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Personal project

Minecraft: Ray Traced

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Abstract

This project attempts to implement a GPU ray tracer in the video game Minecraft, using CUDA. The ray tracing itself is done in CUDA. At first, I attempt to ray trace the vertex buffers given by Minecraft. Then, I implement my own data structures for increased performance.

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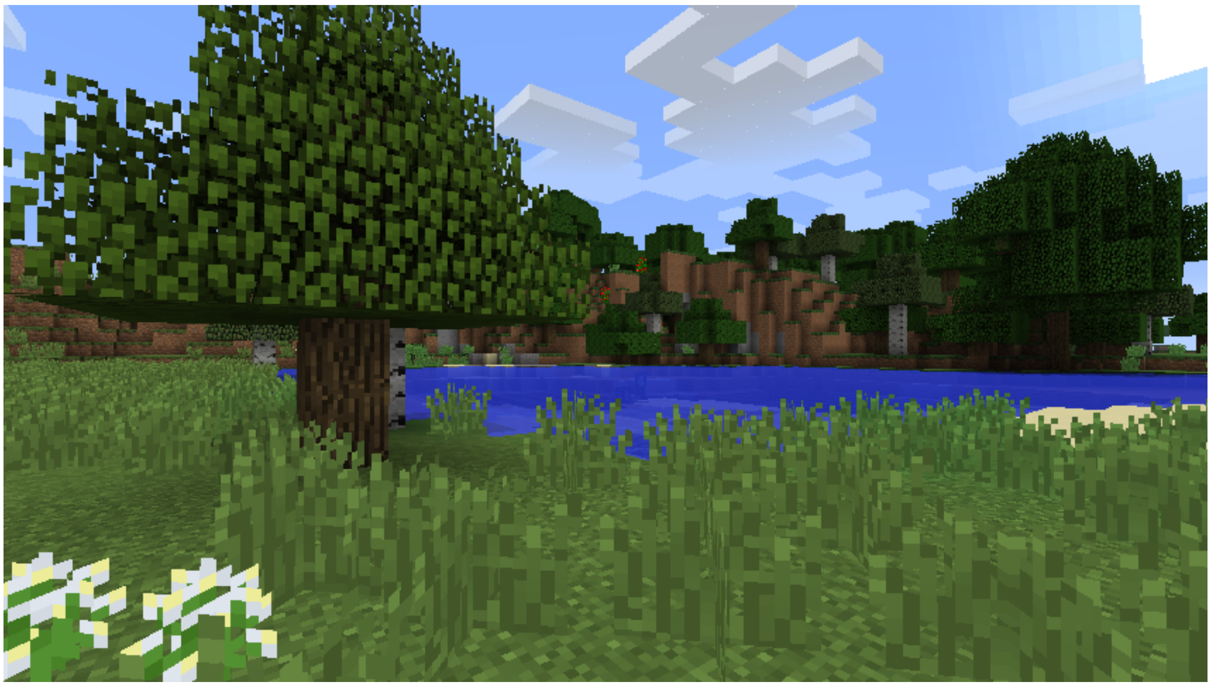


Figure 1: In-game screenshot of Minecraft, without heads-up display (HUD) or viewmodel.

1 Minecraft

Minecraft is a 2011 first-person sandbox video game. Originally created by Markus "Notch" Persson, it is currently maintained by Mojang.

Minecraft comes in multiple editions, for various platforms. This paper focuses on the PC version of Minecraft, released for Windows, macOS, and Linux. The PC version is written in Java.

In Minecraft, the game world consists of a three-dimensional grid. The world is procedurally generated, using a mostly comprised of unit blocks, as shown in Figure 1.

2 Minecraft Renderer

Minecraft uses multi-threaded chunk generation. Minecraft uses OpenGL. Minecraft has two options for rendering static geometry:

Display Lists An OpenGL 1.0 core function. Display Lists are a group of OpenGL commands that have been compiled and sent to the GPU. An object can then be drawn by calling the list. The list can be reused, which means you do not have to send the data over again.

