A Pseudo Cell Approach for Hanging Nodes in Unstructured Meshes

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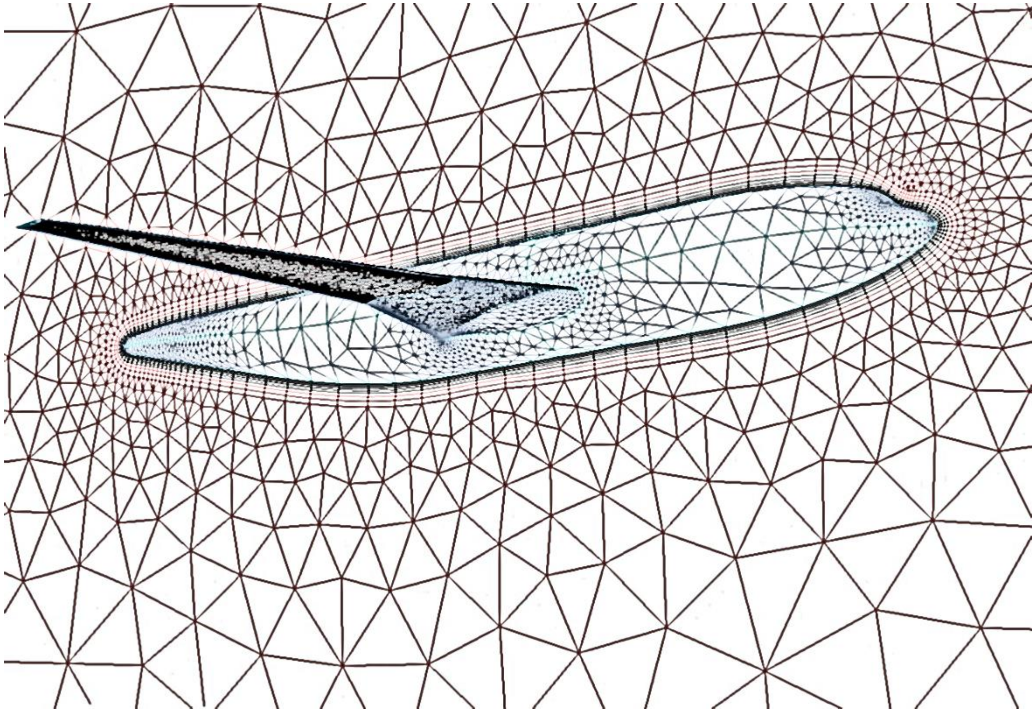
Outline

1. Software Framework
   I. FlowSimulator
   II. FlowSimulator DataManager (FSDM)
   III. Flucs

2. Hanging nodes/faces/edges in unstructured meshes in FSDM

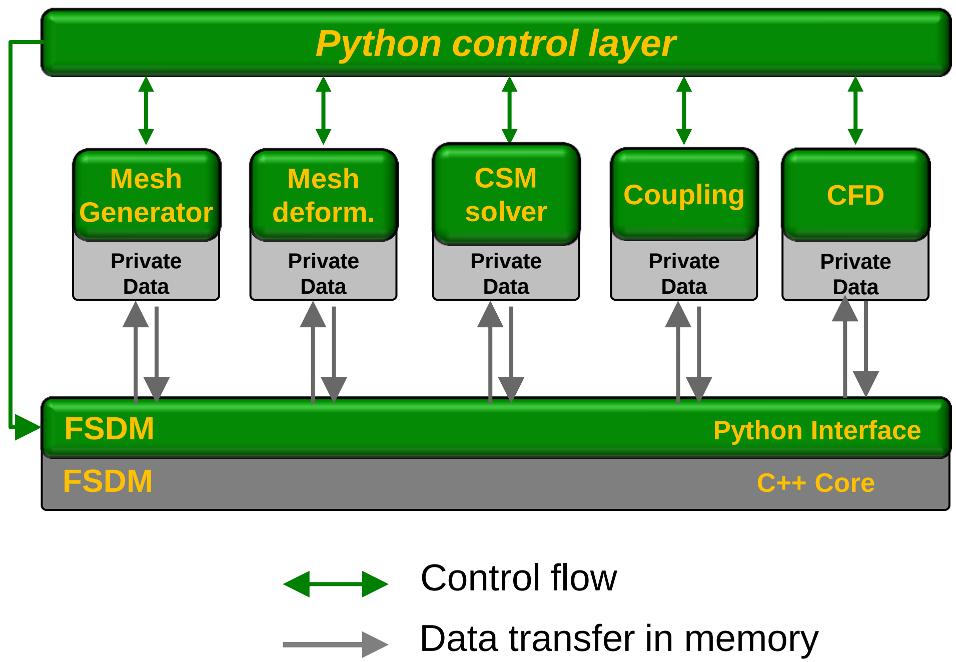
3. Adaptive refinement for meshes in FSDM

