19th OpenFOAM Workshop - Beijing, June 25-28, 2024

Getting started with OpenFOAM-preCICE for FSI simulations

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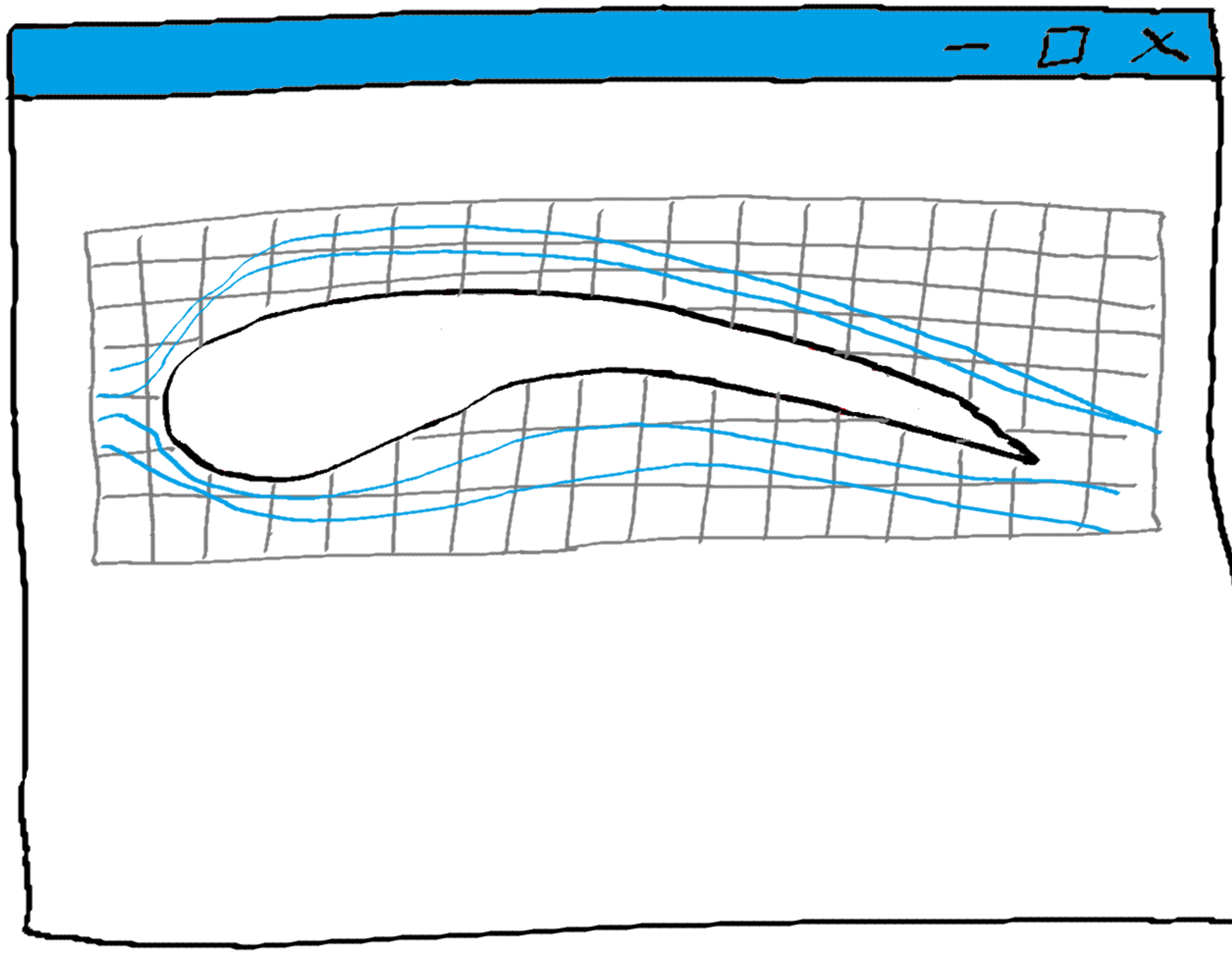
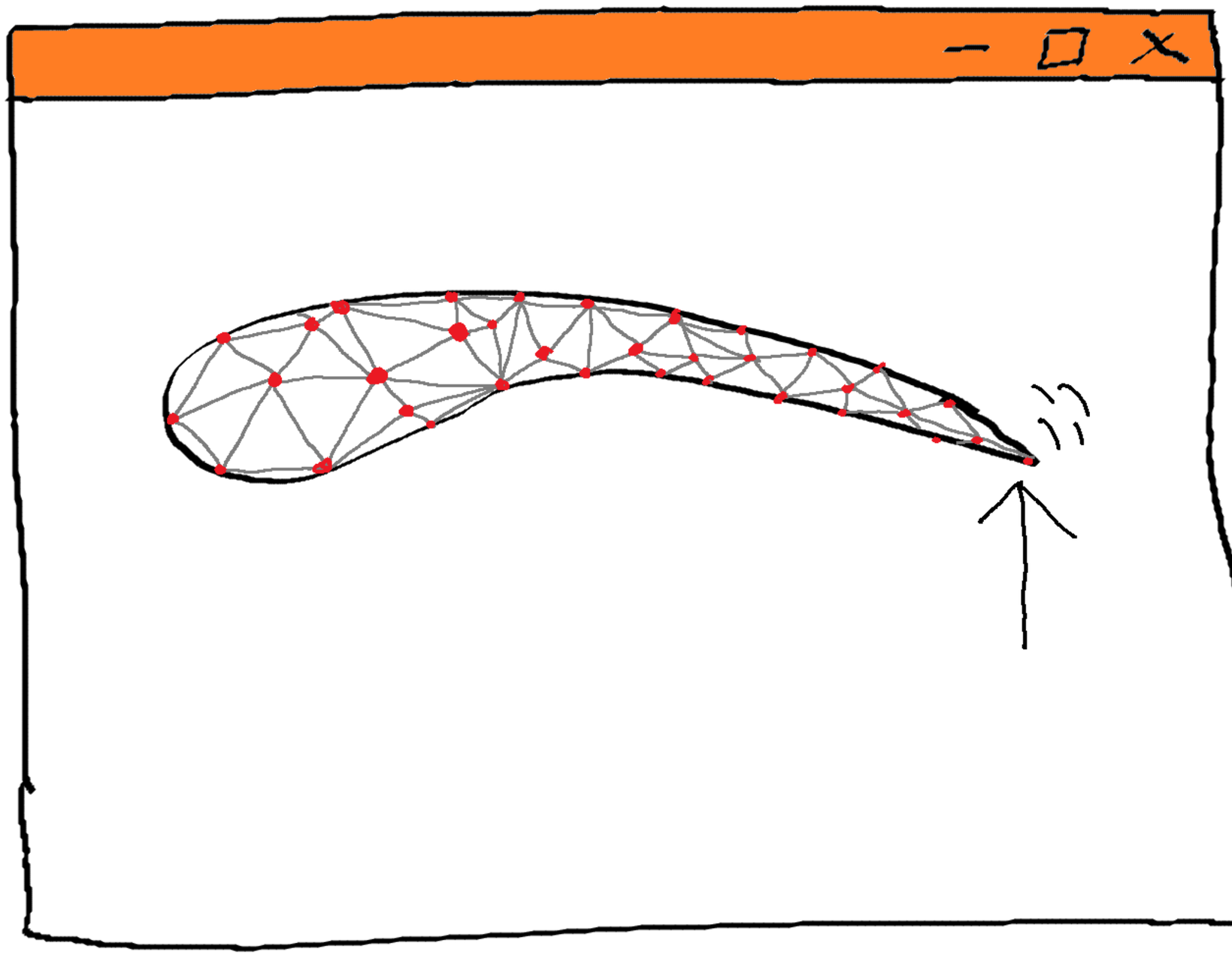
University of Stuttgart
Germany

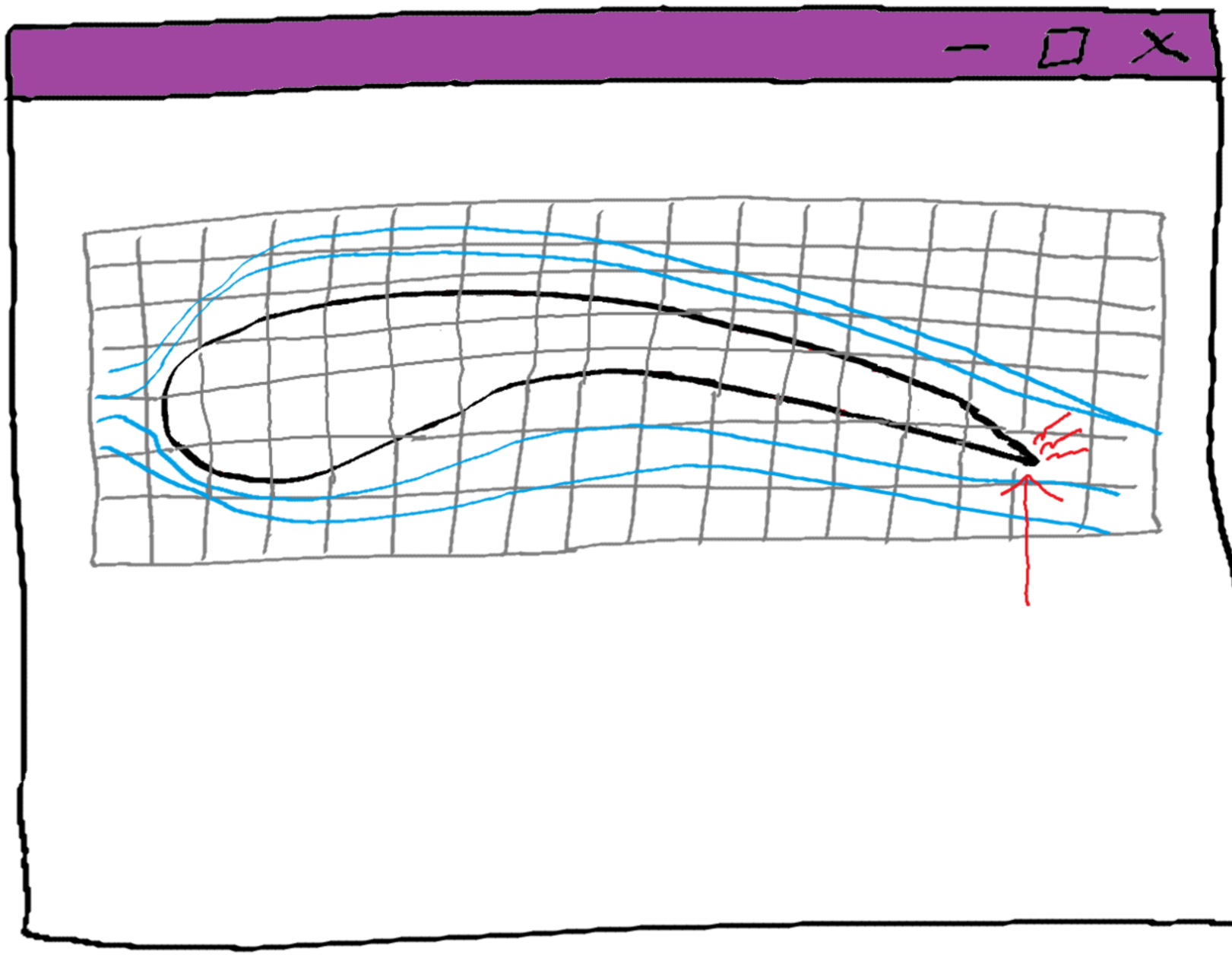
CFD: Simulating flow around a wing



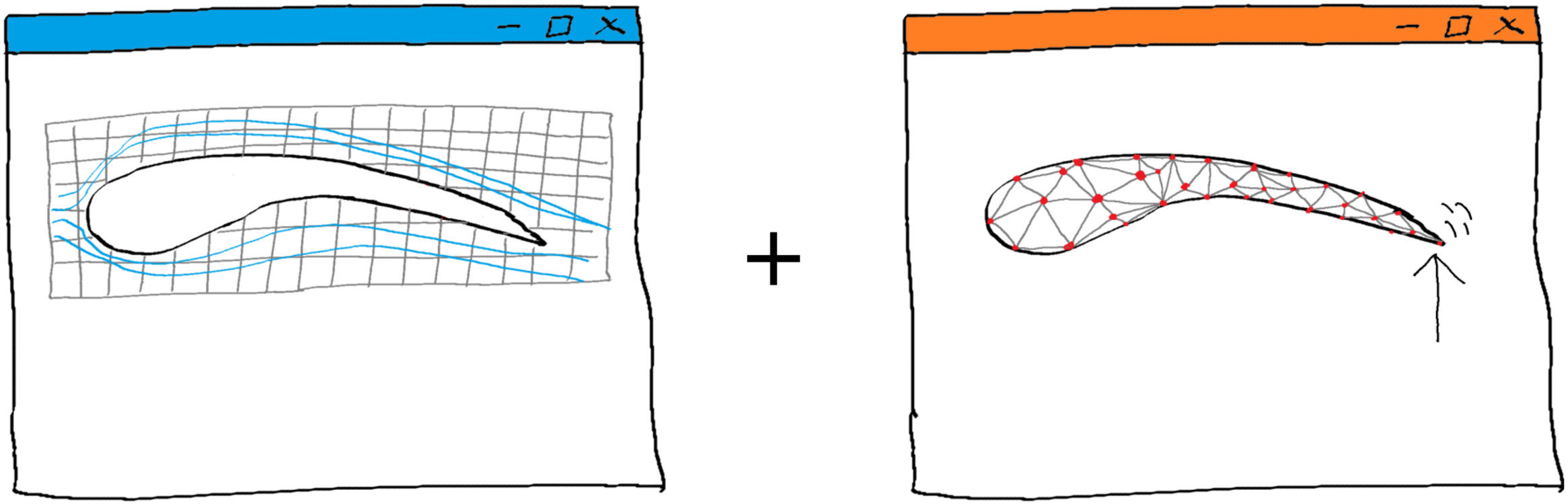
FEM: Simulating stresses on a wing



Can we simulate both at the same time?

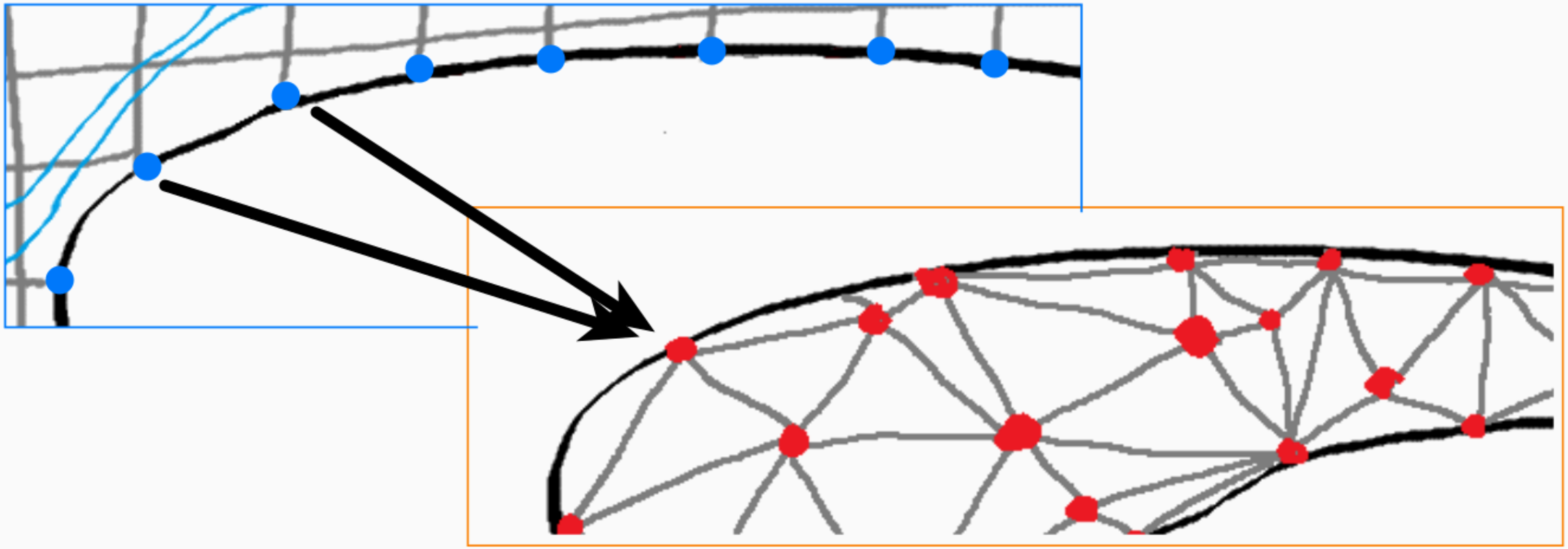


...but reusing the CFD and FEM codes?

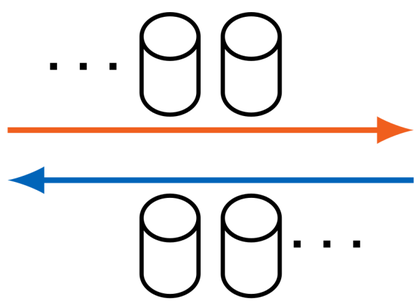


preCICE

From the CFD world to the FEM world



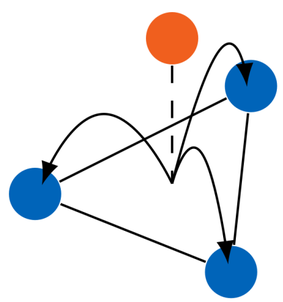
Where preCICE helps



Communication

Options:
- MPI ports (fast)
- TCP sockets (robust)

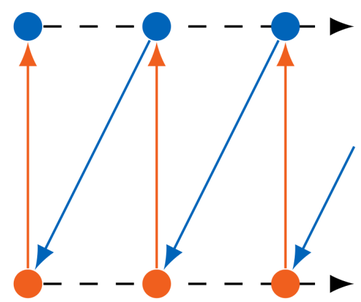
Fully-parallel, peer-to-peer



Data mapping

Options:
- radial-basis functions
- projection-based
- conservative/consistent
- direct mesh access

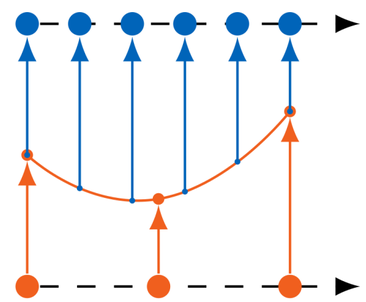
Compute on any side



Coupling schemes

Options:
- serial / parallel
- explicit / implicit
- compositional, multi
- IQN, Aitken, ...

