Animated free-form deformation : an interactive animation technique

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Abstract

Current research efforts focus on providing interactive techniques that make 3D concepts easy to use and accessible to large numbers of people. In this paper, a new interactive technique for animating deformable objects is presented. The technique allows easy specification and control of a class of deformations that cannot be produced by existing techniques without considerable human intervention.

The methodology proposed relies on the Free-Form Deformation (FFD) technique developed by Sederberg and Parry [14]. It makes use of a deformation tool that is animated like any other object.

This approach provides a representation of the deformations independent of the surface geometry, and can be easily integrated into traditional hierarchical animation systems.

AFFD: Une Technique d'Animation Interactive

Résumé

L'objectif des recherches en cours est de faciliter la modélisation et l'animation d'objets déformables par la mise au point de techniques interactives et intuitives.

La technique d'animation présentée dans ce papier permet le contrôle d'une classe de déformations difficiles à spécifier à l'aide des méthodes existantes. Elle est de plus indépendante du modèle géométrique de l'objet à déformer et facilement intégrable dans la plupart des systèmes d'animation traditionnels.

La solution proposée est basée sur une méthode interactive de déformation d'objets, couramment employée en modélisation géométrique 3D, connue sous le nom de FFD (Free-Form Deformation).

CR Categories and Subject Descriptors: I.3.5 [Computer Graphics]: Computational Geometry and Object Modeling - Curve, surface, solid, and object representation; Geometric algorithms, languages, and systems; Hierarchy and geometric transformations; I.3.6 [Computer Graphics]: Methodology and Techniques - Interaction techniques; I.3.7 [Computer Graphics]: Graphics and Realism, Animation.

Additional Keywords and Phrases: Free-Form Deformations.

1 Introduction

Computer-assisted animation embodies a wide variety of techniques which depend on the type of objects they are applied to (rigid, articulated or deformable).

A great deal of work has been done towards the use of physical simulation as a means of animating deformable objects. Considerably less attention has been given to interactively animating non physically-based models.

The only method in current usage is the *inbetweening*, or *metamorphosis* technique, almost systematically used whatever the deformation. On the other hand, we observe that geometric modeling has promoted the developement of various techniques such as extrusion, loft, sweep, which depend on the type of object to be designed.

In this paper, an alternative to the metamorphosis technique is described. It can be used to specify the following deformations:

- the motion of a local deformation such as an arbitrarily shaped bump,
- the motion of a local deformation whose shape changes over time,
- the motion of an object inside a global deformation,
- the motion of an object inside a global deformation whose shape changes over time.

This technique, Animated Free-Form Deformation (AFFD), relies on the Free-Form Deformation (FFD) [14] technique used in geometric modeling. It is interactive, intuitive and independent of the geometric model of the object to be deformed. Furthermore, it can be integrated into most traditional animation systems.

The following section emphasizes the metamorphosis technique and reviews existing animation techniques valid for deformable objects. Section 3 presents two examples and demonstrates the difficulty of animating them with metamorphosis. Section 4 reviews some of the deformation techniques used in geometric modeling.

Section 5.1 is a general presentation of the AFFD technique which is also applied to the previous examples. Section 5.2 integrates the proposed technique into a hierarchical animation system while Section 5.3 explains how the shape of the deformations may change over time.

2 Animating Deformable Objects

This overview will focus on general techniques of specification and control of animated deformations, not specific to an application or to a geometric model. The predominant method in use today is metamorphosis, or inbetweening [9].

Inbetweening is a method used to create intermediary shapes that make a smooth transition between two or more extreme or *key-shapes*. It is useful when every point of the animated model changes from one position to the next at the same time and speed. If this is not the case, metamorphosis may require a large number of key-positions, i.e. considerable human intervention, resulting in an animation that will be, nevertheless, only an approximation of the desired one.

Metamorphosis of polygonal or spline surfaces is very space consuming. For each key-position, the description of the geometry has to be duplicated, making space requirements critical.

A more important limitation is that metamorphosis usually requires the description of topologically equivalent key-shapes, i.e. those shapes having the same number of points distributed in the same way.

Although inspired by traditional key-frame animation, this technique is not very natural. The modeling and the animation processes are too closely related since the description of the deformations is part of the modeling process. A more natural way of thinking would be to design the relaxed shape of each model and independently describe the changes of its shape over time.

Finally, metamorphosis does not allow a given motion to be reused for any other model.

