



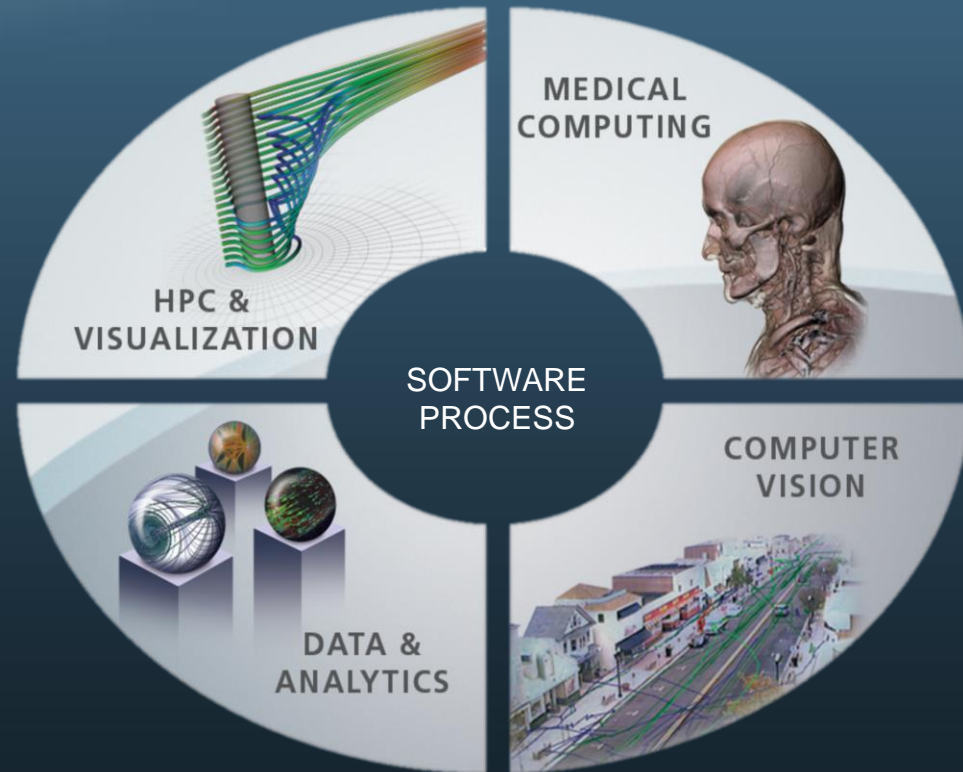
Introduction to ParaView

Andrew Bauer



Kitware

- Collaborative software R&D: algorithms & applications, image & data analysis, support & training
- Industry, government, academia
- Best known for open source toolkits and applications
- 129 employees in US: $\frac{1}{3}$ Masters, $\frac{1}{3}$ PhD
- Founded in 1998; \$28M revenue 2011
- 13 employees in France (Kitware SAS)



We Grow Open Source Solutions

- No licensing costs; proven in products
- Funding & contributions from around the world
- **VTK**—the Visualization Toolkit
- **ParaView**—Large data visualization application
- **ITK**—Insight image analysis Toolkit
- **CMake**—cross-platform build system
 - CDash, CTest, CPack, software process tools
- **OpenView / Tangelo**—Informatics and infovis
- **Kiwi & VES**—Mobile / GLES rendering
- **IGSTK**, Lesion Sizing Toolkit, **CTK**, **vxI**, **Open Chemistry Project**, **VolView**, **tubeTk**, and more...



Contents

- ParaView description, architecture and history
- GUI interface: the Pipeline Browser and the Object Inspector
- ParaView objects: Filters, Representations and Views
- Hands-on practice: vector visualization, data analysis
- Running ParaView in parallel

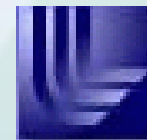
What is ParaView?

An **open-source application** and **architecture** for **display** and **analysis** of scientific datasets

- **Application** - you don't have to write any code to analyze your data
- **Architecture** - designed to be extensible if you want to code
 - Custom apps, plugins, Python scripting, Catalyst for *in situ*, ParaViewWeb
- **Open-source** – BSD 3-clause license
- **Display** - excels at traditional scientific vis qualitative 3D rendering
- **Analysis** - data drill down through charts, stats, all the way to values
- **ParaView** – designed for parallel use: scales from notebooks to world's largest supercomputers

History

- 1999 LANL/Kitware project (via ASCII Views)
 - Build an end user tool from VTK
 - Make VTK scale
 - October 2002 first public release, version 0.6
- 2002-2005 Versions 0.6 through 2.6
 - Continued growth under DOE Tri Labs, Army Research Lab and various other partnerships
- September 2005 ParaQ project started
 - Sandia, Kitware and CSimSoft
 - Make ParaView easier to use
 - Add quantitative analysis
 - May 2007 version 3.0 released
- Continuing to evolve
 - 3.2, 3.4, 3.6, 3.8, 3.10, 3.12, 3.14, 3.98
 - 4.0.1, 4.1, 4.2, 4.3.1 (Cooley@ALCF)
 - 5.0.1, 5.1.2 (Current – 7/2016)
 - http://www.paraview.org/Wiki/ParaView_Release_Notes



User Interface

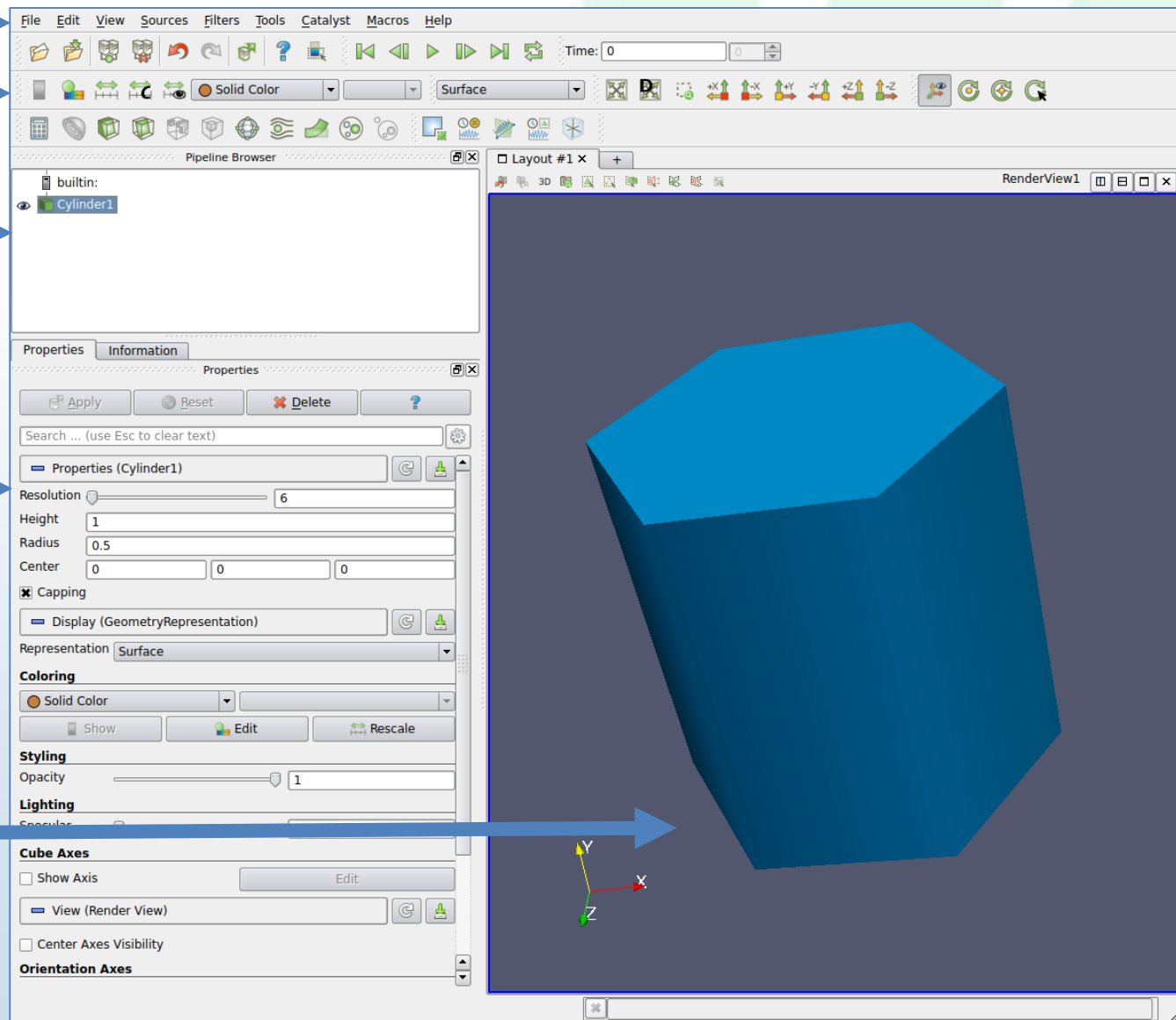
Menu Bar

Toolbars

Pipeline Browser

Object Inspector

View(s)



VTK & ParaView Lexicon

- **Filter:** an object that operates on data: reads its inputs and produces one or more outputs (aka pipeline object)
 - **Reader:** reads a file and produces an output
 - **Source:** produces an output, e.g. a cylinder
- **View:** visual information contained in window, e.g. 2D, 3D, spreadsheet
- **Property:** a filter or view parameter the user can set (e.g. file name, slice plane location, camera angle)
- **Client:** the GUI or Python connection to the server
- **Server:** computer where the data and filters exist
 - **Built-in Server:** client executable also running server
 - **Remote Server:** server is a separate process from the client

Help

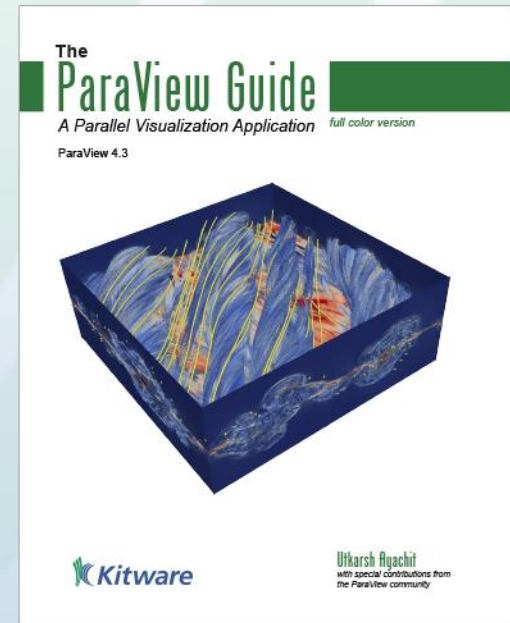


Cylinder (CylinderSource)
Create a 3D cylinder of a given radius and height.

The Cylinder source can be used to add a polygonal cylinder to the 3D scene. The output of the Cylinder source is polygonal data containing both normals and texture coordinates.

Property	Description	Default(s)	Restrictions
Resolution	This property indicates the number of divisions around the cylinder. The higher this number, the closer the polygonal approximation will come to representing a cylinder, and the more polygons it will contain.	6	
Height	This property specifies the height of the cylinder (along the y axis).	1.0	
Radius	This property specifies the radius of the cylinder.	0.5	
Center	This property specifies the coordinate value at the center of the cylinder.	0.0 0.0 0.0	
Capping	If this property is set to 1, the ends of the cylinder will each be capped with a closed polygon. Otherwise, the ends of the cylinder will be open.	1	Accepts boolean values (0 or 1).

