Fast Visualization of Plane-Like Structures in Voxel Data

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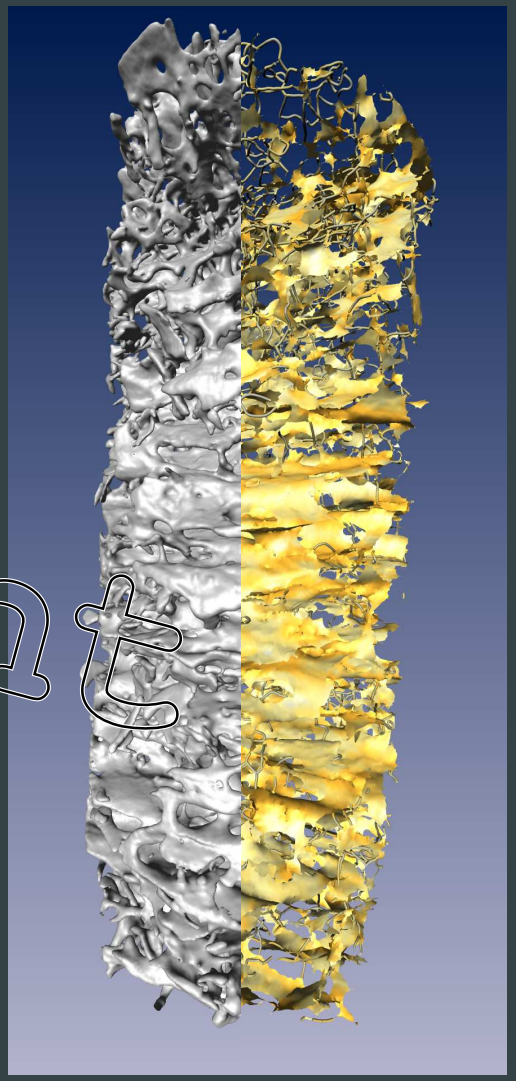
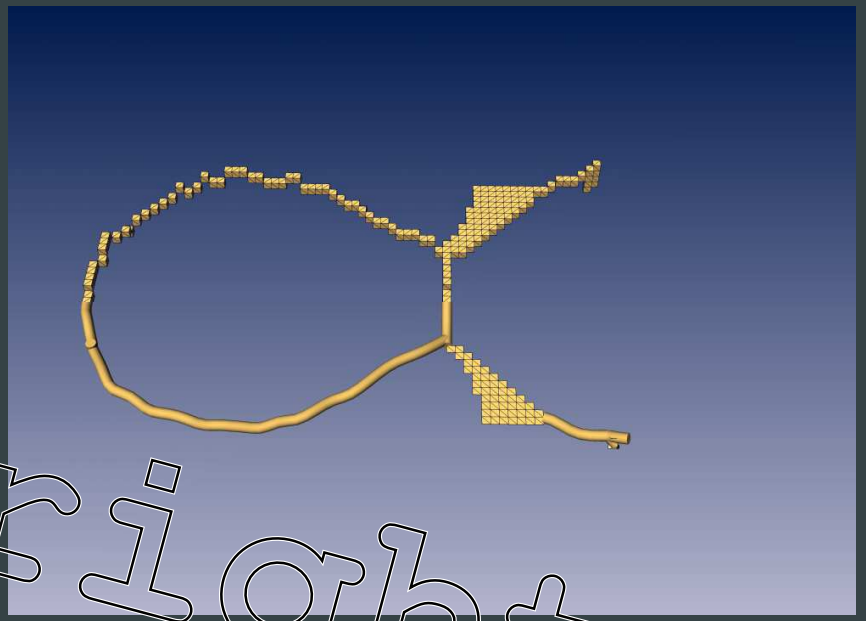
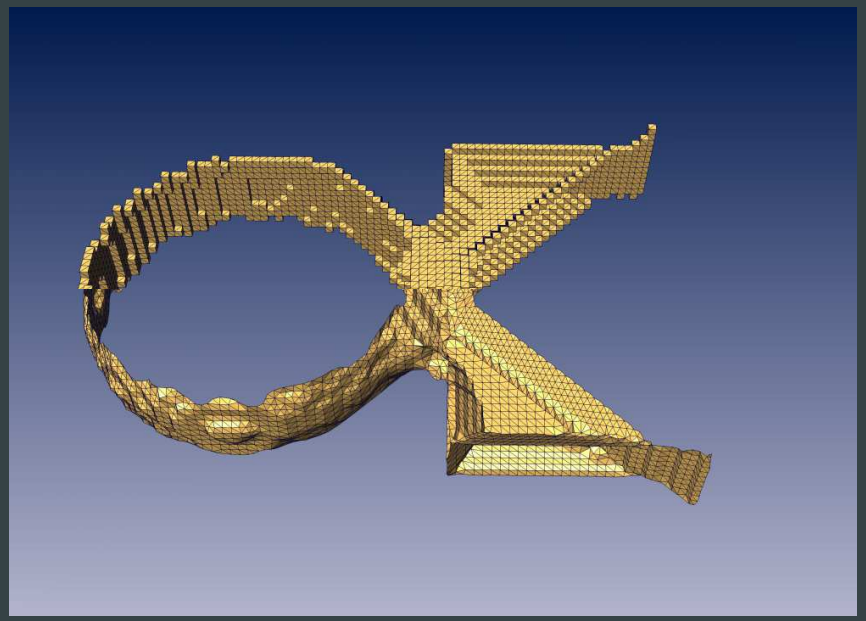
Overview

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



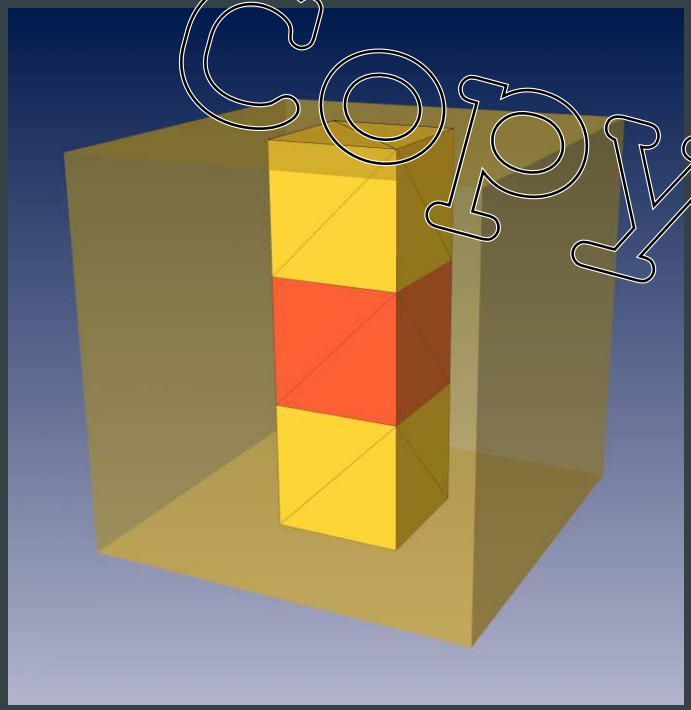
Overview

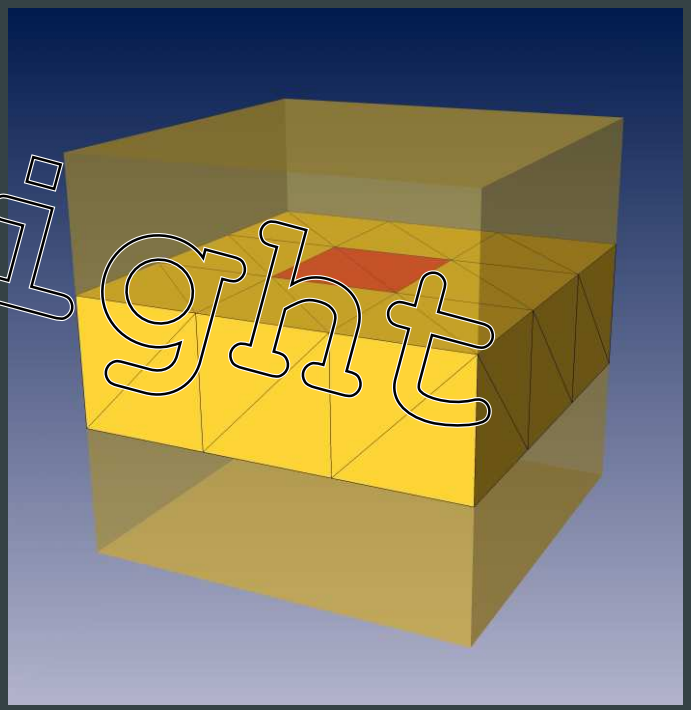




Topological Thinning

- Check local neighborhood
- Keep non-simple points



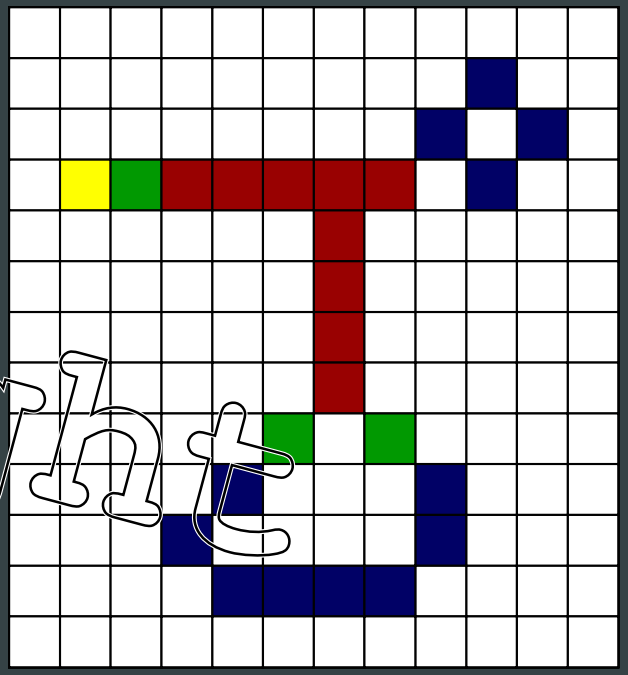


[Kong, Rosenfeld 89], [Lam, Lee, Suen 92], [Bertrand 96]

Distance Ordered Thinning

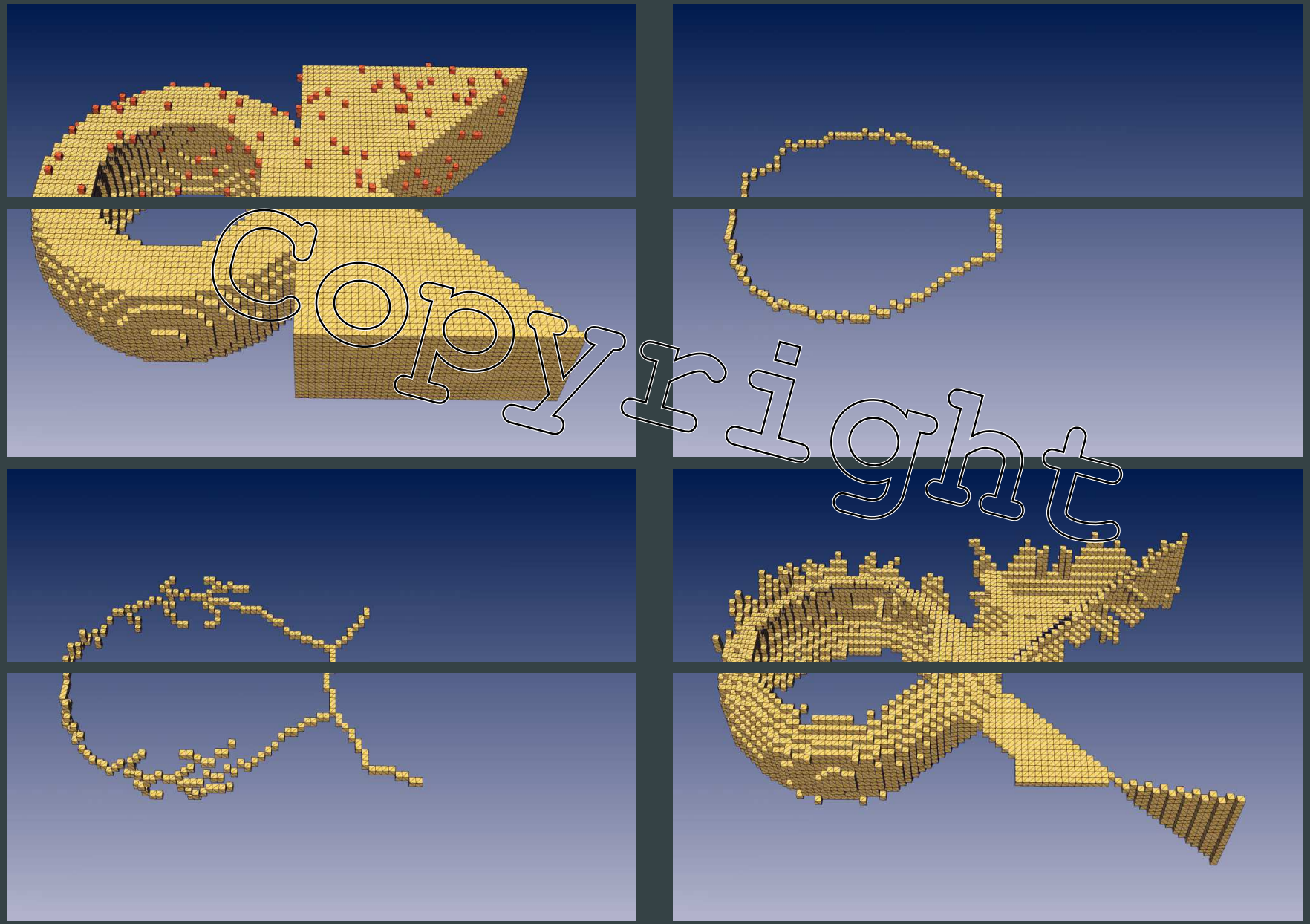
- Calculate distance map
- Queue for every distance
- Process starting with low distance values
- Remove simple points

