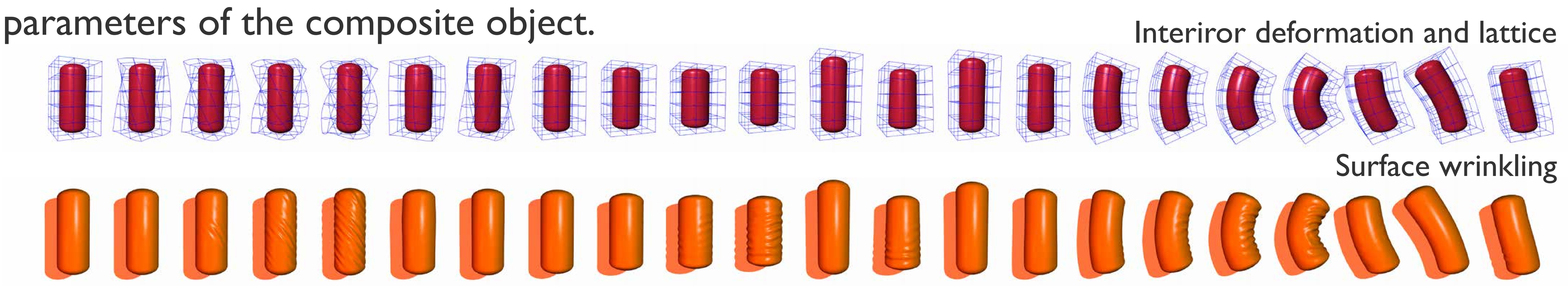
Embedded Thin Shell for Wrinkle Simulation

Olivier Rémillard , Paul G. Kry
School of Computer Science, McGill University

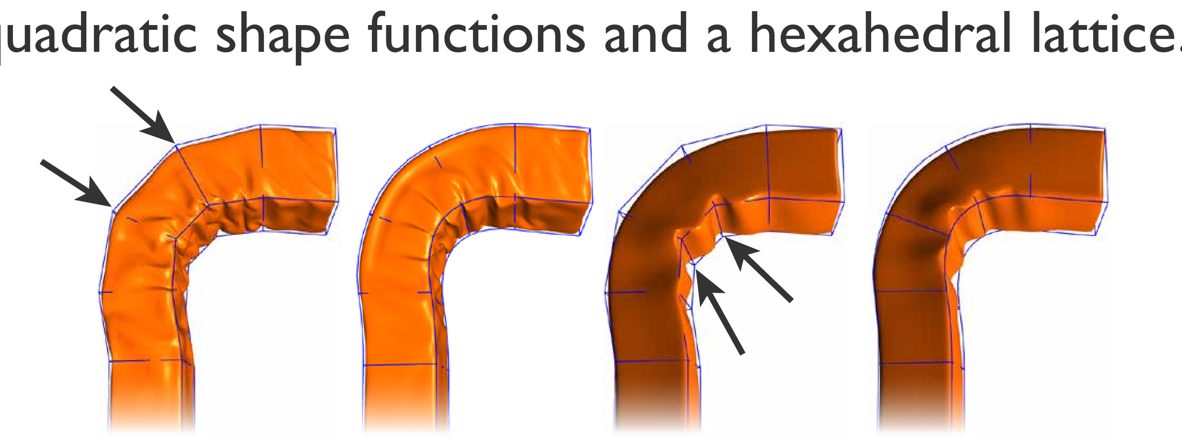
In Brief

Embedded thin shells is a new technique for simulating high resolution surface wrinkling deformations of composite objects consisting of a soft interior and a harder skin. It combines high resolution thin shells with coarse finite element lattices and defines frequency based constraints that allow the formation of wrinkles with properties matching those predicted by the physical parameters of the composite object.



Walk Tzhrough

Our formulation addresses the simulation of wrinkles by coupling a high resolution thin shell to an embedded mesh driven by a low resolution lattice. From a surface mesh, we build a coarse volumetric finite element model to simulate large deformations of the interior. We use B-spline quadratic shape functions and a hexahedral lattice.



Linear shape functions produce artifacts both at high wrinkle frequencies where the C^0 continuity at interior element boundaries is evident, and at low wrinkle frequencies where wrinkles fall at element boundaries.

