02561 Computer Graphics

Animation and Interaction

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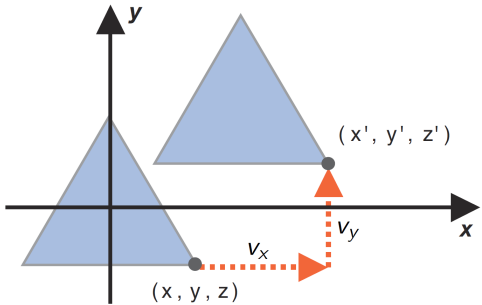
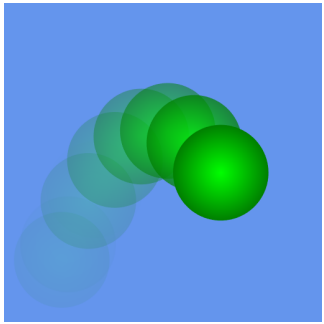
Making things move

- We can move things by translation:





- Add a translation vector $\boldsymbol{v} = (v_x, v_y, v_z)$ to all vertex positions $\boldsymbol{p} = (x, y, z)$ of an object. We can do this in a vertex shader.
- The `gl_Position` $\boldsymbol{p}' = (x', y', z')$ returned by the vertex shader is then

$$\boldsymbol{p}' = \boldsymbol{p} + \boldsymbol{v}\,.$$

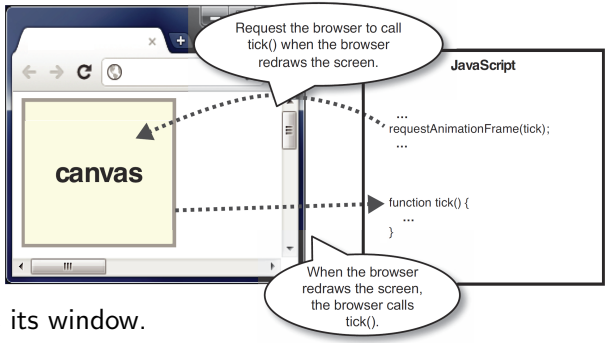
- We make $\boldsymbol{v}$ available in the vertex shader using a uniform variable.

Drawing repeatedly

- Draw when resources are available.
- Avoid queuing up of draw calls. Use:

  `requestAnimationFrame(callback);`

  where `callback` is a function called when the browser redraws its window.



- To draw repeatedly, use

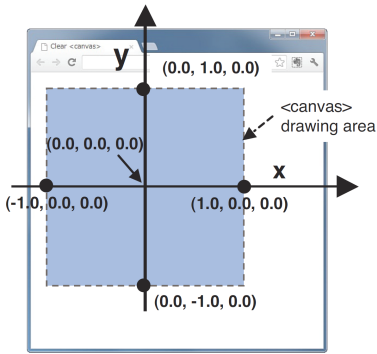
```
window.onload = function init()
{
  ⋮

  function animate() { render(gl, numPoints); requestAnimationFrame(animate); }
  animate();
}
function render(gl, numPoints)
{
  gl.clear(gl.COLOR_BUFFER_BIT);
  gl.drawArrays(..., 0, numPoints);
}
```

Controlling the movement

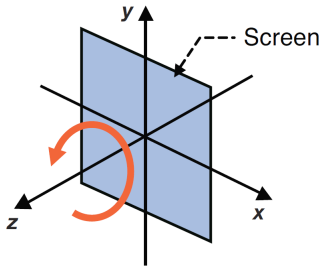
- Use simplistic Newtonian physics.
- Choose a velocity $\boldsymbol{w}$ for your moving object.
- If $\boldsymbol{v}$ is the translation vector of the object, then for every frame: $\boldsymbol{v}_{t+1} = \boldsymbol{v}_t + \boldsymbol{w}$.
- The browser refresh rate (frame rate) is commonly 60 fps (frames per second).
- Recall the default coordinate system.
- If $w_y = 1$ units per frame, the object will be moving through 30 canvases per second!
- Moving through an 0.3 part of the canvas ($w_y = 0.01$) is usually more appropriate.
- Moving back and forth:

