Viskores: Integrating Parallel Scientific Visualization Research into Applications

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Acknowledgements

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This research used resources of the Oak Ridge Leadership Computing Facility at the Oak Ridge National Laboratory, which is supported by the Office of Science of the U.S. Department of Energy under Contract No. DE-AC05-00OR22725.

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This research was supported by the Exascale Computing Project (17-SC-20-SC), a collaborative effort of two U.S. Department of Energy organizations (Office of Science and the National Nuclear Security Administration) responsible for the planning and preparation of a capable exascale ecosystem, including software, applications, hardware, advanced system engineering, and early testbed platforms, in support of the nation’s exascale computing imperative.

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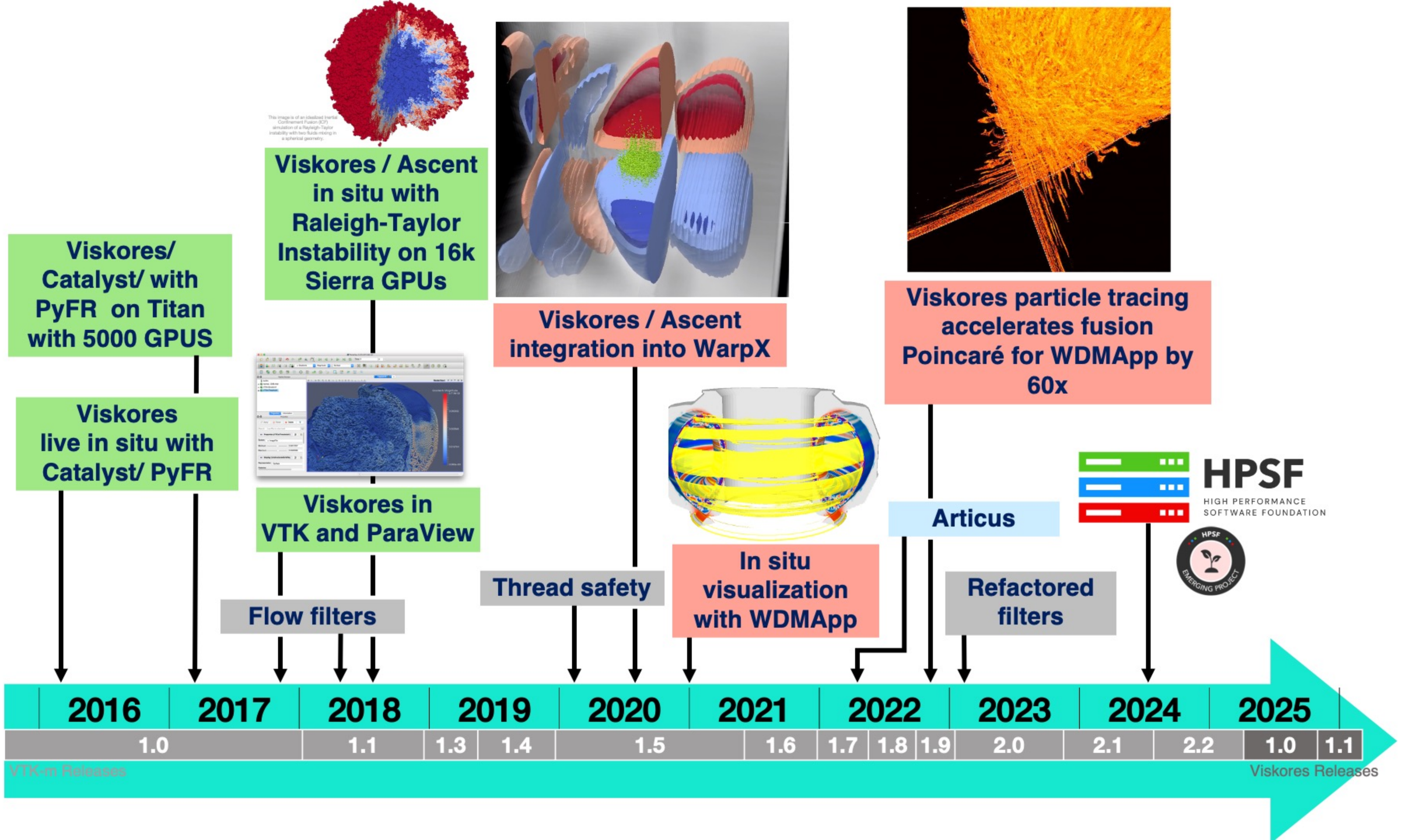
Thanks to many, many partners in labs, universities, and industry.



