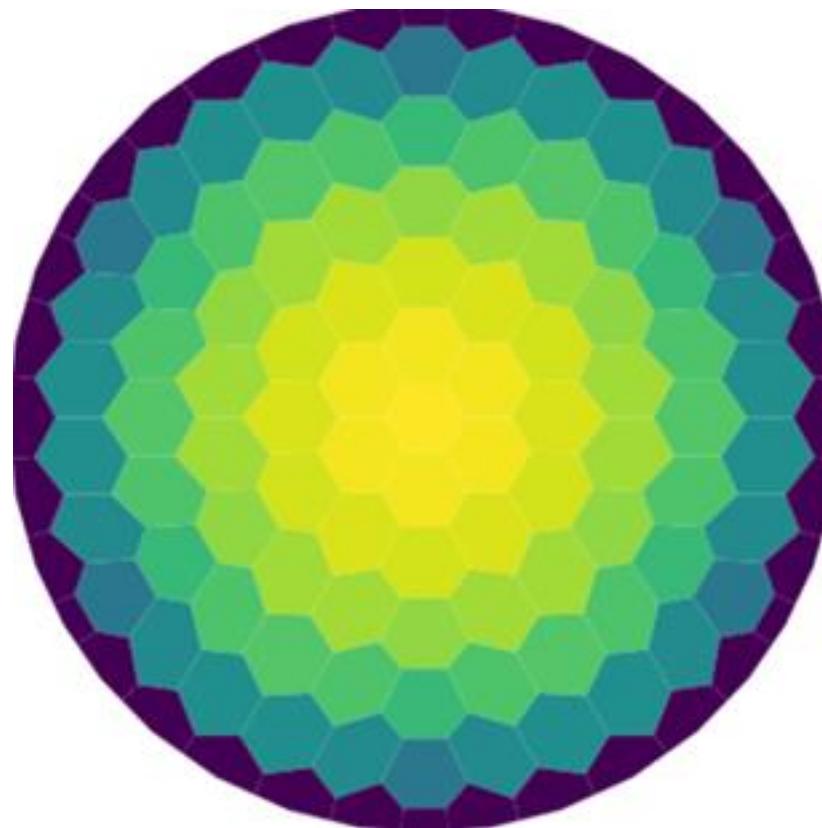


Deltares



Unstructured grids, MODFLOW6,
imod-python

Huite Bootsma

Package overview

Make unstructured grid



Work with unstructured grid



Get data on unstructured grid (“IDFSCALE”); work-in-progress



Write to and read from MODFLOW6



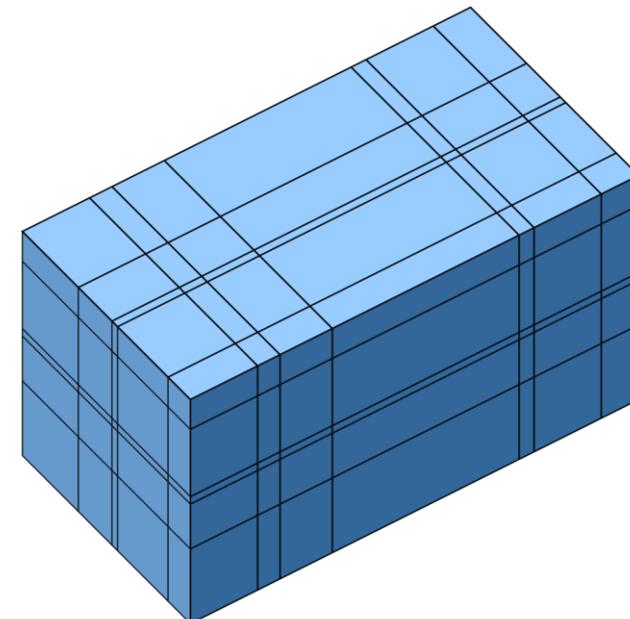
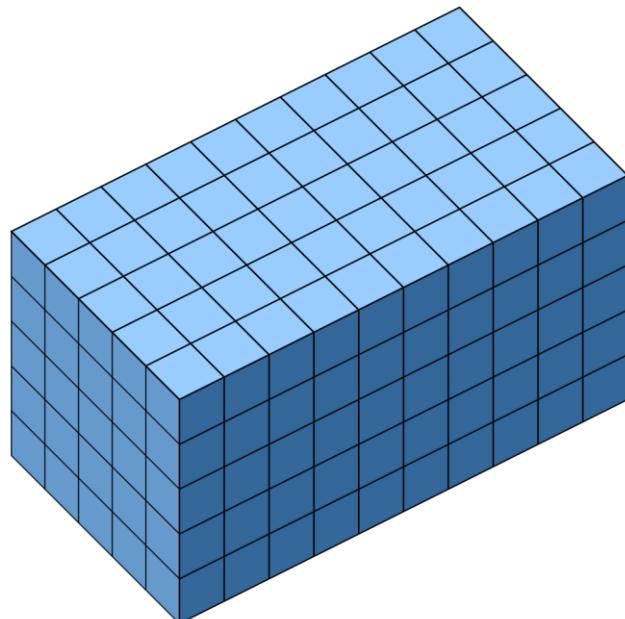
We will wrap and expose these packages in imod-python

But kept separately: serve a more a general purpose beyond MODFLOW6

Why unstructured?

More direct representation of hydrological features

Flexible refinement: goal is efficiency



Problems

Control volume requirements: orthogonality

Generating grids

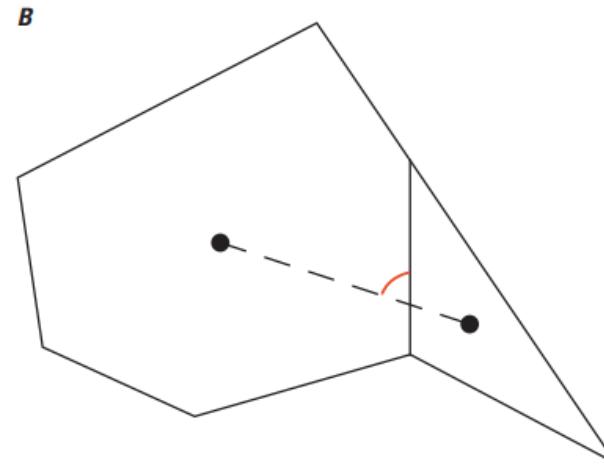
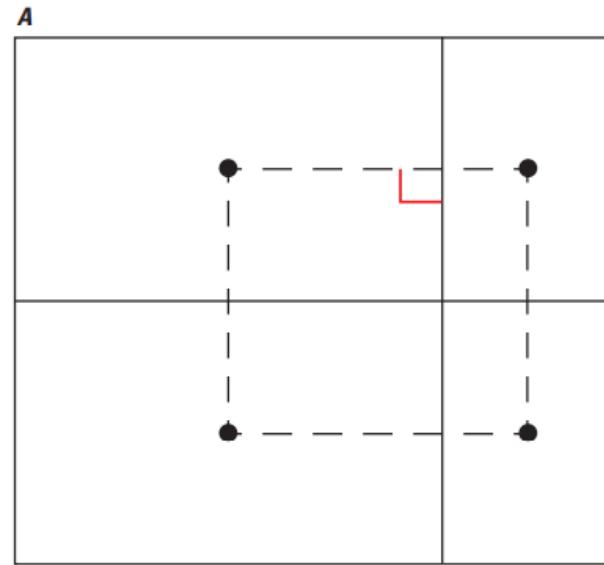
Manipulating and plotting unstructured grids

