CGAL

Computational Geometry Algorithms Library

Laurent Rineau
GeometryFactory

FEniCS`14
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Outline

- Introduction
  - The CGAL Project
  - GeometryFactory
- The CGAL Library
  - Overview
  - Zoom on Mesh Generation

The CGAL Project

Mission Statement

"Make the large body of geometric algorithms developed in the field of computational geometry available for industrial applications"

CGAL EU Project Proposal, 1996

Project = « Planned Undertaking »

- Academic partners make a long term commitment: INRIA, Max-Planck Institute, Tel-Aviv U, ETH Zurich,...
- CGAL Editorial Board
  - Steers and animates the project
  - Reviews submissions
- Development Infrastructure
  - Git server, nightly test suite (~30 configurations)
  - Two 1-week developer meetings per year

CGAL in Numbers

600,000	lines of C++ code
10,000	downloads/year (+ package managers)
3,500	manual pages
3,000	subscribers to cgal-announce
1,000	subscribers to cgal-discuss
150	commercial users
120	software components
20	active developers
6	months release cycle
2	licenses: GPL + commercial

GeometryFactory

GeometryFactory

- 5 engineers, whereof 4 with a PhD

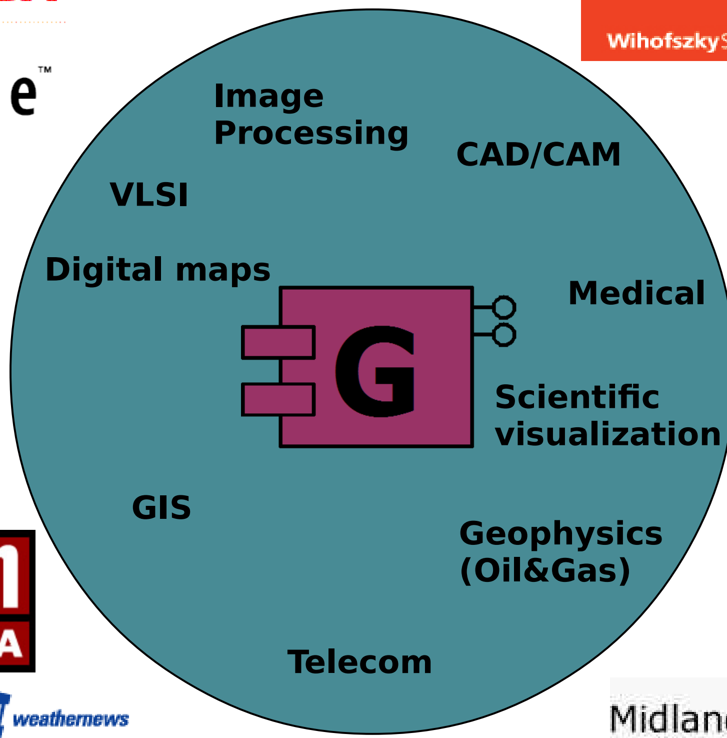
- Sales of CGAL software components
- Support to increase customer productivity (training, integration, ...)

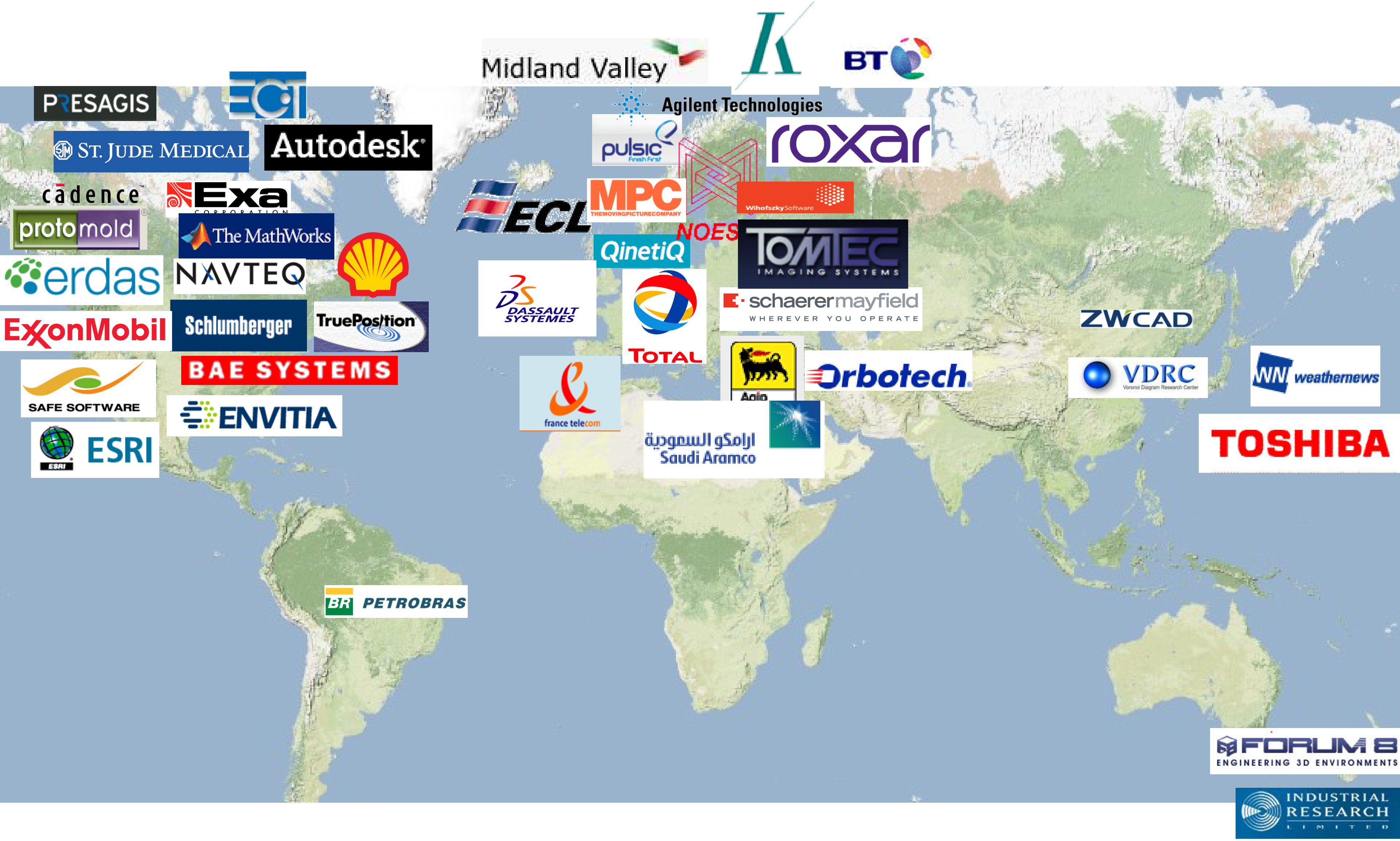
GeometryFactory

- Actively involved in the CGAL Project
  - Development of new components, or improve existing ones (for customers)
  - 3 Editorial Board members,
  - Release Management,
  - Infrastructure
    - testsuite process,
    - testsuite machines,
    - web sites

Some Commercial CGAL Users

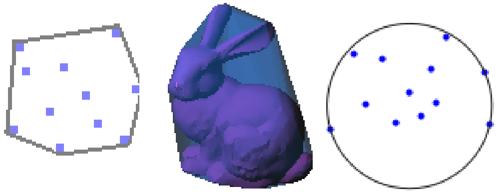
Orbotech, pulsic, VDRC (Voronoi Diagram Research Center), The Ohio State University, NOESIS, protomold, Autodesk, Exa Corporation, ECT, TOSHIBA, cadence, Wihofszky Software, ZWCAD, MPC (The Moving Picture Company), ECL, Dassault Systemes, Agilent Technologies, TomTec Imaging Systems, BAE SYSTEMS, schaerermayfield (Wherever you operate), GE Healthcare, QinetiQ, St. Jude Medical, PRESAGIS, The MathWorks, erdas, Virtualwind, School of Biomedical Sciences, Industrial Research Limited, Safe Software, rm Data, Agip, ESRI, Archivideo, weathernews, NAVTEQ, france telecom, Midland Valley, Total, Schlumberger, roxar, Petrobras, Saudi Aramco, ENVITIA, TruePosition, BT, brgm, ExxonMobil, Shell

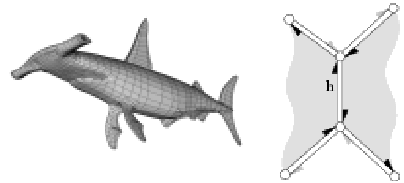


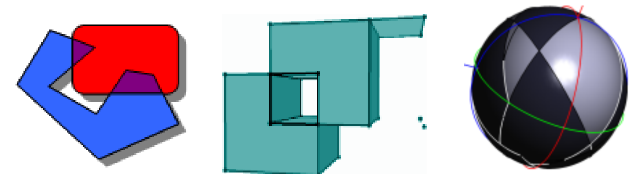

Midland Valley
BT
Agilent Technologies
PRESAGIS
ST. JUDE MEDICAL
Autodesk
pulsic
roxar
cadence
Exa
protomold
The MathWorks
ECL
MPC
Wihofszky Software
NOES
QinetiQ
TOMTEC
IMAGING SYSTEMS
erdas
NAVTEQ
DASSAULT SYSTEMES
TOTAL
schaerermayfield
WHEREVER YOU OPERATE
ZWCAD
ExxonMobil
Schlumberger
TruePosition
BAE SYSTEMS
Orbotech
VDRC
weathernews
SAFE SOFTWARE
ENVITIA
france telecom
أرامكو السعودية
Saudi Aramco
ESRI
TOSHIBA
PETROBRAS
FORUM 8
ENGINEERING 3D ENVIRONMENTS
INDUSTRIAL RESEARCH
LIMITED

