

# Software Development Tools and Methods

## Third practical session, 43rd Week

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October 26, 2016

The aim of this practical session is to learn to use GMSH<sup>1</sup> for creating meshes. We describe briefly how to create a simple mesh, import and handle it with FEEL++<sup>2</sup> or a simple C++ code. Recall that you can find more details about these softwares by consulting the corresponding documentation.

## 1 Meshing using Gmsh

### 1.1 Geometry of the domain

The geometry can be described using an intuitive language. For example, if our domain is the square  $[-1, 1]^2$ , we write a script `square.geo` as follows :

```
1 hSize = 1;
3 Point(1) = {-1, -1, 0, hSize};
  Point(2) = { 1, -1, 0, hSize} ;
5 Point(3) = { 1,  1, 0, hSize} ;
  Point(4) = {-1,  1, 0, hSize} ;
7
9 Line(1) = {1,2} ;
  Line(2) = {2,3} ;
  Line(3) = {3,4} ;
11 Line(4) = {4,1} ;
13
15 Line Loop(5) = {1,2,3,4} ;
  Plane Surface(5) = {5} ;
17
19 Physical Line("Gamma") = {1,2,3,4} ;
  Physical Surface("Omega") = {5} ;
```

In the first line `hSize` denotes the characteristic length (defining the mesh step  $h$ ). The 4 vertices of our square, numbered 1 to 4, are introduced in lines 3 to 6 using four numbers. The first three ones designate the coordinates of the point and the last one is dedicated to the characteristic length. Note that all points must have three components although we work in two dimensions (in this case the third component is zero).

The four edges of the square, numbered 1 to 4, are introduced by lines 8 – 11 of the script. Each edge is a segment defined by both ends. For example, `Line(2)={2,3}` means that the second edge of our square is defined by the points numbers 2 and 3.

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<sup>1</sup><http://www.geuz.org/gmsh/>

<sup>2</sup><http://www.feelpp.org/>

The four segments defined above are combined with the keyword `Loop` to form a loop defining our domain. It is used in the line 15 of the script to define the domain as a plane surface. The last two lines indicate specific regions of the domain. For example in our example,  $\Omega$  designates the interior of the domain and  $\Gamma$  its boundary.

## 1.2 “.msh” ASCII File Format

Thanks to the script `square.geo` described in previous section we can obtain a simple mesh given by the Figure 1. Note that in practice we use meshes much finer. For simplicity reasons, we considered a mesh with very few elements to better understand the use of GMSH.

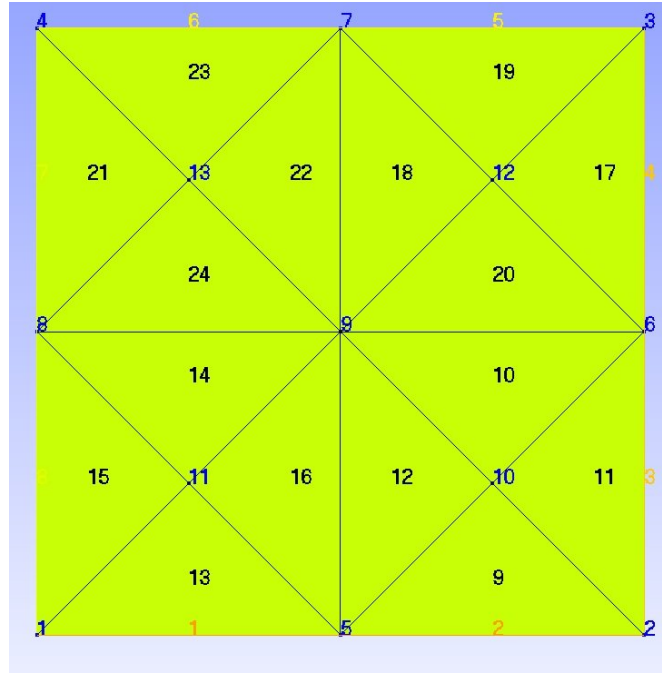


Figure 1: Example of a Coarse Mesh

The so created mesh is saved in the file `square.msh`. Here are its contents:

```

1 $MeshFormat
2 2.2 0 8
3 $EndMeshFormat
4 $PhysicalNames
5 2
6 1 1 "Gamma"
7 2 2 "Omega"
8 $EndPhysicalNames
9 $Nodes
10 13
11 1 -1 -1 0
12 2 1 -1 0
13 3 1 1 0
14 4 -1 1 0
15 5 -2.752797989558076e-12 -1 0
16 6 1 -2.752797989558076e-12 0
17 7 2.752797989558076e-12 1 0
18 8 -1 2.752797989558076e-12 0
19 9 0 0 0
20 10 -0.5000000000013765 -0.4999999999986236 0

