SAND2007-6401P

Large Scale Visualization with ParaView 3

Supercomputing 07 Tutorial

November 12, 2007

Kenneth Moreland John Greenfield
Sandia National Laboratories

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Outline

- Introduction
- Basic Usage
- Visualizing Large Models

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To Follow Along…

- Install ParaView 3.2.
  - http://www.paraview.org/New/download.html
- Get example material.
  - http://www.paraview.org/Wiki/SC07_ParaView_Tutorial
  - Also available on tutorial CD.

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Introduction

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What is ParaView?

- An open-source, scalable, multi-platform visualization application.
- Support for distributed computation models to process large data sets.
- An open, flexible, and intuitive user interface.
- An extensible, modular architecture based on open standards.
- Commercial maintenance and support.

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Current ParaView Usage

- Used by academic, government, and commercial institutions worldwide.
  - Downloaded 5K-10K times/month.
- Used for all ranges of data size.
- Current landmarks of SNL usage:
  - 6 billion structured cells.
  - 250 million unstructured cells.

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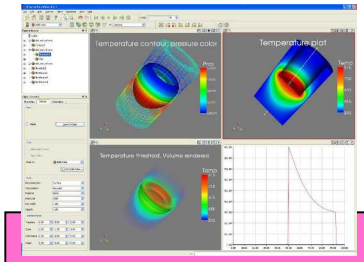
ParaView Application Architecture



ParaView Client	pvpython	Custom App
UI (Qt Widgets, Python Wrappings)		
ParaView Server		
VTK		
OpenGL	MPI	IceT	Etc.

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ParaView Development

- Started in 2000 as collaborative effort between Los Alamos National Laboratories and Kitware Inc. (lead by James Ahrens).
  - ParaView 0.6 released October 2002.
- September 2005: collaborative effort between Sandia National Laboratories, Kitware Inc. and CSimSoft to rewrite user interface to be more user friendly and develop quantitative analysis framework.
  - ParaView 3.0 released in May 2007.

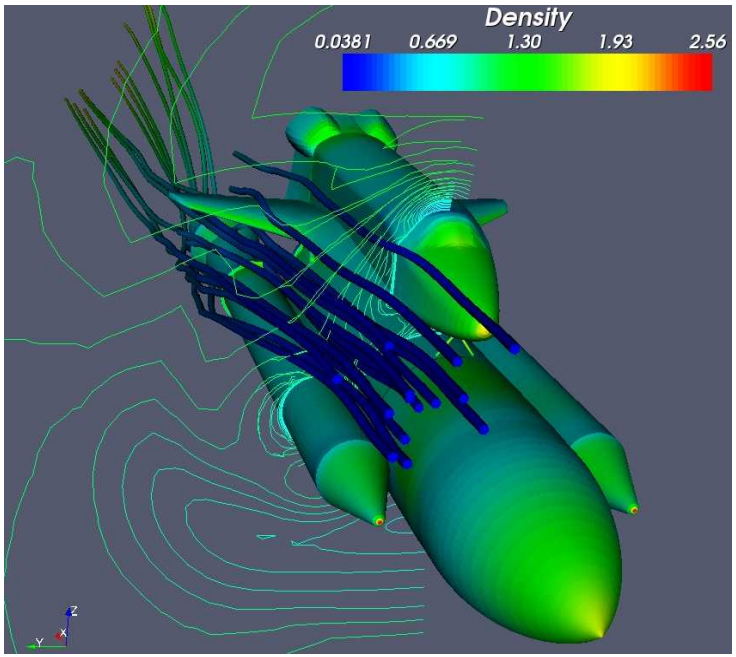
Current Funding

- Army SBIR
- ERDC Contract
- US NSF SBIR
- Other contributors
  - Swiss National Supercomputing Centre

- Support Contracts
  - Electricity de France
  - Mirarco
  - Oil Industry

Basics of Visualization

```
0265640 132304 133732 032051 037334 024721 015013 052226 001662
0265660 025537 064663 054606 043244 074076 124153 135216 126614
0265700 144210 056426 044700 042650 165230 137037 003655 006254
0265720 134453 124327 176005 027034 107614 170774 073702 067274
0265740 072451 007735 147620 061064 157435 113057 155356 114603
0265760 107204 102316 171451 046040 120223 001774 030477 046673
0266000 171317 116055 155117 134444 167210 041405 147127 050505
0266020 004137 046472 124015 134360 173550 053517 044635 021135
0266040 070176 047705 113754 175477 105532 076515 177366 056333
0266060 041023 074017 127113 003214 037026 037640 066171 123424
0266100 067701 037406 140000 165341 072410 100032 125455 056646
0266120 006716 071402 055672 132571 105645 170073 050376 072117
0266140 024451 007424 114200 077733 024434 012546 172404 102345
0266160 040223 050170 055164 164634 047154 126525 112514 032315
0266200 016041 176055 042766 025015 176314 017234 110060 014515
0266220 117156 030746 154234 125001 151144 163706 136237 164376
0266240 137055 062276 161755 115466 005322 132567 073216 002655
0266260 171466 126161 117155 065763 016177 014460 112765 055527
0266300 003767 175367 104754 036436 172172 150750 043643 145410
0266320 072074 000007 040627 070652 173011 002151 125132 140214
0266340 060115 014356 015164 067027 120206 070242 033065 131334
0266360 170601 170106 040437 127277 124446 136631 041462 116321
0266400 020243 005602 004146 121574 124651 006634 071331 102070
0266420 157504 160307 166330 074251 024520 114433 167273 030635
0266440 133614 106171 144160 010652 007365 026416 160716 100413
0266460 026630 007210 000630 121224 076033 140764 000737 003276
0266500 114060 042647 104475 110537 066716 104754 075447 112254
0266520 030374 144251 077734 015157 002513 173526 035531 150003
0266540 146207 015135 024446 130101 072457 040764 165513 156412
0266560 166410 067251 156160 106406 136770 030516 064740 022032
0266600 142166 123707 175121 071170 076357 037233 031136 015232
0266620 075074 016744 044055 102230 110063 033350 052765 172463
```



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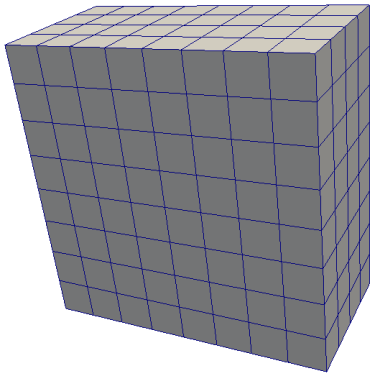
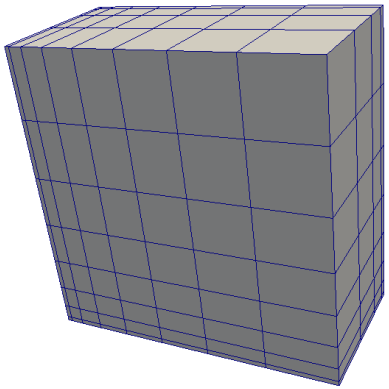
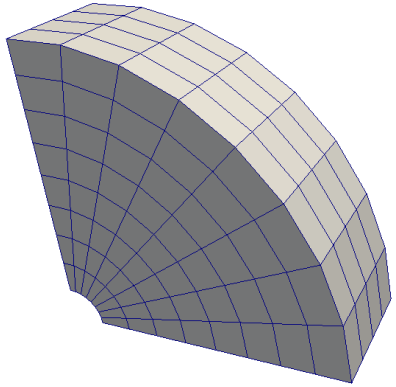
Data Types



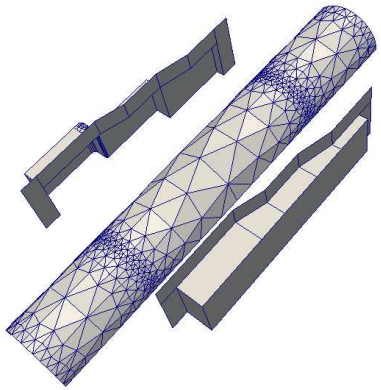
Uniform Rectilinear
(Image Data)



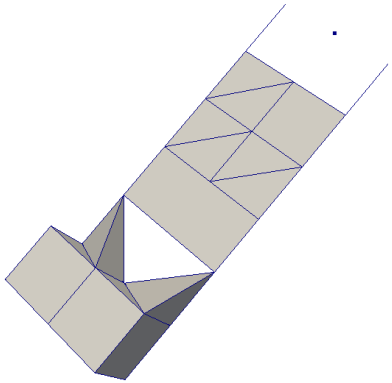
Non-Uniform Rectilinear
(Rectilinear Data)



Curvilinear
(Structured Data)



Polygonal
(Poly Data)



Unstructured Grid

Multi-block

Hierarchical Adaptive Mesh Refinement (AMR)

Hierarchical Uniform AMR

Octree

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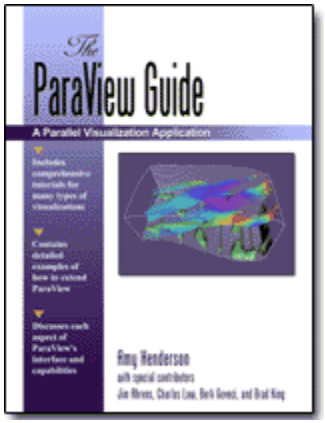
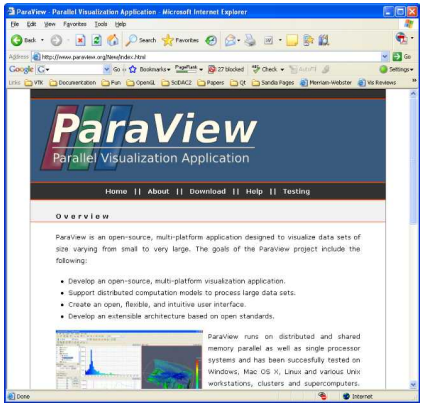
More Information

- Online Help 
- *The ParaView Guide*



- The ParaView web page
  - –www.paraview.org



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Basic Usage

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User Interface

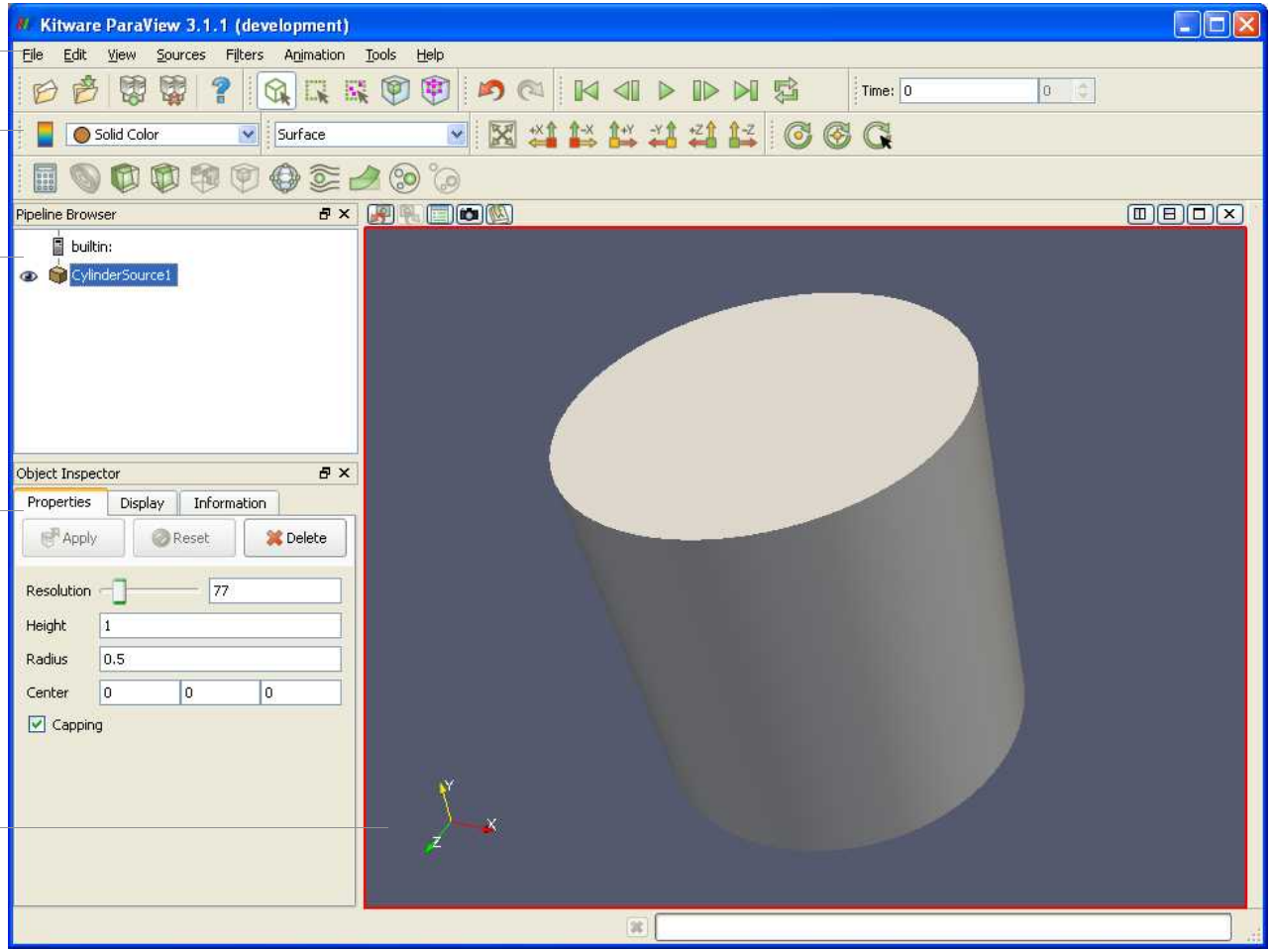
Menu Bar

Toolbars

Pipeline Browser

Object Inspector

3D View



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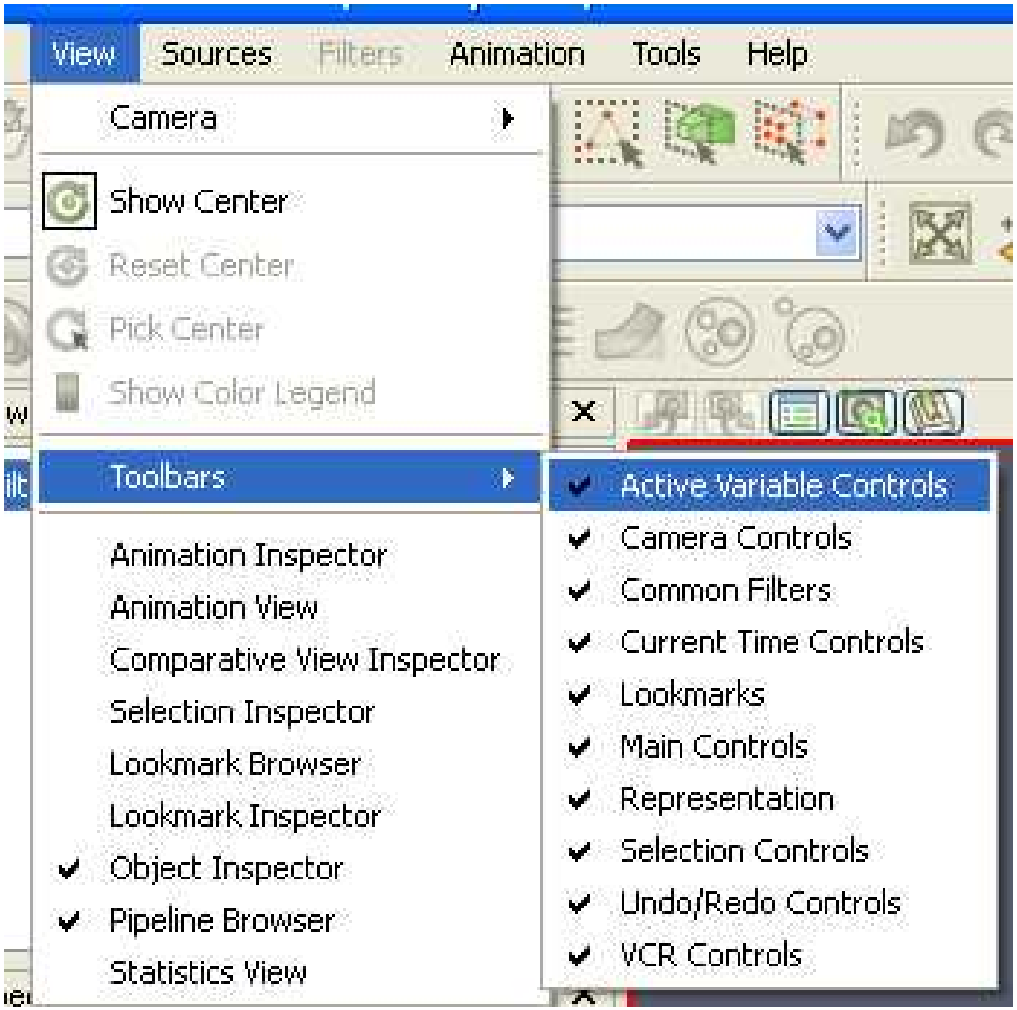
Getting Back GUI Components



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Creating a Cylinder Source

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

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Simple Camera Manipulation

- Drag left, middle, right buttons for rotate, pan, zoom.
  - Also use Shift, Ctrl, Alt modifiers.

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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.