- Optional: locally detect endpoints or edges



[Pudney 98]

Skeletons by Thinning



Summary Thinning

- Suitable to detect centerlines
- Guarantees topology

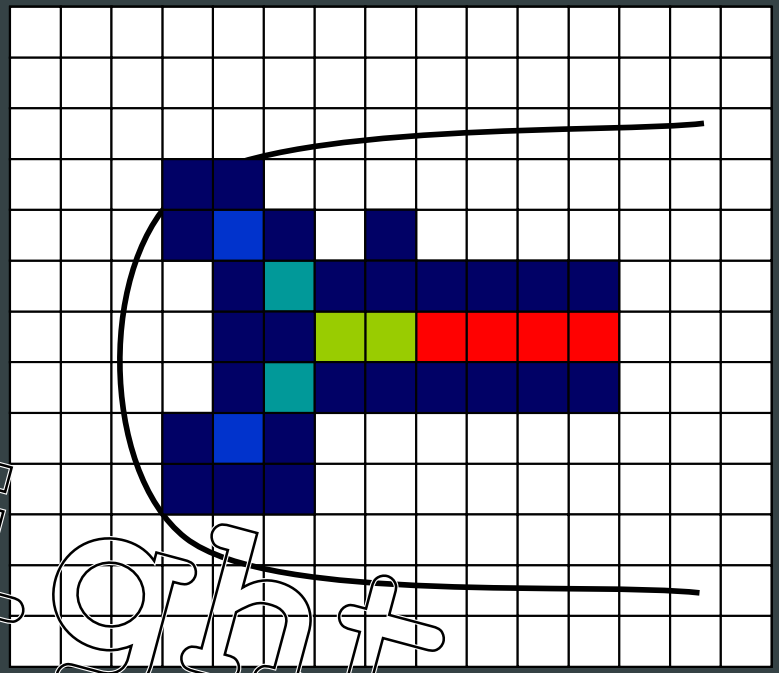
- Do not detect endpoints locally
  - Very unstable under noise

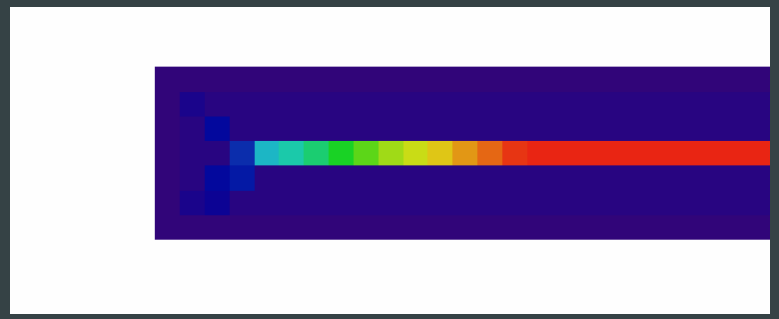
Distance Map Based Measures

- 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

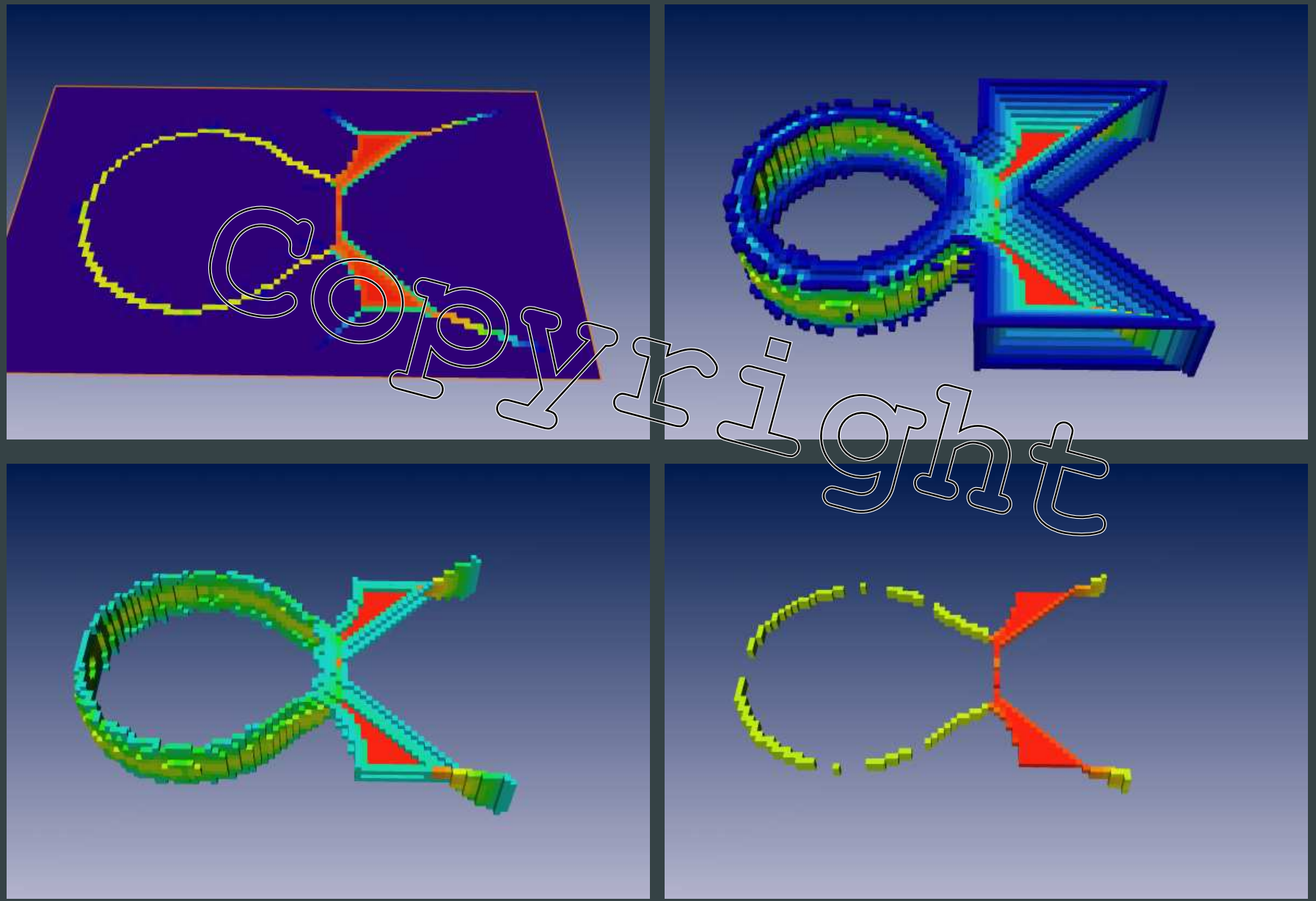
- Maximum of geodesic distance *d* of nearest boundary voxels
  - Propagation to calculate DM and boundary voxels
  - Propagation in boundary to calc. *d*
- Threshold controls sensitivity to noise and features



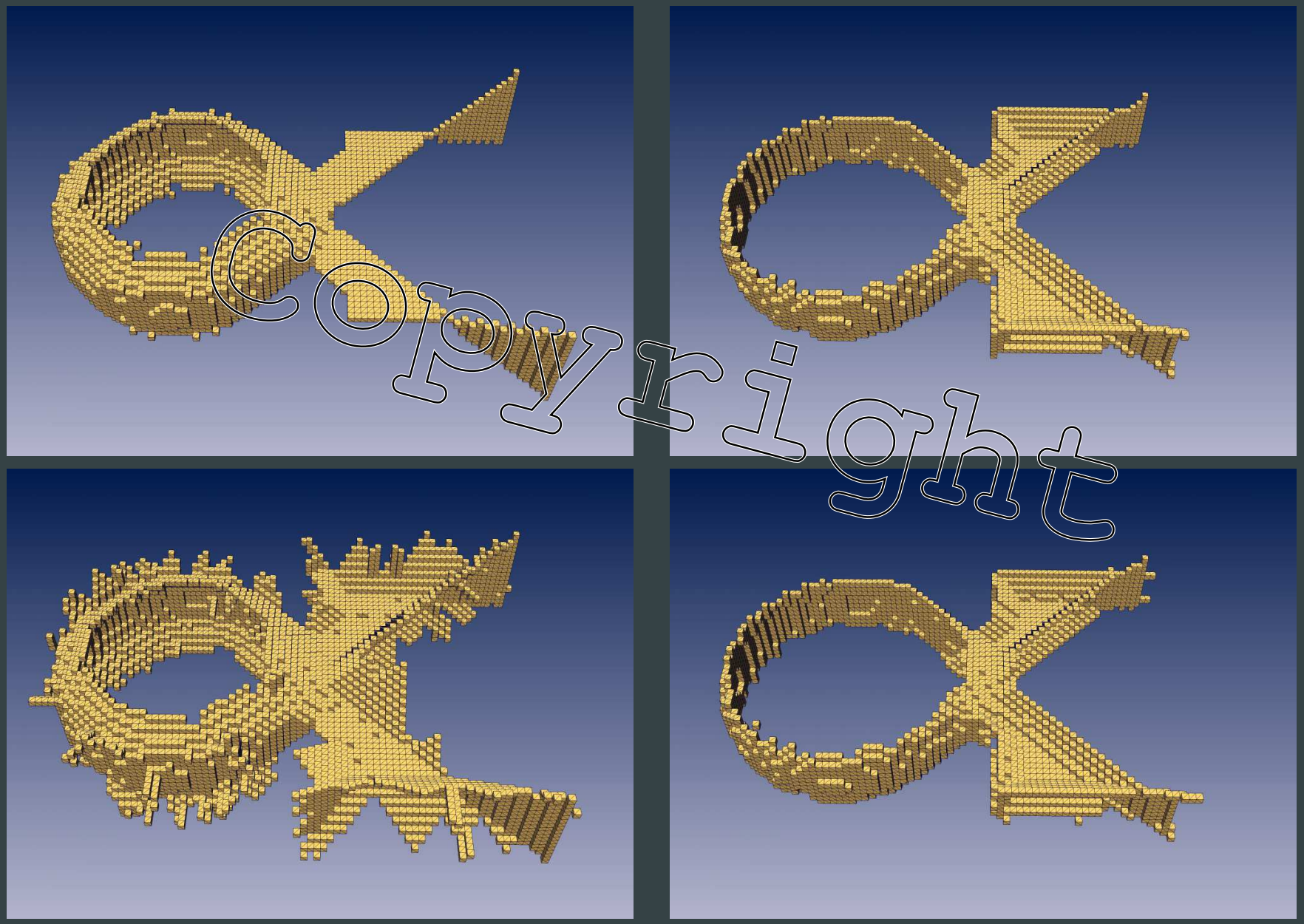


[Costa 99], [Verwer et al. 89]