4. Outlook



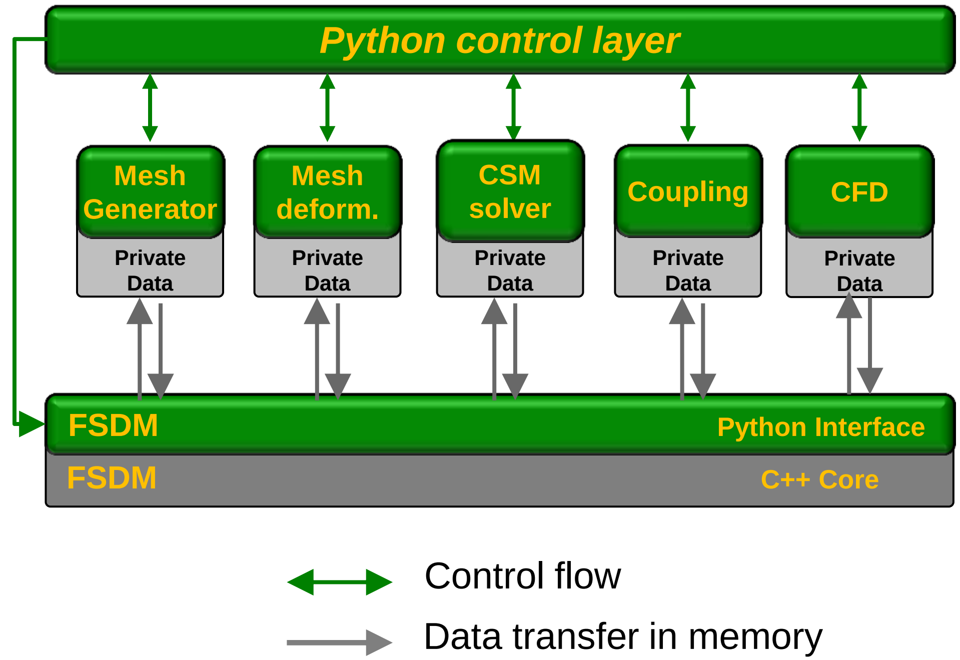
FlowSimulator

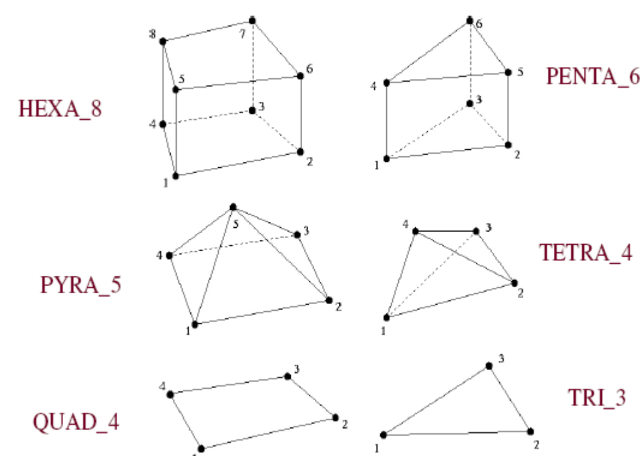
- HPC environment for integration of multiple parallel components into a process chain
- Jointly developed by Airbus, DLR, ONERA, universities, ...
- Components of simulation process chain („Plug-ins“) integrated via
  - Python control interface
  - FSDM data interface
- Definition and control of simulation process chain by Python control script



FlowSimulator DataManager (FSDM)

- FSDM reads/writes data (mesh, solution, log-data) from/to files
- FSDM decomposes data and distributes it over the different MPI domains
- FSDM stores data in container classes (e.g. FSMesh, FSDataSet)
- FSDM offers an interface (Python and C++) to container classes
- FSDM for us means unstructured meshes, can handle structured meshes as well





