simesh Matlab toolbox, User's Guide*

version 0.4.5

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Abstract

This object-oriented Matlab toolbox allows to use simplial meshes generated from `gmsh` (in dimension 2 or 3) or an hypercube triangulation (in any dimension). For graphical representation the toolbox is used.

0 Contents

*LaTeX manual, revision 0.4.5.a, compiled with Matlab 2022a, and toolboxes `fc-simesh`[0.4.5], `fc-tools`[0.0.34], `fc-bench`[0.1.3], `fc-hypermesh`[1.0.4], `fc-amat`[0.1.3], `fc-meshtools`[0.1.4], `fc-graphics4mesh`[0.1.5], `fc-oogmsh`[0.2.4], `fc-siplt`[0.2.5]

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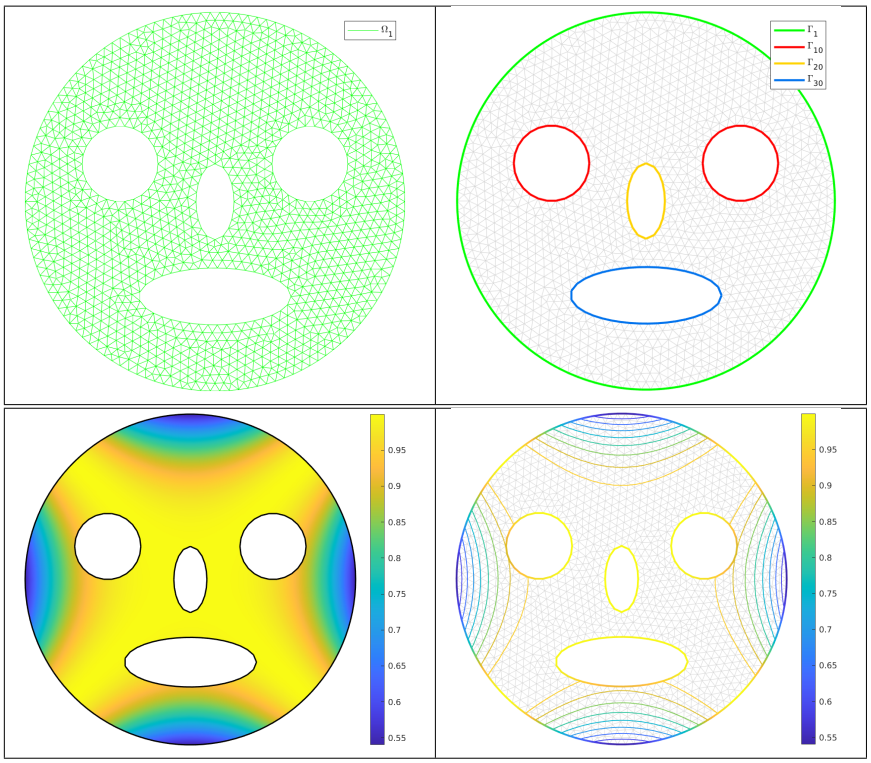
1 Introduction

The Matlab toolbox was created to simplify the use of simplicial meshes and to easily represent data on all or parts of them. In 2D or 3D `gmsh` can be used under Matlab to build triangular or tetrahedral meshes by using the toolbox[1]. Thereafter the mesh stored as a file (.msh) can be read by using the **fc_simesh.siMesh** object. In Listing 1, a 2D example is provided with the 4 generated figures. For graphic representations, the toolbox[2] is used by the **fc_simesh.siMesh** object Th as follows Th.**plotmesh**(...) is **fc_siplt.plotmesh**(Th,...), Th.**plot**(...) is **fc_siplt.plot**(Th,...) and so on.




```
close all
geofile=fc_simesh.get_geo(2,2,'sample2D01.geo');
% Using GMSH >= 4.0.0 to create mesh file
meshfile=fc_oogmsh.gmsh.buildmesh2d(geofile,200,'force',true);
% Creating siMesh object by reading the mesh file
Th=fc_simesh.siMesh(meshfile);
% Computing datas on siMesh object
u=@(x,y) cos(x.^2-y.^2);
U=Th.eval(u);
% Graphics
figure(1)
Th.plotmesh('inlegend',true)
axis image;axis off
fc_graphics4mesh.legend()

figure(2)
Th.plotmesh('color','LightGray')
hold on
Th.plotmesh('d',1,'inlegend',true,'LineWidth',2)
axis image;axis off
fc_graphics4mesh.legend()

figure(3)
Th.plot(U,'plane',true)
colorbar
shading interp
axis image;axis off
hold on
Th.plotmesh('d',1,'LineWidth',1.5,'color','k')

figure(4)
Th.plotmesh('color','LightGray')
axis image;axis off
hold on
Th.plot(U,'d',1,'LineWidth',2,'plane',true)
colorbar
Th.plotiso(U,'niso',10,'LineWidth',1,'plane',true)
```

Listing 1: fc_simesh.demos.sample2D01 script with figure 1 (top left), figure 2 (top right), figure 3 (bottom left) and figure 4 (bottom right).

In higher dimension the toolbox[3] can be used to obtain meshes of an hypercube by using the **fc_simesh**.hypercube function.

2 Installation

One just has to get/download the install file

mfc_simesh_install.m

or get it on the dedicated web page. Thereafter, one run it under Matlab. This command download, extract and configure the fc simesh toolbox and all the required required toolboxes in the current directory.

For example, to install this toolbox in `~/Matlab` directory, one has to copy the file mfc_simesh_install.m in the `~/Matlab` directory. Then in a Matlab terminal run the following commands

```
>> cd ~/Matlab
>> mfc_simesh_install
```

There is the output of the `mfc_simesh_install` command on a Linux computer:

```
Parts of the <fc-simesh> Matlab toolbox.
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1- Downloading and extracting the toolboxes
2- Setting the <fc-simesh> toolbox
Write in ~/Matlab/fc-simesh-full/fc_simesh-0.4.5/configure_loc.m ...
3- Using toolboxes :
   ->              fc-tools : 0.0.34
   ->              fc-bench : 0.1.3
   ->         fc-hypermesh : 1.0.4
   ->               fc-amat : 0.1.3
   ->         fc-meshtools : 0.1.4
   ->     fc-graphics4mesh : 0.1.5
   ->            fc-oogmsh : 0.2.4
   ->              fc-siplt : 0.2.5
 with             fc-simesh : 0.4.5
*** Using instructions
   To use the <fc-simesh> toolbox:
   addpath('~/Matlab/fc-simesh-full/fc_simesh-0.4.5')
   fc_simesh.init()

   See ~/Matlab/mfc_simesh_set.m
```

The complete toolbox (i.e. with all the other needed toolboxes) is stored in the directory `~/Matlab/fc-simesh-full` and, for each Matlab session, one have to set the toolbox by:

```
>> addpath('~/Matlab/fc-simesh-full/fc-simesh-0.4.5')
>> fc_simesh.init()
```

If it's the first time the `fc_simesh.init()` function is used, then its output is

```
Try to use default parameters!
 Use fc_tools.configure to configure.
Write in ~/Matlab/fc-simesh-full/fc_tools-0.0.34/configure_loc.m ...
Try to use default parameters!
 Use fc_bench.configure to configure.
Write in ~/Matlab/fc-simesh-full/fc_bench-0.1.3/configure_loc.m ...
Try to use default parameters!
 Use fc_hypermesh.configure to configure.
Write in ~/Matlab/fc-simesh-full/fc_hypermesh-1.0.4/configure_loc.m ...
Try to use default parameters!
 Use fc_amat.configure to configure.
Write in ~/Matlab/fc-simesh-full/fc_amat-0.1.3/configure_loc.m ...
Try to use default parameters!
 Use fc_meshtools.configure to configure.
Write in ~/Matlab/fc-simesh-full/fc_meshtools-0.1.4/configure_loc.m ...
Try to use default parameters!
 Use fc_graphics4mesh.configure to configure.
Write in ...
    ~/Matlab/fc-simesh-full/fc_graphics4mesh-0.1.5/configure_loc.m ...
Try to use default parameters!
 Use fc_oogmsh.configure to configure.
Write in ~/Matlab/fc-simesh-full/fc_oogmsh-0.2.4/configure_loc.m ...
Try to use default parameters!
 Use fc_siplt.configure to configure.
Write in ~/Matlab/fc-simesh-full/fc_siplt-0.2.5/configure_loc.m ...
Using fc_simesh[0.4.5] with fc_tools[0.0.34], fc_bench[0.1.3], ...
    fc_hypermesh[1.0.4],
                          fc_amat[0.1.3], fc_meshtools[0.1.4], ...
                              fc_graphics4mesh[0.1.5],
                          fc_oogmsh[0.2.4], fc_siplt[0.2.5].
[fc-oogmsh] Configured to use gmsh 4.11.0 with default MSH file format ...
    version 4.1
```

Otherwise, the output of the `fc_simesh.init()` function is

```
Using fc_simesh[0.4.5] with fc_tools[0.0.34], fc_bench[0.1.3], ...
    fc_hypermesh[1.0.4],
                          fc_amat[0.1.3], fc_meshtools[0.1.4], ...
                              fc_graphics4mesh[0.1.5],
                          fc_oogmsh[0.2.4], fc_siplt[0.2.5].
[fc-oogmsh] Configured to use gmsh 4.11.0 with default MSH file format ...
    version 4.1
```

For **uninstalling**, one just have to delete directory

`~/Matlab/fc-simesh-full`

3 Mesh Objects

In geometry, a simplex is a generalization of the notion of a triangle or tetrahedron to arbitrary dimensions. Specifically, a k-simplex in $\mathbb{R}^{\mathrm{dim}}$, $0 \leqslant k \leqslant \mathrm{dim}$, is a polytope which is the convex hull of its $k+1$ vertices of $\mathbb{R}^{\mathrm{dim}}$. More formally, suppose the $k+1$ vertices $\mathrm{q}^0, \cdots, q^k \in \mathbb{R}^{\mathrm{dim}}$ such that $\mathrm{q}^1 - \mathrm{q}^0, \cdots, \mathrm{q}^k - \mathrm{q}^0$ are linearly independent. Then, the k-simplex K determined by them is the set of points

$$K = \left\{ \sum_{i=0}^{k} \lambda_i \mathrm{q}^i \mid \lambda_i \geqslant 0,\ i \in [\![0, k]\!],\ \text{with} \sum_{i=0}^{k} \lambda_i = 1 \right\}.$$

We denote by **k-simplicial elementary mesh** in $\mathbb{R}^{\mathrm{dim}}$, $0 \leqslant k \leqslant \mathrm{dim}$, a mesh with **unique label** only composed with k-simplices.

A **d-simplicial mesh** in $\mathbb{R}^{\mathrm{dim}}$, $0 \leqslant \mathrm{d} \leqslant \mathrm{dim}$, is an union of k-simplicial elementary meshes with $k \in [\![0, \mathrm{d}]\!]$.

3.1 fc_simesh.siMeshElt object

An elementary d-simplicial mesh in dimension dim is represented by the class **fc_simesh.siMeshElt** . We give properties of this class :

Properties of fc_simesh.siMeshElt object for d-simplicial elementary meshes in $\mathbb{R}^{dim}$

dim	:	integer space dimension
d	:	integer ($0 \leqslant d \leqslant dim$)
nq	:	integer number of vertices
nme	:	integer number of elements (d-simplices)
q	:	dim-by-nq array of reals array of vertex coordinates
me	:	$(d+1)$-by-nme array of integers connectivity array for **mesh elements**
vols	:	1-by-nme array of reals array of mesh element volumes
h	:	double mesh step size (=maximum edge length in the mesh)
toGlobal	:	1-by-nq array of integers convert from local to global mesh vertices numbering. Prefer the use of toParents{**end**} instead. *It will be removed in a future release.*
toParent	:	1-by-nq array of integers convert from local to parent mesh vertices numbering (same as toGlobal if not part of a partitioned mesh). Prefer the use of toParents{1} instead. *It will be removed in a future release.*
nqParents	:	1-by-*n* array of integers nqParents(1) number of vertices in the *parent* mesh, nqParents(2) number of vertices in the *parent* of the *parent* mesh, nqParents(**end**) number of vertices in the global mesh.
toParents	:	1-by-*n* cell array toParents{1} indices array which convert local vertices numbering to the *parent* mesh vertices numbering, toParents{2} indices array which convert local vertices numbering to the *parent* of the *parent* mesh, toParents{**end**} indices array which convert local vertices numbering to the global mesh.

More precisely

- q(i,j) is the i-th coordinate of the j-th vertex, $i \in \{1,\dots,dim\}$, $j \in \{1,\dots,nq\}$. The j-th vertex will be also denoted by $q^j = q(:,j)$.

- me(r,k) is the storage index of the r-th vertex of the k-th element (d-simplex), in the array q, for $r \in \{1, ..., d+1\}$ and $k \in \{1, \ldots, nme\}$. So q(:, me(r,k)) represents the coordinates of the r-th vertex of the k-th mesh element.
- vols(k) is the volume of the k-th d-simplex .

3.2 fc_simesh.siMesh object

A d-simplicial mesh in dimension dim, represented as an **fc_simesh.siMesh** object, is an union of **fc_simesh.siMeshElt** objects which are elementary l-simplicial meshes ($0 \leqslant l \leqslant d$) in space dimension dim.

fc_simesh.siMesh object properties

dim	:	integer space dimension
d	:	integer d-dimensional simplicial mesh
sTh	:	array of **fc_simesh.siMeshElt** objects
nsTh	:	number of **fc_simesh.siMeshElt** objects
sThsimp	:	array of nsTh integers i-th **fc_simesh.siMeshElt** object in sTh is a sThsimp(i)-simplicial elementary mesh
sThlab	:	array of nsTh integers in sTh label of i-th **fc_simesh.siMeshElt** object in sTh is number sThlab(i)
nq	:	integer number of vertices in the mesh
toGlobal	:	1-by-nq array of integers convert from local to global mesh vertices numbering. Prefer the use of ndtoParents instead. *It will be removed in a future release.*
toParent	:	1-by-nq array of integers convert from local to parent mesh vertices numbering (same as toGlobal if not part of a partitioned mesh). Prefer the use of toParents1 instead. *It will be removed in a future release.*
nqParents	:	1-by-n array of integers Only used with partitioned mesh and the FC-PSIMESH toolbox.
toParents	:	1-by-n cell array Only used with partitioned mesh and the FC-PSIMESH toolbox.

Let Th be a **fc_simesh.siMesh** object. The global dim-by-(Th.nq) array q of mesh vertices is not explicitly stored in Th, however one can easily build it if necessary:

```
q=zeros(Th.dim,Th.nq);
for  i=Th.find(Th.d)
```

```
  q(:,Th.sTh{i}.toParents{1})=Th.sTh{i}.q;
end
```

3.3 Mesh samples

3.3.1 2-simplicial mesh in $\mathbb{R}^2$

Listing 2: : 2D fc_simesh.siMesh object from sample20.geo

```
meshfile=fc_oogmsh.gmsh.buildmesh2d('sample20',20,'force',false);
Th=fc_simesh.siMesh(meshfile);
fprintf('***_Th:\n')
disp(Th)
fprintf('***_Th.sTh{9}:\n')
disp(Th.sTh{9})
```

Output

```
[fc-oogmsh] Input file : <fc-oogmsh>/geodir/2d/sample20.geo
[fc-oogmsh] Mesh file <fc-oogmsh>/meshes/sample20-20.msh [version 4.1] already exists.
  -> Use "force" flag to rebuild if needed.
*** Th:
  fc_simesh.siMesh with properties:
                  d: 2 double
                dim: 2 double
                sTh: (1x11 cell)
               nsTh: 11 double
           toGlobal: (1x2327 double)
           toParent: (1x2327 double)
            sThsimp: [ 2 2 2 2 1 1 1 1 1 1 1 ] (1x11 double)
             sThlab: [ 1 2 10 20 1 2 20 101 102 103 104 ] (1x11 double)
          sThcolors: (11x3 double)
               bbox: [ -1 1 -1 1 ] (1x4 double)
          sThgeolab: []
         sThphyslab: [ 1 2 10 20 1 2 20 101 102 103 104 ] (1x11 double)
       sThpartlabs: []
      sThboundlabs: []
    sThPhysicalTags: []
                 nq: 2327 double
          nqParents: 2327 double
          toParents: (1x1 cell)
              other: (1x1 struct)
*** Th.sTh{9}:
  siMeshElt with properties:
           d: 1 double
         dim: 2 double
          nq: 41 double
         nme: 40 double
           q: (2x41 double)
          me: (2x40 double)
    toGlobal: (1x41 double)
    nqGlobal: 2327 double
    toParent: (1x41 double)
    nqParent: 2327 double
   nqParents: 2327 double
   toParents: (1x1 cell)
       label: 102 double
         Tag: (1x30 char)
       color: [ 0.0344828 0.448276 0.0689655 ] (1x3 double)
        vols: (1x40 double)
    gradBaCo: (40x2x2 double)
      geolab: []
     normals: (2x40 double)
     partlab: []
        bbox: [ 1 1 -1 1 ] (1x4 double)
           h: 0.05 double
       order: 1 double
```

From the output of the Listing 2 or from the Figure 1 the complete domain is

$$\Omega = \Omega_1 \cup \Omega_2 \cup \Omega_{10} \cup \Omega_{20}$$

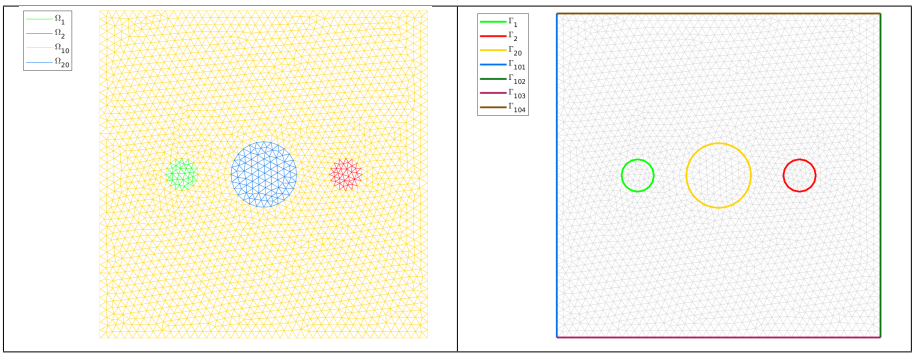


Figure 1: 2D **fc_simesh.siMesh** object from `sample20.geo`

and we note

$$\Gamma = \Gamma_1 \cup \Gamma_2 \cup \Gamma_{20} \cup \Gamma_{101} \cup \Gamma_{102} \cup \Gamma_{103} \cup \Gamma_{104}.$$