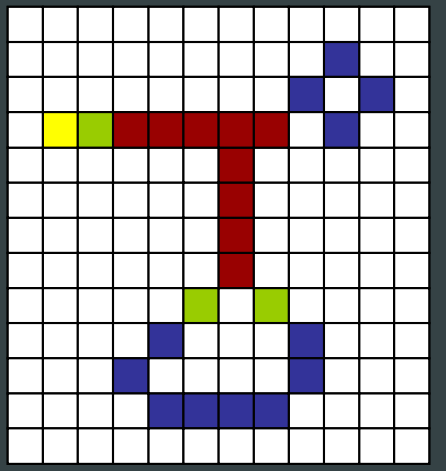
Global Measure



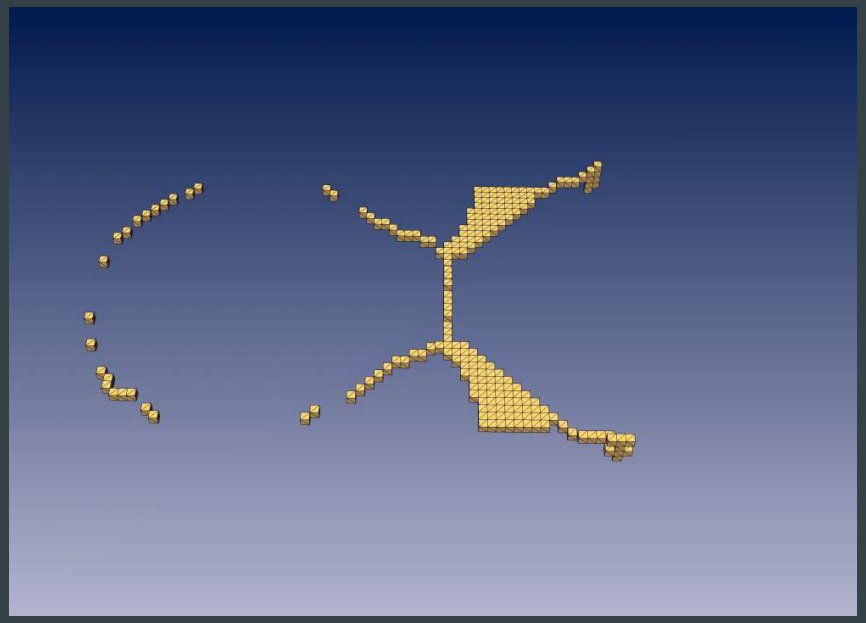
Skeleton by Global Measure

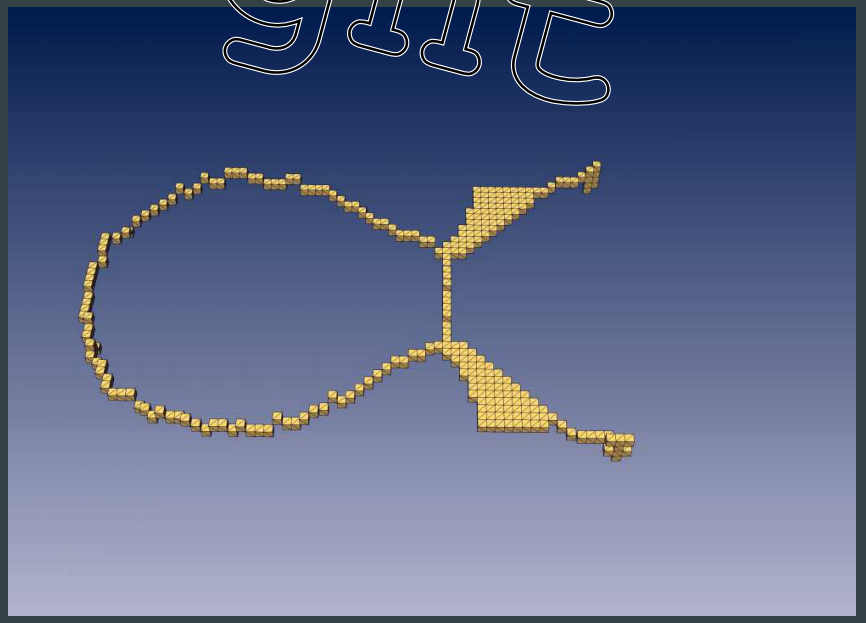


Reconstructing Topology



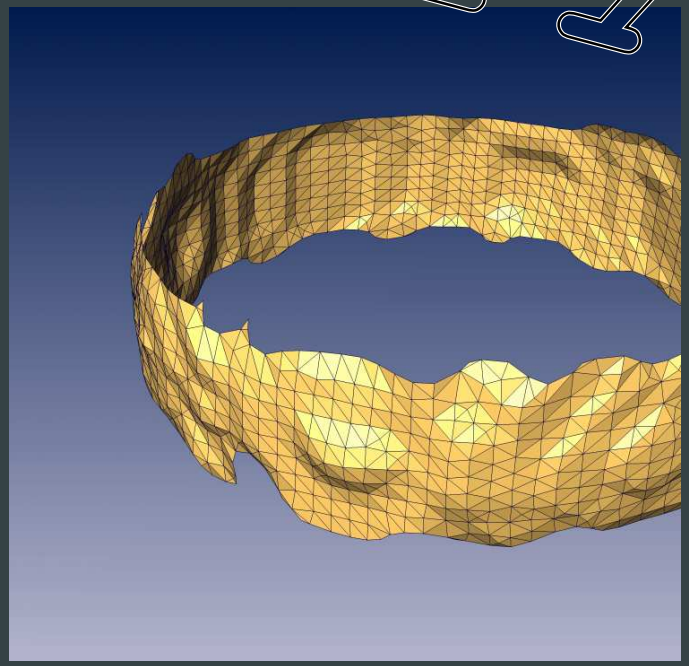
- Threshold might change topology
- Tag skeleton voxels
- Remove all non-simple points by thinning
- Result is homotopic to orginal object





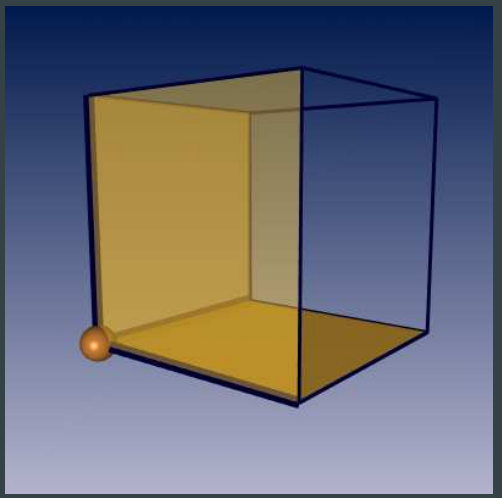
Rendering

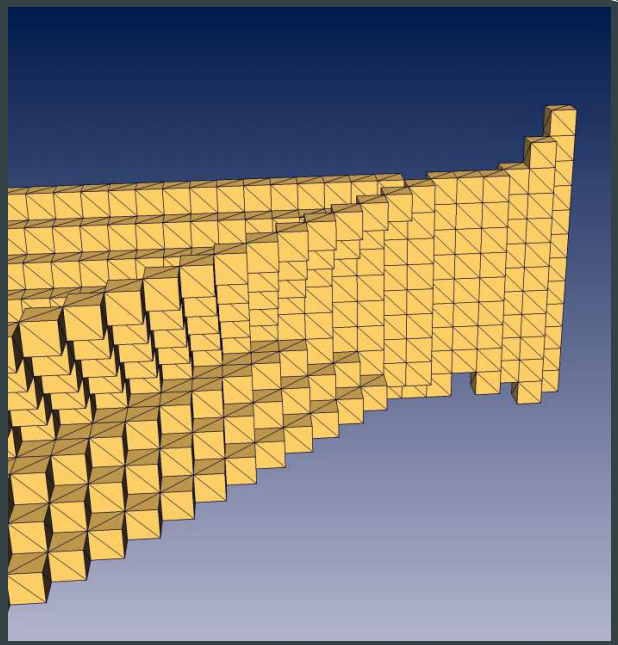
- Plane-like parts as surface
  - Vertices at center of voxels
  - Open surface, not an isosurface
- Rod-like parts as lines

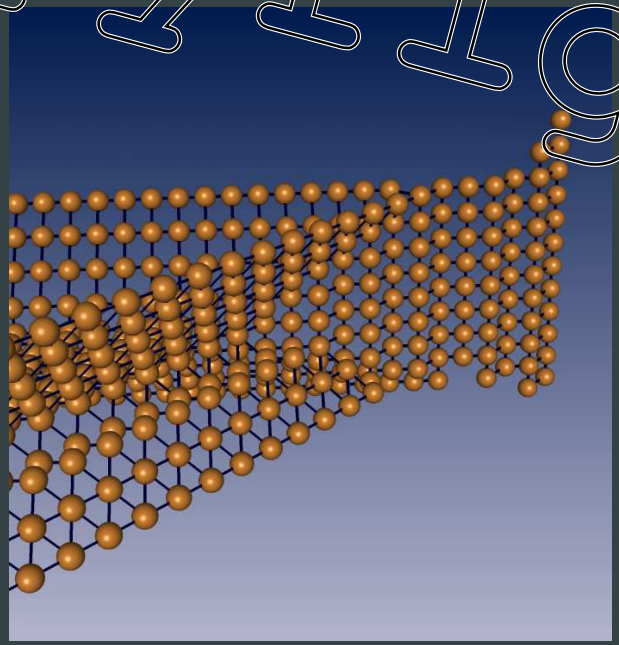


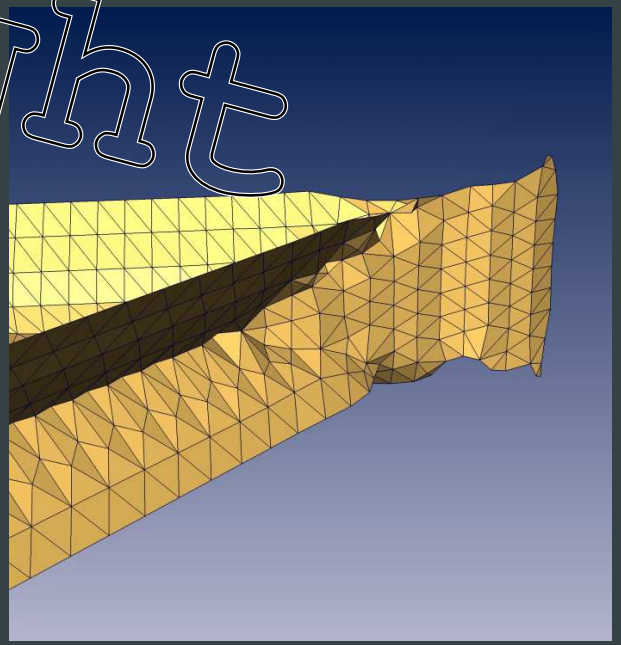
Triangulation

- Solve in unit lattice cell
  - Construct connections
  - Construct triangles
  - Avoid ambiguities



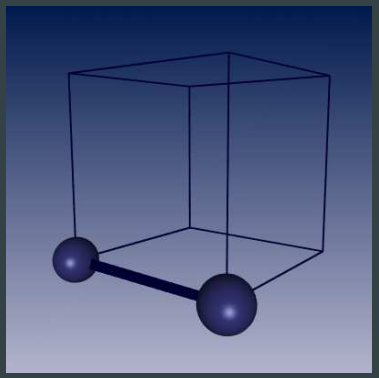


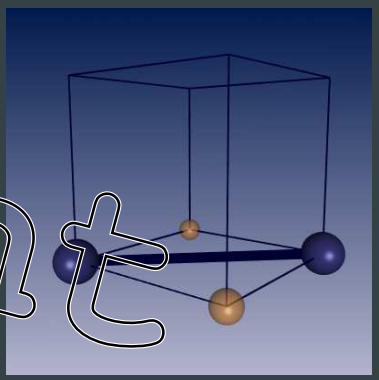


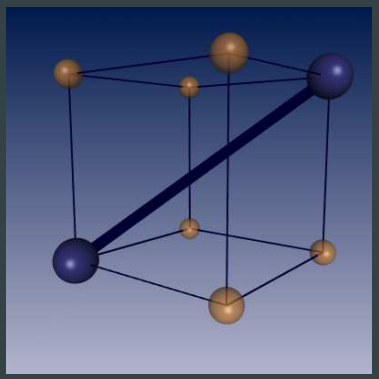


Triangulation, Edges

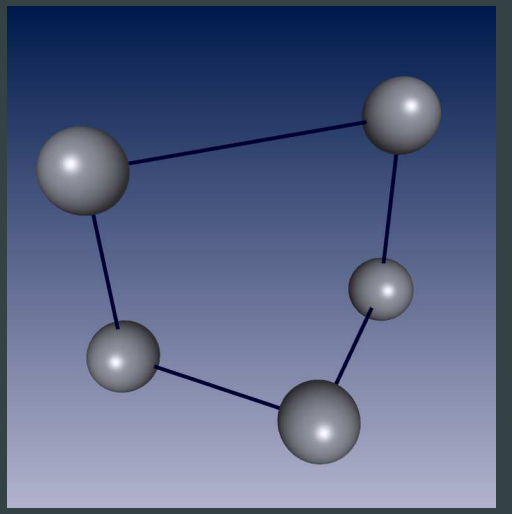
- Connection only possible if voxels in same cell
- Construct edges only if needed
  - Order: 6-, 18-, 26-connections
  - In standard cell:
    - Three 6-conn.
    - Six 18-conn.
    - Four 26-conn.
- Continuous transitions guaranteed
  - 6-conn fully determined by adjacent voxels which are shared by all cells containing the edge
  - 18-conn fully determined by voxels on one face which are shared by all cells containing the face



