Tracking Shape Change using a 3D Skeleton Hierarchy[1]

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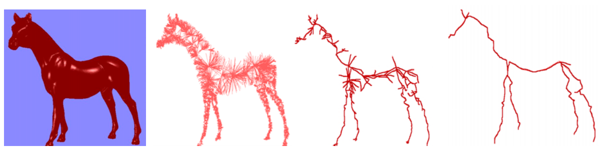
I. INTRODUCTION

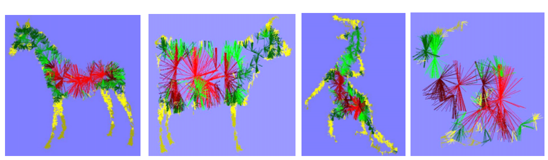
Many skeletonization algorithms have been discussed in the literature, including the medial axis and thinning approaches [BO04][SSZ01] [PSB*01], but these algorithms may not generate stable skeletons. Based on the data processed, these techniques can be grouped under two categories: volume technique or mesh technique. Medical applications often involve volume data, *e.g.* DICOM, and thus volume techniques are commonly used. We propose a mesh technique, which is stable, to generate a hierarchy of skeletons from dense to coarse. An application can choose an appropriate level depending on the detail required. Our approach can also be extended to handle volume data. Figure 1 (b) to (d) shows three levels of detail of a horse object (Figure 1(a)) from dense to coarse.



(a) (b) (c) (d)

Figure 1: *A horse object: (a) original model, (b) to (d) three levels of detail from dense to coarse.*

II. STABLE SKELETONGENERATION



(a) (b) (c) (d)

Figure 2: *Skeleton: (a) horse, (b) cow, (c) dragon and (d) bunny. Different colors are used on the skeleton for easy visualization of the parent-child hierarchy.*

Our technique, inspired by the Sphere Sampling approach [YBM04], uses overlapping maximal spheres to cover the free space inside the 3D object. The following steps are applied:

1) Starting from a user-defined face on the surface, compute its normal and project the reverse normal inside the object on the opposite surface.
2) Fit a maximal sphere along the path inside the object. Record the sphere center as a skeleton point.
3) A fixed number of sample points (children) are placed evenly on the circumference starting from a predefined orientation, based on a user-defined separation angle θ [FLD03]. For each child, a maximal sphere is drawn. If the sphere touches at least two vertices on the surface, the child becomes a skeleton point and is linked to the center of the parent sphere. Also, a sphere is valid only if its radius is larger than a predefined threshold *R*.
4) The valid spheres are pushed into a priority queue in descending radius order.
5) A sphere is popped from the queue and Steps (3) to (5) are repeated until the queue is empty.

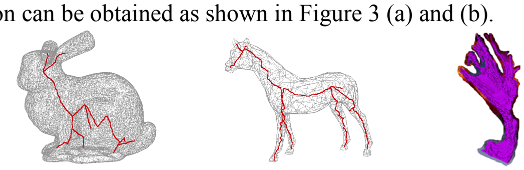
Figure 2 (a) to (d) shows the skeletons of a horse, a cow, a dragon and a bunny models respectively. Different colors are used for easy visualization of the parent-child hierarchy.

Many significant features are built into our algorithm in order to generate a stable skeleton:

a) The mid-point of two children with equal and opposite vectors perpendicular to the surfaces is not taken as a skeleton point in [YBM04] causing valid points missing from the final skeleton. The mid-point is a skeleton point in our approach.
b) The original sphere sampling approach starts with a random point inside the object as the center of a sphere with radius larger than a predefined threshold. Another random point is selected if the sphere cannot fit inside the object. The skeleton stability is not guaranteed due to the random selection. We start from a user-defined location and project the face normal to the opposite surface of the object. If the diameter of a sphere can fit into the space in between, the sphere is valid, otherwise the sphere is adjusted adaptively to fit into that location, so that a stable skeleton can be generated.

III. SKELETON HIERARCHY AND MAIN FEATURES

Note that the generated skeleton is composed of line segments of decreasing lengths. It is important to start from the major axis of the object and place maximal spheres along the major axis so that a skeleton backbone can be constructed from which minor axes of the object can be located. A skeleton hierarchy can be compared with the level-of-detail (LOD) in mesh simplification. By removing shorter line segments, the main features of a skeleton can be obtained as shown in Figure 3 (a) and (b).



(a) (b) (c)

Figure 3: *(a) A bunny mesh and (b) a horse mesh with the main features of their skeleton. (c) 3D model of airway artillery.*

The proposed algorithm is very effective in penetrating spike structures on the mesh surface. The depth of the skeleton hierarchy is controlled by a threshold value *R* discussed in Step (3) above. An application can be to trace vessels and airway artillery in the lung (Figure 3 (c)). A surgeon may want to monitor recovery after an airway operation. CT scans are first taken to compose a 3D model. However, volume data, *e.g.* DICOM, are often used in medical applications. In this case, the surface points can be extracted from the volume data and triangulated to generate a 3D mesh. The appropriate level of the hierarchy can be examined depending on the detail required. The radii of the spheres pushed into the priority queue can be used to track the relative size and length of each segment of the skeleton.

IV. LIMITATION AND FUTURE WORK

In the current implementation, a user-specified location is used to define the first valid sphere, in order to generate a stable skeleton. In future work, we will look into automatically locating the major axis of the object and placing the backbone of the skeleton along the major axis. Also, we will extract skeletons from different level-of-details of a mesh model, and evaluate the performance of different simplification algorithms.

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