Workshop on Octree-based Methods in Computational Physics

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Parallel Mesh Generation for Hierarchical Cartesian Grid Methods

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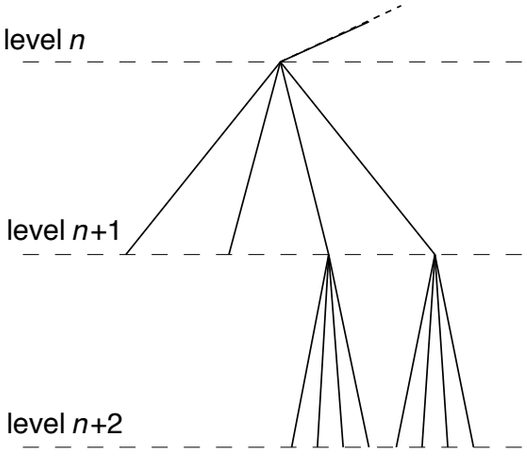
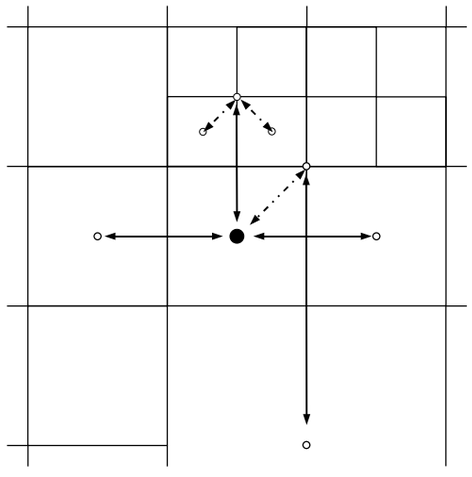
Why using Hierarchical Cartesian Meshes?

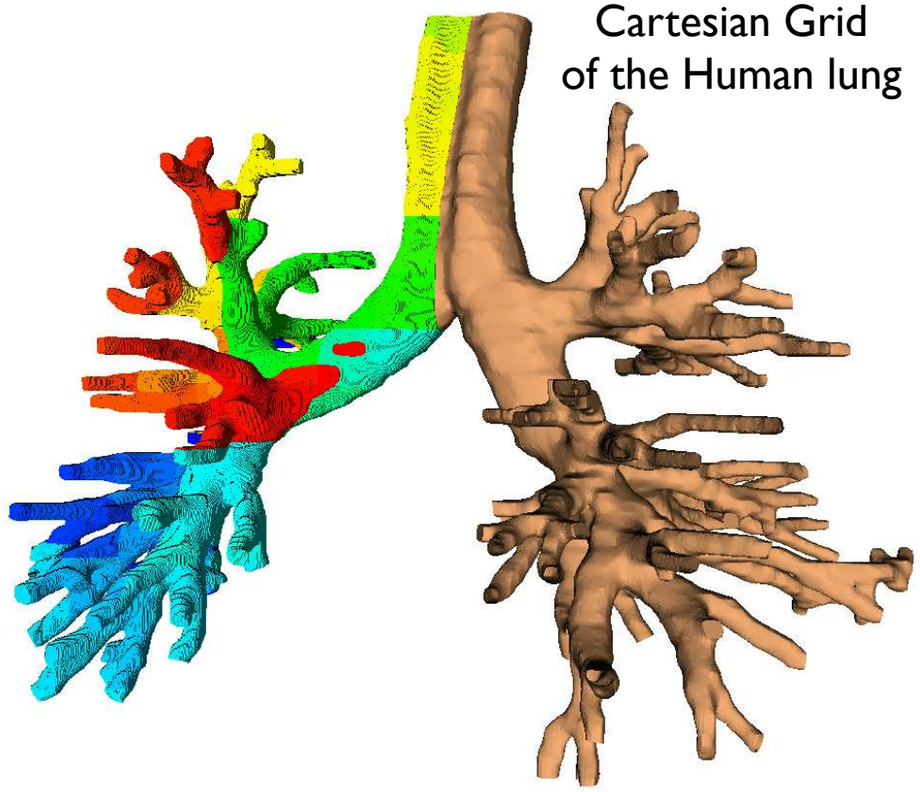
Advantages:

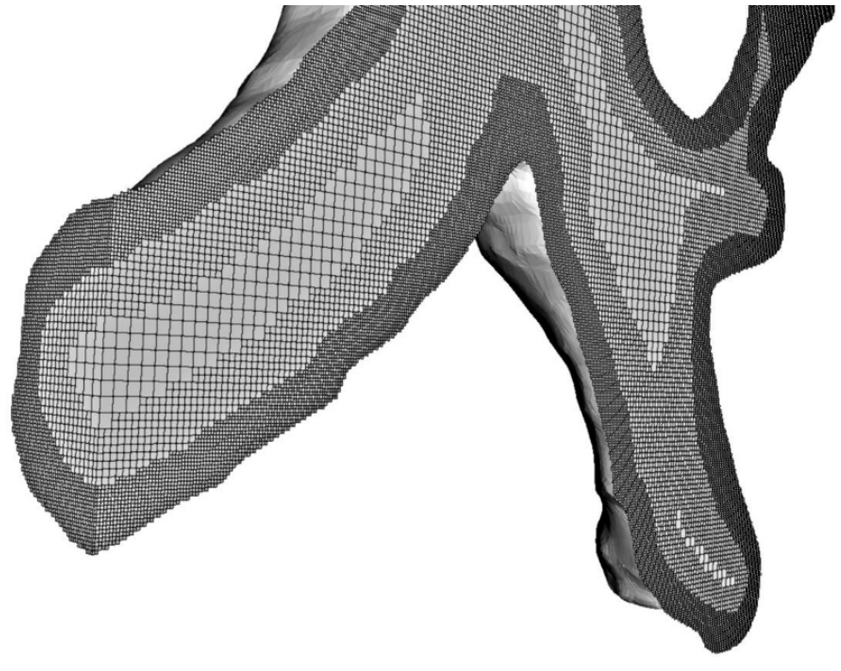
- Fully automatic mesh generation
- Simple generation of solution adaptive meshes
- High accuracy due to orthogonal mesh lines
- Formulation of high-order accurate schemes is possible
- Hierarchical structure enables efficient coupling of different methods





