FAST SIMULATION OF COMPLEX BIOMECHANICAL STRUCTURES USING MOVING FRAMES AND MATERIAL-AWARE SHAPE FUNCTIONS

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\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure1.png}
\caption{A taste of the method. The biomechanical model (a) has a rigid bone and softer muscle and fat, as seen in the volumetric stiffness map (b). Our method can simulate it using only three moving frames and ten integration points (c), running at 500 Hz on an ordinary PC. The frame placement is automatically generated using a novel compliance-scaled distance (d). Observe that when one side of the meat is pulled (e), the bone remains rigid and the two meaty parts are correctly decoupled. Interactive simulations of complex models (f) are achieved at 20 Hz.}
\end{figure}

1 INTRODUCTION

Continuous media mechanics is essential in biomechanics for simulating the behavior of soft objects. The classical approach is the Finite Element Method (FEM) framework, where the degrees of freedom of the discretized model are the vertices of a mesh. A relatively fine mesh is required to capture common deformations such as torsion, leading to expensive simulations. Meshing issues such as guaranteeing the geometric quality of elements while meeting boundary constraints remain open research problems. Meshless methods obviate the need to maintain mesh topology, however the particle-based methods proposed so far are also based on dense clouds not very different from the vertices of an FEM mesh. Moreover, most of the work so far has focused on objects made of a single, homogeneous material. However, many real-world objects, including biological structures, are composed of heterogeneous material. The simulation of such complex objects using the currently available techniques requires a high resolution spatial discretization to resolve the variations of material parameters.

Consequently, the realistic simulation of biological objects has remained a highly compute-intensive task, precluding applications where fast computation times are necessary, such as interactive simulations, or the solution of complex inverse problems. We tackle this challenge using a new type of deformable model which combines the realism of physically based continuum mechanics models and the usability of computer animation methods, allowing the interactive simulation of objects with heterogeneous material properties and complex geometries.

2 METHODS

The degrees of freedom of our model are coordinate frames which move in reaction to internal body forces [2]. Their distribution can be imposed to finely control the deformation modes, or automatically computed based on material properties. The deformation gradient and its derivatives are computed at each sample point of a deformed object and used in the equations of Lagrangian mechanics to achieve physical realism. We introduce novel material-aware shape functions in place of the traditional radial basis functions used in meshless frameworks, allowing coarse deformation functions to efficiently resolve non-uniform stiffnesses [1].

3 RESULTS

Complex models can thus be simulated at high frame rates using a small number of control nodes, as illustrated in Figure 1, and precision has been validated against traditional FEM.

References