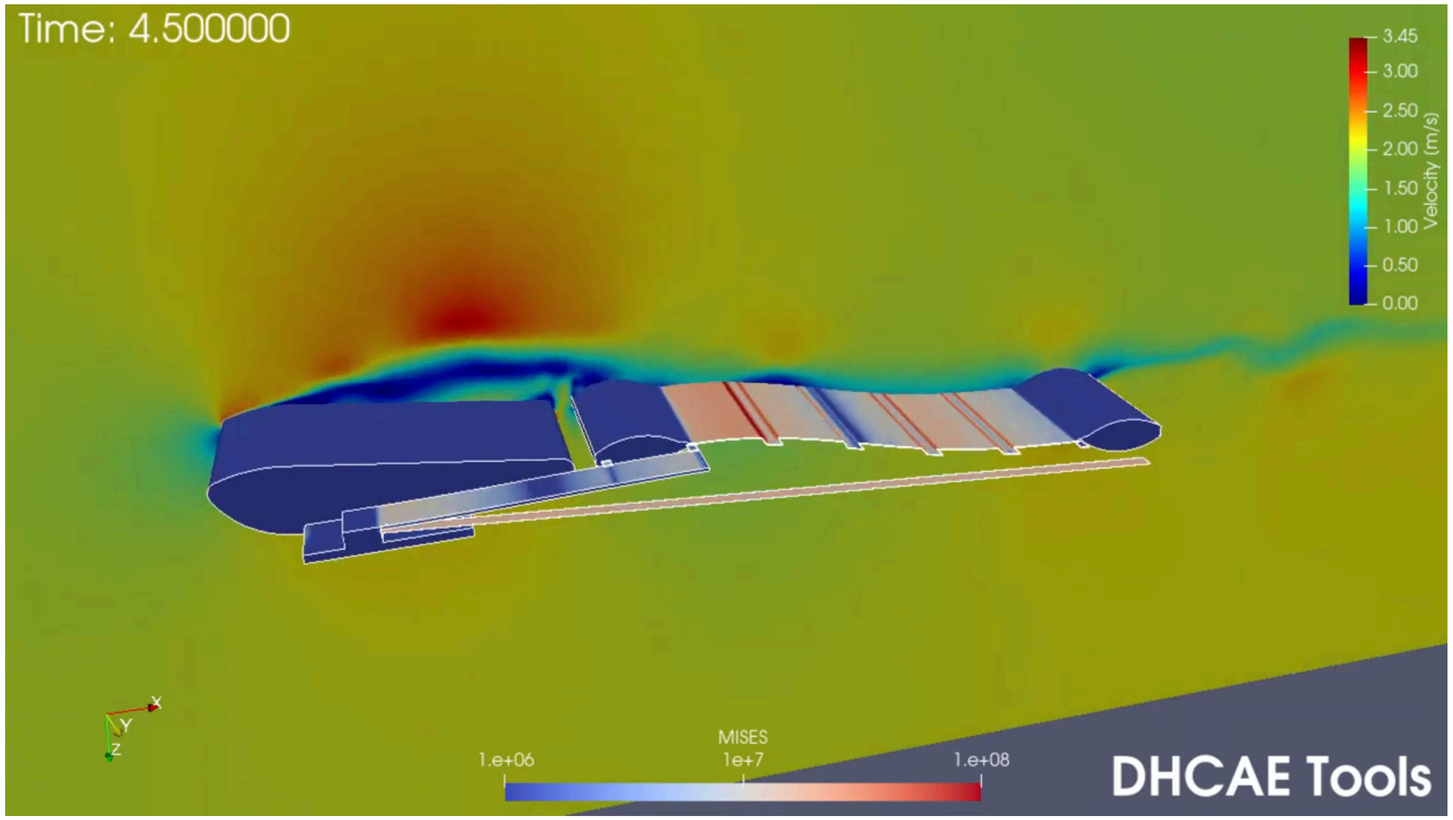
Same high-level API
Configurable at runtime



Time interpolation

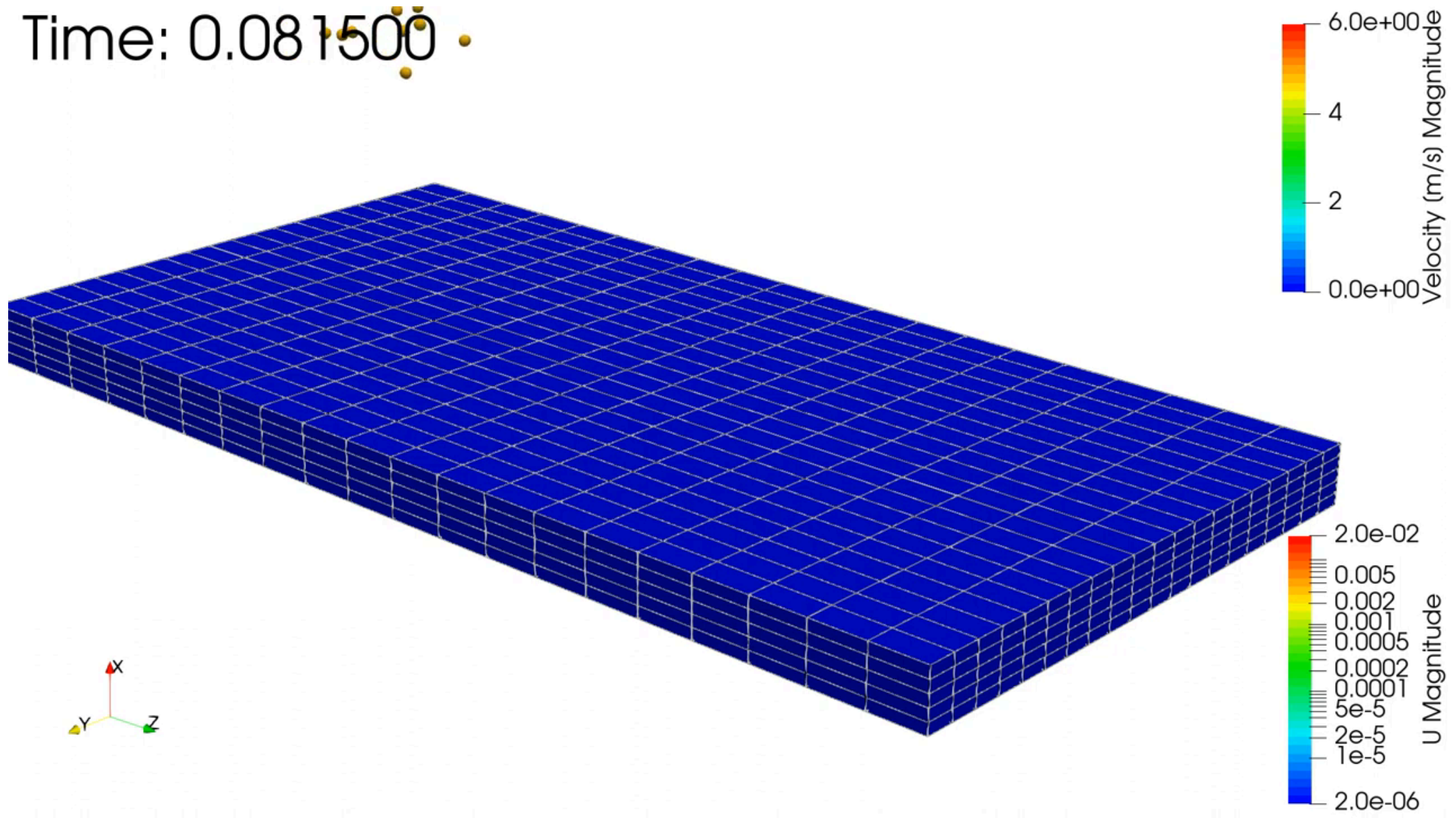
Options:
- waveform iteration

What people do with preCICE (1)



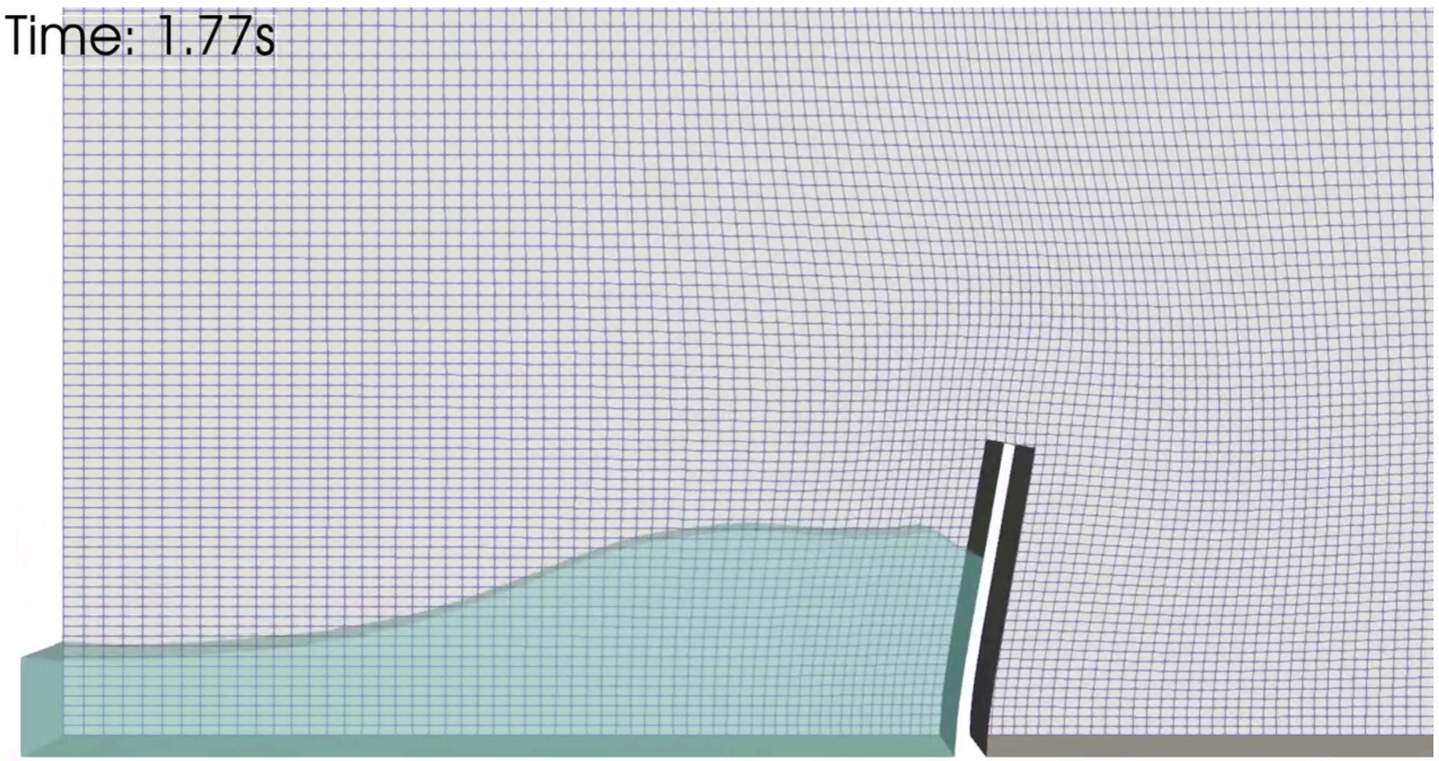
Credit: Ulrich Heck, DHCAE Tools GmbH

What people do with preCICE (2)



Credit: Prasad Adhav, Univ. of Luxembourg

What people do with preCICE (3)



Credit: Utkan Caliskan

In this talk

- The preCICE library: Couple two toy Python solvers
- The preCICE ecosystem: Couple OpenFOAM + deal.II

Get the slides

github.com/MakisH/ofw19-training

Organizational notes

1. You are not expected to try things live.
2. Ask questions live, feel free to interrupt me.
3. Find all software installed in a demo virtual machine: precice.org/installation-vm.html
4. Everything presented here is free software. preCICE and all the adapters are developed publicly on GitHub: github.com/precice

Using the preCICE library

Coupling two toy Python solvers

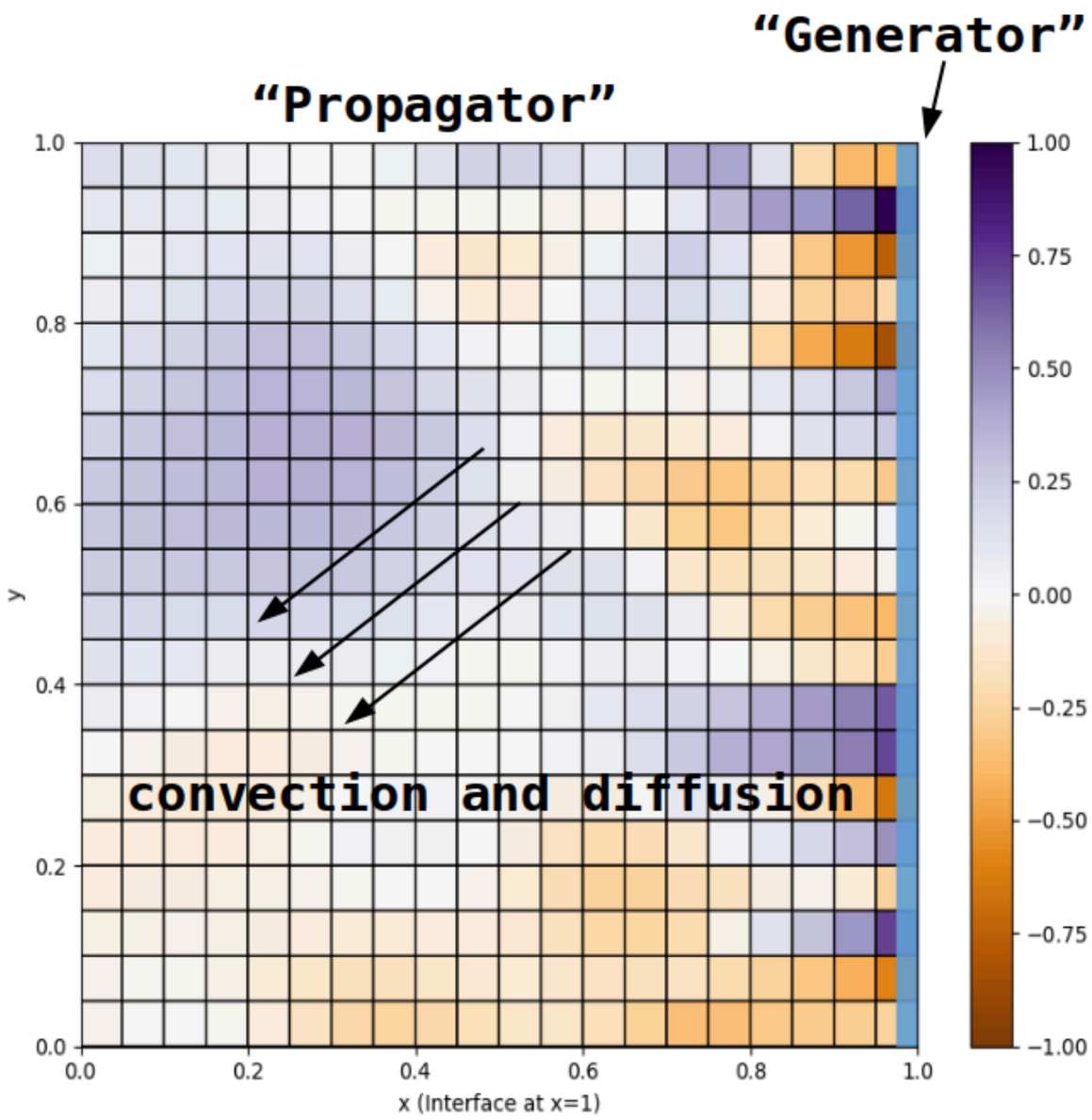
Dependencies

- preCICE v3 (e.g. packages for Ubuntu)
- Python 3
- Python packages `numpy`, `matplotlib`
- preCICE Python bindings:

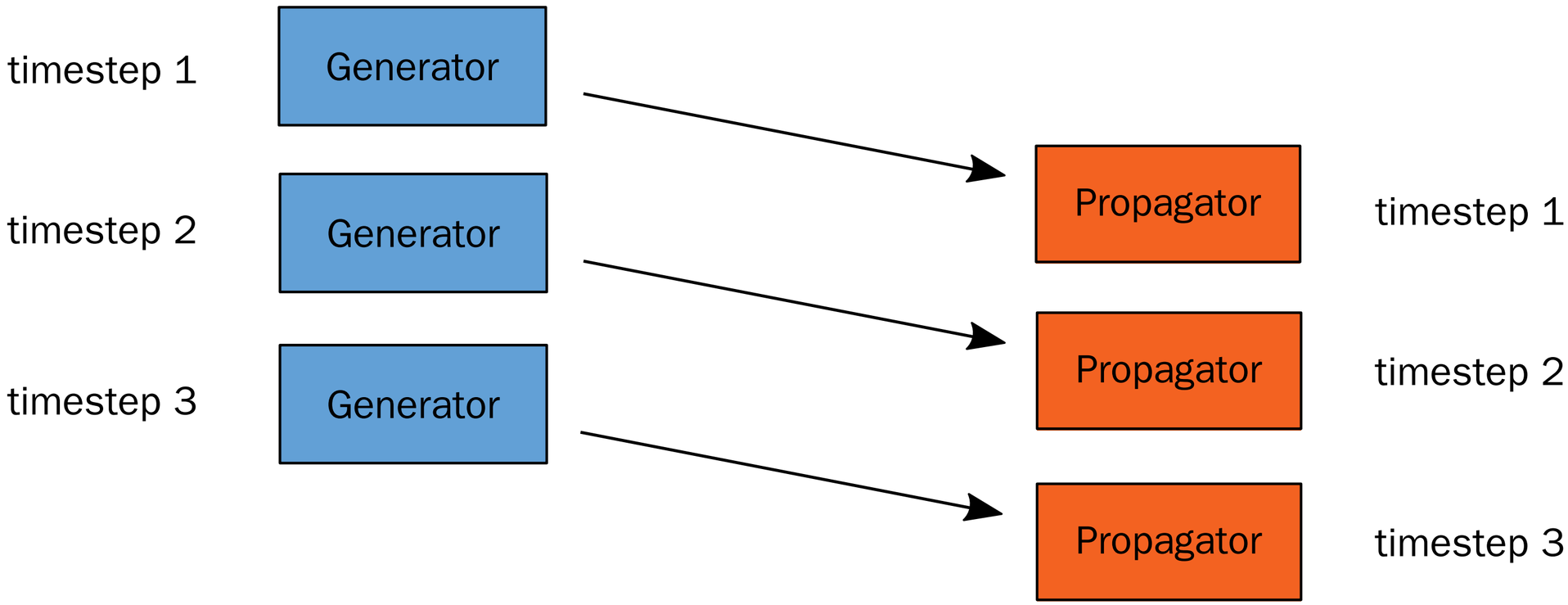
```
pip3 install --upgrade pip
pip3 install --user pyprecice
```

"Generator" and "Propagator"

- `generator.py`: generates random data in a 1D domain
- `propagator.py`: propagates boundary data over a 2D domain



