Input and Interaction

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Objectives

- Introduce the basic input devices
  - Physical Devices
  - Logical Devices
  - Input Modes
- Event-driven input
- Introduce double buffering for smooth animations
- 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)

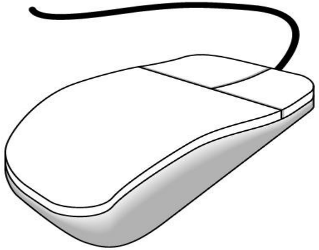
  Object changes (moves, rotates, morphs)

  Repeat

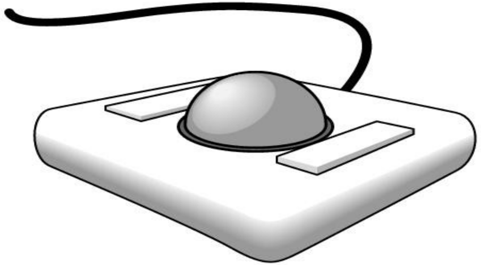
Graphical Input

- 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

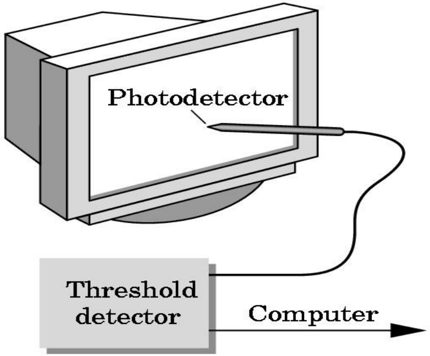
Physical Devices



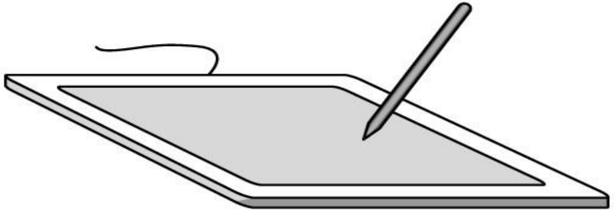
mouse



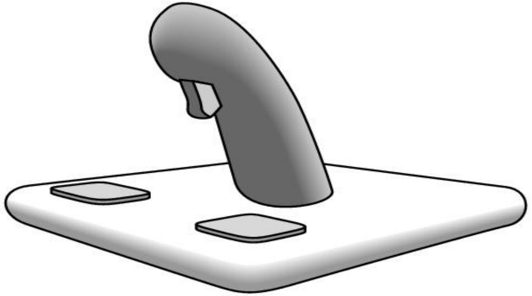
trackball



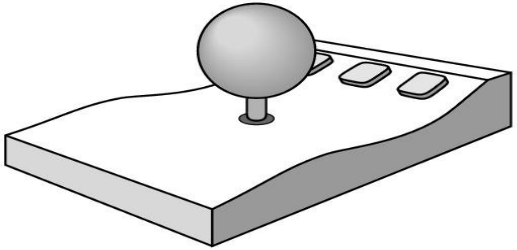
light pen



data tablet



joystick



space ball

Incremental (Relative) Devices

- Devices such as the data tablet return a position directly to the operating system
- Devices such as the mouse, trackball, and joystick 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

Logical Devices

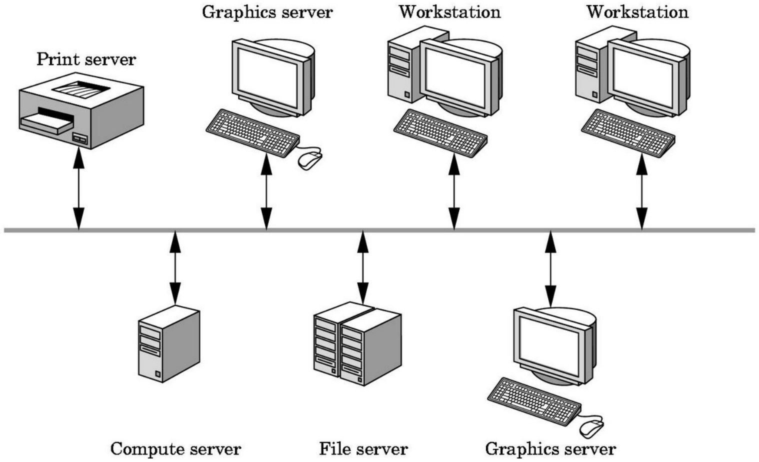
- Consider the C and C++ code
  - C++: **`cin >> x;`**
  - C: **`scanf (“%d”, &x);`**
- What is the input device?
  - Can’t tell from the code
  - Could be keyboard, file, output from another program
- The code provides *logical input*
  - A number (an **`int`**) is returned to the program regardless of the physical device

