Crest Ocean System 4.3 for URP

Wave Harmonic Ltd

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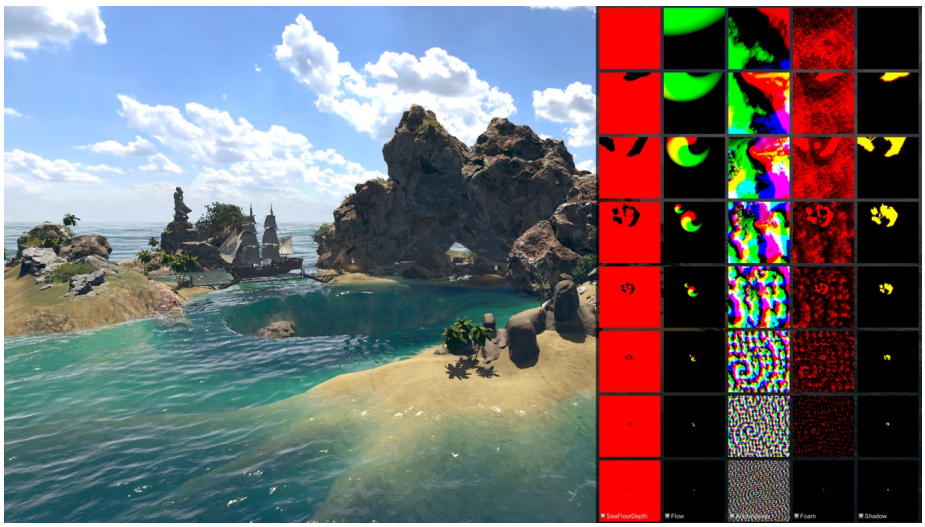


Contents

1 Overview

Crest Ocean System is a technically advanced ocean system for Unity3D. It is architected for performance and makes heavy use of Level of Detail (LOD) strategies and GPU acceleration for fast update and rendering. It is also highly flexible and allows any custom input to the water shape/foam/dynamic waves/etcetera and customizable material appearance.

This documentation covers the version of *Crest* targeted at the Universal Render Pipeline (URP).

2 Initial set up

This section has steps for importing the *Crest* content into a project, and for adding a new ocean surface to a scene.

To augment / complement this written documentation we published a getting started video available here: `https://www.youtube.com/watch?v=TpJf13d_-3E`.

Note When setting up Universal Render Pipeline in Unity, or when making changes to packages, we sometimes find that our projects temporarily appear broken. This may manifest as spurious errors in the log or materials appearing magenta. Often, restarting the Editor fixes it. Clearing out the */Library* folder can also help to reset the project and clear temporary errors. These issues are not specific to *Crest*, but we note them anyway as we find our users regularly encounter them.

2.1 Importing *Crest* files into project

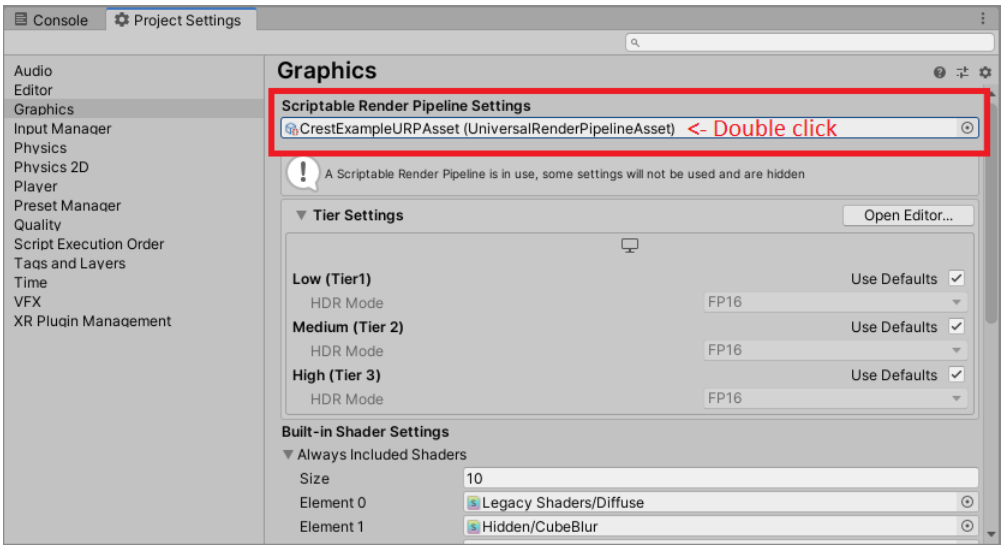
The steps to set up *Crest* in a new or existing project are as follows:

1. Ensure Universal Render Pipeline (URP) is setup and functioning, either by setting up a new project using the URP template or by installing the URP package into an existing project and configuring the Render Pipeline Asset. For more information visit the Unity documentation at `https://docs.unity3d.com/Packages/com.unity.render-pipelines.universal@7.2/manual/InstallingAndConfiguringURP.html`.

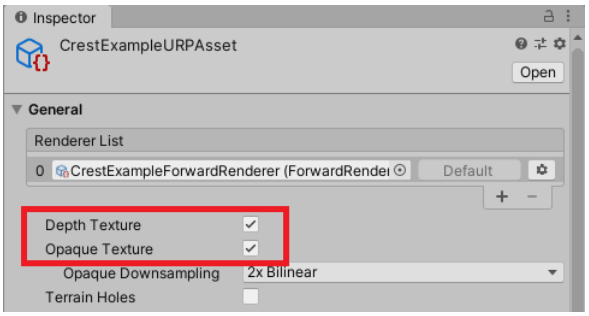
2. Import *Crest* package into project using the *Asset Store* window in the Unity Editor.

   Example content The content in the *Crest-Examples* folder of the package is not required for the core *Crest* functionality, it is provided for demonstration purposes. We recommend that first time users import this content at the beginning.

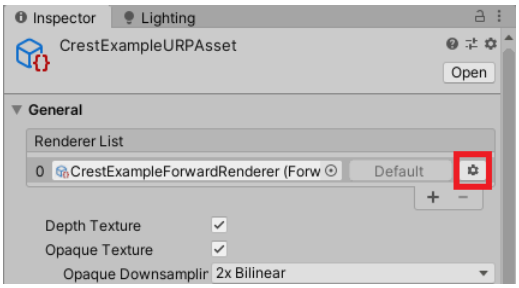
3. **Transparency** To enable the water surface to be transparent, two options must be enabled in the URP configuration. To find the configuration, open *Edit/Project Settings/Graphics* and double click the *Scriptable Render Pipeline Settings* field to open the render pipeline settings. This field will be populated if URP was successfully installed.



