JKU
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Introduction to open source CFD

Session 2/4

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Outline

- Introduction to C++
- Modyfying a solver
- Creating our own boundary condition

Disclaimer

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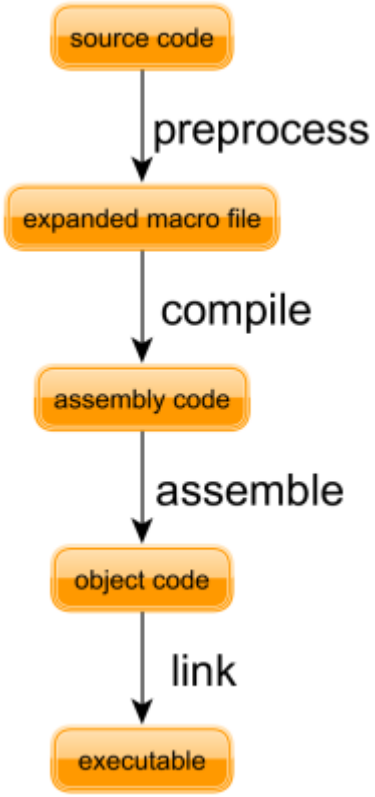
INTRODUCTION TO C++

Introduction to C++
What the object is C++?

- C++ is a programming language that is
  - object-oriented
  - compiled
  - imperative
- OpenFOAM is a **modular** C++ code
  - Libraries such as boundary conditions, turbulence models etc., are compiled as **shared objects**
  - Executables are compiled as **(executable) objects**



Objects, functions, types and classes

- C++ works with
  - **objects** that can **hold data**
  - **methods** (functions) can **manipulate** data held by objects.

- Objects must be declared with a **type**
- A **class** is a formal **model** of how a type behaves

Introduction to C++
Objects

- C++ works with **objects** that can **hold data**. **Methods** (functions) can **manipulate** data held by objects.

- Need to create an object before you can use it:

```
type objectName = value; // pseudo code

int  a          = 4;     // copy assignment
```

Functions/methods

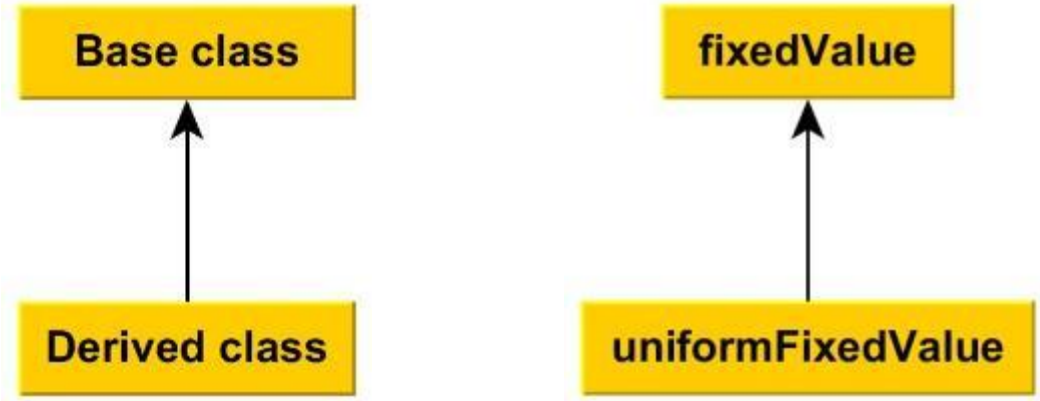
- C++ works with **objects** that can **hold data**. **Methods** (functions) can **manipulate** data held by objects.

- Functions can use an object as argument to a function, or to apply a function to:

```
operator+(a,b)

patch.size()
```

Introduction to C++
Class inheritance

- Classes can **inherit** data and/or functions from other classes.



Polymorphism

- „The ability to obtain type-specific behaviour based on the dynamic type of a reference or pointer.“[1]
- For example, a function behaves differently depending on the type of object it is applied to.

```
a  + b   // adding scalars
P1 + p2  // adding volScalarFields
U1 + U2  // adding volVectorFields
```

[1] See e.g. Chapter 15 of Lippman, S., Lajoie, J, and Moo, B., *C++ Primer*, 4th ed., Edison Wesley, 2005.