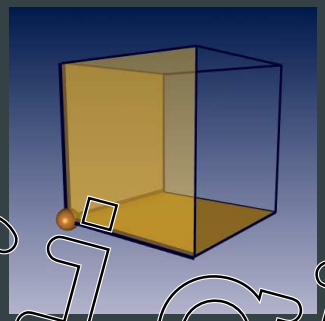


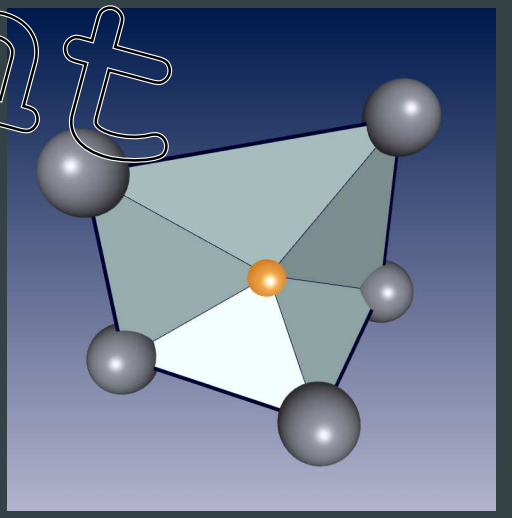


Triangulation, Triangles



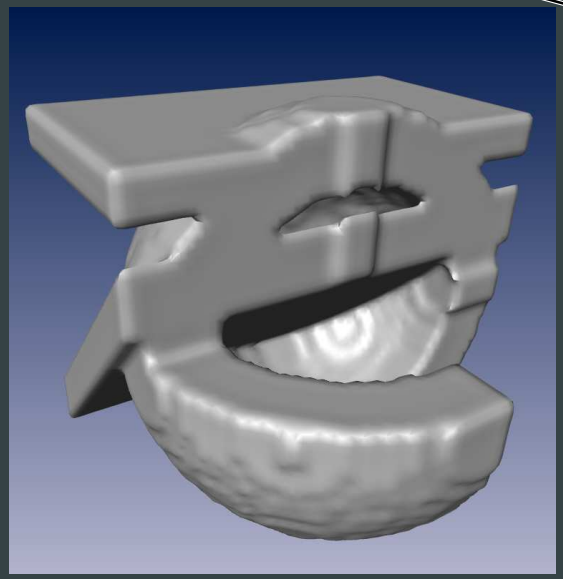
- Construct connections in full cell
- Detect all smallest loops and triangulate
  - Triangles only in reduced cell
  - No 3-loops on face
  - 4-loops allowed to create triangles on faces of standard cell
  - >4-loops not allowed to create triangles on faces of cell. Add center of gravity, if needed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

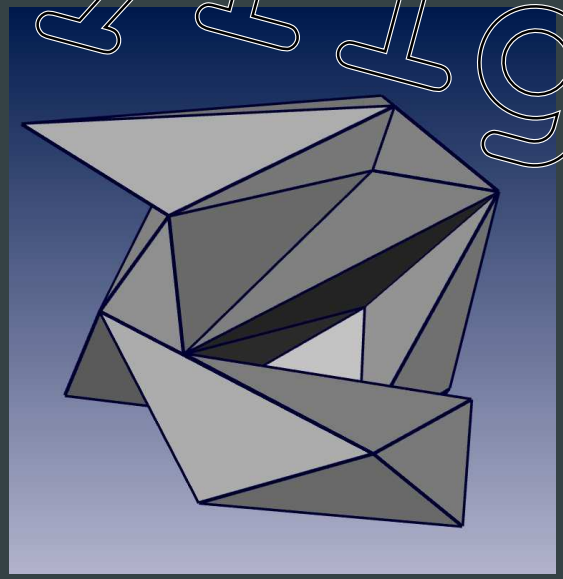


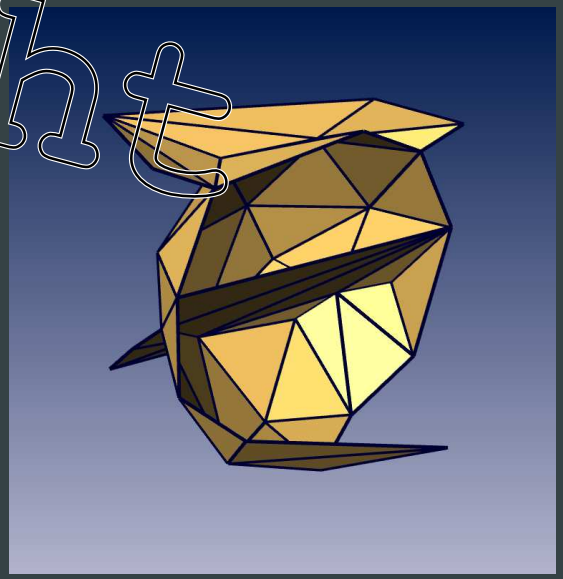


Triangulation, Remarks

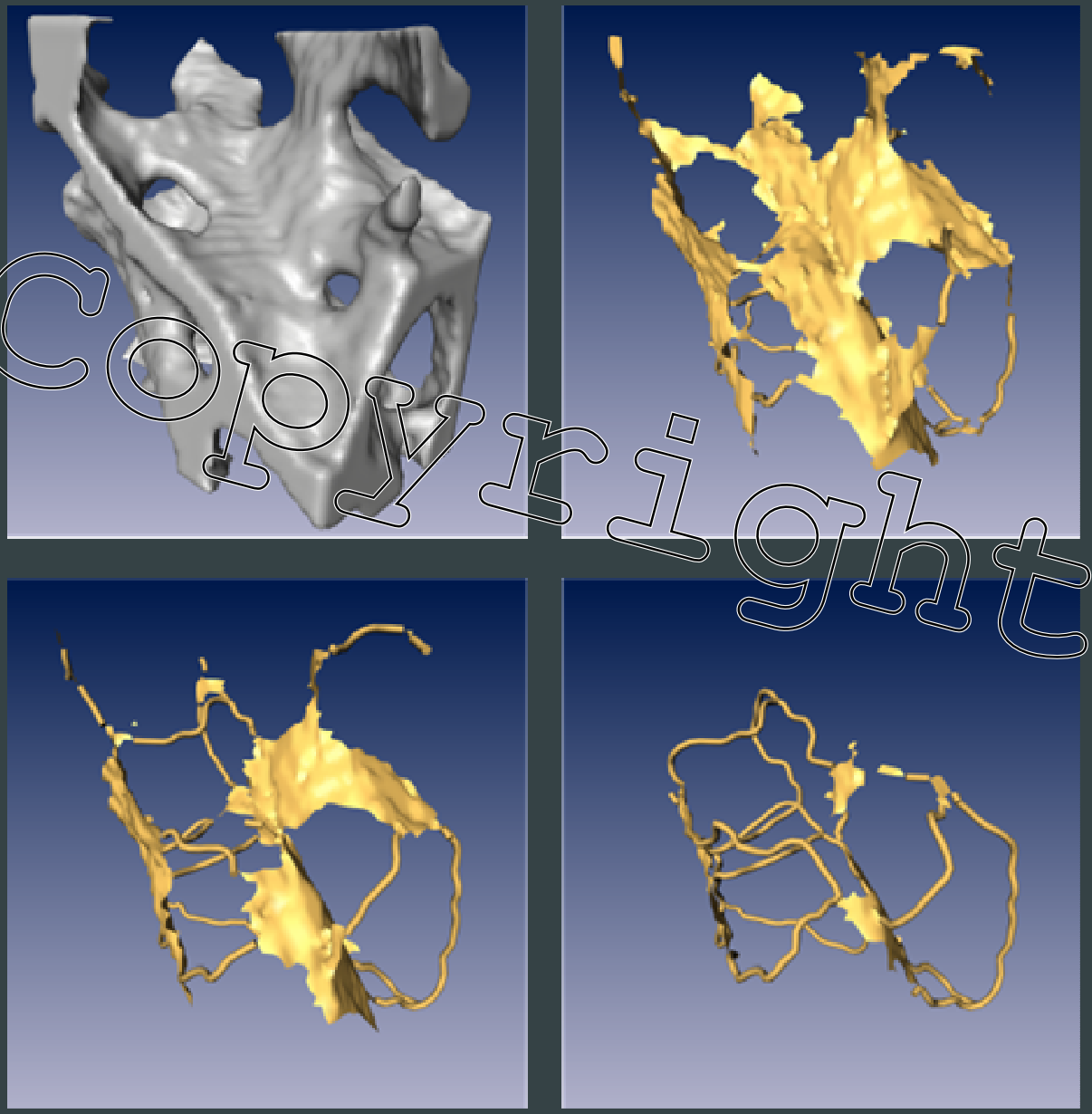
- Cell configurations in lookup table
- Unused connections can be rendered as lines
- Surface simplification works fine on skeleton





