Karlsruhe Institute of Technology
European Synchrotron Radiation Facility

A GPU-based Architecture for Real-Time Data Assessment at Synchrotron Experiments

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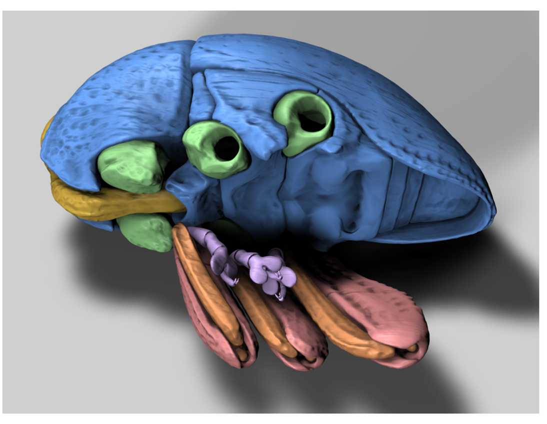
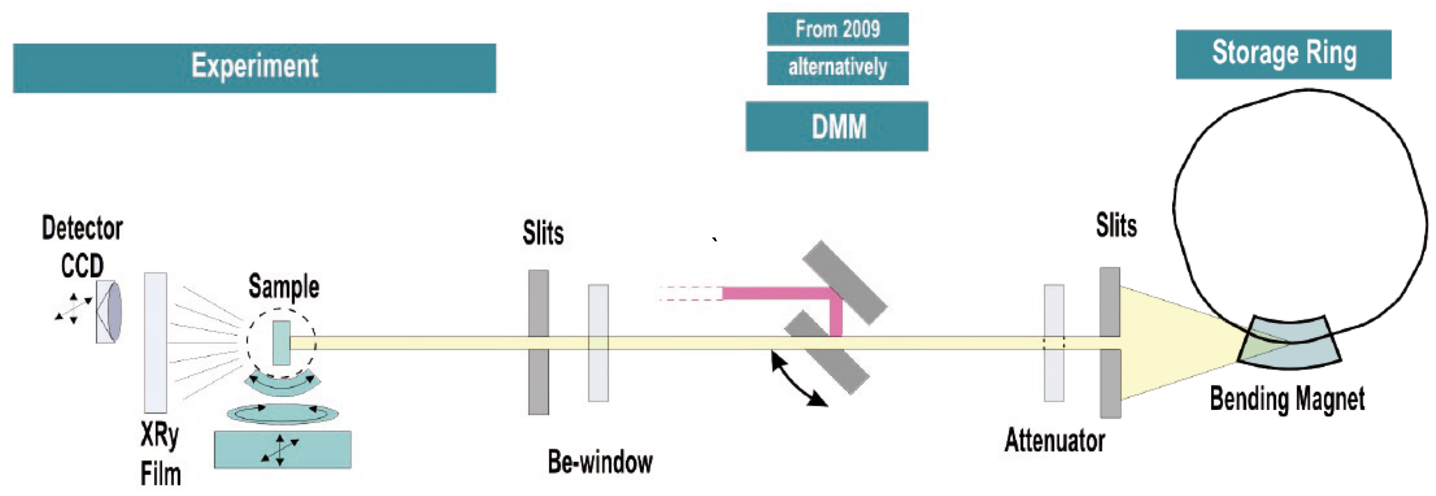
Fast Tomography at Synchrotron Light Sources

X-ray imaging permits spatially resolved visualization of 2D and 3D structures in materials and organisms which is crucial for understanding their properties. Furthermore, it allows one to recognize defects in devices from the macro- down to the nano-scale. Providing millions of pixels, each with a digitization depth of 12 bits or more, and several thousand frames per second, modern synchrotron can produce data sets of gigabytes in a few seconds. We have optimized the reconstruction software employed at the micro-tomography beamline at KIT and ESRF to use the computational power of modern graphic cards and reduced reconstruction time from hours down to few minutes.

