

Real-Time, Empirical, Ocean Simulation & Physically Based Renderer

A-Level Computer Science NEA

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0.1. Abstract

// synopsis

1. Analysis

1.1. Client Introduction

The client is Jahleel Abraham. They are a game developer who require a physically based, performant, configurable simulation of an ocean for use in their game. They also require a physically based lighting model derived from microfacet theory, including PBR specular, and empirical subsurface scattering. Also expected is a fully featured GUI allowing direct control over every input parameter, and a functioning camera controller.

1.2. Interview Questions

Interview notes are paraphrased.

Q: What specific ocean phenomena need to be simulated?

A: The simulation should include waves in all real-world conditions and generate foam. If possible, it should also simulate other ocean phenomena.

Q: What parameters of the simulation need to be configurable?

A: All necessary parameters for simulating real-world conditions, including tile size and individual wave quantity.

Q: Does there need to be an accompanying GUI?

A: Yes, the GUI should allow control over parameters and tile size, display frametime, and show the current state of all parameters.

Q: Do I need to implement an atmosphere/skybox?

A: A basic skybox would be nice, and an atmosphere shader should be included if possible.

Q: Do I need to implement a PBR water shader?

A: Yes, the simulation should use a physically based rendering (PBR) water shader with a microfacet BRDF.

Q: Do I need to implement caustics, reflections, or other light-related phenomena?

A: Caustics are out of scope. Implement approximate subsurface scattering and use GGX distribution with the BRDF to simulate reflections.

Q: Are there any limitations due to existing technology?

A: The client has not started technical implementation, so they are not limited by an existing technical stack.

Q: Does this need to interoperate with existing code?

A: See the response to technical limitations (no existing stack constraints).

Q: Are there limitations due to the target device(s)?

A: The simulation should run on both x86 and ARM64 devices.

Q: Are there other performance-intensive systems in place?

A: See the response to technical limitations.

Q: Is the product targeted to low/mid/high-end systems?

A: The simulation is primarily targeted at mid-to-high-end systems, but ideally, it should also be performant on lower-end hardware.

1.3. Similar Solutions

As this is a fairly niche simulation that is generally used in closed source applications, there were only a few sources I could find that are relevant and have available information in relation to their implementation. Understanding existing implementations, particularly in regard to their spectrum synthesis, has allowed me to develop the correct balance between fidelity and performance.

1.3.1. Sea of Thieves

Sea of thieves is by far the highest profile game utilising an FFT ocean. It focuses on developing a stylised ocean scene over a realistic one so differs in the following ways:

- Does not have exact PBR lighting, but still derives its lighting from PBR theory
- Is intended to have minimal frametime impact while operating on low end hardware, so has a lower resolution, using a less complicated spectrum
- Has a more detailed foam simulation, where they convolve the foam map with a stylised texture, and use Unreal Engine's particle system to simulate sea spray

The implementation is closed source, so I do not have access to any detailed implementation information. Anything I could find was primarily from a conference they held on its development.

1.3.2. Acerola

Acerola's ocean simulation was made as part of a pseudo-educational youtube series on simulating water in games. It has a few notable similarities, and key benefits over others:

- It is a realistic simulation, using a spectrum that is (As far as I am aware) fully in-line with the most recent oceanographic literature
- Uses a highly performant FFT implementation, based on Nvidia WaveWorks
- Is built upon unity and utilises full PBR lighting, as derived from microfacet theory

1.3.3. Jump Trajectory

Jump trajectory created a very detailed video explaining the process of creating an FFT-based ocean simulation, also sharing the source code publically. It is similar to acerolas in most ways, but has a few notable differences:

- uses a “simpler” FFT implementation, that is much easier to understand
- Abstracts his data and algorithms into different compute passes
- Decays foam non-exponentially, using a flat base color for foam

1.4. Success Criteria

- 1 The application opens with a titled, resizable, movable, and closable OS window that follows OS styling.
- 2 A single skybox texture can be loaded from a specified filepath.
- 3 The camera can be controlled via mouse input, with left-click activation, full panning, scroll-based zoom, and stable field of view across window resizes.
- 4 A user interface (UI) is present, featuring resizable, movable, and collapsible panels, color pickers, sliders, an FPS display, and simulation details.
- 5 The ocean simulation exhibits Gaussian wave variance with three controllable length scales and frequency cutoffs.
- 6 The simulation runs at a minimum of 60 FPS on mid-range gaming hardware (GTX 1060 and above).
- 7 The simulation has sensible default parameters
- 8 The ocean has adjustable size, including tile size, instance count, and simulation resolution.
- 9 Foam effects are implemented with adjustable color, decay rate, visibility, and wave-breaking injection settings.
- 10 The ocean conditions are user-adjustable, including depth, gravity, wind parameters, fetch, choppiness, and swell properties.
- 11 A skybox with a correctly transformed sun is rendered, responding correctly to camera view and zoom
- 12 The ocean surface has no obvious pixellation beyond that as a result of the simulation resolution
- 13 The ocean has approximate subsurface scattering, with adjustable scatter color, bubble effects, and lighting properties.
- 14 Real-time reflections from the environment are visible, influenced by user-controllable fresnel effects and refractive indices.
- 15 Specular reflections are implemented with toggleable PBR/non-PBR modes, adjustable shininess, and roughness settings.
- 16 Distance fog is implemented with user-adjustable density, offset, falloff, and height settings.

1.5. Spectrum Synthesis

1.5.1. Nomenclature

To compute the initial spectra, we rely on various input parameters and definitions shared between various functions and parts of the program. Table 1 lists the relevant symbols, meanings and relationships where appropriate. Note that throughout this project we are defining the positive y direction as “up”.

Variable	Definition
\vec{k}	2D Wave Vector
k_x	X Component of wave vector
k_z	Z Component of wave vector
k	Magnitude of the wave vector
t	time
m, n	Indices of summation
M, N	Dimensions of summation
$\vec{x} = [x_x, x_z]$	Position vector in world space
$\omega = \varphi(k)$	Dispersion relation
ω_p	Peak Frequency
g	Gravitational Constant = 9.81
h	Ocean Depth
U_{10}	Wind speed 10m above surface
F	Fetch, distance over which wind blows
θ	Wind direction = $\arctan 2(k_z, k_x) - \theta_0$
θ_0	Wind direction offset
L	Lengthscale
$L_x = L_z$	Simulation Dimensions, power of two
ξ	Swell amount
ξ_r, ξ_i	Gaussian Random Numbers
λ	Choppiness factor
κ	Foam bias
μ	Foam injection threshold
ζ	Foam decay rate
I	Foam value

Table 1: Simulation Variable Definitions

1.5.2. Dispersion Relation

Citations: [4], [5]

The relation between the travel speed of the waves and their wavelength, written as a function relating angular frequency ω to wave number \vec{k} . This simulation involves finite depth, and so we will be using a dispersion relation that considers it.[5]

$$\omega = \varphi(k) = \sqrt{gk \tanh(kh)}$$

$$\frac{d\varphi(k)}{dk} = \frac{g(\tanh(hk) + hk \operatorname{sech}^2(hk))}{2\sqrt{gk \tanh(hk)}}$$

1.5.3. Non-Directional Spectrum (JONSWAP)

Citations: [5], [6], [7], [8]

The JONSWAP energy spectrum is a more parameterised version of the Pierson-Moskowitz spectrum, and an improvement over the Philips Spectrum used in [4], simulating an ocean that is not fully developed (as recent oceanographic literature has determined this does not happen). The increase in parameters allows simulating a wider breadth of real world conditions.

$$S_{\text{JONSWAP}}(\omega) = \frac{\alpha g^2}{\omega^5} \exp \left[-\frac{5}{4} \left(\frac{\omega_p}{\omega} \right)^4 \right] 3.3^r$$

$$r = \exp \left[-\frac{(\omega - \omega_p)^2}{2\omega_p^2 \sigma^2} \right]$$

$$\alpha = 0.076 \left(\frac{U_{10}^2}{Fg} \right)^{0.22}$$

$$\omega_p = 22 \left(\frac{g^2}{U_{10} F} \right)^{\frac{1}{3}}$$

$$\sigma = \begin{cases} 0.07 & \text{if } \omega \leq \omega_p \\ 0.09 & \text{if } \omega > \omega_p \end{cases}$$

1.5.4. Depth Attenuation Function (Approximation of Kitaiigorodskii)

Citations: [5]

JONSWAP was fit to observations of waves in deep water. This function adapts the JONSWAP spectrum to consider ocean depth, allowing a realistic look based on distance to shore. The actual function is quite complex for a relatively simple graph, so can be well approximated as below [5].

$$\Phi(\omega, h) = \begin{cases} \frac{1}{2}\omega_h^2 & \text{if } \omega_h \leq 1 \\ 1 - \frac{1}{2}(2 - \omega_h)^2 & \text{if } \omega_h > 1 \end{cases}$$

$$\omega_h = \omega \sqrt{\frac{h}{g}}$$

1.5.5. Directional Spread Function (Donelan-Banner)

Citations: [5]

The directional spread models how waves react to wind direction [7]. This function is multiplied with the non-directional spectrum in order to produce a direction dependent spectrum [5].

$$D(\omega, \theta) = \frac{\beta_s}{2 \tanh(\beta_s \pi)} \operatorname{sech}^2(\beta_s \theta)$$

$$\beta_s = \begin{cases} 2.61 \left(\frac{\omega}{\omega_p} \right)^{1.3} & \text{if } \frac{\omega}{\omega_p} < 0.95 \\ 2.28 \left(\frac{\omega}{\omega_p} \right)^{-1.3} & \text{if } 0.95 \leq \frac{\omega}{\omega_p} < 1.6 \\ 10^\epsilon & \text{if } \frac{\omega}{\omega_p} \geq 1.6 \end{cases}$$

$$\varepsilon = -0.4 + 0.8393 \exp \left[-0.567 \ln \left(\left(\frac{\omega}{\omega_p} \right)^2 \right) \right]$$

1.5.6. Swell

Citations: [5]

Swell refers to the waves which have travelled out of their generating area [5]. In practice, these would be the larger waves seen over a greater area. the directional spread function including swell is based on combining donelan-banner with a swell function as below. The integral seen in Q_{final} is computed numerically using the rectangle rule. Q_ξ is a normalisation factor to satisfy the condition specified in equation (31) in [5], approximation taken from [7]

$$D_{\text{final}}(\omega, \theta) = Q_{\text{final}}(\omega) D_{\text{base}}(\omega, \theta) D_\varepsilon(\omega, \theta)$$

$$Q_{\text{final}}(\omega) = \left(\int_{-\pi}^{\pi} D_{\text{base}}(\omega, \theta) D_\xi(\omega, \theta) d\theta \right)^{-1}$$

$$D_\xi = Q_\xi(s_\xi) |\cos\left(\frac{\theta}{2}\right)|^{2s_\xi}$$

$$s_\xi = 16 \tanh\left(\frac{\omega_p}{\omega}\right) \xi^2$$

$$Q_\xi(s_\xi) = \begin{cases} -0.000564s_\xi^4 + 0.00776s_\xi^3 - 0.044s_\xi^2 + 0.192s_\xi + 0.163 & \text{if } s_\xi < 5 \\ -4.80 \times 10^{-8}s_\xi^4 + 1.07 \times 10^{-5}s_\xi^3 - 9.53 \times 10^{-4}s_\xi^2 + 5.90 \times 10^{-2}s_\xi + 3.93e-01 & \text{otherwise} \end{cases}$$

1.5.7. Directional Spectrum Function

Citations: [5]

The TMA spectrum below is an undirectional spectrum that considers depth.

$$S_{\text{TMA}}(\omega, h) = S_{\text{JONSWAP}}(\omega)\Phi(\omega, h)$$

This takes inputs ω, h , whilst we need it to take input \vec{k} per Tessendorf [4] - in order to do this we apply the following transformation [5]. Similarly, to make the function directional, we also need to multiply it by the directional spread function [5].

$$S_{\text{TMA}}(\vec{k}) = 2S_{\text{TMA}}(\omega, h) \frac{d\omega}{dk} \frac{1}{k} \Delta k_x \Delta k_z D(\omega, \theta)$$

$$\Delta k_x = \Delta k_z = \frac{2\pi}{L}$$

1.6. Ocean Geometry & Foam

1.6.1. Displacements

Citations: [4], [7], [8], [9]

For a field of dimensions L_x and L_z , we calculate the displacements at positions \vec{x} by summing multiple sinusoids with complex, time dependant amplitudes. [4]. By arranging the equations into a specific format, we can convert the frequency domain representation of the wave into the spatial domain using the inverse discrete fourier transform.

$$\text{Vertical Displacement (y)} : h(\vec{x}, t) = \sum_{\vec{k}} \hat{h}(\vec{k}, t) e^{i\vec{k} \cdot \vec{x}}$$

$$\text{Horizontal Displacement (x)} : \lambda D_x(\vec{x}, t) = \sum_{\vec{k}} -i \frac{\vec{k}_x}{k} \hat{h}(\vec{k}, t) e^{i\vec{k} \cdot \vec{x}}$$

$$\text{Horizontal Displacement (z)} : \lambda D_z(\vec{x}, t) = \sum_{\vec{k}} -i \frac{\vec{k}_z}{k} \hat{h}(\vec{k}, t) e^{i\vec{k} \cdot \vec{x}}$$

1.6.2. Derivatives

Citations: [4], [7]

For lighting calculations and the computation of the jacobian, we require the derivatives of the above displacements. As the derivative of a sum is equal to the sum of the derivatives, we compute exact derivatives using the following summations.

$$\text{X Component of Normal} : \varepsilon_x(\vec{x}, t) = \sum_{\vec{k}} i k_x \hat{h}(\vec{k}, t) e^{i\vec{k} \cdot \vec{x}}$$

$$\text{Z Component of Normal} : \varepsilon_z(\vec{x}, t) = \sum_{\vec{k}} i k_z \hat{h}(\vec{k}, t) e^{i\vec{k} \cdot \vec{x}}$$

$$\text{Jacobian xx} : \frac{dD_x}{dx} = \sum_{\vec{k}} -\frac{k_x^2}{k} \hat{h}(\vec{k}, t) e^{i\vec{k} \cdot \vec{x}}$$

$$\text{Jacobian zz} : \frac{dD_x}{dz} = \sum_{\vec{k}} -\frac{k_z^2}{k} \hat{h}(\vec{k}, t) e^{i\vec{k} \cdot \vec{x}}$$

$$\text{Jacobian xz} : \frac{dD_x}{dz} = \sum_{\vec{k}} -\frac{k_x k_z}{k} \hat{h}(\vec{k}, t) e^{i\vec{k} \cdot \vec{x}}$$

1.6.3. Frequency Spectrum Function

Citations: [4], [7], [8]

This function defines the amplitude of the wave at a given point in space at a given time depending on it's frequency. The frequency is generated via the combination of 2 gaussian random numbers and a energy spectrum in order to simulate real world ocean variance and energies. Note that the

time dependant component of the exponent is pushed into this amplitude, in order to simplify the summation.

$$\hat{h}_0(\vec{k}) = \frac{1}{\sqrt{2}}(\xi_r + i\xi_i)\sqrt{S_{\text{TMA}}(\vec{k})}$$

$$\hat{h}(\vec{k}, t) = \hat{h}_0(\vec{k})e^{i\varphi(k)t} + h_0(-k)e^{-i\varphi(k)t}$$

1.6.4. Box-Muller Transform

Citations: [10]

The ocean exhibits gaussian variance in the possible waves. Due to this the frequency spectrum function is varied by gaussian random numbers with mean 0 and standard deviation 1, which we generate using the box-muller transform converting from uniform variates from 0..1. [4]. Derivation is from polar coordinates, by treating x and y as cartesian coordinates, more details at [10]

$$\xi_r, \xi_i \sim N(0, 1)$$

$$\xi_r = \sqrt{-2.0 \ln(u_1)} \cos(2\pi u_2)$$

$$\xi_i = \sqrt{-2.0 \ln(u_1)} \sin(2\pi u_2)$$

1.6.5. Foam, The Jacobian, and Decay

Citations: [4], [5], [8]

The jacobian describes the “uniqueness” of a transformation. This is useful as where the waves would crash, the jacobian determinant of the displacements goes negative. Per Tessendorf [4], we compute the determinant of the jacobian for the horizontal displacement, $D(\vec{x}, t)$.

$$J(\vec{x}) = J_{xx}J_{zz} - J_{xz}J_{zx}$$

$$J_{xx} = 1 + \lambda \frac{dD_x}{dx}, J_{zz} = 1 + \lambda \frac{dD_z}{dz}$$

$$J_{xz} = J_{zx} = 1 + \lambda \frac{dD_x}{dz}$$

we then threshold the value such that $J(\vec{x}) < \mu$, wherein if true we inject foam into the simulation at the given point. This value should accumulate (and decay) over time to mimic actual ocean foam, which is achieved by modulating the previous foam value (I_0) by an exponential decay function:

$$J_{\text{biased}} = \kappa - J(\vec{x})$$

$$I = \begin{cases} I_0 e^{-\zeta} + J_{\text{biased}} & \text{if } J_{\text{biased}} > \mu \\ I_0 e^{-\zeta} & \text{if } J_{\text{biased}} < \mu \end{cases}$$

1.6.6. Cascades

Citations: [4], [5], [7]

The periodicity of sinusoidal waves leads to visible tiling, even with an amount of waves of order 10^6 . It is possible to increase the simulation resolution to counteract this, but even the FFT becomes computationally impractical at large enough scales. To counteract this, we instead compute the entire simulation multiples times with different lengthscales at a lower resolution - combining the results such that there is no longer any visual tiling. This results in an output with comparable quality to an increase in resolution, while requiring less overall calculations, e.g $3(256^2) < 512^2$. To do this, we have to select low and high cutoffs for each lengthscale such that the waves do not overlap and superposition.

1.6.7. 2D GPGPU Cooley-Tukey Radix-2 Inverse Fast Fourier Transform

Citations: [4], [7]

The Cooley-Tukey FFT is a common implementation of the FFT, used for fast calculation of the DFT. The direct DFT is computed in $O(n^2)$ time whilst the FFT is computed in $O(n \log n)$. This is a significant improvement as we are dealing with n in the order of $10^4 - 10^6$, computed multiple times per frame. The FFT exploits the redundancy in DFT computation in order to increase performance, being able to do so only when $L_x = L_z = M = N = 2^x, x \in \mathbb{Z}$, the coordinates and wave vectors lie on a regular grid, and the summation is in the following format, which are all true save some differences in summation limits.

$$\text{Inverse DFT: } F_n = \sum_{m=0}^{N-1} f_m e^{2\pi i \frac{m}{N} n}$$

$$\text{Wave Summation: } h(\vec{x}, t) = \sum_{m=-\frac{N}{2}}^{\frac{N}{2}} h(t) e^{2\pi i \frac{m}{N} n}$$

1.7. Post Processing

1.7.1. Nomenclature

Definitions of the initial variables and parameters for post processing. Note that there are a lot of omitted scaling variables and similar that are applied throughout the shader, these are all of the format `consts.sim/shader.variable_name`

Variable	Definition
L_{eye}	final light value for a fragment
L_{scatter}	light re-emitted due to subsurface scattering
L_{specular}	light reflected from the sun
$L_{\text{env_reflected}}$	light reflected from the environment
F	Fresnel Reflectance
\hat{H}	Halfway vector
\hat{N}	Surface normal
\hat{V}	Camera view vector
\hat{L}	Light source vector
k_1	Subsurface Height Attenuation
k_2	Subsurface Reflection Scale Factor
k_3	Subsurface Diffuse Scale Factor
k_4	Subsurface Ambient Scale Factor
C_{ss}	Water Scatter Color
C_f	Air Bubbles Color
L_{sun}	Sun Color
P_f	Air Bubbles Density
W_{max}	Max between 0 and wave height
$\langle \omega_a, \omega_b \rangle$	$\max(0, (\omega_a \cdot \omega_b))$
λ_{GGX}	Smith's G_1 masking function
n_1	Refractive index of water
n_1	Refractive index of air
S	The Shininess of the material for fresnel
B	The Shininess of the material for blinn phong
G_2	Smith's G_2 geometric attenuation function
D_{GGX}	GGX Distribution of microfacet normals
α	Roughness of the surface

Table 2: Post Processing Variable Definitions

1.7.2. Rendering Equation

Citations: [1], [8], [11]

This abstract equation models how a light ray incoming to a viewer is “formed” (in the context of this simulation). Due to there only being a single light source (the sun), subsurface scattering [11] can be used to replace the standard L_{diffuse} and L_{ambient} terms.

To include surface foam, we *lerp* between the foam color and L_{eye} based on foam density [11]. We also increase the roughness in areas covered with foam for L_{specular} [11].

$$L_{\text{eye}} = (1 - F)L_{\text{scatter}} + L_{\text{specular}} + FL_{\text{env_reflected}}$$

1.7.3. Normalisation & Surface Normals

Citations: [2], [4], [7]

When computing lighting using vectors, we are only concerned with the direction of a given vector not the magnitude. In order to ensure the dot product of 2 vectors is equal to the cosine of their angle we normalise the vectors.

In order to compute the surface normals we sum, for each lengthscale, the value of $\varepsilon(\vec{x}, t)$ such that the following is true, which is then normalised.

$$\vec{N} = \begin{bmatrix} -\varepsilon_x(\vec{x}, t) \\ 1 \\ -\varepsilon_z(\vec{x}, t) \end{bmatrix}$$

1.7.4. Subsurface Scattering

Citations: [8], [11]

This is the phenomenon where some light absorbed by a material eventually re-exits and reaches the viewer. Modelling this realistically is impossible in a real time context (with my hardware). Specifically within the context of the ocean, we can approximate it particularly well as the majority of light is absorbed. An approximate formula taking into account geometric attenuation, a crude fresnel factor, lamberts cosine law, and an ambient light is used, alongside various artistic parameters to allow for adjustments. [11]

$$L_{\text{scatter}} = \frac{(k_1 W_{\max} \langle \hat{L}, -\hat{V} \rangle^4 (0.5 - 0.5 (\hat{L} \cdot \hat{N}))^3 + k_2 \langle \hat{V}, \hat{N} \rangle^2) C_{\text{ss}} L_{\text{sun}}}{1 + \lambda_{\text{GGX}}}$$

$$L_{\text{scatter}} = k_3 \langle \hat{L}, \hat{N} \rangle C_{\text{ss}} L_{\text{sun}} + k_4 P_f C_f L_{\text{sun}}$$

1.7.5. Fresnel Reflectance (Schlick’s Approximation) [1], [2], [3]

The fresnel factor is a multiplier that scales the amount of reflected light based on the viewing angle. The more grazing the angle the more light is reflected.

$$F(\hat{N}, \hat{V}) = F_0 + (1 - F_0)(1 - \hat{N} \cdot \hat{V})^s$$

$$F_0 = \left(\frac{n_1 - n_2}{n_1 + n_2} \right)^2$$

1.7.6. Blinn-Phong Specular Reflection

Citations: [2]

This is a simplistic, empirical model to determine the specular reflections of a material. It allows you to simulate isotropic surfaces with varying roughnesses whilst remaining very computationally efficient. The model uses “shininess” as an input parameter, whilst the standard to use roughness (due to how PBR models work). In order to account for this when wishing to increase roughness we decrease shininess.

$$L_{\text{specular}} = (\hat{N} \cdot \hat{H})^B$$

$$\hat{H} = \hat{L} + \hat{V}$$

1.7.7. Environment Reflections

Citations: [1], [2]

In order to get the color of the reflection for a given pixel, we compute the reflected vector from the normal and view vector. We then sample the corresponding point on the skybox and use that color as the reflected color.

$$\hat{R} = 2\hat{N}(\hat{N} \cdot \hat{V}) - \hat{V}$$

1.7.8. GGX Distribution

Citations: [12]

The distribution function used in the BRDF to model the proportion of microfacet normals aligned with the halfway vector. This is an improvement over the beckmann distribution due to the graph never reaching 0 and only tapering off at the extremes.

$$D_{\text{GGX}} = \frac{\alpha^2}{\pi((\alpha^2 - 1)(\hat{N} \cdot \hat{H})^2 + 1)^2}$$

1.7.9. Geometric Attenuation

Citations: [12]

Used to counteract the fresnel term, mimics the phenomena of masking & shadowing presented by the microfactets. The λ_{GGX} term changes depending on the distribution function used (GGX). \hat{S} is either the light or view vector.

$$G_2 = G_1(\hat{H}, \hat{L})G_1(\hat{H}, \hat{V})$$

$$G_1(\hat{H}, \hat{S}) = \frac{1}{1 + a\lambda_{\text{GGX}}}$$

$$a = \frac{\hat{H} \cdot \hat{S}}{\alpha\sqrt{1 - (\hat{H} \cdot \hat{S})^2}}$$

$$\lambda_{\text{GGX}} = \frac{-1 + \sqrt{1 + a^{-2}}}{2}$$

1.7.10. Microfacet BRDF

Citations: [8], [11], [12]

This BRDF (Bidirectional Reflectance Distribution Function) is used to determine the specular reflectance of a sample. There are many methods of doing this - the one used here is derived from microfacet theory. D can be any distribution function - the geometric attenuation function G changing accordingly.

$$L_{\text{specular}} = \frac{L_{\text{sun}} F G_2 D_{\text{GGX}}}{4(\hat{N} \cdot \hat{L})(\hat{N} \cdot \hat{V})}$$

1.7.11. Reinhard Tonemapping

Citations: [13]

To account for the HDR output values of some lighting functions, we tonemap the final output to be within a 0..1 range by dividing a color c as follows (given that c is effectively a 3D Vector)

$$c_{\text{final}} = \frac{c}{c + [1, 1, 1]}$$

1.7.12. Distance Fog & Sun

Citations: [1]

To hide the imperfect horizon line we use a distance fog attenuated based on height and distance. This is generated by exponentially decaying a fog factor based on the relative height of the fragment compared to the ocean, then *lerping* between the fog color and sky_color based on this. For the ocean surface we instead *lerp* based on the distance from camera compared to a max distance, and then decaying and offsetting based on input parameters.

To render the sun, I compare the dot product of the ray and sun directions to the cosine of the maximum sky angle the sun can occupy and then *lerp* between the sun and sky color based on a linear falloff factor.

1.8. Prototyping

A prototype was made in order to test the technical stack and gain experience with graphics programming and managing shaders. I created a Halvorsen strange attractor [14], using differential equations, and then did some trigonometry to create a basic camera controller using Winit's event loop.