- Windows & Linux: F1 in the GUI
- Mac: Command+Shift+/
- Mouse hover
- Online help
 - The ParaView Guide
 - The ParaView Tutorial
 - ParaView Mailing Lists
 - ParaView Wiki
 - <http://www.paraview.org/documentation/>




How to Use ParaView

1. Read in data: File → Open, hit 

- Over 100 file formats supported
- Help/Readers - readers compiled in

2. Add a filter to process data:

- Tune filter properties, hit 
- Repeat Step 2 as needed

3. Tune Display (for all Filter, View pairs) and View (for all Views) parameters

4. Save datasets, rendered results (screenshot or animation) or application state



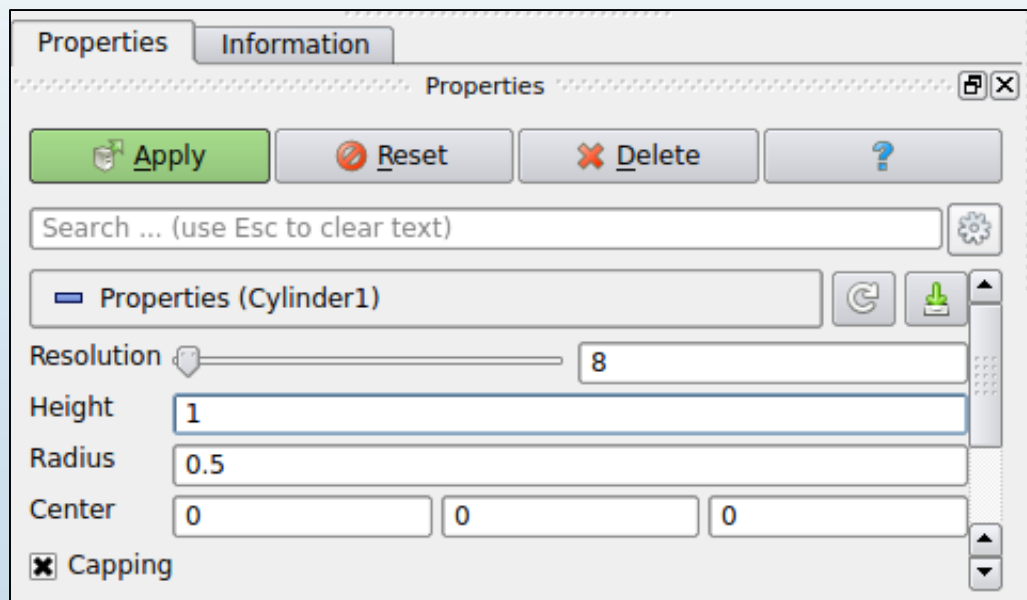
File→Open

http://paraview.org/Wiki/ParaView/Users_Guide/List_of_readers

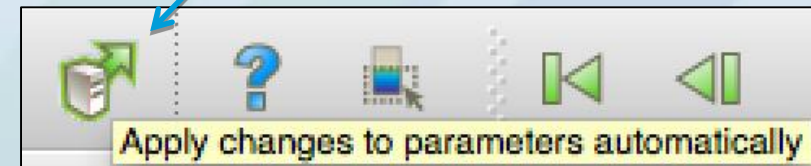
- ParaView Data (.pvd)
- VTK (.vtp, .vtu, .vti, .vts, .vtr)
- VTK Legacy (.vtk)
- VTK Multi Block (.vtm, .vtmb, .vtmg, .vthd, .vthb)
- Partitioned VTK (.pvtu, .pvti, .pvts, .pvtr)
- ADAPT (.nc, .cdf, .elev, .ncd)
- ANALYZE (.img, .hdr)
- ANSYS (.inp)
- AVS UCD (.inp)
- BOV (.bov)
- BYU (.g)
- CAM NetCDF (.nc, .ncdf)
- CCSM MTSD (.nc, .cdf, .elev, .ncd)
- CCSM STSD (.nc, .cdf, .elev, .ncd)
- CEAAucd (.ucd, .inp)
- 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 Unstructured 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)
- Spherical (.spherical, .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

Filter Properties and the Apply Button

- ParaView is meant to process large data – it might take a long time when changing a filter property
- Net result is you won't see any data change until you hit the glowing Apply button on the Properties tab of the Object inspector (unless auto apply is on)

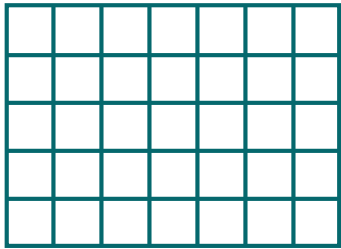


Toggle auto apply

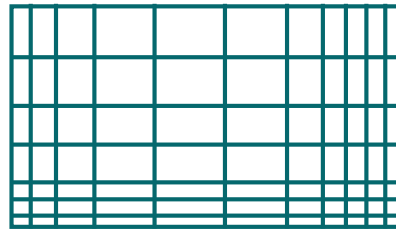


ParaView Dataset Types

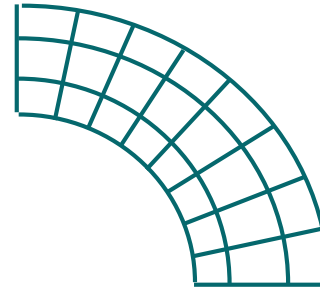
vtkImageData



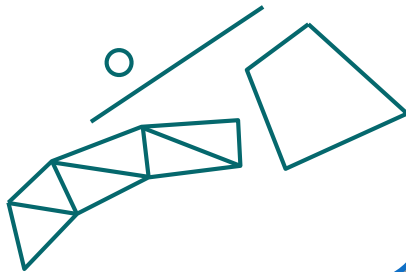
vtkRectilinearGrid



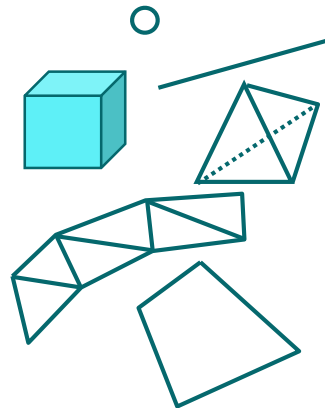
vtkStructuredGrid



vtkPolyData



vtkUnstructuredGrid



Multi-blocks


AMR

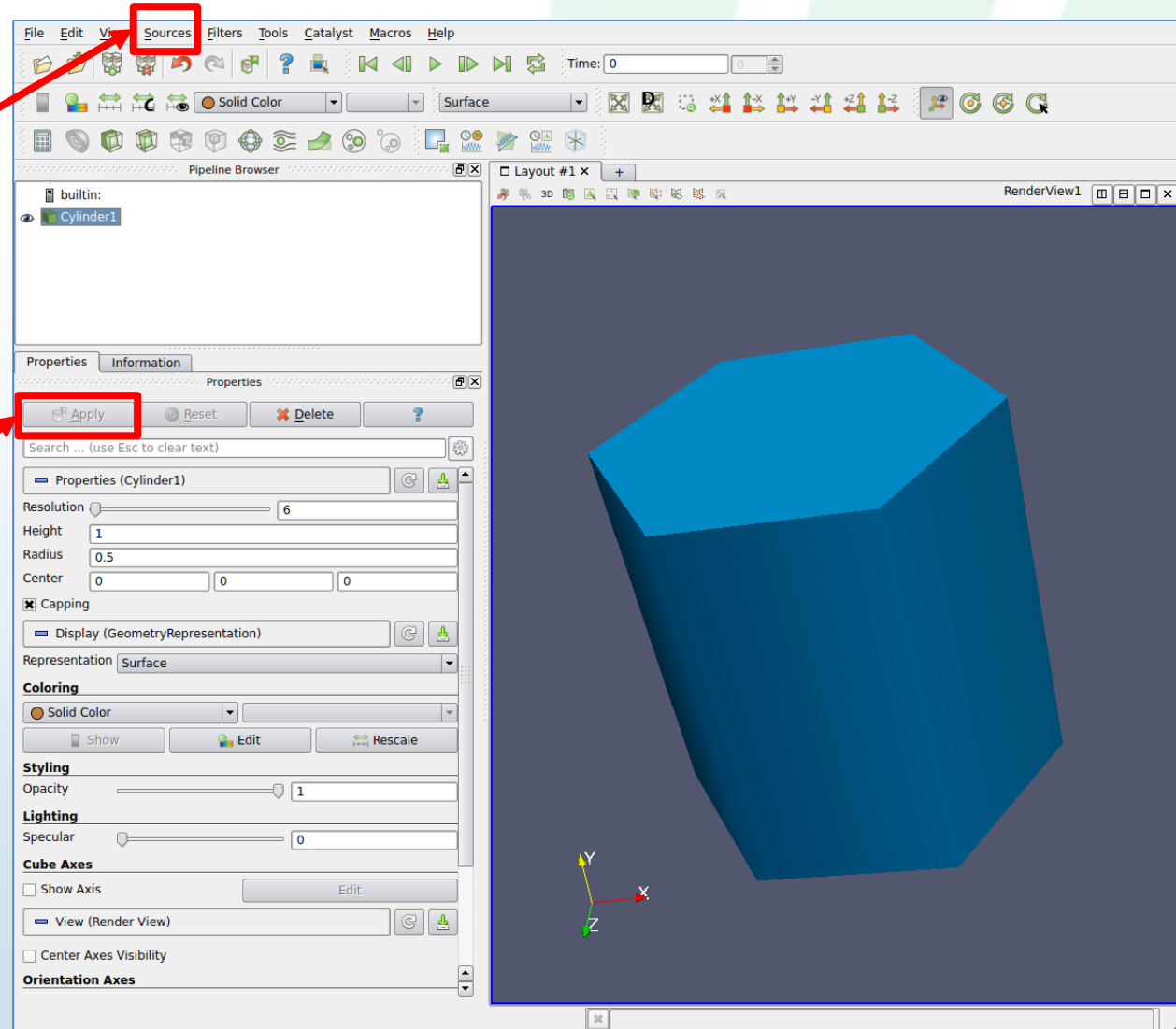
Time-varying data

- points, cells
- values associated with points and/or cells: scalars, vectors, tensors

