18th OpenFOAM Workshop - Genoa, July 11-14, 2023

Getting started with OpenFOAM-preCICE for FSI simulations

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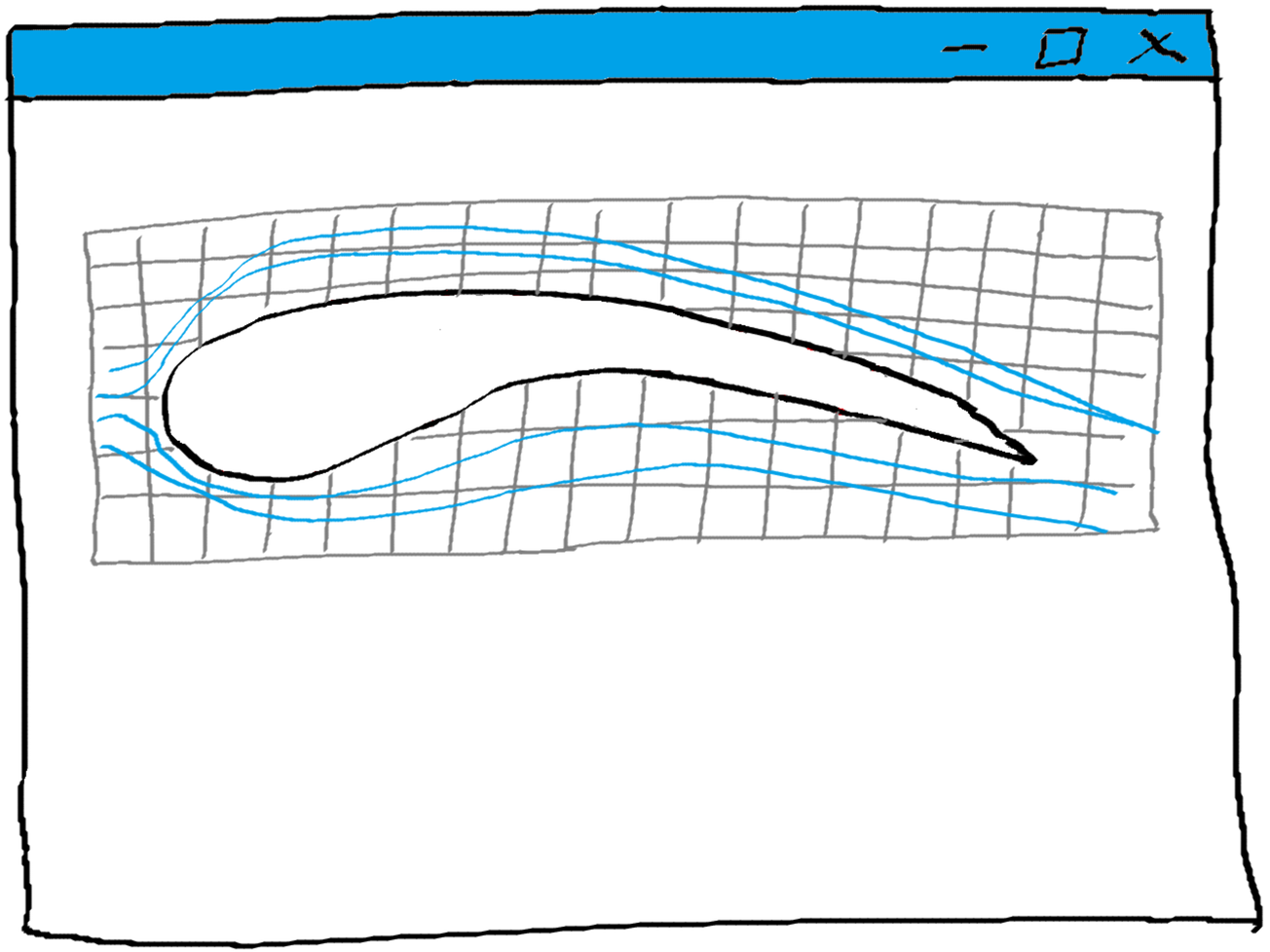
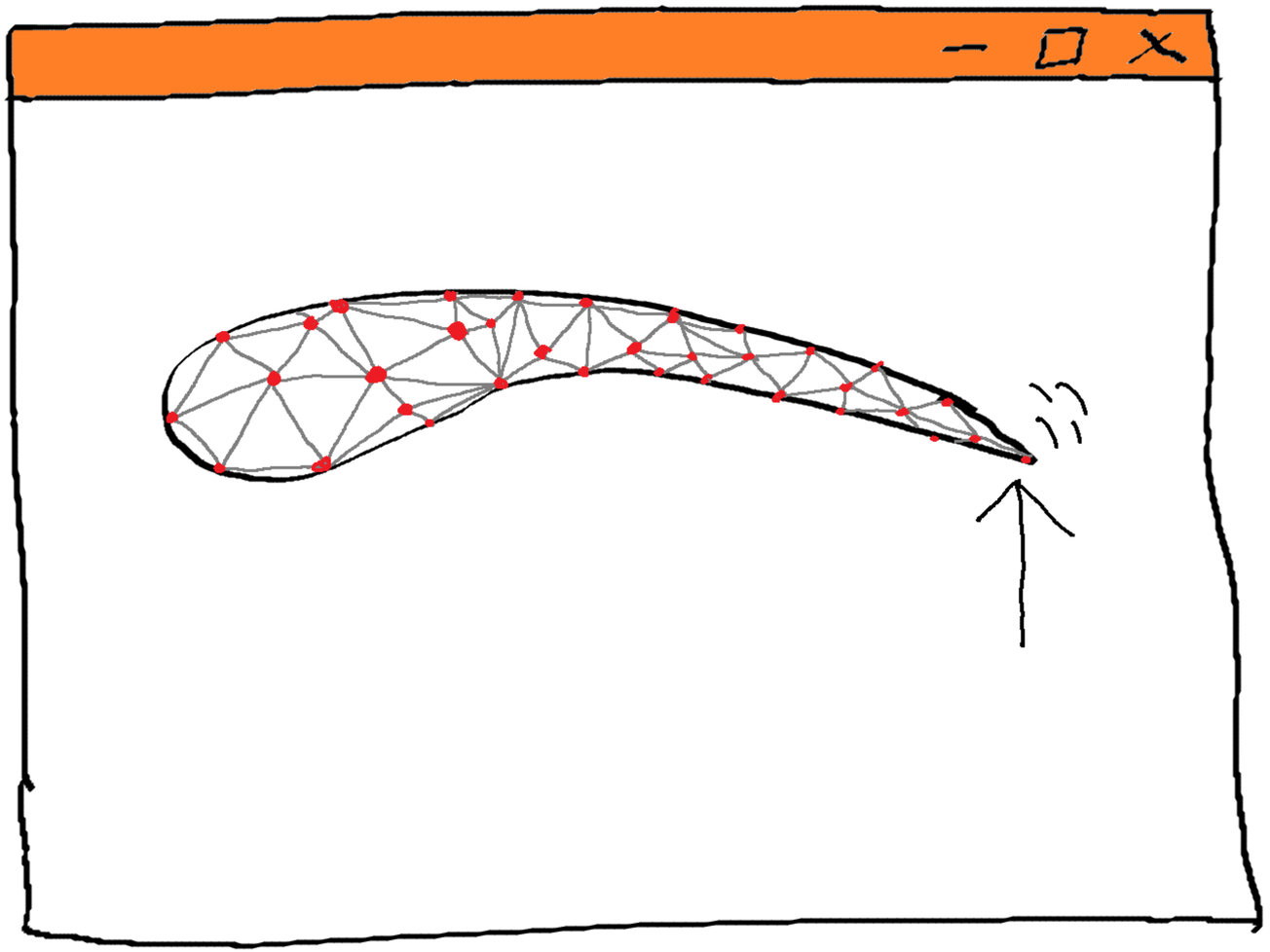
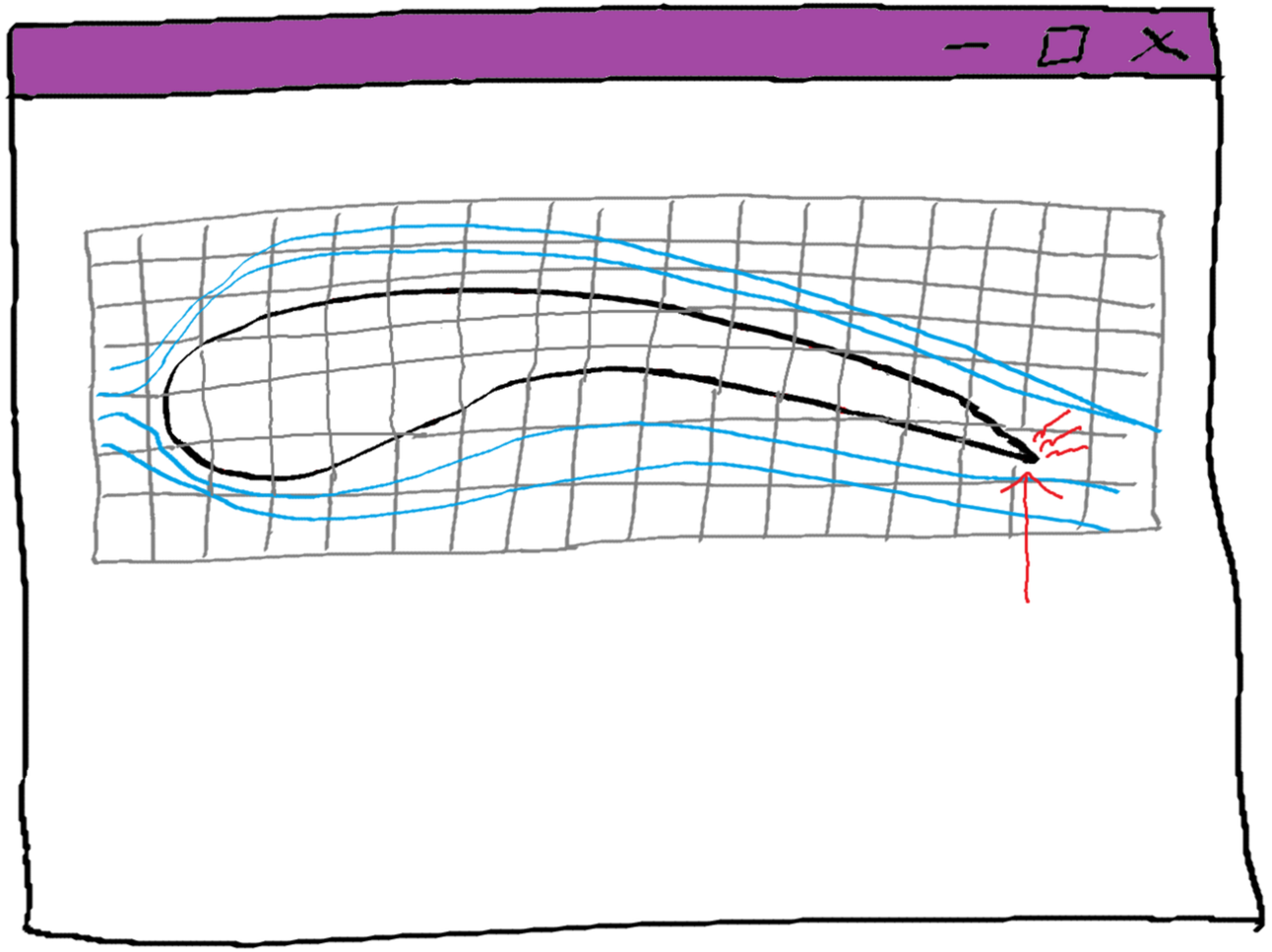
CFD: Simulating flow around a wing



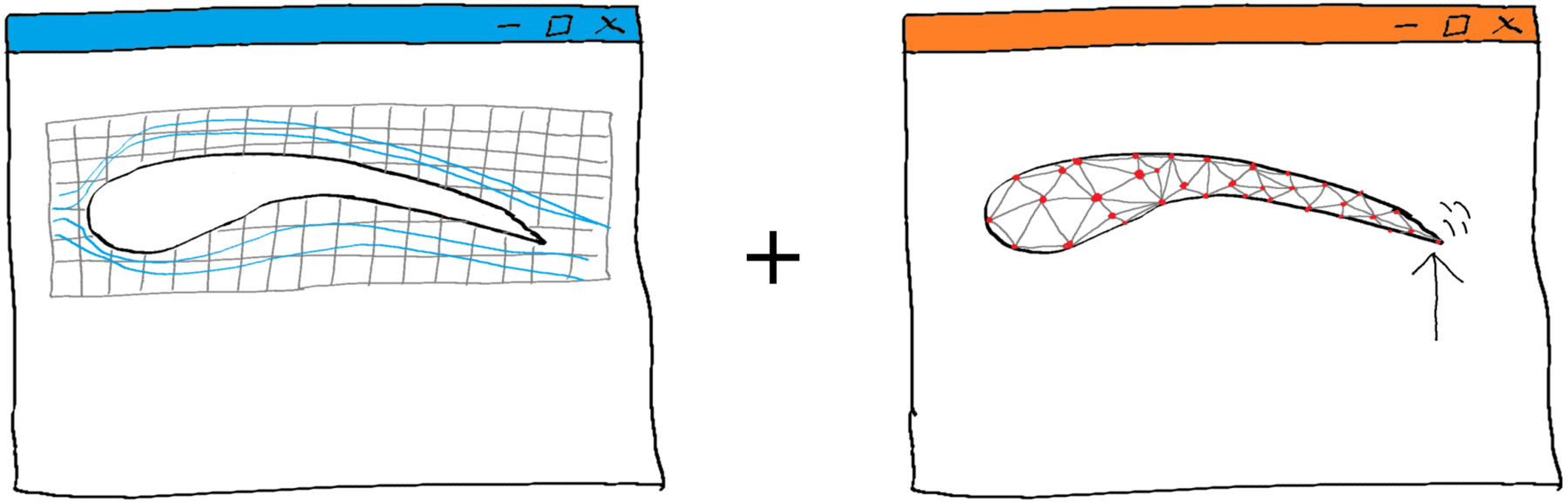
FEM: Simulating stresses on a wing



Can we simulate both at the same time?

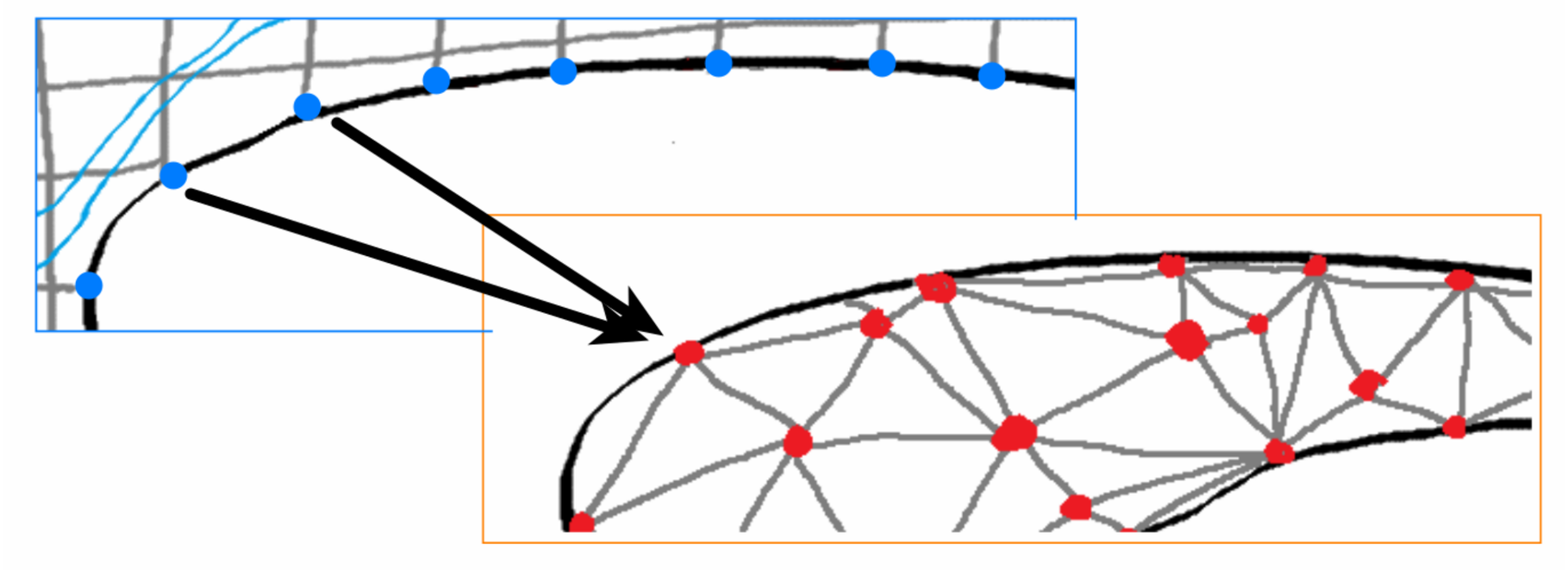


...but reusing the CFD and FEM codes?