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Pipeline Object Controls

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Undo Redo

Undo

Redo

Camera Undo

Camera Redo

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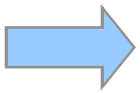
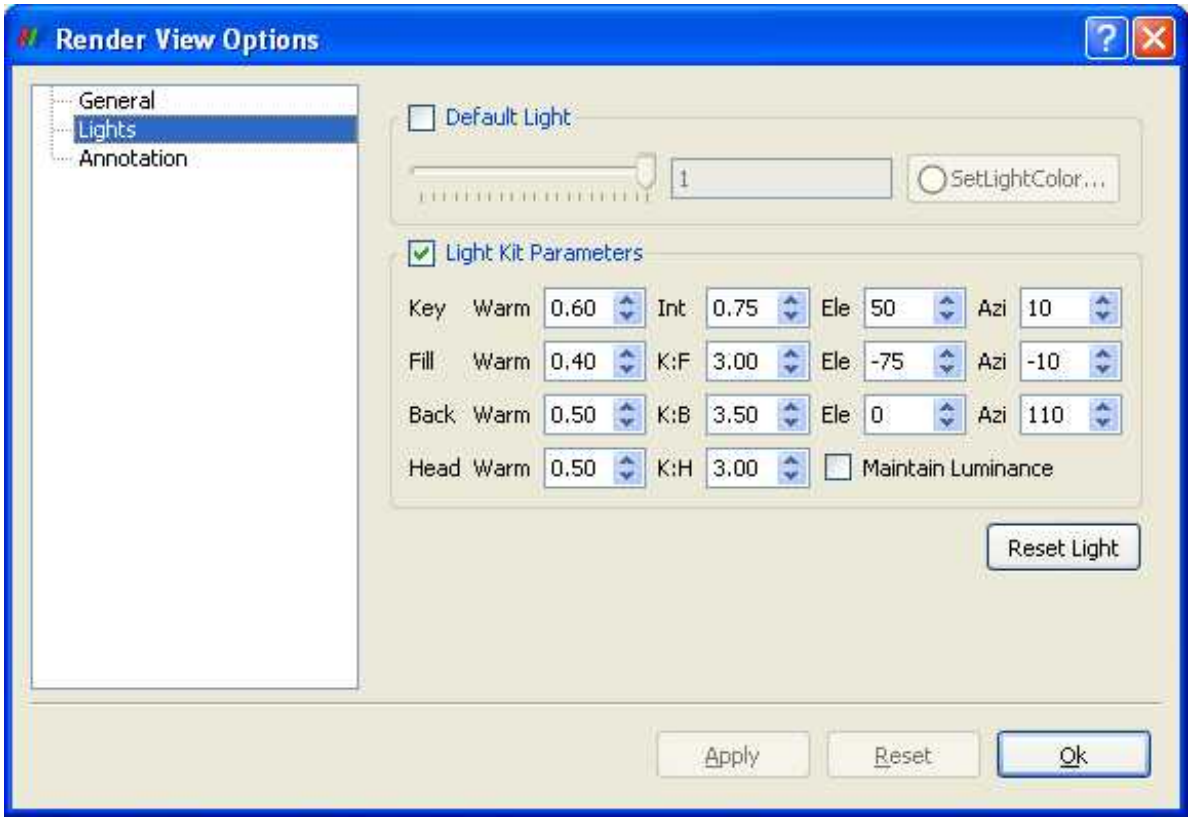
Render View Options





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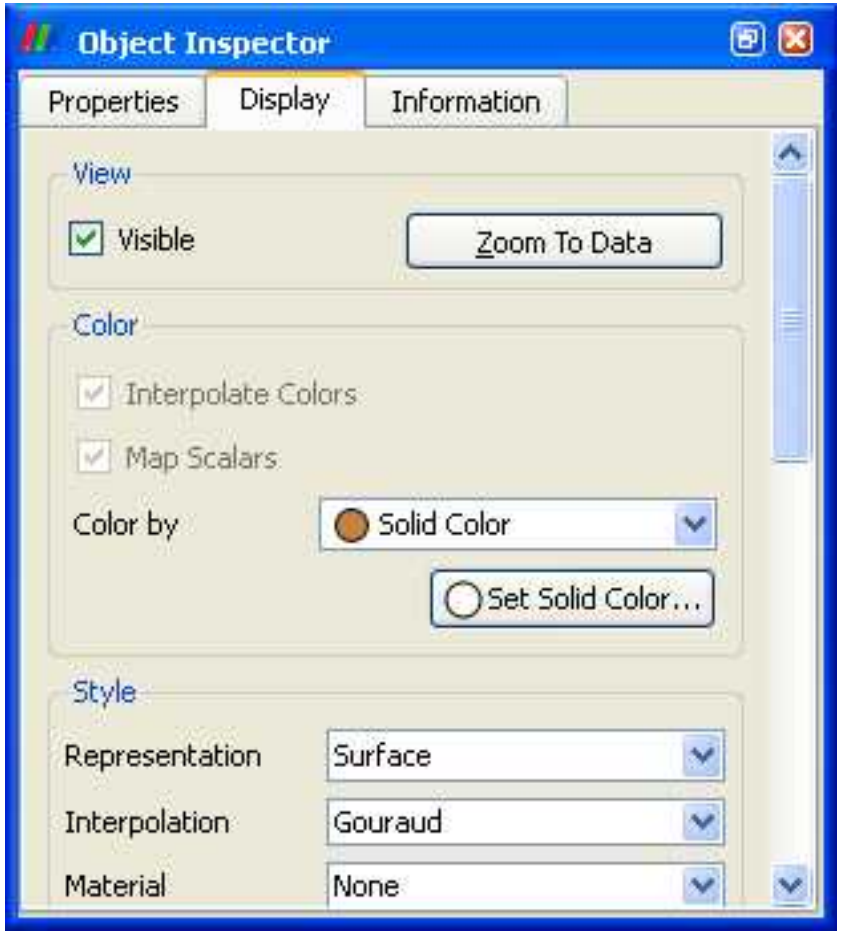
Display Tab



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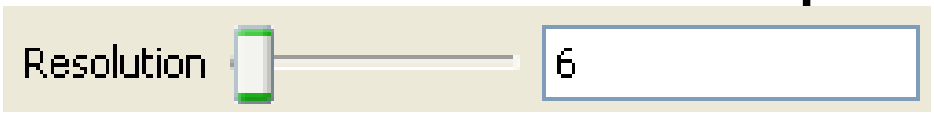
Creating a Cylinder Source

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.
5. Delete the Cylinder. 

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Supported Data Types

- ParaView Data (.pvd)
- VTK (.vtp, .vtu, .vti, .vts, .vtr)
- VTK Multi Block (.vtm, .vtmb, .vtmg, .vthd, .vthb)
- Partitioned VTK (.pvtu, .pvti, .pvts, .pvtr)
- VTK Legacy (.vtk)
- Exodus
- XDMF (.xmf, .xdmf)
- LS-DYNA
- SpyPlot CTH
- EnSight (.case, .sos)
- BYU (.g)
- Protein Data Bank (.pdb)
- XMol Molecule
- PLOT3D
- Digital Elevation Map (.dem)
- VRML (.wrl)
- PLY Polygonal File Format
- Stereo Lithography (.stl)
- Gaussian Cube File (.cube)
- POP Ocean Files
- AVS UCD (.inp)
- Meta Image (.mhd, .mha)
- Facet Polygonal Data
- Phasta Files (.pht)
- PNG Image Files
- Raw Image Files
- Comma Separated Values (.csv)

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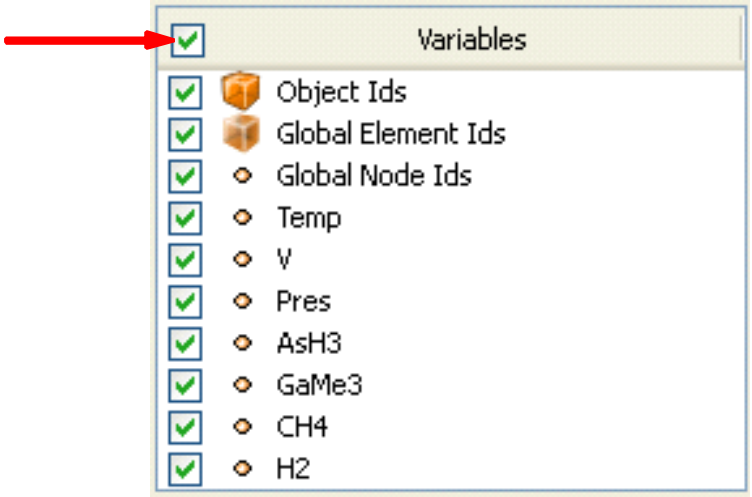
Load disk_out_ref.ex2

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



3. Click 

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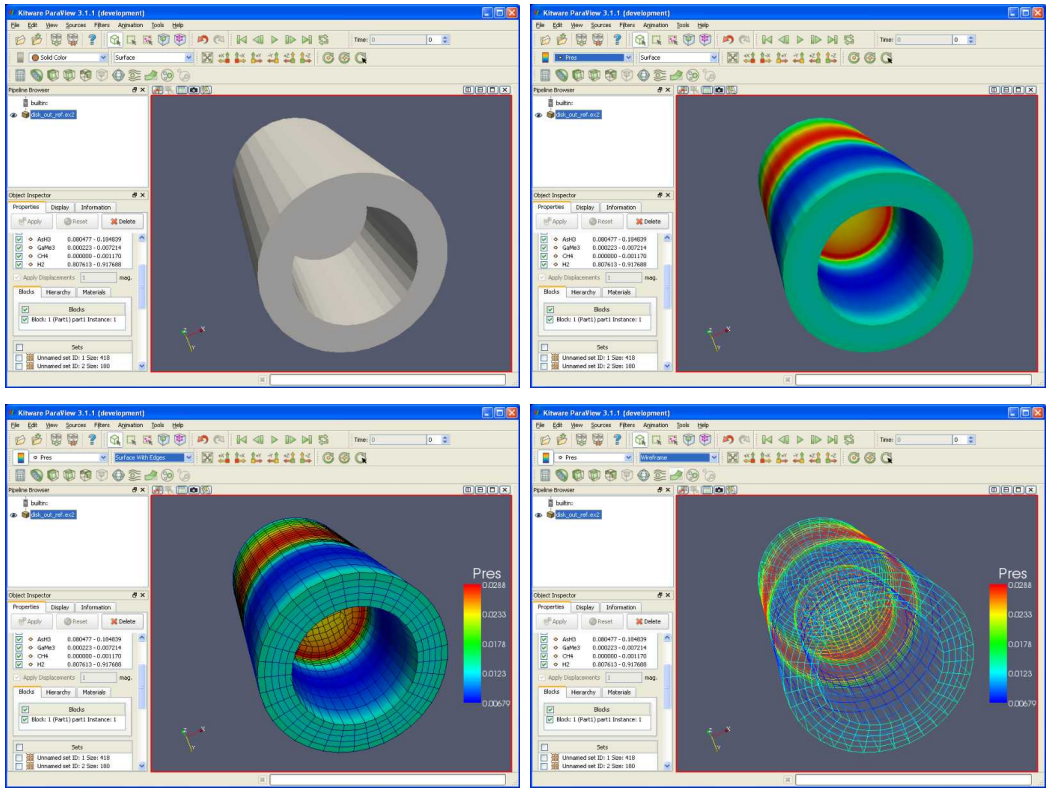
Data Representation

Toggle Color Legend

Choose Variable

Choose Representation



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Common Filters


Calculator


Contour


Clip


Slice


Threshold


Extract Subset


Glyph


Stream Tracer


Warp (vector)


Group Datasets


Extract Group

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Filters Menu

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Apply a Filter

1. Make sure that disk_out_ref.ex2 is selected in the pipeline browser.
2. Select the contour filter. 

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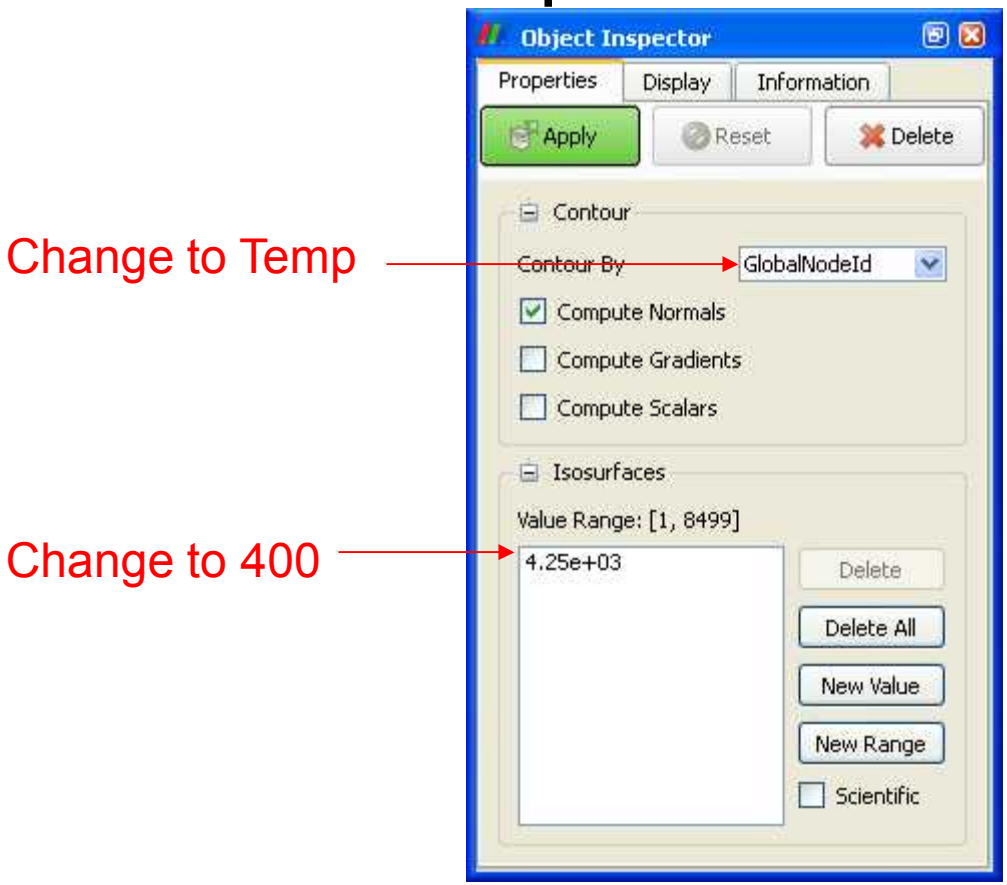
Apply a Filter

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



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Apply a Filter

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

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Create a Cutaway Surface

1. Select disk_out_ref.ex2 in the pipeline browser.
2. From the menu bar, select Filters → Alphabetical → Extract Surface.
3. 

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Create a Cutaway Surface

1. Select disk_out_ref.ex2 in the pipeline browser.
2. From the menu bar, select Filters → Alphabetical → Extract Surface.
3. 

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

6. 

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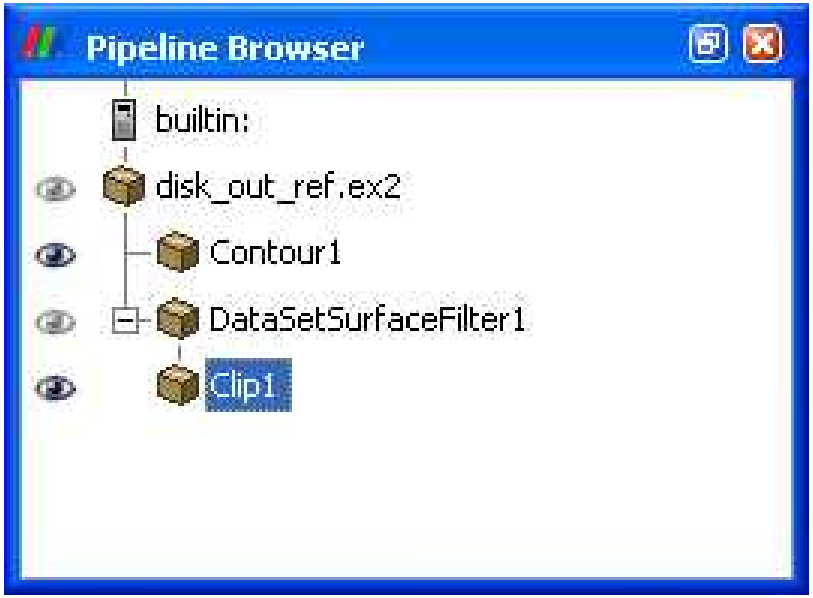
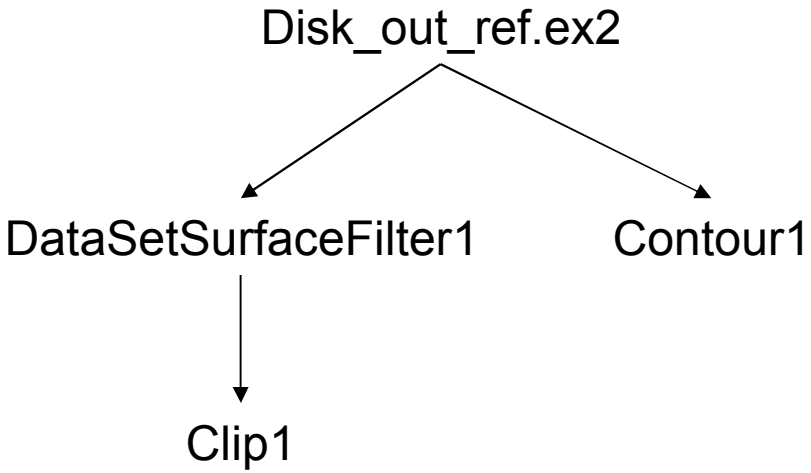
Pipeline Browser Structure





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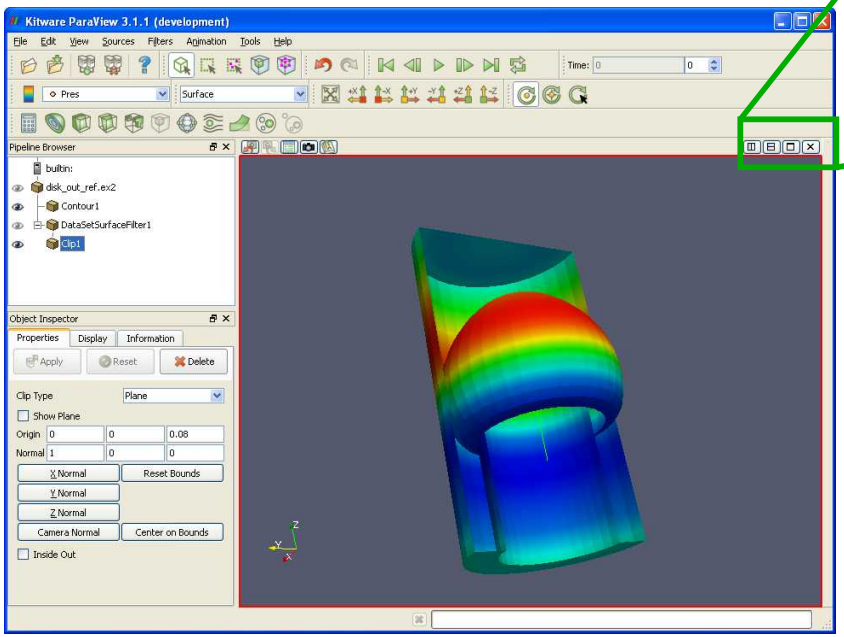
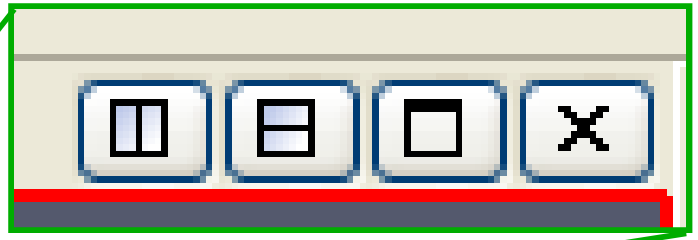
Multiview





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Multiview

1. Split the view horizontally.
2. Make disk_out_ref.ex2 visible. 
3. Color surface by Temp. 

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Multiview

1. Split the view horizontally.
2. Make disk_out_ref.ex2 visible. 
3. Color surface by Temp. 
4. Add clip filter. 
5. Uncheck Show Plane. 

6. 

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Multiview

1. Split the view horizontally.
2. Make disk_out_ref.ex2 visible. 
3. Color surface by Temp. 
4. Add clip filter. 
5. Uncheck Show Plane. 

6. 

7. Right-click view, Link Camera…
8. Click other view.

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Multiview

1. Split the view horizontally. 
2. Make disk_out_ref.ex2 visible.
3. Color surface by Temp.
4. Add clip filter. 
5. Uncheck Show Plane. 

6. 