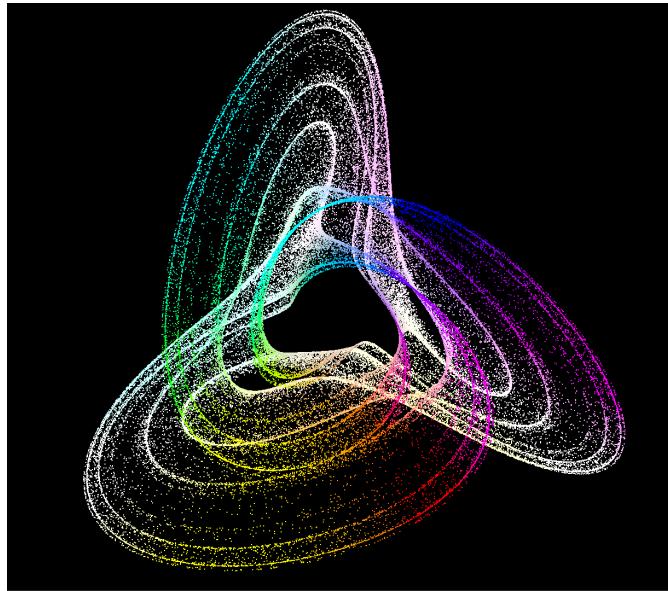


Figure 1: Shader Output, Found at <https://github.com/CmrCrabs/chaotic-attractors>

1.9. Additional Features

If given enough time I would like to implement the following:

- Swell, the waves which have travelled out of their generating area [5].
- Further post processing effects, such as varying tonemapping options and a toggleable bloom pass
- A sky color simulation, as this would allow the complete simulation of a realistic day night cycle for any real world ocean condition.
- LEADR environment reflections, based on the paper by the same name (Linear Efficient Antialiased Displacement and Reflectance Mapping)

1.10. Project Objectives

1.10.1. Engine

- 1 there is an os window created on startup
 - 1.1 the window has an appropriate title
 - 1.2 the window follows the OS's conventions and compositor styling
 - 1.3 the window can be resized without breaking the simulation
 - 1.4 the window can be moved
 - 1.5 the window can move between monitors without breaking
 - 1.6 the window can be closed by pressing the escape key
- 2 the scene has a single mesh stored on the cpu
 - 2.1 the user can resize the mesh
 - 2.2 there are multiple instances of the mesh visible
 - 2.3 the user can control how many instances there are
- 3 a filepath can be specified such that a single skybox .exr texture is read into GPU memory
- 4 the user can control the camera
 - 4.1 the camera can only be controlled when left-click is held down
 - 4.2 the camera's pitch can be controlled by moving the mouse
 - 4.3 the camera's yaw can be controlled by moving the mouse
 - 4.4 the camera's zoom can be controlled by using the scroll wheel
 - 4.5 the camera's render distance is large enough to see the entire ocean
 - 4.6 the cameras field of view does not change upon window resize
 - 4.7 the cameras view direction does not change upon window resize
- 5 the user can only control the camera if the UI is not selected
- 6 the user can access a user interface
 - 6.1 the user can move the UI
 - 6.2 the user can collapse the UI
 - 6.3 the user can edit colors using the UI
 - 6.4 the user can control sliders using the UI
 - 6.5 the user can read the fps from the UI
 - 6.6 the user can get the simulation resolution from the UI
 - 6.7 the user can see the time elapsed from the UI

1.10.2. Simulation

- 1 The simulation exhibits gaussian variance in the possible waves
- 2 The simulation is performant, being able to run at above 60fps on mid-range gaming hardware (gtx 1060+)
- 3 the simulation should have sensible default parameters
- 4 the simulations input parameters should be clamped such that changing parameters cannot permanently break the simulation
- 5 the simulation should not have visible tiling
- 6 the simulation should have 3 lengthscales, with user control over
 - 6.1 all 3 lengthscales
 - 6.2 all 3 low frequency cutoffs

- 6.3 all 3 high frequency cutoffs
- 7 the simulation should have a controllable size
 - 7.1 user adjustable tile size
 - 7.2 user adjustable instance quantity
 - 7.3 user adjustable simulation resolution
- 8 the simulation should support foam, with the following controllable conditions
 - 8.1 the foam color
 - 8.2 how fast the foam decays
 - 8.3 how much foam is visible
 - 8.4 when foam is injected on breaking waves
 - 8.5 how much foam is injected on breaking waves
- 9 the user should be able to control the ocean conditions
 - 9.1 user adjustable ocean depth
 - 9.2 user adjustable gravitational field strength
 - 9.3 user adjustable wind speed
 - 9.4 user adjustable wind angle
 - 9.5 user adjustable fetch
 - 9.6 user adjustable choppiness
 - 9.7 user adjustable amount of swell
 - 9.8 user adjustable integration step for swell computation
 - 9.9 user adjustable height offset for the ocean surface

1.10.3. Renderer

- 1 the scene has a skybox
 - 1.1 the skybox is correctly transformed when the camera view direction is changed
 - 1.2 the skybox is correctly transformed when the camera zoom is changed
 - 1.3 the skybox is correctly transformed when the window is resized
 - 1.4 there is a sun interpolated into the skybox
 - 1.4.1 the sun is in the correct position in the sky relative to the light vector
 - 1.4.2 the sun is correctly transformed when the camera view direction is changed
 - 1.4.3 the sun is correctly transformed when the camera zoom is changed
 - 1.4.4 the sun is correctly transformed when the window is resized
 - 1.4.5 the sun has user controllable parameters
 - 1.4.5.1 user adjustable sun color
 - 1.4.5.2 user adjustable sun x direction
 - 1.4.5.3 user adjustable sun y direction
 - 1.4.5.4 user adjustable sun z direction
 - 1.4.5.5 user adjustable sun angle
 - 1.4.5.6 user adjustable sun distance
 - 1.4.5.7 user adjustable sun size
 - 1.4.5.8 user adjustable sun falloff factor
 - 2 displacement map sampled such that there is no visible pixelation in output
 - 3 normal map sampled such that there is no visible pixelation in output
 - 4 foam map sampled such that there is no visible pixelation in output

- 5 there is visible, user controllable, subsurface scattering for ocean base color
 - 5.1 user adjustable scatter color
 - 5.2 user adjustable bubble color
 - 5.3 user adjustable bubble density
 - 5.4 user adjustable height attenuation factor
 - 5.5 user adjustable reflection strength
 - 5.6 user adjustable diffuse lighting strength
 - 5.7 user adjustable ambient lighting strength
- 6 there is visible reflections from the environment
 - 6.1 user adjustable reflection strength
 - 6.2 there is visible fresnel reflectance affecting reflections
 - 6.2.1 user adjustable water refractive index
 - 6.2.2 user adjustable air refractive index
 - 6.2.3 user adjustable fresnel shine
 - 6.2.4 user adjustable fresnel effect scale factor
 - 6.2.5 user adjustable fresnel normals scale factor
- 7 there is non physically based specular reflections
 - 7.1 user toggleable pbr / non pbr specular
 - 7.2 user adjustable shininess of surface
- 8 there is user controllable physically based specular reflections
 - 8.1 user adjustable specular scale factor
 - 8.2 user adjustable pbr fresnel scale factor
 - 8.3 user adjustable pbr cutoff low
 - 8.4 user adjustable water roughness
 - 8.5 user adjustable foam roughness factor
- 9 there is user controllable distance fog
 - 9.1 user adjustable fog density
 - 9.2 user adjustable fog distance offset
 - 9.3 user adjustable fog falloff factor
 - 9.4 user adjustable fog height offset

2. Documented Design

2.1. Technologies

Library	Version	Purpose	Link
Rust	-	Fast, memory-efficient programming language	https://www.rust-lang.org/
wgpu	23.0.1	Graphics library	https://github.com/gfx-rs/wgpu
Rust GPU	git	(Rust as a) shader language	https://github.com/Rust-GPU/rust-gpu
winit	0.29	Cross-platform window creation and event loop management	https://github.com/rust-windowing/winit
Dear ImGui	0.12.0	Bloat-free GUI library with minimal dependencies	https://github.com/imgui-imgui
imgui-wgpu-rs	0.24.0	only rendering code used, snippets taken directly from source instead of library being imported	https://github.com/yatekii/imgui-wgpu-rs
imgui-winit-support	0.13.0	only datatype translation code used, snippet taken directly from source instead of library being imported	https://github.com/imgui-imgui/imgui-winit-support
GLAM	0.29	Linear algebra operations	https://github.com/bitshifter/glam-rs
Pollster	0.3	Used to read errors (async executor for wgpu)	https://github.com/zesterer/pollster
Env Logger	0.10	Logging for debugging and error tracing	https://github.com/env-logger-rs/env_logger
Image	0.24	Used to read a HDRI from a file into memory	https://github.com/image-rs/image
Nix	-	Creating a declarative, reproducible development environment	https://nixos.org/

2.2. Core Algorithm [4], [5]

Below is a high-level explanation of the core algorithm for the simulation. A visual representation can be seen on the next page.

On Startup:

- Generate gaussian random number pairs, and store them into a texture, on the CPU
- Compute the butterfly operation's twiddle factors, and indices, and store them into a texture

On Parameter Change (For Every Lengthscale):

- Compute the initial wave vectors and dispersion relation, and store into a texture
- Compute the initial frequency spectrum for each wave vector, and store into a texture
- Compute the conjugate of each wave vector, and store into a texture

Frame-by-Frame:

- For Every Lengthscale:
 - Evolve initial frequency spectrum through time
 - Pre-compute & store amplitudes for FFT into textures
 - perform IFFT for height displacement
 - perform IFFT for normal calculation
 - perform IFFT(s) for jacobian
 - Process & merge IFFT results into displacement, normal, and foam maps
- Create a fullscreen quad and render skybox, sun & fog to framebuffer
- Offset tiles based on instance index & centering
- Combine values for all 3 lengthscales & offset vertices based on displacement map
- Compute lighting value and render result to framebuffer

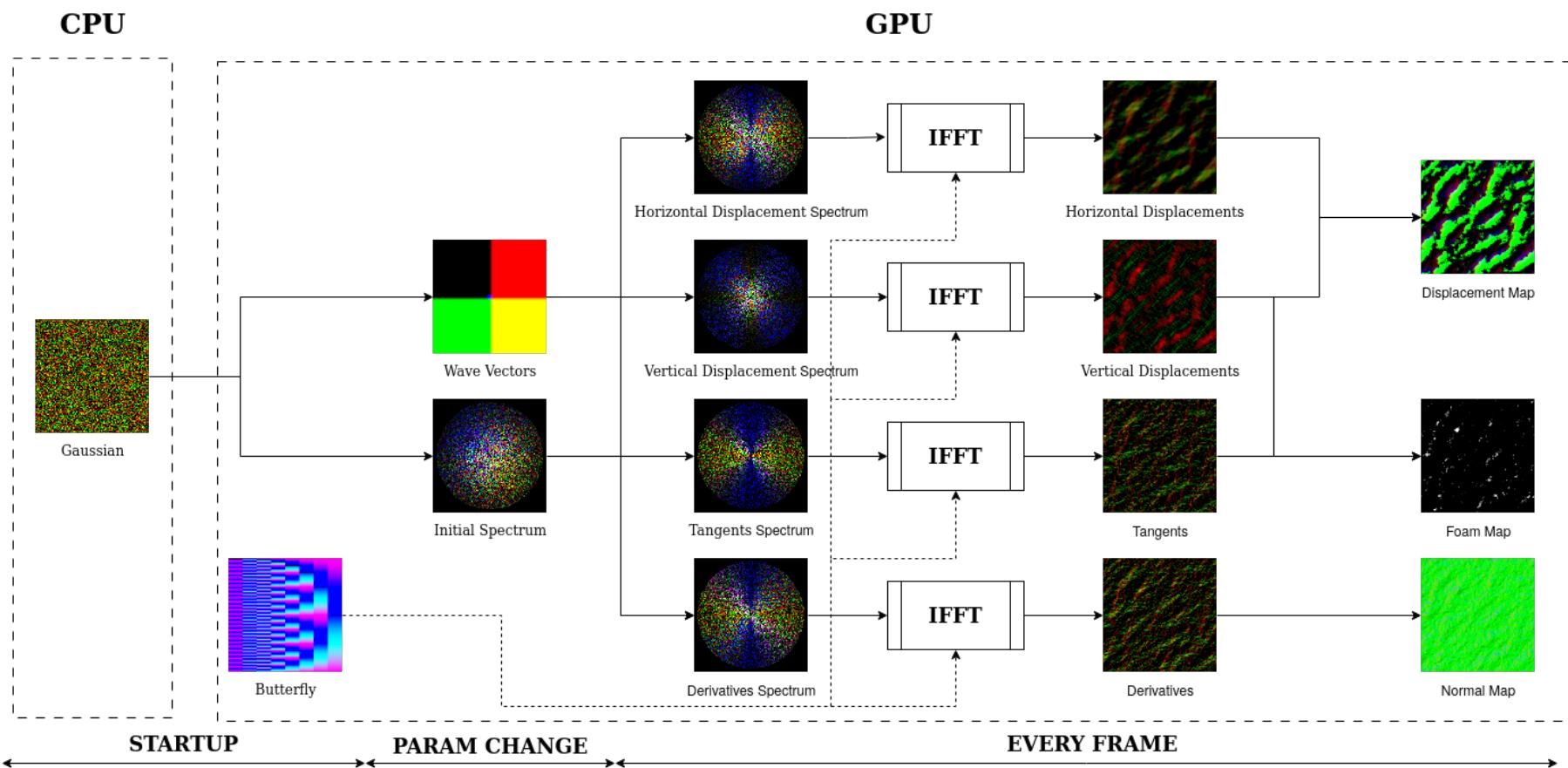


Figure 2: Visualisation of the core algorithm. Texture white / black points are not consistent for ease of demonstration

2.3. The Fourier Transform

Citations: [7], [8], [15], [16]

The IFFT algorithm I am using consists of 3 phases. The first phase involves precomputing the butterfly texture that holds the twiddle factors and input indices on the GPU. The second phase executes horizontal IFFT operations on the GPU, alternating between reading and writing to/from the input texture and a pingpong texture based on the pingpong push constant. The Third phase performs vertical IFFT operations on the same 2 textures.

Note that the “id” referenced in any pseudocode corresponds to the workgroup global invocation id, which is analogous in this context to the pixel coordinate of the texture we are operating over.

```
let pingpong = 0;
for i in 0..log_2(size) {
    dispatch_horizontal_IFFT_shader(i);
    pingpong = (pingpong + 1) % 2;
}
for i in 0..log_2(size) {
    dispatch_vertical_IFFT_shader(i);
    pingpong = (pingpong + 1) % 2;
}
dispatch_permute_shader();
```

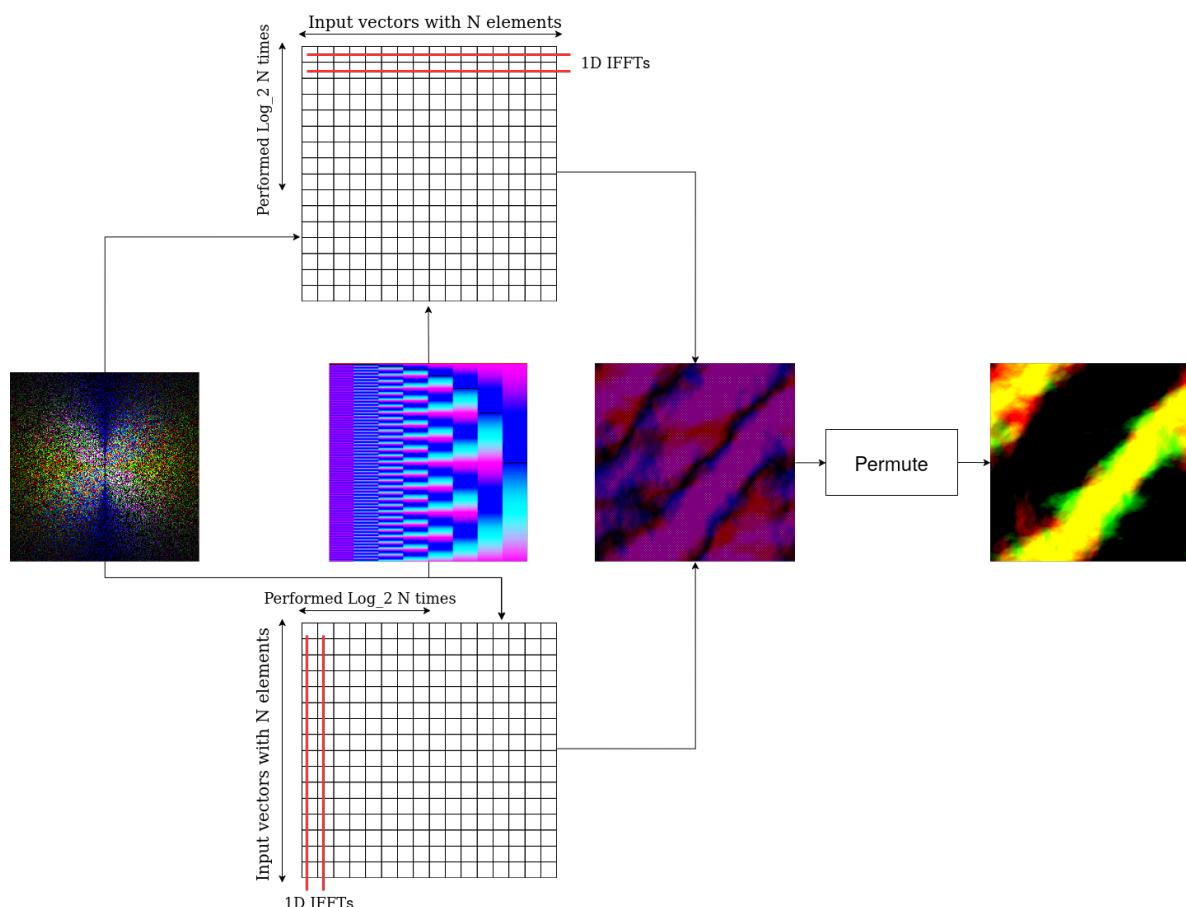


Figure 3: Visualised IFFT Algorithm showing the horizontal and vertical operations on an input texture

2.3.1. Butterfly Texture

Citations: [15]

For the following butterfly operations, input twiddle factors and indices are required. Following [15], we generate a texture with width $\log_2 N$ and height N , storing the real and complex parts of the twiddle factor into the r and g channels of the texture. We then store the input x/y indices into the b and a channels.

the twiddle factor at n is a complex number W_n^k such that

$$k = y_{\text{current}} \frac{n}{2^{\text{stage}} + 1} \bmod n$$

$$W_n^k = \exp\left(\frac{-2\pi ik}{n}\right)$$

which we represent in code using eulers formula as

$$W_n^k = \cos\left(\frac{-2\pi ik}{n}\right) + i \sin\left(\frac{-2\pi ik}{n}\right)$$

for the input indices, we compute a y_t and y_b , being the indices of the top and bottom wing respectively. for the first stage we sort our data in bit reversed order, meaning if we are in the first column of the texture, we should perform a bit reverse on the resulting indices.

We determine whether we are operating in the upper or lower “wing” based on the following equation, where we map 1 to be true and 0 to be false.

$$\text{wing} = y_{\text{current}} \bmod 2^{\text{stage}} + 1$$

```
let yt = id.y;
let yb = id.y;
if id.x == 0 {
    if wing {
        yb += 1;
    } else {
        yt -= 1;
    }
    yt.bit_reverse();
    yb.bit_reverse();
} else {
    if wing {
        yb += step as u32;
    } else {
        yt -= step as u32;
    }
}
```

2.3.2. Butterfly Operations

Citations: [15], [16]

The FFT algorithm is designed to operate over 1D data, however our input is a 2D texture. To amend this, we perform a 1D IFFT on each row horizontally, and each column vertically, as shown in Figure 3. As our textures have 4 channels that can store 2 complex numbers each, we perform the butterfly operation twice per invocation, effectively cutting the needed IFFTs in half.

```
let twiddle_factor = butterfly_texture.read(stage, id.x).rg();
let indices = butterfly_texture.read(stage, id.x).ba();
let top_signal = pingpong0.read(indices.x, id.y);
let bottom_signal = pingpong0.read(indices.y, id.y);
output = top_signal + complex_mult(twiddle_factor, bottom_signal);
```

Listing 1: Horizontal Butterfly Operation, over two sets of inputs

```
let twiddle_factor = butterfly_texture.read(stage, id.y).xy();
let indices = butterfly_texture.read(stage, id.y).zw();
let top_signal = pingpong0.read(id.x, indices.x);
let bottom_signal = pingpong0.read(id.x, indices.y);
output = top_signal + complex_mult(twiddle_factor, bottom_signal);
```

Listing 2: Vertical Butterfly Operation, over two sets of inputs

2.3.3. Permutation

Citations: [15]

Our data needs to be permuted, as per Section 1.6.7 our summation limits are offset compared to those used by the IFFT algorithm. The offset causes our data to flip signs in a gridlike pattern, as is visible in Figure 3.

```
if (id.x+ id.y) % 2 == 0.0 {
    sign = 1.0;
} else {
    sign = -1.0;
}
output = sign * pingpong0.read(id.x, id.y);
```

2.3.4. FFT Stage Visualisation

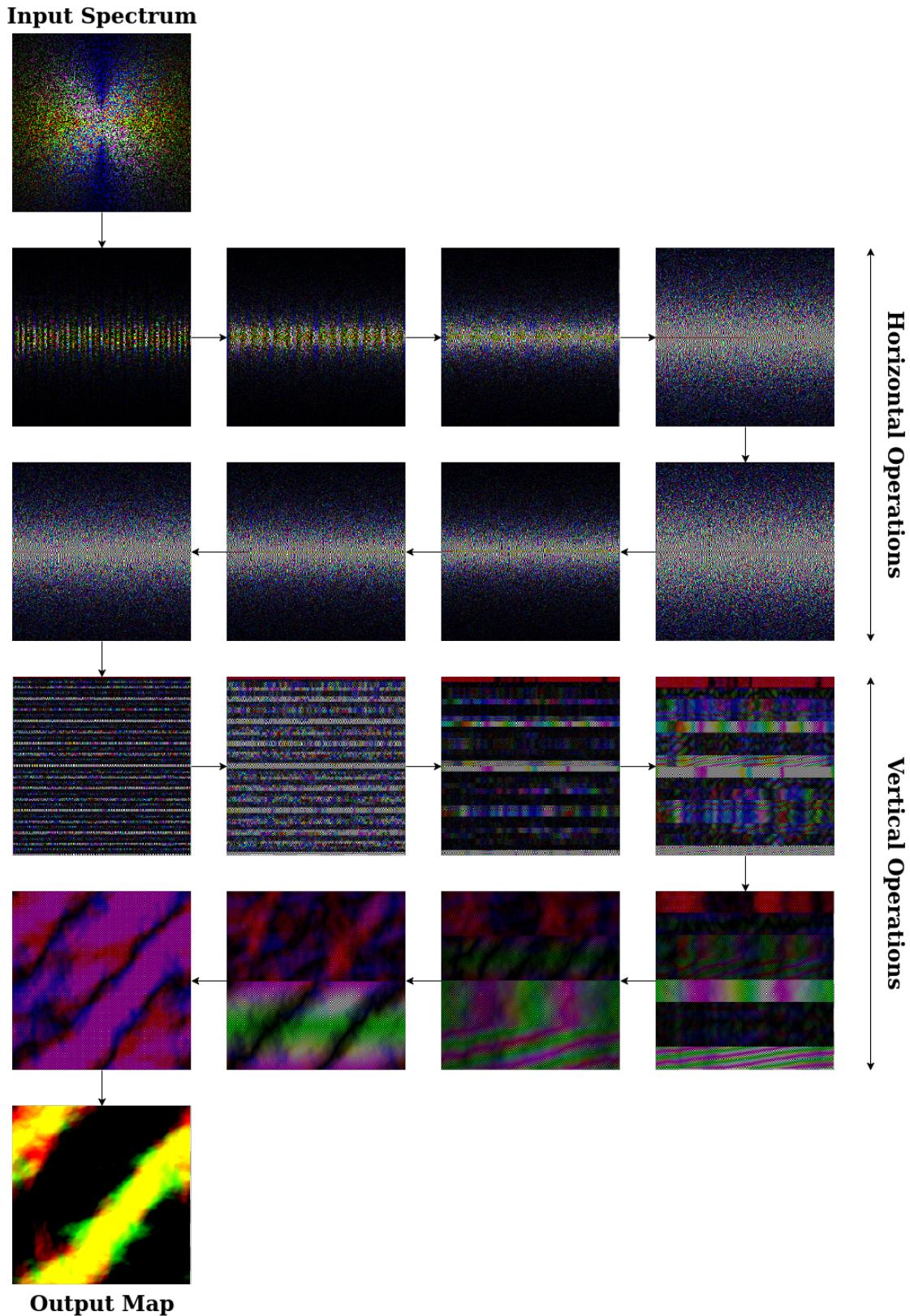


Figure 4: Visualised FFT Steps, black / white points are not consistent for demonstrative purposes.

