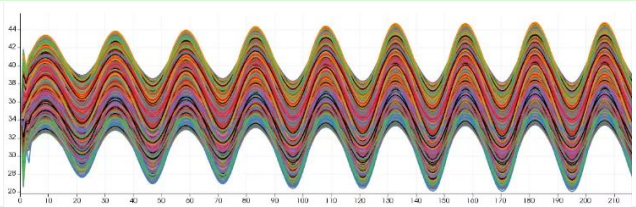
Large Scale Visualization with ParaView

ATPESC 2024



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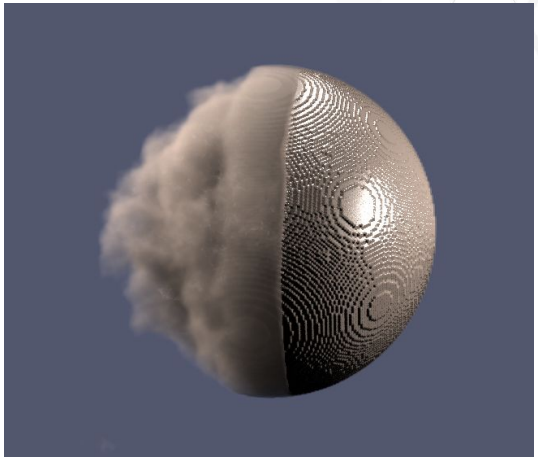
Outline

- Kitware
- Introduction
- Basic Usage
- Visualizing Large Models
- Topics for Future Exploration



Volumetric Rendering in VTK and ParaView: Introducing the Scattering Model on GPU

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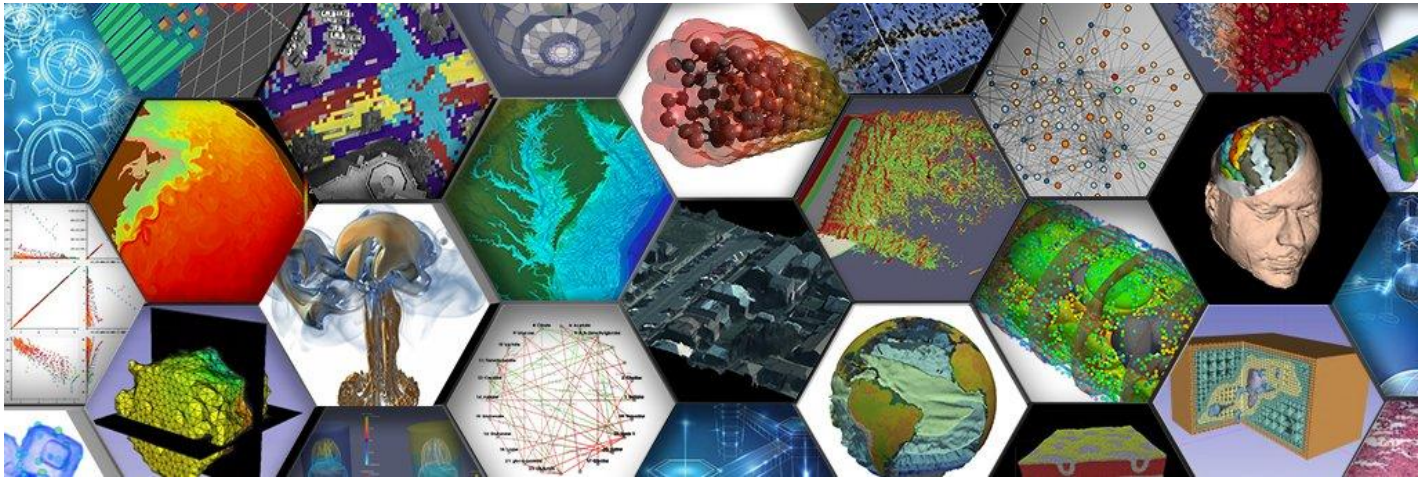
Kitware

- Open-source, software R&D company
- Five core areas of expertise



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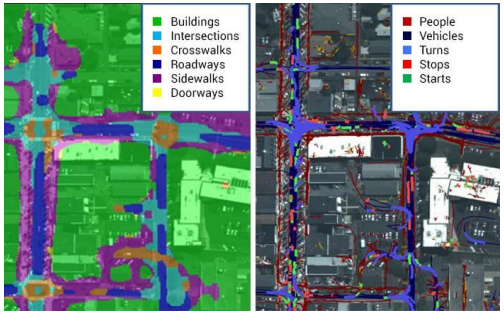
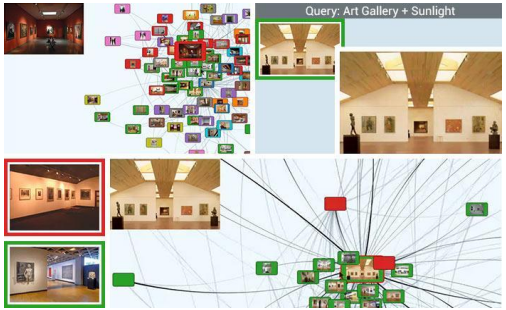
Kitware – Computer Vision

KWIVER

TeleSculptor

VIAME





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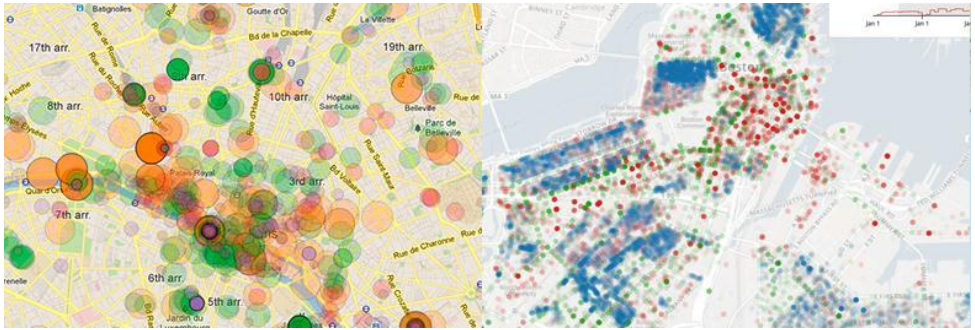
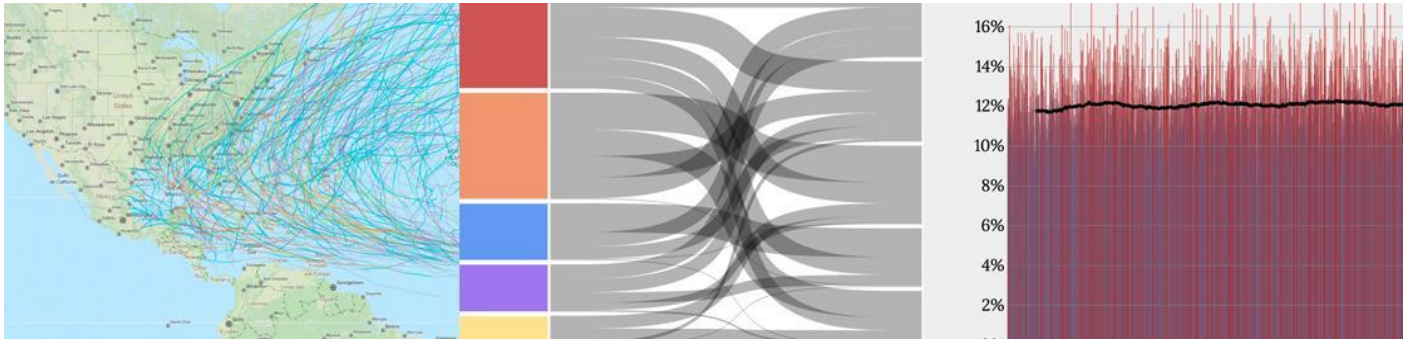
Kitware – Data and Analytics

Resonant





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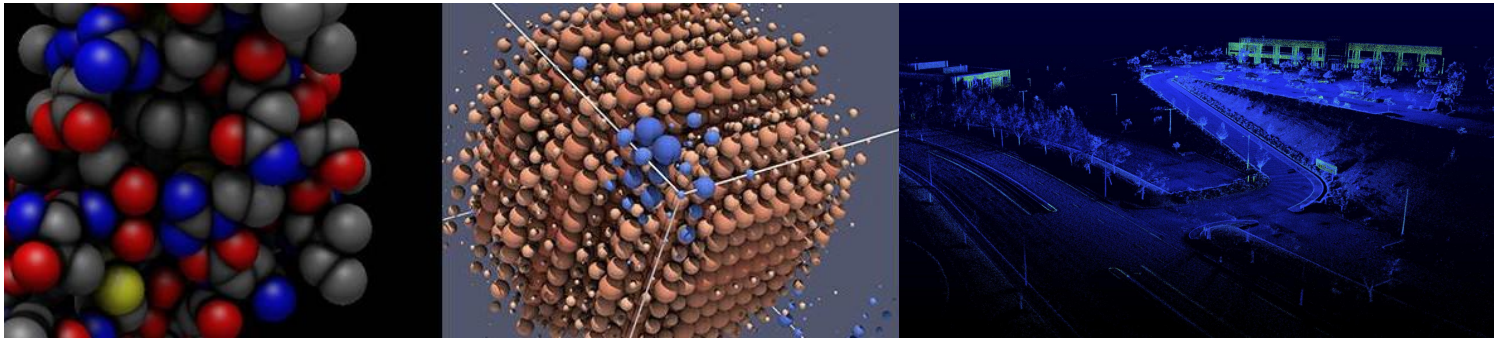
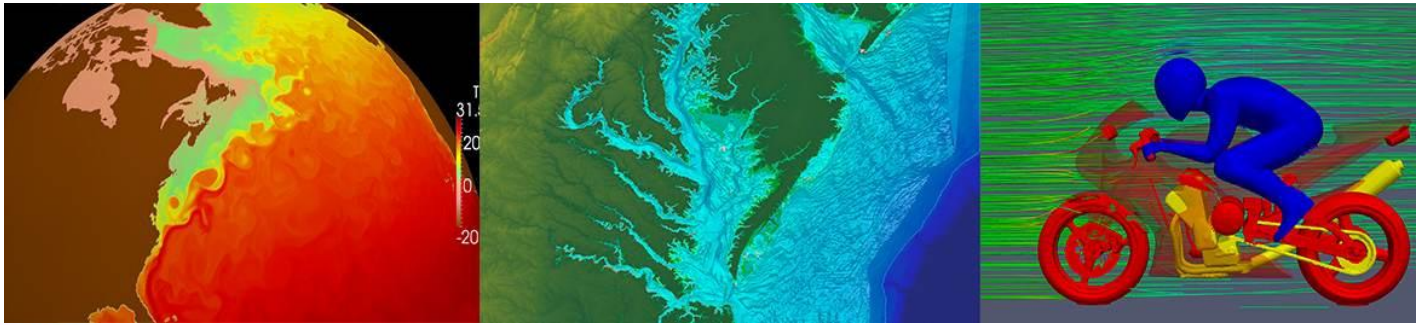
Kitware – HPC and Visualization

VTK ParaView Trame CMB tomviz LidarView





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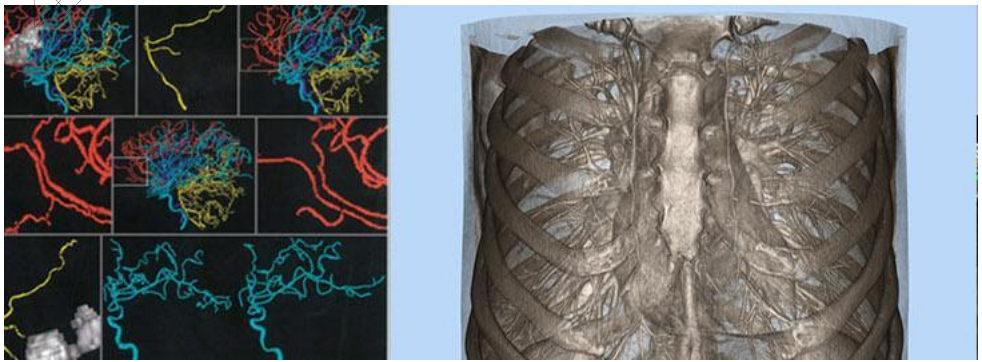
Kitware – Medical Computing

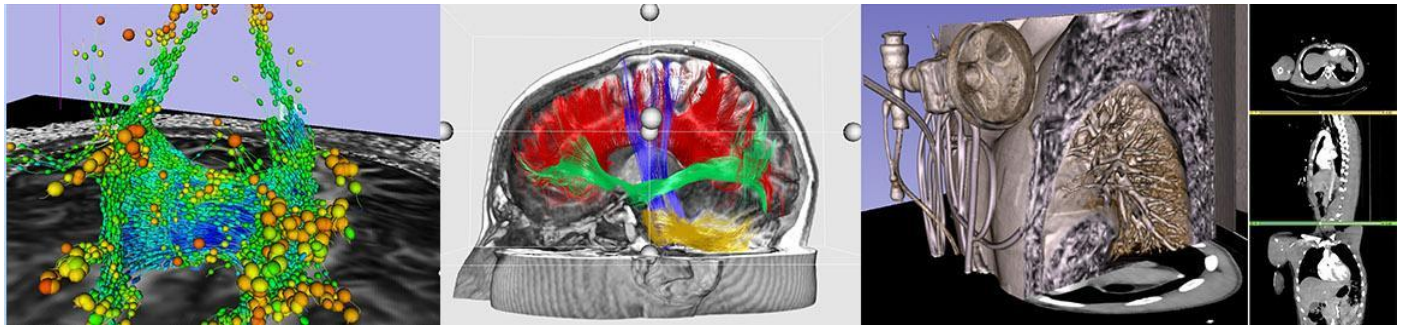
ITK

3DSlicer

Pulse
Physiology Engine

mstk





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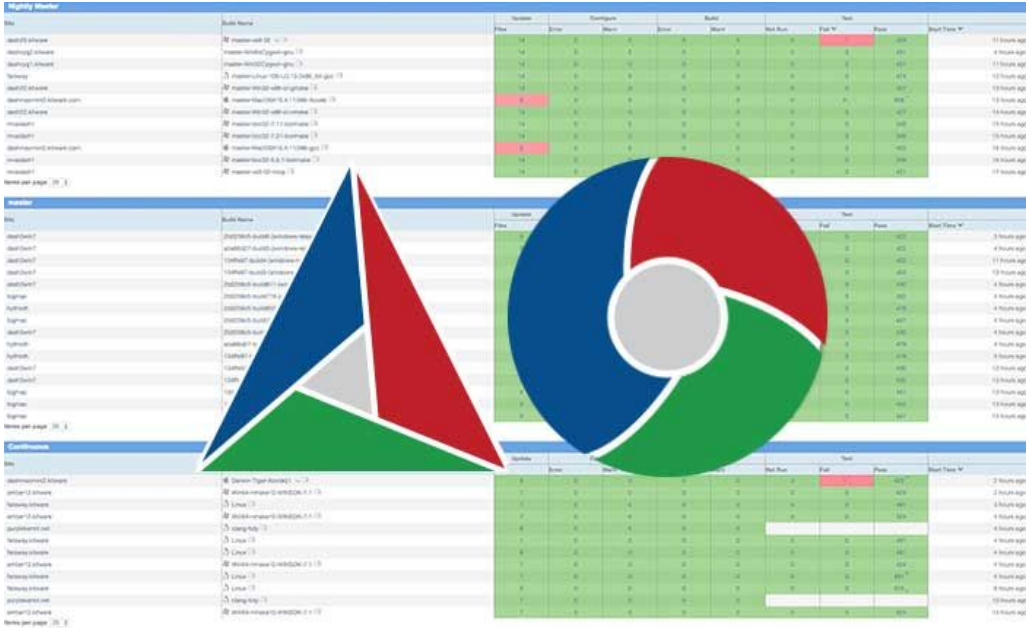
Kitware – Software Process

