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# Subspace methods for retrieval of general 3D models

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ABSTRACT

In statistical shape analysis, subspace methods such as PCA, ICA and NMF are commonplace, whereas they have not been adequately investigated for indexing and retrieval of generic 3D models. The main roadblock to the wider employment of these methods seems to be their sensitivity to alignment, itself an ambiguous task in the absence of common natural landmarks. We present a retrieval scheme based comparatively on three subspaces, PCA, ICA and NMF, extracted from the volumetric representations of 3D models. We find that the most propitious 3D distance transform leading to discriminative subspace features is the inverse distance transform. We mitigate the ambiguity of pose normalization with continuous PCA coupled with the use of all feasible axis labeling and reflections. The performance of the subspace-based retrieval methods on Princeton Shape Benchmark is on a par with the state-of-the-art methods.



## 1. Introduction

Rapidly growing databases of 3D models in many domains give rise to a need for efficient indexing tools for various recognition, classification or retrieval tasks. Manual annotation of objects with keywords being inadequate and impractical, automatic indexing and retrieval of 3D objects is the obvious alternative.

In this work, we explore subspace approaches for the shape-based classification and retrieval of complete 3D object models. This approach is based on the conjecture that 3D shapes have a sparse representation in some appropriate subspace, and hence can be represented with many fewer coefficients as compared to their voxel representation. The subspace can be model-driven, thus spanned by a fixed set of basis functions, and among which the most energetic terms are selected. Discrete Fourier transform, discrete cosine transform, discrete wavelet transform are well-known examples in this category. The subspace can be data-driven where the basis functions are generated from the training data itself. In this work, we demonstrate the advantages of data-driven methods, which capture the statistical characteristics of the 3D objects better for the retrieval task, on several well-known subspace techniques, namely principal component analysis (PCA), independent component analysis (ICA) and nonnegative matrix factorization (NMF).

Subspace techniques have commonly been used for characterization of specific categories of shapes, such as 3D faces, body shapes and anatomical structures [1–6]. However, to the best of our knowledge they have not been extensively studied specifically for indexing and retrieval of general 3D models. Subspace methods are powerful in capturing the essence of the shape space and successful in retrieval provided the query and target models are well represented in the training set. They greatly reduce the dimensionality of the models supplying compact representations, which enable fast searching. The feature extraction procedure is also time efficient since it only involves multiplication with a matrix. However, the success of subspace-based retrieval methods, when applied to general 3D models, depends critically upon the quality of the object pose normalization or registration process due to the lack of common natural landmarks (see Fig. 1).

The primary contribution of this paper is a general subspace-based framework for indexing general 3D objects (see Fig. 2). We propose and explore various alternatives for each component of this framework, namely for data representation, object alignment, choice of the subspace and shape matching. In particular, we use continuous PCA (CPCA) [7] for the alignment problem in conjunction with the distance transform of the voxelized models, which provides smoothness and hence an inherent robustness against minor misalignments (Section 3.3). We present mean shape-based and class-based correction schemes to resolve pose ambiguities resulting from CPCA (Section 5.4). For shape matching, we propose a computationally efficient version of the Munkres algorithm, which we refer to as pose assignment strategy, in order to compute the distance between two models by taking into account all possible mirror reflections and axis relabelings (Section 6). As a result, the PCA, ICA and NMF subspaces, when tailored to the needs of a

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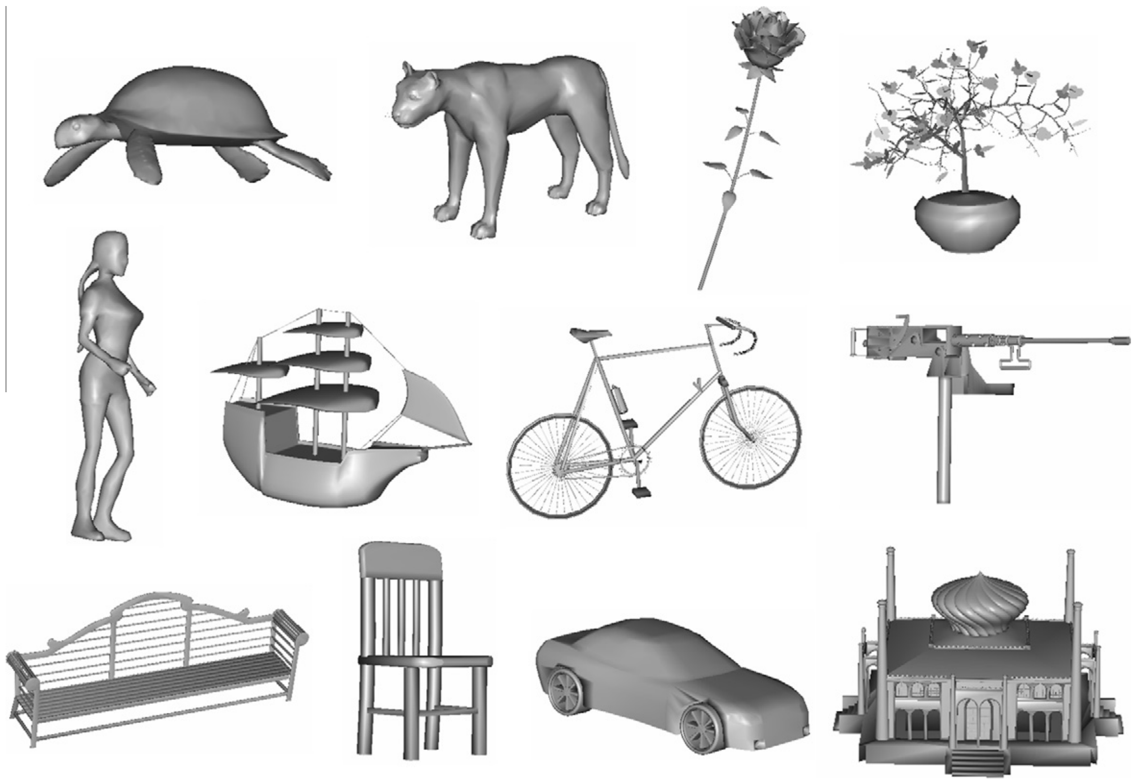

