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Challenges for Implementing PMEM Aware Application with PMDK

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Outline

1. Introduction
2. Background and Motivation
3. How to use PMEM
4. Challenges for implementing PMEM aware applications
5. Challenges for performance evaluation to get valid results

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1. **Introduction**
2. Background and Motivation
3. How to use PMEM
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Introduction

- NTT Software Innovation Center is part of NTT Laboratories
- Worked on system software
  - Distributed file system (HDFS)
  - Operating system (Linux kernel)
- Trying to rewrite open-source software using new storage and new library

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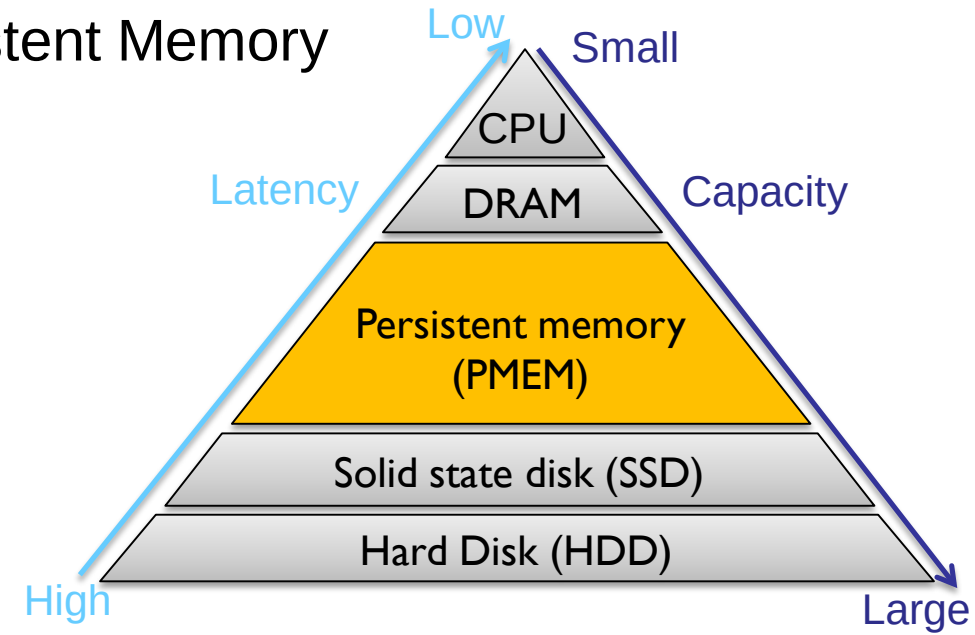
Background

- Persistent memory (PMEM) begins to be supplied
  - NVDIMM-N
  - Intel® Optane™ DC Persistent Memory

- PMEM features are:
  - Memory-like features
    - Low-latency
    - Byte-addressable
  - Storage-like features
    - large-capacity
    - non-volatile



Motivation

- Trying to rewrite storage applications since PMEM features are utilized
  - RDBMS (e.g. PostgreSQL)
  - Message queue systems (e.g. Apache Kafka)
  - etc.

- Let me share my challenges about PMEM
  - Implementation
  - Performance evaluation

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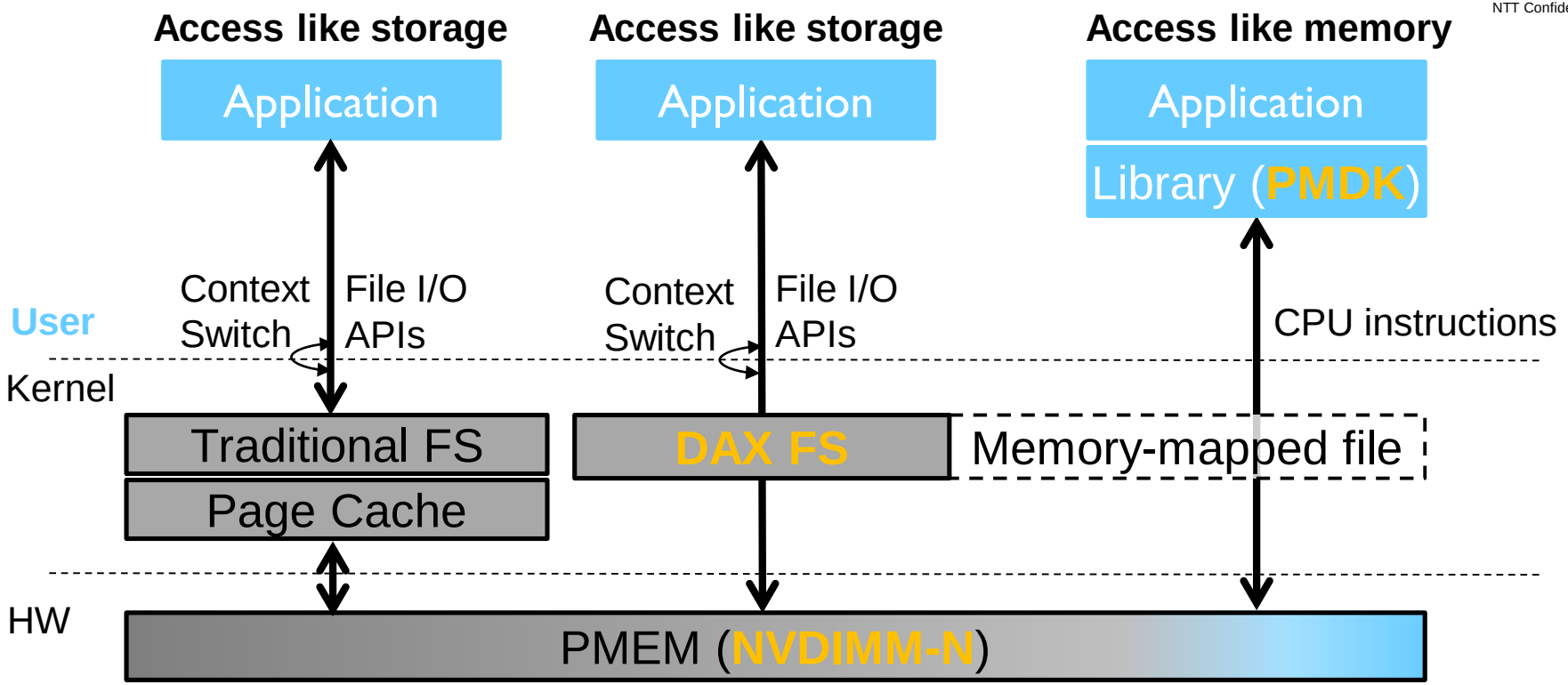
HW/SW components