7. Right-click view, Link Camera…
8. Click other view.
9. Click 

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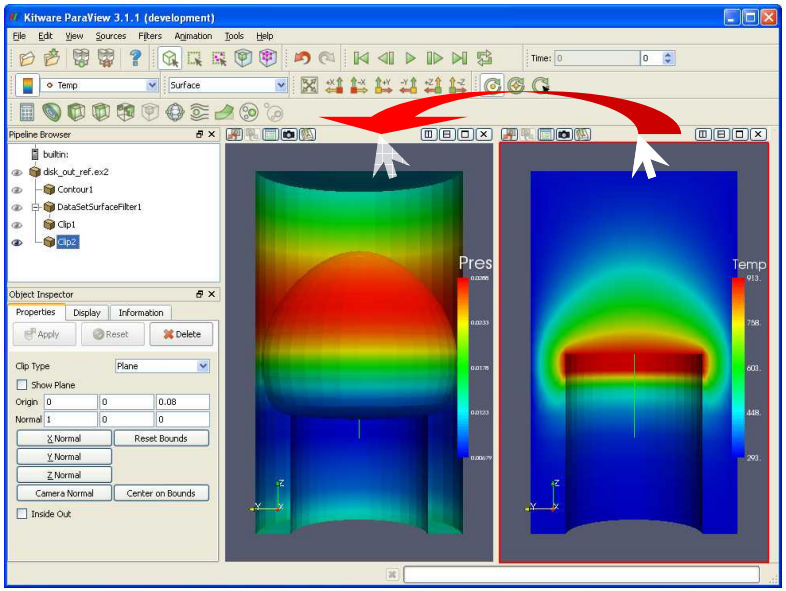
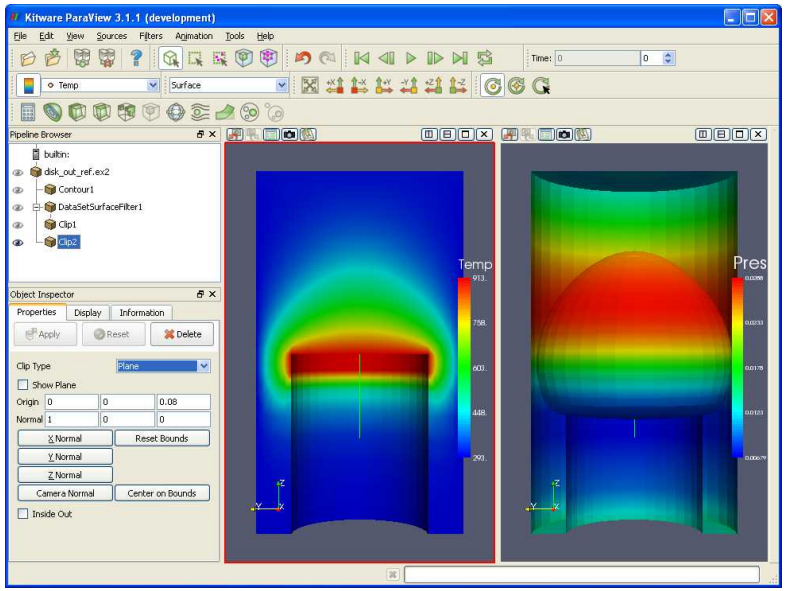
Modifying Views





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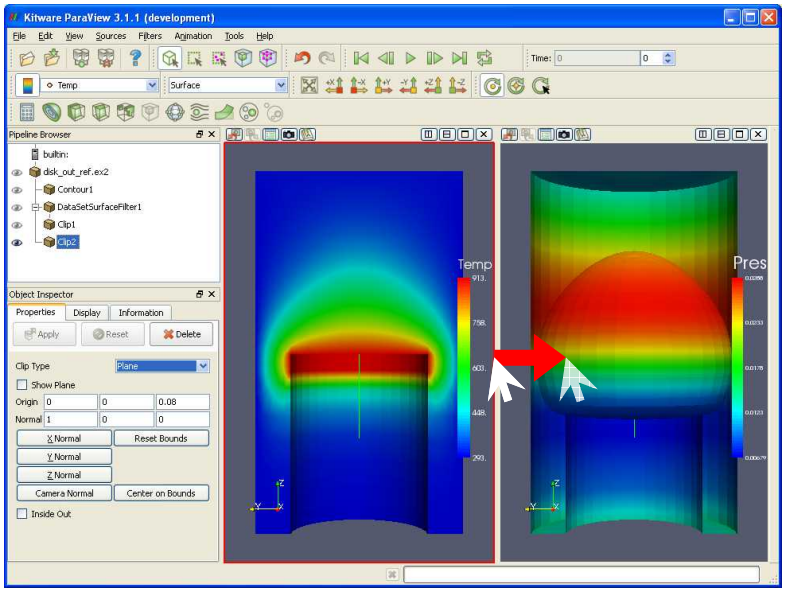
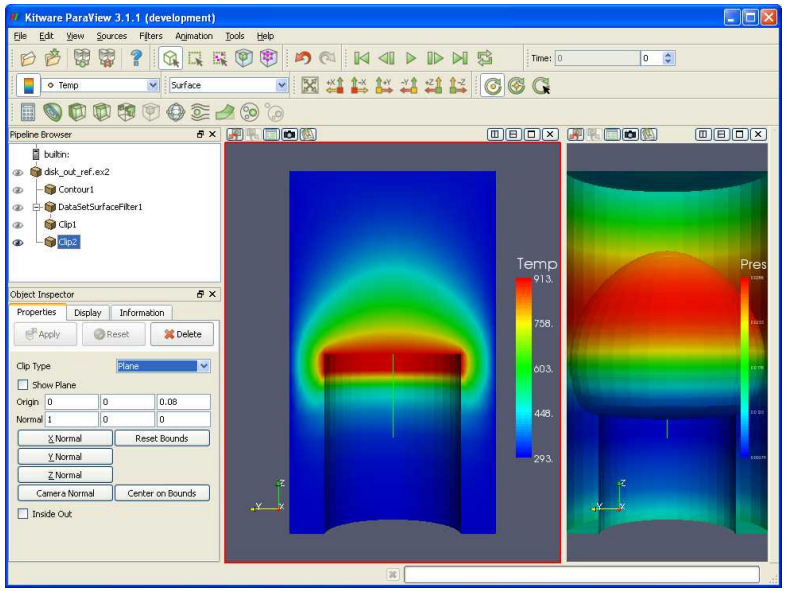
Modifying Views





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Streamlines

1. Split view vertically,  maximize 
2. Make disk_out_ref.ex2 visible 
3. Select disk_out_ref.ex2.
4. Add stream tracer. 
5. 

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Streamlines

1. Split view vertically,  maximize 
2. Make disk_out_ref.ex2 visible 
3. Select disk_out_ref.ex2.
4. Add stream tracer. 
5. 

6. Select Filters → Alphabetical → Tube
7. 

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Getting Fancy

1. Select StreamTracer1.
2. Add glyph filter. 
3. Change Glyph Type to Cone.
4. 

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Getting Answers

- Where is the air moving the fastest? Near the disk or away from it? At the center of the disk or near its edges?
- Which way is the plate spinning?
- At the surface of the disk, is air moving toward the center or away from it?

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Selection


Surface Cell Selection


Surface Point Selection


Through Cell Selection


Through Point Selection

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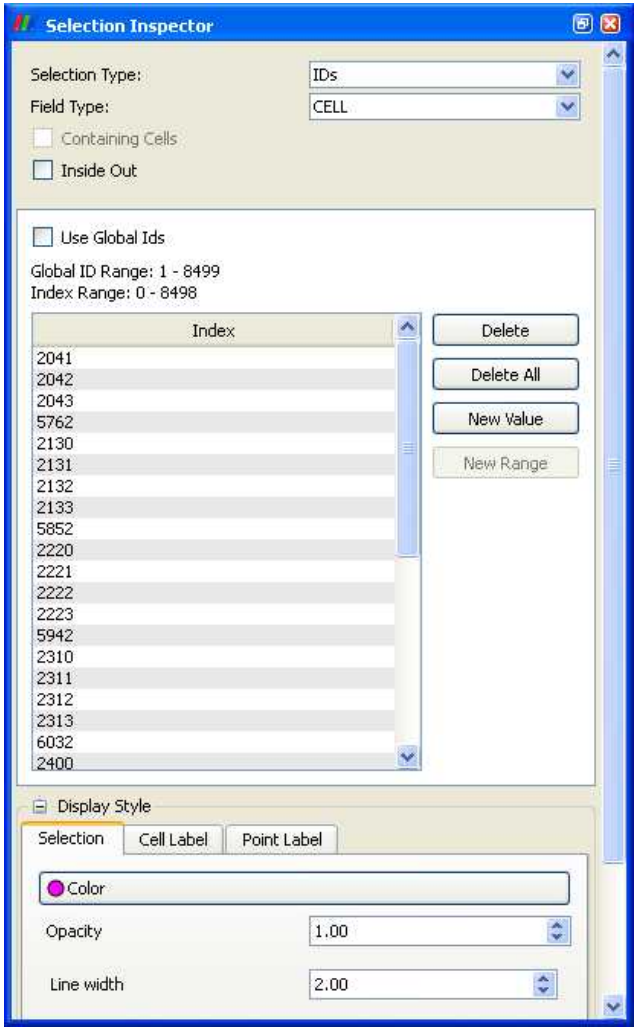
Selection Inspector



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Extracting a Selection

1. Perform a through cell selection.
2. Filters → Data Analysis → Extract Selection
3. Click the Copy Active Selection
4. 

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Extracting a Selection

1. Perform a through cell selection.
2. Filters → Data Analysis → Extract Selection
3. Click the Copy Active Selection.
4. 

5. Delete ExtractSurface1 when done.

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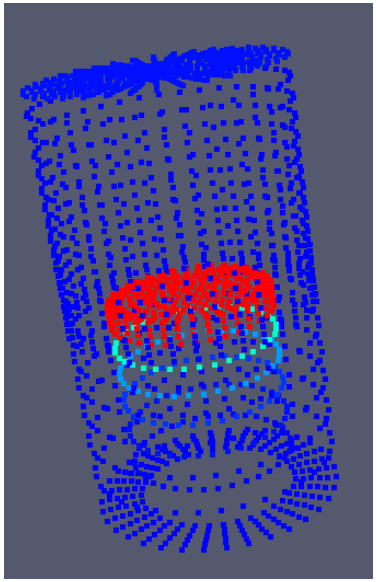
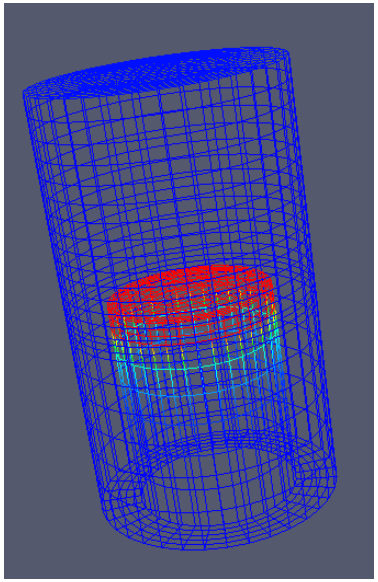
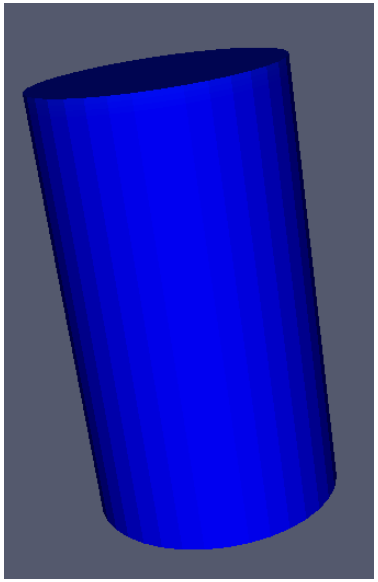
Geometry Representations



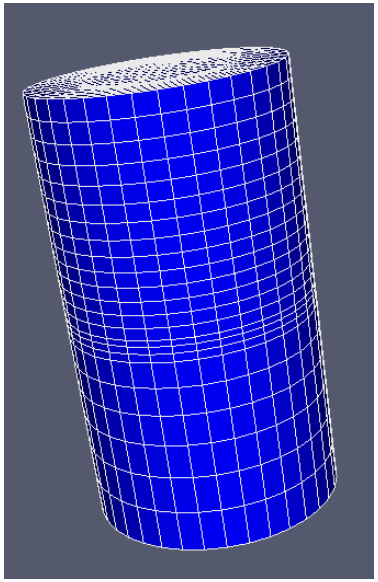
Points



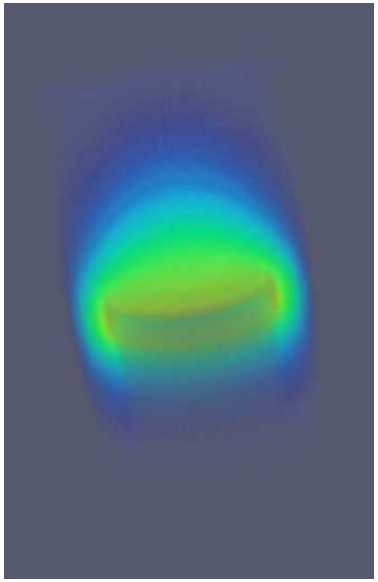
Wireframe



Surface



Surface
with Edges



Volume

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Volume Rendering

1. Select view with temp on clipped mesh.
2. Delete visible clip filter.
3. Make sure disk_out_ref.ex2 selected.
4. Change variable viewed to Temp.
5. Change representation to Volume.

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Volume Rendering + Surface Geometry

1. Select view showing streamlines.
2. Make disk_out_ref.ex2 visible. 
3. Change variable viewed to Temp.
4. Change representation to Volume.

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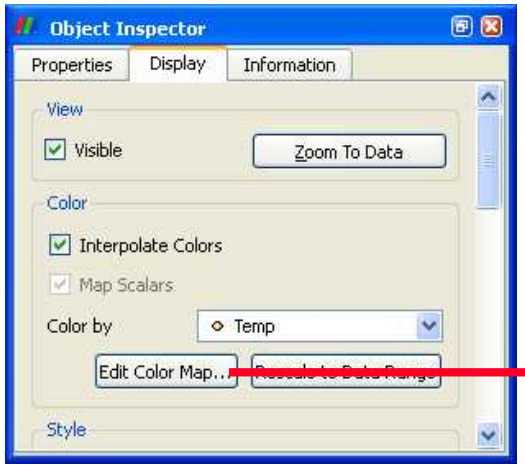
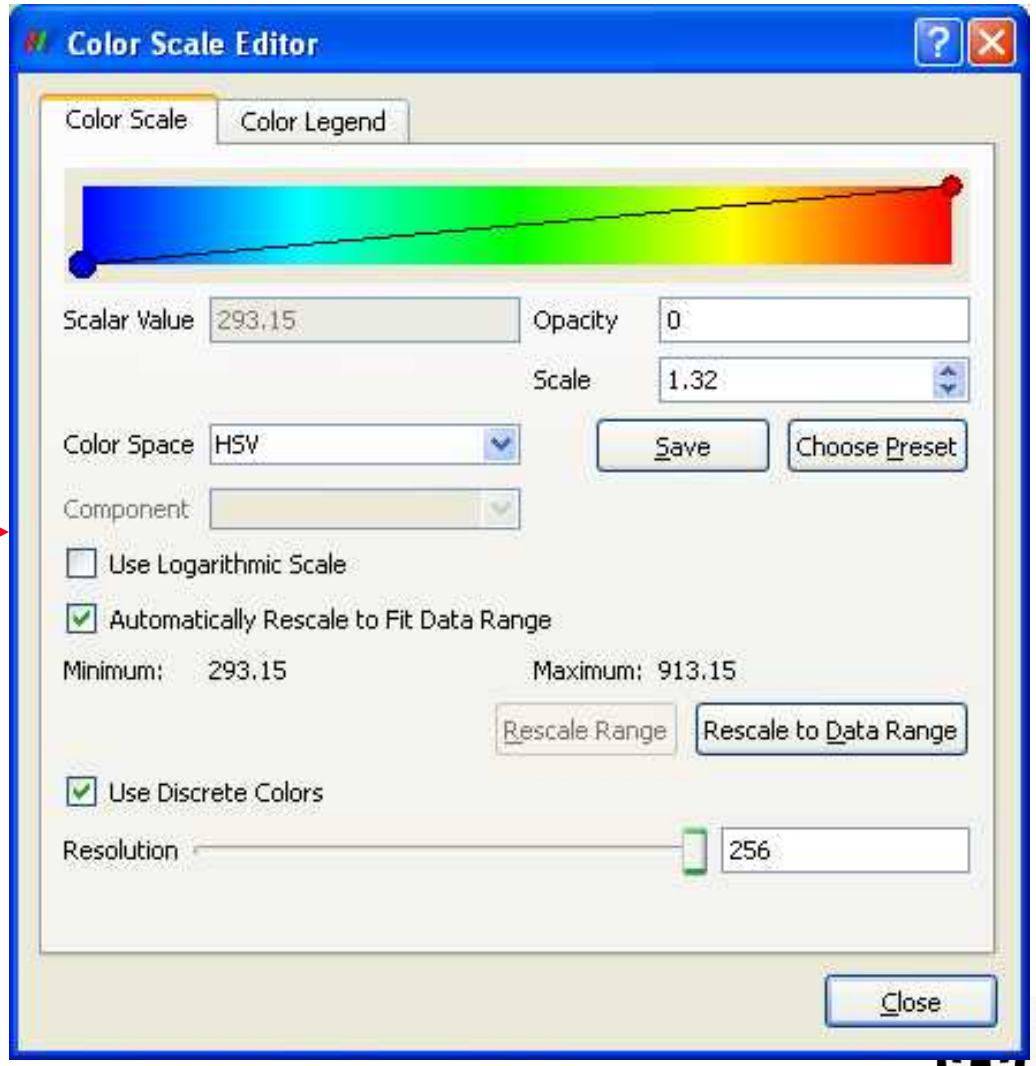
Transfer Function Editor





