Visualization Toolkit: Faster, Better, Open Scientific Rendering and Compute

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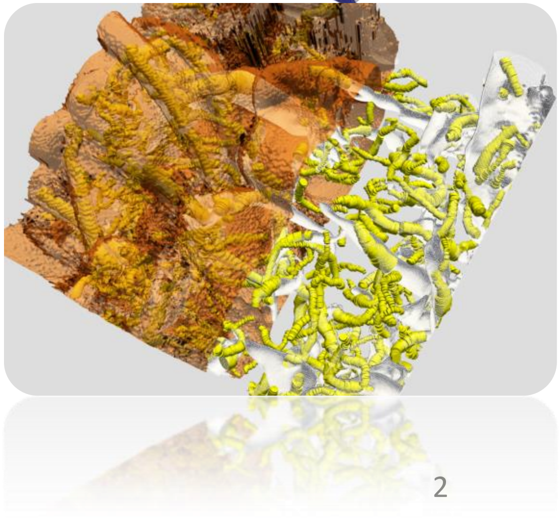
Robert Maynard

Kitware

Accelerating Visualization with Partnerships

- NVIDIA and Kitware collaborate to bring advances in scientific visualization
- Collaboration focuses
  - In-site visualization
  - Advanced rendering
- Improved use of NVIDIA GPUs



Kitware, Inc.

- Founded in 1998 by five former GE Research employees
- 98 current employees; 34 with PhDs
- Privately held, profitable from creation, no debt
- Offices
  - Clifton Park, NY
  - Carrboro, NC
  - Santa Fe, NM
  - Lyon, France

- 2011 Small Business Administration's Tibbetts Award
- HPCWire Readers and Editor's Choice
- Inc's 5000 List since 2008

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Kitware's customers & collaborators

Over 75 **academic** institutions including…

- Harvard
- Massachusetts Institute of Technology
- University of California, Berkeley
- Stanford University
- California Institute of Technology
- Imperial College London
- Johns Hopkins University
- Cornell University
- Columbia University
- Robarts Research Institute
- University of Pennsylvania
- Rensselaer Polytechnic Institute
- University of Utah
- University of North Carolina

Over 50 **government** agencies and labs including…

- National Institutes of Health (NIH)
- National Science Foundation (NSF)
- National Library of Medicine (NLM)
- Department of Defense (DOD)
- Department of Energy (DOE)
- Defense Advanced Research Projects Agency (DARPA)
- Army Research Lab (ARL)
- Air Force Research Lab (AFRL)
- Sandia (SNL)
- Los Alamos National Labs (LANL)
- Argonne (ANL)
- Oak Ridge (ORNL)
- Lawrence Livermore (LLNL)

Over 100 **commercial** companies in fields including…

- Automotive
- Aircraft
- Defense
- Energy technology
- Environmental sciences
- Finance
- Industrial inspection
- Oil & gas
- Pharmaceuticals
- Publishing
- 3D Mapping
- Medical devices
- Security
- Simulation

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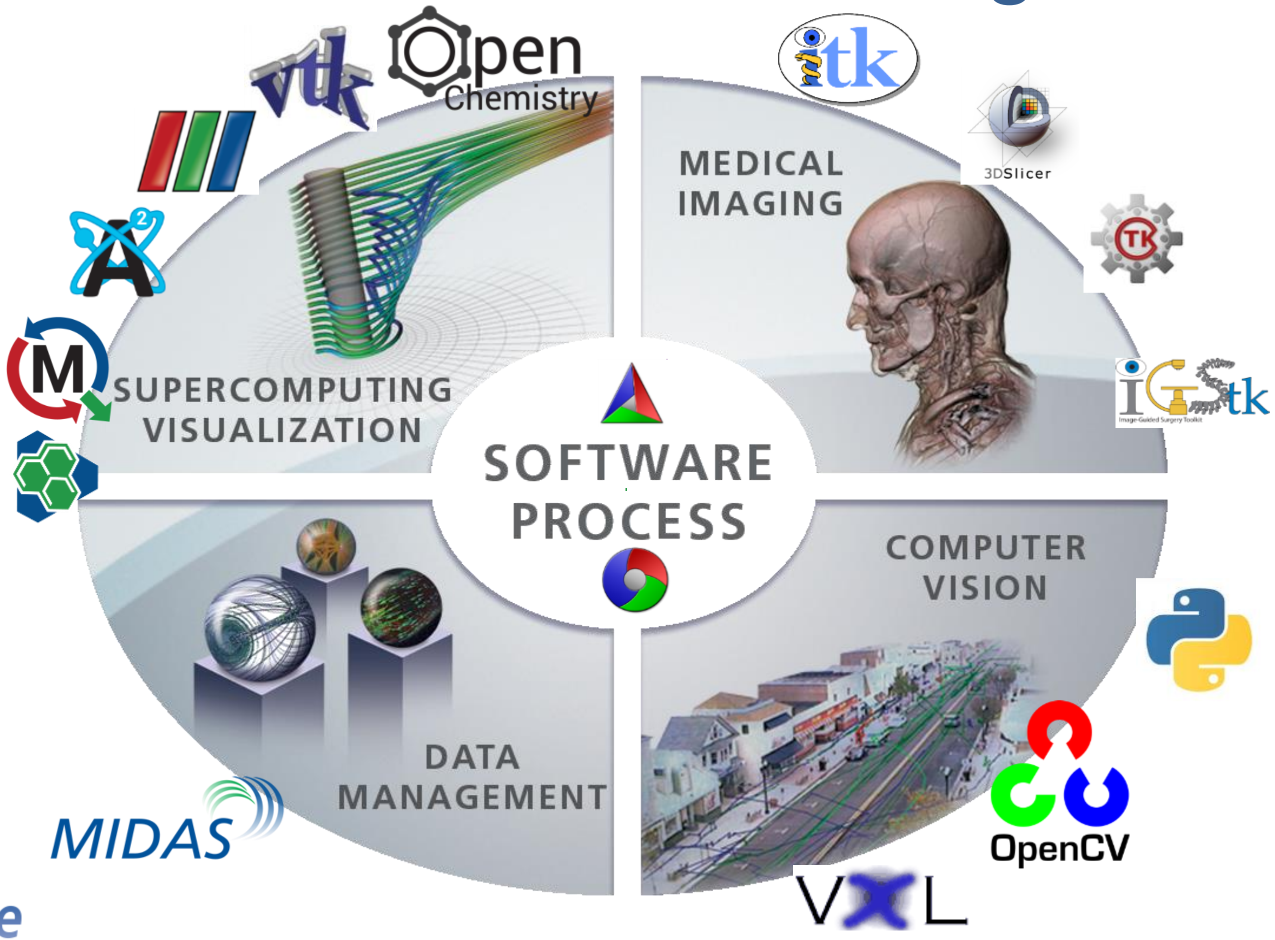
Kitware: Core Technologies

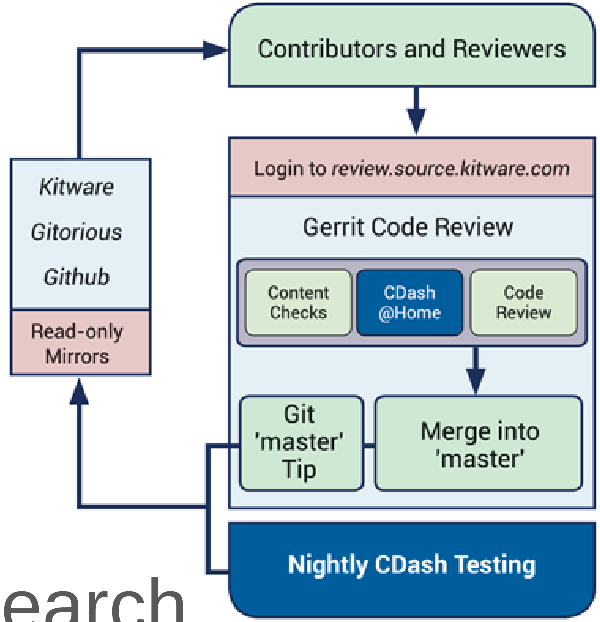


Business Model: Open Source

- Open-source Software
  - Normally BSD-licensed
  - Collaboration platforms
- Collaborative Research and Development
- Technology Integration
- Services, support, and consulting
- Training and webinars