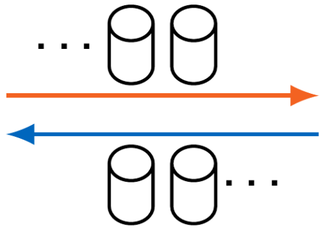


preCICE

From the CFD world to the FEM world



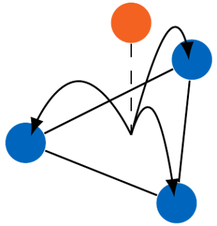
Where preCICE helps



Communication

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

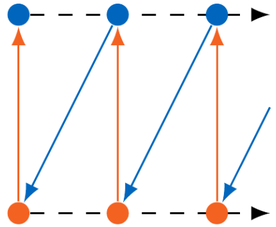
Fully-parallel, peer-to-peer



Data mapping

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

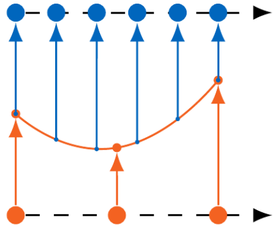
Compute on any side



Coupling schemes

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

Same high-level API
Configurable at runtime

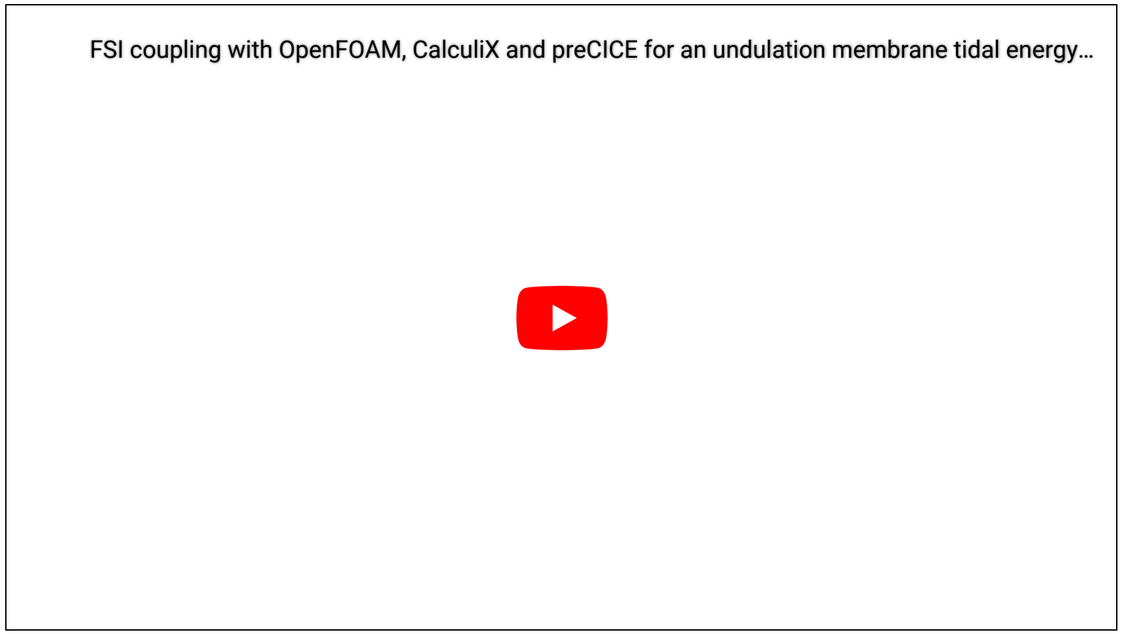


Time interpolation

Options:
- waveform iteration

Experimental since v2.4.0

What people do with preCICE (1)



Credit: Ulrich Heck, DHCAE Tools GmbH

What people do with preCICE (2)

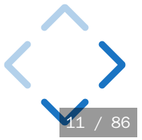
Credit: Prasad Adhav, Univ. of Luxembourg

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 + CalculiX



Organizational notes

1. You are not expected to try things live.
2. Ask questions live, feel free to interrupt me.
3. Get these slides: go.tum.de/530822
4. Some Live USB sticks available during the workshop
5. Find all software installed in a demo virtual machine: precice.org/installation-vm.html
6. 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

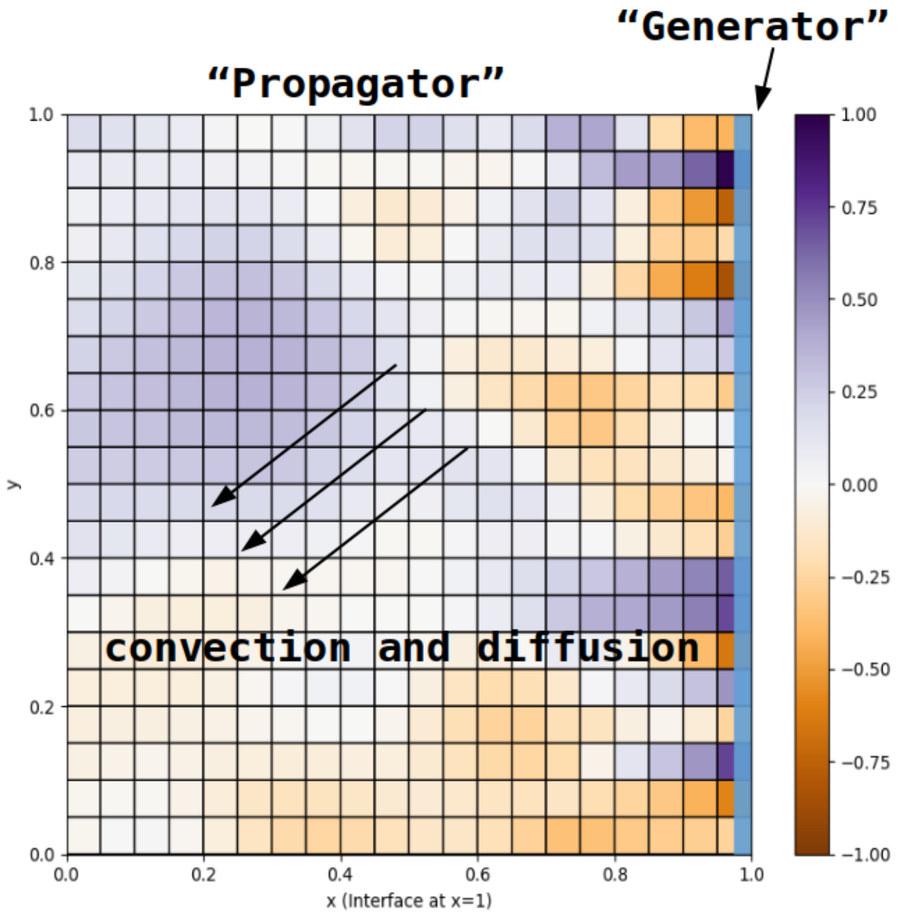
Dependencies

- preCICE v2 (e.g. packages for Ubuntu)
- Python 3
- Python packages `numpy`, `matplotlib`
- preCICE Python bindings:

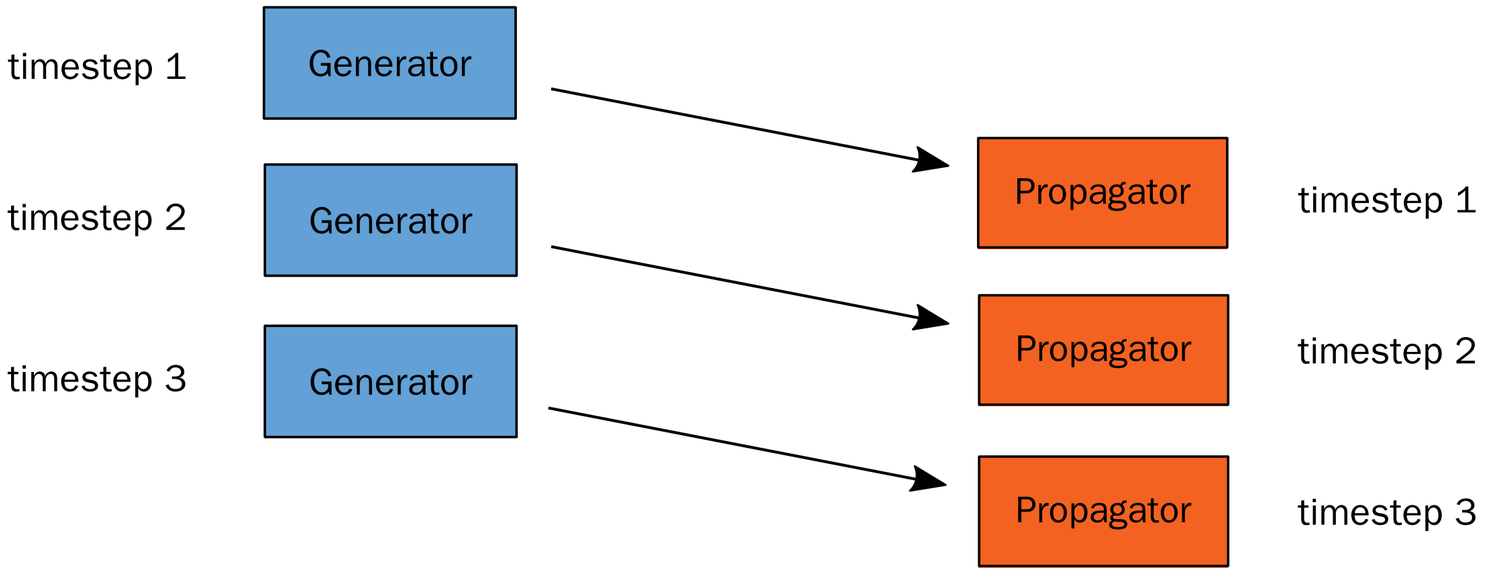
```
pip3 install --upgrade pip
pip3 install --user pyprecice
```

"Generator" and "Propagator"

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



Unidirectional coupling

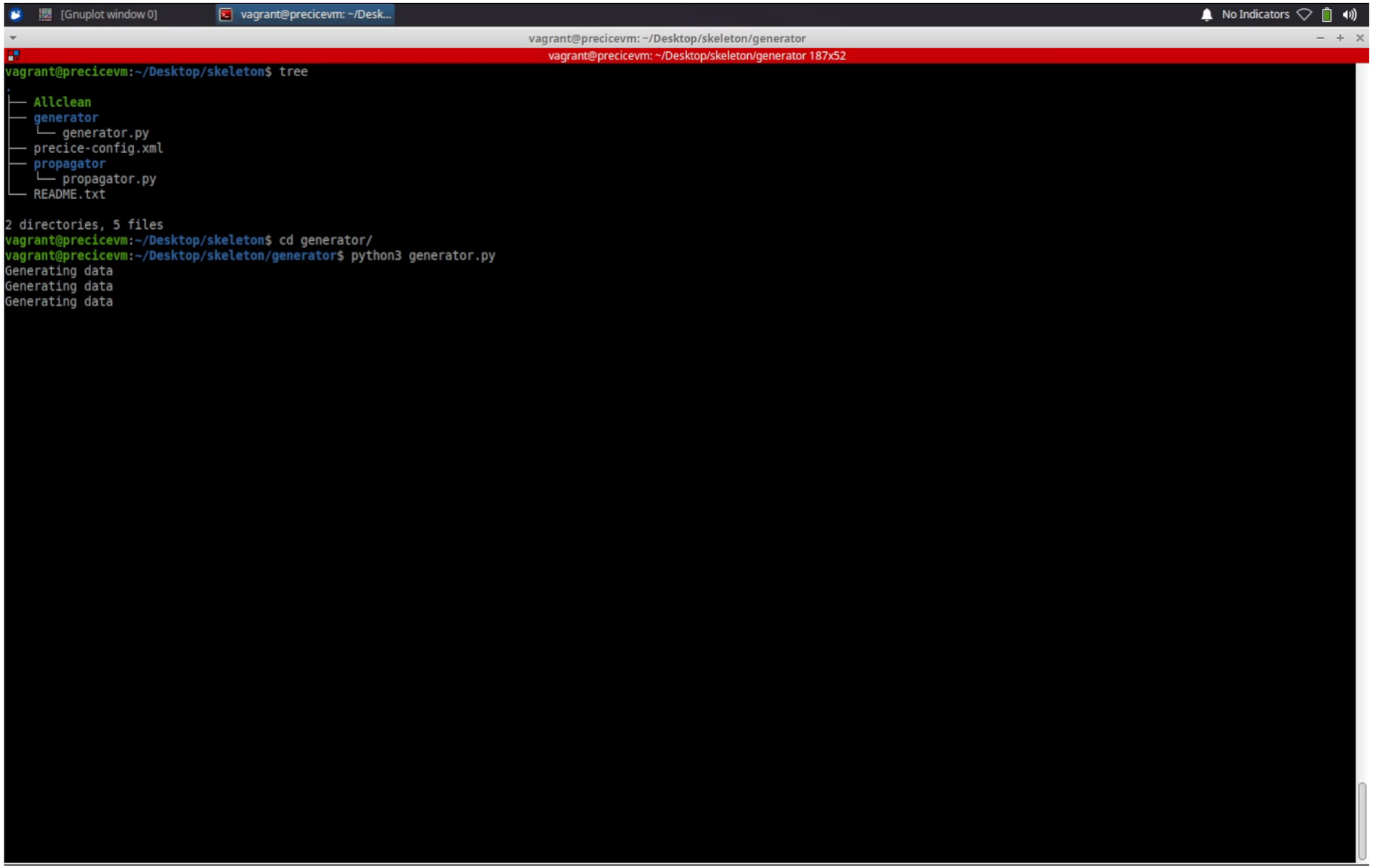


generator.py

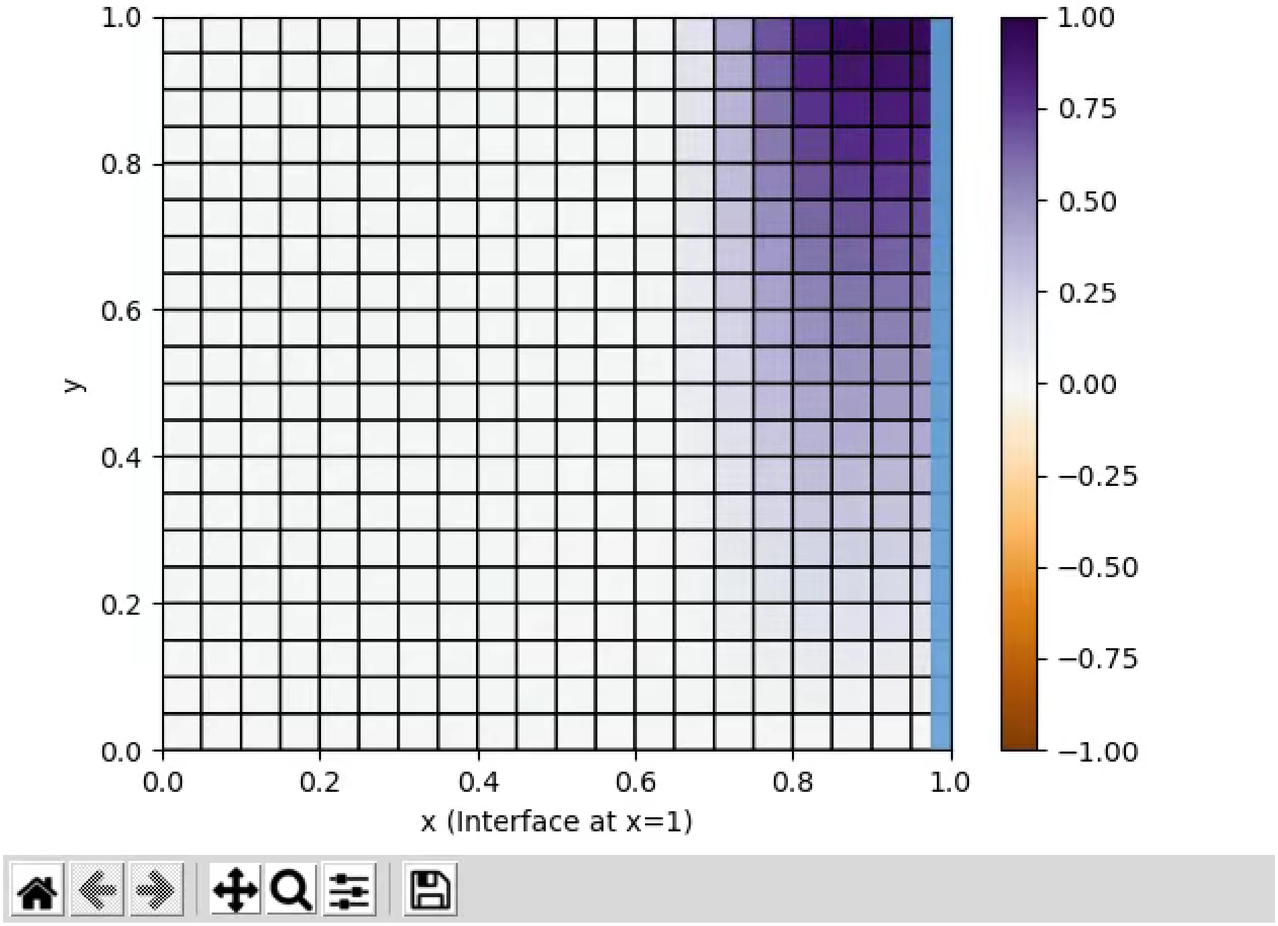
```
import numpy

# 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