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Plotting

1. Select disk_out_ref.ex2
2. Filters → Data Analysis → Plot Over Line

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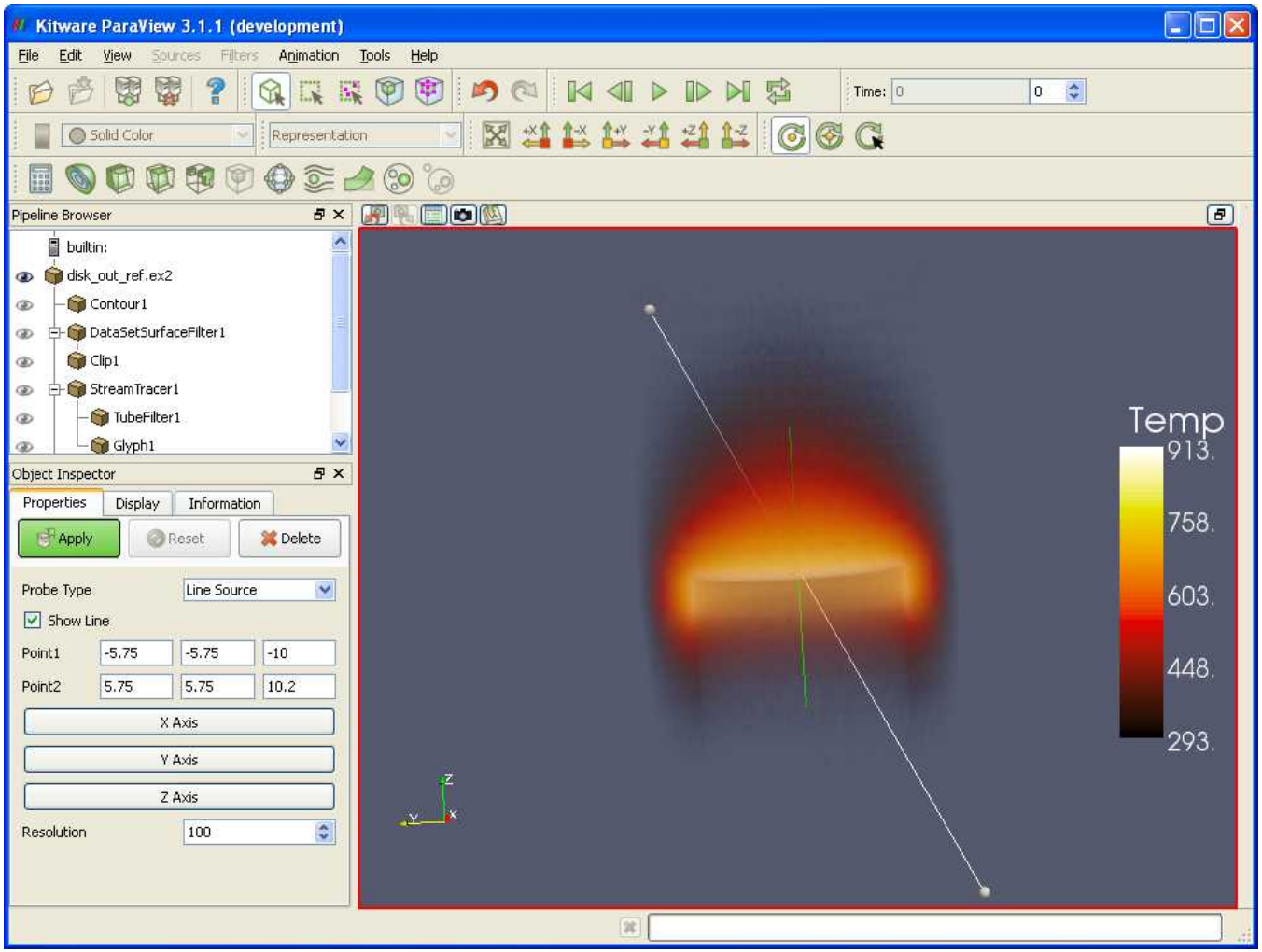
3D Widgets



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Plotting

1. Select disk_out_ref.ex2
2. Filters → Data Analysis → Plot Over Line.
3. Once line satisfactorily located, 

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Interacting with Plots

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

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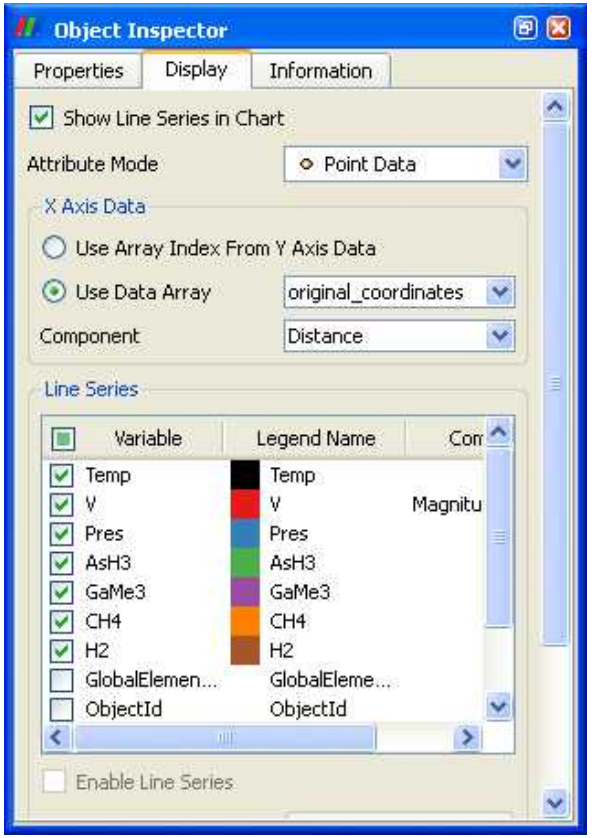
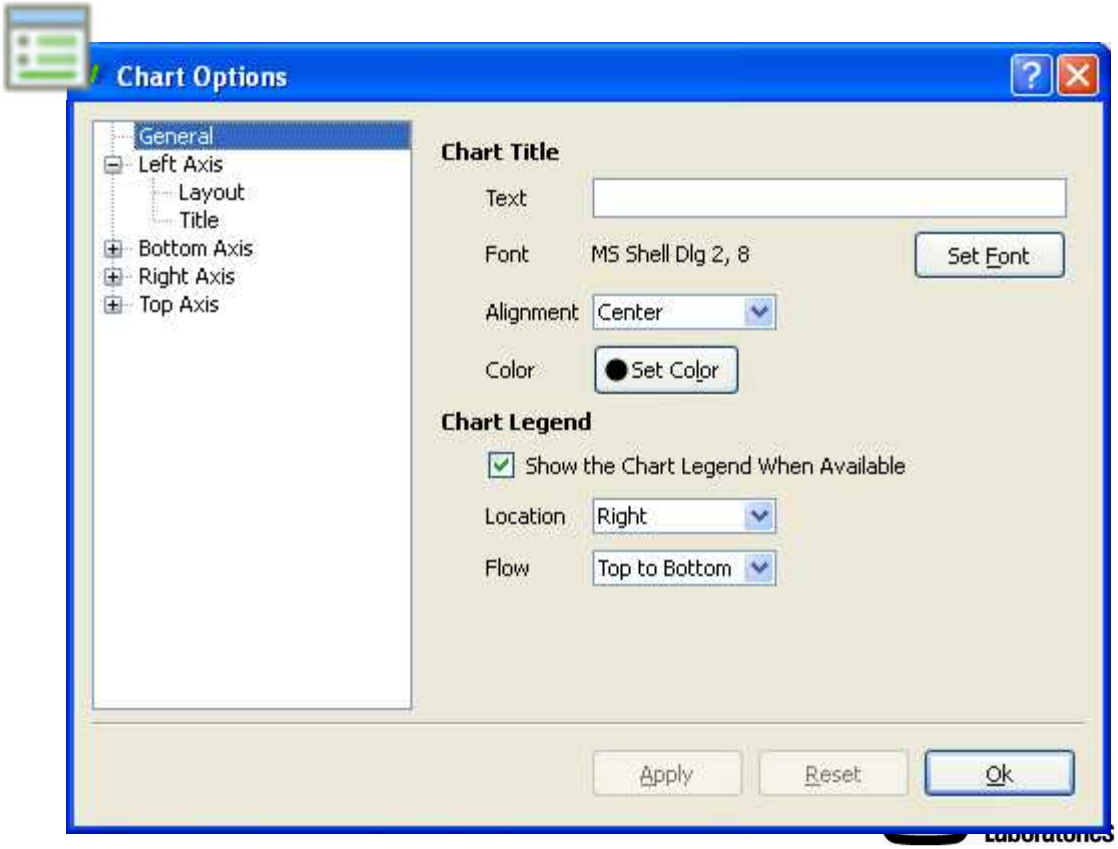
Plots are Views

- Move them like Views.
- Save screenshots (+ vector pdf).





Histogram / Bar Chart

1. Select disk_out_ref.ex2.
2. Filters → Data Analysis → Histogram
3. 

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Reset ParaView

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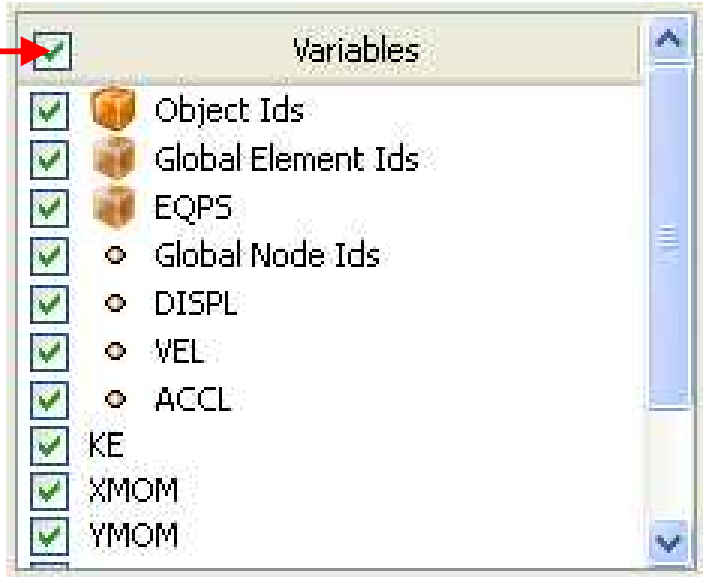
Loading Data with Time

1. Open the file can.ex2.
2. Select all variables.
3. 

4. 

5. 



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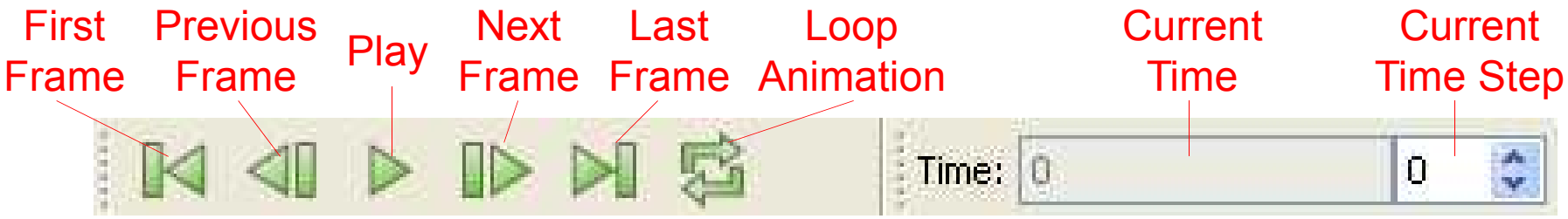
Animation Toolbar



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Animation Pitfall

1. Go to first time step. 
2. Turn on EQPS variable.
3. Turn on color legend. 
4. Play  (or skip to last time step ).

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Animation Pitfall

1. Go to first time step. 
2. Turn on EQPS variable.
3. Turn on color legend. 
4. Play  (or skip to last time step ).
5. Fix with Rescale to Data Range in Display tab. 

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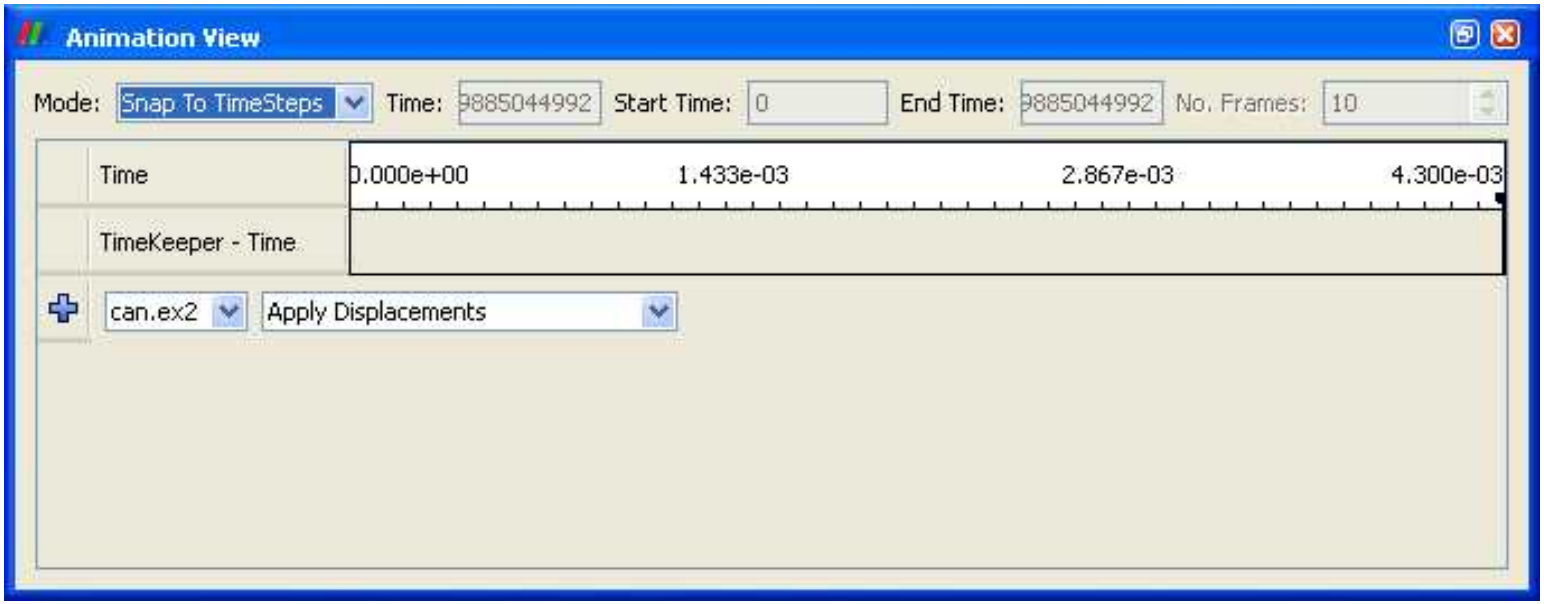
Animation View

View → Animation View



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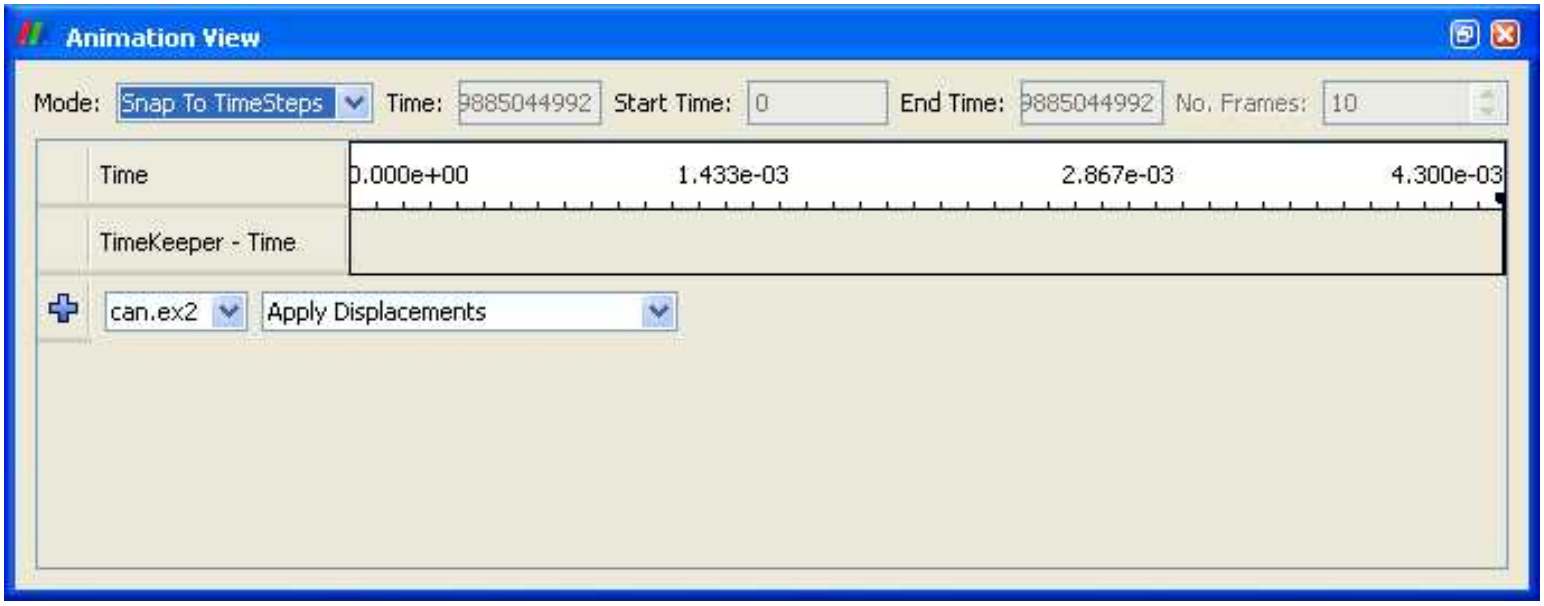
Animation View

View → Animation View



Animation Modes: Sequence, Real Time, and Snap To TimeSteps

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Changing Animation Timing

1. Change animation mode to Real Time.
   - Default animation time is 10 sec.
2. 

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Changing Animation Timing

1. Change animation mode to Real Time.
   - Default animation time is 10 sec.
2. 
3. Change animation time to 30 sec.
4.  again.

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Smoothing the Animation

1. Filters → Alphabetical → Temporal Interpolator
2. 

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Adding Text Annotation

1. Sources → Text
2. Type a message in text edit box
3. 

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Text Position

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Annotate Time

1. Sources → Annotate Time
2. 

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Annotate Time

1. Sources → Annotate Time
2. 

3. Select can.ex2
4. Filters → Alphabetical → Annotate Time
5. 

6. Move annotation around.

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Reset ParaView

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Make an Animation

1. Sources → Sphere, 

2. Make animation view visible.
3. Change No. Frames to 50.
4. Select SphereSource1, Start Theta 

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Make an Animation

1. Sources → Sphere, 

2. Make animation view visible.
3. Change No. Frames to 50.
4. Select SphereSource1, Start Theta
5. Double-click SphereSource1 – Start Theta
6. Make New keyframe.
7. First keyframe→360, second keyframe→0.
8. Click OK.

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Animating Two Properties

1. Open SphereSource1 – Start Theta.
2. Delete the first track (at time step 0).
3. Click OK.
4. Create SphereSource1 – End Theta.
5. Open SphereSource1 – End Theta.
6. Change second key frame time to 0.5.

