Simulating Wind Effects on Cloth and Hair in Disney's Frozen

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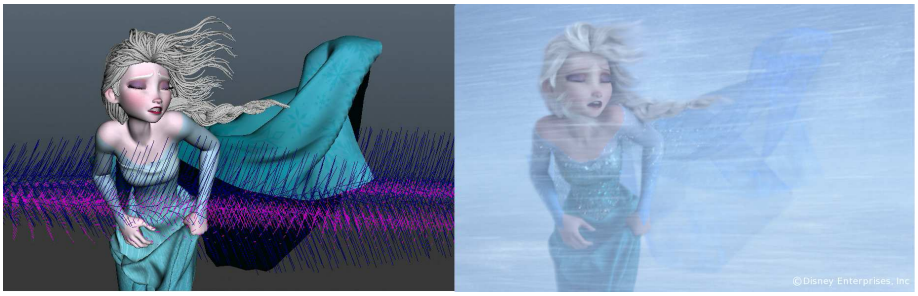

Figure 1: *Visualization of wind fields applied to Elsa's hair and cloth simulation.*

1 Introduction

The winter wonderland of Disney's feature animation *Frozen* presented several unique technical and creative challenges for the Character Simulation team. One of the most prominent was capturing the interaction of wind with the cloth and hair simulations. The approach to meet this challenge involved low level changes to the simulation software, the creation of custom fields and visualizers, and the integration of *windicator* and wind gust rigs into the shot production pipeline. These three primary components gave the artists a tool set that allowed them to hit the desired art direction.

2 Improved Lift and Drag Model

On the simulation solver side, we made two modifications to improve the accuracy of cloth/hair-air interactions. First, we adapted our solvers to take in not only force fields, but also velocity fields which affect the simulation through lift and drag forces. We then made our handling of lift and drag more accurate by switching from lift/drag forces that are linear with respect to the relative velocity (i.e., Stokes' drag) to quadratic forces. This is a better model for fluids with high Reynolds number (e.g., air) and produces more interesting, turbulent effects. We also separated the lift and drag components for greater control.

$$\boldsymbol{F} = \frac{1}{2}\rho A\left((C_D - C_L)(\boldsymbol{v}\cdot\boldsymbol{n})\boldsymbol{v} + C_L|v|^2\boldsymbol{n}\right)$$

Here, ρ is air density, A is the area of the cloth/hair surface, $\boldsymbol{v}$ is the relative velocity, C_L and C_D are user-defined lift and drag coefficients, and $\boldsymbol{n}$ is the geometry normal. Our solver requires SPD force gradients, and we found the substitution $\boldsymbol{v} \approx (\boldsymbol{v}\cdot\boldsymbol{n})\boldsymbol{n}$ after differentiation was sufficient. The new lift and drag model allowed for the simulation of gossamer fabrics like Elsa's ethereal frost cape.

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3 Wind Field Authoring Tools

We developed new tools that allowed artists to author and visualize wind fields using SeExpr, an expression language used throughout the studio, and now available as an open source project[1]. Pre-built wind, ripple, and volume axis fields were provided, as well as the ability to convert arbitrary geometry into fields. Artists could also craft custom fields if desired through the expression interface. The field velocity was taken into account by the solver, directly interacting with the lift and drag models to produce more natural motion. The fields provide control via ramp widgets for shaping the frequency and pattern of the waves in the wind, and attributes for the various magnitudes, noise and turbulence functions.

4 Windicator and Gust Rigs

In addition to technical improvements, we also needed a way for the directors and artists to craft the performance of the wind long before the clothing and hair were simulated. A windicator rig consisting of a simple directional arrow and an animatable control for wind intensity served as the primary source of continuity across departments. A gust rig was provided to animators that allowed them to visualize and tune the timing of the wind gusts to their performances. The windicator and gust rigs were rendered in the shot for reference. This visual feedback proved to be invaluable to the downstream simulation departments and greatly diminished the need for creative and continuity redos.

5 Shot Simulation Wind Workflow

In each shot, the artist checked the windicator and gust rig animation to ensure continuity of wind direction and speed. The lift and drag attributes were exposed and keyframable on the simulation shapes and could be further tuned with painted maps. The artist placed and tuned the SeExpr fields. The real time field visualization allowed tuning of the wind behavior before simulation, which dramatically sped up iteration times. Once the general behavior was defined, the artist could wedge the lift, drag and field attributes to further fine-tune the desired performance.

The artist-friendly design of the lift and drag models, custom SeExpr fields, and windicator and gust rig visualizers made for a suite of tools that allowed the Frozen crew to craft the wind's performance from Layout through Technical Animation and Effects, in a physically plausible way while hitting the desired cloth and hair art direction to a level that was previously unattainable at Disney.

[1] http://www.disneyanimation.com/technology/seexpr.html