行政院國家科學委員會補助專題研究計畫成果報告

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※　　　特徵導向實體資料型態變化演算法之研究　　※

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計畫類別：■個別型計畫　　□整合型計畫

計畫編號：NSC　89－2213－E－009－018-

執行期間： 88 **年**　8　**月**　1　**日至**　89　**年** 7 **月**　31 **日**

計畫主持人：柯皓仁

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特徵導向實體資料型態變化演算法之研究

計畫編號：NSC 89-2213-E-009-018-
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主持人：柯皓仁 副教授 交通大學圖書館
計畫參與人員：施仁忠教授 交通大學資訊科學系
計畫參與人員：蔡玉寶　中央研究院資訊所

中文摘要

許多領域都利用形態變化*(Morphing)****的技術產生令人驚奇的視覺效果。在本研究計畫中我們針對特徵導向實體資料形態變化演算法進行探究，並提出改進的方法。此一改進的方法稱為「階層式特徵導向實體資料形態變化演算法」，其基本概念乃是將實體資料的特徵以階層式的特徵元素****(Hierarchical Feature)****組合起來，用以減少在形態變化過程中產生的不良視覺效果。此外，在本研究計畫中我們還提出了一種新的特徵元素—圓柱場****(Cylinder field)**** – 以方便使用者指定與對應實體資料的特徵。***

關鍵字：特徵導向實體資料形態變化，距離場內插法，圓柱場，特徵元素階層

Abstract

Morphing techniques have been broadly applied in many fields to create astounding visual effects. In this project, a hierarchical feature-based volume morphing algorithm is presented, which leverages the idea of feature-element hierarchy to improve morphing effects significantly. A new type of feature element, the cylinder field, is also given to facilitate the task of feature specification and correspondence.

Keyword: feature-based volume morphing, distance field interpolation, cylinder fields, feature-element hierarchy

1 緣由與目的 (Introduction)

Morphing is a group of techniques that create a series of transformation from one object to another object, and it is broadly used in many applications.

In the past, there have been many researches on image morphing [1][7][11][12]. Image morphing produces a series of intermediate images, which represents a gradual transformation from a source image to a destination image. However, if the source and destination in image morphing are rendered from 3D models, image morphing may reveal a few disadvantages. To overcome the disadvantages of image morphing, 3D morphing can be employed instead.

3D models used in 3D morphing can be either geometric primitives (***geometric morphing***) [4][5][13] or volumetric data (***volume morphing***) [2][3][8]. With the rapid development of volume graphics [6], researches on volume morphing attract more and more attention in recent years.

The primary goal of this project is to enhance one popular method of volume morphing – feature-based volume morphing. We reduce artifacts in feature-based volume morphing by organizing feature elements into hierarchies. A new kind of feature element, the ***cylinder field***, is also proposed to simplify the process of feature specification and correspondence.

2 實施方法概論 (Method Overview)

This section presents an overview of our feature-based volume morphing algorithm, which integrates cylinder fields, ***Distance Field Inteprolation*** (DFI) [3][9], and hierarchical feature elements.

Beier and Neely [1] proposed feature-based image metamorphosis, and Lerios et al. [8] extended their method to three-dimension. Our algorithm is based on the two approaches.The entire morphing process of our algorithm is divided into a *preprocessing* stage and a *morphing* stage. The flow charts of the two stages are shown in Figure 1 and Figure 2.

Given the source *S* and destination *D* volumes, there are two tasks in the preprocessing stage. The first task is to construct the distance field volumes *S-DF* and *D-DF* of *S* and *D*, respectively. We employ the method proposed by Cohen-or [3] to construct distance field volumes. The second task is to specify the corresponding features of *S* and *D* by cylinder fields, and then organize the cylinder fields into hierarchies E_S and E_T, respectively. We shall describe the ideas of cylinder fields and feature-element hierarchies separately in Section 3 and Section 4.

After the preprocessing stage, the morphing stage performs hierarchical feature-based warping (described in Section 3 and Section 4) and DFI [3] to produce intermediate volumes. To render the intermediate volumes, we can either extract the isosurfaces by marching cubes [10] or use direct volume rendering approaches [14].

