Holding the Shape in Hair Simulation

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Figure 1: Example of a single simulation shot of Helen from *Incredibles 2*. Initially the wind forces cause the hair to be pulled back (*left pair*). When Helen comes to rest, the hair simulation constraint forces pull the shape back to the groomed style (*right pair*). The constraint used for this force is based on the centroid of the selected points (shown in white) and can be created once during simulation setup. ©Disney/Pixar

ABSTRACT

Hair simulation models are based on physics, but require additional controls to achieve certain looks or art directions. A common simulation control is to use hard or soft constraints on the kinematic points provided by the articulation of the scalp or explicit rigging of the hair [Kaur et al. 2018; Soares et al. 2012]. While following the rigged points adds explicit control during shot work, we want to author information during the setup phase to better follow the groomed shape automatically during simulation (Figure 1). We have found that there is no single approach that satisfies every artistic requirement, and have instead developed several practical force- and constraint-based techniques over the course of the making of *Brave*, *Inside Out*, *The Good Dinosaur*, *Coco*, *Incredibles 2*, and *Toy Story 4*. We have also discovered that kinematic constraints can sometimes be adversely affected by mesh deformation and discuss how to mitigate this effect for both articulated and simulated hair.

CCS CONCEPTS

• **Computing methodologies** → **Physical simulation**.

KEYWORDS

hair, simulation, groom

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1 MODIFYING THE REST SHAPE

Since *Brave*, our most basic method for holding a hair's groomed shape is to counter the force of gravity by modifying the rest shape. Internally, we call this gravity preloading. While there are optimization approaches to counteract sagging [Twigg and Kačić-Alesić 2011], we are able use a direct approach. We modify the rest target vectors used for bending springs in our proprietary hair simulator Taz [Iben et al. 2013], although this idea could be applied to other models using target vectors for the hair shape. We observed that we can set the gravity force equation, $\boldsymbol{f} = m\boldsymbol{g}$ (m mass, $\boldsymbol{g}$ gravity) equal to the spring force equation from Hooke's Law, $\boldsymbol{f} = -k\boldsymbol{d}$, and solve for the displacement vector $\boldsymbol{d}$. The resulting direction computed during rest target initialization is $\boldsymbol{d} = -(cm\boldsymbol{g})/k$, using the constant c to control the amount of gravity preloading. We recently improved this by summing the mass up to the point being computed, which provided more accurate gravity compensation.

In certain cases, we can dynamically recompute the rest shape to account for deformation of the hair, such as with Joy's movable cowlick on *Inside Out*, or change the rest lengths of hair springs based on the character scaling. While this information affects the hair model, it cannot maintain stylistic features like hair clumps that should move together. Thus, we developed additional artistic controls that either hold the hair styles during motion or allow for more dynamic responses.

2 CENTROID CONSTRAINT

On *Incredibles 2*, Dash's and Helen's hair styles were artistically required to have regions that moved en masse yet be changed dynamically. Initially we tried our previous simulation techniques for hair grouping used on Spot in *The Good Dinosaur*. On that character, we constrained the hair-to-hair contacts that were initially touching at the tips to keep clumps of hairs grouped throughout the simulation. Although this worked well for Spot's groom where

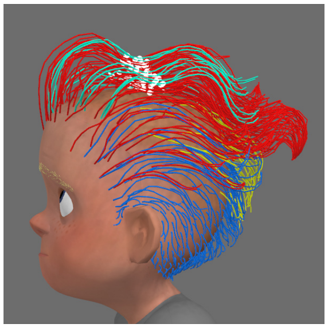

Figure 2: We used a scalp relative constraint in several places on Dash, including the top of his head (shown in white), to aid in groom preservation. ©Disney/Pixar

hairs tips ended near each other, we quickly ran into problems with Helen's hair. It was difficult to have the hair at the tip maintain the shape of the groom and have the hair-to-hair edge contacts be exactly touching to create the constraints; hair contacts would either push the hairs apart when increased or not touch when decreased, which missed hairs that were to be automatically kept together. Dash provided similar challenges with the back swoop of his hair.

To address these issues, we introduced a new constraint by first computing the centroid of a selection of hair points, then constraining each point to this centroid. This centroid was dynamically updated during the simulation based on the simulated points. This approach is similar to shape matching [Müller et al. 2005], but we only maintain the distance from the centroid and not the overall spatial relationship. We instead rely on the already present hair-to-hair edge contact springs to provide soft constraints to neighboring hairs, letting the hair move dynamically. The resulting constraint pulls the hair towards the groom shape while giving dynamic responses to external forces like wind (Figure 1).