So this mesh is 2-simplicial mesh in $\mathbb{R}^2$ and is composed of :

- four 2-simplicial elementary meshes : Ω_i, $\forall i \in \{1, 2, 10, 20\}$
- seven 1-simplicial elementary meshes : Γ_i $\forall i \in \{1, 2, 20, 101, 102, 104\}$

3.3.2 Sample of a 3-simplicial mesh in $\mathbb{R}^3$

Listing 3: : 3D Mesh from quart_sphere2.geo

```
meshfile=fc_oogmsh.gmsh.buildmesh3d('quart_sphere2',5);
Th=fc_simesh.siMesh(meshfile);
fprintf('***_Th:\n')
disp(Th)
fprintf('***_Th.sTh{9}:\n')
disp(Th.sTh{9})
```

Output

```
[fc-oogmsh] Input file : <fc-oogmsh>/geodir/3d/quart_sphere2.geo
[fc-oogmsh] Mesh file <fc-oogmsh>/meshes/quart_sphere2-5.msh [version 4.1] already exists.
  -> Use "force" flag to rebuild if needed.
  Mesh quart_sphere2-5.msh is a 3-dimensional mesh
    Force dimension to 3
*** Th:
  fc_simesh.siMesh with properties:
                  d: 3 double
                dim: 3 double
                sTh: (1x23 cell)
               nsTh: 23 double
          toGlobal: (1x1172 double)
          toParent: (1x1172 double)
           sThsimp: [ 3 3 2 2 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 0 0 0 0 0 ] (1x23 double)
            sThlab: [ 1 2 1 2 3 4 5 6 7 1 2 3 4 5 6 7 8 9 1 2 3 4 5 ] (1x23 double)
         sThcolors: (23x3 double)
              bbox: [ -1 1 0 1 0 1 ] (1x6 double)
          sThgeolab: []
         sThphyslab: [ 1 2 1 2 3 4 5 6 7 1 2 3 4 5 6 7 8 9 1 2 3 4 5 ] (1x23 double)
       sThpartlabs: []
      sThboundlabs: []
    sThPhysicalTags: []
                nq: 1172 double
         nqParents: 1172 double
         toParents: (1x1 cell)
             other: (1x1 struct)
*** Th.sTh{9}:
  siMeshElt with properties:
           d: 2 double
         dim: 3 double
          nq: 203 double
         nme: 359 double
           q: (3x203 double)
          me: (3x359 double)
    toGlobal: (1x203 double)
    nqGlobal: 1172 double
    toParent: (1x203 double)
    nqParent: 1172 double
   nqParents: 1172 double
   toParents: (1x1 cell)
       label: 7 double
         Tag: (1x30 char)
       color: [ 0.517241 0.310345 0 ] (1x3 double)
        vols: (1x359 double)
    gradBaCo: (359x3x3 double)
      geolab: []
     normals: (3x359 double)
     partlab: []
        bbox: [ 0 1 0 1 0 1 ] (1x6 double)
           h: 0.12811 double
       order: 1 double
```

The mesh obtained from Listing 3 is a 3-simplicial mesh in $\mathbb{R}^3$ and is composed of :

- two 3-simplicial elementary meshes : Ω_i, $\forall i \in \{1, 2\}$
- seven 2-simplicial elementary meshes : Γ_i $\forall i \in [\![1, 7]\!]$
- nine 1-simplicial elementary meshes : $\partial\Gamma_i$ $\forall i \in [\![1, 9]\!]$
- five 0-simplicial elementary meshes : $\partial^2\Gamma_i$ $\forall i \in [\![1, 5]\!]$

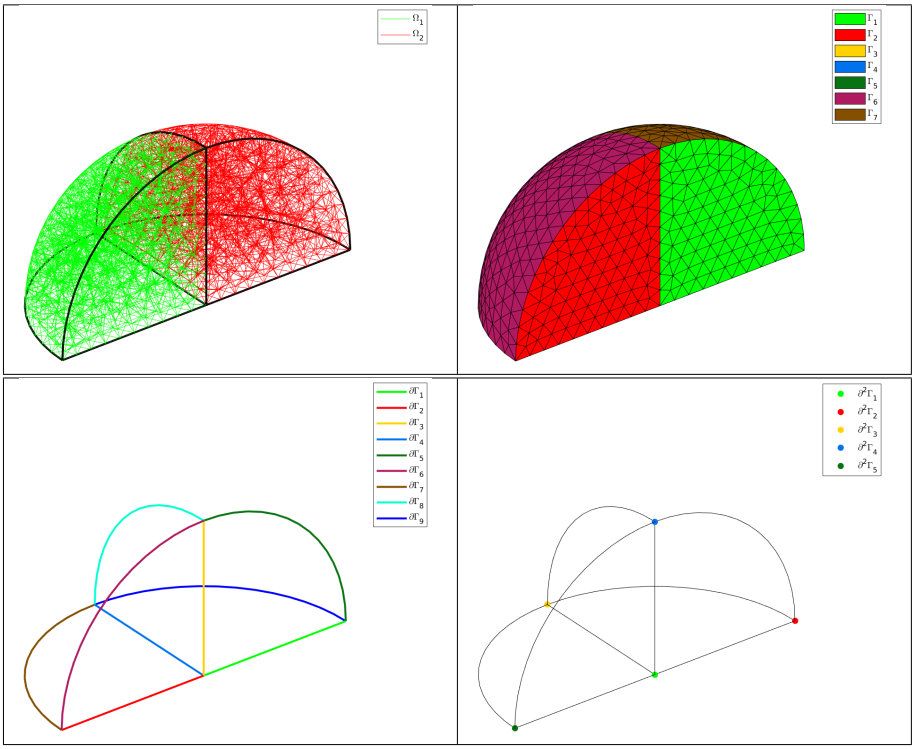


Figure 2: 3D Mesh from `quart_sphere2.geo`

3.3.3 Sample of a 2-simplicial mesh in $\mathbb{R}^3$

Listing 4: : 3D surface Mesh from demisphere4surf.geo

```
meshfile=fc_oogmsh.gmsh.buildmesh3ds('demisphere4surf',5,'force',true);
Th=fc_simesh.siMesh(meshfile);
fprintf('***_Th:\n')
disp(Th)
fprintf('***_Th.sTh{9}:\n')
disp(Th.sTh{9})
```

Output

```
[fc-oogmsh] Input file : <fc-oogmsh>/geodir/3ds/demisphere4surf.geo
[fc-oogmsh] Overwritting mesh file <fc-oogmsh>/meshes/demisphere4surf-5.msh
[fc-oogmsh] Starting building mesh <fc-oogmsh>/meshes/demisphere4surf-5.msh with gmsh 4.11.0
[fc-oogmsh] Using command : gmsh -2 -setnumber N 5 -string "Mesh.MshFileVersion=4.1;" ...
    <fc-oogmsh>/geodir/3ds/demisphere4surf.geo -o <fc-oogmsh>/meshes/demisphere4surf-5.msh
 Be patient...
[fc-oogmsh] Using gmsh 4.11.0 to write MSH file format version 4.1 in ...
    <fc-oogmsh>/meshes/demisphere4surf-5.msh
  Mesh demisphere4surf-5.msh is a 3-dimensional mesh
    Force dimension to 3
*** Th:
  fc_simesh.siMesh with properties:
                 d: 2 double
               dim: 3 double
               sTh: (1x12 cell)
              nsTh: 12 double
          toGlobal: (1x228 double)
          toParent: (1x228 double)
           sThsimp: [ 2 2 2 2 1 1 1 1 1 1 1 1 ] (1x12 double)
            sThlab: [ 1 2 3 4 1 2 3 4 5 6 7 8 ] (1x12 double)
         sThcolors: (12x3 double)
              bbox: [ -1 1 -1 1 0 1 ] (1x6 double)
          sThgeolab: []
         sThphyslab: [ 1 2 3 4 1 2 3 4 5 6 7 8 ] (1x12 double)
       sThpartlabs: []
      sThboundlabs: []
    sThPhysicalTags: []
                nq: 228 double
          nqParents: 228 double
          toParents: (1x1 cell)
              other: (1x1 struct)
*** Th.sTh{9}:
  siMeshElt with properties:
           d: 1 double
         dim: 3 double
          nq: 9 double
         nme: 8 double
           q: (3x9 double)
          me: (2x8 double)
    toGlobal: (1x9 double)
    nqGlobal: 228 double
    toParent: (1x9 double)
    nqParent: 228 double
   nqParents: 228 double
   toParents: (1x1 cell)
       label: 5 double
         Tag: (1x26 char)
       color: [ 0.0344828 0.448276 0.0689655 ] (1x3 double)
        vols: [ 0.196034 0.196034 0.196034 0.196034 0.196034 0.196034 0.196034 0.196034 ] ...
             (1x8 double)
    gradBaCo: (8x2x3 double)
      geolab: []
     normals: (3x8 double)
     partlab: []
        bbox: [ -1 0 0 0 0 1 ] (1x6 double)
           h: 0.196034 double
       order: 1 double
```

The mesh obtained from the Listing 4 or from the Figure 3 is a 2-simplicial mesh in $\mathbb{R}^3$ and is composed of :

- four 2-simplicial elementary meshes : Ω_i, $\forall i \in [\![1, 4]\!]$
- eight 1-simplicial elementary meshes : Γ_i $\forall i \in [\![1, 8]\!]$

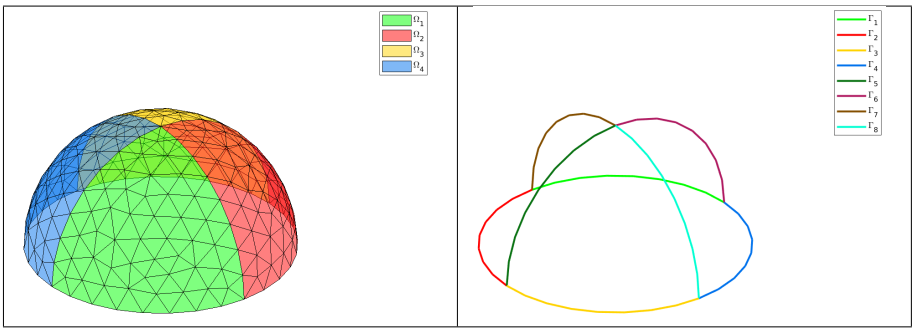


Figure 3: 3D surface Mesh from `demisphere4surf.geo`, label of the domains (left) and label of the boundaries (right)

3.4 Methods of the fc_simesh.siMesh object

3.4.1 fc_simesh.siMesh constructor

The constructor of the **fc_simesh.siMesh** class can initialize the object from various kind of mesh file format : *.msh* (default `gmsh` format), *.mesh* (`FreeFEM++` or `Medit`) or ... (`triangle`).

Syntaxe

```
Th=fc_simesh.siMesh(meshfile)

Th=fc_simesh.siMesh(meshfile,Name,Value)
```

Description

Th=**fc_simesh.siMesh**(meshfile) create the **fc_simesh.siMesh** object $\mathcal{T}_h$ from the mesh file meshfile (`gmsh` format by default).

Th=**fc_simesh.siMesh**(meshfile,Key,Value, ...) specifies function options using one or more Key,Value pair arguments. The string Key options can be

- `'format'` : to specify the format of the mesh file meshfile. Value must be *'medit'*, *'gmsh'* (default), *'freefem'* or *'triangle'*.
- `'dim'` : to specify the space dimension (default 2),
- `'d'` : to specify the dimensions of the simplices to read, (default [dim,dim−1])

Examples The following example use the function **fc_oogmsh.gmsh.buildmesh2d** of the FC-OOGMSH toolbox to build the mesh from the *.geo* file `condenser11.geo`. This .geo file is located in the directory `geodir/2d` of the FC-OOGMSH toolbox.

Listing 5: : fc_simesh.siMesh constructor

```
meshfile=fc_oogmsh.gmsh.buildmesh2d('condenser11',25,'verbose',0);
disp('***_Read_mesh_***')
Th=fc_simesh.siMesh(meshfile)
```

Output

```
*** Read mesh ***

Th =

  fc_simesh.siMesh with properties:
                 d: 2 double
               dim: 2 double
               sTh: (1x19 cell)
              nsTh: 19 double
          toGlobal: (1x3162 double)
          toParent: (1x3162 double)
           sThsimp: [ 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 ] (1x19 double)
            sThlab: [ 2 4 6 8 10 20 1 2 3 4 5 6 7 8 20 101 102 103 104 ] (1x19 double)
         sThcolors: (19x3 double)
              bbox: [ -1 1 -1 1 ] (1x4 double)
          sThgeolab: []
         sThphyslab: [ 2 4 6 8 10 20 1 2 3 4 5 6 7 8 20 101 102 103 104 ] (1x19 double)
       sThpartlabs: []
      sThboundlabs: []
    sThPhysicalTags: []
                nq: 3162 double
          nqParents: 3162 double
          toParents: (1x1 cell)
              other: (1x1 struct)
```

3.4.2 find method

We denote by Th a **fc_simesh.siMesh** object.

- Th.**find**(d) : returns the sorted indices array of the d-simplicial elementary meshes in the array Th.sTh.
- Th.**find**(d,labels) : returns the sorted indices of the d-simplicial elementary meshes with label in labels. labels could be an index, an array of indices. If nothing is found then return [].

Several examples are given in functions:
fc_simesh.demos.find2D(), **fc_simesh**.demos.find3D(), **fc_simesh**.demos.find3Ds()
Now some very basic samples are presented.

Listing 6: : fc_simesh.siMesh find method samples

```
meshfile=fc_oogmsh.gmsh.buildmesh3d('quart_sphere2',5, 'verbose',0);
Th=fc_simesh.siMesh(meshfile,'dim',3);
disp(Th)
idx=Th.find(3);
fprintf('3-simplices siMeshElt \n  indices: [%s], ...
    labels=[%s]\n',num2str(idx),num2str(Th.sThlab(idx)) )
idx=Th.find(2);
fprintf('2-simplices siMeshElt \n  indices: [%s], ...
    labels=[%s]\n',num2str(idx),num2str(Th.sThlab(idx)) )
idx=Th.find(2,4);
fprintf('2-simplices siMeshElt with label==4\n  indices: [%s], ...
    labels=[%s]\n',num2str(idx),num2str(Th.sThlab(idx)) )
idx=Th.find(2,[6,4,2,10]);
fprintf('2-simplices siMeshElt with label in [6,4,2,10]\n  indices: [%s], ...
    labels=[%s]\n',num2str(idx),num2str(Th.sThlab(idx)) )
```

Output

```
  fc_simesh.siMesh with properties:
                d: 3 double
              dim: 3 double
               sTh: (1x23 cell)
             nsTh: 23 double
         toGlobal: (1x1172 double)
         toParent: (1x1172 double)
          sThsimp: [ 3 3 2 2 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 ] (1x23 double)
           sThlab: [ 1 2 1 2 3 4 5 6 7 1 2 3 4 5 6 7 8 9 1 2 3 4 5 ] (1x23 double)
        sThcolors: (23x3 double)
             bbox: [ -1 1 0 1 0 1 ] (1x6 double)
         sThgeolab: []
        sThphyslab: [ 1 2 1 2 3 4 5 6 7 1 2 3 4 5 6 7 8 9 1 2 3 4 5 ] (1x23 double)
       sThpartlabs: []
      sThboundlabs: []
    sThPhysicalTags: []
               nq: 1172 double
         nqParents: 1172 double
         toParents: (1x1 cell)
             other: (1x1 struct)
3-simplices siMeshElt
  indices: [1 2], labels=[1 2]
2-simplices siMeshElt
  indices: [3 4 5 6 7 8 9], labels=[1 2 3 4 5 6 7]
2-simplices siMeshElt with label==4
  indices: [6], labels=[4]
2-simplices siMeshElt with label in [6,4,2,10]
  indices: [8 6 4], labels=[6 4 2]
```

3.4.3 feval method

Evaluates a vectorized function at vertices of the mesh. We denote by Th a **fc_simesh.siMesh** object.

- res=Th.**feval**(fun) : the input parameter fun is either a function or a cell array of function handles for vector-valued functions. If fun is a function then the output is an Th.nq-by-1 array. If fun is a cell array of function handles then the output is an Th.nq-by-**length**(fun) array.
- res=Th.**feval**(fun,key,value,...) specifies function options using one or more key,value pair arguments. The string key options could be
  - `d` : to specify the d-simplicial elementary meshes on which to evaluate the function (default Th.d). A zero value is set on all vertices not in these elementary meshes.
  - `labels` : to specify the labels of the elementary meshes on which to evaluate the function (default is all). A zero value is set on all vertices not in these elementary meshes.

Several examples are given in functions:

fc_simesh.demos.feval2D01(), **fc_simesh**.demos.feval3D01(), ...

We present now some very basic samples.

Sample 1 Let $g : \mathbb{R}^2 \mapsto \mathbb{R}$ defined by $g(x, y) = \cos(x)\sin(y)$. We propose in Listing 7 four approaches to defined this function for using with **feval** method.