This image is of an idealized Inertial Confinement Fusion (ICF) simulation of a Rayleigh-Taylor instability with two fluids mixing in a spherical geometry.
Viskores / Ascent in situ with Raleigh-Taylor Instability on 16k Sierra GPUs
Viskores/ Catalyst/ with PyFR on Titan with 5000 GPUS
Viskores live in situ with Catalyst/ PyFR
Viskores in VTK and ParaView
Flow filters
Thread safety
Viskores / Ascent integration into WarpX
In situ visualization with WDMApp
Viskores particle tracing accelerates fusion Poincaré for WDMApp by 60x
Articus
Refactored filters
HPSF
HIGH PERFORMANCE SOFTWARE FOUNDATION
HPSF EMERGING PROJECT
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
1.0
1.1
1.3
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1.5
1.6
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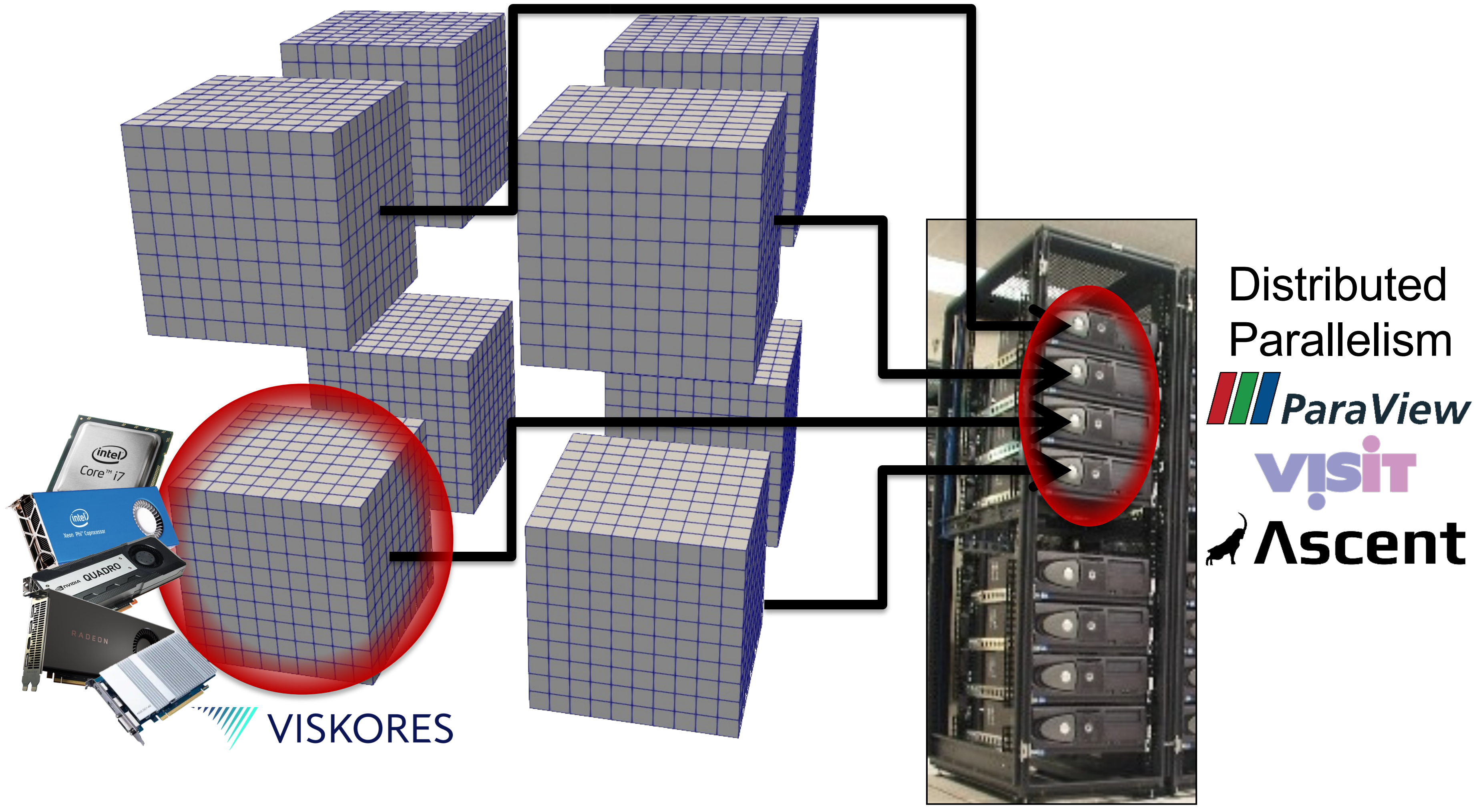
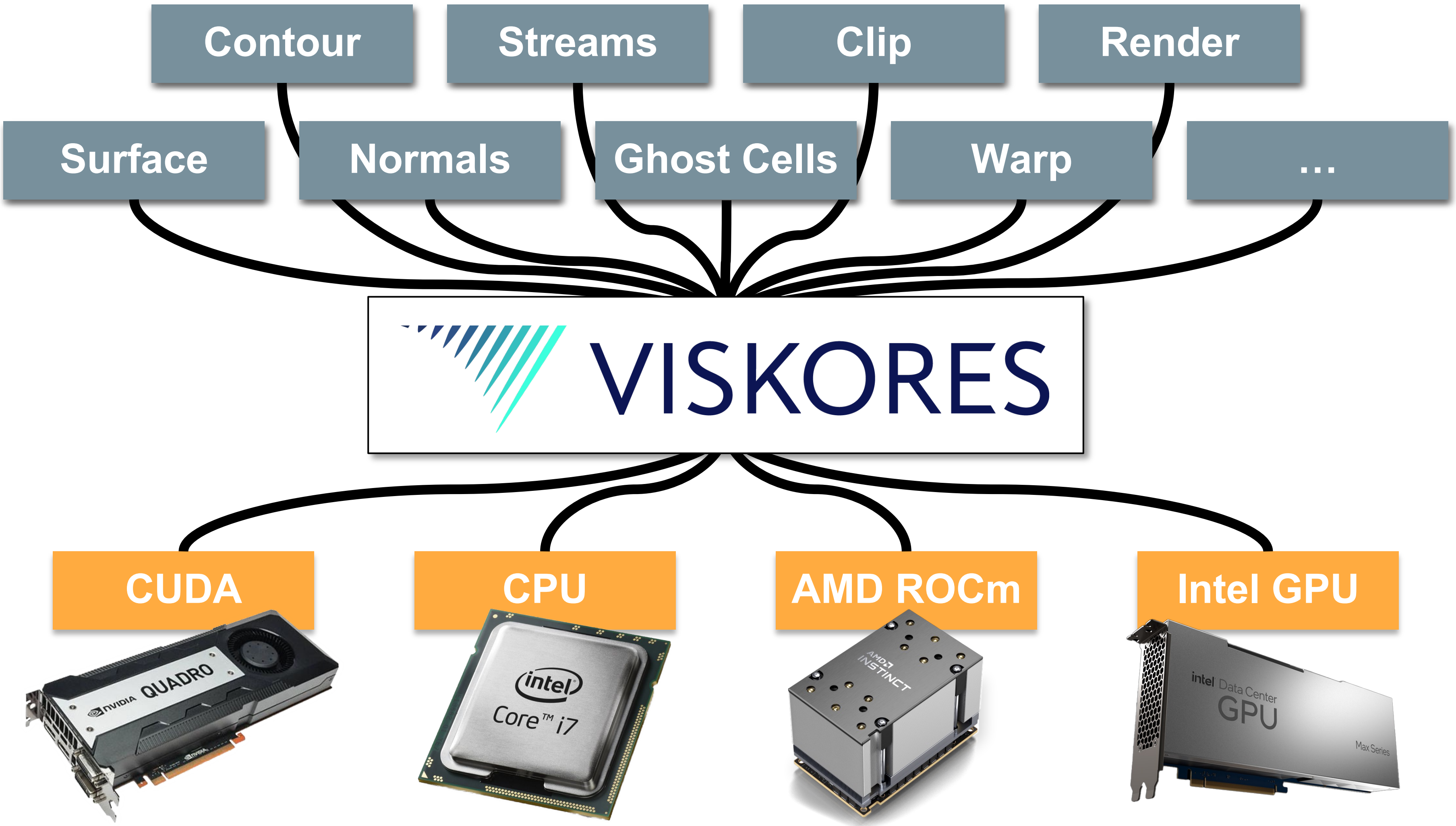
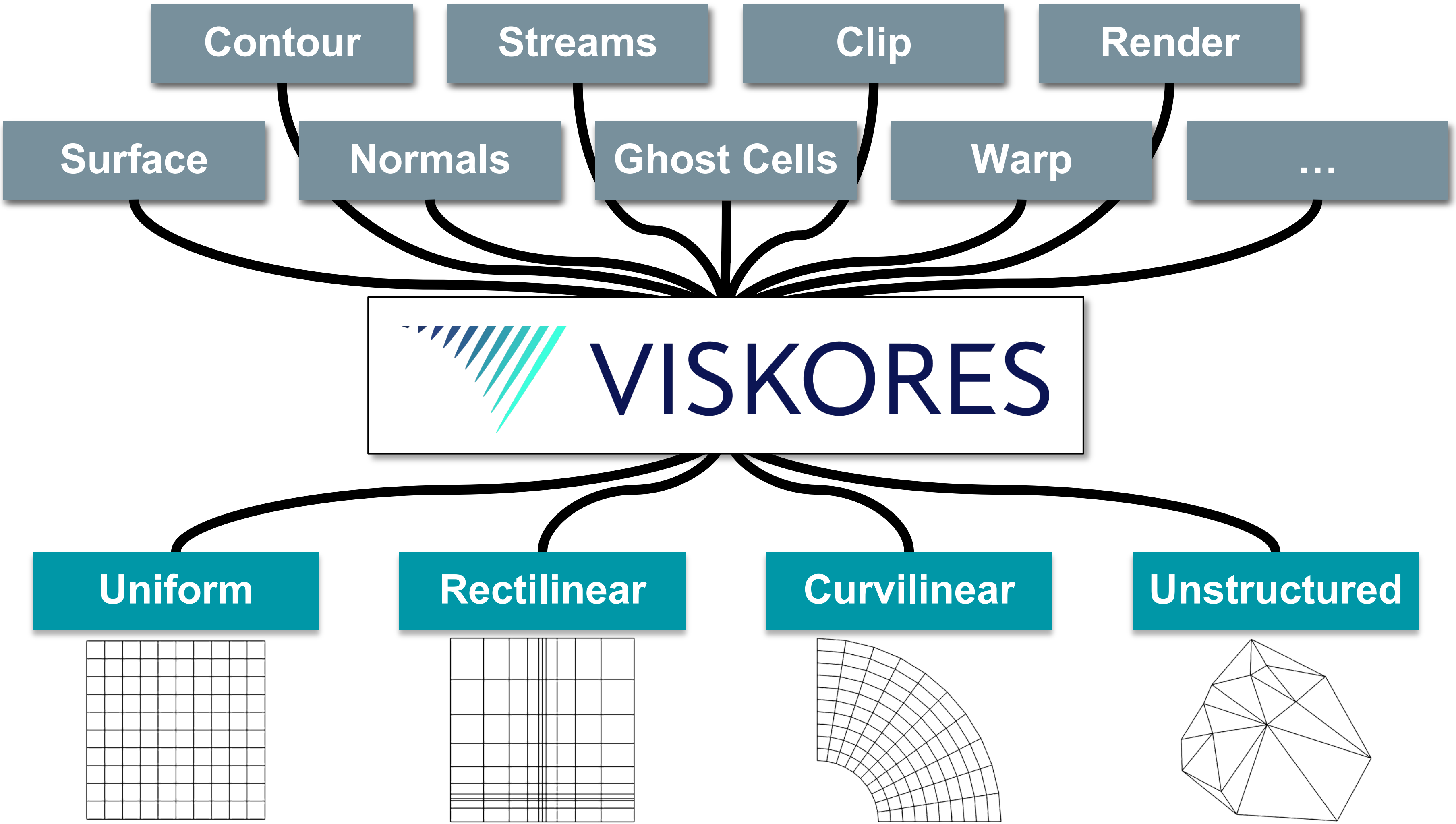
1.1
VTK-m Releases
Viskores Releases

What is Viskores?