Cartesian Grid of the Human lung



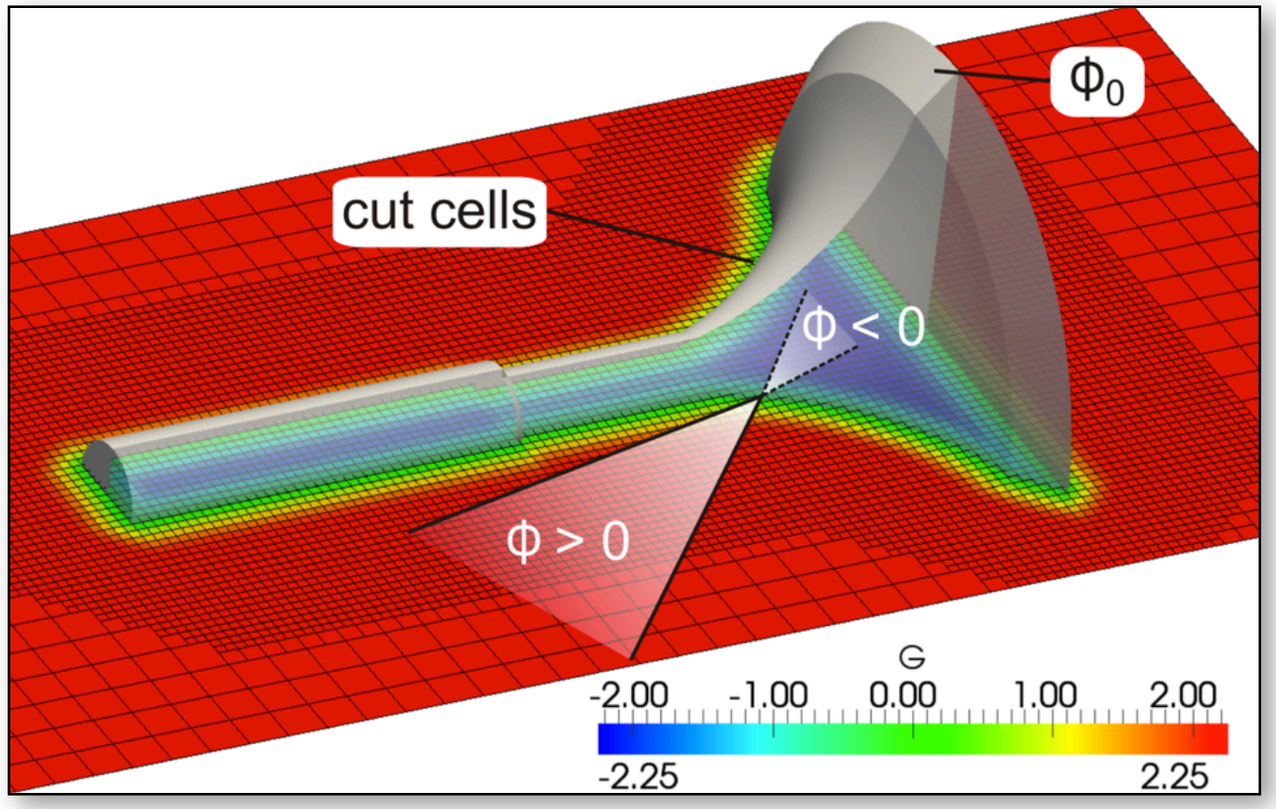


Disadvantages:

- Difficult formulation of boundary conditions (FV)
- Not suitable for the resolution of thin-layers with high gradients

The Level Set Method is used for Tracking Interfaces

- Representation of surfaces by zero contour Φ_0 of a signed distance function $\Phi(x,t)$



Level set representation of an engine valve

- Solve level set equation:

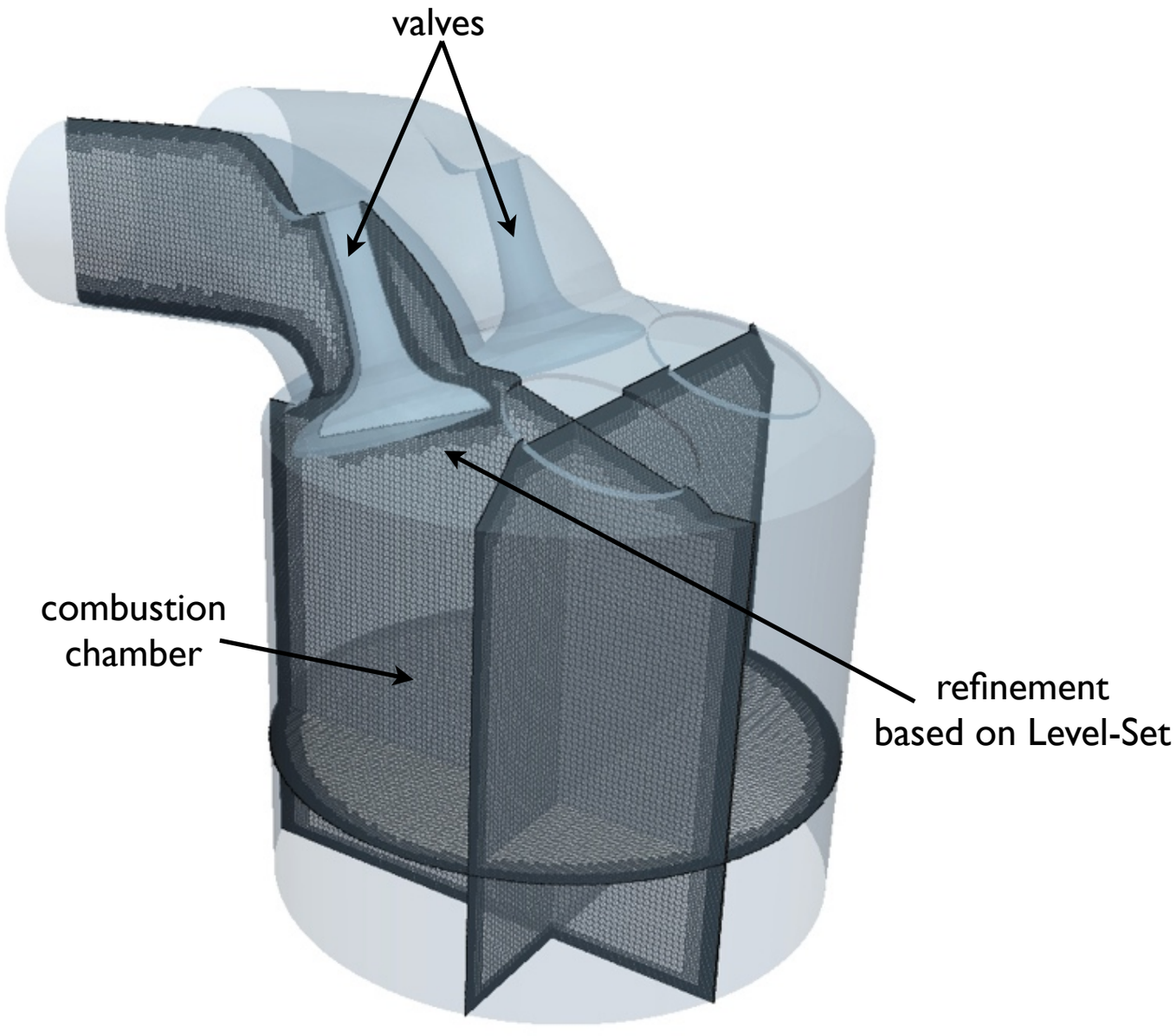
$$\frac{\partial \phi}{\partial t} + \mathrm{f} \cdot \nabla \phi = 0$$

