Large Scale Visualization with ParaView

ATPESC 2024





Outline

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



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



Kitware

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





Kitware – Computer Vision

WKWIVER

TeleSculptor













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Kitware – Data and Analytics

Resonant





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Kitware – HPC and Visualization VTK ParaView Trame EMB Eomviz LidarView







Kitware – Medical Computing



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Kitware – Software Process

cmake, ctest, cdash

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To Follow Along...

Install ParaView 5.12.0

http://www.paraview.org Download









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
- on open standards



ParaView on the Desktop

ParaView 3.12.0.64-bit	_ = ×
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ParaView on the Web

Visualizer, Glance (vtk.js) https://blog.kitware.com/vis-on-the-web/



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ParaView Scripting - Python



Tools > Start Trace ____build a pipeline ____ Tools > Stop Trace



ParaView Immersive and VR





OpenVR, OpenXR



ParaView for HPC





ParaView Catalyst



Uses Conduit Blueprint data description

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

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



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)

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

ParaView (VTK) Cell Types

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





More Information

Heit	
P	Getting Started with ParaView
	ParaView Guide F1
	Reader, Filter, and Writer Reference
P	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







User Interface





Creating a Cylinder Source

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



Simple Camera Manipulation

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



Pipeline Object Properties

- 1. Go to the Source menu and select Cylinder.
- 2. Click the efault button to accept the default parameters.
- 3. Increase the Resolution parameter.
- 4. Resolution 6
 5. Click the Apply button again.



Pipeline Object Controls



Pipeline objects - Sources Filters Readers Extractors



Display Properties

	Properties
P Apply	Reset X Delete ?
Search (us	e Esc to clear text)
😑 Display	(Geome 🗊 🗈 😒 🖬
Representatio	n Surface
Coloring	
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Styling	
Opacity	O 1
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Change Display Properties

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



View Properties

	Properties
P Apply	🥝 Reset 🔀 Delete 💡
Search (use	Esc to clear text)
😑 View (Re	ander V 🛐 🗈 💕 🔒
Q	Edit Axes Grid
Center Axes	; Visibility es
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

	Properties	
	Apply 🥥 Reset 🗱 Delete 💡	Toggle
Search _	Search (use Esc to clear text)	- Advanced
Properties	🗖 Display (GeometryRe	Properties
	Representation Surface +	
	Coloring	
	Solid Color +	
	Show Edit Rescale	
	Styling	
	OpacityO 1	
« kitware	Lighting	

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

 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



	General Camera Render View Color Palette	
Search	(use Esc to clear text)	
Calar	ad when policing surfaces and faces	
O Surfa	ce	
Color us	ed for rendering elements like wireframes, points.	
O Fore	round	
Color us represer	ed for the edges when using 'Surface With Wireframe' tation.	
Edge	s in	
Color us	ed as background for the view.	
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Color us	ed for text and other annotations.	
OText		
Color us	ed for showing selected cells/points.	
O Selec	tion	
You can you can palette.	explicitly set the colors in the application's color palette al load one of the predefined color palettes to initialize the a	bove ctive
-	nalette te lead	

Apply

Cancel

OK

Restore Defaults

Reset



Undo Redo









Reset ParaView

$Edit \rightarrow Reset \ Session$





Supported File Types

ParaView Data (.pvd) VTK (.vtp, .vtu, .vti, .vts, .vtr) VTK Legacy (.vtk) VTK Multi Block (.vtm,.vtmb,.vtmg,.vthd,.vthb) Partitioned VTK (.pvtu, .pvti, .pvts, .pvtr) ADAPT (.nc, .cdf, .elev, .ncd) ANALYZE (.img, .hdr) ANSYS (.inp) AVS UCD (.inp) BOV (.bov) BYU (.g) CAM NetCDF (.nc, .ncdf) CCSM MTSD (.nc, .cdf, .elev, .ncd) CCSM STSD (.nc. .cdf. .elev. .ncd) CEAucd (.ucd, .inp) CGNS (.cgns) CMAT (.cmat) CML (.cml) CTRL (.ctrl) Chombo (.hdf5, .h5) Claw (.claw) Comma Separated Values (.csv) Cosmology Files (.cosmo, .gadget2) Curve2D (.curve. .ultra. .ult. .u)

ve2D (.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 (.tra) Gadget (.gadget) Gaussian Cube File (.cube) JPEG Image (.jpg, .jpeg) LAMPPS Dump (.dump) LAMPPS Structure Files LODI (.nc. .cdf. .elev. .ncd) LODI Particle (.nc, .cdf, .elev, .ncd) LS-DYNA (.k, .lsdyna, .d3plot, d3plot) M3DCI (.h5) MFIX Unstructred Grid (.RES) MM5 (.mm5)

