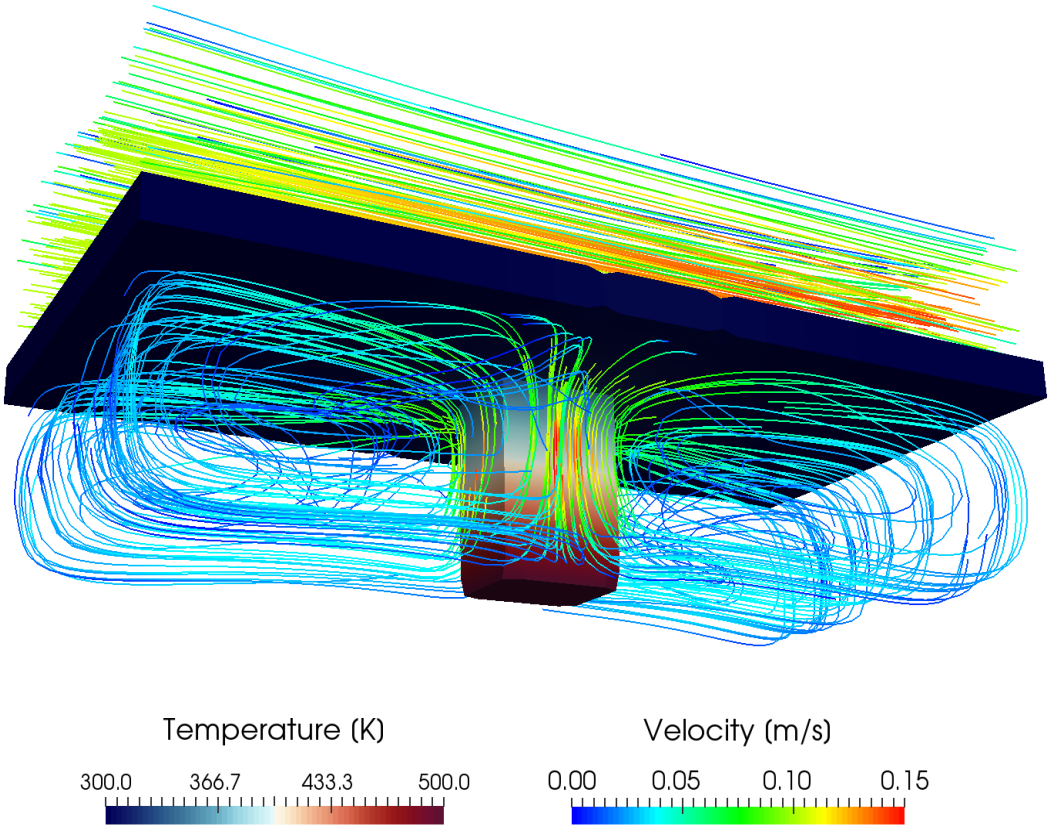
Tutorial Thirteen

snappyHexMesh – Multi-Region



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Editorial board:

- Bahram Haddadi
- Christian Jordan
- Michael Harasek

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Cover picture from:

- Bahram Haddadi

Contributors:

- Bahram Haddadi
- Philipp Schretter
- Yitong Chen

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Background

1. . Multi-region modeling & why do we need it?

In multi-region modeling, the entire computational domain is divided into individual regions, with each region representing a coherent continuum of the same phase. The key feature of this type of modeling is that separate governing transport equations are solved for each region.

In general, two different approaches have been adopted in the past to solve multi-region problems:

- Monolithic: solve using a single coupled matrix equation system
- Partitioned: solve using separate matrix equation systems

In this OpenFOAM® tutorial, we are focusing on the partitioned approach. The fundamental steps in this approach are outlined below:

1. Define the whole mesh domain and the separate regions within it. Assign cells into each region
2. Specify field variables in each region
3. Solve the transport equation in each individual region
4. Multiregional coupling at the interface between different regions
5. Iteration to achieve fully/coupled solution

2. chtMultiRegionFoam solver

This solver is developed to solve heat transfer problems between multiple regions.

snappyHexMesh - snappyMultiRegionHeater

Tutorial outline

The procedure described in this tutorial is structured in the following order:

- Creation of the geometry data
- Tutorial on Meshing a geometry with more than one region
- Run an OpenFOAM® simulation with the generated mesh using chtMultiRegionFOAM

Objectives

- Understanding multi region meshing with the meshing tool snappyHexMesh

Data processing

Import your simulation to ParaView. Analyze the flow field through the flange and the heat distribution in the flange.

