FAnToM
Lessons Learned from Design, Implementation, Administration and Use of a Visualization System for Over 10 years

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The Idea of FAnToM

- **F**ield **An**alysis using **To**pological **M**ethods
  - Visualization of fields in 2D/3D
  - Scalar, vector and tensor fields
  - Provides framework for team’s research in new algorithms
    - Implementation, testing, application
  - Contains many state-of-the-art methods in the field
  - Designed for commodity hardware

- Later:
  - Flow Visualization
  - Gradual extension to medical and graph visualization

Short History

- October 1998 - start at University of Kaiserslautern
  - Grant from “Stiftung Rheinland-Pfalz für Innovation”
  - DFG grant “Visualization of Nonlinear Vector Field Topology” (VNV)
  - PIs: Prof Dr. Hans Hagen, Dr. Gerik Scheuermann
  - Development Lead: Thomas Wischgoll
- November 2001 - DFG VNV II
  - Development Lead: Christoph Garth
- May 2004 - moved to University of Leipzig
  - PI: Prof. Dr. Gerik Scheuermann
  - Development Lead: Mario Hlawitschka and Alexander Wiebel
- April 2005 - DFG VNV III
- June 2008 - DFG VNV IV
- October 2009 current state
  - Development Lead: Dominic Schneider

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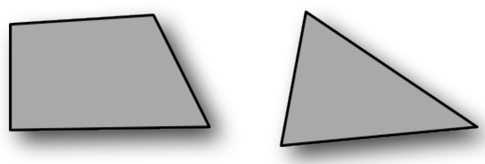
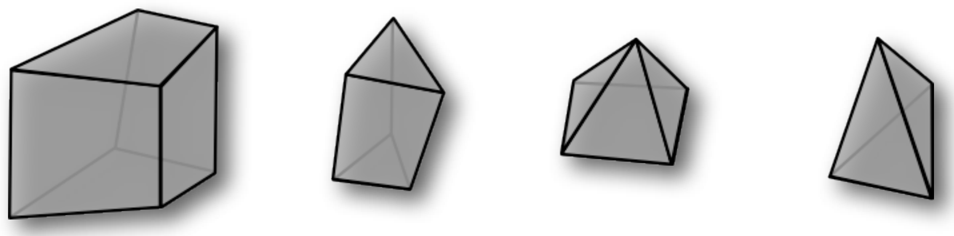
Application Data

- Tailored to fluid dynamics data sets
  - Unstructured meshes
    - 2D: quads, triangles



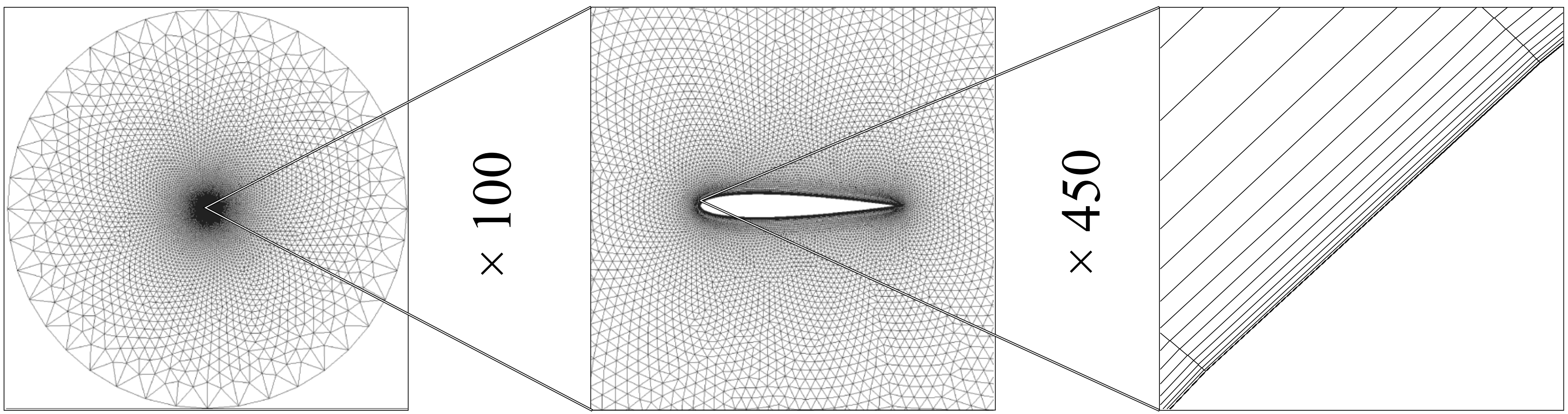
    - 3D: hexahedra, prisms, pyramids, tetrahedra



  - Large meshes (for commodity hardware)
    - millions of cells

Application Data

– Locally refined data
  →Strongly varying cell sizes



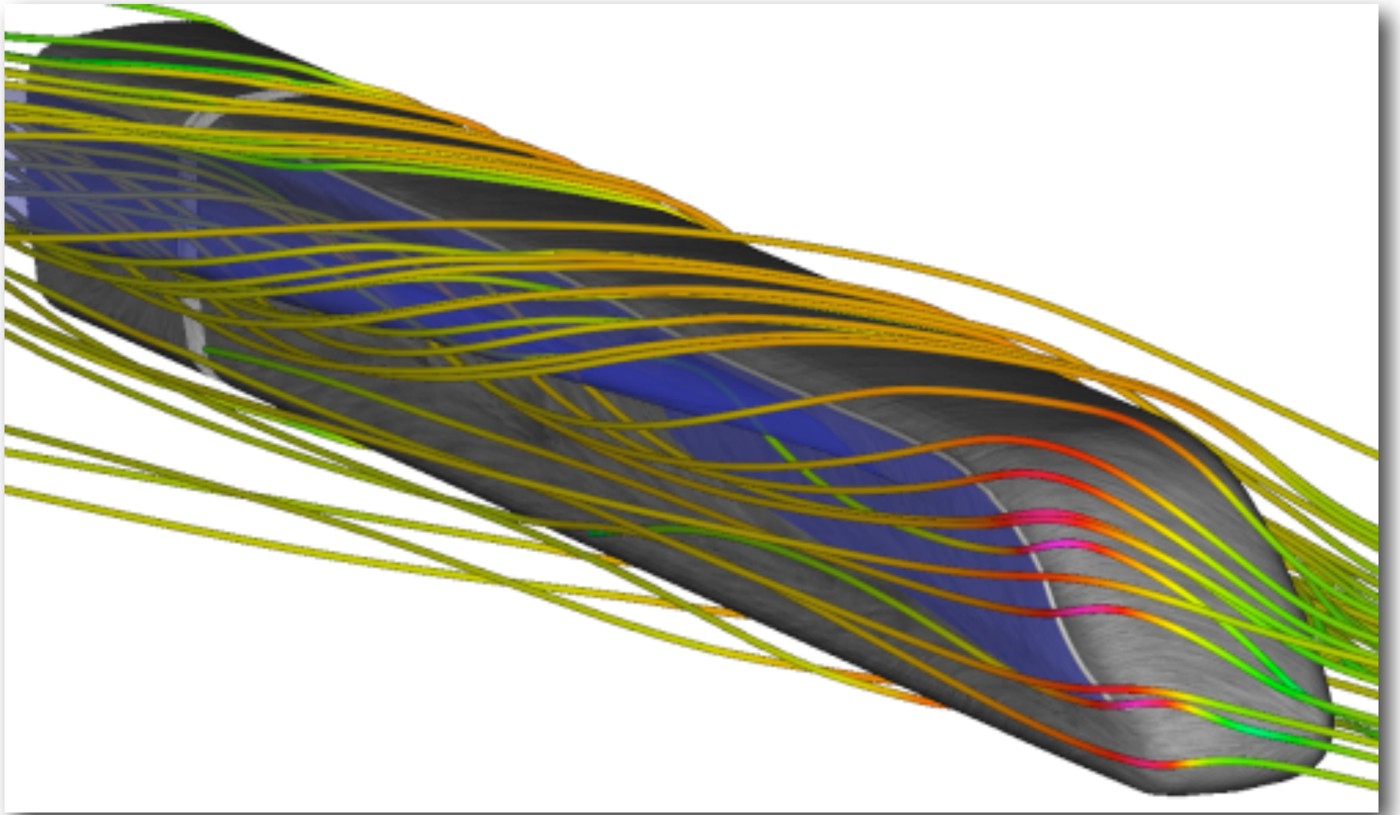
Taken from [LST2003]

Overview

- Point Location
- Algorithm Execution Model
- New and established visualization techniques

Point Location

- Point location is important for line integration
  - Stream lines, streak lines, path lines



Point Location

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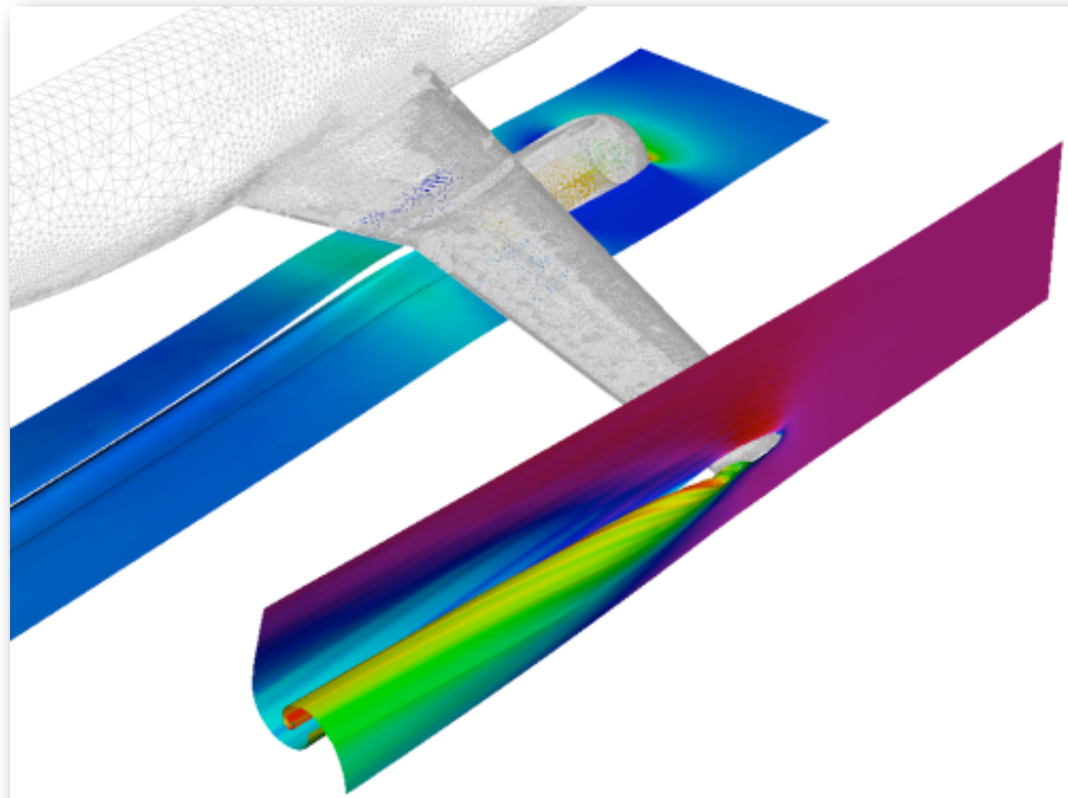
  - Stream lines, streak lines, path lines
  - Stream surfaces



Point Location

- Point location is important for line integration
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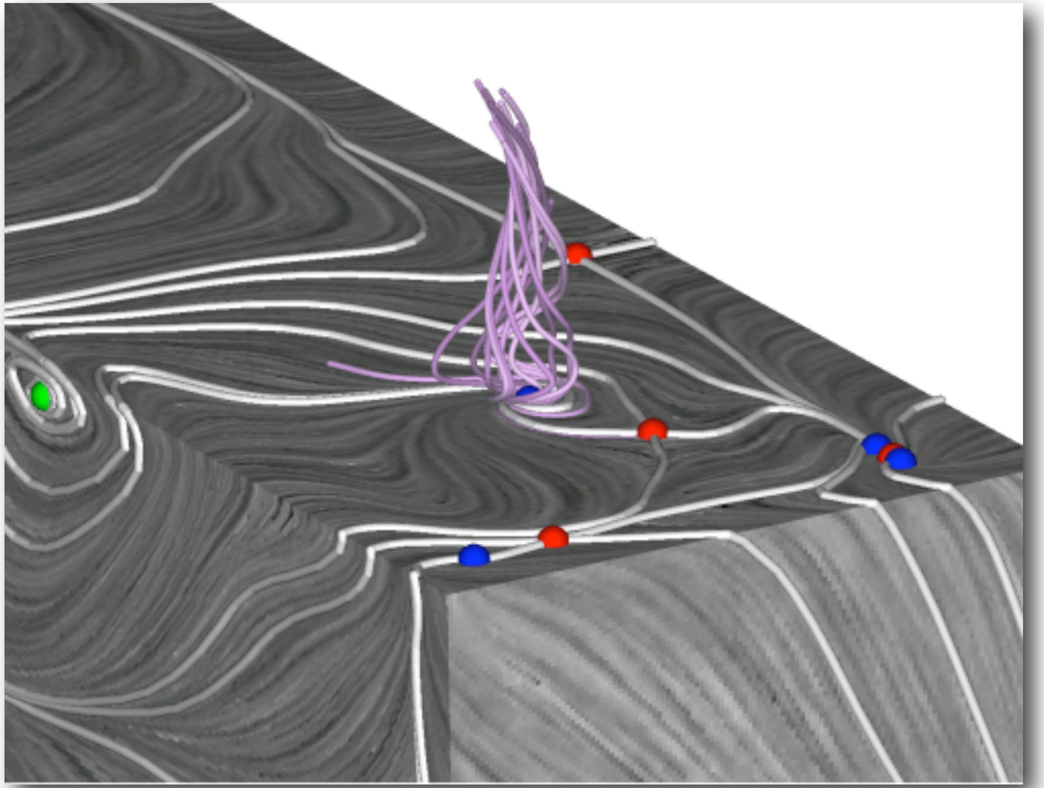
  - Stream surfaces
  - Vector field topology
    → separatrices



Point Location

- Point location is important for line integration
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- Why is it important?
  - Interpolation value at samples between given data points
  - Interpolation performed in cell
    → need to find the cell the sample lies in

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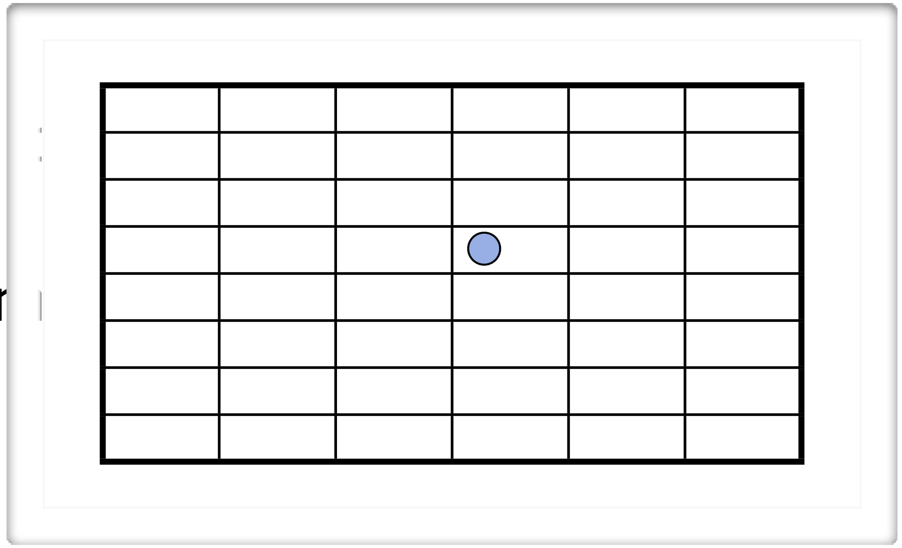

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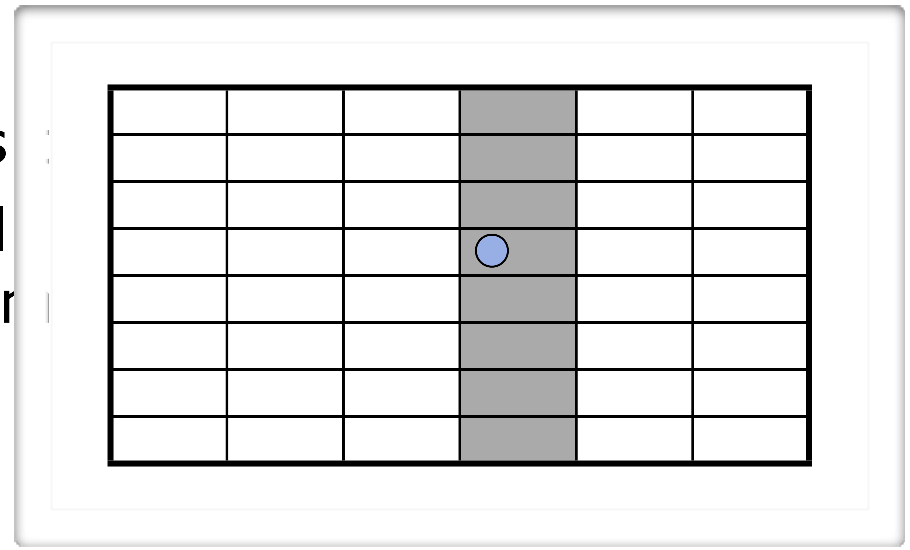

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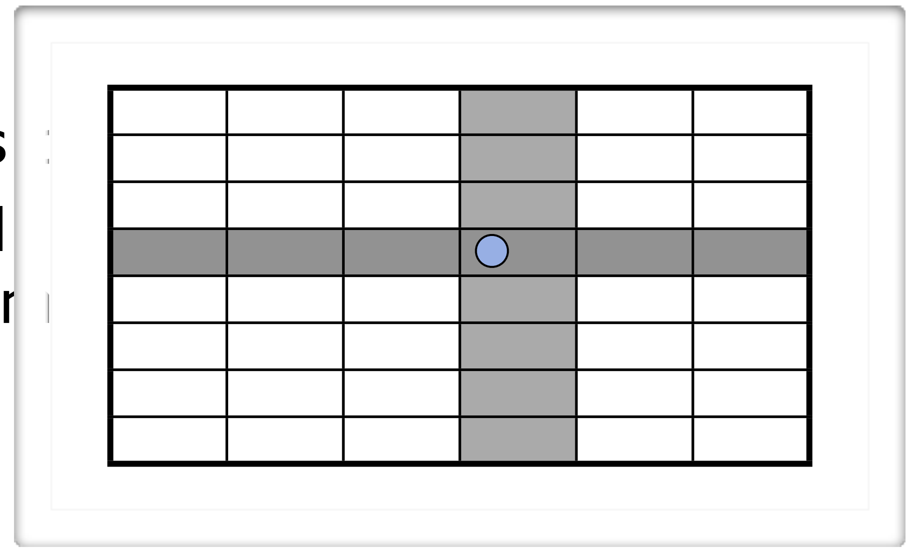

