Large Scale Visualization with ParaView

ATPESC 2021

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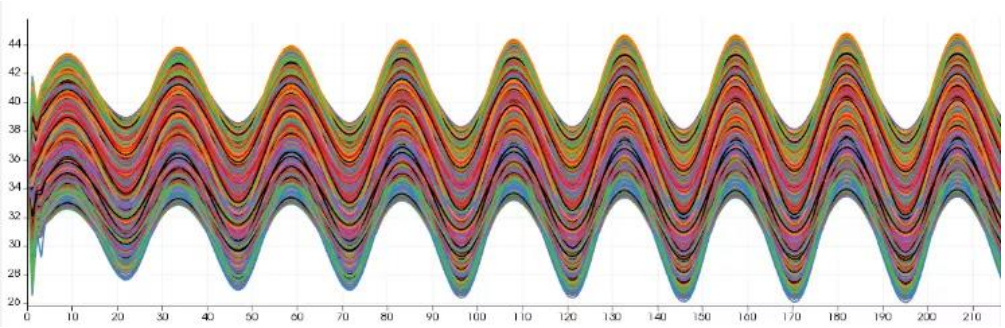
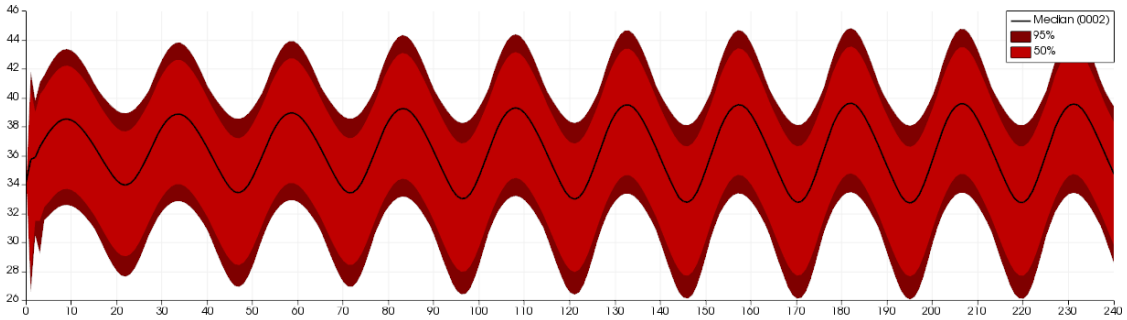
Kitware, Inc.



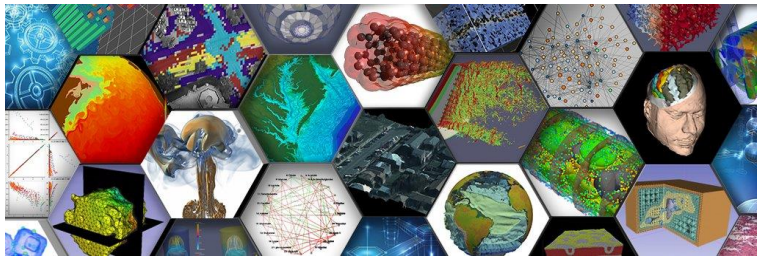
Outline

- Kitware
- Introduction
- Basic Usage
- Visualizing Large Models



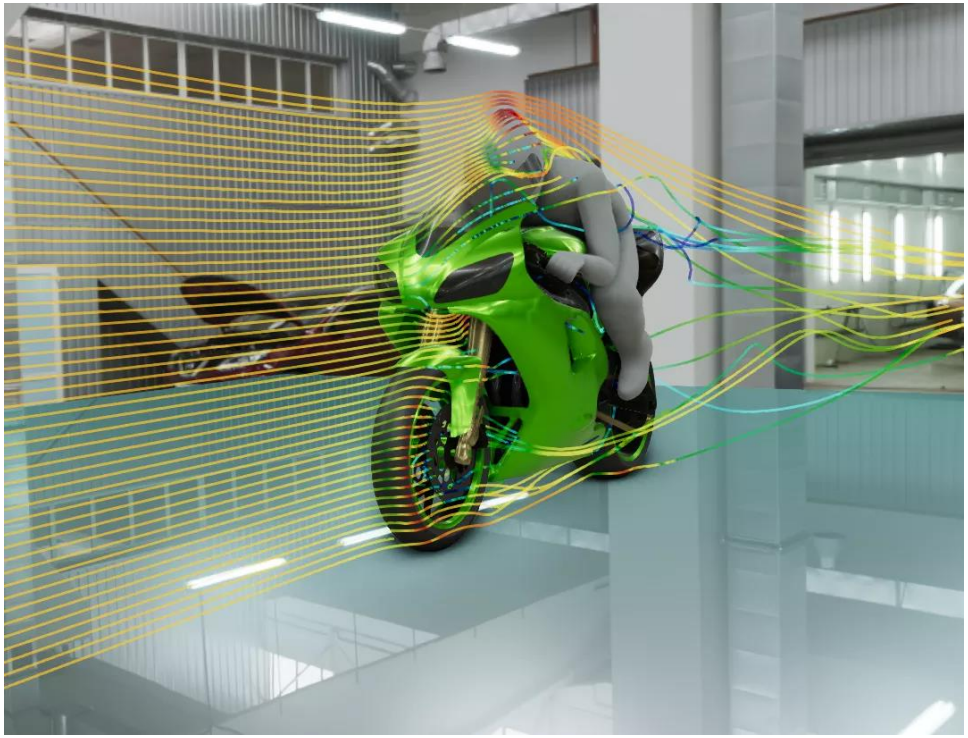
Kitware

- Open-source, software R&D company
- Core areas of expertise
  - Computer Vision
  - Data and Analytics
  - HPC and Visualization
  - Medical Computing
  - Software Process



To Follow Along…

- Install ParaView 5.9.1
  - http://www.paraview.org → Download

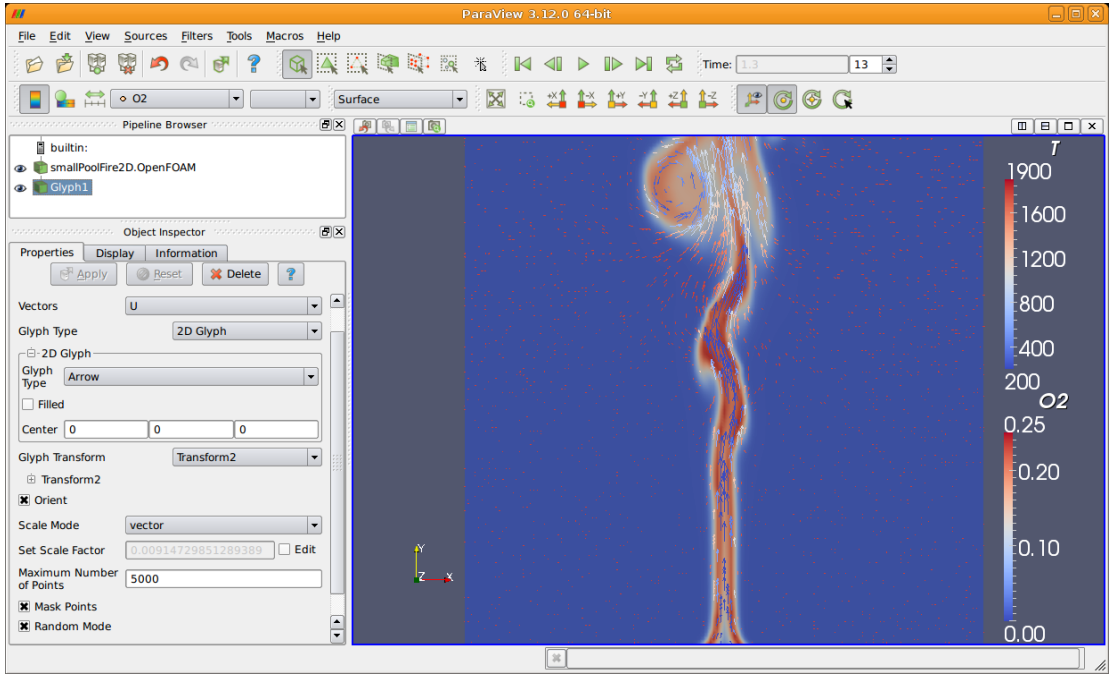


Introduction

What is ParaView?

- An open-source (BSD 3 Clause License), scalable, multi-platform visualization application based on VTK
- Processing paradigms:
  - distributed computing (MPI)
  - shared memory multiprocessing (vtkSMPTools)
  - GPU processing (vtk-m).
- Rendering
  - Physically Based Rendering
  - Ray tracing (Intel OSPRay, NVIDIA OptiX)
- Has an open, flexible, and intuitive user interface
- Has an extensible, **modular architecture** based on open standards

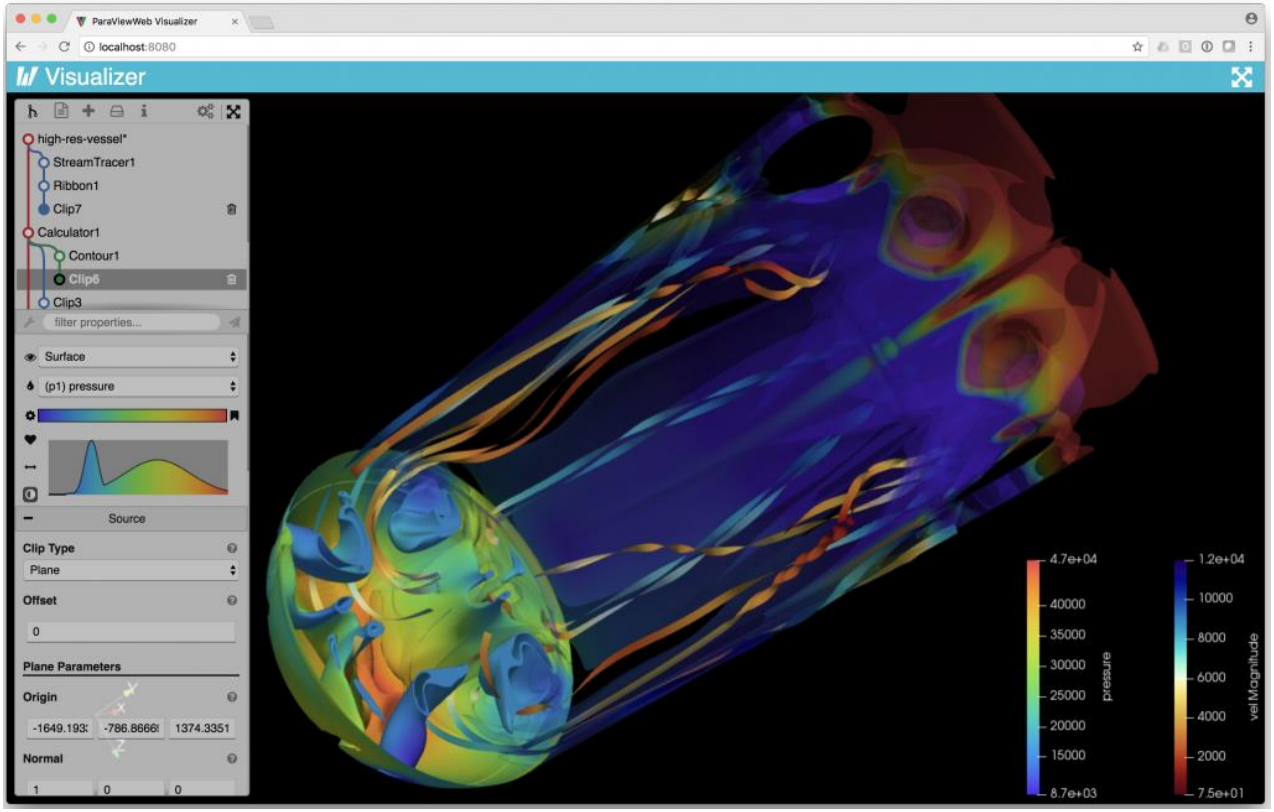
ParaView on the Desktop



ParaView on the Web

Visualizer, Glance (vtk.js)

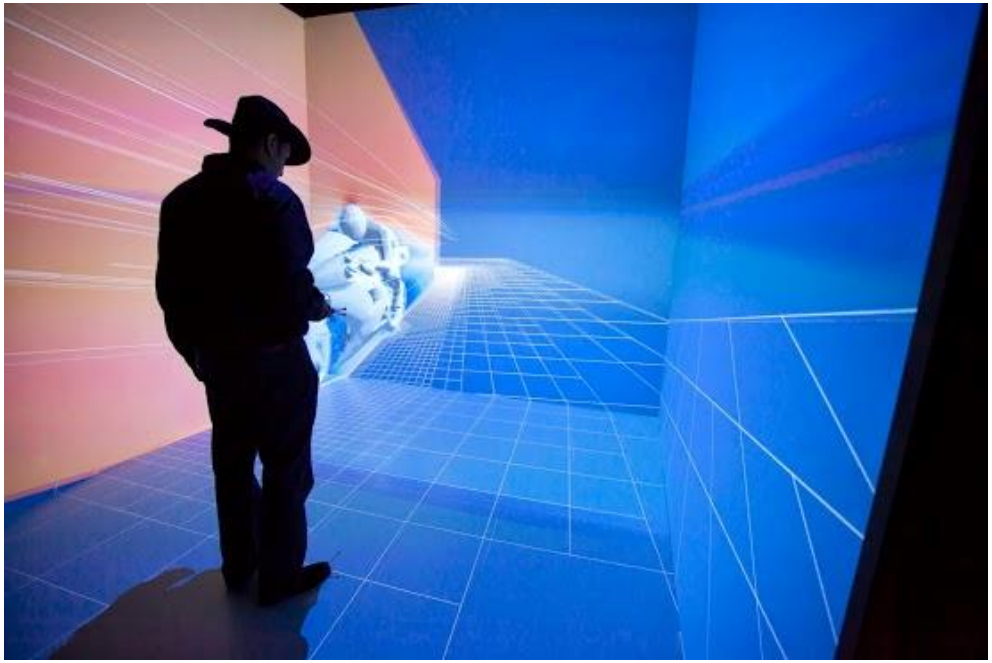
https://blog.kitware.com/vis-on-the-web/



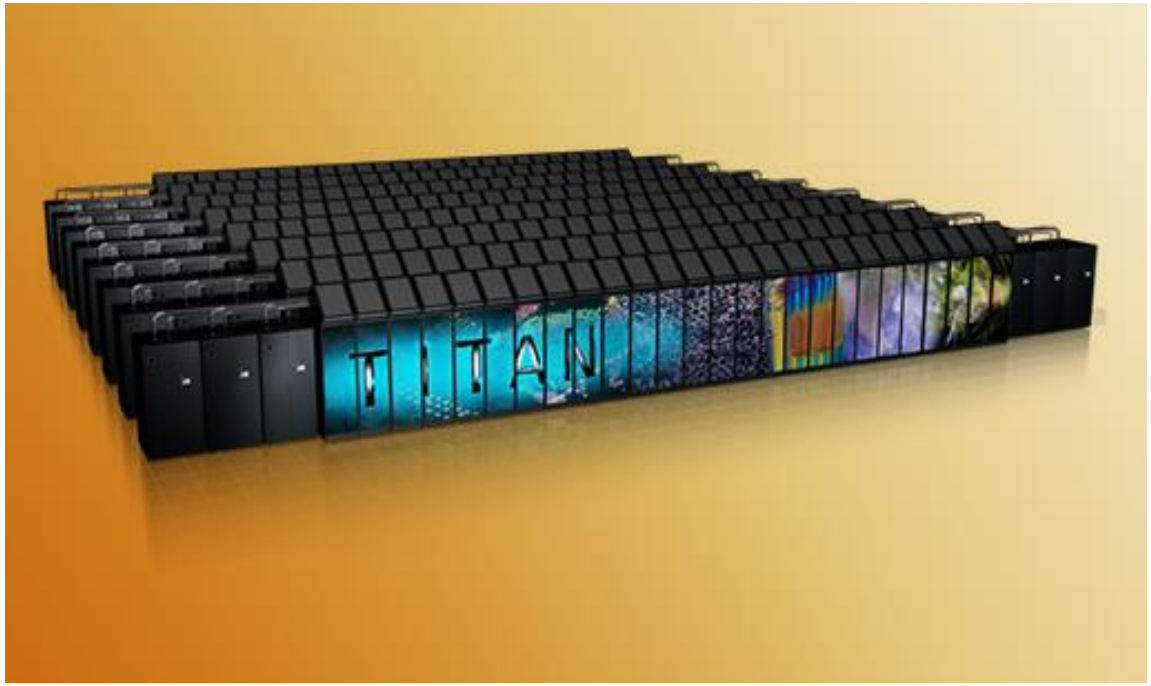
ParaView Scripting - Python

Python scripts can control ParaView, with or without the GUI, in order to create reproducible and customizable visualizations.