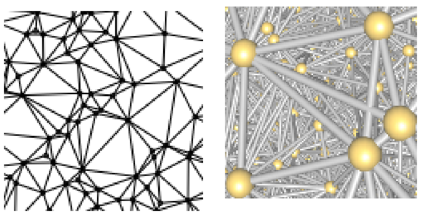
The CGAL Library

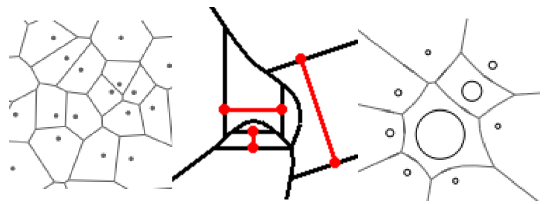
Algorithms and Data Structures

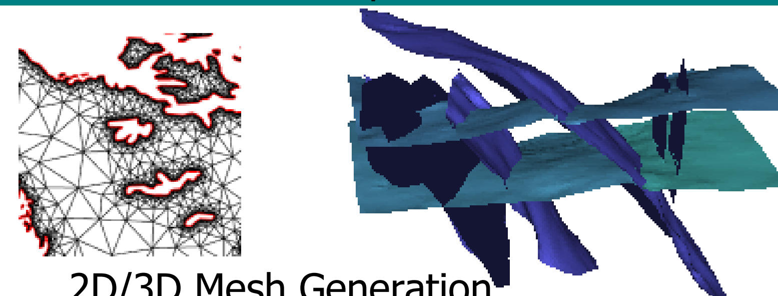

Bounding Volumes


Polyhedral Surface

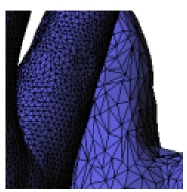

Boolean Operations

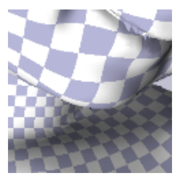

Triangulations

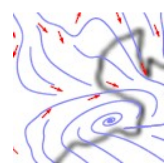

Voronoi Diagrams

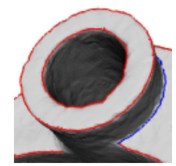

2D/3D Mesh Generation

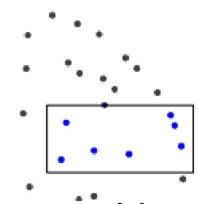

Subdivision

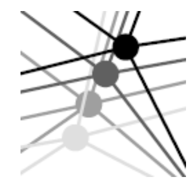

Simplification

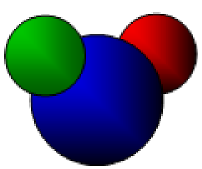

Parameterization

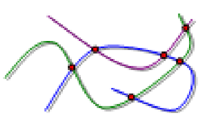

Streamlines

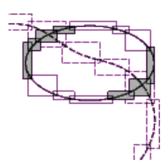

Ridge Detection


Neighbor Search

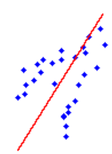

Kinetic Data Structures

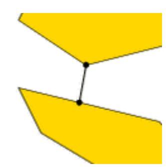

Lower Envelope

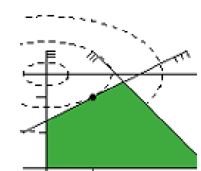

Arrangement


Intersection Detection


Minkowski Sum

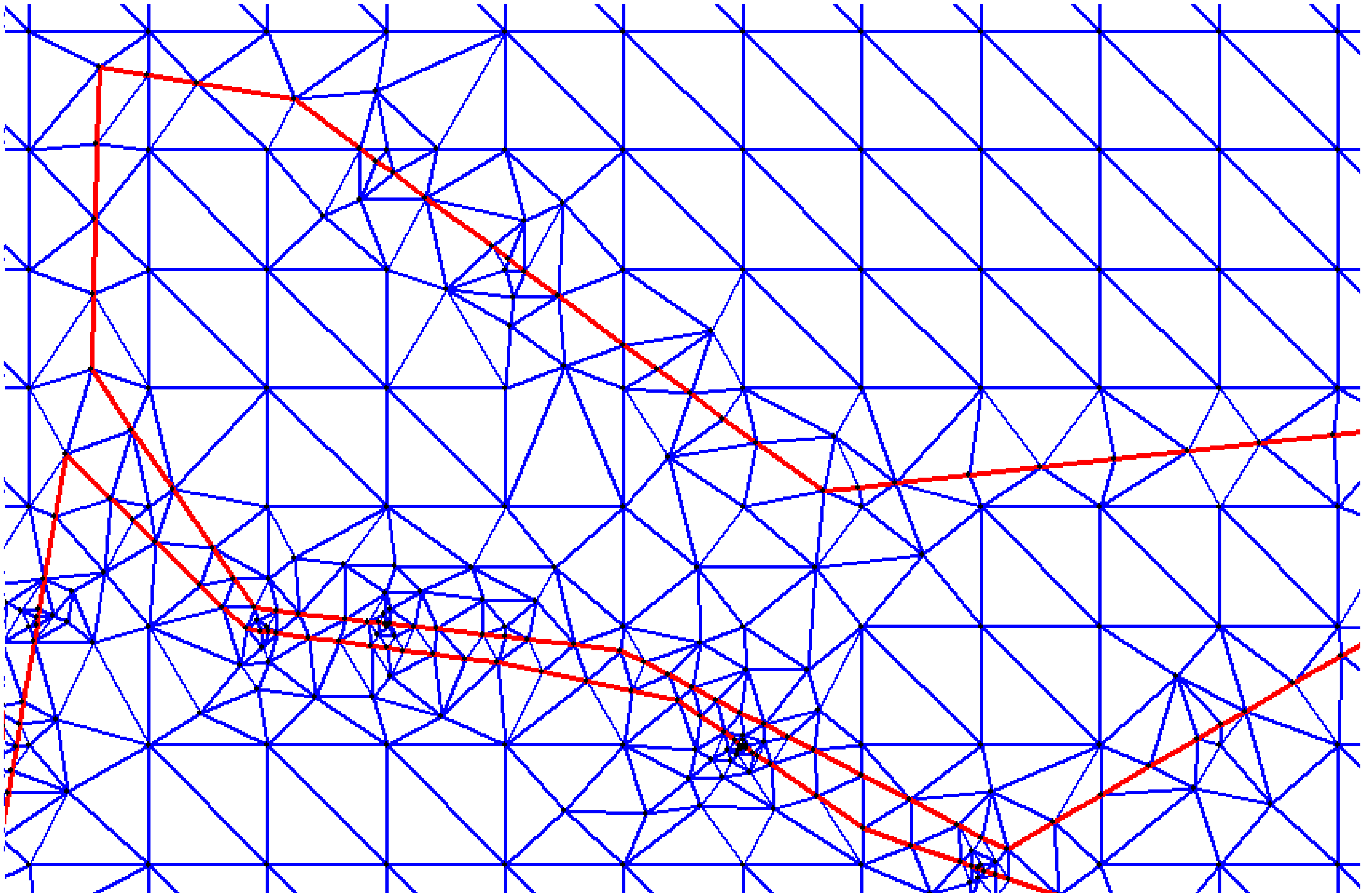

PCA


Polytope Distance


QP Solver

2D Mesh Generation

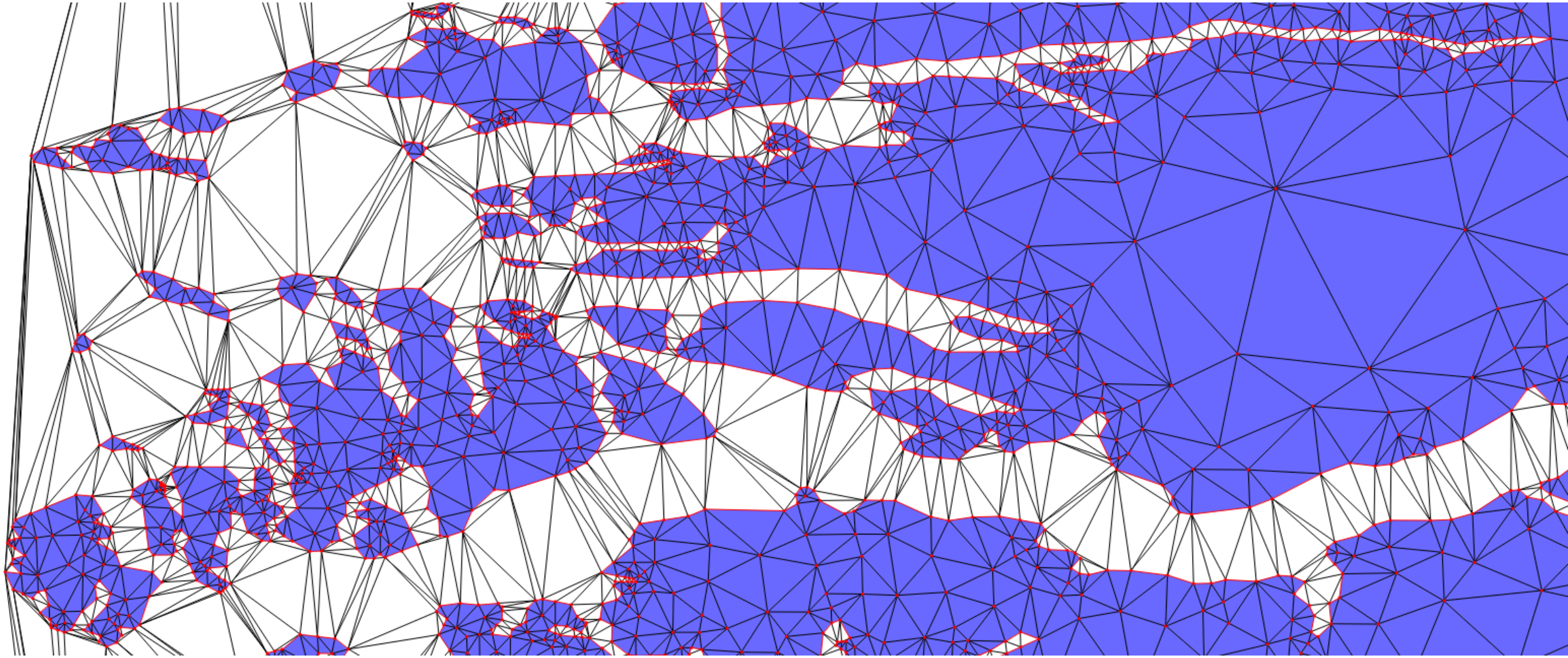
2D Delaunay Mesh Generation



Courtesy: ENI

Triangulating Polygons

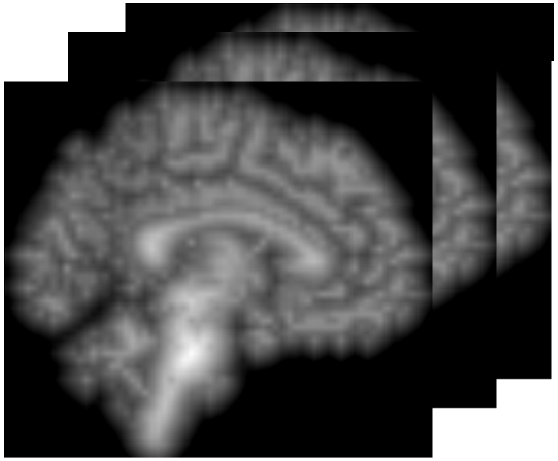
Triangulating Polygons



Added 45K vertices in 0.9s

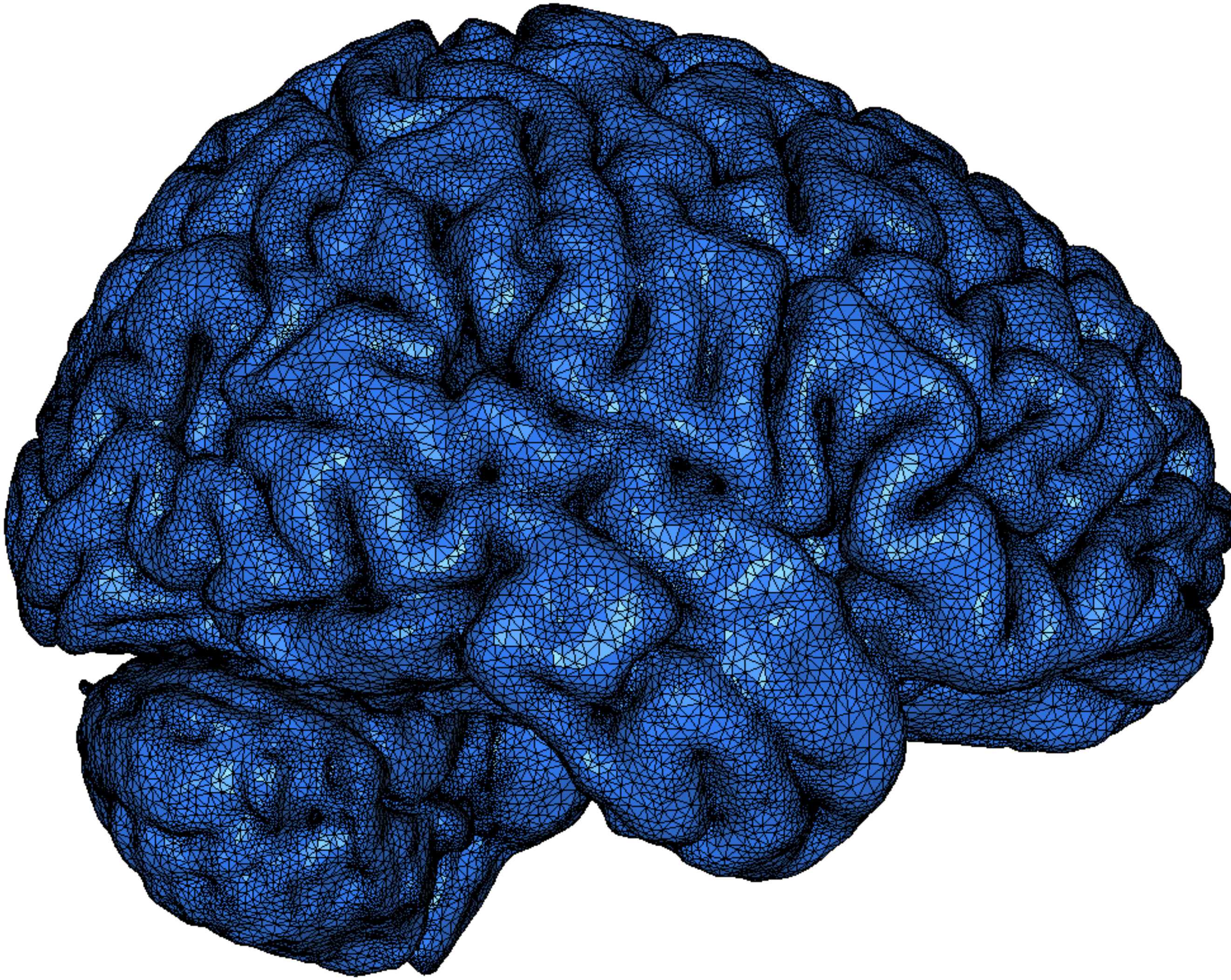
3D Surface and Volume Mesh Generation

Surface Mesh (Greylevel Image)

