WorldEnd: PBRT Meets Volcano ...

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1 Introduction

In this project, We rendered a volcanic scene with dinosaurs. which was inspired by the image shown in Figure. 1. The key challenge in this project was to model and render realistic lava. To model lava, we implemented a fluid simulation system to simulate lava based on our volcano geometry. To render lava, we carefully designed texture mapping base on our lava geometry. We also added ashes and smoke effects to mimic the real eruption. We describe the details in the following sections.

Figure 1: Inspirational image [4].

1.1 Final Image

Figure. 2 shows the final image that we generated.

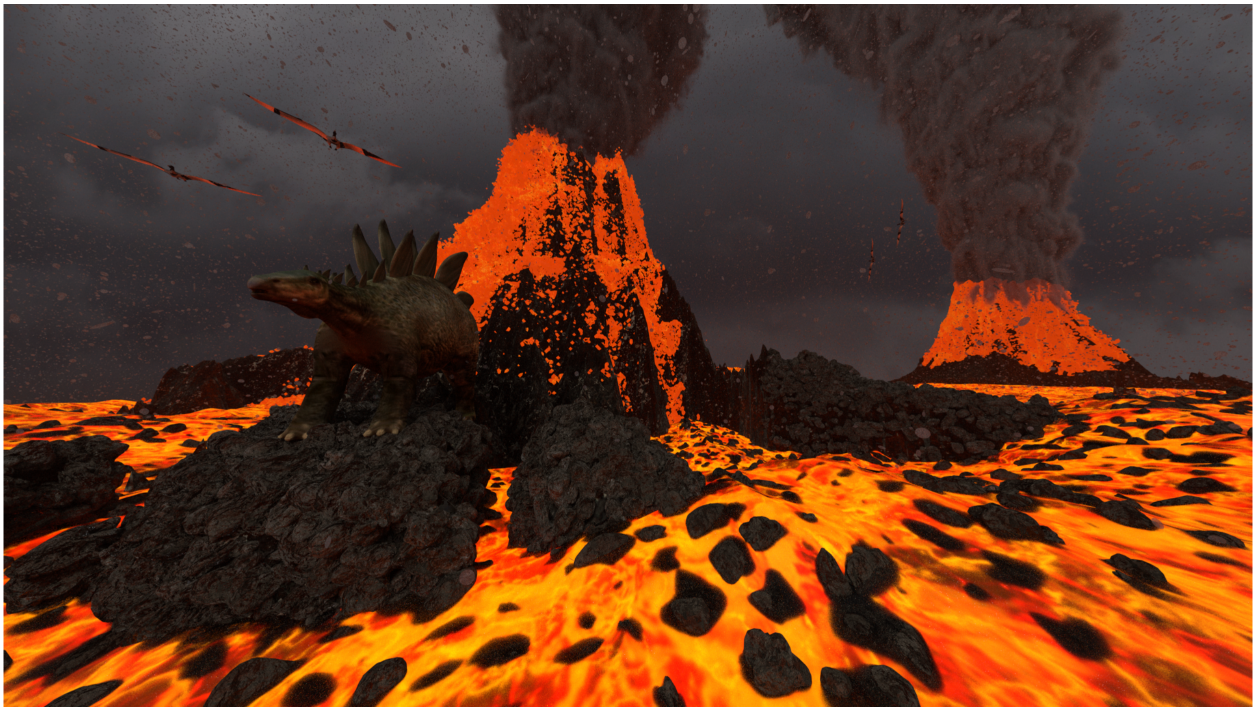


Figure 2: Our final rendered image. The full 4K resolution image can be found in our submission repository at the following address:
`https://github.com/jhong93/cs348b-final-project/blob/master/4k.final.png`.