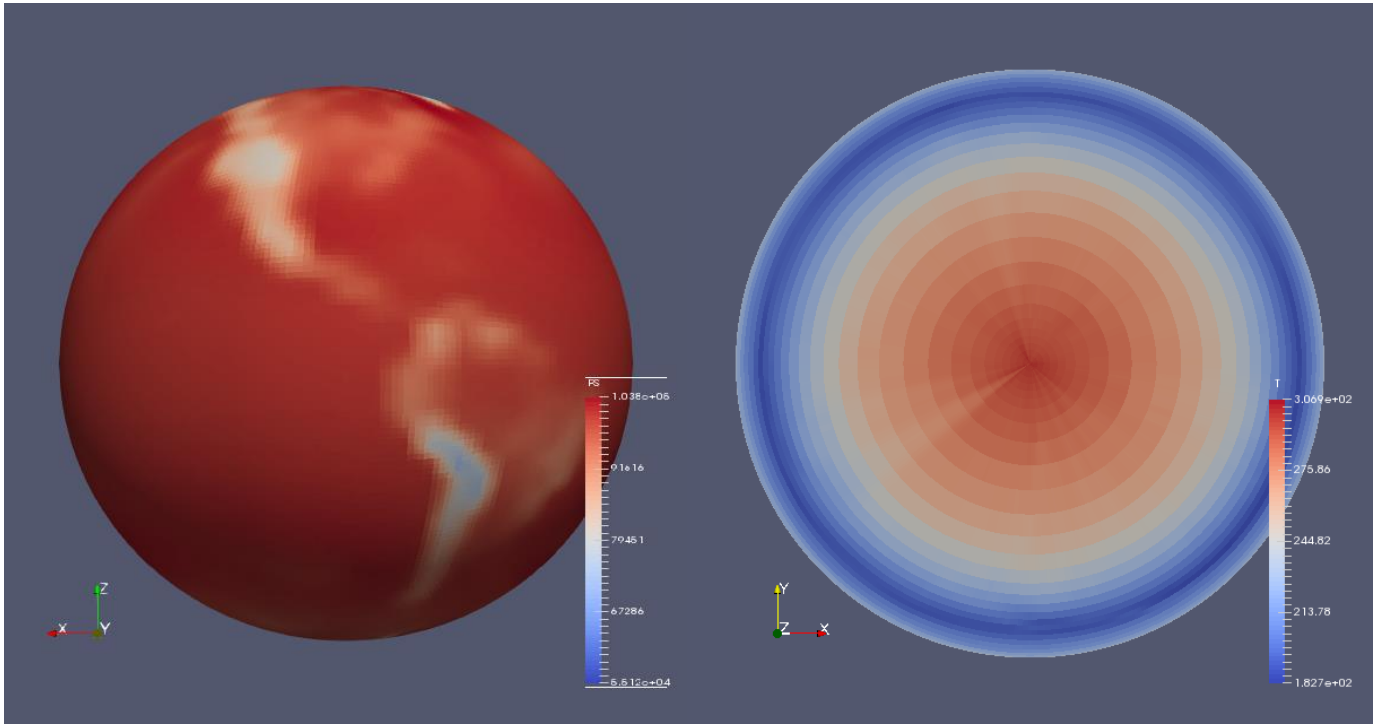
ParaView Immersive



ParaView for HPC

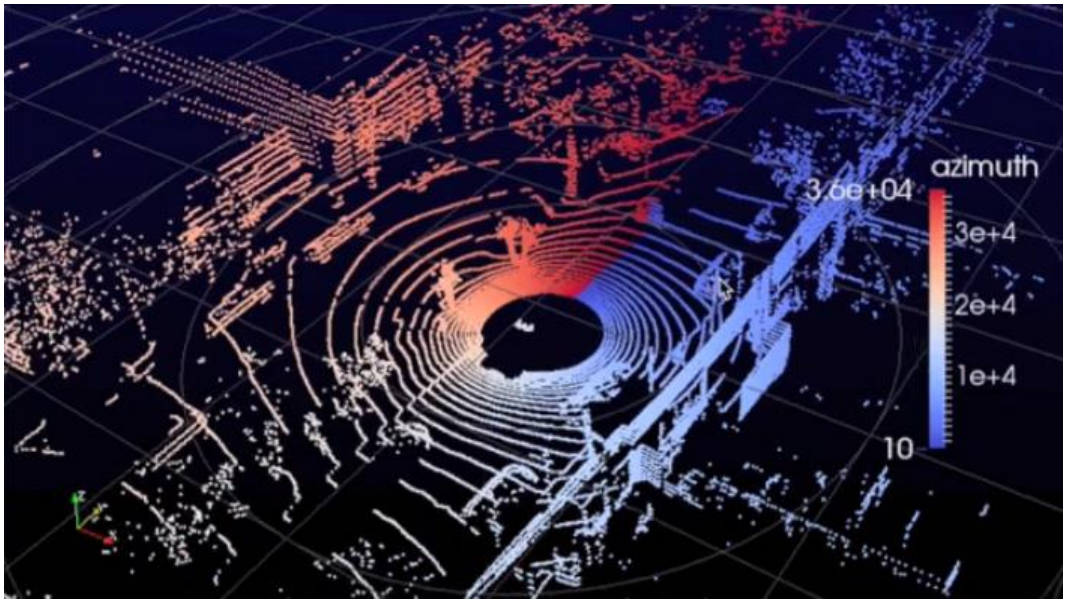


ParaView Catalyst



Community Atmosphere Model (CAM5) 2D (PS) 3D data (T), Spectral Element dynamic module.

ParaView Custom Application VeloView



Visualization of 3D LIDAR data.

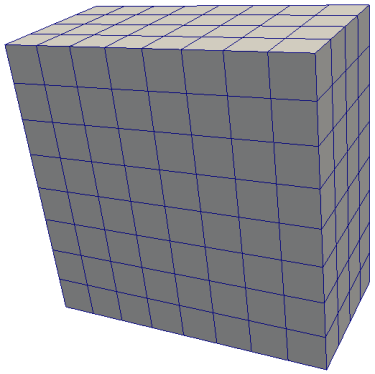
Current ParaView Usage

- Used by academic, government, and commercial institutions worldwide.
- Downloaded ~135K times per year.
- HPCwire Editors' Choice 2010/2016 and HPCwire Readers' Choice 2010/2012/2015 Awards for Best Visualization Product or Technology.

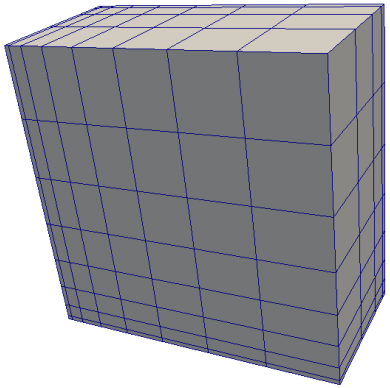
Data Ranges

- Used for all ranges of data size.
- Landmarks of usage:
  - 6 billion structured cells (2005).
  - Billions of AMR cells (2008).
  - 6.33 billion unstructured cells in Catalyst (2016).
  - Scaling test over 1 Trillion cells (2010).

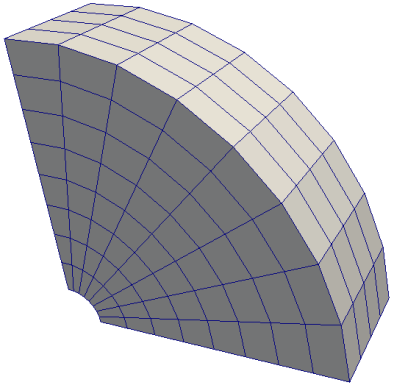
Data Types



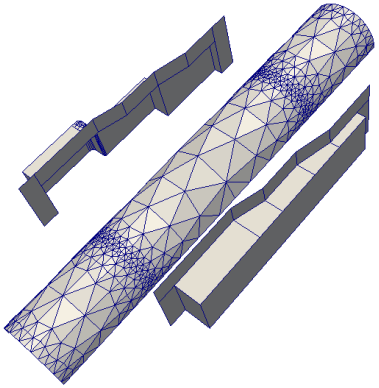
Uniform Rectilinear
(vtkImageData)



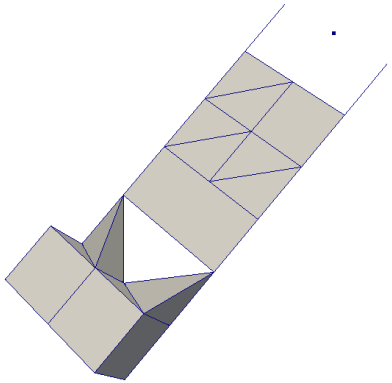
Non-Uniform Rectilinear
(vtkRectilinearData)



Curvilinear
(vtkStructuredData)



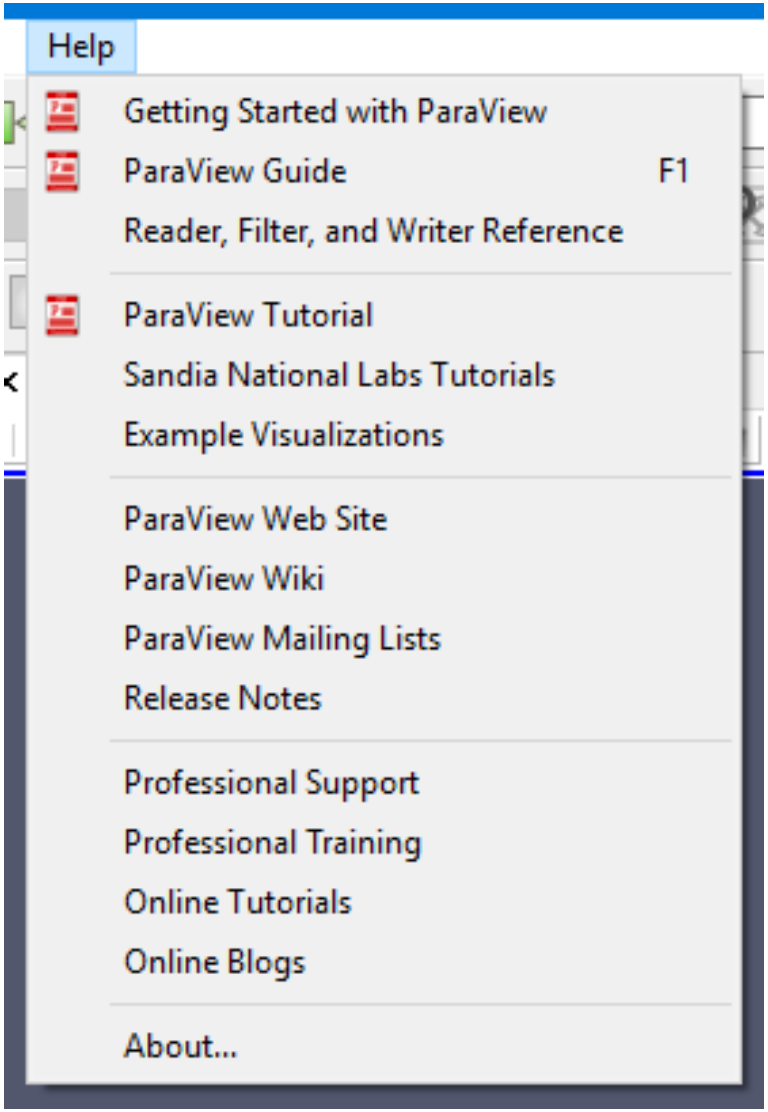
Polygonal
(vtkPolyData)



Unstructured Grid
(vtkUnstructuredGrid)

- Multi-block
- Hierarchical Adaptive Mesh Refinement (AMR)
- Hierarchical Uniform AMR
- Octree

More Information



Basic Usage

User Interface

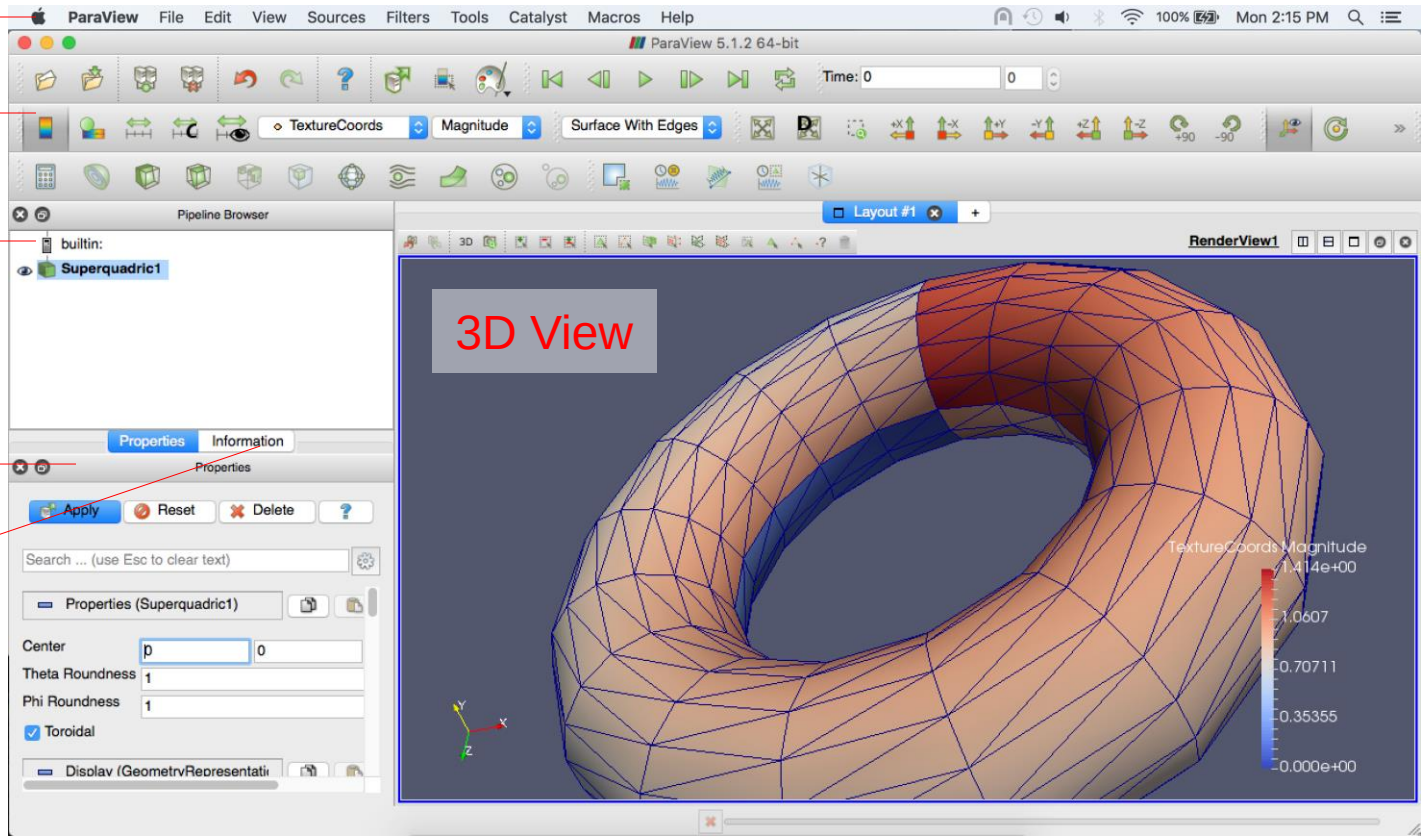
Menu Bar

Toolbars

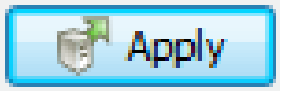
Pipeline Browser

Properties Panel

Information Panel

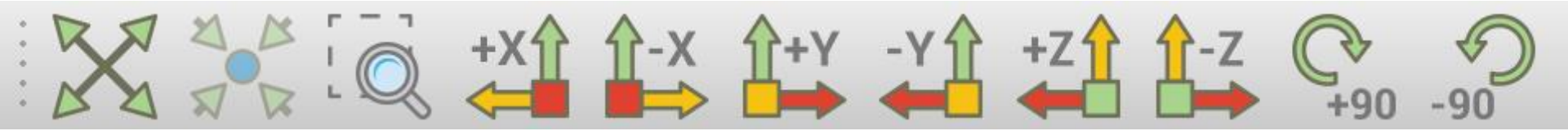


Creating a Cylinder Source

1. Go to the Sources menu and select Cylinder.
2. Click the Apply button to accept the default parameters. 

Simple Camera Manipulation

- Drag left, middle, right buttons for rotate, pan, zoom.
  - Also use Shift, Ctrl modifiers (see Edit > Setting > Camera)
  - Also try holding down x, y, or z.



Creating a Cylinder Source

1. Go to the Source menu and select Cylinder.
2. Click the Apply button to accept the default parameters. 

3. Increase the Resolution parameter.

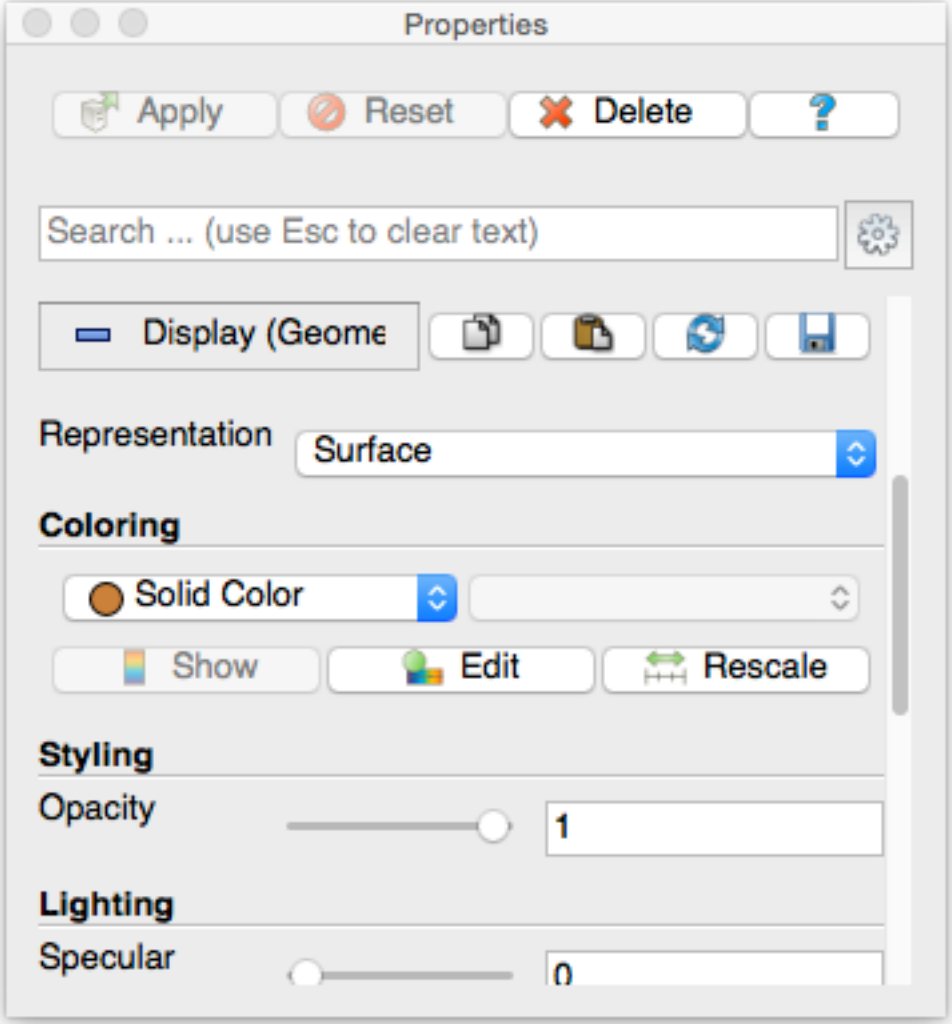
4. Click the 

button again.