Control volume woes

Angles of 90 degrees are required between cell centers and edges

Triangular (Delaunay) meshes do not guarantee such angles

MODFLOW6 solution: XT3D (full cross tensor) or ghost nodes



- EXPLANATION**
- Cell outline
 - Line connecting cell centers
 - Cell center

XT3D

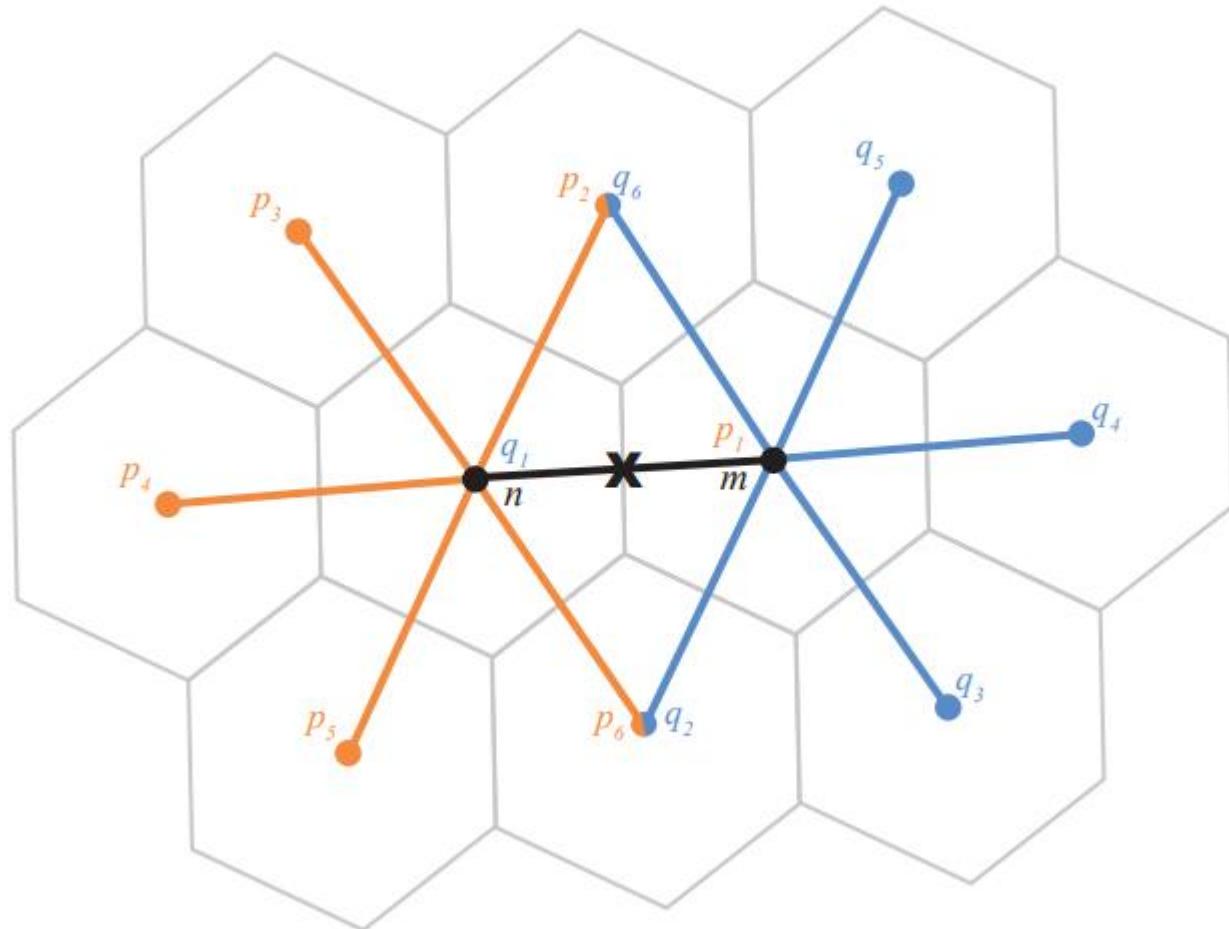
Estimate hydraulic gradient at \mathbf{x} to calculate flow $n \rightarrow m$

Requires all direct neighbors of cells n & m

Also required for non-axis aligned anisotropy

Much more neighbors: more expensive to formulate and solve

Undoes efficiency gains



Control volume woes

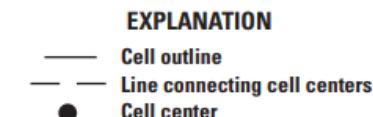
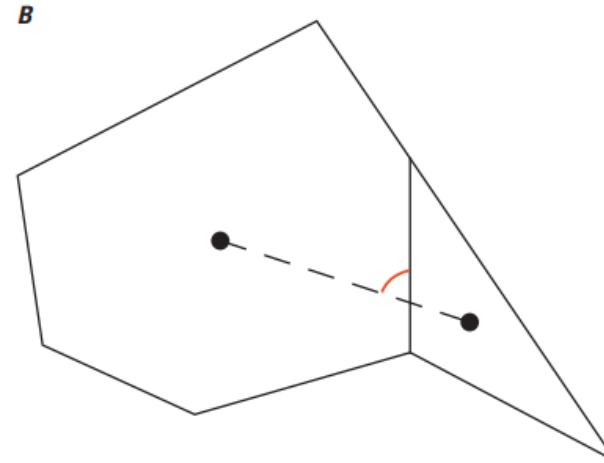
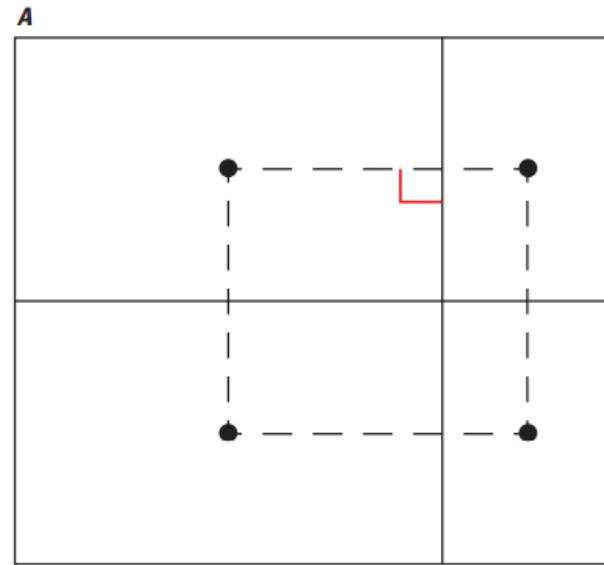
Angles of 90 degrees are required between cell centers and faces