1. Pre-processing

1.1. Copying tutorial

Download the following tutorial to your working directory:

https://github.com/OpenFOAM/OpenFOAM-5.x/tree/master/tutorials/heatTransfer/chtMultiRegionFoam/snappyMultiRegionHeater

Either by creating the folders and then downloading the files and place them in relevant folders or using following webpage:

https://download-directory.github.io/

Rename the constant/triSurface directory to constant/geometry directory. In the system directory, change the name of surfaceFeatureExtractDict to surfaceFeaturesDict.

1.2. 0 directory

Unlike the single region simulations in the 0 directory an individual folder per region exist which stores the files including initial and boundary conditions for that region. Also in the 0 directory some files exists which are just dummy files that will not be used in the simulations. The initial and boundary conditions for each region are changed and updated using the *changeDictionary* utility, which will be explained later.

1.3. constant directory

Also in the constant directory exist a folder per region; in this case, the domain is split into the following regions: bottom air, heater, left solid, right solid and top air. Within the designated folder, there are relevant dictionaries that describe the physical properties, turbulence or radiation behavior of each region, e.g. radiationProperties, momentumTransport and physicalProperties. The following changes should be applied:

- In the bottomAir rename thermoPhysicalProperties file to physicalProperties
- In the bottomAir rename turbulenceProperties file to momentumTransport
- Copy the physicalProperties, momentumTransport and g file from bottomAir to topAir folder
- Update the thermoPhysicalProperties file in the constant/heater folder as following

```
// * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * //

thermoType
{
    type            heSolidThermo;
    mixture         pureMixture;
    transport       constIsoSolid;
    thermo          eConst;
    equationOfState rhoConst;
```

```
    specie          specie;
    energy          sensibleInternalEnergy;
}

mixture
{
    specie
    {
        molWeight   12;
    }

    transport
    {
        kappa   80;
    }

    thermodynamics
    {
        Hf      0;
        Cv      450;
    }

    equationOfState
    {
        rho     8000;
    }
}

// ************************************************************************* //
```

- Copy the thermoPhysicalProperties file from constant/heater folder to constant/leftSolid and constant/rightSolid and replace the old files

The polyMesh directory in the constant folder includes the original mesh while the polyMesh directories in each region folder include the split mesh for that region with the new boundaries between regions.

Unlike polyMesh directories there exist just one geometry folder which stores all the stl files for mesh creation using snappyHexMesh.

In the regionProperties file, the physical phase of each region is specified. As you can see, bottom and top air regions are fluid, whereas heater, left and right solid are in solid phase.

```
// * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
* * * * * *//
regions
(
        fluid                   (bottomAir   topAir)
        solid                   (heater   leftSolid   rightSolid)
);
// * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
* * * * * *//
```

1.4. system directory

Like constant directory also in system directory, a folder per region can be found and all the settings for that region are stored in the corresponding folder, e.g. fvSolution, fvSchemes and decomposeParDict. The fvSchemes file in the system directory is a dummy file while the fvSolution includes the number of outer correctors setting for PIMPLE algorithm. There is also just one controlDict file and it is in main system folder.

Note: For running the simulations in parallel, the decomposeParDict files for all the regions should have the same settings as the main one in the system directory. This is not valid for parallel meshing using snappyHexMesh while it just uses the decomposeParDict file in the main system directory.

Update the surfaceFeaturesDict file as following:

```
// * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * //

surfaces ("bottomAir.stl" "heater.stl" "leftSolid.stl" "rightSolid.stl"
"topAir.stl");
includedAngle   150;
writeFeatureEdgeMesh    yes;

// ********************************************************************** //
```

Change the meshQualityDict as following:

```
// * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * //

// Include defaults parameters from master dictionary
#includeEtc "caseDicts/mesh/generation/meshQualityDict"

// ********************************************************************** //
```

The files needed for creating a multi-region mesh are the same as the mesh for single-region, except for slight differences in snappyHexMeshDict file:

`locationInMesh`: In a multi-region mesh this point is not used but it should be defined just as a place holder.