2.4. Event Loop Control Flow

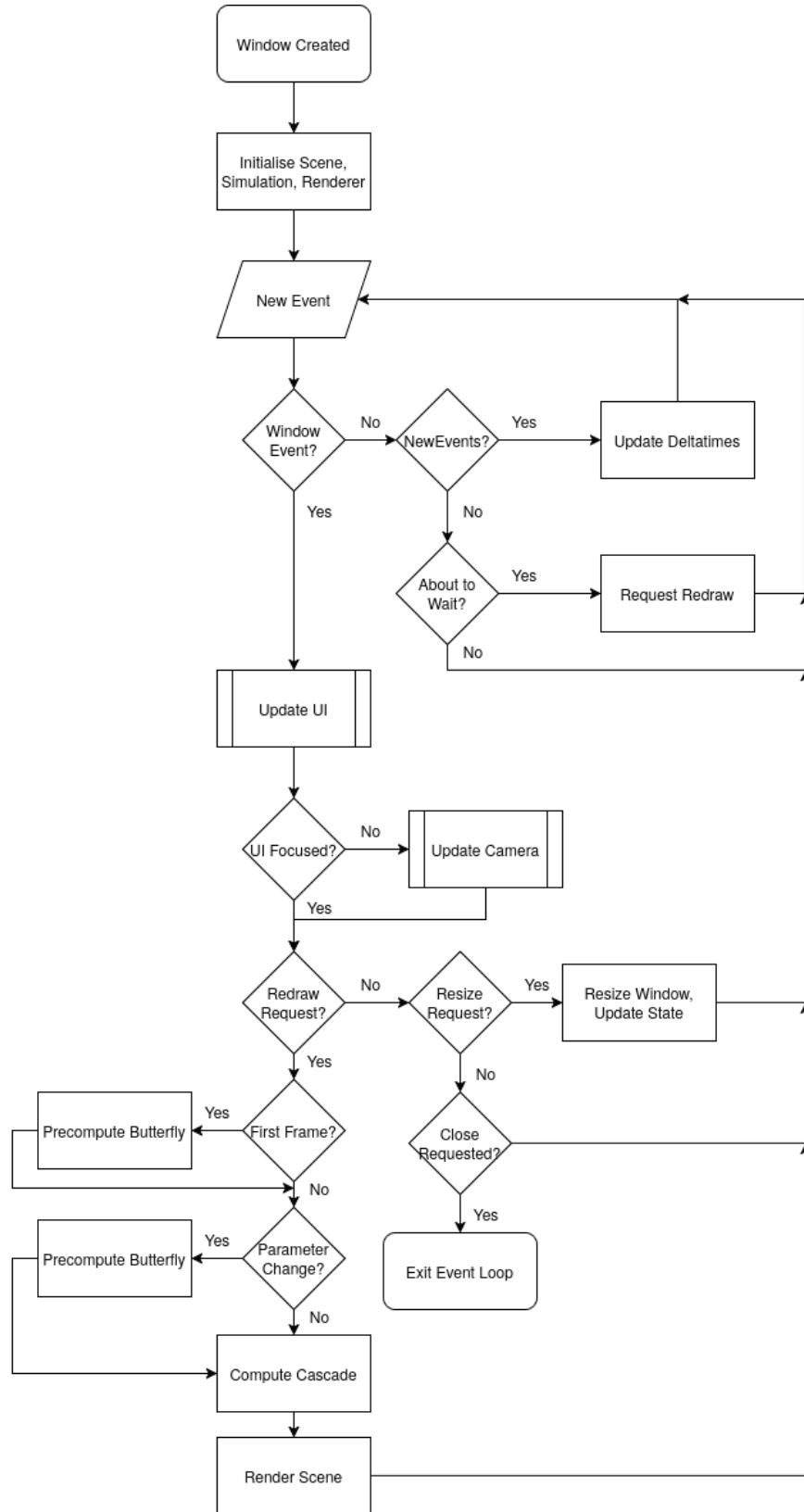


Figure 5: Abstracted event loop control flow flowchart

2.4.1. UI Event Flow

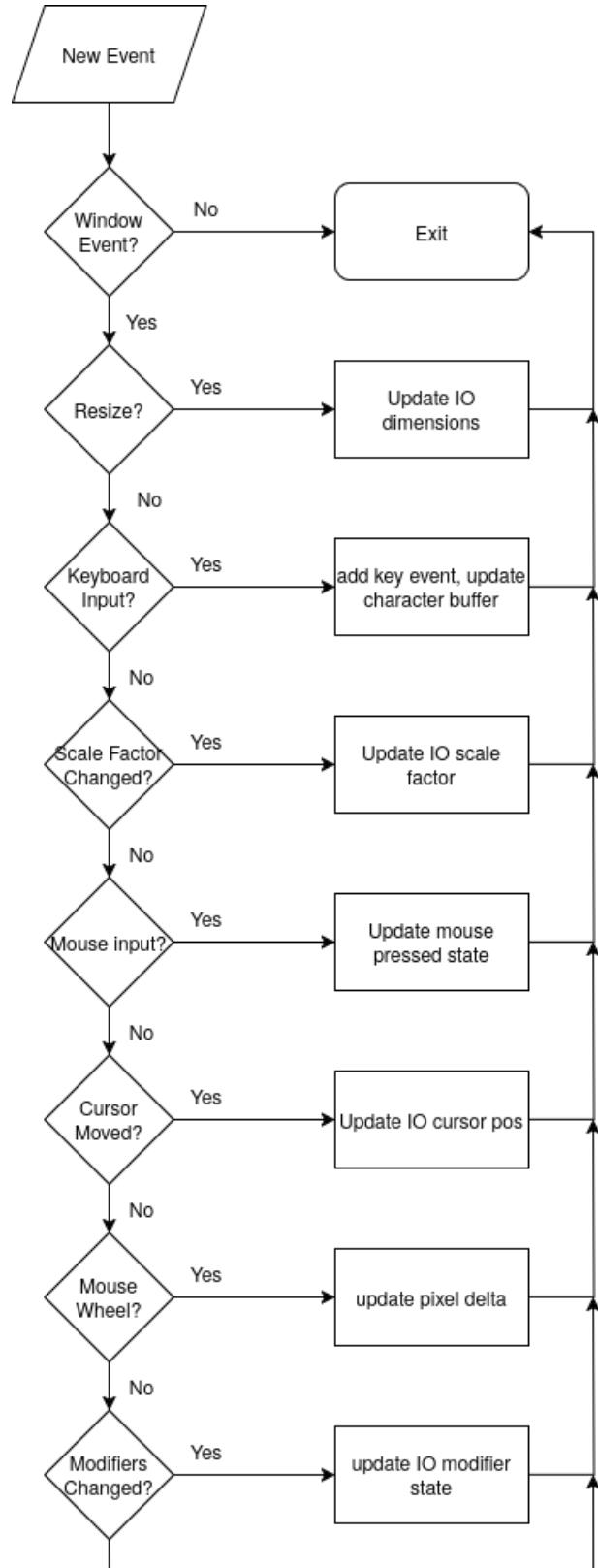


Figure 6: UI Event Handling Flowchart

2.4.2. Camera Controller Flow

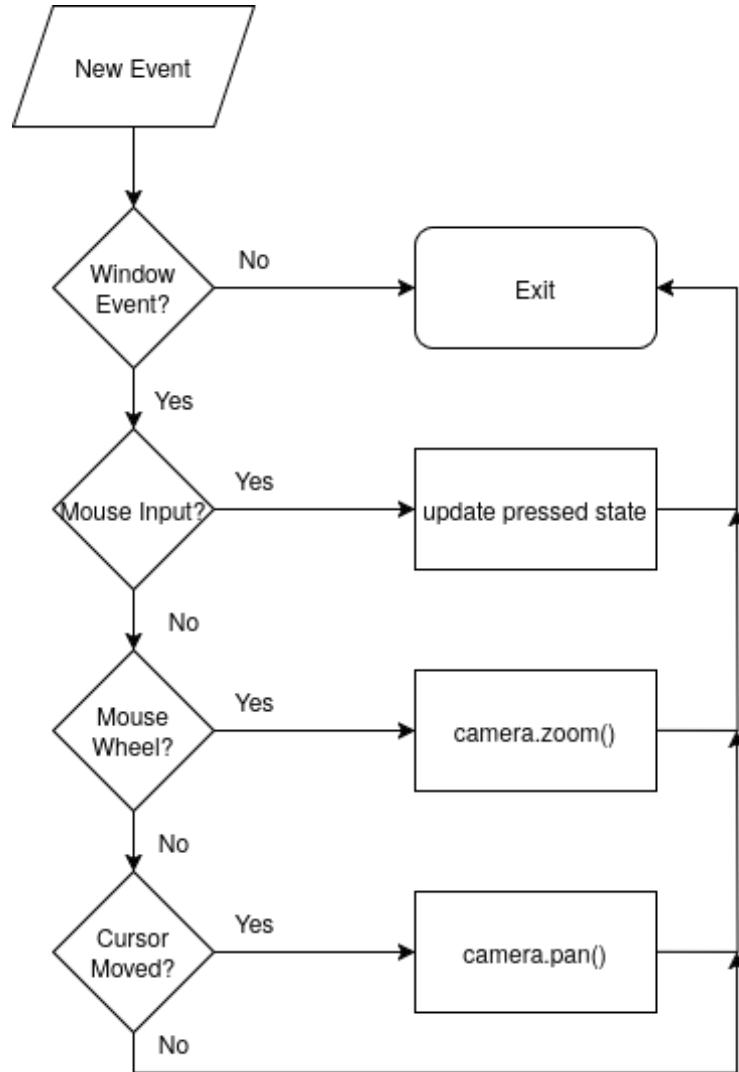


Figure 7: UI Event Handling Flowchart

2.5. Other Algorithms

2.5.1. Cascades

Citations: [7], [16]

To prevent any overlap and wasted computation, we choose lengthscales and cutoffs such that we only have to sample the spectrum at a given lengthscale only once. We select a larger lengthscale for bigger waves, and smaller lengthscale for smaller waves. For a visually pleasing ocean, we follow 3 key principles:

- 1 Avoid smaller waves in larger cascades as they have a coarse spatial resolution
- 2 Avoid larger waves in small cascades, as they will cause visible tiling
- 3 Cutoffs should be chosen such that there are no large gaps in spectrum coverage

Given this, we arrive at the following base cascade setup, altho there is room to change any of the parameters depending on the desired outcome.

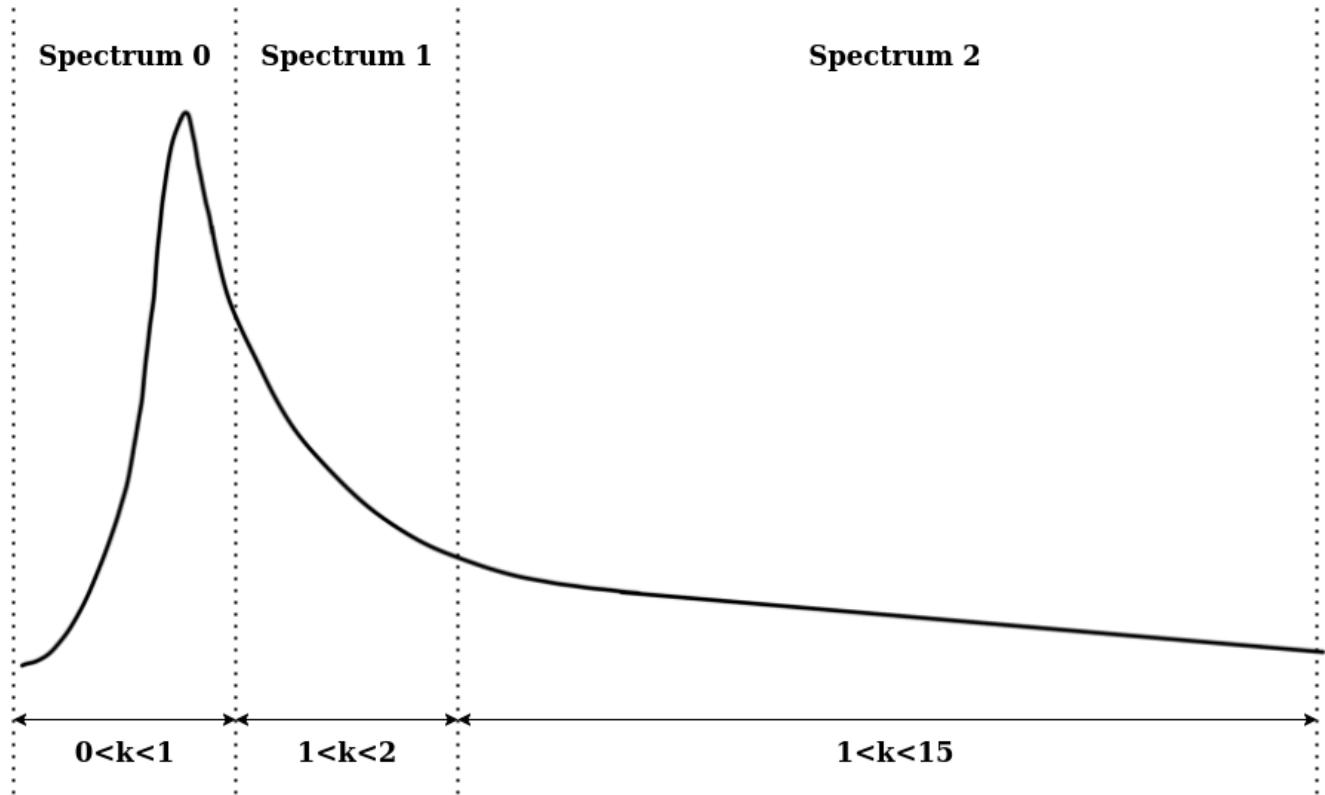


Figure 8: Graphical approximation of the spectrum for demonstrative purposes

2.5.2. Index Buffer

To enable proper backface culling, the vertices of the mesh are connected in a specific (counterclockwise) ordering such that the GPU can discern whether the face is pointed towards the camera. The GPU decides the ordering based on an index buffer, which specifies the index of which vertex is to be connected. The algorithm below only works for a square mesh, and was designed by me so is more than likely inefficient.

```
fn square_mesh_indices(size: u32) -> Vec<u32> {
    let mut indices: Vec<u32> = vec![];
    for y in 0..size - 1 {
        for x in 0..size - 1 {
            indices.push(x + y * size);
            indices.push((x + 1) + (y + 1) * size);
            indices.push(x + (y + 1) * size);
            indices.push(x + y * size);
            indices.push((x + 1) + y * size);
            indices.push((x + 1) + (y + 1) * size);
        }
    }
    indices
}
```

2.6. The Skybox & Equirectangular Projection

Citations: [17]

A standard skybox is rendered using a cubemap, which consists of 6 square textures that are projected onto a cube that is placed surrounding the scene. An alternative method is to use an equirectangular skybox, which is where a single 2D texture is sampled using a 3D vector which is transformed using polar coordinates. Ordinarily, cubemaps are chosen because they can be sampled directly, saving computation, however given that I would have to load the cubemap, pass it to the GPU and manually render the actual sky cube, the performance overhead is worth the significant ease of implementation.

Instead, we send a draw call of only 3 vertices to the GPU, which we then map to create a triangle large enough to cover the screen [17], which all skybox details are rendered to. Below we offset the vertices based on their index to form the triangle in the $[0, 1]$ space, and then convert it to clip space $[-1, 1]$.

```
// Vertex Shader
let out_uv1 = Vec2::new(
    ((vertex_index << 1) & 2) as f32,
    (vertex_index & 2) as f32,
);
*out_pos = Vec4::new(out_uv1.x * 2.0 - 1.0, out_uv1.y * 2.0 - 1.0, 0.0, 1.0);
```

in the fragment shader, we take the 2D fragment coord and convert it to the same $[-1, 1]$ clip space, such that we can then inverse the camera view and projection affine transforms, converting the screen space 2 dimensional coordinate to a 3 dimensional world space coordinate.

```
// Fragment Shader
let uv = Vec2::new(
    frag_coord.x / consts.width * 2.0 - 1.0,
    1.0 - frag_coord.y / consts.height * 2.0,
);

let target = proj_inverse * Vec4::new(uv.x, uv.y, 1.0, 1.0);
let view_pos = (target.truncate() / target.w).extend(1.0);
let world_pos = view_inverse * view_pos;
let ray_dir = world_pos.truncate().normalize();
```

The 3D normalised direction vector is then used to sample the equirectangular HDRI texture, with the resulting value used to color the skybox.

```
// 3D direction vector -> 2D vector for texture reading
fn equirectangular_to_uv(v: Vec3) -> Vec2 {
    Vec2::new(
        (v.z.atan2(v.x) + consts::PI) / consts::TAU,
        v.y.acos() / consts::PI,
    )
}
```

2.7. Spectrum Conjugates

Citations: [4], [7], [16]

From Tessendorf [4], we need to compute the spectrum and its conjugate in order to ensure a real output per Section 1.6.3. “The symmetry of the fourier series allows us to mirror the amplitudes, eliminating the need for complex conjugate recalculation” [16]. Below is pseudocode of the concept from [16] / [7], where N corresponds to the simulation resolution.

```
// The Computed Spectrum
let h0 = spectrum_tex.read(id.x, id.y);
// The Conjugate Spectrum
let h0c = spectrum_tex.read(
    (N - id.x) % N,
    (N - id.y) % N,
);
```

2.8. Xoshiro256plus Pseudorandom Number Generator

Citations: [18]

In order to have consistency between different instances of the simulation, we seed the gaussian numbers such that there is reproducability. To do so, I have chosen the Xoshiro256plus PRNG as it operates in O(1) in both space & time complexity, runs in nanoseconds and is relatively simple to implement. Below is pseudocode showcasing the method.

```
fn next(&mut self) -> u64 {
    let result = self.seed[0].wrapping_add(self.seed[3]);
    let t = self.s[1] << 17;

    self.seed[2] ^= self.seed[0];
    self.seed[3] ^= self.seed[1];
    self.seed[1] ^= self.seed[2];
    self.seed[0] ^= self.seed[3];

    self.seed[2] ^= t;
    self.seed[3] = rol64(self.seed[3], 45);

    result
}
```

2.9. Code Structure

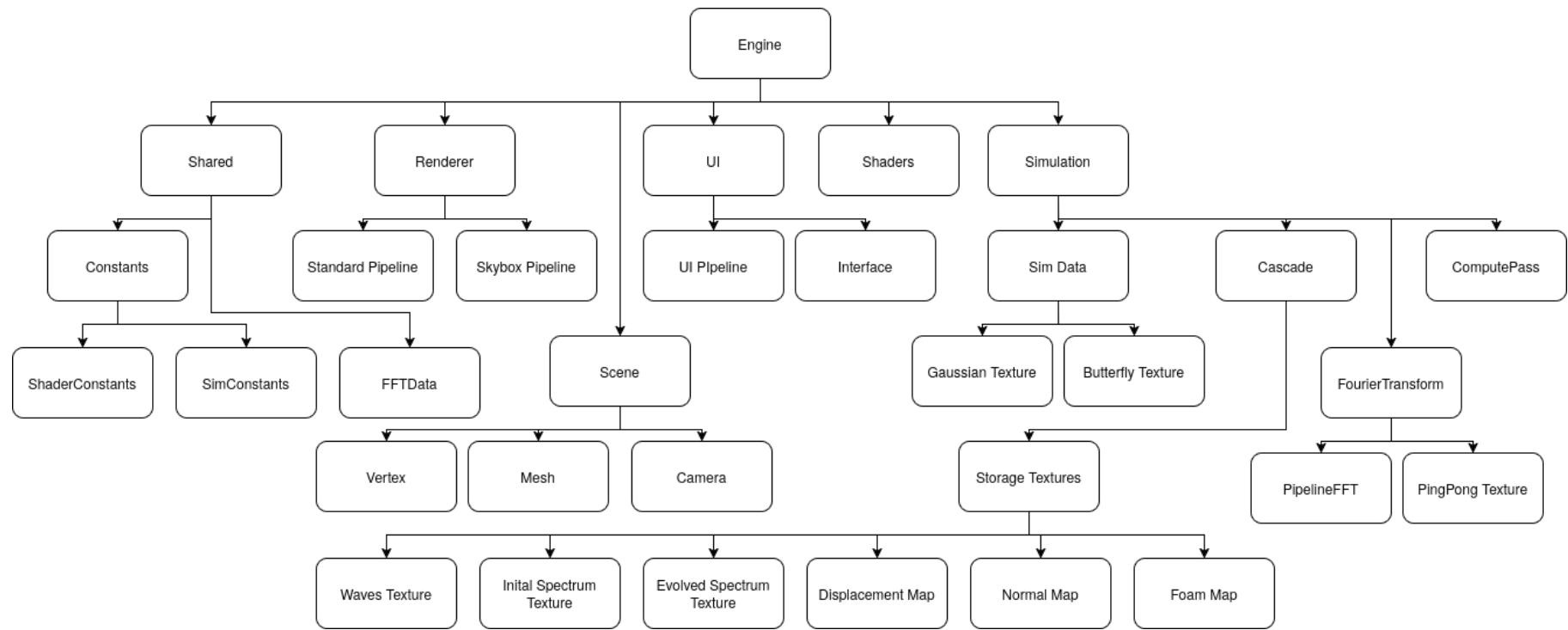


Figure 9: Projects Data structure, in terms of “key” data types - structs, pipelines & textures

3. Technical Solution

3.1. Skills Demonstrated

I believe the GPU / CPU can be seen as an equivalent model to Client / Server. This is because they follow similar key concepts, being:

- Task Delegation, the CPU sends tasks to the GPU in a similar way to server processing requests from clients
- Concurrency / Parallelism, executing and managing data from many GPU threads in parallel is similar to a server handling multiple clients, as both must handle resource allocation and data synchronization
- Communication Overhead, there are similar data transfer bottlenecks for both client/server & gpu/cpu, as I have had to consider data alignment, padding and typing when passing data to the gpu, as well as synchronizing the updating of data between passes and individual invocations
- Synchronization, I have to manage updating data throughout an individual invocation through push constants in a similar manner to how a server would have to update data on a client

Group	Skill	Description / Reasoning	Evidence
A	Complex Scientific Model	Entire Spectrum Synthesis	shaders/sim/initial_spectra.rs entire file
A	Complex Mathematical Model	Implementation of a PBR Lighting Model	shaders/lib.rs entire file
A	Complex Mathematical Model	The computing, storing and processing of a large amount of complex numbers	shaders/evolve_spectra.rs, shaders/process_deltas.rs entire file(s)
A	Complex Control Model	The entire applications event loop and resulting control flow	engine/mod.rs line 92 onwards
A	List Operations	Generation of gaussian texture data, generation of index buffer, manipulation of indices for use in fft	shaders/fft.rs, sim/simdata.rs, engine/scene.rs
A	Hashing	Xoshiro256++ PRNG Implementation	sim/simdata.rs line 83 onwards

A	Advanced Matrix Operations	Various screen / world space transformations, reversing affine transformations	shaders/skybox.rs fragment shader, shaders/lib.rs vertex shader
A	Recursive Algorithms	the 2D GPGPU IFFT I have manually recurses, due to it being on the GPU	sim/fft.rs 66-120, should be clearer after seeing shaders/fft.rs
A	Complex User Defined Algorithms	Computation of the index buffer for the mesh drawing	engine/scene.rs lines 181-191
A	Complex OOP model	Program is based around different objects and classes, objects are generated / regenerated based on user input, designed with composition and inheritance in mind	most demonstrated in engine/mod.rs entire file
A	Complex client-server model	explained in preamble	engine/mod.rs run() function, sim/compute.rs, engine/renderer.rs, sim/fft.rs, sim/mod.rs whole file(s)
B	Multi-Dimensional Arrays	Usage of textures throughout entire project (analogous to 2D arrays), managing data between FFT passes	shaders/*
B	Simple Mathematical Model	Box-Muller Transform, gaussian random number generation	sim/simdata.rs line 62 function(s)

3.2. Completeness of Solution

Everything specified in objectives has been completed, the performance has not been tested on a gtx 1060 level GPU, but given that it is performant at 40-50fps on an Intel Iris Xe integrated graphics card at 256x256x3, it will be easily performant on a discrete GPU. At a more reasonable (given the system) resolution of 128x128x3, the simulation easily reaches 90+fps, while still looking reasonably good. From the additional features, swell has been included in the spectrum synthesis.

3.3. Coding Style

I have followed the rust programming conventions and principles for this project, using the result type for error handling where possible. As the vast majority of possible errors come from wgpu/rust-gpu, errors are in majority handled via the pollster and env_logger crates, where any errors comign from wgpu / rust-gpu are passed up the chain and outputted from the standard log using env_logger. Shader code is written following “standard” shader conventions, with notable stylings being an emphasis on defining variables for every interim step, and swizzling vectors / avoiding unnecessary abstractions where convenient. Smaller things like manually computing the power where convenient and “pre”computing certain values into variables and reusing them where possible are also done.

3.4. Source Code

3.4.1. main.rs

```
rust
1 use engine::Engine;
2 use log::LevelFilter;
3 use std::{mem, slice};
4 use winit::{event_loop::EventLoop, window::WindowBuilder};
5
6 pub mod engine;
7 pub mod sim;
8
9 pub type Result<T = (), E = Box<dyn std::error::Error>> = std::result::Result<T, E>;
10
11 pub const FORMAT: wgpu::TextureFormat = wgpu::TextureFormat::Bgra8UnormSrgb;
12 pub const DEPTH_FORMAT: wgpu::TextureFormat = wgpu::TextureFormat::Depth32Float;
13 pub const WG_SIZE: u32 = 8;
14
15 fn main() -> Result {
16     env_logger::builder().filter_level(LevelFilter::Info).init();
17     // Forces application to run in XWayland on Linux, allows graphics debugger to run
18     std::env::remove_var("WAYLAND_DISPLAY");
19     let event_loop = EventLoop::new()?;
20     let window = WindowBuilder::new().with_title("NEA").build(&event_loop)?;
21
22     let mut engine = Engine::new(&window);
23
24     engine.run(event_loop)?;
25     Ok(())
26 }
27
28 pub fn cast_slice<T>(x: &[T]) -> &[u8] {
29     unsafe { slice::from_raw_parts(x.as_ptr() as _, mem::size_of_val(x)) }
30 }
```

3.4.2. engine

3.4.2.1. mod.rs

rust

```
1 use super::{FORMAT, WG_SIZE};
2 use crate::{cast_slice, Result};
3 use {
4     renderer::Renderer,
5     scene::{Mesh, Scene},
6     crate::sim::Simulation,
7     ui::UI,
8 };
9 use winit::event::{Event, WindowEvent};
10 use winit::event_loop::EventLoop;
11 use winit::keyboard::{KeyCode, PhysicalKey};
12
13 pub mod renderer;
14 pub mod scene;
15 pub mod ui;
16 pub mod util;
17
18 pub struct Engine<'a> {
19     pub device: wgpu::Device,
20     pub queue: wgpu::Queue,
21     pub config: wgpu::SurfaceConfiguration,
22     pub window: &'a winit::window::Window,
23     pub surface: wgpu::Surface<'a>,
24     pub simulation: Simulation,
25     pub renderer: Renderer,
26     pub scene: Scene,
27     pub ui: UI,
28 }
29
30 impl<'a> Engine<'a> {
31     pub fn new(window: &'a winit::window::Window) -> Self {
32         let instance = wgpu::Instance::new(wgpu::InstanceDescriptor::default());
33         let surface = instance.create_surface(window).unwrap();
34         let adapter = pollster::block_on(instance.request_adapter(&wgpu::RequestAdapterOptions {
35             power_preference: wgpu::PowerPreference::default(),
36             force_fallback_adapter: false,
37             compatible_surface: Some(&surface),
38         }));
39         .expect("failed to create adapter");
40
41         let required_limits = wgpu::Limits {
42             max_storage_textures_per_shader_stage: 6,
43             max_bind_groups: 6,
44             max_push_constant_size: 8,
45             ..Default::default()
46         };
47         let (device, queue) = pollster::block_on(adapter.request_device(
48             &wgpu::DeviceDescriptor {
49                 required_features: wgpu::Features::TEXTURE_ADAPTER_SPECIFIC_FORMAT_FEATURES
50                     | wgpu::Features::VERTEX_WRITABLE_STORAGE
51                     | wgpu::Features::PUSH_CONSTANTS,
52                 required_limits,
53                 memory_hints: wgpu::MemoryHints::Performance,
54                 label: None,
```

```

55         },
56         None,
57     ))
58     .expect("failed to create device & queue");
59
60     let shader = device.create_shader_module(wgpu::include_spirv!(env!("shaders.spv")));
61
62     let config = wgpu::SurfaceConfiguration {
63         usage: wgpu::TextureUsages::RENDER_ATTACHMENT,
64         format: FORMAT,
65         width: window.inner_size().width,
66         height: window.inner_size().height,
67         present_mode: wgpu::PresentMode::AutoNoVsync,
68         alpha_mode: wgpu::CompositeAlphaMode::Opaque,
69         view_formats: vec![],
70         desired_maximum_frame_latency: 2,
71     };
72     surface.configure(&device, &config);
73
74     let scene = Scene::new(&device, window);
75     let simulation = Simulation::new(&device, &queue, &shader, &scene);
76     let renderer = Renderer::new(&device, &queue, &shader, window, &simulation, &scene);
77     let ui = UI::new(&device, &queue, window, &shader, &renderer, &scene);
78
79     Self {
80         config,
81         device,
82         queue,
83         surface,
84         window,
85         simulation,
86         scene,
87         renderer,
88         ui,
89     }
90 }
91
92 pub fn run(&mut self, event_loop: EventLoop<()>) -> Result {
93     let mut last_frame = std::time::Instant::now();
94     let mut first_frame = true;
95     let workgroup_size = self.scene.consts.sim.size / WG_SIZE;
96
97     event_loop.run(move |event, elwt| match event {
98         Event::AboutToWait => self.window.request_redraw(),
99         Event::NewEvents(_) => {
100             let now = std::time::Instant::now();
101             self.ui.context.io_mut().update_delta_time(now - last_frame);
102             last_frame = now;
103         }
104         Event::WindowEvent { event, .. } => {
105             self.ui.handle_events(&event);
106             if !self.ui.focused {
107                 self.scene.update_camera(&event, self.window);
108             }
109             match event {
110                 WindowEvent::RedrawRequested => {
111                     self.scene.update_redraw(self.window);
112                 }
113             }
114         }
115     });
116 }

```

```

113         let surface = self
114             .surface
115                 .get_current_texture()
116                     .expect("failed to get surface");
117         let surface_view = surface
118             .texture
119                 .create_view(&wgpu::TextureViewDescriptor::default());
120         let mut encoder = self
121             .device
122                 .create_command_encoder(&wgpu::CommandEncoderDescriptor::default());
123
124         if first_frame {
125             self.simulation.butterfly_recompute_pass.compute(
126                 &mut encoder,
127                     "Recompute Butterfly",
128                     &[
129                         &self.scene.consts_bind_group,
130                             &self.simulation.simdata.bind_group,
131                         ],
132                             self.scene.consts.sim.size.ilog2(),
133                             self.scene.consts.sim.size / WG_SIZE,
134                         );
135         }
136
137         // Compute Initial spectrum on param change
138         if self.scene.consts_changed {
139             self.scene.write(&self.queue);
140             self.simulation.compute_initial(
141                 &mut encoder,
142                     &[
143                         &self.scene.consts_bind_group,
144                             &self.simulation.simdata.bind_group,
145                             &self.simulation.cascade0.bind_group,
146                             ],
147                             0,
148                             workgroup_size,
149                             workgroup_size,
150                         );
151             self.simulation.compute_initial(
152                 &mut encoder,
153                     &[
154                         &self.scene.consts_bind_group,
155                             &self.simulation.simdata.bind_group,
156                             &self.simulation.cascade1.bind_group,
157                             ],
158                             1,
159                             workgroup_size,
160                             workgroup_size,
161                         );
162             self.simulation.compute_initial(
163                 &mut encoder,
164                     &[
165                         &self.scene.consts_bind_group,
166                             &self.simulation.simdata.bind_group,
167                             &self.simulation.cascade2.bind_group,
168                             ],
169                             2,
170                             workgroup_size,

