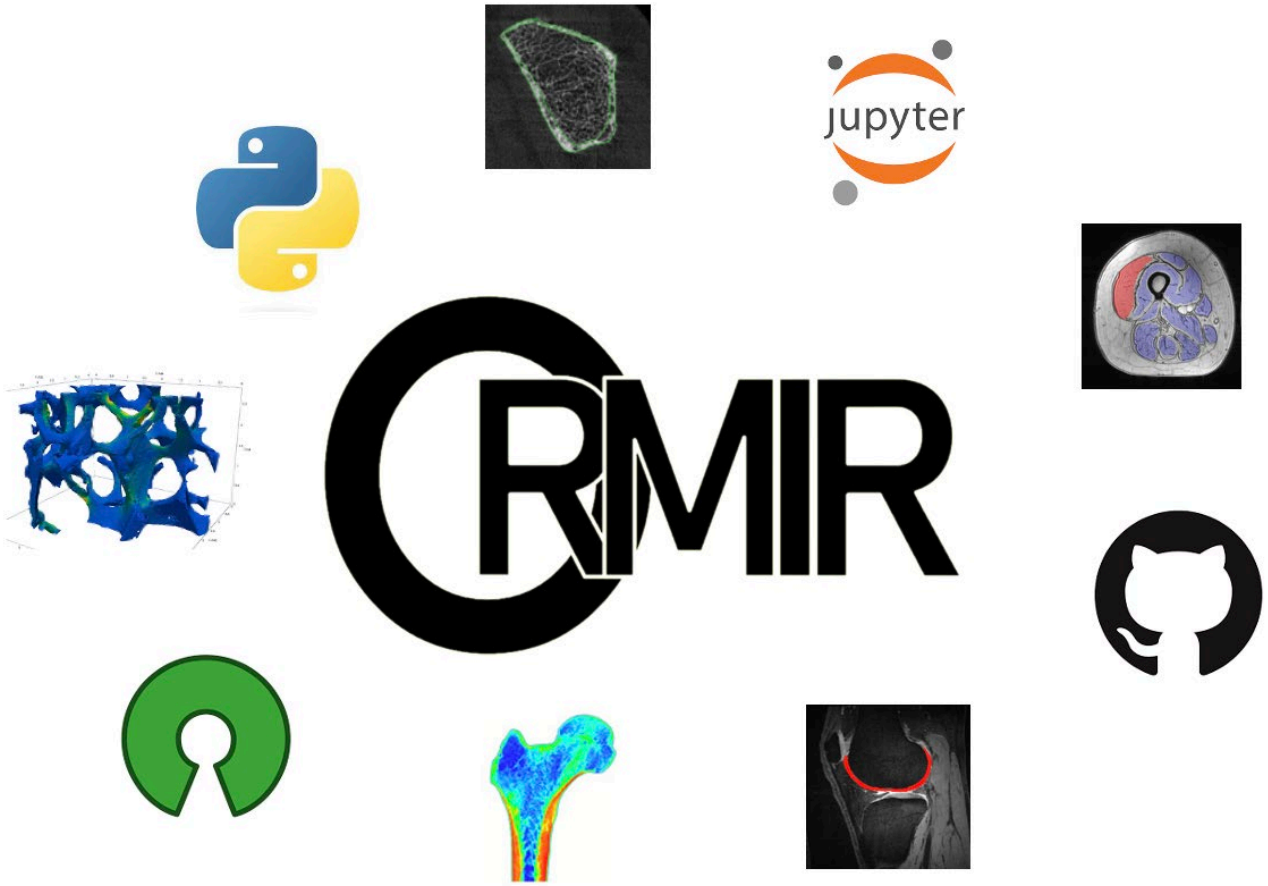


Biomechanics group

Status update, Zurich Jan 18th 2024

Aims

- Develop a wrapper to export properties in **HDF5 files** towards a FE solver (ParOSol) (data robustness, accessibility)

- Develop the **automatic segmentation** pipeline for human femurs from clinical CT images (accessibility, multimodality)

- Widening the modelling strategies from **microCT images** of trabecular bone samples (data versatility)

HDF5




- Why HDF5?
  - Hierarchical Data Format designed to store and organize large amounts of data
  - Open file format
  - Multi-datatype support
  - Architecture independent (data storage)

  - Integrates with the ciclope pipeline
    - Originally using Calculix, now “migrating” towards ParOSol for increased scalability

HDF5

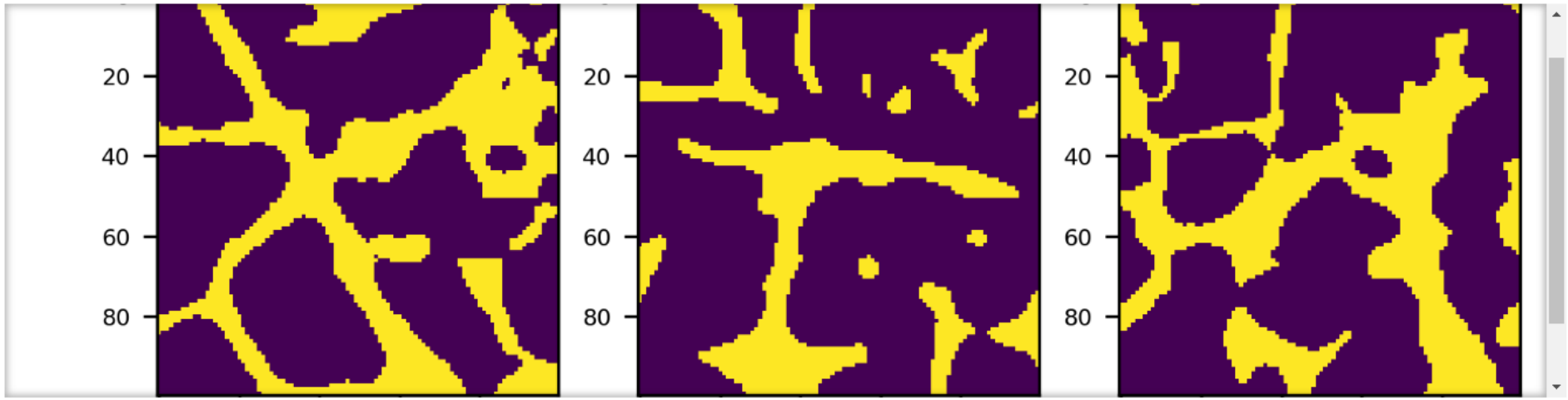
```
def vol2h5ParOSol(voldata, fileout, topDisplacement, voxelsize=1, poisson_ratio=0.3, young_modulus=18e3, topHorizontaFixedlDisplacement=True, verbose=False):
    """Generate ParOSol HDF5 (.h5) input file from 3D volume data.
    Before to generate ParOSol HDF5 file, the Bounding BOX (bbox class) limits the input binary image.
    Info on HDF5 file type for ParOSol solver at: https://github.com/reox/parosol-tu-wien/blob/master/doc/file_format.md

    Parameters
    ----------

    voldata : ndarray
        3D voxel data.
    fileout : str
        Output .h5 file.
    topDisplacement: float
        Vertical displacement imposed at the top.
    voxelsize : float
        3D model voxelsize.
    poisson_ratio: float
        Poisson ratio.
    Young_modulus: float
        Young's modulus [MPa].
    topHorizontaFixedlDisplacement: bool
        if True X and Y displacements fixed at the top; if False no displacements fixed at the top.
    verbose : bool
        Activate verbose output.
    """
```