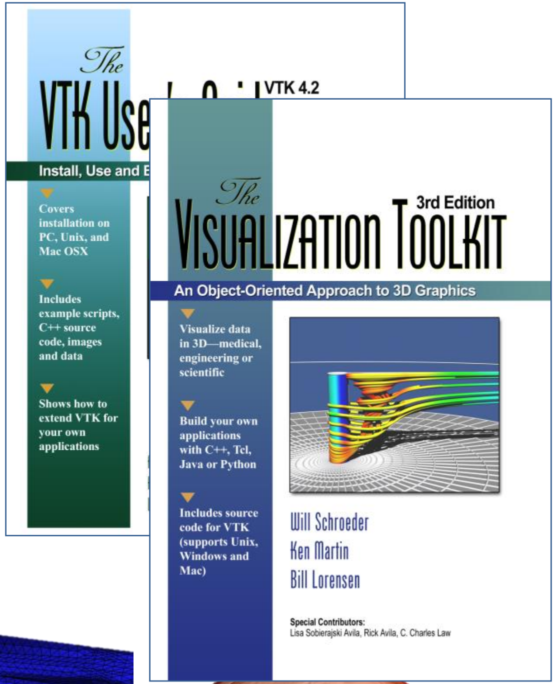
Overview of Software Process

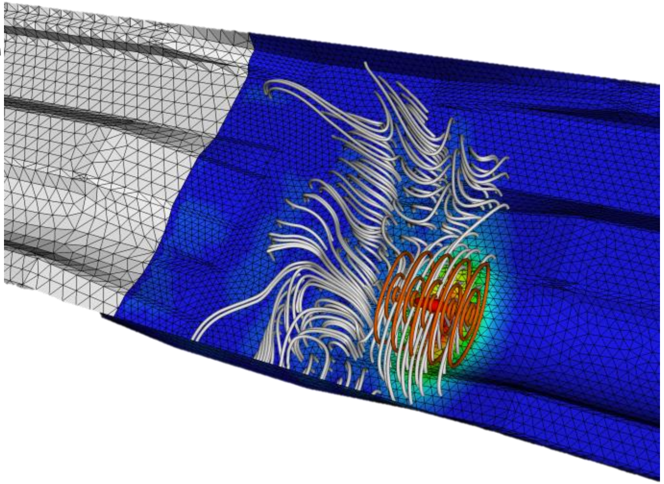
- Openly developed, reusable frameworks
  - Open-source frameworks
  - Developed openly
  - Cross-platform compatibility
  - Tested and verified
  - Contribution model
  - Supported by Kitware experts
- Liberally-licensed to facilitate research

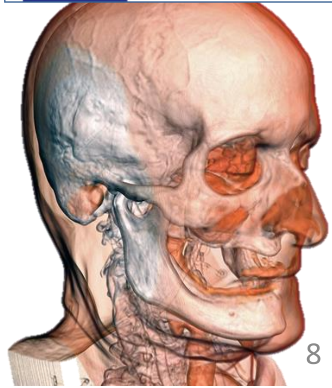


The Visualization Toolkit

- Founded in 1993 as example code for “The Visualization Textbook”.
- Used in many projects developed all over the world
  - ParaView, VisIt
  - Osirix, 3D Slicer
  - Mayavi, MOOSE







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Going From Data to Visualization


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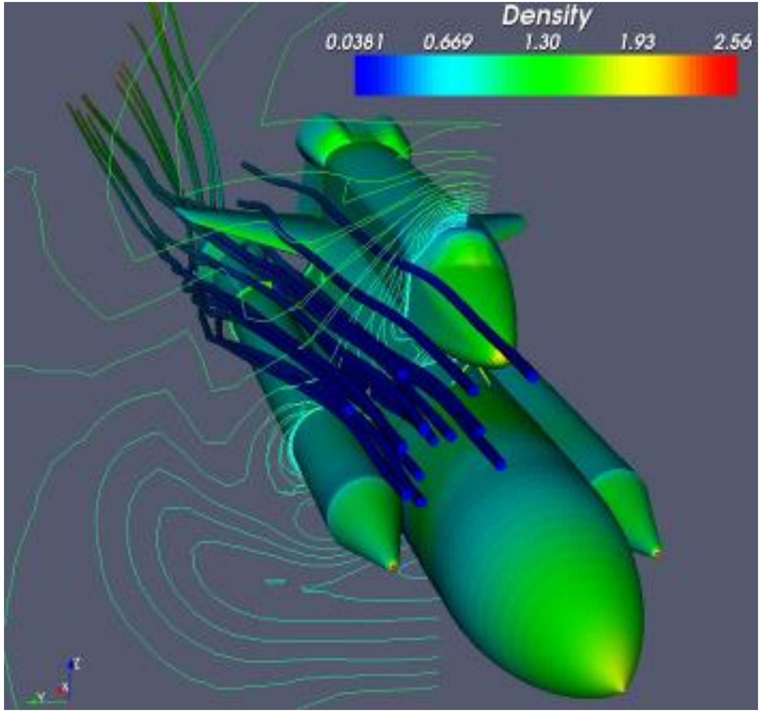
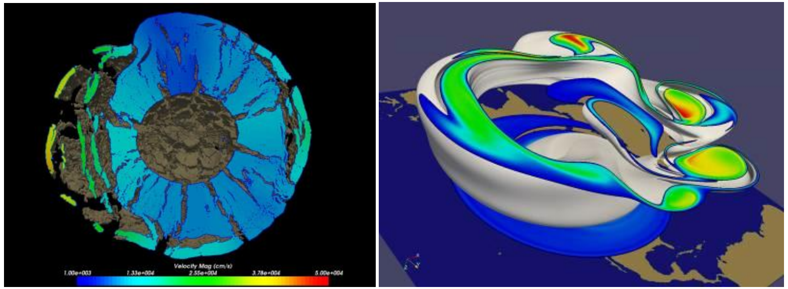
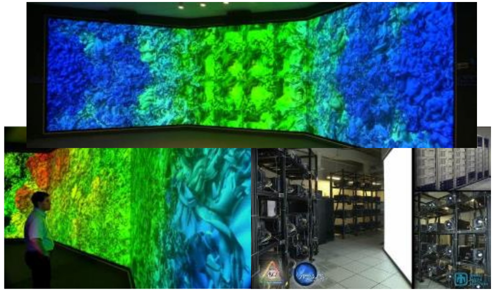


