Reduced Physics:
Physics Based Simulation in Nonlinear Subspace

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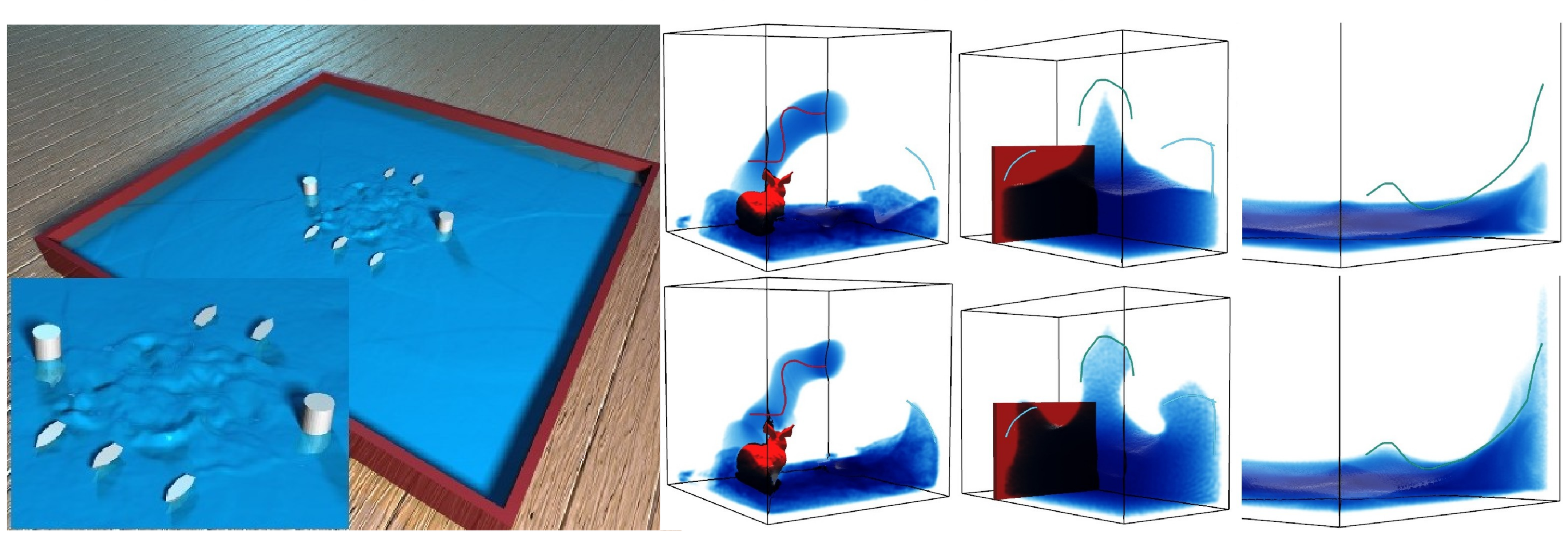
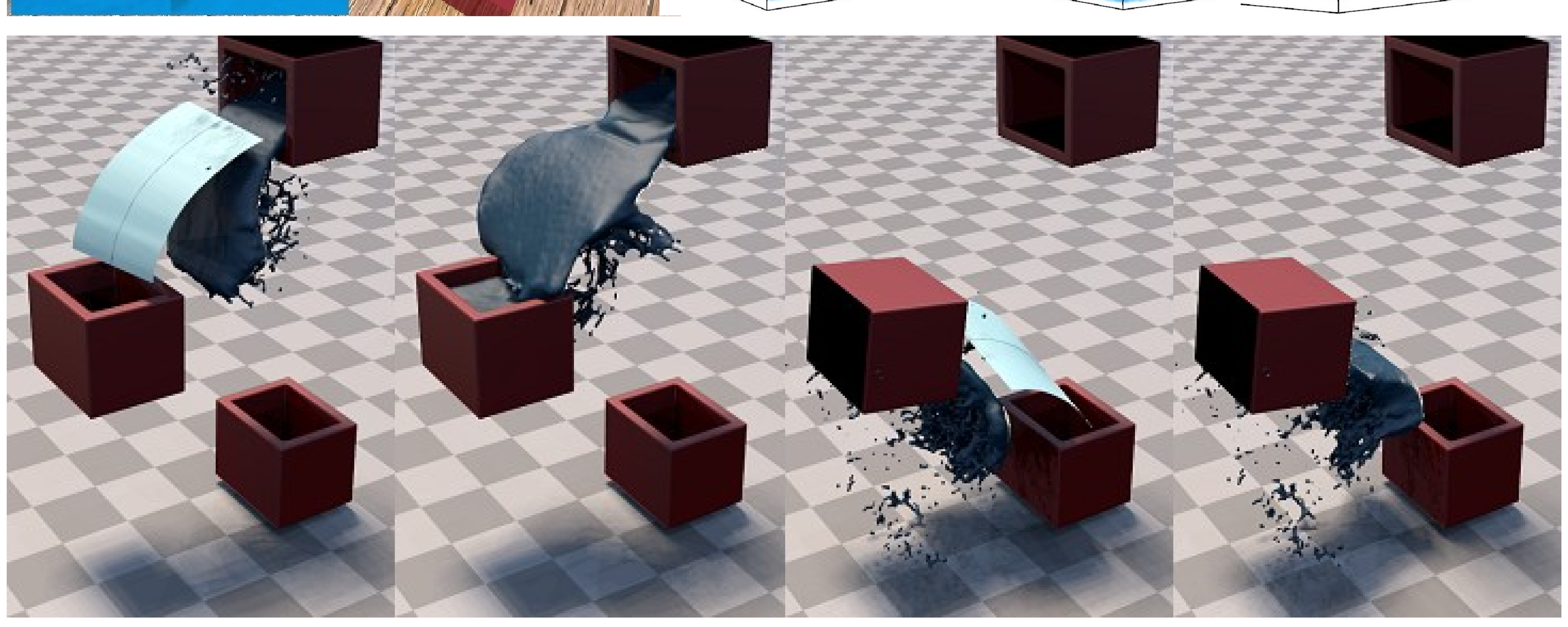
Goals