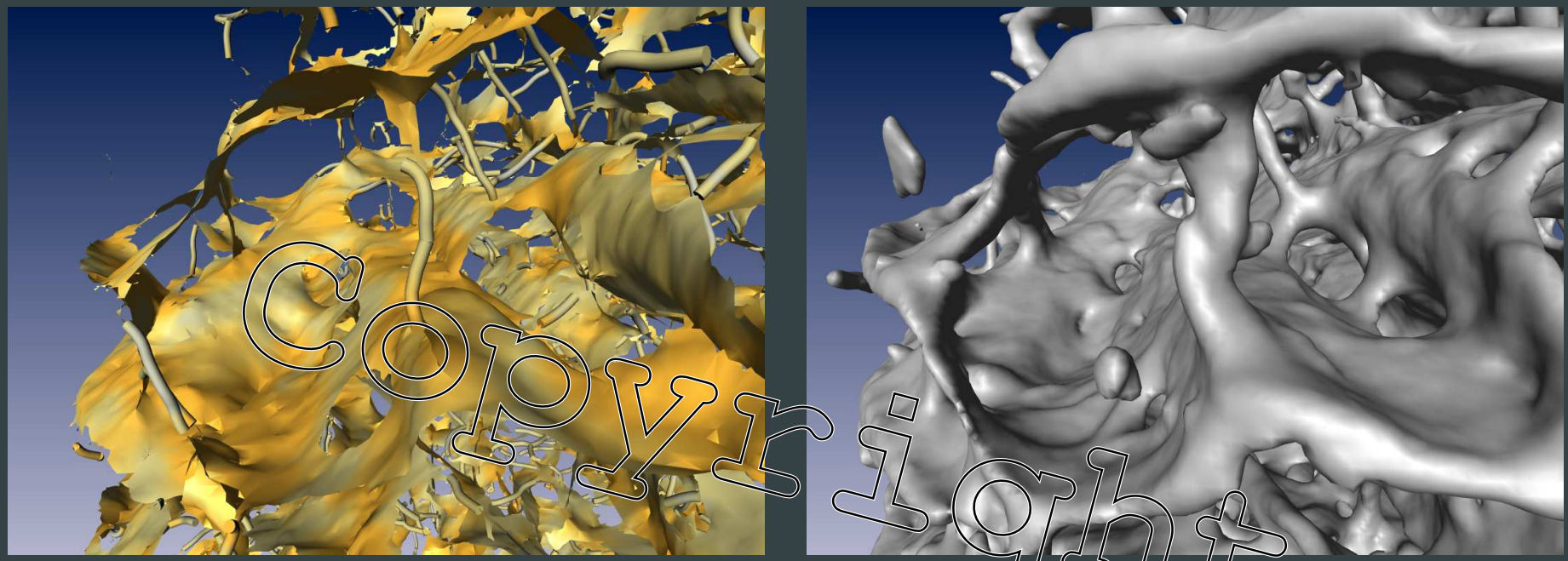


Results



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

Postscriptum

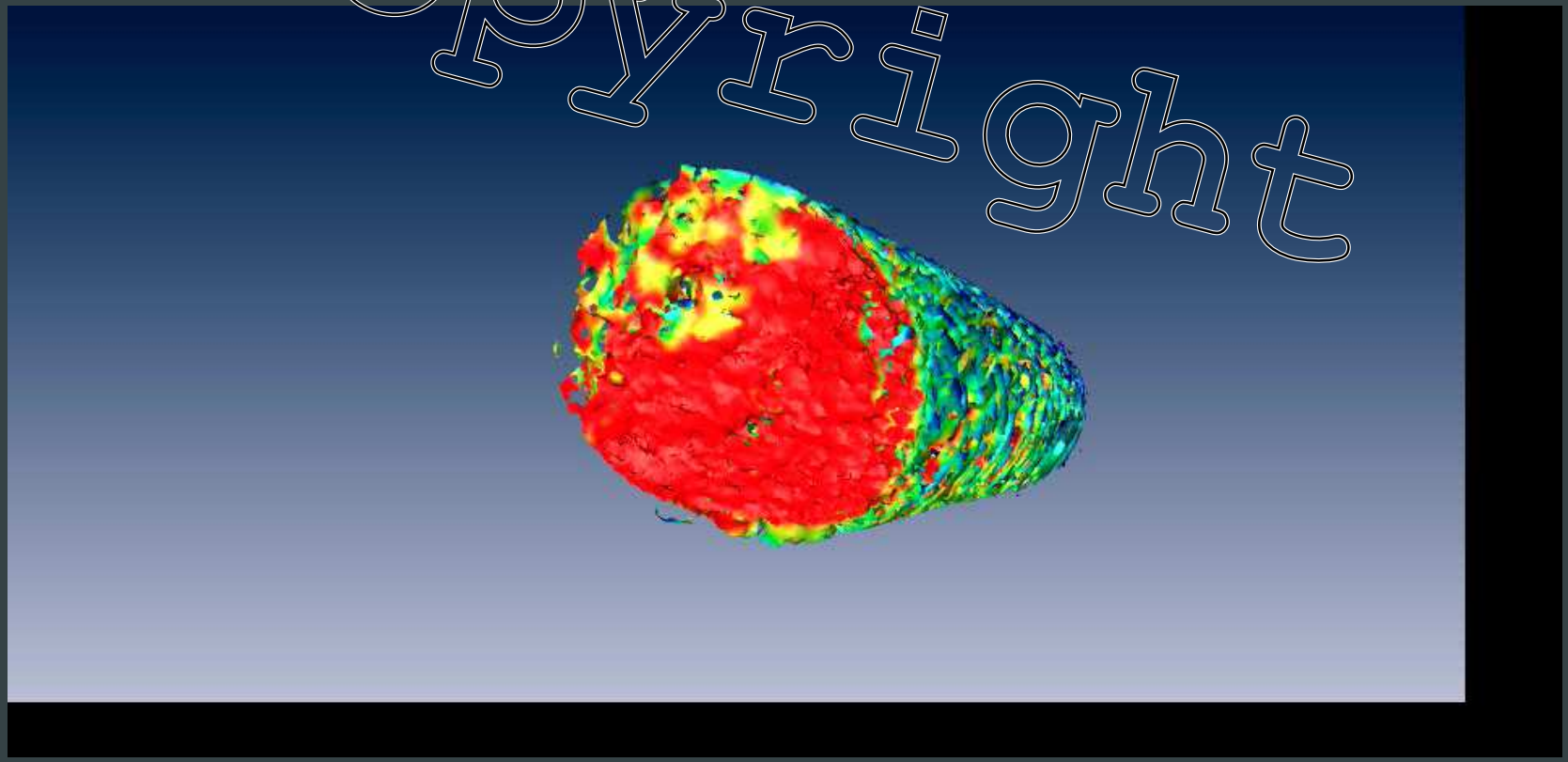
Demo: Thu 3 pm, Fri 10 am

Visualization framework: Amira (amira.zib.de, @TGS booth)

Imagedata: W. Gowin, M. Giehl (Benjamin Franklin Hospital, FU Berlin)

Discussions: Malte Westerhoff

Funding: European Space Agency (ESA), MAP project AO-99-030



Contribution

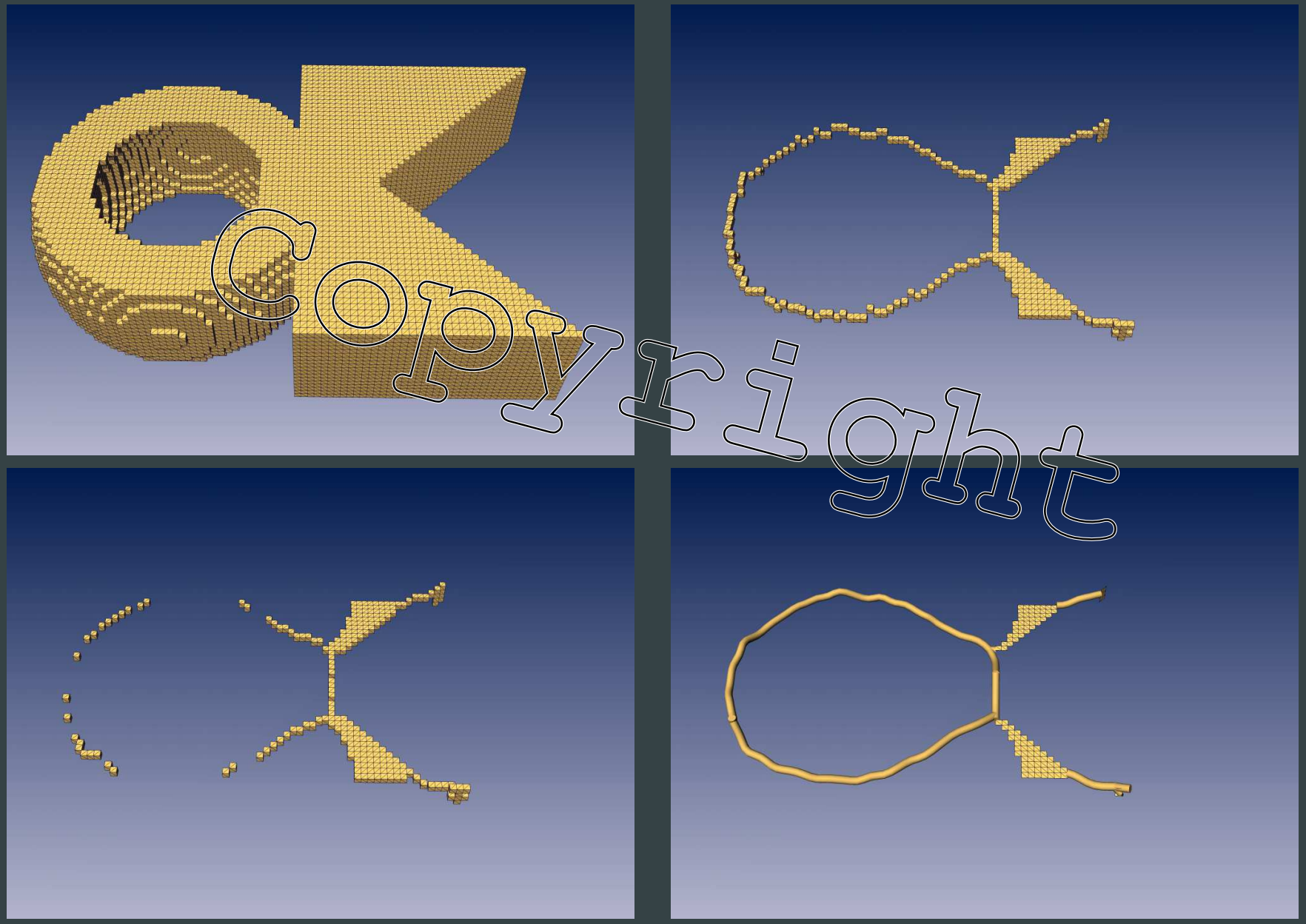
- Combination of skeletonization approaches
  - Measure to detect plane-like parts based on distance map
  - Thinning algorithm to reconstruct topology
- Triangulation scheme
  - Heuristic to generate an open triangulated surface from a voxel surface

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]

