GRAYTONE IMAGE METAMORPHOSIS USING 3D INTERPOLATION FUNCTION

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Keywords: Image metamorphosis, Morphing, Morphological image processing.

Abstract: Image metamorphosis process produces deformation sequence which transforms one input image into another one. The method described in the paper applies morphological approach to achieve this goal. It is based on morphological interpolation which makes use of the interpolation functions produced from geodesic distance functions. The described method allows applying this approach to graytone images via its 3D umbra. It produces 3D interpolation function. Its thresholding at given level followed by inverse umbra transform allows obtaining frame of the interpolated sequence.

1 INTRODUCTION

This paper describes a method for graytone image metamorphosis (also called morphing) by means of binary morphological interpolation (Meyer, 1996; Serra, 1996; Beucher, 1998; Iwanowski and Serra, 2000; Iwanowski, 2000). Interpolation between two images consists in generating a sequence of intermediary images, content of which is transformed from the content of first input image (initial) into the content of the second one (final). A method proposed in the paper is based on the method introduced in (Meyer, 1996), where a content of the interpolated image is obtained by a thresholding of the interpolation function, which is computed from the morphological geodesic distance functions. Using increasing threshold values results in production of successive images which creates the *interpolation sequence* converting one input image into another. The novelty of the proposed method is an application of binary interpolation into graytone images. This is achieved through an umbra transform, which converts 2D graytone image into 3D binary one. The graytone images which are morphed are first converted into their umbras. To interpolate between umbras the method based on interpolation function in 3D is applied. Contrary to methods that already appeared in the literature (Meyer, 1996; Iwanowski, 2000), the proposed one interpolates between 3D binary images - umbras of input graytone images. The interpolated 3D shape is transformed back into graytone image. By producing interpolated image at increasing levels the interpolation sequence (or: morphing sequence) is obtained.

The methods of the morphological interpolation consisting in creation of the intermediary two-dimensional images between two given ones ('inter-frame' interpolation) are developed since 1994. Two principal approaches were introduced. The first one, based on the morphological median, was presented in (Beucher, 1998; Serra, 1996). It is a flexible approach, which is applicable to any kind of image: binary, mosaic and graytone. In (Iwanowski and Serra, 1999) the area of applications of this method was extended into color images, by using a lexicographic ordering of colors in the comparative color space. Another approach is represented by the interpolation function method introduced in (Meyer, 1996). This method is based on the function which describes the relative distance between the objects and can be applied to binary and mosaic images. The results of further research (Iwanowski and Serra, 2000) allowed combining the morphological interpolation with affine transform. A different approach to morphological interpolation was presented in (Soille, 1991), which can be called - contrary to previously described - an 'intraframe' interpolation. It deals with a single incomplete image and it reconstructs the im-

Iwanowski M. (2009).
GRAYTONE IMAGE METAMORPHOSIS USING 3D INTERPOLATION FUNCTION.
In *Proceedings of the Fourth International Conference on Computer Vision Theory and Applications*, pages 5-9
DOI: 10.5220/0001754400050009

age surface starting from the contour lines. This approach makes use of the geodesic distance function obtained by the geodesic propagation.

The morphological approach is automatic in such a sense that it does not require control points, as classic morphing methods does. Lack of input parameters places this method together with well-known cross-dissolving (Wolberg, 1990). It produces however totally different transformation between images. Cross-dissolving produces a kind of blending while morphologically interpolated sequence contains the change of shape of objects on the images.

The paper is organized as follows. Section 2 describes the classic approach to morphological interpolation using the interpolation function. Section 3 presents the proposed approach - the way of applying this interpolation into graytone images. Section 4 shows some results, and finally Section 5 concludes the paper.

2 MORPHOLOGICAL INTERPOLATION FUNCTION

This section recalls the principles of binary interpolation using the distance function (Meyer, 1996; Iwanowski, 2000).

2.1 Binary Object

Binary image i.e. image of pixel values equal either 0 or 1, is usually defined in one of two ways. According to the first one binary image is a *mapping* from definition domain $\mathcal{D}$ into $\{0,1\}$. According to the second one, binary image X is a set of pixels of value 1 (foreground pixels). The complement of this set (X^C) is referred to as image background. Image X can consist of many connected components i.e. subsets of image pixels such that any two pixels belonging to the same subset can be connected by a path of pixels of value 1 entirely included in this subset. The single connected component of binary image will be referred to as *object*. The metamorphosis using interpolation function allows to morph an object on the initial image another object on the final one.