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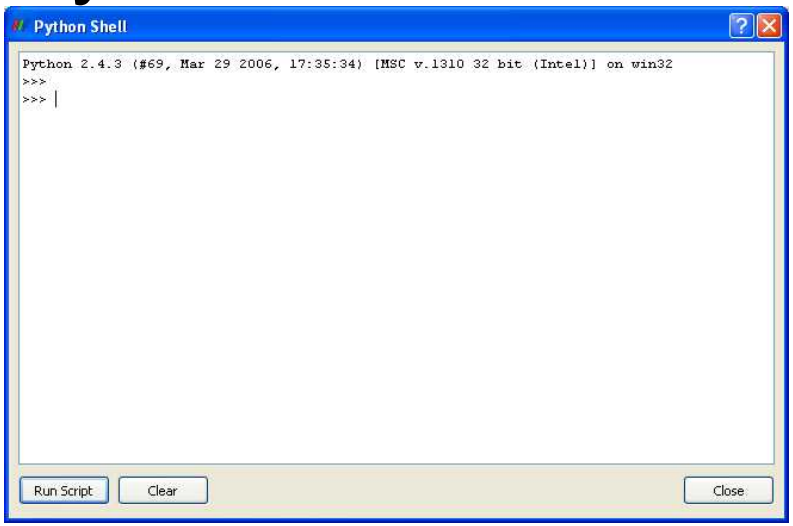
Scripting Options

- Tools → Python Shell



- Filters → Data Analysis → Programmable Filter
- pvpython, pvbatch

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Visualizing Large Models

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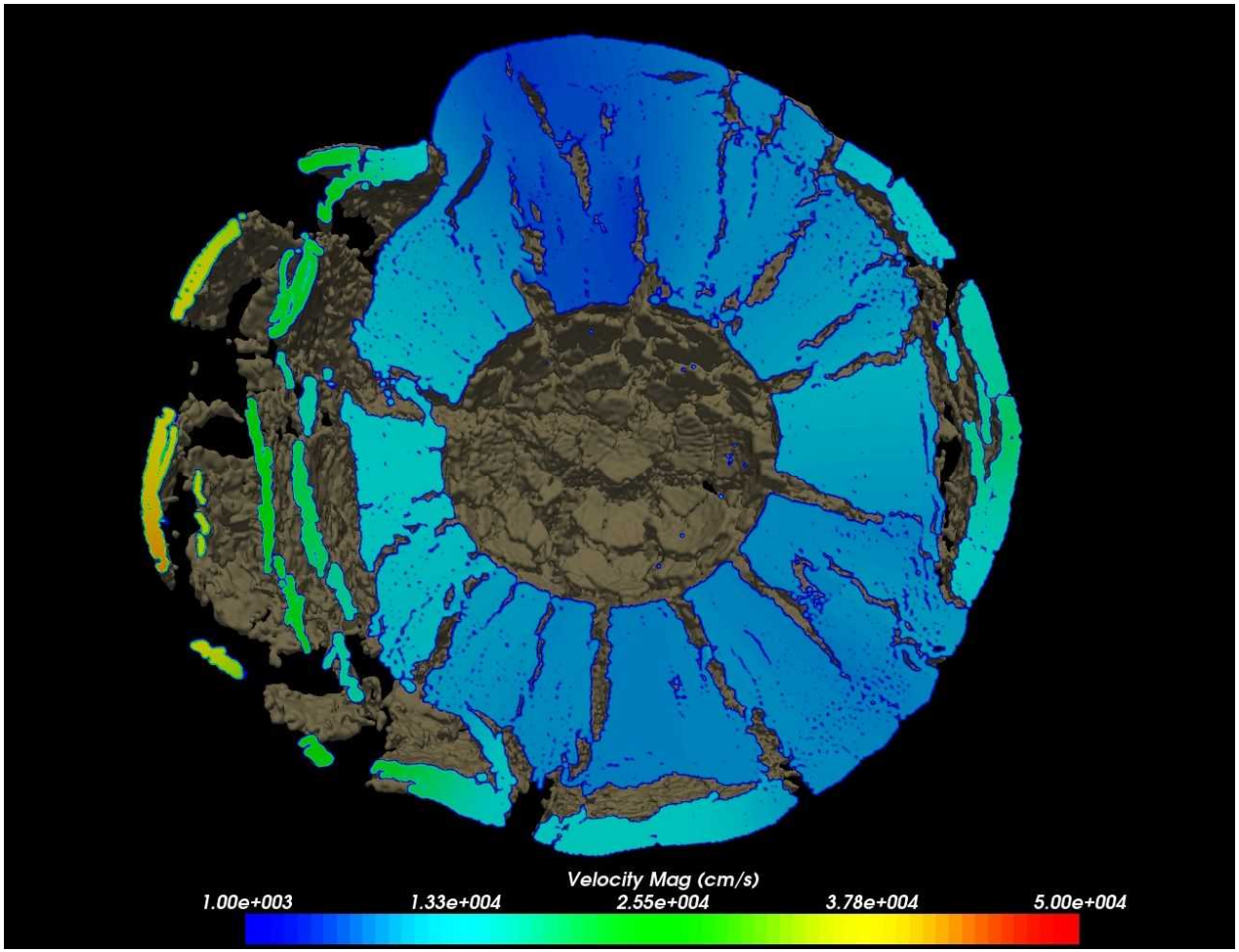
Golevka Asteroid vs. 10 Megaton Explosion

- CTH shock physics, over 1 billion cells



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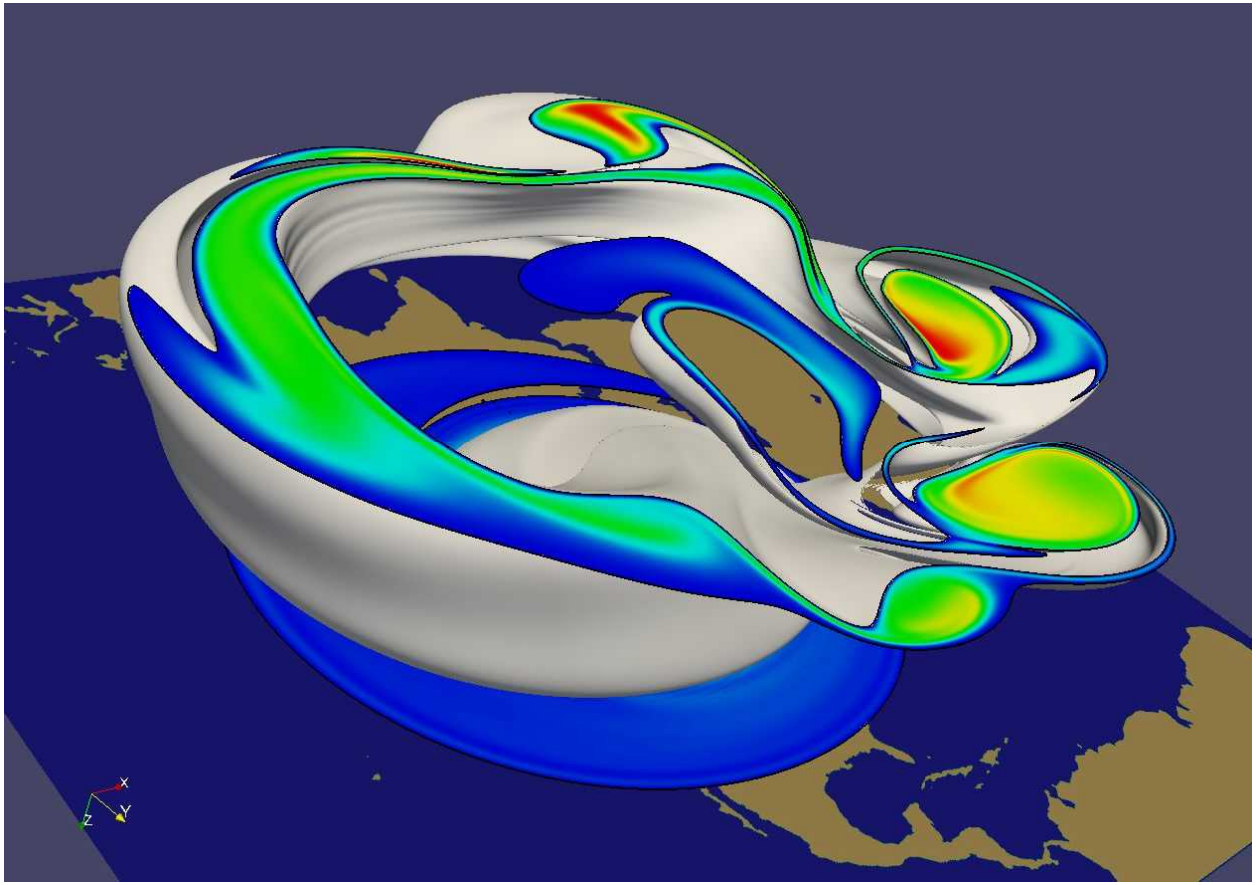
Polar Vortex Breakdown

- SEAM Climate Modeling, 1 billion cells (500 million cells visualized).



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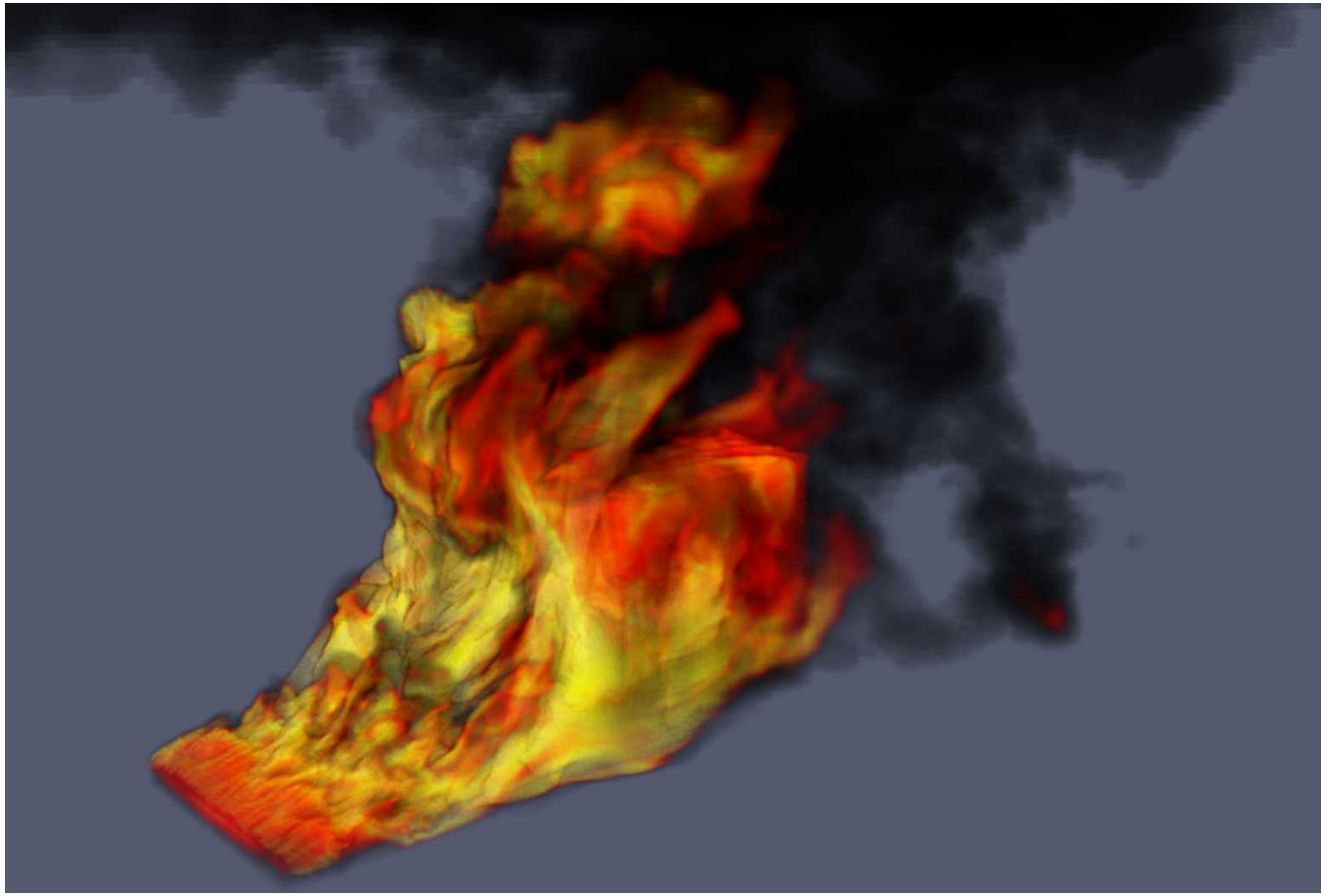
Objects-in-Crosswind Fire

- Coupled SIERRA/Fuego/Syrinx/Calore, 10 million unstructured hexahedra



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ParaView Architecture

- Three tier
  - Data Server
  - Render Server
  - Client

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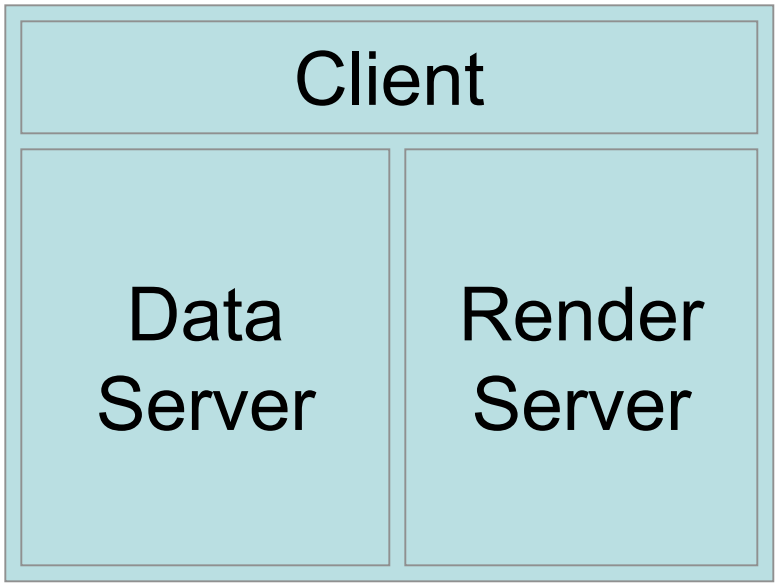
Standalone



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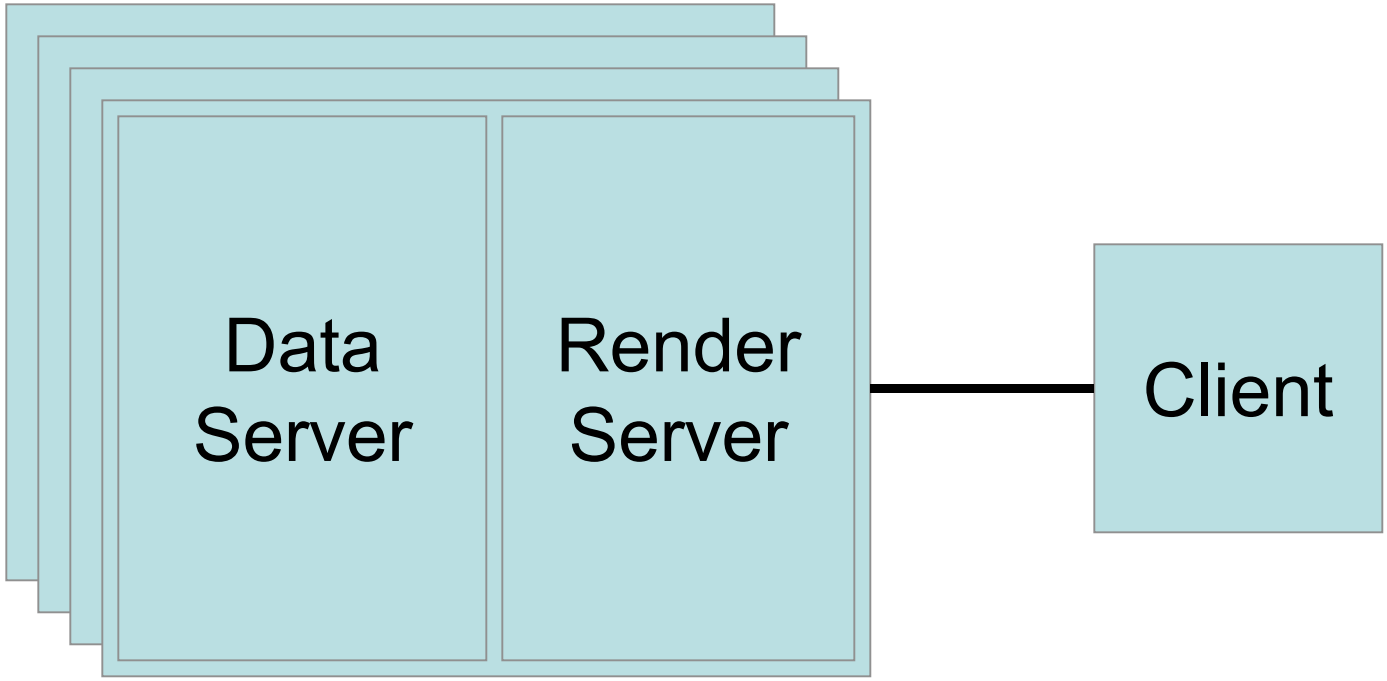
Client-Server



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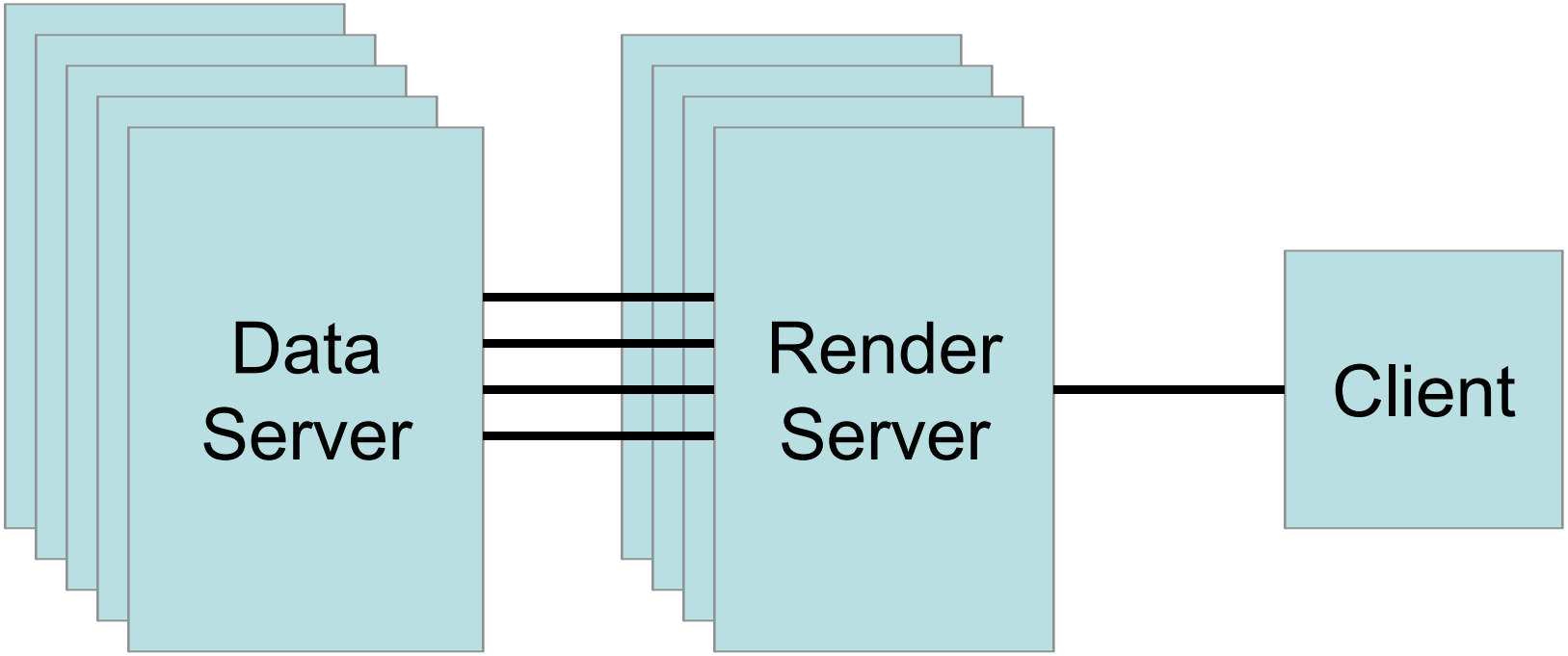
Client-Render Server-Data Server



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Requirements for Installing ParaView Server

- C++
- CMake (www.cmake.org)
- MPI
- OpenGL (or Mesa3D www.mesa3d.org)
- Qt 4.2.3 (optional)
- Python (optional)
- http://www.paraview.org/Wiki/Setting_up_a_ParaView_Server#Compiling