```python
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
```

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:
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  u = 1 - 2 * numpy.random.rand(n)

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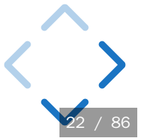
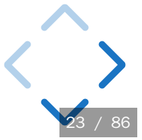



Configure preCICE

```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
interface =
    precice.Interface(
                        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 interface =
14     precice.Interface(
15                         participant_name,
16                         config_file_name,
17                         solver_process_index,
18                         solver_process_size
19                       )
20
21 dt = 0.01
22 t = 0
```

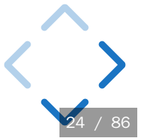


Define the coupling mesh

```
 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 interface =
14     precice.Interface(
15                         participant_name,
16                         config_file_name,
17                         solver_process_index,
18                         solver_process_size
19                       )
20
21 # Get the preCICE mesh id
22 mesh_name   = "Generator-Mesh"
```

Define the coupling mesh

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

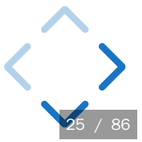


Initialize and finalize preCICE

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

Initialize and finalize preCICE

```
26 vertices   = [[1, y0] for y0 in y[:-1]]
27 vertex_ids = interface.set_mesh_vertices(mesh_id, vertices)
28
29 interface.initialize()
30
31 dt = 0.01
32 t = 0
33
34 while True:
35   print("Generating data")
36   u = 1 - 2 * numpy.random.rand(n)
37
38   t = t + dt
39   if(t > 0.1):
40     break
41
42 interface.finalize()
```

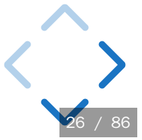


Advance the coupling

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

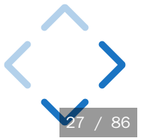
Advance the coupling

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



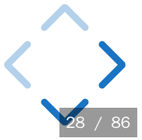
Advance the coupling

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



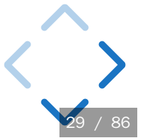
Advance the coupling

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



Advance the coupling

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



Advance the coupling

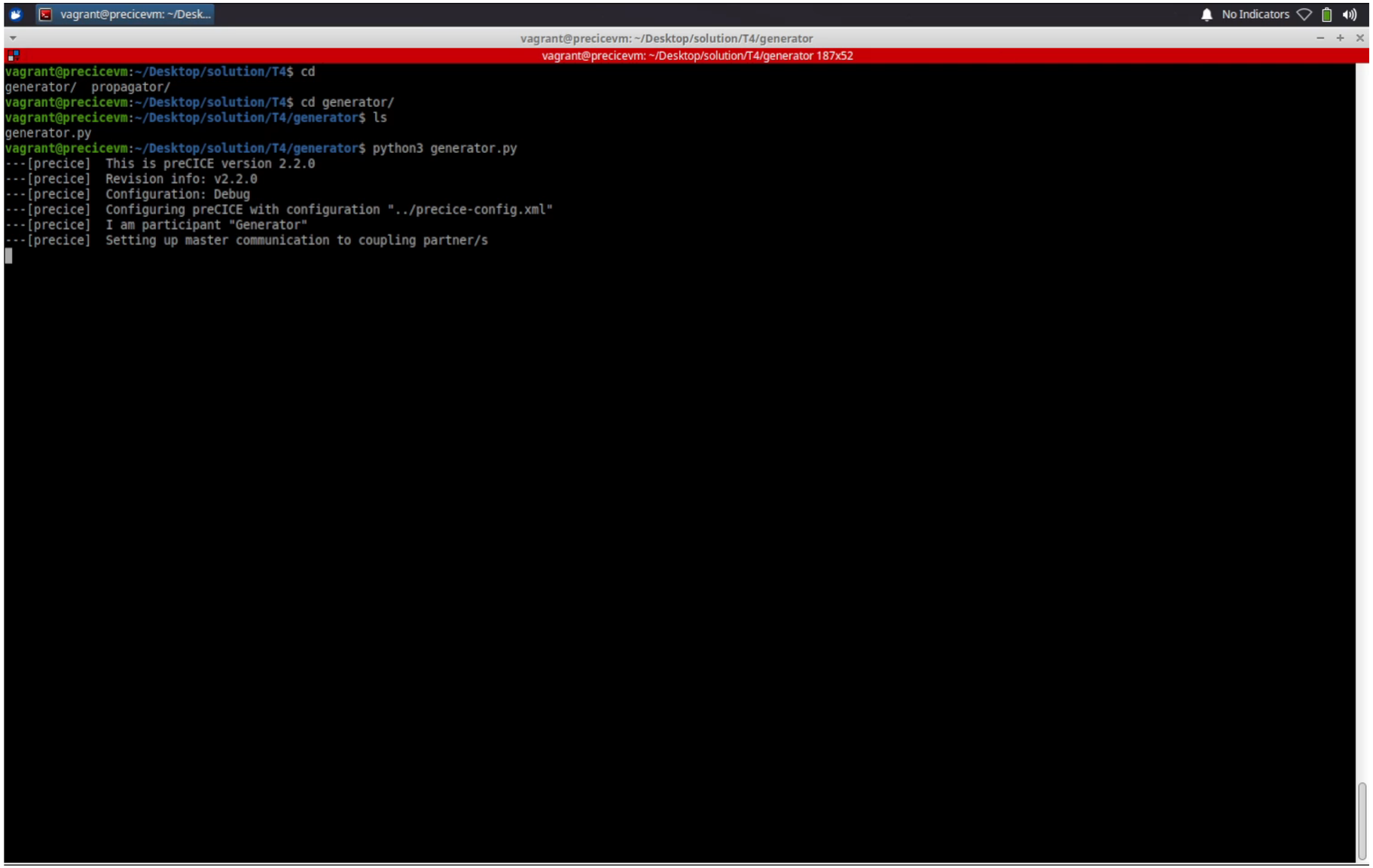
```
28
29 precice_dt = interface.initialize()
30
31 dt = 0.01
32 t = 0
33
34 while interface.is_coupling_ongoing():
35   dt = np.minimum(dt, precice_dt)
36
37   print("Generating data")
38   u = 1 - 2 * numpy.random.rand(n)
39
40   precice_dt = interface.advance(dt)
41
42   t = t + dt
43
44 interface.finalize()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

Advance the coupling

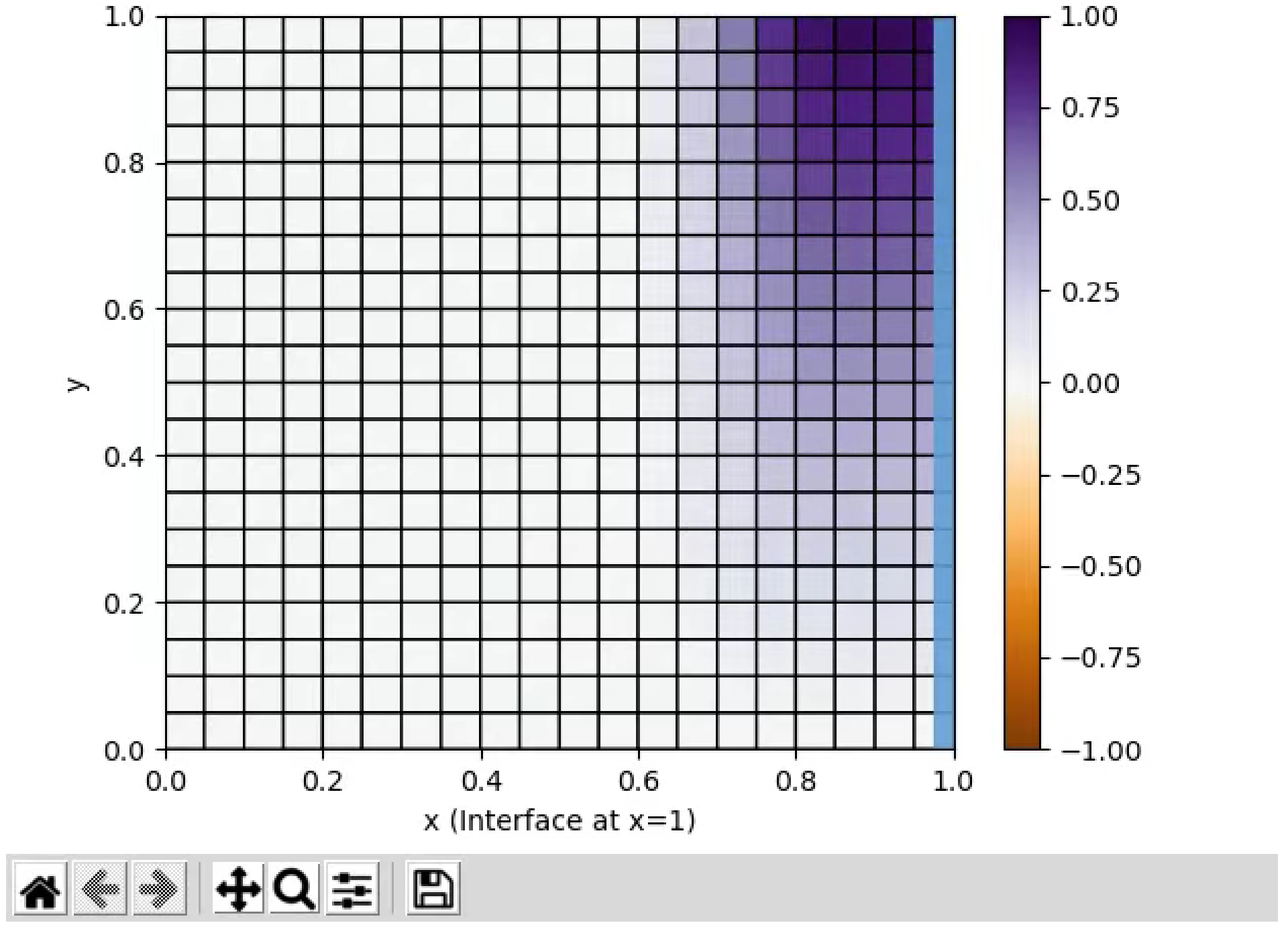
```
27 vertex_ids = interface.set_mesh_vertices(mesh_id, vertices)
28
29 precice_dt = interface.initialize()
30
31 dt = 0.01
32 t = 0
33
34 while interface.is_coupling_ongoing():
35   dt = np.minimum(dt, precice_dt)
36
37   print("Generating data")
38   u = 1 - 2 * numpy.random.rand(n)
39
40   precice_dt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

Not there yet, but let's run it

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


vagrant@precicevm: ~/Desk...
No Indicators
vagrant@precicevm: ~/Desktop/solution/T4/generator
vagrant@precicevm: ~/Desktop/solution/T4/generator 187x52
vagrant@precicevm:~/Desktop/solution/T4$ cd
generator/ propagator/
vagrant@precicevm:~/Desktop/solution/T4$ cd generator/
vagrant@precicevm:~/Desktop/solution/T4/generator$ ls
generator.py
vagrant@precicevm:~/Desktop/solution/T4/generator$ python3 generator.py
---[precice] This is preCICE version 2.2.0
---[precice] Revision info: v2.2.0
---[precice] Configuration: Debug
---[precice] Configuring preCICE with configuration "../precice-config.xml"
---[precice] I am participant "Generator"
---[precice] Setting up master communication to coupling partner/s

Nothing happening?



Did we forget something?

Write & read data

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

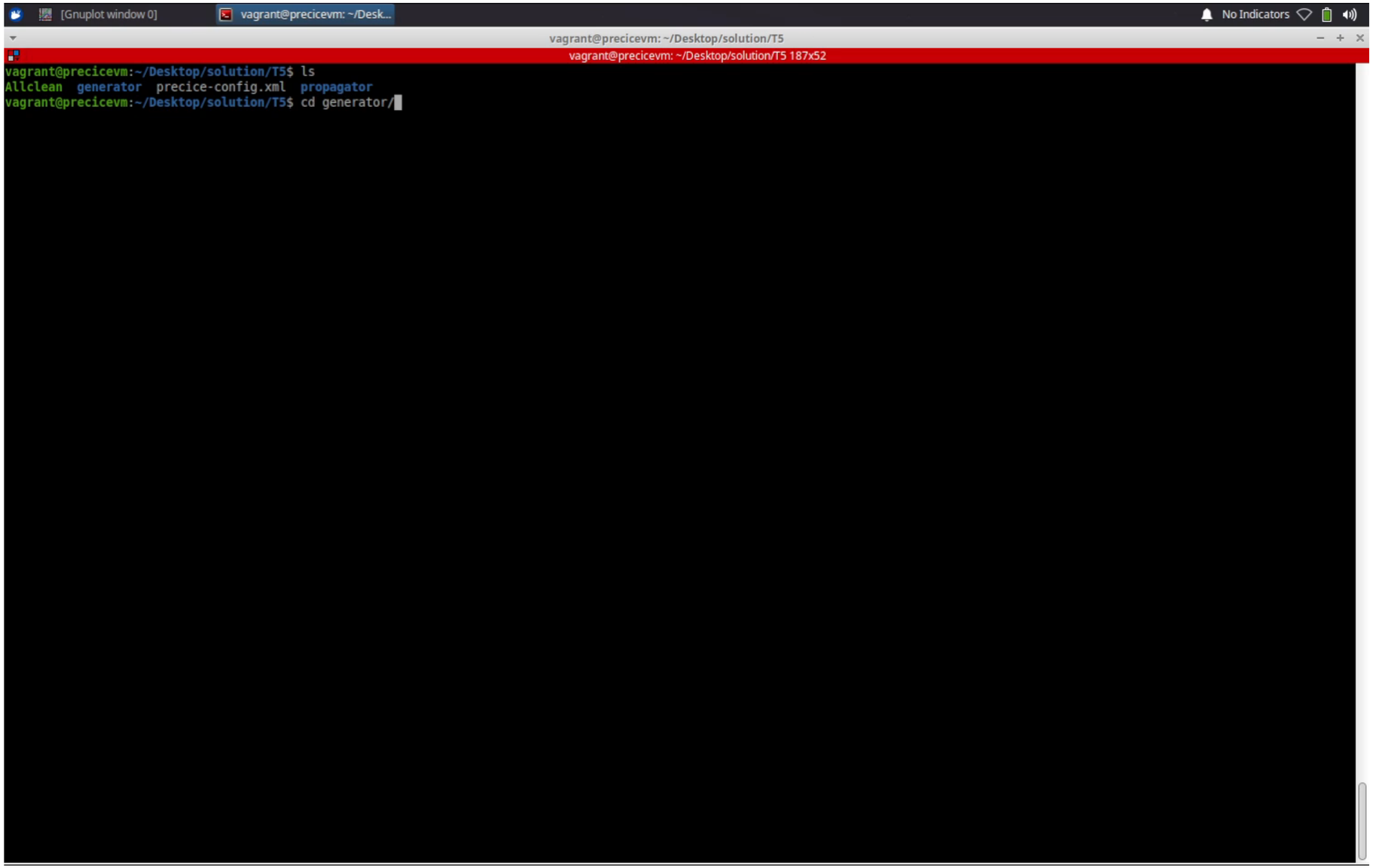
Write & read data

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

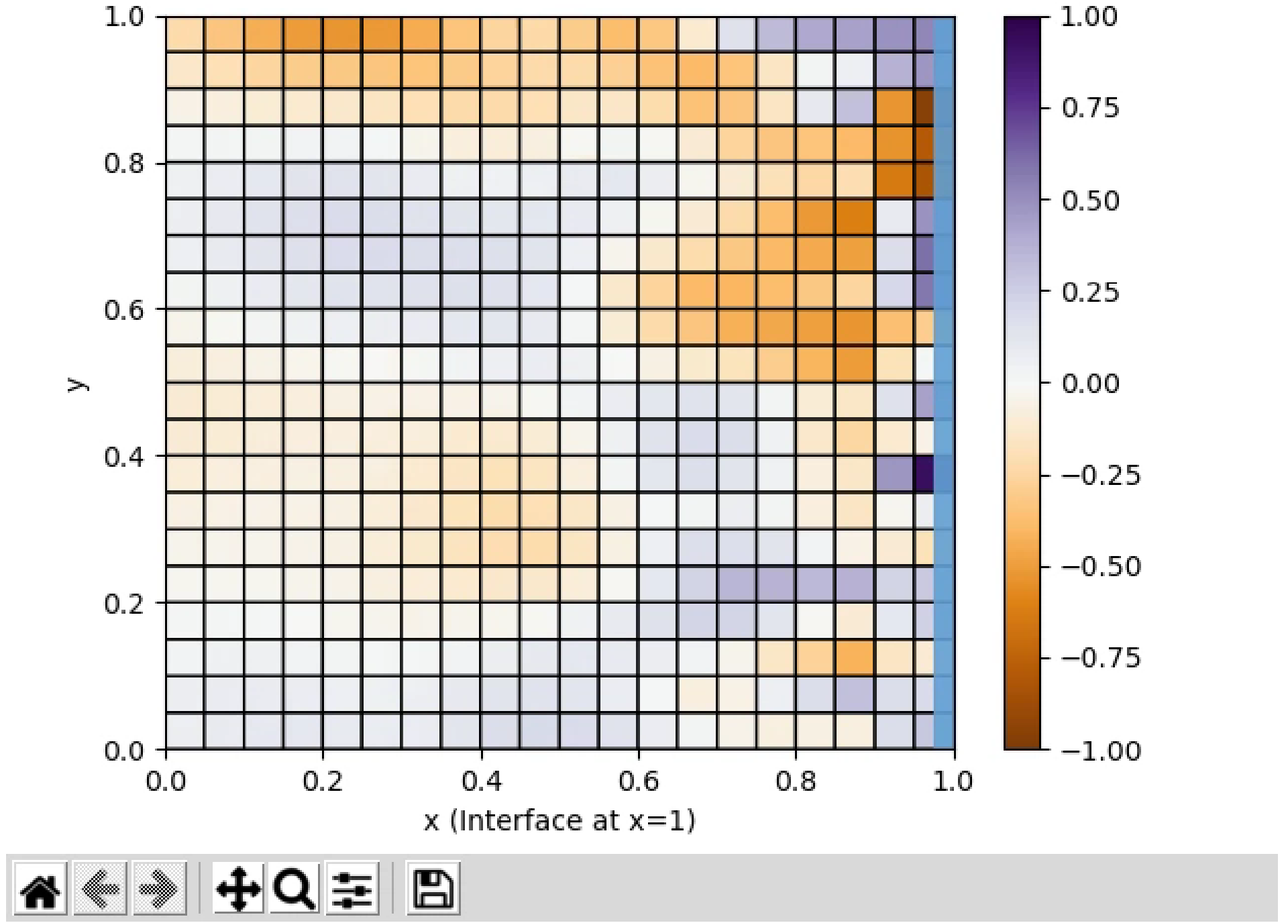
Write & read data

