# Faking Dynamics of Cloth Animation for Animated Films

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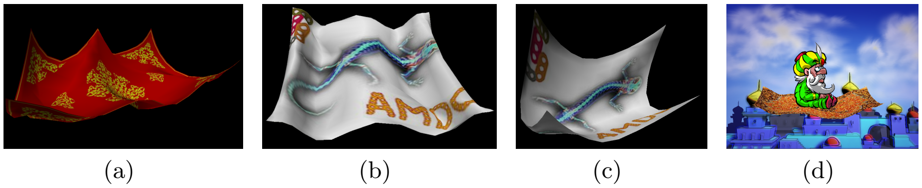


**Fig. 1.** Snapshots of animated cloths using fake dynamics. a) Table cloth being pulled up near the back. b) Undulating flag. c) Swinging with exaggerated elasticity. d) Magic carpet in action.

**Abstract.** In this paper we argue for the concept of *fake dynamics* to allow animators to interactively create visually pleasing animations of cloth models while keeping him/her in full control of the animation process. Existing animation and simulation techniques depend on real dynamics simulation and are often prohibitive in terms of computational cost and user control. Our approach allows the user to interactively model and animate cloth models over time using intuitive deformation tools and keyframe animation techniques. During modelling, the cloth's surface is first approximated by means of 3D catenaries between constraint points. An iterative relaxation process is then performed to arrive at the natural rest shape. Concerning the animation phase, the animator has disposal of many interactive fake dynamics control tools to perform gross modifications or wave-shaped deformations. Multiple instances of deformations can be layered allowing to create realistic as well as exaggerated types of animations. We believe our system is effective in terms of ease-of-use, visual appeal and dynamic behaviour, and offers a new fresh perspective on cloth animation for animated films.

**Key words:** Fake Dynamics, Cloth Animation, Cloth Simulation, Computer Animation, Computer Assisted Animation

## 1 Introduction

**Motivation.** Simulating and animating cloths is much in demand for many purposes ranging from the entertainment industry (movies and games) to the professional clothing industry (fashion and textile).

Existing cloth simulation and animation [1,2] involves a very expensive process in terms of computational cost due to the flexible nature of the cloth objects. However, when targeted for animated movies it also implicates a very expensive process in terms of user control. This is because animators particularly focus on movement and not necessarily on realism. They do not always desire realism, instead they demand for fake, yet very impressive or dramatic animation effects such as squash and stretch, anticipation and surreal exaggerations, which are impracticable when depending on 'real' dynamics simulation [3,4].

High-end feature animation films nevertheless can achieve these subtle animation effects as their production counts with enough resources to enable dedicated programmers and animators working closely together in an elaborate process of trial and error [5].

In this article, however, we look for solutions to be used in smaller-scale productions where animators have to find their way more independently. More specifically, it is our objective to allow the user to interactively create visually pleasing animations of cloth models while keeping him/her in full control of the animation process.

**Contribution.** In this paper we present the concept of *fake dynamics* for cloth animation in animated films, in which a cloth is hanging from arbitrary constraint points. Our system allows the user to interactively create and control the animation by adjusting the shape of models over time using intuitive deformation tools and keyframe animation techniques. Primarily it features following characteristics:

- interactive modelling of a polygonal cloth mesh which can be suspended at arbitrary constraint points;
- the cloth's physical properties are directly configured by the animator (e.g., dimensions, elasticity, constraint points);
- real-time manipulation of the shape using fake dynamics (e.g., waving, swaying and bending deformations);
- multiple instances of all deformations can be used together (i.e. combining multiple waves, swaying etc.) allowing to create realistic as well as exaggerated types of animations;
- immediate and direct control over the animation using a keyframe animation system.

As the goal of this paper is on keeping the animator in full control of the animation process we do not explicitly consider collisions and interactions. However, the most common techniques should easily be integrated because of the underlying polygonal mesh.

The pictures in the inset (Figure 1) show some snapshots of interactively animated cloths using fake dynamics. We emphasise that all animation results were obtained by a completely novice user and that at no time any common cloth modelling techniques nor dynamics simulation were employed to support the modelling and animation processes.

