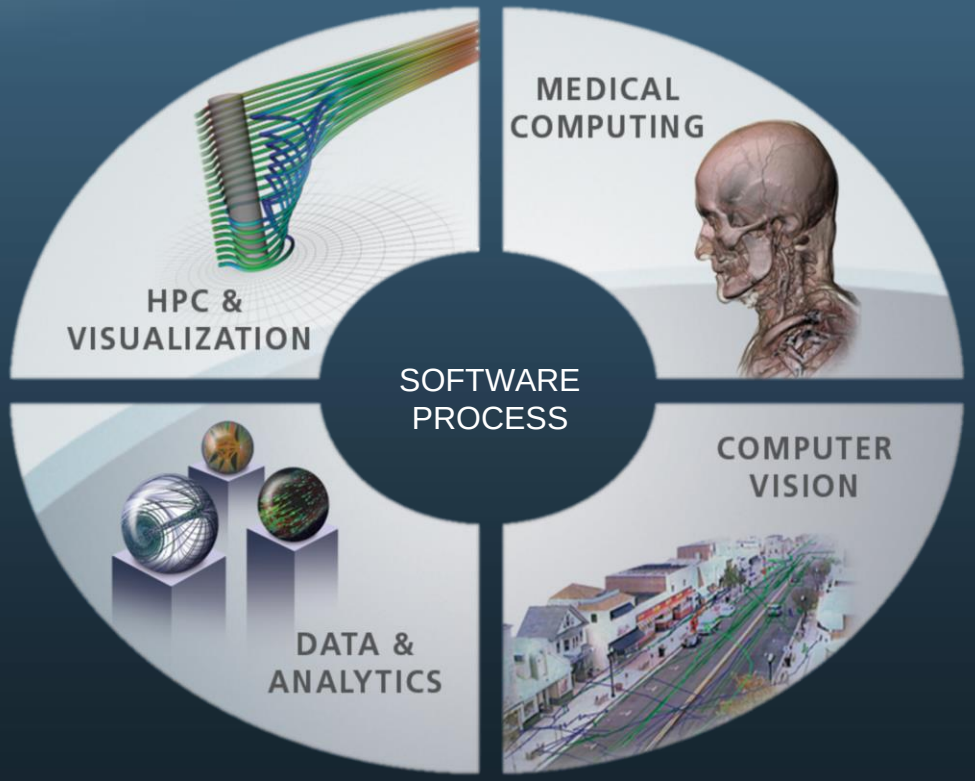
Introduction to ParaView

Andrew Bauer

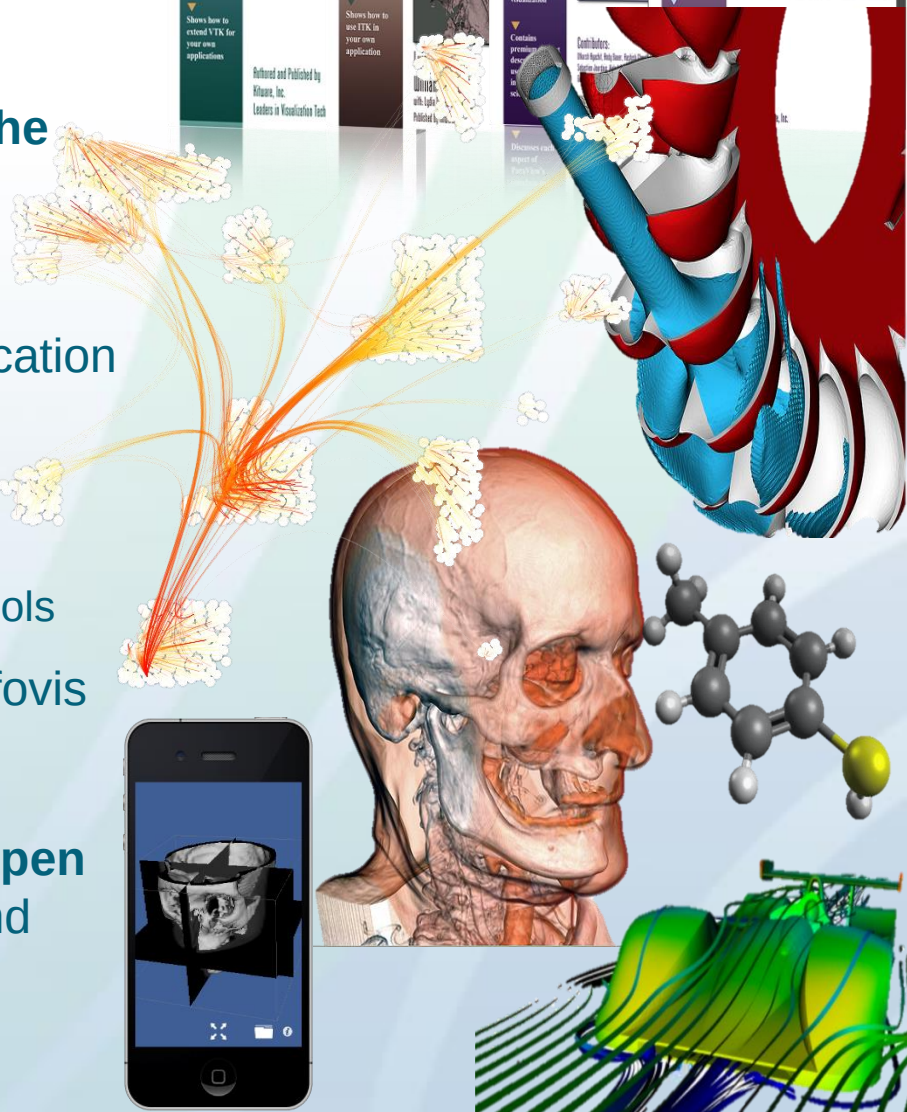
Kitware

- 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: ⅓ Masters, ⅓ 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**, **vxl**, **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

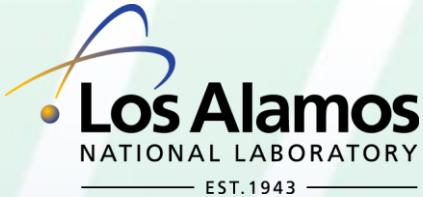
- **Application** - you don't have to write any code to analyze your data
- **Architecture** - designed to be extensible if you want to code
  - Custom apps, plugins, Python scripting, Catalyst for *in situ*, ParaViewWeb
- **Open-source** – BSD 3-clause license

- **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

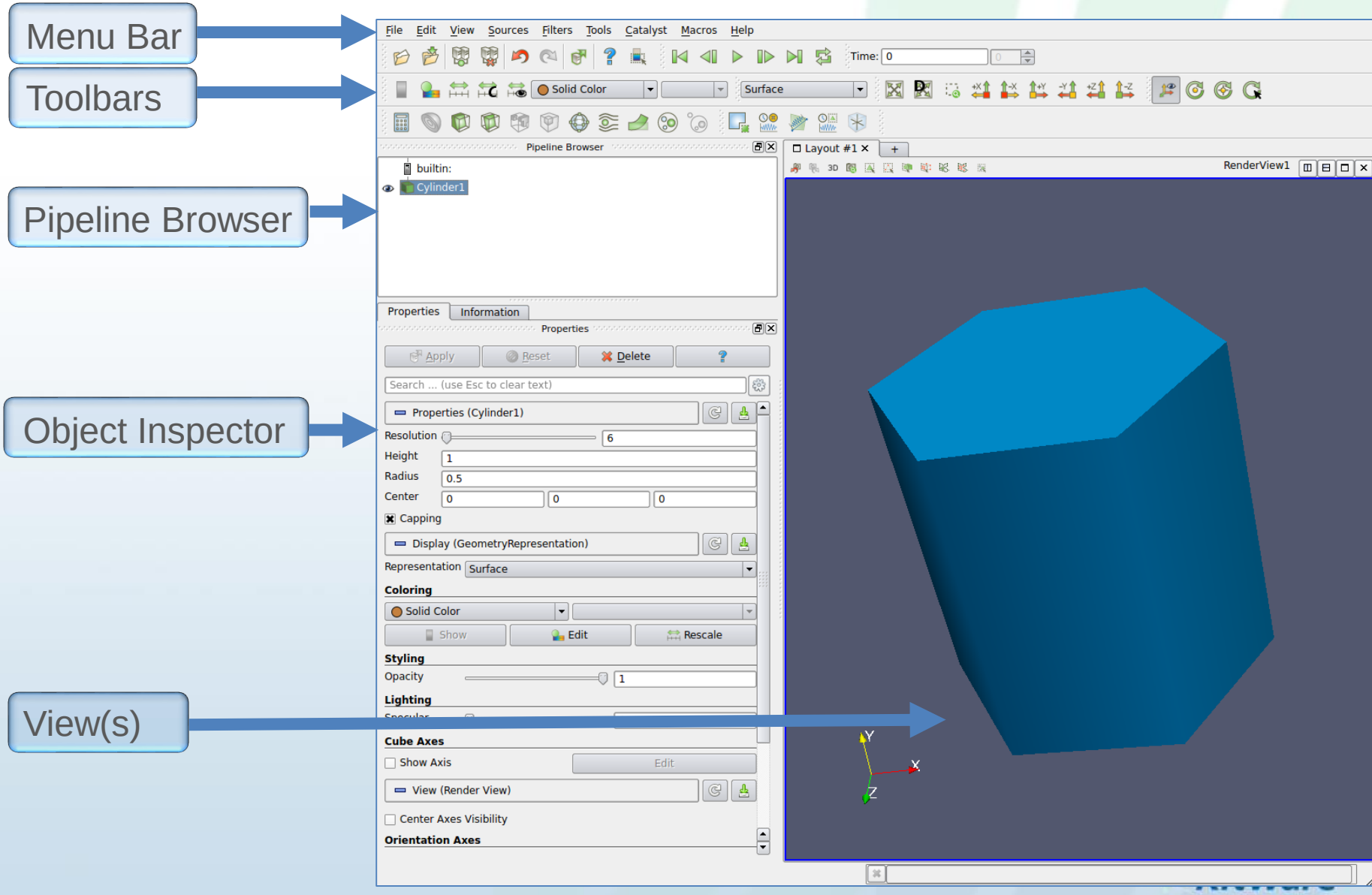
Kitware

History

- 1999 LANL/Kitware project (via ASCI 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



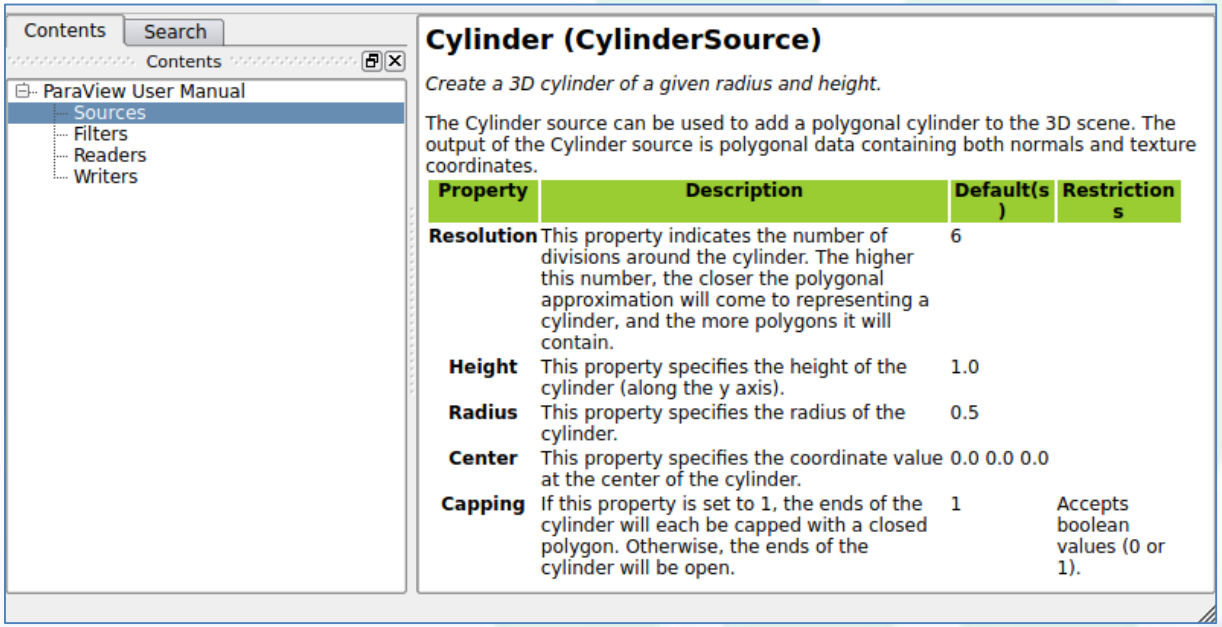
User Interface



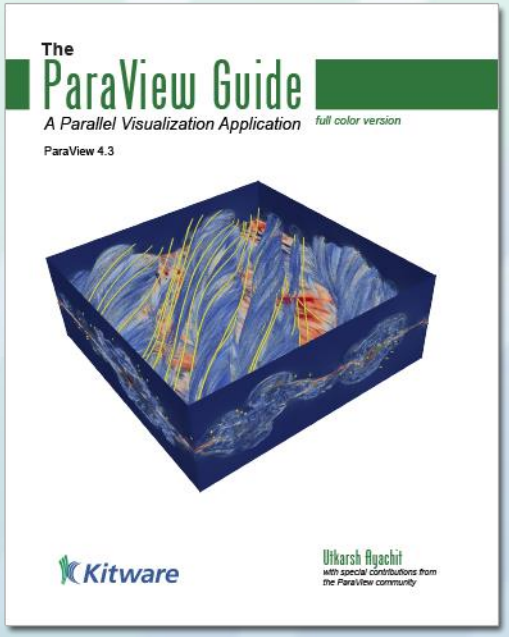
VTK & ParaView Lexicon

- **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

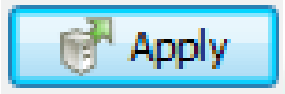


- Windows & Linux: F1 in the GUI
- Mac: Command+Shift+/
- Mouse hover
- Online help
  - The ParaView Guide
  - The ParaView Tutorial
  - ParaView Mailing Lists
  - ParaView Wiki
  - http://www.paraview.org/documentation/