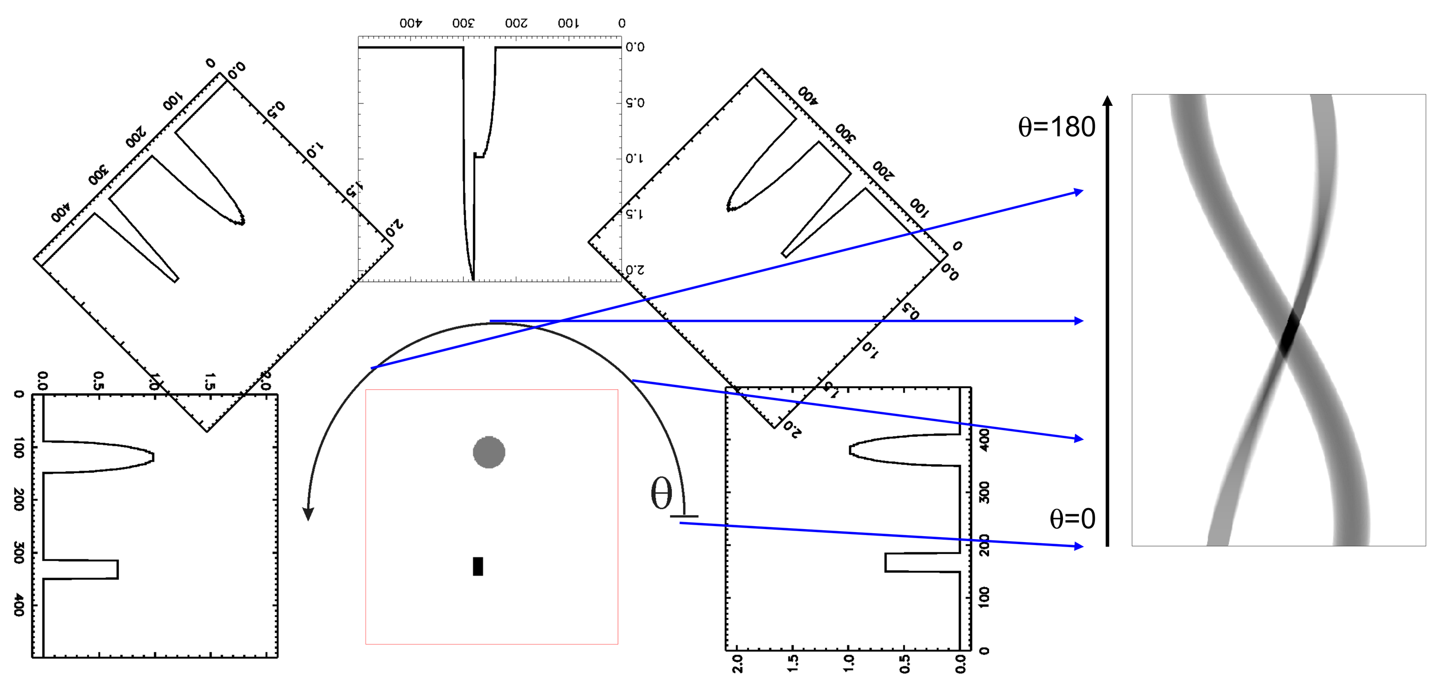


Example for 3D X-Ray imaging. The functional groups of a flightless weevil are colored

Imaging at Synchrotron Light Sources

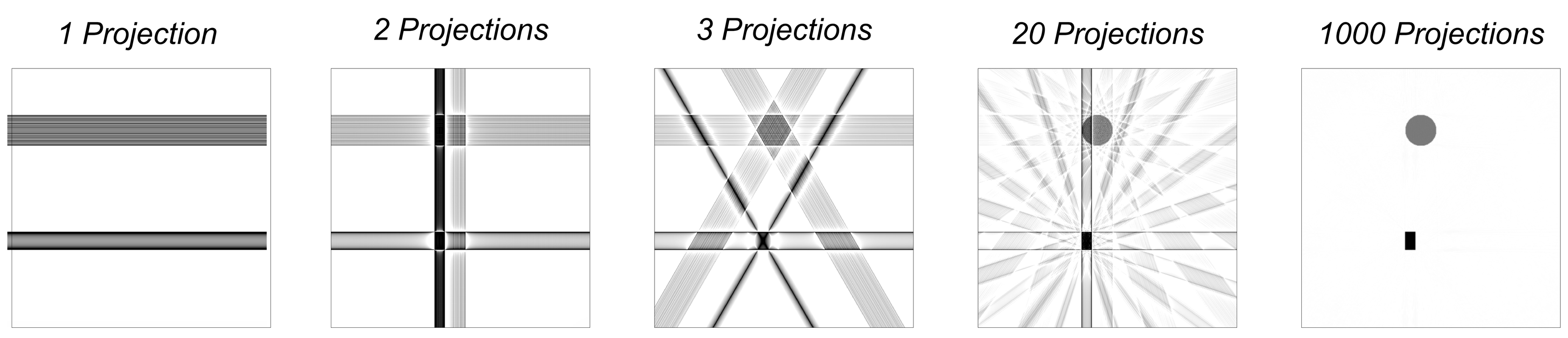


The sample evenly rotating in the front of a pixel detector is penetrated by X-rays produced in the synchrotron