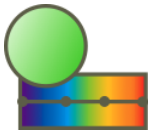
Pipeline Object Controls

Pipeline objects
- Sources
- Filters
- Readers
- Extractors

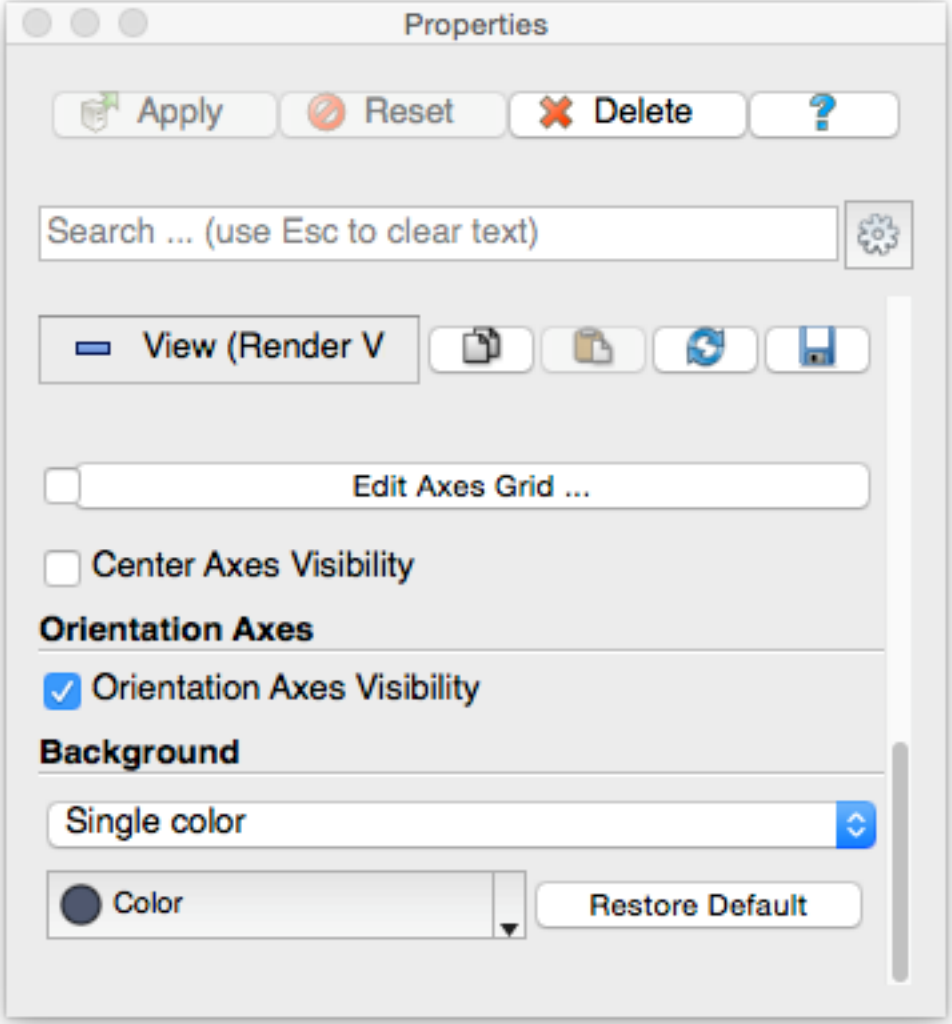
Display Properties



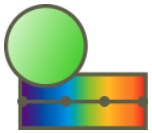
Change Display Properties

1. Scroll down to the Display group.
2. Click the  Edit button. (This button is replicated in the toolbar.)
3. Select a new color for the cylinder.

View Properties

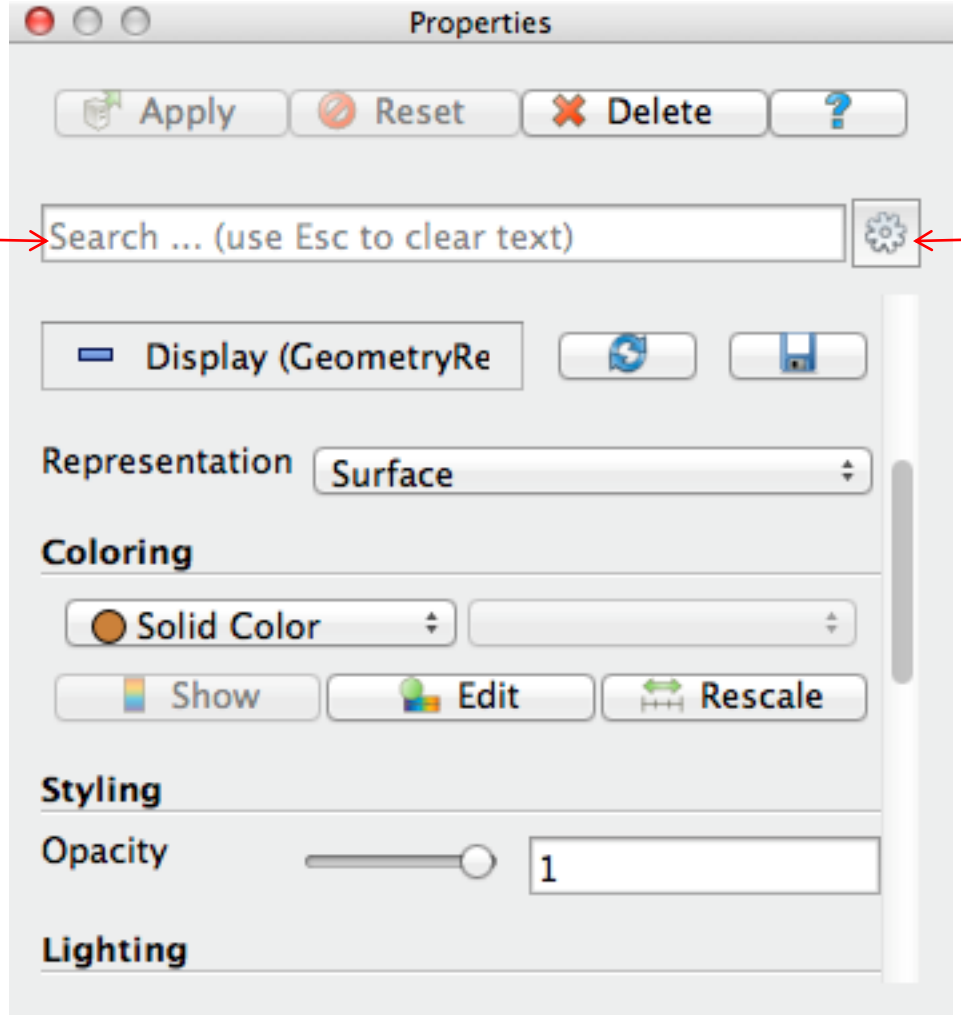


Change View Properties

1. Scroll down to the Display group.
2. Click the  Edit button. (This button is replicated in the toolbar.)
3. Select a new color for the cylinder.
4. Scroll down to the View group.
5. Turn on the Axis Grid.

Advanced Properties

Search Properties



Toggle Advanced Properties

Searching Properties

1. Type “specular” in the properties search box
2. Change Specular value to 1 (makes the cylinder shiny)

Searching Properties

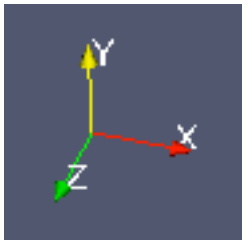
1. Type “specular” in the properties search box
2. Change Specular value to 1 (makes the cylinder shiny)

Other interesting properties:

- Axes Grid
- Opacity

Changing the Color Palette

1. Make sure the orientation axes are visible in the lower left corner. 

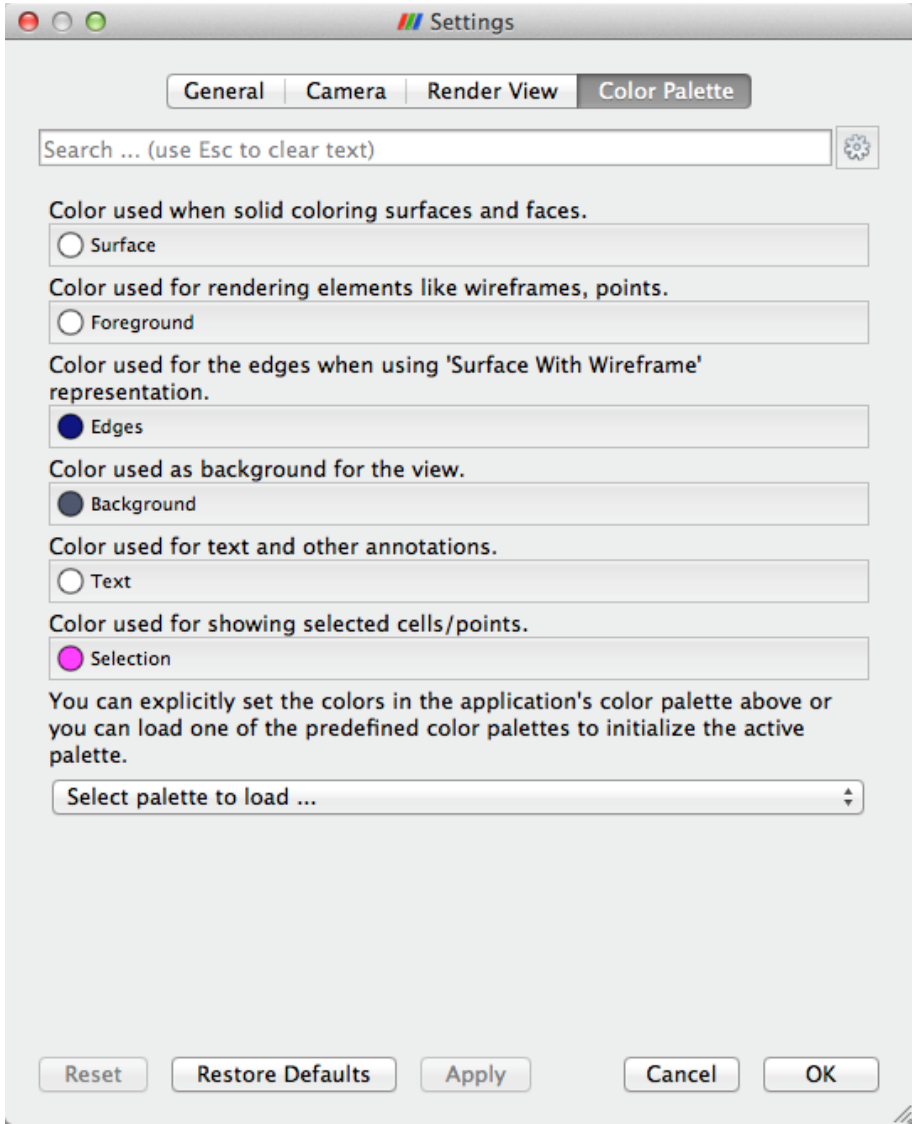


2. Click the color palette button  and change the colors.

3. Try several color palettes.

Color Palettes

→ Edit Current Palette...



Undo Redo

Undo

Redo

Camera Undo

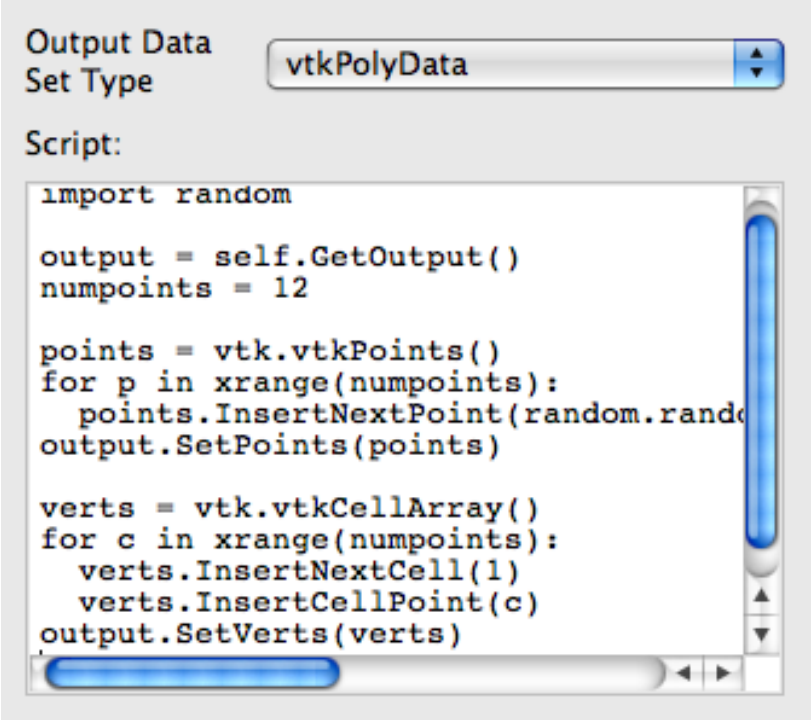
Camera Redo

Supported File Types

- ParaView Data (.pvd)
- VTK (.vtp, .vtu, .vti, .vts, .vtr)
- VTK Legacy (.vtk)
- VTK Multi Block (.vtm,.vtmb,.vtmg,.vthd,.vthb)
- Partitioned VTK (.pvtu, .pvti, .pvts, .pvtr)
- ADAPT (.nc, .cdf, .elev, .ncd)
- ANALYZE (.img, .hdr)
- ANSYS (.inp)
- AVS UCD (.inp)
- BOV (.bov)
- BYU (.g)
- CAM NetCDF (.nc, .ncdf)
- CCSM MTSD (.nc, .cdf, .elev, .ncd)
- CCSM STSD (.nc, .cdf, .elev, .ncd)
- CEAucd (.ucd, .inp)
- CGNS (.cgns)
- CMAT (.cmat)
- CML (.cml)
- CTRL (.ctrl)
- Chombo (.hdf5, .h5)
- Claw (.claw)
- Comma Separated Values (.csv)
- Cosmology Files (.cosmo, .gadget2)
- Curve2D (.curve, .ultra, .ult, .u)
- DDCMD (.ddcmd)
- Digital Elevation Map (.dem)
- Dyna3D(.dyn)
- EnSight (.case, .sos)
- Enzo boundary and hierarchy
- ExodusII (.g, .e, .exe, .ex2, .ex2v.., etc)
- ExtrudedVol (.exvol)
- FVCOM (MTMD, MTSD, Particle, STSD)
- Facet Polygonal Data
- Flash multiblock files
- Fluent Case Files (.cas)
- GGCM (.3df, .mer)
- GTC (.h5)
- GULP (.trg)
- Gadget (.gadget)
- Gaussian Cube File (.cube)
- JPEG Image (.jpg, .jpeg)
- LAMPPS Dump (.dump)
- LAMPPS Structure Files
- LODI (.nc, .cdf, .elev, .ncd)
- LODI Particle (.nc, .cdf, .elev, .ncd)
- LS-DYNA (.k, .lsdyna, .d3plot, d3plot)
- M3DCl (.h5)
- MFIX Unstructred Grid (.RES)
- MM5 (.mm5)
- MPAS NetCDF (.nc, .ncdf)
- Meta Image (.mhd, .mha)
- Miranda (.mir, .raw)
- Multilevel 3d Plasma (.m3d, .h5)
- NASTRAN (.nas, .f06)
- Nek5000 Files
- Nrrd Raw Image (.nrrd, .nhdr)
- OpenFOAM Files (.foam)
- PATRAN (.neu)
- PFLOTRAN (.h5)
- PLOT2D (.p2d)
- PLOT3D (.xyz, .q, .x, .vp3d)
- PLY Polygonal File Format
- PNG Image Files
- POP Ocean Files
- ParaDIS Files
- Phasta Files (.pht)
- Pixie Files (.h5)
- ProSTAR (.cel, .vrt)
- Protein Data Bank (.pdb, .ent, .pdb)
- Raw Image Files
- Raw NRRD image files (.nrrd)
- SAMRAI (.samrai)
- SAR (.SAR, .sar)
- SAS (.sasgeom, .sas, .sasdata)
- SESAME Tables
- SLAC netCDF mesh and mode data
- SLAC netCDF particle data
- Silo (.silo, .pdb)
- Spheral (.spheral, .sv)
- SpyPlot CTH
- SpyPlot (.case)
- SpyPlot History (.hscth)
- Stereo Lithography (.stl)
- TFT Files
- TIFF Image Files
- TSurf Files
- Tecplot ASCII (.tec, .tp)
- Tecplot Binary (.plt)
- Tetrad (.hdf5, .h5)
- UNIC (.h5)
- VASP CHGCA (.CHG)
- VASP OUT (.OUT)
- VASP POSTCAR (.POS)
- VPIC (.vpc)
- VRML (.wrl)
- Velodyne (.vld, .rst)
- VizSchema (.h5, .vsh5)
- Wavefront Polygonal Data (.obj)
- WindBlade (.wind)
- XDMF and hdf5 (.xmf, .xdmf)
- XMol Molecule

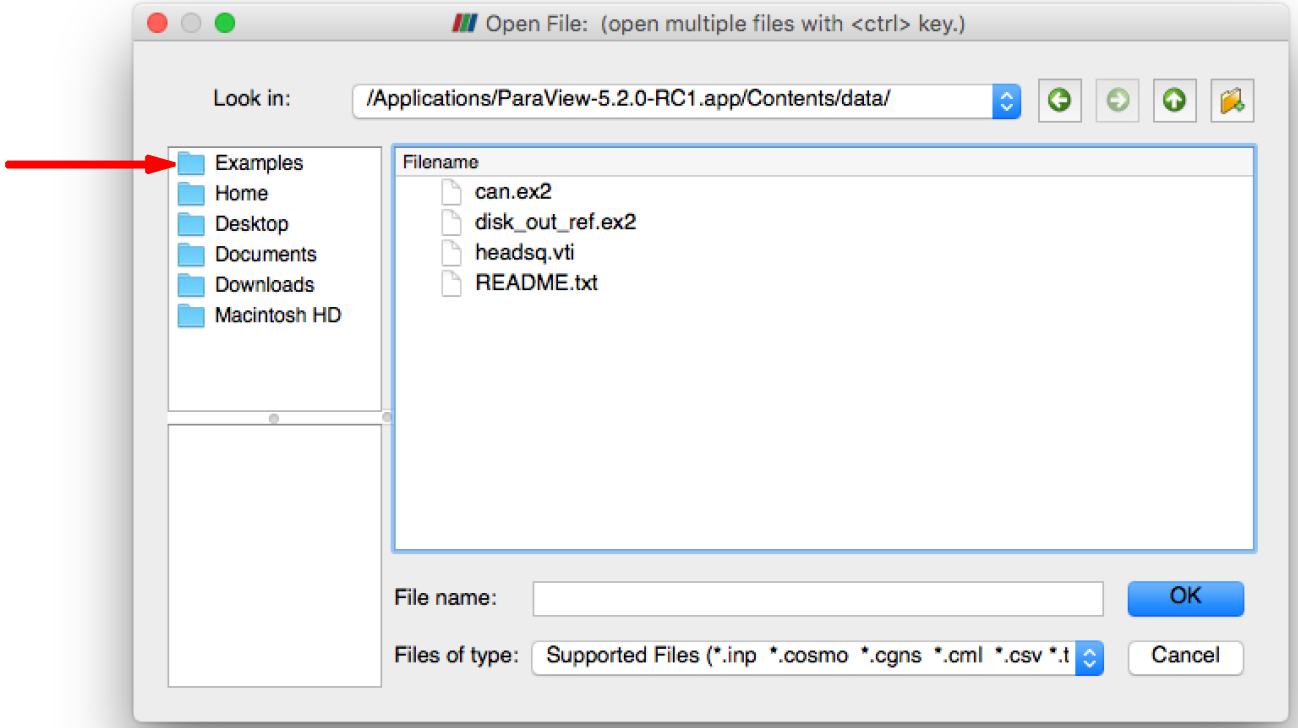
Custom Data Import: Prototype with Python

- A “programmable source” lets you program data readers right in the GUI.
- Uses wrappings for the basic VTK classes.
- Or use Python or C++ plugin.