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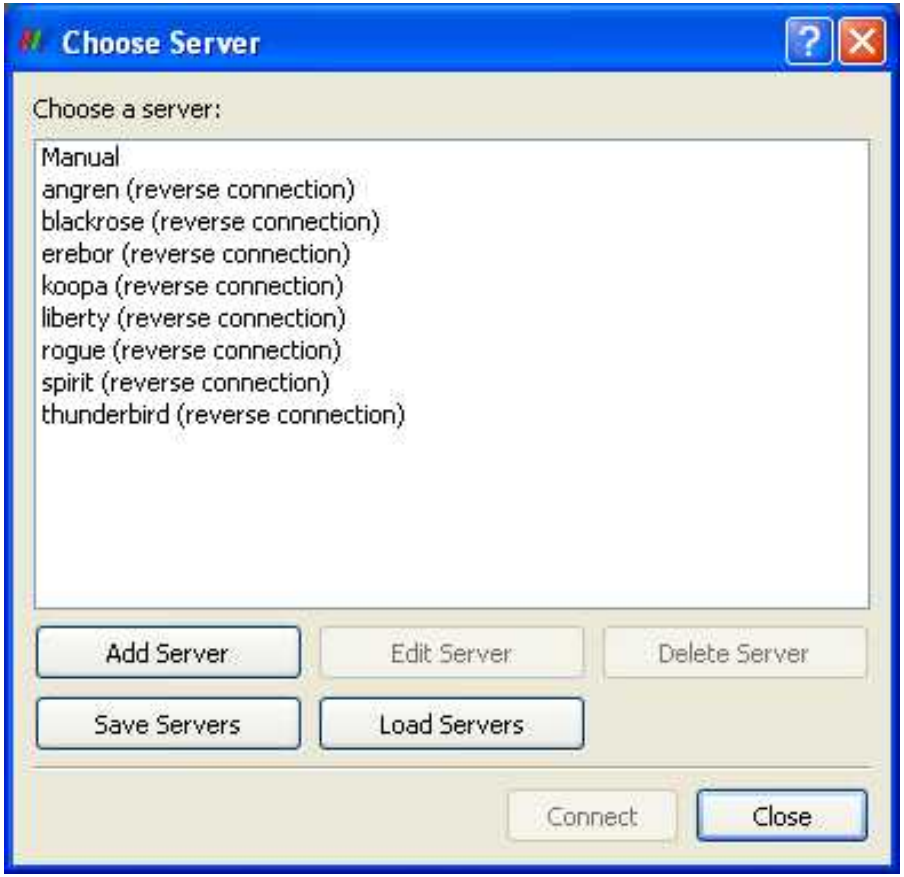
Connecting to a ParaView Server



http://www.paraview.org/Wiki/Setting_up_a_ParaView_Server#Running_the_Server

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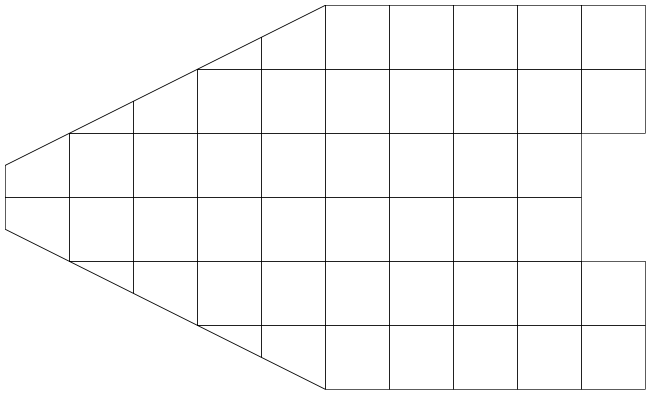
Data Parallel Pipelines

- Duplicate pipelines run independently on different partitions of data.



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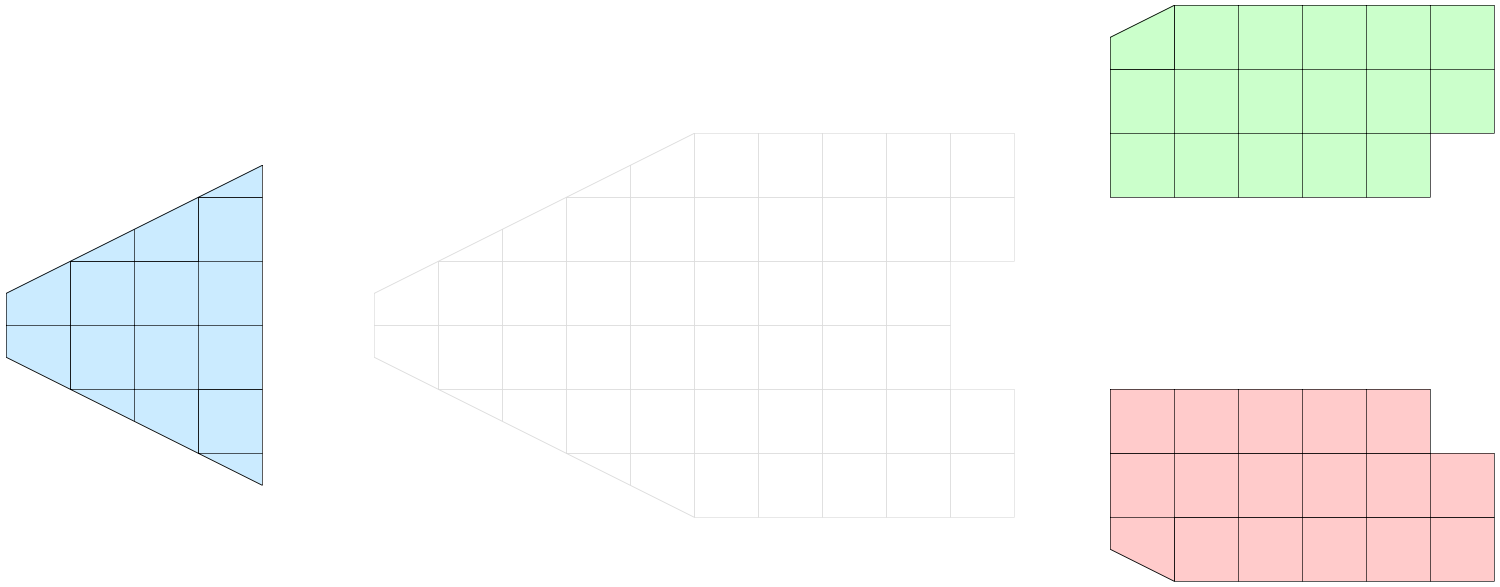

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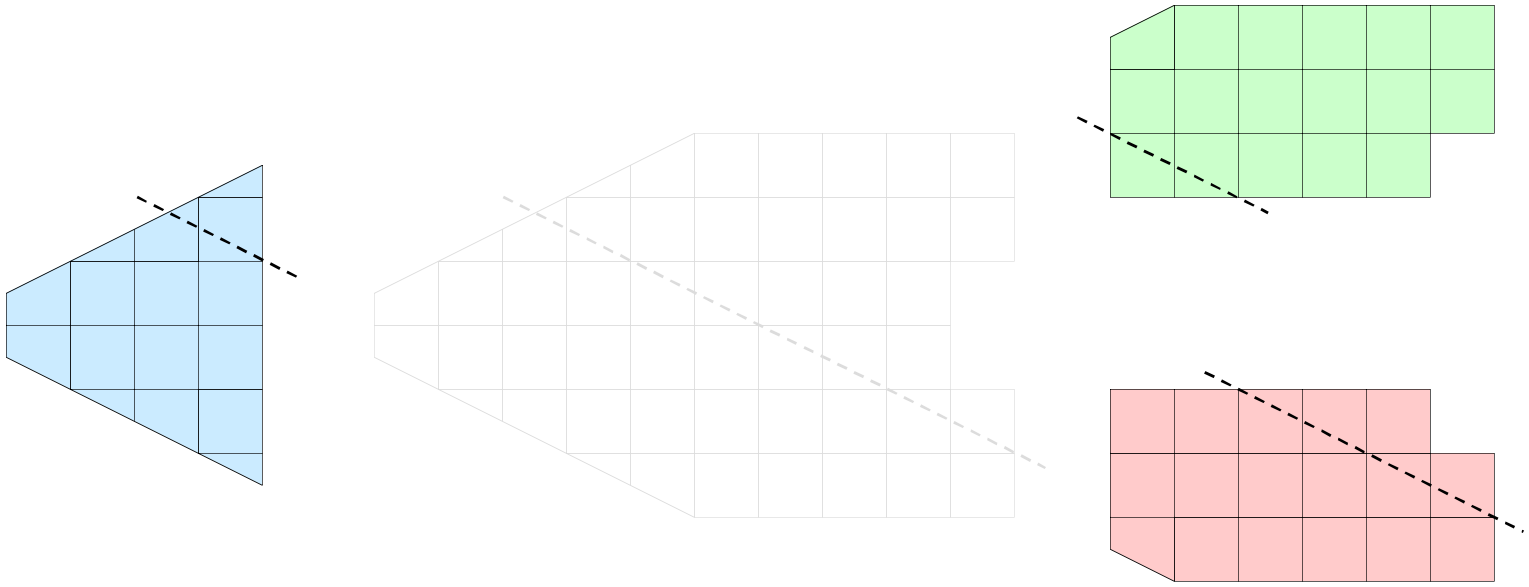
Data Parallel Pipelines

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



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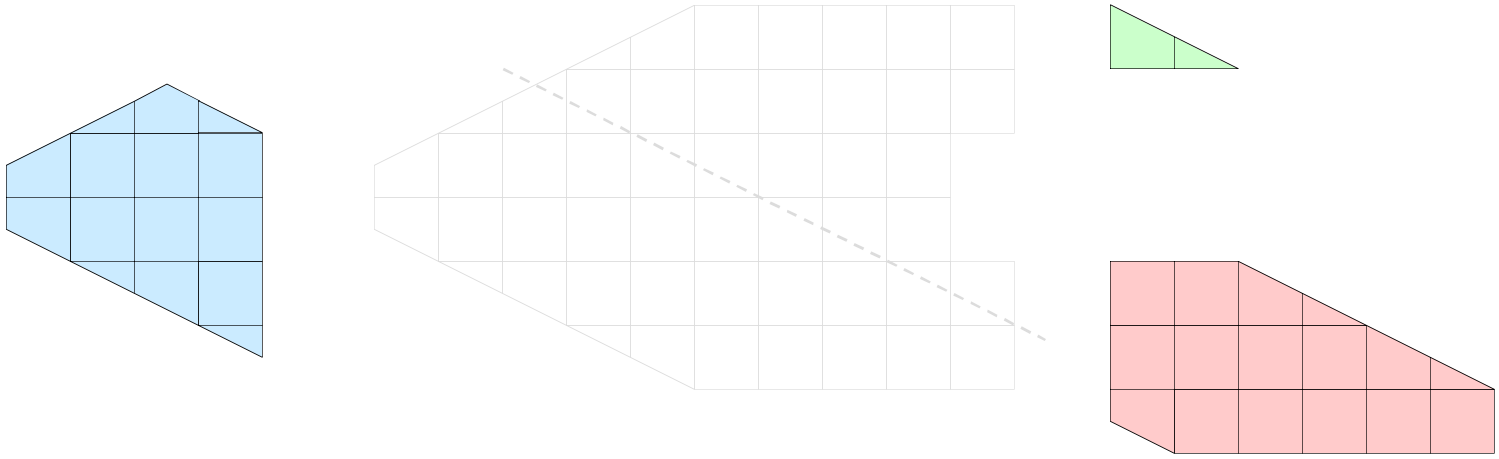

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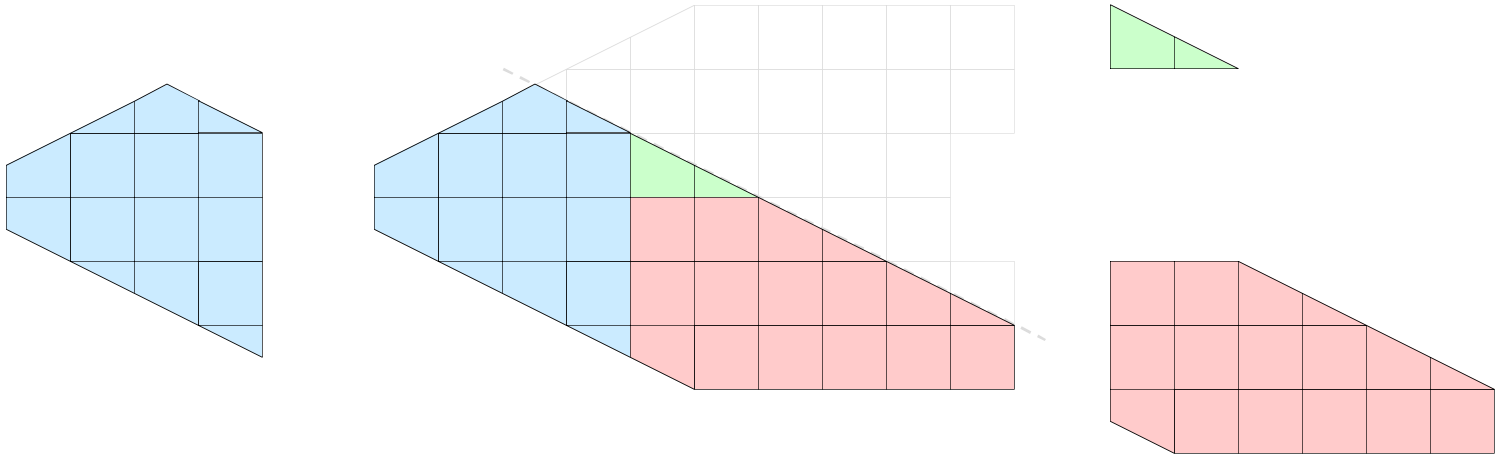

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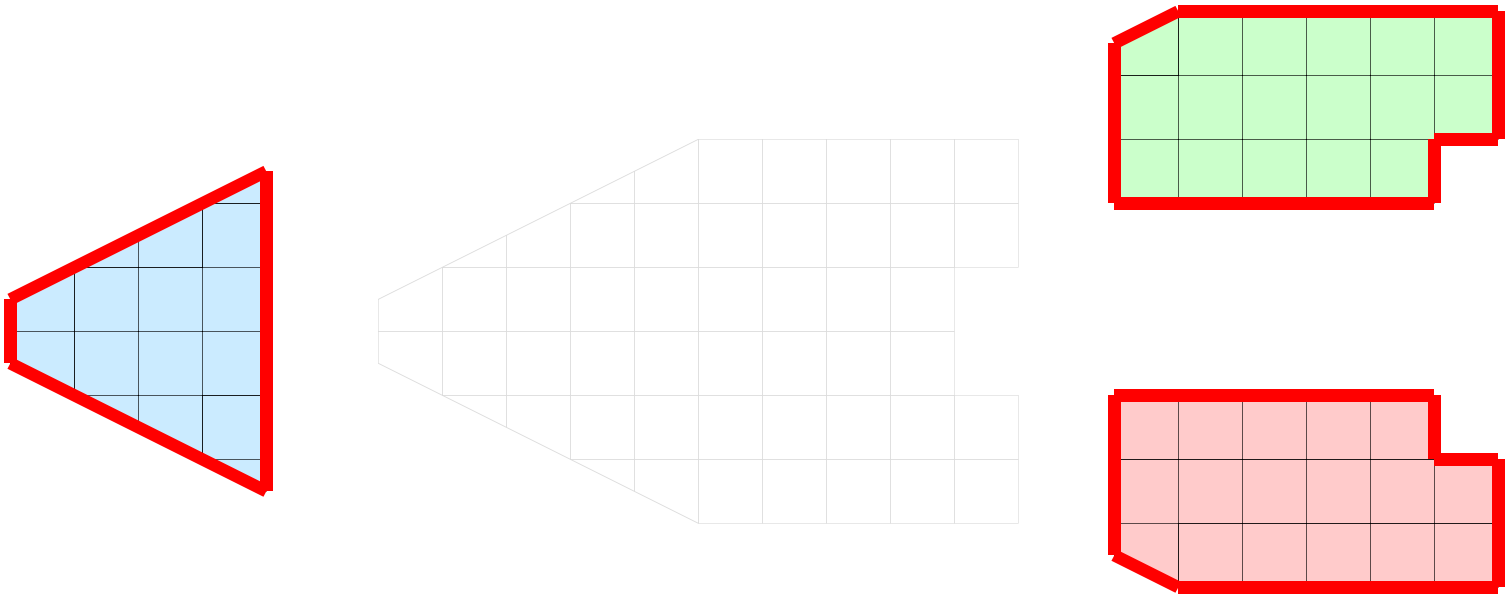
Data Parallel Pipelines

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



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Data Parallel Pipelines

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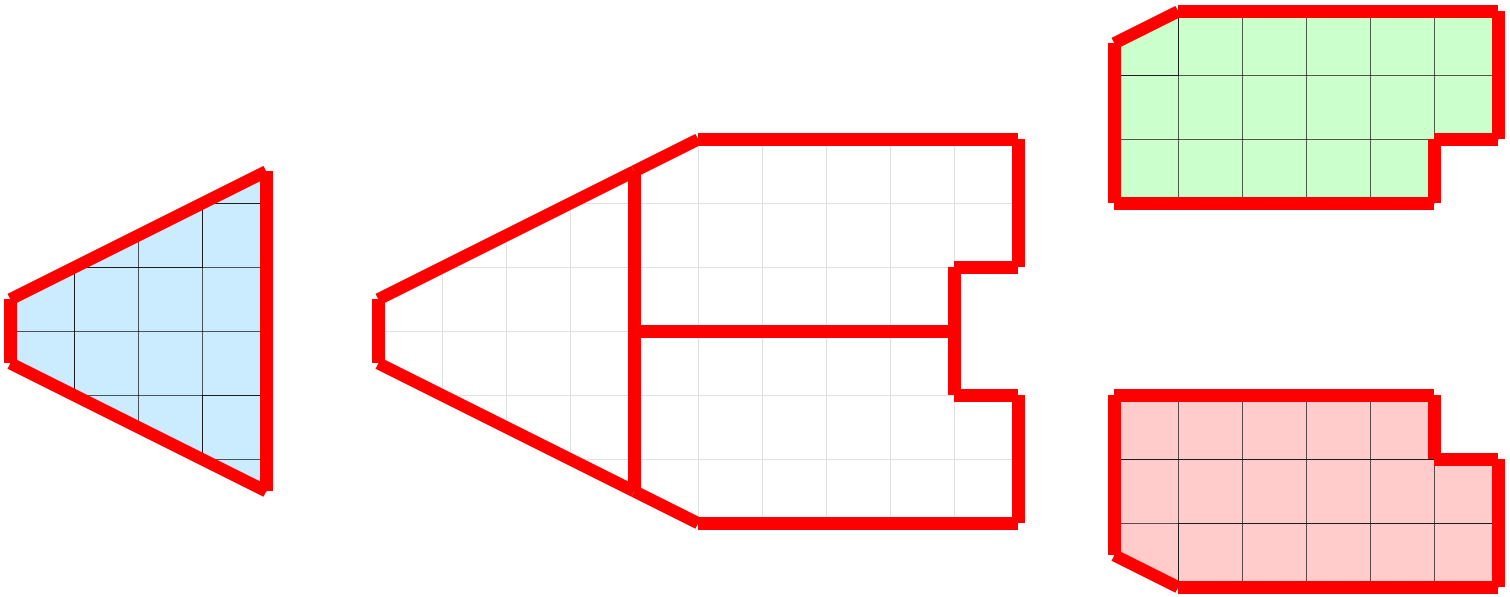

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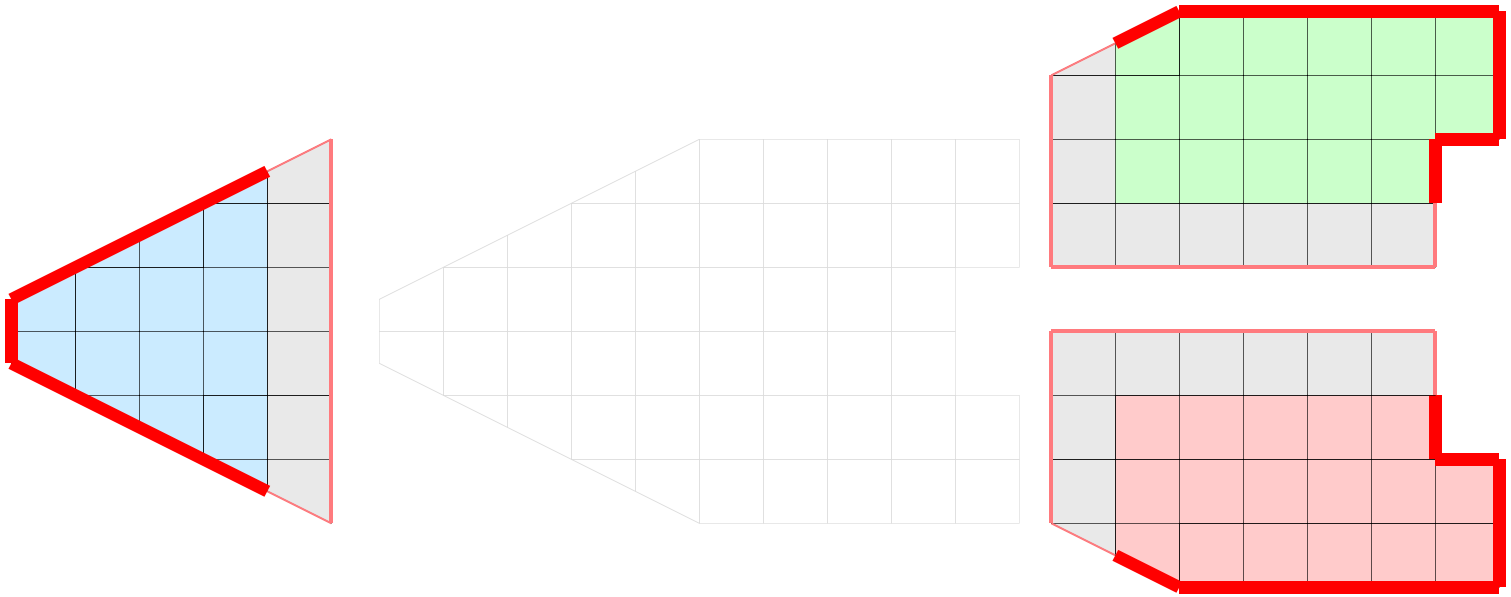
Data Parallel Pipelines

- Ghost cells can solve most of these problems.