- cmake, ctest, cdash



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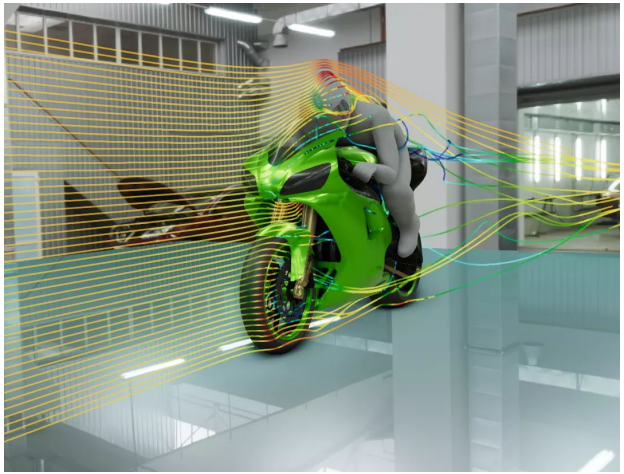
To Follow Along…

Install ParaView 5.12.0

- http://www.paraview.org Download



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Introduction

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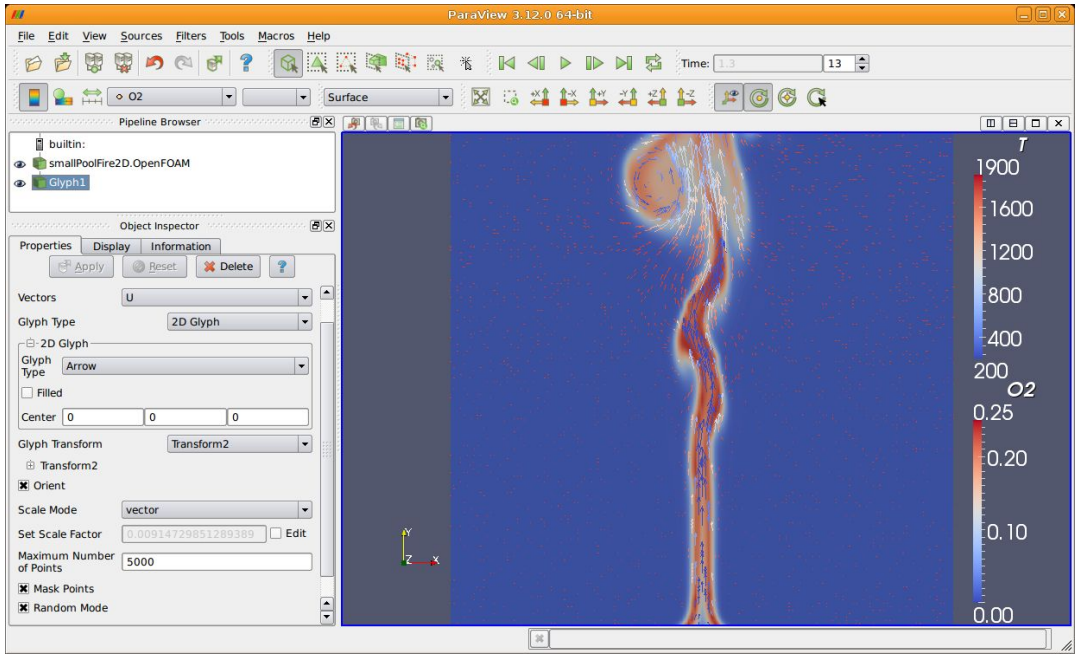
What is ParaView?

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

ParaView on the Desktop



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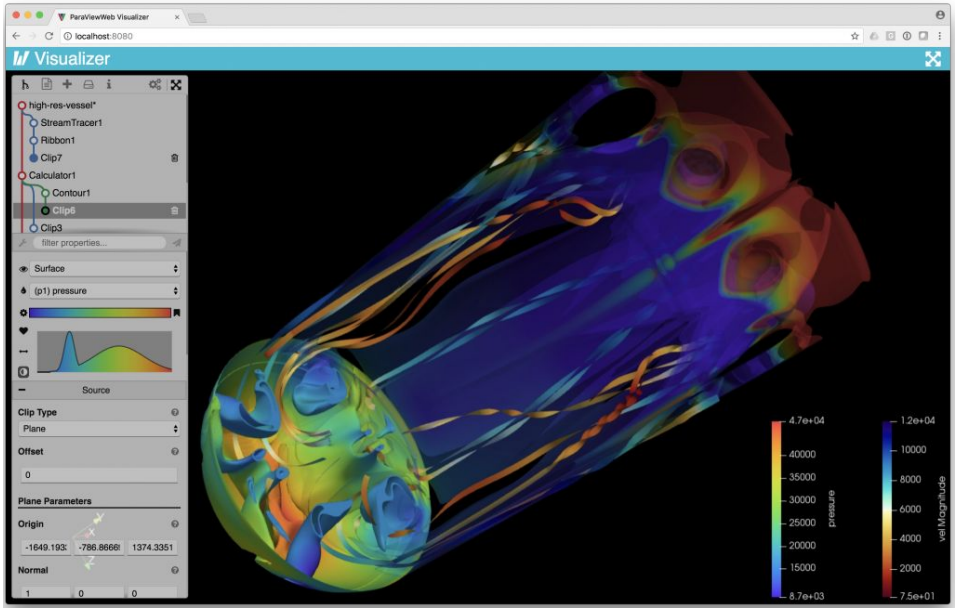
ParaView on the Web

Visualizer, Glance (vtk.js)

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



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ParaView Scripting - Python

Tools > Start Trace

__ build a pipeline __

Tools > Stop Trace

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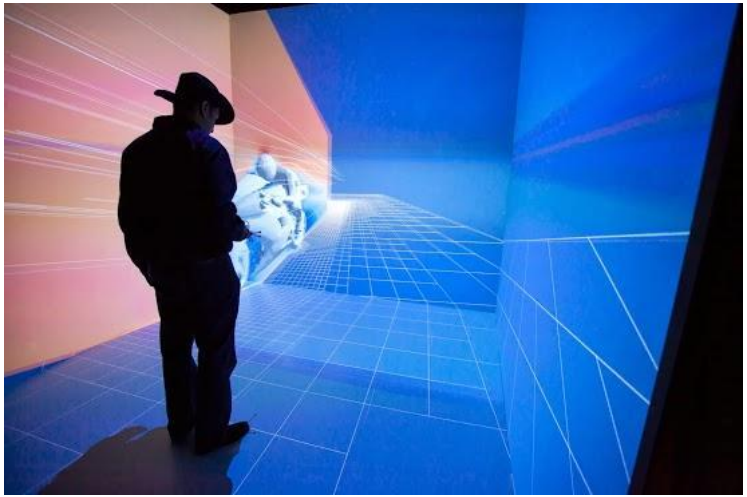
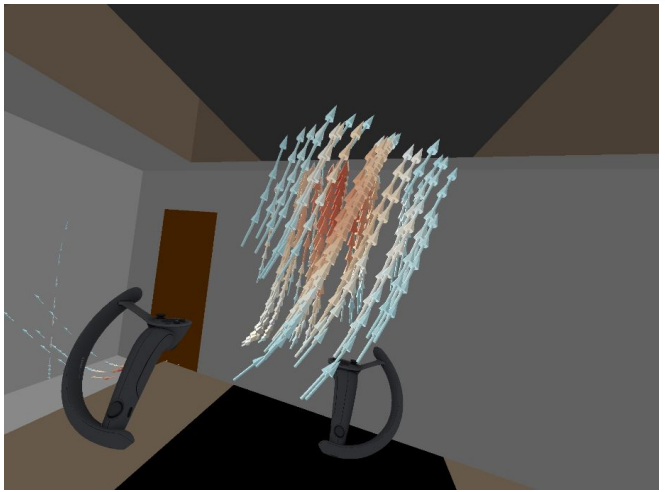
ParaView Immersive and VR





OpenVR, OpenXR

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ParaView for HPC

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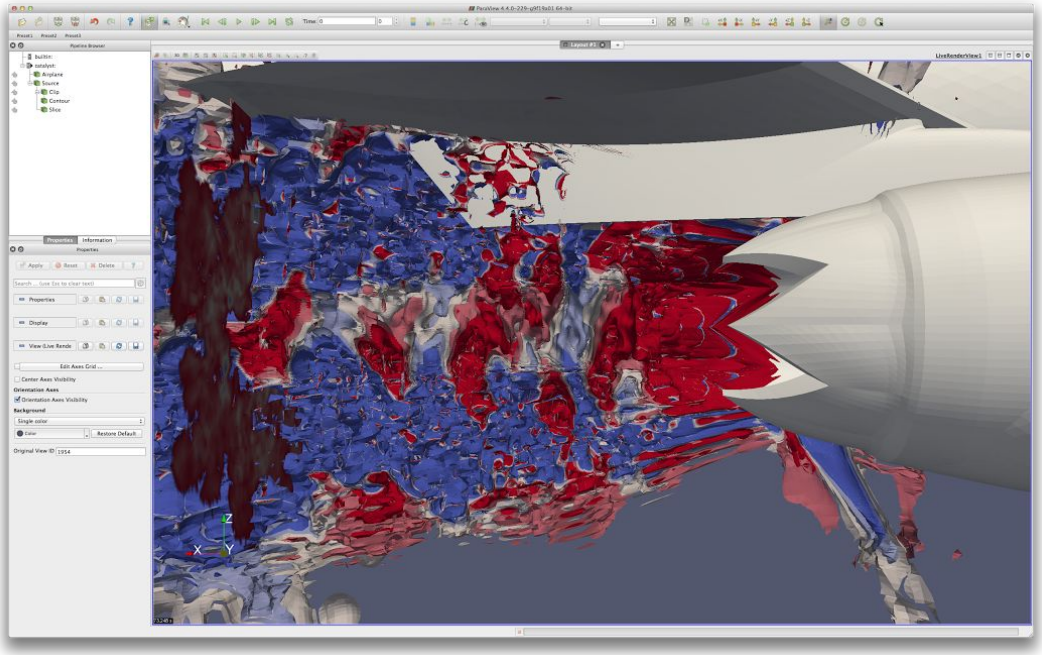
ParaView Catalyst



Uses Conduit Blueprint data description

- No need to compile ParaView
- No need to recompile when ParaView version changes
- Can choose insitu backend at runtime.

Simulations with Catalyst: PyFR, HPCMP CREATE HELIOS, PHASTA, MPAS Ocean, VPIC, RAGE, UH3D, CAM

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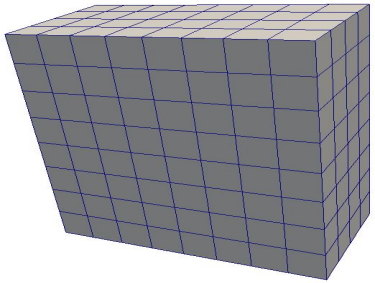
Current ParaView Usage

- 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.

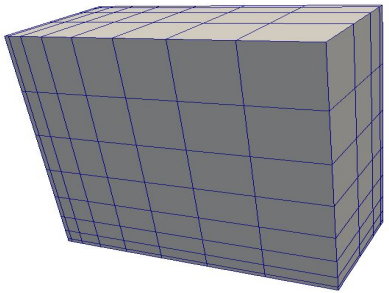
Data Ranges

- 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).