Vertex Buffer Objects Vertex Buffer Objects ("VBOs") were available in OpenGL 1.4 through an extension, and were later added to the core specification in version 2.1. This feature allows you to have a buffer with vertex information, and telling the driver where and how the attributes are stored in the buffer.

My project makes use of Minecraft's VBO rendering, because I can extract the vertex data from the buffers.

2.1 RenderChunks

There are four geometry groups, based on texture properties.

Solid Uses textures that are fully opaque. Most world blocks are in this group.

Cutout Uses textures that have transparent texels.

Mipped Cutout Identical to Cutout, but mipmapped.

Translucent Used for block which have partial transparency (alpha blending).

Every geometry group has its own vertex buffer.

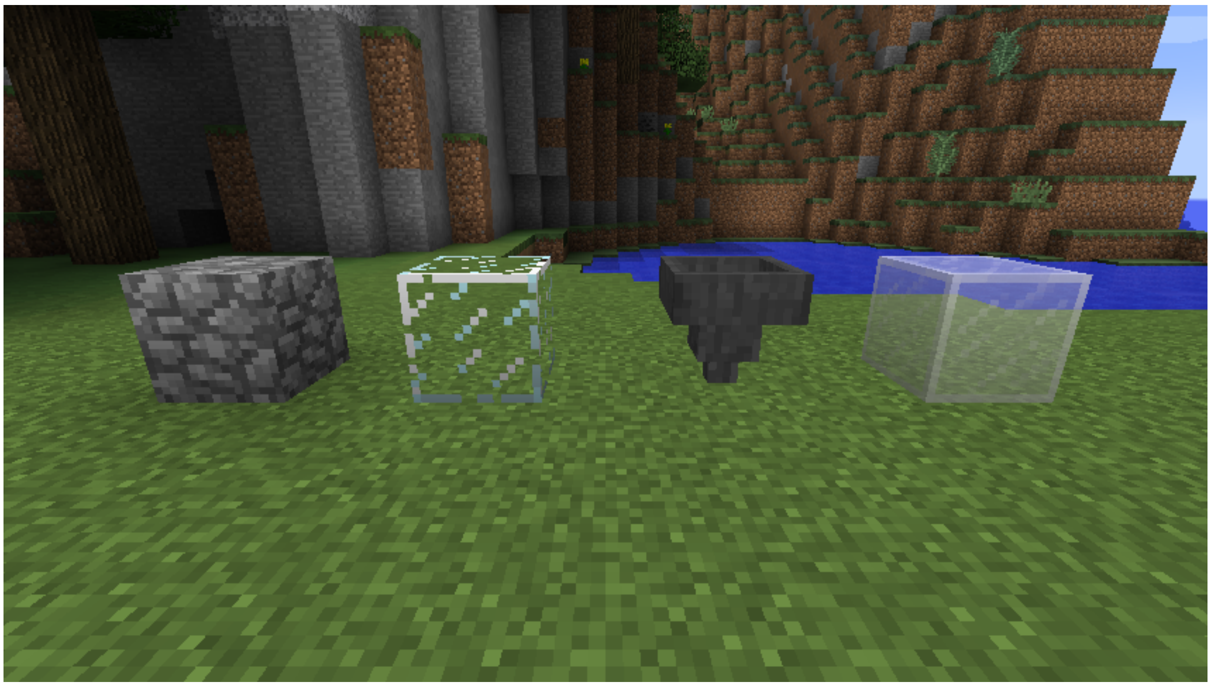


Figure 2: From left to right: Cobblestone (Solid), Glass (Cutout), Hopper (Cutout Mipped), and Stained Glass (Translucent).

3 Minecraft Forge

Minecraft Forge ("Forge") is a community created platform for developing and using modifications ("mods") for Minecraft.[1]

3.1 Setting up a mod development environment

The Mod Development Kit ("MDK") can be downloaded from the Forge website[2]. The MDK distribution includes ForgeGradle[3]. ForgeGradle is a plugin for the Gradle[4] build system. The Minecraft binaries are downloaded, and subsequently decompiled, deobfuscated, The classes are decompiled into srg names.