Triangular (Delaunay) meshes do not guarantee such angles

MODFLOW6 solution: XT3D (full cross tensor)

Alternative: unstructured grids **with** orthogonal angles

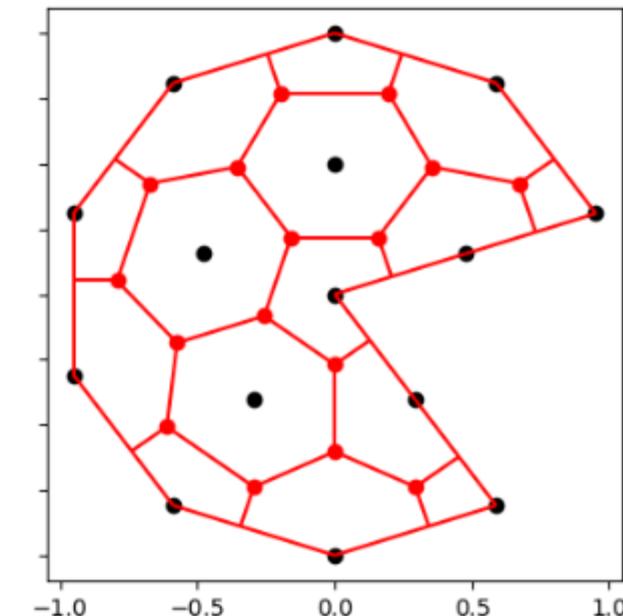
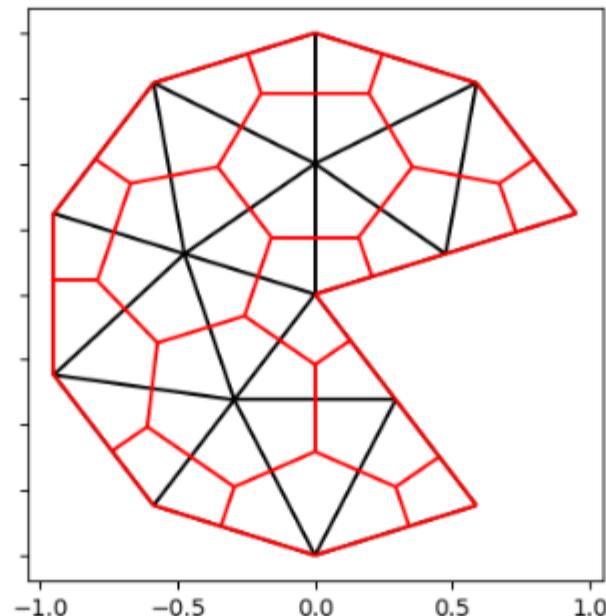
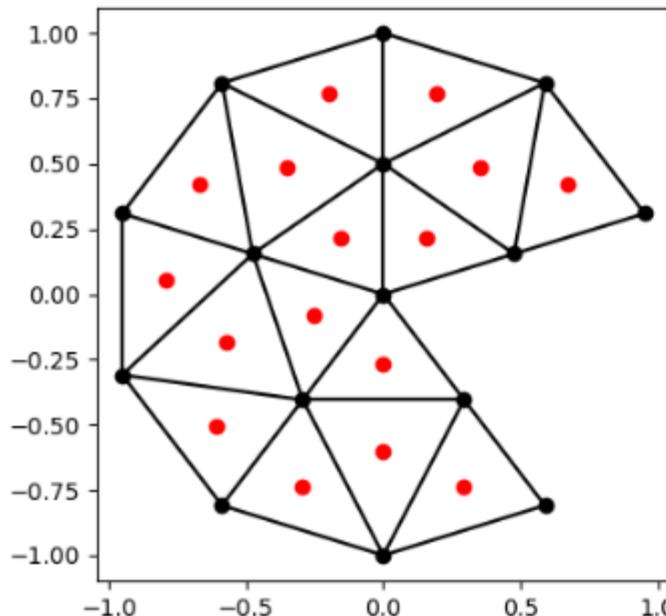
- (Balanced) Quadtree
- Voronoi tessellation



Centroidal Voronoi tessellation

A Delaunay triangulation of set a of vertices (black) is a “dual graph” of the Voronoi diagram (red) for those vertices

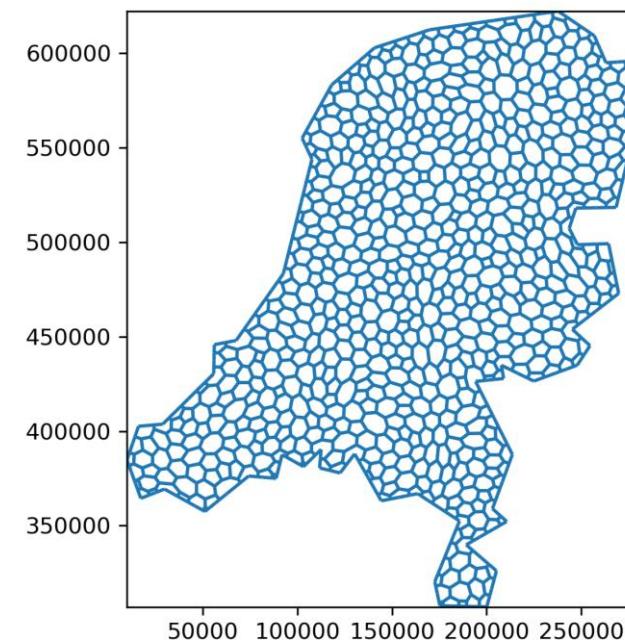
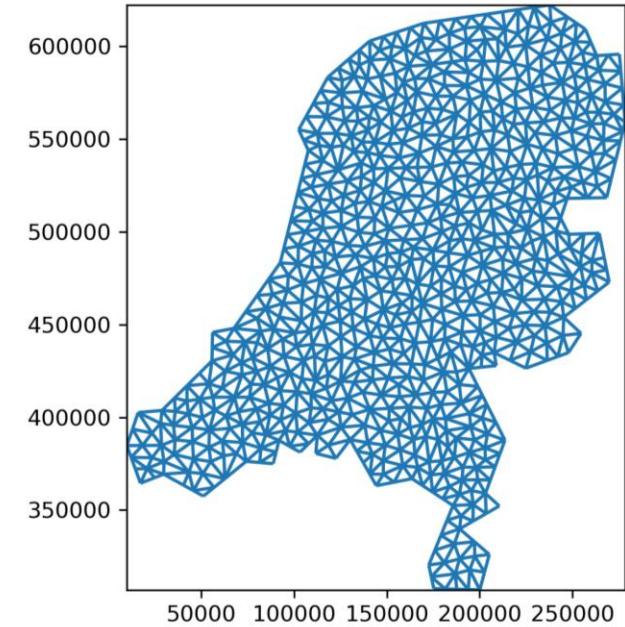
Created by connection the centroid vertices (red)



