A3 Intro: Raytracing & GLSL

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Adapted from Spring 2018
Originally created by Kyle Genova
What is Raycasting?

(1) Trace primary rays into the scene.
(2) Intersect with an object.
(3) Estimate the radiance by summing contribution from each unblocked light to that point.

Raycasting produces results that only account for direct illumination!

(see “Lighting & Reflectance” lecture for more details)
What is Ray Tracing?

Raycasting, but trace secondary rays for specular (mirror) reflection and refraction from point of intersection, if appropriate.

This is recursive!

(see “Lighting & Reflectance” lecture for more details)
What is GLSL?

It’s the Open Graphics Library Shader Language (OpenGL SL)
What is GLSL?

A C-like language (syntactically) with more type safety and no recursion that executes code directly on the GPU.

It is used to write shader programs, which are used by OpenGL applications to render graphics.
Why do we want it for Ray Tracing?
Ray tracing: CPU (i7-4790K) vs. GPU (Titan X)

CPU
- Render time: 1748 seconds
- Rendered at 480 x 400

GPU
- Render time: 16 seconds
- Rendered at 960 x 800

GPU performed ~437 times faster

Tracing with 8 rays per pixel
OpenGL (WebGL) Graphics Pipeline

{ vertices } → Vertex shader → Shape assembly → Geometry shader

OpenGL Graphics Pipeline

Shader Programs. Written in GLSL!

Tests and Blending → Fragment shader → Rasterization
Two Critical Components: Vertex & Fragment Shaders

- **Vertex Shader**: Runs automatically once per vertex. Must output the final vertex position and any attributes the fragment shader needs.
- **Fragment Shader**: Runs automatically once per pixel (AKA fragment). Runs after the vertex shader. Must output the final pixel color.

(Note: Geometry Shader is an optional stage)
What’s Missing in GLSL Syntax: C \ GLSL

- Recursion
- Implicit Casting
- Libraries
- Dynamic memory allocation
- Pointers
- Objects
- Char, String
- Console I/O ?!
GLSL Syntax Extensions: GLSL\C

- varying
- uniform
- attribute
- Parameter qualifiers: in, out, inout
- vecN
  - swizzling: vec3 yxz_comp = some_vec3.yxz;
- Polymorphic builtins: max, min, sqrt, dot, cross...
- Predefined variables: gl_*
  - gl_Position
  - gl_FragCoord
  - gl_FragColor, gl_FragData[]
**Uniform** (AKA Dynamically Uniform)

**Uniform** variables are read-only and statically shared between all vertices and fragments.

Similar to global variables in C, which can be modified and set by the application and then passed into the vertex and fragment shaders.

Common uses: informing the vertex and fragment shaders of the lights and objects in the scene.
**Varying**: The GPU does the heavy lifting

Varying variables are per-vertex outputs in the vertex shader. They are automatically interpolated between triangle vertices by the GPU and passed as per-pixel inputs to the fragment shader.

Varying variables are written by the vertex shader and read by the fragment shader. Used to pass information from the vertex shader to the fragment shader.
**Attribute**: Vertex Shader Only

Attributes are values that are unique per-vertex and are passed into the vertex shader.

Common use: providing a vertex its position or color
**vecN**: Easier vector math

// N = \{2, 3, 4\}

vec3 a = vec3(1.0, 2.0, 3.0);  // make a vec3

vec4 b = vec4(a, 1.0);         // make vec4 from vec3

vec3 c = b.xyz + a.zyx;       // add two vec3 together

vec3 d = 2.0 * c;             // mult vec3 by scalar

vec4 e; e.xyz = c; e[3] = b.w; // can use index or .{xyzw}
Parameter qualifiers: **in**, **out**, and **inout**