3 實施方法 -- 圓柱場 (Cylinder Field)

In feature-based volume morphing, source *S* and destination *D* volumes are associated with pairs of feature elements, which specify the correspondence of key features between *S* and *D*. The warping process to generate intermediate volumes is also controlled and influenced by feature elements.

Many kinds of feature elements are proposed in the literature [1][2][3][8], including points, rectangles, box, and disks. Instead of using these feature elements proposed in the literature, we develop a new kind of feature element in this project–***cylinder fields***.

3.1 Spatial Configuration of a Cylinder Field

The spatial configuration of a cylinder field is shown in Figure 3. A cylinder field can be easily specified by its radial vector $\vec{r}$, normal vector $\vec{n}$, and the world coordinate position c, which represents the center of the base circle. The length of the radial vector, $\|\vec{r}\|$, is the radius of the cylinder field, and the length of the normal vector, $\|\vec{n}\|$, is the height of the cylinder field. Let the normalized radial vector ($\frac{\vec{r}}{\|\vec{r}\|}$) be x-axis of the local coordinate system of a cylinder field, and the normalized normal vector ($\frac{\vec{n}}{\|\vec{n}\|}$) be z-axis. Then, the cross product of z-axis and x-axis is y-axis. In other words, the local coordinate system of a cylinder field can be constructed and represented as $E(c,\vec{x},\vec{y},\vec{z})$, where $\vec{x}=\frac{\vec{r}}{\|\vec{r}\|}$, $\vec{z}=\frac{\vec{n}}{\|\vec{n}\|}$, and $\vec{y}=\vec{z}\otimes\vec{x}$. In general, it can be expressed by a 4 by 4 matrix $M=\begin{bmatrix}\vec{x} & \vec{y} & \vec{z} & c\\ 0 & 0 & 0 & 1\end{bmatrix}$.

Transformations of the cylinder field can be computed by manipulating *M*. Through transformations, cylinder fields can be used to approximate other kinds of feature elements. For example, a cylinder can simulate a line segment by shrinking its x-axis and y-axis. Therefore, cylinder fields offer a single choice with many variations. In addition, the task of feature specification is just to use cylinder fields to enclose object features. It is easy, intuitive, and clear.

3.2 Warping with a Single Pair of Cylinder Fields

Given *S* and *D*, a pair of cylinder fields defines a mapping from one volume to the other. This pair of cylinder fields corresponds to features of *S* and *D*, and their coordinate systems are $E(c,\vec{x},\vec{y},\vec{z})$ and $E(c',\vec{x}',\vec{y}',\vec{z}')$, respectively. To warp *S* (or *D*), we first interpolate $E(c,\vec{x},\vec{y},\vec{z})$ and $E(c',\vec{x}',\vec{y}',\vec{z}')$, according to a parameter t in the range of $[0..1]$, to obtain $E(c'',\vec{x}'',\vec{y}'',\vec{z}'')$.

$E(c'', x'', y'', z'')$ represents a feature in an intermediate volume. Then we compute the value of each point in the intermediate volume form S (or D) by reverse mapping [1].

3.3 Warping with Multiple Pairs of Cylinder Fields

Given two sets of cylinder fields :

$$C_s = \{c_{s,1}, c_{s,2}, ..., c_{s,m}\} \quad \text{and}$$

$$C_t = \{C_{t,1}, C_{t,2}, ..., C_{t,m}\}$$

associated with two volumes S and T, each point p in T can be mapped onto a set of points $\{p_{s,1}, p_{s,2}, ..., p_{s,m}\}$ in S by the reverse mapping. A point p_s is then obtained as a weighted average of $\{p_{s,1}, p_{s,2}, ..., p_{s,m}\}$ and the value of p is equal to the value of p_s. We modify the weighted function proposed by Beier and Neely [1], for calculating the weight of a cylinder field imposed on a point p.

4 實施方法 – 階層式特徵元素 (Hierarchical Feature Elements)

Traditionally, feature elements in feature-based volume morphing are operated independently. From our study, we find independent feature elements may produce dissatisfactory morphing. In this section, we discuss this problem and propose a method, ***hierarchical cylinder fields***, to conquer the problem. We demonstrate the problem by an example shown in Figure 4.

