Mesh Segmentation and Labeling:

A Data Driven Approach

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*Abstract*— Mesh labeling for a 3D mesh is a process to assign a part object label for every face of the mesh. This paper details a some of the data driven approaches to automatically segment and label a 3D mesh minimal or no human intervention. These machine learning algorithms during the training phase, require labeled data and a set of descriptive features which can compactly represent mesh. This paper also gives an overview of various algorithms used to effectively generate a robust description of the given 3D mesh.

*Key Words* – 3D Mesh Segmentation, Convolution neural network, 3D Mesh features.

I Introduction

One of the fundamental problems of shape understanding and processing is segmentation of the shape. Many of the problems require labelled segmentations where parts of the mesh is mapped to identified parts. Segmentation of 3D meshes has extensive applications in mesh editing, deformation, modelling, manufacturing, animation and many other fields.

Manually labeling a mesh can be labour and time intensive and this serves a motivation to devise methods to automate the process. One of the approach to solve the problem is utilizing a specially designed geometric feature of a mesh face and using this signature to match faces having similar signature E.g. Using Shape diameter function as a feature to match the faces. However, these types of geometric features usually work only for very limited types of 3D meshes. Alternatively, a data driven approach can be taken, where in a classifier is trained with the help of a labelled meshes to segment the mesh into its constituent segments.

**I.a Overview**

This paper details the key concepts of five papers. A brief overview of the papers are as follows. The paper [Kalogerakis et al] presented data driven supervised learning approach for mesh segmentation by modeling the problem of simultaneous segmentation and labeling as a conditional random field (CRF). It introduces unary and pairwise terms to improve labeling accuracy at the border of mesh segments. However, this paper assumes a fully labeled mesh to train a Joint boost classifier.

Paper two [Lv et al] introduces idea of semi-supervised learning to handle mislabeled and complex meshes. This paper describes a method to robustly handle inconsistently labeled mesh by making use of results from both supervised and unsupervised learning techniques. It achieves this by building a semi-supervised mesh segmentation model using virtual evidence boosting.

Paper three [Benhabiles et al] focuses on producing smooth closed boundaries on the 3D mesh. An adaboost classifier is used to optimize a boundary function during an off-line step. During the on-line step, the edge function is used to select a set of candidate boundary contours, to close them and to optimize them using a snake movement to produce the final segmentation

Previously mentioned techniques take approximately eight hours to train a classifier on meshes of size 20k-30K faces. Paper four [Xie et al] reduces the training time on the sample meshes by factor of two by using extreme learning technique.

Paper five[GUO] outlines a convolution neural network based deep learning architecture for 3D mesh feature generation and mesh labeling. It utilizes the convolution property of CNN to reduce the dimensions of the feature vectors from 600 features to 128 features. This is done by nonlinearly combining and subsampling the features in the CNN architecture.

Finally, this paper provides an overview of set of algorithms to extract the features. Features such as Curvature, Average geodesic distance, Shape diameter function, volumetric shape images and shape context are crucial in classifier training and label prediction process.

**II) Conditional Random field model for segmentation and modelling z**

**II.a) Objective function.**

The objective of mesh labeling can be defined as assigning a label *l ∈ C*, where *C* is a predefined set of possible labels to every face mesh label *i*. Every mesh face *i* can be described using a set of local surface geometry features ( and context based features such as curvature, shape diameter and shape context. Moreover, in-order to capture the relationship between adjacent features a pairwise term is also introduced. This include features like dihedral angle between pair of mesh faces.

Computing all mesh labels involves minimizing the following objective function**.**

Here denotes the unary term for a mesh face i having the features and label . Similarly denotes the pairwise term for face pair of i,j and labels . Additionally, the terms are weighted by the area of the face and edge length .

In CRF, probability of labeling a mesh label is conditionally defined as:

E denotes the objective function and Z is the normalizing function. The optimized solution to the objective function is evaluated using a joint boost classifier.

**II.b) Unary term.**

Unary termevaluates a joint boost classifier, it evaluates probability of a label depending on the feature vector as an input. The energy of the unary term is equal to negative log of the probability.

Unary classifier alone gives good results in part interiors but performs poorly near the boundaries.

**II.c) Pairwise term.**

Pairwise term is added to improve segmentation at the boundaries i.e. it penalizes neighbouring faces being assigned different labels c. It consists of label compatibility term L weighted by geometry dependent term G.

The consistency between two adjacent labels is measured by a label-compatibility term This term is modelled as a matrix of penalties for each possible pair of labels, where in different pairs of labels to incur different penalties.

Geometry dependent term evaluates a classifier as a measure of likelihood of difference in label as a function of geometry.

evaluates the probability of two adjacent faces having distinct labels. The second term penalizes boundaries between faces with high exterior dihedral angle ***ω***, penalty ***μ*** *is* addedon boundary length to prevent jaggy boundaries. A small constant is added to avoid computing log 0.



*Fig A Fig B*

*Fig A only uses unary term for segmentation, Fig B uses both unary and pairwise terms for segmentation.*

**II.d) Joint Boost classifier.**

A joint boost classifier is used to evaluate both the unary term and geometry dependent term of pairwise term. A joint boost classifier consist of decision stumps which outputs a score for class l, given a feature vector z.

The probability of the class label is computing the soft-max transformation on summation on the decision stump values.

Further, in order to reduce the error between the prediction and ground truth, a Segmented weighed error is introduced. Which is weighed based on is the total area of all the faces segments having label

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