The Mod Coder Pack[5] is a package which is used to decompile, change, and recompile Minecraft Java classes.

The Gradle tasks include:

1. Download Minecraft .jar files.
2. Decompile the Minecraft
3. Generate the Forge Minecraft binary

Forge explicitly supports the Eclipse and IntelliJ integrated development environments ("IDEs"). I used IntelliJ IDEA Community. ForgeGradle gives you the option of debugging and building both client and server sides of Minecraft.

The path to my DLLs is passed to the virtual machine.

3.2 Differences between development and release builds

During development, Java loads my classpath directly. In release mode, my class files would have to be compressed into an archive first.

[1]Modification of Minecraft ("modding") is not officially supported by Mojang. For more information, visit `https://account.mojang.com/terms`

[2]`http://files.minecraftforge.net/`

[3]`https://github.com/MinecraftForge/ForgeGradle`

[4]`https://gradle.org/`

[5]`http://www.modcoderpack.com/website/`

3.3 Changes to Minecraft source code

Forge adds some new features to the Minecraft source code, in order to support multi-mod functionality.

3.4 Creating a mod

In general there are three approaches to creating a mod:

1. Build a mod on top of the Forge Minecraft code
2. Edit the Minecraft source directly
3. Use class transformers in custom mod loading

For most mods, the first approach is sufficient. This also enables the developer to freely distribute their mod. Editing the Minecraft source directly means that the mod cannot be redistributed, because the original Minecraft code is copyrighted.

4 C++ and CUDA

I wanted to create a GPU ray tracer. There are various methods to achieve this. I wanted to take advantage of the vertex buffers in CUDA. Because Minecraft uses OpenGL through the LWJGL[6] library, I could have chosen to use OpenGL compute shaders. However, I have no experience with OpenGL compute shaders, whereas I do have experience with NVIDIA CUDA.

There exist Java bindings for CUDA, but using C++ removes my dependency on a binding layer.

4.1 Java Native Interface

Java Native Interface ("JNI") is a programming framework that allows for Java code to interact with native code.

4.2 CUDA

CUDA is a parallel computing platform and programming model developed by NVIDIA. It is only compatible with NVIDIA hardware. CUDA has two APIs: Runtime and Driver.

4.3 CUDA/OpenGL interoperability

CUDA provides an API for operating on OpenGL primitives.

1. Run the ray tracing kernel
2. Map the OpenGL texture to a CUDA array
3. Copy the kernel output buffer to the CUDA array

4.4 Creating a Visual Studio project

For setting up the native part of the mod, I created a Visual Studio CUDA project. NVIDIA has a CUDA plugin for Visual Studio called Nsight.

4.4.1 Reloading C++

Java IDEs such as IntelliJ support hot-swapping of method bodies by using the HotSwap functionality of the Java Platform Debugger Architecture. I created something similar for my native code by using a technique called DLL reloading. Once a native library has been loaded by the JVM, I cannot make changes to it. Therefore I am using a passthrough DLL, which passes the calls from Java to another DLL. I have shown this in Figure 3.

[6] `https://www.lwjgl.org/`

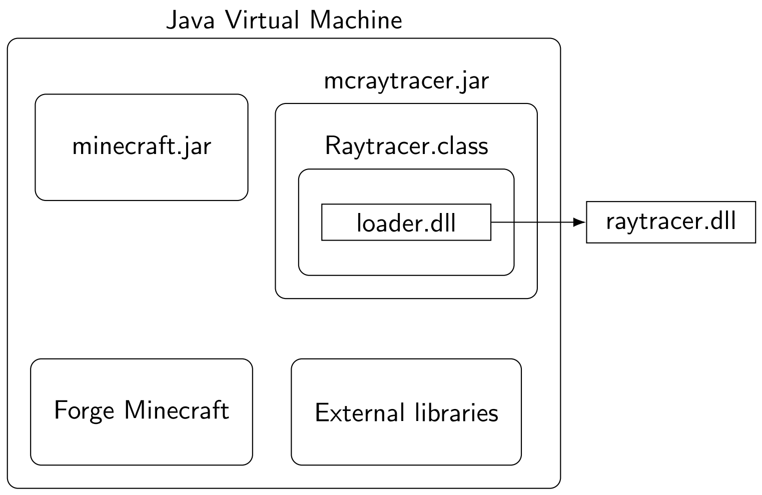


Figure 3: Interaction diagram of the different binaries.

