Large Scale Visualization with ParaView

ATPESC 2022
Outline

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

Volumetric dataset of a cloud - Disney Enterprises, Inc.
Kitware

- Open-source, software R&D company
- Five core areas of expertise
Kitware – Computer Vision

KWIVER

TeleSculptor

VIAME
Kitware – Medical Computing
Kitware – Software Process

- cmake, ctest, cdash
To Follow Along...

Install ParaView 5.10.0

- [http://www.paraview.org](http://www.paraview.org)  Download
Introduction
What is ParaView?

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

Visualizer, Glance (vtk.js)

https://blog.kitware.com/vis-on-the-web/
Python scripts can control ParaView, with or without the GUI, in order to create reproducible and customizable visualizations.
ParaView Immersive and VR

OpenVR, OpenXR
ParaView for HPC
ParaView Catalyst / Catalyst2

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

Uses Conduit Blueprint data description:
- No need to compile ParaView
- No need to recompile when ParaView version changes
- Can switch in situ backend at runtime.
Visualization of 3D LIDAR data.
Current ParaView Usage

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

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

- Uniform Rectilinear (vtkImageData)
- Non-Uniform Rectilinear (vtkRectilinearData)
- Curvilinear (vtkStructuredData)
  - Multi-block
  - Adaptive Mesh Refinement (AMR)
- Polygonal (vtkPolyData)
- Unstructured Grid (vtkUnstructuredGrid)
More Information

Help
- Getting Started with ParaView
  - ParaView Guide
  - Reader, Filter, and Writer Reference
- ParaView Self-directed Tutorial
  - ParaView Classroom Tutorials
  - Example Visualizations
- ParaView Web Site
- ParaView Wiki
- ParaView Community Support
- Release Notes
- Professional Support
- Professional Training
- Online Tutorials
- Online Blogs
- Bug Report
- About...
Basic Usage
User Interface

- Menu Bar
- Toolbars
- Pipeline Browser
- Properties Panel
- Information Panel

3D View
Creating a Cylinder Source

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

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

1. Go to the Source menu and select Cylinder.
2. Click the \textbf{Apply} button to accept the default parameters.
3. Increase the Resolution parameter.
4. \textbf{Resolution} 6
5. Click the \textbf{Apply} button again.
Pipeline Object Controls

Pipepline objects

- Sources
- Filters
- Readers
- Extractors
Display Properties

Properties panel showing options for display properties including:
- Apply, Reset, Delete buttons
- Search bar
- Display properties:
  - Representation: Surface
  - Coloring:
    - Solid Color
  - Styling:
    - Opacity: 1
  - Lighting:
    - Specular: 0
Change Display Properties

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

- View (Render V)
- Edit Axes Grid ...

- Center Axes Visibility
- Orientation Axes
- Orientation Axes Visibility

Background
- Single color
- Color
- Restore Default
Change View Properties

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

Search Properties

Toggle Advanced Properties
Searching Properties

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

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

Other interesting properties:
• Axes Grid
• Opacity
Changing the Color Palette

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

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

3. Try several color palettes.
Color Palettes

→ Edit Current Palette...
Undo Redo

Undo

Redo

Camera Undo

Camera Redo
Supported File Types

ParaView Data (.pvd)
VTK (.vt*, .vot, .vtr, .vts, .vtr)
VTK Legacy (.vtk)
VTK Multi Block (.vtb, .vtmb, .vtmbg, .vthd, .vthb)
Partitioned VTK (.pvt*, .pvts, .pvt, .pvtr)
ADAPT (.nc, .cdf, .elev, .ncd)
ANALYZE (.img, .hdr)
ANSYS (.inp)
AVS UCD (.inp)
BOV (.bvs)
BYU (.g)
CAM NetCDF (.nc, .ncdf)
CCSM MTSD (.nc, .cdf, .elev, .ncd)
CCSM STSD (.nc, .cdf, .elev, .ncd)
CEAucd (.ucd, .inp)
CGNS (.cgnm)
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)
Dyn3D (.dyv, .dyn)
EnSight (.case, .sos)
Enzo boundary and hierarchy
Exodus II (.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)
LAMMPS Dump (.dump)
LAMMPS 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 (.nhd, .mha)
Miranda (.mir, .raw)
Multilevel 3D Plasma (.m3d, .h5)
NASTRAN (.nas, .f06)
Nek5000 Files
Nrrd Raw Image (.nrrd, .nhdr)
OpenFOAM Files (.foam)
PATRAN (.neu)
PFLOTTRAN (.h5)
PLOT2D (.pl2d)
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 (.hcth)
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 (.vlid, .rst)
VizSchema (.h5, .vsh5)
Wavefront Polygonal Data (.obj)
WindBlade (.wind)
XDMF and hdf5 (.xmf, .xdmf)
XMol Molecule
Custom Data Import: Prototype with Python

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

Programmable Source - Create a data reader in the GUI
1. Open the file disk_out_ref.ex2 from the examples directory.
1. Open the file disk_out_ref.ex2 from the examples directory.
2. Load all data variables.
3. Click
Data Representation

- Toggle Color
- Reset Scalar Range
- Reset Range Over All Time
- Mapped Variable
- Vector Component
- Representation
- Edit Colors
- Custom Scalar Range
- Scalar Range to Visible

Images showing different visual representations of data.
Filters Menu

~200 filters

Status bar:
- Short description
- Reason why is grayed
Common Filters

- Calculator
- Contour
- Clip
- Slice
- Threshold
- Extract Subset

- Glyph
- Stream Tracer
- Warp (vector)
- Group Datasets
- Extract Block
Quick Launch

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

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

Specify the data you apply the filter on
3. Change parameters to create an isosurface at Temp = 400K.
Apply Contour

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

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

![Apply button]
Apply ExtractSurface, Clip

1. Select disk_out_ref.ex2 in the pipeline browser.
2. From the quick launch, select Extract Surface.
3. 
4. Select ... Create a clip filter.
5. Uncheck Show Plane
6. 

