Space Deformation for Character Deformation using Multi-Domain Smooth Embedding

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Abstract

We propose a novel space deformation method based on domain-decomposition to animate character skin. The method supports smoothness and local controllability of deformations, and can achieve interactive interpolating rates. Given a character, we partition it into multiple domains according to skinning weights, and attach each to a linear system, without seam artifacts. Examples are presented for articulated deformable characters with localized changes in deformation of each near-rigid body part. An application example is provided by usage in deformation energies, known to offer preservation of shape and volumetric features.

Keywords: space deformation, radial basis functions, character deformation, deformable surface

1 Introduction

Space deformation is a common acceleration strategy used in nonlinear variational deformation (e.g. [1]), supporting preservation of shape-details and volumetric properties, and deformable solids such as Finite Element model [2], offering interior dynamics in addition to quasistatic skins, to produce realistic deformations. In such contexts, a coarse representation loosely enclosing the original mesh surface is established, carrying out the expensive computations, and the resulting deformations are propagated back to the original mesh by efficient space deformation. Shepard's interpolation scheme [3], though, is extensively adopted as space deformation, it is not smooth enough to interpolate surfaces.

Radial basis functions (RBFs) are the most versatile and commonly used smooth interpolation techniques in graphics and animation. Radial basis functions mostly are based on Euclidean distances. In this case, movements of a branch of a model therefore might affect others when they are close to that branch in Euclidean space, often happening in character deformation. Levi and Levin [4] compute geodesic distances to overcome the limitations. Nevertheless, the distance metrics heavily depend upon the mesh topology or representation, leading to a loss of generality.

A skeletal character consists of limb segments and the deformation of each segment is locally controlled. Vaillant et al. [5] propose to partition the character into multiple bone-associated domains, and approximate deformations of each segment by a field function. The method, however, obtains speedups by hardware acceleration, and requires a composition of the field functions into a global field function, which is difficult to realize in practice.

Contribution We propose smooth embedding based on radial basis functions (RBFs) for character deformation. To avoid interplay between mesh branches, we partition the character into multiple domains according to associated skinning weights, and attach each to a small, linear system of a local RBFs. Regions at and around boundaries of contact skin parts are smoothed in the post-processing, avoiding seam artifacts. In contrast to [5, 6] , our method does not blend field functions, instead we only introduce a simple, geometric post-processing to remove seam artifacts.

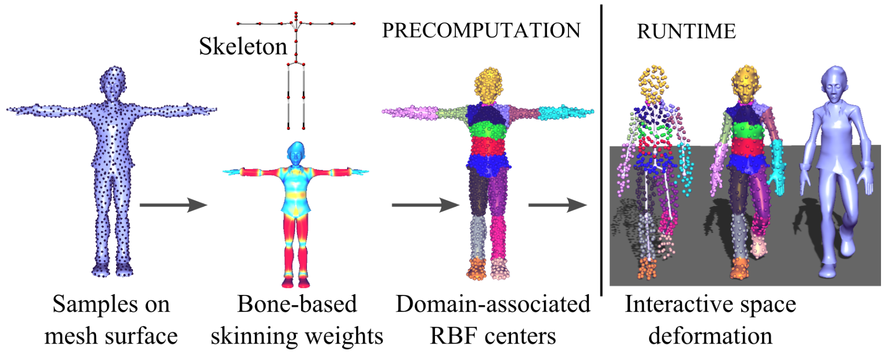

Figure 1: Pipeline overview: We first sample a set of points (black dots), ready to be RBF centers, on the mesh surface, and then partition the character into multiple domains based on skinning weights, indicated by colors. Each segment, indicated by a colour, is accordingly associated with a small group of samples for the construction of a local RBFs interpolation. Our method is applied in interactive applications.

Our multi-domain RBFs interpolation scheme can run at interactive rates and gives rise to smooth shape deformations. We test our method in a nonlinear variational deformation energy. The results demonstrate the effectiveness.

2 Multi-domain smooth space deformation

We use RBFs with compact support to interpolate displacements

$$\Phi(x) = e^{(\frac{-\|x-c\|^2}{\sigma^2})} + a^T \cdot x + b, \qquad (1)$$

where $c \in \mathbb{R}^3$ is the RBF center, and $x \in \mathbb{R}^3$ is the evaluation point. Presence of the linear term helps to reproduce global behavior of the function. The resulting sparse matrix is solved by LU decomposition, leading to the identical result. In our implementation, σ is average distance between RBF centers by the guideline of ALGLIB [7] which is a popular numerical analysis library, guaranteeing that there will be several centers at distance σ around each evaluation point.