Unidirectional coupling

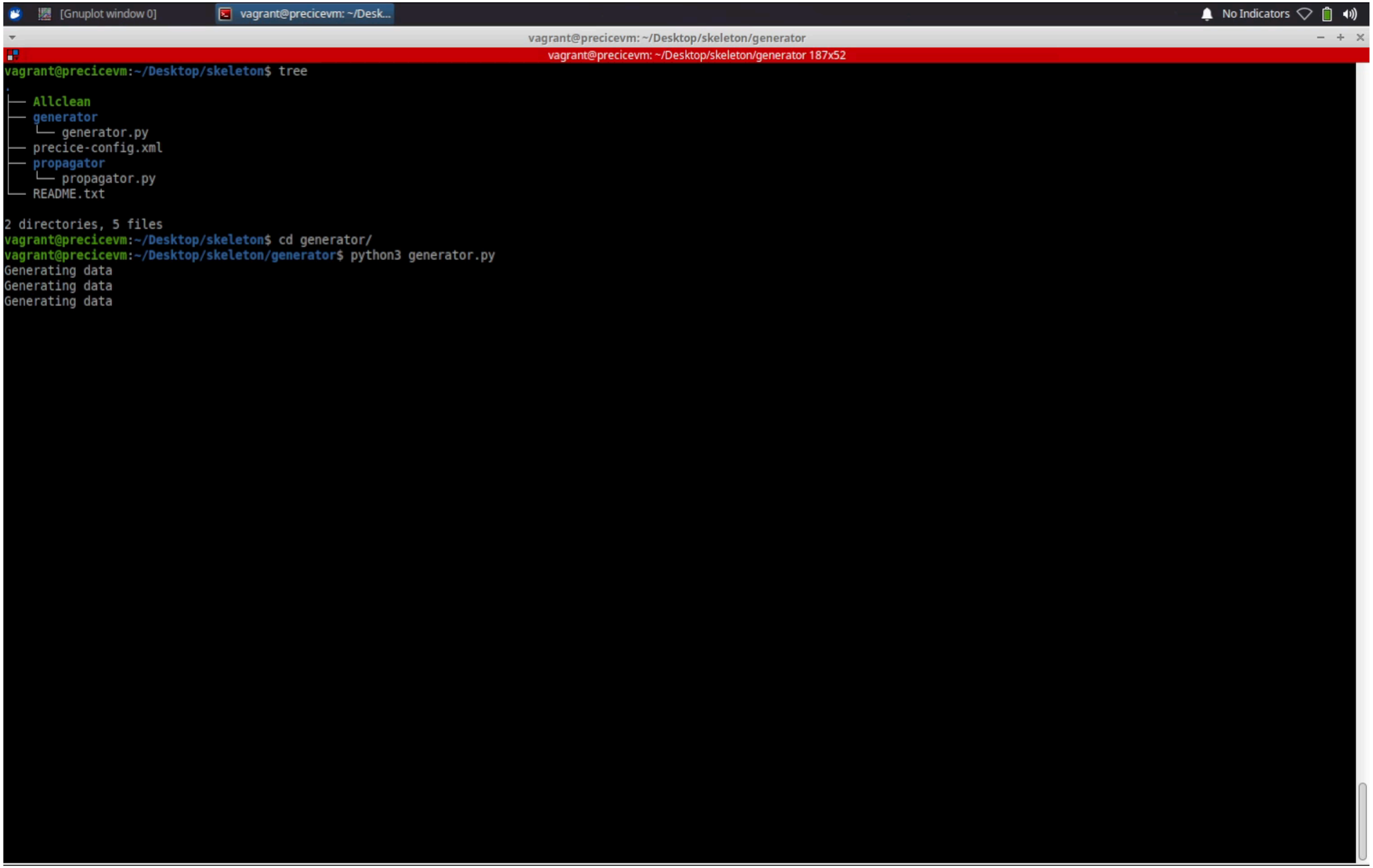


generator.py

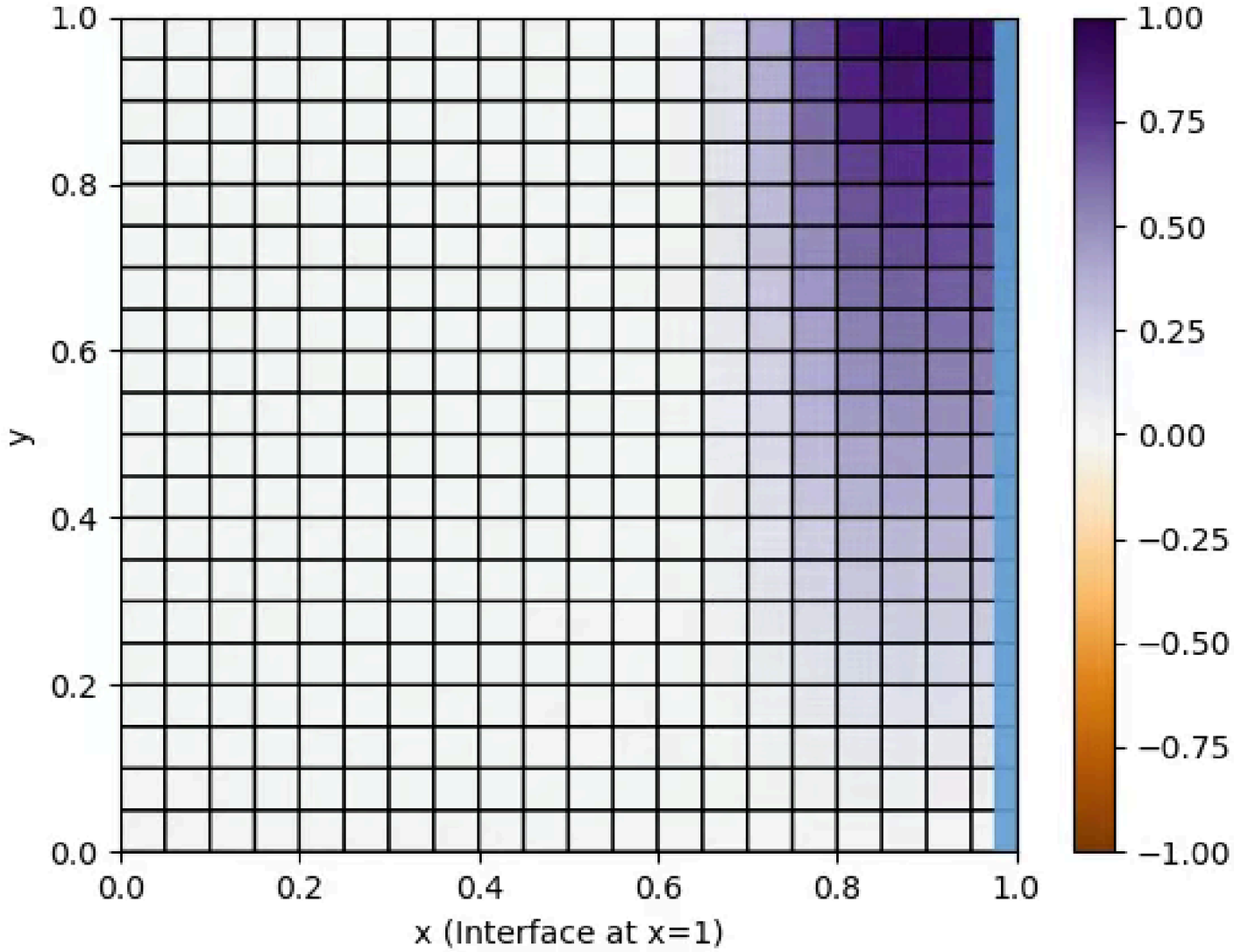
```
import numpy

# generate mesh
n = 20
y = numpy.linspace(0, 1, n + 1)

dt = 0.01
t = 0

while True:
  print("Generating data")
  u = 1 - 2 * numpy.random.rand(n)

  t = t + dt
  if(t > 0.1):
    break
```

propagator.py

```
# generate mesh
n = 20
x = numpy.linspace(0, 1, n+1)
y = numpy.linspace(0, 1, n+1)

# initial data, associated to cell centers
u = numpy.zeros([n, n])

dt = 0.01
t = 0

# boundary condition for u (arbitrary)
u[:,-1] = y[:-1]

while True:

  print("Propagating data")
```


[Gnuplot window 0]
vagrant@precicevm: ~/Desk...
No Indicators
vagrant@precicevm: ~/Desktop/skeleton/generator
vagrant@precicevm: ~/Desktop/skeleton/generator 187x52
vagrant@precicevm:~/Desktop/skeleton$ tree
.
├── Allclean
├── generator
│   └── generator.py
├── precice-config.xml
├── propagator
│   └── propagator.py
└── README.txt
2 directories, 5 files
vagrant@precicevm:~/Desktop/skeleton$ cd generator/
vagrant@precicevm:~/Desktop/skeleton/generator$ python3 generator.py
Generating data
Generating data
Generating data

Uncoupled simulation



Import preCICE

```
1  import numpy
2
3
4  # generate mesh
5  n = 20
6  y = numpy.linspace(0, 1, n + 1)
7
8  dt = 0.01
9  t = 0
10
11 while True:
12   print("Generating data")
13   u = 1 - 2 * numpy.random.rand(n)
14
15   t = t + dt
16   if(t > 0.1):
17     break
```

Import preCICE

```python
import numpy
import precice

# generate mesh
n = 20
y = numpy.linspace(0, 1, n + 1)

dt = 0.01
t = 0

while True:
  print("Generating data")
  u = 1 - 2 * numpy.random.rand(n)

  t = t + dt
  if(t > 0.1):
    break
```

Configure preCICE

```python
import numpy
import precice

# generate mesh
n = 20
y = numpy.linspace(0, 1, n + 1)

# preCICE setup
participant_name      = "Generator"
config_file_name      = "../precice-config.xml"
solver_process_index = 0
solver_process_size  = 1
participant =
    precice.Participant(
                        participant_name,
                        config_file_name,
                        solver_process_index,
```

Configure preCICE

```
 5 n = 20
 6 y = numpy.linspace(0, 1, n + 1)
 7
 8 # preCICE setup
 9 participant_name      = "Generator"
10 config_file_name      = "../precice-config.xml"
11 solver_process_index = 0
12 solver_process_size  = 1
13 participant =
14     precice.Participant(
15                         participant_name,
16                         config_file_name,
17                         solver_process_index,
18                         solver_process_size
19                        )
20
21 dt = 0.01
22 t = 0
```

Define the coupling mesh

```
 5 n = 20
 6 y = numpy.linspace(0, 1, n + 1)
 7
 8 # preCICE setup
 9 participant_name      = "Generator"
10 config_file_name      = "../precice-config.xml"
11 solver_process_index = 0
12 solver_process_size  = 1
13 participant =
14     precice.Participant(
15                         participant_name,
16                         config_file_name,
17                         solver_process_index,
18                         solver_process_size
19                        )
20
21 # Define the coupling mesh name
22 mesh_name   = "Generator-Mesh"
```

Define the coupling mesh

```
16                          config_file_name,
17                          solver_process_index,
18                          solver_process_size
19                        )
20
21  # Define the coupling mesh name
22  mesh_name  = "Generator-Mesh"
23
24  # Define the coupling mesh
25  vertices   = [[1, y0] for y0 in y[:-1]]
26  vertex_ids = participant.set_mesh_vertices(mesh_name, positions)
27
28  dt = 0.01
29  t = 0
30
31  while True:
32    print("Generating data")
```

Initialize and finalize preCICE

```
16                          config_file_name,
17                          solver_process_index,
18                          solver_process_size
19                      )
20
21 # Define the coupling mesh name
22 mesh_name = "Generator-Mesh"
23
24 # Define the coupling mesh
25 vertices = [[1, y0] for y0 in y[:-1]]
26 vertex_ids = participant.set_mesh_vertices(mesh_name, vertices)
27
28 participant.initialize()
29
30 dt = 0.01
31 t = 0
32
```

Initialize and finalize preCICE

```
21 # Define the coupling mesh name
22 mesh_name = "Generator-Mesh"
23
24 # Define the coupling mesh
25 vertices = [[1, y0] for y0 in y[:-1]]
26 vertex_ids = participant.set_mesh_vertices(mesh_name, vertices)
27
28 participant.initialize()
29
30 dt = 0.01
31 t = 0
32
33 while True:
34   print("Generating data")
35   u = 1 - 2 * numpy.random.rand(n)
36
37   t = t + dt
```

Advance the coupling

```
21 # Define the coupling mesh name
22 mesh_name = "Generator-Mesh"
23
24 # Define the coupling mesh
25 vertices = [[1, y0] for y0 in y[:-1]]
26 vertex_ids = participant.set_mesh_vertices(mesh_name, vertices)
27
28 participant.initialize()
29
30 dt = 0.01
31 t = 0
32
33 while True:
34   print("Generating data")
35   u = 1 - 2 * numpy.random.rand(n)
36
37
```

Advance the coupling

```
27
28 participant.initialize()
29
30 dt = 0.01
31 t = 0
32
33 while True:
34   print("Generating data")
35   u = 1 - 2 * numpy.random.rand(n)
36
37
38
39   t = t + dt
40   if(t > 0.1):
41     break
42
43 participant.finalize()
```

Advance the coupling

```
27
28 participant.initialize()
29
30 dt = 0.01
31 t = 0
32
33 while True:
34   print("Generating data")
35   u = 1 - 2 * numpy.random.rand(n)
36
37   participant.advance(dt)
38
39   t = t + dt
40   if(t > 0.1):
41     break
42
43 participant.finalize()
```

Advance the coupling

```
27
28 participant.initialize()
29
30 dt = 0.01
31 t = 0
32
33 while participant.is_coupling_ongoing():
34    print("Generating data")
35    u = 1 - 2 * numpy.random.rand(n)
36
37    participant.advance(dt)
38
39    t = t + dt
40
41
42
43 participant.finalize()
```

Advance the coupling

```
28 participant.initialize()
29
30 dt = 0.01
31 t = 0
32
33 while participant.is_coupling_ongoing():
34   print("Generating data")
35   u = 1 - 2 * numpy.random.rand(n)
36
37   participant.advance(dt)
38   precice_dt = participant.get_max_time_step_size()
39
40   t = t + dt
41
42
43
44 interface.finalize()
```

Advance the coupling

```
27
28 participant.initialize()
29 precice_dt = participant.get_max_time_step_size()
30
31 dt = 0.01
32 t = 0
33
34 while participant.is_coupling_ongoing():
35   print("Generating data")
36   u = 1 - 2 * numpy.random.rand(n)
37
38   participant.advance(dt)
39   precice_dt = participant.get_max_time_step_size()
40
41   t = t + dt
42
43 interface.finalize()
```

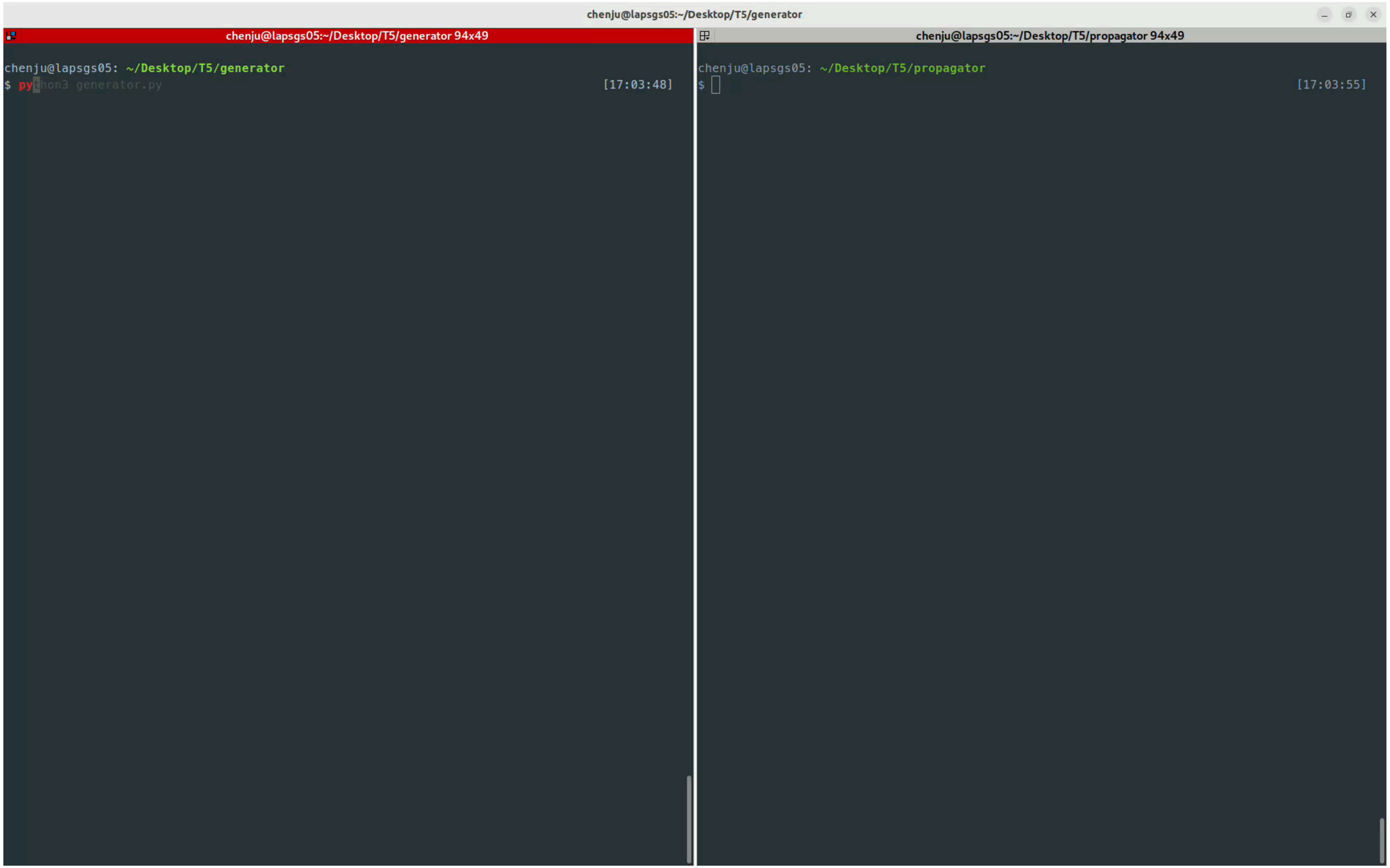
Advance the coupling

```
27
28 participant.initialize()
29 precice_dt = participant.get_max_time_step_size()
30
31 dt = 0.01
32 t = 0
33
34 while participant.is_coupling_ongoing():
35   print("Generating data")
36   u = 1 - 2 * numpy.random.rand(n)
37
38   participant.advance(dt)
39   precice_dt = participant.get_max_time_step_size()
40
41   t = t + dt
42
43 interface.finalize()
```

Not there yet, but let's run it

(similar changes in propagator.py - try it at home)

Nothing happening?



Did we forget something?

Write & read data

```
20
21 # Get the preCICE mesh name
22 mesh_name  = "Generator-Mesh"
23
24 # Define the coupling mesh
25 vertices   = [[1, y0] for y0 in y[:-1]]
26 vertex_ids = participant.set_mesh_vertices(mesh_name, vertices)
27
28
29
30
31
32 participant.initialize()
33 precice_dt = participant.get_max_time_step_size()
34
35 dt = 0.01
36 t = 0
```

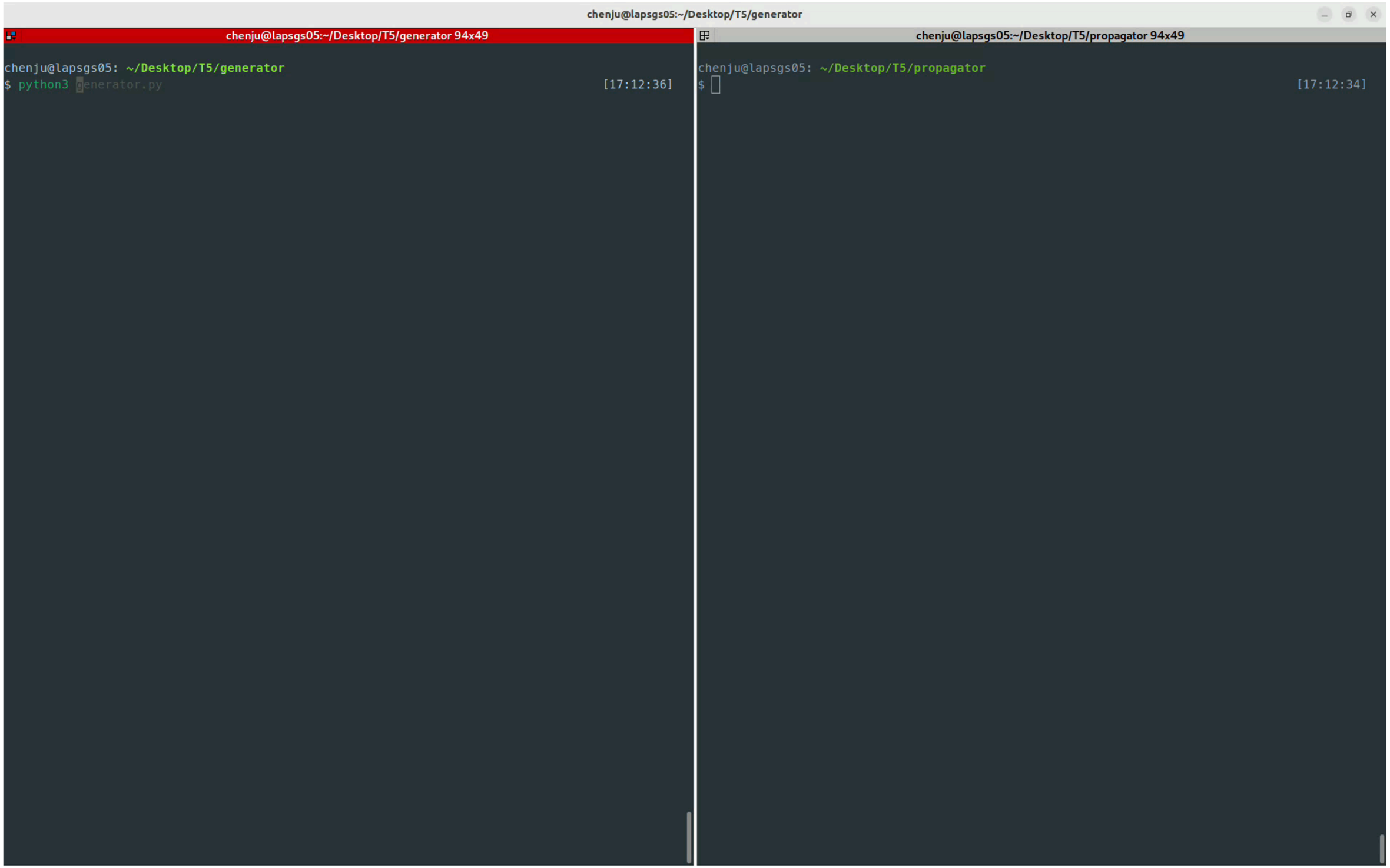
Write & read data

```
20
21 # Get the preCICE mesh name
22 mesh_name  = "Generator-Mesh"
23
24 # Define the coupling mesh
25 vertices   = [[1, y0] for y0 in y[:-1]]
26 vertex_ids = participant.set_mesh_vertices(mesh_id, vertices)
27
28 # Get the exchanged data name
29 data_name = "Data"
30
31 participant.initialize()
32
33 dt = 0.01
34 t = 0
35
36 while participant.is_coupling_ongoing():
```