Graphical Logical Devices

- Graphical input is more varied than input to standard programs which is usually numbers, characters, or bits
- Two older APIs (GKS, PHIGS) defined six types of logical input
    - **Locator**: return a position
    - **Pick**: return ID of an object
    - **Keyboard**: return strings of characters
    - **Stroke**: return array of positions
    - **Valuator**: return floating point number
    - **Choice**: return one of n items

X Window Input

- The X Window System introduced a client-server model for a network of workstations
  - -**Client**: OpenGL program
  - -**Graphics Server**: bitmap display with a pointing device and a keyboard



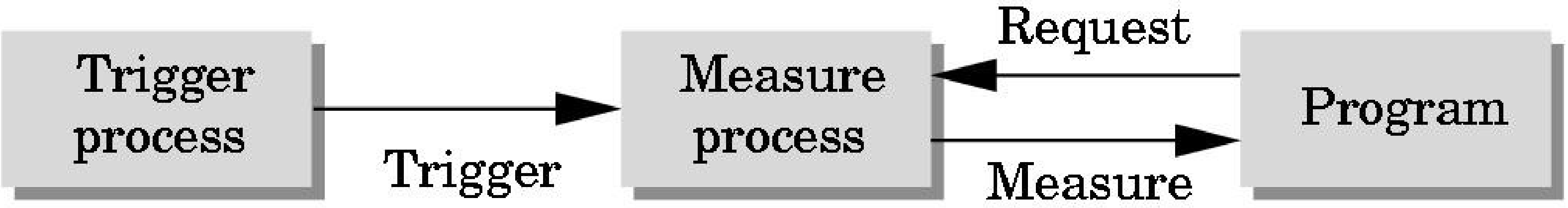
Input Modes

- 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

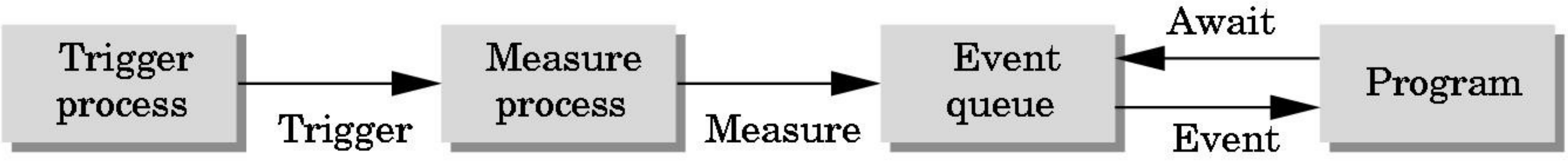
- Input provided to program only when user triggers the device
- Typical of keyboard input

  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

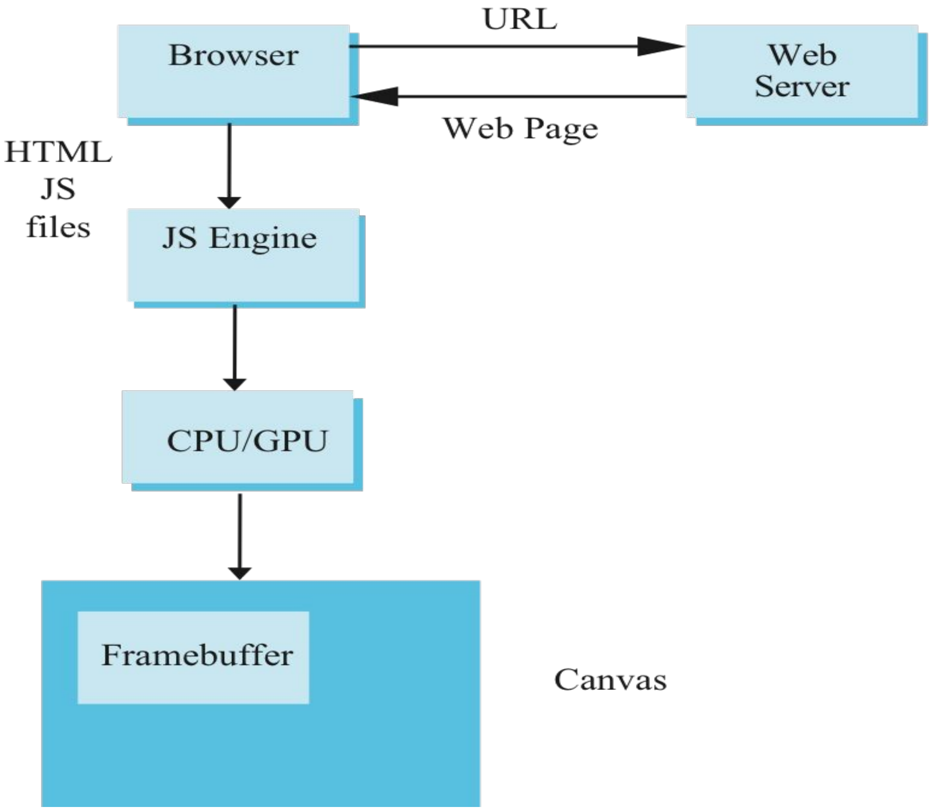
    Define what should be done if no other event is in queue

