A Computationally Efficient Framework for Modeling Soft Body Impact

Sarah F. Frisken, Ronald N. Perry

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Abstract

While there has been significant progress in simulating collisions between rigid bodies, much remains to be done for modeling interactions between soft bodies. Graphical techniques for representing and deforming soft bodies range from non-physical (e.g., control point-based) to physically plausible (e.g., FFD) to physically realistic (e.g., FEM). All of these techniques require three operations to model interactions between soft bodies: 1) detecting collisions between deforming bodies, 2) computing impact forces when bodies collide, and 3) determining deformation forces or contact deformation of the bodies to initialize a deformation technique. In this report, we propose a new framework which performs all three operations quickly, with efficient use of memory, and more accurately than previous methods. The results of these operations can be used in any of the deformation techniques mentioned above.

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Introduction

While there has been significant progress in simulating collisions between rigid bodies [1], much remains to be done for modeling interactions between soft bodies. Graphical techniques for representing and deforming soft bodies range from non-physical (e.g., control point-based) to physically plausible (e.g., FFD) to physically realistic (e.g., FEM) [2]. All of these techniques require three operations to model interactions between soft bodies: 1) detecting collisions between deforming bodies, 2) computing impact forces when bodies collide, and 3) determining deformation forces or contact deformation of the bodies to initialize a deformation technique. In this sketch, we propose a new framework which performs all three operations quickly, with efficient use of memory, and more accurately than previous methods. The results of these operations can be used in any of the deformation techniques mentioned above.

Utilizing ADFs for Modeling Soft Body Impacts

We recently proposed adaptively sampled distance fields (ADFs) as a new shape representation and suggested that they might be useful for collision detection [3]. ADFs adaptively sample the signed distance field of an object and store the sample values in a spatial hierarchy (e.g., an octree) for fast processing. ADFs have several advantages for modeling impacts between soft bodies including: 1) compact representations of complex surfaces, 2) trivial inside/outside and proximity tests, 3) fast localization of potential contact regions, 4) more accurate representation of the overlap region, and 5) simple methods for computing material-dependent contact deformation.

Detecting Collisions, Penetration, and Proximity

The sign of the distance reconstructed from the ADF at any point in space provides a trivial inside/outside test. When detecting collisions between two ADFs, their spatial data structures can be exploited to quickly localize potential regions of overlap. Within these regions, a new ADF of the shape defined by the intersection of the two ADFs is locally generated as illustrated in Figure 1A. (The intersection is a simple *min*() operation on the distance fields of the two ADFs.) If the intersection ADF is non-empty, a collision is detected and the region is further processed. To test for proximity rather than collisions, an ADF defined by the intersection of offset surfaces can be generated as illustrated in Figure 1B.

Computing Impact Forces

There are a number of methods for computing impact forces between two interacting bodies [4]. Penalty-based methods compute impact forces based on how far objects penetrate each other during a discrete time step. Distance fields have been used [5, 6] to determine penetration depth at sample points along the penetrating surface as well as to compute contact forces. From Figure 2, the total force vector, $\mathbf{F}_V$, acting on V due to penetration of U by V is approximated by the sum of forces $\mathbf{f}_{Vi} = k_U(\mathbf{x}_i)\mathrm{dist}_U(\mathbf{x}_i)\mathbf{g}(\mathbf{x}_i)$, where $k_U(\mathbf{x})$ is the material stiffness of U at $\mathbf{x}$, $\mathrm{dist}_U(\mathbf{x})$ is the closest distance from $\mathbf{x}$ to the surface of U, and $\mathbf{g}(\mathbf{x})$ is the normalized gradient vector of U's distance field at $\mathbf{x}$.

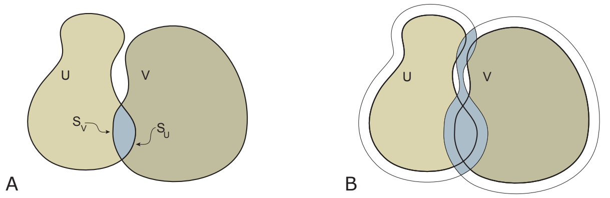

Figure 1. A) The overlap region (in blue) of shapes U and V is determined by local generation of the intersection of U and V. B) The overlap region of the offset surfaces of U and V can also be easily generated for determining proximity information.

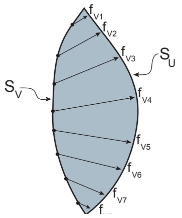

Figure 2. Forces acting on S_V in the overlap region of Figure 1A.