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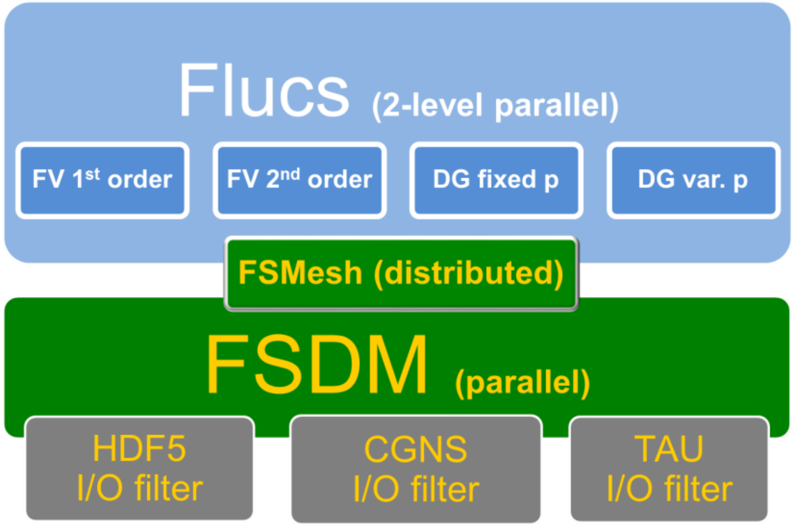
FLUCS the Flexible Unstructured CFD Software

- The “next generation” flow solver currenty developed at DLR
- Solves the Euler-equations, the Navier-Stokes equations, or the RANS equations
- Two discretizations
  - Second-order Finite-Volume
  - Discontinuous Galerkin
- Flucs is designed as an FS plug-in in order facilitate multi-disciplinary simulations



➨ Consequently, development of FSDM and Flucs has to go hand in hand

Why should we care about hanging nodes/edges/faces?

One of the main aims of the DLR:
Virtual design of an aircraft.

- Determine flight characteristics by numerical simulation
  - Key element: numerical flow simulation
  - ➧ CFD software Flucs

Complex 3d transient flows

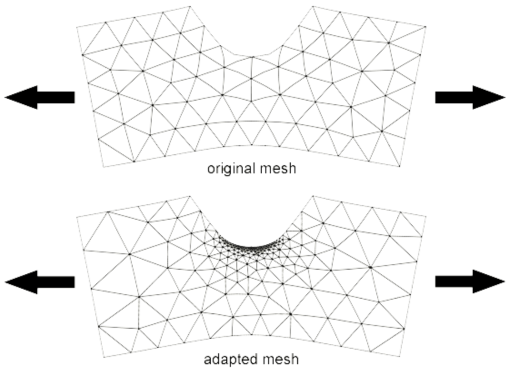
- highly time-consuming
- ➧ use mesh adaptivity

Ok, we are working on a tool for mesh adaptation

- ✕ Creation of hanging mesh entities and non-conforming interfaces

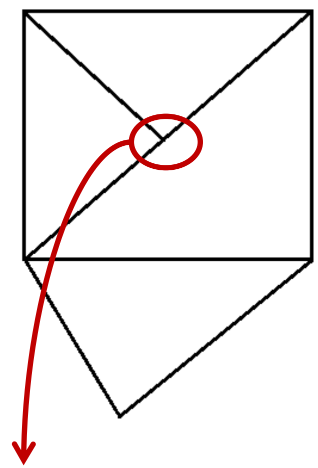
- Multidisciplinary optimization of a transport aircraft configuration.

- Example of mesh adaption from Abaqus User's manual

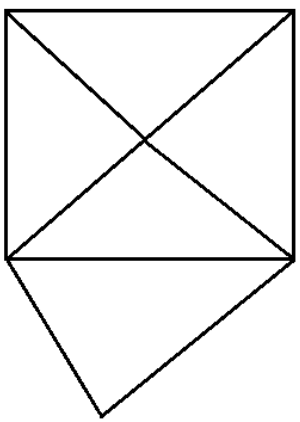


Motivation for Allowing Hanging Nodes/Edges/Faces

- Adaptation leads to creation of hanging nodes along non-conforming interfaces
  - ✗ E.g. disturb continuity of finite element space
  - ✗ Much effort required to remove them