We couple the surface to the interior through position constraints. The constraints force the shell to match the embedded shape, but only at low spatial frequencies, with the null space the constraint allowing for the high spatial frequency deformations necessary to produce wrinkles.

Constraint

We base the construction of our constraints on the expected frequency of wrinkling on the surface. Using the critical wrinkling wavelength for our given object's parameters, we can choose the best cluster density and size to use in the construction of our constraints.

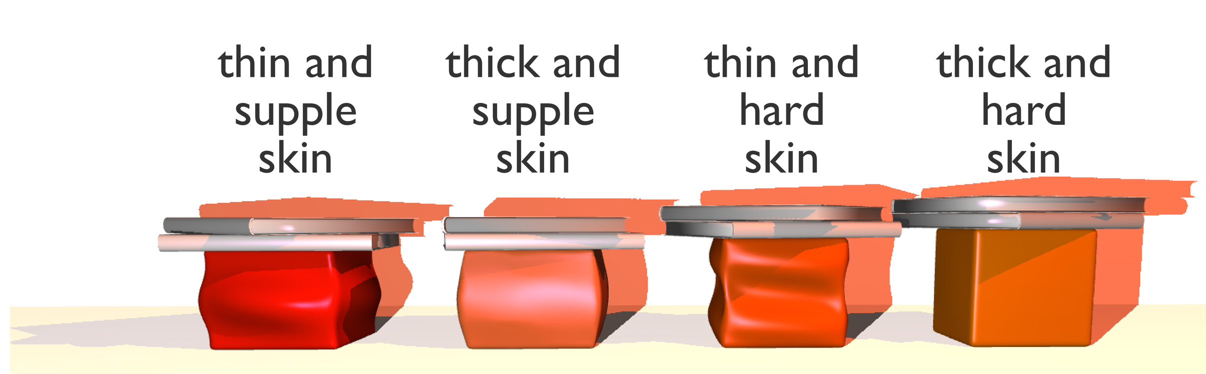
Different scales of wrinkles can be achieved by varying the material properties as displayed by these cushions. The constraint is built to conform to critical wavelength.

The thickness of the skin h, and the Young's modulus and the Poisson ratio of the skin and the interior (E_x, v_x, and E_q, v_q respectively) completely determine the critical wavelength λ of the object's surface.

$$\lambda = 2\pi h \left[\frac{(1-v_q^2)E_x}{(1-v_x^2)E_q} \right]^{1/3}$$

Simulation

Being light and stiff, solving the shell dynamics requires small steps or implicit methods for stability. But the shell stiffness projected onto the interior degrees of freedom is much lower, allowing a wider variety of integration methods and step sizes. Thus we choose to solve the coupled system in a two-step procedure, first computing a quasi-static equilibrium for the shell and then solving the dynamics of the interior while taking into account the shell deformation forces.



Our formulation includes the shell deformation forces in the interior's dynamic system. Each cube is assigned the same interior properties, but their skins properties are varied. They all display different deformation behaviors and resistance to an identical applied weight.

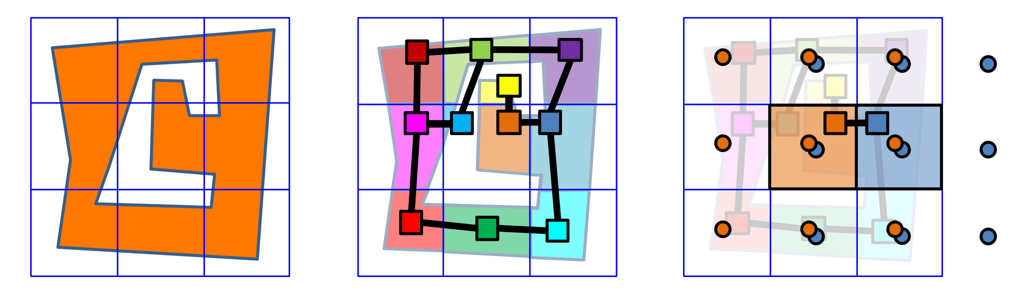
Although skin motion is typically dominated by interior dynamics, our approach cannot produce the high resolution surface dynamics of a fully dynamic simulation, such as traveling surface waves.

