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Efficient 3D reflection symmetry detection: A view-based approach

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ABSTRACT

Symmetries exist in many 3D models while efficiently finding their symmetry planes is important and useful for many related applications. This paper presents a simple and efficient view-based reflection symmetry detection method based on the viewpoint entropy features of a set of sample views of a 3D model. Before symmetry detection, we align the 3D model based on the Continuous Principal Component Analysis (CPCA) method. To avoid the high computational load resulting from a directly combinatorial matching among the sample views, we develop a fast symmetry plane detection method by first generating a candidate symmetry plane based on a matching pair of sample views and then verifying whether the number of remaining matching pairs is within a minimum number. Experimental results and two related applications demonstrate better accuracy, efficiency, robustness and versatility of our algorithm than state-of-the-art approaches.

1. Introduction

Symmetry is an important clue for geometry perception: it is not only in many man-made models, but also widely exists in the nature [1]. Symmetry has been used in many applications such as: 3D alignment [2], shape matching [3], remeshing [4], 3D model segmentation [5] and retrieval [6].

However, existing symmetry detection algorithms still have much room for improvement in terms of both simplicity and efficiency in detecting symmetry planes, as well as the degree of freedom to find approximate symmetry planes for a roughly symmetric 3D model. In addition, most of the existing symmetry detection methods are geometry-based, thus their computational efficiency will be tremendously influenced by the number of vertices of a model. Though sampling and simplification can be used to reduce the number of vertices, they also decrease the shape accuracy and cause deviations in geometry. Therefore, a symmetry detection algorithm often directly uses original models as its input, as can be found in many existing related papers.

Motivated by the symmetric patterns existing in the viewpoint entropy [7] distribution of a symmetric model, we propose a novel and efficient view-based symmetry detection algorithm (see Fig. 1) which finds symmetry plane(s) by matching the viewpoint entropy features of a set of sample views of a 3D model aligned beforehand using Continuous Principal Component Analysis (CPCA) [8]. Based on experimental results, we find that our symmetry detection algorithm is more accurate (in terms of both the positions of detected symmetry planes and sensitivity to minor symmetry differences), efficient, robust (e.g. to the number of vertices and parameter settings such as view sampling), and versatile in finding symmetry planes of diverse models.

In the rest of the paper, we first review the related work in Section 2. In Section 3, we present the viewpoint entropy distribution-based symmetry detection algorithm. Section 4 describes diverse experimental evaluation and comparison

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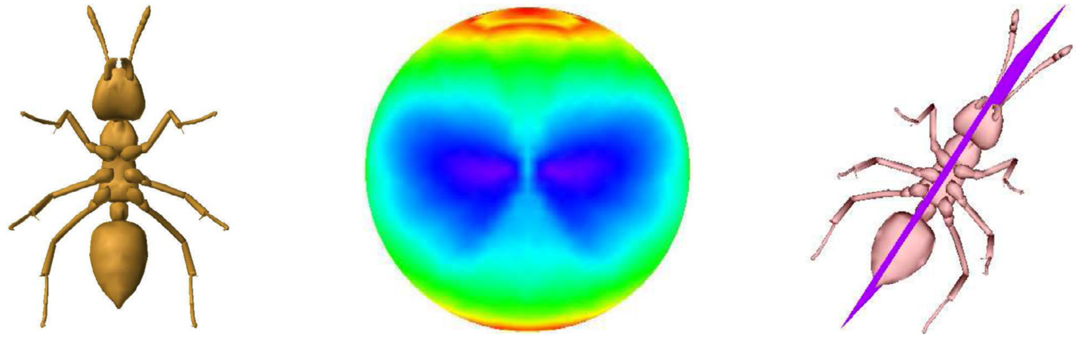

Fig. 1. An overview of our view-based symmetry detection algorithm: an example of an ant model, its viewpoint entropy distribution, and the detected symmetry plane by matching the viewpoints. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

results of the detection algorithm. In Section 5, we show two interesting applications of our symmetry detection idea in 3D model alignment and best view selection. Section 6 concludes the paper and lists several future research directions. This paper is an extension of our prior publication [9].

