

Elastic Facial Caricature Warping

Lyndsey Clarke, Min Chen, Peter Townsend and Benjamin Mora

Department of Computer Science, University of Wales Swansea, United Kingdom
{csllyndsey, m.chen, p.townsend, b.mora}@swansea.ac.uk

Abstract

Caricatures are usually created by skilled artists, and, due to their amusing appearance, they serve mainly as a source of entertainment and humour. This short paper is therefore concerned with a means for generating facial caricatures from given photographs using image warping. In particular, we propose to assign 'virtual' physical and material properties to various facial features in order to specify and render exaggerated transformations in an intuitive manner. Though our objective is not for creating physically accurate photorealism, our physically-based approach enables users to associate virtual displacements in caricatures, with common physical phenomena.

Categories and Subject Descriptors (according to ACM CCS): I.3.3 [Picture/Image Generation]: Display algorithms, I.3.5 [Computational Geometry and Object Modeling]: Physically Based Modeling

1. Introduction

Caricatures are a common form of visual art, in which a subject is portrayed with exaggerated features that emphasize their individual differences from everyone else [Red84]. The aim of a caricature is to maintain the original identity of a subject by creating an exaggerated likeness, which overemphasises the truth in order to achieve the desired, amusing results. The objective of this work therefore is to aid the creation of such artwork for well-intended, responsible entertainment and humour using computer graphics.

In this short paper, we present a new approach to computer-assisted facial caricaturisation. Instead of the explicit specification of displacements, users can assign 'virtual' physical and material properties to the key features in an intuitive manner. Since for most subjects, it would not be practical to obtain their 3D facial models, the system described in this paper relies on only the input of facial images to be caricaturised. We examine and compare three graphical methods, namely the *empirical linear model*, *force-motion model* and *pseudo stress-strain model*, for modeling and rendering exaggerated facial transformations. The use of physical models is not intended for creating physically accurate photorealism. Our objective is instead to provide users with intuitive metaphors for specifying a desired caricaturisation, by associating virtual displacements with common physical phenomena. We demonstrate the effectiveness and usability of our approach with several examples.

2. Related Work

A number of techniques have been proposed which aim to employ computer graphics to generate caricatures. An example-based approach has been developed, which attempts to 'learn' the style of a human caricature artist in order to create caricatures via shape exaggeration of important features [LCXS02]. Other proposed methods include the translation of related point pairs on a texture mapped grid, [APL00], and also the exaggeration of the differences between a subject and an average face [MLN04], which was further explored in [GRG04], to allow deviations from an average face to be created by direct manipulation of a grid which is overlaid on the source image and result in creation of a caricatured effect. Another important area concerned with caricature generation is *image metamorphosis*, which, along with its 3D volumetric extension, is used extensively in computer animation, image processing and scientific visualization. One commonly-used method is *mesh warping* [Wol90], where control structures are defined in the form of a planar or spatial subdivision. The distortion is constrained locally by individual elements in the subdivision mesh, and it can achieve complex transformations through the controlled warping of the mesh. Another approach is *field morphing*, which became popular in the 1990s [BN92, CJT96]. It requires a relatively small number of control features, typically in the form of points and lines, which are normally correlated to the key visual features in the images. A hybrid method

was proposed in [LCSW95], offering a compromise between flexibility and computational costs. Other topics related to this application include *craniofacial anthropometry* [KS97], and *non-photorealistic modeling and rendering* [GG01].

3. Feature Transformation

A facial caricature is typically drawn by emphasising all of the features that make that person different from a reference face perceived or imagined by the caricaturist to be the norm. In [Var04], anthropometric measurements represented by lines are used to specify features, and are exaggerated against a set of reference measurements. A line-based warping algorithm [BN92] is then used to generate a caricature. The critical drawback of this approach is that due to the fact that intersecting lines are not desirable to a line-based warping algorithm, any anthropometric measurements that cross each other cannot be used. Restricting measurements in this way greatly reduces the freedom in modeling exaggeration, resulting in less effectual results [Var04]. In addition, the selection of specific measurements requires both specialised knowledge as well as a balanced judgement between perceptual importance and intersection avoidance.

