Blazing a New Trail of Curls

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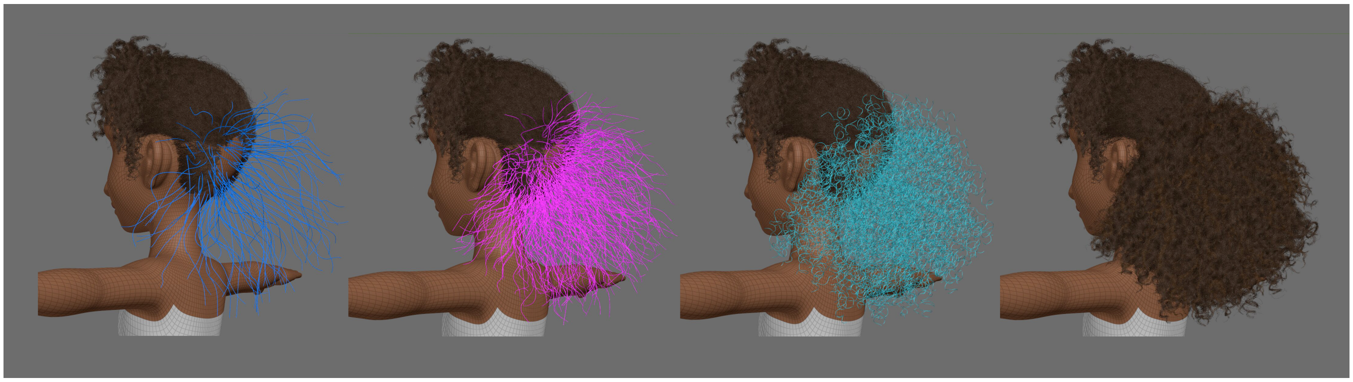

Abstract

For Disney and Pixar's *Toy Story 5*, we created a character named Blaze with tightly coiled, interconnected curls requiring rapid iteration during exploration. We developed a new grooming structure enabling interactive visualization with production designers and art leads, built for flexibility and rapid modification. For dynamics, we deployed *Fizt Strands*, built atop our *Fizt* cloth solver, improving collision and stability in production. These advancements enabled believable curl simulation that complimented the character's ethnicity and personality.

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1 Groom Process

Traditional approaches to curly hair grooming present significant limitations. Procedurally curly render hairs warped to straight simulation guides lose curl fidelity during dynamics, resulting in self-penetration and no curl bounce. Conversely, procedurally-generated curly guides embed curl shape within the modeling process, increasing iteration time during look development. Neither approach satisfied production requirements for rapid iteration and robust shot interaction.

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Our groom solution leverages simple modeling and proceduralism to generate coincident render hairs and groomed guide hairs. The workflow begins with low-resolution guides defining silhouette and length. An intermediate high-resolution representation is generated using procedural operators (scraggle, loft, etc.) to introduce natural variation, while maintaining simple input geometry. Curl procedurals (width, number of curls, etc.) are then applied to produce final groom guides with one-to-one lock representation. Render hairs interpolated from these guides achieve improved warping accuracy due to direct curl correspondence.

This pipeline enabled efficient look exploration during preproduction. Interactive rough sculpting and adjustment to procedural curl attributes during review sessions reduced iteration cycles from weeks to days. Finely tuned curl details were achieved via isolating certain curls from the procedural generation, allowing for further artistic control. However, the approach introduces a computational tradeoff: complete curl representation in simulation guides increases collision complexity and solve time, historically a source of instability in production.

2 Simulation

Taz, our hair simulator debuting in *Brave* [Iben et al. 2013], had stability issues with Blaze's tight curls. Our other simulator, *Fizt*, uses stable implicit integration and has superior collision handling. To support simulation of curves in *Fizt*, we employed an altered version of our cloth dihedral bending[Kim and Eberle 2022] for twist and [Shi et al. 2023] for bending. We call this formulation *Fizt Strands*. For curly hair, there are two virtual triangles for an edge with its neighbors. If one or both of these triangles becomes degenerate, the edge loses the ability to compute a twist force, but what's worse is that if one of these triangle normals flips, it can result in a sudden large forces which violently twist the hair. Our first step to mitigate this behavior is to define our twist stiffness as a factor of bend stiffness that is clamped to $[0, 1]$. It seems implausible that hair would resist twist deformation strongly and easily bend at the same location along a curve. This reduces the magnitude of sudden twist forces from angle discontinuities, but it does not eliminate them.

History tracking of the normals and twist angles was key in detecting and further suppressing these discontinuities. When we detect a triangle normal flip between steps, we assume that this would not occur from a large twist rotation[1]. Negating the appropriate terms for the flipped normal in the dihedral twist formulation prevented most discontinuities, but another mechanism was still required. Let $\Delta\phi_i = \phi_{curr} - \phi_{rest}$ define our twist deformation from rest at the current step. Between time-steps, we examine $|\Delta\phi_i - \Delta\phi_{i-1}|$. If this exceeds π, we adjust our winding number to minimize $\Delta\phi_i$.

There are shape limitations to our *Fizt Strands* model. Let θ_e represent the angle between two consecutive edges along a curve. If $\theta_e > 179.85^\circ$ or $\theta_e < 0.15^\circ$, we deem this configuration to be too straight for our twist model to handle and ignore twisting forces on such elements for the time-step. This formulation seamlessly fits into *Fizt*, which allows for two-way coupling with cloth when necessary. The resulting linear system has poor numerical conditioning, which is handled by using a sparse direct solver. Our simulations remain stable with one Newton step per time-step, but we typically run with five for better motion quality.

3 Testing and Results

The combined approach yielded production-ready stability. Enhanced contact resolution enabled previously problematic interactions, eliminating much of the manual correction required in prior productions. Artists shifted focus from cleanup to performance enhancement, with unified cloth-hair simulation enabling richer coupled dynamics. The modular grooming structure reduced groom variant turnaround from weeks to days, showcased in Blaze's hair down variant.

Utilizing proper collisions posed new challenges and required revisions to our grooming process. Sim guides intersecting the scalp yielded unstable visual results and pops as the solver effectively fixed the accidental intersections. Groom penetrations needed cleanup and regional nailing was required to ensure visual stability. The added stability and collision robustness of *Fizt Strands* comes with longer solve times than *Taz*, but these have extended our artistic reach and reduced the amount of post-sim fixes required.

Preserving designed silhouettes under gravity remains challenging. Previously with *Taz*, the solver would preload bend forces against gravity by modifying the rest shape. While effective, this approach ignored contributions from other forces like contact and friction, sometimes leading to overcompensation and unnatural motion artifacts.

In *Fizt Strands*, lacking that feature, we authored a rest shape externally. We first set dynamic parameters, simulated the hair at rest under gravity and other forces, and used the difference in bend angles between the settled and rest shapes to pre-bend the rest shape proportionally, creating a lofted rest pose.

[1]There's no way to distinguish between a triangle in 3D inverting or rotating in a single linear step.

This addressed *Taz's* overcompensation issues and worked well on several characters. However, the tight coupling between rest shape, simulation parameters, and guide topology made iteration costly in production. Breaking changes required regenerating simulations and poses. In practice, artists often resorted to manually sculpting lofted rest shapes instead. Currently, we are developing a new preload solution and conducting more rigorous testing on differing hairstyles.

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