4.4.2 Setting up the Visual Studio debugger

IntelliJ debug sessions are good for testing if my Java ASM works correctly, and if my JNI bindings are set up properly. However, if an error occurs a native part, the debug session ends immediately. The crash output from IntelliJ is unable to use the debug information from Visual Studio. I wanted to use the Visual Studio debugger for the native part. I had to launch java.exe with the right command line arguments and working directory. I looked at the launch parameters given to java.exe when starting a debug session from IntelliJ. The Visual Studio debugger can be configured to launch Minecraft by copying the command line arguments from an IntelliJ debug session. The JVM uses the access violation signal internally for its memory exception handling. When an access violation is thrown from the JVM, this can be safely ignored. However, Visual Studio can easily block hundreds of these signals. Visual Studio 2017 offers an option to ignore certain exceptions per module, allowing me to break on access violations in my own native code while ignoring those coming from the JVM.

4.5 Kernel overhead on Windows

5 Hardware

This project is developed on the following machines:

	Dell XPS 15 L502X	Desktop
Operating System	Microsoft Windows 10 Pro 64-bit	
Processor	Intel Core i7-2630QM	Intel Core i7-4790
Memory	4 GB DDR3	8 GB DDR3
GPU	NVIDIA GeForce GT 540M	NVIDIA GeForce GTX 970
- CUDA Cores	96	1664
- Shader Multiprocessors	2	13
- Compute Capability	2.1	5.2

$$f(s, ds) = \begin{cases} \frac{\lceil s \rceil - s}{|ds|} & ds > 0 \\ \frac{s - \lfloor s \rfloor}{|ds|} & ds < 0 \\ \infty & ds = 0 \end{cases} \tag{1}$$

6 Ray Tracing OpenGL Vertex Buffers

My initial idea was to ray trace the uploaded VBOs from Minecraft directly.

6.1 Using events

I wanted to see if I could make my mod work using the first approach. Forge adds hooks to the game loop which I could use to intercept the rendering code. The `Raytracer` class listens to the following events:

- `FMLInitializationEvent` - Poep in een drol.
- `TickEvent.ClientTickEvent`
- `GuiScreenEvent.InitGuiEvent.Pre`
- `GuiScreenEvent.DrawScreenEvent.Pre`
- `GuiScreenEvent.DrawScreenEvent.Post`
- `GuiOpenEvent`
  Fired when the top-level menu changes.
- `TickEvent.RenderTickEvent`

6.2 Using Java ASM

Here I explain how the project is set up and the technologies involved.

The Minecraft Forge project allows me to do two things: Listen to specific events using pre-installed hooks Edit Minecraft bytecode before it is loaded Using Java Native Interface (JNI), I can call into C++ code from Java. The C++ code contains the CUDA kernel. Data is passed between OpenGL and CUDA using CUDA's graphics interop layer.

6.3 C++/CUDA

`cudaGraphicsGLRegisterBuffer`

6.4 Results

7 Preprocessing Vertex Buffers

7.1 Obtaining the buffers

In order to get the raw vertex buffers from Java to C++, I had to change three Minecraft classes. My approach was to replace the built-in `VertexBuffer` class with my own class, called `CppVertexBuffer`. Confusingly, the decompiled version of Minecraft has two classes called VertexBuffer in two separate packages.

RenderChunk The class that represents a 16x16x16 chunk of blocks. It contains one OpenGL vertex buffer per render layer.