Reduced models have been around for years to accelerate physics based simulation. However, most reduced models reside in a linear subspace which doesn't respect the underlying governing equation. In our works, we show that, by relating the reduced parameters nonlinearly to the Cartesian coordinates, we are able to satisfy a set of physical constraints so that no explicit formulations are needed for them. This usually allows faster and locking-free time integration of nonlinear system using very few degrees of freedom. Experiments in deformable bodies, developable shells and incompressible fluids verified the efficacy of such methods. And we are further exploring its accuracy with an application in robotic motion planning.

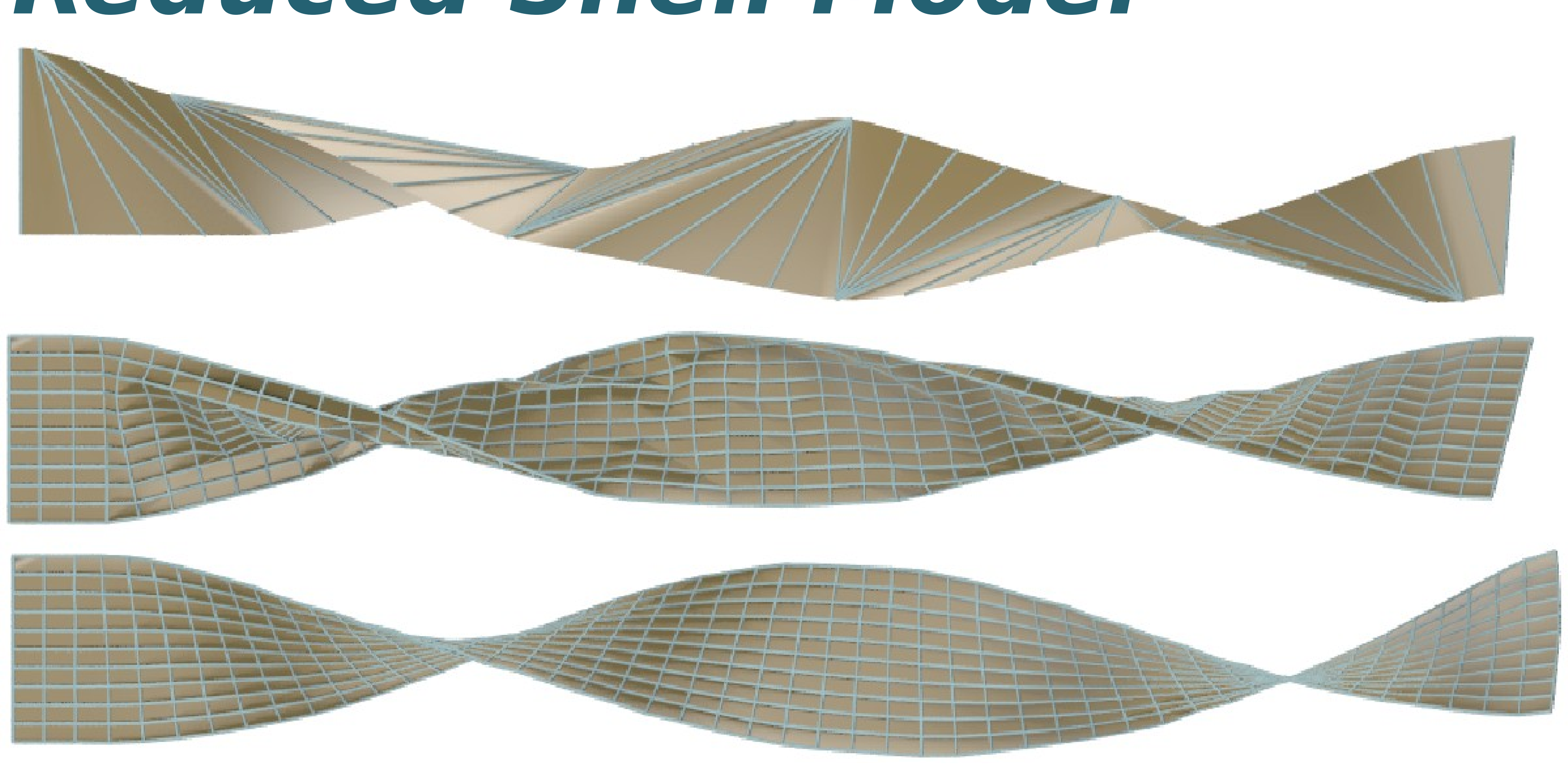
Reduced Fluid Model





Our curl-based reduced fluid model for 3D simulation in a 2D plane (left) or interactively control of 3D keyframe (right) which is then baked into an animation sequence (bottom). Both applications are interactive which is impossible using usually grid based simulation.