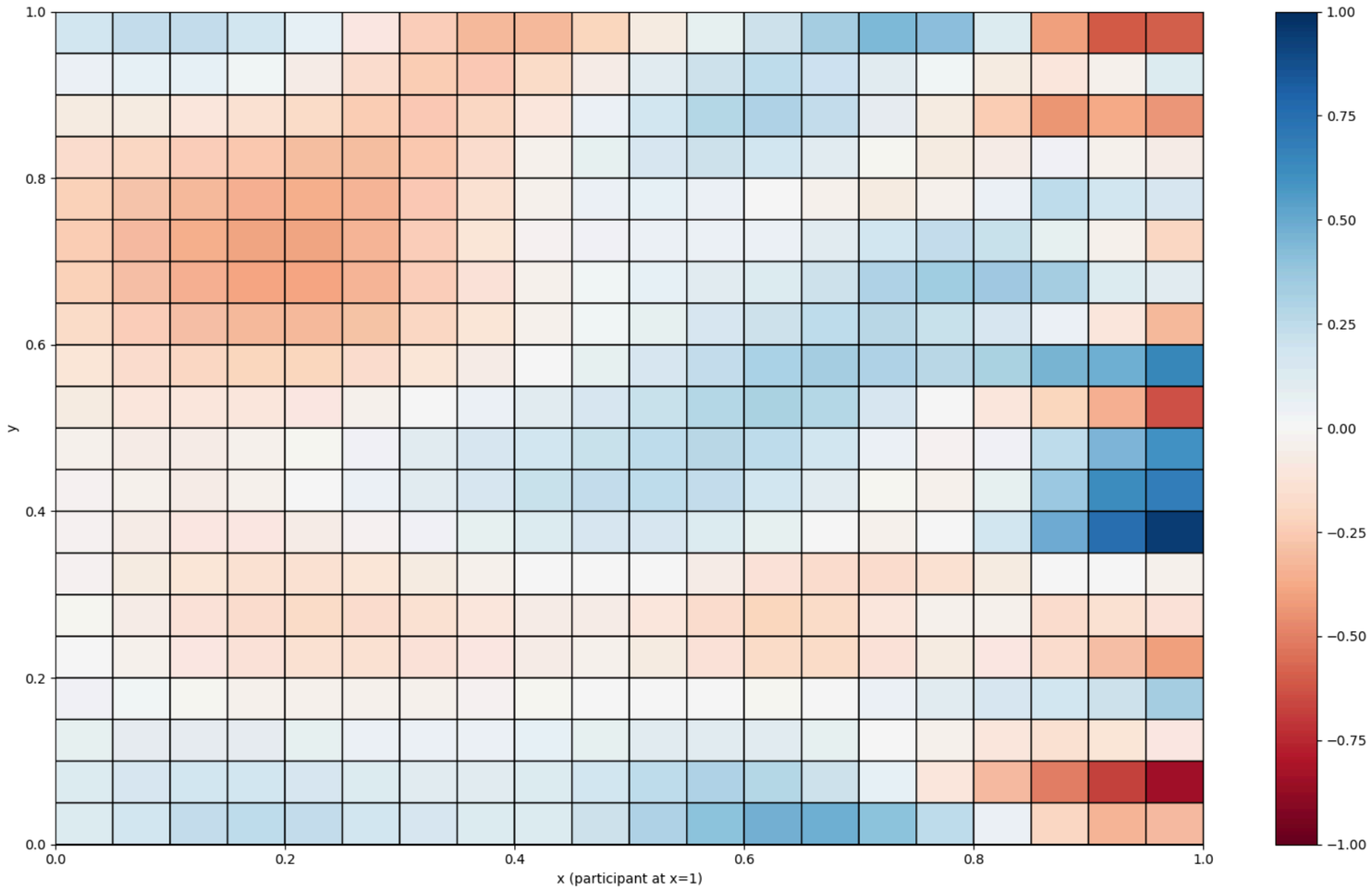
Write & read data

```
32
33 dt = 0.01
34 t = 0
35
36 while participant.is_coupling_ongoing():
37   dt = np.minimum(dt, precice_dt)
38
39   print("Generating data")
40   u = 1 - 2 * numpy.random.rand(n)
41
42   participant.write_data(mesh_name, data_name, vertex_ids, u)
43   precice_dt = participant.advance(dt)
44   # u[:, -1] = participant.read_data(mesh_name, data_name, vertex_ids
45
46   t = t + dt
47
48 participant.finalize()
```

It should work now!

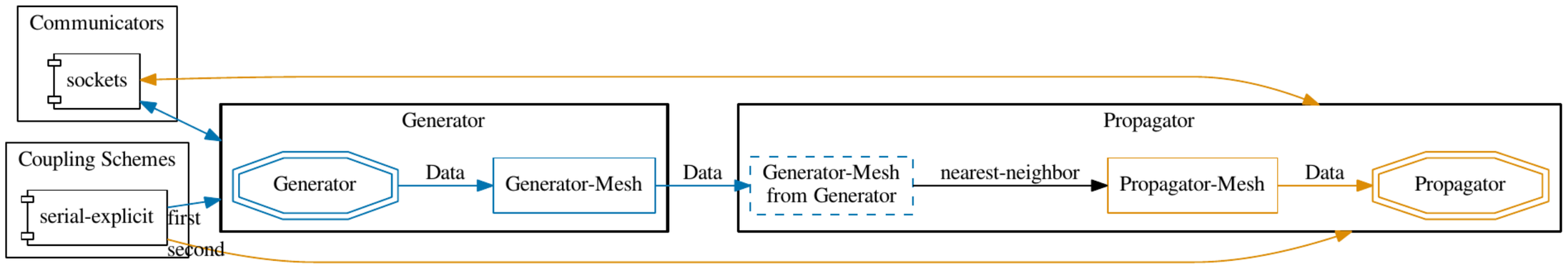

chenju@lapsgs05:~/Desktop/T5/generator
chenju@lapsgs05:~/Desktop/T5/generator 94x49
chenju@lapsgs05: ~/Desktop/T5/generator
$ python3 generator.py
[17:12:36]
chenju@lapsgs05:~/Desktop/T5/propagator 94x49
chenju@lapsgs05: ~/Desktop/T5/propagator
$
[17:12:34]

Data is being transfered!



Most basic case: uni-directional, serial-explicit, nearest-neighbor mapping, ...

preCICE configuration



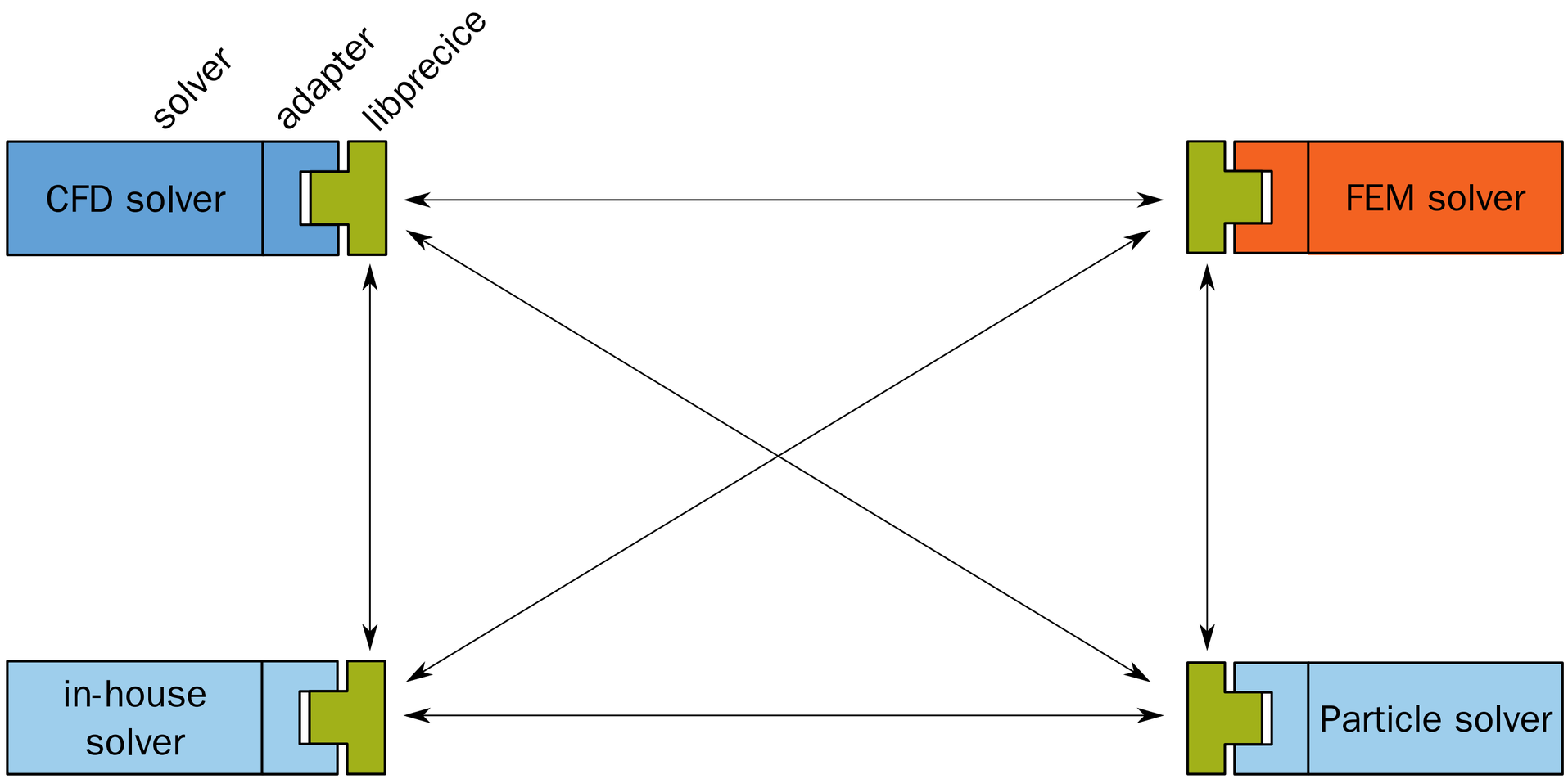
Visual representation of precice-config.xml using the config visualizer.

Using the preCICE ecosystem

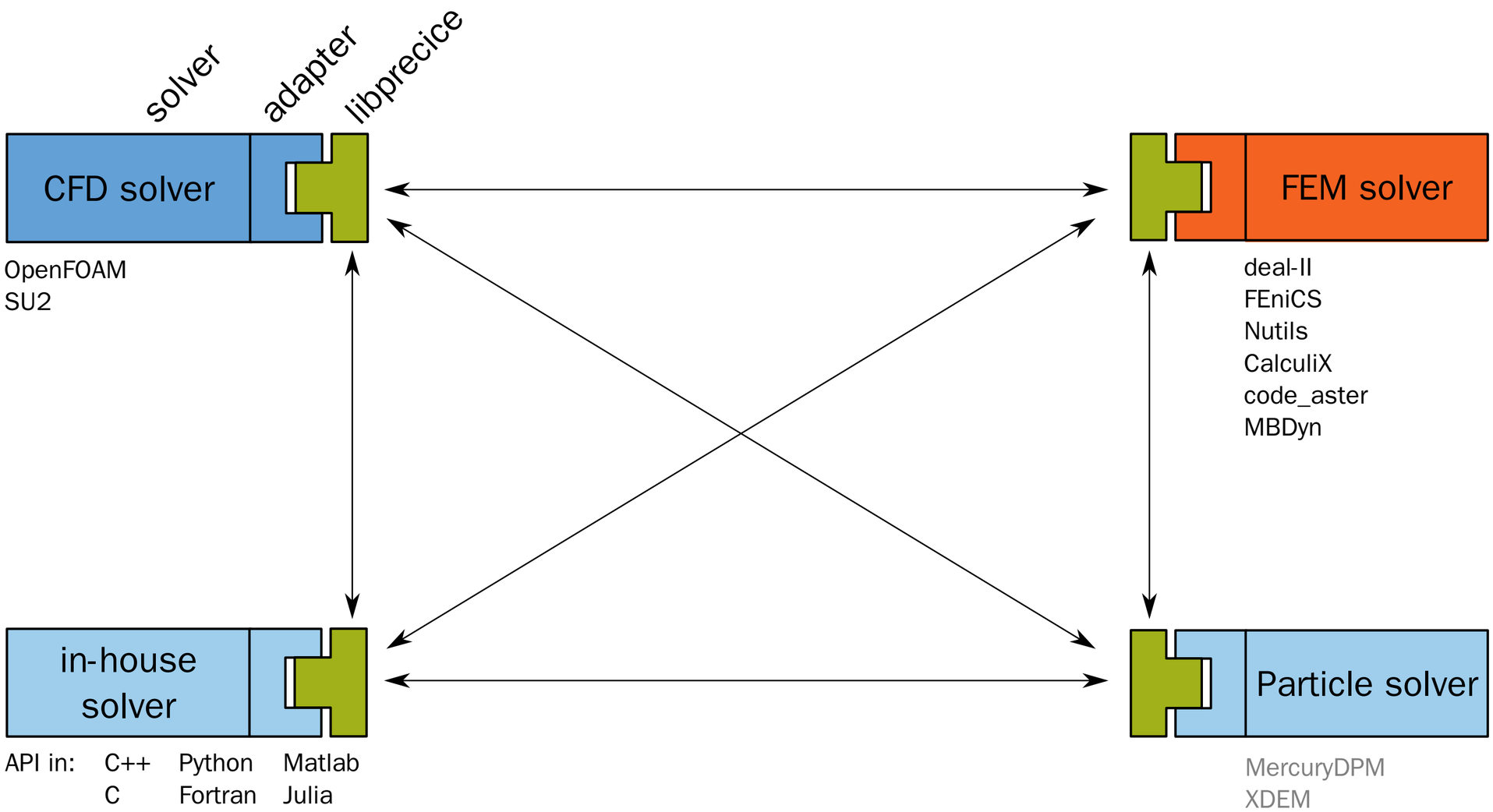
Example: Coupling OpenFOAM and deal.II

The big picture

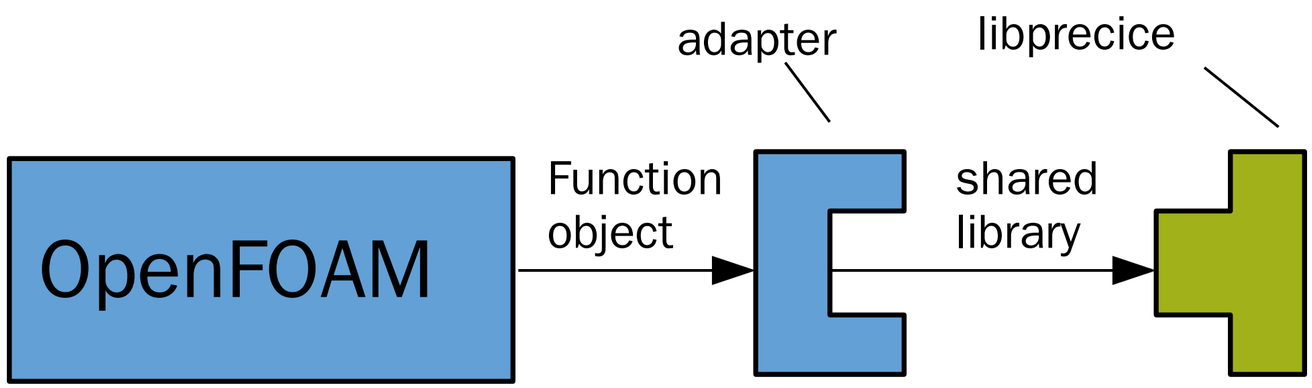
The big picture



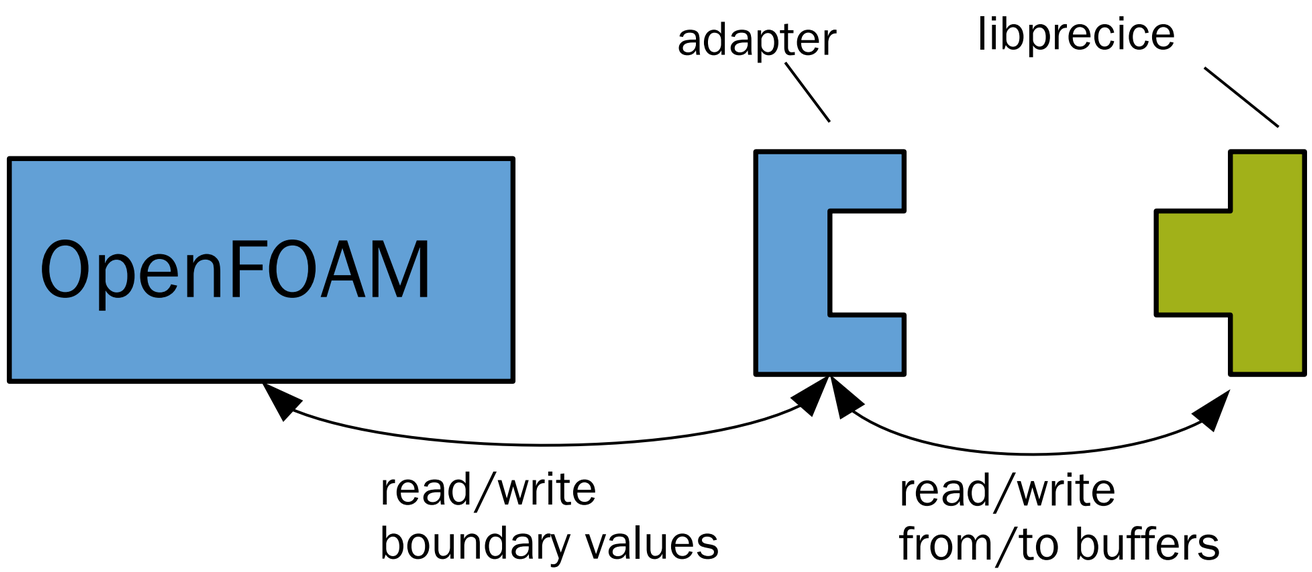
The big picture



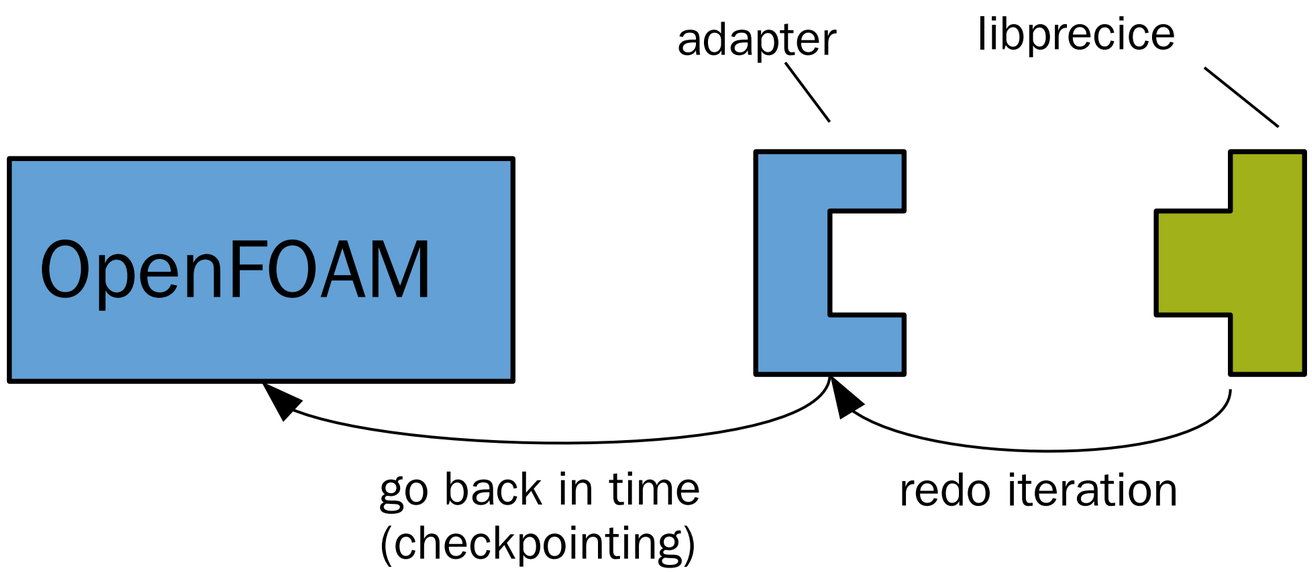
What does the adapter do?



