Predictive rendering for accurate material perception

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Computer graphics rendering is used to simulate the appearance of objects and materials in a wide range of applications. Designers and manufacturers need to rely entirely on rendered images to correctly recognize and differentiate between different types of fabrics, paint finishes, plastics, and metals. Thus, the rendering algorithms producing these images must be predictive of the appearance of materials.

While progress has been made on predictive rendering for metals and plastic, predictive rendering of cloth and fabrics remains particularly challenging. The structure of cloth, with fibers twisted into yarns which are woven into patterns, complicates the reflectance of light. Further, irregularities in the structure of cloth are difficult to model, but are visually important. The value of meso-scale structure is immediately apparent for rendering close-up views of cloth where these details are visible. But equally importantly, the shape and arrangement of fibers and yarns in the weave also determines the macro-scale appearance of the material—the shape and quality of specular highlights, and how appearance varies with illumination and view. For example, the structure of the pile in velvet dictates its fuzzy appearance, and its characteristic highlights at grazing angles (referred to as 'asperity scattering').

For cloth, predictive rendering requires the acquisition of detailed models representing the macro-scale and meso-scale structure of fibers and yarns, better optical models, and volumetric light transport algorithms that simulate the scattering of light within the volume of structured fibers and yarns. We have developed new scattering models and light transport algorithms that create highly realistic images of cloth. But they require detailed 3D structural models as input. Currently, modeling the 3D volumetric structure of cloth is difficult, requiring special-purpose procedural algorithms for each fabric, based on expert knowledge of the fabric structure. But this modeling is time consuming, error-prone, and requires significant expertise. Further, the resulting models lack the visual complexity of real materials with their naturally-arising irregularities.

We introduce an entirely different approach to building volume appearance models for cloth, by using X-ray computed tomography (CT) to acquire detailed geometric structure. For example, for woven cloth, these scans automatically capture the structure of the cloth with a detailed view of the interlaced yarns and their component fibers, showing exactly how the fibers are oriented and how the yarns are positioned. The density and orientation information from these CT scans is augmented with optical properties (albedo and gloss) inferred from a reference photograph. This powerful approach can easily produce volume appearance models with extreme detail in closeup, and at larger scales, with the distinctive textures and highlights of a range of very different fabrics like satin, velvet, and wool. This is achieved simply by having accurate meso-scale geometry.

Coupling detailed structural information with volumetric light transport algorithms is a first step towards predictive rendering for cloth. But how do changes in the structure of cloth affect our perception of cloth? Future work is needed to understand the perceptual dimensions of cloth appearance.