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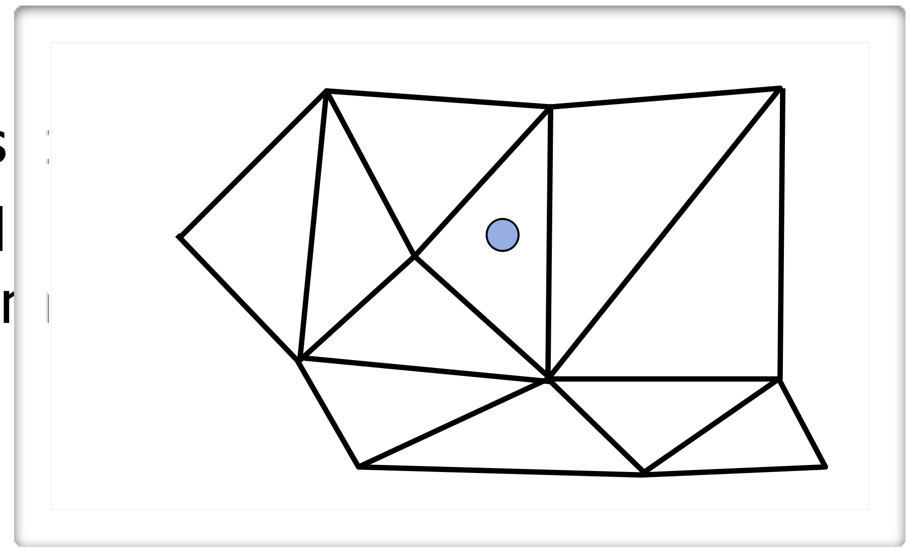
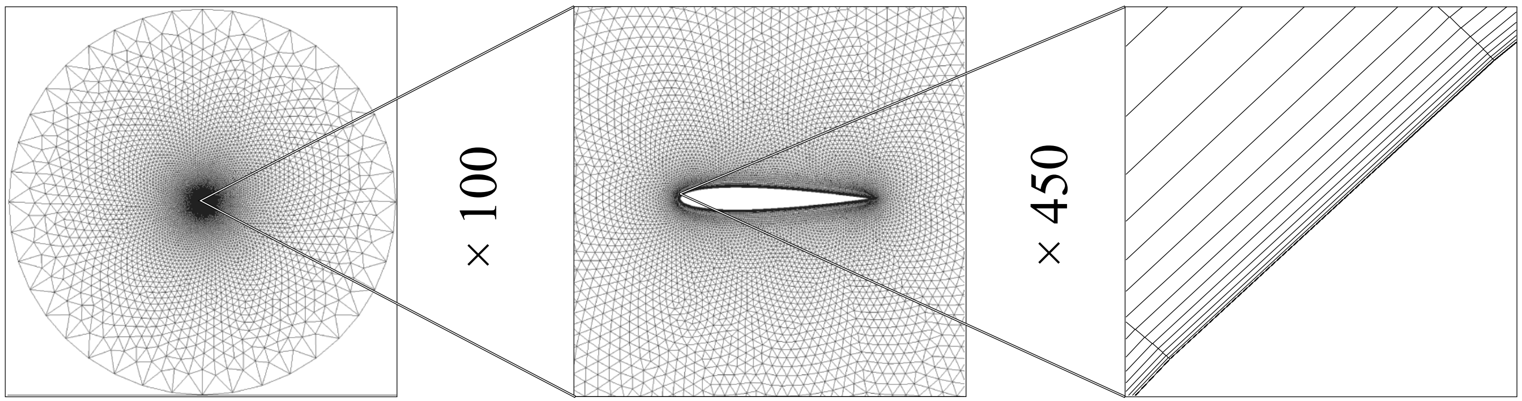


Point Location

- Point location of VTK not appropriate for data
  - Uniform subdivision of octree wastes memory



Taken from [LST2003]

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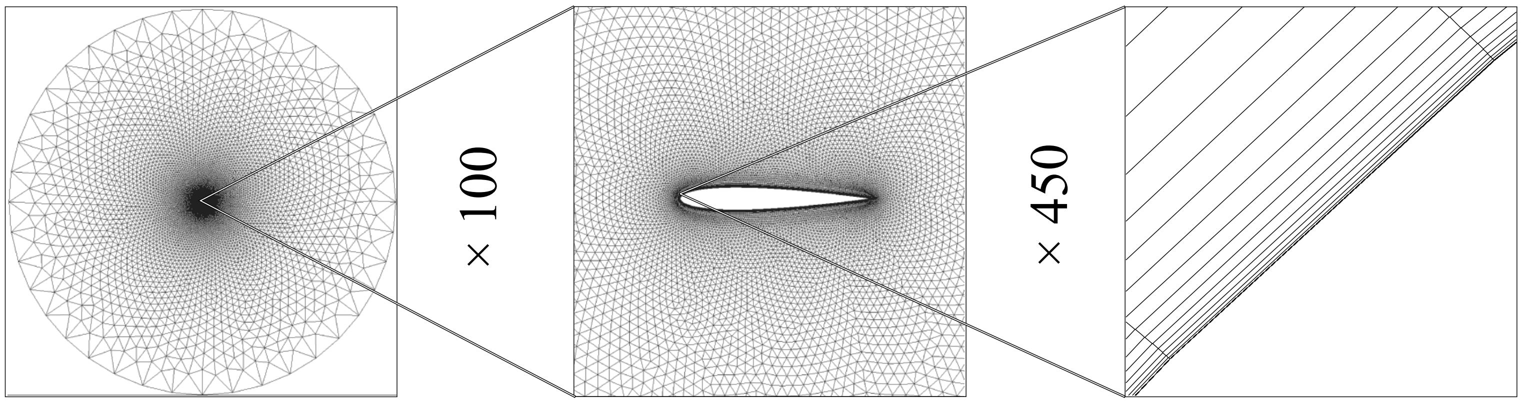
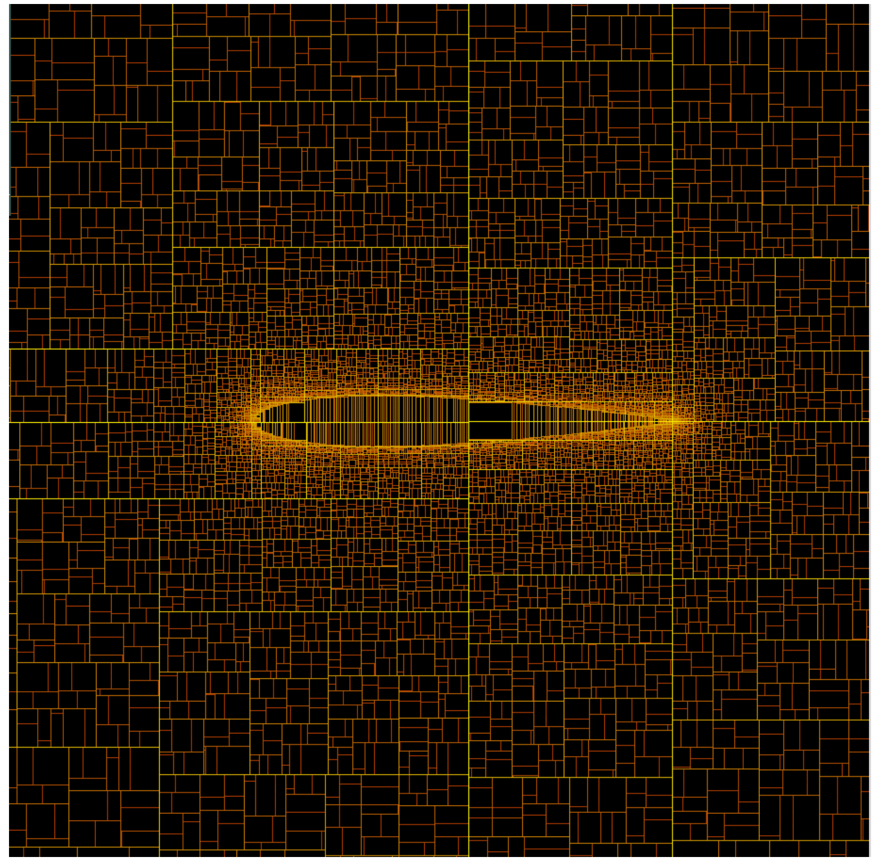


Taken from [LST2003]

- Method developed specifically for FAnToM
  - [LST2003] Max Langbein, Gerik Scheuermann, Xavier Tricoche. *An Efficient Point Location Method for Visualization in Large Unstructured Grids*.

Efficient Point Location

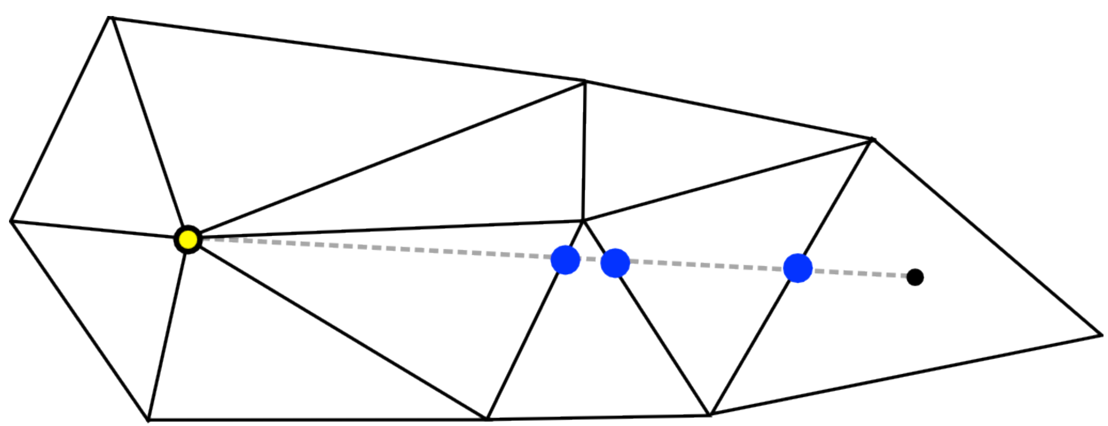
- Adaptive kD-tree
  - ~1% of mesh vertices



Taken from [LST2003]

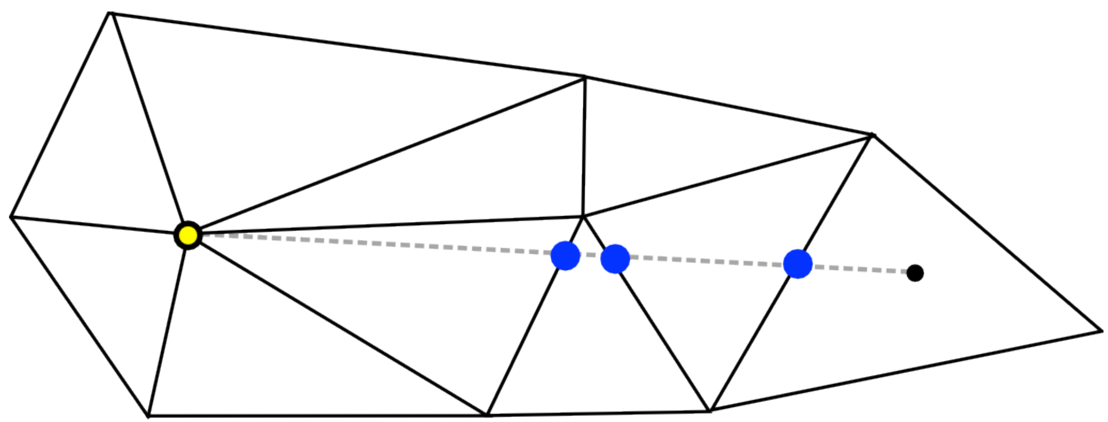
Efficient Point Location

- Adaptively subdivided kD-tree
  - ~1% of mesh vertices
- Identifies vertex close to point

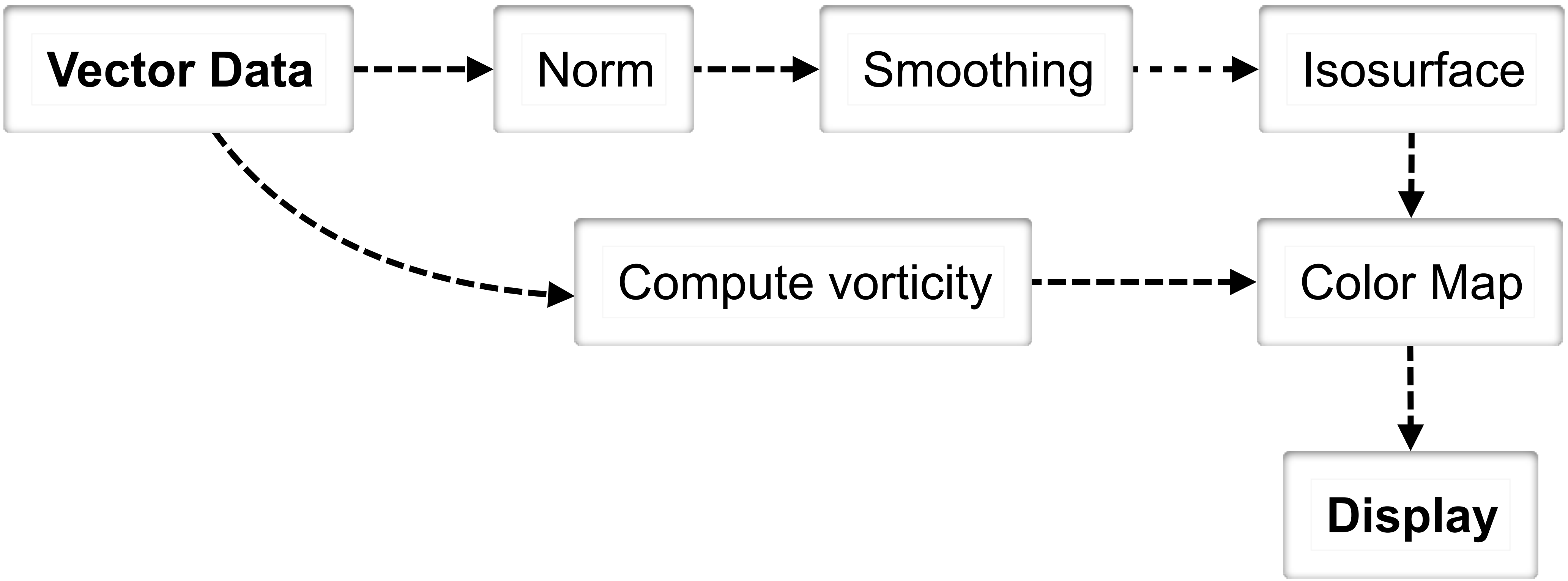


Efficient Point Location

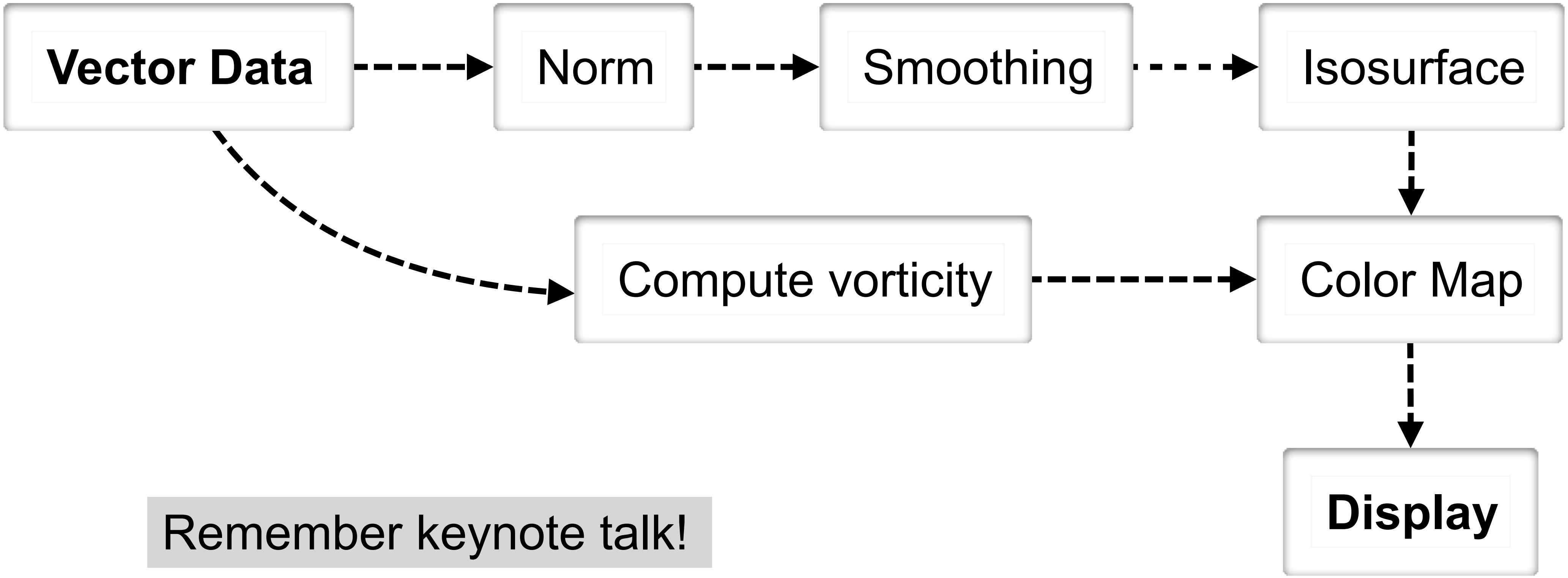
- Adaptively subdivided kD-tree
  - ~1% of mesh vertices
- Identifies vertex close to point
- Cast ray to sought position
- Follow ray using cell adjacency information



Data Flow Networks



Data Flow Networks



Remember keynote talk!

