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Storage System at the supercomputer Fugaku

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Outline

- FEFS: Lustre-based file system enhanced by FUJITSU LIMITED
- Storage system at the K computer
- Overview of the supercomputer Fugaku
- Three-level hierarchical storage system
- Monitoring and log collection
- Summary

FEFS: Lustre-based file system enhanced by FUJITSU LIMITED

Introduced FEFS in our site

- **FEFS: Fujitsu Exabyte File System**
  - Enhanced Lustre by FUJITSU LIMITED

- **FEFS based on Lustre ver. 1.8**
  - Adopted in the two-level file system of the K computer (hereinafter, “K”)
  - High I/O throughput under the huge number of clients
  - Many enhancements to have stable and high performance operations

- **FEFS based on Lustre ver. 2.10 (<- Long Term Support)**
  - Adopted in the 2nd layer storage system of the supercomputer Fugaku (hereinafter, “Fugaku”)
  - Cooperative operation with the 1st layer storage system built by SSDs for high throughput I/O in computing and mitigation of load of the 2nd layer storage system
  - Full deployment and optimization are still in progress.

Notable Features of FEFS

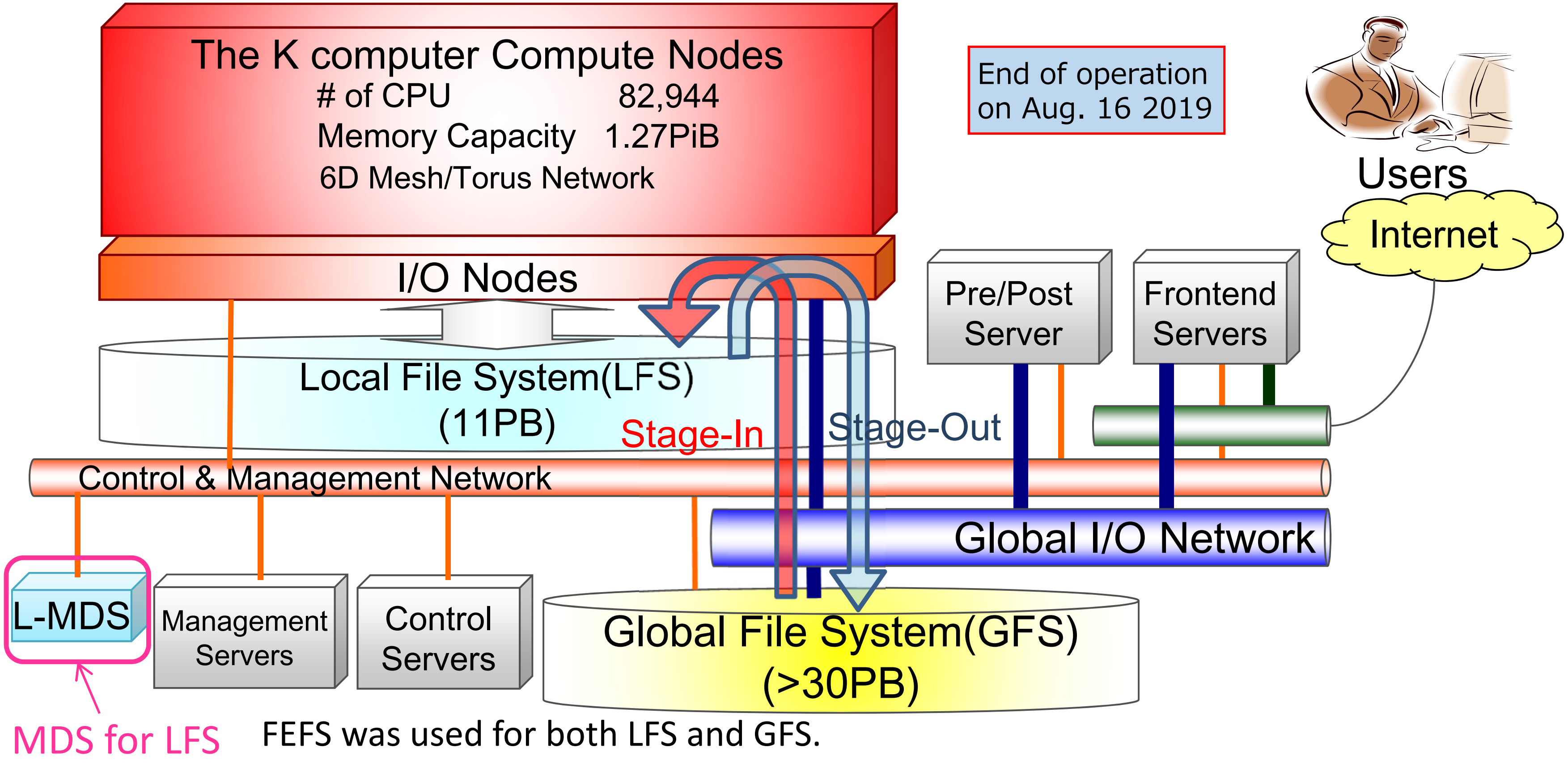
- **Enhancements based on Lustre 2.x may contribute to the Lustre community.**
  - FUJITSU LIMITED is a member of the community and they will continue to report bug-fixes and feedbacks to the community with cross relationship.

