MemXCT: Memory-Centric X-ray CT Reconstruction with Massive Parallelization

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ABSTRACT

X-ray computed tomography (XCT) is used regularly at synchrotron light sources to study the internal morphology of materials at high resolution. However, experimental constraints, such as radiation sensitivity, can result in noisy or undersampled measurements. Further, depending on the resolution, sample size and data acquisition rates, the resulting noisy dataset can be terabyte-scale. Advanced iterative reconstruction techniques can produce high-quality images from noisy measurements, but their computational requirements have made their use exception rather than the rule. We propose here a novel memory-centric approach that avoids redundant computations at the expense of additional memory complexity. We develop a system, MemXCT, that uses an optimized SpMV implementation with two-level pseudo-Hilbert ordering and multi-stage input buffering. We evaluate MemXCT on various supercomputer architectures involving KNL and GPU. MemXCT can reconstruct a large (11K×11K) mouse brain tomogram in ~10 seconds using 4096 KNL nodes (256K cores), the largest iterative reconstruction achieved in near-real time.

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1 INTRODUCTION

X-ray computed tomography (XCT) is a widely used nondestructive 3D imaging technique for observing and understanding the internal morphology of samples and materials. Synchrotron light sources, such as the Advanced Photon Source (APS), can provide high-brilliance x-rays that enable tomographic imaging of centimeter sized samples at sub-micrometer (μm) spatial resolution and these experiments can generate few GBs up to TBs of data volumes in short time with the typical pixelated detectors that can run at 16GiB/s [1]. However, the quality of data collected from CT experiments depends heavily on factors such as radiation exposure time

(dose) and target spatial resolution. Much effort has been devoted to develop and implement advanced reconstruction algorithms to improve image quality when collected data is noisy or imperfect (e.g., due to limited dose.)

Modern x-ray reconstruction approaches involve either (i) direct solvers based on analytical inversion or (ii) iterative solvers when one can accurately model experimental conditions or constraint the solution based on prior knowledge of the sample. Analytical methods such as the filtered backprojection (FBP) algorithm are computationally efficient, but reconstruction quality is often poor when measurements are noisy or undersampled. Iterative methods, on the other hand, can use advanced optimization and regularization techniques to handle inherent noise in x-ray measurements [3–9]. However, these methods are computationally more demanding than the analytical methods, since forward and backprojection operations require many (irregular) accesses and computation at each iteration. Thus, efficient implementation and parallelization are crucial for high-quality large-scale image reconstructions.

Most state-of-the-art reconstruction software and libraries can perform parallel reconstruction to some extent. However, these implementations mostly rely on data replication [10, 11] and/or redundant computations [12, 13], each of which significantly limits the runtime performance of the system due to repeated computation of intermediate indices of ray tracing and irregular data accesses.

We propose here a novel memory-centric approach to avoid redundant computation by removing on-the-fly operations at the expense of greater memory complexity. Our system, MemXCT, uses an optimized sparse matrix-vector multiplication (SpMV) implementation with *multi-stage buffering* and *two-level pseudo-Hilbert ordering* to optimize data communication, partitioning, and accesses at different analysis levels and on both measurement (sinogram) and reconstructed (tomogram) data.

MemXCT memoizes on-the-fly operations and therefore requires more memory than alternatives. However, its overall per-node memory footprint decreases linearly with increasing computing resources, promoting scalability with massive parallelization and enabling iterative reconstruction of extremely large datasets with efficient resource use. Further, MemXCT stores intermediate data structures in compressed format to minimize memory footprint.

To illustrate the practical implications of MemXCT optimizations, we show in Fig. 1 a 2D tomogram from a 3D mouse brain image with total size 11 293×11 293×11 293, obtained by reconstructing a sinogram with 4501×11 293 dimensions. This single-slice reconstruction was generated with 30 conjugate gradient (CG) iterations in about 10 seconds on 4096 KNL nodes (256K cores) using MemXCT. This high speed capability makes it feasible, for the first time, to apply

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Figure 1: Multiple zooms on a single 11 293×11 293 2D slice of a mouse brain image generated by reconstruction, with the methods described here, from a single sinogram with size 4501×11 293. Data were collected by Dyer et al. [2] at the APS. Single-slice reconstruction with 30 CG iterations on 4096 KNL nodes takes ~10 seconds. Memory footprint of the application is 10.2 TiB. The full mouse brain consists of 11 293 slices.

advanced iterative reconstruction algorithms to extremely large CT datasets. The multi-scale nature of the reconstruction is presented by zooming progressively to the brain arteries, where great detail can be seen. High reconstruction quality at such scales is important as subsequent data analysis steps, such as segmentation of blood vessels and myelinated axon tracts, are highly dependent on the quality of the reconstruction.

The principal contributions of this paper are as follows:

- We propose a memory-centric approach that uses an *extended SpMV* to address race conditions due to scatter operations. Our implementation replaces scatter operations on sinogram and tomogram domains with gather operations.
- We implement a *two-level pseudo-Hilbert ordering* to organize communication and data access pattern, further improving communication performance, utilization of different levels of memory hierarchy, and cache utilization.
- We introduce a *multi-stage input buffering*. Domain partitioning improves process-level data communication and locality; multi-stage buffering enables data reuse in first-level caches and minimizes memory latency.
- We extensively evaluate *MemXCT* performance on both KNL and GPU systems up to 4096 nodes, and show architecture-specific considerations and optimizations.

2 BACKGROUND AND MOTIVATION

We first explain XCT experiments and their data acquisition process. Then, we describe the steps involved in iterative image reconstruction. Finally, we explain computational bottlenecks in iterative reconstruction approaches and introduce our solutions.

2.1 Data Acquisition and Measurement Process

In an XCT experiment, the sample is placed on a rotation stage and illuminated by an x-ray source, while collecting 2D images through a detector as the sample is being rotated: see Fig. 2. The mathematical model of the measurement process is based on Beer's law [14] that describes interaction between X-rays and matter:

$I_\theta(s) = I_0(s) \exp[-p_\theta(s)]$, where $I_0(s)$ is the incident x-ray illumination on the sample and $I_\theta(s)$ are the collected measurements at a number of different θ angles as a result of a tomographic scan.

In Fig. 2, a set of collected projections from a sample is shown with p_{θ_i} . Considering parallel beam geometry, the sinogram $p_\theta(s)$ is a cross section of projections (shown in blue grid on p_{θ^*}) that consists of I_θ measurements from f . The goal of a tomographic reconstruction algorithm is to recover 2D image slice (tomogram) from its corresponding sinogram $p_\theta(s)$.

2.2 Iterative Formulation

Tomographic reconstruction solves the problem

$$\hat{x} = \underset{x \in C}{\operatorname{argmin}} \|y - Ax\|^2 + R(x), \quad (1)$$

where $\hat{x}$ is the reconstructed tomogram, A is the forward model, y is the sinogram, $R(x)$ is a regularizer functional, x is the search variable, and C is a constraint on x .

Almost all iterative solvers based on gradient descent perform three common steps in each iteration as depicted in Fig. 2. Specifically, for iteration i : first, the residual $r_i = y - Ax_i$ is found through *forward projection*; second, the gradient is found through *backprojection* as $\nabla\|y - Ax_i\|^2 = A^T r_i$; and finally, the candidate solution is updated in the negative-gradient direction as $x_{i+1} = x_i - \alpha \nabla\|y - Ax_i\|^2$, where α is the step size. Iterative approaches can also involve additional updates due to regularizer $R(x)$ and constraint C . However, this paper focuses on the common computational costs involving aforementioned steps.

2.3 Forward and Backprojection

Forward and backprojections are the two most computationally demanding kernels in iterative tomographic reconstruction approaches. Many reconstruction libraries, e.g. Trace and TomoPy[10, 13], implement Siddon's algorithm [15] to perform ray tracing on tomogram domain so that the exact length and weight information on each voxel can be computed for each intersecting x-ray. For forward model, these information are used for computing the residuals, whereas for backprojection they are used for gradient and update operations. Since storing voxel indices and length information for all rays and voxels require significant memory, most

Figure 2: Fig. (a) illustrates an experimental setup where a target object is illuminated with a synchrotron light source. Photons are attenuated by different amounts according to the object’s attenuation coefficient profile and the photons’ travel distance within the object. Fig. (b) presents how the detector measurements are organized and stored as projections (from different angles). Once the experiment is completed, the sinograms are extracted from the projections, and the images corresponding to the object are iteratively reconstructed as shown in Fig. (c).

state-of-the-art approaches perform ray tracing computations on-the-fly. For instance, a sinogram with 1501×2048 dimensions require 56GiB memory to store intermediate data structures. Listing 1 illustrates the high level implementation of iterative reconstruction and repetitive computations of indices and lengths arrays. We term reconstruction algorithms that compute on-the-fly ray tracing information as *compute-centric XCT* (CompXCT).

Listing 1: High Level Implementation of CompXCT

```

1 for(int i = 0; i < num_iters; ++i){ //iterations
2   for(int j = 0; j < sinogram_rows; ++j){
3     float theta = rotations(j); //Corresponding  $\theta$  for row j
4     for(int k = 0; k < sinogram_cols; ++k){
5       int **indices = intersecting_voxels(j, k, theta, tomogram);
6       float **lengths = compute_lengths(j, k, theta, tomogram);
7       float m = sinogram[j, k]; //Measured data for simulated ray
8       float residual = forward_model(m, indices, lengths, tomogram);
9       // Apply inverse model and then update tomogram
10      backprojection(residual, indices, lengths, tomogram);
11    }
12  }
13 }
```

2.4 Computational Bottlenecks and Overview of Our Solution: MemXCT

Fig. 3 illustrates the techniques used for traditional CompXCT and proposed MemXCT approaches in yellow boxes. The existing bottlenecks and their influence are given next to the areas for potential optimizations with different shades of black, in which darker shades indicate higher contribution to performance bottleneck.

CompXCT eliminates the need for storing intermediate data structures; however, since these data structures are recalculated for each iteration, they introduce additional computational complexity

Figure 3: Memory-centric and compute-centric approaches for XCT and their areas for potential optimizations. Shades of black color indicate higher contribution to performance bottleneck.

to the execution. Further, on-the-fly calculation of indices limits the optimizations for vectorization as repeated sorting and padding operations nullify any performance benefit. As a remedy, MemXCT embraces a memory-centric approach that memoizes ray-tracing operations and performs efficient SpMV using compressed (vectorizable) data structures on both sinogram and tomogram domains. Further, the irregular data access patterns are normalized using pseudo-Hilbert ordering and first level cache utilization are improved using multi-stage buffering. These optimizations result in high-performance computations and converts performance bottlenecks from computation to memory.

The parallelization of CompXCT approaches is typically based on x-rays, where each measured ray can independently be projected on tomogram domain. This type of parallelization performs well for forward projection kernel (residual computation) since the main operation is reading the intersected voxel values from tomogram domain, i.e. rays perform *gather operations* during forward projection. However, subsequent backprojection and update steps require synchronization among parallelized rays since there can be many updates from different rays on the same voxel, i.e. rays perform *scatter operations* during backprojection and updates. Recent work deals with race conditions by either applying atomic operations [16] or duplicating the pixel domain across threads/processes and then performing a reduction [10, 11]. Unfortunately, the performance of atomic operations hinges on hardware implementations, which differ substantially across architectures [17], and typically results in significant performance degradation on massively parallel architectures. Domain duplication is also impractical for GPU-like architectures, since each parallel unit requires a replica of the domain and the total memory footprint almost always exceed available resources. Further, distributed memory parallelization using duplication can result in redundant communication cost [10].

In contrast, MemXCT partitions both sinogram and tomogram domains among parallel units and transforms scatter operations to gathers. Note that this transformation can result in irregular data accesses on both domains, however our pseudo-Hilbert index ordering coupled with multilevel buffering amortize performance penalty

due to irregular data accesses. MemXCT also exploits Hilbert ordering (hence named two-level pseudo-Hilbert ordering) for process-level domain partitioning, which results in efficient communication and better connectivity between processes [18, 19]. We describe these optimization in detail in the following section.

3 MemXCT OPTIMIZATIONS

In this section, we provide detailed information about MemXCT. First, we explain the *baseline implementation* of MemXCT, in which we focus on explicit SpMV operations. Then, we present our system optimizations that use *two-level pseudo-Hilbert ordering* and *multi-stage input buffer*. We also explain our distributed memory parallelization considerations with MPI.

3.1 Baseline Implementation

MemXCT performs forward and backprojection operations as explicit SpMV operations to remove redundant and inefficient computations. Listing 2 shows the baseline Compressed Sparse Row (CSR) SpMV kernel used for both forward and back projection. In forward projection, *x* and *y* correspond to tomogram and sinogram data, respectively, and vice-versa in backprojection. In either case, *ind* and *val* data correspond to precomputed pixel-ray intersection indices and lengths that are reused to avoid redundant computation.

Listing 2: Baseline MemXCT Kernel

```

1 #pragma omp parallel for schedule(dynamic, partsize)
2 for(int i = 0; i < numrow; ++i){
3     float acc = 0;
4     //vectorize
5     for(int j = displ[i]; j < displ[i+1]; ++j)
6         acc += x[ind[j]]*val[j];
7     y[i] = acc;
8 }

```

3.1.1 Regular and Irregular Accesses. Each fused multiply-add (FMA) operation in Listing 2 performs three important memory accesses: *ind* and *val* are *regular*, and *x* is *irregular*. The *regular* accesses are sequential and hence exhibit low memory latency. The *irregular* accesses to *x* exhibit long latency due to high L2 miss rates. MemXCT addresses this problem by improving cache reuse through novel data layout techniques that increase locality, as illustrated in Section 3.2.

3.1.2 Row Partitioning & Parallelization. Listing 2 involves gather operations only and hence is suitable for massive parallelization. MemXCT parallelizes the outer loop among *row partitions*. On KNL, partitions are distributed across dynamically scheduled OpenMP threads. On GPU, each partition corresponds to a CUDA thread block. Each OpenMP thread processes many row partitions, whereas each CUDA thread processes a single row in a partition.

3.1.3 Vectorization on KNL. MemXCT enables efficient instruction-level parallelization through vectorization of the inner loop in Listing 2. Each KNL vector-processing unit (VPU) can load multiple regular and irregular data, and multiply them in one step with an AVX-512 instruction. Then, they perform parallel reductions on partial data, and add results to the accumulator. We provide necessary data alignments for efficient vectorization.

Figure 4: Two-level pseudo-Hilbert ordering and domain decomposition: (a) the first level, and then the lower level on (b) process and (c) thread levels.

3.1.4 Coalesced Memory Access on GPU. Our GPU implementation modifies Listing 2 to use the ELL (column-major) storage format instead of CSR. Transposed ELL data structures provide coalesced memory access through consecutive threads accessing consecutive memory locations. We minimize redundant computations and memory accesses due to ELL format by performing zero padding on thread-block (i.e., partition) level, rather than on matrix level.

3.2 Two-Level Pseudo-Hilbert Ordering

MemXCT implements a two-level pseudo-Hilbert ordering on both tomogram and sinogram data of arbitrary size. Fig. 4 shows an example for a 13x11 domain. First, the domain is tiled with a minimum number of equi-sized square tiles with dimension a power of two. In the figure, tile size is 4x4 and 12 tiles are used to cover the 13x11 domain. These tiles are indexed with a Hilbert ordering for rectangular domains [20], as shown in Fig. 4(a). A second-level Hilbert ordering is then applied to the data within each tile. Necessary rotations are performed to provide data connectivity among tiles, so as to achieve both data locality and connectivity for domain decomposition at the process and thread levels, as discussed next. The process-level domain decomposition is essential for MPI parallelization, as discussed in Section 3.4.

3.2.1 Irregular Data Access Patterns. As shown in Fig. 5, the processing of a single sinogram or tomogram results in a linear or a sinusoidal memory access footprint, respectively. In this example, they perform 25 and 30 accesses on respective domains. With row-major (naive) ordering of 2D data and 64 B cache line, each row in Fig. 5 would correspond to a single cache line. In this case, both tomogram and sinogram data would have 16 cache misses, yielding miss rates of 64% and 53%, respectively. Row-major (or column-major) ordering of 2D domains is very inefficient for XCT because of its poor cache locality. That is, a single cache line does not provide enough data reuse except on a few instances.

3.2.2 Cache Locality. In Fig. 5, Hilbert ordering maps each cache line to a 4x4 block in a 2D domain, increasing cache data reuse. As a result, cache misses are reduced to six and seven, yielding rates of 24% and 23% for forward and back projection, respectively. Hilbert ordering is portable to different cache-line sizes thanks to its recursive nature. The cache locality provided by Hilbert ordering

Figure 5: Data access patterns on 2D domains.

eliminates the memory latency bound of MemXCT to a great extent, as results show in Section 4.2.2.

3.2.3 Partition Locality. Hilbert ordering not only provides cache locality but also partition locality. That is, the outer loop of SpMV in Listing 2 is partitioned with respect to the index of y , as described in Section 3.1.2. In MemXCT, each partition remains connected at both the process and thread levels, thanks to the connectivity provided by two-level pseudo Hilbert ordering. In contrast, a Morton ordering would yield disconnected partitions, since it does not guarantee adjacent memory locations to have adjacent locations in the 2D domain. Partition locality is essential for our further optimizations.

3.3 Multi-Stage Input Buffering

MemXCT implements a multi-stage buffering mechanism for: (1) further reducing L2 cache miss rates of irregular data by explicit staging of corresponding accesses on an L1 buffer, and (2) reducing memory bandwidth consumed for index data by using two-byte addressing. Listing 3 shows SpMV kernel with input buffering, where `stagedispl` and `stagenz` arrays correspond to starting points of (multi-stage) buffers and number of (nonzero) elements in buffers, respectively.

Listing 3: Optimized MemXCT Kernel

```

1  #pragma omp parallel for schedule(dynamic)
2  for(int part = 0; part < numparts; ++part){
3      float output[partsize] = {0};
4      float input[bufferize];
5      for(int stage=partdispl[part]; stage<partdispl[part+1]; ++stage){
6          int start = stagedispl[stage];
7          //vectorize
8          for(int i = 0; i < stagenz[stage]; ++i)
9              input[i] = x[map[start+i]];
10         for(int j = 0; j < partsize; ++j){
11             int start = stage*partsize;
12             //vectorize
13             for(int i = displ[start+j]; i < displ[start+j+1]; ++i)
14                 output[j] += input[ind[i]]*val[i];
15         }
16     }
17     int start = part*partsize;
18     //vectorize
19     for(int i = 0; i < partsize; ++i)
20         if(start+i < numrows)
21             y[start+i] += output[i];
22 }

```

3.3.1 Data Reuse from Input Buffer. Fig. 6(a) shows memory access footprints for processing a 64×64 tomogram and sinogram partition in a 256×256 tomogram and sinogram domain, respectively. The tomogram partition reads from the sinogram domain and the sinogram partition from the tomogram domain. Data access footprints are shown in tomogram and sinogram domains. Darker shades represents higher data reuse. For processing each partition, MemXCT explicitly moves required data from memory to an L1

Figure 6: (a) Tomogram and sinogram partitions and respective data access footprints, and (b) multi-stage buffer shapes.

buffer through map at line 9 of Listing 3. Then it reuses buffered data for irregular accesses and hence performs less memory access.

3.3.2 Multi-Staging. In a single-stage (naive) buffering, the required buffer size grows with the problem geometry. If the buffer is too large, it cancels the buffering benefit since it leaks into L2 or even memory [21]. As a remedy, MemXCT implements a multi-stage buffering strategy with a constant buffer size. In this case, irregular data is accessed through multiple buffer stagings. Stages are determined with respect to Hilbert ordering, ensuring data locality. As an example, Fig. 6(b) shows mapping of buffer stages on 2D tomogram and sinogram domains. With a buffer size of 32 KB, MemXCT performs irregular accesses through four and three stages for projection and backprojection, respectively. On KNLs, buffer size should be smaller than 32 KB L1 cache to avoid L2 leak. On GPUs, the buffer is allocated through CUDA shared memory, guaranteeing reuse from L1 cache.

3.3.3 Staging Overhead. Input buffering involves a staging overhead. On KNL, an OpenMP thread stays idle while waiting staging to be completed. Similarly on GPU, CUDA threads across warps stall for synchronization before and after each staging. Input buffering also consumes some additional memory bandwidth for reading map data. The next two subsections describe two techniques for hiding buffering overhead and also to save some bandwidth.

3.3.4 Overlapping Staging and FMAs. MemXCT multi-stage buffering lends itself well to be used by the underlined hardware to hide staging overhead. On KNL, this is done through SMT (simultaneous multithreading): when there are multiple threads running on a single core, the hardware scheduler finds overlapping opportunities across buffer stagings and FMAs among threads. As a result,

MemXCT enables effective SMT utilization. Similarly, GPU hardware also takes advantage of overlapping through block scheduling on SMs (streaming multiprocessors).

3.3.5 Saving Memory Bandwidth. Hilbert ordering and input buffering eliminate most of the memory latency due to irregular data accesses, and therefore MemXCT is bounded by memory-bandwidth consumed by regular data. To alleviate this bottleneck, we use 16-bit addressing to access input buffer (see `ind` at line 14 on Listing 3), rather than 32-bit addressing (as in `ind` at line 6 on Listing 2). 16-bit addressing can address buffer sizes up to 256 KB. This saves 25% of total bandwidth consumption of regular data, and provides additional speedup (see Section 4.2.3 for results.)

3.4 MPI Parallelization

Traditionally, one domain (either tomogram or sinogram) is partitioned while the other is duplicated across all processes. MemXCT partitions both tomogram and sinogram domains by distributing tiles evenly across MPI processes, as seen in Fig 4(b). Each process is responsible for a single *tomogram subdomain* and a single *sinogram subdomain*. Each subdomain consists of a single or several tiles, e.g., subdomain 0 consists of tiles 0–2. While processes are not perfectly load balanced, it can be improved by finer tile granularity at the cost of more preprocessing.

3.4.1 Sparse Communications. MemXCT communicates only necessary data through `MPI_Alltoallv`. To explain, Fig. 7(b) shows communication footprint of two 256×256 tomogram subdomains shown in Fig. 7(a). For example, tomogram subdomain 7 interacts only with sinogram subdomains 1, 2, 8–11, 13, and 14. Fig. 7(c) shows the corresponding communication matrix, where each entry represents communication between two processes. Communication size between each pair depends on the interaction footprint, e.g., process 7 sends more data to process 1 than 14, as seen in Fig. 7(d). Partition locality provided by two-level pseudo-Hilbert ordering (described in Section 3.2) minimizes the footprint, and hence increase data reuse and reduce communications.

3.4.2 Overlapped Interactions. MemXCT communicates sinogram data rather than tomogram data because: (1) sinogram data is smaller in many applications, and (2) it yields more data reuse as compared to tomogram data. In forward projection, tomogram subdomains send partial sinogram data to corresponding sinogram subdomains where overlapped data is reduced, e.g., process 8, 9, and 11 reduces partial sinogram data received from process 7 and 10. In backprojection, processes duplicates overlapped sinogram data and send them to interacted processes which perform backprojections on their respective tomogram subdomains. The communication matrix for backprojection is the transpose of the one in Fig. 7(c). The total amount of communications and load balancing for all processes is shown in Fig. 7(e).

3.4.3 Parallelization Overhead. MemXCT parallelization of forward projection mathematically corresponds to a factorization of the projection matrix as $A = RCA_p$. As a result, forward projection can be modeled as three fundamental steps: A_p , C , and R which correspond to partial forward projection, communication, and reduction operations. Backprojection can also be seen as simply

Figure 7: Communication footprint of two (a) tomogram subdomains on (b) sinogram subdomains. (c) Resulting communication matrix for all processes. (d) The amount of outgoing/incoming data from/to process 7 to/from others. (e) Total incoming and outgoing data for all processes.

$A^T = A_p^T C^T R^T$. The multiplication costs of A_p and original A are the same because they involve the same number of $O(MN^2)$ nonzeros. Thus, communication C and reduction R can be seen as the MemXCT parallelization overhead. Both C and R have $O(MN\sqrt{P})$ nonzeros, where P is the number of processes. It is because when P quadruples, total communication footprint on sinogram domain doubles. For communications, there is an extra $O(\sqrt{P})$ term comes due to the handshake overhead between processes. On the other hand, compute-centric approach involves race conditions and hence it duplicates the tomogram domain across all processes [10]. In that case, duplicated domains has to be reduced through `MPI_Allreduce` at the end of each backprojection, yielding $O(N^2 \log P)$ parallelization overhead. Resulting computational complexities are shown in Table 1.

Table 1: Computational Complexities

	Sequential	Trace	MemXCT
Memory	$MN + N^2$	$MN/P + N^2$	$MN^2/P + MN/\sqrt{P}$
Comput.	MN^2	MN^2/P	$MN^2/P + MN/\sqrt{P}$
Comm.	N/A	$N^2 \log P$	$MN/\sqrt{P} + \sqrt{P}$

M : # of projections, N : # of channels P : # of processes

3.5 Other Details

MemXCT requires an extra preprocessing step for avoiding redundant and inefficient computations as opposed to a compute-centric approach. The preprocessing involve: (1) Hilbert ordering and domain decomposition, (2) ray tracing for constructing forward projection matrix, (3) sparse transposition for constructing backprojection matrix, and (4) row partitioning and building corresponding buffer data structures. Preprocessing is MPI+OpenMP parallel and is performed on CPU.

3.5.1 Preserving Data Locality. MemXCT preserves data locality through all matrix manipulations, which is essential for our performance optimizations. For example, constructing backprojection matrix requires a sparse matrix transposition of the forward projection matrix. MemXCT performs this through a scan-based matrix

transposition [22] which preserves data ordering, rather than an atomic-based transposition which randomizes data ordering.

3.5.2 Iterative Solution. There is a plethora of solution schemes for iterative XCT. To mention a few, recent work implements SIRT [10], SGD [16], and ICD [23] iterations. Any of them can be implemented for our proposed memory-centric approach in a plug-and-play manner with minor modifications. Nevertheless, MemXCT implements CG iterations [24], which has a faster convergence rate than any of them (at a higher per-iteration cost). It is simply because: (1) a full gradient is found rather than a partial gradient, (2) optimal step size is found analytically via an additional forward projection, and (3) visiting redundant directions is prevented via three-term recursion. We use a heuristic early termination of iterations to prevent *over-fitting*, which is practically considered as a regularization method. Convergence results are shown in Section 4.1.2.

4 NUMERICAL RESULTS

All experiments in this paper are performed on ALCF Theta [25], NCSA Blue Waters [26], ALCF Cooley [27], an IBM Minsky node [28], and an Nvidia DGX-1 node [29]. Table 2 characterizes these machines. Mem. B/W is theoretical on-chip memory bandwidth; we assume that ECC (error correcting code) degrades theoretical bandwidth of K20X and K80 by 15% [30]. Link describes interface between host and device.

Table 2: Key Features of Machines Used for Experiments

Machine	Nodes	Accel.	On-Chip Mem.	Mem. B/W	Mem.	Link
Theta	4392	KNL	16 GB MCDRAM	400 GB/s	192 GB	90 GB/s
Blue W.	4228	K20X	6 GB DDR5	121.5 GB/s	32 GB	PCIe
Cooley	126	2xK80	12 GB DDR5	204 GB/s	384 GB	PCIe
Minsky	1	4xP100	16 GB HBM2	720 GB/s	128 GB	NVLink
DGX-1	1	8xV100	16 GB HBM2	900 GB/s	512 GB	NVLink

We used six datasets, as shown in Table 3, in order to evaluate application performance. The first four are artificially created for performance evaluation and the latter two are from real synchrotron experiments at APS. Measurement sinograms are given for a single slice. The artificial datasets follow parallel raster scan geometry just as the real datasets. The irregular and regular data footprints, defined in Section 3.1.1, are given for all datasets in Table 3. The first/second entry for memory footprints are accessed in forward/backprojection, respectively. RDS1 involves a shale sample [31] and RDS2 involves a brain sample. RDS1 is available open source [32], and RDS2 is proprietary.

4.1 Evaluating Overall Performance

4.1.1 Comparison with Compute-Centric Approach. We compare our memory-centric MemXCT with compute-centric Trace [10], an open-source high-performance implementation that employs SIRT iterations. To enable a one-to-one comparison, we implement SIRT, and run 45 iterations with both codes on a single KNL for the ADS2 and RDS1 datasets (see Table 3). Table 4 reports solution times and corresponding speedups. In the best case, where MemXCT memory footprint fits within MCDRAM, it performs each iteration 49.2× faster than Trace. In the worst case, where MemXCT is bounded by slow DRAM bandwidth due to its large memory footprint, it still performs each iteration 6.86× faster. Trace memory footprint fits

within MCDRAM in both cases, but it has to perform redundant and inefficient computation.

Table 3: Dataset Details and Memory Footprints

Name	Sinogram (M×N)	Sample	Irregular Data	Regular Data
ADS1	360×256	Artificial	256/360 KB	215/215 MB
ADS2	750×512	Artificial	1.0/1.5 MB	1.8/1.8 GB
ADS3	1500×1024	Artificial	4.0/6.0 MB	14/14 GB
ADS4	2400×2048	Artificial	16/19 MB	90/90 GB
RDS1	1501×2048	Shale Rock	16/12 MB	56/56 GB
RDS2	4501×11 283	Mouse Brain	500/198 MB	5.1/5.1 TB

Table 4: Comparison with Compute-Centric Approach

		Preproc.	Reconst.	Per-Iter.	Speedup
ADS2	Trace	N/A	26.05 s	579 ms	1×
	MemXCT	4.00 s	0.53 s	11.8 ms	49.2×
RDS1	Trace	N/A	425.3 s	9.45 s	1×
	MemXCT	146.3 s	62.00 s	1.37 s	6.86×

Table 4 reports preprocessing overhead of MemXCT. Although the preprocessing step appears to be a significant fraction of overall time, when it comes to many-slice reconstruction, the preprocessing cost is paid only once for the first slice. It is then reused for all the remaining slices, as shown in Table 5.

4.1.2 Iterative Convergence. MemXCT uses CG for iterative solutions, as discussed in Section 3.5.2, as opposed to SIRT used by Trace. Fig. 8(a) presents convergence properties by comparing L-curves of CG and SIRT up to 500 iterations: horizontal and vertical axes represents residual and reconstruction norms, respectively (see Section 2.2 for iterative formulation). As L-curve suggests, CG solution experiences overfitting soon after 30 iterations where the image does not further improve, but instead starts to be polluted by noise. Therefore we terminate CG solution after 30 iterations. On the other hand, SIRT does not converge even with 500 iterations. Fig. 8(b) shows a single-slice reconstruction from RDS1, and (c) and (d) compare image details after 30 CG iterations with MemXCT and 45 SIRT iterations with Trace, respectively.

4.1.3 Machine-Specific Considerations. We reconstruct RDS1 on small number of Theta, Cooley, and Blue Waters nodes. Machines were described briefly earlier. Unfortunately, reconstruction does not fit within DGX-1 or on less than eight nodes of Cooley or 32 nodes of Blue Waters, due to limited memory of their respective GPUs and the large memory complexity of MemXCT. Nevertheless, reconstruction fits well into a single Theta node thanks to its large DRAM capacity.

Table 5: Reconstruction on Various Nodes-Machines

Nodes-Machine	Preproc.	Speed.	Recon.	Speed.	All Slices
1-Theta (1 KNL)	139 s	1×	63.3 s	1×	1.44 d*
8-Theta (8 KNL)	16.5 s	8.42×	3.33 s	19.0×	1.89 h
8-Cooley (16 K80)	25.5 s	5.45×	2.89 s	21.9×	1.64 h
32-Blue W. (32 K20X)	14.6 s	9.52×	1.82 s	34.8×	62.1 m
32-Theta (32 KNL)	4.54 s	30.6×	1.37 s	46.2×	46.8 m
32-Cooley (64 K80)	6.31 s	22.0×	1.22 s	51.9×	41.6 m

* Calculated based on single-slice execution time.

Figure 8: For RDS1: (a) L-curves for CG and SIRT iterations. (b) Single-slice reconstruction with (c) CG and (d) SIRT iterations.

Table 5 reports RDS1 preprocessing and reconstruction times on various numbers of nodes-machines. Results show that 32 nodes of all machines enjoy comparable time to solution: reconstruction of all slices reduces from 1.44 days down to about or less than an hour. Preprocessing time also scales well and, in fact, it is insignificant compared to reconstruction time of all slices. Table 5 also shows the super-linear speedup property of MemXCT on KNLs: 8-Theta is 19 $\times$ faster than 1-Theta. This is a result of shrinking per-node memory footprint and extra memory bandwidth gain when it fits within 16 GB MCDRAM capacity. The super-linear speedup also demonstrates effective domain decomposition and reduced communications described in Section 3.

4.2 Performance Optimizations

This subsection presents single-device performance gains due to the optimizations described in Section 3. Fig. 9 shows forward and backprojection performance metrics for ADS1 through ADS4 on KNL and GPU. ADS3 and ADS4 are too large to fit in a single GPU (see Table 3). Hilbert ordering and input buffering are applied to the baseline in order because the first optimization enables the second. Since performance is dependent on both dataset and device, we tune all results (including the baseline) independently for maximum GFLOPS as described in Section 4.2.4.

Since there are two FLOPs per non-zero element in the projection matrix (one multiplication and one addition per FMA), GFLOPS metric is calculated as $2N_{nz}/t$, where t is the time measured for a single forward/backprojection. Similarly, average memory bandwidth utilization is calculated for regular data only as $N_{nz} \times B_{reg}/t$, where B_{reg} is regular data (in bytes) read from memory per FMA, respectively. L2 miss rates are measured by Intel VTune profiler. The performance metrics are aggregated over many iterations.

4.2.1 The Baseline GFLOPS on KNL drops as dataset size increases, regardless of whether or not it fits into high-bandwidth MCDRAM. The reason for this behaviour is that the baseline is bounded by memory latency rather than memory bandwidth, due to the high L2 miss rates of irregular access. As a result, larger datasets suffer more performance degradation due to their higher L2 miss rates, as seen in Fig. 9(b). In contrast, GPU performance improves slightly with larger datasets, as more parallelism hides the latency.

4.2.2 Pseudo-Hilbert Ordering provides data locality and reduces the L2 miss rates for all datasets as seen in Fig. 9(b). ADS1 does not benefit from Hilbert ordering as much as other datasets due

Figure 9: KNL performance: (a) GFLOPS, (b) L2 miss rate, and (c) memory bandwidth utilization. GPU GFLOPS performance: (d) K80, (e) P100, and (f) V100.

to its small size. Nevertheless, as opposed to the baseline, the performance of Hilbert ordering is bounded by memory bandwidth consumed by regular data rather than memory latency. On KNL, regular data smaller than 16 GBs (ADS1 and ADS2) fits completely into MCDRAM and performs better whereas large regular data

(ADS3 and ADS4) does not and is bounded by low DRAM memory bandwidth. On GPUs, the improvement is less noticeable with larger L2 cache because irregular data is better cached. As a result, pseudo-Hilbert ordering speeds up K80, P100, and V100 baselines about 1.93 $\times$, 1.39 $\times$, and 1.03 $\times$, respectively.

This analysis shows that ADS1 and ADS2 use at least 78% and 74% of the theoretical MCDRAM bandwidth, respectively. The ADS3 regular data (28 GB) is larger than MCDRAM (16 GB) where it is cached partially. We cannot say the same for ADS4 because it has too large regular data to be significantly cached at MCRAM. As a result, we deduce that ADS4 uses at least 73% of the theoretical DRAM bandwidth. These utilizations agree well with STREAM benchmarks in previous work [33]. Similarly, K80, P100 and V100 use 78%, 69%, and 92% of their theoretical HBM bandwidths, respectively. These numbers agree well with benchmark measurements in previous work [34].

4.2.3 Multi-Stage Buffering as we described in Section 3.3, comes with an staging overhead. On KNL, the gain amortizes the overhead when dataset is large, as seen in ADS2 and up. ADS1 is not large enough to show any further performance improvement with input buffering. The bandwidth utilization for input buffering in Fig. 9(c) and Fig. 9(d)–(f) is adjusted with respect to additional memory-to-buffer mappings as well as reduced bytes for buffer-address indices.

It is worth to comment that reduced L2 miss rate saves significant memory bandwidth on K80 since its utilization due to regular data increases to at least 67% of theoretical peak as seen in Fig. 9(d). The respective utilizations on P100 and V100 drop slightly, if not remain the same, because their L2 miss rates are already low and bandwidth utilizations are already high thanks to Hilbert ordering and their large L2 capacity. As a result, we can deduce that GFLOPS improvements on P100 and V100 are solely provided by the bandwidth saving due to reduced number of bytes needed for addressing shared-memory.

4.2.4 Tuning the baseline and Hilbert ordering are relatively simple on both KNL and GPU architectures. We perform an exhaustive search and find out that blocks size of 128 scheduled dynamically among 128 threads (2 SMT/core) provides good single KNL performance for ADS1 through ADS4. Similarly, block size of 32 or 64 provides good single GPU performance.

For input buffering optimization, parameters should be re-tuned along with buffer size for effective SMT utilization on KNL. Fig. 10(a)–(c) shows GFLOPS heat maps for ADS2 with various block and buffer sizes, and different numbers of SMT/core. Results show that input buffering can use more SMTs per core because it finds opportunity to overlap buffer stagings and accesses among SMTs. The following factors need to be considered when using SMTs in this way: A larger block size increases the per-block memory footprint and thus data reuse from the buffer, but also increases the number of buffer stagings per block, which comes with an overhead. In that case, it is better to increase buffer size for limiting the number of stagings. However, too few stagings decreases the opportunity to overlap buffer stagings and accesses among SMTs. Also, too large a buffer size can result in leaks to L2.

On KNL, peak GFLOPS performance for ADS1 and ADS2 is achieved with 4 SMT/core and buffer size of 8 KB. Tuning for ADS3 and ADS4 is cumbersome since they are severely limited by DRAM

Figure 10: Tuning input buffer and block size for (a)-(c) various SMT/core on KNL and (d) for V100.

bandwidth and SMT effect is not that apparent. Therefore we use 2 SMT/core, and buffer size of 16 KB for them. Block size of 128 provides good performance for all datasets.