Grid creation

```
import geopandas  
import pandamesh  
  
geodataframe = geopandas.read_file("netherlands.shp")  
  
mesher = pandamesh.TriangleMesher(geodataframe)  
triangle_grid = mesher.generate_ugrid()  
voronoi_grid = triangle_grid.tesselate_centroidal_voronoi()
```

The TriangleMesher is quite fast:
Netherlands with ~250 m sized triangles (2.1 million
cells) takes around 1.25 seconds





Working with unstructured grids is more complicated:

- Finding cells based on location
- Intersection of irregular geometries
- Determine cell to cell connection

Xugrid makes this easy!

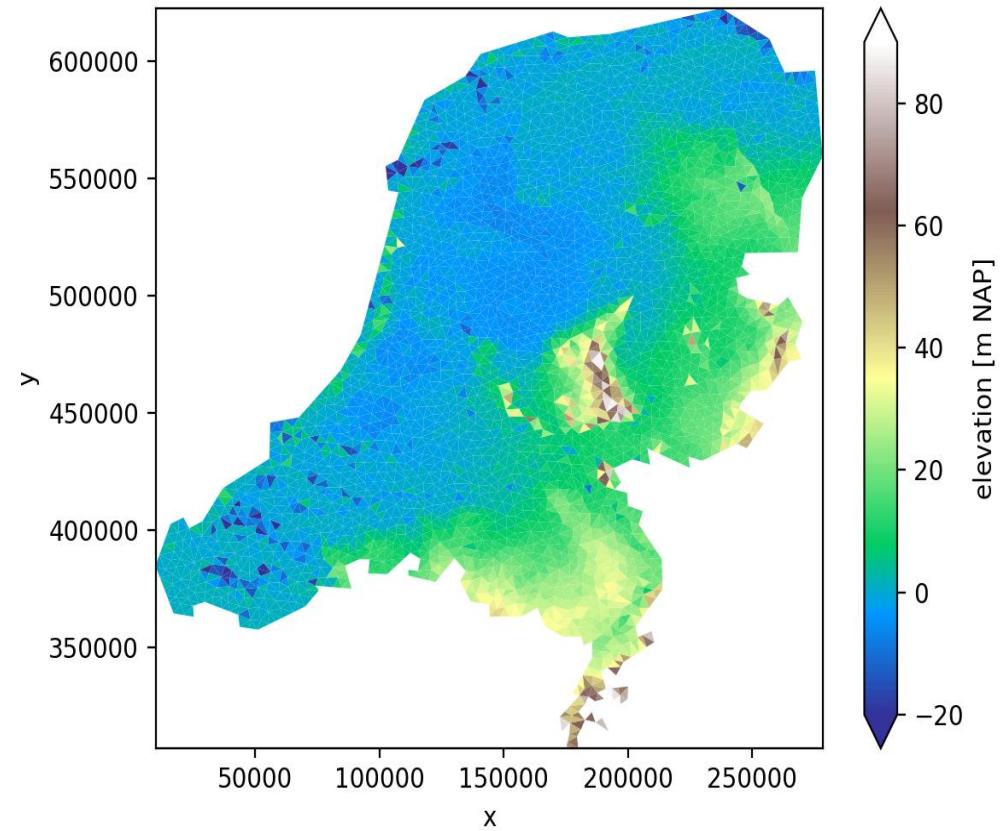
Xugrid: selection

Xugrid



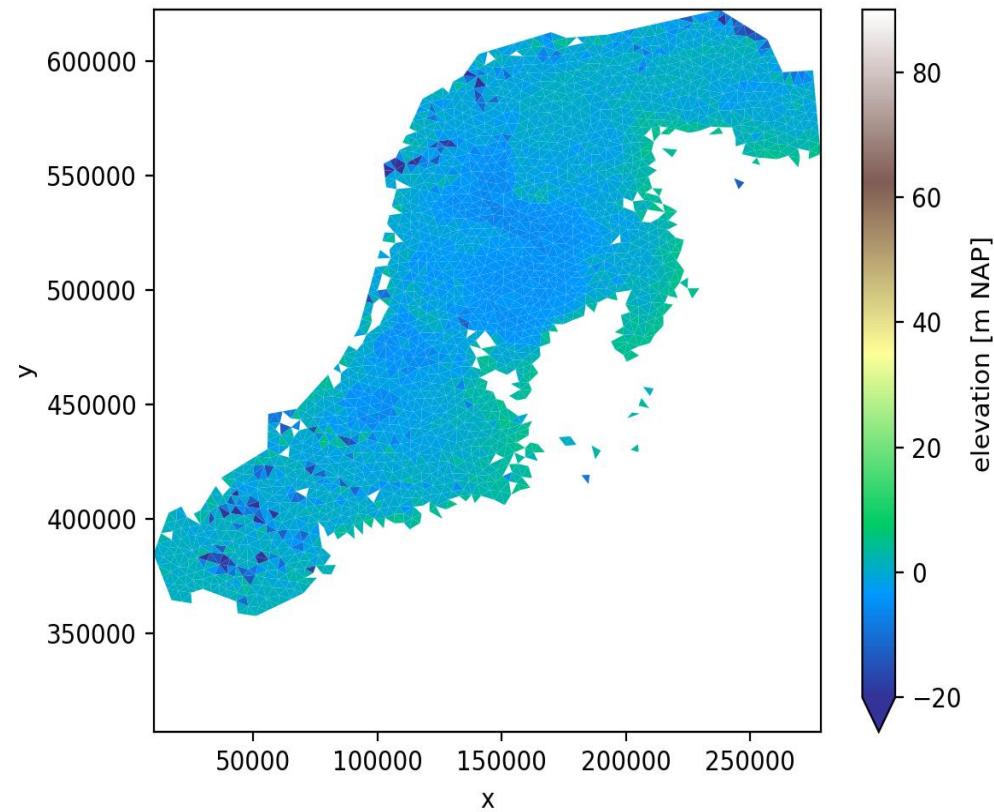
Full dataset

```
uda.ugrid.plot(  
    ax=ax0, vmin=-20, vmax=90, cmap="terrain"  
)
```