An overview of our method is shown in Figure 1. We employ Poisson disk sampling [8] to sample the RBF centers on the mesh surface, and based on the resulting segmentation, we consequently put them into corresponding clusters. In our space deformation, only the RBF centers are embedded, and the original surface is left to a set of domain-associated RBFs interpolation systems. For complex figures such as human hand, our method still addresses the limitations, given a proper weight map. In practice, such weights are often painted by skillful artists to provide a guarantee. We also computed exact geodesic distances [9] as alternatives to Euclidean metrics. Single RBFs with these values, though, yields similar results to our method, it might have drawbacks, e.g., low order smoothness at and around contact regions. Figure 2 shows the comparisons.

We iteratively employ Laplacian smoothing to remove the sharp features at and around the boundaries of contact regions, specifically using

$$v_i^{t+1} = v_i^t + \frac{1}{\sum_{j\in\mathcal{N}(i)} \omega_{i,j}} \sum_{j\in\mathcal{N}(i)} \omega_{i,j}(v_j^t - v_i^t), \qquad (2)$$

where $\mathcal{N}(i)$ is N one-ring neighboring vertices of v_i, and $\omega_{i,j}$ is cotangent weight [10]. The method is efficient even in complex motions including twisting and bending, as illustrated in Figure 3.

3 Results

An experiment is conducted to investigate how the number of samples affects the performance. We increase the number of RBF centers, and report the resulting timings in Table 1, which shows the efficiency of our method for larger number of RBF centers.

Our method succeeds in volumetric deformation using volumetric PriMO energy [1] for instance, as shown in Figure 4. In more detail, the

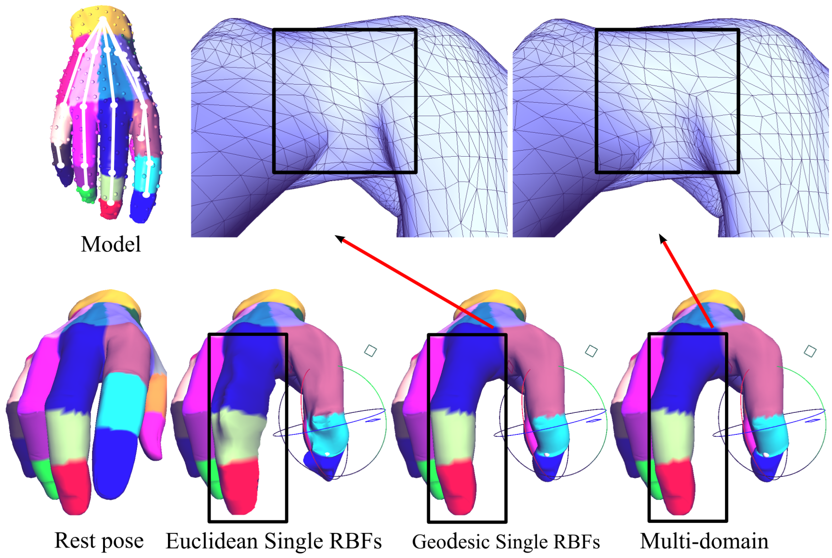

Figure 2: Both single RBFs with geodesic distances and our method avoid interplay between fingers, whereas single BRFs with Euclidean distances does not. Our method, however, supports higher order smoothness than geodesic single-RBFs. The trackball indicates rotating motion of a finger.

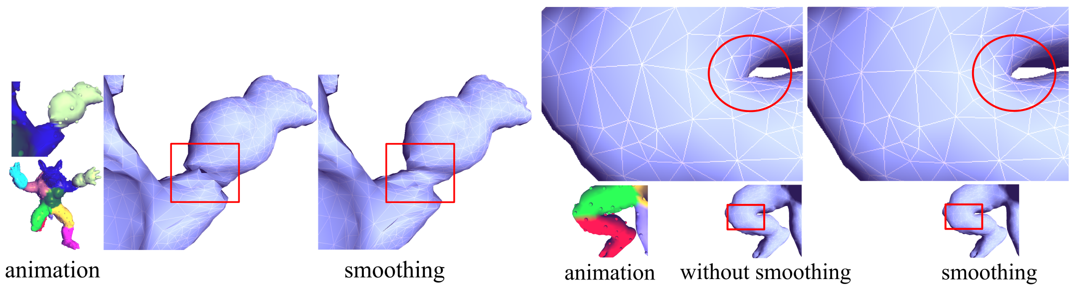

Figure 3: Elbow twisting (left). Laplacian smoothing by 5 iterations. Leg bending (right). Smoothing by 3 iterations.

