Fast Visualization of Plane-Like Structures in Voxel Data

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Overview

- Image data
  - Huge
  - Intricate structure
- Skeletonization
  - Topological thinning
  - Measures based on distance map
- Rendering
  - Triangulation of voxel surface
  - Few triangles compared to isosurface
Topological Thinning

- Check local neighborhood
- Keep non-simple points

[Kong, Rosenfeld 89], [Lam, Lee, Suen 92], [Bertrand 96]
Distance Ordered Thinning

- Calculate distance map
- Queue for every distance
- Process starting with low distance values
- Remove simple points

- Optional: locally detect endpoints or edges

[Pudney 98]
Skeletons by Thinning
Summary Thinning

- Suitable to detect centerlines
- Guarantees topology

- Do not detect endpoints locally
  - Very unstable under noise
Distance Map Based Measures

- Parameter-Controlled Volume Thinning
  [Gagvani, Silver 99]
  - Local neighborhood
  - Mean of neighbors’ distance transform (MNT)

- Euclidian Skeletons
  [Malandain, Fernández-Vidal 98]
  - Distance/Angle between nearest boundary points
  - Topological reconstruction

- Hierachic Voronoi Skeletons
  [Ogniewicz, Kübler 95]
  - Geodesic distance along the boundary (2D)
Global Measure

- Maximum of geodesic distance $d$ of nearest boundary voxels
  - Propagation to calculate DM and boundary voxels
  - Propagation in boundary to calc. $d$

- Threshold controls sensitivity to noise and features

[Costa 99], [Verwer et al. 89]
Skeleton by Global Measure
Reconstructing Topology

- Threshold might change topology
- Tag skeleton voxels
- Remove all non-simple points by thinning
- Result is homotopic to original object
- Plane-like parts as surface
  - Vertices at center of voxels
  - Open surface, not an isosurface
- Rod-like parts as lines
Triangulation

- Solve in unit lattice cell
  - Construct connections
  - Construct triangles
  - Avoid ambiguities
Connection only possible if voxels in same cell

Construct edges only if needed
  - Order: 6-, 18-, 26-connections
  - In standard cell:
    • Three 6-conn.
    • Six 18-conn.
    • Four 26-conn.

Continuous transitions guaranteed
  - 6-conn fully determined by adjacent voxels which are shared by all cells containing the edge
  - 18-conn fully determined by voxels on one face which are shared by all cells containing the face
Triangulation, Triangles

- Construct connections in full cell
- Detect all smallest loops and triangulate
  - Triangles only in reduced cell
  - No 3-loops on face
  - 4-loops allowed to create triangles on faces of standard cell
  - >4-loops not allowed to create triangles on faces of cell. Add center of gravity, if needed
- Heuristic avoids coplanar triangles except for one case → paper
Triangulation, Remarks

- Cell configurations in lookup table
- Unused connections can be rendered as lines
- Surface simplification works fine on skeleton
Results
Results, Bone Biopsy
Results, Bone Biopsy

- Size 350×285×730, 5% object
- Skeleton has 16% of triangles of isosurface (depends on structure)
Summary, Future Work

- Measure to detect plane-skeletons
- Topological reconstruction
- Heuristic to create open triangle-surface from voxel surface
- Deal with bad configurations
- Remove asymmetry in triangulation
- Design unified datastructure for surfaces and lines to preserve connectivity during simplification
- Include volumetric parts
Demo: Thu 3 pm, Fri 10 am
Visualization framework: Amira (amira.zib.de, @TGS booth)
Imagedata: W. Gowin, M. Giehl (Benjamin Franklin Hospital, FU Berlin)
Discussions: Malte Westerhoff
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Contribution

- Combination of skeletonization approaches
  - Measure to detect plane-like parts based on distance map
  - Thinning algorithm to reconstruct topology
- Triangulation scheme
  - Heuristic to generate an open triangulated surface from a voxel surface
Skeletonization

- Basic properties
  - Homotopy (keep topology of original object)
  - Invariance under transformations
  - Reconstructability
  - Thin set

- Approaches
  - Simulation of grassfire
  - Analytic computation of the medial axis
  - Topological thinning
  - Extraction from a distance map

[Blum 67]
Skeletonization Algorithms

- Simulation of grassfire
- Analytic computation of the medial axis
- Topological thinning
- Extraction from a distance map
- Last two relevant for voxel objects
Skeletons by Thinning
Influence of Noise on Thinning
Global Measures

- Mean of neighbors’ distance transform (MNT)
- Thinness parameter (TP)
- Compare DT with MNT locally

FIG. 5. A maple leaf and its skeletons at various thinness values. Thinness is increasing from left to right.

FIG. 4. Mean neighbor distance transform (MNT) and its relation to the maximum thinness (TP). The dark voxel will be included in the skeleton if TP is less than DT-MNT.

[Gagvani, Silver]
Global Measures

- Distance between nearest boundary points
- Angle between nearest boundary points
- Detection of spurious branches

Fig. 6. Different kinds of skeleton branch.

[Malandain, Fernández-Vidal]
Global Measures

- Voronoi diagrams (2D)
- Geodesic distance along the boundary

Fig. 3. 3-D View of Potential Residual. (a) The DVMA after regularization with threshold $T = 0.0$. The selection of a useful threshold will be explained later. (b) The 3-dimensional plot of the potential residual $\Delta R_P$.

[Ogniewicz, Kübler]
Global Measure

- Maximum of geodesic distance $d$ of nearest boundary voxels
  - Propagation to calculate DM and boundary voxels
  - Propagation in boundary to calc. $d$

- Threshold controls sensitivity to noise and features

[Costa 99], [Verwer et al. 89]
Reconstructing Topology
Skeleton by Global Measure
Global Measure and Noise
Triangulation

- Solve problem for every unit lattice cell
- Reduced cell
  - Represented by corner voxel
  - Including edges and faces adjacent to representing voxel
  - Excluding other faces, edges and corners
  - Divide space univocally
  - Fill up whole space
- Full cell
  - Including all edges and faces
Triang., Special Cases

Avoid double triangles

Standard case

Nicer triangulation
- Cell configurations in lookup table
- Unused connections can be rendered as lines
- Surface simplification works fine on skeleton
- Bad configurations
Results