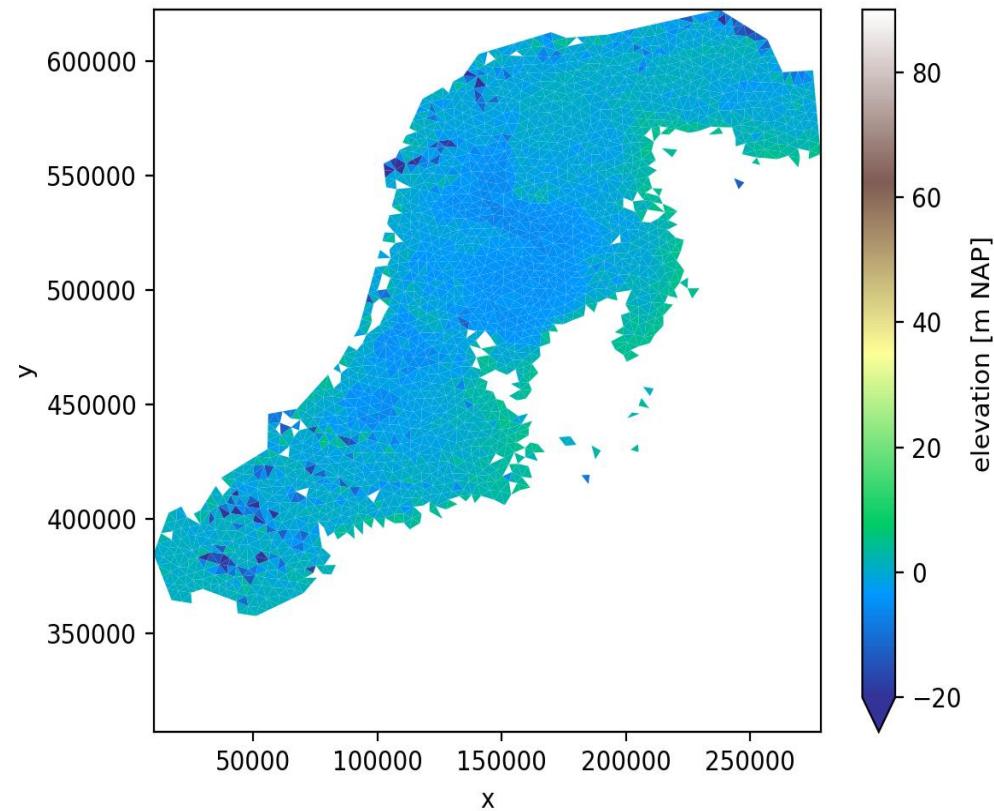
Xugrid: selection

```
below_5 = elevation.where(  
    elevation < 5.0  
)
```



Xugrid: selection

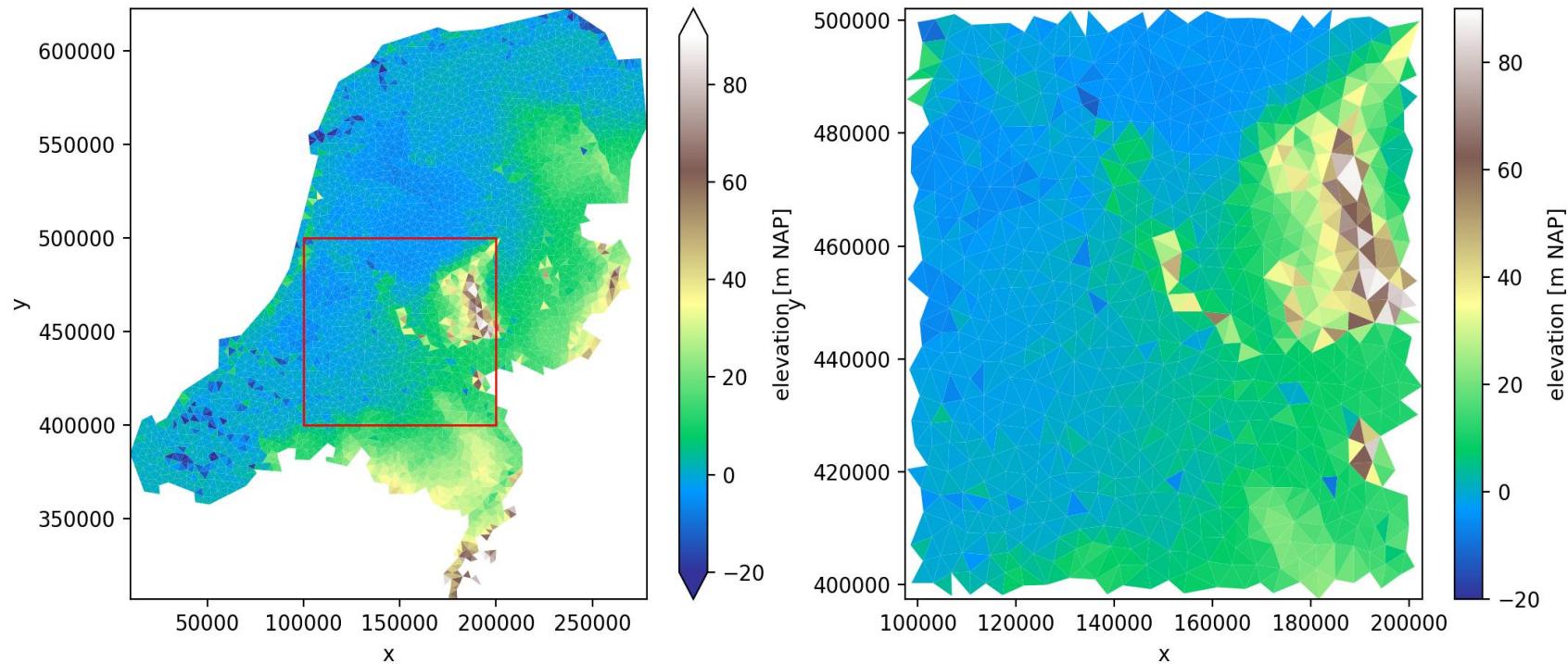
```
below_5 = elevation.where(  
    elevation < 5.0  
)
```



