fc-simesh Matlab toolbox, User's Guide[*]

version 0.4.0

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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 fc-siplt toolbox is used.

0 Contents

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[*] LaTeX manual, revision 0.4.0.a, compiled with Matlab 2019a, and toolboxes `fc-simesh`[0.4.0], `fc-tools`[0.0.30], `fc-bench`[0.1.2], `fc-hypermesh`[1.0.3], `fc-amat`[0.1.2], `fc-meshtools`[0.1.3], `fc-graphics4mesh`[0.1.1], `fc-oogmsh`[0.2.2], `fc-siplt`[0.2.0]

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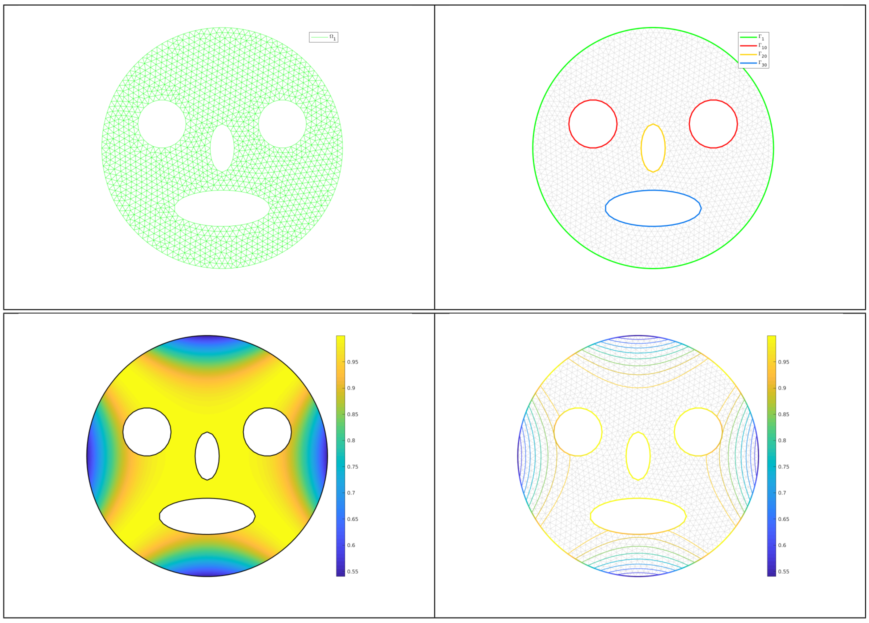
1 Introduction

The fc-simesh 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 fc-oogmsh 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 fc-siplt 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
legend()

figure(2)
Th.plotmesh('color','LightGray')
hold on
Th.plotmesh('d',1,'inlegend',true,'LineWidth',2)
axis image;axis off
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 fc hypermesh toolbox[3] can be used to obtain meshes of an hypercube by using the **fc_simesh**.HyperCube function.

2 Installation

This toolbox was tested on various OS with Matlab releases:

Operating system	2017a	2017b	2018a	2018b	2019a
CentOS 7.7.1908	✓	✓	✓	✓	✓
Debian 9.11	✓	✓	✓	✓	✓
Fedora 29	✓	✓	✓	✓	✓
OpenSUSE Leap 15.0	✓	✓	✓	✓	✓
Ubuntu 18.04.3 LTS	✓	✓	✓	✓	✓
MacOS High Sierra 10.13.6	✓	✓	✓	✓	✓
MacOS Mojave 10.14.4	✓	✓	✓	✓	✓
MacOS Catalina 10.15.2	✓	✓	✓	✓	✓
Windows 10 (1909)	✓	✓	✓	✓	✓

It is not compatible with Matlab releases prior to R2015b.

2.1 Installation automatic, all in one (recommanded)

For this method, one just have 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* and the required toolboxes (*fc-tools*, *fc-oogmsh*, *fc-hypermesh*) in the current directory.

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

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

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

```
Parts of the <fc-simesh> Matlab toolbox.
Copyright (C) 2016-2020 F. Cuvelier

1- Downloading and extracting the toolboxes
2- Setting the <fc-simesh> toolbox
Write in ...
     ~/Matlab/toolboxes/fc-simesh-full/fc_simesh-0.4.0/configure_loc.m ...
3- Using toolboxes :
   ->              fc-tools : 0.0.30
   ->              fc-bench : 0.1.2
   ->          fc-hypermesh : 1.0.3
   ->               fc-amat : 0.1.2
   ->          fc-meshtools : 0.1.3
   ->      fc-graphics4mesh : 0.1.1
   ->             fc-oogmsh : 0.2.2
   ->              fc-siplt : 0.2.0
 with             fc-simesh : 0.4.0
*** Using instructions
   To use the <fc-simesh> toolbox:
   addpath('~/Matlab/toolboxes/fc-simesh-full/fc_simesh-0.4.0')
   fc_simesh.init()

   See ~/Matlab/toolboxes/mfc_simesh_set.m
```

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

```
>> addpath('~/Matlab/toolboxes/fc-simesh-full/fc-simesh-0.4.0')
>> 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/toolboxes/fc-simesh-full/fc_tools-0.0.30/configure_loc.m ...
Try to use default parameters!
 Use fc_bench.configure to configure.
Write in ...
     ~/Matlab/toolboxes/fc-simesh-full/fc_bench-0.1.2/configure_loc.m ...
Try to use default parameters!
 Use fc_hypermesh.configure to configure.
Write in ...
     ~/Matlab/toolboxes/fc-simesh-full/fc_hypermesh-1.0.3/configure_loc.m ...
     ...
Try to use default parameters!
 Use fc_amat.configure to configure.
Write in ...
     ~/Matlab/toolboxes/fc-simesh-full/fc_amat-0.1.2/configure_loc.m ...
Try to use default parameters!
 Use fc_meshtools.configure to configure.
Write in ...
     ~/Matlab/toolboxes/fc-simesh-full/fc_meshtools-0.1.3/configure_loc.m ...
     ...
Try to use default parameters!
 Use fc_graphics4mesh.configure to configure.
Write in ...
     ~/Matlab/toolboxes/fc-simesh-full/fc_graphics4mesh-0.1.1/configure_loc.m ...
     ...
Try to use default parameters!
 Use fc_oogmsh.configure to configure.
Write in ...
     ~/Matlab/toolboxes/fc-simesh-full/fc_oogmsh-0.2.2/configure_loc.m ...
Configured to use gmsh 4.5.1 with default MSH file format version 4.1
Try to use default parameters!
 Use fc_siplt.configure to configure.
Write in ...
     ~/Matlab/toolboxes/fc-simesh-full/fc_siplt-0.2.0/configure_loc.m ...
Using fc_simesh[0.4.0] with fc_tools[0.0.30], fc_bench[0.1.2], ...
     fc_hypermesh[1.0.3],
       fc_amat[0.1.2], fc_meshtools[0.1.3], fc_graphics4mesh[0.1.1], ...
            fc_oogmsh[0.2.2], fc_siplt[0.2.0].
```

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

```
Configured to use gmsh 4.5.1 with default MSH file format version 4.1
Using fc_simesh[0.4.0] with fc_tools[0.0.30], fc_bench[0.1.2], ...
     fc_hypermesh[1.0.3],
       fc_amat[0.1.2], fc_meshtools[0.1.3], fc_graphics4mesh[0.1.1], ...
            fc_oogmsh[0.2.2], fc_siplt[0.2.0].
```

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

`~/Matlab/toolboxes/fc-simesh-full`

2.1.1 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 $\mathbb{R}^{\text{dim}}$. More formally, suppose the $k+1$ vertices $\mathrm{q}^0, \cdots, q^k \in \mathbb{R}^{\text{dim}}$ 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 $\mathbb{R}^{\text{dim}}$, $0 \leqslant k \leqslant \text{dim}$, a mesh with **unique label** only composed with k-simplices.

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

2.2 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 $\mathbb{R}^{\text{dim}}$

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 $\in \{1, \ldots,$ dim$\}$, j $\in \{1, \ldots,$ 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 .