```
34
35 dt = 0.01
36 t = 0
37
38 while interface.is_coupling_ongoing():
39   dt = np.minimum(dt, precice_dt)
40
41   print("Generating data")
42   u = 1 - 2 * numpy.random.rand(n)
43
44   interface.write_block_scalar_data(data_id, vertex_ids, u)
45   precice_dt = interface.advance(dt)
46   # interface.read_block_scalar_data(data_id, vertex_ids, u)
47
48   t = t + dt
49
50 interface.finalize()
```

It should work now!

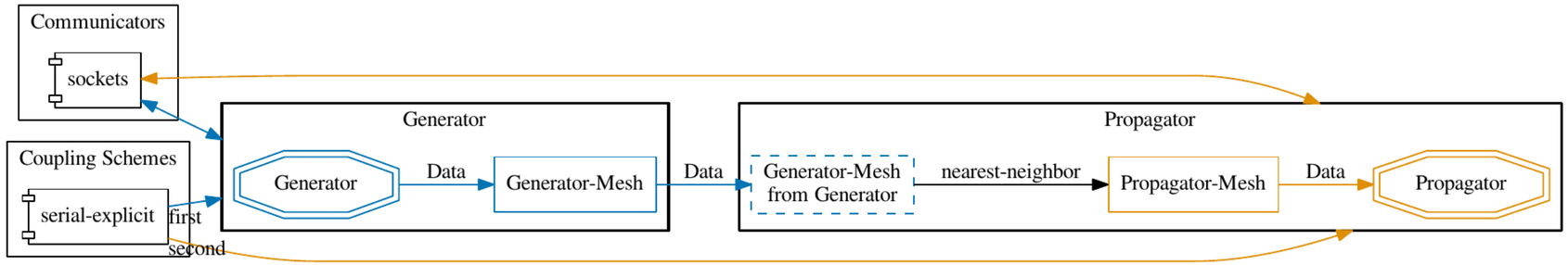

[Gnuplot window 0]
vagrant@precicevm: ~/Desk...
No Indicators
vagrant@precicevm: ~/Desktop/solution/T5
vagrant@precicevm: ~/Desktop/solution/T5 187x52
vagrant@precicevm:~/Desktop/solution/T5$ ls
Allclean generator precice-config.xml propagator
vagrant@precicevm:~/Desktop/solution/T5$ cd generator/

Data is being transfered!



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

preCICE configuration



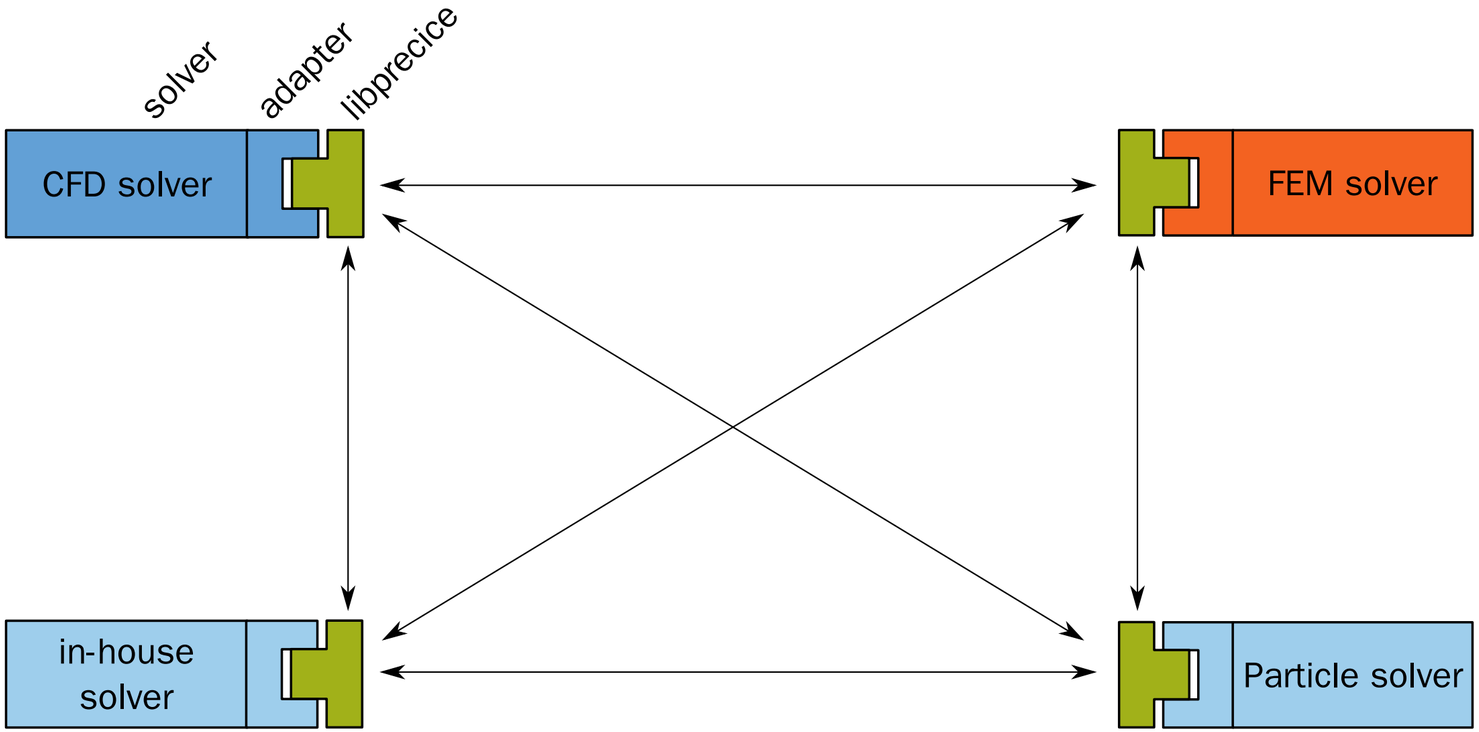
Visual representation of precice-config.xml using the config visualizer.

Using the preCICE ecosystem

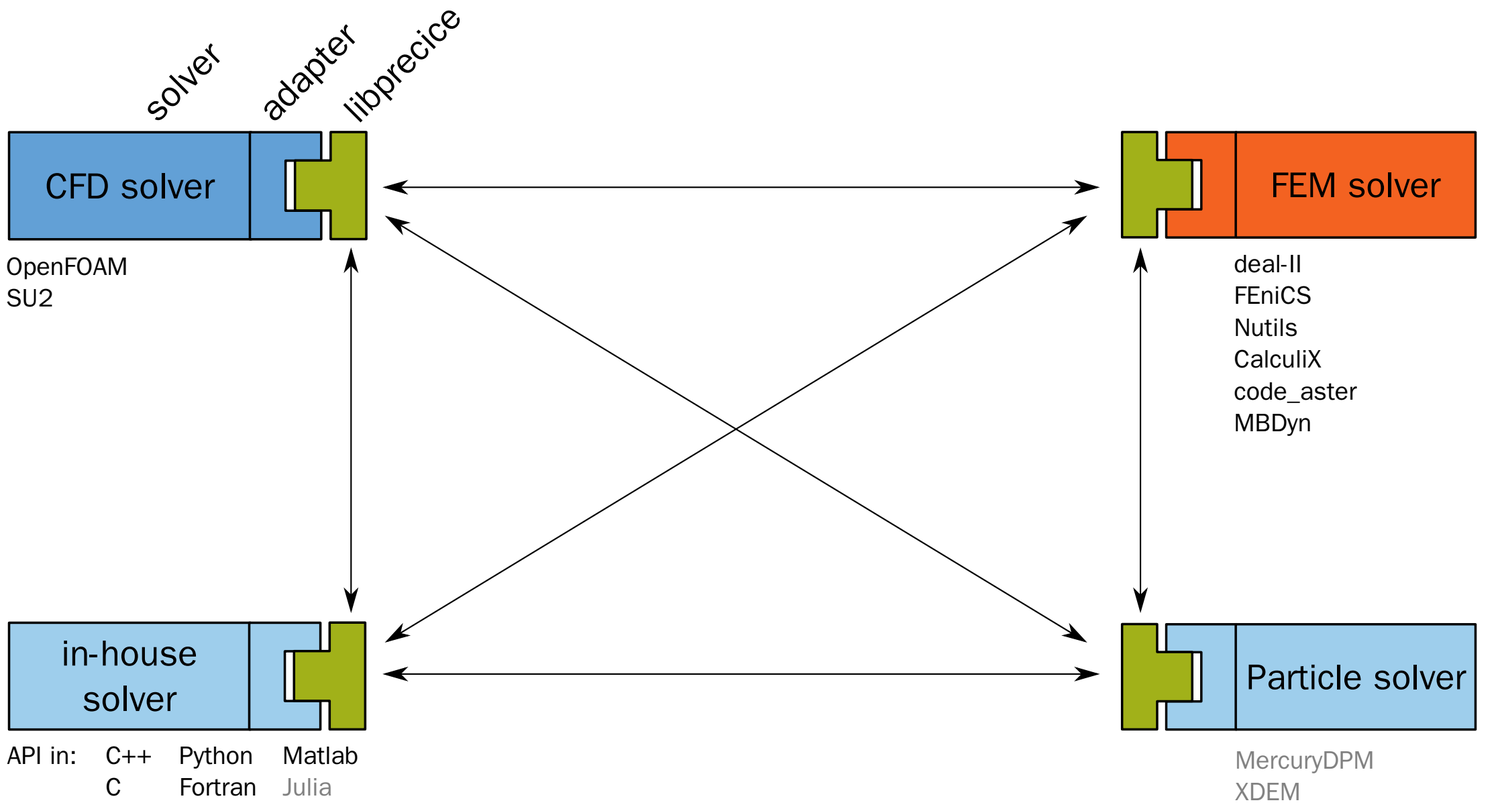
Example: Coupling OpenFOAM and CalculiX

The big picture

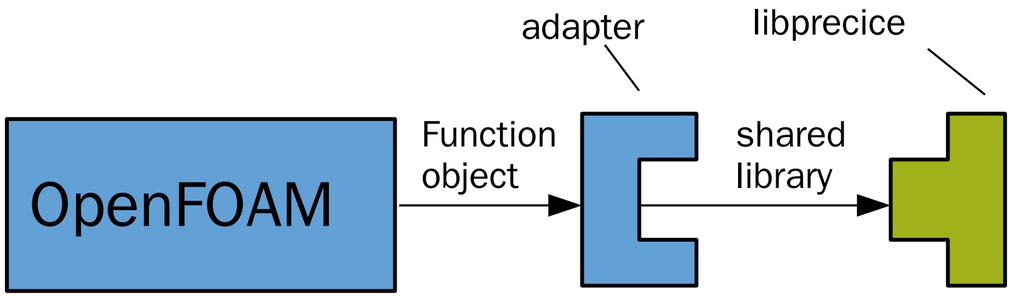
The big picture



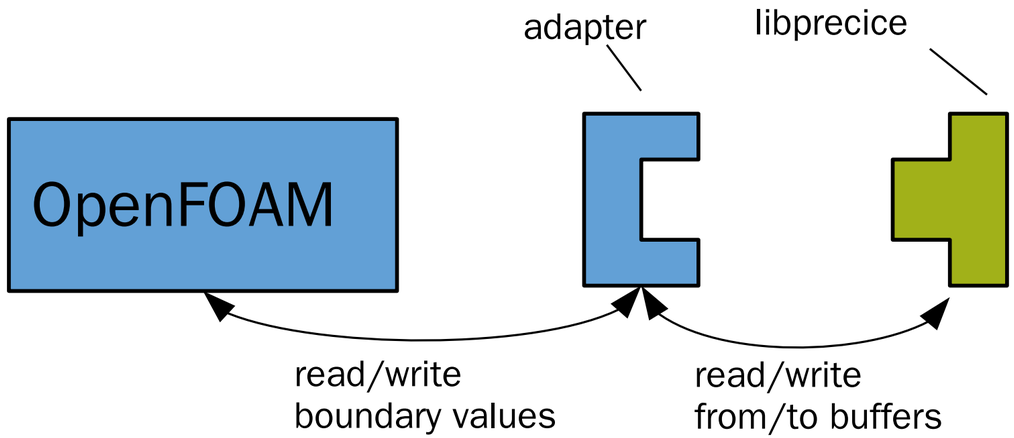
The big picture



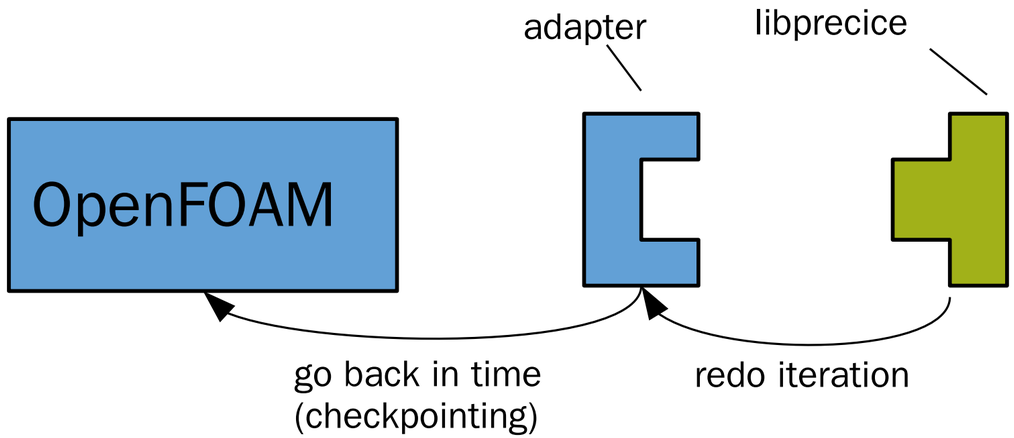
What does the adapter do?



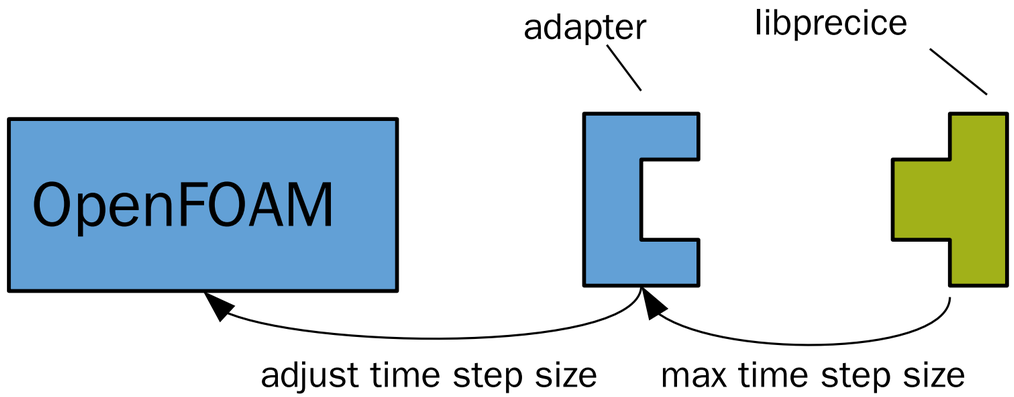
What does the adapter do?



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

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, a longer talk on the fundamentals, or click through a tutorial in your browser.

Installation

1. Get and install preCICE. For Ubuntu 20.04 (Focal Fossa), this is pretty easy: download and install our binary package by clicking on it or using the following commands:

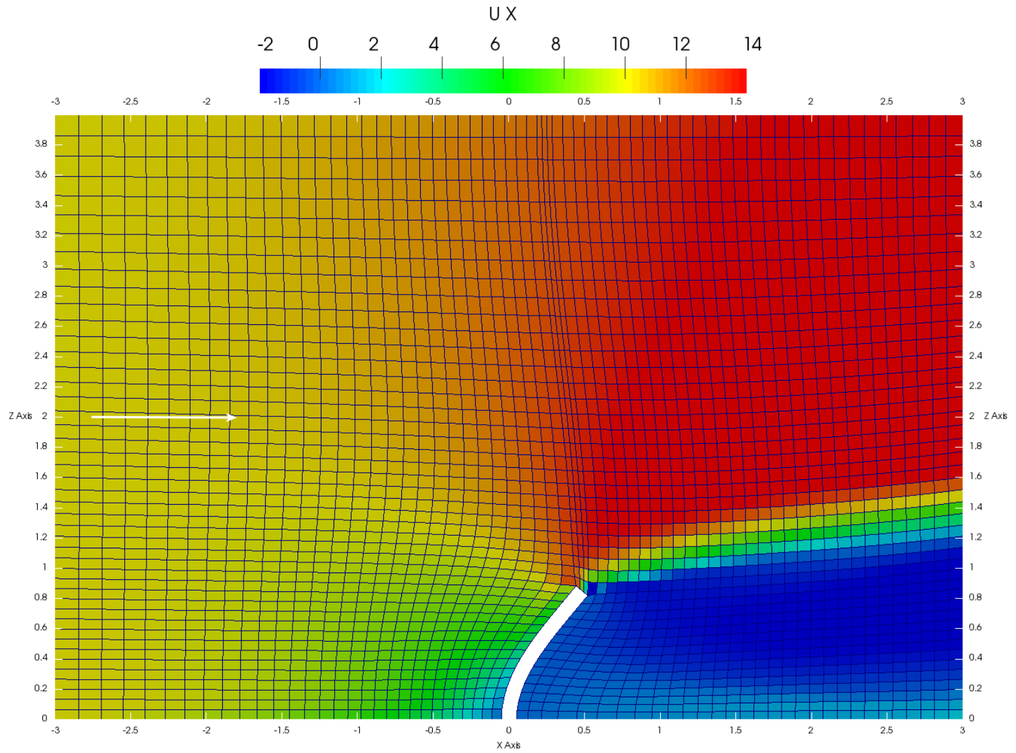
```
wget https://github.com/precice/precice/releases/download/v2.5.0/libprecice2_2.5.0_focal.deb
sudo apt install ./libprecice2_2.5.0_focal.deb
```

   - Are you using something else? Just pick what suits you best on this overview page.
   - Facing any problems? Ask for help.

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

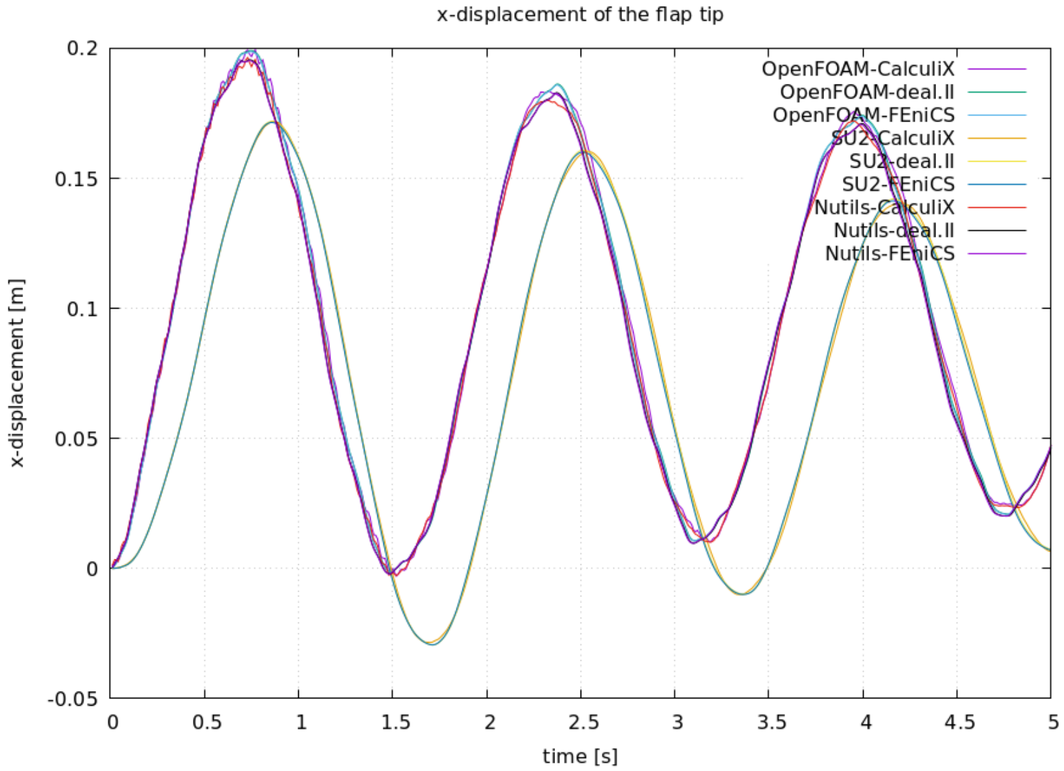
```
# Add the signing key, add the repository, update (check this):
wget -q -O - https://dl.openfoam.com/add-debian-repo.sh | sudo bash
# Install OpenFOAM v2206:
sudo apt install openfoam2206-dev
# Enable OpenFOAM by default in your system and apply now:
echo "source /usr/lib/openfoam/openfoam2206/etc/bashrc" >> ~/.bashrc
source ~/.bashrc
```

Tutorial: Channel with a perpendicular flap



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

Arbitrary solver combinations



Dependencies

- preCICE v2 (e.g. packages for Ubuntu)
- Recent OpenFOAM (e.g., v2306)
- OpenFOAM-preCICE adapter v1
- CalculiX 2.20
- CalculiX-preCICE adapter 2.20.0

File structure