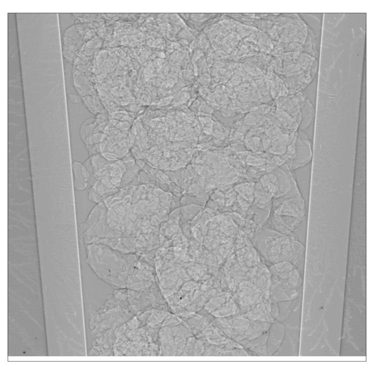
The pixel detector registers series of parallel 2D projections of the sample density at different angles.

3D Image Reconstruction

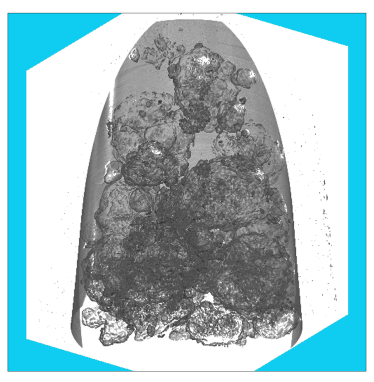


Filtered back-projection is used to reconstruct 3D images from a manifold of 2D projections. The projection values are smeared back over 2D cross sections and integrated over all projection angles. To reduce blurring effect the projections are filtered in the Fourier space before being back projected.