```

```

171             workgroup_size,
172         );
173         // updates mesh based on mesh_step input, technically redundant to do
174         // on every param change but not an issue in any practical sense
175         self.scene.mesh = Mesh::new(&self.device, &self.scene.consts);
176     }
177
178         // per frame computation
179         self.simulation.compute_cascade(&mut encoder, &self.simulation.cascade0,
180             &mut self.scene, workgroup_size, 0);
181             self.simulation.compute_cascade(&mut encoder, &self.simulation.cascade1,
182                 &mut self.scene, workgroup_size, 1);
183                 self.simulation.compute_cascade(&mut encoder, &self.simulation.cascade2,
184                     &mut self.scene, workgroup_size, 2);
185
186             // Render Skybox
187             self.renderer
188                 .render_skybox(&mut encoder, &surface_view, &self.scene);
189
190             // Standard Render Pass
191             self.queue.write_buffer(
192                 &self.scene.consts_buf,
193                     0,
194                         cast_slice(&[self.scene.consts]),
195                     );
196             self.renderer.render_standard(
197                 &mut encoder,
198                     &self.renderer.std_pipeline,
199                     &[
200                         &self.scene.consts_bind_group,
201                             &self.renderer.sampler_bind_group,
202                                 &self.renderer.hdri.bind_group,
203                                     &self.simulation.cascade0.bind_group,
204                                         &self.simulation.cascade1.bind_group,
205                                             &self.simulation.cascade2.bind_group,
206                                             ],
207                                         ],
208                                         &surface_view,
209                                         &self.scene.mesh,
210                                         self.scene.consts.sim.instances,
211                                         );
212
213         // UI Pass
214         let consts_copy = self.scene.consts;
215         self.ui.update_cursor(self.window);
216         let ui_frame = self.ui.context.frame();
217         self.ui.focused = ui::build(ui_frame, &mut self.scene.consts);
218         self.ui.render(
219             &self.device,
220                 &self.queue,
221                     &mut encoder,
222                         &surface_view,
223                             &self.renderer.sampler_bind_group,
224                                 &self.scene,
225                                 );
226
227         // updating some rendering logic
228         self.scene.consts_changed = consts_copy != self.scene.consts;
229         first_frame = false;

```

```

226
227          // Submitting queue to be computed
228          self.queue.submit([encoder.finish()]);
229          surface.present();
230      }
231      WindowEvent::Resized(size) => {
232          self.config = wgpu::SurfaceConfiguration {
233              usage: wgpu::TextureUsages::RENDER_ATTACHMENT,
234              format: FORMAT,
235              width: size.width,
236              height: size.height,
237              present_mode: wgpu::PresentMode::AutoNoVsync,
238              alpha_mode: wgpu::CompositeAlphaMode::Opaque,
239              view_formats: vec![],
240              desired_maximum_frame_latency: 2,
241          };
242          self.surface.configure(&self.device, &self.config);
243          self.renderer.new_depth_view(&self.device, self.window);
244
245          self.scene.camera.update_fov(self.window);
246          self.scene.consts.camera_viewproj =
247              self.scene.camera.proj * self.scene.camera.view;
248      }
249      WindowEvent::CloseRequested => elwt.exit(),
250      WindowEvent::KeyboardInput { event, .. } => if let
251          PhysicalKey::Code(KeyCode::Escape) = event.physical_key {
252              elwt.exit()
253          },
254          _ => {}
255      }
256      _ => {}
257  })?;
258  Ok(())
259 }
260 }
261

```

3.4.2.2. renderer.rs

rust

```
1 use super::util::Texture;
2 use crate::{DEPTH_FORMAT, FORMAT};
3 use super::scene::{Mesh, Scene};
4 use super::Simulation;
5
6 pub struct Renderer {
7     pub sampler_bind_group: wgpu::BindGroup,
8     pub sampler_layout: wgpu::BindGroupLayout,
9     pub depth_view: wgpu::TextureView,
10    pub std_pipeline: wgpu::RenderPipeline,
11    pub hdri: Texture,
12    pub skybox_pipeline: wgpu::RenderPipeline,
13 }
14
15 impl Renderer {
16     pub fn new(
17         device: &wgpu::Device,
18         queue: &wgpu::Queue,
19         shader: &wgpu::ShaderModule,
20         window: &winit::window::Window,
21         sim: &Simulation,
22         scene: &super::scene::Scene,
23     ) -> Self {
24         let sampler = device.create_sampler(&wgpu::SamplerDescriptor::default());
25         let sampler_layout = device.create_bind_group_layout(&wgpu::BindGroupLayoutDescriptor {
26             entries: &[wgpu::BindGroupLayoutEntry {
27                 binding: 0,
28                 visibility: wgpu::ShaderStages::VERTEX_FRAGMENT,
29                 ty: wgpu::BindingType::Sampler(wgpu::SamplerBindingType::NonFiltering),
30                 count: None,
31             }],
32             label: None,
33         });
34         let sampler_bind_group = device.create_bind_group(&wgpu::BindGroupDescriptor {
35             layout: &sampler_layout,
36             entries: &[wgpu::BindGroupEntry {
37                 binding: 0,
38                 resource: wgpu::BindingResource::Sampler(&sampler),
39             }],
40             label: None,
41         });
42
43         let hdri = Texture::from_file(device, queue, "HDRI", "./assets/kloofendal.exr");
44
45         let depth_texture = device.create_texture(&wgpu::TextureDescriptor {
46             label: None,
47             size: wgpu::Extent3d {
48                 width: window.inner_size().width,
49                 height: window.inner_size().height,
50                 depth_or_array_layers: 1,
51             },
52             mip_level_count: 1,
53             sample_count: 1,
54             dimension: wgpu::TextureDimension::D2,
55             format: DEPTH_FORMAT,
56             usage: wgpu::TextureUsages::RENDER_ATTACHMENT | wgpu::TextureUsages::TEXTURE_BINDING,
```

```

57         view_formats: &[],
58     });
59     let depth_view = depth_texture.create_view(&wgpu::TextureViewDescriptor::default());
60
61     let skybox_pipeline_layout =
62         device.create_pipeline_layout(&wgpu::PipelineLayoutDescriptor {
63             bind_group_layouts: &[&scene.consts_layout, &hdri.layout, &sampler_layout],
64             push_constant_ranges: &[],  

65             label: None,
66         });
67     let skybox_pipeline = device.create_render_pipeline(&wgpu::RenderPipelineDescriptor {
68         layout: Some(&skybox_pipeline_layout),
69         vertex: wgpu::VertexState {
70             module: shader,
71             entry_point: Some("skybox::skybox_vs"),
72             buffers: &[],  

73             compilation_options: Default::default(),
74         },
75         fragment: Some(wgpu::FragmentState {
76             module: shader,
77             entry_point: Some("skybox::skybox_fs"),
78             targets: &[Some(wgpu::ColorTargetState {
79                 format: FORMAT,
80                 blend: Some(wgpu::BlendState::ALPHA_BLENDING),
81                 write_mask: wgpu::ColorWrites::ALL,
82             })],
83             compilation_options: Default::default(),
84         }),
85         primitive: wgpu::PrimitiveState::default(),
86         depthStencil: Some(wgpu::DepthStencilState {
87             format: DEPTH_FORMAT,
88             depth_write_enabled: true,
89             depth_compare: wgpu::CompareFunction::Less,
90             stencil: wgpu::StencilState::default(),
91             bias: wgpu::DepthBiasState::default(),
92         }),
93         multisample: wgpu::MultisampleState::default(),
94         multiview: None,
95         label: None,
96         cache: None,
97     });
98
99     let std_pipeline_layout = device.create_pipeline_layout(&wgpu::PipelineLayoutDescriptor {
100         bind_group_layouts: &[
101             &scene.consts_layout,
102             &sampler_layout,
103             &hdri.layout,
104             &sim.cascade0.layout,
105             &sim.cascade1.layout,
106             &sim.cascade2.layout,
107         ],
108         push_constant_ranges: &[],  

109         label: None,
110     });
111     let std_pipeline = device.create_render_pipeline(&wgpu::RenderPipelineDescriptor {
112         layout: Some(&std_pipeline_layout),
113         vertex: wgpu::VertexState {
114             module: shader,

```

```

115         entry_point: Some("main_vs"),
116         buffers: &[wgpu::VertexBufferLayout {
117             array_stride: std::mem::size_of::<super::scene::Vertex>() as _,
118             step_mode: wgpu::VertexStepMode::Vertex,
119             attributes: &wgpu::vertex_attr_array![0 => Float32x4, 1=> Uint32x2],
120         }],
121         compilation_options: Default::default(),
122     },
123     fragment: Some(wgpu::FragmentState {
124         module: shader,
125         entry_point: Some("main_fs"),
126         targets: &[Some(wgpu::ColorTargetState {
127             format: FORMAT,
128             blend: Some(wgpu::BlendState::ALPHA_BLENDING),
129             write_mask: wgpu::ColorWrites::ALL,
130         })],
131         compilation_options: Default::default(),
132     }),
133     primitive: wgpu::PrimitiveState::default(),
134     depthStencil: Some(wgpu::DepthStencilState {
135         format: DEPTH_FORMAT,
136         depth_write_enabled: true,
137         depth_compare: wgpu::CompareFunction::Less,
138         stencil: wgpu::StencilState::default(),
139         bias: wgpu::DepthBiasState::default(),
140     }),
141     multisample: wgpu::MultisampleState::default(),
142     multiview: None,
143     label: None,
144     cache: None,
145 });
146
147     Self {
148         sampler_layout,
149         sampler_bind_group,
150         depth_view,
151         std_pipeline,
152         hdri,
153         skybox_pipeline,
154     }
155 }
156
157 pub fn new_depth_view(&mut self, device: &wgpu::Device, window: &wininit::window::Window) {
158     let depth_texture = device.create_texture(&wgpu::TextureDescriptor {
159         label: None,
160         size: wgpu::Extent3d {
161             width: window.inner_size().width,
162             height: window.inner_size().height,
163             depth_or_array_layers: 1,
164         },
165         mip_level_count: 1,
166         sample_count: 1,
167         dimension: wgpu::TextureDimension::D2,
168         format: DEPTH_FORMAT,
169         usage: wgpu::TextureUsages::RENDER_ATTACHMENT | wgpu::TextureUsages::TEXTURE_BINDING,
170         view_formats: &[],
171     });
172     self.depth_view = depth_texture.create_view(&wgpu::TextureViewDescriptor::default())

```

```

173     }
174
175     pub fn render_skybox<'a>(
176         &'a self,
177         encoder: &'a mut wgpu::CommandEncoder,
178         surface_view: &wgpu::TextureView,
179         scene: &Scene,
180     ) {
181         let mut pass = encoder.begin_render_pass(&wgpu::RenderPassDescriptor {
182             color_attachments: &[Some(wgpu::RenderPassColorAttachment {
183                 view: surface_view,
184                 resolve_target: None,
185                 ops: wgpu::Operations {
186                     load: wgpu::LoadOp::Clear(wgpu::Color::BLACK),
187                     store: wgpu::StoreOp::Store,
188                 },
189             })],
190             depth_stencil_attachment: Some(wgpu::RenderPassDepthStencilAttachment {
191                 view: &self.depth_view,
192                 depth_ops: Some(wgpu::Operations {
193                     load: wgpu::LoadOp::Clear(1.0),
194                     store: wgpu::StoreOp::Store,
195                 }),
196                 stencil_ops: None,
197             }),
198             timestamp_writes: None,
199             occlusion_query_set: None,
200             label: None,
201         });
202         pass.set_pipeline(&self.skybox_pipeline);
203         pass.set_bind_group(0, &scene.consts_bind_group, &[]);
204         pass.set_bind_group(1, &self.hdri.bind_group, &[]);
205         pass.set_bind_group(2, &self.sampler_bind_group, &[]);
206         // Draw fullscreen triangle
207         pass.draw(0..3, 0..1);
208     }
209
210     pub fn render_standard<'a>(
211         &'a self,
212         encoder: &'a mut wgpu::CommandEncoder,
213         pipeline: &wgpu::RenderPipeline,
214         bind_groups: &[&wgpu::BindGroup],
215         surface_view: &wgpu::TextureView,
216         mesh: &Mesh,
217         instances: u32,
218     ) {
219         let mut pass = encoder.begin_render_pass(&wgpu::RenderPassDescriptor {
220             color_attachments: &[Some(wgpu::RenderPassColorAttachment {
221                 view: surface_view,
222                 resolve_target: None,
223                 ops: wgpu::Operations {
224                     load: wgpu::LoadOp::Load,
225                     store: wgpu::StoreOp::Store,
226                 },
227             })],
228             depth_stencil_attachment: Some(wgpu::RenderPassDepthStencilAttachment {
229                 view: &self.depth_view,
230                 depth_ops: Some(wgpu::Operations {

```

```
231             load: wgpu::LoadOp::Clear(1.0),
232             store: wgpu::StoreOp::Store,
233         },
234         stencil_ops: None,
235     },
236     timestamp_writes: None,
237     occlusion_query_set: None,
238     label: None,
239 );
240 pass.set_pipeline(pipeline);
241 for (i, bind_group) in bind_groups.iter().enumerate() {
242     pass.set_bind_group(i as _, *bind_group, &[]);
243 }
244 pass.set_vertex_buffer(0, mesh.vtx_buf.slice(..));
245 pass.set_index_buffer(mesh.idx_buf.slice(..), wgpu::IndexFormat::Uint32);
246 // Draw multiple mesh instances for tiling
247 pass.draw_indexed(0..(mesh.length as _), 0, 0..(instances * instances));
248 }
249 }
250 }
```

3.4.2.3. scene.rs

rust

```
1 use crate::cast_slice;
2 use glam::{Mat4, Vec3, Vec4};
3 use shared::{Constants, ShaderConstants, SimConstants};
4 use std::{f32::consts::PI, mem, time::Instant};
5 use wgpu::{util::DeviceExt, Buffer};
6 use winit::event::WindowEvent;
7 use winit::{dpi::PhysicalPosition, event::MouseScrollDelta, window::Window};
8
9 pub struct Scene {
10     start_time: Instant,
11     cursor_down: bool,
12     pub camera: Camera,
13     pub mesh: Mesh,
14     pub consts: Constants,
15     pub consts_layout: wgpu::BindGroupLayout,
16     pub consts_buf: wgpu::Buffer,
17     pub consts_bind_group: wgpu::BindGroup,
18     pub consts_changed: bool,
19 }
20
21 pub struct Camera {
22     pub proj: Mat4,
23     pub view: Mat4,
24     pitch: f32,
25     yaw: f32,
26     zoom: f32,
27     eye: Vec3,
28     target: Vec3,
29     up: Vec3,
30     aspect: f32,
31     fovy: f32,
32     znear: f32,
33     zfar: f32,
34 }
35
36 pub struct Mesh {
37     pub _vertices: Vec<Vertex>,
38     pub idx_buf: Buffer,
39     pub vtx_buf: Buffer,
40     pub length: usize,
41 }
42
43 #[repr(C, align(16))]
44 pub struct Vertex {
45     pos: Vec4,
46     uv: glam::UVec2,
47 }
48
49 impl Scene {
50     pub fn new(device: &wgpu::Device, window: &Window) -> Self {
51         let cursor_down = false;
52         let camera = Camera::new(window);
53         let consts = Constants {
54             time: 0.0,
55             deltatime: 0.0,
56             width: 0.0,
```

```

57         height: 0.0,
58         camera_viewproj: camera.proj * camera.view,
59         eye: camera.eye.extend(1.0),
60         shader: ShaderConstants::default(),
61         sim: SimConstants::default(),
62     };
63     let mesh = Mesh::new(device, &consts);
64     let start_time = Instant::now();
65
66     let consts_layout = device.create_bind_group_layout(&wgpu::BindGroupLayoutDescriptor {
67         entries: &[wgpu::BindGroupLayoutEntry {
68             binding: 0,
69             visibility: wgpu::ShaderStages::VERTEX_FRAGMENT | wgpu::ShaderStages::COMPUTE,
70             ty: wgpu::BindingType::Buffer {
71                 ty: wgpu::BufferBindingType::Uniform,
72                 has_dynamic_offset: false,
73                 min_binding_size: None,
74             },
75             count: None,
76         }],
77         label: None,
78     });
79     let mem_size = (mem::size_of::<Constants>()
80         + mem::size_of::<SimConstants>()
81         + mem::size_of::<ShaderConstants>()) as u64;
82     let consts_buf = device.create_buffer(&wgpu::BufferDescriptor {
83         size: mem_size as u64,
84         mapped_at_creation: false,
85         usage: wgpu::BufferUsages::UNIFORM | wgpu::BufferUsages::COPY_DST,
86         label: Some("Consts Buffer"),
87     });
88     let consts_bind_group = device.create_bind_group(&wgpu::BindGroupDescriptor {
89         layout: &consts_layout,
90         entries: &[wgpu::BindGroupEntry {
91             binding: 0,
92             resource: consts_buf.as_entire_binding(),
93         }],
94         label: Some("Consts Bind Group"),
95     });
96
97     // set to true so the initial spectrum is computed for frame 1
98     let consts_changed = true;
99
100    Self {
101        cursor_down,
102        start_time,
103        consts,
104        camera,
105        mesh,
106        consts_layout,
107        consts_buf,
108        consts_bind_group,
109        consts_changed,
110    }
111 }
112
113 pub fn update_redraw(&mut self, window: &Window) {
114     // Update the constants for use in shaders

```

```

115     let duration = self.start_time.elapsed().as_secs_f32();
116     self.consts.deltatime = duration - self.consts.time;
117     self.consts.time = duration;
118
119     self.consts.eye = self.camera.eye.extend(1.0);
120     self.consts.shader.proj_mat = self.camera.proj;
121     self.consts.shader.view_mat = self.camera.view;
122
123     self.consts.shader.light = (Vec3::new(
124         self.consts.shader.sun_x,
125         self.consts.shader.sun_y,
126         self.consts.shader.sun_z,
127     ) * self.consts.shader.sun_distance).extend(1.0);
128     self.consts.shader.light =
129         Mat4::from_rotation_y(self.consts.shader.sun_angle) * self.consts.shader.light;
130     self.consts.sim.logsize = self.consts.sim.size.ilog2();
131
132     // update incase resized
133     let dimensions = window.inner_size();
134     self.consts.width = dimensions.width as f32;
135     self.consts.height = dimensions.height as f32;
136 }
137
138 pub fn write(&self, queue: &wgpu::Queue) {
139     queue.write_buffer(&self.consts_buf, 0, cast_slice(&[self.consts]));
140 }
141
142 pub fn update_camera(&mut self, event: &WindowEvent, window: &Window) {
143     match event {
144         WindowEvent::MouseInput { state, button, .. } => if button ==
145             &winit::event::MouseButton::Left {
146                 self.cursor_down = state.is_pressed()
147             },
148             WindowEvent::MouseWheel { delta, .. } => {
149                 self.camera.zoom(*delta);
150                 self.consts.camera_viewproj = self.camera.proj * self.camera.view;
151             }
152             WindowEvent::CursorMoved { position, .. } => {
153                 if self.cursor_down {
154                     self.camera.pan(*position, window);
155                     self.consts.camera_viewproj = self.camera.proj * self.camera.view;
156                 }
157             }
158         }
159     }
160 }
161
162 impl Mesh {
163     pub fn new(device: &wgpu::Device, consts: &Constants) -> Self {
164         let scale = consts.sim.size;
165         let step = consts.sim.mesh_step;
166         // create vertices, stepping from 0,0 towards the top right, offset in shader for centring
167         let mut vertices: Vec<Vertex> = vec![];
168         for z in 0..scale {
169             for x in 0..scale {
170                 let pos = Vec4::new(x as f32 * step, 0.0, z as f32 * step, 1.0);
171                 let uv = glam::UVec2::new(x, z);

```

```

172             vertices.push(Vertex { pos, uv });
173         }
174     }
175     let vtx_buf = device.create_buffer_init(&wgpu::util::BufferInitDescriptor {
176         contents: cast_slice(&vertices),
177         usage: wgpu::BufferUsages::VERTEX,
178         label: None,
179     });
180
181     let mut indices: Vec<u32> = vec![];
182     for y in 0..scale - 1 {
183         for x in 0..scale - 1 {
184             indices.push(x + y * scale);
185             indices.push((x + 1) + (y + 1) * scale);
186             indices.push(x + (y + 1) * scale);
187             indices.push(x + y * scale);
188             indices.push((x + 1) + y * scale);
189             indices.push((x + 1) + (y + 1) * scale);
190         }
191     }
192
193     let idx_buf = device.create_buffer_init(&wgpu::util::BufferInitDescriptor {
194         contents: cast_slice(&indices),
195         usage: wgpu::BufferUsages::INDEX,
196         label: None,
197     });
198     let length = indices.len();
199
200     Self {
201         _vertices: vertices,
202         vtx_buf,
203         idx_buf,
204         length,
205     }
206 }
207 }
208
209 impl Camera {
210     pub fn new(window: &Window) -> Camera {
211         let pitch: f32 = -PI / 2.0;
212         let yaw: f32 = PI / 12.0;
213         let zoom: f32 = 50.0;
214
215         let mut camera = Camera {
216             pitch,
217             yaw,
218             zoom,
219             eye: Vec3::new(
220                 zoom * yaw.cos() * pitch.sin(),
221                 zoom * yaw.sin(),
222                 zoom * yaw.cos() * pitch.cos(),
223             ),
224             target: Vec3::new(0.0, 0.0, 0.0),
225             // defined y axis as up
226             up: Vec3::new(0.0, 1.0, 0.0),
227             aspect: window.inner_size().width as f32 / window.inner_size().height as f32,
228             fovy: PI / 4.0,
229             znear: 0.1,

```

```

230         // set high enough to not be an issue
231         zfar: 100000.0,
232         proj: Mat4::ZERO,
233         view: Mat4::ZERO,
234     };
235
236     camera.proj = Mat4::perspective_rh(camera.fovy, camera.aspect, camera.znear, camera.zfar);
237     camera.view = Mat4::look_at_rh(camera.eye, camera.target, camera.up);
238     camera
239 }
240
241 pub fn zoom(&mut self, delta: MouseScrollDelta) {
242     match delta {
243         MouseScrollDelta::LineDelta(_, y) => {
244             self.zoom -= y;
245         }
246         MouseScrollDelta::PixelDelta(winit::dpi::PhysicalPosition { y, .. }) => {
247             self.zoom -= y as f32;
248         }
249     }
250     self.eye = Vec3::new(
251         self.zoom * self.yaw.cos() * self.pitch.sin(),
252         self.zoom * self.yaw.sin(),
253         self.zoom * self.yaw.cos() * self.pitch.cos(),
254     );
255     self.view = Mat4::look_at_rh(self.eye, self.target, self.up);
256 }
257
258 pub fn pan(&mut self, position: PhysicalPosition<f64>, window: &Window) {
259     let PhysicalPosition { x, y } = position;
260     // +0.01 to prevent edge case at screen borders
261     self.yaw = (PI / window.inner_size().height as f32)
262         * (y as f32 - (window.inner_size().height as f32 / 2.0) + 0.01);
263     self.pitch = ((2.0 * PI) / window.inner_size().width as f32)
264         * (x as f32 - (window.inner_size().width as f32 / 2.0));
265     self.eye = Vec3::new(
266         self.zoom * -self.yaw.cos() * self.pitch.sin(),
267         self.zoom * self.yaw.sin(),
268         self.zoom * self.yaw.cos() * self.pitch.cos(),
269     );
270     self.view = Mat4::look_at_rh(self.eye, self.target, self.up);
271 }
272
273 pub fn update_fov(&mut self, window: &Window) {
274     self.aspect = window.inner_size().width as f32 / window.inner_size().height as f32;
275     self.proj = Mat4::perspective_rh(self.fovy, self.aspect, self.znear, self.zfar);
276 }
277 }
278 }
```

3.4.2.4. ui.rs

rust

```
1 use {crate::{cast_slice, FORMAT}, super::renderer::Renderer, super::scene::Scene,
2      super::util::Texture};
3 use imgui::{BackendFlags, DrawVert, FontSource, Key, MouseCursor, TreeNodeFlags, Ui};
4 use shared::Constants;
5 use std::{f32::consts::PI, mem};
6 use wgpu::{util::DeviceExt, Buffer, Device, Queue, RenderPipeline};
7 use winit::{
8     event::{MouseButton, MouseScrollDelta, WindowEvent},
9     keyboard::{KeyCode, PhysicalKey},
10    window::{CursorIcon, Window},
11 };
12 pub struct UI {
13     pub pipeline: RenderPipeline,
14     pub vtx_buf: Buffer,
15     pub idx_buf: Buffer,
16     pub context: imgui::Context,
17     pub focused: bool,
18     texture: Texture,
19 }
20
21 impl UI {
22     pub fn new(
23         device: &Device,
24         queue: &Queue,
25         window: &Window,
26         shader: &wgpu::ShaderModule,
27         renderer: &Renderer,
28         scene: &Scene,
29     ) -> Self {
30         let mut context = imgui::Context::create();
31         context.set_ini_filename(None);
32
33         let hidpi_factor = window.scale_factor();
34         let dimensions = window.inner_size();
35
36         let io = context.io_mut();
37         io.backend_flags.insert(BackendFlags::HAS_MOUSE_CURSORS);
38         io.backend_flags.insert(BackendFlags::HAS_SET_MOUSE_POS);
39         io.backend_flags
40             .insert(BackendFlags::RENDERER_HAS_VTX_OFFSET);
41         io.display_size = [dimensions.width as _, dimensions.height as _];
42         io.display_framebuffer_scale = [hidpi_factor as f32, hidpi_factor as f32];
43
44         let style = context.style_mut();
45         style.window_rounding = 4.0;
46         style.popup_rounding = 4.0;
47         style.frame_rounding = 2.0;
48         style.scale_all_sizes(hidpi_factor as_);
49
50         let fonts = context.fonts();
51         fonts.add_font(&[FontSource::DefaultFontData { config: None }]);
52         let font_texture = fonts.build_rgba32_texture();
53         let texture = Texture::new_sampled(
54             font_texture.width,
55             font_texture.height,
```

```

56         wgpu::TextureFormat::Rgba8UnormSrgb,
57         device,
58         "Font Atlas",
59     );
60     texture.write(queue, font_texture.data, 4);
61
62     let pipeline_layout = device.create_pipeline_layout(&wgpu::PipelineLayoutDescriptor {
63         label: None,
64         bind_group_layouts: &[
65             &scene.consts_layout,
66             &texture.layout,
67             &renderer.sampler_layout,
68         ],
69         push_constant_ranges: &[],
70     });
71     let pipeline = device
72         .create_render_pipeline(&wgpu::RenderPipelineDescriptor {
73             layout: Some(&pipeline_layout),
74             vertex: wgpu::VertexState {
75                 module: shader,
76                 entry_point: Some("ui::ui_vs"),
77                 buffers: &[wgpu::VertexBufferLayout {
78                     array_stride: mem::size_of::<DrawVert>() as _,
79                     step_mode: wgpu::VertexStepMode::Vertex,
80                     attributes: &wgpu::vertex_attr_array![0 => Float32x2, 1 => Float32x2, 2 =>
81                         Unorm8x4],
82                 }],
83                 compilation_options: Default::default(),
84             },
85             fragment: Some(wgpu::FragmentState {
86                 module: shader,
87                 entry_point: Some("ui::ui_fs"),
88                 targets: &[Some(wgpu::ColorTargetState {
89                     format: FORMAT,
90                     blend: Some(wgpu::BlendState::ALPHA_BLENDING),
91                     write_mask: wgpu::ColorWrites::ALL,
92                 })],
93                 compilation_options: Default::default(),
94             }),
95             primitive: wgpu::PrimitiveState::default(),
96             depth_stencil: None,
97             multisample: wgpu::MultisampleState::default(),
98             multiview: None,
99             cache: None,
100            label: None,
101        });
102     let vtx_buf = device.create_buffer(&wgpu::BufferDescriptor {
103         size: 0,
104         usage: wgpu::BufferUsages::VERTEX,
105         mapped_at_creation: false,
106         label: None,
107     });
108     let idx_buf = device.create_buffer(&wgpu::BufferDescriptor {
109         size: 0,
110         usage: wgpu::BufferUsages::INDEX,
111         mapped_at_creation: false,
112         label: None,
113     });