```

```

21 11 0.4999999999988027 -0.5000000000011973 0
12 0.5000000000011973 0.4999999999988027 0
23 13 -0.4999999999986235 0.5000000000013765 0
$EndNodes
25 $Elements
24
27 1 1 2 1 1 1 5
2 1 2 1 1 5 2
29 3 1 2 1 2 2 6
4 1 2 1 2 6 3
31 5 1 2 1 3 3 7
6 1 2 1 3 7 4
33 7 1 2 1 4 4 8
8 1 2 1 4 8 1
35 9 2 2 2 5 9 10 5
10 2 2 2 5 6 9 11
37 11 2 2 2 5 7 9 12
12 2 2 2 5 13 8 10
39 13 2 2 2 5 11 9 5
14 2 2 2 5 12 9 6
41 15 2 2 2 5 13 9 7
16 2 2 2 5 9 13 10
43 17 2 2 2 5 1 10 8
18 2 2 2 5 2 11 5
45 19 2 2 2 5 3 12 6
20 2 2 2 5 4 13 7
47 21 2 2 2 5 1 5 10
22 2 2 2 5 2 6 11
49 23 2 2 2 5 3 7 12
24 2 2 2 5 4 8 13
51 $EndElements

```

The first three lines in the file `square.msh` describe the mesh format. The first number indicates the version number (2 in our case). The second one concerns the mesh file type (0 for ASCII and 1 for binary). The third index indicates how data are stored (using 8 bits in this case. *i.e.* `sizeof(double)=8`).

Between keywords `$PhysicalNames` and `$EndPhysicalNames` we have dimension, number and names of physical parts of the mesh. We find also the numbers which they are assigned automatically. In our case we have considered two “Physical Names” : **Omega** for the domain (two dimensions) and **Gamma** (one dimension) for its boundary. The mesh generator has attributed the 1 index for **Gamma** and 2 for **Omega**.

From the 9th line begins the mesh nodes description : their number first, then, in each line we have the number of the corresponding node followed by its coordinates.

The description of various elements of the mesh begins after the keyword `$Elements`. First, we have the number of elements (26th line of the file `square.msh`). Then, there is a detailed description of all elements of the mesh. In our case we have two types of elements: segments belonging to the boundary **Gamma** and triangles of the domain **Omega**. Each element is described by several indices. We detail those which correspond to the element of line 31 (an edge of the boundary **Gamma**) and those corresponding to the element of line 47 (a triangle). These two elements are also presented in figure 1.

	<i>elt-nbr</i>	<i>elt-type</i>	<i>tags-nbr</i>	<i>elt-ref</i>	<i>region-ref</i>	<i>part-ref</i>	<i>node1</i>	<i>node2</i>	<i>node3</i>
<b>line 31</b>	5	1	3	1	3	0	3	7	-
<b>line 47</b>	21	2	3	2	5	0	13	4	8

where

:

- *elt-nbr* : element number (5 for element described at the 31st line and 21 for element at 47th line)
- *elt-type* : element type : 1 for segments, 2 for triangles with three degrees of freedom, 3 for quadrangles with four degrees of freedom, etc ...
- *tags-nbr* : number of tags describing the element. In our case this index is 3 referring to the three indices of columns 4, 5 et 6 (*elt-ref*, *region-ref* and *part-ref*).

- *elt-ref* : element reference. In our example, 1 for elements belonging to the boundary  $\Gamma$  and 2 for those belonging to  $\Omega$  (see lines 6 and 7 of file `square.msh`)
- *region-ref* : region reference to which the element belongs. In our example 3 and 5 (cf. lines 10 and 15 of the script `square.geo`)
- *part-ref* : partition reference. In our case this index is zero since we have considered only one partition.
- *node1*, *node2*, *node3* : these indices refer to nodes that constitute our element. The segment of line 31st is formed by the two nodes number 3 and 7. The triangle of line 47 is formed by vertices number 13, 4 and 8. (See figure 1).