Introduction to C++
A basic example

- Create a text file named windows.C containing

```
#include <iostream>

int main()
{
    std::cout << "I love windows!" << std::endl;

    return 0;
}
```

- Compile the code by

```
g++ windows.C –o Windows
```

- Run Windows by

```
./windows
```

Introduction to C++
A basic example – OpenFOAM style

- Create a text file named `changedMyMind.C` containing

```
#include "fvCFD.H"

int main(int argc, char *argv[])
{
    Info<< "I changed my mind ..." << std::endl;

    return 0;
}
```

- We will is wmake to compile, which needs a Make directory containing `files` and `options`.

Introduction to C++
A basic example – OpenFOAM style

- Create a directory called Make in the location where the code resides

```
> mkdir Make
```

- Create a text file named `files` in the Make directory

```
> gedit Make/files &
```

- ... with the following content

```
changedMyMind.C

EXE = $(FOAM_USER_APPBIN)/changedMyMind
```

Introduction to C++
A basic example – OpenFOAM style

- ... and a file named options `options`

```
> gedit Make/options &
```

- ... With the following content

```
EXE_INC = \
    -I$(LIB_SRC)/finiteVolume/lnInclude

EXE_LIBS = \
    -lfiniteVolume
```

A basic example – OpenFOAM style

- Finally, compile

```
> wmake
```

- ... and run

```
> changedMyMind
```

Compiling OpenFOAM code

- In short, we can compile two types of things
  - code that can be executed (solvers, utilities)

```
> wmake
```

  - code that is used by executable code (boundary conditions, turbulence models, etc.)

```
> wmake libso
```

Introduction to C++
Some resources

- Lippman, Lajoie and Moo, *C*++ Primer.
- Deitel and Deitel, C++ How to program.
- Meyers, Effective C++.
- Koenig and Moo, Accelerated C++.
- Ullman and Signer, C++ Programming: Visual QuickStart Guide.

- www.cplusplus.com
- www.learncpp.com
- https://buckysroom.org/videos.php

MODIFYING A SOLVER

Modifying a solver
Overview

Aims:

- Implement a massless species transport equation in a transient solver
- Use the new solver
- Apply a time-varying boundary condition to the species field

- We will implement a transport equation for massless species C in the incompressible RAS/LES solver `pimpleFoam`

$$\frac{\partial}{\partial t}C+\nabla\cdot\left(\vec{U}C\right)-\nabla\cdot\left(D_C\nabla C\right)=0$$

Modifying a solver
Overview

Aims:

- Implement a massless species transport equation in a transient solver
- Use the new solver
- Apply a time-varying boundary condition to the species field

Steps

- Copy the `pimpleFoam` solver to your user directory
- Rename and compile
- Implement species transport equation
- Copy standard `pimpleFoam` tutorial to run directory
- Modify the tutorial to handle the new solver

Modifying a solver
Recommended file structure

- Create a directory to store your models

```
student-2.3.x           # this is WM_PROJECT_USER_DIR
├── run                 # dir to run cases
├── src                 # dir for model libraries
└── applications
    ├── utilities
    └── solvers
```

Modifying a solver
Solver

- Go to the run directory and copy the solver

```
> mkdir -p $WM_PROJECT_USER_DIR/applications/solvers
> cd  $WM_PROJECT_USER_DIR/applications/solvers
> cp -r $FOAM_SOLVERS/incompressible/pimpleFoam pimpleSpeciesTransportFoam
> cd pimpleSpeciesTransportFoam
```

- Rename the solver

```
> mv pimpleFoam.C pimpleSpeciesTransportFoam.C
```

- Remove unneccesary directories

```
> rm -r pimpleDyMFoam SRFPimpleFoam
```

Modifying a solver
Solver

- Edit `Make/files` to look like below

```
pimpleSpeciesTransportFoam.C

EXE = $(FOAM_USER_APPBIN)/pimpleSpeciesTransportFoam
```

- … and compile

```
> wclean
> wmake
```

Modifying a solver
Solver

- Now edit `pimpleSpeciesTransportFoam.C` by adding the transport equation after the PIMPLE loop and before `runTime.write()`

```
    if (pimple.turbCorr())
    {
        turbulence->correct();
    }
}

fvScalarMatrix Ceqn
(
    fvm::ddt(C)
  + fvm::div(phi, C)
  - fvm::laplacian(DC, C)
);

CEqn.solve();

runTime.write();
```

