Coherent Behavior with Level-of-detail in Cloth Simulation

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Abstract

We describe a scheme for optimizing the material properties of cloth simulation of different resolutions to provide coherent behavior for reduced level-of-detail (LOD) in mass-spring system (MMS) meshes. The global optimal material coefficients are derived to match the behavior of the provided reference mesh. The proposed method provides the insight of the levels of reduction that we can achieve to maintain systematic behavioral coherency among different resolution of mass-spring models. The experimental results provides visually acceptable coherent behaviors for cloth models based on error metric and identifies that the proposed method can significantly reduce the resolution of objects.

Keywords*:* Coherent Behavior; Mass-spring LOD; Resolution Reduction; Mass-spring Material Optimization

1. Introduction

Mass-spring systems have been widely used in the simulation of several types of objects, including cloth, hair, and deformable solids[1, 2, 3, 4, 5]. Due to its simplicity and computational efficiency, MSS is still very popular for interactive applications and large-scale deformable object simulations. Level of detail of mesh structures has been widely research for representing meshed geometry in various detail levels, however when we adopt similar concept to the mass-spring systems for deformable objects, it provides highly unlikely behavioral coherency when the same elastic coefficients are used. This problem is caused by the anisotropic and geometric properties of mass-spring systems and different mesh structures and resolutions introduce different connections within the solid mesh.

This paper describes a novel method for deriving the optimal material coefficients of lower resolution mass-spring systems based on a higher resolution mass-spring system. This provides the ability to introduce levels-of-detail of mass-spring system to account for visual appearance in behavior and performance.

2. Coherent Behavior for Cloth Simulation

The evaluation of dynamic behaviors and optimization of material coefficients to provide consistent behavior between two simulated meshes defines the process of generating coherent dynamic behaviors. We precisely define the coherent behavior between two simulated mass-spring systems by two quantitative metrics: global trajectory and localized deformation behaviors. These metrics define the similarity between two simulated objects based on their global trajectory and the behaviors of the elastic material properties that defines how meshes deform over time.

The general cost metrics for global trajectory and local deformation are defined as functions of the isotropic elastic material properties of the mass-spring system: the uniform spring constant $k_{i,j}$ and the damping coefficient $c_{i,j}$. To define the differences in the discrete representation of the simulated meshes, we denote the high resolution model as the reference model as $\mathbf{MSS}^{ref}$ and the low resolution optimized simulation model as $\mathbf{MSS}^{sim}$. The process of optimizing the material properties of the input meshes to obtain the coherent behavior provided by the $\mathbf{MSS}^{opt}$ is shown in **Fig. 1**.

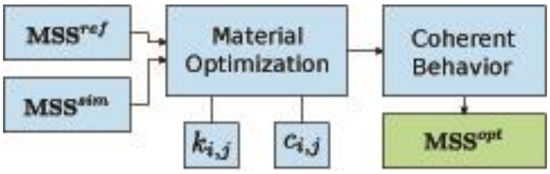

Fig. 1. The optimization process for coherent MSS behavior using material property

3. Modeling of Cloth using MSS

The generation of cloth models for mass-spring simulations is well established as the generation of two dimensional patch surfaces defined by structural springs, bend springs, and shear springs. Based on this standard formulation, we provide a basic cloth model composed of these components with a maximal spring length constraint. The tessellation of the patch surface used to generate the cloth model is defined by the depth of the number of subdivisions.

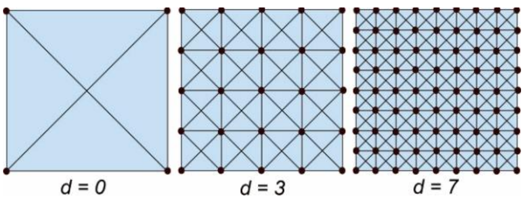

Fig. 2. Different level of tessellated cloth models.

To define the patch subdivision for the cloth model we start with a single square, with $d = 0$ for the basic structure containing 4 nodes. We then subdivide this surface based on the provided depth. The depth d denotes the number nodes between two edge points on the patch, thus the number of nodes is $(d + 2)^2$, as shown for various depths in **Fig. 2**.

4. Optimization Method

Our goal is to study the coherent relation between a higher resolution model and a lower resolution model, thus, we need to derive the material property of lower resolution model based on a higher resolution model. Our optimization approach focus on the parameter of stiffness coefficient and damping coefficient. The objective of the optimization process is to identify the optimal k value that provides coherent behavior between the $\mathbf{MSS}ref$ and $\mathbf{MSS}^{sim}$, that is, the displacement and curvature error between the two meshes is minimized.

In order to evaluate the coherent behavior between the two simulated meshes, we use nodal displacement and the velocity cosine angle between $\mathbf{MSS}^{ref}$ and $\mathbf{MSS}^{sim}$ nodes as our numerical error metrics. This is achieved by using the coherent points from $\mathbf{MSS}^{ref}$ matched to the nodes in $\mathbf{MSS}^{sim}$ to compute the error metric for each time-step and then accumulate those errors for all nodes within the system.

To provide accurate physical behaviors of objects using mass-spring models, damping is commonly applied to mimic the loss of kinetic energy due to internal friction and heat generated by the spring. The damping coefficient is optimized based on the function which is introduced by Silva et al.[6].

5. Experimental Result

The experimental result of proposed method is applied to cloth based patches. The experimental results are directly compared by super-imposing with reference model. In **Fig. 3**, the left image is the simulation result with regular cloth simulation using same stiffness and damping coefficients showing a large discrepancy.

The right image is the simulation result with proposed optimal material properties showing plausible motion behaviors with reference cloth model. Also knowing the fact that vastly different resolutions would result in irreconcilable behaviors, obtaining limits of lower bounds of remeshing is very useful for the modeling and simulation of deformable objects.

From our analysis of the simulated cloth simulation, we observe that we can reduce the cloth model by 25% while maintaining reasonably and plausibly coherent behavior.

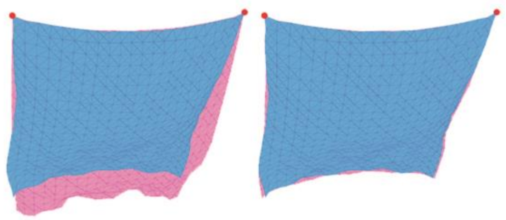

Fig. 3. Simulation example of the cloth model

6. Conclusion

In this paper, we have presented an MSS material property optimization method for providing coherent deformation behaviors between meshes with different geometric resolutions. From the optimization of the MSS material properties for ensuring similar behaviors can be computed by proposed method. We also observed that cloth meshes can be significantly reduced with optimal parameters to achieve coherent behaviors and believe that it can be widely applied to real-time simulation without extra computational costs.

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