2.3 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 ndtoParentsinstead. *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
```

2.4 Mesh samples

2.4.1 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] Starting building mesh <fc-oogmsh>/meshes/sample20-20.msh with gmsh 4.5.2
[fc-oogmsh] Using command : gmsh -2 -setnumber N 20 -string "Mesh.MshFileVersion=4.1;" ...
    <fc-oogmsh>/geodir/2d/sample20.geo -o <fc-oogmsh>/meshes/sample20-20.msh
 Be patient...
[fc-oogmsh] Using gmsh 4.5.2 to write MSH file format version 4.1 in ...
    <fc-oogmsh>/meshes/sample20-20.msh
*** Th:
  fc_simesh.siMesh with properties:
              d: 2 double
            dim: 2 double
            sTh: (1x11 cell)
           nsTh: 11 double
       toGlobal: (1x2326 double)
       toParent: (1x2326 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 ] (1x4 double)
    sThpartlabs: []
   sThboundlabs: []
             nq: 2326 double
      nqParents: 2326 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: 41 double
    toParent: (1x41 double)
    nqParent: 41 double
   nqParents: 41 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: []
     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

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

and we note

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

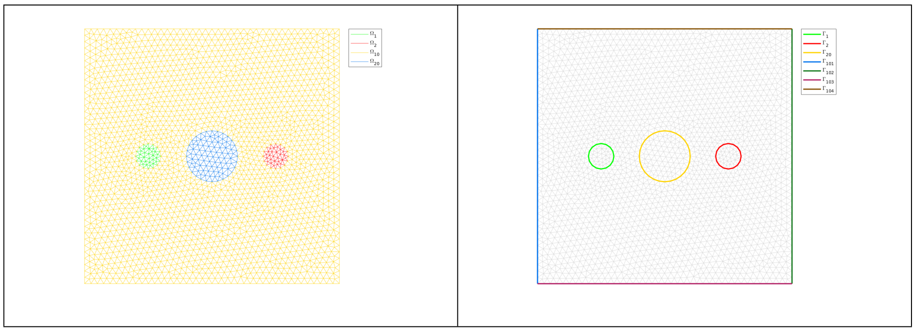


Figure 1: 2D **fc_simesh.siMesh** object from `sample20.geo`

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 $\forall i \in \{1, 2, 20, 101, 102, 104\}$

2.4.2 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] Starting building mesh <fc-oogmsh>/meshes/quart_sphere2-5.msh with gmsh 4.5.2
[fc-oogmsh] Using command : gmsh -3 -setnumber N 5 -string "Mesh.MshFileVersion=4.1;" ...
    <fc-oogmsh>/geodir/3d/quart_sphere2.geo -o <fc-oogmsh>/meshes/quart_sphere2-5.msh
 Be patient...
[fc-oogmsh] Using gmsh 4.5.2 to write MSH file format version 4.1 in ...
    <fc-oogmsh>/meshes/quart_sphere2-5.msh
  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: (1x1171 double)
       toParent: (1x1171 double)
        sThsimp: [ 3 3 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 ] (1x2 double)
    sThpartlabs: []
   sThboundlabs: []
             nq: 1171 double
      nqParents: 1171 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: 203 double
    toParent: (1x203 double)
    nqParent: 203 double
   nqParents: 203 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: []
     partlab: []
        bbox: [ 0 1 0 1 0 1 ] (1x6 double)
           h: 0.127349 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 : $\partial\Gamma_i$ $\forall i \in [\![1, 9]\!]$

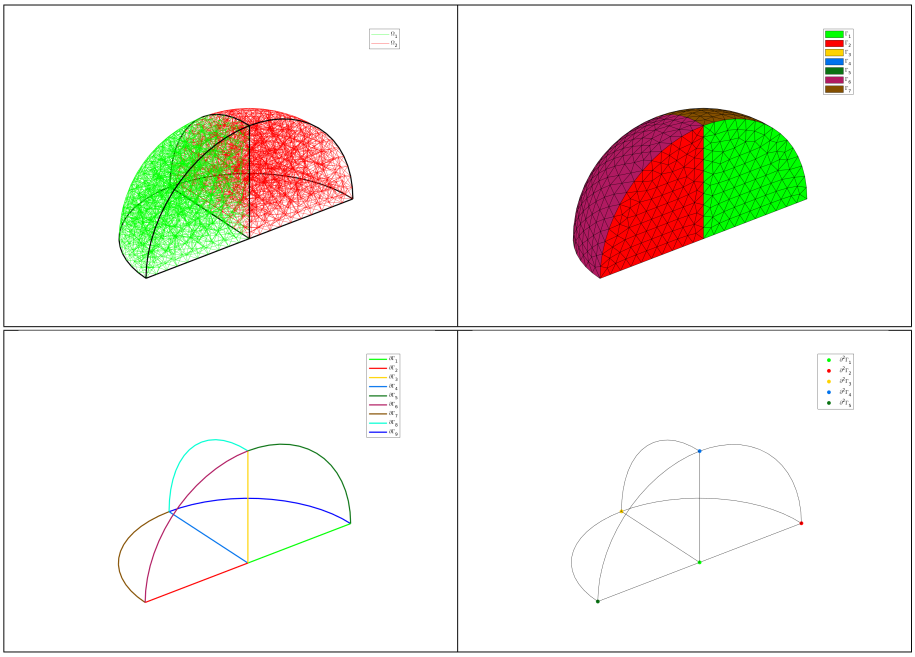


Figure 2: 3D Mesh from `quart_sphere2.geo`

- five 0-simplicial elementary meshes : $\partial^2\Gamma_i$ $\forall i \in [\![1, 5]\!]$

2.4.3 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] Starting building mesh <fc-oogmsh>/meshes/demisphere4surf-5.msh with gmsh 4.5.2
[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 4.5.2 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 ] (1x4 double)
    sThpartlabs: []
   sThboundlabs: []
            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: 9 double
    toParent: (1x9 double)
    nqParent: 9 double
   nqParents: 9 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: []
     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 $\forall i \in [\![1,8]\!]$

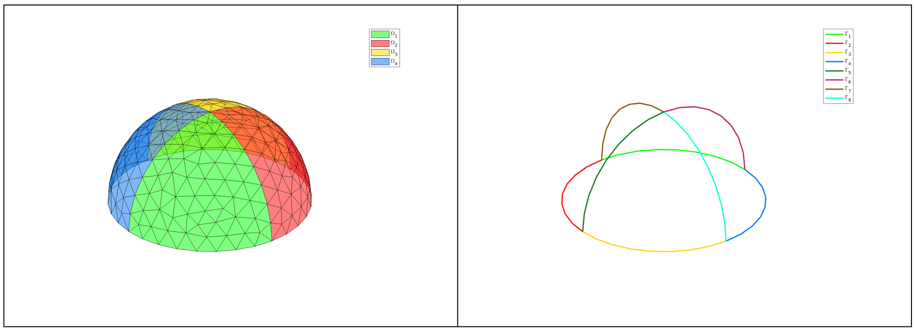


Figure 3: 3D surface Mesh from `demisphere4surf.geo`, label of the domains (left) and label of the boundaries (right)

2.5 Methods of the fc_simesh.siMesh object

2.5.1 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 ] (1x6 double)
   sThpartlabs: []
  sThboundlabs: []
            nq: 3162 double
     nqParents: 3162 double
     toParents: (1x1 cell)
         other: (1x1 struct)
```

2.5.2 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: (1x1171 double)
       toParent: (1x1171 double)
        sThsimp: [ 3 3 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 ] (1x2 double)
    sThpartlabs: []
   sThboundlabs: []
             nq: 1171 double
      nqParents: 1171 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: [4 6 8], labels=[2 4 6]
```

2.5.3 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

```
[fc-oogmsh] Using gmsh 4.5.2 to write MSH file format version 4.1 in ...
    <fc-oogmsh>/meshes/condenser11-50.msh
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]',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 ] (1x6 double)
    sThpartlabs: []
   sThboundlabs: []
             nq: 11945 double
      nqParents: 11945 double
      toParents: (1x1 cell)
          other: (1x1 struct)
*** nq=11945, size(z)==[11945,3]
```

2.5.4 eval method

Evaluates numerical datas or vectorized functions at vertices of the mesh. We denote by Th a **fc_simesh.siMesh** object and $\mathrm{n_q}$ = 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]
```

2.5.5 get_h method

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

- h=Th.get_h()

2.5.6 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
```

2.5.7 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 : 4784
Number of 2-simplices : 1651
Number of 1-simplices : 115
Number of 0-simplices : 5
Number of 2-simplices in union of label's 1 to 4 : 748
```

2.5.8 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 : 1171
Number of vertices in 2-simplices elementary meshes : 811
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
```

2.5.9 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

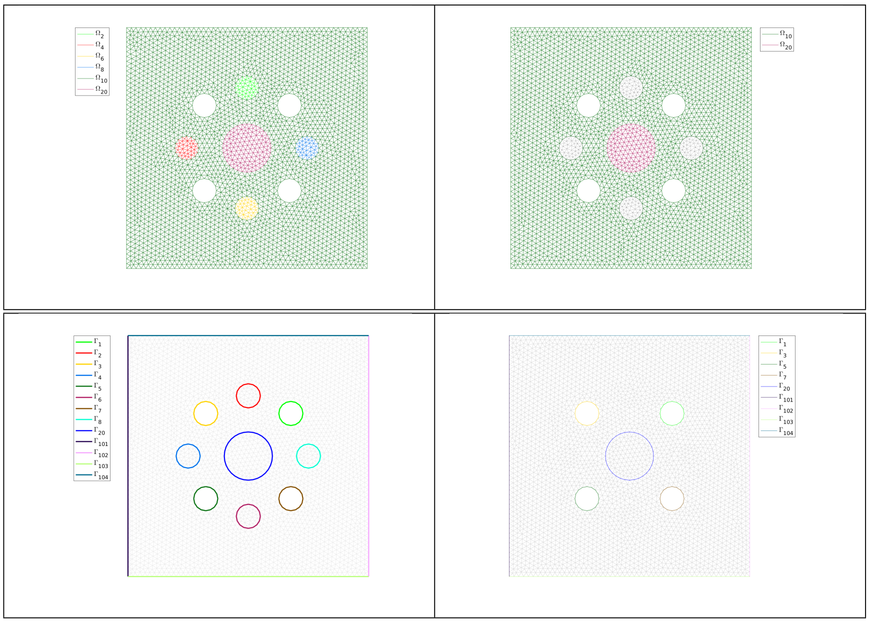
$$P(i,1)\,x + P(i,2)\,y + P(i,3)\,z + P(i,4) = 0.$$

  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,

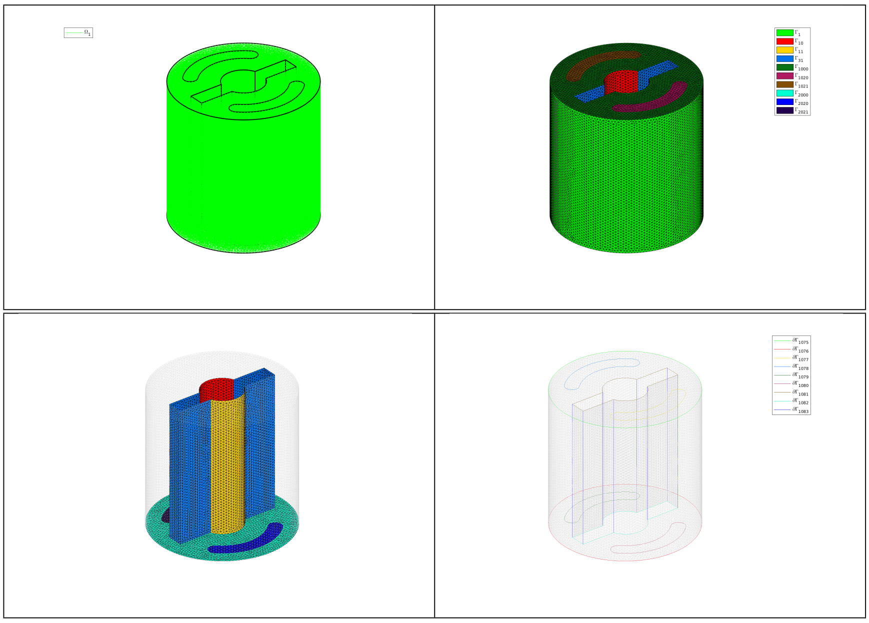
2D example The following example use the *.geo* file `condenser11.geo` which is in the directory `geodir` of the toolbox ....



```
meshfile=fc_oogmsh.gmsh.buildmesh2d('condenser11',25,'verbose',0);
Th=fc_simesh.siMesh(meshfile);
figure(1)
Th.plotmesh('inlegend',true)
axis off;axis image;
set(legend('show'),'Location','NorthWestOutside','fontsize',12)
figure(2)
Th.plotmesh('labels',[10,20],'inlegend',true)
hold on;axis off;axis image
Th.plotmesh('labels',[2,4,6,8],'Color','k','Linestyle',':')
set(legend('show'),'Location','NorthEastOutside','fontsize',12)
figure(3)
Th.plotmesh('Color',0.9*[1,1,1])
hold on;axis off;axis image;
Th.plotmesh('d',1,'inlegend',true,'LineWidth',2)
set(legend('show'),'Location','NorthWestOutside','fontsize',12)
figure(4)
Th.plotmesh('Color','LightGray')
hold on;axis off;axis image
Th.plotmesh('d',1,'inlegend',true,'labels',[1:2:7,20,101:104])
set(legend('show'),'Location','NorthEastOutside','fontsize',12)
```

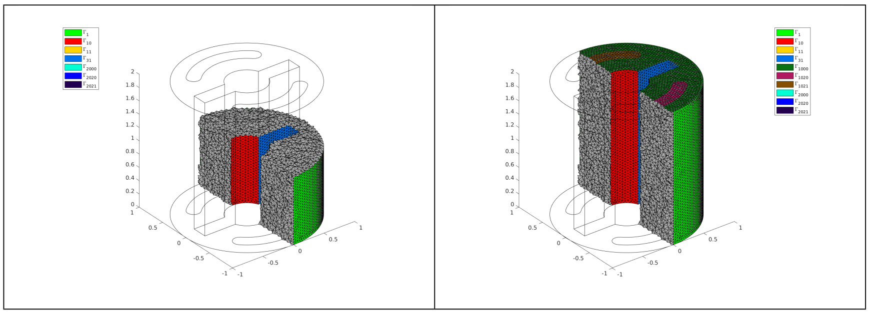
Listing 14: 2D mesh : **plotmesh** method

3D example The following example use the *.geo* file `cylinderkey.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.