Kitware

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

Kitware

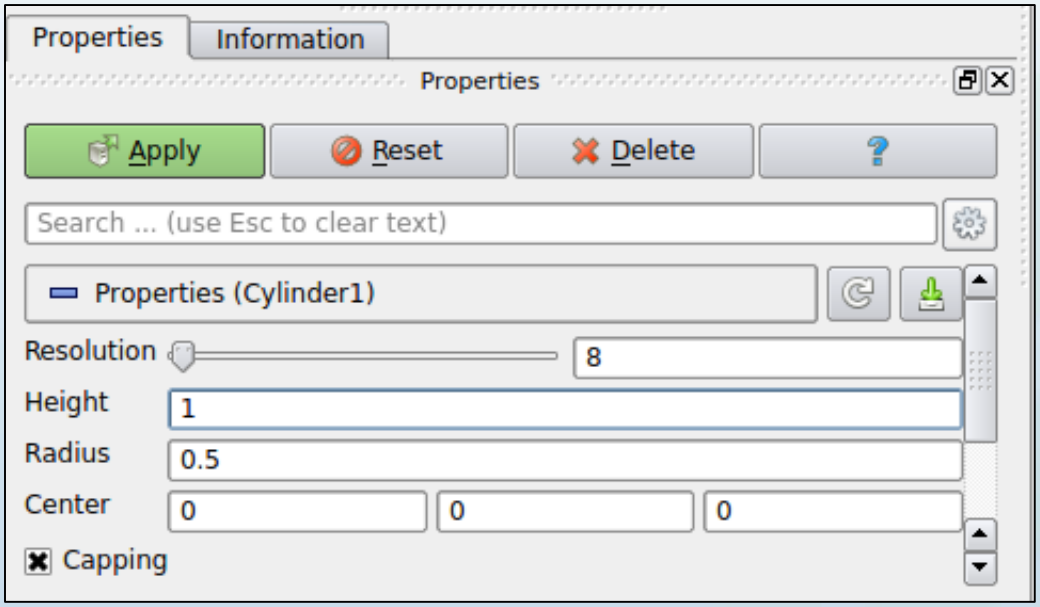
File→Open

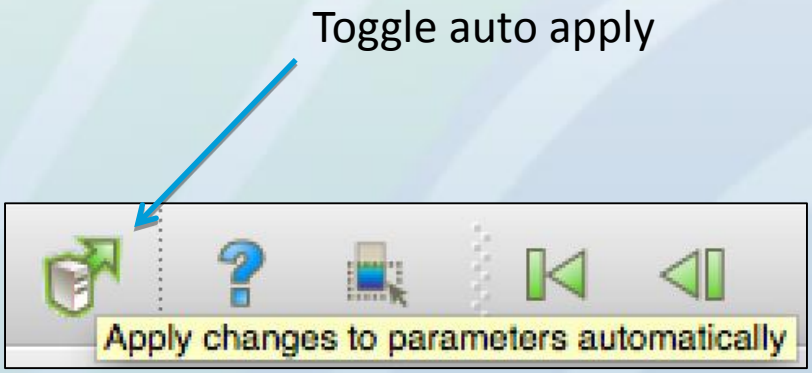
http://paraview.org/Wiki/ParaView/Users_Guide/List_of_readers

- 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)
- CEAucd (.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)
- M3DCl (.h5)
- MFIX Unstructred Grid (.RES)
- MM5 (.mm5)
- MPAS NetCDF (.nc, .ncdf)
- Meta Image (.mhd, .mha)
- Miranda (.mir, .raw)
- Multilevel 3d Plasma (.m3d, .h5)
- NASTRAN (.nas, .f06)
- Nek5000 Files
- Nrrd Raw Image (.nrrd, .nhdr)
- OpenFOAM Files (.foam)
- PATRAN (.neu)
- PFLOTRAN (.h5)
- PLOT2D (.p2d)
- PLOT3D (.xyz, .q, .x, .vp3d)
- PLY Polygonal File Format
- PNG Image Files
- POP Ocean Files
- ParaDIS Files
- Phasta Files (.pht)
- Pixie Files (.h5)
- ProSTAR (.cel, .vrt)
- Protein Data Bank (.pdb, .ent, .pdb)
- Raw Image Files
- Raw NRRD image files (.nrrd)
- SAMRAI (.samrai)
- SAR (.SAR, .sar)
- SAS (.sasgeom, .sas, .sasdata)
- SESAME Tables
- SLAC netCDF mesh and mode data
- SLAC netCDF particle data
- Silo (.silo, .pdb)
- Spheral (.spheral, .sv)
- SpyPlot CTH
- SpyPlot (.case)
- SpyPlot History (.hscth)
- Stereo Lithography (.stl)
- TFT Files
- TIFF Image Files
- TSurf Files
- Tecplot ASCII (.tec, .tp)
- Tecplot Binary (.plt)
- Tetrad (.hdf5, .h5)
- UNIC (.h5)
- VASP CHGCA (.CHG)
- VASP OUT (.OUT)
- VASP POSTCAR (.POS)
- VPIC (.vpc)
- VRML (.wrl)
- Velodyne (.vld, .rst)
- VizSchema (.h5, .vsh5)
- Wavefront Polygonal Data (.obj)
- WindBlade (.wind)
- XDMF and hdf5 (.xmf, .xdmf)
- XMol Molecule

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)

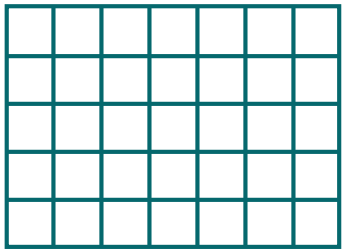




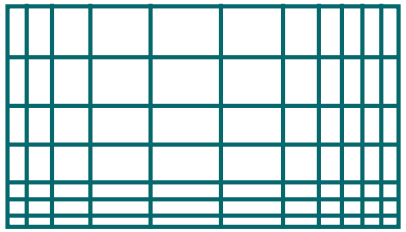
Kitware

ParaView Dataset Types

vtkImageData

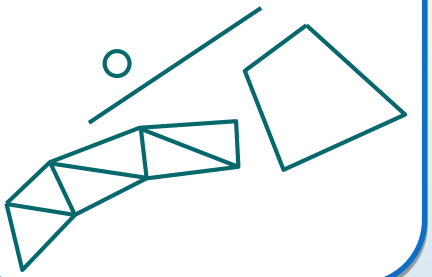


vtkRectilinearGrid

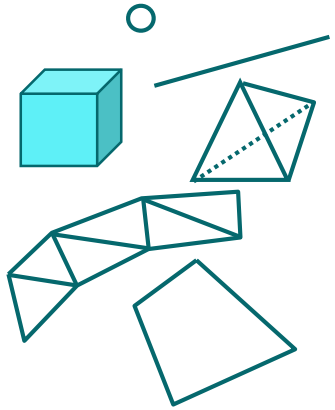


vtkStructuredGrid

vtkPolyData



vtkUnstructuredGrid



Multi-blocks

AMR

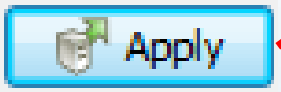
Time-varying data

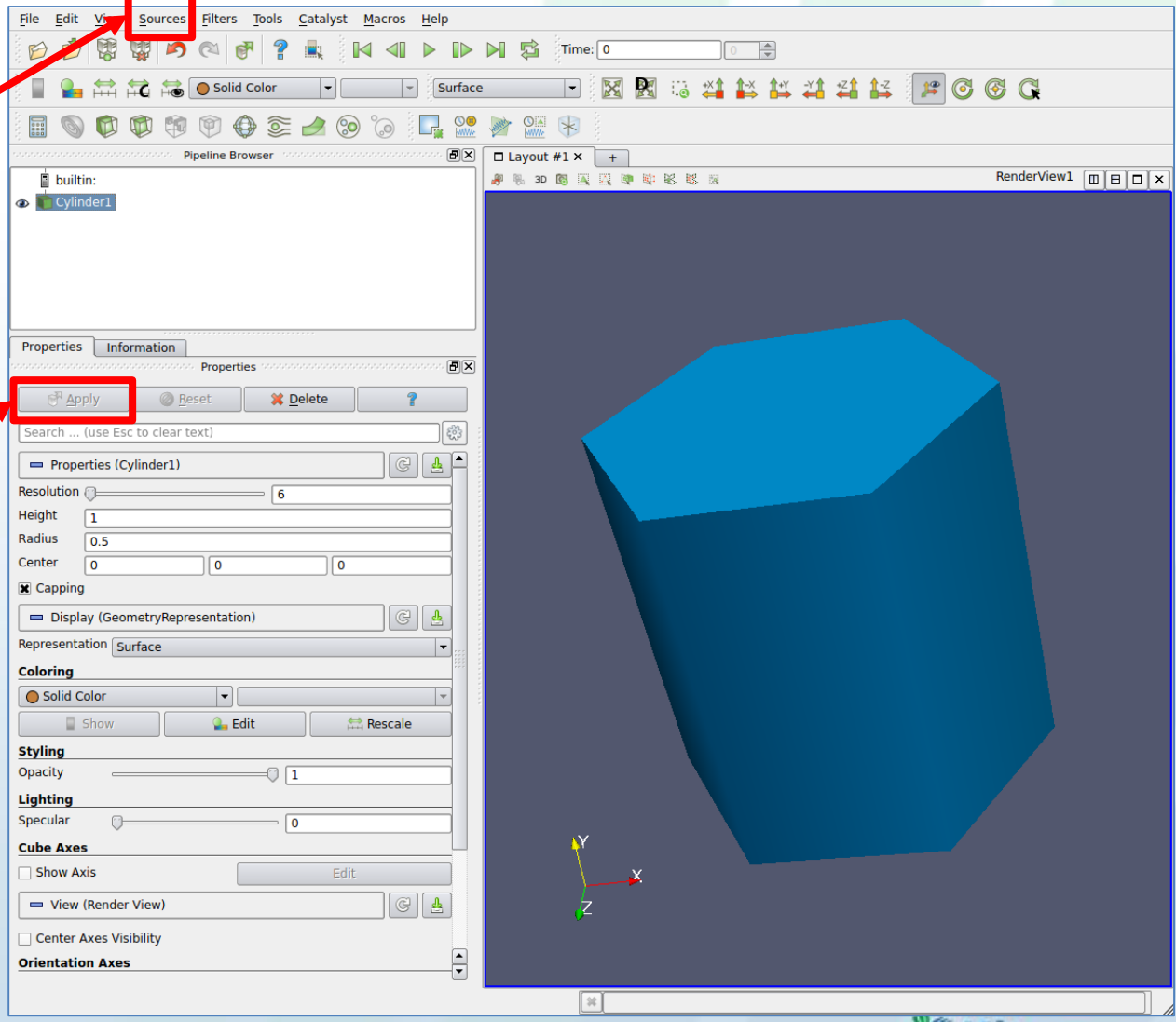
- points, cells
- values associated with points and/or cells: scalars, vectors, tensors

Kitware

First Hands-On Example

Create a Cylinder source

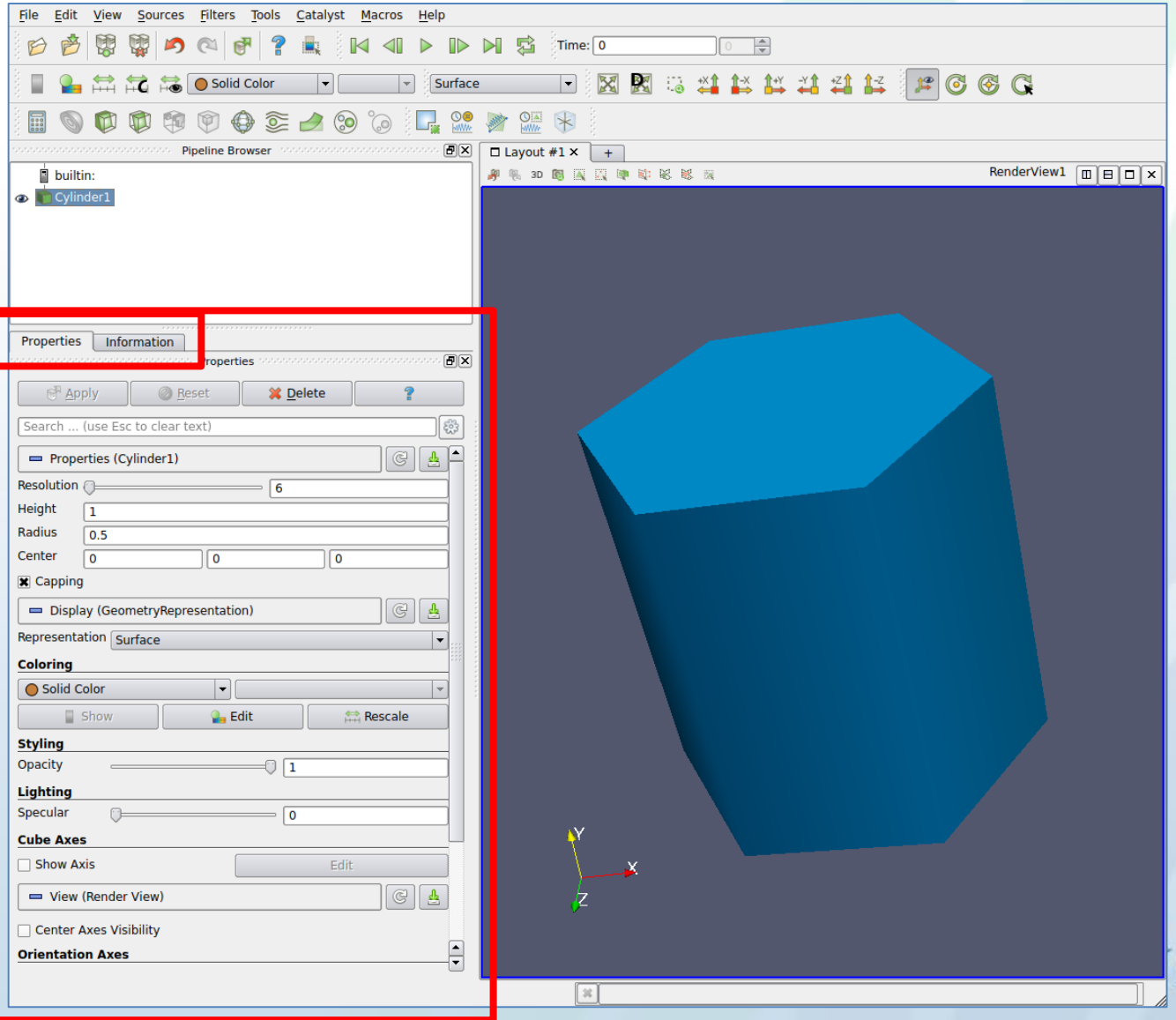
- Click on Sources menu and select Cylinder
- Click 