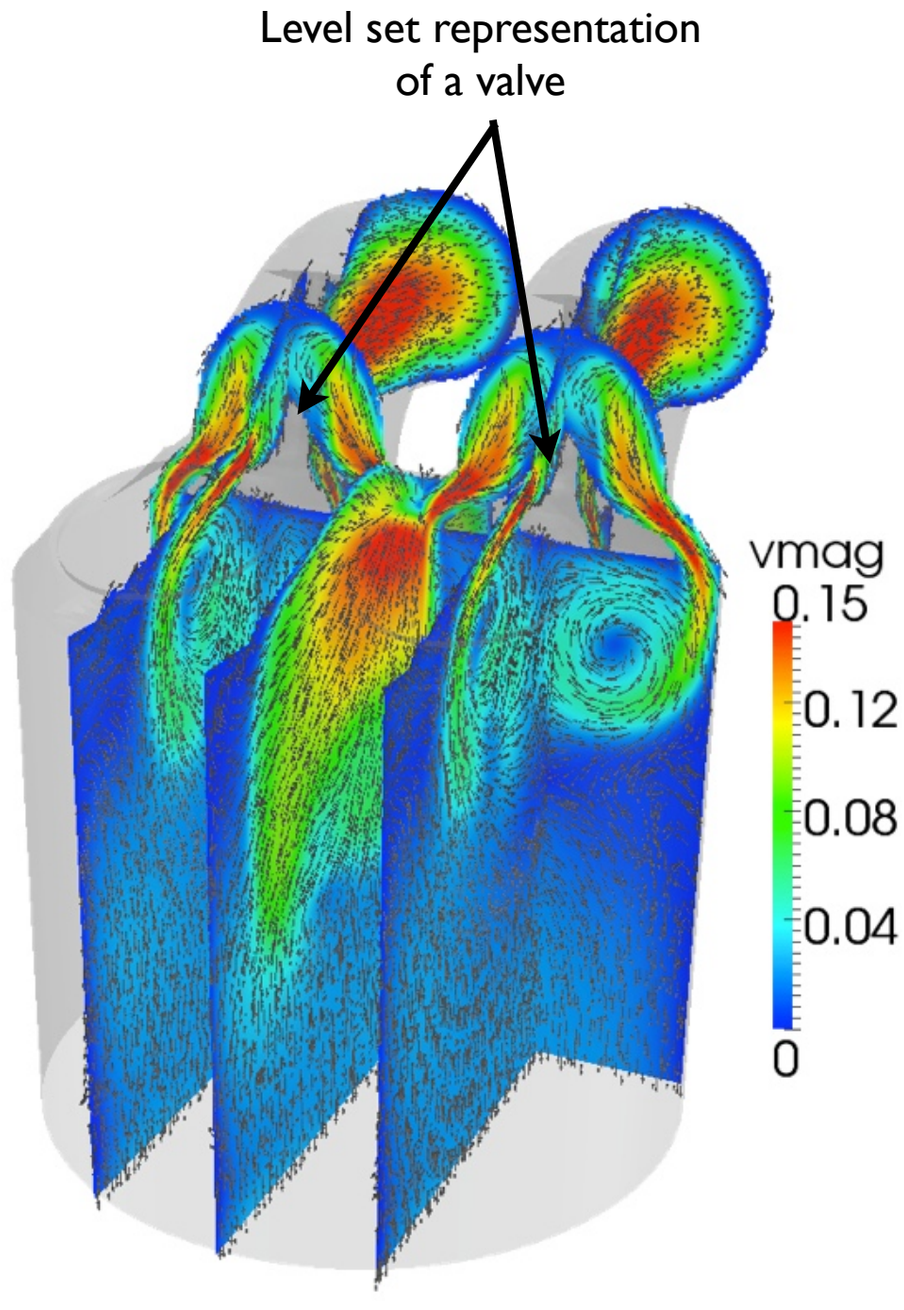
f: body velocity

Hartmann et al., J. Comput Phys., 227:6821-6845, 2008;
Hartmann et al., J. Comput. Phys., 229:1514-1535, 2010;
Hartmann et al., Combust. Flame, 158:1318-1339, 2010

