Supercomputer "Fugaku" and Beyond

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K computer was shut down in August, 2019 after 7 years of operation.

The last rack of Supercomputer “Fugaku” was delivered in May 2020.

Software adjustment is ongoing for the general use scheduled in FY2021.

Fugaku tech FX1000 & FX700 are GA already, and A64FX CPU is supplied to HPE.
## Benchmark Results and “Fugaku” Specification

<table>
<thead>
<tr>
<th>System spec.</th>
<th>K computer, SPARC64 VIIIfx</th>
<th>Fugaku, A64FX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instruction set architecture</td>
<td>SPARC-V9 HPC-ACE</td>
<td>Armv8.2-A SVE 512bit</td>
</tr>
<tr>
<td>Double precision performance</td>
<td>11.28 Petaflops</td>
<td>537 Petaflops</td>
</tr>
<tr>
<td>Half precision (AI) performance</td>
<td>-</td>
<td>2.15 Exaflops in half precision</td>
</tr>
<tr>
<td>Total memory bandwidth</td>
<td>5.64 PB/s</td>
<td>163 PB/s</td>
</tr>
<tr>
<td>Interconnect</td>
<td>Tofu interconnect</td>
<td>Tofu interconnect D</td>
</tr>
<tr>
<td>TOP500 (Petaflops)</td>
<td>10.51 (#1 at June/Nov. of 2011)</td>
<td>415.5 (#1)</td>
</tr>
<tr>
<td>HPCG (Petaflops)</td>
<td>0.6027 (#1 Nov. 2016~Nov. 2017)</td>
<td>13.366 (#1)</td>
</tr>
<tr>
<td>HPL-AI (Petaflops)</td>
<td>—</td>
<td>1,421 (#1)</td>
</tr>
<tr>
<td>Graph500 (GTEPS)</td>
<td>31,302.4 (2014~2019.6 #1)</td>
<td>70,980 (2020.6 #1)</td>
</tr>
</tbody>
</table>

- TOP500: Performance of solving the linear equation (dense matrix) $Ax = b$, which is common in science and engineering. The standard performance indicator for supercomputers.
- HPCG: Performance of solving the linear equation with sparse coefficient matrix using Conjugate Gradient method.
- HPL-AI: Performance of solving the linear equation utilizing lower precision floating point calc., like fp16, which AI often utilizes.
- Graph500: Performance of big data processing. Integer and memory access speed related to the graph search/traverse are evaluated.
Technical Innovations and Features of “Fugaku”

**Faster applications: Leading-edge technology**
- The world's first CPU w/ Arm’s HPC extension, SVE, for which Fujitsu collaborated as a lead partner
- An arithmetic unit (512 bit SIMD) with 4x of K and half-precision (FP16) used in AI
- HBM2 for high memory BW
- Tofu interconnect D for efficient massively parallel processing (Enhanced Tofu for K)

**Energy efficient and reliable: in-house hardware and software**
- Original CPU, system, and software for stable and improved operation of large systems
- Efficient hardware with software control of power-saving features (power knob)
- Fujitsu's CPU design and leading-edge Si-tech to achieve world-class power efficiency

**Ease and breadth of use: Adoption of industry standards**
- Original CPU "A64FX" using Arm architecture widely used in smartphones and IOT devices
- Red Hat Enterprise Linux (RHEL 8.1), which is widely used for servers, etc.
"Fugaku" from Launch to Benchmark

- **Dec. 2\(^{nd}\), 2019** Shipment began

  ~ Lock-down around the world ~

  Supply chain (routes, etc.) was modified
  Work sharing w/ suppliers was optimized
  Manufacturing and assembly order were modified
  to minimize the impact of stockout
  Domestic production of substitutes was considered

- **Apr. 7\(^{th}\), 2020** COVID-19 related research trial use of “Fugaku”

  1/6 of computing resource of “Fugaku”

- **May 13\(^{th}\), 2020** Shipment completed

  ~ Benchmark run ~

  Work remotely, except for hardware replacement

COVID-19 Measures and Benchmark Results

COVID-19 measures

- Work remotely, on-site to the minimum
- Avoid crowded trains. Sometimes walk instead
- Separate rooms and restrooms to reduce risk
- Thorough implementation of rules such as take & record temperature, sanitize hands, and wear mask
- Backup system dividing into more than two groups
- Range of disinfection and procedures were simulated

Prevention of infection

Minimizing infection effects

No infection, no delay, installation completed!

