Computer Vision and Image Understanding 141 (2015) 1–17

Contents lists available at ScienceDirect

Computer Vision and Image Understanding

journal homepage: www.elsevier.com/locate/cviu

Computational caricaturization of surfaces

Matan Sela*, Yonathan Aflalo, Ron Kimmel

Geometric Image Processing Lab, Technion-Israel Institute of Technology, Haifa 32000, Israel

ARTICLE INFO

Article history:
Received 17 August 2014
Accepted 27 May 2015

Keywords:
Poisson equation
Isometry/pose invariance
Gaussian curvature
Laplace–Beltrami operator

ABSTRACT

The question whether a caricature of a 2D sketch, or an object in 3D can be generated automatically is probably as old as the attempt to answer the question of what defines art. In an attempt to provide a partial answer, we propose a computational approach for automatic caricaturization. The idea is to rely on intrinsic geometric properties of a given model that are invariant to poses, articulations, and gestures. A property of a surface that is preserved while it undergoes such deformations is self-isometry. In other words, while smiling, running, and posing, we do not change much the intrinsic geometry of our facial surface, the area of our body, or the size of our hands. The proposed method locally amplifies the area of a given surface based on its Gaussian curvature. It is shown to produce a natural comic exaggeration effect which can be efficiently computed as a solution of a Poisson equation. We demonstrate the power of the proposed method by applying it to a variety of meshes such as human faces, statues, and animals. The results demonstrate enhancement and exaggeration of the shape's features into an artistic caricature. As most poses and postures are almost isometries, the use of the Gaussian curvature as the scaling factor allows the proposed method to handle animated sequences while preserving the identity of the animated creature.

1. Introduction

A caricature is an illustration of an object in which some features are exaggerated. The terms *feature exaggeration* usually refers to an operation that relates measures of a given object to those of a reference one. For example, a small mouth, relates the size of a given mouth to its average in a given population. The procedure we have in mind is one that emphasizes and extends such discrepancies. An interesting question is what happens when there is no reference population or an average to relate to. At the other end, it would be intriguing to design a caricaturization procedure that would have the same effect on an articulated object which is not affected by its pose, or posture (Fig. 1).

The oldest caricatures known today were drawn in ancient Egypt at about 3000 BC [2]. Later, the Greek and the Roman Empires used caricatures to intimidate people and spread their propaganda. The characters in these ancient caricatures were often monstrous hybridizations of humans and animals, see for example Fig. 2. In the fifteenth century, there was a change in the attitude towards caricatures. It has probably started with Leonardo da-Vinci, who in his study and exploration for shapes and forms searched for people with extremely deformed facial characteristics, that he used for his scientific art. Followers of da-Vinci started to emphasize properties of faces by exaggerating features in their drawings.

Drawing professional caricatures is a skill that requires long practice and innate talent. Skilled caricaturists are intimately familiar with human faces and their saddle variations. They can perceptually differentiate key features in one's face from an average one. Before drawing, a caricaturist finds the discrepancy of common parts and memorizes them. Then, she draws the subject while amplifying the more distinct characteristics. The process is described in Fig. 3. The choice of features and the ability to exaggerate while maintaining the identity is where art comes into play. Obviously, personal touch and drawing skills would lead to different projections onto different artists perceptions of reality.

Several papers attempt to automate a process of caricature drawing. The main efforts in this area can be divided into model-based and geometry-based approaches. The model based procedures are usually designed specifically for human faces that are represented by some parametric model. The discrepancies between the representations of a given subject face and an average one are exaggerated. In the geometry-based approach, intrinsic features of a shape are exaggerated. Here, we show how the proposed framework bridges between these two models.

While designing an automatic exaggeration procedure a fundamentally important property is robustness to isometric deformations, such as rigid body transformations, as well as changes of expressions and poses. Based on the above arguments, the two axioms we would

* Corresponding author.
E-mail address: matansel@tx.technion.ac.il (M. Sela).

http://dx.doi.org/10.1016/j.cviu.2015.05.013
1077-3142/

Fig. 1. Caricaturization of a synthetic model [1]. Left to right: original model, caricature with exaggeration parameter $\gamma = 0.25$, and $\gamma = 0.5$.

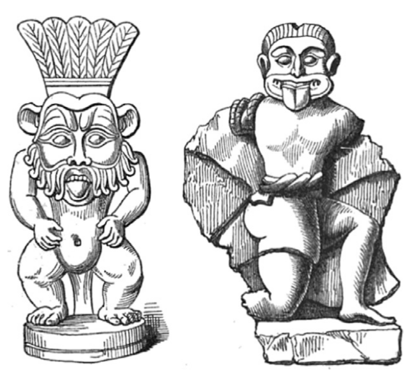

Fig. 2. The Egyptian God Typhoon (left) probably goes back to 3000 BC and a Greek Gordon (right) 600 BC as reproduced in [2].

like to have for an automatic shape caricaturization procedure are thereby

- The ability to extend discrepancies with respect to a reference model.
- Robustness or invariance to isometric deformations.

Indeed, when exaggerating a shape in motion, a key principle is to ensure that the processed sequence of exaggerated shapes are all related in a similar fashion to the original one. This property would enable applying the algorithm to animated figures and 3D scans while preserving the identity of the modified creature. Here, we propose a caricaturization framework that obeys these guidelines. Our axiomatic construction is based on the analysis provided in [4] by which facial expressions and articulations are almost isometries. Next, the simplest differential isometry invariant measure is the Gaussian curvature. We show how to efficiently modify the geometry of a given surface such that its area is locally amplified by some scalar function of the Gaussian curvature. The proposed model links between the two schools of thoughts of computerized caricaturization. Given the correspondence between the subject shape and a reference average shape, the relation between the curvatures at corresponding points determines the local stretching of the shape. The results of the algorithm are demonstrated to be robust to almost isometric deformations. It is simple to incorporate the proposed framework as part of a real-time system using the implementation consideration we provide.

The organization of this paper is as follows. We start by reviewing caricature generation related papers in Section 2. We next introduce the proposed approach by briefly reviewing a classical surface modification technique to which we apply our axiomatically designed amplification factor in Section 3. Details about discretization and boundary conditions are given in Section 5. Section 6 discusses experimental results of the model applied to synthetic and real surfaces, as well as potential applications. We conclude with future directions in Section 7.

2. Related work

The challenge of automatically generating caricatures occupied researchers since the 1980's. Brennan [3] introduced the idea of exaggerating the discrepancies between a sketch of a subject and an average face. She developed an interactive system in which the user picks feature points on a facial image. Simple interpolation of these points provides a sketch of the faces. Then, the sketch is aligned and registered to an average one, and the distances between matched feature points are exaggerated to construct a caricature.

Blanz and Vetter [5] proposed an extension of Brennan's concept to facial surfaces embedded in $\mathbb{R}^3$. By finding bijective correspondences between approximately 200 faces, they constructed a linear model for facial geometries and facial textures. The caricature