Netgen-DMPlex and FEniCSx

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NetGen-DMPlex

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January 2023 — First NetGen to DMPlex interface for Firedrake.

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Why NetGen?

NetGen is an advancing front 2D/3D-mesh generator, with many interesting features. Among the most important:

- Python wrapping (through pybind11),
- Multiple ways of describing the geometry to be meshed, i.e. its builtin **Constructive Solid Geometry** (**CSG**) and the **Open Cascade Technology** (**OCCT**) geometry kernel,
- Supports mesh refinement (also anisotropic mesh refinement).

Getting Started – Installing NetGen

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NetGen

```
pip install --pre ngsolve
```

NetGen/NGSolve can also be installed from source, just but be careful to link against the correct MPI.

PETSc

If you are using an external PETSc installation, it should be updated to include commit `654059db` and `text4aa747ac`.

Getting Started – Unstructured Mesh

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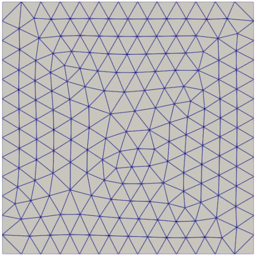
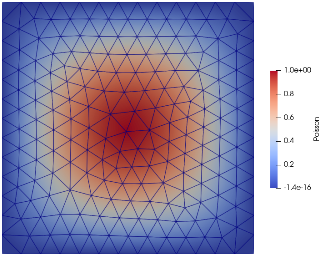
```python
import netgen.gui
from netgen.geom2d import SplineGeometry
geo = SplineGeometry()
geo.AddRectangle((0,0),(np.pi,np.pi))
domain  = ngsio.model_to_mesh(geo, MPI.COMM_WORLD,
    hmax=0.25, gdim=2)
V = FunctionSpace(domain, ("CG", 3))
u = Function(V, dtype=default_scalar_type)
u.interpolate(lambda x: x[0]*x[1])
integrand = form(u*dx)
print(assemble_scalar(integrand))
with XDMFFile(domain.comm, "XDMF/triang.xdmf", "w") as
     xdmf:
    xdmf.write_mesh(domain)
```

Getting Started – Unstructured Mesh

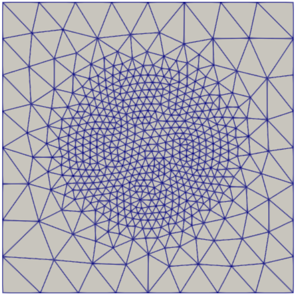




Getting Started – CSG 2D


```python
from netgen.geom2d import SplineGeometry
geo = SplineGeometry()
geo.AddRectangle(p1=(-1,-1),p2=(1,1),bc="rectangle",
     leftdomain=1,rightdomain=0)
geo.AddCircle(c=(0,0),r=0.5,bc="circle",
     leftdomain=2,rightdomain=1)
geo.SetMaterial (1, "outer")
geo.SetMaterial (2, "inner")
geo.SetDomainMaxH(2, 0.05)
domain  = ngsio.model_to_mesh(geo, MPI.COMM_WORLD, hmax=0.25, gdim=2)
with XDMFFile(domain.comm, "XDMF/csg2D.xdmf", "w") as xdmf:
     xdmf.write_mesh(domain)
```

Getting Started – CSG 2D



Getting Started – CSG 3D

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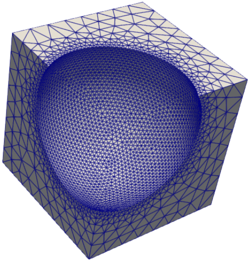
```python
from netgen.csg import CSGeometry, Sphere, OrthoBrick, Pnt
geo = CSGeometry()
brick = OrthoBrick(Pnt(-1,-1,-1),Pnt(1,1,1))
sphere = Sphere(Pnt(0.5,0.5,0.5),1)
sphere.maxh(0.05)
geo.Add(brick-sphere)
domain  = ngsio.model_to_mesh(geo, MPI.COMM_WORLD, hmax=0.25, gdim=3)
with XDMFFile(domain.comm, "XDMF/csg3D.xdmf", "w") as xdmf:
    xdmf.write_mesh(domain)
```



The Open Cascade Technology Kernel

- Basic OCCT objects can be used in NetGen such as: `Box`, `Cylinder`, `Point`, `Segment` and `ArcOfCircle`.
- The `fuse`, `cut` and `common` operations between OCCT objects have been wrapped in NetGen.
- Transformation operations such as `Move` and `Rotate` have also been wrapped into NetGen.

The Open Cascade Technology Kernel

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```python
from netgen.csg import CSGeometry, Sphere, OrthoBrick,
    Pnt
box = Box(Pnt(0,0,0), Pnt(1,1,1))
cyl = Cylinder(Pnt(1,0.5,0.5), X, r=0.3, h=0.5)
solid1 = box + cyl
solid2 = solid1.Rotate(Axis((0,0,0),Y),180).Move
    ((2.5,0.,1.))
solid = solid2 + solid1
geo = OCCGeometry(solid)
domain  = ngsio.model_to_mesh(geo, MPI.COMM_WORLD,
    hmax=0.25, gdim=3)
with XDMFFile(domain.comm, "XDMF/csg3D.xdmf", "w") as
    xdmf:
    xdmf.write_mesh(domain)
```

The Open Cascade Technology Kernel

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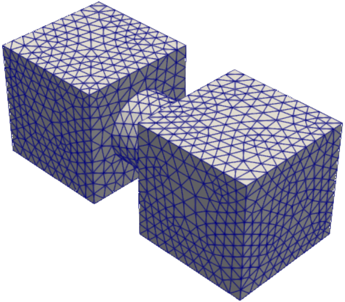
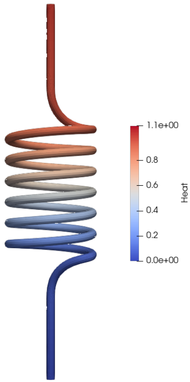


The OCCT Kernel – Poisson Problem