To overcome this limitation we specify points to define key features such as the nose, mouth, ears and chin, and then the distance between every pair of these points implicitly encodes an anthropometric measurement. Any craniofacial measurement on the visible part of a face can be represented in the control structure as long as its two end-points are defined as feature points. Through various combinations of points, the control structure also encodes numerous non-textbook measurements, many of which may be at least useful, if not crucial, in the perception of exaggerated likeness.

Let I_{in} be an input image of a subject to be caricatured; I_{ref} be a reference image, representing the ‘norm’ which is typically constructed as the average of a set of faces; and I_{out} be an output image as the caricature to be generated. Given a feature point \mathbf{p} on image I_{in} and its corresponding feature point \mathbf{r} on I_{ref} , as illustrated in Figure 1, we would like to determine \mathbf{q} on I_{out} as the exaggerated feature point.

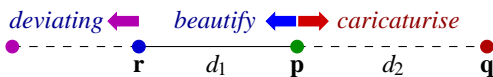


Figure 1: Transformation of a feature point.

The displacement from the norm \mathbf{r} to the actuality \mathbf{p} makes a distinctive feature of the subject. The displacement from the actuality \mathbf{p} to the virtuality \mathbf{q} represents an exaggeration. Normally, when \mathbf{q} is moving further away from \mathbf{r} , it is called *caricaturising*. When \mathbf{q} is moving towards \mathbf{r} , we call this *beautifying* because the subject is transformed towards the symmetrical, average face. When \mathbf{q} continues to move away from \mathbf{r} after passing over \mathbf{r} , we call it *deviating* as the desired likeness in caricaturisation is no longer maintained.

4. Image Warping Pipeline

The system implemented includes a GUI for specifying features and for selecting different models and schemes that are to be discussed below. We use the multi-resolution image warping algorithm by [LCSW95] because it is a point-based warping algorithm, and offers a good balance between quality of warping and computational costs.

Initial feature points are assigned to an input image, I_{in} , automatically based on the chosen reference image I_{ref} . Users can add, modify and remove feature points through the user interface, and local parameters can be assigned to individual features if they are allowed in the model used. With one or a few global parameters, the user can activate the process of caricaturisation, and the system will compute the displacement of each feature, d_2 , and invoke the image warping algorithm with all displaced features as a control structure, resulting in a caricature in an output image I_{out} .

5. Empirical Linear Model

Considering \mathbf{p} in relation to \mathbf{r} , the *likeness* can be modeled as the direction of vector $(\mathbf{p} - \mathbf{r})$, and the *strength* or *distinguishability* of the individual feature as the magnitude of the vector. Scaling the vector along the same direction, therefore, implies the change of feature strength. A lengthened magnitude indicates exaggeration or caricaturisation, and a shortened magnitude indicates beautification. This gives us an empirical linear model for determining \mathbf{q} as:

$$\mathbf{q} = \alpha(\mathbf{p} - \mathbf{r}) + \mathbf{r},$$

where α is a scaling factor of the feature strength, and it defines both the scale and the type of the warping from \mathbf{p} to \mathbf{q} . When $\alpha > 1$, we have a caricaturising warping; when $\alpha = 1$, no warping; when $0 \leq \alpha < 1$, beautifying; and when $\alpha < 0$, deviating. Although the meaning of α is rather abstract, the value range of α is not difficult to comprehend. From the perspective of a user, it is easy to use α as a global control parameter, which correlates well with the overall level of exaggeration. When α is used as a local parameter for each feature point, assigning values of such an abstract property to many feature points is not so intuitive. Furthermore, being a linear model also places constraints on the visual effects that can be applied to caricatures.