Figure 4 illustrates the intersection of feature elements during interpolation, caused by independently interpolating multiple pairs of cylinder fields. The source and destination objects are shown in Figure 4 (a) and (c). The cylinder fields of the source, (E_1, E_2), and destination, (E'_1, E'_2), are shown in (b) and (d), respectively. Figure 4 (e) is the interpolation process from (E_1, E_2) to (E'_1, E'_2). It is obvious that we can rotate E_1 180° counterclockwise about z-axis to get E'_1, and move E_2 to the right side of the first cylinder field and then rotate 180° clockwise to get E'_2. Guided by the process shown in Figure 4 (e), a warping from the source to the destination is given in (f). From Figure 4 (e) and (f), We can see the object associated with E_2 is intruded into the object associated with E_1 during warping. But in fact, we can obtain the destination object simply by rotating the source object 180° counterclockwise about z-axis. To avoid the above problem and get better morphing results, we propose in this section the idea of ***feature-element hierarchy*** to organize cylinder fields.

We introduce the idea of hierarchical feature elements in the following. After adding corresponding feature elements in the source and destination volumes, we group these feature elements into a hierarchy. A hierarchy is represented by a tree structure, and the two trees of the source and destination volumes are isomorphic. Each node of a tree is associated with a feature element. A child node inherits the transformation effect of all its ancestors.

Now, we apply idea of feature-element hierarchy to Figure 4. The cylinder fields and their transformation of the source and destination objects are shown in Figure 5 (a) and (b), respectively. The tree representation of the feature-element hierarchy is shown in Figure 5 (c). Relative to the first cylinder fields, the transformation M_2 in Figure 5 (a) is identical to M'_2 in Figure 5 (b). During interpolation, we interpolate the father node pair first, i.e. M_1 to M'_1, and then interpolate the child node pair, i.e. M_2 to M'_2. As (e), the first cylinder field is rotated 180° counterclockwise about z-axis. The second cylinder field does not perform any interpolation. It is just guided by the interpolation of E_1 and E'_1 and circles around the first cylinder field. The interpolation process of the two pairs of cylinder fields with a hierarchical structure is shown in Figure 6 (a), and (b) is the warping result guided by (a). Comparing Figure 4 (f) and Figure 6 (b), the result in Figure 6 (b) is more nature.

5 結果與討論 (Implementation and Results)

To implement our ideas proposed in this project, we exploit a popular modeling tool, 3D Studio Max, to specify and organize hierarchical cylinder primitives, and use the VRML file format to store cylinder fields. We also use 3D Studio Max to define keyframes of volume animation. Except the above tasks, all other procedures described in this report are implemented by the C++ language with OpenGL library in Visual C++ environment, and run on Pentium II 450MHz PC. After intermediate volumes are produced, we use marching cubes to reconstruct object shapes.

Figure 7 and Figure 8 illustrate morphing results from a teapot to a few geometric objects. In Figure 7, we operate cylinder fields independently, but in Figure 12 we organize cylinder fields into a hierarchy. The source and destination objects are shown in Figure 7 (a) and (c). In this case, we use 4 pairs of cylinder fields to specify key features, which are shown in Figure 7 (b) and (d), respectively. Figure 7 (e) shows the transitions of the cylinder fields without feature hierarchy. The handhold and beak of the source are corresponding to the cone and torus of the destination. In Figure 7 (e), we can see that the purple and blue features impenetrate the green feature and intersect each other. Figure 7 (f) shows the morphing result guided by (e).

Figure 8 uses the idea of feature hierarchy to guide morphing. Figure 8 (a) shows the feature hierarchy, and (b) shows the transition of the cylinder fields with feature hierarchy. We can see that the purple and the blue features just circle around the green feature. The morphing result is shown in Figure 8 (c), and it depicts a smooth transition from source to destination.

Comparing Figure 7 with Figure 8, it is evident that the idea of feature hierarchy improves feature-based volume morphing significantly.

6 計畫成果自評 (Conclusions)

In this project, we propose an algorithm that integrates the ideas of distance field interpolation (DFI), feature-based warping, and feature-element hierarchy to accomplish volume morphing. For feature-based warping, we propose a new kind of feature element, the ***cylinder field***. The cylinder field can enable users to intuitively define object features and thus achieve warping easily. In addition, the cylinder field can approximate other kinds of feature elements proposed in the literature. In this project, we also prove that grouping cylinder fields into hierarchies can solve the problem of unexpected intersection of features during feature-based warping, and thus can improve feature-based volume morphing significantly.

