Research Statement

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My main research interests are in the field of geometric modelling for computer graphics and scientific visualization. Computer graphics is a growing field with many applications: mechanical design, medical imaging, scientific simulation, virtual reality, entertainment, and digital visual arts (e.g., computer-generated painting). Many of these applications make use of 3D models, such as the digital vehicle models that are used in the automobile industries, and the computer-generated dinosaurs in the movie Jurassic Park. There are two research issues that I consider fundamental to future geometric modelling. First, shape understanding is key to automating geometric processing techniques and improving the quality of these methods. For instance, many existing techniques are well-tuned for recognizing local features, such as bumps and sharp edges. Perhaps in the future we can develop automatic techniques that can recognize and match global features, e.g., facial features and limbs between two digitized human models. Second, many graphics applications deal with high-dimensional datasets that are geometric in nature. In my opinion, however, this aspect deserves more attention. For instance, the existing geometric techniques for 3D surfaces might one day find their use in processing higher-dimensional datasets, such as tensor fields, or configuration spaces for human character animation. I will discuss both shaping analysis and geometric processing for higher-dimensional datasets in the following sections.

Scientific visualization is concerned with creating image representations of geometric datasets to help people understand scientific and medical data, such as flow visualization and medical imaging. There are two key issues: the efficiency of the representations and the interactivity of display. I am interested in both issues from several angles. First, surface visibility information can be used to reduce the amount of data that need to be processed, therefore, increasing the interactivity. Second, topological analysis of datasets often result in more efficient representations of datasets, e.g., vector field skeleton for vector field visualization. I will come back to these topics later.

I hope that it is understood that this is not an exhaustive list of my future research directions. I expect to develop new ideas through collaboration with my future colleagues, students, and other collaborators.

1 Visibility

Visibility refers to determining which parts of a surface are visible from a given viewpoint. A relatively new research direction is to analyze the surface visibility due to self-occlusion and make use of this information for interactive rendering of large models. Many complex models from CAD systems and medical imaging have large portions of the model that are interior or in hard-to-see regions. For opaque style rendering, these regions contribute little to the final images and do not need to be processed. In my previous work with Greg Turk [1], I defined a view-independent surface visibility measure and used it for mesh simplification (figure 1). Visibility-guided simplification can maintain the same visual appearance as traditional geometric-based simplification techniques at a lower polygon count. In the future, I plan to make continuous efforts to searching for visibility calculation techniques that can handle more complex models. I also plan to investigate how to use surface visibility for other applications, such as morphing and texture synthesis. Texture synthesis refers to creating patterns on geometric objects, often based on a given example image.
Figure 1: In (a), surface visibility measure [1] of the dragon model is colored coded (from white, red, yellow, to green, the visibility increases). In (b), a motor model (middle) is simplified to the same polygon count either using visibility information (right) [1] and without using it (left). Compare the shape of the trunk and the attached mechanical parts.

Another visibility-related problem is image-based surface coverage, i.e., to determine the minimal number of viewpoints that collectively cover a given surface. Solving this problem will benefit image-based rendering, in which a surface is represented as a collection of images. My preliminary research suggests that surface visibility is useful for solving the surface coverage problem. I plan to further investigate on the issue as well as on how image-based rendering could benefit from the surface coverage.

2 Parameterization

Surface parameterization refers to segmenting a 3D surface into one or more patches and unfolding these patches onto a plane. This process is necessary for many graphics applications in which surface properties (colors, normals) are sampled and stored in a texture map for subsequent interactive rendering. Unfolding curved patches often causes stretch and uneven sampling rates across the surface. In my previous work with Konstantin Mischaikow and Greg Turk, I proposed an automatic surface parameterization technique which borrows results from computational topology to divide a curved surface into a collection of patches, each of which can be unfolded with relatively little stretch. The key idea is to analyze some surface distance-based functions for detecting large protrusions in the surface and then to segment the surface into a collection of simple shapes: cylinders, cones, spheres, and planes (figure 2). I plan to investigate other types of parameterization techniques, in which the surface is parameterized based on a canonical domain, such as a sphere or a torus, therefore removing the need for surface segmentation.

3 Shape Analysis

Many graphics applications can benefit from feature analysis of the underlying surfaces. I have discussed in the preceding sections two such examples, namely, hard-to-see regions for visibility-guided simplification and protrusions for surface parameterization. Different applications often have different definitions for the term feature. I am interested in finding shape descriptors that can be used to reveal the locations of features for various other graphics applications, such as remeshing and morphing. Remeshing refers to improving mesh quality by redistributing surface samples (vertices) and connectivity (edges). There are two sets of available mathematical techniques that may serve the purpose: differential geometry and algebraic topology. Classical differential geometry assumes
4 Vector Fields and Tensor Fields

Vector fields and tensor fields are very common in scientific domains, for instance, aerodynamics, fluid simulation, and medical imaging. Effective visualization of vector fields and tensor fields will help people better understand their datasets. There are two important research topics that I think will receive increasing attention: analysis and visualization of vector fields that are defined on curved surfaces, and vector fields synthesis. I am currently investigating the problem of allowing users to create synthetic vector fields on 3D surfaces for texture synthesis and non-photorealistic rendering. Once completed, I plan to look at the following problems: controlling fluid simulation through vector field design, and tensor field synthesis. Solving these problems will benefit both the special effect industries and the scientific visualization community. These tools may also be useful for teaching purposes.

5 Geometric Processing of Higher Dimensional Datasets

Most existing geometric modelling techniques focus on 3D surfaces, i.e., two-dimensional manifolds. A natural question to ask is whether these methods can be extended to handle higher-dimensional datasets, such as deformable surfaces, configuration spaces for computer animation, and vector fields on surfaces. While there are many excellent techniques that handle these datasets in their respective fields, many basic questions remain, e.g., how to effectively represent and visualize them. Geometric processing of higher dimensional datasets is a new and important research area. I think future researches in this area will benefit both the geometric modelling field as well as other graphics areas in which higher dimensional datasets are present. I plan to start with the problem of feature analysis of three-dimensional manifolds (from deformable surfaces) to gain insights on the fundamental issues as well as efficient data representations and geometric processing techniques.

References