HDF5

```
[25]: plot_midplanes(L)
      plt.show()
```

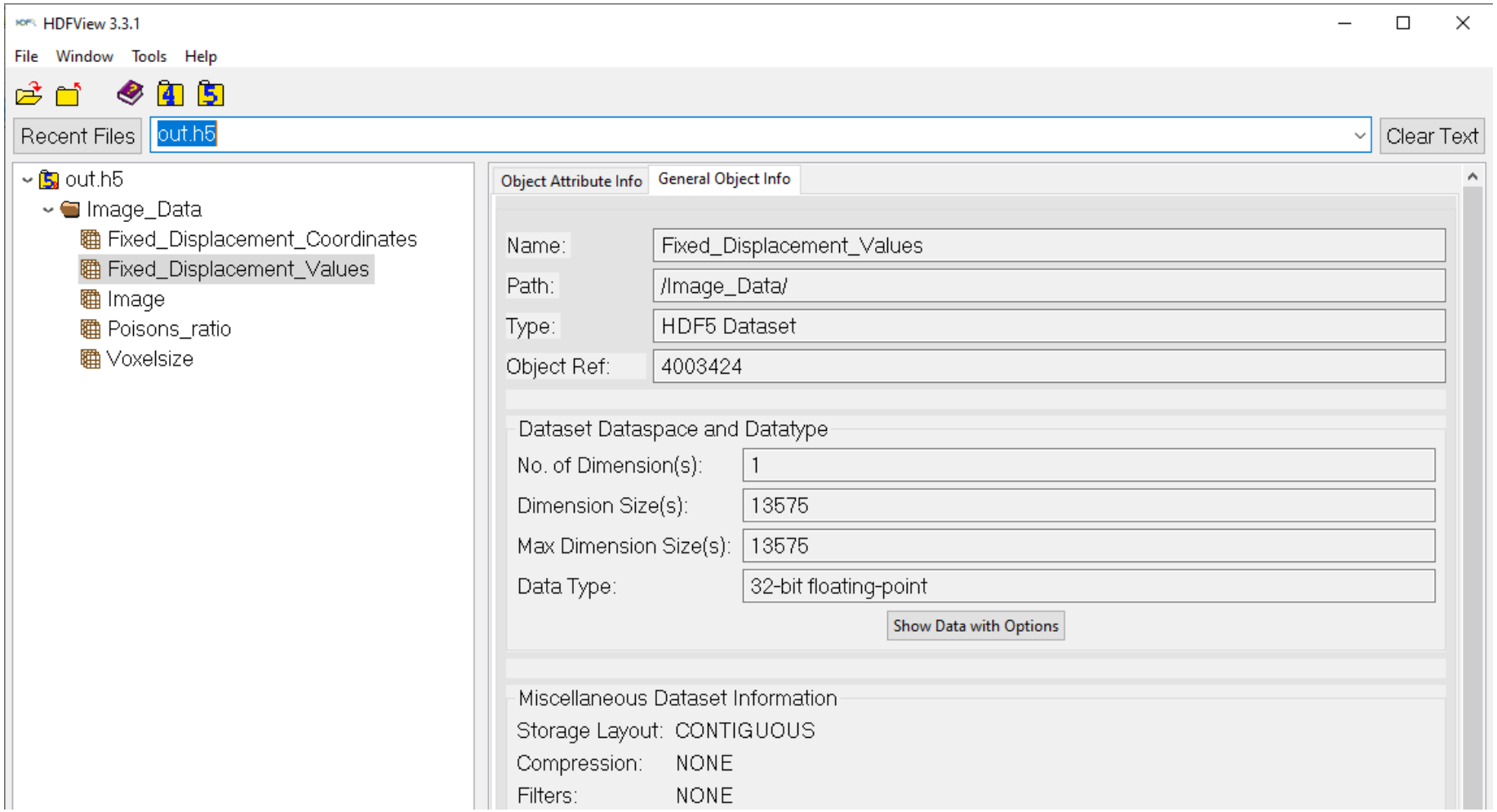


Generate ParOSol hdf5 from volume data

```
[29]: ciclope.core.voxelFE.vol2h5ParOSol(L, 'paroSOLout.h5', -0.4, 1, 0.3,18e3,True,True )
```

```
INFO:root:Opening Output file
INFO:root:creating h5 Image_Data Group
INFO:root:creating Image dataset...
INFO:root:Setting voxel size
INFO:root:Setting Poisson ratio
INFO:root:Creating Fixed_Displacement_Coordinates
INFO:root:Creating Fixed_Displacement_Values
INFO:root:hdf5 export done!
```

HDF5


HDFView 3.3.1
File Window Tools Help
Recent Files
out.h5
Clear Text
out.h5
Image_Data
Fixed_Displacement_Coordinates
Fixed_Displacement_Values
Image
Poisons_ratio
Voxelsize
Object Attribute Info
General Object Info
Name: Fixed_Displacement_Values
Path: /Image_Data/
Type: HDF5 Dataset
Object Ref: 4003424
Dataset Dataspace and Datatype
No. of Dimension(s): 1
Dimension Size(s): 13575
Max Dimension Size(s): 13575
Data Type: 32-bit floating-point
Show Data with Options
Miscellaneous Dataset Information
Storage Layout: CONTIGUOUS
Compression: NONE
Filters: NONE