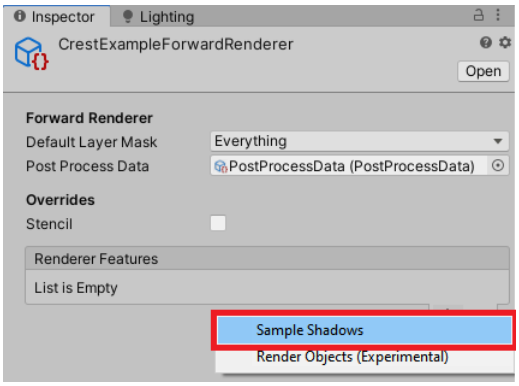
After double clicking the graphics settings should appear in the Inspector. Transparency requires the following two options to be enabled, *Depth Texture* and *Opaque Texture*:



4. **Shadowing** To enable shadowing of the water surface to darken the appearance in shadows, open the *Forward Renderer Data* by clicking the gear icon in the render pipeline settings from the previous step:

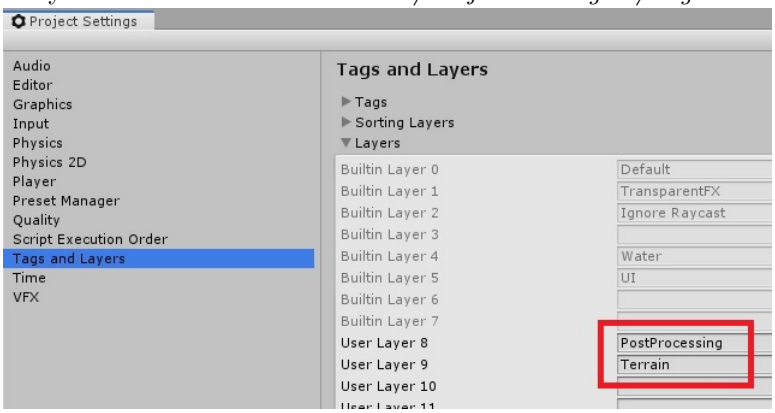


In the *Forward Renderer Data* add the *SampleShadows* render feature using the Add button:



5. Switch to Linear space rendering under *Edit/Project Settings/Player/Other Settings*. If your platform(s) require Gamma space, the material settings will need to be adjusted to compensate.

6. To run the Crest example scenes, add a layer named *PostProcessing* and a layer named *Terrain* under *Edit/Project Settings.../Tags and Layers*.



7. If you opted to import the Crest example content under *Crest-Examples*, you may now open an example scene such as *Assets/Crest/Crest-Examples/PirateCove/PirateCove-Day* and press Play and the ocean will get generated.

2.2 Adding an ocean to a scene

The steps to add an ocean to an existing scene are as follows:

1. Create a new GameObject for the ocean, give it a descriptive name such as *Ocean*.

   (a) Assign the *OceanRenderer* component to it. On startup this component will generate the ocean geometry and do all required initialisation.

   (b) Assign the desired ocean material to the *OceanRenderer* script - this is a material using the *Crest/Ocean* shader.

   (c) Set the Y coordinate of the position to the desired sea level for your world.

2. Tag a primary camera as *MainCamera* using the Inspector if one is not tagged already, or set the *Viewpoint* property on the *OceanRenderer* script. If you need to switch between multiple cameras, update the *Viewpoint* field at run-time to ensure the ocean follows the correct view.

3. To add waves, create a new GameObject and add the *Shape Gerster Batched* component.

   (a) On startup this script creates a default ocean shape. To edit the shape, create an asset of type *Crest/Ocean Wave Spectrum* and provide it to this script.

   (b) Smooth blending of ocean shapes can be achieved by adding multiple *Shape Gerstner Batched* scripts and cross-fading them using the *Weight* parameter.

4. For geometry that should influence the ocean (attenuate waves, generate foam):

   (a) Static geometry should render ocean depth just once on startup into an *Ocean Depth Cache* - the island in the main scene in the example content demonstrates this.

   (b) Dynamic objects that need to render depth every frame should have a *Register Sea Floor Depth Input* component attached.

5. Be sure to generate lighting from the Lighting window - the ocean lighting takes the ambient intensity from the baked spherical harmonics.

2.3 Frequent setup issues

The following are kinks or bugs with the install process which come up frequently.

Errors present, or visual issues Try restarting Unity as a first step.

Compile errors in the log, not possible to enter play mode, visual issues in the scene Verify that URP is installed and enabled in the settings. See here for documentation: `https://docs.unity3d.com/Packages/com.unity.render-pipelines.universal@7.1/manual/InstallURPIntoAProject.html`.

Compile errors in the log, not possible to enter play mode There are a couple of scenarios where compile errors may appear. As a first step, try making a backup of your project and removing the Crest files and reinstalling from the Asset Store. If this does not help, It may be necessary to delete the Library folder for the project and delete the cached package from a path like *C:/Users/yourusername/AppData/Roaming/Unity/Asset Store-5.x/Unity Technologies*. If these steps do not fix it, please report the issue to us.

Possible to enter play mode, but errors appear in the log at run-time that mention missing 'kernels' Recent versions of Unity have a bug that makes shader import unreliable. Please try reimporting the *Crest/Shaders* folder using the right click menu in the project view, or simply close Unity and delete the Library folder and restart which will trigger everything to reimport.

3 Configuration

3.1 Overview

Some quick start pointers for changing the ocean look and behaviour:

- Ocean material / shading: The active ocean material is assigned to the *OceanRenderer* script. The material parameters are described in section 3.2. Turn off unnecessary features to maximize performance.
- Animated waves / ocean shape: Configured on the *ShapeGerstnerBatched* script by providing an *Ocean Wave Spectrum* asset. This asset has an equalizer-style interface for tweaking different scales of waves, and also has some parametric wave spectra from the literature for comparison.
- Ocean foam: Configured on the *OceanRenderer* script by providing a *Sim Settings Foam* asset.
- Dynamic wave simulation: Configured on the *OceanRenderer* script by providing a *Sim Settings Wave* asset, described in section 4.2.2.
- A big strength of *Crest* is that you can add whatever contributions you like into the system. You could add your own shape or deposit foam onto the surface where desired. Inputs are generally tagged with the *Register* scripts and examples can be found in the example content scenes.

All settings can be changed at run-time and live authored. When tweaking ocean shape it can be useful to freeze time (from script, set *Time.timeScale* to 0) to clearly see the effect of each octave of waves.

3.2 Material parameters

Note: This section was originally written for the LWRP ocean material. The material parameters may change for Crest URP. We are investigating building the ocean material on ShaderGraph and the material options and parameter names may change. When URP is released and these options are finalised this documentation will be updated.

