The Ocean and Water Pipeline of Disney's Moana

Sean Palmer, Jonathan Garcia, Sara Drakeley, Patrick Kelly, Ralf Habel
Walt Disney Animation Studios

ABSTRACT

Disney's *Moana* was the largest and most complex water project the studio had ever undertaken. Over 900 shots required ocean interaction, which included boat wakes, splashes, shorelines, walls of water, and highly art-directed sentient water. Our previous films' water techniques would not scale to address the complexity and volume of work required by *Moana* and staffing and time constraints necessitated automating large parts of the process. We redesigned our pipeline to provide a flexible authoring process for a lightweight implicit ocean representation. This new workflow allowed artists to visualize and edit specific parts of the water setup and easily share their updates with other departments.

CCS CONCEPTS

•**Computing methodologies** →*Procedural animation; Physical simulation;* Graphics systems and interfaces;

KEYWORDS

production pipeline, water

ACM Reference format:
Sean Palmer, Jonathan Garcia, Sara Drakeley, Patrick Kelly, Ralf Habel. 2017. The Ocean and Water Pipeline of Disney's Moana. In *Proceedings of SIGGRAPH '17 Talks, Los Angeles, CA, USA, July 30 - August 03, 2017,* 2 pages.
DOI: http://dx.doi.org/10.1145/3084363.3085067

1 DEFINING CHARACTER

Our previous films represented water surfaces as explicit polygonal meshes, either displaced by animated signals or from meshed simulation data. This was limited, but sufficient for small-scale or single department work. To address *Moana's* need to collaboratively create a large-scale ocean for two thirds of the shots in the film, we created an implicit water representation that used a compositing node graph to encode height fields, level sets, and operators. The level set operators blended a memory-compact procedural expression for the entire surface with water simulation data stitched into specific regions, resulting in a single seamless surface. We defined a new pipeline (Fig. 1) around this node graph.

To generate physically-plausible wave behavior, our Environments team used a new custom function influenced by Horvath's extension of Tessendorf waves [Horvath 2015] [Tessendorf 2004] which provided principled controls for wind speed, fetch, and depth. This ensured effects simulations would match the base ocean surface. An additional low-frequency, high-amplitude wave function created art-directable ocean swells to influence the motion of canoes and characters. Using painted masks, artists defined distinct ocean regions with different wave functions within a single expression.

Layout artists determined the overall character of the ocean, so to simplify editing the node graph Maya prop rigs [Garcia et al. 2016] helped interactively visualize and adjust the character and timing of the oceans. Automated buoyancy simulations integrated the canoes with the final ocean surface and added realistic motion.

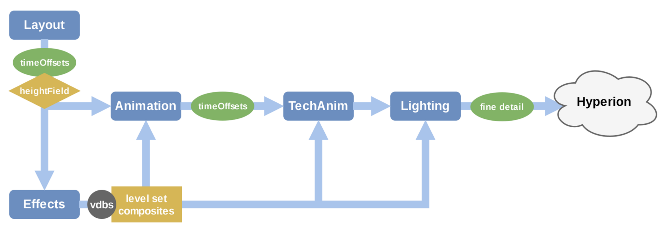

Figure 1: Basic data flow of our water and ocean assets.

2 PERFORMANCE AND SIMULATION

The Effects Department was the only group to directly author the node graph (Fig. 2). Regions requiring water interaction were selectively cut from the height field using bounding boxes, as simulating the entire ocean was not practical. These could be used for simulating swells and wakes, based off the ocean expression and boat and character contact, or separate particle splashes and sentient water performance. The results were injected into the graph through unioned simulation nodes and stitched into the height field using a custom blend node. To integrate with the procedural expression, the blend node dampened the simulation as it approached the region boundary. Shorelines were created by stitching wave and lapping water simulations with the lagoon and outer ocean expressions. In our previous system, these were separate surfaces or else were meshed together by Effects, which would be impractical in terms

SIGGRAPH '17 Talks, Los Angeles, CA, USA
 978-1-4503-5008-2/17/07…$15.00
DOI: http://dx.doi.org/10.1145/3084363.3085067

of compute time and storage size at this scale and detail level. The limited simulated regions still required several terabytes of storage per simulation (the largest had over one billion particles and required over 20 TB to store). Our simulation disk volume was over a petabyte, an order of magnitude larger than any prior show, but we still nearly hit its capacity several times during production.

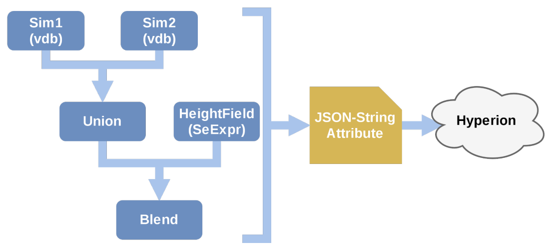

Figure 2: Example node graph.

