Hanging nodes in FSDM

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DLR

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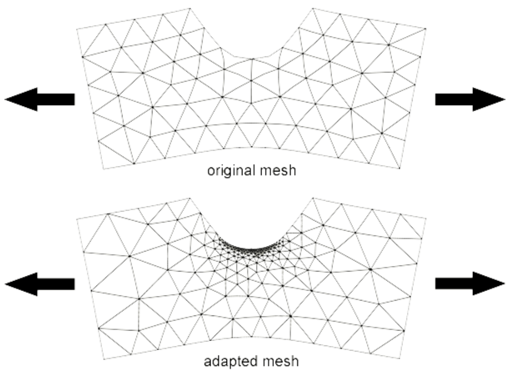
Motiviation: Hanging Nodes

- DLR goal: virtual design of an aircraft.
  - Flight characteristics determined by numerical simulation
  - Key element: numerical flow simulation
  - → CFD software Flucs
- Complex 3d transient flows
  - highly time-consuming
  - → use mesh adaptivity
- → Creation of hanging nodes along non-conforming interfaces

- Multidisciplinary optimization of a transport aircraft configuration.



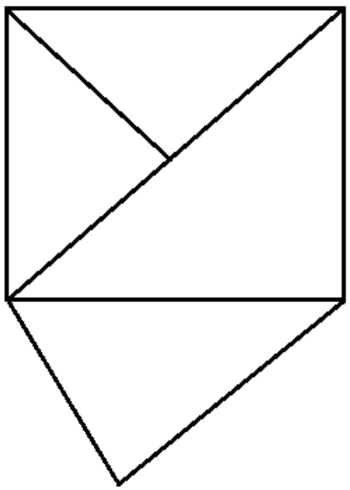
Why we like them

Normally:

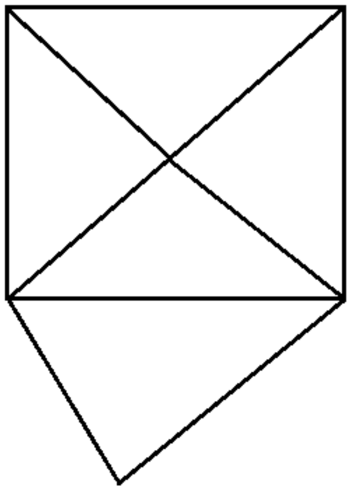
- Disturb continuity of finite element space
- Much effort required to remove hanging nodes

However:

- Hanging nodes allow for very flexible grid structures and adaptivity
- Discontinuous Galerkin methods & Finite-Volume methods: very general non-matching grids containing hanging nodes allowed
- Go well with the next Generation flow solver Flucs in the DLR