On GPUs block size of 512 or 1024 and buffer size of 48 KB or 96 KB provides good single-GPU performance for all GPUs. It is worth to note that addressable shared-memory size is limited to 48 KB on P100 and K80 and therefore tuning space is half the size. We follow a similar tuning strategy for GPUs as explained for KNL, as seen in Fig. 10(d).

4.2.5 Comparison with Existing Libraries. We compare MemXCT forward/backprojection kernel performance with SpMV functions of existing libraries. We use Intel MKL library on KNL, and Nvidia cuSPARSE library on GPU. Table 6 reports speedups of our MemXCT baseline implementation and optimizations compared to CSR (on KNL) and column-major ELL (on GPU) SpMV of respective libraries. Evidently, MemXCT baseline implementation is faster than the existing libraries, with the exception for K80. This is due to K80 small L2 cache compared to P100 and V100 GPUs. On P100 and V100, our baseline is 1.39 $\times$ and 1.79 $\times$ faster since cuSPARSE pads CSR matrix with -1 [35] which requires extra branches whereas we pad with 0 and perform redundant multiplication with 0 to avoid thread divergence on GPUs. Also, cuSPARSE pads CSR on a matrix level whereas we pad on a thread-block (partition) level, which saves some of the redundant operations. As a result, we outperform existing libraries thanks to our application-specific SpMV optimizations. Nevertheless, both MKL and cuSPARSE are optimized for general SpMV whereas our kernels are optimized for XCT application.

Table 6: Comparison with MKL and cuSPARSE for ADS2

	KNL	K80	P100	V100
MKL/cuSPARSE	1 $\times$	1 $\times$	1 $\times$	1 $\times$
MemXCT Baseline	1.42 $\times$	0.52 $\times$	1.39 $\times$	1.79 $\times$
Pseudo-Hilbert Ordering	4.99 $\times$	1.13 $\times$	1.93 $\times$	1.84 $\times$
Multi-Stage Buffering	6.55 $\times$	1.56 $\times$	2.23 $\times$	2.11 $\times$

Figure 11: Weak scaling: (a) ADS3/Theta, (b) ADS2/Blue Waters. Strong scaling: (c) RDS2/Theta, (d) ADS3/Blue Waters.

4.3 Scalability

For presenting scaling of MemXCT on a large number of nodes, we perform weak and strong scaling experiments on Theta and Blue Waters. For each experiment, we perform a full solution with 30 CG iterations, and report total reconstruction times as well as A_p , C , and R kernel times as they are defined in Section 3.4. Kernel times involve both forward and backprojection. In order to accurately measure each individual kernel, we placed the necessary artificial barriers, though they slightly increase total execution time. Among the kernels, C involves inter-node communication therefore we include its host-device communication times. For demonstrating scaling, $O(\sqrt{P})$ and $O(1/P)$ curves are included in Fig. 11 as well as the sinogram data dimensions.

4.3.1 Weak Scaling. Each weak scaling experiment is performed by starting from the reconstruction of a root dataset, and then doubling the number of channels and projections in a sinogram on each step. As computational cost increases eight times per step, the number of nodes is increased eight times accordingly. Fig. 11(a)–(b) show weak scaling of root datasets ADS3 and ADS2 on Theta and Blue Waters, respectively. Both experiments exhibit good weak scaling except communication operations C because of its $O(\sqrt{P})$ complexity, as explained in Table 1. On Blue Waters, weak scaling is bounded by communication on 512 nodes and up; on Theta, communication is not the bounding component, but rather A_p . The difference is due to architectural differences across machines.

4.3.2 Strong Scaling. For strong scaling, we reconstruct RDS2 (brain) and RDS1 (shale) samples on Theta and Blue Waters respectively. We increase numbers of nodes and the dataset sizes are fixed. The minimum number of nodes needed for RDS2 and RDS1 to fit well within their respective systems is 128 and 32 nodes respectively. Reconstructions are scaled up to 4096 nodes of each system. Fig. 11(c)–(d) show strong scaling results. Theta exhibits good scaling up to 2048 nodes where as Blue Waters scales up to 128 nodes. The main reason (apart from the difference in network bandwidth and topology) is that the RDS2 solution is $\sim 91\times$ more costly than the RDS1, and therefore the former scales better than

the latter. Also, A_p kernel exhibits super-linear speedup, demonstrating efficient domain partitioning and high-bandwidth memory utilization, as discussed in Section 4.1.3. RDS2 reconstruction results are in Fig. 1. In contrast, A_p performance saturates on 1024 nodes of Blue Waters (and up) since smaller per-node computation penalizes GPU performance.

Table 7: Comparison of Theta and Blue Waters

	RDS1	RDS2	12 000×8192
BW	805 ms (128 K20X)	74 s (4096 K20X)	24.4 s (4096 K20X)
Theta	474 ms (128 KNL)	10 s (2048 KNL)	3.25 s (4096 KNL)

4.3.3 Comparison of Theta and Blue Waters Systems. For cross-comparing Theta and Blue Waters systems, we pick the fastest reconstructions of both RDS datasets and their corresponding weak scaling versions when ran on 4096 nodes. Results are shown in Table 7. RDS1 (shale) sample reconstruction runs fastest on 128 nodes on both Theta and Blue Waters. In this case, Theta is about $1.7\times$ faster than Blue Waters. RDS2 (brain) sample reconstruction runs fastest on 2048 nodes of Theta and requires at least 4096 nodes to fit well into Blue Waters. In this case, Theta is $7.4\times$ faster than Blue Waters. Lastly, Theta is about $7.5\times$ faster on reconstructing the 12 000×8192 dataset.

5 RELATED WORK AND DISCUSSION

Iterative reconstruction algorithms provide superior image quality considering analytical approaches, however their usage has so far been limited with their computational demands [36–38].

The multicore parallelization of iterative reconstruction algorithms has long been studied [39–42]. However, most prior approaches provide limited scalability and only consider optimizations in the object domain. Further, they suffer from redundant computations when dealing with large datasets.

With the emergence of high-throughput many-core architectures and state-of-the-art reconstruction algorithms, the applicability of iterative techniques has become more feasible [12, 23, 43, 44]. Especially in medical imaging, iterative reconstruction approaches

have been extensively used to provide high-quality 3D reconstructions [45–47] in order to limit patient radiation exposure [3, 48]. Most of these approaches rely on GPUs to meet computational requirements of these algorithms [49–51]. Although GPUs can provide sufficient computational throughput, their limited memory can accommodate only small- to medium-scale datasets. For large-scale dataset host-device communication is known to be dominating overhead in GPUs [52]. Further, most of these approaches rely on on-the-fly computation of ray tracing, i.e. CompCXT type of data access pattern, which shows suboptimal performance compared to MemCXT.

Li et al. developed cuMBIR [16], a framework for model-based iterative reconstruction on GPUs. They implement two solvers ICD and SGD, and propose several optimizations including unified thread mapping. Their method is also based on on-the-fly computation of A matrix, and performs redundant computations. Further, their solution focuses on small to medium scale datasets that can fit into single node GPUs. In comparison, MemCXT is optimized for very large tomographic datasets that require not only single node performance but also efficient large-scale execution.

Wang et al. [43] use KNL many-core capabilities to reconstruct 1024^2 tomograms (or 1024^3 3D volumes). They introduce the *non-uniform parallel super-voxel* to exploit sinusoidal bands in sinograms and optimize data access patterns. Our approach shares similarities with their work, but we consider parallelization and performance optimizations in both the tomogram and sinogram domains. Moreover, we further improve data access patterns and communication using two-level pseudo Hilbert ordering and multi-stage input buffering on both domains. Our evaluation also extends to extremely large objects ($11\,293^2$ rather than 1024^2), showing the usability of our approach for very large datasets.

First space-filling curve example was presented by Peano in 1890 [53]. Later, space-filling curves have been successfully applied to improve performance of many applications [54–60]. In [61], Mellor-Crummey et al. showed that data and computation reordering based on space-filling curves can improve the performance of irregular applications significantly. Moon et al. analyzed clustering properties of Hilbert space-filling curve [62] on different query shapes [63]. Reissmann et al. showed the effects of Hilbert and Morton curves [64] on energy and locality [60]. In our work, we applied two-level pseudo Hilbert ordering to optimize the performance of tomographic reconstruction data access patterns and inter-process communication.

6 CONCLUSION

We have described a memory-centric approach to XCT reconstruction. Our implementation, MemXCT, performs projection and back-projection operations as explicit SpMV with no on-the-fly (redundant) computations or race conditions; these features allow it to achieve up to 50× speedup over a high-performance compute-centric approach. Although MemXCT has high memory complexity, its per-node memory footprint decreases linearly with increasing number of compute resources, which favors large-scale resources. For solving the performance bottlenecks in traditional iterative reconstruction approaches, we propose and implement two-level pseudo-Hilbert ordering and multi-stage input buffering techniques

in MemXCT. We compare the performance of our computational kernels on KNL and several generations of GPUs, and demonstrate scaling up to 4096 nodes using ALCF Theta (KNL) and NCSA Blue Waters (GPU) systems. We show that MemXCT can reconstruct a large-scale (11Kx11K) mouse brain tomogram in ~10 seconds using 4096 KNL nodes: the largest iterative reconstruction ever achieved in near-real time.

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Appendix: Artifact Description/Artifact Evaluation

SUMMARY OF THE EXPERIMENTS REPORTED

We evaluated our system MemXCT using 5 different systems: Theta at ALCF, Blue Waters at NCSA, Cooley at ALCF, Minsky at NCSA, and with a DGX-1 machine at JLSE at ALCF. We used the default mpi implementations on these systems. Six different datasets were used during the experiments: four of them simulated data and two of them are real world datasets (a mouse brain sample and a shale sample). MemXCT generates the simulated datasets according to the user parameters. Real world datasets were collected at Advanced Photon Source at APS. Among the real-world datasets, shale sample is available at TomoBank (the tomo_00001 dataset at <https://tomobank.readthedocs.io/en/latest/source/data/docs.data.roundrobin.html>); mouse brain dataset is not publicly available yet. Both real-world datasets were converted from hdf5 to binary format before reconstruction process is initiated.

ARTIFACT AVAILABILITY

Software Artifact Availability: Some author-created software artifacts are NOT maintained in a public repository or are NOT available under an OSI-approved license.

Hardware Artifact Availability: There are no author-created hardware artifacts.

Data Artifact Availability: Some author-created data artifacts are NOT maintained in a public repository or are NOT available under an OSI-approved license.

Proprietary Artifacts: There are associated proprietary artifacts that are not created by the authors. Some author-created artifacts are proprietary.

List of URLs and/or DOIs where artifacts are available:

MemXCT is not publicly available yet. It is currently
↪ being maintained under DOE resources.

BASELINE EXPERIMENTAL SETUP, AND MODIFICATIONS MADE FOR THE PAPER

Relevant hardware details: We used five supercomputers/machines: Theta (System: ALCF/ANL; Host: Xeon Phi 7230, 16GiB MCDRAM, 192GiB DDR4), Cooley (System: ALCF/ANL; Accelerator: 2xK20X GPUs per node, 12GiB DDR5; Host Mem: 384GiB; Host-Accelerator Link: PCIe), Blue waters (System: NCSA/UIUC; Accelerator: K20X GPU, 6GiB DDR5; Host Mem: 32GiB; Host-Accelerator Link: PCIe), DGX1 (System: JLSE/ANL; Accelerator: 8xV100 GPUs, 16 GiB HBM2; Host Mem: 512GiB; Host-Accelerator Link: NVLink) and Minsky (Accelerator: 4 P100, 16GiB HBM2; Host Mem: 512GiB; Host-Accelerator Link: NVLink)

Operating systems and versions: Theta System (our base system); Cray Linux Environment (includes SUSE Linux SLES11, HSS and SMW software)

Compilers and versions: Theta System (our base system): icpc (ICC) 18.0.0 20170811 (craype 2.5.15 driver)

Libraries and versions: Theta System (our base system): MPI 3.0, Cray SHMEM, other standard MPI libraries using CCM. Cray Apprentice and CrayPAT™ performance tools. Intel Parallel Studio Development Suite

Key algorithms: We used conjugate gradient for the reconstruction of 2D sinogram data. We introduced two-level pseudo-Hilbert ordering to improve application performance.

Input datasets and versions: We used simulated and real-world datasets. One of the real-world dataset was taken from Tomobank. The dataset (tomo_00001) can be accessed from: <https://tomobank.readthedocs.io/en/latest/source/data/docs.data.roundrobin.html>

Output from scripts that gathers execution environment information.

We used five systems. Below we listed all the systems' outputs from the given script.

Theta System (Our Base System)

```
PE_TPSSL_64_DEFAULT_GENCOMPS_INTEL_mic_knl=160
PE_SMA_DEFAULT_PKGCONFIG_VARIABLES=PE_SMA_COMPFLAG_@
↪ prgenv@
PE_LIBSCI_VOLATILE_PRGENV=CRAY GNU INTEL
MKLR00T=/opt/intel/compilers_and_libraries_2018.0.12
↪ 8/linux/mkl
KSH_AUTOLOAD=1
MODULE_VERSION_STACK=3.2.11.1
LESSKEY=/etc/lesskey.bin
PE_CXX_PKGCONFIG_LIBS=mpichcxx
PE_TPSSL_DEFAULT_GENCOMPS_INTEL_x86_skylake=160
PE_PETSC_DEFAULT_GENCOMPS_CRAY_skylake=86
PE_PETSC_DEFAULT_GENCOMPILERS_CRAY_sandybridge=8.6
PE_PAPI_DEFAULT_ACCEL_FAMILY_LIBS_nvidia=-lcupti,-l
↪ cudart,-lcuda
NNTPSERVER=news
DB2INSTANCE=db2cat
```

```

MANPATH=/opt/cray/pe/mpt/7.7.3/gni/man/mpich:/opt/cr
↪ ay/pe/perftools/7.0.4/man:/opt/cray/pe/papi/5.6.
↪ 0.4/share/pdoc/man:/opt/cray/pe/atp/2.1.3/man:/o
↪ pt/cray/pe/pmi/5.0.14/man:/opt/cray/pe/libsci/18
↪ .07.1/man:/opt/cray/pe/man/csmversion:/opt/cray
↪ /pe/craype/2.5.15/man:/opt/intel/man/common:/opt
↪ /intel/compilers_and_libraries_2018.0.128/linux/
↪ mpi/man:/opt/intel/documentation_2017/en/debugge
↪ r//gdb-ia/man:/opt/intel/documentation_2017/en/
↪ debugger//gdb-mic/man:/opt/intel/documentation_
↪ 2017/en/debugger//gdb-igfx/man:/opt/cray/cfguti
↪ ls/man:/opt/cray/llm/21.3.530-6.0.7.1_5.4__g3b42
↪ 30e.ari/man:/opt/cray/alps/6.6.43-6.0.7.1_5.45__
↪ ga796da32.ari/man:/opt/cray/pe/modules/3.2.11.1/
↪ share/man:/usr/local/man:/usr/share/man:/usr/man
↪ :/opt/cray/share/man:/opt/cray/pe/man
SSS_WRAPPER=1
XDG_SESSION_ID=861
COBALT_BLOCKNAME=3826
PE_TRILINOS_DEFAULT_GENCOMPS_CRAY_x86_64=87
PE_TPSSL_64_DEFAULT_GENCOMPS_INTEL_interlagos=160
PE_PETSC_DEFAULT_GENCOMPILERS_INTEL_mic_knl=16.0
PE_FFTW_DEFAULT_TARGET_mic_knl=mic_knl
CRAY_UDREG_INCLUDE_OPTS=-I/opt/cray/udreg/2.3.2-6.0.
↪ 7.1_5.13__g5196236.ari/include
IBM_DB_LIB=/dbhome/db2cat/sql/lib/lib
HOSTNAME=thetamom3
PE_TRILINOS_DEFAULT_VOLATILE_PKGCONFIG_PATH=/opt/cra
↪ y/pe/trilinos/12.12.1.1/@PRGENV@/PE_TRILINOS_DE
↪ FAULT_GENCOMPS@/PE_TRILINOS_DEFAULT_TARGET@/lib
↪ /pkgconfig
PE_SMA_DEFAULT_COMPFLAG_GNU=-fcray-pointer
PE_PARALLEL_NETCDF_DEFAULT_VOLATILE_PKGCONFIG_PATH=/
↪ opt/cray/pe/parallel-netcdf/1.8.1.3/@PRGENV@/PE
↪ _PARALLEL_NETCDF_DEFAULT_GENCOMPS@/lib/pkgconfig
PE_NETCDF_DEFAULT_VOLATILE_PKGCONFIG_PATH=/opt/cray/
↪ pe/netcdf/4.6.1.3/@PRGENV@/PE_NETCDF_DEFAULT_GE
↪ NCOMPS@/lib/pkgconfig
RCLOCAL_BASEOPTS=true
LIBRARYMODULES=acml:alps:cray-dwarf:cray-fftw:cray-g
↪ a:cray-hdf5:cray-hdf5-parallel:cray-libsci:cray-
↪ libsci_acc:cray-mpich:cray-mpich2:cray-mpich-abi
↪ :cray-netcdf:cray-netcdf-hdf5parallel:cray-paral
↪ lel-netcdf:cray-petsc:cray-petsc-complex:cray-sh
↪ mem:cray-tpsl:cray-trilinos:cudatoolkit:fftw:ga:
↪ hdf5:hdf5-parallel:iobuf:libfast:netcdf:netcdf-h
↪ df5parallel:ntk:onesided:papi:petsc:petsc-comple
↪ x:pmi:tpsl:trilinos:xt-libsci:xt-mpich2:xt-mpt:x
↪ t-papi
CRAY_SITE_LIST_DIR=/etc/opt/cray/pe/modules
XKEYSYMDB=/usr/X11R6/lib/X11/XKeysymDB
PE_TPSSL_64_DEFAULT_GENCOMPILERS_CRAY_x86_64=8.6
PE_SMA_DEFAULT_COMPFLAG=
PE_MPICH_ALTERNATE_LIBS_dpm=_dpm
PE_HDF5_DEFAULT_GENCOMPILERS_GNU=8.2 7.1 6.1 5.3 4.9
PE_ENV=INTEL

```

```

IPPROOT=/opt/intel/compilers_and_libraries_2018.0.12
↪ 8/linux/ipp
INTEL_LICENSE_FILE=/opt/intel/compilers_and_libraries_
↪ s_2018.0.128/linux/licenses:/opt/intel/licenses:
↪ /intel/licenses
PKGCONFIG_ENABLED=1
PE_TPSSL_DEFAULT_GENCOMPS_CRAY_x86_skylake=86
HOST=thetamom3
TERM=xterm-256color
SHELL=/bin/bash
PE_TPSSL_DEFAULT_GENCOMPILERS_GNU_x86_skylake=8.2 7.1
↪ 6.1
PE_PETSC_DEFAULT_GENCOMPS_CRAY_sandybridge=86
INTEL_MINOR_VERSION=0.128
PROFILEREAD=true
HISTSIZE=1000
APRUN_OVERLAP_ORDINAL=0
PE_TRILINOS_DEFAULT_VOLATILE_PRGENV=CRAY GNU INTEL
PE_TPSSL_DEFAULT_REQUIRED_PRODUCTS=PE_MPICH:PE_LIBSCI
PE_TPSSL_DEFAULT_GENCOMPS_GNU_sandybridge=82 71 53 49
PE_TPSSL_64_DEFAULT_GENCOMPS_INTEL_x86_skylake=160
PE_PETSC_DEFAULT_GENCOMPS_INTEL_haswell=160
PE_PETSC_DEFAULT_GENCOMPS_GNU_haswell=71 53 49
PE_PARALLEL_NETCDF_DEFAULT_VOLATILE_PRGENV=GNU
PE_NETCDF_DEFAULT_VOLATILE_PRGENV=GNU
GDBSERVER_MIC=/opt/intel/debugger_2017/gdb/targets/m
↪ ic/bin/gdbserver
CRAYPE_DIR=/opt/cray/pe/craype/2.5.15
CRAY_XPMEM_POST_LINK_OPTS=-L/opt/cray/xpmem/2.2.15-6
↪ .0.7.1_5.11__g7549d06.ari/lib64
CRAY_UGNI_POST_LINK_OPTS=-L/opt/cray/ugni/6.0.14.0-6
↪ .0.7.1_3.13__gea1d3d.ari/lib64
SSH_CLIENT=10.236.1.194 50720 22
CRAY_MPICH2_DIR=/opt/cray/pe/mpt/7.7.3/gni/mpich-int
↪ el/16.0
PE_PETSC_DEFAULT_GENCOMPS_CRAY_interlagos=86
PE_NETCDF_HDF5PARALLEL_DEFAULT_VOLATILE_PKGCONFIG_PA
↪ TH=/opt/cray/pe/netcdf-hdf5parallel/4.6.1.3/@PRG
↪ ENV@/PE_NETCDF_HDF5PARALLEL_DEFAULT_GENCOMPS@/l
↪ ib/pkgconfig
PE_HDF5_PARALLEL_DEFAULT_VOLATILE_PKGCONFIG_PATH=/op
↪ t/cray/pe/hdf5-parallel/1.10.2.0/@PRGENV@/PE_HD
↪ F5_PARALLEL_DEFAULT_GENCOMPS@/lib/pkgconfig
PE_HDF5_DEFAULT_VOLATILE_PRGENV=GNU
PE_FFTW_DEFAULT_VOLATILE_PKGCONFIG_PATH=/opt/cray/pe
↪ /fftw/3.3.8.1/@PE_FFTW_DEFAULT_TARGET@/lib/pkgco
↪ nfig

```


MemXCT: Memory-Centric X-Ray CT Reconstruction with Massive Parallelization

```
LIBRARY_PATH=/opt/intel/compilers_and_libraries_2018.0.128/linux/ipp/lib/intel64:/opt/intel/compilers_and_libraries_2018.0.128/linux/compiler/lib/intel64:/opt/intel/compilers_and_libraries_2018.0.128/linux/mkl/lib/intel64:/opt/intel/compilers_and_libraries_2018.0.128/linux/tbb/lib/intel64/gcc4.4:/opt/intel/compilers_and_libraries_2018.0.128/linux/daal/lib/intel64_lin:/opt/intel/compilers_and_libraries_2018.0.128/linux/daal/../compiler/lib/intel64_lin
PE_TPSL_DEFAULT_GENCOMPS_CRAY_mic_knl=86
PE_TPSL_64_DEFAULT_GENCOMPILERS_CRAY_interlagos=8.6
PE_LIBSCI_DEFAULT_GENCOMPS_GNU_x86_64=71 61 51 49
PE_GA_DEFAULT_VOLATILE_PRGENV=GNU
INTEL_PATH=/opt/intel/compilers_and_libraries_2018.0.128
DARSHAN_PRELOAD=/soft/perftools/darshan/darshan-3.1.5/lib/libdarshan.so
PE_MPICH_GENCOMPS_GNU=71 51 49
PE_TPSL_DEFAULT_GENCOMPS_INTEL_x86_64=160
PE_PKGCONFIG_PRODUCTS=PE_MPICH:PE_LIBSCI
PE_MPICH_DEFAULT_GENCOMPILERS_GNU=7.1 5.1 4.9
PERFTOOLS_VERSION=7.0.4
FPATH=/opt/cray/pe/modules/3.2.11.1/init/sh_funcs/no_redirect:/opt/cray/pe/modules/3.2.11.1/init/sh_funcs/no_redirect
IBM_DB_DIR=/dbhome/db2cat/sqlllib
MORE=-s1
PE_TPSL_64_DEFAULT_VOLATILE_PKGCONFIG_PATH=/opt/cray/pe/tps1/18.06.1/@PRGENV64/@PE_TPSL_64_DEFAULT_GENCOMPS/@PE_TPSL_64_DEFAULT_TARGET/lib/pkgconfig
PE_TPSL_64_DEFAULT_GENCOMPS_CRAY_haswell=86
PE_PETSC_DEFAULT_REQUIRED_PRODUCTS=PE_MPICH:PE_LIBSCI
PE_PAPI_DEFAULT_ACCEL_LIBS_nvidia35=-lcupti,-lcuda
PE_TRILINOS_DEFAULT_GENCOMPILERS_CRAY_x86_64=8.7
PE_CRAY_DEFAULT_FIXED_PKGCONFIG_PATH=/opt/cray/pe/parallel-netcdf/1.8.1.3/CRAY/8.6/lib/pkgconfig:/opt/cray/pe/netcdf-hdf5parallel/4.6.1.3/CRAY/8.6/lib/pkgconfig:/opt/cray/pe/netcdf/4.6.1.3/CRAY/8.6/lib/pkgconfig:/opt/cray/pe/hdf5-parallel/1.10.2.0/CRAY/8.6/lib/pkgconfig:/opt/cray/pe/hdf5/1.10.2.0/CRAY/8.6/lib/pkgconfig:/opt/cray/pe/ga/5.3.0.8/CRAY/8.6/lib/pkgconfig
XALT_COBALT_ACCOUNT=CSC249ADC01
PE_FORTRAN_PKGCONFIG_LIBS=mpichf90
PE_TPSL_64_DEFAULT_GENCOMPILERS_CRAY_sandybridge=8.6
PE_PETSC_DEFAULT_GENCOMPS_CRAY_x86_64=86
PE_LIBSCI_DEFAULT_OMP_REQUIRES_openmp=mp
```

```
MIC_LD_LIBRARY_PATH=/opt/intel/compilers_and_libraries_2018.0.128/linux/mpi/mic/lib:/opt/intel/compilers_and_libraries_2018.0.128/linux/compiler/lib/mic:/opt/intel/compilers_and_libraries_2018.0.128/linux/ipp/lib/mic:/opt/intel/compilers_and_libraries_2018.0.128/linux/compiler/lib/mic:/opt/intel/compilers_and_libraries_2018.0.128/linux/mkl/lib/mic:/opt/intel/compilers_and_libraries_2018.0.128/linux/tbb/lib/mic
SSH_TTY=/dev/pts/3
ALLINEA_QUEUE_DLL=/opt/cray/pe/mpt/7.7.3/gni/mpich-intel/16.0/lib/libtvmpt.so.3.0.1
PE_SMA_DEFAULT_VOLATILE_PKGCONFIG_PATH=/opt/cray/pe/mpt/7.7.3/gni/sma@PE_SMA_DEFAULT_DIR_DEFAULT64/lib64/pkgconfig
CRAYPAT_LD_LIBRARY_PATH=/opt/cray/pe/gcc-libs:/opt/cray/gcc-libs:/opt/cray/pe/perftools/7.0.4/lib64
CRAYPAT_ALPS_COMPONENT=/opt/cray/pe/perftools/7.0.4/sbin/pat_alps
ALPS_APP_ID=13076151
CRAY_MPICH_BASEDIR=/opt/cray/pe/mpt/7.7.3/gni
PE_TRILINOS_DEFAULT_GENCOMPS_INTEL_x86_64=160
PE_TPSL_64_DEFAULT_GENCOMPS_INTEL_haswell=160
PE_TPSL_64_DEFAULT_GENCOMPS_CRAY_x86_skylake=86
PE_NETCDF_HDF5PARALLEL_DEFAULT_GENCOMPILERS_GNU=8.2 7.1 6.1 5.3 4.9
PE_HDF5_PARALLEL_DEFAULT_GENCOMPILERS_GNU=8.2 7.1 6.1 5.3 4.9
JRE_HOME=/usr/lib64/jvm/java/jre
USER=USER
LS_COLORS=no=00:fi=00:di=01;34:ln=00;36:pi=40;33:so=00;35:do=01;35:bd=40;33;01:cd=40;33;01:or=41;33;01:ex=00;32:*.cmd=00;32:*.exe=01;32:*.com=01;32:*.bat=01;32:*.btm=01;32:*.dll=01;32:*.tar=00;31:*.tbz=00;31:*.tgz=00;31:*.rpm=00;31:*.deb=00;31:*.arj=00;31:*.taz=00;31:*.lzh=00;31:*.lzma=00;31:*.zip=00;31:*.zoo=00;31:*.z=00;31:*.Z=00;31:*.gz=00;31:*.bz2=00;31:*.tb2=00;31:*.tz2=00;31:*.tbz2=00;31:*.xz=00;31:*.avi=01;35:*.bmp=01;35:*.fl_i=01;35:*.gif=01;35:*.jpg=01;35:*.jpeg=01;35:*.mng=01;35:*.mov=01;35:*.mpg=01;35:*.pcx=01;35:*.pbm=01;35:*.pgm=01;35:*.png=01;35:*.ppm=01;35:*.tga=01;35:*.tif=01;35:*.xbm=01;35:*.xpm=01;35:*.dwl=01;35:*.gl=01;35:*.wmv=01;35:*.aiff=00;32:*.au=00;32:*.mid=00;32:*.mp3=00;32:*.ogg=00;32:*.vocal=00;32:*.wav=00;32:
PE_TRILINOS_DEFAULT_GENCOMPILERS_INTEL_x86_64=16.0
PE_TRILINOS_DEFAULT_GENCOMPILERS_GNU_x86_64=8.2 7.3 5.1 4.9
PE_TPSL_DEFAULT_GENCOMPS_CRAY_x86_64=86
PE_TPSL_64_DEFAULT_GENCOMPILERS_INTEL_mic_knl=16.0
PE_PETSC_DEFAULT_GENCOMPILERS_INTEL_interlagos=16.0
PE_LIBSCI_DEFAULT_VOLATILE_PRGENV=CRAY GNU INTEL
PE_FFTW_DEFAULT_TARGET_interlagos=interlagos
PE_MPICH_FIXED_PRGENV=INTEL
PE_TPSL_64_DEFAULT_GENCOMPILERS_INTEL_haswell=16.0
```

```

PE_TPSL_64_DEFAULT_GENCOMPILERS_GNU_sandybridge=8.2
↪ 7.1 5.3 4.9
PE_PKGCONFIG_LIBS=darshan-runtime:mpich:cray-rca:Atp
↪ SigHandler:libsci_mpi:libsci
PE_PETSC_DEFAULT_VOLATILE_PRGENV=CRAY CRAY64 GNU
↪ GNU64 INTEL INTEL64
PE_LIBSCI_PKGCONFIG_VARIABLES=PE_LIBSCI_OMP_REQUIRES
↪ _@openmp@:PE_SCI_EXT_LIBPATH:PE_SCI_EXT_LIBNAME
CRAY_RCA_POST_LINK_OPTS=-L/opt/cray/rca/2.2.18-6.0.7
↪ .1_5.47__g2aa4f39.ari/lib64
↪ -lrca
PE_TPSL_DEFAULT_GENCOMPS_GNU_haswell=82 71 53 49
PE_PETSC_DEFAULT_GENCOMPS_INTEL_sandybridge=160
PE_PETSC_DEFAULT_GENCOMPS_INTEL_interlagos=160
PE_PETSC_DEFAULT_GENCOMPS_GNU_sandybridge=71 53 49
PE_PETSC_DEFAULT_GENCOMPS_GNU_interlagos=71 53 49
PE_PETSC_DEFAULT_GENCOMPILERS_INTEL_skylake=16.0
PE_PETSC_DEFAULT_GENCOMPILERS_CRAY_x86_64=8.6
PE_PETSC_DEFAULT_GENCOMPILERS_CRAY_mic_knl=8.6
XNLSPATH=/usr/share/X11/nls
MPICH_DIR=/opt/cray/pe/mpt/7.7.3/gni/mpich-intel/16.0
PE_TPSL_64_DEFAULT_GENCOMPS_INTEL_sandybridge=160
PE_TPSL_64_DEFAULT_GENCOMPILERS_GNU_interlagos=8.2
↪ 7.1 5.3 4.9
PE_PETSC_DEFAULT_GENCOMPS_INTEL_mic_knl=160
PE_PETSC_DEFAULT_GENCOMPS_GNU_mic_knl=53
PE_PETSC_DEFAULT_GENCOMPILERS_CRAY_haswell=8.6
PE_PAPI_DEFAULT_PKGCONFIG_VARIABLES=PE_PAPI_ACCEL_LI
↪ BS_@accelerator@
↪ PE_PAPI_ACCEL_FAMILY_LIBS_@accelerator_family@
PE_LIBSCI_DEFAULT_GENCOMPS_CRAY_x86_64=86
MPICH_ABORT_ON_ERROR=1
MIC_LIBRARY_PATH=/opt/intel/compilers_and_libraries_
↪ 2018.0.128/linux/mpi/mic/lib:/opt/intel/compiler
↪ s_and_libraries_2018.0.128/linux/compiler/lib/mi
↪ c:/opt/intel/compilers_and_libraries_2018.0.128/
↪ linux/tbb/lib/mic
INTEL_VERSION=18.0.0.128
PE_MPICH_FORTRAN_PKGCONFIG_LIBS=mpichf90
PE_TPSL_64_DEFAULT_GENCOMPILERS_CRAY_haswell=8.6
PE_PETSC_DEFAULT_GENCOMPILERS_INTEL_sandybridge=16.0
PE_NETCDF_HDF5PARALLEL_DEFAULT_REQUIRED_PRODUCTS=PE_
↪ HDF5_PARALLEL
PE_HDF5_PARALLEL_DEFAULT_REQUIRED_PRODUCTS=PE_MPICH
PE_FFTW_DEFAULT_TARGET_sandybridge=sandybridge
PE_FFTW_DEFAULT_REQUIRED_PRODUCTS=PE_MPICH
CPATH=/opt/intel/compilers_and_libraries_2018.0.128/
↪ linux/ipp/include:/opt/intel/compilers_and_libra
↪ ries_2018.0.128/linux/mkl/include:/opt/intel/com
↪ pilers_and_libraries_2018.0.128/linux/tbb/includ
↪ e:/opt/intel/compilers_and_libraries_2018.0.128/
↪ linux/daal/include
ATP_POST_LINK_OPTS=-Wl,-L/opt/cray/pe/atp/2.1.3/libA
↪ pp/
HOSTTYPE=x86_64
COBALT_PARTNAME=3826

```

```

PE_PETSC_DEFAULT_GENCOMPILERS_GNU_mic_knl=5.3
RCLOCAL_PRGENV=true
IBM_DB_HOME=/dbhome/db2cat/sqllib
PE_TPSL_DEFAULT_GENCOMPS_GNU_interlagos=82 71 53 49
PE_TPSL_DEFAULT_GENCOMPILERS_CRAY_x86_64=8.6
PE_LIBSCI_GENCOMPS_INTEL_x86_64=160
PE_LIBSCI_DEFAULT_GENCOMPILERS_INTEL_x86_64=16.0
OFFLOAD_INIT=on_start
CHPL_CG_CPP_LINES=1
PE_PRODUCT_LIST=CRAYPE_MIC-KNL:CRAY_RCA:CRAY_PMI:CRAY
↪ Y_LIBSCI:CRAYPE:INTEL:CRAY_XPMEM:CRAY_DMAPP:CRAY
↪ _UGNI:CRAY_UDREG:CRAY_ALPS:PERFTOOLS:CRAYPAT
FROM_HEADER=
CRAY_MPICH_ROOTDIR=/opt/cray/pe/mpt/7.7.3
PE_TPSL_DEFAULT_GENCOMPS_GNU_x86_skylake=82 71 61
PE_PETSC_DEFAULT_GENCOMPILERS_GNU_x86_64=7.1 5.3 4.9
PAGER=less
ALPS_APP_PE=0
PE_MPICH_MODULE_NAME=cray-mpich
PE_MPICH_GENCOMPILERS_CRAY=8.6
PE_TPSL_64_DEFAULT_GENCOMPILERS_INTEL_x86_64=16.0
PE_PETSC_DEFAULT_GENCOMPS_INTEL_skylake=160
PE_PETSC_DEFAULT_GENCOMPS_GNU_skylake=61
PE_LIBSCI_GENCOMPILERS_GNU_x86_64=7.1 6.1 5.1 4.9
CSHEDIT=emacs
PE_TPSL_DEFAULT_GENCOMPS_CRAY_sandybridge=86
PE_TPSL_DEFAULT_GENCOMPS_CRAY_haswell=86
PE_TPSL_64_DEFAULT_REQUIRED_PRODUCTS=PE_MPICH:PE_LIB
↪ SCI
PE_MPICH_TARGET_VAR_nvidia20=-lcudart
PE_MPICH_DEFAULT_VOLATILE_PRGENV=CRAY GNU
PE_LIBSCI_GENCOMPS_CRAY_x86_64=86
PE_LIBSCI_DEFAULT_GENCOMPILERS_CRAY_x86_64=8.6
INTEL_MAJOR_VERSION=18.0
CRAYPAT_ROOT=/opt/cray/pe/perftools/7.0.4
XDG_CONFIG_DIRS=/etc/xdg
PE_TPSL_64_DEFAULT_GENCOMPS_GNU_x86_64=82 71 53 49
PE_TPSL_64_DEFAULT_GENCOMPS_GNU_mic_knl=71 53
PE_PARALLEL_NETCDF_DEFAULT_GENCOMPS_GNU=51 49
PE_NETCDF_DEFAULT_GENCOMPS_GNU=
PE_LIBSCI_PKGCONFIG_LIBS=libsci_mpi:libsci
CRAY_LIBSCI_DIR=/opt/cray/pe/libsci/18.07.1
CRAY_LIBSCI_BASE_DIR=/opt/cray/pe/libsci/18.07.1
CRAY_DMAPP_INCLUDE_OPTS=-I/opt/cray/dmapp/7.1.1-6.0.
↪ 7.1_5.45__g5a674e0.ari/include
↪ -I/opt/cray/gni-headers/5.0.12.0-6.0.7.1_3.11__g
↪ 3b1768f.ari/include