```
geofile=fc_simesh.get_geo(3,3,'cylinderkey03');
meshfile=fc_oogmsh.buildmesh3d(geofile,ns*5,'verbose',0);
Th=fc_simesh.siMesh(meshfile);
figure(1)
Th.plotmesh('inlegend',true)
hold on;axis off;axis image
Th.plotmesh('d',1,'Color','k','Linewidth',1.5)
set(legend('show'),'Location','NorthWestOutside')
figure(2)
Th.plotmesh('d',2,'inlegend',true)
view(3);hold on;axis off;axis image
set(legend('show'),'Location','NorthEastOutside')
figure(3)
Th.plotmesh('d',2,'labels',[1,1000,1020,1021], 'EdgeColor','LightGray', ...
    'EdgeAlpha',0.4,'FaceColor','none')
hold on;axis off;axis image
%Th.plotmesh('d',2,'labels',1000,'bounds',true,'color','k')
Th.plotmesh('d',2, 'labels',[10,11,31,2000,2020,2021])
figure(4)
Th.plotmesh('d',2, 'EdgeColor','LightGray', 'EdgeAlpha',0.4,'FaceColor','none')
hold on;axis off;axis image
Th.plotmesh('d',1,'inlegend',true)
set(legend('show'),'Location','NorthEastOutside')
```

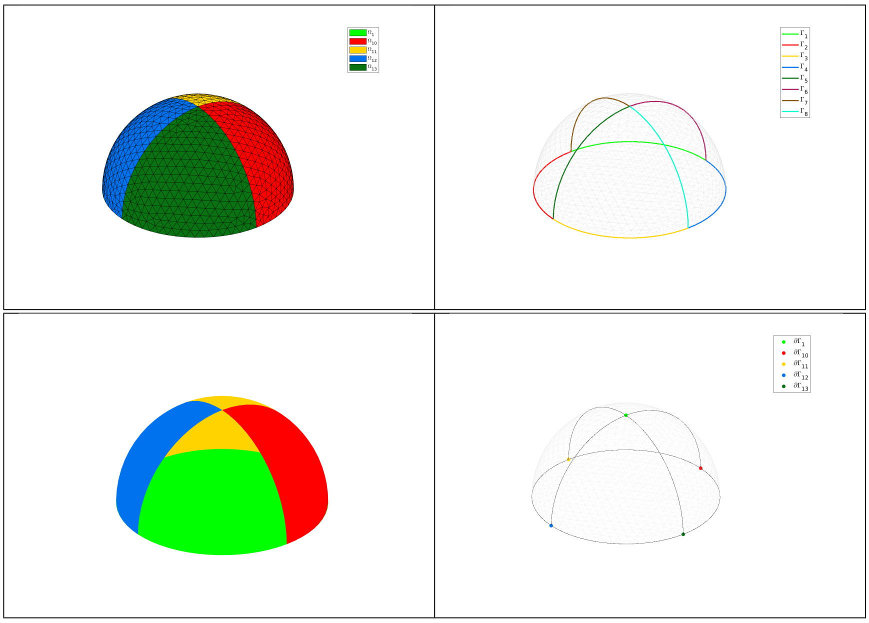
Listing 15: 3D plot mesh



```
geofile=fc_simesh.get_geo(3,3,'cylinderkey03');
meshfile=fc_oogmsh.buildmesh3d(geofile,ns*5,'verbose',0);
figure(5)
P=[fc_tools.graphics.PlaneCoefs([0 0 1], [0 0 1]); ...
   fc_tools.graphics.PlaneCoefs([0 0 1],[-1 0 0])];
Th.plotmesh('d',1,'color','black')
hold on;axis image;view(-75,36)
Th.plotmesh('cutPlane',P,'Color','DarkGrey')
Th.plotmesh('d',2,'cutPlane',P,'inlegend',true);
set(legend('show'),'Location','NorthWestOutside')
figure(6)
P=fc_tools.graphics.PlaneCoefs([0 0 1],[-1 0 0]);
Th.plotmesh('d',1,'color','black')
hold on;axis image;view(-75,36)
Th.plotmesh('cutPlane',P,'Color','DarkGrey')
Th.plotmesh('d',2,'cutPlane',P,'inlegend',true);
set(legend('show'),'Location','NorthEastOutside')
```

Listing 16: 3D mesh : **plotmesh** method

3D surface example The following example use the *.geo* file `demisphere5.geo` which is in the directory `geodir` of the toolbox. This file contains description of a 3D surface mesh with simplices of dimensions 1 and 2.



```
meshfile=fc_oogmsh.buildmesh3ds('demisphere5',ns*5,'verbose',0);
Th=fc_simesh.siMesh(meshfile);
figure(1)
Th.plotmesh('inlegend',true)
axis off;axis equal;legend('show')
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)
set(legend('show'),'Location','NorthEastOutside','FontSize',12)
figure(3)
Th.plotmesh('labels',[1,10,11,12],'EdgeColor','none')
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)
set(legend('show'),'Location','NorthEastOutside','FontSize',12)
```

Listing 17: 3D surface mesh : **plotmesh** method

2.5.10 plot method

The **plot** method displays scalar datas on the mesh or parts of the mesh defined by an **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.

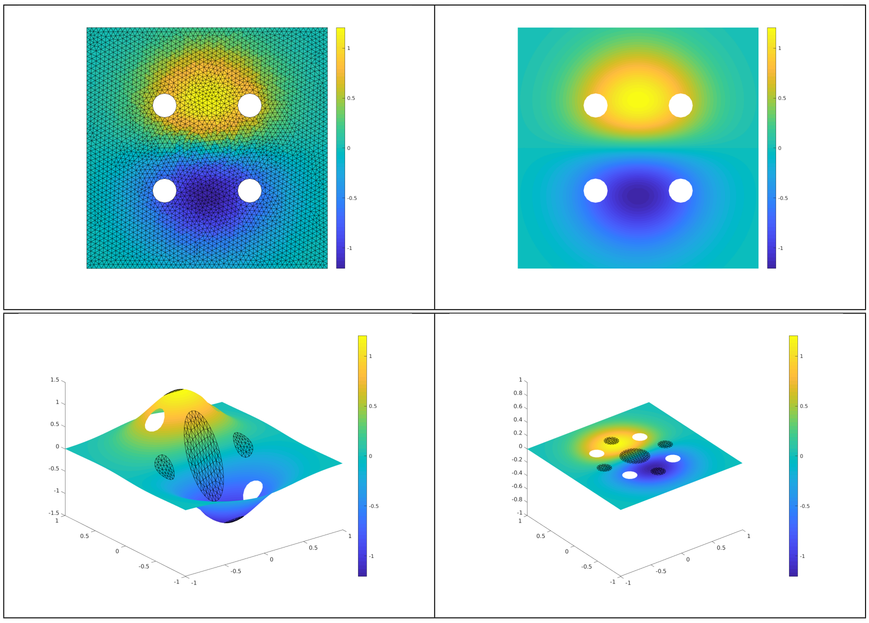
Th.**plot**(u,Name,Value, ...) specifies function options using one or more Name,Value pair arguments. Options of first level are

- '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

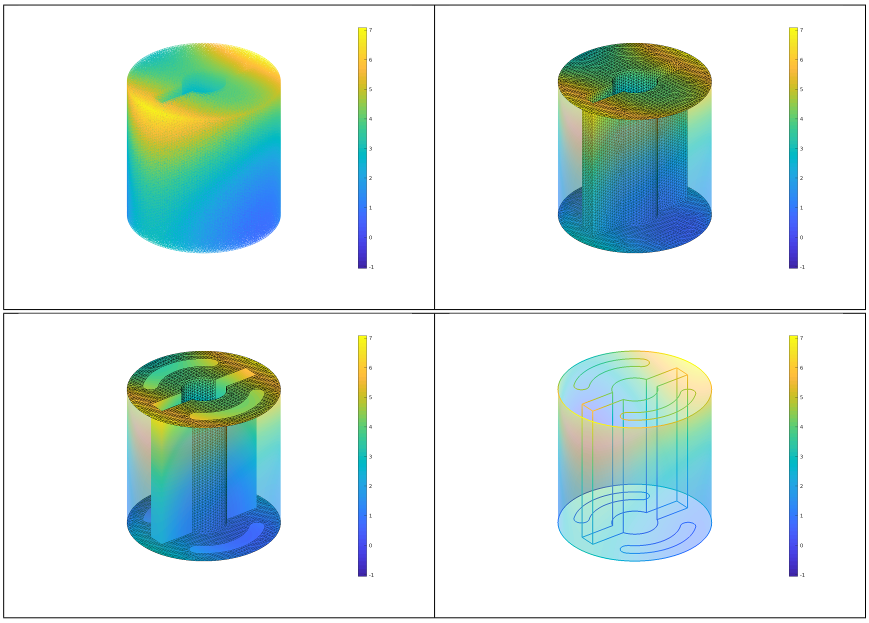
2D example The following example use the *.geo* file `condenser11.geo` which is in the directory `geodir` of the toolbox.