A non-conforming mesh with 1 hanging node

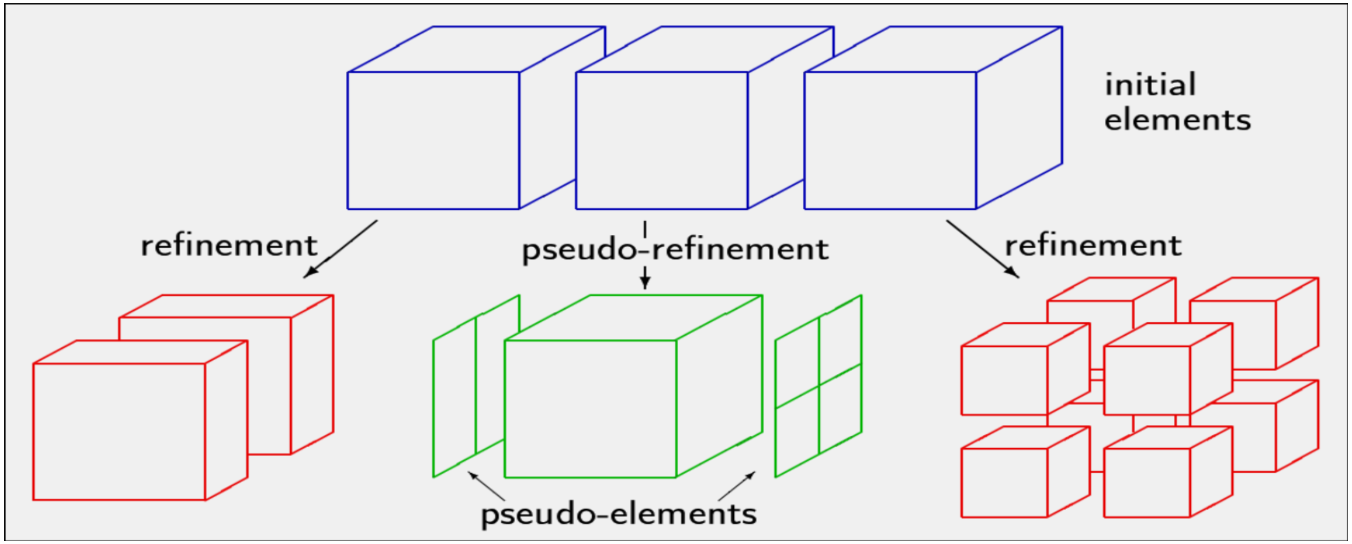


A conforming mesh

Note: One of the main use cases for is a new mesh adaptation that is currently being developed in DLR Project VicTtoria.

→ So far not accounted for in FSDM

Main Idea: Hanging Nodes via Pseudo Elements



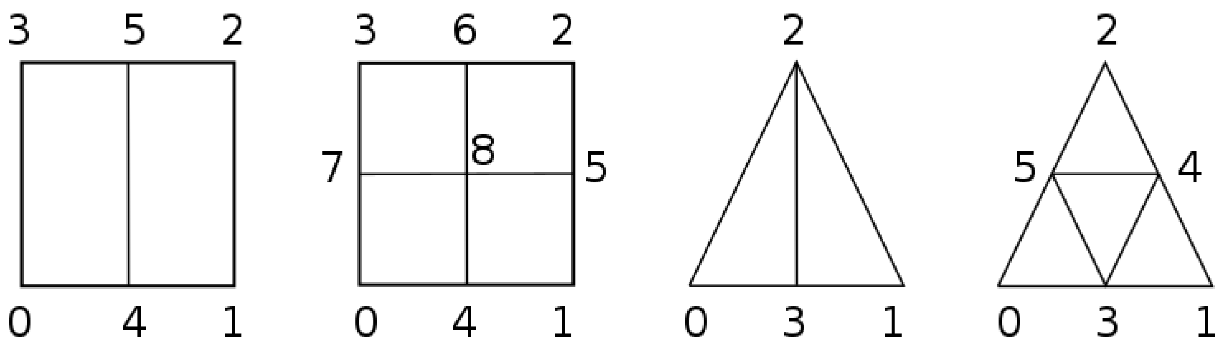
- In-between the real elements with hanging faces
- “Pseudo-conform” grid
- Pseudo elements can be treated like normal elements to a certain extent

