The Effect of Emerging Architectures on Data Science (and other thoughts)

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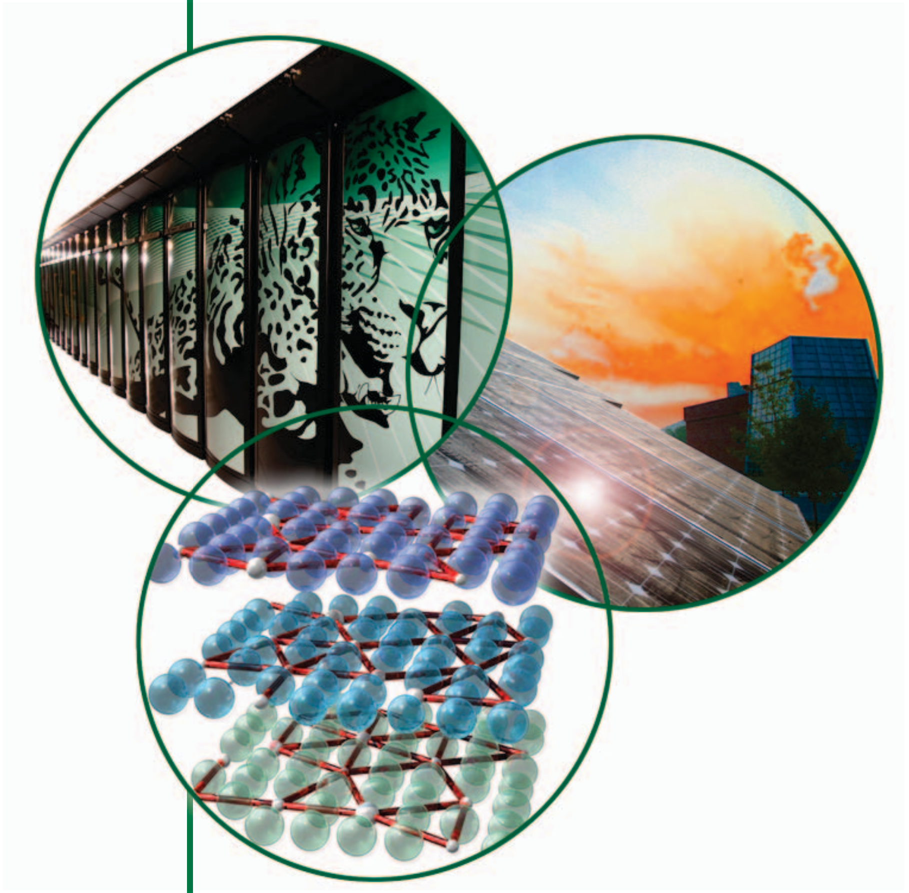
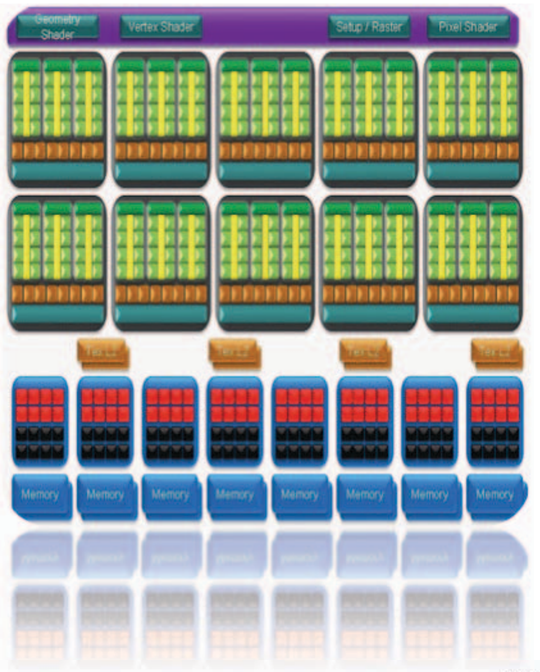
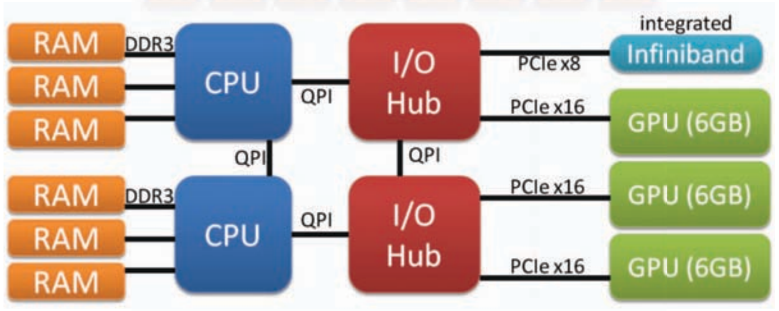