```
geofile=fc_simesh.get_geo(2,2,'condenser11');
meshfile=fc_oogmsh.gmsh.buildmesh2d(geofile,25,'verbose',0);
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')
```

Listing 18: 2D mesh : plot method

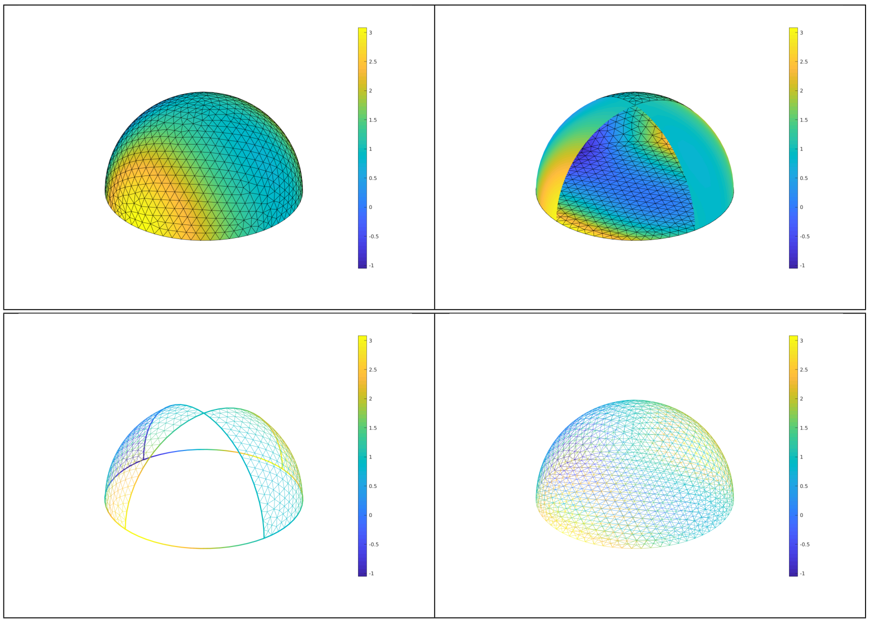
3D example The following example use the *.geo* file `cylinderkey.geo` which is in the directory `geodir` of the toolbox. This file contains description of a 3D mesh with simplices of dimensions 1, 2 and 3.



```
geofile=fc_simesh.get_geo(3,3,'cylinderkey03');
meshfile=fc_oogmsh.buildmesh3d(geofile,ns*5);
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 19: 3D mesh : plot method

3D surface example The following example use the *.geo* file `demisphere5.geo` which is in the directory `geodir` of the toolbox. This file contains description of a 3D surface mesh with simplices of dimensions 1 and 2.



```
geofile=fc_simesh.get_geo(3,2,'demisphere5');
meshfile=fc_oogmsh.buildmesh3ds(geofile,ns*5,'verbose',0);
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 20: 3D surface mesh : **plot** method

2.5.11 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**)

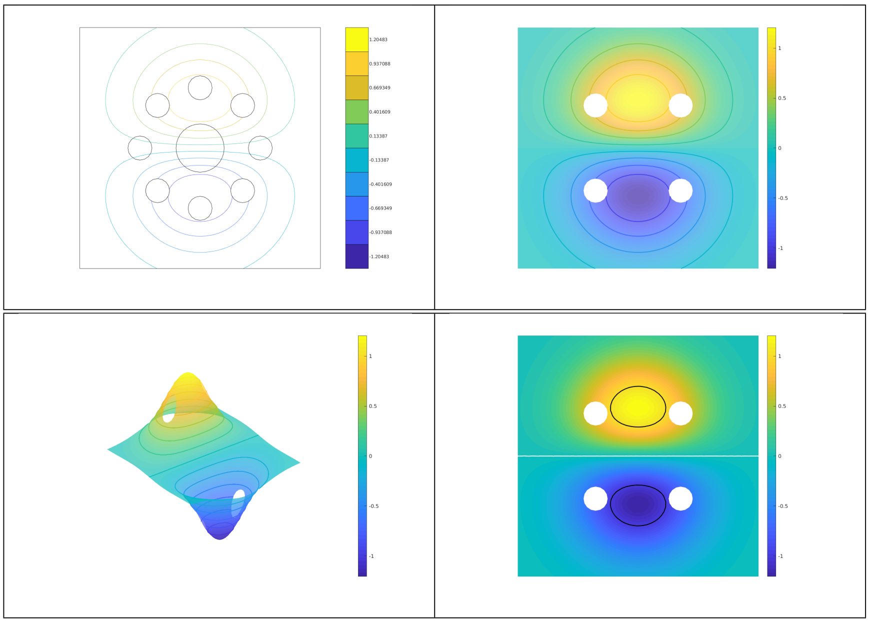
The options of second level are all options of

- **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.

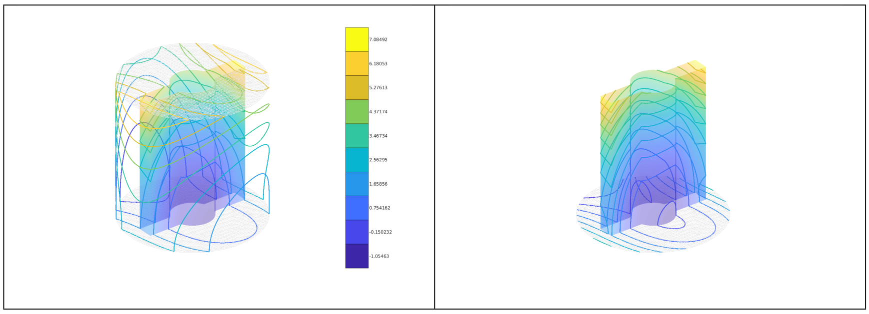
2D example The following example use the *.geo* file `condenser11.geo` which is in the directory `geodir` of the toolbox.



```
meshfile=fc_oogmsh.gmsh.buildmesh2d('condenser11',25,'verbose',0);
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 21: 2D mesh : **plotiso** method

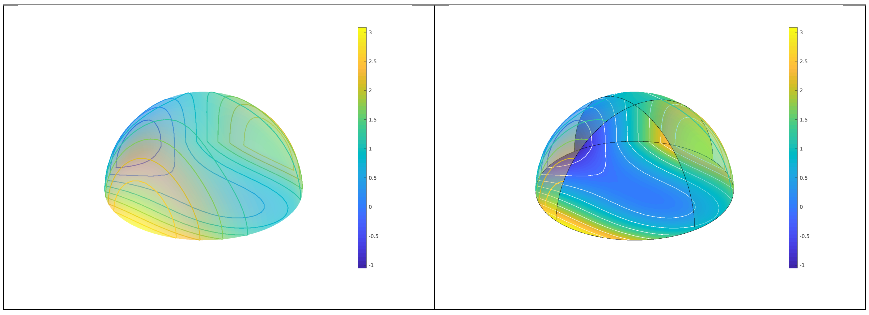
3D example The following example use the *.geo* file `cylinderkey.geo` which is in the directory `geodir` of the toolbox. This file contains description of a 3D mesh with simplices of dimensions 1, 2 and 3.



```
geofile=fc_simesh.get_geo(3,3,'cylinderkey03');
meshfile=fc_oogmsh.gmsh.buildmesh3d(geofile,ns*5,'verbose',0);
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 22: 3D mesh : plotiso method

3D surface example The following example use the *.geo* file `demisphere5.geo` which is in the directory `geodir` of the toolbox. This file contains description of a 3D surface mesh with simplices of dimensions 1 and 2.



```
meshfile=fc_oogmsh.gmsh.buildmesh3ds('demisphere5',ns*5,'verbose',0);
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 23: 3D surface mesh : plotiso method

2.5.12 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, ...)
```

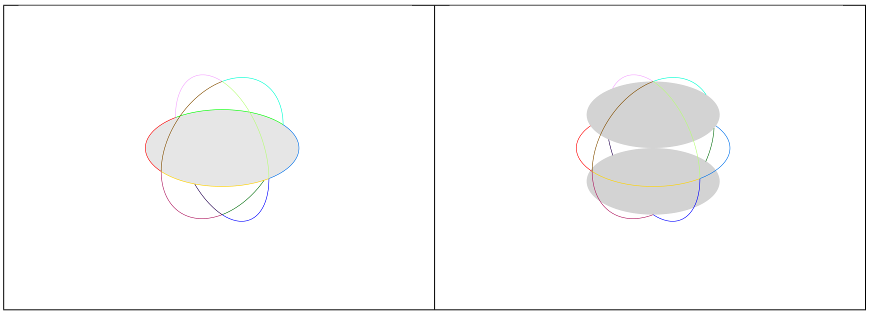
Description

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 fc tools 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 24: 3D mesh : slicemesh method

2.5.13 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, ...)
```