- **Own enhancements about RAS, system operability, tolerance under high I/O load, and fair-share management among clients are expected to perform well at the 2nd layer storage system.**

Storage system at the K computer

Storage system at the K computer

- **File staging with two-level local/global file system**



The K computer Compute Nodes
# of CPU 82,944
Memory Capacity 1.27PiB
6D Mesh/Torus Network

End of operation on Aug. 16 2019

Users

Internet

I/O Nodes

Pre/Post Server

Frontend Servers

Local File System(LFS) (11PB)

Stage-In

Stage-Out

Control & Management Network

Global I/O Network

L-MDS

Management Servers

Control Servers

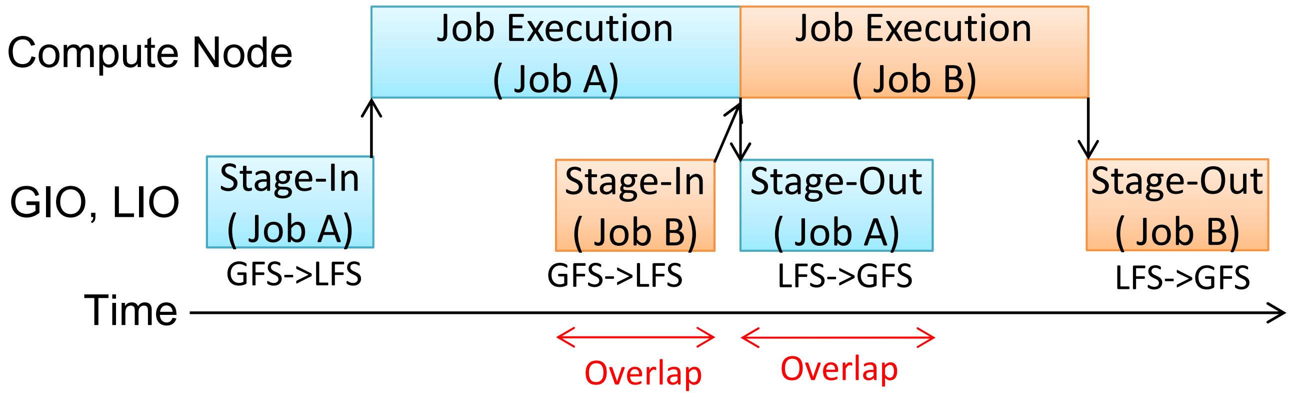
Global File System(GFS) (>30PB)

MDS for LFS

FEFS was used for both LFS and GFS.
(FEFS: Fujitsu Exabyte File System based on Lustre technology)

File Staging

- **Asynchronous file staging for effective job scheduling and I/O**



- Pros:
- ✓ Stable application performance for jobs with the help of overlaps between job executions and file staging
- Cons:
- ✓ Pre-defining file name of stage-in/out operation lacks of usability.
- ✓ Data-intensive application which requires a huge storage space affects system utilization because of waiting stage-in/out processing of other jobs.