```

```

113
114     let focused = true;
115
116     Self {
117         pipeline,
118         vtx_buf,
119         idx_buf,
120         context,
121         texture,
122         focused,
123     }
124 }
125
126 pub fn render<'a>(
127     &'a mut self,
128     device: &Device,
129     queue: &Queue,
130     encoder: &'a mut wgpu::CommandEncoder,
131     surface_view: &'a wgpu::TextureView,
132     sampler_bind_group: &wgpu::BindGroup,
133     scene: &Scene,
134 ) {
135     let mut renderpass = encoder.begin_render_pass(&wgpu::RenderPassDescriptor {
136         color_attachments: &[Some(wgpu::RenderPassColorAttachment {
137             view: surface_view,
138             resolve_target: None,
139             ops: wgpu::Operations {
140                 load: wgpu::LoadOp::Load,
141                 store: wgpu::StoreOp::Store,
142             },
143         })],
144         depth_stencil_attachment: None,
145         timestamp_writes: None,
146         occlusion_query_set: None,
147         label: None,
148     });
149
150     let draw_data = self.context.render();
151     if draw_data.total_idx_count == 0 {
152         return;
153     }
154     let mut vertices = Vec::with_capacity(draw_data.total_vtx_count as _);
155     let mut indices = Vec::with_capacity(draw_data.total_idx_count as _);
156     for draw_list in draw_data.draw_lists() {
157         vertices.extend_from_slice(draw_list.vtx_buffer());
158         indices.extend_from_slice(draw_list.idx_buffer());
159     }
160
161     indices.resize(
162         indices.len() + wgpu::COPY_BUFFER_ALIGNMENT as usize
163             - indices.len() % wgpu::COPY_BUFFER_ALIGNMENT as usize,
164         0,
165     );
166
167     // Logic taken from https://github.com/Yatekii/imgui-wgpu-rs/blob/master/src/lib.rs
168     if (self.idx_buf.size() as usize) < indices.len() * mem::size_of::<u16>() {
169         self.idx_buf = device.create_buffer_init(&wgpu::util::BufferInitDescriptor {
170             contents: cast_slice(&indices),

```

```

171             usage: wgpu::BufferUsages::INDEX | wgpu::BufferUsages::COPY_DST,
172             label: None,
173         );
174     } else {
175         queue.write_buffer(&self.idx_buf, 0, cast_slice(&indices));
176     }
177
178     if (self.vtx_buf.size() as usize) < vertices.len() * mem::size_of::<DrawVert>() {
179         self.vtx_buf = device.create_buffer_init(&wgpu::util::BufferInitDescriptor {
180             contents: cast_slice(&vertices),
181             usage: wgpu::BufferUsages::VERTEX | wgpu::BufferUsages::COPY_DST,
182             label: None,
183         });
184     } else {
185         queue.write_buffer(&self.vtx_buf, 0, cast_slice(&vertices));
186     }
187
188     queue.write_buffer(&scene.consts_buf, 0, cast_slice(&[scene.consts]));
189     renderpass.set_pipeline(&self.pipeline);
190     renderpass.set_bind_group(0, &scene.consts_bind_group, &[]);
191     renderpass.set_bind_group(1, &self.texture.bind_group, &[]);
192     renderpass.set_bind_group(2, sampler_bind_group, &[]);
193     renderpass.set_vertex_buffer(0, self.vtx_buf.slice(..));
194     renderpass.set_index_buffer(self.idx_buf.slice(..), wgpu::IndexFormat::Uint16);
195
196     // Logic taken from https://github.com/Yatekii/imgui-wgpu-rs/blob/master/src/lib.rs
197     let mut vtx_offset = 0;
198     let mut idx_offset = 0;
199     for draw_list in draw_data.draw_lists() {
200         for cmd in draw_list.commands() {
201             if let imgui::DrawCmd::Elements { count, cmd_params } = cmd {
202                 renderpass.set_scissor_rect(
203                     cmd_params.clip_rect[0].floor() as _,
204                     cmd_params.clip_rect[1].floor() as _,
205                     (cmd_params.clip_rect[2] - cmd_params.clip_rect[0].ceil()) as _,
206                     (cmd_params.clip_rect[3] - cmd_params.clip_rect[1].ceil()) as _,
207                 );
208                 let start = idx_offset as u32 + cmd_params.idx_offset as u32;
209                 renderpass.draw_indexed(
210                     start..(start + count as u32),
211                     vtx_offset as i32 + cmd_params.vtx_offset as i32,
212                     0..1,
213                 );
214             }
215         }
216         vtx_offset += draw_list.vtx_buffer().len();
217         idx_offset += draw_list.idx_buffer().len();
218     }
219 }
220
221 pub fn update_cursor(&mut self, window: &Window) {
222     if let Some(cursor) = self.context.mouse_cursor() {
223         window.set_cursor_visible(true);
224         window.set_cursor_icon(to_winit_cursor(cursor));
225     } else {
226         window.set_cursor_visible(false);
227     }
228 }
```

```

229
230     pub fn handle_events(&mut self, event: &WindowEvent) {
231         let io = self.context.io_mut();
232         match event {
233             WindowEvent::Resized(size) => {
234                 io.display_size = [size.width as _, size.height as _];
235             }
236             WindowEvent::KeyboardInput { event, .. } => {
237                 if let PhysicalKey::Code(key) = event.physical_key {
238                     for k in to_imgui_keys(key) {
239                         io.add_key_event(*k, event.state.is_pressed());
240                     }
241                 }
242                 if event.state.is_pressed() {
243                     if let Some(txt) = &event.text {
244                         for ch in txt.chars() {
245                             io.add_input_character(ch);
246                         }
247                     }
248                 }
249             }
250             WindowEvent::ScaleFactorChanged { scale_factor, .. } => {
251                 io.display_framebuffer_scale = [*scale_factor as_; 2];
252             }
253             WindowEvent::MouseInput { state, button, .. } => match button {
254                 MouseButton::Left => io.mouse_down[0] = state.is_pressed(),
255                 MouseButton::Right => io.mouse_down[1] = state.is_pressed(),
256                 MouseButton::Middle => io.mouse_down[2] = state.is_pressed(),
257                 _ => {}
258             },
259             WindowEvent::CursorMoved { position, .. } => {
260                 io.mouse_pos = [position.x as _, position.y as _];
261             }
262             WindowEvent::MouseWheel { delta, .. } => {
263                 // Adjusting scroll speed
264                 let sf = 0.01;
265                 let (h, v) = match delta {
266                     MouseScrollDelta::LineDelta(h, v) => (*h, *v),
267                     MouseScrollDelta::PixelDelta(pos) => (sf * pos.x as f32, sf * pos.y as f32),
268                 };
269                 io.mouse_wheel_h = h;
270                 io.mouse_wheel = v;
271             }
272             WindowEvent::ModifiersChanged(modifiers) => {
273                 io.key_shift = modifiers.state().shift_key();
274                 io.key_alt = modifiers.state().alt_key();
275                 io.key_ctrl = modifiers.state().control_key();
276                 io.key_super = modifiers.state().super_key();
277             }
278             _ => {}
279         }
280     }
281 }
282
283 pub fn build(ui: &Ui, consts: &mut Constants) -> bool {
284     let mut focused = false;
285     let mut pbr_bool = consts.shader.pbr != 0;
286     ui.window("NEA Ocean Simulation")

```

```

287     .always_auto_resize(true)
288     .build() {
289         ui.text("Parameters marked with (*) generally should not be changed");
290         ui.text("Info:");
291         ui.text(format!("{} Elapsed", consts.time, 2));
292         ui.text(format!(
293             "A {}x{} simulation, running at {} fps",
294             consts.sim.size,
295             consts.sim.size,
296             ui.io().framerate
297         ));
298         if ui.collapsing_header("Simulation Parameters", TreeNodeFlags::DEFAULT_OPEN) {
299             ui.text("Waves");
300             ui.slider("Depth", 1.0, 50.0, &mut consts.sim.depth);
301             ui.slider("Gravity", 0.1, 100.0, &mut consts.sim.gravity);
302             ui.slider("Wind Speed", 0.1, 100.0, &mut consts.sim.wind_speed);
303             ui.slider("Wind Offset", -PI, PI, &mut consts.sim.wind_offset);
304             ui.slider("Fetch", 1000.0, 10000.0, &mut consts.sim.fetch);
305             ui.slider("Choppiness", 0.0, 1.0, &mut consts.sim.choppiness);
306             ui.slider("Swell", 0.001, 1.0, &mut consts.sim.swell);
307
308             ui.text("Lengthscales");
309             ui.slider("Lengthscale 0", 1, consts.sim.size, &mut consts.sim.lengthscale0);
310             ui.slider("Cutoff Low 0*", 0.00000, 0.00001, &mut consts.sim.cutoff_low0);
311             ui.slider("Cutoff High 0", 0.01, 15.0, &mut consts.sim.cutoff_high0);
312             ui.slider("Lengthscale 0 Scale Factor", 0.0, 1.0, &mut
313                 consts.sim.lengthscale0_sf);
314
315             ui.slider("Lengthscale 1", 1, consts.sim.size, &mut consts.sim.lengthscale1);
316             ui.slider("Cutoff Low 1", 0.00000, 15.0, &mut consts.sim.cutoff_low1);
317             ui.slider("Cutoff High 1", 0.01, 15.0, &mut consts.sim.cutoff_high1);
318             ui.slider("Lengthscale 1 Scale Factor", 0.0, 1.0, &mut
319                 consts.sim.lengthscale1_sf);
320
321             ui.slider("Lengthscale 2", 1, consts.sim.size, &mut consts.sim.lengthscale2);
322             ui.slider("Cutoff Low 2", 0.00000, 15.0, &mut consts.sim.cutoff_low2);
323             ui.slider("Cutoff High 2", 0.0, 15.0, &mut consts.sim.cutoff_high2);
324             ui.slider("Lengthscale 2 Scale Factor", 0.0, 1.0, &mut
325                 consts.sim.lengthscale2_sf);
326
327             ui.text("Foam");
328             ui.color_edit4("Foam Color", consts.shader.foam_color.as_mut());
329             ui.slider("Decay", 0.0, 0.3, &mut consts.sim.foam_decay);
330             ui.slider("Bias", 0.00, 2.0, &mut consts.sim.foam_bias);
331             ui.slider("Injection Threshold", -1.00, 1.0, &mut consts.sim.injection_threshold);
332             ui.slider("Injection Amount", 0.00, 2.0, &mut consts.sim.injection_amount);
333             ui.text("Misc");
334             ui.slider("Instances per Axis", 1, 10, &mut consts.sim.instances);
335             ui.slider("Instance micro Offset", 0.9, 1.0, &mut
336                 consts.sim.instance_micro_offset);
337             ui.slider("Mesh Step", 0.0, 1.0, &mut consts.sim.mesh_step);
338             ui.slider("Integration Step*", 0.001, 0.02, &mut consts.sim.integration_step);
339         }
340         ui.separator();
341         if ui.collapsing_header("Shader Parameters", TreeNodeFlags::DEFAULT_OPEN) {
342             ui.text("PBR");
343             ui.checkbox("PBR", &mut pbr_bool);
344             ui.slider("PBR Specular Scale Factor", 0.0, 10.0, &mut consts.shader.pbr_sf);

```

```

341             ui.slider("PBR Fresnel Effect Scale Factor", 0.0, 1.0, &mut
342             consts.shader.fresnel_pbr_sf);
343             ui.slider("PBR Cutoff Low*", 0.0, 0.2, &mut consts.shader.pbr_cutoff);
344             ui.slider("Water Roughness", 0.0, 0.5, &mut consts.shader.roughness);
345             ui.slider("Foam Roughness Modifier", 0.0, 2.0, &mut consts.shader.foam_roughness);
346             ui.text("Fresnel");
347             ui.slider("Water Refractive Index", 0.0, 2.0, &mut consts.shader.water_ri);
348             ui.slider("Air Refractive Index**", 0.0, 2.0, &mut consts.shader.air_ri);
349             ui.slider("Fresnel Shine", 0.0, 10.0, &mut consts.shader.fresnel_shine);
350             ui.slider("Fresnel Effect Scale Factor", 0.0, 1.0, &mut consts.shader.fresnel_sf);
351             ui.slider("Fresnel Normal Scale Factor", 0.0, 1.0, &mut
352             consts.shader.fresnel_normal_sf);
353             ui.text("Subsurface Scattering");
354             ui.color_edit4("Scatter Color", consts.shader.scatter_color.as_mut());
355             ui.color_edit4("Bubble Color", consts.shader.bubble_color.as_mut());
356             ui.slider("Height Attenuation", 0.0, 1.0, &mut consts.shader.ss_height);
357             ui.slider("Reflection Strength", 0.0, 1.0, &mut consts.shader.ss_reflected);
358             ui.slider("Diffuse Strength", 0.0, 1.0, &mut consts.shader.ss_lambert);
359             ui.slider("Ambient Light Strength", 0.0, 1.0, &mut consts.shader.ss_ambient);
360             ui.slider("Air Bubble Density", 0.0, 1.0, &mut consts.shader.bubble_density);
361             ui.text("Fog");
362             ui.color_edit4("Fog Color", consts.shader.fog_color.as_mut());
363             ui.slider("Fog Density", 0.0, 10.0, &mut consts.shader.fog_density);
364             ui.slider("Fog Offset", 0.0, 500.0, &mut consts.shader.fog_offset);
365             ui.slider("Fog Falloff", 0.0, 10.0, &mut consts.shader.fog_falloff);
366             ui.slider("Fog Height", 0.0, 100.0, &mut consts.shader.fog_height);
367             ui.text("Misc");
368             ui.slider("Blinn Phong Shininess", 0.0, 50.0, &mut consts.shader.shininess);
369             ui.slider("Reflections Strength", 0.0, 10.0, &mut consts.shader.reflection_sf);
370         }
371         ui.separator();
372         if ui.collapsing_header("World Parameters", TreeNodeFlags::DEFAULT_OPEN) {
373             ui.text("Sun");
374             ui.color_edit4("Sun Color", consts.shader.sun_color.as_mut());
375             ui.slider("Sun X", -1.0, 1.0, &mut consts.shader.sun_x);
376             ui.slider("Sun Y", -1.0, 1.0, &mut consts.shader.sun_y);
377             ui.slider("Sun Z", -1.0, 1.0, &mut consts.shader.sun_z);
378             ui.slider("Sun Angle", -PI, PI, &mut consts.shader.sun_angle);
379             ui.slider("Sun Distance", 0.0, 500.0, &mut consts.shader.sun_distance);
380             ui.slider("Sun Size", 0.0, PI / 18.0, &mut consts.shader.sun_size);
381             ui.slider("Sun Falloff", 0.0, 10000.0, &mut consts.shader.sun_falloff);
382             ui.slider("Height Offset", 0.0, 50.0, &mut consts.sim.height_offset);
383         }
384         focused = ui.is_window_focused();
385     );
386     focused
387 }
388
389 // code adapted from https://github.com/imgui-rs/imgui-winit-support
390 fn to_winit_cursor(cursor: MouseCursor) -> CursorIcon {
391     match cursor {
392         MouseCursor::Arrow => CursorIcon::Default,
393         MouseCursor::TextInput => CursorIcon::Text,
394         MouseCursor::ResizeAll => CursorIcon::Move,
395         MouseCursor::ResizeNS => CursorIcon::NsResize,
396         MouseCursor::ResizeEW => CursorIcon::EwResize,

```

```

397     MouseCursor::ResizeNESW => CursorIcon::NeswResize,
398     MouseCursor::ResizeNWSE => CursorIcon::NwseResize,
399     MouseCursor::Hand => CursorIcon::Grab,
400     MouseCursor::NotAllowed => CursorIcon::NotAllowed,
401 }
402 }
403
404 // code adapted from https://github.com/imgui-rs/imgui-winit-support
405 fn to_imgui_keys(keycode: KeyCode) -> &'static [Key] {
406     match keycode {
407         KeyCode::Tab => &[Key::Tab],
408         KeyCode::ArrowLeft => &[Key::LeftArrow],
409         KeyCode::ArrowRight => &[Key::RightArrow],
410         KeyCode::ArrowUp => &[Key::UpArrow],
411         KeyCode::ArrowDown => &[Key::DownArrow],
412         KeyCode::PageUp => &[Key::PageUp],
413         KeyCode::PageDown => &[Key::PageDown],
414         KeyCode::Home => &[Key::Home],
415         KeyCode::End => &[Key::End],
416         KeyCode::Insert => &[Key::Insert],
417         KeyCode::Delete => &[Key::Delete],
418         KeyCode::Backspace => &[Key::Backspace],
419         KeyCode::Space => &[Key::Space],
420         KeyCode::Enter => &[Key::Enter],
421         KeyCode::Escape => &[Key::Escape],
422         KeyCode::ControlLeft => &[Key::LeftCtrl, Key::ModCtrl],
423         KeyCode::ShiftLeft => &[Key::LeftShift, Key::ModShift],
424         KeyCode::AltLeft => &[Key::LeftAlt, Key::ModAlt],
425         KeyCode::SuperLeft => &[Key::LeftSuper, Key::ModSuper],
426         KeyCode::ControlRight => &[Key::RightCtrl, Key::ModCtrl],
427         KeyCode::ShiftRight => &[Key::RightShift, Key::ModShift],
428         KeyCode::AltRight => &[Key::RightAlt, Key::ModAlt],
429         KeyCode::SuperRight => &[Key::RightSuper, Key::ModSuper],
430         KeyCode::ContextMenu => &[Key::Menu],
431         KeyCode::Digit0 => &[Key::Alpha0],
432         KeyCode::Digit1 => &[Key::Alpha1],
433         KeyCode::Digit2 => &[Key::Alpha2],
434         KeyCode::Digit3 => &[Key::Alpha3],
435         KeyCode::Digit4 => &[Key::Alpha4],
436         KeyCode::Digit5 => &[Key::Alpha5],
437         KeyCode::Digit6 => &[Key::Alpha6],
438         KeyCode::Digit7 => &[Key::Alpha7],
439         KeyCode::Digit8 => &[Key::Alpha8],
440         KeyCode::Digit9 => &[Key::Alpha9],
441         KeyCode::KeyA => &[Key::A],
442         KeyCode::KeyB => &[Key::B],
443         KeyCode::KeyC => &[Key::C],
444         KeyCode::KeyD => &[Key::D],
445         KeyCode::KeyE => &[Key::E],
446         KeyCode::KeyF => &[Key::F],
447         KeyCode::KeyG => &[Key::G],
448         KeyCode::KeyH => &[Key::H],
449         KeyCode::KeyI => &[Key::I],
450         KeyCode::KeyJ => &[Key::J],
451         KeyCode::KeyK => &[Key::K],
452         KeyCode::KeyL => &[Key::L],
453         KeyCode::KeyM => &[Key::M],
454         KeyCode::KeyN => &[Key::N],

```

```

455     KeyCode::Key0 => &[Key::0],
456     KeyCode::KeyP => &[Key::P],
457     KeyCode::KeyQ => &[Key::Q],
458     KeyCode::KeyR => &[Key::R],
459     KeyCode::KeyS => &[Key::S],
460     KeyCode::KeyT => &[Key::T],
461     KeyCode::KeyU => &[Key::U],
462     KeyCode::KeyV => &[Key::V],
463     KeyCode::KeyW => &[Key::W],
464     KeyCode::KeyX => &[Key::X],
465     KeyCode::KeyY => &[Key::Y],
466     KeyCode::KeyZ => &[Key::Z],
467     KeyCode::F1 => &[Key::F1],
468     KeyCode::F2 => &[Key::F2],
469     KeyCode::F3 => &[Key::F3],
470     KeyCode::F4 => &[Key::F4],
471     KeyCode::F5 => &[Key::F5],
472     KeyCode::F6 => &[Key::F6],
473     KeyCode::F7 => &[Key::F7],
474     KeyCode::F8 => &[Key::F8],
475     KeyCode::F9 => &[Key::F9],
476     KeyCode::F10 => &[Key::F10],
477     KeyCode::F11 => &[Key::F11],
478     KeyCode::F12 => &[Key::F12],
479     KeyCode::Quote => &[Key::Apostrophe],
480     KeyCode::Comma => &[Key::Comma],
481     KeyCode::Minus => &[Key::Minus],
482     KeyCode::Period => &[Key::Period],
483     KeyCode::Slash => &[Key::Slash],
484     KeyCode::Semicolon => &[Key::Semicolon],
485     KeyCode::Equal => &[Key::Equal],
486     KeyCode::BracketLeft => &[Key::LeftBracket],
487     KeyCode::Backslash => &[Key::Backslash],
488     KeyCode::BracketRight => &[Key::RightBracket],
489     KeyCode::Backquote => &[Key::GraveAccent],
490     KeyCode::CapsLock => &[Key::CapsLock],
491     KeyCode::ScrollLock => &[Key::ScrollLock],
492     KeyCode::NumLock => &[Key::NumLock],
493     KeyCode::PrintScreen => &[Key::PrintScreen],
494     KeyCode::Pause => &[Key::Pause],
495     KeyCode::Numpad0 => &[Key::Keypad0],
496     KeyCode::Numpad1 => &[Key::Keypad1],
497     KeyCode::Numpad2 => &[Key::Keypad2],
498     KeyCode::Numpad3 => &[Key::Keypad3],
499     KeyCode::Numpad4 => &[Key::Keypad4],
500     KeyCode::Numpad5 => &[Key::Keypad5],
501     KeyCode::Numpad6 => &[Key::Keypad6],
502     KeyCode::Numpad7 => &[Key::Keypad7],
503     KeyCode::Numpad8 => &[Key::Keypad8],
504     KeyCode::Numpad9 => &[Key::Keypad9],
505     KeyCode::NumpadDecimal => &[Key::KeypadDecimal],
506     KeyCode::NumpadDivide => &[Key::KeypadDivide],
507     KeyCode::NumpadMultiply => &[Key::KeypadMultiply],
508     KeyCode::NumpadSubtract => &[Key::KeypadSubtract],
509     KeyCode::NumpadAdd => &[Key::KeypadAdd],
510     KeyCode::NumpadEnter => &[Key::KeypadEnter],
511     KeyCode::NumpadEqual => &[Key::KeypadEqual],
512     _ => &[],

```

```
513      }
514 }
515
```

3.4.2.5. util.rs

rust

```
1 use image::io::Reader;
2 use image::GenericImageView;
3 use std::fs::File;
4 use std::io::Cursor;
5 use std::io::Read;
6 use wgpu::util::DeviceExt;
7 use wgpu::Queue;
8
9 pub struct Texture {
10     pub texture: wgpu::Texture,
11     pub view: wgpu::TextureView,
12     pub bind_group: wgpu::BindGroup,
13     pub layout: wgpu::BindGroupLayout,
14 }
15
16 impl Texture {
17     pub fn new_sampled(
18         width: u32,
19         height: u32,
20         format: wgpu::TextureFormat,
21         device: &wgpu::Device,
22         label: &str,
23     ) -> Self {
24         let texture = device.create_texture(&wgpu::TextureDescriptor {
25             size: wgpu::Extent3d {
26                 width,
27                 height,
28                 depth_or_array_layers: 1,
29             },
30             mip_level_count: 1,
31             sample_count: 1,
32             dimension: wgpu::TextureDimension::D2,
33             format,
34             usage: wgpu::TextureUsages::TEXTURE_BINDING | wgpu::TextureUsages::COPY_DST,
35             view_formats: &[],
36             label: Some(label),
37         });
38         let view = texture.create_view(&wgpu::TextureViewDescriptor::default());
39         let layout = device.create_bind_group_layout(&wgpu::BindGroupLayoutDescriptor {
40             entries: &[sampled_bind_group_descriptor(0)],
41             label: Some(label),
42         });
43         let bind_group = device.create_bind_group(&wgpu::BindGroupDescriptor {
44             layout: &layout,
45             entries: &[wgpu::BindGroupEntry {
46                 binding: 0,
47                 resource: wgpu::BindingResource::TextureView(&view),
48             }],
49             label: Some(label),
50         });
51
52         Self {
53             texture,
54             view,
55             bind_group,
56             layout,
```

```

57         }
58     }
59
60     pub fn new_storage(
61         width: u32,
62         height: u32,
63         format: wgpu::TextureFormat,
64         device: &wgpu::Device,
65         label: &str,
66     ) -> Self {
67         let texture = device.create_texture(&wgpu::TextureDescriptor {
68             size: wgpu::Extent3d {
69                 width,
70                 height,
71                 depth_or_array_layers: 1,
72             },
73             mip_level_count: 1,
74             sample_count: 1,
75             dimension: wgpu::TextureDimension::D2,
76             format,
77             usage: wgpu::TextureUsages::STORAGE_BINDING
78                 | wgpu::TextureUsages::COPY_DST
79                 | wgpu::TextureUsages::TEXTURE_BINDING,
80             view_formats: &[],
81             label: Some(label),
82         });
83         let view = texture.create_view(&wgpu::TextureViewDescriptor::default());
84         let layout = device.create_bind_group_layout(&wgpu::BindGroupLayoutDescriptor {
85             entries: &[bind_group_descriptor(0, format)],
86             label: Some(label),
87         });
88         let bind_group = device.create_bind_group(&wgpu::BindGroupDescriptor {
89             layout: &layout,
90             entries: &[wgpu::BindGroupEntry {
91                 binding: 0,
92                 resource: wgpu::BindingResource::TextureView(&view),
93             }],
94             label: Some(label),
95         });
96
97         Self {
98             texture,
99             view,
100            layout,
101            bind_group,
102        }
103    }
104
105    pub fn write(&self, queue: &Queue, data: &[u8], size: u32) {
106        queue.write_texture(
107            wgpu::ImageCopyTexture {
108                texture: &self.texture,
109                mip_level: 0,
110                origin: wgpu::Origin3d::ZERO,
111                aspect: wgpu::TextureAspect::All,
112            },
113            data,
114            wgpu::ImageDataLayout {

```

```

115             offset: 0,
116             bytes_per_row: Some(size * self.texture.width()),
117             rows_per_image: Some(self.texture.height()),
118         },
119         self.texture.size(),
120     );
121 }
122
123 pub fn from_file(device: &wgpu::Device, queue: &Queue, label: &str, file: &str) -> Self {
124     // cant include_bytes! as filepath is non static
125     let mut file_data = Vec::new();
126     File::open(file)
127         .expect("failed to open file")
128         .read_to_end(&mut file_data)
129         .expect("failed to read file");
130
131     let diffuse_image = Reader::new(Cursor::new(file_data))
132         .with_guessed_format()
133         .expect("failed to guess format")
134         .decode()
135         .expect("failed to decode image");
136     let diffuse_rgba = diffuse_image.to_rgba32f();
137     let dimensions = diffuse_image.dimensions();
138     let texture_size = wgpu::Extent3d {
139         width: dimensions.0,
140         height: dimensions.1,
141         depth_or_array_layers: 1,
142     };
143
144     let texture = device.create_texture_with_data(
145         queue,
146         &wgpu::TextureDescriptor {
147             size: texture_size,
148             mip_level_count: 1,
149             sample_count: 1,
150             dimension: wgpu::TextureDimension::D2,
151             format: wgpu::TextureFormat::Rgba32Float,
152             usage: wgpu::TextureUsages::TEXTURE_BINDING | wgpu::TextureUsages::COPY_DST,
153             label: None,
154             view_formats: &[],
155         },
156         wgpu::util::TextureDataOrder::default(),
157         super::cast_slice(diffuse_rgba.as_raw()),
158     );
159     let view = texture.create_view(&wgpu::TextureViewDescriptor::default());
160     let layout = device.create_bind_group_layout(&wgpu::BindGroupLayoutDescriptor {
161         entries: &[sampled_bind_group_descriptor(0)],
162         label: Some(label),
163     });
164     let bind_group = device.create_bind_group(&wgpu::BindGroupDescriptor {
165         layout: &layout,
166         entries: &[wgpu::BindGroupEntry {
167             binding: 0,
168             resource: wgpu::BindingResource::TextureView(&view),
169         }],
170         label: Some(label),
171     });
172     Self {