**Fig. 1.** Samples of general 3D models.

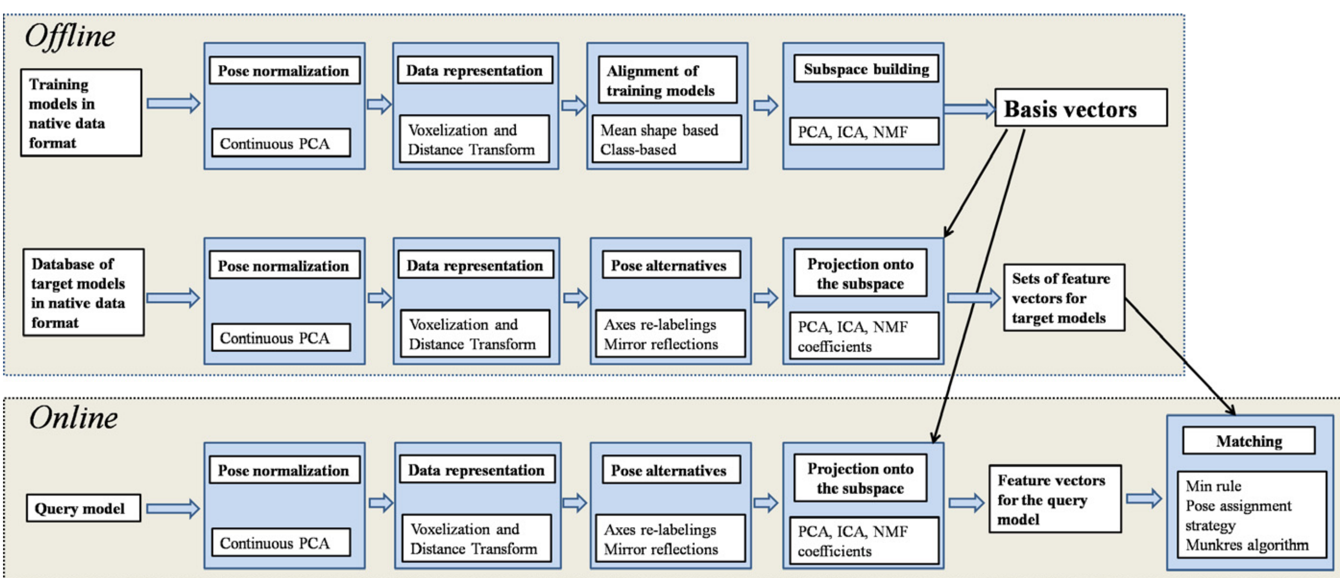


**Fig. 2.** General framework of subspace-based indexing scheme.

retrieval problem and applied to voxelized 3D shapes (Section 5), provide state-of-the-art performance.The retrieval performance of the proposed framework is demonstrated on Princeton Shape Benchmark (PSB) database. The subspace-based methods, when combined with other state-of-the-art descriptors in the literature, achieve the highest retrieval performance reported so far on PSB test set.

The paper is organized as follows: In Section 2, we overview the related work on shape-based retrieval of 3D models. In Section 3, we give details of the voxelization process and of the distance transform. Direct voxel comparison in Section 4 aims to serve as a baseline method. In Section 5, we describe the subspace techniques and the alignment of the training models for subspace building. In Section 6, we present the matching process between a query model and target models in terms of their pose alternatives. We provide experimental results in Section 7 and finally conclude in Section 8.

## 2. Related work

The large amount of research carried on the retrieval of general 3D models from large databases within the last 10 years is thor-