Distributed
Parallelism
ParaView
VisIt
Ascent
VISKORES


Contour
Streams
Clip
Render
Surface
Normals
Ghost Cells
Warp
...
VISKORES
CUDA
CPU
AMD ROCm
Intel GPU
NVIDIA QUADRO
intel Core™ i7
AMD INSTINCT
intel Data Center GPU
Max Series


Contour
Streams
Clip
Render
Surface
Normals
Ghost Cells
Warp
...
VISKORES
Uniform
Rectilinear
Curvilinear
Unstructured


Contour
Streams
Clip
Render
Surface
Normals
Ghost Cells
Warp
...
VISKORES
VTK
ParaView
Momentum Density
rho_electrons
Ascent
ADIOS

What is Available

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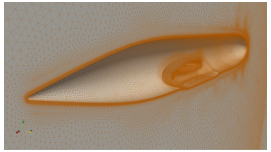
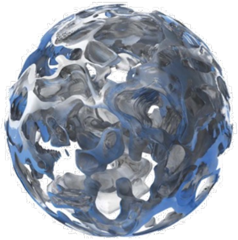
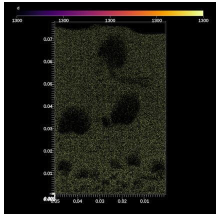
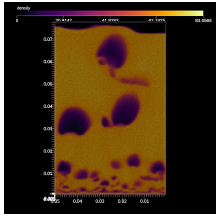
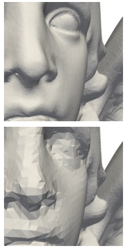
Available Features

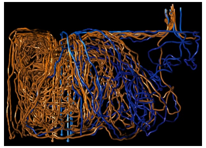
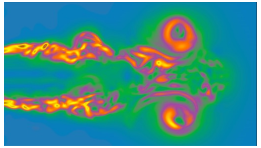
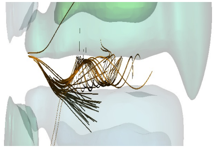
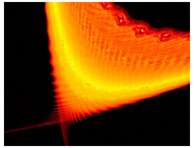
Fundamental Algorithms

- Contour / Slicing / Clipping / Thresholding
- Cleaning / External Faces
- Density Estimation
- Surface Coarsening

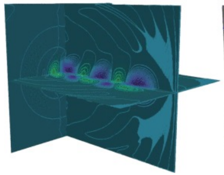
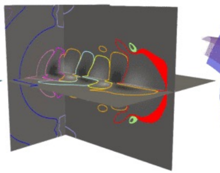
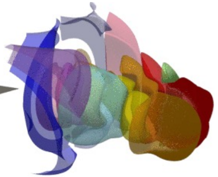
Flow Algorithms

- Streamlines / Pathlines / Stream Surfaces
- FTLE
- Lorentz-Force
- Poncaré Puncture Plot

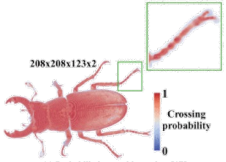
Topology Algorithms

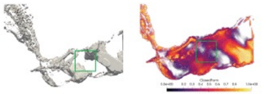
- Contour Trees
- Branch Decomposition

Uncertainty Visualization

- Uncertain Contours / Fiber Surfaces



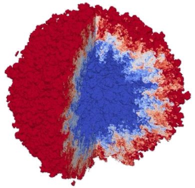
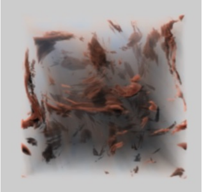


(f) Red Sea Dataset with Mean

(g) Red Sea Dataset with Uncertainty

Rendering

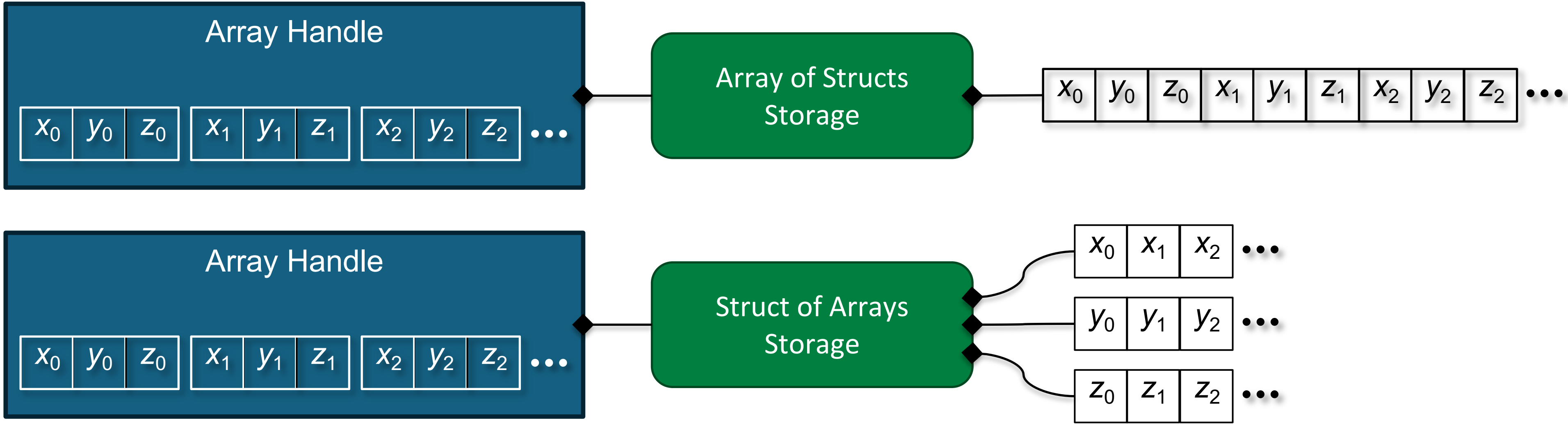
- Surface / Volume

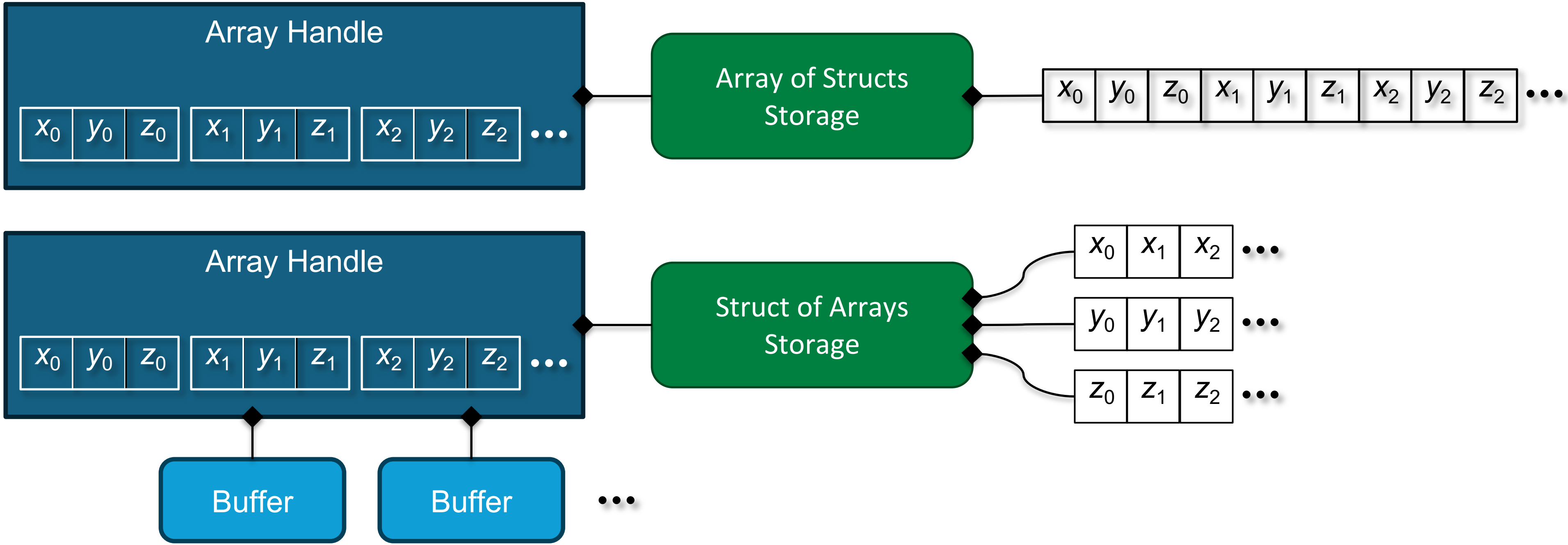
Idealized Inertial Confinement Fusion (ICF) simulation of a Rayleigh-Taylor instability with two fluids mixing in a spherical geometry