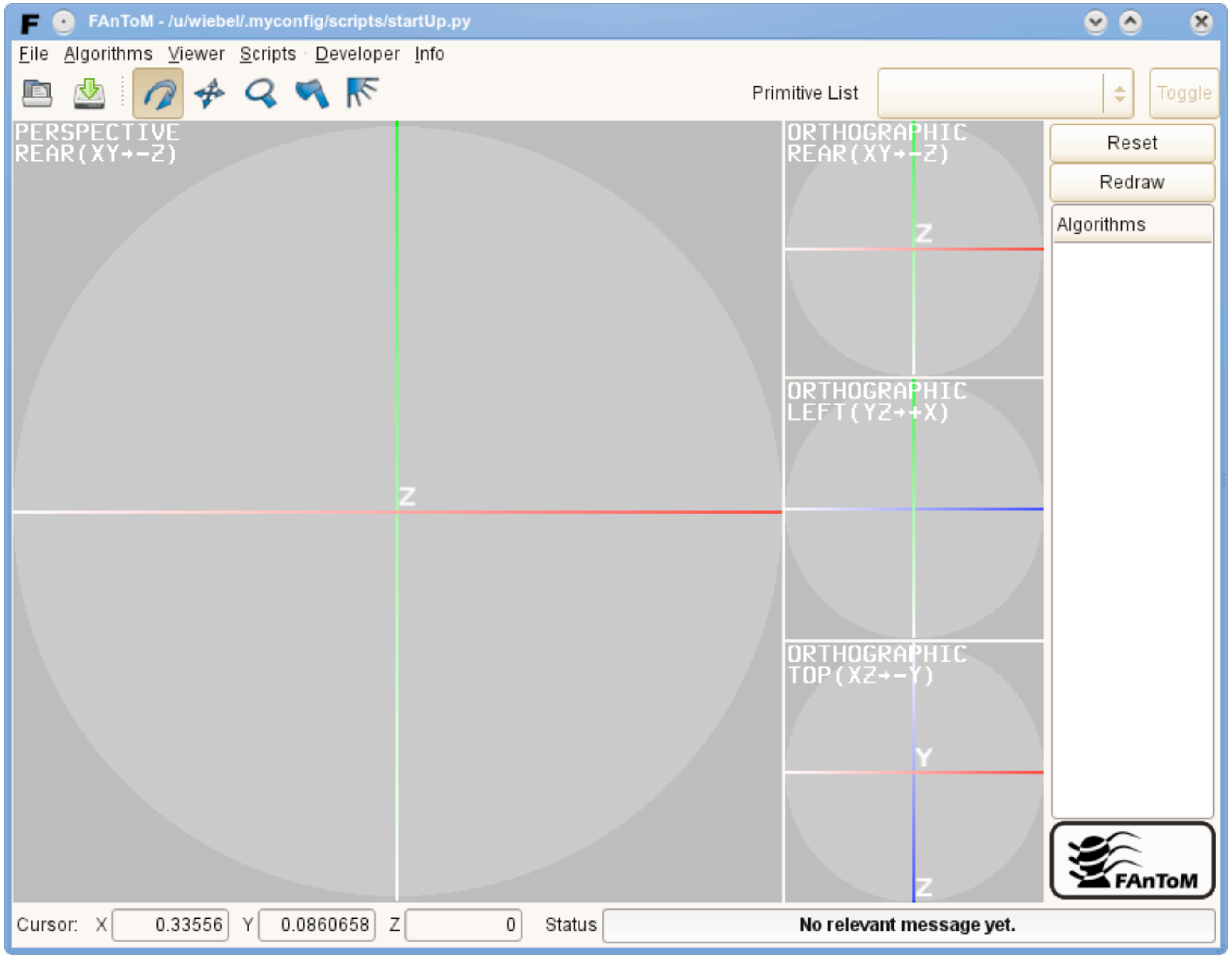
FAnToM: Explicit Execution Control

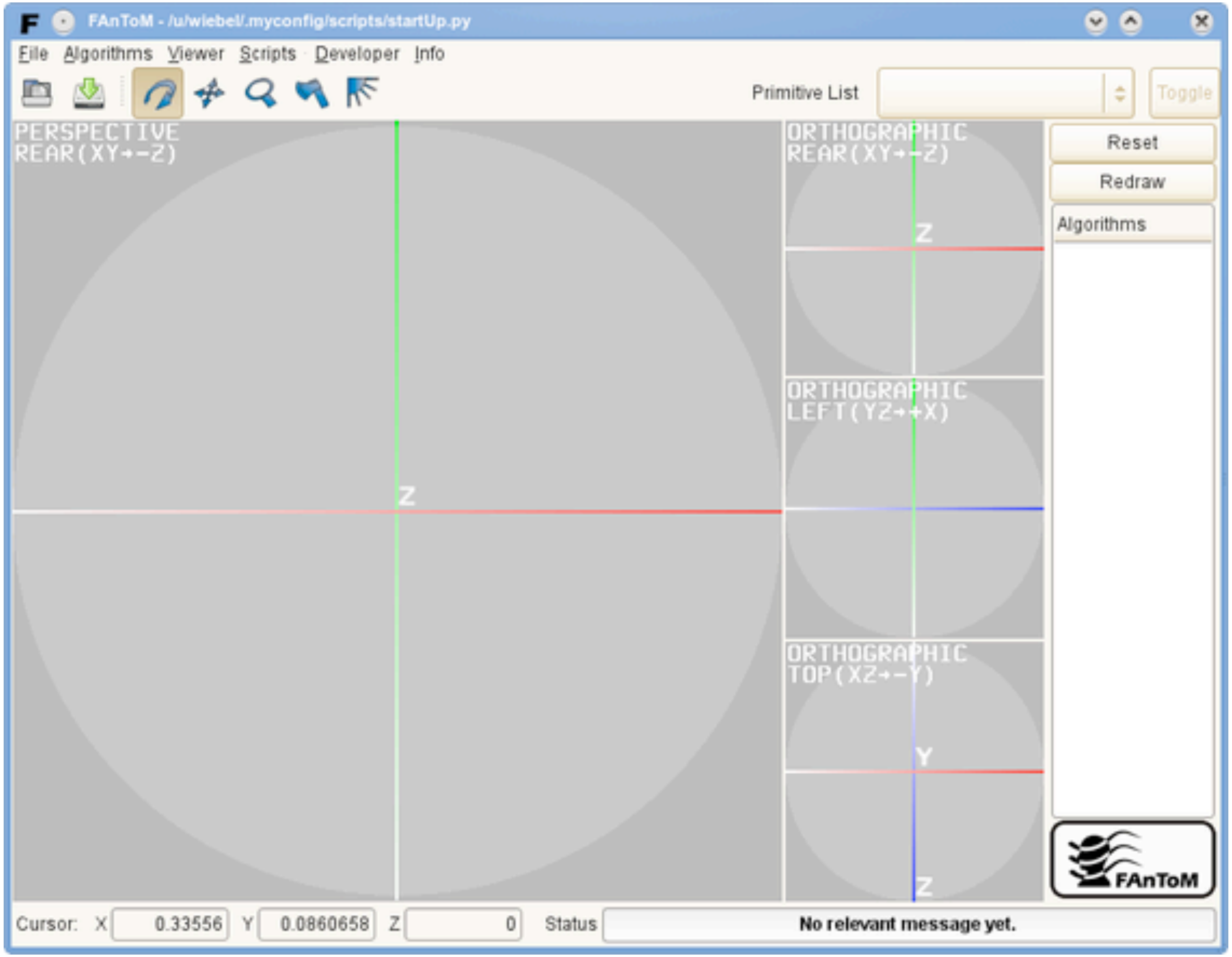
- Two kinds of elementary algorithms
  - Data algorithms
    - Transform data sets
    - Write/Re-load
  - Visualization algorithms
    - Produce graphical representations from data
- (Re)Execution explicitly controlled by user
  - Possibly by scripting engine

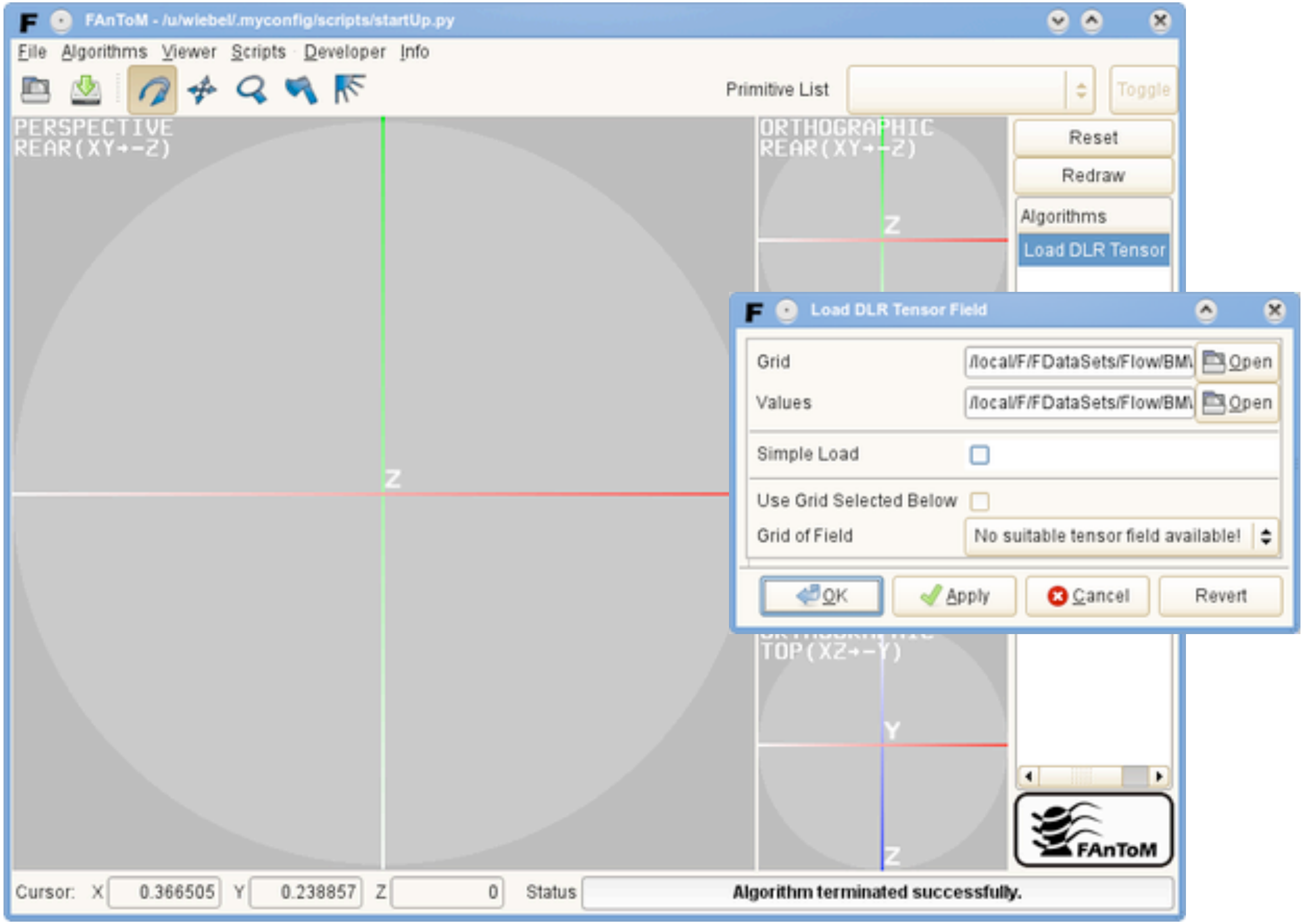
Explicit Execution Control: Advantages

- Large data sets on commodity hardware
  - Splitting of pipeline at user-define points
  - Do not need to recompute the network
- Additional flexibility
  - Increased interactivity of visualization process
- During development of new algorithms
  - Fast sanity checks