6. Force-Motion Model

To introduce some non-linearity and to provide an intuitive means for assigning local parameters, one can imagine each feature point as a particle in motion. Although this is not correct in terms of the physically-based modeling of human faces, it allows users to associate the displacement of facial features with some everyday phenomena related to force and motion. At the same time, it brings an extra dimension of amusement to an application that does not aim for physical correctness and photo-realism at the first place.

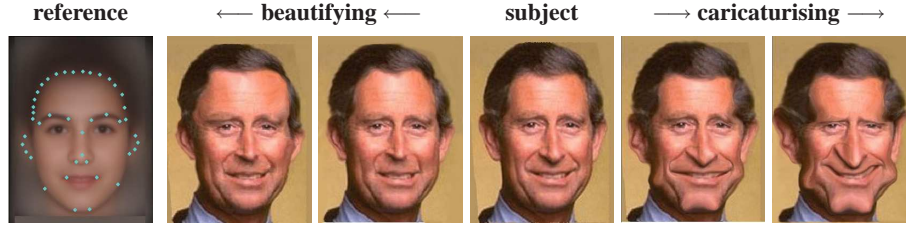


Figure 2: *Pseudo stress-strain model, with which local parameters κ and η are used to control individual features.*

Consider Newton’s laws of motion in the form of:

$$d(t) = v_0t + \frac{1}{2}at^2 = v_0t + \frac{F}{2m}t^2 \quad (1)$$

where d is the displacement, v_0 is the initial velocity, t is the time, a is the acceleration, F is the force and m is the mass. The general meaning of these terms are understood by most ordinary people and teenagers, so therefore they can be used as local and global parameters for controlling a warp. However, as these variables are inter-related, there can be many different schemes for selecting appropriate parameters for users to specify a warp, which are detailed below.

Scheme A: Controlling by Time. Imagine that all particles on a subject’s face are travelling from their individual origins on the reference image over a period of time. Let the initial velocity of a particle at \mathbf{r} be 0, and it takes time $\Delta t_1 > 0$ for the particle to move to position \mathbf{p} under some force. Assume that the force and the mass of the particle do not change, and the user can extend or cut short the travelling time by setting a parameter $\Delta t_2 \in R$. From Eq. (1), we can obtain:

$$\mathbf{q} = \frac{d_2}{d_1}(\mathbf{p} - \mathbf{r}) + \mathbf{p} = \frac{\Delta t_2}{\Delta t_1^2}(\Delta t_2 + 2\Delta t_1)(\mathbf{p} - \mathbf{r}) + \mathbf{p}.$$

Scheme B: Controlling by Force and Mass. Since using the notion of particles moving through time might seem difficult to imagine and employ in this particular instance, perhaps a much more instinctive ‘virtual’ physical property is mass, as it is intuitive to give each particle a weight. One can also apply force to particles with either a global parameter or independent local parameters. Given a global parameter Δt_2 and known variable d_1 , we have:

$$d_2 = \frac{F}{2m} \left(\sqrt{\frac{2d_1m}{F}} + \Delta t_2 \right)^2 - d_1,$$

from which, we can easily derive \mathbf{q} .

7. Pseudo Stress-Strain Model

It is natural to associate caricaturisation with the process of deformation by stretching or compressing different parts of a face. This directly leads to the use of metaphors related to material properties and mechanics. The behaviour of a solid material under a tensile or compressive loading is typically described by a *stress-strain graph*, where *stress* (F/A) is measured as the force F applied to a unit cross-section area

A , and *strain* (e/l) is the ratio between the extended or compressed displacement e and the original length l . There is a huge collection of measured stress-strain curves for different materials [Boy02], and such a graph reveals many physical and mechanical properties of a material, such as its *elasticity modulus*, *yield point*, *elastic limit*, and *ultimate strength*.