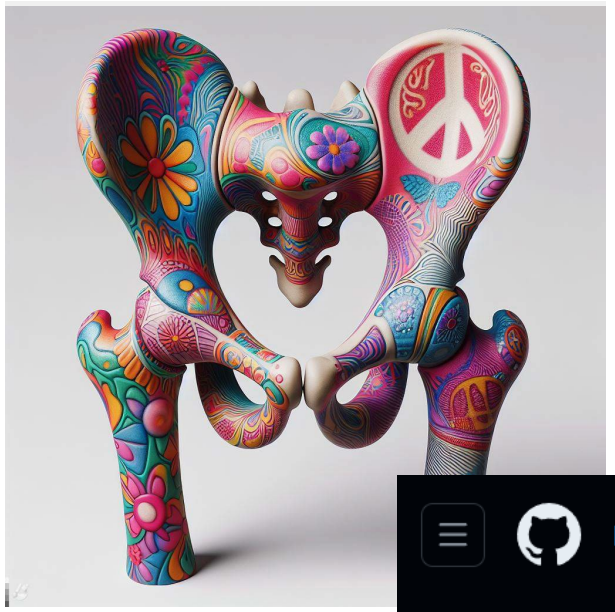
HDF5

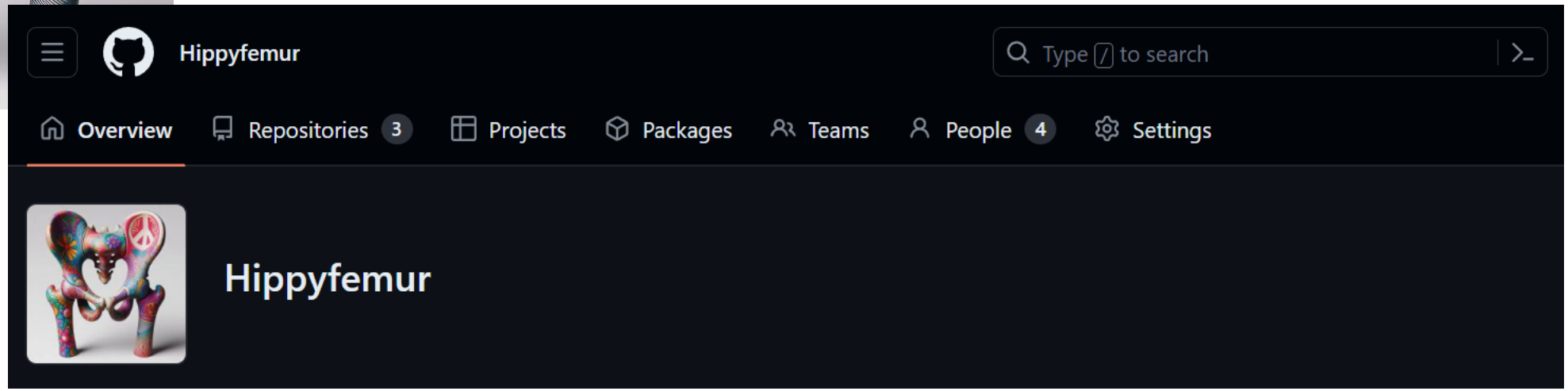
- Next steps:
  - Solve the FE problem with ParOSol
  - Read and visualize the hdf5 output from ParOSol

Automatic segmentation

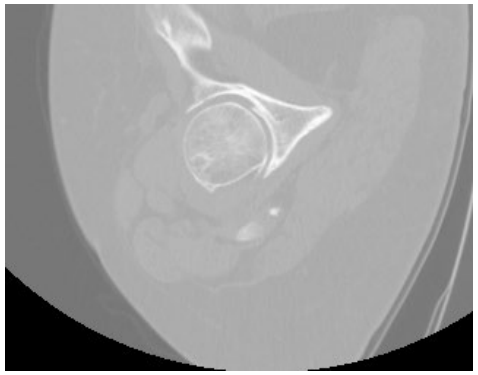
- Not much code
- No organization
- No logo

Automatic segmentation





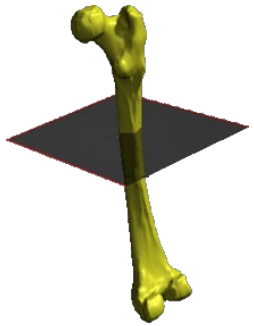
Automatic segmentation



CT images
Metadata
Patient information

Automatic segmentation DL

Binarized volume
Triangulated surface

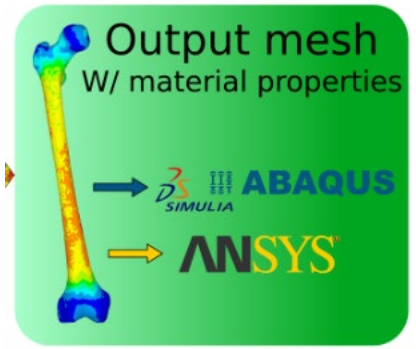


Refined segmentation with sub-pixel accuracy

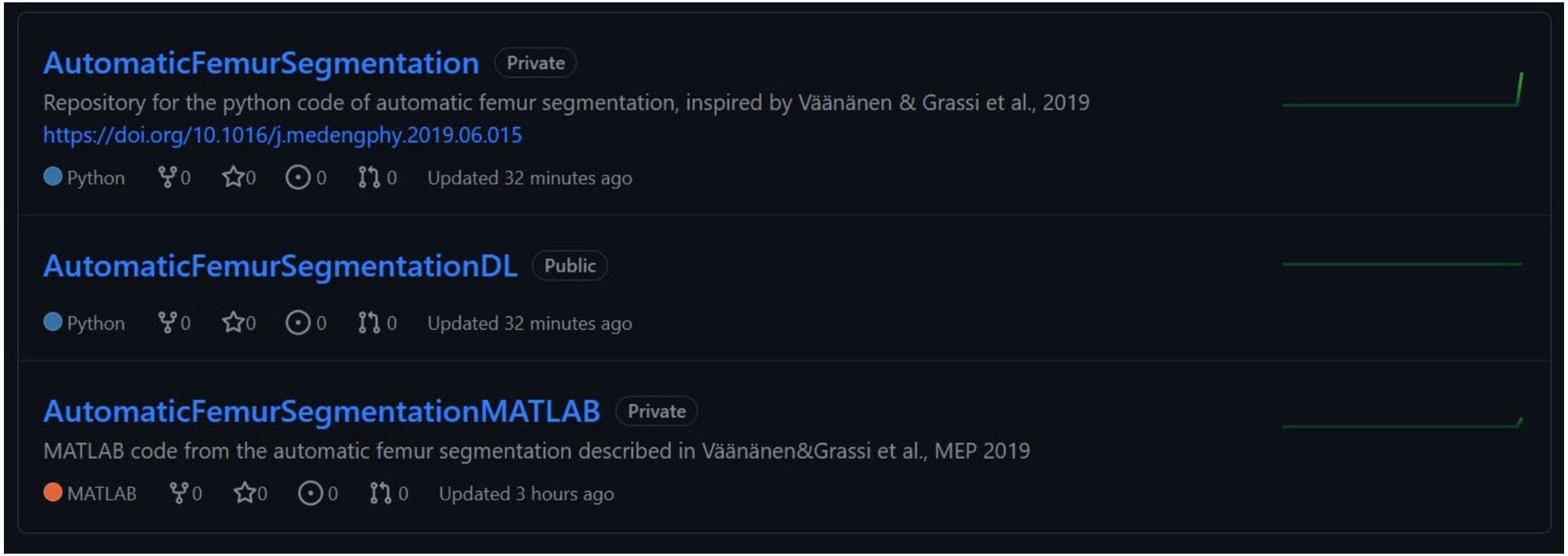
Binarized volume
Triangulated surface
Cortical thickness and density