Modifying a solver
Solver

- Create the necessary objects in `createFields.H`. First, create species field C

```
Info<< "Reading field C\n" << endl;

volScalarField C
(
    Ioobject
    (
        "C",
        runTime.timeName(),
        mesh,
        IOobject::MUST_READ,
        IOobject::AUTO_WRITE
    ),
    mesh
);
```

Modifying a solver
Solver

- Create the necessary objects in `createFields.H`. Then, read the diffusion coefficient from a dictionary

```
Info<< "Reading transportProperties\n" << endl;
IOdictionary transportProperties
(
    IOobject
    (
        "transportProperties",
        runTime.constant(),
        mesh,
        IOobject::MUST_READ_IF_MODIFIED,
        IOobject::NO_WRITE
    )
);

dimensionedScalar DC
(
    transportProperties.lookup("DC")
);
```

Modifying a solver
Solver

- Adjust the header to detail your changes

- Compile the solver

```
> wmake
```

Modifying a solver
Test case

- Let's set up our beloved `pitzDaily` case for our new solver
- Go to the run directory and copy the `pimpleFoam pitzDaily` case in there

```
> run
> cp -r \
  $FOAM_TUTORIALS/incompressible/pimpleFoam/pitzDaily \
  pitzDailySpeciesTransport
> cd pitzDailySpeciesTransport
```

Modifying a solver
Test case

- Now create a new field `C` in the `0` directory

```
> cp 0/p 0/C
```

- … and edit the `0/C` file so that the content looks like

```
FoamFile
{
    version     2.0;
    format      ascii;
    class       volScalarField;
    object      C;
}
// * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * //

dimensions      [0 0 0 0 0 0 0];

internalField   uniform 0;
```

Modifying a solver
Test case

- Add our new variable to `system/fvSolution`

```
"(U|k|epsilon|C)"
{
    solver          smoothSolver;
    smoother        symGaussSeidel;
    tolerance       1e-05;
    relTol          0.1;
}

"(U|k|epsilon|C)Final"
{
    $U;
    relTol          0;
}
```

Modifying a solver
Test case

- … and to `system/fvSchemes`

```
divSchemes
{
    default         none;
    ...
    div((nuEff*dev(T(grad(U))))) Gauss linear;
    div(phi,C)      bounded Gauss upwind;
}

laplacianSchemes
{
    default         none;
    ...
    laplacian(DC,C) Gauss linear corrected;
    laplacian(DnuTildaEff,nuTilda) Gauss linear corrected;
}
```

Modifying a solver
Test case

- Finally, change the kinematic viscosity and add the diffusion coefficient in `constant/transportProperties`

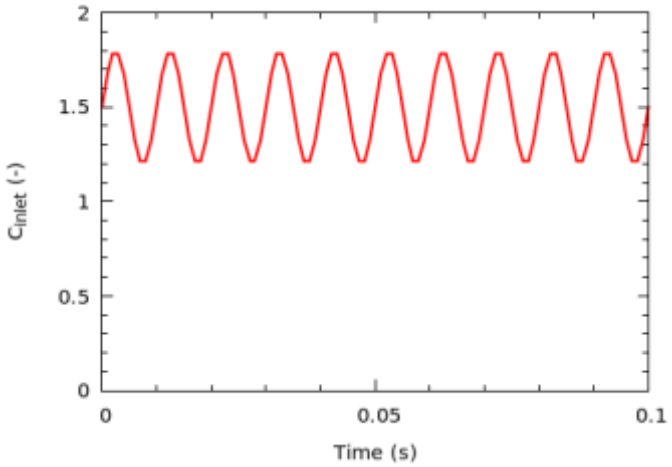
```
nu              nu [ 0 2 -1 0 0 0 0 ] 1e-6;

DC              DC [ 0 2 -1 0 0 0 0 ] 1e-7;
```

