FEniCS Course

Lecture 20: Tools for visualization programming

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Visualisation in FEniCS

Three main options for visualisation

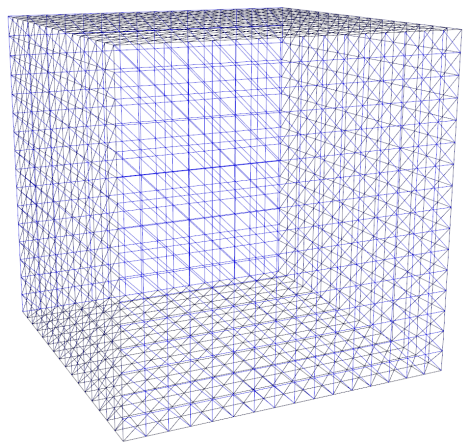
- Built-in VTK plotting
- matplotlib
- ParaView

Built-in VTK plotting

Built-in plotting functionality for FEniCS

- Plot meshes, functions, mesh functions
- Not available on all FEniCS installations
- Limited 3D capabilities

```
from fenics import *
parameters["plotting_backend"] = "vtk"

mesh = UnitCubeMesh(16, 16, 16)
plot(mesh)
interactive()
```



matplotlib

Plotting libarary for Python and Numpy

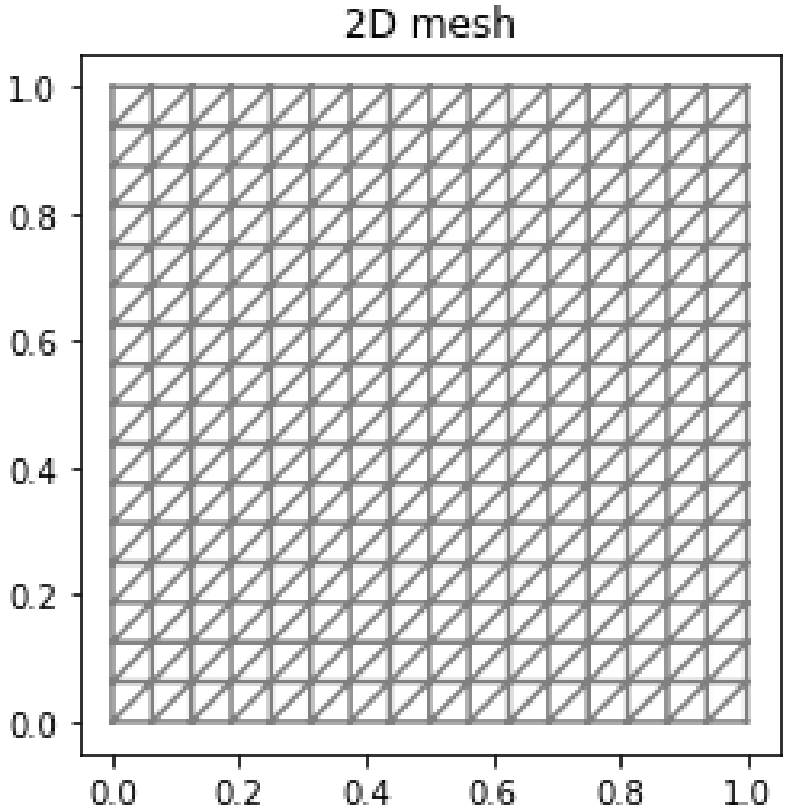
- Part of a standard Python installation
- Has a MATLAB-like interface
- Produces high-quality 1D and 2D plots