3.2.1 Normal Mapping

Enable Whether to add normal detail from a texture. Can be used to add visual detail to the water surface
Normal Map Normal map texture (should be set to Normals type in the properties)
Strength Strength of normal map influence
Scale Scale of normal map texture

3.2.2 Scattering

Diffuse Base colour when looking straight down into water
Diffuse Grazing Base colour when looking into water at shallow/grazing angle
Shadowing Changes colour in shadow. Requires 'Create Shadow Data' enabled on OceanRenderer script.
Diffuse (Shadow) Base colour in shadow

3.2.3 Subsurface Scattering

Enable Whether to to emulate light scattering through the water volume
Colour Colour tint for primary light contribution
Base Mul Amount of primary light contribution that always comes in
Sun Mul Primary light contribution in direction of light to emulate light passing through waves
Sun Fall-Off Fall-off for primary light scattering to affect directionality

3.2.4 Shallow Scattering

Enable Enable light scattering in shallow water
Depth Max Max depth that is considered 'shallow'
Depth Power Fall off of shallow scattering
Shallow Colour Colour in shallow water
Shallow Colour (Shadow) Shallow water colour in shadow (see comment on Shadowing param above)

3.2.5 Reflection Environment

Specular Strength of specular lighting response
Smoothness Smoothness of surface
Vary Smoothness Over Distance Helps to spread out specular highlight in mid-to-background. From a theory point of view, models transfer of normal detail to microfacets in BRDF.
Smoothness Far Material smoothness at far distance from camera
Smoothness Far Distance Definition of far distance
Smoothness Power How smoothness varies between near and far distance
Softness Acts as mip bias to smooth/blur reflection
Light Intensity Multiplier Main light intensity multiplier
Fresnel Power Controls harshness of Fresnel behaviour
Refractive Index of Air Index of refraction of air. Can be increased to almost 1.333 to increase visibility up through water surface.
Refractive Index of Water Index of refraction of water. Typically left at 1.333.
Planar Reflections Dynamically rendered 'reflection plane' style reflections. Requires OceanPlanarReflection script added to main camera.
Planar Reflections Distortion How much the water normal affects the planar reflection

3.2.6 Procedural Skybox

Enable Enable a simple procedural skybox, not suitable for realistic reflections, but can be useful to give control over reflection colour especially in stylized/non realistic applications
Base Base sky colour
Towards Sun Colour in sun direction
Directionality Direction fall off
Away From Sun Colour away from sun direction

3.2.7 Foam

Enable Enable foam layer on ocean surface
Texture Foam texture
Scale Foam texture scale
Light Scale Scale intensity of lighting
White Foam Color Colour tint for whitecaps / foam on water surface
Bubble Foam Color Colour tint bubble foam underneath water surface
Bubble Foam Parallax Parallax for underwater bubbles to give feeling of volume
Shoreline Foam Min Depth Proximity to sea floor where foam starts to get generated
Wave Foam Feather Controls how gradual the transition is from full foam to no foam
Wave Foam Bubbles Coverage How much underwater bubble foam is generated

3.2.8 Foam 3D Lighting

Enable Generates normals for the foam based on foam values/texture and use it for foam lighting
Normals Strength Strength of the generated normals
Specular Fall-Off Acts like a gloss parameter for specular response
Specular Boost Strength of specular response

3.2.9 Transparency

Enable Whether light can pass through the water surface
Fog Density Scattering coefficient within water volume, per channel
Refraction Strength How strongly light is refracted when passing through water surface

3.2.10 Caustics

Enable Approximate rays being focused/defocused on underwater surfaces
Caustics Caustics texture
Scale Caustics texture scale

Texture Average Value The 'mid' value of the caustics texture, around which the caustic texture values are scaled
Strength Scaling / intensity
Focal Depth The depth at which the caustics are in focus
Depth Of Field The range of depths over which the caustics are in focus
Distortion Strength How much the caustics texture is distorted
Distortion Scale The scale of the distortion pattern used to distort the caustics

3.2.11 Underwater

Enable Whether the underwater effect is being used. This enables code that shades the surface correctly from underneath.
Cull Mode Ordinarily set this to *Back* to cull back faces, but set to *Off* to make sure both sides of the surface draw if the underwater effect is being used.

3.2.12 Flow

Enable Flow is horizontal motion in water as demonstrated in the 'whirlpool' example scene. 'Create Flow Sim' must be enabled on the OceanRenderer to generate flow data.

3.3 Reflections

Reflections contribute hugely to the appearance of the ocean. The Index of Refraction settings control how much reflection contributes for different view angles.

The base reflection comes from a one of these sources:

- Unity's specular cubemap. This is the default and is the same as what is applied to glossy objects in the scene. It will support reflection probes, as long as the probe extents cover the ocean tiles, which enables real-time update of the reflection environment (see Unity documentation for more details).
- Override reflection cubemap. If desired a cubemap can be provided to use for the reflections. For best results supply a HDR cubemap.
- Procedural skybox - developed for stylized games, this is a simple approximation of sky colours that will give soft results.

This base reflection can then be overridden by dynamic planar reflections. This can be used to augment the reflection with 3D objects such as boat or terrain. This can be enabled by applying the *Ocean Planar Reflections* script to the active camera and configuring which layers get reflected (don't include the *Water* layer). This renders every frame by default but can be configured to render less frequently. This only renders one view but also only captures a limited field of view of reflections, and the reflection directions are scaled down to help keep them in this limited view, which can give a different appearance. Furthermore 'planar' means the surface is approximated by a plane which is not

the case for wavey ocean, so the effect can break down. This method is good for capturing local objects like boats and etcetera.

A good strategy for debugging the use of Unity's specular cubemap is to put another reflective/glossy object in the scene near the surface, and verify that it is lit and reflects the scene properly. Crest tries to use the same inputs for lighting/reflections, so if it works for a test object it should work for the water surface as well.

3.4 Ocean construction parameters

There are a small number of parameters that control the construction of the ocean shape and geometry:

- **Lod Data Resolution** - the resolution of the various ocean LOD data including displacement textures, foam data, dynamic wave sims, etc. Sets the 'detail' present in the ocean - larger values give more detail at increased run-time expense.
- **Geometry Down Sample Factor** - geometry density - a value of 2 will generate one vert per 2x2 LOD data texels. A value of 1 means a vert is generated for every LOD data texel. Larger values give lower fidelity surface shape with higher performance.
- **Lod Count** - the number of levels of detail / scales of ocean geometry to generate. The horizontal range of the ocean surface doubles for each added LOD, while GPU processing time increases linearly. It can be useful to select the ocean in the scene view while running in editor to inspect where LODs are present.
- **Max Scale** - the ocean is scaled horizontally with viewer height, to keep the meshing suitable for elevated viewpoints. This sets the maximum the ocean will be scaled if set to a positive value.
- **Min Scale** - this clamps the scale from below, to prevent the ocean scaling down to 0 when the camera approaches the sea level. Low values give lots of detail, but will limit the horizontal extents of the ocean detail.

4 Ocean simulation

The following sections cover the major elements of the ocean simulation. All of these can be directly controlled with user input, as covered in this video: `https://www.youtube.com/watch?v=sQIakAjSq4Y`.

4.1 Animated waves

4.1.1 Overview

The Animated Waves simulation contains the animated surface shape. This typically contains the ocean waves, but can be modified as required. For example parts of the water can be pushed down below geometry if required.

The animated waves sim can be configured by assigning an Animated Waves Sim Settings asset to the OceanRenderer script in your scene (*Create/Crest/Animated Wave Sim Settings*).

The waves will be dampened/attenuated in shallow water if a *Sea Floor Depth* LOD data is used (see section 4.4). The amount that waves are attenuated is configurable using the *Attenuation In Shallows* setting.

4.1.2 User inputs

To add some shape, add some geometry into the world which when rendered from a top down perspective will draw the desired displacements. Then assign the*RegisterAnimWavesInput* script which will tag it for rendering into the shape. This is demonstrated in this video: `https://www.youtube.com/watch?v=sQIakAjSq4Y`.