Example of Typical Setup

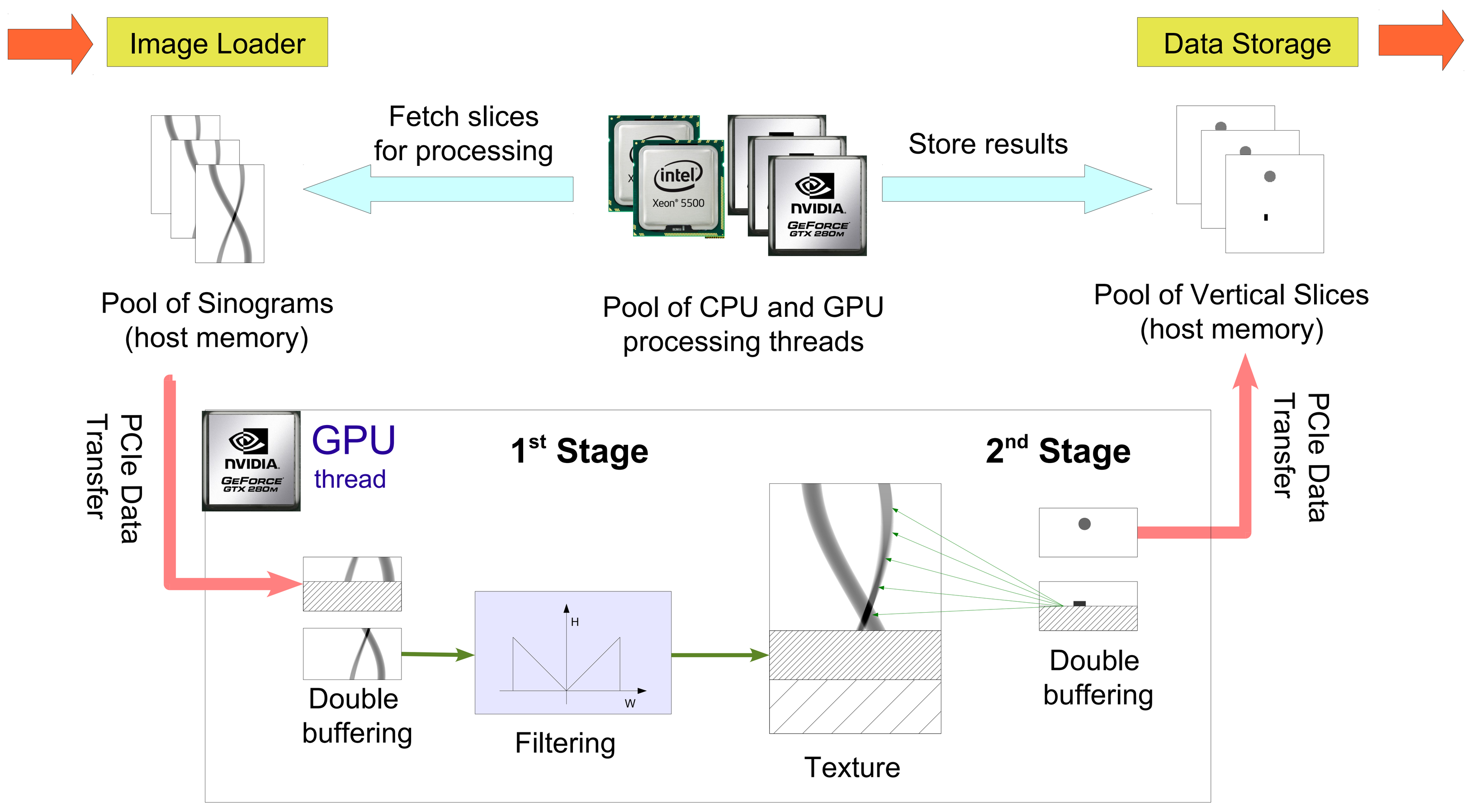


Sample:	Plastic holder with porose polyethylene grains
Source data:	24GB (2000 projections, 3 Mpix, 32 bits)
3D Image:	11GB (3 Gpix, 32 bits)
Complexity:	53 Tflop back-projection + 0.6 Tflop filtering



Goal: Reconstruct 3D image in 1 minute

Software Optimizations



Architecture
- All GPUs and CPUs available in the system are used to process slices
- To fully utilize disk I/O the data is prefetched and preprocessed while GPUs are crunching prepared data
- All system and GPU memory is allocated once at application startup

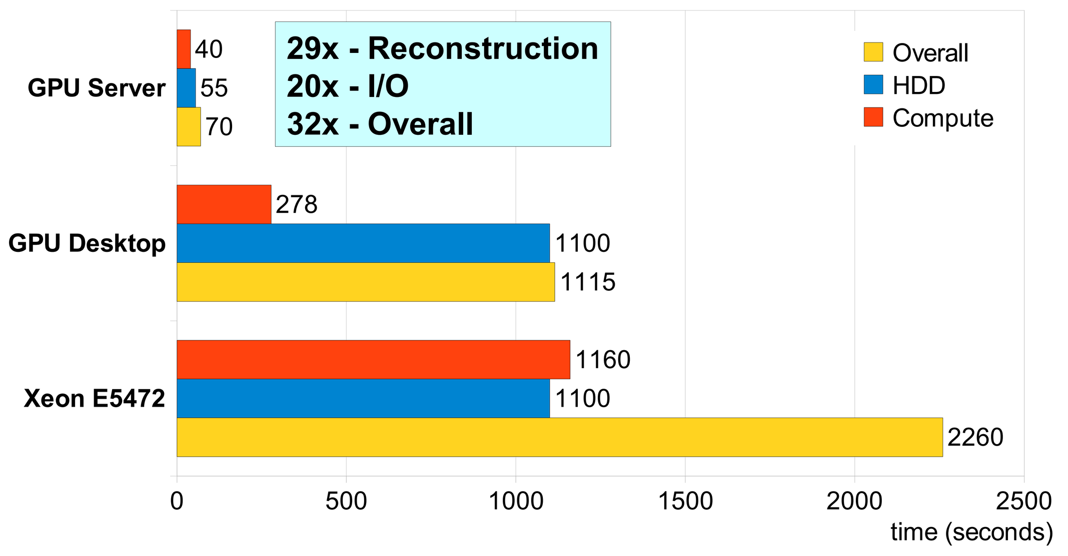
Data Transfer
- The pinned (unswappable) memory buffer is used to exchange the data with GPU
- The slice is split in blocks and the data transfer of next block is interleaved with computation of current one
- Still the blocks are big enough to fully utilize GPU multiprocessors

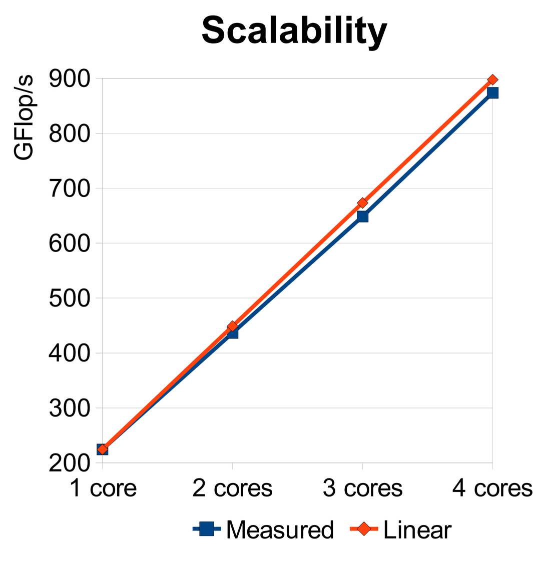
Filtering
- Data is padded to a size equal to the closest power of 2
- Multiple vectors are processed together using batched calls
- Two real convolutions are computed using a single complex cuFFT transform