ChunkRenderDispatcher

VertexBufferUploader

7.2 Acceleration structure

8 Future work

I only got to work on the world rendering of the game. Viewmodels (player-held items) are not ray traced. Non-playable characters ("NPCs") are not ray traced.

9 References

[1] John Amanatides, Andrew Woo, et al. A fast voxel traversal algorithm for ray tracing. In *Eurographics*, volume 87, pages 3–10, 1987.

[2] Paulo Ivson, Leonardo Duarte, and Waldemar Celes. Gpu-accelerated uniform grid construction for ray tracing dynamic scenes. *Master's thesis, Departamento de Informatica, Pontificia Universidade Catolica, Rio de Janeiro*, 2009.

[3] Erik Reinhard, Brian Smits, and Charles Hansen. Dynamic acceleration structures for interactive ray tracing. In *Rendering Techniques 2000*, pages 299–306. Springer, 2000.

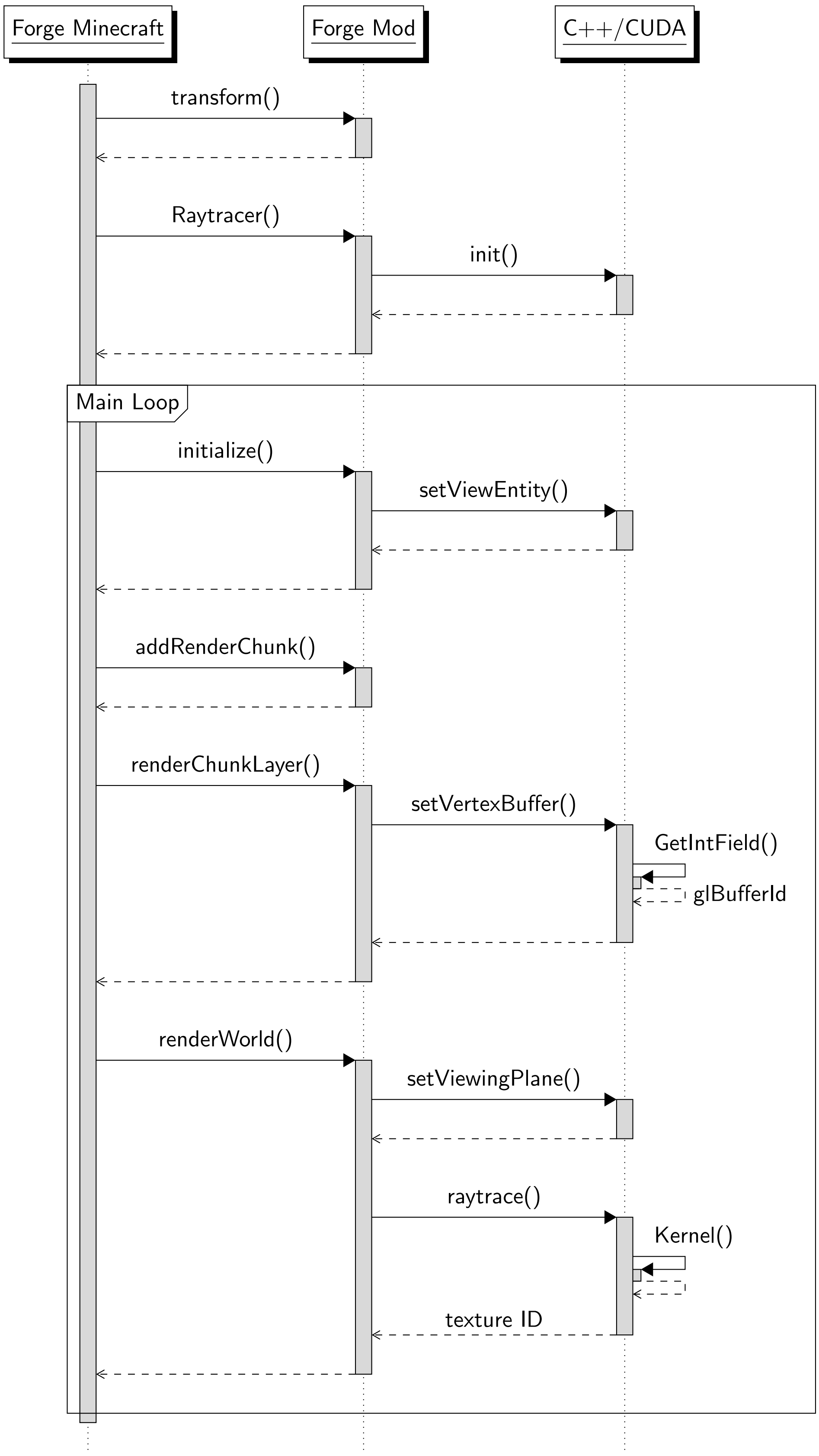


Figure 4: Sequence diagram showing interaction between the modules

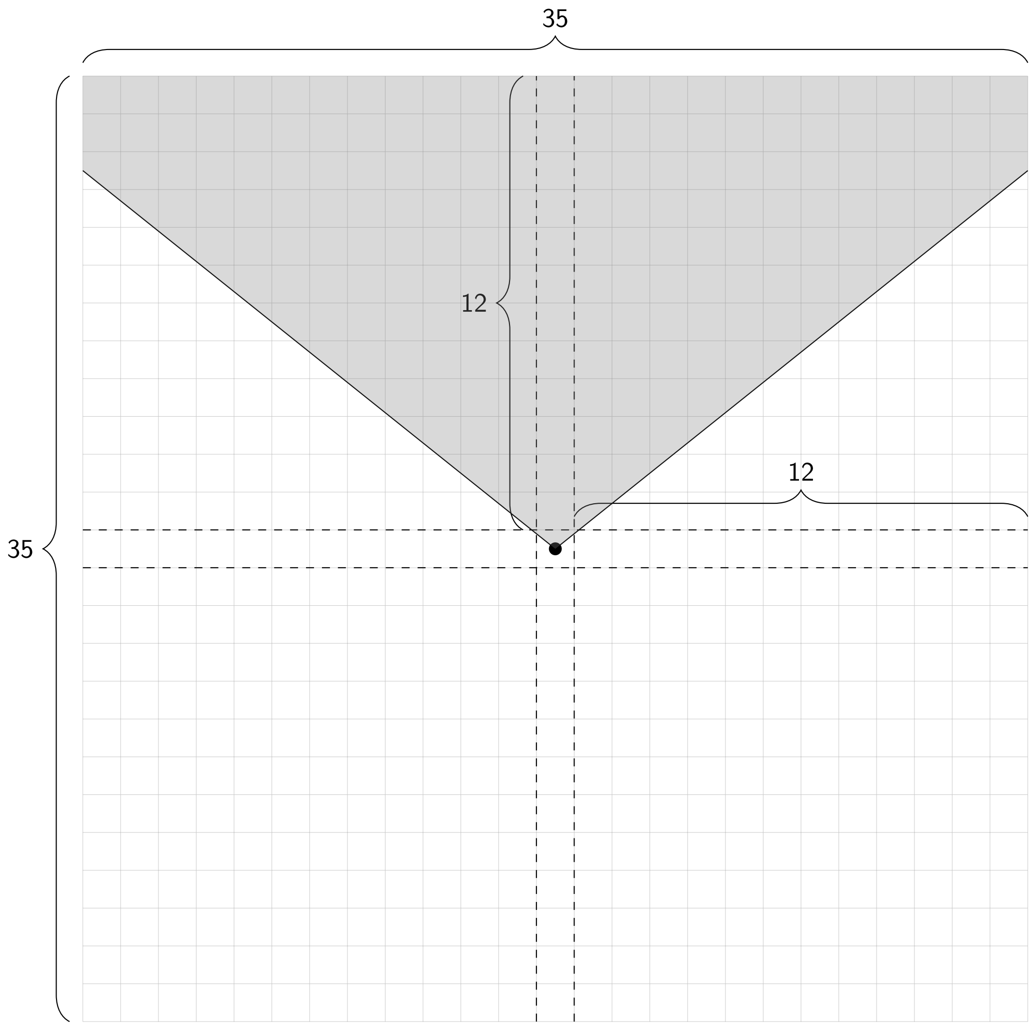


Figure 5: A top-down view of the vertex buffer array, assuming a render distance of 12. The player's view cone is shown facing north. Each cell contains 16 RenderChunks. When the player crosses a horizontal chunk boundary, every buffer in the grid is moved once space.