Several alternative approaches that solve some of the previous problems have been proposed. In [16], Wyvill discusses metamorphosis of implicit surfaces defined by skeletons. Unfortunately, this approach cannot be applied to other geometric models. Chadwick et al. [3] propose a multi-layered approach that includes kinematic, dynamic and sculpted deformations. Sculpted deformations are defined by applying metamorphosis to the FFD 3D lattice, leading to an easy-to-use and less space consuming metamorphosis technique.

Geometric deformations can also be mathematically specified. This approach would not usually fit interactive systems.

In addition to the previous approaches, most of the motion control techniques valid for non-rigid objects focus on the simulation of the physical properties of the object models [1, 15, 8]. For most of these methods, the model has intrinsic properties such as a spring force relationship between points. The computation of the deformation depends on both the physical properties of the object and the forces applied. This technique is effective for some natural deformations that are not overly complex, but in some cases, describing deformations with physics may be tedious or impossible.

3 Examples

A set of deformations which are at present difficult to produce by existing techniques, can be easily treated with the AFFD technique.

The first example is a swollen cylinder, i.e. a cylinder which contains a swelling made to move along it. The second example consists of a soft surface following a given path, like a paper sheet inside a copier. The former represents the motion of a local deformation while the latter represents the motion of an object inside a global deformation. Both examples have been animated with metamorphosis in Figures 4c and 5c, where only the side views are shown.

In Figure 4c, the first and the last images correspond to two successive key-positions of the cylinder whereas the other four images are inbetween frames computed by interpolating the key-shapes. Notice that quite a large number of key-positions would be necessary to produce this animation on a long cylinder, and would yield in any case an incorrect result.

The sheet example leads to similar conclusions. In Figure 5c, the blue curve represents the curve the sheet should follow. The white curve represents the sheet at 6 uniformly distributed times. Three key-positions have been used to describe the sheet movement: the first and the last correspond to the first and the last frames while the third key-position is positioned between the third and the fourth frames. Once again, the shape of intermediate sheets is far from correct.

These examples show that deformations which look simple may be difficult to describe accurately with metamorphosis.

4 Deformations and Geometric Modeling

Deformations are changes in the shape of the object's geometry. In geometric modeling, one can distinguish two classes of deformation techniques, depending on whether the deformation can be reproduced or not. For instance, the deformation technique that consists of interactively moving the control points of a spline surface generates deformations that cannot be reproduced, i.e. that cannot be used for similarly deforming another surface. Piegl [12, 13] or Forsey and Bartels [6] deformations techniques belong to the class of deformations that cannot be reproduced.

On the other hand, the set of high level transformations introduced by Barr [2], or the region warp and the skeletal warp proposed by Cobb [4], as well as the Free-Form Deformation (FFD) [14, 11] technique, generate deformations that can be reproduced.

The animation technique proposed in this paper works only with deformations that can be reproduced. The Free-Form Deformation technique, of which the Extended Free-Form Deformation (EFFD) is an extension, [5] has been chosen for the following reasons:

- it is an interactive and intuitive deformation technique,
- it allows the design of arbitrarily shaped deformations,
- it works with different geometric models including polygonal, B-spline or Bézier surfaces.

Free-Form Deformation consists of embedding the geometric model, or the region of the model to be deformed, into a user defined 3D lattice. The deformations of the 3D lattice are then automatically passed on to the model. This 3D lattice represents a trivariate hyperpatch or piecewise parametric solid. The FFD technique is broken down into two steps:

1. before deforming the 3D lattice, the u, v and w coordinates in the lattice parameter space of each object point are computed,
2. after deforming the 3D lattice, the deformed position of each object point is derived from the u, v and w coordinates and the equation of the deformed 3D lattice.

5 Animated Free-Form Deformations

5.1 Presentation

This section concentrates on two types of animated deformations:

- the motion of a local deformation,
- the motion of a surface inside a global deformation.

Until now, except by Chadwick et al. [3], FFD has mainly been exploited as a geometric modeling technique. Animated deformations are thus obtained by using FFD for the design of each key-shape of the metamorphosis technique. These key-shapes are then interpolated in order to compute the inbetween shapes. This technique leads to the results presented in Section 3.