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

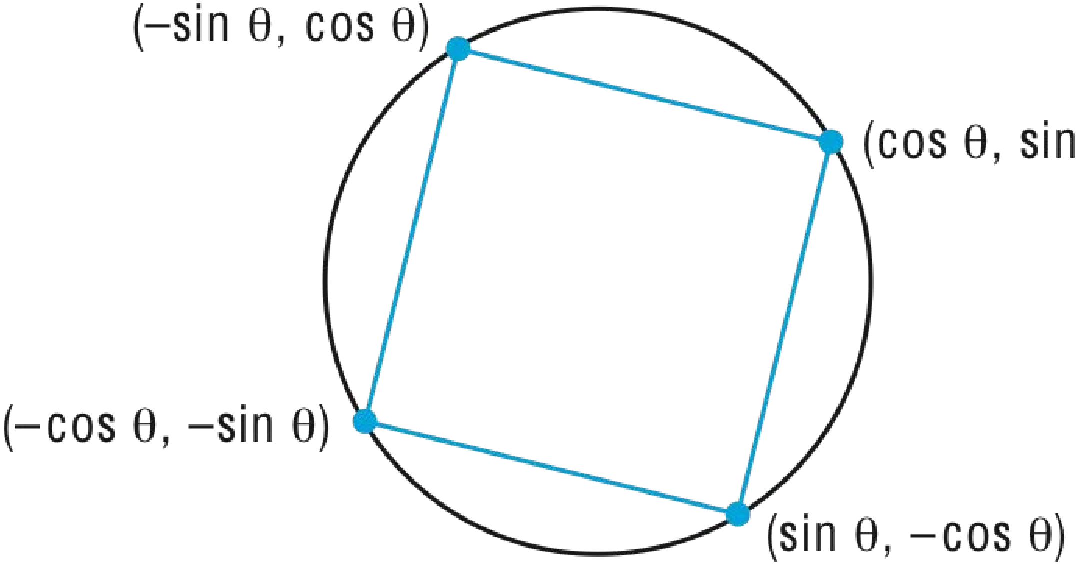
onload Event

- 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 on the unit circle



Animate display by re-rendering 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 goes always 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 through 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);
```

- Note an interval of 0 generates buffer swaps *as fast as possible*

requestAnimFrame

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

Add an Interval

```
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);
}
```

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>
```

Controling 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);
}
```

Video

rotatingSquare1

rotatingSquare2

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; };
```