2.2 The Interpolator

An interpolator provides a transformation which produces an interpolated object. It is a function of three principal arguments: two input objects (initial and final) and an interpolation level α. *An interpolation level* is a real number α such that $0 \leq \alpha \leq 1$. In this paper the interpolator is denoted as: $Int_P^Q(\alpha)$, where Q represents the initial binary object, P - the final one. Shapes of interpolated objects are turning from a shape of the object Q to shape of the object P. For $\alpha = 0$, the interpolated image is equal to the initial one ($Int_P^Q(0) = Q$); for $\alpha = 1$ - to the final image ($Int_P^Q(1) = P$). A sequence of interpolated images produced for increasing values of α is an *interpolation sequence*.

2.3 Interpolation Method

The way of defining the interpolator depends on the mutual relation between input objects. First, the case of nested objects will be considered where objects located on the initial image are included in appropriated objects on the final image. Later on, the general case of any two images will be described.

Let X and Y be nested objects ($X \subset Y$). The interpolation function proposed in (Meyer, 1996) is defined as:

$$int_Y(X)[p] = \frac{d_Y(X)[p]}{d_Y(X)[p] + d_{X^C}(Y^C)[p]}, \quad (1)$$

where X^C and Y^C stand for the complements of binary images X and Y respectively. $d_A(B)$ stands for the geodesic distance function describing the distance to B inside A ($B \subset A$). Geodesic distance is defined as the length of the shortest path connecting given pixel in $Y \setminus X$ with the set X. In digital grid various ways of computing the distance function are in common use. The simplest way is propagation in either 4- or 8-connectivity in 2D and 6,18 or 26 connectivity in 3D. This however is not an Euclidean distance. The latter could be obtained using specialized algorithms (Vincent, 1991).

The interpolator based on the Eq. 1 is defined as:

$$Int_Y^X(\alpha) = T_{[\alpha]}(int_Y(X)), \quad (2)$$

where $T_{[\alpha]}$ stands for the thresholding operator at level α which sets 1 for graylevels below threshold α, and 0 otherwise.

The case of two input objects which are not nested (but which have a non-empty intersection) is split into two interpolations between nested sets.

Let P and Q be the initial and final objects - nested or intersected. A final result of the interpolation at given level α is obtained as an sum of two interpolations of nested objects:

$$Int_P^Q(\alpha) = Int_P^{P\cap Q}(\alpha) \cup Int_Q^{P\cap Q}(1-\alpha). \quad (3)$$

The interpolator in the general case (defined by the Eq. 3) is based on two interpolators. Each of them transforms the input image into the intersection of both input images. This approach requires two interpolation functions. In order to speed up with the computations, the single function can be computed. This case is described in section 3.

The interpolated object at level $\alpha = 0.5$ is located in the midway between both input objects. This object is also referred to as *morphological median* (Beucher, 1998) defined as:

$$M = \cup_{\lambda \geq 0} \{((P \cap Q) \oplus \lambda B) \cap ((P \cup Q) \ominus \lambda B)\}, \quad (4)$$

where $\oplus$ stands for morphological dilation and $\ominus$ - for erosion.

3 METAMORPHOSIS OF GRAYTONE IMAGES

3.1 Umbra

Let $f : \mathcal{D} \rightarrow \mathcal{V}$ be two-dimensional graytone image where: $\mathcal{D} = \{0,1,...,x_{max}-1\} \times \{0,1,...,y_{max}-1\}$ is the set of pixels coordinates - image definition domain and $\mathcal{V} = \{0,1,...,g_{max}-1\}$ is set of possible graytones. x_{max} and y_{max} are sizes of graytone image and g_{max} is the highest possible graytone value of this image.

Graytone image can be transformed into 3D umbra, which is 3D binary image - a 'relief' of a terrain whose map is the input 2D graytone image. The umbra transformation is defined as follows:

$$U[f] = \{(p,q) \in \mathcal{D} \times \mathcal{V} : f(p) \geq q\}. \quad (5)$$

The above equation describes the transformation which converts 2D graytone image into 3D umbra. The inverse transformation, which transforms umbra back into graytone image, is denoted as follows:

$$f = U^{-1}[X] \Leftrightarrow X = U[f]. \quad (6)$$

3.2 Interpolation Function for Graytone Images

Let f_A and f_B be to input graytone images. In the first step their umbra are computed:

$$X_A = U[f_A]\,;\, X_B = U[f_B]. \quad (7)$$

In order to produce the interpolation function, their sum and intersection have to be computed, respectively:

$$X_\cap = X_A \cap X_B = U[f_A \wedge f_B], \quad (8)$$

$$X_\cup = X_A \cup X_B = U[f_A \vee f_B], \quad (9)$$

where $\wedge$ and $\vee$ stand for the point-wise minimum and maximum of two graytone images, respectively. These two 3D binary objects are always nested: $X_\cap \subset X_\cup$. Owing to this, the geodesic distance functions in $X_\cup \setminus X_\cap$ can be computed (for any input images) and combined together to obtain the interpolation function according to the Eq. 1.

