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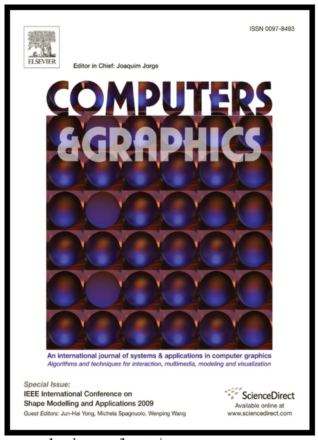

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Optimized Subspaces for Deformation-Based Modeling and Shape Interpolation

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Abstract

We propose a novel construction of subspaces for real-time deformation-based modeling and shape interpolation. The scheme constructs a subspace that optimally approximates the manifold of deformations relevant for a specific modeling or interpolation problem. The idea is to automatically sample the deformation manifold and construct the subspace that best-approximates these snapshots. This is realized by writing the shape modeling and interpolation problems as parametrized optimization problems with few parameters. The snapshots are generated by sampling the parameter domain and computing the corresponding minimizers. Finally, the optimized subspaces are constructed using a mass-dependent principle component analysis. The optimality provided by this scheme contrasts it from alternative approaches, which aim at constructing spaces containing low-frequency deformations. The benefit of this construction is that compared to alternative approaches a similar approximation quality is achieved with subspaces of significantly smaller dimension. This is crucial because the run-times and memory requirements of the real-time shape modeling and interpolation schemes mainly depend on the dimensions of the subspaces.

Keywords: Shape Deformation, Shape Interpolation, Shape Modeling

1. Introduction

Creating digital geometric content is an important task for applications in various areas including digital manufacturing, computer animation, and virtual reality. Acquisition technologies, like 3D-scanning, allow for creating accurate digital copies of detailed real-world objects. Therefore, methods for modeling a single shape and for synthesizing new ones from a collection of shapes are essential for customizing digital content to the demands of users and applications. Here we consider two such methods: *deformation-based modeling* and *shape interpolation*. Deformation-based modeling tools provide a user with simple and intuitive interfaces for modifying a digital shape. For example, a user can translate and rotate parts of the object, so-called handles, and the rest of the shape follows automatically. Physical models of deformable objects are used to produce deformations that match the users intuition. For shape interpolation, we consider a set of example shapes, *e.g.*, different poses of one character. Shape interpolation allows for creating new "in-between shapes" and is a crucial module of schemes for tasks like morphing, deformation transfer, example-based shape editing, example-based materials for controlling simulations, and shape exaggeration.

A fundamental problem for both methods, modeling and interpolation, is that on the one hand, processing tools need to solve high-dimensional non-linear optimization problems to compute the deformed shapes, and, on the other hand, users expect fast or even interactive responses. Therefore, it is essential to design efficient approximation algorithms for these problems. Subspace methods proved to be very effective. The principle is to construct a low-dimensional approximation of the complex problem in a preprocess (offline phase) and to solve only the low-dimensional system in the interactive (online) phase. Different schemes for constructing subspaces for deformation-based modeling have been introduced based on space deformations, radial basis functions, bi-harmonic problems, low-frequency Laplace–Beltrami eigenfunctions or vibration modes. The common goal of these methods is to construct subspaces containing low-frequency deformations. An alternative approach is to learn the subspaces from observations. Methods following this idea, such as the method of snapshots, are prominent for the reduction of physical simulations.

In this work, we introduce constructions of subspaces that are optimized for deformation-based shape modeling and shape interpolation tasks. The constructions involve the following technical contributions. We formulate general frameworks for shape modeling and interpolation as parameterized optimization problems with low-dimensional compact parameter domains. Then, observations of the shape modeling or interpolation tasks can be obtained by samplings the solution space of the optimization problem. This in turn can be done by sampling the parameter domain of the optimization problem and computing the corresponding deformations. For shape interpolation, the parameters are the interpolation weights. Since the interpolation weights are positive and sum to one, the set of weights forms a simplex, whose dimension is one less than the number of example shapes to be interpolated. To generate the snapshots for the interpolation problem, we sample the simplex and compute the corresponding interpolating shapes. For deformation-based modeling, we consider deformation handles that can be translated and rotated in space. To obtain a compact parameter domain, we introduce a maximum translation for the handles, *e.g.*, the length of the objects bounding box di-