Emerging (Emerged?) Technology I

- Accelerators (DOE Vancouver, NSF Keeneland)
  - Graphics Processing Units (GPUs)
  - Manycore (e.g., Intel's Many Integrated Core)
  - Field Programmable Gate Arrays (FPGAs)
  - Potential for many more threads of execution
    - Great performance, if you can make use of them
    - Many more "events" per walltime unit
  - Tighter coupling between CPU and accelerator (e.g., GPUs/FPGAs in HyperTransport sockets, AMD Fusion)
  - Open architectural questions about relative role of host to accelerator
    - Reduced role of host (CPU) – e.g., NVIDIA project Denver
    - NIC integrated with the GPU?





Emerging (Emerged?) Technology II

- Memory Hierarchy
  - NVRAM (e.g., flash, Phase Change Memory) (DOE Blackcomb project)
  - Solid State Drives (SSDs)
  - Higher performance (but smaller capacity) storage, close to the processor
  - Open questions in programmability (as memory or as disk? Memory mapped?)
  - Potential uses:
    - Burst buffers (e.g., for checkpoints, event traces)
    - Out-of-core algorithms
- Networking
  - High bandwidth traditional networking technologies (e.g., FDR InfiniBand), smart (programmable) NICS
  - Photonics – High throughput, low latency increases effectiveness of in situ analysis
- Programming Models
  - CUDA, OpenCL, OpenACC, OpenMP
  - Domain Specific Languages
  - Interesting that no one at the workshop talked about the community darling programming models (MapReduce)

http://keeneland.gatech.edu

Keeneland

Full Scale WIP

[illegible]

[illegible]