Kitware

Object Inspector: Properties and Information Tabs

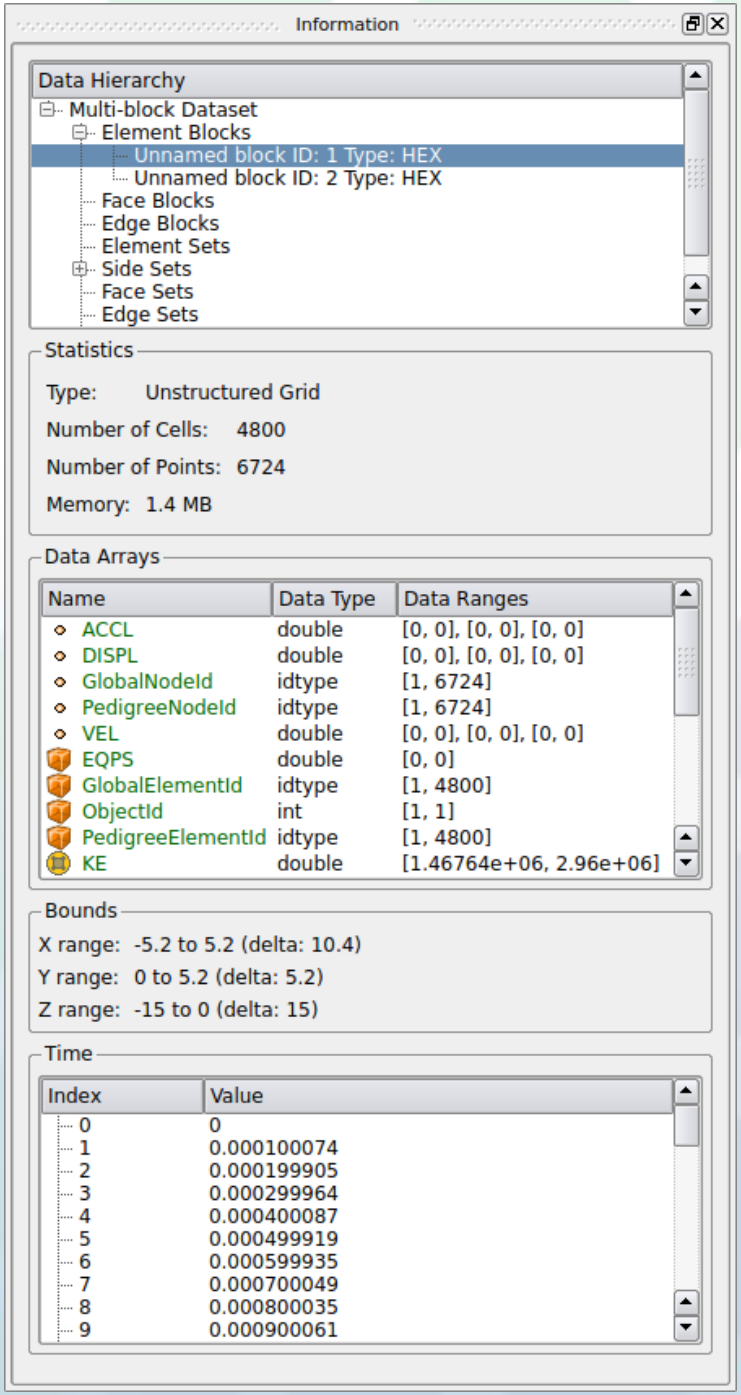
Active Filter highlighted



Kitware

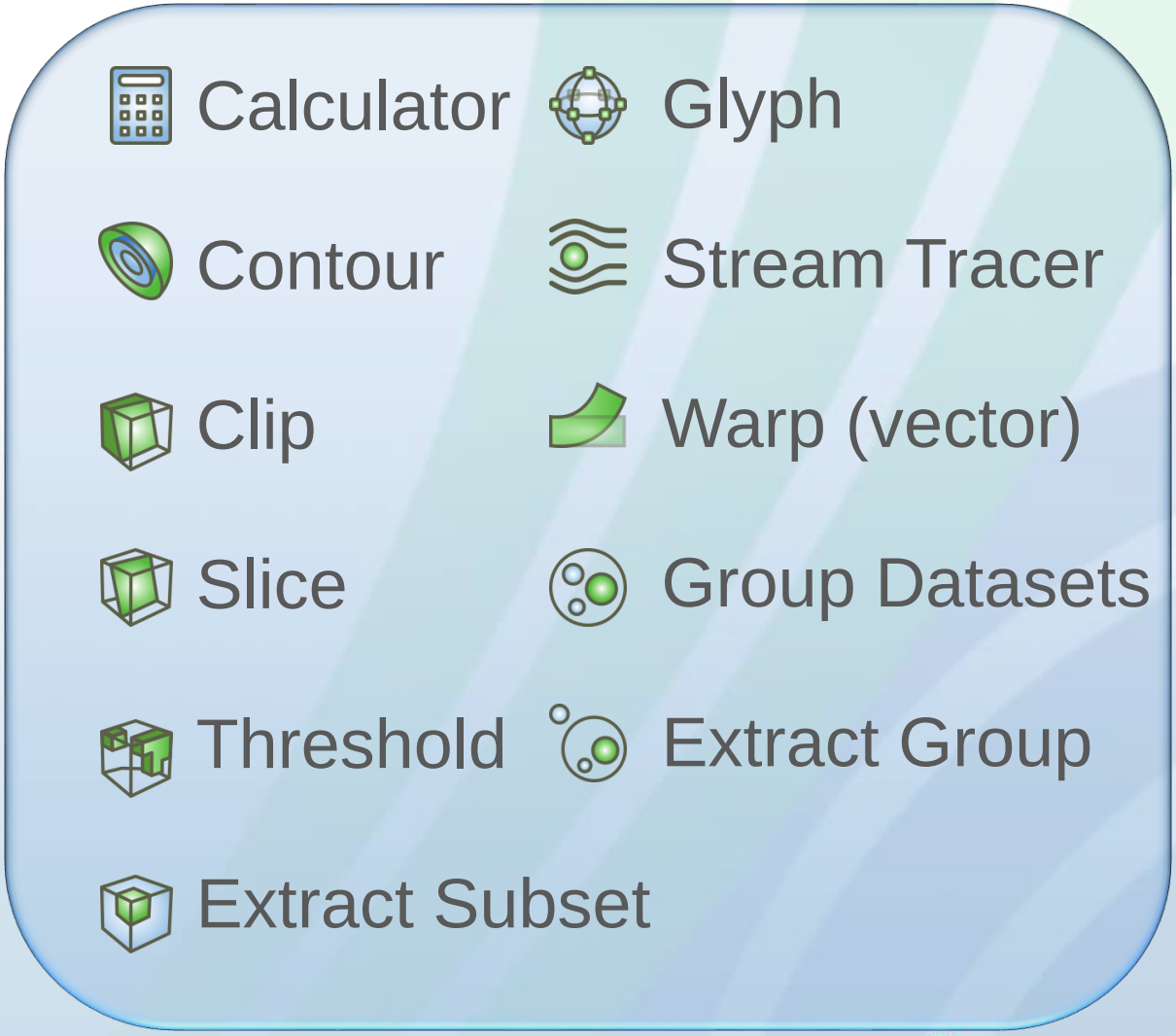
Object Inspector: Information Tab

- 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



Manipulate the Data

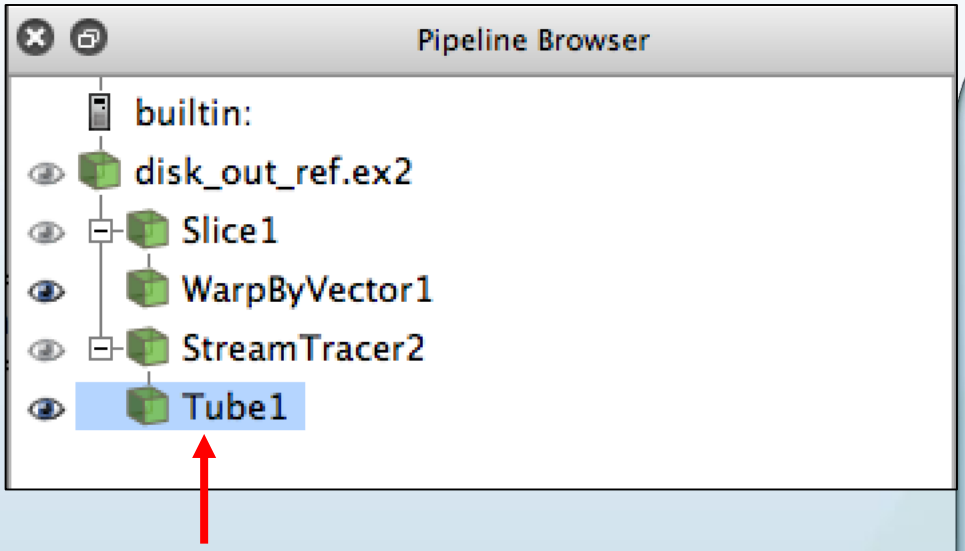
- Filters Menu
  - Recent
  - Common
  - Data Analysis
  - Statistical
  - Temporal
  - Alphabetical
- Quick Launch
  - PC/Linux
    CTRL-Space
  - Mac
    ALT-Space
- Apply Undo/Redo



