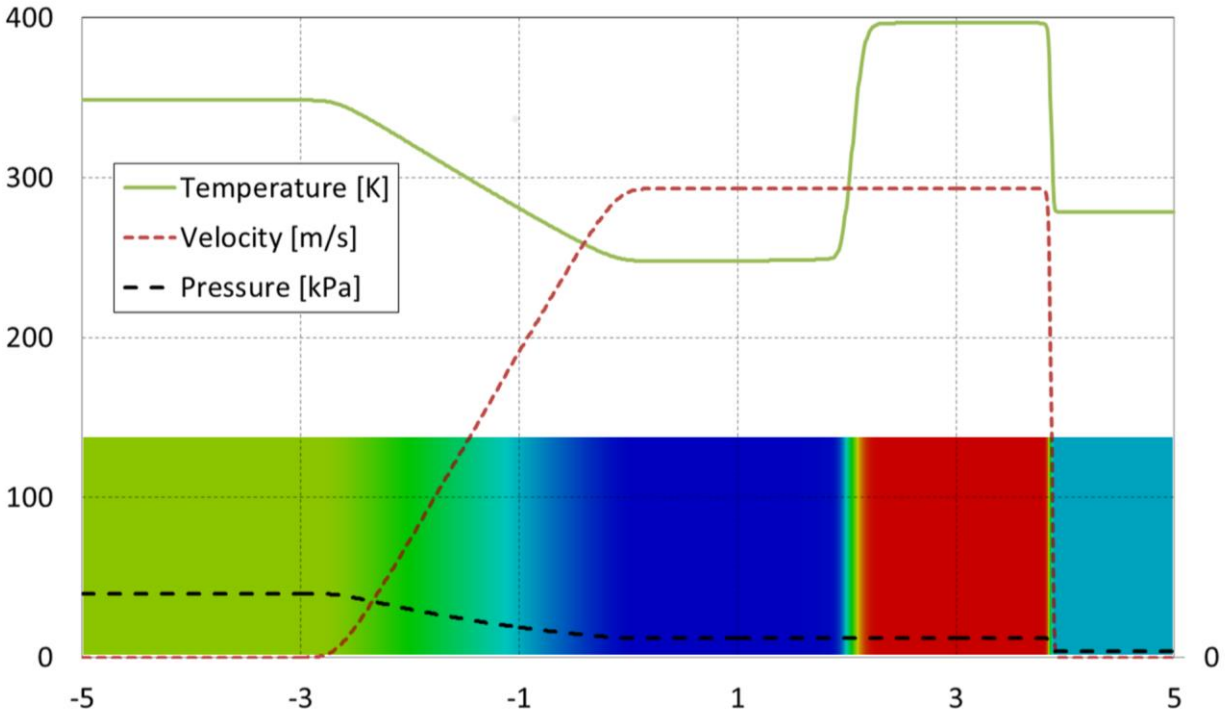
Tutorial Fourteen

Sampling



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Compatibility:
- OpenFOAM® 5.0
- OpenFOAM® v1712

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Background

1. Introduction to sampling

This tutorial is an introduction to the OpenFOAM® sampling utility. With this utility one can extract sample data from certain selected surfaces or points in ones simulation after or while running the simulation. If data is sampled while running one can use sampling to observe the progress of the simulation and the correctness of the solution without even reaching a write-interval.

Using a *sample* file in the system directory data can be sampled after the simulation or by adding the needed functions to the *controlDict* it can be done while running a simulation.

At the beginning of this tutorial the implementation for sampling using the *sample* and the *controlDict* will be introduced and afterwards the different sampling options in OpenFOAM® will be discussed.

sonicFoam – shockTube

Tutorial outline

Simulate the flow along a shock tube for 0.007 s and use OpenFOAM® sampling utility for extracting the data along a line during the simulation and after the simulation.

Objectives

- Understand the function of sampling and how to use the sampling utility

Data processing

Import your simulation to ParaView to visualize it and analyze the extracted data with sampling tool.

1. Pre-processing

1.1. Copying tutorial

To test the sampling feature, we will use the shockTube tutorial covered in Tutorial Three and extract data over a line between (-5 0 0) and (5 0 0).

$FOAM_TUTORIALS/compressible/sonicFoam/laminar/shockTube/system

1.2. system directory

1.2.1. sample dictionary

The *sample* file can be found in the system directory.