	Method	50	100	150	200	250	300	350
Initialize (ms)	Single	1.02	3.92	13.63	27.98	52.34	91.48	144.99
	Multi-domain	0.18	0.43	1.08	1.90	3.26	5.53	8.51
Runtime (ms)	Single	19.54	30.51	44.94	57.81	72.56	86.56	103.09
	Multi-domain	28.17	42.52	58.77	74.11	89.81	105.73	119.82
Total (ms)	Single	20.56	34.43	58.57	85.79	124.90	178.04	248.08
	Multi-domain	28.35	42.95	59.85	**76.01**	**93.07**	**111.26**	**128.33**

Table 1: Timings: Multi-domain interpolation shows advantage increased in number of samples. Note that the additional runtime cost in our method, with respect to single RBFs interpolation, is introduced by the smoothing step rather than solving multiple linear systems themselves. The time is in milliseconds. The model has 5,103 vertices, 10,202 triangles and six domains.

volumetric PriMO energy as a nonlinear variational deformation technique, while keeping deformation as-rigid-as-possible, is computationally expensive. In our test, of the Armadillo model with $5,406$ vertices, $10,808$ triangles and 300 samples on surface (Figure 4), the space deformation using multi-domain smooth embedding, only takes average 0.07 s per frame, whereas the volumetric deformation costs average 1.64 s per frame, showing that the runtime cost of space deformation is minimum without introducing significant overload.

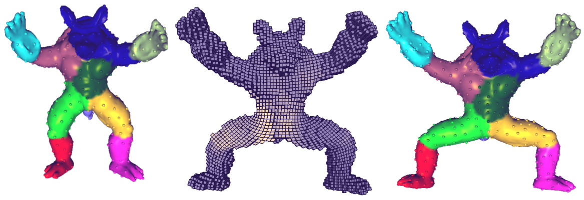

Figure 4: We apply multi-domain space deformation in an energy minimization based deformation technique, namely the volumetric PriMO energy with voxels [1].

4 Conclusion

In this paper, we presented a method of space deformation based on domain-decomposition for character deformation. The method is based on radial basis functions, supporting smoothness without seam artifacts. We have applied our method in a nonlinear variational deformation technique, demonstrating the efficiency of the method.

Our method is likely to yield domains with very small number of samples for skinned model with many bones, making the resulting interpolation matrices inefficient. A possible solution is to group the contact domains associating with minimum number of samples as a new domain, and update the RBFs accordingly.

Our domain decomposition method holds promise to perform surface deformation in real-time animation and simulation applications on commodity laptops in the near future.

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References

[1] Mario Botsch, Mark Pauly, Martin Wicke, and Markus Gross. Adaptive space deformations based on rigid cells. *Computer Graphics Forum*, 26(3):339–347, 2007.

[2] Theodore Kim and Doug L. James. Physics-based character skinning using multi-domain subspace deformations. In *Proceedings of the 2011 ACM SIGGRAPH/Eurographics Symposium on Computer Animation*, SCA '11, pages 63–72, 2011.

[3] R.E Barnhill, R.P Dube, and F.F Little. Properties of shepard's surfaces. *Journal of Mathematics*, 13(2), 1983.

[4] Zohar Levi and David Levin. Shape deformation via interior rbf. *Visualization and Computer Graphics, IEEE Transactions on*, 20(7):1062–1075, July 2014.

[5] Rodolphe Vaillant, Loïc Barthe, Gaël Guennebaud, Marie-Paule Cani, Damien Rohmer, Brian Wyvill, Olivier Gourmel, and Mathias Paulin. Implicit skinning: Real-time skin deformation with contact modeling. *ACM Trans. Graph.*, 32(4):125:1–125:12, July 2013.

[6] Rodolphe Vaillant, Gäel Guennebaud, Loïc Barthe, Brian Wyvill, and Marie-Paule Cani. Robust iso-surface tracking for interactive character skinning. *ACM Trans. Graph.*, 33(6):189:1–189:11, November 2014.

[7] Alglib: a cross-platform numerical analysis and data processing library. available online at `http://www.alglib.net/`. Accessed: 2015-03-03.

[8] Kenric B. White, David Cline, and Parris K. Egbert. Poisson disk point sets by hierarchical dart throwing. In *Proceedings of the 2007 IEEE Symposium on Interactive Ray Tracing*, RT '07, pages 129–132, 2007.

[9] Shi-Qing Xin and Guo-Jin Wang. Improving chen and han's algorithm on the discrete geodesic problem. *ACM Trans. Graph.*, 28(4):104:1–104:8, September 2009.

[10] Mark Meyer, Mathieu Desbrun, Peter Schröder, and Alan H Barr. Discrete differential-geometry operators for triangulated 2-manifolds. In *Visualization and mathematics III*, pages 35–57. Springer, 2003.