Implemented types of pseudo elements

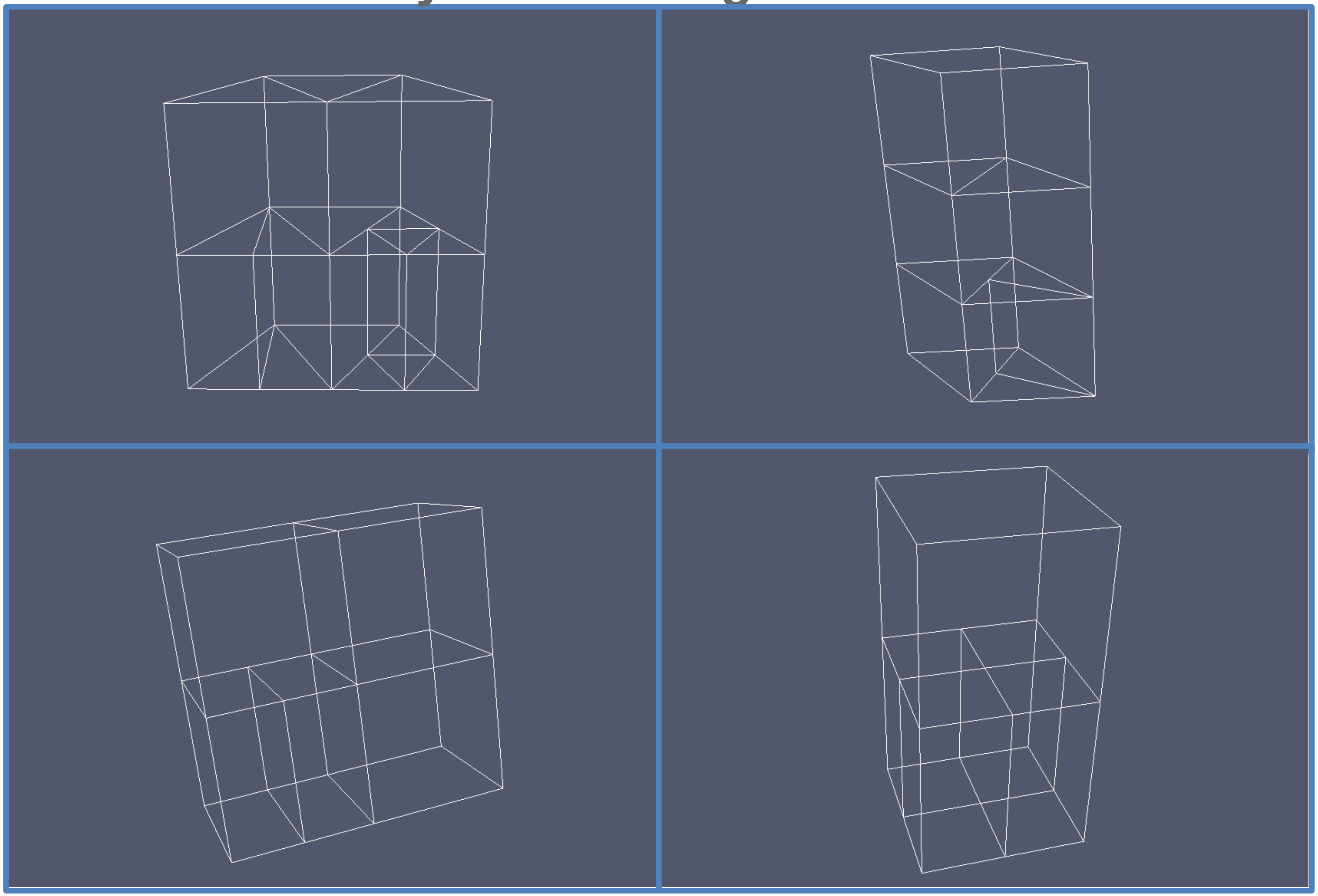
1. PCT_Quad2Quad with 3 faces
2. PCT_Quad4Quad with 5 faces
3. PCT_Tri2Tri with 3 faces
4. PCT_Tri4Tri with 5 faces
5. PCT_Node1Node: 1d-element that is equivalent to an edge and simply connects 2 nodes (Kolja’s “virtual edge”).

→ Belong to the unstructured cell types in FSDM, but neither to the volume nor the surface cell types

→ Definition of cell types and test cases in FSDM (Verena Muckhoff)



Addition of many small test grids…



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 → `GetFaceConnectivity()`
- Pseudo elements are handled in a natural way by the existing face extraction algorithm

Adaptions

- The tricky part is the step that removes the pseudo elements from this list → `PrepareFaceConnectivity()`
- At process borders, additional communication is required (parts of the cells connected to pseudo faces may be distributed among the processes)
- Also holds for higher order cells in FSDM: only corners are relevant

Additions (moved from Flucs to FSDM → `GetFaceNodeCoordinates()`)

- Computation of the pre-defined node ordering for all face types
- Computing the node coordinates