```

MemXCT: Memory-Centric X-Ray CT Reconstruction with Massive Parallelization

```

USERMODULES=acml:alps:apprentice:apprentice2:atp:blc
↳ r:cce:chapel:cray-ccdb:cray-fftw:cray-ga:cray-hd
↳ f5:cray-hdf5-parallel:cray-lgdb:cray-libsci:cray
↳ -libsci_acc:cray-mpich:cray-mpich2:cray-mpich-com
↳ pat:cray-netcdf:cray-netcdf-hdf5parallel:cray-pa
↳ rallel-netcdf:craypat:craype:cray-petsc:cray-pet
↳ sc-complex:craypkg-gen:cray-shmem:cray-snplaunch
↳ er:cray-tpsl:cray-trilinos:cuatoolkit:ddt:fftw:
↳ ga:gcc:hdf5:hdf5-parallel:intel:iobuf:java:lgdb:
↳ libfast:libsci_acc:mpich1:netcdf:netcdf-hdf5para
↳ llel:netcdf-nofsync:netcdf-nofsync-hdf5parallel:
↳ ntk:onesided:papi:parallel-netcdf:pathscale:perf
↳ tools:perftools-lite:petsc:petsc-complex:pgi:pmi
↳ :PrgEnv-cray:PrgEnv-gnu:PrgEnv-intel:PrgEnv-path
↳ scale:PrgEnv-pgi:stat:totalview:tpsl:trilinos:xt
↳ -asyncpe:xt-craypat:xt-lgdb:xt-libsci:xt-mpich2:x
↳ t-mpt:xt-papi:xt-shmem:xt-totalview
LIBGL_DEBUG=quiet
MINICOM=-c on
PE_MPICH_GENCOMPILERS_GNU=7.1 5.1 4.9
PE_TPSL_DEFAULT_GENCOMPS_CRAY_interlagos=86
PE_TPSL_DEFAULT_GENCOMPILERS_GNU_x86_64=8.2 7.1 5.3
↳ 4.9
PE_PKGCONFIG_DEFAULT_PRODUCTS=PE_TRILINOS:PE_TPSL_64
↳ :PE_TPSL:PE_PETSC:PE_PARALLEL_NETCDF:PE_NETCDF_H
↳ DF5PARALLEL:PE_NETCDF:PE_MPICH:PE_LIBSCI:PE_HDF5
↳ _PARALLEL:PE_HDF5:PE_GA:PE_FFTW
PE_HDF5_DEFAULT_VOLATILE_PKGCONFIG_PATH=/opt/cray/pe
↳ /hdf5/1.10.2.0/@PRGENV@/@PE_HDF5_DEFAULT_GENCOMP
↳ S@/lib/pkgconfig
PAT_REPORT_PRUNE_NAME=_cray$mt_execute_,_cray$mt_sta
↳ rt_,_cray_hwpc_,f_cray_hwpc_,cstart_,_pat_,pat_
↳ region_,PAT_,OMP.slave_loop,slave_entry,_new_sla
↳ ve_entry,_thread_pool_slave_entry,THREAD_POOL_jo
↳ in,_libc_start_main,_start_,_start_thread_
↳ ,_wrap_,UPCADIO_,_upc_,_upc_,_caf_,_pgas_,sys
↳ call,_device_stub
MODULE_VERSION=3.2.11.1
MAIL=/var/mail/USER

```

```

PATH=/opt/xalt/bin:/soft/buildtools/trackdeps/bin:/s
↳ oft/perftools/darshan/darshan-3.1.5/bin:/opt/mod
↳ ulefiles/nompirun/bin:/opt/cray/pe/mpt/7.7.3/gni
↳ /bin:/opt/cray/pe/perftools/7.0.4/bin:/opt/cray/
↳ pe/papi/5.6.0.4/bin:/opt/cray/rca/2.2.18-6.0.7.1
↳ _5.47__g2aa4f39.ari/bin:/opt/cray/pe/craype/2.5.
↳ 15/bin:/opt/intel/compilers_and_libraries_2018.0
↳ .128/linux/bin/intel64:/opt/intel/compilers_and_
↳ libraries_2018.0.128/linux/mpi/intel64/bin:/opt/
↳ intel/debugger_2017/gdb/intel64_mic/bin:/opt/cra
↳ y/cfgutils/bin:/opt/cray/nodehealth/5.6.14-6.0.7
↳ .1_8.45__gd6a82f3.ari/bin:/opt/cray/llm/21.3.530
↳ -6.0.7.1_5.4__g3b4230e.ari/bin:/opt/cray/sdb/3.3.
↳ 777-6.0.7.1_6.2__g5ddb0ab.ari/bin:/opt/cray/node
↳ stat/2.3.85-6.0.7.1_5.30__gc6218bb.ari/bin:/opt/
↳ cray/alps/6.6.43-6.0.7.1_5.45__ga796da32.ari/sbi
↳ n:/opt/cray/alps/6.6.43-6.0.7.1_5.45__ga796da32.
↳ ari/bin:/opt/cray/pe/modules/3.2.11.1/bin:/usr/l
↳ ocal/bin:/usr/bin:/bin:/usr/bin/X11:/usr/games:/
↳ dbhome/db2cat/sqllib/bin:/dbhome/db2cat/sqllib/a
↳ dm:/dbhome/db2cat/sqllib/misc:/usr/lib/mit/bin:/
↳ usr/lib/mit/sbin:/opt/cray/pe/bin
XALT_COBAL_QUEUE=debug-cache-quad
ALPS_APP_DEPTH=1
PE_TPSL_DEFAULT_GENCOMPILERS_GNU_haswell=8.2 7.1 5.3
↳ 4.9
PE_TPSL_64_DEFAULT_GENCOMPILERS_GNU_x86_skylake=8.2
↳ 7.1 6.1
PE_PETSC_DEFAULT_GENCOMPS_CRAY_mic_knl=86
PE_PARALLEL_NETCDF_DEFAULT_GENCOMPILERS_GNU=5.1 4.9
PE_NETCDF_DEFAULT_GENCOMPILERS_GNU=8.2 7.1 6.1 5.3 4.9
PE_FFTW_DEFAULT_TARGET_abudhabi=abudhabi
ATP_IGNORE_SIGTERM=1
XTPE_NETWORK_TARGET=aries
CPU=x86_64
_=/usr/bin/env
PE_TPSL_64_DEFAULT_GENCOMPILERS_CRAY_x86_skylake=8.6
PE_SMA_DEFAULT_DIR_CRAY_DEFAULT64=64
PE_NETCDF_HDF5PARALLEL_DEFAULT_GENCOMPS_GNU=
PE_NETCDF_HDF5PARALLEL_DEFAULT_FIXED_PRGENV=CRAY
↳ INTEL
PE_HDF5_PARALLEL_DEFAULT_GENCOMPS_GNU=
PE_HDF5_PARALLEL_DEFAULT_FIXED_PRGENV=CRAY INTEL
JAVA_BINDIR=/usr/lib64/jvm/java/bin
SSH_SENDS_LOCALE=yes
TBBROOT=/opt/intel/compilers_and_libraries_2018.0.12
↳ 8/linux/tbb
PE_TPSL_DEFAULT_GENCOMPS_INTEL_interlagos=160
PE_TPSL_DEFAULT_GENCOMPILERS_CRAY_mic_knl=8.6
PE_TPSL_64_DEFAULT_VOLATILE_PRGENV=CRAY CRAY64 GNU
↳ GNU64 INTEL INTEL64
PE_TPSL_64_DEFAULT_GENCOMPS_CRAY_sandybridge=86
CRAY_UDREG_POST_LINK_OPTS=-L/opt/cray/udreg/2.3.2-6.
↳ 0.7.1_5.13__g5196236.ari/lib64
PE_MPICH_VOLATILE_PRGENV=CRAY GNU
PE_TPSL_DEFAULT_GENCOMPS_GNU_mic_knl=71 53

```



```

CRAYPE_VERSION=2.5.15
CRAY_ALPS_POST_LINK_OPTS=-L/opt/cray/alps/6.6.43-6.0.7.1_5.45__ga796da32.ari/lib64
INPUTRC=/etc/inputrc
PWD=/gpfs/mira-home/USER
PE_TPSSL_DEFAULT_GENCOMPILERS_INTEL_haswell=16.0
PE_PETSC_DEFAULT_GENCOMPILERS_GNU_sandybridge=7.1
  5.3 4.9
PE_MPICH_DEFAULT_GENCOMPS_CRAY=86
PE_LIBSCI_DEFAULT_OMP_REQUIRES=
_LMFILES=/opt/cray/pe/modulefiles/modules/3.2.11.1:
  /opt/cray/ari/modulefiles/alps/6.6.43-6.0.7.1_5.45__ga796da32.ari:/opt/cray/ari/modulefiles/node
  stat/2.3.85-6.0.7.1_5.30__gc6218bb.ari:/opt/cray
  /ari/modulefiles/sdb/3.3.777-6.0.7.1_6.2__g5ddb0
  ab.ari:/opt/cray/ari/modulefiles/udreg/2.3.2-6.0.7.1_5.13__g5196236.ari:/opt/cray/ari/modulefile
  s/ugni/6.0.14.0-6.0.7.1_3.13__gea11d3d.ari:/opt/
  cray/ari/modulefiles/gni-headers/5.0.12.0-6.0.7.1_3.11__g3b1768f.ari:/opt/cray/ari/modulefiles/d
  mapp/7.1.1-6.0.7.1_5.45__g5a674e0.ari:/opt/cray/
  ari/modulefiles/xpmem/2.2.15-6.0.7.1_5.11__g7549
  d06.ari:/opt/cray/ari/modulefiles/llm/21.3.530-6.0.7.1_5.4__g3b4230e.ari:/opt/cray/ari/modulefil
  es/nodehealth/5.6.14-6.0.7.1_8.45__gd6a82f3.ari:/
  /opt/cray/ari/modulefiles/system-config/3.5.2790
  -6.0.7.1_7.1__g7767d3c6.ari:/opt/modulefiles/Base
  -opts/2.4.135-6.0.7.1_5.6__g718f891.ari:/opt/modu
  lefiles/intel/18.0.0.128:/opt/cray/pe/craype/2.5
  .15/modulefiles/craype-network-aries:/opt/cray/p
  e/modulefiles/craype/2.5.15:/opt/cray/pe/modulef
  iles/cray-libsci/18.07.1:/opt/cray/pe/modulefile
  s/pmi/5.0.14:/opt/cray/pe/modulefiles/atp/2.1.3:/
  /opt/cray/ari/modulefiles/rca/2.2.18-6.0.7.1_5.4
  7__g2aa4f39.ari:/opt/cray/pe/modulefiles/perftoo
  ls-base/7.0.4:/opt/cray/pe/modulefiles/PrgEnv-in
  tel/6.0.4:/opt/cray/pe/craype/2.5.15/modulefiles
  /craype-mic-knl:/opt/cray/pe/modulefiles/cray-mp
  ich/7.7.3:/opt/modulefiles/nompirun/nompirun:/so
  ft/environment/modules/modulefiles/darshan/3.1.5
  :/soft/environment/modules/modulefiles/trackdeps
  :/soft/environment/modules/modulefiles/xalt

```

```

TARGETMODULES=craype-abudhabi:craype-abudhabi-cu:cray
  ype-accel-host:craype-accel-nvidia20:craype-acce
  l-nvidia30:craype-accel-nvidia35:craype-barcelon
  a:craype-broadwell:craype-haswell:craype-hugepag
  es128K:craype-hugepages128M:craype-hugepages16M:
  craype-hugepages256M:craype-hugepages2M:craype-h
  ugepages32M:craype-hugepages4M:craype-hugepages5
  12K:craype-hugepages512M:craype-hugepages64M:cray
  ype-hugepages8M:craype-intel-knc:craype-interlag
  os:craype-interlagos-cu:craype-istanbul:craype-i
  vybridge:craype-mc12:craype-mc8:craype-mic-knl:c
  raype-network-aries:craype-network-gemini:craype
  -network-infiniband:craype-network-none:craype-ne
  twork-seastar:craype-sandybridge:craype-shanghai
  :craype-target-compute_node:craype-target-local_
  host:craype-target-native:craype-xeon:xtpe-barce
  lona:xtpe-interlagos:xtpe-interlagos-cu:xtpe-ist
  anbul:xtpe-mc12:xtpe-mc8:xtpe-network-gemini:xtpe
  e-network-seastar:xtpe-shanghai:xtpe-target-nati
  ve:xtpe-xeon
JAVA_HOME=/usr/lib64/jvm/java
PE_TPSSL_DEFAULT_GENCOMPILERS_GNU_mic_knl=7.1 5.3
PE_TPSSL_DEFAULT_GENCOMPILERS_CRAY_interlagos=8.6
PE_PETSC_DEFAULT_GENCOMPILERS_CRAY_skylake=8.6
PE_LIBSCI_MODULE_NAME=cray-libsci/18.07.1
PE_INTEL_FIXED_PKGCONFIG_PATH=/opt/cray/pe/mpt/7.7.3
  /gni/mpich-intel/16.0/lib/pkgconfig
PE_TPSSL_64_DEFAULT_GENCOMPS_GNU_x86_skylake=82 71 61
GDB_CROSS=/opt/intel/debugger_2017/gdb/intel64_mic/b
  in/gdb-mic
LANG=en_US.UTF-8
PE_MPICH_VOLATILE_PKGCONFIG_PATH=/opt/cray/pe/mpt/7.
  7.3/gni/mpich-@PRGENV@PE_MPICH_DIR_DEFAULT64/@
  PE_MPICH_GENCOMPS@/lib/pkgconfig
PE_MPICH_NV_LIBS_nvidia20=-lcudart
PE_LIBSCI_GENCOMPILERS_CRAY_x86_64=8.6
PYTHONSTARTUP=/etc/pythonstart
MODULEPATH=/opt/cray/pe/perftools/7.0.4/modulefiles:
  /opt/cray/pe/craype/2.5.15/modulefiles:/opt/cray
  /pe/modulefiles:/opt/cray/modulefiles:/opt/modul
  efiles:/soft/environment/modules/modulefiles:/op
  t/cray/craype/default/modulefiles:/opt/cray/ari/
  modulefiles
SHMEM_ABORT_ON_ERROR=1

```

MemXCT: Memory-Centric X-Ray CT Reconstruction with Massive Parallelization

```

LOADED_MODULES=modules/3.2.11.1:alps/6.6.43-6.0.7.1_5
↪ .45__ga796da32.ari:nodestat/2.3.85-6.0.7.1_5.30_
↪ _gc6218bb.ari:sdb/3.3.777-6.0.7.1_6.2__g5ddb0ab.
↪ ari:udreg/2.3.2-6.0.7.1_5.13__g5196236.ari:ugni/
↪ 6.0.14.0-6.0.7.1_3.13__gea11d3d.ari:gni-headers/
↪ 5.0.12.0-6.0.7.1_3.11__g3b1768f.ari:dmapp/7.1.1-
↪ 6.0.7.1_5.45__g5a674e0.ari:xpmem/2.2.15-6.0.7.1_
↪ 5.11__g7549d06.ari:llm/21.3.530-6.0.7.1_5.4__g3b
↪ 4230e.ari:nodehealth/5.6.14-6.0.7.1_8.45__gd6a82
↪ f3.ari:system-config/3.5.2790-6.0.7.1_7.1__g7767
↪ d3c6.ari:Base-opts/2.4.135-6.0.7.1_5.6__g718f891
↪ .ari:intel/18.0.0.128:craype-network-aries:crayp
↪ e/2.5.15:cray-libsci/18.07.1:pmi/5.0.14:atp/2.1.
↪ 3:rca/2.2.18-6.0.7.1_5.47__g2aa4f39.ari:perftool
↪ s-base/7.0.4:PrgEnv-intel/6.0.4:craype-mic-kenl:c
↪ ray-mpich/7.7.3:nompirun/nompirun:darshan/3.1.5:
↪ trackdeps:xalt
SDK_HOME=/usr/lib64/jvm/java
COBALT_JOBID=329035
PE_TPSL_DEFAULT_GENCOMPILERS_INTEL_mic_kenl=16.0
PE_TPSL_64_DEFAULT_GENCOMPS_GNU_interlagos=82 71 53
↪ 49
PE_PKG_CONFIG_PATH=/opt/cray/pe/cti/1.0.7/lib/pkgcon
↪ fig:/opt/cray/pe/cti/1.0.6/lib/pkgconfig:/opt/cr
↪ ay/pe/cti/1.0.4/lib/pkgconfig:/opt/cray/pe/cti/1
↪ .0.5/lib/pkgconfig
PE_FFTW_DEFAULT_TARGET_x86_skylake=x86_skylake
PE_FFTW_DEFAULT_TARGET_share=share
PE_FFTW_DEFAULT_TARGET_ivybridge=ivybridge
CRAY_DMAPP_POST_LINK_OPTS=-L/opt/cray/dmapp/7.1.1-6.
↪ 0.7.1_5.45__g5a674e0.ari/lib64
PE_TPSL_DEFAULT_GENCOMPILERS_CRAY_x86_skylake=8.6
PE_PETSC_DEFAULT_GENCOMPILERS_GNU_skylake=6.1
PE_LIBSCI_OMP_REQUIRES_openmp=_mp
PAT_BUILD_PAPI_BASEDIR=/opt/cray/pe/papi/5.6.0.4
CRAY_RCA_INCLUDE_OPTS=-I/opt/cray/rca/2.2.18-6.0.7.1
↪ _5.47__g2aa4f39.ari/include
↪ -I/opt/cray/krca/2.2.4-6.0.7.1_5.43__g8505b97.ar
↪ i/include
↪ -I/opt/cray/hss-devel/9.0.0/include
COBALT_PARTSIZE=1
PE_MPICH_CXX_PKGCONFIG_LIBS=mpichcxx
CRAY_MPICH_DIR=/opt/cray/pe/mpt/7.7.3/gni/mpich-inte
↪ 1/16.0
PE_TPSL_DEFAULT_GENCOMPILERS_INTEL_x86_64=16.0
PE_TPSL_64_DEFAULT_GENCOMPS_CRAY_mic_kenl=86
PE_MPICH_PKGCONFIG_VARIABLES=PE_MPICH_NV_LIBS@accel
↪ erator@:PE_MPICH_ALTERNATE_LIBS@multithreaded@:
↪ PE_MPICH_ALTERNATE_LIBS@dpm@
PE_LIBSCI_DEFAULT_GENCOMPS_INTEL_x86_64=160
DAALROOT=/opt/intel/compilers_and_libraries_2018.0.1
↪ 28/linux/daal
DB2_HOME=/dbhome/db2cat/sqllib
COBALT_NODEFILE=/var/tmp/cobalt.329035
PE_MPICH_PKGCONFIG_LIBS=mpich
CRAY_MPICH2_VER=7.7.3

```

```

PE_TPSL_DEFAULT_VOLATILE_PKGCONFIG_PATH=/opt/cray/pe
↪ /tpsl/18.06.1/@PRGENV@/@PE_TPSL_DEFAULT_GENCOMPS
↪ @/@PE_TPSL_DEFAULT_TARGET@/lib/pkgconfig
PE_TPSL_DEFAULT_GENCOMPILERS_INTEL_x86_skylake=16.0
PE_TPSL_64_DEFAULT_GENCOMPILERS_CRAY_mic_kenl=8.6
PE_HDF5_DEFAULT_FIXED_PRGENV=CRAY_INTEL
MPM_LAUNCHER=/opt/intel/debugger_2017/mpm/mic/bin/st
↪ art_mpm.sh
CRAY_PMI_POST_LINK_OPTS=-L/opt/cray/pe/pmi/5.0.14/li
↪ b64
APP2_STATE=7.0.4
PE_PARALLEL_NETCDF_DEFAULT_FIXED_PRGENV=CRAY_INTEL
PE_NETCDF_DEFAULT_FIXED_PRGENV=CRAY_INTEL
PE_MPICH_ALTERNATE_LIBS_multithreaded=_mt
PE_LIBSCI_VOLATILE_PKGCONFIG_PATH=/opt/cray/pe/libsc
↪ i/18.07.1/@PRGENV@/@PE_LIBSCI_GENCOMPS@/@PE_LIBS
↪ CI_TARGET@/lib/pkgconfig
PE_GA_DEFAULT_GENCOMPILERS_GNU=5.3 4.9
INTEL_PYTHONHOME=/opt/intel/debugger_2017/python/int
↪ el64/
GPG_TTY=/dev/pts/3
PE_TPSL_64_DEFAULT_GENCOMPS_GNU_haswell=82 71 53 49
PE_PKGCONFIG_PRODUCTS_DEFAULT=PE_PAPI
PE_NETCDF_HDF5PARALLEL_DEFAULT_VOLATILE_PRGENV=GNU
PE_MPICH_TARGET_VAR_nvidia35=-lcudart
PE_HDF5_PARALLEL_DEFAULT_VOLATILE_PRGENV=GNU
CRAY_LIBSCI_VERSION=18.07.1
QT_SYSTEM_DIR=/usr/share/desktop-data
JDK_HOME=/usr/lib64/jvm/java
SHLVL=5
HOME=/home/USER
PE_TPSL_DEFAULT_GENCOMPILERS_INTEL_interlagos=16.0
IBM_DB_INCLUDE=/dbhome/db2cat/sqlib/include
LESS_ADVANCED_PREPROCESSOR=no
OSTYPE=linux
PE_TPSL_DEFAULT_VOLATILE_PRGENV=CRAY CRAY64 GNU GNU64
↪ INTEL INTEL64
PE_PETSC_DEFAULT_GENCOMPILERS_CRAY_interlagos=8.6
PE_MPICH_DEFAULT_VOLATILE_PKGCONFIG_PATH=/opt/cray/p
↪ e/mpt/7.7.3/gni/mpich-@PRGENV@/@PE_MPICH_DEFAULT_
↪ DIR_DEFAULT64@/@PE_MPICH_DEFAULT_GENCOMPS@/lib/p
↪ kgconfig
LS_OPTIONS=-N --color=none -T 0
PE_TPSL_DEFAULT_GENCOMPS_INTEL_sandybridge=160
PE_TPSL_64_DEFAULT_GENCOMPS_CRAY_interlagos=86
CRAY_PMI_INCLUDE_OPTS=-I/opt/cray/pe/pmi/5.0.14/incl
↪ ude
XCURSOR_THEME=DMZ
PE_MPICH_DIR_CRAY_DEFAULT64=64
PKG_CONFIG_PATH_DEFAULT=/opt/cray/pe/papi/5.6.0.4/li
↪ b64/pkgconfig
PE_TPSL_DEFAULT_GENCOMPILERS_CRAY_haswell=8.6
ATP_MRNET_COMM_PATH=/opt/cray/pe/atp/2.1.3/libexec/a
↪ tp_mrnet_commnodewrapper
CRAYPE_NETWORK_TARGET=aries

```

```

PRGENVMODULES=PrgEnv-cray:PrgEnv-gnu:PrgEnv-intel:PrgEnv-pgi
WINDOWMANAGER=
XALT_COBALT_JOB_NUM_CORES=64
PE_TPSSL_DEFAULT_GENCOMPILERS_INTEL_sandybridge=16.0
PE_TPSSL_DEFAULT_GENCOMPILERS_GNU_interlagos=8.2 7.1
    ↪ 5.3 4.9
PE_TPSSL_64_DEFAULT_GENCOMPILERS_GNU_mic_knl=7.1 5.3
PE_PETSC_DEFAULT_GENCOMPILERS_GNU_haswell=7.1 5.3 4.9
COBALT_JOBSIZE=1
PE_TRILINOS_DEFAULT_REQUIRED_PRODUCTS=PE_MPICH:PE_HDF5
    ↪ F5_PARALLEL:PE_NETCDF_HDF5PARALLEL:PE_LIBSCI:PE_TPSSL
PE_TPSSL_DEFAULT_GENCOMPS_GNU_x86_64=82 71 53 49
PE_TPSSL_64_DEFAULT_GENCOMPILERS_INTEL_sandybridge=16.0
    ↪ .0
PE_TPSSL_64_DEFAULT_GENCOMPILERS_GNU_haswell=8.2 7.1
    ↪ 5.3 4.9
PE_NETCDF_DEFAULT_REQUIRED_PRODUCTS=PE_HDF5
PE_MPICH_NV_LIBS=
PE_HDF5_DEFAULT_GENCOMPS_GNU=
CRAY_LIBSCI_PREFIX_DIR=/opt/cray/pe/libsci/18.07.1/Intel/16.0/x86_64
CRAY_GNI_HEADERS_INCLUDE_OPTS=-I/opt/cray/gni-header/s/5.0.12.0-6.0.7.1_3.11_g3b1768f.ari/include
G_FILENAME_ENCODING=@locale,UTF-8,ISO-8859-15,CP1252
LESS=-M -I -R
MACHTYPE=x86_64-suse-linux
LOGNAME=USER
PE_MPICH_GENCOMPS_CRAY=86
PE_TRILINOS_DEFAULT_GENCOMPS_GNU_x86_64=82 73 51 49
PE_MPICH_DEFAULT_GENCOMPILERS_CRAY=8.6
PE_LIBSCI_OMP_REQUIRES=
DMAPP_ABORT_ON_ERROR=1
CVS_RSH=ssh
COBALT_BLOCKSIZE=1
TRACKDEPS_CMDS=cc1 cc1plus f951 clang clang-3.9
    ↪ clang-4.0 clang-5.0 clang-6.0 clang-7.0 cpp as
    ↪ mcpcom fortcom ccfe ftnfe driver ar ld.bfd
    ↪ ld.gold ld
PE_TPSSL_DEFAULT_GENCOMPILERS_CRAY_sandybridge=8.6
PE_TPSSL_64_DEFAULT_GENCOMPILERS_INTEL_interlagos=16.0
PE_MPICH_DEFAULT_GENCOMPS_GNU=71 51 49
PE_MPICH_DEFAULT_FIXED_PRGENV=INTEL
PE_LIBSCI_DEFAULT_REQUIRED_PRODUCTS=PE_MPICH
TOOLMODULES=apprentice:apprentice2:atp:chapel:cray-ld:cray-gdb:craypat:craypkg-gen:cray-snp-launcher:ddt:gdb:
    ↪ iobuf:papi:perftools:perftools-lite:stat:totalview
    ↪ iew:xt:craypat:xt-lgdb:xt-papi:xt-totalview
XDG_DATA_DIRS=/usr/share

```

```

CLASSPATH=/opt/intel/compilers_and_libraries_2018.0.128/linux/daal/lib/daal.jar:/dbhome/db2cat/sqljdbc_12.0/
    ↪ b/java/db2java.zip:/dbhome/db2cat/sqljdbc_12.0/java/sqljdbc_12.0/
    ↪ 1j.zip:/dbhome/db2cat/sqljdbc_12.0/function:/dbhome/db2cat/sqljdbc_12.0/
    ↪ 2cat/sqljdbc_12.0/java/db2jcc_license_cu.jar:/dbhome/db2cat/sqljdbc_12.0/
    ↪ 1lib/tools/jline-0.9.93.jar:/dbhome/db2cat/sqljdbc_12.0/b/java/db2jcc.jar:
SSH_CONNECTION=10.236.1.194 50720 10.237.16.104 22
TRACKDEPS_LOG_PATH=/lus/theta-fs0/logs/trackdeps
PE_TPSSL_DEFAULT_GENCOMPILERS_GNU_sandybridge=8.2 7.1
    ↪ 5.3 4.9
PE_LIBSCI_DEFAULT_VOLATILE_PKGCONFIG_PATH=/opt/cray/pe/libsci/18.07.1/@PRGENV@/@PE_LIBSCI_DEFAULT_TARGET@/lib/pkgconfig
    ↪ NCOMPS@/@PE_LIBSCI_DEFAULT_TARGET@/lib/pkgconfig
PE_GA_DEFAULT_FIXED_PRGENV=CRAY_INTEL
CRAY_PRGENVINTEL=loaded
MODULESHOME=/opt/cray/pe/modules/3.2.11.1
PELOCAL_PRGENV=true
COMPILER_PATH=/opt/xalt/bin
PE_PETSC_DEFAULT_VOLATILE_PKGCONFIG_PATH=/opt/cray/pe/petsc/3.8.4.0/complex/@PRGENV@/@PE_PETSC_DEFAULT_TARGET@/lib/pkgconfig
    ↪ LT_GENCOMPS@/@PE_PETSC_DEFAULT_TARGET@/lib/pkgconfig
    ↪ nfig
PE_MPICH_NV_LIBS_nvidia35=-lcudart
PKG_CONFIG_PATH=/soft/perftools/darshan/darshan-3.1.5/lib/pkgconfig:/opt/cray/rca/2.2.18-6.0.7.1_5.4.7__g2aa4f39.ari/lib64/pkgconfig:/opt/cray/pe/pmi/5.0.14/lib64/pkgconfig:/opt/cray/pe/craype/2.5.15/pkg-config:/opt/cray/pe/iobuf/2.0.8/lib/pkgconfig:/opt/cray/llm/21.3.530-6.0.7.1_5.4__g3b4230.ari/lib64/pkgconfig:/opt/cray/xpmem/2.2.15-6.0.7.1_5.11__g7549d06.ari/lib64/pkgconfig:/opt/cray/y/dmapp/7.1.1-6.0.7.1_5.45__g5a674e0.ari/lib64/pkgconfig:/opt/cray/gni-headers/5.0.12.0-6.0.7.1_3.11__g3b1768f.ari/lib64/pkgconfig:/opt/cray/ugn/6.0.14.0-6.0.7.1_3.13__gea11d3d.ari/lib64/pkgconfig:/opt/cray/udreg/2.3.2-6.0.7.1_5.13__g51962.ari/lib64/pkgconfig:/opt/cray/alps/6.6.43-6.0.7.1_5.45__ga796da32.ari/lib64/pkgconfig:/opt/cray/pe/atp/2.1.3/lib/pkgconfig
LESSOPEN=lessopen.sh %s
PE_TPSSL_64_DEFAULT_GENCOMPS_INTEL_x86_64=160
LIBSCI_BASE_DIR=/opt/cray/pe/libsci/18.07.1
CRAYPAT_OPTS_EXECUTABLE=sbin/pat-opts
PE_TPSSL_DEFAULT_GENCOMPS_INTEL_mic_knl=160
PE_TPSSL_64_DEFAULT_GENCOMPS_GNU_sandybridge=82 71 53
    ↪ 49
PE_MPICH_NV_LIBS_nvidia60=-lcudart
PE_LIBSCI_DEFAULT_VOLATILE_PKGCONFIG_VARIABLES=PE_LIBSCI_DEFAULT_OMP_REQUIRES=@openmp:PE_LIBSCI_EXT_LIBPATH:PE_LIBSCI_EXT_LIBNAME
LIBSCI_VERSION=18.07.1

```


MemXCT: Memory-Centric X-Ray CT Reconstruction with Massive Parallelization

```

INFOPATH=/opt/intel/documentation_2017/en/debugger//
↳ gdb-ia/info:/opt/intel/documentation_2017/en/de
↳ bugger//gdb-mic/info:/opt/intel/documentation_2
↳ 017/en/debugger//gdb-igfx/info/
CRAY_CPU_TARGET=mic-knl
PE_TPSL_64_DEFAULT_GENCOMPILERS_GNU_x86_64=8.2 7.1
↳ 5.3 4.9
PE_LIBSCI_GENCOMPILERS_INTEL_x86_64=16.0
PE_FFTW_DEFAULT_TARGET_broadwell=broadwell
CRAY_PRE_COMPILE_OPTS=-hnetwork=aries
CRAY_ALPS_INCLUDE_OPTS=-I/opt/cray/alps/6.6.43-6.0.7
↳ .1.5.45__ga796da32.ari/include
XDG_RUNTIME_DIR=/run/user/31353
craype_already_loaded=0
PE_TPSL_64_DEFAULT_GENCOMPS_CRAY_x86_64=86
PE_PAPI_DEFAULT_ACCELL_FAMILY_LIBS=
PE_LIBSCI_REQUIRED_PRODUCTS=PE_MPICH
CRAY_XPMEM_INCLUDE_OPTS=-I/opt/cray/xpmem/2.2.15-6.0
↳ .7.1.5.11__g7549d06.ari/include
CRAY_UGNI_INCLUDE_OPTS=-I/opt/cray/ugni/6.0.14-6.0
↳ .7.1.3.13__gea11d3d.ari/include
PE_TPSL_DEFAULT_GENCOMPS_INTEL_haswell=160
PE_LIBSCI_GENCOMPS_GNU_x86_64=71 61 51 49
PE_LIBSCI_DEFAULT_GENCOMPILERS_GNU_x86_64=7.1 6.1 5.1
↳ 4.9
PE_PETSC_DEFAULT_GENCOMPILERS_INTEL_x86_64=16.0
PE_FFTW_DEFAULT_TARGET_x86_64=x86_64
ATP_HOME=/opt/cray/pe/atp/2.1.3
DB2LIB=dbhome/db2cat/sql/lib/lib
LESSCLOSE=lessclose.sh %s %s
PE_TPSL_64_DEFAULT_GENCOMPILERS_INTEL_x86_skylake=16
↳ .0
PE_SMA_DEFAULT_DIR_PGI_DEFAULT64=64
PE_PETSC_DEFAULT_GENCOMPILERS_INTEL_haswell=16.0
PE_PETSC_DEFAULT_GENCOMPILERS_GNU_interlagos=7.1 5.3
↳ 4.9
PE_PAPI_DEFAULT_ACCEL_LIBS=
PE_INTEL_DEFAULT_FIXED_PKGCONFIG_PATH=/opt/cray/pe/p
↳ arallel-netcdf/1.8.1.3/INTEL/16.0/lib/pkgconfig:
↳ /opt/cray/pe/netcdf-hdf5parallel/4.6.1.3/INTEL/1
↳ 6.0/lib/pkgconfig:/opt/cray/pe/netcdf/4.6.1.3/IN
↳ TEL/16.0/lib/pkgconfig:/opt/cray/pe/mpt/7.7.3/gn
↳ i/mpich-intel/16.0/lib/pkgconfig:/opt/cray/pe/hd
↳ f5-parallel/1.10.2.0/INTEL/16.0/lib/pkgconfig:/o
↳ pt/cray/pe/hdf5/1.10.2.0/INTEL/16.0/lib/pkgconfi
↳ g:/opt/cray/pe/ga/5.3.0.8/INTEL/18.0/lib/pkgconf
↳ ig
PE_GA_DEFAULT_VOLATILE_PKGCONFIG_PATH=/opt/cray/pe/g
↳ a/5.3.0.8/@PRGENV@/@PE_GA_DEFAULT_GENCOMPS@/lib/
↳ pkgconfig
PE_GA_DEFAULT_GENCOMPS_GNU=53 49
PE_FFTW_DEFAULT_TARGET_haswell=haswell

```

```

CRAY_LD_LIBRARY_PATH=/opt/cray/pe/mpt/7.7.3/gni/mpic
↳ h-intel/16.0/lib:/opt/cray/pe/perftools/7.0.4/li
↳ b64:/opt/cray/rca/2.2.18-6.0.7.1_5.47__g2aa4f39.
↳ ari/lib64:/opt/cray/pe/pmi/5.0.14/lib64:/opt/cra
↳ y/pe/libsci/18.07.1/INTEL/16.0/x86_64/lib:/opt/c
↳ ray/llm/21.3.530-6.0.7.1_5.4__g3b4230e.ari/lib64
↳ :/opt/cray/xpmem/2.2.15-6.0.7.1_5.11__g7549d06.a
↳ ri/lib64:/opt/cray/dmapp/7.1.1-6.0.7.1_5.45__g5a
↳ 674e0.ari/lib64:/opt/cray/ugni/6.0.14-6.0.7.1_
↳ 3.13__gea11d3d.ari/lib64:/opt/cray/udreg/2.3.2-6
↳ .0.7.1_5.13__g5196236.ari/lib64:/opt/cray/alps/6
↳ .6.43-6.0.7.1_5.45__ga796da32.ari/lib64
G_BROKEN_FILENAMES=1
intel_already_loaded=0
PE_PETSC_DEFAULT_GENCOMPS_INTEL_x86_64=160
PE_PETSC_DEFAULT_GENCOMPS_GNU_x86_64=71 53 49
PE_PETSC_DEFAULT_GENCOMPS_CRAY_haswell=86
PE_MPICH_DEFAULT_DIR_CRAY_DEFAULT64=64
I_MPI_ROOT=/opt/intel/compilers_and_libraries_2018.0
↳ .128/linux/mpi
JAVA_ROOT=/usr/lib64/jvm/java
COLORTERM=1
BASH_FUNC_module%%=( ) { eval
↳ ` /opt/cray/pe/modules/3.2.11.1/bin/modulecmd
↳ bash $* `
}
+ lsb_release -a
LSB Version:          n/a
Distributor ID:       SUSE
Description:          SUSE Linux Enterprise Server 12
↳ SP3
Release:              12.3
Codename:              n/a
+ uname -a
Linux nid03826 4.4.103-6.38.4.0.153-cray_ari_c #1 SMP
↳ Thu Nov 1 16:05:05 UTC 2018 (6ef8fef) x86_64
↳ x86_64 x86_64 GNU/Linux
+ lscpu
Architecture:         x86_64
CPU op-mode(s):       32-bit, 64-bit
Byte Order:           Little Endian
CPU(s):               256
On-line CPU(s) list:  0-255
Thread(s) per core:   4
Core(s) per socket:   64
Socket(s):            1
NUMA node(s):         1
Vendor ID:            GenuineIntel
CPU family:           6
Model:                87
Model name:           Intel(R) Xeon Phi(TM) CPU 7230
↳ @ 1.30GHz
Stepping:             1
CPU MHz:              1301.000
CPU max MHz:          1301.0000
CPU min MHz:          1000.0000

