02561 Computer Graphics

Benefits of the browser environment

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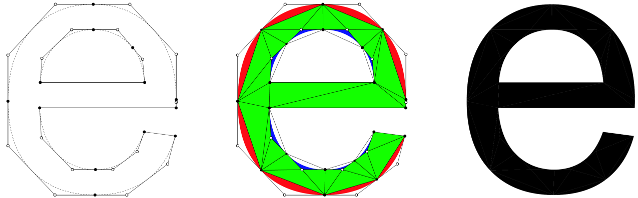
September 2020

How to render text properly?

- Reading text is critical to civilization.
- Rendering text properly is important.
- Scaling an image of a letter is suboptimal: (up) s s S S S S S s s (down)
- Text should be rendered in vector graphics. Quality is then resolution independent.
- Characters (glyphs) are usually specified by closed paths of parametric curves.



- Browsers are good at text rendering. It's an important part of their job.
- Let's see if we can exploit this.

Reference

- Loop, C., and Blinn, J. Resolution independent curve rendering using programmable graphics hardware. *ACM Transactions on Graphics (SIGGRAPH 2005) 24*(3), pp. 1000–1009. July 2005.

Rendering 2D text in WebGL

- Head Up Display (HUD)
  - a transparent display originally developed for aircrafts.
  - Present data without requiring users to look away from their usual viewpoints.
  - Overlay textual information on a 3D scene.

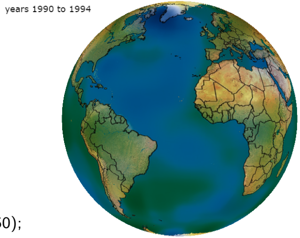
The pilot's view through a Rockwell Collins HGS head-up display.

- How to make a HUD in WebGL:
  - Create a 2D canvas element that can exploit the browser's text rendering capabilities.
  - Place the 2D canvas on top of the WebGL canvas. HTML example:

```
<canvas id="webgl" width="960" height="540" style="position: absolute; z-index: 0">No HTML5 canvas.</canvas>
<canvas id="hud" width="960" height="540" style="position: absolute; z-index: 1"></canvas>
```

  - Writing in the HUD in Javascript:

```
function init() {
        var hud = document.getElementById('hud');
        var ctx = hud.getContext('2d');
        .
        .
        .
}
function draw2D(ctx, year) {
        ctx.clearRect(0, 0, 960, 540);
        ctx.font = '18px "Verdana"'; ctx.fillStyle = 'rgba(0, 0, 0, 1)';
        ctx.fillText('years ' + year.toString() + ' to ' + (year + 4).toString(), 120, 50);
}
```

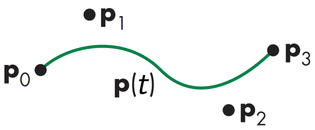


Parametric curves

- A parametric curve is a vector valued function of a single variable.
- Example: rational nth degree power basis curve

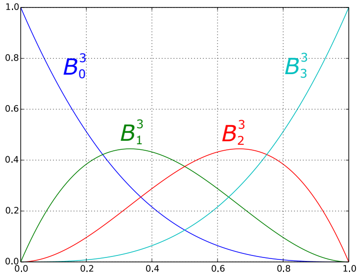
$$C(t) = \boldsymbol{Ct}\,, \quad \boldsymbol{C} = \begin{bmatrix} x_0 & \cdots & x_n \\ y_0 & \cdots & y_n \\ w_0 & \cdots & w_n \end{bmatrix}, \quad \boldsymbol{t} = \begin{bmatrix} 1 & t & \cdots & t^n \end{bmatrix}^T, \quad t \in [0,1]\,.$$

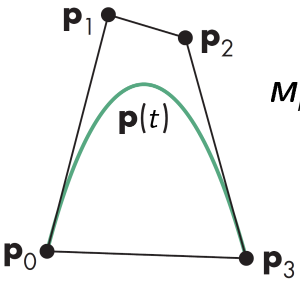
- The vector $C(t) = \begin{bmatrix} x & y & w \end{bmatrix}^T$ is in **homogeneous coordinates**.
  This means that the position in the plane is $\boldsymbol{p} = \left(\frac{x}{w}, \frac{y}{w}\right)$.
- The idea of this construction is to enable matrix representation of rational curves.