2 Lava Simulation

2.1 The Navier-Strokes Equations

In physics, the Navier-Strokes equations are used to describe the motion of viscous fluid substances. The equations are a set of two differential equations which describe the velocity field of fluids. The first equation, also known as the incompressible condition is given by:

$$\nabla \cdot \mathbf{u} = 0, \tag{1}$$

where $\mathbf{u}$ is defined as the velocity vector for each fluid volume. This equation can be explained as the amount of fluid flowing into any volume in space must be equal to the amount of fluid flowing out. It is only used to define the incompressible fluids

The other equation specifies how velocity changes over time, and is given by:

$$\frac{\partial \mathbf{u}}{\partial t} = -(\nabla \cdot \mathbf{u})\mathbf{u} - \frac{1}{\rho}\nabla p + v\nabla^2 \mathbf{u} + \mathbf{F}, \tag{2}$$

where the left term $\frac{\partial \mathbf{u}}{\partial t}$ describes the velocity change. The right four terms represent four types of factors attributing to velocity changes. $-(\nabla \cdot \mathbf{u})\mathbf{u}$ represents the advection term, which arises from the conservation of momentum and indicates that the momentum of the fluid is "advected" through the velocity field itself. $\frac{1}{\rho}\nabla p$ represents the pressure term, where ρ is defined as the density and p is defined as the pressure. This term captures the internal force in fluid caused by the difference in pressure. We will use this term combined with the first equation to make the fluid incompressible. $v\nabla^2\mathbf{u}$ represents the viscosity term, where v is defined as the kinematic viscosity of the fluid. The value of v gets bigger when fluid becomes thicker. $\mathbf{F}$ represents the external force added on the fluid. The only force used in our simulation is gravity.

2.2 Algorithm

We implemented Marker and Cell(MAC) [12] for fluid simulation. The algorithm framework is given as follows.

Algorithm 1 Fluid simulation algorithm

1: Calculate the simulation time step Δt
2: Update the particles position according to the current velocity field
3: Update each cell type as fluid or air according to whether it contains particles
4: Set boundary conditions for new fluid cells
5: Update the current velocity field based on the Navier-Strokes Equations
  a: Apply advection using semi- Lagrangian method
  b: Apply external forces
  c: Apply viscosity
  d: Apply the pressure projection
  e: Extrapolate fluid velocities into nearby air cells
  f: Set boundary conditions for solid cells and cells on the free surface

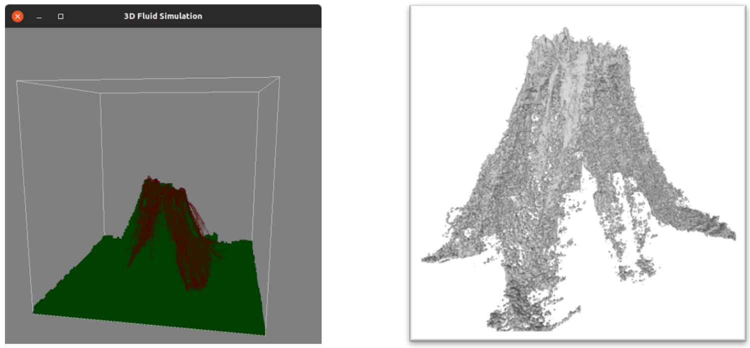
To get fluid surface, we used Marching Cube [13] to generate a blobby implicit surface enclosing all the marker particles.

2.3 Implementation details

The final resolution of the simulation grid is $500 \times 500 \times 500$, with each cell containing 6 particles initially. We put fluid source inside the volcano pit and let the fluid overflow around the volcano. At the final stage, our simulation involves about 10 million marker particles. A screen shot of the fluid simulation demo is shown in Figure. 2.3(a) and generated lava mesh is shown in Figure. 2.3(b).

3 Scene Design

Our final scene consists of two erupting volcanoes in the background, a stegosaurus in the foreground, and four pterodactyls flying in the air. We trapped the stegosaurus on a cliff surrounded by lava on three sides in order to convey the horror of the natural disaster



(a) (b)

Figure 3: Visualization of simulated fluid: (a) Screen shot of the 3D simulation demo (b) Generated fluid surface mesh.

unfoldin around it. We used the perspective camera in PBRT set to a wide 105 degree field of view in order to make the scene more dramatic. (Unfortunately, we were unable to find a realistic camera lens that could capture this wide field of view and subtly de-focus the background.) In the far background, we use a photo of an overcast day as a backdrop [10].

We were also able to find the dinosaur models online [2, 9] and modify the textures to be more visually appealing in the scene. For the two ash plumes, we started with the smoke-plumes scene in the PBRT v3 scenes distribution [8]. We rescaled, rotated, and transposed the mediums to the tops of the volcanoes. Depending on the lighting, we also carefully tuned the scattering and absorption coefficients to make the plume look more like volcanic ash.