Explicit Algorithm Execution Example




FAnToM - /u/wiebel/.myconfig/scripts/startUp.py
File Algorithms Viewer Scripts Developer Info
Primitive List
Toggle
PERSPECTIVE
REAR(XY→-Z)
ORTHOGRAPHIC
REAR(XY→-Z)
ORTHOGRAPHIC
LEFT(YZ→+X)
ORTHOGRAPHIC
TOP(XZ→-Y)
Reset
Redraw
Algorithms
FAnToM
Cursor: X 0.33556 Y 0.0860658 Z 0
Status
No relevant message yet.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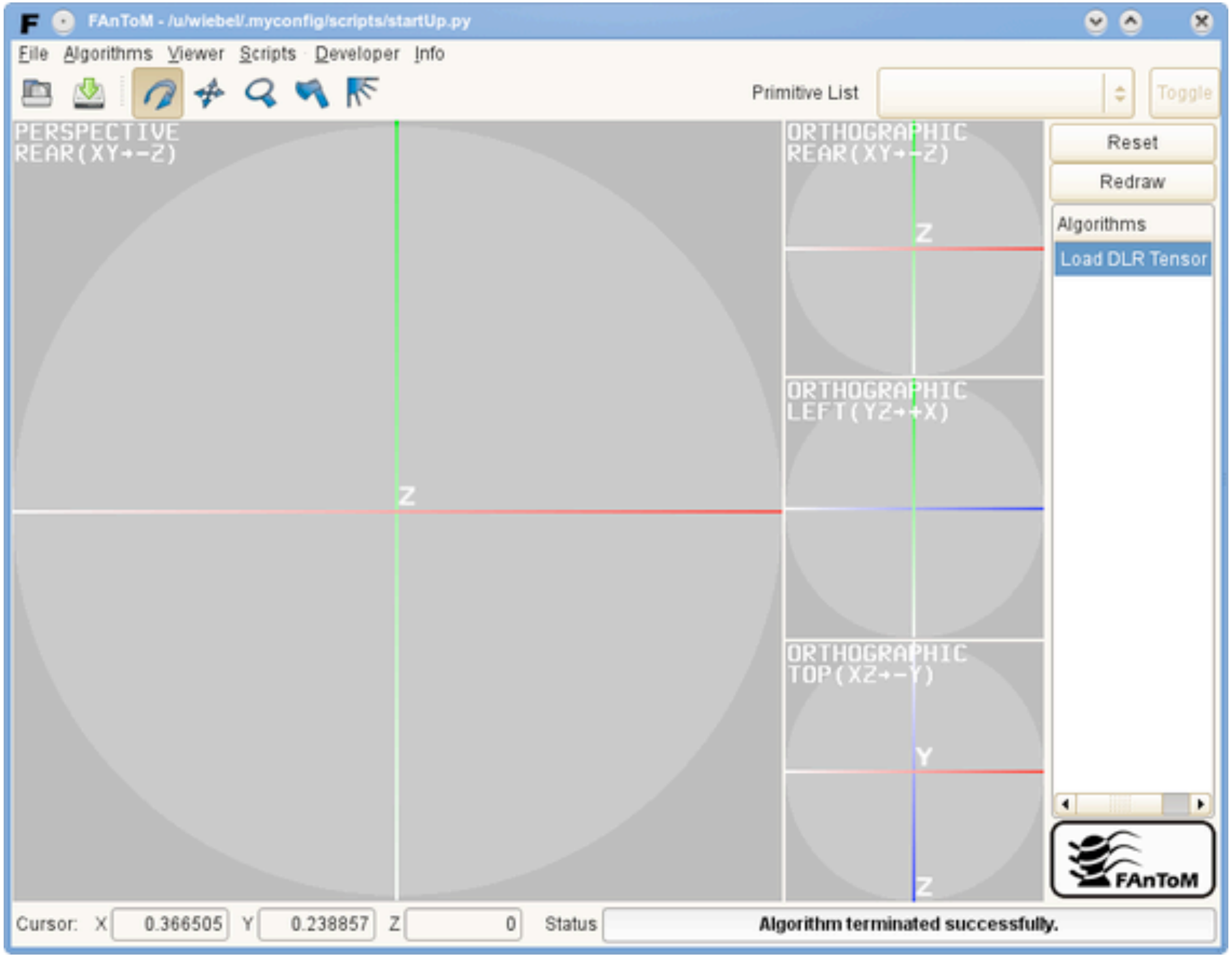
Primitive List
Toggle
PERSPECTIVE
REAR(XY→-Z)
ORTHOGRAPHIC
REAR(XY→-Z)
Reset
Redraw
Algorithms
Load DLR Tensor
Load DLR Tensor Field
Grid
/local/F/FDataSets/Flow/BM\
Open
Values
/local/F/FDataSets/Flow/BM\
Open
Simple Load
Use Grid Selected Below
Grid of Field
No suitable tensor field available!
OK
Apply
Cancel
Revert
TOP(XZ→-Y)
FAnToM
Cursor: X 0.366505 Y 0.238857 Z 0
Status
Algorithm terminated successfully.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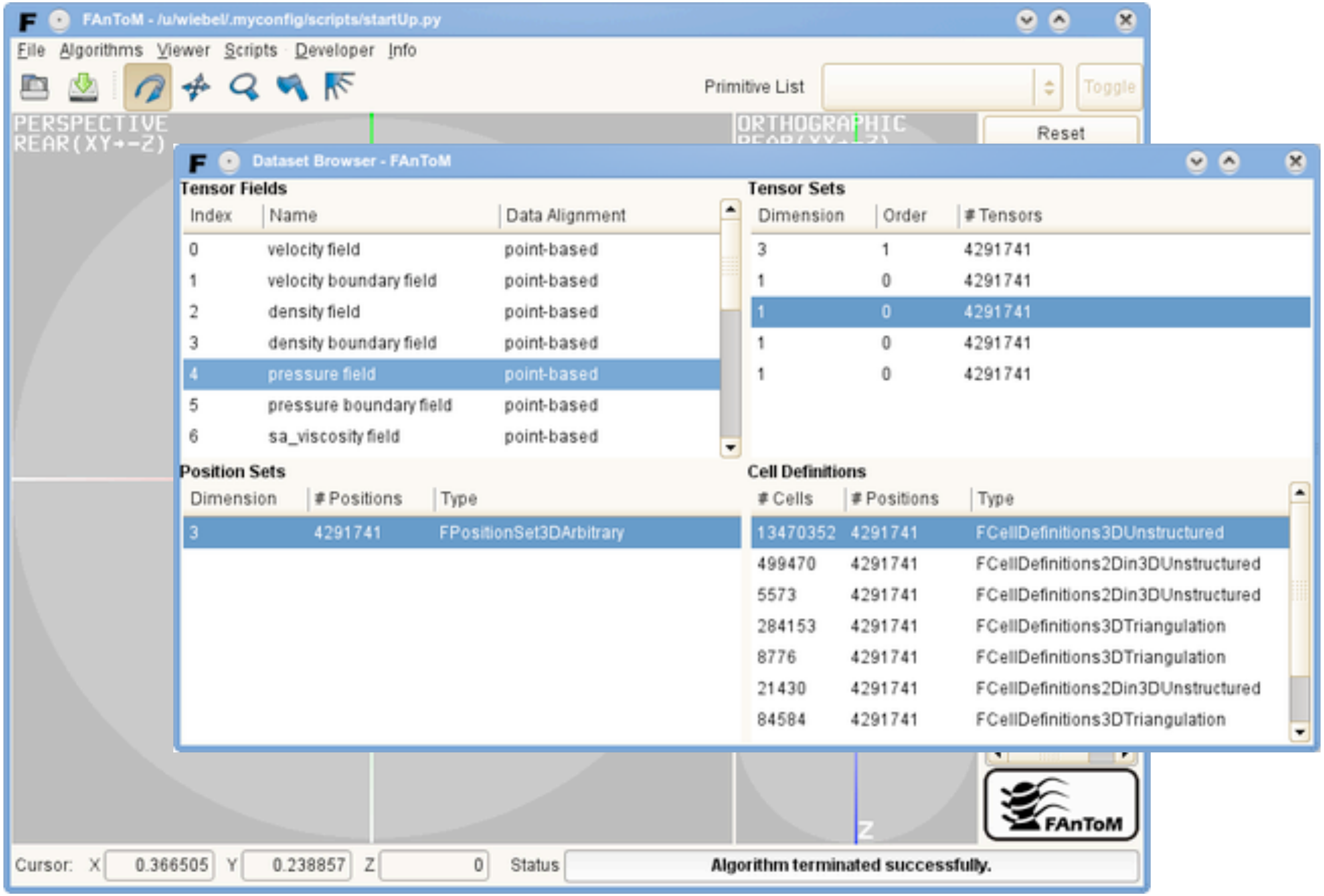
Primitive List
Toggle
PERSPECTIVE REAR(XY→-Z)
ORTHOGRAPHIC REAR(XY→-Z)
ORTHOGRAPHIC LEFT(YZ→+X)
ORTHOGRAPHIC TOP(XZ→-Y)
Reset
Redraw
Algorithms
Load DLR Tensor
FAnToM
Cursor: X 0.366505 Y 0.238857 Z 0
Status
Algorithm terminated successfully.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File Algorithms Viewer Scripts Developer Info
Primitive List
Toggle
PERSPECTIVE
REAR(XY→-Z)
ORTHOGRAPHIC
Reset
Dataset Browser - FAnToM
Tensor Fields
Index Name Data Alignment
0 velocity field point-based
1 velocity boundary field point-based
2 density field point-based
3 density boundary field point-based
4 pressure field point-based
5 pressure boundary field point-based
6 sa_viscosity field point-based
Tensor Sets
Dimension Order # Tensors
3 1 4291741
1 0 4291741
1 0 4291741
1 0 4291741
1 0 4291741
Position Sets
Dimension # Positions Type
3 4291741 FPositionSet3DArbitrary
Cell Definitions
Cells # Positions Type
13470352 4291741 FCellDefinitions3DUnstructured
499470 4291741 FCellDefinitions2Din3DUnstructured
5573 4291741 FCellDefinitions2Din3DUnstructured
284153 4291741 FCellDefinitions3DTriangulation
8776 4291741 FCellDefinitions3DTriangulation
21430 4291741 FCellDefinitions2Din3DUnstructured
84584 4291741 FCellDefinitions3DTriangulation
FAnToM
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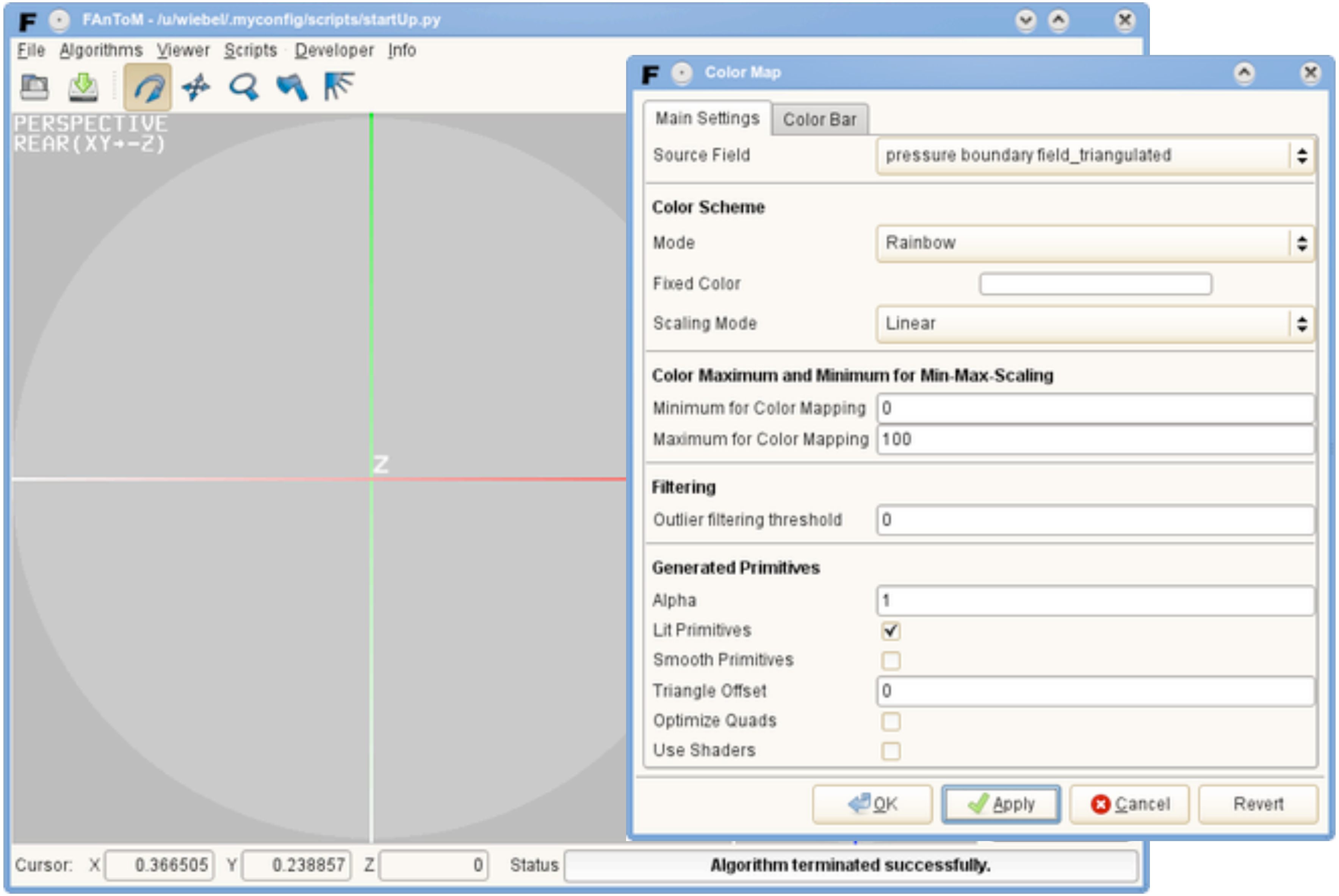
Status Algorithm terminated successfully.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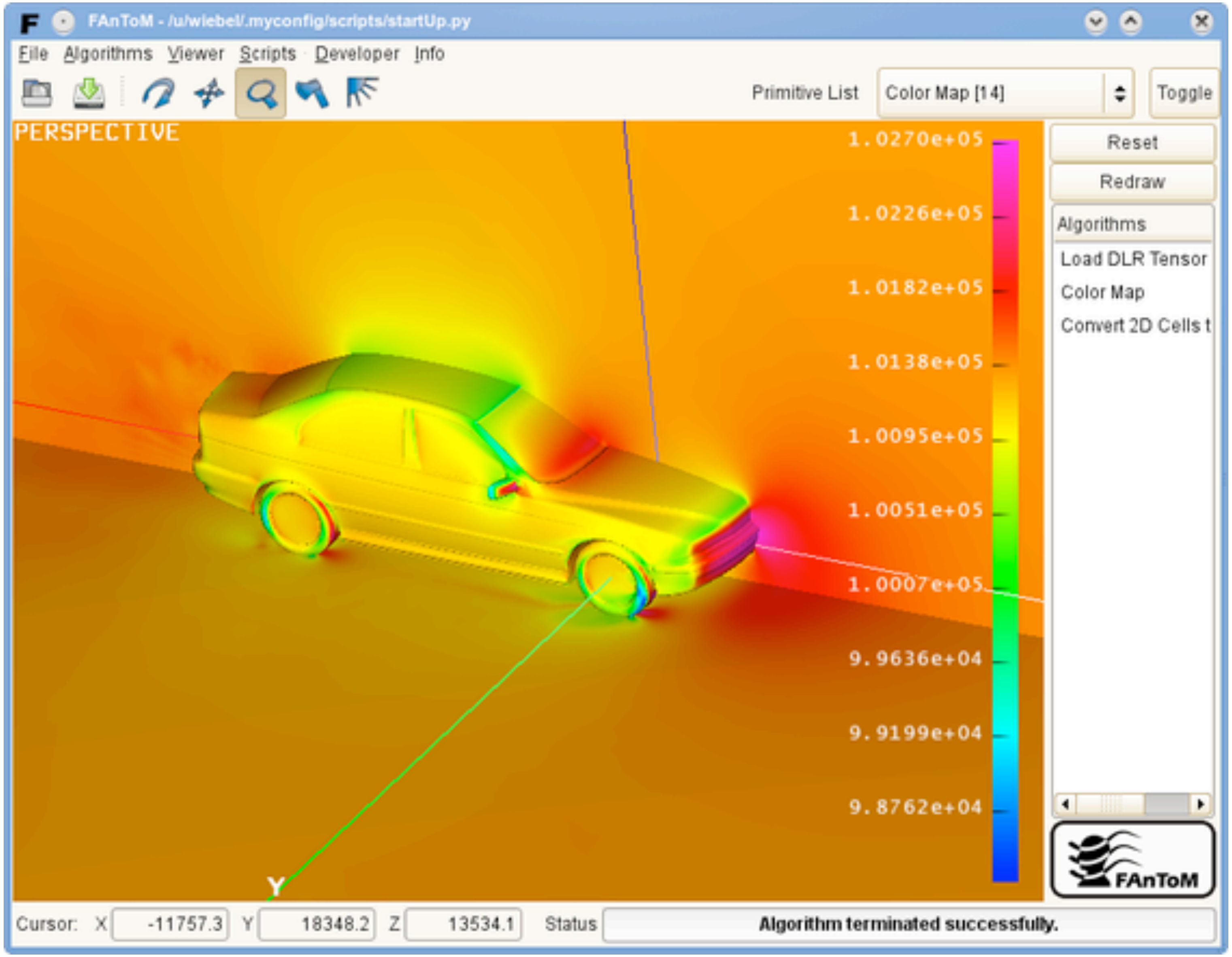
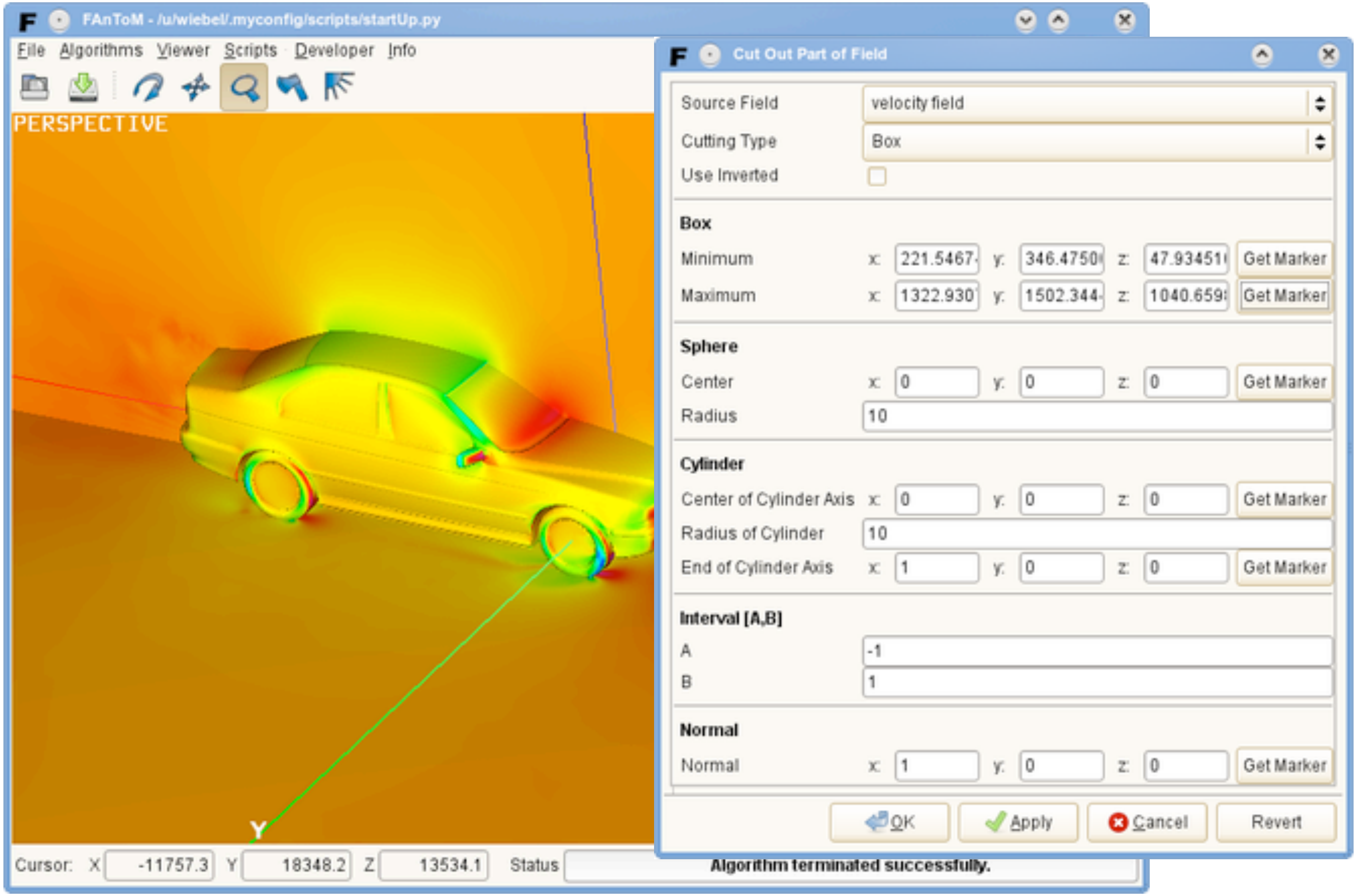
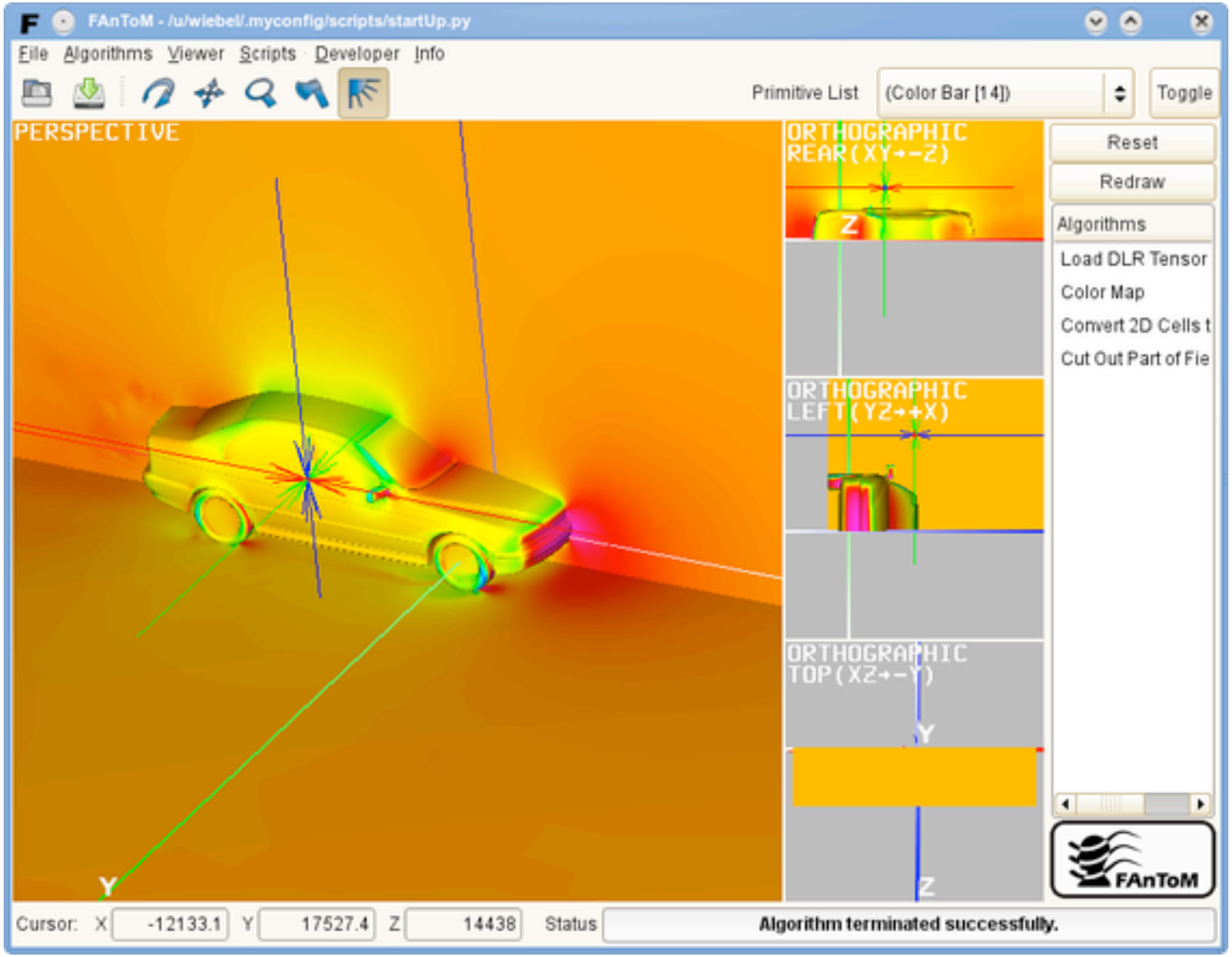
File Algorithms Viewer Scripts Developer Info
PERSPECTIVE
REAR(XY→-Z)
Z
Cursor: X 0.366505 Y 0.238857 Z 0 Status Algorithm terminated successfully.
Color Map
Main Settings Color Bar
Source Field pressure boundary field_triangulated
Color Scheme
Mode Rainbow
Fixed Color
Scaling Mode Linear
Color Maximum and Minimum for Min-Max-Scaling
Minimum for Color Mapping 0
Maximum for Color Mapping 100
Filtering
Outlier filtering threshold 0
Generated Primitives
Alpha 1
Lit Primitives
Smooth Primitives
Triangle Offset 0
Optimize Quads
Use Shaders
OK Apply Cancel Revert


FAnToM - /u/wiebel/.myconfig/scripts/startUp.py
File Algorithms Viewer Scripts Developer Info
Primitive List
Color Map [14]
Toggle
PERSPECTIVE
1.0270e+05
1.0226e+05
1.0182e+05
1.0138e+05
1.0095e+05
1.0051e+05
1.0007e+05
9.9636e+04
9.9199e+04
9.8762e+04
Y
Reset
Redraw
Algorithms
Load DLR Tensor
Color Map
Convert 2D Cells t
FAnToM
Cursor: X -11757.3 Y 18348.2 Z 13534.1
Status Algorithm terminated successfully.