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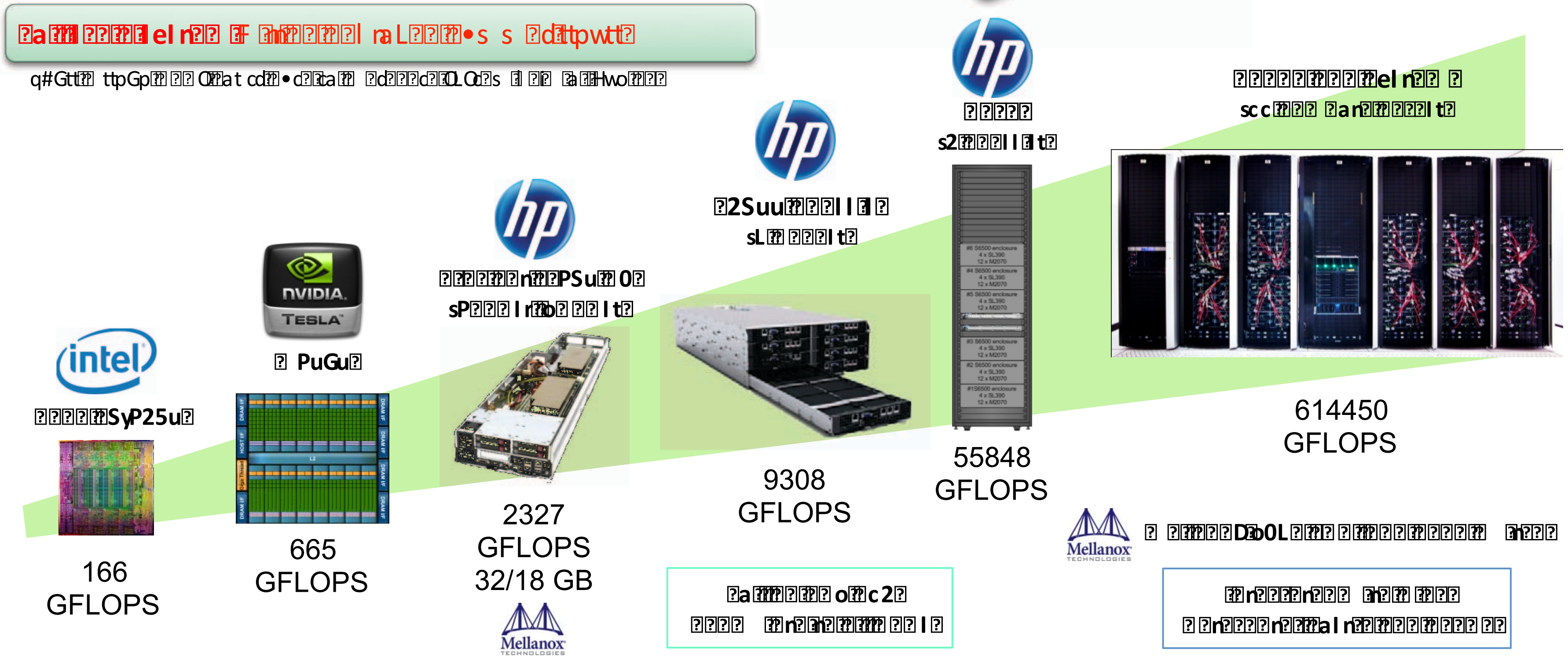
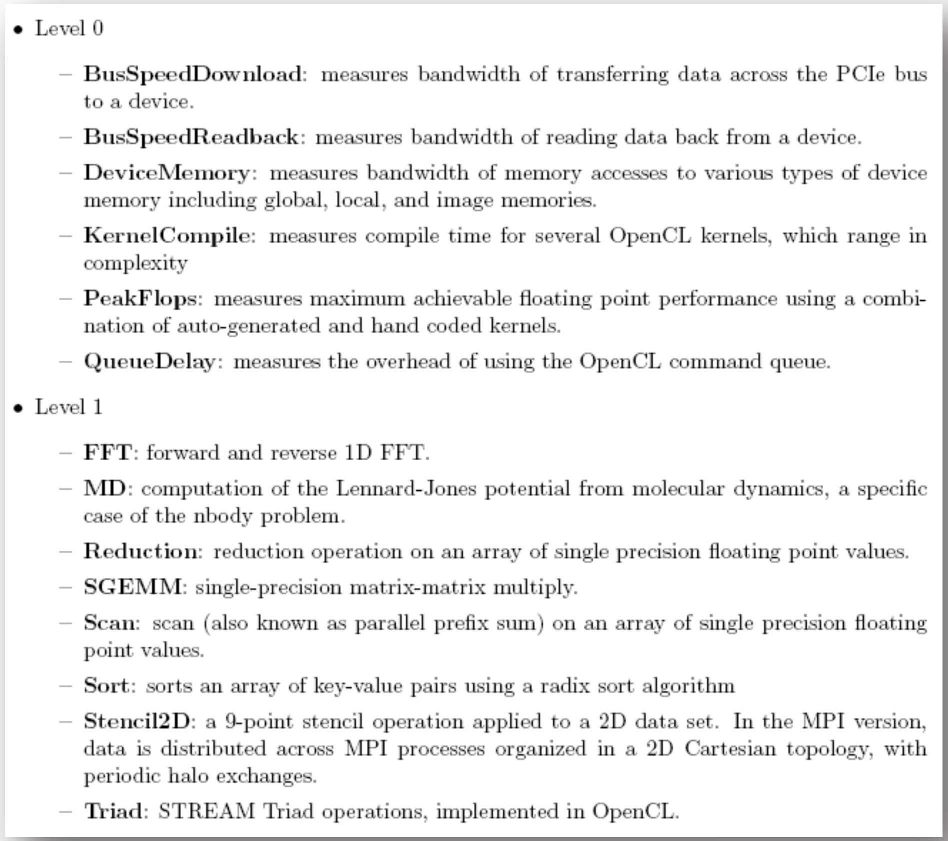


