Advantage of Arm processor in High Energy Physics

Arm User Group Session at SC19

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About KEK

- High Energy Physics research institute in Japan
- Founded in 1971
  - Will mark its 50th anniversary in 2021
- Mission:
  - Make discoveries that address the most compelling questions in a wide range of fields, including particle physics, nuclear physics, materials science, and life science.
Particle Accelerators & Detectors

- Accelerates particles almost to the speed of light
- Smashes them at the collision point
- Installed at the collision point
- Detects particle interactions

Source: SuperKEKB Design Report
KEK Central Computer System

- Linux cluster + Data storage (GPFS/HPSS)
  - CPU: 10,024 cores (Intel Xeon E5-2693 v3)
- In production since 2016
- Used for data analysis and numerical simulations in experiments
- More than 80% CPU utilization in average

Up to 4GB/s

Detected particle interactions
Motivation

• TCO (Total Cost of Ownership) is our concern
  • Costs of electrical power grow rapidly after the 3.11 earthquake in 2011
  • Cooling facility costs also impact a lot
• We seek the most efficient platform for detector simulation
  • More than 50% of computing resources are used
• Arm processors can be a solution?
First Test Environment

- Marvell ThunderX2 Sabre platform
- CPU: Marvell ThunderX2 CN9980 x2
  - 32 cores/CPU
- Memory: 256 GB
  - 16GB DDR4 2666 DIMM x16
- Chipset configuration in BIOS
  - Turbo/CPPC Mode: Autonomous - CPPC on
  - Symmetric Multi-Thread: 1, 2, 4
    - Measured with changing this parameter
- Kernel: 4.14.0-115.el7a.0.1.aarch64
- OS: CentOS 7.6.1810 (AltArch)
Geant4: Used for Detector Simulation

• A software toolkit to simulate the interaction of particles with matter by Monte Carlo method.
  • Integer operations are more important than floating operations.
  • Loops an event which shoots primary particle and simulates particle interactions.

• Widely used in particle physics, space science, medicine, etc…

Event 1
Event 2
Event 3

Primary particle...
G4Bench: Geant4-based Benchmark Tool

• Provides three types of Geant4-based Monte Carlo simulation workloads:
  • Vgeo: Simulation of voxel geometry water phantom for medical application.
  • Ecal: Simulation of Electromagnetic calorimeter array.
  • Hcal: Simulation of hadron sandwich calorimeter of Lead and Scintillator.

• We executed the applications and measured performance by changing the number of threads.
Results: Comparison of SMT-Mode Performances

- 1SMT mode is scaled ideally.
- Total throughputs of 2SMT and 4SMT modes are better than 1SMT’s.
  - 2SMT: 1.43 times better
  - 4SMT: 1.86 times better
- We haven’t found out the reason of the performance degradations yet.
Evaluation of Power Consumption

- We performed G4Bench on the ThunderX2 server and the Intel E5 family server and measured the power consumptions.
Evaluation of Power Consumption

- ThunderX2 got better results than Xeon E5 in terms of performance and power efficiency.
Bought HPE Apollo 70 for Further Tests

- The G4Bench performance of Apollo 70 is equivalent to the Marvell test server
- Installed an HPE AR64z 2U Arm node on an HPE Apollo z70 chassis
- CPU: Marvell ThunderX2 CN9980 x2
  - 32 cores/CPU
- Memory: 256 GB
  - 16GB DDR4 2666 DIMM x16
- Chipset configuration in BIOS
  - Turbo/CPPC Mode: Autonomous - Turbo
  - Symmetric Multi-Thread: 1, 2, 4
- Kernel: 4.18.0-80.7.2.el7.aarch64
- OS: CentOS 7.7.1908 (AltArch)
ThunderX2 vs. Intel Xeon Gold 6148: Performance comparison

- Xeon Gold and ThunderX2 performances are scaled up to 80 and 256 threads respectively.
- On light and middle-weight workload tests, total throughput of ThunderX2 exceeds the Xeon Gold.
ThunderX2 vs. Intel Xeon Gold 6148: Events/kWh comparison

- Xeon Gold got better results.
- ThunderX2 server consumes much power than Xeon Gold server.
## Who Consumes Much Power?