The intersection ADF represents the ***volumetric*** overlap region to high precision. Previous penalty methods compute $\mathbf{F}_V$ from a small number of points *restricted* to the penetrating surface. Using ADFs, penetration forces can be computed over the surface or the *volume* of the overlap region. Forces can be computed at an arbitrary number of well-spaced sample points seeded on the surface or throughout the volume and we are investigating methods to analytically interpolate forces throughout the overlap region. These advantages of ADFs provide the opportunity to compute impact forces more accurately than previous methods.

Determining Contact Deformation

When using ADFs, there are two methods for determining the initial contact deformation. The first follows common practice and uses the impact forces computed above together with a deformation technique. The second uses the implicit nature of distance fields to compute contact deformation by combining the distance fields within the overlap region. Various methods can be used to combine the fields and achieve material dependent deformation [7, 8] (see Figure 3). Figure 4 shows a simulation for the impact of two soft bodies.

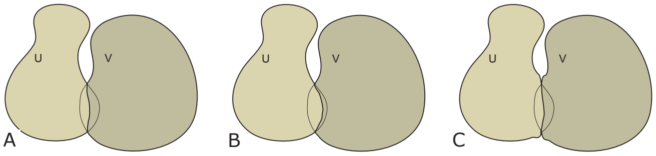

Figure 3. Contact deformation of the objects of Figure 1 with A) similar material densities, B) V softer than U, and C) volume preserving deformation (after [7, 8]).