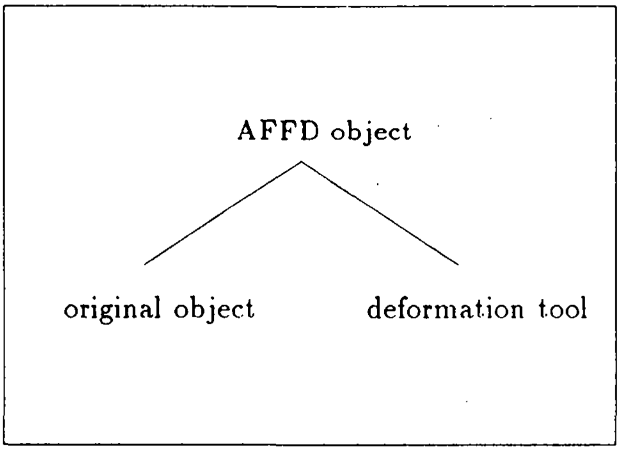

Figure 1: Tree structure of an AFFD object

The animation technique described in this paper consists of taking advantage of the *deformation tool* paradigm. The deformation tool, must fully describe the deformation. In FFD, the deformation tool is composed of two 3D lattices: the initial and the final lattice. The initial lattice is a user defined lattice that is embeded in the region of the model to be deformed. The final lattice is a copy of the initial one that has been deformed by the user.

In order to deform an object, the deformation tool must be associated with this object, thus forming what we call an AFFD object (see Figure 1).

Differentiating the deformation tool from the object turns out to be a fruitful approach. It allows the definition of a motion for the deformation tool and a different one for the object. In this paragraph, the well-known key-frame animation technique [7] is used to define the motion of each element. In its simplest form, the key-frame technique, valid for rigid objects, consists of specifying parameters such as the position, the orientation or the scaling factors of objects at some key-positions, and computing the inbetween values by interpolating the key-parameters.

This approach makes the control of the motion of a local deformation easy. Assuming that the object and the deformation tool have been designed, the motion of the deformation tool is interactively specified by using the key-frame technique. The computation process is as follows: for each frame, the position of the tool is computed according to the tool motion, then, the object is updated by applying the FFD transformation defined by the deformation tool.

This solution has been used to animate the swollen cylinder. First, the constant radius cylinder is designed. The deformation tool is described independently: the initial lattice of the deformation tool is a cube, i.e. a parallelepipedical lattice, while the final lattice is a copy of the initial one deformed as shown in Figure 6 (in every picture, the green objects represent initial lattices, and the red the final ones).

The animation of the swelling is specified by translating the deformation tool along the cylinder. Thus, the shape of the deformed cylinder is always accurate. For each frame visualized, the initial lattice and the undeformed cylinder are represented in Figure 4a while the deformed lattice and the deformed cylinder are represented in Figure 4b.

Rather than animate the deformation tool, the object itself may be animated, making possible the control of the motion of an object inside a global deformation.

Figures 5a, 5b and 7, illustrate the AFFD technique applied to the sheet when it is made to move inside the initial lattice.

In order to make possible a comparison with the metamorphosis technique, the selected frames are the same for both techniques.

5.2 AFFD and Hierarchical Animation Systems

The AFFD technique can easily be integrated into hierarchical animation systems [10]. These systems allow the grouping of objects into clusters. A hierarchy of motion is created in which the position of an object is subordinated to the motion of its ancestors.

