

Worksheet 1

Ray tracing is the easiest and the most general technique for visualising 3D models. It is easy to create many sophisticated lighting effects using ray tracing, but ray tracing is still slower than rasterization. Hence, ray tracing is used primarily for rendering of photorealistic images in applications where image quality rather than a high frame rate is the primary concern. The purpose of the exercises for the first weeks is to help you learn how a ray tracer works.

Learning Objectives

- Implement ray casting (tracing rays from eye to first surface intersection).
- Use a pinhole camera model for generating rays in a digital scene.
- Compute intersection of rays with three-dimensional primitive objects (planes, triangles, spheres).
- Compute shading of diffuse surfaces using Kepler's inverse square law and Lambert's cosine law.

Getting Started

We will build a minimalistic framework for ray tracing using WebGPU. This means that we will write HTML and JavaScript files and test them by opening the HTML file in an internet browser. The advantages are that we get all the loading, display, and interface functionalities of the browser and it runs on any platform. All you need is an internet browser that supports WebGPU (check current support status: <https://caniuse.com/webgpu>) and your favorite text editor for writing code.

Useful resources for you to familiarize yourself with WebGPU:

- Your first WebGPU app: <https://codelabs.developers.google.com/your-first-webgpu-app>
- WebGPU Fundamentals: <https://webgpufundamentals.org/>
- WebGPU specification: <https://www.w3.org/TR/webgpu/>
- WGSL - WebGPU Shading Language - specification: <https://www.w3.org/TR/WGSL/>

We will do most of the ray tracing work using WGSL. The WebGPU code needed on the JavaScript side will be kept at a minimum.

Ray Casting

In this first exercise, your job is to implement the very basics of ray tracing: ray generation, ray-object intersection, and shading of diffuse surfaces. This simple, non-recursive, visible-surface ray tracing is typically referred to as ray casting.

Save a .html and a .js file for each part that you solve. In the end, your lab journal will be a collection of these files documenting your progress and providing us with easy inspection of code and results.

1. Create a canvas and generate rays using a pinhole camera model.¹
 - 1.a Create an html file with a canvas element of resolution 512×512 , and let it load a JavaScript file that initializes WebGPU and clears the canvas to black.
 - 1.b Create a script in the html file with WGSL code that defines a rectangle from $(-0.9, -0.9)$ to $(0.9, 0.9)$ and set its colour to $(r, g, b, a) = (0.1, 0.3, 0.6, 1.0)$. In the JavaScript file, get the text in the script and use it to create a shader module and a render pipeline. Set up a render pass that draws the four vertices of the rectangle as a triangle strip.

¹See the short lecture note "Ray Generation Using a Pinhole Camera Model" for more details. It is available on DTU Learn.

- 1.c Change the vertices of the rectangle to be from $(-1.0, -1.0)$ to $(1.0, 1.0)$ so that the rectangle fills out the canvas and pass the image plane location from the vertex to the fragment shader. Create a struct (Ray) for holding ray information and generate rays using a pinhole camera model. As a test, output the ray direction as the pixel color. Multiply by one half and add one half to ensure that you get positive color values. The result should be a dark blue image with red increasing from left to right and green increasing from bottom to top.
2. Create a struct of uniform variables. Let it contain the aspect ratio of the canvas and the camera constant (zoom). Change the width and height of the canvas to demonstrate that you can accurately use the aspect ratio of the canvas to render with a non-square resolution. In addition, use the `MV.js` library to precompute the basis of the image plane in JavaScript and upload the eye position and the basis vectors as uniforms.
3. Create a struct (HitInfo) for recording hit information and implement ray-plane intersection, ray-sphere intersection, and ray-triangle intersection. Call these intersection functions in the fragment shader to render the default scene (specified below). Assign the designated object colour to the pixel when a ray intersects it. Use the light blue rectangle colour from before as background colour if no intersection was found. Adjust the maximum trace distance of your ray (t_{\max}) if you have an intersection to ensure that you end up with the closest intersection.
4. Create a struct (Light) for returning the radiance (L_i) incident from and the direction ($\vec{\omega}$) toward a light source. Implement a point light sample function and a shade function for diffuse surfaces sampling the point light in the scene. Use Kepler's inverse square law of radiation and Lambert's cosine law to render a shaded image of the default scene (store observed radiance L_o in the pixels).
5. Make a zoom interface in HTML/JavaScript (use a slider or the scroll wheel of the mouse) that changes the camera constant. Re-render the scene when the zoom changes. [Optionally, make an interface for changing the gamma value in the gamma correction.]

Default scene description

Camera:	eye point (2.0, 1.5, 2.0)	look-at point (0.0, 0.5, 0.0)	up-vector (0.0, 1.0, 0.0)	camera constant 1.0
Plane:	position (0.0, 0.0, 0.0)	normal (0.0, 1.0, 0.0)	rgb colour (0.1, 0.7, 0.0)	
Triangle:	\mathbf{v}_0 (-0.2, 0.1, 0.9)	\mathbf{v}_2 (0.2, 0.1, 0.9)	\mathbf{v}_2 (-0.2, 0.1, -0.1)	rgb colour (0.4, 0.3, 0.2)
Sphere:	center (0.0, 0.5, 0.0)	radius 0.3	refractive index 1.5	shininess 42 rgb colour (0.0, 0.0, 0.0)
Point light:	position (0.0, 1.0, 0.0)	rgb intensity (π, π, π)		

Reading Material

The curriculum for Worksheet 1 is (105 pages)

B Chapters 1–2. *Introduction and Miscellaneous Math.*

B Chapters 3–5. *Raster Images, Ray Tracing, and Surface Shading.*

Supplementary reading material:

- Frisvad, J. R. *Ray Generation Using a Pinhole Camera Model*. Lecture Note, Technical University of Denmark, August 2012.
- Frisvad, J. R. *Ray-Triangle Intersection*. Lecture Note, Technical University of Denmark, July 2011.