CSCE 735: Minor Project **Sidharth Edupuganti**

The first certified supercomputer was released in 1964. It has been a little over half a century since, and the number of supercomputers has increased exponentially. This increase in supercomputers comes from their ability to visualize data and predict future interactions pertaining to all types of scientific research. These machines are of great importance as they help pave the way for future research and development. Currently the top 2 known supercomputers in the world are Frontier, and Fugaku, respectively. Despite being ranked next to one another, these supercomputers differ vastly. Emphasizing these differences between the two will not only explain how far the world has come since the first supercomputer, but also what are ways to improve the current leading machines.

Frontier is the world's first exascale supercomputer. Frontiers' manufacturer is Hewlett Packard Enterprise (HPE). The location of this computer is at the Oak Ridge National Laboratory, which is in the United States. This supercomputer can conduct 2 quintillion calculations per second hence one of the reasons it is number 1 on the *TOP500* list**.** The computer is also AMD-powered, in which it utilizes AMD EPYC "Trento" 64 core 2 GHZ CPUs. This also means that the computer is using 606,208 cores for the CPUs, while also using the Radeon Instinct MI250X GPUs which translates to 8,335,360 cores. These two figures are of extreme importance as it marks one of the reasons that Frontier placed first amongst others in the TOP500 list. The CPUs derive from the EPYC microprocessors, which are developed by AMD. Besides the microprocessors' powerful specifications, it features two features called AMD Infinity Guard and AMD Infinity Architecture. The Infinity Guard was designed to mitigate any security risks pertaining to data century security (AMD). The Infinity Architecture is a piece of technology that optimizes the currently existing EPYC brand by increasing scalability and performance. These processors contain 8 memory channels per socket as well as roughly a 410 GB/s DRAM bandwidth. The I/O bandwidth includes 128 PCIe 4.0 lanes in a single socket, while also having 160 lanes in a dual socket. This CPU is a very powerful tool that allows Frontier to be the exascale supercomputer today. The Radeon Distinct, also being developed and sold by AMD, contains more critical infrastructure that supports the supercomputer. The GPU utilizes AMD CDNA 2 architecture, whose purpose is designed for "the most taxing scientific computing and machine learning applications (AMD). The accelerator was built specifically for exascale supercomputers, which is how Frontier's existence came to be. Frontier also contains a Linpack benchmark [R_{max}] of 1,102 PFlop/s and a theoretical peak [R_{peak}] of 1,685.65 PFlop/s. AMD had collaborated with the U.S. Department of Energy and HPE to create this supercomputer. The supercomputer utilizes HPE's very own Cray OS, which has been designed to run scalable and highly complex applications. Cray OS is very small in order to maximize performance for the Frontier supercomputer and contains integrated container support to validate compute nodes. Apart from the software, Frontier uses 21 MW of power. Frontier employs Cray's MPICH. This allows GPU buffers to be able to pass directly into MPI call. Frontier is a powerful $600 million supercomputer that is expected to help visualize scientific research and has been used to create AI models that are much larger, which in turn increases predictability as well as time-to-discovery (Patra).

Supercomputer Fugaku has been in development since 2014 and was only completed on March 9, 2021. Ranked second in the *TOP500* list, Fugaku is an extremely powerful supercomputer dedicated to exploring a plethora of data. One of its most recent use cases examined how droplets containing COVID-19 spread from the mouth, and what are some possible treatments for the virus (Kyodo News). In 2017, the scientist leading the Fugaku project, Satoshi Matsuoka, stated that the supercomputer will "allow you to achieve much better precision with respect to what the climate may look like given the effect of the carbon dioxide emissions" (Tsukimori), when discussing how Fugaku will contribute to. Fugaku also has been known to be utilized for developments in solar and fuel cells. In order to support these recent contributions, the supercomputer has been updated over time until 2021, which means the specifications of the supercomputer will not change much from its current capabilities. Fugaku is currently located at the Riken Center for Computational Science in Japan where it is being maintained. The supercomputer contains 158, 976 nodes, and utilizes Fujitsu's own A64FX processor alongside Fujitsu's extensions, which include: sector cache, hardware barrier, and prefetch. This processor was built to conform around the current ARMv8.2-A SVE 512-bit architecture which allows the computer to support 7,630,848 cores. Fugaku also contains the second generation of High Bandwidth Memory at 1024 GB/s. The supercomputer utilizes 48 computational cores, while also having various assistant cores to help support the machine. Performance-wise, the machine has a Rmax of 442.01 PFlop/s with a R_{peak} of 537.21 PFlop/s. Apart from the hardware, Fugaku also uses a multi-kernel operating system. The computer encompasses Red Hat Enterprise Linux 8 (RHEL), as well as McKernel, which are both ran on the Interface for Heterogenous Kernels (IHK). McKernel is dedicated to running any high-performance simulations, while RHEL is utilized for any other services (e.g., POSIX-related). Both kernels are used for high power computing as well as to reduce machine noise greatly (Zhang). Fugaku's software contains Fujitsu's in-house MPI which is based on OpenMPI, and RIKEN-MPICH, which is based on MPICH. These two interfaces are dedicated for different things within the supercomputer as OpenMPI focuses on usage and network conduits, while MPICH focuses on being a high-quality implementation for very niche cases. Finally, power consumption of the supercomputer is around 29 MW. Despite being completed, Fugaku is expected to be used for quite some time now. The $1 billion computer has already been used during the COVID-19 pandemic to visualize how masks are able to help against the virus. Many more scenarios where the computer will help benefit society are bound to come soon.