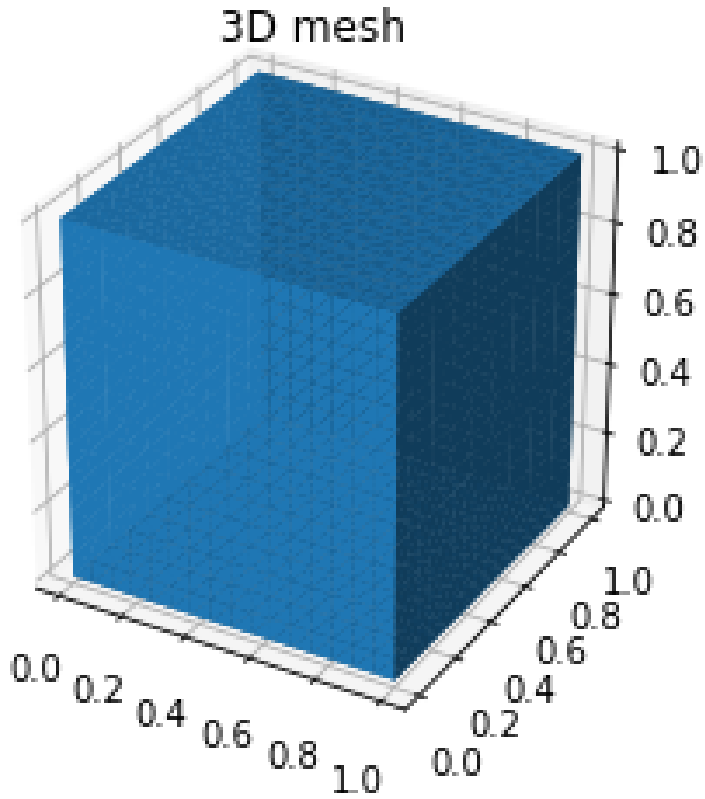
Related projects

- Pandas
- Seaborn

matplotlib example

```
from dolfin import *
from matplotlib import pyplot
parameters["plotting_backend"] = "matplotlib"

mesh2D = UnitSquareMesh(16,16)
mesh3D = UnitCubeMesh(16, 16, 16)

plot(mesh2D)
plot(mesh3D)
pyplot.show()
```