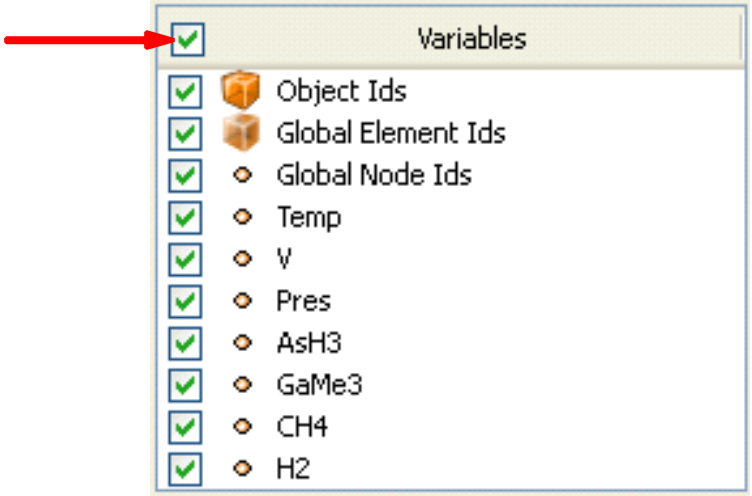
Load disk_out_ref.ex2

1. Open the file disk_out_ref.ex2 from the examples directory.



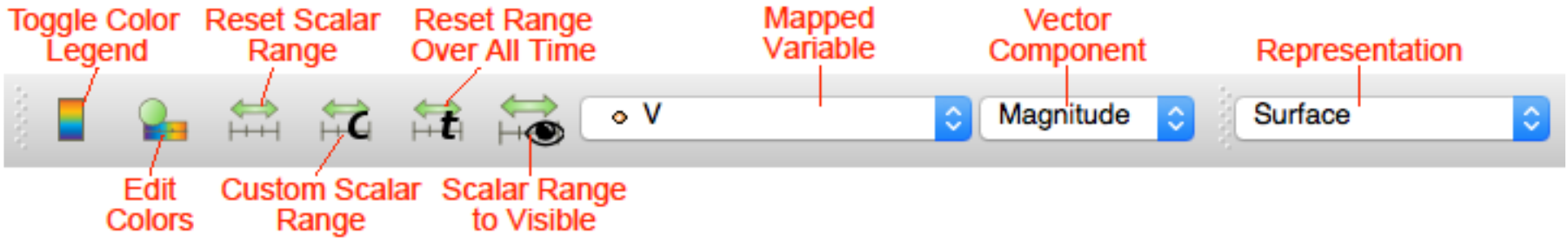
Load disk_out_ref.ex2

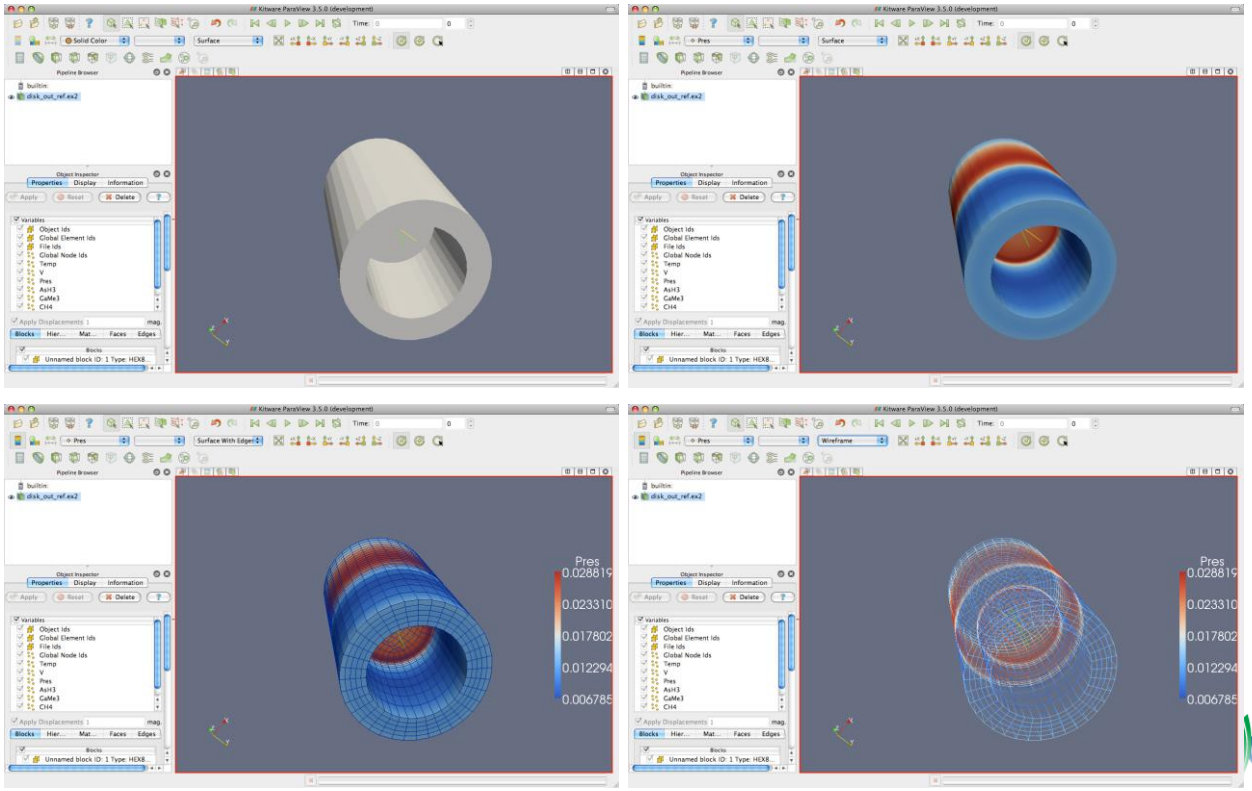
1. Open the file disk_out_ref.ex2 from the examples directory.
2. Load all data variables.



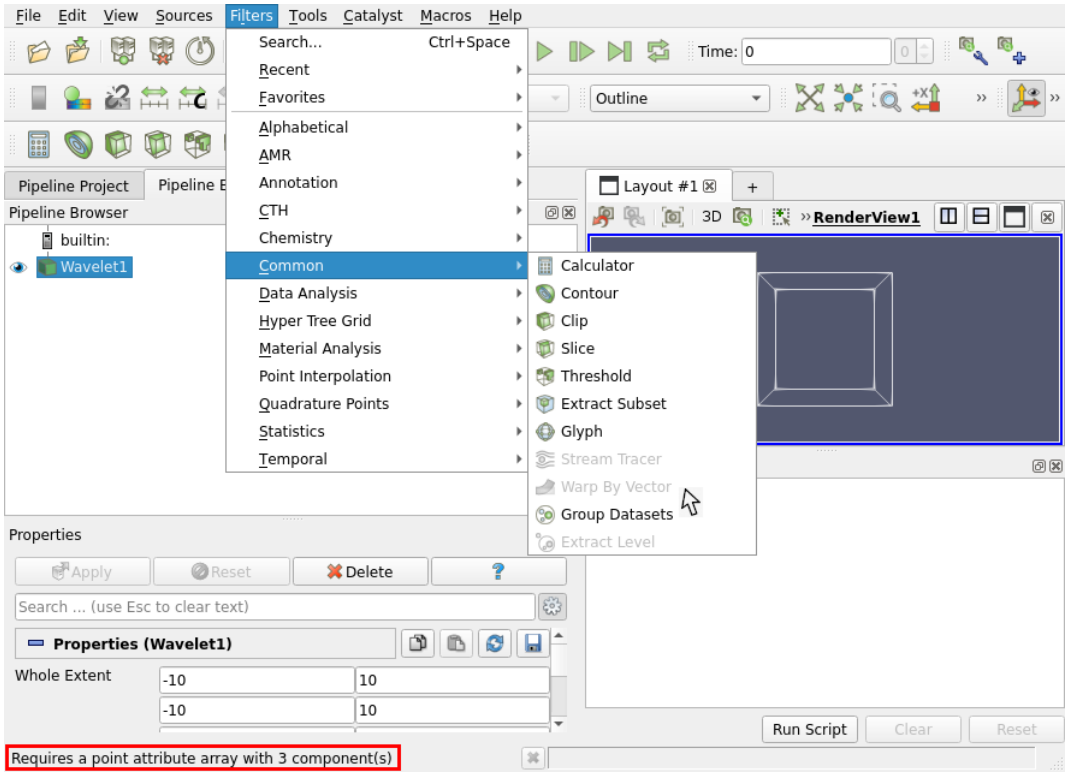
3. Click 

Data Representation





Filters Menu



~200 filters

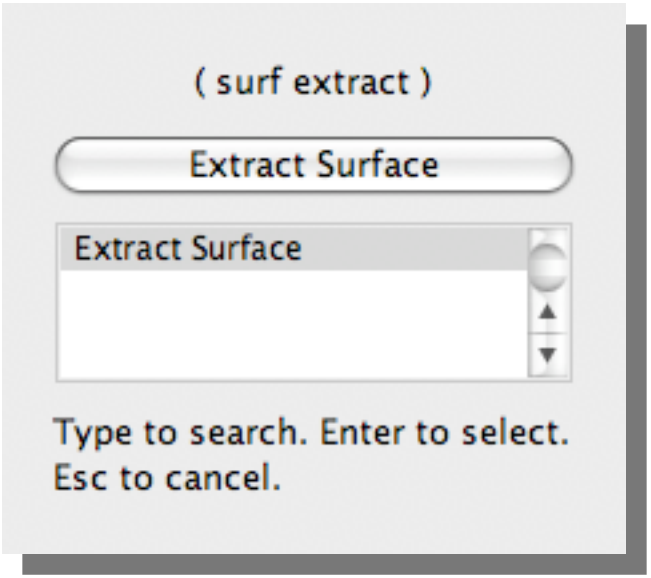
Status bar:

- Short description
- Reason why is grayed

Common Filters

- Calculator
- Contour
- Clip
- Slice
- Threshold
- Extract Subset
- Glyph
- Stream Tracer
- Warp (vector)
- Group Datasets
- Extract Level

Quick Launch



- Used for searching for filters by name
- Keyboard shortcut
  - Ctrl-space for Windows & Linux
  - Alt-space for Mac

Apply Contour

1. Select disk_out_ref.ex2 in the pipeline browser.
2. Press the contour filter. 

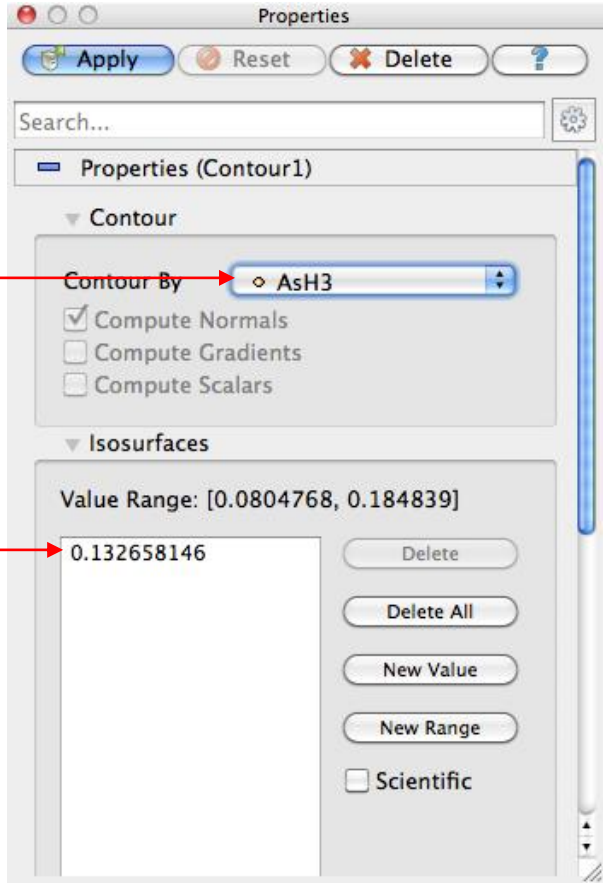
Specify the data you apply the filter on

Apply Contour

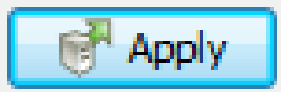
3. Change parameters to create an isosurface at Temp = 400K.

Change to Temp

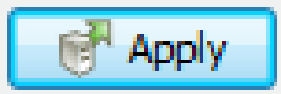
Change to 400



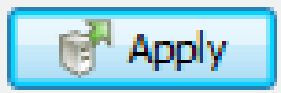
Apply Contour

1. Select disk_out_ref.ex2 in the pipeline browser.
2. Select the contour filter. 
3. Change parameters to create an isosurface at Temp = 400K.
4. 

Apply ExtractSurface

1. Select disk_out_ref.ex2 in the pipeline browser.
2. From the quick launch, select Extract Surface.
3. 

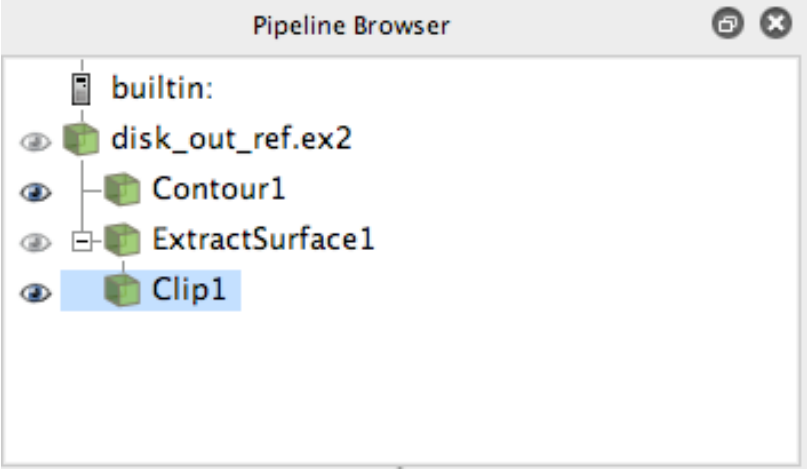
Apply ExtractSurface, Clip

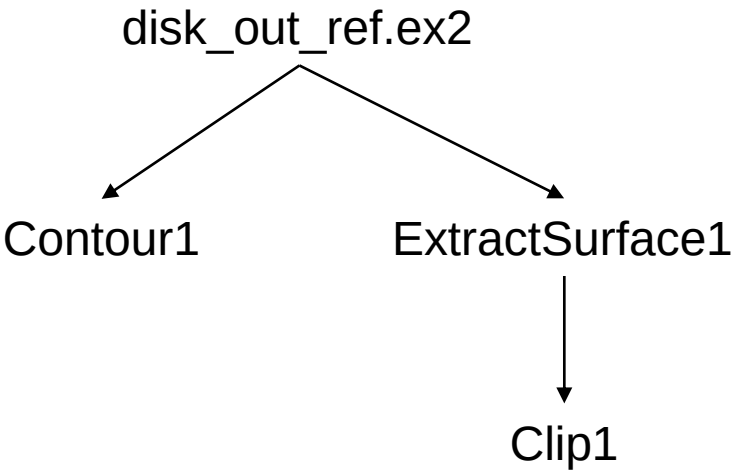
1. Select disk_out_ref.ex2 in the pipeline browser.
2. From the quick launch, select Extract Surface.
3. 

4. Select … Create a clip filter. 
5. Uncheck Show Plane. 

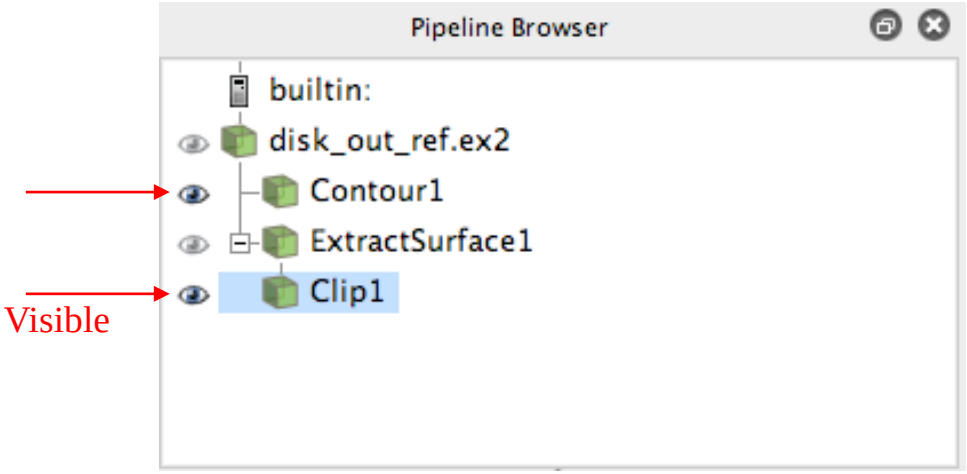
6. 