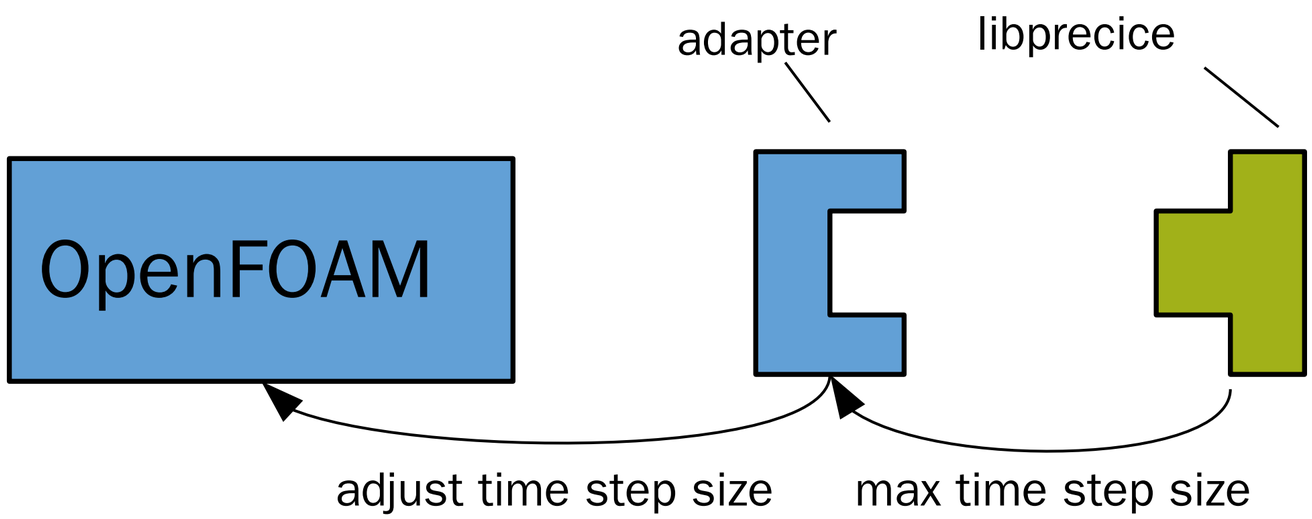
What does the adapter do?



What does the adapter do?



What does the adapter do?



Quickstart

> **Summary:** Install preCICE on Linux (e.g. via a Debian package) and couple an OpenFOAM fluid solver (using the OpenFOAM-preCICE adapter) with an example rigid body solver in C++.

Edit me

Updated 05 Jun 24

This is the first step you may want to try if you are new to preCICE: install preCICE and some solvers, and run a simple coupled case.

To get a feeling what preCICE does, watch a short presentation or a longer talk on the fundamentals.

Installation

1. Get and install preCICE. For Ubuntu 22.04 (Jammy Jellyfish), this is pretty easy: download and install our binary package by clicking on it or using the following commands:

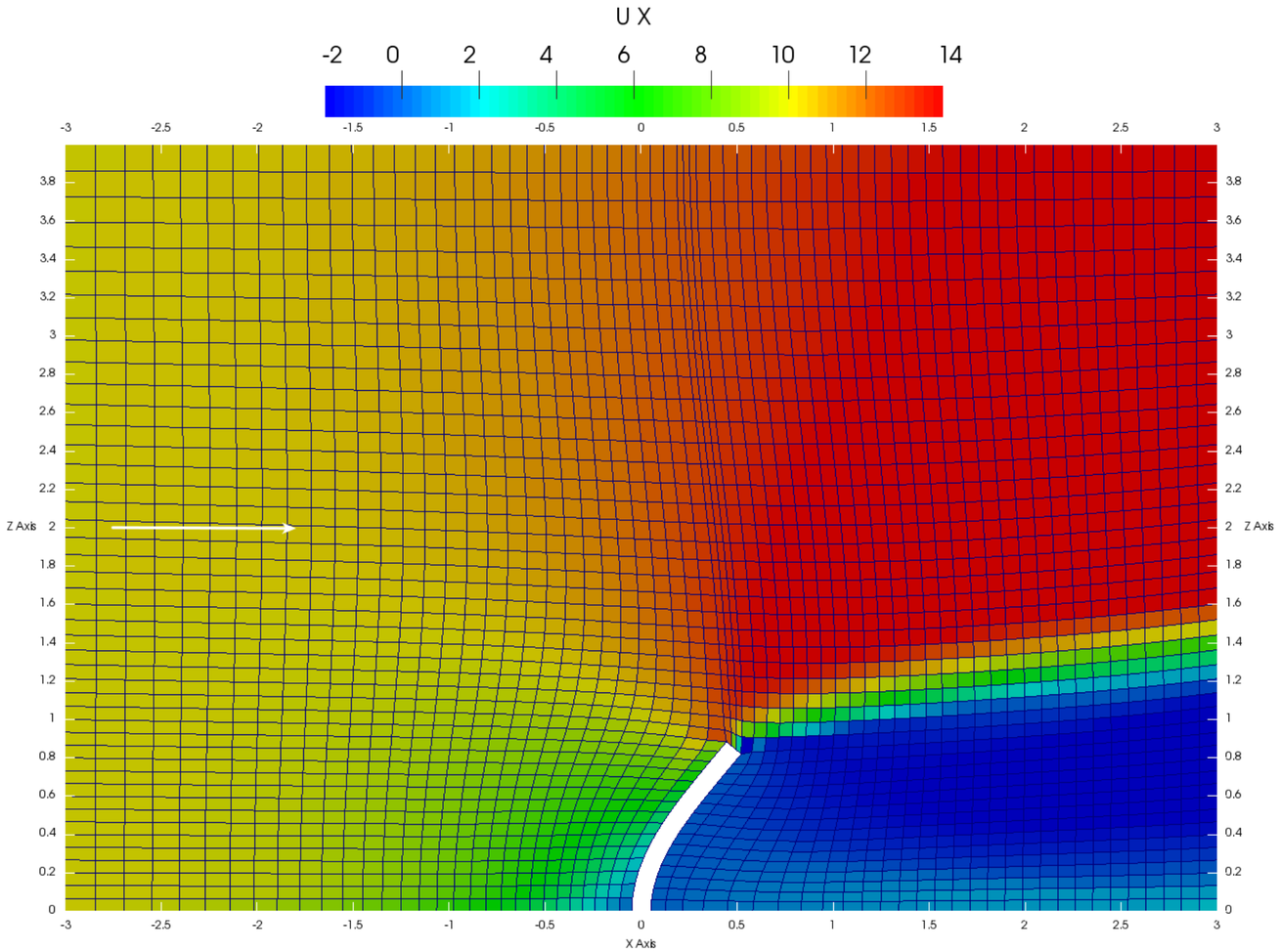
```
wget https://github.com/precice/precice/releases/download/v3.1.1/libprecice3_3.1.1_jammy.deb
sudo apt install ./libprecice3_3.1.1_jammy.deb
```

OS	Package
Ubuntu 20.04 Focal Fossa	`libprecice3_3.1.1_focal.deb`
Ubuntu 22.04 Jammy Jellyfish	`libprecice3_3.1.1_jammy.deb`
Debian 11 “bullseye”	`libprecice3_3.1.1_bullseye.deb`
Debian 12 “bookworm”	`libprecice3_3.1.1_bookworm.deb`
Something else	See an overview of options

   - Facing any problems? Ask for help.

2. We will use OpenFOAM here and in many of our tutorial cases, so install OpenFOAM:

Tutorial: Channel with a perpendicular flap

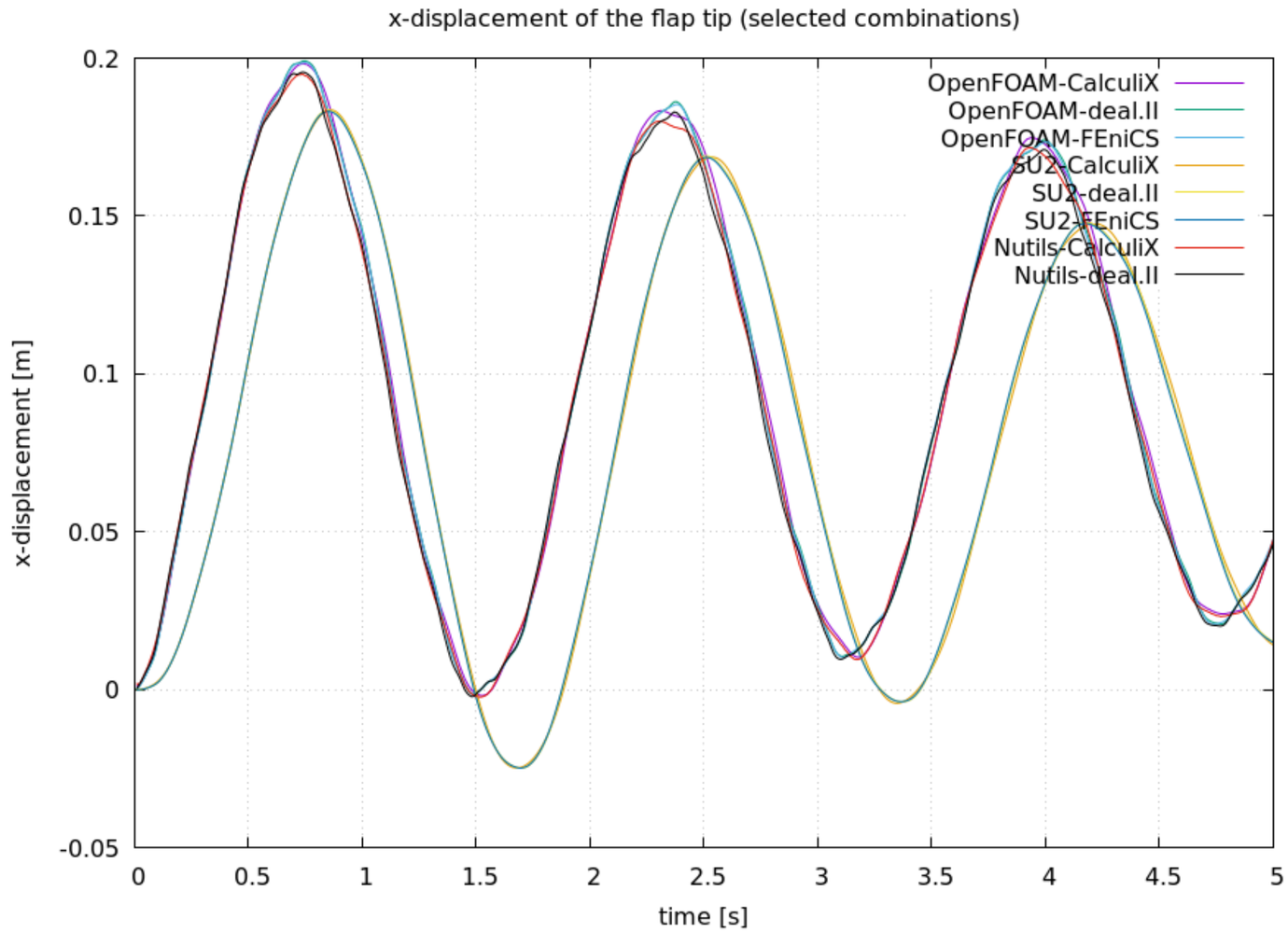


Find this tutorial on precice.org/tutorials-perpendicular-flap.html.

Arbitrary solver combinations

FLUID	SOLID
pimpleFoam	CalculiX
SU2	deal.II
Nutils	FEniCS
	DUNE
	solidDisplacementFoam
	solids4Foam
	Nutils

Arbitrary solver combinations



Dependencies

- preCICE v3 (e.g. packages for Ubuntu)
- Recent OpenFOAM (e.g., v2312)
- OpenFOAM-preCICE adapter v1.3.0
- deal.II 9.2 or greater
- deal.II-preCICE adapter 9.5.0

File structure

```
- precice-config.xml
- fluid-openfoam/
    - 0/U ...
    - constant/dynamicMeshDict ...
    - system/
      - controlDict
      - preciceDict
    - ...
- solid-dealii/
    - parameters.prm
    - ...
```

For demonstration purposes

- In `precice-config.xml`:
  - Reduce the `max-time` from 5s to 1.5s
  - Switch to a serial-explicit coupling scheme
- In `solid-dealii/parameters.prm`:
  - Lower the solid density from 3000 to 42

Configure OpenFOAM

```
// fluid-openfoam/0/U

flap
{
    type            movingWallVelocity;
    value           uniform (0 0 0);
}
```

```
// fluid-openfoam/0/pointDisplacement

flap
{
    type            fixedValue;
    value           $internalField;
}
```

```
// fluid-openfoam/constant/dynamicMeshDict

solver      displacementLaplacian;
```

Load the OpenFOAM adapter

```
// fluid-openfoam/system/controlDict
functions
{
    preCICE_Adapter
    {
        type preciceAdapterFunctionObject;
        libs ("libpreciceAdapterFunctionObject.so");
    }
}

// Don't forget to build the adapter with Allwmake
```

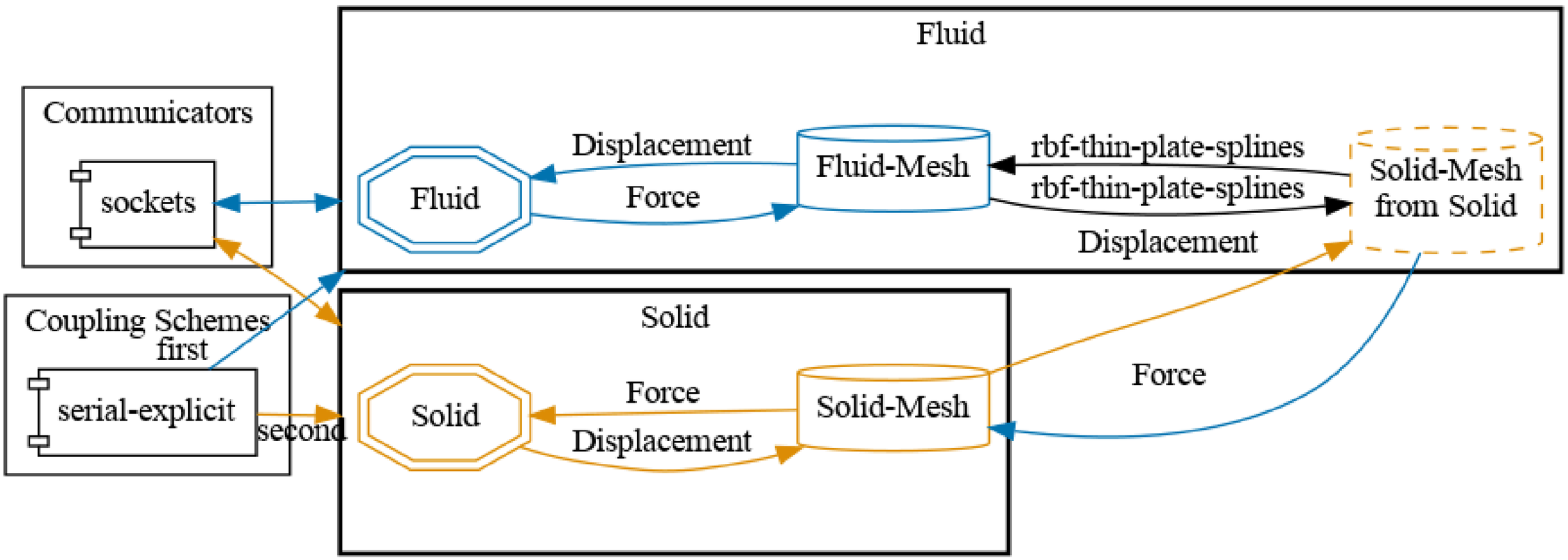
Configure the OpenFOAM adapter

```
// fluid-openfoam/system/preciceDict
preciceConfig "../precice-config.xml";
participant Fluid;

modules (FSI);

interfaces {
  Interface1 {
    mesh Fluid-Mesh;
    patches (flap);
    locations faceCenters;

    readData (Displacement);

    writeData (Force);
  };
};
```

Configure the dealii adapter

```
// solid-dealii/parameters.prm

subsection precice configuration
# Cases: FSI3 or PF for perpendicular flap
set Scenario = PF

# Name of the precice configuration file
set precice config-file = ../precice-config.xml

# Name of the participant in the precice-config.xml file
set Participant name = Solid

# Name of the coupling mesh in the precice-config.xml file
set Mesh name = Solid-Mesh

# Name of the read data in the precice-config.xml file
set Read data name = Force
```

Configure preCICE



Configure preCICE

```
<data:vector name="Force" />
<data:vector name="Displacement" />

<mesh name="Fluid-Mesh" dimensions="2">
  <use-data name="Force" />
  <use-data name="Displacement" />
</mesh>

<mesh name="Solid-Mesh" dimensions="2">
  <use-data name="Displacement" />
  <use-data name="Force" />
</mesh>

<participant name="Fluid">
  <export:vtk directory="results" />
  <provide-mesh name="Fluid-Mesh" />
  <receive-mesh name="Solid-Mesh" from="Solid" />
```

Notice the serial-explicit coupling scheme

Configure preCICE

```
<data:vector name="Force" />
<data:vector name="Displacement" />

<mesh name="Fluid-Mesh" dimensions="2">
  <use-data name="Force" />
  <use-data name="Displacement" />
</mesh>

<mesh name="Solid-Mesh" dimensions="2">
  <use-data name="Displacement" />
  <use-data name="Force" />
</mesh>

<participant name="Fluid">
  <export:vtk directory="results" />
  <provide-mesh name="Fluid-Mesh" />
  <receive-mesh name="Solid-Mesh" from="Solid" />
```

Notice the serial-explicit coupling scheme

Configure preCICE

```
14 <participant name="Fluid">
15   <export:vtk directory="results" />
16   <provide-mesh name="Fluid-Mesh" />
17   <receive-mesh name="Solid-Mesh" from="Solid" />
18   <write-data name="Force" mesh="Fluid-Mesh" />
19   <read-data name="Displacement" mesh="Fluid-Mesh" />
20   <mapping:rbf-thin-plate-splines
21     direction="write"
22     from="Fluid-Mesh"
23     to="Solid-Mesh"
24     constraint="conservative" />
25   <mapping:rbf-thin-plate-splines
26     direction="read"
27     from="Solid-Mesh"
28     to="Fluid-Mesh"
29     constraint="consistent" />
30 </participant>
```

Notice the serial-explicit coupling scheme

Configure preCICE

```
14 <participant name="Fluid">
15   <export:vtk directory="results" />
16   <provide-mesh name="Fluid-Mesh" />
17   <receive-mesh name="Solid-Mesh" from="Solid" />
18   <write-data name="Force" mesh="Fluid-Mesh" />
19   <read-data name="Displacement" mesh="Fluid-Mesh" />
20   <mapping:rbf-thin-plate-splines
21     direction="write"
22     from="Fluid-Mesh"
23     to="Solid-Mesh"
24     constraint="conservative" />
25   <mapping:rbf-thin-plate-splines
26     direction="read"
27     from="Solid-Mesh"
28     to="Fluid-Mesh"
29     constraint="consistent" />
30 </participant>
```

Notice the serial-explicit coupling scheme

Configure preCICE

```
14 <participant name="Fluid">
15   <export:vtk directory="results" />
16   <provide-mesh name="Fluid-Mesh" />
17   <receive-mesh name="Solid-Mesh" from="Solid" />
18   <write-data name="Force" mesh="Fluid-Mesh" />
19   <read-data name="Displacement" mesh="Fluid-Mesh" />
20   <mapping:rbf-thin-plate-splines
21     direction="write"
22     from="Fluid-Mesh"
23     to="Solid-Mesh"
24     constraint="conservative" />
25   <mapping:rbf-thin-plate-splines
26     direction="read"
27     from="Solid-Mesh"
28     to="Fluid-Mesh"
29     constraint="consistent" />
30 </participant>
```

Notice the serial-explicit coupling scheme

Configure preCICE

```
31
32 <participant name="Solid">
33   <provide-mesh name="Solid-Mesh" />
34   <receive-data name="Displacement" mesh="Solid-Mesh" />
35   <read-data name="Force" mesh="Solid-Mesh" />
36   <watch-point mesh="Solid-Mesh" name="Flap-Tip" coordinate="0.0;1" /
37 </participant>
38
39 <m2n:sockets acceptor="Fluid" connector="Solid" exchange-directory=".
40
41 <coupling-scheme:serial-explicit>
42   <participants first="Fluid" second="Solid" />
43   <max-time value="1.5" />
44   <time-window-size value="0.01" />
45   <exchange data="Force" mesh="Solid-Mesh" from="Fluid" to="Solid" />
46   <exchange data="Displacement" mesh="Solid-Mesh" from="Solid" to="Fl
47 </coupling-scheme:serial-explicit>
```