**Approach.** Technically the challenge is to achieve a stable and controllable cloth model that easily can be animated in a key framed manner. Whilst just turning to cutting edge simulation techniques [1,2] would seem obvious, this is often prohibitive in terms of user control. Especially for animation movies realistic behaviour is not always desired. Many dramatic animation effects (including squash and stretch, anticipation and surreal exaggerations) are almost unfeasible when the simulation is subject to real dynamics.

To tackle this challenge, we distinguish between a modelling phase and a separate animation phase. In the modelling phase a cloth is conceived starting from a rectangular grid structure on which arbitrary constraint points have to been chosen indicating the points from which the cloth will hang. Then the shape of the cloth, which is defined by the surface interior to the constraint points, is approximated by means of 3D catenaries. Next, a relaxation process is performed on all points on the surface to arrive at the natural rest shape. The result is a three dimensional cloth object which is hanging and supported by the constraint points. Concerning the animation phase, animators directly create motion by placing keyframes in time and indicating how to generate the in-betweens. Key frames are easily created by building new rest shapes through adding, removing or moving constraint points, or manipulating the relaxation process (e.g., making the cloth's fabric more or less stiff). Furthermore, the user has disposal of many interactive fake dynamics controls (e.g., to perform gross modification or wave-shaped deformation of the natural rest shapes).

This way animators interactively create and control visually pleasing animation of cloth models while staying in full control of the animation process.

**Paper Organisation.** This paper is structured as follows. Section 2 surveys work we consider related to our goals. Section 3 describes the important factors of our approach, starting from the cloth representation and the use of fake dynamics to the animation process. Section 4 elaborates on a system use case example. Finally, Section 5 is our concluding section in which we also set the context for future work.

## 2 Related Work

One of the first attempts to restrain from real dynamics for cloth animation was made in the 1992 Disney feature animation movie *Aladdin* [6] for creating the Magic Carpet. Initially, a CGI model was about to be employed to ease the animators' work, in particular for applying the detailed Persian texture. However, although texturally very pleasing, the cloth dynamics worked out bad for the animation itself as it looked too computerish [5]. As a solution, a hybrid (2D and 3D) approach was followed. That is, the magic carpet animation was entirely drawn on paper by a traditional animator after which a 3D model artist carefully laid out a computer model over the drawn carpet, frame after frame. Then, for each frame a texture map (depicting the Persian texture) was applied to the surface of the carpet model. Finally, the corner tassels were manually drawn on top of the textured carpet. Through this approach, a realistic appearance is achieved while preserving the artist's animation style but at the (labour intensive) cost of manually creating each frame twice.

Barzel's work on fake dynamics describes a simple method for modelling 1D flexible linear bodies such as ropes and springs without using dynamic simulation [7]. His approach has been used successfully in the Toy Story movies. The idea is to provide a default natural rest shape and provide controls that perform gross modification and wave-shaped deformation of the rest shape. Animators then create motion by adjusting the shape of models over time using traditional keyframe methods. Unfortunately, this approach is limited to the 1D case only and the author states that it is not trivially suited for modelling 2D bodies including cloth and clothing.

Other works on flexible objects in computer graphics include hair animation [8] and rope simulation [9], but their connection to cloth simulation is tenuous due to their relatively simple geometry.

## 3 Approach

In this section we describe the steps involved in modelling and animating cloths. The system we envisage is inspired by Barzel's idea of faking dynamics by adjusting the shape of models over time using intuitive deformation tools and keyframe animation. Figure 2 depicts a schematic overview of the main parts involved when modelling and animating a piece of cloth.

Starting from a grid structure the user first specifies some constraint points from which the cloth will hang, as well as some textile parameters such as the fabric's elasticity. An approximation of the cloth's surface is then made within the convex hull of the constraint points by tracing 3D catenaries between pairs of constraint points. After this, the user still can reshape the cloth by repositioning the constraint points. The next step involves an iterative relaxation process on all points on the surface to come to a final rest shape. The entire process can be repeated more than once where each rest shape can act as a key frame for the final animation. Dynamic motions can be superimposed by interactive controls that perform gross modifications or wave-shaped deformations of the cloth's surface. Convincing cloth animation is then achieved by layering these deformations (i.e. combining multiple dynamic motions together) and varying all parameters over time.