Interface

- Prepare calls to faces of the mesh
  `fex = FSMeshFaceExtractor()`

- Don't match remote faces*, keep pseudo cells
  `fex.PrepareFaceConnectivity(mesh, False, True)`
- Or match remote faces, keep pseudo cells
  `fex.PrepareFaceConnectivity(mesh, True, True)`
- Default: match remote faces, remove pseudo-cells
  `fex.PrepareFaceConnectivity(mesh)`

- After: if desired we can also ask for the coordinates of the faces
  `fex.PrepareFaceNodeCoordinates(FSQuantityDescArray())`

- Wrapped to Python primarily for testing: `example/Advanced/howToInitPseudoCellMeshAndExtractFaces.py`

* whether to communicate and fill unmatched faces between processes.

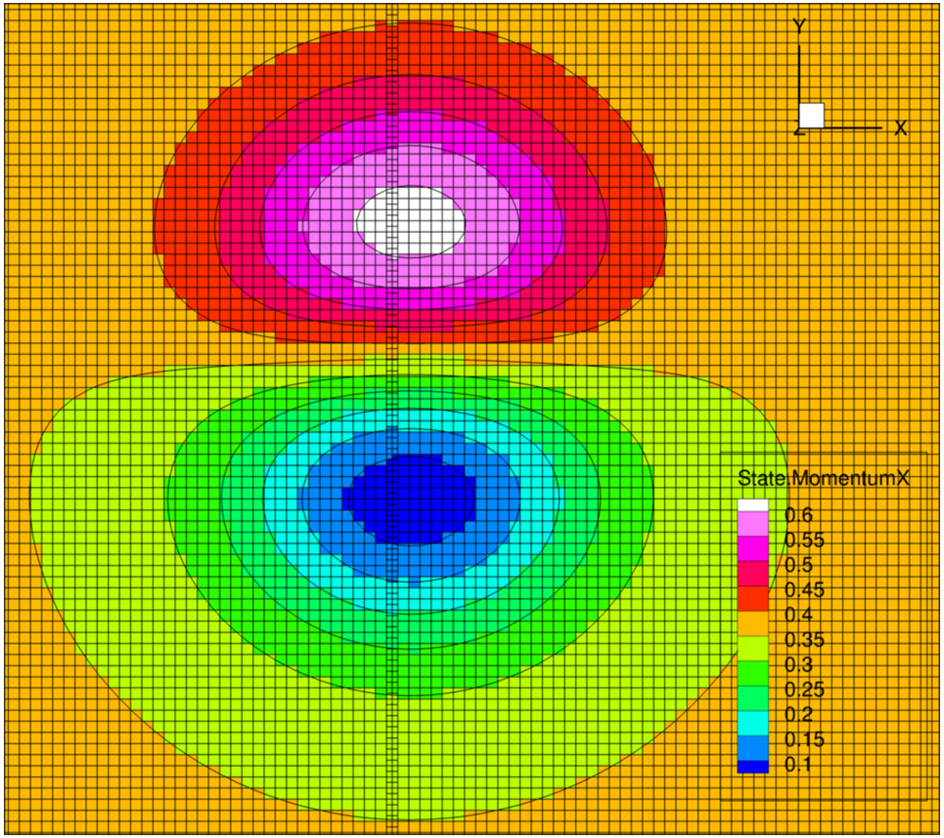
A Numerical Example

- Demonstration for a simple convection problem: Kok-vortex transport
- Mesh contains regular hexahedra, one column of hexahedra was refined with hanging nodes in a 1:2 fashion
- Mesh generation by FSDM Python script
- Results are nearly identical for both Finite-Volume and Discontinuous-Galerkin discretization in Flucs.
- Minuscule differences probably due to the temporarily higher resolution while convecting across the refined region