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

type sets;
libs           ("libsampling.so")

interpolationScheme      cellPoint;

setFormat   raw;

sets
(
    data
    {
        type             uniform;
        axis             x;
        start            (-4.995 0 0);
        end              (4.995 0 0);
        nPoints          1000;
    }
);

fields                   (T mag(U) p);

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

In the `type` the type of data to be sampled is defined, e.g. `sets` or `surfaces`. The different options for `interpolationScheme` and `setFormat` will be discussed in a later section.

In the `sets` sub-dictionary each set of data should be given a name, which is freely chosen by the user, in this case the name is simply '`data`'. In the bracket for the set of data, we need to specify the following criteria:

- `type`: specifies the method of sampling. Here uniform was chosen to make a sample on a line with equally distributed number of points.
- `axis`: to define how the point coordinates are written. In this case, x means that only the x coordinate for each point will be written.
- `Start/end`: the endpoints of the line-sample are defined
- `nPoints`: number of points on our line

Outside of the data and sets bracket in the `fields` we have to define which fields we want to sample.

1.2.2.controlDict

To have the option to sample for each time step instead of each write-interval or sampling while the solver is running; instead of the *sample* dictionary additions in the *controlDict* are needed.

In this part one will change the *controlDict* of the shockTube tutorial so that our line-sampling from before will be executed while running, and per time step.

Add the following code to the end of the `function` sub-dictionary in the *controlDict*.

```
// * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
* * * * * */// 
…

functions
{
    #includeFunc mag(U)

    linesample
    {
        type                      sets;
        functionObjectLibs        ("libsampling.so");
        writeControl              timeStep;
        outputInterval            1;

        interpolationScheme      cellPoint;

        setFormat   raw;

        sets
        (
           data
            {
                type               uniform;
                axis              x;
                start             (-4.995 0 0);
                end               (4.995 0 0);
                nPoints           1000;
            }
        );

        fields                    (T mag(U) p);
    }
}
// * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
* * * * * *//
```

`linesample` sub-dictionary includes the settings for the sampling tool. Any arbitrary name can be chosen instead of `linesample`. The chosen name will be the name of the folder in the *postProcessing* directory after running the solver.

Inside our linesample sub-dictionary:

- `type`: `sets` or `surfaces` can be chosen. More types will be covered in a later section.

- `functionObjectLibs`: provides the operations needed for the sampling tasks.

- `writeControl`: specifies the intervals in which sampling data should be collected in the case of timeStep, depending on the `outputInterval`, sampling data will get saved in dependence of the `timeStep`. In the case of

`outputInterval` being equal to 1, every time step sampling data will be saved. Changing the interval to 2 means that data will be saved every 2 time steps.

2. Running simulation

To run the Tutorial go to your case directory in the terminal and use the following commands:

```
>blockMesh
>setFields
>sonicFoam
```

3. Post-processing

After sonicFoam solver finishes running, based on your sampling approach the following steps should be performed:

3.1.sample dictionary

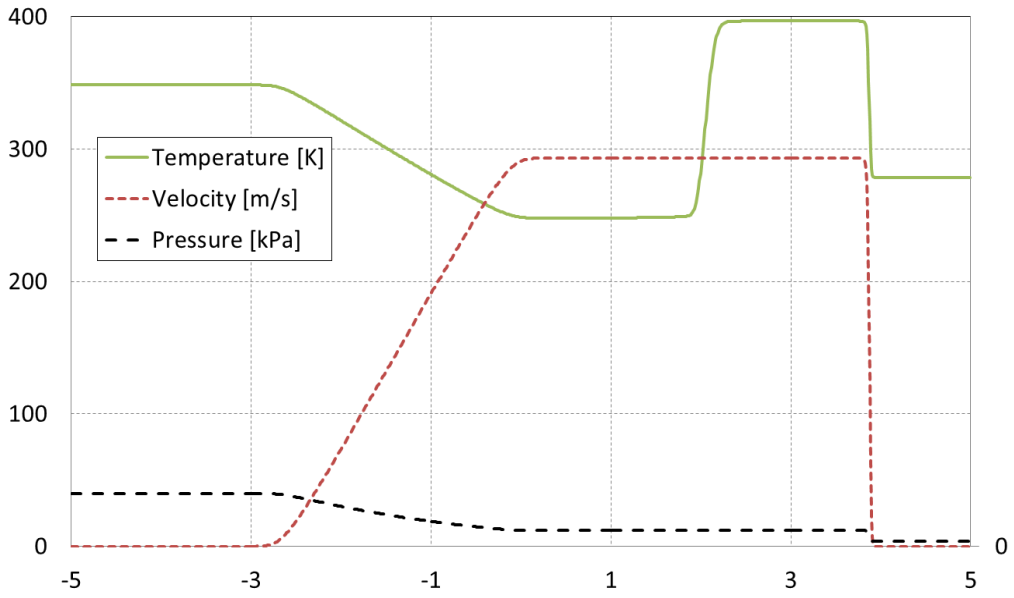
use the sample command to extract your sample-data.

```
>postProcess -func sample
```

A new folder will appear in your case directory named *postProcessing* and in it a folder named *sample*. In this folder all the sampling data will be stored in separate folders for each write-interval.