Video

rotatingSquare3

Position Input

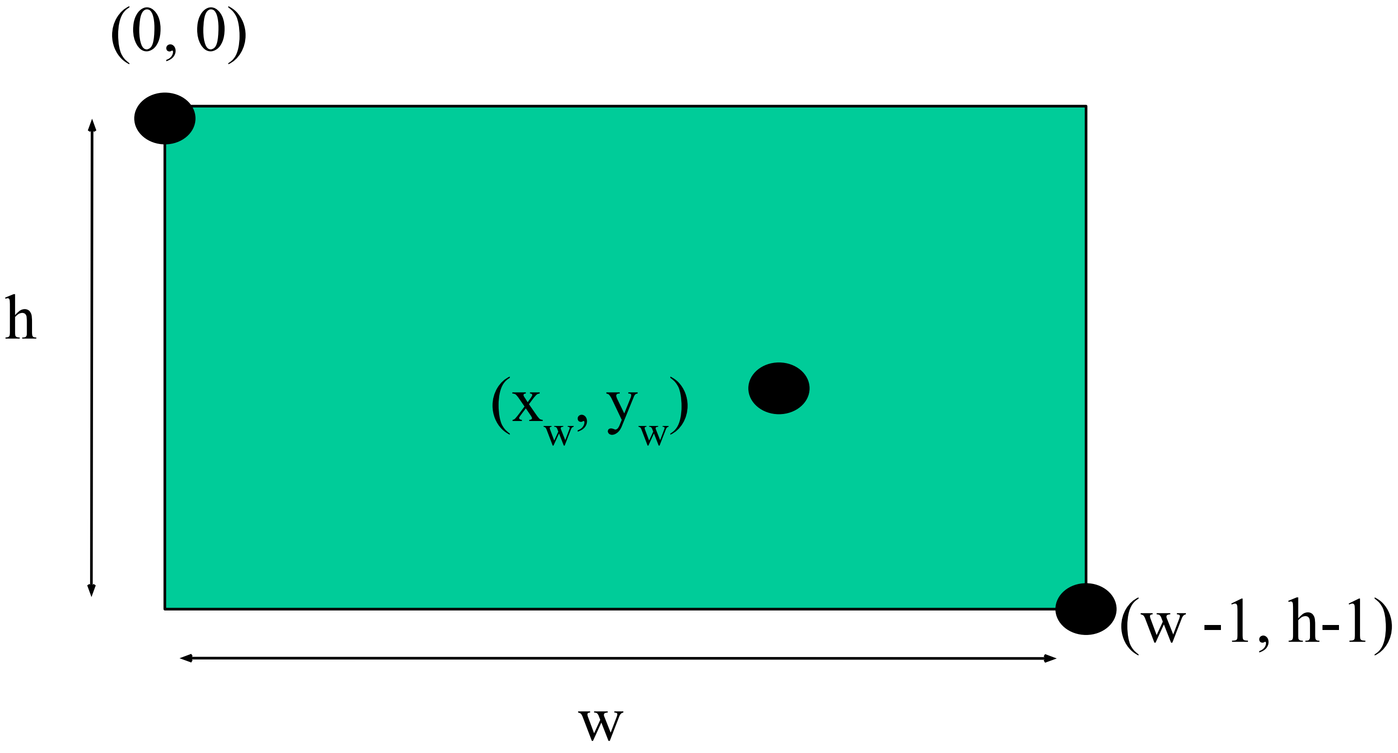
Objectives

- 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



Window to Clip Coordinates

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

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

$$x = -1 + \frac{2 * x_w}{w}$$

$$y = -1 + \frac{2 * (h - y_w)}{h}$$

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++;
});
```

CAD-like Examples

`www.cs.upt.ro/~sorin/webgl/Code/w04/`

`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

Video

www.cs.upt.ro/~sorin/webgl/Code/w04/

square

triangle

cad1

cad2

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`
- Example: maintaining a square display

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 do 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

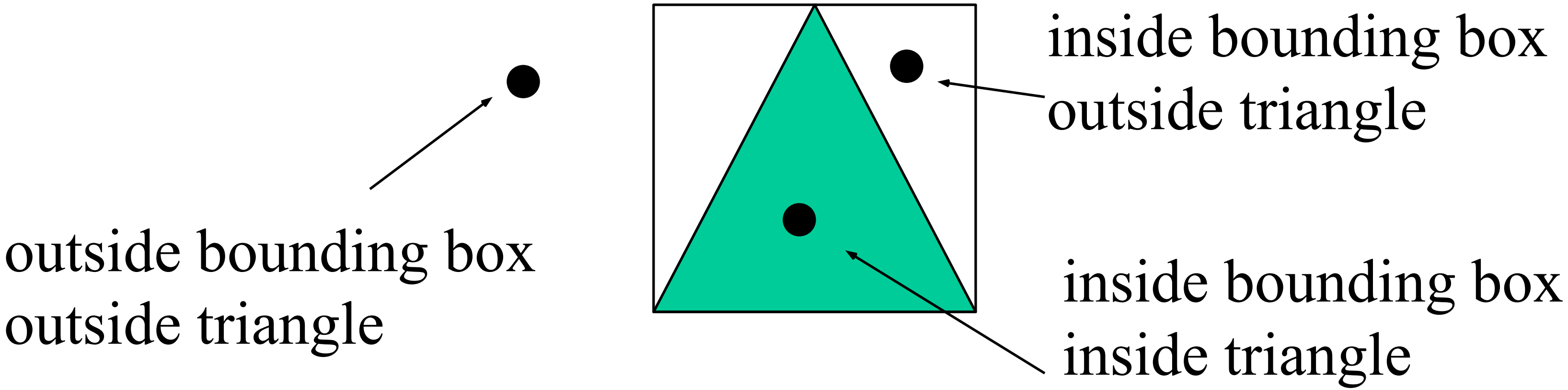
- Implement by creating a window that corresponds to small area around mouse
    - We can track whether or not a primitive renders to this window
    - Do not want to display this rendering
    - Render off-screen to an extra color buffer or user back buffer and don’t do a swap
- Requires a rendering 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



Geometry

Objectives

- Introduce the elements of geometry
  - Scalars
  - Vectors
  - Points
- Develop mathematical operations among them in a coordinate-free manner
- Define basic primitives
  - Line segments
  - Polygons

Basic Elements