Notice the serial-explicit coupling scheme

Configure preCICE

```
31
32 <participant name="Solid">
33   <provide-mesh name="Solid-Mesh" />
34   <receive-data name="Displacement" mesh="Solid-Mesh" />
35   <read-data name="Force" mesh="Solid-Mesh" />
36   <watch-point mesh="Solid-Mesh" name="Flap-Tip" coordinate="0.0;1" /
37 </participant>
38
39 <m2n:sockets acceptor="Fluid" connector="Solid" exchange-directory=".
40
41 <coupling-scheme:serial-explicit>
42   <participants first="Fluid" second="Solid" />
43   <max-time value="1.5" />
44   <time-window-size value="0.01" />
45   <exchange data="Force" mesh="Solid-Mesh" from="Fluid" to="Solid" />
46   <exchange data="Displacement" mesh="Solid-Mesh" from="Solid" to="Fl
47 </coupling-scheme:serial-explicit>
```

Notice the serial-explicit coupling scheme

vagrant@precicevm: ~/tutor... fsi-course - File Manager No Indicators

vagrant@precicevm: ~/tutorials/fsi-course/fluid-openfoam

vagrant@precicevm: ~/tutorials/fsi-course 160x3

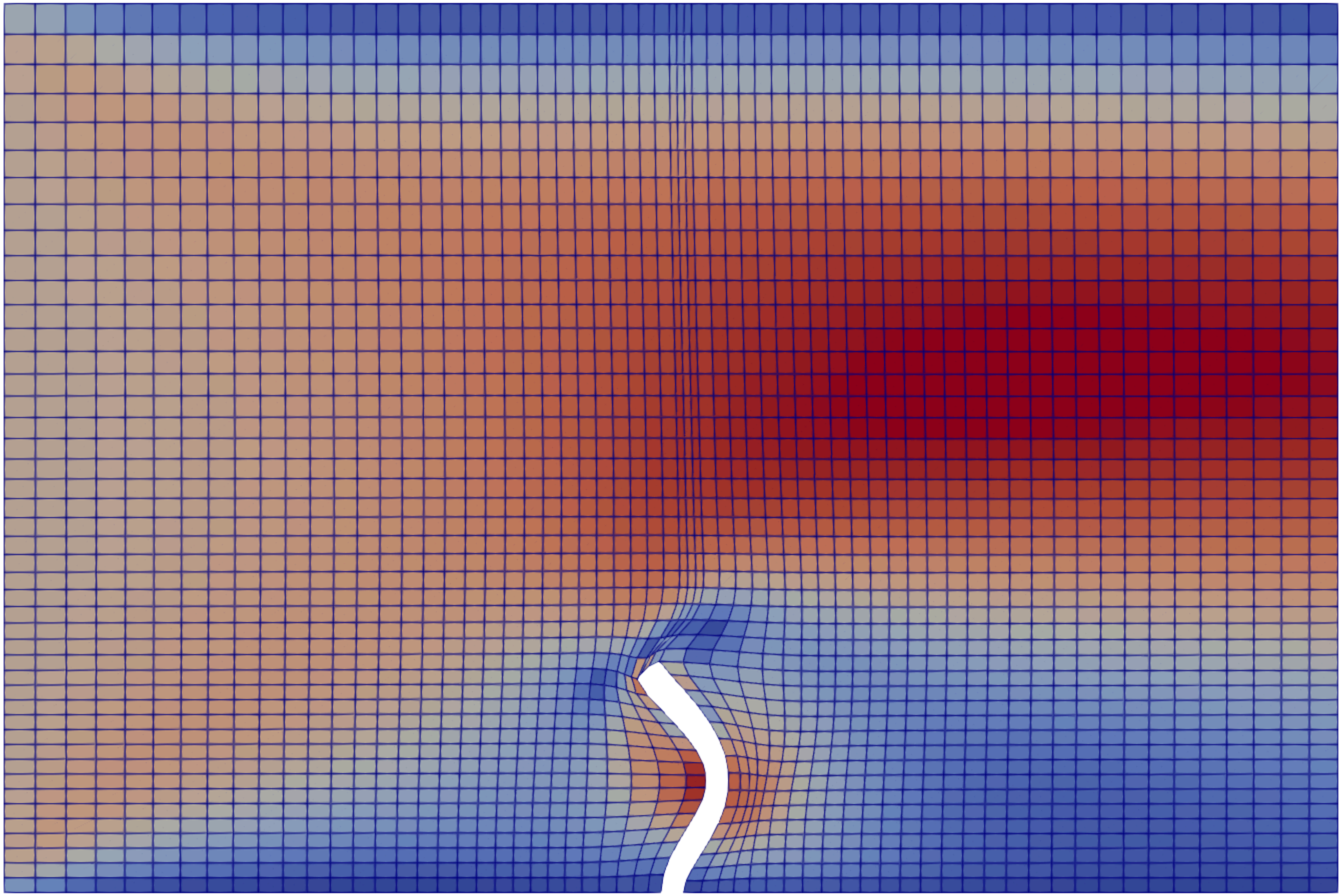
```
vagrant@precicevm:~/tutorials/fsi-course$ ls
clean-tutorial.sh  fluid-openfoam  plot-displacement.sh  precice-config.xml  solid-calculix
vagrant@precicevm:~/tutorials/fsi-course$
```

vagrant@precicevm: ~/tutorials/fsi-course/fluid-openfoam 79x44

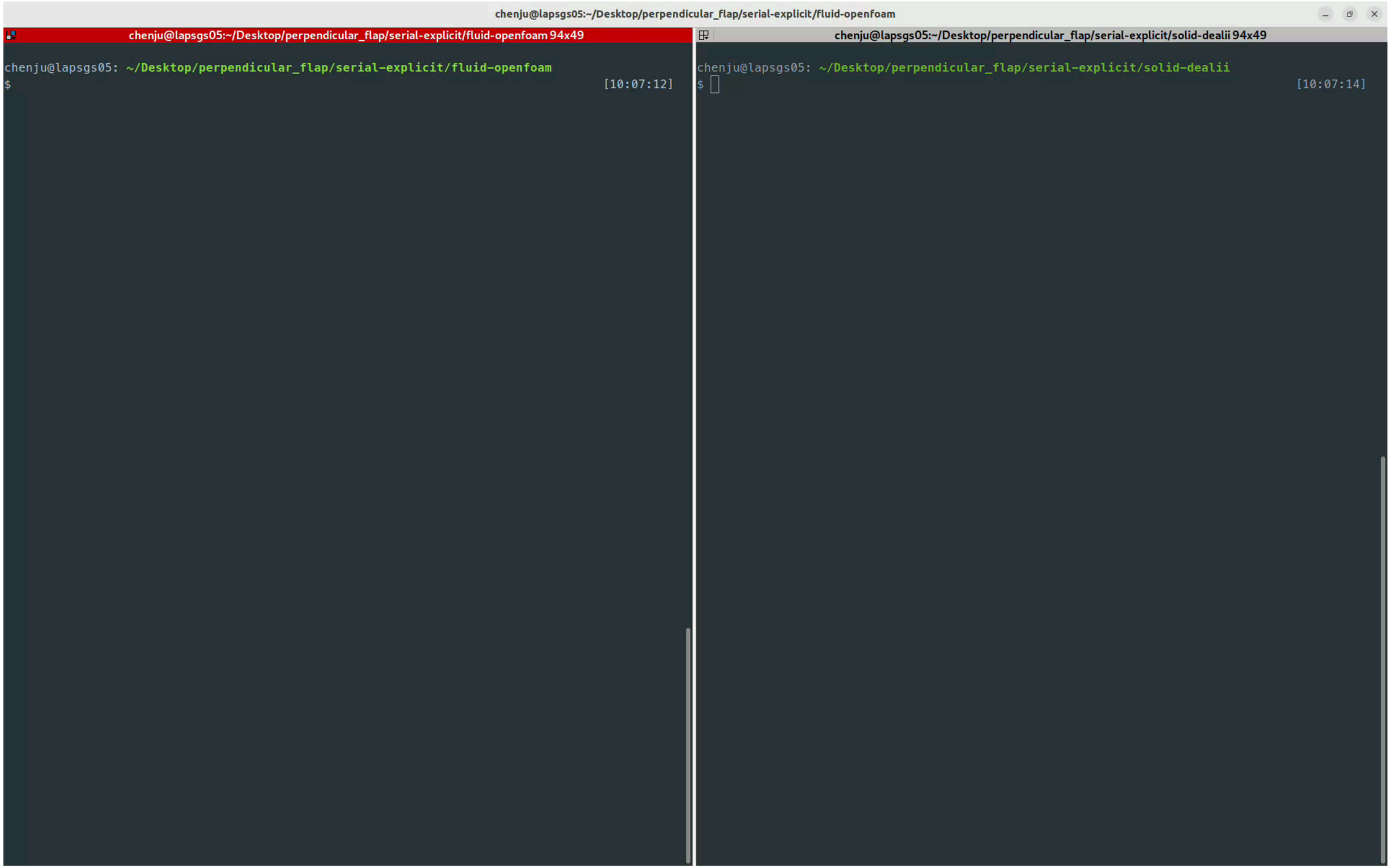
```
vagrant@precicevm:~/tutorials/fsi-course/fluid-openfoam$ tree
.
├── 0
│   ├── p
│   ├── phi
│   ├── pointDisplacement
│   └── U
├── clean.sh
├── constant
│   ├── dynamicMeshDict
│   ├── transportProperties
│   └── turbulenceProperties
├── run.sh
└── system
    ├── blockMeshDict
    ├── controlDict
    ├── decomposeParDict
    ├── fvSchemes
    ├── fvSolution
    └── preciceDict

3 directories, 15 files
vagrant@precicevm:~/tutorials/fsi-course/fluid-openfoam$ ./run.sh
```

vagrant@precicevm: ~/tutorials/fsi-course/solid-calculix 79x44

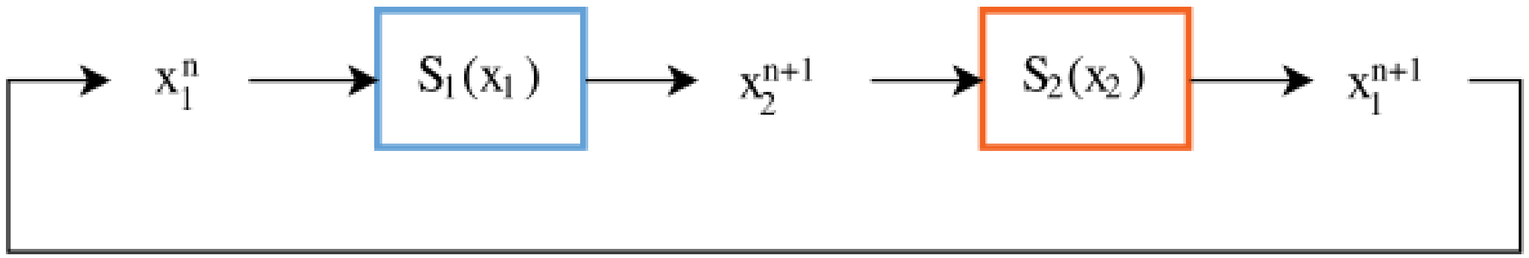
```
vagrant@precicevm:~/tutorials/fsi-course/solid-calculix$ ls
all.msh    config.yml     flap.inp        frequency.inp       run.sh
clean.sh   fix1_beam.nam  flap_modal.inp  interface_beam.nam
vagrant@precicevm:~/tutorials/fsi-course/solid-calculix$ ./run.sh
```



When we decrease the solid density further to 1, the participants have stronger coupling, then:

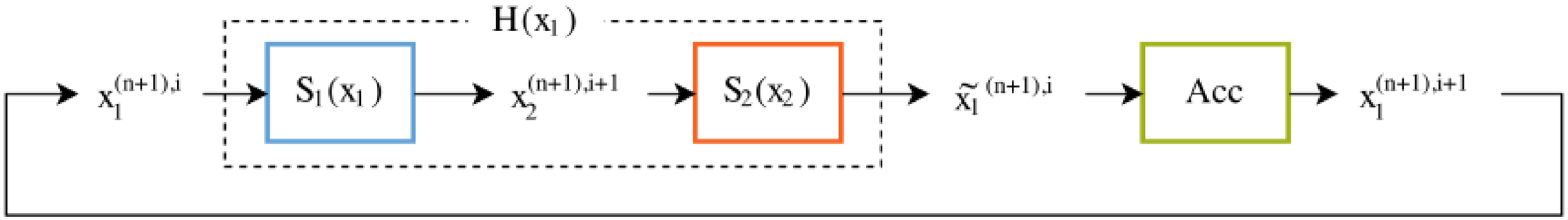


What we did so far: serial-explicit scheme



$n \leftarrow n + 1$

Let's try an implicit coupling scheme



$$i \leftarrow i+1, \quad S_1 \leftarrow S_1^{(n)}, \quad S_2 \leftarrow S_2^{(n)}$$

Configure the coupling scheme

```
<coupling-scheme:serial-implicit>
  <participants first="Fluid" second="Solid" />
  <max-time value="1.5" />
  <time-window-size value="0.01" />
  <exchange data="Force" mesh="Solid-Mesh" from="Fluid" to="Solid" />
  <exchange data="Displacement" mesh="Solid-Mesh" from="Solid" to="Fl
  <relative-convergence-measure limit="5e-3" data="Displacement" mesh
  <relative-convergence-measure limit="5e-3" data="Force" mesh="Solid
  <max-iterations value="50" />
</coupling-scheme:serial-implicit>
```

Only change from explicit to implicit coupling

Configure the coupling scheme

```
<coupling-scheme:serial-implicit>
  <participants first="Fluid" second="Solid" />
  <max-time value="1.5" />
  <time-window-size value="0.01" />
  <exchange data="Force" mesh="Solid-Mesh" from="Fluid" to="Solid" />
  <exchange data="Displacement" mesh="Solid-Mesh" from="Solid" to="Fl
  <relative-convergence-measure limit="5e-3" data="Displacement" mesh
  <relative-convergence-measure limit="5e-3" data="Force" mesh="Solid
  <max-iterations value="50" />
</coupling-scheme:serial-implicit>
```

Only change from explicit to implicit coupling

Configure the coupling scheme

```
<coupling-scheme:serial-implicit>
  <participants first="Fluid" second="Solid" />
  <max-time value="1.5" />
  <time-window-size value="0.01" />
  <exchange data="Force" mesh="Solid-Mesh" from="Fluid" to="Solid" />
  <exchange data="Displacement" mesh="Solid-Mesh" from="Solid" to="Fl
  <relative-convergence-measure limit="5e-3" data="Displacement" mesh
  <relative-convergence-measure limit="5e-3" data="Force" mesh="Solid
  <max-iterations value="50" />
</coupling-scheme:serial-implicit>
```

Only change from explicit to implicit coupling

Configure the coupling scheme

```
<coupling-scheme:serial-implicit>
  <participants first="Fluid" second="Solid" />
  <max-time value="1.5" />
  <time-window-size value="0.01" />
  <exchange data="Force" mesh="Solid-Mesh" from="Fluid" to="Solid" />
  <exchange data="Displacement" mesh="Solid-Mesh" from="Solid" to="Fl
  <relative-convergence-measure limit="5e-3" data="Displacement" mesh
  <relative-convergence-measure limit="5e-3" data="Force" mesh="Solid
  <max-iterations value="50" />
</coupling-scheme:serial-implicit>
```

Only change from explicit to implicit coupling

Configure the coupling scheme

```
<coupling-scheme:serial-implicit>
  <participants first="Fluid" second="Solid" />
  <max-time value="1.5" />
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  <exchange data="Force" mesh="Solid-Mesh" from="Fluid" to="Solid" />
  <exchange data="Displacement" mesh="Solid-Mesh" from="Solid" to="Fl
  <relative-convergence-measure limit="5e-3" data="Displacement" mesh
  <relative-convergence-measure limit="5e-3" data="Force" mesh="Solid
  <max-iterations value="50" />
</coupling-scheme:serial-implicit>
```
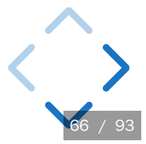
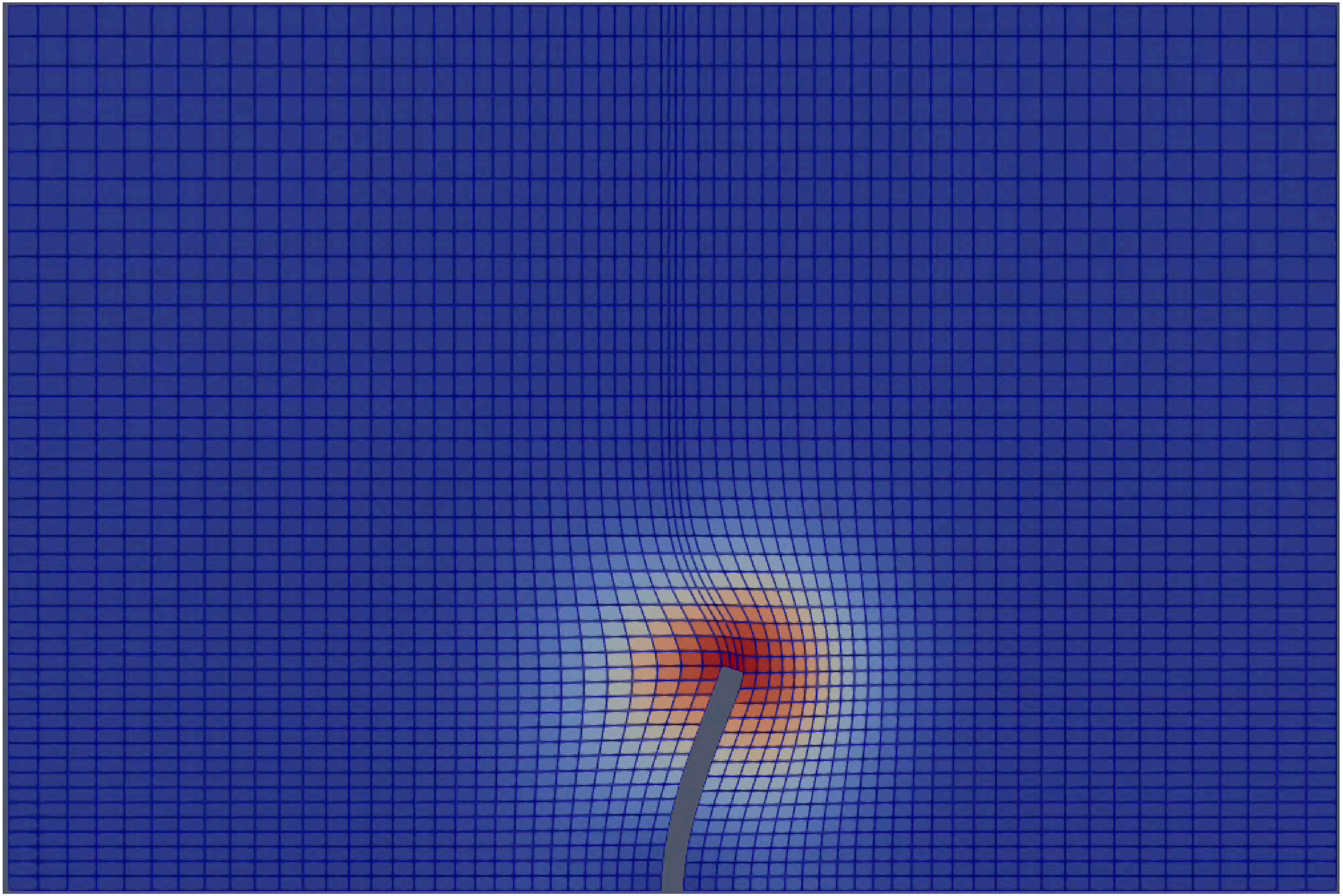

Only change from explicit to implicit coupling



With solid density equal to 42:



Average iteration number per time step: 3.41

With solid density equal to 1: break again!