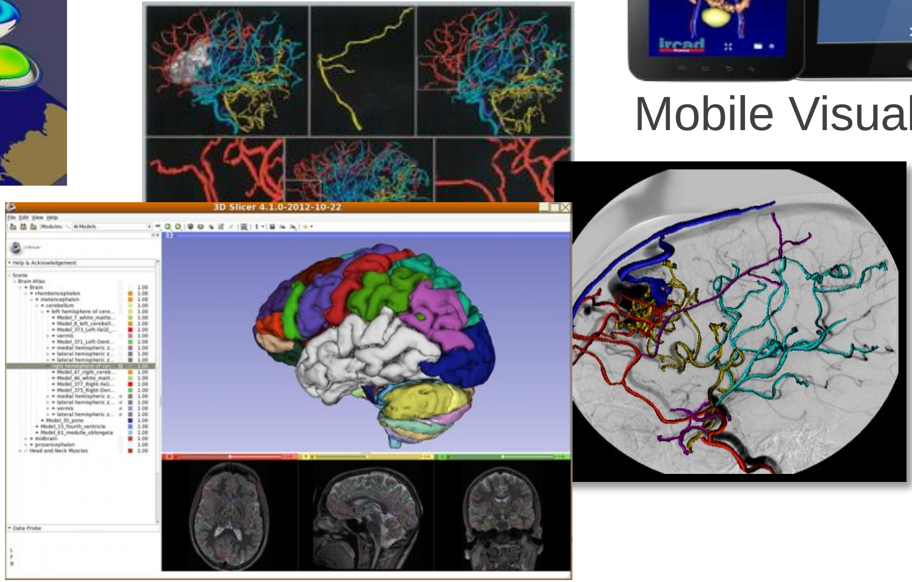
VTK Visualizations



HPC Visualization



Large Displays and Virtual Reality



Interactive Medical Application and Visualization

Mobile Visualization

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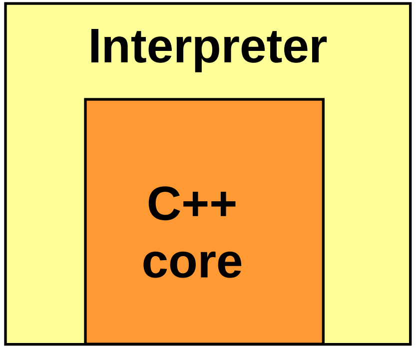
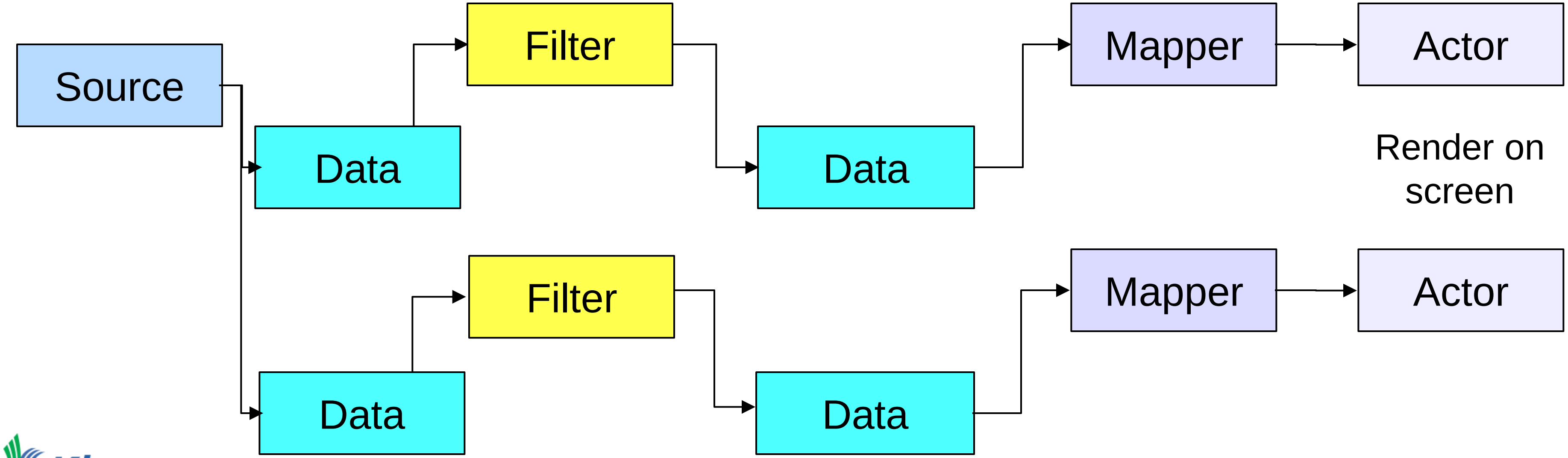
VTK Architecture

- Hybrid approach
  - Compiled C++ core (faster algorithms)
  - Interpreted applications (rapid development)
  - Interpreted layer generated automatically



The Visualization Pipeline

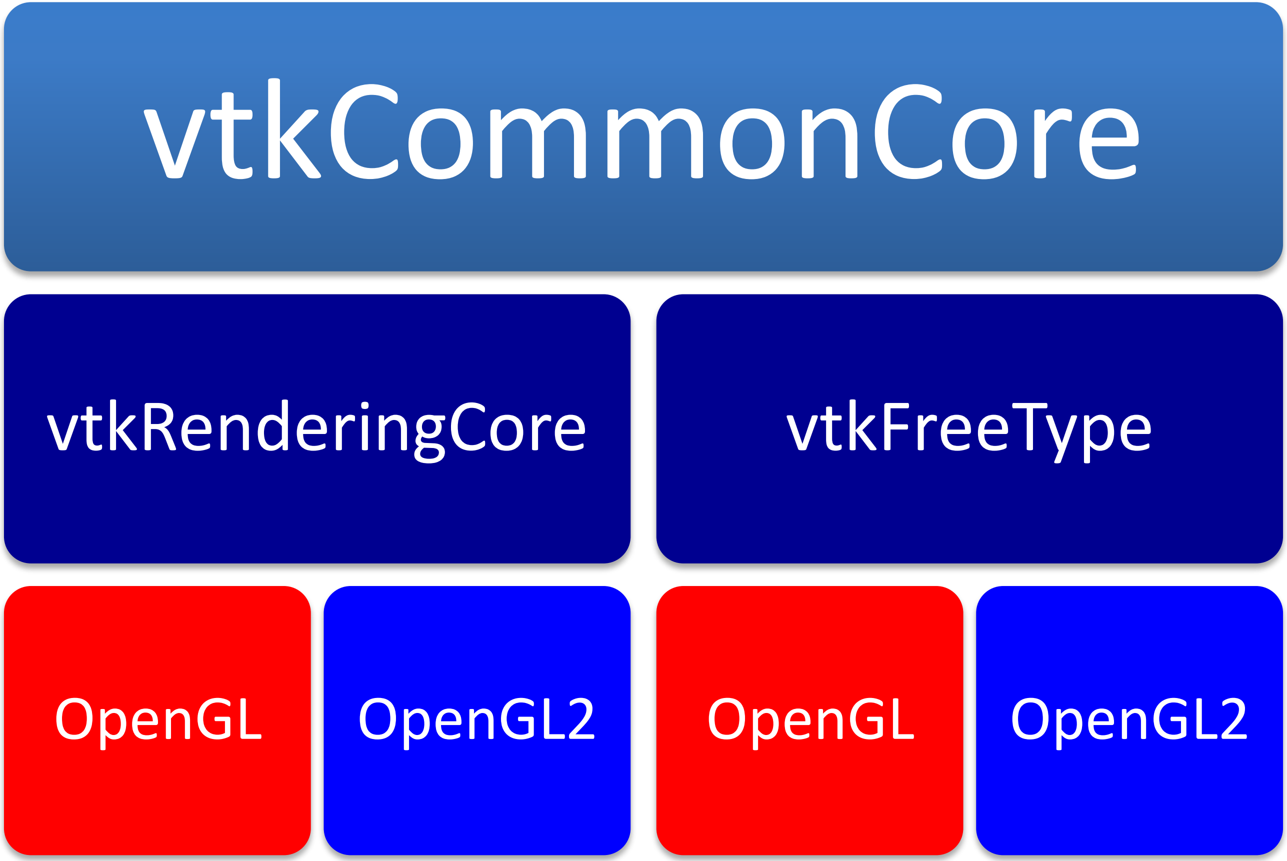
- A sequence of algorithms that operate on data objects to generate geometry



VTK Organization

- Libraries with public APIs
- Cross-platform, open-source, for reuse
- Implementation modules use factories
  - Rendering API uses OpenGL backend
  - Core rendering does not link to/use OpenGL

Basic Library Hierarchy



Legacy Rendering

- Based on OpenGL 1.1 APIs
  - Optionally uses some extensions
- Heavy use of display lists for interaction
- A “Painter” API to enable custom rendering
  - Virtual functions, switches, …
    - In tight loops for all vertices, normals, colors, etc

Polygonal Rendering Rewrite

- New minimum OpenGL version
  - OpenGL 2.1, OpenGL ES 2.0
- Rewrite to use minimal common subset
- Major overhaul of the rendering code
  - Use VBOs, VAOs, shaders, “new” OpenGL
- Retain same high level API

Volume Rendering Rewrite

- Improve portability of GPU code
  - Works well on Linux, Mac, and Windows
  - Uses less extensions, more core GL 2.1+
- Refactored to compute more in shaders
- Replicates important features
- Easier to develop new techniques

Removing Old Calls

- Not using matrix stacks
- GLSL, using modern approaches
- Optional extensions detected at runtime
- Not a single glVertex call, highly batched
- Some data structures need further work
  - vtkPolyData needs packed triangles

Performance Improvements

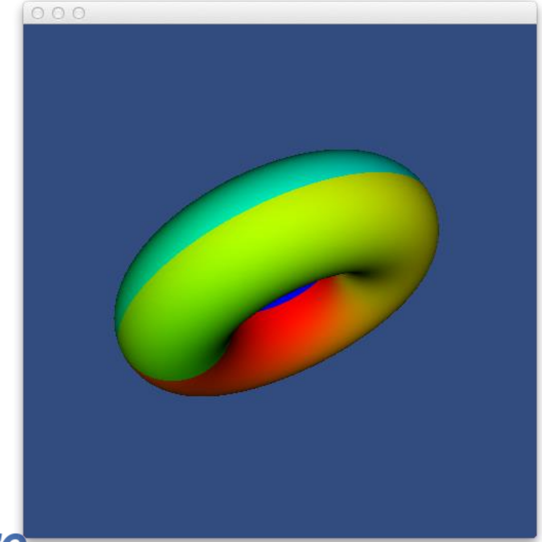
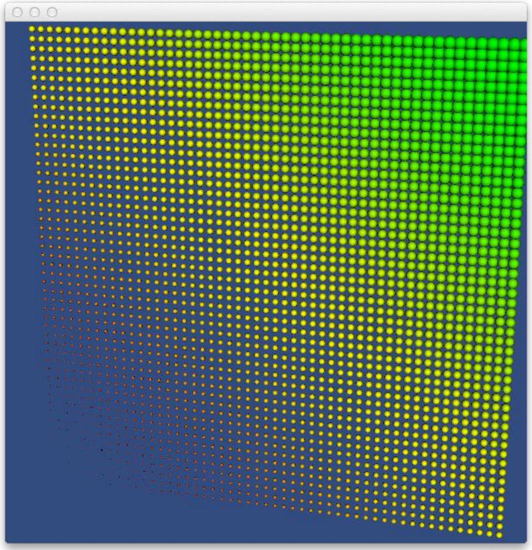
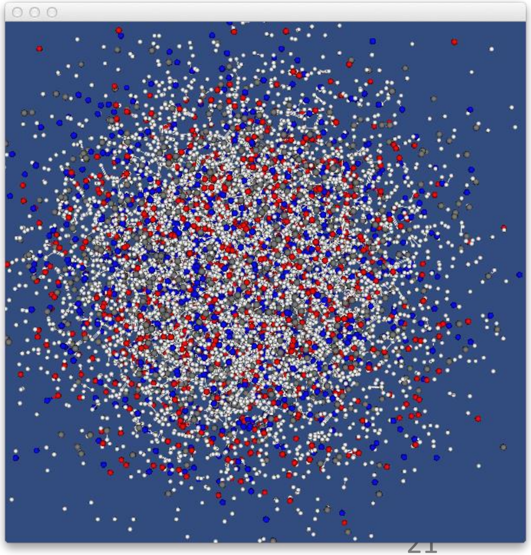
- In many cases now GPU bound
  - Previously large systems CPU bound
- Large polygonal models >100x faster!
- Much more portable depth peeling
- Reduced memory footprint significantly
- Initial render times reduced