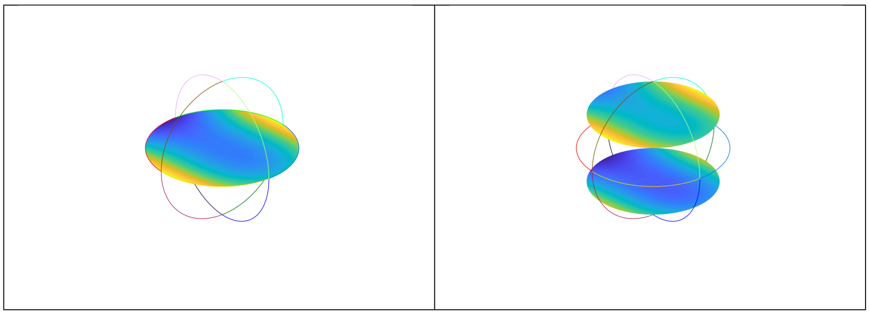
Description

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 fc tools 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)
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);
hold on;axis off;axis image;
Th.slice(u,P,'Facecolor','interp')
```

Listing 25: 3D mesh :**slice** method

2.5.14 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 fc tools 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

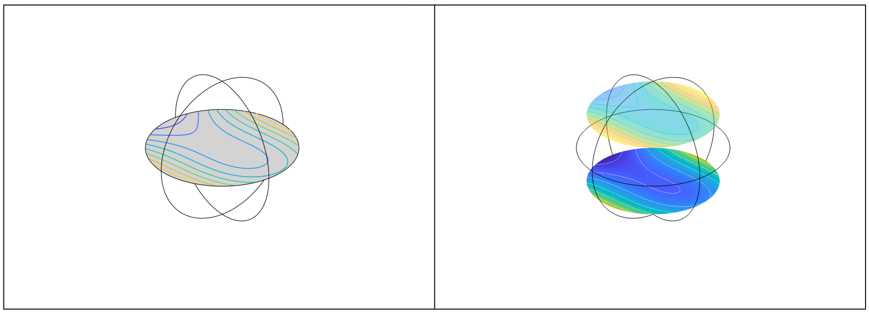
- 'labels' : to select the labels of the elements to intersect,
- 'niso' : to specify the number of isolines (default : 10)
- 'isorange' : to specify the list of isovalues (default : empty)
- 'color' : to specify one color for all isolines (default : empty)
- 'isocolorbar' : if true display a colorbar.Default 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 26: 3D mesh :**sliceiso** method

2.5.15 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.

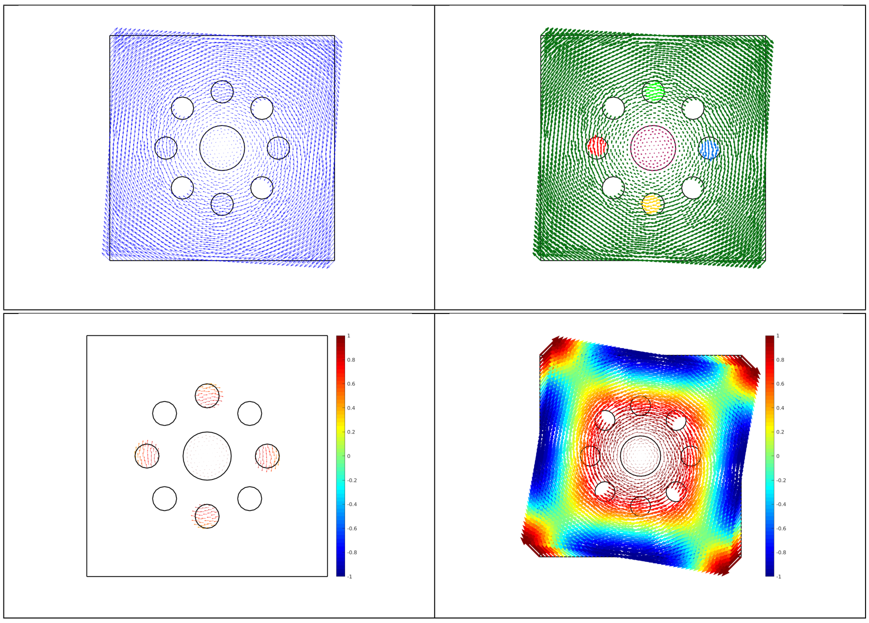
Th.**plotquiver**(V,Key,Value, ...) specifies function options using one or more Key,Value pair arguments. Options of first level are

- '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.

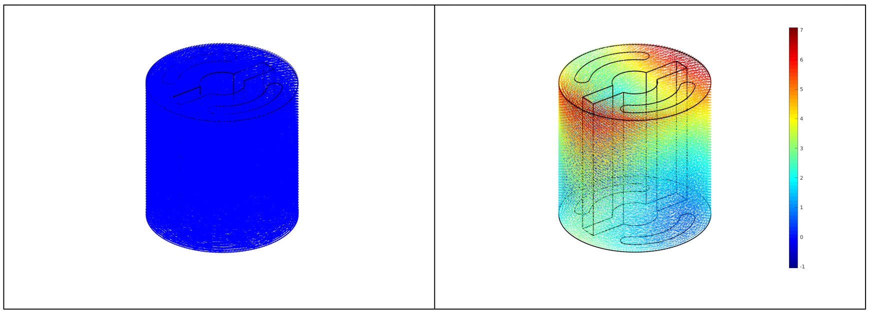
2D example The following example use the *.geo* file `condenser11.geo`.



```
geofile=fc_simesh.get_geo(2,2,'condenser11');
meshfile=fc_oogmsh.buildmesh2d(geofile,25,'verbose',0);
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 27: 2D mesh : **plotquiver** method

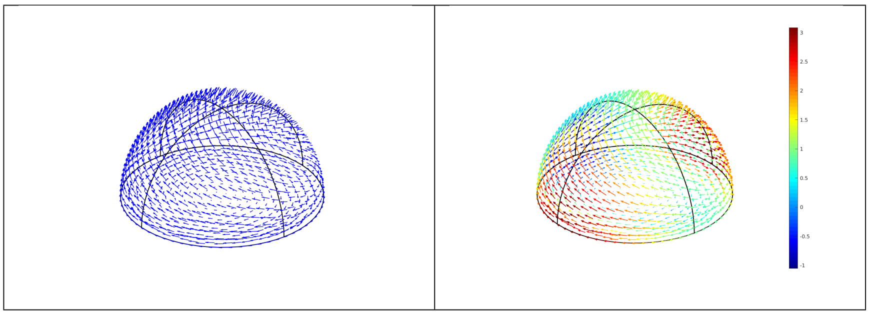
3D example The following example use the *.geo* file `cylinderkey03.geo`. This file contains description of a 3D mesh with simplices of dimensions 1, 2 and 3.



```
geofile=fc_simesh.get_geo(3,3,'cylinderkey03');
meshfile=fc_oogmsh.buildmesh3d(geofile,ns*5);
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);
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 28: 3D mesh : fc_siplt.plotquiver function

3D surface example The following example use the *.geo* file `demisphere5.geo` which is in the directory `geodir` of the toolbox. This file contains description of a 3D surface mesh with simplices of dimensions 1 and 2.



```
geofile=fc_simesh.get_geo(3,2,'demisphere5');
meshfile=fc_oogmsh.gmsh.buildmesh3ds(geofile,ns*5,'verbose',0);
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,'colordata',u, 'scale',0.1)
colormap('jet');colorbar
```

Listing 29: 3D surface mesh : fc_siplt.plotquiver function

2.6 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,...) :

2.6.1 2D hypercube

In Listing 30 a usage example generating a 2D hypercube as a **fc_simesh.siMesh** object is given. This **fc_simesh.siMesh** object is representing in Figure 4 by using the FC-SIPLT toolbox.

Listing 30: 2D Hypercube **fc_simesh.siMesh** object generated with the function **siMesh**.HyperCube

```
Th=fc_simesh.HyperCube(2,10);
disp(Th)
```

Output

```
fc_simesh.siMesh with properties:
             d: 2 double
           dim: 2 double
           sTh: (1x9 cell)
          nsTh: 9 double
      toGlobal: (1x121 double)
      toParent: (1x121 double)
       sThsimp: [ 2 1 1 1 1 0 0 0 0 ] (1x9 double)
        sThlab: [ 1 1 2 3 4 1 2 3 4 ] (1x9 double)
     sThcolors: (9x3 double)
          bbox: [ 0 1 0 1 ] (1x4 double)
     sThgeolab: []
    sThphyslab: 1 double
   sThpartlabs: []
  sThboundlabs: []
            nq: 121 double
     nqParents: 121 double
     toParents: (1x1 cell)
         other: []
```

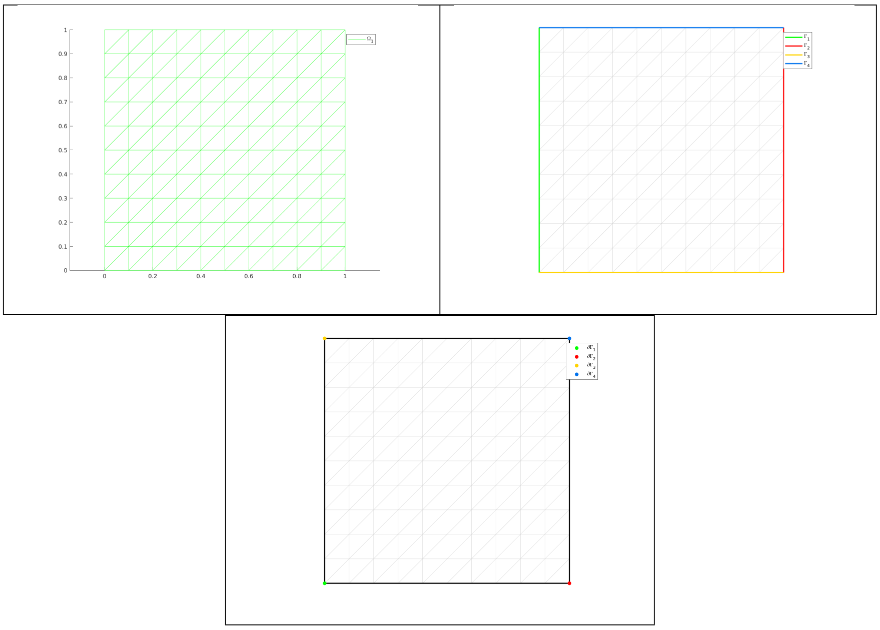


Figure 4: 2D Hypercube **fc_simesh.siMesh** object generated with the function **fc_simesh**.HyperCube, representation of the elementary meshes with 2-simplices (top left), 1-simplices (top right) and 0-simplices (bottom)

2.6.2 3D hypercube

In Listing 31 a usage example generating a 3D hypercube as a **fc_simesh.siMesh** object is given. This **fc_simesh.siMesh** object is representing in Figure 5 by using the the FC-SIPLT toolbox. .

Listing 31: 3D Hypercube **fc_simesh.siMesh** object generated with the function **fc_simesh**.HyperCube

```
Th=fc_simesh.HyperCube(3,10);
disp(Th)
```

Output

```
fc_simesh.siMesh with properties:
              d: 3 double
            dim: 3 double
            sTh: (1x27 cell)
           nsTh: 27 double
       toGlobal: (1x1331 double)
       toParent: (1x1331 double)
        sThsimp: (1x27 double)
         sThlab: (1x27 double)
      sThcolors: (27x3 double)
           bbox: [ 0 1 0 1 0 1 ] (1x6 double)
      sThgeolab: []
     sThphyslab: 1 double
    sThpartlabs: []
   sThboundlabs: []
             nq: 1331 double
      nqParents: 1331 double
      toParents: (1x1 cell)
          other: []
```

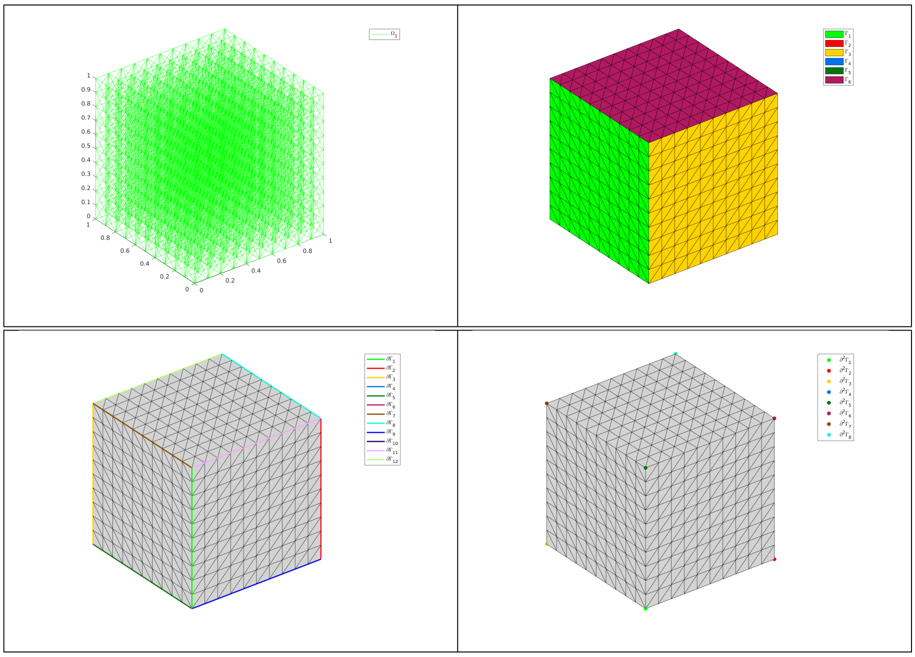


Figure 5: 3D Hypercube **fc_simesh.siMesh** object generated with the function **siMesh**.HyperCube, representation of the elementary meshes with 3-simplices (top left), 2-simplices (top right), 1-simplices (bottom left) and 0-simplices (bottom right)

2.6.3 4D hypercube

In Listing 32 a usage example generating a 4D hypercube as a **fc_simesh.siMesh** object is given.

Listing 32: 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: []
             nq: 14641 double
      nqParents: 14641 double
      toParents: (1x1 cell)
          other: []
```

2.6.4 5D hypercube

In Listing 32 a usage example generating a 5D hypercube as a **fc_simesh.siMesh** object is given.