3.2.controlDict

The *postProcessing* directory and all its subdirectories have been generated after the first time step. Now it can be seen that for every time step a folder is generated instead of only every write interval.



Extracted data using sampling tool after 0.007 s

4. Types of sampling

There are 2 main types of sampling. The sets type, which was used in our example above, and the surfaces type.

In the sets type of sampling different kinds of point samplings, like the line sampling we used before, or some kind of cloud sampling are included. In the surface type whole surfaces are sampled, like near a patch, or on a plane defined by a point and a normal vector.

Let's discuss the similarities between the set and surface types. If the sampling happens in the *controlDict* the 4 entries discussed in the *controlDict* section of this tutorial need to be included for both types. On top of that both types need an interpolation scheme. Here only two of the schemes: cell and `cellPoint` will be discussed. The cell scheme assumes that the cell centre value as constant in the whole cell. The `cellPoint` scheme will carry out linear interpolation between the cell centre and vertex values. Lastly the field bracket looks the same for both cases.

4.1. sets

All sets need a `setFormat`, for example csv which needs to be included after the `interpolationScheme`.
After that the sets sub-dictionary begins where a bracket with an arbitrary name begins in which the sets sampling type and the geometrical location of the sampling points will be chosen. In the following a few of sampling types will be discussed.

4.1.1. uniform

This one was used in the above example. A line from a start point to an end point with a fixed number of points evenly distributed along it.

`axis` determines what is written for the point coordinate in the output file. `distance` means it will only write the distance between sampled point and start point in the file.

```
lineX1
    {
        type                    uniform;
        axis                    distance;

        start                   (0.0201  0.05101  0.00501);
        end                     (0.0601  0.05101  0.00501);
        nPoints                 10;
    }
```

4.1.2. face

This type also samples along a line from a defined start to endpoint, but only writes in the log file for every face the line cuts.

```
lineX2
    {
        type                    face;
        axis                    x;

        start                   (0.0001  0.0525  0.00501);
```

```
        end                         (0.0999  0.0525  0.00501);
    }
```

4.1.3. cloud

The cloud type samples data at specific points defined in the points bracket.

```
somePoints
    {
        type                        cloud;
        axis                        xyz;
        points                      ((0.049 0.049 0.00501)(0.051 0.049 0.00501));
    }
```

4.1.4. patchSeed

The `patchSeed` sampling type is used for sampling patches of the type wall. One can for example sample the surface adsorption on a wall with this type.

```
patchSeed
    {
        type        patchSeed;
        axis        xyz;
        patches     (".*Wall.*");
        maxPoints   100;
    }
```

Please note that for patches only a patch of type wall can be used. If you choose a wrong type, nothing will be sampled and you receive no error message.

4.2. surfaces

All surfaces need a `surfaceFormat` specified. Practical formats would be the vtk format which can be opened with paraview and the raw format which can be used for gnuplots. Instead of the `sets` bracket now a `surfaces` bracket must be used and the `type` is of course also `surfaces`. Inside the surfaces brackets one can now sample an arbitrary number of surfaces, each in its own inner brackets. The different types of surface sampling like the `plane` in the example below will be discussed in the next sections.

```
    type                surfaces;

    interpolationScheme cellPoint;
    surfaceFormat       vtk;

     fields
     (
         U
     );

     surfaces
     (
           yoursurfacename
           {
            type          plane;
            basePoint     (0.1 0.1 0.1);
            normalVector  (0.1 0 0);
            triangulate   false;
           }
     );
```

4.2.1. plane

The type plane creates a flat plane with an origin in the `basePoint` normal to the `normalVector`. This `normalvector` starts in the origin, not in the `basePoint`. To turn the triangulation of the surface off one has to add `triangulate false`.

```
constantPlane
    {
        type            plane;    // always triangulated
        basePoint       (0.0501 0.0501 0.005);
        normalVector    (0.1 0.1 1);

        //- Optional: restrict to a particular zone
        // zone        zone1;

        //- Optional: do not triangulate (only for surfaceFormats that support
        //            polygons)
        //triangulate     false;
        //interpolate     true;
    }
```