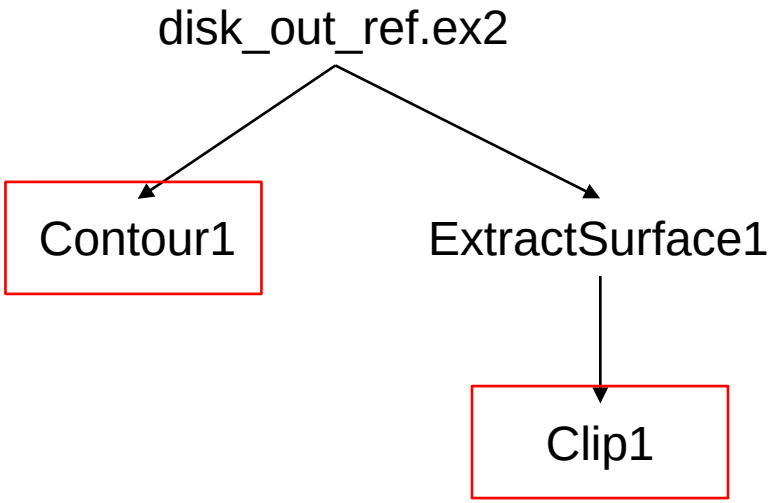
Pipeline Browser Structure



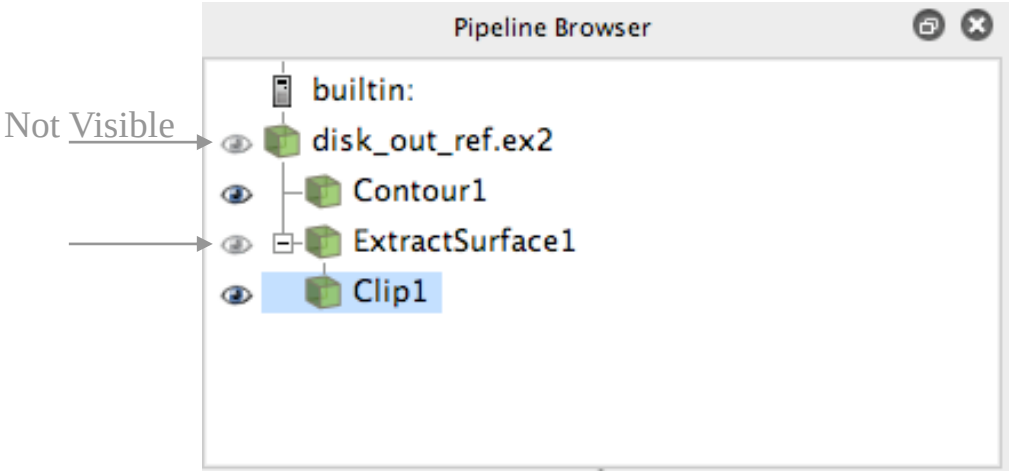


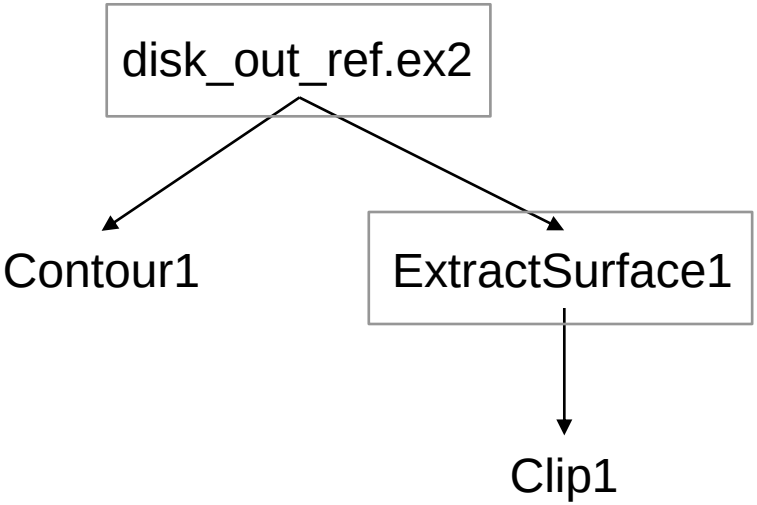
Pipeline Browser Structure



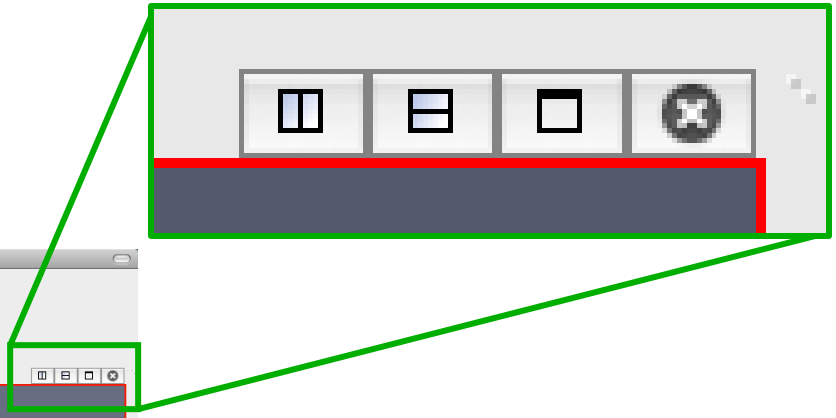


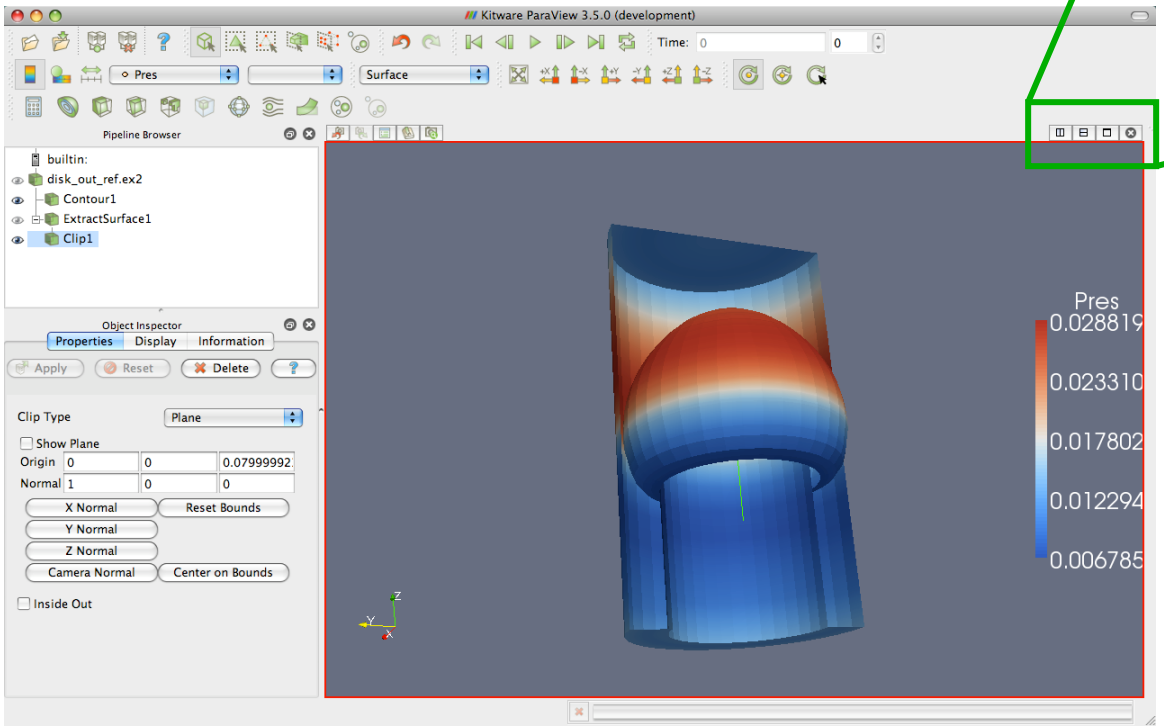
Pipeline Browser Structure





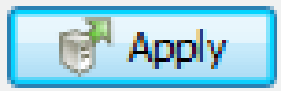
Multiview




Kitware ParaView 3.5.0 (development)
Time:
Pres
Surface
Pipeline Browser
builtin:
disk_out_ref.ex2
Contour1
ExtractSurface1
Clip1
Object Inspector
Properties
Display
Information
Apply
Reset
Delete
Clip Type
Plane
Show Plane
Origin
Normal
X Normal
Reset Bounds
Y Normal
Z Normal
Camera Normal
Center on Bounds
Inside Out
Pres
0.028819
0.023310
0.017802
0.012294
0.006785

Multiview

1. Select disk_out_ref.ex2 in the pipeline browser.
2. Add Clip filter. 
3. Uncheck Show Plane. 

4. 

5. Hide Clip2 

Multiview

6. Split the view horizontally. 
7. Make Clip2 visible. 
8. Color surface by Temp.

Multiview

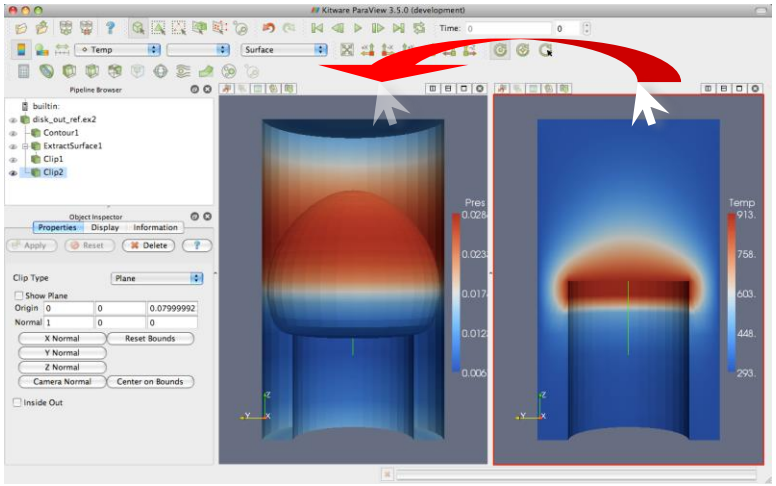
6. Split the view horizontally.
7. Make Clip2 visible.
8. Color surface by Temp.
9. Right-click view, Link Camera...
10. Click other view.

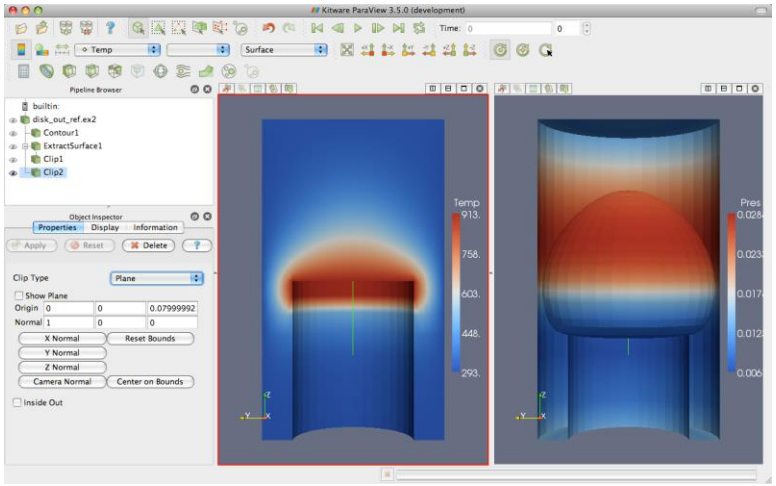
Multiview

6. Split the view horizontally. 
7. Make Clip1 visible. 
8. Color surface by Temp.
9. Right-click view, Link Camera...
10. Click other view.
11. Click 

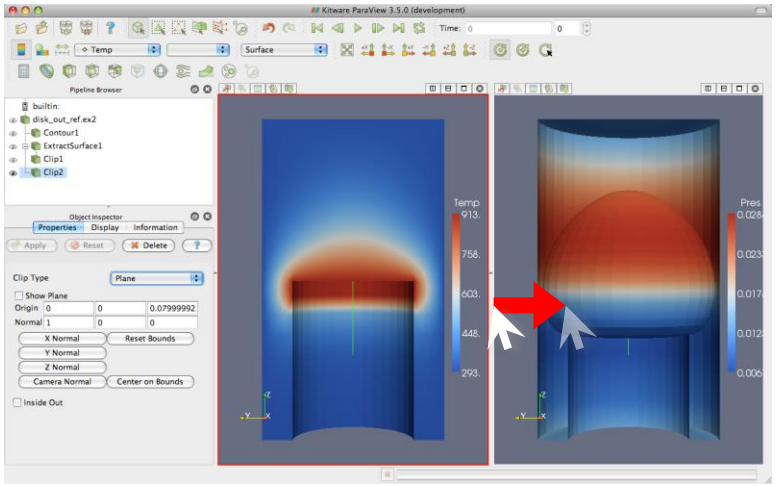
and zoom in a bit.

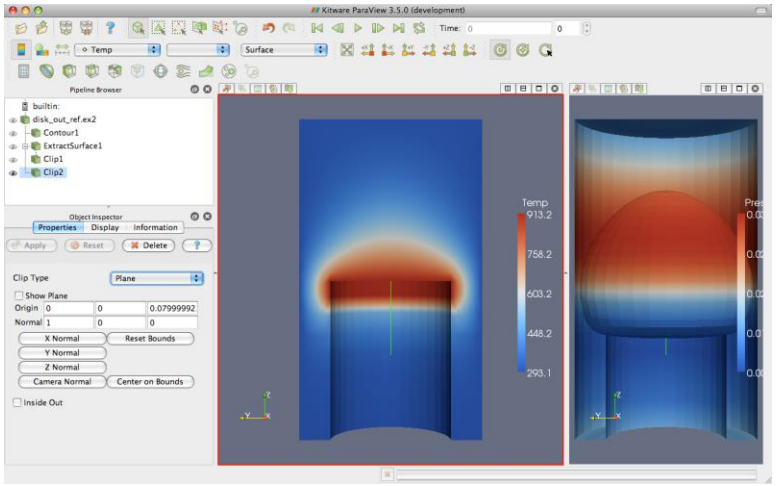
Modifying Views





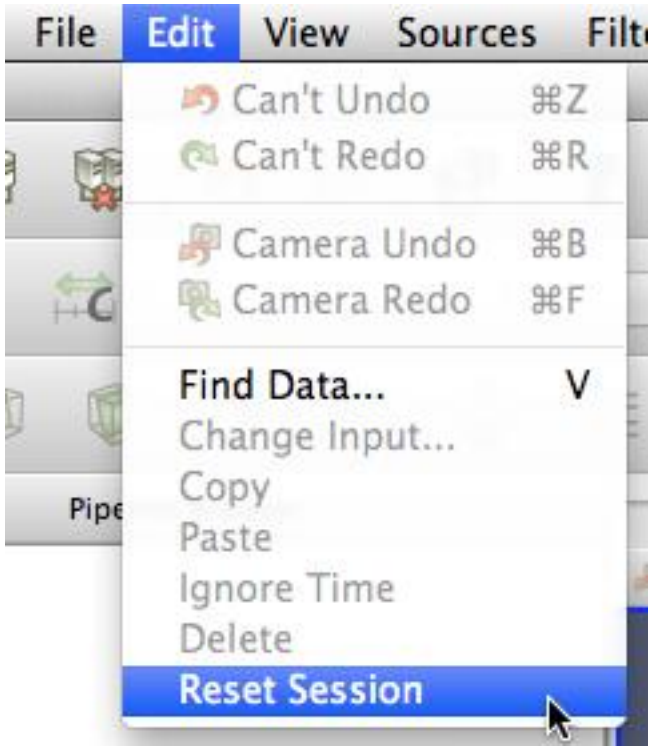
Modifying Views



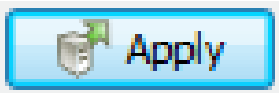


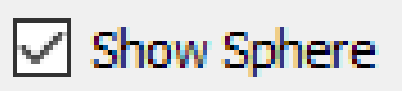
Reset ParaView

Edit → Reset Session



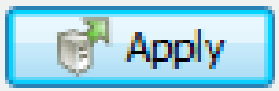
Streamlines

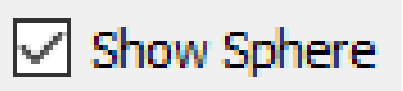
1. Open disk_out_ref.ex2. Load all variables. 

2. Add Stream Tracer. 
3. Change Seed Type to Point Source.
4. Uncheck Show Sphere. 

5. 

Streamlines

1. Open disk_out_ref.ex2. Load all variables. 

2. Add Stream Tracer. 
3. Change Seed Type to Point Source.
4. Uncheck Show Sphere. 

5. 

6. From the quick launch, select Tube
7. 

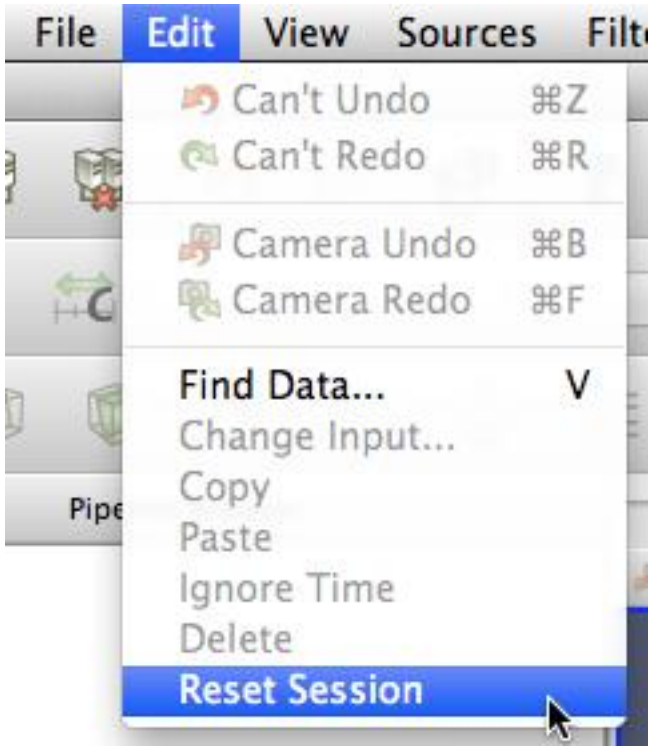
Getting Fancy

8. Select StreamTracer1.
9. Add Glyph filter. 
10. Change Glyph Type to Cone.
11. Change Orientation Array and Scale Array to V.
12. Change Vector Scale Mode to Scale By Magnitude.
13. Click reset  next to Scale Factor.
14. 