J.S. Vetter, R. Glassbrook *et al.*, *"Keeneland: Bringing heterogeneous GPU computing to the computational science community," IEEE Computing in Science and Engineering*, 13(5):90-5, 2011, http://dx.doi.org/10.1109/MCSE.2011.83.

The Scalable HeterOgeneous Computing (SHOC) Benchmark Suite

- **Benchmark suite with a focus on scientific computing workloads, including common kernels like SGEMM, FFT, Stencils**
- **Parallelized with MPI, with support for multi-GPU and cluster scale comparisons**
- **Implemented in CUDA and OpenCL for a 1:1 performance comparison**
  - **Will be adding OpenACC versions soon**
  - **Have contributions from Intel for MIC**
- **Includes stability tests**



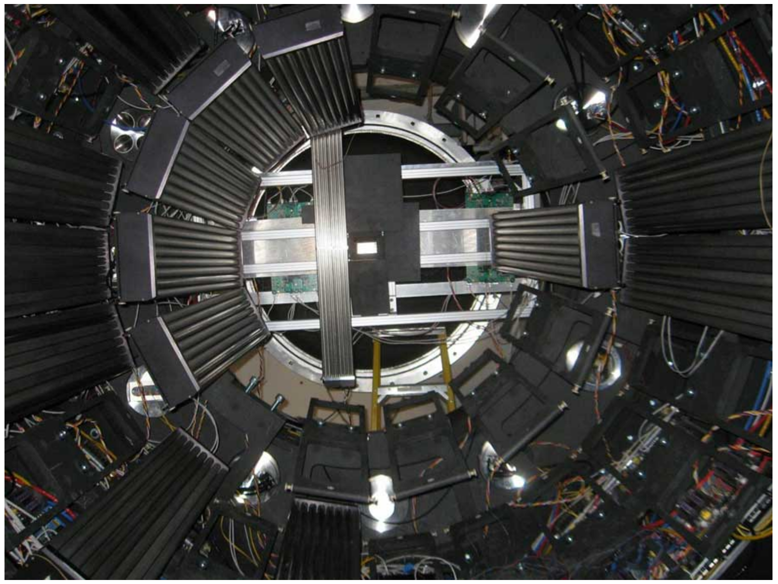
- Level 0
  - **BusSpeedDownload**: measures bandwidth of transferring data across the PCIe bus to a device.
  - **BusSpeedReadback**: measures bandwidth of reading data back from a device.
  - **DeviceMemory**: measures bandwidth of memory accesses to various types of device memory including global, local, and image memories.
  - **KernelCompile**: measures compile time for several OpenCL kernels, which range in complexity
  - **PeakFlops**: measures maximum achievable floating point performance using a combination of auto-generated and hand coded kernels.
  - **QueueDelay**: measures the overhead of using the OpenCL command queue.
- Level 1
  - **FFT**: forward and reverse 1D FFT.
  - **MD**: computation of the Lennard-Jones potential from molecular dynamics, a specific case of the nbody problem.
  - **Reduction**: reduction operation on an array of single precision floating point values.
  - **SGEMM**: single-precision matrix-matrix multiply.
  - **Scan**: scan (also known as parallel prefix sum) on an array of single precision floating point values.
  - **Sort**: sorts an array of key-value pairs using a radix sort algorithm
  - **Stencil2D**: a 9-point stencil operation applied to a 2D data set. In the MPI version, data is distributed across MPI processes organized in a 2D Cartesian topology, with periodic halo exchanges.
  - **Triad**: STREAM Triad operations, implemented in OpenCL.