3D-Engine Flows

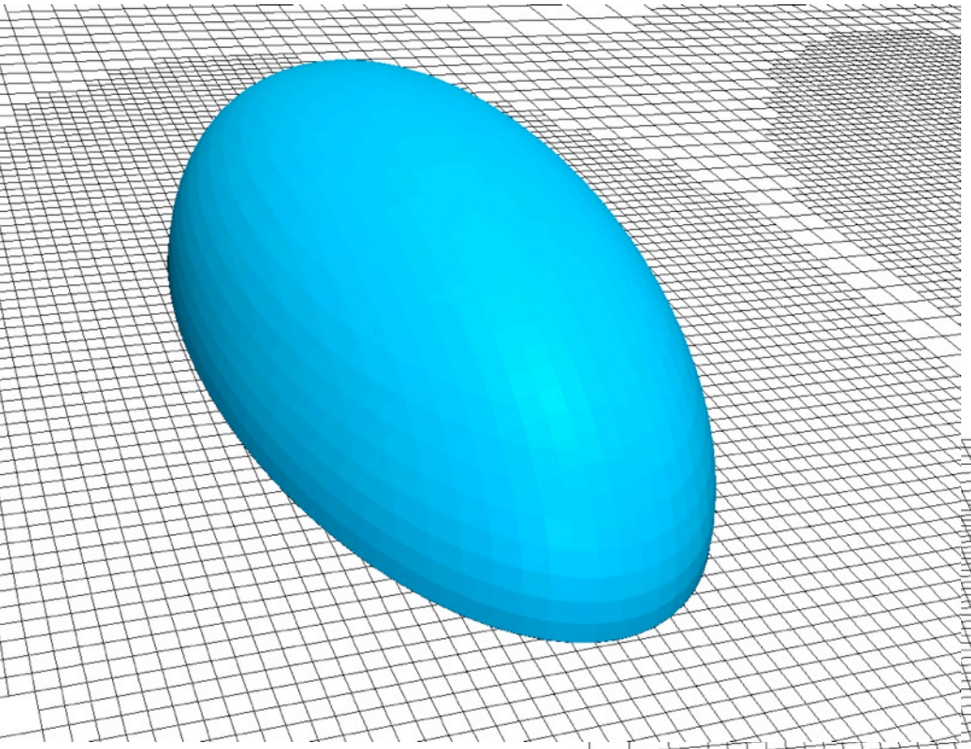
- Unsteady 3D simulation of engine flow
  - full DNS requires 3.0 x 10^9 cells
  - simulation is only possible on HPC systems



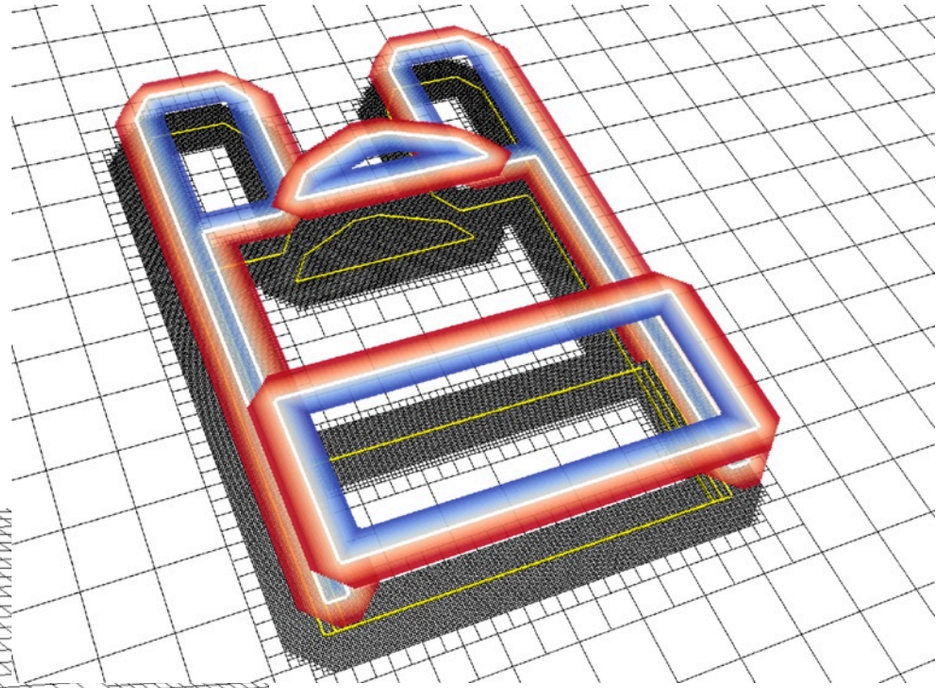


Moving Boundaries and Particle Tracking

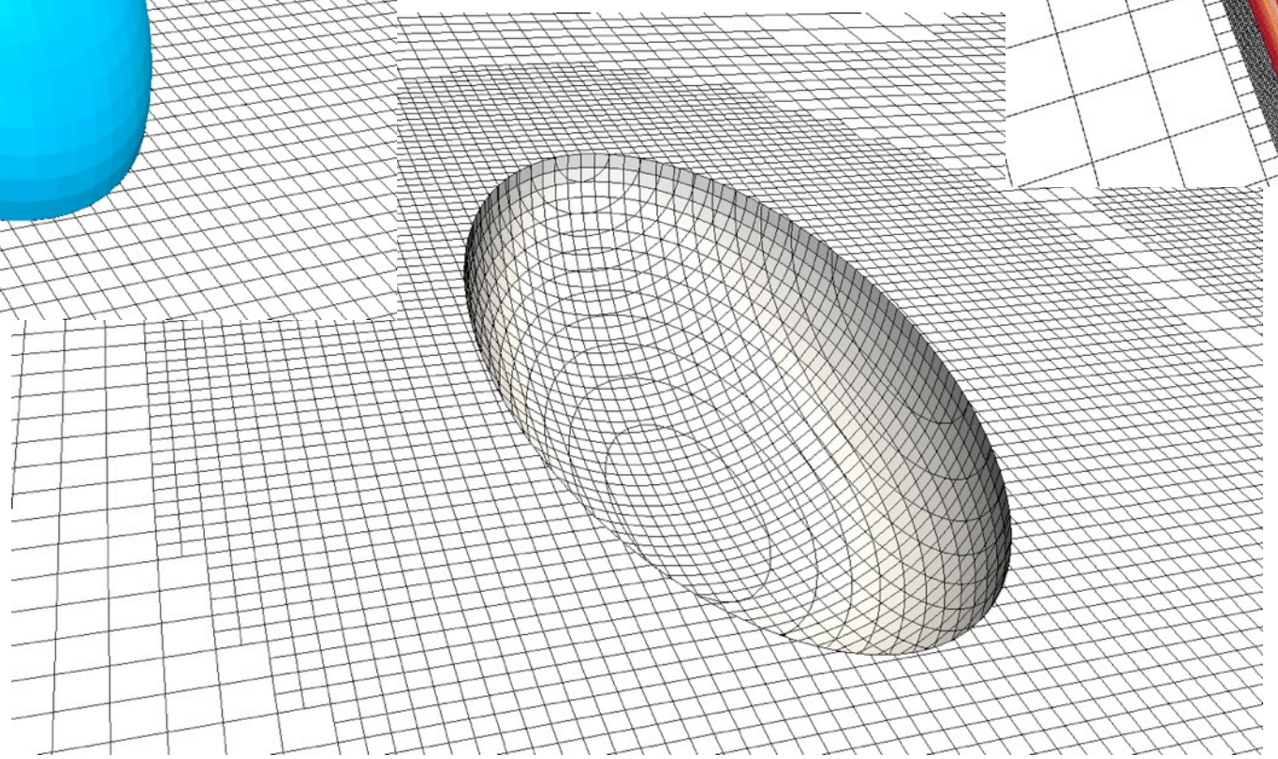
- Tracking of moving boundaries with level set interface
  - allows fast determination & location of cut cells in octree
  - developed method is conservative and leads to sharp boundary representations
  - automatic remeshing and support for touching surfaces (multi-level set)