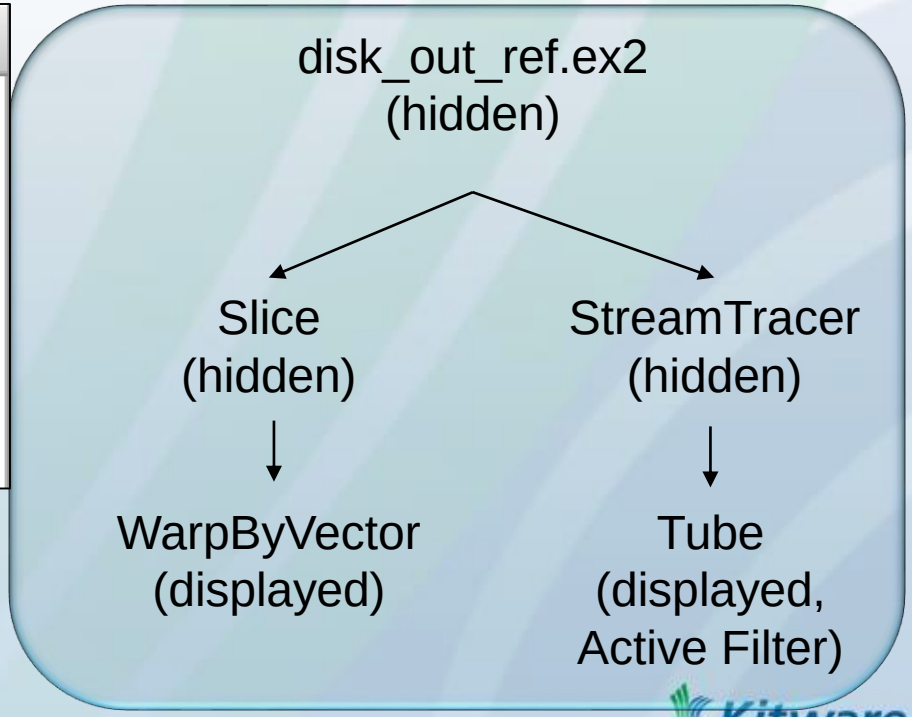
Kitware

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



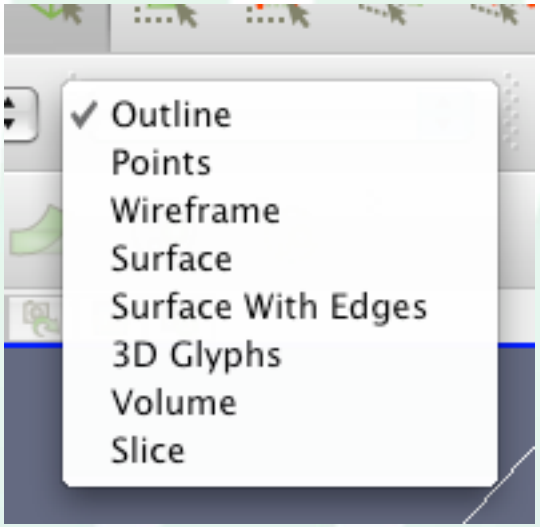
Active Filter highlighted

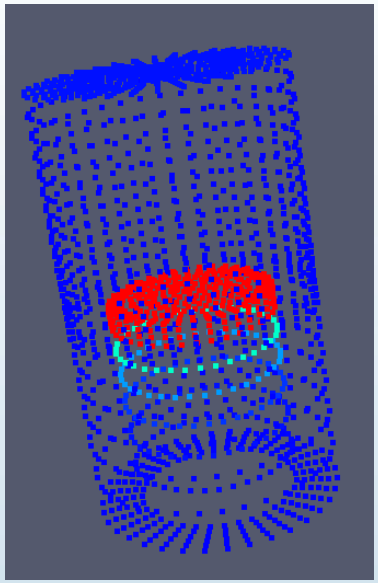


Kitware

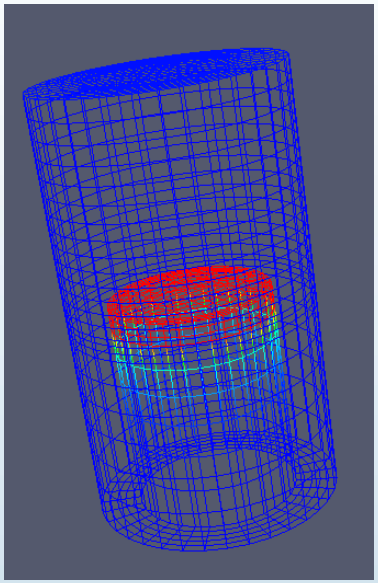
Display the Data

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

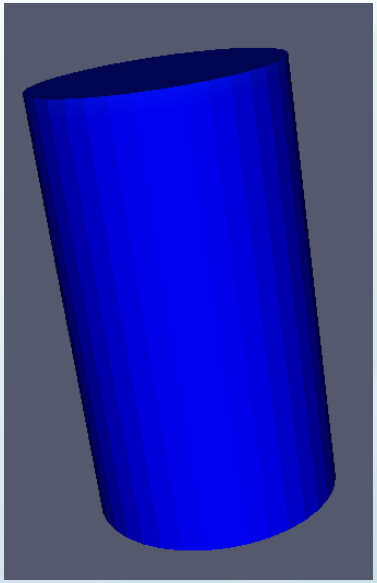




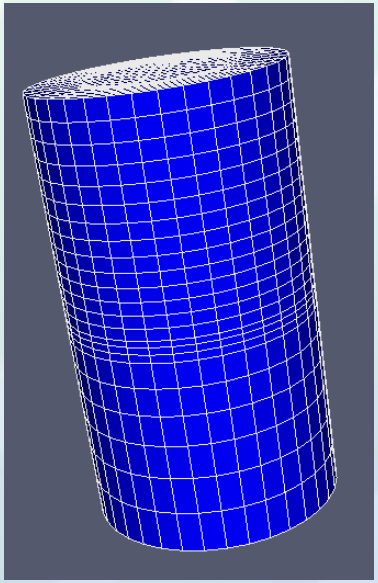
Points



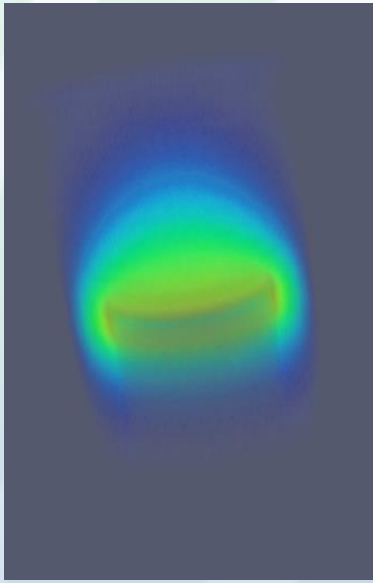
Wireframe



Surface



Surface with Edges



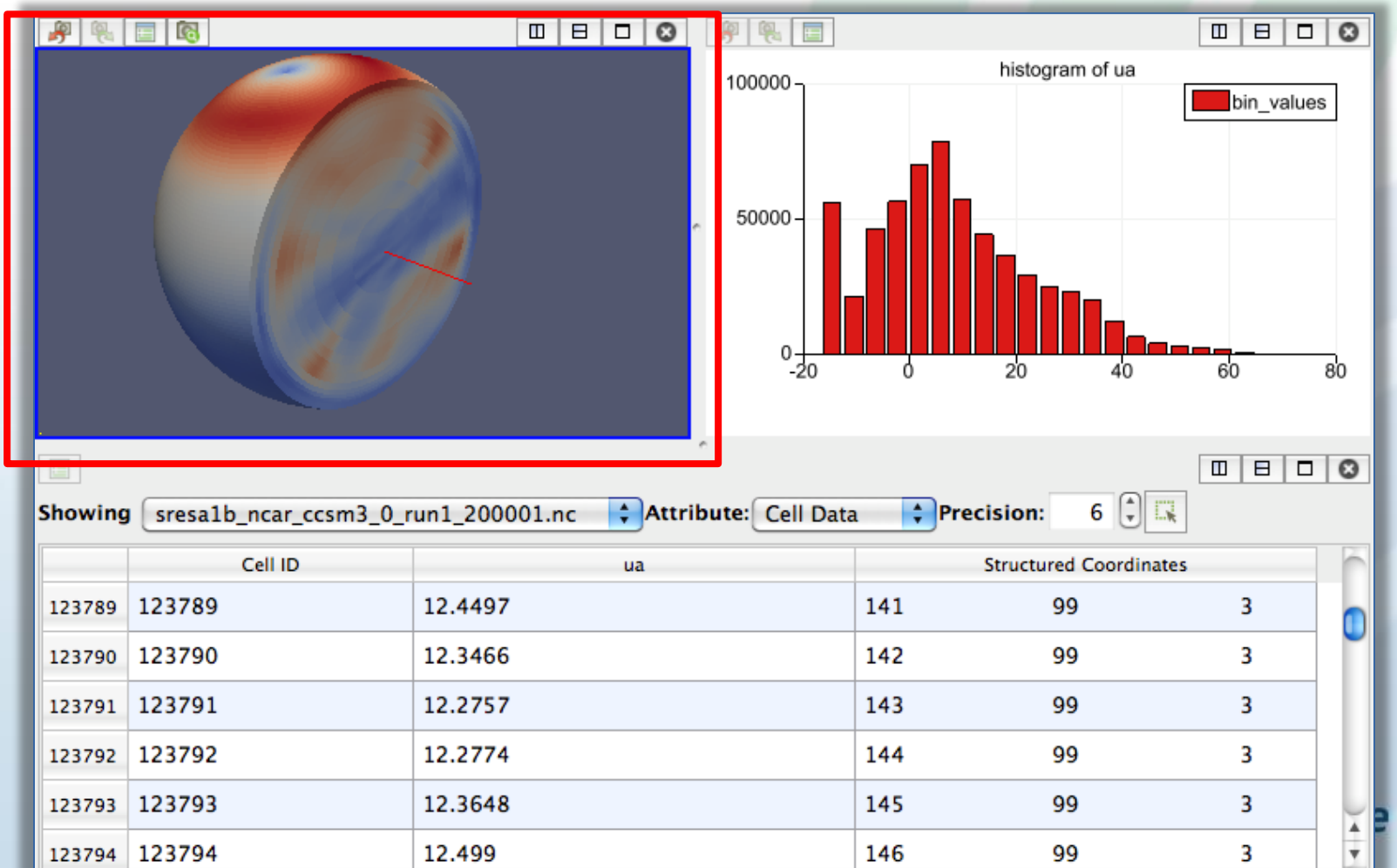
Volume

Kitware

Display the Data

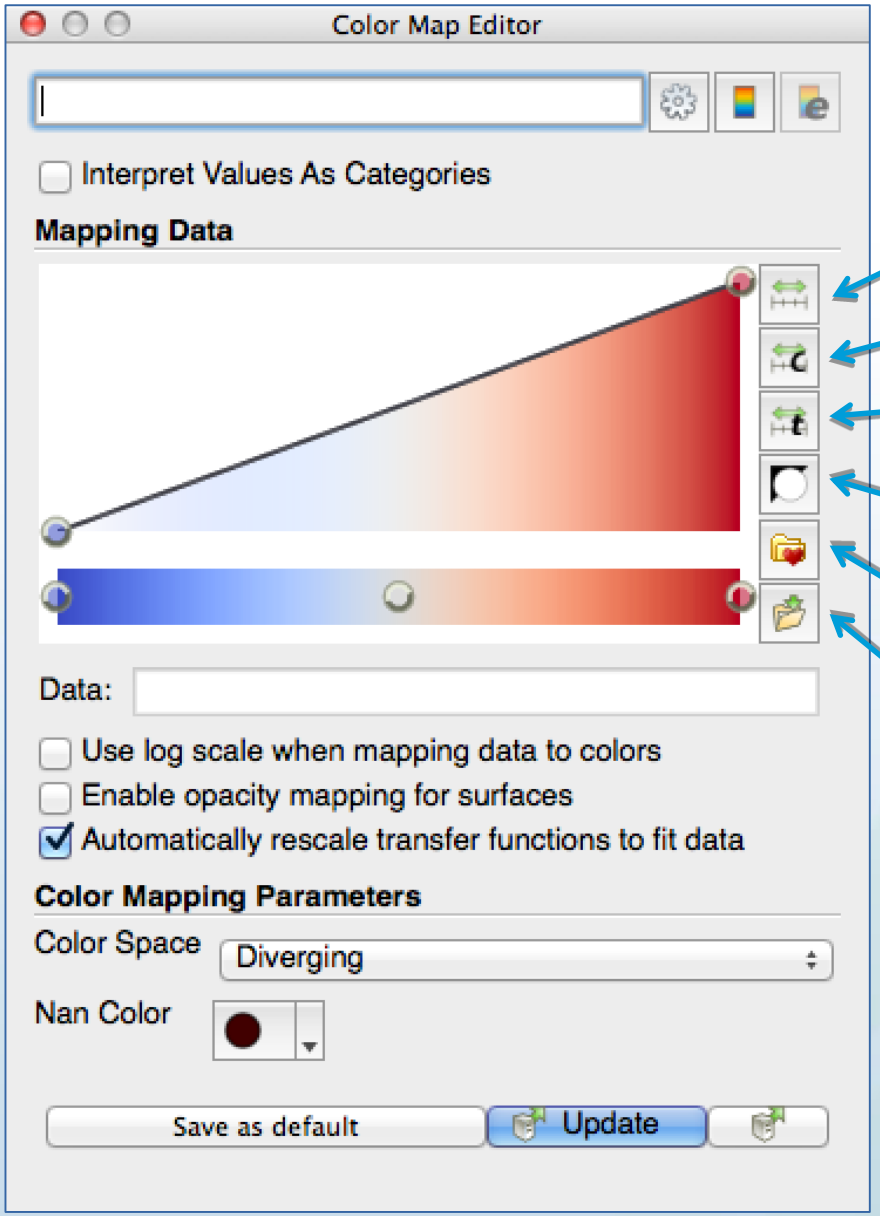
Views – Windows onto one or more data sets