There is an example in the *boat.unity* scene, GameObject *wp0*, where a smoothstep bump is added to the water shape. This is an efficient way to generate dynamic shape. This renders with additive blend, but other blending modes are possible such as alpha blend, multiplicative blending, and min or max blending, which give powerful control over the shape.

The following input shaders are provided under *Crest/Inputs/Animated Waves*:

- **Add From Texture** allows any kind of shape added to the surface from a texture. Can ether be a heightmap texture (1 channel) or a 3 channel XYZ displacement texture. Optionally the alpha channel can be used to write to subsurface scattering which increases the amount of light emitted from the water volume, which is useful for approximating light scattering.
- **Add Water Height From Geometry** allows the sea level (average water height) to be offset some amount. The top surface of the geometry will provide the water height, and the waves will apply on top.
- **Push Water Under Convex Hull** Pushes the water underneath the geometry. Can be used to define a volume of space which should stay 'dry'.
- **Set Water Height To Geometry** Snaps the water surface to the top surface of the geometry. Will override any waves.
- **Wave Particle** A 'bump' of water. Many bumps can be combined to make interesting effects such as wakes for boats or choppy water. Based loosely on `http://www.cemyuksel.com/research/waveparticles/`.

4.2 Dynamic waves

4.2.1 Overview

This LOD data is a multi-resolution dynamic wave simulation, which gives dynamic interaction with the water. To turn on this feature, enable the *Create Dynamic Wave Sim* option on the *OceanRenderer* script.

One use case for this is boat wakes. In the *boat.unity* scene, the geometry and shader on the *WaterObjectInteractionSphere0* will render forces into the sim. It has the *RegisterDynWavesInput* script that tags it as input.

After the simulation is advanced, the results are converted into displacements and copied into the displacement textures to affect the final ocean shape. The sim is added on top of the existing Gerstner waves.

The dynamic waves sim can be configured by assigning a Dynamic Wave Sim Settings asset to the OceanRenderer script in your scene (*Create/Crest/Dynamic Wave Sim Settings*).

4.2.2 Simulation setup

This is the recommended workflow for configuring the dynamic wave simulation. All of the settings below refer to the *Dynamic Wave Sim Settings*.

1. Set the *Gravity Multiplier* to the lowest value that is satisfactory. Higher values will make the simulated waves travel faster, but make the simulation more unstable and require more update steps / expense.

2. Increase *Damping* as high as possible. Higher values make the sim easier to solve, but makes the waves fade faster and limits their range.

3. Set the *Courant Number* to the highest value which still yields a stable sim. Higher values reduce cost but reduce stability. Put the camera low down near the water while testing as the most detailed waves are the most unstable.

4. Reduce *Max Sim Steps Per Frame* as much as possible to reduce the simulation cost. This may slow down waves in the lower LOD levels, which are the most detailed waves. Hopefully this slight slow down in just the smallest wavelengths is not noticeable/objectionable for the player. If waves are visible travelling too slow, increase it.

The *OceanDebugGUI* script gives the debug overlay in the example content scenes and reports the number of sim steps taken and sim step dt at each frame.

4.2.3 User inputs

User provided contributions can be rendered into this simulation to create dynamic wave effects. An example can be found in the boat prefab. Each LOD sim runs independently and it is desirable to add interaction forces into all appropriate sims. The *ObjectWaterInteraction* script takes into account the boat size and counts how many sims are appropriate, and then weights the interaction forces based on this number, so the force is spread evenly to all sims. As noted above, the sim results will be copied into the dynamic waves LODs and then accumulated up the LOD chain to reconstruct a single simulation.

The following input shaders are provided under *Crest/Inputs/Dynamic Waves*:

- **Add Bump** adds a round force to pull the surface up (or push it down). This can be moved around to create interesting effects.

- **Object Interaction** can be used in conjunction with the *ObjectWaterInteraction* script to simulate the interaction of an object with the water. Can be used for boat wakes. See the boat example scenes.

- **Sphere-Water Interaction** is a more specialized and accurate version of the *Object Interaction* input. It models the interaction between a sphere and takes into account how submerged the sphere is. Multiple spheres can be composed into compound shapes. See the *Spinner* object in the *boat.unity* example scene for an example

4.3 Foam

4.3.1 Overview

The Foam LOD Data is simple type of simulation for foam on the surface. Foam is generated by choppy water (specifically when the surface is *pinched*). Each frame, the foam values are reduced to model gradual dissipation of foam over time.

To turn on this feature, enable the *Create Foam Sim* option on the *Ocean-Renderer* script, and ensure the *Enable* option is ticked in the Foam group on the ocean material.

The foam sim can be configured by assigning a Foam Sim Settings asset to the OceanRenderer script in your scene (*Create/Crest/Foam Sim Settings*). There are also parameters on the material which control the appearance of the foam.

4.3.2 User inputs

User provided foam contributions can be added similar to the Animated Waves. In this case the *RegisterFoamInput* script should be applied to any inputs. There is no combine pass for foam so this does not have to be taken into consideration - one must simply render 0-1 values for foam as desired. See the *DepositFoamTex* object in the *whirlpool.unity* scene for an example. This is also demonstrated in this video: `https://www.youtube.com/watch?v=sQIakAjSq4Y`.

The following input shaders are provided under *Crest/Inputs/Foam*:

- **Add From Texture** adds foam values read from a user provided texture. Can be useful for placing 'blobs' of foam as desired, or can be moved around at runtime to paint foam into the sim.
- **Add From Vert Colours** can be applied to geometry and uses the red channel of vertex colours to add foam to the sim. Similar in purpose to *Add From Texture*, but can be authored in a modelling workflow instead of requiring at texture.

4.4 Sea floor depth

This simulation stores water depth information. This is useful information for the system; it is used to attenuate large waves in shallow water, to generate foam near shorelines, and to provide shallow water shading. It is calculated by rendering the render geometry in the scene for each LOD from a top down perspective and recording the Y value of the surface.

The following will contribute to ocean depth:

- Objects that have the *RegisterSeaFloorDepthInput* component attached. These objects will render every frame. This is useful for any dynamically moving surfaces that need to generate shoreline foam, etc.

- It is also possible to place world space depth caches. The scene objects will be rendered into this cache once, and the results saved. Once the cache is populated it is then copied into the Sea Floor Depth LOD Data. The cache has a gizmo that represents the extents of the cache (white outline) and the near plane of the camera that renders the depth (translucent rectangle). The cache should be placed at sea level and rotated/scaled to encapsulate the terrain.

When the water is e.g. 250m deep, this will start to dampen 500m wavelengths, so it is recommended that the sea floor drop down to around this depth away from islands so that there is a smooth transition between shallow and deep water without a visible boundary.

4.5 Clip Surface

This data drives clipping of the ocean surface, as in carving out holes. This can be useful for hollow vessels or low terrain that goes below sea level. Data can come from geometry (convex hulls) or a texture.

To turn on this feature, enable the *Create Clip Surface Data* option on the *OceanRenderer* script, and ensure the *Enable* option is ticked in the *Clip Surface* group on the ocean material.

The data contains 0-1 values. Holes are carved into the surface when the values is greater than 0.5.