Despite the huge gulf between the science of material mechanics and the art of creating non-photorealistic caricatures, the everyday notions, such as ‘as hard as diamond’ or ‘as flexible as rubber’, are intuitive metaphors for specifying a facial transformation. We therefore propose a *pseudo stress-strain model* that captures some common characteristics of real-world materials, and builds on the Force-Motion Model by introducing a more instinctive and natural means of controlling the caricature creation. In order to show the physical basis of this model, we give here a rather ‘physical’ description of it. In our user interface, however, we do not expect users to have a full understanding of the physical concepts involved, but instead, provide users with a collection of virtual materials for controlling a warp.

We refer to materials as ‘virtual’ because we consider only the strain on loading (i.e., the displacement under the force), and leave out the elastic behaviour that a solid, such as rubber, regains its original length on unloading. This facilitates WYSIWYG in user interface design. We also assume that all ‘virtual materials’ are totally unbreakable, but use a *maximum strength* value, τ , to control the maximum stress allowed. In this way, we omitted the necking behaviour, which is a phenomenon where the cross-sectional area of a solid decreases when the loading is continued beyond the ultimate strength. Without the necking behaviour, it also allows to set A to a constant 1. With the above assumptions, our *pseudo stress-strain model* can thus be given as:

$$F/A = \kappa \left(e/l \right)^\eta$$

where κ is called *Hookean coefficient*, which is in effect the modulus of elasticity (Young’s modulus). When $\eta = 1$ and the Hooke’s law applies. We introduce $\eta > 0$ as the *non-Hookean coefficient*. When $\eta < 1$, the virtual material exhibits a stress-strain relationship typically shown by real-world plastic materials. When $\eta > 1$, the virtual material exhibits the so-called strain-hardening behaviour.

Each virtual material can be used as a metaphor for specifying the local behaviour of features. With a reasonable col-

lection of virtual materials, it is not necessary for users to understand the precise physical meaning of the variables in this model and their relationships.

Scheme C: Non-uniform Original Length. Let the original length l be the existing displacement d_1 between a feature point on a subject \mathbf{p} and that on the reference image \mathbf{r} as shown in Figure 1. Using the pseudo stress-strain model, we can calculate the extension e , that is, d_2 , as:

$$d_2 = d_1 \left(F/\kappa \right)^{\frac{1}{\eta}}$$

We can apply a tensile force for caricaturising the subject and a compressive force for beautifying the subject. In most cases, a global parameter for the force, F , is adequate for controlling the scale of warping in either direction. Figure 2 shows an example of using this scheme for caricaturisation, and includes the reference image that was used in the transformation, along with its associated feature points.

Scheme D: Uniform Original Length. It is sometimes useful to estimate κ and η from known d_1 and d_2 , with a global parameter F . We hence devise an alternative scheme by assuming that the line segment between \mathbf{r} and \mathbf{p} has already been stretched from an original length, which is set as a global constant $u > 0$. Given that d_1 is known, we require only two parameters among F , κ and η . For example, the user can specify F as a global parameter, and κ as a local parameter. For each feature, we can derive its η as:

$$\eta = \frac{\ln(F/\kappa)}{\ln(|d_1 - u|/u)}$$

We can then compute d_2 under a scaled force σF as:

$$d_2 = u \left(\sigma F/\kappa \right)^{\frac{1}{\eta}} + u$$

Note that σ has a similar behaviour as α in the empirical linear model. When $\sigma > 1$, we have caricaturising; when $\sigma > 1$, no warping; and when $0 \leq \sigma < 1$, beautifying. However, $\sigma = 0$, we obtain a transformation that is close to the norm with all feature points displaced for the constant distance u . Alternatively, we can assume that different forces are applied to individual feature points for causing the initial warping to their positions in the input image. Given local parameters κ and η , we can compute the local parameter F as:

$$F = \kappa \left(|d_1 - u|/u \right)^{\eta}$$

Similarly, we can then compute d_2 with a local force scaled by a global parameter σ . Here we assume that before the second force σF is applied to the feature, the initial force F is removed, and the feature retains its original length u . In other words, there is no permanent strain after any force, and all materials are assumed to be totally elastic.

