Simulating Rapunzel's Hair in Disney's *Tangled*

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1   Introduction

Hair simulation is known to be a complex problem in animation. In *Tangled* we have the extreme task of simulating 70 feet of hair for the film's main character, Rapunzel. The excessive hair length in addition to the loose style and intricate structure of the hair present many unique challenges in simulation. Moreover, the specific art direction of the film adds to the complexity of the simulation.

2   Simulation Features

To simulate Rapunzel's hair we use our proprietary hair simulation software, *dynamicWires*, which utilizes a mass-spring system for the dynamics of curves. We have extended this system to handle the unique challenges of Rapunzel's hair.

Hair Piling and Volume Preservation   Rapunzel's hair constantly piles on top of itself on the ground and any other objects or characters in the scene. During simulation, spring forces are applied to colliding segments on the fly to help maintain the volume as well as act as a frictional force on the strands moving over each other or moving apart. The springs only form on direct contact and break after the curve segments have moved beyond a distance threshold that is tuned based on how the hair strands need to slide over each other or stick together.

For run-time efficiency we offset the complexity of simulating the immense length of hair by simulating a sparse set of guide curves, around 200. The lack of dense coverage of the curves is most evident near her head where it is easy for curves on the outer, most-visible regions of the hair to fall through the gaps in the hair volume into the inner, bottom layers of hairs. We add extra collision support structures to fill the gaps in the hair volume by connecting the control points of neighboring curves and use the segments that are created from the connections as additional collision influences. The simulation curves then collide with these support structures as they do with any other curve.

Effortless Dragging   In reality, Rapunzel would need to exert a great deal of physical effort to drag her hair behind her. The art direction of the film calls for Rapunzel to be quite adept at moving with this massive amount of hair; the hair needs to glide easily with her when she moves, causing no strain on her motion, and come to a rest when she stops.

To control the degree of pull on her hair, we add a tangential friction parameter for the ground contacts by separating the component of friction that lies in the direction tangent to the hair strands. The tangential friction component is then scaled down by as much as two orders of magnitude in comparison with the remaining friction. The hair is then able to easily slide along its length without spreading outward on the ground. Moreover, using a high static friction for ground contacts helps stop the hair from continually sliding along the ground after she stops moving.

Simulation Freezing   Considering that the visible length and activity of the hair vary per shot, the minimum length of hair needed for simulation also varies per shot. We use a simulation-freezing feature that turns-off the simulation for the back part of the hair, allowing us to adjust the length of simulated hair per-shot, accelerating the run-time of the simulation significantly.

For scenes where the back of the hair is not visible but Rapunzel is still quite active, the non-visible, non-simulating end of the hair is detached from the rest of the hair so it does not pull back on the still active portions. When the detachment makes the weight of the hair appear too light, a constraint is added to the end of the simulated portion to pull back slightly, giving the illusion of weight.

Alternatively, large amounts of hair are often visible lying on the ground but are not in motion. When these inactive portions of hair are visibly connected to active portions we keep the frozen section attached and use spring forces to smoothly blend from the simulating to the non-simulating portions. The computational resources of the simulation are thus used for the highly active regions of the hair without wasting time simulating regions of the hair that do not move.

Hair-Hair Constraints   Controlling the hair while still allowing it to move naturally takes special consideration. We place loose springs between nearby curves to subtly influence the hair to hold its resting configuration, preventing it from falling everywhere, such as spilling over her shoulders, covering her face and body. Given a distance breakaway parameter, these constraints automatically attenuate their strength past a certain distance and break completely beyond another distance. This keeps the hair generally together without forcing it to move as a single mass. The hair can still break apart from the volume into smaller pieces, giving a natural look to the overall motion.

3   Results

The simulation features described have enabled us to simulate the extreme length of Rapunzel's hair. Simulation freezing and the collision support structures helped us to simulate only a fraction of her total amount of hair per shot, easing the burden of this complex hair immensely. Effortless dragging and hair-hair constraints gave us control over the hair's motion to let the hair move naturally yet still adhere to the art direction of the film.