```

```

BogoMIPS:          2599.90
L1d cache:         32K
L1i cache:         32K
L2 cache:          1024K
NUMA node0 CPU(s): 0-255
Flags:              fpu vme de pse tsc msr pae mce
                  ↪ cx8 apic sep mtrr pge mca cmov pat pse36 clflush
                  ↪ dts acpi mmx fxsr sse sse2 ss ht tm pbe syscall nx
                  ↪ pdpe1gb rdtscp lm constant_tsc arch_perfmon pebs
                  ↪ bts rep_good nopl xtopology nonstop_tsc
                  ↪ ring3mwait aperfmperf eagerfpu pni pclmulqdq
                  ↪ dtes64 monitor ds_cpl est tm2 ssse3 fma cx16 xtpr
                  ↪ pdcm sse4_1 sse4_2 x2apic movbe popcnt
                  ↪ tsc_deadline_timer aes xsave avx f16c rdrand
                  ↪ lahf_lm abm 3dnowprefetch ida arat epb pln pts
                  ↪ dtherm spec_ctrl kaiser fsgsbase tsc_adjust bmi1
                  ↪ avx2 smep bmi2 erms avx512f rdseed adx avx512pf
                  ↪ avx512er avx512cd xsaveopt
+ cat /proc/meminfo
MemTotal:          197936884 kB
MemFree:           196074544 kB
MemAvailable:      194868048 kB
Buffers:           2260 kB
Cached:            127536 kB
SwapCached:        0 kB
Active:            61364 kB
Inactive:          107616 kB
Active(anon):      55580 kB
Inactive(anon):    95540 kB
Active(file):       5784 kB
Inactive(file):    12076 kB
Unevictable:       6056 kB
Mlocked:           6056 kB
SwapTotal:         0 kB
SwapFree:          0 kB
Dirty:             0 kB
Writeback:         0 kB
AnonPages:         45360 kB
Mapped:            50904 kB
Shmem:            109188 kB
Slab:              432236 kB
SReclaimable:      27848 kB
SUnreclaim:        404388 kB
KernelStack:       34944 kB
PageTables:        3028 kB
NFS_Unstable:      0 kB
Bounce:            0 kB
WritebackTmp:      0 kB
CommitLimit:       98968440 kB
Committed_AS:      172612 kB
VmallocTotal:      34359738367 kB
VmallocUsed:        0 kB
VmallocChunk:      0 kB
HardwareCorrupted: 0 kB
HugePages_Total:   0
HugePages_Free:    0
HugePages_Rsvd:    0

```

```

HugePages_Surp:    0
Hugepagesize:      2048 kB
DirectMap4k:       10088 kB
DirectMap2M:       1988608 kB
DirectMap1G:       201326592 kB
+ inxi -F -c0
/var//opt/cray/alps/spool/13076151/collect_environment
↪ nt.sh: line 14: inxi: command not
↪ found
+ lsblk -a
NAME MAJ:MIN RM SIZE RO TYPE MOUNTPOINT
loop0 7:0 0 1.8M 0 loop
↪ /var/opt/cray/imps-distribution/squash/mounts/
loop1 7:1 0 192K 0 loop
↪ /var/opt/cray/imps-distribution/squash/mounts/
loop2 7:2 0 2.8G 1 loop /.rootfs_lower_ro
loop3 7:3 0 50.8G 1 loop
↪ /var/opt/cray/imps-image-binding/PE/squash_mou
loop4 7:4 0 1.6G 1 loop
↪ /var/opt/cray/imps-image-binding/diags/squash_
loop5 7:5 0 0 loop
loop6 7:6 0 0 loop
loop7 7:7 0 0 loop
nvme0n1 259:0 0 119.2G 0 disk
└─compute-scratch
    254:0 0 119.2G 0 lvm /local/scratch
+ lsscsi -s
+ module list
++ /opt/cray/pe/modules/3.2.11.1/bin/modulecmd bash
↪ list
Currently Loaded Modulefiles:
 1) modules/3.2.11.1
 2) alps/6.6.43-6.0.7.1_5.45__ga796da32.ari
 3) udreg/2.3.2-6.0.7.1_5.13__g5196236.ari
 4) ugni/6.0.14.0-6.0.7.1_3.13__gea11d3d.ari
 5) gni-headers/5.0.12.0-6.0.7.1_3.11__g3b1768f.ari
 6) dmapp/7.1.1-6.0.7.1_5.45__g5a674e0.ari
 7) xpmem/2.2.15-6.0.7.1_5.11__g7549d06.ari
 8) llm/21.3.530-6.0.7.1_5.4__g3b4230e.ari
 9) nodehealth/5.6.14-6.0.7.1_8.45__gd6a82f3.ari
10) system-config/3.5.2790-6.0.7.1_7.1__g7767d3c6.ari
11) Base-opts/2.4.135-6.0.7.1_5.6__g718f891.ari
12) intel/18.0.0.128
13) craype-network-aries
14) craype/2.5.15
15) cray-libsci/18.07.1
16) pmi/5.0.14
17) atp/2.1.3
18) rca/2.2.18-6.0.7.1_5.47__g2aa4f39.ari
19) perftools-base/7.0.4
20) PrgEnv-intel/6.0.4
21) craype-mic-knl
22) cray-mpich/7.7.3
23) nompurun/nompurun
24) darshan/3.1.5
25) trackdeps

```

MemXCT: Memory-Centric X-Ray CT Reconstruction with Massive Parallelization

```

26) xalt
+ eval
+ nvidia-smi
NVIDIA-SMI has failed because it couldn't communicate
↳ with the NVIDIA driver. Make sure that the latest
↳ NVIDIA driver is installed and running.

+ cat
+ lshw -short -quiet -sanitize
/var//opt/cray/alps/spool/13076151/collect_environment
↳ nt.sh: line 19: lshw: command not
↳ found
+ lspci
/var//opt/cray/alps/spool/13076151/collect_environment
↳ nt.sh: line 19: lspci: command not
↳ found
Application 13076151 resources: utime ~0s, stime ~1s,
↳ Rss ~6236, inblocks ~2926, outblocks ~0

-----
Cooley System
-----
CPLUS_INCLUDE_PATH=
MANPATH=/soft/compilers/gcc/4.8.1/share/man:/soft/li
↳ braries/mpi/mvapich2/gcc/share/man:/soft/version
↳ ing/git/2.3.0/share/man:/soft/libraries/anaconda
↳ /share/man:/home/USER/man:/soft/environment/soft
↳ env-1.6.2/man:/usr/share/man:/usr/local/man:/usr
↳ /X11R6/man
HOSTNAME=cc018
SHELL=/bin/bash
TERM=xterm-256color
HISTSIZE=1000
SSH_CLIENT=172.23.100.210 48530 22
LIBRARY_PATH=
LD_PRELOAD=/soft/buildtools/trackdeps/${LIB}/trackde
↳ ps.so
NCARG_FONTCAPS=/usr/lib64/ncarg/fontcaps
SSH_TTY=/dev/pts/0
INCLUDE_PATH=
MIC_LD_LIBRARY_PATH=
GIT_BASE=/soft/versioning/git/2.3.0
QT_GRAPHICSSYSTEM_CHECKED=1
USER=USER
LD_LIBRARY_PATH=/home/USER/local/lib:/home/USER/proj
↳ ects/hdf5-1.10.1/lib:/soft/compilers/gcc/4.8.1/l
↳ ib64:/soft/compilers/gcc/4.8.1/lib:/soft/compile
↳ rs/llvm/5.0/lib:/soft/compilers/llvm/5.0/mvapich
↳ 2-flang/lib:/soft/libraries/mpi/mvapich2/gcc/lib
↳ :/soft/versioning/git/2.3.0/lib64

```

```

LS_COLORS=rs=0:di=38;5;27:ln=38;5;51:mh=44;38;5;15:p
↳ i=40;38;5;11:so=38;5;13:do=38;5;5:bd=48;5;232;38
↳ ;5;11:cd=48;5;232;38;5;3:or=48;5;232;38;5;9:mi=0
↳ 5;48;5;232;38;5;15:su=48;5;196;38;5;15:sg=48;5;1
↳ 1;38;5;16:ca=48;5;196;38;5;226:tw=48;5;10;38;5;1
↳ 6:ow=48;5;10;38;5;21:st=48;5;21;38;5;15:ex=38;5;
↳ 34:*.tar=38;5;9:*.tgz=38;5;9:*.arc=38;5;9:*.arj=
↳ 38;5;9:*.taz=38;5;9:*.lha=38;5;9:*.lz4=38;5;9:*.
↳ lzh=38;5;9:*.lzma=38;5;9:*.tlz=38;5;9:*.txz=38;5
↳ ;9:*.tzo=38;5;9:*.t7z=38;5;9:*.zip=38;5;9:*.z=38
↳ ;5;9:*.Z=38;5;9:*.dz=38;5;9:*.gz=38;5;9:*.lrz=38
↳ ;5;9:*.lz=38;5;9:*.lzo=38;5;9:*.xz=38;5;9:*.bz2=
↳ 38;5;9:*.bz=38;5;9:*.tbz=38;5;9:*.tbz2=38;5;9:*.
↳ tz=38;5;9:*.deb=38;5;9:*.rpm=38;5;9:*.jar=38;5;9
↳ :*.war=38;5;9:*.ear=38;5;9:*.sar=38;5;9:*.rar=38
↳ ;5;9:*.alz=38;5;9:*.ace=38;5;9:*.zoo=38;5;9:*.cp
↳ io=38;5;9:*.7z=38;5;9:*.rz=38;5;9:*.cab=38;5;9:
↳ *.jpg=38;5;13:*.jpeg=38;5;13:*.gif=38;5;13:*.bmp=
↳ 38;5;13:*.pbm=38;5;13:*.pgm=38;5;13:*.ppm=38;5;1
↳ 3:*.tga=38;5;13:*.xbm=38;5;13:*.xpm=38;5;13:*.ti
↳ f=38;5;13:*.tiff=38;5;13:*.png=38;5;13:*.svg=38;
↳ 5;13:*.svgz=38;5;13:*.mng=38;5;13:*.pcx=38;5;13:
↳ *.mov=38;5;13:*.mpg=38;5;13:*.mpeg=38;5;13:*.m2v
↳ =38;5;13:*.mkv=38;5;13:*.webm=38;5;13:*.ogm=38;5
↳ ;13:*.mp4=38;5;13:*.m4v=38;5;13:*.mp4v=38;5;13:
↳ *.vob=38;5;13:*.qt=38;5;13:*.nuv=38;5;13:*.wmv=38
↳ ;5;13:*.asf=38;5;13:*.rm=38;5;13:*.rmvb=38;5;13:
↳ *.flc=38;5;13:*.avi=38;5;13:*.fli=38;5;13:*.flv=
↳ 38;5;13:*.gl=38;5;13:*.dl=38;5;13:*.xcf=38;5;13:
↳ *.xwd=38;5;13:*.yuv=38;5;13:*.cgm=38;5;13:*.emf=
↳ 38;5;13:*.axv=38;5;13:*.anx=38;5;13:*.ogv=38;5;1
↳ 3:*.ogx=38;5;13:*.aac=38;5;45:*.au=38;5;45:*.fla
↳ c=38;5;45:*.mid=38;5;45:*.midi=38;5;45:*.mka=38;
↳ 5;45:*.mp3=38;5;45:*.mpc=38;5;45:*.ogg=38;5;45:
↳ *.ra=38;5;45:*.wav=38;5;45:*.axa=38;5;45:*.oga=38
↳ ;5;45:*.spx=38;5;45:*.xspf=38;5;45:
TIMEFORMAT=
real %3R          user %3U          sys %3S          pcpu %P

CPATH=
GCCDIR=/soft/compilers/gcc/4.8.1
MV2_USE_HUGEPAGES=0
MV2_ENABLE_AFFINITY=0
NCARG_GRAPHCAPS=/usr/lib64/ncarg/graphcaps
PAGER=less
NLSPATH=
PATH=/home/local/bin:/soft/compilers/gcc/4.8.1/bin:/
↳ soft/compilers/llvm/5.0/bin:/soft/compilers/llvm
↳ /mpi:/soft/libraries/mpi/mvapich2/gcc/bin:/soft/
↳ versioning/git/2.3.0/bin:/soft/libraries/anacond
↳ a/bin:/soft/visualization/unsupported/Fiji/20170
↳ 215/Fiji.app:/home/USER/bin:/soft/environment/so
↳ ftenv-1.6.2/bin:/bin:/usr/bin:/sbin:/usr/sbin:/u
↳ sr/local/bin:/usr/X11R6/bin:/soft/buildtools/tra
↳ ckdeps/bin:/opt/ibutils/bin
MAIL=/var/spool/mail/USER

```



```

_=/bin/env
SOFTENV_ALIASES=/soft/environment/softenv-1.6.2/etc/_j
↪ softenv-aliases.sh
C_INCLUDE_PATH=
PWD=/home/USER/projects/tests/sc_env_collect
NCARG_ROOT=/usr
LANG=en_US.UTF-8
WHATAMI=linux-rhel_7-x86_64
MODULEPATH=
NCARG_DATABASE=/usr/lib64/ncarg/database
COBALT_JOBID=1795545
PLATFORM=linux-rhel_7-x86_64
COBALT_NODEFILE=/var/tmp/cobalt.1795545
LM_LICENSE_FILE=
HISTIGNORE=&:bg:fg:ll:h
HISTCONTROL=ignoredups
NCARG_LIB=/usr/lib64/ncarg
SOFTENV_LOAD=/soft/environment/softenv-1.6.2/etc/sof_j
↪ tenv-load.sh
TEXINPUTS=
HOME=/home/USER
SHLVL=2
NCARG_NCARG=/usr/share/ncarg
LESSCHARSET=latin1
LOGNAME=USER
PYTHONPATH=
MV2_IBA_HCA=mlx5_0
LESS=-i -N -w -z-4 -g -e -M -X -F -R -P%t?f%f \
:stdin .?pb%pb\%:7lbLine %lb:?bbByte %bb:-...
CVS_RSH=ssh
SSH_CONNECTION=172.23.100.210 48530 172.23.100.114 22
TRACKDEPS_CMDS=cc1 cc1plus f951 clang clang-3.8
↪ clang-3.9 clang-4.0 clang-5.0 clang-6.0 cpp as
↪ fatbinary ptxas cudafe cudafe cudafe++ bin2c
↪ nvlink cicc mcpcom fortcom ar ld.bfd ld.gold ld
TRACKDEPS_LOG_PATH=/gpf/mira-fs0/logs/trackdeps
LESSOPEN=|/usr/bin/lesspipe.sh %s 2>&-
ARCH=linux-rhel_7-x86_64
DISPLAY=:0.0
HISTTIMEFORMAT=[1;36m[%d/%m %H:%M:%S]][m
+ lsb_release -a
LSB Version:          :core-4.1-amd64:core-4.1-noarch
Distributor ID:       RedHatEnterpriseServer
Description:          Red Hat Enterprise Linux Server
↪ release 7.6 (Maipo)
Release:              7.6
Codename:             Maipo
+ uname -a
Linux cc018 3.10.0-957.10.1.el7.x86_64 #1 SMP Thu Feb
↪ 7 07:12:53 UTC 2019 x86_64 x86_64 x86_64 GNU/Linux
+ lscpu
Architecture:         x86_64
CPU op-mode(s):       32-bit, 64-bit
Byte Order:           Little Endian
CPU(s):               12
On-line CPU(s) list:  0-11

```

```

Thread(s) per core:    1
Core(s) per socket:   6
Socket(s):             2
NUMA node(s):         2
Vendor ID:             GenuineIntel
CPU family:           6
Model:                63
Model name:           Intel(R) Xeon(R) CPU E5-2620 v3
↪ @ 2.40GHz
Stepping:             2
CPU MHz:              2472.802
CPU max MHz:          3200.0000
CPU min MHz:          1200.0000
BogoMIPS:             4789.04
Virtualization:       VT-x
L1d cache:            32K
L1i cache:            32K
L2 cache:             256K
L3 cache:             15360K
NUMA node0 CPU(s):    0-5
NUMA node1 CPU(s):    6-11
Flags:                fpu vme de pse tsc msr pae mce
↪ cx8 apic sep mtrr pge mca cmov pat pse36 clflush
↪ dts acpi mmx fxsr sse sse2 ss ht tm pbe syscall nx
↪ pdpe1gb rdtscp lm constant_tsc arch_perfmon pebs
↪ bts rep_good nopl xtopology nonstop_tsc
↪ aperfmperf eagerfpu pni pclmulqdq dtes64 monitor
↪ ds_cpl vmx smx est tm2 ssse3 sdbg fma cx16 xtpr
↪ pdcm pcid dca sse4_1 sse4_2 x2apic movbe popcnt
↪ tsc_deadline_timer aes xsave avx f16c rdrand
↪ lahf_lm abm epb intel_ppin ssbd ibrs ibpb stibp
↪ tpr_shadow vnmi flexpriority ept vpid fsgsbase
↪ tsc_adjust bmi1 avx2 smep bmi2 erms invpcid cqm
↪ xsaveopt cqm_llc cqm_occup_llc dtherm ida arat
↪ pln pts spec_ctrl intel_stibp flush_l1d
+ cat /proc/meminfo
MemTotal:             395970792 kB
MemFree:              386480572 kB
MemAvailable:         386841972 kB
Buffers:              269916 kB
Cached:              996784 kB
SwapCached:           0 kB
Active:              1180080 kB
Inactive:            517756 kB
Active(anon):        432504 kB
Inactive(anon):      33352 kB
Active(file):        747576 kB
Inactive(file):      484404 kB
Unevictable:         4194304 kB
Mlocked:             4194304 kB
SwapTotal:           5242876 kB
SwapFree:            5242876 kB
Dirty:               16 kB
Writeback:           0 kB
AnonPages:           4624256 kB
Mapped:              672260 kB

```

MemXCT: Memory-Centric X-Ray CT Reconstruction with Massive Parallelization

```

Shmem:          34740 kB
Slab:           614136 kB
SReclaimable:   271552 kB
SUnreclaim:     342584 kB
KernelStack:    15744 kB
PageTables:     20556 kB
NFS_Unstable:   0 kB
Bounce:         0 kB
WritebackTmp:   0 kB
CommitLimit:    203228272 kB
Committed_AS:   5015228 kB
VmallocTotal:   34359738367 kB
VmallocUsed:    1938708 kB
VmallocChunk:   34156476176 kB
HardwareCorrupted: 0 kB
AnonHugePages:  4378624 kB
CmaTotal:       0 kB
CmaFree:        0 kB
HugePages_Total: 0
HugePages_Free: 0
HugePages_Rsvd: 0
HugePages_Surp: 0
Hugepagesize:   2048 kB
DirectMap4k:    7728060 kB
DirectMap2M:    237541376 kB
DirectMap1G:    159383552 kB
+ inxi -F -c0
./collect_environment.sh: line 14: inxi: command not
↪ found
+ lsblk -a
NAME            MAJ:MIN RM   SIZE RO TYPE MOUNTPOINT
sda              8:0    0 465.8G  0 disk
↳ â"€â"€sda1            8:1    0   300M  0 part
â", â"€â"€md0           9:0    0 299.7M  0 raid1 /boot
â"€â"€sda2            8:2    0 465.5G  0 part
  â"€â"€md1            9:1    0 465.4G  0 raid1
    â"€â"€vg0-root      253:0    0    20G  0 lvm  /
    â"€â"€vg0-swap      253:1    0     5G  0 lvm  [SWAP]
    â"€â"€vg0-scratch   253:2    0   350G  0 lvm
      ↪ /scratch
    â"€â"€vg0-tmp        253:3    0    20G  0 lvm  /tmp
    â"€â"€vg0-var        253:4    0    40G  0 lvm  /var
    â"€â"€vg0-opt        253:5    0    20G  0 lvm  /opt
sdb             8:16    0 465.8G  0 disk
↳ â"€â"€sdb1            8:17    0   300M  0 part
â", â"€â"€md0           9:0    0 299.7M  0 raid1 /boot
â"€â"€sdb2            8:18    0 465.5G  0 part
  â"€â"€md1            9:1    0 465.4G  0 raid1
    â"€â"€vg0-root      253:0    0    20G  0 lvm  /
    â"€â"€vg0-swap      253:1    0     5G  0 lvm  [SWAP]
    â"€â"€vg0-scratch   253:2    0   350G  0 lvm
      ↪ /scratch
    â"€â"€vg0-tmp        253:3    0    20G  0 lvm  /tmp
    â"€â"€vg0-var        253:4    0    40G  0 lvm  /var
    â"€â"€vg0-opt        253:5    0    20G  0 lvm  /opt
+ lsscsi -s

```

```

[4:0:0:0]      disk      ATA      ST9500620NS      SN03
↪ /dev/sda      500GB
[5:0:0:0]      disk      ATA      ST9500620NS      SN03
↪ /dev/sdb      500GB
+ module list
./collect_environment.sh: line 17: module: command
↪ not found
+ nvidia-smi
Wed Apr 10 07:21:00 2019
+-----+
↪ -----+
| NVIDIA-SMI 410.104      Driver Version: 410.104
↪ CUDA Version: 10.0      |
|-----+-----+
↪ ---+-----+
| GPU  Name            Persistence-M| Bus-Id        Disp.A
↪ | Volatile Uncorr. ECC |
| Fan  Temp  Perf  Pwr:Usage/Cap|      Memory-Usage
↪ | GPU-Util  Compute M. |
|=====+=====+
↪ ===+=====+
|  0   Tesla K80           On      | 00000000:07:00.0 Off
↪ |                        0  |
| N/A   28C    P8      26W / 149W |      68MiB / 11441MiB
↪ |      0%      Default |
+-----+-----+
↪ ---+-----+
|  1   Tesla K80           On      | 00000000:08:00.0 Off
↪ |                        0  |
| N/A   25C    P8      29W / 149W |      68MiB / 11441MiB
↪ |      0%      Default |
+-----+-----+
↪ -----+
| Processes:
↪      GPU Memory |
| GPU      PID  Type  Process name
↪      Usage      |
|=====+=====+
↪ =====+
|  0      67291    G    /usr/bin/Xorg
↪                      67MiB |
|  1      67291    G    /usr/bin/Xorg
↪                      67MiB |
+-----+-----+
↪ -----+
+ cat
+ lshw -short -quiet -sanitize
WARNING: you should run this program as super-user.
H/W path      Device      Class      Description
=====+=====+
↪ ==

```

/0	system bus	Computer Motherboard	/0/100/5.1	generic	Xeon E7
/0/0	memory	384GiB	↪ v3/Xeon E5 v3/Core i7 Hot Plug		
↪ System memory			/0/100/5.2	generic	Xeon E7
/0/1	processor	Intel(R)	↪ v3/Xeon E5 v3/Core i7 RAS, Control Status and		
↪ Xeon(R) CPU E5-2620 v3 @ 2.40GHz			↪ Global Errors		
/0/6	processor	Intel(R)	/0/100/5.4	generic	Xeon E7
↪ Xeon(R) CPU E5-2620 v3 @ 2.40GHz			↪ v3/Xeon E5 v3/Core i7 I/O APIC		
/0/100	bridge	Xeon E7	/0/100/11	generic	C610/X99
↪ v3/Xeon E5 v3/Core i7 DMI2			↪ series chipset SPSR		
/0/100/1	bridge	Xeon E7	/0/100/11.1	bus	C610/X99
↪ v3/Xeon E5 v3/Core i7 PCI Express Root Port 1			↪ series chipset MS SMBus 0		
/0/100/2	bridge	Xeon E7	/0/100/11.4	storage	C610/X99
↪ v3/Xeon E5 v3/Core i7 PCI Express Root Port 2			↪ series chipset sSATA Controller [AHCI mode]		
/0/100/2.2	bridge	Xeon E7	/0/100/14	bus	C610/X99
↪ v3/Xeon E5 v3/Core i7 PCI Express Root Port 2			↪ series chipset USB xHCI Host Controller		
/0/100/2.2/0	eth0	Ethernet	/0/100/16	communication	C610/X99
↪ Controller 10-Gigabit X540-AT2			↪ series chipset MEI Controller #1		
/0/100/2.2/0.1	eth1	Ethernet	/0/100/16.1	communication	C610/X99
↪ Controller 10-Gigabit X540-AT2			↪ series chipset MEI Controller #2		
/0/100/3	bridge	Xeon E7	/0/100/1a	bus	C610/X99
↪ v3/Xeon E5 v3/Core i7 PCI Express Root Port 3			↪ series chipset USB Enhanced Host Controller #2		
/0/100/3/0	bridge	PEX 8747	/0/100/1c	bridge	C610/X99
↪ 48-Lane, 5-Port PCI Express Gen 3 (8.0 GT/s)			↪ series chipset PCI Express Root Port #4		
↪ Switch			/0/100/1c/0	display	MGA G200e
/0/100/3/0/8	bridge	PEX 8747	↪ [Pilot] ServerEngines (SEP1)		
↪ 48-Lane, 5-Port PCI Express Gen 3 (8.0 GT/s)			/0/100/1d	bus	C610/X99
↪ Switch			↪ series chipset USB Enhanced Host Controller #1		
/0/100/3/0/8/0	display	GK210GL	/0/100/1f	bridge	C610/X99
↪ [Tesla K80]			↪ series chipset LPC Controller		
/0/100/3/0/10	bridge	PEX 8747	/0/100/1f.2	storage	C610/X99
↪ 48-Lane, 5-Port PCI Express Gen 3 (8.0 GT/s)			↪ series chipset 6-Port SATA Controller [AHCI mode]		
↪ Switch			/0/100/1f.3	bus	C610/X99
/0/100/3/0/10/0	display	GK210GL	↪ series chipset SMBus Controller		
↪ [Tesla K80]			/0/7	generic	Xeon E7
/0/100/4	generic	Xeon E7	↪ v3/Xeon E5 v3/Core i7 QPI Link 0		
↪ v3/Xeon E5 v3/Core i7 DMA Channel 0			/0/8	generic	Xeon E7
/0/100/4.1	generic	Xeon E7	↪ v3/Xeon E5 v3/Core i7 QPI Link 0		
↪ v3/Xeon E5 v3/Core i7 DMA Channel 1			/0/9	generic	Xeon E7
/0/100/4.2	generic	Xeon E7	↪ v3/Xeon E5 v3/Core i7 QPI Link 0		
↪ v3/Xeon E5 v3/Core i7 DMA Channel 2			/0/a	generic	Xeon E7
/0/100/4.3	generic	Xeon E7	↪ v3/Xeon E5 v3/Core i7 R3 QPI Link 0 & 1 Monitoring		
↪ v3/Xeon E5 v3/Core i7 DMA Channel 3			/0/b	generic	Xeon E7
/0/100/4.4	generic	Xeon E7	↪ v3/Xeon E5 v3/Core i7 R3 QPI Link 0 & 1 Monitoring		
↪ v3/Xeon E5 v3/Core i7 DMA Channel 4			/0/c	generic	Xeon E7
/0/100/4.5	generic	Xeon E7	↪ v3/Xeon E5 v3/Core i7 R3 QPI Link 0 & 1 Monitoring		
↪ v3/Xeon E5 v3/Core i7 DMA Channel 5			/0/d	generic	Xeon E7
/0/100/4.6	generic	Xeon E7	↪ v3/Xeon E5 v3/Core i7 Unicast Registers		
↪ v3/Xeon E5 v3/Core i7 DMA Channel 6			/0/e	generic	Xeon E7
/0/100/4.7	generic	Xeon E7	↪ v3/Xeon E5 v3/Core i7 Unicast Registers		
↪ v3/Xeon E5 v3/Core i7 DMA Channel 7			/0/f	generic	Xeon E7
/0/100/5	generic	Xeon E7	↪ v3/Xeon E5 v3/Core i7 Unicast Registers		
↪ v3/Xeon E5 v3/Core i7 Address Map, Vtd_Misc,			/0/10	generic	Xeon E7
↪ System Management			↪ v3/Xeon E5 v3/Core i7 Unicast Registers		

MemXCT: Memory-Centric X-Ray CT Reconstruction with Massive Parallelization

/0/11	generic	Xeon E7	/0/27	generic	Xeon E7
↪ v3/Xeon E5 v3/Core i7 Unicast Registers			↪ v3/Xeon E5 v3/Core i7 Integrated Memory		
/0/12	generic	Xeon E7	↪ Controller 0 Channel 1 Thermal Control		
↪ v3/Xeon E5 v3/Core i7 Unicast Registers			/0/28	generic	Xeon E7
/0/13	generic	Xeon E7	↪ v3/Xeon E5 v3/Core i7 Integrated Memory		
↪ v3/Xeon E5 v3/Core i7 Buffered Ring Agent			↪ Controller 0 Channel 0 ERROR Registers		
/0/14	generic	Xeon E7	/0/29	generic	Xeon E7
↪ v3/Xeon E5 v3/Core i7 Buffered Ring Agent			↪ v3/Xeon E5 v3/Core i7 Integrated Memory		
/0/15	generic	Xeon E7	↪ Controller 0 Channel 1 ERROR Registers		
↪ v3/Xeon E5 v3/Core i7 System Address Decoder &			/0/2a	generic	Xeon E7
↪ Broadcast Registers			↪ v3/Xeon E5 v3/Core i7 DDRIO (VMSE) 0 & 1		
/0/16	generic	Xeon E7	/0/2b	generic	Xeon E7
↪ v3/Xeon E5 v3/Core i7 System Address Decoder &			↪ v3/Xeon E5 v3/Core i7 DDRIO (VMSE) 0 & 1		
↪ Broadcast Registers			/0/2c	generic	Xeon E7
/0/17	generic	Xeon E7	↪ v3/Xeon E5 v3/Core i7 Integrated Memory		
↪ v3/Xeon E5 v3/Core i7 System Address Decoder &			↪ Controller 0 Channel 2 Thermal Control		
↪ Broadcast Registers			/0/2d	generic	Xeon E7
/0/18	generic	Xeon E7	↪ v3/Xeon E5 v3/Core i7 Integrated Memory		
↪ v3/Xeon E5 v3/Core i7 PCIe Ring Interface			↪ Controller 0 Channel 3 Thermal Control		
/0/19	generic	Xeon E7	/0/2e	generic	Xeon E7
↪ v3/Xeon E5 v3/Core i7 PCIe Ring Interface			↪ v3/Xeon E5 v3/Core i7 Integrated Memory		
/0/1a	generic	Xeon E7	↪ Controller 0 Channel 2 ERROR Registers		
↪ v3/Xeon E5 v3/Core i7 Scratchpad & Semaphore			/0/2f	generic	Xeon E7
↪ Registers			↪ v3/Xeon E5 v3/Core i7 Integrated Memory		
/0/1b	generic	Xeon E7	↪ Controller 0 Channel 3 ERROR Registers		
↪ v3/Xeon E5 v3/Core i7 Scratchpad & Semaphore			/0/30	generic	Xeon E7
↪ Registers			↪ v3/Xeon E5 v3/Core i7 Integrated Memory Controller		
/0/1c	generic	Xeon E7	↪ 1 Target Address, Thermal & RAS Registers		
↪ v3/Xeon E5 v3/Core i7 Scratchpad & Semaphore			/0/31	generic	Xeon E7
↪ Registers			↪ v3/Xeon E5 v3/Core i7 DDRIO Channel 2/3 Broadcast		
/0/1d	generic	Xeon E7	/0/32	generic	Xeon E7
↪ v3/Xeon E5 v3/Core i7 Home Agent 0			↪ v3/Xeon E5 v3/Core i7 DDRIO Global Broadcast		
/0/1e	generic	Xeon E7	/0/33	generic	Xeon E7
↪ v3/Xeon E5 v3/Core i7 Home Agent 0			↪ v3/Xeon E5 v3/Core i7 Integrated Memory		
/0/1f	generic	Xeon E7	↪ Controller 1 Channel 0 Thermal Control		
↪ v3/Xeon E5 v3/Core i7 Integrated Memory Controller			/0/34	generic	Xeon E7
↪ 0 Target Address, Thermal & RAS Registers			↪ v3/Xeon E5 v3/Core i7 DDRIO (VMSE) 2 & 3		
/0/20	generic	Xeon E7	/0/35	generic	Xeon E7
↪ v3/Xeon E5 v3/Core i7 Integrated Memory Controller			↪ v3/Xeon E5 v3/Core i7 DDRIO (VMSE) 2 & 3		
↪ 0 Target Address, Thermal & RAS Registers			/0/36	generic	Xeon E7
/0/21	generic	Xeon E7	↪ v3/Xeon E5 v3/Core i7 DDRIO (VMSE) 2 & 3		
↪ v3/Xeon E5 v3/Core i7 Integrated Memory			/0/37	generic	Xeon E7
↪ Controller 0 Channel Target Address Decoder			↪ v3/Xeon E5 v3/Core i7 DDRIO (VMSE) 2 & 3		
/0/22	generic	Xeon E7	/0/38	generic	Xeon E7
↪ v3/Xeon E5 v3/Core i7 Integrated Memory			↪ v3/Xeon E5 v3/Core i7 Power Control Unit		
↪ Controller 0 Channel Target Address Decoder			/0/39	generic	Xeon E7
/0/23	generic	Xeon E7	↪ v3/Xeon E5 v3/Core i7 Power Control Unit		
↪ v3/Xeon E5 v3/Core i7 Integrated Memory			/0/3a	generic	Xeon E7
↪ Controller 0 Channel Target Address Decoder			↪ v3/Xeon E5 v3/Core i7 Power Control Unit		
/0/24	generic	Xeon E7	/0/3b	generic	Xeon E7
↪ v3/Xeon E5 v3/Core i7 DDRIO Channel 0/1 Broadcast			↪ v3/Xeon E5 v3/Core i7 Power Control Unit		
/0/25	generic	Xeon E7	/0/3c	generic	Xeon E7
↪ v3/Xeon E5 v3/Core i7 DDRIO Global Broadcast			↪ v3/Xeon E5 v3/Core i7 Power Control Unit		
/0/26	generic	Xeon E7	/0/3d	generic	Xeon E7
↪ v3/Xeon E5 v3/Core i7 Integrated Memory			↪ v3/Xeon E5 v3/Core i7 VCU		
↪ Controller 0 Channel 0 Thermal Control					

/0/3e	generic	Xeon E7	/0/47	generic	Xeon E7
↪ v3/Xeon E5 v3/Core i7 VCU			↪ v3/Xeon E5 v3/Core i7 Unicast Registers		
/0/2	bridge	Xeon E7	/0/48	generic	Xeon E7
↪ v3/Xeon E5 v3/Core i7 PCI Express Root Port 2			↪ v3/Xeon E5 v3/Core i7 Unicast Registers		
/0/2/0	ib1 network	MT27600	/0/49	generic	Xeon E7
↪ [Connect-IB]			↪ v3/Xeon E5 v3/Core i7 Unicast Registers		
/0/3	bridge	Xeon E7	/0/4a	generic	Xeon E7
↪ v3/Xeon E5 v3/Core i7 PCI Express Root Port 3			↪ v3/Xeon E5 v3/Core i7 Unicast Registers		
/0/3.2	bridge	Xeon E7	/0/4b	generic	Xeon E7
↪ v3/Xeon E5 v3/Core i7 PCI Express Root Port 3			↪ v3/Xeon E5 v3/Core i7 Buffered Ring Agent		
/0/3.2/0	eth2 network	MT27500	/0/4c	generic	Xeon E7
↪ Family [ConnectX-3]			↪ v3/Xeon E5 v3/Core i7 Buffered Ring Agent		
/0/4	generic	Xeon E7	/0/4d	generic	Xeon E7
↪ v3/Xeon E5 v3/Core i7 DMA Channel 0			↪ v3/Xeon E5 v3/Core i7 System Address Decoder & Broadcast Registers		
/0/4.1	generic	Xeon E7	/0/4e	generic	Xeon E7
↪ v3/Xeon E5 v3/Core i7 DMA Channel 1			↪ v3/Xeon E5 v3/Core i7 System Address Decoder & Broadcast Registers		
/0/4.2	generic	Xeon E7	/0/4f	generic	Xeon E7
↪ v3/Xeon E5 v3/Core i7 DMA Channel 2			↪ v3/Xeon E5 v3/Core i7 System Address Decoder & Broadcast Registers		
/0/4.3	generic	Xeon E7	/0/50	generic	Xeon E7
↪ v3/Xeon E5 v3/Core i7 DMA Channel 3			↪ v3/Xeon E5 v3/Core i7 PCIe Ring Interface		
/0/4.4	generic	Xeon E7	/0/51	generic	Xeon E7
↪ v3/Xeon E5 v3/Core i7 DMA Channel 4			↪ v3/Xeon E5 v3/Core i7 PCIe Ring Interface		
/0/4.5	generic	Xeon E7	/0/52	generic	Xeon E7
↪ v3/Xeon E5 v3/Core i7 DMA Channel 5			↪ v3/Xeon E5 v3/Core i7 Scratchpad & Semaphore Registers		
/0/4.6	generic	Xeon E7	/0/53	generic	Xeon E7
↪ v3/Xeon E5 v3/Core i7 DMA Channel 6			↪ v3/Xeon E5 v3/Core i7 Scratchpad & Semaphore Registers		
/0/4.7	generic	Xeon E7	/0/54	generic	Xeon E7
↪ v3/Xeon E5 v3/Core i7 DMA Channel 7			↪ v3/Xeon E5 v3/Core i7 Scratchpad & Semaphore Registers		
/0/5	generic	Xeon E7	/0/55	generic	Xeon E7
↪ v3/Xeon E5 v3/Core i7 Address Map, Vtd_Misc, System Management			↪ v3/Xeon E5 v3/Core i7 Home Agent 0		
/0/5.1	generic	Xeon E7	/0/56	generic	Xeon E7
↪ v3/Xeon E5 v3/Core i7 Hot Plug			↪ v3/Xeon E5 v3/Core i7 Home Agent 0		
/0/5.2	generic	Xeon E7	/0/57	generic	Xeon E7
↪ v3/Xeon E5 v3/Core i7 RAS, Control Status and Global Errors			↪ v3/Xeon E5 v3/Core i7 Integrated Memory Controller 0 Target Address, Thermal & RAS Registers		
/0/5.4	generic	Xeon E7	/0/58	generic	Xeon E7
↪ v3/Xeon E5 v3/Core i7 I/O APIC			↪ v3/Xeon E5 v3/Core i7 Integrated Memory Controller 0 Target Address, Thermal & RAS Registers		
/0/3f	generic	Xeon E7	/0/59	generic	Xeon E7
↪ v3/Xeon E5 v3/Core i7 QPI Link 0			↪ v3/Xeon E5 v3/Core i7 Integrated Memory Controller 0 Channel Target Address Decoder		
/0/40	generic	Xeon E7	/0/5a	generic	Xeon E7
↪ v3/Xeon E5 v3/Core i7 QPI Link 0			↪ v3/Xeon E5 v3/Core i7 Integrated Memory Controller 0 Channel Target Address Decoder		
/0/41	generic	Xeon E7	/0/5b	generic	Xeon E7
↪ v3/Xeon E5 v3/Core i7 QPI Link 0			↪ v3/Xeon E5 v3/Core i7 Integrated Memory Controller 0 Channel Target Address Decoder		
/0/42	generic	Xeon E7	/0/5c	generic	Xeon E7
↪ v3/Xeon E5 v3/Core i7 R3 QPI Link 0 & 1 Monitoring			↪ v3/Xeon E5 v3/Core i7 DDRIO Channel 0/1 Broadcast		
/0/43	generic	Xeon E7			
↪ v3/Xeon E5 v3/Core i7 R3 QPI Link 0 & 1 Monitoring					
/0/44	generic	Xeon E7			
↪ v3/Xeon E5 v3/Core i7 R3 QPI Link 0 & 1 Monitoring					
/0/45	generic	Xeon E7			
↪ v3/Xeon E5 v3/Core i7 Unicast Registers					
/0/46	generic	Xeon E7			
↪ v3/Xeon E5 v3/Core i7 Unicast Registers					

MemXCT: Memory-Centric X-Ray CT Reconstruction with Massive Parallelization

```

/0/5d                generic      Xeon E7
↳ v3/Xeon E5 v3/Core i7 DDRIO Global Broadcast
/0/5e                generic      Xeon E7
↳ v3/Xeon E5 v3/Core i7 Integrated Memory
↳ Controller 0 Channel 0 Thermal Control
/0/5f                generic      Xeon E7
↳ v3/Xeon E5 v3/Core i7 Integrated Memory
↳ Controller 0 Channel 1 Thermal Control
/0/60                generic      Xeon E7
↳ v3/Xeon E5 v3/Core i7 Integrated Memory
↳ Controller 0 Channel 0 ERROR Registers
/0/61                generic      Xeon E7
↳ v3/Xeon E5 v3/Core i7 Integrated Memory
↳ Controller 0 Channel 1 ERROR Registers
/0/62                generic      Xeon E7
↳ v3/Xeon E5 v3/Core i7 DDRIO (VMSE) 0 & 1
/0/63                generic      Xeon E7
↳ v3/Xeon E5 v3/Core i7 DDRIO (VMSE) 0 & 1
/0/64                generic      Xeon E7
↳ v3/Xeon E5 v3/Core i7 Integrated Memory
↳ Controller 0 Channel 2 Thermal Control
/0/65                generic      Xeon E7
↳ v3/Xeon E5 v3/Core i7 Integrated Memory
↳ Controller 0 Channel 3 Thermal Control
/0/66                generic      Xeon E7
↳ v3/Xeon E5 v3/Core i7 Integrated Memory
↳ Controller 0 Channel 2 ERROR Registers
/0/67                generic      Xeon E7
↳ v3/Xeon E5 v3/Core i7 Integrated Memory
↳ Controller 0 Channel 3 ERROR Registers
/0/68                generic      Xeon E7
↳ v3/Xeon E5 v3/Core i7 Integrated Memory Controller
↳ 1 Target Address, Thermal & RAS Registers
/0/69                generic      Xeon E7
↳ v3/Xeon E5 v3/Core i7 DDRIO Channel 2/3 Broadcast
/0/6a                generic      Xeon E7
↳ v3/Xeon E5 v3/Core i7 DDRIO Global Broadcast
/0/6b                generic      Xeon E7
↳ v3/Xeon E5 v3/Core i7 Integrated Memory
↳ Controller 1 Channel 0 Thermal Control
/0/6c                generic      Xeon E7
↳ v3/Xeon E5 v3/Core i7 DDRIO (VMSE) 2 & 3
/0/6d                generic      Xeon E7
↳ v3/Xeon E5 v3/Core i7 DDRIO (VMSE) 2 & 3
/0/6e                generic      Xeon E7
↳ v3/Xeon E5 v3/Core i7 DDRIO (VMSE) 2 & 3
/0/6f                generic      Xeon E7
↳ v3/Xeon E5 v3/Core i7 DDRIO (VMSE) 2 & 3
/0/70                generic      Xeon E7
↳ v3/Xeon E5 v3/Core i7 Power Control Unit
/0/71                generic      Xeon E7
↳ v3/Xeon E5 v3/Core i7 Power Control Unit
/0/72                generic      Xeon E7
↳ v3/Xeon E5 v3/Core i7 Power Control Unit

```

```

/0/73                generic      Xeon E7
↳ v3/Xeon E5 v3/Core i7 Power Control Unit
/0/74                generic      Xeon E7
↳ v3/Xeon E5 v3/Core i7 Power Control Unit
/0/75                generic      Xeon E7
↳ v3/Xeon E5 v3/Core i7 VCU
/0/76                generic      Xeon E7
↳ v3/Xeon E5 v3/Core i7 VCU
/0/77                system       PnP device
↳ PNP0b00
/0/78                system       PnP device
↳ PNP0c02
/0/79                communication PnP device
↳ PNP0501
/0/7a                communication PnP device
↳ PNP0501
/1                   eth2.2200 network Ethernet
↳ interface
/2                   eth2.2330 network Ethernet
↳ interface
/3                   ib0         network interface
WARNING: output may be incomplete or inaccurate, you
↳ should run this program as super-user.