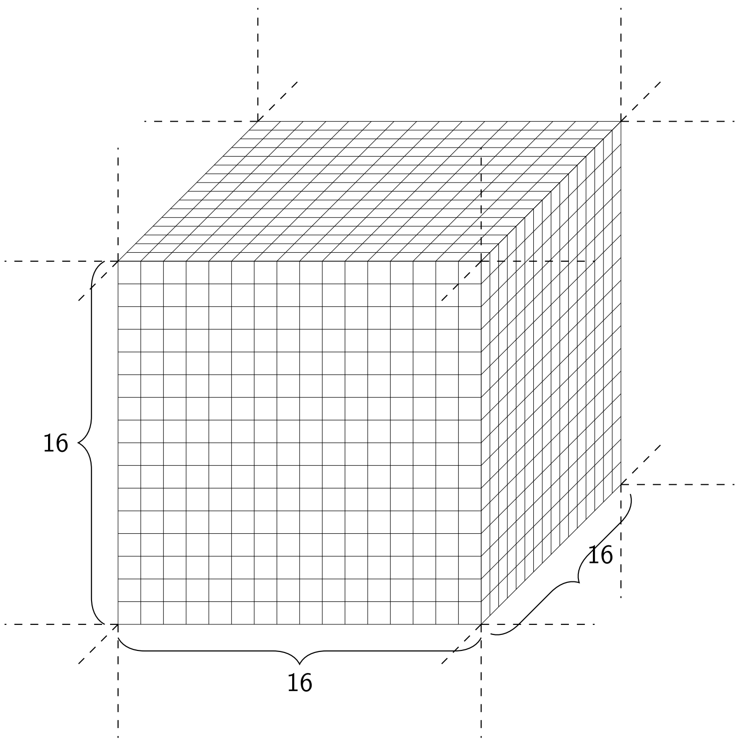
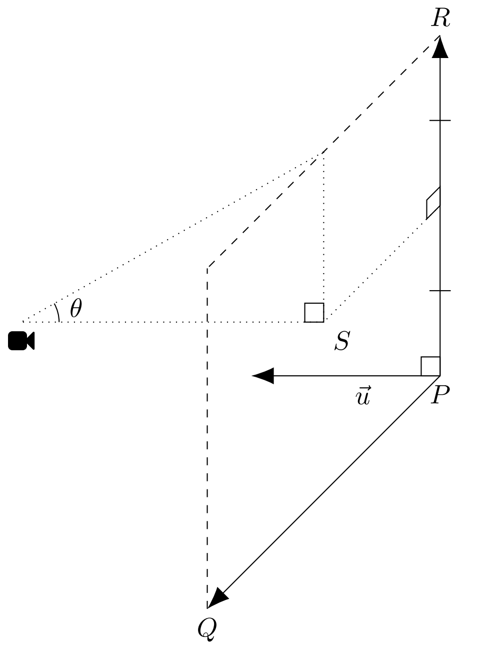


Figure 6: A single, completely filled RenderChunk.



$$
\begin{aligned}
\theta &= \frac{vertical\ field\ of\ view}{2} \\
\vec{u} &= \overrightarrow{PQ} \times \overrightarrow{PR} \\
S &= \frac{Q+R}{2} \\
\text{🎥}_{pos} &= S + \frac{\vec{u}}{||\vec{u}||} \cdot \frac{||\overrightarrow{PR}||}{2\tan(\theta)}
\end{aligned} \tag{2}
$$

Figure 7: Ray origin calculations