Bézier curves

- Bernstein basis functions: $B_i^n(t) = \binom{n}{i}(1-t)^{n-i}t^i$.
- Bézier curve:
  $$B(t) = \boldsymbol{B}\left[\begin{array}{cccc} B_0^n(t) & B_1^n(t) & \cdots & B_n^n(t) \end{array}\right]^T, \quad \boldsymbol{B} = \left[\begin{array}{cccc} \boldsymbol{b}_0 & \boldsymbol{b}_1 & \cdots & \boldsymbol{b}_n \end{array}\right],$$
  where $\boldsymbol{b}_i$ are $n+1$ Bézier control points.
- We can find matrices so that $\boldsymbol{C} = \boldsymbol{B}\boldsymbol{M}^n$, for example $\boldsymbol{M}^2 = \begin{bmatrix} 1 & -2 & 1 \\ 0 & 2 & -2 \\ 0 & 0 & 1 \end{bmatrix}$.

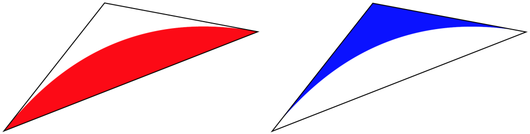




$$\boldsymbol{M}^n_{k+1,i+1} = (-1)^{i-k}\binom{n}{i}\binom{i}{k}$$

Rational quadratic Bézier curves in triangles

- Consider the curve $\boldsymbol{p}(t) = (t, t^2)$. Or: $F(t) = \boldsymbol{Ft} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} 1 \\ t \\ t^2 \end{bmatrix}$.
- This curve has the implicit form: $x^2 - y = 0$, $x, y \in [0, 1]$.
- The Bézier control points of the curve: $\boldsymbol{B} = \boldsymbol{F}(\boldsymbol{M}^2)^{-1} = \begin{bmatrix} 0 & \frac{1}{2} & 1 \\ 0 & 0 & 1 \\ 1 & 1 & 1 \end{bmatrix}$.
- Suppose we draw a triangle with a varying vertex attribute $\boldsymbol{c} = (u, v)$ defined by the given Bézier control points: $\boldsymbol{c}_0 = (0, 0)$, $\boldsymbol{c}_1 = (0.5, 0)$, $\boldsymbol{c}_2 = (1, 1)$.
- For every fragment, we can now evaluate $f(u, v) = u^2 - v$ to see if the fragment is close to the curve $|f(u, v)| < \epsilon$ or on one side or the other.
- The triangle shape (vertex positions) determine the shape of the curve.
- The same control points work for **any** rational quadratic Bézier curve.



Reference

- Loop, C., and Blinn, J. Resolution independent curve rendering using programmable graphics hardware. *ACM Transactions on Graphics (SIGGRAPH 2005) 24*(3), pp. 1000–1009. July 2005.

Curve rendering in the HUD

- The head up display (HUD) provides vector graphics rendering of text and curves.
- It has a clear function: ctx.clearRect(x, y, width, height).
- And a number of draw options for setting state:
  - ctx.font (a text string describing the font)
  - ctx.textAlign (alignment: left, right, center)
  - ctx.fillStyle (a color or pattern)
  - ctx.strokeStyle (a color or pattern)
  - ctx.lineWidth (in pixel)

- Text is drawn using: ctx.fillText(text, x, y).
- The coordinates (x, y) are in canvas space.
- Bézier curves are drawn in a similar way:

  ctx.moveTo(a_x, a_y); ctx.quadraticCurveTo(b_x, b_y, c_x, c_y); ctx.stroke();

  ctx.moveTo(a_x, a_y); ctx.bezierCurveTo(b_x, b_y, c_x, c_y, d_x, d_y); ctx.stroke();

  where $\boldsymbol{a}$, $\boldsymbol{b}$, $\boldsymbol{c}$, $\boldsymbol{d}$ are the control points in canvas space coordinates.

Rendering vector graphics in a 3D scene

- To render text well in 3D, we need Loop's and Blinn's method or its newest reincarnation.

- A simplistic alternative is to use communication between 2D canvas and WebGL.
- What we draw in a canvas, we can store in GPU memory as a texture image.

References

- Loop, C., and Blinn, J. Rendering vector art on the GPU. In *GPU Gems 3*, Chapter 25, pp. 543–562. Pearson Education, 2008.
- Dokter, M., Hladky, J., Parger, M., Schmalstieg, D., Seidel, H.-P., and Steinberger, M. Hierarchical rasterization of curved primitives for vector graphics rendering on the GPU. *Computer Graphics Forum 38*(2):93–103. May 2019.