```
- precice-config.xml
- fluid-openfoam/
    - 0/U ...
    - constant/dynamicMeshDict ...
    - system/
      - controlDict
      - preciceDict
    - ...
- solid-calculix/
    - flap.inp
    - config.yml
    - ...
```

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-calculix/flap.inp`:
  - Lower the solid density from 3000 to 30

Configure OpenFOAM

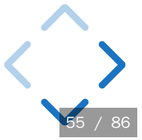
```
// fluid-openfoam/0/U

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

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

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

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

solver      displacementLaplacian;
```

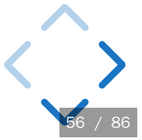
Load the OpenFOAM adapter

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

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



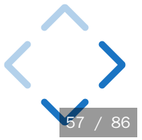
Configure the OpenFOAM adapter

```
// 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);
  };
};
```

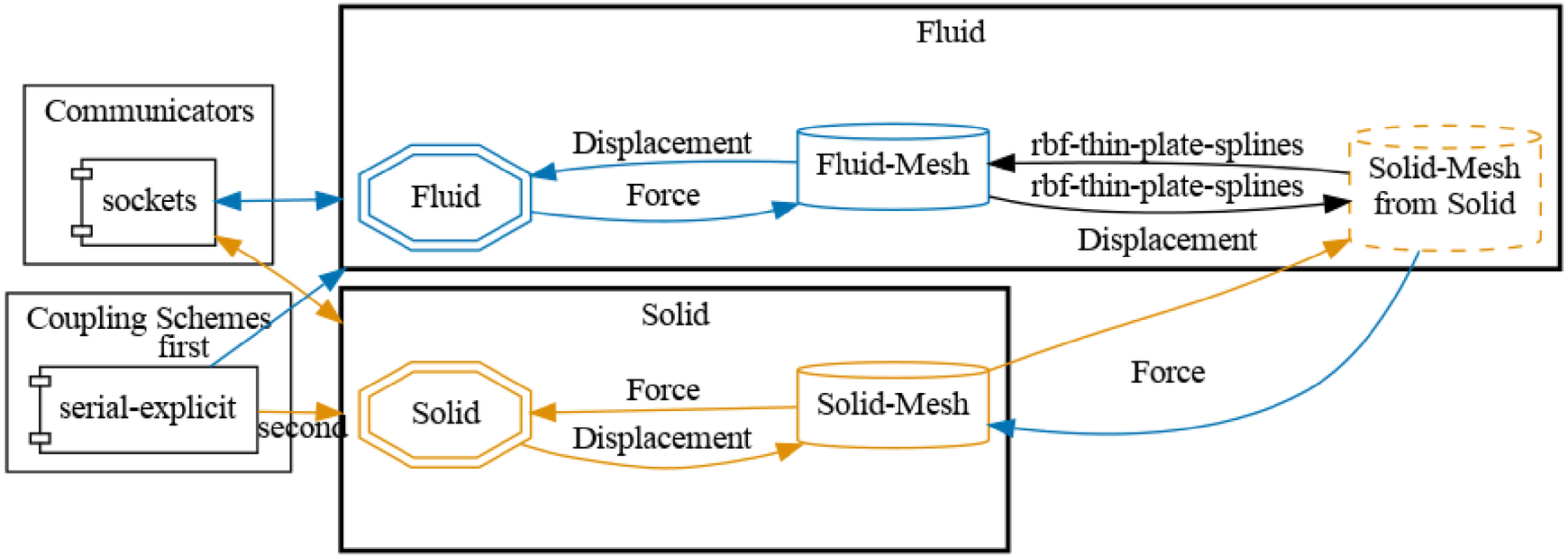


Configure the CalculiX adapter

```yaml
// solid-calculix/config.yml

participants:

    Solid:
        interfaces:
        - nodes-mesh: Solid-Mesh
          patch: surface
          read-data: [Force]
          write-data: [Displacement]

precice-config-file: ../precice-config.xml
```



Configure preCICE



Configure preCICE

```
<solver-interface dimensions="2">
  <data:vector name="Force" />
  <data:vector name="Displacement" />

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

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

  <participant name="Fluid">
    <export:vtk directory="results" />
    <use-mesh name="Fluid-Mesh" provide="yes" />
```

Notice the serial-explicit coupling scheme

Configure preCICE

```
<solver-interface dimensions="2">
  <data:vector name="Force" />
  <data:vector name="Displacement" />

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

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

  <participant name="Fluid">
    <export:vtk directory="results" />
    <use-mesh name="Fluid-Mesh" provide="yes" />
```

Notice the serial-explicit coupling scheme

Configure preCICE

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

Notice the serial-explicit coupling scheme

Configure preCICE

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

Notice the serial-explicit coupling scheme

Configure preCICE

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

Notice the serial-explicit coupling scheme

Configure preCICE

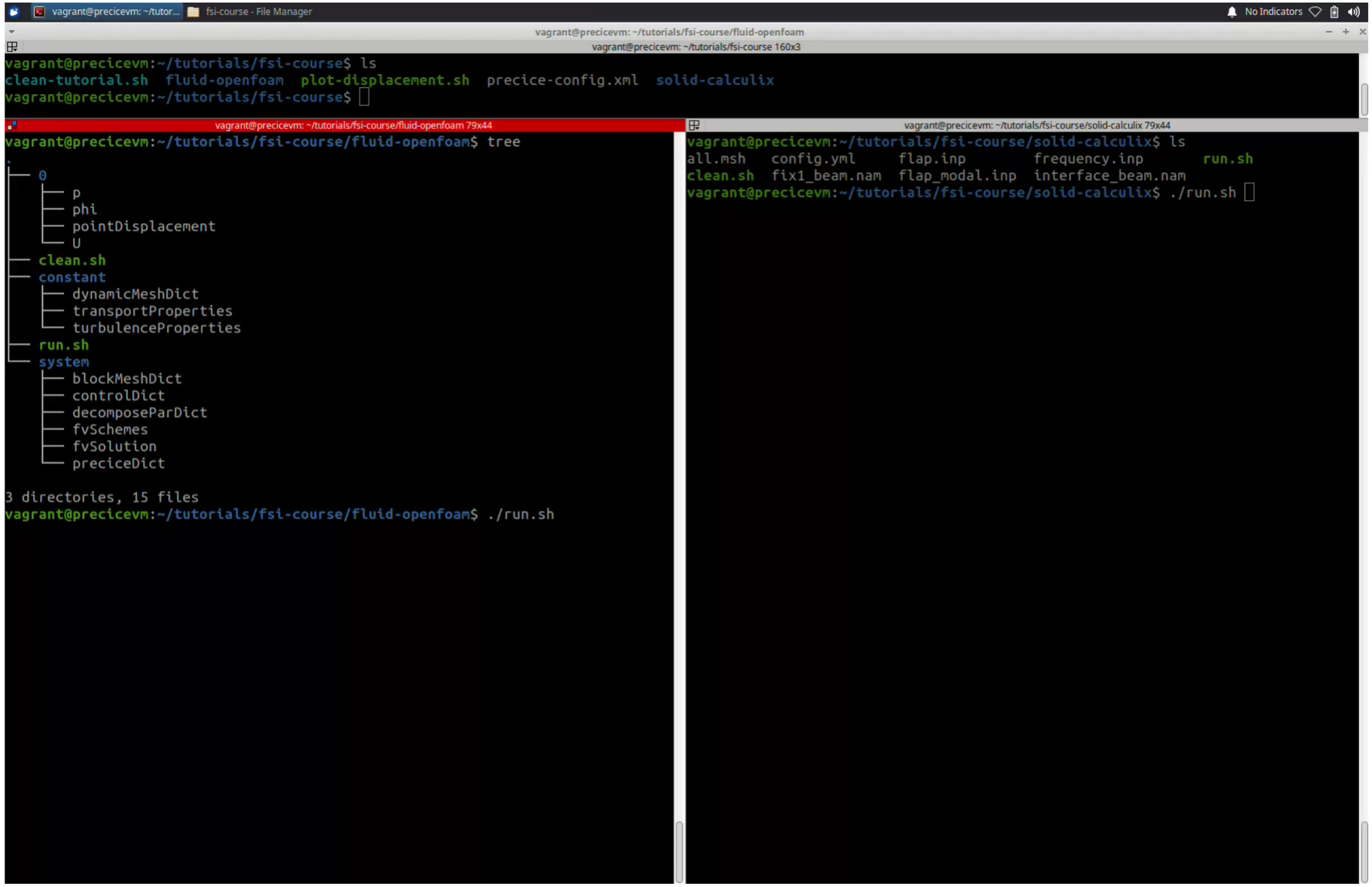
```
32
33    <participant name="Solid">
34      <use-mesh name="Solid-Mesh" provide="yes" />
35      <write-data name="Displacement" mesh="Solid-Mesh" />
36      <read-data name="Force" mesh="Solid-Mesh" />
37      <watch-point mesh="Solid-Mesh" name="Flap-Tip" coordinate="0.0;1"
38    </participant>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