Droplet boundaries as seen by the flow solver

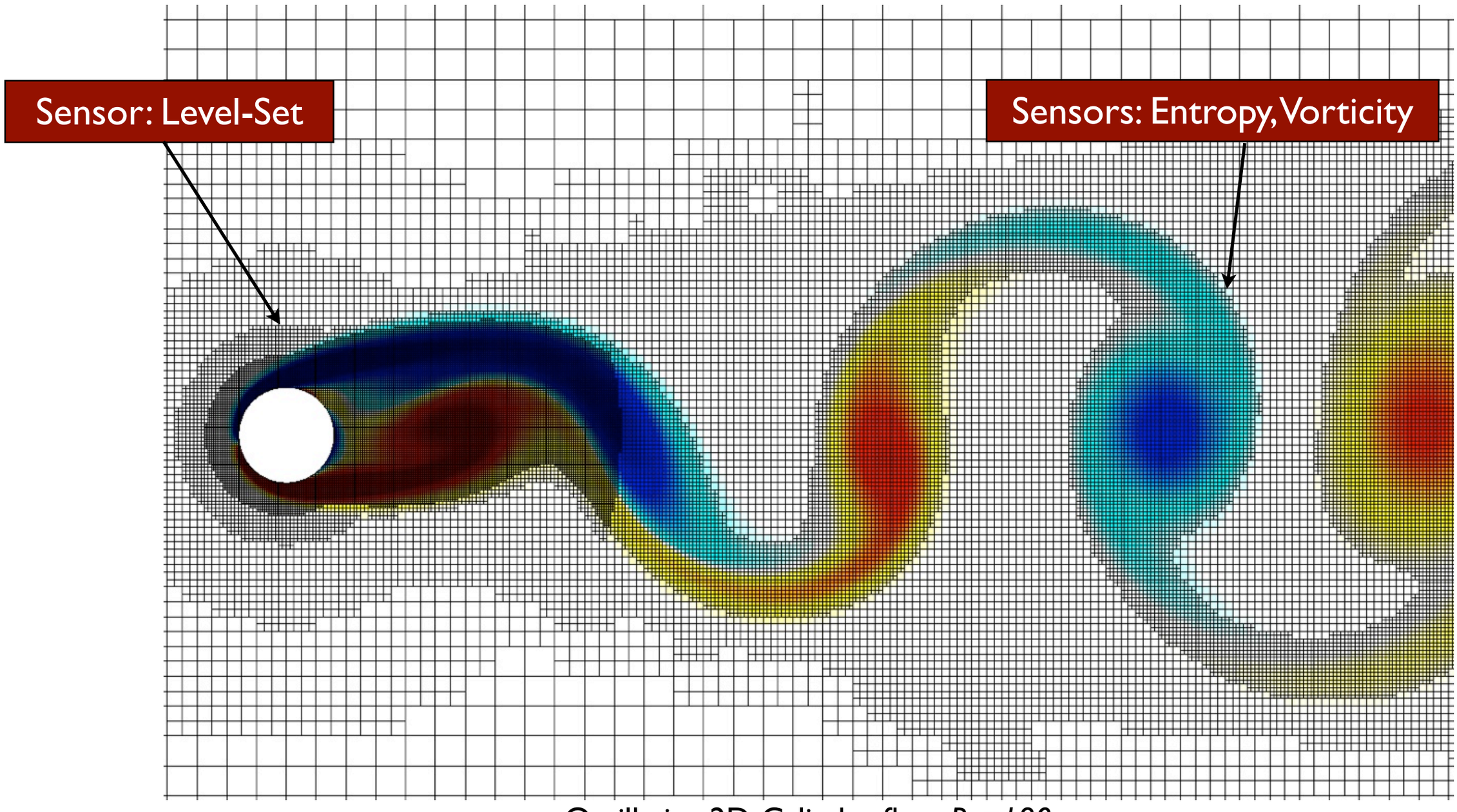


Multi-level set for touching surfaces



Level Sets and Solution-Adaptive Refinement

Schneiders et al., *An accurate moving boundary formulation in cut-cell method,* submitted to J. Comput Phys.