MPAS NetCDF (.nc, .ncdf) Meta Image (.mhd. .mha) Miranda (.mir, .raw) Multilevel 3d Plasma (.m3d, .h5) NASTRAN (.nas, .f06) Nek5000 Files Nrrd Raw Image (.nrrd, .nhdr) OpenFOAM Files (.foam) PATRAN (.neu) PFLOTRAN (.h5) PLOT2D (.p2d) PLOT3D (.xyz, .q, .x, .vp3d) PLY Polygonal File Format **PNG Image Files** POP Ocean Files ParaDIS Files Phasta Files (.pht) Pixie Files (.h5) ProSTAR (.cel, .vrt) Protein Data Bank (.pdb, .ent, .pdb) Raw Image Files Raw NRRD image files (.nrrd) SAMRAI (.samrai) SAR (.SAR. .sar) SAS (.sasgeom, .sas, .sasdata) SESAME Tables

SLAC netCDF mesh and mode data SLAC netCDF particle data Silo (.silo, .pdb) Spheral (.spheral, .sv) SpyPlot CTH SpvPlot (.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

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



Load disk_out_ref.ex2

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

Look in:	/Applications/ParaView-5.2.0-RC1.app/Contents/data/
Examples Home Desktop Documents Downloads Macintosh HD	Filename Can.ex2 disk_out_ref.ex2 headsq.vti README.txt
	File name: OK Files of type: Supported Files (*.inp.*.cosmo.*.cons.*.cml.*.csv.*.t.^) Cancel

Load disk_out_ref.ex2

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



Data Representation



Filters Menu



~200 filters

Status bar:

- Short description
- Reason why is grayed



Common Filters



Calculator



Contour

















Extract Subset

Glyph Stream Tracer





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.

Press the contour filter.

Specify the data you apply the filter on





Apply Contour

3. Change parameters to create an isosurface at Temp

= 400k		O Properties Image: Apply Image: Reset Image: Reset		
		Search Properties (Contour1) Contour		
	Change to Temp –	Contour By ABH3 Compute Normals Compute Gradients Compute Scalars Isosurfaces		
	Change to 400	Value Range: [0.0804768, 0.184839] 0.132658146 Delete Delete All New Value		
« kitware		New Range		

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.





Apply ExtractSurface

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



Apply ExtractSurface, Clip

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





Pipeline Browser Structure







Pipeline Browser Structure







Pipeline Browser Structure











Multiview - Disk colored by Temp

- 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.



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



- 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 4×3 and zoom in a bit.



Modifying Views







Modifying Views







Saving a DataSet

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

111		Save File:			? ×
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	File name:				ОК
	Files of type: CS	V File(*.csv)		-	Cancel



Saving a Screenshot

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

Save Scr	eenshot Optic	ons ?	×
Save only sel	ected view		
Select res	olution for the ir	mage to sav	/e
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Current Palette			-
Ster	eo Mode (if app	licable)	
No Stereo			•
	Ok	Can	cel

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Saving the State

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



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Reset ParaView

$Edit \rightarrow Reset \ Session$





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. Show Sphere







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. Show Sphere
- 5. Provide State S
- 6. From the quick launch, select Tube
- 7. 🛃 Apply





Adding Glyphs

- 1. Select StreamTracer1.
- 2. Add Glyph filter.
- 3. Change Glyph Type to Cone.
- 4. Change Orientation Array and Scale Array to V.
- 5. Change Vector Scale Mode to Scale By Magnitude.
- 6. Click reset 😂 next to Scale Factor.
- 7. Provide Apply
- 8. Color by Temp.

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Common Data Analysis Filters



Extract Selection



Plot Global Variables Over Time



Plot Selection Over Time



Plot Over Line



Probe Location



Plotting

- 1. Open disk_out_ref.ex2. Load all variables.
- 2. Clip, muncheck, Show Plane, Apply
- 3. Select disk_out_ref.ex2.
- 4. Add Plot Over Line filter.




3D Widgets

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Placing 3D Line Widget Endpoints

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



Plotting

Apply

- 1. Open disk_out_ref.ex2. Load all variables.
- 2. Clip, 🕅 uncheck, 🔽 Show Plane,
- 3. Select disk_out_ref.ex2.
- 4. Add Plot Over Line filter.
- 5. Once line is satisfactorily located,

6. 🛃 Apply





Interacting with Plots

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





Plots are Views

- Move them like Views.
- Save screenshots.



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😑 View (Line	Chart View 🚺 📘	
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Chart Title		
Annotation		
Show Legend		
Left Axis		
Left Axis Title		
Left Axis Range		
Left Axis Log	Scale	
Left Axis Use	Custom Range	
Bottom Axis		
Bottom Axis Title		

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Adjusting Plots

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



Reset ParaView

$Edit \rightarrow Reset \ Session$





Volume Rendering

Apply

- 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 🔂 .
- 4. Select Black-Body Radiation. Apply. Close.
- 5. Try adding and changing control points.