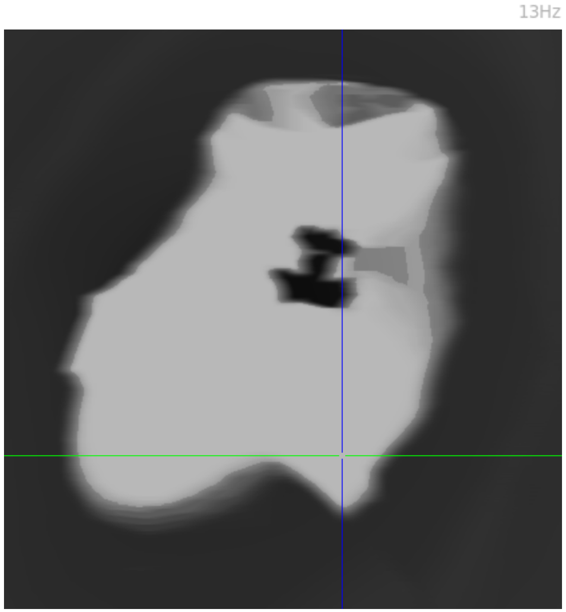


input

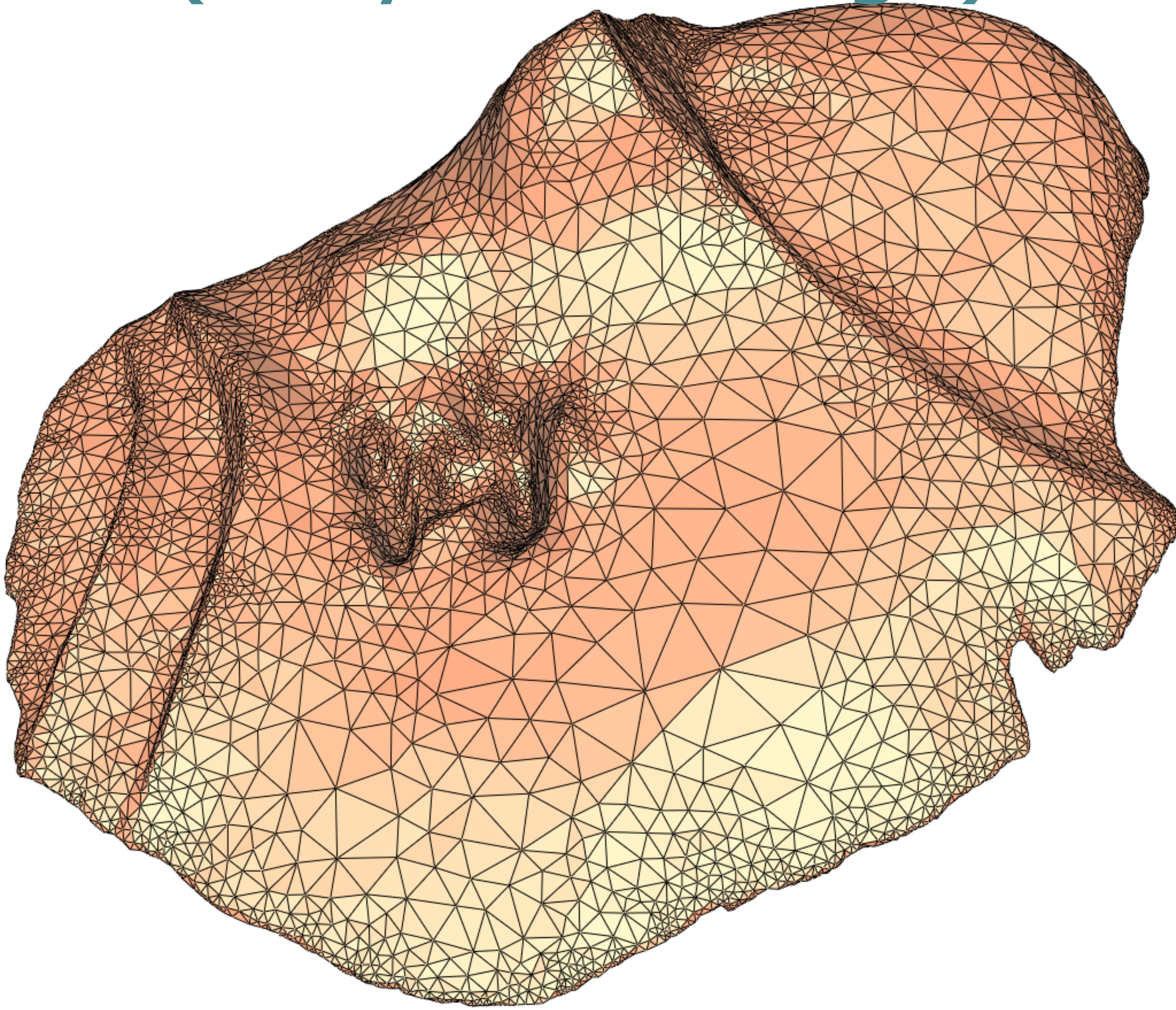
Triangle surface mesh approximating isosurface of input 3D image



Surface Mesh (Greylevel Image)

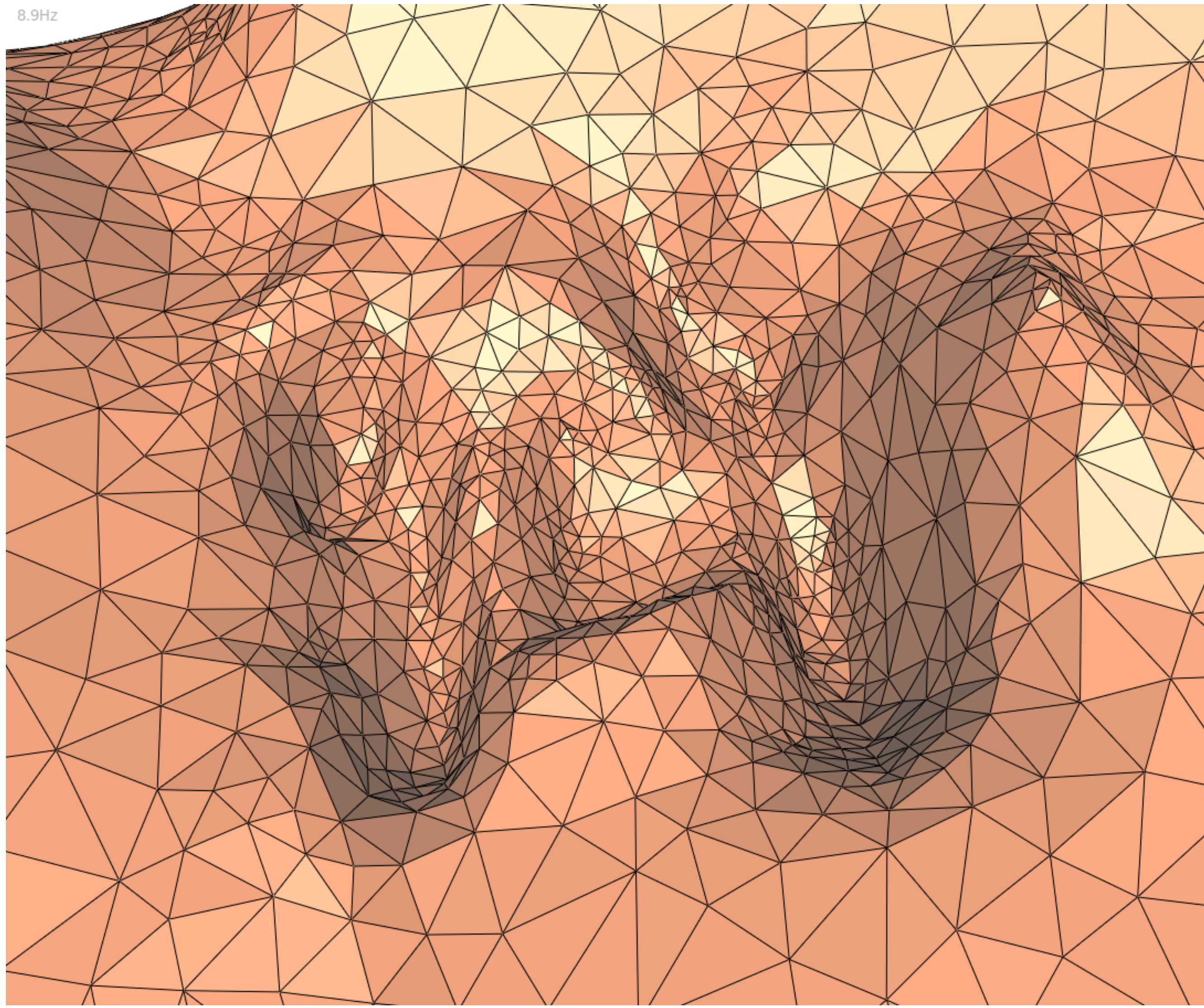


Input:
3D voxel data for
SEG Salt Model



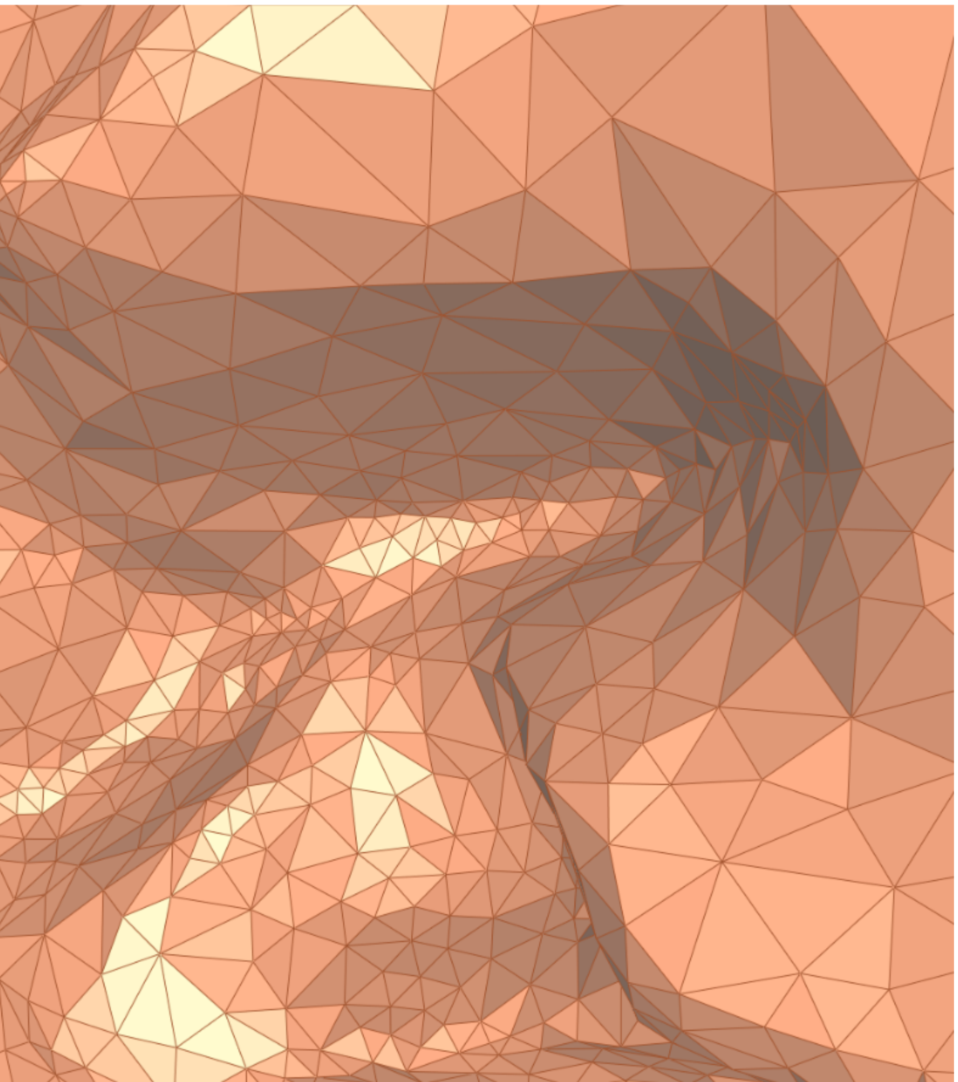
Surface Mesh (Greylevel Image)