Automatic meshing

FE mesh
Material properties
Boundary conditions



Automatic segmentation

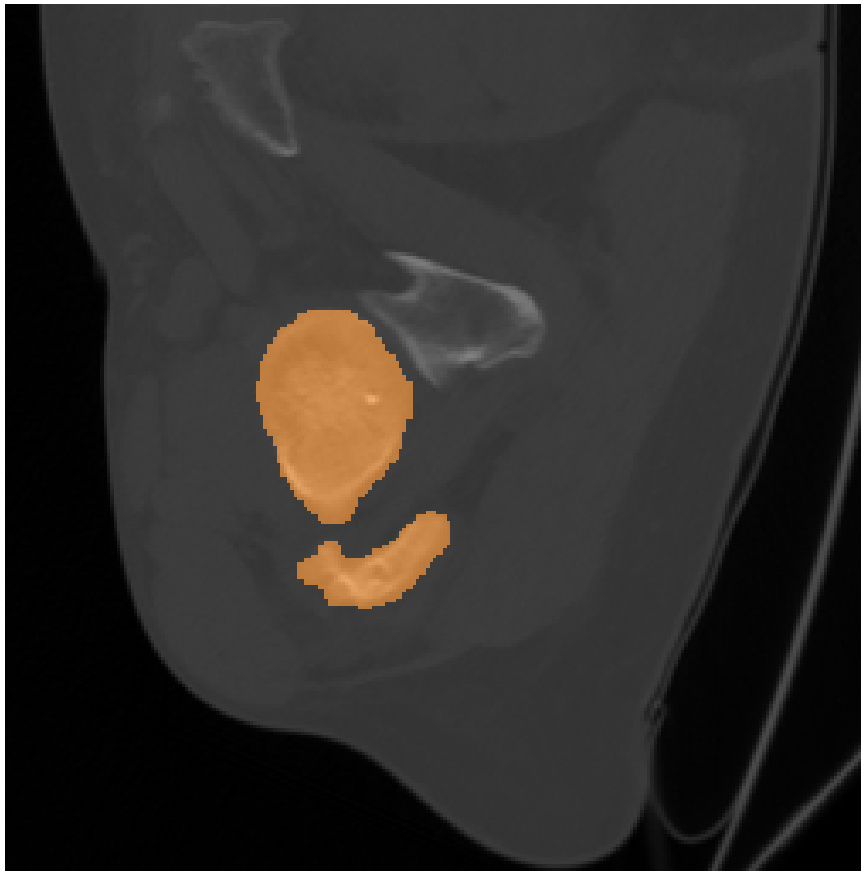


Automatic segmentation DL

- Trained on openly available repository
  - Zenodo link
- Works on each individual 2D slice

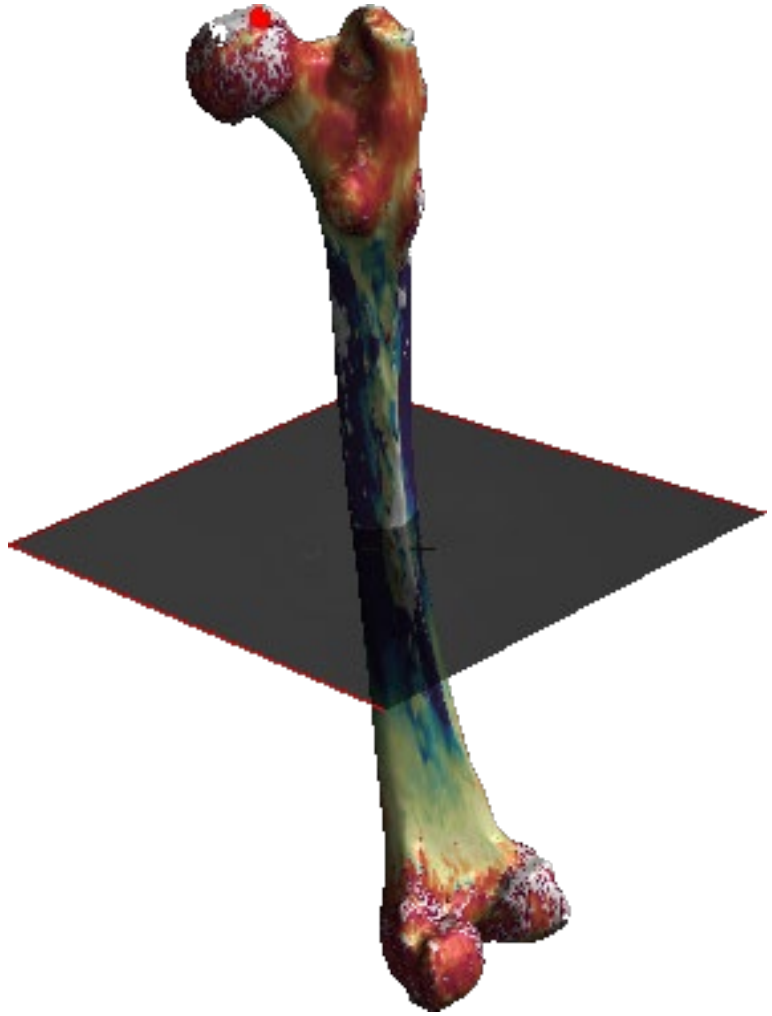
- Intersection over union = 0.95

- Public repository
  - Needs increased testing
  - Documentation



Automatic segmentation sub-pixel resolution

- Main idea:
  - run optimization using Stradview (freeware) using 3 sets of parameters
  - Combine output from the 3 runs
- Struggling with changes in Stradview compared to 2017
  - The 3 optimizations run, need to combine the outputs

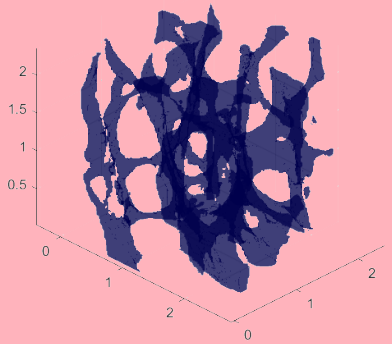


Beam FE modelling

- https://github.com/gianthk/ciclope/blob/master/examples/ipynb/ciclope_ex05.1_beamFE-skel.ipynb