Reduced Shell Model

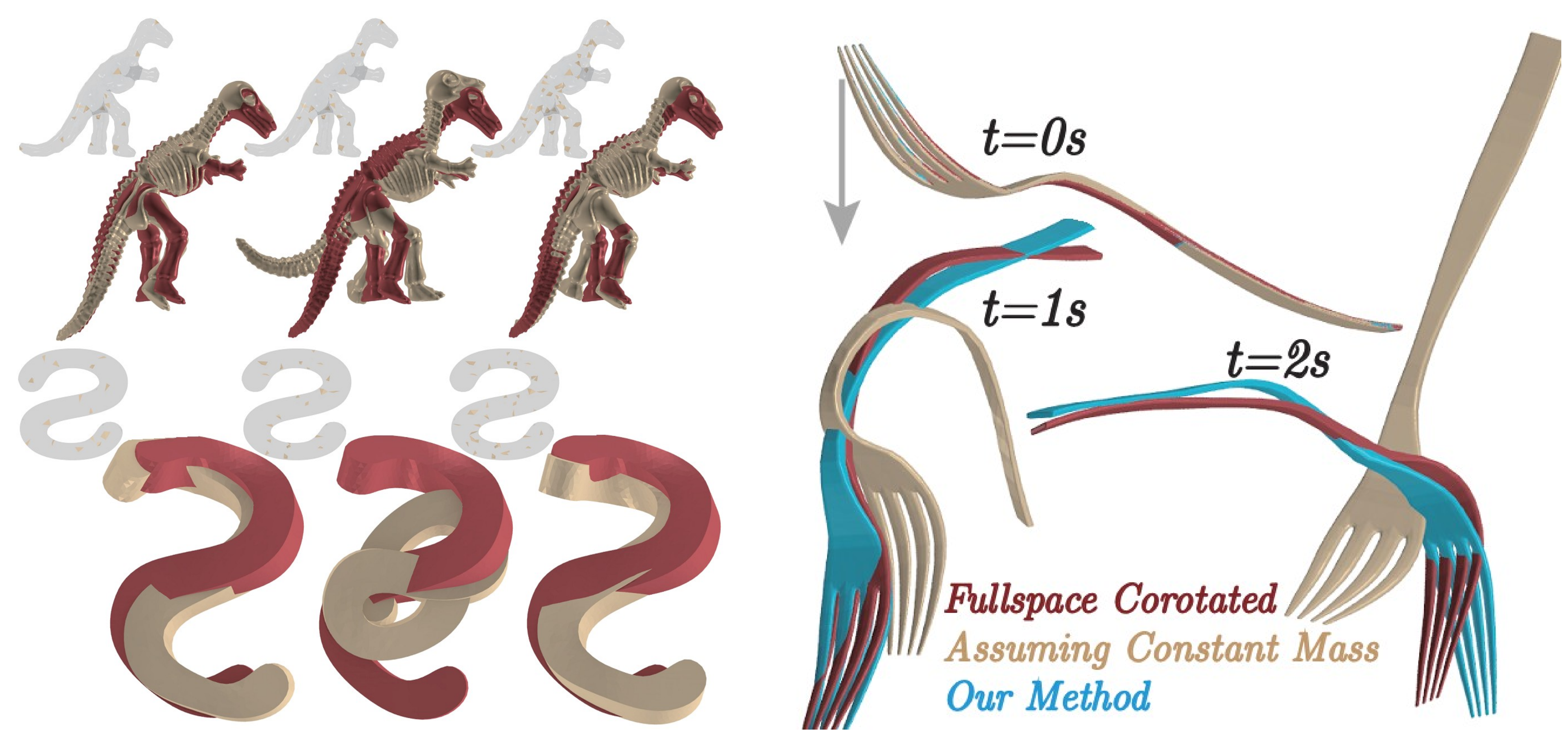


Our developable shell model (top) using one-tenth of the elements compared with FEM simulation (bottom) achieving higher accuracy by regenerating the triangular ruling pattern when the ribbon is under strong twisting force.

What constraints do we respect?