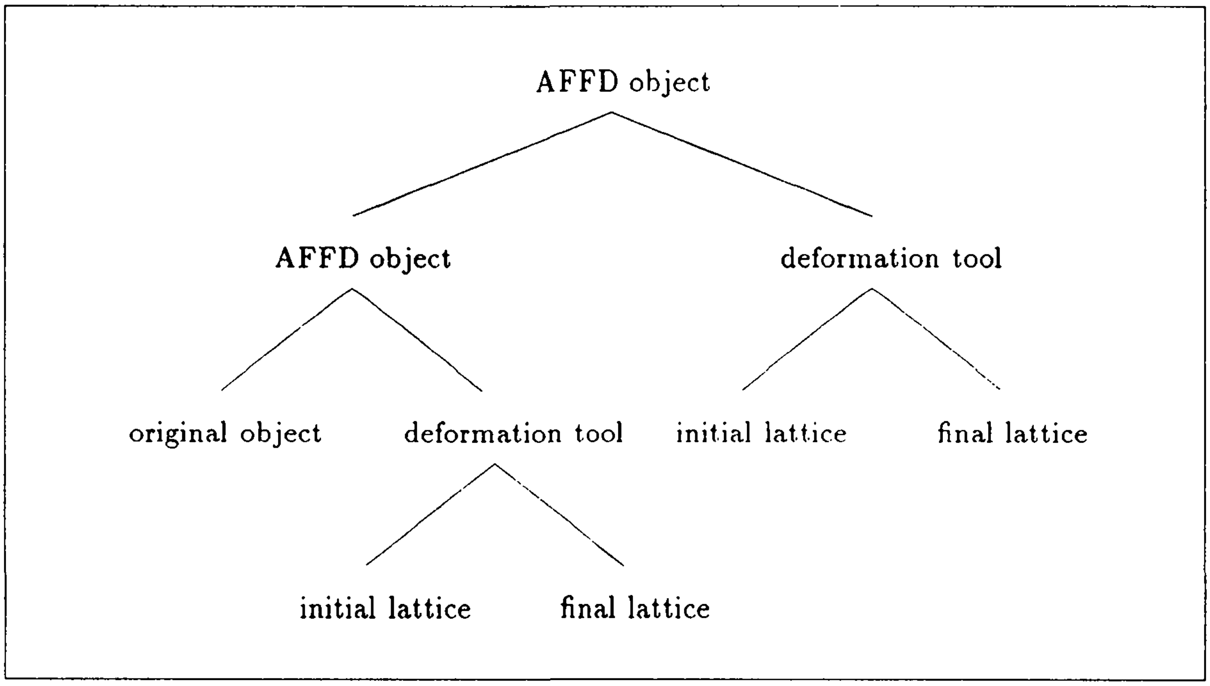

Figure 2: Tree structure for an object deformed twice with AFFD

Integrating AFFD into such systems only consists of adding one new class of objects, the 3D lattices, and two new classes of clusters, the deformation tools and the AFFD objects. According to the previous section, a deformation tool is made of two 3D lattices, while an AFFD object is composed of an object and a deformation tool. A motion can be associated with each of these new classes.

The AFFD computation is integrated into the recursive evaluation process specific to hierarchical animation systems. To evaluate an AFFD node you must:

- evaluate its two subtrees,
- apply the subtrees geometric transformations according to their key-frame parameters,
- compute the FFD transformation.

Integrating AFFD into traditional hierarchical animation systems allows applying several deformations successively. Two deformations can be applied to an object by defining the tree structure shown in Figure 2.

The spring in Figures 8 and 9 demonstrates the use of several successive deformations. The original object is a long cylinder. It is first deformed by a deformation tool equivalent to the one used for the swollen cylinder. Then the result is deformed by a second deformation tool composed of the lattices shown in Figure 8. As the cylinder enters the initial lattice, it is smoothly transformed into a spring. Figure 9 presents 6 frames from an animation test. The change of the size of the swelling will be explained in the next paragraph.

5.3 Deforming Deformations

As we have seen, metamorphosis and AFFD are complementary. Metamorphosis can be integrated into hierarchical animation systems by adding one new cluster class: the *metamorphic object*, made of several objects, each of them representing one key-shape.

Metamorphosis and AFFD can be combined in different ways. The simplest method consists of applying a deformation tool to a metamorphic object.

The metamorphosis technique may also be applied to the deformation tool. This approach allows the specification of new animated deformations where the shape of the deformation changes over time. Figure 3 presents the tree structure used.

Figures 10 and 11 illustrate this situation. The original object is a planar surface and a changing shape is sculpted into it.

The first key-tool has a circular shape while the second key-tool has a hand-like shape (see first and last frames of Figure 10). The initial 3D lattice positioned on the original surface is shown in Figure 10. Figure 11 presents five frames from the resulting animation. The last frame is duplicated in order to show the deformed lattice.