- Geometry is the study of the relationships among objects in an n-dimensional space
  - In computer graphics, we are interested in objects that exist in three dimensions
- Want a minimum set of primitives from which we can build more sophisticated objects
- We will need three basic elements
  - Scalars
  - Vectors
  - Points

Coordinate-Free Geometry

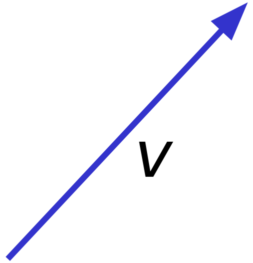
- When we learned simple geometry, most of us started with a Cartesian approach
  - Points were at locations in space **p**=(x,y,z)
  - We derived results by algebraic manipulations involving these coordinates
- This approach was nonphysical
  - Physically, points exist regardless of the location of an arbitrary coordinate system
  - Most geometric results are independent of the coordinate system
  - Example: Euclidean geometry: two triangles are identical if two corresponding sides and the angle between them are identical

Scalars

- Need three basic elements in geometry
  - Scalars, Vectors, Points
- Scalars can be defined as members of sets which can be combined by two operations (addition and multiplication) obeying some fundamental axioms (associativity, commutativity, inverses)
- Examples include the real and complex number systems under the ordinary rules with which we are familiar
- Scalars alone have no geometric properties

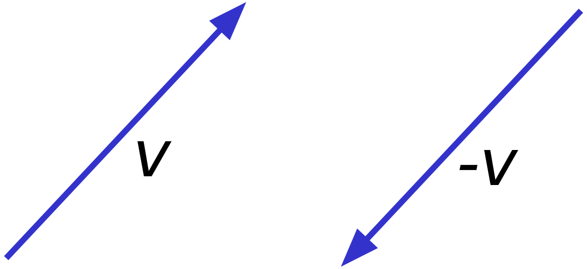
Vectors

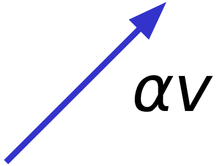
- Physical definition: a vector is a quantity with two attributes