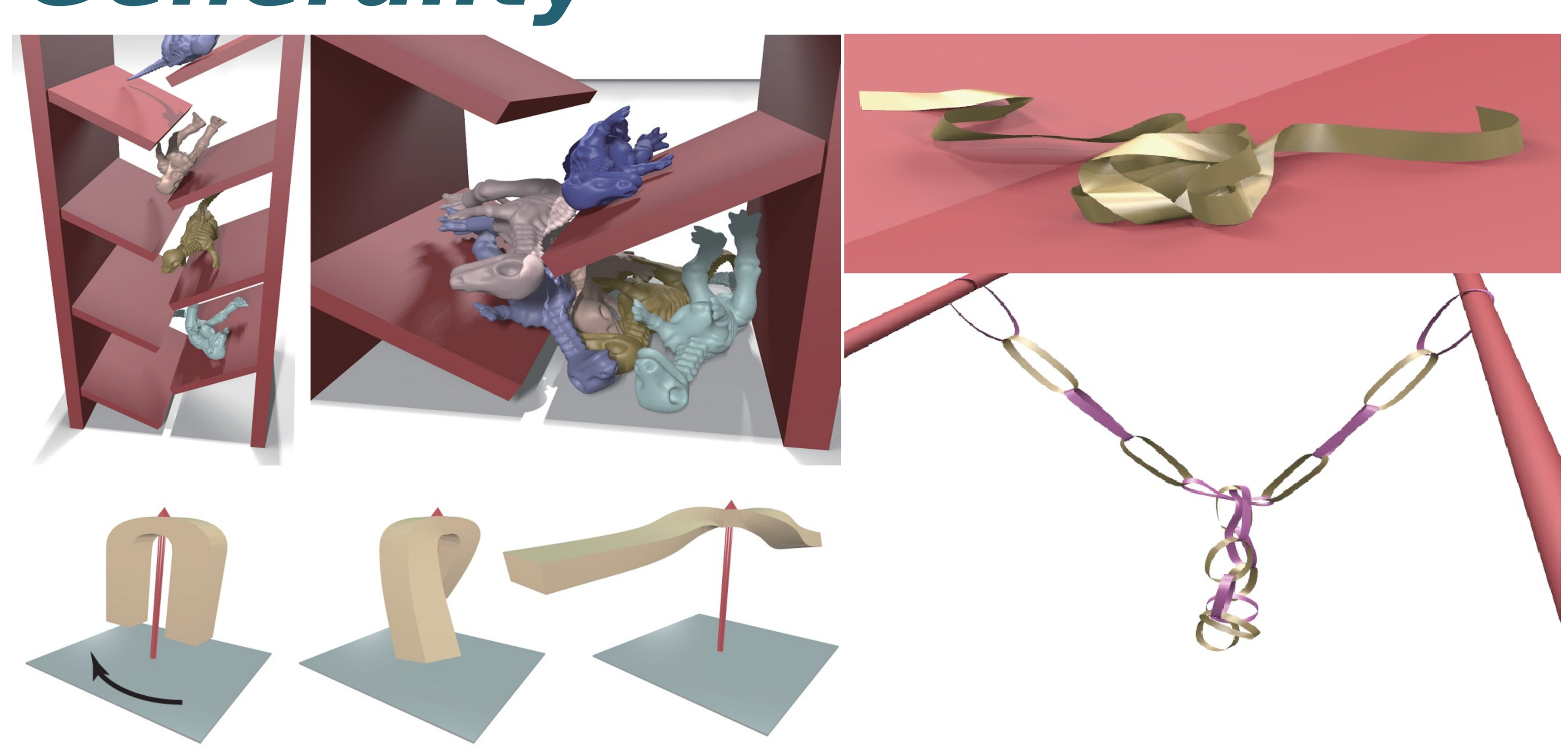
- An incompressible fluid should be volume conserving
- A developable shell cannot have any shear
- A deformable body has zero potential energy under rigid rotation
- Various boundary conditions

Reduced Deformable



We perform quantitative comparison of our deformable model with FEM method. (Left) We sample a small subset of elements to approximate the fullbody dynamics. Using our method, only one-third of the samples are needed to achieve similar accuracy with FEM method. (Right) We achieve high consistency with fullbody dynamics compared with previous reduced models.

Generality



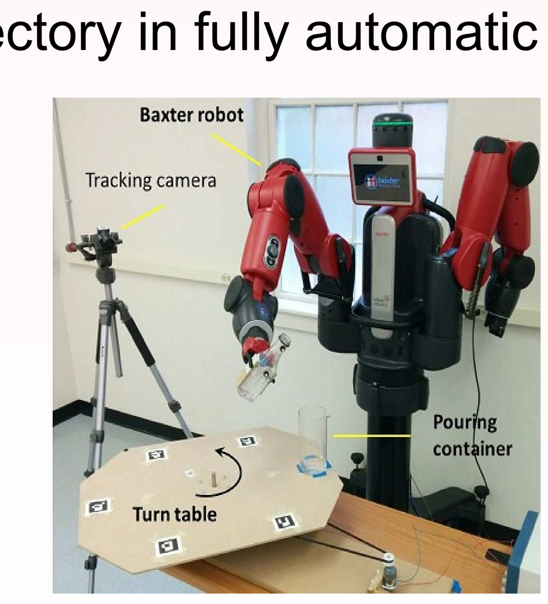
One concern of our method is generality. Fortunately, this is usually not an issue. We can do full-featured simulation involving collisions, contacts or even coupled simulations.

What we cannot do?

- Changing topology: material cutting
- Changing material property
- Large scale simulation and large sized bodies

To this point, we have only explored applications in computer graphics. It is still unknown if such method can produce results consistent with real-life experiments. In view of this, our current focus is on applying such reduced models to robotic motion planning with fluid constraints.

To make robot accomplish fluid manipulation tasks such as water pouring into a rotating container (left), where even human demonstration is difficult, such method could efficiently find a feasible trajectory in fully automatic manner.



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