OpenSWR: A Scalable High-Performance Software Rasterizer for SciVis

Intel HPC Developer Conference
November 14, 2015
Software Defined Visualization: Our Approach

Option 1: Support existing APIs (OpenGL*)
- Works with existing applications
- No code changes or recompilation required
- OpenSWR software rasterizer

Option 2: Enable new functionality and improved performance through a new API
- Good option for new applications
- Integration underway for existing Key applications (ParaView*, VisIt, VMD, ....)
- OSPRay ray tracing based rendering engine [built on Embree kernel library]

Our SDVis solutions support BOTH options!

1 Intel® Xeon® processor,
2 Intel® Xeon Phi™ coprocessor.
Outline

- OpenSWR
  - Motivation and goals
  - Alpha Progress
  - SWR Core (a peek under the hood)
  - Early Results
  - Next steps
## OpenSWR: Why Another Software Rasterizer?

<table>
<thead>
<tr>
<th></th>
<th>llvmpipe</th>
<th>SWR</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Threading model</strong></td>
<td>Single threaded vertex processing, up to 16 threads for rasterization</td>
<td>Common thread pool (1 to N threads) that pick up frontend (vertex) or backend (fragment) work as available</td>
</tr>
<tr>
<td><strong>Vertex Processing</strong></td>
<td>Entire draw call processed in single pass</td>
<td>Large draws chopped into segments that can be operated on in parallel</td>
</tr>
<tr>
<td><strong>Frontend/Backend coupling</strong></td>
<td>Separate binning pass in the single threaded frontend</td>
<td>Frontend vertex processing and binning combined in a single pass</td>
</tr>
<tr>
<td><strong>Primitive Assembly and Binning</strong></td>
<td>JIT, hand-coded SSE, and Scalar C One primitive at a time</td>
<td>x86-intrinsics (Intel® Streaming SIMD Extensions, Intel® Advanced Vector Extensions) working on vectors of primitives</td>
</tr>
</tbody>
</table>
OpenSWR: Alpha1 Release

- December 2014
- SWR core rasterizer with prototype OpenGL* driver
- Roughly OpenGL* 1.4 equivalent
- Fixed function pipeline, no exposed shaders
- Just enough functionality to run key applications (ParaView, VisIt)
- Source available on github ([https://github.com/OpenSWR/openswr](https://github.com/OpenSWR/openswr))
OpenSWR: Alpha2 Release

- September 2015
- SWR core rasterizer with Mesa3D 11.0 driver layer
- OpenGL* 3.x functionality with stream-out
- Vertex and Fragment shaders using GLSL version 130.
- Key applications supported: ParaView, VisIt, EnSight
- Began Mesa community review process by posting source to github (https://github.com/OpenSWR/openswr-mesa)
OpenSWR: Alpha1 vs Alpha2

- Current performance is still quite good, but lost a lot in switching from prototype OpenGL* driver to Mesa – 70% in some cases!
- due to interface issues that need tuning
- differences in shader code generation
- due to conformance and feature additions to the SWR core
- Functionality improvements were well worth the switch
- a modern OpenGL* driver from scratch is a large and complex task!
- Hopeful to recover most of this performance back
OpenSWR: Architecture Within Mesa3D

- Application
- Mesa3D OpenGL* API Layer
- gallium state tracker
- llvmpipe driver
- OpenSWR driver
- OpenSWR Core
- Vertex/Fragment Shader Cores
- Texture Unit
SWR Core
(a peek under the hood)
SWR Core: Features

- High performance, highly scalable software rasterizer
- Core provides threading model and fixed-function rasterization units
  - Features include tessellation, stream-output, 16x MSAA
- Driver layer provides shader callbacks
- Goal is to become a conformant, full-featured rasterizer
- Can support any API with appropriate driver
SWR Core: API

- SWR Core has a modern GPU-like API
  - Device/Context
  - State objects
  - Queries
  - Draw functions for execution
  - Serves as a “hardware interface” on which to write a standard driver
SWR Core: Pipeline Overview

Frontend (FE)

- Fetch Shader (FS)
- Vertex Shader (VS)
- Tessellator (HS/TS/DS)
- Geometry Shader (GS)
- Stream Output (SO)
- Binner

Memory Resources

- Rasterizer (RS)
- Pixel Shader (PS)
- Blend Shader (BS / OM)

Backend (BE)
SWR Core: Frontend Features

- Fully multithreaded vertex processing
  - Common thread pool (1 to N threads)
  - All threads can work on frontend (vertex) or backend (fragment) tasks
  - All threads can participate in vertex processing – crucial for HPC
  - Large draws broken up into smaller draws to aid parallelism

- Vertex pipeline is fully vectorized up to AVX2
  - SIMD abstraction and LLVM use enables path to AVX512
  - Frontend optimized for each primitive type
SWR Core: Frontend Features (continued)

- Vertex memory management designed for low overhead
  - Only requires storage for vertices of 8 primitives
  - Custom arena allocator
  - Small binning memory for each triangle (40 bytes)

- Advanced vectorized culling techniques
  - Necessary for large triangle count workloads seen in HPC/SciVis
  - Zero area
  - Viewport/scissor cull
  - Cull between pixel centers (very small triangles)
SWR Core: Frontend Features (continued)

- Quick early-rasterization phase to further cull primitives around pixel centers
  - Triangles that get processed through this phase pass the resulting coverage mask to the backend to completely skip rasterization stage
  - Have seen > 90% triangles of large workloads culled, significantly reducing unnecessary binning/rasterization