Input:
3D voxel data for
SEG Salt Model

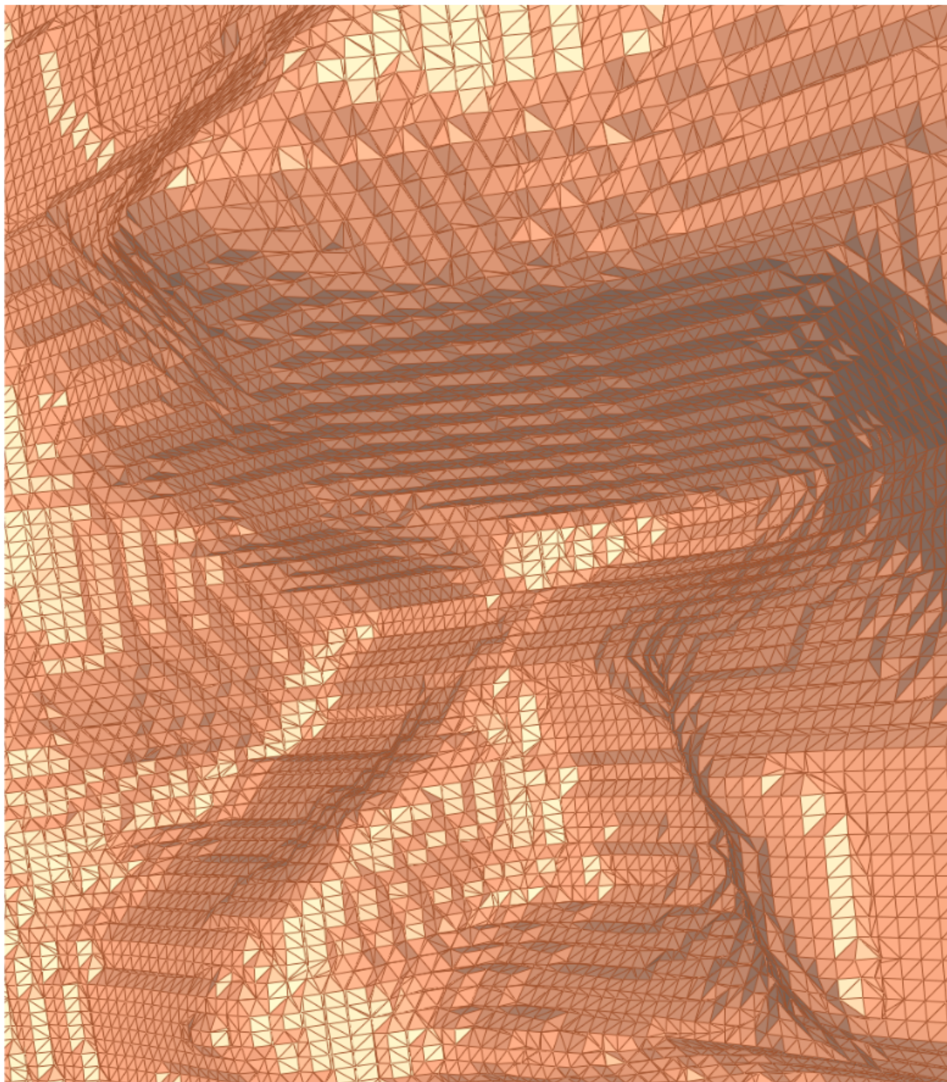


Comparison with Marching Cubes

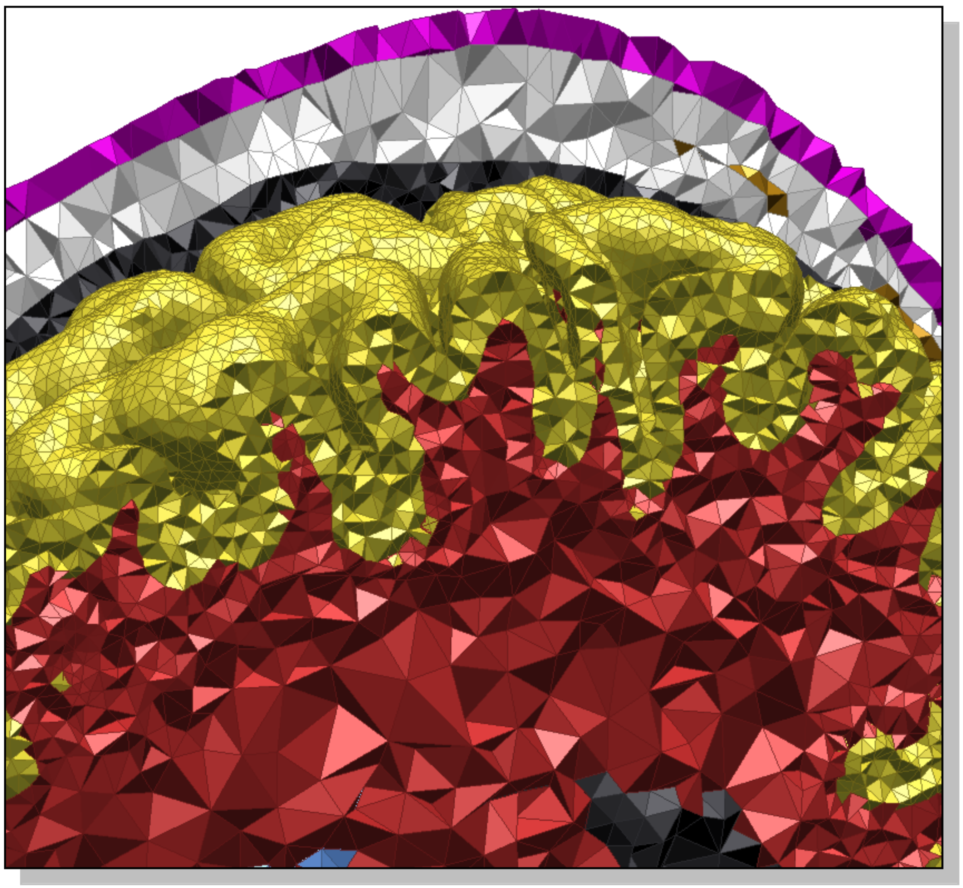
Delaunay refinement

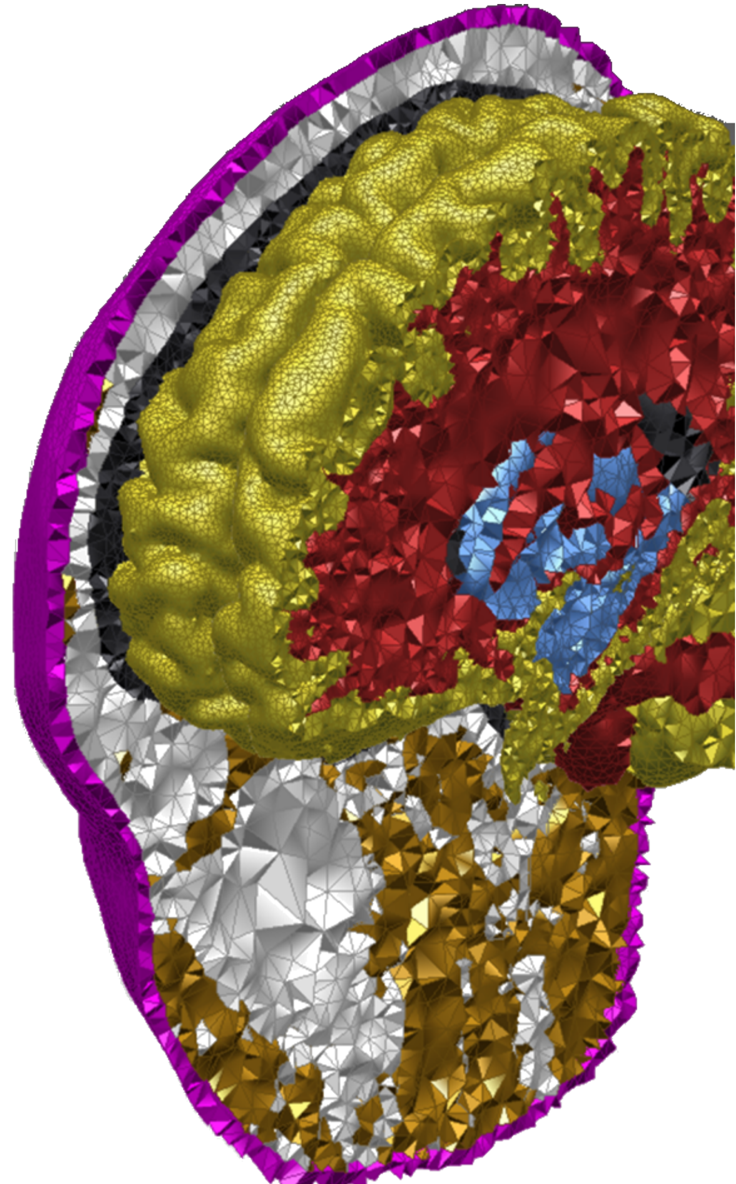


Marching cubes in octree

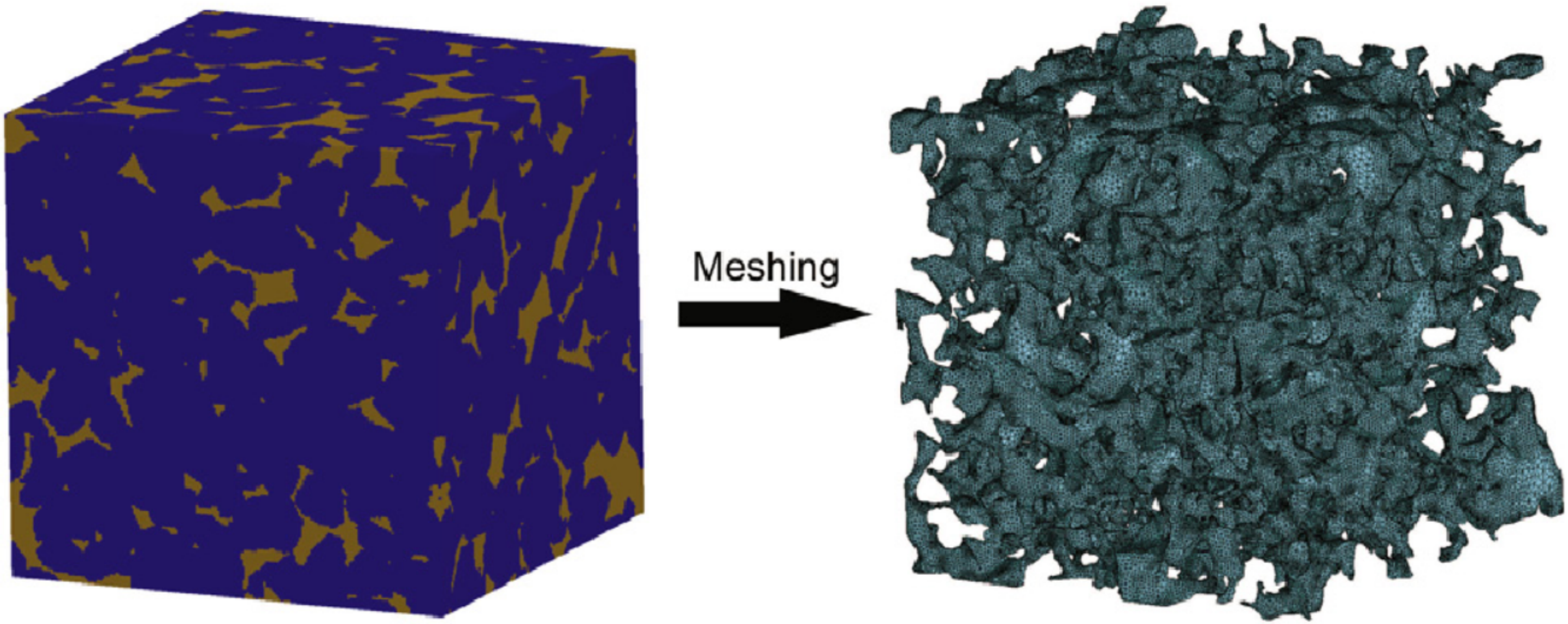


Volume Mesh (Segmented Image)





Volume Mesh (Segmented Image)

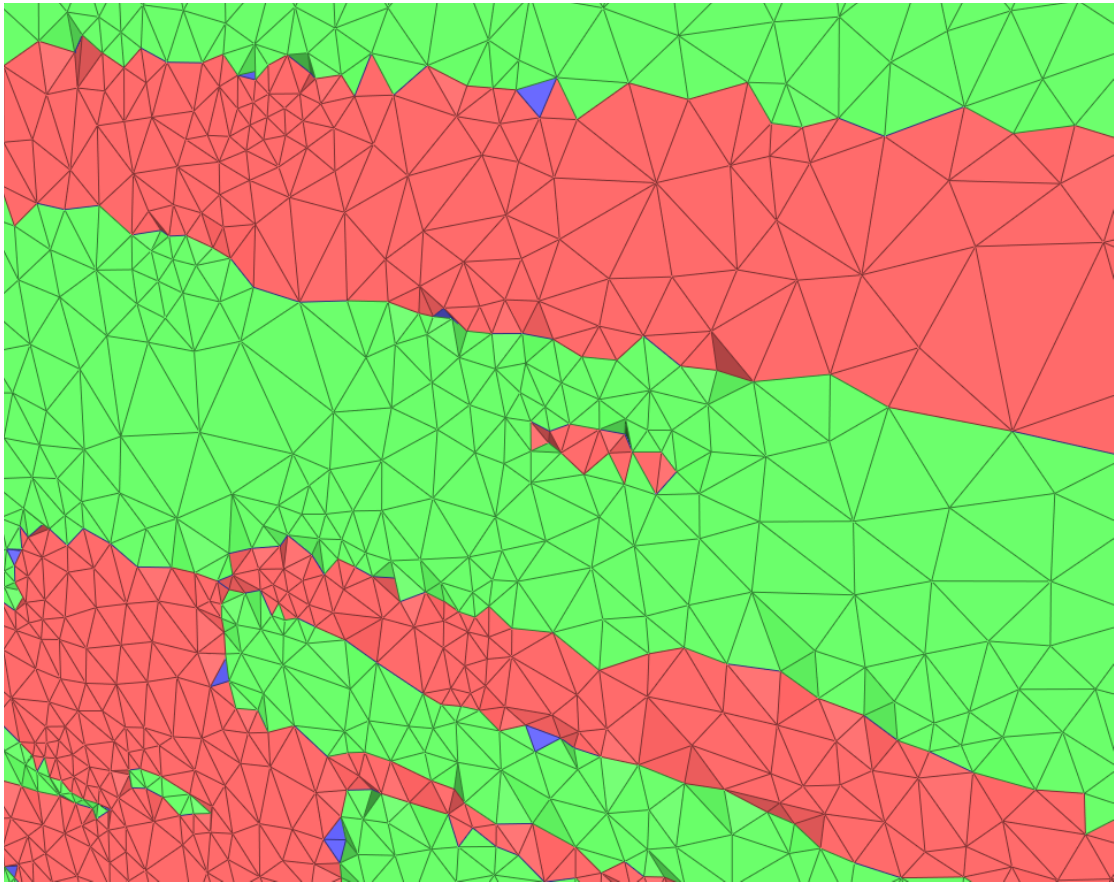


Efficient flow and transport simulations in reconstructed 3D pore geometries

Yan Zaretskiy a, Sebastian Geiger a, Ken Sorbie a, Malte Förster b
a Institute of Petroleum Engineering, Heriot-Watt University, EH14 4AS Edinburgh, UK
b Fraunhofer Institute for Algorithms and Scientific Computing, Schloss Birlinghoven, D-53754 Sankt Augustin, Germany