Instantaneous snapshot of the simulation

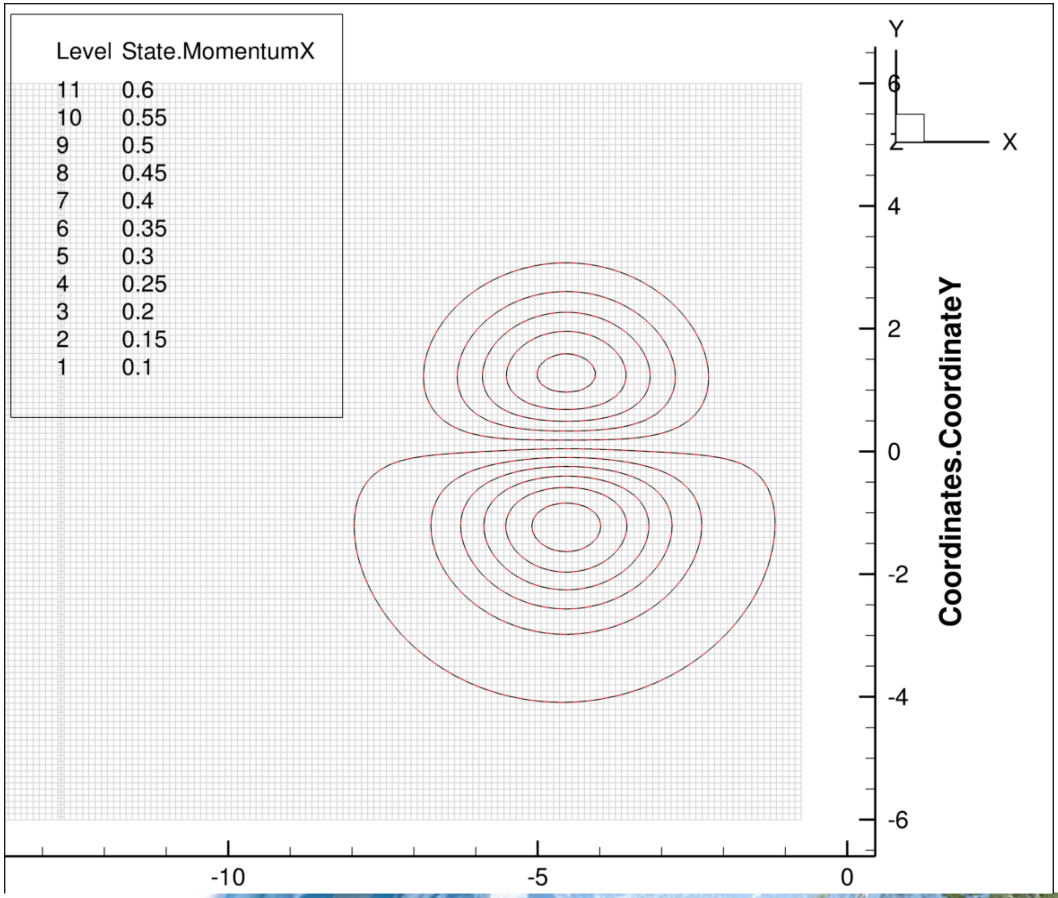
- 2nd order Finite-Volume discretization of the Euler equations
- Mach=0.3, time-step = 0.025 using RK4 time-integration
- Vortex is convecting from left to right

- 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.
- Other quantities (and discretizations) are similarly accurate.

