Development of ARCHER-CT, a Fast Monte Carlo Code for Patient-Specific CT Dose Calculations Using Nvidia GPU and Intel Coprocessor Technologies

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Introduction

I. Increased clinical use of the X-ray Computed Tomography (CT) as an imaging tool has aroused a wide concern among the radiology research community because of the increased amount of ionizing radiation delivered to the patient population. Accurate, fast, patient-specific quantification of the radiation dose is an important undertaking.

II. Monte Carlo (MC) method is practically the only computational approach to achieve this goal, but demands a prohibitively long computation time.

III. Nvidia GPUs and Intel Xeon Phi coprocessor provide a new pathway to accelerate MC. But existing production codes cannot be compiled or run on either of the platforms.

IV. Motivated by the clinical needs and technical advances, our team has endeavored to develop a new generation of parallel MC code called ARCHER-CT (Accelerated Radiation-transport Computation in Heterogeneous Environments) to accurately and rapidly calculate patient dose on Intel multicore CPUs (ARCHER-CTCPU), Nvidia GPUs (ARCHER-CTGPU) and Intel Xeon Phi coprocessors (ARCHER-CTCop).

Methods

III. Extensive library of computational patient phantoms

- RPI-Adult males with body weights of 63, 74, 85, 100, and 122 kg
- RPI-Adult females with body weights of 56, 68, 86, 100, and 122 kg
- RPI-Fat women with 3, 6, and 9 months of gestation
- RPI-Adult males with body weights of 73, 88, 103, 117, and 142 kg

IV. Code development

<table>
<thead>
<tr>
<th>code variant</th>
<th>programming model</th>
<th>compiler for the kernel</th>
<th>hardware</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARCHER-CTCPU</td>
<td>MPI-OpenMP</td>
<td>g++</td>
<td>Intel Xeon 5650 CPU</td>
</tr>
<tr>
<td>ARCHER-CTGPU</td>
<td>CUDA</td>
<td>nvcc</td>
<td>M2090, K20, K40 GPU</td>
</tr>
<tr>
<td>ARCHER-CTCop</td>
<td>MPI-OpenMP</td>
<td>icpc</td>
<td>Intel Xeon Phi 5110p coprocessor</td>
</tr>
</tbody>
</table>

Results

I. Benchmark against the production code

- Simulate a 142kg RPI-Adult male obese patient undergoing a hypothetical whole-body CT scan.
- Benchmark against the production code Monte Carlo N-Particle eXtended (MCNPX). Organ doses calculated by ARCHER-CT agrees with those by MCNPX within 0.76%.
- ARCHER-CT is significantly faster than MCNPX.
- ARCHER-CTGPU running on Nvidia Fermi and Kepler GPUs outperforms ARCHER-CTCop on Intel Knights Corner coprocessor.

<table>
<thead>
<tr>
<th>condition</th>
<th>time[sec]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 M2090 GPU</td>
<td>6.44</td>
</tr>
<tr>
<td>6 M2090 GPUs</td>
<td>1.45</td>
</tr>
<tr>
<td>1 K20 GPU</td>
<td>5.09</td>
</tr>
<tr>
<td>1 K40 GPU</td>
<td>4.16</td>
</tr>
</tbody>
</table>

Conclusion

I. The accelerator-based new Monte Carlo code ARCHER-CT is proven useful for accurate and fast CT imaging dose calculations.

II. Our GPU code running on Nvidia Fermi and Kepler device is found to be more efficient than our coprocessor code on Intel Knights Corner device.