```

Blue Waters System

```

LESSKEY=/etc/lesskey.bin
MODULE_VERSION_STACK=3.2.10.5
KSH_AUTOLOAD=1
PE_LIBSCI_VOLATILE_PRGENV=CRAY GNU INTEL PGI
PE_SMA_DEFAULT_PKGCONFIG_VARIABLES=PE_SMA_COMPFLAG_@
↳ prgenv@
CRAY_CUDAToolKIT_VERSION=9.1.85_3.10-1.0502.df1cc54.
↳ 3.1
MANPATH=/opt/nvidia/cudatoolkit9.1/9.1.85_3.10-1.050
↳ 2.df1cc54.3.1/doc/man:/opt/cray/atp/2.0.4/man:/o
↳ pt/cray/libsci/16.11.1/man:/opt/cray/man/csmlver
↳ sion:/opt/gcc/4.9.3/snos/share/man:/sw/EasyBuild
↳ /software/gnuplot/5.0.5/share/man:/sw/EasyBuild/
↳ software/wget/1.19.4/share/man:/sw/EasyBuild/sof
↳ tware/cURL/7.59.0/share/man:/sw/user/man:/opt/mo
↳ ab/9.1.2/share/man:/opt/torque/6.0.4/share/man:
↳ /opt/cray/mpt/7.5.0/gni/man/mpich:/opt/cray/cray
↳ pe/2.5.8/man:/opt/cray/llm/default/man:/opt/cray
↳ /lustre-cray_gem_s/2.5_3.0.101_0.46.1_1.0502.887
↳ 1.43.1-1.0502.21728.74.6/man:/opt/cray/alps/5.2.
↳ 4-2.0502.9774.31.12.gem/man:/opt/modules/3.2.10.
↳ 5/share/man:/opt/roab/9.1.2/share/man:/usr/local
↳ /man:/usr/share/man:/usr/man:/opt/cray/share/man
↳ :/opt/cray/man:/u/sciteam/USER/man
INFODIR=/usr/local/info:/usr/share/info:/usr/info
NNTPSERVER=news
PE_PETSC_DEFAULT_GENCOMPILERS_CRAY_sandybridge=8.3

```



```

PE_CXX_PKGCONFIG_LIBS=mpichcxx
PE_MPICH_GENCOMPILERS_PGI=15.3
GNU_VERSION=4.9.3
PE_LIBSCI_DEFAULT_GENCOMPS_GNU_mic_knl=51
XALT_ETC_DIR=/opt/xalt/0.7.6/sles11.3/etc
MODIMP_KEEP_MODULE_LIST_IN_ENV=no
PE_HDF5_DEFAULT_REQUIRED_PRODUCTS=PE_MPICH
HOSTNAME=nid25333
CRAY_UDREG_INCLUDE_OPTS=-I/opt/cray/udreg/2.3.2-1.05
↳ 02.10518.2.17.gem/include
PE_FFTW_DEFAULT_TARGET_mic_knl=mic_knl
PE_LIBSCI_ACC_DEFAULT_PKGCONFIG_VARIABLES=PE_LIBSCI_
↳ ACC_DEFAULT_NV_SUFFIX_@accelerator@
PE_PETSC_DEFAULT_GENCOMPS_PGI_x86_64=153
PE_TPSSL_64_DEFAULT_GENCOMPS_INTEL_interlagos=150
PE_TRILINOS_DEFAULT_GENCOMPS_CRAY_x86_64=85
EBROOTGIT=/sw/EasyBuild/software/git/2.17.0
PBS_VERSION=TORQUE-6.1.2
XKEYSYMDB=/usr/share/X11/XKeysymDB
CRAY_SITE_LIST_DIR=/etc/opt/cray/modules
LIBRARYMODULES=/opt/modules/3.2.10.5/init/.librarymo
↳ dules:acml:alps:cray-dwarf:cray-fftw:cray-ga:cray
↳ y-hdf5:cray-hdf5-parallel:cray-libsci:cray-libsc
↳ i_acc:cray-mpich:cray-mpich-abi:cray-mpich2:cray
↳ -netcdf:cray-netcdf-hdf5parallel:cray-parallel-ne
↳ tcdf:cray-petsc:cray-petsc-complex:cray-shmem:cr
↳ ay-tpsl:cray-trilinos:cudatoolkit:fftw:ga:hdf5:h
↳ df5-parallel:iobuf:libfast:netcdf:netcdf-hdf5par
↳ allel:ntk:onesided:papi:petsc:petsc-complex:pmi:
↳ tpsl:trilinos:xt-libsci:xt-mpich2:xt-mpt:xt-papi
↳ :/etc/opt/cray/modules/site_librarymodules
RCLOCAL_BASEOPTS=true
PE_ACML_DEFAULT_DIR_GNU=gfortran64
PE_NETCDF_DEFAULT_VOLATILE_PKGCONFIG_PATH=/opt/cray/
↳ netcdf/4.4.1/@PRGENV@/PE_NETCDF_DEFAULT_GENCOMP
↳ S@/lib/pkgconfig
PE_PARALLEL_NETCDF_DEFAULT_VOLATILE_PKGCONFIG_PATH=/
↳ opt/cray/parallel-netcdf/1.7.0/@PRGENV@/PE_PARA
↳ LLEL_NETCDF_DEFAULT_GENCOMPS@/lib/pkgconfig
PE_SMA_DEFAULT_COMPFLAG_GNU=-fcray-pointer
PE_TPSSL_64_DEFAULT_GENCOMPS_PGI_x86_64=153
PE_TRILINOS_DEFAULT_VOLATILE_PKGCONFIG_PATH=/opt/cra
↳ y/trilinos/12.6.3.3/@PRGENV@/PE_TRILINOS_DEFAULT
↳ T_GENCOMPS@/PE_TRILINOS_DEFAULT_TARGET@/lib/pkg
↳ config
PE_ACML_DEFAULT_DIR_DEFAULT64=_int64
PE_ENV=GNU
PE_HDF5_DEFAULT_GENCOMPILERS_GNU=5.1 4.9
PE_SMA_DEFAULT_COMPFLAG=
PE_TPSSL_64_DEFAULT_GENCOMPILERS_CRAY_x86_64=8.3
EBDEVELOPENSSL=/sw/EasyBuild/software/OpenSSL/1.0.2m
↳ /easybuild/OpenSSL-1.0.2m-easybuild-devel
SHELL=/bin/bash
TERM=xterm-256color
HOST=nid25333
PE_ACML_DEFAULT_TARGET_interlagos=_fma4

```

```

PKGCONFIG_ENABLED=1
EBDEVELGNUPLOT=/sw/EasyBuild/software/gnuplot/5.0.5/
↳ easybuild/gnuplot-5.0.5-easybuild-devel
HISTSIZE=1000
PROFILEREAD=true
PE_PETSC_DEFAULT_GENCOMPS_CRAY_sandybridge=83
XTOS_VERSION=5.2.82
PBS_JOBNAME=STDIN
CRAY_UGNI_POST_LINK_OPTS=-L/opt/cray/ugni/6.0-1.0502
↳ .10863.8.28.gem/lib64
CRAY_XPMEM_POST_LINK_OPTS=-L/opt/cray/xpmem/0.1-2.05
↳ 02.64982.7.24.gem/lib64
CRAYPE_DIR=/opt/cray/craype/2.5.8
PE_NETCDF_DEFAULT_VOLATILE_PRGENV=GNU
PE_PARALLEL_NETCDF_DEFAULT_VOLATILE_PRGENV=GNU
PE_PETSC_DEFAULT_GENCOMPS_GNU_haswell=51 49
PE_PETSC_DEFAULT_GENCOMPS_INTEL_haswell=150
PE_PETSC_DEFAULT_GENCOMPS_PGI_interlagos=153
PE_TPSSL_DEFAULT_GENCOMPS_GNU_sandybridge=51 49
PE_TPSSL_DEFAULT_REQUIRED_PRODUCTS=PE_MPICH:PE_LIBSCI
PE_TRILINOS_DEFAULT_VOLATILE_PRGENV=CRAY GNU
PE_MPICH_DIR_PGI_DEFAULT64=64
PERL5LIB=/opt/maab/9.1.2/lib/perl5
PE_ACML_DEFAULT_DIR_CRAY=gfortran64
PE_FFTW_DEFAULT_VOLATILE_PKGCONFIG_PATH=/opt/cray/ff
↳ tw/3.3.6.5/@PE_FFTW_DEFAULT_TARGET@/lib/pkgconfig
PE_HDF5_DEFAULT_VOLATILE_PRGENV=GNU
PE_HDF5_PARALLEL_DEFAULT_VOLATILE_PKGCONFIG_PATH=/op
↳ t/cray/hdf5-parallel/1.10.0/@PRGENV@/PE_HDF5_PA
↳ RALLEL_DEFAULT_GENCOMPS@/lib/pkgconfig
PE_LIBSCI_DEFAULT_GENCOMPILERS_CRAY_mic_knl=8.5
PE_LIBSCI_GENCOMPS_CRAY_mic_knl=85
PE_NETCDF_HDF5PARALLEL_DEFAULT_VOLATILE_PKGCONFIG_PA
↳ TH=/opt/cray/netcdf-hdf5parallel/4.4.1/@PRGENV@/
↳ @PE_NETCDF_HDF5PARALLEL_DEFAULT_GENCOMPS@/lib/pk
↳ gconfig
PE_PETSC_DEFAULT_GENCOMPILERS_PGI_x86_64=15.3
PE_PETSC_DEFAULT_GENCOMPS_CRAY_interlagos=83
PE_TPSSL_64_DEFAULT_GENCOMPILERS_PGI_interlagos=15.3
CRAY_MPICH2_DIR=/opt/cray/mpt/7.5.0/gni/mpich-gnu/4.9
ALT_LINKER=/opt/xalt/0.7.6/sles11.3/bin/ld
XALT_DIR=/opt/xalt/0.7.6/sles11.3
LIBRARY_PATH=/sw/EasyBuild/software/cURL/7.59.0/lib:
↳ /sw/EasyBuild/software/OpenSSL/1.0.2m/lib
PE_GA_DEFAULT_VOLATILE_PRGENV=GNU
PE_LIBSCI_DEFAULT_GENCOMPS_GNU_x86_64=51 49
PE_TPSSL_64_DEFAULT_GENCOMPILERS_CRAY_interlagos=8.3
PE_TPSSL_DEFAULT_GENCOMPS_CRAY_mic_knl=85
CRAY_CUDAToolKIT_POST_LINK_OPTS=-L/opt/nvidia/cudato
↳ olkit9.1/9.1.85_3.10-1.0502.df1cc54.3.1/lib64
↳ -L/opt/nvidia/cudatoolkit9.1/9.1.85_3.10-1.0502.
↳ df1cc54.3.1/extras/CUPTI/lib64 -Wl,--as-needed
↳ -Wl,-lcupti -Wl,-lcudart -Wl,--no-as-needed
↳ -L/opt/cray/nvidia/default/lib64 -lcuda
PBS_ENVIRONMENT=PBS_INTERACTIVE
MORE--s1

```

MemXCT: Memory-Centric X-Ray CT Reconstruction with Massive Parallelization

```
FPATH=/opt/modules/3.2.10.5/init/sh_funcs/no_redire_
↪ ct:/opt/modules/3.2.10.5/init/sh_funcs/no_redire_
↪ ct
PE_LIBSCI_ACC_DEFAULT_GENCOMPS_CRAY_x86_64=83
PE_LIBSCI_ACC_DEFAULT_REQUIRED_PRODUCTS=PE_MPICH:PE_
↪ LIBSCI
PE_LIBSCI_GENCOMPILERS_CRAY_mic_knl=8.5
PE_MPICH_DEFAULT_GENCOMPILERS_GNU=5.1 4.9
PE_PKGCONFIG_PRODUCTS=PE_LIBSCI:PE_MPICH
PE_TPSL_DEFAULT_GENCOMPS_INTEL_x86_64=150
PE_MPICH_GENCOMPS_GNU=51 49
MODIMP_ENABLE_DYNAMIC_PROMPT=no
QTDIR=/usr/lib/qt3
PE_PAPI_DEFAULT_ACCEL_LIBS_nvidia35=-lcupti,-lcudar_
↪ t,-lcuda
PE_PETSC_DEFAULT_REQUIRED_PRODUCTS=PE_MPICH:PE_LIBSC_
↪ I:PE_HDF5_PARALLEL:PE_TPSL
PE_TPSL_64_DEFAULT_GENCOMPS_CRAY_haswell=83
PE_TPSL_64_DEFAULT_VOLATILE_PKGCONFIG_PATH=/opt/cray_
↪ /tpsl/16.07.1/@PRGENV@64/@PE_TPSL_64_DEFAULT_GEN_
↪ COMPS@/@PE_TPSL_64_DEFAULT_TARGET@/lib/pkgconfig
PE_CRAY_DEFAULT_FIXED_PKGCONFIG_PATH=/opt/cray/paral_
↪ lel-netcdf/1.7.0/CRAY/8.3/lib/pkgconfig:/opt/cra_
↪ y/netcdf-hdf5parallel/4.4.1/CRAY/8.3/lib/pkgconfi_
↪ g:/opt/cray/netcdf/4.4.1/CRAY/8.3/lib/pkgconfig
↪ :/opt/cray/hdf5-parallel/1.10.0/CRAY/8.3/lib/pkg_
↪ config:/opt/cray/hdf5/1.10.0/CRAY/8.3/lib/pkgcon_
↪ fig:/opt/cray/ga/5.3.0.7/CRAY/8.4/lib/pkgconfig
PE_TRILINOS_DEFAULT_GENCOMPILERS_CRAY_x86_64=8.5
PBS_O_WORKDIR=/mnt/a/u/sciteam/USER
PE_LIBSCI_DEFAULT_OMP_REQUIRES_openmp=_mp
PE_PETSC_DEFAULT_GENCOMPILERS_PGI_interlagos=15.3
PE_PETSC_DEFAULT_GENCOMPS_CRAY_x86_64=83
PE_TPSL_64_DEFAULT_GENCOMPILERS_CRAY_sandybridge=8.3
PE_TPSL_64_DEFAULT_GENCOMPILERS_PGI_x86_64=15.3
PE_FORTRAN_PKGCONFIG_LIBS=mpichf90
PE_SMA_DEFAULT_VOLATILE_PKGCONFIG_PATH=/opt/cray/mpt_
↪ /7.5.0/gni/sma@PE_SMA_DEFAULT_DIR_DEFAULT64@/lib_
↪ 64/pkgconfig
LC_ALL=POSIX
PE_ACML_DEFAULT_DIR_INTEL=ifort64
PE_LIBSCI_ACC_DEFAULT_VOLATILE_PRGENV=CRAY GNU
CRAY_MPICH_BASEDIR=/opt/cray/mpt/7.5.0/gni
EBROOTWGET=/sw/EasyBuild/software/wget/1.19.4
USER=USER
PBS_TASKNUM=1
JRE_HOME=/usr/lib64/jvm/java/jre
PE_ACML_DEFAULT_TARGET_x86_64=
PE_HDF5_PARALLEL_DEFAULT_GENCOMPILERS_GNU=5.1 4.9
PE_NETCDF_HDF5PARALLEL_DEFAULT_GENCOMPILERS_GNU=5.1
↪ 4.9
PE_TPSL_64_DEFAULT_GENCOMPS_INTEL_haswell=150
```

```
LS_COLORS=no=00:fi=00:di=01;34:ln=00;36:pi=40;33:so=
↪ 01;35:do=01;35:bd=40;33;01:cd=40;33;01:or=41;33;
↪ 01:ex=00;32:*.cmd=00;32:*.exe=01;32:*.com=01;32:
↪ *.bat=01;32:*.btm=01;32:*.dll=01;32:*.tar=00;31:
↪ *.tbz=00;31:*.tgz=00;31:*.rpm=00;31:*.deb=00;31:
↪ *.arj=00;31:*.taz=00;31:*.lzh=00;31:*.lzma=00;31
↪ :*.zip=00;31:*.zoo=00;31:*.z=00;31:*.Z=00;31:*.g
↪ z=00;31:*.bz2=00;31:*.tb2=00;31:*.tz2=00;31:*.tb
↪ z2=00;31:*.avi=01;35:*.bmp=01;35:*.fli=01;35:*.g
↪ if=01;35:*.jpg=01;35:*.jpeg=01;35:*.mng=01;35:*.
↪ mov=01;35:*.mpg=01;35:*.pcx=01;35:*.pbm=01;35:*.
↪ pgm=01;35:*.png=01;35:*.ppm=01;35:*.tga=01;35:*.
↪ tif=01;35:*.xbm=01;35:*.xpm=01;35:*.dl=01;35:*.g
↪ l=01;35:*.wmv=01;35:*.aiff=00;32:*.au=00;32:*.mi
↪ d=00;32:*.mp3=00;32:*.ogg=00;32:*.voc=00;32:*.wa
↪ v=00;32:
PE_FFTW_DEFAULT_TARGET_interlagos=interlagos
PE_LIBSCI_DEFAULT_VOLATILE_PRGENV=CRAY GNU INTEL PGI
PE_LIBSCI_GENCOMPILERS_GNU_mic_knl=5.1
PE_PETSC_DEFAULT_GENCOMPILERS_INTEL_interlagos=15.0
PE_TPSL_DEFAULT_GENCOMPS_CRAY_x86_64=83
PE_TRILINOS_DEFAULT_GENCOMPILERS_GNU_x86_64=5.1 4.9
LD_LIBRARY_PATH=/opt/gcc/4.9.3/snos/lib64:/sw/xe/dar_
↪ shan/3.1.3/darshan-3.1.3/lib:/sw/EasyBuild/softw_
↪ are/openssl/1.0.2m/lib
CRAYPE_LINK_TYPE=dynamic
PBS_O_HOME=/u/sciteam/USER
PE_LIBSCI_PKGCONFIG_VARIABLES=PE_LIBSCI_OMP_REQUIRES_
↪ _openmp@
PE_PETSC_DEFAULT_VOLATILE_PRGENV=CRAY CRAY64 GNU
↪ GNU64 INTEL INTEL64 PGI PGI64
PE_PKGCONFIG_LIBS=cray-cudatoolkit:AtpSigHandler:lib_
↪ mpi:libsci:darshan-runtime:mpich
PE_TPSL_64_DEFAULT_GENCOMPILERS_GNU_sandybridge=5.1
↪ 4.9
PE_TPSL_64_DEFAULT_GENCOMPILERS_INTEL_haswell=15.0
PE_MPICH_FIXED_PRGENV=INTEL
XNLSPATH=/usr/share/X11/nls
PE_PETSC_DEFAULT_GENCOMPILERS_CRAY_mic_knl=8.5
PE_PETSC_DEFAULT_GENCOMPILERS_CRAY_x86_64=8.3
PE_PETSC_DEFAULT_GENCOMPS_GNU_interlagos=51 49
PE_PETSC_DEFAULT_GENCOMPS_GNU_sandybridge=51 49
PE_PETSC_DEFAULT_GENCOMPS_INTEL_interlagos=150
PE_PETSC_DEFAULT_GENCOMPS_INTEL_sandybridge=150
PE_TPSL_DEFAULT_GENCOMPS_GNU_haswell=51 49
ENV=/etc/bash.bashrc
MPICH_ABORT_ON_ERROR=1
PE_LIBSCI_DEFAULT_GENCOMPS_CRAY_x86_64=83
PE_PAPI_DEFAULT_PKGCONFIG_VARIABLES=PE_PAPI_ACCEL_LI_
↪ BS:@accelerator@
PE_PETSC_DEFAULT_GENCOMPILERS_CRAY_haswell=8.3
PE_TPSL_64_DEFAULT_GENCOMPILERS_GNU_interlagos=5.1
↪ 4.9
PE_TPSL_64_DEFAULT_GENCOMPS_INTEL_sandybridge=150
MPICH_DIR=/opt/cray/mpt/7.5.0/gni/mpich-gnu/4.9
EBVERSIONCURL=7.59.0
```

```

HOSTTYPE=x86_64
ATP_POST_LINK_OPTS=-Wl,-L/opt/cray/atp/2.0.4/libApp/
PE_FFTW_DEFAULT_REQUIRED_PRODUCTS=PE_MPICH
PE_FFTW_DEFAULT_TARGET_sandybridge=sandybridge
PE_HDF5_PARALLEL_DEFAULT_REQUIRED_PRODUCTS=PE_MPICH
PE_NETCDF_HDF5PARALLEL_DEFAULT_REQUIRED_PRODUCTS=PE_
↳ HDF5_PARALLEL:PE_MPICH
PE_PETSC_DEFAULT_GENCOMPILERS_INTEL_sandybridge=15.0
PE_TPSL_64_DEFAULT_GENCOMPILERS_CRAY_haswell=8.3
PE_MPICH_FORTRAN_PKGCONFIG_LIBS=mpichf90
CRAY_PRGENVGNU=loaded
PBS_WALLTIME=1800
RCLOCAL_PRGENV=true
EBDEVELGIT=/sw/EasyBuild/software/git/2.17.0/easybui
↳ ld/git-2.17.0-easybuild-devel
PBS_MOMPORT=15003
PBS_GPUFILE=/var/spool/torque/aux//9808461.bwgpu
FROM_HEADER=
PE_PRODUCT_LIST=CRAY_PMI:CRAY_LIBSCI:GNU:GCC:CRAYPE:
↳ CRAYPE_INTERLAGOS:CRAY_LLM:CRAY_XPMEM:CRAY_DMAPP
↳ :CRAY_UGNI:CRAY_UDREG:CRAY_ALPS
PE_LIBSCI_DEFAULT_GENCOMPILERS_INTEL_x86_64=15.0
PE_LIBSCI_GENCOMPS_INTEL_x86_64=150
PE_TPSL_DEFAULT_GENCOMPILERS_CRAY_x86_64=8.3
PE_TPSL_DEFAULT_GENCOMPS_GNU_interlagos=51 49
GCC_VERSION=4.9.3
PAGER=less
PE_MPICH_DEFAULT_GENCOMPS_PGI=153
PE_PETSC_DEFAULT_GENCOMPILERS_GNU_x86_64=5.1 4.9
CRAY_MPICH_ROOTDIR=/opt/cray/mpt/7.5.0
CSHEDIT=emacs
PE_LIBSCI_GENCOMPILERS_GNU_x86_64=5.1 4.9
PE_TPSL_64_DEFAULT_GENCOMPILERS_INTEL_x86_64=15.0
PE_MPICH_GENCOMPILERS_CRAY=8.4
PE_MPICH_MODULE_NAME=cray-mpich
PBS_O_QUEUE=high
XDG_CONFIG_DIRS=/etc/xdg
PE_LIBSCI_DEFAULT_GENCOMPILERS_CRAY_x86_64=8.3
PE_LIBSCI_GENCOMPS_CRAY_x86_64=83
PE_MPICH_DEFAULT_VOLATILE_PRGENV=CRAY GNU PGI
PE_MPICH_TARGET_VAR_nvidia20=-lcudart
PE_TPSL_64_DEFAULT_REQUIRED_PRODUCTS=PE_MPICH:PE_LIB
↳ SCI
PE_TPSL_DEFAULT_GENCOMPS_CRAY_haswell=83
PE_TPSL_DEFAULT_GENCOMPS_CRAY_sandybridge=83
MINICOM=-c on

```

```

USERMODULES=/opt/modules/3.2.10.5/init/.usermodules:
↳ PrgEnv-cray:PrgEnv-gnu:PrgEnv-intel:PrgEnv-paths
↳ cale:PrgEnv-pgi:acml:alps:apprentice:apprentice2
↳ :atp:blcr:cce:chapel:cray-cddb:cray-fftw:cray-ga
↳ :cray-hdf5:cray-hdf5-parallel:cray-lgdb:cray-lib
↳ sci:cray-libsci_acc:cray-mpich:cray-mpich-compat
↳ :cray-mpich2:cray-netcdf:cray-netcdf-hdf5paralle
↳ l:cray-parallel-netcdf:cray-petsc:cray-petsc-com
↳ plex:cray-shmem:cray-snp launcher:cray-tpsl:cray-
↳ trinos:craypat:craype:craypkg-gen:cuda toolkit:
↳ ddt:fftw:ga:hdf5:hdf5-parallel:intel:iobuf:java:
↳ lgdb:libfast:libsci_acc:mpich1:netcdf:netcdf-hdf
↳ 5parallel:netcdf-nofsync:netcdf-nofsync-hdf5para
↳ llel:ntk:onesided:papi:parallel-netcdf:pathsca
↳ :perf tools:perf tools-lite:petsc:petsc-complex:pg
↳ i:pmi:stat:totalview:tpsl:trinos:xt-asyncpe:xt
↳ -craypat:xt-lgdb:xt-libsci:xt-mpich2:xt-mpt:xt-pa
↳ pi:xt-shmem:xt-totalview:/etc/opt/cray/modules/s
↳ ite_usermodules
CRAY_DMAPP_INCLUDE_OPTS=-I/opt/cray/dmapp/7.0.1-1.05
↳ 02.11080.8.74.gem/include
↳ -I/opt/cray/gni-headers/4.0-1.0502.10859.7.8.gem
↳ /include
CRAY_LIBSCI_BASE_DIR=/opt/cray/libsci/16.11.1
CRAY_LIBSCI_DIR=/opt/cray/libsci/16.11.1
PE_ACML_DEFAULT_DIR_PGI=pgi64
PE_LIBSCI_ACC_DEFAULT_VOLATILE_PKGCONFIG_PATH=/opt/c
↳ ray/libsci_acc/16.03.1/@PRGENV@/@PE_LIBSCI_ACC_D
↳ EFAULT_GENCOMPS@/@PE_LIBSCI_ACC_DEFAULT_TARGET@/
↳ lib/pkgconfig
PE_LIBSCI_PKGCONFIG_LIBS=libsci_mpi:libsci
PE_NETCDF_DEFAULT_GENCOMPS_GNU=51 49
PE_PARALLEL_NETCDF_DEFAULT_GENCOMPS_GNU=51 49
PE_TPSL_64_DEFAULT_GENCOMPS_GNU_x86_64=51 49
EBDEVELWGET=/sw/EasyBuild/software/wget/1.19.4/easyb
↳ uild/wget-1.19.4-easybuild-devel
MODIMP_AVAILABLE_MODULES=