Listing 33: function **siMesh**.HyperCube

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

Output

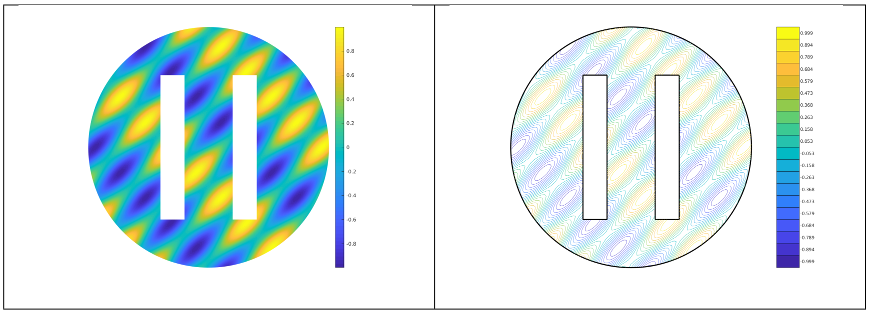
```
fc_simesh.siMesh with properties:
            d: 5 double
          dim: 5 double
          sTh: (1x243 cell)
         nsTh: 243 double
     toGlobal: (1x16807 double)
     toParent: (1x16807 double)
      sThsimp: (1x243 double)
       sThlab: (1x243 double)
    sThcolors: (243x3 double)
      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

3 Graphic representations on fc_simesh.siMeshElt object

Actually the siplt toolbox is used as graphic kernel of the **fc_simesh.siMesh** objects. So for each methods **plot**, **plotmesh**, **plotiso**, **plotquiver**, **slice**, **slicemesh** and **sliceiso** one can refers to the corresponding functions of the siplt toolbox: For a **fc_simesh.siMesh** object, named Th, we have

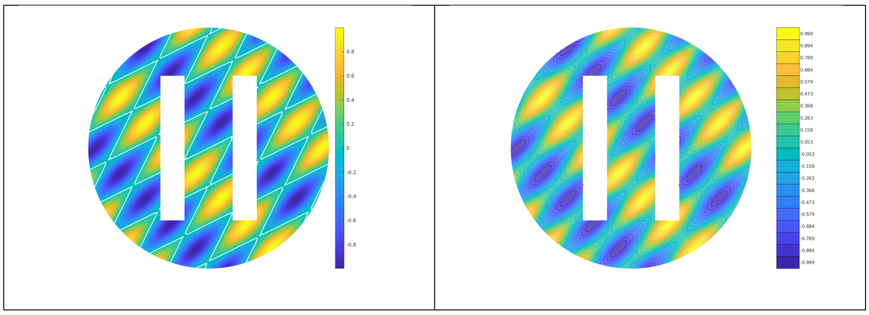
- Th.**plotmesh**(...): calls of the function **fc_siplt.plotmesh**(Th,...)
- Th.**plot** (...) : calls of the function **fc_siplt.plot**(Th,...)
- Th.**plotiso** (...) : calls of the function **fc_siplt.plotiso**(Th,...)
- Th.**plotquiver**(...): calls of the function **fc_siplt.plotquiver**(Th,...)
- Th.**slicemesh**(...): calls of the function **fc_siplt.slicemesh**(Th,...)
- Th.**slice** (...) : calls of the function **fc_siplt.slice**(Th ,...)
- Th.**sliceiso** (...) : calls of the function **fc_siplt.sliceiso**(Th ,...)

3.1 Data 2D mesh



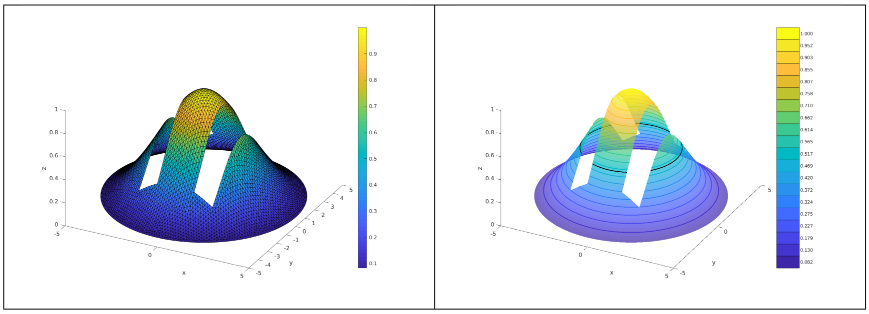
```
meshfile=fc_oogmsh.gmsh.buildmesh2d('condenser',10);
Th=fc_simesh.siMesh(meshfile);
u=@(x,y) cos(2*x-y).*sin(x-2*y);
U=Th.eval(u);
figure(1);
Th.plot(U)
shading interp;axis off;axis image
colorbar
figure(2)
Th.plotmesh('d',1,'color','k','Linewidth',2);
hold on;axis off;axis image
Th.plotiso(U,'niso',20,'isocolorbar',true,'format','%.3f');
```

Listing 34: Data representations on a 2D mesh



```
meshfile=fc_oogmsh.gmsh.buildmesh2d('condenser',10);
Th=fc_simesh.siMesh(meshfile);
u=@(x,y) cos(2*x-y).*sin(x-2*y);
U=Th.eval(u);
figure(1);
Th.plot(U)
hold on
Th.plotiso(U,'isorange',0, 'color','w', 'Linewidth',1.5);
axis off,axis image,shading interp,colorbar
figure(2)
Th.plot(U,'FaceAlpha',0.8)
hold on
[Colors,isorange]=Th.plotiso(U,'niso',20, 'Linewidth',1.5);
axis off,axis image, shading interp
fc_tools.graphics.colorbarIso(Colors,isorange,'%.3f')
```

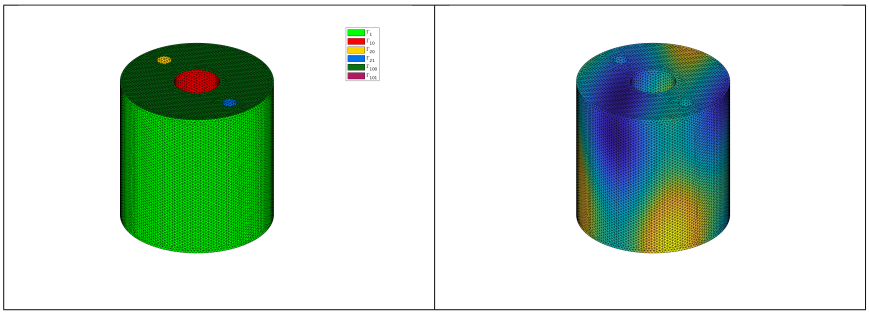
Listing 35: Data representations on a 2D mesh. White lines are zero isolines (left)



```
meshfile=fc_oogmsh.gmsh.buildmesh2d('condenser',7);
Th=fc_simesh.siMesh(meshfile);
u=@(x,y)exp(-(x.^2+y.^2)/10);
U=Th.eval(u);
figure(1)
Th.plot(U)
colorbar
view(27,39)
xlabel('x'),ylabel('y'),zlabel('z')
figure(2);
Th.plot(U,'FaceAlpha',0.7)
hold on
Th.plotiso(U,'niso',20,'Linewidth',1.5, 'isocolorbar',true,'format','%.3f');
Th.plotiso(U,'isorange',0.5, 'color','k', 'Linewidth',1.5);
shading interp
view(27,39)
xlabel('x'),ylabel('y'),zlabel('z')
```

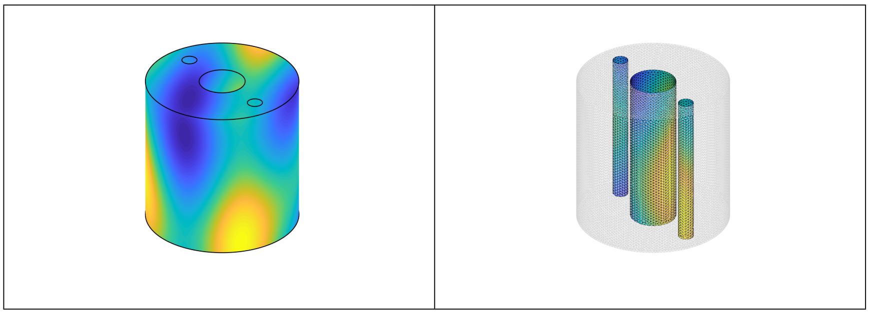
Listing 36: Data representations on a 2D mesh. Black lines are zero isolines (right)

3.2 3D mesh



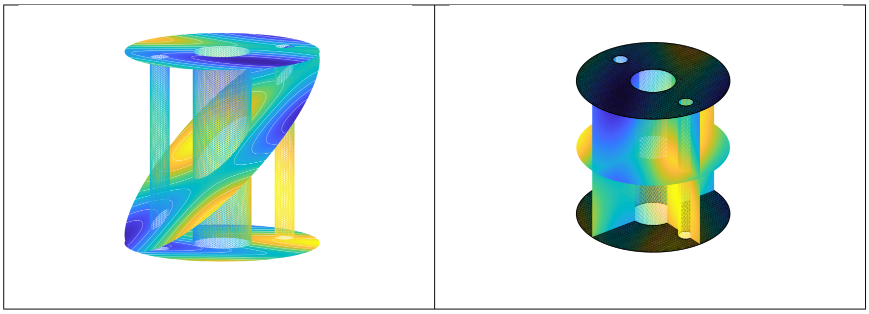
```
meshfile=fc_oogmsh.gmsh.buildmesh3d('cylinder3holes',ns*5);
Th=fc_simesh.siMesh(meshfile);
u=@(x,y,z) cos(2*x-y-z).*sin(x-2*y+z);
U=Th.eval(u);
figure(1);
Th.plotmesh('d',2,'inlegend',true)
axis off;axis image;legend('show')
figure(2)
Th.plot(U,'d',2)
axis off;axis image
```

Listing 37: Data representations on a 3D mesh



```
meshfile=fc_oogmsh.gmsh.buildmesh3d('cylinder3holes',ns*5);
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.plot(U,'d',2)
caxis([min(U),max(U)])
axis off;axis image
shading interp
hold on
Th.plotmesh('d',1, 'color','k', 'Linewidth',1.5)
figure(2)
Th.plotmesh('d',2, 'FaceColor','none', 'EdgeColor','LightGray')
hold on;axis off;axis image;caxis([min(U),max(U)])
Th.plot(U,'d',2,'labels',[10,20,21])
```

Listing 38: Data representations on a 3D mesh