First Hands-On Example

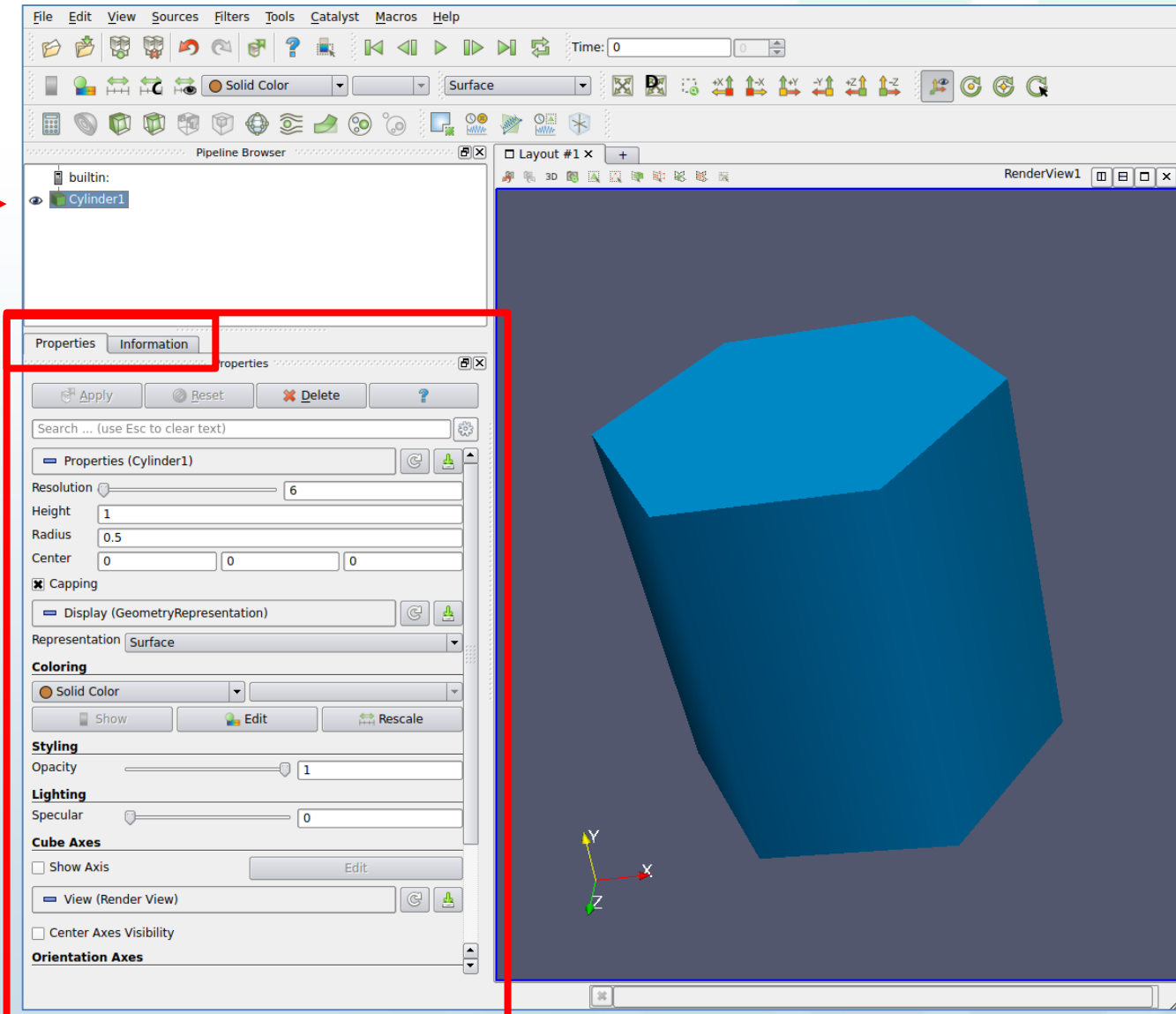
Create a Cylinder source

- Click on Sources menu and select Cylinder
- Click 





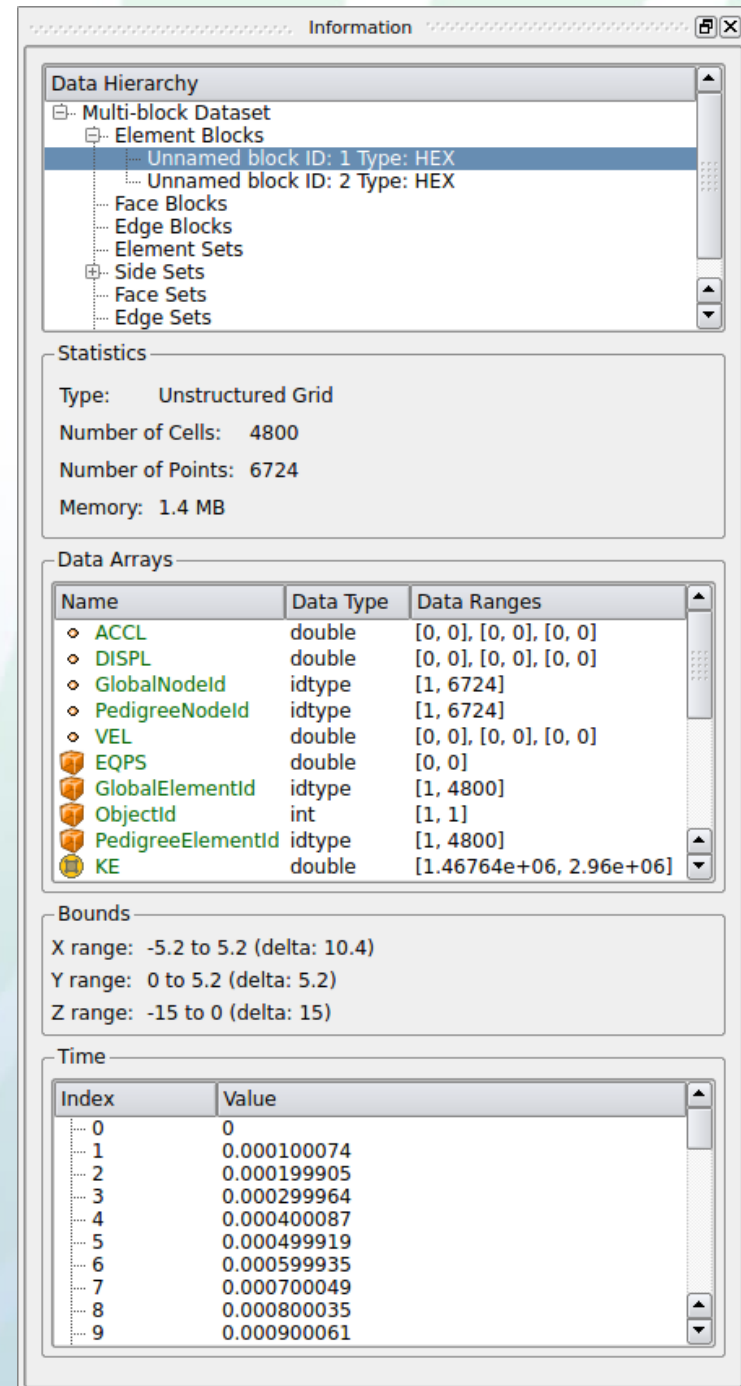
Object Inspector: Properties and Information Tabs

Active Filter highlighted



Object Inspector: Information Tab

- Information about the Active Filter's output
- Dataset type
- Size (bytes, #points, #cells)
- Geometric bounds
- Structured bounds
- Arrays:
 - Name
 - Association  =point,  =cell
 - Data Type
 - Data Ranges (and scalar/vector)
- Temporal Domain



Information

Data Hierarchy

- Multi-block Dataset
 - Element Blocks
 - Unnamed block ID: 1 Type: HEX
 - Unnamed block ID: 2 Type: HEX
 - Face Blocks
 - Edge Blocks
 - Element Sets
 - Side Sets
 - Face Sets
 - Edge Sets

Statistics

Type: Unstructured Grid

Number of Cells: 4800

Number of Points: 6724

Memory: 1.4 MB

Data Arrays

Name	Data Type	Data Ranges
ACCL	double	[0, 0], [0, 0], [0, 0]
DISPL	double	[0, 0], [0, 0], [0, 0]
GlobalNodeId	idtype	[1, 6724]
PedigreeNodeId	idtype	[1, 6724]
VEL	double	[0, 0], [0, 0], [0, 0]
EQPS	double	[0, 0]
GlobalElementId	idtype	[1, 4800]
ObjectId	int	[1, 1]
PedigreeElementId	idtype	[1, 4800]
KE	double	[1.46764e+06, 2.96e+06]

Bounds

X range: -5.2 to 5.2 (delta: 10.4)

Y range: 0 to 5.2 (delta: 5.2)

Z range: -15 to 0 (delta: 15)

Time

Index	Value
0	0
1	0.000100074
2	0.000199905
3	0.000299964
4	0.000400087
5	0.000499919
6	0.000599935
7	0.000700049
8	0.000800035
9	0.000900061

Manipulate the Data

- Filters Menu
 - Recent
 - Common
 - Data Analysis
 - Statistical
 - Temporal
 - Alphabetical
- Quick Launch
 - PC/Linux
CTRL-Space
 - Mac
ALT-Space
- Apply Undo/Redo



Calculator



Glyph



Contour



Stream Tracer



Clip



Warp (vector)



Slice



Group Datasets



Threshold




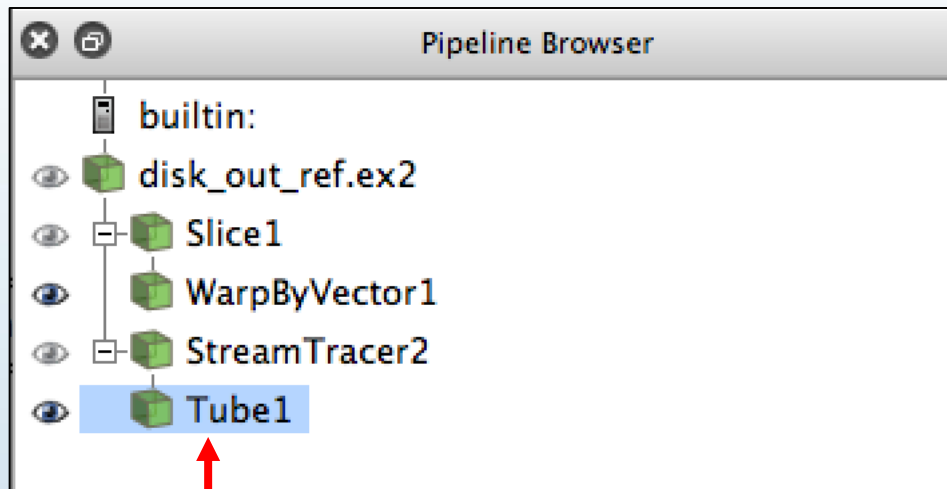
Extract Group



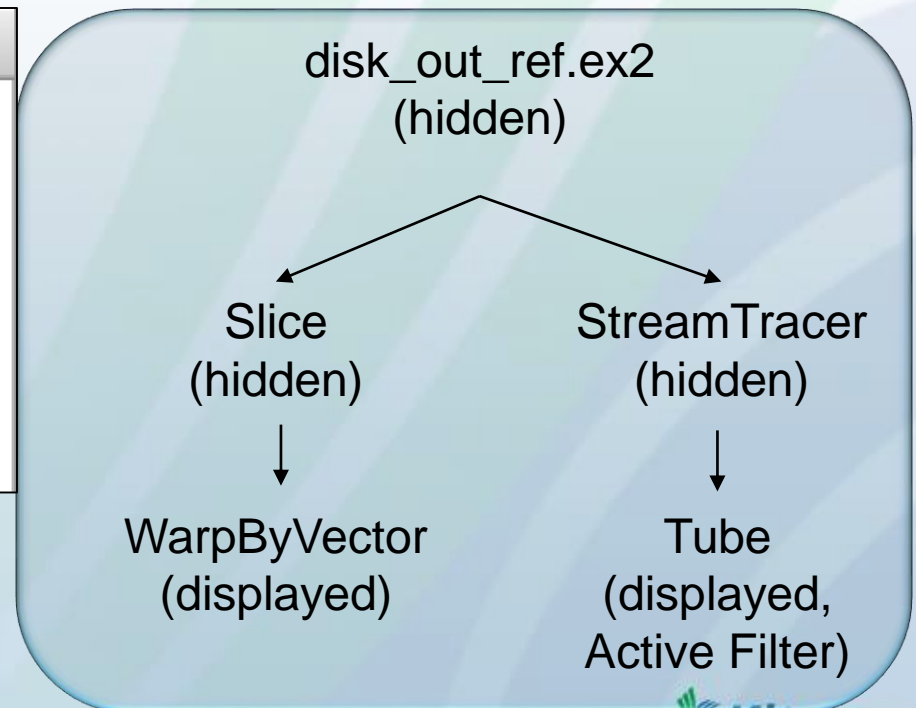
Extract Subset

Pipeline Browser: Condensed Pipeline Graph

- Use pipeline browser to navigate the graph
- Select a reader/filter to make it active, then object inspector, information tab and display tab pertain to it
- Eyeball  is to show/hide filter output in active view

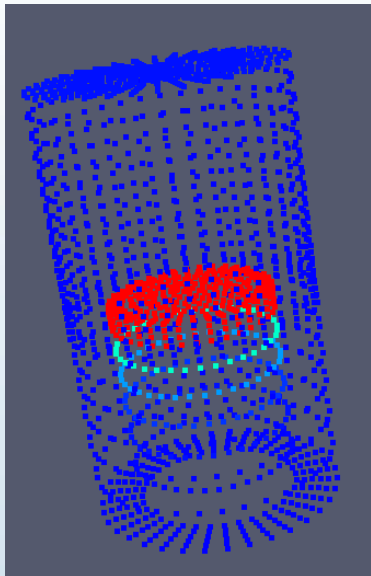
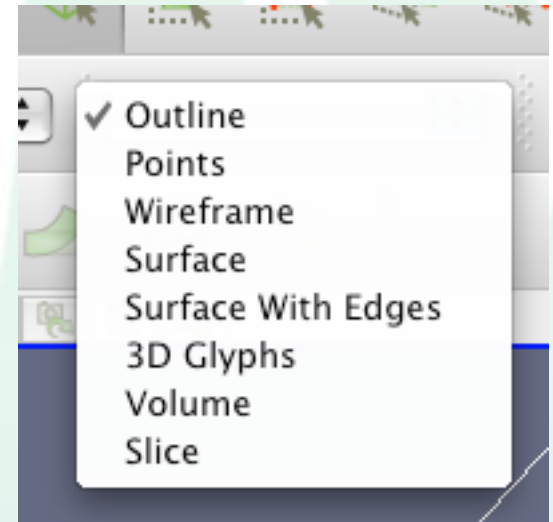


Active Filter highlighted

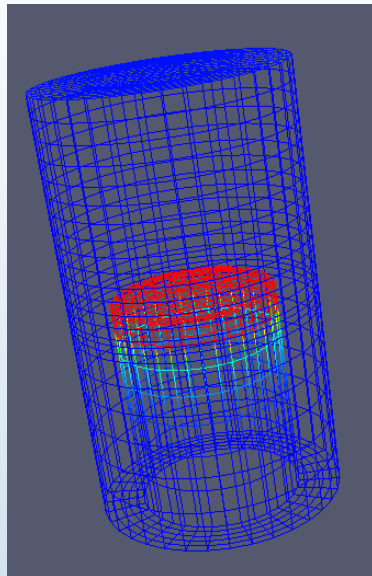


Display the Data

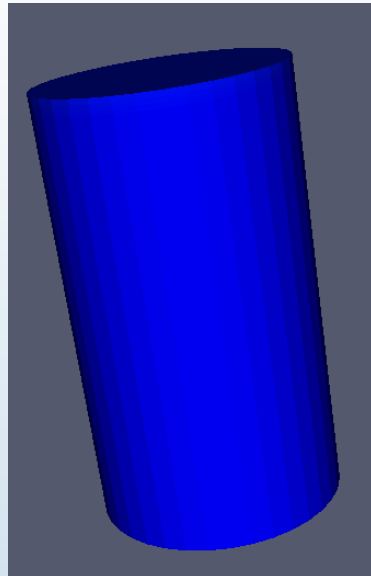
Representations (aka Displays):
visual characteristics of one particular
data set in one particular view



