Fall 2017:
Computational and Variational Methods for Inverse Problems
CSE 397/GEO 391/ME 397/ORI 397

Getting started with FEniCS

1. FEniCS overview

FEniCS is a powerful, open-source suite of tools for automated solution of PDEs using finite elements. Part of the power for FEniCS is the ease with which one can create FE solvers by describing PDEs using weak forms in nearly-mathematical notation. The FEniCS project can be found at: http://fenicsproject.org/ and comes with an extensive documentation and examples.

FEniCS includes a number of powerful features that include:

- Automated solution of variational problems;
- Automated error control and adaptivity;
- An extensive library of finite elements;
- High performance linear algebra through backends to such libraries as PETSc and Trilinos;
- Visualization via a simple interactive plotting function, as well as output in VTK format;
- Python and C++ interfaces;
- Extensive documentation (see for instance: https://fenicsproject.org/documentation/).

2. FEniCS resources

The documentation for FEniCS is extensive. Resources include:

- **The FEniCS Tutorial.** The book *Solving PDEs in Python: The FEniCS Tutorial Volume I* is the is the perfect guide for new users. The tutorial explains fundamental concepts of the finite element method, FEniCS programming, and demonstrates how to quickly solve a number of PDEs.

  The PDF version of the book can be downloaded (legally and for free) from
  https://fenicsproject.org/pub/tutorial/pdf/fenics-tutorial-vol1.pdf.

  Python scripts for all the examples described in the tutorial can be found at
  https://github.com/hplgit/fenics-tutorial/tree/master/pub/python/vol1

- **FEniCS Demos.** These documented demonstration programs are a great way to learn the different features in FEniCS. They come already packaged in FEniCS when you install it and are available on-line at:
  https://fenicsproject.org/olddocs/dolfin/2016.2.0/python/demo/index.html.

- **Quick Programmer's References.** Some of the classes and functions in DOLFIN are more frequently used than others. The Python implementations are described in
  https://fenicsproject.org/olddocs/dolfin/2016.2.0/python/quick_reference.html.

- **Complete Programmer's References.** If you need more details on a particular class or function, you can also consult the Complete Programmer's References at
  https://fenicsproject.org/olddocs/dolfin/2016.2.0/python/programmers-reference/index.html .

- **Getting Help.** See: https://fenicsproject.org/community/

Other resources, although a little outdated and not fully compatible with the latest versions of FEniCS, include:

- **The FEniCS Book:** All 732 pages of the FEniCS book (*Automated Solution of Differential Equations by the Finite Element Method*) can be downloaded (legally!) from here: http://launchpad.net/fenics-book/trunk/final/+download/fenics-book-2011-10-27-final.pdf. This is the comprehensive reference to FEniCS, along with many examples of the applications of FEniCS to problems in science and engineering. You will notice that the first chapter of the book is just the FEniCS Tutorial (with some minor editorial differences).
- **The FEniCS Manual.** This is a 200-page excerpt from the FEniCS Book, including the FEniCS Tutorial, an introduction to the finite element method, and documentation of DOLFIN and UFL: http://launchpad.net/fenics-book/trunk/final/+download/fenics-manual-2011-10-31.pdf. Since it's an excerpt from the FEniCS Book, you probably won't need it.

3. Installing FEniCS

In this class we will use FEniCS (http://fenicsproject.org/) version 2016.2. Please follow the install instructions given on the FEniCS page: https://fenicsproject.org/download/ to install the correct FEniCS version, and make sure this is compatible with your system. Below you can find a quick summary for the installation.

3.1. Docker installation

Docker is the recommended way to run FEniCS on your MacOS/Windows computer.

- **MacOS El Capitan 10.11 or above**
  1. Download `Docker for Mac` from https://download.docker.com/mac/stable/Docker.dmg.
  2. Open a new terminal shell.
  3. Create a folder that will contain all the codes used for this class.
  4. Go inside that folder and type the following commands

```
docker run --name fenics-notebook -w /home/fenics/shared -v "$(pwd)":/home/fenics/shared -d  \
       -p 127.0.0.1:8888:8888 quay.io/fenicsproject/stable:2016.2.0 \
       "jupyter-notebook --NotebookApp.token='ip' --ip=0.0.0.0"
docker stop fenics-notebook
echo 'docker run --rm -v "$(pwd)":/home/fenics/shared \
      -w /home/fenics/shared quay.io/fenicsproject/stable:2016.2.0 "python $@"' > fenics-app
chmod +x fenics-app
```

  To execute a python script (e.g. `test.py`) inside Docker, simply type

  `./fenics-app test.py`

  To use the jupyter notebooks

  1. Start the jupyter notebook server
     `docker start fenics-notebook`

2. Open your browser at the address
   http://localhost:8888/?token=ip
3. Remember to stop the server when you are done with the notebook
   `docker stop fenics-notebook`

