Avatar: The Way of Hair, Cloth, and Coupled Simulation Supplemental Technical Document

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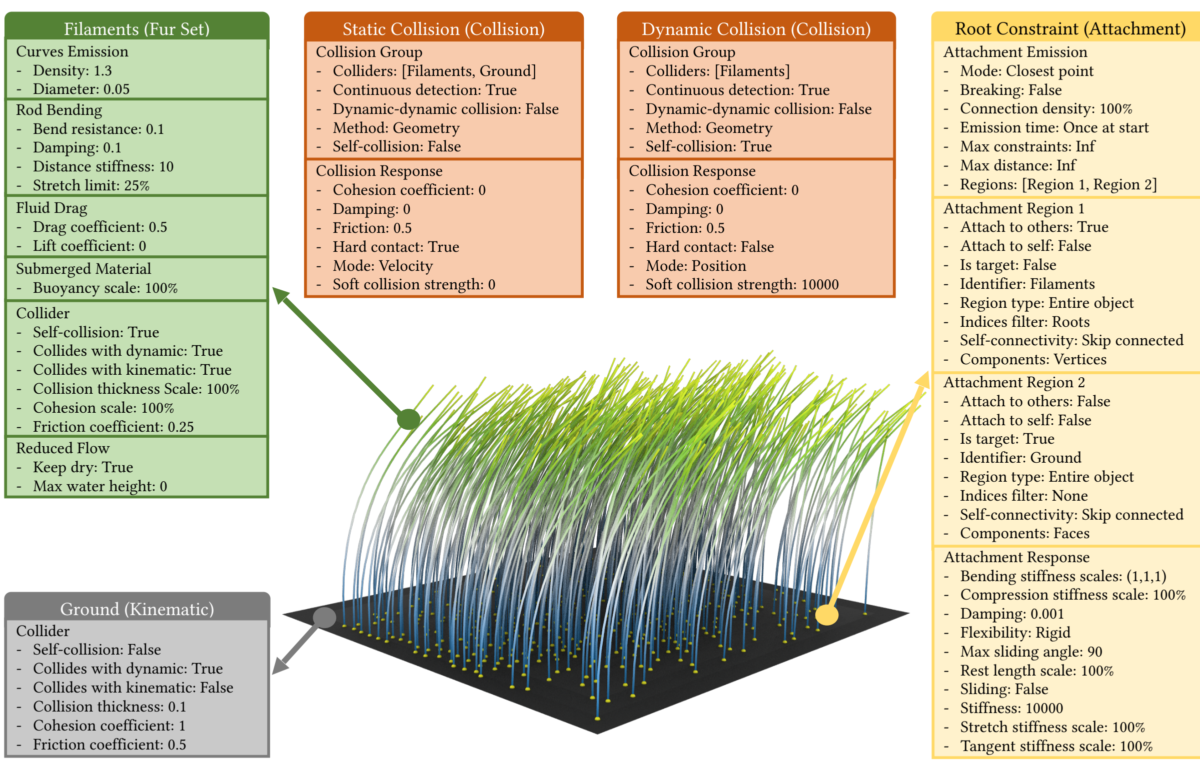

Figure 1: A sample scene configuration. Boxes represent Scene Elements; each contains Scene Element Components that specify per-object attributes. The Attachment and Collision Scene Elements contain no scene data, but represent attachment instances and collision groups within the scene.

1 SCENE ELEMENT COMPONENTS

Setting up a scene with a reusable Behavior tree is typically preferable to manually configuring each object instance. Doing so condenses many repetitive and error-prone operations into a standard and automatic procedure. In addition, it organizes the scene on a per-domain level, offering a hierarchy for the existing phenomena and straightforward extensibility to other domains such as drips or muscles. However, material properties usually exist on a per-object rather than a per-phenomena basis. For this purpose, we introduce a novel construct called a *Scene Element Component (SEC)* to carry local parameters for each object.