Parts of the approximation and relaxation step in the modelling phase are based on Weil's work on physically simulating the threads in a cloth [10]. We,

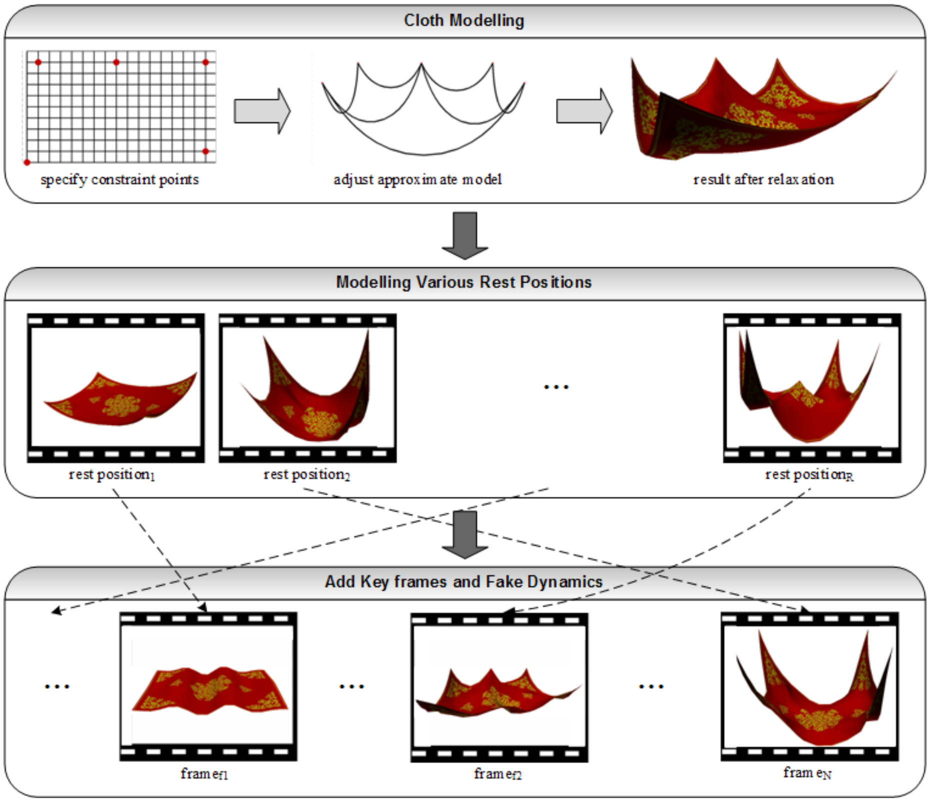


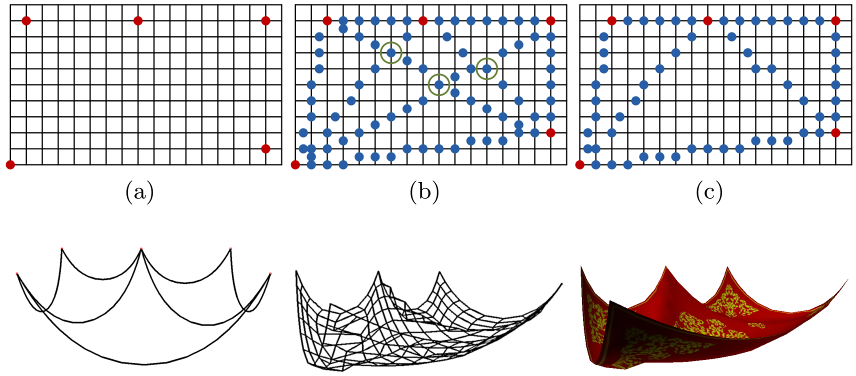
**Fig. 2.** Schematic overview of the main parts of the modelling and animation steps.

however, diverged from it in the approximation step as we were not satisfied with the resulting shape. The following subsections describe all steps in detail.

### 3.1 Cloth Modelling

This section discusses how to represent and create a cloth model.