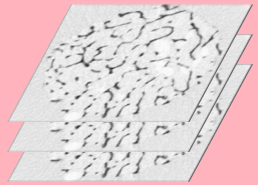
Beam FE model of the trabecular structure

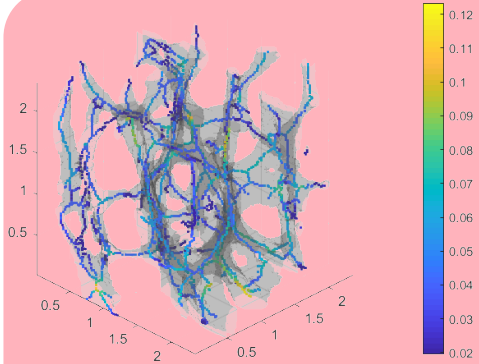
- Each trabecula can be modelled as a beam element (circular cross = thickness of each trabecula).
- Isotropic and homogeneous material with linear elastic constitutive law ($E = 19\ GPa, \nu = 0.3$).
- Kinematic Boundary Conditions to replicate the uni-axial compression test (nodes at the bottom layer fully constrained, nodes at the top layer imposed a vertical displacement and null transversal displacement).



Binarisation

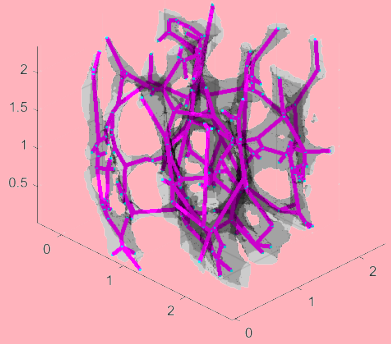
Fixed global threshold based on histology.





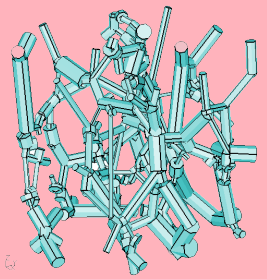
Skeletonisation

The skeleton is identified on binarised images [2]. For each point of the skeleton, the distance form the nearest point on the trabecular surface is calculated to assess the trabecular thickness.



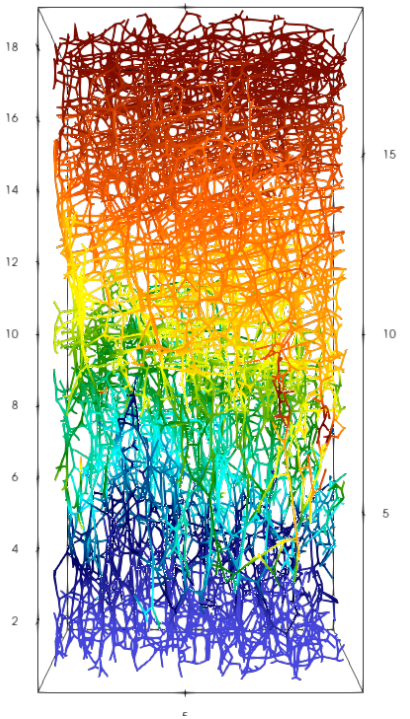
Spatial Graph

The skeleton is converted into a graph connecting the nodes where the skeleton forms branches. The connectivity selection is performed keeping the biggest graph.



Beam FE model

Each arc of the graph is converted into a beam element; circular cross sections are retrieved form the distance map defined on the skeleton.



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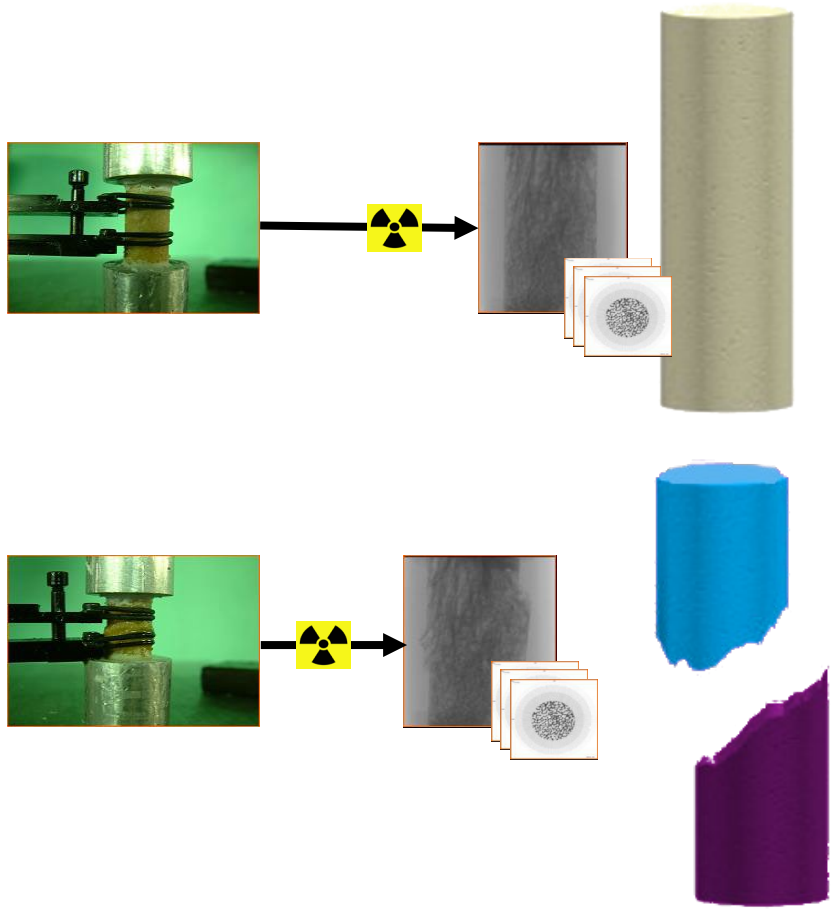
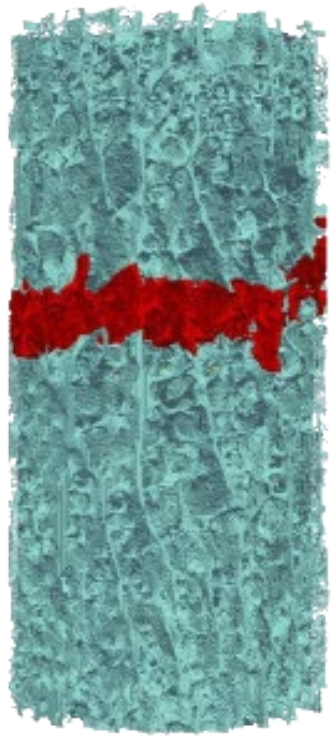
Fracture identification (as per the previous study)