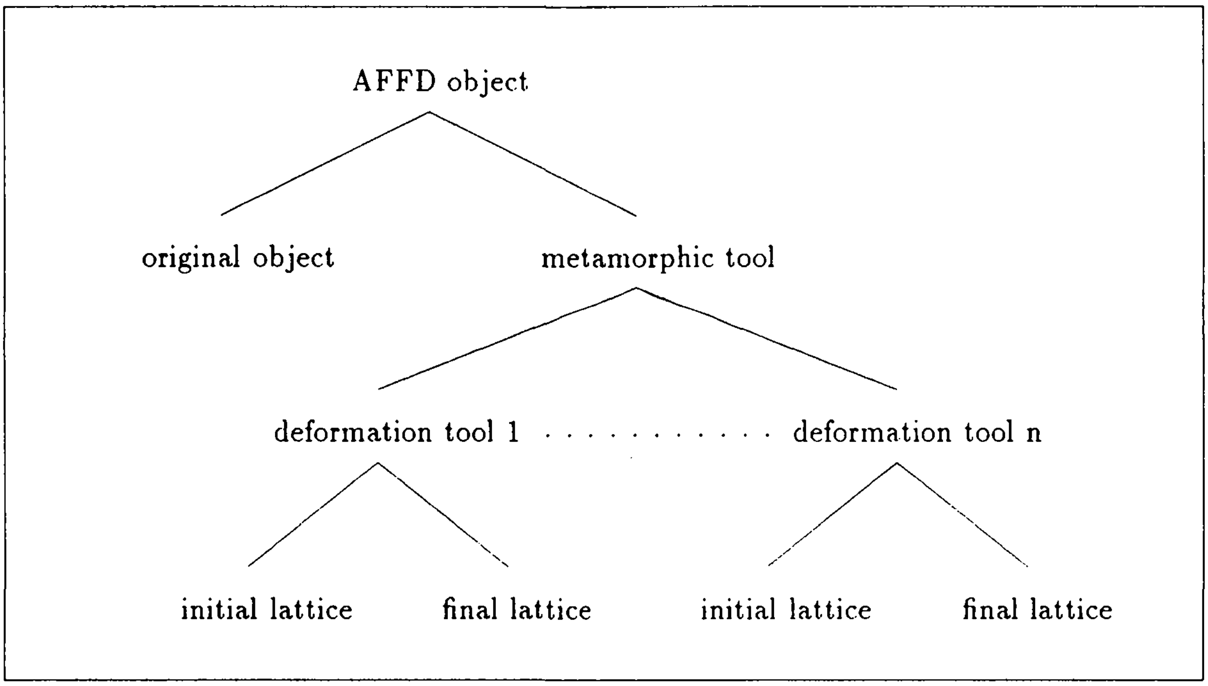

Figure 3: Tree structure of an AFFD object including a metamorphic tool

The change of the size of the swelling in the spring example is obtained by applying metamorphosis to the final lattice of the deformation tool. Note that this last alternative, the interpolation of the final lattice, was already used by Chadwick et al. in [3].

Other techniques may be used as well to change the shape of the deformation tool, in particular the AFFD technique.

6 Concluding Remarks

In addition to the ability to accurately control a new set of animated deformations, AFFD offers the following advantages:

- Since the deformation is independent of the object it is applied to, it can be reused to deform other objects.
- AFFD is less space consuming than metamorphosis because the geometric model does not have to be duplicated for each key-position. Furthermore, the surface can be adaptively subdivided for each frame according to the current deformation.
- Hierarchical animation systems can easily be modified to include the AFFD capability.
- The user has better control of the animated deformation, whether by adjusting any of the 3D lattices or by modifying the motion.
- AFFD is very intuitive and fully interactive.

The examples presented are the result of a combination of the AFFD technique with the key-frame and metamorphosis techniques. Other animation techniques, such as dynamic motion, may be combined with AFFD as well.

In this paper, FFD is the foundation of the animation technique. It should be noted, however, that the ability to integrate different deformation techniques into motion control systems provides the framework for the developement of a set of new animation techniques. Furthermore, we believe that the deformation tool paradigm opens the door to other new and exciting uses of deformations.

AFFD is part of ACTION3D, a general interactive system developed jointly by SOGITEC and INRIA.

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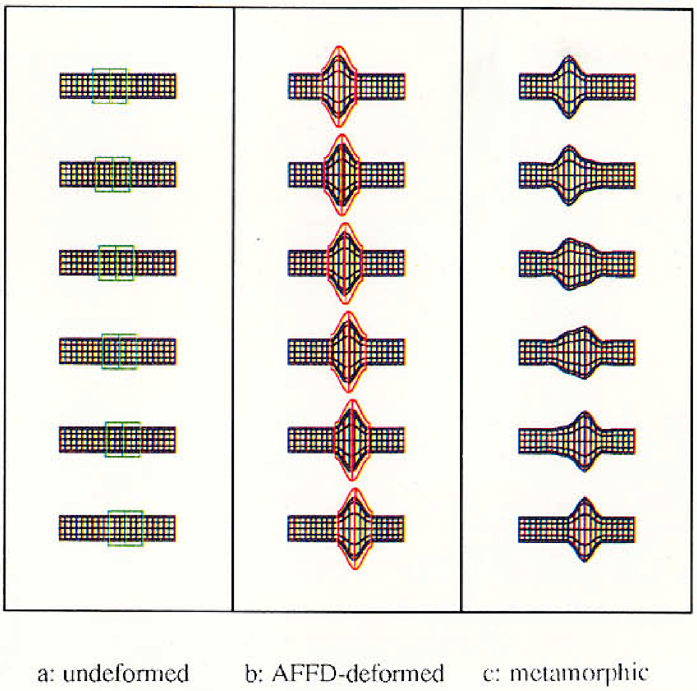