The solid ash particles in the air were generated randomly. In the volume around the camera, we uniform randomly placed 1 million small disks of random sizes. On each disk, we used a translucent material, tuned to look like ash, and used a Perlin noise for the bump map. Because of the large field of view of our camera and the lack of realistic focus from the perspective camera, we rejected samples that were too close to the camera since these would become extremely stretched. A realistic wide angle lens would have probably helped here since the extremely close ash would not be in sharp focus.

To light the scene, we used a combination of the emissive lava mesh, an off-screen spherical light source to the right, and a cloudy day environment map. The purpose of the environment map and spherical light was to counter the red hue from the lava and to add more illumination to the scene overall, especially on he background and the stegosaurus.

4 Volcano Modeling and Texture

As a start, we downloaded a free dormant volcano mesh as a starting point for modeling [11]. The first modifications that we made were to increase the height of the volcano. We also duplicated the volcano in our final scene. The initial problems that we encountered were that (1) the modifications to the volcano mesh distorted the UV-mapping on the stretched faces and (2) the volcano mesh is of low resolution, which is extremely noticeable when viewed from close up. This is shown in Figure. 4.

Figure 4: The original volcano mesh after vertical stretching.

We addressed the first issue by increasing the resolution of the mesh in our scene foreground and generating a new UV map. We also realized that the original texture was too green for our eruption scene and replaced it with a rock texture that we downloaded from [5].

To address the second issue, we needed to generate a more convincing volcanic rock texture for the foreground scene. Initially, we experimented with bump maps in PBRT, starting with the one corresponding to the rock texture that we had selected earlier and by using the noise textures in PBRT. We also tried various parameters for scaling these textures. However, these attempts were unsuccessful as we were unable to generate enough noise on the low resolution mesh for the texture and edges to be convincing.

For our final algorithm (which we call the "RockMyWorld" algorithm), we sampled faces on the volcano foreground mesh and randomly placed rocks on them. Starting from a few rock models that we found online [1, 3], we applied random transformations such as rotation and scaling and placed them on randomly sampled points. Our hope was that by placing down enough rocks, with more detailed geometry (1000 faces each) and some overlapping, the surface would become more rough and realistic. We also added a noise bump map on the rocks to add more detail. The result appears somewhat volcanic, like an accumulation of old lava or pumice.

5 Lava Modeling and Texture

We took different approaches for rendering the lava on the mountains and the lava on the floor. For the lava on the mountain, we took the resulting mesh of our fluid simulation and added Perlin noise bumps to increase the perceived resolution. We made the mesh emissive while also applying lava texture (which was a mix of two image maps [6, 7]).

For the ground, we took the ground mesh and made it a light emitter (an orange-ish light). We then took the same ground mesh and shifted it up a little and set it to be glass material. The transmittance of the glass was set to an image mapped texture for lava. Figure. 5 shows the starting image textures, which we manipulated through tiling (seamlessly). The reason we decided to use two different textures for lava was to increase variety while also blending with other rocks in the scene.

We also ran fluid experiments for lava on the ground, but it was difficult to simulate sufficient amounts of fluid at high enough resolution to achieve the effect in our final image.

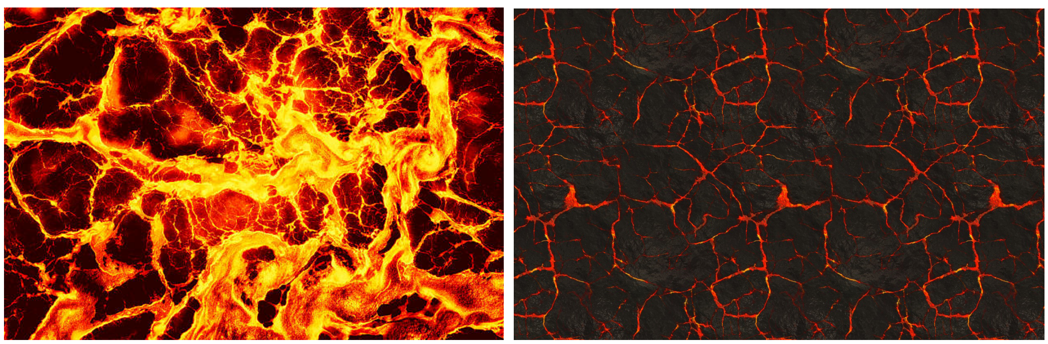


Figure 5: The original lava image textures.

