Overview

This is a documentation for executable file Hex2Spline.exe, which has two main functions:

- Mesh quality improvement (Pillowing, Smoothing and Optimization)
- Generate BEXT file and ABAQUS inp file for volumetric mesh.

If the input hexahedral mesh is already in good quality, the user can skip the quality improvement and directly generate BEXT file and ABAQUS inp file using the spline construction function in our program.

I/O

Input:

- manifold unstructured hex mesh in the **vtk format.**
- If needed, sharp feature definition in "sharp.txt" file.
- If needed, local refinement definition in "levX_rfid.txt" file.

Output: there are two parts of output from the program

- The hex mesh after quality improvement in vtk format:
  - "XXX_smooth.vtk": the output mesh after smoothing
  - "XXX_pillow.vtk": the output mesh after pillowing
  - "XXX_opt.vtk": the output mesh after optimization
- Bezier extraction information of the constructed volumetric spline for ABAQUS (.inp and .NB files).
- Bezier extraction information of the constructed volumetric spline for LS-DYNA (XXX_BEXT.txt file).
- Visualization files for the constructed spline in vtk format.

All .vtk file can be visualized using Paraview.

Usage of executable file:

User can run the executable file "Hex2Spline.exe" through command line.

Several files end with ".dll" are external libraries (MKL) used to run the program.

Each file that ends with ".bat" contains a series of line commands for the specific model. User can run the file to get the ideal results for each model. User can also open the file with text editor to check the detailed commands.

Here, we will use the following file structure to explain the usage of the program:

Generator for Volumetric Mesh/

Hex2Spline.exe

example/

cube_with_hole/

helicopter/

rod_quality/

rod_demo/

The quality improvement and spline construction are explained using the model in rod_quality folder ("rod_OctreePhys_hex.vtk" as input file). The sharp feature is set manually using "sharp.txt" file.

The options to run the code are explained as follow:

Help Interface ("-h" or "--help")

User can use this option to check the help information

Example: Hex2Spline.exe -h

```
PS C:\Users\LAR\Dropbox\GEM\Software Package\Volume> .\Hex2Spline.exe -h
CMU Solid Software
Usage:
  C:\Users\LAR\Dropbox\GEM\Software Package\Volume\Hex2Spline.exe [OPTION...]

 General Settings options:
  -h, --help        Print help
  -Q, --quality     Mesh quality improvement mode
  -S, --spline      Spline construction mode
  -s, --sharp arg   0-No sharp feature, 1-Automatic sharp feature, 2-Manual
                    sharp feature
  -t, --stol arg    Tolerance for automatically detecting sharp feature
  -I, --input arg   Input file

 Mesh Quality Improvement options:
  -m, --method arg      Improvement methods: 0-Laplacian Smoothing interior
                        points (Give iternation number -n); 1-Pillowing (Give
                        pillow layer number -n); 2-Smoothing (Give iteration
                        number -n and smooth step -p); 3-Optimization (Give
                        iteration number -n and optimization step -p)
  -n, --number arg      Pillowing layer number, Smoothing and Optimization
                        number of steps
  -p, --parameter arg   Smoothing / Optimization step size

 Spline Construction options:
  -g, --globalref arg   Set the level of global refinement, default is 0
  -l, --localref arg    Set the level of local refinement, default is 0
```

Input mesh setting ("-I" or "--input")

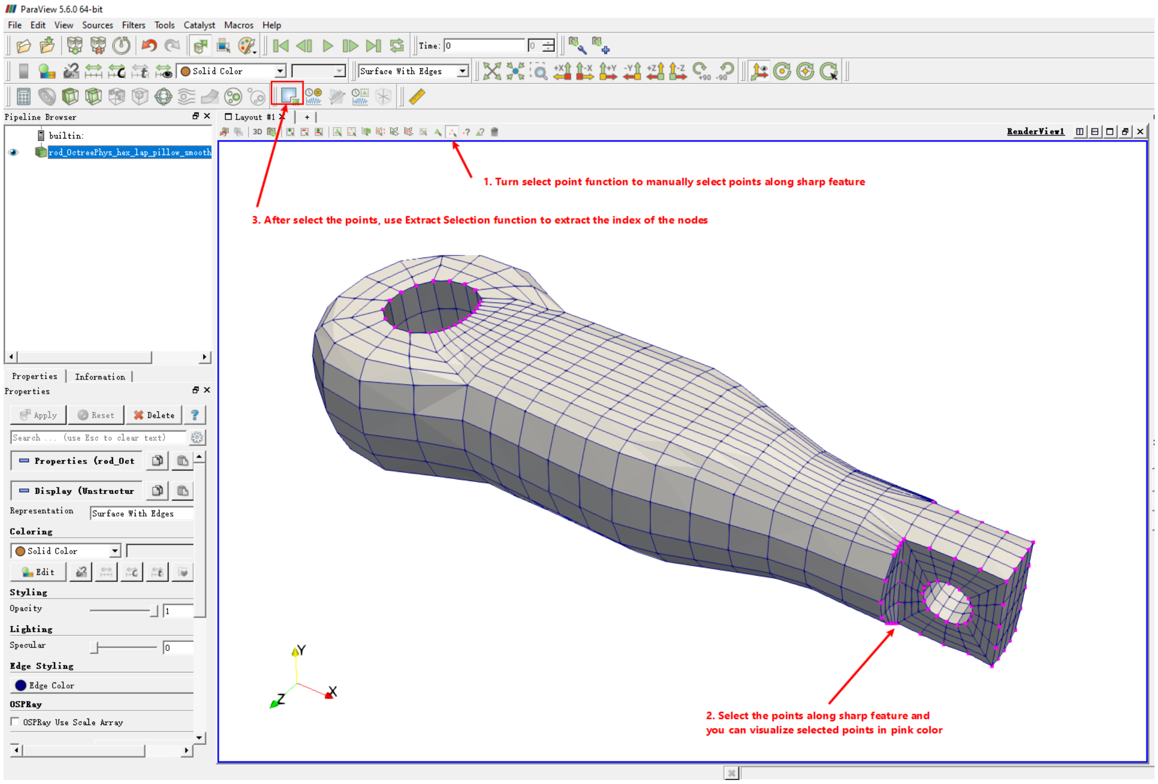
User need to set the input mesh file using this option. The example is shown in the following options.