**Representation.** For reasons of simplicity the cloth's surface will be modelled using as a quadrilateral mesh. To this end, the cloth is initially represented by a 2D grid consisting of 3D coordinates (see Figure 3(a)). The density and dimensions of the grid are user specified, as well as the corner points and inner constraint points from which the cloth will hang (depicted by the red dots).


(a) (b) (c)

(d) (e) (f)

**Fig. 3.** Cloth modelling. a) Grid representation with constraint points (red dots). b-c) Conflicting catenaries (conflicting points in green). Before and after. d) Approximated cloth model. e-f) Cloth model after relaxation.

**Surface Approximation.** For determining the shape of the cloth only the interior and constraint points will be taken into account as the remaining exterior points do not contribute to the cloth model.

As at this point only the positions of the constraint points are known, the following logical step is to determine the internal points between each pair. This narrows down to calculating a catenary between each pair of constraint points taking into account the grid distance and the elasticity (Equation 1).

$$y = a\cosh(\frac{x}{a}) \tag{1}$$

Notice that when looking at the grid catenaries can cross each other (Figure 3(b)) at an internal point. This causes the internal point to be positioned differently in 3D depending on which catenary to use. We know by definition that catenaries are built as low as they naturally can fall. Thus, during the relaxation step they only can be lifted but never will fall any further. This means that we can remove the lowest catenary passing through a conflicting point. Once we have processed only the points for the highest located catenaries, we end up with a triangular structure as depicted in Figure 3(c).

At this point Weil suggests subdividing each triangle in two subtriangles using the highest of the three catenaries passing from the vertices through the triangle's centroid. This should be repeated recursively until all interior points have been positioned in 3D. Unfortunately, as Equation 1 only outputs the height coordinate $y$, the $x$ en $z$ coordinates have to be approximated using interpolation. We noticed, however, that due to the recursive process the approximation errors add up when calculating new catenaries and this is noticeable when positioning the remaining interior points.

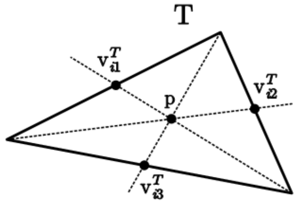


**Fig. 4.**

To overcome this issue, our system also takes into account each point's position in the grid when positioning in 3D. So, after deriving the first triangular structure (Figure 3(c)) we immediately show the corresponding catenaries (Figure 3(d)). At this point the user still can reposition the constraint points (and, hence, the catenaries) in order to adjust the cloth's shape to his desire. Then, we process all remaining interior points at once, hence skipping the subdivision steps. For each point $p$ we first lookup the triangle $T$ it belongs to. Next, we draw straight lines between the vertices of $T$ and $p$; the intersections of these lines with the triangle's edges are called $v_{i1}^T$, $v_{i2}^T$ and $v_{i3}^T$ (see Figure 4). We compute the 3D positions for each $v_i^T$ as follows: the $x$ and $z$ coordinates are derived directly by interpolating between the edge's end points (which are constraint points), for the $y$ coordinate a catenary is constructed between the edge's end points after which an arc length function is employed to find its value. Lastly, we construct catenaries between the vertices of $T$ and $v_{i1}^T$, $v_{i2}^T$ and $v_{i3}^T$. The coordinates $p_x$ and $p_z$ are then calculated by interpolation while for $p_y$ the highest located catenary is employed.

In the end, our method advances Weil's algorithm as all internal points are correctly positioned relying on the initial constraint points.

**Relaxation.** The relaxation process is intended for fine-tuning the cloth's surface. This is an iterative process and involves displacing the grid points until some constraints are obeyed. As we aim for visually compelling and controllable results, real physical constraints are not essential. So, in our case the following constraints suffice [10]: for each point, (i) its placement is at a certain distance $d$ from its neighbours ($d$ is influenced by the point's position on the catenary and the elasticity parameter), and (ii) the angle formed with consecutive neighbours is related to the stiffness parameter. The final result is depicted in Figure 3(e) and Figure 3(f).

### 3.2 Cloth Dynamics

In this section we elaborate on how to superimpose dynamic motion in a key framed manner. We show this by means of two cases: swaying and waving.