- 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

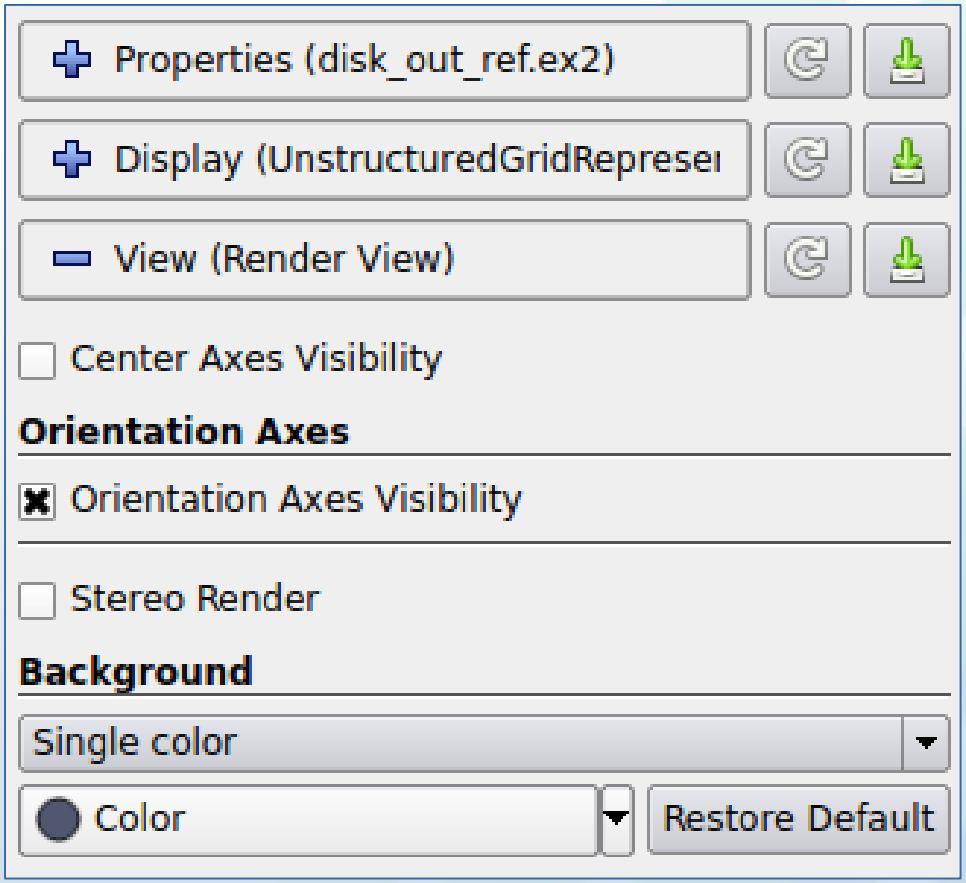
Choose preset

Save to preset

Kitware

View Properties

Properties associated with the Active View

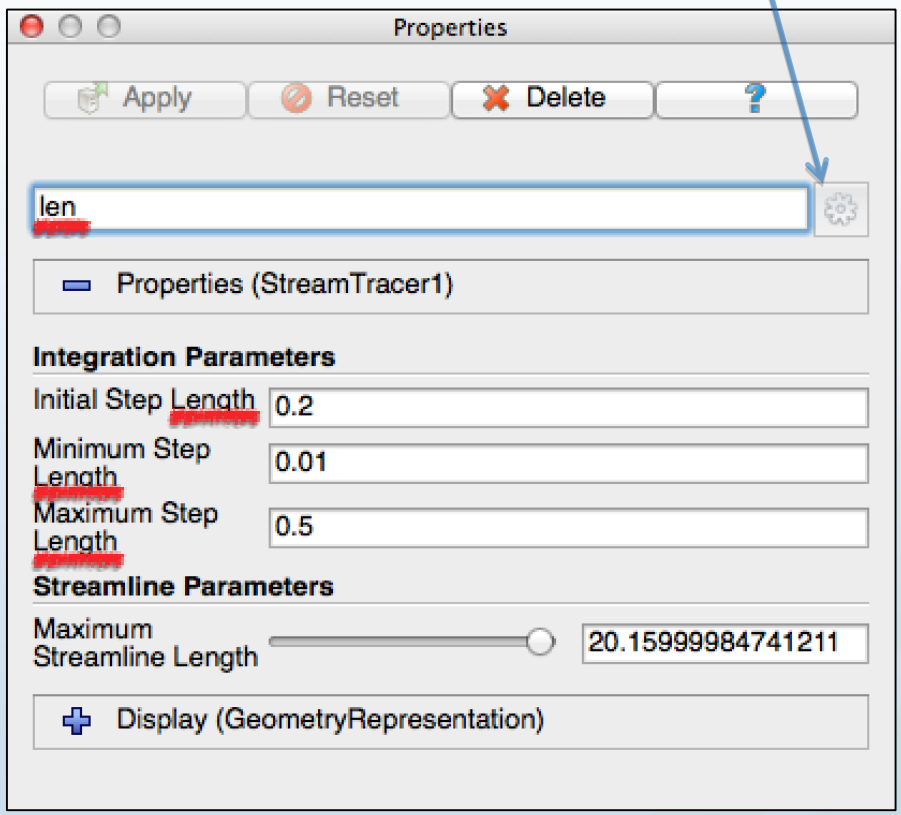


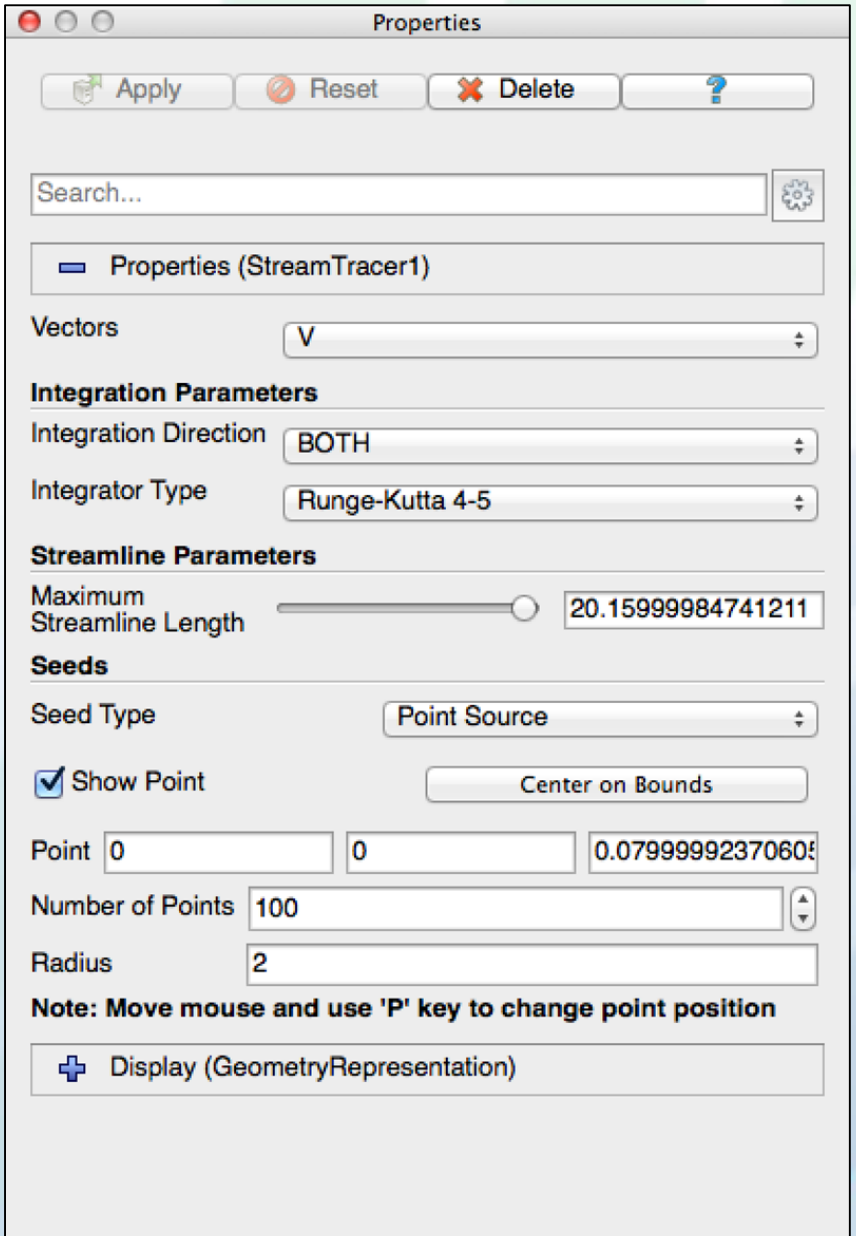
Kitware

Find Properties (for Filters, Displays and Views)

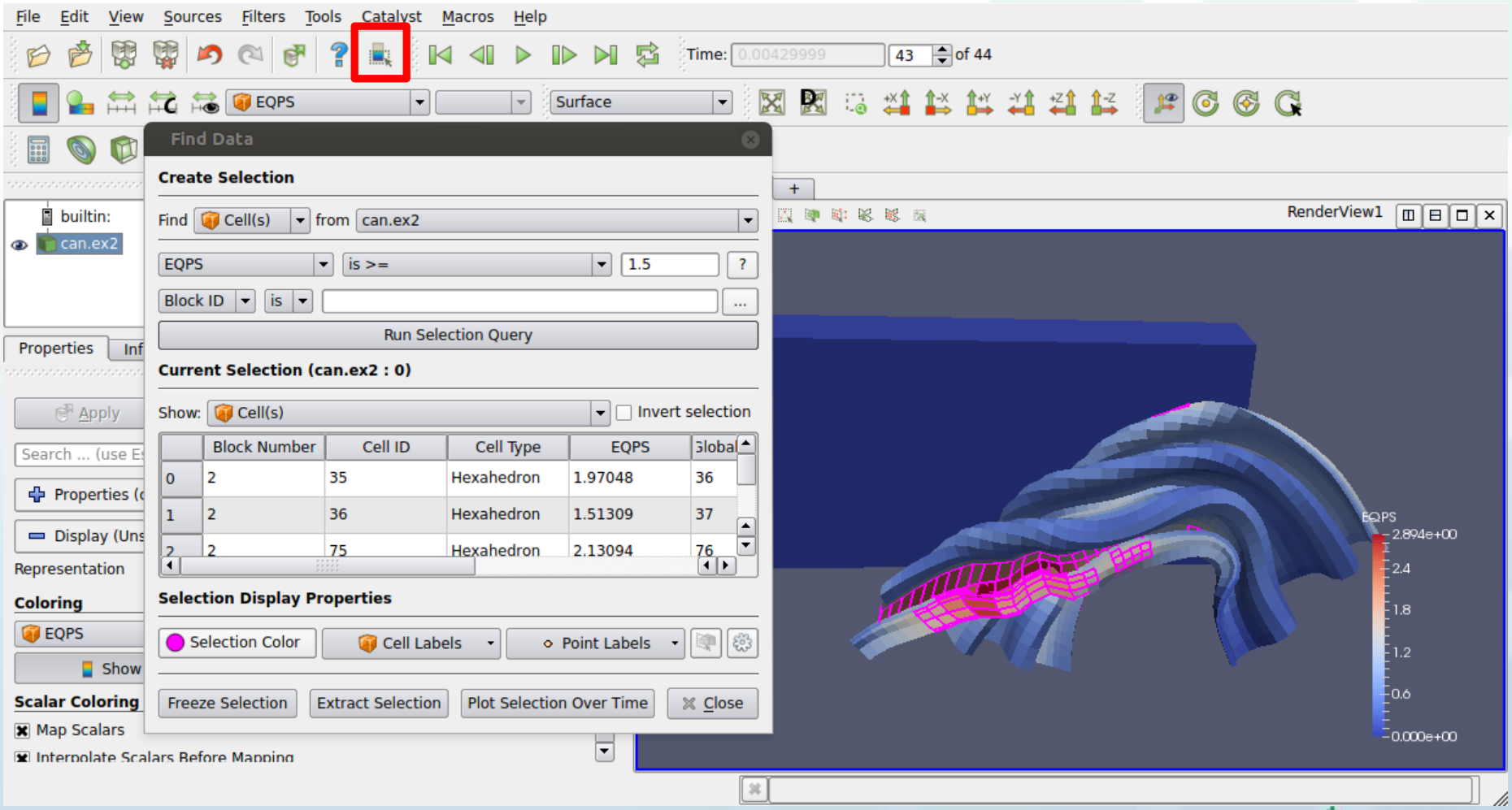
- Search for properties
- Toggle on/off advanced properties

Advanced Properties





Query Data by Attributes' Values – Find Data Dialog



Kitware

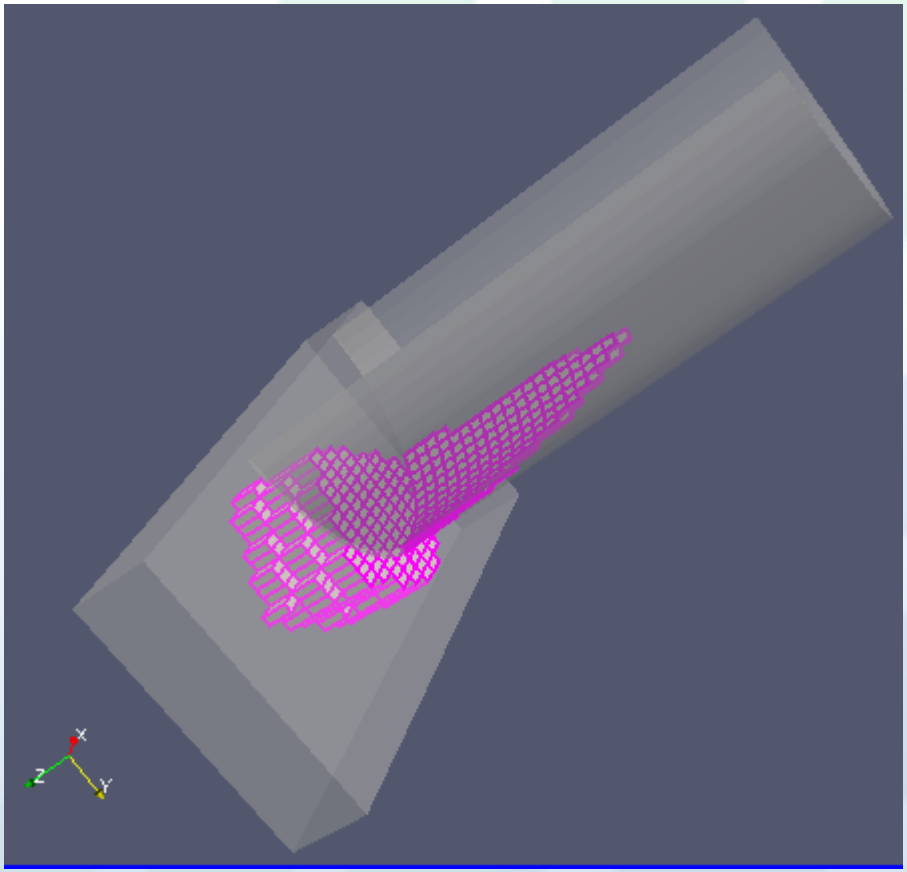
Query Data Visually - Selection

- 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



Kitware

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, Ensight, 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

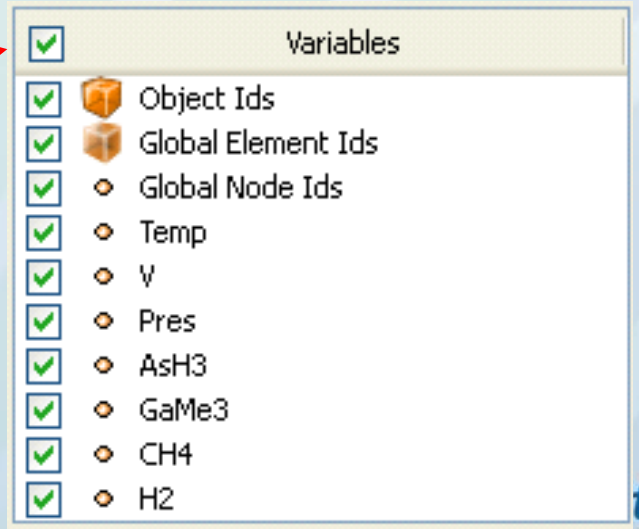
Shortcuts for Repetitive Tasks

- 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)