[illegible]

Software available at https://github.com/spaffy/shoc/wiki

Data Intensive *Computer* Science

- Usual focus is on data problems from science domain
  - Computational science (simulations)
  - Scientific instruments (e.g., particle detectors)
- System administration and monitoring tools can cause data-related problems too



NOMAD detector
Image courtesy Dr. Jörg Neuefeind, ORNL

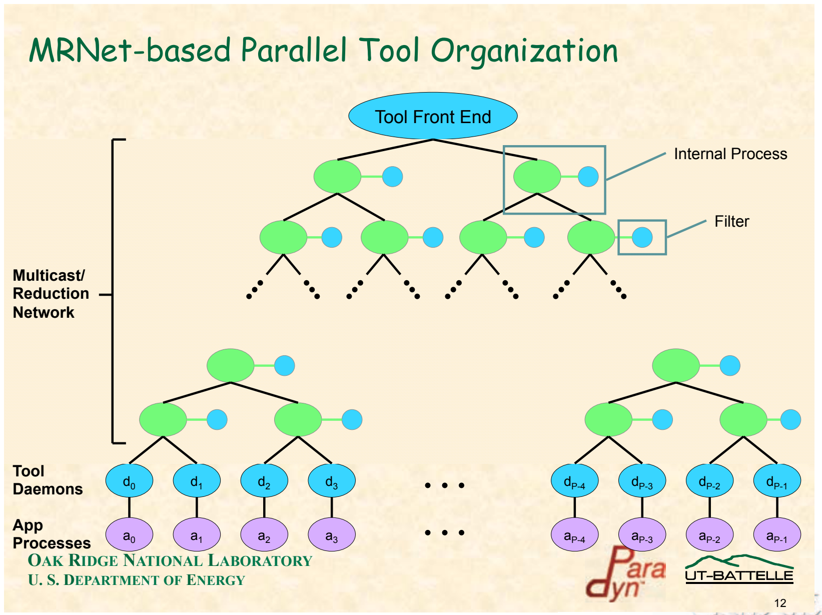
- Event tracing is notorious for causing data *collection*, *management*, and *analysis* problems
  - Similar to that particle detector…
  - …except that we often want to analyze the data *online* so we can make some change
  - Emerging architecture (e.g., GPUs) can greatly exacerbate the problem

Data Intensive *Computer* Science: Example

- Example from my past: Paradyn parallel performance tool (RIP), Bart Miller, U. Wisconsin
- Tool used calipers (inserted using Dynamic Instrumentation) to generate performance data
  - On-line analysis feeds decisions about what instrumentation to insert/remove as program runs
- Tool daemons sampled that data and sent to tool's front end for analysis
- Performance data volume could be large, due to:
  - High sampling rate
  - Large number of active metrics
  - Large number of monitored processes

Data Intensive *Computer* Science: Example

- Our approach: develop and use a multicast/reduction network (MRNet) to reduce data within an overlay network before it reaches the tool's front end
- Interesting analogous to in situ analysis
  - Where to run MRNet internal processes?
  - What filters are needed? How to synchronize streaming data in filters?
- Today: Hadoop (in a separate analysis cluster)? GPU accelerated reduction filters?
- Another example: Tiwari et al, "Quantifying the Potential for Program Analysis Peripherals," PACT 09 – shows benefit of using FPGAs to accelerate valgrind-based analysis tools