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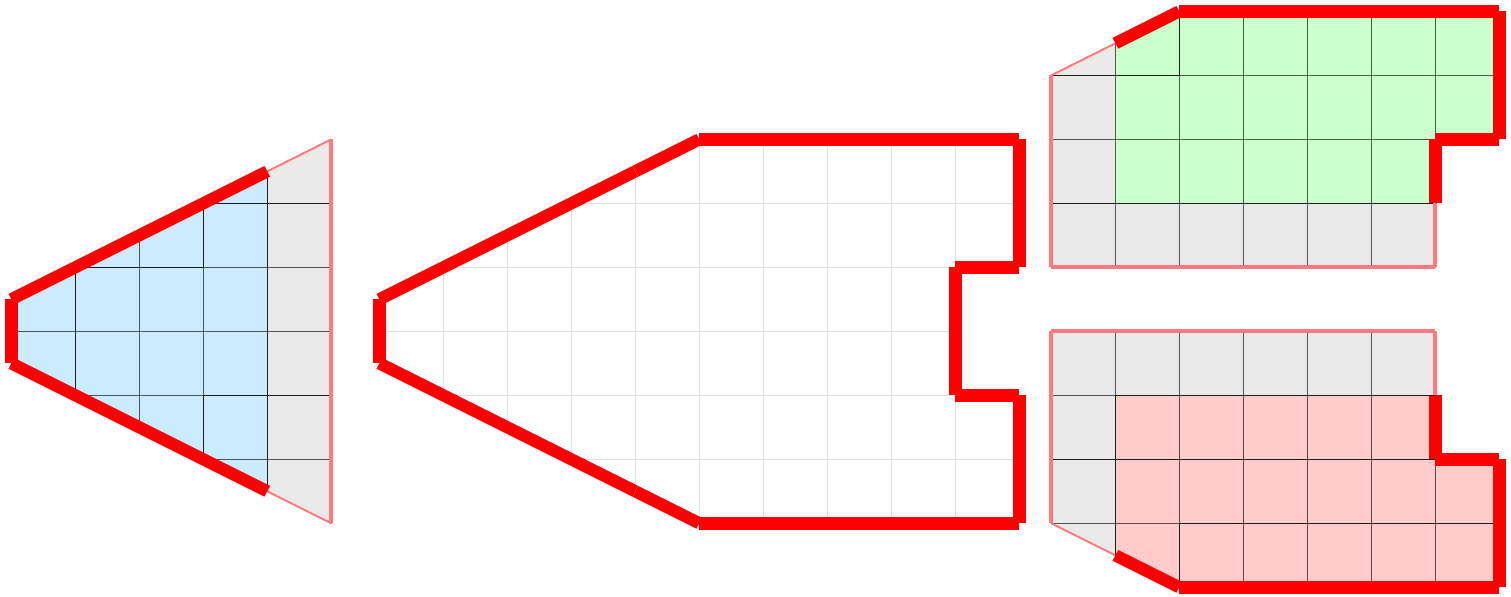

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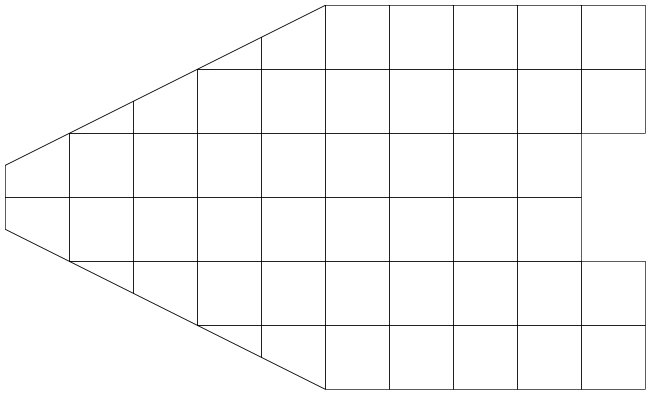
Data Partitioning

- Partitions should be load balanced and spatially coherent.



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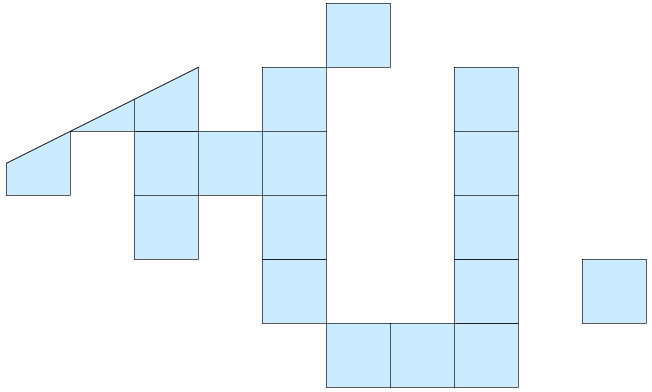

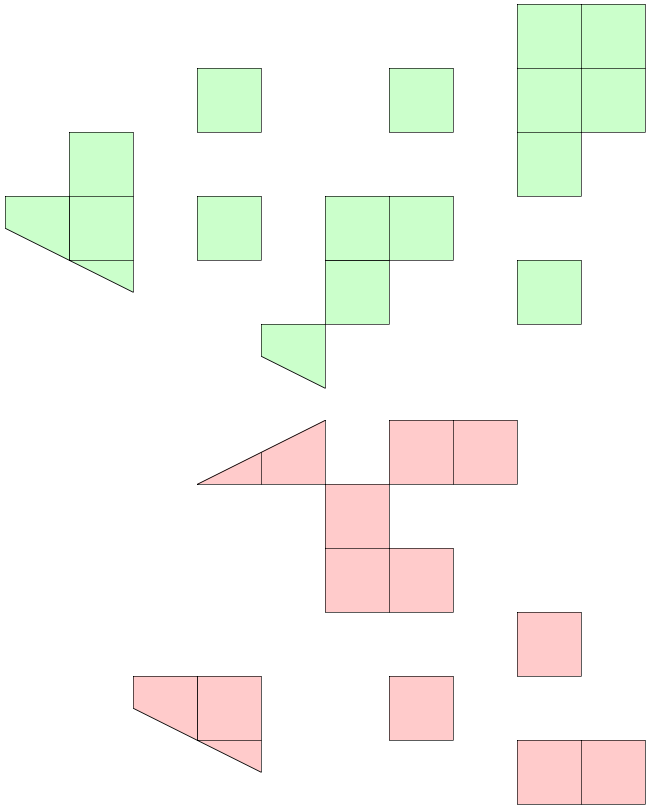

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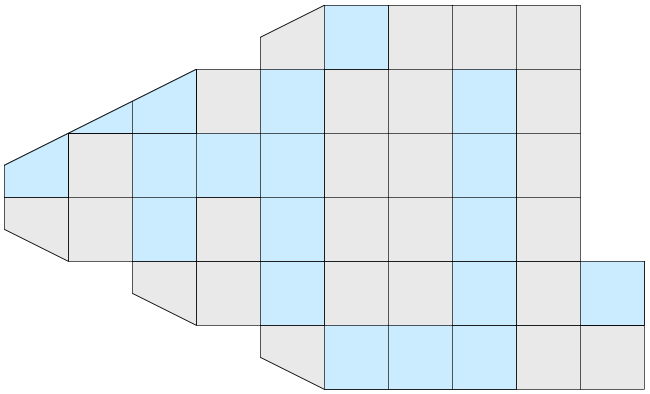

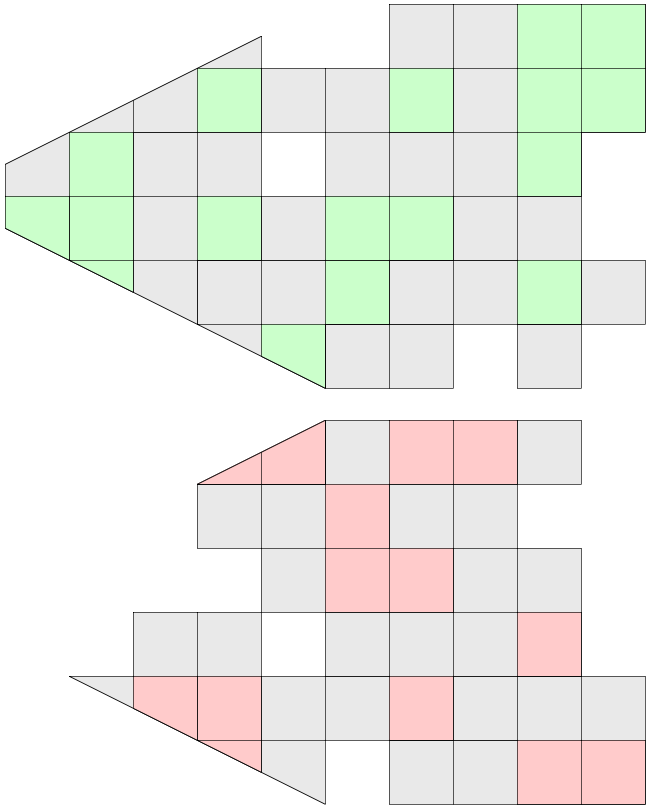

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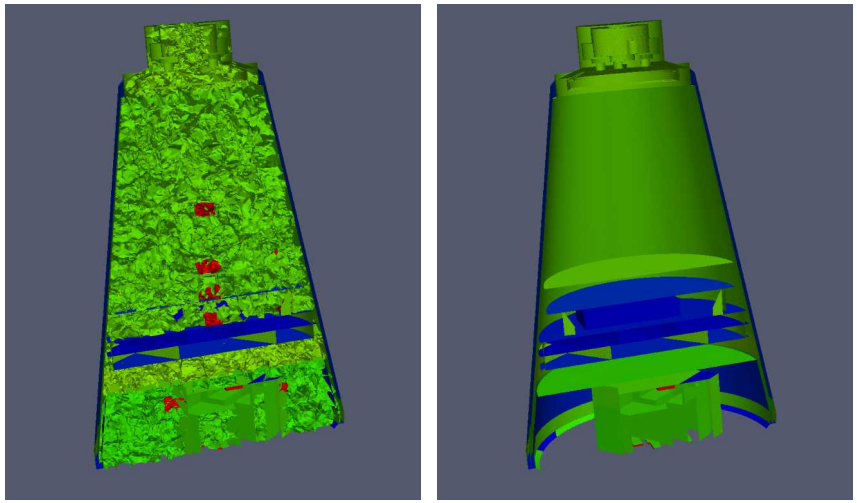
Load Balancing/Ghost Cells

- Automatic for Structured Meshes.
- Partitioning/ghost cells for unstructured is “manual.”
- Use the D3 filter for unstructured
  - (Filters → Alphabetical → D3)



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Job Size Rules of Thumb

- Structured Data
  - Try for max 20 M cell/processor.
  - Shoot for 5 – 10 M cell/processor.
- Unstructured Data
  - Try for max 1 M cell/processor.
  - Shoot for 250 – 500 K cell/processor.

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Avoiding Data Explosion

- Pipeline may cause data to be copied, created, converted.
- This advice **only for dealing with very large amounts of data**.
  - Remaining available memory is low.

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Topology Changing, No Reduction

- Append Datasets
- Append Geometry
- Clean
- Clean to Grid
- Connectivity
- D3
- Delaunay 2D
- Extract Edges
- Linear Extrusion
- Loop Subdivision
- Reflection
- Rotational Extrusion
- Shrink
- Smooth
- Subdivide
- Tessellate
- Tetrahedralize
- Triangle Strips
- Triangulate

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Topology Changing, Moderate Reduction

- Clip 
- Decimate
- Extract Cells by Region
- Extract Selections
- Extract Thresholds
- Quadric Clustering
- Threshold 

Similar: Extract Subset 

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Topology Changing, Dimension Reduction

- Cell Centers
- Contour 
- Extract CTH Parts
- Extract Surface
- Feature Edges
- Mask Points
- Outline (curvilinear)
- Slice 
- Stream Tracer 

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Adds Field Data

- Calculator 
- Cell Data to Point Data
- Curvature
- Elevation
- Gradient
- Gradient (Unstructured)
- Gradient Magnitude
- Level Scalars
- Median
- Mesh Quality
- Normals Generation
- Octree Depth Limit
- Octree Depth Scalars
- Point Data to Cell Data
- Process Id Scalars
- Random Vectors
- Resample with dataset
- Surface Flow
- Surface Vectors
- Transform
- Warp (scalar)
- Warp (vector) 

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Total Shallow Copy or Output Independent of Input

- Annotate Time
- Append Attributes
- Extract Datasets
- Extract Group 
- Glyph 
- Group Datasets 
- Histogram
- Integrate Variables
- Outline
- Outline Corners
- Plot Cell over Time
- Plot Field Variable over Time
- Plot Over Line
- Plot Point over Time
- Probe Location
- Probe Location over Time
- Temporal Shift Scale

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Special Cases

- Temporal Filters
  - Temporal Interpolator
  - Particle Tracer
  - Temporal Cache
- Programmable Filter

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Culling Data

- Reduce dimensionality early.

  - Contour and slice “see” inside volumes.
- Prefer data reduction of extraction.
  - Slice instead of Clip.
  - Contour instead of Threshold.
- Only extract when reducing an order of magnitude or more.
  - Can still run into troubles.

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Culling Data

- Experiment with subsampled data.
  - Extract Subset
- Use caution.
  - Subsampled data may be lacking.
  - Use full data to draw final conclusions.

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Rendering Modes

- Still Render
  - Full detail render.
- Interactive Render
  - Sacrifices detail for speed.
  - Provides quick rendering rate.
  - Used when interacting with 3D view.

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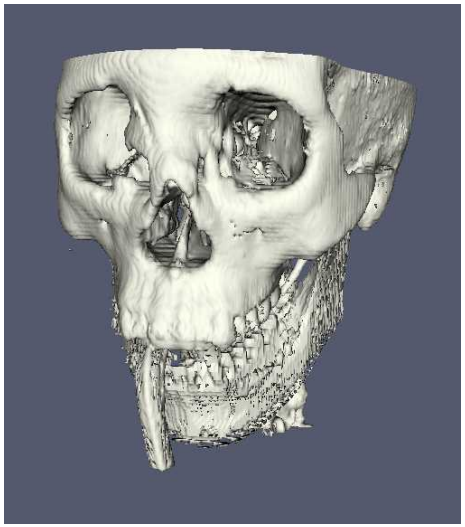
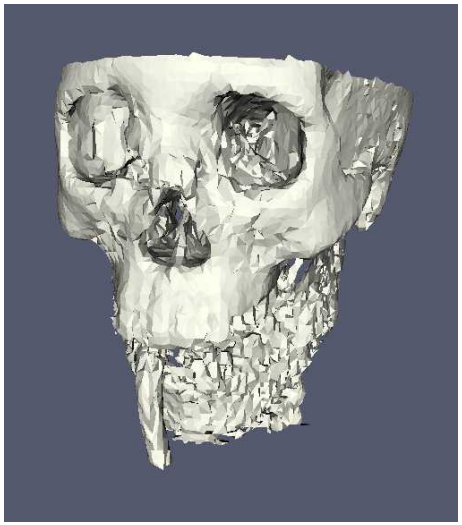
Level of Detail (LOD)