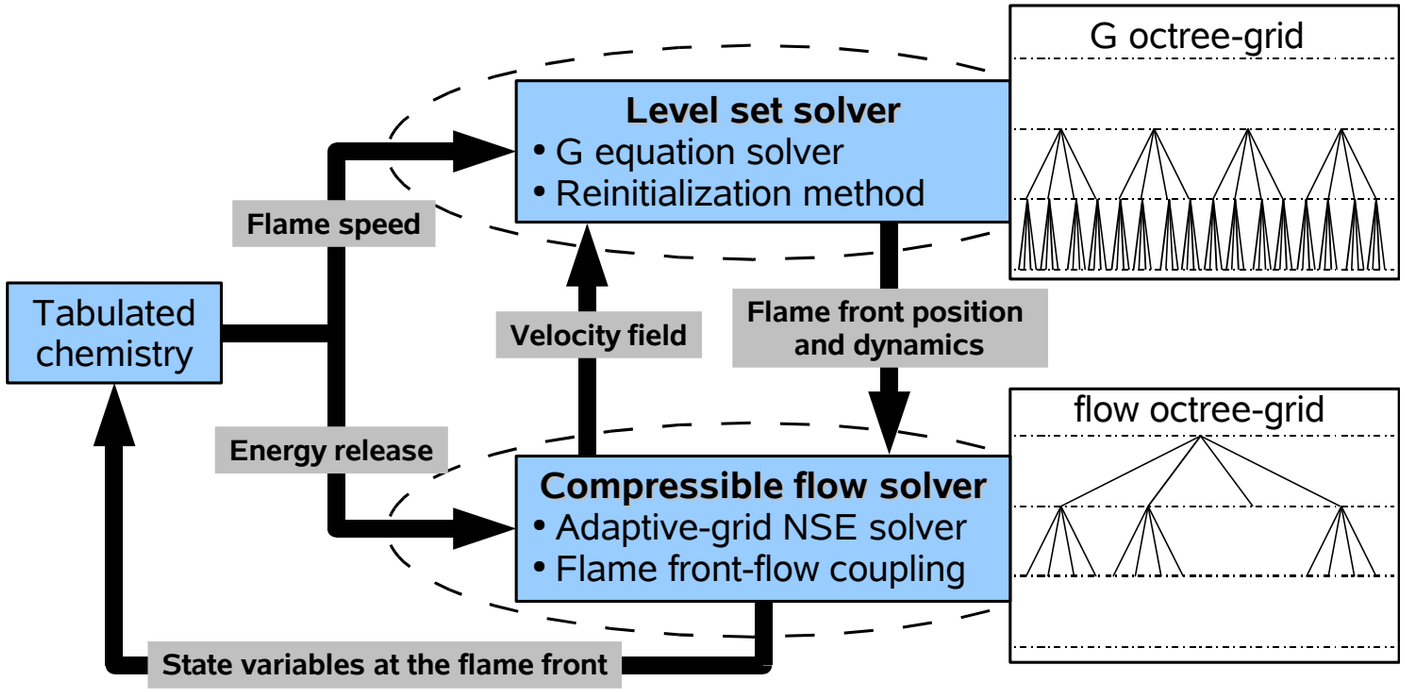


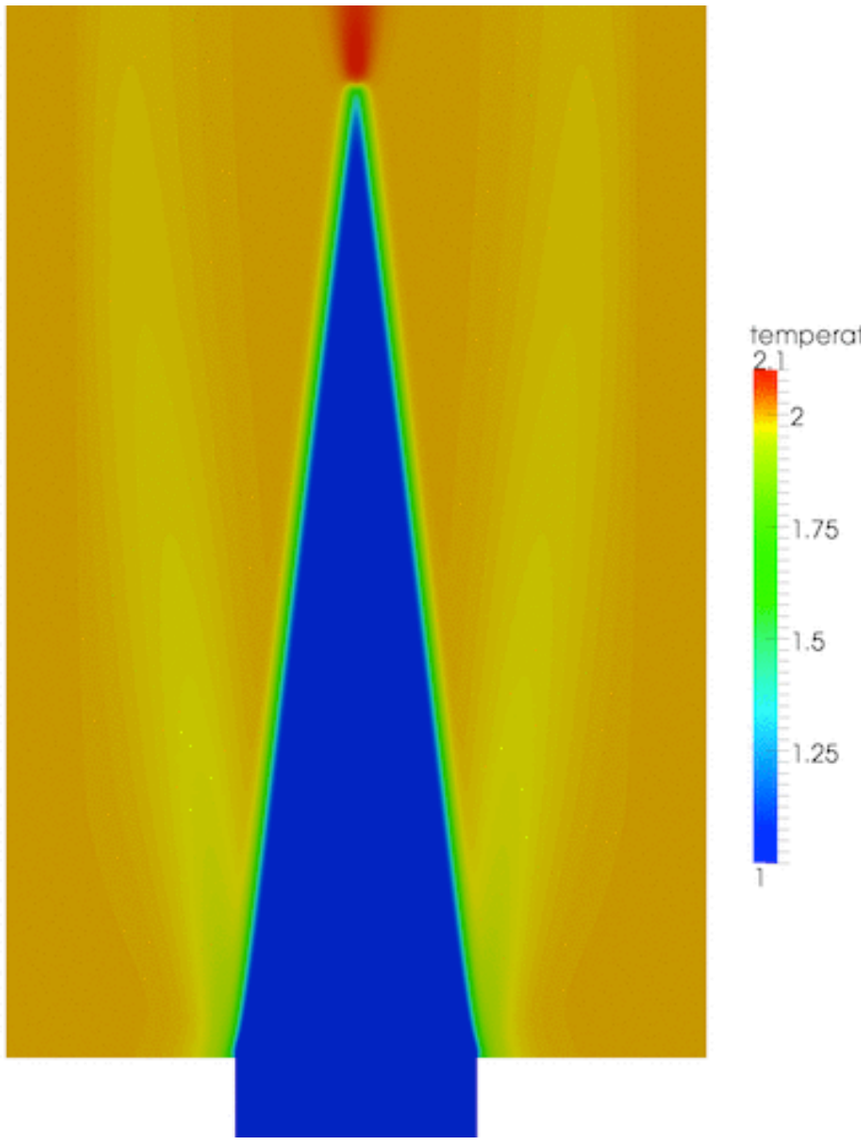
Oscillating 2D-Cylinder flow, *Re=180*

Solution-Adaptive Refinement works in 2D and 3D!