Back Projection
- Texture engine is used to accelerate random access and for linear interpolation

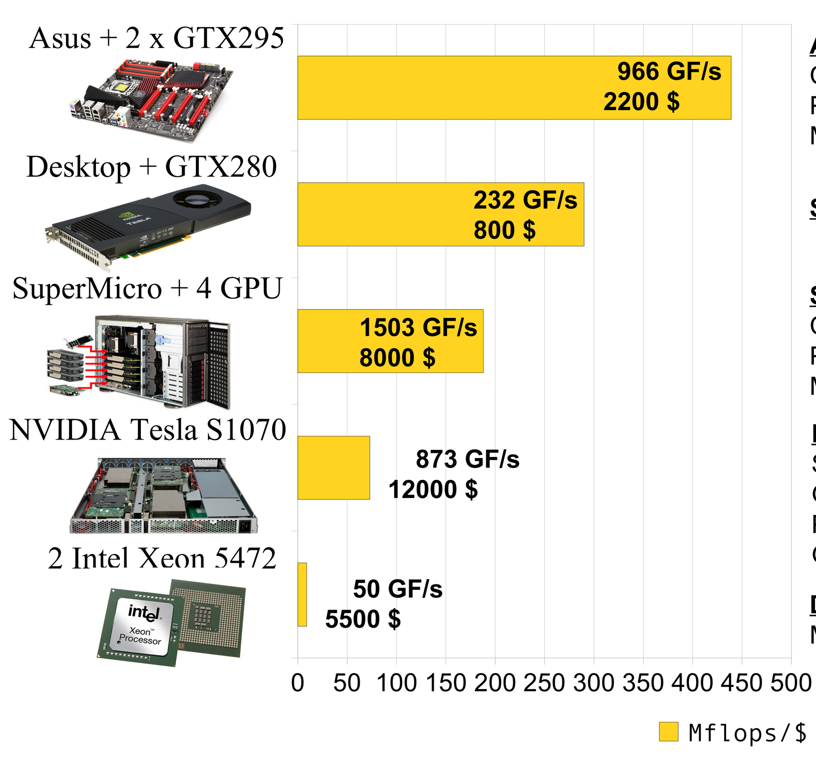
Results

	Xeon Server	GPU Desktop	GPU Server
Type of Computation	CPU / Xeon E5472 8 core, 3 GHz	**GeForce GTX 280 1 core**	**2 x GTX295 + 2 x GTX480 6 cores**
CPU	2 x Xeon E5472	Core2 E6300	2 x Xeon E5540
Memory	16GB DDR3	4GB DDR2	96GB DDR3
HDD	WDC5000AACS	WDC5000AACS	**2 x Intel X25-E / Raid-0**
Price	5500$ (2000$ CPU)	1000$ (400$ GPU)	9000$ (2000$ GPU, 800$ SSD)
Software	OpenSuSe 11.2, CUDA 3.0, Intel MKL 10.2.1, gcc4.4 -O3 -march=nocona -mfpmath=sse		





Evaluation of Computation Platforms



Asus Rampage III Extreme (2200$ = Core i7 + 2 x GTX295 + 6 GB)
Chipset: x58, 36 PCIe 2.0 lanes; 6 DDR3 slots (48 GB max)
PCIe 2.0 x16: 4 (x8 if all 4 are used)
Max Peak Performance (NVidia): 7.15 Tflops / 595 GFlops

Standard Desktop (800$ = Core2 + GTX285 + 2 GB)

SuperMicro 7046GT-TRF (~8000$ = 2 Xeon + 4 GPU + 96 GB)
Chipset: Dual Intel 5520, 72 PCIe 2.0 lanes, 12 DDR3 slots (192GB max)
PCIe 2.0 x16: 4 (full speed), x4: 2 (in x16 slots); PCIe 1.0 x4: (in x8 slot)
Max Peak Performance (NVidia): 7.15 TFlops / 2.5 Tflops

NVIDIA Tesla S1070 (~8000$ + 4000$ host)
System: Requires separate host server
GPU Devices: 4 x Tesla C1060 (960 parallel processors at 1.44 GHz)
Peak performance: 4.14 Tflops / 345 Gflops
GPU Memory Size: 16 GB

Dual Xeon 5472 Server (5500$ = 16 GB)
Max Peak Performance: 96 Gflops / 48 GFlops