

Boundary Representation of Anatomical Features

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Introduction

In medical applications, the characterization of shape is traditionally based on volume schema. The fundamental units for calculations and rendering are voxels, which indeed proved very practical, specially regarding mass properties such as mass, volume, area, inertia, etc. From the field of Geometric and Solid Modelling, such representation schema are called spatial occupancy or exhaustive enumeration schema. Typical variations of them are Quadtree (2D) and Octree (3D) structures, which limit used space when compared to general exhaustive enumeration techniques. However, they are still data intensive when compared to boundary representation (b-rep) schema. Although in the past exhaustive enumeration served the domain of medical applications sufficiently, the current needs of the fields require a leaner and more engineering-oriented structure.

Applications in the near future imply the simulation and emulation of anatomic parts from the bio-

mechanics, fluid dynamics and kinematic points of view. These applications require topological information on the region of interest (which exhaustive enumeration does not provide). Meanwhile, these questions have been answered by boundary representations. It is therefore advantageous to apply such knowledge in the medical field. In particular, the purpose of this article is to present the application of surface reconstruction techniques in medical examples traditionally dealt with by voxel-based representations.

Material and Method

Surface reconstruction from planar samples has traditionally presented two main algorithmic directions: (i) local geometric-proximity and (ii) topological evolution.

Algorithms based on local geometric proximity connect filled regions of consecutive slices with tetrahedra. Adjacent tetrahedra are merged into a b-rep, until portions of the manifold M_{i+1} are distilled. The process is repeated

German Abstract

In Simulationen für Bestrahlungstherapieplanung und andere medizinischen und bioingenieurwissenschaftlichen Anwendungen hat man traditionellerweise die anatomischen Eigenschaften mittels volumenbasierten Techniken angezeigt. Trotzdem, während der Bedarf an Behandlung, Organsimulation und Erzeugung von Prothese präziser wird, reicht es nicht die Menge und die Position von solchen Features zu wissen, sondern auch Detailstufen, die vergleichbar sind zu denjenigen, die man für ingenieurwissenschaftliche Techniken verwendet (finite element analysis, rapid prototyping, Herstellung, usw.). Dieser Artikel präsentiert Bemühungen und Ergebnisse in der Anwendung von computerunterstützten geometrischen Algorithmen auf biomedizinischen Applikationen, wobei diese Algorithmen sich ursprünglich auf die Begrenzung von Formen gerichtet haben, die auf Planarmustern von anatomischen Zielregionen basierten.

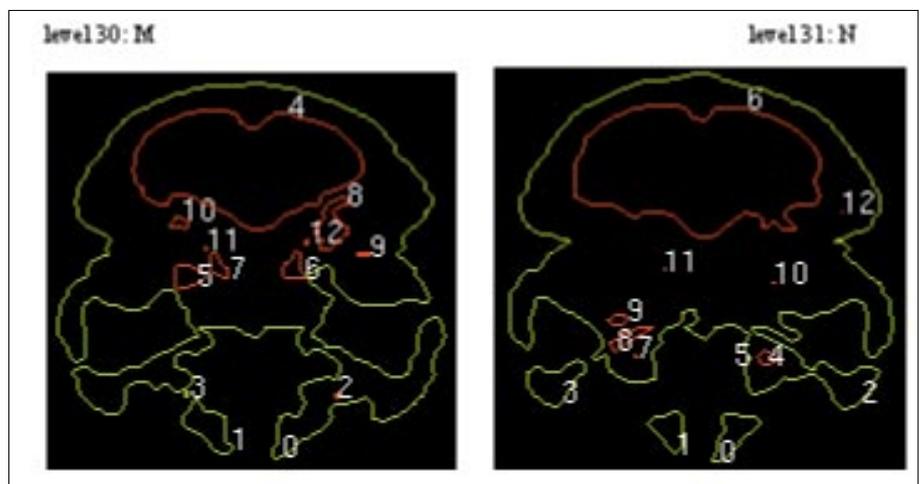


Figure 1: Consecutive slices of Ape Skull data set. Topology evolution and partial result of the contour matching algorithms