Listing 7: : feval method, four ways to defined a function

```
meshfile=fc_oogmsh.gmsh.buildmesh2d('condenser11',50,'verbose',0);
Th=fc_simesh.siMesh(meshfile);

g1=@(x,y) cos(x).*sin(y); % .* for vectorized function
g2=@(X) cos(X(1,:)).*sin(X(2,:));

z1=Th.feval(g1);
z2=Th.feval(g2);

fprintf('max(abs(z2-z1))=%e\n',max(abs(z2-z1)))
```

Output

```
max(abs(z2-z1))=0.000000e+00
```

Sample 2

Listing 8: : feval method with a vector-valued function

```
meshfile=fc_oogmsh.gmsh.buildmesh2d('condenser11',50,'verbose',0);
Th=fc_simesh.siMesh(meshfile)

% f : R^2 -> R^3
f={@(x,y) cos(2*x).*sin(3*y),@(x,y) cos(3*x).*sin(4*y),@(x,y) cos(4*x).*sin(5*y)};
z=Th.feval(f);
fprintf('*** nq=%d, size(z)==[%d,%d]\n',Th.nq,size(z))
```

Output

```
Th =

  fc_simesh.siMesh with properties:
                  d: 2 double
                dim: 2 double
                sTh: (1x19 cell)
               nsTh: 19 double
           toGlobal: (1x11945 double)
           toParent: (1x11945 double)
            sThsimp: [ 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 ] (1x19 double)
             sThlab: [ 2 4 6 8 10 20 1 2 3 4 5 6 7 8 20 101 102 103 104 ] (1x19 double)
          sThcolors: (19x3 double)
               bbox: [ -1 1 -1 1 ] (1x4 double)
          sThgeolab: []
         sThphyslab: [ 2 4 6 8 10 20 1 2 3 4 5 6 7 8 20 101 102 103 104 ] (1x19 double)
        sThpartlabs: []
      sThboundlabs: []
    sThPhysicalTags: []
                 nq: 11945 double
          nqParents: 11945 double
          toParents: (1x1 cell)
              other: (1x1 struct)
*** nq=11945, size(z)==[11945,3]
```

3.4.4 eval method

Evaluates numerical datas or vectorized functions at vertices of the mesh. We denote by Th a **fc_simesh.siMesh** object and n_q = Th.nq the total number of vertices.

- res=Th.**eval**(data) : the input parameter data could be

- a scalar,
- a handle to a vectorized function,
- a n_q-by-1 array,
- a 1-by-m cell array of mixed previous kinds, ($m \geqslant 1$).

The return value is a n_q-by-1 array if the input parameter data is not a cell array otherwise it's a n_q-by-m array.

- res=Th.**eval**(data,key,value,...) specifies function options using one or more key,value pair arguments. The string key options could be
  - `d` : to specify the d-simplicial elementary meshes on which to evaluate data (default Th.d). A zero value is set on all vertices not in these elementary meshes.
  - `labels` : to specify the labels of the elementary meshes on which to evaluate data (default is all). A zero value is set on all vertices not in these elementary meshes.

Several examples are given in functions:
fc_simesh.demos.eval2D01(), **siMesh**.demos.eval3D01(), ...
We present now some very basic samples.

Sample 1

Listing 9: : eval method, four ways to defined a function

```
meshfile=fc_oogmsh.gmsh.buildmesh2d('condenser11',50,'verbose',0);
Th=fc_simesh.siMesh(meshfile);

g1=pi*ones(Th.nq,1);
g2=pi*ones(1,Th.nq);
g3=@(X) pi;

z1=Th.eval(g1);
z2=Th.eval(g2);
z3=Th.eval(g3);

fprintf('size(z1)=[%d,%d]\n',size(z1))
fprintf('size(z2)=[%d,%d]\n',size(z2))
fprintf('size(z3)=[%d,%d]\n',size(z3))
fprintf('max(abs(z2-z1))=%e\n',max(abs(z2-z1)))
fprintf('max(abs(z3-z1))=%e\n',max(abs(z3-z1)))
```

Output

```
size(z1)=[11945,1]
size(z2)=[11945,1]
size(z3)=[11945,1]
max(abs(z2-z1))=0.000000e+00
max(abs(z3-z1))=0.000000e+00
```

Sample 2

Listing 10: : eval method with a vector-valued function

```
meshfile=fc_oogmsh.gmsh.buildmesh2d('condenser11',50,'verbose',0);
Th=fc_simesh.siMesh(meshfile);
u=Th.feval(@(x,y) cos(3*x).*sin(4*y));
% f : R^2 -> R^3
f={@(x,y) cos(2*x).*sin(3*y),u,@(x,y) cos(4*x).*sin(5*y),pi};
z=Th.eval(f);
fprintf('*** nq=%d, size(z)==[%d,%d] ',Th.nq,size(z))
```

Output

```
*** nq=11945, size(z)==[11945,4]
```

3.4.5 get_h method

returns the maximum edges length of the mesh. We denote by Th a **fc_simesh.siMesh** object.

- h=Th.get_h()

3.4.6 get_mesh method

Returns a vertices array q, a connectivity array me and a toGlobal indices array.

- [q,me,toGlobal]=Th.get_mesh() : returns the global vertices array q, the connectivity array me (i.e. all the Th.d-simplices of the mesh). In this case, toGlobal is just 1:Th.nq.
- [q,me,toGlobal]=Th.get_mesh(key,value,...) specifies function options using one or more key,value pair arguments. The string key options could be
  - 'd' : to specify the d-simplicial elementary meshes to consider.
  - 'labels' : to specify the labels of the elementary meshes to consider.

  In this case, toGlobal is a 1-by-**length**(q) array (subset of 1:Th.nq). If we denote by qglob the global vertices array then
  qglob(:,toGlobal)==q

Several examples are given in functions:
fc_simesh.demos.get_mesh2D(), **siMesh**.demos.get_mesh3D(), **siMesh**.demos.get_mesh3Ds()

Listing 11: : get_mesh method, four ways to defined a function

```
meshfile=fc_oogmsh.gmsh.buildmesh2d('condenser11',50,'verbose',0);
Th=fc_simesh.siMesh(meshfile);

[q,me,toGlobal]=Th.get_mesh();
[q2,me2,toGlobal2]=Th.get_mesh('labels',2:2:8);
[q1,me1,toGlobal1]=Th.get_mesh('d',1,'labels',1:8);

fprintf('norm(q(:,toGlobal2)-q2,Inf)=%e\n',norm(q(:,toGlobal2)-q2,Inf))
fprintf('norm(q(:,toGlobal1)-q1,Inf)=%e\n',norm(q(:,toGlobal1)-q1,Inf))
```

Output

```
norm(q(:,toGlobal2)-q2,Inf)=0.000000e+00
norm(q(:,toGlobal1)-q1,Inf)=0.000000e+00
```

3.4.7 get_nme method

Returns the number of d-simplicial elements with $d = \mathcal{T}_h$.d by default. We denote by Th a **fc_simesh.siMesh** object.

- nme=Th.get_nme() : returns the number of Th.d-simplicial elements in the mesh.
- nme=Th.get_mesh(key,value,...) specifies function options using one or more key,value pair arguments. The string key options could be
  - 'd' : to specify the d-simplicial elementary meshes to consider.

– 'labels' : to specify the labels of the elementary meshes to consider.

Listing 12: : get_nme method

```
meshfile=fc_oogmsh.gmsh.buildmesh3d('quart_sphere2',5);
Th=fc_simesh.siMesh(meshfile);
for d=[Th.d:-1:0]
  fprintf('Number_of_%d-simplices_:_%d\n',d,Th.get_nme('d',d))
end

nme=Th.get_nme('d',2,'labels',1:4);
fprintf('Number_of_2-simplices_in_union_of_label''s_1_to_4_:_%d\n',nme);
```

Output

```
[fc-oogmsh] Input file : <fc-oogmsh>/geodir/3d/quart_sphere2.geo
[fc-oogmsh] Mesh file <fc-oogmsh>/meshes/quart_sphere2-5.msh [version 4.1] already exists.
  -> Use "force" flag to rebuild if needed.
  Mesh quart_sphere2-5.msh is a 3-dimensional mesh
    Force dimension to 3
Number of 3-simplices : 4778
Number of 2-simplices : 1653
Number of 1-simplices : 115
Number of 0-simplices : 5
Number of 2-simplices in union of label's 1 to 4 : 748
```

3.4.8 get_nq method

Returns the number of vertices in the union of some elementary meshes. By default all the (Th.d)-simplicial elementary meshes are selected. We denote by Th a **fc_simesh.siMesh** object.

- nq=Th.get_nq() : returns the number of vertices in the union of the Th.*d*-simplicial elementary meshes.
- nq=Th.get_nq(key,value,...) specifies function options using one or more key,value pair arguments. The string key options could be
  - 'd' : to specify the d-simplicial elementary meshes to consider.
  - 'labels' : to specify the labels of the elementary meshes to consider.

Listing 13: : get_nqe method

```
meshfile=fc_oogmsh.gmsh.buildmesh3d('quart_sphere2',5);
Th=fc_simesh.siMesh(meshfile);
for d=[Th.d:-1:0]
  fprintf('Number_of_vertices_in_%d-simplices_elementary_meshes_:_...
      %d\n',d,Th.get_nq('d',d))
end

nq=Th.get_nq('d',2,'labels',1:4);
fprintf('Number_of_vertices_in_the_union_of_2-simplices_elementary_meshes_of_...
    label''s_1_to_4_:_%d\n',nq);
```

Output

```
[fc-oogmsh] Input file : <fc-oogmsh>/geodir/3d/quart_sphere2.geo
[fc-oogmsh] Mesh file <fc-oogmsh>/meshes/quart_sphere2-5.msh [version 4.1] already exists.
  -> Use "force" flag to rebuild if needed.
  Mesh quart_sphere2-5.msh is a 3-dimensional mesh
    Force dimension to 3
Number of vertices in 3-simplices elementary meshes : 1172
Number of vertices in 2-simplices elementary meshes : 812
Number of vertices in 1-simplices elementary meshes : 111
Number of vertices in 0-simplices elementary meshes : 5
Number of vertices in the union of 2-simplices elementary meshes of label's 1 to 4 : 405
```

3.4.9 get_labels method

Returns the labels of the d-simplicial elementary meshes. We denote by Th a **fc_simesh.siMesh** object.

- labels=Th.get_labels(d) : the labels of the d-simplicial elementary meshes.

Listing 14: : get_labels method

```
geofile=fc_simesh.get_geo(3,3,'quart_sphere2');
meshfile=fc_oogmsh.gmsh.buildmesh3d(geofile,10);
Th=fc_simesh.siMesh(meshfile);
lab3=Th.get_labels(3)
lab2=Th.get_labels(2)
lab2=Th.get_labels(1)
lab2=Th.get_labels(0)
```

Output

```
[fc-oogmsh] Input file : <fc-oogmsh>/geodir/3d/quart_sphere2.geo
[fc-oogmsh] Mesh file <fc-oogmsh>/meshes/quart_sphere2-10.msh [version 4.1] already exists.
  -> Use "force" flag to rebuild if needed.
  Mesh quart_sphere2-10.msh is a 3-dimensional mesh
    Force dimension to 3

lab3 =

    1    2


lab2 =

    1    2    3    4    5    6    7


lab2 =

    1    2    3    4    5    6    7    8    9


lab2 =

    1    2    3    4    5
```

We can refer to Figure 2 to validate the output results.

3.4.10 move method

Moving a mesh. We denote by Th a **fc_simesh.siMesh** object.

- Th.move(u,dims) : the input parameter u is the displacement vector which is either a numerical array or a cell array of numerical array. The second parameter dims is uses to specify the dimensions where displacement vector is applied.
  - Let U=u if u is an n-by-n_q array and U=u.' if u is an n_q-by-n array. Then dims is a vector of length n and all nodes array q in Th are replaced by

    Th.sThi.q(dims,:)=q(dims,:)+U(:,Th.sThi.toGlobal))

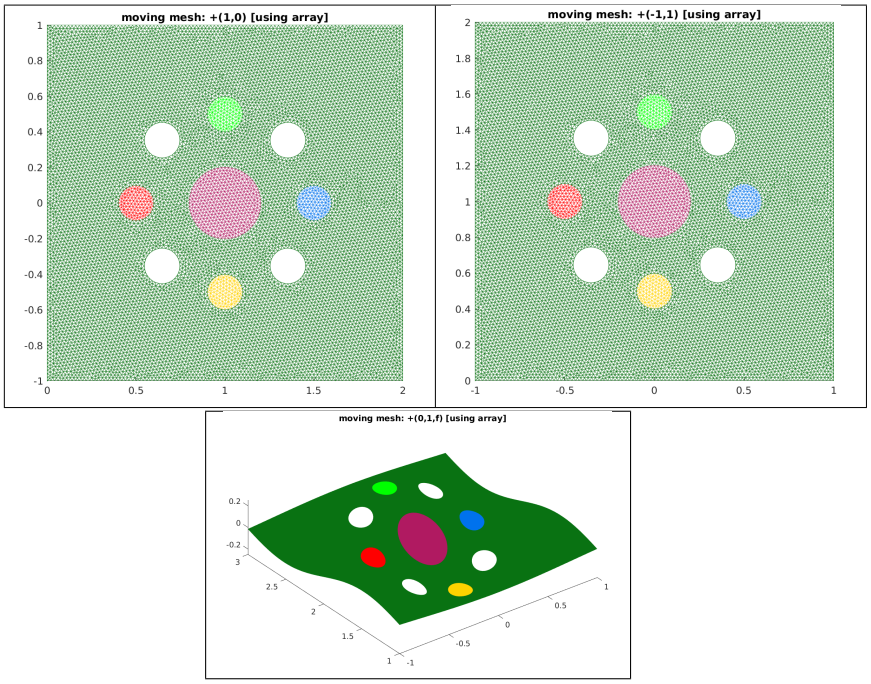
  - u is a cell array of length d. Let U=u{k} if u{k} is an 1-by-n_q array and U=u{k}.' if fcmcodeu{i} is an n_q-by-1 array.

    Th.sThi.q(dims(k),:)=q(dims(k),:)+U(:,Th.sThi.toGlobal))

remark 3.1

1. Take care that modification in Th are done *inplace*. One can use the command Th1=Th.copy() which make a deep copy of the Th object (modifying one object not change its deep copy).
2. If **max**(dims) greather than Th.dim, then the mesh dimension is automaticaly increased and new dimensions in nodes array are set to zeros.

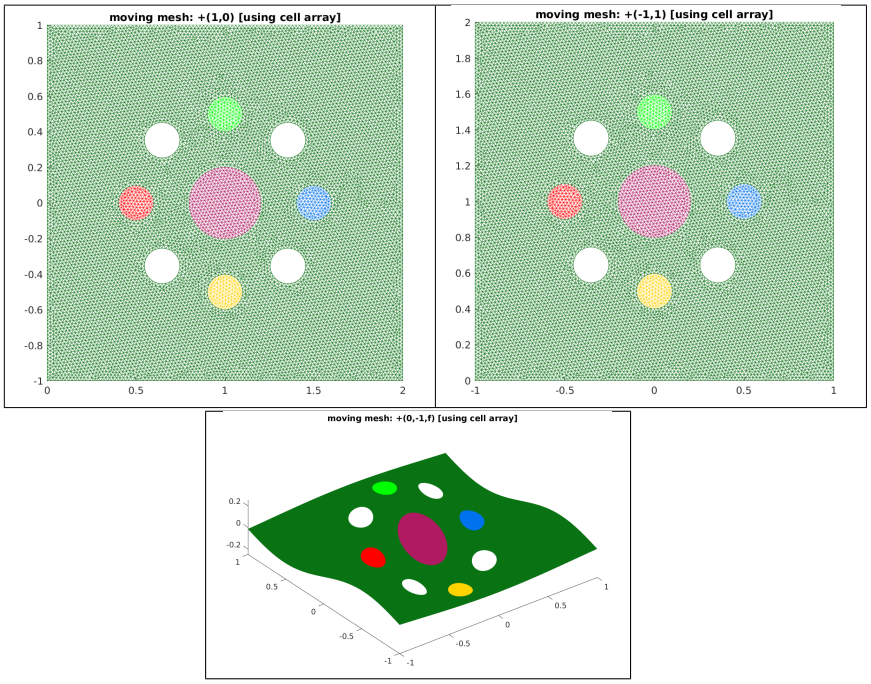
2D example : the following code is part of the **fc_simesh.demos.moveArray2D** function.




```
Th1=Th.copy(); % Deep copy of Th
f=@(x,y) cos(2*x).*sin(3*y)/4;
U=ones(1,Th.nq);

Th1.move(U,1)
figure(1)
Th1.plotmesh();
axis image; title('moving mesh: +(1,0) [using array]')

Th1.move([-U;U],1:2)
figure(2)
Th1.plotmesh();
axis image; title('moving mesh: +(-1,1) [using array]')

Th1.move([U;Th.eval(f)'],2:3) % [U;Th.eval(f)'] OK
figure(3)
Th1.plotmesh('edgecolor','none');
```

Listing 15: Using fc_simesh.moveArray function with a 2D mesh

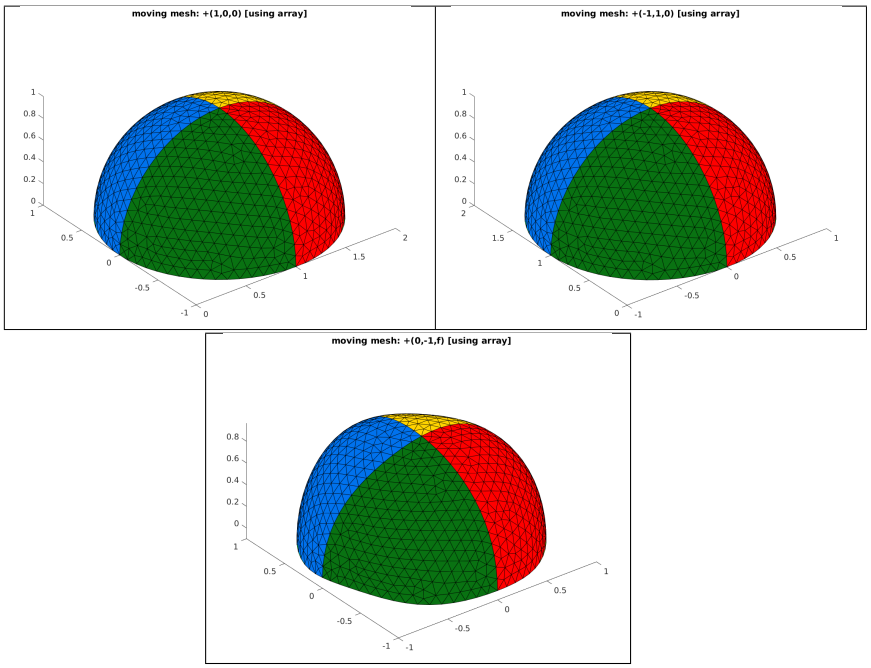
2D example : the following code is part of the **fc_simesh.demos.moveCell2D** function.




```
Th1=Th.copy(); % Deep copy of Th
f=@(x,y) cos(2*x).*sin(3*y)/4;
U=ones(1,Th.nq);

Th1.move({U}, 1) % Th1.move(U, 1) also is OK!
figure(1)
Th1.plotmesh();
axis image; title('moving mesh: +(1,0) [using cell array]')

Th1.move({-U,U}, 1:2)
figure(2)
Th1.plotmesh();
axis image; title('moving mesh: +(-1,1) [using cell array]')

Th1.move({-U;Th.eval(f)},2:3) % Th1 is now a 3D mesh
figure(3)
Th1.plotmesh('edgecolor','none');
```