Xugrid: selection



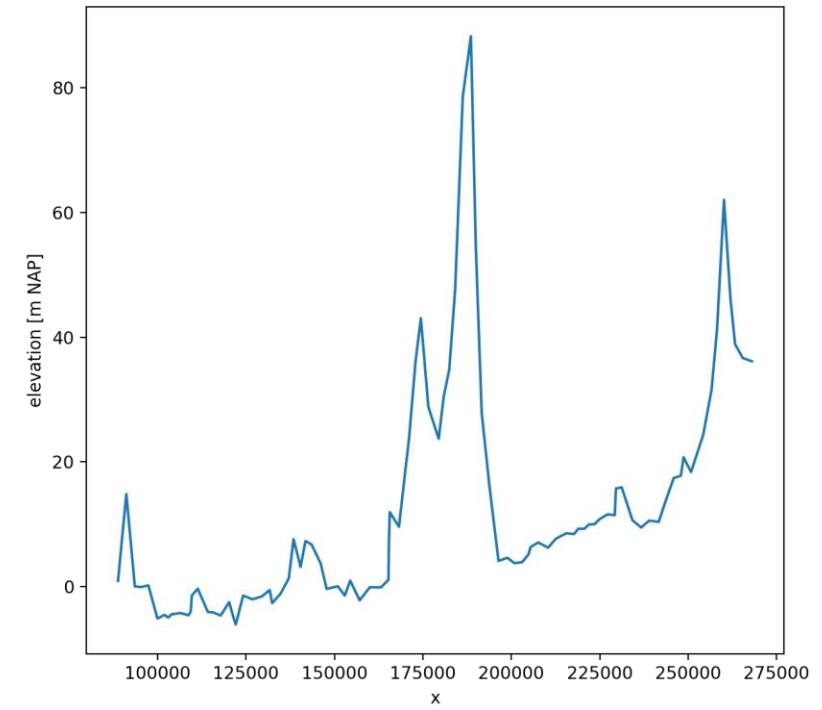
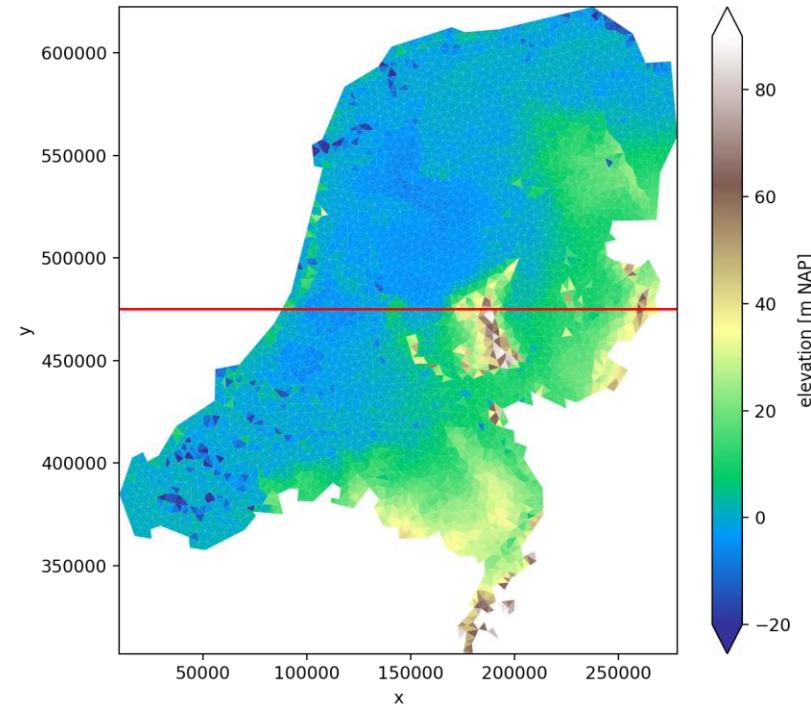
```
selection = uda.ugrid.sel(  
    x=slice(100_000.0, 200_000.0),  
    y=slice(400_000.0, 500_000.0),  
)
```