    - Direction
    - Magnitude
- Examples include
    - Force
    - Velocity
    - Directed line segments
        - Most important example for graphics
        - Can map to other types

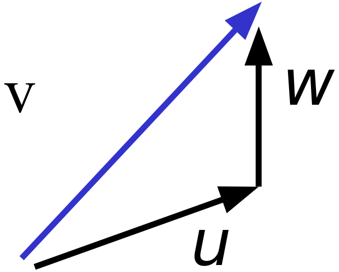


Vector Operations

- Every vector has an inverse
  - Same magnitude but points in opposite direction
- Every vector can be multiplied by a scalar
- There is a zero vector
  - Zero magnitude, undefined orientation
- The sum of any two vectors is a vector
  - Use head-to-tail axiom







Linear Vector Spaces

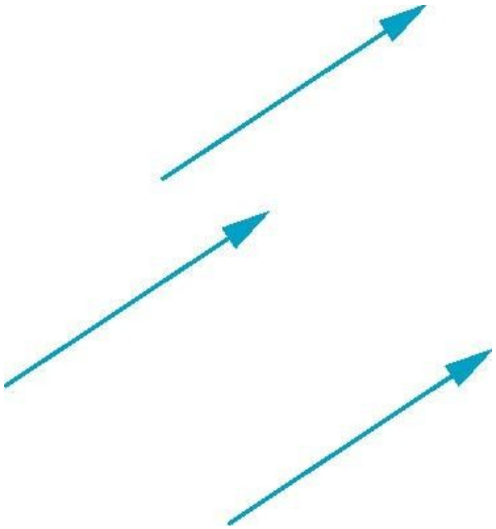
- Mathematical system for manipulating vectors
- Operations
  - Scalar-vector multiplication $u=\alpha v$
  - Vector-vector addition: $w=u+v$
- Expressions such as

  $v=u+2w-3r$

Make sense in a vector space

Vectors Lack Position

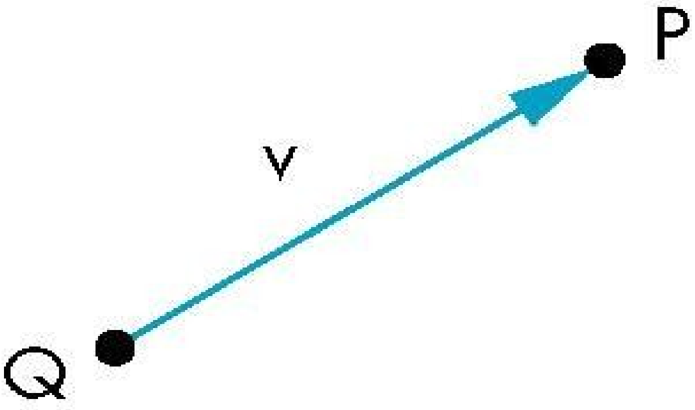
- These vectors are identical
  - -Same length and magnitude



- Vectors spaces insufficient for geometry
  - -Need points

Points

- Location in space
- Operations allowed between points and vectors
  - -Point-point subtraction yields a vector
  - -Equivalent to point-vector addition



$v=P-Q$

$P=v+Q$

Affine Spaces

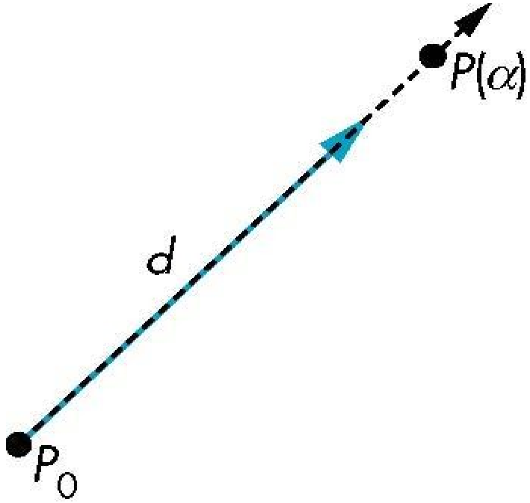
- Point + a vector space
- Operations
  - Vector-vector addition
  - Scalar-vector multiplication
  - Point-vector addition
  - Scalar-scalar operations
- For any point define

-1 • P = P

-0 • P = **0** (zero vector)

Lines

- Consider all points of the form