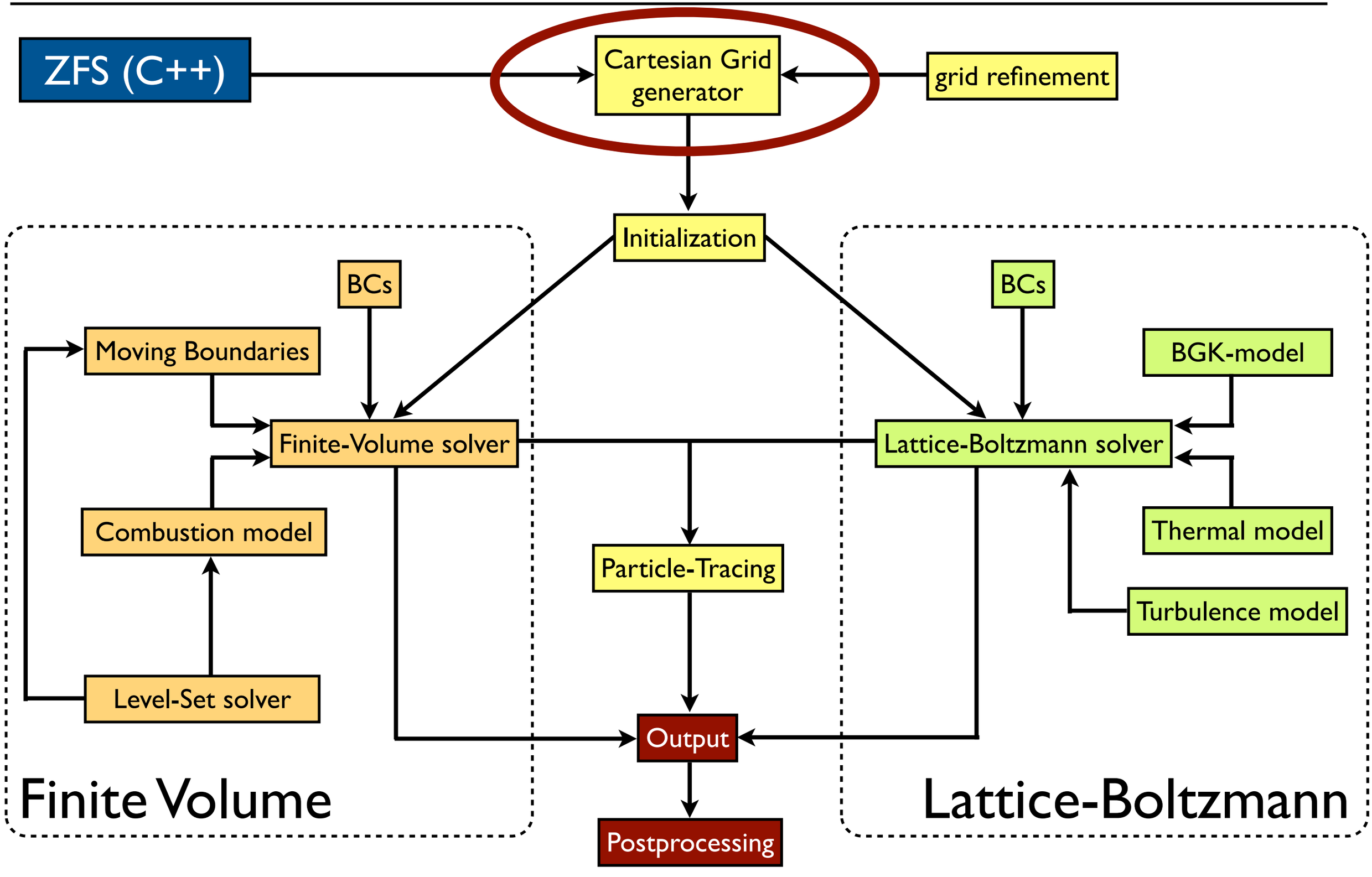
Dynamic Remeshing with Level-Sets

- Flame Front Propagation:





Flow solver ZFS: an Overview



Parallel Grid Generation Process

1. Read Geometry

- build *KD-Tree*
- calculate bounding box

2. Initialize Grid

- initialize surrounding cube
- scale by reduction factor
  - steers cell size

3. Initial Grid

- uniformly refine grid
  - until initial level is reached
  - delete parent levels
  - delete outliers
- decompose domain
  - calc. Hilbert index for cells
  - sort all cells along curve
  - split grid, keep own domain

perform in parallel

4. Start Grid

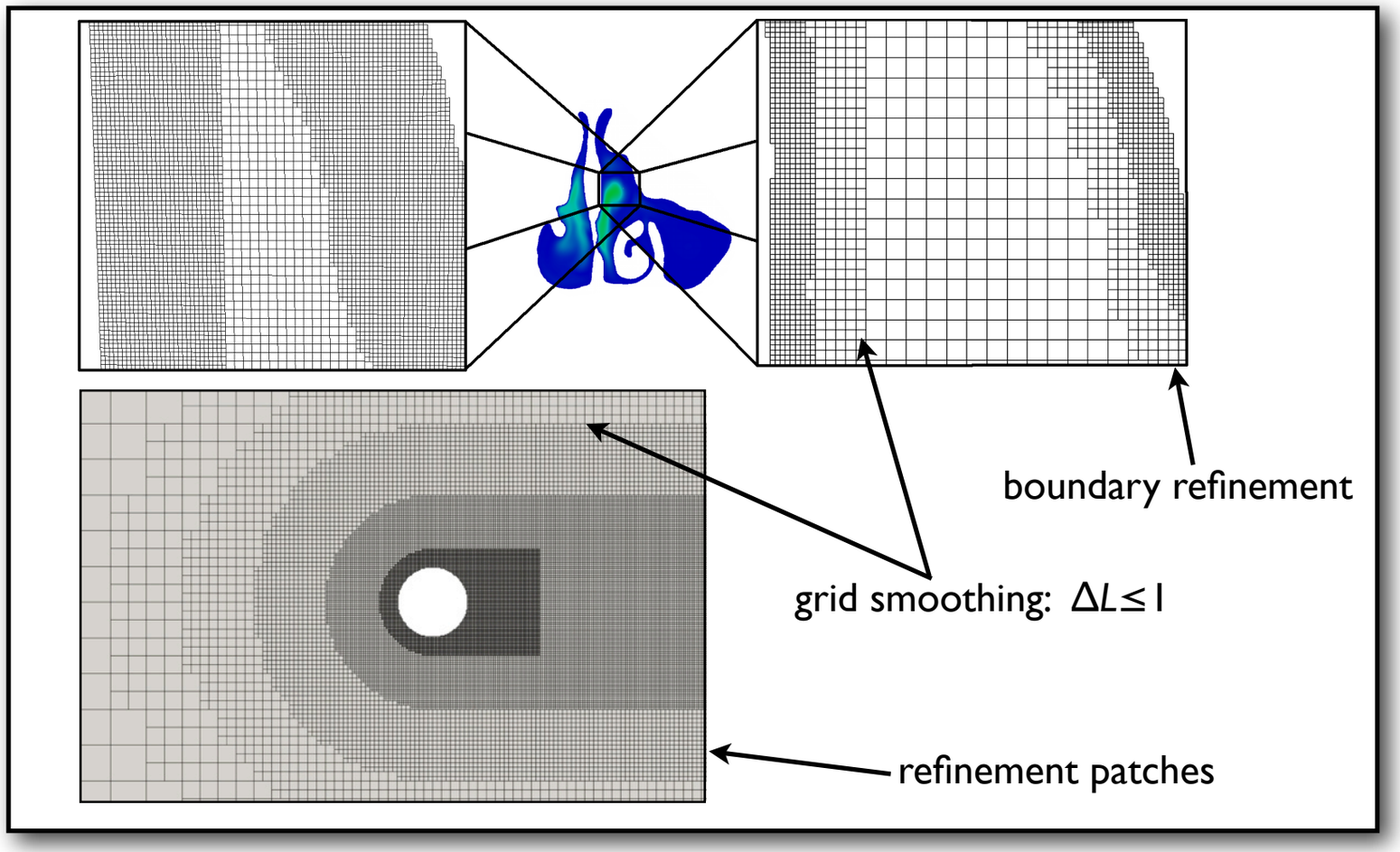
- uniformly refine local grid
  - until base level is reached
  - delete outliers
- communicate cell information