## 2 Application. Meshing the domain of the project

The aim of this section is to apply the previous method to mesh the domain of our interest in the project. Note that this domain has the geometry given by figure 2

- Recall that we have to create a mesh with different physical parts
- Each sub-domain  $\Omega_1$ ,  $\Omega_2$ ,  $\Omega_3$  and  $\Omega_4$  must have a different physical name
- The external boundaries  $\Gamma_1$ ,  $\Gamma_2$ ,  $\Gamma_3$  and  $\Gamma_4$  and each part of the internal boundaries  $\partial\Omega_1$  and  $\partial\Omega_2$  have to be considered as different physical parts too

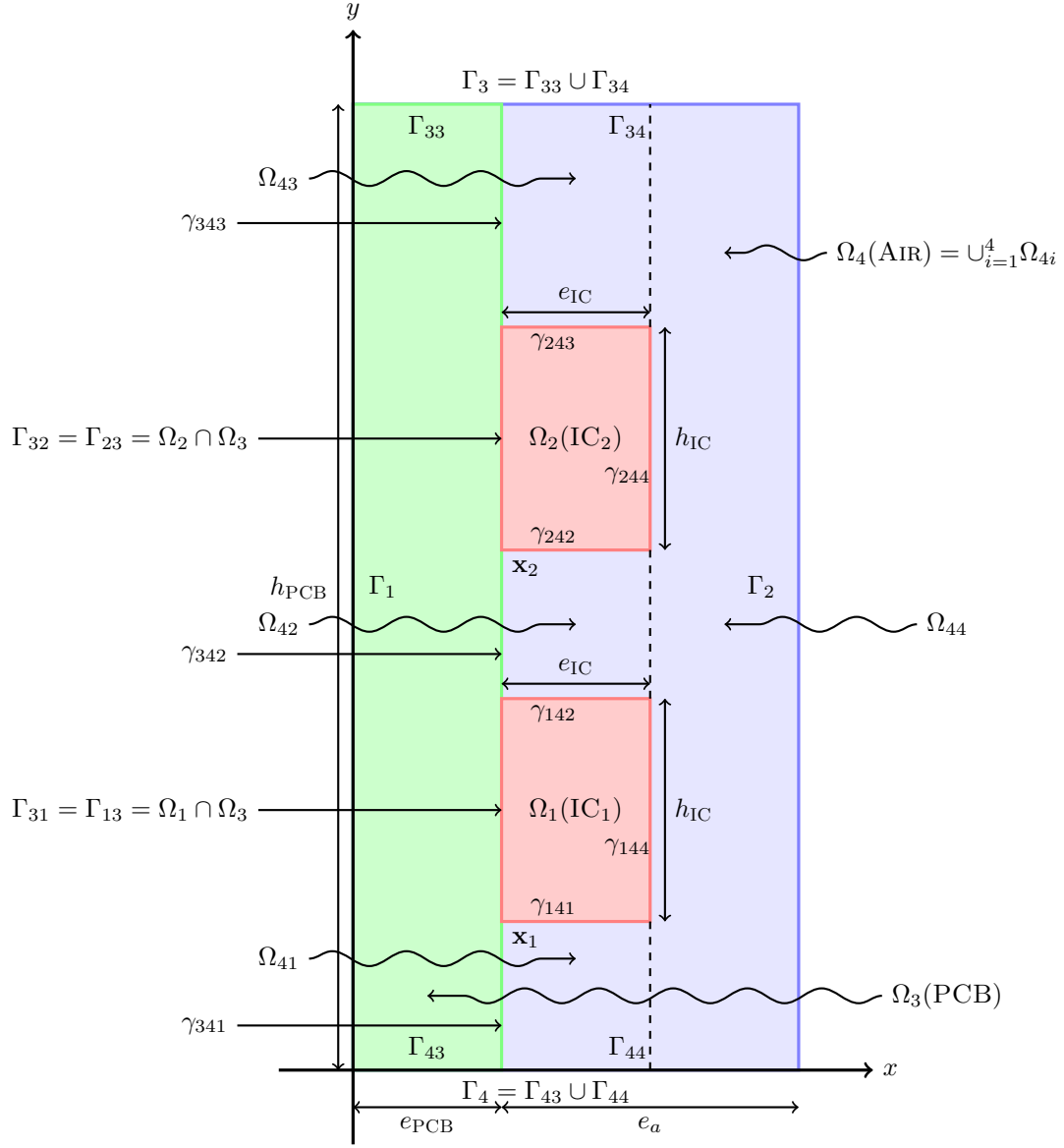


Figure 2: Geometry of  $\Omega = \cup_{i=1}^4 \Omega_i$  with  $\partial\Omega = \cup_{i=1}^4 \Gamma_i$