Performance: Old vs New

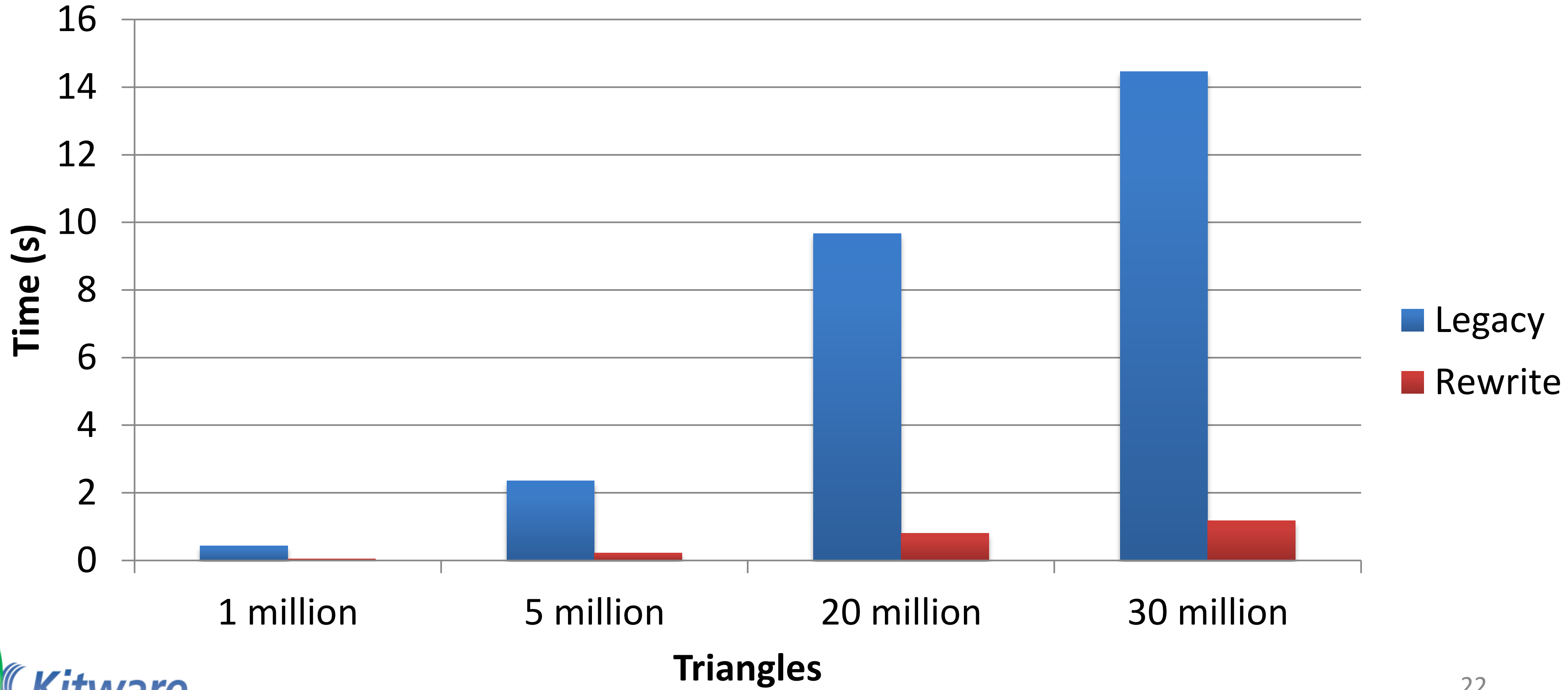
- Looking at static scenes
  - Time to first render
  - Average time of rotated subsequent renders
- Legacy rendering hits maximum size
  - Memory errors/limits
  - Only possible to compare smaller geometries

Benchmarking Tools (Polygonal)

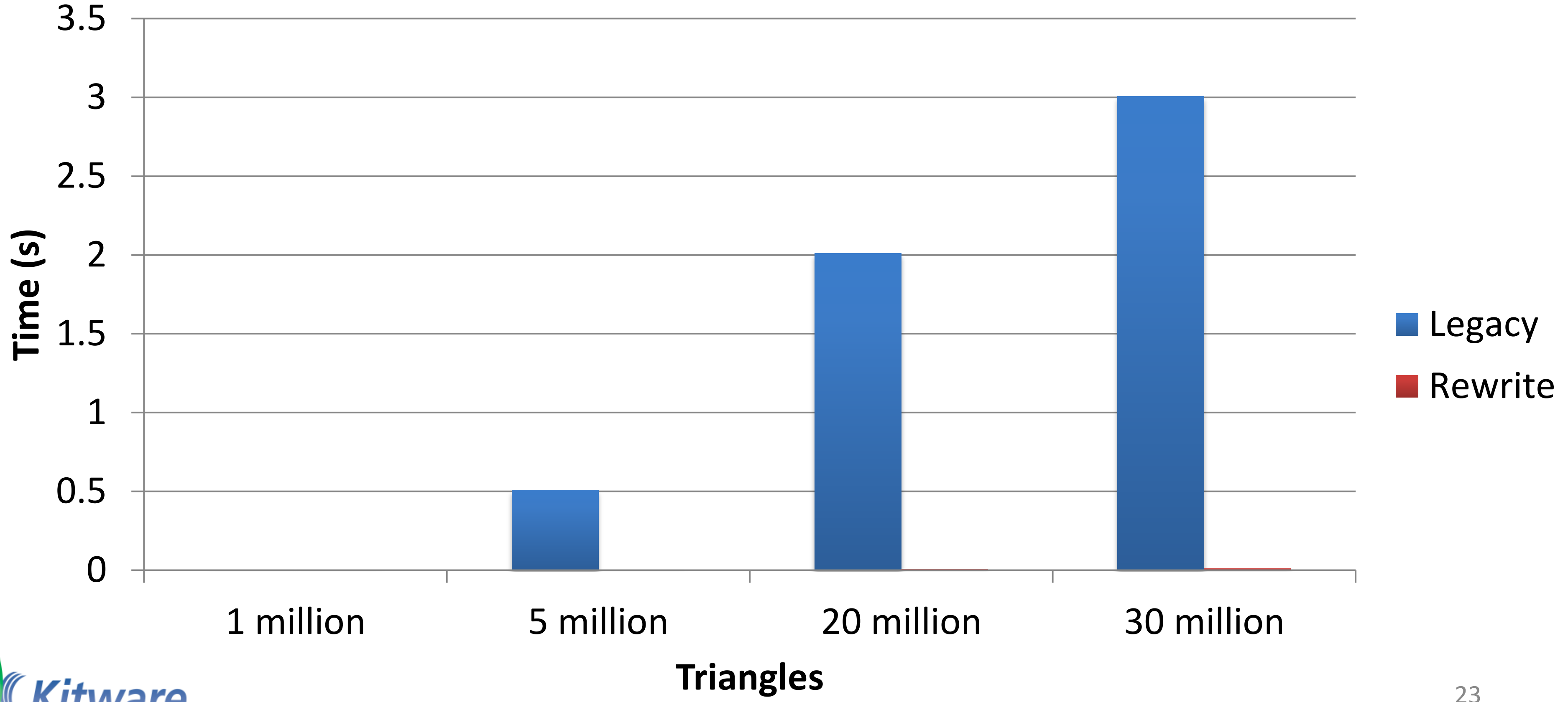
- Added some new benchmarking tools
- Aim to provide systematic comparison