Partial achievement of this project has been presented in *1999 National Computer Symposium* (NCS'99) (one of the best papers). Full Achievement of this project has accepted by *Journal of Information Science and Engineering* (JISE).

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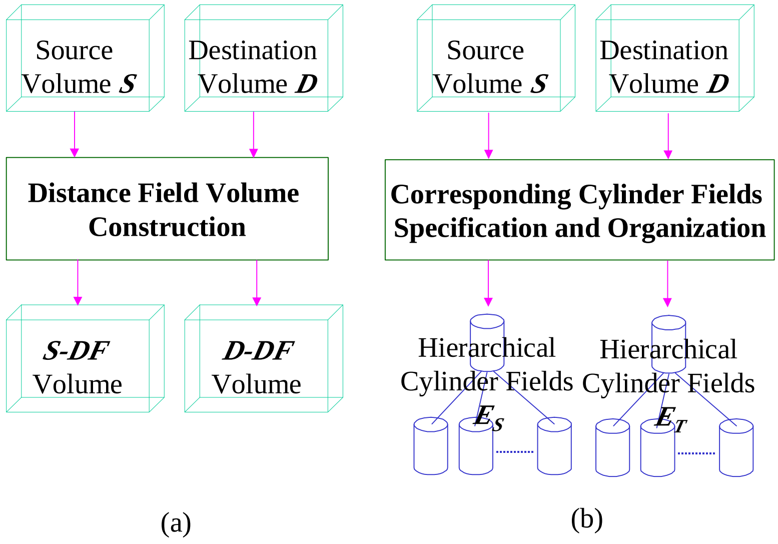

Figure 1 The preprocessing stage of our hierarchical feature-based volume morphing algorithm. (a) Construct distance field volumes. (b) Specify and organize cylinder fields.

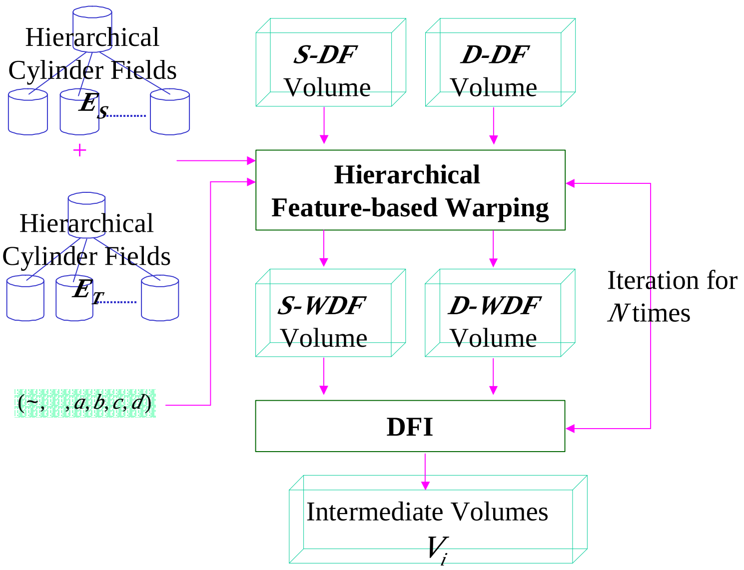

Figure 2 The morphing stage of our hierarchical feature-based volume morphing algorithm. ~ , , *a*, *b*, *c*, and *d* are controlling parameters specified by users, and *N* is the total number of intermediate volumes to be produced.

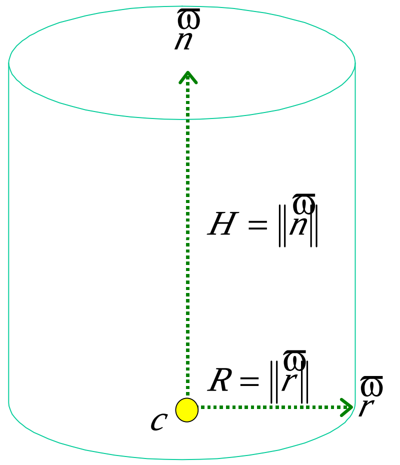

Figure 3 Spatial configuration of a cylinder field.