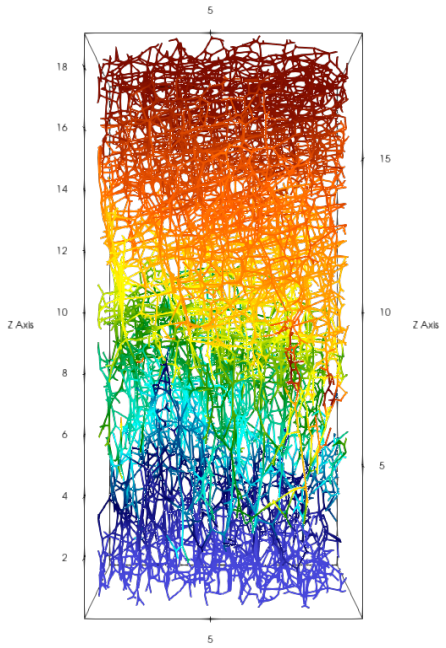


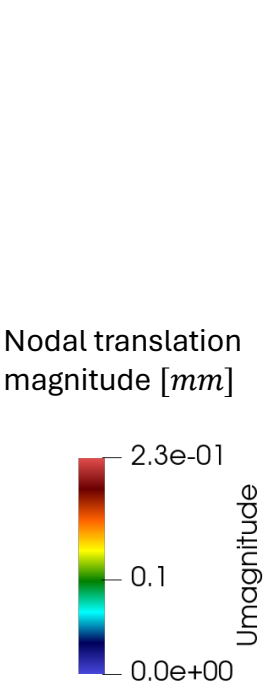
Images from the damaged specimen are rigidly registered on the dataset of the intact condition. Regions were the registration is not possible are classified as "fracture" [3].

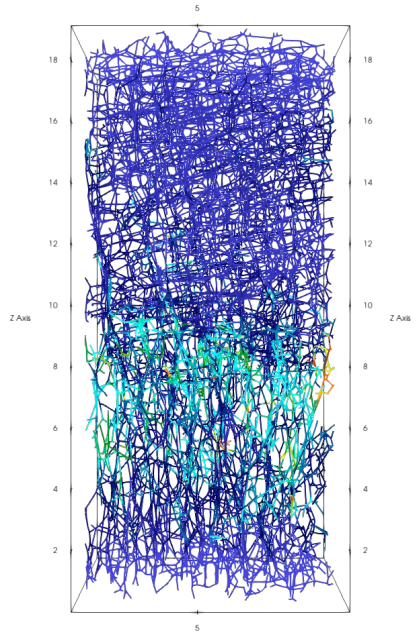


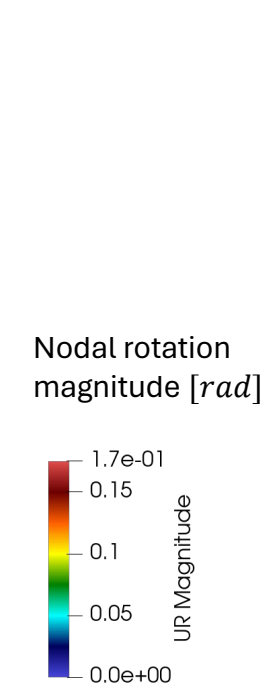
Output/Comparison

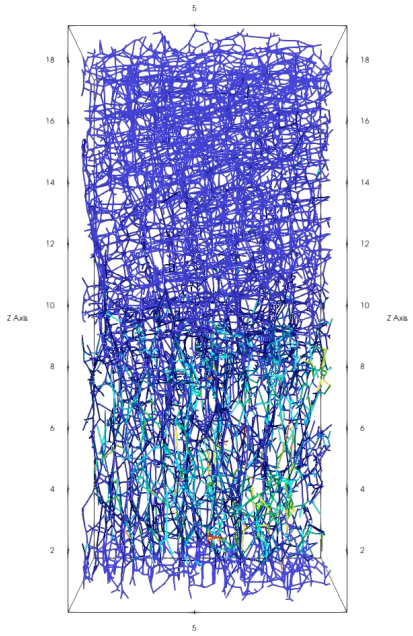
- For arch beam element, the differential axial rotation of its nodes was divided by the length of the element, defining the specific torsion [rad/mm].
- The map of the element specific torsion presented peaks matching the map of the fractured volumes.
- The difference in the axial positioning between torsion peaks and fractured volumes ranged between 0.67% and 2.46% of the total length of the specimen (20 mm).