Modifying a solver
Test case

- Just because it is fun, use an oscillating inlet BC for the species field `C`. Edit `0/C`:

$$\phi_p = (1 + a \sin(2\pi f))\phi_{ref} + \phi_0$$

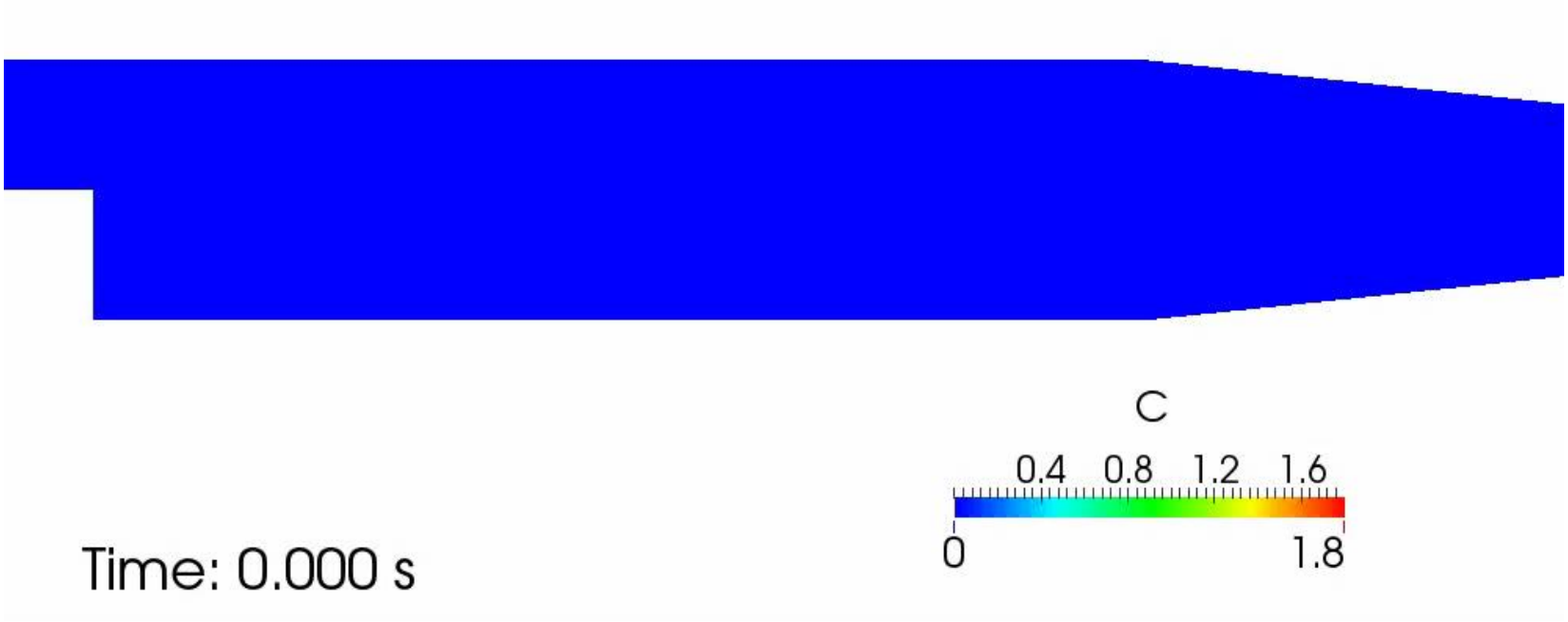
```
boundaryField
{
    inlet
    {
        type            oscillatingFixedValue;
        refValue        uniform 1.0;
        offset          0.5;
        amplitude       constant 0.3;
        frequency       constant 100;
    }
```



Modifying a solver
Test case

```
    outlet
    {
        type            inletOutlet;
        inletValue      uniform 0;
        value           uniform 0;
    }
    upperWall
    {
        type            zeroGradient;
    }
    lowerWall
    {
        type            zeroGradient;
    }
    frontAndBack
    {
        type            empty;
    }
}
```