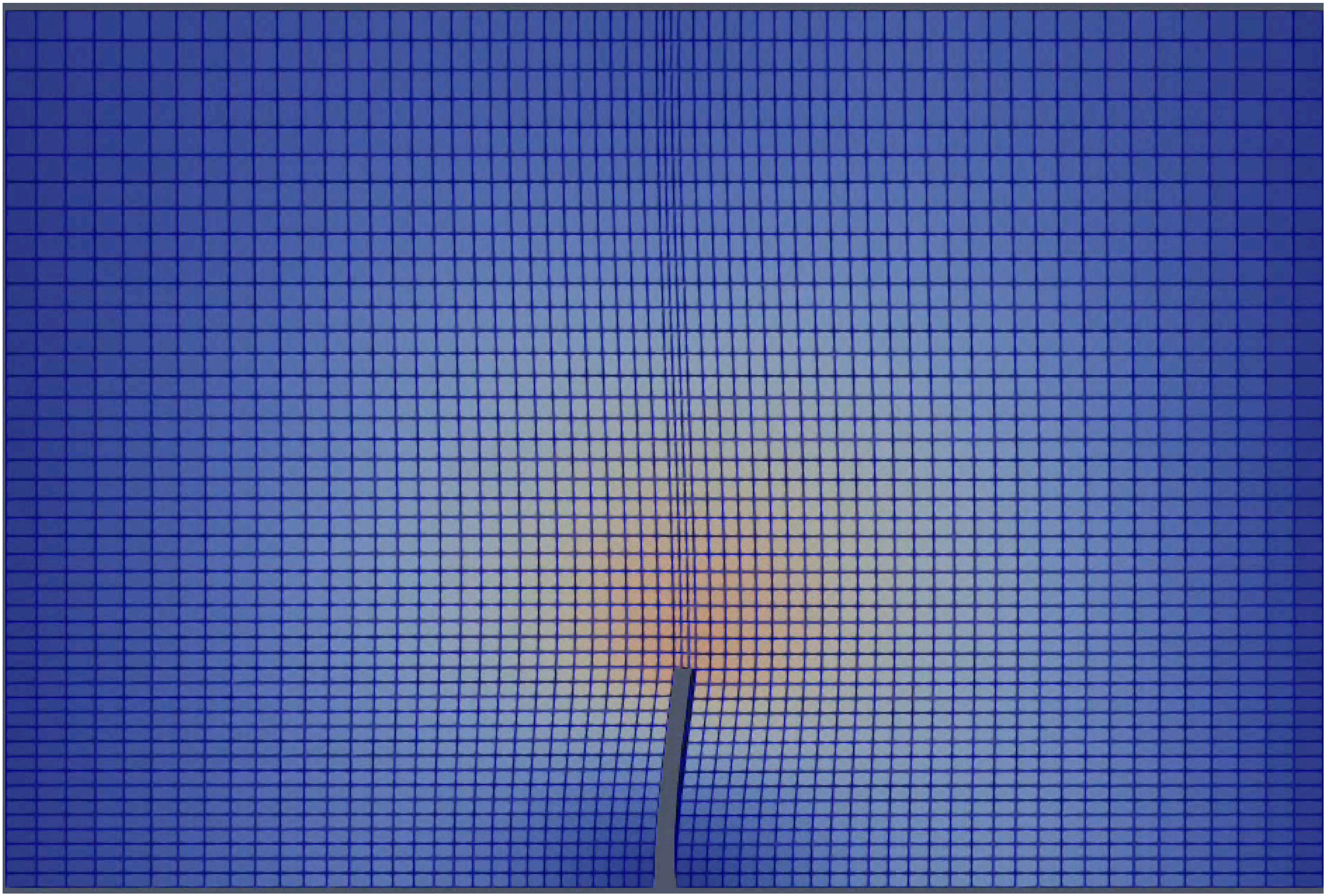
Still not enough stability for strong coupling!

Configure the coupling scheme

```
<coupling-scheme:serial-implicit>
  <participants first="Fluid" second="Solid" />
  <max-time value="1.5" />
  <time-window-size value="0.01" />
  <exchange data="Force" mesh="Solid-Mesh" from="Fluid" to="Solid" />
  <exchange data="Displacement" mesh="Solid-Mesh" from="Solid" to="Fl
  <relative-convergence-measure limit="5e-3" data="Displacement" mesh
  <relative-convergence-measure limit="5e-3" data="Force" mesh="Solid
  <max-iterations value="50" />
  <acceleration:constant>
    <relaxation value="0.5" />
  </acceleration:constant>
</coupling-scheme:serial-implicit>
```

Simplest acceleration: constant under-relaxation

With solid density equal to 1:



Too slow! Can we do better?

Improvement 1: Aitken under-relaxation

```
<acceleration:aitken>
  <data name="Displacement" mesh="Solid-Mesh" />
  <initial-relaxation value="0.5" />
</acceleration:aitken>
```

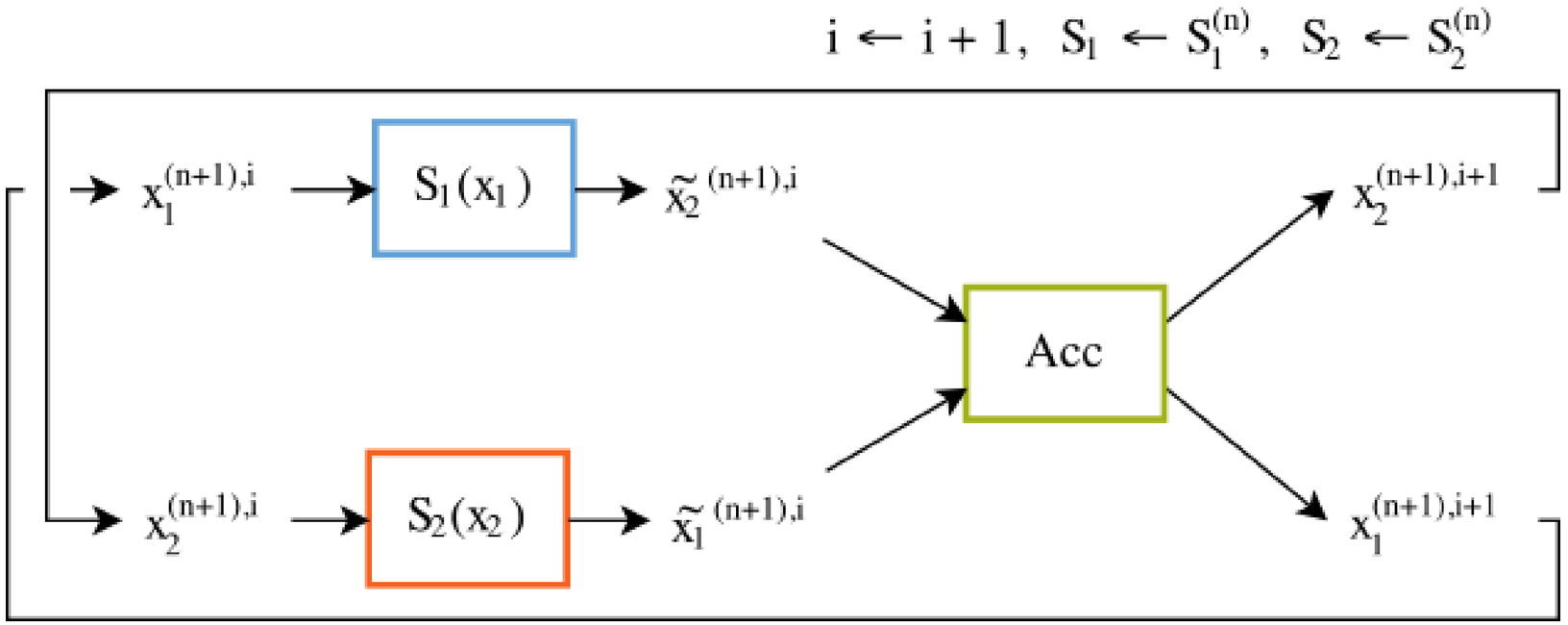
Improvement 2: Anderson acceleration

```
<acceleration:IQN-ILS>
  <data name="Displacement" mesh="Solid-Mesh" />
  <initial-relaxation value="0.5" />
  <preconditioner type="residual-sum" />
  <filter type="QR2" limit="1e-2" />
  <max-used-iterations value="100" />
  <time-windows-reused value="15" />
</acceleration:IQN-ILS>
```

Improvement 2: Anderson acceleration

```
<acceleration:IQN-ILS>
  <data name="Displacement" mesh="Solid-Mesh" />
  <initial-relaxation value="0.5" />
  <preconditioner type="residual-sum" />
  <filter type="QR2" limit="1e-2" />
  <max-used-iterations value="100" />
  <time-windows-reused value="15" />
</acceleration:IQN-ILS>
```

There are also parallel schemes



Can use fields from both / all participants

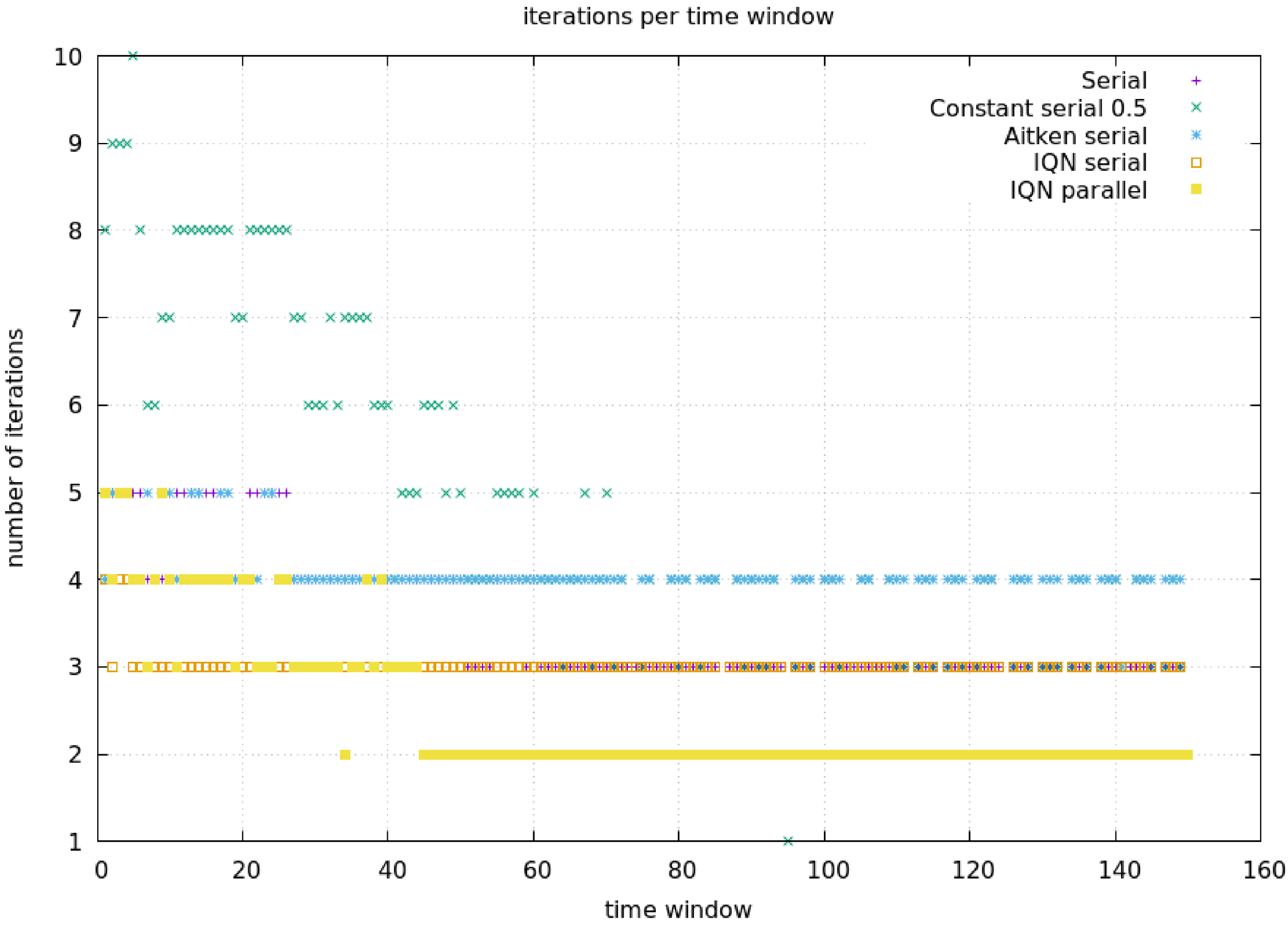
Improvement 3: Parallel coupling schemes

```
<coupling-scheme:parallel-implicit>
  <time-window-size value="0.01" />
  <max-time value="1.5" />
  <participants first="Fluid" second="Solid" />
  <exchange data="Force" mesh="Solid-Mesh" from="Fluid" to="Solid" />
  <exchange data="Displacement" mesh="Solid-Mesh" from="Solid" to="Fl
  <max-iterations value="50" />
  <relative-convergence-measure limit="5e-3" data="Displacement" mesh
  <relative-convergence-measure limit="5e-3" data="Force" mesh="Solid
  <acceleration:IQN-ILS>
    <data name="Displacement" mesh="Solid-Mesh" />
    <data name="Force" mesh="Solid-Mesh" />
    <initial-relaxation value="0.5" />
    <preconditioner type="residual-sum" />
    <filter type="QR2" limit="1e-2" />
    <max-used-iterations value="100" />
    <time-windows-reused value="15" />
```

Improvement 3: Parallel coupling schemes

```
3     <max-time value="1.5" />
4     <participants first="Fluid" second="Solid" />
5     <exchange data="Force" mesh="Solid-Mesh" from="Fluid" to="Solid" />
6     <exchange data="Displacement" mesh="Solid-Mesh" from="Solid" to="Fl
7     <max-iterations value="50" />
8     <relative-convergence-measure limit="5e-3" data="Displacement" mesh
9     <relative-convergence-measure limit="5e-3" data="Force" mesh="Solid
10    <acceleration:IQN-ILS>
11      <data name="Displacement" mesh="Solid-Mesh" />
12      <data name="Force" mesh="Solid-Mesh" />
13      <initial-relaxation value="0.5" />
14      <preconditioner type="residual-sum" />
15      <filter type="QR2" limit="1e-2" />
16      <max-used-iterations value="100" />
17      <time-windows-reused value="15" />
18    </acceleration:IQN-ILS>
19  </coupling-scheme:parallel-implicit>
```

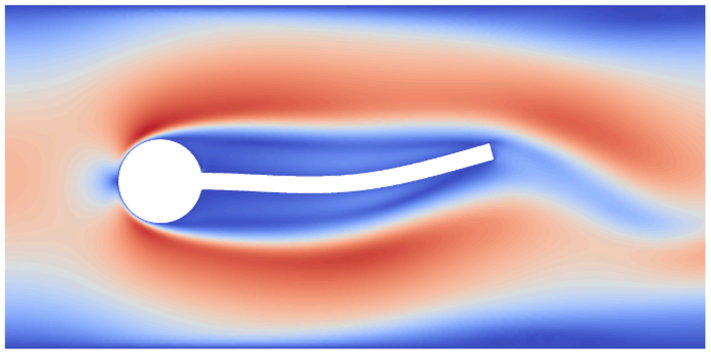
	density = 42	density = 1
serial-explicit	div	div
se-implicit	3.41	div
se-im-const	4.48	5.27
se-im-Aitken	3.74	5.3
se-im-ILS	2.95	3.07
parallel-im-ILS	2.46	2.33



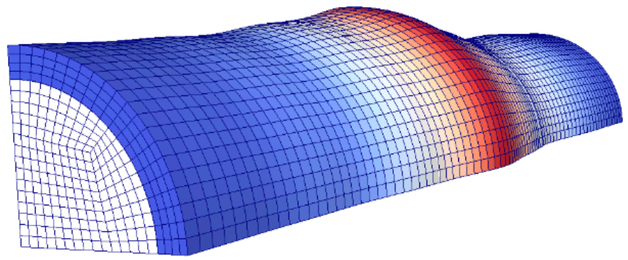
Beware: Configuration not fine-tuned, not rigorous comparison, application context.

Rigorous comparison from the literature

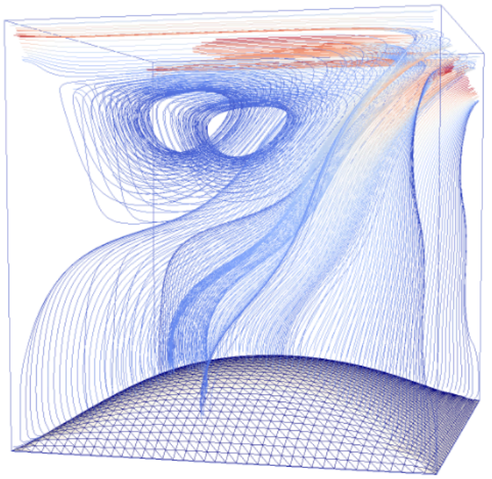
FSI3



3D-Tube



Driven Cavity

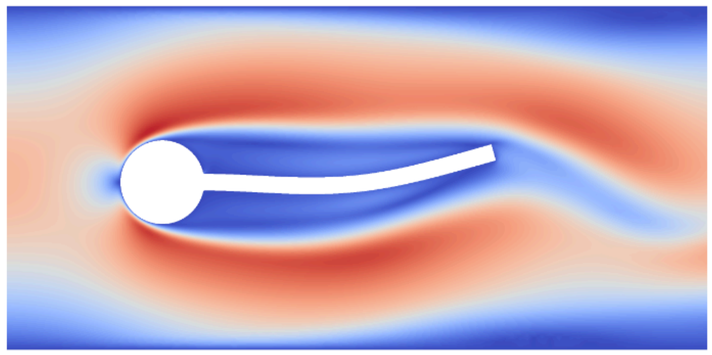


Mean Iterations	Aitken	Quasi-Newton
FSI3	17.0	3.7
3D-Tube	Div.	7.5
Driven Cavity	7.4	3.0

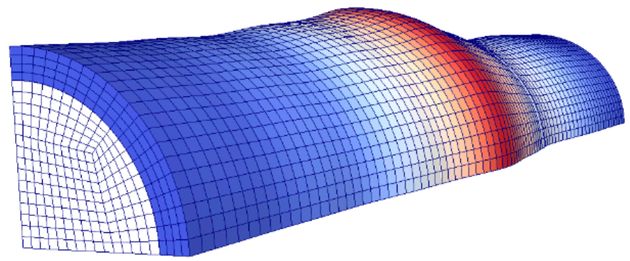
Source: Dissertation of Benjamin Uekermann (2016)

Rigorous comparison from the literature

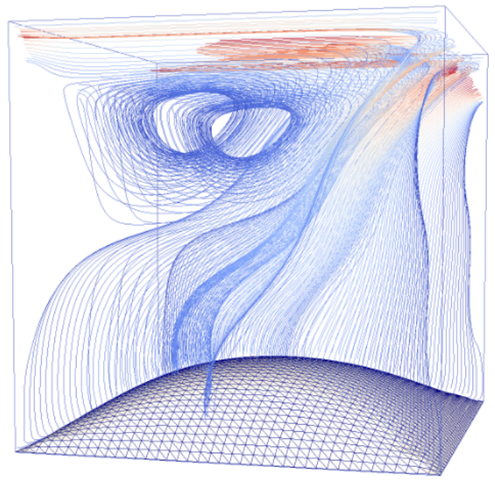
FSI3



3D-Tube



Driven Cavity



Mean Iterations	Serial Coupling	Parallel Coupling
FSI3	3.7	**3.3**
3D-Tube	**7.5**	10.4
Driven Cavity	3.0	**2.0**

Source: Dissertation of Benjamin Uekermann (2016)

Resources

Start here: precice.org

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Registration for the preCICE workshop 2024 is now open! Submit your abstract until June 30.

Welcome to preCICE

The coupling library for partitioned multi-physics simulations.

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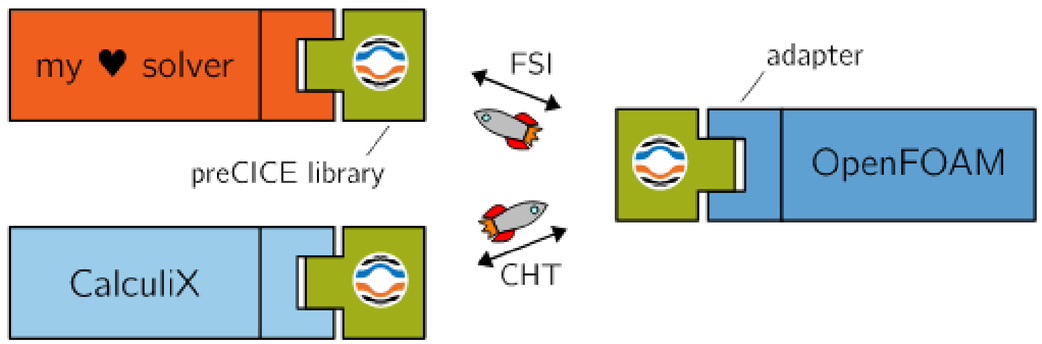
preCICE is an **open-source coupling library** for partitioned multi-physics simulations, including, but not restricted to fluid-structure interaction and conjugate heat transfer simulations.