```
cyl = Cylinder((0,0,0), Z, r=0.01, h=0.03).faces[0]
heli = Edge(Segment((0,0), (12*pi, 0.03)), cyl)
ps,vs,pe,ve = heli.start, heli.start_tangent, heli.end, heli.end_tangent
e1 = Segment((0,0,-0.03), (0,0,-0.01))
c1 = BezierCurve( [(0,0,-0.01), (0,0,0), ps-vs, ps])
e2 = Segment((0,0,0.04), (0,0,0.06))
c2 = BezierCurve( [pe, pe+ve, (0,0,0.03), (0,0,0.04)])
spiral = Wire([e1, c1, heli, c2, e2])
circ, coil = Face(Wire([Circle((0,0,-0.03), Z, 0.001)])), Pipe(spiral, circ)
geo = OCCGeometry(coil)
```



PETSc Transform – Quad Mesh


```python
import netgen.gui
from netgen.geom2d import SplineGeometry
geo = SplineGeometry()
geo.AddRectangle((0,0),(1,1))
tr = PETSc.DMPlexTransform().create(comm=PETSc.COMM_WORLD)
tr.setType(PETSc.DMPlexTransformType.REFINETOBOX)
domain  = ngsio.model_to_mesh(geo, MPI.COMM_WORLD, hmax=0.2, gdim=2, transform=tr)
with XDMFFile(domain.comm, "XDMF/quad.xdmf", "w") as xdmf:
     xdmf.write_mesh(domain)
```

PETSc Transform – Quad Mesh

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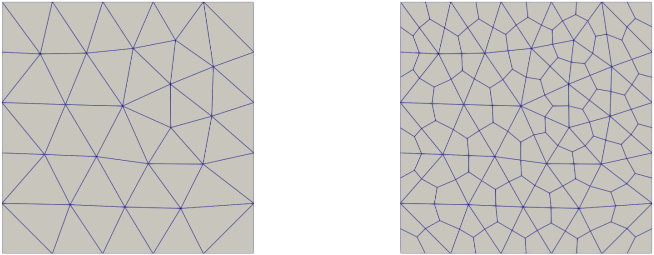

PETSc Transform – Barycentric Mesh

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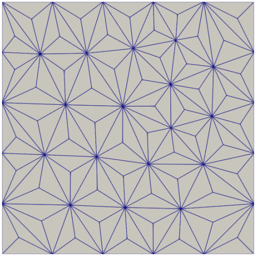
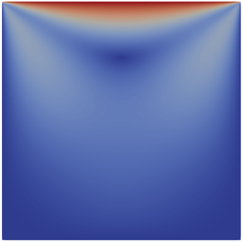
```
import netgen.gui
from netgen.geom2d import SplineGeometry
geo = SplineGeometry()
geo.AddRectangle((0,0),(1,1))
tr = PETSc.DMPlexTransform().create(comm=PETSc.
    COMM_WORLD)
tr.setType(PETSc.DMPlexTransformType.REFINEALFELD)
msh = ngsio.model_to_mesh(geo, MPI.COMM_WORLD, hmax
    =0.01, gdim=2, transform=tr)
```

PETSc Transform – Barycentric Refinement





Anisotropic Refinement

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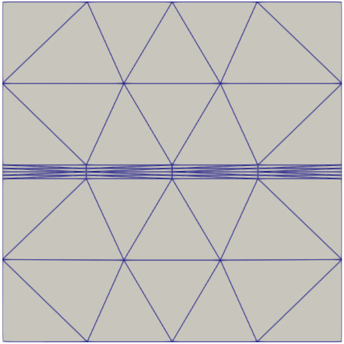
```
geo = CSGeometry()
box = OrthoBrick(Pnt(0,0,0),Pnt(1,1,1))
top = Plane(Pnt(0,0,0.52),Vec(0,0,1))
bot = Plane(Pnt(0,0,0.48),Vec(0,0,-1))
plate = box * top * bot
geo.Add((box-top).mat("air"))
geo.Add(plate.mat("plate"))
geo.Add((box-bot).mat("air"))
geo.CloseSurfaces(bot,top)
nmesh = geo.GenerateMesh(maxh=0.25)
def ngs_routine(msh,geo):
    ZRefinement(msh,geo); msh.Split2Tets();
    return msh, geo
domain  = ngsio.model_to_mesh(geo, MPI.COMM_WORLD,
    hmax=0.25, gdim=3,transform=None,routine=
    ngs_routine)
```

Anisotropic Refinement



Conclusion

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- It is now possible to describe the geometry using NetGen, this allows for **anisotropic mesh** refinement.
- It is possible to use **Open Cascade** to describe a geometry, through NetGen.
- It is now possible to use DMPlex transformation in two and three dimensions. Such as **Alfeld, Powell-Sabin** refinements.