Time For First Frame (K6000)



Time for Subsequent Frames (K6000)



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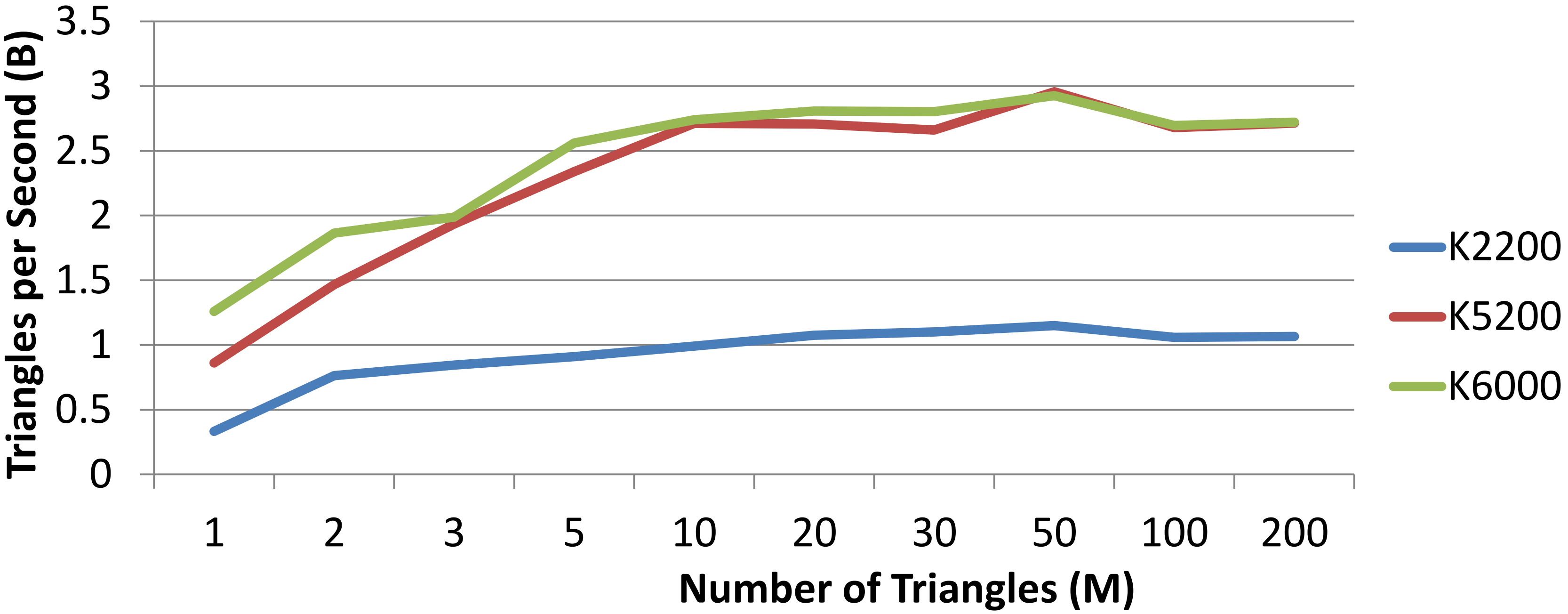
Rendering Speeds

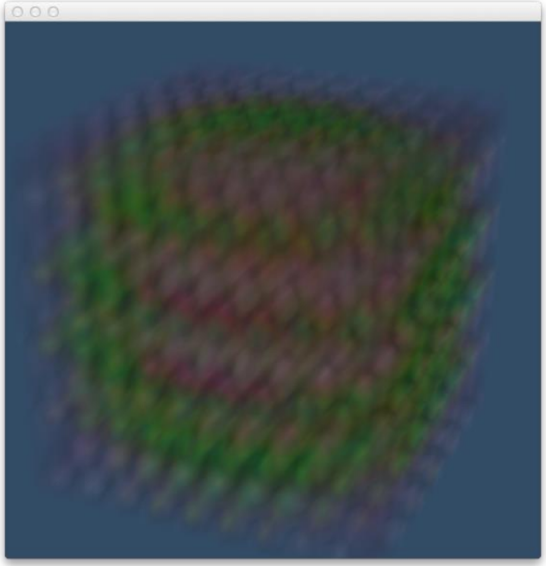
- Two orders of magnitude faster!
- Legacy rendering maxes out at 30 million
  – Not possible to compare above this
- Measured on a modern Linux system
  – Same on Windows, and Mac
- Memory footprint about half for triangles

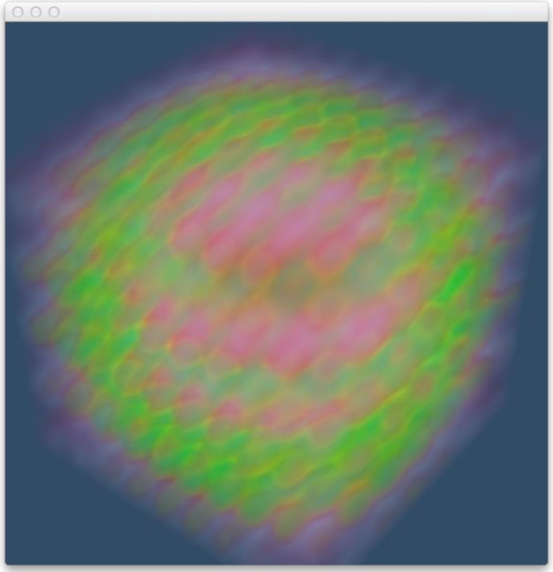
Comparison of Cards (Rewrite)



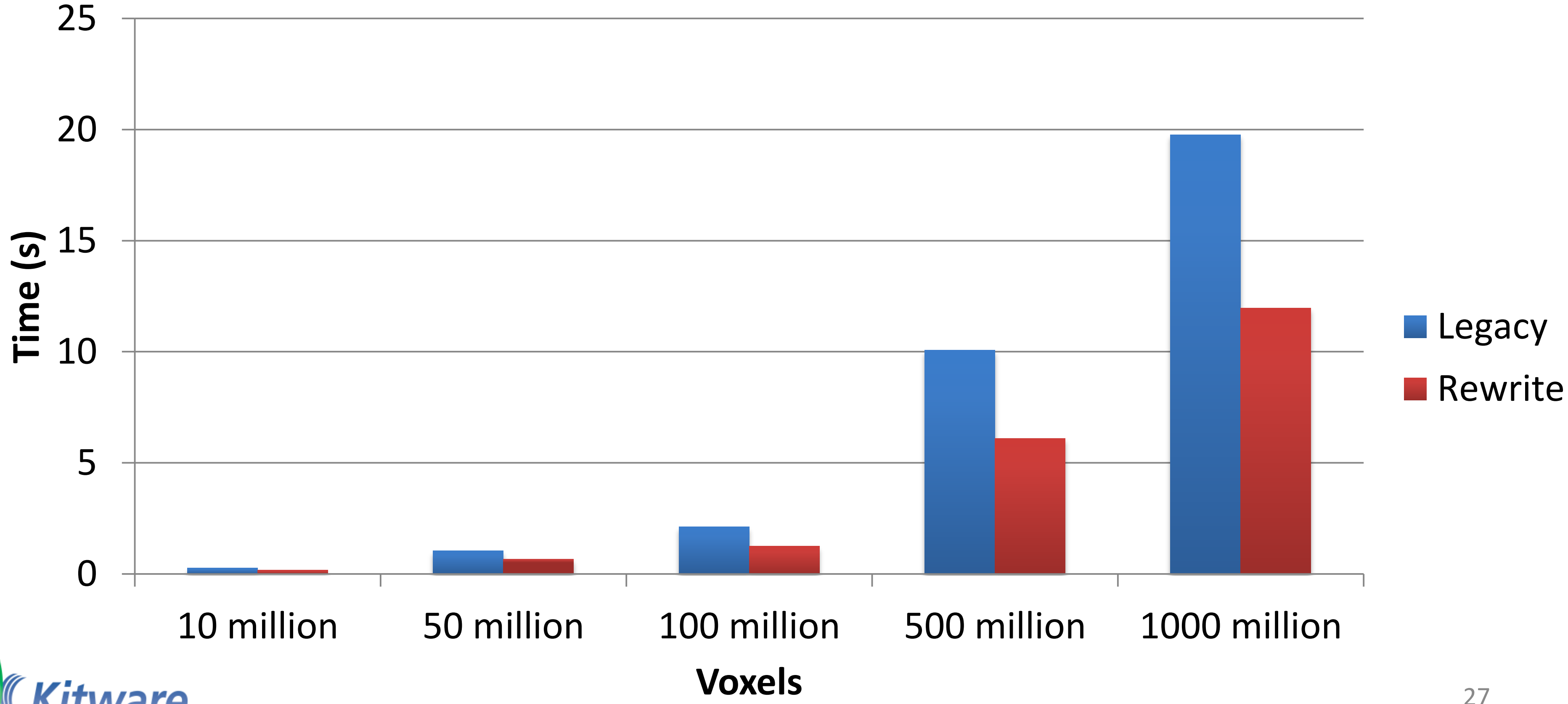
Benchmarking Tools (Volume)