5. Computational Grid

- non-uniformly refine local grid
  - until final level is reached
  - use refinement patches
  - boundary refinement
  - smooth grid
  - delete outliers
- communicate cell information
- recalculate *global ids*

6. Write Parallel Output

- as NETCDF sorted by *global id*



Grid-Preprocessing prior to Solver Run

1. Read Geometry

- build *KD-Tree*
- calulate bounding box

2. Read Grid in parallel

- determine domain offsets
- read from offset

3. Window/Halo cell creation

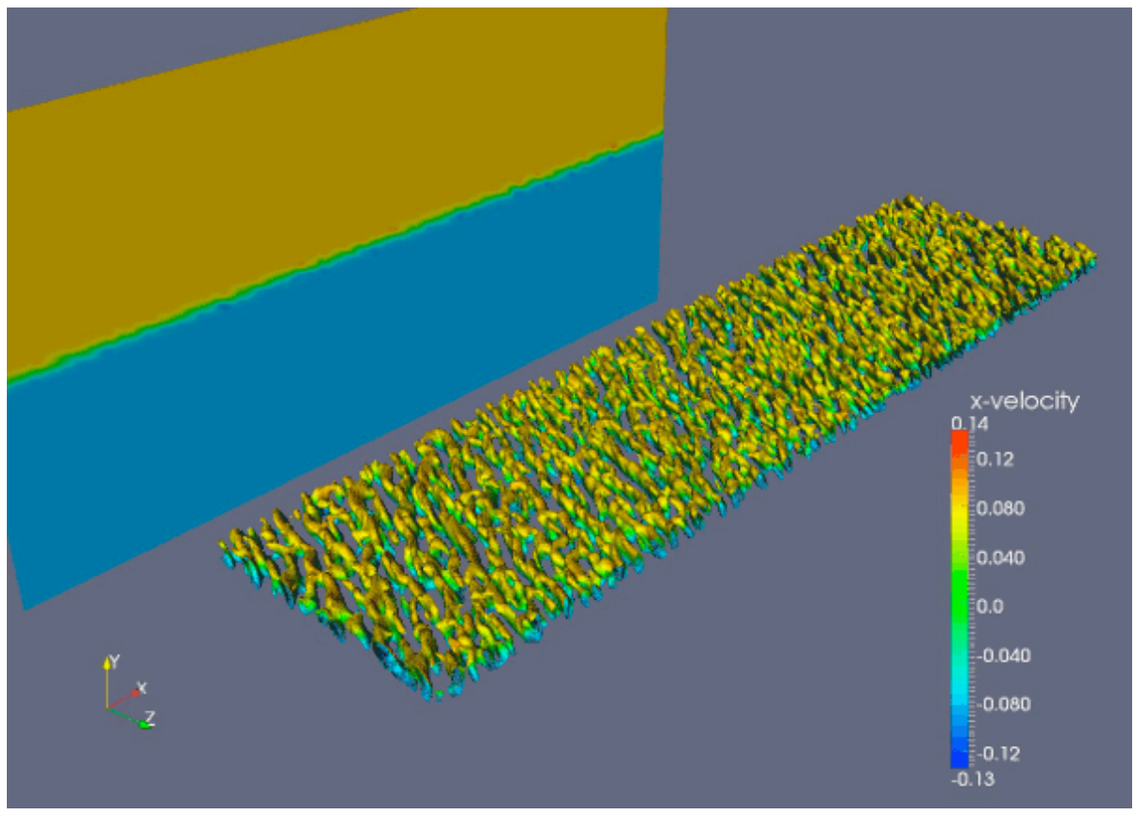
- find window cells
- send window cells to neighbor
  - create halo cells
- transform *global ids* to *local ids*

4. Initialize solver

- find boundary cells
- FV: use *Cut-Cell Method*
- LBM: calculate wall distances
- create Level-Set grid

6. Flow Simulation

- FV: solve NSE in integral form
- LBM: solve Lattice-BKG eq.
- update Level-Sets
- exchange fluxes, primitive vars



turbulent mixing layer (LBM)

Summary and Conclusions

- Octree-based Cartesian grids offer certain advantages for complex flow simulations
  - Automatic and parallel grid generation
  - Domain decomposition and dynamic load balancing based on space-filling curves
  - Dynamic mesh refinement depending on flow solution and moving boundaries
  - Solving the level set equation allows efficient tracking of surfaces
  - Use of hierarchical structure is beneficial for coupling different methods of different order and at different scales