```


MemXCT: Memory-Centric X-Ray CT Reconstruction with Massive Parallelization

```
PATH=/opt/nvidia/cudatoolkit9.1/9.1.85_3.10-1.0502.d
↳ flcc54.3.1/bin:/opt/nvidia/cudatoolkit9.1/9.1.85
↳ _3.10-1.0502.df1cc54.3.1/libnvvp:/opt/cray/pmi/5
↳ .0.10-1.0000.11050.179.3.gem/bin:/opt/gcc/4.9.3/
↳ bin:/sw/xe/darshan/3.1.3/darshan-3.1.3/bin:/sw/E
↳ asyBuild/software/gnuplot/5.0.5/bin:/sw/EasyBuil
↳ d/software/wget/1.19.4/bin:/sw/EasyBuild/softwar
↳ e/git/2.17.0/bin:/sw/EasyBuild/software/cURL/7.5
↳ 9.0/bin:/sw/EasyBuild/software/openssl/1.0.2m/bi
↳ n:/sw/admin/scripts:/sw/user/scripts:/opt/xalt/0
↳ .7.6/sles11.3/libexec:/opt/xalt/0.7.6/sles11.3/b
↳ in:/opt/robin/9.1.2/sbin:/opt/torque/6.0.4/sbin:/
↳ opt/torque/6.0.4/bin:/opt/cray/mpt/7.5.0/gni/bin
↳ :/opt/cray/craype/2.5.8/bin:/opt/cray/llm/default
↳ t/bin:/opt/cray/llm/default/etc:/opt/cray/xpmmem/
↳ 0.1-2.0502.64982.7.24.gem/bin:/opt/cray/ugni/6.0
↳ -1.0502.10863.8.28.gem/bin:/opt/cray/udreg/2.3.2-
↳ 1.0502.10518.2.17.gem/bin:/opt/cray/lustre-cray_
↳ gem_s/2.5.3.0.101_0.46.1_1.0502.8871.43.1-1.0502
↳ .21728.74.6/sbin:/opt/cray/lustre-cray_gem_s/2.5
↳ _3.0.101_0.46.1_1.0502.8871.43.1-1.0502.21728.74
↳ .6/bin:/opt/cray/alps/5.2.4-2.0502.9774.31.12.ge
↳ m/sbin:/opt/cray/alps/5.2.4-2.0502.9774.31.12.ge
↳ m/bin:/opt/cray/sdb/1.1-1.0502.63652.4.27.gem/bi
↳ n:/opt/cray/nodestat/2.2-1.0502.60539.1.31.gem/b
↳ in:/opt/modules/3.2.10.5/bin:/opt/robin/9.1.2/bin
↳ :/u/sciteam/USER/bin:/usr/local/bin:/usr/bin:/bi
↳ n:/usr/bin/X11:/usr/X11R6/bin:/usr/games:/usr/li
↳ b/mit/bin:/usr/lib/mit/sbin:/usr/lib/qt3/bin:/
↳ opt/cray/bin
PBS_LOCATION=<none>@<none>
PBS_O_LOGNAME=USER
MAIL=/var/spool/mail/USER
MODULE_VERSION=3.2.10.5
PE_HDF5_DEFAULT_VOLATILE_PKGCONFIG_PATH=/opt/cray/hd
↳ f5/1.10.0/@PRGENV@/PE_HDF5_DEFAULT_GENCOMPS@/li
↳ b/pkgconfig
PE_PKGCONFIG_DEFAULT_PRODUCTS=PE_TRILINOS:PE_TPSSL_64
↳ :PE_TPSSL:PE_PETSC:PE_PARALLEL_NETCDF:PE_NETCDF_H
↳ DF5PARALLEL:PE_NETCDF:PE_MPICH:PE_LIBSCI_ACC:PE_
↳ LIBSCI:PE_HDF5_PARALLEL:PE_HDF5:PE_GA:PE_FFTW:PE
↳ _ACML
PE_TPSSL_DEFAULT_GENCOMPILERS_GNU_x86_64=5.1 4.9
PE_TPSSL_DEFAULT_GENCOMPILERS_PGI_x86_64=15.3
PE_TPSSL_DEFAULT_GENCOMPS_CRAY_interlagos=83
PE_MPICH_GENCOMPILERS_GNU=5.1 4.9
PBS_O_LANG=en_US.UTF-8
CPU=x86_64
XTPE_NETWORK_TARGET=gemini
ATP_IGNORE_SIGTERM=1
PE_FFTW_DEFAULT_TARGET_abudhabi=abudhabi
PE_LIBSCI_DEFAULT_GENCOMPS_PGI_x86_64=153
PE_MPICH_DEFAULT_DIR_PGI_DEFAULT64=64
PE_NETCDF_DEFAULT_GENCOMPILERS_GNU=5.1 4.9
PE_PARALLEL_NETCDF_DEFAULT_GENCOMPILERS_GNU=5.1 4.9
PE_PETSC_DEFAULT_GENCOMPS_CRAY_mic_knl=85
```

```
PE_TPSSL_DEFAULT_GENCOMPILERS_GNU_haswell=5.1 4.9
_=/usr/bin/env
PBS_JOBCOOKIE=8BB5785A429DCBB52EBBAEA490DA44FE
JAVA_BINDIR=/usr/lib64/jvm/java/bin
PE_HDF5_PARALLEL_DEFAULT_FIXED_PRGENV=CRAY PGI INTEL
PE_HDF5_PARALLEL_DEFAULT_GENCOMPS_GNU=51 49
PE_NETCDF_HDF5PARALLEL_DEFAULT_FIXED_PRGENV=CRAY PGI
↳ INTEL
PE_NETCDF_HDF5PARALLEL_DEFAULT_GENCOMPS_GNU=51 49
PE_SMA_DEFAULT_DIR_CRAY_DEFAULT64=64
CRAY_UDREG_POST_LINK_OPTS=-L/opt/cray/udreg/2.3.2-1.
↳ 0502.10518.2.17.gem/lib64
PE_LIBSCI_DEFAULT_GENCOMPILERS_INTEL_mic_knl=15.0
PE_LIBSCI_GENCOMPS_INTEL_mic_knl=150
PE_TPSSL_64_DEFAULT_GENCOMPS_CRAY_sandybridge=83
PE_TPSSL_64_DEFAULT_VOLATILE_PRGENV=CRAY CRAY64 GNU
↳ GNU64 INTEL INTEL64 PGI PGI64
PE_TPSSL_DEFAULT_GENCOMPILERS_CRAY_mic_knl=8.5
PE_TPSSL_DEFAULT_GENCOMPS_INTEL_interlagos=150
PWD=/u/sciteam/USER
INPUTRC=/u/sciteam/USER/.inputrc
CRAY_ALPS_POST_LINK_OPTS=-L/opt/cray/alps/5.2.4-2.05
↳ 02.9774.31.12.gem/lib64
CRAYPE_VERSION=2.5.8
PE_MPICH_VOLATILE_PRGENV=CRAY GNU PGI
EBROOTOPENSSL=/sw/EasyBuild/software/openssl/1.0.2m
JAVA_HOME=/usr/lib64/jvm/java
TARGETMODULES=/opt/modules/3.2.10.5/init/.targetmodu
↳ les:craype-abudhabi:craype-abudhabi-cu:craype-ac
↳ cel-host:craype-accel-nvidia20:craype-accel-nvid
↳ ia30:craype-accel-nvidia35:craype-barcelona:cray
↳ pe-broadwell:craype-haswell:craype-hugepages128K
↳ :craype-hugepages128M:craype-hugepages16M:craype
↳ -hugepages256M:craype-hugepages2M:craype-hugepage
↳ s32M:craype-hugepages4M:craype-hugepages512K:cray
↳ ype-hugepages512M:craype-hugepages64M:craype-hug
↳ epages8M:craype-intel-knc:craype-interlagos:cray
↳ pe-interlagos-cu:craype-istanbul:craype-ivybridg
↳ e:craype-mc12:craype-mc8:craype-mic-knl:craype-n
↳ etwork-aries:craype-network-gemini:craype-networ
↳ k-infiniband:craype-network-none:craype-network-
↳ seastar:craype-sandybridge:craype-shanghai:crayp
↳ e-target-compute_node:craype-target-local_host:c
↳ raype-target-native:craype-xeon:xtpe-barcelona:x
↳ tpe-interlagos:xtpe-interlagos-cu:xtpe-istanbul:
↳ xtpe-mc12:xtpe-mc8:xtpe-network-gemini:xtpe-netw
↳ ork-seastar:xtpe-shanghai:xtpe-target-native:xtp
↳ e-xeon:/etc/opt/cray/modules/site_targetmodules
```

```

_LMFILES=/opt/modulefiles/modules/3.2.10.5:/opt/cra
y/gem/modulefiles/nodestat/2.2-1.0502.60539.1.31
.gem:/opt/cray/gem/modulefiles/sdb/1.1-1.0502.63
652.4.27.gem:/opt/cray/gem/modulefiles/alps/5.2.
4-2.0502.9774.31.12.gem:/opt/cray/modulefiles/lu
stre-cray_gem_s/2.5_3.0.101_0.46.1_1.0502.8871.4
3.1-1.0502.21728.74.6:/opt/cray/gem/modulefiles/
udreg/2.3.2-1.0502.10518.2.17.gem:/opt/cray/gem/
modulefiles/ugni/6.0-1.0502.10863.8.28.gem:/opt/
cray/gem/modulefiles/gni-headers/4.0-1.0502.1085
9.9.24.gem:/opt/cray/gem/modulefiles/dmapp/7.0.1
-1.0502.11080.8.74.gem:/opt/cray/gem/modulefiles/
xpmem/0.1-2.0502.64982.7.24.gem:/opt/modulefiles
/hss-llm/7.2.0:/opt/modulefiles/Base-opts/1.0.2-
1.0502.60680.2.4.gem:/opt/modulefiles/gcc/4.9.3:
/opt/cray/craype/2.5.8/modulefiles/craype-networ
k-gemini:/opt/cray/craype/2.5.8/modulefiles/cray
pe-interlagos:/opt/cray/modulefiles/craype/2.5.8
:/opt/cray/modulefiles/cray-mpich/7.5.0:/opt/mod
ulefiles/torque/6.0.4:/opt/modulefiles/moab/9.1.
2-sles11:/opt/modulefiles/xalt/0.7.6.local:/sw/x
e/modulefiles/scripts:/sw/EasyBuild/modules/all/
OpenSSL/1.0.2m:/sw/EasyBuild/modules/all/cURL/7.
59.0:/sw/EasyBuild/modules/all/git/2.17.0:/sw/Ea
syBuild/modules/all/wget/1.19.4:/sw/xe/modulefil
es/user-paths:/sw/EasyBuild/modules/all/gnuplot/
5.0.5:/sw/xe/modulefiles/darshan/3.1.3:/opt/cray
/modulefiles/cray-libsci/16.11.1:/opt/cray/gem/m
odulefiles/pmi/5.0.10-1.0000.11050.179.3.gem:/op
t/cray/modulefiles/atp/2.0.4:/opt/cray/modulefil
es/PrgEnv-gnu/5.2.82:/opt/cray/modulefiles/cudat
oolkit/9.1.85_3.10-1.0502.df1cc54.3.1
PE_LIBSCI_DEFAULT_GENCOMPS_INTEL_mic_knl=150
PE_LIBSCI_DEFAULT_OMP_REQUIRES=
PE_MPICH_DEFAULT_GENCOMPS_CRAY=84
PE_PETSC_DEFAULT_GENCOMPILERS_GNU_sandybridge=5.1 4.9
PE_TPSSL_DEFAULT_GENCOMPILERS_INTEL_haswell=15.0
XALT_TRANSMISSION_STYLE=directdb
PE_LIBSCI_ACC_DEFAULT_NV_SUFFIX_nvidia20=nv20
PE_LIBSCI_MODULE_NAME=cray-libsci/16.11.1
PE_TPSSL_DEFAULT_GENCOMPILERS_CRAY_interlagos=8.3
LANG=en_US.UTF-8
PBS_NODENUM=0
PE_LIBSCI_DEFAULT_GENCOMPILERS_PGI_x86_64=15.3
PE_LIBSCI_GENCOMPS_PGI_x86_64=153
PE_INTEL_FIXED_PKGCONFIG_PATH=/opt/cray/mpt/7.5.0/gn
i/mpi-intel/16.0/lib/pkgconfig
MOABHOMEDIR=/var/spool/moab
PYTHONSTARTUP=/etc/pythonstart
MODULEPATH=/sw/EasyBuild/modules/all:/sw/bw/modulefi
les:/sw/xe/modulefiles:/opt/cray/craype/2.5.8/mo
dulefiles:/opt/cray/gem/modulefiles:/opt/cray/mo
dulefiles:/opt/modulefiles

```

```

PE_ACML_DEFAULT_VOLATILE_PKGCONFIG_PATH=/opt/acml/5.
3.1/@PE_ACML_DEFAULT_DIR@PE_ACML_DEFAULT_TARGET
@@PE_ACML_DEFAULT_DIR_OPENMP@PE_ACML_DEFAULT_DI
R_DEFAULT64@/lib/pkgconfig
PE_LIBSCI_GENCOMPILERS_CRAY_x86_64=8.3
PE_MPICH_NV_LIBS_nvidia20=-lcudart
PE_MPICH_VOLATILE_PKGCONFIG_PATH=/opt/cray/mpt/7.5.0
/gni/mpi-intel@PRGENV@PE_MPICH_DIR_DEFAULT64@/PE_
MPICH_GENCOMPS@/lib/pkgconfig
PBS_NUM_NODES=1
SDK_HOME=/usr/lib64/jvm/java
LOADEDMODULES=modules/3.2.10.5:nodestat/2.2-1.0502.6
0539.1.31.gem:sdb/1.1-1.0502.63652.4.27.gem:alps
/5.2.4-2.0502.9774.31.12.gem:lustre-cray_gem_s/2
.5_3.0.101_0.46.1_1.0502.8871.43.1-1.0502.21728.
74.6:udreg/2.3.2-1.0502.10518.2.17.gem:ugni/6.0-
1.0502.10863.8.28.gem:gni-headers/4.0-1.0502.108
59.9.24.gem:dmapp/7.0.1-1.0502.11080.8.74.gem:xp
mem/0.1-2.0502.64982.7.24.gem:hss-llm/7.2.0:Base
-opts/1.0.2-1.0502.60680.2.4.gem:gcc/4.9.3:craype
-network-gemini:craype-interlagos:craype/2.5.8:cr
ay-mpich/7.5.0:torque/6.0.4:moab/9.1.2-sles11:xa
lt/0.7.6.local:scripts:OpenSSL/1.0.2m:cURL/7.59.
0:git/2.17.0:wget/1.19.4:user-paths:gnuplot/5.0.
5:darshan/3.1.3:cray-libsci/16.11.1:pmi/5.0.10-1
.0000.11050.179.3.gem:atp/2.0.4:PrgEnv-gnu/5.2.8
2:cudatoolkit/9.1.85_3.10-1.0502.df1cc54.3.1
SHMEM_ABORT_ON_ERROR=1
CRAY_DMAPP_POST_LINK_OPTS=-L/opt/cray/dmapp/7.0.1-1.
0502.11080.8.74.gem/lib64
PE_FFTW_DEFAULT_TARGET_ivybridge=ivybridge
PE_FFTW_DEFAULT_TARGET_share=share
PE_FFTW_DEFAULT_TARGET_x86_skylake=x86_skylake
PE_PKG_CONFIG_PATH=/opt/cray/cti/1.0.4/lib/pkgconfig
PE_TPSSL_64_DEFAULT_GENCOMPS_GNU_interlagos=51 49
PE_TPSSL_DEFAULT_GENCOMPS_PGI_x86_64=153
PBS_O_SHELL=/bin/bash
PE_LIBSCI_OMP_REQUIRES_openmp=_mp
PE_TPSSL_64_DEFAULT_GENCOMPS_CRAY_mic_knl=85
PE_TPSSL_DEFAULT_GENCOMPILERS_INTEL_x86_64=15.0
CRAY_MPICH_DIR=/opt/cray/mpt/7.5.0/gni/mpi-intel-gnu/4.9
PE_MPICH_CXX_PKGCONFIG_LIBS=mpichcxx
PBS_JOBID=9808461.bw
PE_LIBSCI_ACC_DEFAULT_GENCOMPILERS_GNU_x86_64=4.9
PE_LIBSCI_DEFAULT_GENCOMPS_INTEL_x86_64=150
PE_MPICH_PKGCONFIG_VARIABLES=PE_MPICH_NV_LIBS_@accel
erator@:PE_MPICH_MULTITHREADED_LIBS_@multithread
ed@
LM_LICENSE_FILE=1701@bwlm1.ncsa.illinois.edu:1701@bw
lm2.ncsa.illinois.edu:1703@bwlm1.ncsa.illinois.e
du:1703@bwlm2.ncsa.illinois.edu:1705@bwlm1.ncsa.
illinois.edu:1705@bwlm2.ncsa.illinois.edu:1707@b
wlm1.ncsa.illinois.edu:1707@bwlm2.ncsa.illinois.
edu
CRAY_PMI_POST_LINK_OPTS=-L/opt/cray/pmi/5.0.10-1.000
0.11050.179.3.gem/lib64

```

MemXCT: Memory-Centric X-Ray CT Reconstruction with Massive Parallelization

```
PE_HDF5_DEFAULT_FIXED_PRGENV=CRAY PGI INTEL
PE_TPSL_64_DEFAULT_GENCOMPILERS_CRAY_mic_knl=8.5
PE_TPSL_DEFAULT_VOLATILE_PKGCONFIG_PATH=/opt/cray/tp
↪ s1/16.07.1/@PRGENV@/@PE_TPSL_DEFAULT_GENCOMPS@/@
↪ PE_TPSL_DEFAULT_TARGET@/lib/pkgconfig
CRAY_MPICH2_VER=7.5.0
PE_MPICH_PKGCONFIG_LIBS=mpich
PE_GA_DEFAULT_GENCOMPILERS_GNU=5.1 4.9
PE_LIBSCI_ACC_DEFAULT_GENCOMPS_GNU_x86_64=49
PE_LIBSCI_VOLATILE_PKGCONFIG_PATH=/opt/cray/libsci/1
↪ 6.11.1/@PRGENV@/@PE_LIBSCI_GENCOMPS@/@PE_LIBSCI_
↪ TARGET@/lib/pkgconfig
PE_NETCDF_DEFAULT_FIXED_PRGENV=CRAY PGI INTEL
PE_PARALLEL_NETCDF_DEFAULT_FIXED_PRGENV=CRAY PGI
↪ INTEL
PE_TPSL_DEFAULT_GENCOMPS_PGI_interlagos=153
EBVERSIONGNUPLOT=5.0.5
HOME=/u/sciteam/USER
SHLVL=2
JDK_HOME=/usr/lib64/jvm/java
QT_SYSTEM_DIR=/usr/share/desktop-data
CRAY_LIBSCI_VERSION=16.11.1
PE_HDF5_PARALLEL_DEFAULT_VOLATILE_PRGENV=GNU
PE_MPICH_TARGET_VAR_nvidia35=-lcudart
PE_NETCDF_HDF5PARALLEL_DEFAULT_VOLATILE_PRGENV=GNU
PE_PKGCONFIG_PRODUCTS_DEFAULT=PE_PAPI
PE_TPSL_64_DEFAULT_GENCOMPS_GNU_haswell=51 49
EBVERSIONGIT=2.17.0
CUDAToolKIT_HOME=/opt/nvidia/cudatoolkit9.1/9.1.85_3
↪ .10-1.0502.df1cc54.3.1
OSTYPE=linux
LESS_ADVANCED_PREPROCESSOR=no
PE_LIBSCI_GENCOMPILERS_PGI_x86_64=15.3
PE_TPSL_DEFAULT_GENCOMPILERS_INTEL_interlagos=15.0
CURL_INCLUDES=/sw/EasyBuild/software/cURL/7.59.0/inc
↪ lude
PE_ACML_DEFAULT_DIR_OPENMP=mp
PE_MPICH_DEFAULT_VOLATILE_PKGCONFIG_PATH=/opt/cray/m
↪ pt/7.5.0/gni/mpich-@PRGENV@/@PE_MPICH_DEFAULT_DIR
↪ _DEFAULT64@/@PE_MPICH_DEFAULT_GENCOMPS@/lib/pkgc
↪ onfig
PE_PETSC_DEFAULT_GENCOMPILERS_CRAY_interlagos=8.3
PE_TPSL_DEFAULT_VOLATILE_PRGENV=CRAY CRAY64 GNU GNU64
↪ INTEL INTEL64 PGI PGI64
EBDEVELCURL=/sw/EasyBuild/software/cURL/7.59.0/easyb
↪ uild/cURL-7.59.0-easybuild-devel
PBS_O_HOST=h2o1ogin1.ncsa.illinois.edu
XCURSOR_THEME=crystalwhite
LS_OPTIONS=--color=auto
CRAY_PMI_INCLUDE_OPTS=-I/opt/cray/pmi/5.0.10-1.0000.
↪ 11050.179.3.gem/include
PE_TPSL_64_DEFAULT_GENCOMPS_CRAY_interlagos=83
PE_TPSL_DEFAULT_GENCOMPS_INTEL_sandybridge=150
WINDOWMANAGER=
```

```
PRGENVMODULES=/opt/modules/3.2.10.5/init/.prgenvmodu
↪ les:PrgEnv-cray:PrgEnv-gnu:PrgEnv-intel:PrgEnv-p
↪ athscale:PrgEnv-pgi
CRAY_LLM_DIR=/opt/cray/llm/default
CRAYPE_NETWORK_TARGET=gemini
ATP_MRNET_COMM_PATH=/opt/cray/atp/2.0.4/libexec/atp_
↪ mrnet_commnnode_wrapper
PE_TPSL_DEFAULT_GENCOMPILERS_CRAY_haswell=8.3
PKG_CONFIG_PATH_DEFAULT=/opt/cray/papi/5.5.0.1/lib64
↪ /pkgconfig
PE_MPICH_DIR_CRAY_DEFAULT64=64
GCC_PATH=/opt/gcc/4.9.3
CRAY_CUDAToolKIT_DIR=/opt/nvidia/cudatoolkit9.1/9.1.
↪ 85_3.10-1.0502.df1cc54.3.1
CRAY_CUDAToolKIT_INCLUDE_OPTS=-I/opt/nvidia/cudatool
↪ kit9.1/9.1.85_3.10-1.0502.df1cc54.3.1/include
↪ -I/opt/nvidia/cudatoolkit9.1/9.1.85_3.10-1.0502.
↪ df1cc54.3.1/extras/CUPTI/include
↪ -I/opt/nvidia/cudatoolkit9.1/9.1.85_3.10-1.0502.
↪ df1cc54.3.1/extras/Debugger/include
PBS_VNODENUM=0
PE_LIBSCI_GENCOMPILERS_INTEL_mic_knl=15.0
PE_MPICH_MULTITHREADED_LIBS_multithreaded=_mt
PE_PAPI_DEFAULT_TARGET_VAR_nvidia35=-lcupti,-lcudar
↪ t,-lcuda
PE_PETSC_DEFAULT_GENCOMPILERS_GNU_haswell=5.1 4.9
PE_TPSL_DEFAULT_GENCOMPILERS_GNU_interlagos=5.1 4.9
PE_TPSL_DEFAULT_GENCOMPILERS_INTEL_sandybridge=15.0
PE_TPSL_DEFAULT_GENCOMPILERS_PGI_interlagos=15.3
EBVERSIONWGET=1.19.4
EBROOTGNUPLOT=/sw/EasyBuild/software/gnuplot/5.0.5
LOGNAME=USER
MACHTYPE=x86_64-suse-linux
LESS=-M -I
G_FILENAME_ENCODING=@locale,UTF-8,ISO-8859-15,CP1252
CRAY_GNI_HEADERS_INCLUDE_OPTS=-I/opt/cray/gni-header
↪ s/4.0-1.0502.10859.9.24.gem/include
PYTHONPATH=/opt/xalt/0.7.6/sles11.3/libexec:/opt/cra
↪ y/sdb/1.1-1.0502.63652.4.27.gem/lib64/py
CRAY_LIBSCI_PREFIX_DIR=/opt/cray/libsci/16.11.1/GNU/
↪ 4.9/x86_64
PE_HDF5_DEFAULT_GENCOMPS_GNU=51 49
PE_MPICH_NV_LIBS=
PE_NETCDF_DEFAULT_REQUIRED_PRODUCTS=PE_HDF5
PE_TPSL_64_DEFAULT_GENCOMPILERS_GNU_haswell=5.1 4.9
PE_TPSL_64_DEFAULT_GENCOMPILERS_INTEL_sandybridge=15
↪ .0
PE_TPSL_DEFAULT_GENCOMPS_GNU_x86_64=51 49
PE_TRILINOS_DEFAULT_REQUIRED_PRODUCTS=PE_MPICH:PE_HD
↪ F5_PARALLEL:PE_NETCDF_HDF5PARALLEL:PE_LIBSCI:PE_
↪ TPSL
EBROOTCURL=/sw/EasyBuild/software/cURL/7.59.0
CVS_RSH=ssh
DMAPP_ABORT_ON_ERROR=1
PE_LIBSCI_OMP_REQUIRES=
PE_MPICH_DEFAULT_GENCOMPILERS_CRAY=8.4
```

```

PE_TRILINOS_DEFAULT_GENCOMPS_GNU_x86_64=51 49
PE_MPICH_GENCOMPS_CRAY=84
PBS_QUEUE=high
XDG_DATA_DIRS=/usr/share:/etc/opt/kde3/share:/opt/kd
↳ e3/share
TOOLMODULES=/opt/modules/3.2.10.5/init/.toolmodules:
↳ apprentice:apprentice2:atp:chapel:cray-lgdb:cray
↳ -snplauncher:craypat:craypkg-gen:ddt:gdb:iobuf:pa
↳ pi:perftools:perftools-lite:stat:totalview:xt-cr
↳ aypat:xt-lgdb:xt-papi:xt-totalview:/etc/opt/cray
↳ /modules/site_toolmodules
PE_LIBSCI_ACC_DEFAULT_GENCOMPILERS_CRAY_x86_64=8.3
PE_LIBSCI_ACC_DEFAULT_NV_SUFFIX_nvidia35=nv35
PE_LIBSCI_DEFAULT_REQUIRED_PRODUCTS=PE_MPICH
PE_MPICH_DEFAULT_FIXED_PRGENV=INTEL
PE_MPICH_DEFAULT_GENCOMPS_GNU=51 49
PE_TPSL_64_DEFAULT_GENCOMPILERS_INTEL_interlagos=15.0
PE_TPSL_DEFAULT_GENCOMPILERS_CRAY_sandybridge=8.3
MODULESHOME=/opt/modules/3.2.10.5
PE_GA_DEFAULT_FIXED_PRGENV=CRAY PGI INTEL
PE_LIBSCI_DEFAULT_VOLATILE_PKGCONFIG_PATH=/opt/cray/
↳ libsci/16.11.1/@PRGENV@/@PE_LIBSCI_DEFAULT_GENCO
↳ MPS@/@PE_LIBSCI_DEFAULT_TARGET@/lib/pkgconfig
PE_TPSL_DEFAULT_GENCOMPILERS_GNU_sandybridge=5.1 4.9
PBS_O_MAIL=/var/mail/USER
PBS_O_SUBMIT_FILTER=/usr/local/sbin/torque_submitfil
↳ ter
PBS_MICFILE=/var/spool/torque/aux//9808461.bwmic
LESSOPEN=lessopen.sh %s
PKG_CONFIG_PATH=/opt/nvidia/cudatoolkit9.1/9.1.85.3.
↳ 10-1.0502.df1cc54.3.1/lib64/pkgconfig:/sw/xe/dar
↳ shan/3.1.3/darshan-3.1.3/lib/pkgconfig:/sw/EasyB
↳ uild/software/cURL/7.59.0/lib/pkgconfig:/sw/Easy
↳ Build/software/OpenSSL/1.0.2m/lib/pkgconfig:/opt
↳ /cray/rca/1.0.0-2.0502.60530.1.63.gem/lib64/pkgc
↳ onfig:/opt/cray/pmi/5.0.10-1.0000.11050.179.3.ge
↳ m/lib64/pkgconfig:/opt/cray/craype/2.5.8/pkg-con
↳ fig:/opt/cray/iobuf/2.0.7/lib/pkgconfig:/opt/cra
↳ y/xpmmem/0.1-2.0502.64982.7.24.gem/lib64/pkgconfi
↳ g:/opt/cray/dmapp/7.0.1-1.0502.11080.8.74.gem/li
↳ b64/pkgconfig:/opt/cray/gni-headers/4.0-1.0502.1
↳ 0859.9.24.gem/lib64/pkgconfig:/opt/cray/ugni/6.0
↳ -1.0502.10863.8.28.gem/lib64/pkgconfig:/opt/cray/
↳ udreg/2.3.2-1.0502.10518.2.17.gem/lib64/pkgconfi
↳ g:/opt/cray/alps/5.2.4-2.0502.9774.31.12.gem/lib
↳ 64/pkgconfig:/opt/cray/atp/2.0.4/lib/pkgconfig
PE_MPICH_NV_LIBS_nvidia35=-lcudart
PE_PETSC_DEFAULT_VOLATILE_PKGCONFIG_PATH=/opt/cray/p
↳ etsc/3.7.2.1/complex/@PRGENV@/@PE_PETSC_DEFAULT_
↳ GENCOMPS@/@PE_PETSC_DEFAULT_TARGET@/lib/pkgconfig
PELOCAL_PRGENV=true
LIBSCI_BASE_DIR=/opt/cray/libsci/16.11.1
PE_TPSL_64_DEFAULT_GENCOMPS_INTEL_x86_64=150
INFOPATH=/opt/gcc/4.9.3/snos/share/info:/usr/local/i
↳ nfo:/usr/share/info:/usr/info
LIBSCI_VERSION=16.11.1

```

```

PE_LIBSCI_DEFAULT_PKGCONFIG_VARIABLES=PE_LIBSCI_DEFA
↳ ULT_OMP_REQUIRES=@openmp@
PE_TPSL_64_DEFAULT_GENCOMPS_GNU_sandybridge=51 49
ACLOCAL_PATH=/sw/EasyBuild/software/cURL/7.59.0/shar
↳ e/aclocal
PBS_NP=16
CRAY_ALPS_INCLUDE_OPTS=-I/opt/cray/alps/5.2.4-2.0502
↳ .9774.31.12.gem/include
CRAY_PRE_COMPILE_OPTS=-hnetwork=gemini
PE_FFTW_DEFAULT_TARGET_broadwell=broadwell
PE_LIBSCI_GENCOMPILERS_INTEL_x86_64=15.0
PE_PGI_DEFAULT_FIXED_PKGCONFIG_PATH=/opt/cray/parall
↳ el-netcdf/1.7.0/PGI/15.3/lib/pkgconfig:/opt/cray
↳ /netcdf-hdf5parallel/4.4.1/PGI/15.3/lib/pkgconfi
↳ g:/opt/cray/netcdf/4.4.1/PGI/15.3/lib/pkgconfig:
↳ /opt/cray/hdf5-parallel/1.10.0/PGI/15.3/lib/pkgc
↳ onfig:/opt/cray/hdf5/1.10.0/PGI/15.3/lib/pkgconf
↳ ig:/opt/cray/ga/5.3.0.7/PGI/15.3/lib/pkgconfig
PE_TPSL_64_DEFAULT_GENCOMPILERS_GNU_x86_64=5.1 4.9
CRAY_CPU_TARGET=interlagos
PBS_O_SERVER=bwsched
PBS_NUM_PPN=16
CRAY_UGNI_INCLUDE_OPTS=-I/opt/cray/ugni/6.0-1.0502.1
↳ 0863.8.28.gem/include
CRAY_XPMEM_INCLUDE_OPTS=-I/opt/cray/xpmmem/0.1-2.0502
↳ .64982.7.24.gem/include
PE_LIBSCI_DEFAULT_GENCOMPS_CRAY_mic_knl=85
PE_LIBSCI_REQUIRED_PRODUCTS=PE_MPICH
PE_MPICH_DEFAULT_GENCOMPILERS_PGI=15.3
PE_TPSL_64_DEFAULT_GENCOMPS_CRAY_x86_64=83
PE_MPICH_GENCOMPS_PGI=153
XTPE_LINK_TYPE=dynamic
PE_LIBSCI_DEFAULT_GENCOMPILERS_GNU_mic_knl=5.1
PE_LIBSCI_DEFAULT_GENCOMPILERS_GNU_x86_64=5.1 4.9
PE_LIBSCI_GENCOMPS_GNU_mic_knl=51
PE_LIBSCI_GENCOMPS_GNU_x86_64=51 49
PE_TPSL_DEFAULT_GENCOMPS_INTEL_haswell=150
LMOD_DIR=/opt/xalt/0.7.6/sles11.3
LESSCLOSE=lessclose.sh %s %s
ATP_HOME=/opt/cray/atp/2.0.4
PE_FFTW_DEFAULT_TARGET_x86_64=x86_64
PE_PETSC_DEFAULT_GENCOMPILERS_INTEL_x86_64=15.0
PBS_NODEFILE=/var/spool/torque/aux//9808461.bw
G_BROKEN_FILENAMES=1
CRAY_LD_LIBRARY_PATH=/opt/nvidia/cudatoolkit9.1/9.1.
↳ 85.3.10-1.0502.df1cc54.3.1/lib64:/opt/nvidia/cud
↳ atoolkit9.1/9.1.85.3.10-1.0502.df1cc54.3.1/extra
↳ s/CUPTI/lib64:/opt/cray/pmi/5.0.10-1.0000.11050.
↳ 179.3.gem/lib64:/opt/cray/libsci/16.11.1/GNU/4.9
↳ /x86_64/lib:/opt/cray/mpt/7.5.0/gni/mpich-gnu/4.
↳ 9/lib:/opt/cray/xpmmem/0.1-2.0502.64982.7.24.gem/
↳ lib64:/opt/cray/dmapp/7.0.1-1.0502.11080.8.74.ge
↳ m/lib64:/opt/cray/ugni/6.0-1.0502.10863.8.28.gem
↳ /lib64:/opt/cray/udreg/2.3.2-1.0502.10518.2.17.g
↳ em/lib64:/opt/cray/alps/5.2.4-2.0502.9774.31.12.
↳ gem/lib64

```


MemXCT: Memory-Centric X-Ray CT Reconstruction with Massive Parallelization

```

CRAYOS_VERSION=5.2.82
PE_FFTW_DEFAULT_TARGET_haswell=haswell
PE_GA_DEFAULT_GENCOMPS_GNU=51 49
PE_GA_DEFAULT_VOLATILE_PKGCONFIG_PATH=/opt/cray/ga/5.3.0.7/@PRGENV@/@PE_GA_DEFAULT_GENCOMPS@/lib/pkgconfig
PE_INTEL_DEFAULT_FIXED_PKGCONFIG_PATH=/opt/cray/parallel/1.7.0/INTEL/15.0/lib/pkgconfig:/opt/cray/netcdf-hdf5parallel/4.4.1/INTEL/15.0/lib/pkgconfig:/opt/cray/netcdf/4.4.1/INTEL/15.0/lib/pkgconfig:/opt/cray/mpt/7.5.0/gni/mpich-intel/16.0/INTEL/15.0/lib/pkgconfig:/opt/cray/hdf5-parallel/1.10.0/INTEL/15.0/lib/pkgconfig:/opt/cray/hdf5/1.10.0/INTEL/15.0/lib/pkgconfig:/opt/cray/ga/5.3.0.7/INTEL/15.0/lib/pkgconfig
PE_PAPI_DEFAULT_ACCEL_LIBS=
PE_PETSC_DEFAULT_GENCOMPILERS_GNU_interlagos=5.1 4.9
PE_PETSC_DEFAULT_GENCOMPILERS_INTEL_haswell=15.0
PE_SMA_DEFAULT_DIR_PGI_DEFAULT64=64
PBS_0_PATH=/opt/nvidia/cudatoolkit9.1/9.1.85_3.10-1.0502.df1cc54.3.1/bin:/opt/nvidia/cudatoolkit9.1/9.1.85_3.10-1.0502.df1cc54.3.1/libnvvp:/opt/cray/rca/1.0.0-2.0502.60530.1.63.gem/bin:/opt/cray/als/5.2.4-2.0502.9774.31.12.gem/sbin:/opt/cray/dvs/2.5.0-9.0-1.0502.2188.1.113.gem/bin:/opt/cray/xpmmem/0.1-2.0502.64982.5.3.gem/bin:/opt/cray/pmi/5.0.10-1.0000.11050.179.3.gem/bin:/opt/cray/ugni/6.0-1.0502.10863.8.28.gem/bin:/opt/cray/udreg/2.3.2-1.0502.10518.2.17.gem/bin:/opt/gcc/4.9.3/bin:/sw/xe/darshan/3.1.3/darshan-3.1.3/bin:/sw/EasyBuild/software/gnuplot/5.0.5/bin:/sw/EasyBuild/software/wget/1.19.4/bin:/sw/EasyBuild/software/git/2.17.0/bin:/sw/EasyBuild/software/cURL/7.5.9.0/bin:/sw/EasyBuild/software/openssl/1.0.2m/bin:/sw/admin/scripts:/sw/user/scripts:/opt/xalt/0.7.6/sles11.3/libexec:/opt/xalt/0.7.6/sles11.3/bin:/usr/local/gsi-openssh-7.5p1b/bin:/usr/local/gsi-openssh-7.5p1b/libexec:/opt/java/jdk1.8.0_51/bin:/usr/local/globus-6.0/bin:/usr/local/globus-6.0/sbin:/opt/roam/9.1.2/sbin:/opt/torque/6.0.4/sbin:/opt/torque/6.0.4/bin:/opt/cray/mpt/7.5.0/gni/bin:/opt/cray/craype/2.5.8/bin:/opt/cray/eslo/gin/eswrap/1.3.3-1.020200.1280.0/bin:/opt/module/3.2.10.4/bin:/opt/roam/9.1.2/bin:/u/sciteam/USER/bin:/usr/local/bin:/usr/bin:/bin:/usr/bin/X11:/usr/X11R6/bin:/usr/games:/usr/lib/mit/bin:/usr/lib/mit/sbin:/usr/lib/qt3/bin:/opt/cray/bin
COLORTERM=1
JAVA_ROOT=/usr/lib64/jvm/java
PE_MPICH_DEFAULT_DIR_CRAY_DEFAULT64=64
PE_PETSC_DEFAULT_GENCOMPS_CRAY_haswell=83
PE_PETSC_DEFAULT_GENCOMPS_GNU_x86_64=51 49
PE_PETSC_DEFAULT_GENCOMPS_INTEL_x86_64=150
PE_TPSL_64_DEFAULT_GENCOMPS_PGI_interlagos=153
EBVERSIONOPENSSL=1.0.2m
DARSHAN_LOGPATH=/projects/system/darshan/

```

```

BASH_FUNC_modimp_tabcomplete_off()=() { export
  MODIMP_AVAILABLE_MODULES="";
  complete -r module;
  rm -f /tmp/.modimp_available_${USER}_*
}
BASH_FUNC_modimp_module_to_stdout_on()=() { if [ -f
  $HOME/.no_modimp ]; then
    return;
  fi;
  if [ -f $HOME/.no_modimp_warning ]; then
    echo "The file $HOME/.no_modimp_warning exists;
    modimp commands will not load.";
    return;
  fi;
  function moduleraw ()
  {
    eval `${MODULESHOME}/bin/modulecmd bash $*`
  };
  function module ()
  {
    if [[ $1 == "purge" ]]; then
      echo "";
      echo "BEWARE: Running \"module purge\" puts your
      environment in an unreliable state.";
      echo "Doing so makes it difficult to debug problems
      or for support staff to help";
      echo "you. Please structure your build so that you
      don't have to do this.";
      echo "";
    fi;
    if [[ $1 == "PrgEnvLoad" ]]; then
      PRGMOD=`echo $LOADED_MODULES | tr ":" "\n" | grep
      PrgEnv`;
      if [[ $PRGMOD == "" ]]; then
        moduleraw load $2 $3 $4 $5 $6 2>&1;
        return;
      fi;
      moduleraw swap $PRGMOD $2 $3 $4 $5 $6 2>&1;
      return;
    fi;
    moduleraw $* 2>&1
  };
  export -f moduleraw;
  export -f module
}
BASH_FUNC_autocomplete_modules()=() { subcommands=load:
  add:show:display:available:unload:rm:swap:switch:use:
  unuse:PrgEnvLoad";
  read -a command_line_array <<< "$COMP_LINE";
  num_command_line_elements=${#command_line_array[@]};
  if [[ $num_command_line_elements -eq 1 ]]; then
    echo "load";
    echo "add";
    echo "show";
    echo "display";
    echo "available";
  fi;
}

```

```

echo "unload";
echo "rm";
echo "list";
echo "swap";
echo "switch";
echo "use";
echo "unuse";
echo "PrgEnvLoad";
exit;
fi;
module_sub_command=${command_line_array[1]};
being_completed=$2;
being_completed_length=${#being_completed};
loaded_modules_array=$(echo $LOADED_MODULES | tr ":"
↪ "\n");
if [ $MODIMP_KEEP_MODULE_LIST_IN_ENV != "yes" ]; then
dated_modulefile_name="/tmp/.modimp_available_${USE_
↪ R}_`date
↪ +%Y_%m_%d`";
if [ ! -f ${dated_modulefile_name} ]; then
autocomplete_modules_setup;
fi;
read -r MODIMP_AVAILABLE_MODULES <
↪ ${dated_modulefile_name};
fi;
available_modules_array=$(echo
↪ $MODIMP_AVAILABLE_MODULES | tr ":" "\n");
case "$module_sub_command" in
load | add | show | display | available | avail)
possible_completions_array=("${available_modules_ar_
↪ ray[@]}")
;;
unload | rm | list)
possible_completions_array=("${loaded_modules_array_
↪ ray[@]}")
;;
PrgEnvLoad)
PrgEnv_array=$(echo $MODIMP_AVAILABLE_MODULES | tr
↪ ":" "\n" | grep PrgEnv);
possible_completions_array=("${PrgEnv_array[@]}")
;;
swap | switch)
case "$num_command_line_elements" in
2)
possible_completions_array=("${loaded_modules_array_
↪ ray[@]}")
;;
4)
possible_completions_array=("${available_modules_ar_
↪ ray[@]}")
;;
3)
if [[ $being_completed_length -eq 0 ]]; then
initial_completions_array=("${available_modules_arr_
↪ ay[@]}");
raw_module_to_be_swapped=${command_line_array[2]};

```

```

position_of_slash=$(echo $raw_module_to_be_swapped |
↪ grep -b -o "/" | awk 'BEGIN {FS=":"}{print $1}');
second_completions_array="";
if [[ $position_of_slash -gt 0 ]]; then
base_module_length=$position_of_slash;
else
base_module_length=${#raw_module_to_be_swapped};
fi;
module_name_prefix=${raw_module_to_be_swapped:0:6};
if [[ $module_name_prefix == "PrgEnv" ]]; then
base_module_length=6;
fi;
base_module_to_be_swapped=${raw_module_to_be_swappe_
↪ d:0:base_module_length};
version_length=${#raw_module_to_be_swapped}-positio_
↪ n_of_slash-1;
for comp in $initial_completions_array;
do
match_string=${comp:0:base_module_length};
if [ $match_string == $base_module_to_be_swapped ];
↪ then
second_completions_array+=$comp;
second_completions_array+=" ";
fi;
done;
possible_completions_array=$(echo
↪ $second_completions_array | tr ":" "\n");
else
possible_completions_array=("${loaded_modules_array_
↪ ray[@]}");
fi
;;
esac
;;
use | unuse)
dir_completions=(`ls -l -d -p ${being_completed}*
↪ 2>/dev/null`);
num_possible=${#dir_completions[@]};
blah="\t";
if (( num_possible == 1 )); then
echo ${dir_completions[0]};
echo ${dir_completions[0]}$blah;
else
for item in "${dir_completions[@]}";
do
echo $item;
done;
fi;
return
;;
*)
if [[ $3 == "module" ]]; then
possible_completions_array=$(echo $subcommands_list
↪ | tr ":" "\n");
fi
;;