FEniCS demo programs are located inside the Docker container under
`/home/fenics/demo`

For additional resources, see the `Docker for Mac` tutorial
https://docs.docker.com/docker-for-mac/

- **Windows 7 or above**

1. Download `Docker Toolbox` from
   https://github.com/docker/toolbox/releases/download/v1.12.0/DockerToolbox-1.12.0.exe
2. Double click on `Docker Quickstart Terminal`. A Linux-like shell will open.
3. Create a folder that will contain all the codes used for this class.
4. Go inside that folder and type the following commands

```
docker run --name fenics-notebook -w /home/fenics/shared -v "$(pwd)":/home/fenics/shared \
       -d -p $(docker-machine ip $(docker-machine active)):8888:8888 \
       quay.io/fenicsproject/stable:2016.2.0 "jupyter-notebook --NotebookApp.token='ip' --ip=0.0.0.0"
docker stop fenics-notebook
echo 'docker run --rm  -v "$(pwd)":/home/fenics/shared -w /home/fenics/shared \
      quay.io/fenicsproject/stable:2016.2.0 "python $@"' > fenics-app
chmod +x fenics-app
```

5. Type the command docker-machine ip `$(docker-machine active)` and take note of the IP address of the virtual machine (XXX.XXX.XXX). The notebook will be available at `http://<ip-of-virtual-machine>:8888` in your web browser.

To execute a python script (e.g. `test.py`) inside Docker, simply type

`./fenics-app test.py`

To use the jupyter notebooks

1. Start the jupyter notebook server
   `docker start fenics-notebook`
2. Open your browser at the address
   http://<ip-of-virtual-machine>:8888/?token=ip
3. Remember to stop the server when you are done with the notebook
   `docker stop fenics-notebook`

FEniCS demo programs are located inside the Docker container under
`/home/fenics/demo`

For additional resources, see
https://docs.docker.com/toolbox/toolbox_install_windows/

3.2. Native OS installation

- **Ubuntu LTS 14.04 or above:**[1]
  Open a shell and run the following commands:

  ```
  sudo add-apt-repository ppa:fenics-packages/fenics-2016.2.0
  sudo apt-get update
  sudo apt-get install --no-install-recommends fenics
  sudo apt-get dist-upgrade
  sudo apt-get install -y ipython-notebook
  sudo apt-get install -y paraview
  sudo apt-get install -y git
  ```

  If in the future you decide to uninstall FEniCS and remove all its dependencies, you can run the following commands:

  ```
  sudo apt-get purge --auto-remove fenics
  sudo add-apt-repository --remove ppa:fenics-packages/fenics-2016.2.0
  ```

  FEniCS demo programs are located under
  `/usr/share/dolfin/demo/` .

- **ICES Linux Desktop:**
  Open a shell and run the following commands:

  ```
  module purge
  module load c7 gcc/5.2 fenics-m/2016.1
  ```

  Note: you will have to run the above commands each time you open a new shell. If you would like to run FEniCS without having to type these commands each time you open a new shell, you can add the commands in your default shell profile (e.g. `.bashrc` if your default shell is bash).
  Warning: The version of FEniCS installed on the ICES Desktops is slightly outdated.
  FEniCS demo programs are located under
  `/opt/apps/ossw/applications/fenics-m/fenics-2016.1/bld/dolfin/ovcf3cq3tjma/share/dolfin/demo`
  You should copy this folder to your home directory if you wish to run any of the examples.

4. Check the FEniCS installation

To check the FEniCS installation on your system, go to the `demo` folder (see above for the exact location of this folder in your system) and run `demo_poisson.py` by typing the following at the command lines:

```
cd documented/poisson/python/
python demo_poisson.py
```

After compilation, you'll get a message saying

[1] The same installation instructions may also work for different version of Ubuntu or other Debian-based versions of Linux.

```
Solving linear variational problem.
```

and a simple plot of the solution will pop up in a new window. If you mouse over the `Help` tag in the low left, you'll get a list of some keyboard commands for interactive visualization. You can quit this run by typing `q` or `Q`.

5. Additional software

In this class we will also make use of the following software:

- Python 2.7, a high-level programming language
  https://docs.python.org/2/
- Numpy, Scipy, and Matplotlib, three Python packages that offer similar functionality to Matlab
  http://www.numpy.org/; https://www.scipy.org/, and http://matplotlib.org/
- Jupyter notebooks, a convenient way to write, run and document Python code using your web browser
  http://jupyter.readthedocs.io/en/latest/index.html
- Docker, a software containerization platform that provides the simplest way to run FEniCS on your computer
  https://www.docker.com/
- Paraview, a powerful data analysis and visualization application
  http://www.paraview.org/

6. Additional help

If you have questions regarding FEniCS or have problems running with the FEniCS examples provided in this class, please feel free to contact Umberto Villa (uvilla@ices.utexas.edu).