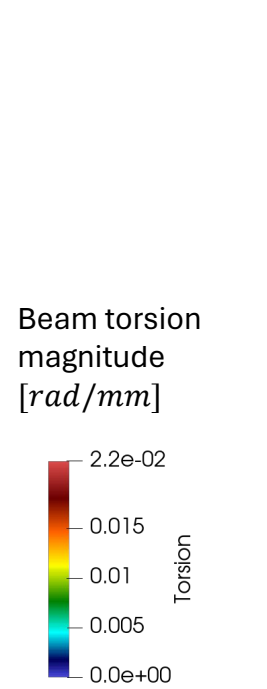












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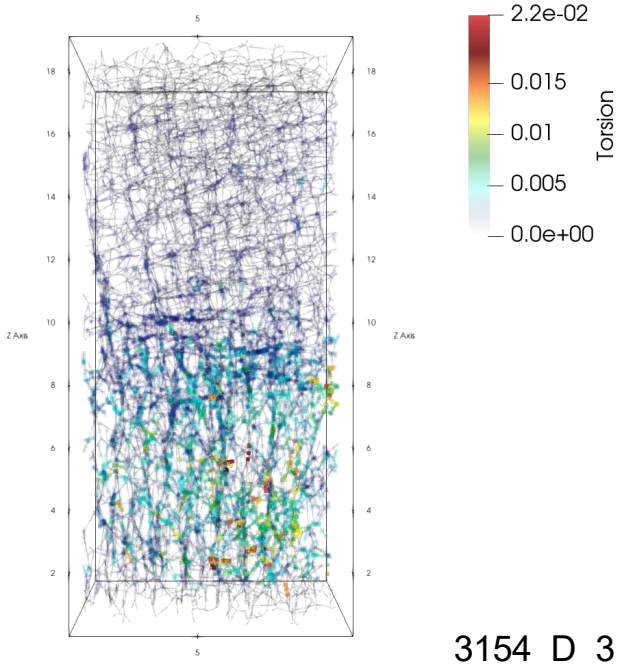
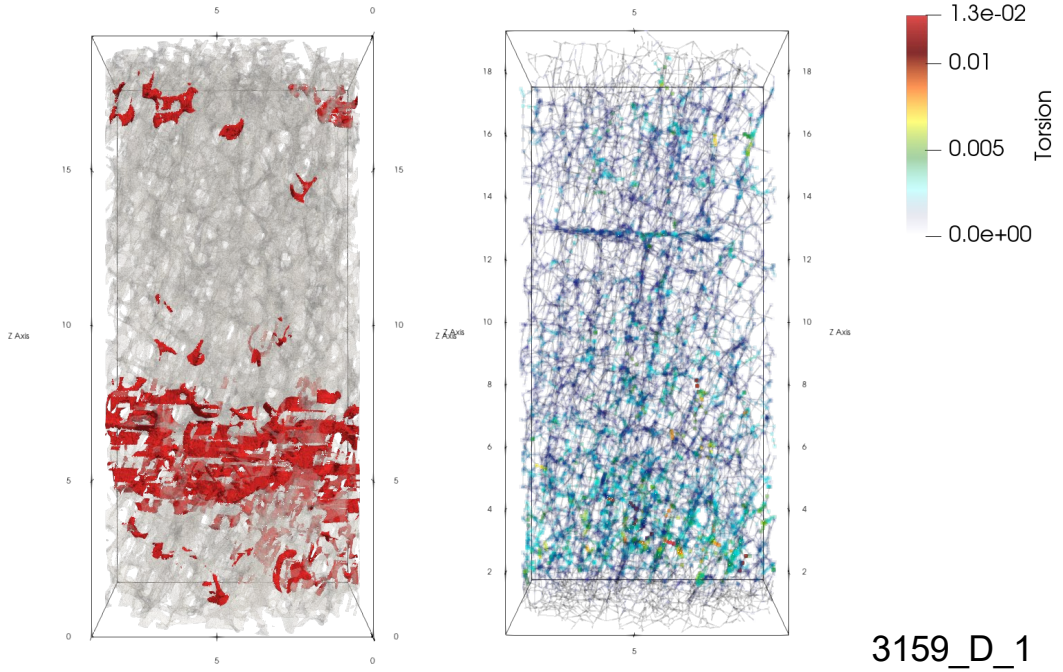
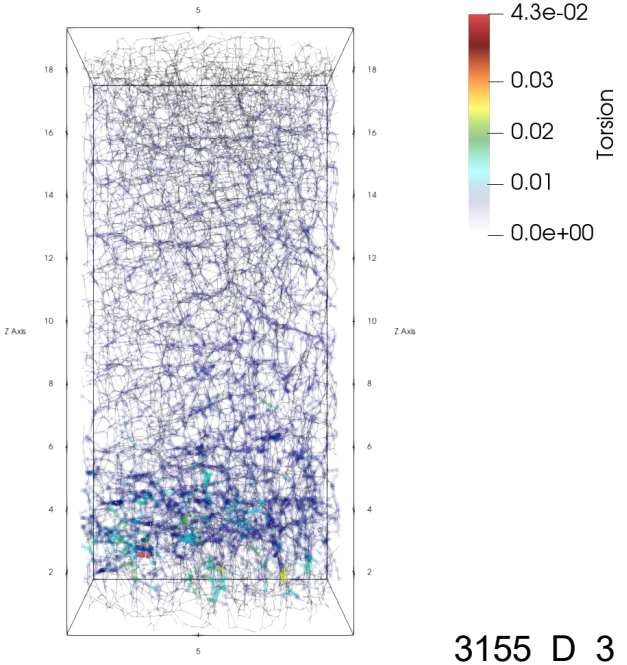
Results