  - $P(\alpha)=P_0 + \alpha\, \mathbf{d}$
  - Set of all points that pass through P_0 in the direction of the vector **d**



Parametric Form

- This form is known as the parametric form of the line
    - -More robust and general than other forms
    - -Extends to curves and surfaces
- Two-dimensional forms
    - -Explicit: $y = mx + h$
    - -Implicit: $ax + by + c = 0$
    - -Parametric:

$$x(\alpha) = \alpha x_0 + (1-\alpha)x_1$$

$$y(\alpha) = \alpha y_0 + (1-\alpha)y_1$$

Rays and Line Segments

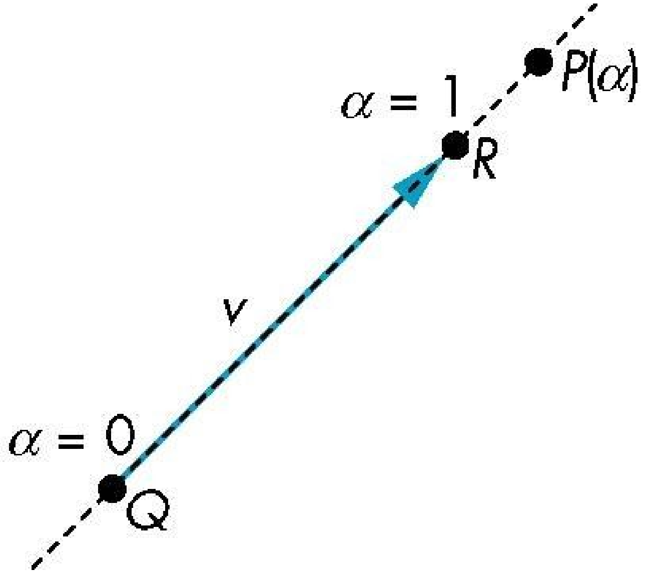
- If $\alpha >= 0$, then $P(\alpha)$ is the *ray* leaving P_0 in the direction **d**

If we use two points to define v, then

$P(\alpha) = Q + \alpha (R-Q)=Q+\alpha v$

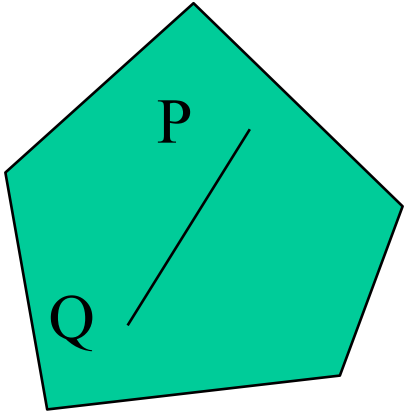
$=\alpha R + (1-\alpha)Q$

For $0<=\alpha<=1$ we get all the points on the *line segment* joining R and Q

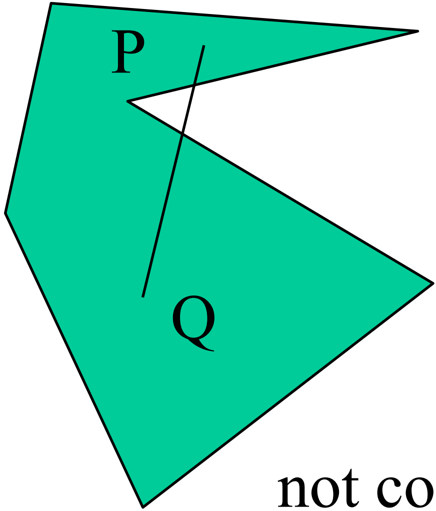


Convexity

- An object is *convex* iff for any two points in the object all points on the line segment between these points are also in the object



convex



not convex

Affine Sums

- Consider the “sum”

$P=\alpha_1 P_1+\alpha_2 P_2+\ldots..+\alpha_n P_n$

Can show by induction that this sum makes sense iff

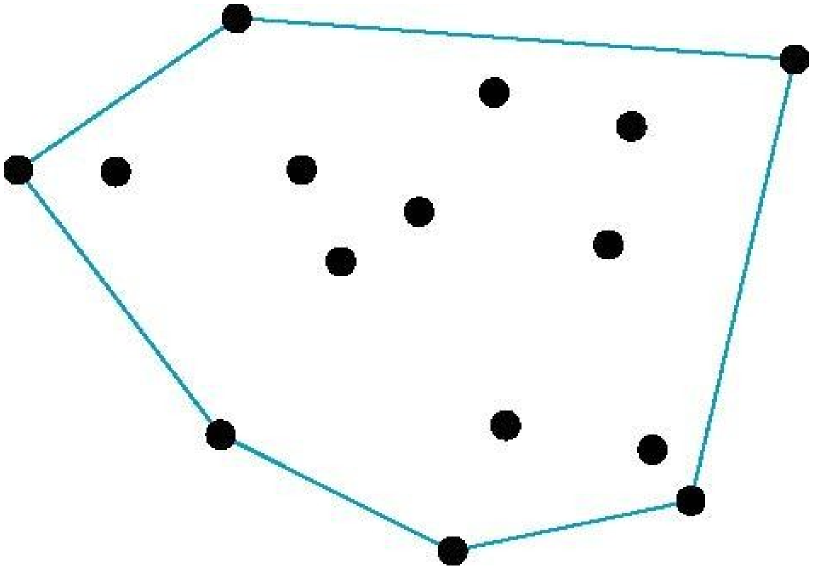
$\alpha_1+\alpha_2+\ldots..\alpha_n=1$

in which case we have the *affine sum* of the points $P_1, P_2, \ldots.. P_n$

- If, in addition, $\alpha_i >= 0$, we have the *convex hull* of $P_1, P_2, \ldots.. P_n$