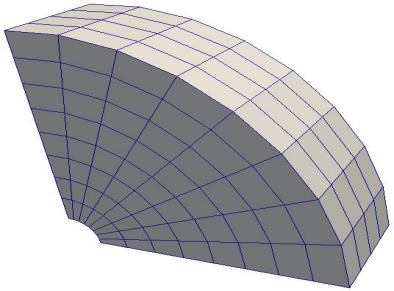
ParaView (VTK) Data Types



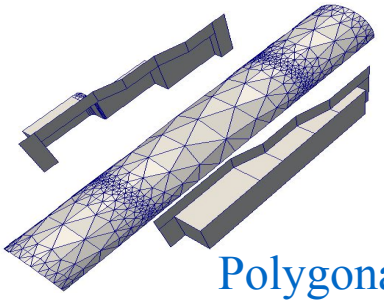
Uniform Rectilinear
(vtkImageData)



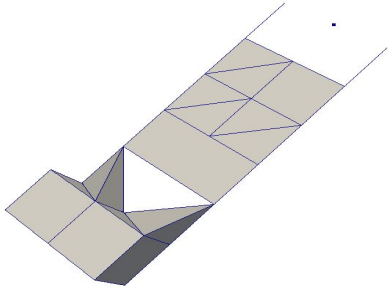
Non-Uniform Rectilinear
(vtkRectilinearData)



Curvilinear
(vtkStructuredData)



Polygonal
(vtkPolyData)



Unstructured Grid
(vtkUnstructuredGrid)

- Partitioned Dataset
- Partitioned Dataset Collection
- Adaptive Mesh Refinement (AMR)

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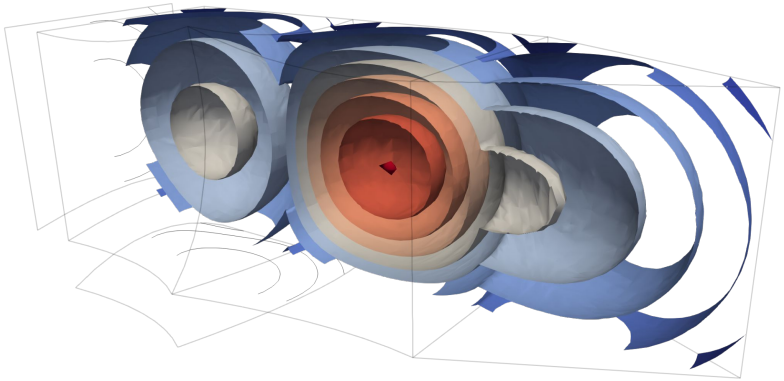
ParaView (VTK) Cell Types

- Cell types (linear, nonlinear), interpolation
- Arbitrary order Lagrange Finite Elements
- Discontinuous Galerkin elements and other novel cell-types/function-spaces



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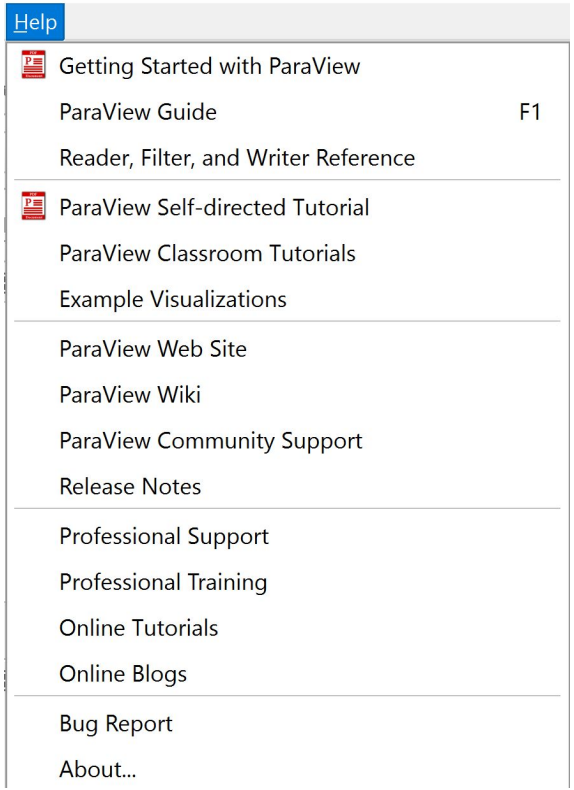
More Information



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Basic Usage

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User Interface

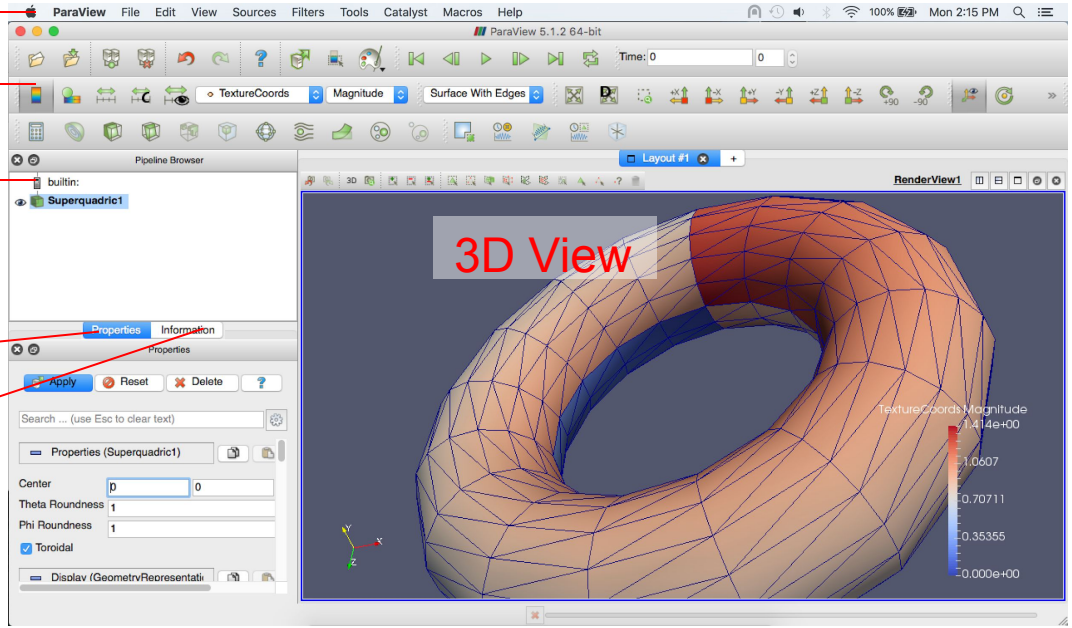
Menu Bar

Toolbars

Pipeline Browser

Properties Panel

Information Panel



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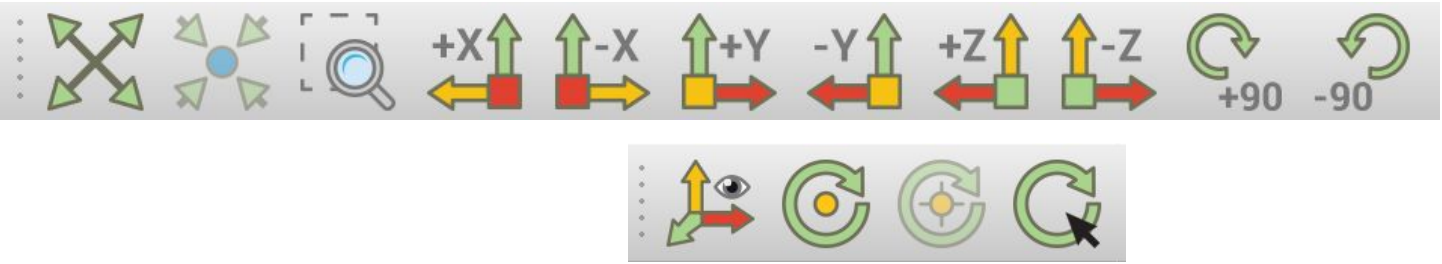
Creating a Cylinder Source

1. Go to the Sources menu and select Cylinder.
2. Click the 

button to accept the default parameters.

Simple Camera Manipulation

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



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Pipeline Object Properties

1. Go to the Source menu and select Cylinder.
2. Click the 

button to accept the default parameters.
3. Increase the Resolution parameter.
4. 

5. Click the 

button again.

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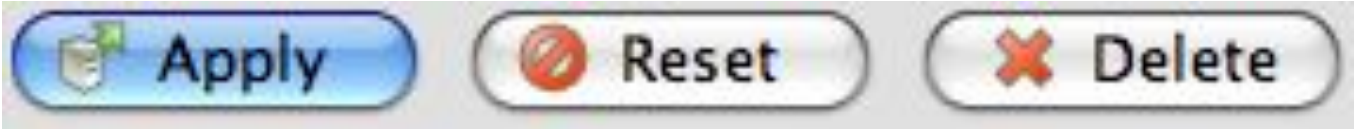
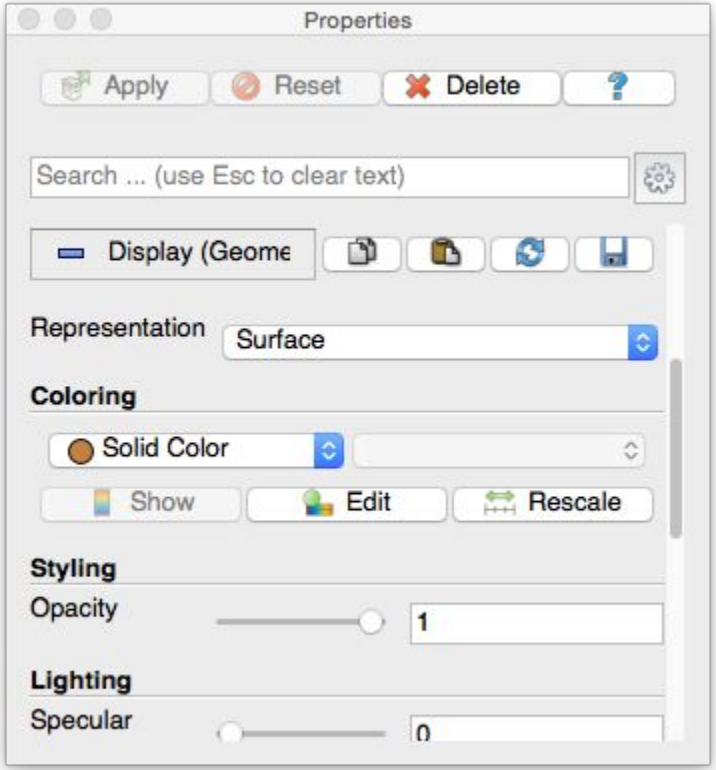
Pipeline Object Controls



Pipeline objects
- Sources
- Filters
- Readers
- Extractors

Display Properties



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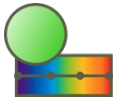
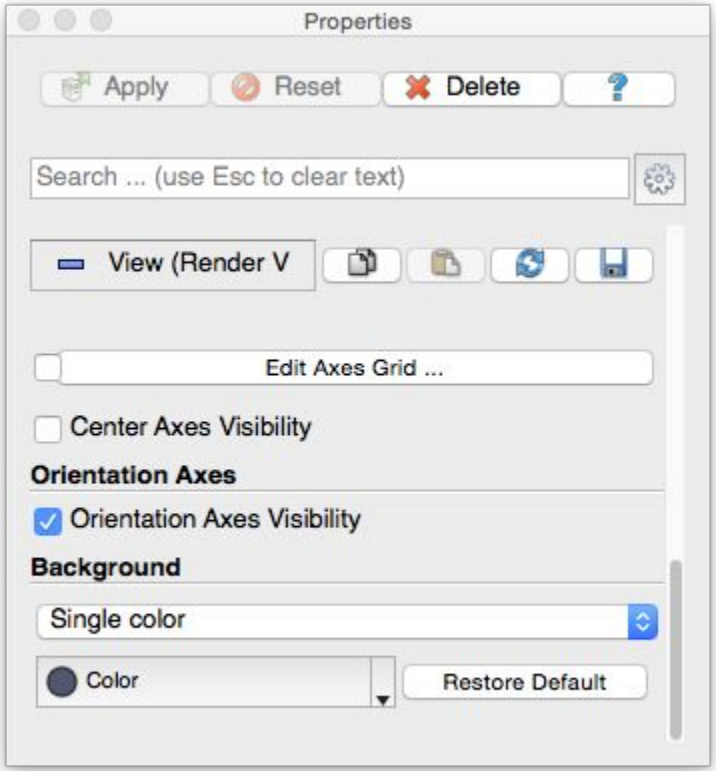
Change Display Properties

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

View Properties



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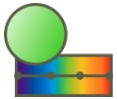
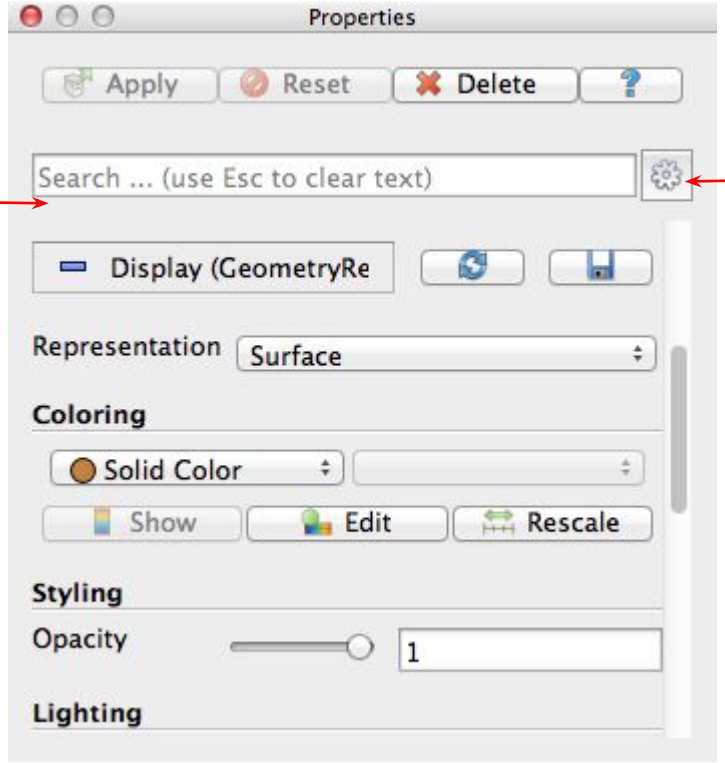
Change View Properties

1. Scroll down to the Display group.
2. Click the  Edit Color Map 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

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Searching Properties

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

Searching Properties

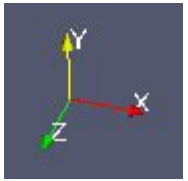
1. Type “specular” in the properties search box
2. Change Specular value to 1 (makes the cylinder shiny)

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.