Listing 16: Using fc_simesh.moveCell function with a 2D mesh

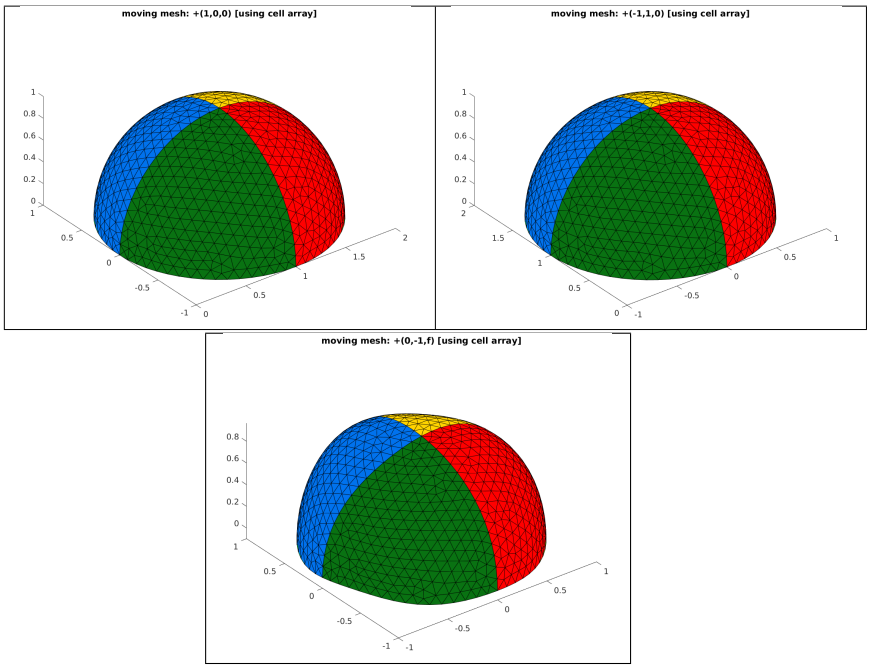
3Ds example : the following code is part of the **fc_simesh.demos.moveArray3Ds** function.




```
Th1=Th.copy(); % Deep copy of Th
f=@(x,y,z) cos(2*x+z).*sin(3*y-z)/10;
U=ones(1,Th.nq);

Th1.move(U,1)
figure(1)
Th1.plotmesh();
axis image; title('moving_mesh:_+(1,0,0)_[using_array]')

Th1.move([-U;U], 1:2)
figure(2)
Th1.plotmesh();
axis image; title('moving_mesh:_+(-1,1,0)_[using_array]')

Th1.move([-U;Th.eval(f)'], 2:3)
figure(3)
Th1.plotmesh();
```

Listing 17: Using fc_simesh.moveArray function with a 3Ds mesh

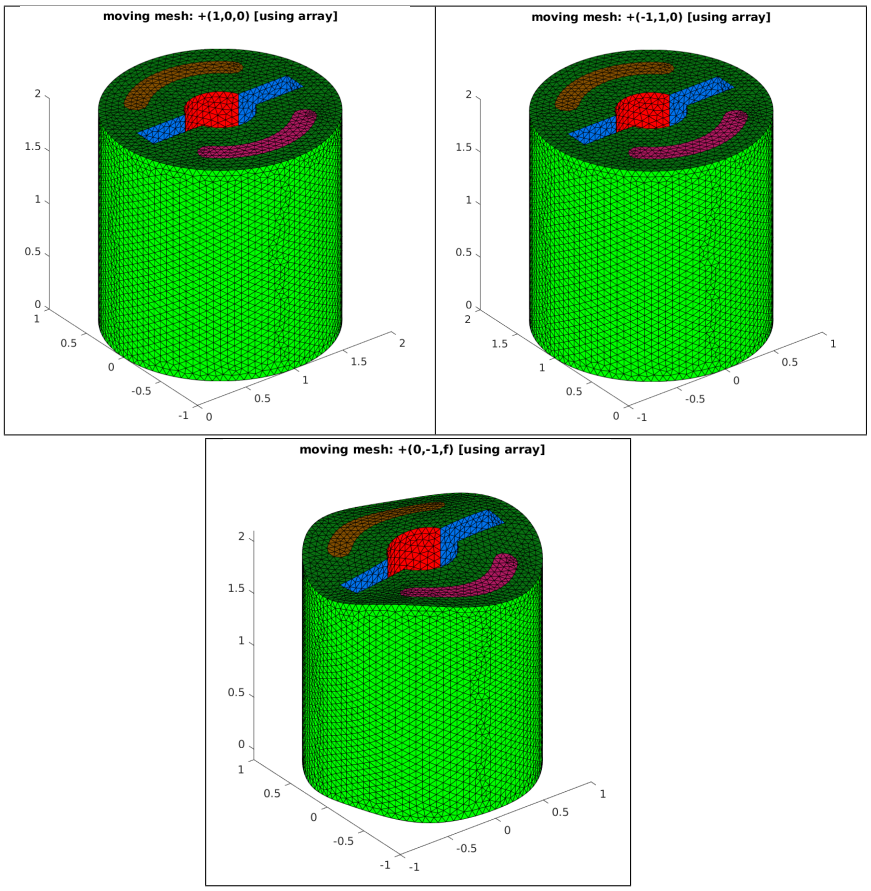
3Ds example : the following code is part of the **fc_simesh.demos.moveCell3Ds** function.




```
Th1=Th.copy();   % Deep copy of Th
f=@(x,y,z) cos(2*x+z).*sin(3*y-z)/10;
U=ones(1,Th.nq);

Th1.move({U},1)
figure(1)
Th1.plotmesh();
axis image;title('moving_mesh:_+(1,0,0)_[using_cell_array]')

Th1.move({-U,U},1:2)
figure(2)
Th1.plotmesh();
axis image;title('moving_mesh:_+(-1,1,0)_[using_cell_array]')

Th1.move({-U;Th.eval(f)}, 2:3)
figure(3)
Th1.plotmesh();
```

Listing 18: Using fc_simesh.moveCell function with a 3Ds mesh

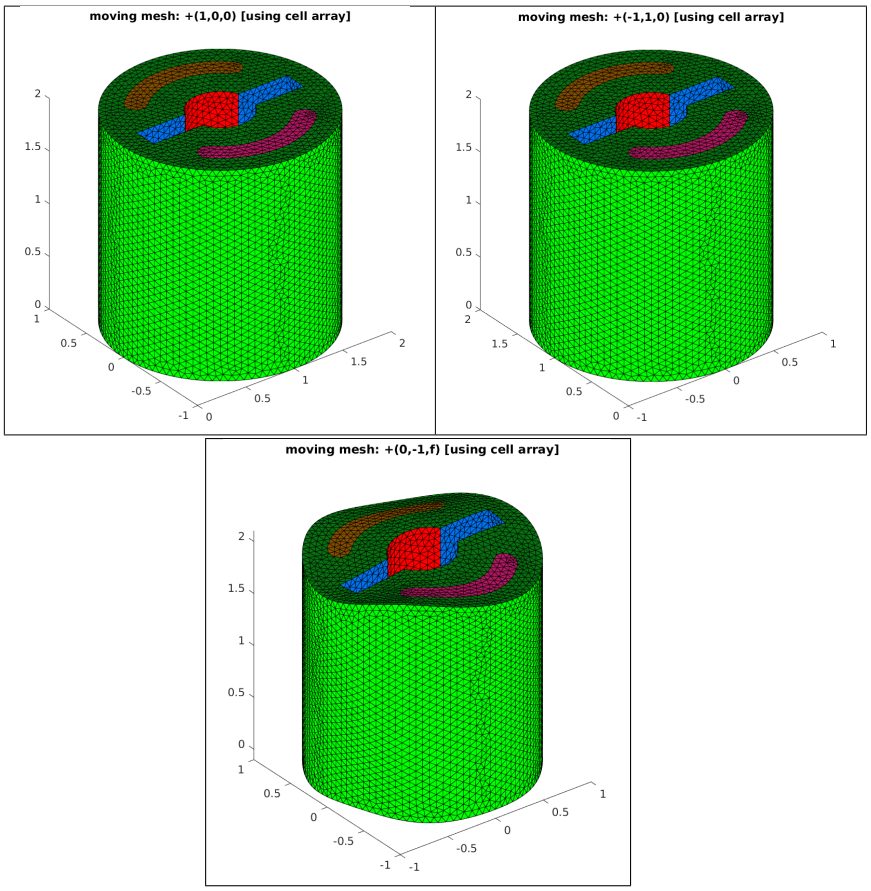
3D example : the following code is part of the **fc_simesh.demos.moveArray3D** function.




```
Th1=Th.copy(); % Deep copy of Th
f=@(x,y,z) cos(2*x+z).*sin(3*y-z)/10;
U=ones(1,Th.nq);

Th1.move(U,1)
figure(1)
Th1.plotmesh('d',2);
axis image; title('moving_mesh:_+(1,0,0)_[using_array]')

Th1.move([-U;U], 1:2)
figure(2)
Th1.plotmesh('d',2);
axis image; title('moving_mesh:_+(-1,1,0)_[using_array]')

Th1.move(['-U',Th.eval(f)]', 2:3) % [-U',Th.eval(f)] is also OK
figure(3)
Th1.plotmesh('d',2);
```

Listing 19: Using fc_simesh.moveArray function with a 3D mesh

3D example : the following code is part of the **fc_simesh.demos.moveCell3D** function.




```
  Th1=Th.copy(); % Deep copy of Th
  f=@(x,y,z) cos(2*x+z).*sin(3*y-z)/10;
  U=ones(1,Th.nq);

  Th1.move({U},1)
  figure(1)
  Th1.plotmesh('d',2);
  axis image; title('moving mesh: +(1,0,0) [using cell array]')

  Th1.move({-U,U}, 1:2)
  figure(2)
  Th1.plotmesh('d',2);
  axis image; title('moving mesh: +(-1,1,0) [using cell array]')

  Th1.move({-U;Th.eval(f)}, 2:3)
  figure(3)
  Th1.plotmesh('d',2);
  axis image; title('moving mesh: +(0,-1,f) [using cell array]')% :start:

  fc_tools.graphics.monitors.autoGrid('covers',0.9);
  if nargout==1,varargout{1}=Th;end
end
```

Listing 20: Using fc_simesh.moveCell function with a 3D mesh

3.4.11 plotmesh method

The plotmesh method displays the mesh or parts of the mesh defined by an fc_simesh.siMesh object.

Syntaxe

```
Th.plotmesh()
Th.plotmesh(Name,Value, ...)
```

Description

`Th.plotmesh()` displays all the (Th.d)-dimensional simplices elements of Th, a **fc_simesh.siMesh** object.

`Th.plotmesh(Name,Value, ...)` specifies function options using one or more Name,Value pair arguments. Options of first level are

- 'd' : to specify the dimension of the simplices elements (default : Th.d)
- 'labels' : to select the labels of the elements to display,
- 'color' : to specify the color of the displayed mesh elements. (default : use one color by displayed mesh elements),
- 'inlegend' : add a legend name to graph if true (default : **false**)
- 'bounds' : If **true**, draw the borders of the selected elementaries mesh elements (only for 2-dimensional simplices). (default : **false**)
- 'cutPlane' : cut mesh by n plans given by n-by-4 array P where the equation of the i-th cut plane is given by

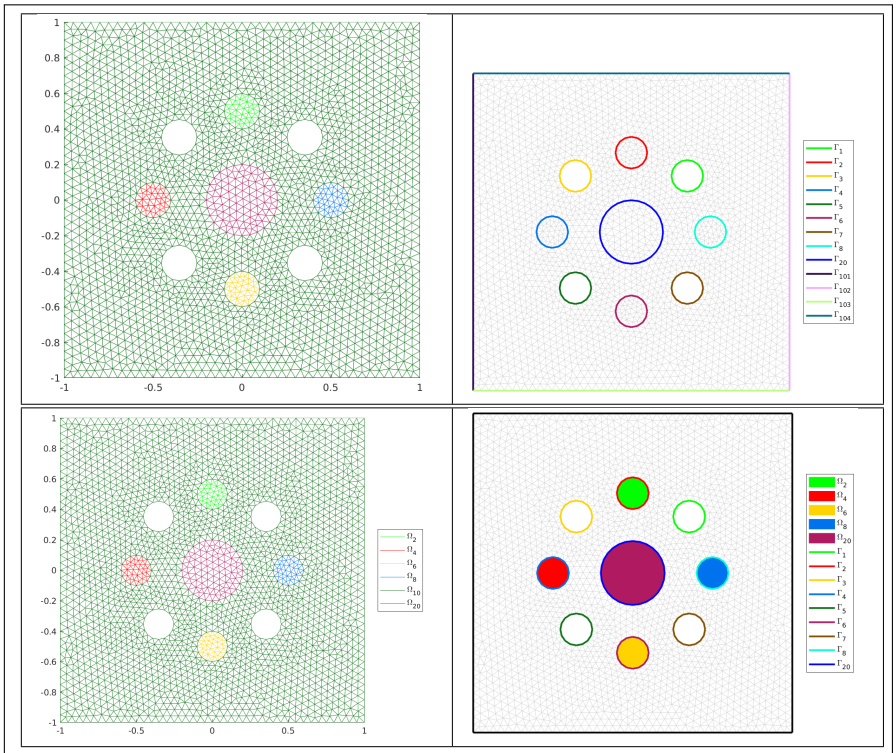
$$P(i,1)\,x + P(i,2)\,y + P(i,3)\,z + P(i,4) = 0.$$

  The normal vector $P(i,1:3)$ pointed to the part of the mesh not displayed. (only for simplices in dimension 3) default : [] (no cut).

The options of second level depend on the type of elementaries mesh elements to represent.
One can use any option of the following functions according to the type of d-simplex to be represented.

- In dimension 3,
  - if $d == 3$, **patch** function is used,
  - if $d == 2$, **trimesh** function is used,
  - if $d == 1$, **plot3** function is used,
  - if $d == 0$, **plot3** function is used,
- In dimension 2,
  - if $d == 2$, **trimesh** function is used,
  - if $d == 1$, **plot** function is used,
  - if $d == 0$, **plot** function is used,
- In dimension 1,
  - if $d == 1$, **line** function is used,
  - if $d == 0$, **plot** function is used,

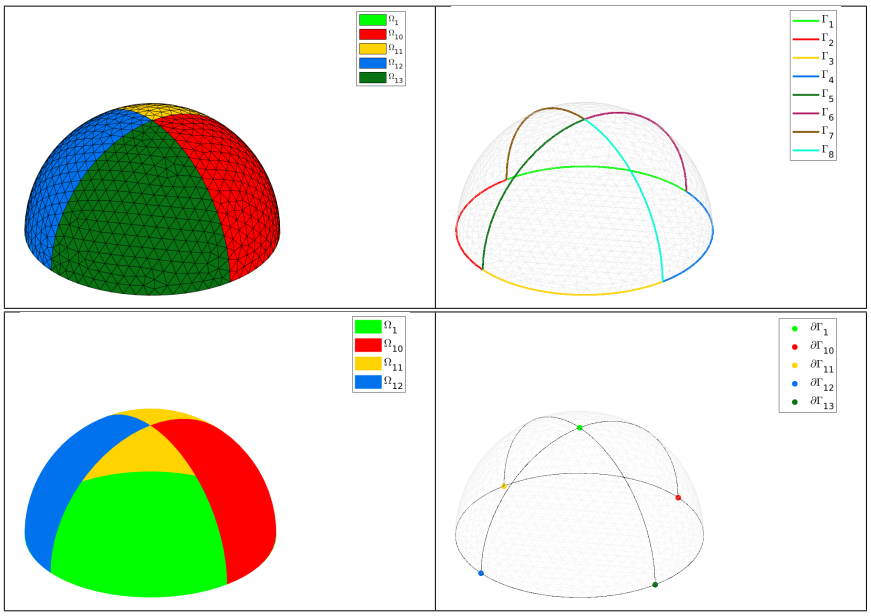
2D example : the following code is part of the **fc_simesh.demos.plotmesh2D** function.



```
meshfile=fc_oogmsh.gmsh.buildmesh2d('condenser11',20,varargin{:});
Th=fc_simesh.siMesh(meshfile);
fc_tools.graphics.monitors.onGrid(2,2);
figure(1)
Th.plotmesh();
axis image

figure(2)
Th.plotmesh('color','LightGray')
hold on;axis image;axis off
Th.plotmesh('d',1,'Linewidth',2,'inlegend',true);
fc_graphics4mesh.legend('Location','eastoutside')

figure(3)
Th.plotmesh('inlegend',true);
axis image
fc_graphics4mesh.legend('Location','eastoutside')

figure(4)
Th.plotmesh('color','LightGray','labels',10)
hold on;axis image;axis off
Th.plotmesh('fill',true,'labels',[2:2:8,20],'inlegend',true)
Th.plotmesh('d',1,'Linewidth',2,'inlegend',true,'labels',[1:8,20]);
Th.plotmesh('d',1,'Linewidth',2,'color','k','labels',[101:104]);
fc_graphics4mesh.legend('Location','eastoutside')
```

