - What is returned to program via API
      - A position
      - An object identifier
- Modes
  - How and when input is obtained
    - Request or event

Physical Devices



Incremental (Relative) Devices

- Devices such as the data tablet return a position directly to the operating system
- Devices such as the mouse, trackball, and joy stick return incremental inputs (or velocities) to the operating system
  - Must integrate these inputs to obtain an absolute position
    - Rotation of cylinders in mouse
    - Roll of trackball
    - Difficult to obtain absolute position
    - Can get variable sensitivity

Input Modes

- Input devices contain a *trigger* which can be used to send a signal to the operating system
  - Button on mouse
  - Pressing or releasing a key
- When triggered, input devices return information (their *measure*) to the system
  - Mouse returns position information
  - Keyboard returns ASCII code

Request Mode

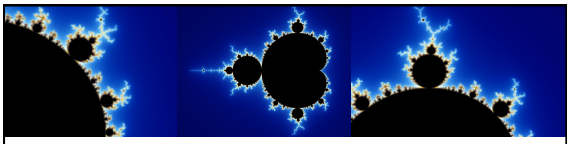
- Input provided to program only when user triggers the device
- Typical of keyboard input
  - Can erase (backspace), edit, correct until enter (return) key (the trigger) is depressed

Event Mode

- Most systems have more than one input device, each of which can be triggered at an arbitrary time by a user
- Each trigger generates an *event* whose measure is put in an *event queue* which can be examined by the user program

Event Types

- Window: resize, expose, iconify
- Mouse: click one or more buttons
- Motion: move mouse
- Keyboard: press or release a key
- Idle: nonevent
  - Define what should be done if no other event is in queue



Working with Callbacks

Objectives

- Learn to build interactive programs using event listeners
  - Buttons
  - Menus
  - Mouse
  - Keyboard
  - Reshape

Adding a Button

- Let's add a button to control the rotation direction for our rotating cube
- In the render function we can use a var direction which is true or false to add or subtract a constant to the angle

```
var direction = true; // global initialization

// in render()

if(direction) theta += 0.1;
else theta -= 0.1;
```


The Button

- In the HTML file

```
<button id="DirectionButton">Change Rotation Direction</button>
```

  - Uses HTML button tag
  - id gives an identifier we can use in JS file
  - Text "Change Rotation Direction" displayed in button
- Clicking on button generates a click event
- Note we are using default style and could use CSS or jQuery to get a prettier button

Button Event Listener

- We still need to define the listener
  - no listener and the event occurs but is ignored
- Two forms for event listener in JS file

```
var myButton = document.getElementById("DirectionButton");

myButton.addEventListener  ("click", function() {
                                        direction = !direction;
                                    }
                          );
```

```
document.getElementById("DirectionButton").onclick =
      function() {
          direction = !direction;
      };
```


onclick Variants

```
myButton.addEventListener("click", function() {
if (event.button == 0) { direction = !direction; }
});
```

```
myButton.addEventListener("click", function() {
if (event.shiftKey == 0) { direction = !direction; }
});
```

```
<button onclick="direction = !direction"></button>
```


Controlling Rotation Speed

```
var delay = 100;

function render()
{
    setTimeout(function() {
        requestAnimFrame(render);
        gl.clear(gl.COLOR_BUFFER_BIT);
        theta += (direction ? 0.1 : -0.1);
        gl.uniform1f(thetaLoc, theta);
        gl.drawArrays(gl.TRIANGLE_STRIP, 0, 4);
        },

        delay);
}
```


Menus

- Use the HTML select element
- Each entry in the menu is an option element with an integer value returned by click event

```
<select id="mymenu" size="3">
    <option value="0">Toggle Rotation Direction</option>
    <option value="1">Spin Faster</option>
    <option value="2">Spin Slower</option>
</select>
```


Menu Listener

```
var m = document.getElementById("mymenu");

m.addEventListener("click", function() {
  switch (m.selectedIndex) {
    case 0:
      direction = !direction;
      break;
    case 1:
      delay /= 2.0;
      break;
    case 2:
      delay *= 2.0;
      break;
    }
});
```


Using keydown Event

```
window.addEventListener("keydown", function() {

    switch (event.keyCode) {
        case 49: // '1' key
                direction = !direction;
                break;
        case 50: // '2' key
                delay /= 2.0;
                break;
        case 51: // '3' key
                delay *= 2.0;
                break;
  }
});
```

