Stable, Art-Directable Skin and Flesh Using Biphasic Materials

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Disney·Pixar's *Brave* featured a number of characters that required ballistic flesh and skin motion that tracks a variety of exaggerated art directed animated performances. As these endeavors are typically at odds, the key to achieving this was to develop and employ simulation techniques targeted towards delivering specific ballistic behavior. These endeavors employ constitutive models that work across a range of situations that dynamically retarget their FEM rest state towards animated target shapes. Given a FEM flesh simulation model [Irving et al. 2004], we introduce a new finite element model for sliding skin that tracks the flesh. To keep the flesh and the skin motion stable, we use biphasic constitutive models to adapt the simulation parameters in such a way that each simulation remains stable in the presence of large forces and fast accelerations. To allow for high–quality deformation and efficient tracking in the sliding skin simulation, we introduce a hybrid time integration scheme. Our method combines an adaptive semi–implicit material update and a fully–implicit update for resolving the tracking forces.

Figure 1: *FEM flesh and skin were instrumental in creating compelling dynamic behavior in Disney·Pixar's* Brave*.*

1 Biphasic FEM Flesh and Skin

To mitigate complexity in achieving art directed results, we simulate volumetric flesh and sliding skin independently. Flesh simulation is allowed to break the profile of the character, skin sliding is not. To allow FEM flesh simulation to track a target keyframe animation, we adaptively retarget the rest state of the tetrahedral mesh, while preserving ballistic energy [Irving et al. 2008]. Given the target surface generated from the flesh simulation, we now need to simulate sliding skin that accurately tracks the target surface.

For sliding motion, we constrain a triangular finite element model of the skin surface to track the surface generated by the flesh simulation. The finite element formulation allows us to accurately model realistic stretching and compression behavior in the skin. To match the skin simulation to the shape of the target surface, we progressively alter the triangular rest states at each time step to match the target surface. The skin simulation is bound to the target surface with two independent constraint forces. The first is normal to the target surface, and the second in the tangent space. We use high stiffness values in the normal direction for accurate shape preservation, and low tangential values to allow for loose sliding motion.

To construct the constraint forces, we bind each point of the skin mesh to the closest point on the target surface. As the skin simulation progresses, the binding point is updated at each time step. We limit the update to a topological local region in the target surface to avoid sudden jumps in the binding when the target surface has geometric folds. Such folds can originate from both the keyframe animation used as input, and from the flesh simulation. As these constraint forces are independent, they can be applied sequentially, without requiring the construction and solution of a linear system.

Biphasic materials model nonlinear stretching behavior; in particular, we use biphasic material to model the increase in resistance to deformation that occurs as flesh is stretched or compressed. This allows for natural secondary volumetric and sliding motion to appear under slow speeds, but for resistance to increase at high accelerations to avoid over–stretching. Linear material models for flesh simulation can behave badly, given sudden exaggerated target animation. This necessitates multiple simulation parameters sets for different classes of motion. Instead, the biphasic material allows the simulation to automatically adapt, both spatially and continuously, to changing energy states in the animation. This is true for sliding skin as well. Linear models can cause the skin to stretch unrealistically across portions of the character while compressing and folding over in others. Introducing a biphasic response to stretch and strain prevents this, without requiring an overall increase in stiffness that would limit the quality of the dynamics.

2 Time Integration

We update our constitutive models using an adaptive, semi-implicit time stepping scheme to efficiently retain realistic dynamics in the deformation response. However, the tracking constraints typically have high stiffness values, which would drive down the step size under this scheme. In addition, allowing constraint forces to drive the time step would work to resolve the high frequency oscillations in the constraints, which are aesthetically objectionable.

To address these issues, we apply fully implicit updates for the tracking forces, which avoids the need to take small time steps to retain stability. This also dampens out high frequency oscillations of the constraint forces, without reducing the quality of the deformation response. Alternatively we could use a fully implicit update for the entire model, but this can dampen out important dynamic response when practical step sizes are used.

Overall, these decoupled biphasic models allowed non–technical users to work with stable simulation rigs that performed robustly in a wide variety of shots. As each simulation is independent, animators could apply local edits to independently attenuate or exaggerate the volumetric and sliding responses to match specific art direction.

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References

IRVING, G., TERAN, J., AND FEDKIW, R. 2004. Invertible Finite Elements for Robust Simulation of Large Deformation. In *Proceedings of SCA 2004.*, 131–140.

IRVING, G., , KAUTZMAN, R., CAMERON, G., AND CHONG, J. 2008. Simulating the Devolved: Finite Elements on WALL-E. In *SIGGRAPH 2008 Talks*.

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