Listing 21: Using fc_simesh.plotmesh function with a 2D mesh

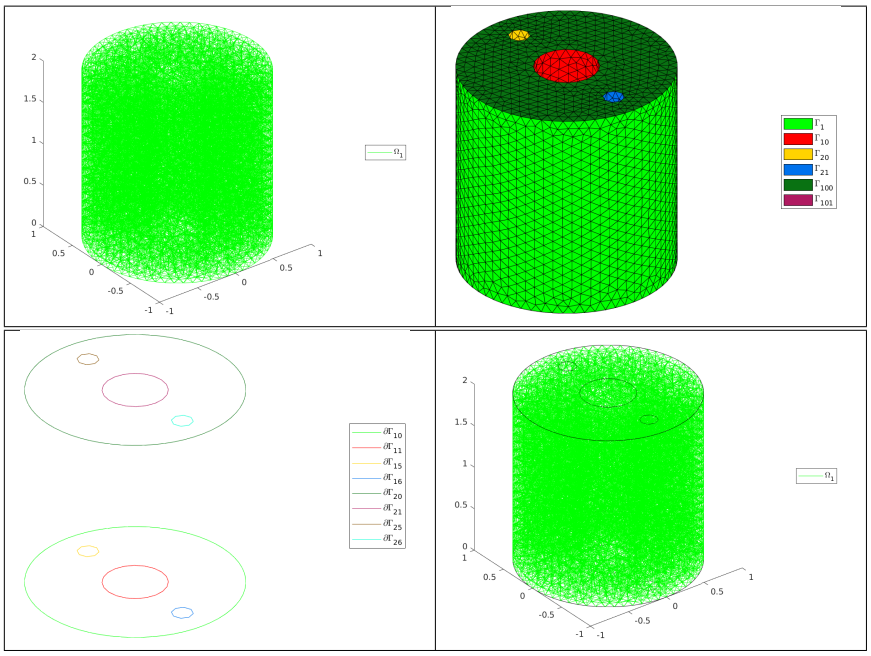
3Ds example : the following code is part of the **fc_simesh.demos.plotmesh3Ds** function.



```
meshfile=fc_oogmsh.buildmesh3ds('demisphere5',10,varargin{:});
Th=fc_simesh.siMesh(meshfile);
fc_tools.graphics.monitors.onGrid(2,2);
figure(1)
Th.plotmesh('inlegend',true)
axis off;axis equal;
fc_graphics4mesh.legend()

figure(2)
Th.plotmesh('EdgeColor','LightGray', 'EdgeAlpha',0.4,'FaceColor','none')
view(3);hold on;axis off;axis equal
Th.plotmesh('d',1,'inlegend',true,'LineWidth',2)
fc_graphics4mesh.legend()
set(legend(),'Location','NorthEastOutside','FontSize',12)

figure(3)
Th.plotmesh('labels',[1,10,11,12],'EdgeColor','none','inlegend',true)
fc_graphics4mesh.legend('Location','NorthEastOutside','FontSize',12)
axis off;axis equal

figure(4)
Th.plotmesh('EdgeColor',0.9*[1,1,1], 'EdgeAlpha',0.4,'FaceColor','none')
hold on;axis off;axis equal
Th.plotmesh('d',1,'color','k')
Th.plotmesh('d',0,'inlegend',true)
fc_graphics4mesh.legend('Location','NorthEastOutside','FontSize',12)
```

Listing 22: Using fc_simesh.plotmesh function with a 3Ds mesh

3D example : the following code is part of the **fc_simesh.demos.plotmesh3D** function.



```
meshfile=fc_oogmsh.gmsh.buildmesh3d('cylinder3holes',10,varargin{:});
Th=fc_simesh.siMesh(meshfile);
fc_tools.graphics.monitors.onGrid(3,3,'figures',1:7);
figure(1)
Th.plotmesh('inlegend',true)
axis image
fc_graphics4mesh.legend('Location','EastOutside')

figure(2)
Th.plotmesh('d',2,'inlegend',true);
axis image;axis off
fc_graphics4mesh.legend('Location','EastOutside')

figure(3)
Th.plotmesh('d',1,'inlegend',true);
axis image;axis off
fc_graphics4mesh.legend('Location','EastOutside')

figure(4)
Th.plotmesh('inlegend',true)
hold on
Th.plotmesh('d',1,'color','k');
axis image
fc_graphics4mesh.legend('Location','EastOutside')

figure(5)
Th.plotmesh('d',2,'inlegend',true);
axis image
fc_graphics4mesh.legend('Location','EastOutside')

figure(6)
Th.plotmesh('d',2,'edgecolor',0.8*[1 1 1],'facecolor','None','edgealpha',0.5)
hold on;axis image
Th.plotmesh('d',1,'inlegend',true);
fc_graphics4mesh.legend('Location','EastOutside')

figure(7)
P=[fc_tools.graphics.PlaneCoefs([0 0 1],[0 0 1]); ...
    fc_tools.graphics.PlaneCoefs([0 0 1],[-1 0 0])];
Th.plotmesh('cutPlane',P,'Color','DarkGrey')
hold on;axis image
Th.plotmesh('d',2,'cutPlane',P,'inlegend',true);
fc_graphics4mesh.legend('Location','EastOutside')
```

Listing 23: Using fc_simesh.plotmesh function with a 3D mesh

3.4.12 plot method

The **plot** method displays scalar datas on the mesh or parts of the mesh defined by an **fc_simesh.siMesh** object. We denote by Th a **fc_simesh.siMesh** object.

Syntaxe

```
Th.plot(u)
Th.plot(u,Name,Value, ...)
```

Description

Th.**plot**(u) displays data u on all the (Th.d)-dimensional simplices elements of Th, a **fc_simesh.siMesh** object. The data u is an 1D-array of size Th.nq or Th.nqGlobal or Th.nqParent.

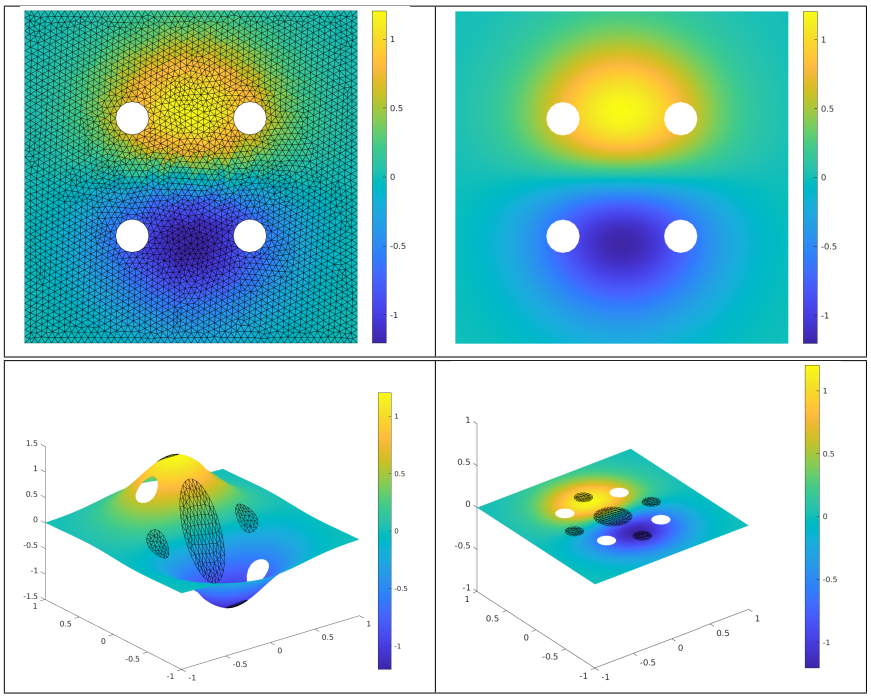
Th.**plot**(u,Name,Value, ...) specifies function options using one or more Name,Value pair arguments. Options of first level are

- 'd' : to specify the dimension of the simplices elements (default : Th.d)
- 'labels' : to select the labels of the elements to display data,
- 'plane' : if true, made a 2D representation in the xy-plane, otherwise made a 3D representation with z-value set to u (default : **false**)

The options of second level depend on the type of elementaries mesh elements on which we want to represent datas.
One can use any option of the following functions according to the type of d-simplex.

- In dimension 3, **patch** function is used for $d \in [\![1, 3]\!]$.
- In dimension 2,
  - for $d == 2$, if 'plane' option is true, **patch** function is used, otherwise it's **trisurf** function,
  - for $d == 1$, **patch** function is used.
- In dimension 1 and $d == 1$, **plot** function is used

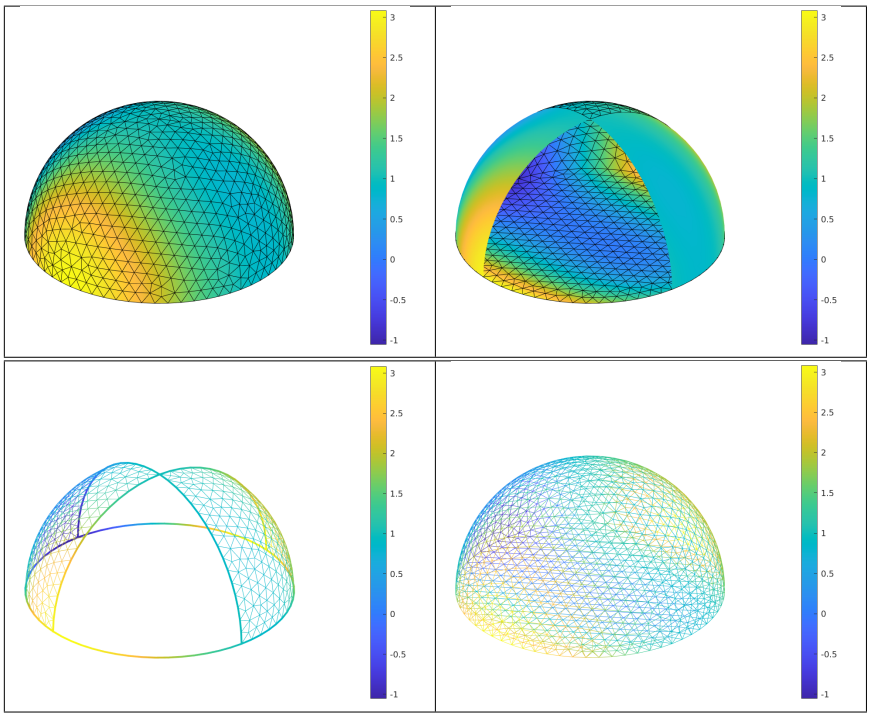
2D example : the following code is part of the **fc_simesh.demos.plot2D** function.



```
geofile=fc_simesh.get_geo(2,2,'condenser11');
meshfile=fc_oogmsh.gmsh.buildmesh2d(geofile,25,'verbose',0,varargin{:});
Th=fc_simesh.siMesh(meshfile);
u=Th.eval(@(x,y) 5*exp(-3*(x.^2+y.^2)).*cos(x).*sin(y));
figure(1)
Th.plot(u)
axis off;axis image;colorbar

figure(2)
Th.plot(u)
axis off;axis image;shading interp;colorbar

figure(3)
Th.plot(u,'labels',[2:2:8,20],'FaceColor','interp')
view(3);hold on;colorbar
Th.plot(u,'labels',10,'FaceColor','interp','EdgeColor','none')

figure(4)
Th.plot(u,'labels',[2:2:8,20], 'plane',true ,'FaceColor','interp')
view(3);hold on;axis image;colorbar
Th.plot(u,'labels',10, 'plane',true, 'FaceColor','interp','EdgeColor','none')
colorbar
```

Listing 24: Using fc_simesh.plot function with a 2D mesh

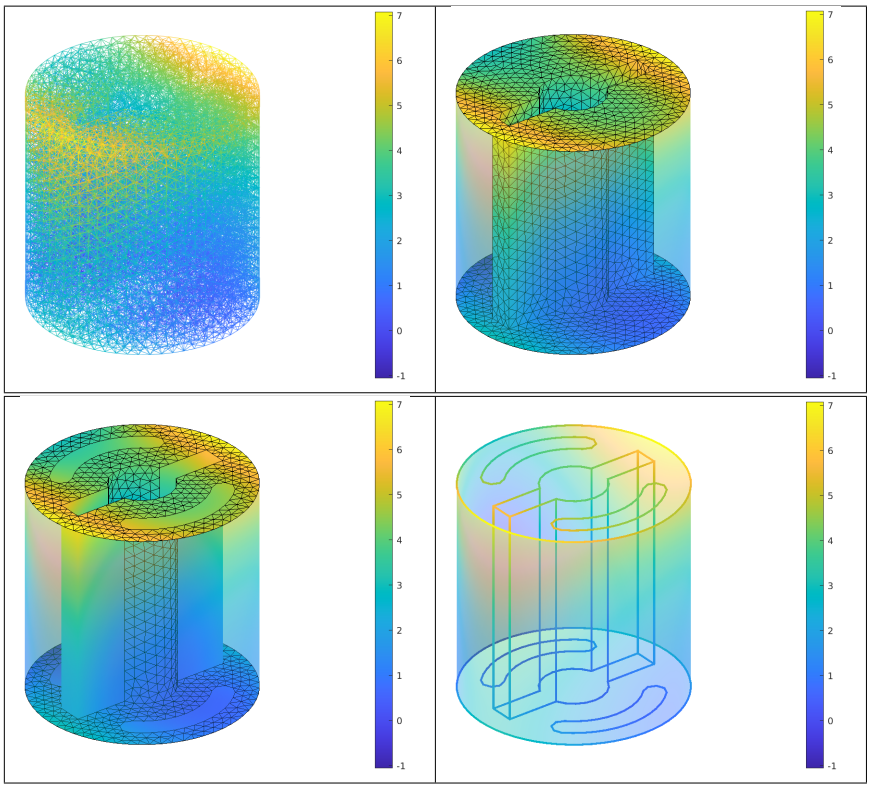
3Ds example : the following code is part of the **fc_simesh.demos.plot3Ds** function.



```
geofile=fc_simesh.get_geo(3,2,'demisphere5');
meshfile=fc_oogmsh.buildmesh3ds(geofile,10,varargin{:});
Th=fc_simesh.siMesh(meshfile);
u=Th.eval(@(x,y,z) 3*x.^2-y.^3+z.^2+x.*y);
figure(1)
Th.plot(u)
axis off;axis image;colorbar;
figure(2)
Th.plot(u,'labels',[1,11])
hold on;axis off;axis image;colorbar;
Th.plot(u,'labels',[10,12], 'FaceColor','interp', 'EdgeColor','none')
figure(3)
Th.plot(u,'d',1,'LineWidth',2)
hold on;axis off;axis image;colorbar
Th.plot(u,'labels',[10,12], 'FaceColor','none', 'EdgeColor','interp')
figure(4)
Th.plot(u,'FaceColor','none', 'EdgeColor','interp')
axis off;axis image;colorbar;
```

Listing 25: Using fc_simesh.plot function with a 3Ds mesh

3D example : the following code is part of the **fc_simesh.demos.plot3D** function.



```
geofile=fc_simesh.get_geo(3,3,'cylinderkey03');
meshfile=fc_oogmsh.buildmesh3d(geofile,10,varargin{:});
Th=fc_simesh.siMesh(meshfile);
u=Th.eval(@(x,y,z) 3*x.^2-y.^3+z.^2+x.*y);
figure(1)
Th.plot(u);
axis off;axis image;colorbar
figure(2)
Th.plot(u,'d',2,'labels',[10,11,31,1000,1020,1021,2000,2020,2021])
hold on;axis off;axis image;colorbar
Th.plot(u,'d',2,'labels',1,'FaceColor','interp', ...
    'EdgeColor','none','FaceAlpha',0.4)
figure(3)
Th.plot(u,'d',2,'labels',1,'FaceColor','interp', ...
    'EdgeColor','none','FaceAlpha',0.4)
hold on;axis off;axis image;colorbar
Th.plot(u,'d',2,'labels',[10,11,1000,2000])
Th.plot(u,'d',2,'labels',[31,1020,1021,2020,2021], ...
    'FaceColor','interp','EdgeColor','none')
figure(4)
Th.plot(u,'d',2,'labels',1,'FaceColor','interp', ...
    'EdgeColor','none','FaceAlpha',0.4)
hold on;axis off;axis image;colorbar
Th.plot(u,'d',1,'LineWidth',2)
```

Listing 26: Using fc_simesh.plot function with a 3D mesh

3.4.13 plotiso method

The plotiso method displays isolines from datas on the mesh or parts of the mesh defined by an fc_simesh.siMesh object. This function only works with 2-simplices in space dimension 2 or 3.

Syntaxe

```
Th.plotiso(u)
Th.plotiso(u,Name,Value, ...)
```

Description

`Th.plotiso(u)` displays data u on all the 2-dimensional simplices elements of Th, a **fc_simesh.siMesh** object.. The data u is an 1D-array of size Th.nq or Th.nqGlobal or Th.nqParent.

`Th.plotiso(u,key,value, ...)` specifies function options using one or more key,value pair arguments. Options of first level are

- 'niso' : to specify the number of isolines (default : 10)
- 'isorange' : to specify the list of isovalues (default : empty)
- 'isocolorbar' : if **true**, colorbar with isovalues is drawn (default : **false**)
- 'format' : to specify the format of the isovalues on the colorbar (default : '%g')
- 'labels' : to select the labels of the elements to display data,
- 'plane' : if true, isolines are in the xy-plane, otherwise isolines are in 3D with z-value set to u (default : **false**)
- 'color' : to specify one color for all isolines (default : empty)
- 'mouse' : if **true**, display information on clicked isoline (default : **false**)

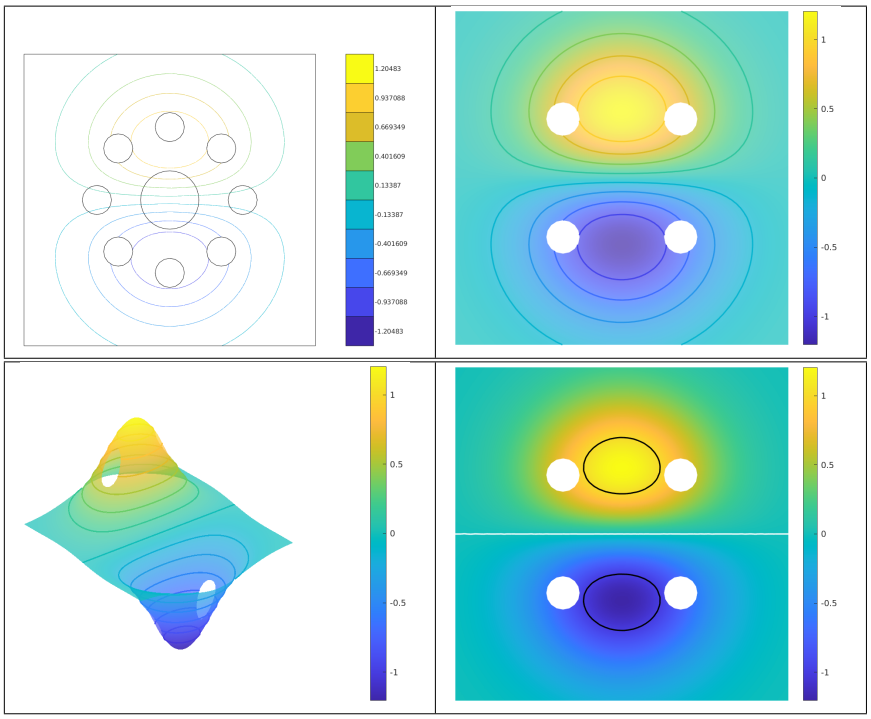
The options of second level are all options of

- **plot3** function in dimension 3 or in dimension 2 with 'plane' option set to **false**
- **plot** function in 2 with 'plane' option set to **true**

This function accepts until 4 output arguments :

- 1st output is the colors of the isolines
- 2nd output is the isovalues of the isolines
- 3th output is the handle of the colobar iso.
- 4th output is all the handles of the isolines as an 2D-array of dimension N-by-niso, where N is the number of 2-simplex elementary meshes where isolines are drawn.