`refinementSurfaces`: Different regions are defined in here. E.g. for the region BottomAir all the faces and cells inside the bottomAir stl (each region stl should be a closed volume) file are marked with `bottomAir` flag (in `faceZone` and `cellZone`).

```
// * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
* * * *//
castellatedMeshControls
{
    maxLocalCells 100000;
    maxGlobalCells 2000000;
    minRefinementCells 10;
    nCellsBetweenLevels 2;

    features
    (
        {
            file "bottomAir.eMesh";
            level 1;
        }
…
        {
            file "topAir.eMesh";
            level 1;
        }
    );

    refinementSurfaces
    {
        bottomAir
        {
            level (1 1);
            faceZone bottomAir;
            cellZone bottomAir;
            cellZoneInside inside;
        }
```

```
…
       rightSolid
        {
            level (1 1);
            faceZone rightSolid;
            cellZone rightSolid;
            cellZoneInside inside;
        }
    }

    resolveFeatureAngle 30;

    refinementRegions
    {
    }
    locationInMesh (0.01 0.01 0.01);
    allowFreeStandingZoneFaces false;
}
// * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
* * * *//
```

After creation of the mesh and splitting to different regions, the initial and boundary conditions for each region can be manually set in the relevant region folders in 0 directory. This process can be also automated using the changeDictionary utility. The dictionary file for this utility for each region is in the relevant region folder in the system directory: changeDictionaryDict.

See below the changeDictionaryDict file for the heater region. In the `boundary` sub-dictionary type of boundaries for `minY`, `MinZ` and `maxZ` are set to patch. Then for `T` the internal field will be overwritten with `uniform 300`. In the next step all the boundaries in the T file for heater region will be set to `zeroGradient` (`".*"` means all the boundaries with any name) and after that the bounadries with the name `"heater_to_.*"` will be changed to `turbulentTemperatureCoupledBaffleMixed` and `minY` will be changed to `fixedValue`.

```
  // * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
* * * * * *//
boundary
{
minY
{
     type              patch;
}
minZ
{
     type              patch;
}
maxZ
{
     type              patch;
}
}

T
{
internalField          uniform 300;

boundaryField
{
    ".*"
    {
       type                zeroGradient;
       value               uniform 300;
 }
```

```
"heater_to_.*"
{
   type               compressible::turbulentTemperatureCoupledBaffleMixed;
   Tnbr               T;
   knappaMethod       solidThermo;
   value              uniform 300;
}
minY
{
   type               fixedValue;
   value              uniform 500;
}
}
    }
   // * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
* * * * *//
```

In the meshQualityDict file, change the following line:

```
#includeEtc "caseDicts/meshQualityDict"
```

to

```
#includeEtc "caseDicts/mesh/generation/meshQualityDict.cfg"
```

Note: Add the missing ";" to the fvSolution files for bottomAir and topAir regions:

```
"(rho|rhoFinal)"
{
    solver          PCG;
    preconditioner  DIC;
    tolerance       1e-7;
    relTol          0;
}
```

Update the laplacianSchemes in the the system/heater/fvSchemes file as following:

```
laplacianSchemes
{
    default              Gauss linear corrected;
    laplacian(alpha,h)   Gauss linear corrected;
}
```

In the system/heater/fvSolution change the h and hFinal to e and eFinal.

Copy and replace the fvScheme and fvSolution files from system/leftSolid and system/rightSolid with the ones from system/heater

Copy fvSchemes and fvSolution from bottomAir to topAir (replace the files)

2. Mesh creation and running simulation

The background mesh is created with blockMesh.

```
>blockMesh
```

Equal to the single region case, the command `surfaceFeatures` creates the **eMesh** files from the stl files with the geometry data. Also the folder *extendedFeatureEdgeMesh* is created in the constant directory. The creation of eMesh files with the command `surfaceFeatures` is not obligatory. This step is only necessary, if certain edges need to be refined.

```
>surfaceFeatures
```

For performing the meshing in parallel, the geometry needs to be decomposed prior to running *snappyHexMesh*. Depending on the number of subdomains, defined in the *decomposeParDict*, the processor folders are created accordingly.

```
>decomposePar
```

*Note: It is **recommended**, not to use the scotch method to decompose the region. Rather, the hierarchical or the simple method should be used. In case of scotch method, errors can occur while executing snappyHexMesh or while reconstructing the mesh.*

In order to prevent the creation of the folders 1, 2 (castellation and snapping features are turned on while layering is turned off) and only keep the final time step folder with the final mesh, the command *-overwrite* can be added after *snappyHexMesh.* In this case, only one folder, *0,* is created with the files **pointLevel** and **cellLevel**. The mesh data in this case is located in constant/polyMesh.

```
>mpirun -np 4 snappyHexMesh -parallel -overwrite
```

Note: If castellatedMesh and snap are set on true in the **snappyHexMeshDict**, only the snapped mesh is stored, whereas the intermediate step castellatedMesh is overwritten. If castellatedMesh, snap and addLayers are set on true in the **snappyHexMeshDict**, only the layered mesh is stored and the previous intermediate steps castellatedMesh and snap are overwritten.