- Other ideas in development
  - Position-only shading
  - Deferred attribute shading
  - NUMA aware rasterization
OpenSWR Early Results
Performance: OpenSWR vs MESA* llvmpipe

- Intel® Xeon® E5-2699 v3 Processor 2 x 18 cores, 2.3 GHz
- ParaView® 4.3.1
- OpenSWR “alpha 2”
  - (full system configuration on slide 20)

Software and workloads used in performance tests may have been optimized for performance only on Intel microprocessors. Performance tests, such as SYSmark® and MobileMark®, are measured using specific computer systems, components, software, operations and functions. Any change to any of those factors may cause the results to vary. You should consult other information and performance tests to assist you in fully evaluating your contemplated purchases, including the performance of that product when combined with other products. For more information go to http://www.intel.com/performance.
Performance: OpenSWR

Scene Complexity vs Core Count

- Intel® Xeon® E5-2699 v3 Processor 2 x 18 cores, 2.3 GHz
- ParaView® 4.3.1
- OpenSWR “alpha 2”
  - (full system configuration on slide 20)

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# Performance Test Configuration

<table>
<thead>
<tr>
<th>Node count</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Platform</strong></td>
<td>Cottonwood Pass Platform (Intel)</td>
</tr>
<tr>
<td><strong>CPU</strong></td>
<td>Intel® Xeon® processor E5-2699 v3 LGA2011 2.3GHz 45MB 145W (DP) Dual socket 18 core</td>
</tr>
<tr>
<td><strong>RAM</strong></td>
<td>128 GB total 8*16GB 2133MHz Reg ECC DDR4</td>
</tr>
</tbody>
</table>
| **BIOS** | Vendor: Intel Corporation  
Version: SE5C610.86B.01.01.0005.101720141054  
Release Date: 10/17/2014  
BIOS Configuration: default |
| **Hard drive** | Intel® SSD SA2M160G2GC  
1x160 GB SATA* SSD |
| **NVIDIA Co-Processor** | NVIDIA® GeForce® GTX® Titan X  
3072 CUDA Cores  
12GB memory  
Software Details: CUDA Version 7.0.28  
OptiX Version 3.8.0  
NVIDIA Driver Version 346.46 |
| **OS / Kernel** | CentOS release 6.6 / 2.6.32-504.23.4.el6.x86_64 |
OpenSWR Testing Results

- VTK (OpenGL2\(^*\) and OSMesa backends)
  - ctest suite passing 99% (~1600 tests)
- ParaView (OpenGL2\(^*\) backend)
  - ctest suite passing 96% (~1150 tests)
- VisIt v2.8.1 conformance suite
  - Passing 85% automated testing
  - Some real issues that we’re fixing.
  - But, many are minor pixel differences between OpenSWR and gold images.
- EnSight\(^*\)
  - Autotests passing at 95% (failing 31/679 tests)
  - “Almost all failed tests are due to line rendering issues” versus gold images.
  - Usage testing has uncovered some issues that we’re debugging.
- OpenGL\(^*\) conformance and Mesa piglit testing will follow
  - Results are currently poor due to missing GS support.
OpenSWR: Apps Experience

- ParaView
  - IPCC Lightening Talk
  - Kitware booth demo
- VisIt
  - IPCC Lightening Talk
  - University of Tennessee booth demo
- EnSight*
  - Sean Ahern, CEI
    "Rendering in EnSight with OpenSWR"
  - SuperMicro* booth demo
# Roadmap

<table>
<thead>
<tr>
<th>2015</th>
<th>2016</th>
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<tbody>
<tr>
<td><strong>Alpha2 – Source available Now</strong></td>
<td></td>
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<tr>
<td>- OpenGL® 3.x+, GLSL</td>
<td></td>
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<tr>
<td>- Mesa3D Environment</td>
<td></td>
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<tr>
<td>- VTK 6, 7 / ParaView® 4, 5 / VisIt 2.10</td>
<td></td>
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<tr>
<td><strong>Beta1 – Q4</strong></td>
<td></td>
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<tr>
<td>- Initial Intel AVX-512 support</td>
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<tr>
<td>- Planned source upstream to Mesa3D</td>
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<tr>
<td>- CEI EnSight® support</td>
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<tr>
<td><strong>Beta2 – 1H 2016</strong></td>
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<tr>
<td>- Optimized Intel AVX-512</td>
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<tr>
<td>- Additional app support in planning</td>
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All products, computer systems, dates and figures specified are preliminary based on current expectations, and are subject to change without notice.

Intel® Advanced Vector Extensions (Intel® AVX);
Summary

- OpenSWR offers a compelling advantage over the standard Mesa software renderers for large-data visualization applications
- Both driver and core development are fully supported
- Planned open source upstream to Mesa master branch
- Works with existing OpenGL* applications
- No code changes or recompilation required

<table>
<thead>
<tr>
<th>Application</th>
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<tbody>
<tr>
<td>OpenGL* Renderer</td>
<td>OSPRay Renderer</td>
<td></td>
</tr>
<tr>
<td>OpenGL(MESA3D)</td>
<td>OSPRay+Embree</td>
<td></td>
</tr>
<tr>
<td>OpenSWR</td>
<td></td>
<td>Xeon(^1) + Xeon Phi(^2)</td>
</tr>
</tbody>
</table>

\(^1\) Intel® Xeon® processor, \(^2\) Intel® Xeon Phi™ coprocessor.
Q&A
Call to Action

http://www.openswr.org

Source available on github (https://github.com/OpenSWR/openswr-mesa)

Information about all of the Software Defined Visualization open source products can be found on http://sdvis.org/
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