Xugrid: selection



```
section = uda.ugrid.sel(y=475_000.0)
```



Xugrid: locating performance

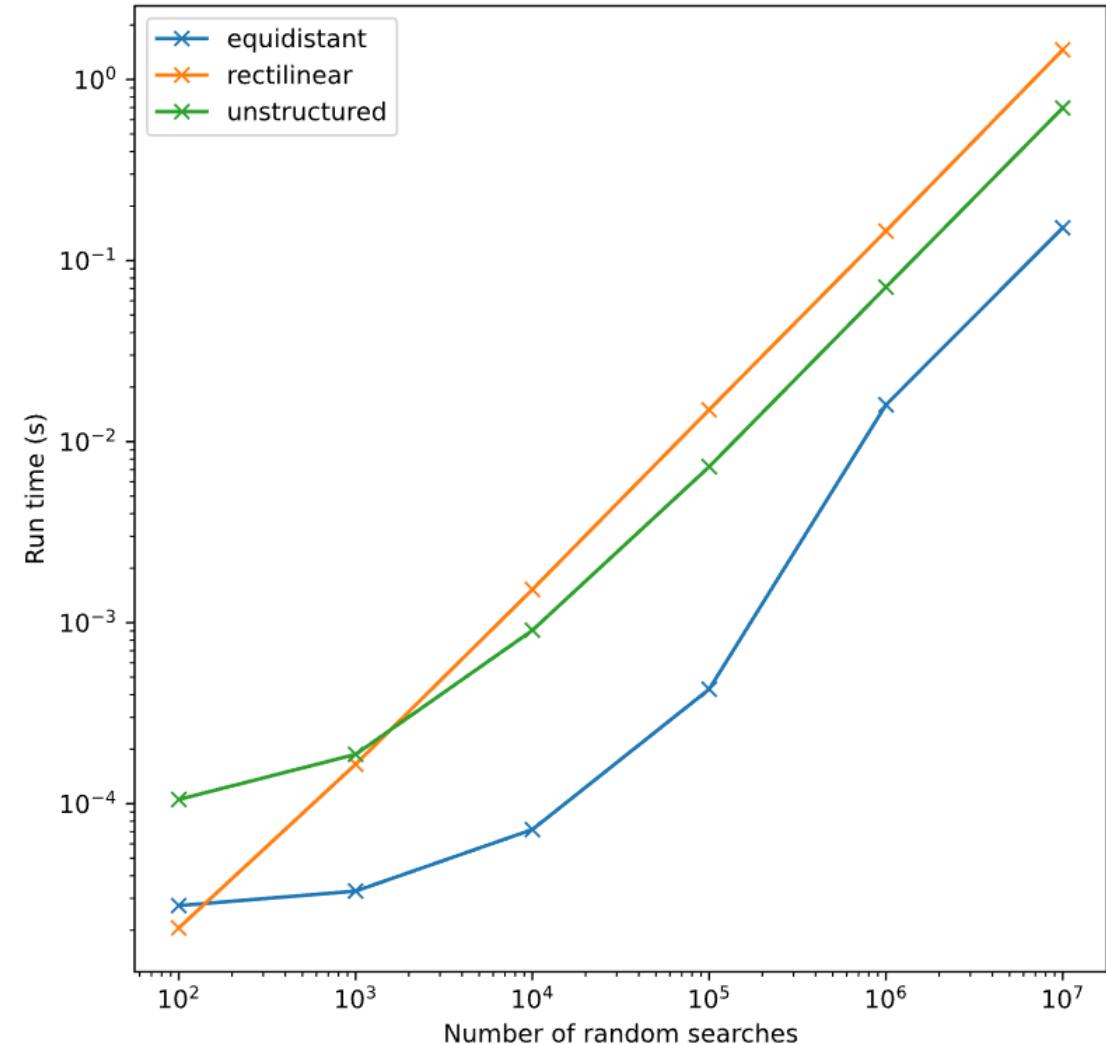
Xugrid



Same domain:

- Structured grid: 1.35 million cells
- Unstructured triangular grid: 2.1 million cells

Unstructured lookup: ~10 times slower than structured equidistant



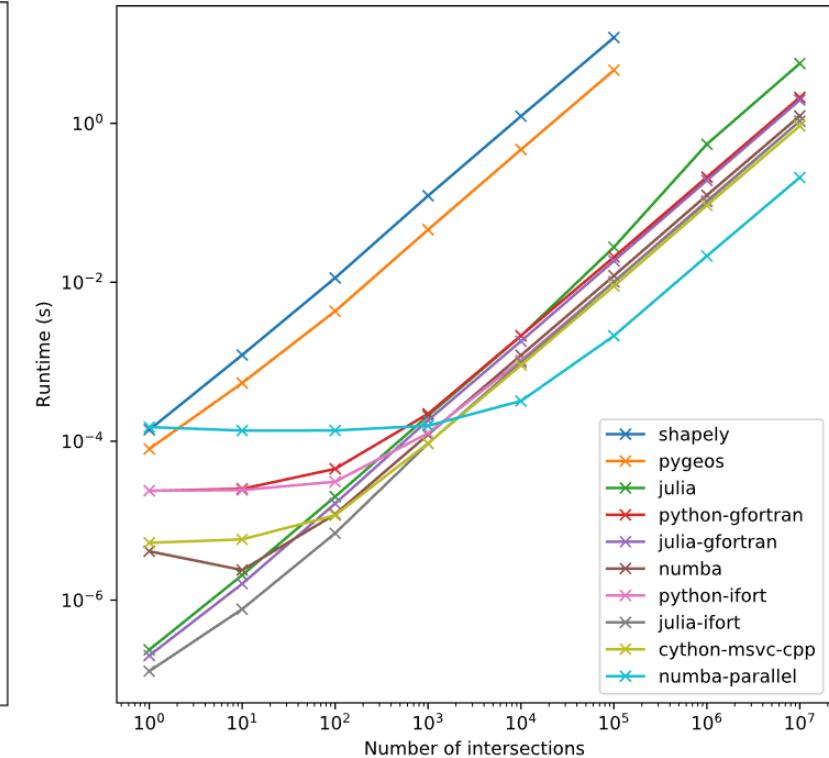
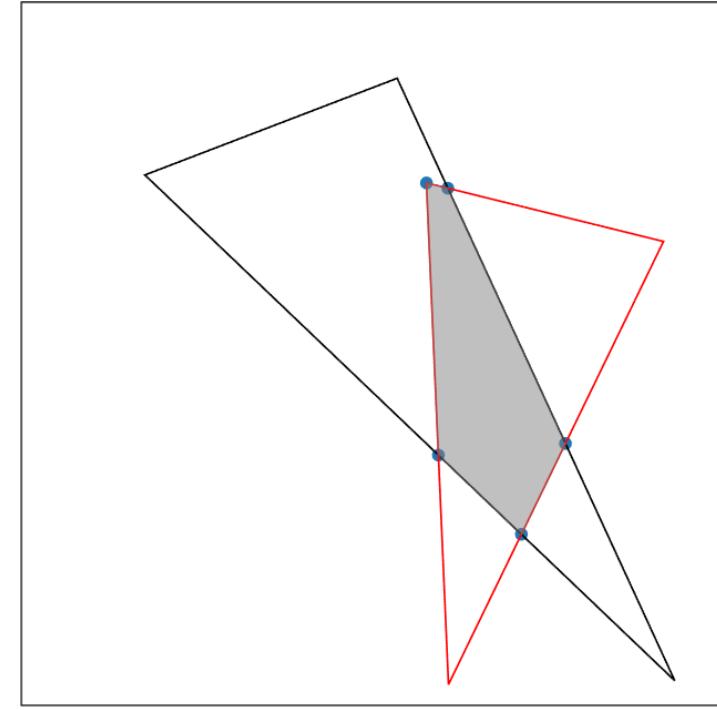
Xugrid: intersection performance



Easiest way to intersect is GIS routines (shapely / pygeos)