Overview of the supercomputer Fugaku

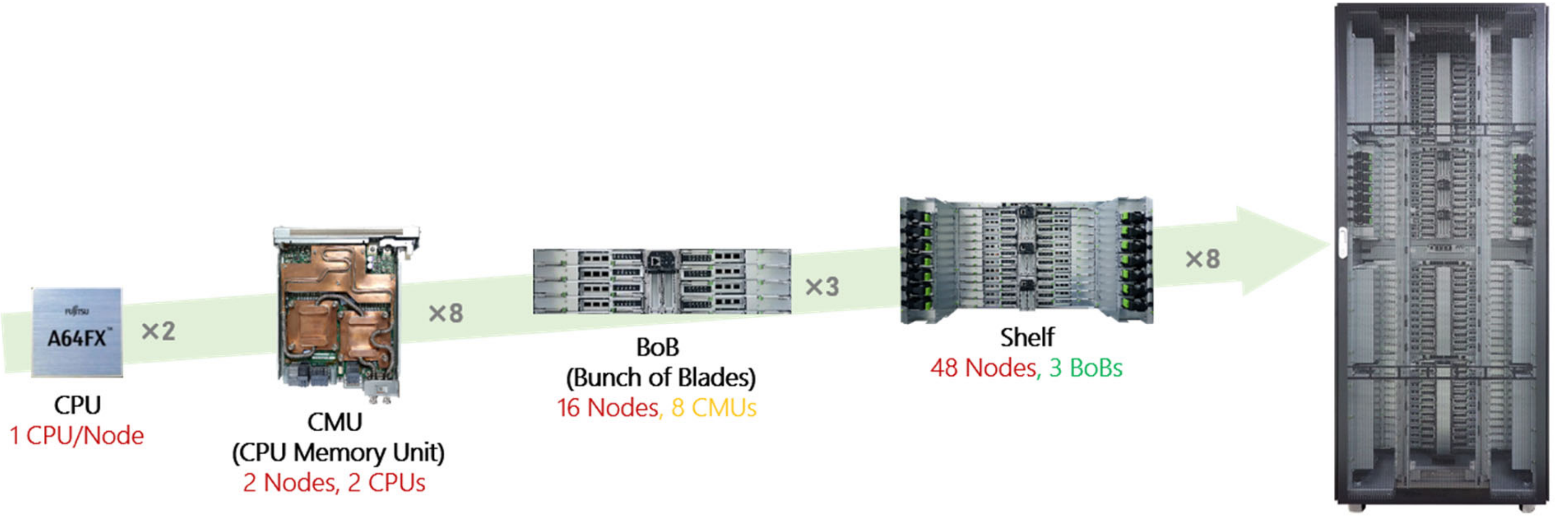
From “K” to “Fugaku”

- Performance of ten racks of “Fugaku” is almost the same performance of “K”(864 racks).