Volume Mesh (Segmented Image)

Low quality of iso-surface where it intersects the borders of the bounding cube

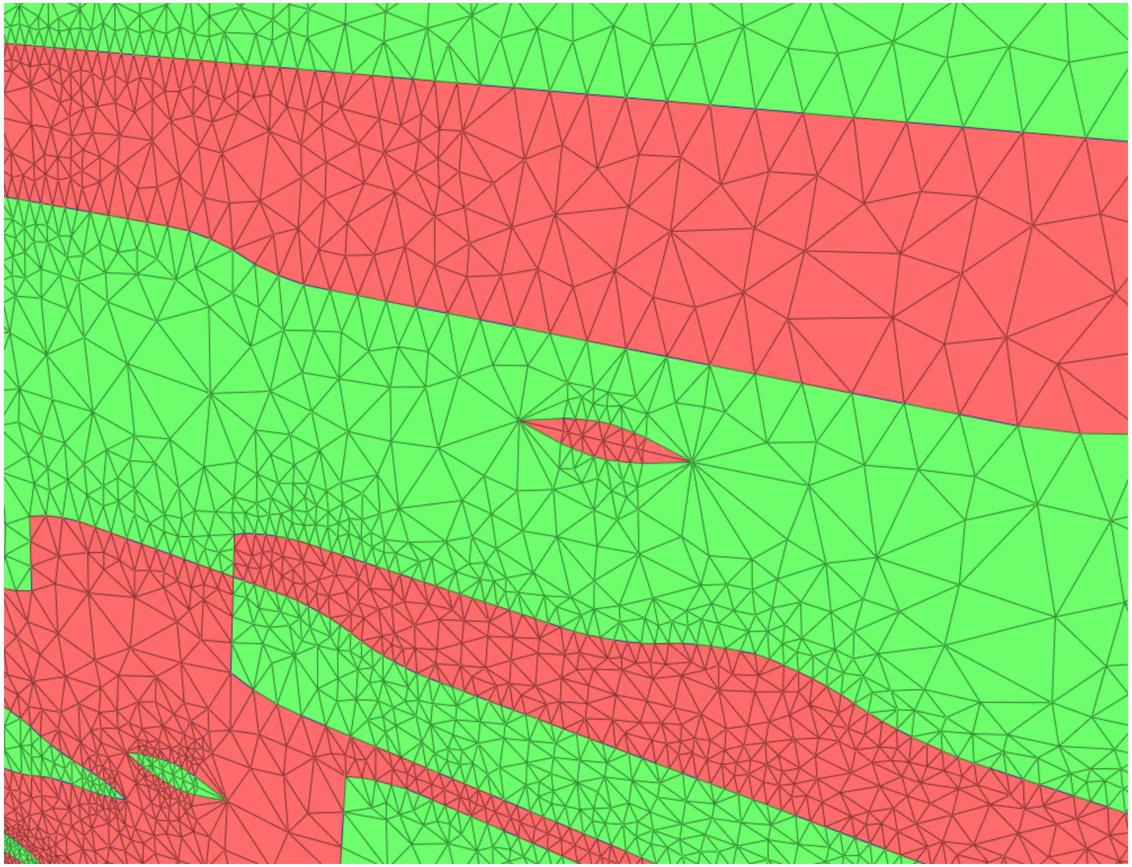


Volume Mesh (Segmented Image)

Fixed
(not yet released)

Sponsored by
terafrac.org

(→ David Bernstein
at 12:00)

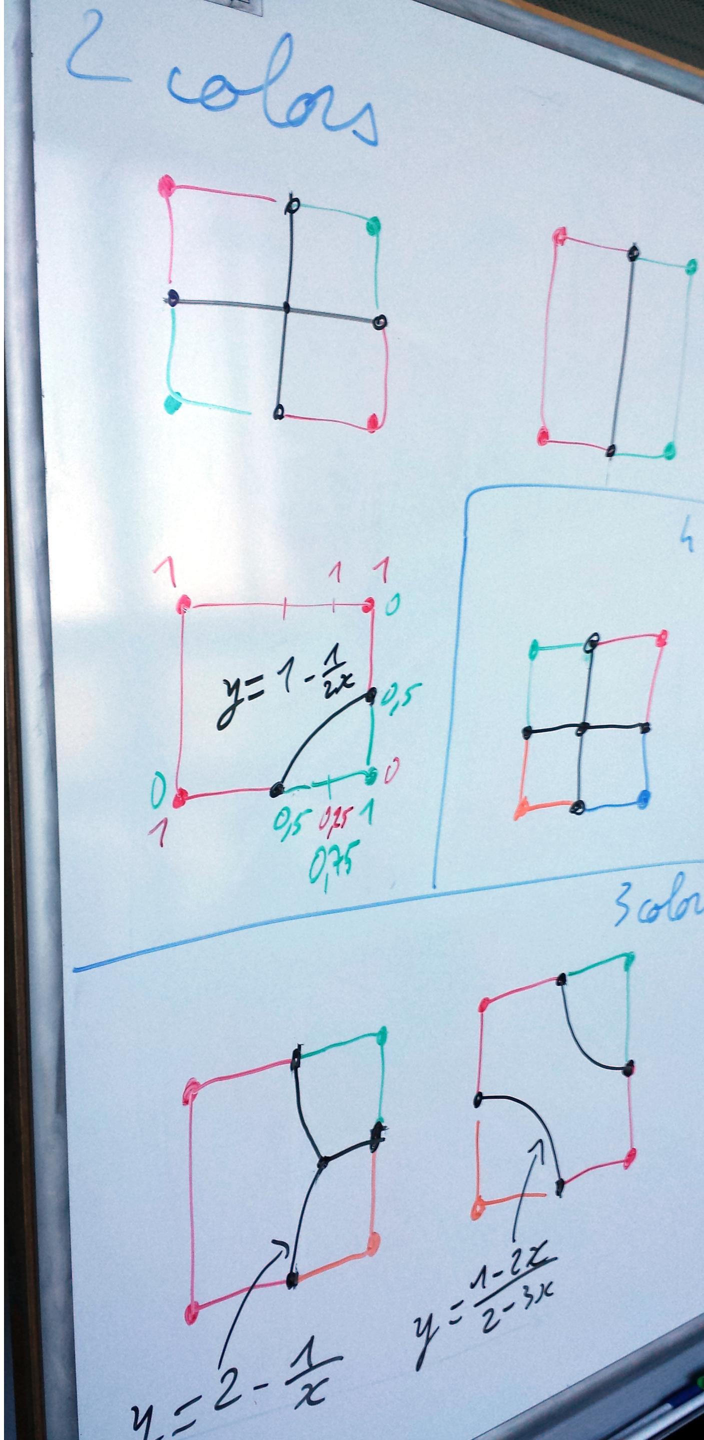


Volume Mesh

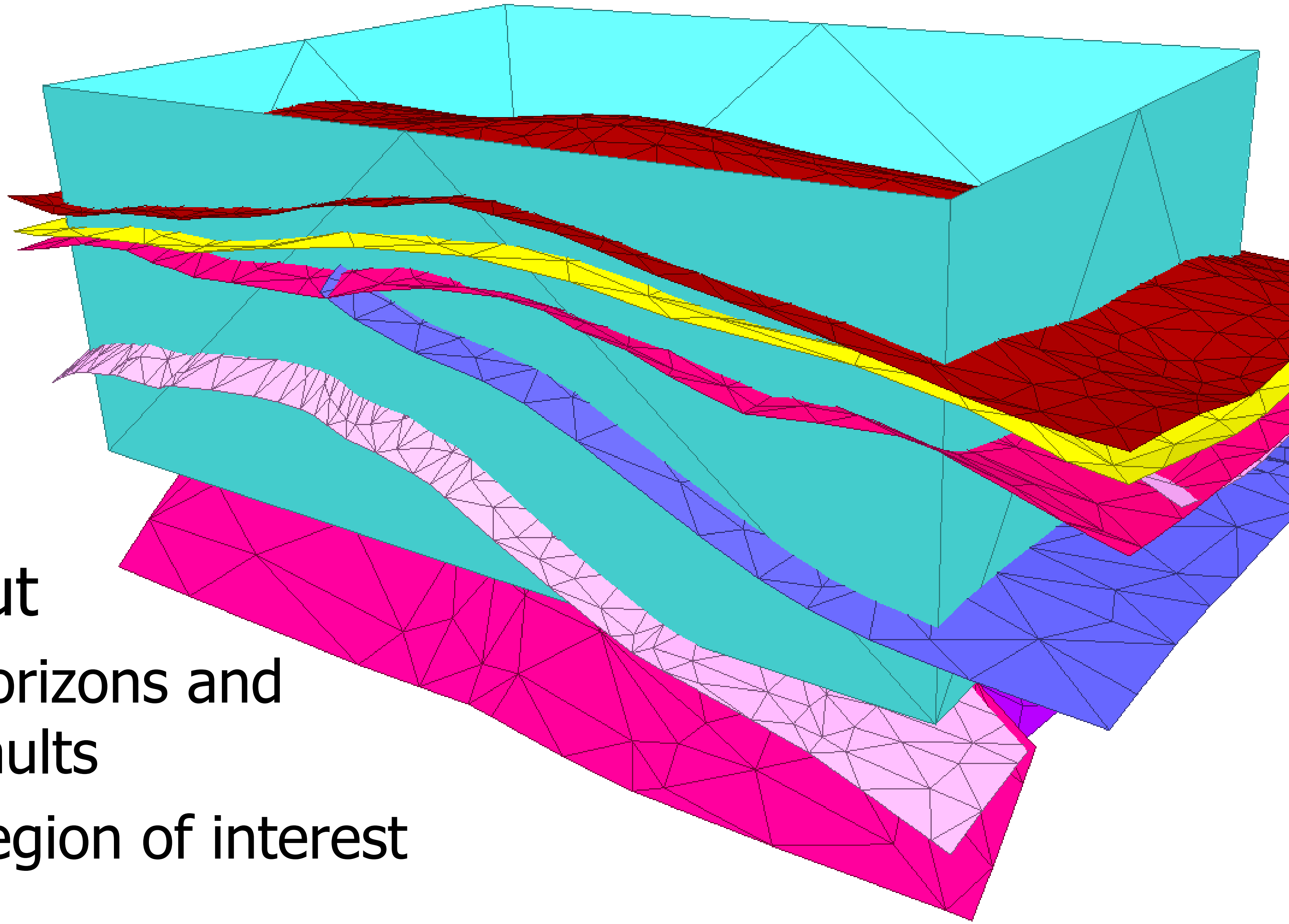
A similar problem arises inside the cube

where three materials meet.