- Uses same framework as polygonal
- Volumes of increasing size





Time For First Frame (K40c)



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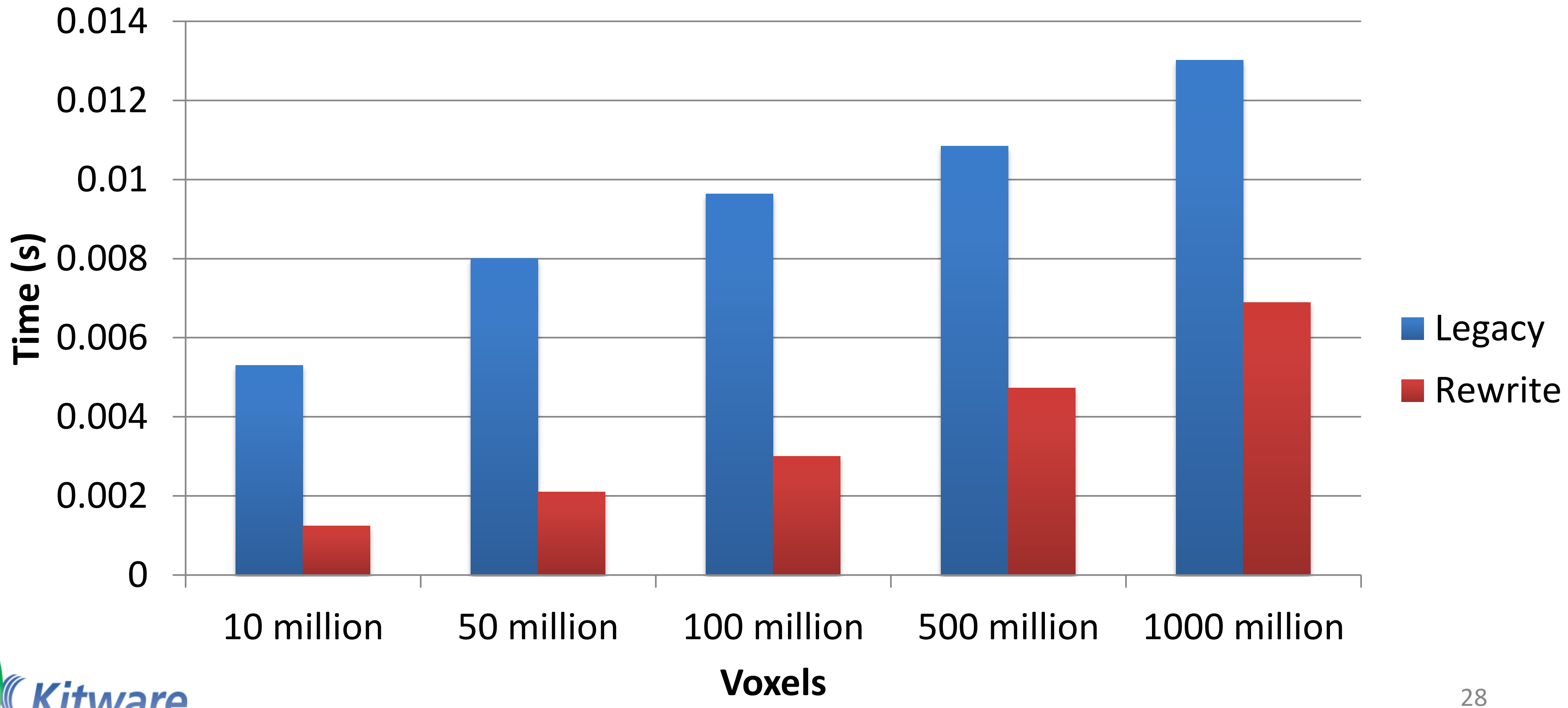
Time for Subsequent Frames (K40c)



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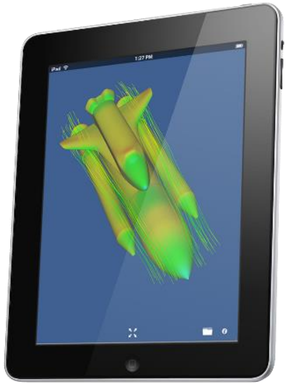
Mobile/Embedded

- New rendering can target ES 2.0+
- Some testing on Android and iOS
- Largely shared code with desktop code
- Simple multitouch interaction support



Custom Rendering

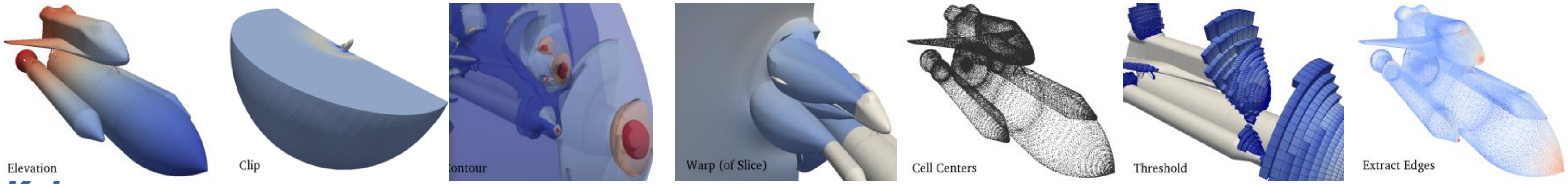
- Shaders can be overridden in mappers
- VBOs/IBOs created by reusable helpers
- Override the vtkMapper class
- Several examples of different rendering
  - Glyphing, impostors, composite data
  - Offer a reasonable starting point

Porting/Using New Rendering

- Many applications just change backend
  - VTK_RENDERING_BACKEND=OpenGL2
  - Compile time option, with possible link change
  - vtkRenderingOpenGL -> vtkRendering${VTK_RENDERING_BACKEND}
- Custom OpenGL will need to be ported

VTK-m Project Goals

- A single place for the visualization community to collaborate, contribute, and leverage massively threaded algorithms.
- Reduce the challenges of writing highly concurrent algorithms by using data parallel algorithms



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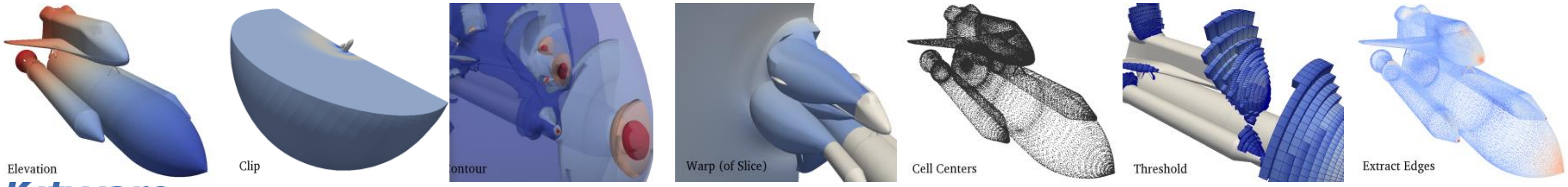
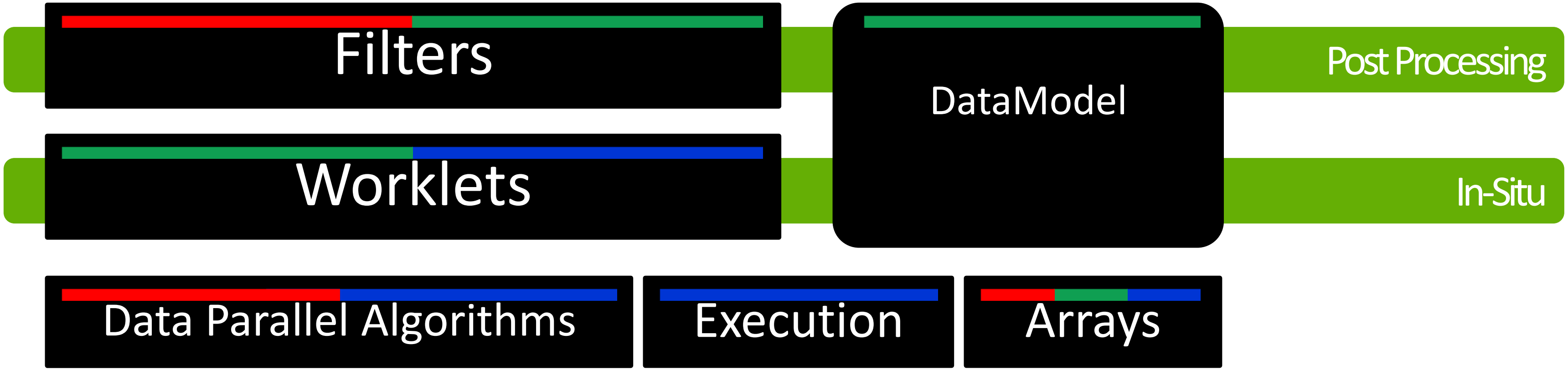
VTK-m Project Goals

- Make it easier for simulation codes to take advantage these parallel visualization and analysis tasks on a wide range of current and next-generation hardware.