**Sway Deformation.** Cloths typically can swing back and forth or to and fro when an external force (e.g., the wind) is exerted on the entire model. To simulate a swaying deformation we calculate a displacement vector for each point $p$ according to following equation:

$$\overrightarrow{d^p_{sway}} = \frac{d^p_{cp}}{d_{max}} \times m \times \overrightarrow{dir} \times v \tag{2}$$

In this equation, $d^p_{cp}$ stands for the distance between $p$ and its closest constraint point, $d_{max}$ is the maximal distance found between an internal point and a constraint point, while $m$, $\overrightarrow{dir}$ and $v$ are adjustable parameters indicating the magnitude, direction and speed of swaying. This way the displacement of a point is in proportion to its distance to the closest constraint point. Now, if we choose to variate, for example, $m$ over time in the interval $[-d_{max}, +d_{max}]$ we get a smooth swinging animation. Figure 5 shows some snapshots of a carpet swinging from side to side.

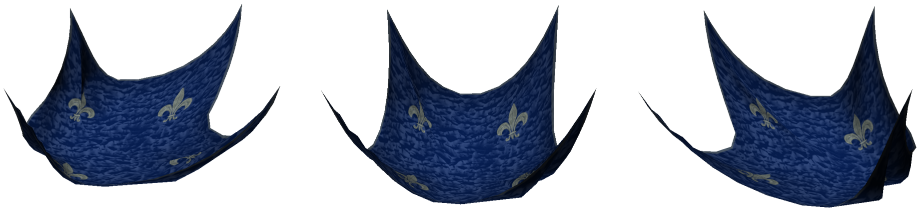
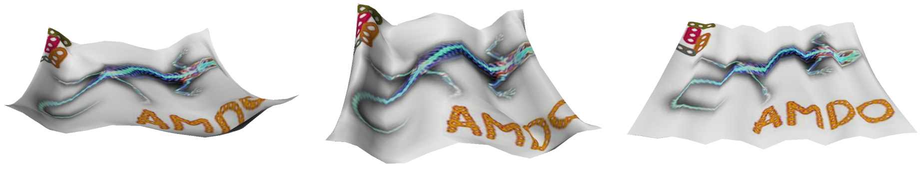


**Fig. 5.** Snapshots depicting a sway from left to right.

**Wave Deformation.** A typical wave deformation is defined by the parameters *magnitude*, *frequency*, *phase* and *azimuth*. For our cloth animation, however, we leave out the azimuth as it will twist the cloth making it look less realistic. To create an undulating surface Equation 3 is employed in which the magnitude, frequency and startphase are denoted by $m$, $freq$ and $startphase$ respectively. We also added a time ($t$) and speed ($v$) parameter to shift, and thus animate, the waves in time. In addition we multiply the whole by an attenuation coefficient $a$ which causes a larger waving effect in the centre of the cloth and a fall off near the constraint points; $d^p_{cp}$ stands for the distance between $p$ and its closest constraint point while $d_{max}$ is the maximal distance found between an internal point and a constraint point. Figure 6 illustrates the effect of the magnitude and frequency parameters for an undulating motion.

$$y = m \times \sin(x \times freq + startphase + t \times v) \times a \tag{3}$$

$$a = \frac{d^p_{cp}}{d_{max}} \tag{4}$$



(a) (b) (c)

**Fig. 6.** Undulating flag. a) Default magnitude and frequency. b) Increased magnitude. c) Increased frequency.

### 3.3 Cloth Animation

For creating animations, a keyframe animation system is employed as it is essential in allowing animators to easily adjust and edit pose and timing with per-frame accuracy [3,4,7].

Key frames are easily created by building rest shapes as described in Section 3.1. That is, the user specifies the elasticity and the constraint points from which the cloth will hang, adjusts the rough shape of the cloth, and after relaxation use the rest shape as a key frame. The entire process can be repeated more than once and so different key frames can consist of different and a different number of constraint points. This is illustrated in Figure 7.

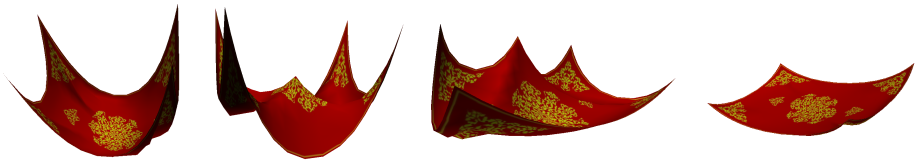


**Fig. 7.** Different rest shapes of the same cloth model.

Dynamic motions as discussed in Section 3.2 are then incorporated in the timeline easily by superimposing them on the key and in-between frames. Moreover, multiple instances of all deformations can be used together. It is this layered approach and varying all parameters over time which leads to convincing animations.