Sharp feature preservation ("-s" or "—sharp")

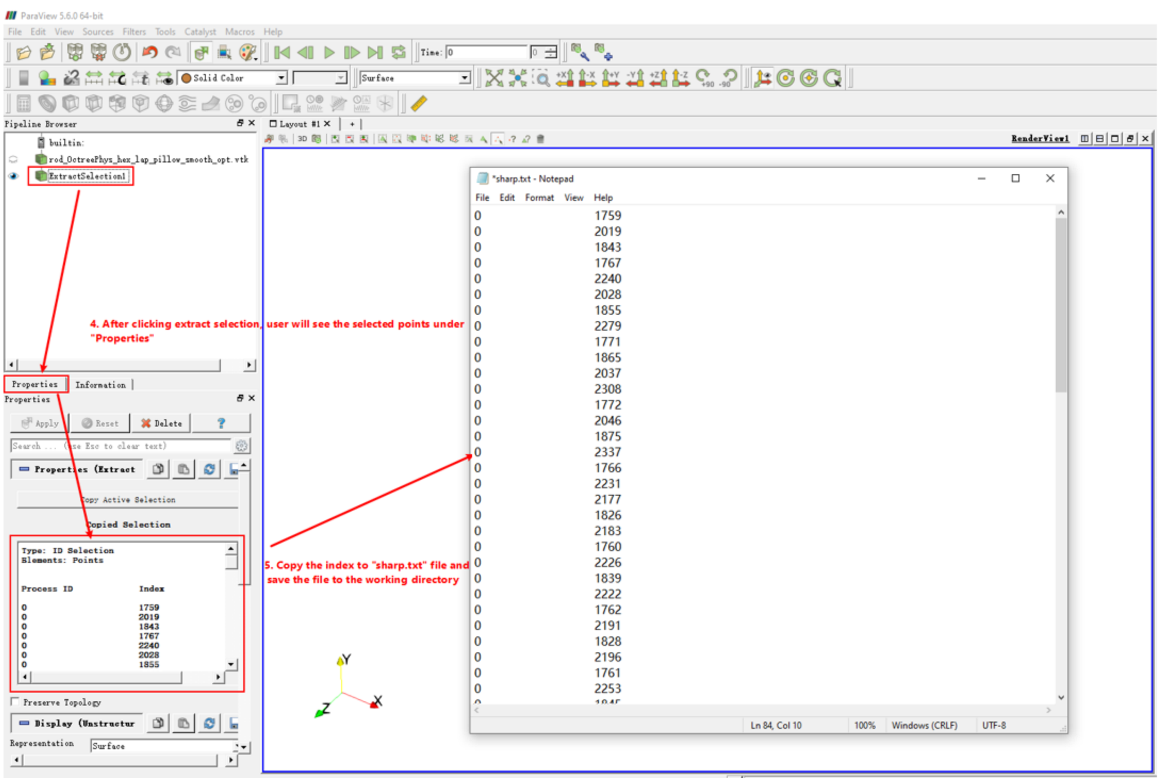
User can use this option to control if sharp feature is preserved.

- --sharp=0: No sharp feature preserve
- --sharp=1: Detect sharp feature automatically, set tolerance by "--stol"
- --sharp=2: Manually select sharp feature points in "sharp.txt" file

Sharp feature selection in Paraview:



1. Turn select point function to manually select points along sharp feature
3. After select the points, use Extract Selection function to extract the index of the nodes
2. Select the points along sharp feature and
you can visualize selected points in pink color



4. After clicking extract selection, user will see the selected points under
"Properties"
5. Copy the index to "sharp.txt" file and
save the file to the working directory

Mesh Quality Improvement Mode ("-Q" or "--quality")

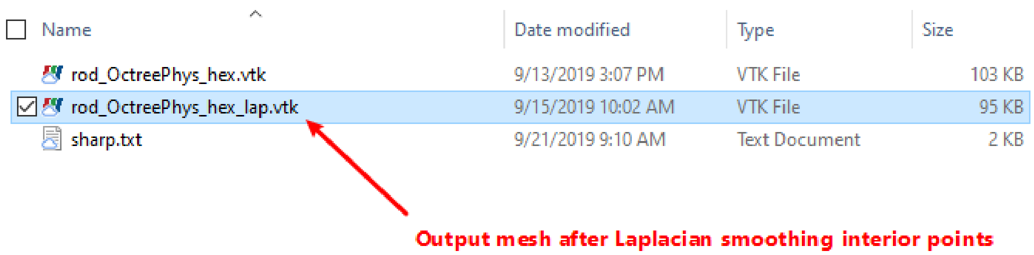
Use this option to turn on mesh quality improvement mode for the program. Here we have three improvement method:

1. **Laplacian smoothing (-m 0 or --method=0):**
   Set smoothing steps through "--number=n", this function will smooth nodes inside the model.

Example: Hex2Spline.exe -I .\example\rod_quality\rod_OctreePhys_hex.vtk -Q --method 0 --number 50

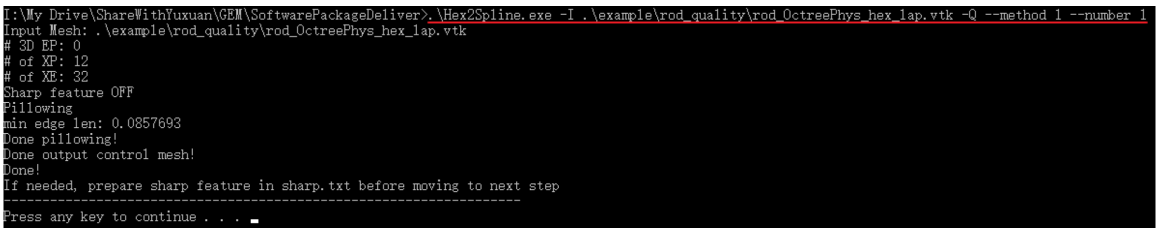
```
I:\My Drive\ShareWithYuxuan\GEM\SoftwarePackageDeliver>.\Hex2Spline.exe -I .\example\rod_quality\rod_OctreePhys_hex.vtk -Q -m 0 -n 20
Input Mesh: .\example\rod_quality\rod_OctreePhys_hex.vtk
# 3D EP: 0
# of XP: 12
# of XE: 32
Sharp feature OFF

Laplace Smoothing...
istep: 0
minJacob eid nBad: -0.996715 1102 968
minJacob eid nBad: -0.993422 381 659
istep: 1
minJacob eid nBad: -0.993422 381 659
minJacob eid nBad: -0.996182 41 521
istep: 2
minJacob eid nBad: -0.996182 41 521
minJacob eid nBad: -0.987734 443 393
istep: 3
minJacob eid nBad: -0.987734 443 393
minJacob eid nBad: -0.982401 1102 295
istep: 4
minJacob eid nBad: -0.982401 1102 295
minJacob eid nBad: -0.989754 443 204
istep: 5
minJacob eid nBad: -0.989754 443 204
minJacob eid nBad: -0.981704 1095 133
istep: 6
minJacob eid nBad: -0.981704 1095 133
minJacob eid nBad: -0.980819 1095 74
istep: 7
minJacob eid nBad: -0.980819 1095 74
minJacob eid nBad: -0.984833 1103 30
istep: 8
minJacob eid nBad: -0.984833 1103 30
minJacob eid nBad: -0.9836 1103 16
istep: 9
minJacob eid nBad: -0.9836 1103 16
minJacob eid nBad: -0.835802 1103 4
istep: 10
minJacob eid nBad: -0.835802 1103 4
minJacob eid nBad: 0.253045 1107 0
istep: 11
minJacob eid nBad: 0.253045 1107 0
minJacob eid nBad: 0.3102 825 0
istep: 12
minJacob eid nBad: 0.3102 825 0
minJacob eid nBad: 0.3102 825 0
istep: 13
minJacob eid nBad: 0.3102 825 0
minJacob eid nBad: 0.3102 825 0
istep: 14
minJacob eid nBad: 0.3102 825 0
minJacob eid nBad: 0.3102 825 0
istep: 15
minJacob eid nBad: 0.3102 825 0
minJacob eid nBad: 0.3102 825 0
istep: 16
minJacob eid nBad: 0.3102 825 0
minJacob eid nBad: 0.3102 825 0
istep: 17
minJacob eid nBad: 0.3102 825 0
minJacob eid nBad: 0.3102 825 0
istep: 18
```