Canvas as texture

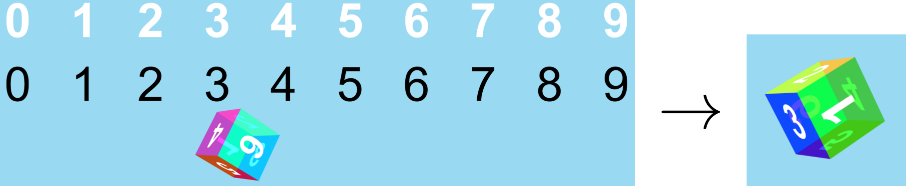
- WebGL supports direct use of a canvas element as texture image data.

```
var tex = gl.createTexture();
gl.bindTexture(gl.TEXTURE_2D, tex);
gl.pixelStorei(gl.UNPACK_FLIP_Y_WEBGL, true);
gl.texParameteri(gl.TEXTURE_2D, gl.TEXTURE_MIN_FILTER, gl.LINEAR);
gl.texParameteri(gl.TEXTURE_2D, gl.TEXTURE_MAG_FILTER, gl.LINEAR);
gl.texParameteri(gl.TEXTURE_2D, gl.TEXTURE_WRAP_S, gl.CLAMP_TO_EDGE);
gl.texParameteri(gl.TEXTURE_2D, gl.TEXTURE_WRAP_T, gl.CLAMP_TO_EDGE);
draw2D(ctx);
gl.texImage2D(gl.TEXTURE_2D, 0, gl.RGBA, gl.RGBA, gl.UNSIGNED_BYTE, ctx.canvas);
```

- We can map what was drawn in the drawing program to a surface in a 3D scene.
- We can draw font characters in appropriate size to a hidden canvas and use these to get decent text in 3D:

  <canvas id="text" style="position: absolute; visibility: hidden"></canvas>

- A rolling semi-transparent die with numbers as an example



Adapting to browser window size (resize)

- The browser triggers a "resize" event when the user resizes the browser window.
- We can use this to ensure that a canvas always fills out the entire client area.
- We can also set the font size to be used in a HUD or a hidden text canvas.

- Example from the init function of the rolling die program:

```
function resize() {
  canvas.width = window.innerWidth;
  canvas.height = window.innerHeight;
  gl.viewport(0, 0, canvas.width, canvas.height);
  var fontsize = Math.ceil(canvas.height*0.1);
  makeTextTexture(gl, textctx, texttex, '0123456789', fontsize + 'px ' + font, ...);
}
window.addEventListener('resize', resize);
resize();
```

- This is important when making a program suitable for different devices.

Sound effects

- The browser also makes it easy to include sound effects.
- We can make a function that becomes a playable sound object:

```
function sound(src) {
  this.sound = document.createElement("audio");
  this.sound.src = src;
  this.sound.setAttribute("preload", "auto");
  this.sound.setAttribute("controls", "none");
  this.sound.style.display = "none";
  document.body.appendChild(this.sound);
  this.play = function () {
    var playPromise = this.sound.play();
    if(playPromise !== undefined) {
      playPromise.then(_ => { /* Show playing UI. */ }).catch(error => { /* Show paused UI. */ });
    }
  }
  this.stop = function () { this.sound.pause(); }
  this.load = function () { this.sound.load(); }
}
```

- Initialization: `var clickSound = new sound("sounds/click.mp3");`
- and we can then later play the sound (in a click event function, for example) using clickSound.play();

Time-stamped animation

- The callback function used with requestAnimationFrame can optionally take a timestamp argument. Example:

```
var init_anim = true;
var time0;
function tick(timestamp) {
  if(init_anim) {
    time0 = timestamp;
    if(time0) init_anim = false;
  }
  if(!init_anim) {
    var t = timestamp - time0; // Animation time
    .
    .
    .

  }
  requestAnimationFrame(tick);
}
```

- Time `t` is measured in milliseconds.
- If `time0` is reset for every frame, we can do relative updates based on the time since last frame `t` and the current velocity of the object.
- If `time0` is only reset at animation initialization, we can do keyframe animation: Pre-staged interpolation between keyframes based on the time `t` since initialization.

Other graphics techniques needed to make a rolling die

- Perspective projection and object rotation.
  - We use the concept of homogeneous coordinates in 3D and construct 4×4 transformation matrices for manipulating scene content.
- Blending and draw order.
  - We use the alpha-channel (in RGBA colors) and specify a blend function.
  - Drawing order becomes important when surfaces are semi-transparent.
- Texturing.
  - Mapping images to surface.
  - Using filters to deal with aliasing problems (pixelation / staircases / jaggies).
  - Drawing to an off-screen buffer and using it as a texture.
- These are all subjects that we will investigate during the course.
- The rolling die program has been uploaded to DTU Learn for you to explore. Think of it as a simple demo of many graphics concepts.

Drawing multiple objects

- Vertex specification best practices:
  - As few vertex buffers as possible (separate buffers for different attributes is ok).
  - Switch vertex buffer, shader program, etc. as infrequently as possible.
  - Standard mode of operation: one draw call per object.
  - Include multiple objects in one draw call when possible (batch drawing).
  - Use the same vertices for drawing several different objects by changing color/transformation variables (instancing).

https://www.khronos.org/opengl/wiki/Vertex_Specification_Best_Practices