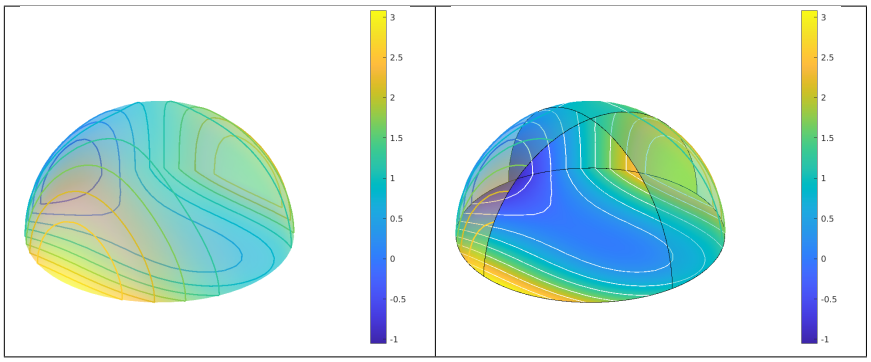
2D example : the following code is part of the **fc_simesh.demos.plotiso2D** function.



```
meshfile=fc_oogmsh.gmsh.buildmesh2d('condenser11',25,varargin{:});
Th=fc_simesh.siMesh(meshfile);
u=Th.eval(@(x,y) 5*exp(-3*(x.^2+y.^2)).*cos(x).*sin(y));
figure(1)
Th.plotmesh('d',1,'color','k')
hold on;axis off;axis image;
Th.plotiso(u,'isocolorbar',true)
figure(2)
Th.plot(u,'plane',true,'FaceAlpha',0.7)
hold on;axis off;axis image;shading interp;
Th.plotiso(u,'plane',true,'LineWidth',1.5)
colorbar
figure(3)
Th.plot(u,'FaceAlpha',0.7)
view(3)
shading interp;hold on;axis off;axis image;
Th.plotiso(u,'niso',15,'LineWidth',1.5)
colorbar
figure(4)
Th.plot(u,'plane',true)
shading interp;hold on;axis off;axis image;
Th.plotiso(u,'isorange',0, 'LineWidth',1.5, 'color','w')
Th.plotiso(u,'isorange',[-1,1], 'LineWidth',1.5, 'color','k','plane',true)
axis off;axis image;colorbar
```

Listing 27: Using fc_simesh.plotiso function with a 2D mesh

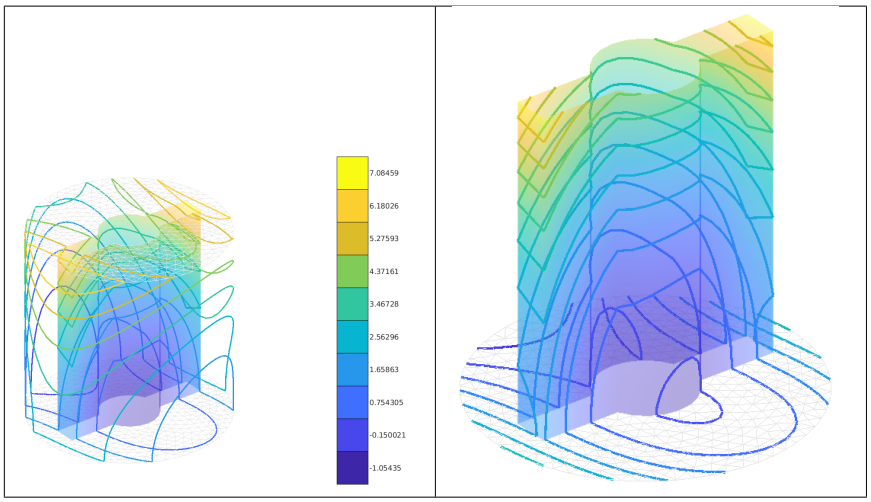
3Ds example : the following code is part of the **fc_simesh.demos.plotiso3Ds** function.



```
meshfile=fc_oogmsh.gmsh.buildmesh3ds('demisphere5',10,varargin{:});
Th=fc_simesh.siMesh(meshfile);
u=Th.eval(@(x,y,z) 3*x.^2-y.^3+z.^2+x.*y);
figure(1)
Th.plot(u,'FaceColor','interp', 'EdgeColor','none','FaceAlpha',0.4)
hold on;axis off;axis equal;colorbar
Th.plotiso(u,'LineWidth',1.5)
figure(2)
Th.plot(u,'labels',[1,11],'FaceColor','interp', 'EdgeColor','none')
hold on;axis off;axis equal;colorbar;
Th.plotiso(u,'labels',[1,11],'LineWidth',1.,'color','w')
Th.plot(u,'labels',[10,12],'FaceColor','interp', ...
    'EdgeColor','none','FaceAlpha',0.4)
Th.plotiso(u,'labels',[10,12],'LineWidth',1.5)
Th.plotmesh('d',1,'Color','k')
```

Listing 28: Using fc_simesh.plotiso function with a 3Ds mesh

3D example : the following code is part of the **fc_simesh.demos.plotiso3D** function.




```
geofile=fc_simesh.get_geo(3,3,'cylinderkey');
meshfile=fc_oogmsh.gmsh.buildmesh3d(geofile,10,varargin{:});
Th=fc_simesh.siMesh(meshfile);
u=Th.eval(@(x,y,z) 3*x.^2-y.^3+z.^2+x.*y);
figure(1)
Th.plot(u,'d',2,'labels',[10,11,31],'FaceColor','interp', ...
    'EdgeColor','none','FaceAlpha',0.4)
hold on;view(3);axis off;axis equal;
Th.plotmesh('d',2,'labels',[1000,1020,1021,2000,2020,2021], ...
    'FaceColor','none','EdgeColor',0.9*[1,1,1])
Th.plotiso(u,'isocolorbar',true,'LineWidth',1.5)
figure(2)
Th.plot(u,'d',2,'labels',[10,11,31],'FaceColor','interp', ...
    'EdgeColor','none','FaceAlpha',0.4)
hold on;axis off;axis equal;
Th.plotmesh('d',2,'labels',[2000,2020,2021], ...
    'FaceColor','none','EdgeColor',0.9*[1,1,1])
Th.plotiso(u,'labels',[10,11,31,2000,2020,2021],'LineWidth',1.5, 'niso',15)
```

Listing 29: Using fc_simesh.plotiso function with a 3D mesh

3.4.14 slicemesh method

The **slicemesh** method displays intersection of a plane and a 3D mesh or parts of a 3D mesh defined by an **fc_simesh.siMesh** object.

Syntaxe

```
Th.slicemesh(P)
Th.slicemesh(P,Name,Value, ...)
```

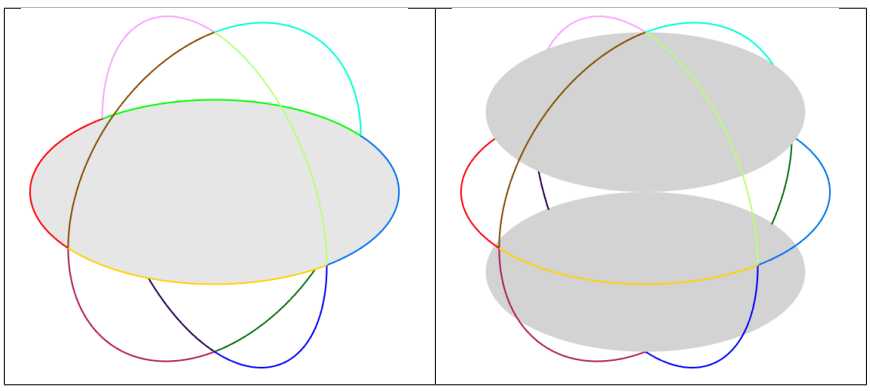
Description

Th.**slicemesh**(P) displays intersection of the plane defined by $P(1)x+P(2)y+P(3)z+P(4)=0$ and all the 3-dimensional simplices elements of Th, a **fc_simesh.siMesh** object. To compute P one can use the function fc_tools.graphics.PlaneCoefs of the toolbox. With this function, the array P, is obtained with P=fc_tools.graphics.PlaneCoefs(Q,V) where Q is a point in the plane and V is a vector orthogonal to it.

Th.**slicemesh**(P,Name,Value, ...) specifies function options using one or more Name,Value pair arguments. Options of first level are

- 'color' : to specify the slice color (default : 'lightgrey', rgb =[0.9,0.9,0.9])
- 'labels' : to select the labels of the elements to intersect,

3D example The following example use the *.geo* file `ball8.geo` which is in the directory `geodir` of the toolbox. This file contains description of a 3D mesh with simplices of dimensions 1, 2 and 3.



```
meshfile=fc_oogmsh.buildmesh3d('ball8',ns*10,'verbose',0);
Th=fc_simesh.siMesh(meshfile);
figure(1)
Th.plotmesh('d',1,'LineWidth',1)
hold on;axis off;axis image;
P=fc_tools.graphics.PlaneCoefs([0 0 0],[0 0 1]);
Th.slicemesh(P,'color',0.9*[1 1 1])
figure(2)
P=[fc_tools.graphics.PlaneCoefs([0 0 -0.5],[0 0 1]); ...
   fc_tools.graphics.PlaneCoefs([0 0 0.5],[0 0 1])];
Th.plotmesh('d',1,'LineWidth',1);
hold on;axis off;axis image;
Th.slicemesh(P,'Color','LightGray')
```

Listing 30: 3D mesh : slicemesh method

3.4.15 slice method

The method slice method displays datas on the intersection of a plane and a 3D mesh or parts of a 3D mesh defined by an fc_simesh.siMesh object.

Syntaxe

```
Th.slice(u,P)
Th.slice(u,P,Name,Value, ...)
```

Description

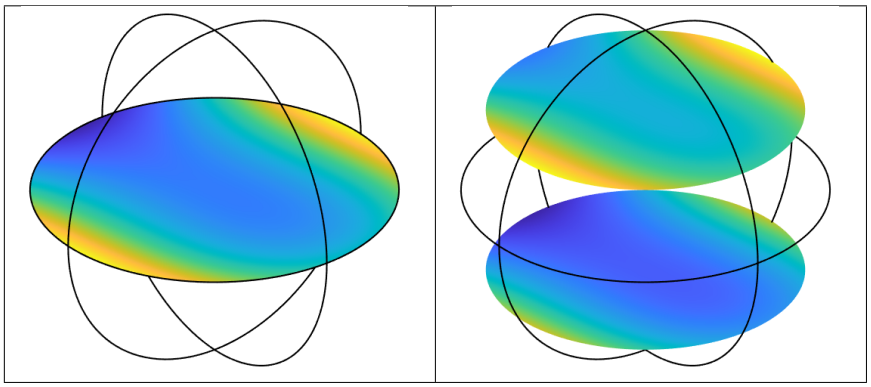
Th.**slice**(u,P) displays u data on the intersection of the plane defined by $P(1)x + P(2)y + P(3)z + P(4) = 0$ and all the 3-dimensional simplices elements of Th, a fc_simesh.siMesh object. The data u is an 1D-array of

size Th.nq or Th.nqGlobal or Th.nqParent. To compute P one can use the function fc_tools.graphics.PlaneCoefs of the toolbox. With this function, the array P, is obtained with P=fc_tools.graphics.PlaneCoefs(Q,V) where Q is a point in the plane and V is a vector orthogonal to it.

Th.**slice**(u,P,Name,Value, ...) specifies function options using one or more Name,Value pair arguments. Options of first level are

- 'labels' : to select the labels of the elements to intersect,

3D example The following example use the *.geo* file `ball8.geo` which is in the directory `geodir` of the toolbox. This file contains description of a 3D mesh with simplices of dimensions 1, 2 and 3.



```
meshfile=fc_oogmsh.buildmesh3d('ball8',ns*10,'verbose',0);
Th=fc_simesh.siMesh(meshfile);
u=Th.eval(@(x,y,z) 3*x.^2-y.^3+z.^2+x.*y+z);
figure(1)
Th.plotmesh('d',1,'LineWidth',1,'color','k')
hold on;axis off;axis image;
P=fc_tools.graphics.PlaneCoefs([0 0 0],[0 0 1]);
Th.slice(u,P,'Facecolor','interp')
figure(2)
P=[fc_tools.graphics.PlaneCoefs([0 0 -0.5],[0 0 1]); ...
   fc_tools.graphics.PlaneCoefs([0 0 0.5],[0 0 1])];
Th.plotmesh('d',1,'LineWidth',1,'color','k');
hold on;axis off;axis image;
Th.slice(u,P,'Facecolor','interp')
```

Listing 31: 3D mesh :slice method

3.4.16 sliceiso method

The **sliceiso** method displays isolines of data on the intersection of a plane and a 3D mesh or parts of a 3D mesh defined by an **fc_simesh.siMesh** object.

Syntaxe

```
Th.sliceiso(u,P)
Th.sliceiso(u,P,Name,Value, ...)
```

Description

Th.**sliceiso**(u,P) displays u data as isolines on the intersection of the plane defined by $P(1)x + P(2)y + P(3)z + P(4) = 0$ and all the 3-dimensional simplices elements of Th, a **fc_simesh.siMesh** object. The data u is an 1D-array of size Th.nq or Th.nqGlobal or Th.nqParent. To compute P one can use the function fc_tools.graphics.PlaneCoefs of the toolbox. With this function, the array P, is obtained with P=fc_tools.graphics.PlaneCoefs(Q,V) where Q is a point in the plane and V is a vector orthogonal to the plane.

Th.**sliceiso**(u,P,key,value, ...) allows additional key/value pairs to be used when displaying u. The key strings could be

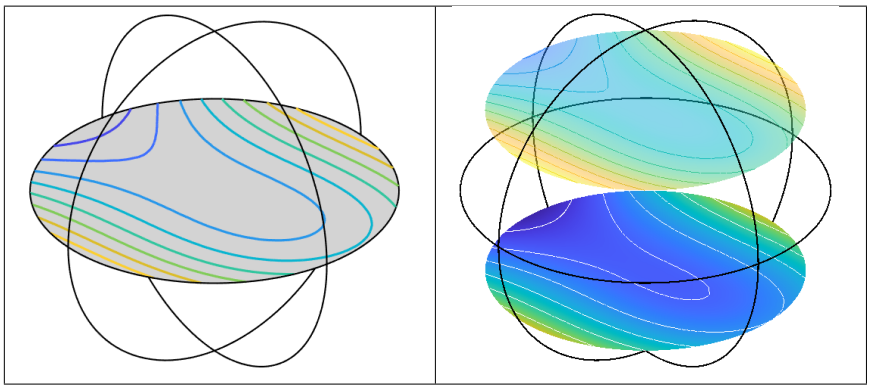
- 'labels' : to select the labels of the elements to intersect,
- 'niso' : to specify the number of isolines (default : 10)
- 'isorange' : to specify the list of isovalues (default : empty)
- 'color' : to specify one color for all isolines (default : empty)
- 'isocolorbar' : if true display a colorbar.Default is false.
- 'format' : to specify the format of the isovalues print in the colorbar. Default is `'%g'`.

For key strings, one could also used any options of the plot3 function.

This function accepts until 4 output arguments :

- 1st output is the colors of the isolines
- 2nd output is the isovalues of the isolines
- 3th output is the handle of the colobar iso.
- 4th output is all the handles of the isolines as an 2D-array of dimension N-by-niso, where N is the number of elementary meshes where isolines are drawn.

3D example The following example use the *.geo* file `ball8.geo` which is in the directory `geodir` of the toolbox. This file contains description of a 3D mesh with simplices of dimensions 1, 2 and 3.



```
meshfile=fc_oogmsh.buildmesh3d('ball8',ns*10,'verbose',0);
Th=fc_simesh.siMesh(meshfile);
u=Th.eval(@(x,y,z) 3*x.^2-y.^3+z.^2+x.*y+z);
figure(1)
Th.plotmesh('d',1,'LineWidth',1,'color','k')
hold on;axis off;axis image;
P=fc_tools.graphics.PlaneCoefs([0 0 0],[0 0 1]);
Th.slicemesh(P)
Th.sliceiso(u,P,'LineWidth',1.5)
figure(2)
Th.plotmesh('d',1,'LineWidth',1,'color','k')
hold on;axis off;axis image;
P2=fc_tools.graphics.PlaneCoefs([0 0 -0.5],[0 0 1]);
Th.slice(u,P2)
Th.sliceiso(u,P2,'color','w')
P3=fc_tools.graphics.PlaneCoefs([0 0 0.5],[0 0 1]);
Th.slice(u,P3,'FaceAlpha',0.5)
Th.sliceiso(u,P3,'niso',15)
```

Listing 32: 3D mesh :sliceiso method

3.4.17 plotquiver method

The **plotquiver** method displays vector field datas on the mesh or parts of the mesh defined by an **fc_simesh.siMesh** object.

Syntaxe

```
Th.plotquiver(V)
Th.plotquiver(V,Key,Value, ...)
```

Description

Th.**plotquiver**(V) displays vector field U on all the d-dimensional simplices elements in dimension $d = 2$ or $d = 3$. The data V is an 2D-array of size Th.nq-by-d or 2-by-Th.nq.