Overlapping meshes will not work correctly in all cases. There will be cases where one mesh will overwrite another resulting in ocean surface appearing where it should not. Overlapping boxes aligned on the axes will work well whilst spheres may have issues.

Clip areas can be added by adding geometry that covers the desired hole area to the scene and then assigning the *RegisterClipSurfaceInput* script. See the *FloatingOpenContainer* object in the *boat.unity* scene for an example usage.

To use other available shaders like *ClipSurfaceRemoveArea* or *ClipSurfaceRemoveAreaTexture*: create a material, assign to renderer and disable *Assign Clip Surface Material* option. For the *ClipSurfaceRemoveArea* shaders, the geometry should be added from a top down perspective and the faces pointing upwards.

4.6 Shadows

The shadow data consists of two channels. One is for normal shadows as would be used to block specular reflection of the light. The other is a much softer shadowing value that can approximately variation in light scattering in the water volume.

To turn on this feature, enable the *Create Shadow Data* option on the *OceanRenderer* script, and ensure the *Shadowing* option is ticked on the ocean material.

This data is captured from the shadow maps Unity renders. These shadow maps are always rendered in front of the viewer. The Shadow LOD Data then reads these shadow maps and copies shadow information into its LOD textures.

We have provided an example configuration with shadows enabled; *Assets/Crest/CrestExampleURPAsset*, which should be set to use the following Custom Renderer: *Assets/Crest/ForwardRendererCrestShadows*. In the setup instructions in section 2, steps to use this asset and renderer were given, and no further action is required if this setup is used.

To create this setup from scratch, the steps are the following.

1. On the scriptable render pipeline asset (either the asset provided with Crest *Assets/Crest/CrestExampleURPAsset*, or the one used in your project), ensure that shadow cascades are enabled. Crest requires cascades to be enabled to obtain shadow information.

2. Create a new renderer which will have the sample shadows feature enabled. Right click a folder under Assets and select *Create/Rendering/Universal Render Pipeline/Forward Renderer*. Select the asset and click the '+' icon and select *Crest/SampleShadows*.

3. Enable the new renderer. Select your URP pipeline asset and set *General/Renderer Type* to *Custom* and assign the asset created in the previous step.

4. Enable shadowing in Crest. Enable *Create Shadow Data* on the OceanRenderer script.

5. On the same script, assign a *Primary Light* for the shadows. This light needs to have shadows enabled, if not an error will be reported accordingly.

6. If desired the shadow sim can be configured by assigning a *Shadow Sim Settings* asset (*Create/Crest/Shadow Sim Settings*).

7. Enable *Shadowing* on the ocean material to compile in the necessary shader code

The shadow sim can be configured by assigning a Shadow Sim Settings asset to the OceanRenderer script in your scene (*Create/Crest/Shadow Sim Settings*). In particular, the soft shadows are very soft by default, and may not appear for small/thin shadow casters. This can be configured using the *Jitter Diameter Soft* setting.

Note: URP should allow sampling the shadow maps directly in the ocean shader which would be an alternative to using this shadow data, although it would not give the softer shadow component. This would likely work on 2018.

4.7 Flow

4.7.1 Overview

Flow is the horizontal motion of the water volumes. It is used in the *whirlpool.unity* example scene to rotate the waves and foam around the vortex. It does not affect wave directions, but transports the waves horizontally. This horizontal motion also affects physics.

4.7.2 User inputs

Crest supports adding any flow velocities to the system. To add flow, add some geometry into the world which when rendered from a top down perspective will draw the desired displacements. Then assign the *RegisterFlowInput* script which will tag it for rendering into the flow, and apply a material using one of the following shaders.

The following input shaders are provided under *Crest/Inputs/Flow*:

The *Crest/Inputs/Flow/Add Flow Map* shader writes a flow texture into the system. It assumes the x component of the flow velocity is packed into 0-1 range in the red channel, and the z component of the velocity is packed into 0-1 range in the green channel. The shader reads the values, subtracts 0.5, and multiplies them by the provided scale value on the shader. The process of adding ocean inputs is demonstrated in the following video: `https://www.youtube.com/watch?v=sQIakAjSq4Y`.

5 Wave conditions

5.1 Authoring

To add waves, add the *ShapeGerstnerBatched* component to a GameObject.

The appearance and shape of the waves is determined by a *wave spectrum*. A default wave spectrum will be created if none is specified. To change the waves, right click in the Project view and select *Create/Crest/Ocean Wave Spectrum*, and assign the new asset to the *Spectrum* property of the *ShapeGerstnerBatched* script.

The spectrum has sliders for each wavelength to control contribution of different scales of waves. To control the contribution of 2m wavelengths, use the slider labelled '2'.

The *Wave Direction Variance* controls the spread of wave directions. This controls how aligned the waves are to the wind direction.

The *Chop* parameter scales the horizontal displacement. Higher chop gives crisper wave crests but can result in self-intersections or 'inversions' if set too high, so it needs to be balanced.

To aid in tweaking the spectrum values we provide implementations of common wave spectra from the literature. Select one of the spectra by toggling the button, and then tweak the spectra inputs, and the spectrum values will be set according to the selected model. When done, toggle the button off to stop overriding the spectrum.

Together these controls give the flexibility to express the great variation one can observe in real world seascapes.

5.2 Local waves

By default the Gerstner waves will apply everywhere throughout the world, so 'globally'. They can also be applied 'locally' - in a limited area of the world.

This is done by setting the *Mode* to *Geometry*. In this case the system will look for a *MeshFilter/MeshRenderer* on the same GameObject and it will generate waves over the area of the geometry. The geometry must be 'face up' - it must be visible from a top-down perspective in order to generate the waves.

It must also have a material using the *Crest/Inputs/Animated Waves/Gerstner Batch Geometry* shader applied.

For a concrete example, see the *GerstnerPatch* object in *boat.unity*. It has a *MeshFilter* component with the *Quad* mesh applied, and is rotated so the quad is face up. It has a *MeshRenderer* component with a material assigned with a Gerstner material. Additionally, the material has the *Feather at UV Extents* option enabled, which will fade down the waves where the UVs go to 0 or 1 (at the edges of the quad). The end result is a local patch of waves that are smoothly blended over the area of the quad.

6 Shallow water and shorelines

We published a video on this topic, available here: `https://www.youtube.com/watch?v=jcmqUlboTUk`.

Crest requires water depth information to attenuate large waves in shallow water, to generate foam near shorelines, and to provide shallow water shading. It is calculated by rendering the render geometry in the scene for each LOD from a top down perspective and recording the Y value of the surface.

When the ocean is e.g. 250m deep, this will start to dampen 500m wavelengths, so it is recommended that the sea floor drop down to around this depth away from islands so that there is a smooth transition between shallow and deep water without a 'step' in the sea floor which appears as a discontinuity and/or line of foam on the surface.

One way to inform *Crest* of the seabed is to attach the *RegisterSeaFloorDepthInput* component. *Crest* will record the height of these objects every frame, so they can be dynamic.