References

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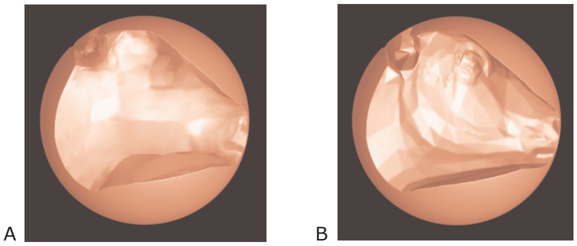
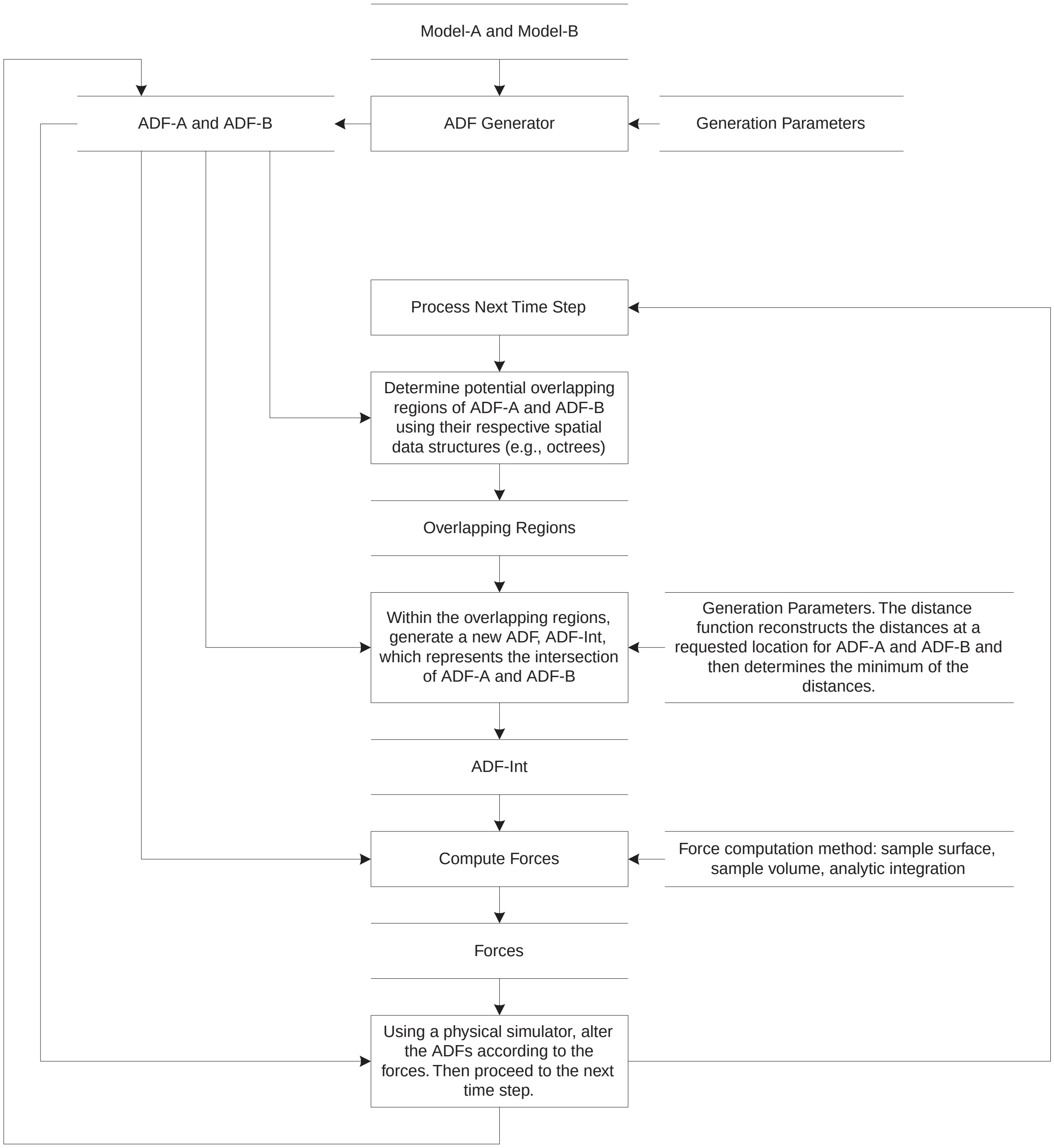
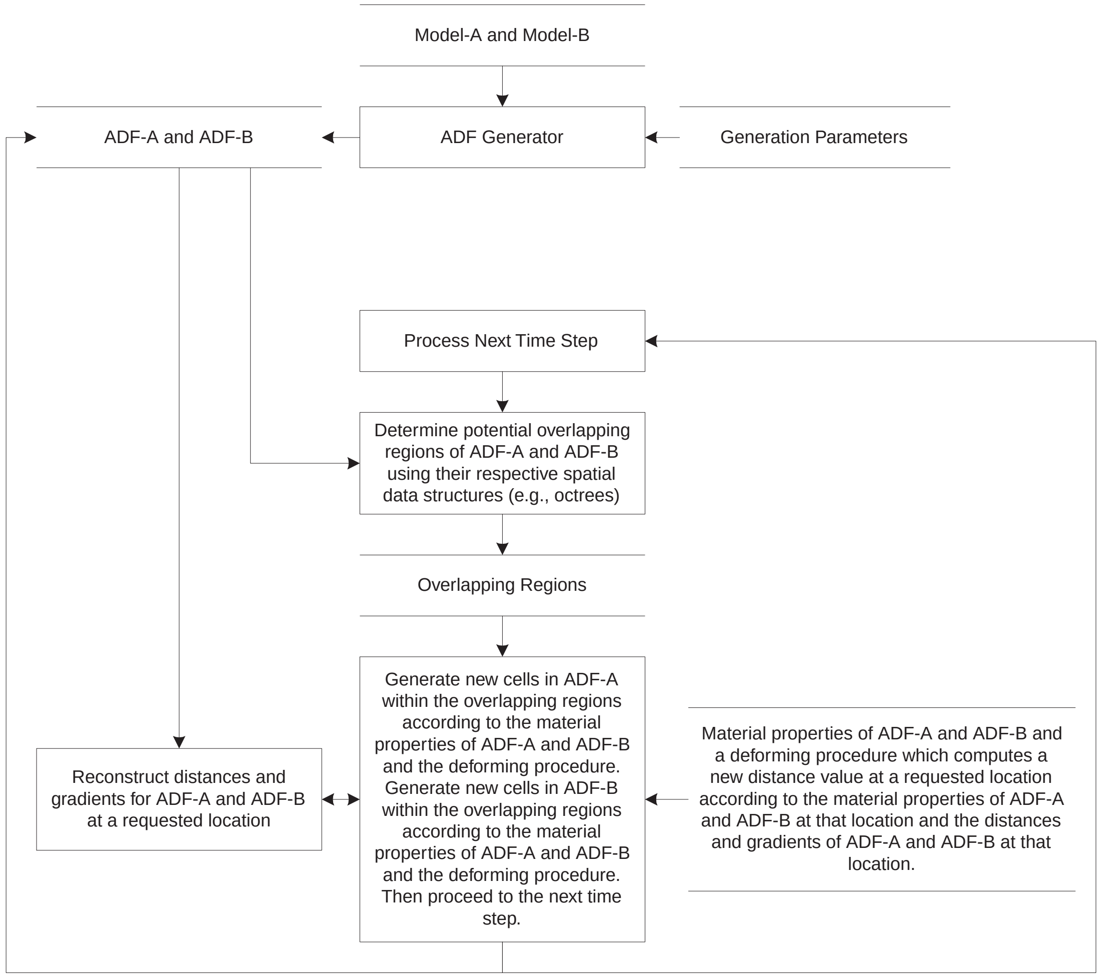