```
meshfile=fc_oogmsh.gmsh.buildmesh3d('cylinder3holes',ns*10);
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);
P=fc_tools.graphics.PlaneCoefs([0 0 1],[0 1 1]);
Th.slice(U,P, 'FaceColor','interp', 'EdgeColor','none')
axis off,axis image,hold on
Th.plot(U,'d',2,'labels',[100,101], 'FaceColor','interp', 'EdgeColor','none')
caxis([min(U),max(U)])
isorange=linspace(min(U),max(U),10);
Th.plot(U,'d',2,'labels',[10,20,21], 'FaceColor','none', 'EdgeColor','interp')
Th.plotiso(U,'labels',[100,101], 'isorange',isorange, 'color','w')
Th.sliceiso(U,P,'isorange',isorange, 'color','w')
view(-114,11)
figure(2)
P=[fc_tools.graphics.PlaneCoefs([0 0 1],[1 0 0]); ...
   fc_tools.graphics.PlaneCoefs([0 0 1],[0 1 0]); ...
   fc_tools.graphics.PlaneCoefs([0 0 1],[0 0 1])];
Th.slice(U,P, 'FaceColor','interp', 'EdgeColor','none')
hold on;axis off,axis image;caxis([min(U),max(U)])
Th.plot(U,'d',2,'labels',[100,101], 'FaceColor','interp')
Th.plot(U,'d',2,'labels',[10,20,21], 'FaceColor','none', 'EdgeColor','interp')
Th.plotmesh('d',1, 'Color','k', 'Linewidth',1.5)
```

Listing 39: Data representations on a 3D mesh

3.2.1 Mapping of the unit ball

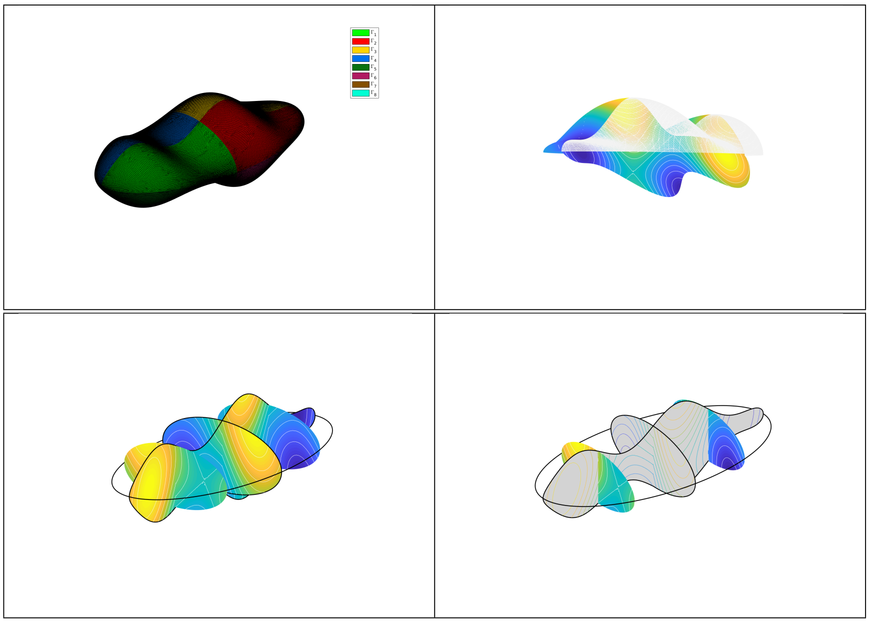
The 3D domain Ω is constructed by mapping a discretization of the unit ball onto Ω by

$$F(y_1, y_2, y_3) = \begin{pmatrix} 2y_1 \\ y_2 \\ \frac{1}{2}y_3(1 + \frac{1}{2}\sin(2\pi y_1)) \end{pmatrix}, \quad \forall \boldsymbol{y} = (y_1, y_2, y_3), \text{ such that } \|\boldsymbol{y}\|_2 \leqslant 1$$

We represent the function

$$u(x, y, z) = \cos(2x - y - z)\sin(x - 2y + z)$$

on Ω by mapping the unit ball obtained from `gmsh` with `ball8.geo`.



```
trans=@(q) [2*q(1,:);q(2,:);0.5*q(3,:).*(1+0.5*sin(2*pi*q(1,:)))];
meshfile=fc_oogmsh.gmsh.buildmesh3d('ball8',ns*10);
Th=fc_simesh.siMesh(meshfile,'trans',trans);
u=@(x,y,z) cos(2*x-y-z).*sin(x-2*y+z);
U=Th.eval(u);
figure(1)
Th.plotmesh('d',2,'inlegend',true);
axis off;axis image;legend('show')
figure(2)
P=fc_tools.graphics.PlaneCoefs([0 0 0],[0 1 1]);
Th.slice(U,P)
hold on;caxis([min(U),max(U)])
Th.plot(U,'d',2,'labels',[1,2], 'EdgeColor','None')
isorange=linspace(min(U),max(U),15);
Th.plotmesh('d',2,'labels',[3,4], 'FaceColor','none', 'EdgeColor',0.95*[1,1,1])
Th.plotiso(U,'labels',[3,4],'isorange',isorange, 'color','w' )
Th.sliceiso(U,P,'isorange',isorange, 'color','w')
axis off;axis image
view(127,-1)
figure(3)
P=[fc_tools.graphics.PlaneCoefs([0 0 1],[1 0 0]); ...
   fc_tools.graphics.PlaneCoefs([0 0 1],[0 1 0]); ...
   fc_tools.graphics.PlaneCoefs([0 0 1],[0 0 1]); ...
   fc_tools.graphics.PlaneCoefs([-1 0 0],[1 0 0]); ...
   fc_tools.graphics.PlaneCoefs([1 0 0],[1 0 0]) ];
Th.slice(U,P, 'FaceColor','interp', 'EdgeColor','none')
hold on
Th.sliceiso(U,P,'isorange',isorange, 'color','w')
Th.plotmesh('d',1, 'color','k','Linewidth',1.5)
axis off;axis image
view(-52,20)
figure(4)
Th.slicemesh(P(1:2,:),'Color','LightGray')
hold on;axis off;axis image;view(-52,20)
Th.sliceiso(U,P(1:2,:),'isorange',isorange)
Th.slice(U,P(3:5,:));
Th.sliceiso(U,P(3:5,:),'isorange',isorange, 'color','w')
Th.plotmesh('d',1, 'color','k', 'Linewidth',1.5)
```

Listing 40: Data representations on a 3D mesh

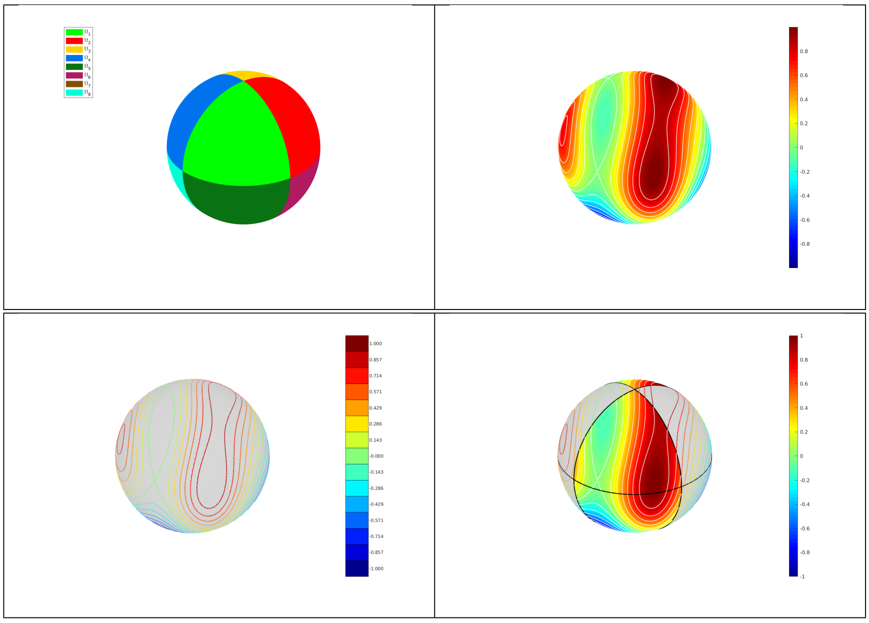
3.3 3D surface meshes

3.3.1 Unit sphere

We represent the function

$$u(x, y, z) = \cos(2x - y - z\sin(x - 2y + z)$$

on the unit sphere obtained from `gmsh` with `sphere8surf.geo`.