Don't Know Unicode

```
window.onkeydown = function(event) {

  var key = String.fromCharCode(event.keyCode);

  switch (key) {
    case '1':
          direction = !direction;
          break;
    case '2':
          delay /= 2.0;
          break;
    case '3':
          delay *= 2.0;
          break;
  }
};
```

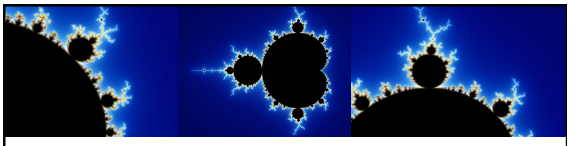

Slider Element

- Puts slider on page
  - Give it an identifier
  - Give it minimum and maximum values
  - Give it a step size needed to generate an event
  - Give it an initial value
- Use div tag to put below canvas

```
<div>
speed 0    <input id="slide" type="range"
  min="0" max="100" step="10" value="50" />  100
</div>
```


onchange Event Listener

```
document.getElementById("slide").onchange =
  function() { delay = event.srcElement.value; };
```

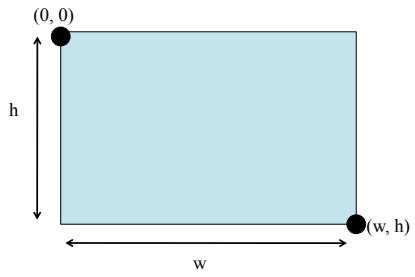



Position Input

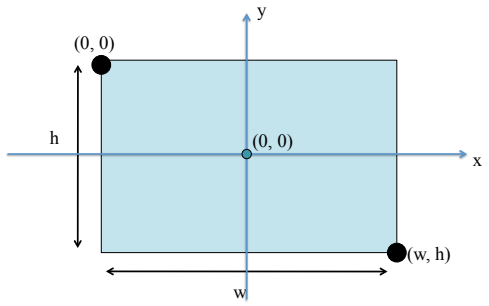
Objectives

- Learn to use the mouse to give locations
  - Must convert from position on canvas to position in application
- Respond to window events such as reshapes triggered by the mouse

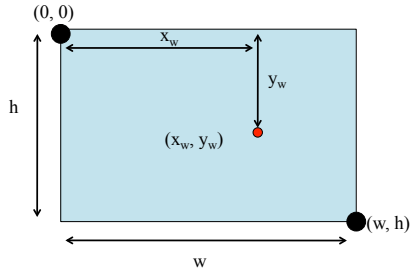
Window Coordinates



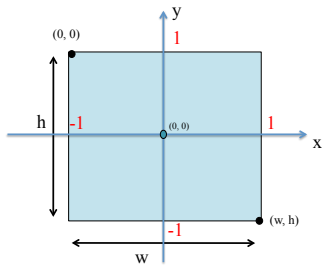
Clip Coordinates



Window Coordinates



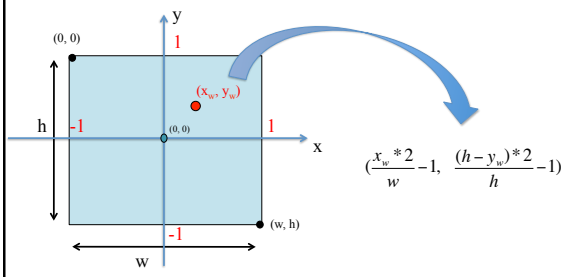
Clip Coordinates



$$(0,0) \rightarrow (-1,1)$$
$$(0,h) \rightarrow (-1,-1)$$
$$(w,0) \rightarrow (1,1)$$
$$(w,h) \rightarrow (1,-1)$$

$$x = \frac{x_w * 2}{w} - 1$$
$$y = \frac{(h - y_w) * 2}{h} - 1$$

Clip Coordinates



$$(\frac{x_w * 2}{w} - 1, \quad \frac{(h - y_w) * 2}{h} - 1)$$

Returning Position from Click Event

Canvas specified in HTML file of size
canvas.width x canvas.height

Returned window coordinates are event.clientX and event.clientY

```
// add a vertex to GPU for each click
canvas.addEventListener("click", function() {
    gl.bindBuffer(gl.ARRAY_BUFFER, vBuffer);

    var t = vec2(-1 + 2*event.clientX/canvas.width,
      -1 + 2*(canvas.height-event.clientY)/canvas.height);

    gl.bufferSubData(gl.ARRAY_BUFFER, sizeof['vec2']*index, t);
    index++;
});
```