8. Conclusions

We have described a physically-based approach to computer-assisted caricaturisation. We have presented two

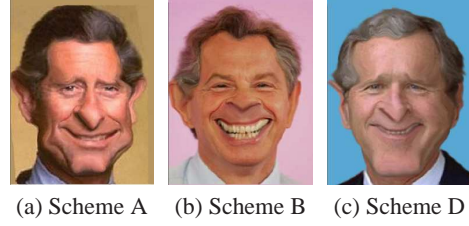


Figure 3: Some example results from the different schemes.

such models, the *force-motion model* and the *pseudo stress-strain model*, together with an *empirical linear model* as a benchmark. We have presented the schemes for implementing such models, discussed their relative merits and limitations, and included some example results (see Figure 3).

We have also developed a method for obtaining ‘virtual’ physical and material properties from hand-drawn caricatures, which will be detailed in a forthcoming report. Our future work will include improvements to the warping algorithm; the introduction of new metaphors, such as temperature, into the pseudo stress-strain model, and also the development of an ‘edutainment’ software system for teaching children the concepts of physics and material mechanics.

Acknowledgment Source images used in this work are taken from http://en.wikipedia.org/wiki/George_W._Bush, <http://www.chortler.com/1667tbtan.shtml>, and <http://www.earthisland.org/project/newsPage2.cfm?newsID=767&pageID=177&subSiteID=44>

References

- [APL00] AKLEMAN E., PALMER J., LOGAN R.: Making extreme caricatures with a new interactive 2d deformation technique with simplicial complexes. *Visual 2000* (2000), 165–170.
- [BN92] BEIER T., NEELY S.: Feature-based image metamorphosis. *Computer Graphics (Proc. SIGGRAPH 92)* 26, 2 (1992), 35–42.
- [Boy02] BOYER H. E. (Ed.): *Atlas of Stress-strain Curves*. ASM International, 2002.
- [CJT96] CHEN M., JONES M. W., TOWNSEND P.: Volume distortion and morphing using disk fields. *Computers and Graphics* 20, 4 (1996), 567–575.
- [GG01] GOOCH B., GOOCH A.: *Non-photorealistic Rendering*. A K Peters, 2001.
- [GRG04] GOOCH B., REINHARD E., GOOCH A.: Human facial illustrations: Creation and psychophysical evaluation. *ACM Transactions on Graphics* 23, 1 (2004), 27–44.
- [KS97] KOLAR J. C., SALTER E. M.: *Craniofacial Anthropometry: Practical Measurement of the Head and Face for Clinical, Surgical, and Research Use*. Charles C Thomas Pub Ltd., 1997.
- [LCSW95] LEE S.-Y., CHWA K.-Y., SHIN S. Y., WOLBERG G.: Image metamorphosis using snakes and free-form deformations. In *Computer Graphics (Proc. SIGGRAPH 95)* (1995), Addison-Wesley, pp. 439–448.
- [LCXS02] LIANG L., CHEN H., XU Y. Q., SHUM H. Y.: Example-based caricature generation with exaggeration. *10th Pacific Conference on Computer Graphics and Applications* (2002), 386.
- [MLN04] MO Z., LEWIS J., NEUMANN U.: Improved Automatic Caricature by Feature Normalization and Exaggeration. In *ACM SIGGRAPH 2004 Conference Abstracts and Applications* (New York, 2004), ACM Press.
- [Red84] REDMAN L.: *How to Draw Caricatures*. Contemporary Books, Chicago, 1984.
- [Var04] VARSHNEY L.: Face metamorphosis and face caricature : A user’s guide. <http://people.cornell.edu/~pages/lrv2/publications/>, October 2004.
- [Wol90] WOLBERG G.: *Digital Image Warping*. IEEE Computer Society Press, Los Alamitos, CA, 1990.