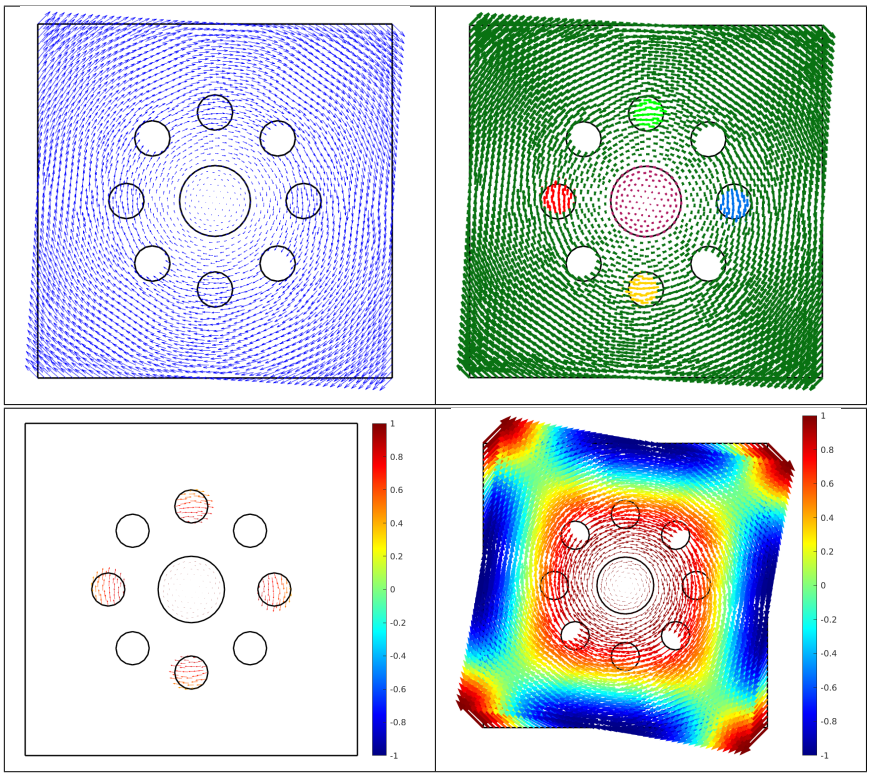
Th.**plotquiver**(V,Key,Value, ...) specifies function options using one or more Key,Value pair arguments. Options of first level are

- 'labels' : to select the labels of the elements to display data,
- 'freq' : quiver frequencie, (default : 1)
- 'scale' : quiver scale, (default : ...)
- 'colordata' : set colors on each quiver (default : empty).

The options of second level depend on space dimension and 'colordata' option. One can use any option of the following functions

- **quiver** function in dimension 2 with an empty 'colordata'
- quiver3 function in dimension 3 with an empty 'colordata'
- vfield3 function in dimension 2 or 3 with 'colordata' set to an 1D-array of length Th.nq.

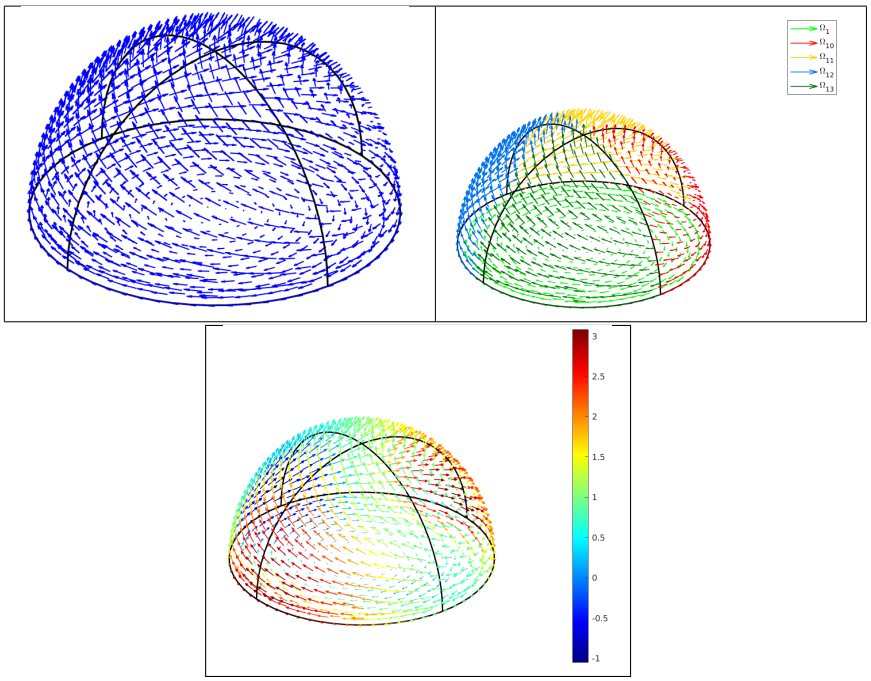
2D example : the following code is part of the **fc_simesh.demos.plotquiver2D** function.



```
geofile=fc_simesh.get_geo(2,2,'condenser11');
meshfile=fc_oogmsh.buildmesh2d(geofile,25,varargin{:});
Th=fc_simesh.siMesh(meshfile);

u=@(x,y) cos(pi*x.^2).*cos(pi*y.^2);
U=Th.eval(u);
w={@(x,y) y.*cos(-(x.^2+y.^2)/10),@(x,y) -x.*cos(-(x.^2+y.^2)/10)};
W=Th.eval(w);

figure(1)
Th.plotmesh('d',1,'color','k', 'LineWidth',1.5)
hold on;axis off;axis image
Th.plotquiver(W)

figure(2)
Th.plotmesh('d',1,'color','k', 'LineWidth',1.5)
hold on;axis off;axis image
Th.plotquiver(W,'LineWidth',2,'merge',false)

figure(3)
Th.plotmesh('d',1,'color','k', 'LineWidth',1.5)
hold on;axis off;axis image
Th.plotquiver(W,'colordata',U,'labels',[2:2:8,20])
caxis([min(U) max(U)])
colormap('jet');colorbar

figure(4)
Th.plotmesh('d',1,'color','k', 'LineWidth',1.5)
hold on;axis off;axis image
Th.plotquiver(W,'colordata',U, 'scale',0.2)
colormap('jet');colorbar
```

Listing 33: Using fc_simesh.plotquiver function with a 2D mesh

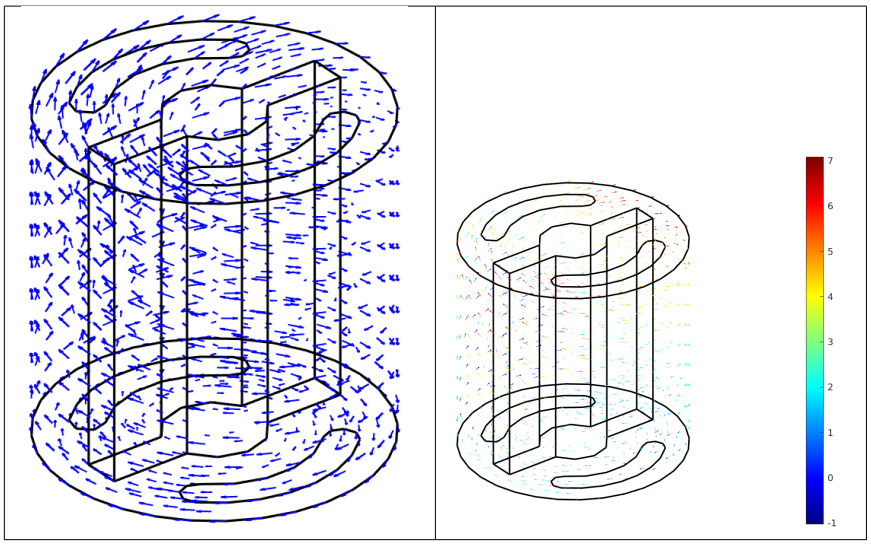
3Ds example : the following code is part of the **fc_simesh.demos.plotquiver3Ds** function.



```
geofile=fc_simesh.get_geo(3,2,'demisphere5');
meshfile=fc_oogmsh.gmsh.buildmesh3ds(geofile,10,varargin{:});
Th=fc_simesh.siMesh(meshfile);

w={@(x,y,z) y.*cos(-(x.^2+y.^2)/10),@(x,y,z) -x.*cos(-(x.^2+y.^2)/10),@(x,y,z) ...
    z };
W=Th.eval(w);
u=Th.eval(@(x,y,z) 3*x.^2-y.^3+z.^2+x.*y);

figure(1)
Th.plotmesh('d',1,'color','k', 'LineWidth',1.5)
hold on;axis off;axis image
Th.plotquiver(W,'LineWidth',1)

figure(2)
Th.plotmesh('d',1,'color','k', 'LineWidth',1.5)
hold on;axis off;axis image
Th.plotquiver(W,'LineWidth',1,'merge',false,'inlegend',true)
fc_graphics4mesh.legend()

figure(3)
Th.plotmesh('d',1,'color','k', 'LineWidth',1.5)
hold on;axis off;axis image
Th.plotquiver(W,'colordata',u, 'scale',0.1)
colormap('jet');colorbar
```

Listing 34: Using fc_simesh.plotquiver function with a 3Ds mesh

3D example : the following code is part of the **fc_simesh.demos.plotquiver3D** function.



```
geofile=fc_oogmsh.get_geo(3,3,'cylinderkey');
meshfile=fc_oogmsh.buildmesh3d(geofile,5,varargin{:});
Th=fc_simesh.siMesh(meshfile);

w={@(x,y,z) y.*cos(-(x.^2+y.^2)/10),@(x,y,z) -x.*cos(-(x.^2+y.^2)/10),@(x,y,z) ...
    z/5 };
W=Th.eval(w);
u=Th.eval(@(x,y,z) 3*x.^2-y.^3+z.^2+x.*y);
fc_tools.graphics.monitors.onGrid(1,2);
figure(1)
Th.plotmesh('d',1,'color','k', 'LineWidth',1.5)
hold on
Th.plotquiver(W,'LineWidth',1)
axis off;axis image

figure(2)
Th.plotmesh('d',1,'color','k', 'LineWidth',1.5)
hold on
Th.plotquiver(W,'colordata',u, 'scale',0.05)
axis off;axis image
colormap('jet');colorbar
```

Listing 35: Using fc_simesh.plotquiver function with a 3D mesh

3.4.18 scatter method

The scatter method displays scalar datas as colorized points on the mesh or parts of the mesh defined by an **fc_simesh.siMesh** object.

Syntaxe

```
Th.scatter(u)
Th.scatter(u,Name,Value, ...)
```

Description

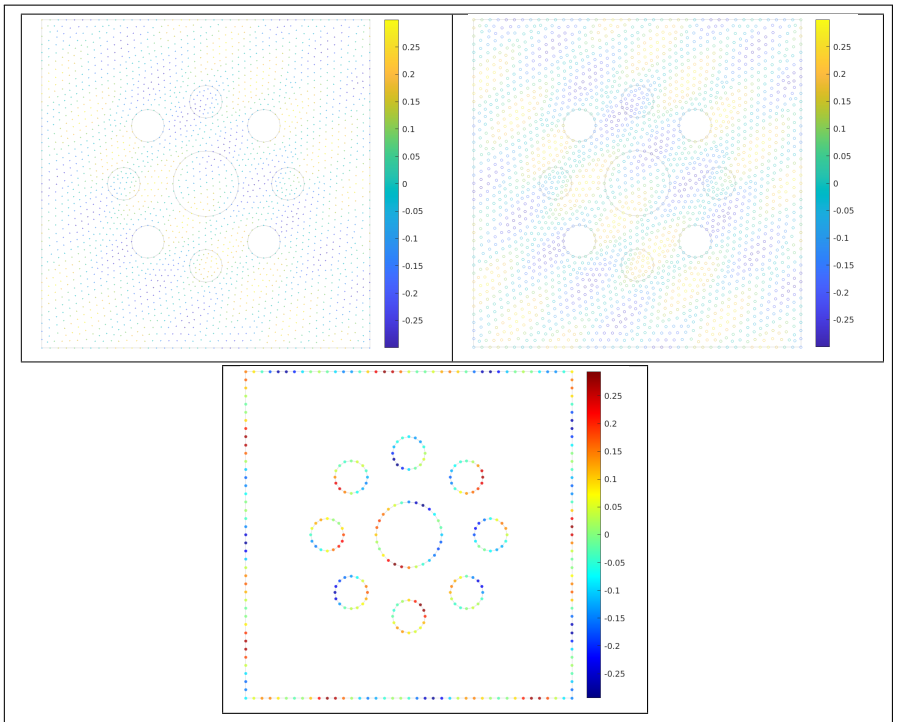
Th.scatter(u) displays data u on all the (Th.d)-dimensional simplices elements of Th, a **fc_simesh.siMesh** object. The data u is an 1D-array of size Th.nq or Th.nqGlobal or Th.nqParent.

`Th.scatter(u,Name,Value, ...)` specifies function options using one or more Name,Value pair arguments. Options of first level are

- 'd' : to specify the dimension of the simplices elements (default : Th.d)
- 'labels' : to select the labels of the elements to display data,
- 'MarkerSize' : size of the marker. Default is 1.
- 'ForcePatch' : if **true**, uses **patch** function, otherwise uses scatter function in dimension 2 or scatter3 function in dimension 3. Default is **false**.

The options of second level are those of the function used (see 'ForcePatch' option).

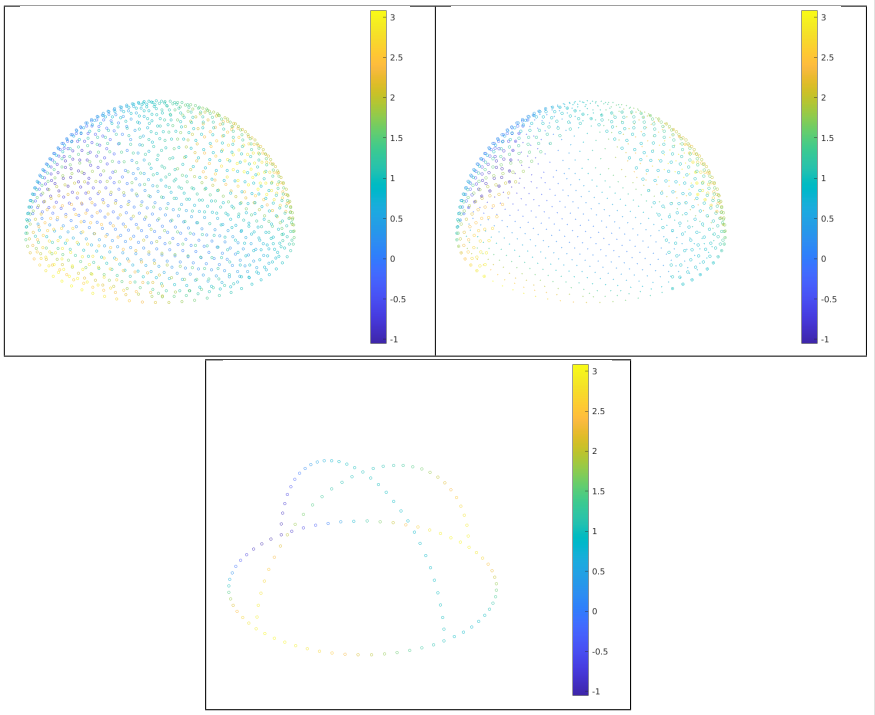
2D example : the following code is part of the **fc_simesh.demos.scatter2D** function.



```
meshfile=fc_oogmsh.gmsh.buildmesh2d('condenser11',20,varargin{:});
Th=fc_simesh.siMesh(meshfile);
u=@(x,y) 0.3*cos(5*(2*x-y)).*sin(5*(x-2*y));
U=Th.eval(u);
figure(1)
Th.plotmesh('d',1,'color','LightGray')
hold on
Th.scatter(U);
axis image;axis off;
colorbar
figure(2)
Th.plotmesh('d',1,'color','LightGray')
hold on  % '*Alpha' options not yet implemented under Octave
Th.scatter(U,'MarkerSize',8,'MarkerEdgeAlpha',0.6);
axis off;axis image
colorbar
figure(3)
Th.plotmesh('d',1,'color','LightGray')
hold on  % '*Alpha' options not yet implemented under Octave
Th.scatter(U,'d',1,'MarkerSize',12,'MarkerEdgeAlpha',0,'MarkerFaceColor', ...
    'flat','MarkerFaceAlpha',0.8)
axis off;axis image
colormap('jet')
colorbar
```

Listing 36: Using fc_simesh.scatter function with a 2D mesh

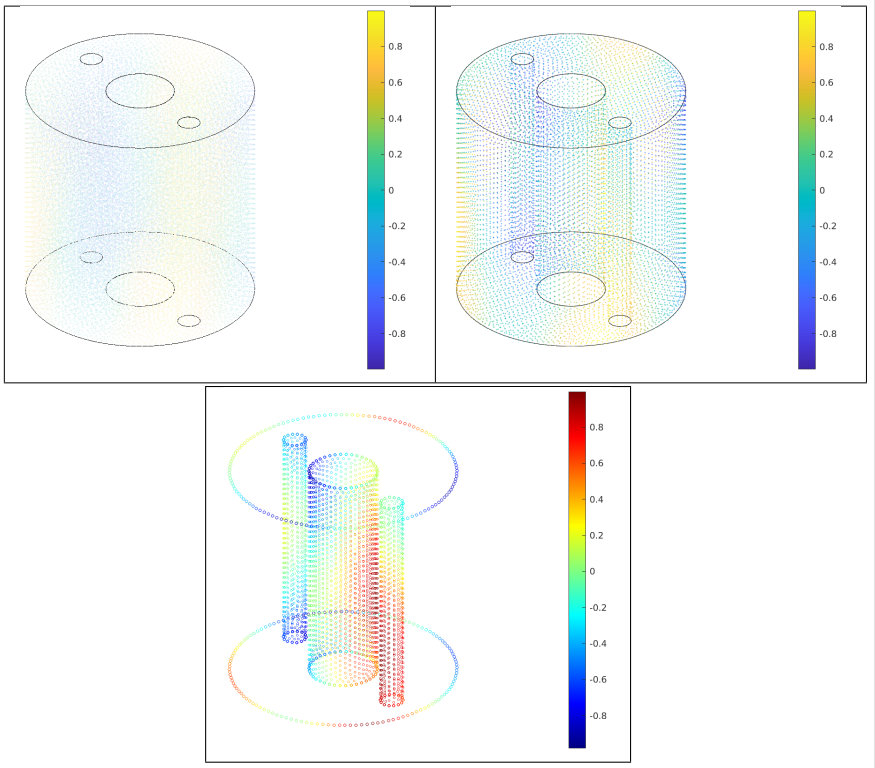
3Ds example : the following code is part of the **fc_simesh.demos.scatter3Ds** function.



```
geofile=fc_simesh.get_geo(3,2,'demisphere5');
meshfile=fc_oogmsh.buildmesh3ds(geofile,10,varargin{:});
Th=fc_simesh.siMesh(meshfile);
u=Th.eval(@(x,y,z) 3*x.^2-y.^3+z.^2+x.*y);
figure(1)
Th.scatter(u,'MarkerSize',7)
view(3);axis off;axis image;colorbar;
figure(2)
Th.scatter(u,'labels',[1,11])
hold on;axis off;axis image;colorbar;
Th.scatter(u,'labels',[10,12], 'MarkerSize',9)
view(3)
figure(3)
Th.scatter(u,'d',1,'MarkerSize',9)
axis off;axis image;colorbar
view(3)
```