A non-conforming mesh with 1 hanging node

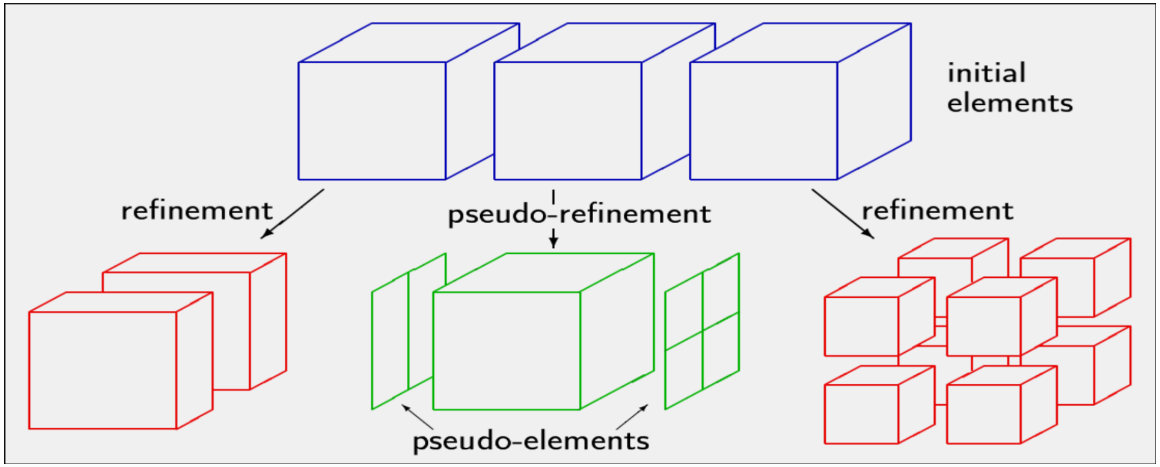


A conforming mesh

- Allow for very flexible grid structures and flexible adaptivity
  - ✓ Go well with our new mesh adaption tool (currently under development)
- Discontinuous Galerkin & Finite Volume methods allow for very general non-matching grids with hanging nodes
  - ✓ Go well with the next generation flow solver Flucs

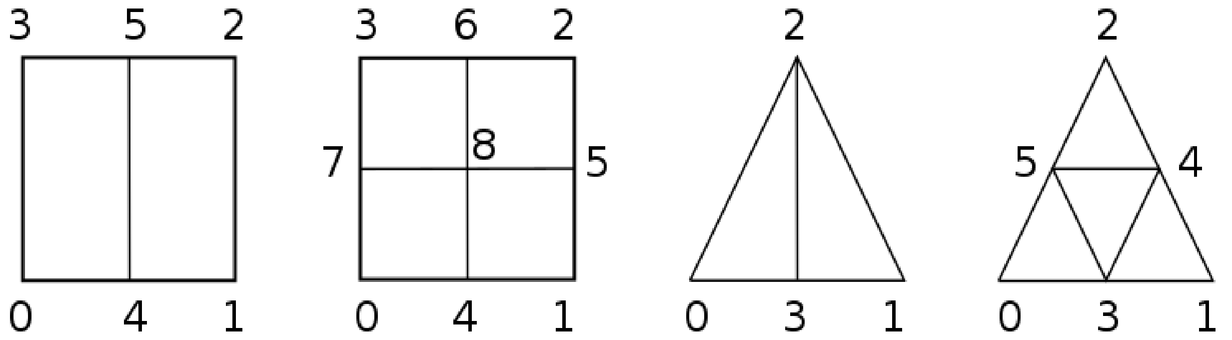
→ **So far not accounted for in FSDM**

Basic Idea for Hanging Edges



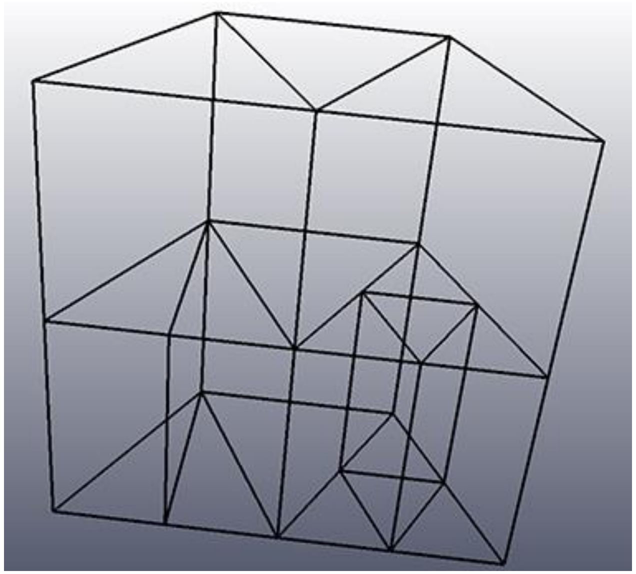
- Pseudo element types represent the types of “hanging” connections, one possibility of storing the hanging connectivity,
- Ignored by the solver, have no volume and no solution values, used by the face extractor to create the face based grid,
- Complete the hanging node grid to a kind of (pseudo) conformity,
- Enable the adaptation to work on hanging elements in the same way (only with other element types) as on conforming elements.