That is not yet implemented. If you have such data, we can implement that for you…

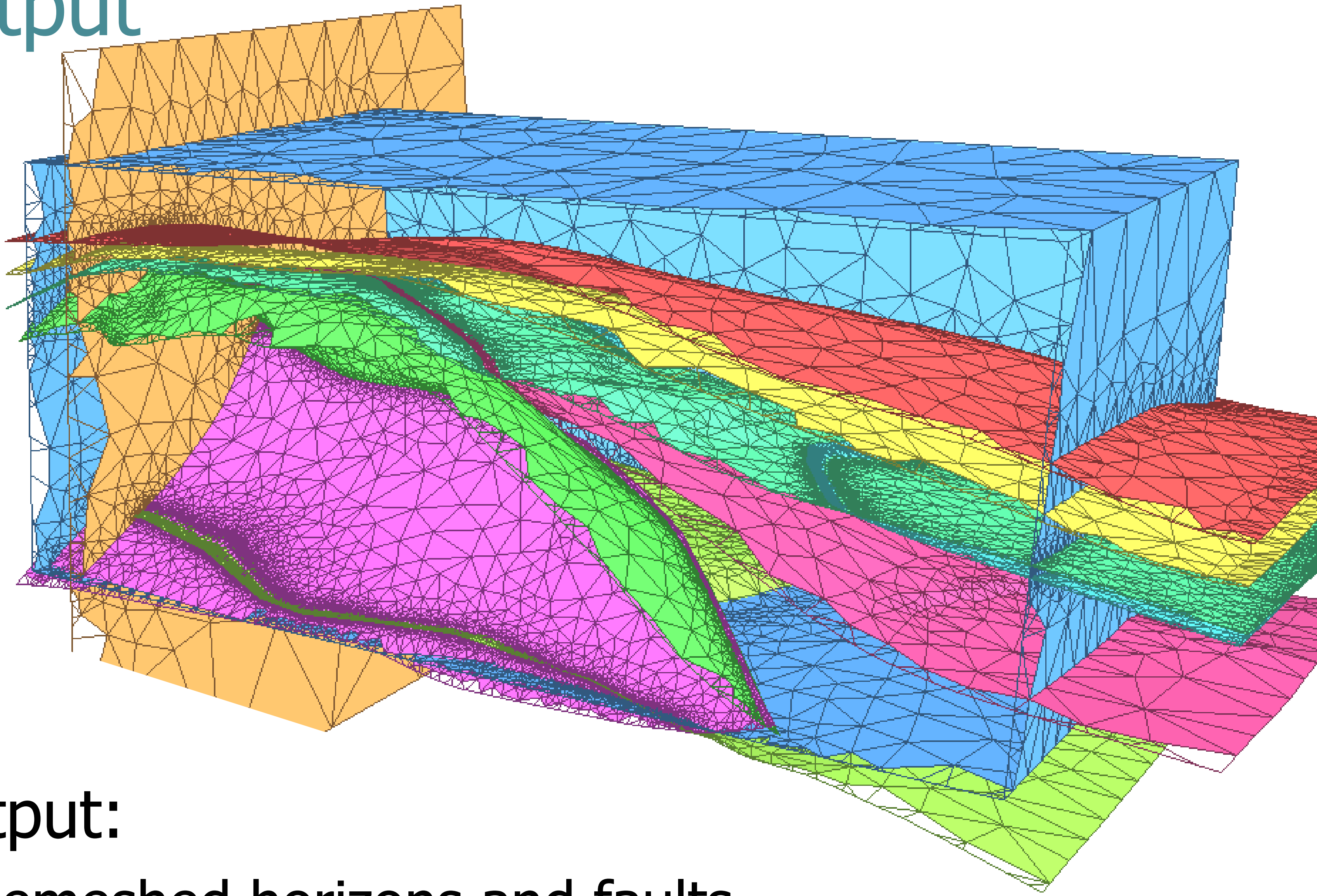


Volume Mesh (Constraint Surfaces)



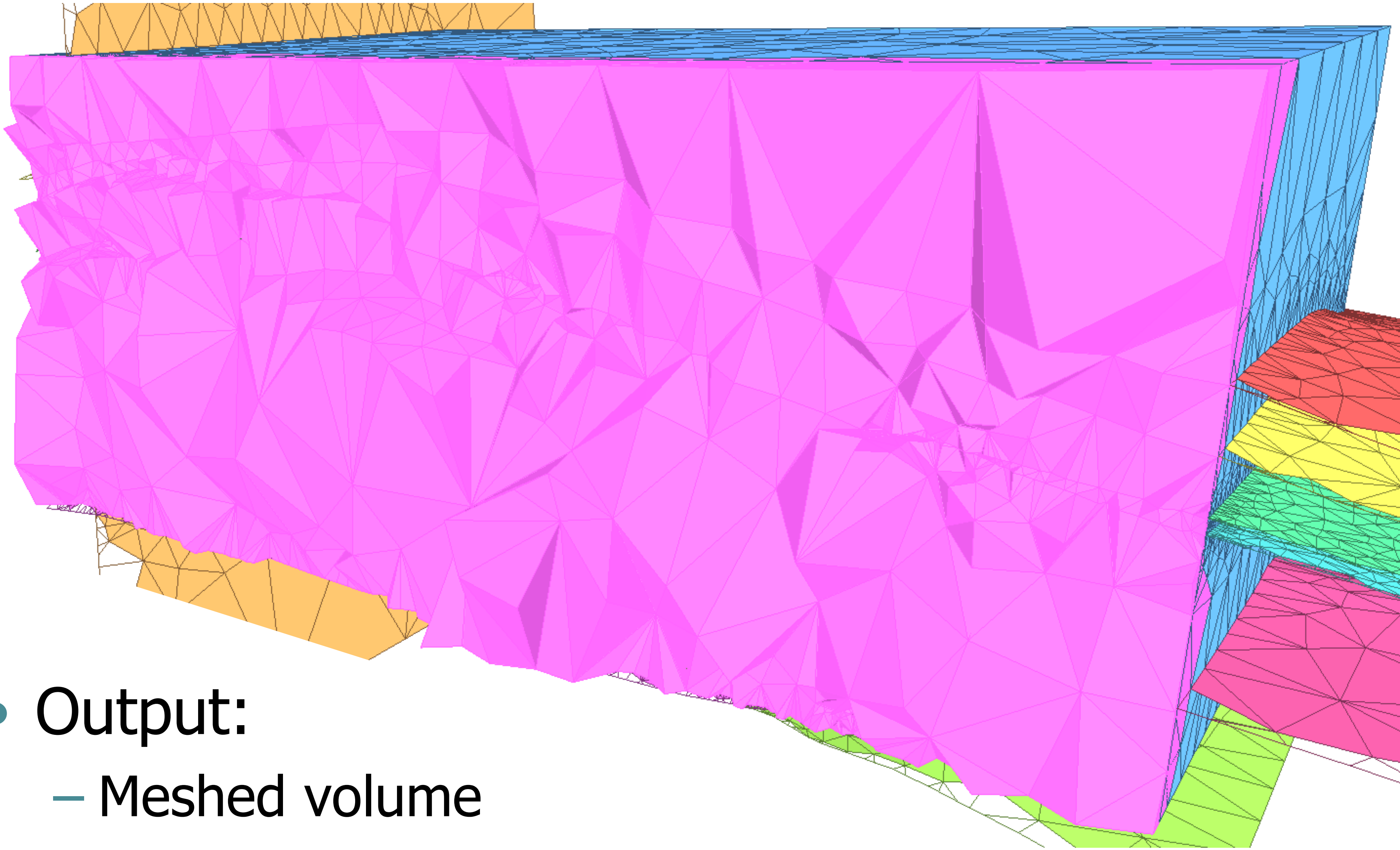
- Input
  - Horizons and Faults
  - Region of interest

Output



- Output:
  - Remeshed horizons and faults

Output

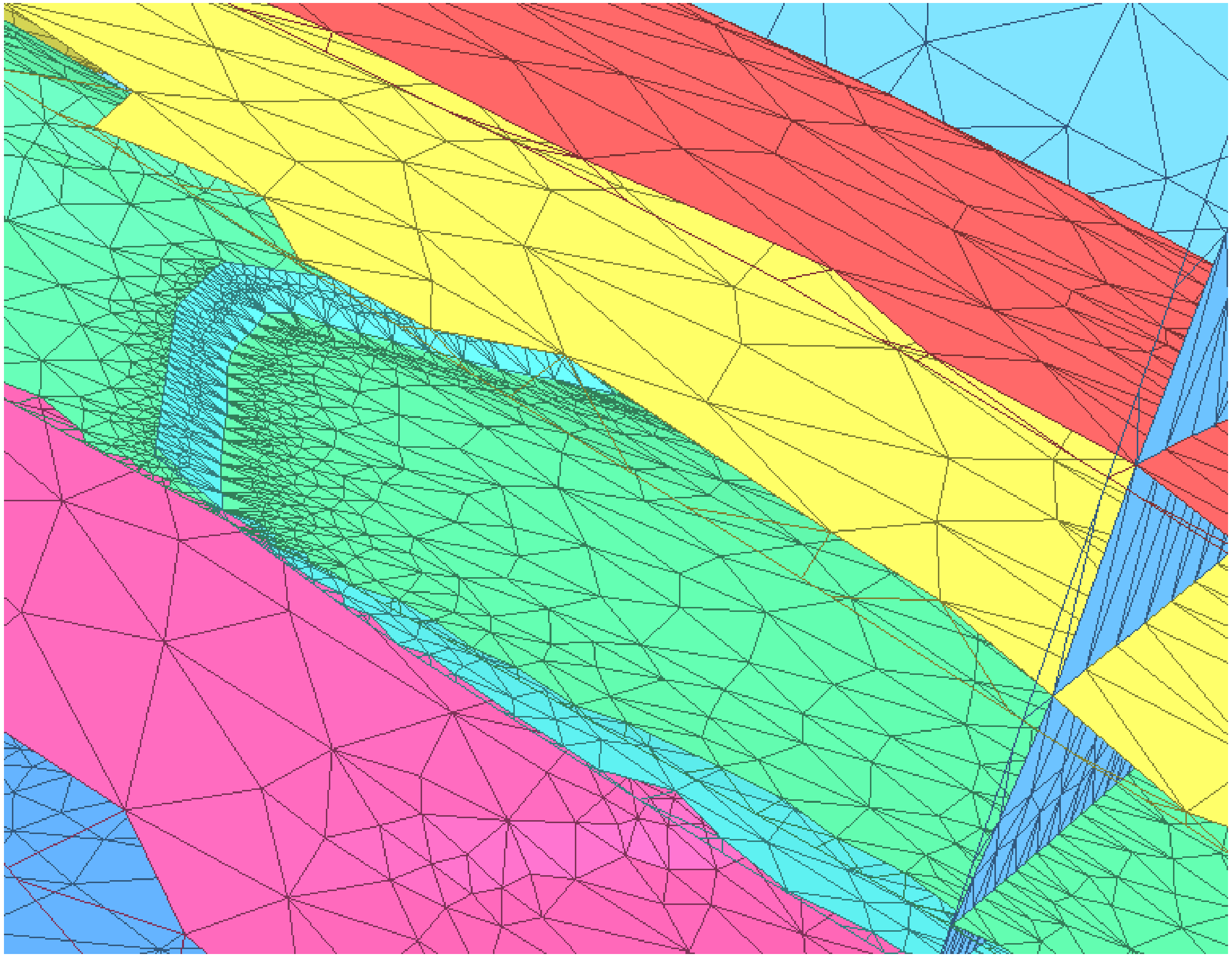


- Output:
  - Meshed volume

Output

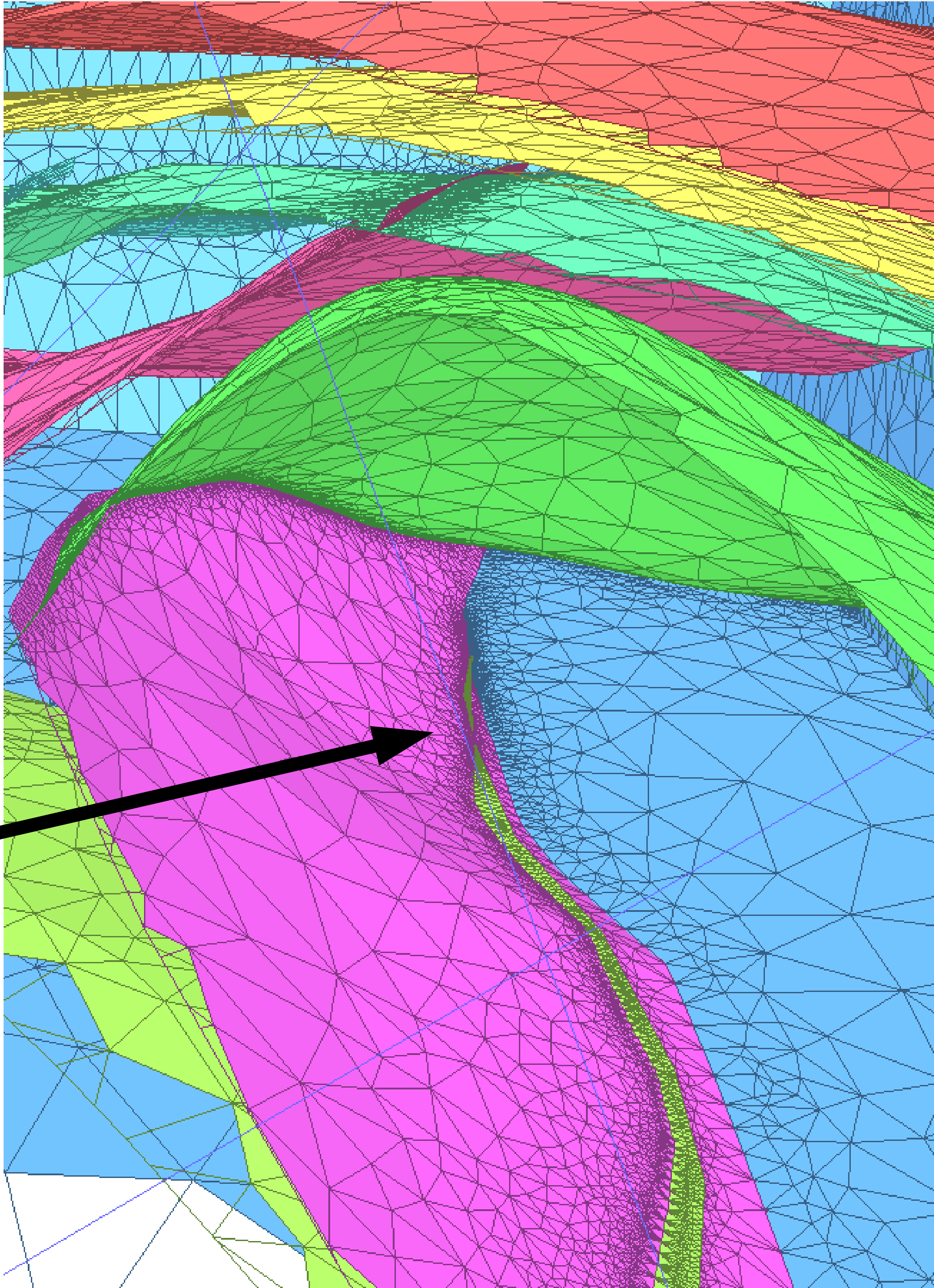
Close surfaces
lead to small
tetrahedra
and hence to
small triangles