Once we have emissive lava, the next problem to solve is the hard edges between the volcanic rock geometry (output by our "RockMyWorld" algorithm) and the lava on the floor. Figure. 6 shows this problem. To reduce this problem we added two more layers of diffusing glass on top of the lava, using the ground mesh. We set a small amount of roughness on these layers of diffusing glass and shifted them so that they are slightly above the texture glass, with a small gap in between. This produces a diffusing effect that can be seen in our final image. A better approach for this is to use volume scattering, but our current approach does not require additional geometry.

Figure 6: Final image with hard lava edges.

6 Rendering

Our final scene contains ≈160K faces from the two volcanoes, ≈1.2M faces from the lava mesh, ≈6M faces from our generated rock texture, ≈1M ash disks, ≈56K faces from the dinosaurs (≈ 16K, for the stegosaurus and ≈ 10K per pterodactyl). We rendered the scene using BDPT with bounces and a spatial light sampling strategy and using the "02sequence" sampler (because of limits on the sample dimensionality with the Halton and Sobal sampler implementations). Rendering the scene took roughly 1 hour on 40 physical cores (80 hyperthreaded cores).

One challenge that we ran into when rendering was the lack of support for mixed mediums. This was problematic when we tried to apply a homogeneous medium to simulate the atmosphere, while also rendering the plumes of ash. In the end, decided to render two images, one with the plumes and one with the atmosphere, and interpolate between them. The results before interpolation are shown in Figure. 7 and Figure. 8. If we had more time, one improvement that we would have liked to make is to merge the two media for the ash plume and the atmosphere.

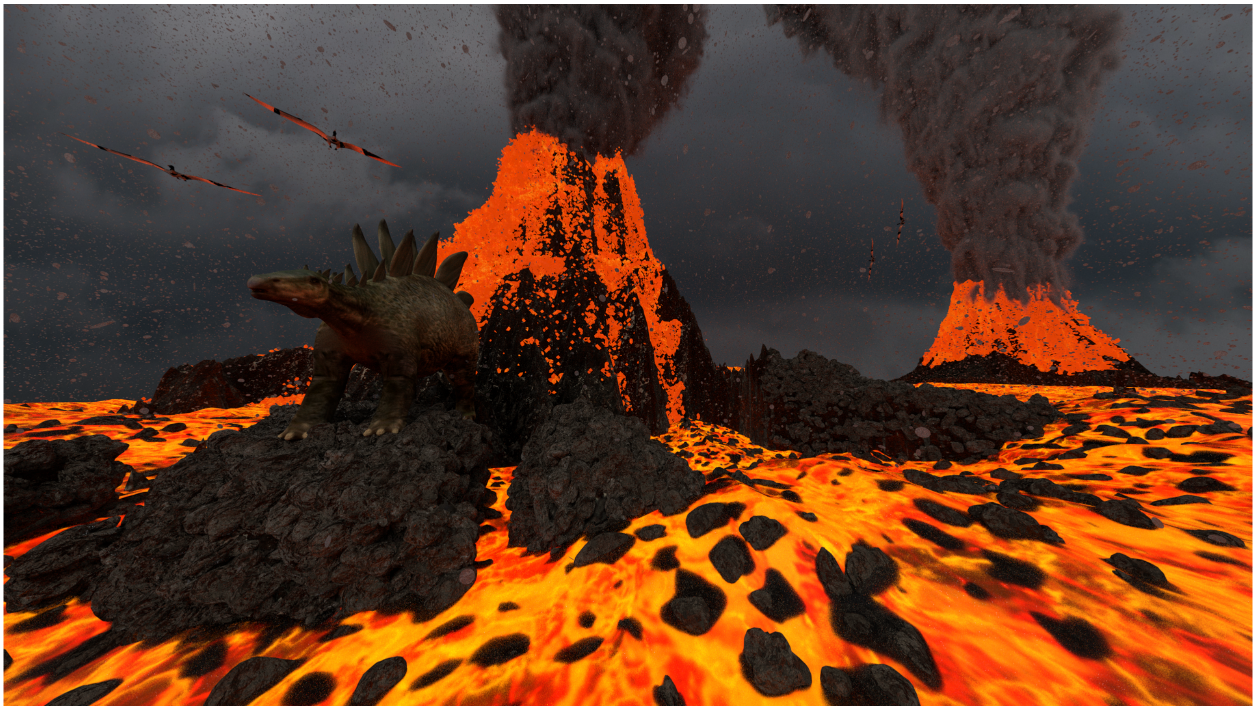


Figure 7: The scene with ash plumes and particles at 64 samples per pixel at 4K resolution.