3 EFFECTS OF MESH DEFORMATION

During the development of *Coco*, we found that some hair styles were more difficult to setup for simulation, such as a bun that has a shape relative to the scalp. In this case, we initially constrained the hair tips to the kinematic location provided to the simulator. However, articulation of the scalp, such as when a character raises her eyebrows or smiles, quickly precluded this constraint type as an option. Because the articulation propagates through the scalp geometry, it rotates the kinematic hair away from the scalp and creates invalid target points for the constraint. As is common practice, we then created a constraint type that automatically finds the closest point on the hair's scalp upon initialization, using barycentric coordinates for tracking. This hard or soft constraint then maintains the distance to the computed scalp point during simulation. We have used this scalp relative constraint on several grooms, including *Incredibles 2's* Dash (Figure 2) and *Toy Story 4's* Bonnie, and found it gives better control over the desired shape of the hair.

However, while this addressed the immediate constraint problem, the deformation of the mesh was still an issue. The primitives to which hairs are rooted can undergo large deformations, especially around the joints of furry characters. After unexpected behavior

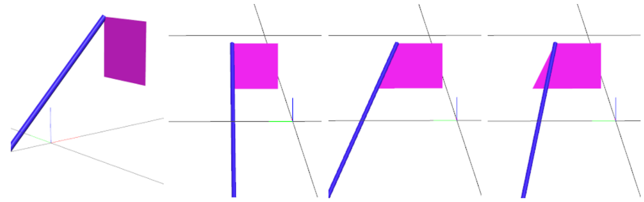

Figure 3: We created a square and attached a non-orthogonal hair to its surface (*a, b*) to test the effects of mesh deformation on hair. When we use the deformed surface directly to compute the hair transformation (*c*), the hair undergoes large rotations. When we compute this transformation in an unbiased way, the rotation is reduced (*d*). ©Disney/Pixar

on *Coco's* Pepita and *Incredibles 2's* Dash, we discovered that our unsimulated hair was being affected by the mesh deformation in an inconsistent way, most noticeably when hairs that are not grown perpendicular to the scalp (Figure 3(*a, b*)).

This inconsistency was caused by the chosen computation method for the coordinate frame. The common approach we were using in both our proprietary animation system, Presto, and Taz was to construct an orthonormal coordinate frame using cross products given two vectors from the scalp as input. The vectors used depend on the discretization of the surface; we use two triangle edges for a mesh and the limit frame for a subdivision surface. However, this coordinate frame can undergo large rotations when mesh deformations include stretches and shears (Figure 3*c*). This approach is also biased by the choice of edges used for coordinate frame construction; choosing two different edges of the triangle can yield a different rotation or be degenerate.

To avoid this issue, we construct a rotation for each hair root that best fits the scalp deformation between the rest pose and current pose. We apply this rotation to an orthonormal rest frame to obtain the frame of the current pose. This approach avoids unnecessarily large rotations of the hair root (Figure 3*d*) and avoids bias in the frame computation. Our approach is based on previous techniques that extract a minimal rigid transformation from an arbitrary deformation. This construction provides more stable root frames during scalp deformation for both the kinematic points and dynamically simulated hair and is in use on all the characters in *Toy Story 4*, including the furry Bunny and Ducky.

REFERENCES

Hayley Iben, Mark Meyer, Lena Petrovic, Olivier Soares, John Anderson, and Andrew Witkin. 2013. Artistic Simulation of Curly Hair. In *Proc. of the 12th ACM SIGGRAPH/Eurographics Symposium on Computer Animation*. 63–71.

Avneet Kaur, Maryann Simmons, and Brian Whited. 2018. Hierarchical Controls for Art-directed Hair at Disney. In *ACM SIGGRAPH 2018 Talks*. 13:1–13:2.

Matthias Müller, Bruno Heidelberger, Matthias Teschner, and Markus Gross. 2005. Meshless Deformations Based on Shape Matching. *ACM Trans. Graph.* 24, 3 (July 2005), 471–478.

Olivier Soares, Samantha Raja, Rich Hurrey, and Hayley Iben. 2012. Curls Gone Wild: Hair Simulation in Brave. In *ACM SIGGRAPH 2012 Talks*. 22:1–22:1.

Christopher D. Twigg and Zoran Kačić-Alesić. 2011. Optimization for Sag-free Simulations. In *Proceedings of the 2011 ACM SIGGRAPH/Eurographics Symposium on Computer Animation*. 225–236.