Shape Analysis and Segmentation for Point Cloud Models

Reed M. Williams & Horea T. Ilieş
reed.williams@engr.uconn.edu

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Recent increased availability of 3D imaging hardware (e.g., Microsoft Kinect) which generate depth maps of observed scenes calls attention to the need for shape analysis techniques which operate on this fundamental model type. Generally, shape analysis of point cloud models seeks to compute compact descriptors of shapes (e.g., shape signatures), measure shape similarity, and perform comparison and shape segmentation of point cloud models.

1 Shape Analysis for Mesh Models

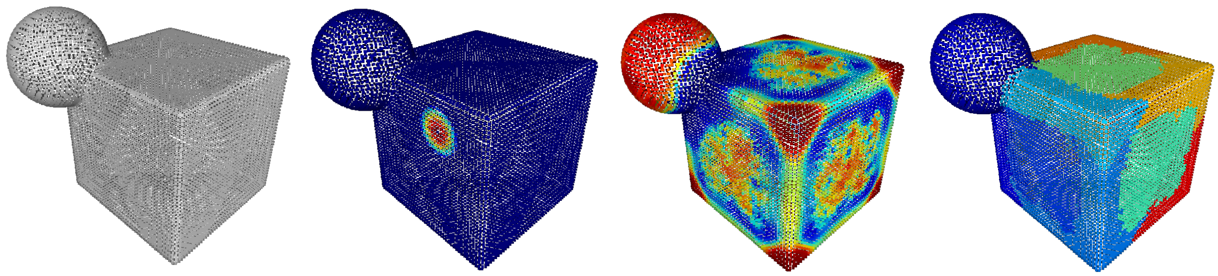
Shape analysis is well-studied on mesh models. The connectivity information provided by the common triangular mesh allows the geometer to easily operate on or reason about the surface under consideration. A recently popular class of method for understanding the shape of a mesh model is called "spectral shape signatures", which are computed from the eigensystem of a fundamental operator on the model. Examples of this kind of shape signature include the Wave Kernel Signature[3], ShapeDNA[1], and Heat Kernel Signature[2].

These signatures provide a similarity measure which enables shape analysts to compare shapes described by mesh models. Additionally, by clustering the values of these signatures either by themselves or by restriction over the mesh model itself, useful segmentations of the shapes under consideration may be discovered. However, creating a mesh from a point cloud is an ill-posed problem and different meshes built from the same point cloud may result in different shape analysis results. As well, obtaining a quality surface mesh from a noisy or even potentially incomplete point cloud may be challenging.

2 Our Recent Work on Point Cloud Models

These techniques are well-developed on mesh models but have seen only occasional ad-hoc use on point cloud models. Our forthcoming paper seeks to innervate this underdeveloped space, providing a convergent symmetric Laplace-Beltrami estimate for point clouds, discussing rigorously the requirements for applying spectral shape signatures on point cloud models, and developing clustering methods which operate without the explicit connectivity information provided by a mesh. We also introduce a method based on the Vietoris-Rips filtration for grouping segmented subshapes on point cloud models.

We demonstrate the use of our methods, providing an example of a unified analysis procedure for shape description, shape similarity, and shape segmentation on general noisy point cloud models like those produced by modern range cameras. This work provides a highly-automatable integrated analysis procedure for comparing and segmenting shapes of engineering objects from point cloud models.



a) Point cloud model b) Local description c) Similarity measure d) Automatic segmentation

Figure 1: These images, generated by our Matlab code, show each of the stages of our point cloud model analysis procedure, from model to SPCL to an HKS vector to one of many possible segmentations.

2.1 Method Overview

Our shape analysis procedure for point cloud model analysis may be divided into three distinct phases of effort:

1. Describe the local neighborhoods on the shape via our Symmetric Point Cloud Laplacian.
2. Define similarity by computing a spectral shape signature.
3. Segment the model by clustering the signature values over the point cloud neighborhoods.

The input to the process is a point cloud, as produced by the output of a range camera. After the analysis steps, useful outputs (vector descriptions of the signature(s) on the model, lists of points belonging to different segmentations, etc.) may be recorded and application-specific tasks performed (models matched and/or classified, model files tagged, CAD files associated, etc.).

We first compute a symmetric and discrete estimate of the Laplace-Beltrami operator. This provides a local description of our input surface at each point in the cloud. We apply spectral shape signatures to point cloud models, leveraging the physical information they carry for shape similarity on this more fundamental model type. Additionally, our method of segmenting point cloud models into regions representing salient features exploits the physicality of spectral shape signatures by clustering signature values over model neighborhoods which we infer from our Laplacian estimate.

This abstract describes our framework for shape analysis of point cloud models for real objects of engineering interest. We develop physics-based shape signatures for use on point cloud models, the key advantage of which is that, by combining our symmetric point cloud Laplace-Beltrami operator with shape signatures and unique clustering techniques derived from topological persistence, we obtain practical shape analysis capabilities that operate directly on point clouds. We demonstrate our methods and show their utility on representative noisy point cloud models. The techniques described herein open the doors to automatic understanding of and reasoning about point clouds that correspond to shapes seen by 3D imaging systems.

References

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