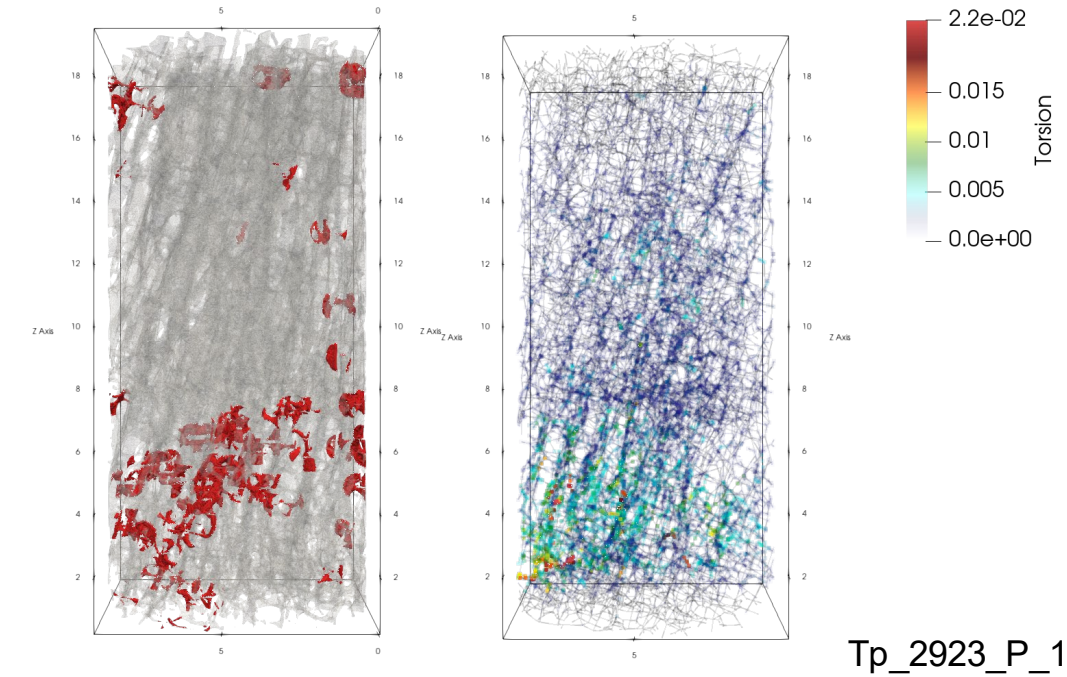
3154_D_3



3159_D_1



3155_D_3



Tp_2923_P_1

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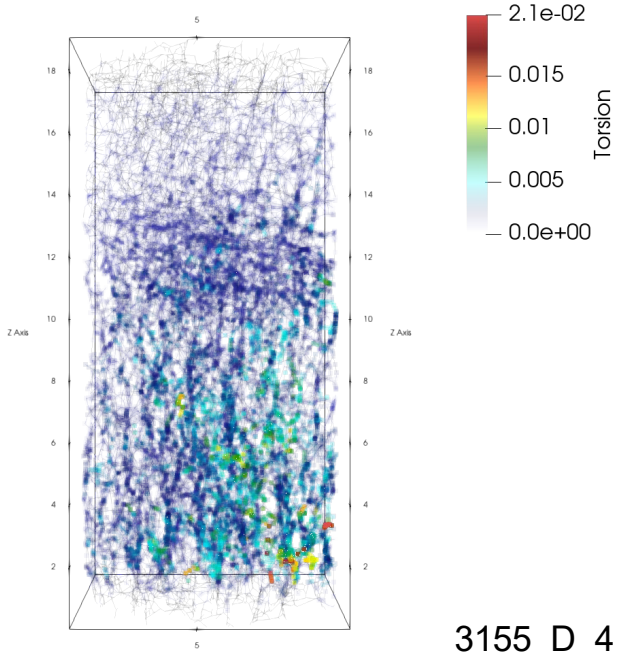
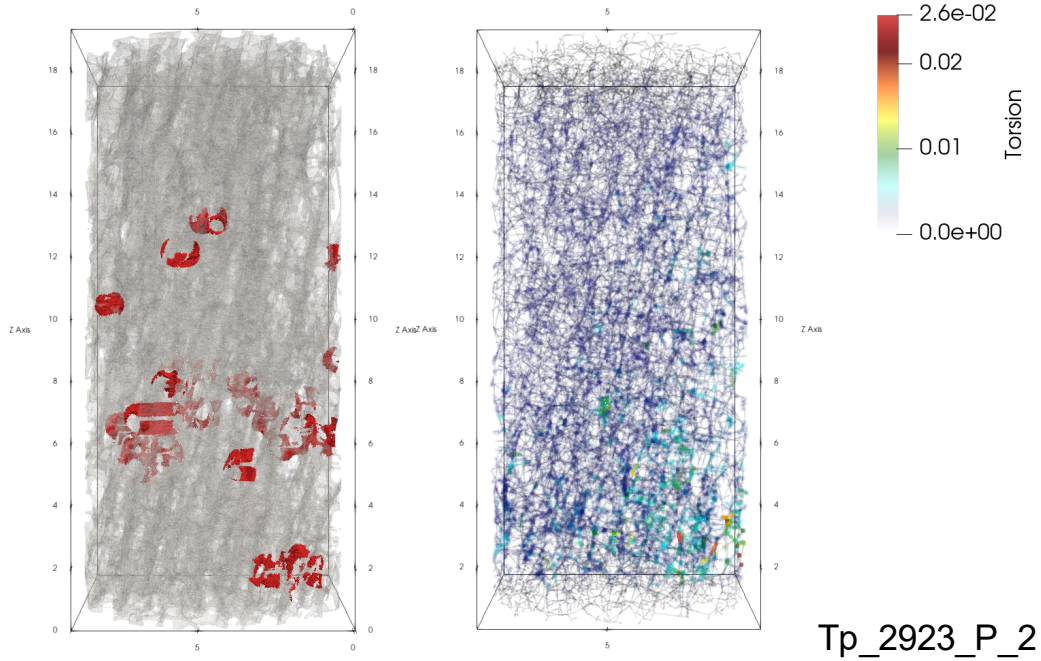
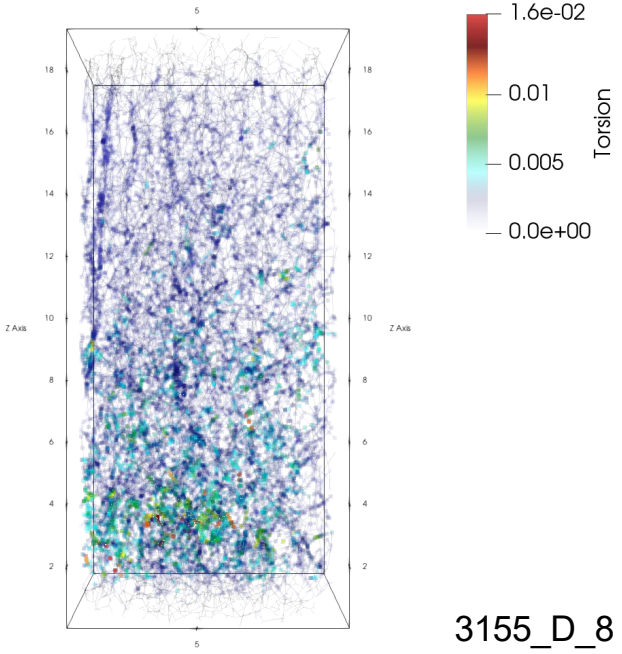
Results



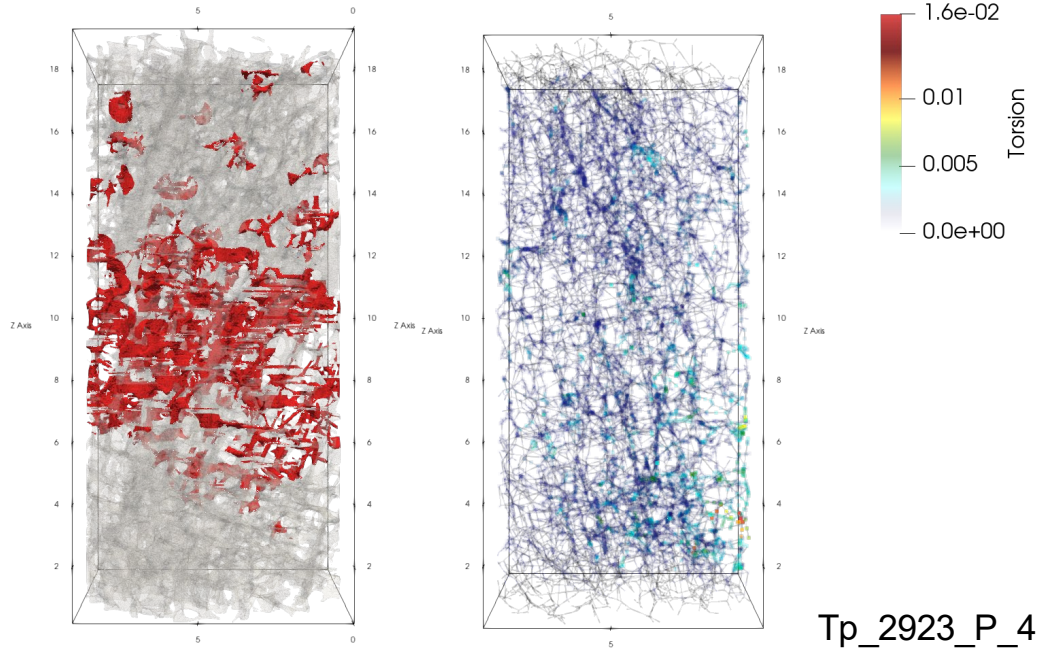
3155_D_4



Tp_2923_P_2



3155_D_8



Tp_2923_P_4

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