MRNet-based Parallel Tool Organization
Tool Front End
Internal Process
Filter
Multicast/ Reduction Network
Tool Daemons
App Processes
d_0 d_1 d_2 d_3 . . . d_{P-4} d_{P-3} d_{P-2} d_{P-1}
a_0 a_1 a_2 a_3 . . . a_{P-4} a_{P-3} a_{P-2} a_{P-1}
Oak Ridge National Laboratory
U. S. Department of Energy
Paradyn
UT-Battelle
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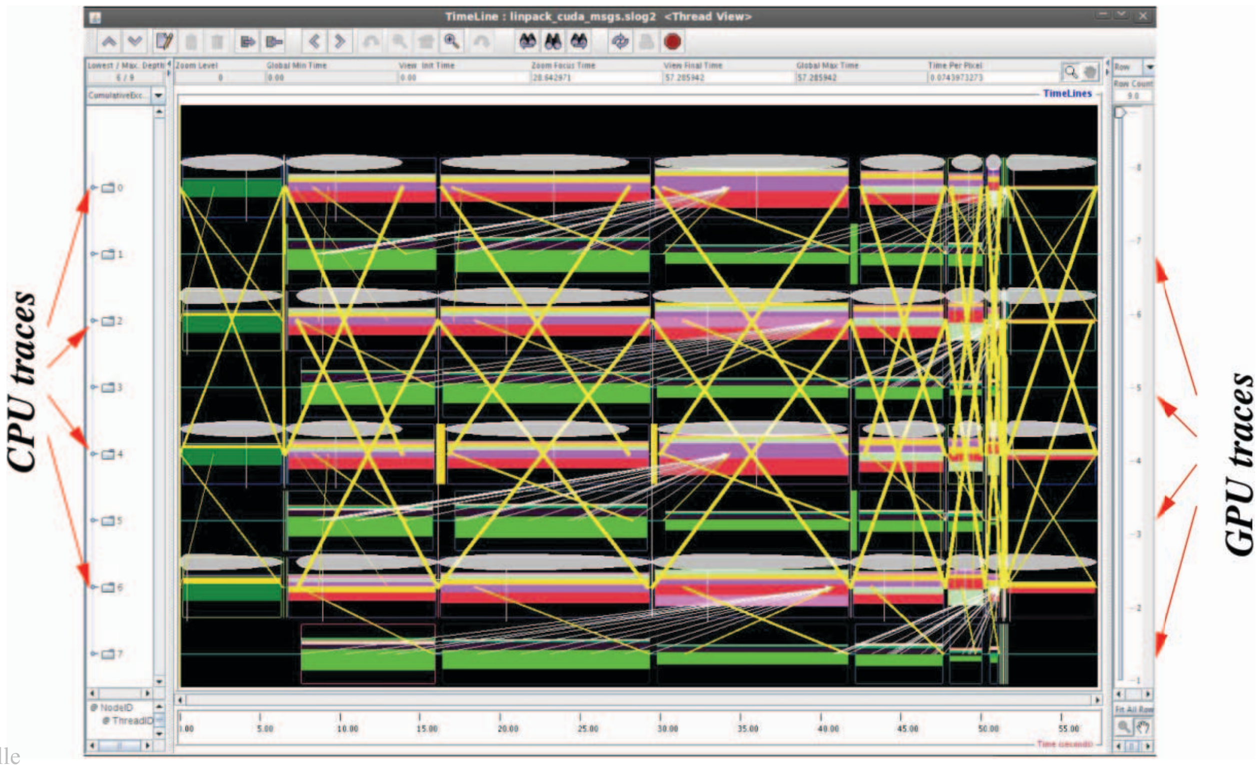
Visualizing Performance Data

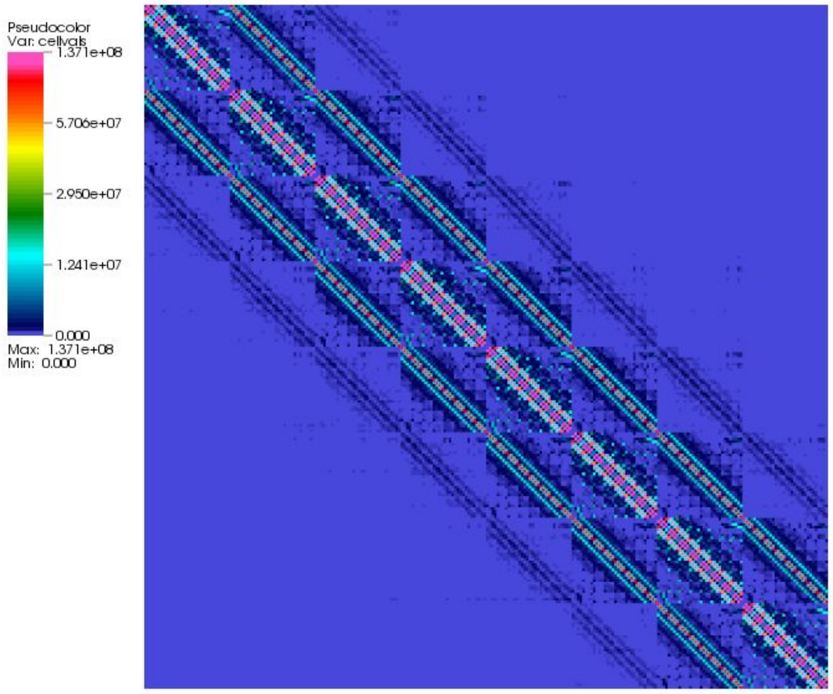
- **Machines have long been large enough to motivate research into scalable performance data visualization**
- **Architectures with GPUs, manycore exacerbate the problem (greater data volume)**