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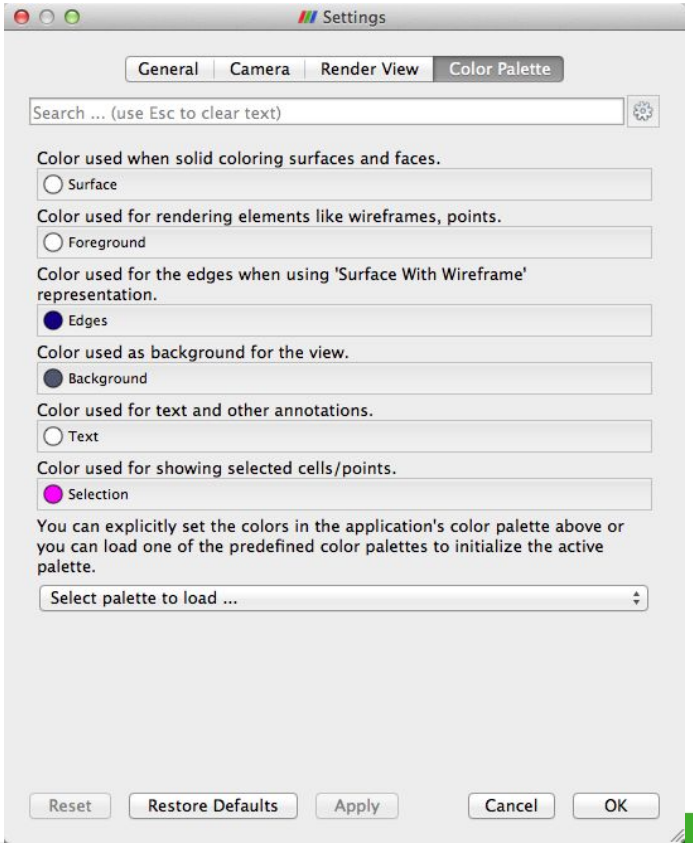
Color Palettes

→ Edit Current Palette…



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Undo Redo

Undo

Redo

Camera Undo

Camera Redo

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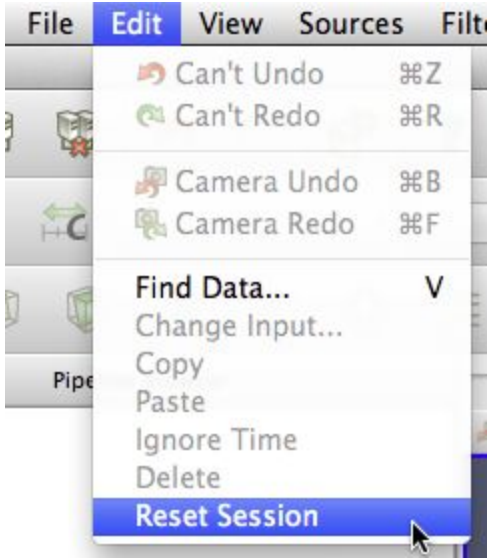
Reset ParaView

Edit → Reset Session



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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)
M3DCI (.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

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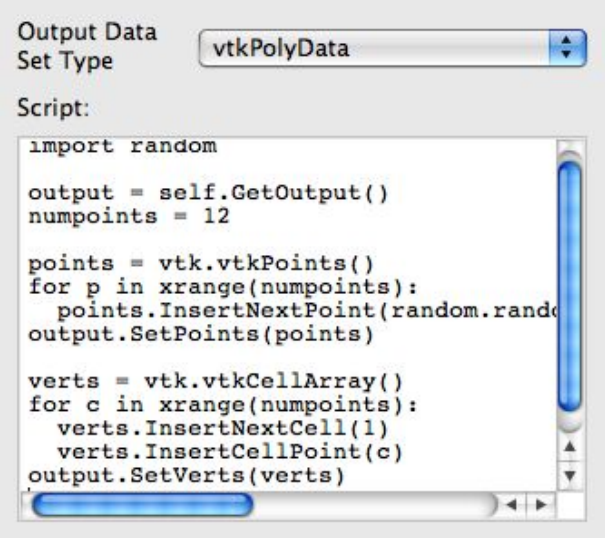
Custom Data Import: Prototype with Python

- Program data readers right in the GUI.
- Or use Python or C++ plugin.



Programmable Source - Create a data reader in the GUI

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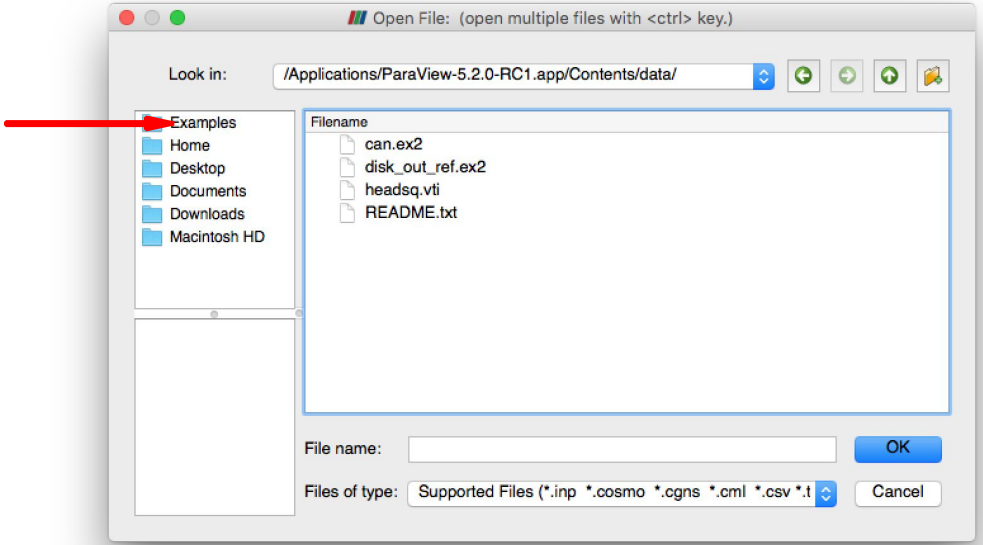
Load disk_out_ref.ex2

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



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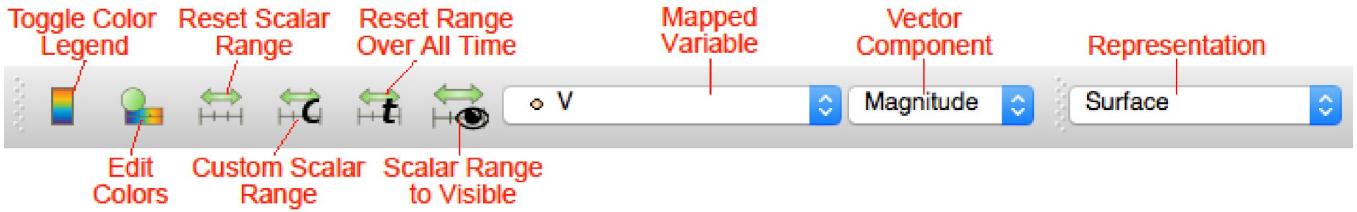
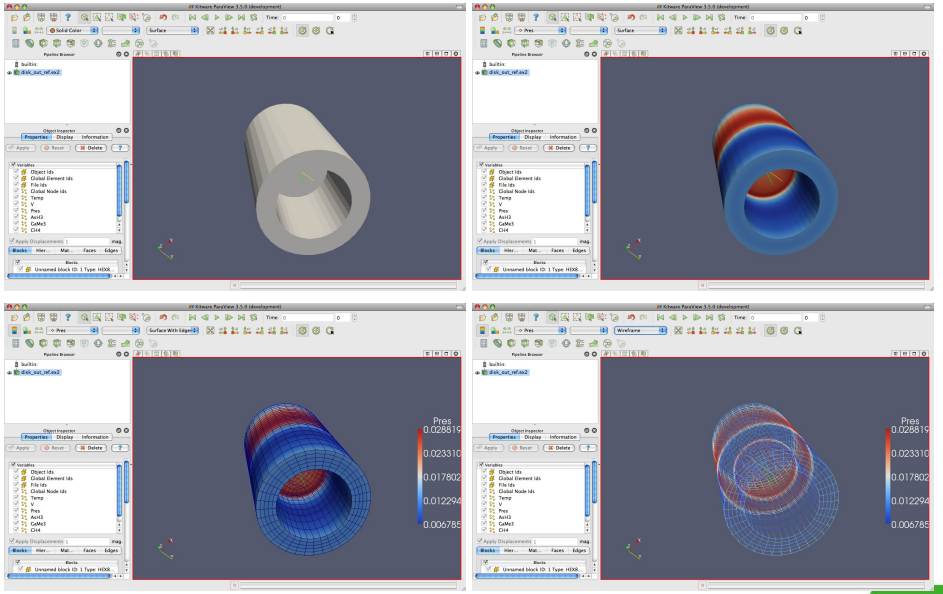
Load disk_out_ref.ex2

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

Data Representation





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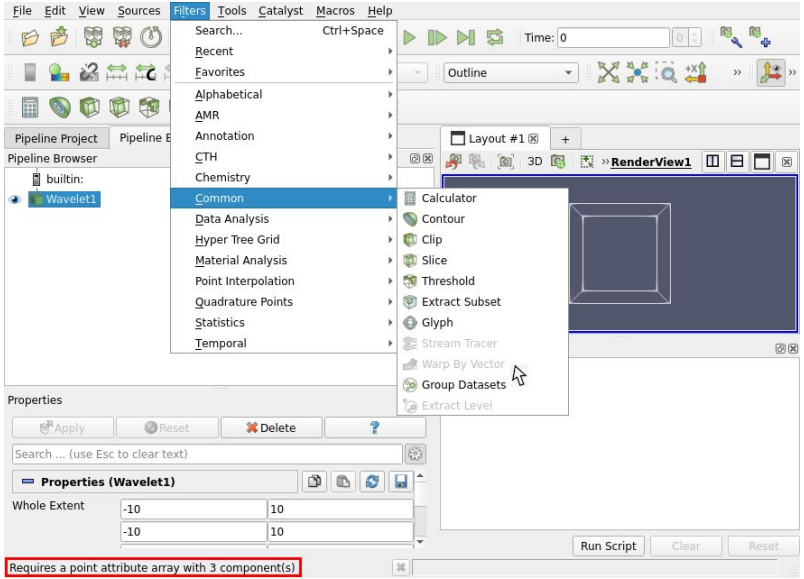
Filters Menu



~200 filters

Status bar:

- Short description
- Reason why is grayed

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Common Filters


Calculator


Contour


Clip


Slice


Threshold


Extract Subset


Glyph


Stream Tracer


Warp (vector)


Group Datasets


Extract Block

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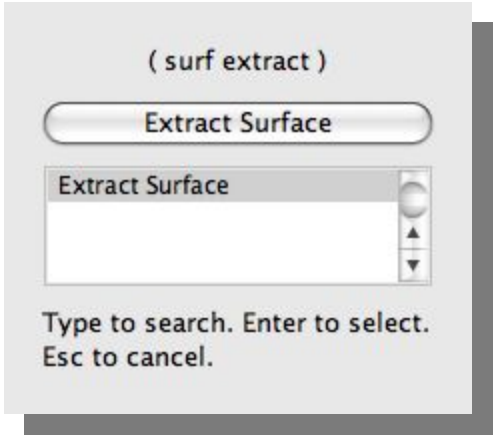
Quick Launch



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

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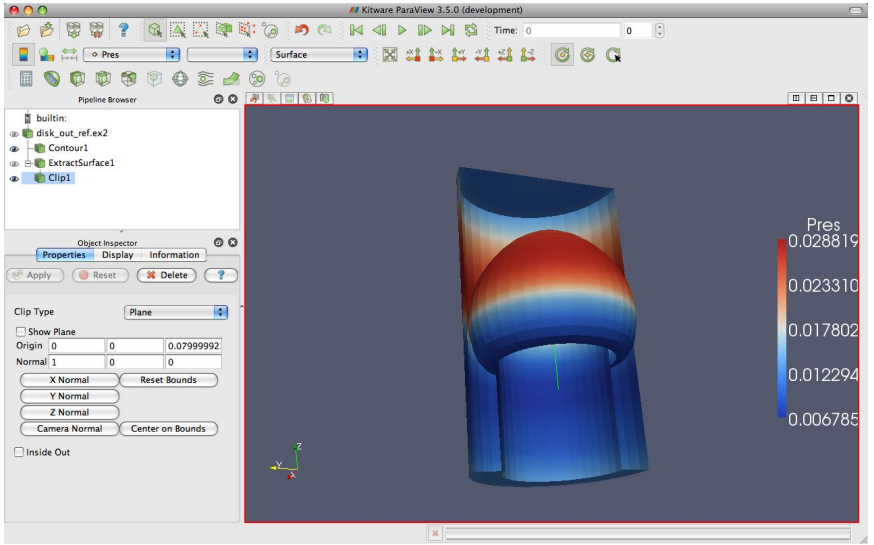
Apply Contour

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

Specify the data you apply the filter on

Goal



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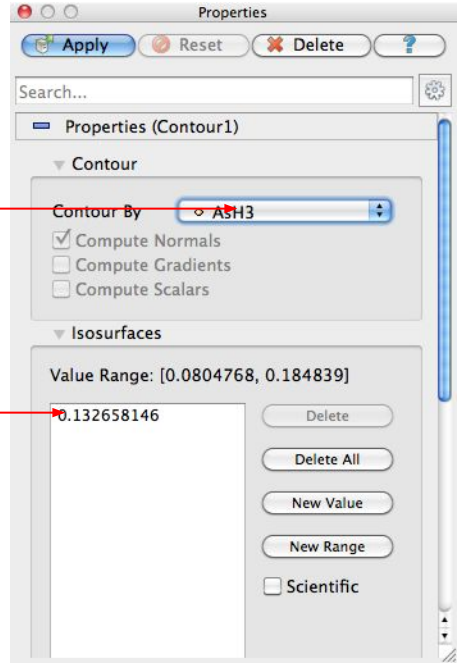
Apply Contour

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



Change to Temp

Change to 400

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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. 

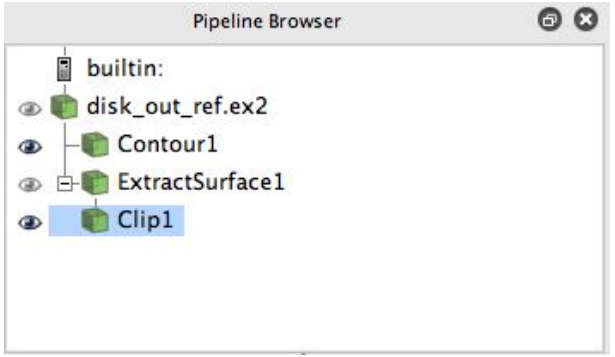
Apply ExtractSurface, Clip

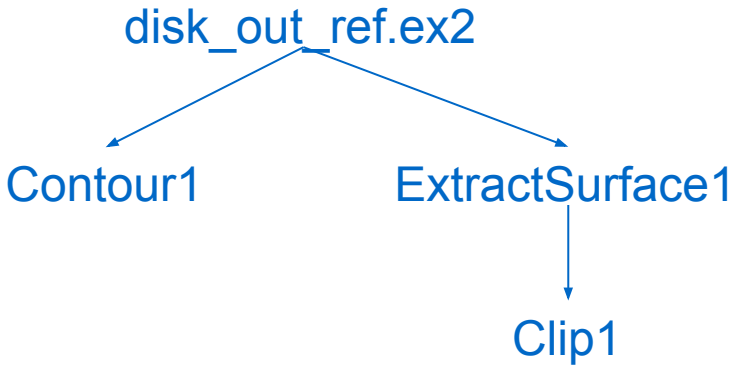
1. Select disk_out_ref.ex2 in the pipeline browser.
2. From the quick launch, select Extract Surface.
3. 