This dynamic update comes at a cost. For parts for of the seabed which are static, *Crest* has a mechanism for recording their heights just once, instead of updating every frame, using an ocean depth cache. The *main.unity* example scene has an example of a cache set up around the island. The cache GameObject is called *IslandDepthCache* and has a *OceanDepthCache* component attached. The following are the key points of its configuration:

- The transform position X and Z are centered over the island
- The transform position y value is set to the sea level
- The transform scale is set to 540 which sets the size of the cache. If gizmos are visible and the cache is selected, the area is demarcated with a white rectangle.
- The *Camera Max Terrain Height* is the max height of any surfaces above the sea level that will render into the cache. If gizmos are visible and the cache is selected, this cutoff is visualised as a translucent gray rectangle.
- The *Layer Names* field contains the layer that the island is assigned to - *Terrain*. Only objects in these layer(s) will render into the cache.

On startup, validation is done on the cache. Check the log for warnings and errors.

At runtime, a child object underneath the cache will be created with the prefix *Draw_* it will have a material with a *Texture* property. By double clicking the icon to the right of this field, one can inspect the contents of the cache.

By default the cache is populated in the *Start()* function. It can instead be configured to populate from script by setting the *Refresh Mode* to *On Demand* and calling the *PopulateCache()* method on the component from script.

Once populated the cache contents can be saved to disk by clicking the *Save cache to file* button that will appear in the Inspector in play mode. Once saved, the *Type* field can be set to *Baked* and the saved data can be assigned to the *Saved Cache* field.

7 Collision Shape for Physics

The system has a few paths for computing information about the water surface such as height, displacement, flow and surface velocity. These paths are covered in the following subsections, and are configured on the *Animated Waves Sim Settings*, assigned to the OceanRenderer script, using the Collision Source dropdown.

The system supports sampling collision at different resolutions. The query functions have a parameter *Min Spatial Length* which is used to indicate how much detail is desired. Wavelengths smaller than half of this min spatial length will be excluded from consideration.

To simplify the code required to get the ocean height or other data from C#, two helpers are provided, *SampleHeightHelper* and *SampleFlowHelper*. Use of these is demonstrated in the example content.

7.1 Compute Shader Queries

This is the default and recommended choice. Query positions are uploaded to a compute shader which then samples the ocean data and returns the desired results. The result of the query accurately tracks the height of the surface, including all shape deformations and waves.

Using the GPU to perform the queries is efficient, but the results can take a couple of frames to return to the CPU. This has a few non-trivial impacts on how it must be used.

Firstly, queries need to be registered with an ID so that the results can be tracked and retrieved from the GPU later. This ID needs to be globally unique, and therefore should be acquired by calling *GetHashCode()* on an object/component which will be guaranteed to be unique. **Queries should only be made once per frame from an owner - querying a second time using the same ID will stomp over the last query points**. A primary reason why *SampleHeightHelper* is useful is that it is an object in itself and there can pass its own ID, hiding this complexity from the user.

Secondly, even if only a one-time query of the height is needed, the query function should be called every frame until it indicates that the results were successfully retrieved. See *SampleHeightHelper* and its usages in the code - its *Sample()* function should be called until it returns true. Posting the query and polling for its result are done through the same function.

Finally due to the above properties, the number of query points posted from a particular owner should be kept consistent across frames. The helper classes always submit a fixed number of points this frame, so satisfy this criteria.

7.2 Gerstner Waves CPU

This collision option is serviced directly by the *GerstnerWavesBatched* component which implements the *ICollProvider* interface, check this interface to see functionality. This sums over all waves to compute displacements, normals, velocities, etc. In contrast to the displacement textures the horizontal range of this collision source is unlimited.

A drawback of this approach is the CPU performance cost of evaluating the waves. It also does not include wave attenuation from water depth or any custom rendered shape. A final limitation is the current system finds the first *GerstnerWavesBatched* component in the scene which may or may not be the correct one. The system does not support cross blending of multiple scripts.

8 Underwater

Crest supports seamless transitions above/below water. This is demonstrated in the *main.unity* scene in the example content. The ocean in this scene uses the material *Ocean-Underwater.mat* which enables rendering the underside of the surface, and has the prefab *UnderWaterCurtainGeom* parented to the camera which renders the underwater effect. It also has the prefab *UnderWaterMeniscus* parented which renders a subtle line at the intersection between the camera lens and the water to visually help the transition.

Out-scattering is provided as an example script which reduces environmental lighting with depth underwater. See *UnderwaterEnvironmentalLighting*.

Checklist for using underwater:

- Configure the ocean material for underwater rendering - in the *Underwater* section of the material params, ensure *Enabled* is turned on and *Cull Mode* is set to *Off* so that the underside of the ocean surface renders. See *Ocean-Underwater.mat* for an example.
- Place *UnderWaterCurtainGeom* and *UnderWaterMeniscus* prefabs under the camera (with cleared transform).
- Use opaque or alpha test materials for underwater surfaces. Transparents materials will not render correctly underwater.
- For performance reasons, the underwater effect is disabled if the viewpoint is not underwater. If there are multiple cameras, the *Viewpoint* property of the *OceanRenderer* component must be set to the current active camera.

9 Other features

9.1 Floating origin

Crest has support for 'floating origin' functionality, based on code from the Unity community wiki. See the original wiki page for an overview and original

code: `http://wiki.unity3d.com/index.php/Floating_Origin`.

It is tricky to get pop free results for world space texturing. To make it work the following is required:

- Set the floating origin threshold to a power of 2 value such as 4096.
- Set the size/scale of any world space textures to be a smaller power of 2. This way the texture tiles an integral number of times across the threshold, and when the origin moves no change in appearance is noticeable. This includes the following textures:
  - Normals - set the Normal Mapping Scale on the ocean material
  - Foam texture - set the Foam Scale on the ocean material
  - Caustics - also should be a power of 2 scale, if caustics are visible when origin shifts happen

By default the *FloatingOrigin* script will call *FindObjectsOfType()* for a few different component types, which is a notoriously expensive operation. It is possible to provide custom lists of components to the 'override' fields, either by hand or programmatically, to avoid searching the entire scene(s) for the components. Managing these lists at run-time is left to the user.

9.2 Buoyancy / floating physics

SimpleFloatingObject is a simple buoyancy script that attempts to match the object position and rotation with the surface height and normal. This can work well enough for small water craft that don't need perfect floating behaviour, or floating objects such as buoys, barrels, etc.

BoatProbes is a more advanced implementation that computes buoyancy forces at a number of *ForcePoints* and uses these to apply force and torque to the object. This gives more accurate results at the cost of more queries.

BoatAlignNormal is a rudimentary boat physics emulator that attaches an engine and rudder to *SimpleFloatingObject*. It is not recommended for cases where high animation quality is required.

9.2.1 Adding boats

Setting up a boat with physics can be a dark art. The authors recommend duplicating and modifying one of the existing boat prefabs, and proceeding slowly and carefully as follows:

1. Pick an existing boat to replace. Only use *BoatAlignNormal* if good floating behaviour is not important, as mentioned above. The best choice is usually boat probes.
2. Duplicate the prefab of the one you want to replace, such as *crest/Assets/Crest/Crest-Examples/BoatDev/Data/BoatProbes.prefab*
3. Remove the render meshes from the prefab, and add the render mesh for your boat. We recommend lining up the meshes roughly.