Figure 4: Animating a swollen cylinder

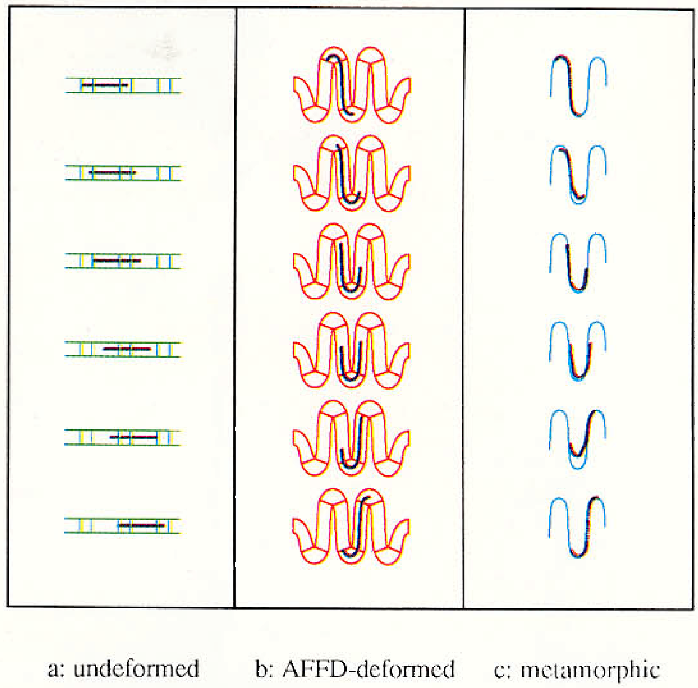

Figure 5: Animating a paper sheet

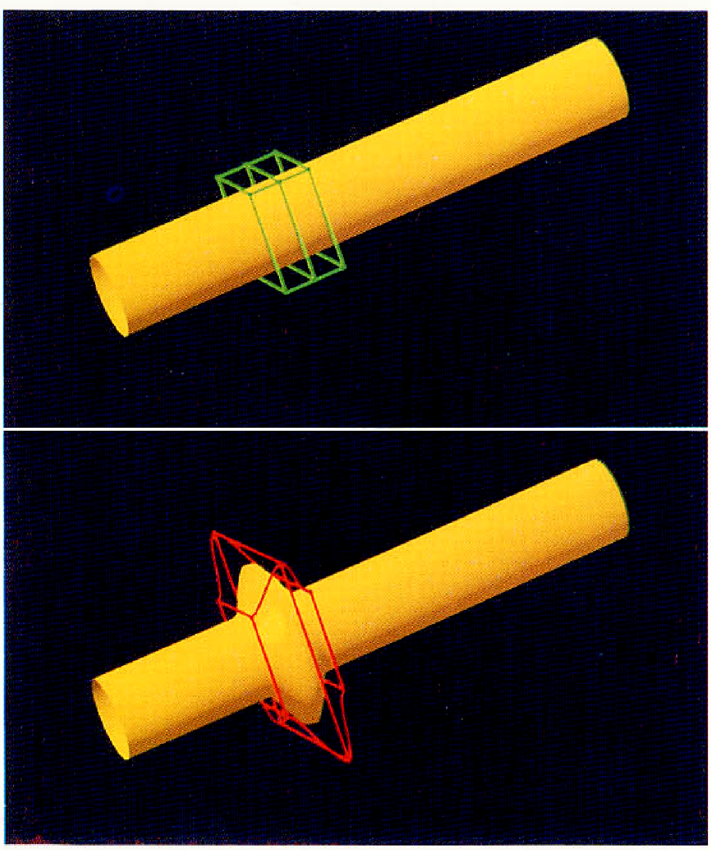

Figure 6: The swollen cylinder lattices

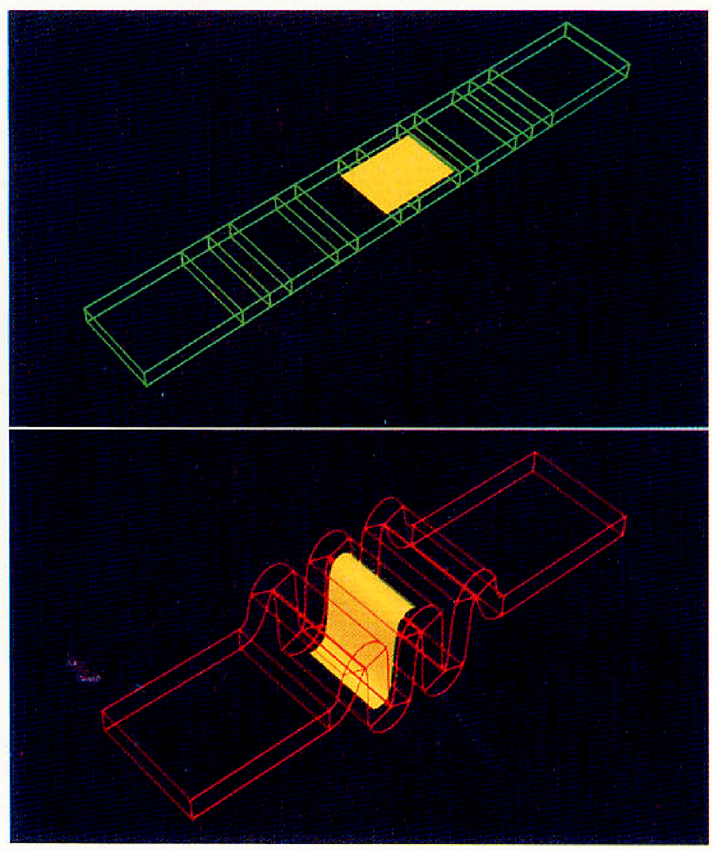