```

```

173         texture,
174         view,
175         layout,
176         bind_group,
177     }
178 }
179 }
180
181
182 // debatably redundant as not app agnostic, but reduces LOC significantly
183 pub fn bind_group_descriptor(
184     binding: u32,
185     format: wgpu::TextureFormat,
186 ) -> wgpu::BindGroupLayoutEntry {
187     wgpu::BindGroupLayoutEntry {
188         binding,
189         visibility: wgpu::ShaderStages::COMPUTE | wgpu::ShaderStages::VERTEX_FRAGMENT,
190         ty: wgpu::BindingType::StorageTexture {
191             access: wgpu::StorageTextureAccess::ReadWrite,
192             format,
193             view_dimension: wgpu::TextureViewDimension::D2,
194         },
195         count: None,
196     }
197 }
198
199 pub fn sampled_bind_group_descriptor(binding: u32) -> wgpu::BindGroupLayoutEntry {
200     wgpu::BindGroupLayoutEntry {
201         binding,
202         visibility: wgpu::ShaderStages::VERTEX_FRAGMENT,
203         ty: wgpu::BindingType::Texture {
204             sample_type: wgpu::TextureSampleType::Float { filterable: false },
205             view_dimension: wgpu::TextureViewDimension::D2,
206             multisampled: false,
207         },
208         count: None,
209     }
210 }
211

```

3.4.3. simulation

3.4.3.1. mod.rs

rust

```
1 use super::sim::compute::ComputePass;
2 use super::sim::fft::FourierTransform;
3 use simdata::SimData;
4 use crate::cast_slice;
5 use crate::engine::scene::Scene;
6 use cascade::Cascade;
7
8 pub mod compute;
9 pub mod fft;
10 pub mod cascade;
11 pub mod simdata;
12
13
14 pub struct Simulation {
15     pub simdata: SimData,
16     pub cascade0: Cascade,
17     pub cascade1: Cascade,
18     pub cascade2: Cascade,
19     pub butterfly_precompute_pass: ComputePass,
20     pub initial_spectra_pass: ComputePass,
21     pub conjugates_pass: ComputePass,
22     pub evolve_spectra_pass: ComputePass,
23     pub process_deltas_pass: ComputePass,
24     pub fft: FourierTransform,
25 }
26
27 impl Simulation {
28     pub fn new(
29         device: &wgpu::Device,
30         queue: &wgpu::Queue,
31         shader: &wgpu::ShaderModule,
32         scene: &Scene,
33     ) -> Self {
34         let simdata = SimData::new(device, &scene.consts);
35
36         let cascade0 = Cascade::new(device, &scene.consts, "0");
37         let cascade1 = Cascade::new(device, &scene.consts, "1");
38         let cascade2 = Cascade::new(device, &scene.consts, "2");
39
40         let push_constant_ranges = &[wgpu::PushConstantRange {
41             stages: wgpu::ShaderStages::COMPUTE,
42             range: 0..std::mem::size_of::<u32>() as u32,
43         }];
44         let initial_spectra_pass = ComputePass::new(
45             &[&scene.consts_layout, &simdata.layout, &cascade0.layout],
46             push_constant_ranges,
47             device,
48             shader,
49             "Initial Spectra",
50             "sim::initial_spectra::main",
51         );
52         let butterfly_precompute_pass = ComputePass::new(
53             &[&scene.consts_layout, &simdata.layout],
54             &[]
55         );
56     }
57 }
```

```

55         device,
56         shader,
57         "Precompute Butterfly",
58         "sim::fft::precompute_butterfly",
59     );
60     let conjugates_pass = ComputePass::new(
61         &[&scene.consts_layout, &simdata.layout, &cascade0.layout],
62         &[],
63         device,
64         shader,
65         "Pack Conjugates",
66         "sim::initial_spectra::pack_conjugates",
67     );
68     let evolve_spectra_pass = ComputePass::new(
69         &[
70             &scene.consts_layout,
71             &cascade0.layout,
72             &cascade0.h_displacement.layout,
73             &cascade0.v_displacement.layout,
74             &cascade0.h_slope.layout,
75             &cascade0.jacobian.layout,
76         ],
77         &[],
78         device,
79         shader,
80         "Evolve Spectra",
81         "sim::evolve_spectra::main",
82     );
83     let process_deltas_pass = ComputePass::new(
84         &[
85             &scene.consts_layout,
86             &cascade0.h_displacement.layout,
87             &cascade0.v_displacement.layout,
88             &cascade0.h_slope.layout,
89             &cascade0.jacobian.layout,
90             &cascade0.layout,
91         ],
92         &[],
93         device,
94         shader,
95         "Process Deltas",
96         "sim::process_deltas::main",
97     );
98     let fft = FourierTransform::new(device, shader, scene, &simdata);
99
100    simdata
101        .gaussian_tex
102        .write(queue, cast_slice(&simdata.gaussian_noise.clone()), 16);
103
104    Self {
105        cascade0,
106        cascade1,
107        cascade2,
108        simdata,
109        initial_spectra_pass,
110        butterfly_precompute_pass,
111        conjugates_pass,
112        evolve_spectra_pass,

```

```

113         process_deltas_pass,
114         fft,
115     }
116 }
117 pub fn compute_cascade<'a>(
118     &'a self,
119     encoder: &'a mut wgpu::CommandEncoder,
120     cascade: &Cascade,
121     scene: &mut Scene,
122     workgroup_size: u32,
123     index: u32,
124 ) {
125     self.evolve_spectra_pass.compute(
126         encoder,
127         "Evolve Spectra",
128         &[
129             &scene.consts_bind_group,
130             &cascade.bind_group,
131             &cascade.h_displacement.bind_group,
132             &cascade.v_displacement.bind_group,
133             &cascade.h_slope.bind_group,
134             &cascade.jacobian.bind_group,
135         ],
136         workgroup_size,
137         workgroup_size,
138     );
139     self.fft.ifft2d(
140         encoder,
141         scene,
142         &self.simdata,
143         &cascade.h_displacement,
144         index,
145     );
146     self.fft.ifft2d(
147         encoder,
148         scene,
149         &self.simdata,
150         &cascade.v_displacement,
151         index,
152     );
153     self.fft.ifft2d(
154         encoder,
155         scene,
156         &self.simdata,
157         &cascade.h_slope,
158         index,
159     );
160     self.fft.ifft2d(
161         encoder,
162         scene,
163         &self.simdata,
164         &cascade.jacobian,
165         index,
166     );
167     self.process_deltas_pass.compute(
168         encoder,
169         "Process Deltas",
170

```

```

171     &[
172         &scene.consts_bind_group,
173         &cascade.h_displacement.bind_group,
174         &cascade.v_displacement.bind_group,
175         &cascade.h_slope.bind_group,
176         &cascade.jacobian.bind_group,
177         &cascade.bind_group,
178     ],
179     workgroup_size,
180     workgroup_size,
181 );
182 }
183 // creating a proper abstraction for a compute pass would just involve recreating a
184 // computepipeline struct from scratch, so instead as this isn't a true "engine" I have just
185 // special cased a computepass that requires push constants
186 pub fn compute_initial<'a>(
187     &'a self,
188     encoder: &'a mut wgpu::CommandEncoder,
189     bind_groups: &[&wgpu::BindGroup],
190     pc: u32,
191     x: u32,
192     y: u32,
193 ) {
194     let mut pass = encoder.begin_compute_pass(&wgpu::ComputePassDescriptor {
195         timestamp_writes: None,
196         label: Some("Initial Spectra"),
197     });
198
199     pass.set_pipeline(&self.initial_spectra_pass.pipeline);
200     for (i, bind_group) in bind_groups.iter().enumerate() {
201         pass.set_bind_group(i as _, *bind_group, &[]);
202     }
203     pass.set_push_constants(0, cast_slice(&[pc]));
204     pass.dispatch_workgroups(x, y, 1);
205     drop(pass);
206
207     let mut pass = encoder.begin_compute_pass(&wgpu::ComputePassDescriptor {
208         timestamp_writes: None,
209         label: Some("Conjugates"),
210     });
211
212     pass.set_pipeline(&self.conjugates_pass.pipeline);
213     for (i, bind_group) in bind_groups.iter().enumerate() {
214         pass.set_bind_group(i as _, *bind_group, &[]);
215     }
216     pass.dispatch_workgroups(x, y, 1);
217 }
218 }
219

```

3.4.3.2. simdata.rs

rust

```
1 use glam::{Vec2, Vec4};
2 use crate::engine::util::{bind_group_descriptor, Texture};
3 use shared::Constants;
4
5 pub struct SimData {
6     pub gaussian_noise: Vec<Vec4>,
7     pub gaussian_tex: Texture,
8     pub layout: wgpu::BindGroupLayout,
9     pub bind_group: wgpu::BindGroup,
10 }
11
12 impl SimData {
13     pub fn new(device: &wgpu::Device, consts: &Constants) -> Self {
14         let gaussian_tex = Texture::new_storage(
15             consts.sim.size,
16             consts.sim.size,
17             wgpu::TextureFormat::Rgba32Float,
18             device,
19             "Gaussian",
20         );
21         let gaussian_noise = Self::guassian_noise(consts);
22
23         let butterfly_tex = Texture::new_storage(
24             consts.sim.size.ilog2(),
25             consts.sim.size,
26             wgpu::TextureFormat::Rgba32Float,
27             device,
28             "Butterfly",
29         );
30
31         let layout = device.create_bind_group_layout(&wgpu::BindGroupLayoutDescriptor {
32             entries: &[
33                 bind_group_descriptor(0, wgpu::TextureFormat::Rgba32Float),
34                 bind_group_descriptor(1, wgpu::TextureFormat::Rgba32Float),
35             ],
36             label: Some("Sim Data Layout"),
37         });
38         let bind_group = device.create_bind_group(&wgpu::BindGroupDescriptor {
39             layout: &layout,
40             entries: &[
41                 wgpu::BindGroupEntry {
42                     binding: 0,
43                     resource: wgpu::BindingResource::TextureView(&gaussian_tex.view),
44                 },
45                 wgpu::BindGroupEntry {
46                     binding: 1,
47                     resource: wgpu::BindingResource::TextureView(&butterfly_tex.view),
48                 },
49             ],
50             label: Some("Sim Data Textures"),
51         });
52
53         Self {
54             gaussian_tex,
55             gaussian_noise,
56             bind_group,
```

```

57         layout,
58     }
59 }
60
61 fn gaussian_noise(consts: &Constants) -> Vec<Vec4> {
62     let mut rng = Xoshiro256plus::new(consts.sim.seed as_);
63     let mut data = vec![];
64     for _ in 0..(consts.sim.size * consts.sim.size) {
65         let gaussian_pair =
66             Self::gaussian_number(
67                 rng.next() as_,
68                 rng.next() as_,
69             );
70         data.push(Vec4::new(gaussian_pair.x, gaussian_pair.y, 0.0, 1.0));
71     }
72     data
73 }
74 // box muller transform, gaussian pair technically not needed but is slightly cooler
75 fn gaussian_number(u1: f32, u2: f32) -> Vec2 {
76     Vec2::new(
77         (-2.0 * u1.ln()).sqrt() * (2.0 * std::f32::consts::PI * u2).cos(),
78         (-2.0 * u1.ln()).sqrt() * (2.0 * std::f32::consts::PI * u2).sin(),
79     )
80 }
81 }
82
83 struct Xoshiro256plus {
84     seed: [u64; 4]
85 }
86
87 impl Xoshiro256plus {
88     pub fn rol64(x: u64, k: i32) -> u64 {
89         (x << k) | (x >> (64 - k))
90     }
91     fn new(seed: u64) -> Self {
92         let mut rng = SplitMix::new(seed);
93         Xoshiro256plus {
94             seed: [rng.next(), rng.next(), rng.next(), rng.next()],
95         }
96     }
97     fn next(&mut self) -> f64 {
98         let result = self.seed[0].wrapping_add(self.seed[3]);
99         let t = self.seed[1] << 17;
100
101         self.seed[2] ^= self.seed[0];
102         self.seed[3] ^= self.seed[1];
103         self.seed[1] ^= self.seed[2];
104         self.seed[0] ^= self.seed[3];
105
106         self.seed[2] ^= t;
107         self.seed[3] = Xoshiro256plus::rol64(self.seed[3], 45);
108
109         (result >> 11) as f64 * (1.0 / (1u64 << 53) as f64)
110     }
111 }
112
113 pub struct SplitMix {
114     seed: u64,

```

```
115 }
116
117
118 impl SplitMix {
119     fn new(seed: u64) -> Self {
120         SplitMix { seed }
121     }
122     /// from https://xoshiro.di.unimi.it/splitmix64.c
123     fn next(&mut self) -> u64 {
124         self.seed = self.seed.wrapping_add(0x9e3779b97f4a7c15);
125         let mut z: u64 = self.seed;
126         z = (z ^ (z >> 30)).wrapping_mul(0xbff58476d1ce4e5b9);
127         z = (z ^ (z >> 27)).wrapping_mul(0x94d049bb133111eb);
128         z ^ (z >> 31)
129     }
130 }
131 }
```

3.4.3.3. cascade.rs

rust

```
1 use crate::engine::util::{bind_group_descriptor, Texture};
2 use shared::Constants;
3
4 pub struct Cascade {
5     pub bind_group: wgpu::BindGroup,
6     pub layout: wgpu::BindGroupLayout,
7     pub h_displacement: Texture,
8     pub h_slope: Texture,
9     pub v_displacement: Texture,
10    pub jacobian: Texture,
11 }
12
13 impl Cascade {
14     pub fn new(device: &wgpu::Device, consts: &Constants, index: &str) -> Self {
15         let wave_texture = Texture::new_storage(
16             consts.sim.size,
17             consts.sim.size,
18             wgpu::TextureFormat::Rgba32Float,
19             device,
20             &format!("Waves {}", index),
21         );
22         let initial_spectrum_texture = Texture::new_storage(
23             consts.sim.size,
24             consts.sim.size,
25             wgpu::TextureFormat::Rgba32Float,
26             device,
27             &format!("Initial Spectrum {}", index),
28         );
29         let evolved_spectrum_texture = Texture::new_storage(
30             consts.sim.size,
31             consts.sim.size,
32             wgpu::TextureFormat::Rgba32Float,
33             device,
34             &format!("Evolved Spectrum {}", index),
35         );
36         let displacement_map = Texture::new_storage(
37             consts.sim.size,
38             consts.sim.size,
39             wgpu::TextureFormat::Rgba32Float,
40             device,
41             &format!("Displacement Map {}", index),
42         );
43         let normal_map = Texture::new_storage(
44             consts.sim.size,
45             consts.sim.size,
46             wgpu::TextureFormat::Rgba32Float,
47             device,
48             &format!("Normal Map{}", index),
49         );
50         let foam_map = Texture::new_storage(
51             consts.sim.size,
52             consts.sim.size,
53             wgpu::TextureFormat::Rgba32Float,
54             device,
55             &format!("Foam {}", index),
56         );
57     }
58 }
```

```

57
58     let layout = device.create_bind_group_layout(&wgpu::BindGroupLayoutDescriptor {
59         entries: &[
60             bind_group_descriptor(0, wgpu::TextureFormat::Rgba32Float),
61             bind_group_descriptor(1, wgpu::TextureFormat::Rgba32Float),
62             bind_group_descriptor(2, wgpu::TextureFormat::Rgba32Float),
63             bind_group_descriptor(3, wgpu::TextureFormat::Rgba32Float),
64             bind_group_descriptor(4, wgpu::TextureFormat::Rgba32Float),
65             bind_group_descriptor(5, wgpu::TextureFormat::Rgba32Float),
66         ],
67         label: Some("Storage Textures Layout"),
68     });
69     let bind_group = device.create_bind_group(&wgpu::BindGroupDescriptor {
70         layout: &layout,
71         entries: &[
72             wgpu::BindGroupEntry {
73                 binding: 0,
74                 resource: wgpu::BindingResource::TextureView(&wave_texture.view),
75             },
76             wgpu::BindGroupEntry {
77                 binding: 1,
78                 resource: wgpu::BindingResource::TextureView(&initial_spectrum_texture.view),
79             },
80             wgpu::BindGroupEntry {
81                 binding: 2,
82                 resource: wgpu::BindingResource::TextureView(&evolved_spectrum_texture.view),
83             },
84             wgpu::BindGroupEntry {
85                 binding: 3,
86                 resource: wgpu::BindingResource::TextureView(&displacement_map.view),
87             },
88             wgpu::BindGroupEntry {
89                 binding: 4,
90                 resource: wgpu::BindingResource::TextureView(&normal_map.view),
91             },
92             wgpu::BindGroupEntry {
93                 binding: 5,
94                 resource: wgpu::BindingResource::TextureView(&foam_map.view),
95             },
96         ],
97         label: Some(&format!("Storage Textures {}", index)),
98     });
99
100    let h_displacement = Texture::new_storage(
101        consts.sim.size,
102        consts.sim.size,
103        wgpu::TextureFormat::Rgba32Float,
104        device,
105        &format!("h_displacement {}", index),
106    );
107    let h_slope = Texture::new_storage(
108        consts.sim.size,
109        consts.sim.size,
110        wgpu::TextureFormat::Rgba32Float,
111        device,
112        &format!("h_slope {}", index),
113    );
114    let jacobian = Texture::new_storage(

```

```
115     consts.sim.size,
116     consts.sim.size,
117     wgpu::TextureFormat::Rgba32Float,
118     device,
119     &format!("jacobian {}", index),
120 );
121 let v_displacement = Texture::new_storage(
122     consts.sim.size,
123     consts.sim.size,
124     wgpu::TextureFormat::Rgba32Float,
125     device,
126     &format!("v_displacement {}", index),
127 );
128
129 Self {
130     layout,
131     bind_group,
132     h_slope,
133     h_displacement,
134     v_displacement,
135     jacobian,
136 }
137 }
138 }
139 }
```

3.4.3.4. compute.rs

rust

```
1 pub struct ComputePass {
2     pub pipeline: wgpu::ComputePipeline,
3 }
4
5 impl ComputePass {
6     pub fn new(
7         bind_group_layouts: &[&wgpu::BindGroupLayout],
8         push_constant_ranges: &[wgpu::PushConstantRange],
9         device: &wgpu::Device,
10        shader: &wgpu::ShaderModule,
11        label: &str,
12        entry_point: &str,
13    ) -> Self {
14         let pipeline_layout = device.create_pipeline_layout(&wgpu::PipelineLayoutDescriptor {
15             bind_group_layouts,
16             push_constant_ranges,
17             label: Some(label),
18         });
19         let pipeline = device.create_compute_pipeline(&wgpu::ComputePipelineDescriptor {
20             entry_point: Some(entry_point),
21             layout: Some(&pipeline_layout),
22             module: shader,
23             compilation_options: Default::default(),
24             cache: None,
25             label: Some(label),
26         });
27
28         Self { pipeline }
29     }
30     pub fn compute<'a>(
31         &'a self,
32         encoder: &'a mut wgpu::CommandEncoder,
33         label: &str,
34         bind_groups: &[&wgpu::BindGroup],
35         x: u32,
36         y: u32,
37     ) {
38         let mut pass = encoder.begin_compute_pass(&wgpu::ComputePassDescriptor {
39             timestamp_writes: None,
40             label: Some(label),
41         });
42
43         pass.set_pipeline(&self.pipeline);
44         for (i, bind_group) in bind_groups.iter().enumerate() {
45             pass.set_bind_group(i as _, *bind_group, &[]);
46         }
47         pass.dispatch_workgroups(x, y, 1);
48     }
49 }
50 }
```

3.4.3.5. fft.rs

rust

```
1 use super::SimData;
2 use crate::{cast_slice, engine::{Scene, util::Texture}, WG_SIZE};
3 use shared::FFTData;
4 use std::mem;
5
6 pub struct FourierTransform {
7     h_ifft: PipelineFFT,
8     v_ifft: PipelineFFT,
9     permute: PipelineFFT,
10    pingpong1: Texture,
11 }
12
13 impl FourierTransform {
14     pub fn new(
15         device: &wgpu::Device,
16         shader: &wgpu::ShaderModule,
17         scene: &Scene,
18         simdata: &SimData,
19     ) -> Self {
20         let pingpong1 = Texture::new_storage(
21             scene.consts.sim.size,
22             scene.consts.sim.size,
23             wgpu::TextureFormat::Rgba32Float,
24             device,
25             "PingPong 1",
26         );
27         let bind_group_layouts = &[&simdata.layout, &pingpong1.layout, &pingpong1.layout]; // layout is same for 0 and 1
28         let push_constant_ranges = &[wgpu::PushConstantRange {
29             stages: wgpu::ShaderStages::COMPUTE,
30             range: 0..mem::size_of::<FFTData>() as u32,
31         }];
32
33         let h_ifft = PipelineFFT::new(
34             bind_group_layouts,
35             push_constant_ranges,
36             device,
37             shader,
38             "H-Step IFFT",
39             "sim::fft::hstep_ifft",
40         );
41         let v_ifft = PipelineFFT::new(
42             bind_group_layouts,
43             push_constant_ranges,
44             device,
45             shader,
46             "V-Step IFFT",
47             "sim::fft::vstep_ifft",
48         );
49         let permute = PipelineFFT::new(
50             bind_group_layouts,
51             push_constant_ranges,
52             device,
53             shader,
54             "Permute",
55             "sim::fft::permute",
```

```

56     );
57
58     Self {
59         h_ifft,
60         v_ifft,
61         permute,
62         pingpong1,
63     }
64 }
65
66 pub fn ifft2d<'a>(
67     &'a self,
68     encoder: &'a mut wgpu::CommandEncoder,
69     scene: &Scene,
70     simdata: &SimData,
71     pingpong0: &Texture,
72     index: u32,
73 ) {
74     let bind_groups = &[
75         &simdata.bind_group,
76         &pingpong0.bind_group,
77         &self.pingpong1.bind_group,
78     ];
79     let wg_size = scene.consts.sim.size / WG_SIZE;
80     let mut data = FFTData {
81         stage: 0,
82         pingpong: 0,
83     };
84
85     for stage in 0..scene.consts.sim.size.ilog2() {
86         data.stage = stage;
87         self.h_ifft.compute(
88             encoder,
89             bind_groups,
90             cast_slice(&[data]),
91             &format!("H-Step {}, {}", stage, index),
92             wg_size,
93             wg_size,
94         );
95         data.pingpong = (data.pingpong + 1) % 2;
96     }
97
98     for stage in 0..scene.consts.sim.size.ilog2() {
99         data.stage = stage;
100        self.v_ifft.compute(
101            encoder,
102            bind_groups,
103            cast_slice(&[data]),
104            &format!("V-Step {}, {}", stage, index),
105            wg_size,
106            wg_size,
107        );
108        data.pingpong = (data.pingpong + 1) % 2;
109    }
110
111    self.permute.compute(
112        encoder,
113        bind_groups,

```

```

114     cast_slice(&[data]),
115     &format!("Permute {}", index),
116     wg_size,
117     wg_size,
118   );
119 }
120 }
121
122 // abstraction of the pipeline is just to make code significantly nicer
123 pub struct PipelineFFT {
124   pipeline: wgpu::ComputePipeline,
125 }
126
127 impl PipelineFFT {
128   pub fn new(
129     bind_group_layouts: &[&wgpu::BindGroupLayout],
130     push_constant_ranges: &[wgpu::PushConstantRange],
131     device: &wgpu::Device,
132     shader: &wgpu::ShaderModule,
133     label: &str,
134     entry_point: &str,
135   ) -> Self {
136     let pipeline_layout = device.create_pipeline_layout(&wgpu::PipelineLayoutDescriptor {
137       bind_group_layouts,
138       push_constant_ranges,
139       label: Some(label),
140     });
141     let pipeline = device.create_compute_pipeline(&wgpu::ComputePipelineDescriptor {
142       entry_point: Some(entry_point),
143       layout: Some(&pipeline_layout),
144       module: shader,
145       compilation_options: Default::default(),
146       cache: None,
147       label: Some(label),
148     });
149     Self { pipeline }
150   }
151
152   pub fn compute<'a>(
153     &'a self,
154     encoder: &'a mut wgpu::CommandEncoder,
155     bind_groups: &[&wgpu::BindGroup],
156     push_constants: &[u8],
157     label: &str,
158     x: u32,
159     y: u32,
160   ) {
161     let mut pass = encoder.begin_compute_pass(&wgpu::ComputePassDescriptor {
162       timestamp_writes: None,
163       label: Some(label),
164     });
165
166     pass.set_pipeline(&self.pipeline);
167     for (i, bind_group) in bind_groups.iter().enumerate() {
168       pass.set_bind_group(i as _, *bind_group, &[]);
169     }
170     pass.set_push_constants(0, push_constants);
171     pass.dispatch_workgroups(x, y, 1);

