Massively Parallel Iterative Reconstruction

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Model Based Iterative Reconstruction (MBIR)

• Advantages:
  o leads to more accurate detection of explosives and reduce false alarm in CT security imaging.
  o Has wide applications in security imaging, scientific imaging, and medical imaging.

• Disadvantages:
  o very computationally demanding!

• Super-Voxel algorithm
  o 188x speedup on 68 cores, 2015x speedup on 29920 cores
  o Dramatically improves memory reuse and parallel operations
Image Quality Comparison

An Example Slice from ALERT task order 3 (TO3) dataset, obtained from an Imatron C-300 Scanner
Prior Model: $p(x)$

Forward model $f(x)$

Physical System

Difference

$x \rightarrow$ Physical System $\rightarrow$ Forward model $f(x) \rightarrow$ Difference

$\hat{x} \leftarrow \arg \min_x \{ \|y - Ax\|_2^2 + u(x) \}$

So why is MBIR so computationally demanding?
Tomographic Reconstruction

Detector

row

channel

Parallel X-ray Source

Detector

Parallel X-ray Source

Detector

Parallel X-ray Source

Parallel X-ray Source

Reconstruction
Irregular Memory Layout

- Observation: sinusoidal path

Sinogram Space

- Relevant measurements for given voxel
Limitations of Baseline MBIR

- Update voxels
  - Inefficient cache utilization
  - Difficult to parallelize
Super-Voxel In 3D Volume

- Voxel trace is **straighter**
  - Much faster prefetch
Hierarchical Parallelism

Node P¹

super-voxel

volume

Node P²

super-voxel

Sinogram

SVB #1

SVB #2

Sinogram

SVB #3

SVB #4
TO3 Dataset Speedup

- **Dataset (TO3 dataset):**
  - 1024 channels; 720 views; parallel view
  - 512 x 512 x 3200 reconstruction

- **Computer:**
  - NERSC supercomputer from Berkeley National Lab (knights landing clusters)
  - Each node: 68 cores Intel processors

- **Algorithm:** the baseline MBIR, and the super-voxel algorithm

<table>
<thead>
<tr>
<th>Nodes</th>
<th>1 Node</th>
<th>4 Nodes</th>
<th>40 Nodes</th>
<th>440 Nodes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cores</td>
<td>68 Core</td>
<td>272 Cores</td>
<td>2720 Cores</td>
<td>29920 Cores</td>
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<tr>
<td>baseline</td>
<td>45033.6</td>
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<td>Super-Voxel</td>
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<td>59.1</td>
<td>18.0</td>
<td>15.9</td>
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<td>Speedup</td>
<td>188.34</td>
<td>542.05</td>
<td>1779</td>
<td>2015</td>
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