The output is shown below:



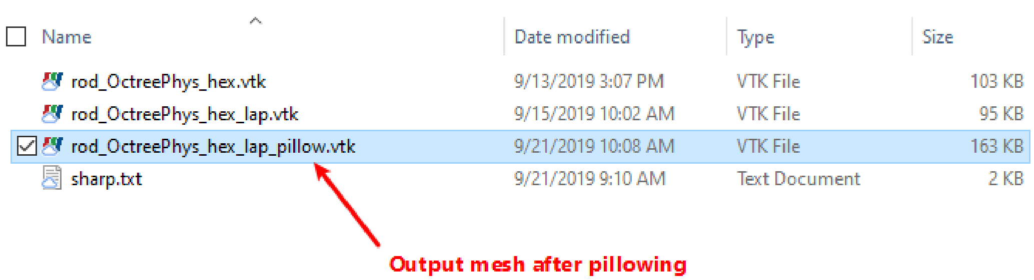
2. **Pillowing (-m 1 or --method=1):**
   Set pillowing layer through "--number=n"

Example: Hex2Spline.exe -I .\example\rod_quality\rod_OctreePhys_hex_lap.vtk -Q --method 1 --number 1



```
I:\My Drive\ShareWithYuxuan\GEM\SoftwarePackageDeliver>.\Hex2Spline.exe -I .\example\rod_quality\rod_OctreePhys_hex_lap.vtk -Q --method 1 --number 1
Input Mesh: .\example\rod_quality\rod_OctreePhys_hex_lap.vtk
# 3D EP: 0
# of XP: 12
# of XE: 32
Sharp feature OFF
Pillowing
min edge len: 0.0857693
Done pillowing!
Done output control mesh!
Done!
If needed, prepare sharp feature in sharp.txt before moving to next step
----------------------------------------------------------------------
Press any key to continue . . .
```

The output is shown below:



3. **Smoothing (-m 2 or --method=2):**
   Set step size through "--parameter=size", Set step number through "--number=n"

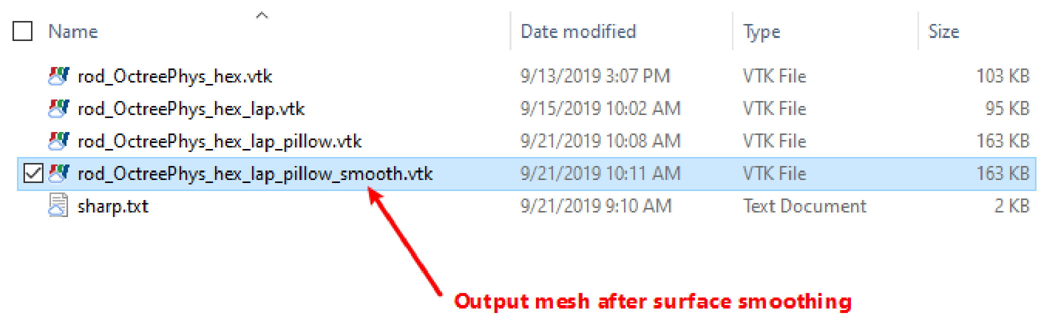
Example: Hex2Spline.exe -I .\example\rod_quality\rod_OctreePhys_hex_lap_pillow.vtk -Q --method 2 --parameter 0.001 --number 50 --sharp 2

(We use "--sharp" here to keep sharp feature, sharp feature is selected using Paraview)

```
I:\My Drive\ShareWithYuxuan\GEM\SoftwarePackageDeliver>.\Hex2Spline.exe -I .\example\rod_quality\rod_OctreePhys_hex_lap_pillow.vtk -Q --method 2 --pa
rameter 0.001 --number 50 --sharp 2
Input Mesh: .\example\rod_quality\rod_OctreePhys_hex_lap_pillow.vtk
# 3D EP: 12
# of XP: 228
# of XE: 664
Manually apply sharp feature ON

Smoothing...
it: 0
minJacob eid nBad: 0.193854 1723 0
minJacob eid nBad: 0.200396 1723 0
it: 1
minJacob eid nBad: 0.200396 1723 0
minJacob eid nBad: 0.206657 1723 0
it: 2
minJacob eid nBad: 0.206657 1723 0
minJacob eid nBad: 0.212642 1723 0
it: 3
minJacob eid nBad: 0.212642 1723 0
minJacob eid nBad: 0.21836 1723 0
it: 4
minJacob eid nBad: 0.21836 1723 0
minJacob eid nBad: 0.223817 1723 0
it: 5
minJacob eid nBad: 0.223817 1723 0
minJacob eid nBad: 0.229022 1723 0
it: 6
minJacob eid nBad: 0.229022 1723 0
minJacob eid nBad: 0.233986 1723 0
it: 7
minJacob eid nBad: 0.233986 1723 0
minJacob eid nBad: 0.238716 1723 0
it: 8
minJacob eid nBad: 0.238716 1723 0
minJacob eid nBad: 0.243223 1723 0
it: 9
minJacob eid nBad: 0.243223 1723 0
minJacob eid nBad: 0.247518 1723 0
it: 10
minJacob eid nBad: 0.247518 1723 0
minJacob eid nBad: 0.251609 1723 0
it: 11
minJacob eid nBad: 0.251609 1723 0
minJacob eid nBad: 0.255507 1723 0
it: 12
minJacob eid nBad: 0.255507 1723 0
minJacob eid nBad: 0.259221 1723 0
it: 13
minJacob eid nBad: 0.259221 1723 0
minJacob eid nBad: 0.26276 1723 0
it: 14
minJacob eid nBad: 0.26276 1723 0
minJacob eid nBad: 0.266134 1723 0
it: 15
minJacob eid nBad: 0.266134 1723 0
minJacob eid nBad: 0.269352 1723 0
it: 16
minJacob eid nBad: 0.269352 1723 0
minJacob eid nBad: 0.272422 1723 0
it: 17
minJacob eid nBad: 0.272422 1723 0
minJacob eid nBad: 0.275352 1723 0
```