### 3 Handle your mesh with a simple C++ code (for students don't attending scicomp)

Write a simple C++ code that reads your .geo file and calls automatically Gmsh to generate the corresponding .msh file. You can skip this section and go to the next one if you want to use the FEEL++ library<sup>3</sup>. To do this, you will have to install this library under Linux (Debian or Ubuntu distribution) or MacOS (using brew<sup>4</sup>). Before doing this, be sure that your computer has at least 8Go of memory.

### 4 Handle your mesh with a Feel++ application (only for students attending scicomp)

The example files `myapp.cpp` and `mymesh.cpp` could help you to create your first FEEL++ application and handle interfacing with GMSH. These files are located at `/usr/local/share/doc/feel/examples/`.

More precisely you can use the function `createGMSHMesh`<sup>5</sup> with at least two arguments as follow :

- assume that your project class has a member `projectMesh` of type `mesh_ptrtype` :

```
1 typedef Feel::Simplex<Dim, 1,Dim> entity_type;
2 typedef Feel::Mesh<entity_type> mesh_type;
3 typedef boost::shared_ptr<mesh_type> mesh_ptrtype;
```

- This member can be initialized by one of your project constructors using the FEEL++ BOOST function `createGMSHMesh`<sup>6</sup>. For example :

```
1 projectMesh = createGMSHMesh( Feel::_mesh=new mesh_type,
2                               Feel::_desc=myCreateGeoFunction(<list
3                               of arguments> ) );
```

Where `myCreateGeoFunction` is a function that you created to generate your GMSH .geo file. An example of this function to create the `square.geo` file of section 1.1 is given by :

```
1 Feel::gmsh_ptrtype
2 myCreateGeoFunction( double h,
3                     double xmin, double xmax,
4                     double ymin, double ymax )
5 {
6     std::ostringstream ostr;
7     std::ostringstream nameStr;
8     ostr << "h=" << h << ";\n"
9     << "xmin=" << xmin << ";\n"
10    << "xmax=" << xmax << ";\n"
11    << "ymin=" << ymin << ";\n"
12    << "ymax=" << ymax << ";\n"
13    << "\n"
14    << "Point(1) = {xmin, ymin, 0, h};\n"
15    << "Point(2) = {xmax, ymin, 0, h};\n"
16    << "Point(3) = {xmax, ymax, 0, h};\n"
17    << "Point(4) = {xmin, ymax, 0, h};\n"
18    << "\n"
19    << "Line(1) = {1,2};\n"
20    << "Line(2) = {2,3};\n"
21    << "Line(3) = {3,4};\n"
22    << "Line(4) = {4,1};\n"
```

<sup>3</sup><http://www.feelpp.org/>

<sup>4</sup><http://brew.sh>

<sup>5</sup>don't forget to include the header files `feel/feelfilters/gmsh.hpp` and `feel/feelfilters/exporter.hpp`

<sup>6</sup>see `/usr/local/include/feel/feelfilters/gmsh.hpp`

```

23     << "\n"
24     << "Line Loop(5) = {1,2,3,4};\n"
25     << "Plane Surface(5) = {5};\n"
26     << "\n"
27     << "Physical Line(\"Gamma\") = {1,2,3,4};\n"
28     << "Physical Surface(\"Omega\") = {5};\n";
29     nameStr << "square";
30     return Feel::gmsh_ptrtype(new Feel::gmsh_type);
31 }

```

This function has to be adapted to the geometry of your project domain. Its arguments could be : the mesh size parameters,  $e_{\text{PCB}}$ ,  $e_a$ ,  $h_{\text{PCB}}$ ,  $h_{\text{IC}}$ ,  $e_{\text{IC}}$ ,  $h_1$  and  $h_2$ . Recall that  $h_1$  and  $h_2$  are the second coordinates of points  $\mathbf{x}_1 = (e_{\text{PCB}}, h_1)$  and  $\mathbf{x}_2 = (e_{\text{PCB}}, h_2)$ .