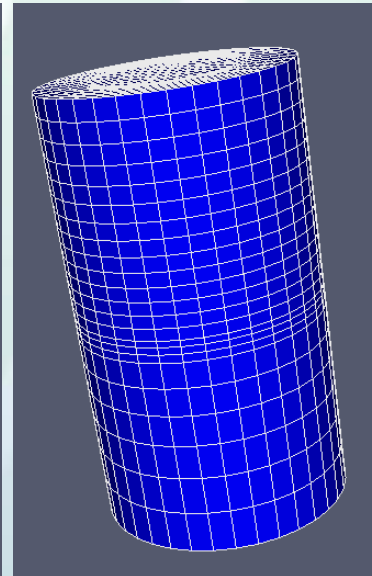
Points



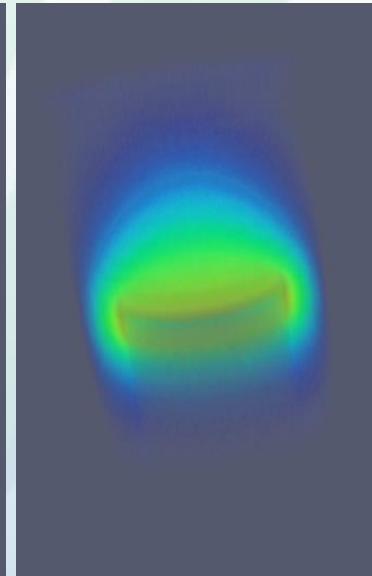
Wireframe



Surface



Surface
with Edges

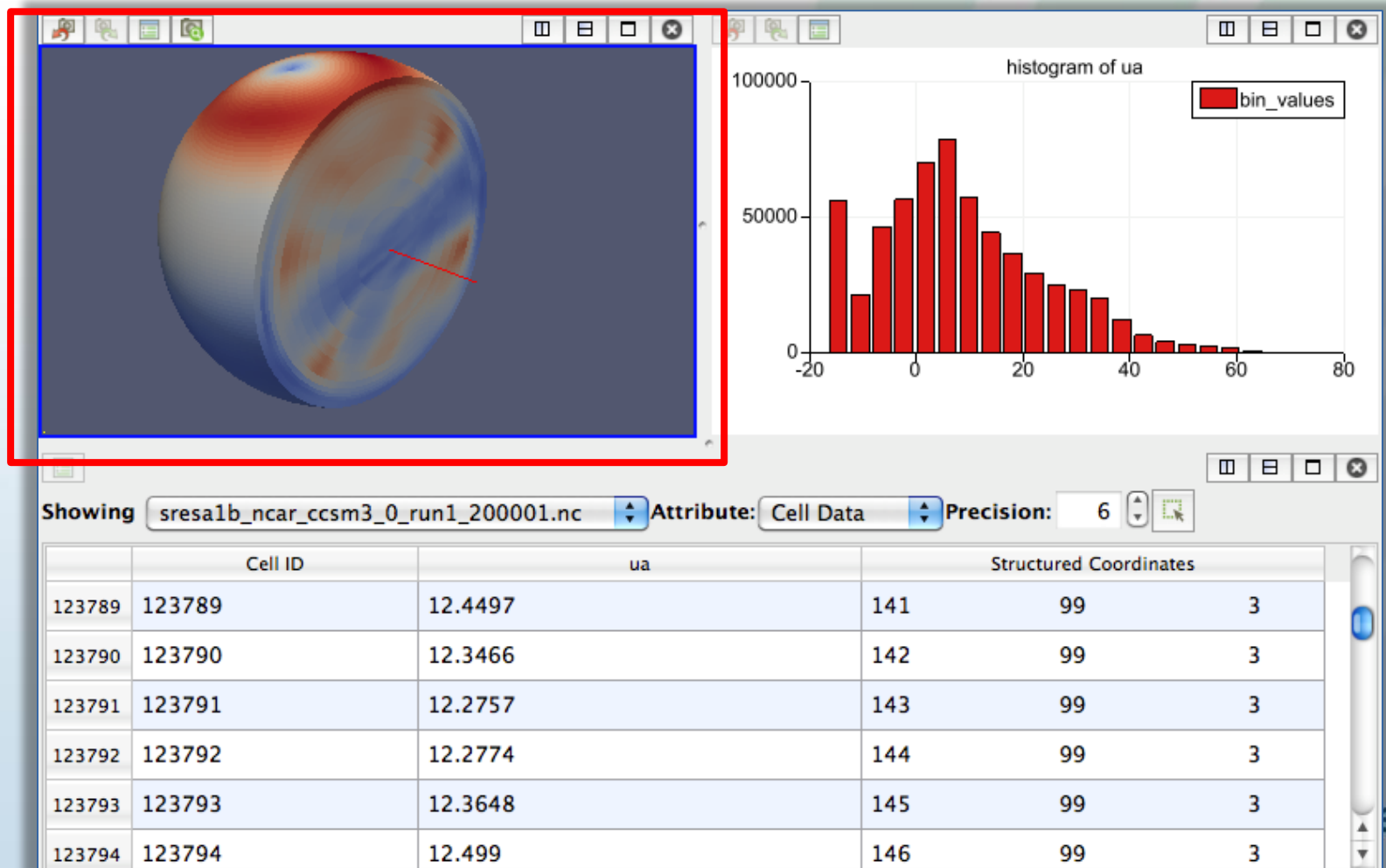


Volume

Display the Data

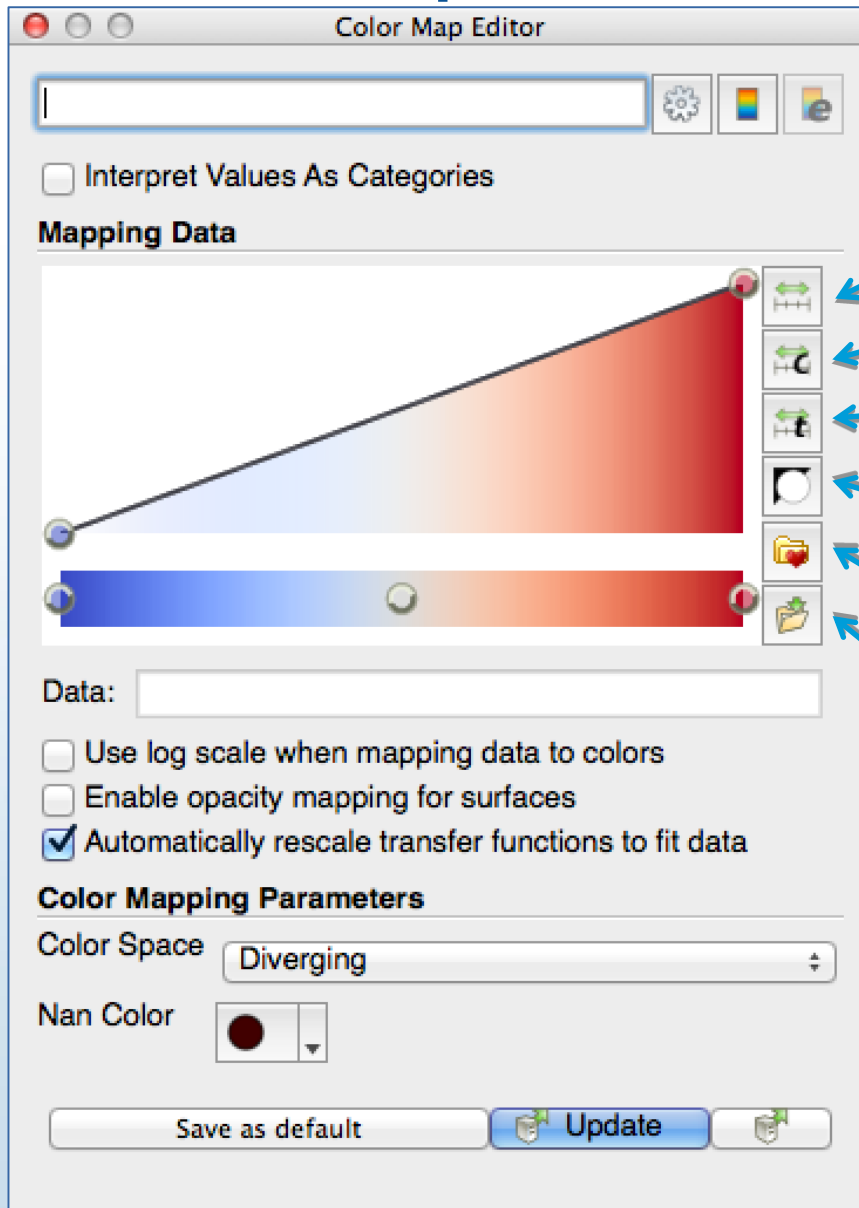
Views – Windows onto one or more data sets

- Active View has blue border



Color Map Editor

Mapping
Scalar Range – Color Palette



Rescale to data range

Rescale to custom range

Rescale to data range
over all time-steps













Invert the transfer
function

Choose preset

Save to preset

View Properties

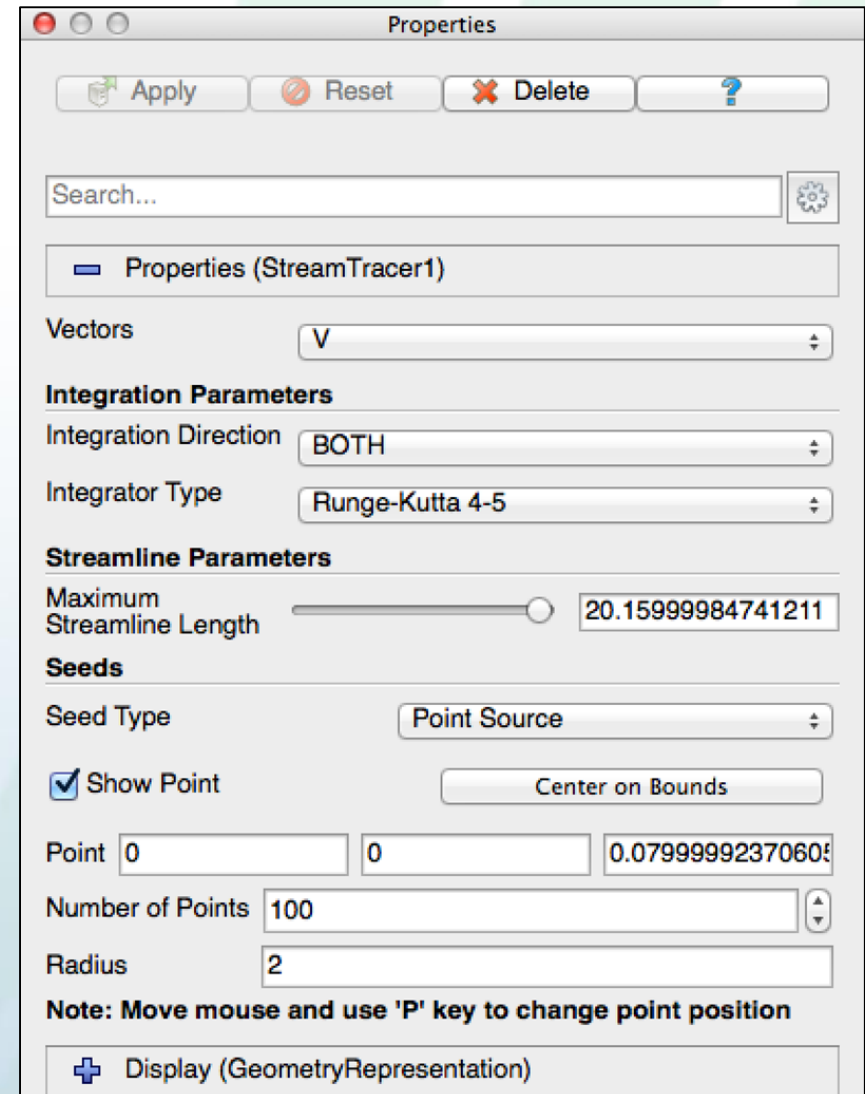
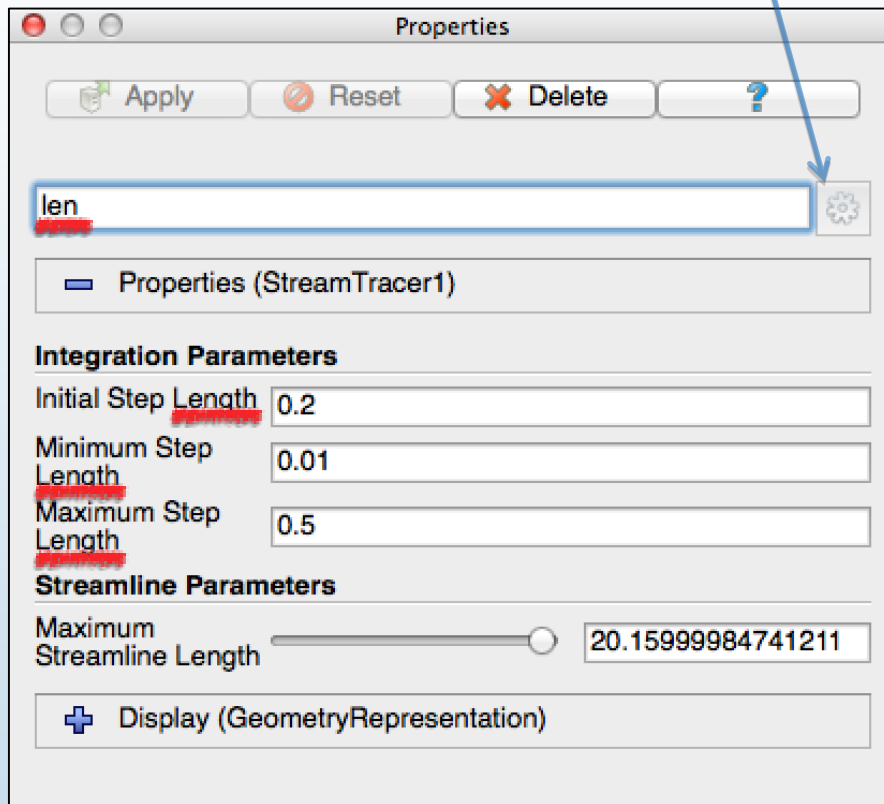
Properties associated with the Active View