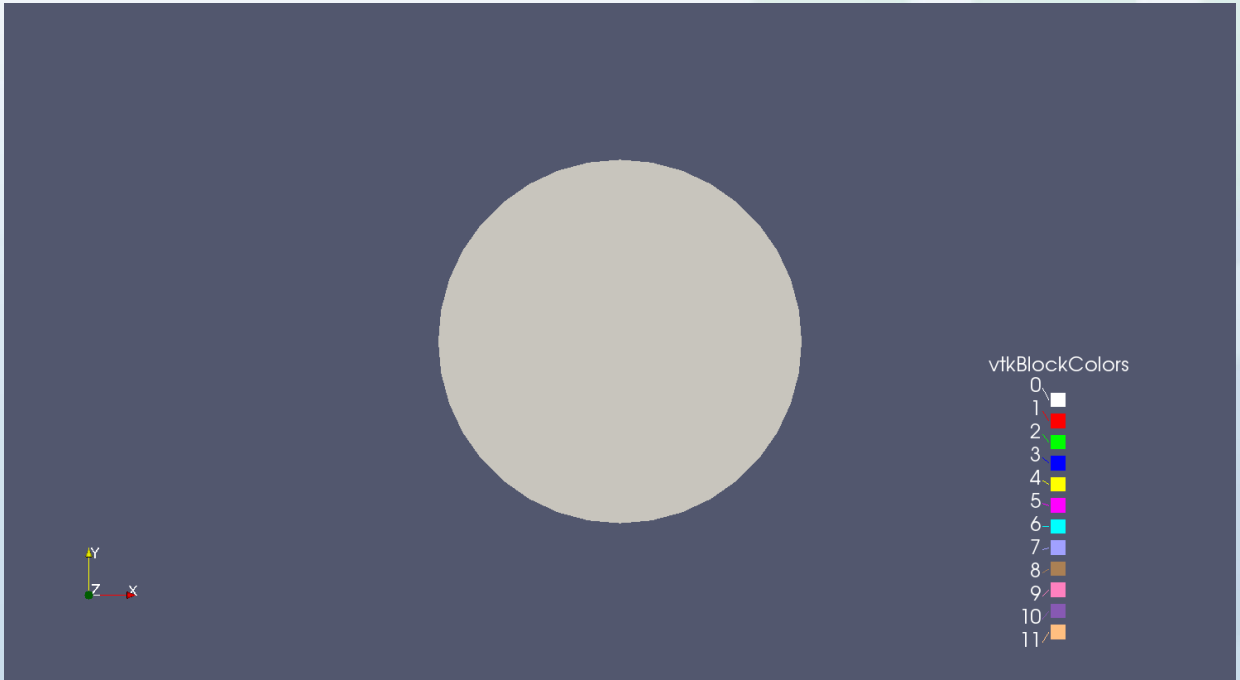
- Load disk_out_ref.ex2
  - Tarball/zip file available on above link
  - 5.1.2 installers included at:
    - Windows: <install location>/ParaView 5.1.2/data
    - Linux: <install location>/share/paraview-5.1/data
    - Mac: <install location>/paraview.app/Contents/data
  - An Exodus format file
  - Load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



Data Set Details

Shown in the Information tab

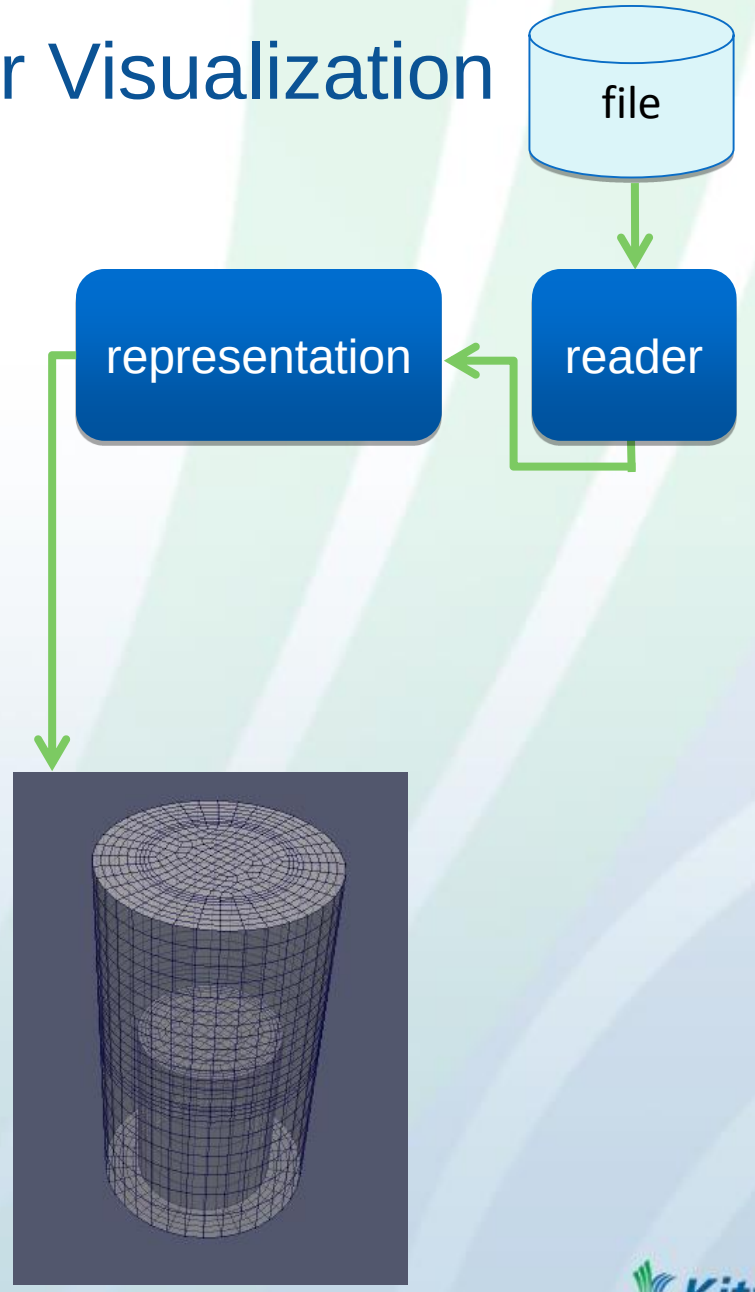
- Multi-block (group of data sets)
- Not time varying
- Roughly 8000 cells and points, 2MB
- 11.5 units in diameter, 20 units in height



Kitware

Hands on Practice: Vector Visualization

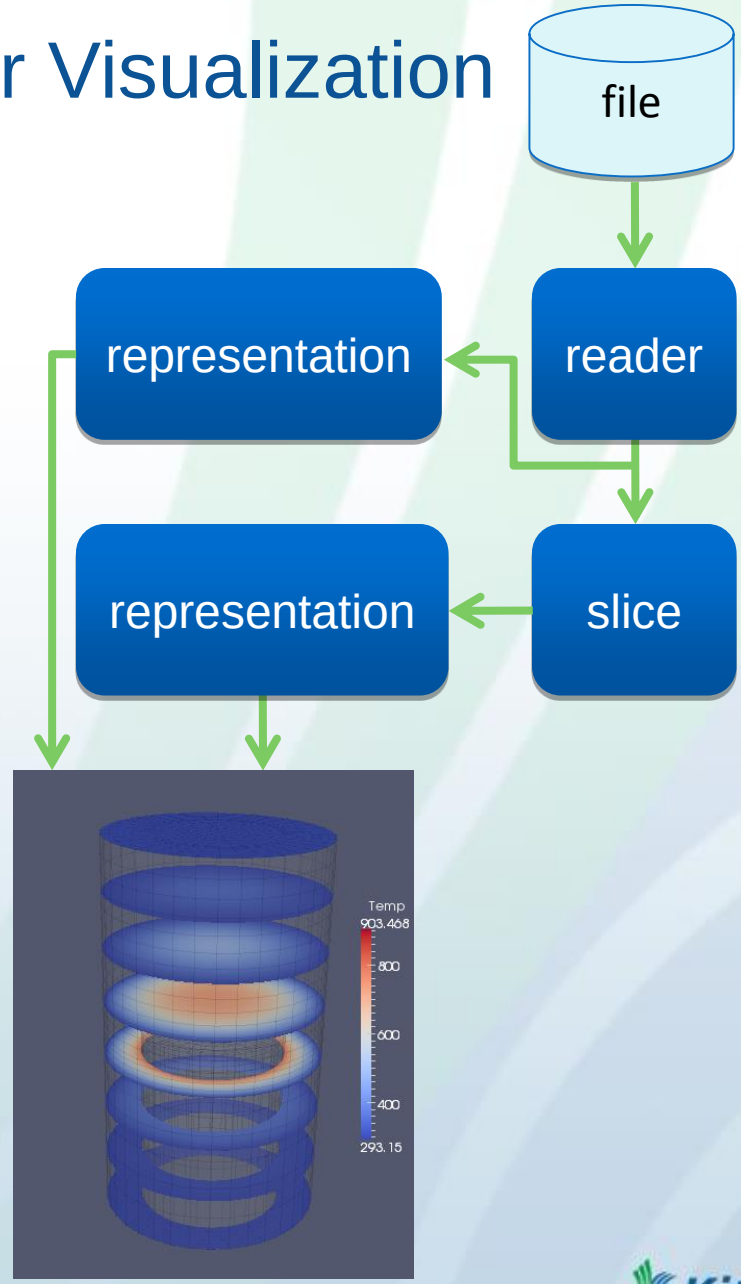
- Show as surface with edges to see structure
- Set opacity to 0.5
- Looks like a cylinder with a recess



Kitware

Hands on Practice: Vector Visualization

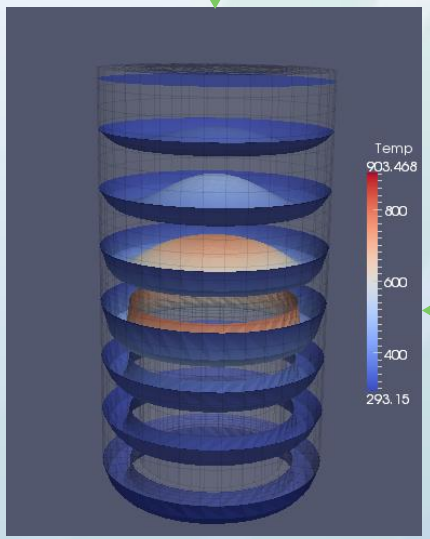
- Apply slice filter
  - Align with z and use 10 offset values
- Color by Temp
- Show Temp lookup table
- Adjust opacity of reader(0.1) and slice(1.0) to see temperature variation clearly