FAnToM - /u/wiebel/.myconfig/scripts/startUp.py
File Algorithms Viewer Scripts Developer Info
PERSPECTIVE
Cursor: X -11757.3 Y 18348.2 Z 13534.1 Status Algorithm terminated successfully.
Cut Out Part of Field
Source Field velocity field
Cutting Type Box
Use Inverted
Box
Minimum x: 221.5467 y: 346.4750 z: 47.93451 Get Marker
Maximum x: 1322.930 y: 1502.344 z: 1040.659 Get Marker
Sphere
Center x: 0 y: 0 z: 0 Get Marker
Radius 10
Cylinder
Center of Cylinder Axis x: 0 y: 0 z: 0 Get Marker
Radius of Cylinder 10
End of Cylinder Axis x: 1 y: 0 z: 0 Get Marker
Interval [A,B]
A -1
B 1
Normal
Normal x: 1 y: 0 z: 0 Get Marker
OK Apply Cancel Revert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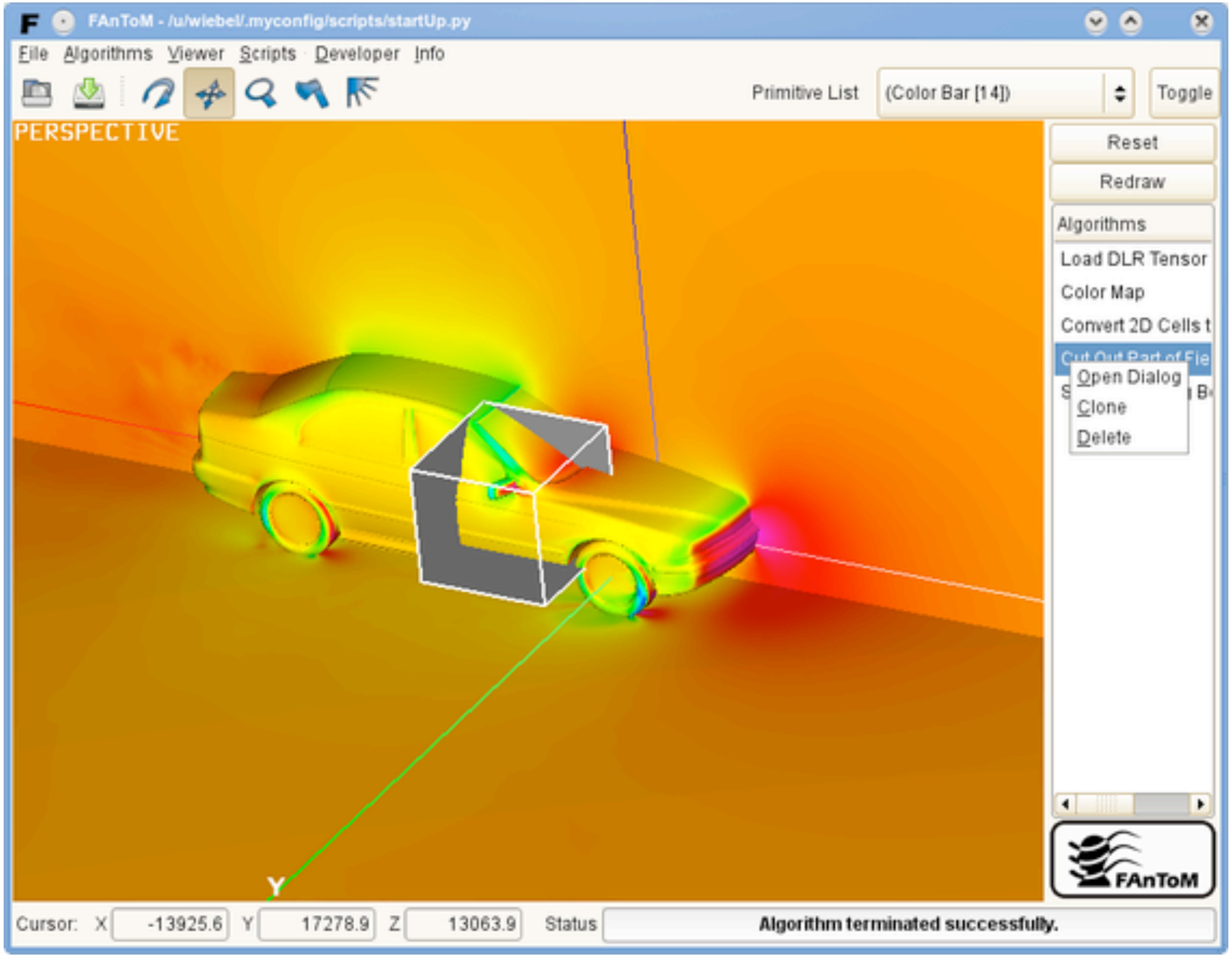
Primitive List
(Color Bar [14])
Toggle
PERSPECTIVE
ORTHOGRAPHIC REAR(XY→-Z)
ORTHOGRAPHIC LEFT(YZ→+X)
ORTHOGRAPHIC TOP(XZ→-Y)
Reset
Redraw
Algorithms
Load DLR Tensor
Color Map
Convert 2D Cells t
Cut Out Part of Fie
FAnToM
Cursor: X -12133.1 Y 17527.4 Z 14438 Status
Algorithm terminated successfully.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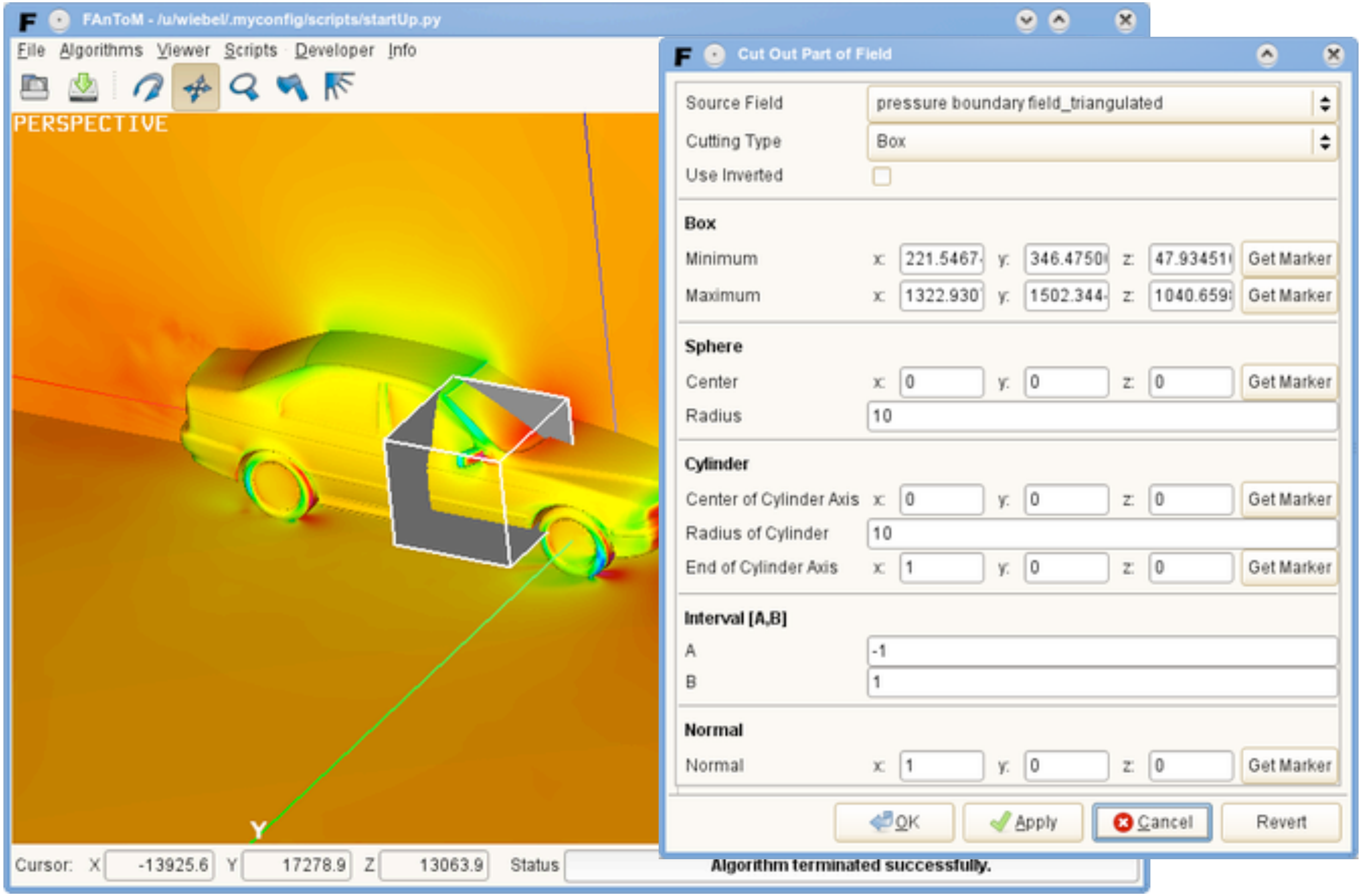
File Algorithms Viewer Scripts Developer Info
Primitive List
(Color Bar [14])
Toggle
PERSPECTIVE
Reset
Redraw
Algorithms
Load DLR Tensor
Color Map
Convert 2D Cells t
Open Dialog
Clone
Delete
FAnToM
Cursor: X -13925.6 Y 17278.9 Z 13063.9 Status
Algorithm terminated successfully.


FAnToM - /u/wiebel/.myconfig/scripts/startUp.py
File Algorithms Viewer Scripts Developer Info
PERSPECTIVE
Y
Cursor: X -13925.6 Y 17278.9 Z 13063.9 Status
Algorithm terminated successfully.
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Minimum x: 221.5467 y: 346.4750 z: 47.93451 Get Marker
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Cylinder
Center of Cylinder Axis x: 0 y: 0 z: 0 Get Marker
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End of Cylinder Axis x: 1 y: 0 z: 0 Get Marker
Interval [A,B]
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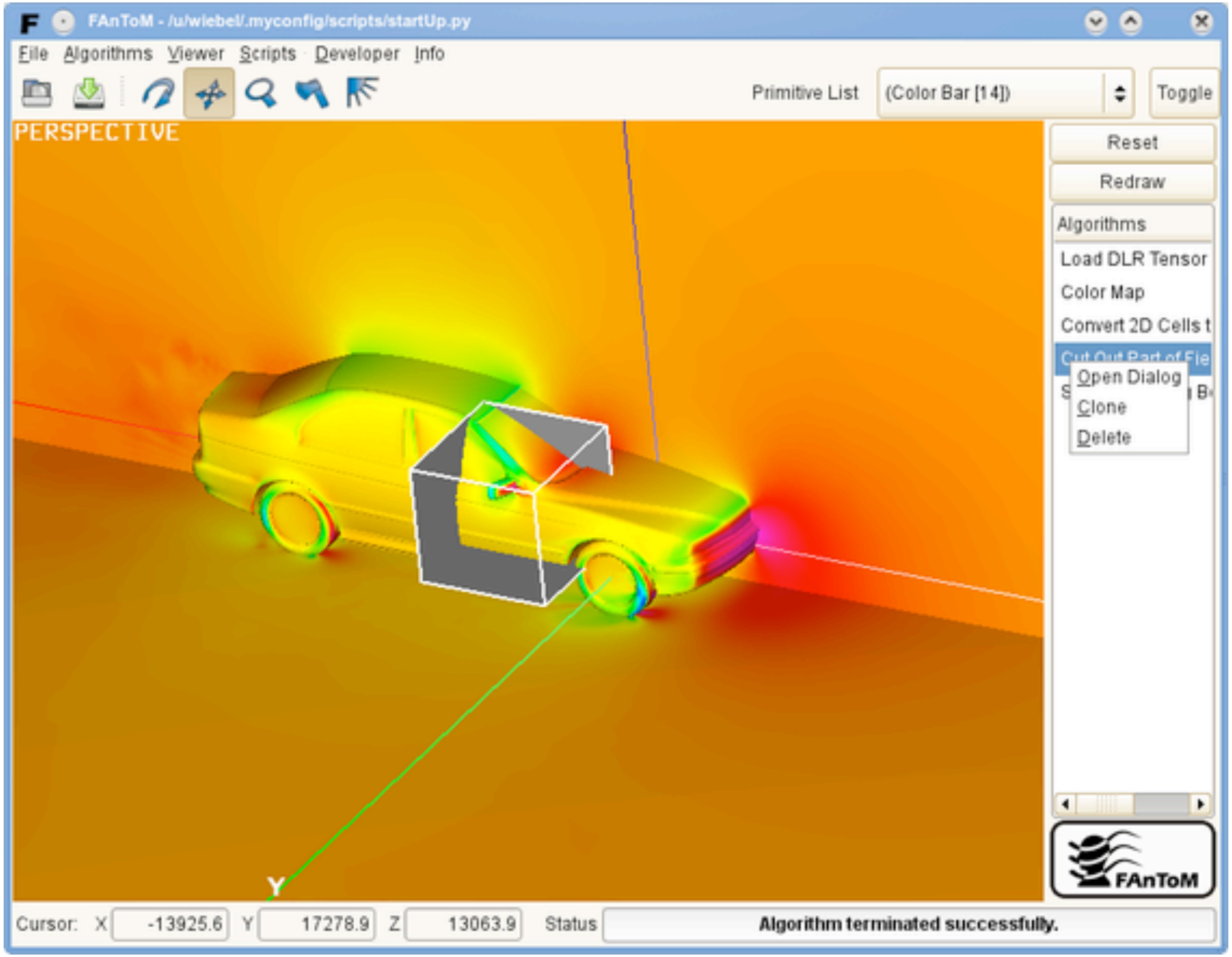
B 1
Normal
Normal x: 1 y: 0 z: 0 Get Marker
OK Apply Cancel Revert



