# A Level Set Model for Realistic Cloth Simulation

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# 1 Introduction

The realistic modeling and simulation of cloth is a long-standing problem in both engineering and computer graphics. For textile engineers, it is useful to simulate the properties of synthetic materials to test if they will have the desired properties. In computer graphics, a bad cloth model is often the fastest way to destroy any suspension of disbelief. People are used to highly stylized pantings and animation, however they are not tolerant of inaccurate physics.

## 1.1 Current Cloth Models

While there are many models of cloth currently in use, most fall into two general categories: continuous and discrete, or finite element models are they are most commonly referred to. Continuous models are use physical constraints such as energy applied to the cloth to simulate it's motion. Finite element models break the cloth up into mechanical systems of masses and springs, solving large systems of ODEs to model the cloth behavior. What makes cloth such a difficult material to model is that real cloth has aspects of both of these views. A cursory glance at any fabric suggests a continuous sheet of cloth. However looking only a bit closer, we can see a detailed discrete mechanical structure. The mechanical structure of cloth is too large to simply be smoothed out.

Both of these models share several similar difficulties. First, most any basic physical model will allow for a cloth to intersect itself, a clearly undesirable behavior. This event must be handled outside the general model. Second, cloth is prone to forming discontinuities and folding over itself. Neither the finite or discrete models easily exhibit this property.

## 1.2 Why Level Sets

Paper [8] describes an application of level sets to an unrelated problem of surface editing. Surface editing shares some difficulties with cloth modeling, such as self intersection. The motivation for applying level set methods to surface editing was that, by construction, self intersection can not occur. Furthermore, changes in topology such as the development of discontinuities at folds are handled in the method and do not require a special case. These two properties suggested that it was worth trying to apply level set methods to cloth simulation.

## 1.3 Why Not Level Sets

The level set method is not without it's problems. First, we move the problem from the motion of a 2D cloth into a 3D manifold, thus going from $\mathcal{O}(n^2)$ to $\mathcal{O}(n^3)$. While this seems bad at first, removing the time for performing self collision may make up for the increased order, we do not know yet. Another problem is that level sets are based not on the overall motion of the object, but only the tangental motion. It may be possible to simply apply the perpendicular motion afterward to fix this, but again, we do not know yet, and this is a potential problem.

## 2 The Level Set Method

Generally, the level set method is intended as a simple and versatile method for computing and analyzing the motion of an interface $\Gamma$ in $n$ dimensions under some motion $\vec{v}$. The interface is embedded as the zero level set of the function $\phi(\vec{x}, t)$ where $\phi$ is the signed distance from the surface to some point $\vec{x}$. By defining $\phi$ in this way, $\phi$ is guarenteed to be Lipschitz continuous at the very least. Now the surface $\Gamma$ is effectively embedded in $\phi$, and can be read out easy by simply finding the zero level set $\Gamma(t) = \{\vec{x}|\phi(\vec{x}, t) = 0\}$. The desired velocity of the surface is applied to $\phi$ as a whole, moving to the next time step according to the equation

$$\frac{\partial \phi}{\partial t} + \mathbf{v} \cdot \nabla \phi = 0$$

Where $\mathbf{v}$ is the desired velocity on the level set, and arbitrary elsewhere. This is not entirely correct, the problem of extending $\mathbf{v}$ over the entire domain is complicated and varies with respect to what you are trying to model. For our purposes, we choose to use the fast marching method on a narrow band about the level set[1]. The level set equation is rewritten such that the velocity at each point in the front is solely in terms of the normal, giving the more canonical version of the level set equation

$$\frac{\partial \phi}{\partial t} + F|\nabla \phi| = 0$$

where $F$ is an arbitrary function of the normal at whatever other physical parameters are needed to get the correct action.

For example, in the paper on level set surface editing operators that motivated this project, each operation such as smoothing or embossing is represented as a different $F$, however the same method are used to solve the equation. While we have some initial guesses for our $F$, most of the work in finding $F$ will be based on experimental observations. Additionally, Breen's book on cloth modeling[3] lists several other more objective tests for accuracy of cloth simulation which we may potentially try.

## 3 Current Work

We made slow work this semester, mainly due to my lack of background in PDEs and numerical solutions to PDEs. Furthermore, we spent quite a bit of time simply understanding the basics of the level set method independent of any application. We were just beginning on an implementation as the semester ended, and are continuing to work on this project through the summer. With better course background in the necessary subjects and a more through understanding of the level set method, we are moving much faster than before.

## References


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