4. Switch out the collision shape as desired. Some people report issues if the are multiple overlapping physics collision primitives (or multiple rigidbodies which should never be the case). We recommend keeping things as simple as possible and using only one collider if possible.

5. We recommend placing the render mesh so its approximate center of mass matches the center of the collider and is at the center of the boat transform. Put differently, we usually try to eliminate complex hierarchies or having nested non-zero'd transforms whenever possible within the boat hierarchy, at least on or above physical parts.

6. If you have followed these steps you will have a new boat visual mesh and collider, with the old rigidbody and boat script. You can then modify the physics settings to move the behaviour towards how you want it to be.

7. The mass and drag settings on the boat scripts and rigdibody help to give a feeling of weight.

8. Set the boat dimension:

    - BoatProbes: Set the *Min Spatial Length* param to the width of the boat.
    - BoatAlignNormal: Set the boat Boat Width and Boat Length to the width and length of the boat.
    - If, even after experimenting with the mass and drag, the boat is responding too much to small waves, increase these parameters (try doubling or quadrupling at first and then compensate).

9. There are power settings for engine turning which also help to give a feeling of weight

10. The dynamic wave interaction is driven by the object in the boat hierarchy called *WaterObjectInteractionSphere*. It can be scaled to match the dimensions of the boat. The *Weight* param controls the strength of the interaction.

The above steps should maintain a working boat throughout - we recommend testing after each step to catch issues early.

10 Technical documentation

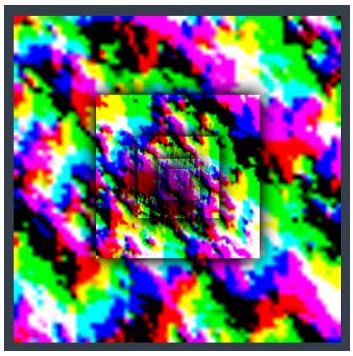
We have published details of the algorithms and approaches we use. See the following publications:

- Crest: *Novel Ocean Rendering Techniques in an Open Source Framework*, Advances in Real-Time Rendering in Games, ACM SIGGRAPH 2017 courses `http://advances.realtimerendering.com/s2017/index.html`
- *Multi-resolution Ocean Rendering in* Crest Ocean System, Advances in Real-Time Rendering in Games, ACM SIGGRAPH 2019 courses `http://advances.realtimerendering.com/s2019/index.htm`

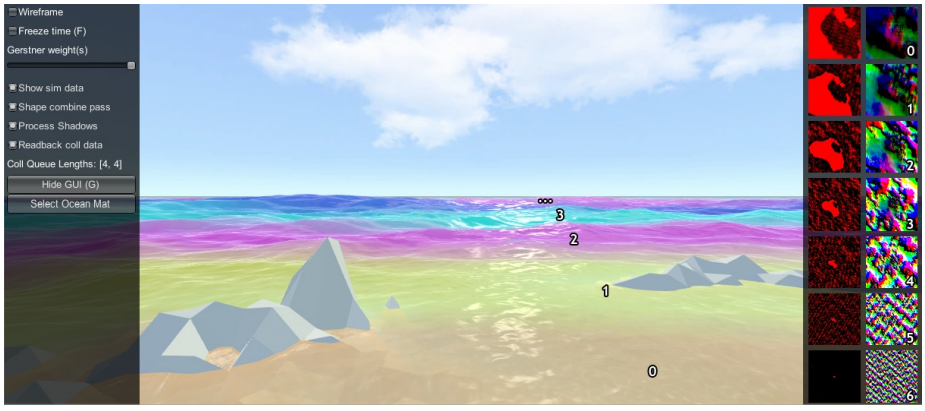
10.1 Core data structure

The backbone of *Crest* is an efficient Level Of Detail (LOD) representation for data that drives the rendering, such as surface shape/displacements, foam values, shadowing data, water depth, and others. This data is stored in a multi-resolution format, namely cascaded textures that are centered at the viewer. This data is generated and then sampled when the ocean surface geometry is rendered. This is all done on the GPU using a command buffer constructed each frame by *BuildCommandBuffer*.

Let's study one of the LOD data types in more detail. The surface shape is generated by the Animated Waves LOD Data, which maintains a set of *displacement textures* which describe the surface shape. A top down view of these textures laid out in the world looks as follows:



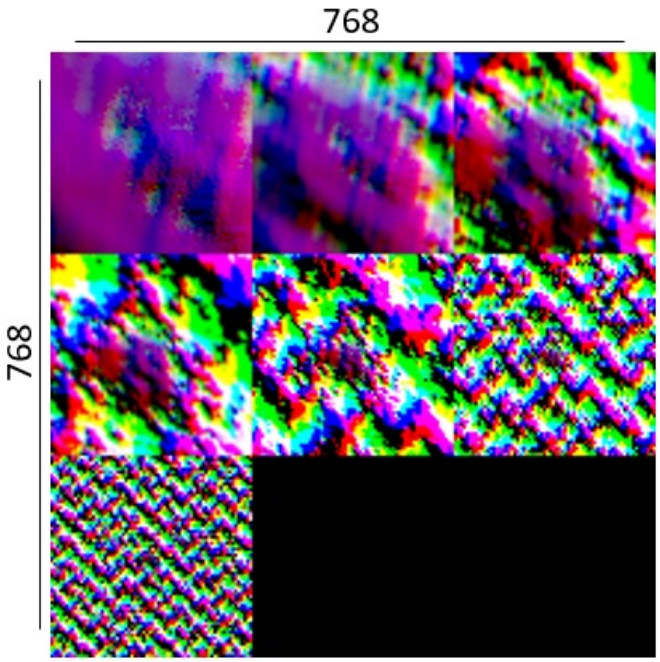
Each LOD is the same resolution (256x256 here), configured on the *OceanRenderer* script. In this example the largest LOD covers a large area (4km squared), and the most detail LOD provides plenty of resolution close to the viewer. These textures are visualised in the Debug GUI on the right hand side of the screen:



In the above screenshot the foam data is also visualised (red textures), and the scale of each LOD is clearly visible by looking at the data contained within. In the rendering each LOD is given a false colour which shows how the LODs are arranged around the viewer and how they are scaled. Notice also the smooth

blend between LODs - LOD data is always interpolated using this blend factor so that there are never pops are hard edges between different resolutions.

In this example the LODs cover a large area in the world with a very modest amount of data. To put this in perspective, the entire LOD chain in this case could be packed into a small texel area:



A final feature of the LOD system is that the LODs change scale with the viewpoint. From an elevated perspective, horizontal range is more important than fine wave details, and the opposite is true when near the surface. The *OceanRenderer* has min and max scale settings to set limits on this dynamic range.

When rendering the ocean, the various LOD data are sample for each vert and the vert is displaced. This means that the data is carried with the waves away from its rest position. For some data like wave foam this is fine and desirable. For other data such as the depth to the ocean floor, this is not a quantity that should move around with the waves and this can currently cause issues, such as shallow water appearing to move with the waves as in issue 96.