- Geometric decimation.
- Used only with Interactive Render



Original Data



Divisions: 50x50x50

Divisions: 10x10x10

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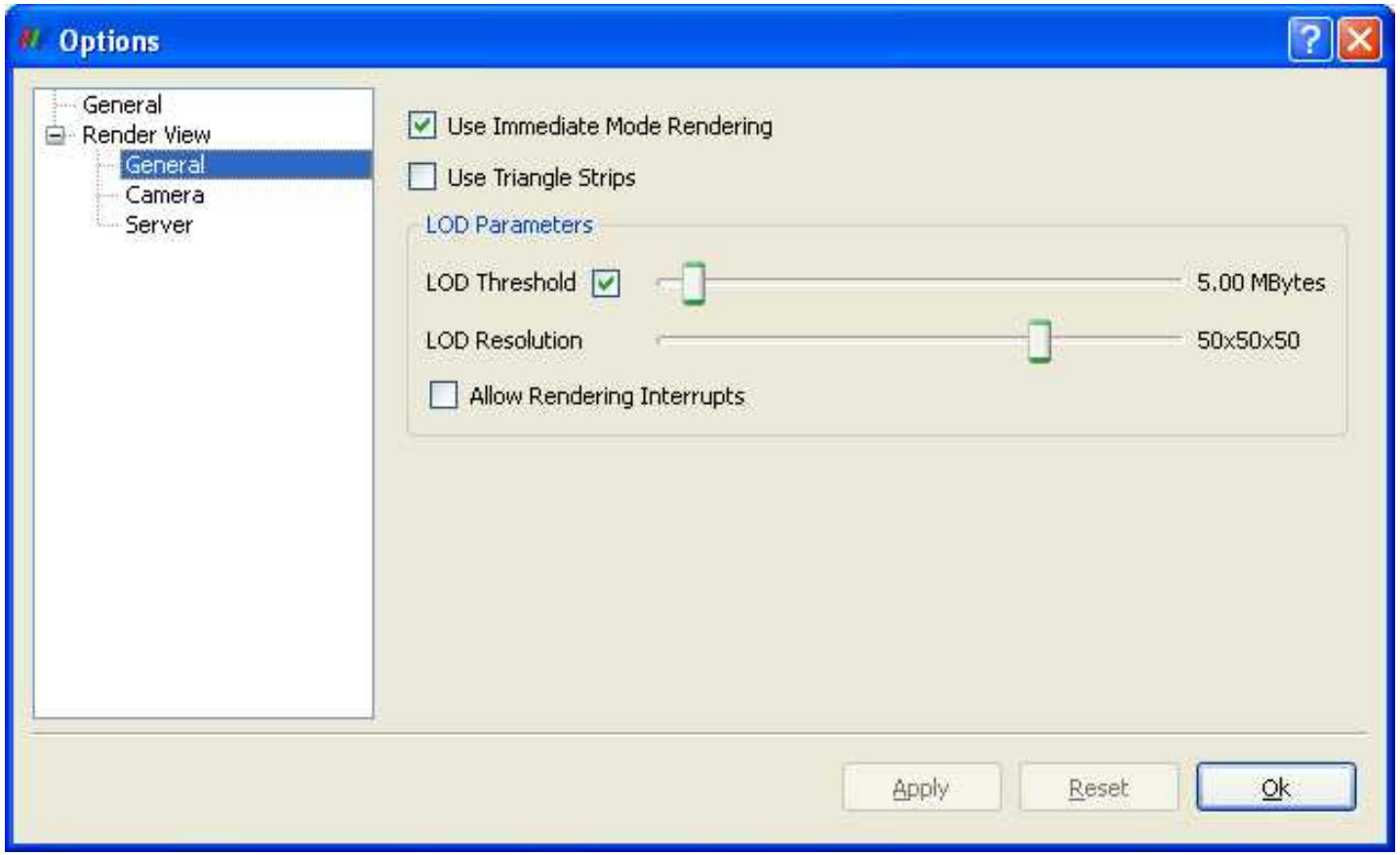
3D Rendering Parameters

Edit → Settings, Render View → General



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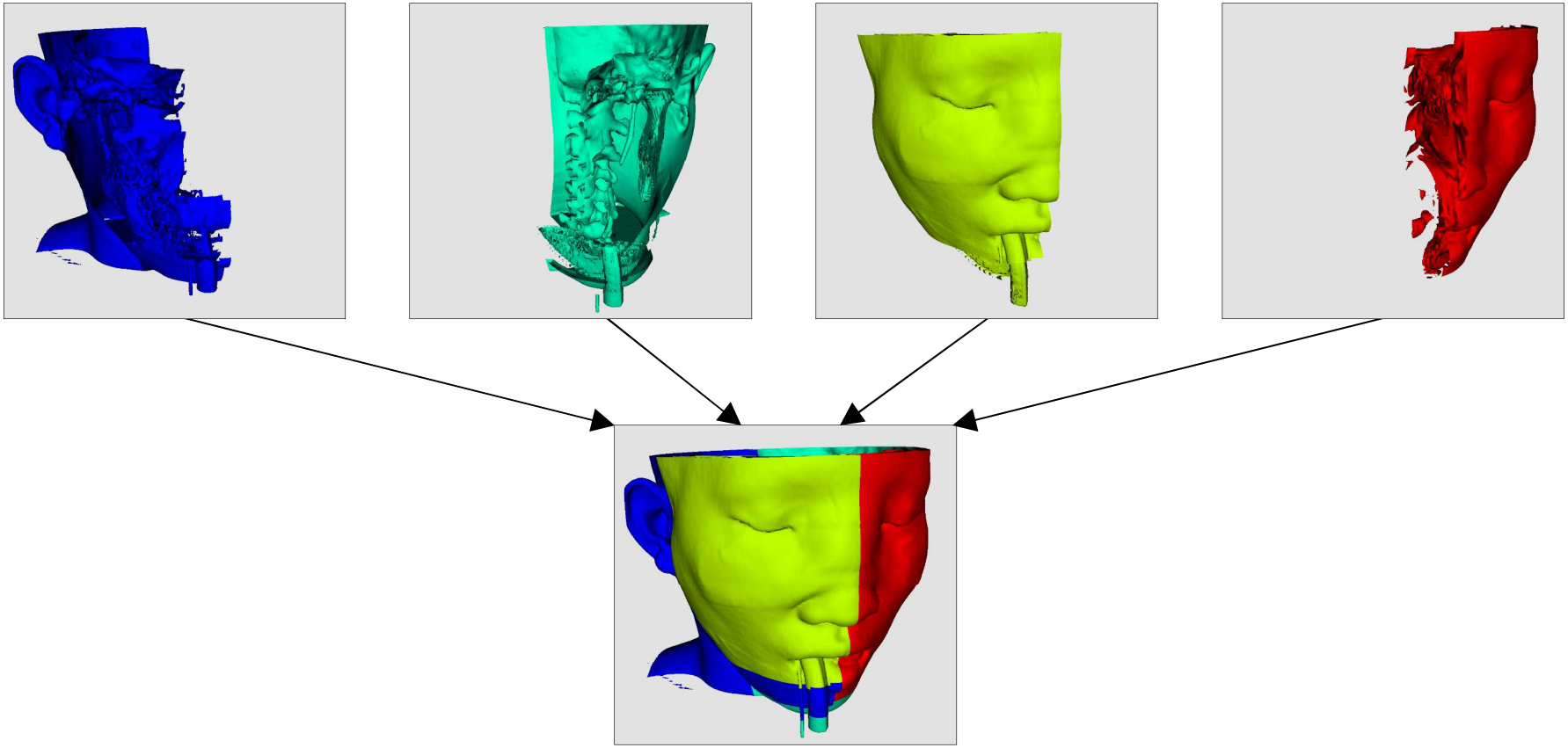
Parallel Rendering



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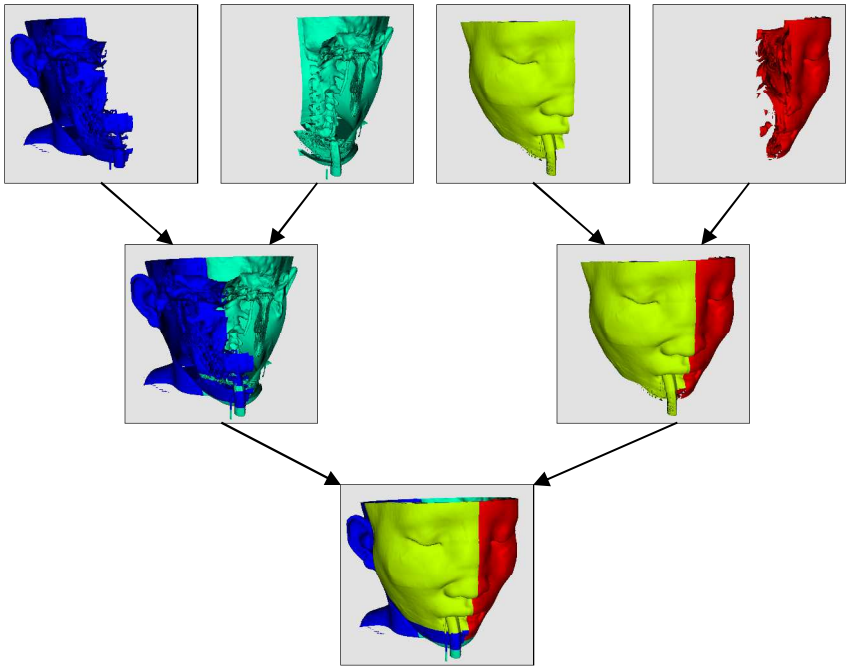
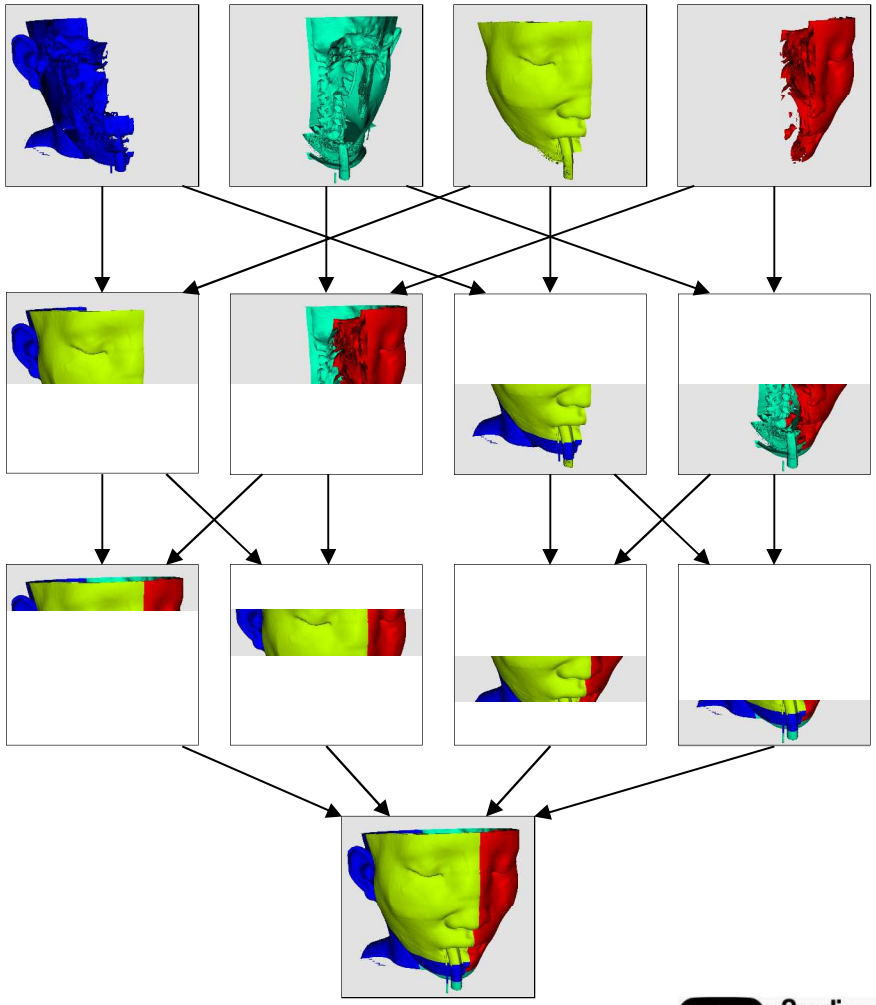
Parallel Rendering





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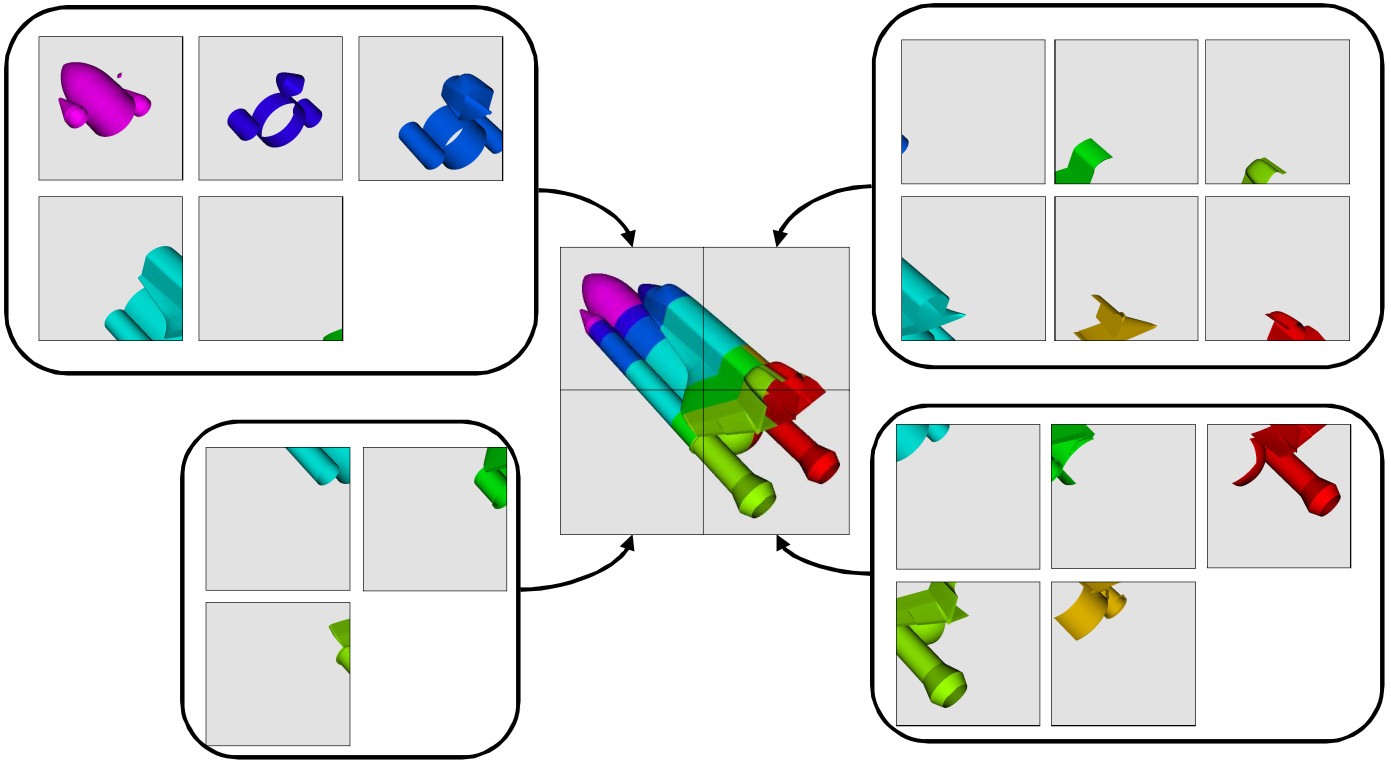
Tiled Displays



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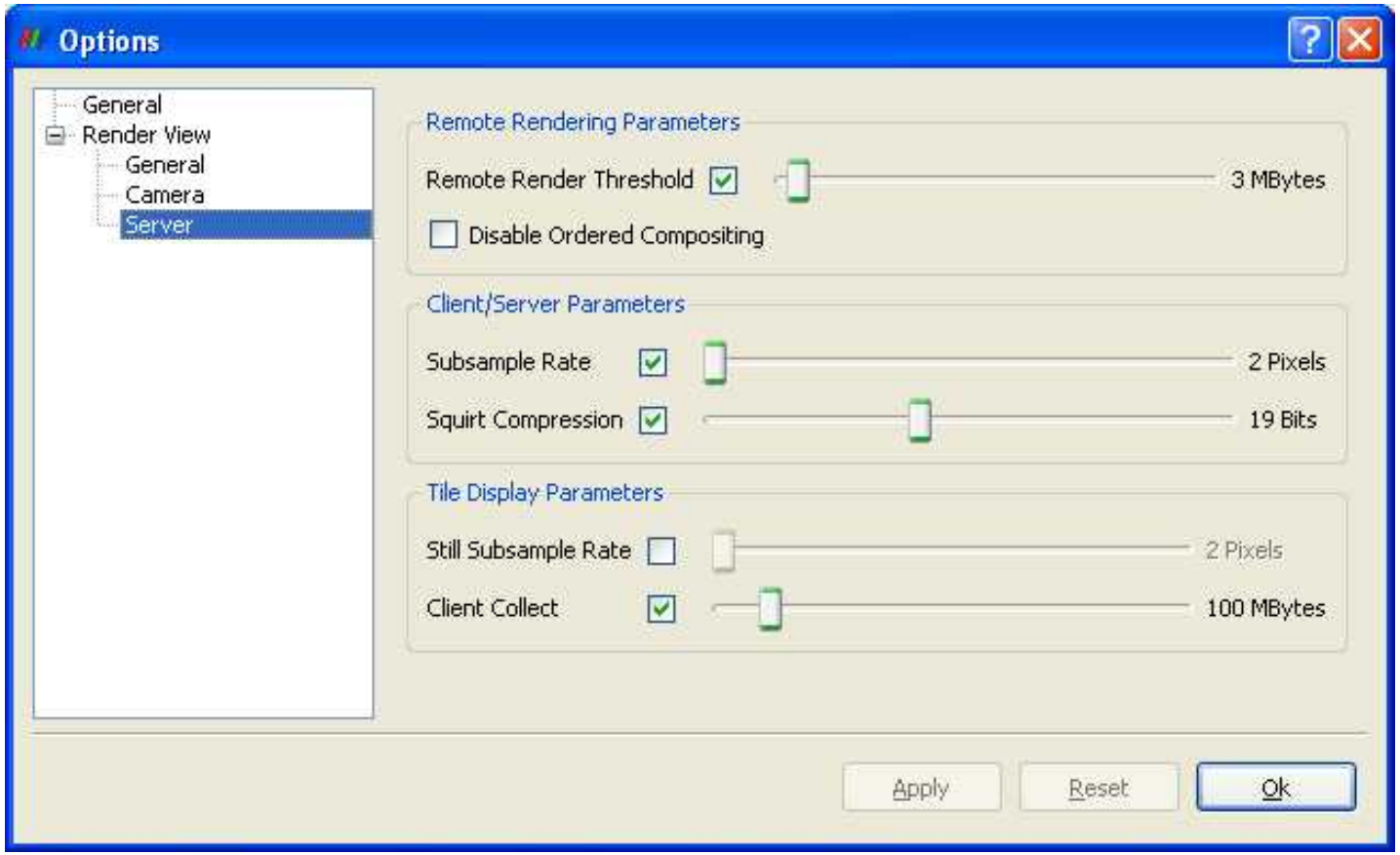
Parallel Rendering Parameters

Edit → Settings, Render View → Server



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Parameters for Large Data

- Use Immediate Mode Rendering on.
- Use Triangle Strips off.
- Try LOD Threshold *off*.
  - Also try LOD Resolution 10x10x10.
- Always have remote rendering on.
- Turn on subsampling.
  - Try larger subsampling rates.
- Squirt Compression on.

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Further Reading

- Amy Henderson Squillacote. *The ParaView Guide*. Kitware, Inc., 2006.
- http://www.paraview.org/Wiki/ParaView
- http://www.paraview.org/Wiki/Setting_up_a_ParaView_Server

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Further Reading
Visualization and Customization

- Will Schroeder, Ken Martin, and Bill Lorensen. *The Visualization Toolkit*. Kitware, Inc., fourth edition, 2006.
- Kitware Inc. *The VTK User's Guide*. Kitware, Inc., 2006.
- Jasmin Blanchette and Mark Summerfield. *C++ GUI Programming with Qt 4*. Prentice Hall, 2006.

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Further Reading
Parallel VTK Topics

- James Ahrens, Charles Law, Will Schroeder, Ken Martin, and Michael Papka. “A Parallel Approach for Efficiently Visualizing Extremely Large, Time-Varying Datasets.” Technical Report #LAUR-00-1620, Los Alamos National Laboratory, 2000.
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