2. Related work

Symmetry types. Though there are different types of symmetry, reflection symmetry is the most important and commonly studied. Chaouch and Verroust-Blondet [2] introduced four types of reflection symmetries, which are cyclic (several mirror planes passing through a fixed axis), dihedral (several mirror planes passing through a fixed axis with one perpendicular to the axis), rotational symmetry (looks similar after rotation, e.g., different platonic solids, like tetrahedron, octahedron, icosahedron and dodecahedron) and unique symmetry (only one mirror plane, for instance, many natural and most man-made objects). Most symmetric objects are mirror rather than rotational symmetric [10].

Symmetry detection. Symmetry detection is to search the (partial or full) symmetry planes of a 3D object. The latest review on symmetry detection is available in [11]. We classify current symmetry detection techniques into the following four groups according to the features employed.

Symmetry detection based on pairing point features. This type of approach first samples points on the surface of a 3D model and then extracts their features. After that, it finds point pairs by matching the points. Based on the point pairs, symmetry evidences are accumulated to decide the symmetry plane. Two typical algorithms are [12] and [13]. To decide the symmetry plane, Mitra et al. [12] adopted a stochastic clustering and region-growing approach, while Calliere et al. [13] followed the same framework of pairing and clustering, but utilized 3D Hough transform to extract significant symmetries. In fact, the initial idea of this approach can be traced back to the symmetry distance defined in [14]. Podolak et al. [15] proposed a planar-reflective symmetry transform and based on the transform they defined two 3D features named center of symmetry and principal symmetry axes, which are useful for related applications such as 3D model alignment, segmentation, and viewpoint selection.

Symmetry detection based on pairing line features. Bokeloh et al. [16] targeted on the so-called rigid symmetries by matching feature lines. Rigid symmetries are the reoccurring components with differences only in rigid transformations (translation, rotation and mirror). They first extracted feature lines of a 3D model, then performed feature line matching, and finally validated the symmetry based on the feature correspondence information by adopting a region growing approach, as well.

Symmetry detection based on 2D image features. Sawada and Pizlo [10,17] performed symmetry detection based on a single 2D image of a volumetric shape. First, a polyhedron is recovered from the single 2D image based on a set of constraints including 3D shape symmetry, minimum surface area, maximum 3D compactness and maximum planarity of contours. Then, they directly compared the two halves of the polyhedron to decide its symmetry degree. From a psychological perspective, Zou and Lee [18,19] proposed one method to detect the skewed rotational and mirror symmetry respectively from a CAD line drawing based on a topological analysis of the edge connections.

Other symmetry detection approaches. Martinet et al. [20] proposed a 3D feature named generalized moments for symmetry detection. Rather than directly computing original moments features, they mapped them into another feature space by spherical harmonics transform and then searched for the global symmetry in the new feature space. Xu et al. [21] developed an algorithm to detect partial intrinsic reflectional symmetry based on an intrinsic reflectional symmetry axis transform. After that, a multi-scale partial intrinsic symmetry detection algorithm was proposed in [22]. There are also techniques to detect some other specific symmetries, such as curved symmetry [23] and symmetries of non-rigid models [24,25], as well as symmetry hierarchy of a man-made 3D model [26]. Kim et al. [27] detected global intrinsic symmetries of a 3D model based on Möbius Transformations [28], a stereographic projection approach in geometry. Recently, Wang et al. [29] proposed Spectral Global Intrinsic Symmetry Invariant Functions (GISIFs), which are robust to local topological changes compared to the GISIFs obtained from geodesic distances. Their generality and flexibility outperform the two classical GISIFs: Heat Kernel Signature (HKS) [30] and Wave Kernel Signature (WKS) [31].

All above and existing symmetry detection techniques can be categorized into geometry-based approach. However, distinctively different from them, we adopt a view-based approach to accumulate the geometrical information of many