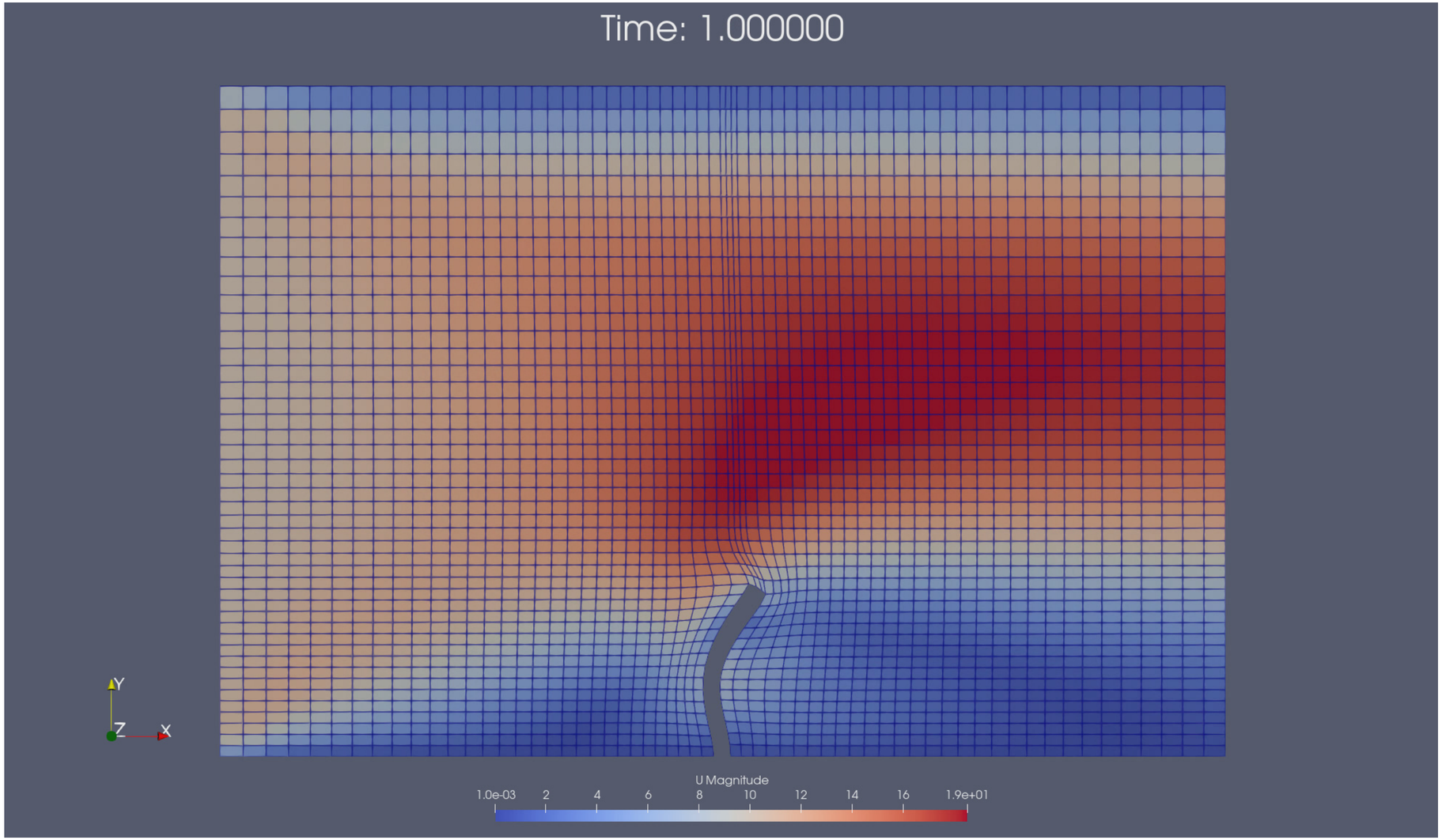
Notice the serial-explicit coupling scheme

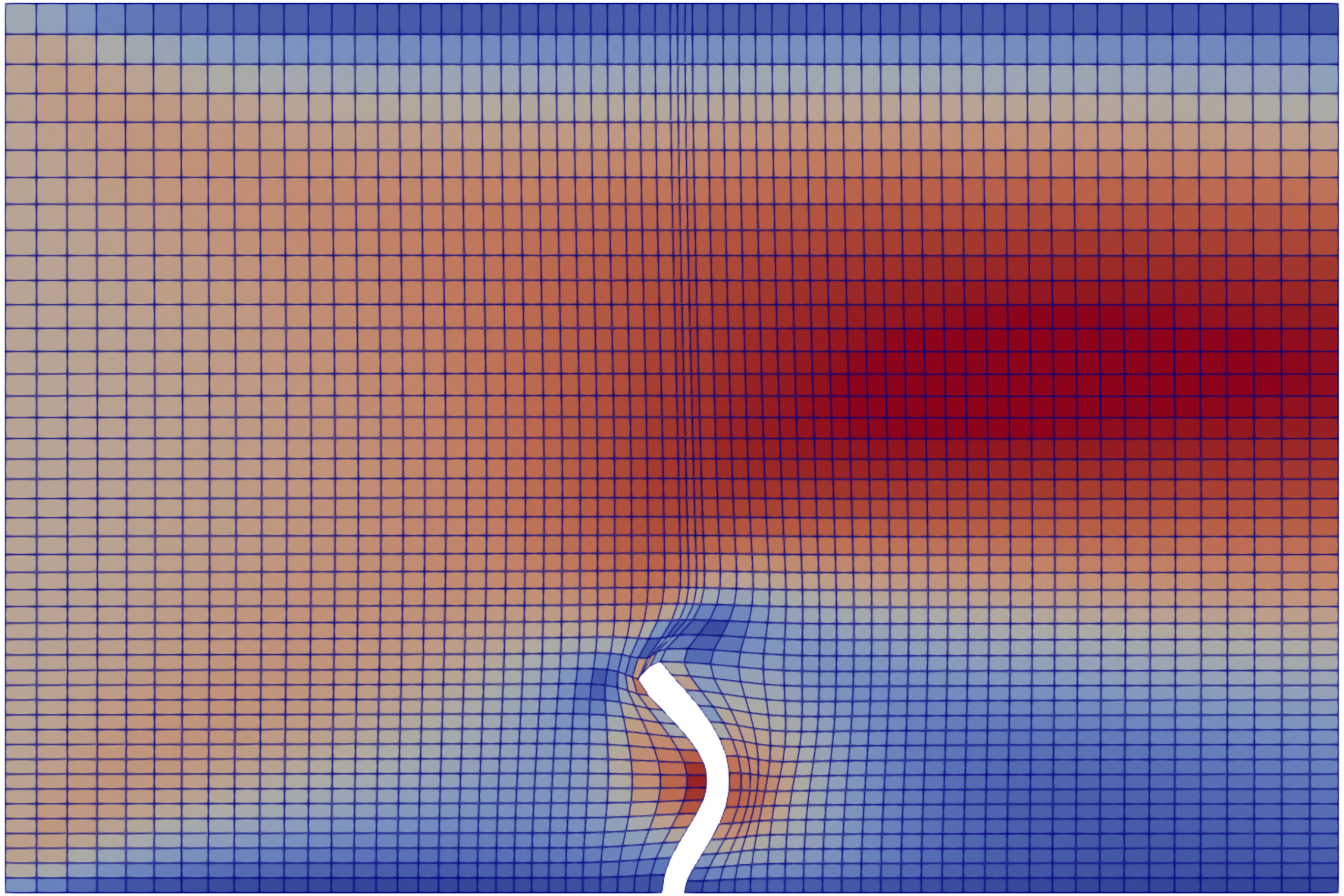
Configure preCICE

```
34      <use-mesh name="Solid-Mesh" provide="yes" />
35      <write-data name="Displacement" mesh="Solid-Mesh" />
36      <read-data name="Force" mesh="Solid-Mesh" />
37      <watch-point mesh="Solid-Mesh" name="Flap-Tip" coordinate="0.0;1"
38    </participant>
39
40    <m2n:sockets from="Fluid" to="Solid" exchange-directory=".." />
41
42    <coupling-scheme:serial-explicit>
43      <participants first="Fluid" second="Solid" />
44      <max-time value="1.5" />
45      <time-window-size value="0.01" />
46      <exchange data="Force" mesh="Solid-Mesh" from="Fluid" to="Solid"
47      <exchange data="Displacement" mesh="Solid-Mesh" from="Solid" to="
48    </coupling-scheme:serial-explicit>
49
50  </solver-interface>
```

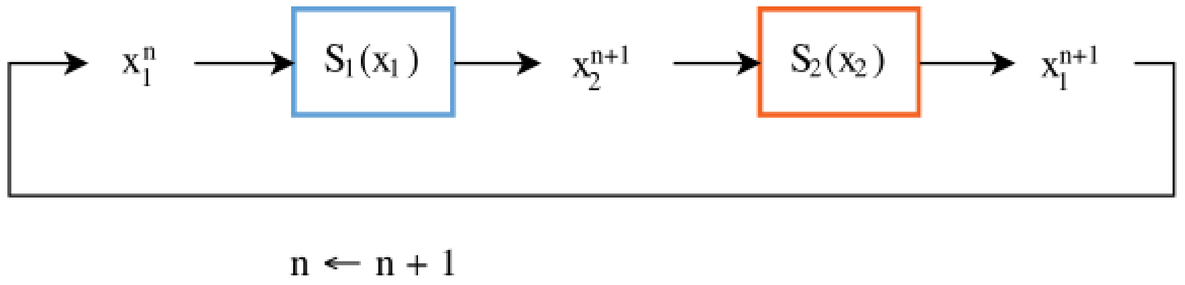
Notice the serial-explicit coupling scheme


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

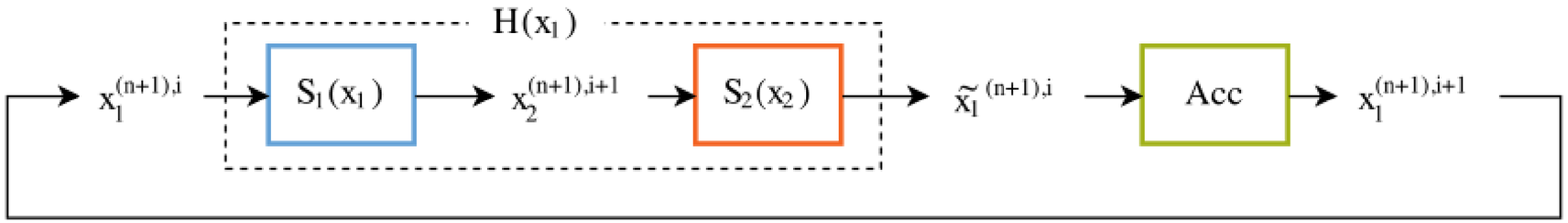

Time: 1.000000
Y
Z
X
U Magnitude
1.0e-03
2
4
6
8
10
12
14
16
1.9e+01



What we did so far: serial-explicit scheme



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" />
  <acceleration:constant>
    <relaxation value="0.5" />
  </acceleration:constant>
</coupling-scheme:serial-implicit>
```

Simplest case: constant under-relaxation

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 case: constant under-relaxation

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 case: constant under-relaxation

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 case: constant under-relaxation

Configure the coupling scheme

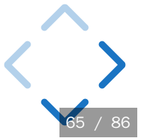
```
<coupling-scheme:serial-implicit>
  <participants first="Fluid" second="Solid" />
  <max-time value="1.5" />
  <time-window-size value="0.01" />
  <exchange data="Force" mesh="Solid-Mesh" from="Fluid" to="Solid" />
  <exchange data="Displacement" mesh="Solid-Mesh" from="Solid" to="Fl
  <relative-convergence-measure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

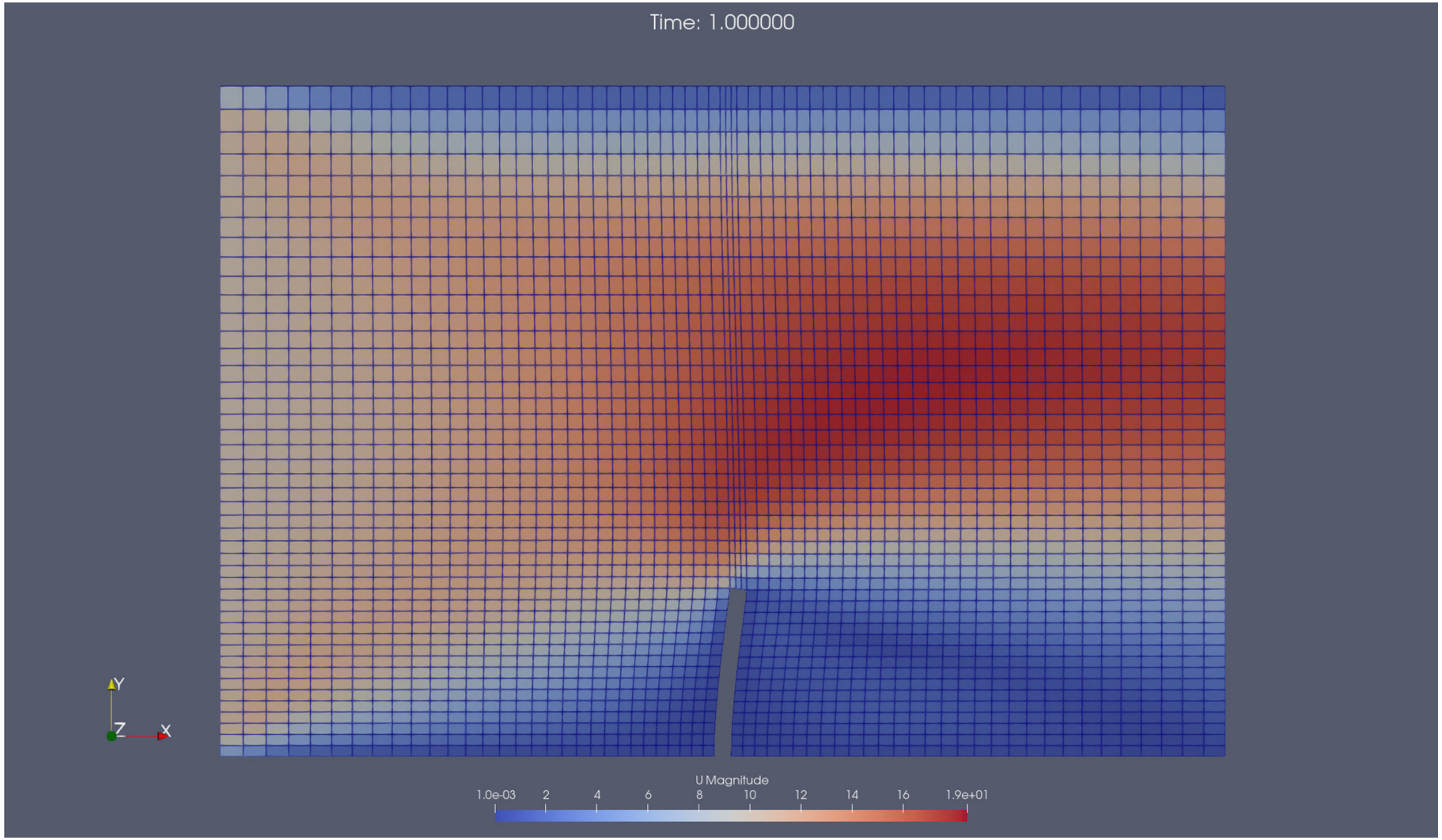
Simplest case: constant under-relaxation

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 case: constant under-relaxation




Time: 1.000000
Y
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U Magnitude
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2
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6
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12
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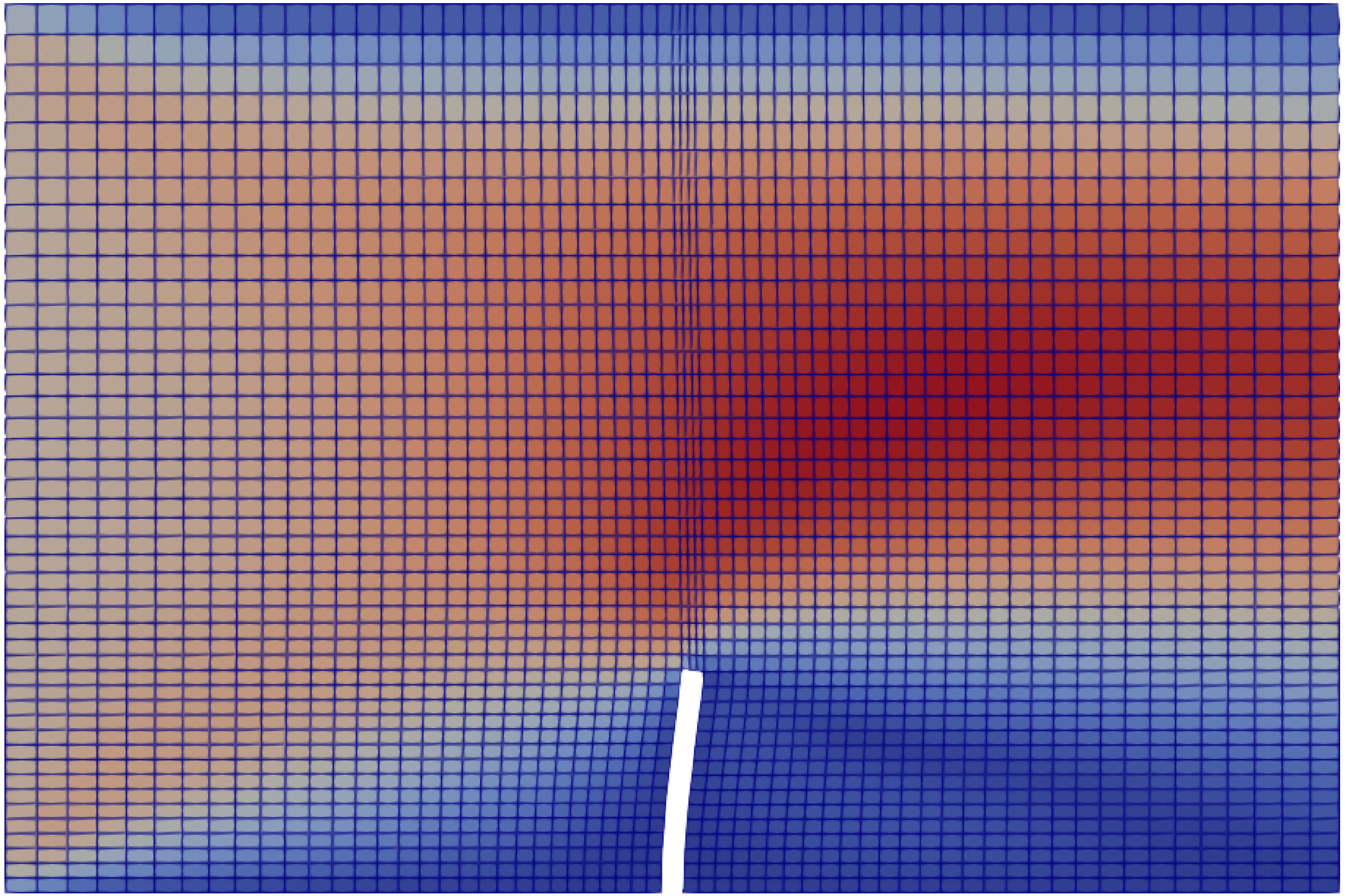
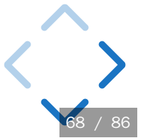
16
1.9e+01



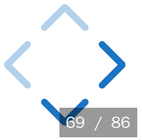
Too slow! Can we do better?