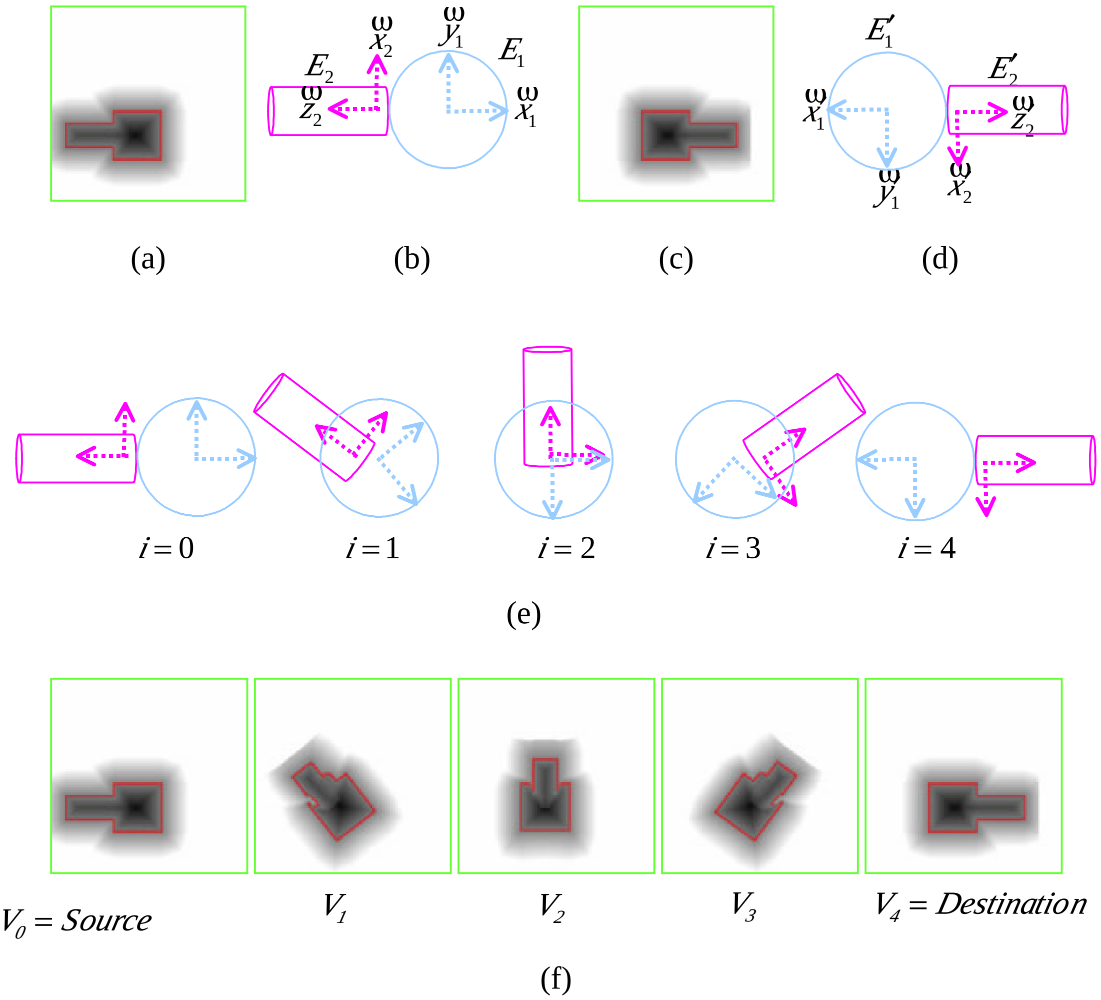

Figure 4 Intersection of cylinder fields during interpolation. (a) The source object (shape delineated by solid lines) and its distance field volume. (b) The cylinder fields of the source object. (c) The destination object and its distance field volume. (d) The cylinder fields of the destination object. (e) The interpolation process of the cylinder fields (the total number of intermediate volumes is three) for producing V_i. (f) The warping result guided by (e).