Easily over 500 (!) times slower than a specialized implementation

Python implementation achieves Fortran / C++ speeds

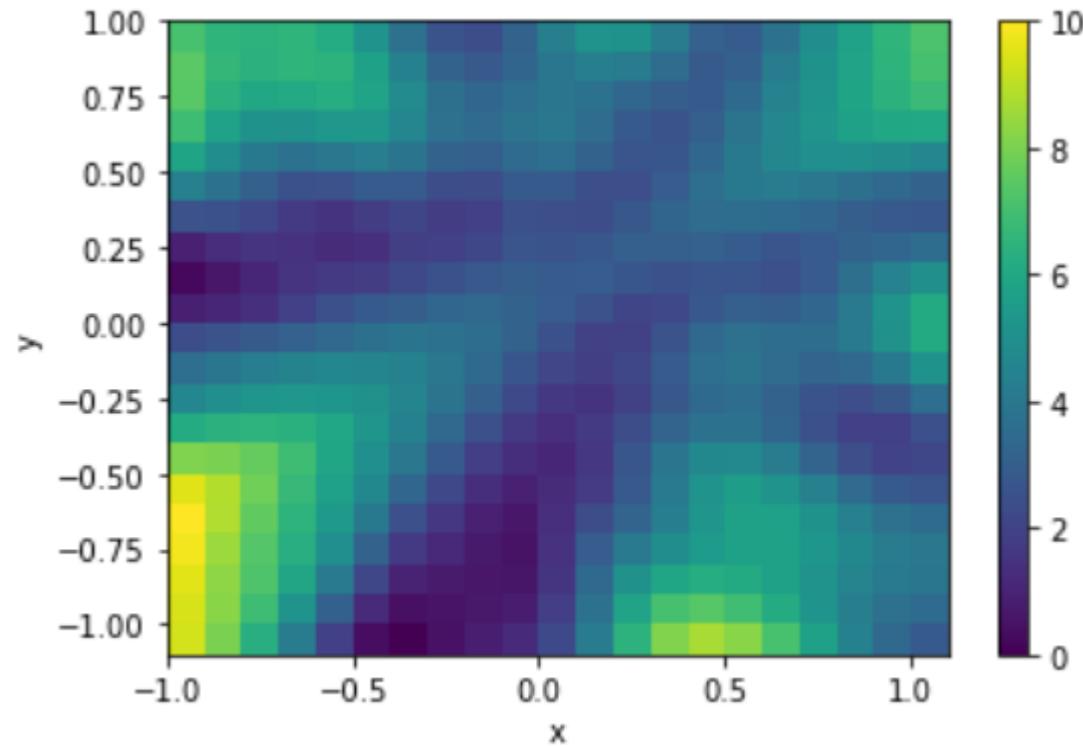


Xarray vs Xugrid

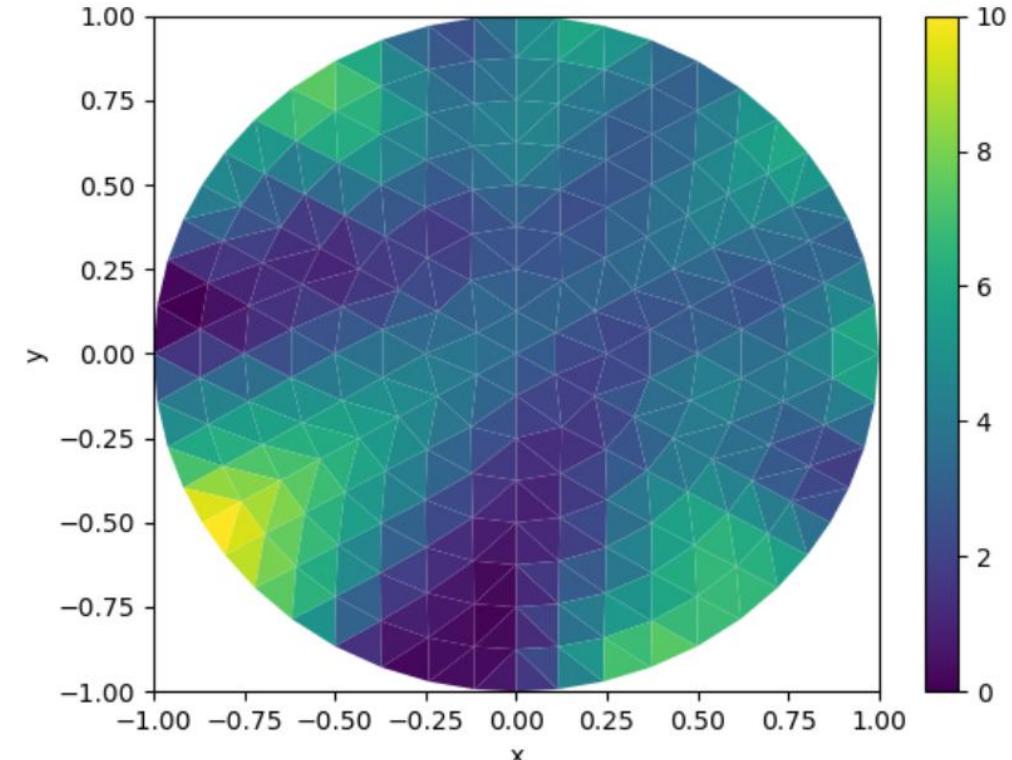
Xugrid



`structured.plot()`



`unstructured.ugrid.plot()`



Deltares

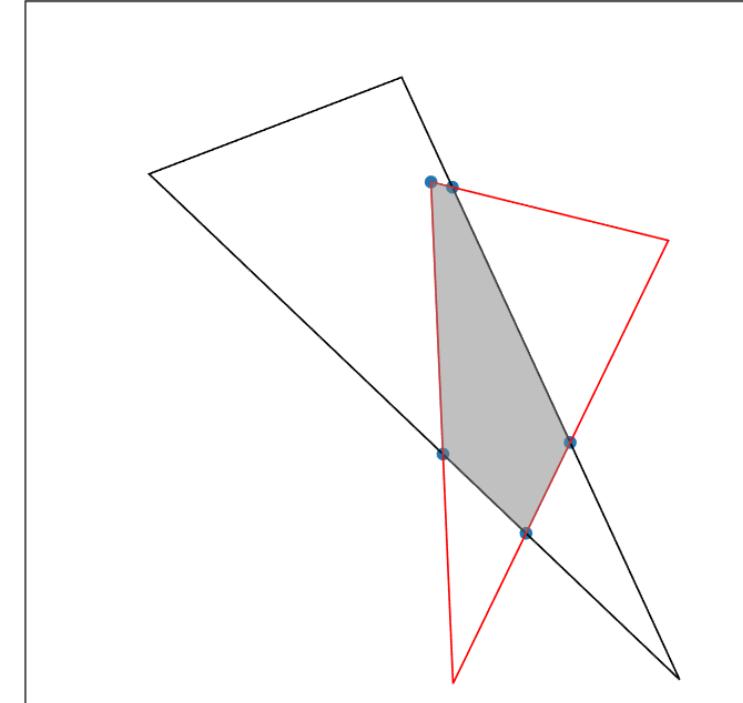
Rexgrid

Rexgrid



Multiple methods of regridding, generally area-weighted:

- mean (heads, stages)
- harmonic mean (vertical permeability)
- geometric mean (horizontal permeability)
- maximum
- minimum
- maximum overlap
- percentile (overland flow drainage)
- conductance (first-order conservative)



Thank you!

Make unstructured grid



github.com/deltares/pandamesh

Work with unstructured grid



github.com/deltares/xugrid

Get data on unstructured grid (“IDFSCALE”); work-in-progress



github.com/deltares/rexgrid

Write to and read from MODFLOW6



gitlab.com/deltares/imod/imod-python