Reset ParaView

$Edit \rightarrow Reset \ Session$





Query-Based Selection

- 1. Open can.ex2. Select all variables.
- 2. Go to last time step. 树
- 3. Edit \rightarrow Find Data.
- 4. Top combo box: Find Cells.
- 5. Next row: EQPS, is >=, and 1.5.
- 6. Click Run Selection Query.



Query-Based Selection

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KICMALE							

Brush Selection



Surface Cell Selection (shortcut: s) Surface Point Selection (shortcut: d)



Through Cell Selection (shortcut: f) Through Point Selection (shortcut: g)







Block Selection (shortcut: b)



Ц,

- Interactively Select Cells
- Interactively Select Points
- ? Hover Point Query
- A Hover Cell Query



Adding Labels

- 1. Go to the last time step. 树
- 2. Interactively Select Cells 🔺
- 3. Open Find Data.
- 4. In the Cell Labels chooser, select EQPS.
- 5. Try again: Interactively Select Cells 🔺
- 6. Similarly: Hover Cells On



Reset ParaView

$Edit \rightarrow Reset \ Session$





Visualizing Large Models



 Duplicate pipelines run independently on different partitions of data.





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



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- Many operations will work regardless.
 - Example: Clipping





- Many operations will work regardless.
 - Example: Clipping







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ParaView's Running Modes

Builtin aka Standalone aka Serial	DS RS Client	all components within one process (client may be GUI or pvpython) paraview or pvpython
Combined Server	DS RS Client	data processing and parallel rendering in MPI job of combined processes. control from TCP connected client. mpiexec -n x pvserver &; paraview # or pvpython #+Connect
Batch	DS RS	<pre>server is an MPI job which directly runs a python script mpiexec -n x pvbatch \ vis_script.py</pre>

DS = data server

RS = render server



Connect ParaView Client to the Server

Prerequisites:

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



File > Connect > Fetch Servers Git clone https://gitlab.kitware.com/paraview/pvsc.git Load Servers

ANL/server_polaris.pvsc ANL/server_polaris_windows.pvsc OR

Fetch Server Configurations			' ×
Configuration Name	Server	Source	4
POLARIS@ANL	>	Kitware Inc.	
windows to POLARIS@ANL		Kitware Inc.	
EDISON@NERSC		Kitware Inc.	
windows to		Kitware Inc.	
CORI@NERSC		Kitware Inc.	
LANL VLGate: Gadget (UNIX)		Kitware Inc.	
LANL Turquoise: Lightshow		Kitware Inc.	
LANL Turquoise: Lightshow		Kitware Inc.	
LANL Turquoise: Moonligh		Kitware Inc.	
LANL Turquoise: Moonligh		Kitware Inc.	
NICCA Plue Waters from		Kitwara lac	



Connect Unix/Mac

Mac Os: Install Xquartz

Connection Options f	or "POLARIS@ANL" ×
Xterm executable	/usr/bin/xterm
SSH executable	ssh
Remote machine	polaris.alcf.anl.gov
Username	danlipsa
ParaView version	5.12.0-EGL
Client port	11111
Server port	44995
Number of nodes to reserve	2
Number of ranks per node	
Number of minutes to reserv	e 20
Account	ATPESC_Instructors
Queue	debug
File Systems	home:eagle:grand
ob name	paraview_server
	K Cancel ₩ <u>O</u> K



Connect Windows

	/// Connection Options for "window	vs to POLARIS@ANL" ?	×	– quotes	are required
- 1	SSH executable	"C:\Program Files\PuTTY\plink.e	xe"	1	
	Remote machine	polaris.alcf.anl.gov			
	Username (danlipsa			
	ParaView version	5.12.0-EGL			
	Client port	11111	*		
	Server port	2181	•		
IIY	Number of nodes to reserve	2	*		
	Number of ranks per node (1			
	Number of minutes to reserve	20	•		
	Account	ATPESC_Instructors			
	Queue	debug			
	File Systems	home:eagle:grand			
	Job name	paraview_server			
		ОК Са	ancel		

Windows: Install PuTTY

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Advanced Data Parallel Pipelines

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









Advanced Data Parallel Pipelines

• Ghost cells can solve most of these problems.



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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

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Coord esult Ar coordsX Clear sin asin sinh v1.v2 Scalar	tinate Re ray Name *iHat+co (cos acos cosh mag s	sults Result ordsY*jHa) tan atan tanh norm	iHat abs ceil x^y In Vectors	jHat sqrt floor exp log10	kHat + - * /			

Calculator

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Python Calculator

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Copy Arrays			

Programmable Filter

Python Algorithms

Plugins



Animation

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





Advanced Rendering

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





Questions