<table>
<thead>
<tr>
<th>Qualifier</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>in</strong></td>
<td>Variable value is copied into the function. This is the default if no qualifier is specified. (“copy and pass by value”)</td>
</tr>
<tr>
<td><strong>out</strong></td>
<td>Function cannot read the variable, but can write to the variable. The changes are visible outside of the function. (“pass by reference, but write-only”)</td>
</tr>
<tr>
<td><strong>inout</strong></td>
<td>Function can both read and write to the variable. The changes are visible outside of the function. (“pass by reference”)</td>
</tr>
</tbody>
</table>
Parameter qualifiers: **in**, **out**, and **inout**

- "value" is an **inout** variable
- Function can **read** the variable
- Function can **modify** the variable

```c
void multiplyByTwo(inout float value) {
    value *= 2;
}

void main() {
    float t = 2;
    multiplyByTwo(t);
    // t is now 4
}
```
Parameter qualifiers: **in**, **out**, and **inout**

- “intersect” is an **out** variable
- Function **cannot read** the struct
- Function **can modify** the struct directly (e.g. its position and normal fields)
**gl\_Position** and other **gl\_*** values: Built-ins

- **gl\_Position**  The key vertex shader output. The vertex position.

- **gl\_FragColor**  The key fragment shader output. The pixel color.

- **gl\_FragCoord**  The pixel location in window space.
A Simple Vertex Shader

```cpp
attribute vec2 a_position;
void main() {
    gl_Position = vec4(a_position, 0, 1);
}
```
void main() {
    gl_FragColor = vec4(gl_FragCoord.x / canvas_width,
                           gl_FragCoord.y / canvas_height,
                           0, 1);
}

A Simple Fragment Shader
void main() {
    float cX = gl_FragCoord.x - width/2.0;
    float cY = gl_FragCoord.y - height/2.0;
    if (sqrt(cX*cX + cY*cY) < 80.0){
        gl_FragColor = vec4(1.0, 0.0, 0.0, 1.0);
    } else {
        gl_FragColor = vec4(0.0, 0.0, 0.0, 1.0);
    }
}
How to Avoid Recursion in a Recursive Ray Tracer

```c
#define MAX_RECURSION 10
function g() {
    float x = 0.0, weight = 1.0, res = 0.0;
    float cur_contrib;
    for (int i = 0; i < MAX_RECURSION; i++) {
        cur_contrib = f();
        res = res + weight * cur_contrib;
        weight = weight * 0.8;
    }
    return res;
}
```
So how are we doing raytracing with a shader program?

- Think of the rendered scene in your browser as a large rectangle made up of 2 triangles.
- There are 4 vertices in total (2 are shared between the 2 triangles).
- **The fragment shader** operates on each of the pixels inside this rectangle and computes that pixel’s color.
- (Note that each pixel's position was interpolated from the original 4 vertices!)

... What is that color?
- It’s what we get from tracing a ray for the corresponding "pixel" in the camera!
void main() {
    float cameraFOV = 0.8;
    vec3 direction = vec3(v_position.x * cameraFOV * width / height,
                          v_position.y * cameraFOV, 1.0);

    Ray ray;
    ray.origin = vec3(uMVMMatrix * vec4(camera, 1.0));
    ray.direction = normalize(vec3(uMVMMatrix * vec4(direction, 0.0)));

    // trace the ray for this pixel
    vec3 res = traceRay(ray);

    // paint the resulting color into this pixel
    gl_FragColor = vec4(res.x, res.y, res.z, 1.0);
}
Visual Debugging

No console IO or breakpoints makes traditional debugging techniques ineffective. Instead, you must do “visual debugging,” which is simply creative use of the one fragment shader output you have: the pixel color.

Some simple suggestions:

- Output red for sphere, yellow for triangle, green for cylinder, etc.
- Output the normal vector of the surface directly.
- if (some_condition) then GREEN else normal shading. This can track down which pixels are problematic.
- Move around in the scene! The real-time performance of the raytracer is a huge asset.
Additional Learning Resources

https://www.opengl.org/wiki/Core_Language_%28GLSL%29

http://www.shaderific.com/glsl-qualifiers

See assignment FAQ for more!

We use WebGL (which is an implementation of the OpenGL ES 2.0 specification) to run our raytracer in the browser.

It uses GLSL ES 1.00!