



Introduction

For my final project, I wanted to do a sunset scene in a simple landscape with some focus on clouds and the sky. It seemed like an easy way to get a good-looking photo from just a few elements in a scene. Over the course of the project, however, I ended up implementing a bit more than I initially expected. By the end of the project I had done Rayleigh scattering simulation for the atmosphere, procedural cloud generation, simple landscape modeling (from heightscans), procedural landscape texturing (evaluated in the renderer), semi-procedural fern modeling (using geometry nodes in Blender), and a simple thin-lens model depth of field.

To Run

Building requires a compiler that supports C++20 (sorry, just realized this when submitting). It just uses the new struct initialization syntax which is a little nicer, but that's it. The scene file is `scenes/final.xml`. Most new code is in `vol_path_tracing.h`, `materials/terrain.inl`, `media/atmosphere_media.inl`, and `phase_functions/atmosphere_phase.inl`. The cloud generator (separate project) is in the `cloudgen/` folder.

Atmosphere Simulation

I based my atmosphere off the models described by Riley et al. in [*Efficient Rendering of Atmospheric Phenomena*](#).

I wrote a new `AtmosphereMedium` that reduces the scattering and absorption coefficients of the medium as the sample position's height increases. For the absorption coefficient I used the same formula, but also added a parameter `a_mult` to control how much absorption there was so I could use this medium to describe both Rayleigh and Mie scattering. Both media were modeled by two very large spheres.

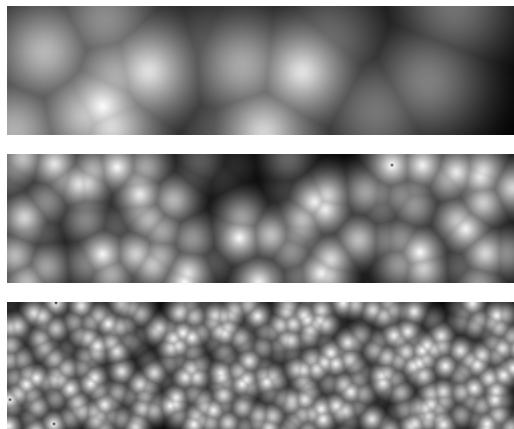
I also added two new phase functions: `RayleighPhase` and `MiePhase` to describe the two media that make up the atmosphere. With just Rayleigh scattering the atmosphere at sunset looked like:



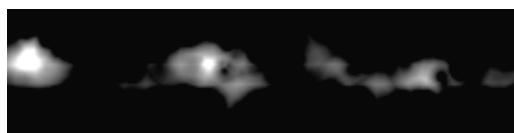
Unfortunately the atmosphere looked strange when I added Mie scattering, so I omitted it and approximated it in the final photo with a large homogenous sphere volume with some slight absorption. I was really going more for artistic points anyways.

Clouds

For the clouds, I generated a few 3D voronoi SDF textures of various scales. I was inspired by tutorials like [this excellent one](#) on how to generate clouds in Blender. Here are a few slices:



I then combined them by multiplying, adding, and subtracting them to get a nice-looking cloud volume. I also ramped down the density as the cloud reached the top or bottom. Here is a slice:



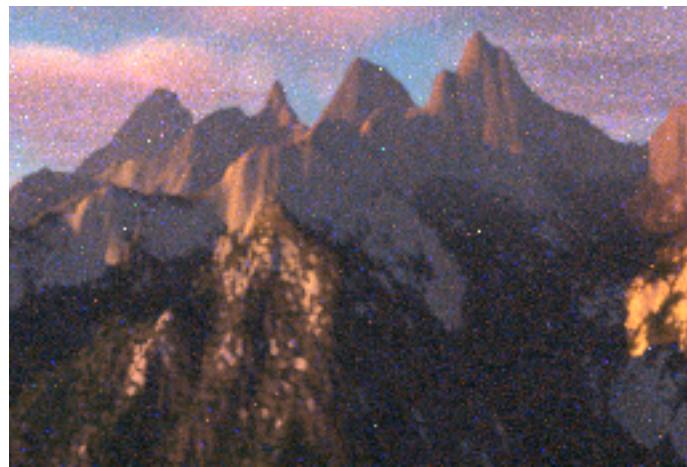
Landscape

I didn't want anything fancy for the landscape since I figured the focus would be on the clouds, so I used the (very helpful) website heightmap.skydark.pl to download some height and color scans of the Alps. I then used Blender to subdivide and displace a plane into the terrain model and exported it as an OBJ.