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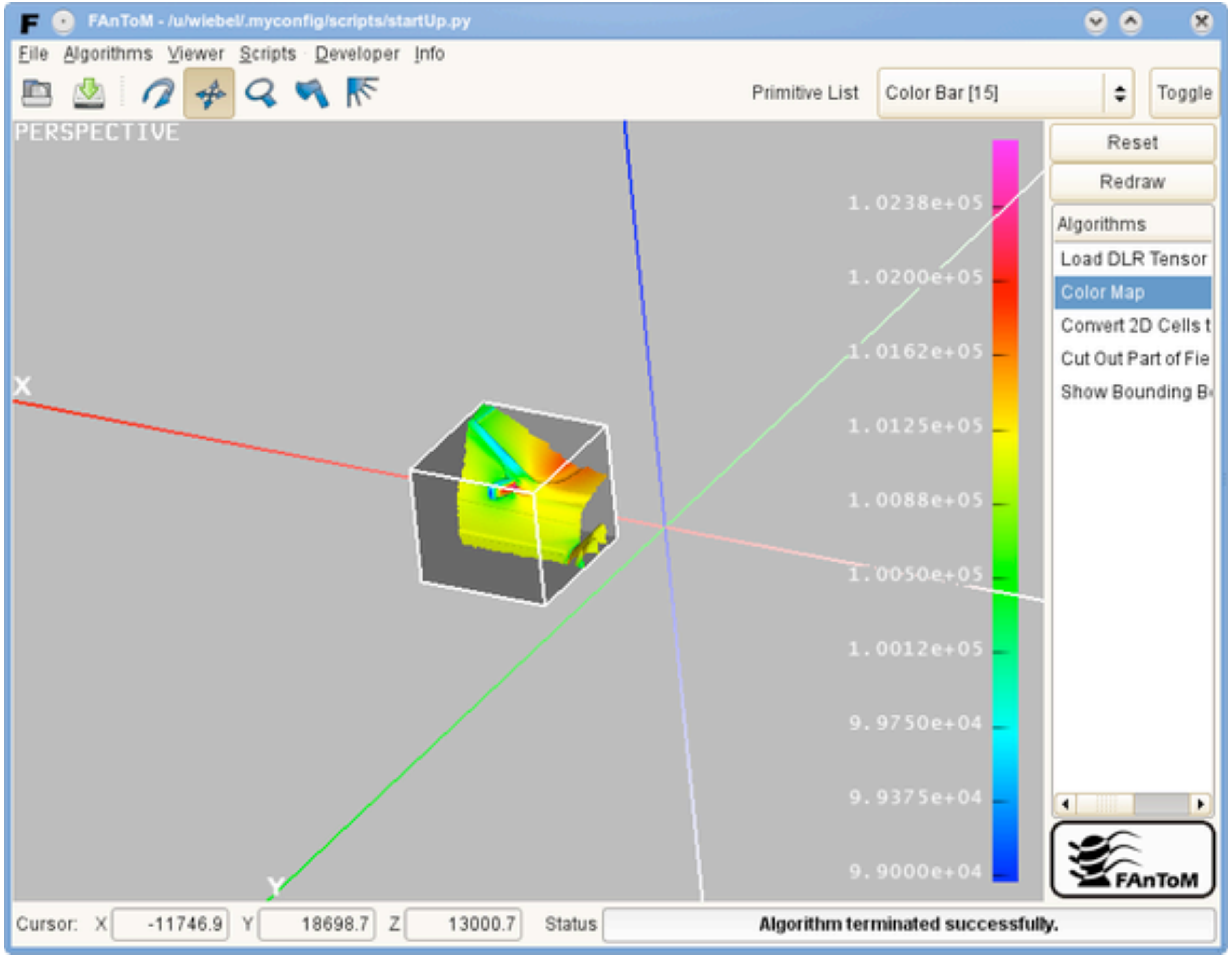
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Color Bar [15]
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Cut Out Part of Fie
Show Bounding B
1.0238e+05
1.0200e+05
1.0162e+05
1.0125e+05
1.0088e+05
1.0050e+05
1.0012e+05
9.9750e+04
9.9375e+04
9.9000e+04
X
Y
FAnToM
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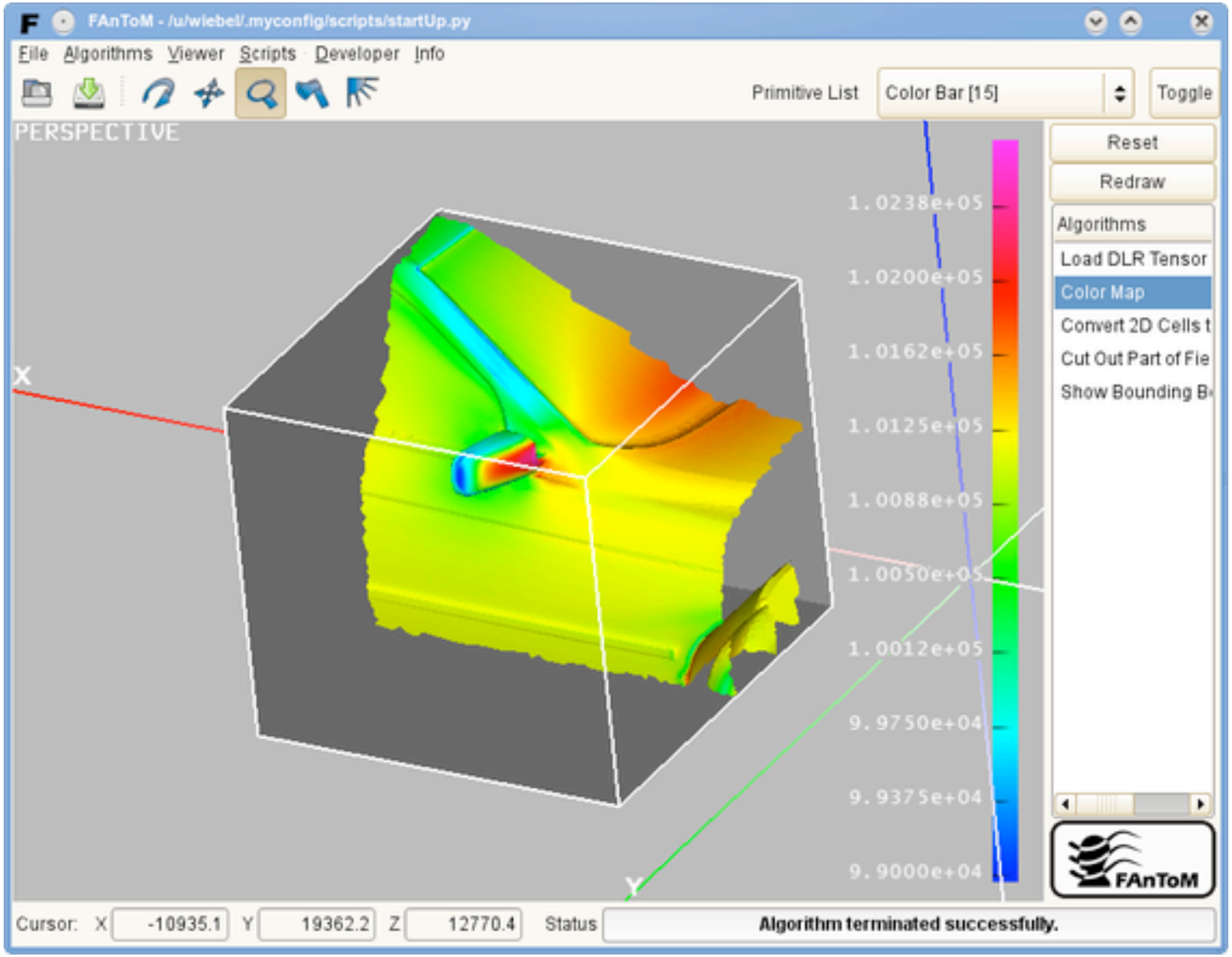
Status Algorithm terminated successfully.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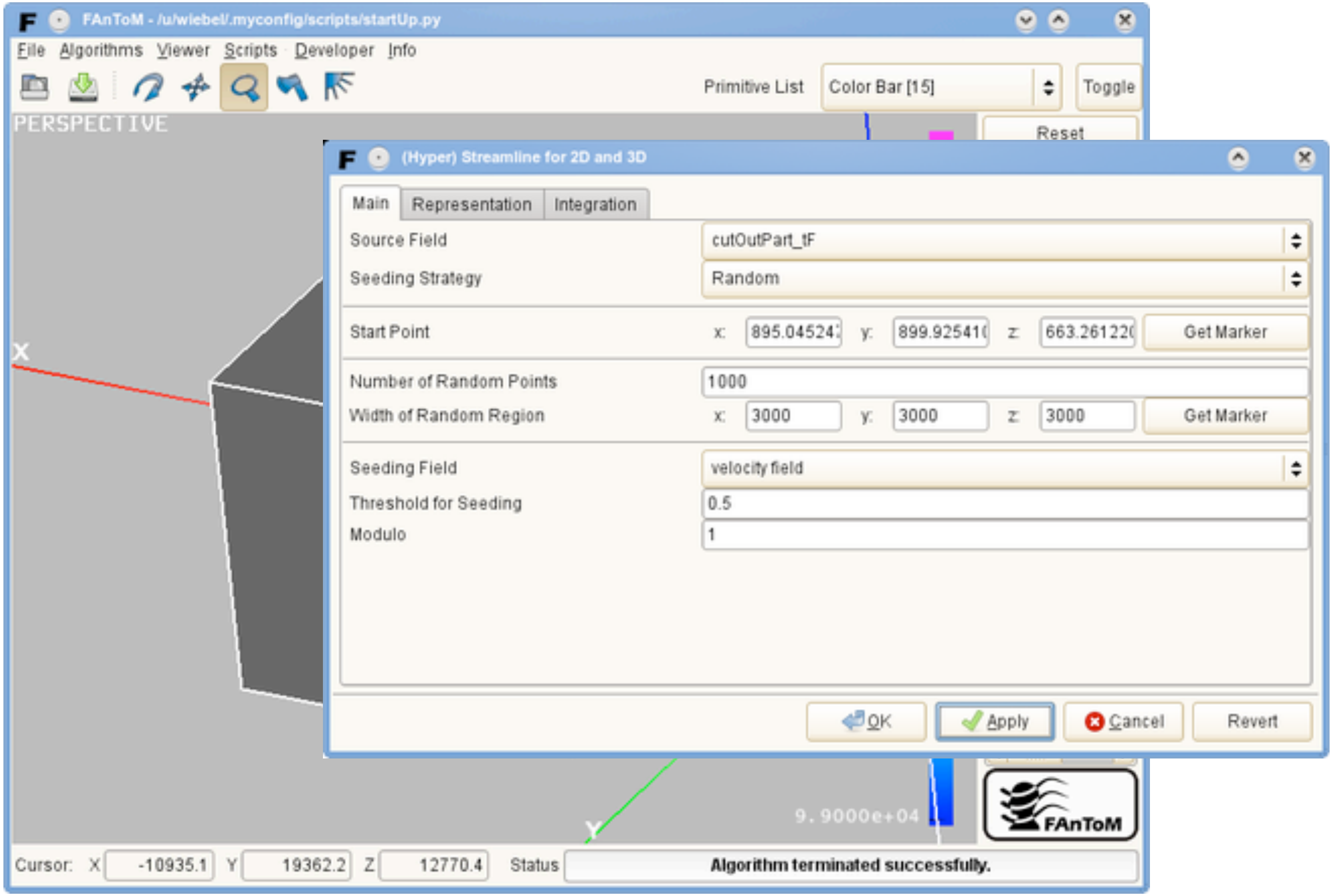
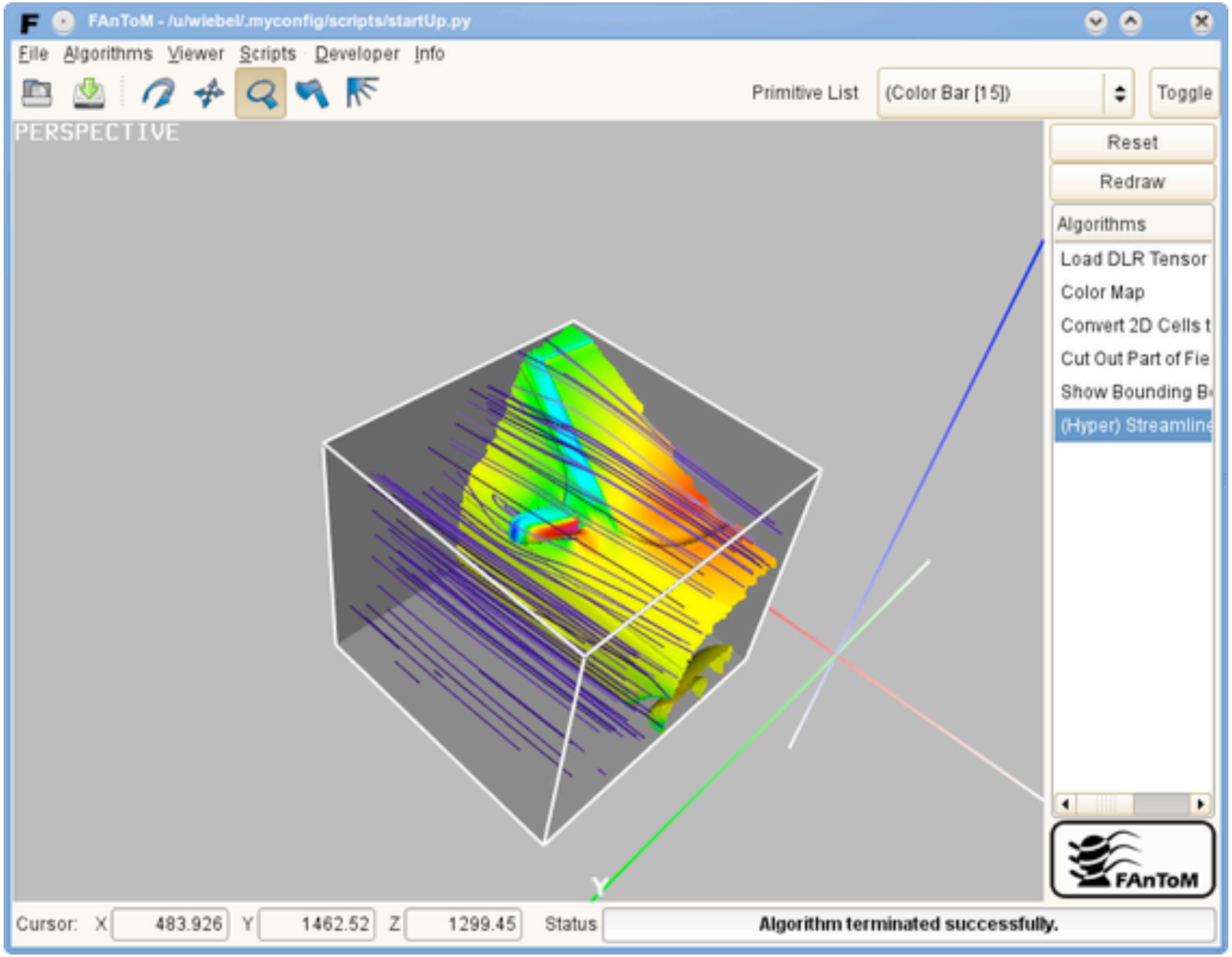
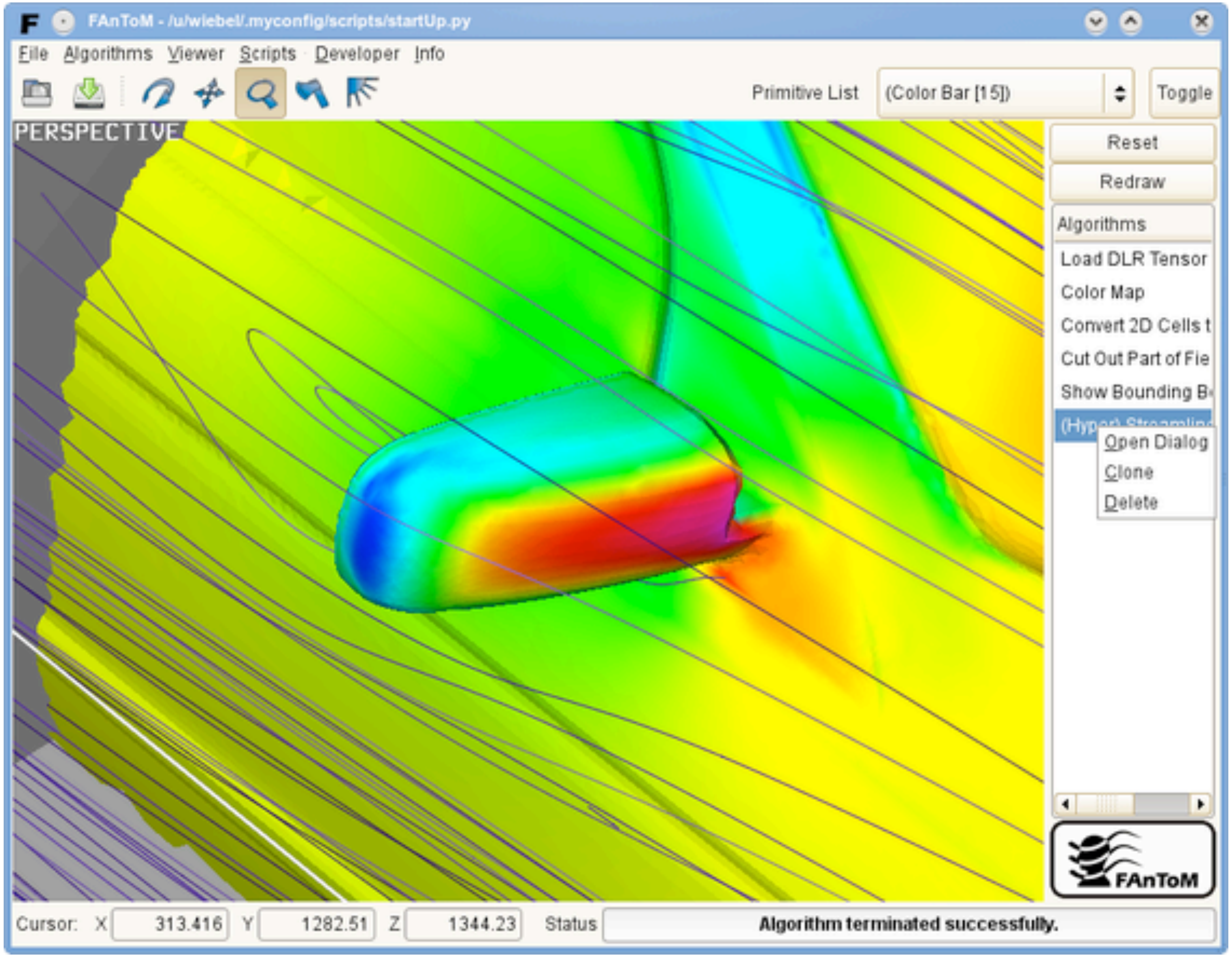
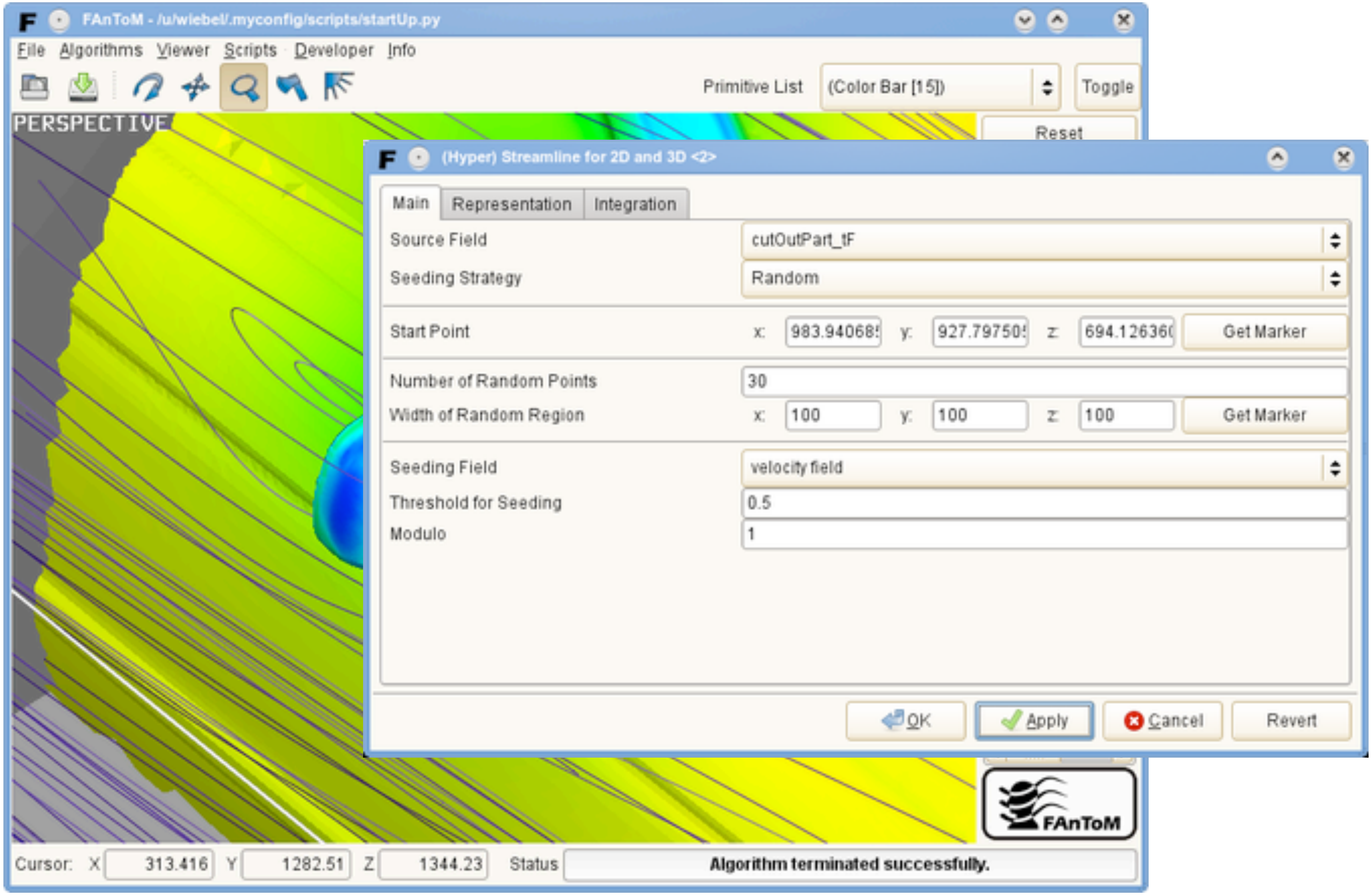
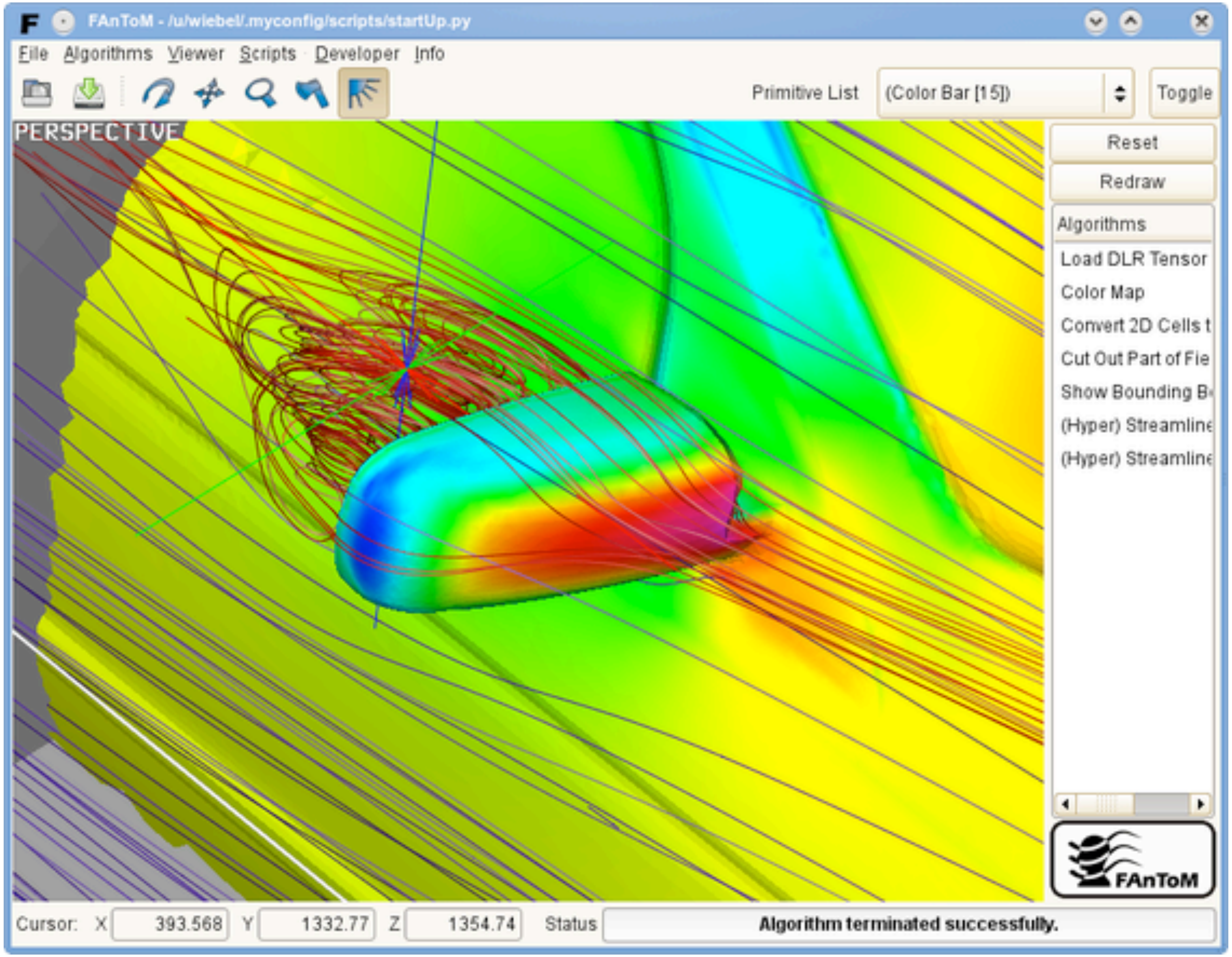
1.0162e+05
1.0125e+05
1.0088e+05
1.0050e+05
1.0012e+05
9.9750e+04
9.9375e+04
9.9000e+04
X
Y
FAnToM
Cursor: X -10935.1 Y 19362.2 Z 12770.4 Status
Algorithm terminated successfully.


FAnToM - /u/wiebel/.myconfig/scripts/startUp.py
File Algorithms Viewer Scripts Developer Info
Primitive List
Color Bar [15]
Toggle
Reset
PERSPECTIVE
(Hyper) Streamline for 2D and 3D
Main
Representation
Integration
Source Field
cutOutPart_tF
Seeding Strategy
Random
Start Point
Get Marker
Number of Random Points
1000
Width of Random Region
3000
Seeding Field
velocity field
Threshold for Seeding
0.5
Modulo
1
OK
Apply
Cancel
Revert
9.9000e+04
FAnToM
Cursor:
-10935.1
19362.2
12770.4
Status
Algorithm terminated successfully.