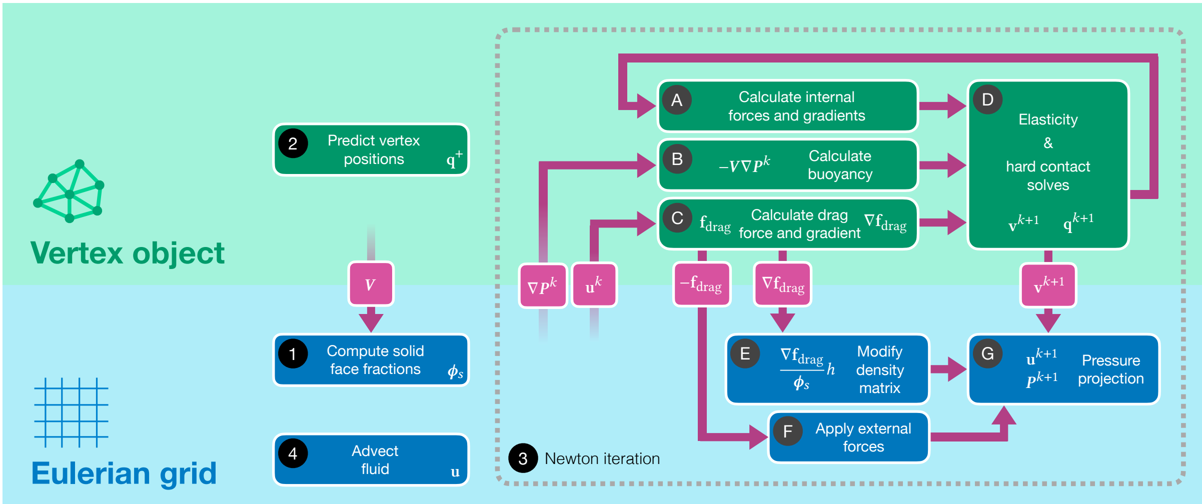

Figure 2: Our scheme for coupling a Lagrangian vertex object (hair, cloth) with an Eulerian fluid (water, air). For every time step, stages 1-4 are executed in order. Stages A-G are executed in order for each Newton step to obtain the next set of approximations $\mathbf{v}^{k+1}$, P^{k+1}, and $\mathbf{u}^{k+1}$. ©Wētā FX.

An SEC is a suite of attributes that gets attached to a Scene Element and configures the corresponding behaviors. For example, a Discrete Shell SEC includes Young's Modulus, Poisson's Ratio, bend resistance, damping coefficient, and the channel name for rest positions, so the Discrete Shell Material Behavior can set up these properties for an individual piece of cloth. Depending on the object type, a Scene Element may carry different combinations of SECs. A fur set may carry a Rod Bending SEC and a Drag SEC to configure the corresponding Rod Bending Material and Drag Force Behaviors. In the absence of an expected SEC, a Behavior will apply default parameters to the corresponding objects and actions.

SECs may also be used to specify interactions. This is achieved by creating Scene Elements that hold no data but still carry SECs. For instance, a collision Scene Element would contain a Collision Group SEC and a Collision Response SEC. The Collision Group SEC specifies a list of colliders and methods for collision detection. During runtime, the detected collisions of this group will be resolved using the strength and damping from the Collision Response SEC in same Scene Element. To appoint multiple collision methods, additional collision Scene Elements could be created, each containing its own Collision Group and Collision Response SECs. At the same time, dedicated objects may have their own Collider SEC to fine tune local collision properties like friction or collision thickness. A more comprehensive example of SECs working in practice is shown in Figure 1.

2 COUPLING

The coupling between Lagrangian cloth and hair and the Eulerian air or water is through a porous material approximation that follows the "weakly" coupled approach of prior works [Stomakhin et al. 2020; Wretborn et al. 2022]. Figure 2 shows an overview of our coupling scheme.

At the beginning of each time step, we rasterize the solids onto the Eulerian grid as the solid face fraction ϕ_s, and predict the vertex positions with forward advection $\mathbf{q}^+ = \mathbf{q}^0 + \mathbf{v}^0 h$, where $\mathbf{q}^0$ and $\mathbf{v}^0$ are the initial vertex positions and velocities, and h is the size of the time step. Newton's method then iteratively updates the positions $\mathbf{q}$ and velocities $\mathbf{v}$ for solids as well as the pressure P and velocity $\mathbf{u}$ fields for fluid. The time step ends with the advection on fluid.

The k-th Newton iteration starts with an implicit solid solve by assuming prescribed fluid from last iteration. This includes collecting all forces and force gradients, internal and external, including drag and buoyancy given fluid velocities $\mathbf{u}^k$ and pressures P^k, and performing an implicit elastic solve with hard contacts [Daviet 2020] to update the solid velocities $\mathbf{v}^{k+1}$ and positions $\mathbf{q}^{k+1}$. The drag force $\mathbf{f}_{\text{drag}}$ and their gradients $\nabla\mathbf{f}_{\text{drag}}$ are then negated and rasterized to the Eulerian grid, followed by a pressure solve assuming prescribed motion on solids $\mathbf{v}^{k+1}$.

Anisotropic Drag Force. We use the anisotropic drag model presented by [Fei et al. 2018]. Here we briefly reiterate the formulation for completeness. According to the Ergun equation, the anisotropic drag coefficients $C_\perp$ and $C_{||}$ are

$$C_l = \frac{1}{k_l} + \xi_N \frac{1.75}{\sqrt{150 k_l}} \frac{1}{(1-\gamma)^{3/2}} \left(\frac{\rho D |\Delta \mathbf{v}|}{\mu}\right)^c, \; l \in \{\perp, ||\} \quad (1)$$