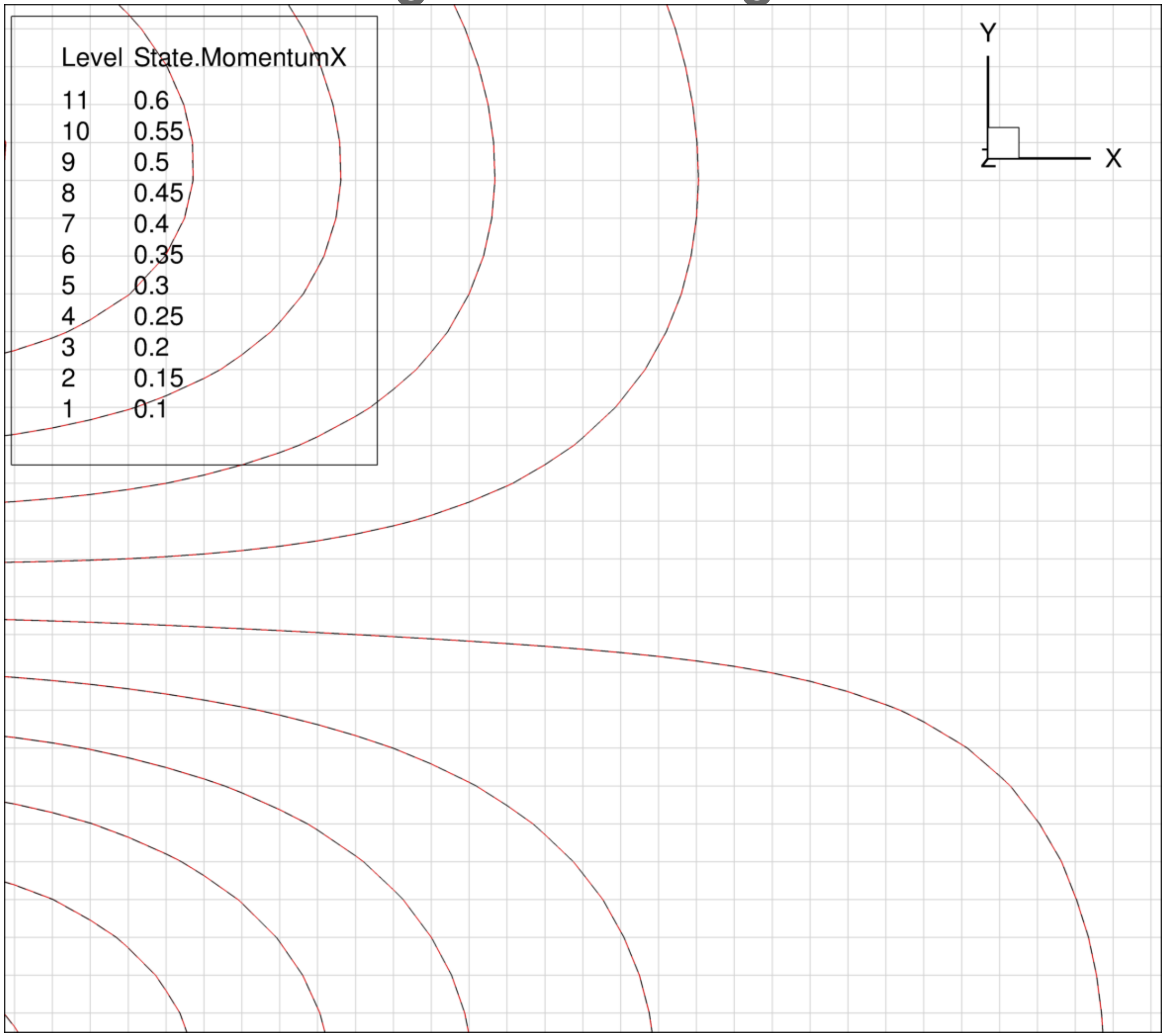


After vortex convection

- Result after vortex convection across the mesh
- The black line represents the x-momentum on the regular mesh
- Dashed red lines shows the x-momentum on the mesh with hanging nodes



Zoom in on the right-hand edge of the vortex



Testing (with Hanging Nodes)

- **Multiple** different ways that FSDM functionality is tested.
- Python scripts, tests in Flucs itself and a Google Test framework for FSDM (which is so far only used by DLR-SC)
- Google test framework: large number of small test meshes containing all types of pseudo cell faces were created, continuous testing with new face extractor
- Meshes also exist as HDF5-files to be used by Python scripts (test the correct ordering of the nodes)
- Since some functionality was moved from Flucs to FSDM, also tests there

Testing (all in all)

- **Multiple** different ways that FSDM functionality is tested.
- Python scripts
- C++-tests hard-coded in FSDM
- Google test framework (used by SC and by Sogeti)

→ Maybe find a unified way to do this?

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Open Questions

- So far the hanging nodes are in a separate branch
- In this branch the `#ifdefs` for higher-order cells are removed
- Can we merge into the trunk?
- Can we find a common ground for testing FSDM functionality?