## 4 Results

In this section we elaborate on a system use case example which was carried out to capture the system's effectiveness in terms of *ease-of-use*, *visual appeal* and *dynamic behaviour*. To this end an external animator was involved who was not acquainted with our system at all.

Figure 8 shows the animator's thumbnail storyboard which led to the magic carpet animation shown in Figure 9. The animation is guided by 5 key frames and several interpolation algorithms (including ease-in/ease-out and speed up/down) were used to generate the in-betweens. For the key frames four different rest shapes were created and in particular the elasticity coefficient was used to establish the bending effect. Dynamic motion was added by superimposing animated deformations. For example, the transition between the bending and moving carpet is established by slowly increasing the magnitude of the wave deformation. This cloth animation (not counting drawing the background and the character) took our animator less than 30 minutes to model all rest shapes and to establish the dynamics, clearly illustrating the effectiveness of our system.

All other results (shown in the figures throughout this article) were created by novice users, i.e. the authors, illustrating all the more the ease of use of our approach.

All examples run at an interactive frame rate on a commodity personal computer (Pentium Dual-Core 2.67 GHz, onboard graphics card).

## 5 Conclusion and Future Work

In this paper we presented the concept of *fake dynamics* for cloth animation in animated films, in which a cloth is hanging from arbitrary constraint points.

Existing animation and simulation techniques are often prohibitive in terms of user control. Especially for animation movies realistic behaviour is not always desired, instead they demand for fake, yet very impressive or dramatic animation effects (including squash and stretch, anticipation and surreal exaggerations) which are impracticable when real dynamics are involved.

Our system allows the user to interactively model and animate cloth models over time using intuitive deformation tools and keyframe animation techniques. We believe our system is effective in terms of ease-of-use, visual appeal and dynamic behaviour, and offers solutions to be used in smaller-scale productions where animators have to find their way more independently.

**Future Work.** In this paper, we did not explicitly consider collisions and interactions. However, we believe most common approaches should easily be integrated because of the underlying polygon mesh of the cloth objects.

Furthermore, it is possible that during relaxation displacements of grid points cause the cloth surface to intersect itself. Imposing extra constraints (i.e. predicting intersections before displacing grid points) can prevent this, although we did not experiment any problems in the cases we tested.

## Acknowledgements

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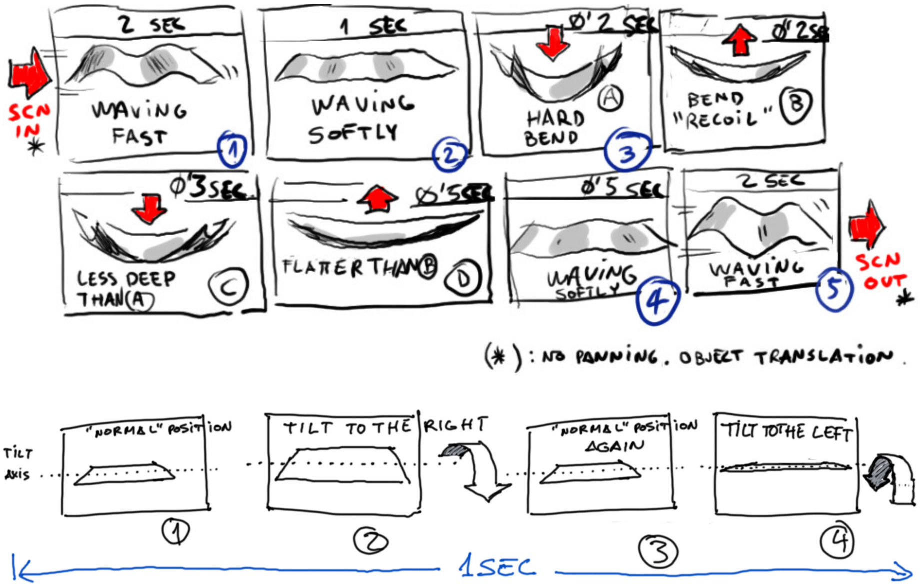

