Time-variant Volumetric Colors for Metamorphosis

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Figure 1: *Metamorphosis with time-variant colors starting from a Manga character to a cut watermelon, and then to a banana using the proposed method.*

Abstract

We propose to treat any changes in colors and textures in shape metamorphosis between two objects as time-dependent transformations of the volumetric distribution of materials. The main idea is to represent geometry of both objects with scalar fields with distance properties, to leave a time gap in where the geometric metamorphosis happens, and to use the scalar fields to apply shape-driven interpolation to volumetric material attributes within this time gap. The proposed solution is analytical, does not require heavy numerical computations essential to fluid simulations, and can be implemented in real-time applications.

Categories and Subject Descriptors (according to ACM CCS): I.3.5 [Computer Graphics]: Computational Geometry and Object Modeling—Curve, surface, solid, and object representations I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism—Color, shading, shadowing, and texture

1. Introduction

Metamorphosis in 2D and 3D space has been relatively well studied including the topological changes in genus and the number of components of the source and target objects. While morphing between two boundary representation objects is possible, it is often complicated, in particular if they do not have the same topology or complexity.

The methods based on scalar fields are known to be simpler to use and more efficient for metamorphosis. However, the colors, textures and general material information is not handled as efficiently as geometry by using these methods. The problem is more apparent with interactive or real-time metamorphosis of objects. Most of the existing methods to solve the transformation of colors and textures in metamorphosis, for example, particle tracking systems [SS96] or solving differential equations [DYT05] are computationally expensive, and therefore not suitable for interactive applications. On the other hand, the very well known linear interpolation between colors in metamorphosis process results in unintuitive colors in the intermediate frames.

We propose to treat any changes in colors and textures in metamorphosis as transformations of the volumetric distribution of materials happening in the space-time. Our approach is based on the interpolation of material based on fields with distance properties presented in [BST04]. The main point is to leave a time gap in space-time where the geometry transition happens, and to use the scalar fields to apply the shape-driven interpolation to material attributes within this time gap. The method allows us to obtain a good color transformation without being computationally expensive hence allowing to use it for interactive applications. There are no restrictions on the geometry of the initial and target models as long as they can be represented by scalar fields with the distance property.

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2. Method overview

Let us have a source object G_1 and target object G_2 with real-valued functions $f_1(x,y,z)$ and $f_2(x,y,z)$ defining the geometry and vector functions $\mathbf{c_1}(x,y,z)$ and $\mathbf{c_2}(x,y,z)$ defining the color attributes of the source and target objects respectively. The sign of the function $f_i(x,y,z)$ defines the surface of the object ($f_i(x,y,z)=0$), its interior ($f_i(x,y,z)>0$) and exterior ($f_i(x,y,z)<0$). We require the functions $f_1(x,y,z)$ and $f_2(x,y,z)$ to have a distance property, i.e. for any two points $\mathbf{p_1}$ and $\mathbf{p_2}$ whose Euclidean distance to the object G_i is equal $d(\mathbf{p_1})$ and $d(\mathbf{p_2})$ respectively, $d(\mathbf{p_1})>d(\mathbf{p_2}) \rightarrow f(\mathbf{p_1})>f(\mathbf{p_2})$.

For a shape transformation $G(t)$ where $t\in[0,1]$, $G(0)=G_1$ and $G(1)=G_2$, we apply separate procedures for geometry and for color attributes. A variety of time-variant shape deformations can be applied to get intermediate shapes between G_1 and G_2, such as linear metamorphosis, space-time blending or 4D variational formulation. However for color attributes these methods are not suitable.

We propose to use a shape-driven interpolation similar to the material transformation method presented in [BST04]. The color attribute at the given point for the given time can be represented as follows:

$$\mathbf{c}(x,y,z,t)=\mathbf{c_1}(x,y,z)\times w_1(t)+\mathbf{c_2}(x,y,z)\times w_2(t)$$

where w_1 and w_2 are the weighting functions with the following constraints: $w_1(0)=1$, $w_1(1)=0$, $w_2(0)=0$, $w_2(1)=1$ and $w_1(t)+w_2(t)=1, \forall t\in[0,1]$. The color transformation is performed in HSV space to make the transitions smooth. We define the weighting functions to be dependent on the inverse defining functions for the source and target objects with an additional time gap between two objects:

$$g_1(x,y,z,t)=f_1(x,y,z)\wedge_0(-t)$$

$$g_2(x,y,z,t)=f_2(x,y,z)\wedge_0(t-1)$$

$$w_1(x,y,z,t)=\frac{g_2(x,y,z,t)}{g_1(x,y,z,t)+g_2(x,y,z,t)}$$

$$w_2(x,y,z,t)=\frac{g_1(x,y,z,t)}{g_1(x,y,z,t)+g_2(x,y,z,t)}$$

where $\wedge_0$ denotes an R-function for the set intersection.

3. Implementation and results

As we stated above, we transform the geometry and the colors separately. The choice of method for the geometry transformation in metamorphosis depends on the specific requirements of applications. In interactive applications the metamorphosis process should be as fast as possible while in off-line geometry processing application the result should be discernible by the user's eye. In our tests we have used space-time blending [PPK04] as it provides better results than linear metamorphosis, and in addition is computationally inexpensive. To define colors we used three different approaches:

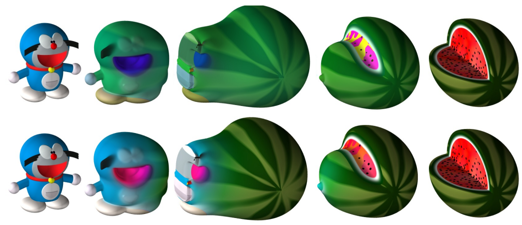

Figure 2: *Top image: linear interpolation in HSV space for volumetric material distribution; bottom image: volume material distribution with the presented method.*

- Procedural texturing, where we explicitly define the color value for each point in the space by using function-based definition (the "watermelon" model in Figure 1).
- Space enumeration, where we define the constant color for a given space partition. For the partitions where color is not defined, we use default color, such as white or gray (the "Doraemon the cat" model in Figure 1).
- Texture sampling from polygonal mesh. In case our initial model is a textured polygonal object, the geometry in our method is represented by the signed distance field and we can naturally obtain texture coordinates of the closest point in the mesh when performing a signed distance query. The color information hence can be obtained from the texture (the "banana" model in Figure 1).

Note that the presented color transformation technique allows the objects to be separated in space as well as share the space. Figure 2 shows that the proposed method provides superior results than the linear color interpolation technique. In particular, one can notice the better transfer of the colors for the points in space located far from the initial object. It is worth to note that the proposed solution does not require heavy numerical computations and can be implemented in real time applications.

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