Overview

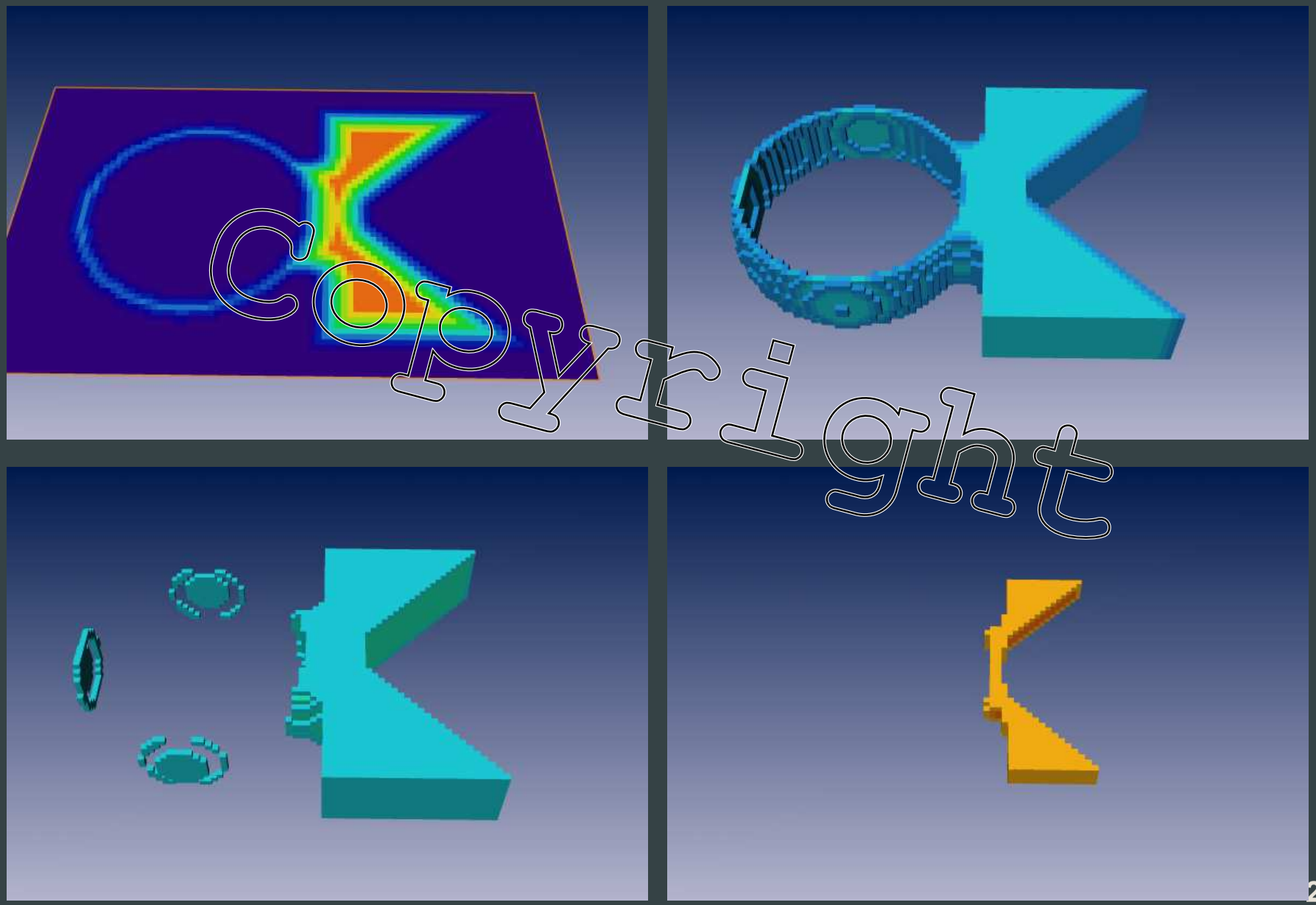


Skeletonization Agorithms

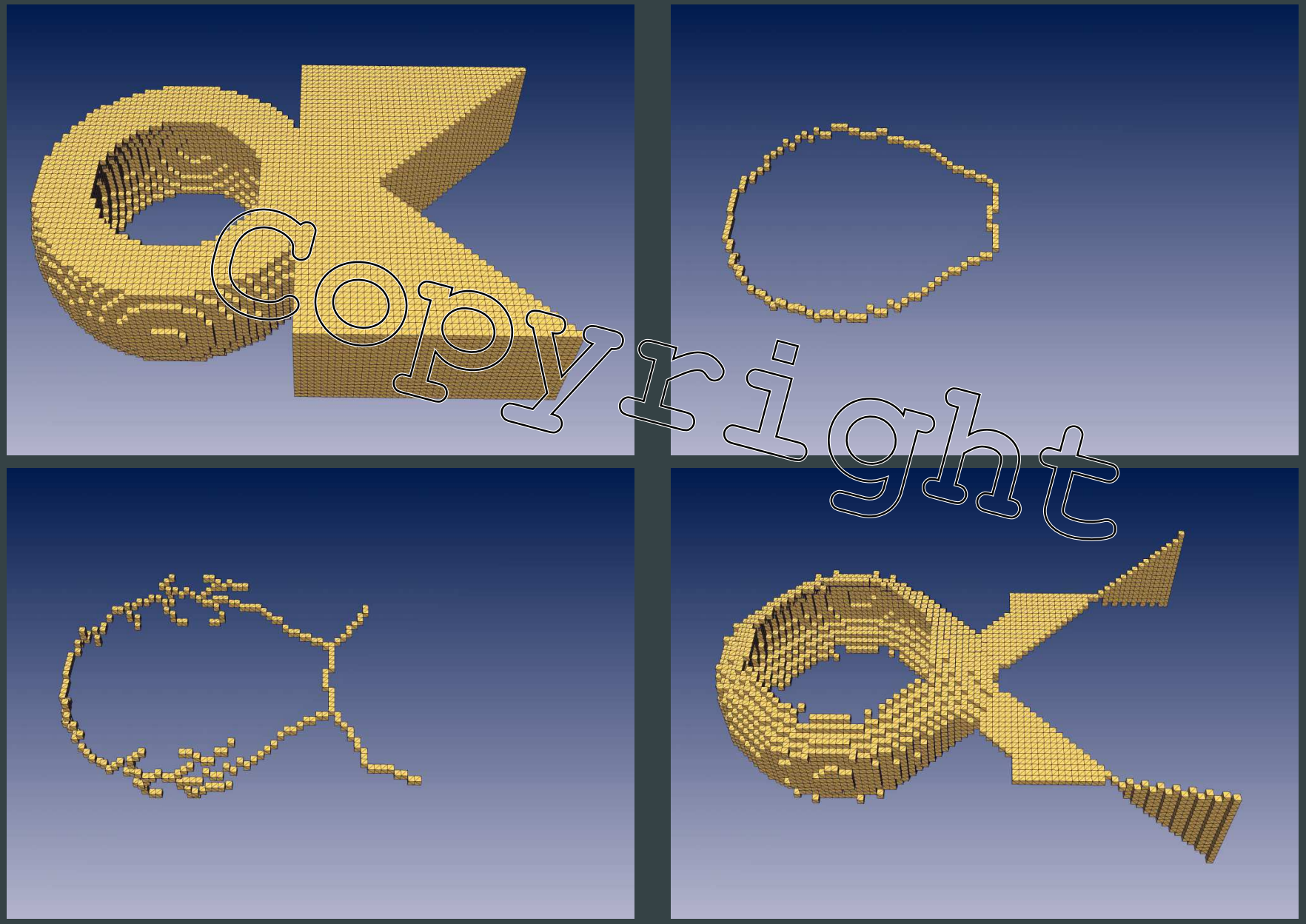
- Simulation of grassfire
- Analytic computation of the medial axis
- Topological thinning
- Extraction from a distance map

- Last two relevant for voxel objects

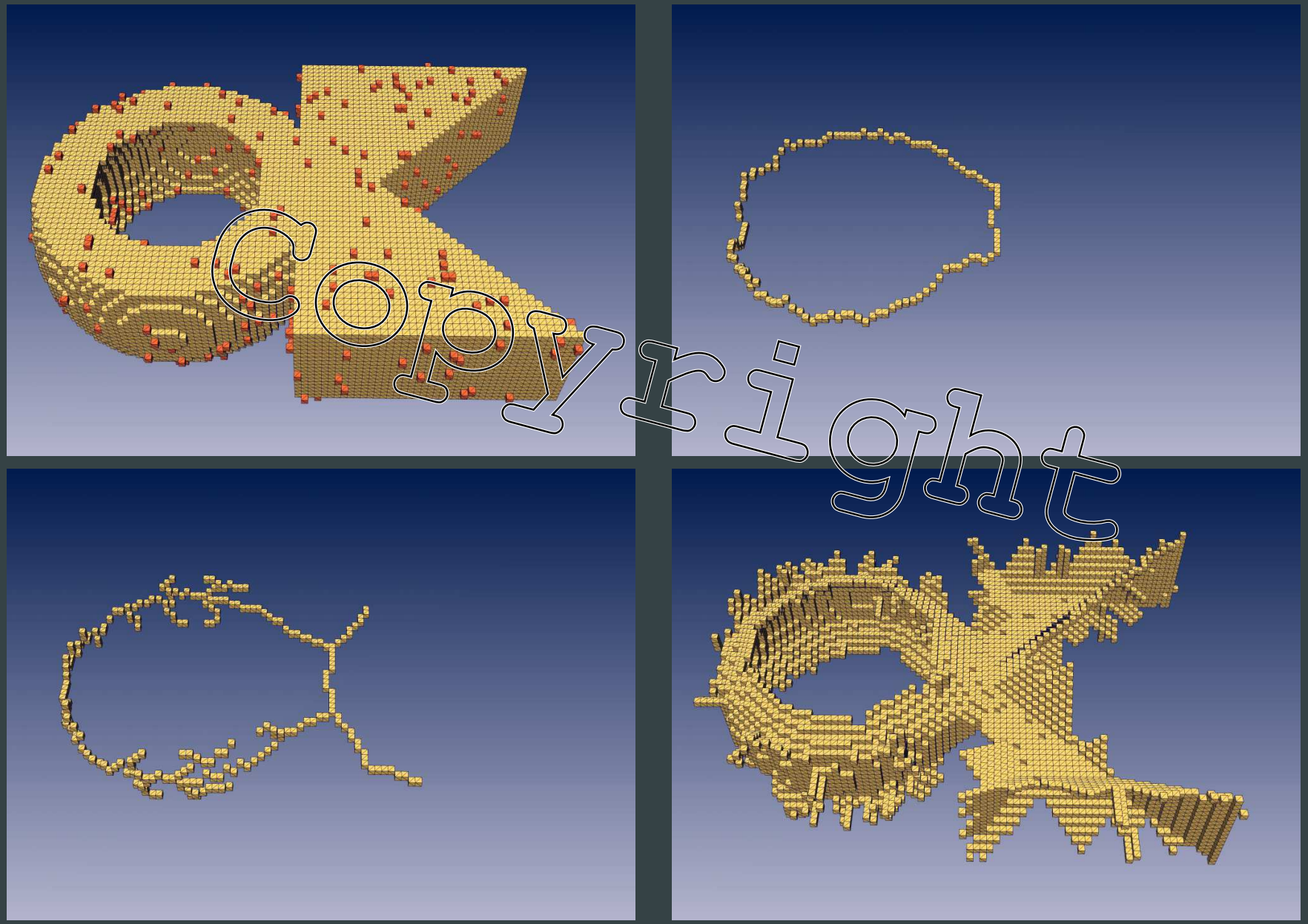
Distance Map



Skeletons by Thinning



Influence of Noise on Thinning



Global Measures

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

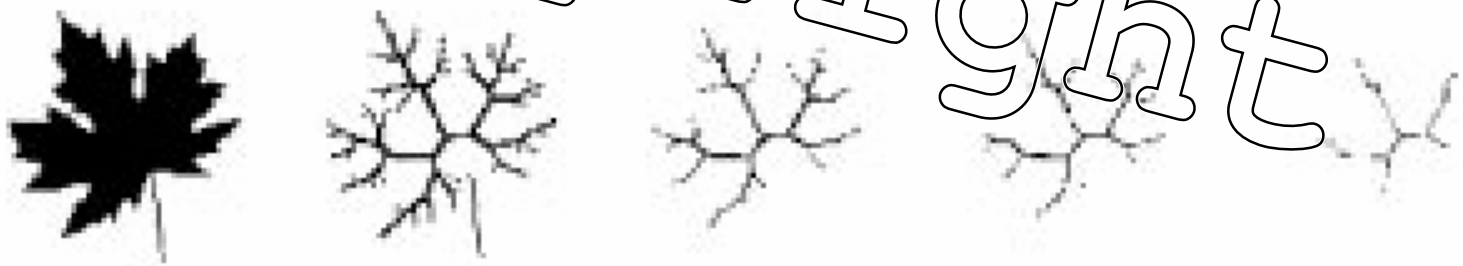


FIG. 5. A maple leaf and its skeletons at various thinness values. Thinness is increasing from left to right.

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

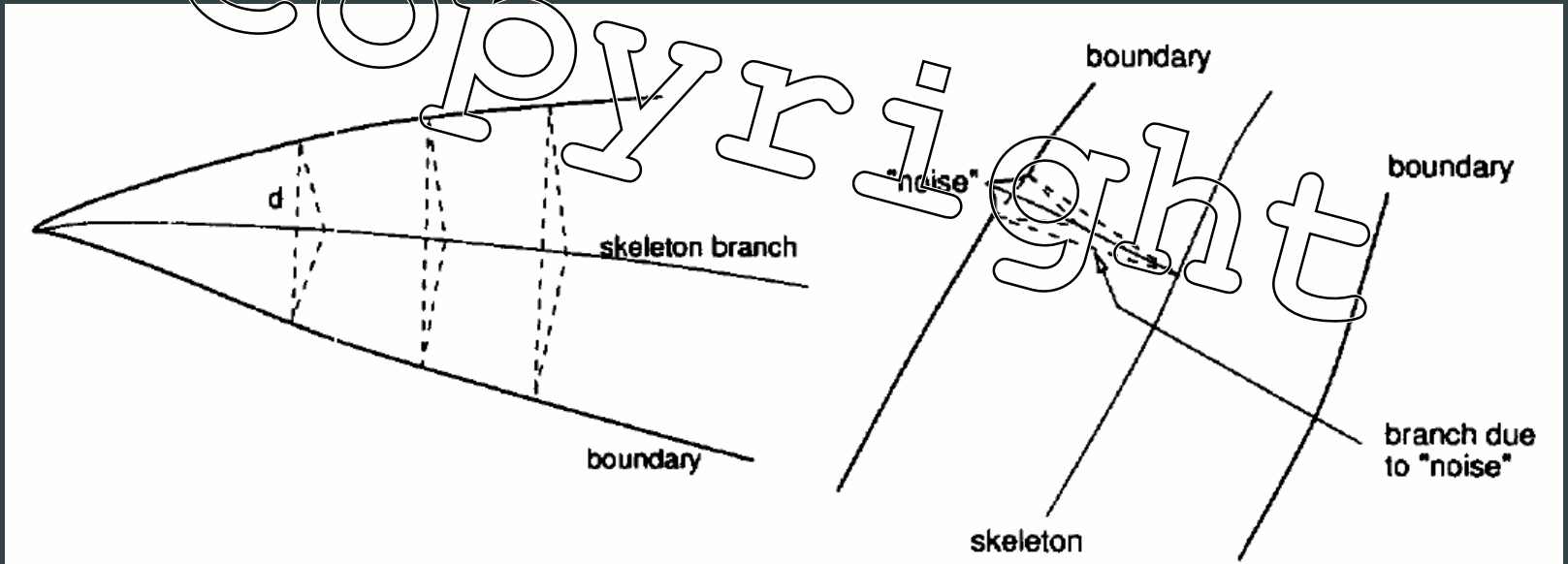


Fig. 6. Different kinds of skeleton branch.