for fluid density ρ, dynamic viscosity μ, relative velocity $\Delta\mathbf{v}$, the material permeability $k_\perp$ and $k_{||}$ in the material normal and tangential directions, material fraction γ, fiber diameter D, a user-controlled coefficient ξ_N to scale the non-linear contribution, and the drag degree c. [Fei et al. 2018] proposed equations for $k_\perp$ and $k_{||}$; however, for art directability, we opted to let the users specify them. Considering that the artists are usually more familiar with the drag coefficients than permeability, we defined the anisotropic user drag scales $\xi_\perp$ and $\xi_{||}$ for normal and tangential components by

$$\begin{pmatrix} 1/k_\perp \\ 1/k_{||} \end{pmatrix} = \frac{\xi_D}{10^4} \begin{pmatrix} \xi_\perp \\ \xi_{||} \end{pmatrix}, \quad (2)$$

where ξ_D is a global drag scale that affects both components. The denominator 10^4 in Equation (2) was chosen arbitrarily such that most simulations could be done with $\xi_D \approx 1$.

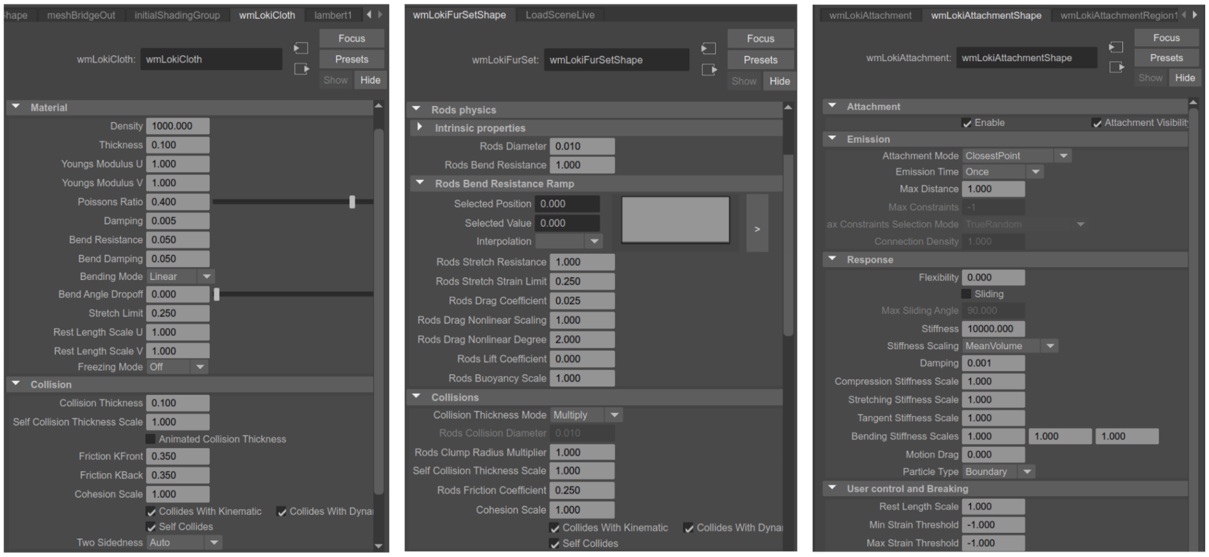

Figure 3: Examples of the conversion nodes (cloth, hair and attachment) in Maya for subsequent Loki graph evaluation. ©Wētā FX.

The final drag force is defined as

$$\mathbf{f}_{\text{drag}} = -\frac{\mu V}{D^2} \boldsymbol{R}\boldsymbol{C}\boldsymbol{R}^T \Delta\mathbf{v}, \tag{3}$$

where $\boldsymbol{C}$ is $diag(C_\perp, C_\perp, C_{||})$ for rods or $diag(C_\perp, C_{||}, C_{||})$ for faces, $\boldsymbol{R}$ is the rotation matrix from the element's local space to the world space, and V is the volume of the solid element.

Lift force. We also provide a lift force that is proportional to the drag force, but orthogonal to the relative velocity. We define the lift force as

$$\mathbf{f}_{\text{lift}} = -\xi_L (\boldsymbol{Q} - \frac{\boldsymbol{Q} \cdot \Delta\mathbf{v}}{|\Delta\mathbf{v}|^2} \Delta\mathbf{v}), \tag{4}$$

where $\boldsymbol{Q} = \boldsymbol{e}_{||} \times (\boldsymbol{e}_{||} \times \mathbf{f}_{\text{drag}})$, and ξ_L is a user-controlled lift scale. The second term in Equation (4) projects out any contribution of lift in the direction of the relative velocity. This resembles the one provided in Maya's Nucleus.

3 MAYA INTERFACE

Figure 3 shows examples of the Maya conversion nodes that wrap data into Scene Elements and attach SECs for CreLoki node graph evaluation. The interface resembles Maya's Nucleus to ease artists' transitions between simulators, although Loki's design principles and algorithm arsenal are fundamentally different. A few examples of familiar concepts include bend angle dropoff, wrap/freeze mode, and sliding attachments. Meanwhile, Loki offers additional features, such as anisotropic cloth, cohesive contacts, and rigid attachments, which help the users push the simulation realism to the next level with minimum effort.

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