Topological “badness”
avoids triangles that
connect different
surfaces



Output

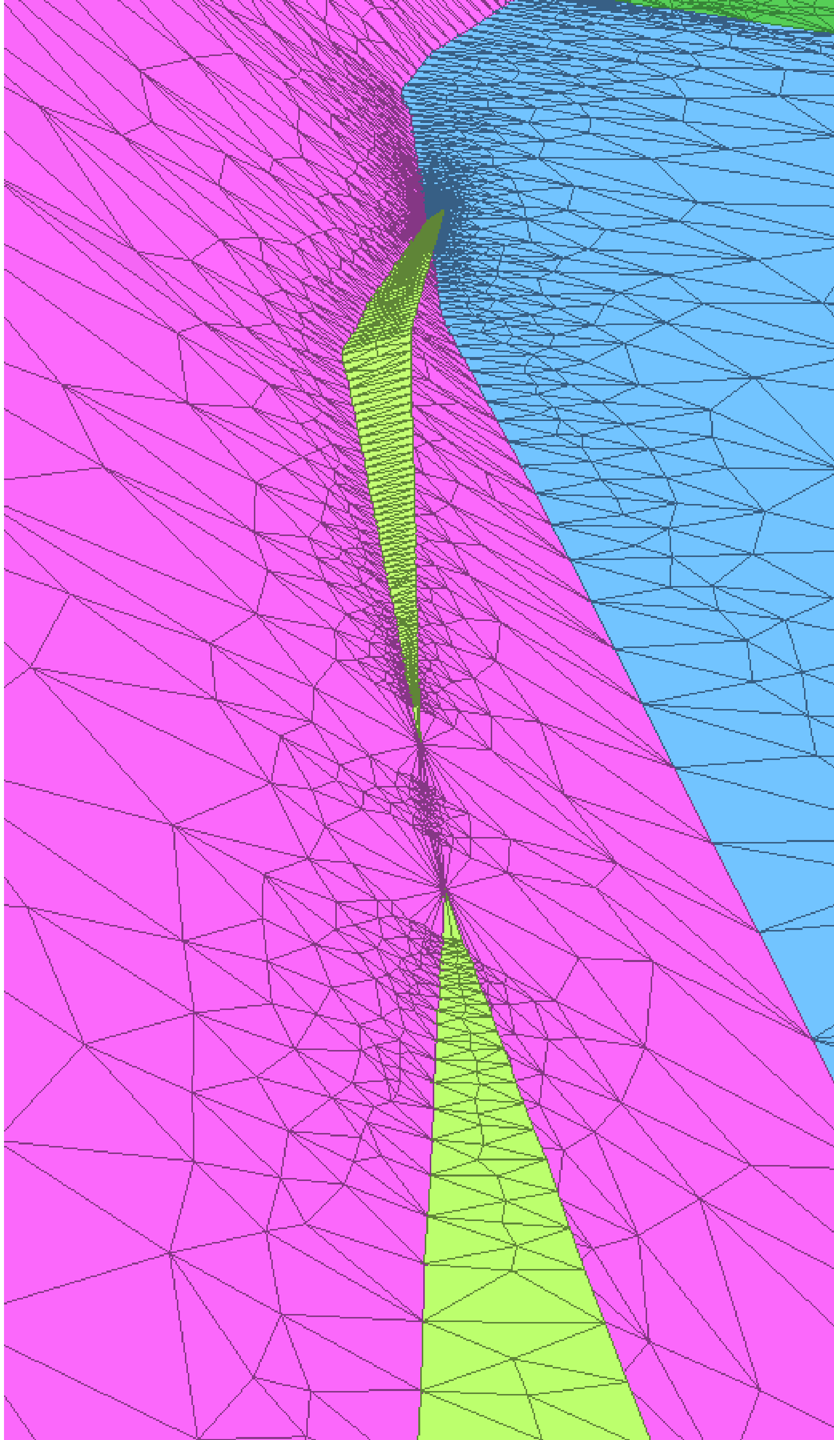
Protruding surfaces and gaps lead to small triangles



Output

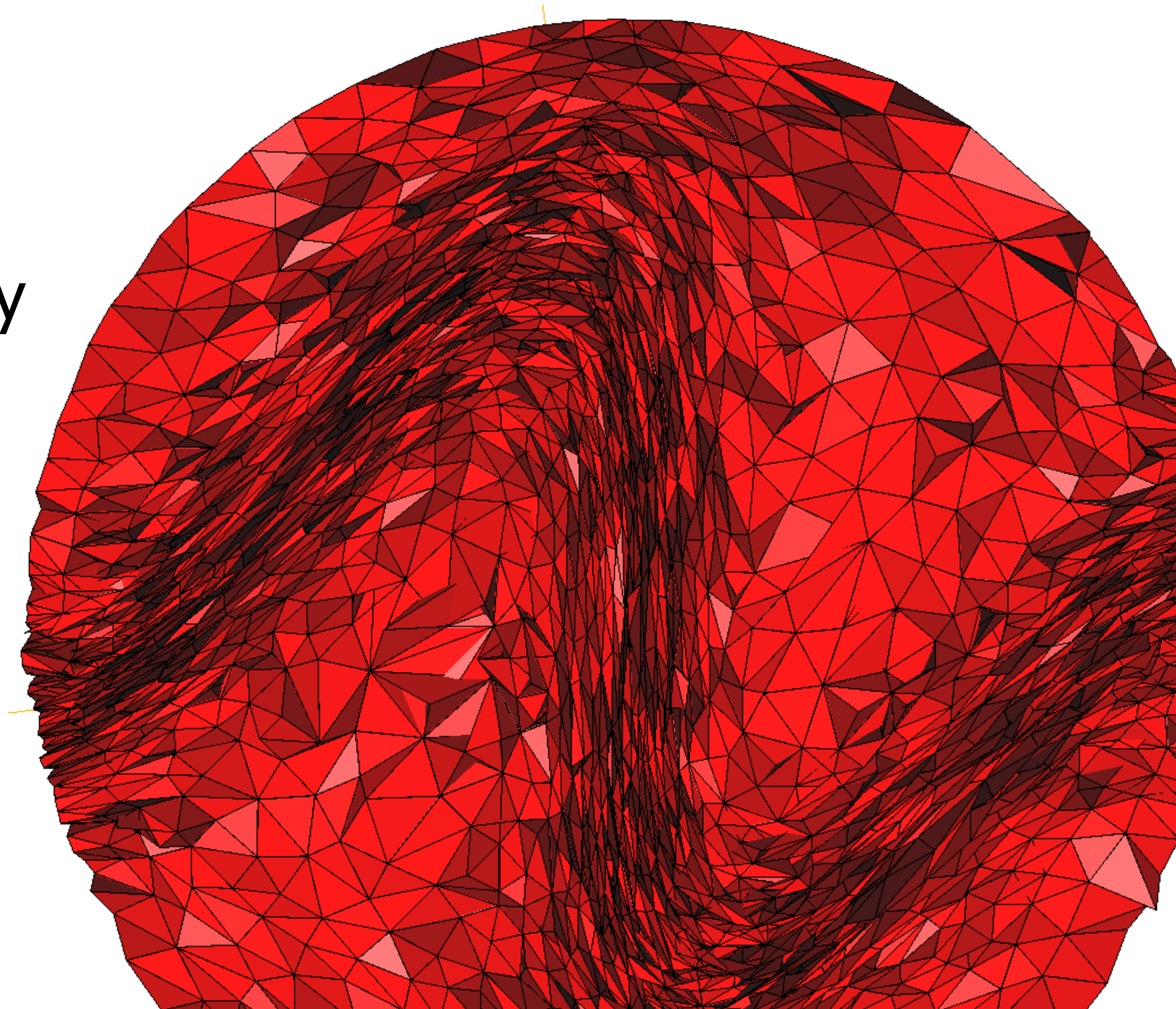
Protruding surfaces and gaps lead to small triangles

Work in Progress:
Clipping and Snapping



Anisotropic Mesh Generation - WIP

PhD student working at GeometryFactory



Anisotropic Mesh Generation

Questions to you: What are your needs?

- Is a metric-based approach useful for you?
- How strongly should the metric be honored?
- What other constraints would be useful:
  - -number of vertices?
  - -maximum angle?
  - -...?
- Do you have real world data for our research?

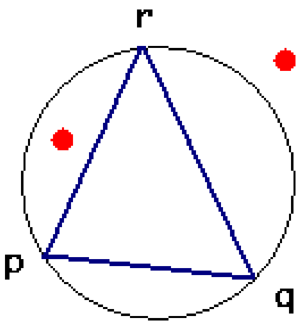
Generic Programming

Genericity in the STL

```
template <class Key, class Less>
class set {
  Less less;
public:

  void insert(Key k)
  {
     if (less(k, treenode.key))
       insertLeft(k);
     else
       insertRight(k);
  }
};
```

Genericity in CGAL (à la STL)

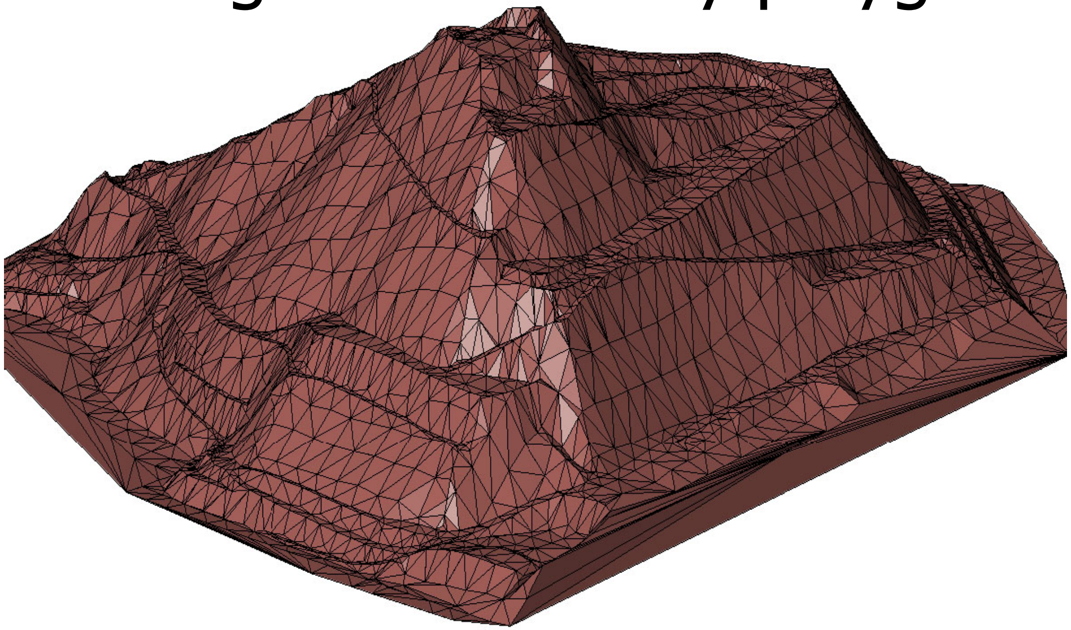
```
template < class Geometry >
class Delaunay_triangulation_2 {
    Geometry::Orientation orientation;
    Geometry::In_circle in_circle;

    void insert(Geometry::Point t) {
        ...
        if(in_circle(p,q,r,t)) {...}
        ...
        if(orientation(p,q,r){...}
    }
};
```