[Malandain, Fernández-Vidal]

Global Measures

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

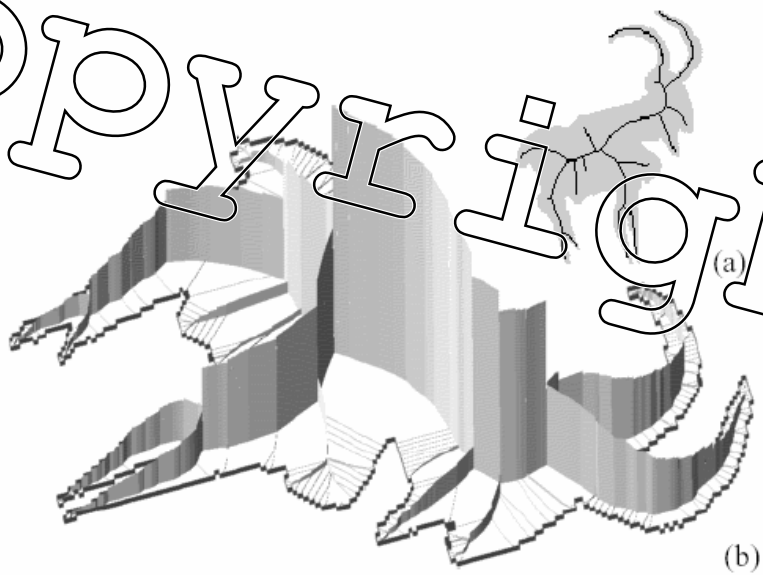
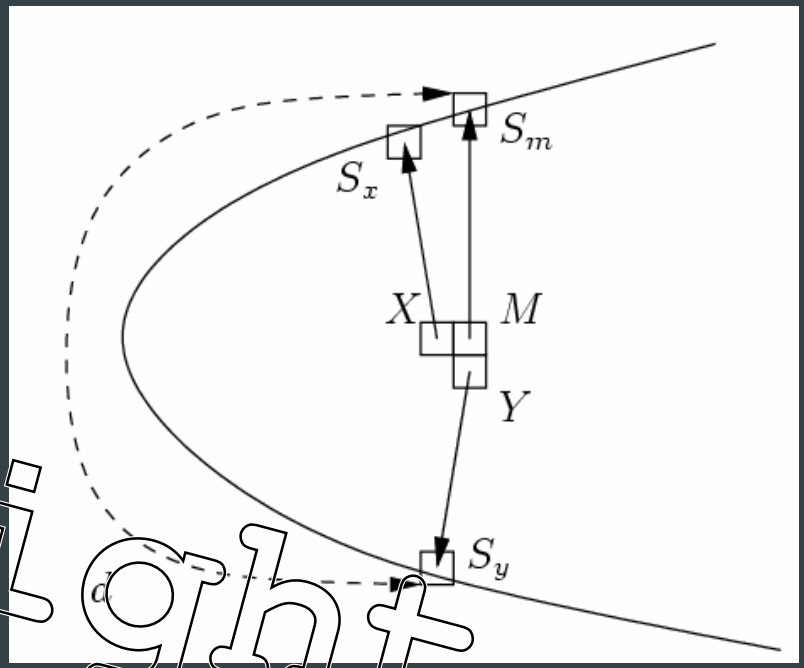


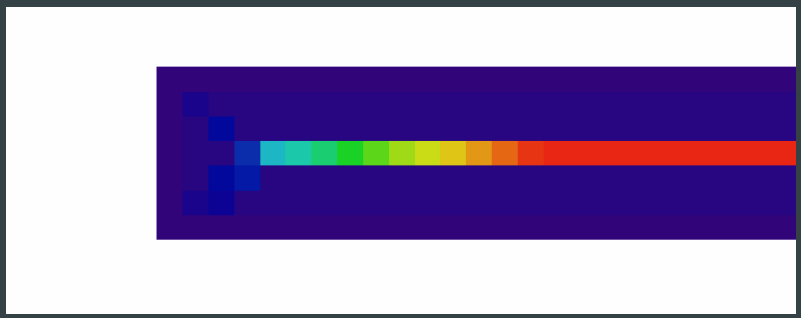
Fig. 3. 3-D View of Potential Residual. (a) The DVMA after regularization with threshold $T = 9.0$. The selection of a useful threshold will be explained later. (b) The 3-dimensional plot of the potential residual ΔR_P.

[Ogniewicz, Kübler]

Global Measure

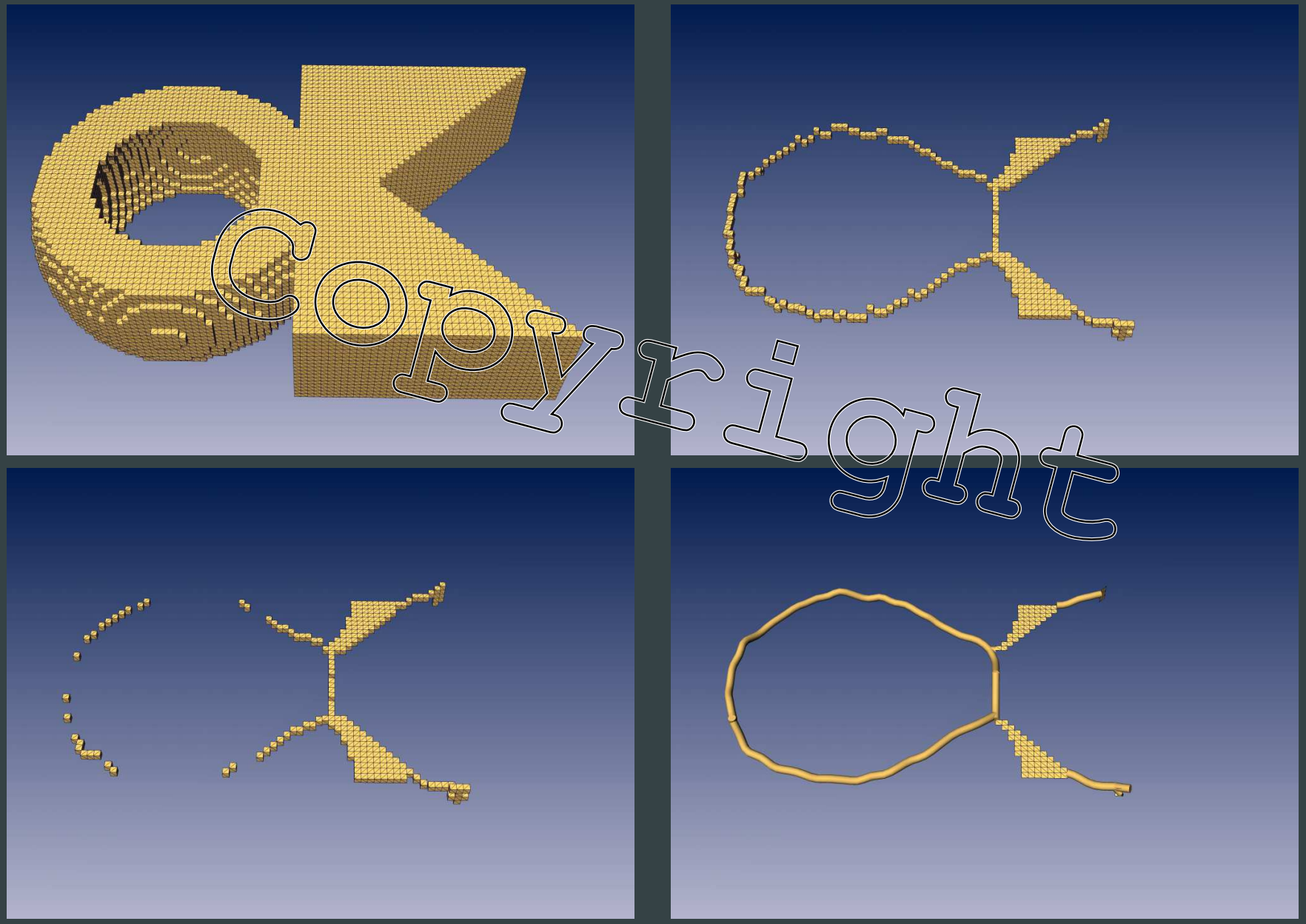
- Maximum of geodesic distance *d* of nearest boundary voxels
  - Propagation to calculate DM and boundary voxels
  - Propagation in boundary to calc. *d*
- Threshold controls sensitivity to noise and features



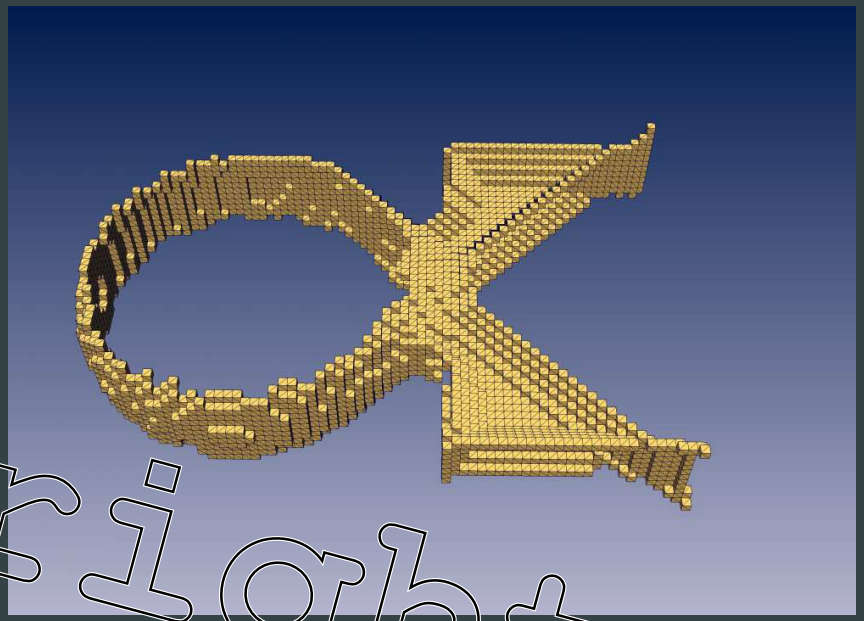


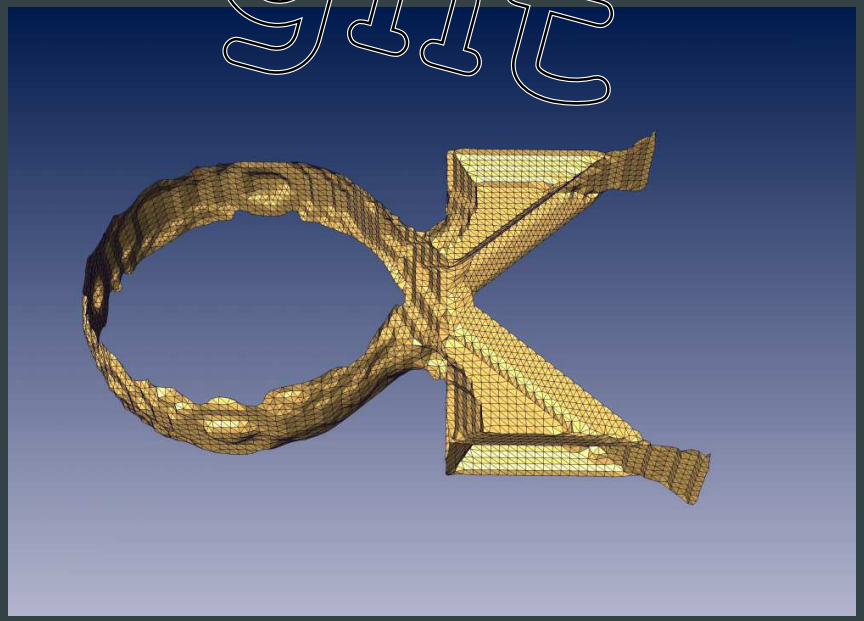
[Costa 99], [Verwer et al. 89]