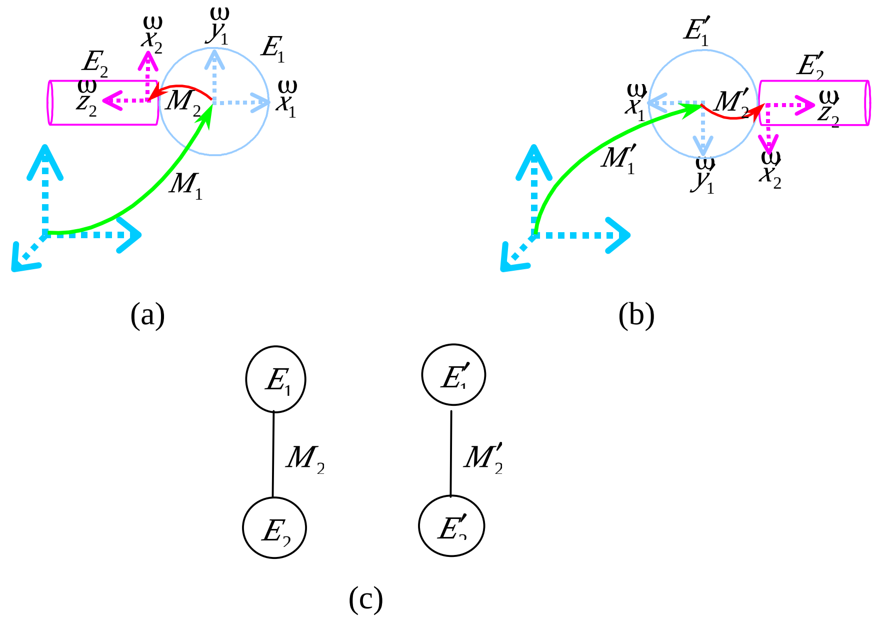

Figure 5 Apply a hierarchical structure to the cylinder fields in Figure 4. (a) The cylinder fields in the source object. (b) The cylinder fields in the destination object. (c) The feature-element hierarchy.

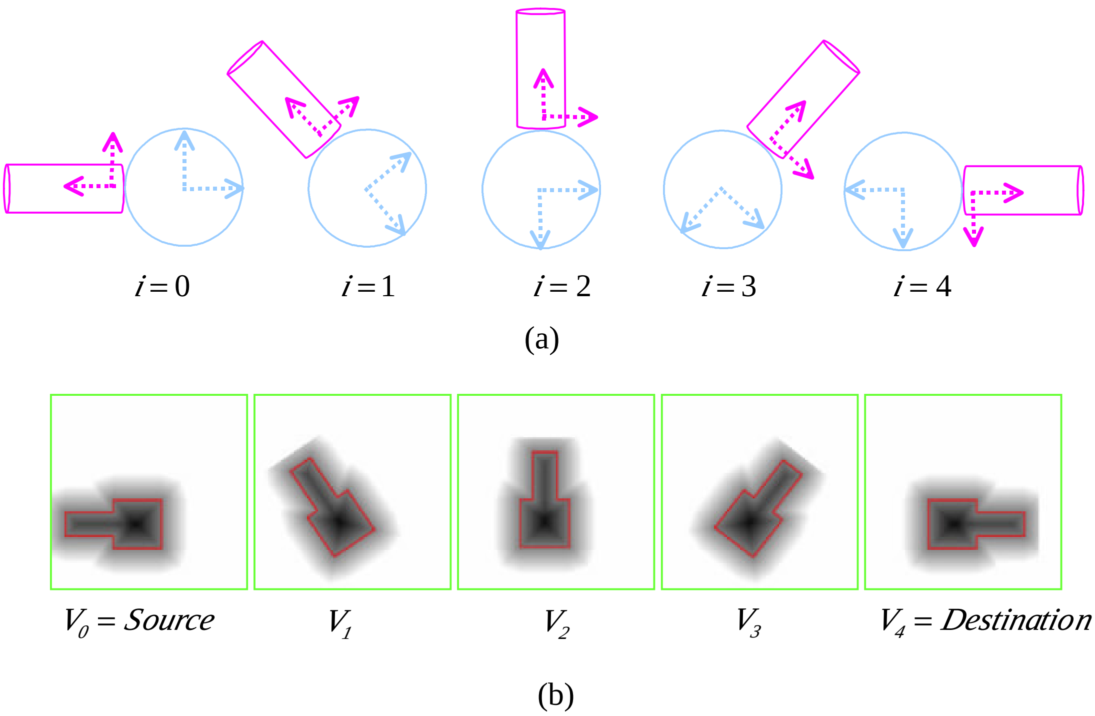

Figure 6 The warping process by means of hierarchical feature elements. (a) The interpolation process of the cylinder fields for producing V_i. (b) The warping result guided by (a).