Data Representation

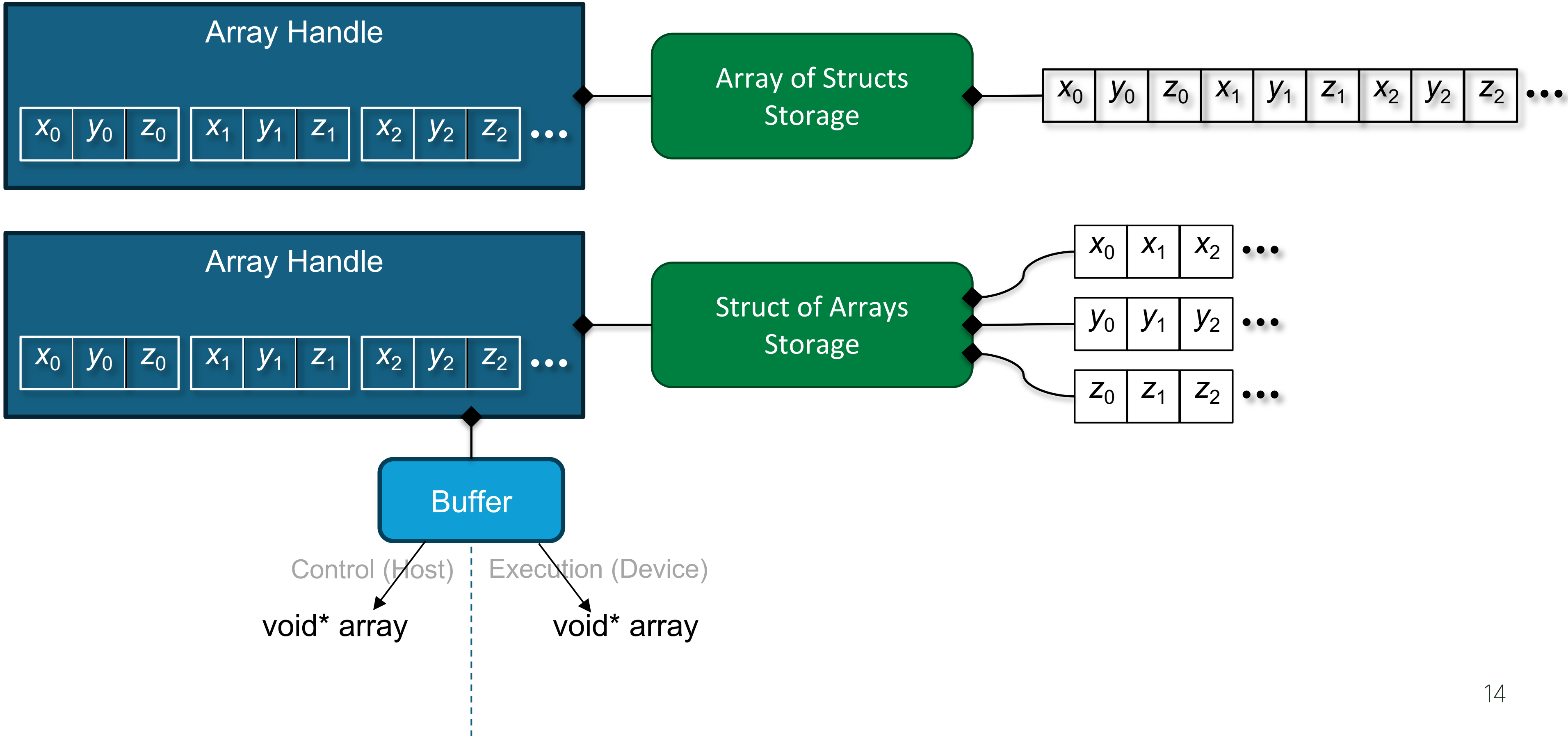
Array Handle Interface



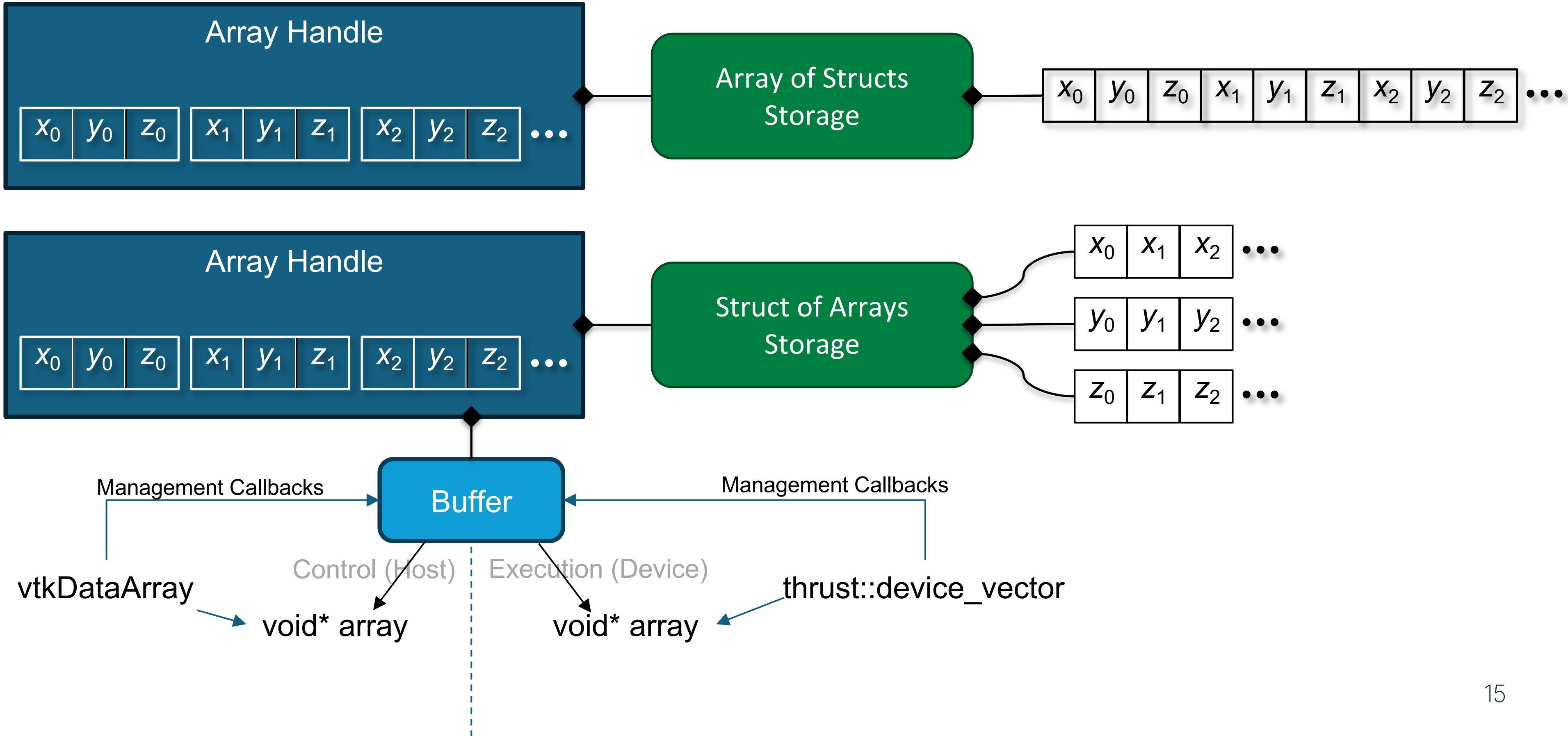
Array-Buffer Interface



Array-Buffer Interface



Array-Buffer Interface



Managing Polymorphism