		“Fugaku”	“K”
CPU Architecture		A64FX Arm v8.2-A SVE (512 bit SIMD)	SPARC64VIIIfx
Node	Cores	48	8
	Peak DP performance	2.7+ TF	0.128 TF
	Main Memory	32 GiB	16 GiB
	Peak Memory Bandwidth	1,024 GB/s	64 GB/s
	Peak Network Performance	40.8 GB/s	20 GB/s
Rack	Nodes	384	102
	Peak DP Performance	1+ PF	< 0.013 PF
Process Technology		7 nm FinFET	45 nm

Hardware Configuration of “Fugaku”

- **From CPU to Rack**



CPU
1 CPU/Node

CMU
(CPU Memory Unit)
2 Nodes, 2 CPUs

BoB
(Bunch of Blades)
16 Nodes, 8 CMUs

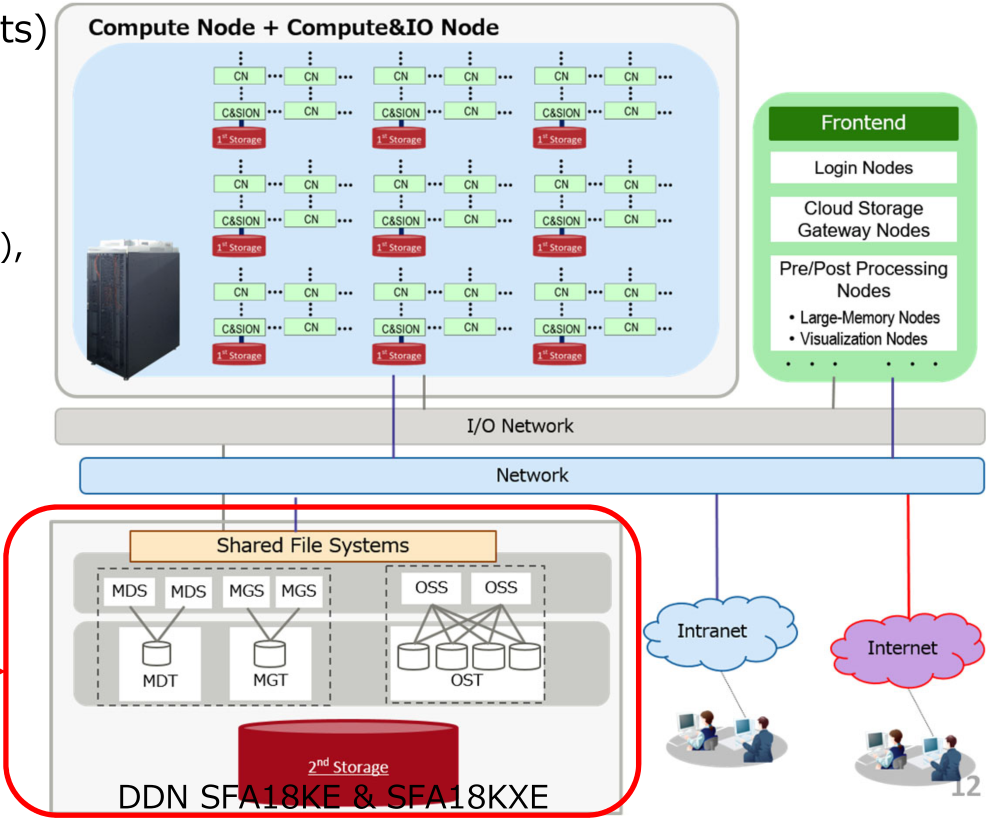
Shelf
48 Nodes, 3 BoBs

Rack
384 Nodes, 8 Shelves

Courtesy of FUJITSU LIMITED

System Configuration

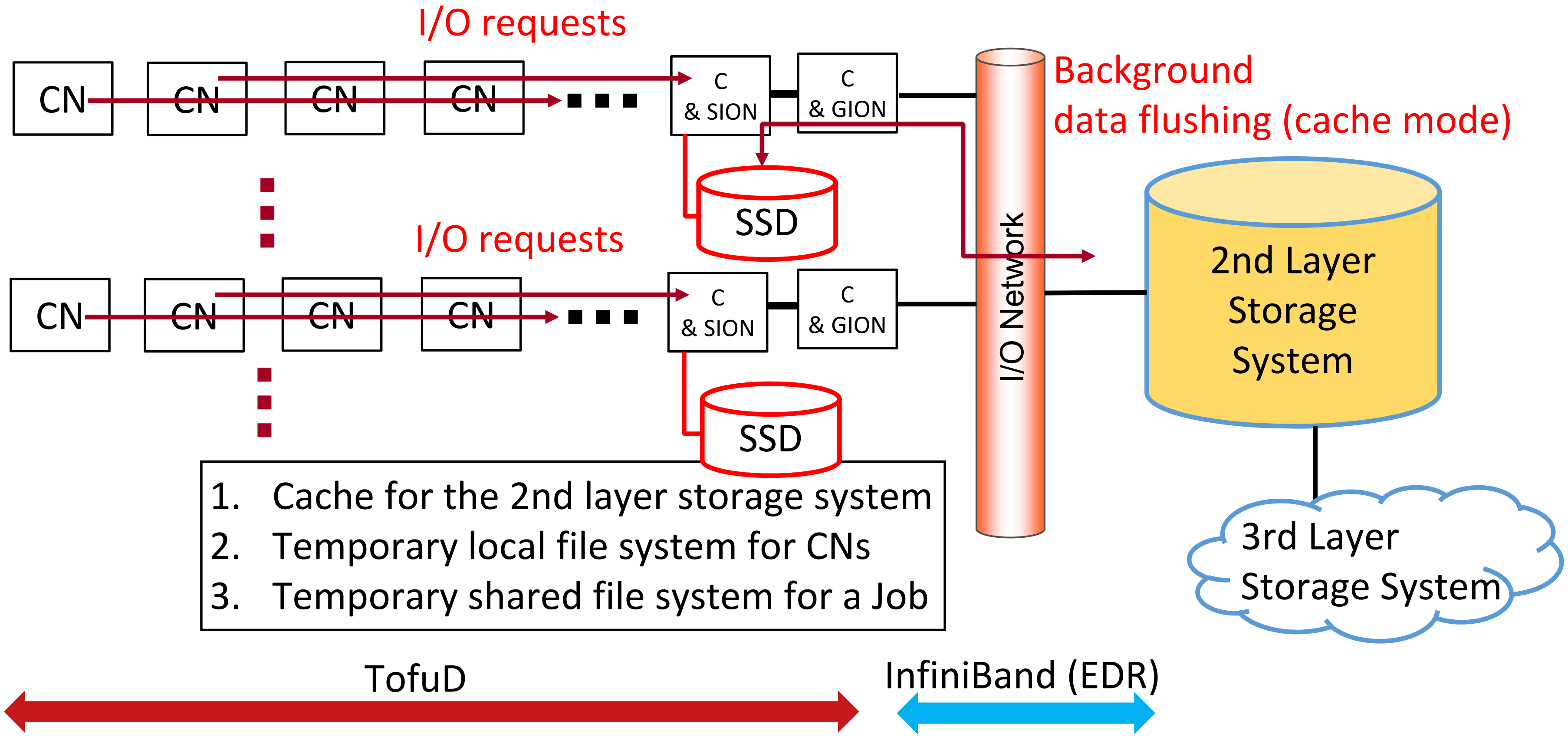
- **158,976 nodes**
- **Two types of nodes**
  - Compute node and Compute & I/O node connected by Fujitsu TofuD (6D mesh/torus Interconnects)
- **3-level hierarchical storage system**
  - 1st layer
    - One of 16 compute nodes (CN), called compute & storage I/O node (C & SION), has SSD about 1.6 TB
    - Its services
      - Cache for the 2nd layer file system
      - Temporary file systems
        - ✓ Local file system for CNs
        - ✓ Shared file system for a job
  - 2nd layer (~150 PB, multiple volumes)
    - Fujitsu FEFS: Lustre-based file system →
  - 3rd layer
    - Cloud storage service



Three-level hierarchical storage system

LLIO: Lightweight Layered I/O Accelerator

- Cooperative operations with the 2nd layer storage system



1. Cache for the 2nd layer storage system
2. Temporary local file system for CNs
3. Temporary shared file system for a Job