Benchmark run succeeded thru new normal work style

RIKEN/Fujitsu benchmark teams

Fujitsu’s engineers

Tight & close cooperation but remotely

RIKEN facilities operation team

22 guys in remote conference working on the benchmark at 21:50, May 29
“Fugaku” and Fujitsu Commercial Supercomputers

<table>
<thead>
<tr>
<th>Fugaku “富岳”</th>
<th>FUJITSU Supercomputer PRIMEHPC</th>
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<tbody>
<tr>
<td>Developed with RIKEN</td>
<td>PRIMEHPC FX1000 for highly scalable system</td>
</tr>
<tr>
<td>• 150k nodes</td>
<td>• 384 nodes/ Rack</td>
</tr>
<tr>
<td>• Water-cooled</td>
<td>• Water-cooled</td>
</tr>
<tr>
<td>• Tofu interconnect D</td>
<td>• Tofu interconnect D</td>
</tr>
<tr>
<td>• Fujitsu / RIKEN original software</td>
<td>• Fujitsu original software</td>
</tr>
</tbody>
</table>

PRIMEHPC FX700 easier adoption w/ de facto tech

• 8 nodes/ 2U Chassis
• Air-cooled
• InfiniBand
• OSS/ ISV software
**A64FX Performance and Power using OSS Real Apps**

**Performance scaling of a A64FX over 2x x86**

<table>
<thead>
<tr>
<th>Application</th>
<th>Calculation speed</th>
<th>Power Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>OpenFOAM Fluid dynamics</td>
<td>1.1</td>
<td>3.0</td>
</tr>
<tr>
<td>FrontISTR Structural analysis</td>
<td>1.8</td>
<td>4.7</td>
</tr>
<tr>
<td>ARINIT First principles calculation</td>
<td>1.5</td>
<td>3.7</td>
</tr>
<tr>
<td>SALMON First principles calculation</td>
<td>1.3</td>
<td>2.8</td>
</tr>
<tr>
<td>SPECFEM3D Seismic wave propagation</td>
<td>1.2</td>
<td>2.3</td>
</tr>
<tr>
<td>WRF Weather Research and Forecasting</td>
<td>1.3</td>
<td>2.8</td>
</tr>
<tr>
<td>MPAS Model for Prediction Across Scales</td>
<td>0.9</td>
<td>2.4</td>
</tr>
</tbody>
</table>

- Latest x86 and A64FX w/ the same number of cores*
  - Up to 1.8 times faster
  - Up to 4.7 times lower energy

* A64FX: 48 cores ×1 CPU (2.2 GHz)  
  x86 CPU: 24 cores ×2 CPU (2.9 GHz)

- Scalable performance obtained by
  - Enhanced microarchitecture for HPC
  - Energy-saving design & implementation
Commercial Applications

Fujitsu works with vendors to make commercial apps available for FX1000, also for FX700 and Fugaku with binary compatibility.

<table>
<thead>
<tr>
<th>Available soon</th>
<th>In a research &amp; development phase (as of June 2020)</th>
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<tbody>
<tr>
<td><strong>Engineering (Structural analysis, Fluid dynamics and Electronics)</strong></td>
<td></td>
</tr>
<tr>
<td><strong>LS-DYNA</strong> (by Ansys, Inc.)</td>
<td><strong>Altair Radioss™</strong> (by Altair Engineering, Inc.)</td>
</tr>
<tr>
<td><strong>Poynting</strong> (by Fujitsu Limited)</td>
<td><strong>Ansys Fluent</strong> (by Ansys, Inc.)</td>
</tr>
<tr>
<td><strong>Chemistry</strong>*</td>
<td><strong>Marc</strong> (by MSC Software Ltd.)</td>
</tr>
<tr>
<td><strong>Amber</strong> (by Gaussian, Inc.)</td>
<td><strong>scFLOW</strong> (by Software Cradle Co., Ltd.)</td>
</tr>
<tr>
<td><strong>Gaussian16</strong> (by Gaussian, Inc.)</td>
<td><strong>VPS (PAM-CRASH)</strong> (by ESI Group)</td>
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</tbody>
</table>

*Collaboration with Australian National University

**All application names used in this slide are trademarks or registered trademarks of their respective vendors.**
Global Partnership

- Supercomputer partnership with Cray (inherited to HPE)
  - HPE sells commercial supercomputer w/ A64FX

- Apps evaluation & ecosystem development on Arm SVE with overseas leading research institutes
  - Provides evaluation environment
    - Jülich Supercomputing Centre (Germany)
    - EPCC (Britain), etc.
  - Collaboration to build up an ecosystem with Barcelona Supercomputing Center in Spain

https://www.cray.com/products/computing/cs-series/fujitsu-arm-processor
Solving the Social Issues by Supercomputer

Social issues
- Health and longevity
- Safe and secure society
- Climate problem
- Industrial competitiveness
- Sustainable energy

Specific area
- Life science
- Disaster prevention and the environment
- Manufacturing
- Energy

Future
- [Simulation]
  - Fluid dynamics
  - Crash and structure
  - Materials

Now
- [Data analysis]
  - AI (Deep Learning)
  - Big data analysis

Past

~ Supercomputer ~

Supercomputer will be used as the infrastructure to support solving the social issues & digital transformation.
Summary

- Flagship supercomputer "Fugaku" is designed and developed thru co-design with RIKEN effort and Fujitsu’s full range of over 40 years experience of development on hardware and software of supercomputers
- Ranked #1 in many benchmarks by design and implementation for high "Fugaku" application performance
- The world's fastest "Fugaku" performance is expected to help realize Society 5.0, which requires high speed simulation and AI capabilities
  - Advanced use for COVID-19 related research, for example
- Developing Fugaku tech, A64FX and PRIMEHPC FX1000 & FX700, into business globally

Fujitsu aims to provide a prosperous future through the fruits of supercomputers around the world. With the advent of the digital age, high speed simulation with AI capable supercomputers will be widely used in many fields.