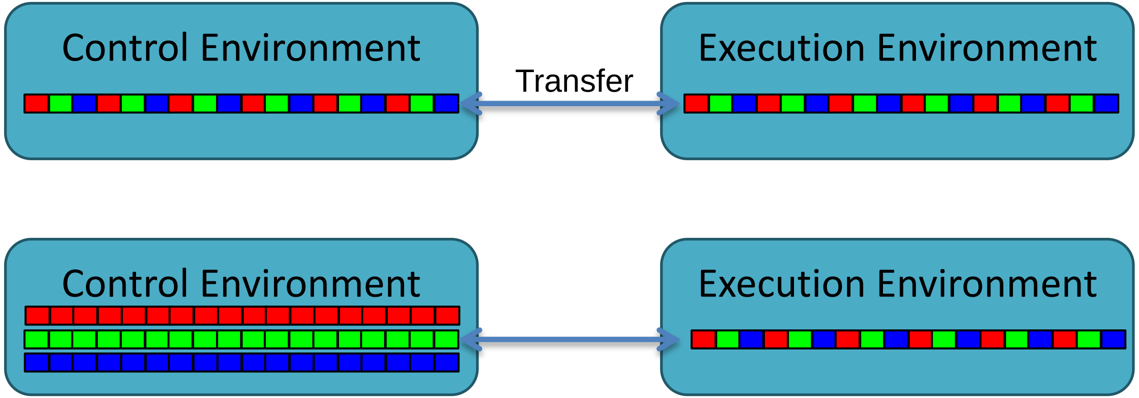
VTK-m Architecture

- Combines strengths of multiple projects:
  - EAVL, Oak Ridge National Laboratory
  - DAX, Sandia National Laboratory
  - PISTON, Los Alamos National Laboratory



VTK-m Arbitrary Composition

- VTK-m allows clients to access different memory layouts through the Array Handle and Dynamic Array Handle.
  - –Allows for efficient in-situ integration
  - –Allows for reduced data transfer



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VTK-m Arbitrary Composition

- VTK-m allows clients to construct data sets from cell and point arrangements that exactly match their original data
  - –In effect, this allows for hybrid and novel mesh types

Cells	Coordinates	Point Arrangement: Explicit	Logical	Implicit
Structured	Strided	✓	✓	✓
	Separated	✓	✓	✓
Unstructured	Strided	✓	✓	✓
	Separated	✓	✓	✓

VTK-m Data Set

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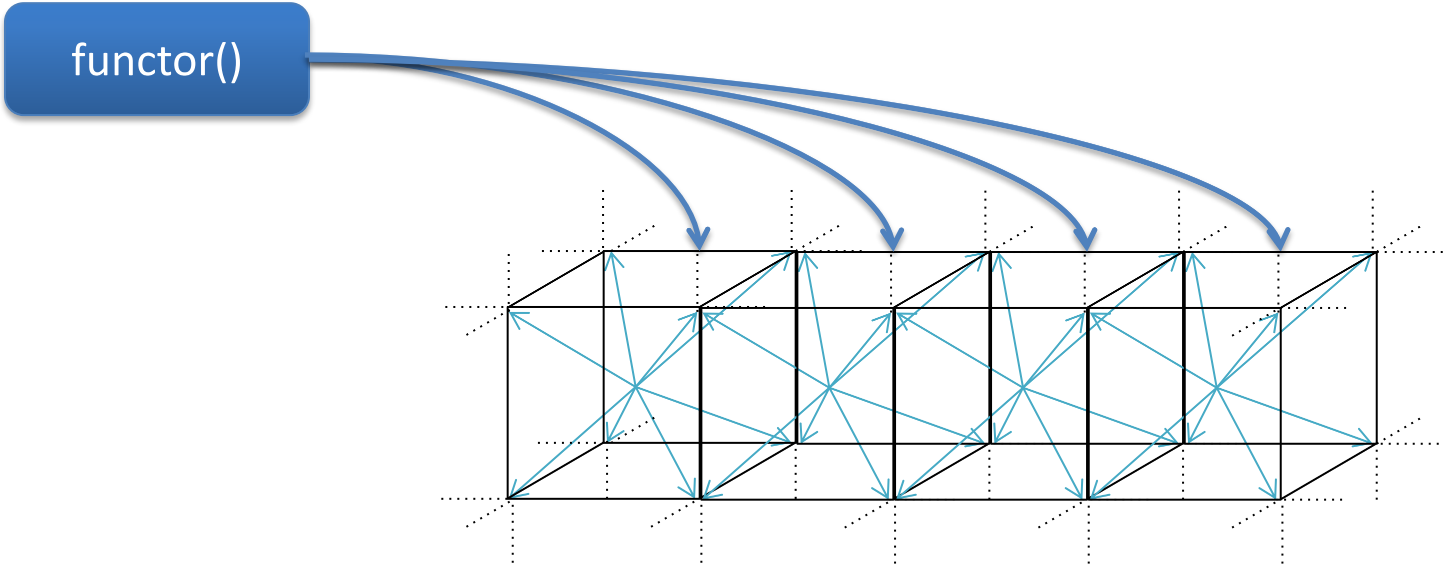
[Baker, et al. 2010]

Functor Mapping Applied to Topologies



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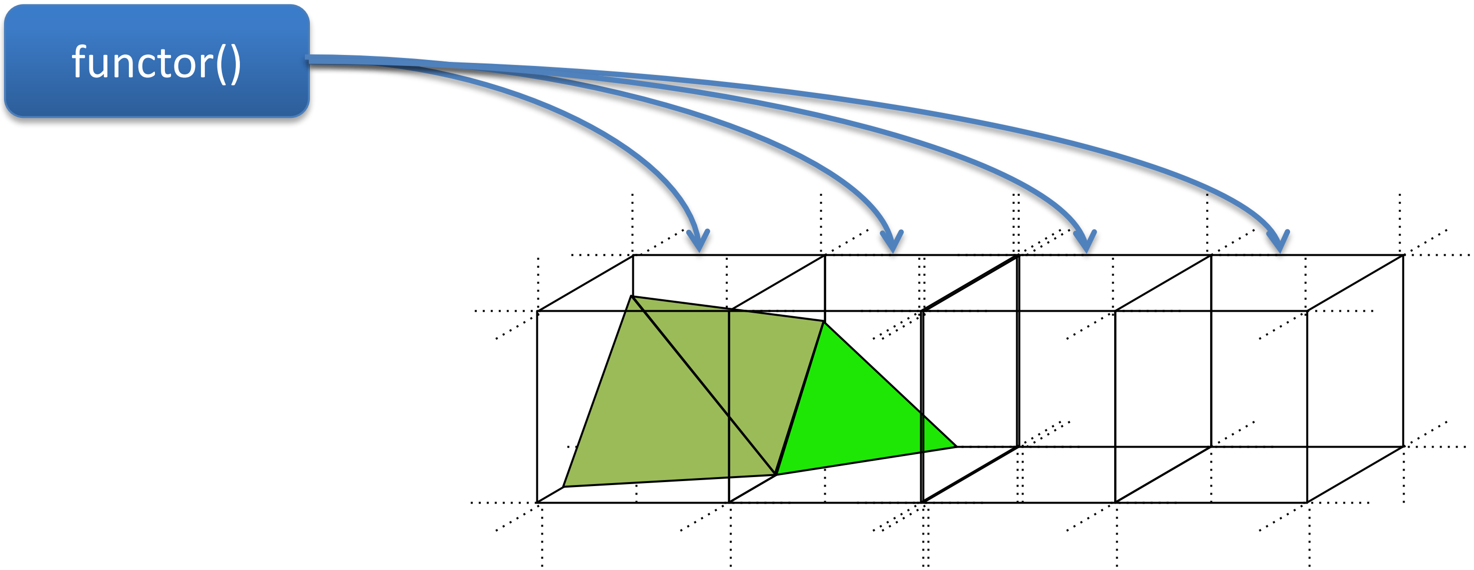
[Baker, et al. 2010]