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

6. 

Pipeline Browser Structure





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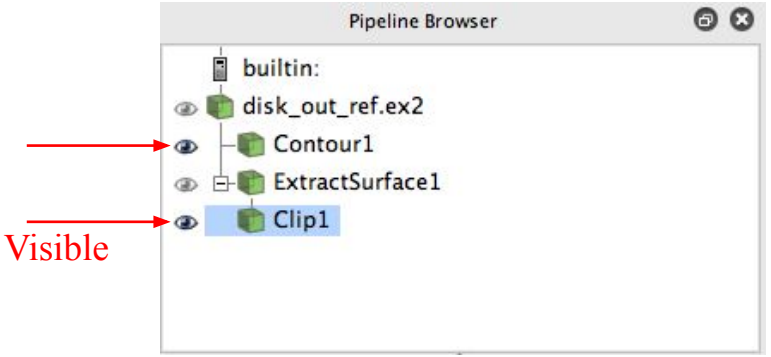
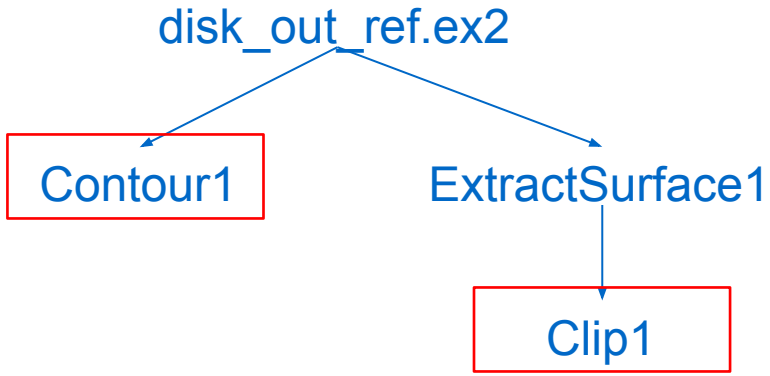
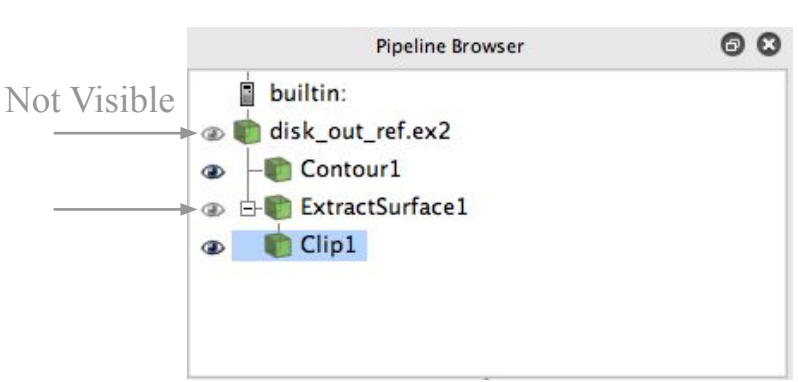
Pipeline Browser Structure

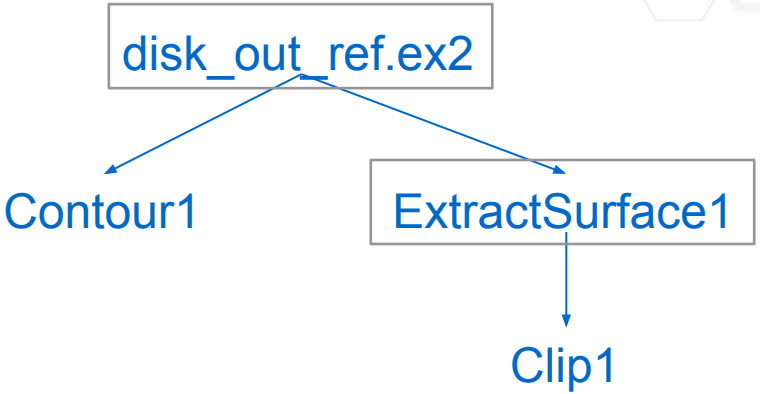




kitware

Pipeline Browser Structure





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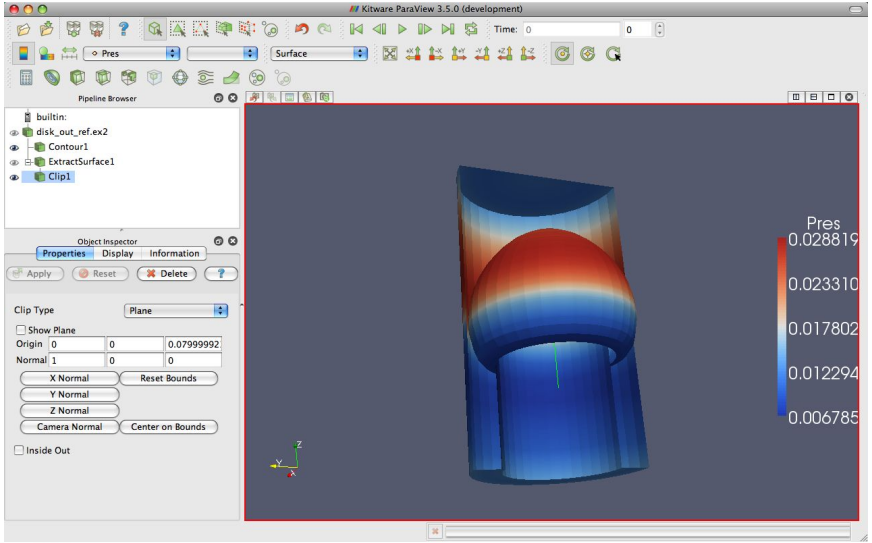
Multiview


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
Y Normal
Z Normal
Reset Bounds
Camera Normal
Center on Bounds
Inside Out
Pres
0.028819
0.023310
0.017802
0.012294
0.006785

Multiview - Disk colored by Temp

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

4. 

5. Hide Clip2 

Multiview

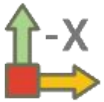
1. Split the view horizontally. 
2. Make Clip2 visible. 
3. Color surface by Temp.

Multiview

1. Split the view horizontally. 
2. Make Clip2 visible. 
3. Color surface by Temp.
4. Right-click view, Link Camera...
5. Click other view.

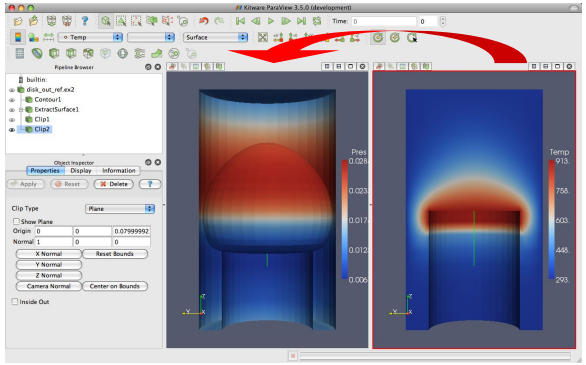
kitware

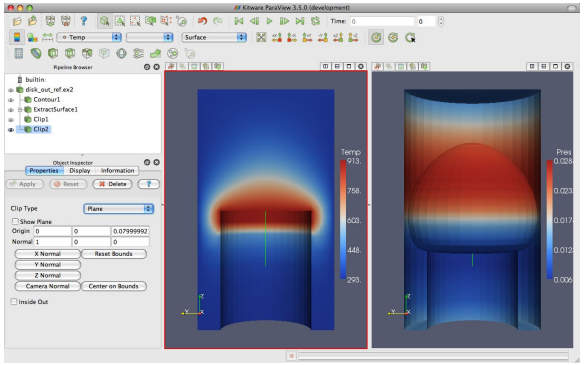
Multiview

1. Split the view horizontally. 
2. Make Clip1 visible. 
3. Color surface by Temp.
4. Right-click view, Link Camera...
5. Click other view.
6. Click 

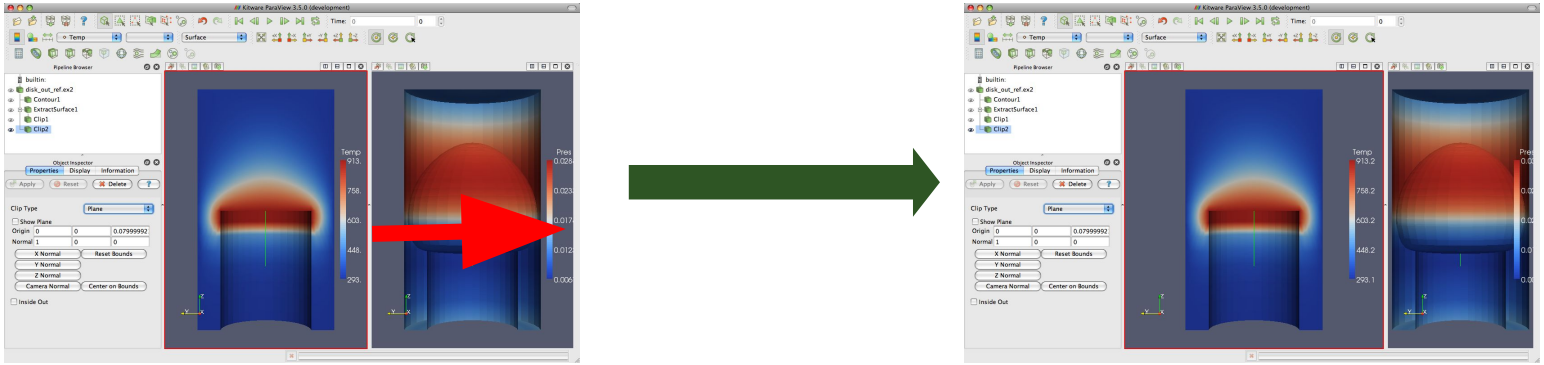
and zoom in a bit.

Modifying Views



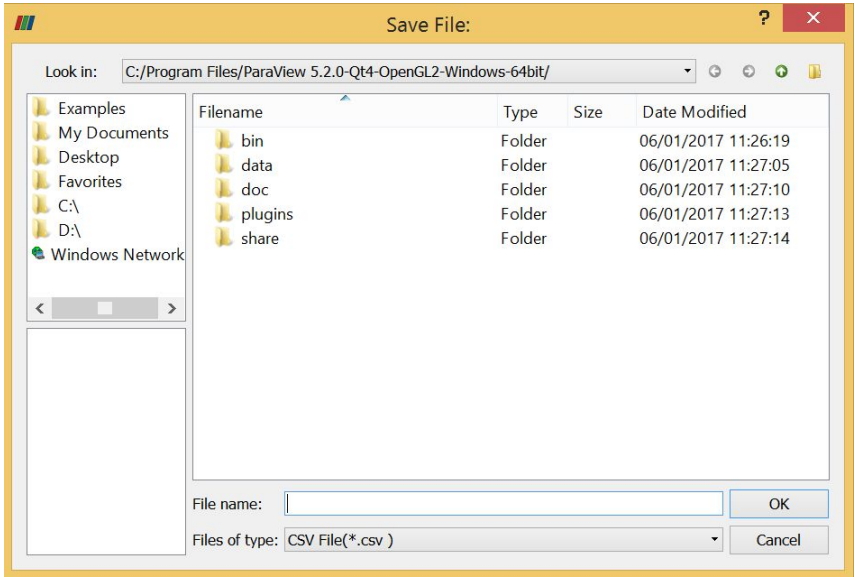


Modifying Views



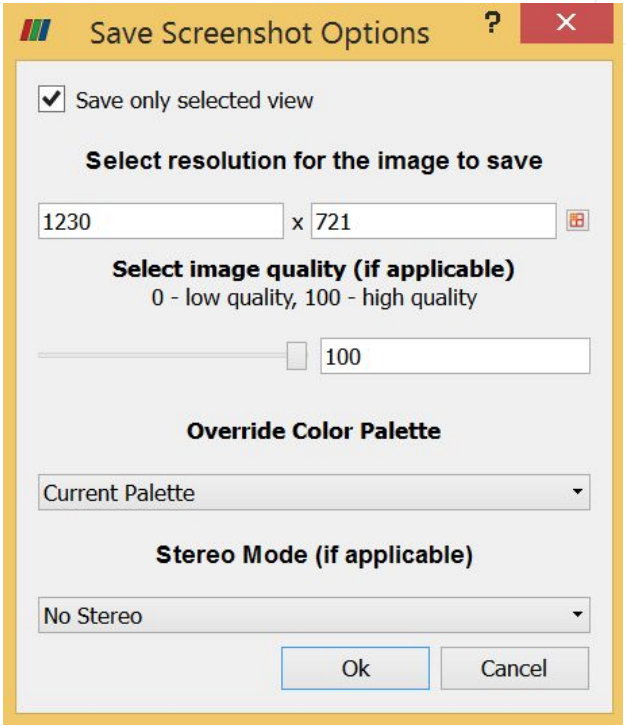
Saving a DataSet

- Save Data saves the dataset output of the current active pipeline object
- *File -> Save Data*
- Options to configure writer



Saving a Screenshot

- Saves an image from the view
- *File -> Save Screenshot*
- Set Resolution and Quality

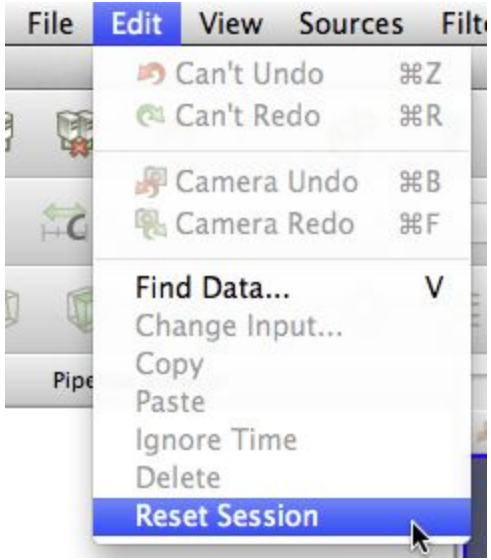


Saving the State

- **Save the current state of the application**
- ***File -> Save State***
- **Include Pipeline, Views, Layouts, all properties…**
- **PVSM State file : Robust, based on proxy state**
  - Descriptive Approach
  - Enable user to modify file path
  - Use with File -> Load State
  - Use for sharing with colleagues
- **Python State file : User-friendly, based on UI actions**
  - Just a python script
  - Use python shell or in pvpython

Reset ParaView

Edit → Reset Session



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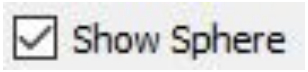
Streamlines

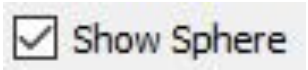
1. Open disk_out_ref.ex2. Load all variables.
2. Add Stream Tracer. 