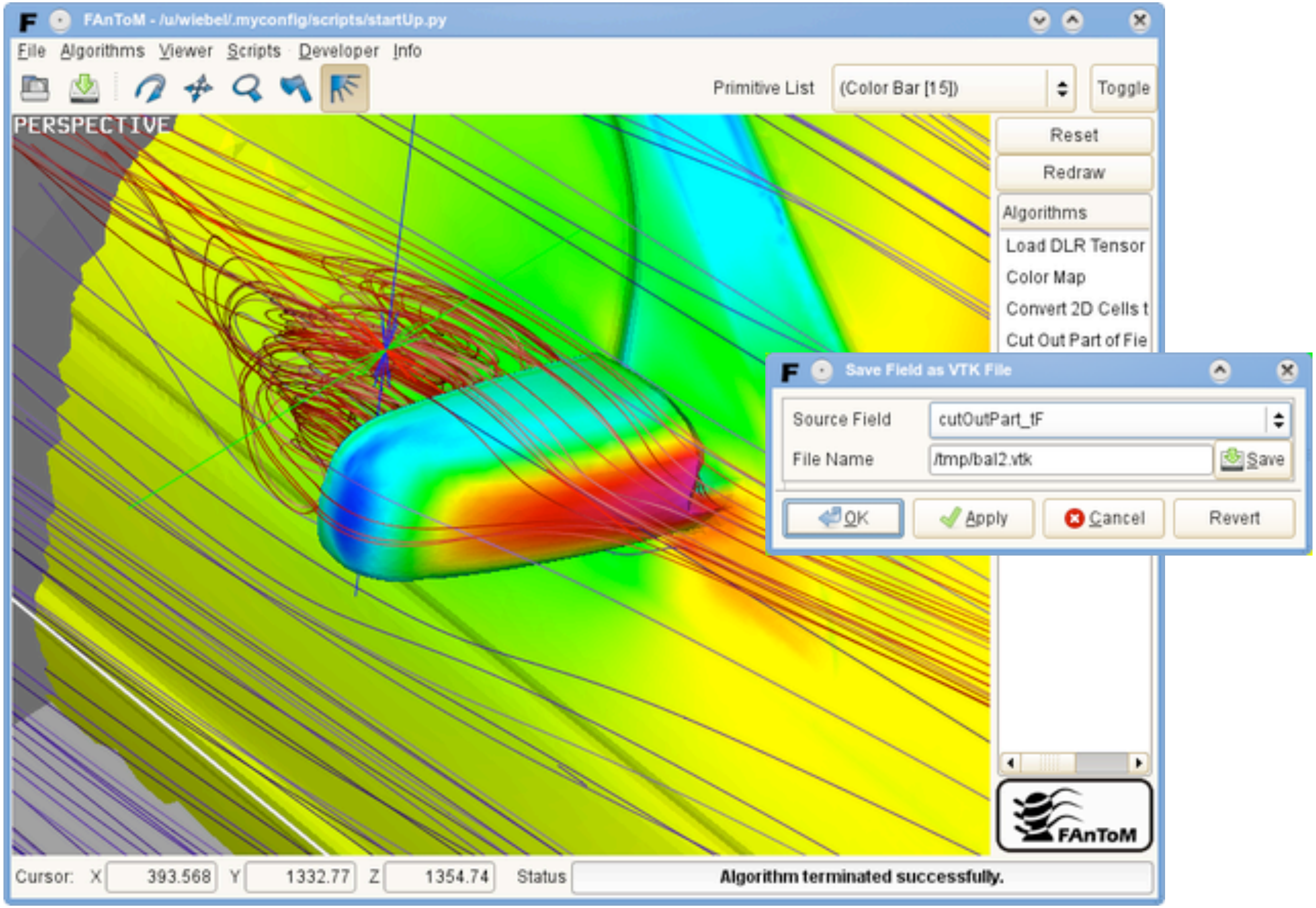

FAnToM - /u/wiebel/.myconfig/scripts/startUp.py
File Algorithms Viewer Scripts Developer Info
Primitive List
(Color Bar [15])
Toggle
PERSPECTIVE
Reset
Redraw
Algorithms
Load DLR Tensor
Color Map
Convert 2D Cells t
Cut Out Part of Fie
Show Bounding B
(Hyper) Streamline
FAnToM
Cursor: X 483.926 Y 1462.52 Z 1299.45 Status
Algorithm terminated successfully.

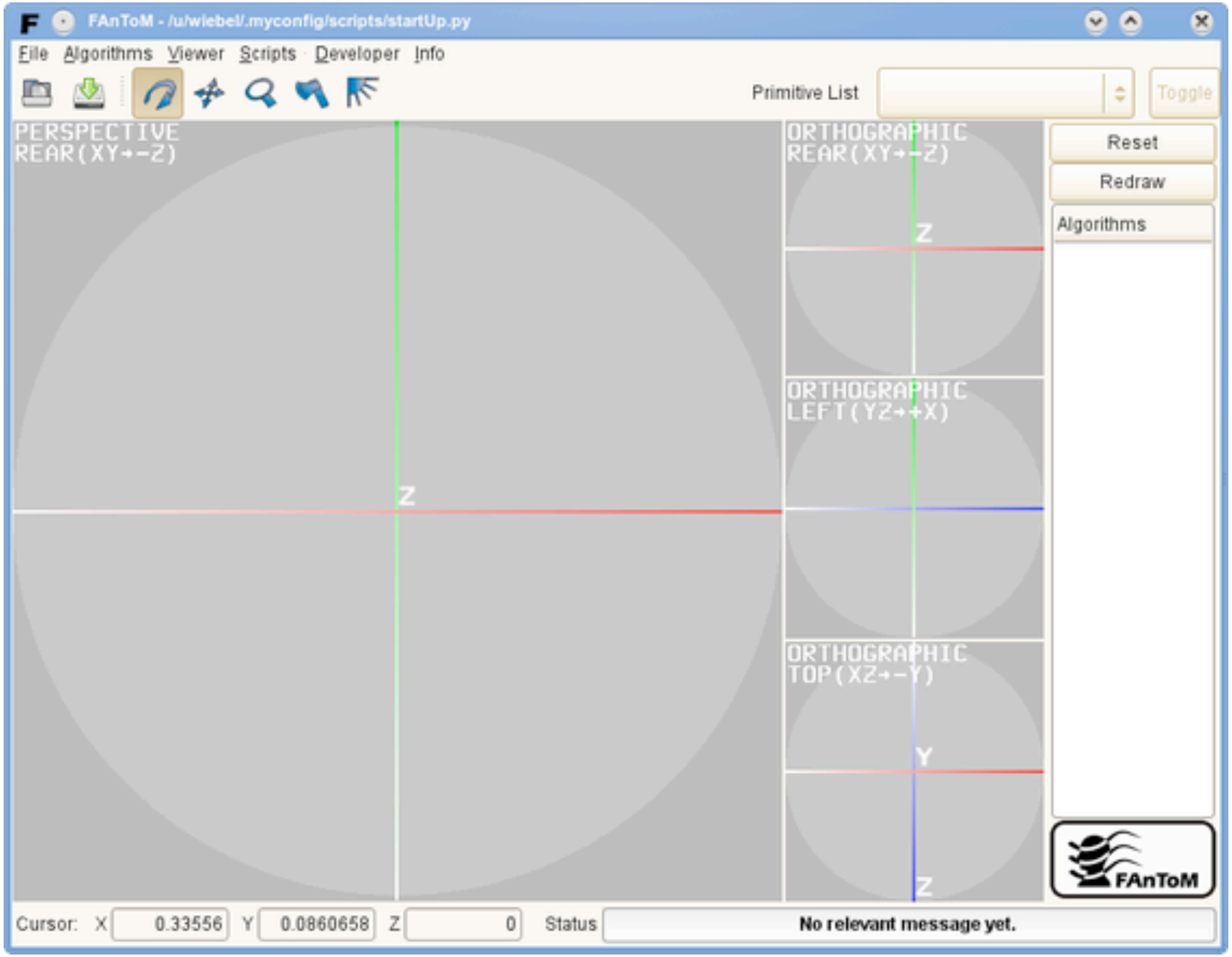

FAnToM - /u/wiebel/.myconfig/scripts/startUp.py
File Algorithms Viewer Scripts Developer Info
Primitive List
(Color Bar [15])
Toggle
PERSPECTIVE
Reset
Redraw
Algorithms
Load DLR Tensor
Color Map
Convert 2D Cells t
Cut Out Part of Fie
Show Bounding B
Open Dialog
Clone
Delete
FAnToM
Cursor: X 313.416 Y 1282.51 Z 1344.23 Status
Algorithm terminated successfully.

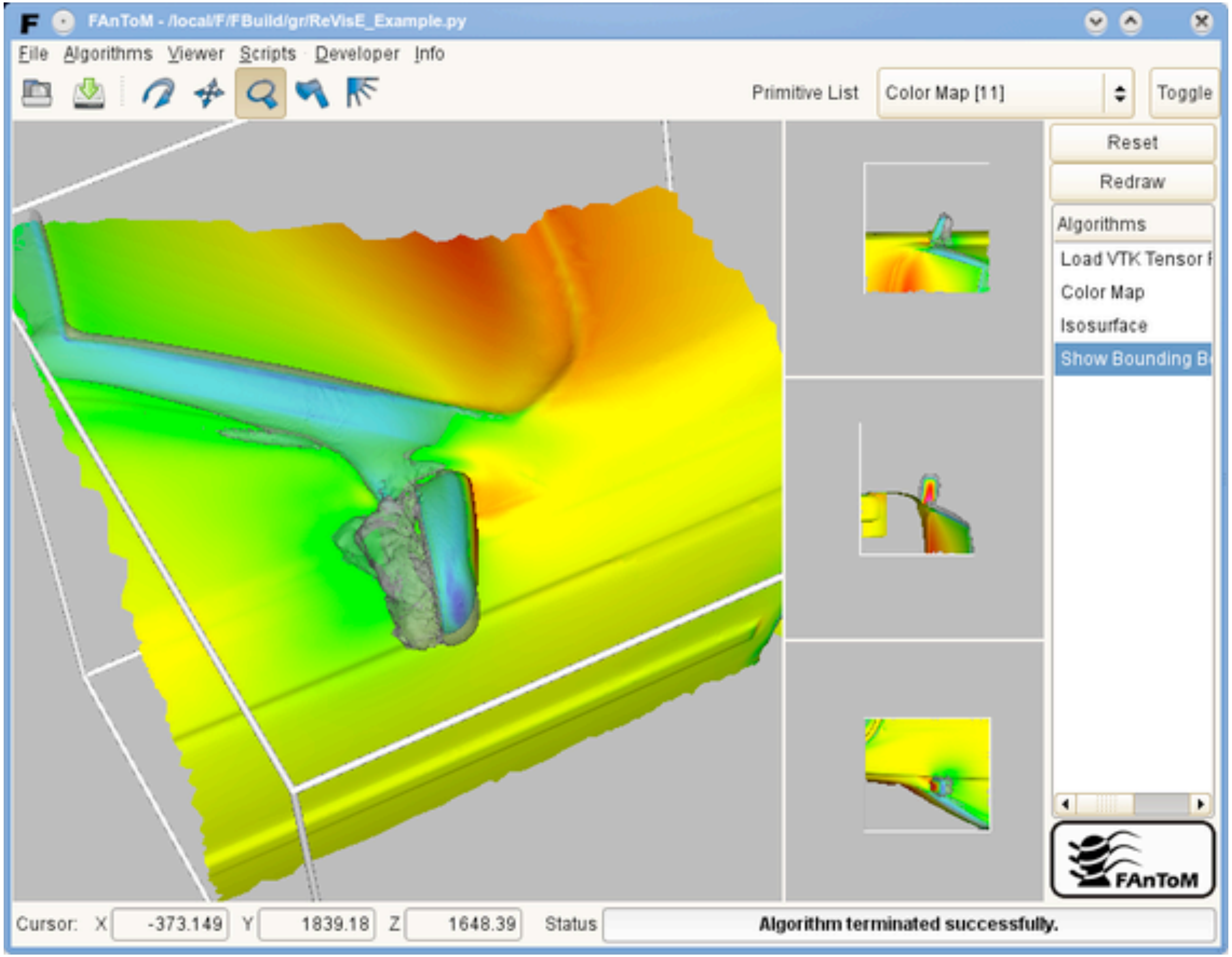

FAnToM - /u/wiebel/.myconfig/scripts/startUp.py
File Algorithms Viewer Scripts Developer Info
Primitive List
(Color Bar [15])
Toggle
PERSPECTIVE
Reset
(Hyper) Streamline for 2D and 3D <2>
Main
Representation
Integration
Source Field
cutOutPart_tF
Seeding Strategy
Random
Start Point
983.94068
927.79750
694.12636
Get Marker
Number of Random Points
30
Width of Random Region
100
100
100
Get Marker
Seeding Field
velocity field
Threshold for Seeding
0.5
Modulo
1
OK
Apply
Cancel
Revert
FAnToM
Cursor: X 313.416 Y 1282.51 Z 1344.23
Status
Algorithm terminated successfully.



Montag, 12. Oktober 2009


FAnToM - /u/wiebel/.myconfig/scripts/startUp.py
File Algorithms Viewer Scripts Developer Info
Primitive List
(Color Bar [15])
Toggle
PERSPECTIVE
Reset
Redraw
Algorithms
Load DLR Tensor
Color Map
Convert 2D Cells t
Cut Out Part of Fie
Save Field as VTK File
Source Field
cutOutPart_tF
File Name
/tmp/bal2.vtk
Save
OK
Apply
Cancel
Revert
FAnToM
Cursor: X 393.568 Y 1332.77 Z 1354.74 Status
Algorithm terminated successfully.


FAnToM - /u/wiebel/.myconfig/scripts/startUp.py
File Algorithms Viewer Scripts Developer Info
Primitive List
Toggle
PERSPECTIVE
REAR(XY→-Z)
ORTHOGRAPHIC
REAR(XY→-Z)
ORTHOGRAPHIC
LEFT(YZ→+X)
ORTHOGRAPHIC
TOP(XZ→-Y)
Reset
Redraw
Algorithms
FAnToM
Cursor: X 0.33556 Y 0.0860658 Z 0
Status
No relevant message yet.


FAnToM - /local/F/FBuild/gr/ReVisE_Example.py
File Algorithms Viewer Scripts Developer Info
Primitive List
Color Map [11]
Toggle
Reset
Redraw
Algorithms
Load VTK Tensor F
Color Map
Isosurface
Show Bounding Bo
FAnToM
Cursor: X -373.149 Y 1839.18 Z 1648.39
Status
Algorithm terminated successfully.

Integration of New and Established Visualization Techniques

- Application scientist trust their methods
  - Understand them (e.g. mathematically)
  - Often yielded valid results
- They distrust new methods

Integration of New and Established Visualization Techniques

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- Present new methods together with well-established ones
- User may gain confidence in new method
- User will learn to use new methods faster in known context

Conclusion

- Good performance handling of large unstructured data on commodity hardware by
  - Small memory footprint data structure
  - Efficient point location
  - Explicit algorithm execution model

- Provide well-known techniques together with new ones

Acknowledgements

- Developers in Leipzig, Kaiserslautern and the USA
  - Active Developers: *Dominic Schneider, Wieland Reich, Clemens Fritzsch, Cornelius Müller, Mario Hlawitschka, Markus Rohrschneider, Mathias Goldau, Patrick Oesterling, Christoph Garth, Alexander Wiebel, Sebastian Eichelbaum, Xavier Tricoche*
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MAX PLANCK INSTITUTE FOR HUMAN COGNITIVE AND BRAIN SCIENCES LEIPZIG

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Image and Signal Processing
University of Leipzig

Gerik Scheuermann

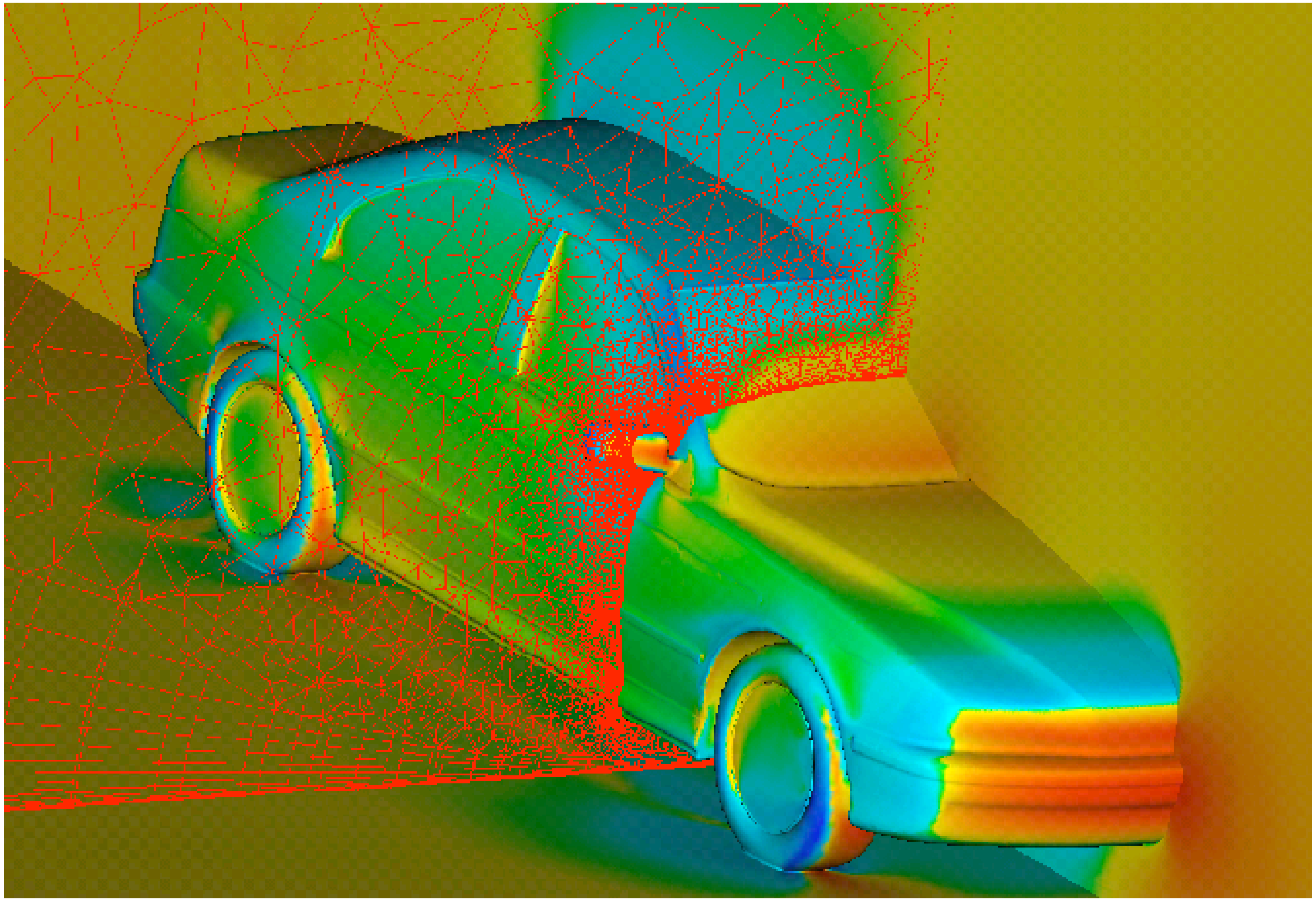
IDAV Institute for Data Analysis and Visualization

Christoph Garth
Mario Hlawitschka

Advanced Visual Data Analysis
Wright State University

Thomas Wischgoll

Local Adaptive Refinement of Mesh



Taken from [LST2003]