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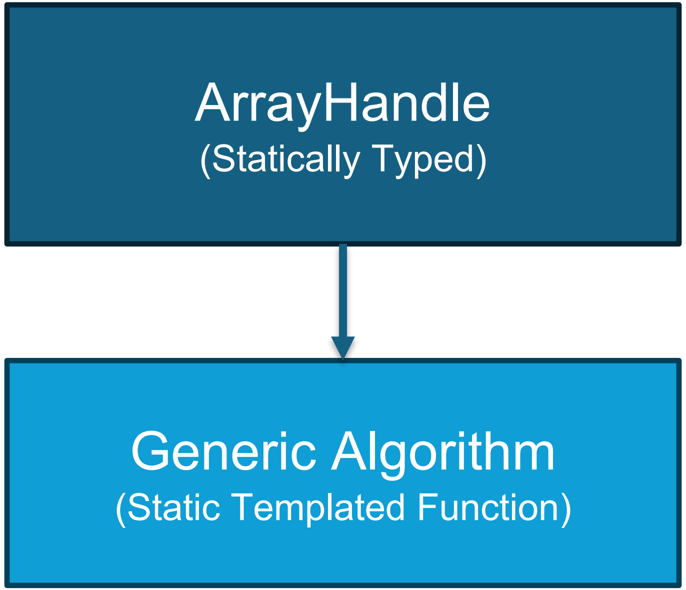
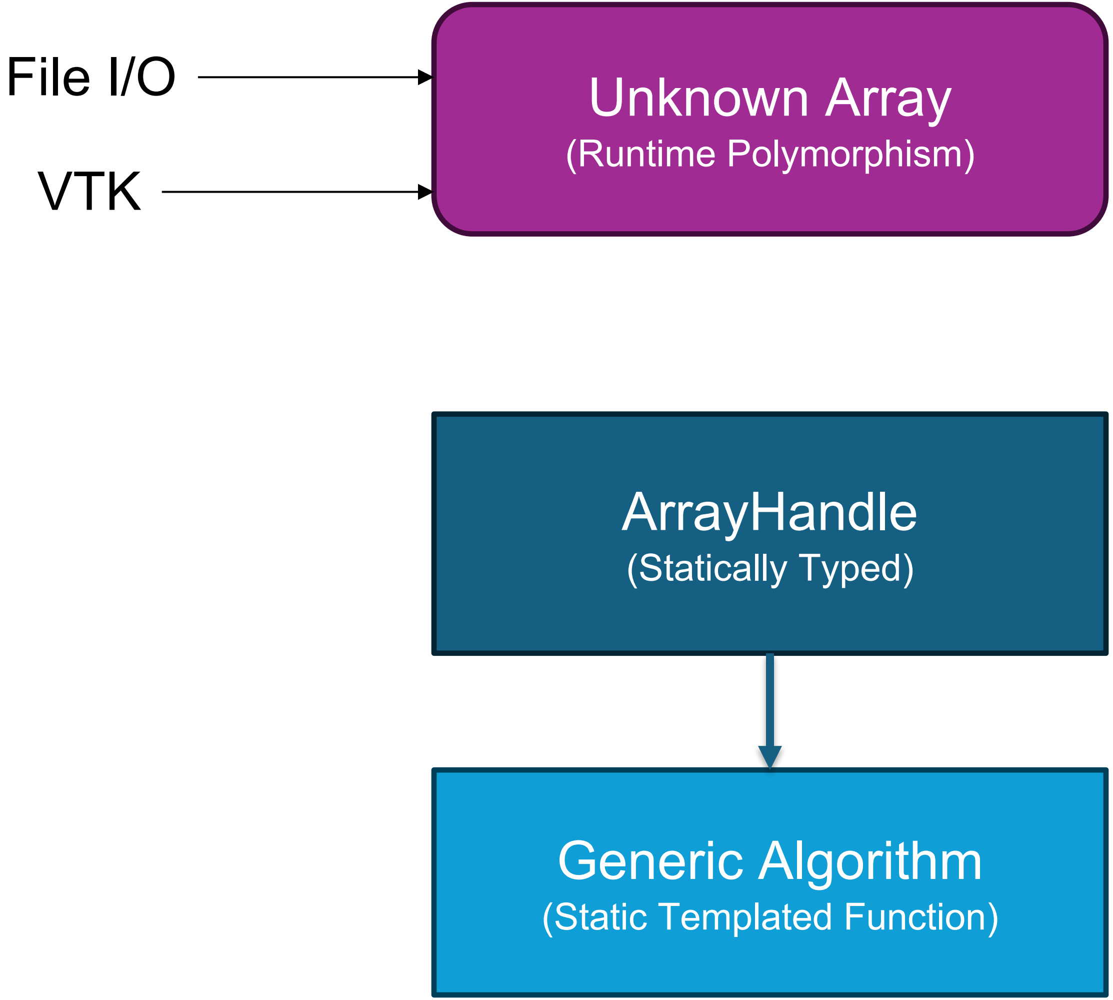
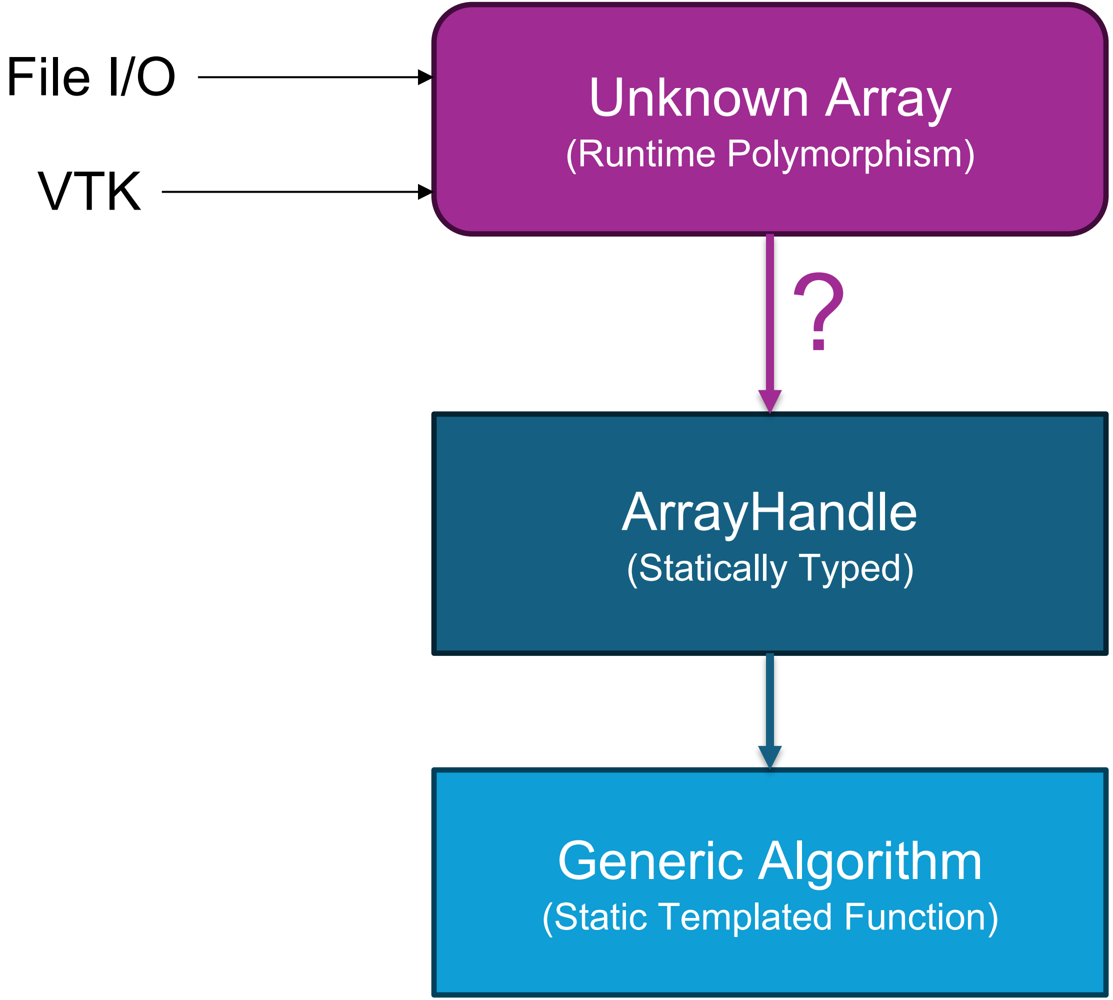
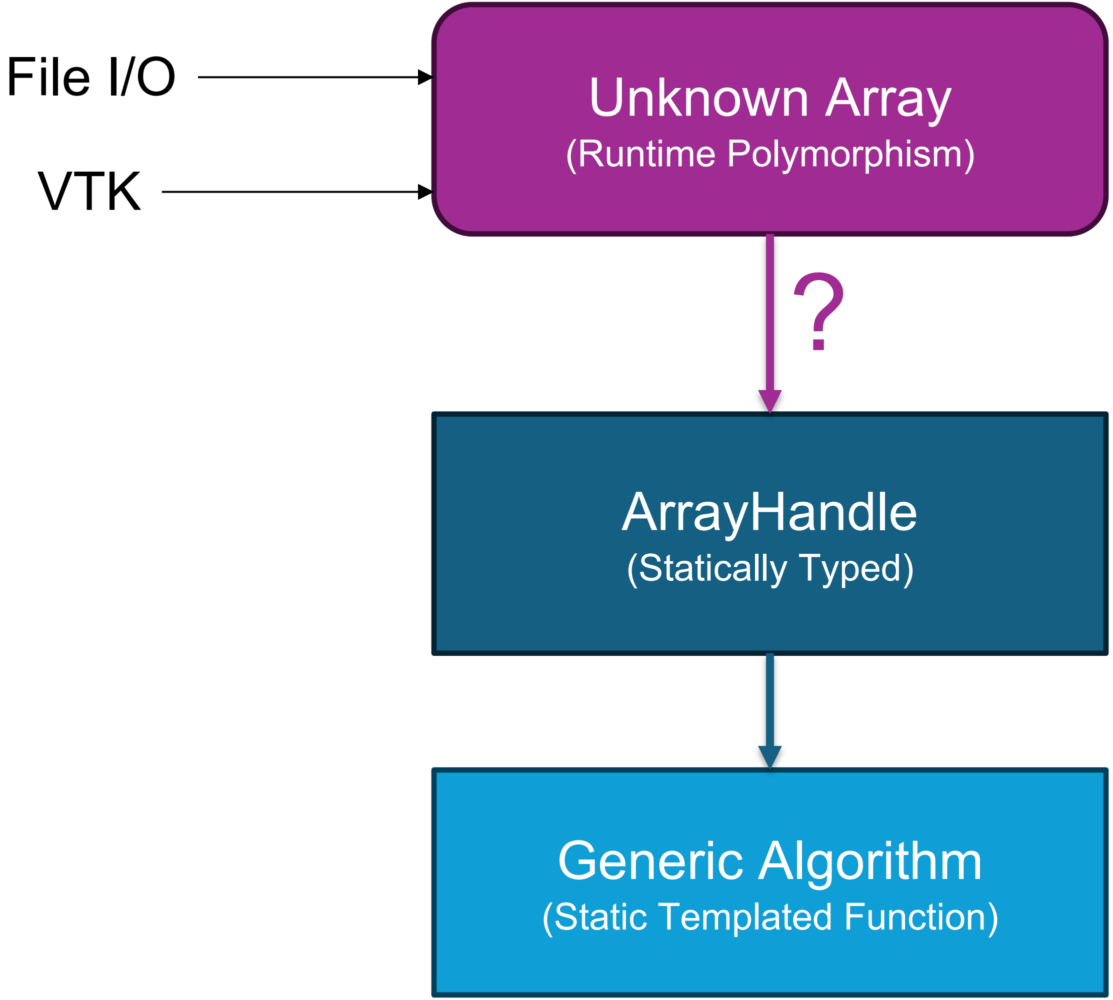