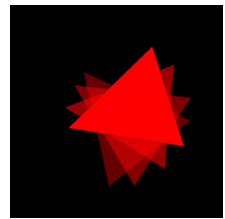
$$\begin{aligned} \boldsymbol{v}_{t+1} &= \boldsymbol{v}_t + \boldsymbol{w}_t \\ \boldsymbol{w}_{t+1} &= \operatorname{sgn}(1 - r - |\boldsymbol{v}_t|)\boldsymbol{w}_t \,. \end{aligned}$$

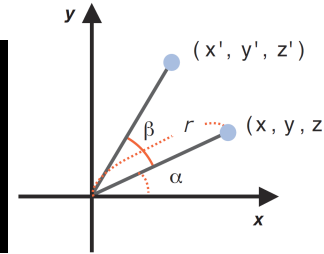
where r is for example the radius of the object.



Rotational movement (2D)







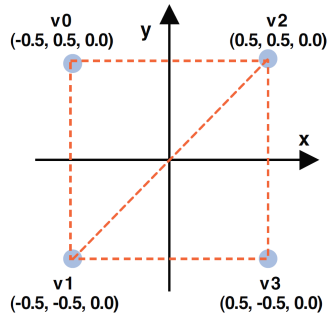
- In 2D, we usually rotate around the z-axis.
- We can then work in polar coordinates: $\boldsymbol{p} = (x, y, z) = (r\cos\alpha, r\sin\alpha, z)$.
- Then, after rotation by the angle β, we have (using angle addition formulae)

$$\boldsymbol{p}' = \begin{bmatrix} r\cos(\alpha+\beta) \\ r\sin(\alpha+\beta) \\ z \end{bmatrix} = r \begin{bmatrix} \cos\alpha\cos\beta - \sin\alpha\sin\beta \\ \sin\alpha\cos\beta + \cos\alpha\sin\beta \\ 0 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ z \end{bmatrix} = \cos\beta \begin{bmatrix} x \\ y \\ 0 \end{bmatrix} + \sin\beta \begin{bmatrix} -y \\ x \\ 0 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ z \end{bmatrix}.$$

- We make β available in the vertex shader using a uniform variable.

Orbital angular velocity

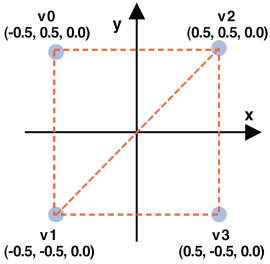
- Choose an orbital angular velocity ω for rotational movement: $\beta_{t+1} = \beta_t + \omega$.
- Consider a square with $x \in [-\frac{1}{2}, \frac{1}{2}]$ and $y \in [-\frac{1}{2}, \frac{1}{2}]$.
- The radius of its circumcircle is $r = \frac{\sqrt{2}}{2}$.
- The browser frame rate is commonly 60 fps.
- For $\omega = 1$ radians per frame, the square would do $\frac{60}{2\pi} \approx 9.5$ full rotations per second.
- The vertices would move $60\frac{\sqrt{2}}{2} \approx 42$ distance units (21 canvases) per second.
- Around one tenth of a full rotation per second ($\omega = 0.01$) is usually more appropriate.

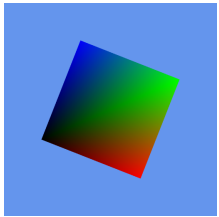


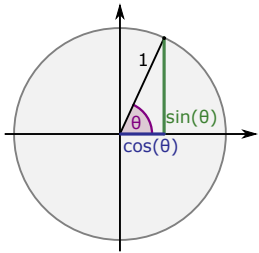
- We could then implement our tick function as follows:

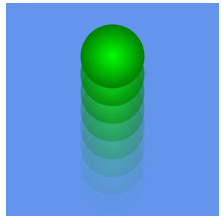
```
var betaLoc = gl.getUniformLocation(program, "beta");
var beta = 0.0;
function animate() {
  beta += 0.01;          gl.uniform1f(betaLoc, beta);
  render(gl, numPoints); requestAnimationFrame(animate);
}
```

Exercises: simple animation (W01P4, W01P5)



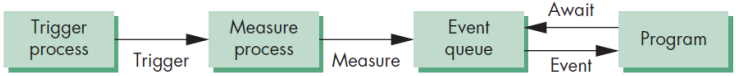






- Draw repeatedly (`requestAnimationFrame`).
- Draw a quad (`gl.TRIANGLES`, `gl.TRIANGLE_STRIP`, or `gl.TRIANGLE_FAN`).
- Use a uniform angle (β) and implement rotational motion in the vertex shader.
- Draw a circle (`gl.TRIANGLE_FAN`, see slide from Week 1).
- Use a uniform translation vector ($\boldsymbol{v}$, or offset v_y) and implement back and forth motion in the vertex shader.

Interaction through input events



- Event-handling callback functions: "event listeners".
- Event listeners can be added to any element of a webpage.
- Example (listen for canvas mouse clicks):
  - In webpage HTML source

```
<canvas id="webgl" width="512" height="512">Please use a browser that supports HTML5 canvas.</canvas>
```

  - In JavaScript init function

```
var canvas = document.getElementById("webgl");
canvas.addEventListener("click", function (ev) {

    ⋮      // my callback function

});
```

- The list of events that we can listen for is extensive. Examples:

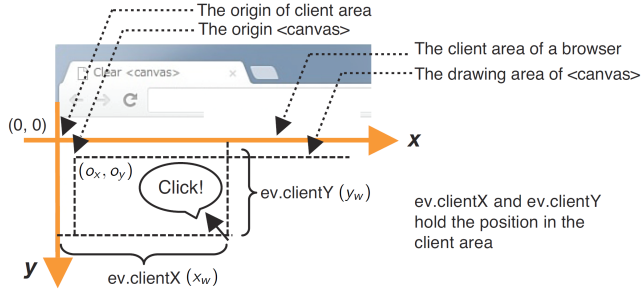
click, mousedown, mouseup, mousemove, keypress, keydown, keyup, touchstart, touchmove, touchend, ...

  - https://www.w3schools.com/jsref/dom_obj_event.asp

Position input

- Let's make the bouncing ball chase the mouse.
- We need the position of each mouse event. [**A**: 3.7]

$$\left(2\frac{x_w}{w} - 1,\ 2\frac{h - y_w - 1}{h} - 1\right)$$




```
var offset = vec2(0.0, 0.0);    // v_t
var velocity = vec2(0.0, 0.0);  // w_t
var mousepos = vec2(0.0, 0.0);
canvas.addEventListener("mousemove", function (ev) {
  mousepos = vec2(2*ev.clientX/canvas.width - 1, 2*(canvas.height - ev.clientY - 1)/canvas.height - 1);
  velocity = vec2((mousepos[0] - offset[0])*speed, (mousepos[1] - offset[1])*speed);
});
```

- Shift of origin between client area and canvas: $\left(2\frac{x_w - o_x}{w} - 1,\ 2\frac{h - (y_w - o_y) - 1}{h} - 1\right)$
- Retrieve the bounding box of the canvas in the client area and use it for correction:

```
canvas.addEventListener("mousemove", function (ev) {
  var bbox = ev.target.getBoundingClientRect();
  mousepos = vec2(2*(ev.clientX - bbox.left)/canvas.width - 1, 2*(canvas.height - ev.clientY + bbox.top - 1)/canvas.height - 1);
  velocity = vec2((mousepos[0] - offset[0])*speed, (mousepos[1] - offset[1])*speed);
});
```