Partitioned means that **preCICE couples existing programs/solvers** capable of simulating a subpart of the complete physics involved in a simulation. This allows for the high flexibility that is needed to keep a decent time-to-solution for complex multi-physics scenarios.

The software offers convenient methods for transient equation coupling, communication, and data mapping.



Built & hosted on GitHub Pages.
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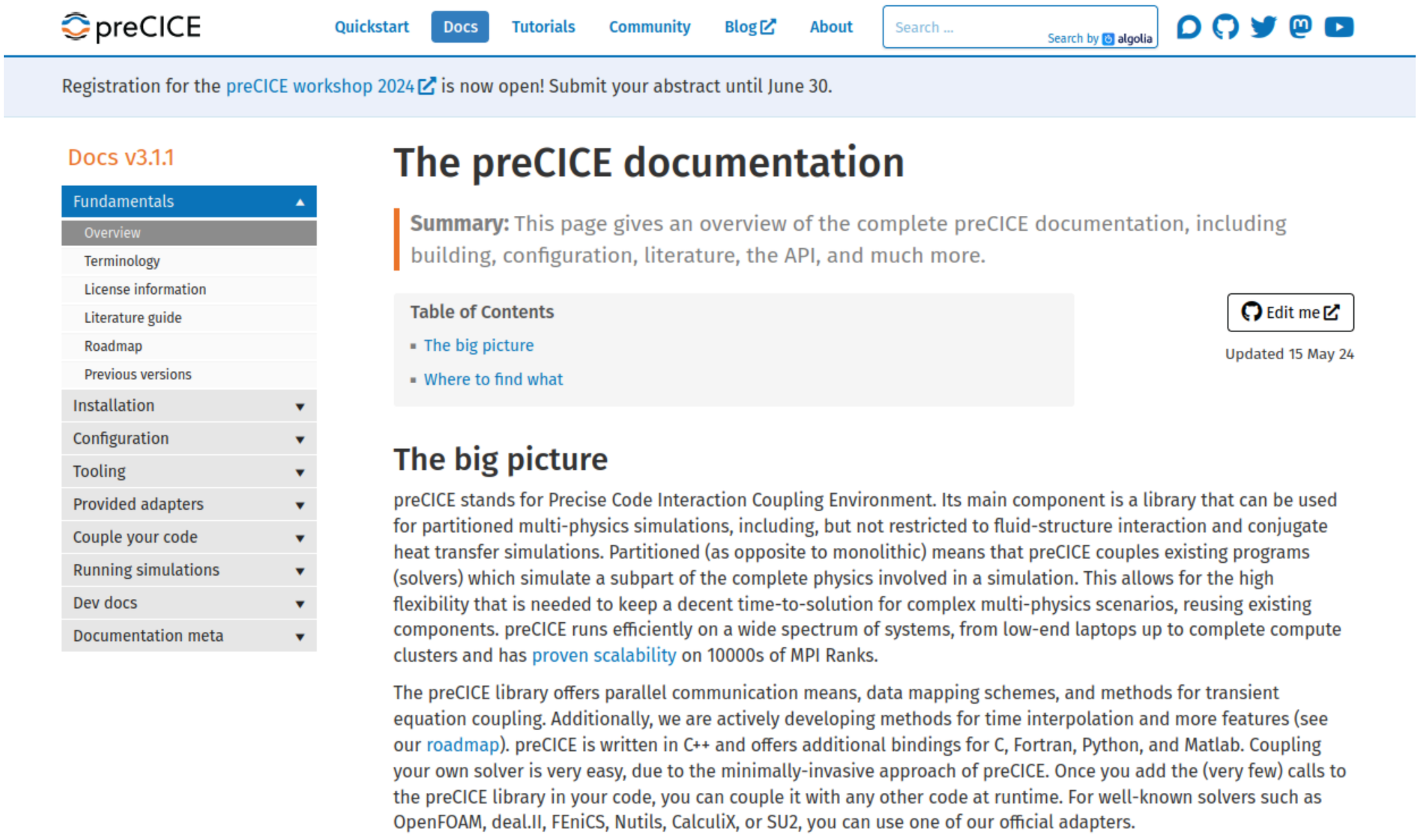
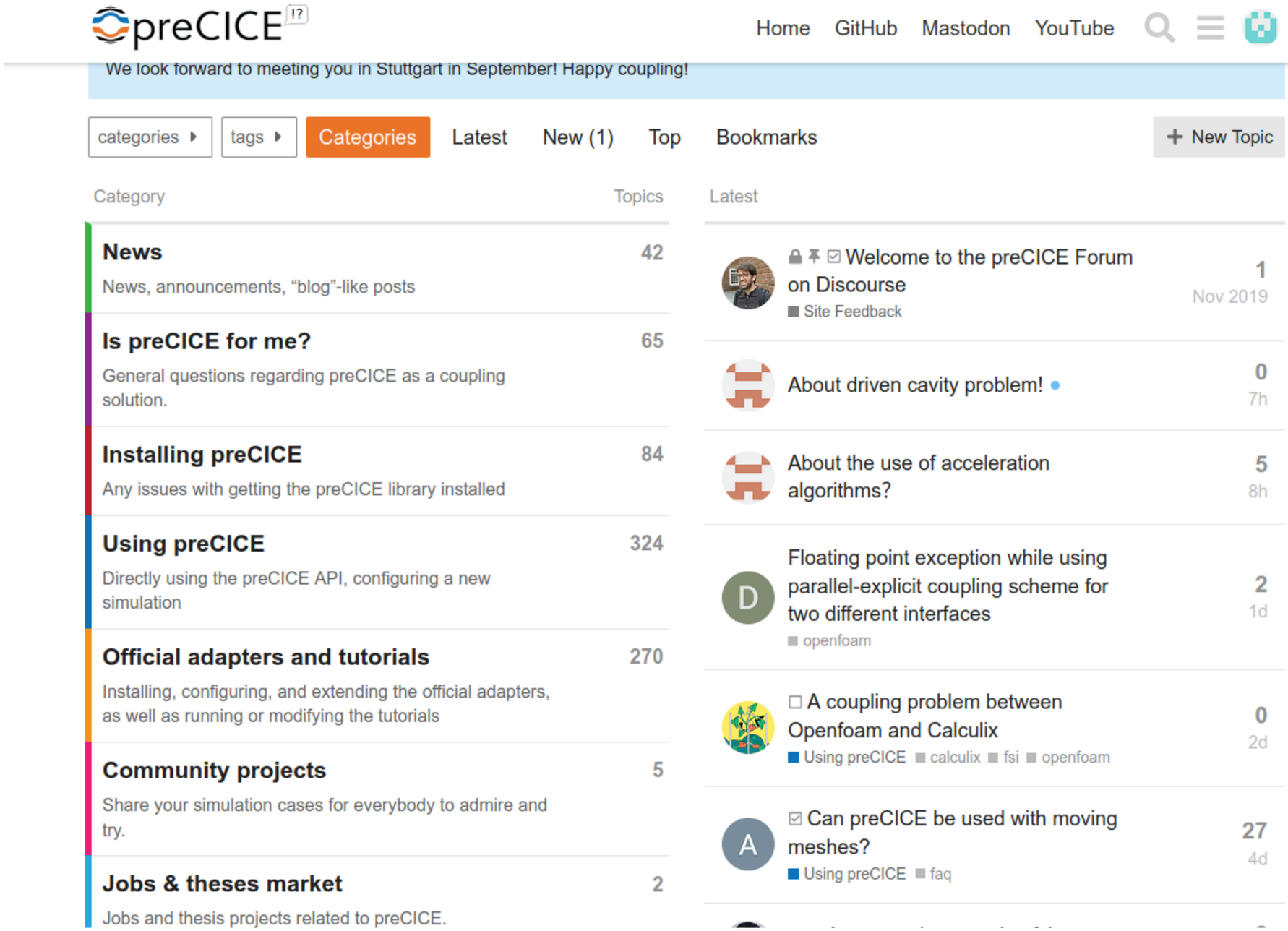
Documentation



Everything in one place, user-editable on GitHub, 100+ pages

Discuss & get help



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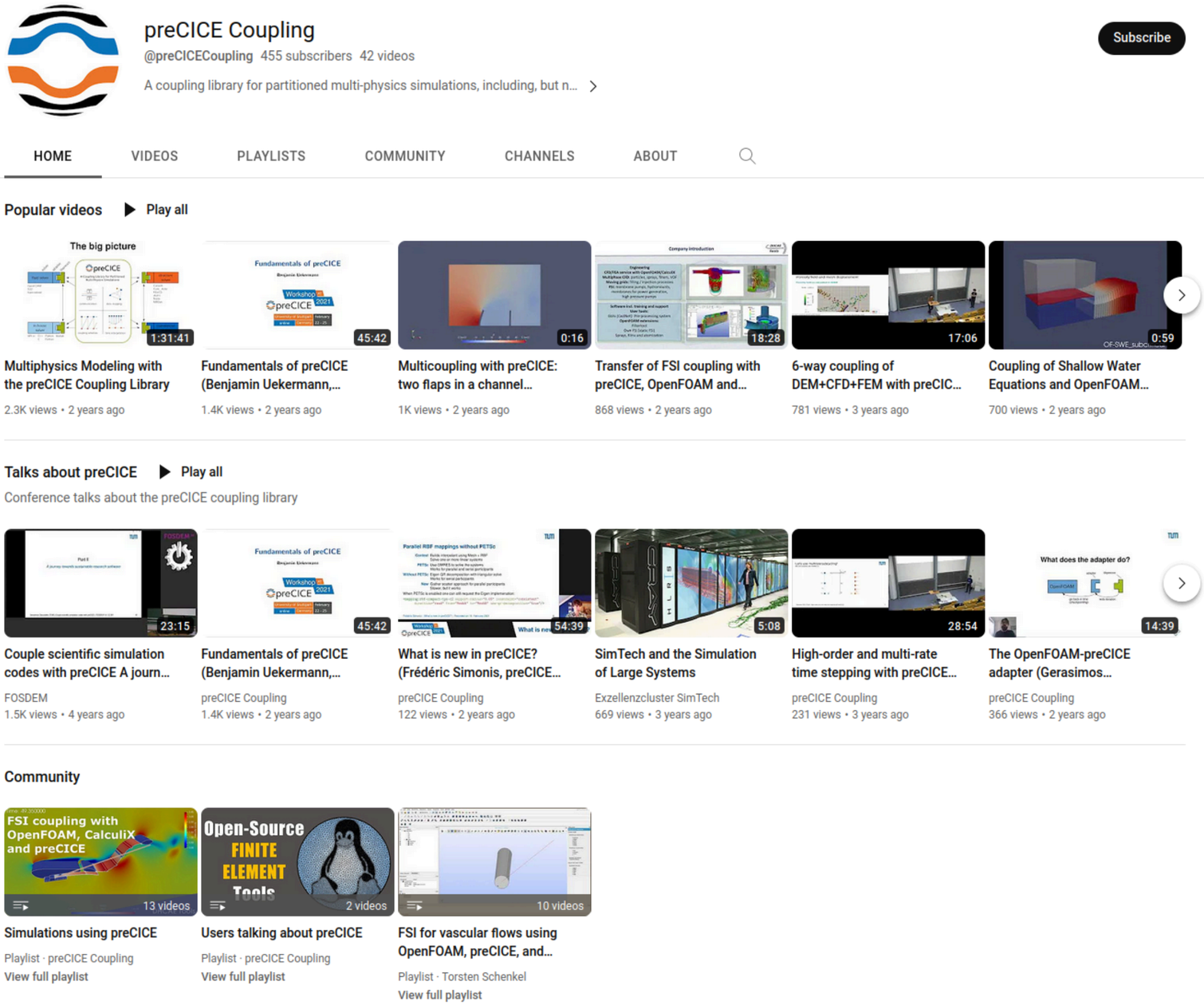

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Active since 2018, 400+ followers
also on `@precice@fosstodon.org`

Read more: OpenFOAM-preCICE paper

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OpenFOAM-preCICE: Coupling OpenFOAM with External Solvers for Multi-Physics Simulations

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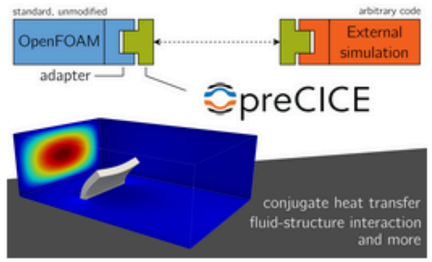
DOI: https://doi.org/10.51560/ofj.v3.88



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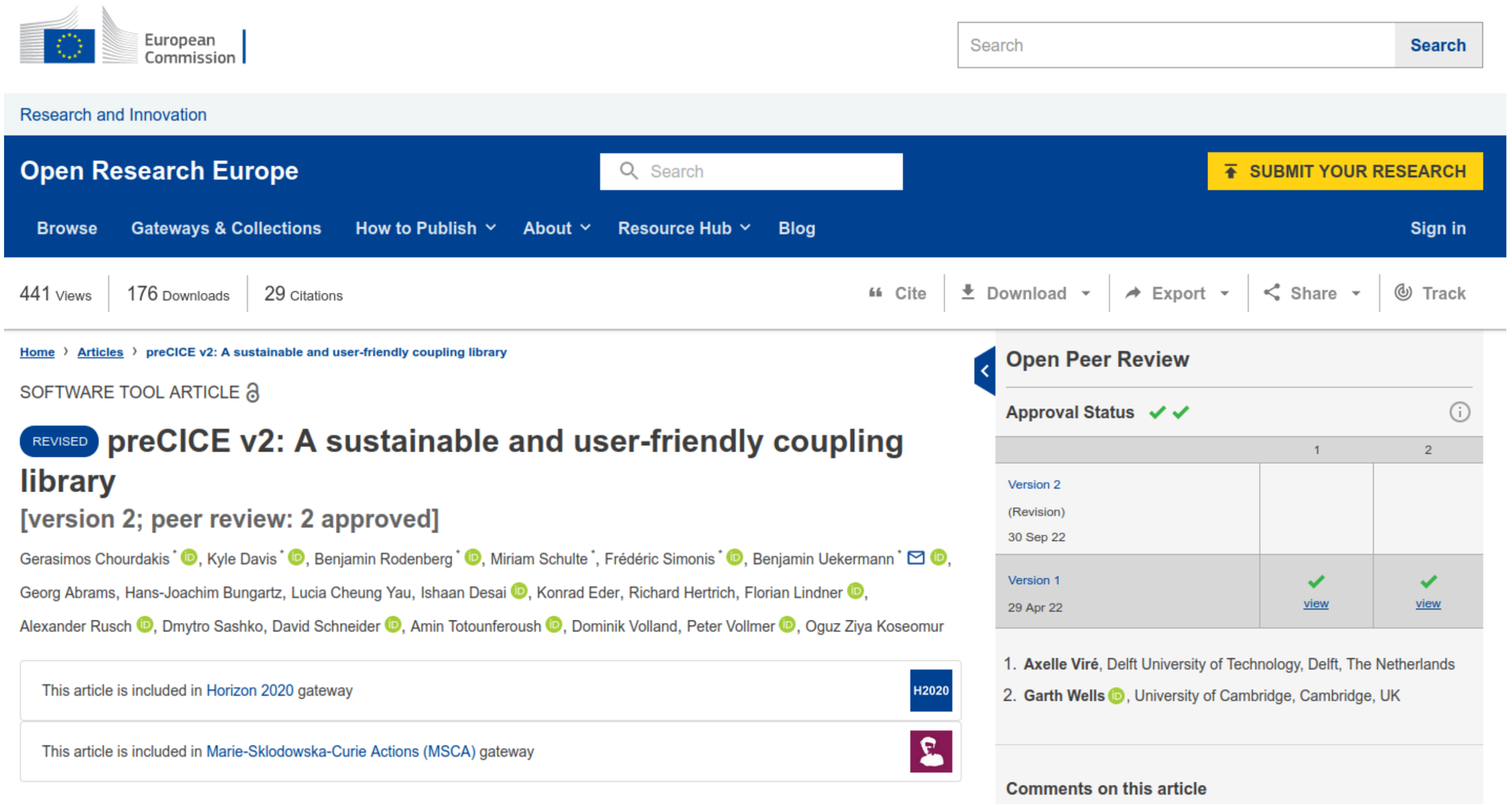
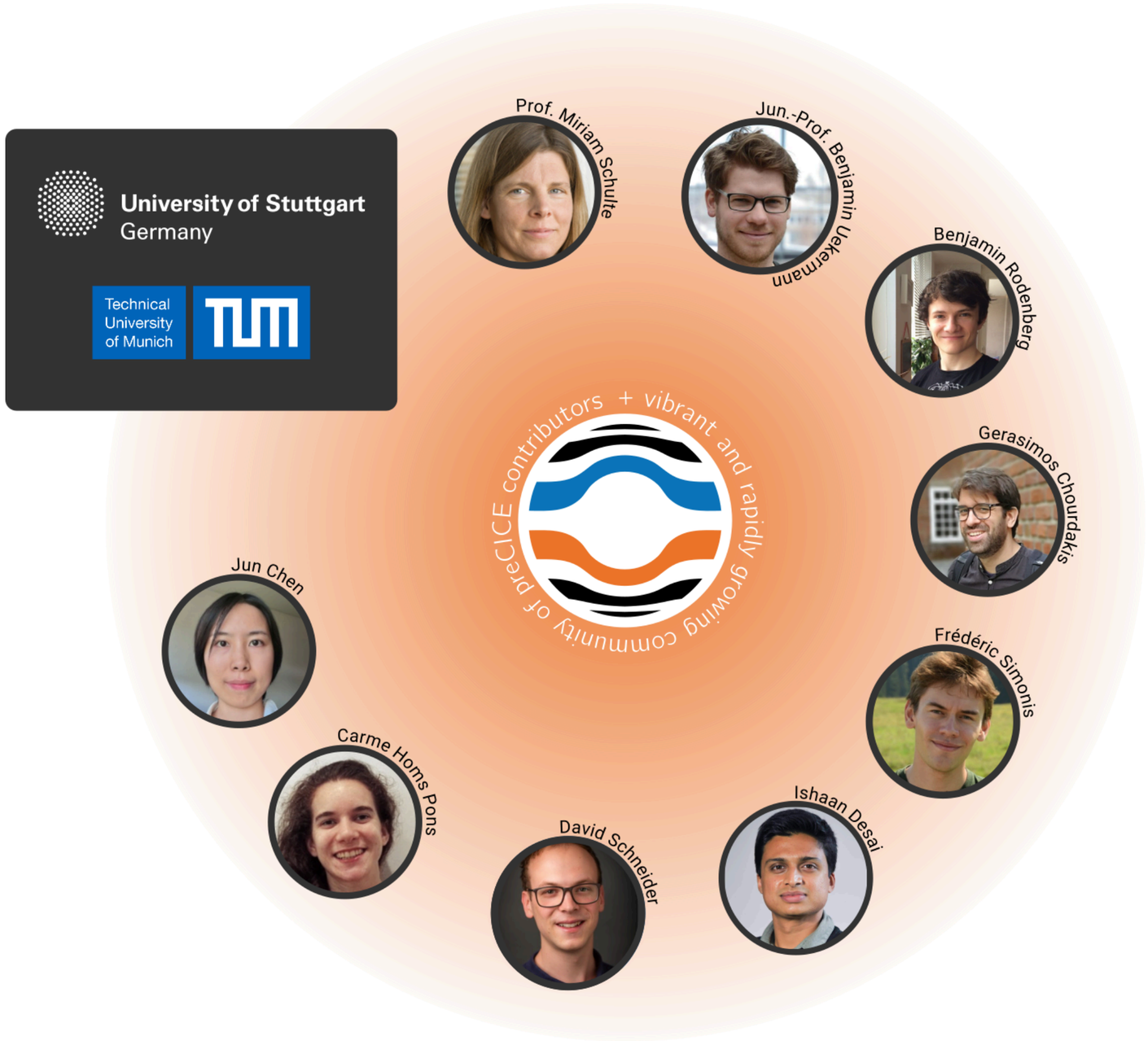
Read more: preCICE paper



The people behind preCICE



Meet the people

Incoming Workshop

University of Stuttgart

Germany

September

24 - 27

preCICE is free because of

Research Software
Sustainability

EXC 2075
SimTech

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 754462

and the code/issues/testing/documentation contributions of people like you (thank you!).

Summary

1. Both for developers and for users

2. Many efficient algorithms are one setting away

Jun Chen(UST) + Gerasimos Chourdakis (UST/TUM) + many more (see precice.org/about)

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