15. Color by Temp.

Reset ParaView

Edit → Reset Session



Common Data Analysis Filters

Extract Selection

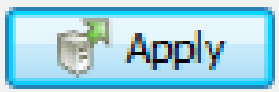
Plot Global Variables Over Time

Plot Over Line

Plot Selection Over Time

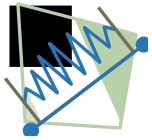
Probe Location

Plotting

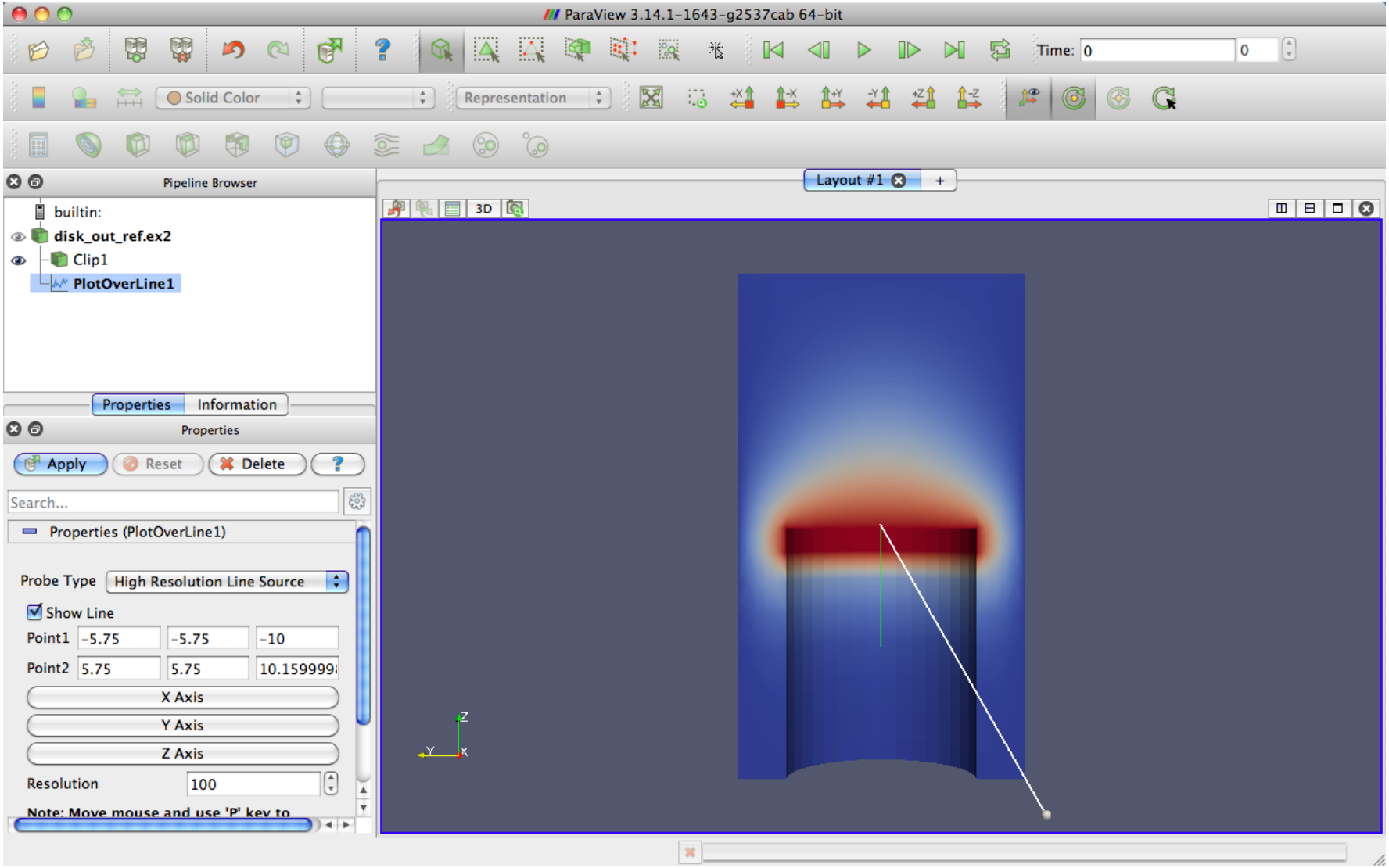
1. Open disk_out_ref.ex2. Load all variables. 

2. Clip,  uncheck, 

, 

3. Select disk_out_ref.ex2.
4. Add Plot Over Line filter. 

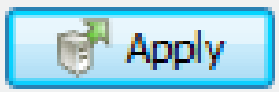
3D Widgets


ParaView 3.14.1-1643-g2537cab 64-bit
Time: 0
0
Solid Color
Representation
Pipeline Browser
builtin:
disk_out_ref.ex2
Clip1
PlotOverLine1
Layout #1
3D
Properties
Information
Properties
Apply
Reset
Delete
Search...
Properties (PlotOverLine1)
Probe Type
High Resolution Line Source
Show Line
Point1
-5.75
-5.75
-10
Point2
5.75
5.75
10.159999
X Axis
Y Axis
Z Axis
Resolution
100
Note: Move mouse and use 'P' key to

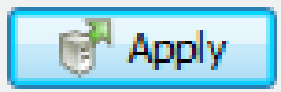
Placing 3D Line Widget Endpoints

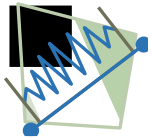
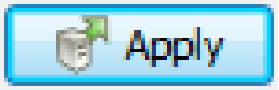
- Use the p key to place alternating points.
  - Ctrl+p places at nearest mesh point.
- Use the 1 or 2 key to place the start or end point.
  - Ctrl+1 or Ctrl+2 places at mesh point.
- Drag the endpoints.
  - Use x, y, or z key to constrain to axis.
- Use widgets in Properties panel
  - E.g. Use Z Axis button and then edit points to place from (0,0,0) to (0, 0, 10).

Plotting

1. Open disk_out_ref.ex2. Load all variables. 

2. Clip,  uncheck, 

, 

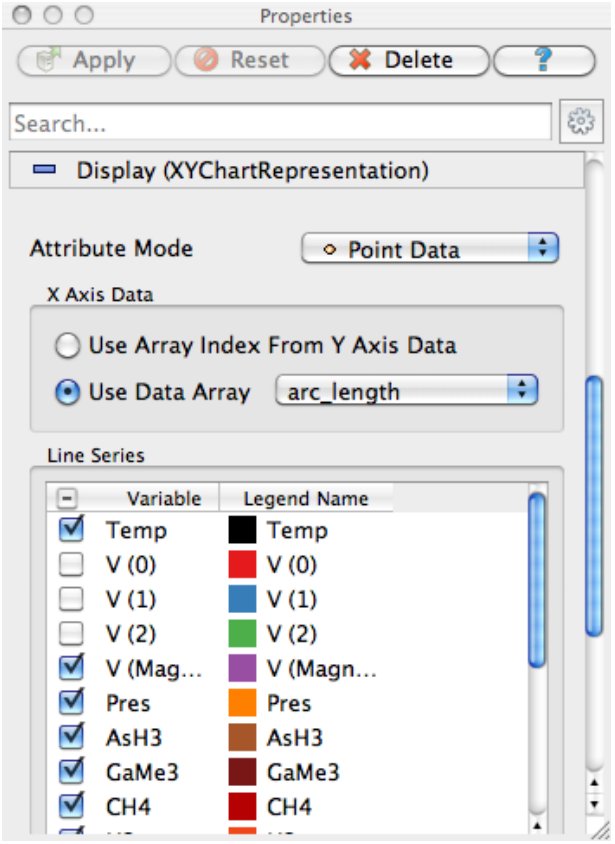
3. Select disk_out_ref.ex2.
4. Add Plot Over Line filter. 
5. Once line is satisfactorily located, 

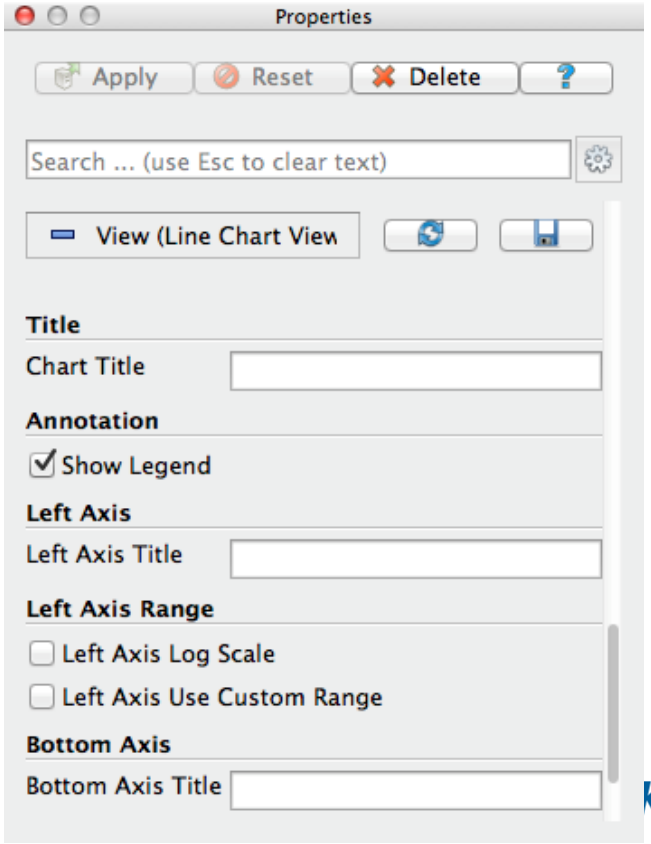
Interacting with Plots

- Left, middle, right buttons to pan, zoom.
- Mouse wheel to zoom.
- Reset view to plot ranges. 

Plots are Views

- Move them like Views.
- Save screenshots.

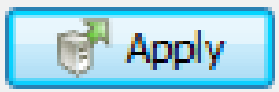




Adjusting Plots

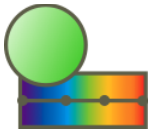
1. In Display section of properties panel, turn off all variables except Temp and Pres.
2. Select Pres in the Display options.
3. Change Chart Axis to Bottom – Right.
4. Verify the relationship between temperature and pressure.

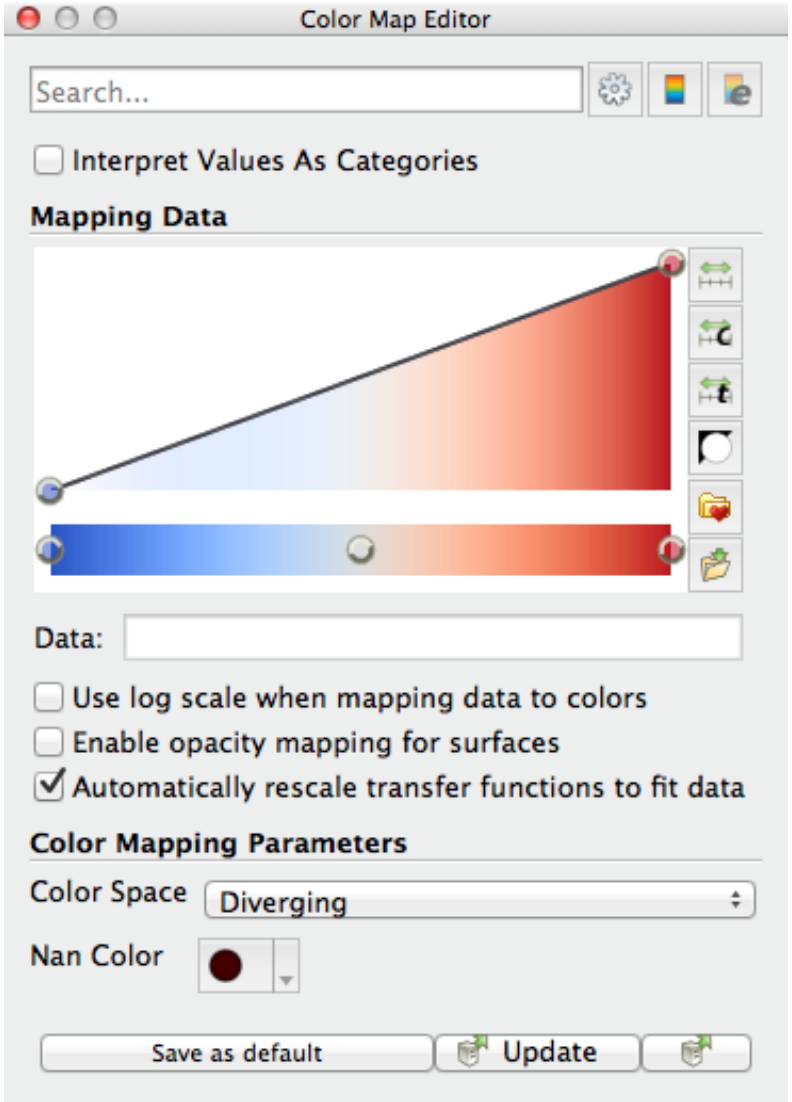
Volume Rendering

1. Open disk_out_ref.ex2. Load all variables. 

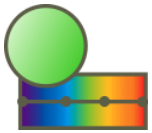
2. Change variable viewed to Temp.
3. Change representation to Volume.
4. In the Are you Sure dialog box, click Yes.

Transfer Function Editor



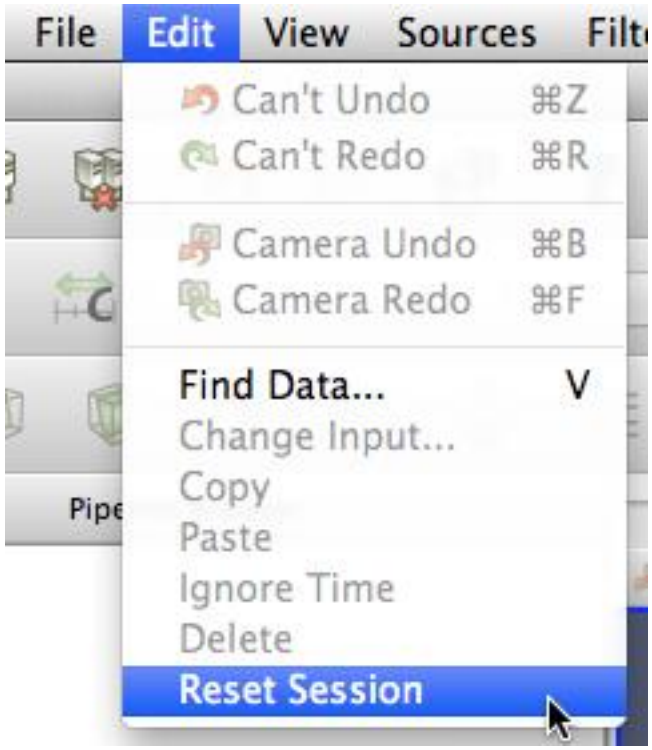


Modify Transfer Function

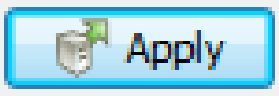
1. Select disk_out_ref.ex2.
2. Click Edit Color Map  .
3. Click Choose preset  .
4. Select Black-Body Radiation. Apply. Close.
5. Try adding and changing control points.

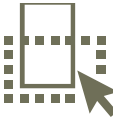
Reset ParaView

Edit → Reset Session

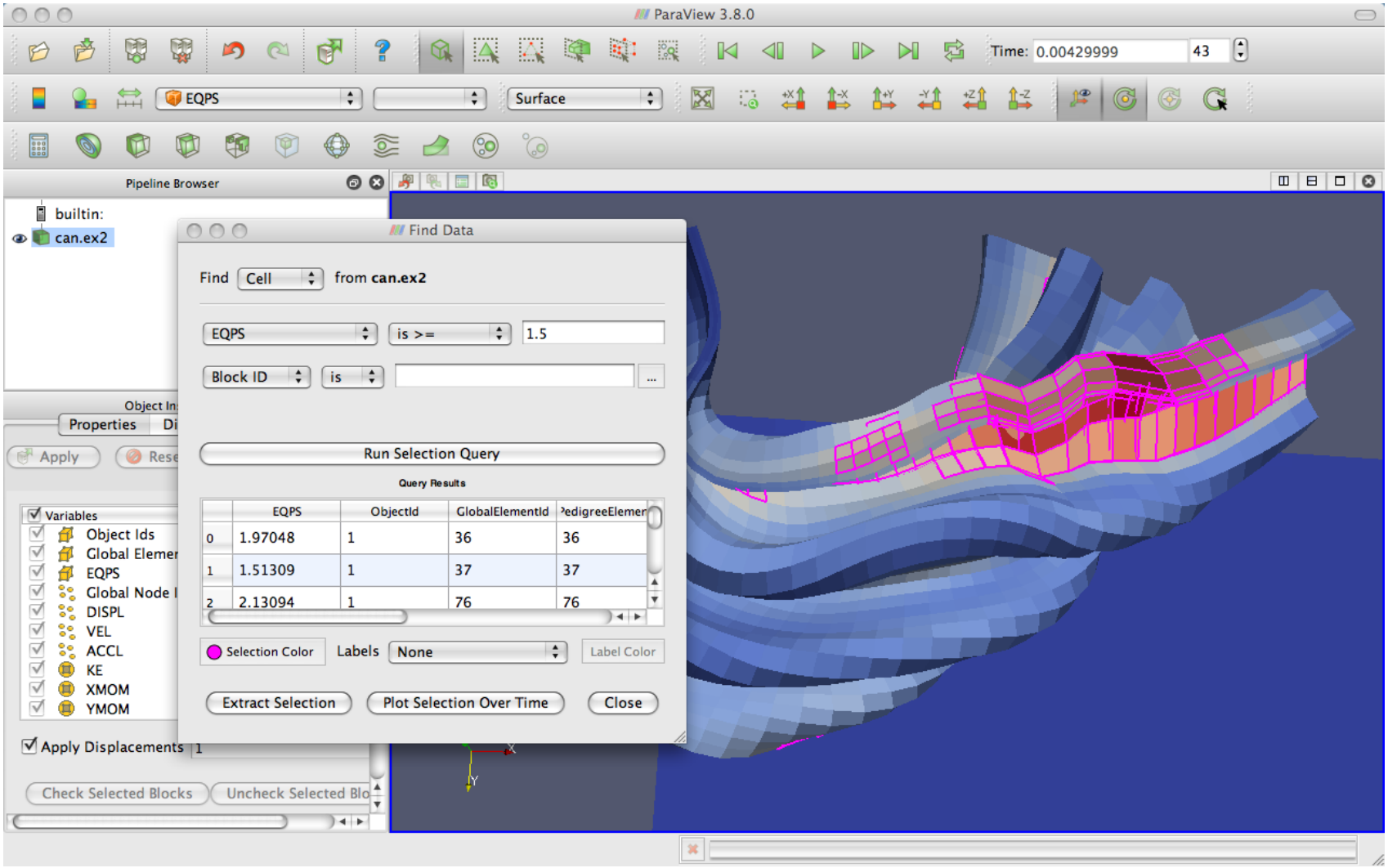


Query-Based Selection

1. Open can.ex2. All variables. 

2. Go to last time step. 
3. Edit → Find Data. 
4. Top combo box: find Cells.
5. Next row: EQPS, is >=, and 1.5.
6. Click Run Selection Query.