To simplify the calculations of the interpolations function, single function can be computed instead of two as stated in the Eq. 3. Let define the interpolation function between intersection $X_\cap$ and union $X_\cup$ denoted by $Int_{X_\cup}^{X_\cap}$. The following relation holds:

$$Int_{X_A}^{X_\cap}(\alpha) = Int_{X_\cup}^{X_\cap}(\alpha) \cap X_A, \quad (10)$$

$$Int_{X_B}^{X_\cap}(\alpha) = Int_{X_\cup}^{X_\cap}(\alpha) \cap X_B. \quad (11)$$

The result of thresholding of the interpolation function have finally to be converted from the umbra form into graytone image using U^{-1} transform (Eq. 6). The complete interpolator can be thus formulated as follows:

$$f_\alpha = U^{-1}\left[\left(Int_{X_\cup}^{X_\cap}(\alpha) \cap X_A\right) \cup (Int_{X_\cup}^{X_\cap}(1-\alpha) \cap X_B)\right]. \quad (12)$$

Having in mind earlier considerations the above equation can be re-written as follows:

$$\begin{aligned} f_\alpha \quad = \quad & \left(U^{-1}\left[Int_{X_\cup}^{X_\cap}(\alpha)\right] \wedge f_A\right) \vee \\ & \left(U^{-1}\left[Int_{X_\cup}^{X_\cap}(1-\alpha)\right] \wedge f_B\right), \end{aligned} \quad (13)$$

where f_α stands for the morphologically interpolated graytone image at level α.

Similiarily to the binary case, in the graytone one, the image $f_{0.5}$ is referred to morphological median of graytone images (Beucher, 1998).

By producing the interpolated images at increasing levels, the sequence of frames is computed - the interpolation sequence.

4 RESULTS

Figure 1 shows the interpolation sequence produced using the proposed method starting from two input test images containing rectangles of different graytones. The sequence consists of 6 interpolated

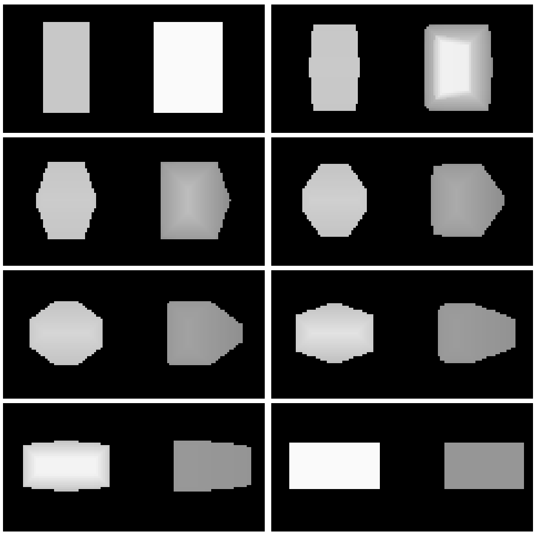

Figure 1: Morphological interpolation of test images.

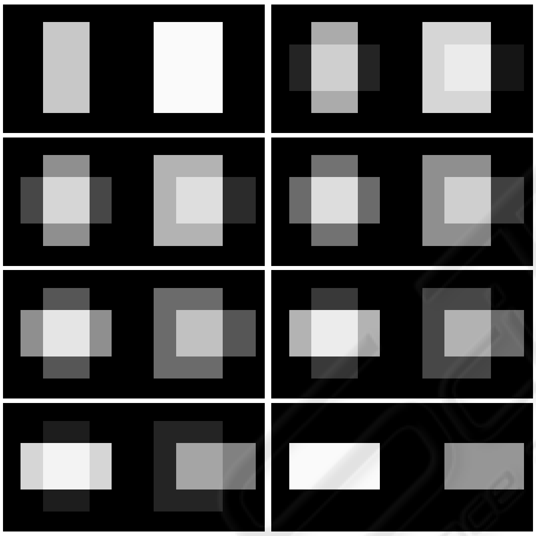

Figure 2: Cross-dissolving of test images.