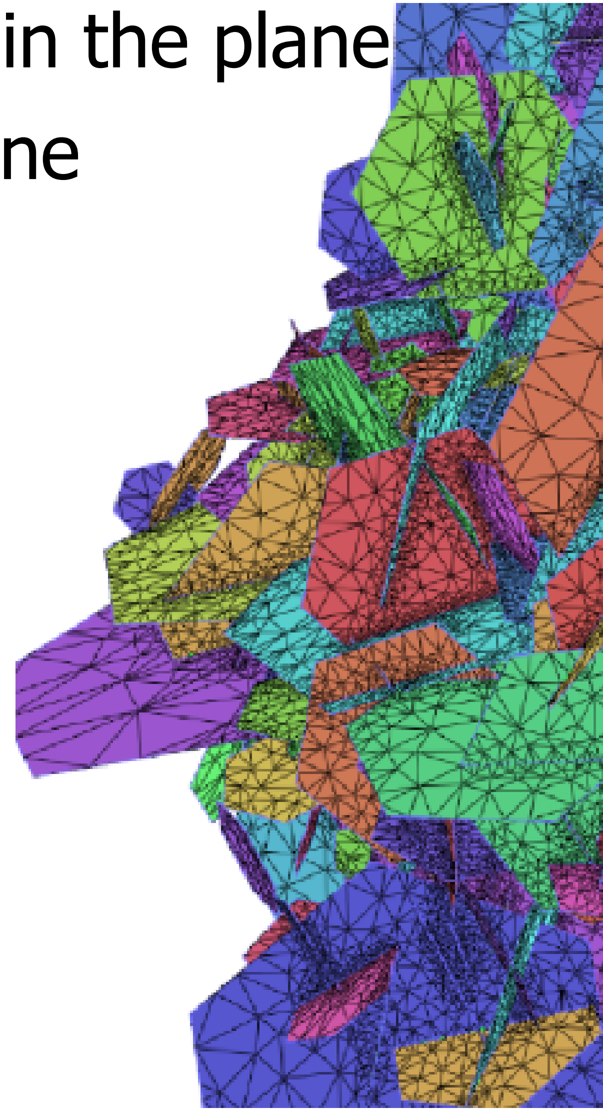
CGAL Genericity

Without explicit conversion to points in the plane

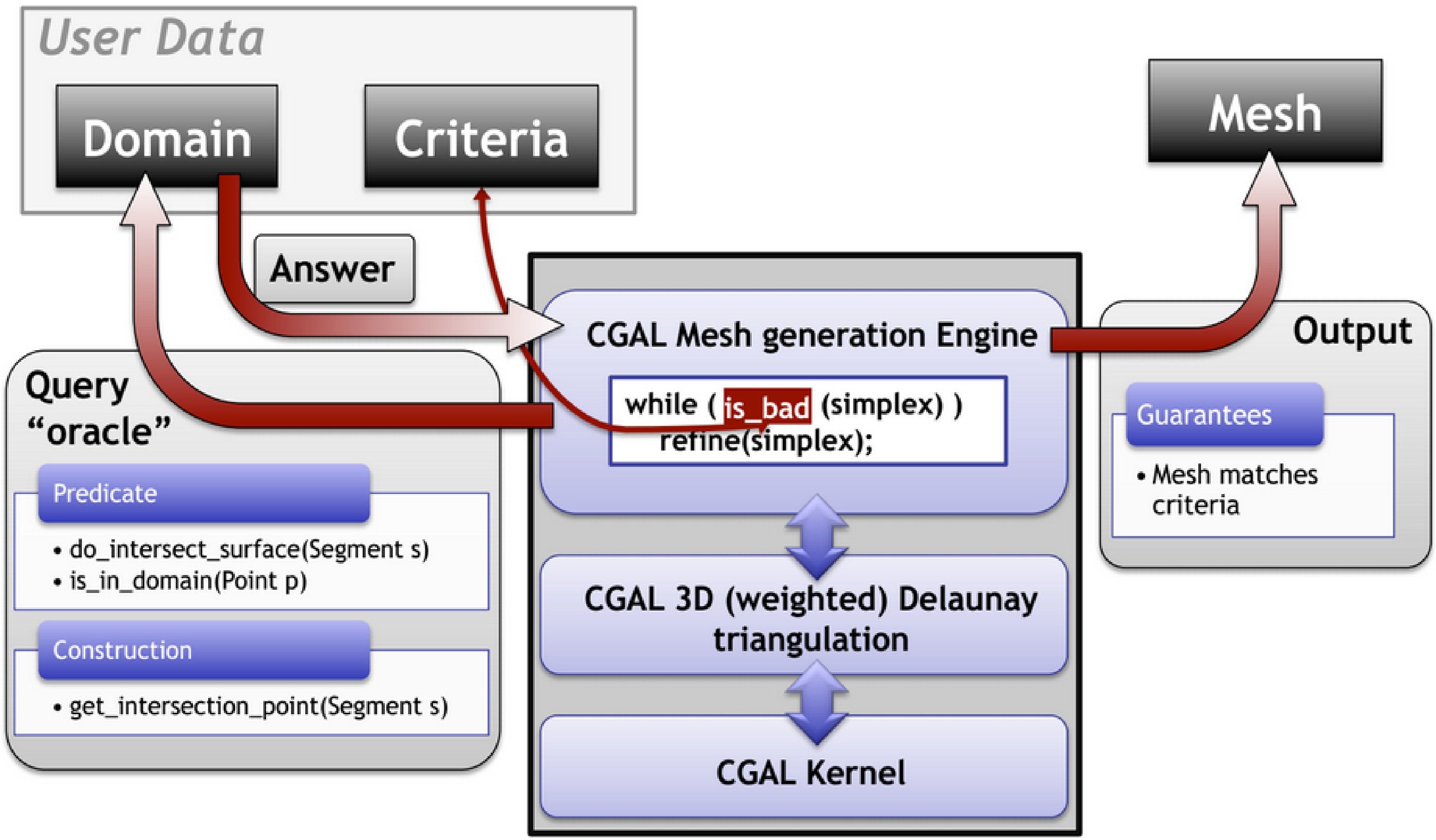
- Triangulate the terrain in an xy-plane
- Triangulate arbitrary polygons



Courtesy: IPF,Vienna University of Technology & Inpho GmbH



Genericity in Mesh Generation

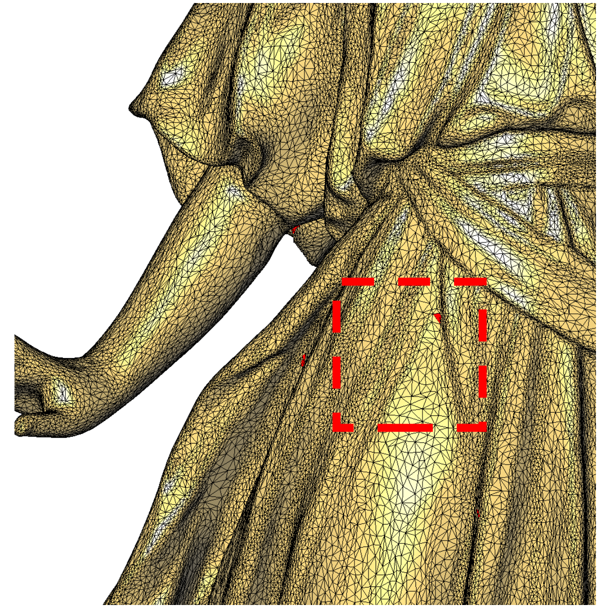


Beyond Mesh Generation

Interesting for FeniCS ?

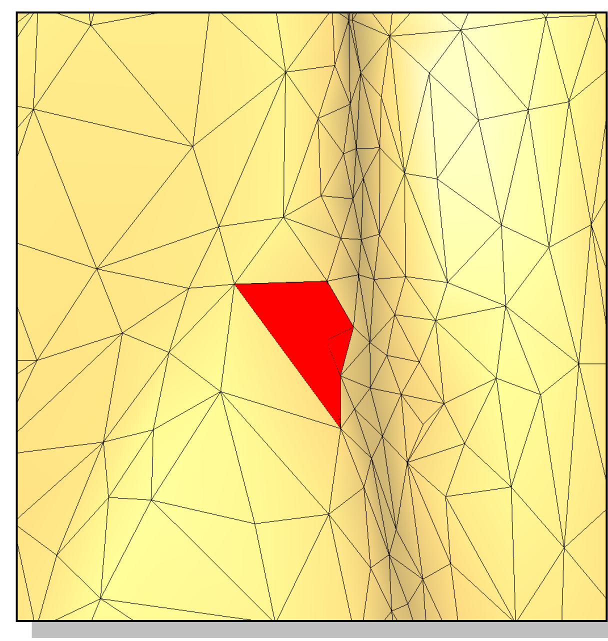
Intersection Detection

- Efficient algorithm for finding all intersecting pairs for large numbers of axis-aligned bounding boxes.



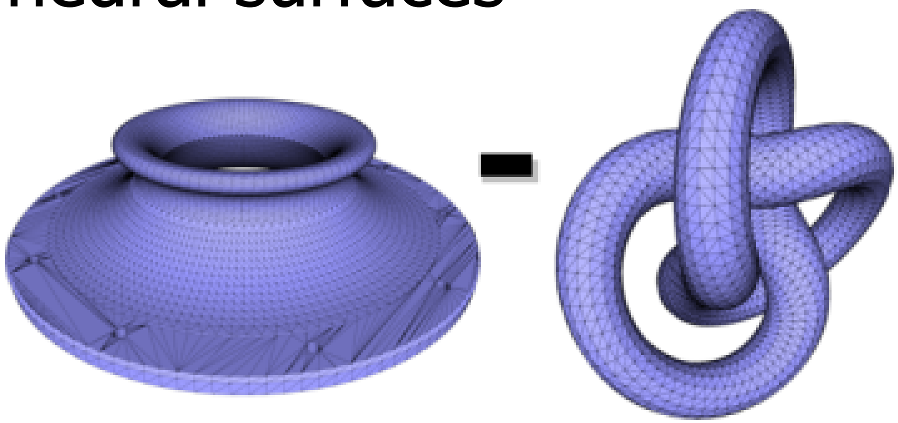
500K vertices

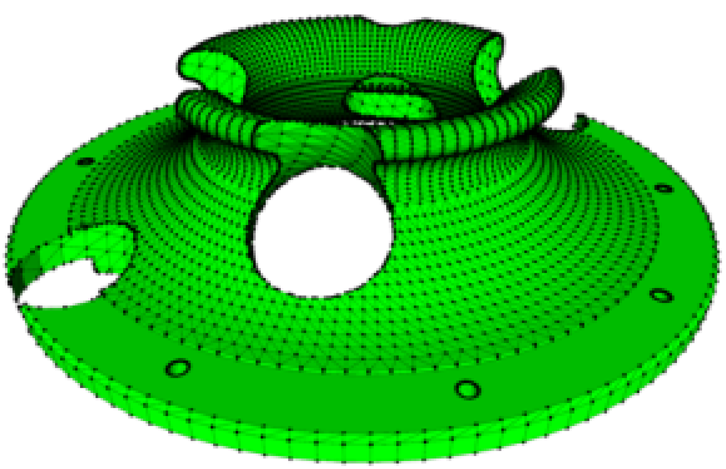
486 intersecting triangles in 4s

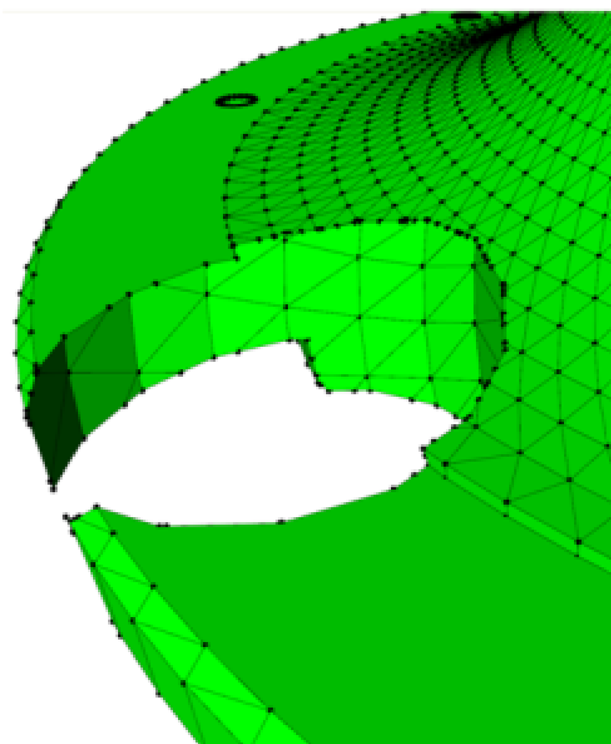


3D Boolean Operations

- Mathematically generic, but slow version in CGAL
- Coming Soon: Fast and robust version, restricted to polyhedral surfaces







L. Rineau CGAL/GeometryFactory

Conclusion

- CGAL is a collection of adaptable, extensible geometric software components
  See: http://www.cgal.org/packages

- CGAL does not offer a mesh generation application but the building blocks for such applications

- GeometryFactory offers
  - commercial licenses for CGAL components
  - support and development for customers

Questions?

Remember I also have questions about needs of anisotropic meshes...

Meet me:

- during lunch,
- or at the “Meet the developers” time after the afternoon session...