 Properties (disk_out_ref.ex2)		
 Display (UnstructuredGridReprese		
 View (Render View)		
<input type="checkbox"/> Center Axes Visibility		
Orientation Axes		
<input checked="" type="checkbox"/> Orientation Axes Visibility		
<input type="checkbox"/> Stereo Render		
Background		
Single color 		
 Color 	Restore Default	

Find Properties (for Filters, Displays and Views)

- Search for properties
- Toggle on/off advanced properties

Advanced Properties



Query Data by Attributes' Values – Find Data Dialog

The screenshot shows the 'Find Data' dialog box in a software application. The dialog is titled 'Find Data' and is used to query data by attributes. The 'Create Selection' section shows the search criteria: 'Find Cell(s) from can.ex2' with the EQPS attribute 'is >= 1.5'. The 'Current Selection (can.ex2 : 0)' section shows a table of results:

	Block Number	Cell ID	Cell Type	EQPS	Global
0	2	35	Hexahedron	1.97048	36
1	2	36	Hexahedron	1.51309	37
2	2	75	Hexahedron	2.13094	76

The dialog also includes options for 'Show: Cell(s)', 'Invert selection', and 'Selection Display Properties' (Selection Color, Cell Labels, Point Labels). There are buttons for 'Run Selection Query', 'Freeze Selection', 'Extract Selection', 'Plot Selection Over Time', and 'Close'. The background shows a 3D rendering of a surface with a color scale for EQPS values ranging from 0.000e+00 to 2.894e+00.

Query Data Visually - Selection

- Visually select interesting data
- shown in all compatible views
- can then label, extract etc

- 'Select Cells On' to get nearest cells on surface



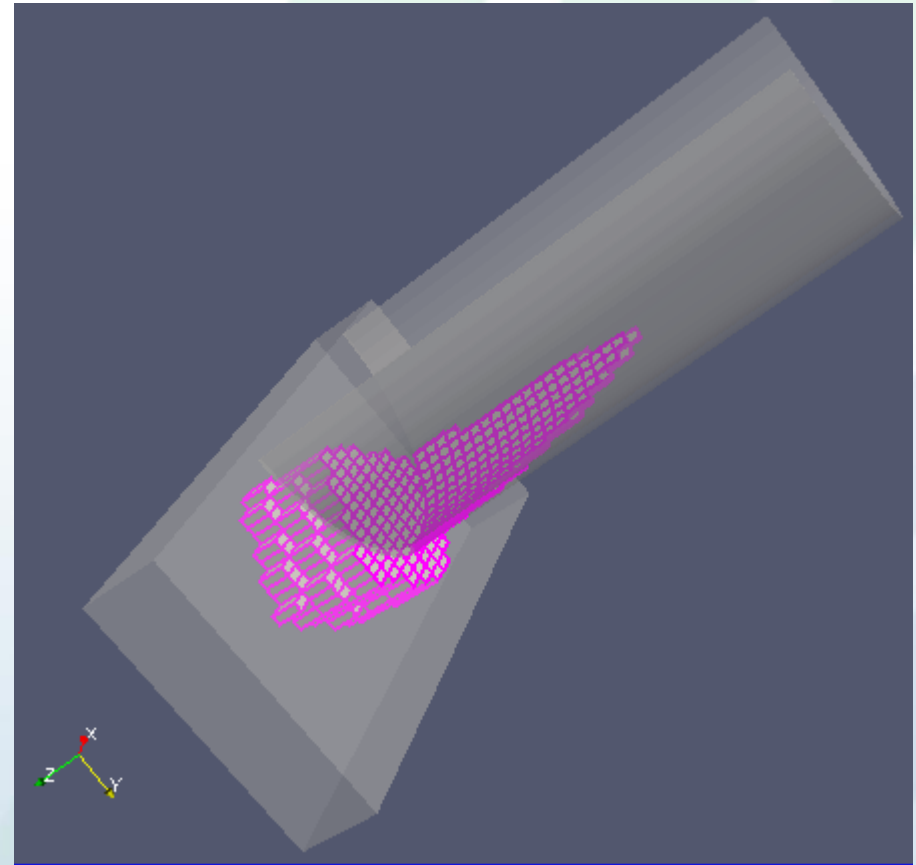
- 'Select Points On' to get nearest points on surface



- 'Select Cells Through' to get all cells intersecting a frustum



- 'Select Points Through' for selecting points inside a frustum



Exporting Data, Images & Movies

- Data
 - File → Save Data...
 - Active filter's data, prompted for file format
 - Only list of valid file formats shown. Primarily VTK formats + Exodus, Enight, XDMF/HDF5, csv
- Images
 - File → Save Screenshot...
 - Either selected view or all
 - png, bmp, tif, ppm, jpg formats
 - Override Color Palette to get print, presentation, etc. style
 - File → Export Scene...
 - Export visible scene in a format for high quality rendering
 - eps, pdf, ps, svg, pov, vrml, webgl, x3d, x3db formats
- Movies
 - File → Save Animation...
 - avi, ogg, ffmpeg → avi formats

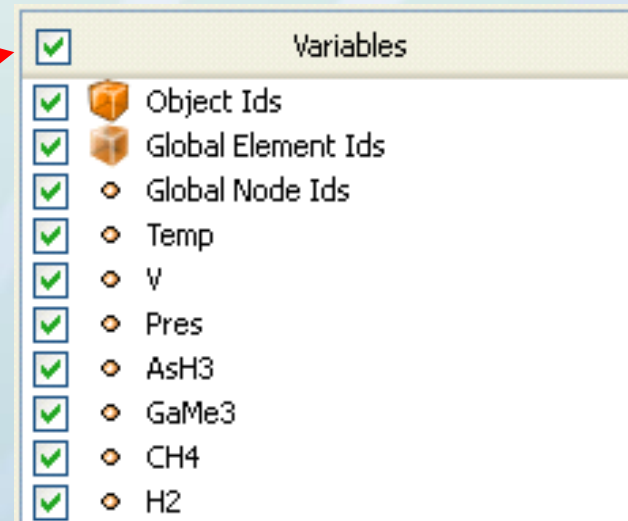
Shortcuts for Repetitive Tasks

- State files
 - File → Save State... & File → Load State...
 - .pvsm extension for XML based state file
 - Will prompt for file locations for readers
- Python tracing
 - Tools → Start Trace & Tools → Stop Trace
 - Logs GUI actions and shows the corresponding actions in ParaView's Python API
 - Can create a GUI macro button to replay the trace steps

Hands on Practice: Vector Visualization

(see also http://www.paraview.org/Wiki/The_ParaView_Tutorial)

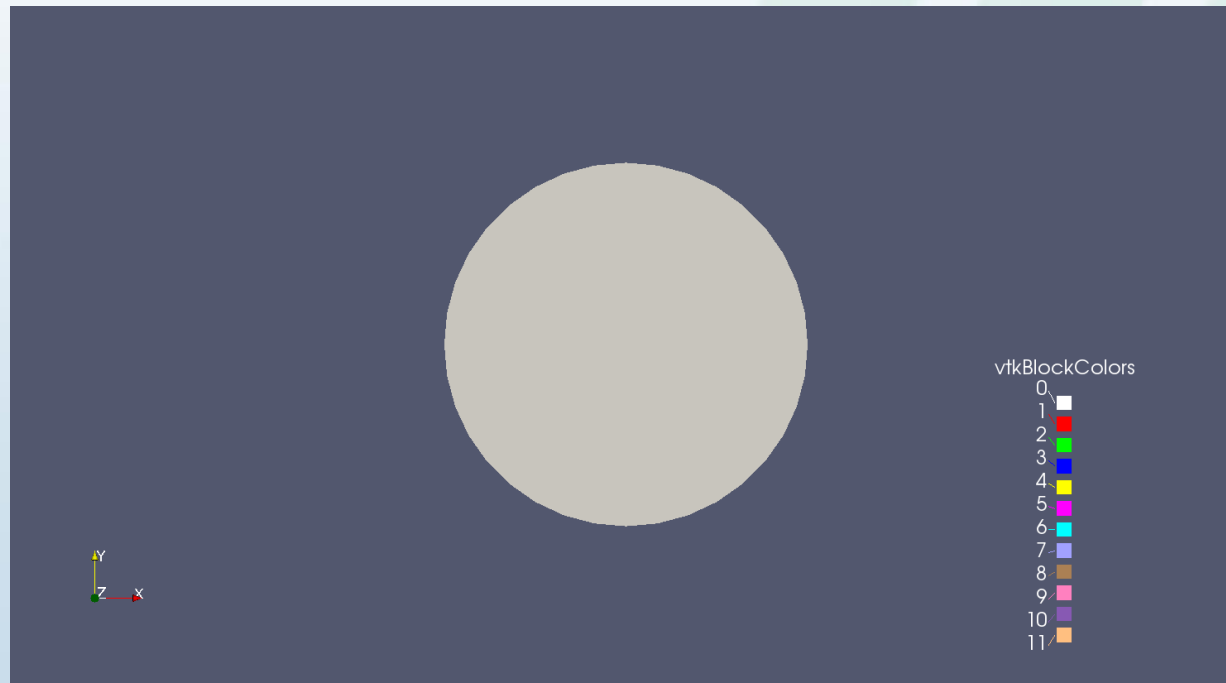
- Load disk_out_ref.ex2
 - Tarball/zip file available on above link
 - 5.1.2 installers included at:
 - Windows: <install location>/ParaView 5.1.2/data
 - Linux: <install location>/share/paraview-5.1/data
 - Mac: <install location>/paraview.app/Contents/data
 - An Exodus format file
 - Load all variables