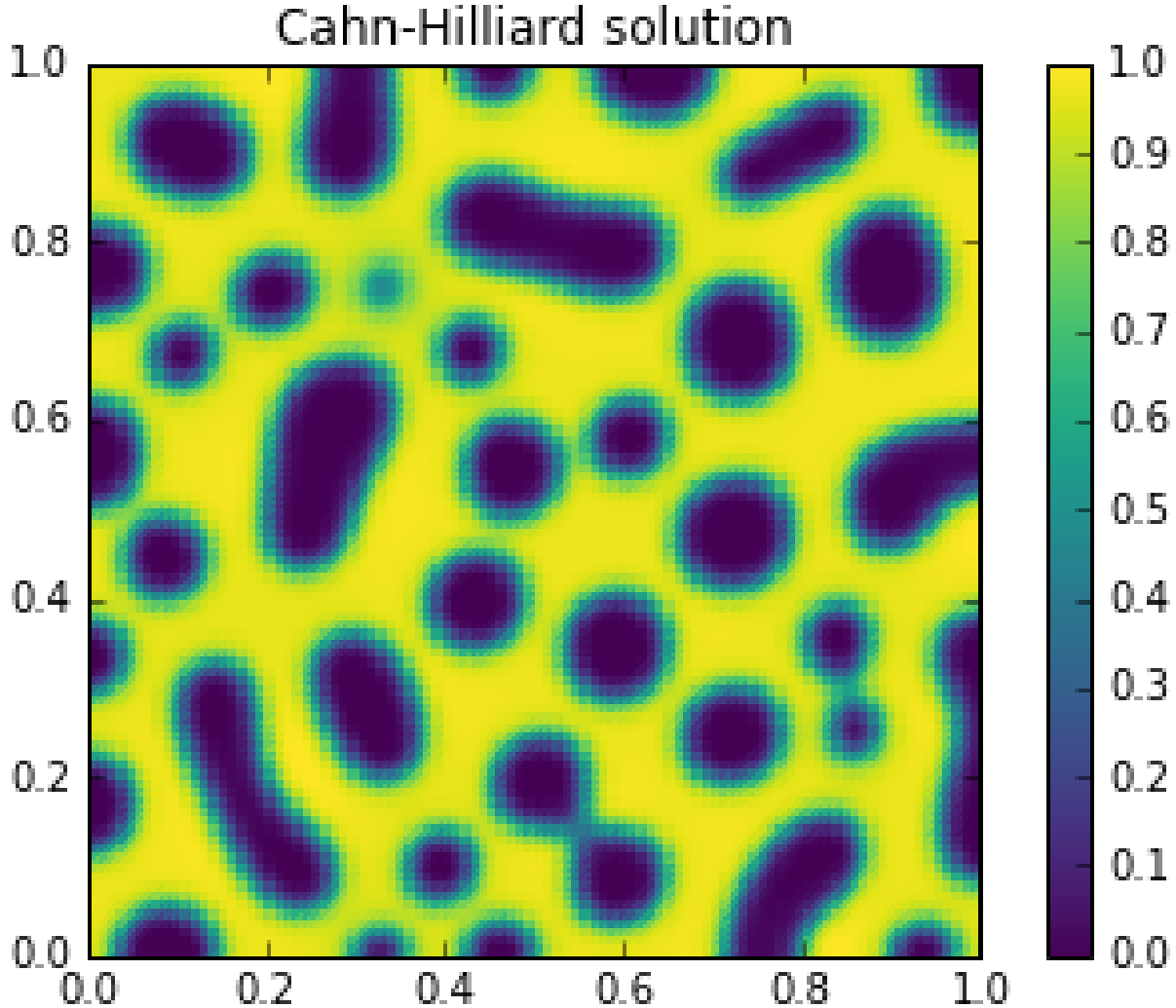

2D mesh
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0


3D mesh
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
0.0
0.2
0.4
0.6
0.8
1.0

matplotlib example II

```
# appended to Cahn-Hilliard demo
parameters["plotting_backend"] = "matplotlib"
from matplotlib import pyplot

# call the plot command from dolfin
p = plot(u[0])

# set colormap
p.set_cmap("viridis")
p.set_clim(0.0, 1.0)

# add a title to the plot
pyplot.title("Cahn-Hilliard solution")

# add a colorbar
pyplot.colorbar(p);

# save image to disk
pyplot.savefig("demo_cahn-hilliard.png")
```

matplotlib example II



matplotlib with FEniCS on mac and Windows

Displaying figures are more difficult when using a Docker installation of FEniCS
The options are:

1. Saving figures to file and open them on the host system (inconvenient)
2. Use Jupyter Notebook:
   Create and start a Docker container with the commands

Bash code

```
fenicsproject notebook fenics-nb stable
fenicsproject start fenics-nb
```

Direct your web browser to address and port number printed to the screen

Jupyter Notebook

Jupyter Notebook is part of the Project Jupyter (www.jupyter.org), which evolved from IPython.

- Web application
- Provides interactive environment for Python code (and other languages!)
- Combine code, equations and visualisation in one interactive document

To display figures inside the notebook, add this line to the notebook:

```
%matplotlib inline
```

ParaView

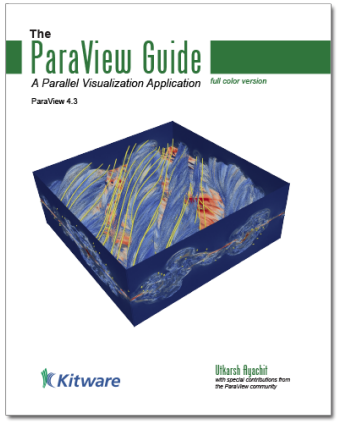
ParaView is a freely available, open source, multi-platform data visualisation application.

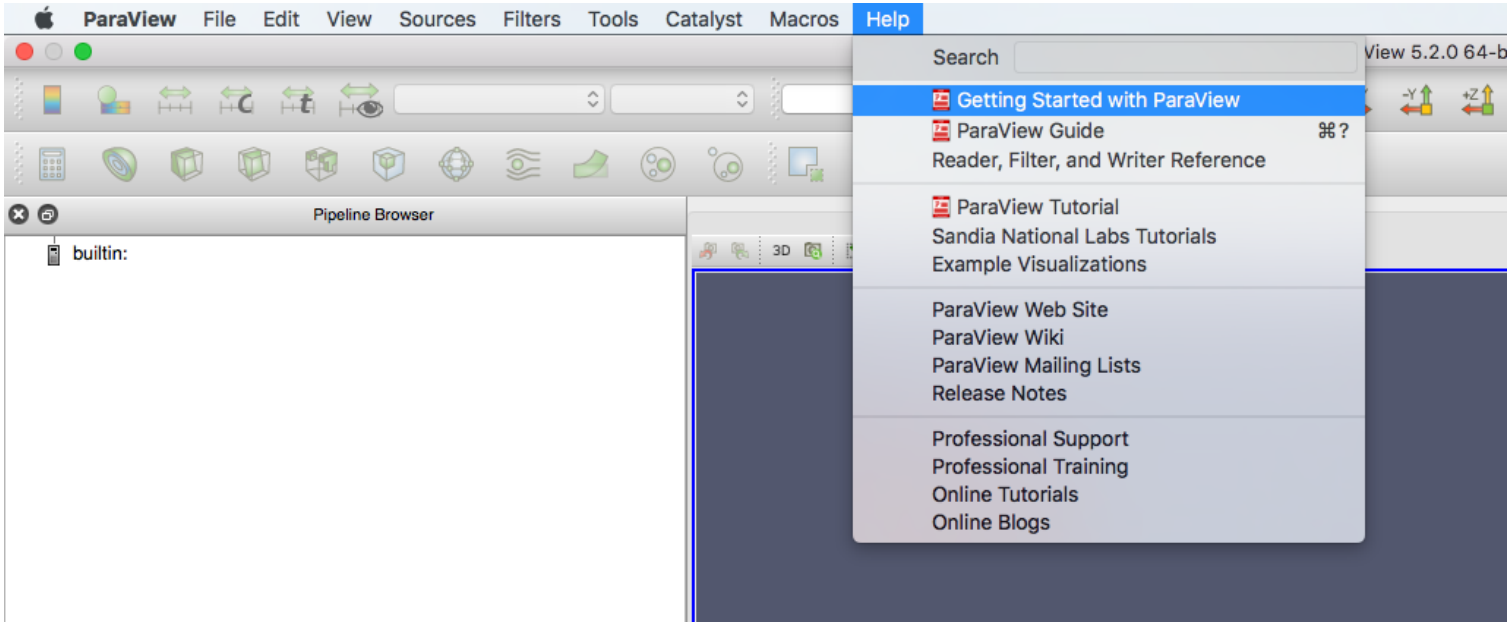
- Publication-quality figures
- Provides sophisticated data analysis functions
  - Stream lines
  - Time averages
  - Isosurfaces
  - ... and much more
- Can handle very large (and parallelized) data sets
- Support data file formats used by FEniCS:
  - ParaView files (.pvd)
  - VTK files (.vtu)
  - XDMF files (.xdmf)