```
meshfile=fc_oogmsh.gmsh.buildmesh3ds('sphere8surf',ns*10);
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('inlegend',true,'EdgeColor','None')
axis off;axis image
legend('show','Location','NorthWestOutside')
figure(2);
colormap(jet)
Th.plot(U,'d',2)
hold on;axis off, axis image
Th.plotiso(U,'niso',15,'color','w', 'Linewidth',1)
caxis([min(U),max(U)])
shading interp
colorbar;
figure(3)
colormap(jet)
Th.plotmesh('FaceColor',0.9*[1 1 1], 'EdgeColor',0.8*[1 1 1]);
hold on;axis off, axis image
Th.plotiso(U,'niso',15,'Linewidth',1.5, 'isocolorbar',true,'format','%.3f')
figure(4);
colormap(jet)
Th.plot(U,'d',2,'labels',[1:2:8],'FaceColor','interp','EdgeColor','None')
hold on
Th.plotiso(U,'labels',[1:2:8],'niso',15,'color',[1 1 1], 'Linewidth',1)
Th.plotmesh('labels',[2:2:8], 'FaceColor',0.9*[1 1 1], 'EdgeColor',0.8*[1 1 1]);
Th.plotiso(U,'labels',[2:2:8],'niso',15, 'Linewidth',1.5)
axis off, axis image
Th.plotmesh('d',1,'color',[0 0 0], 'Linewidth',1.5)
colorbar
```

Listing 41: Data representations on a 3D surface mesh

3.3.2 Mapping of the unit sphere

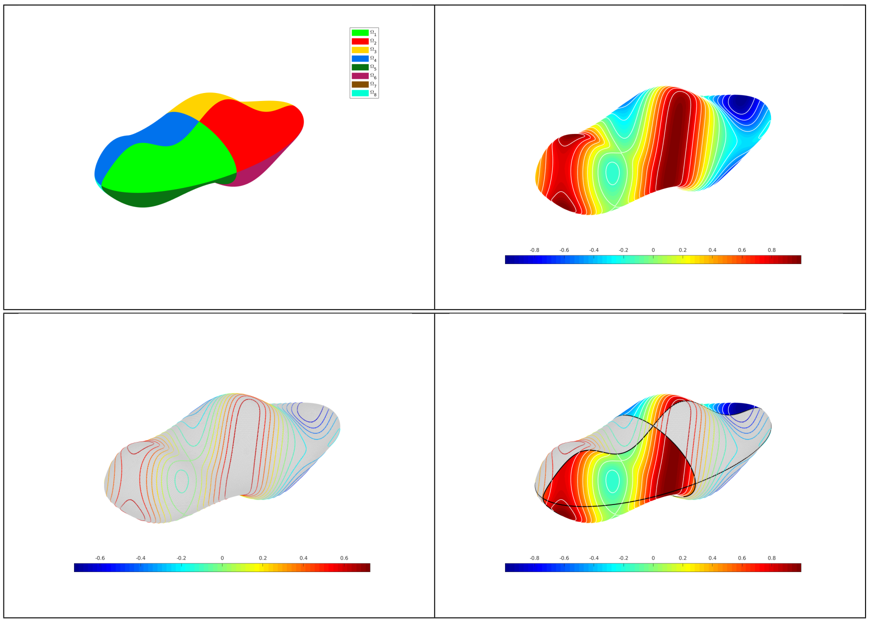
The hypersurface is constructed by mapping a discretization of the unit sphere S^2 onto the surface Ω by

$$F(y_1, y_2, y_3) = \begin{pmatrix} 2y_1 \\ y_2 \\ \frac{1}{2}y_3(1 + \frac{1}{2}\sin(2\pi y_1)) \end{pmatrix}, \quad \forall \boldsymbol{y} = (y_1, y_2, y_3) \in S^2$$

We represent the function

$$u(x, y, z) = \cos(2x - y - z)\sin(x - 2y + z)$$

on the surface Ω by mapping the unit sphere obtained from `gmsh` with `sphere8surf.geo`.

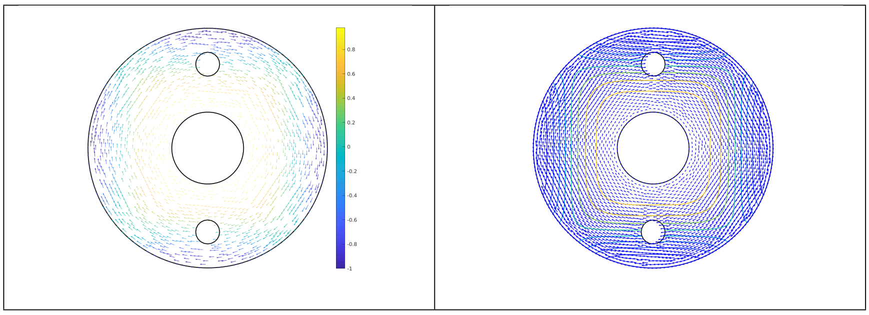


```
meshfile=fc_oogmsh.gmsh.buildmesh3ds('sphere8surf',ns*10);
Th=fc_simesh.siMesh(meshfile);
u=@(x,y,z) cos(2*x-y-z).*sin(x-2*y+z);
U=Th.eval(u);
figure(1)
Th.plotmesh('inlegend',true,'EdgeColor','None')
axis off;axis image
legend('show','Location','NorthWestOutside')
figure(2);
colormap(jet)
Th.plot(U,'d',2)
hold on;axis off, axis image
Th.plotiso(U,'niso',15,'color','w', 'Linewidth',1)
caxis([min(U),max(U)])
shading interp
colorbar;
figure(3)
colormap(jet)
Th.plotmesh('FaceColor',0.9*[1 1 1], 'EdgeColor',0.8*[1 1 1]);
hold on;axis off, axis image
Th.plotiso(U,'niso',15,'Linewidth',1.5, 'isocolorbar',true,'format','%.3f')
figure(4);
colormap(jet)
Th.plot(U,'d',2,'labels',[1:2:8],'FaceColor','interp','EdgeColor','None')
hold on
Th.plotiso(U,'labels',[1:2:8],'niso',15,'color',[1 1 1], 'Linewidth',1)
Th.plotmesh('labels',[2:2:8], 'FaceColor',0.9*[1 1 1], 'EdgeColor',0.8*[1 1 1]);
Th.plotiso(U,'labels',[2:2:8],'niso',15, 'Linewidth',1.5)
axis off, axis image
Th.plotmesh('d',1,'color',[0 0 0], 'Linewidth',1.5)
colorbar
```

Listing 42: Data representations on a 3D surface mesh

3.4 Vector field representation on meshes

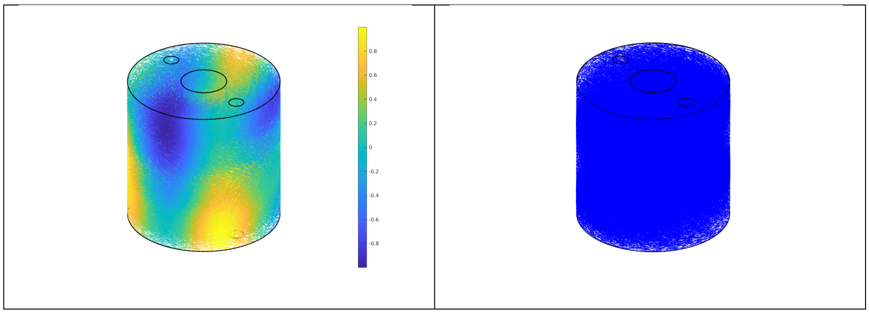
3.4.1 2D mesh



```
meshfile=fc_oogmsh.gmsh.buildmesh2d('disk3holes',30);
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
Th.plotquiver(W,'colordata',U,'freq',2, 'scale',0.05)
axis off;axis image
colorbar
figure(2)
Th.plotmesh('d',1,'color','k', 'LineWidth',1.5)
hold on
Th.plotquiver(W,'LineWidth',1, 'scale',0.05)
Th.plotiso(U, 'LineWidth',1.5)
axis off;axis image
colormap('jet')
```

Listing 43: Vector field representations on a 2D mesh

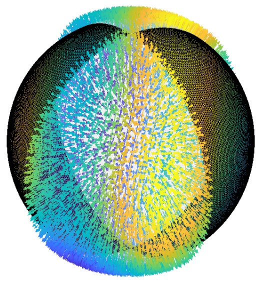
3.4.2 3D mesh



```
meshfile=fc_oogmsh.gmsh.buildmesh3d('cylinder3holes',ns*10);
Th=fc_simesh.siMesh(meshfile);
u=@(x,y,z) cos(2*x-y-z).*sin(x-2*y+z);
U=Th.eval(u);
w={@(x,y,z) y.*cos(-(x.^2+y.^2)/10), @(x,y,z) -x.*cos(-(x.^2+y.^2)/10), @(x,y,z) ...
    sin(2*pi*z)};
W=[Th.eval(w{1}),Th.eval(w{2}),Th.eval(w{3})];
figure(1);
Th.plotmesh('d',1, 'color','k', 'Linewidth',1.5)
hold on
Th.plotquiver(W,'colordata',U, 'freq',3,'scale',0.05)
view(3)
axis off;axis image
colorbar
figure(2)
Th.plotmesh('d',1, 'color','k', 'Linewidth',1.5)
hold on
Th.plotquiver(W,'freq',3)
view(3)
axis off;axis image
```

Listing 44: Vector field representations on a 3D mesh

3.4.3 3D surface mesh



```
meshfile=fc_oogmsh.gmsh.buildmesh3ds('sphere8surf',ns*10);
Th=fc_simesh.siMesh(meshfile);
u=@(x,y,z) cos(2*x-y-z).*sin(x-2*y+z);
U=Th.eval(u);
w={@(x,y,z) x;@(x,y,z) y; @(x,y,z) z};
W=[Th.eval(w{1}),Th.eval(w{2}),Th.eval(w{3})];
figure(1)
Th.plotmesh('labels',1:2:8, 'FaceColor','none', 'EdgeColor',0.8*[1 1 1], ...
    'EdgeAlpha',0.3);
hold on
Th.plotiso(U,'labels',[1:2:8], 'niso',15, 'Linewidth',1);
Th.plotquiver(W,'colordata',U, 'labels',1:2:8, 'freq',3,'scale',0.1)
Th.plot(U,'d',2,'labels',[2:2:8]);
axis off;axis image
```

Listing 45: Vector field representation on a 3D surface 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 fcsimesh Matlab toolbox

git informations on the toolboxes used to build this manual

```
-------------------------------------------------------
  name : fc-simesh
   tag : 0.4.0
commit : 9e234702263df3e1dc19cfff57bbdf5248859725
  date : 2020-02-20
  time : 10-01-30
status : 0
-------------------------------------------------------
  name : fc-tools
   tag : 0.0.30
commit : 42054f06c3f484c5fc7d0a0cb425d727b50e8994
  date : 2020-02-18
  time : 06-46-53
status : 0
-------------------------------------------------------
  name : fc-bench
   tag : 0.1.2
commit : 666dc60d1277f5fa9c99dee4ae1c33270f22c57d
  date : 2020-02-16
  time : 06-38-46
status : 0
-------------------------------------------------------
  name : fc-hypermesh
   tag : 1.0.3
commit : c520b34cfd7eb0dbf9e4ecd459fd7162db73cc58
  date : 2020-02-16
  time : 08-34-19
status : 0
-------------------------------------------------------
  name : fc-amat
   tag : 0.1.2
commit : 957340f6e71d805dbd8b9d04c434b24fd3f92591
  date : 2020-02-16
  time : 06-39-42
status : 0
-------------------------------------------------------
  name : fc-meshtools
   tag : 0.1.3
commit : cdbc41bc98af4e4faccc1746024aced1f21aae53
  date : 2020-02-17
  time : 10-52-56
status : 0
-------------------------------------------------------
  name : fc-graphics4mesh
   tag : 0.1.1
commit : d8e283fc3e1ce5fac855064062e196750a0a0cd4
  date : 2020-02-19
  time : 08-50-23
status : 0
-------------------------------------------------------
  name : fc-oogmsh
   tag : 0.2.2
commit : 90fc9826fea6eb8dd66afc3a58677564c8f7f442
  date : 2020-02-17
  time : 13-31-05
status : 0
-------------------------------------------------------
  name : fc-siplt
   tag : 0.2.0
commit : e9cac51a2239a52ce34125ddcd2f1de4377dda5f
  date : 2020-02-20
  time : 09-50-32
status : 0
-------------------------------------------------------
```

git informations on the $\LaTeX$ package used to build this manual

```
--------------------------------------------------
  name : fctools
   tag :
 commit : 57968c4a96c2593cccc9da9efd3e52b2ff012cb5
  date : 2020-02-07
  time : 06:41:09
 status : 1
--------------------------------------------------
```

Using the remote configuration repository:

url	`ssh://lagagit/MCS/Cuvelier/Matlab/fc-config`
commit	`b837af396f81fb38264a3affb2f2d5c779818b6c`