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. 

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Adding Glyphs

1. Select StreamTracer1.
2. Add Glyph filter. 
3. Change Glyph Type to Cone.
4. Change Orientation Array and Scale Array to V.
5. Change Vector Scale Mode to Scale By Magnitude.
6. Click reset  next to Scale Factor.
7. 

8. Color by Temp.

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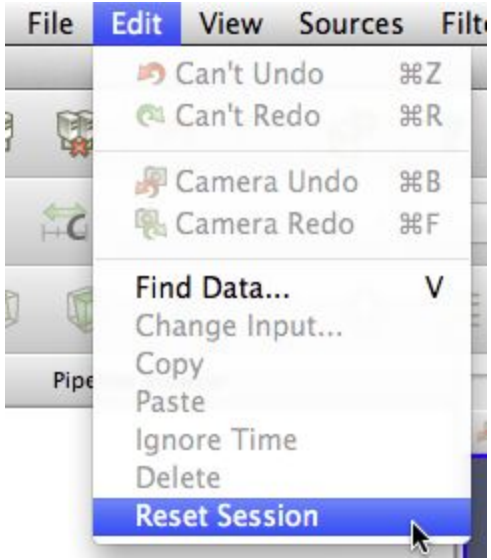
Reset ParaView

Edit → Reset Session



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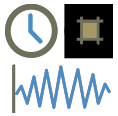
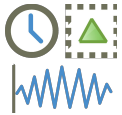
Common Data Analysis Filters

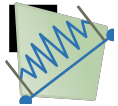
Extract Selection



Plot Global Variables Over Time



Plot Selection Over Time



Plot Over Line

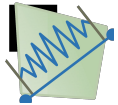
Probe Location

Plotting

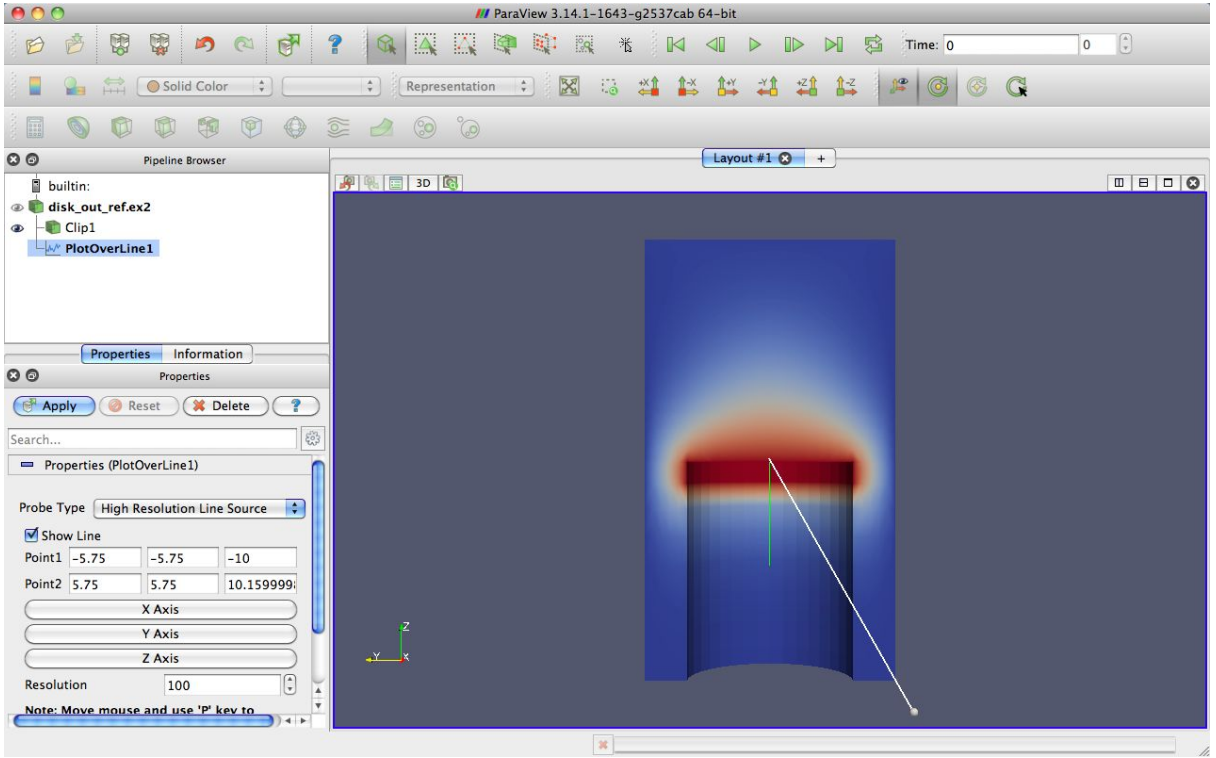
1. Open disk_out_ref.ex2. Load all variables. 

2. Clip,  uncheck, 

, 

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

3D Widgets



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Placing 3D Line Widget Endpoints

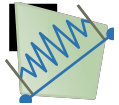
- Use the p key to place alternating points.
  - Ctrl+p places at nearest mesh point.
- Use the 1 or 2 key to place the start or end point.
  - Ctrl+1 or Ctrl+2 places at mesh point.
- Drag the endpoints.
  - Use x, y, or z key to constrain to axis.
- Use widgets in Properties panel
  - E.g. Use Z Axis 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,
6. 

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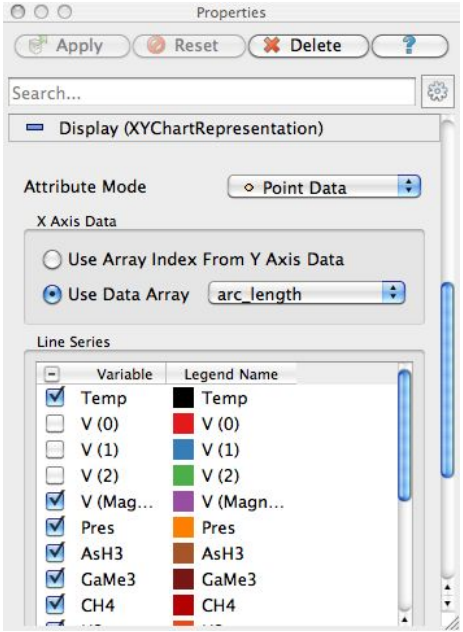
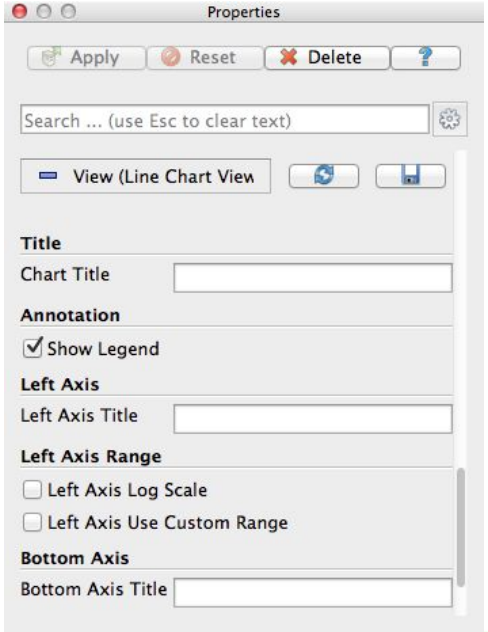
Interacting with Plots

- 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.





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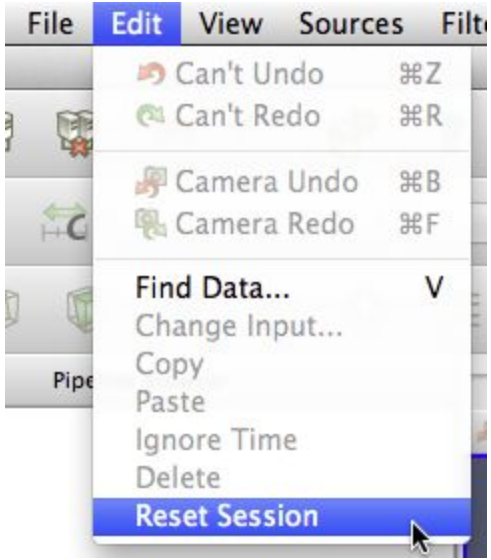
Adjusting Plots

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.

Reset ParaView

Edit → Reset Session



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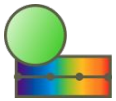
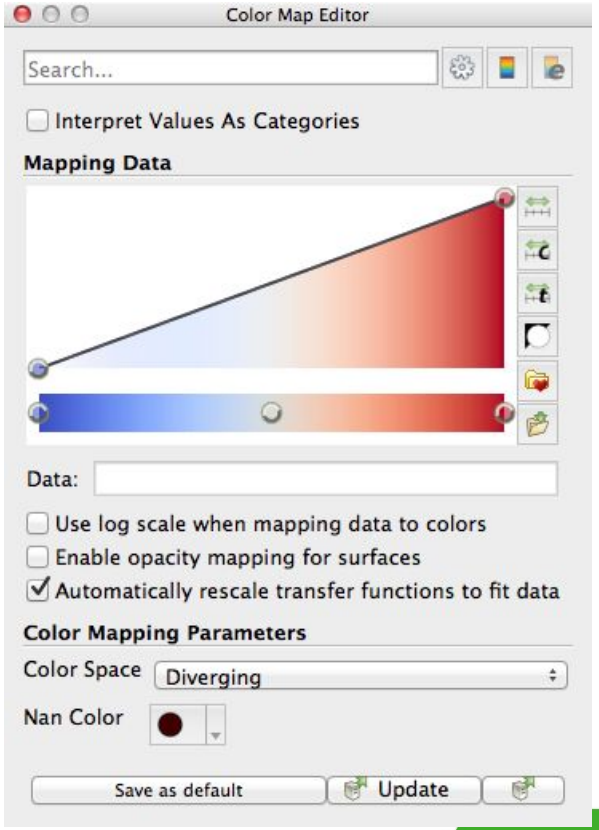
Volume Rendering

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





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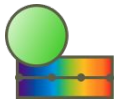
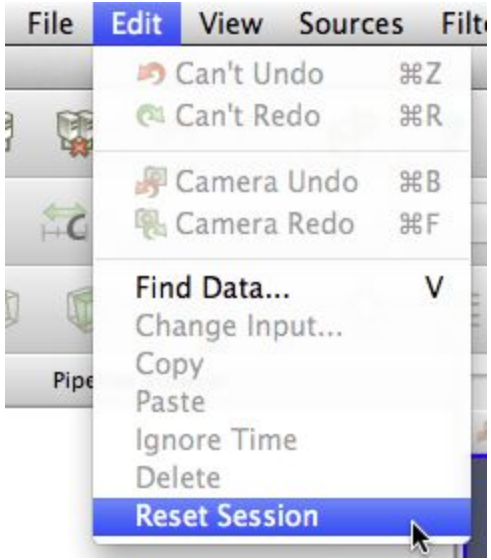
Modify Transfer Function

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



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Query-Based Selection

1. Open can.ex2. Select 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.

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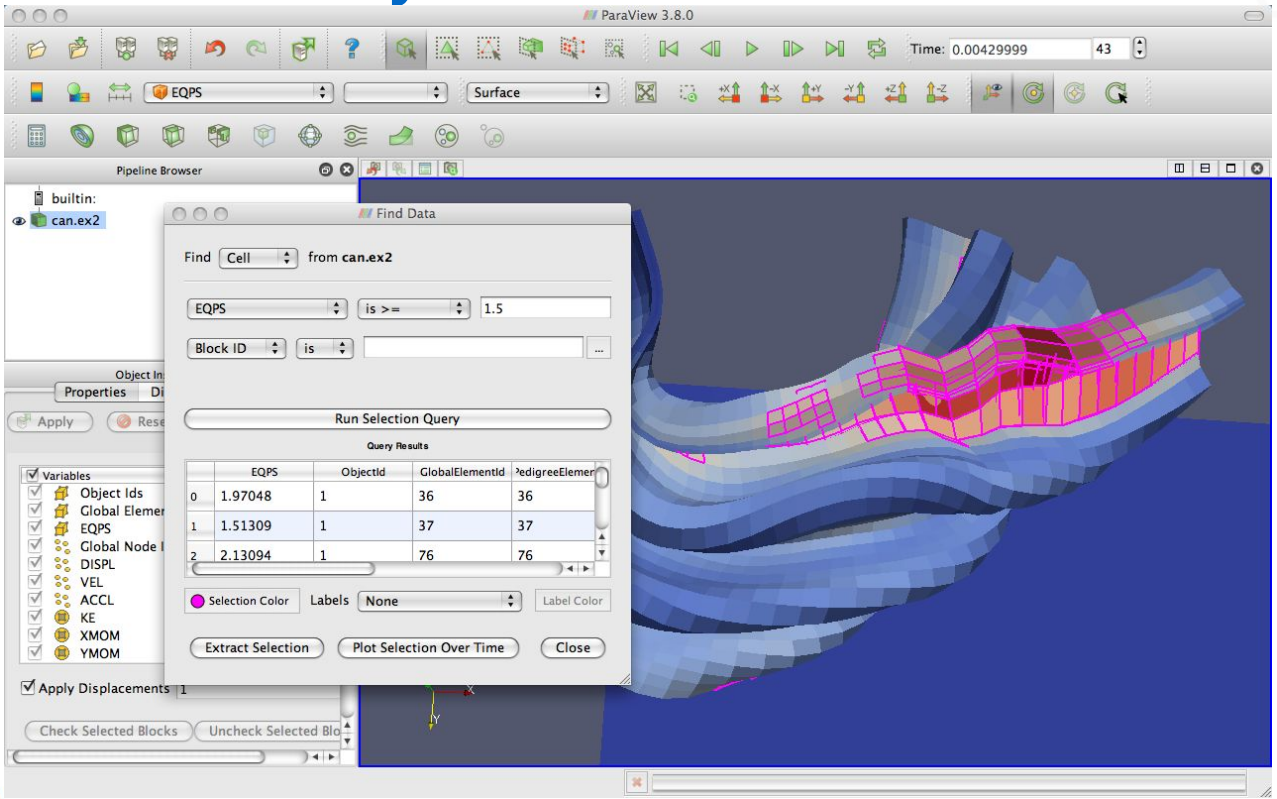
Query-Based Selection