Implemented pseudo element types

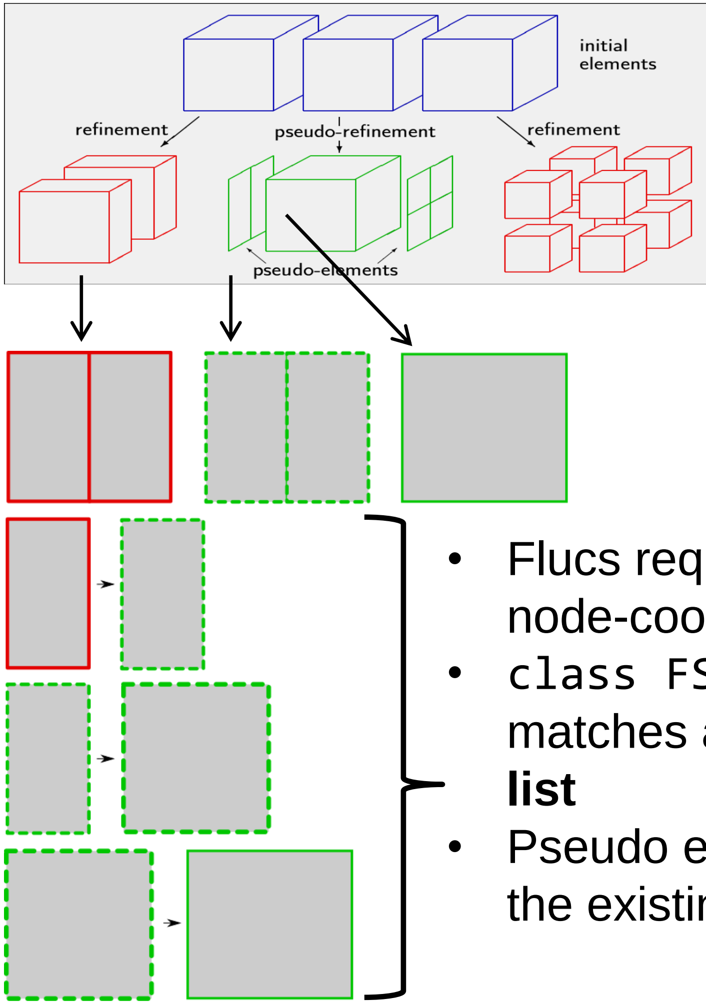


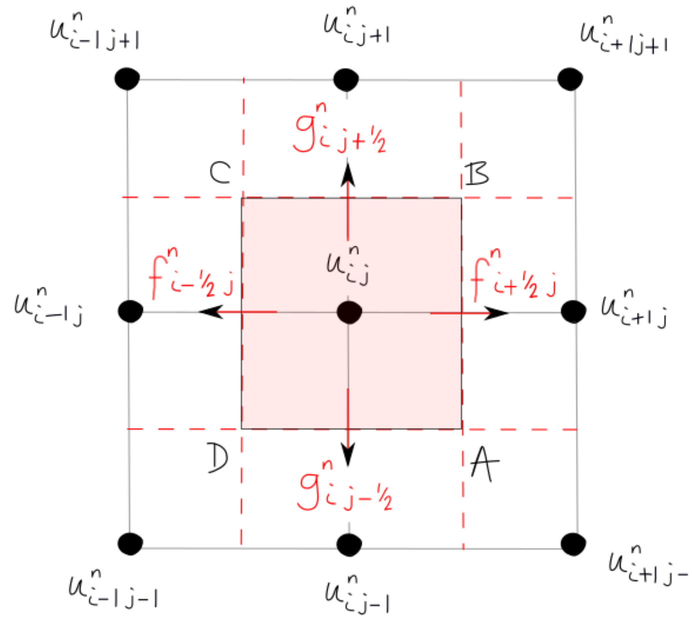
1. PCT_Quad2Quad with 3 faces
2. PCT_Quad4Quad with 5 faces
3. PCT_Tri2Tri with 3 faces
4. PCT_Tri4Tri with 5 faces
5. PCT_Node1Node: 1d-element that is equivalent to an edge and simply connects 2 nodes