**Fig. 8.** Thumbnail storyboard for the magic carpet animation shown in Figure 9.

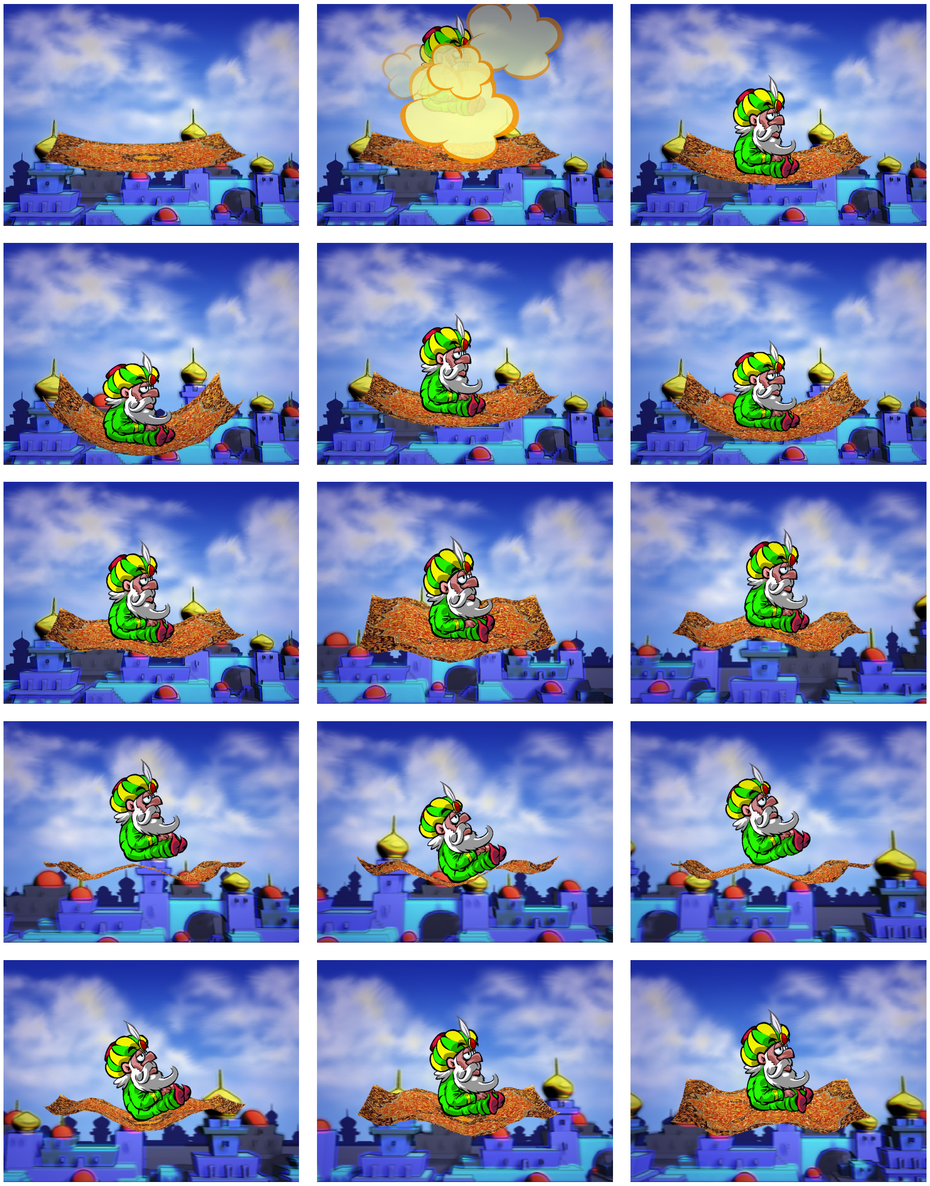

**Fig. 9.** Snapshots of an animated magic carpet illustrating subtle animation effects (including a squash and stretch bend and an undulating motion) achieved by fake dynamics.