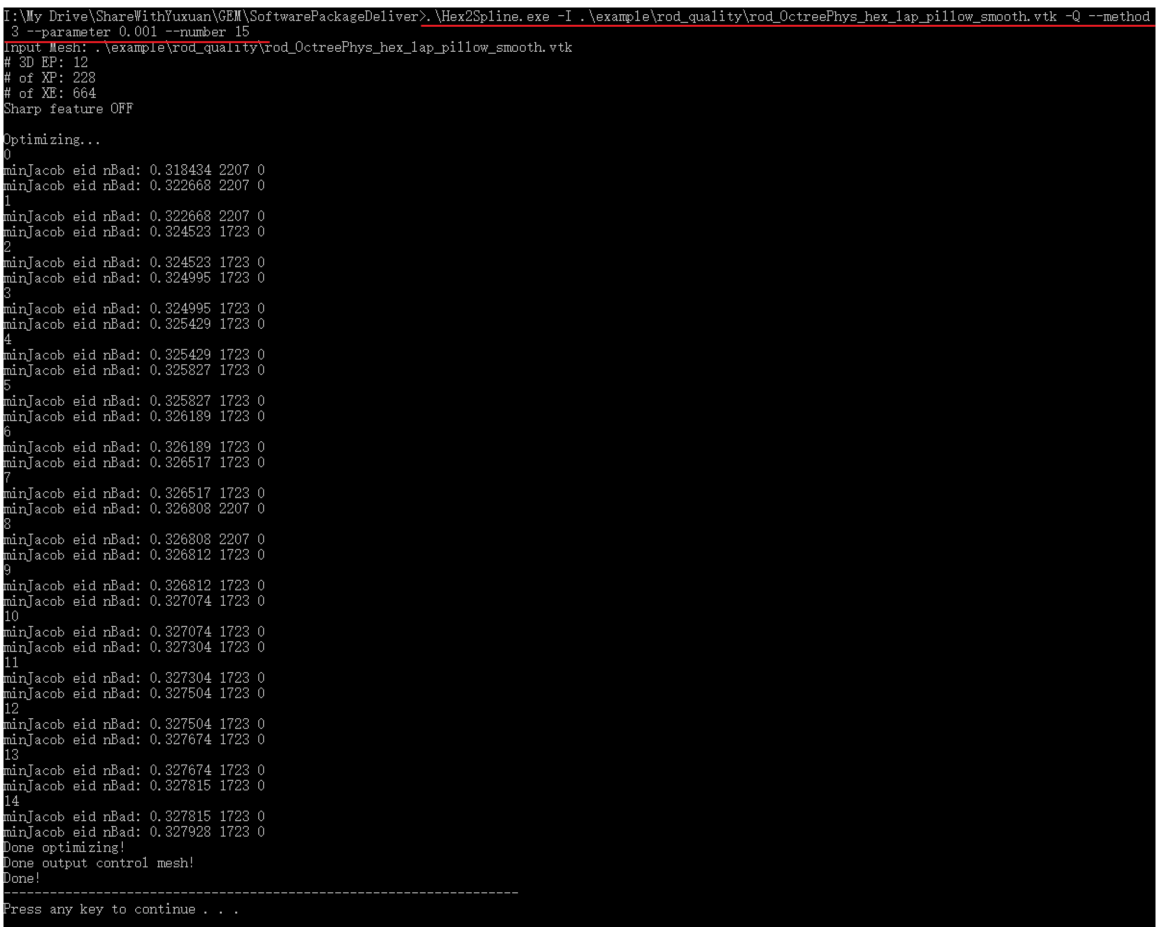
```
it: 38
minJacob eid nBad: 0.314034 1723 0
minJacob eid nBad: 0.315316 1723 0
it: 39
minJacob eid nBad: 0.315316 1723 0
minJacob eid nBad: 0.316558 1723 0
it: 40
minJacob eid nBad: 0.316558 1723 0
minJacob eid nBad: 0.317764 1723 0
it: 41
minJacob eid nBad: 0.317764 1723 0
minJacob eid nBad: 0.318934 1723 0
it: 42
minJacob eid nBad: 0.318934 1723 0
minJacob eid nBad: 0.320071 1723 0
it: 43
minJacob eid nBad: 0.320071 1723 0
minJacob eid nBad: 0.321177 1723 0
it: 44
minJacob eid nBad: 0.321177 1723 0
minJacob eid nBad: 0.322252 1723 0
it: 45
minJacob eid nBad: 0.322252 1723 0
minJacob eid nBad: 0.323085 2207 0
it: 46
minJacob eid nBad: 0.323085 2207 0
minJacob eid nBad: 0.321932 2207 0
it: 47
minJacob eid nBad: 0.321932 2207 0
minJacob eid nBad: 0.320806 2207 0
it: 48
minJacob eid nBad: 0.320806 2207 0
minJacob eid nBad: 0.319706 2207 0
it: 49
minJacob eid nBad: 0.319706 2207 0
minJacob eid nBad: 0.318632 2207 0
Done smoothing!
Done output control mesh!
Done!
---------------------------------------------------------------------
Press any key to continue . . .
```

Output: On the command window, you can see the smallest Jacobian value, the element ID that has the minimum Jacobian and number of elements with negative Jacobian. User can try different settings of the parameter to improve the mesh until the Jacobian meets requirement. And the smoothed mesh is output as below:

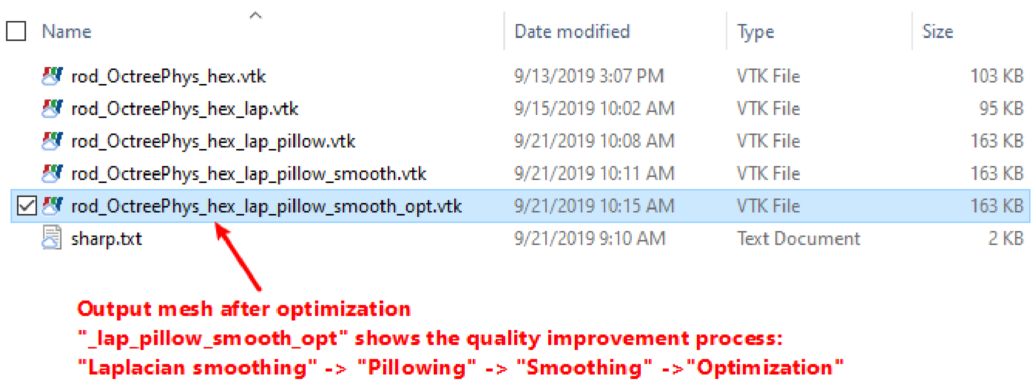


4. **Optimization (-m 3 or --method=3):**
   Set step size through "--parameter=size", Set step number through "--number=n"

Example: Hex2Spline.exe -I .\example\rod_quality\rod_OctreePhys_hex_lap_pillow_smooth.vtk -Q --method 3 --parameter 0.001 --number 15



Output: On the command window, you can see the smallest Jacobian value, the element ID that has the minimum Jacobian and number of elements with negative Jacobian. User can try different settings of the parameter to improve the mesh until the Jacobian meets requirement. And the smoothed mesh is output as below:

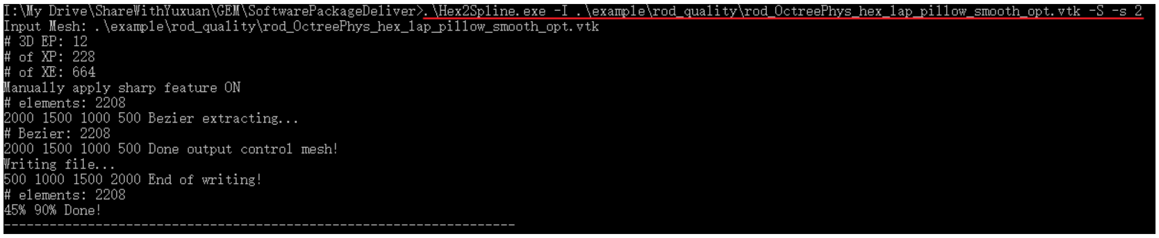


Spline construction mode ("-S" or "--spline")

User can use this option to construct spline model and generate BEXT file. To preserve sharp feature, use sharp feature option ("--sharp") to define sharp feature.