Pipeline Browser Structure

disk_out_ref.ex2

Contour1

ExtractSurface1

Clip1
Pipeline Browser Structure

- disk_out_ref.ex2
- Contour1
- ExtractSurface1
- Clip1

Visible
Pipeline Browser Structure

- disk_out_ref.ex2
- Contour1
- ExtractSurface1
- Clip1

Not Visible
Multiview
Multiview

1. Select disk_out_ref.ex2 in the pipeline browser.
2. Add Clip filter.
3. Uncheck Show Plane
4. Apply
5. Hide Clip2
1. Split the view horizontally.
2. Make Clip2 visible.
3. Color surface by Temp.
Multiview

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

1. Split the view horizontally.
2. Make Clip1 visible.
3. Color surface by Temp.
4. Right-click view, Link Camera...
5. Click other view.
6. Click and zoom in a bit.
Modifying Views
Modifying Views
Reset ParaView

Edit → Reset Session
Streamlines

1. Open disk_out_ref.ex2. Load all variables.
2. Add Stream Tracer.
3. Change Seed Type to Point Source.
4. Uncheck Show Sphere.
5. "Apply"
Streamlines

1. Open disk_out_ref.ex2. Load all variables.
2. Add Stream Tracer.
3. Change Seed Type to Point Source.
4. Uncheck Show Sphere.
5. 
6. From the quick launch, select Tube
7. 
Adding Glyphs

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

Edit → Reset Session
Common Data Analysis Filters

- Extract Selection
- Plot Global Variables Over Time
- Plot Selection Over Time
- Plot Over Line
- Probe Location
Plotting

1. Open disk_out_ref.ex2.  Load all variables.
2. Clip, uncheck, ,
3. Select disk_out_ref.ex2.
4. Add Plot Over Line filter.
3D Widgets
Placing 3D Line Widget Endpoints

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

1. Open disk_out_ref.ex2. Load all variables.
2. Clip, uncheck,
3. Select disk_out_ref.ex2.
4. Add Plot Over Line filter.
5. Once line is satisfactorily located,
Interacting with Plots

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

- Move them like Views.
- Save screenshots.
Adjusting Plots

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

1. Open disk_out_ref.ex2. Load all variables.
2. Change variable viewed to Temp.
3. Change representation to Volume.
4. In the Are you Sure dialog box, click Yes.
Transfer Function Editor
Modify Transfer Function

1. Select disk_out_ref.ex2.
2. Click Edit Color Map.
3. Click Choose preset.
5. Try adding and changing control points.
Reset ParaView

Edit → Reset Session
Query-Based Selection

1. Open can.ex2. Select all variables.
2. Go to last time step.
3. Edit → Find Data.
4. Top combo box: Find Cells.
5. Next row: EQPS, is $\geq$, and 1.5.
6. Click Run Selection Query.
Query-Based Selection
**Brush Selection**

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

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

Edit → Reset Session
Visualizing Large Models
Data Parallel Pipelines

- Duplicate pipelines run independently on different partitions of data.
Data Parallel Pipelines

- Many operations will work regardless.
  - Example: Clipping.
Data Parallel Pipelines

- Many operations will work regardless.
  - Example: Clipping
Data Parallel Pipelines

- Many operations will work regardless.
  - Example: Clipping
N component Data Parallelism for X GByte

Data Server

Render Server

Client

Control, Display and Rendering of Small Data

Depth Composite

Reader

Filter

Reader

Filter

Reader

Filter

…

MPI

X/N GB

X/N GB
### ParaView’s Running Modes

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

**DS** = data server  
**RS** = render server
Fetch Server Configuration

- File > Connect > Fetch Servers

**Table:**

<table>
<thead>
<tr>
<th>Configuration Name</th>
<th>Server</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>COOLEY@ANL</td>
<td>Kitware Inc.</td>
<td></td>
</tr>
<tr>
<td>windows to COOLEY@ANL</td>
<td>Kitware Inc.</td>
<td></td>
</tr>
<tr>
<td>THETA@ANL</td>
<td>Kitware Inc.</td>
<td></td>
</tr>
<tr>
<td>windows to THETA@ANL</td>
<td>Kitware Inc.</td>
<td></td>
</tr>
<tr>
<td>EDISON@NERSC</td>
<td>Kitware Inc.</td>
<td></td>
</tr>
<tr>
<td>windows to EDISON@NERSC</td>
<td>Kitware Inc.</td>
<td></td>
</tr>
<tr>
<td>CORI@NERSC</td>
<td>Kitware Inc.</td>
<td></td>
</tr>
</tbody>
</table>

Buttons:
- Edit Sources
- Import Selected
- Cancel
Connect Unix/Mac

**Mac Os**: Install Xquartz

![Connection Options for "COOLEY@ANL"](image)
Windows: Install PuTTY
Advanced Data Parallel Pipelines

- Some operations will have problems.
  - Example: External Faces
Advanced Data Parallel Pipelines

- Ghost cells can solve most of these problems.
Balanced Partitioning + Ghost Cells

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

Extract Surface without ghost cells

Extract Surface after D3
Topics for future exploration
Python Scripting

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

Calculator

Python Calculator

Programmable Filter

Python Algorithms

Plugins
Animation

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

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