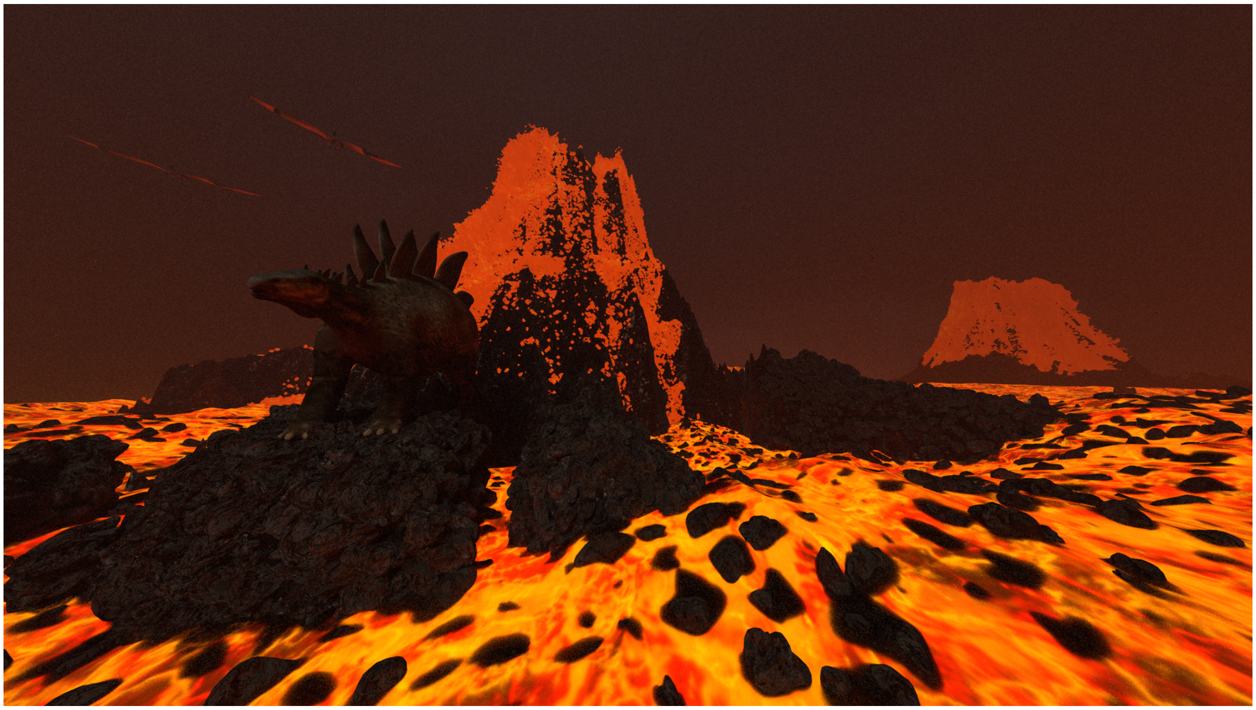


Figure 8: The scene with the atmospheric medium at 128 samples per pixel at 4K resolution.

7 Individual Contributions

In this project, Haotian implemented the fluid simulation system, as well as modeled volcano and ground lava geometry. James contributed the general scene design, rock and lava textures, and ash/smoke effects and handled most of the parameter tuning. Both members collaborated on writing this report.

8 Limitations and Future Work

Although we physically modeled the lava geometry, we did not physically render lava, such as taking into account temperature to determine viscosity and emissivity. The texture mapping added variety to the lava rendering, but it still remains unnatural, especially at the intersection between lava and rock. The future direction will be considering heat transfer and model temperature variation at simulation time.

Given additional time, we would have liked to spend more time tuning the parameters on the rock, lava and ash materials as well.

9 Acknowledgments

We would like to acknowledge Hubert, Brennan and Kavyon for their advice on tackling many challenges.

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