Vertex buffer pre-allocation

- Suppose we would like to draw a point for every mouse click.
- GPU memory allocation for buffer data is expensive. So we should pre-allocate.
- When the data is not known in advance, we choose a buffer size (in bytes).
- In the init function

```
var max_verts = 1000;
var index = 0; var numPoints = 0;
var vBuffer = gl.createBuffer();
gl.bindBuffer(gl.ARRAY_BUFFER, vBuffer);
gl.bufferData(gl.ARRAY_BUFFER, max_verts*sizeof['vec2'], gl.STATIC_DRAW);
```

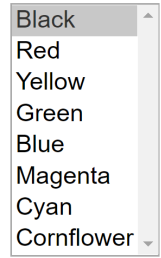
- We can then later insert data from a position vector p at an index.
- In an event callback function

```
gl.bufferSubData(gl.ARRAY_BUFFER, index*sizeof['vec2'], flatten(p));
numPoints = Math.max(numPoints, ++index); index %= max_verts;
```

Buttons and selection menus

- Create a user interface for your program using HTML.
- Add buttons and selection menus.

```
<select id="colorMenu" size="8">
    <option value="0" selected>Black</option>
    :
    <option value="7">Cornflower</option>
</select>
<select id="clearMenu" size="1">
    <option value="0">Black</option>
    :
    <option value="7" selected>Cornflower</option>
</select><br/>
<button id="clearButton">clear canvas</button>
```

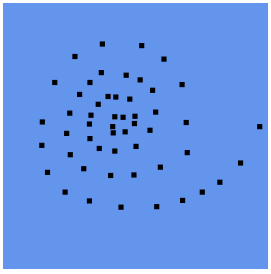


- Define a colors array in JavaScript [**A**: 3.10], then

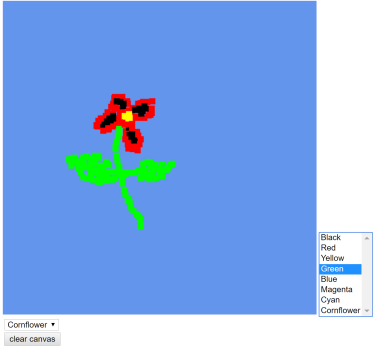
```
var clearMenu = document.getElementById("clearMenu");
var clearButton = document.getElementById("clearButton");
clearButton.addEventListener("click", function(event) {
  var bgcolor = colors[clearMenu.selectedIndex];
  gl.clearColor(bgcolor[0], bgcolor[1], bgcolor[2], bgcolor[3]);

  ...

});
```

Exercises: simple interaction (W02P1, W02P2)

- Pre-allocate a buffer for vertex positions.
- Add an event listener to the canvas retrieving the position of mouse clicks.
- Insert coordinates of each clicked point into the pre-allocated buffer.



- Pre-allocate a buffer for vertex colors.
- Add selection menus and clear button and associated click event listener(s).
- Insert the currently selected RGBA color into the pre-allocated color buffer for each clicked point.
- Let the clear button clear the canvas with the currently selected clear color (restart insertion of points at index 0).



Draw mode and drawing all objects as triangles

- With one large vertex buffer, we can draw many different shapes.

  `gl.drawArrays(draw_mode, index_offset, no_of_vertices);`

- We either need to know what parts of the vertex buffer to draw with a particular draw mode, or we need to specify all objects for the same draw mode.
- In our drawing program, let us specify all objects as triangles.
- A point then consists of 6 vertices (2 triangles). For vertex positions:

```
function add_point(array, point, size)
{
  const offset = size/2;
  var point_coords = [ vec2(point[0] - offset, point[1] - offset), vec2(point[0] + offset, point[1] - offset),
                       vec2(point[0] - offset, point[1] + offset), vec2(point[0] - offset, point[1] + offset),
                       vec2(point[0] + offset, point[1] - offset), vec2(point[0] + offset, point[1] + offset) ];
  array.push.apply(array, point_coords);
}
```

- Similarly, we need to add the color of the point into a color buffer (same color for each vertex).
- To draw a circle using `gl.TRIANGLES`, two additional vertices are needed for each vertex in the corresponding triangle fan.