Pandora in Motion: Plant Simulation in the Avatar Sequels

Alex Nowotny
Wētā FX
New Zealand
alexno@wetafx.co.nz

Steve Lesser
Wētā Digital
New Zealand
slesser@wetafx.co.nz

Christopher J. Dean
Wētā FX
New Zealand
cdean@wetafx.co.nz

Eston Schweickart
Wētā Digital
United States
eschweickart@wetafx.co.nz

Sebastian H. Schmidt
Wētā Digital
New Zealand
sschmidt@wetafx.co.nz

David Caeiro
Wētā FX
New Zealand
dcaeiro@wetafx.co.nz

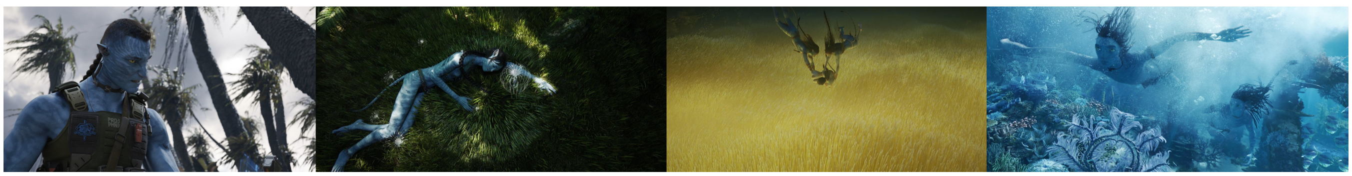

Figure 1: From left to right: background palm trees using ambient motion simulations; magical impulse field fed into grass simulation; field of anemone using ambient motion with offset timing giving a wave pattern; and layout bristling with animated underwater flora. ©Disney.

ABSTRACT

We introduce a new workflow for plant animation built for *Avatar: The Way of Water*. The workflow combines new solver features with a suite of procedural workflows to streamline the massive scope of setting the virtual world of Pandora in motion, while pushing the final quality beyond Wētā FX's previous plant simulation capabilities. More physically principled plant simulations including codimensional simulations and coupling of multiple solvers, a production workflow for asset library motions, and procedural tools to help run and apply the high-fidelity solvers to scene plants are a few of the improvements introduced to bring Pandora to vivid life.

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1 INTRODUCTION

Plant motion in visual effects plays a subtle but critical role in immersing audiences in computer generated environments. From immense jungles to small, intricate leaves, plants are often the most complex geometry in visual effects shots and need to be convincingly animated to fit into photoreal digital environments.

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The most common approaches for production plant animation are to use procedural tools or simple physical models such as Wētā FX's previous Discrete Elastic Rods-based solver [Aubry and Xiao 2014]. However, the lush world of Pandora in *Avatar: The Way of Water* required a much wider variety of terrestrial and underwater plants to be animated at a more demanding scale and level of realism than existing tools were able to provide. In particular, the inaccuracy of collisions, the lack of fluid coupling, and a Maya-only workflow for an increasingly Houdini-centric user base were limitations of the previous plant motion approach.

We created a new plant simulation framework both to deliver the show and to set a new standard for plant motion, covering cases such as underwater coral motion, close-up character-plant interactions, and complex plant shapes incompatible with simple curve approximations. Key components of the new approach were:

- *Simulation:* A simulation framework that could simultaneously handle curve, surface, volume, and fluid elements was necessary to handle the variety and quality of interactions.
- *Production Tasks:* Organizing artist tasks into asset-based ambient motion libraries or shot-specific hero plant interaction made the scope of work manageable.
- *Proceduralism:* New procedural workflows let the slower but higher quality simulations be applied to nearly every plant.

2 IMPLEMENTATION

Data Representation. Our plant models were mostly created with Lumberjack, an internal tool to represent hierarchies of trunks, branches, stems, and leaves. Internally, each segment was represented as a curve-based skeleton with per-vertex anisotropic thickness data. However, meshes were used for some geometries, such as broad kelp leaves. We wanted our new approach to be compatible with this existing representation.