Data Set Details

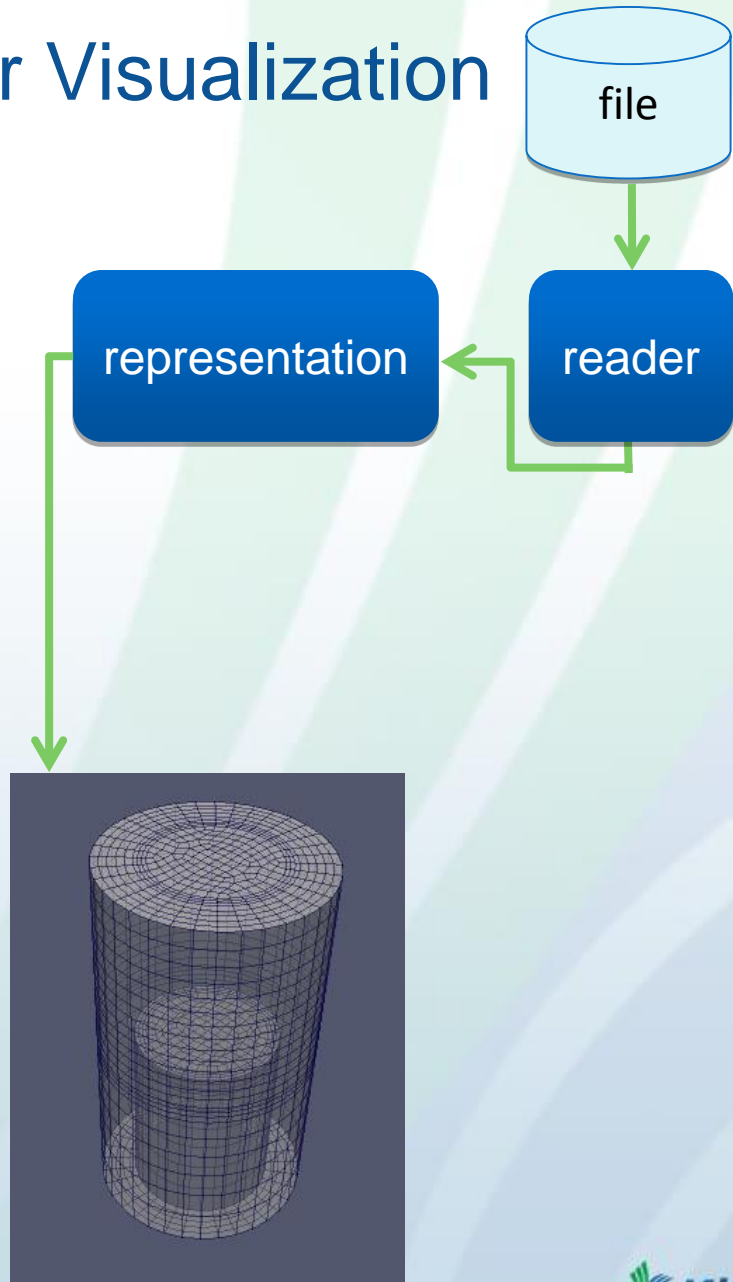
Shown in the Information tab

- Multi-block (group of data sets)
- Not time varying
- Roughly 8000 cells and points, 2MB
- 11.5 units in diameter, 20 units in height



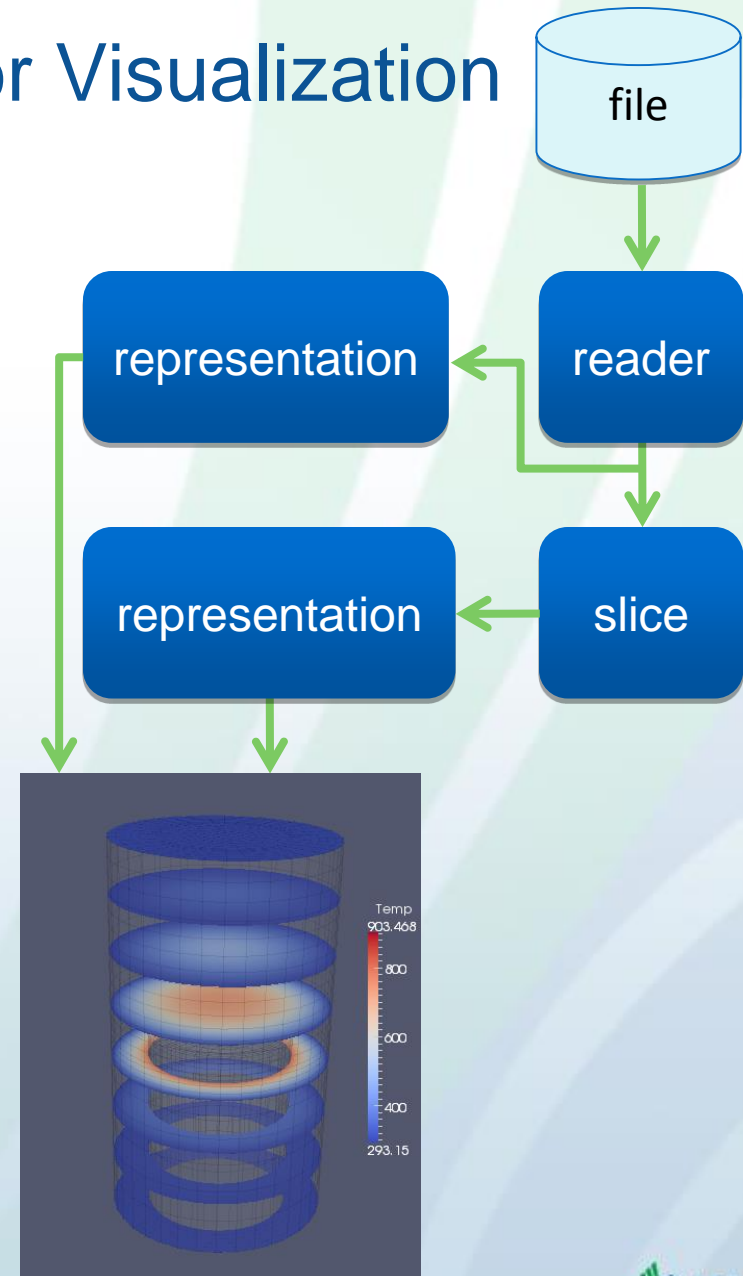
Hands on Practice: Vector Visualization

- Show as surface with edges to see structure
- Set opacity to 0.5
- Looks like a cylinder with a recess



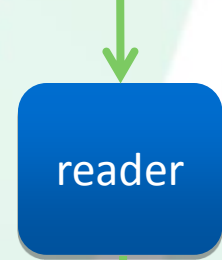
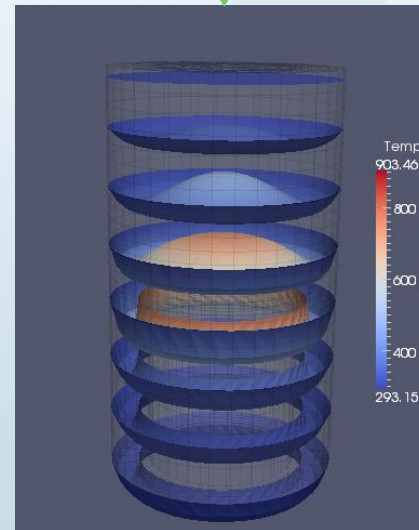
Hands on Practice: Vector Visualization

- Apply slice filter
 - Align with z and use 10 offset values
- Color by Temp
- Show Temp lookup table
- Adjust opacity of reader(0.1) and slice(1.0) to see temperature variation clearly



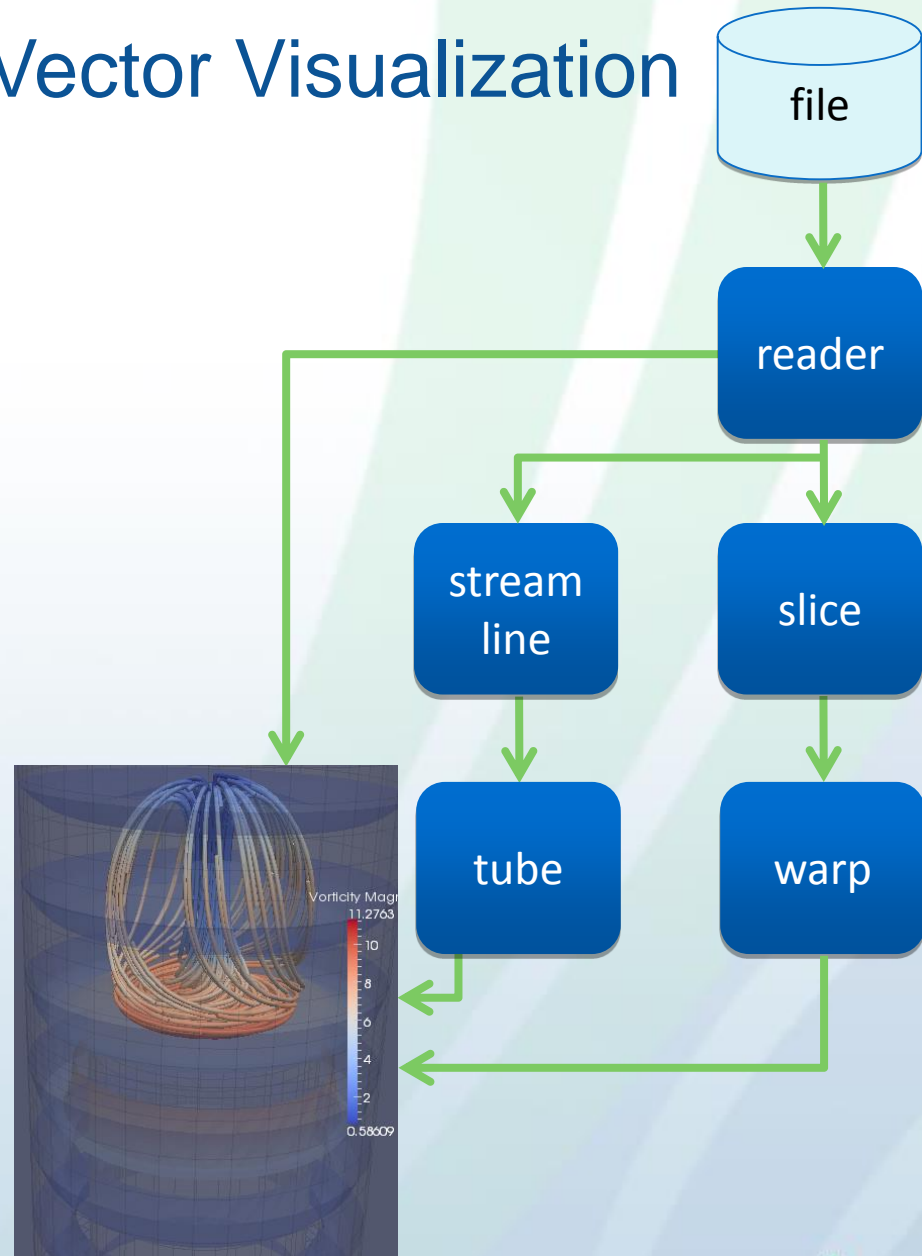
Hands on Practice: Vector Visualization

- Apply warp filter
 - Warp slices along V vector field with a scale factor of 0.1
- Compare with display of slice
 - Can see how vector field pushes up in center and down further out
 - Seeing convection of a heated gas, it rises at the heat source



Hands on Practice: Vector Visualization

- Change warp opacity to .2
- Apply streamline filter
 - Starts from seed points and advects along vector field to show vector flow
- Apply tube filter
 - Gives infinitely thin streamlines volume so we can see them well
- Set opacity to 1.0 and color by vorticity
 - We are seeing rotation
 - A heated plate is spinning in gas
- Manipulate streamline's seed points

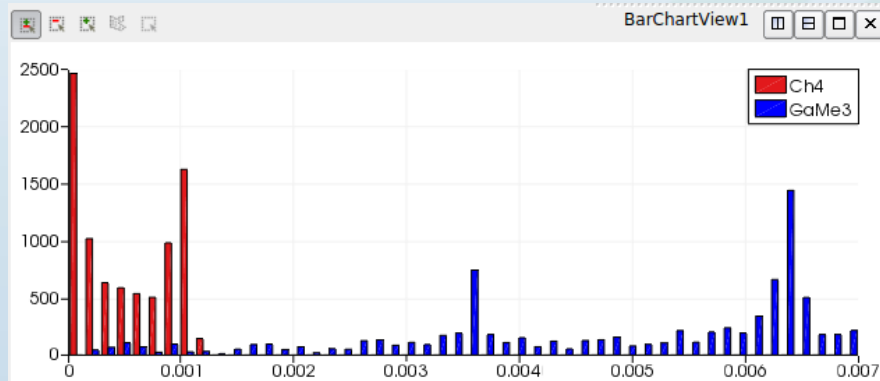
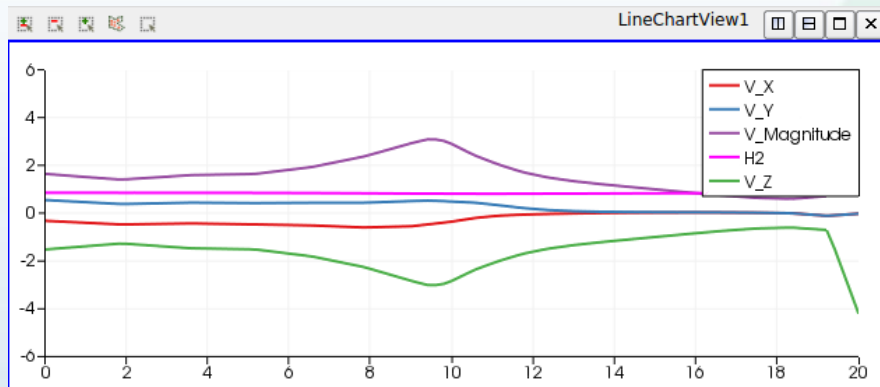


Putting It Together: Data Analysis

SpreadSheetView1

Showing disk_out_ref.ex2 Attribute: Point Data Precision: 6

	Block Number	Point ID	AsH3	CH4	GaMe3	GlobalNo
0	2	0	0.183459	0.000971915	0.00628244	143
1	2	1	0.155209	0.000883944	0.00513434	706
2	2	2	0.155209	0.000883943	0.00513428	3173
3	2	3	0.183458	0.000971913	0.00628236	1829
4	2	4	0.181883	0.00102504	0.00602588	6566
5	2	5	0.152606	0.000928225	0.00486082	6690



reader

view 2

view 3

view 4

plot over line

histogram

What to Expect from Parallel ParaView

- Amdahl's Law

$$\text{Speedup}(CPUs) = \frac{1}{\text{Serial} + \frac{\text{Parallel}}{CPUs}}$$

aka Strong scaling:

If data size is fixed, can't always expect great scalability.