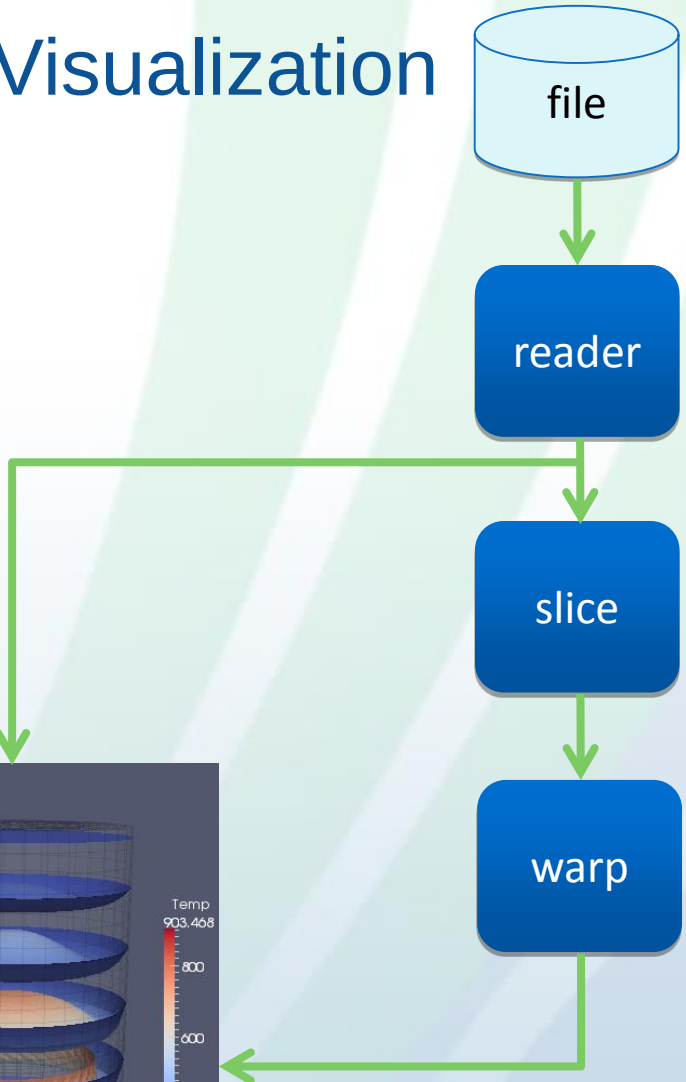


Kitware

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

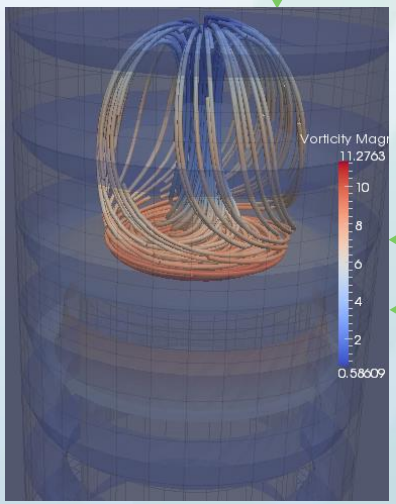


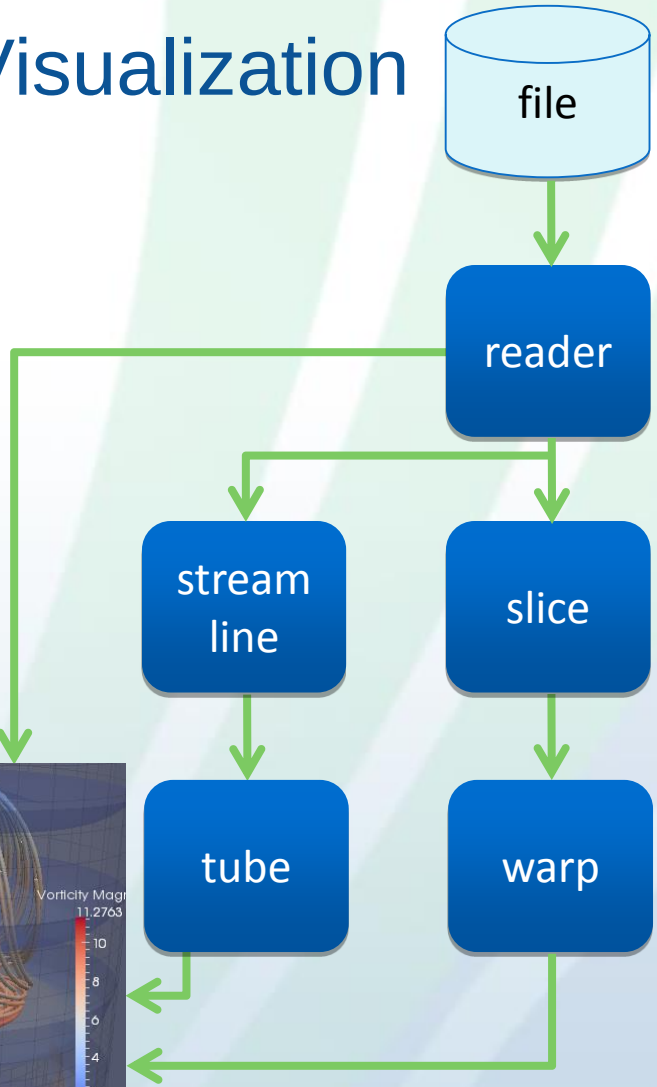


Kitware

Hands on Practice: Vector Visualization

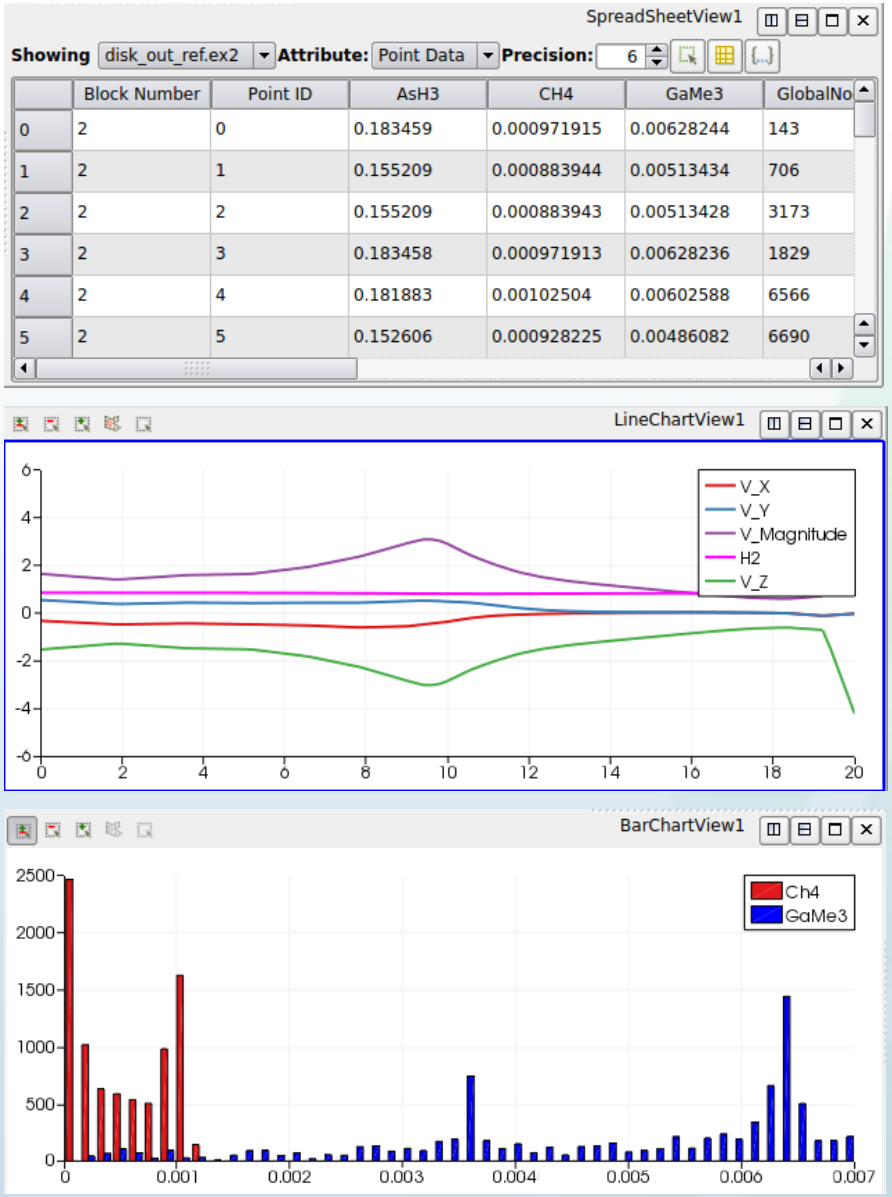
- Change warp opacity to .2
- Apply streamline filter
  - Starts from seed points and advects along vector field to show vector flow
- Apply tube filter
  - Gives infinitely thin streamlines volume so we can see them well
- Set opacity to 1.0 and color by vorticity
  - We are seeing rotation
  - A heated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





Kitware

Putting It Together: Data Analysis



reader

view 2

plot over line

view 3

histogram

view 4

Kitware

What to Expect from Parallel ParaView

- Amdahl's Law

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

aka Strong scaling:

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

More processors != faster

- Gustafson's Law

$$Speedup(Machines) = Machines - Serial * (Machines - 1)$$

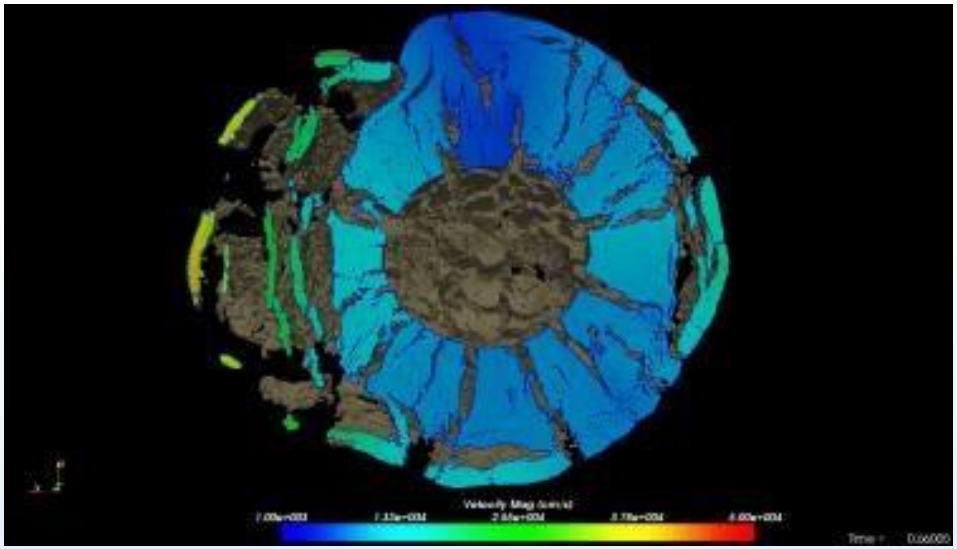
aka Weak scaling:

As data size grows, you must have more resources.

More disk and memory = higher resolution possible

Kitware

Large Data Processed by ParaView



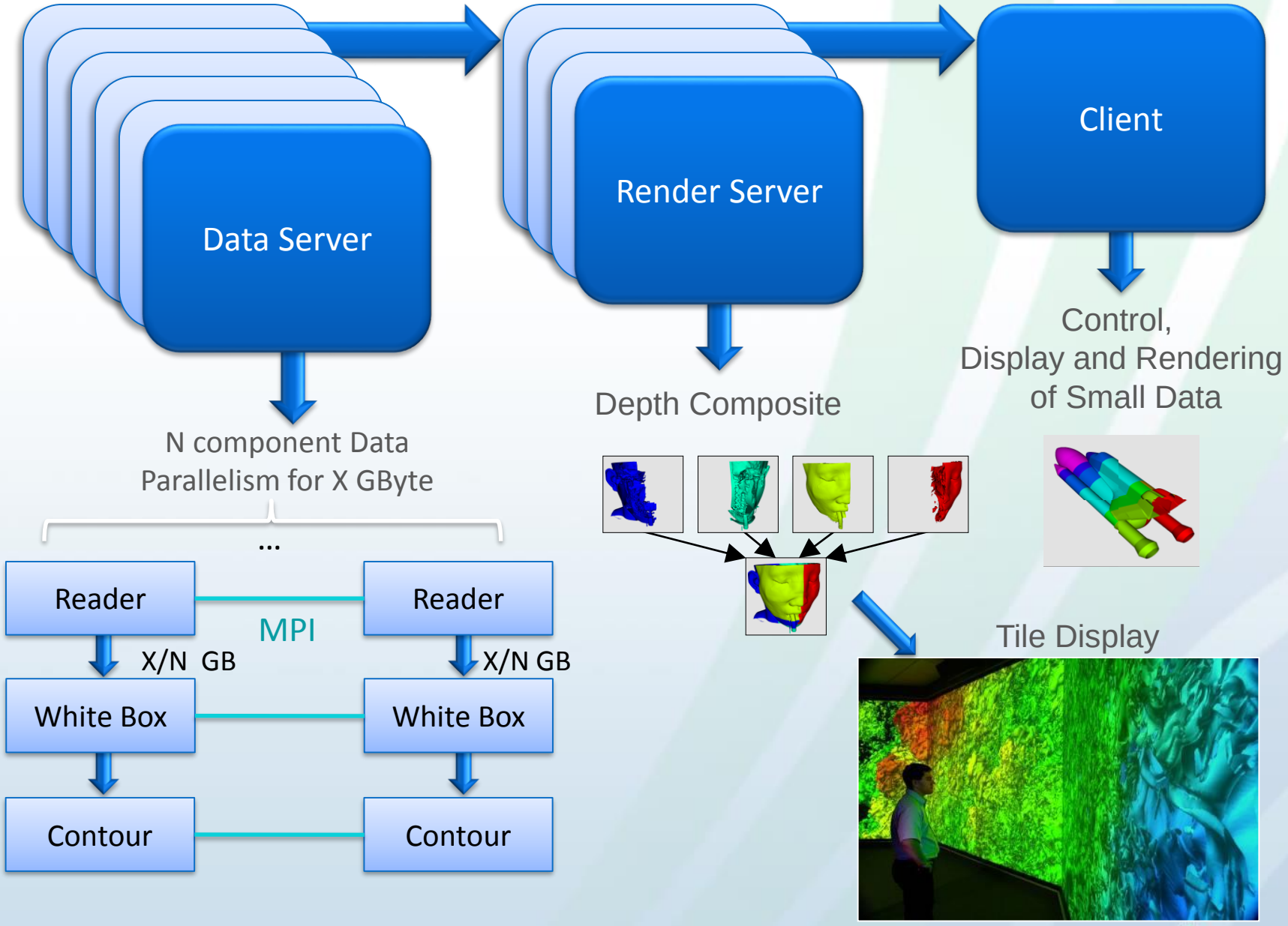
1 billion cell asteroid detonation simulation

source: Sandia National Labs

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

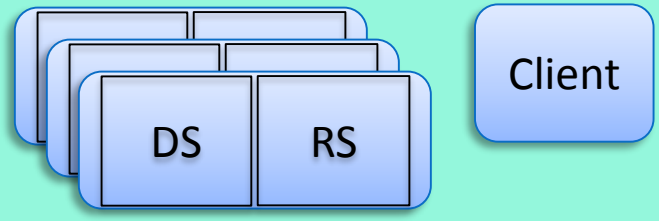
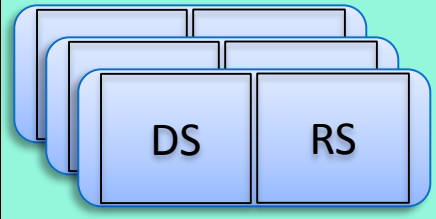
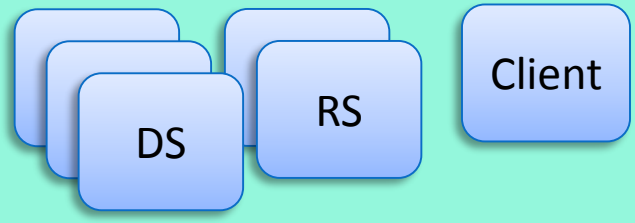
source: Kitware, UC Boulder (Jansen & Rasquin)

Kitware



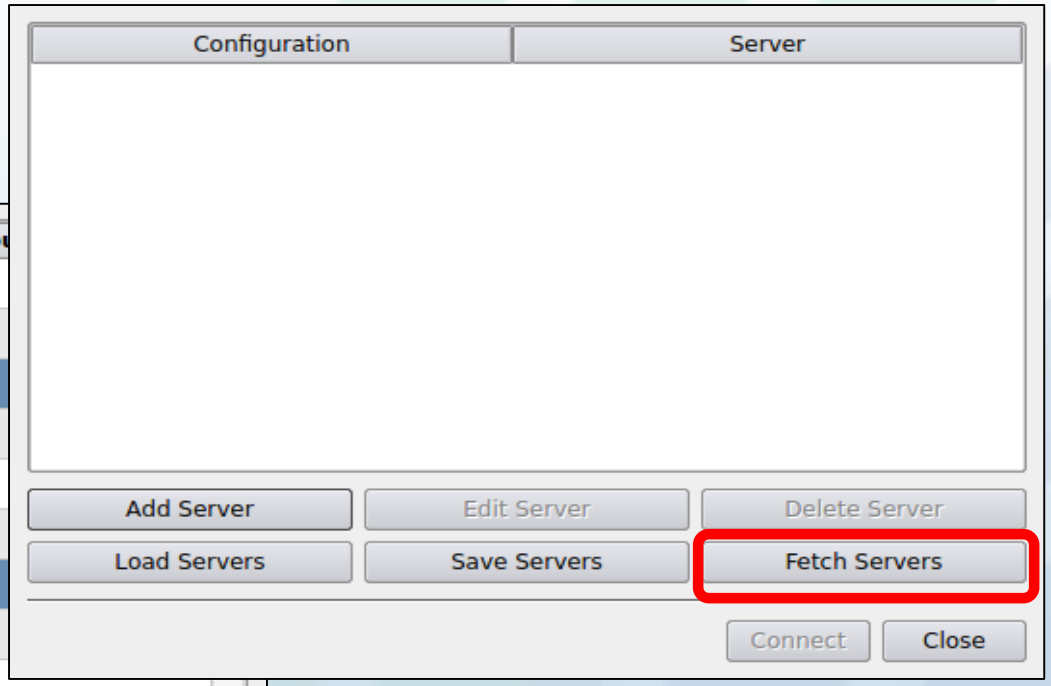
www.paraview.org/Wiki/ParaView/ParaView_Readers_and_Parallel_Data_Distribution