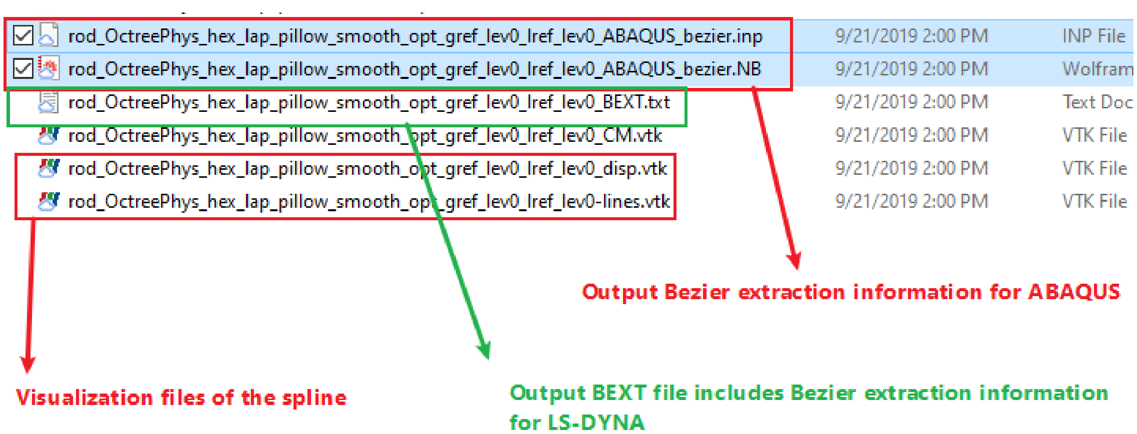
Example of spline construction given input control mesh (Sharp feature is set manually):

Hex2Spline.exe -I .\example\rod_quality\rod_OctreePhys_hex_lap_pillow_smooth_opt.vtk -S --sharp 2



```
I:\My Drive\ShareWithYuxuan\GEM\SoftwarePackageDeliver>.\Hex2Spline.exe -I .\example\rod_quality\rod_OctreePhys_hex_lap_pillow_smooth_opt.vtk -S -s 2
Input Mesh: .\example\rod_quality\rod_OctreePhys_hex_lap_pillow_smooth_opt.vtk
# 3D EP: 12
# of XP: 228
# of XE: 664
Manually apply sharp feature ON
# elements: 2208
2000 1500 1000 500 Bezier extracting...
# Bezier: 2208
2000 1500 1000 500 Done output control mesh!
Writing file...
500 1000 1500 2000 End of writing!
# elements: 2208
45% 90% Done!
--------------------------------------------------------------------
```

The output file is shown below:

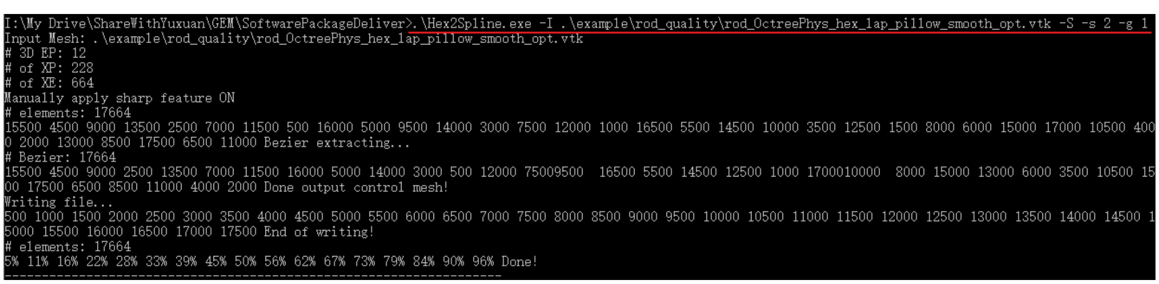


The spline construction module also supports global and local refinement:

1. **Global refinement ("-g" or "--globalref")**
   User can use this option to perform global refinement .

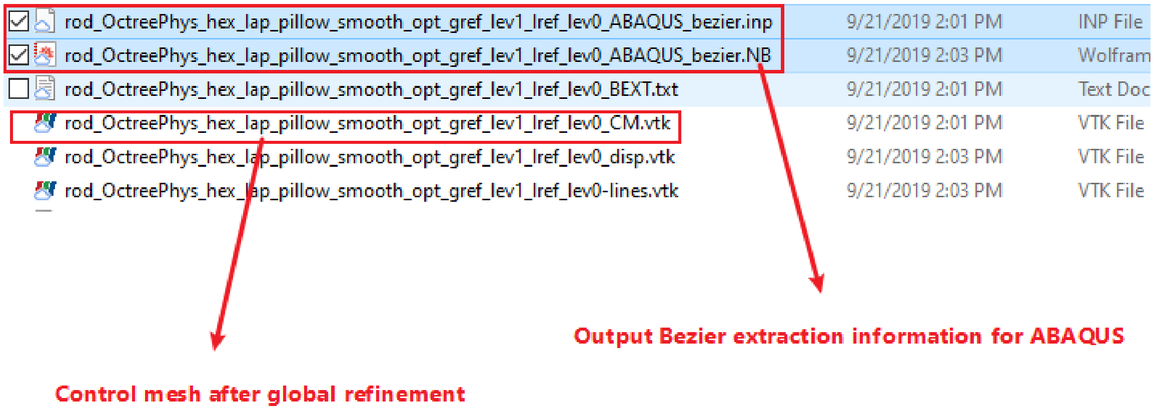
Example of spline construction with one level global refinement (Sharp feature is set manually):