ArrayHandle
(Statically Typed)
Generic Algorithm
(Static Templated Function)


File I/O
VTK
Unknown Array
(Runtime Polymorphism)
ArrayHandle
(Statically Typed)
Generic Algorithm
(Static Templated Function)


File I/O
VTK
Unknown Array
(Runtime Polymorphism)
?
ArrayHandle
(Statically Typed)
Generic Algorithm
(Static Templated Function)



Three Strategies:

1. Static Type Visitation
2. Strided Component Reference
3. Copy Fallback

Static Type Visitation

- Provide a type list.
- Execute generic function once for each type conditioned on the data being that type.
- Pros:
  - Each function instance optimized for specific type.
- Cons:
  - Can lead to the function being compiled thousands of times.
  - Any missed type just fails.

Unknown Array
(Runtime Polymorphism)

+

```
List<T1, T2, T3, T4,…>
```

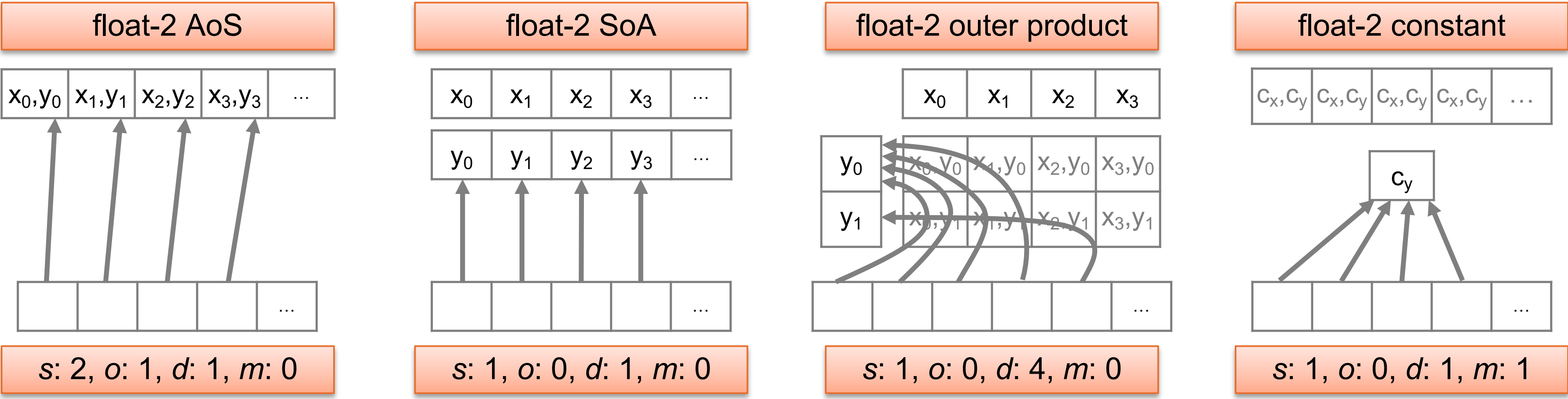
↓

```
if array is T1
   f(cast array as T1)
else if array is T2
   f(cast array as T2)
else if array is T3
   f(cast array as T2)
...
```

Strided Component Reference

A special ArrayHandle can reference array values from runtime selected offset, stride, divisor, and modulus

These can be combined to reference data from nearly any regular data layout



Array Copy Fallback

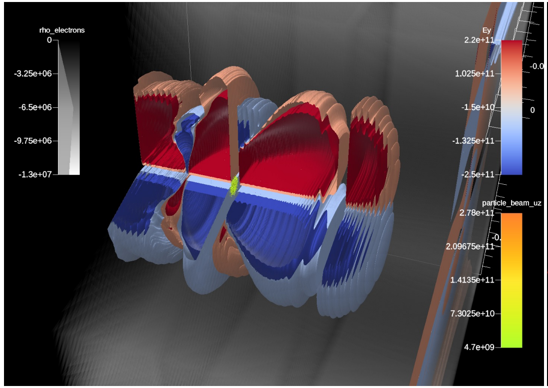
If all else fails, copy the array to a known type.

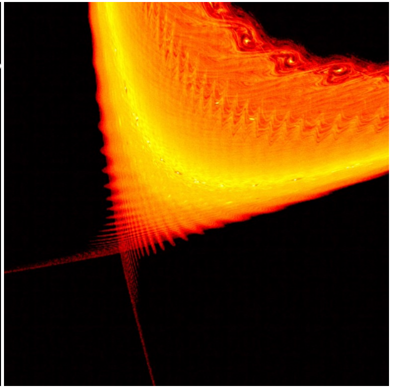
The extra time and memory added is not great.

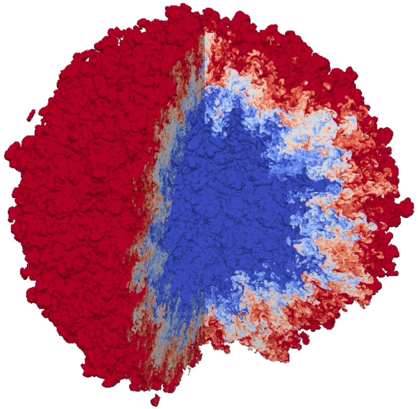
However, it is a graceful fallback from truly unexpected types.

Conclusion

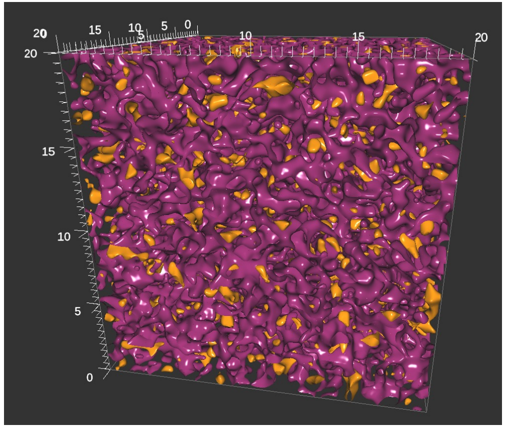
- Viskores provides a plethora of scientific visualization algorithms.
- Several production tools already leverage Viskores libraries.
- The Viskores framework is designed to simplify transitioning experimental algorithms into a deployed library.
- Viskores is designed to interface with existing software.