→ Definition of cell types and lots of small test meshes in data manager FSDM



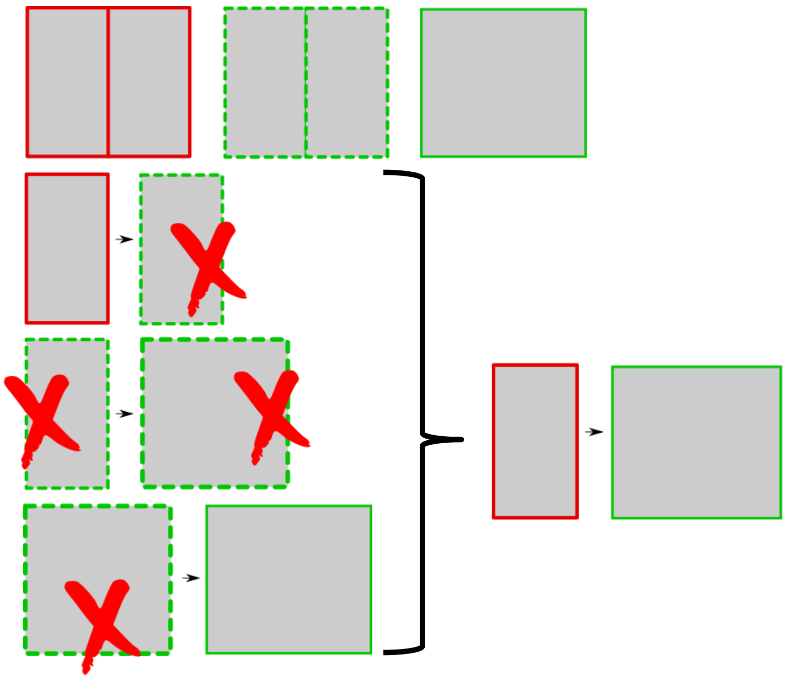
Original Face Extraction Algorithm





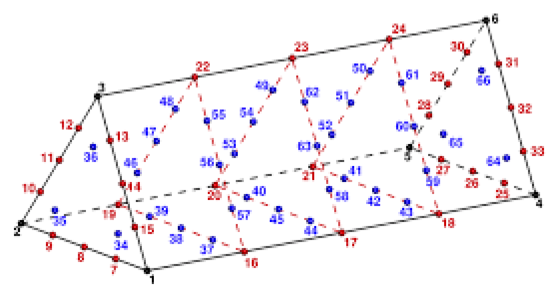
- Flucs requires the connectivity information and the node-coordinates of the faces of the mesh
- `class FSMeshFaceExtractor`: Extracts and matches all unstructured faces and writes them in a **list**
- Pseudo elements are handled in a natural way by the existing face extraction algorithm

Modified Face Extraction Algorithm



- Tricky part: Removal of pseudo elements from list
- At process borders, additional communication is required
  - Parts of the cells connected to pseudo faces may be distributed among the processes
  - Pseudo cell faces themselves may belong to different MPI domains
  - Lots of different subcases to consider

- Also holds for higher order cells in FSDM: only corners are relevant

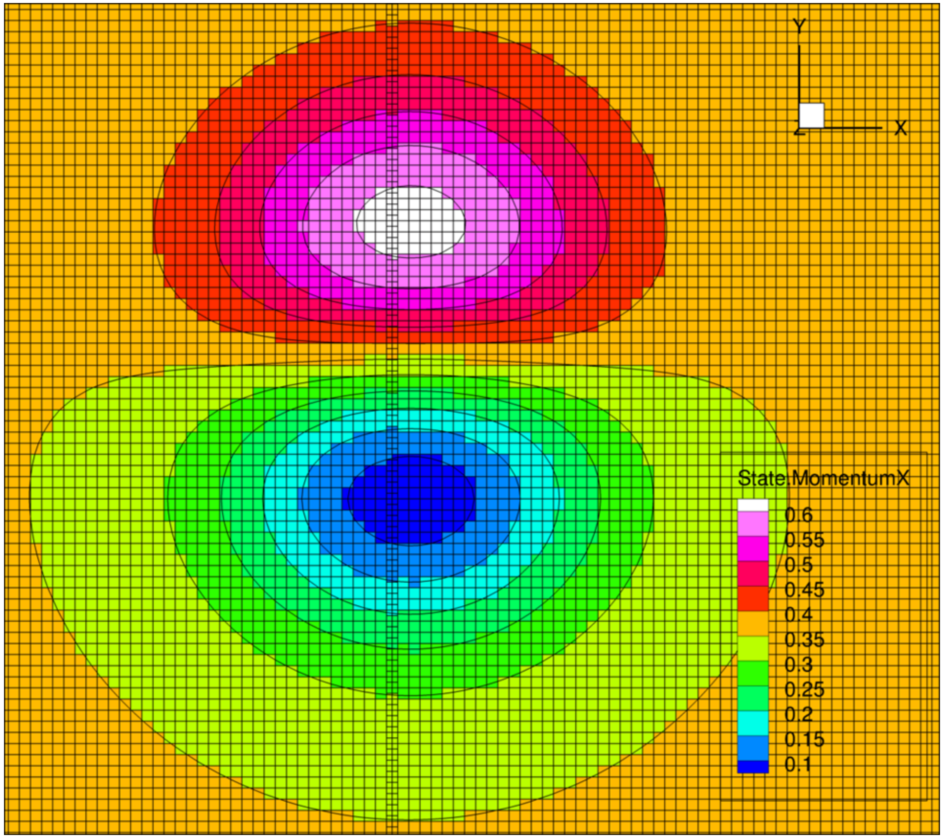


Simple Vortex Transport from left to right from (*)

