

# Eulerian-on-Lagrangian Cloth

Kyle Piddington<sup>1</sup> David I. W. Levin<sup>2</sup> Dinesh K. Pai<sup>3</sup> Shinjiro Sueda<sup>1</sup>

<sup>1</sup>California Polytechnic State University <sup>2</sup>Disney Research Boston <sup>3</sup>University of British Columbia

## Abstract

We present a new, Eulerian-on-Lagrangian approach for modeling cloth. When a cloth modeled using the traditional Lagrangian approach is moved around an object with sharp corners, such as the edge of a table, the cloth cannot always bend smoothly around the object because it can bend only at its nodes. With our method, these constraints are built into the discretization of the cloth, giving us an equation of motion that directly honors these constraints. This allows the cloth to bend and move smoothly around such constraints. We show how our method can efficiently handle challenging simulations, such as pulling a table cloth from under wine glasses without knocking them over.

**CR Categories:** I.6.8 [Simulation and Modeling]: Types of Simulation—Combined

**Keywords:** Lagrangian mechanics, Simulation, Cloth

Cloth simulation has been an important part of computer animation over the years. Starting from the seminal work by Baraff and Witkin [1998], we have seen many approaches and improvements to make cloth simulation more efficient, realistic, and robust (*e.g.*, [Goldenthal et al. 2007; Narain et al. 2012]). These methods, however, have one shortcoming that has not been addressed so far: they do not allow the cloth to smoothly bend around sharp corners.

A cloth draped over a table naturally bends around the edge of the table, as shown in Fig. 1a. This is challenging for models based on purely Lagrangian approaches because where the cloth can bend depends on the discretization of the cloth. With these methods, cloth can only bend at the nodes, which are fixed to the material coordinates of the cloth. If the cloth is pulled around the edge of the table, as shown in Fig. 1b, the Lagrangian discretization of the cloth makes the elements of the cloth bend unnaturally around the constraint, as the application point of the constraint moves from one element to another.

The obvious approach to overcome this problem is to increase the resolution of the cloth. However, this does not eliminate the problem—the problem still persists at a higher resolution. The cloth is still not able to bend continuously and suffers from spurious bending noise around the constraint. Furthermore, the efficiency is decreased due to the larger system size and the associated reduction in the time step size. Perfectly discretizing the cloth at run time around the constraint helps, but it also does not solve the problem entirely. To see why, suppose we discretize the cloth so that the nodes are placed exactly where the edge of the table is. For the next time step, what constraints would we need to apply to these nodes? On the one hand, if we apply a constraint using the normal of the table, the cloth still cannot bend at these perfectly aligned nodes. On the other hand, if we do not apply a constraint, the cloth will penetrate the table.



**Figure 1:** (Left) Table cloth draped over a rectangular table. (Right) Pulling the cloth from underneath the wine glasses.

Our solution is to use the Eulerian-on-Lagrangian (EOL) discretization, which has been used for cables [Sueda et al. 2011], tendons [Sachdeva et al. 2015], skin [Li et al. 2013], and contacting solids [Fan et al. 2013]. In an Eulerian discretization, each degree of freedom (DOF) is fixed in space, allowing the material to pass through. In a Lagrangian discretization, each DOF is fixed to the material coordinate, which moves in space. The EOL discretization mixes both of these, allowing a node to contain both Eulerian and Lagrangian DOFs. In our EOL cloth, we use EOL nodes at the constraints so that the cloth material can move through these nodes while the spatial positions of the nodes stay fixed. Thus, the EOL method decouples the discretization of the dynamics from the constraints. The EOL cloth is able to bend naturally over sharp corners, and this allows the simulation of challenging scenarios, such as pulling a table cloth from under wine glasses without toppling them over.

## References

- BARAFF, D., AND WITKIN, A. 1998. Large steps in cloth simulation. In *Proc. SIGGRAPH 1998*, vol. 32 of *Computer Graphics Proc., Annual Conference Series*, ACM, 43–54.
- FAN, Y., LITVEN, J., LEVIN, D. I. W., AND PAI, D. K. 2013. Eulerian-on-Lagrangian simulation. *ACM Trans. Graph.* 32, 3 (July), 22:1–22:9.
- GOLDENTHAL, R., HARMON, D., FATTAL, R., BERCOVIER, M., AND GRINSPUN, E. 2007. Efficient simulation of inextensible cloth. *ACM Trans. Graph.* 26, 3 (July).
- LI, D., SUEDA, S., NEOG, D. R., AND PAI, D. K. 2013. Thin skin elastodynamics. *ACM Trans. Graph.* 32, 4 (July), 49:1–49:10.
- NARAIN, R., SAMII, A., AND O'BRIEN, J. F. 2012. Adaptive anisotropic remeshing for cloth simulation. *ACM Trans. Graph.* 31, 6 (Nov.), 152:1–152:10.
- SACHDEVA, P., SUEDA, S., BRADLEY, S., FINE, M., AND PAI, D. K. 2015. Biomechanical simulation and control of hands and tendinous systems. *ACM Trans. Graph.* 34, 4 (July).
- SUEDA, S., JONES, G. L., LEVIN, D. I. W., AND PAI, D. K. 2011. Large-scale dynamic simulation of highly constrained strands. *ACM Trans. Graph.* 30, 4 (July), 39:1–39:10.

Permission to make digital or hard copies of all or part of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. Copyrights for components of this work owned by others than ACM must be honored. For all other uses, contact the Owner/Author. Copyright is held by the owner/author(s). SCA '15, August 7–9, 2015, Los Angeles, California. ACM 978-1-4503-3496-9/15/08. <http://dx.doi.org/10.1145/2786784.2795138>