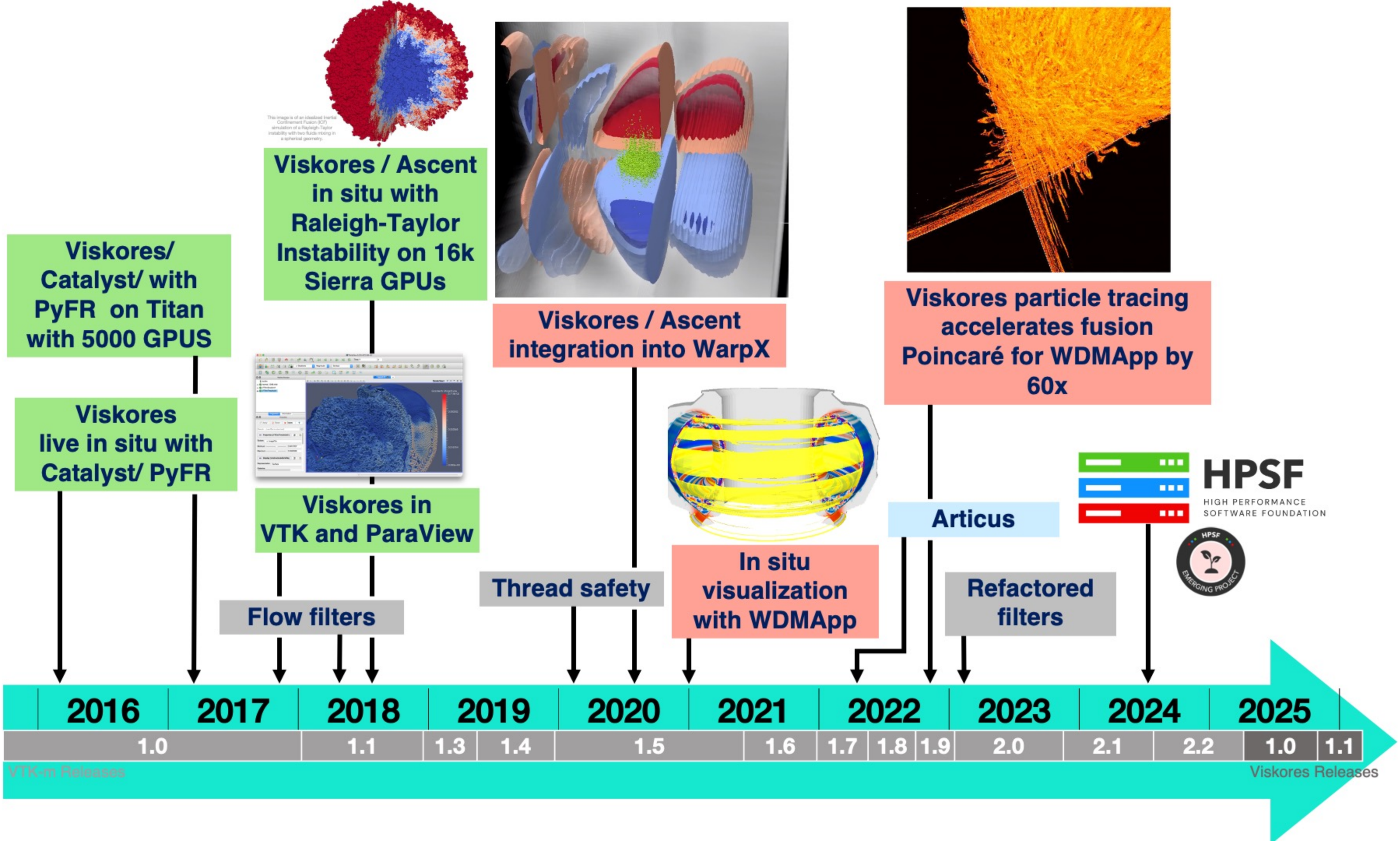




Idealized Inertial Confinement Fusion (ICF) simulation of a Rayleigh-Taylor instability with two fluids mixing in a spherical geometry



Auxiliary Slides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1.8
1.9
2.0
2.1
2.2
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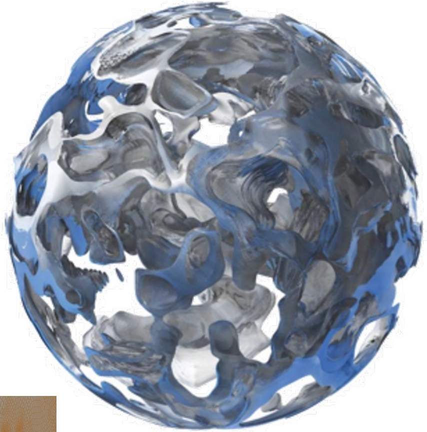
1.1
VTK-m Releases
Viskores Releases

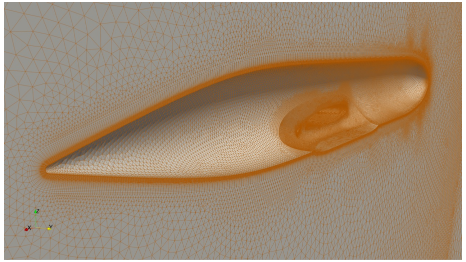
What is Available

Fundamental Algorithms

- Thresholding
- Contouring/Clipping

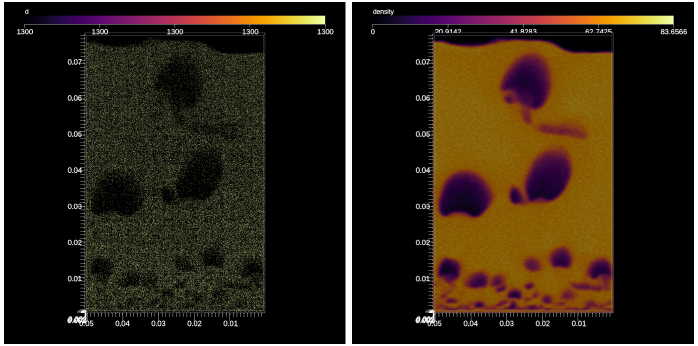


- Grid Cleaning
- External Faces

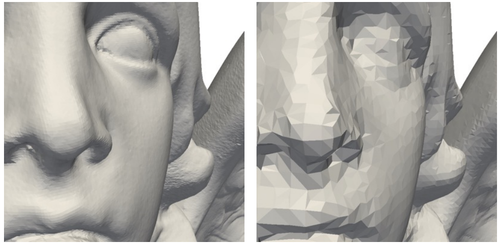


Tsalikis, et al., “Memory-Aware External Facelist Calculation: A Data-Parallel Atomic Hash Counting Approach,” 2026

- Density Estimation



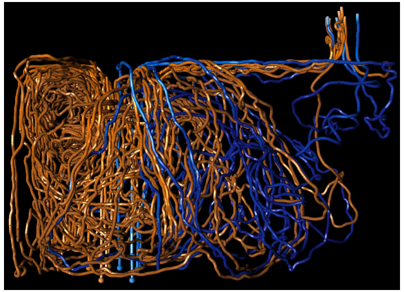
- Surface Coarsening



Moreland, et al., “VTK-m: Accelerating the Visualization Toolkit for Massively Threaded Architectures,” 2016

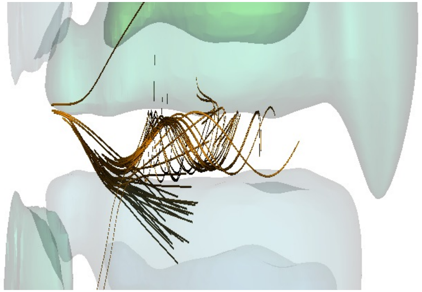
Flow Algorithms

- Streamlines/Pathlines
- Stream Surfaces



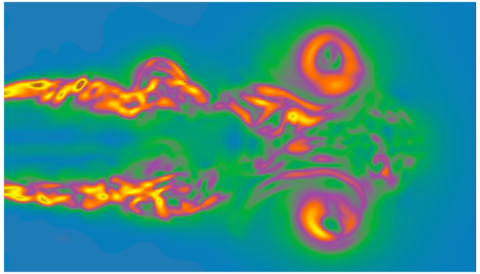
Pugmire, et al., "Performance-Portable Particle Advection with VTK-m," 2018.

- Lorentz-Force in laser wakefields



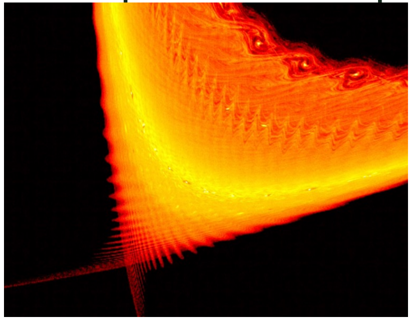
Moreland, et al., "Visualization at exascale: Making it all work with VTK-m. The International Journal of High Performance Computing Applications," 2024.

- FTLE



Sane, et al., "Scalable In Situ Computation of Lagrangian Representations via Local Flow Maps," 2021.

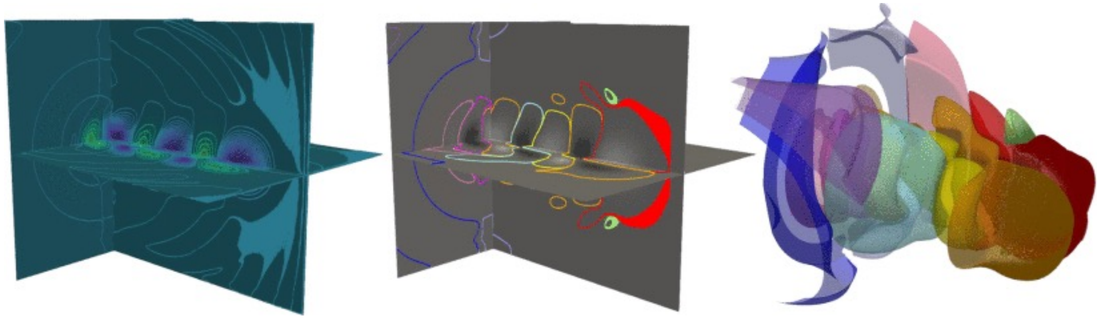
- Poincaré puncture maps in tokamak



Pugmire, et al., "Performance Improvements of Poincaré Analysis for Exascale Fusion Simulations", 2024.