Figure 7: The paper sheet lattices

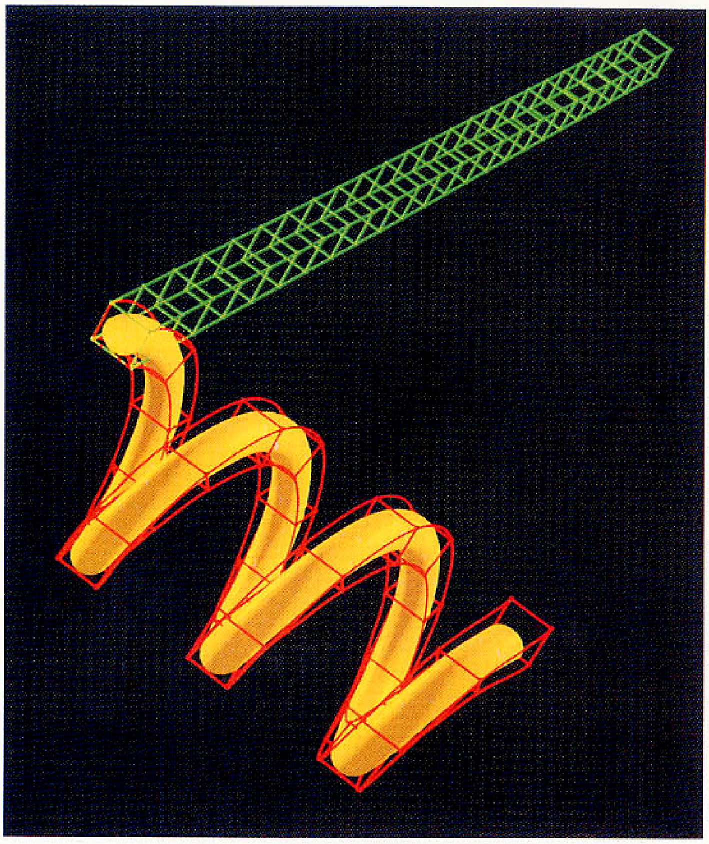

Figure 8: The spring lattices

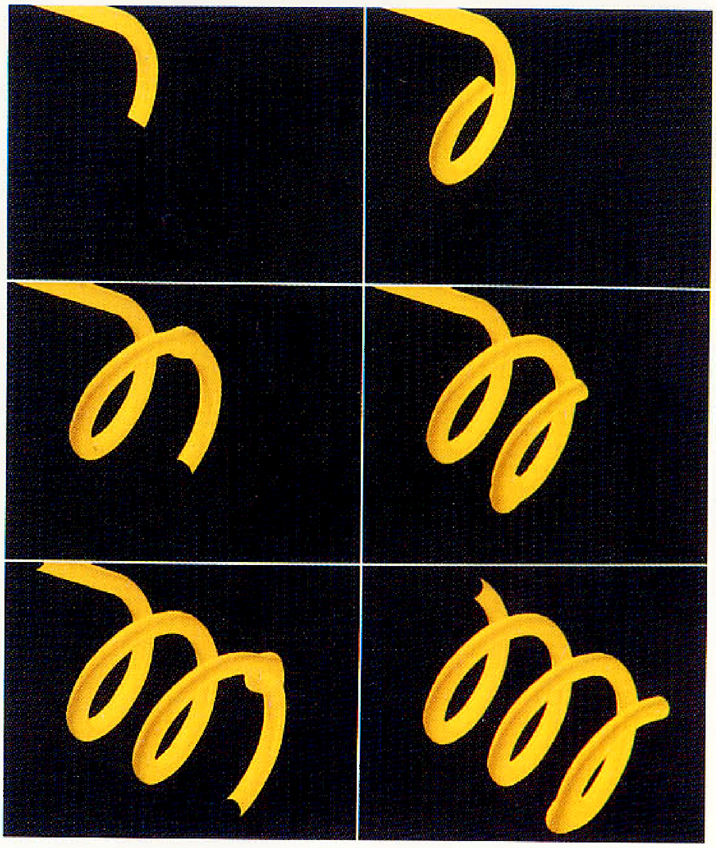

Figure 9: From a cylinder to a spring

