Optimizing CAD and Mesh Generation Workflow for SeisSol

Sebastian Rettenberger
rettenbs@in.tum.de

Cameron W. Smith
smithc11@rpi.edu

Christian Pelties
pelties@geophysik.uni-muenchen.de

Background

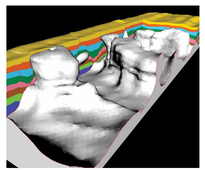
SeisSol:

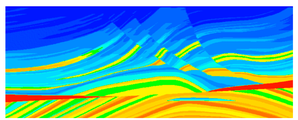
- Seismic wave propagation in heterogeneous media
- Complex muliphysics earthquake simulation including dynamic rupture
- Unstructured tetrahedral meshes for complicated geometries

Goals:

- Adress fundamental questions in earthquake dynamics
- Generate realistic earthquake scenarios for hazard assessment

Examples of multi-layer geometric data sets





Current method of generating models and meshes using GAMBIT is unsatisfactory:

- Tools require many person -hours of manual editing
- Including multiple geometric model layers is difficult

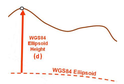
Geometric Model Layers of Interest:

- Earth surface topography and ocean
- Sedimentary interface
- Upper and lower crust interfaces
- The Mohorovicic discontinuity

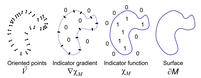
CAD Generation

For each geometric model layer:

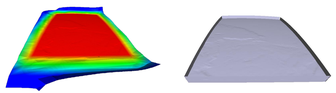
- Project the source data to Cartesian coordinates.
  - Geological data is typically given in latitude, longitude, and depth (d) w.r.t. a reference ellipsoid.
  - Transformation of each point via PyPROJ.
- Compute the point normals.
- Run MeshLab Poisson surface reconstruction.
- Trim the surface based on distance to original point cloud.



Point projection.



Poisson surface reconstruction.

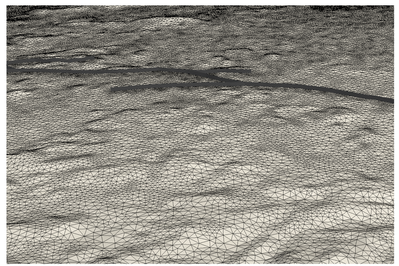


The distance field (left) and the trimmed surface with bounding box(right).

- Generate a bounding surface and project to reference ellipsoid.
- Generate the non-manifold model with Simmetrix GeomSim surface booleans.
- Remove interface intersection artifacts and 'small' features.

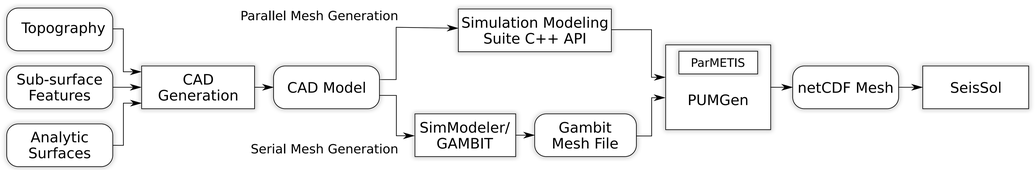
Parallel Mesh Generation

- Fully automated parallel mesh generation with Simmetrix Simulation Modeling Suite
- Creates meshes with hundreds of millions of elements on small clusters
- Mesh directly accessible through C++ API (no intermediate I/O required)
- Includes boundary condition defined in the CAD model



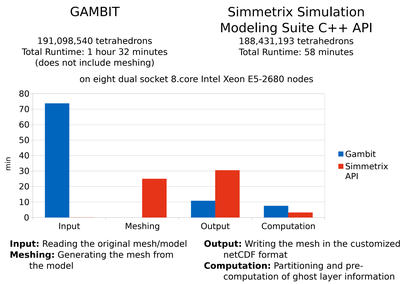
184.433.310 element mesh including detailed topography and fault geometry

Automated Workflow for SeisSol's Meshes



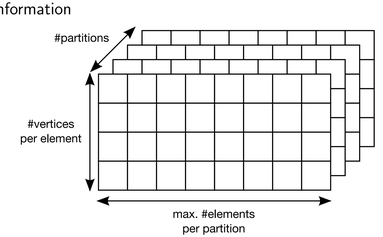
PUMGen

- Generator for SeisSol's custom netCDF format
- Can use different sources:
  - Simmetrix Simulation Modeling Suite C++ API
  - Legacy mesh formats (e.g. GAMBIT)
  - ...
- Parallelized using MPI



Customized netCDF format:

- Binary format for SeisSol meshes
- Partitioned data layout allows fast collective MPI-I/O
- Contains precomputed ghost layers and connectivity information

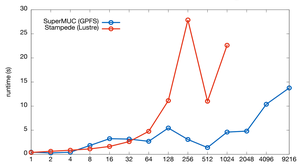


Initialization in SeisSol

- New mesh format reduces initialization in SeisSol from hours to seconds for very large meshes
- Collective I/O operations are possible due to simple access patterns

Mesh Initialization – Weak Scaling

- 400,000 tetrahedrons per node
- Dual socket 8-core Intel Xeon E5-2680 nodes



All tests with less than 4,096 nodes are performed during normal user operation and include variations due to different occupancy rates of the file system.

Closing Remarks and Future Work

Optimized CAD and mesh generation workflow:

- Simplified CAD generation
- Parallel meshing with Simmetrix Simulation Modeling Suite
  → Completely avoids slow serial I/O
- Automated workflow saves many person-hours of manual processing
- Mesh initialization within seconds on several thousand nodes in SeisSol

Future work:

- Direct discrete surface creation from structured point cloud data with Simmetrix tools.
- Generalize workflow for other applications

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