ParaView resources

Official site: www.paraview.org

- Binaries for mac, ubuntu, windows
- ParaView tutorials
- The ParaView Guide





Using ParaView with FEniCS

Consider following example solving a Poisson problem:

```
from dolfin import *

mesh = UnitCubeMesh(16, 16, 16)
V = FunctionSpace(mesh, "P", 1)

u = TrialFunction(V)
v = TestFunction(V)
f = Constant(1.0)

a = inner(grad(u), grad(v)) * dx
L = f * v * dx

bc = DirichletBC(V, 0.0, "on_boundary")

uh = Function(V)
solve(a == L, uh, bc)
```

How can we visualise the solution?

Using ParaView with FEniCS

First step is to store the solution to disk

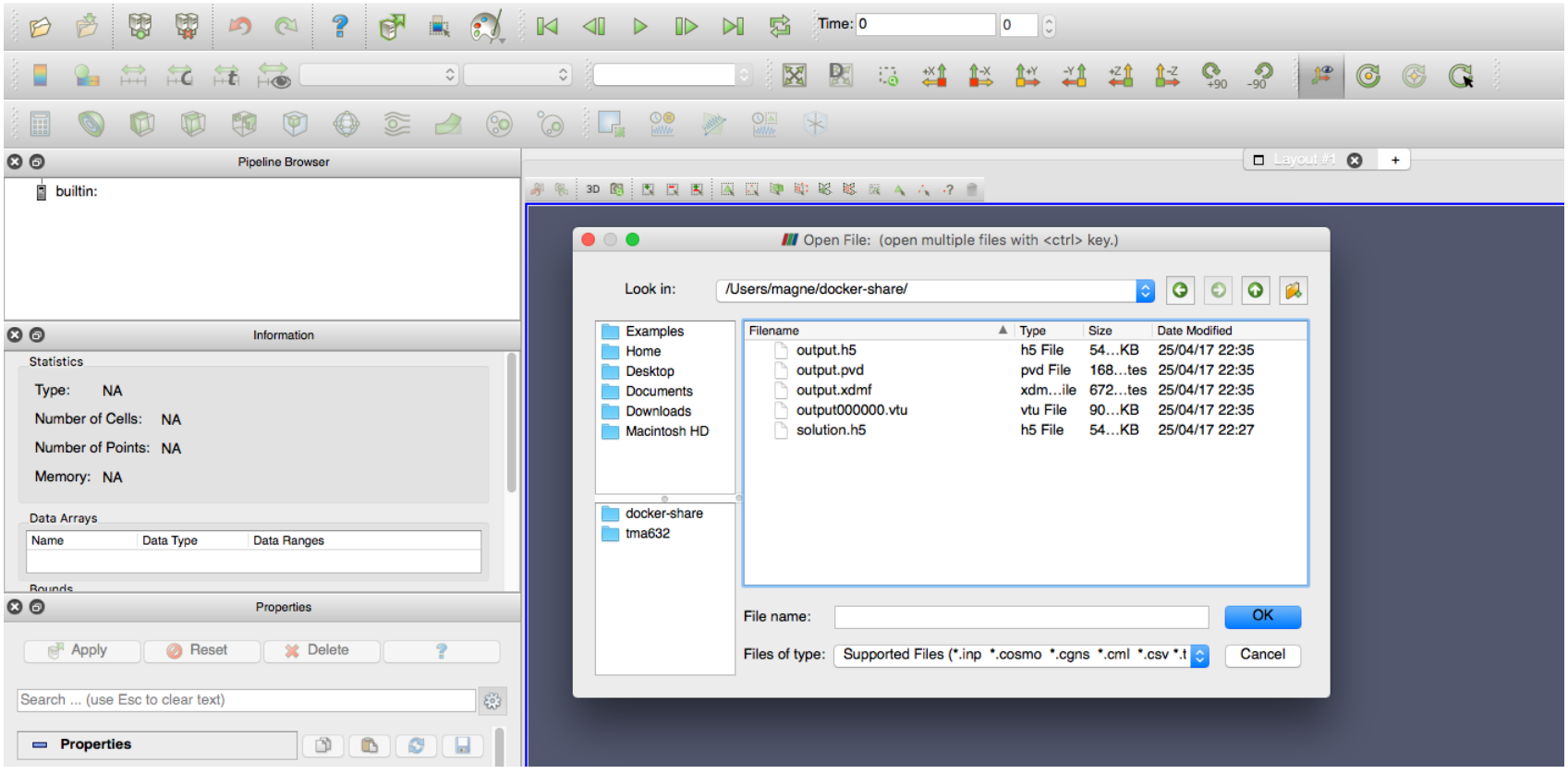
```
# save solution in XDMF format
file = XDMFFile("output.xdmf")
file.write(uh, 0)
```