Matching the detail of the implicit ocean function in a water simulation was impractical from a time and data size standpoint. To allow the mesh resolution to be customized without affecting the look, we split the expression into high and low frequency bands. Low-frequency components contributed to the meshed result, while high-frequency components were deferred to rendered displacement. A threshold value band-limited the representable frequencies and coarsened the mesh for artistic intent. In this way, Effects could simulate at a reasonable resolution and publish the chosen filter setting. This would act as a high-pass filter applied to the height-field in a displacement shader, restoring the complete signal by applying the fine detail to the entire blended ocean mesh.

To reduce or eliminate the amount of time spent on a given shot, we automated the water interaction process as much as possible. After a publish of the height field settings, an Effects work area was automatically set up to run and render initial simulations for boat wakes and buoyancy. These auto-sims were sometimes approved with no further adjustments. If the shot needed artist intervention, the auto-sim was a starting point to adjust simulation parameters.

3 RENDERING

A custom geometric procedural was created to generate and render level set graphs directly within Disney's Hyperion renderer. This eliminated the complications of generating a per-frame mesh from separate vendor products. This procedural operated on the input node graph to mesh a composite signed distance function. In collaboration with Pixar, we employed a variant of improved marching cubes based on [Cignoni et al. 2000][Horvath 2015] to generate the final mesh. The meshing was done from the camera to the far clipping plane, so even with fully-adaptive tessellation, it produced an enormous, computationally-expensive mesh. To accelerate this, we made approximations to the general signed distance query. For the ocean expression, we pre-tessellated the surface into an adaptive height field. This allowed the signed distance query to project the more general 3-dimensional problem into a 2-dimensional space. For simulation data, we accelerated volumetric processing with an internal MIP representation to provide quicker bounds culling and smoothing. These optimizations significantly reduced meshing times, but it remained a generally overnight process, with median times around 30 minutes per frame for the required production resolution of a full shoreline-to-horizon surface.

To amortize this generation cost, we developed a serialization process to cache the meshed water surfaces whenever node graph updates were published. This level set cache was decorated with its generation attributes, allowing us to implement an automated lazy-construction process in the shot pipeline. Lighting could fine-tune the surface displacement with exposed shader controls to amplify or filter out high-frequency detail in the near-field, far-field, or both. Because these shot adjustments only affected the displacement, no mesh regeneration was required. Overall, the disk footprint of our level set caches was minimal (1 to 10 GB per frame on average) when compared to the lengthy reconstruction cost. It also bypassed the direct consumption of hundreds of gigabytes of volumetric data at render time, which significantly improved disk, and therefore render, performance. We also leveraged the caching process to generate lightweight, cropped preview meshes for artists.

In practice, tuning the ocean aesthetic was required to ensure continuity and create nuanced realism. To address this without overwhelming Lighting, we created a new Water-Finaling department. Its job was to define and maintain continuity of the ocean looks throughout the film, dialing in settings before shots reached Lighting. To add realism, for example, artists broke up the surface uniformity via noise-based adjustments of the frequency filter. Most of the visual enhancement was accomplished through shader adjustments, eliminating the expense of regenerating ocean meshes.

4 FINDING OUR WAY

For all of its capabilities, the system had some intrinsic limitations. It was difficult to correlate artifacts in the output mesh with specific graph settings. To analyze these render-time meshing issues, we could only visualize the level set cache, which was often difficult to preview at full resolution. Caustics and light transmission through the ocean exacerbated this problem by magnifying small meshing flaws. In the future, we intend to separate the level set mesher from the renderer and provide better tools to inspect the graph.

Our flexible and robust level set compositing workflow, coupled with the automation of common simulation setups, allowed for easy creation and use of our water assets. These tools helped us deliver water at a scale and complexity that was beyond anything we had previously attempted. Our pipeline created water with a high level of nuance and artistic finesse, from the close-up caress of a hand on the ocean's surface, to a giant churning wall of water, out to the line where the sky meets the sea.

REFERENCES

Paolo Cignoni, Fabio Ganovelli, Claudio Montani, and Roberto Scopigno. 2000. Reconstruction of topologically correct and adaptive trilinear isosurfaces. *Computers & Graphics* 24, 3 (2000), 399–418.

Jonathan Garcia, Sara Drakeley, Sean Palmer, Erin Ramos, David Hutchins, Ralf Habel, and Alexey Stomakhin. 2016. Rigging the Oceans of Disney's "Moana". In *SIGGRAPH ASIA 2016 Technical Briefs (SA '16)*. ACM, New York, NY, USA, Article 30, 4 pages. DOI: http://dx.doi.org/10.1145/3005358.3005379

Christopher J. Horvath. 2015. Empirical Directional Wave Spectra for Computer Graphics. In *Proceedings of the 2015 Symposium on Digital Production (DigiPro '15)*. ACM, New York, NY, USA, 29–39. DOI: http://dx.doi.org/10.1145/2791261.2791267

Jerry Tessendorf. 2004. Simulating Ocean Surfaces. In *ACM SIGGRAPH 2004 Course Notes (SIGGRAPH '04)*. ACM, New York, NY, USA, Article 32.