Multi-Physics Solver. No single existing solver could handle the range of plants or their interactions with water, wind, or characters to the fidelity level required by the show. We therefore adopted the in-house multi-physics framework Loki [Lesser et al. 2022] to mix and match combinations of geometric and fluid representations, complete with a more accurate collision model. Mostly commonly, we simulated Lumberjack curve hierarchies with elastons [Martin et al. 2010]. We found this model to be a good fit for plants as it can naturally handle the transition from branching 1D curves to 2D sheets within the same object. Discrete Elastic Rods [Bergou et al. 2008] were used for performance when no curve hierarchies or complex geometries were needed, such as grass fields. Collision fidelity was key for all geometry representations and often relied on Loki's robust hard contact system [Daviet 2020]. All geometry representations could couple with Loki's volumetric or free surface fluid solvers through buoyancy and drag forces to reliably model water and wind interaction.

Guiding. Occasionally a plant performance needed to be driven by upstream animation or follow motion which was not physically motivated. An extension termed *partial kinematics* was added to Loki to describe a plant as partially kinematic (driven by artist animation, e.g., around character interactions) and partially dynamic (simulated) based on vertex-varying targets and weights.

Production Tasks. Tasks were split into two categories: ambient motion and hero interaction.

Ambient motion consisted of building libraries of animation for a particular plant which could be used in many instances and shots. Each entry was generated based on wind or underwater simulations across multiple directions and were applied to plant instances in shots based on orientation with time and amplitude offsets.

Hero interactions were often close to camera and involved interaction with shot-specific elements such as character motion or a water surface, so the simulations could not be reused. In these cases, accurate collisions, partial kinematics, and simulated geometry which closely mapped to the rendered geometry were key.

Proceduralisation. The complex scenes in *Avatar: The Way of Water* contained hundreds of thousands of plants and trees. The integration of Wētā's Lumberjack as Houdini custom primitives offered procedural workflows and speedy visualizations for plants and corals, including high-level information to aid procedural and manual selection of plants and plant components. Artists were able to procedurally analyze the scene for interacting plants, and then extract skeleton data from relevant plants from root to leaf to allow holistic high-fidelity simulations.

Before Loki simulation, plants needed to be individually parameterized by the artist with intrinsic physical properties such as density, thickness, and young's modulus, which were stored against each asset for sharing and future reuse.

The parameterized skeleton data was seamlessly transported via Houdini to the Loki Solvers. Artists were able to apply simulation results to the lumberjack plants in Houdini to judge the visual performance in-viewport. This rapid preview facilitated artists to post-process and refine the simulation data before handover to the lighting department. The Houdini integration allowed artists to rip leaves from trees, break and remove branches, craft complex leaf-deformations, hide plant components, or extract hero geometry components for further processing to suit the shot's requirements.

3 PRODUCTION USE

Submerged coral. The adoption of these tools afforded artists an opportunity to realistically simulate underwater plants that were directly driven by procedural ocean waves, underwater currents, or the wakes of swimming creatures. Some coral could be simulated procedurally as 2D lumberjack curve skeletons, while more fantastical coral required proxy mesh representations that served as a motion guide under a cloth simulation. For closeup plant interactions, Loki's robust collision system [Daviet 2020] ensured that pixel-perfect collision response was maintained, and after a number of iterations tweaking the plant properties, the animation quality was outstanding.

Underwater plants were simulated with multiple current directions and applied en masse to layouts via the ambient motion approach. The animation directionality and time offsets were determined by each scene's water fields or current direction. This is best illustrated in the underwater anemone field (Fig. 1, center right), which featured only 8 plant animations.

Art direction. In Kiri's glade (Fig. 1, center left), a physically-based grass simulation was combined with a magical wave pulse force. Loki accepts custom artist-defined fields for creating any imaginable movement while maintaining collisions and physical realism.

In the film's funeral scene, sea anemone were partially animated to grasp and submerge a character. Loki's kinematic curve solver granted artistic control for blending hand-animated motion with simulated animations, mixing real world physics with fantastical alien plant movements.

Solver mixing. Seaweed on the rocky beach posed a challenge wherein buoyant plants floated on the water's surface, partially underwater, disturbed by characters as tidal waves lapped against the surface of a rock. This scene was achieved thanks to Loki's solver mixing and the physically-based model for underwater pressure and plant buoyancy, using the direct result from water simulation.

During scenes of heavy rainfall, particle solvers were coupled with the elaston solvers to achieve a realistic rain droplet impact effect, where the plant and droplets both may influence one another. The result was a truly life-like animation that could be applied to entire jungle layouts via the ambient motion technique.

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