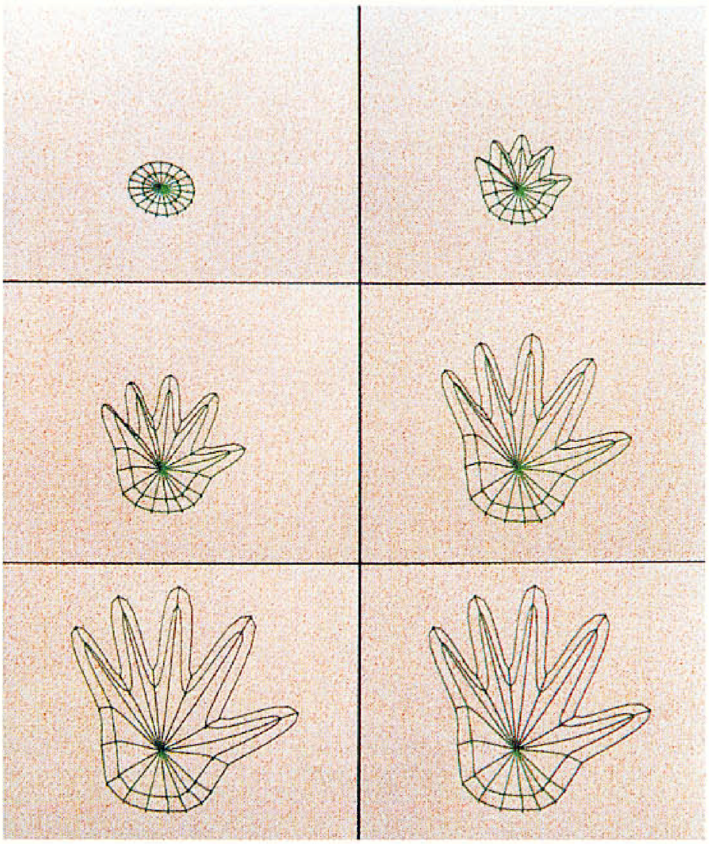

Figure 10: From a disc to a hand
(initial lattices)

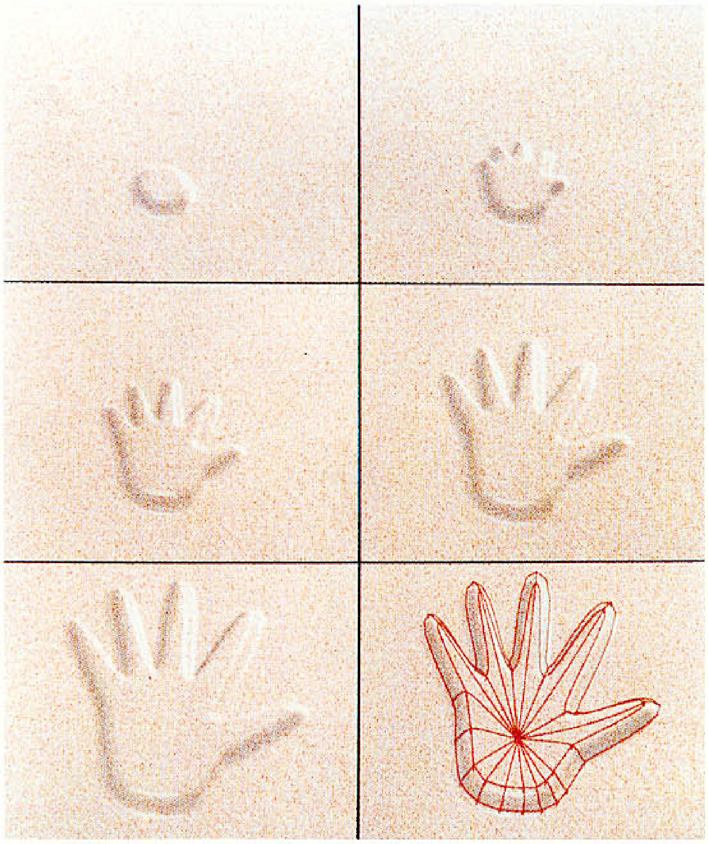

Figure 11: From a disc to a hand
(AFFD-deformed)

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