More processors != faster

- Gustafson's Law

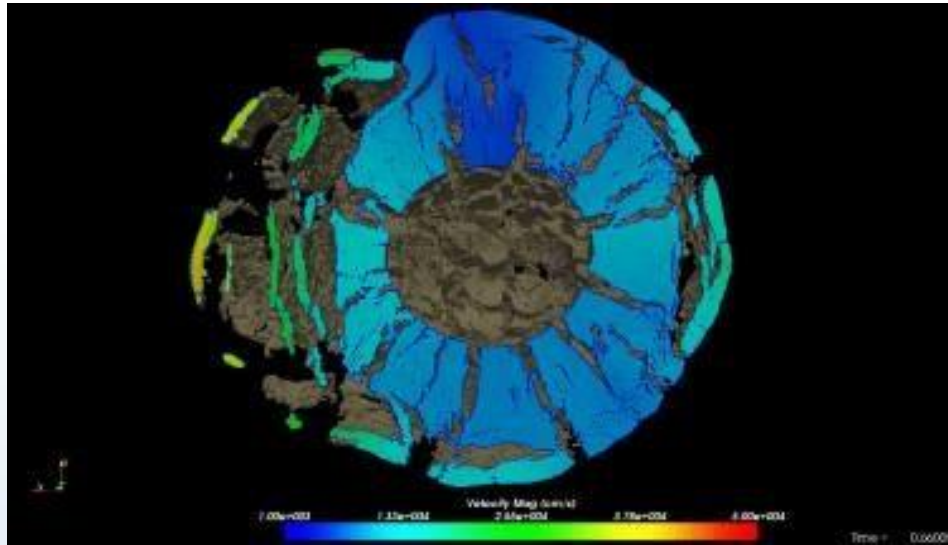
$$\text{Speedup}(Machines) = \text{Machines} - \text{Serial} * (\text{Machines} - 1)$$

aka Weak scaling:

As data size grows, you must have more resources.

More disk and memory = higher resolution possible

Large Data Processed by ParaView



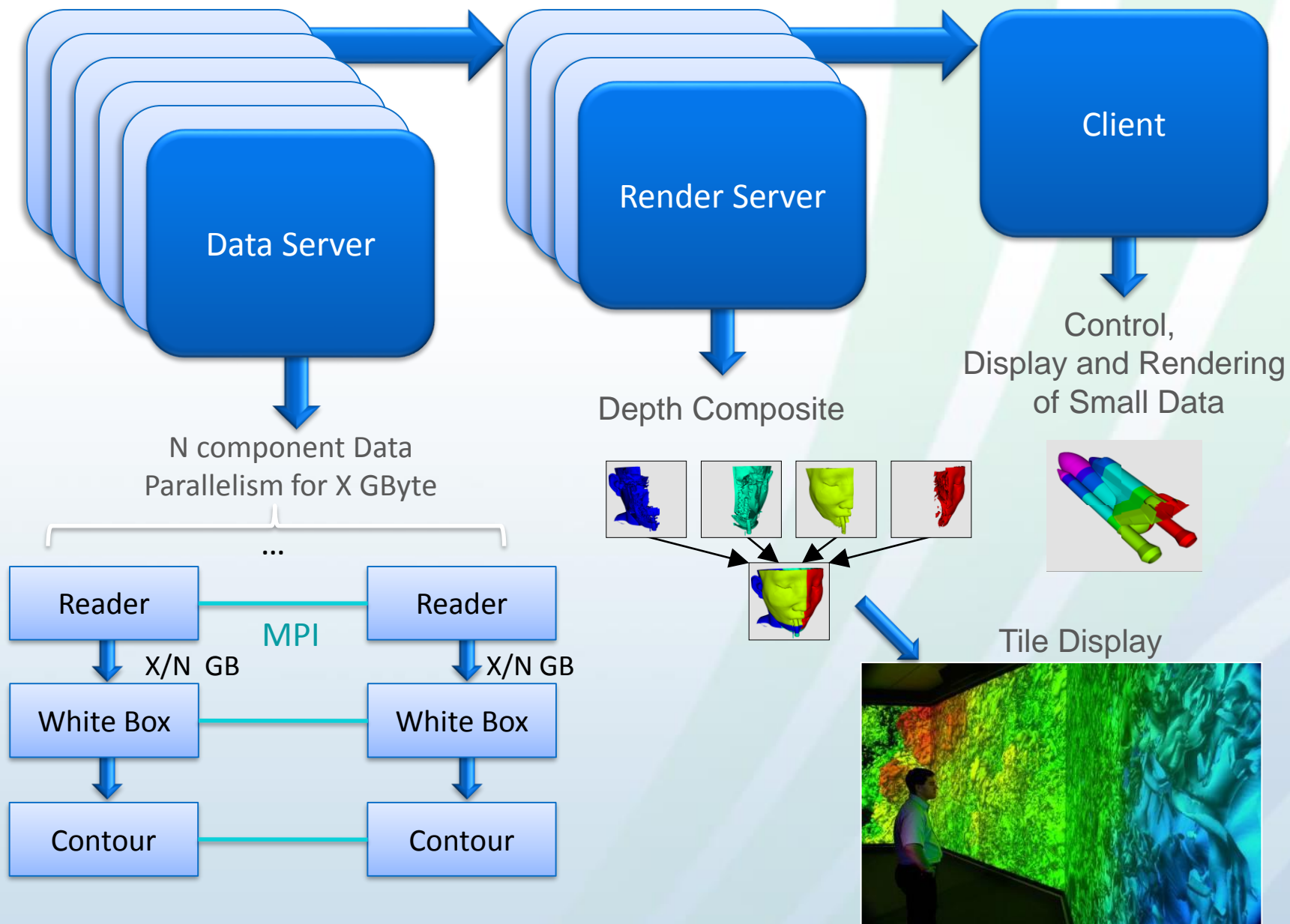
1 billion cell asteroid
detonation simulation

source: Sandia National Labs


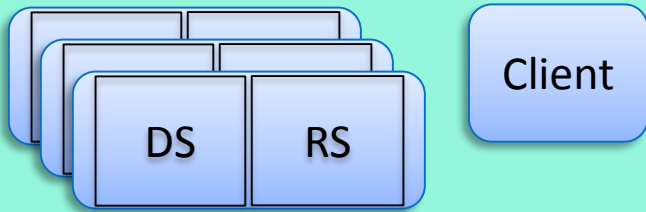
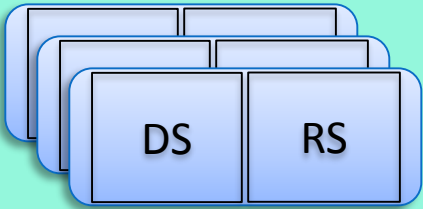
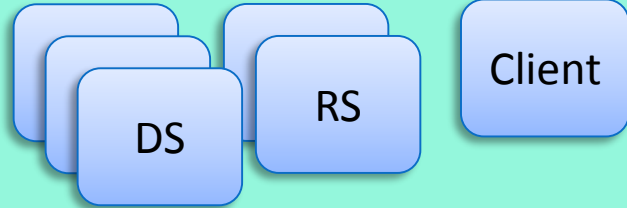
6 billion cell CFD
simulation on 1M MPI
ranks using ParaView
Catalyst on Mira

source: Kitware, UC Boulder
(Jansen & Rasquin)





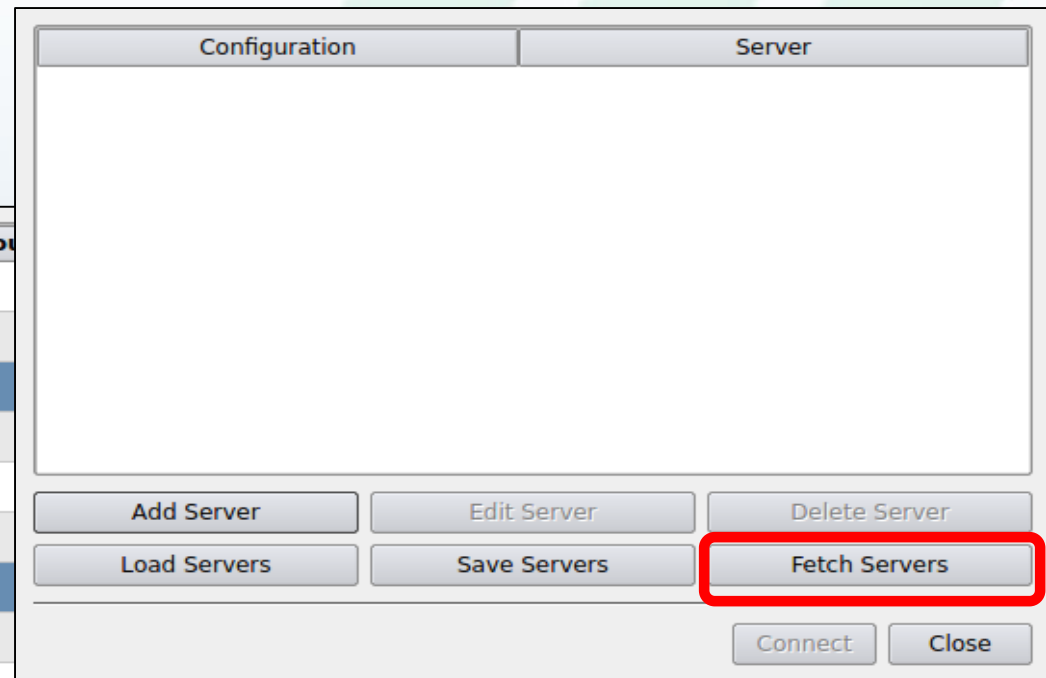
ParaView's running modes

<p>Built-in aka Standalone aka Serial</p>		<p>all components within one process (client may be GUI or pvpython) <code>"paraview" "pvpython"</code></p>
<p>Combined Server</p>		<p>data processing and parallel rendering in MPI job of combined processes. control from TCP connected client. <code>"mpiexec -n x pvserver & paraview" # pvpython #+ Connect</code></p>
<p>Batch</p>		<p>Server is an MPI job which directly runs a python script <code>"mpiexec -n x pvbatch \ vis_script.py"</code></p>
<p>Split server</p>		<p>Data processing and parallel rendering are both MPI jobs. " <code>mpiexec -n x pvdataserver& \ mpiexec -n y pvrenderserver & \ paraview" #+ Connect</code></p>