Hex2Spline.exe -I .\example\rod_quality\rod_OctreePhys_hex_lap_pillow_smooth_opt.vtk -S --sharp 2 -g 1



```
I:\My Drive\ShareWithYuxuan\GEM\SoftwarePackageDeliver>.\Hex2Spline.exe -I .\example\rod_quality\rod_OctreePhys_hex_lap_pillow_smooth_opt.vtk -S -s 2 -g 1
Input Mesh: .\example\rod_quality\rod_OctreePhys_hex_lap_pillow_smooth_opt.vtk
# 3D EP: 12
# of XP: 228
# of XE: 664
Manually apply sharp feature ON
# elements: 17664
15500 4500 9000 13500 2500 7000 11500 500 16000 5000 9500 14000 3000 7500 12000 1000 16500 5500 14500 10000 3500 12500 1500 8000 6000 15000 17000 10500 400
0 2000 13000 8500 17500 6500 11000 Bezier extracting...
# Bezier: 17664
15500 4500 9000 2500 13500 7000 11500 16000 5000 14000 3000 500 12000 75009500  16500 5500 14500 12500 1000 1700010000  8000 15000 13000 6000 3500 10500 15
00 17500 6500 8500 11000 4000 2000 Done output control mesh!
Writing file...
500 1000 1500 2000 2500 3000 3500 4000 4500 5000 5500 6000 6500 7000 7500 8000 8500 9000 9500 10000 10500 11000 11500 12000 12500 13000 13500 14000 14500 1
5000 15500 16000 16500 17000 17500 End of writing!
# elements: 17664
5% 11% 16% 22% 28% 33% 39% 45% 50% 56% 62% 67% 73% 79% 84% 90% 96% Done!
--------------------------------------------------------------------
```

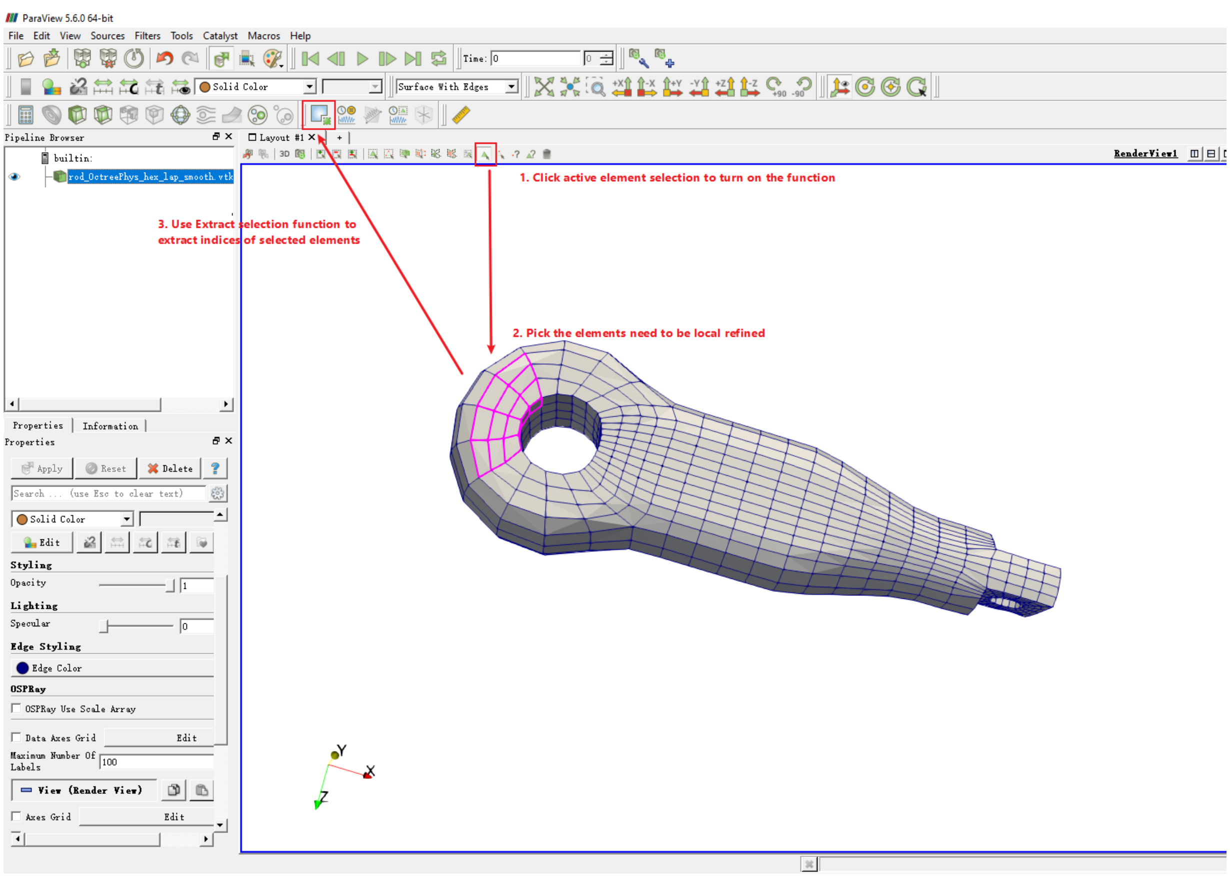
The output files are shown below:

