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Technical Perspective
The Intricate Dance of Fabric and Light

By Szymon Rusinkiewicz

WHAT IS IT about different materials, beyond their color, that gives them their characteristic appearance? Over the decades this fundamental question has given rise to a branch of computer graphics that can truly be called a science: the search to understand how complex materials interact with light. And as with any science, this understanding comes from the combination of sophisticated mathematical modeling and detailed experimental work.

As light encounters any material, it may be reflected, scattered, or absorbed. Producing accurate and believable computer graphics renderings requires algorithms that reproduce these interactions. In the simplest systems, the models for how light reflects from a surface are far from realistic, giving all surfaces the plastic appearance that has become so commonly associated with computer graphics. Curing this problem, especially for fabrics, requires a series of conceptual leaps, leading to more complex models and requiring more complex algorithms.

First, it is necessary to abandon the notion that fabrics are surfaces. Though we may speak of the "surface" of a piece of cloth, a realistic simulation of light requires treating the cloth as a volume of small, but definitely non-zero, thickness. This volume is populated by fibers, all of which can scatter or absorb light. We thus must shift from a rendering system in which light is thought of as being reflected from surfaces, to one in which it is scattered inside volumes. Though volume rendering has been commonly used to model translucent objects such as clouds or marble or even human skin, it is only in recent years that researchers, such as the authors of the following paper, have understood how important it is to model cloth in this way. A volumetric simulation can give rise to an appearance that "looks right" not only from far away, but also in extreme close-up.

Once we accept that fabric will be modeled as a collection of fibers, it is necessary to actually locate all of those fibers in space. In some cases the fibers are ordered, as in a weave or knit. In others, such as felt, they are arranged randomly. For years, our only option in graphics has been to write programs that simulate these arrangements, requiring tweaks to both the algorithms and their myriad parameters for each new fabric.

The following paper solves the problem in a creative way, by making use of actual fabric samples and micro-CT imaging. This is an instance of a trend in graphics that has been important since the mid-1990s: the use of new imaging and acquisition technologies (ranging from digital cameras to 3D scanners and even industrial MRI machines) to capture the complexity of the real world that is difficult to model analytically or with simple algorithms.

The authors present a state-of-the-art example of how algorithms, math, and measurement all combine to help our understanding of how fabrics interact with light.

Finally, we must model the way light is scattered and absorbed by each individual fiber. Here, the authors use a combination of theory and experiment. They propose an analytic model that is consistent with the underlying physics (for example, energy conservation) while having a number of unknown free parameters. Those parameters, in turn, are selected such that a rendering (including the full volumetric light scattering simulation and the measured fiber arrangement) matches the statistics of a photograph of the actual fabric. Of course, this process allows for proper experimental procedure, in which parameters that are fit from one photograph yield predictions that may be compared against another photograph.

The authors of the following paper present a state-of-the-art example of how algorithms (for volumetric light scattering simulation), math (dictating how scattering happens at a single point in the volume), and measurement (micro-CT to obtain fiber arrangement) all combine to help our understanding of how fabrics interact with light. The paper not only epitomizes the modern approach to understanding appearance, but also introduces new theoretical and experimental tools that will translate to many other kinds of materials.

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