Functor Mapping Applied to Topologies



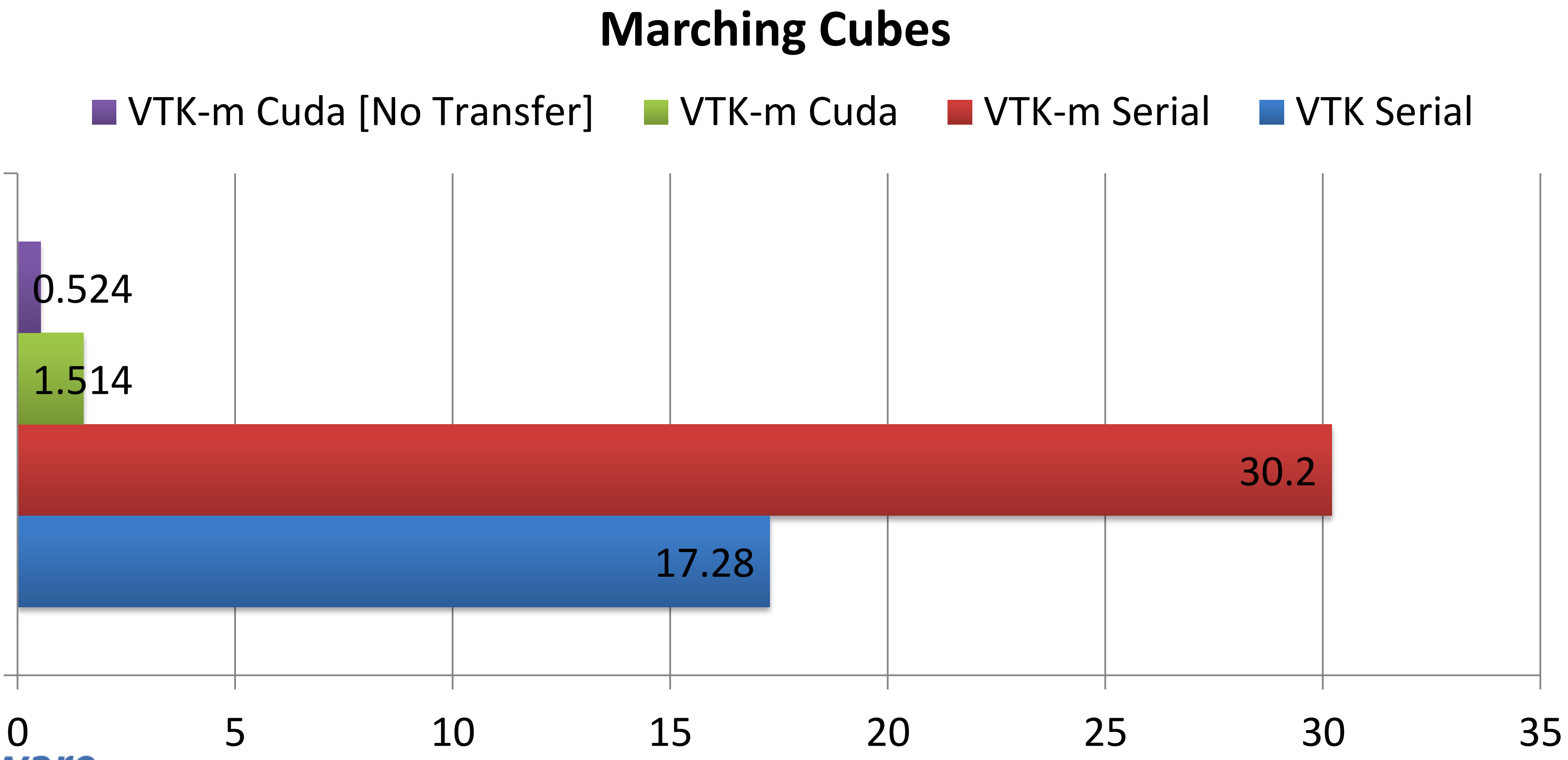
What We Have So Far

- Features
  - Core Types
  - Statically and Dynamically Typed Arrays
  - Device Interface (Serial, Cuda, TBB under development)
  - Basic Worklet and Dispatcher

What We Have So Far

- Compiles with
  - gcc (4.8+), clang, msvc (2010+), icc, and pgi
- User Guide
- Ready for larger collaboration

2 x Intel Xeon CPU E5-2620 v3 @ 2.40GHz + NVIDIA Tesla K40c
Data: 1024^3 (floats)



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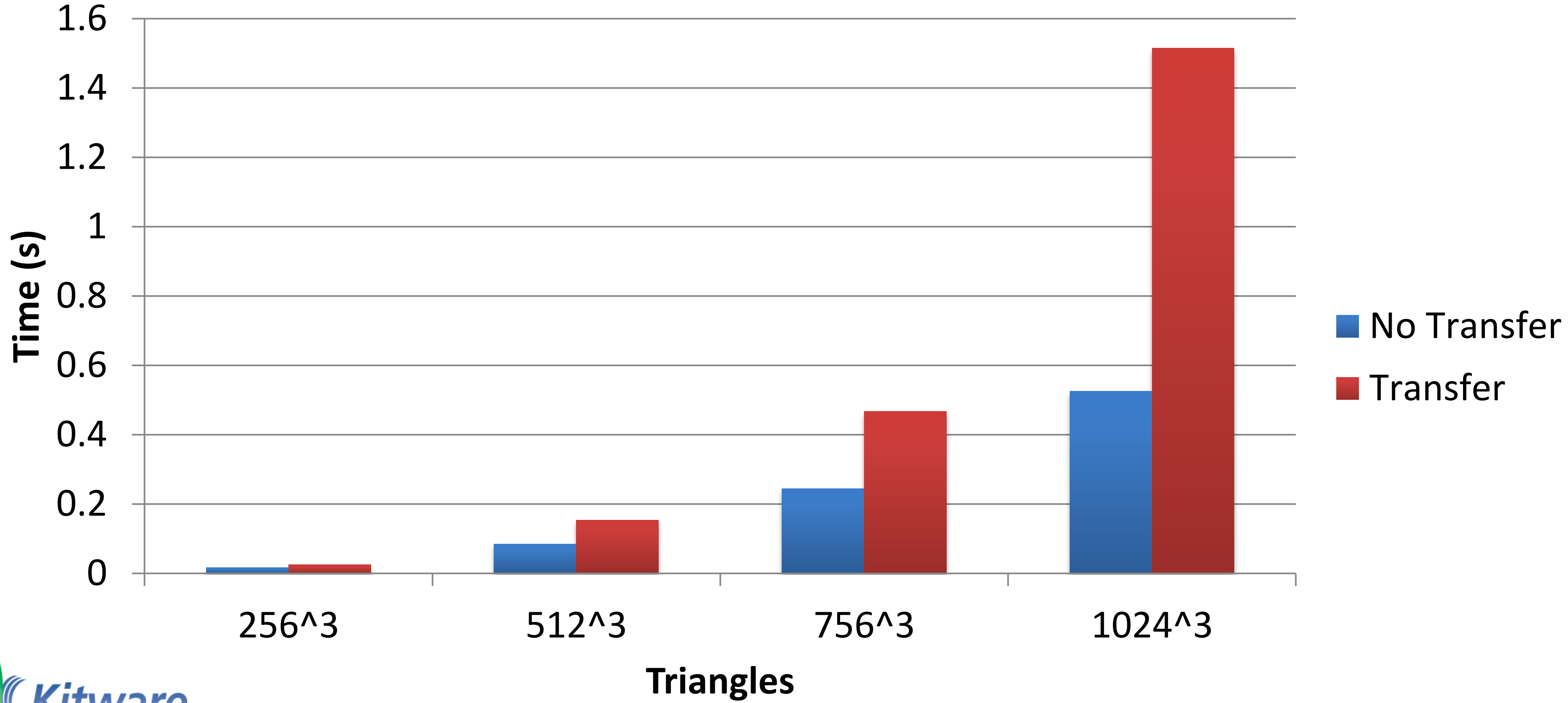

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Future Directions

- Make custom rendering easier
- Improved support for mobile
- Improved support for multitouch
- Extend approaches to the web
- Optionally use new features (OpenGL 4.4)

Coprocessing/In-situ

- Use of VTK and VTK-m
  - Process data in place using VTK-m
  - Visualize and analyze using VTK
- Bringing highly parallelized visualization and analytics in science to all
- Create bridges between VTK and VTK-m

Thank You!

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Checkout out Kitware @ www.kitware.com and VTK @ www.vtk.org

Please complete the Presenter Evaluation sent to you by email or through the GTC Mobile App. Your feedback is important!