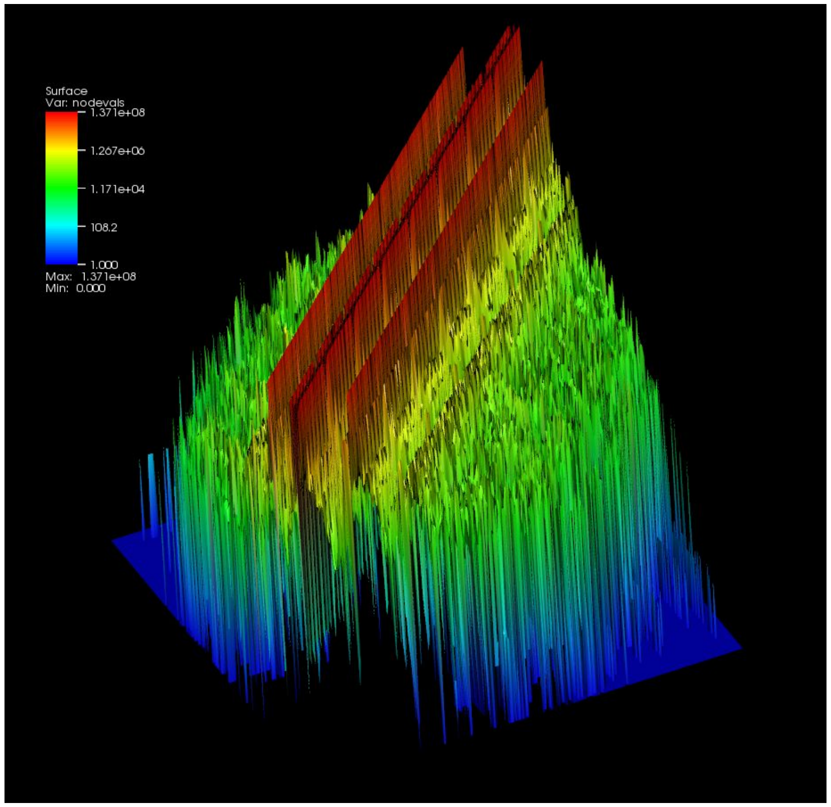
TAU images courtesy Allen Malony, U. Oregon, http://tau.uoregon.edu

Visualizing Performance Data

- **How well do traditional science visualization techniques apply to performance data?**



VisIt images courtesy Jeremy Meredith, ORNL



Summary

- Emerging technology in compute, memory hierarchy, and interconnect
  - Promise of increased performance, larger opportunities for online analysis like in situ visualization
  - But: can make performance data analysis and visualization much more difficult

- Don't forget: there are data problems in computer science domain too
  - Do same techniques apply?

- For more information:
  - rothpc@ornl.gov
  - http://ft.ornl.gov

  - Keeneland (NSF Track 2D): http://keeneland.gatech.edu
  - Vancouver (DOE X-Stack): http://ft.ornl.gov/trac/vancouver
  - Institute for Sustained Performance, Energy, and Resilience (SUPER, DOE SciDAC-3): http://super-scidac.org