Cell Location at Boundary

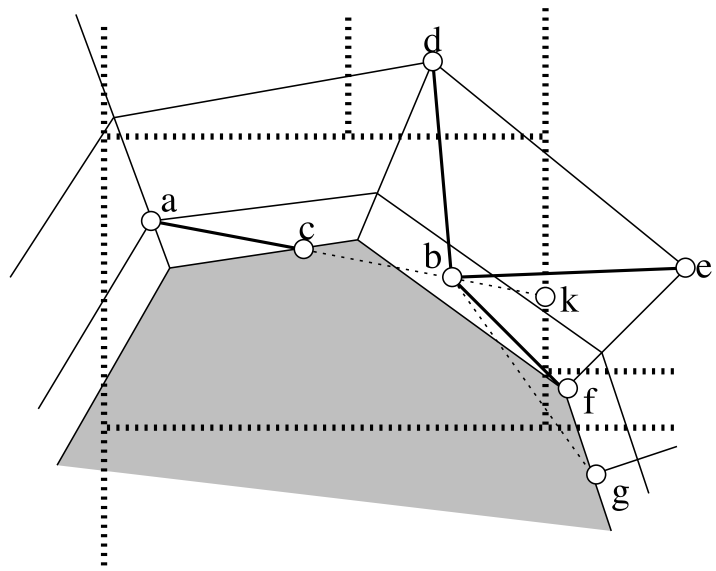


Figure 3: search ray started at vertex a to find cell for point b hits the boundary at c, kdtree leaf face k is cut in elongation of search ray and alternative search rays can be started from vertices d-g , which lie in kdtree leaves neighboring to k, and the ray from d finds the correct answer

Taken from [LST2003]

Performance of Point Location Infrastructure

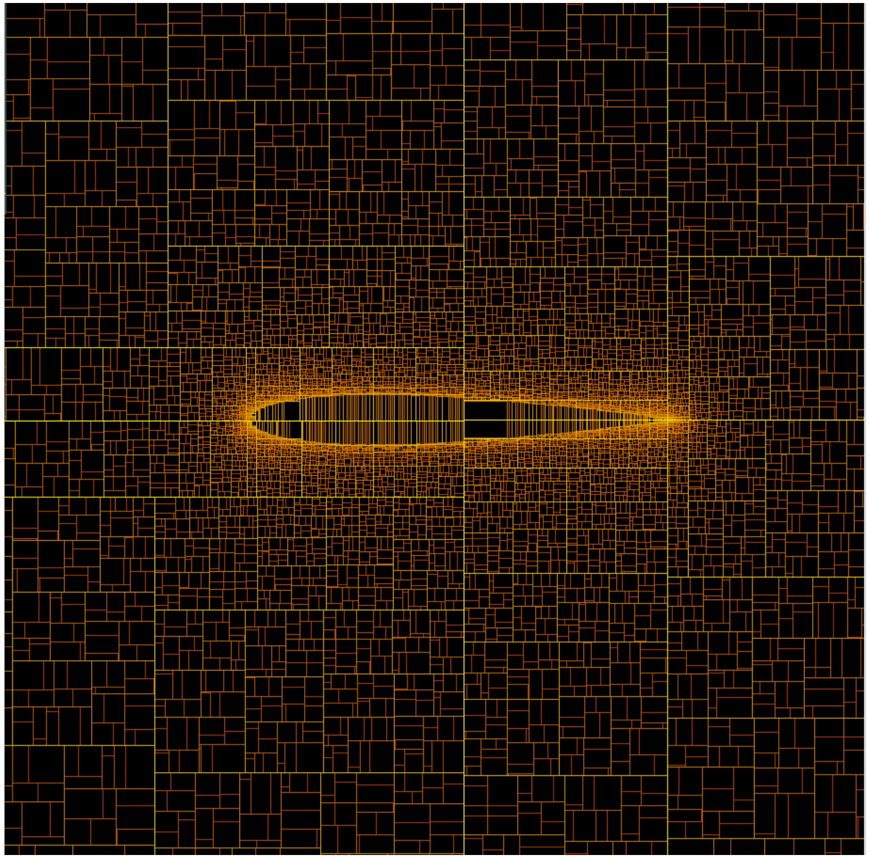
Dataset	NACA	GBK	ICE	DELTA	F6	BMW
Number of points	24K	32K	1.0M	1.9M	3.6M	4.3M
Number of cells	38K	174K	2.6M	6.3M	8.4M	13.5M
Tetrahedrons	-	174K	0.9M	3.9M	2.2M	7.8M
Prisms	-	-	1.7M	2.4M	6.2M	5.6M
Pyramids	-	-	15k	-	15k	130k
max edge ratio	10000	7.8	45355	2797	38298	20779
max cells per point	7	50	88	88	308	77
total used memory	6MB	22MB	191MB	464MB	783MB	1085MB
kdtree statistics						
memory for kdtree	0.4MB	0.4MB	26MB	26MB	52MB	104MB
building time for kdtree(s)	0.63	0.8	31.8	63.5	128	152
divided by $n\lceil\log_2(n)\rceil$	1.75	1.67	1.59	1.59	1.61	1.53
search in kdtree(μs)	3.33	3.13	6.05	6.73	7.28	7.28
divided by $\lceil\log_2(n)\rceil$	0.222	0.208	0.303	0.321	0.331	0.317
point location statistics						
mean μs per search	93	147	180	181	219	163
mean cells gone	2.89	4.42	4.68	4.78	5.76	4.36
max cells gone	33	16	6127	414	10032	50856
# re-search after boundary hit	53	0	69413	36129	361878	222348
mean # rays per re-search	1.47	-	4.60	1.90	2.35	2.74
maximum # rays per re-search	6	-	730	43	150	658

Table 1: Test statistics for the six chosen data sets NACA, GBK, ICE, F6 and BMW.

Taken from [LST2003]

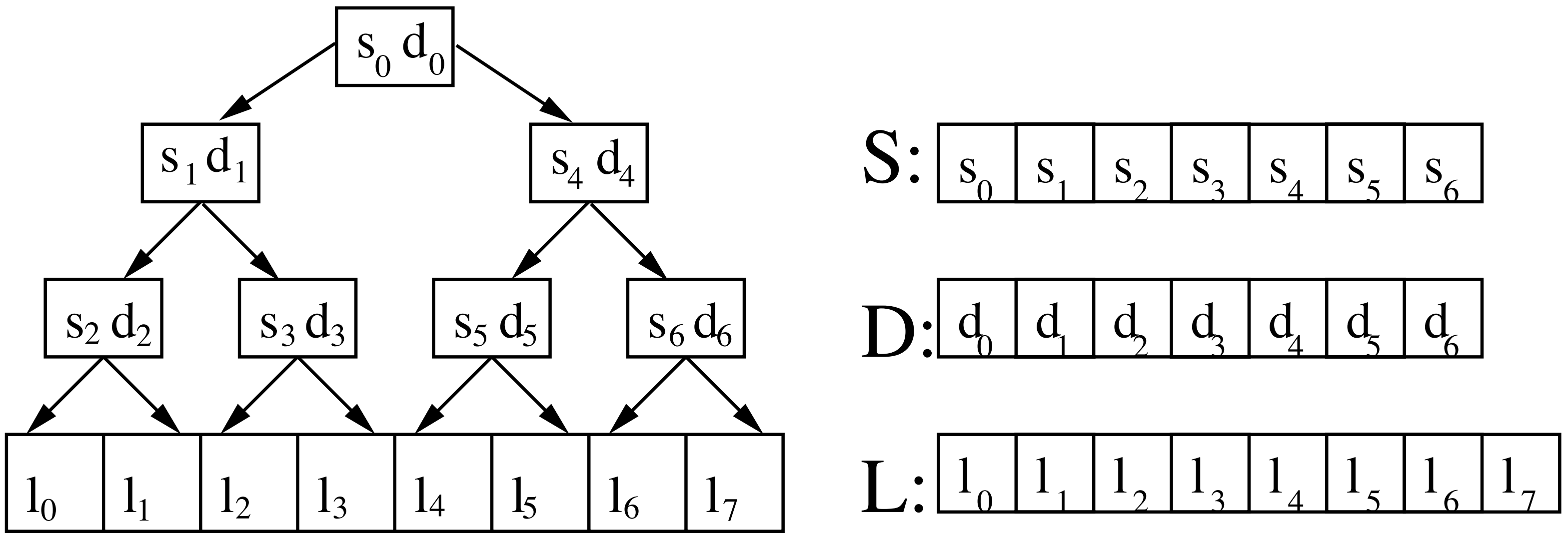
Efficient Point Location

- Adaptively subdivided kD-tree
  - ~1% of mesh vertices
  - Identifies cell close to point
- Cast ray to sought position
- Follow ray using cell adjacency
  - Special treatment:
    - mesh holes
    - boundaries



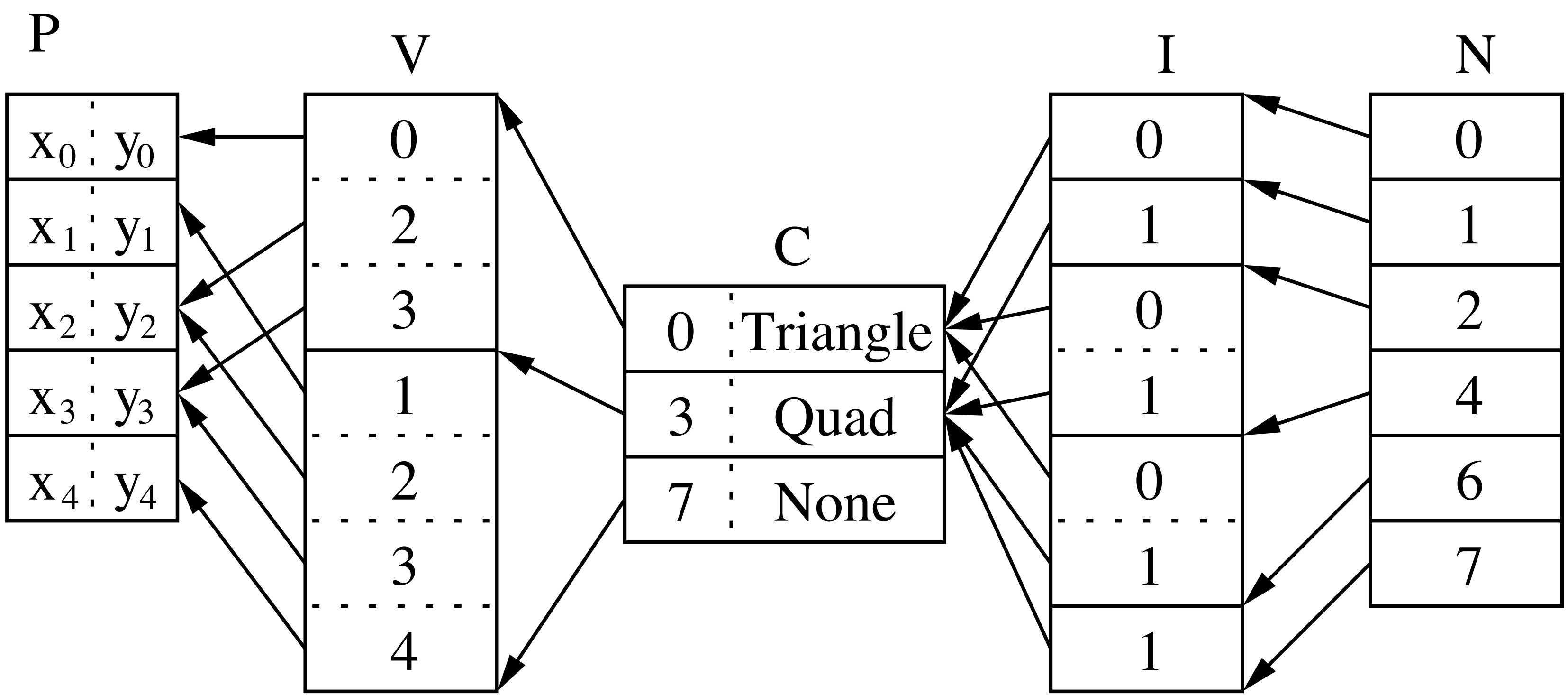
Taken from [LST2003]

kD-tree Data Structure



Taken from [LST2003]

Cell Vertex and Neighborhood Information

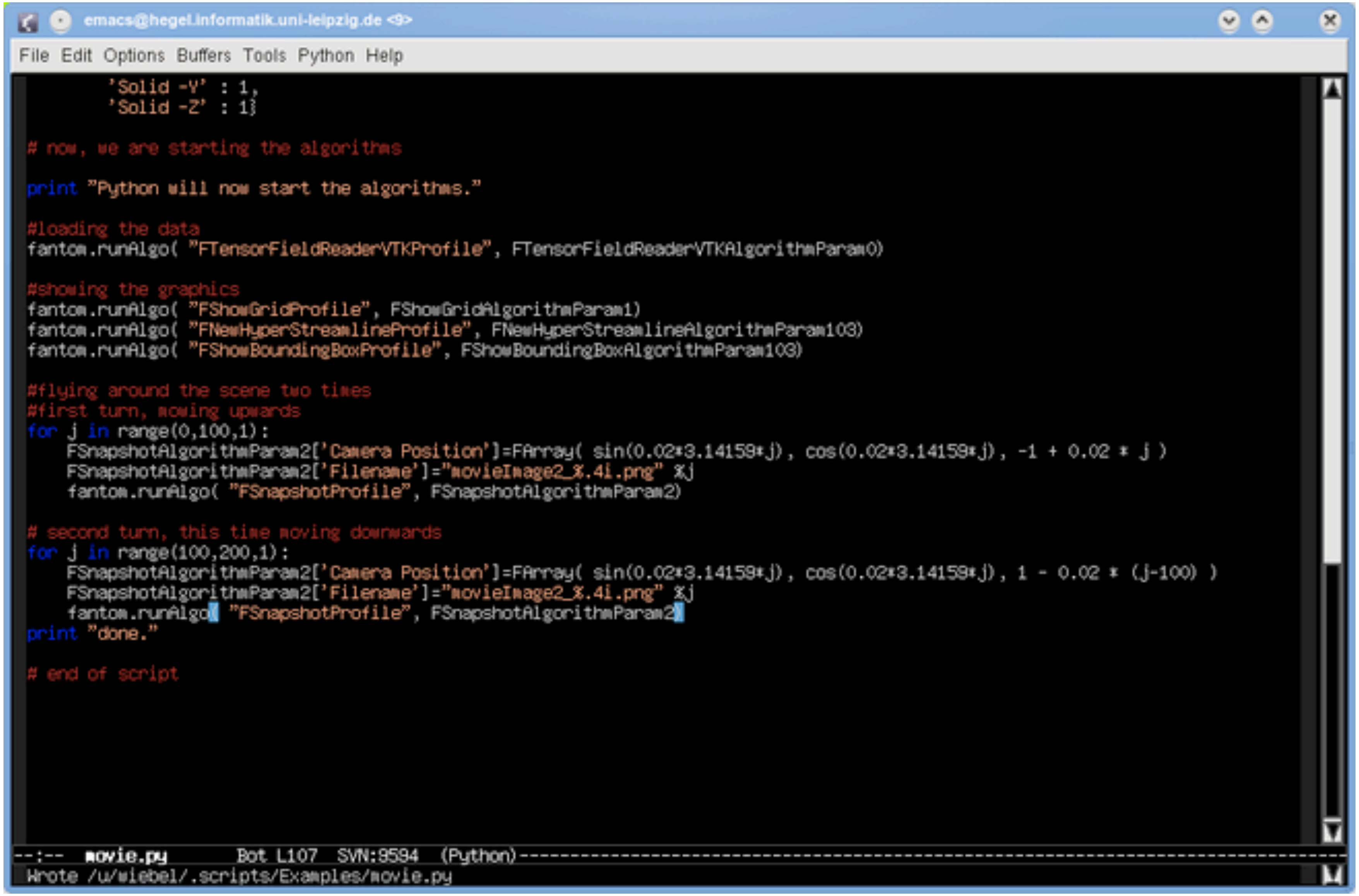


Taken from [LST2003]

File Edit Options Buffers Tools Python Help

```
FIsosurfaceAlgorithmParam2 = {
        'Alpha' : 0.5,
        'Color of Isosurface' : FColor( 0.588235, 0.588235, 0.588235 ),
        'Enable Backface Lighting' : 1,
        'Isovalue / Percentile [%]' : 20,
        'Method to be Used' : 1,
        'Mode' : 0,
        'Position' : FArray( 0, 0, 0 ),
        'Smooth Isosurface' : 1,
        'Tensorfield' : FIndex(0),
        'Use Acceleration' : 1,
        'Use Lit Triangles' : 1}

FShowBoundingBoxAlgorithmParam3 = {
        'Draw as Tubes' : 1,
        'Field' : FIndex(0),
        'Line Color' : FColor( 1, 1, 1 ),
        'Line Width' : 5,
        'Side Color' : FColor( 0.499992, 0.499992, 0.499992 ),
        'Solid +X' : 0,
        'Solid +Y' : 0,
        'Solid +Z' : 0,
        'Solid -X' : 0,
        'Solid -Y' : 0,
        'Solid -Z' : 0}



# now, we are starting the algorithms

print "Python will now start the algorithms."
fantom.runAlgo( "FTensorFieldReaderVTKProfile", FTensorFieldReaderVTKAlgorithmParam0)
fantom.runAlgo( "FColorMapProfile", FColorMapAlgorithmParam1)
fantom.runAlgo( "FIsosurfaceProfile", FIsosurfaceAlgorithmParam2)
fantom.runAlgo( "FShowBoundingBoxProfile", FShowBoundingBoxAlgorithmParam3)
print "Python script execution done."

# end of script
```

--:-- ReVisE_Example.py Bot L51 (Python)------------------------------------


emacs@hegel.informatik.uni-leipzig.de <9>
File Edit Options Buffers Tools Python Help
'Solid -Y' : 1,
'Solid -Z' : 1}
now, we are starting the algorithms
print "Python will now start the algorithms."
#loading the data
fantom.runAlgo("FTensorFieldReaderVTKProfile", FTensorFieldReaderVTKAlgorithmParam0)
#showing the graphics
fantom.runAlgo("FShowGridProfile", FShowGridAlgorithmParam1)
fantom.runAlgo("FNewHyperStreamlineProfile", FNewHyperStreamlineAlgorithmParam103)
fantom.runAlgo("FShowBoundingBoxProfile", FShowBoundingBoxAlgorithmParam103)
#flying around the scene two times
#first turn, moving upwards
for j in range(0,100,1):
FSnapshotAlgorithmParam2['Camera Position']=FArray(sin(0.02*3.14159*j), cos(0.02*3.14159*j), -1 + 0.02 * j)
FSnapshotAlgorithmParam2['Filename']="movieImage2_%.4i.png" %j
fantom.runAlgo("FSnapshotProfile", FSnapshotAlgorithmParam2)
# second turn, this time moving downwards
for j in range(100,200,1):
FSnapshotAlgorithmParam2['Camera Position']=FArray(sin(0.02*3.14159*j), cos(0.02*3.14159*j), 1 - 0.02 * (j-100))
FSnapshotAlgorithmParam2['Filename']="movieImage2_%.4i.png" %j
fantom.runAlgo("FSnapshotProfile", FSnapshotAlgorithmParam2)
print "done."
end of script
--:-- movie.py Bot L107 SVN:9594 (Python)
Wrote /u/wiebel/.scripts/Examples/movie.py


1.0712e+00
1.0531e+00
1.0350e+00
1.0169e+00
9.9886e-01
9.8078e-01
9.6270e-01
9.4462e-01
9.2654e-01
9.0846e-01