Material Aware Mesh Deformations

Tiberiu Popa[*]
University of British Columbia

Dan Julius[†]
University of British Columbia

Alla Sheffer[‡]
University of British Columbia

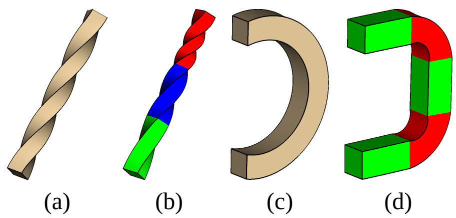


Figure 1: Twisting and bending a bar using two anchor triangles: (a), (c) uniform materials; (b), (d) non-uniform materials.

1 Introduction

Mesh deformation is a key task in modeling and animation of digital models. In this work we present a method for deformation of meshes that incorporates material properties. While previous methods, such as [Yu et al. 2004], distribute the deformation evenly within the region of interest, our method is the first to our knowledge, to support a variation in stiffness across the mesh. Using material properties to control stiffness, we provide users with a simple and intuitive method of controlling the deformation propagation, thus yielding more realistic results.

The traditional way to specify rigid and flexible segments of articulated models is to use skeletons. However, skeletons are tedious to construct, thus recent deformation methods try to avoid them. The use of material properties provides an intuitive alternative to skeletons allowing even finer control when specifying desired behaviors. While skeletons allow only two levels of stiffness, our method allows multiple levels, which are essential for complex deformations e.g., Figure 1(b). While allowing greater flexibility and control our algorithm is extremely simple and efficient requiring only minimal user interaction.

2 Method Overview

We base our method on the concept of transforming local triangle coordinate frames, where each frame is defined by a mesh triangle and a normal to it. The following four stages describe the general flow of our algorithm:

1. The user specifies optional material information.
2. The user manually transforms one or more *anchor* triangles.
3. Anchor triangle transformation are propagated to the rest of the triangles. In this central stage of the algorithm we need to find an appropriate transformation for each triangle, which matches the user prescribed anchor transformations, is continuous i.e., adjacent triangles have close transformations and finally, is as rigid as possible subject to the material properties.
4. Vertex positions are found such that adjacent triangles agree on the position of their shared vertices.

[*]e-mail: stpopa@cs.ubc.ca
[†]e-mail: djulius@cs.ubc.ca
[‡]e-mail: sheffa@cs.ubc.ca

For the first two steps we created a simple to use set of tools for mesh manipulation. Material properties are defined using a paintbrush style tool. Regions of the mesh which have not been painted are assigned default stiffness values. Triangles are rotated using a simple click and drag interface. Other operations such as scaling and translation are performed in a similar manner.

The third step is the center of our algorithm. In order to find an appropriate set of transformations we define, per triangle, a transformation matrix which is a weighted combination of the anchor transformations [Alexa 2002]. As weights we use a vector $\omega_i \in R^k$ for each triangle, where k is the number of anchors. The weights are chosen s.t. the resulting transformations blend the anchor transformations in a smooth manner while capturing the material properties. The optimal weights ω_i are found by minimzing the following function:

$$\min_{\omega_i} \sum_{i,j \in \tilde{E}} \mu_i \mu_j \parallel \omega_i - \omega_j \parallel_2^2,$$

where $\tilde{E}$ is the set of adjacent triangles s.t. $(i, j) \in \tilde{E}$ if either triangle i or triangle j (or both) are not anchors and μ_i, μ_j are the stiffness coefficients of the triangles.

The resulting transformations for adjacent triangles are close but not identical. Hence, the final step of the algorithm modifies the transformations such that adjacent triangles agree on the positions of their shared vertices. We use [Sumner and Popovic 2004] to find optimal vertex positions such that each local frame is transformed in an as similar as possible manner (in the least squares sense) to the previously calculated transformation.

3 Results

Figures 1 and 2 show examples of material usage. In Figure 2 the material properties are used to correct the deformation of the beak on the eagle.

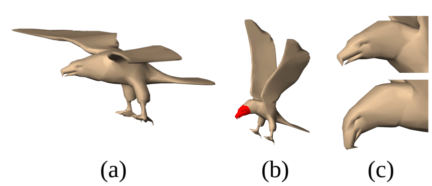


Figure 2: Posing the eagle: (a) the original model; (b) deformed model (highlighting the stiff region); (c) top - correct head; bottom - incorrect head when using a uniform material.

References

ALEXA, M. 2002. Linear combination of transformations. In *SIGGRAPH '02: Proceedings of the 29th annual conference on Computer graphics and interactive techniques*, ACM Press, New York, NY, USA, 380–387.

SUMNER, R. W., AND POPOVIC, J. 2004. Deformation transfer for triangle meshes. *ACM Trans. Graph. 23*, 3, 399–405.

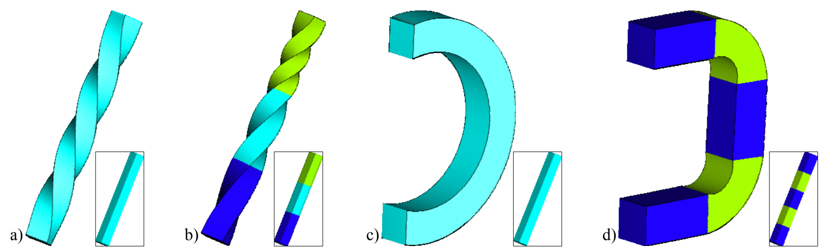
YU, Y., ZHOU, K., XU, D., SHI, X., BAO, H., GUO, B., AND SHUM, H.-Y. 2004. Mesh editing with poisson-based gradient field manipulation. *ACM Trans. Graph. 23*, 3, 644–651.