Modifying a solver
Test case

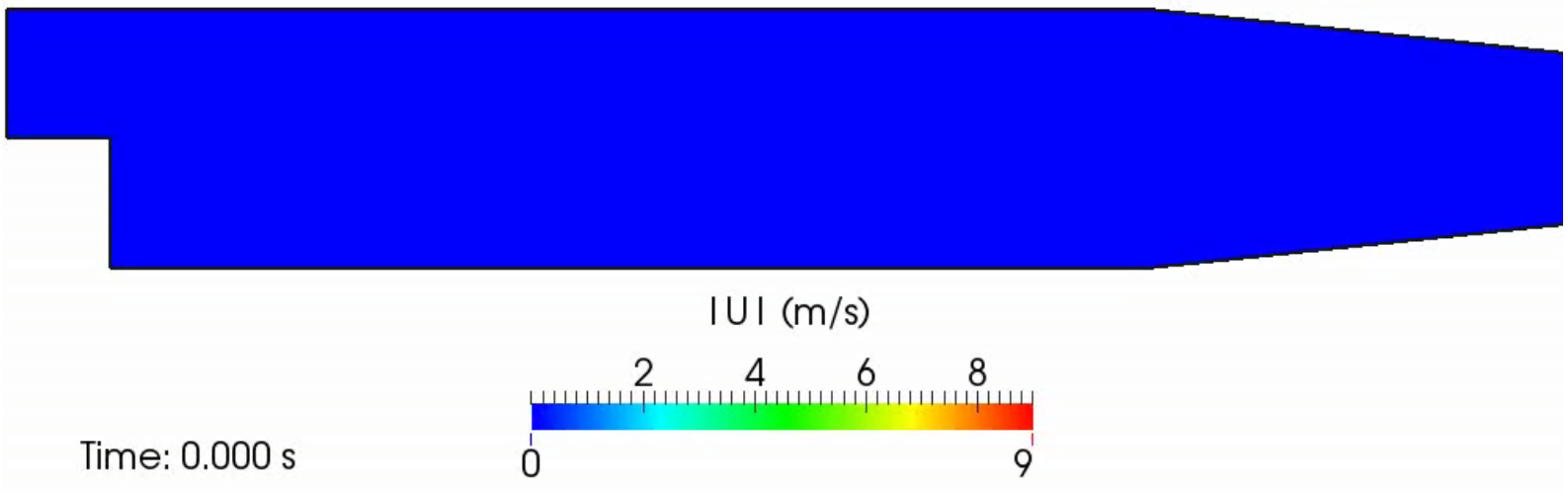


CREATING A BOUNDARY CONDITION

Creating a boundary condition (BC)
Overview

Aims:

- Create a library
- Create a new boundary condition
- Use the new BC on a case



Creating a boundary condition (BC)
Overview

- Let's have a look what BCs are available

```
> find $FOAM_SRC -name "*vPatchFields"
```

- Look more specifically at the common FVM BCs

```
> src

> cd finiteVolume/fields/fvPatchFields

> ls -1
basic
constraint
derived
doc
fvPatchField
```

Creating a boundary condition (BC)
Find an example to start from

- Create a boundary condition that randomises inlet flow rate

- First, let's see whether we can find a good starting point:

```
> src
> cd finiteVolume/fields/fvPatchFields/derived
> ls
```

Creating a boundary condition (BC)

- Create a directory to store your models

```
student-2.3.x              # this is WM_PROJECT_USER_DIR
├── run                    # dir to run cases
├── src                    # dir for model libraries
└── applications
    ├── utilities
    └── solvers
```

- … and copy the flowRateInletVelocity BC

```
> cd $WM_PROJECT_USER_DIR
> mkdir -p src/fvPatchFields
> cd src/fvPatchFields
> BCS="$FOAM_SRC/finiteVolume/fields/fvPatchFields/derived"
> cp -r $BCS/flowRateInletVelocity randomisedFlowRateInletVelocity
> cp randomisedFlowRateInletVelocity
```

Creating a boundary condition (BC)

- First, rename the file names (on debian-ish system!)[1]

```
> rename 's/flowRateInletVelocity/randomisedFlowRateInletVelocity/g' *.*
```

- Then, change the instances inside the files

```
> sed -i 's/flowRateInletVelocity/randomisedFlowRateInletVelocity/g' *.*
```

- … using sed. Some explanation on sed syntax:

```
sed -i 's/string1/string2/g' file
sed: stream editor
-i:  "in place" (as in "insert here")
s:   substituteg: append pattern space ("global")
```

[1] On an rpm-ish system the syntax for rename is:

```
> rename string1 string2
```

Creating a boundary condition (BC)

- The flowRateInletVelocity BC does not have a Make directory, so we need to create it

```
> mkdir Make
```

- … and create `Make/files` as

```
randomizedFlowRateInletVelocityFvPatchVectorField.C

LIB = $(FOAM_USER_LIBBIN)/libfancyStuff
```

Creating a boundary condition (BC)

- … and create `Make/options` as

```
EXE_INC = \
    -I$(LIB_SRC)/finiteVolume/lnInclude \
    -I$(LIB_SRC)/postProcessing/foamCalcFunctions/lnInclude \
    -I$(LIB_SRC)/OpenFOAM/lnInclude

LIB_LIBS = \
    -lfiniteVolume \
    -lfoamCalcFunctions \
    -lOpenFOAM
```