```

```
172      }
173 }
174
```

3.4.4. shaders

3.4.4.1. lib.rs

rust

```
1 #![no_std]
2 pub mod sim;
3 pub mod ui;
4 pub mod skybox;
5
6 use core::f32::consts;
7 use core::ops::{Add, Mul};
8
9 use spirv_std::glam::{Vec4, Vec3, UVec2, Vec2};
10 use spirv_std::image::Image2d;
11 use spirv_std::Sampler;
12 use spirv_std::{spirv, image::Image};
13 use spirv_std::num_traits::Float;
14 use shared::Constants;
15
16 type StorageImage = Image!(2D, format = rgba32f, sampled = false);
17
18 #[spirv(vertex)]
19 pub fn main_vs(
20     pos: Vec4,
21     uv: UVec2,
22     #[spirv(instance_index)] instance_index: u32,
23     #[spirv(uniform, descriptor_set = 0, binding = 0)] consts: &Constants,
24     #[spirv(descriptor_set = 3, binding = 3)] displacement_map0: &StorageImage,
25     #[spirv(descriptor_set = 3, binding = 4)] normal_map0: &StorageImage,
26     #[spirv(descriptor_set = 3, binding = 5)] foam_map0: &StorageImage,
27     #[spirv(descriptor_set = 4, binding = 3)] displacement_map1: &StorageImage,
28     #[spirv(descriptor_set = 4, binding = 4)] normal_map1: &StorageImage,
29     #[spirv(descriptor_set = 4, binding = 5)] foam_map1: &StorageImage,
30     #[spirv(descriptor_set = 5, binding = 3)] displacement_map2: &StorageImage,
31     #[spirv(descriptor_set = 5, binding = 4)] normal_map2: &StorageImage,
32     #[spirv(descriptor_set = 5, binding = 5)] foam_map2: &StorageImage,
33     #[spirv(position)] out_pos: &mut Vec4, out_normal: &mut Vec3,
34     out_foam: &mut Vec3,
35     out_world_pos: &mut Vec4,
36 ) {
37     let mut displacement = displacement_map0.read(uv) * consts.sim.lengthscale0_sf;
38     displacement += displacement_map1.read(uv) * consts.sim.lengthscale1_sf;
39     displacement += displacement_map2.read(uv) * consts.sim.lengthscale2_sf;
40     let mut normal = normal_map0.read(uv) * consts.sim.lengthscale0_sf;
41     normal += normal_map1.read(uv) * consts.sim.lengthscale1_sf;
42     normal += normal_map2.read(uv) * consts.sim.lengthscale2_sf;
43     normal.y = 1.0;
44     let mut foam = foam_map0.read(uv) * consts.sim.lengthscale0_sf;
45     foam += foam_map1.read(uv) * consts.sim.lengthscale1_sf;
46     foam += foam_map2.read(uv) * consts.sim.lengthscale2_sf;
47
48     let width = consts.sim.size as f32 * consts.sim.mesh_step;
49     let x = instance_index % consts.sim.instances;
50     let z = instance_index / consts.sim.instances;
51     let tiling_offset = Vec4::new(x as f32 * width, 0.0, z as f32 * width, 0.0) *
52         consts.sim.instance_micro_offset;
53     let positive_offset = Vec4::new(width * 0.5, 0.0, width * 0.5, 0.0) * (consts.sim.instances as
54         f32 - 1.0);
```

```

53
54     let centring_offset = Vec4::new(0.5 * width, consts.sim.height_offset, 0.5 * width, 0.0);
55
56     let mut resultant_pos = pos + displacement - centring_offset + tiling_offset -
57         positive_offset;
58     resultant_pos.w = 1.0;
59     *out_pos = consts.camera_viewproj * resultant_pos;
60     *out_normal = normal.truncate();
61     *out_foam = foam.truncate();
62     *out_world_pos = resultant_pos;
63 }
64 #[inline(never)]
65 #[spirv(fragment)]
66 pub fn main_fs(
67     normal: Vec3,
68     foam: Vec3,
69     world_pos: Vec4,
70     #[spirv(uniform, descriptor_set = 0, binding = 0)] consts: &Constants,
71     #[spirv(descriptor_set = 1, binding = 0)] sampler: &Sampler,
72     #[spirv(descriptor_set = 2, binding = 0)] hdri: &Image2d,
73     output: &mut Vec4,
74 ) {
75     let pos = world_pos.truncate();
76     let n = normal.normalize();
77     let l = (consts.shader.light.truncate() - pos).normalize();
78     let v = (consts.eye.truncate() - pos).normalize();
79     let h = (l + v).normalize();
80
81     let dist = (consts.eye - world_pos).length();
82     let max_dist = (consts.eye - 0.5 * consts.sim.size as f32 * consts.sim.mesh_step *
83         consts.sim.instances as f32).length();
84     let t = ((dist - consts.shader.fog_offset) / (max_dist - consts.shader.fog_offset)).clamp(0.0,
85         1.0);
86     let fog = t.powf(consts.shader.fog_falloff) * consts.shader.fog_density;
87
88     let foam = foam.x.max(0.0).min(1.0);
89
90     let roughness = consts.shader.roughness + foam * consts.shader.foam_roughness;
91
92     let fresnel = fresnel(n, v, &consts) * consts.shader.fresnel_sf;
93     let l_scatter = subsurface_scattering(l, v, n, pos.y, roughness, consts);
94     let l_env_reflected = hdri.sample(*sampler, equirectangular_to_uv(reflect(n, v))).truncate() *
95         consts.shader.reflection_sf;
96     let l_specular = match consts.shader.pbr {
97         1 => pbr_specular(l, h, n, v, consts, roughness) * consts.shader.pbr_sf,
98         _ => blinn_phong(n, h, consts) * fresnel,
99     };
100    let l_eye = lerp(
101        (1.0 - fresnel) * l_scatter + l_specular + fresnel * l_env_reflected,
102        consts.shader.foam_color.truncate(),
103        foam,
104    );
105    let l_eye = lerp(
106        l_eye,
107        consts.shader.fog_color.truncate(),
108        fog,
109    );

```

```

107
108     *output = reinhard_tonemap(l_eye).extend(1.0);
109 }
110
111 fn fresnel(n: Vec3, v: Vec3, consts: &Constants) -> f32 {
112     let fresnel_n = Vec3::new(n.x * consts.shader.fresnel_normal_sf, n.y, n.z *
113         consts.shader.fresnel_normal_sf); let f0 = ((consts.shader.air_ri - consts.shader.water_ri) /
114             (consts.shader.air_ri + consts.shader.water_ri)).powf(2.0);
115     f0 + (1.0 - f0) * (1.0 - fresnel_n.dot(v)).powf(consts.shader.fresnel_shine)
116 }
117
118 fn subsurface_scattering(l: Vec3, v: Vec3, n: Vec3, height: f32, roughness: f32, consts: &Constants) -> Vec3 {
119     let height_factor = consts.shader.ss_height * height.max(0.0) * l.dot(-v).max(0.0).powf(4.0) *
120         (0.5 - 0.5 * l.dot(n)).powf(3.0);
121     let reflection_factor = consts.shader.ss_reflected * v.dot(n).max(0.0).powf(2.0);
122     let lambert_factor = consts.shader.ss_lambert * l.dot(n).max(0.0) *
123         consts.shader.scatter_color.truncate() * consts.shader.sun_color.truncate();
124     let ambient_factor = consts.shader.ss_ambient * consts.shader.bubble_density *
125         consts.shader.bubble_color.truncate() * consts.shader.sun_color.truncate();
126
127     ((height_factor + reflection_factor) * consts.shader.scatter_color.truncate() *
128         consts.shader.sun_color.truncate()) / (1.0 + lambda_ggx(roughness))
129     + lambert_factor + ambient_factor
130 }
131
132 fn pbr_specular(l: Vec3, h: Vec3, n: Vec3, v: Vec3, consts: &Constants, roughness: f32) -> Vec3 {
133     consts.shader.sun_color.truncate() * microfacet_brdf(l, h, n, v, consts, roughness)
134 }
135
136 fn microfacet_brdf(l: Vec3, h: Vec3, n: Vec3, v: Vec3, consts: &Constants, roughness: f32) -> f32 {
137     let f = fresnel(h, v, consts) * consts.shader.fresnel_pbr_sf;
138     let g = smith_g2(h, l, v, roughness);
139     let d = ggx(n, h, roughness);
140     let div = (4.0 * n.dot(l) * n.dot(v)).max(consts.shader.pbr_cutoff);
141     f * g * d / div
142 }
143
144 fn ggx(n: Vec3, h: Vec3, roughness: f32) -> f32 {
145     let nh = n.dot(h).max(0.0001).min(0.9999);
146     roughness * roughness / (consts::PI *
147         ((roughness * roughness - 1.0) * nh.powf(2.0) + 1.0).powf(2.0))
148 }
149
150 fn smith_g2(h: Vec3, l: Vec3, v: Vec3, roughness: f32) -> f32 {
151     1.0 / (1.0 + smith_g1(h, l, roughness) + smith_g1(h, v, roughness))
152 }
153
154 fn smith_g1(h: Vec3, s: Vec3, roughness: f32) -> f32 {
155     let alpha = roughness * roughness;
156     let hs = h.dot(s);
157     let a = hs / (alpha * (1.0 - hs * hs).sqrt());
158     1.0 / (1.0 + lambda_ggx(a))
159 }
160
161 fn lambda_ggx(a: f32) -> f32 {
162     ((1.0 + 1.0 / (a * a)).sqrt() - 1.0) * 0.5

```

```

159 }
160
161 fn lerp<T: Add<Output = T> + Mul<f32, Output = T>>(a: T, b: T, t: f32) -> T {
162     a * (1.0 - t) + b * t
163 }
164
165 fn blinn_phong(n: Vec3, h: Vec3, consts: &Constants) -> Vec3 {
166     n.dot(h).max(0.0).powf(consts.shader.shininess) * consts.shader.sun_color.truncate()
167 }
168
169 fn reflect(n: Vec3, v: Vec3) -> Vec3 {
170     2.0 * (n * n.dot(v)) - v
171 }
172
173 fn equirectangular_to_uv(v: Vec3) -> Vec2 {
174     Vec2::new(
175         (v.z.atan2(v.x) + consts::PI) / consts::TAU,
176         v.y.acos() / consts::PI,
177     )
178 }
179
180 fn reinhard_tonemap(c: Vec3) -> Vec3 {
181     c / (c + Vec3::splat(1.0))
182 }
183

```

3.4.4.2. skybox.rs

rust

```
1 use spirv_std::glam::{Vec4, Vec2, Vec3};
2 use spirv_std::{spirv,image::Image2d, Sampler};
3 use spirv_std::num_traits::Float;
4 use shared::Constants;
5 use crate::{equirectangular_to_uv, reinhard_tonemap, lerp};
6
7 #[inline(never)]
8 #[spirv(vertex)]
9 pub fn skybox_vs(
10     #[spirv(vertex_index)] vertex_index: u32,
11     #[spirv(position)] out_pos: &mut Vec4,
12 ) {
13     let out_uvl = Vec2::new(
14         ((vertex_index << 1) & 2) as f32,
15         (vertex_index & 2) as f32,
16     );
17     *out_pos = Vec4::new(out_uvl.x * 2.0 - 1.0,out_uvl.y * 2.0 - 1.0, 0.0, 1.0);
18 }
19
20 #[inline(never)]
21 #[spirv(fragment)]
22 pub fn skybox_fs(
23     #[spirv(frag_coord)] frag_coord: Vec4, // Get screen-space fragment coordinates
24     #[spirv(uniform, descriptor_set = 0, binding = 0)] consts: &Constants,
25     #[spirv(descriptor_set = 1, binding = 0)] hdri: &Image2d,
26     #[spirv(descriptor_set = 2, binding = 0)] sampler: &Sampler,
27     out_color: &mut Vec4,
28 ) {
29     let proj_inverse = consts.shader.proj_mat.inverse();
30     let view_inverse = consts.shader.view_mat.inverse();
31
32     let uv = Vec2::new(
33         frag_coord.x / consts.width * 2.0 - 1.0,
34         1.0 - frag_coord.y / consts.height * 2.0,
35     );
36
37     let target = proj_inverse * Vec4::new(uv.x, uv.y, 1.0, 1.0);
38     let view_pos = (target.truncate() / target.w).extend(1.0);
39     let world_pos = view_inverse * view_pos;
40     let ray_dir = world_pos.truncate().normalize();
41
42     let h = (ray_dir.y / consts.eye.normalize().y).clamp(0.0, 1.0);
43     let fog = (-h * consts.shader.fog_density - consts.shader.fog_height).exp();
44
45     let sky_col = reinhard_tonemap(hdri.sample(
46         *sampler,
47         equirectangular_to_uv(ray_dir),
48     ).truncate()).extend(1.0);
49
50     let sky_col = sky_col + dist_to_sun(ray_dir, &consts) *
51         consts.shader.sun_color.truncate().extend(1.0);
52     *out_color = lerp(
53         sky_col,
54         consts.shader.fog_color,
55         fog,
56     );
57 }
```

```
56 }
57
58 fn dist_to_sun(ray: Vec3, consts: &Constants) -> f32 {
59     let dot = ray.dot(consts.shader.light.truncate().normalize());
60     let cos = consts.shader.sun_size.cos();
61     (dot - cos).max(0.0) * consts.shader.sun_falloff
62 }
63
```

3.4.4.3. ui.rs

rust

```
1 use spirv_std::glam::{Vec4, Vec2};
2 use spirv_std::spirv,image::Image2d, Sampler;
3 use shared::Constants;
4
5 #[spirv(vertex)]
6 pub fn ui_vs(
7     pos: Vec2,
8     uv: Vec2,
9     col: Vec4,
10    #[spirv(uniform, descriptor_set = 0, binding = 0)] consts: &Constants,
11    #[spirv(position)] out_pos: &mut Vec4,
12    out_uv: &mut Vec2,
13    out_col: &mut Vec4,
14 ) {
15     *out_pos = Vec4::new(
16         2.0 * pos.x / consts.width - 1.0,
17         1.0 - 2.0 * pos.y / consts.height,
18         0.0,
19         1.0,
20     );
21     *out_uv = uv;
22     *out_col = col;
23 }
24
25 #[spirv(fragment)]
26 pub fn ui_fs(
27     uv: Vec2,
28     col: Vec4,
29     #[spirv(descriptor_set = 1, binding = 0)] tex: &Image2d,
30     #[spirv(descriptor_set = 2, binding = 0)] sampler: &Sampler,
31     out_col: &mut Vec4,
32
33 ) {
34     *out_col = tex.sample(*sampler, uv) * col.powf(1.2);
35 }
```

3.4.4.4. sim/mod.rs

rust

```
1 pub mod initial_spectra;  
2 pub mod evolve_spectra;  
3 pub mod fft;  
4 pub mod process_deltas;  
5
```

3.4.4.4.1. evolve_spectra.rs

rust

```
1 use spirv_std::{
2     spirv,
3     num_traits::Float,
4 };
5 use spirv_std::glam::{UVec3, Vec3Swizzles, Vec2, Vec4, Vec4Swizzles};
6 use shared::Constants;
7 use crate::StorageImage;
8
9 #[spirv(compute(threads(8,8)))]
10 pub fn main(
11     #[spirv(global_invocation_id)] id: UVec3,
12     #[spirv(uniform, descriptor_set = 0, binding = 0)] consts: &Constants,
13     #[spirv(descriptor_set = 1, binding = 0)] wave_tex: &StorageImage,
14     #[spirv(descriptor_set = 1, binding = 1)] initial_spectrum_tex: &StorageImage,
15     #[spirv(descriptor_set = 2, binding = 0)] h_displacement: &StorageImage,
16     #[spirv(descriptor_set = 3, binding = 0)] v_displacement: &StorageImage,
17     #[spirv(descriptor_set = 4, binding = 0)] h_slope: &StorageImage,
18     #[spirv(descriptor_set = 5, binding = 0)] jacobian: &StorageImage,
19 ) {
20     // Evolving spectra
21     let wave = wave_tex.read(id.xy());
22     let spectrum = initial_spectrum_tex.read(id.xy());
23     let h0 = spectrum.xy();
24     let h0c = spectrum.zw();
25     let phase = wave.w * consts.time;
26     let exponent = euler(phase);
27     let negative_exponent = Vec2::new(exponent.x, -exponent.y);
28
29     // Precalculating Amplitudes
30     let h = complex_mult(h0, exponent) + complex_mult(h0c, negative_exponent);
31     let ih = Vec2::new(-h.y, h.x);
32
33     // Displacement in x,y,z
34     let dx = -ih * wave.x * wave.z;
35     let dy = h;
36     let dz = -ih * wave.y * wave.z;
37
38     // normal
39     let nx = ih * wave.x;
40     let nz = ih * wave.y;
41
42     // jacobian
43     let j_xx = -h * wave.x * wave.x * wave.z;
44     let j_zz = -h * wave.y * wave.y * wave.z;
45     let j_xz = -h * wave.x * wave.y * wave.z;
46
47     unsafe {
48         h_displacement.write(id.xy(), Vec4::new(dx.x, dx.y, dz.x, dz.y));
49         v_displacement.write(id.xy(), Vec4::new(dy.x, dy.y, j_xz.x, j_xz.y));
50         h_slope.write(id.xy(), Vec4::new(nx.x, nx.y, nz.x, nz.y));
51         jacobian.write(id.xy(), Vec4::new(j_xx.x, j_xx.y, j_zz.x, j_zz.y));
52     }
53 }
54
55 pub fn complex_mult(a: Vec2, b: Vec2) -> Vec2 {
56     Vec2::new(a.x * b.x - a.y * b.y, a.x * b.y + a.y * b.x)
```

```
57 }
58
59 pub fn euler(exp: f32) -> Vec2 {
60     Vec2::new(exp.cos(), exp.sin())
61 }
62
63 pub fn complex_exp(a: Vec2) -> Vec2 {
64     Vec2::new(a.y.cos(), a.y.sin()) * a.x.exp()
65 }
66
```

3.4.4.2. fft.rs

rust

```
1 use spirv_std::{
2     spirv,
3     num_traits::Float,
4 };
5 use core::f32::consts;
6 use crate::{sim::evolve_spectra::complex_mult, StorageImage};
7 use shared::{Constants, FFTData};
8 use spirv_std::glam::{UVec3, UVec2, Vec3Swizzles, Vec2, Vec4, Vec4Swizzles};
9
10 #[spirv(compute(threads(8,8)))]
11 pub fn hstep_ifft(
12     #[spirv(global_invocation_id)] id: UVec3,
13     #[spirv(push_constant)] data: &FFTData,
14     #[spirv(descriptor_set = 0, binding = 1)] butterfly_tex: &StorageImage,
15     #[spirv(descriptor_set = 1, binding = 0)] pingpong0: &StorageImage,
16     #[spirv(descriptor_set = 2, binding = 0)] pingpong1: &StorageImage,
17 ) {
18     let butterfly_data: Vec4 = butterfly_tex.read(UVec2::new(data.stage, id.x));
19     let twiddle: Vec2 = butterfly_data.xy();
20     let indices: UVec2 = UVec2::new(butterfly_data.z as u32, butterfly_data.w as u32);
21
22     if data.pingpong == 0 {
23         let top_signal0 = pingpong0.read(UVec2::new(indices.x, id.y)).xy();
24         let top_signal1 = pingpong0.read(UVec2::new(indices.x, id.y)).zw();
25         let bottom_signal0 = pingpong0.read(UVec2::new(indices.y, id.y)).xy();
26         let bottom_signal1 = pingpong0.read(UVec2::new(indices.y, id.y)).zw();
27
28         let h0 = top_signal0 + complex_mult(twiddle, bottom_signal0);
29         let h1 = top_signal1 + complex_mult(twiddle, bottom_signal1);
30
31         unsafe {
32             pingpong1.write(id.xy(), Vec4::new(h0.x, h0.y, h1.x, h1.y));
33         }
34     } else if data.pingpong == 1 {
35         let top_signal0 = pingpong1.read(UVec2::new(indices.x, id.y)).xy();
36         let top_signal1 = pingpong1.read(UVec2::new(indices.x, id.y)).zw();
37         let bottom_signal0 = pingpong1.read(UVec2::new(indices.y, id.y)).xy();
38         let bottom_signal1 = pingpong1.read(UVec2::new(indices.y, id.y)).zw();
39
40         let h0 = top_signal0 + complex_mult(twiddle, bottom_signal0);
41         let h1 = top_signal1 + complex_mult(twiddle, bottom_signal1);
42
43         unsafe {
44             pingpong0.write(id.xy(), Vec4::new(h0.x, h0.y, h1.x, h1.y));
45         }
46     }
47 }
48
49 #[spirv(compute(threads(8,8)))]
50 pub fn vstep_ifft(
51     #[spirv(global_invocation_id)] id: UVec3,
52     #[spirv(push_constant)] data: &FFTData,
53     #[spirv(descriptor_set = 0, binding = 1)] butterfly_tex: &StorageImage,
54     #[spirv(descriptor_set = 1, binding = 0)] pingpong0: &StorageImage,
55     #[spirv(descriptor_set = 2, binding = 0)] pingpong1: &StorageImage,
```

```

57 ) {
58     let butterfly_data: Vec4 = butterfly_tex.read(UVec2::new(data.stage, id.y));
59     let twiddle: Vec2 = butterfly_data.xy();
60     let indices: UVec2 = UVec2::new(butterfly_data.z as u32, butterfly_data.w as u32);
61
62     if data.pingpong == 0 {
63         let top_signal0 = pingpong0.read(UVec2::new(id.x, indices.x)).xy();
64         let top_signal1 = pingpong0.read(UVec2::new(id.x, indices.x)).zw();
65         let bottom_signal0 = pingpong0.read(UVec2::new(id.x, indices.y)).xy();
66         let bottom_signal1 = pingpong0.read(UVec2::new(id.x, indices.y)).zw();
67
68         let h0 = top_signal0 + complex_mult(twiddle, bottom_signal0);
69         let h1 = top_signal1 + complex_mult(twiddle, bottom_signal1);
70
71         unsafe {
72             pingpong1.write(id.xy(), Vec4::new(h0.x, h0.y, h1.x, h1.y));
73         }
74     } else if data.pingpong == 1 {
75         let top_signal0 = pingpong1.read(UVec2::new(id.x, indices.x)).xy();
76         let top_signal1 = pingpong1.read(UVec2::new(id.x, indices.x)).zw();
77         let bottom_signal0 = pingpong1.read(UVec2::new(id.x, indices.y)).xy();
78         let bottom_signal1 = pingpong1.read(UVec2::new(id.x, indices.y)).zw();
79
80         let h0 = top_signal0 + complex_mult(twiddle, bottom_signal0);
81         let h1 = top_signal1 + complex_mult(twiddle, bottom_signal1);
82
83         unsafe {
84             pingpong0.write(id.xy(), Vec4::new(h0.x, h0.y, h1.x, h1.y));
85         }
86     }
87 }
88
89 #[spirv(compute(threads(8,8)))]
90 pub fn permute(
91     #[spirv(global_invocation_id)] id: UVec3,
92     #[spirv(descriptor_set = 1, binding = 0)] pingpong0: &StorageImage,
93 ) {
94     let sign = match ((id.x + id.y) % 2) as f32 {
95         0.0 => 1.0,
96         _ => -1.0,
97     };
98
99     let h0 = sign * pingpong0.read(id.xy()).x;
100    let h1 = sign * pingpong0.read(id.xy()).z;
101    unsafe {
102        pingpong0.write(id.xy(), Vec4::new(h0, h1, 0.0, 1.0));
103    }
104 }
105
106 #[spirv(compute(threads(1,8)))]
107 pub fn precompute_butterfly(
108     #[spirv(global_invocation_id)] id: UVec3,
109     #[spirv(uniform, descriptor_set = 0, binding = 0)] consts: &Constants,
110     #[spirv(descriptor_set = 1, binding = 1)] butterfly_tex: &StorageImage,
111 ) {
112     let k = (id.y as f32 * consts.sim.size as f32 / 2.0_f32.powf(id.x as f32 + 1.0)) %
113         consts.sim.size as f32;
114     let exp = -2.0 * consts::PI * k / consts.sim.size as f32;

```

```

114 let twiddle = Vec2::new(exp.cos(), exp.sin());
115
116 let step = 2.0_f32.powf(id.x as f32);
117 let wing = id.y as f32 % 2.0_f32.powf(id.x as f32 + 1.0) < step;
118
119 let mut yt: u32 = id.y;
120 let mut yb: u32 = id.y;
121
122 if id.x == 0 {
123     if wing {
124         yb += 1;
125     } else {
126         yt -= 1;
127     }
128     yt = bit_reverse(yt, consts.sim.logsize);
129     yb = bit_reverse(yb, consts.sim.logsize);
130 } else {
131     if wing {
132         yb += step as u32;
133     } else {
134         yt -= step as u32;
135     }
136 }
137
138 unsafe {
139     butterfly_tex.write(id.xy(), Vec4::new(twiddle.x, twiddle.y, yt as f32, yb as f32));
140 }
141 }
142
143 // algorithm from https://stackoverflow.com/questions/746171/efficient-algorithm-for-bit-reversal-from-msb-lsb-to-lsb-msb-in-c
144 fn bit_reverse(mut x: u32, size: u32) -> u32 {
145     let mut n: u32 = 0;
146     let mask: u32 = 0x1;
147     for _ in 0..size {
148         n <= 1;
149         n |= x & mask;
150         x >= 1;
151     }
152     n
153 }
154

```

3.4.4.4.3. initial_spectra.rs

rust

```
1 use spirv_std::{
2     spirv,
3     num_traits::Float,
4 };
5 use crate::StorageImage;
6 use core::f32::consts::{self, PI};
7 use spirv_std::glam::{UVec3, UVec2, Vec3Swizzles, Vec2, Vec4, Vec4Swizzles};
8 use shared::{Constants, SimConstants};
9
10 #[spirv(compute(threads(8,8)))]
11 pub fn main(
12     #[spirv(global_invocation_id)] id: UVec3,
13     #[spirv(push_constant)] cascade: &u32,
14     #[spirv(uniform, descriptor_set = 0, binding = 0)] consts: &Constants,
15     #[spirv(descriptor_set = 1, binding = 0)] gaussian_tex: &StorageImage,
16     #[spirv(descriptor_set = 2, binding = 0)] wave_tex: &StorageImage,
17     #[spirv(descriptor_set = 2, binding = 1)] spectrum_tex: &StorageImage
18 ) {
19     let lengthscale = match cascade {
20         0 => consts.sim.lengthscale0,
21         1 => consts.sim.lengthscale1,
22         _ => consts.sim.lengthscale2,
23     } as f32;
24     let cutoff_high = match cascade {
25         0 => consts.sim.cutoff_high0,
26         1 => consts.sim.cutoff_high1,
27         _ => consts.sim.cutoff_high2,
28     };
29     let cutoff_low = match cascade {
30         0 => consts.sim.cutoff_low0,
31         1 => consts.sim.cutoff_low1,
32         _ => consts.sim.cutoff_low2,
33     };
34
35     let dk: f32 = 2.0 * consts::PI / lengthscale;
36     let n = id.x as f32 - 0.5 * consts.sim.size as f32;
37     let m = id.y as f32 - 0.5 * consts.sim.size as f32;
38     let k: Vec2 = Vec2::new(n, m) * dk;
39     let k_length = k.length();
40
41     if k_length <= cutoff_high && k_length >= cutoff_low {
42         let theta = angle(k, consts.sim.wind_offset);
43         let omega = dispersion_relation(k_length, &consts.sim);
44         let domega_dk = dispersion_derivative(k_length, &consts.sim); //Derivative
45         let omega_peak = 22.0 * ((consts.sim.gravity * consts.sim.gravity) /
46             (consts.sim.wind_speed * consts.sim.fetch)).powf(1.0 / 3.0);
47         let jonswap = jonswap(omega, omega_peak, &consts.sim);
48         let depth_attenuation = depth_attenuation(omega, &consts.sim);
49         let tma = jonswap * depth_attenuation;
50         let spread = final_spread(omega, omega_peak, theta, &consts);
51         let spectrum = 2.0 * tma * spread * domega_dk.abs() * dk * dk / k_length;
52         let h0 = 1.0 / 2.0_f32.sqrt() * gaussian_tex.read(id.xy()).xy() * spectrum.sqrt();
53
54         unsafe {
55             wave_tex.write(id.xy(), Vec4::new(k.x, k.y, 1.0 / k_length, omega));
56             spectrum_tex.write(id.xy(), Vec4::new(h0.x, h0.y, 0.0, 1.0));
57         }
58     }
59 }
```

```

56         }
57     } else {
58         unsafe {
59             wave_tex.write(id.xy(), Vec4::new(k.x, k.y, 0.0, 1.0));
60             spectrum_tex.write(id.xy(), Vec4::ZERO);
61         }
62     }
63 }
64
65 fn dispersion_relation(k: f32, consts: &SimConstants) -> f32 {
66     (consts.gravity * k * (k * consts.depth).min(20.0).tanh()).sqrt()
67 }
68
69 fn dispersion_derivative(k: f32, consts: &SimConstants) -> f32 {
70     let tanh = (consts.depth * k).min(20.0).tanh();
71     let sech = 1.0 / (consts.depth * k).cosh();
72     (consts.gravity * (tanh + consts.depth * k * sech * sech)) / (2.0 * (consts.gravity * k *
73         tanh).sqrt())
74 }
75 // from biebras TODO: credit
76 fn angle(k: Vec2, offset: f32) -> f32 {
77     let mut angle: f32 = (k.y).atan2(k.x) - offset;
78     angle = fmod(angle + PI, 2.0 * PI);
79     if angle < 0.0 {
80         angle += 2.0 * PI;
81     }
82     angle - PI
83 }
84 fn fmod(a: f32, b: f32) -> f32 {
85     a - b * (a / b).floor()
86 }
87
88 fn jonsswap(omega: f32, omega_p: f32, consts: &SimConstants) -> f32 {
89     let sigma: f32;
90     if omega <= omega_p {
91         sigma = 0.07;
92     } else {
93         sigma = 0.09;
94     }
95     let alpha = 0.076 * (
96         (consts.wind_speed * consts.wind_speed)
97         / (consts.fetch * consts.gravity)
98     ).powf(0.22);
99     let r = (
100         -1.0 * (omega - omega_p) * (omega - omega_p)
101         / (2.0 * omega_p * omega_p * sigma * sigma)
102     ).exp();
103     alpha * consts.gravity * consts.gravity /
104     (omega * omega * omega * omega * omega) * (-consts.beta * (omega_p / omega).powf(4.0)).exp() *
105     consts.gamma.powf(r)
106 }
107 fn depth_attenuation(omega: f32, consts: &SimConstants) -> f32 {
108     let omega_h = omega * (consts.depth / consts.gravity).sqrt();
109     if omega_h <= 1.0 {
110         0.5 * omega_h * omega_h
111     } else if omega_h < 2.0 {