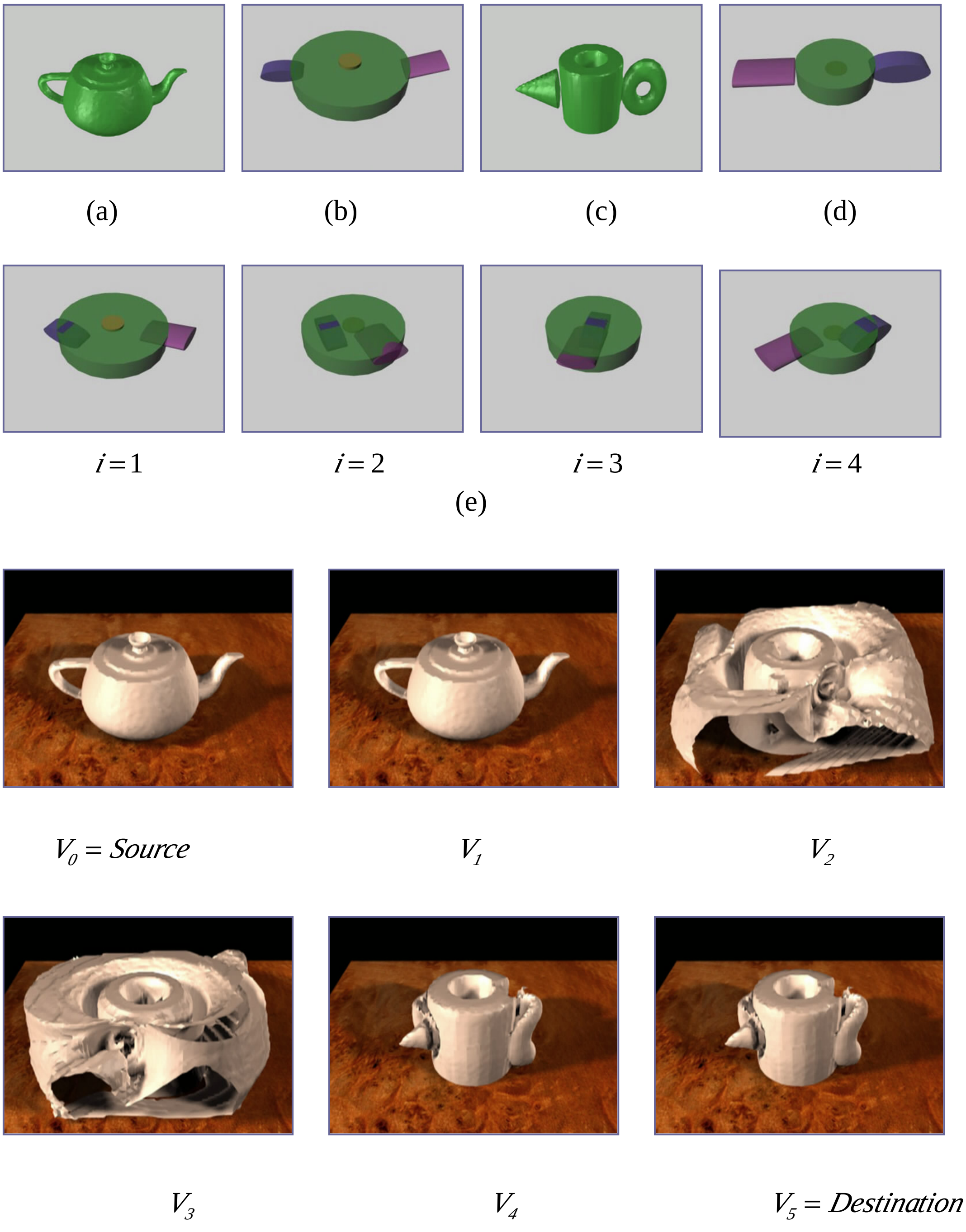

Figure 7 A morphing from a teapot to a few geometric objects without feature hierarchy. (a) The source object. (b) The cylinder fields of the source object. (c) The destination object. (d) The cylinder fields of the destination object. (e) The transitions of the cylinder fields for producing V_i (the total number of intermediate volumes is four). (f) The morphing result.