Both supercomputers are extremely powerful however as time progresses, there is always a need for a more powerful machine with updated architecture and specifications. Frontier has only surpassed Fugaku in becoming the known top supercomputer in the world. It is to be expected that the same will occur to Frontier in due time. Despite both being very powerful tools, it's important to examine how they differ. One of the biggest ways where both supercomputers differ is in their architecture. Frontier utilizes an AMD-based processor while Fugaku contains an ARM-based processor. This is interesting as ARM-based processors typically offer lower performance despite having lower consumption power, however this is not the case with Frontier. Despite using AMD EPYC processor, Frontier has been found to only be consuming 21 MW of power while still outputting 52.227 (Top500), making which charts it at rank number 2 on the Green500 list. Frontier

also supports 8,730,112 cores and Fugaku has support for 7,630,848 cores, which also explains how Fugaku was dethroned as the number 1 supercomputer. Both machines also differ in many other things. Frontier utilizes the Slingshot-11 interconnect while Fugaku uses Tofu interconnect D. The Slingshot-11 was designed specifically for exascale computing. While both supercomputers have impeccable performance, Frontier displays much better performance over Fugaku. Frontier's R_{max} is 1,102.00 PFlop/s which is much larger than Fugaku's R_{max} which is 442.01 PFlop/s. Frontier can perform at an incredible rate that is much more massive than Fugaku while also consuming much less power than the latter. Both computers also support their own proprietary MPI's. Frontier uses the Cray MPICH, while Fugaku uses Fujitsu OpenMPI, and RIKEN-MPICH. Crays MPICH is used as Frontier contains Cray OS as its main operating system, and the "default and preferred MPI implementation on Cray systems is Cray MPICH," (NERSC). This is also due to the usage of the Radeon Instinct MI250X GPUs that Frontier houses. This implementation allows data to be copied from the GPU to the Network Interface Card [NIC], which means that the host memory does not have to be used. Fujitsu MPI and RIKEN-MPICH allow for collectives, such as barrier, to be offloaded (RIKEN). Another difference between the two is that Fugaku contains a multi-kernel while Frontier only uses HPE's Cray OS. Cray OS, which is based on SUSE Linux Enterprise Server, was designed to be lightweight while still being able to run highly demanding applications (HPE). Fugaku runs on Red Hat Enterprise Linux 8 as well as McKernel to enhance performance for the machine. Many POSIX-based applications are run in RHEL8 while McKernel is a lightweight OS used for high-performance computing, which aligns with the goals of Cray OS. It is also important to recognize that the two computers finished development at different times. Frontier was recently employed for operational use and its program cost $600 million. Fugaku, on the other hand, was $1 billion and was introduced in 2020. The results of both projects were powerful tools, with one of them being the first exascale supercomputer. The use cases for both computers are similar as both supercomputers are expected to and have been used to analyze, visualize, and even predict future data to help aid in all types of scientific research. As Frontier only recently became operational in 2022, not much has been discussed in its use case besides the fact that this tool is the first tool to operate past the exascale barrier. The idea behind exascale computing is to help aid in creating "more realistic Earth system and climate models," (DoJ). **Table 1** displays the different specifications of each machine. Supercomputers Frontier, and Fugaku are extremely powerful machines that are being used on the forefront of climate data and fossil fuels. Despite working towards the same goal, both tools are vastly different in their architecture and other components. This difference allows Frontier to be much more superior than Fugaku, and Rank 1 on the *Top500* list. The future of exascale computing does not stop here either. The U.S Department of Energy has already planned their next exascale supercomputer, Aurora, and is expected to complete the project by late 2022. The manufacturers for this supercomputer will be Intel and Cray.

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Tables

Table 1. Supercomputers Frontier and Fugaku Specifications

	Frontier	Fugaku
Location	Oak Ridge National Laboratory	RIKEN Center for Computational Science
Manufacturer	HPE	Fujitsu
Cores	8,730,112	7,630,848
Processor	AMD EPYC 64C 2GHz	A64FX 48C 2.2GHz
Interconnect	Slingshot-11	Tofu Interconnect D
Debut	2022	2020
R_max	1,102.00 PFlop/s	442.01 PFlops/s
R_peak	1,685.65 PFlop/s	537.21 PFlops/s
Power Consumption	21 MW	29.8 MW
Operating System	HPE Cray OS	RHEL8, McKernel
Cost	$600 Million	$1 Billion