2nd Layer Storage System

- **Requirements for the 2nd layer storage system of “Fugaku”**
  1. High capacity
  2. High redundancy
  3. High performance

- **FEFS: Lustre-based file system provided from FUJITSU LIMITED**
  - Many experiences and fruitful knowledge through the K computer operation (~8 years) with the FEFS based on Lustre ver. 1.8

- **Installation of FEFS based on Lustre ver.2.10 with enhancements by FUJITSU LIMITED for the 2nd layer storage system of “Fugaku”**
  - RAS (e.g., High availability)
  - QoS
  - Optimized I/O performance
  - Storage management, etc.

Optimizations and parameter setting are in progress.

I/O nodes and Interconnects

- **I/O nodes and interconnects associated with the 2nd layer storage system**
  - “C & SION”, “C & GION”
  - TofuD among “C & SION”, “C & GION”, and “C & BION”
  - InfiniBand among “C & GION” and the 2nd layer storage system

- **Activities of interconnects and I/O nodes impact performance of the storage system**
  - Monitoring activities of those components with I/O performance/metrics of the storage system would be useful according to our experience at the K computer.
    - Y. Tsujita, “Characterizing I/O Optimization Effect Through Holistic Log Data Analysis of Parallel File Systems and Interconnects,” LNCS 12321, pp. 177–190 (2020)

Monitoring and log collection

Monitoring and Log Collection

- **Monitoring and log collection of “Fugaku” (in progress)** [*]
  - Log and metric collection
    - Log collection
      - Logstash/Filebeat
    - Metric collection
      - Prometheus
  - Monitoring/alerting and analysis
    - Database
      - Elasticsearch, PostgreSQL
    - Monitoring/alerting
      - Prometheus
    - Visualization
      - kibana, redash, Grafana

→ Towards stable operation including the storage system

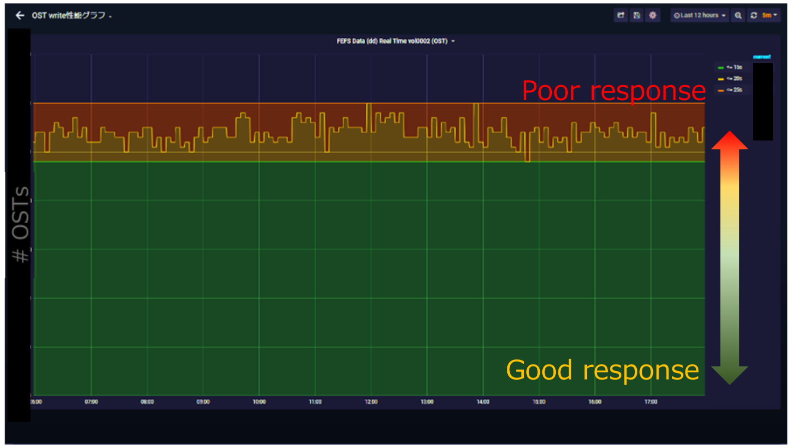
- Node metrics of MDS, MGS, OSS by *node_exporter*
  CPU, memory, disk, network, …
- Lustre(FEFS) metrics by *lustre_exporter* [**]
  Bandwidth, IOPS, Stats, …
- and, more …

[*] K. Yamamoto, “Operational Data Processing Pipeline,” BoF: Operational Data Analytics@SC’19
https://eehpcwg.llnl.gov/conf_sc19.html