- Mesh contains regular hexahedra, **one column of hexahedra is refined** with hanging edges in a 1:2 fashion

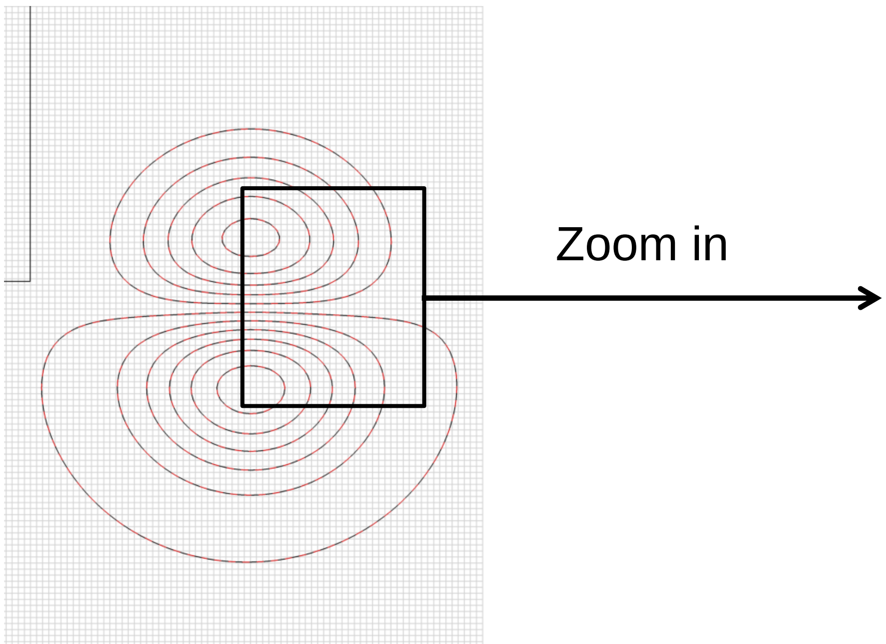
- 2nd order Finite-Volume discretization of the **Euler equations**
- Mach = 0.3, time-step = 0.025 using RK4 time-integration

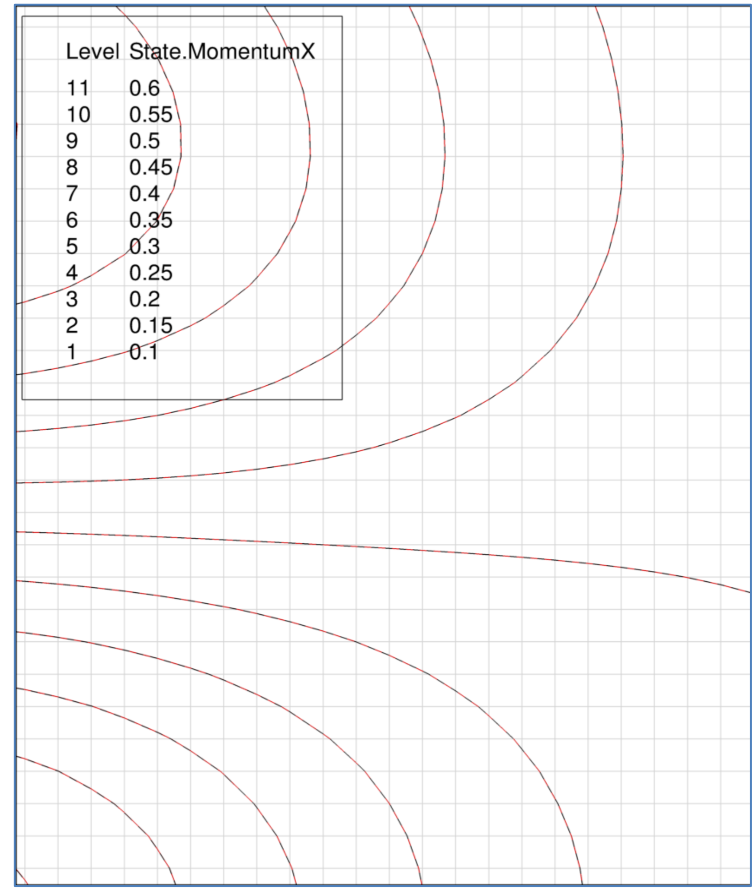
- **contour *lines*** show the x-component of the momentum on the regular mesh while the ***flood colors*** show the x-momentum on the mesh with hanging nodes.



