Ill-Loom-inating *Brave's* Handmade Fabric

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1. Introduction

One of the key challenges faced during production of the movie Brave was the shading and rendering of characters' hand-made clothing. Previous Pixar films often used Polynomial Texture maps to describe subtle inter-yarn shadowing behavior. However PTMs don't solve the problem of rendering thick hole-filled cloth with loose yarns. Brave required much more natural detail than existing techniques would allow.

We created two solutions to solve these problems.
Firstly a volumetric surface shader which shaded cloth by performing adaptive curved ray marching of an implicit tangent-space distance field.
Secondly a system for generating Renderman curves over the surface of a subdivision mesh. These curves represented yarns which effectively modeled a woven surface at render-time. The yarn-curves could be shaded using the previously described volumetric shader.
These techniques were further extended to allow design and rendering of complex embroidery used for the tapestry.

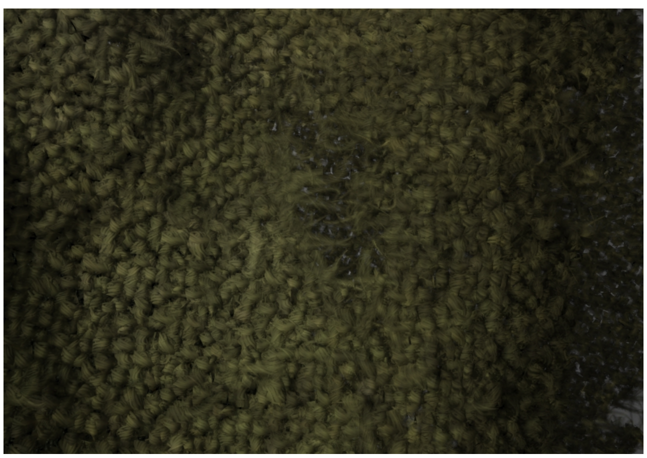

Figure 1. Closeup of hole in the Witch's shawl. © Disney/Pixar

2. Distance field shading

We designed a volumetric shader evaluated in tangent space which ray-marched through a weave pattern described as an implicit distance field. The distance field is computed on-the-fly at very low computational cost. We used an adaptive marching step-size for efficiency and used curved marching paths based on an extrapolation of local surface curvature to allow rendering of broken silhouette edges. The shader took input from a weave matrix to allow a wide variety of patterns to be created.
The technique offers major benefits such as automatic generation of a local ambient occlusion signal directly from the distance field at almost zero cost. We could adapt weave description to the local stretch of the surface allowing yarns to separate realistically while retaining their width. This was extended to compute detailed sub-yarn (fiber) separation.

Figure 2. Plane rendered using ray-marching. © Disney/Pixar

3. Curve-cloth generation

In addition we designed a renderman plugin which built a cloth weave structure from curves over the surface of a subdivision mesh at rendertime. Many problems had to be solved for this such as global weave coherence issues. UV space to subdivision space mapping and numerous shading issues. Curves were computed in per-face batches keep memory use to a minimum. To achieve face-to-face yarn coherence we pre-computed warp and weft (u & v) coordinates in a parent RiProcedural. To avoid uv to world space distortion we applied one Newton iteration to the initial yarn positions. Shading signals (such as local occlusion) were baked into the curves as they were generated. A simplified version of the distance field shader was used to render sub-yarn fibers.

4. Embroidery design

The tapestry featured prominently in Brave is seen in extreme closeups and must also be torn to reveal frayed edges. It required specific layout of stitches to form embroidery. As well as being a technical challenge this was a difficult user input problem. We created a Maya plugin which converted arbitrary NURBS geometry (Patches, Curves or Trimmed surfaces) to a stitch pattern. This along with auxiliary data was written to a custom cache file. The cache was then used as direct input for the general curve cloth system. Tearing was achieved by dynamically animating surface mesh vertex varying primitive variables which were interpreted by the curve cloth DSO as holes or edges.

Figure 3. Tapestry as seen in Brave. © Disney/Pixar

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