10.2 Implementation notes

On startup, the *OceanRenderer* script initialises the ocean system and asks the *OceanBuilder* script to build the ocean surface. As can be seen by inspecting the ocean at run-time, the surface is composed of concentric rings of geometry tiles. Each ring is given a different power of 2 scale.

At run-time, the ocean system updates its state in *LateUpdate*, after game state update and animation, etc. *OceanRenderer* updates before other scripts

and first calculates a position and scale for the ocean. The ocean GameObject is placed at sea level under the viewer. A horizontal scale is computed for the ocean based on the viewer height, as well as a *_viewerAltitudeLevelAlpha* that captures where the camera is between the current scale and the next scale ($\times 2$), and allows a smooth transition between scales to be achieved.

Next any active ocean data are updated, such as animated waves, simulated foam, simulated waves, etc. The data can be visualised on screen if the *OceanDebugGUI* script from the example content is present in the scene, and if the *Show shape data* on screen toggle is enabled. As one of the ocean data types, the ocean shape is generated by rendering Gerstner wave components into the animated waves data. Each wave component is rendered into the shape LOD that is appropriate for the wavelength, to prevent over- or under- sampling and maximize efficiency. A final pass combines the shape results from the different Gerstner components together. Disable the *Shape combine pass* option on the *OceanDebugGUI* to see the shape contents before this pass.

Finally *BuildCommandBuffer* constructs a command buffer to execute the ocean update on the GPU early in the frame before the graphics queue starts. See the *BuildCommandBuffer* code for the update scheduling and logic.

The ocean geometry is rendered by Unity as part of the graphics queue, and uses the *Crest/Ocean* shader. The vertex shader snaps the verts to grid positions to make them stable. It then computes a *lodAlpha* which starts at 0 for the inside of the LOD and becomes 1 at the outer edge. It is computed from taxicab distance as noted in the course. This value is used to drive the vertex layout transition, to enable a seamless match between the two. The vertex shader then samples any required ocean data for the current and next LOD scales and uses *lodAlpha* to interpolate them for a smooth transition across displacement textures. Finally, it passes the LOD geometry scale and *lodAlpha* to the ocean fragment shader.

The fragment shader samples normal and foam maps at 2 different scales, both proportional to the current and next LOD scales, and then interpolates the result using *lodAlpha* for a smooth transition. It combines the normal map with surface normals computed directly from the displacement texture.

10.3 Render order

A typical render order for a frame is the following:

- Opaque geometry is rendered, writes to opaque depth buffer
- Sky is rendered, probably at zfar with depth test enabled so it only renders outside the opaque surfaces
- Frame colours and depth are copied out for use later in postprocessing
- Ocean 'curtain' renders, draws underwater effect from bottom of screen up to water line (queue = Transparent-110)
    * It is set to render before ocean in UnderwaterEffect.cs
    * Sky is at zfar and will be fully fogged/obscured by the water volume
- Ocean renders early in the transparent queue (queue = Transparent-100)
    * It samples the postprocessing colours and depths, to do refraction

* It reads and writes from the frame depth buffer, to ensure waves are sorted correctly

* It stomps over the underwater curtain to make a correct final result

* It stomps over sky - sky is at zfar and will be fully fogged/obscured by the water volume

- Particles and alpha render. If they have depth test enabled, they will clip against the surface
- Postprocessing runs with the postprocessing depth and colours

11 Performance

The foundation of *Crest* is architected for performance from the ground up with an innovative LOD system. It is tweaked to achieve a good balance between quality and performance in the general case, but getting the most out of the system requires tweaking the parameters for the particular use case. These are documented below.

11.1 Quality parameters

These are available for tweaking out of the box and should be explored on every project:

- See section 3.4 for parameters that directly control how much detail is in the ocean, and therefore the work required to update and render it. These are the primary quality settings from a performance point of view.
- The ocean shader has accrued a number of features and has become a reasonably heavy shader. Where possible these are on toggles and can be disabled, which will help the rendering cost (see section 3.2).

11.2 Potential optimisations

The following are optimisation ideas that have not been explored further in *Crest* yet, but are listed as ideas in case the reader has the resources to try them out.

- The ocean update runs as a command buffer, portions of which could potentially be ran asynchronously which may improve GPU utilisation. For example dynamic waves and Gerstner waves could be computed in parallel before the combine pass merges them together. We attempted this but found platform support is currently too limited to allow us to implement this in core *Crest*.
- Create multiple ocean materials with different sets of features and switch between them at run-time. An obvious use case would be one for shallow water and one for deep water and perhaps switch between them on a per-tile basis.

- Limit resolution range of LOD data. There is currently a min/max grid size option on the dynamic wave sim to limit what resolutions it runs at, this could be rolled out to other sim types.
- Set LOD data resolution per LOD type - e.g. the ocean depth and foam sim could potentially be stored at half resolution or lower.
- GPU-instance ocean material tiles. Discussed in issue #27 on the *Crest* GitHub. An idea we plan to pursue in the future is to perform height queries on the GPU in a compute shader, thus avoiding the need to transfer data back to the CPU at all. Not currently planned for *Crest*.
- Pre-rendered wave displacements - sample waves from texture instead of computing them on the fly. We did some initial experimentation in the branch *feature/baked-waves* and found it challenging to get good shape without interpolation artifacts. Given that the baking step is also inconvenient, there are no plans to explore this further.

12 Q&A

Is *Crest* well suited for medium-to-low powered mobile devices? *Crest* is built to be performant by design and has numerous quality/performance levers. However it is also built to be very flexible and powerful and as such can not compete with a minimal, mobile-centric ocean renderer such as the one in the *BoatAttack* project. Therefore we target *Crest* at PC/console platforms.

Which platforms does *Crest* support? Testing occurs primarily on Windows. We have users targeting Windows, Mac, Linux, PS4, XboxOne, Switch and iOS/Android. Performance is a challenge on Switch and mobile platforms - see the previous question. WebGL is unfortunately not supported as this platform currently does not support compute shaders which are required by Crest.

Is Crest well suited for localised bodies of water such as lakes? Currently Crest is currently targeted towards large bodies of water. The water could be pushed down where it's not wanted which would allow it to achieve rivers and lakes to some extent.

Does *Crest* support third party sky assets? We have heard of *Crest* users using TrueSky, AzureSky. These may require some code to be inserted into the ocean shader - there is a comment referring to this, search *Ocean.shader* for 'Azure'.

Can *Crest* work with multiplayer? Yes the animated waves are deterministic and easily synchronized. See discussion in `https://github.com/huwb/crest-oceanrender/issues/75`. However, the dynamic wave sim is not fully deterministic and can not currently be relied upon in networked situations.

Errors are present in the log that report *Kernel 'xxx.yyy' not found* Unity sometimes gets confused and needs assets reimported. This can be done by clicking the *Crest* root folder in the Project window and clicking *Reimport*. Alternatively the *Library* folder can be removed from the project root which will force all assets to reimport.

Compile errors are present Multiple *Crest* packages are present on the Asset Store and target different versions of Unity. If the Unity version is changed, then *Crest* must be removed and reimported into the project to ensure the correct version is served.

Can I push the ocean below the terrain? Yes, this is demonstrated in this video: `https://www.youtube.com/watch?v=sQIakAjSq4Y`.