Connecting to a Server

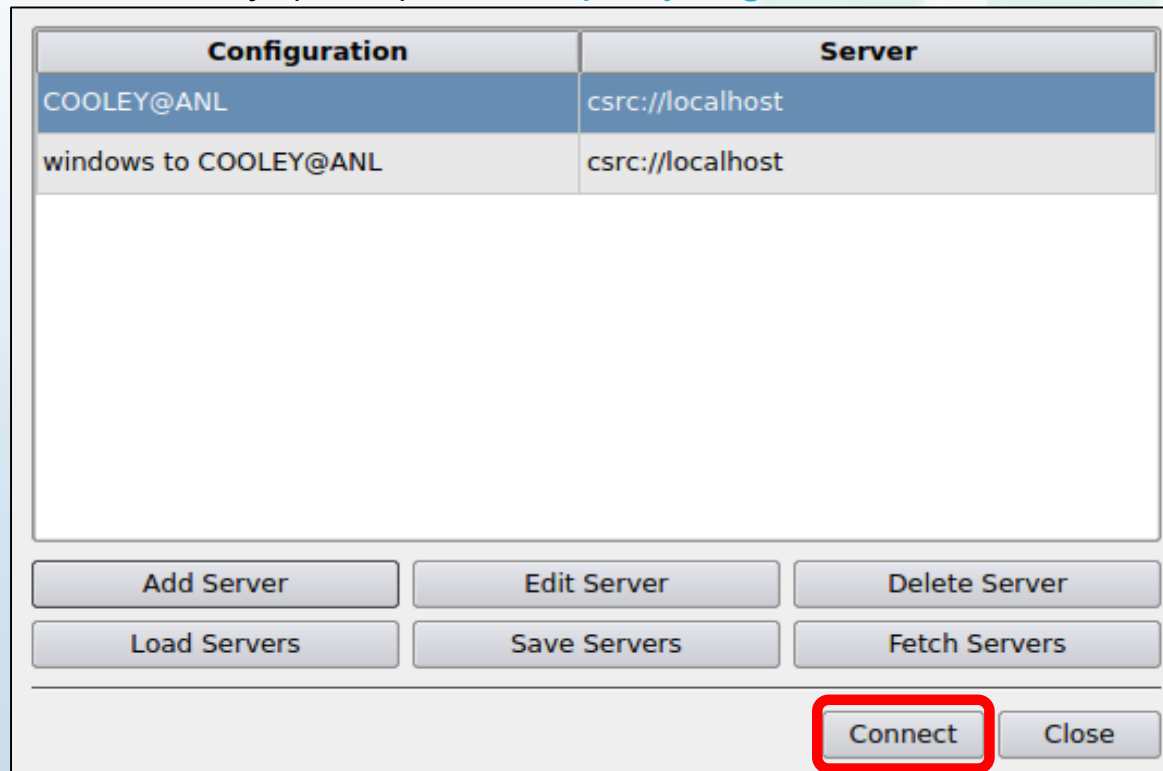
- Follow instructions at www.alcf.anl.gov/user-guides/paraview-cooley – currently use ParaView 4.3.1 (5.1.2 being set up on Cooley)
- Fetch Servers
 - **Windows to COOLEY@ANL or COOLEY@ANL**
 - Import Selected

Configuration Name	Server	Source
windows to EDISON@NERSC		Kitware Inc.
Gadget@LANL		Kitware Inc.
windows to COOLEY@ANL		Kitware Inc.
CORI@NERSC		Kitware Inc.
windows to TITAN@ORNL		Kitware Inc.
TITAN@ORNL		Kitware Inc.
COOLEY@ANL		Kitware Inc.
RHEA@ORNL		Kitware Inc.
windows to RHEA@ORNL		Kitware Inc.
EDISON@NERSC		Kitware Inc.



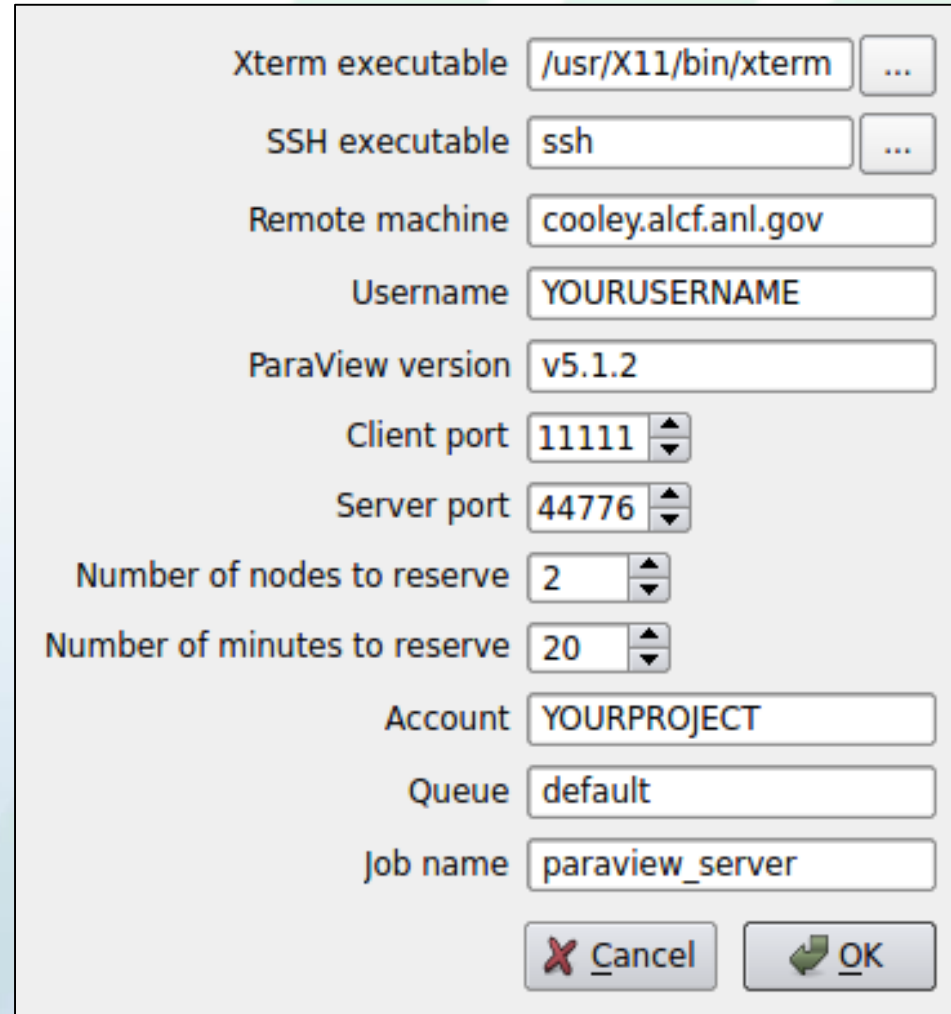
Connecting to a Server (2)

- GUI version must match pvserver version
- File → Connect
- Requirements:
 - Mac – XQuartz (X11) – www.xquartz.org
 - Windows – Putty (SSH) – www.putty.org



Connecting to a Server (3)

- Set:
 - Xterm executable
 - Linux & Mac
 - SSH executable
 - plink on Windows
 - Username
 - ParaView version (v4.3.1 or v5.1.2 for bleeding edge)
 - Number of nodes to reserve
 - Number of minutes to reserve
 - Account (ATPESC2016)
 - Queue

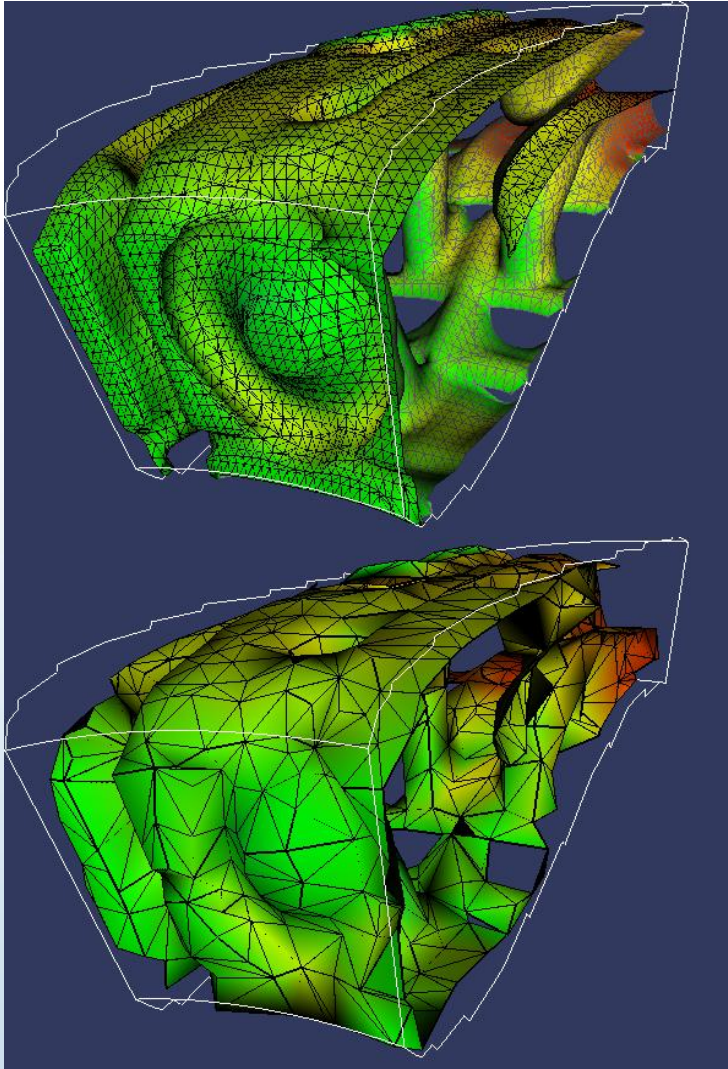


The screenshot shows a configuration dialog box with the following fields and values:

Xterm executable	/usr/X11/bin/xterm	...
SSH executable	ssh	...
Remote machine	cooley.alcf.anl.gov	
Username	YOURUSERNAME	
ParaView version	v5.1.2	
Client port	11111	▲▼
Server port	44776	▲▼
Number of nodes to reserve	2	▲▼
Number of minutes to reserve	20	▲▼
Account	YOURPROJECT	
Queue	default	
Job name	paraview_server	

At the bottom, there are two buttons: **Cancel** (with a red X icon) and **OK** (with a green checkmark icon).

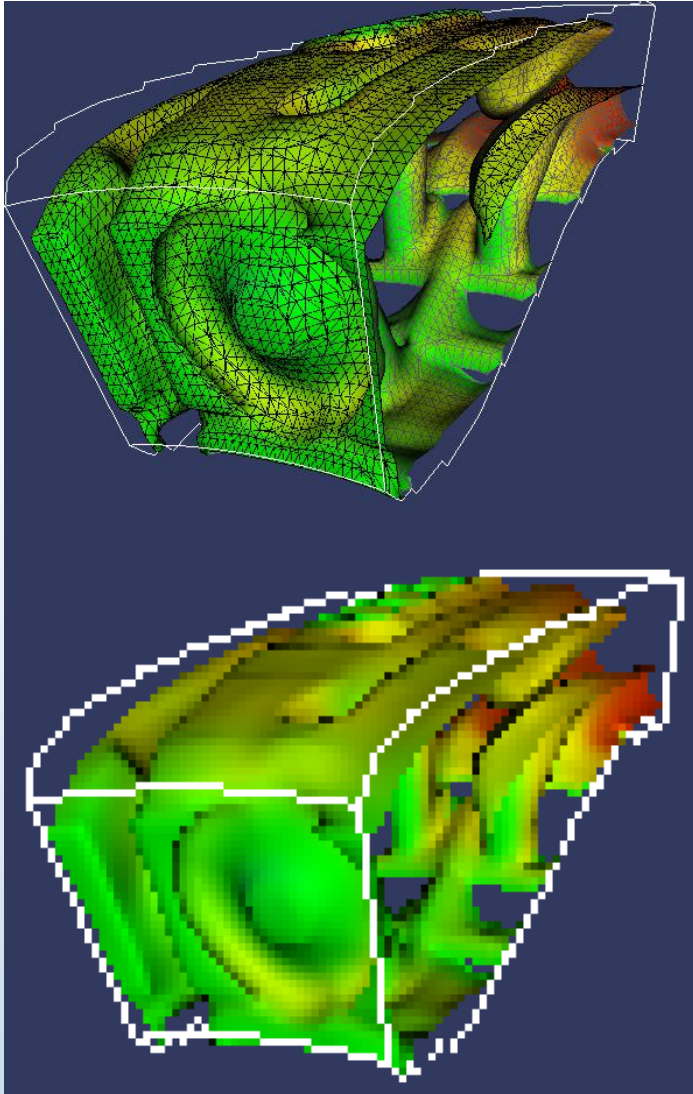
Level of Detail – Maintain Interactivity



Type 1: Geometrically based

- Edit → Settings → Render View →
- LOD threshold = 0.1
- Down-samples geometry while interacting

Level of Detail – Maintain Interactivity



Type 2: Image Based

- Edit → Settings → Render View →
- Remote Render Threshold = 0.1
- Image Reduction Factor = 10
- Down-samples pixels while interacting

Current Directions

- Catalyst
 - *In situ* ParaView <http://catalyst.paraview.org>
- Web and Mobile
 - ParaViewWeb front end <http://paraviewweb.kitware.com/PW>
 - VES/KiwiViewer <http://www.kiwiviewer.org>
- OpenGL rendering overhaul
 - <https://blog.kitware.com/new-opengl-rendering-in-vtk/>
- Ray tracing
 - <https://blog.kitware.com/vtk-and-paraview-now-with-ray-traced-rendering/>
- SMP and GPGPU acceleration
 - VTK-m http://m.vtk.org/index.php/Main_Page
 - vtkSMPTools <https://blog.kitware.com/simple-parallel-computing-with-vtksmptools-2/>

Thank You!

Questions?