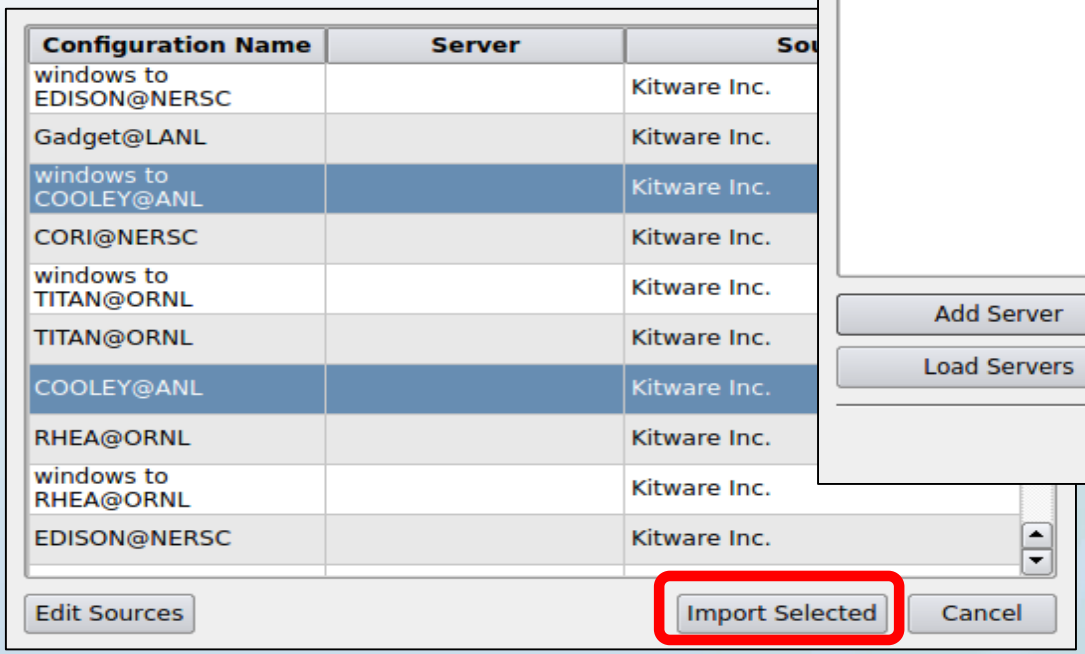
ParaView's running modes

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

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

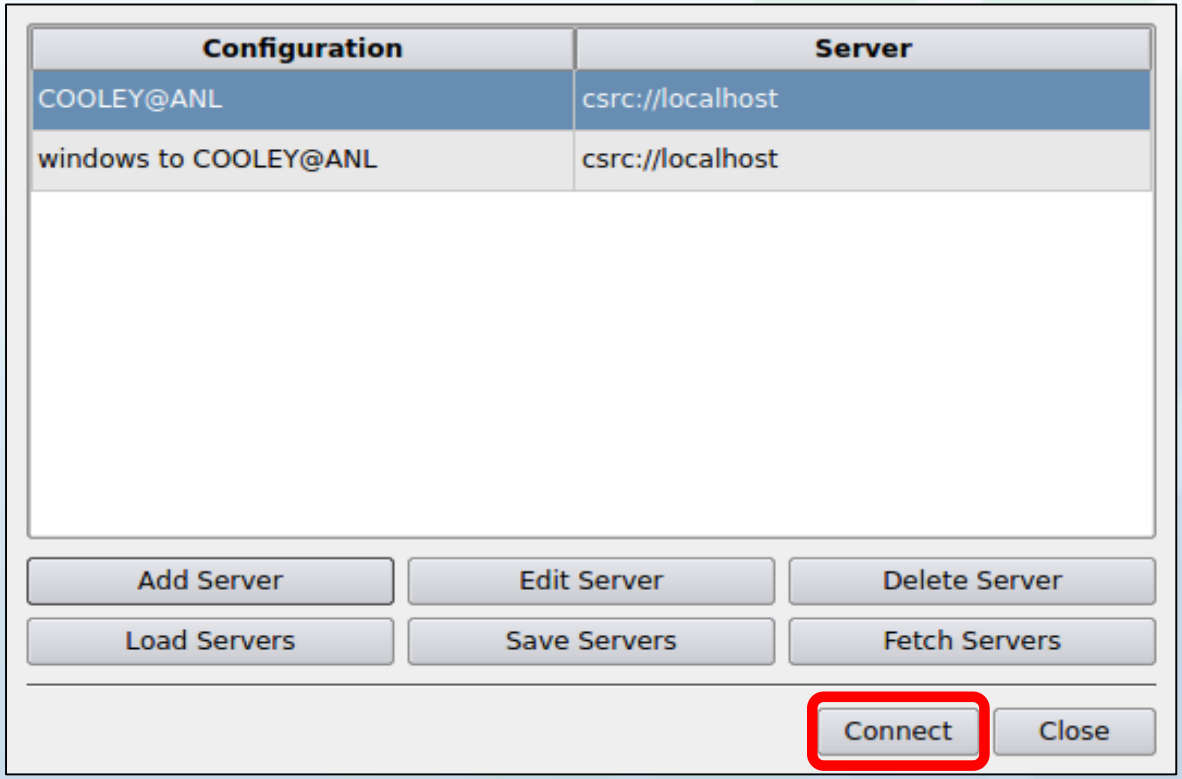




Kitware

Connecting to a Server (2)

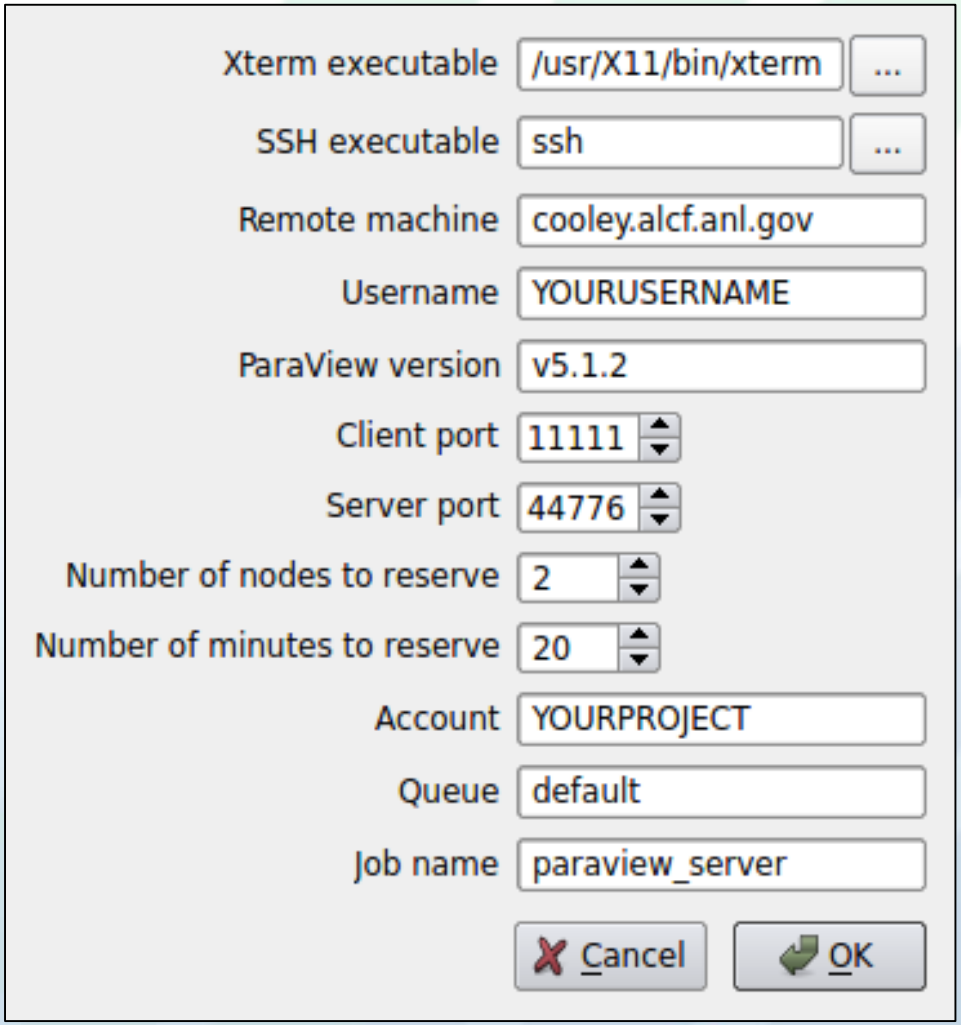
- GUI version must match pvserver version
- File → Connect
- Requirements:
  - Mac – XQuartz (X11) – www.xquartz.org
  - Windows – Putty (SSH) – www.putty.org



Kitware

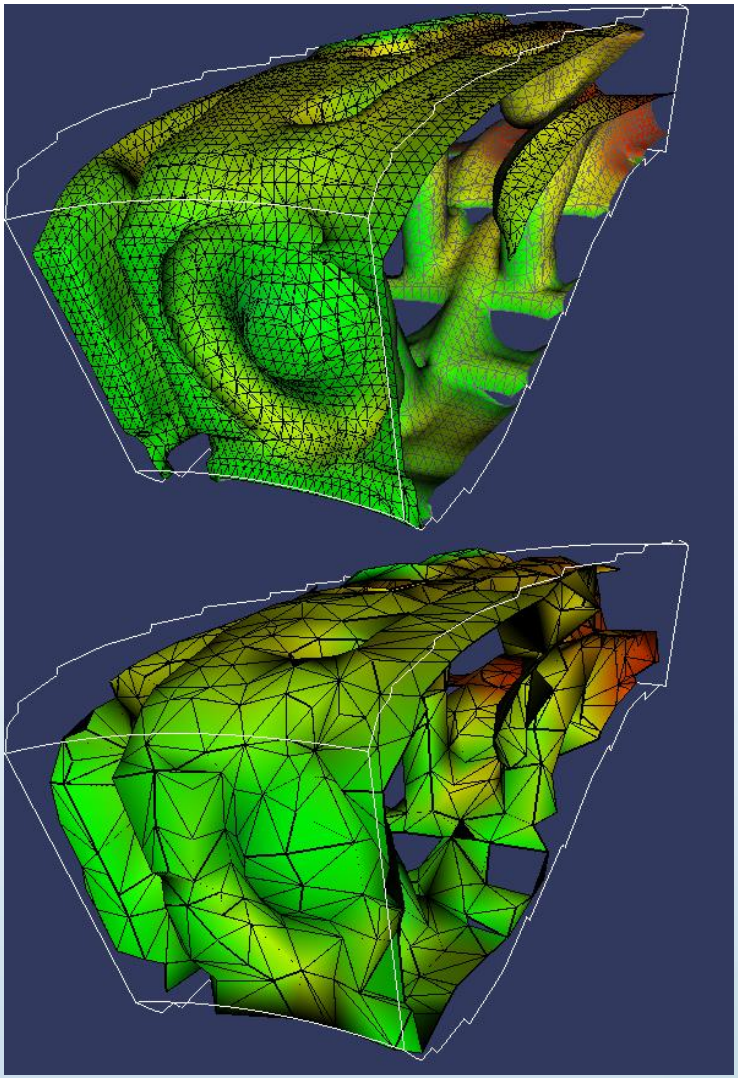
Connecting to a Server (3)

- 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



Kitware

Level of Detail – Maintain Interactivity

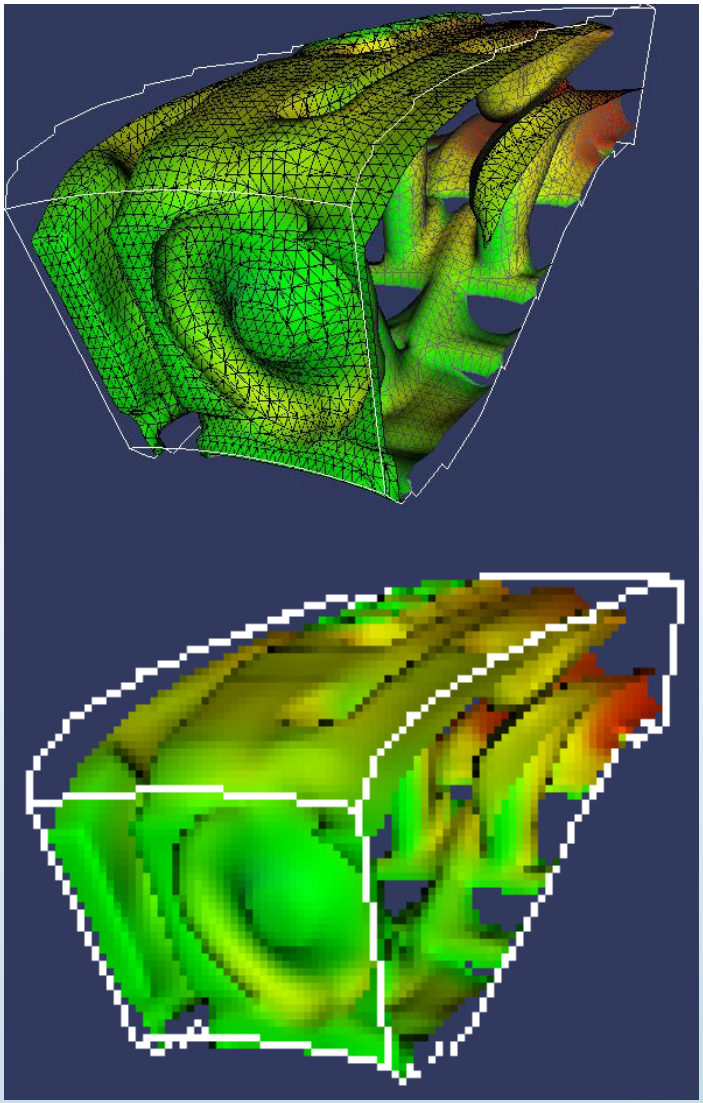


Type 1: Geometrically based

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

Kitware

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

Kitware

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?

Kitware