```

MemXCT: Memory-Centric X-Ray CT Reconstruction with Massive Parallelization

```

esac;
if [[ $being_completed_length -eq 0 ]]; then
for x in $possible_completions_array;
do
echo "$x";
done;
else
for x in $possible_completions_array;
do
match_string=${x:0:being_completed_length};
if [ $match_string == $being_completed ]; then
echo "$x";
fi;
cray_prepend_length=$((($being_completed_length+5)
↪ );
cray_prepend_match_string=${x:0:cray_prepend_length};
cray_prepend_being_completed="cray-";
cray_prepend_being_completed+=$being_completed;
if [ $cray_prepend_match_string ==
↪ $cray_prepend_being_completed ]; then
echo "$x";
fi;
craype_prepend_length=$((($being_completed_length+
↪ 7));
craype_prepend_match_string=${x:0:craype_prepend_length};
craype_prepend_being_completed="craype-";
craype_prepend_being_completed+=$being_completed;
if [ $craype_prepend_match_string ==
↪ $craype_prepend_being_completed ]; then
echo "$x";
fi;
xt_prepend_length=$((($being_completed_length+3));
xt_prepend_match_string=${x:0:xt_prepend_length};
xt_prepend_being_completed="xt-";
xt_prepend_being_completed+=$being_completed;
if [[ $xt_prepend_match_string ==
↪ $xt_prepend_being_completed ]]; then
echo "$x";
fi;
done;
fi
}
BASH_FUNC_modulera()=( ) { eval
↪ ` ${MODULESHOME}/bin/modulecmd bash $* `
}
BASH_FUNC_modimp_show_all_if_ambiguous_on()=( ) { if
↪ [ -f $HOME/.no_modimp ]; then
return;
fi;
if [ -f $HOME/.no_modimp_warning ]; then
echo "The file $HOME/.no_modimp_warning exists;
↪ modimp commands will not load.";
return;
fi;
bind 'set show-all-if-ambiguous on'
}
BASH_FUNC_modimp_tabcomplete_on()=( ) { if [ -f
↪ $HOME/.no_modimp ]; then
return;
fi;
if [ -f $HOME/.no_modimp_warning ]; then
echo "The file $HOME/.no_modimp_warning exists;
↪ modimp commands will not load.";
return;
fi;
autocomplete_modules_setup;
complete -C autocomplete_modules module
}
BASH_FUNC_module()=( ) { if [[ $1 == "purge" ]]; then
echo "";
echo "BEWARE: Running \"module purge\" puts your
↪ environment in an unreliable state.";
echo "Doing so makes it difficult to debug problems
↪ or for support staff to help";
echo "you. Please structure your build so that you
↪ don't have to do this.";
echo "";
fi;
if [[ $1 == "PrgEnvLoad" ]]; then
PRGMOD=`echo $LOADEDMODULES | tr ":" "\n" | grep
↪ PrgEnv`;
if [[ $PRGMOD == "" ]]; then
modulera load $2 $3 $4 $5 $6 2>&1;
return;
fi;
modulera swap $PRGMOD $2 $3 $4 $5 $6 2>&1;
return;
fi;
modulera $* 2>&1
}
BASH_FUNC_autocomplete_modules_setup()=( ) { if [
↪ $MODIMP_KEEP_MODULE_LIST_IN_ENV != "yes" ]; then
dated_modulefile_name="/tmp/.modimp_available_${USER}_
↪ R`date
↪ +%Y_%m_%d`;
if [ ! -e ${dated_modulefile_name} ]; then
rm -f /tmp/.modimp_available_${USER}_*;
fi;
fi;
MODIMP_AVAILABLE_MODULES="";
mod_dir_list=$(echo $MODULEPATH | tr ":" "\n");
for mod_dir in $mod_dir_list;
do
directory_name_length=${#mod_dir};
file_list=$(find $mod_dir 2> /dev/null);
for filename in $file_list;
do
modname_position=$((($directory_name_length+1));

```

```

modname_and_version_length=$(( ${#filename} - $modname_
↪ _position ));
modulename_and_version=${filename:$modname_position_
↪ :$modname_and_version_length};
modname_leading_character=${modulename_and_version:_
↪ 0:1};
if [[ $modname_leading_character == "." ]]; then
continue;
fi;
if [[ $modulename_and_version =~ \/\\. ]]; then
continue;
fi;
MODIMP_AVAILABLE_MODULES+=$modulename_and_version;
MODIMP_AVAILABLE_MODULES+=" ";
done;
done;
if [ $MODIMP_KEEP_MODULE_LIST_IN_ENV != "yes" ]; then
echo $MODIMP_AVAILABLE_MODULES >
↪ ${dated_modulefile_name};
export MODIMP_AVAILABLE_MODULES="";
else
export MODIMP_AVAILABLE_MODULES;
fi
}
BASH_FUNC_modimp_show_all_if_ambiguous_off()=( ) {
↪ bind 'set show-all-if-ambiguous off'
}
BASH_FUNC_modimp_module_to_stdout_off()=( ) {
↪ function module ( )
{
if [[ $1 == "purge" ]]; then
echo "";
echo "BEWARE: Running \"module purge\" puts your
↪ environment in an unreliable state.";
echo "Doing so makes it difficult to debug problems
↪ or for support staff to help";
echo "you. Please structure your build so that you
↪ don't have to do this.";
echo "";
fi;
eval `${MODULESHOME}/bin/modulecmd bash $*`
};
export -f module
}
BASH_FUNC_modimp_resync()=( ) { rm -f
↪ /dev/shm/.modimp_available_${USER}_*;
autocomplete_modules_setup
}
LSB Version:      core-2.0-noarch:core-3.2-noarch:_
↪ core-4.0-noarch:core-2.0-x86_64:core-3.2-x86_64:_
↪ core-4.0-x86_64:desktop-4.0-amd64:desktop-4.0-no_
↪ arch:graphics-2.0-amd64:graphics-2.0-noarch:grap_
↪ hics-3.2-amd64:graphics-3.2-noarch:graphics-4.0-_
↪ amd64:graphics-4.0-noarch
Distributor ID:   SUSE LINUX

```

```

Description:      SUSE Linux Enterprise Server 11
↪ (x86_64)
Release:          11
Codename:          n/a
Linux nid25333 3.0.101-0.46.1_1.0502.8871-cray_gem_s
↪ #1 SMP Mon Oct 8 17:41:07 UTC 2018 x86_64 x86_64
↪ x86_64 GNU/Linux
Architecture:     x86_64
CPU op-mode(s):   32-bit, 64-bit
Byte Order:       Little Endian
CPU(s):           32
On-line CPU(s) list: 0-31
Thread(s) per core: 2
Core(s) per socket: 8
Socket(s):        2
NUMA node(s):     4
Vendor ID:        AuthenticAMD
CPU family:       21
Model:            1
Stepping:         2
CPU MHz:          2300.000
BogoMIPS:         4599.94
Virtualization:   AMD-V
L1d cache:        16K
L1i cache:        64K
L2 cache:         2048K
L3 cache:         6144K
NUMA node0 CPU(s): 0-7
NUMA node1 CPU(s): 8-15
NUMA node2 CPU(s): 16-23
NUMA node3 CPU(s): 24-31
MemTotal:         66175076 kB
MemFree:          4112148 kB
Buffers:          0 kB
Cached:           47340656 kB
SwapCached:       0 kB
Active:           9434996 kB
Inactive:         38029256 kB
Active(anon):     144920 kB
Inactive(anon):   4996 kB
Active(file):     9290076 kB
Inactive(file):   38024260 kB
Unevictable:      413480 kB
Mlocked:          413480 kB
SwapTotal:        0 kB
SwapFree:         0 kB
Dirty:            48 kB
Writeback:        0 kB
AnonPages:        536876 kB
Mapped:           44304 kB
Shmem:            2888 kB
Slab:             12474464 kB
SReclaimable:     406820 kB
SUnreclaim:       12067644 kB
KernelStack:      10864 kB
PageTables:       9776 kB

```


MemXCT: Memory-Centric X-Ray CT Reconstruction with Massive Parallelization

```
NFS_Unstable:      0 kB
Bounce:            0 kB
WritebackTmp:      0 kB
CommitLimit:      33087536 kB
Committed_AS:      3773312 kB
VmallocTotal:      34359738367 kB
VmallocUsed:        4938904 kB
VmallocChunk:      34304251512 kB
HugePages_Total:    0
HugePages_Free:     0
HugePages_Rsvd:     0
HugePages_Surp:     0
Hugepagesize:      2048 kB
DirectMap4k:        4096 kB
DirectMap2M:        3141632 kB
DirectMap1G:        63963136 kB
```

NAME	MAJ:MIN	RM	SIZE	RO	MOUNTPOINT
ram0	1:0	0	78.1M	0	
ram1	1:1	0	78.1M	0	
ram2	1:2	0	78.1M	0	
ram3	1:3	0	78.1M	0	
ram4	1:4	0	78.1M	0	
ram5	1:5	0	78.1M	0	
ram6	1:6	0	78.1M	0	
ram7	1:7	0	78.1M	0	
ram8	1:8	0	78.1M	0	
ram9	1:9	0	78.1M	0	
ram10	1:10	0	78.1M	0	
ram11	1:11	0	78.1M	0	
ram12	1:12	0	78.1M	0	
ram13	1:13	0	78.1M	0	
ram14	1:14	0	78.1M	0	
ram15	1:15	0	78.1M	0	
loop0	7:0	0		1	
loop1	7:1	0		1	
loop2	7:2	0		0	
loop3	7:3	0		0	
loop4	7:4	0		0	
loop5	7:5	0		0	
loop6	7:6	0		0	
loop7	7:7	0		0	

```
++ /opt/modules/3.2.10.5/bin/modulecmd bash list
```

Currently Loaded Modulefiles:

- 1) modules/3.2.10.5
- 2) nodestat/2.2-1.0502.60539.1.31.gem
- 3) sdb/1.1-1.0502.63652.4.27.gem
- 4) alps/5.2.4-2.0502.9774.31.12.gem
- 5) lustre-cray_gem_s/2.5_3.0.101_0.46.1_1.0502.887 ↵
↵ 1.43.1-1.0502.21728.74.6
- 6) udreg/2.3.2-1.0502.10518.2.17.gem
- 7) ugni/6.0-1.0502.10863.8.28.gem
- 8) gni-headers/4.0-1.0502.10859.9.24.gem
- 9) dmapp/7.0.1-1.0502.11080.8.74.gem
- 10) xpmem/0.1-2.0502.64982.7.24.gem
- 11) hss-llm/7.2.0
- 12) Base-opts/1.0.2-1.0502.60680.2.4.gem

- 13) gcc/4.9.3
 - 14) craype-network-gemini
 - 15) craype-interlagos
 - 16) craype/2.5.8
 - 17) cray-mpich/7.5.0
 - 18) torque/6.0.4
 - 19) moab/9.1.2-sles11
 - 20) xalt/0.7.6.local
 - 21) scripts
 - 22) OpenSSL/1.0.2m
 - 23) cURL/7.59.0
 - 24) git/2.17.0
 - 25) wget/1.19.4
 - 26) user-paths
 - 27) gnuplot/5.0.5
 - 28) darshan/3.1.3
 - 29) cray-libsci/16.11.1
 - 30) pmi/5.0.10-1.0000.11050.179.3.gem
 - 31) atp/2.0.4
 - 32) PrgEnv-gnu/5.2.82
 - 33) cudatoolkit/9.1.85_3.10-1.0502.df1cc54.3.1
- + eval

```
-----
Minsky System
-----
```

```
LESSOPEN=| /usr/bin/lesspipe %s
MAIL=/var/mail/USER
SSH_CLIENT=192.17.148.253 51202 22
USER=USER
SHLVL=1
HOME=/home/USER
SSH_TTY=/dev/pts/0
LOGNAME=USER
_=./script.sh
XDG_SESSION_ID=30364
TERM=xterm-256color
PATH=/home/USER/bin:/home/USER/.local/bin:/usr/local_
↵ /sbin:/usr/local/bin:/usr/sbin:/usr/bin:/sbin:/b
↵ in:/usr/games:/usr/local/games:/snap/bin
XDG_RUNTIME_DIR=/run/user/1010
LANG=en_US.UTF-8
```

```

LS_COLORS=rs=0:di=01;34:ln=01;36:mh=00:pi=40;33:so=0
↪ 1;35:do=01;35:bd=40;33;01:cd=40;33;01:or=40;31;0
↪ 1:mi=00:su=37;41:sg=30;43:ca=30;41:tw=30;42:ow=3
↪ 4;42:st=37;44:ex=01;32:*.tar=01;31:*.tgz=01;31:*
↪ .arc=01;31:*.arj=01;31:*.taz=01;31:*.lha=01;31:*
↪ .lz4=01;31:*.lzh=01;31:*.lzma=01;31:*.tlz=01;31:
↪ *.txz=01;31:*.tzo=01;31:*.t7z=01;31:*.zip=01;31:
↪ *.z=01;31:*.Z=01;31:*.dz=01;31:*.gz=01;31:*.lrz=
↪ 01;31:*.lz=01;31:*.lzo=01;31:*.xz=01;31:*.bz2=01
↪ ;31:*.bz=01;31:*.tbz=01;31:*.tbz2=01;31:*.tz=01;
↪ 31:*.deb=01;31:*.rpm=01;31:*.jar=01;31:*.war=01;
↪ 31:*.ear=01;31:*.sar=01;31:*.rar=01;31:*.alz=01;
↪ 31:*.ace=01;31:*.zoo=01;31:*.cpio=01;31:*.7z=01;
↪ 31:*.rz=01;31:*.cab=01;31:*.jpg=01;35:*.jpeg=01;
↪ 35:*.gif=01;35:*.bmp=01;35:*.pbm=01;35:*.pgm=01;
↪ 35:*.ppm=01;35:*.tga=01;35:*.xbm=01;35:*.xpm=01;
↪ 35:*.tif=01;35:*.tiff=01;35:*.png=01;35:*.svg=01
↪ ;35:*.svgz=01;35:*.mng=01;35:*.pcx=01;35:*.mov=0
↪ 1;35:*.mpg=01;35:*.mpeg=01;35:*.m2v=01;35:*.mkv=
↪ 01;35:*.webm=01;35:*.ogm=01;35:*.mp4=01;35:*.m4v
↪ =01;35:*.mp4v=01;35:*.vob=01;35:*.qt=01;35:*.nuv
↪ =01;35:*.wmv=01;35:*.asf=01;35:*.rm=01;35:*.rmvb
↪ =01;35:*.flc=01;35:*.avi=01;35:*.fli=01;35:*.flv
↪ =01;35:*.gl=01;35:*.dl=01;35:*.xcf=01;35:*.xwd=0
↪ 1;35:*.yuv=01;35:*.cgm=01;35:*.emf=01;35:*.ogv=0
↪ 1;35:*.ogx=01;35:*.aac=00;36:*.au=00;36:*.flac=0
↪ 0;36:*.m4a=00;36:*.mid=00;36:*.midi=00;36:*.mka=
↪ 00;36:*.mp3=00;36:*.mpc=00;36:*.ogg=00;36:*.ra=0
↪ 0;36:*.wav=00;36:*.oga=00;36:*.opus=00;36:*.spx=
↪ 00;36:*.xspf=00;36:

```

```

SHELL=/bin/bash
LESSCLOSE=/usr/bin/lesspipe %s %s
PWD=/home/USER
XDG_DATA_DIRS=/usr/local/share:/usr/share:/var/lib/s
↪ napd/desktop
SSH_CONNECTION=192.17.148.253 51202 192.17.103.137 22
Distributor ID:      Ubuntu
Description:          Ubuntu 16.04.4 LTS
Release:              16.04
Codename:              xenial
Linux minsky1 4.4.0-130-generic #156-Ubuntu SMP Thu
↪ Jun 14 08:51:21 UTC 2018 ppc64le ppc64le ppc64le
↪ GNU/Linux
Architecture:        ppc64le
Byte Order:           Little Endian
CPU(s):               160
On-line CPU(s) list:  0-159
Thread(s) per core:   8
Core(s) per socket:   10
Socket(s):            2
NUMA node(s):        2
Model:                1.0 (pvr 004c 0100)
Model name:           POWER8NVL (raw), altivec
↪ supported
CPU max MHz:          4023.0000
CPU min MHz:          2061.0000

```

```

Hypervisor vendor:    horizontal
Virtualization type:  full
L1d cache:            64K
L1i cache:            32K
L2 cache:             512K
L3 cache:             8192K
NUMA node0 CPU(s):    0-79
NUMA node1 CPU(s):    80-159
MemTotal:             535677632 kB
MemFree:              169815232 kB
MemAvailable:         527434624 kB
Buffers:              6851456 kB
Cached:               339326400 kB
SwapCached:           0 kB
Active:               258826368 kB
Inactive:             87923840 kB
Active(anon):         1721664 kB
Inactive(anon):       603776 kB
Active(file):         257104704 kB
Inactive(file):       87320064 kB
Unevictable:          4416 kB
Mlocked:              4416 kB
SwapTotal:            151600064 kB
SwapFree:             151600064 kB
Dirty:                704 kB
Writeback:            0 kB
AnonPages:            582336 kB
Mapped:               194240 kB
Shmem:                1750528 kB
Slab:                 17960256 kB
SReclaimable:         14636032 kB
SUNreclaim:           3324224 kB
KernelStack:          29344 kB
PageTables:           8512 kB
NFS_Unstable:         0 kB
Bounce:               0 kB
WritebackTmp:         0 kB
CommitLimit:          419438848 kB
Committed_AS:         6059840 kB
VmallocTotal:         8589934592 kB
VmallocUsed:           0 kB
VmallocChunk:         0 kB
HardwareCorrupted:    0 kB
AnonHugePages:        0 kB
CmaTotal:              26853376 kB
CmaFree:               26853376 kB
HugePages_Total:      0
HugePages_Free:       0
HugePages_Rsvd:       0
HugePages_Surp:       0
Hugepagesize:         16384 kB
NAME MAJ:MIN RM SIZE RO TYPE MOUNTPOINT
sda   8:0  1  3.5T 0 disk
├─sda1 8:1  1    7M 0 part
├─sda2 8:2  1  3.4T 0 part /
└─sda3 8:3  1 144.6G 0 part [SWAP]

```

MemXCT: Memory-Centric X-Ray CT Reconstruction with Massive Parallelization

```
sdb      8:16  1    3.5T  0 disk
sdc      8:32  1          0 disk
sdd      8:48  1          0 disk
sde      8:64  1          0 disk
sdf      8:80  1          0 disk
sdg      8:96  1          0 disk
sdh      8:112 1          0 disk
sdi      8:128 1          0 disk
sdj      8:144 1          0 disk
sr0     11:0   1   1024M  0 rom
sr1     11:1   1   1024M  0 rom
sr2     11:2   1   1024M  0 rom
sr3     11:3   1   1024M  0 rom
loop0    7:0   0          0 loop
loop1    7:1   0          0 loop
loop2    7:2   0          0 loop
loop3    7:3   0          0 loop
loop4    7:4   0          0 loop
loop5    7:5   0          0 loop
loop6    7:6   0          0 loop
loop7    7:7   0          0 loop
Wed Apr 10 02:58:57 2019
+-----+
| NVIDIA-SMI 396.26                Driver Version:
| 396.26                          |
+-----+
| GPU Name      Persistence-M| Bus-Id        Disp.A
+-----+-----+
| 0  Tesla P100-SXM2...  On   | 00000002:01:00.0 Off
+-----+-----+
| N/A    36C      P0       32W / 300W |      0MiB / 16280MiB
+-----+-----+
| 1  Tesla P100-SXM2...  On   | 00000003:01:00.0 Off
+-----+-----+
| N/A    32C      P0       34W / 300W |      0MiB / 16280MiB
+-----+-----+
| 2  Tesla P100-SXM2...  On   | 0000000A:01:00.0 Off
+-----+-----+
| N/A    35C      P0       31W / 300W |      0MiB / 16280MiB
+-----+-----+
| 3  Tesla P100-SXM2...  On   | 0000000B:01:00.0 Off
+-----+-----+
```

```
| N/A    30C      P0       31W / 300W |      0MiB / 16280MiB
+-----+-----+
| Processes:
+-----+
| GPU      PID   Type   Process name
+-----+-----+
| No running processes found
+-----+
H/W path      Device      Class      Description
+-----+-----+
/0             system     8335-GTB
/0/0           bus        Motherboard
/0/0           memory     510GiB System
/0/1           processor  POWER8NVL
/0/2           processor  POWER8NVL
/0/3           processor  POWER8NVL
/0/4           processor  POWER8NVL
/0/5           processor  POWER8NVL
/0/6           processor  POWER8NVL
/0/7           processor  POWER8NVL
/0/8           processor  POWER8NVL
/0/9           processor  POWER8NVL
/0/a           processor  POWER8NVL
/0/b           processor  POWER8NVL
/0/c           processor  POWER8NVL
/0/d           processor  POWER8NVL
/0/e           processor  POWER8NVL
/0/f           processor  POWER8NVL
```

[illegible]

MemXCT: Memory-Centric X-Ray CT Reconstruction with Massive Parallelization

/0/46	processor	POWER8NVL	/0/61	processor	POWER8NVL
↪ (raw), altivec supported			↪ (raw), altivec supported		
/0/47	processor	POWER8NVL	/0/62	processor	POWER8NVL
↪ (raw), altivec supported			↪ (raw), altivec supported		
/0/48	processor	POWER8NVL	/0/63	processor	POWER8NVL
↪ (raw), altivec supported			↪ (raw), altivec supported		
/0/49	processor	POWER8NVL	/0/64	processor	POWER8NVL
↪ (raw), altivec supported			↪ (raw), altivec supported		
/0/4a	processor	POWER8NVL	/0/65	processor	POWER8NVL
↪ (raw), altivec supported			↪ (raw), altivec supported		
/0/4b	processor	POWER8NVL	/0/66	processor	POWER8NVL
↪ (raw), altivec supported			↪ (raw), altivec supported		
/0/4c	processor	POWER8NVL	/0/67	processor	POWER8NVL
↪ (raw), altivec supported			↪ (raw), altivec supported		
/0/4d	processor	POWER8NVL	/0/68	processor	POWER8NVL
↪ (raw), altivec supported			↪ (raw), altivec supported		
/0/4e	processor	POWER8NVL	/0/69	processor	POWER8NVL
↪ (raw), altivec supported			↪ (raw), altivec supported		
/0/4f	processor	POWER8NVL	/0/6a	processor	POWER8NVL
↪ (raw), altivec supported			↪ (raw), altivec supported		
/0/50	processor	POWER8NVL	/0/6b	processor	POWER8NVL
↪ (raw), altivec supported			↪ (raw), altivec supported		
/0/51	processor	POWER8NVL	/0/6c	processor	POWER8NVL
↪ (raw), altivec supported			↪ (raw), altivec supported		
/0/52	processor	POWER8NVL	/0/6d	processor	POWER8NVL
↪ (raw), altivec supported			↪ (raw), altivec supported		
/0/53	processor	POWER8NVL	/0/6e	processor	POWER8NVL
↪ (raw), altivec supported			↪ (raw), altivec supported		
/0/54	processor	POWER8NVL	/0/6f	processor	POWER8NVL
↪ (raw), altivec supported			↪ (raw), altivec supported		
/0/55	processor	POWER8NVL	/0/70	processor	POWER8NVL
↪ (raw), altivec supported			↪ (raw), altivec supported		
/0/56	processor	POWER8NVL	/0/71	processor	POWER8NVL
↪ (raw), altivec supported			↪ (raw), altivec supported		
/0/57	processor	POWER8NVL	/0/72	processor	POWER8NVL
↪ (raw), altivec supported			↪ (raw), altivec supported		
/0/58	processor	POWER8NVL	/0/73	processor	POWER8NVL
↪ (raw), altivec supported			↪ (raw), altivec supported		
/0/59	processor	POWER8NVL	/0/74	processor	POWER8NVL
↪ (raw), altivec supported			↪ (raw), altivec supported		
/0/5a	processor	POWER8NVL	/0/75	processor	POWER8NVL
↪ (raw), altivec supported			↪ (raw), altivec supported		
/0/5b	processor	POWER8NVL	/0/76	processor	POWER8NVL
↪ (raw), altivec supported			↪ (raw), altivec supported		
/0/5c	processor	POWER8NVL	/0/77	processor	POWER8NVL
↪ (raw), altivec supported			↪ (raw), altivec supported		
/0/5d	processor	POWER8NVL	/0/78	processor	POWER8NVL
↪ (raw), altivec supported			↪ (raw), altivec supported		
/0/5e	processor	POWER8NVL	/0/79	processor	POWER8NVL
↪ (raw), altivec supported			↪ (raw), altivec supported		
/0/5f	processor	POWER8NVL	/0/7a	processor	POWER8NVL
↪ (raw), altivec supported			↪ (raw), altivec supported		
/0/60	processor	POWER8NVL	/0/7b	processor	POWER8NVL
↪ (raw), altivec supported			↪ (raw), altivec supported		

/0/7c	processor	POWER8NVL
↪ (raw), altivec supported		
/0/7d	processor	POWER8NVL
↪ (raw), altivec supported		
/0/7e	processor	POWER8NVL
↪ (raw), altivec supported		
/0/7f	processor	POWER8NVL
↪ (raw), altivec supported		
/0/80	processor	POWER8NVL
↪ (raw), altivec supported		
/0/81	processor	POWER8NVL
↪ (raw), altivec supported		
/0/82	processor	POWER8NVL
↪ (raw), altivec supported		
/0/83	processor	POWER8NVL
↪ (raw), altivec supported		
/0/84	processor	POWER8NVL
↪ (raw), altivec supported		
/0/85	processor	POWER8NVL
↪ (raw), altivec supported		
/0/86	processor	POWER8NVL
↪ (raw), altivec supported		
/0/87	processor	POWER8NVL
↪ (raw), altivec supported		
/0/88	processor	POWER8NVL
↪ (raw), altivec supported		
/0/89	processor	POWER8NVL
↪ (raw), altivec supported		
/0/8a	processor	POWER8NVL
↪ (raw), altivec supported		
/0/8b	processor	POWER8NVL
↪ (raw), altivec supported		
/0/8c	processor	POWER8NVL
↪ (raw), altivec supported		
/0/8d	processor	POWER8NVL
↪ (raw), altivec supported		
/0/8e	processor	POWER8NVL
↪ (raw), altivec supported		
/0/8f	processor	POWER8NVL
↪ (raw), altivec supported		
/0/90	processor	POWER8NVL
↪ (raw), altivec supported		
/0/91	processor	POWER8NVL
↪ (raw), altivec supported		
/0/92	processor	POWER8NVL
↪ (raw), altivec supported		
/0/93	processor	POWER8NVL
↪ (raw), altivec supported		
/0/94	processor	POWER8NVL
↪ (raw), altivec supported		
/0/95	processor	POWER8NVL
↪ (raw), altivec supported		
/0/96	processor	POWER8NVL
↪ (raw), altivec supported		

/0/97	processor	POWER8NVL
↪ (raw), altivec supported		
/0/98	processor	POWER8NVL
↪ (raw), altivec supported		
/0/99	processor	POWER8NVL
↪ (raw), altivec supported		
/0/9a	processor	POWER8NVL
↪ (raw), altivec supported		
/0/9b	processor	POWER8NVL
↪ (raw), altivec supported		
/0/9c	processor	POWER8NVL
↪ (raw), altivec supported		
/0/9d	processor	POWER8NVL
↪ (raw), altivec supported		
/0/9e	processor	POWER8NVL
↪ (raw), altivec supported		
/0/9f	processor	POWER8NVL
↪ (raw), altivec supported		
/0/a0	processor	POWER8NVL
↪ (raw), altivec supported		
/0/100	bridge	IBM
/0/101	bridge	IBM
/0/102	bridge	IBM
/0/102/0	display	NVIDIA
↪ Corporation		
/0/103	bridge	IBM
/0/103/0	display	NVIDIA
↪ Corporation		
/0/104	bridge	IBM
/0/105	bridge	IBM
/0/106	bridge	IBM
/0/107	bridge	IBM
/0/108	bridge	IBM
/0/109	bridge	IBM
/0/10a	bridge	IBM
/0/10b	bridge	IBM
/0/10c	bridge	IBM
/0/10d	bridge	IBM
/0/10d/0	bridge	PEX 8718
↪ 16-Lane, 5-Port PCI Express Gen 3 (8.0 GT/s)		
↪ Switch		
/0/10d/0/1	bridge	PEX 8718
↪ 16-Lane, 5-Port PCI Express Gen 3 (8.0 GT/s)		
↪ Switch		
/0/10d/0/1/0	bus	TUSB73x0
↪ SuperSpeed USB 3.0 xHCI Host Controller		
/0/10d/0/2	bridge	PEX 8718
↪ 16-Lane, 5-Port PCI Express Gen 3 (8.0 GT/s)		
↪ Switch		
/0/10d/0/2/0	storage	88SE9235 PCIe
↪ 2.0 x2 4-port SATA 6 Gb/s Controller		
/0/10d/0/3	bridge	PEX 8718
↪ 16-Lane, 5-Port PCI Express Gen 3 (8.0 GT/s)		
↪ Switch		

MemXCT: Memory-Centric X-Ray CT Reconstruction with Massive Parallelization

```

/0/10d/0/3/0      bridge      AST1150      LIBRARY_PATH=/soft/compilers/intel/compilers_and_lib
↳ PCI-to-PCI Bridge      raries_2018.1.163/linux/ipp/lib/intel64:/soft/co
/0/10d/0/3/0/0    display      ASPEED      mpilers/intel/compilers_and_libraries_2018.1.163
↳ Graphics Family      /linux/compiler/lib/intel64_lin:/soft/compilers/
/0/10d/0/4        bridge      PEX 8718    intel/compilers_and_libraries_2018.1.163/linux/m
↳ 16-Lane, 5-Port PCI Express Gen 3 (8.0 GT/s)    kl/lib/intel64_lin:/soft/compilers/intel/compile
↳ Switch      rs_and_libraries_2018.1.163/linux/tbb/lib/intel6
/0/10d/0/4/0      enP9p7s0f0    network      NetXtreme    4/gcc4.7:/soft/compilers/intel/compilers_and_lib
↳ BCM5719 Gigabit Ethernet PCIe      raries_2018.1.163/linux/tbb/lib/intel64/gcc4.7:/
/0/10d/0/4/0.1    enP9p7s0f1    network      NetXtreme    soft/compilers/intel/compilers_and_libraries_201
↳ BCM5719 Gigabit Ethernet PCIe      8.1.163/linux/daal/lib/intel64_lin:/soft/compile
/0/10e            bridge      IBM      rs/intel/compilers_and_libraries_2018.1.163/linu
/0/10e/0          display      NVIDIA    x/daal/./tbb/lib/intel64_lin/gcc4.4
↳ Corporation      CONDA_PROMPT_MODIFIER=(base)
/0/10f            bridge      IBM      SSH_TTY=/dev/pts/0
/0/10f/0          display      NVIDIA    VTUNE_AMPLIFIER_XE_2017_DIR=/soft/compilers/intel/vt
↳ Corporation      une_amplifier_xe_2017.4.0.518798
/1                scsi4        storage    QT_GRAPHICSSYSTEM_CHECKED=1
/2                scsi5        storage    USER=USER
/3                scsi6        storage    LD_LIBRARY_PATH=/soft/compilers/intel/compilers_and_
/4                veth60ce576    network    Ethernet    libraries_2018.1.163/linux/compiler/lib/intel64:
↳ interface      /soft/compilers/intel/compilers_and_libraries_20
/5                veth31bcced    network    Ethernet    18.1.163/linux/compiler/lib/intel64_lin:/soft/co
↳ interface      mpilers/intel/compilers_and_libraries_2018.1.163
/0/10f/0          display      NVIDIA    /linux/mpi/intel64/lib:/soft/compilers/intel/com
↳ Corporation      pilers_and_libraries_2018.1.163/linux/mpi/mic/li
/0/10f/0          display      NVIDIA    b:/soft/compilers/intel/compilers_and_libraries_
↳ Corporation      2018.1.163/linux/ipp/lib/intel64:/soft/compilers
/0/10f/0          display      NVIDIA    /intel/compilers_and_libraries_2018.1.163/linux/
↳ Corporation      compiler/lib/intel64_lin:/soft/compilers/intel/c
/0/10f/0          display      NVIDIA    mpilers_and_libraries_2018.1.163/linux/mkl/lib/
↳ Corporation      intel64_lin:/soft/compilers/intel/compilers_and_
/0/10f/0          display      NVIDIA    libraries_2018.1.163/linux/tbb/lib/intel64/gcc4.
↳ Corporation      7:/soft/compilers/intel/compilers_and_libraries_
/0/10f/0          display      NVIDIA    2018.1.163/linux/tbb/lib/intel64/gcc4.7:/soft/co
↳ Corporation      mpilers/intel/debugger_2018/iga/lib:/soft/compil
/0/10f/0          display      NVIDIA    ers/intel/debugger_2018/libipt/intel64/lib:/soft
↳ Corporation      /compilers/intel/compilers_and_libraries_2018.1.
/0/10f/0          display      NVIDIA    163/linux/daal/lib/intel64_lin:/soft/compilers/i
↳ Corporation      ntel/compilers_and_libraries_2018.1.163/linux/da
/0/10f/0          display      NVIDIA    al/./tbb/lib/intel64_lin/gcc4.4:/home/USER/.loc
↳ Corporation      al/lib:
-----
DGX1 System
-----
MKLROOT=/soft/compilers/intel/compilers_and_libraries_
↳ s_2018.1.163/linux/mkl
MANPATH=/soft/compilers/intel/man/common:/soft/compil
↳ lers/intel/compilers_and_libraries_2018.1.163/li
↳ nux/mpi/man:/soft/compilers/intel/documentation_
↳ 2018/en/debugger//gdb-ia/man:/soft/compilers/in
↳ tel/documentation_2018/en/debugger//gdb-igfx/man
↳ /:/usr/local/share/man:/usr/share/man/overrides:
↳ /usr/share/man:
XDG_SESSION_ID=30986
C=mpiicc
HOSTNAME=dgx2.ftm.alcf.anl.gov
INTEL_LICENSE_FILE=/soft/compilers/intel/compilers_a
↳ nd_libraries_2018.1.163/linux/licenses:/opt/inte
↳ l/licenses:/home/USER/intel/licenses
IPPROOT=/soft/compilers/intel/compilers_and_libraries_
↳ s_2018.1.163/linux/ipp
TERM=xterm-256color
SHELL=/bin/bash
HISTSIZE=1000
GDBSERVER_MIC=/soft/compilers/intel/debugger_2018/gd
↳ b/targets/intel64/x200/bin/gdbserver
SSH_CLIEN=10.17.6.11 34972 22
CONDA_SHLVL=1

```

```

LS_COLORS=rs=0:di=38;5;27:ln=38;5;51:mh=44;38;5;15:p
↪ i=40;38;5;11:so=38;5;13:do=38;5;5:bd=48;5;232;38
↪ ;5;11:cd=48;5;232;38;5;3:or=48;5;232;38;5;9:mi=0
↪ 5;48;5;232;38;5;15:su=48;5;196;38;5;15:sg=48;5;1
↪ 1;38;5;16:ca=48;5;196;38;5;226:tw=48;5;10;38;5;1
↪ 6:ow=48;5;10;38;5;21:st=48;5;21;38;5;15:ex=38;5;
↪ 34:*.tar=38;5;9:*.tgz=38;5;9:*.arc=38;5;9:*.arj=
↪ 38;5;9:*.taz=38;5;9:*.lha=38;5;9:*.lz4=38;5;9:*.
↪ lzh=38;5;9:*.lzma=38;5;9:*.tlz=38;5;9:*.txz=38;5
↪ ;9:*.tzo=38;5;9:*.t7z=38;5;9:*.zip=38;5;9:*.z=38
↪ ;5;9:*.Z=38;5;9:*.dz=38;5;9:*.gz=38;5;9:*.lrz=38
↪ ;5;9:*.lz=38;5;9:*.lzo=38;5;9:*.xz=38;5;9:*.bz2=
↪ 38;5;9:*.bz=38;5;9:*.tbz=38;5;9:*.tbz2=38;5;9:*.
↪ tz=38;5;9:*.deb=38;5;9:*.rpm=38;5;9:*.jar=38;5;9
↪ :*.war=38;5;9:*.ear=38;5;9:*.sar=38;5;9:*.rar=38
↪ ;5;9:*.alz=38;5;9:*.ace=38;5;9:*.zoo=38;5;9:*.cp
↪ i=38;5;9:*.7z=38;5;9:*.rz=38;5;9:*.cab=38;5;9:*.
↪ .jpg=38;5;13:*.jpeg=38;5;13:*.gif=38;5;13:*.bmp=
↪ 38;5;13:*.pbm=38;5;13:*.pgm=38;5;13:*.ppm=38;5;1
↪ 3:*.tga=38;5;13:*.xbm=38;5;13:*.xpm=38;5;13:*.ti
↪ f=38;5;13:*.tiff=38;5;13:*.png=38;5;13:*.svg=38;
↪ 5;13:*.svgz=38;5;13:*.mng=38;5;13:*.pcx=38;5;13:
↪ *.mov=38;5;13:*.mpg=38;5;13:*.mpeg=38;5;13:*.m2v
↪ =38;5;13:*.mkv=38;5;13:*.webm=38;5;13:*.ogm=38;5
↪ ;13:*.mp4=38;5;13:*.m4v=38;5;13:*.mp4v=38;5;13:*.
↪ .vob=38;5;13:*.qt=38;5;13:*.nuv=38;5;13:*.wmv=38
↪ ;5;13:*.asf=38;5;13:*.rm=38;5;13:*.rmvb=38;5;13:
↪ *.flc=38;5;13:*.avi=38;5;13:*.fli=38;5;13:*.flv=
↪ 38;5;13:*.gl=38;5;13:*.dl=38;5;13:*.xcf=38;5;13:
↪ *.xwd=38;5;13:*.yuv=38;5;13:*.cgm=38;5;13:*.emf=
↪ 38;5;13:*.axv=38;5;13:*.anx=38;5;13:*.ogv=38;5;1
↪ 3:*.ogx=38;5;13:*.aac=38;5;45:*.au=38;5;45:*.fla
↪ c=38;5;45:*.mid=38;5;45:*.midi=38;5;45:*.mka=38;
↪ 5;45:*.mp3=38;5;45:*.mpc=38;5;45:*.ogg=38;5;45:*.
↪ .ra=38;5;45:*.wav=38;5;45:*.axa=38;5;45:*.oga=38
↪ ;5;45:*.spx=38;5;45:*.xspf=38;5;45:
PSTLROOT=/soft/compilers/intel/compilers_and_librari
↪ es_2018.1.163/linux/pstl
CONDA_EXE=/home/USER/miniconda3/bin/conda
CPATH=/soft/compilers/intel/compilers_and_libraries_
↪ 2018.1.163/linux/ipp/include:/soft/compilers/int
↪ el/compilers_and_libraries_2018.1.163/linux/mkl/
↪ include:/soft/compilers/intel/compilers_and_libr
↪ aries_2018.1.163/linux/pstl/include:/soft/compil
↪ ers/intel/compilers_and_libraries_2018.1.163/lin
↪ ux/tbb/include:/soft/compilers/intel/compilers_a
↪ nd_libraries_2018.1.163/linux/tbb/include:/soft/
↪ compilers/intel/compilers_and_libraries_2018.1.1
↪ 63/linux/daal/include
NLSPATH=/soft/compilers/intel/compilers_and_librarie
↪ s_2018.1.163/linux/compiler/lib/intel64/locale/%
↪ l_%t/%N:/soft/compilers/intel/compilers_and_libr
↪ aries_2018.1.163/linux/mkl/lib/intel64_lin/local
↪ e/%l_%t/%N:/soft/compilers/intel/debugger_2018/g
↪ db/intel64/share/locale/%l_%t/%N
MAIL=/var/spool/mail/USER