In this case, only the steps *castellatedMesh* and *snap* are set to *true*, as these steps are applied to the whole mesh. The following command reconstructs the final mesh:

```
>reconstructParMesh -constant
```

After this step, all the regions are meshed but the meshes are connected and needs to be split. In the meshing step each region cells are marked with a flag and this flag will be used in the next step to split the mesh. Mesh regions can be split using the following command which split the mesh based on the flagged cellZones and overwrite the old meshes in the polyMesh directories in the region folders (if any exist):

```
>splitMeshRegions -cellZones -overwrite
```

With the mesh ready, the next step is to apply appropriate field values to each region, according to the *changeDictionaryDict*. This command needs to be repeated for each region, with the name of the region specified after the prefix `'-region'`.

```
>changeDictionary -region heater

>changeDictionary -region topAir

>changeDictionary -region bottomAir
```

```
>changeDictionary -region rightSolid
>changeDictionary -region leftSolid
```

Now the solver chtMultiRegionFoam is ready to be run.

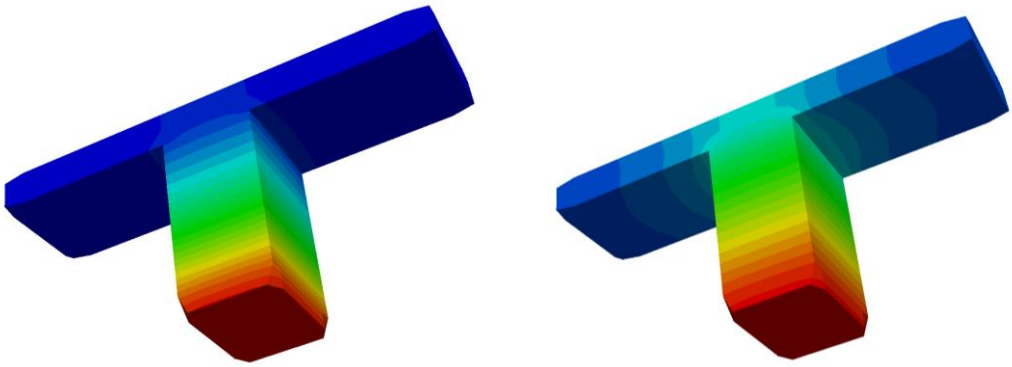
```
>chtMultiRegionFoam
```

Note: chtMultiRegionFoam can also be run on several processors.

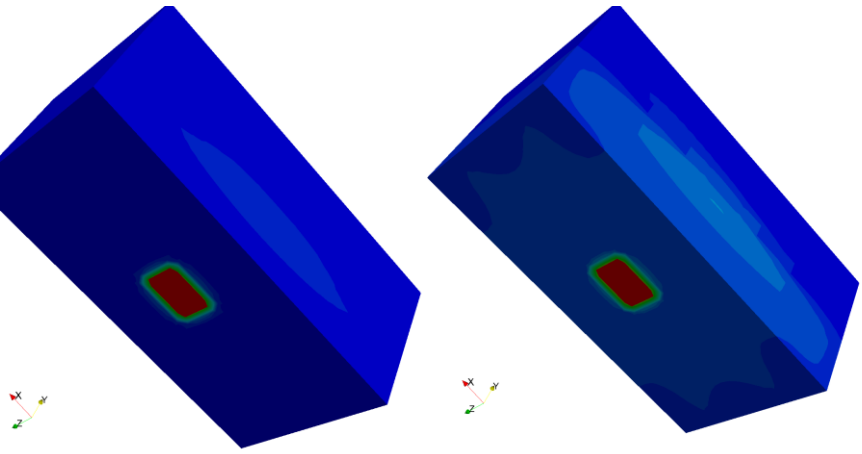
3. Post-processing

The results need to be converted to VTK files for each region with flag `-region`.

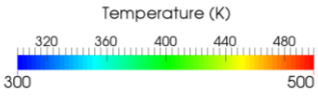
```
>foamToVTK -region heater
>foamToVTK -region topAir
```



Temperature profile of heater region at time 15s and 75s



Temperature profile of entire mesh at time 15s and 75s



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