Listing 37: Using fc_simesh.scatter function with a 3Ds mesh

3D example : the following code is part of the **fc_simesh.demos.scatter3D** function.



```
meshfile=fc_oogmsh.gmsh.buildmesh3d('cylinder3holes',20,varargin{:});
Th=fc_simesh.siMesh(meshfile);
u=@(x,y,z) cos(2*x-y-z).*sin(x-2*y+z);
U=Th.eval(u);
figure(1)
Th.plotmesh('d',1,'color','k')
hold on
Th.scatter(U,'MarkerEdgeAlpha',0.1);
axis image;axis off;view(3)
colorbar
figure(2)
Th.plotmesh('d',1,'color','k')
hold on
Th.scatter(U,'d',2);
axis image;axis off;view(3)
colorbar
figure(3)
colormap('jet')
Th.scatter(U,'d',1,'MarkerSize',8);
hold on
Th.scatter(U,'d',2,'MarkerSize',5,'labels',[10,20,21]);
axis image;axis off;view(3)
colorbar
```

Listing 38: Using fc_simesh.scatter function with a 3D mesh

3.5 Hypercube as a fc_simesh.siMesh object

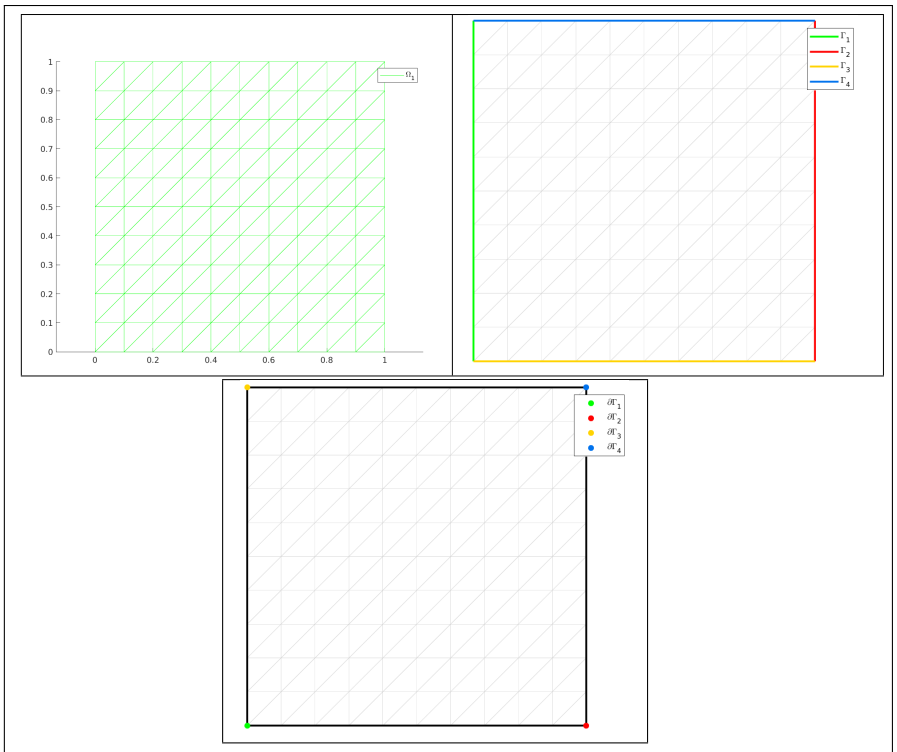
The function **fc_simesh**.hypercube allows to create a **fc_simesh.siMesh** object representing an hypercube in any dimension. It uses the FC-HYPERMESH Matlab toolbox.

- Th=**fc_simesh**.hypercube(dim,N) : return a **fc_simesh.siMesh** object representing an hypercube in dimension dim and ...

- Th=**fc_simesh**.hypercube(dim,N,Key,Value,...) :

3.5.1 2D hypercube

In Listing 1 a usage example generating a 2D hypercube as a **fc_simesh.siMesh** object is given with reprensentation of its elementary meshes.

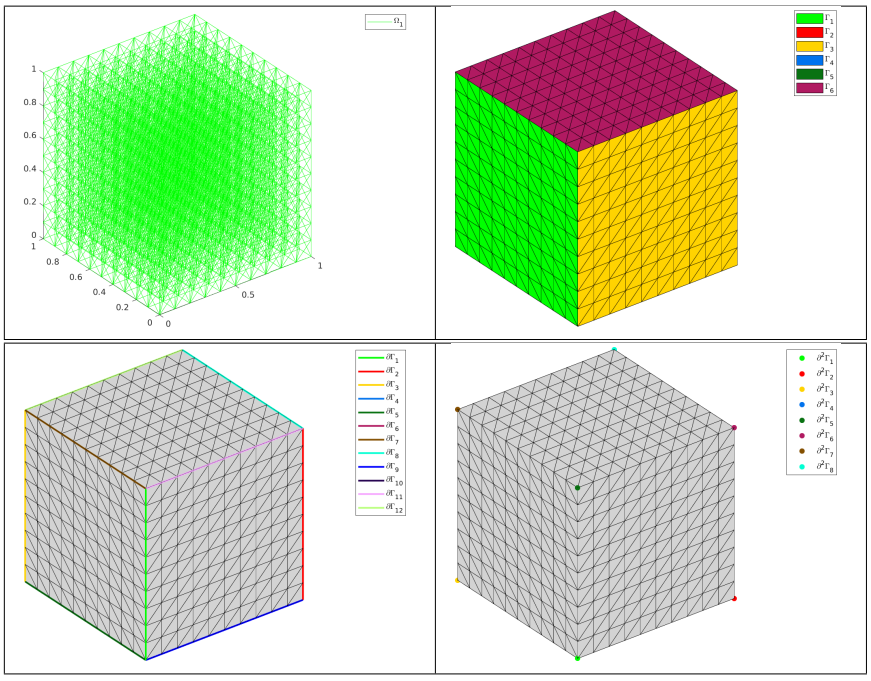


```
Th=fc_simesh.hypercube(2,10);
figure(1)
Th.plotmesh('inlegend',true)
axis equal;fc_graphics4mesh.legend()
figure(2)
Th.plotmesh('color','LightGray')
hold on;axis equal;axis off;
Th.plotmesh('d',1,'linewidth',2,'inlegend',true)
fc_graphics4mesh.legend()
figure(3)
Th.plotmesh('color','LightGray')
hold on;axis equal;axis off;
Th.plotmesh('d',1,'color','Black','linewidth',2)
Th.plotmesh('d',0,'inlegend',true)
fc_graphics4mesh.legend()
```

Listing 39: 2D Hypercube **fc_simesh.siMesh** object returned by the function **fc_simesh.hypercube** with representation of the elementary meshes with 2-simplices (top left), 1-simplices (top right) and 0-simplices (bottom) (code is part of the **fc_simesh.demos.hypercube2D** function)

3.5.2 3D hypercube

In Listing 1 a usage example generating a 3D hypercube as a **fc_simesh.siMesh** object is given with reprensentation of its elementary meshes.



```
Th=fc_simesh.hypercube(3,10);
figure(1)
Th.plotmesh('inlegend',true)
axis equal;fc_graphics4mesh.legend()
figure(2)
Th.plotmesh('d',2,'inlegend',true)
hold on;axis equal;axis off;
fc_graphics4mesh.legend()
figure(3)
Th.plotmesh('d',2,'color','LightGray')
hold on;axis equal;axis off;
Th.plotmesh('d',1,'linewidth',2,'inlegend',true)
fc_graphics4mesh.legend()
figure(4)
Th.plotmesh('d',2,'color','LightGray')
hold on;axis equal;axis off;
Th.plotmesh('d',0,'inlegend',true)
fc_graphics4mesh.legend()
```

Listing 40: 3D Hypercube fc_simesh.siMesh object returned by the function fc_simesh.hypercube with representation of the elementary meshes with 3-simplices (top left), 2-simplices (top right), 1-simplices (bottom left) and 0-simplices (bottom right) (code is part of the fc_simesh.demos.hypercube3D function)

3.5.3 4D hypercube

In Listing 41 a usage example generating a 4D hypercube as a fc_simesh.siMesh object is given.

Listing 41: : function fc_simesh.hypercube

```
Th=fc_simesh.hypercube(4,10)  ;
disp(Th)
```

Output

```
fc_simesh.siMesh with properties:
               d: 4 double
             dim: 4 double
              sTh: (1x81 cell)
             nsTh: 81 double
         toGlobal: (1x14641 double)
         toParent: (1x14641 double)
          sThsimp: (1x81 double)
           sThlab: (1x81 double)
        sThcolors: (81x3 double)
             bbox: [ 0 1 0 1 0 1 0 1 ] (1x8 double)
         sThgeolab: []
        sThphyslab: 1 double
      sThpartlabs: []
     sThboundlabs: []
  sThPhysicalTags: []
              nq: 14641 double
        nqParents: 14641 double
        toParents: (1x1 cell)
            other: []
```

3.5.4 5D hypercube

In Listing 42 a usage example generating a 5D hypercube as a **fc_simesh.siMesh** object is given.

Listing 42: : function siMesh.HyperCube

```
Th=fc_simesh.hypercube(5,6);
disp(Th)
```

Output

```
fc_simesh.siMesh with properties:
               d: 5 double
             dim: 5 double
              sTh: (1x243 cell)
             nsTh: 243 double
         toGlobal: (1x16807 double)
         toParent: (1x16807 double)
          sThsimp: (1x243 double)
           sThlab: (1x243 double)
        sThcolors: (243x3 double)
             bbox: [ 0 1 0 1 0 1 0 1 0 1 ] (1x10 double)
         sThgeolab: []
        sThphyslab: 1 double
      sThpartlabs: []
     sThboundlabs: []
  sThPhysicalTags: []
              nq: 16807 double
        nqParents: 16807 double
        toParents: (1x1 cell)
            other: []
```

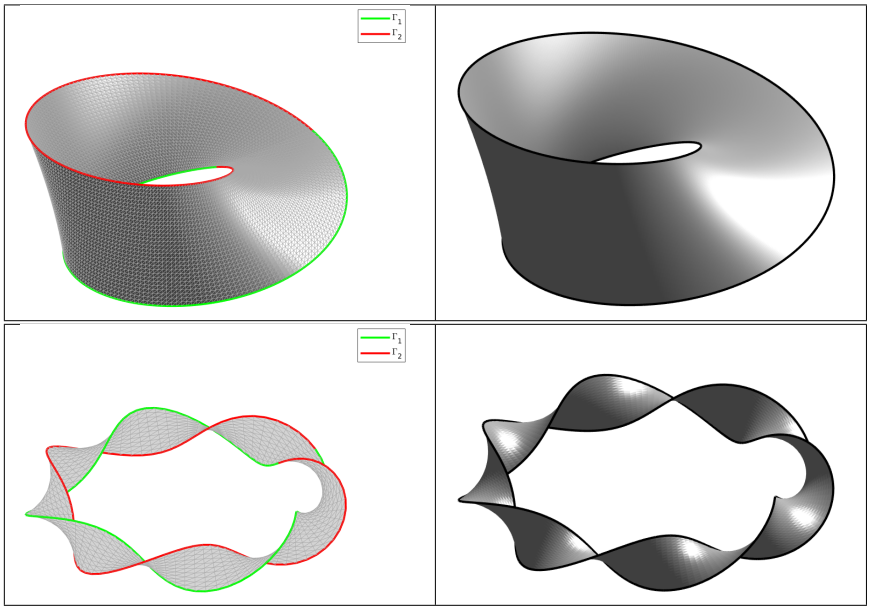
3.5.5 Möbius strip as a fc_simesh.siMesh object

The function **fc_simesh**.mobius allows to create a **fc_simesh.siMesh** object representing a Möbius strip in dimension 3.

- Th=**fc_simesh**.mobius(N) : return a **fc_simesh.siMesh** object representing a mobious strip. The N value is the number of discretisations in θ (angle) and r (radius). if N is an array of length 2, then N(1) and N(2) are respectively the number of discretisations in θ and the number of discretisations in r. If N is a scalar then N is taken for the both values.

- Th=**fc_simesh**.mobius(N,Name,Value,...) : specifies function options using one or more Name,Value pair arguments,
  - 'radius' : to specify the radius of the mid circle. Default is 1.
  - 'width' : to specify the width of the strip.

3D example : the following code is part of the **fc_simesh.demos.mobius3D** function.



```
Th=fc_simesh.mobius(30); % :start:
figure(1)
Th.plotmesh('FaceColor','LightGray','EdgeColor','DarkGray')
hold on
Th.plotmesh('d',1,'inlegend',true,'LineWidth',2)
axis equal;axis off;
fc_graphics4mesh.legend('Location','northeast')
light

Th=fc_simesh.mobius(100);
figure(2)
Th.plotmesh('FaceColor','LightGray','EdgeColor','None')
hold on
Th.plotmesh('d',1,'color','k','LineWidth',2)
axis equal;axis off;
light

Th=fc_simesh.mobius([10,90],'k',3,'radius',3,'width',1);
figure(3)
Th.plotmesh('FaceColor','LightGray','EdgeColor','DarkGray')
hold on
Th.plotmesh('d',1,'inlegend',true,'LineWidth',2)
axis equal;axis off;
fc_graphics4mesh.legend('Location','northeast')

Th=fc_simesh.mobius([20,180],'k',3,'radius',3,'width',1);
figure(4)
Th.plotmesh('FaceColor','LightGray','EdgeColor','None')
hold on
Th.plotmesh('d',1,'color','k','LineWidth',2)
axis equal;axis off;
light
```

Listing 43: Using fc_simesh.mobius function with a 3D mesh

Appendices

A Listings

B References

[1] F. Cuvelier. fc_oogmsh: an object-oriented Matlab toolbox to run **gmsh** and read mesh files. `http://www.math.univ-paris13.fr/~cuvelier/software/`, 2017. User's Guide.

[2] F. Cuvelier. fc_siplt: an add-on to the fc_simesh Matlab toolbox for displaying simplices meshes or datas on simplices meshes. `http://www.math.univ-paris13.fr/~cuvelier/software/`, 2017. User's Guide.

[3] F. Cuvelier. fc_hypermesh: a object-oriented Matlab toolbox to mesh any d-orthotopes (hyperrectangle in dimension d) and their m-faces with high order simplices or orthotopes. `http://www.math.univ-paris13.fr/~cuvelier/software/`, 2019. User's Guide.

Informations for git maintainers of the simesh Matlab toolbox

git informations on the toolboxes used to build this manual

```
-------------------------------------------------
  name : fc-simesh
   tag : 0.4.5.a
commit : 2435c8c22b6280df5521be7d137c3a206f3d455d
  date : 2022-12-21
  time : 14-27-51
status : 0
-------------------------------------------------
  name : fc-tools
   tag : 0.0.34
commit : 34edf9393425222cdb72914e51e6465f50aa6760
  date : 2022-12-21
  time : 09-28-20
status : 0
-------------------------------------------------
  name : fc-bench
   tag : 0.1.3
commit : 6c8969bb49b90c7cae34e70c88dd2f968766376b
  date : 2022-12-17
  time : 13-58-43
status : 0
-------------------------------------------------
  name : fc-hypermesh
   tag : 1.0.4
commit : 7f56fea428e57d2f30ae9d7b1f99bd6078807d23
  date : 2022-12-19
  time : 09-35-48
status : 0
-------------------------------------------------
  name : fc-amat
   tag : 0.1.3
commit : 90dbaa2839188cf8e01629817e5f8ba1b7188052
  date : 2022-12-19
  time : 07-41-33
status : 0
-------------------------------------------------
  name : fc-meshtools
   tag : 0.1.4.a
commit : 57826462a8280dec5aa1eff0d424877097187b41
  date : 2022-12-19
  time : 08-27-27
status : 0
-------------------------------------------------
  name : fc-graphics4mesh
   tag : 0.1.5.a
commit : b994b7b2a57399848541708cae3c33f79787cb1a
  date : 2022-12-19
  time : 08-28-40
status : 0
-------------------------------------------------
  name : fc-oogmsh
   tag : 0.2.4.a
commit : 8738562fc0b1cbdb028a8b58c5ba4f019e452831
  date : 2022-12-21
  time : 14-42-29
status : 0
-------------------------------------------------
  name : fc-siplt
   tag : 0.2.5
commit : b4d6a9b05dccd6ac643d7235a057f89704c7e72a
  date : 2022-12-21
  time : 13-26-51
status : 0
-------------------------------------------------
```

git informations on the LaTeX package used to build this manual

```
--------------------------------------------------
   name : fctools
    tag :
 commit : c9a33ce7b4dacf90f66e5e49856e69afa1dac0a3
   date : 2022-12-17
   time : 07:57:20
 status : 1
--------------------------------------------------
```

Using the remote configuration repository:

url	`ssh://lagagit/MCS/Cuvelier/Matlab/fc-config`
commit	`1ddb965ef261410ecee4ce178be4ceb85939de04`