Conclusion

Embedded thin shells can simulate a variety of different kinds of objects with soft interior and a harder skin. Our approach is straightforward and uses intuitive frequency limited constraints to tie the high resolution shell to a low resolution dynamic simulation of the interior deformations. The result demonstrate that fine surface wrinkles can be produced without the computational expense of simulating a large number of volumetric element to model deformations under the surface.

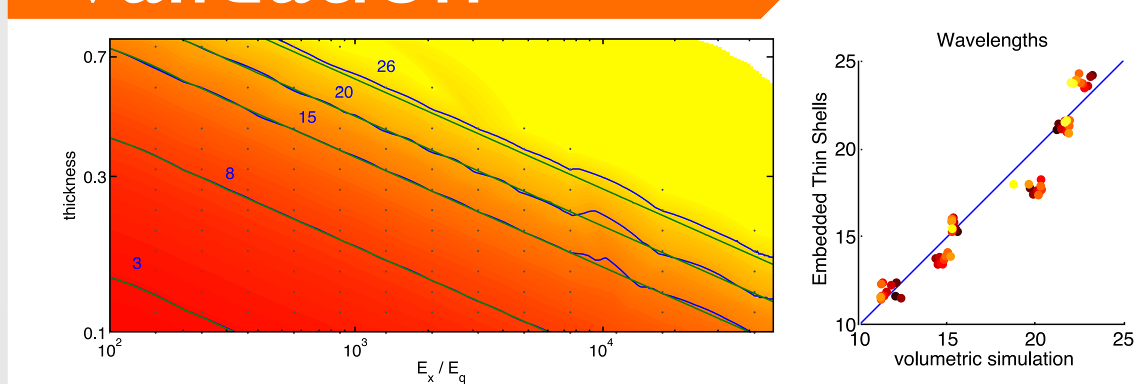
Coarse Lattice

When building the coarse model, we use a spatial hash to determine the element to which a vertex belongs; however, care must be taken not to lump separate parts of the mesh into the same element. We use superimposed elements with node duplication to accommodate these situations.

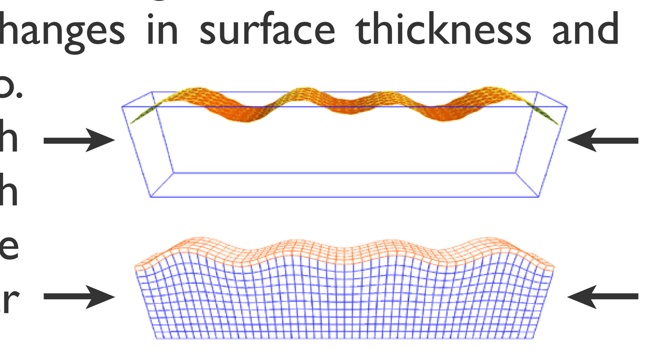


Left, the mesh is sliced along the lattice boundaries. Middle, the mesh segments are closed using the lattice cell faces, a finite element denoted by a colored square is created for each, and connectivity across cell faces forms a graph. Right, visiting each edge of the graph, we merge overlapping nodes in order to mechanically connect the elements.

Validation



Our embedded thin shell model closely matches the behavior of theorical and full simulations. A comparison of our model and the dense volumetric simulation can be seen above right. Above left, we compare predicted wrinkle wavelengths for a large variety of different skin thicknesses and Young's modulus ratios. The figure shows isocontours of equal wavelength for changes in surface thickness and Young's modulus ratio. Measured wavelength samples are shown with grey dots and involve running a simulation similar to this one.



Face Wrinkles

We compute muscle activations for a lattice in which a face is embedded, and estimate these muscle activations from a blend shape deformation model. This allows the interior to undergo novel and dynamic deformations, as opposed to results which could be produced using static blend shapes to drive the shell.

Reference

Rémillard, O., and Kry, P. G. 2013. Embbeded thin shells for wrinkle simulation. *ACM Transactions on Graphics SIGGRAPH.* 32, 4(July), to appear.