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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

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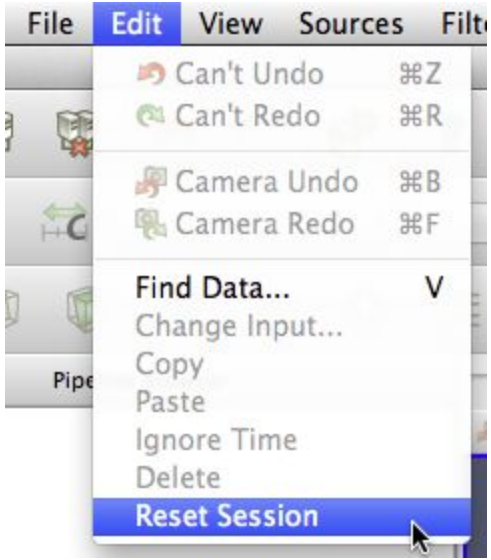
Adding Labels

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 
6. Similarly: Hover Cells On

Reset ParaView

Edit → Reset Session



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Visualizing Large Models

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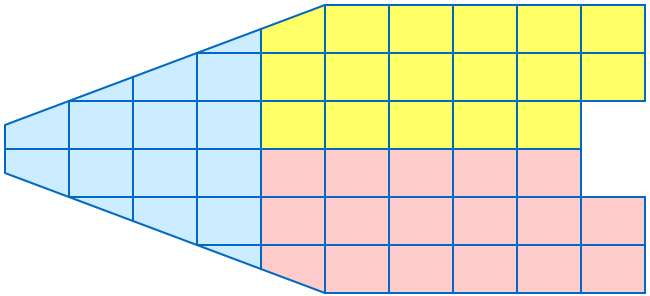
Data Parallel Pipelines

- Duplicate pipelines run independently on different partitions of data.



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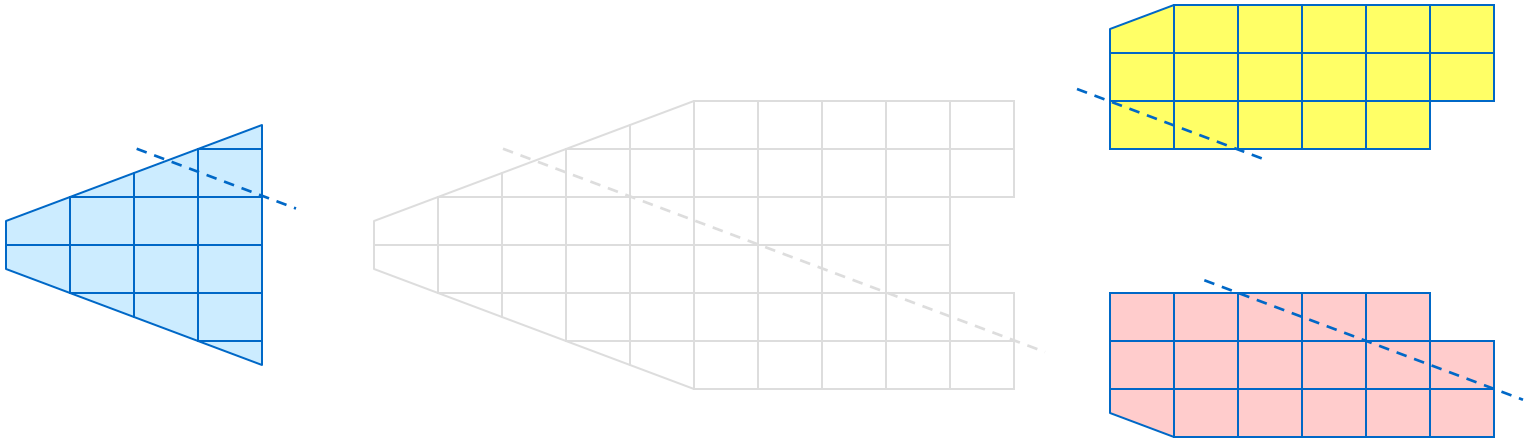
Data Parallel Pipelines

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



kitware

Data Parallel Pipelines

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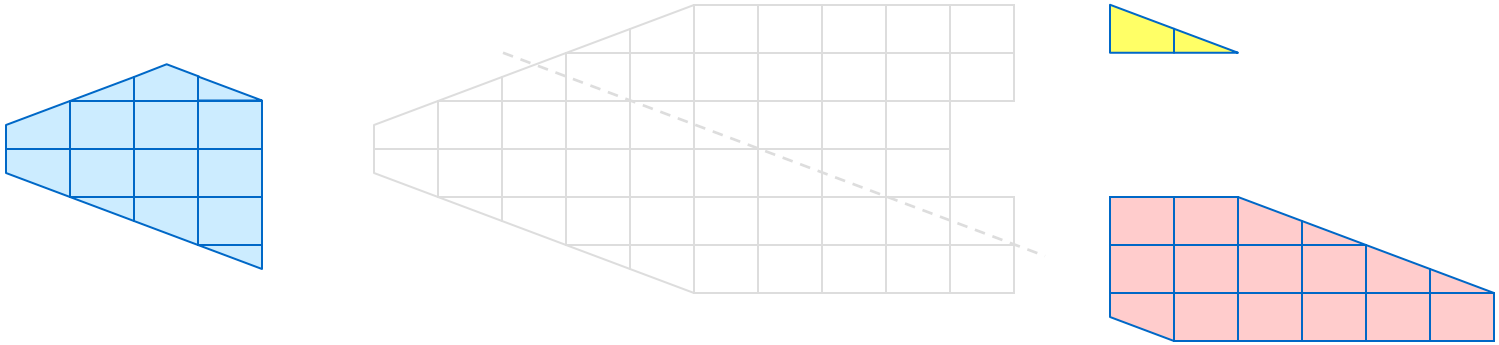
  - Example: Clipping



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Data Parallel Pipelines

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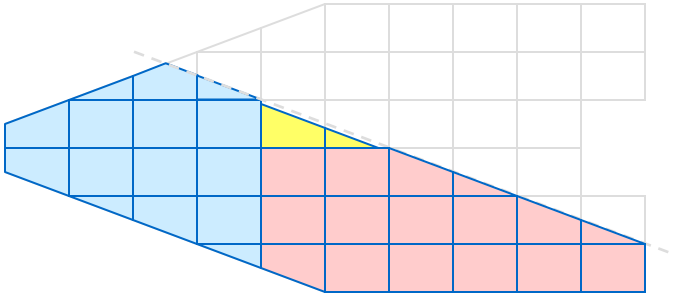
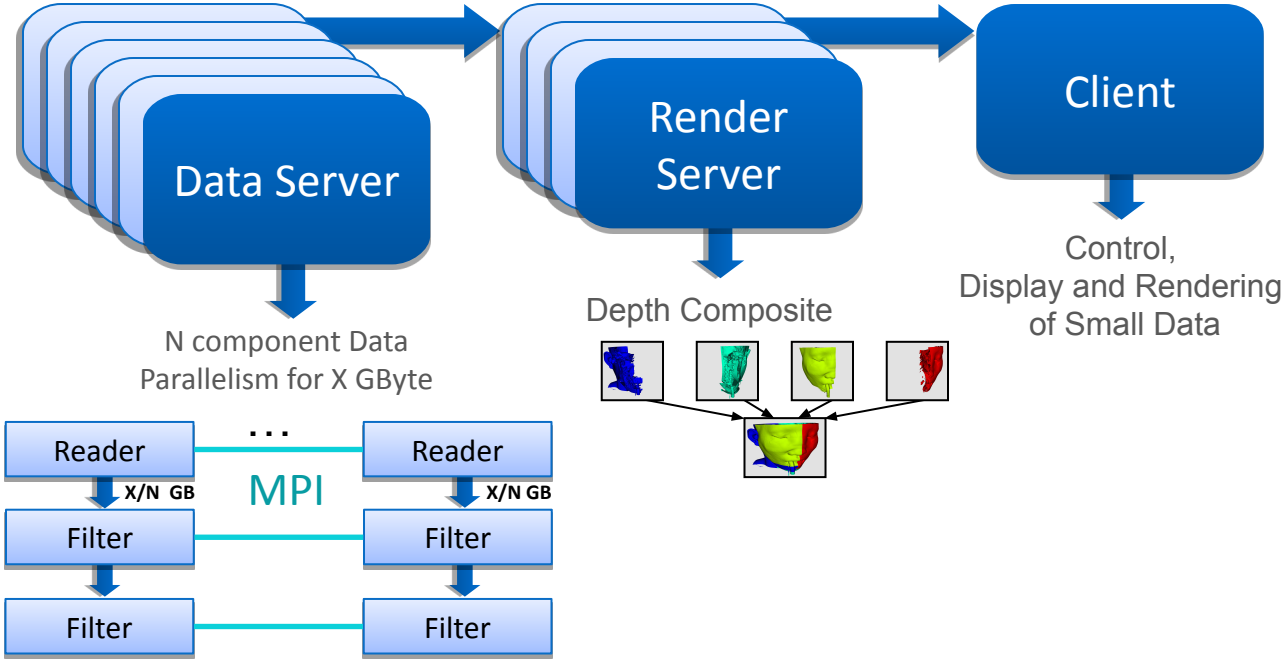
  - Example: Clipping




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

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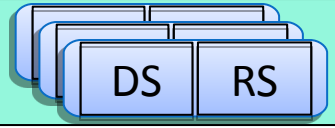
ParaView's Running Modes

Builtin aka Standalone aka Serial		all components within one process (client may be GUI or pvpython) `paraview` or `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

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Connect ParaView Client to the Server

Prerequisites:

- Able to use ssh to connect to the server
- Have a project allocation
- Check paraview versions on server: module avail paraview (or check documentation)
- Use client with the same major.minor version (5.12)

File > Connect > Fetch Servers

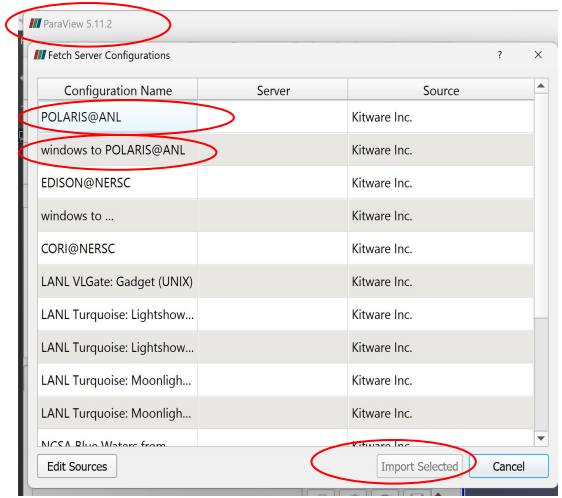
Bug in 5.12: Fetch Servers does not fetch

git clone https://gitlab.kitware.com/paraview/pvsc.git

Load Servers

ANL/server_polaris.pvsc
ANL/server_polaris_windows.pvsc

OR



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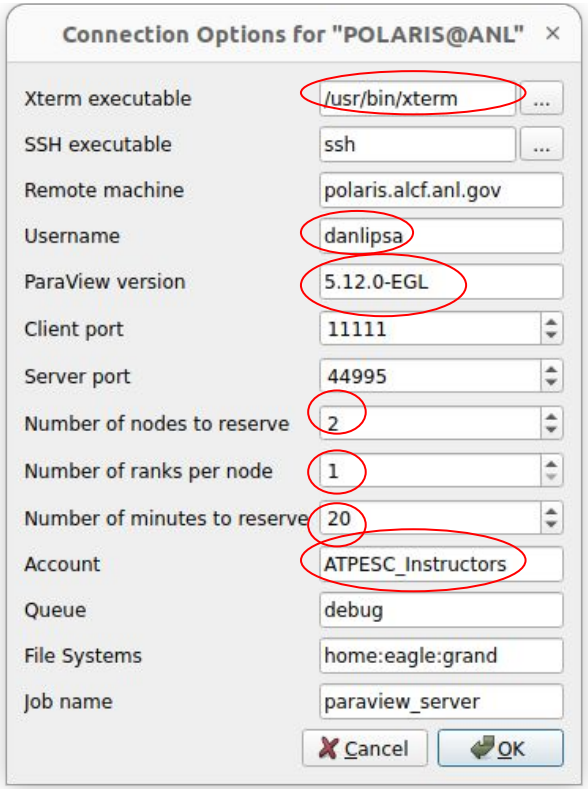
Connect Unix/Mac