* J.C. Kok: A high-order low-dispersion symmetry-preserving finite-volume method for compressible flow on curvilinear grids

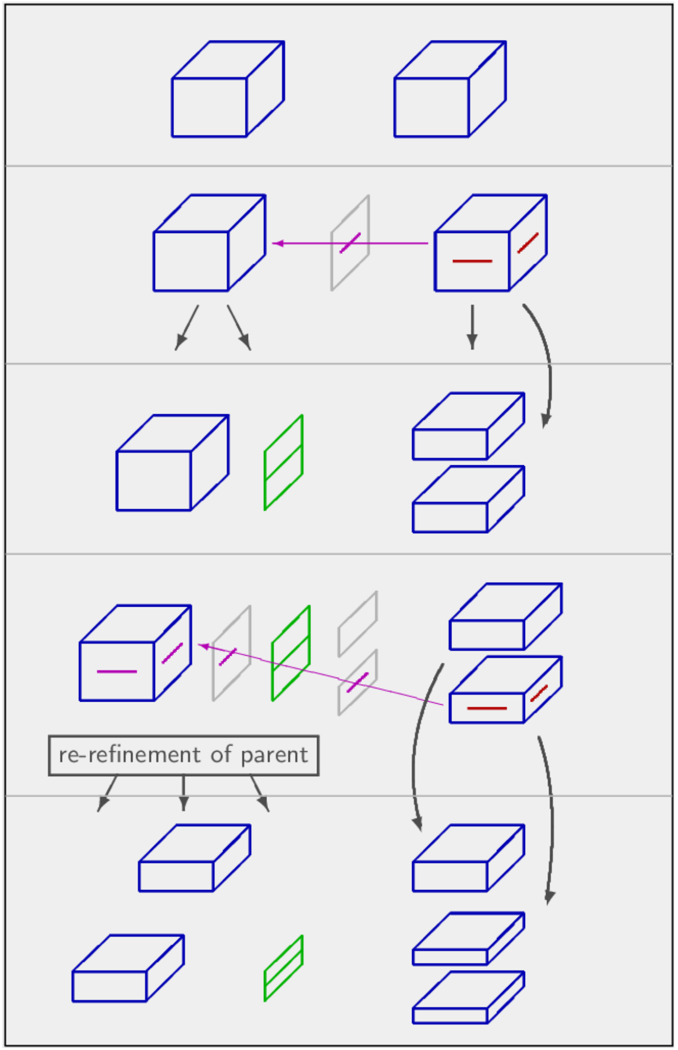
Results after convection





- The black line represents the x-momentum on the regular mesh
- Dashed red lines shows the x-momentum on the mesh with hanging nodes
- Other quantities are similarly accurate

Idea: Mesh adaptation and pseudo cells



Initial grid of 2 hexahedra (blue).

1st adaptation:
mark for subdivision by indicator (red),
refinement information transport (magenta)
via (internal) faces (grey).

1st refined grid with pseudo element (green)
between hanging faces.

2nd adaptation:
mark for subdivision by indicator (red),
refinement information transport (magenta)
via faces (grey) and pseudo element (green).

2nd refined grid with pseudo element (green)
between hanging faces.

Outlook

- Mesh adaptation as FSDM-plug-in “FSMeshAdaptation”
  - Support of hanging nodes
  - Anisotropic refinement
  - Hybrid parallelization
- General polyhedric cells in FSDM

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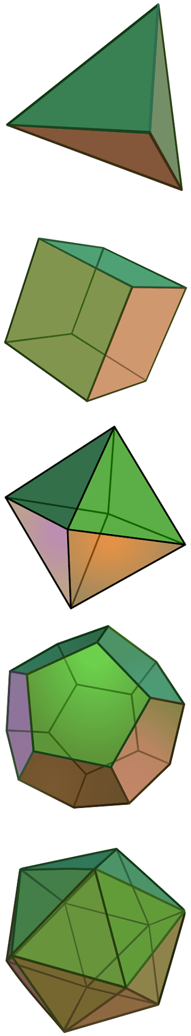

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