Topology Algorithms

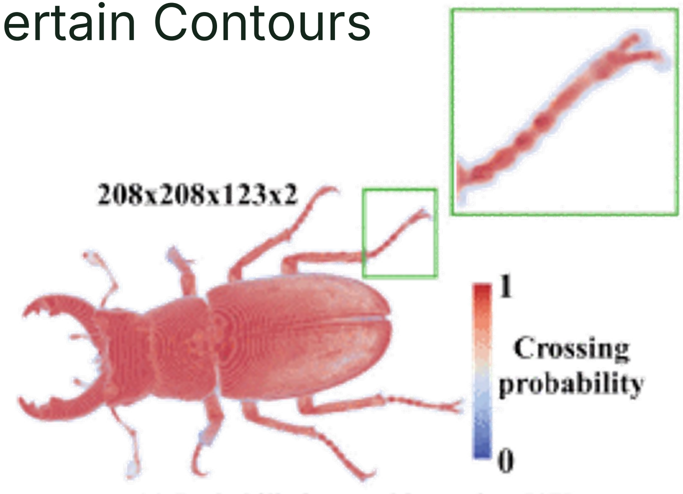
- Contour Trees
  - Single Node + Distributed
- Branch Decomposition
  - Feature ranking
- Corresponding Contour Connected Components



Li, et al., “Distributed Augmentation, Hypersweeps, and Branch Decomposition of Contour Trees for Scientific Exploration,” 2025.

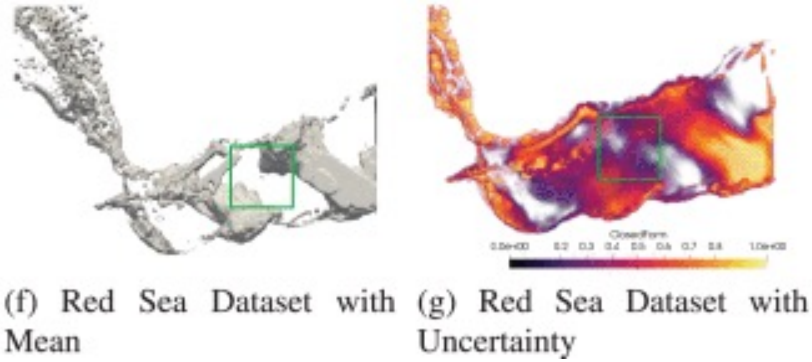
Uncertainty Visualization

- Uncertain Contours



Athawale, et al., “Uncertainty Visualization of the Marching Squares and Marching Cubes Topology Cases,” 2021.

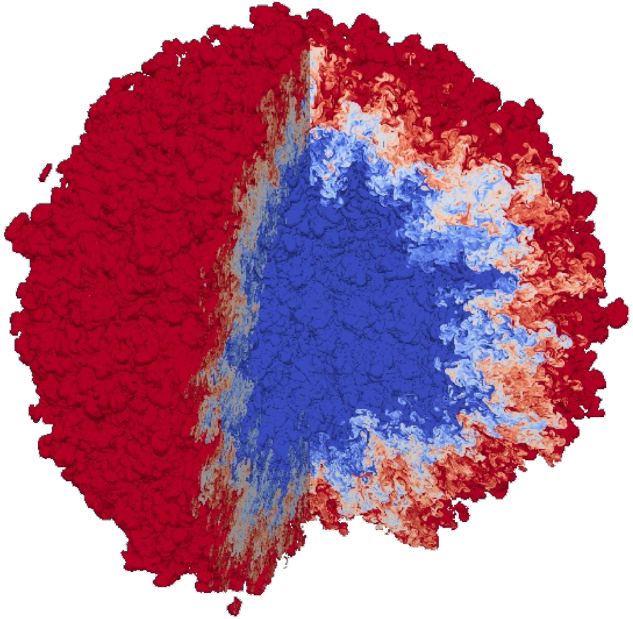
- Uncertain Fiber Surfaces



Hari, et al., “FunM^{2}C: A Filter for Uncertainty Visualization of Multivariate Data on Multi-Core Devices,” 2024.

Rendering

- Surface



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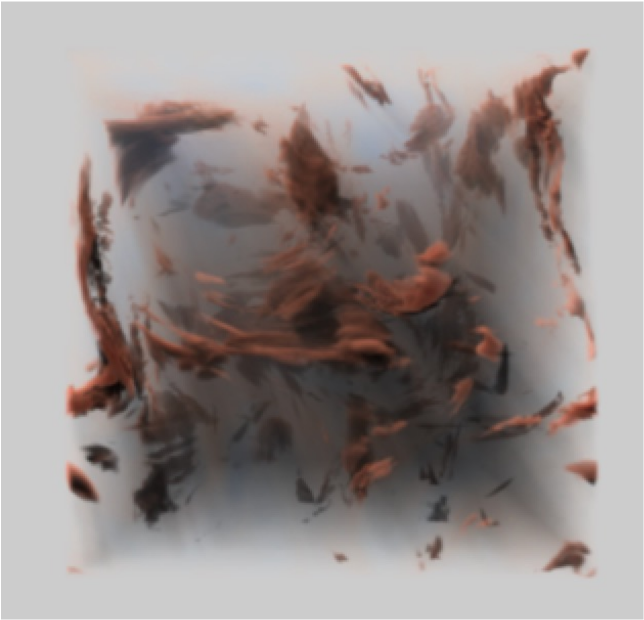
- Volume



Data Representation

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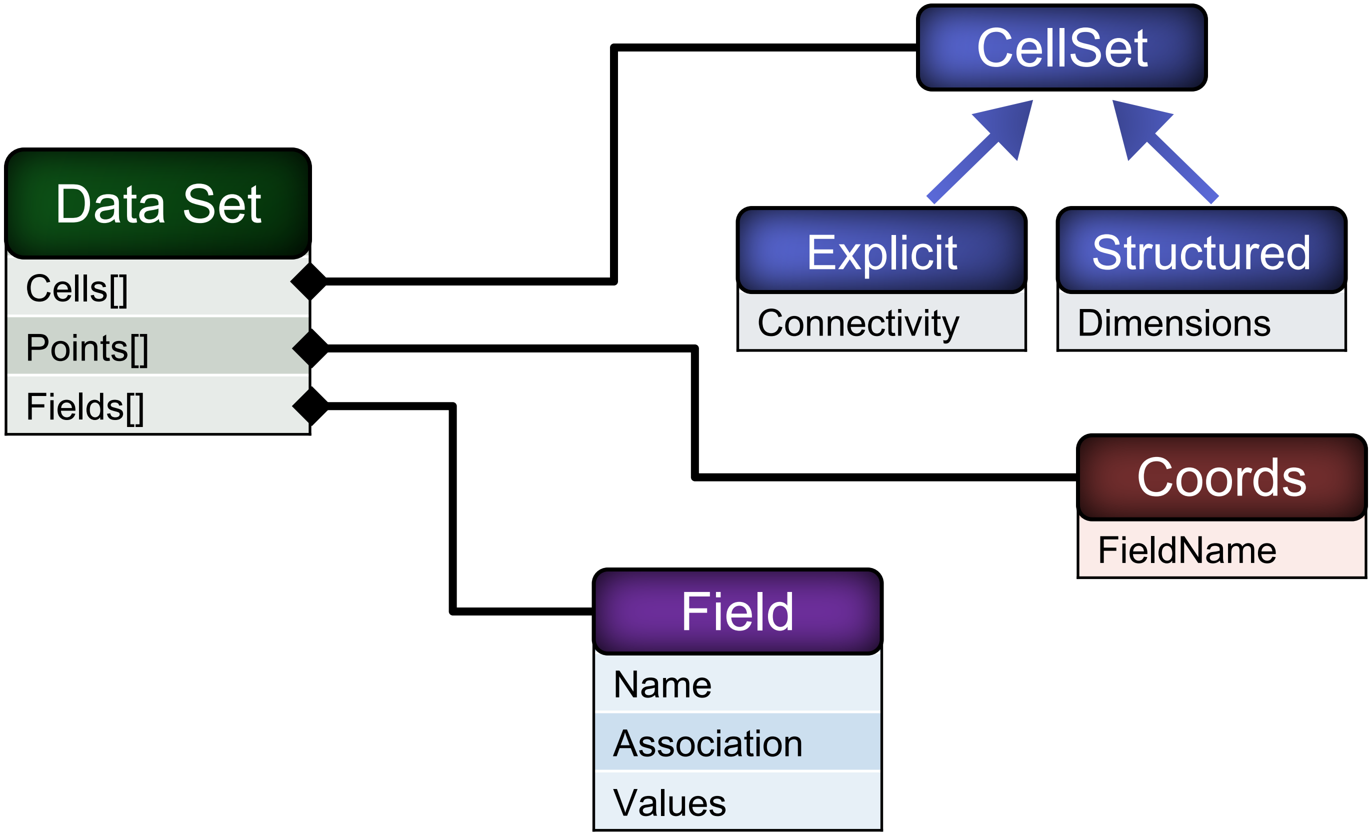
The Viskores Data Set Model



Array Handle Interface