One can also set a new origin for the `basePoint` and `normalVector` with

```
coordinateSystem
        {
            origin      (0.0501 0.0501 0.005);
        }
```

4.2.2. patch

A sampling of type `patch` can sample data on a whole patch. Please note that while the syntax looks the same as in the `patchSeed` case, also patches that are not of type wall work. Default option will triangulate the surface, this can be turned off with `triangulate false`.

```
walls_interpolated
    {
        type            patch;
        patches         ( ".*Wall.*" );
        //interpolate     true;
        // Optional: whether to leave as faces (=default) or triangulate
        // triangulate     false;
    }
```

4.2.3. patchInternalField

Similar to the `patch` type, this type needs a patch on which it samples. It will sample data that's a certain distance away in normal direction (`offsetMode normal`). There is also the option to define the distance in other ways seen in the commented section of the code.

Note: While the sampling happens not on the patch but a distance away from it, the geometric position of the sampled values in the output file will be written as the position of the patch.

Once again the default triangulation can be turned off with `triangulate false`.

```
nearWalls_interpolated
    {
        // Sample cell values off patch.
        // Does not need to be the near-wall
        // cell, can be arbitrarily far away.
        type            patchInternalField;
        patches         ( ".*Wall.*" );
        interpolate     true;


        // Optional: specify how to obtain
        // sampling points from the patch
        // face centres (default is 'normal')
```

```
        //
        //  //- Specify distance to
        // offset in normal direction
        offsetMode  normal;
        distance    0.1;
        //
        //  //- Specify single uniform offset
        //  offsetMode  uniform;
        //  offset      (0 0 0.0001);
        //
        //  //- Specify offset per patch face
        //  offsetMode  nonuniform;
        //  offsets     ((0 0 0.0001) (0 0 0.0002));


        // Optional: whether to leave
        // as faces (=default) or triangulate
        // triangulate     false;
    }
```

4.2.4. triSurfaceSampling

With the `triSurfaceSampling` type data can be sampled in planes which are provided as a trisurface stl file. To create such a file one can use the command below. The command will generate a .stl file of one (or more) of your patches.

```
>surfaceMeshTriangulate name.stl -patches "(yourpatch)"
```

Here your patch needs to be replaced with the name of one of your patches defined in the constant/polyMesh/boundary file. Starting the command without the patches option will generate a stl file of your whole mesh boundary. Next make a directory in the constant folder named triSurface if it doesn't already exist and copy the .stl file there. In the code you now have to specify your stl file as the surface. For the source the use of `boundaryFaces` seems to be a good option of the stl file is one of your patches.

```
triSurfaceSampling
    {
        // Sampling on triSurface
        type        sampledTriSurfaceMesh;
        surface     integrationPlane.stl;
        source      boundaryFaces;
        // What to sample: cells (nearest cell)
        // insideCells (only triangles inside cell)
        // boundaryFaces (nearest boundary face)
        interpolate true;
    }
```

Note: Most CAD software can export the surface of 3D drawings as stl files.

4.2.5. isoSurface

The `isoSurface` sampling type is quite different to what was discussed before in this tutorial. Until now all the sampling types had a constant position in space and changing field values at that position were extracted. With the `isoSurface` sampling one tracks the position of a defined value in space. The example below can be copied into the shocktube tutorials *sample file* (of course it needs all the other options needed for surface type sampling).

Using `vtk` for the `surfaceFormat` one can visualize the moving shockwave in space. Note that both the vtk of the sampling and the whole shocktube case can be opened together in paraview to compare the results.
Note that the `isoField` needs to be a `scalarfield`.

```
interpolatedIso
    {
        // Iso surface for interpolated values only
        type            isoSurface;
        // always triangulated
        isoField        p;
        isoValue        9e4;
        interpolate     true;

        //zone            ABC;
        // Optional: zone only
        //exposedPatchName fixedWalls;
        // Optional: zone only

        // regularise      false;
        // Optional: do not simplify

        // mergeTol        1e-10;
        // Optional: fraction of mesh bounding box
        // to merge points (default=1e-6)
    }
```

4.2.6. isoSurfaceCell

The `isoSurfaceCell` type is very similar to the one we discussed before, but this one doesn't cross any cell with its surface and doesn't interpolate values.

```
constantIso
    {
        // Iso surface for constant values.
        // Triangles guaranteed not to cross cells.
        type            isoSurfaceCell;
        // always triangulated
        isoField        rho;
        isoValue        0.5;
        interpolate     false;
        regularise      false;
        // do not simplify
        // mergeTol        1e-10;
        // Optional: fraction of mesh bounding box
        // to merge points (default=1e-6)
    }
```