<table>
<thead>
<tr>
<th></th>
<th>CPU</th>
<th>Total TDP</th>
<th>Cooling-fan Wattage on the tested server</th>
<th>Fan Wattage/Total TDP</th>
<th>Server-level power consumption*1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intel Xeon E5 server</td>
<td>Intel Xeon E5 2630 v3 x2</td>
<td>85W x2 = 170W</td>
<td>14.5W x6 + 23W x2 = 133W</td>
<td>0.78</td>
<td>299W</td>
</tr>
<tr>
<td>ThunderX2 server (HPE Apollo 70)</td>
<td>Marvell ThunderX2 CN9980 x2</td>
<td>180W x2 = 360W</td>
<td>54.5W x4 = 218W</td>
<td>0.61</td>
<td>588W</td>
</tr>
<tr>
<td>Intel Xeon Gold server</td>
<td>Intel Xeon Gold 6148 x2</td>
<td>150W x2 = 300W</td>
<td>18W x5 + 12.6W x2 = 115W</td>
<td>0.38</td>
<td>392W</td>
</tr>
</tbody>
</table>

- Cooling fans of ThunderX2 server consume much power.
- Although total TDP of the ThunderX2 is only 1.2 times higher than the Xeon Gold, the server power consumption difference is much more.
- The Xeon Gold can be cooled by less fan power than the Xeon E5.

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*1 Average power consumption during G4Bench Ecal simulation.
## Comparison of Processors

<table>
<thead>
<tr>
<th></th>
<th>Xeon E5-2630 v3</th>
<th>Xeon Gold 6148</th>
<th>ThunderX2 CN9980</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of cores</td>
<td>8</td>
<td>20</td>
<td>32</td>
</tr>
<tr>
<td>SMT</td>
<td>1, 2</td>
<td>1, 2</td>
<td>1, 2, 4</td>
</tr>
<tr>
<td>Frequency</td>
<td>2.4 GHz</td>
<td>2.4 GHz</td>
<td>2.2 GHz</td>
</tr>
<tr>
<td>Memory channel</td>
<td>4</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>TDP</td>
<td>85 W</td>
<td>150 W</td>
<td>180 W</td>
</tr>
<tr>
<td>USD/core</td>
<td>USD667(^*1/8=USD83)</td>
<td>USD3072(^*1/20=USD154)</td>
<td>USD1795(^*2/32=USD56)</td>
</tr>
</tbody>
</table>

### Cost performance

<table>
<thead>
<tr>
<th></th>
<th>Light</th>
<th>Middle</th>
<th>Heavy</th>
<th>Cost/second/2CPU price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Events/second</td>
<td>1.53</td>
<td>1.44</td>
<td>1.39</td>
<td>2.25</td>
</tr>
<tr>
<td>Events/second</td>
<td>0.33</td>
<td>0.31</td>
<td>0.30</td>
<td>1.32</td>
</tr>
<tr>
<td>Energy efficiency</td>
<td>0.46</td>
<td>0.39</td>
<td>0.37</td>
<td>1.00</td>
</tr>
</tbody>
</table>

### Server-level performance

|                     | Light | Middle | Heavy | Energy efficiency:
<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Events/second/node</td>
<td>0.33</td>
<td>0.31</td>
<td>0.30</td>
<td>Events/kWh</td>
</tr>
<tr>
<td>Energy efficiency</td>
<td>0.46</td>
<td>0.39</td>
<td>0.37</td>
<td>1.00</td>
</tr>
</tbody>
</table>

*1 Recommended Customer Price on [https://ark.intel.com](https://ark.intel.com)

Summary

• We have evaluated Marvell ThunderX2 performance using Geant4-based Monte Carlo simulation benchmark.
  • ThunderX2 cost performance is very attractive.
  • ThunderX2 server-level performance is better than Xeon Gold server on light and middle-weight workload tests.
  • Intel Xeon Gold server is more power efficient than ThunderX2 server.

• We are looking forward to the next Arm processor!

• Future work:
  • Execute memory intensive benchmark.
  • Execute other HEP software.

• Thanks to Marvell for the preparation of the ThunderX2 test server and for giving us useful advice.
IBM System x3550 M5

• CPU: Intel Xeon E5-2630 v3 x2
  • 8 cores/CPU
• Memory: 64 GB
  • 16GB DDR4 1866 DIMM x4
• Kernel: 3.10.0-693.21.1.el7.x86_64
• OS: CentOS 7.6.1810 (Core)
HPE ProLiant DL360 Gen10

- CPU: Intel Xeon Gold 6148 x2
  - 20 cores/CPU
- Memory: 256 GB
  - 16GB DDR4 2666 DIMM x16
- Kernel: 4.15.0-66-generic
- OS: Ubuntu 18.04.3 LTS
Cooling Fans

• IBM System x3550 M5
  • Nidec UltraFlo 12V, 1.21A x6
  • DELTA ELECTRONICS 12V, 1.9A x2

• HPE Apollo 70:
  • Nidec UltraFlo: 12V, 4.54A x4

• HPE ProLiant DL360 Gen10:
  • DELTA ELECTRONICS: 12V, 1.5A x5
  • SUNON: 12V, 1.05A x2