Improvement 1: Aitken under-relaxation

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

Average iterations drop from 3.85 (constant) to 3.49 (Aitken)
Note: This simulation is reaching a steady-state, thus differences diffuse



Improvement 2: Anderson acceleration

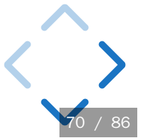
```
<acceleration:IQN-ILS>
  <data name="Displacement" mesh="Solid-Mesh" />
  <initial-relaxation value="0.5" />
  <preconditioner type="residual-sum" />
  <filter type="QR2" limit="1e-2" />
  <max-used-iterations value="100" />
  <time-windows-reused value="15" />
</acceleration:IQN-ILS>
```

Average iterations drop from 3.49 (Aitken) to 2.91 (IQN)

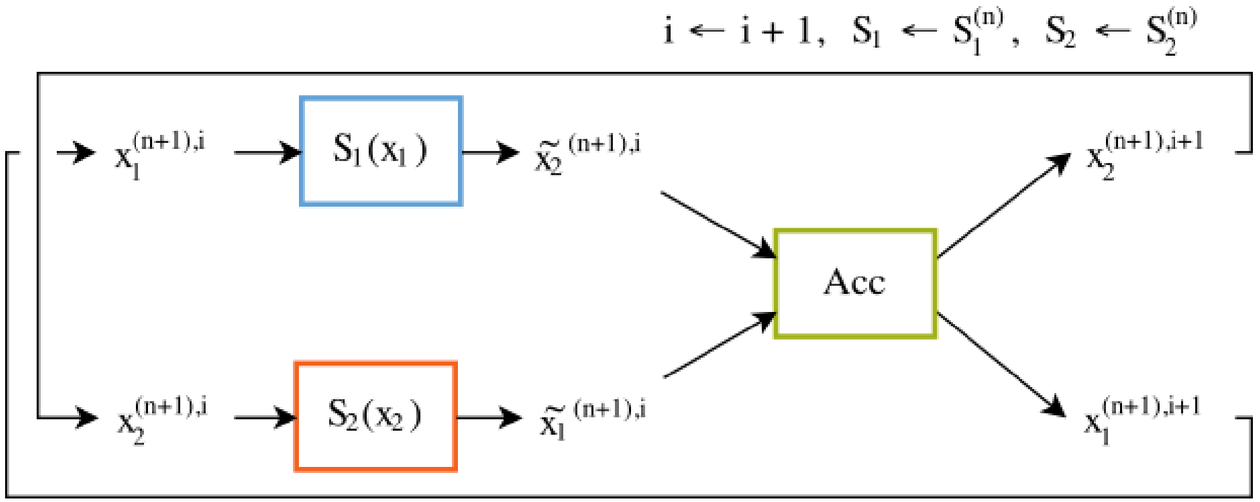
Improvement 2: Anderson acceleration

```
<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>
```

Average iterations drop from 3.49 (Aitken) to 2.91 (IQN)



There are also parallel schemes



Can use fields from both / all participants

Improvement 3: Parallel coupling schemes

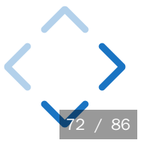
```
<coupling-scheme:parallel-implicit>
  <time-window-size value="0.01" />
  <max-time value="1.5" />
  <participants first="Fluid" second="Solid" />
  <exchange data="Force" mesh="Solid-Mesh" from="Fluid" to="Solid" />
  <exchange data="Displacement" mesh="Solid-Mesh" from="Solid" to="Fl
  <max-iterations 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" />
```

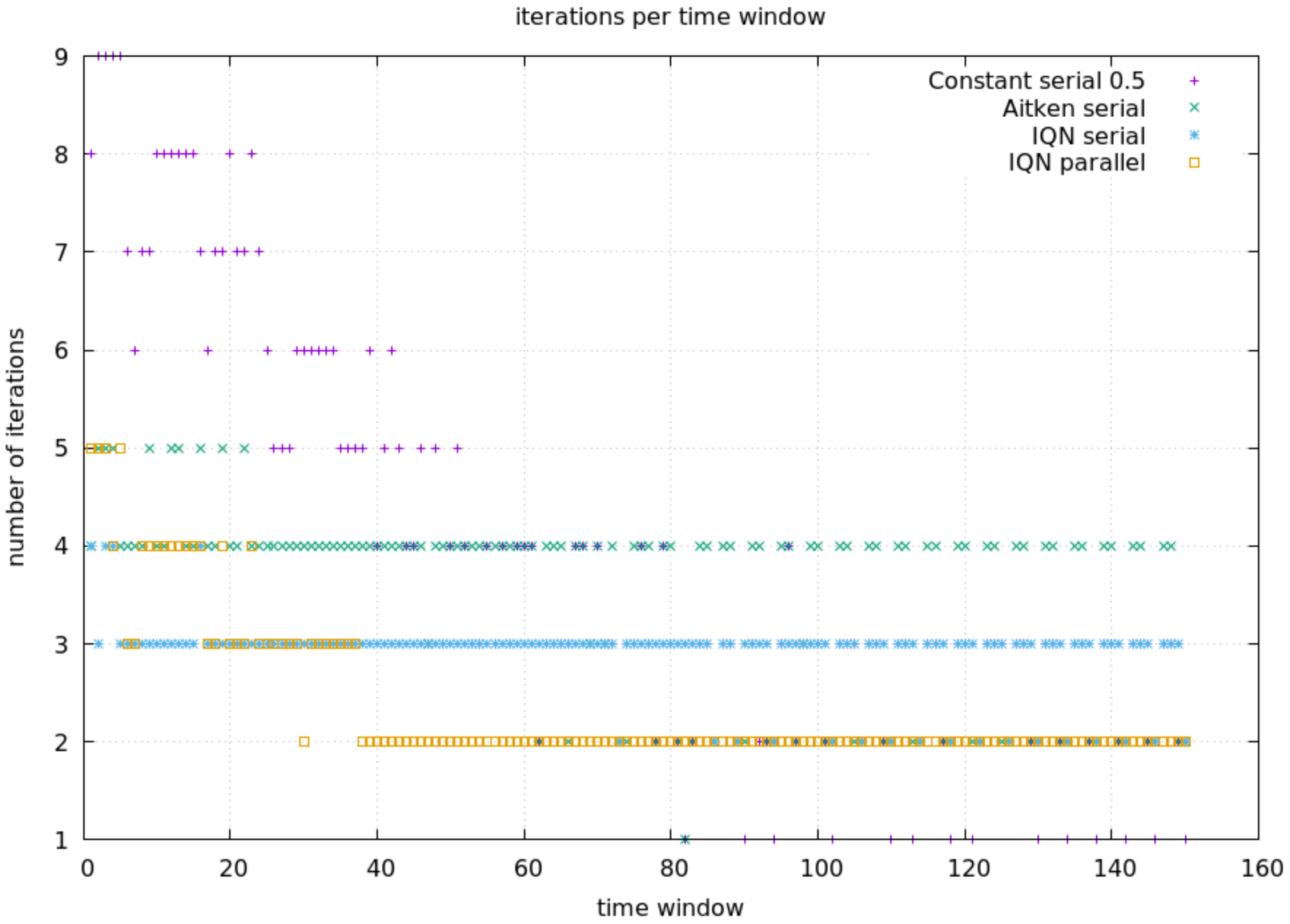
Average iterations drop from 2.91 (serial-implicit IQN) to 2.37 (parallel-implicit IQN)

Improvement 3: Parallel coupling schemes

```
  <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" />
  </acceleration:IQN-ILS>
</coupling-scheme:parallel-implicit>
```

Average iterations drop from 2.91 (serial-implicit IQN) to 2.37 (parallel-implicit IQN)





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

Resources

Start here: precice.org

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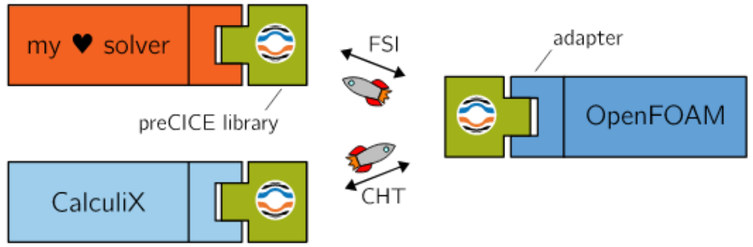
Partitioned means that **preCICE couples existing programs/solvers** capable of simulating a subpart of the complete physics involved in a simulation. This allows for the high flexibility that is needed to keep a decent time-to-solution for complex multi-physics scenarios.

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



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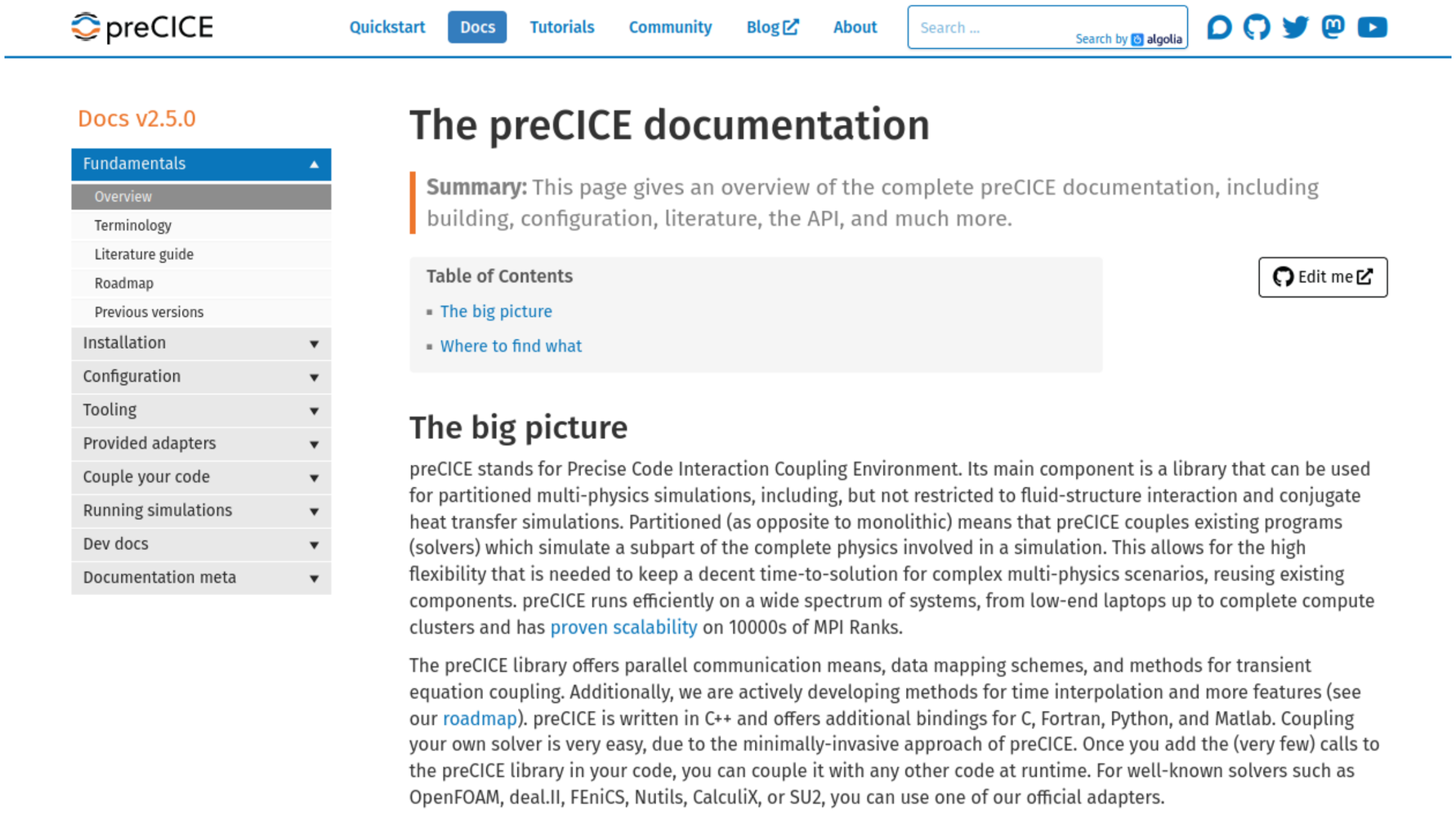

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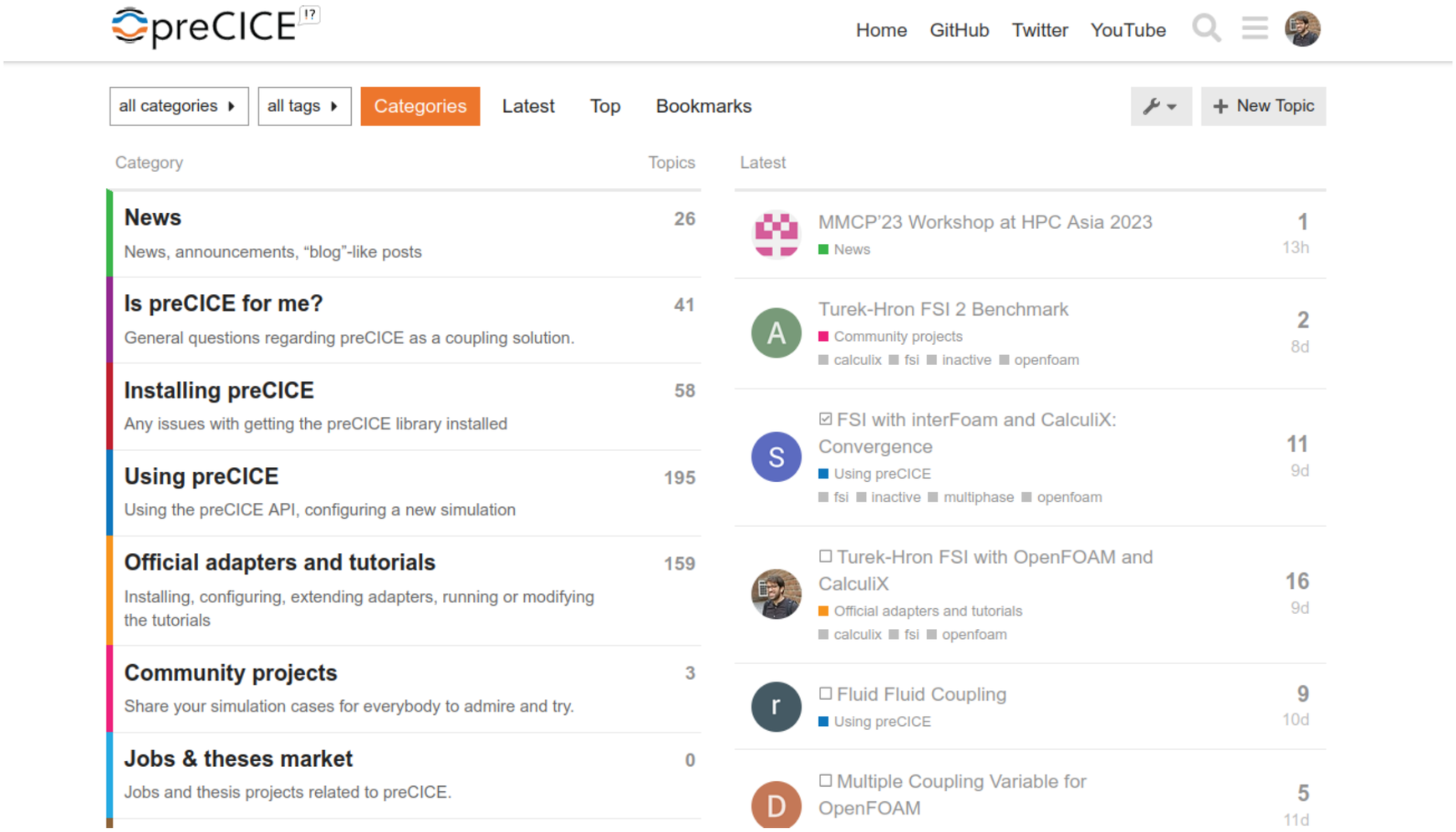