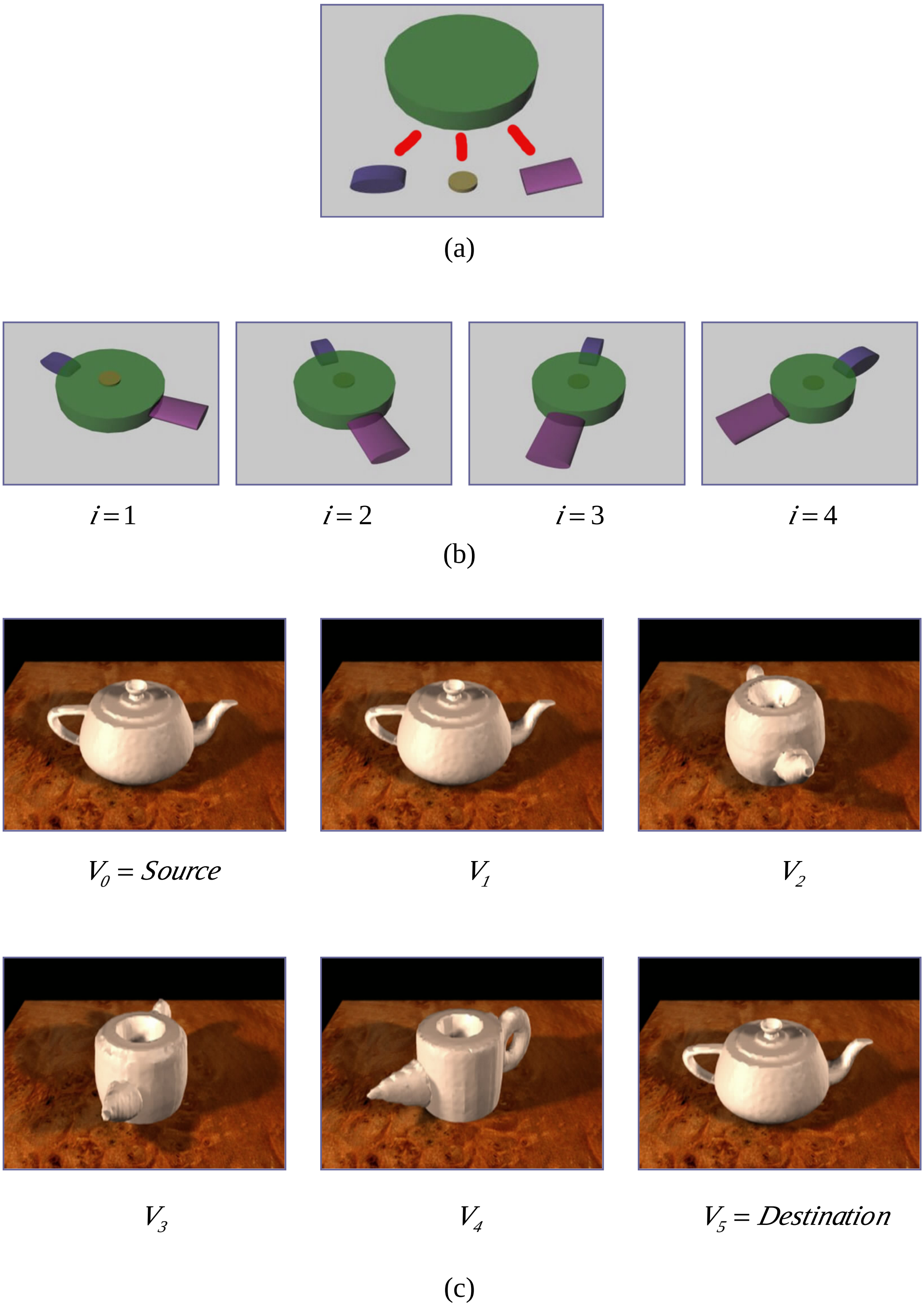

Figure 8 A morphing from a teapot to a few geometric objects with feature hierarchy. (a) The hierarchy of cylinder fields. (b) The transitions of the cylinder fields for producing V_i (the total number of intermediate volumes is four). (c) The morphing result.