Mac Os: Install Xquartz



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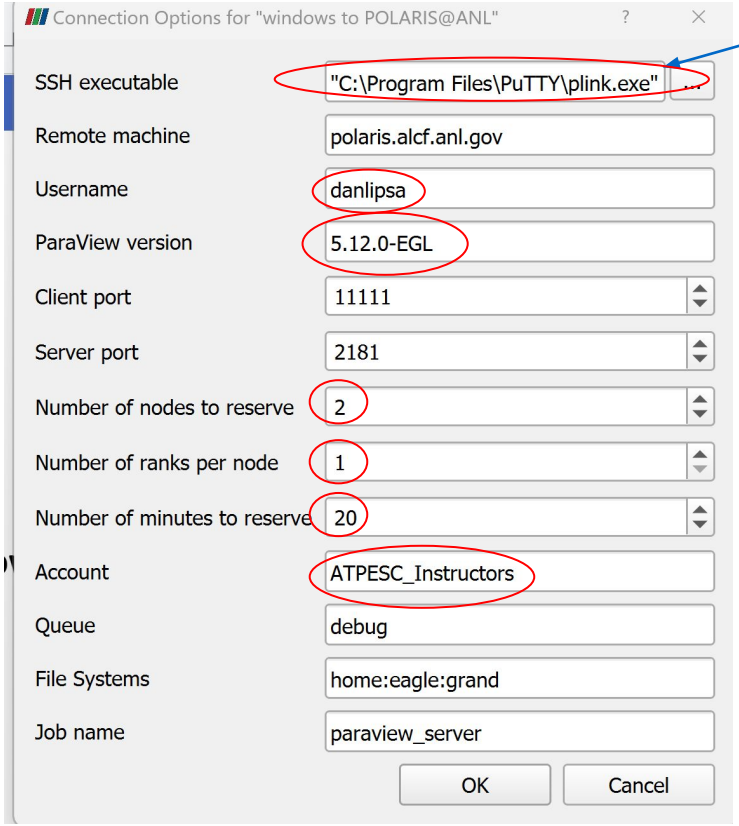
Connect Windows

Windows: Install PuTTY



quotes are required

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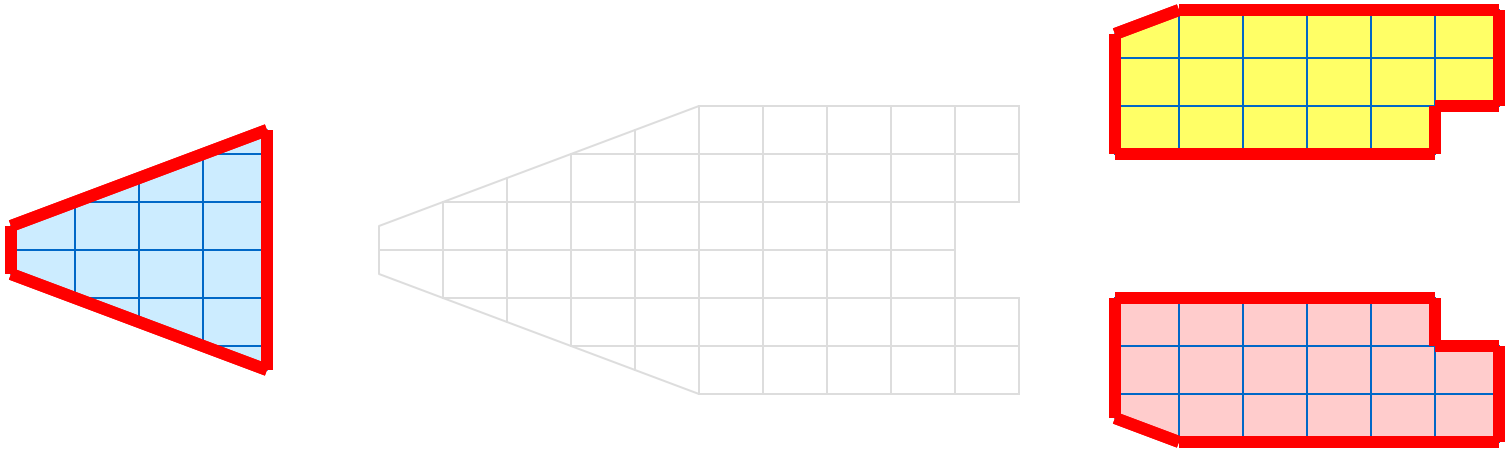
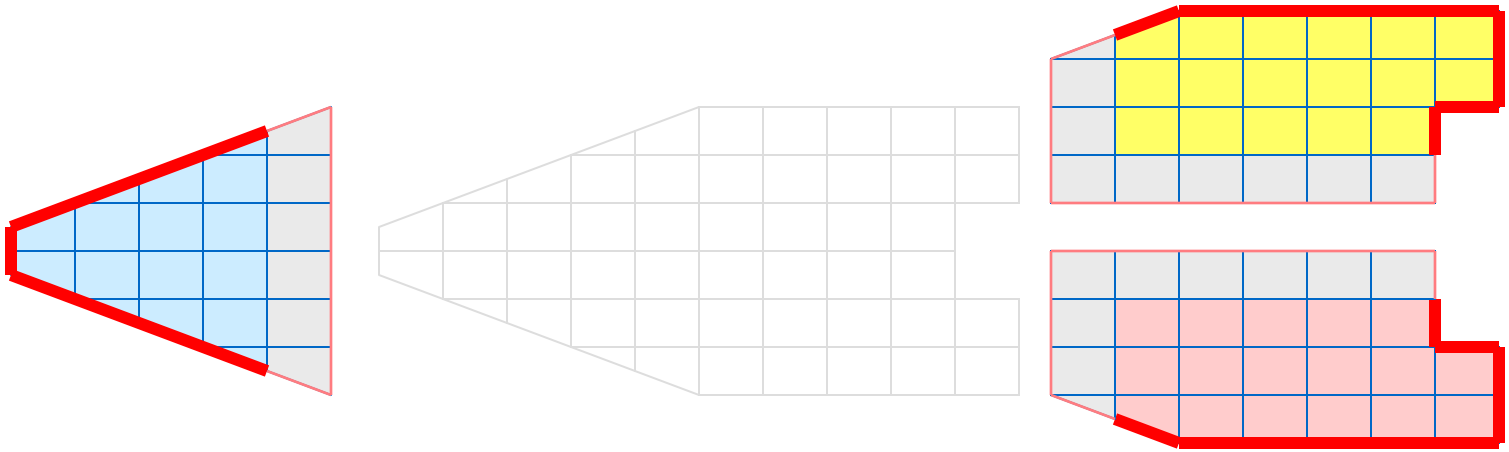
Advanced Data Parallel Pipelines

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



Advanced Data Parallel Pipelines

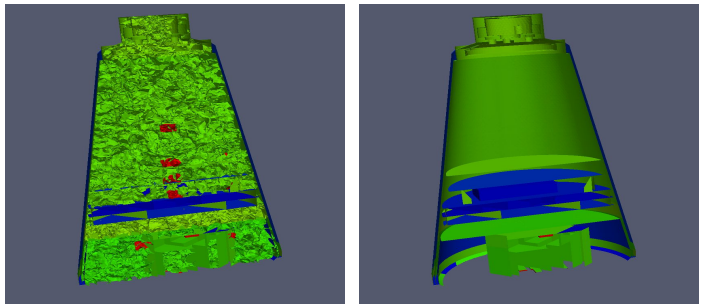
- Ghost cells can solve most of these problems.



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

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Topics for future exploration

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Python Scripting

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

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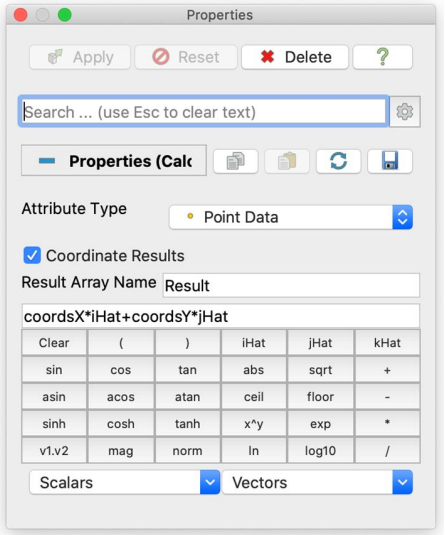
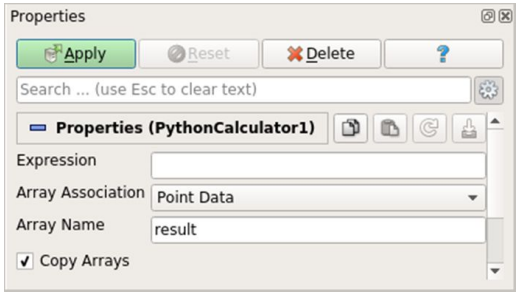
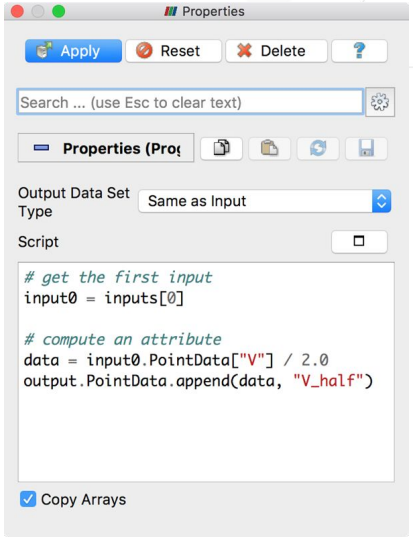
User Defined Filters



Calculator



Python Calculator



Programmable Filter

Python Algorithms

Plugins

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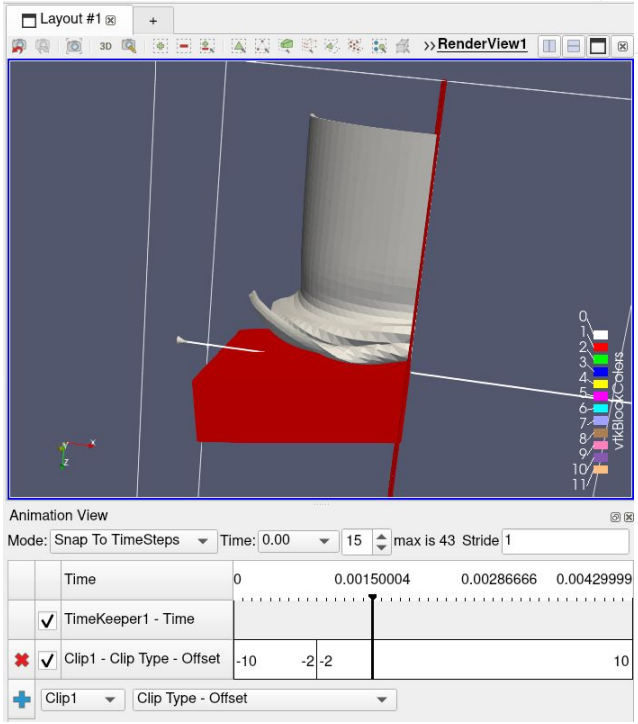
Animation

- Temporal data
- Fly over your data
- Animate filter parameters



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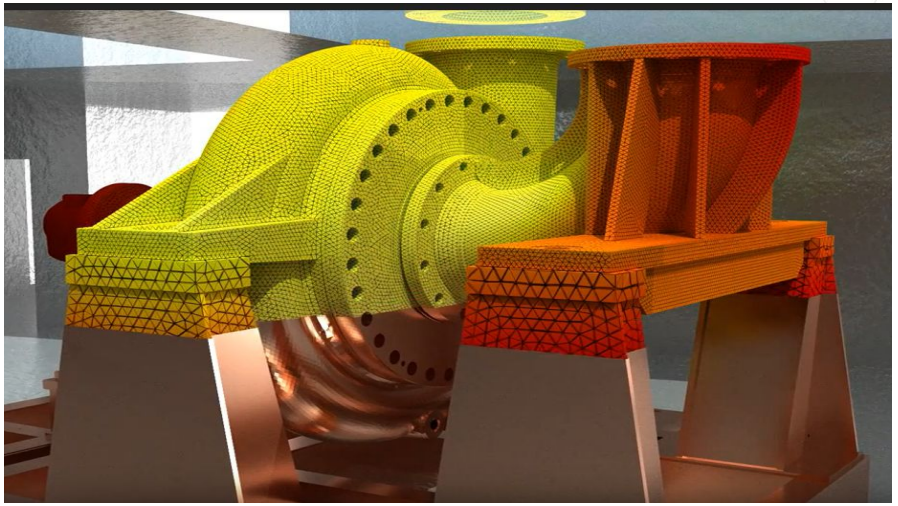
Advanced Rendering

- Physically Based Rendering (PBR)
- Ray Tracing (Intel OSPRay, Nvidia OptiX)



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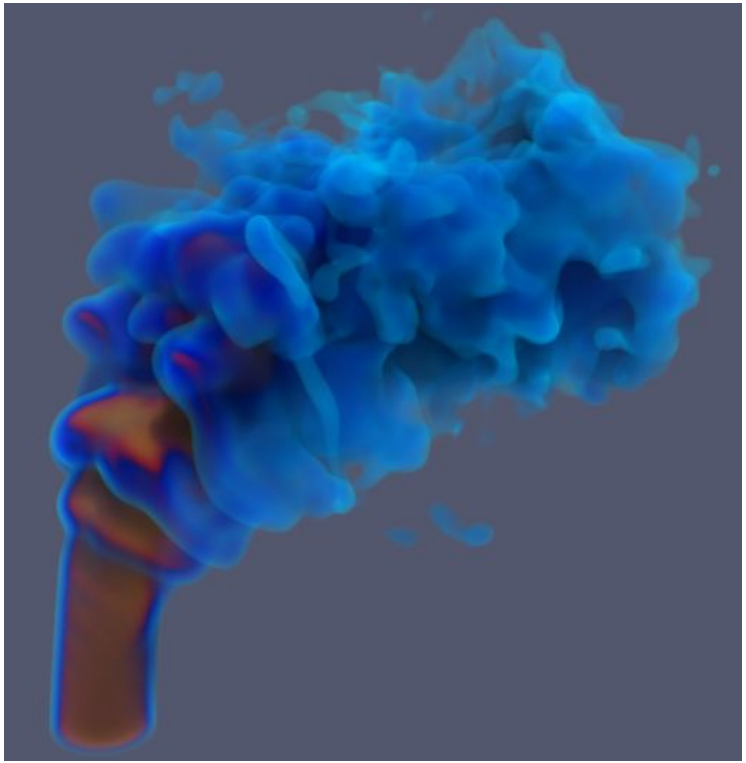
Questions



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