```

```

PATH=/home/USER/miniconda3/bin:/home/USER/miniconda3
↪ /condabin:/home/USER/miniconda3/bin:/soft/compil
↪ ers/cuda/cuda-10.0.130/bin:/soft/compilers/intel
↪ /vtune_amplifier_xe_2017.4.0.518798/bin64:/soft/
↪ compilers/intel/compilers_and_libraries_2018.1.1
↪ 63/linux/bin/intel64:/soft/compilers/intel/compil
↪ ers_and_libraries_2018.1.163/linux/mpi/intel64/
↪ bin:/usr/local/bin:/usr/bin:/usr/local/sbin:/usr
↪ /sbin:/usr/lpp/mmfs/bin:/home/USER/bin
CUDA_BIN_PATH=/soft/compilers/cuda/cuda-10.0.130/bin
CONDA_PREFIX=/home/USER/miniconda3
TBBROOT=/soft/compilers/intel/compilers_and_librarie
↪ s_2018.1.163/linux/tbb
PWD=/home/USER
XMODIFIERS=@im=none
GDB_CROSS=/soft/compilers/intel/debugger_2018/gdb/in
↪ tel64/bin/gdb-ia
LANG=en_US.UTF-8
MODULEPATH=/usr/share/Modules/modulefiles:/etc/modul
↪ efiles
LOADED_MODULES=
COBALT_JOBID=81880
DAALROOT=/soft/compilers/intel/compilers_and_librari
↪ es_2018.1.163/linux/daal
COBALT_NODEFILE=/var/tmp/cobalt.81880
MPM_LAUNCHER=/soft/compilers/intel/debugger_2018/mpm
↪ /mic/bin/start_mpm.sh
HISTCONTROL=ignoredups
INTEL_PYTHONHOME=/soft/compilers/intel/debugger_2018
↪ /python/intel64/
SHLVL=1
HOME=/home/USER
CONDA_PYTHON_EXE=/home/USER/miniconda3/bin/python
LOGNAME=USER
CVS_RSH=ssh
CLASSPATH=/soft/compilers/intel/compilers_and_librar
↪ ies_2018.1.163/linux/mpi/intel64/lib/mpi.jar:/so
↪ ft/compilers/intel/compilers_and_libraries_2018.
↪ 1.163/linux/daal/lib/daal.jar
SSH_CONNECTION=10.17.6.11 34972 10.17.6.20 22
FORTRAN=mpiifort
MODULESHOME=/usr/share/Modules
CONDA_DEFAULT_ENV=base
PKG_CONFIG_PATH=/soft/compilers/intel/compilers_and_
↪ libraries_2018.1.163/linux/mkl/bin/pkgconfig
LESSOPEN=||/usr/bin/lesspipe.sh %s
INFOPATH=/soft/compilers/intel/documentation_2018/en
↪ /debugger//gdb-ia/info:/soft/compilers/intel/do
↪ cumentation_2018/en/debugger//gdb-igfx/info/
CC=mpiicpc
XDG_RUNTIME_DIR=/run/user/6823
I_MPI_ROOT=/soft/compilers/intel/compilers_and_libra
↪ ries_2018.1.163/linux/mpi
BASH_FUNC_module()=( ) { eval ` /usr/bin/modulecmd
↪ bash $* `
}

```


MemXCT: Memory-Centric X-Ray CT Reconstruction with Massive Parallelization

```

_=/usr/bin/env
++ lsb_release -a
-bash: lsb_release: command not found
++ uname -a
Linux dgx2.ftm.alcf.anl.gov
↳ 3.10.0-862.14.4.el7.x86_64 #1 SMP Fri Sep 21
↳ 09:07:21 UTC 2018 x86_64 x86_64 x86_64 GNU/Linux
++ lscpu
Architecture:          x86_64
CPU op-mode(s):        32-bit, 64-bit
Byte Order:            Little Endian
CPU(s):                80
On-line CPU(s) list:   0-79
Thread(s) per core:    2
Core(s) per socket:    20
Socket(s):             2
NUMA node(s):         2
Vendor ID:             GenuineIntel
CPU family:            6
Model:                79
Model name:            Intel(R) Xeon(R) CPU E5-2698 v4
↳ @ 2.20GHz
Stepping:              1
CPU MHz:               2201.000
CPU max MHz:           2201.0000
CPU min MHz:           1200.0000
BogoMIPS:              4389.88
Virtualization:        VT-x
L1d cache:             32K
L1i cache:             32K
L2 cache:              256K
L3 cache:              51200K
NUMA node0 CPU(s):    0-19,40-59
NUMA node1 CPU(s):    20-39,60-79
Flags:                 fpu vme de pse tsc msr pae mce
↳ cx8 apic sep mtrr pge mca cmov pat pse36 clflush
↳ dts acpi mmx fxsr sse sse2 ss ht tm pbe syscall nx
↳ pdpe1gb rdtscp lm constant_tsc arch_perfmon pebs
↳ bts rep_good nopl xtopology nonstop_tsc
↳ aperfmperf eagerfpu pni pclmulqdq dtes64 monitor
↳ ds_cpl vmx smx est tm2 ssse3 sdbg fma cx16 xtpr
↳ pdcm pcid dca sse4_1 sse4_2 x2apic movbe popcnt
↳ aes xsave avx f16c rdrand lahf_lm abm
↳ 3dnowprefetch epb cat_l3 cdp_l3 intel_ppin
↳ intel_pt tpr_shadow vnm1 flexpriority ept vpid
↳ fsgsbase tsc_adjust bmi1 hle avx2 smep bmi2 erms
↳ invpcid rtm cqm rdt_a rdseed adx smap xsaveopt
↳ cqm_llc cqm_occup_llc cqm_mbm_total cqm_mbm_local
↳ dtherm ida arat pln pts
++ cat /proc/meminfo
MemTotal:              528274612 kB
MemFree:               174588504 kB
MemAvailable:          317342816 kB
Buffers:               0 kB
Cached:                344224252 kB
SwapCached:            0 kB

```

```

Active:                186590996 kB
Inactive:              157910984 kB
Active(anon):          136746080 kB
Inactive(anon):        65139676 kB
Active(file):          49844916 kB
Inactive(file):        92771308 kB
Unevictable:           1048576 kB
Mlocked:               1048576 kB
SwapTotal:             0 kB
SwapFree:              0 kB
Dirty:                 0 kB
Writeback:             0 kB
AnonPages:             1326424 kB
Mapped:                387672 kB
Shmem:                 201608028 kB
Slab:                  2279420 kB
SReclaimable:          1538320 kB
SUnreclaim:            741100 kB
KernelStack:           17648 kB
PageTables:            11088 kB
NFS_Unstable:          0 kB
Bounce:                0 kB
WritebackTmp:          0 kB
CommitLimit:           264137304 kB
Committed_AS:          203107540 kB
VmallocTotal:          34359738367 kB
VmallocUsed:           1698416 kB
VmallocChunk:          34089242576 kB
HardwareCorrupted:     0 kB
AnonHugePages:         1091584 kB
CmaTotal:              0 kB
CmaFree:               0 kB
HugePages_Total:       0
HugePages_Free:        0
HugePages_Rsvd:        0
HugePages_Surp:        0
Hugepagesize:          2048 kB
DirectMap4k:           72067496 kB
DirectMap2M:           456302592 kB
DirectMap1G:           10485760 kB
++ inxi -F -c0
-bash: inxi: command not found
++ lsblk -a
NAME MAJ:MIN RM SIZE RO TYPE MOUNTPOINT
sda 8:0 0 446.6G 0 disk
└─sda1 8:1 0 121.8M 0 part
└─sda2 8:2 0 446.5G 0 part
sdb 8:16 0 7T 0 disk
└─sdb1 8:17 0 7T 0 part
loop0 7:0 0 1 loop
++ lsscsi -s
[10:0:20:0] enclosu NVIDIA DGX-1 0600 -
↳ -
[10:2:0:0] disk AVAGO MRROMB 4.66
↳ /dev/sda 479GB

```

```
[10:2:1:0] disk AVAGO MRROMB 4.66
↳ /dev/sdb 7.67TB
++ module list
+++ /usr/bin/modulecmd bash list
No Modulefiles Currently Loaded.
++ eval
++ nvidia-smi
Wed Apr 10 08:22:53 2019

+-----+
| NVIDIA-SMI 410.48 Driver Version:
| 410.48 |
+-----+
| GPU Name Persistence-M| Bus-Id Disp.A
| Volatile Uncorr. ECC |
| Fan Temp Perf Pwr:Usage/Cap| Memory-Usage
| GPU-Util Compute M. |
+-----+
| 0 Tesla V100-SXM2... On | 00000000:06:00.0 Off
| N/A 31C P0 43W / 300W | 0MiB / 16130MiB
| 0% Default |
+-----+
| 1 Tesla V100-SXM2... On | 00000000:07:00.0 Off
| N/A 33C P0 43W / 300W | 0MiB / 16130MiB
| 0% Default |
+-----+
| 2 Tesla V100-SXM2... On | 00000000:0A:00.0 Off
| N/A 35C P0 45W / 300W | 0MiB / 16130MiB
| 0% Default |
+-----+
| 3 Tesla V100-SXM2... On | 00000000:0B:00.0 Off
| N/A 32C P0 41W / 300W | 0MiB / 16130MiB
| 0% Default |
+-----+
| 4 Tesla V100-SXM2... On | 00000000:85:00.0 Off
| N/A 35C P0 42W / 300W | 0MiB / 16130MiB
| 0% Default |
+-----+
| 5 Tesla V100-SXM2... On | 00000000:86:00.0 Off
| N/A 36C P0 43W / 300W | 0MiB / 16130MiB
| 0% Default |
```

```
+-----+
| 6 Tesla V100-SXM2... On | 00000000:89:00.0 Off
| N/A 37C P0 43W / 300W | 0MiB / 16130MiB
| 0% Default |
+-----+
| 7 Tesla V100-SXM2... On | 00000000:8A:00.0 Off
| N/A 33C P0 44W / 300W | 0MiB / 16130MiB
| 0% Default |
+-----+

+-----+
| Processes:
| GPU Memory |
| GPU PID Type Process name
| Usage |
+-----+
| No running processes found
+-----+

++ cat
++ lshw -short -quiet -sanitize
-bash: lshw: command not found
++ lspci
00:00.0 Host bridge: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D DMI2 (rev 01)
00:01.0 PCI bridge: Intel Corporation Xeon E7 v4/Xeon
↳ E5 v4/Xeon E3 v4/Xeon D PCI Express Root Port 1
↳ (rev 01)
00:02.0 PCI bridge: Intel Corporation Xeon E7 v4/Xeon
↳ E5 v4/Xeon E3 v4/Xeon D PCI Express Root Port 2
↳ (rev 01)
00:03.0 PCI bridge: Intel Corporation Xeon E7 v4/Xeon
↳ E5 v4/Xeon E3 v4/Xeon D PCI Express Root Port 3
↳ (rev 01)
00:05.0 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D
↳ Map/VTd_Misc/System Management (rev 01)
00:05.1 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D IIO Hot Plug (rev
↳ 01)
00:05.2 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D IIO RAS/Control
↳ Status/Global Errors (rev 01)
00:05.4 PIC: Intel Corporation Xeon E7 v4/Xeon E5
↳ v4/Xeon E3 v4/Xeon D I/O APIC (rev 01)
00:11.0 Unassigned class [ff00]: Intel Corporation
↳ C610/X99 series chipset SPSR (rev 05)
```

MemXCT: Memory-Centric X-Ray CT Reconstruction with Massive Parallelization

00:11.4 SATA controller: Intel Corporation C610/X99
↳ series chipset sSATA Controller [AHCI mode] (rev 05)
00:16.0 Communication controller: Intel Corporation
↳ C610/X99 series chipset MEI Controller #1 (rev 05)
00:16.1 Communication controller: Intel Corporation
↳ C610/X99 series chipset MEI Controller #2 (rev 05)
00:1a.0 USB controller: Intel Corporation C610/X99
↳ series chipset USB Enhanced Host Controller #2
↳ (rev 05)
00:1c.0 PCI bridge: Intel Corporation C610/X99 series
↳ chipset PCI Express Root Port #1 (rev d5)
00:1d.0 USB controller: Intel Corporation C610/X99
↳ series chipset USB Enhanced Host Controller #1
↳ (rev 05)
00:1f.0 ISA bridge: Intel Corporation C610/X99 series
↳ chipset LPC Controller (rev 05)
00:1f.2 SATA controller: Intel Corporation C610/X99
↳ series chipset 6-Port SATA Controller [AHCI mode]
↳ (rev 05)
00:1f.3 SMBus: Intel Corporation C610/X99 series
↳ chipset SMBus Controller (rev 05)
00:1f.6 Signal processing controller: Intel
↳ Corporation C610/X99 series chipset Thermal
↳ Subsystem (rev 05)
01:00.0 Ethernet controller: Intel Corporation
↳ Ethernet Controller 10-Gigabit X540-AT2 (rev 01)
01:00.1 Ethernet controller: Intel Corporation
↳ Ethernet Controller 10-Gigabit X540-AT2 (rev 01)
03:00.0 PCI bridge: PLX Technology, Inc. Device 8764
↳ (rev ab)
04:04.0 PCI bridge: PLX Technology, Inc. Device 8764
↳ (rev ab)
04:08.0 PCI bridge: PLX Technology, Inc. Device 8764
↳ (rev ab)
04:0c.0 PCI bridge: PLX Technology, Inc. Device 8764
↳ (rev ab)
05:00.0 Infiniband controller: Mellanox Technologies
↳ MT27700 Family [ConnectX-4]
06:00.0 3D controller: NVIDIA Corporation GV100GL
↳ [Tesla V100 SXM2] (rev a1)
07:00.0 3D controller: NVIDIA Corporation GV100GL
↳ [Tesla V100 SXM2] (rev a1)
08:00.0 PCI bridge: PLX Technology, Inc. Device 8780
↳ (rev ab)
09:04.0 PCI bridge: PLX Technology, Inc. Device 8780
↳ (rev ab)
09:08.0 PCI bridge: PLX Technology, Inc. Device 8780
↳ (rev ab)
09:0c.0 PCI bridge: PLX Technology, Inc. Device 8780
↳ (rev ab)
09:10.0 PCI bridge: PLX Technology, Inc. Device 8780
↳ (rev ab)
09:11.0 PCI bridge: PLX Technology, Inc. Device 8780
↳ (rev ab)
09:12.0 PCI bridge: PLX Technology, Inc. Device 8780
↳ (rev ab)
09:13.0 PCI bridge: PLX Technology, Inc. Device 8780
↳ (rev ab)
0a:00.0 3D controller: NVIDIA Corporation GV100GL
↳ [Tesla V100 SXM2] (rev a1)
0b:00.0 3D controller: NVIDIA Corporation GV100GL
↳ [Tesla V100 SXM2] (rev a1)
0c:00.0 Infiniband controller: Mellanox Technologies
↳ MT27700 Family [ConnectX-4]
11:00.0 PCI bridge: ASPEED Technology, Inc. AST1150
↳ PCI-to-PCI Bridge (rev 03)
12:00.0 VGA compatible controller: ASPEED Technology,
↳ Inc. ASPEED Graphics Family (rev 30)
7f:08.0 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D QPI Link 0 (rev 01)
7f:08.2 Performance counters: Intel Corporation Xeon
↳ E7 v4/Xeon E5 v4/Xeon E3 v4/Xeon D QPI Link 0 (rev 01)
7f:08.3 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D QPI Link 0 (rev 01)
7f:09.0 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D QPI Link 1 (rev 01)
7f:09.2 Performance counters: Intel Corporation Xeon
↳ E7 v4/Xeon E5 v4/Xeon E3 v4/Xeon D QPI Link 1 (rev 01)
7f:09.3 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D QPI Link 1 (rev 01)
7f:0b.0 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D R3 QPI Link 0/1
↳ (rev 01)
7f:0b.1 Performance counters: Intel Corporation Xeon
↳ E7 v4/Xeon E5 v4/Xeon E3 v4/Xeon D R3 QPI Link 0/1
↳ (rev 01)
7f:0b.2 Performance counters: Intel Corporation Xeon
↳ E7 v4/Xeon E5 v4/Xeon E3 v4/Xeon D R3 QPI Link 0/1
↳ (rev 01)
7f:0b.3 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D R3 QPI Link Debug
↳ (rev 01)
7f:0c.0 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Caching Agent (rev 01)
7f:0c.1 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Caching Agent (rev 01)
7f:0c.2 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Caching Agent (rev 01)
7f:0c.3 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Caching Agent (rev 01)

7f:0c.4 System peripheral: Intel Corporation Xeon E7
 ↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Caching Agent (rev
 ↳ 01)

7f:0c.5 System peripheral: Intel Corporation Xeon E7
 ↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Caching Agent (rev
 ↳ 01)

7f:0c.6 System peripheral: Intel Corporation Xeon E7
 ↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Caching Agent (rev
 ↳ 01)

7f:0c.7 System peripheral: Intel Corporation Xeon E7
 ↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Caching Agent (rev
 ↳ 01)

7f:0d.0 System peripheral: Intel Corporation Xeon E7
 ↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Caching Agent (rev
 ↳ 01)

7f:0d.1 System peripheral: Intel Corporation Xeon E7
 ↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Caching Agent (rev
 ↳ 01)

7f:0d.2 System peripheral: Intel Corporation Xeon E7
 ↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Caching Agent (rev
 ↳ 01)

7f:0d.3 System peripheral: Intel Corporation Xeon E7
 ↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Caching Agent (rev
 ↳ 01)

7f:0d.4 System peripheral: Intel Corporation Xeon E7
 ↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Caching Agent (rev
 ↳ 01)

7f:0d.5 System peripheral: Intel Corporation Xeon E7
 ↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Caching Agent (rev
 ↳ 01)

7f:0d.6 System peripheral: Intel Corporation Xeon E7
 ↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Caching Agent (rev
 ↳ 01)

7f:0d.7 System peripheral: Intel Corporation Xeon E7
 ↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Caching Agent (rev
 ↳ 01)

7f:0e.0 System peripheral: Intel Corporation Xeon E7
 ↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Caching Agent (rev
 ↳ 01)

7f:0e.1 System peripheral: Intel Corporation Xeon E7
 ↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Caching Agent (rev
 ↳ 01)

7f:0e.2 Unassigned class [ffff]: Intel Corporation
 ↳ Device 6ff2 (rev 01)

7f:0e.3 Unassigned class [ffff]: Intel Corporation
 ↳ Device 6ff3 (rev 01)

7f:0f.0 System peripheral: Intel Corporation Xeon E7
 ↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Caching Agent (rev
 ↳ 01)

7f:0f.1 System peripheral: Intel Corporation Xeon E7
 ↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Caching Agent (rev
 ↳ 01)

7f:0f.2 System peripheral: Intel Corporation Xeon E7
 ↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Caching Agent (rev
 ↳ 01)

7f:0f.3 System peripheral: Intel Corporation Xeon E7
 ↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Caching Agent (rev
 ↳ 01)

7f:0f.4 System peripheral: Intel Corporation Xeon E7
 ↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Caching Agent (rev
 ↳ 01)

7f:0f.5 System peripheral: Intel Corporation Xeon E7
 ↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Caching Agent (rev
 ↳ 01)

7f:0f.6 System peripheral: Intel Corporation Xeon E7
 ↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Caching Agent (rev
 ↳ 01)

7f:10.0 System peripheral: Intel Corporation Xeon E7
 ↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D R2PCIe Agent (rev
 ↳ 01)

7f:10.1 Performance counters: Intel Corporation Xeon
 ↳ E7 v4/Xeon E5 v4/Xeon E3 v4/Xeon D R2PCIe Agent
 ↳ (rev 01)

7f:10.5 System peripheral: Intel Corporation Xeon E7
 ↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Ubox (rev 01)

7f:10.6 Performance counters: Intel Corporation Xeon
 ↳ E7 v4/Xeon E5 v4/Xeon E3 v4/Xeon D Ubox (rev 01)

7f:10.7 System peripheral: Intel Corporation Xeon E7
 ↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Ubox (rev 01)

7f:12.0 System peripheral: Intel Corporation Xeon E7
 ↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Home Agent 0 (rev
 ↳ 01)

7f:12.1 Performance counters: Intel Corporation Xeon
 ↳ E7 v4/Xeon E5 v4/Xeon E3 v4/Xeon D Home Agent 0
 ↳ (rev 01)

7f:12.2 System peripheral: Intel Corporation Xeon E7
 ↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Home Agent 0 Debug
 ↳ (rev 01)

7f:12.4 System peripheral: Intel Corporation Xeon E7
 ↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Home Agent 1 (rev
 ↳ 01)

7f:12.5 Performance counters: Intel Corporation Xeon
 ↳ E7 v4/Xeon E5 v4/Xeon E3 v4/Xeon D Home Agent 1
 ↳ (rev 01)

7f:12.6 System peripheral: Intel Corporation Xeon E7
 ↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Home Agent 1 Debug
 ↳ (rev 01)

7f:13.0 System peripheral: Intel Corporation Xeon E7
 ↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Memory Controller
 ↳ 0 - Target Address/Thermal/RAS (rev 01)

7f:13.1 System peripheral: Intel Corporation Xeon E7
 ↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Memory Controller
 ↳ 0 - Target Address/Thermal/RAS (rev 01)

7f:13.2 System peripheral: Intel Corporation Xeon E7
 ↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Memory Controller
 ↳ 0 - Channel Target Address Decoder (rev 01)

7f:13.3 System peripheral: Intel Corporation Xeon E7
 ↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Memory Controller
 ↳ 0 - Channel Target Address Decoder (rev 01)

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7f:13.6 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D DDRIO Channel 0/1
↳ Broadcast (rev 01)

7f:13.7 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D DDRIO Global
↳ Broadcast (rev 01)

7f:14.0 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Memory Controller
↳ 0 - Channel 0 Thermal Control (rev 01)

7f:14.1 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Memory Controller
↳ 0 - Channel 1 Thermal Control (rev 01)

7f:14.2 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Memory Controller
↳ 0 - Channel 0 Error (rev 01)

7f:14.3 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Memory Controller
↳ 0 - Channel 1 Error (rev 01)

7f:14.4 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D DDRIO Channel 0/1
↳ Interface (rev 01)

7f:14.5 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D DDRIO Channel 0/1
↳ Interface (rev 01)

7f:14.6 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D DDRIO Channel 0/1
↳ Interface (rev 01)

7f:14.7 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D DDRIO Channel 0/1
↳ Interface (rev 01)

7f:16.0 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Target
↳ Address/Thermal/RAS (rev 01)

7f:16.1 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Target
↳ Address/Thermal/RAS (rev 01)

7f:16.2 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Channel Target
↳ Address Decoder (rev 01)

7f:16.3 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Channel Target
↳ Address Decoder (rev 01)

7f:16.6 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D DDRIO Channel 2/3
↳ Broadcast (rev 01)

7f:16.7 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D DDRIO Global
↳ Broadcast (rev 01)

7f:17.0 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Memory Controller
↳ 1 - Channel 0 Thermal Control (rev 01)

7f:17.1 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Memory Controller
↳ 1 - Channel 1 Thermal Control (rev 01)

7f:17.2 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Memory Controller
↳ 1 - Channel 0 Error (rev 01)

7f:17.3 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Memory Controller
↳ 1 - Channel 1 Error (rev 01)

7f:17.4 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D DDRIO Channel 2/3
↳ Interface (rev 01)

7f:17.5 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D DDRIO Channel 2/3
↳ Interface (rev 01)

7f:17.6 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D DDRIO Channel 2/3
↳ Interface (rev 01)

7f:17.7 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D DDRIO Channel 2/3
↳ Interface (rev 01)

7f:1e.0 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Power Control Unit
↳ (rev 01)

7f:1e.1 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Power Control Unit
↳ (rev 01)

7f:1e.2 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Power Control Unit
↳ (rev 01)

7f:1e.3 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Power Control Unit
↳ (rev 01)

7f:1e.4 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Power Control Unit
↳ (rev 01)

7f:1f.0 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Power Control Unit
↳ (rev 01)

7f:1f.2 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Power Control Unit
↳ (rev 01)

80:01.0 PCI bridge: Intel Corporation Xeon E7 v4/Xeon
↳ E5 v4/Xeon E3 v4/Xeon D PCI Express Root Port 1
↳ (rev 01)

80:02.0 PCI bridge: Intel Corporation Xeon E7 v4/Xeon
↳ E5 v4/Xeon E3 v4/Xeon D PCI Express Root Port 2
↳ (rev 01)

80:03.0 PCI bridge: Intel Corporation Xeon E7 v4/Xeon
↳ E5 v4/Xeon E3 v4/Xeon D PCI Express Root Port 3
↳ (rev 01)

80:05.0 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D
↳ Map/VTd_Misc/System Management (rev 01)

80:05.1 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D IIO Hot Plug (rev
↳ 01)

80:05.2 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D IIO RAS/Control
↳ Status/Global Errors (rev 01)

80:05.4 PIC: Intel Corporation Xeon E7 v4/Xeon E5
↳ v4/Xeon E3 v4/Xeon D I/O APIC (rev 01)

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81:00.0 RAID bus controller: LSI Logic / Symbios Logic
↳ MegaRAID SAS-3 3108 [Invader] (rev 02)
82:00.0 PCI bridge: PLX Technology, Inc. Device 8764
↳ (rev ab)
83:04.0 PCI bridge: PLX Technology, Inc. Device 8764
↳ (rev ab)
83:08.0 PCI bridge: PLX Technology, Inc. Device 8764
↳ (rev ab)
83:0c.0 PCI bridge: PLX Technology, Inc. Device 8764
↳ (rev ab)
84:00.0 Infiniband controller: Mellanox Technologies
↳ MT27700 Family [ConnectX-4]
85:00.0 3D controller: NVIDIA Corporation GV100GL
↳ [Tesla V100 SXM2] (rev a1)
86:00.0 3D controller: NVIDIA Corporation GV100GL
↳ [Tesla V100 SXM2] (rev a1)
87:00.0 PCI bridge: PLX Technology, Inc. Device 8780
↳ (rev ab)
88:04.0 PCI bridge: PLX Technology, Inc. Device 8780
↳ (rev ab)
88:08.0 PCI bridge: PLX Technology, Inc. Device 8780
↳ (rev ab)
88:0c.0 PCI bridge: PLX Technology, Inc. Device 8780
↳ (rev ab)
88:10.0 PCI bridge: PLX Technology, Inc. Device 8780
↳ (rev ab)
88:11.0 PCI bridge: PLX Technology, Inc. Device 8780
↳ (rev ab)
88:12.0 PCI bridge: PLX Technology, Inc. Device 8780
↳ (rev ab)
88:13.0 PCI bridge: PLX Technology, Inc. Device 8780
↳ (rev ab)
89:00.0 3D controller: NVIDIA Corporation GV100GL
↳ [Tesla V100 SXM2] (rev a1)
8a:00.0 3D controller: NVIDIA Corporation GV100GL
↳ [Tesla V100 SXM2] (rev a1)
8b:00.0 Infiniband controller: Mellanox Technologies
↳ MT27700 Family [ConnectX-4]
ff:08.0 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D QPI Link 0 (rev
↳ 01)
ff:08.2 Performance counters: Intel Corporation Xeon
↳ E7 v4/Xeon E5 v4/Xeon E3 v4/Xeon D QPI Link 0 (rev
↳ 01)
ff:08.3 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D QPI Link 0 (rev
↳ 01)
ff:09.0 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D QPI Link 1 (rev
↳ 01)
ff:09.2 Performance counters: Intel Corporation Xeon
↳ E7 v4/Xeon E5 v4/Xeon E3 v4/Xeon D QPI Link 1 (rev
↳ 01)
ff:09.3 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D QPI Link 1 (rev
↳ 01)
ff:0b.0 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D R3 QPI Link 0/1
↳ (rev 01)
ff:0b.1 Performance counters: Intel Corporation Xeon
↳ E7 v4/Xeon E5 v4/Xeon E3 v4/Xeon D R3 QPI Link 0/1
↳ (rev 01)
ff:0b.2 Performance counters: Intel Corporation Xeon
↳ E7 v4/Xeon E5 v4/Xeon E3 v4/Xeon D R3 QPI Link 0/1
↳ (rev 01)
ff:0b.3 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D R3 QPI Link Debug
↳ (rev 01)
ff:0c.0 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Caching Agent (rev
↳ 01)
ff:0c.1 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Caching Agent (rev
↳ 01)
ff:0c.2 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Caching Agent (rev
↳ 01)
ff:0c.3 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Caching Agent (rev
↳ 01)
ff:0c.4 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Caching Agent (rev
↳ 01)
ff:0c.5 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Caching Agent (rev
↳ 01)
ff:0c.6 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Caching Agent (rev
↳ 01)
ff:0c.7 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Caching Agent (rev
↳ 01)
ff:0d.0 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Caching Agent (rev
↳ 01)
ff:0d.1 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Caching Agent (rev
↳ 01)
ff:0d.2 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Caching Agent (rev
↳ 01)
ff:0d.3 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Caching Agent (rev
↳ 01)
ff:0d.4 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Caching Agent (rev
↳ 01)
ff:0d.5 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Caching Agent (rev
↳ 01)

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ff:0d.6 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Caching Agent (rev 01)

ff:0d.7 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Caching Agent (rev 01)

ff:0e.0 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Caching Agent (rev 01)

ff:0e.1 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Caching Agent (rev 01)

ff:0e.2 Unassigned class [ffff]: Intel Corporation
↳ Device 6ff2 (rev 01)

ff:0e.3 Unassigned class [ffff]: Intel Corporation
↳ Device 6ff3 (rev 01)

ff:0f.0 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Caching Agent (rev 01)

ff:0f.1 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Caching Agent (rev 01)

ff:0f.2 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Caching Agent (rev 01)

ff:0f.3 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Caching Agent (rev 01)

ff:0f.4 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Caching Agent (rev 01)

ff:0f.5 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Caching Agent (rev 01)

ff:0f.6 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Caching Agent (rev 01)

ff:10.0 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D R2PCIe Agent (rev 01)

ff:10.1 Performance counters: Intel Corporation Xeon
↳ E7 v4/Xeon E5 v4/Xeon E3 v4/Xeon D R2PCIe Agent (rev 01)

ff:10.5 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Ubox (rev 01)

ff:10.6 Performance counters: Intel Corporation Xeon
↳ E7 v4/Xeon E5 v4/Xeon E3 v4/Xeon D Ubox (rev 01)

ff:10.7 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Ubox (rev 01)

ff:12.0 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Home Agent 0 (rev 01)

ff:12.1 Performance counters: Intel Corporation Xeon
↳ E7 v4/Xeon E5 v4/Xeon E3 v4/Xeon D Home Agent 0 (rev 01)

ff:12.2 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Home Agent 0 Debug (rev 01)

ff:12.4 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Home Agent 1 (rev 01)

ff:12.5 Performance counters: Intel Corporation Xeon
↳ E7 v4/Xeon E5 v4/Xeon E3 v4/Xeon D Home Agent 1 (rev 01)

ff:12.6 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Home Agent 1 Debug (rev 01)

ff:13.0 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Memory Controller
↳ 0 - Target Address/Thermal/RAS (rev 01)

ff:13.1 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Memory Controller
↳ 0 - Target Address/Thermal/RAS (rev 01)

ff:13.2 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Memory Controller
↳ 0 - Channel Target Address Decoder (rev 01)

ff:13.3 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Memory Controller
↳ 0 - Channel Target Address Decoder (rev 01)

ff:13.6 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D DDRIO Channel 0/1
↳ Broadcast (rev 01)

ff:13.7 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D DDRIO Global
↳ Broadcast (rev 01)

ff:14.0 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Memory Controller
↳ 0 - Channel 0 Thermal Control (rev 01)

ff:14.1 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Memory Controller
↳ 0 - Channel 1 Thermal Control (rev 01)

ff:14.2 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Memory Controller
↳ 0 - Channel 0 Error (rev 01)

ff:14.3 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Memory Controller
↳ 0 - Channel 1 Error (rev 01)

ff:14.4 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D DDRIO Channel 0/1
↳ Interface (rev 01)

ff:14.5 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D DDRIO Channel 0/1
↳ Interface (rev 01)

ff:14.6 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D DDRIO Channel 0/1
↳ Interface (rev 01)

ff:14.7 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D DDRIO Channel 0/1
↳ Interface (rev 01)

ff:16.0 System peripheral: Intel Corporation Xeon E7
↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Target
↳ Address/Thermal/RAS (rev 01)

ff:16.1 System peripheral: Intel Corporation Xeon E7
 ↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Target
 ↳ Address/Thermal/RAS (rev 01)

ff:16.2 System peripheral: Intel Corporation Xeon E7
 ↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Channel Target
 ↳ Address Decoder (rev 01)

ff:16.3 System peripheral: Intel Corporation Xeon E7
 ↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Channel Target
 ↳ Address Decoder (rev 01)

ff:16.6 System peripheral: Intel Corporation Xeon E7
 ↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D DDRIO Channel 2/3
 ↳ Broadcast (rev 01)

ff:16.7 System peripheral: Intel Corporation Xeon E7
 ↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D DDRIO Global
 ↳ Broadcast (rev 01)

ff:17.0 System peripheral: Intel Corporation Xeon E7
 ↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Memory Controller
 ↳ 1 - Channel 0 Thermal Control (rev 01)

ff:17.1 System peripheral: Intel Corporation Xeon E7
 ↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Memory Controller
 ↳ 1 - Channel 1 Thermal Control (rev 01)

ff:17.2 System peripheral: Intel Corporation Xeon E7
 ↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Memory Controller
 ↳ 1 - Channel 0 Error (rev 01)

ff:17.3 System peripheral: Intel Corporation Xeon E7
 ↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Memory Controller
 ↳ 1 - Channel 1 Error (rev 01)

ff:17.4 System peripheral: Intel Corporation Xeon E7
 ↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D DDRIO Channel 2/3
 ↳ Interface (rev 01)

ff:17.5 System peripheral: Intel Corporation Xeon E7
 ↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D DDRIO Channel 2/3
 ↳ Interface (rev 01)

ff:17.6 System peripheral: Intel Corporation Xeon E7
 ↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D DDRIO Channel 2/3
 ↳ Interface (rev 01)

ff:17.7 System peripheral: Intel Corporation Xeon E7
 ↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D DDRIO Channel 2/3
 ↳ Interface (rev 01)

ff:1e.0 System peripheral: Intel Corporation Xeon E7
 ↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Power Control Unit
 ↳ (rev 01)

ff:1e.1 System peripheral: Intel Corporation Xeon E7
 ↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Power Control Unit
 ↳ (rev 01)

ff:1e.2 System peripheral: Intel Corporation Xeon E7
 ↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Power Control Unit
 ↳ (rev 01)

ff:1e.3 System peripheral: Intel Corporation Xeon E7
 ↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Power Control Unit
 ↳ (rev 01)

ff:1e.4 System peripheral: Intel Corporation Xeon E7
 ↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Power Control Unit
 ↳ (rev 01)

ff:1f.0 System peripheral: Intel Corporation Xeon E7
 ↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Power Control Unit
 ↳ (rev 01)

ff:1f.2 System peripheral: Intel Corporation Xeon E7
 ↳ v4/Xeon E5 v4/Xeon E3 v4/Xeon D Power Control Unit
 ↳ (rev 01)

ARTIFACT EVALUATION

Verification and validation studies: We ran our tests several times on each cluster/system and presented the performance results. We evaluated our approaches on five different systems, each with different accelerator and scale. Our results were consistent in each run.

Accuracy and precision of timings: MPI timings (with and without barriers) are used for timings. Several runs are performed.

Quantified the sensitivity of results to initial conditions and/or parameters of the computational environment: We have checked the residual and error norms for each iteration at each run. We evaluated if our system and parallelization methods (with conjugate gradient approach) have any effect on convergence to the solution.

Controls, statistics, or other steps taken to make the measurements and analyses robust to variability and unknowns in the system. Our compute resources were explicitly allocated during the system evaluation; therefore, there should be minimum noise in terms of computation performance evaluation. The network resources were shared within cluster, thus there might be some network contention that we couldn't profile. However, all tests were run several times and no anomalies had been observed.