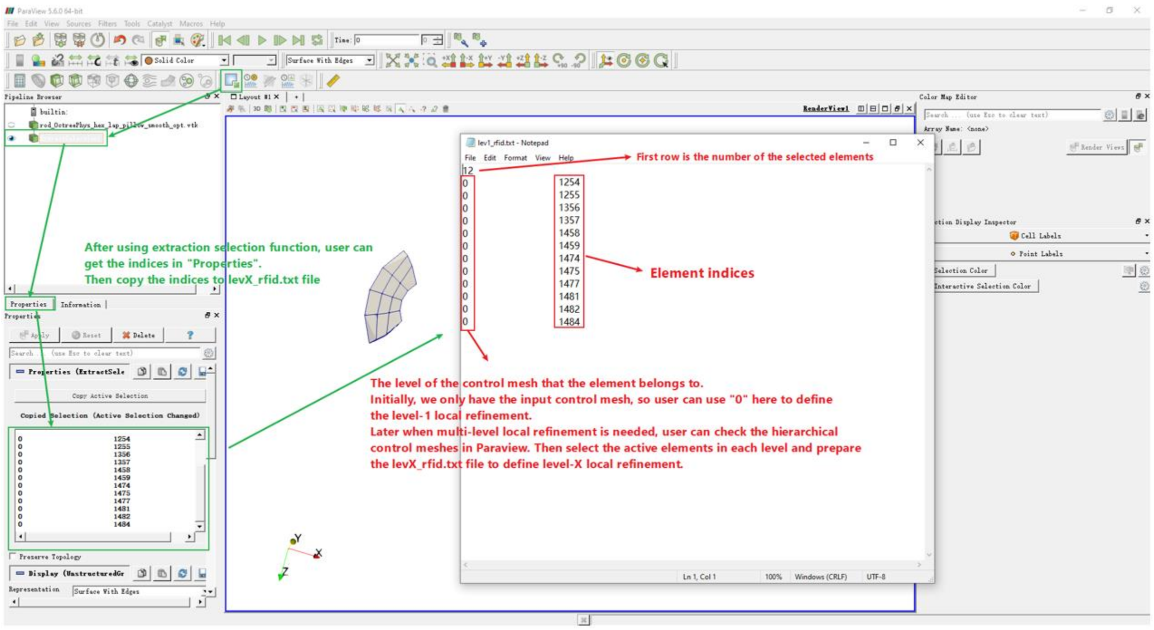


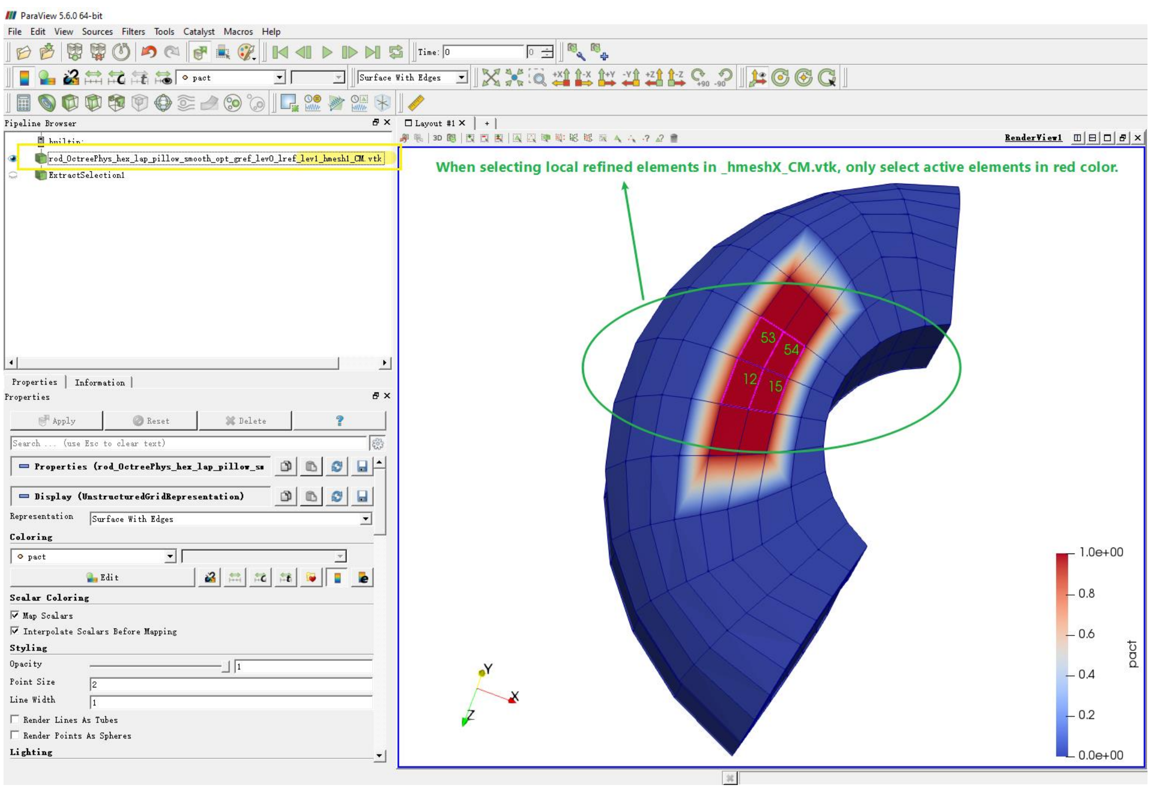
2. Local refinement ("-l" or "--localref")

User can use this option to perform local refinement. User also needs to prepare **levX_rfid.txt** file (X=0,1,…) to define local refined elements. In this file, the first row is the number of elements to be refined. The rest of file has two numbers **{i, j}** on each row, the first number **i** is the level of the mesh and the second number **j** is the index of the element in the **i-th** level mesh. To define the first level of local refinement, user can use the input mesh and the level number is 0. (See **lev0_rfid.txt** in /rod_quality folder)

Local refinement elements selection in Paraview:





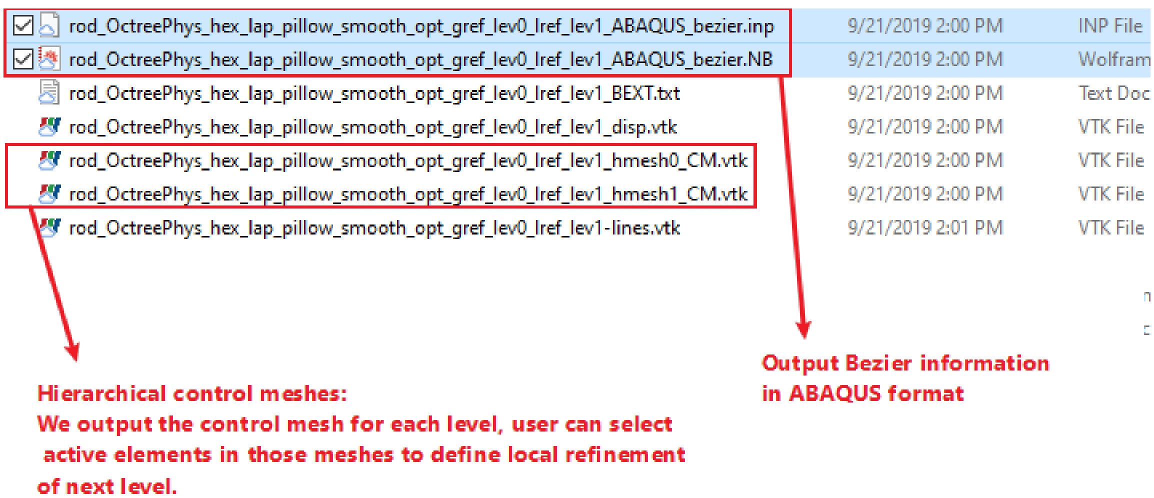


Example of spline construction with one level local refinement (Sharp feature is set manually; the first level of local refinement is defined in lev1_rfid.txt file):