```

```

112     1.0 - 0.5 * (2.0 - omega_h) * (2.0 - omega_h)
113 } else {
114     1.0
115 }
116 }
117
118 fn donelan_banner(omega: f32, omega_p: f32, theta: f32) -> f32 {
119     let k = omega / omega_p; // arbitrary shorthand
120     let beta_s: f32;
121     if k < 0.95 {
122         beta_s = 2.61 * k.abs().powf(1.3);
123     } else if k <= 1.6 && k >= 0.95 {
124         beta_s = 2.28 * k.abs().powf(-1.3);
125     } else {
126         beta_s = 10.0_f32.powf(-0.4 + 0.8393 * (-0.567 * (k * k).ln()).exp())
127     }
128     let sech = 1.0 / (beta_s * theta).cosh();
129     beta_s / (2.0 * (beta_s * PI).tanh()) * sech * sech
130 }
131
132 fn directional_spread(omega: f32, omega_p: f32, theta: f32, consts: &Constants) -> f32 {
133     let base = donelan_banner(omega, omega_p, theta);
134     let swell = d_epsilon(omega, omega_p, theta, consts);
135     base * swell
136 }
137
138 fn final_spread(omega: f32, omega_p: f32, theta: f32, consts: &Constants) -> f32 {
139     let spread = directional_spread(omega, omega_p, theta, consts);
140     let integral = integral(omega_p, omega, consts);
141     spread * integral
142 }
143
144 fn integral(omega_p: f32, omega: f32, consts: &Constants) -> f32 {
145     let mut sum = 0.0;
146     let steps = 2.0 * PI / consts.sim.integration_step;
147
148     for i in 0..steps as usize {
149         let angle = i as f32 * consts.sim.integration_step - PI;
150         sum += directional_spread(omega, omega_p, angle, consts) * consts.sim.integration_step;
151     }
152     1.0 / sum
153 }
154
155 fn d_epsilon(omega: f32, omega_p: f32, theta: f32, consts: &Constants) -> f32 {
156     let s = 16.0 * (omega_p / omega).tanh() * consts.sim.swell * consts.sim.swell;
157     normalisation_factor(s) * (theta / 2.0).cos().abs().powf(2.0 * s)
158 }
159
160 fn normalisation_factor(s: f32) -> f32 {
161     let s2 = s * s;
162     let s3 = s2 * s;
163     let s4 = s3 * s;
164
165     if s < 5.0 {
166         -0.000564 * s4 + 0.00776 * s3 - 0.044 * s2 + 0.192 * s + 0.163
167     } else {
168         -4.80e-08 * s4 + 1.07e-05 * s3 - 9.53e-04 * s2 + 5.90e-02 * s + 3.93e-01
169     }

```

```
170 }
171
172 // TODO: explained in biebras -> explain
173 #[spirv(compute(threads(8,8)))]
174 pub fn pack_conjugates(
175     #[spirv(global_invocation_id)] id: UVec3,
176     #[spirv(uniform, descriptor_set = 0, binding = 0)] consts: &Constants,
177     #[spirv(descriptor_set = 2, binding = 1)] spectrum_tex: &StorageImage,
178 ) {
179     let h0 = spectrum_tex.read(id.xy());
180     let h0c = spectrum_tex.read(UVec2::new(
181         (consts.sim.size - id.x) % consts.sim.size,
182         (consts.sim.size - id.y) % consts.sim.size
183     ).xy());
184     unsafe {
185         spectrum_tex.write(id.xy(), Vec4::new(h0.x, h0.y, h0c.x, -h0c.y));
186     }
187 }
188
```

3.4.4.4. process_deltas.rs

rust

```
1 use spirv_std::{
2     spirv,
3     num_traits::Float,
4 };
5 use spirv_std::glam::{UVec3, Vec3Swizzles, Vec3, Vec4};
6 use shared::Constants;
7 use crate::StorageImage;
8
9 #[spirv(compute(threads(8,8)))]
10 pub fn main(
11     #[spirv(global_invocation_id)] id: UVec3,
12     #[spirv(uniform, descriptor_set = 0, binding = 0)] consts: &Constants,
13     #[spirv(descriptor_set = 1, binding = 0)] h_displacement: &StorageImage,
14     #[spirv(descriptor_set = 2, binding = 0)] v_displacement: &StorageImage,
15     #[spirv(descriptor_set = 3, binding = 0)] h_slope: &StorageImage,
16     #[spirv(descriptor_set = 4, binding = 0)] jacobian: &StorageImage,
17     #[spirv(descriptor_set = 5, binding = 3)] displacement_map: &StorageImage,
18     #[spirv(descriptor_set = 5, binding = 4)] normal_map: &StorageImage,
19     #[spirv(descriptor_set = 5, binding = 5)] foam_map: &StorageImage,
20 ) {
21     let dy = v_displacement.read(id.xy()).x;
22     let dx = h_displacement.read(id.xy()).x;
23     let dz = h_displacement.read(id.xy()).y;
24     let displacement = Vec4::new(dx * consts.sim.choppiness, dy, dz * consts.sim.choppiness, 1.0);
25
26     let nx = h_slope.read(id.xy()).x;
27     let nz = h_slope.read(id.xy()).y;
28     let normal = Vec3::new(-nx, 1.0, -nz).normalize().extend(1.0);
29
30     let jxx = 1.0_f32 + consts.sim.choppiness * jacobian.read(id.xy()).x;
31     let jzz = 1.0_f32 + consts.sim.choppiness * jacobian.read(id.xy()).y;
32     let jxz = consts.sim.choppiness * v_displacement.read(id.xy()).y;
33
34     let jacobian = consts.sim.foam_bias - (jxx * jzz - jxz * jxz);
35     let mut accumulation = foam_map.read(id.xy()).x * (-consts.sim.foam_decay).exp();
36     if jacobian >= consts.sim.injection_threshold {
37         accumulation += jacobian * consts.sim.injection_amount;
38     }
39     let foam = Vec3::splat(accumulation).extend(1.0);
40
41     unsafe {
42         displacement_map.write(id.xy(), displacement);
43         normal_map.write(id.xy(), normal);
44         foam_map.write(id.xy(), foam);
45     }
46 }
```

3.4.5. build.rs

rust

```
1 use spirv_builder::{MetadataPrintout, SpirvBuilder};  
2  
3 fn main() -> Result<(), Box4     SpirvBuilder::new("shaders", "spirv-unknown-spv1.5")  
5         .capability(spirv_builder::Capability::StorageImageExtendedFormats)  
6         //.capability(spirv_builder::Capability::StoragePushConstant8)  
7         .print_metadata(MetadataPrintout::Full)  
8         .build()?;
9     Ok(())
10 }
11
```

3.4.6. shared/lib.rs

rust

```
1 #![no_std]
2
3 use core::f32;
4 use glam::{Vec4, Mat4};
5
6 #[repr(C)]
7 #[derive(Clone, Copy, PartialEq, Debug)]
8 pub struct Constants {
9         pub time: f32,
10        pub deltatime: f32,
11        pub width: f32,
12        pub height: f32,
13        pub camera_viewproj: Mat4,
14        pub eye: Vec4,
15        pub shader: ShaderConstants,
16        pub sim: SimConstants,
17 }
18
19 #[derive(Clone, Copy, PartialEq, Debug)]
20 pub struct ShaderConstants {
21         pub light: Vec4,
22         pub sun_x: f32,
23         pub sun_y: f32,
24         pub sun_z: f32,
25         pub sun_angle: f32,
26         pub sun_distance: f32,
27         pub foam_color: Vec4,
28         pub water_ri: f32,
29         pub air_ri: f32,
30         pub roughness: f32,
31         pub foam_roughness: f32,
32         pub ss_height: f32,
33         pub ss_reflected: f32,
34         pub ss_lambert: f32,
35         pub ss_ambient: f32,
36         pub bubble_density: f32,
37         pub bubble_color: Vec4,
38         pub scatter_color: Vec4,
39         pub sun_color: Vec4,
40         pub shininess: f32,
41         pub pbr: u32,
42         pub reflection_sf: f32,
43         pub view_mat: Mat4,
44         pub proj_mat: Mat4,
45         pub fresnel_sf: f32,
46         pub fresnel_pbr_sf: f32,
47         pub pbr_sf: f32,
48         pub fresnel_normal_sf: f32,
49         pub fresnel_shine: f32,
50         pub sun_size: f32,
51         pub sun_falloff: f32,
52         pub pbr_cutoff: f32,
53         pub fog_density: f32,
54         pub fog_color: Vec4,
55         pub fog_offset: f32,
56         pub fog_falloff: f32,
```

```

57     pub fog_height: f32,
58 }
59 impl Default for ShaderConstants {
60     fn default() -> Self {
61         Self {
62             light: Vec4::new(0.0,0.0,0.0,1.0),
63             sun_x: 1.0,
64             sun_y: 0.08,
65             sun_z: 0.034,
66             sun_angle: 0.0,
67             sun_distance: 100.0,
68             foam_color: Vec4::new(0.79,0.92,0.96, 1.0),
69             water_ri: 1.33,
70             air_ri: 1.003,
71             roughness: 0.05,
72             foam_roughness: 0.1,
73             ss_height: 0.76,
74             ss_reflected: 1.0,
75             ss_lambert: 1.0,
76             ss_ambient: 0.75,
77             bubble_density: 0.35,
78             bubble_color: Vec4::new(0.0, 0.15, 0.15, 1.0),
79             scatter_color: Vec4::new(0.04, 0.06, 0.14, 1.0),
80             sun_color: Vec4::new(1.0, 0.8, 0.55, 1.0),
81             shininess: 50.0,
82             pbr: 1,
83             reflection_sf: 1.0,
84             view_mat: Mat4::ZERO,
85             proj_mat: Mat4::ZERO,
86             fresnel_sf: 1.0,
87             fresnel_pbr_sf: 1.0,
88             pbr_sf: 1.0,
89             fresnel_normal_sf: 0.60,
90             fresnel_shine: 4.5,
91             sun_size: 0.02,
92             sun_falloff: 5000.0,
93             pbr_cutoff: 0.1,
94             fog_color: Vec4::new(0.9,0.9,0.9,1.0),
95             fog_density: 2.47,
96             fog_offset: 24.5,
97             fog_falloff: 3.54,
98             fog_height: 2.04,
99         }
100     }
101 }
102
103 #[derive(Clone, Copy, PartialEq, Debug)]
104 pub struct SimConstants {
105     pub size: u32,
106     pub lengthscale0: u32,
107     pub cutoff_low0: f32,
108     pub cutoff_high0: f32,
109     pub lengthscale1: u32,
110     pub cutoff_low1: f32,
111     pub cutoff_high1: f32,
112     pub lengthscale2: u32,
113     pub cutoff_low2: f32,
114     pub cutoff_high2: f32,

```

```

115     pub lengthscale0_sf: f32,
116     pub lengthscale1_sf: f32,
117     pub lengthscale2_sf: f32,
118     pub mesh_step: f32,
119     pub standard_deviation: f32,
120     pub mean: f32,
121     pub depth: f32,
122     pub gravity: f32,
123     pub beta: f32,
124     pub gamma: f32,
125     pub wind_speed: f32,
126     pub wind_offset: f32,
127     pub fetch: f32,
128     pub choppiness: f32,
129     pub logsize: u32,
130     pub swell: f32,
131     pub integration_step: f32,
132     pub foam_bias: f32,
133     pub foam_decay: f32,
134     pub injection_threshold: f32,
135     pub injection_amount: f32,
136     pub height_offset: f32,
137     pub instances: u32,
138     pub instance_micro_offset: f32,
139     pub seed: u32,
140 }
141 impl Default for SimConstants {
142     fn default() -> Self {
143         // Defining simulation resolution, cannot be updated at runtime so defined here
144         let size = 256;
145         // Defining seed for gaussian number
146         let seed = 1;
147         Self {
148             depth: 500.0,
149             size,
150             // Calm Ocean
151             //
152             //lengthscale0: 40,
153             //cutoff_low0: 0.00000001,
154             //cutoff_high0: 1.0,
155             //lengthscale0_sf: 1.0,
156             //lengthscale1: 106,
157             //cutoff_low1: 1.0,
158             //cutoff_high1: 2.0,
159             //lengthscale1_sf: 1.0,
160             //lengthscale2: 180,
161             //cutoff_low2: 2.0,
162             //cutoff_high2: 999.0,
163             //lengthscale2_sf: 1.0,
164             //wind_speed: 5.0,
165             //fetch: 4000.0,
166             //choppiness: 0.2,
167             //
168             // Choppy Ocean
169             //
170             lengthscale0: 20,
171             cutoff_low0: 0.00000001,
172             cutoff_high0: 1.0,

```

```

173     lengthscale0_sf: 1.0,
174     lengthscale1: 124,
175     cutoff_low1: 1.0,
176     cutoff_high1: 2.0,
177     lengthscale1_sf: 1.0,
178     lengthscale2: 256,
179     cutoff_low2: 2.0,
180     cutoff_high2: 999.0,
181     lengthscale2_sf: 1.0,
182     wind_speed: 0.5,
183     fetch: 100000.0,
184     choppiness: 0.6,
185
186     mesh_step: 0.4 * 128.0 / size as f32,
187     standard_deviation: 1.0,
188     mean: 0.0,
189     gravity: 9.81,
190     beta: 5.0 / 4.0,
191     gamma: 3.3,
192     wind_offset: f32::consts::FRAC_PI_4,
193     logsize: 0,
194     swell: 0.1,
195     integration_step: 0.01,
196     foam_bias: 0.92,
197     foam_decay: 0.3,
198     injection_threshold: -0.3,
199     injection_amount: 1.0,
200     height_offset: 4.5,
201     instances: 5,
202     instance_micro_offset: 0.99,
203     seed,
204 }
205 }
206 }
207
208 #[derive(Clone, Copy, PartialEq, Debug)]
209 pub struct FFTData {
210     pub stage: u32,
211     pub pingpong: u32,
212 }
213

```

3.4.7. cargo.toml

toml

```
1 [package]
2 name = "nea"
3 version = "0.1.0"
4 edition = "2021"
5
6 # See more keys and their definitions at https://doc.rust-lang.org/cargo/reference/manifest.html
7
8 [dependencies]
9 winit = { version = "0.29", features = ["rwh_05"] }
10 wgpu = { version = "23.0.1", features = ["spirv"] }
11 pollster = "0.3"
12 log = "0.4"
13 glam = { version = "0.29", features = ["mint"] }
14 env_logger = "0.10"
15 image = { version = "0.24", default-features = false, features = ["png", "jpeg", "exr"] }
16 imgui = "0.12.0"
17
18 shared = { path = "./shared" }
19
20 [build-dependencies]
21 spirv-builder = { git="https://github.com/Rust-GPU/rust-gpu", default-features = false, features =
22   ["use-installed-tools"] }
22
23 [profile.dev]
24 opt-level = 1
25
26 [profile.dev.package."*"]
27 opt-level = 3
28
29 [target.x86_64-pc-windows-msvc]
30 linker = "rust-lld.exe"
31 rustflags = ["-Zshare-generics=off"]
32
```

3.4.8. rust-toolchain.toml

toml

```
1 [toolchain]
2 channel = "nightly-2024-11-22"
3 components = ["rust-src", "rustc-dev", "llvm-tools"]
4
```

3.4.9. default.nix

nix

```
1 # from rust-gpu
2
3 let
4   pkgs = import <nixpkgs> {};
5 in with pkgs; stdenv.mkDerivation rec {
6   name = "rust-gpu";
7
8   hardeningDisable = [ "fortify" ];
9
10  SSL_CERT_FILE = "${cacert}/etc/ssl/certs/ca-bundle.crt";
```

```
11
12 nativeBuildInputs = [ rustup ];
13
14 LD_LIBRARY_PATH = with xorg; lib.makeLibraryPath [
15   vulkan-loader
16
17   wayland libxkbcommon
18
19   libX11 libXcursor libXi libXrandr
20 ];
21 }
22
```

4. Testing

4.1. Testing Strategy

The testing will be done primarily with a video, as the ocean is best showcased in movement.

4.2. Testing Table(s)

All testing timestamps can be seen in testing1.mp4. Those that can be seen in testing2.mp4 are marked with (2) in the timestamps. The closing and restarting of the window is me restarting it to reset settings. A lot of parameter tweaking is required for the ocean to look good, adjusting individual parameters without compensating with others generally does not lead to a visually pleasing ocean.

4.2.1. Window Tests

Test Description	Status	Timestamp
Window can be resized without breaking simulation	Pass	0:11
Window can be moved	Pass	0:09
Window can move between monitors without breaking	Pass	0:14
Window can be closed by pressing escape key	Pass	6:24

4.2.2. Mesh Tests

Test Description	Status	Timestamp
User can resize mesh	Pass	2:52

4.2.3. Skybox Tests

Test Description	Status	Timestamp
Skybox transforms correctly with window resize	Pass	0:11
Sun is interpolated into skybox	Pass	0:11
Sun color is user adjustable	Pass	0:29
Sun X direction is user adjustable	Pass	0:33
Sun Y direction is user adjustable	Pass	0:36
Sun Z direction is user adjustable	Pass	0:40
Sun angle is user adjustable	Pass	0:40

Sun distance is user adjustable	Pass	0:43
Sun size is user adjustable	Pass	0:46
Sun falloff factor is user adjustable	Pass	0:49
Sun position is correct relative to light vector	Pass	0:33
Sun transforms correctly with camera view direction changes	Pass	6:13
Sun transforms correctly with camera zoom changes	Pass	(2) 0:44
Sun transforms correctly with window resize	Pass	0:12

4.2.4. Camera Tests

Test Description	Status	Timestamp
Camera view direction unchanged on window resize	Pass	0:11
Camera only controllable when left-click held down	Pass	6:10
Camera pitch controlled by mouse movement	Pass	6:10
Camera yaw controlled by mouse movement	Pass	6:10
Camera zoom controlled by scroll wheel	Pass	(2) 0:44
Camera controllable when UI not selected	Pass	6:10

4.2.5. UI Tests

Test Description	Status	Timestamp
UI displays simulation resolution	Pass	0:18
UI displays time elapsed	Pass	0:18
UI can be collapsed	Pass	0:23
UI allows color editing	Pass	4:24
UI allows slider control	Pass	throughout

4.2.6. Simulation Tests

Test Description	Status	Timestamp
Input parameters clamped to prevent simulation breakage	Pass	throughout
No obvious visible tiling in simulation	Pass	0:11
Simulation has 3 lengthscales with user control	Pass	1:33
User can control all 3 low frequency cutoffs	Pass	1:33
User can control all 3 high frequency cutoffs	Pass	1:33
User can adjust instance quantity	Pass	2:41
User can adjust tile size	Pass	2:52
User can adjust simulation resolution	Pass	0:01
Foam color is user controllable	Pass	(2) 0:03
Foam decay rate is user controllable	Pass	2:16
Foam visibility amount is user controllable	Pass	2:22
Breaking wave foam injection threshold is user controllable	Pass	2:29
Breaking wave foam injection amount is user controllable	Pass	2:33
Ocean depth is user adjustable	Pass	1:01
Gravitational field strength is user adjustable	Pass	1:05
Wind speed is user adjustable	Pass	1:09
Wind angle is user adjustable	Pass	1:16
Fetch is user adjustable	Pass	1:19
Choppiness is user adjustable	Pass	1:24
Swell amount is user adjustable	Pass	1:27
Swell computation integration step is user adjustable	Pass	2:58
Ocean surface height offset is user adjustable	Pass	0:52

4.2.7. Renderer Tests

Test Description	Status	Timestamp
Foam map sampled without visible pixelation	Pass	below image
Subsurface scattering visible and user controllable	Pass	4:15
Scatter color is user adjustable	Pass	4:25
Bubble color is user adjustable	Pass	4:36
Bubble density is user adjustable	Pass	5:10
Height attenuation factor is user adjustable	Pass	4:56
Reflection strength is user adjustable	Pass	5:00
Diffuse lighting strength is user adjustable	Pass	5:03
Ambient lighting strength is user adjustable	Pass	5:06
Environment reflections are visible	Pass	4:15
Reflection strength is user adjustable	Pass	6:01
Fresnel reflectance affects reflections visibly	Pass	4:15
Water refractive index is user adjustable	Pass	3:50
Air refractive index is user adjustable	Pass	3:57
Fresnel shine is user adjustable	Pass	4:01
Fresnel effect scale factor is user adjustable	Pass	4:05
Fresnel normals scale factor is user adjustable	Pass	4:10
Non-PBR specular reflections are visible	Pass	3:07
PBR/non-PBR specular toggle works	Pass	3:07
Surface shininess is user adjustable	Pass	5:55
PBR specular reflections are visible and user controllable	Pass	3:10
Specular scale factor is user adjustable	Pass	3:10

PBR fresnel scale factor is user adjustable	Pass	3:19
PBR cutoff low is user adjustable	Pass	3:23
Water roughness is user adjustable	Pass	3:28
Foam roughness factor is user adjustable	Pass	3:40
Distance fog is visible and user controllable	Pass	5:22
Fog color is user adjustable	Pass	(2) 0:24
Fog density is user adjustable	Pass	5:22
Fog distance offset is user adjustable	Pass	5:27
Fog falloff factor is user adjustable	Pass	5:33
Fog height offset is user adjustable	Pass	5:43

4.2.8. Pixellation

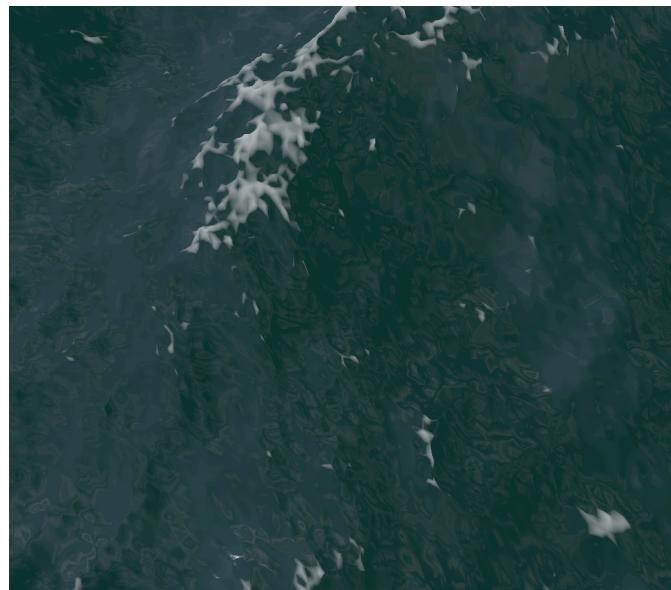


Figure 10: No visible pixellation, at 128x128, zoomed in heavily

5. Evaluation

5.1. Results

A demo video is attached “demo.mp4”, showcasing the scene in Figure 15 with the skybox from Figure 11



Figure 11: Calm Ocean. $L_0 = 40, L_1 = 106, L_2 = 180, U_{10} = 5, F = 4000, \lambda = 0.2, h = 500$



Figure 12: Choppy Ocean. $L_0 = 55, L_1 = 102, L_2 = 256, U_{10} = 36, F = 10000, \lambda = 0.2, h = 500$



Figure 13: Stormy Ocean. $L_0 = 41$, $L_1 = 106$, $L_2 = 180$, $U_{10} = 62$, $F = 10000$, $\lambda = 0.8$, $h = 500$

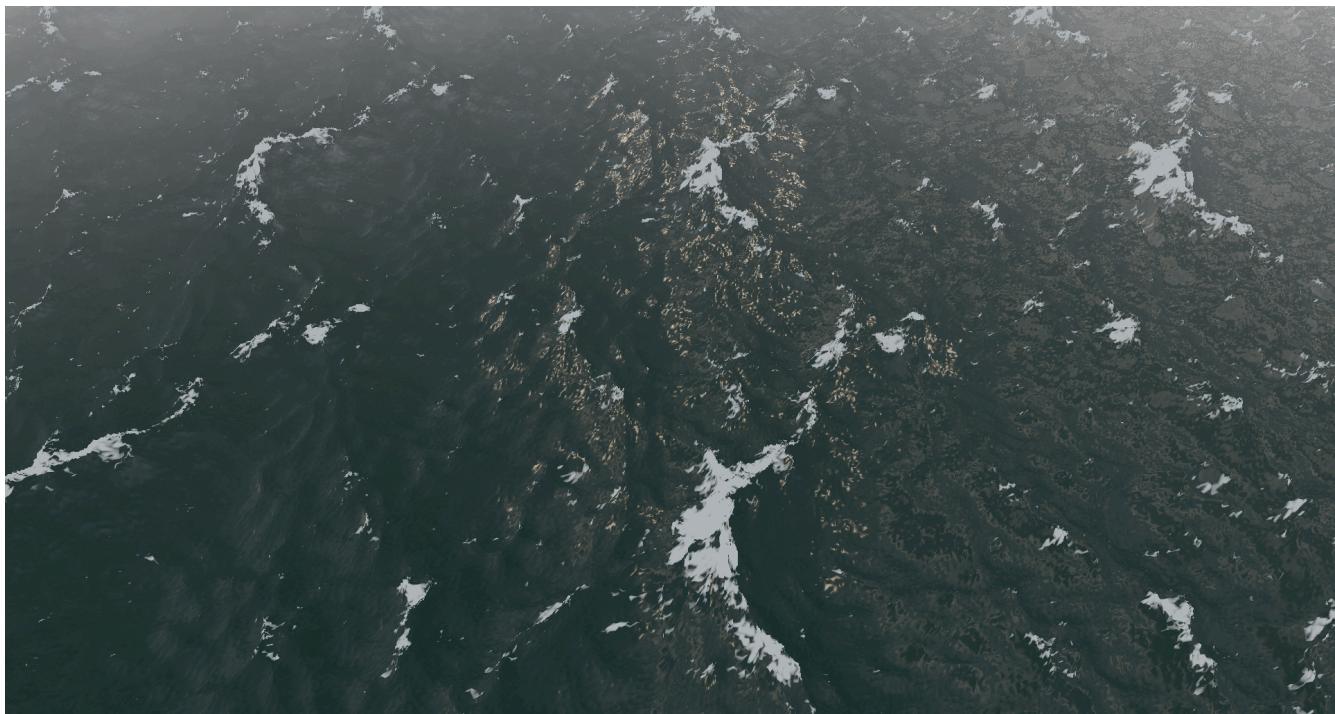


Figure 14: Alternative Angle. $L_0 = 41$, $L_1 = 106$, $L_2 = 180$, $U_{10} = 62$, $F = 10000$, $\lambda = 0.8$, $h = 500$



Figure 15: Early Morning Ocean. $L_0 = 20$, $L_1 = 124$, $L_2 = 256$, $U_{10} = 0.5$, $F = 100000$, $\lambda = 0.1$, $h = 30$

5.2. Evaluation Against Criteria

5.3. Client Feedback

5.4. Evaluation of Feedback

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