Alternatively save as .pvd format

```
# save solution in ParaView format
file = File("output.pvd")
file << uh
```

Using ParaView with FEniCS

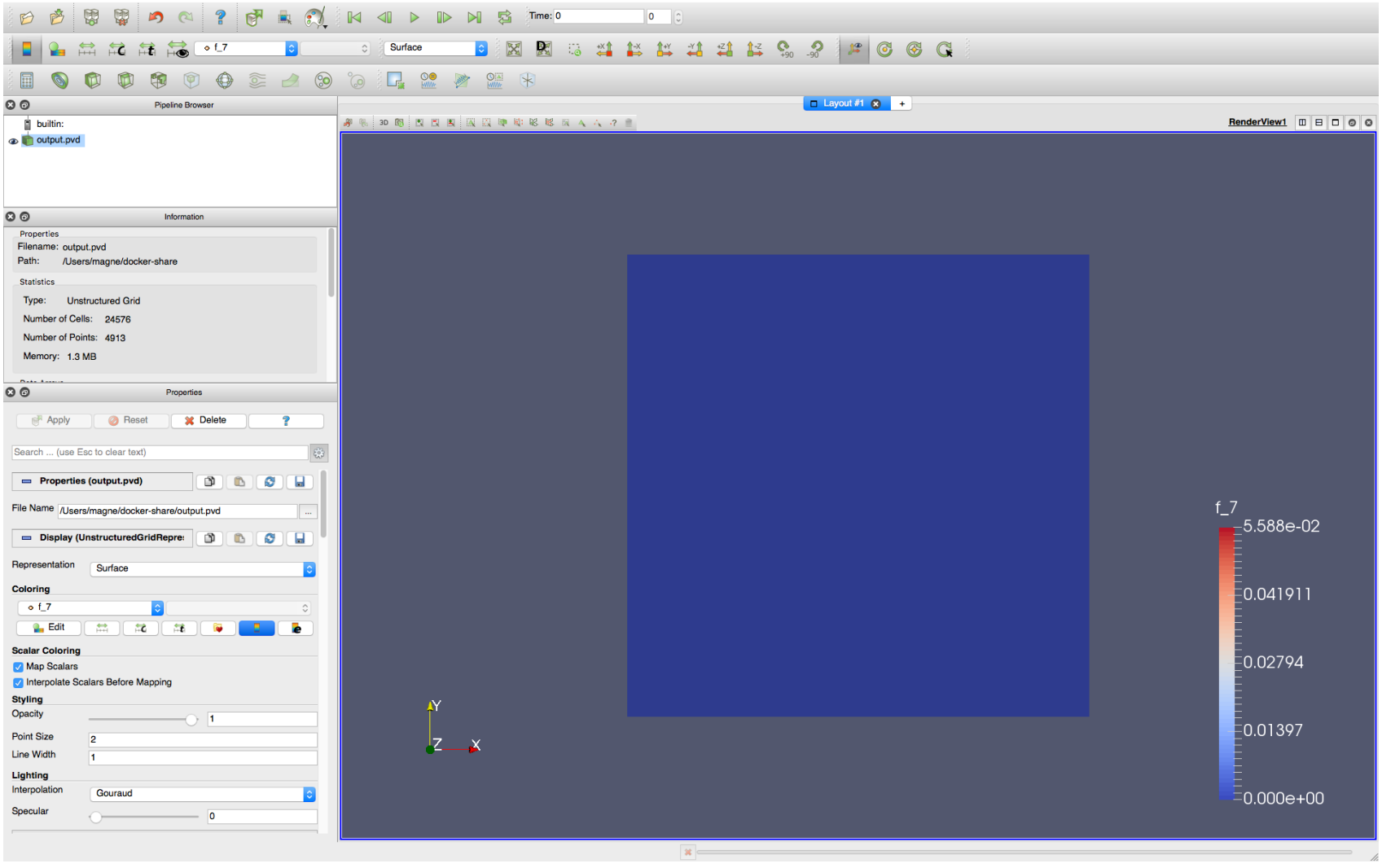
Start ParaView and open the file (Button in top left corner)