Unfortunately, the texture that I downloaded from the Cities: Skylines map generator ended up looking super trashy:



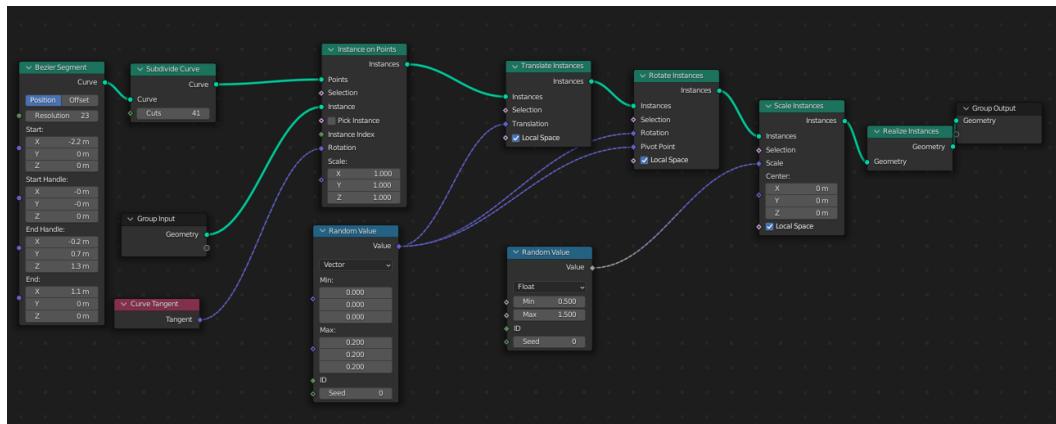
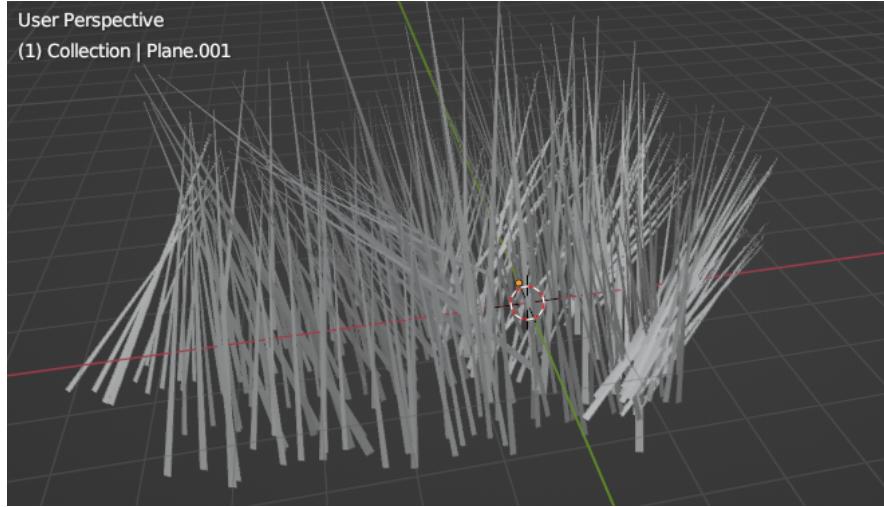
To solve this, I wrote a simple procedural landscape material that blended from dark green (grass/brush) to gray (rock) to white (snow) depending on the height and slope of the vertex hit.



This had more of the dramatic look I wanted but it still looked a little off, so I increased the amount of haze in the scene and added some blurred-out ferns in the foreground to cover some of it up.

Ferns

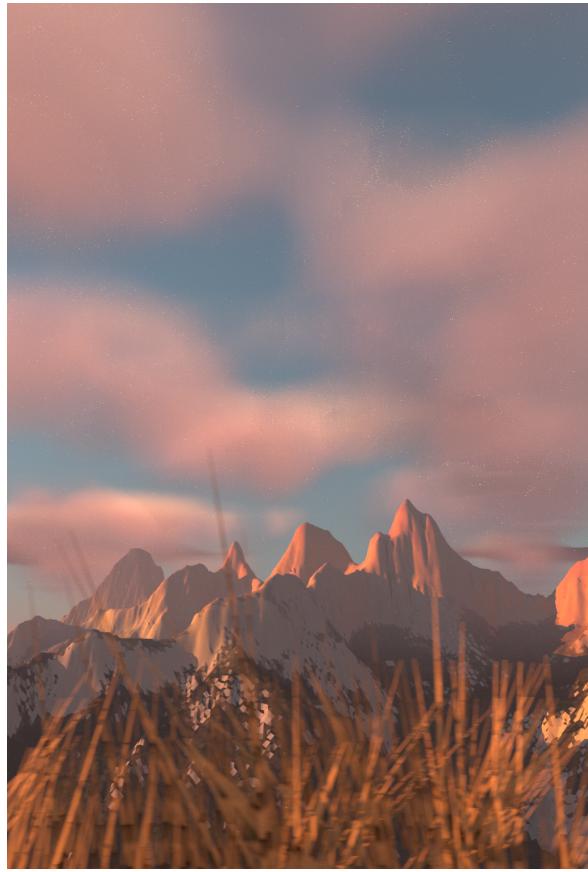
I decided to model the ferns in Blender using its new geometry nodes feature. I just pinched a plane into a thin stick, duplicated it along a few bezier curves, and then did some random scaling, rotating, and translating.



The final result in the photo still ended up looking a little fake and staged in my opinion, but unfortunately I didn't have the time to address this.

Conclusion

The final render was 1028×1536 pixels at 16,384 spp (a little embarrassing). The default gamma tone mapping in tev looked a little flat, so I imported the image into Affinity Photo and did a few simple exposure adjustments to get the final tonemapped PNG. I still have included the original .exr if this is too much. Without special tone mapping, the image with a simple gamma tone map looked like:



Overall, I learned a lot about the artistic side of rendering, especially on the many ways parts of a scene can be generated procedurally. I also learned a lot about the science behind atmospheric scattering, even if I wasn't able to get Mie scattering working properly.