Volume-Preserving LSM Deformations

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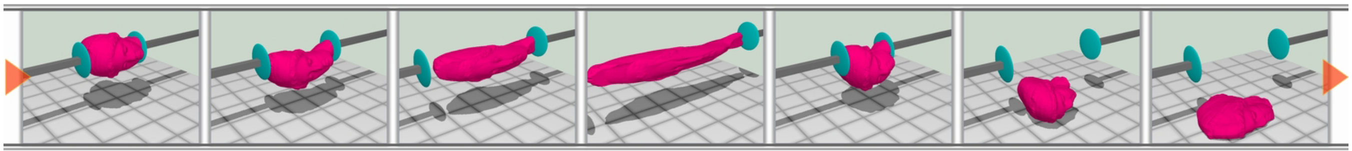

Figure 1: *LSM deformation with preserved object volume: Stretching and dropping of a Venus' head.*

1 Introduction

Surface deformations based on physically-based simulations are used to represent elastic motions such as human skins or clothes in the field of 3DCG applications. LSM (Lattice Shape Matching) [Rivers and James 2007] has particularly attracted attention as a fast and robust method which achieves elastic-like motions. However, the original LSM deformation method generates far from realistic motions especially when stretching an object, because volume is not preserved.

We propose a novel volume-preserving deformation method based on LSM. Our method can achieve more elastic-like motions than the original LSM while maintaining fast and robust computations.

2 Volume-Preserving LSM Deformations

Given a surface mesh M to be deformed, we voxelize the object to construct a lattice of cubic cells L covering the mesh. Our deformation method is applied to such a constructed lattice L. Our algorithm sequentially executes the following three processes at each time step; LSM deformation, volume-preserving correction, and mesh update.

LSM Deformation. We first compute the deformed positions of a lattice L at the current time step by using LSM [Rivers and James 2007]. Note that the volume-preserving correction described later does not affect LSM deformations, thus ensuring that deformation computations are still robust.

Volume-Preserving Correction. We next apply the volume-preserving correction to a deformed lattice. Our correction method is an extension of the volume-preserving mesh-skinning method [von Funck et al. 2008] to an arbitrary (non-skinned) shape.

Consider vertex positions $\boldsymbol{P} = \{\boldsymbol{p}_1, ..., \boldsymbol{p}_n\}$ and deformed vertex positions by LSM $\acute{\boldsymbol{P}} = \{\acute{\boldsymbol{p}}_1, ..., \acute{\boldsymbol{p}}_n\}$ in L. We define a *volume* of $\boldsymbol{p}_i$, $vol(\boldsymbol{p}_i)$, by using six neighboring vertices of a lattice. The whole volume of L is defined as: $vol(\boldsymbol{P}) = \sum_{i=1}^{n} vol(\boldsymbol{p}_i)$. We also prepare a deformation field $\boldsymbol{V} = \{\boldsymbol{v}_1, ..., \boldsymbol{v}_n\}$ to represent the direction of movements of $\boldsymbol{P}$ for volume-preserving correction.

A volume-preserving equation is formulated as follows,

$$vol(\acute{\boldsymbol{P}} + \lambda \cdot \boldsymbol{V}) = vol(\boldsymbol{P}), \qquad (1)$$

where λ denotes an unknown scale parameter. Equation (1) is a cubic equation for λ and can be solved only once for each time step. We adopt the minimum absolute value of up to three solutions to correct vertex positions $\ddot{\boldsymbol{P}} = \acute{\boldsymbol{P}} + \lambda \cdot \boldsymbol{V}$ in L.

It is crucial to define $\boldsymbol{V}$ appropriately. For boundary vertices in L, $\boldsymbol{v}_i$ is set as a normal vector which is computed by the relationship between existing neighboring vertices. We next compute $\boldsymbol{v}_i$of interior vertices by propagating from $\boldsymbol{v}$ at the boundary. $\boldsymbol{v}_i$ is then scaled so that its length is equal to 1 at the boundary and approaches zero towards the center of the object. We consider rotations computed in LSM to update $\boldsymbol{v}_i$ at each time step.

The displacement field $\boldsymbol{V}$ defined above shrinks or expands an object uniformly. $\boldsymbol{V}$ is not adequate when an object intersects with other objects and then suffers external forces. In such a case, it is desirable not to shrink or expand in the direction of such external forces to prevent interference between objects. Therefore, we modify $\boldsymbol{v}_i$ according to an external force $\boldsymbol{f}_i$ as follows,

$$\boldsymbol{v}_i = \boldsymbol{v}_i - \left(\boldsymbol{v}_i \cdot \dot{\boldsymbol{f}}_i\right) \dot{\boldsymbol{f}}_i, \quad \dot{\boldsymbol{f}}_i = \frac{\boldsymbol{f}_i}{|\boldsymbol{f}_i|}. \qquad (2)$$

In Equation (2), a part of an external force $\boldsymbol{f}_i$ parallel to $\boldsymbol{v}_i$ is canceled.

Mesh Update. A mesh M is deformed according to the deformed lattice L with vertices $\ddot{\boldsymbol{P}}$. Each vertex position of a mesh is updated by using the trilinear interpolation of corresponding lattice vertices. Note that $\ddot{\boldsymbol{P}}$ is used only for deforming M: To keep the computation robust, $\acute{\boldsymbol{P}}$ is used to update positions of L at the next time step in LSM deformation.

3 Results and Conclusion

Figure 1 demonstrates LSM deformation with preserved object volume. In this figure, a Venus' head (approximately 60,000 vertices) is stretched thin. Such thinning is the effect of volume preservation. In our experiment, a lattice with approximately 1,000 vertices is created to compute LSM deformations. The decrease in speed is within 18% of the original LSM deformation. Consequently, our simulation with volume preservation still maintains 30-40 fps which is enough for interactive applications. Other examples are demonstrated in the attached video.

References

RIVERS, A. R., AND JAMES, D. L. 2007. FastLSM: Fast lattice shape matching for robust real-time deformation. *ACM Transaction on Graphics (Proc. SIGGRAPH 2007) 26*, 3, 82:1–82:6.

VON FUNCK, W., THEISEL, H., AND SEIDEL, H.-P. 2008. Volume-preserving mesh skinning. In *13th International Fall Workshop on Vision, Modeling and Visualization*, 407–414.