frames, generated for equidistanced interpolation levels: 0.14;0.18;0.43;0.57;0.72;0.86. The shapes of objects on the sequence are changing from the initial to the final image. In the same time the gray-value assigned to every rectangle is varying accordingly. Comparing to the alternative way of producing the image metamorphosis - cross-dissolving shown in Fig. 2, the morphological interpolation gives a real change of shape instead of linear combination of pixels as cross-dissolving method generates. The umbras of graytone images are shown in Fig. 3. Pictures 3(a) and (b) show input images, picture (c) shows the intersection of both, (d) - the union. Picture 3(e) presents the umbra of interpolated image at level $\alpha = 0.5$ (which is equivalent to morphological median of im-

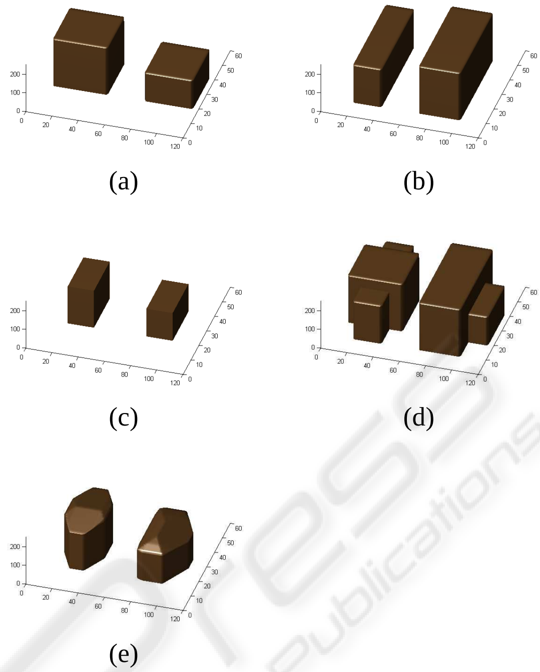

Figure 3: Umbra of test images: (a),(b) input images, (c) - their intersection, (d) - sum, (e) median image.

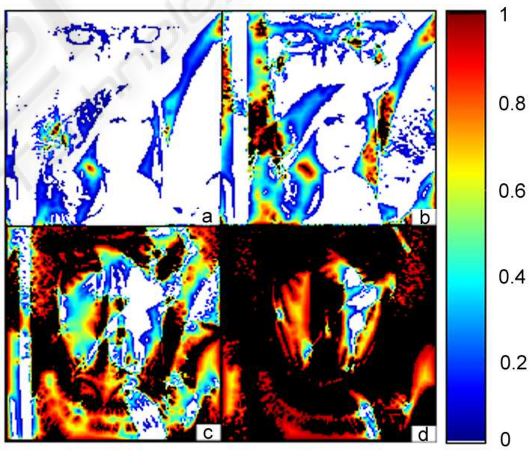

Figure 4: Cross-section of interpolation function for various values of 'z'-coordinate: (a) $z = 70$; (b) $z = 110$; (c) $z = 150$; (d) $z = 190$.

ages shown in (a) and (b)).

The result of morphological interpolation of real images are shown in Fig. 5. The 'lena' image is morphed into 'baboon'. This time the whole sequence (including input images) consist of 12 images, which was produced for interpolation levels: 0;0.09;0.18;0.27;0.36;0.45;0.54;0.63;0.72;0.81; 0.9;1. The cross-sections of 3D interpolation function are shown in Fig. 4. These cross-sections was produced by cutting the 3D interpolation function at various levels along the 'z'-coordinate. White

Figure 5: First morphing sequence obtained by morphological interpolation.

Figure 6: Second morphing sequence.

regions belongs to the intersection of both umbras (where interpolation function is not computed), black regions - to the regions which are above the union of them (here again the interpolation function is not computed), colors refer to values of the interpolation function (between 0 and 1).

Another example of interpolation sequence is shown in Fig. 6. This sequence counts 16 frames produced, as in the prvious case, for equidistanced consecutive values of interpolation levels.

5 CONCLUSIONS

In the paper a method for transforming one graytone image into another was proposed. The method is based on the morphological interpolation using the interpolation function. 2D graytone image image is transformed into 3D binary image (its umbra) and interpolated morphologically. The interpolated 3D object is transformed back into graytone image. The method can be applied to produce image metamorphosis for visual special effects. It is fully automatic, the only parameter is the number of frames of the output morphing sequence. Comparing with the cross-dissolving the morphological interpolation produces a real change of shapes of objects instead of blending produced by the cross-dissolving. Further research plans includes the application of the proposed approach to color images.

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