Material Aware Mesh Deformations

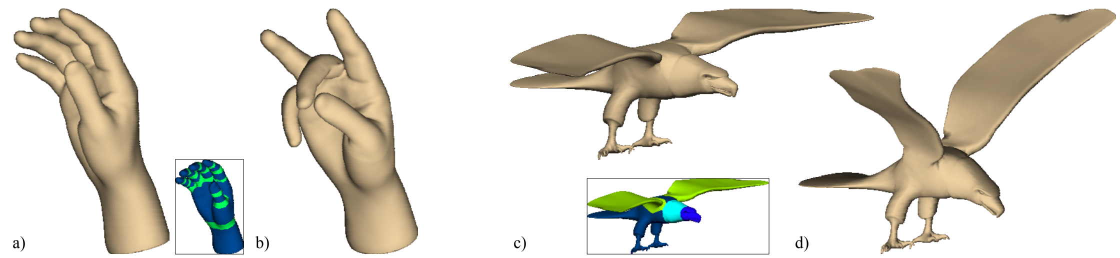
Tiberiu Popa   Dan Julius   Alla Sheffer

{stpopa | djulius | sheffa}@cs.ubc.ca

Department of Computer Science, University of British Columbia

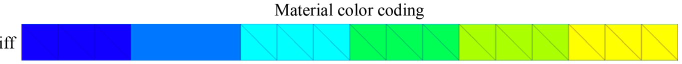


Twisting and bending a bar : (a), (c) uniform materials; (b), (d) non-uniform materials



Deformation results: (a), (c) original models; (b), (d) deformations using our system

Material color coding

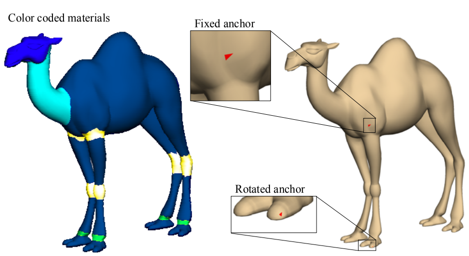


Introduction:

We present a novel method for deformation of meshes that incorporates material properties to control stiffness.

•Material properties provide a fine and continuous control of the surface behavior.
•Users specify materials using a simple painting-like interface.
•Our method does not require a tedious skeleton construction while providing much finer control.

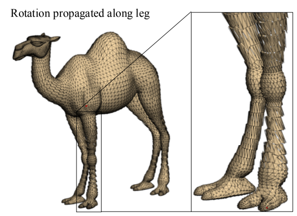
User input:

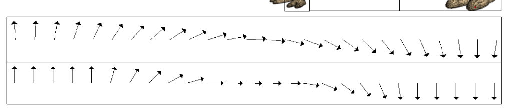


Algorithm overview:

1.Transformation propagation

- Propagate anchor transformations to the rest of the triangles.
- Propagated transformations should be:
  - Continuous across the surface
  - Consistent with material properties
  - As rigid as possible
  - Match user defined transformations
- Triangle transformations are weighted combinations of anchor transformations.
  - The weights determine the behavior of the deformation.





Normal vectors rotated along the bent bar above: (top) uniform material (bar (c)); (bottom) non-uniform material (bar (d))

•Choosing good weights is the central stage of our algorithm.
•Weights are chosen such that:
- Material properties are captured
- Transformations are combined smoothly

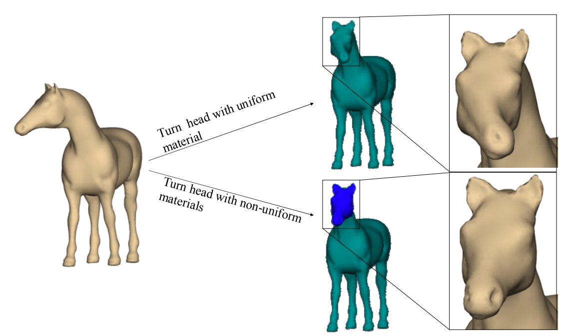
•To combine transformations we use the algebra introduced by [Alexa 2002].

• Optimal weights ω_i found by minimizing:

$$\min_{\omega_i \in R^k} \sum_{i,j \in \tilde{E}} \mu_i \mu_j \left\| \omega_i - \omega_j \right\|_2^2$$

Adjacent faces

Face stiffness coefficients



2. Vertex positioning:

• Ensure adjacent triangles agree on shared vertices.
•Based on material properties, distortion is directed toward flexible regions.
•Transformations remain as close as possible to the target transformations.
•Use a variation of [Sumner and Popovic 2004] to position vertices.

Final result:

Conclusions:

• First method, to our knowledge, to support continuous variation of stiffness.
• Material properties provide a simpler and more powerful alternative to skeleton construction.
•Triangle transformations are as rigid as possible subject to material properties.
•Requires minimal user interaction.
•Simple and efficient linear formulation.

References and related work:

ALEXA, M. 2002. Linear combination of transformations. *SIGGRAPH '02*
SUMNER, R. W., AND POPOVIC, J. 2004. Deformation transfer for triangle meshes. *ACM Trans. Graph. 23*, 3, 399–405.
YU, Y., ZHOU, K., XU, D., SHI, X., BAO, H., GUO, B., AND SHUM, H.-Y. 2004. Mesh editing with poisson-based gradient field manipulation. *ACM Trans. Graph.23*, 3, 644–651.