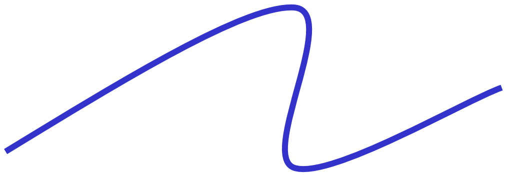
Convex Hull

- Smallest convex object containing $P_1, P_2, \ldots.. P_n$
- Formed by “shrink wrapping” points

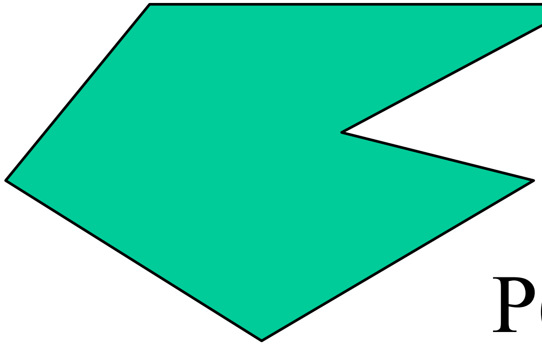


Curves and Surfaces

- Curves are one parameter entities of the form $P(\alpha)$ where the function is nonlinear
- Surfaces are formed from two-parameter functions $P(\alpha, \beta)$
  - -Linear functions give planes and polygons



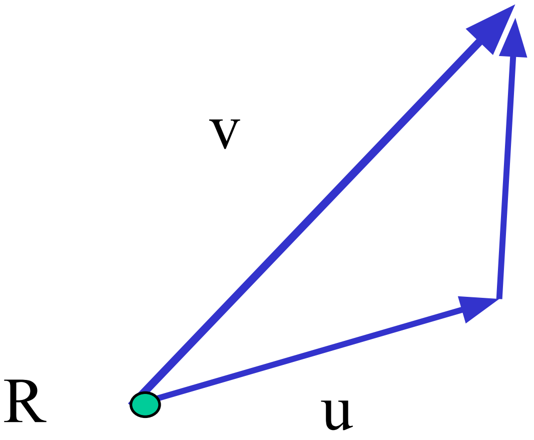
$P(\alpha)$



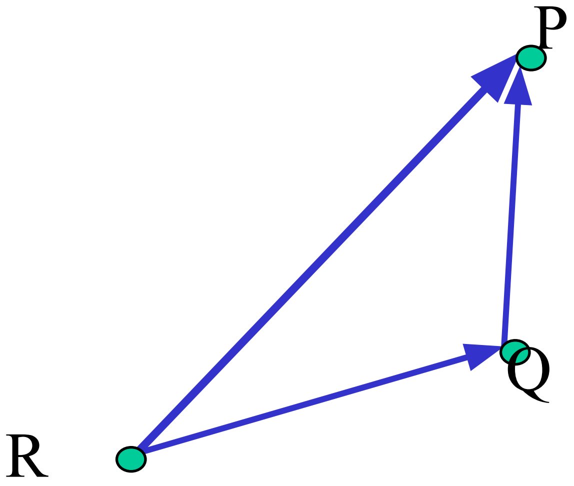
$P(\alpha, \beta)$

Planes

- A plane can be defined by a point and two vectors or by three points

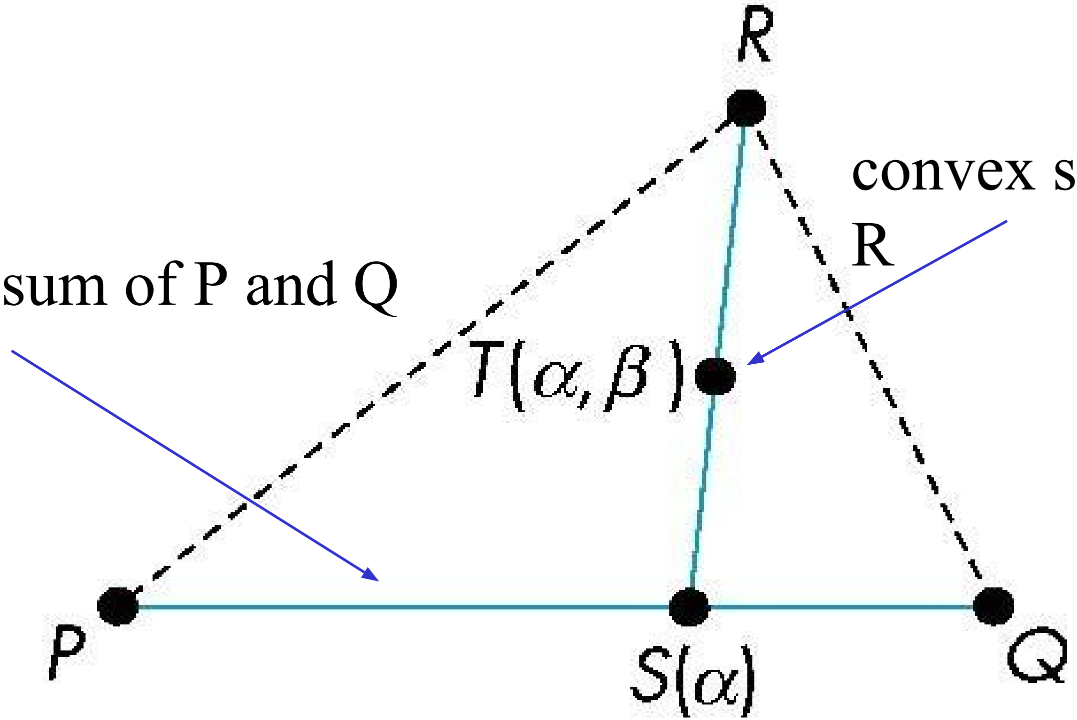


$P(\alpha,\beta)=R+\alpha u+\beta v$



$P(\alpha,\beta)=R+\alpha(Q-R)+\beta(P-Q)$

Triangles



convex sum of S(α) and R

convex sum of P and Q

for 0<=α,β<=1, we get all points in triangle

Barycentric Coordinates

Triangle is convex so any point inside can be represented as an affine sum

$P(\alpha_{1,}\ \alpha_{2,}\ \alpha_3)=\alpha_1 P+\alpha_2 Q+\alpha_3 R$

where

$\alpha_1 + \alpha_2 + \alpha_3 = 1$

$\alpha_i >= 0$

The representation is called the **barycentric coordinate** representation of P

Normals

- In three dimensional spaces, every plane has a vector n perpendicular or orthogonal to it called the **normal vector**
- From the two-point vector form $P(\alpha,\beta)=P+\alpha u+\beta v$, we know we can use the cross product to find $n = u \times v$ and the equivalent form

$(P(\alpha, \beta)-P) \cdot n=0$