After opening the file click the Apply button

Using ParaView with FEniCS

Your screen should look similar to this:



After opening the file click the Apply button

Using ParaView with FEniCS

ParaView has a nice GUI so you can easily play around with the many functions and settings available.

The functions for slicing, and contours and streamlines are particularly useful for 3D data:

Save results using `File->SaveScreenshot` or `File->ExportScene` from the menu.

Good practices for visualisation of data

Automate visualisation (and other post-processing) with Python scripting.

- Ensures consistent results
- Saves time
- With ParaView: Manually make your figures *once* using the GUI. You can save the state (`File->SaveState`) and reuse it your python scripts.

Separate post-processing from solver code.

Saving data to files

Save data for plotting in XDMF or paraview formats:

```
uh = Function(V)

# saving uh to XDMF file
xdmf_file = XDMFFile("output.xdmf")
xdmf_file.write(uh, 0)

# saving uh to ParaView file
pvd_file = File("output.pvd")
pvd_file << uh
```

Saving data to files

Different formats have to be used for *reading* from file:

```
# saving to HDF5 file
hdf5_file = HDF5File(mpi_comm_world(), \
                     "output.hdf5", "w")
hdf5_file.write(uh, "solution")

# saving to compressed XML file
xml_file = File("output.xml.gz")
xml_file << uh
```

We can read from these files at later time:

```
# reading from HDF5 file
hdf5_file = HDF5File(mpi_comm_world(), \
                     "output.hdf5", "r")
hdf5_file.read(vh, "solution")

# reading from compressed XML file
xml_file = File("output.xml.gz")
xml_file >> vh
```

Writing/reading meshes and meshfunctions

A FEniCS `Mesh` or `MeshFunction` are handled similarly:

```
mesh = UnitSquareMesh(16, 16)
mf = MeshFunction("size_t", mesh, 0)
# Save mesh data:
hdf5_file = HDF5File(mpi_comm_world(), \
                     "mesh_data.hdf5", "w")
hdf5_file.write(mesh, "Mesh")
mvc = MeshValueCollection("size_t", mesh, mf)
hdf5_file.write(facet_domains, "Mesh/SubDomains")
```

Reading saved mesh data:

```
hdf5_file = HDF5File(mpi_comm_world(), \
                     "mesh_data.hdf5", "r")
# read mesh data
mesh = Mesh()
hdf5_file.read(mesh, "Mesh", False)
mvc = MeshValueCollection("size_t", mesh, 0)
hdf5_file.read(mvc, "Mesh/SubDomains")
mf = MeshFunction("size_t", mesh, mvc)
```

Exercises

1. Modify the nonlinear Poisson solver to solve a problem on a `UnitCubeMesh`
2. Try to make some nice figures of the 3D data usng ParaView. Experiment with slices and contours, and try changing the colormap.
3. Visualise the output of the hyperelasticity solver. Experiment with (glyphs arrows to represent vectors) and the warp-by-vector function.