Query-Based Selection



Brush Selection

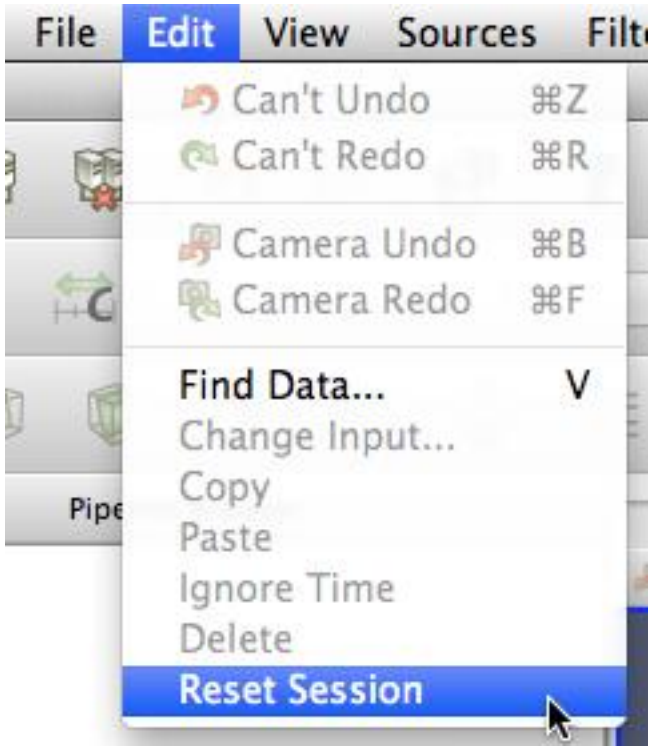
- Surface Cell Selection (shortcut: s)
- Surface Point Selection (shortcut: d)
- Through Cell Selection (shortcut: f)
- Through Point Selection (shortcut: g)
- Select Cells (polygon)
- Select Points (polygon)
- Block Selection (shortcut: b)
- Interactively Select Cells
- Interactively Select Points
- Hover Point Query
- Hover Cell Query

Adding Labels

1. Go to the last time step.
2. Interactively Select Cells
3. Open Find Data.
4. In the Cell Labels chooser, select EQPS.
5. Try again: Interactively Select Cells

Reset ParaView

Edit → Reset Session



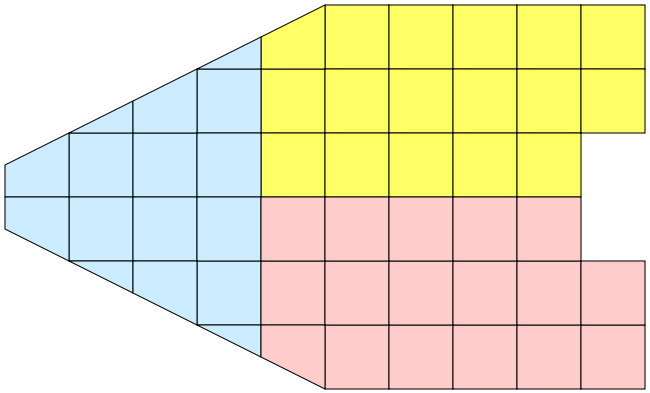
Python Scripting

- Tools > Start Trace
- Build visualization pipeline with UI
- Tools > End Trace
- Save Python script

Visualizing Large Models

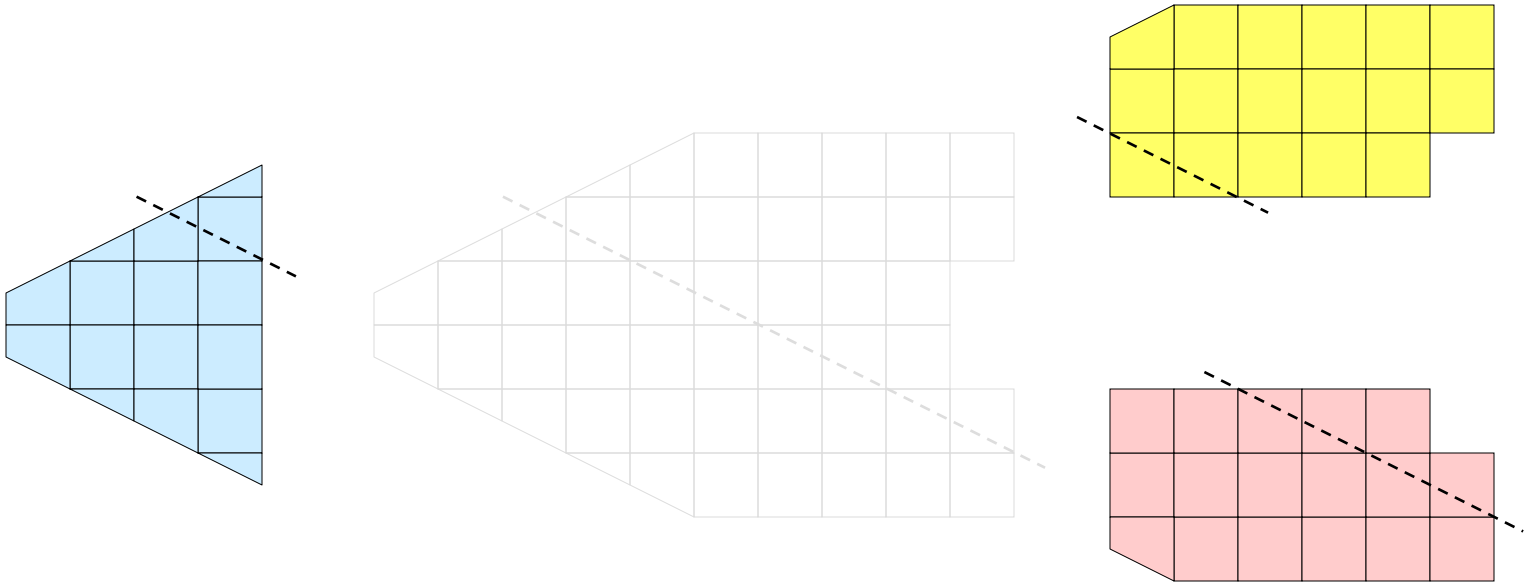
Data Parallel Pipelines

- Duplicate pipelines run independently on different partitions of data.



Data Parallel Pipelines

- Many operations will work regardless.
  - Example: Clipping.



Data Parallel Pipelines

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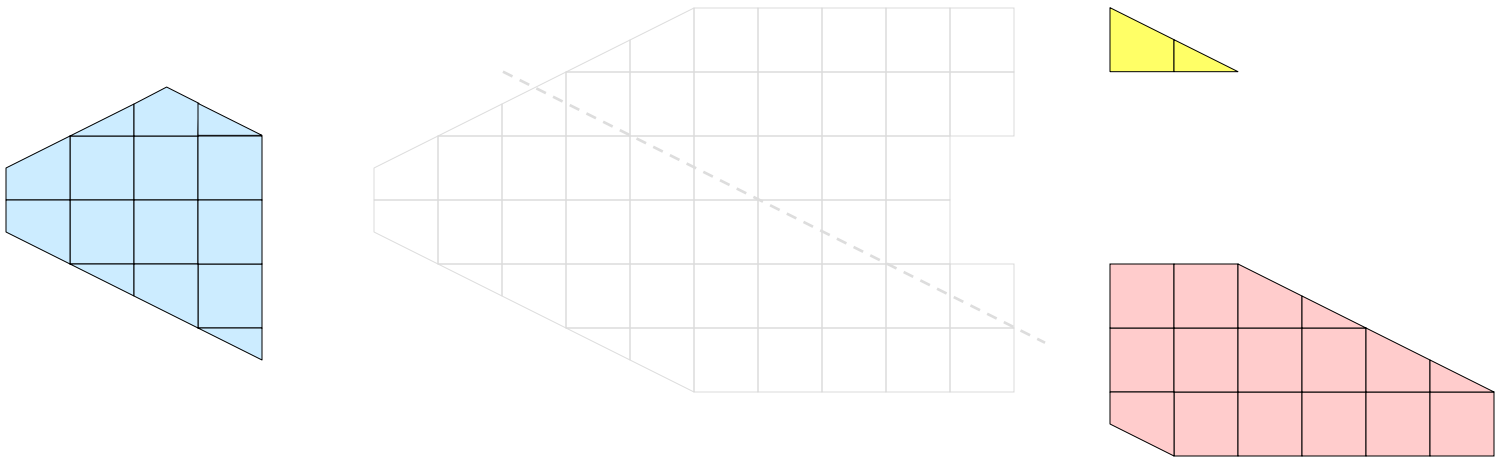
  - Example: Clipping.



Data Parallel Pipelines

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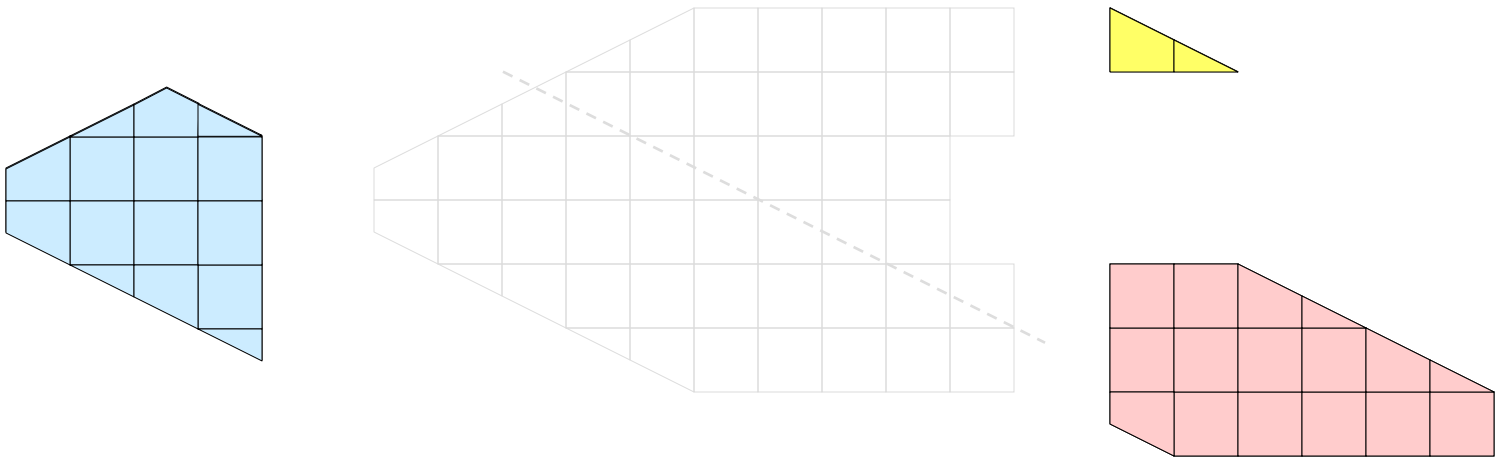
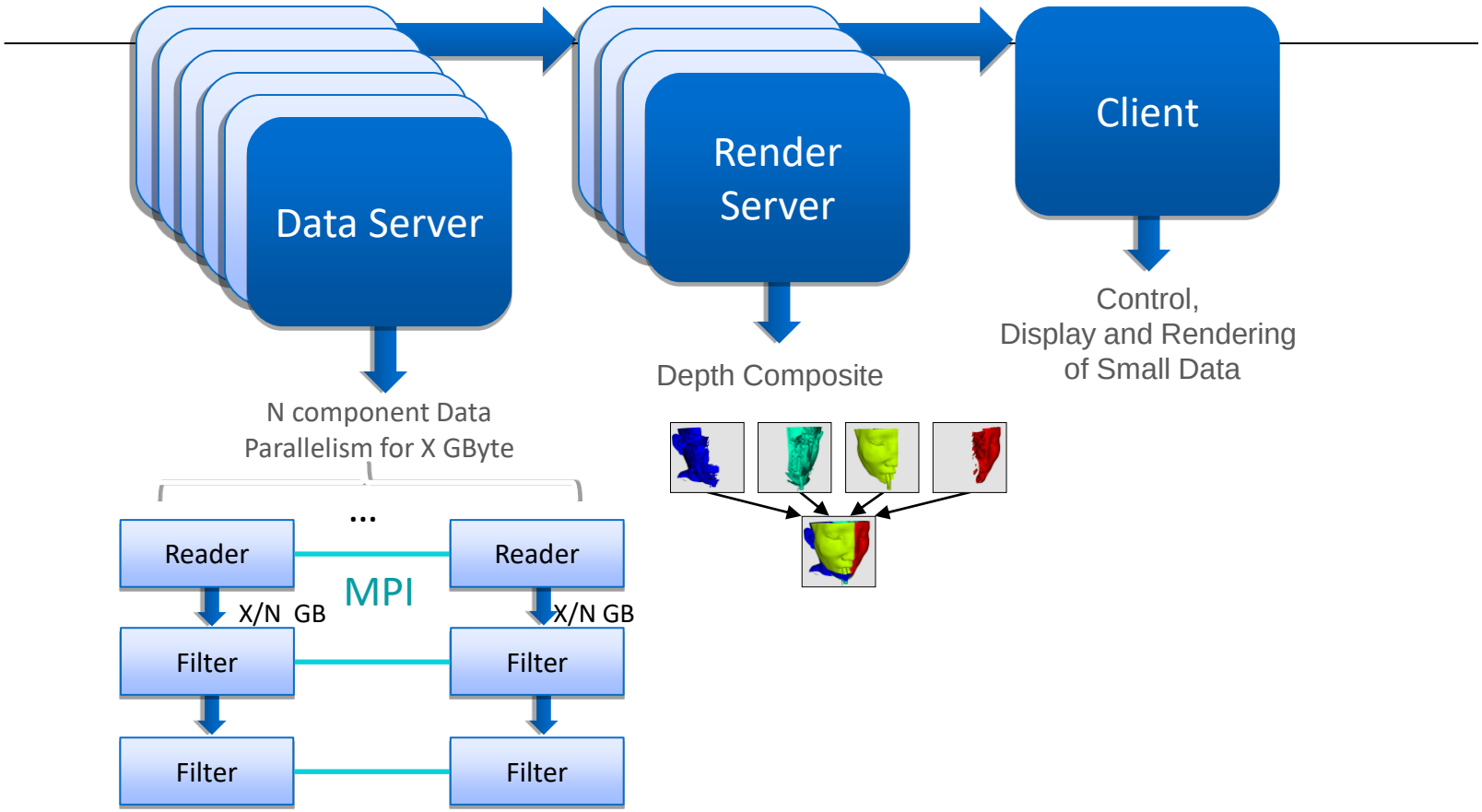
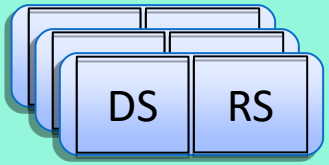
  - Example: Clipping.