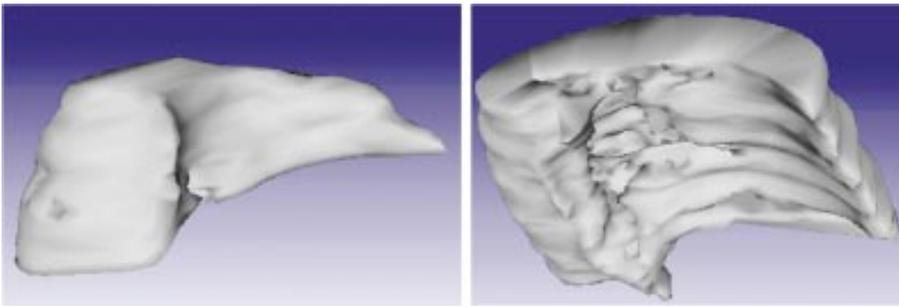


Figure 2: Reconstruction from Lungs data set, with topological interruption and surface waves due to patient breathing

for all the slices. As mentioned above, this approach is mostly guided by geometry, and therefore, regions that are geometrically proximal but topologically disjoint may mislead the algorithm. In these cases, the algorithm builds a manifold that is topologically correct but does not correspond to the actual object. These are extremely fast algorithms.

In contrast, topology-evolution algorithms explain, with the help of Morse theory, the topological events that produce changes in the traces of the manifold adjacent slices, therefore determining the topology of $M_{i,i+1}$. Morse theory demonstrates that there are only three possible types of events that produce such an evolution. The events are the addition of three simple »handles« to $M_{i,i}$:

- (i) cup or 0-handle,
- (ii) saddle or 1-handle, and
- (iii) inverted cup or 2-handle.

These elements affect the number of contours in the slice. Since there can be several simultaneous handle additions at once, topology must be reinforced by geometrical



Figure 4: Reconstruction from noise-contaminated Vertebra and Disk data set

considerations, establishing the changes and on which contours they were applied. In literature, this step appears to be only fragmentarily solved. Finally, the skin should be materialized, when the contours involved in handle addition operations have been identified. This part is missing in literature of topology-based surface reconstruction.

The approach presented here seeks to (a) locate the topological transitions between one slice and the next, and (b) realize the skin, by using local geometry based methods. Since the topology-based approach precludes the bias due to local geometric reasoning, and the latter has advantages in actually building the skin, the two approaches must be combined to achieve both topological correctness and surface construction.

Results

Figure 1 shows slices i and $i+1$ in a sampling from an ape skull. The fragmentation and merging of contours dramatically changes the topology of the resulting manifold. The contour-matching algorithm successfully replays the topological evolution of the sampling, based on 2D shape similarity between sets of contours. Mapping groups of p to q contours are created. Each group represents one connected component of the $M_{i,i+1}$ manifold (called $p:q$ loft) with a p -component boundary in level i and q -component boundary in level $i+1$.

The construction of each predetermined $p:q$ loft is then made by a constrained version of the NUAGES algorithm by Boissonat & Geiger (figure 3), that only syn-

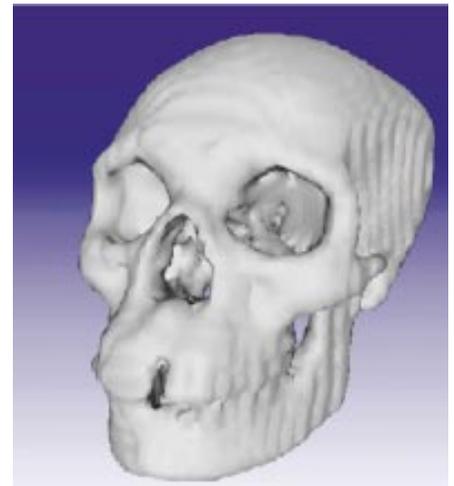


Figure 3: Representation from Ape Skull data set

thesises connected manifolds. This restriction avoids spurious constructions caused when only local geometric proximity is considered as criterion.

Figure 2 shows one example in which the NUAGES algorithm is applied to a data set corresponding to a lung. Note the ondulation of the data caused by the breathing of the patient. Figure 4 shows the results on vertebrae scans.

Future Developments

At the present stage, the boundary representation or surface reconstruction module is used only as a graphical feature. Future advances include to fully use it for the calculation of mass properties of an anatomical entity and features of geometry replication and physical simulation. Also, data sets which present deterministic noise (for example patient breathing) or stochastic noise (sampling error) must be addressed.

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