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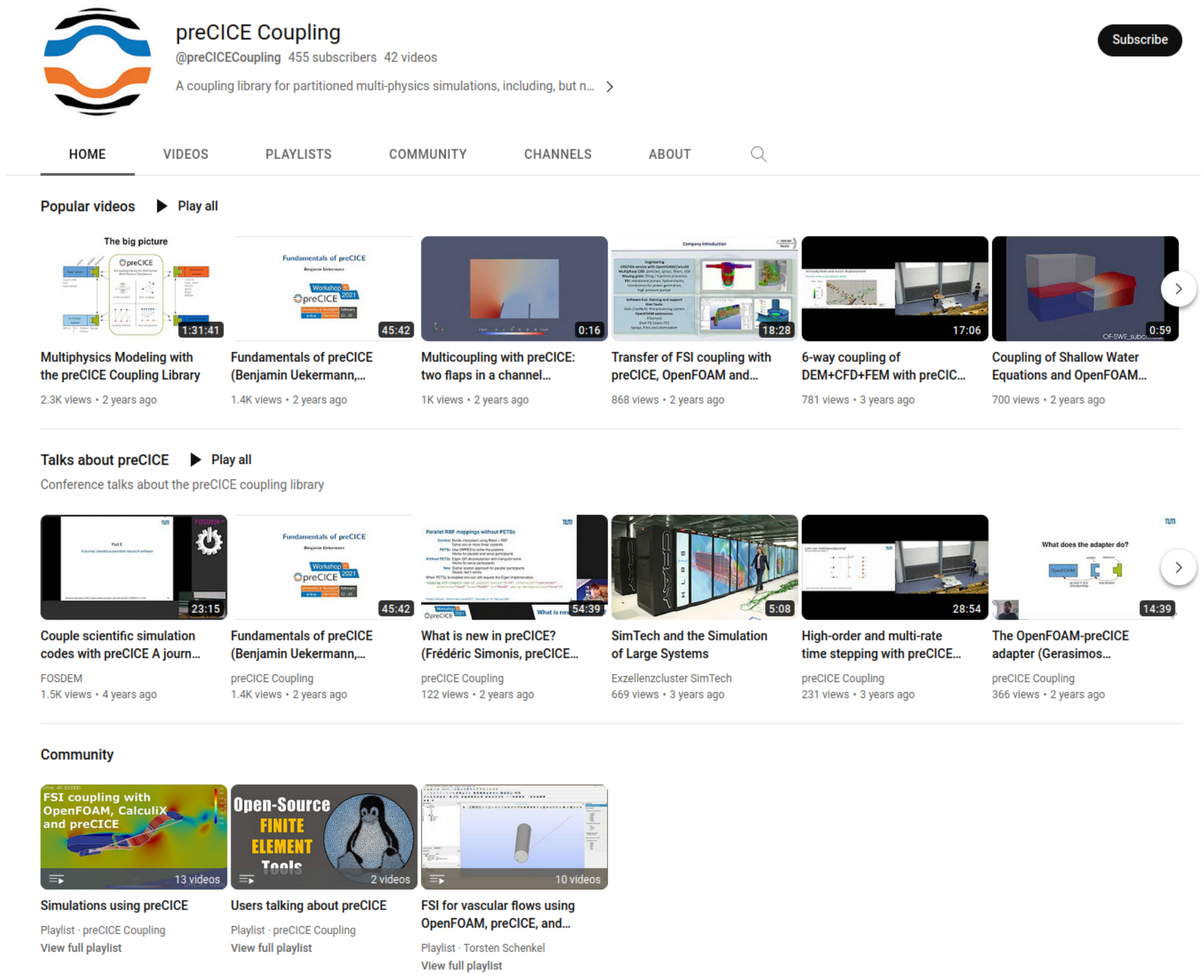

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OpenFOAM-preCICE: Coupling OpenFOAM with External Solvers for Multi-Physics Simulations

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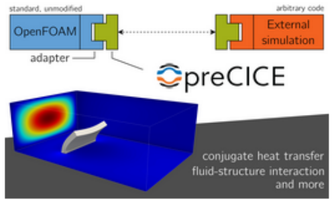
DOI: https://doi.org/10.51560/ofj.v3.88



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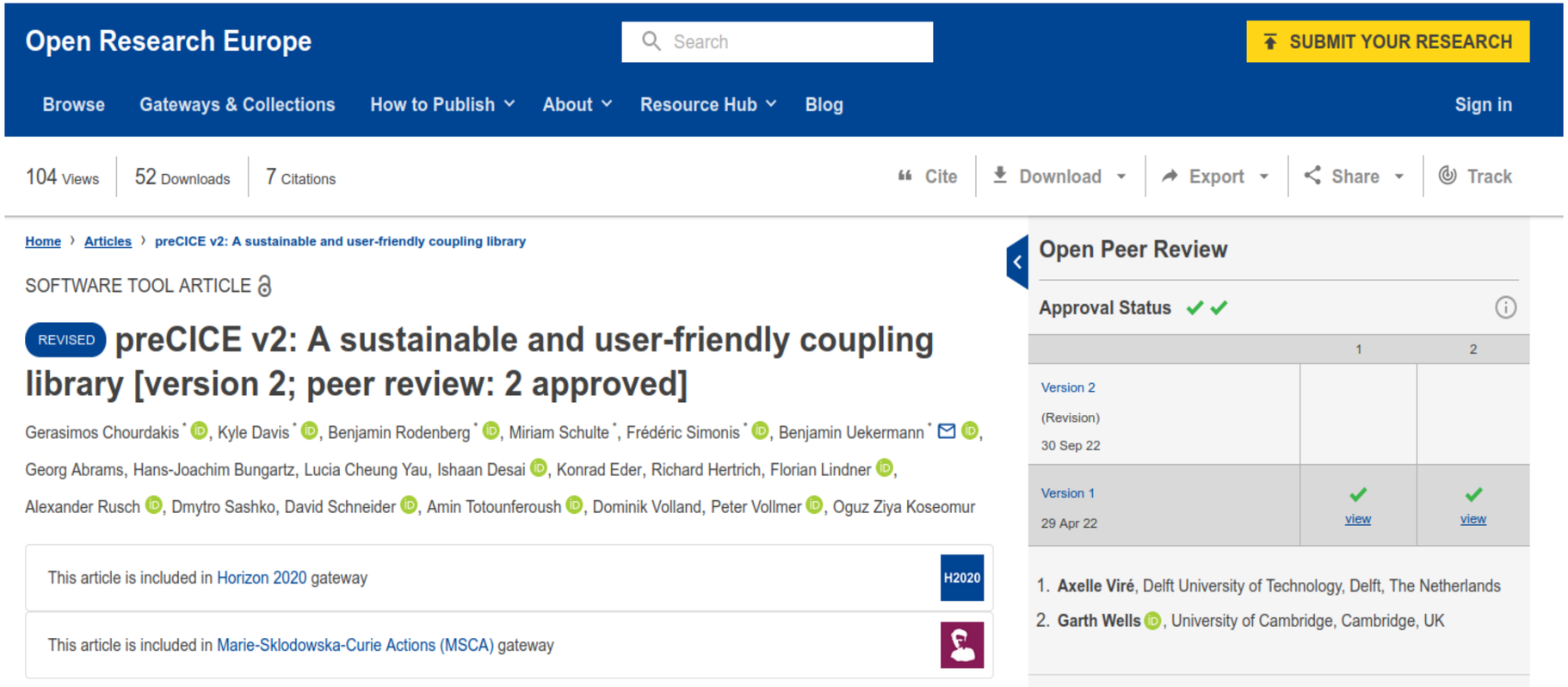

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SOFTWARE TOOL ARTICLE

REVISED

preCICE v2: A sustainable and user-friendly coupling library [version 2; peer review: 2 approved]

Gerasimos Chourdakis, Kyle Davis, Benjamin Rodenberg, Miriam Schulte, Frédéric Simonis, Benjamin Uekermann, Georg Abrams, Hans-Joachim Bungartz, Lucia Cheung Yau, Ishaan Desai, Konrad Eder, Richard Hertrich, Florian Lindner, Alexander Rusch, Dmytro Sashko, David Schneider, Amin Totounferoush, Dominik Volland, Peter Vollmer, Oguz Ziya Koseomur

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Open Peer Review

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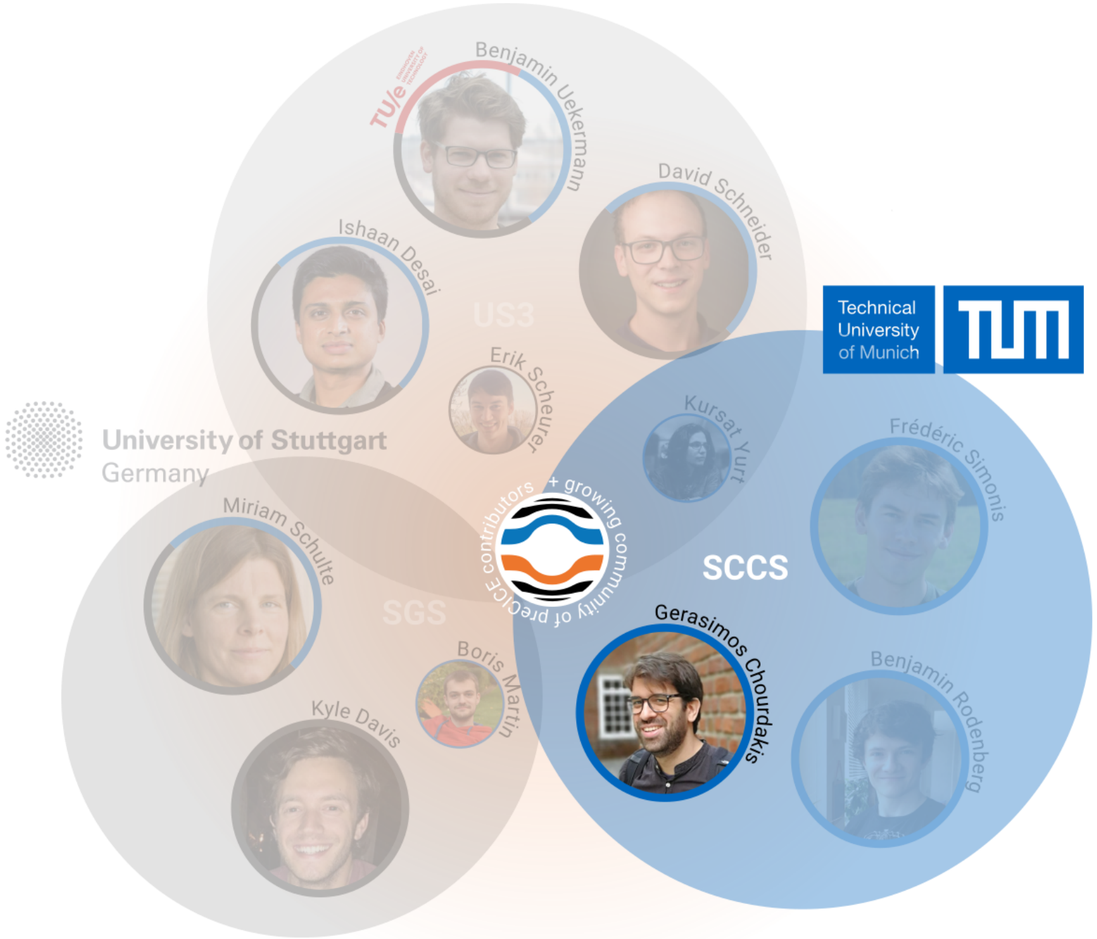
	1	2
Version 2 (Revision) 30 Sep 22		
Version 1 29 Apr 22	✓ view	✓ view

1. **Axelle Viré**, Delft University of Technology, Delft, The Netherlands
2. **Garth Wells**, University of Cambridge, Cambridge, UK

The people behind preCICE



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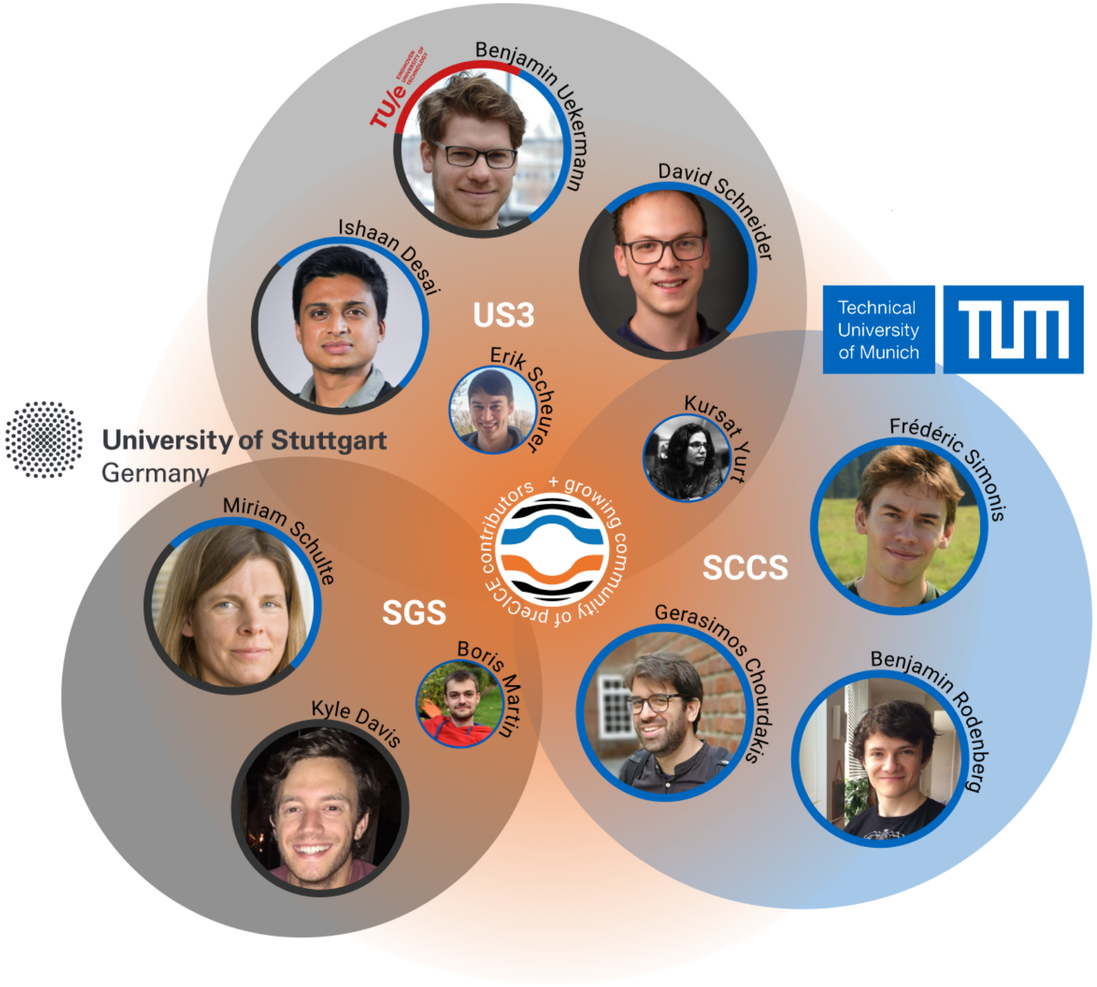

Meet the people

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

Both for developers and for users,
many efficient algorithms to choose from via just config

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

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