- Will discuss those that don’t later


Data Server
Render Server
Client
Control,
Display and Rendering
of Small Data
Depth Composite
N component Data
Parallelism for X GByte
...
Reader
Reader
MPI
X/N GB
X/N GB
Filter
Filter
Filter
Filter

ParaView's Running Modes

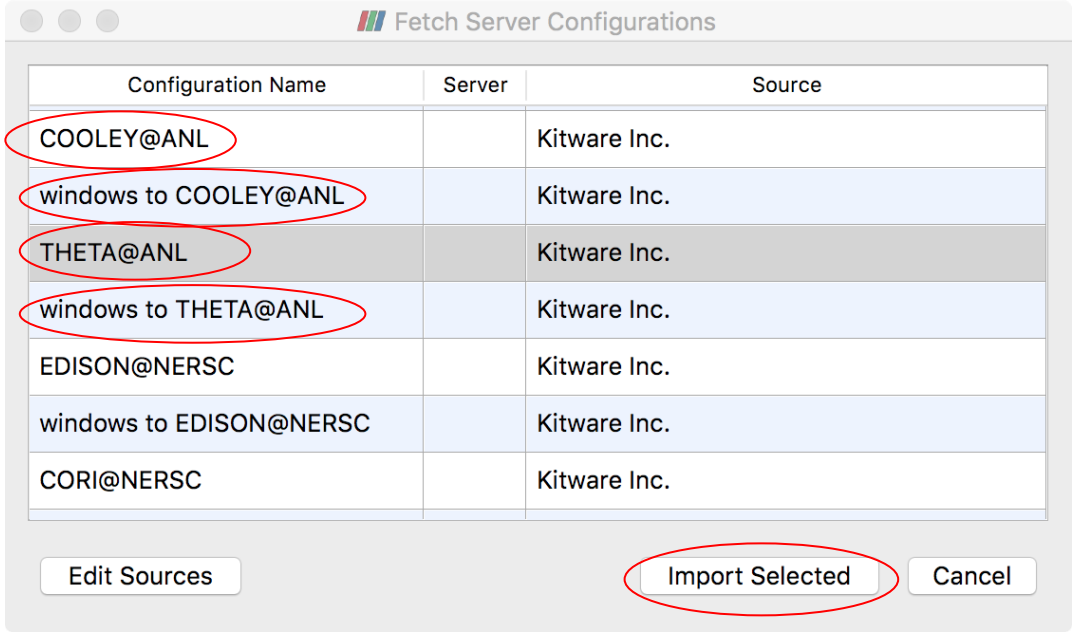
Builtin aka Standalone aka Serial		all components within one process (client may be GUI or pvpython) `paraview || pvpython`
Combined Server		data processing and parallel rendering in MPI job of combined processes. control from TCP connected client. `mpiexec -n x pvserver &; paraview #` or `pvpython #`+ Connect
Batch		server is an MPI job which directly runs a python script `mpiexec -n x pvbatch \ vis_script.py`

DS = data server

RS = render server

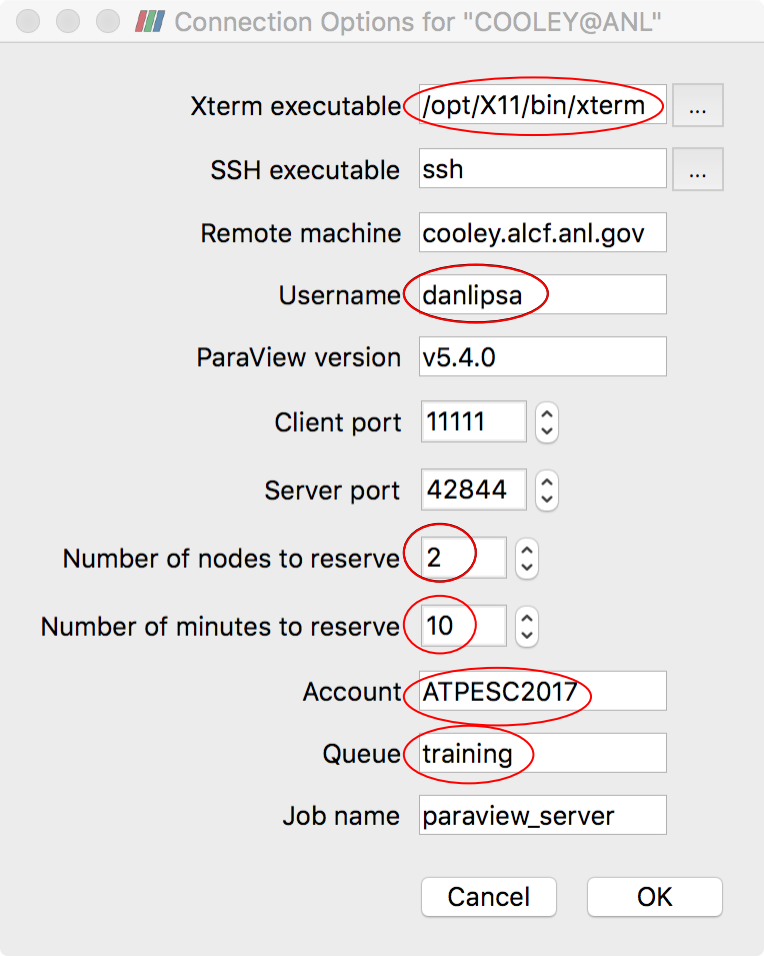
Fetch Server Configuration

- File > Connect > Fetch Servers



Connect Unix/Mac

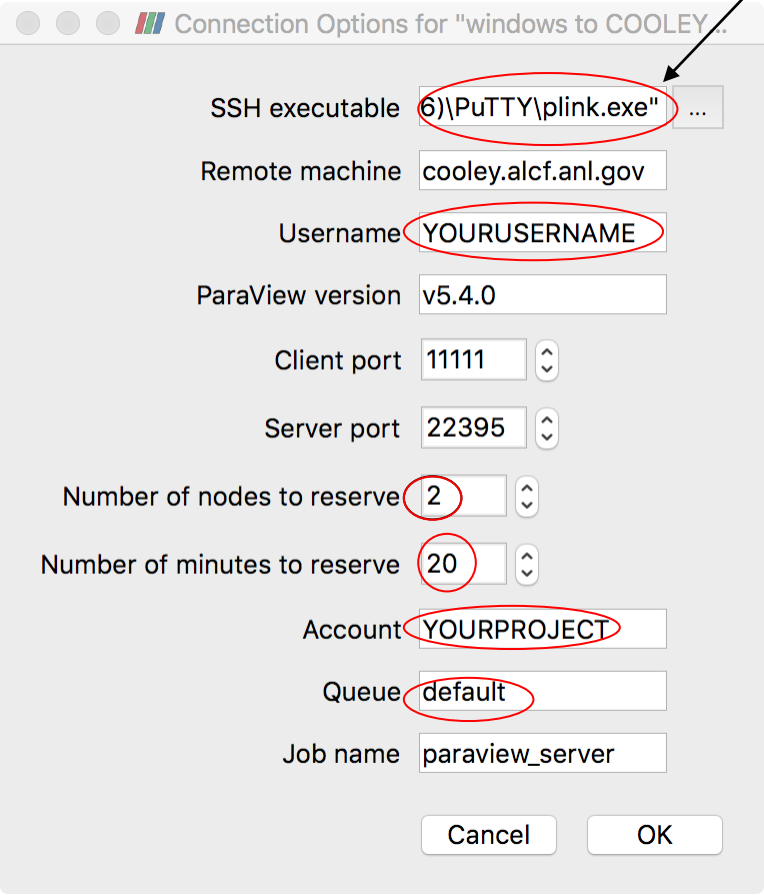
Mac Os: Install Xquartz



Connect Windows

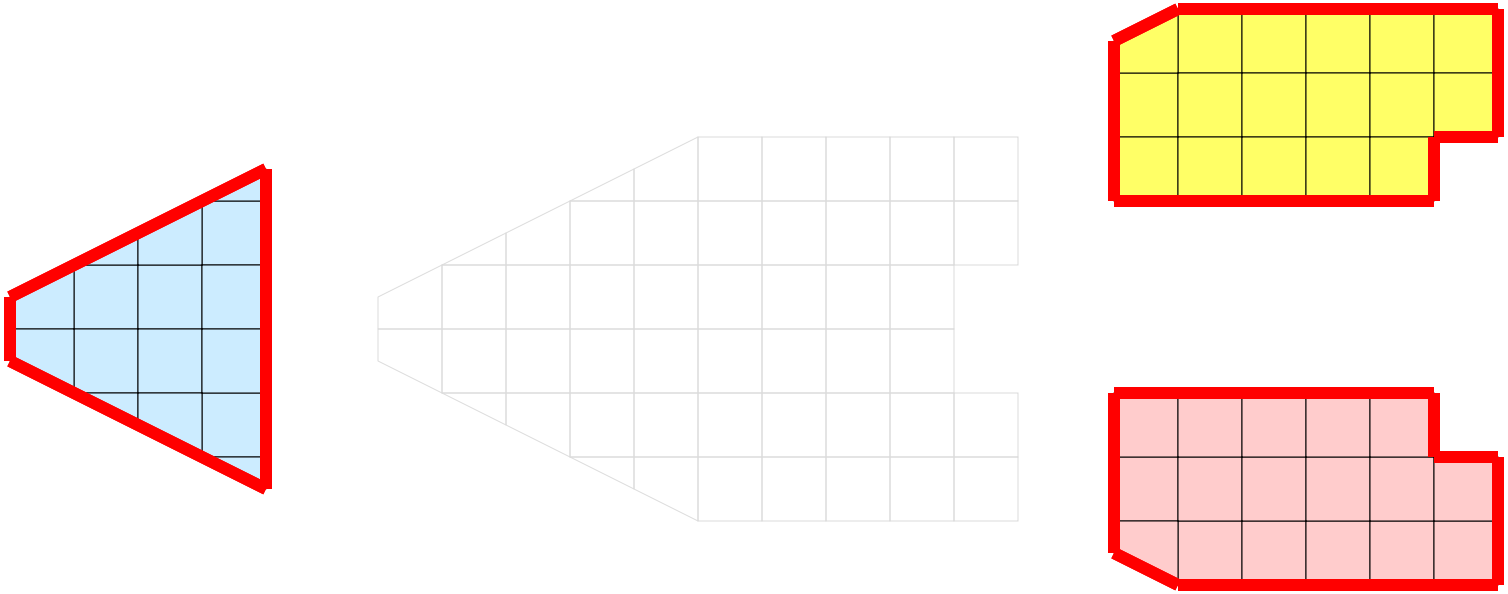
quotes are required

Windows: Install PuTTY



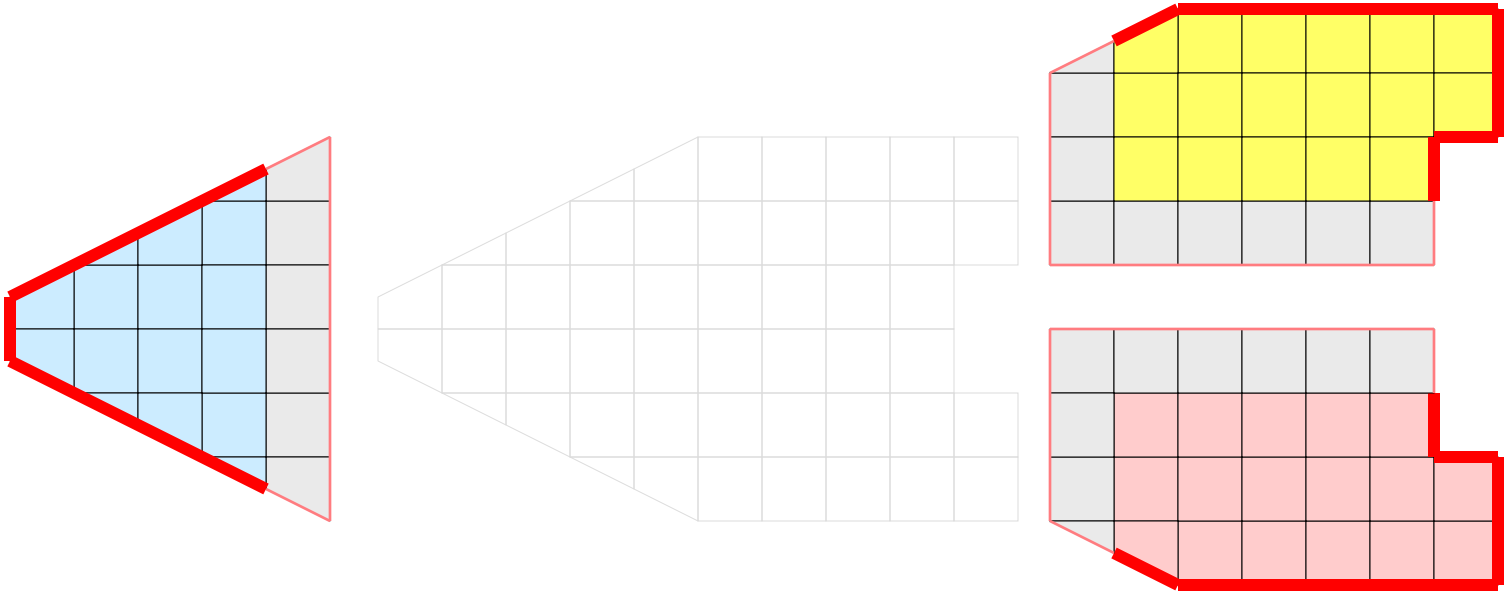
Advanced Data Parallel Pipelines

- Some operations will have problems.
  - Example: External Faces



Advanced Data Parallel Pipelines

- Ghost cells can solve most of these problems.



Advanced Data Parallel Pipelines

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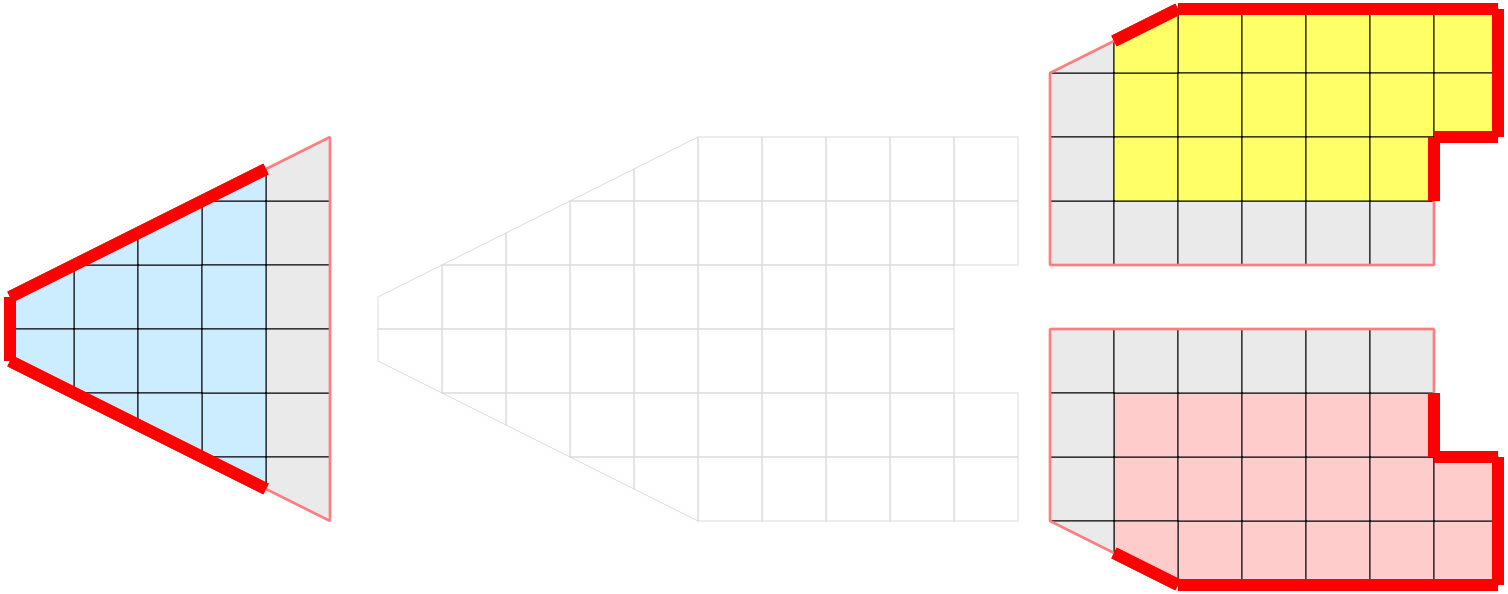
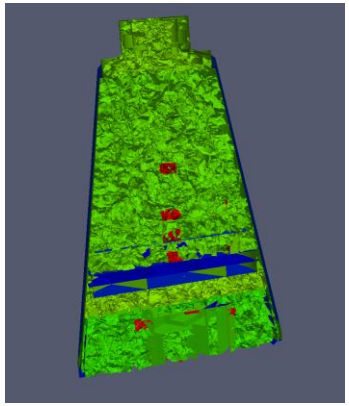
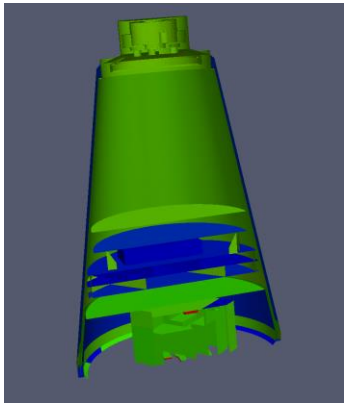


Balanced Partitioning + Ghost Cells

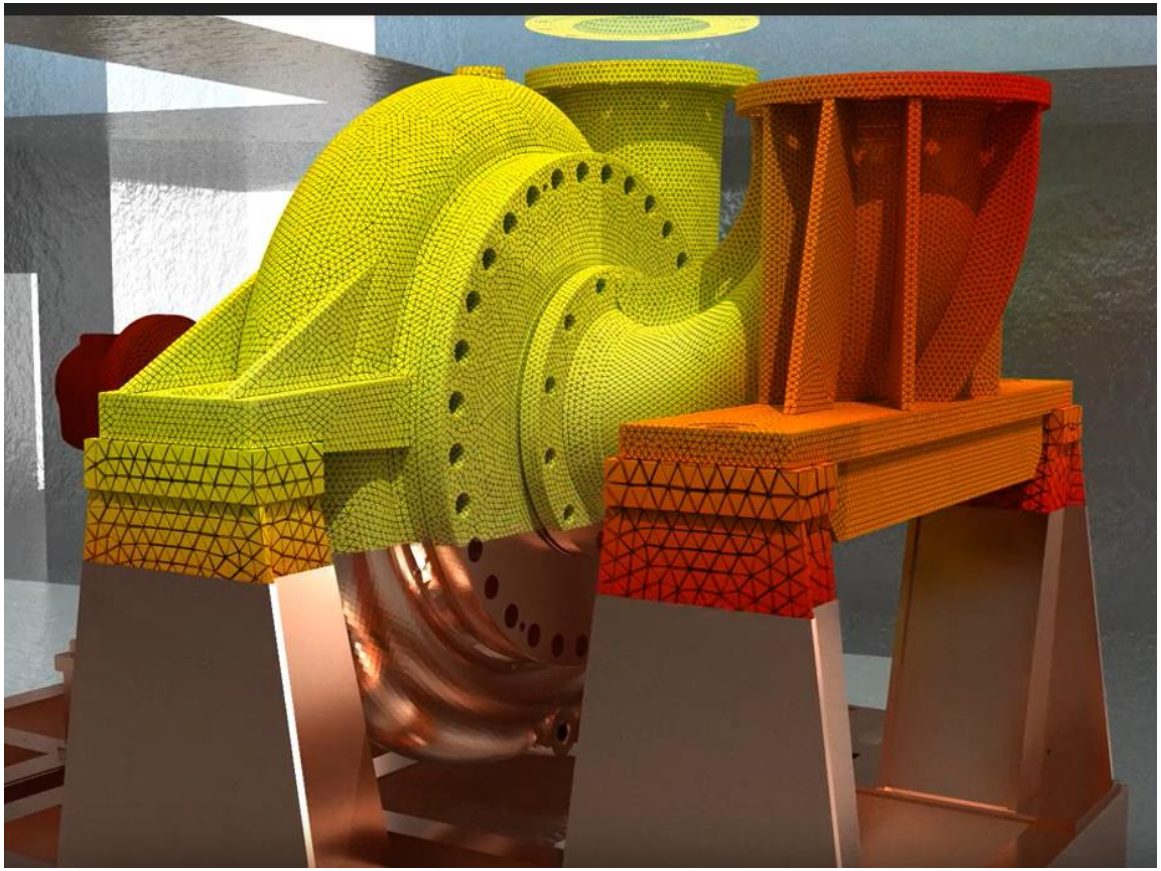
- Automatic when reading structured data.
- For unstructured data:
  - Ghost Level Generator: creates ghost cells (if data is partitioned on disk)
  - D3: also creates a balanced partition.

Extract Surface without ghost cells





Extract Surface after D3



Thank you!

Questions?