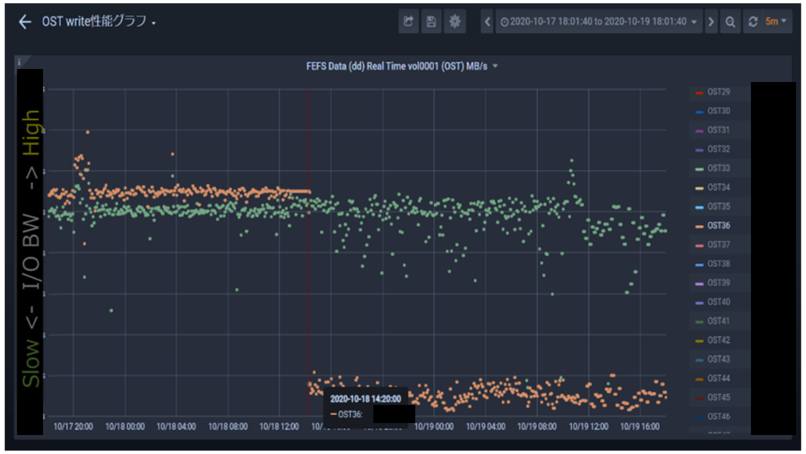
[**] With some enhancements for “Fugaku” configuration

Monitoring for *dd* write at the 2nd layer storage

- ***dd*’s write time monitoring of OSTs of each volume (preliminary)**
  - Periodical monitoring of write times using *dd* on every OST
    - Quick investigation of slow OSTs in each volume
    - Such approach effectively leads to further investigation about heavy I/O by jobs, system problems, …



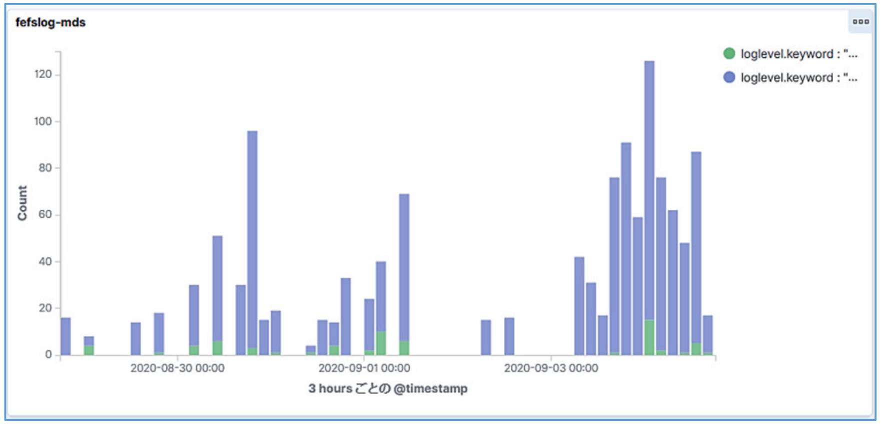
I/O write times over time with indicating by colors for several performance groups
(Some of OSTs were slow under some I/O workload stress test.)



I/O BW of each OST over time before/after I/O subsystem problem indicated by vertical red colored bar
(* Focusing the slowest OST indicated by orange plots)

Elasticsearch for FEFS log

- **Kibana for Elasticsearch visualization (preliminary)**
  - Quick trouble shooting from a large collection of log data
  - Arrangement in "Fugaku" operation is in progress based on our experiences at the K computer.



Example of evict events generated by MDS (includes both WARN and ERR levels)

Summary

- **Three-level hierarchical storage system has been introduced at the supercomputer Fugaku.**
- **The 1st layer storage system plays three roles in cooperation with the 2nd layer storage system.**
- **Lustre-based file system (FEFS) developed by FUJITSU LIMITED has been deployed at the 2nd layer storage system based on our experiences at the K computer.**
  - Many enhancements to cope with numerous demands in I/O operations are expected to play important roles at the supercomputer Fugaku.
- **Monitoring activities of I/O nodes and interconnects would be also important aspect at the supercomputer Fugaku based on our experiences at the K computer.**
- **Monitoring/log collection environment is in progress towards stable storage system operation.**
  - Alerting failures and finding root-causes
  - Finding performance bottlenecks and further optimizations, and more…