Reconstructing Topology

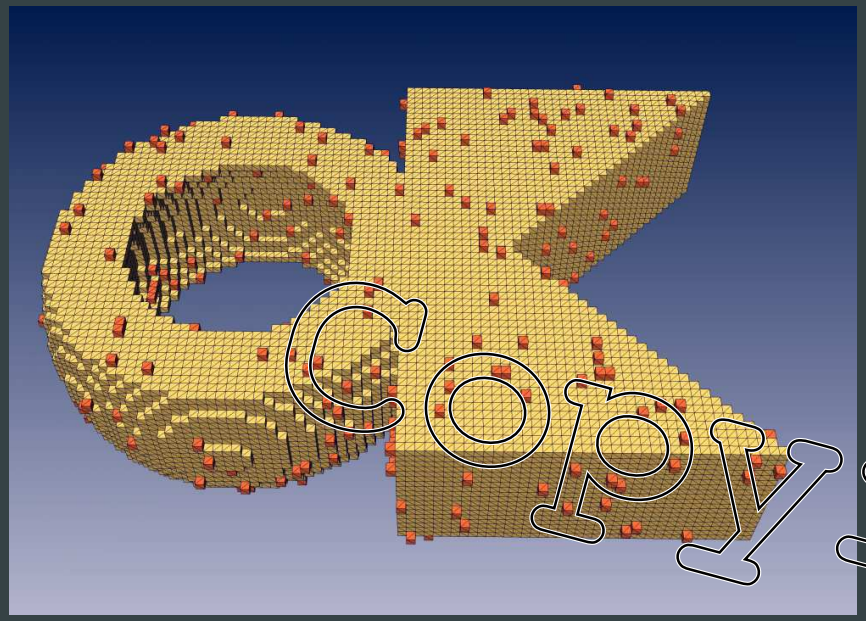


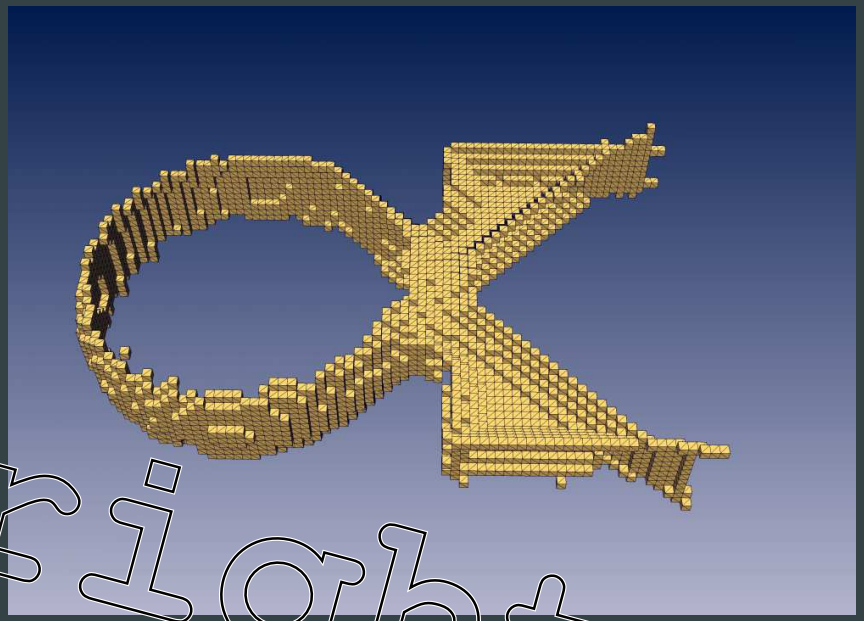
Skeleton by Global Measure

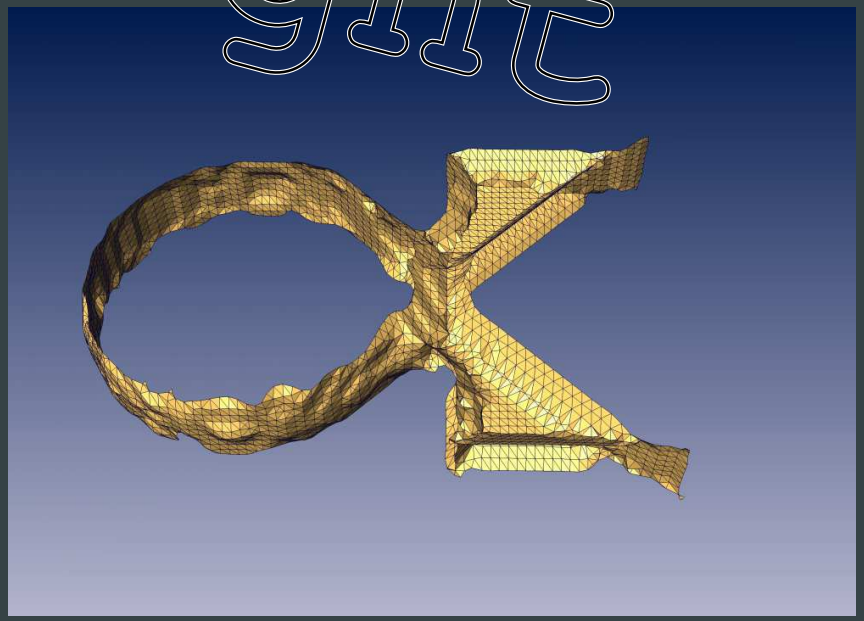




Global Measure and Noise

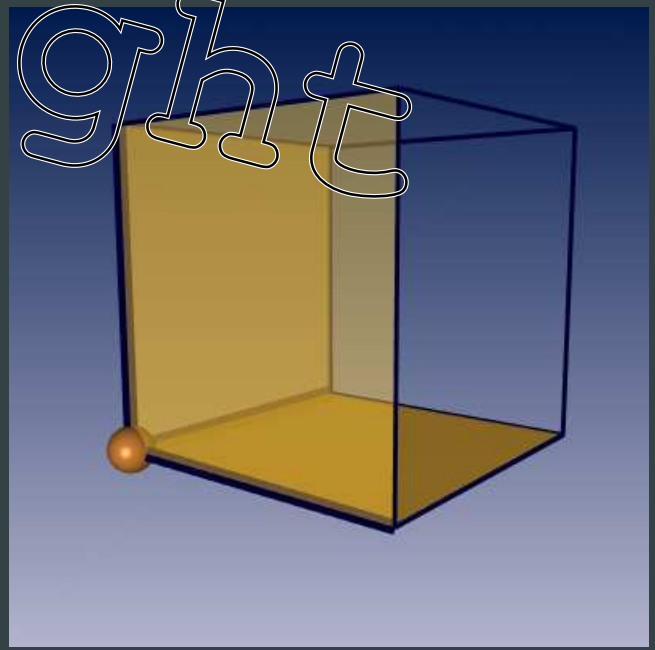




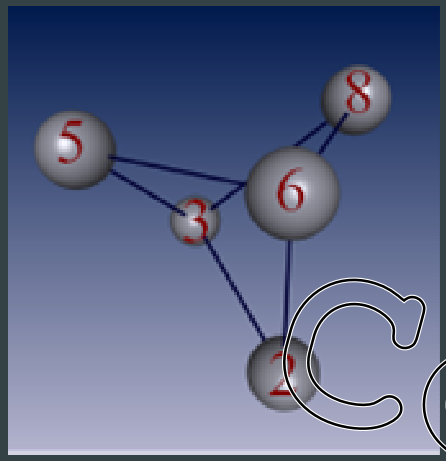


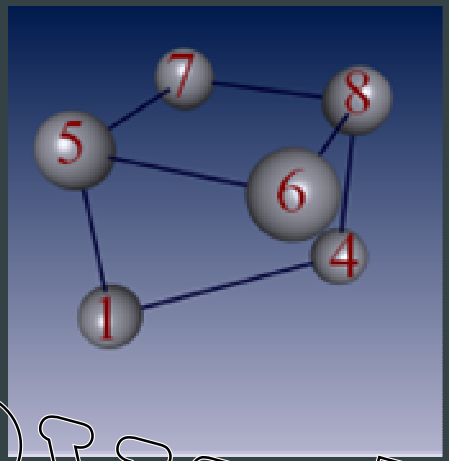
Triangulation

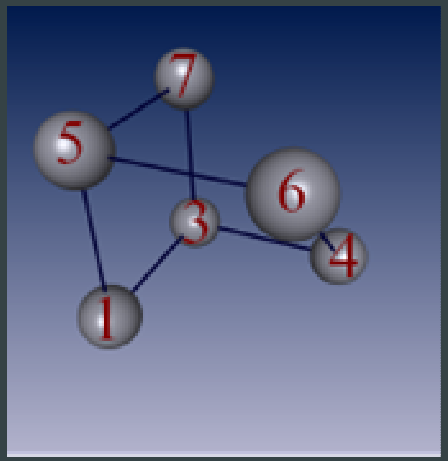
- Solve problem for every unit lattice cell
- Reduced cell
  - Represented by corner voxel
  - Including edges and faces adjacent to representing voxel
  - Excluding other faces, edges and corners
  - Divide space univocally
  - Fill up whole space
- Full cell
  - Including all edges and faces

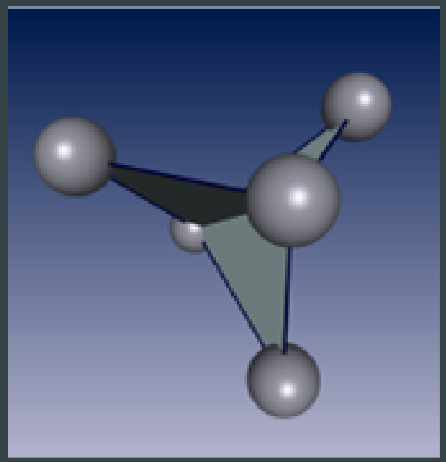


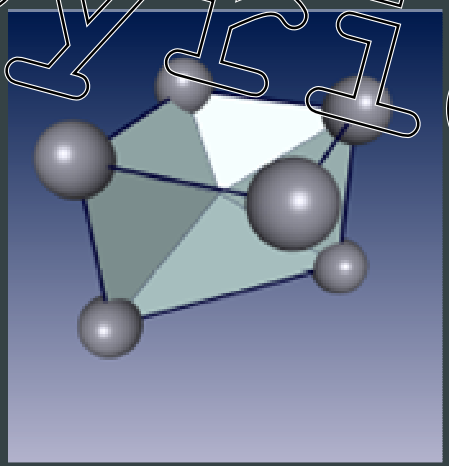
Triang., Special Cases

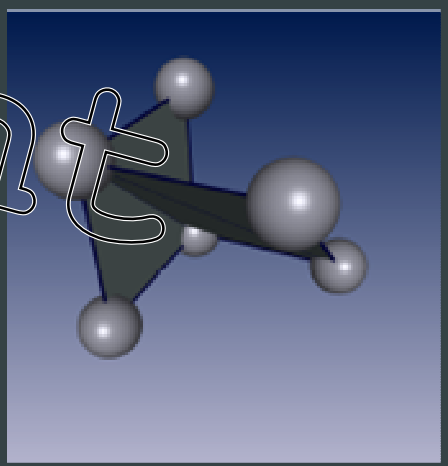












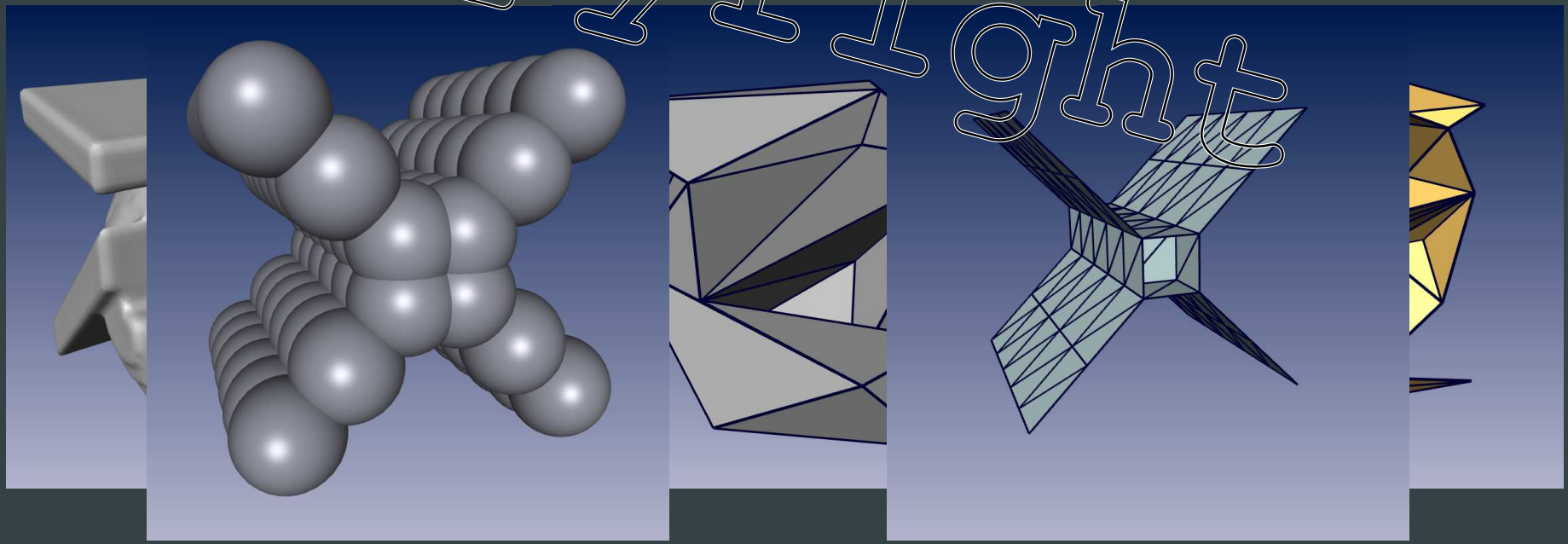
Avoid double triangles

Standard case

Nicer triangulation

Triangulation, Remarks

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



Results