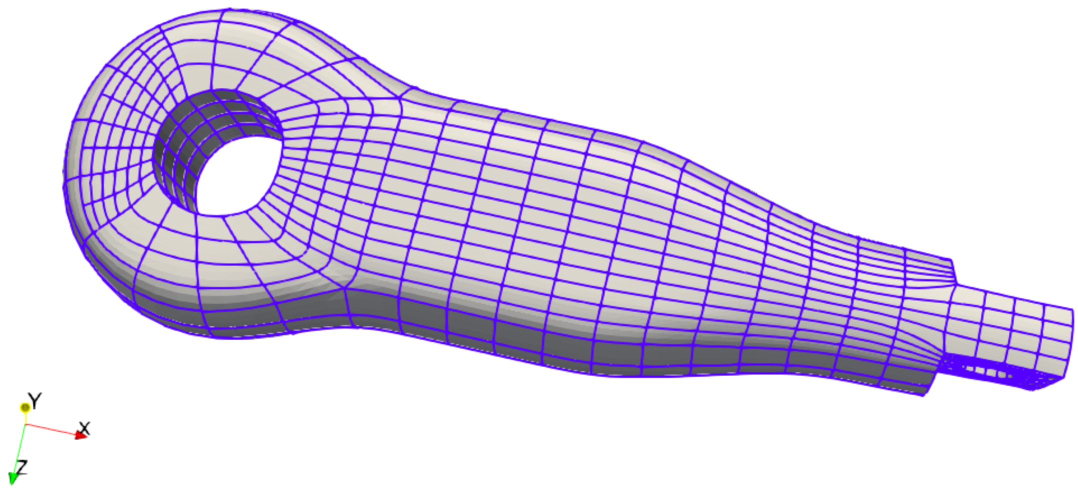
Hex2Spline.exe -I .\example\rod_quality\rod_OctreePhys_hex_lap_pillow_smooth_opt.vtk -S --sharp 2 --localref 1

```
Spline construction of Rod model with level-1 local refinement

I:\My Drive\ShareWithYuxuan\GEM\SoftwarePackageDeliver>.\Hex2Spline.exe -I .\example\rod_quality\rod_OctreePhys_hex_lap_pillow_smooth_opt.vtk -S -s 2 -1 1
Input Mesh: .\example\rod_quality\rod_OctreePhys_hex_lap_pillow_smooth_opt.vtk
# 3D EP: 12
# of XP: 228
# of XE: 664
Manually apply sharp feature ON
# elements: 2208
2000 1500 1000 500 0
0 refining...
# of rfid: 12
# of to-be-refined elements: 12
# of to-be-refined ghost: 42
Refining done
hmesh size: 2
Run fitting...
Building linear system...
npt: 2609
neq: 1005
nel: 1028
1000 Done fitting!
Bezier extracting...
1500 1000 2000 500 Writing file...
500 1000 1500 2000 End of writing!
# elements: 2292
43% 87% Done!
-------------------------------------------------------------------
Press any key to continue . . .
```

The output files are shown below:



User can visualize the Bezier mesh in ParaView by using two VTK files ends with "_disp.vtk" and "-lines.vtk", the visualization is shown below:



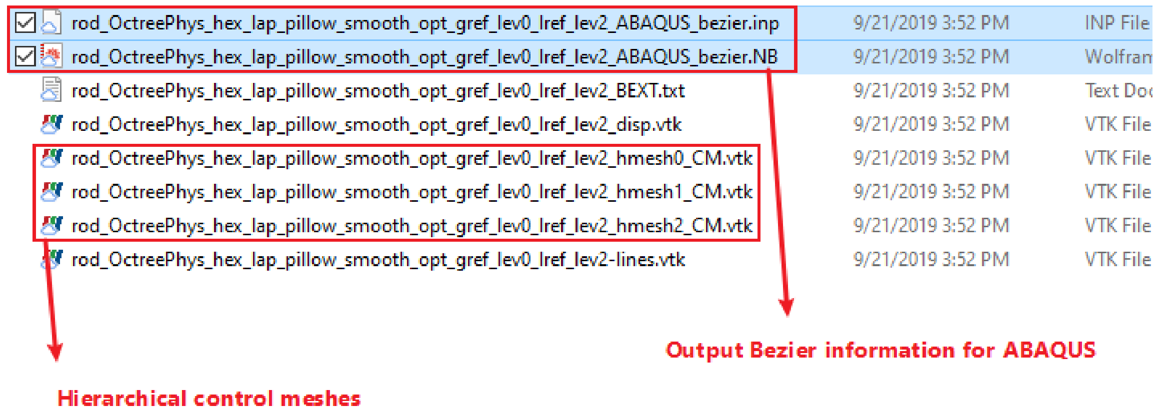
To define the second or more level of local refinement, user can use the output "X_hmeshX_CM.vtk" file and select elements needs refinement using paraview. (See **lev1_rfid.txt** in /rod_quality folder)

Example of spline construction with one level local refinement (Sharp feature is set manually; the local refined elements are defined in lev2_rfid.txt file):

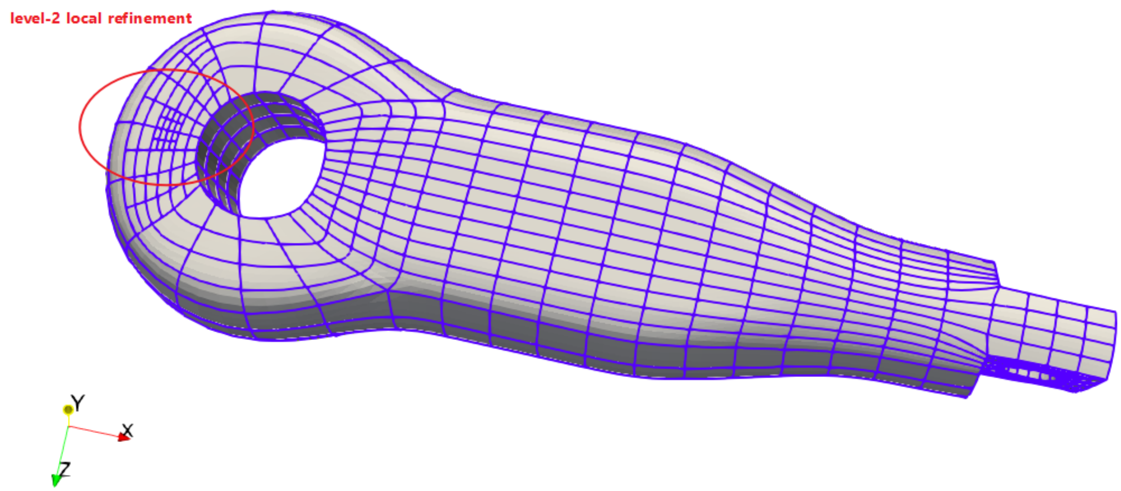
Hex2Spline.exe -I .\example\rod_quality\rod_OctreePhys_hex_lap_pillow_smooth_opt.vtk -S --sharp 2 --localref 2

```
Spline construction of Rod model with level-2 local refinement

I:\My Drive\ShareWithYuxuan\GEM\SoftwarePackageDeliver>.\Hex2Spline.exe -I .\example\rod_quality\rod_OctreePhys_hex_lap_pillow_smooth_opt.vtk -S -s 2 -l 2
Input Mesh: .\example\rod_quality\rod_OctreePhys_hex_lap_pillow_smooth_opt.vtk
# 3D EP: 12
# of XP: 228
# of XE: 664
Manually apply sharp feature ON
# elements: 2208
1500 2000 1000 500 0
0 refining...
# of rfid: 12
# of to-be-refined elements: 12
# of to-be-refined ghost: 42
Refining done
hmesh size: 2
0
1 refining...
# of rfid: 4
# of to-be-refined elements: 4
# of to-be-refined ghost: 28
Refining done
hmesh size: 3
Run fitting...
Building linear system...
npt: 2610
neq: 1006
nel: 1040
1000 Done fitting!
Bezier extracting...
1500 1000 2000 500 Writing file...
500 1000 1500 2000 End of writing!
# elements: 2320
43% 86% Done!
--------------------------------------------------------------------
```

The output files are shown below:



The visualization of the output Bezier mesh is shown below:



References

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