- Finally, compile before making code changes

```
> wmake libso
```

Creating a boundary condition (BC)

- Add necessary headers to `randomizedFlowRateInletVelocityFvPatchVectorField.H`

```
#include "DataEntry.H"

#include "calcType.H"
#include "Random.H"

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

Creating a boundary condition (BC)

- Add private data to the class declaration in `randomizedFlowRateInletVelocityFvPatchVectorField.H`

```
        //- Rho initialisation value (for start; if value not supplied)
        scalar rhoInlet_;

        //- Random number generator
        Random ranGen_;

        //- Fluctuating scale
        scalar fluctuationScale_;

    public:
```

Creating a boundary condition (BC)

- Initialize randGen_ and fluctuationScale_ in the constructors in `randomizedFlowRateInletVelocityFvPatchVectorField.C`

- First and second constructors

```
    rhoInlet_(0.0),
    ranGen_(label(0)),
    fluctuationScale_(0.0)
{}
```

- Third constructor

```
    rhoInlet_(dict.lookupOrDefault<scalar>("rhoInlet", -VGREAT)),
    ranGen_(label(0)),
    fluctuationScale_(readScalar(dict.lookup("fluctuationScale")))
{
    if (dict.found("volumetricFlowRate"))
```

Creating a boundary condition (BC)

- Initialize randGen_ and fluctuationScale_ in the constructors in `randomizedFlowRateInletVelocityFvPatchVectorField.C`

- Fourth and fifth constructors

```
    rhoInlet_(ptf.rhoInlet_),
    ranGen_(ptf.ranGen_),
    fluctuationScale_(ptf.fluctuationScale_)
{}
```

Creating a boundary condition (BC)

- Now modify the `updateCoeffs` function in `randomizedFlowRateInletVelocityFvPatchVectorField.C`

```
// a simpler way of doing this would be nice
const scalar avgU = -flowRate_->value(t)/gSum(patch().magSf());

fvPatchVectorField& patchField = *this;

scalarField randomField(this->size());

forAll(patchField, facei)
{
    ranGen_.randomise(randomField[facei]);
}
```

Creating a boundary condition (BC)

- Now modify the `updateCoeffs` function in `randomizedFlowRateInletVelocityFvPatchVectorField.C`

```
scalarField rndScale =
    pTraits<scalar>::one + fluctuationScale_*randomField;

tmp<vectorField> n = patch().nf();

if (volumetric_ || rhoName_ == "none")
{
    // volumetric flow-rate or density not given
    operator==(n*avgU*rndScale);
}
```

Creating a boundary condition (BC)

- Last, but not least, update the `write` function in `randomizedFlowRateInletVelocityFvPatchVectorField.C`

```
void Foam::randomizedFlowRateInletVelocityFvPatchVectorField::write
(
    Ostream& os
) const
{
    fvPatchField<vector>::write(os);
    flowRate_->writeData(os);
    os.writeKeyword("fluctuationScale")
        << fluctuationScale_ << token::END_STATEMENT << nl;
    if (!volumetric_)
    {
        writeEntryIfDifferent<word>(os, "rho", "rho", rhoName_);
        writeEntryIfDifferent<scalar>(os, "rhoInlet", -VGREAT, rhoInlet_);
    }
    writeEntry("value", os);
}
```

Creating a boundary condition (BC)

- Finally, compile the library

```
> wmake libso
```

- Change to the run directory and copy a tutorial to test the BC

```
> run
> cp -r \
  $FOAM_TUTORIALS/incompressible/pimpleFoam/pitzDaily \
  pitzDailyRandomisedInlet
> cd pitzDailyRandomisedInlet
```

Creating a boundary condition (BC)

- Apply the new BC to the inlet patch in `0/U`

```
inlet
{
    type            randomizedFlowRateInletVelocity;
    volumetricFlowRate  0.002;
    fluctuationScale    0.1;
    value           uniform (0 0 0); // placeholder
}
```

- … and add your model library to the run-time selection table by adding the following to `system/controlDict`, e.g. at top or bottom of file

```
libs
(
    "libOpenFOAM.so"
    "libfancyStuff.so"
);
```

Creating a boundary condition (BC)

- Run the solver

```
> pimpleFoam
```