Gl.bufferSubData

- Gl.bufferSubData: update a subset of a buffer object's data store

  void **glBufferSubData**(GLenum *target*,
  GLintptr *offset*,
  GLsizeiptr *size*,
  const GLvoid * *data*);

- *Target* - Specifies the target buffer object. The symbolic constant must be GL_ARRAY_BUFFER or GL_ELEMENT_ARRAY_BUFFER.
- *Offset* - Specifies the offset into the buffer object's data store where data replacement will begin, measured in bytes.
- *Size* - Specifies the size in bytes of the data store region being replaced.
- *Data* - Specifies a pointer to the new data that will be copied into the data store.
- glBufferSubData redefines some or all of the data store for the buffer object currently bound to *target*. Data starting at byte offset *offset* and extending for *size* bytes is copied to the data store from the memory pointed to by *data*. An error is thrown if *offset* and *size* together define a range beyond the bounds of the buffer object's data store.

CAD-like Examples

square.html: puts a colored square at location of each mouse click

triangle.html: first three mouse clicks define first triangle of triangle strip. Each succeeding mouse clicks adds a new triangle at end of strip

cad1.html: draw a rectangle for each two successive mouse clicks

cad2.html: draws arbitrary polygons

Window Events

- Events can be generated by actions that affect the canvas window
  - moving or exposing a window
  - resizing a window
  - opening a window
  - iconifying/deiconifying a window a window
- Note that events generated by other application that use the canvas can affect the WebGL canvas
  - There are default callbacks for some of these events

Reshape Events

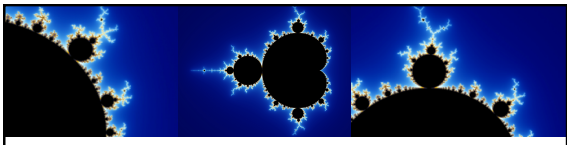
- Suppose we use the mouse to change the size of our canvas
- Must redraw the contents
- Options
  - Display the same objects but change size
  - Display more or fewer objects at the same size
- Almost always want to keep proportions

onresize Event

- Returns size of new canvas is available through window.innerHeight and window. innerWidth
- Use innerHeight and innerWidth to change canvas.height and canvas.width

Keeping Square Proportions

```
window.onresize = function() {
        var min = innerWidth;
        if (innerHeight < min) {
                min = innerHeight;
        }
        if (min < canvas.width || min < canvas.height) {
                gl.viewport(0, canvas.height-min, min, min);
        }
};
```

Picking

Objectives

- How do we identify objects on the display
- Overview three methods
  - selection
  - using an off-screen buffer and color
  - bounding boxes

Why is Picking Difficult?

- Given a point in the canvas how to map this point back to an object?
- Lack of uniqueness
- Forward nature of pipeline
- Take into account difficulty of getting an exact position with a pointing device

Selection

- Supported by fixed function OpenGL pipeline
- Each primitive is given an id by the application indicating to which object it belongs
- As the scene is rendered, the id's of primitives that render near the mouse are put in a hit list
- Examine the hit list after the rendering

Selection

- Implement by creating a window that corresponds to small area around mouse
  - We can track whether or not a primitive renders to this window
  - Do not want to display this rendering
  - Render off-screen to an extra color buffer or user back buffer and don't do a swap
- Requires a rendering which puts depths into hit record
- Possible to implement with WebGL

Picking with Color

- We can use gl.readPixels to get the color at any location in window
- Idea is to use color to identify object but
  - Multiple objects can have the same color
  - A shaded object will display many colors
- Solution: assign a unique color to each object and render off-screen
  - Use gl.readPixels to get color at mouse location
  - Use a table to map this color to an object

Picking with Bounding Boxes

- Both previous methods require an extra rendering each time we do a pick
- Alternative is to use a table of (axis-aligned) bounding boxes
- Map mouse location to object through table