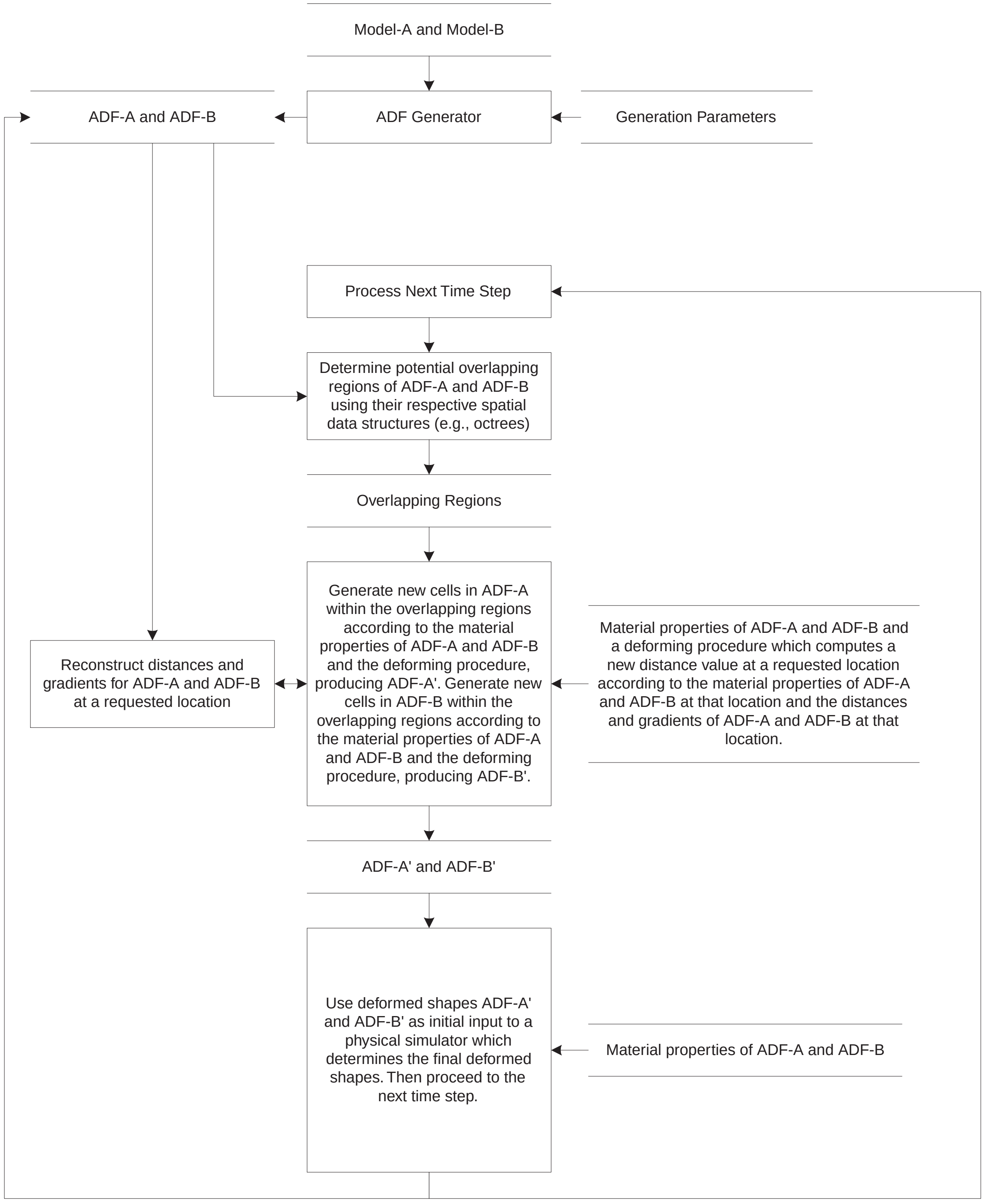
Figure 4. Indentation of a sphere after impact with an ADF of a complex cow model. Contact deformation of the sphere after impact with A) a soft cow and B) a hard cow.



A data flow diagram for a system computing forces from the intersection ADF; the resulting forces serve as input to a physical simulator which determines the deformed shapes for the current time step.



A data flow diagram for a system that deforms interacting bodies represented as ADFs by applying a deformation (blending) procedure on the ADFs.



A data flow diagram for a system that deforms interacting bodies represented as ADFs by applying a deformation (blending) procedure on the ADFs; the resulting ADFs serve as input to a physical simulator which determines the final deformed shapes.