- What kind of PMEM is used?
  - **NVDIMM-N**
- What Linux kernel support is necessary to use PMEM?
  - **Direct-Access for files (DAX)**
    - Supported by ext4 and xfs
- What user library is used?
  - **Persistent Memory Development Kit (PMDK)**

DAX FS and PMDK



Benefits of DAX FS and PMDK

- With DAX FS only
  - Not necessary to rewrite applications
- With DAX FS and PMDK
  - Necessary to rewrite applications
  - Performance of I/O-intensive workload is greatly improved

PMDK features

- Application accesses PMEM like memory
  - Memory-mapped file (mmap file)
- Application developers can select fine-grained sync size
  - Details are on the next slide
- CPU instructions suitable for copy data size are selected
  - 8 / 16 / 32 / 64 bytes registers
  - MOVNT & SFENCE
    - without CPU caches

PMDK sync function

- pmem_msync()
  - File metadata and written data are flushed
    - pmem_msync() calls msync syscall
    - msync syscall is general sync API for mmap file
- pmem_drain()
  - Only written data is flushed
  - pmem_drain() is faster than pmem_msync()

	pmem_msync()	Pmem_drain()
Durability	○ (Flush file metadata and written data)	△ (Flush written data only)
Performance	×	○

Implementing application with PMDK

- Trying to rewrite storage applications with PMDK
  - RDBMS – PostgreSQL (PG)
  - Message queue systems - Apache Kafka

- Let me share know-how gained by rewriting PG
  - Checkpoint file
    - Many writes occur during checkpoint
  - Write ahead logging (WAL)
    - Critical for transaction performance

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4. Challenges for implementation

1. How to resize checkpoint file
2. How to select sync function for WAL

4. Challenges for implementation

1. **How to resize checkpoint file**
2. How to select sync function for WAL

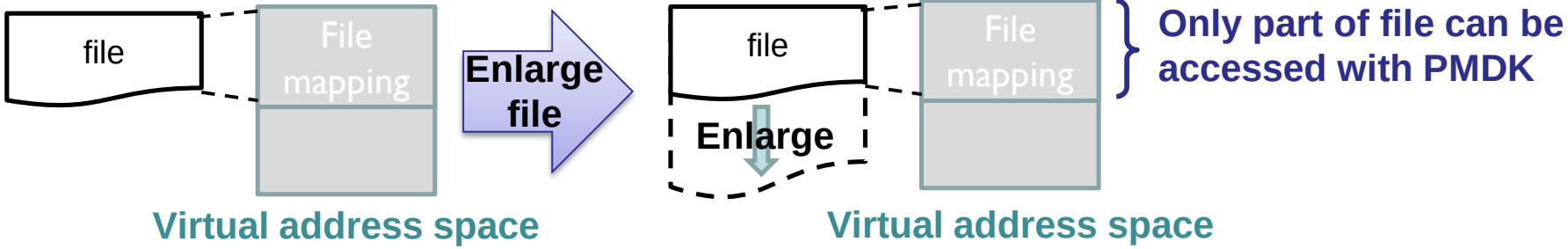
Resizing checkpoint file

- Huge table and so forth consist of multiple checkpoint files
  - Variable length up to 1GB
  - Necessary to resizing checkpoint file

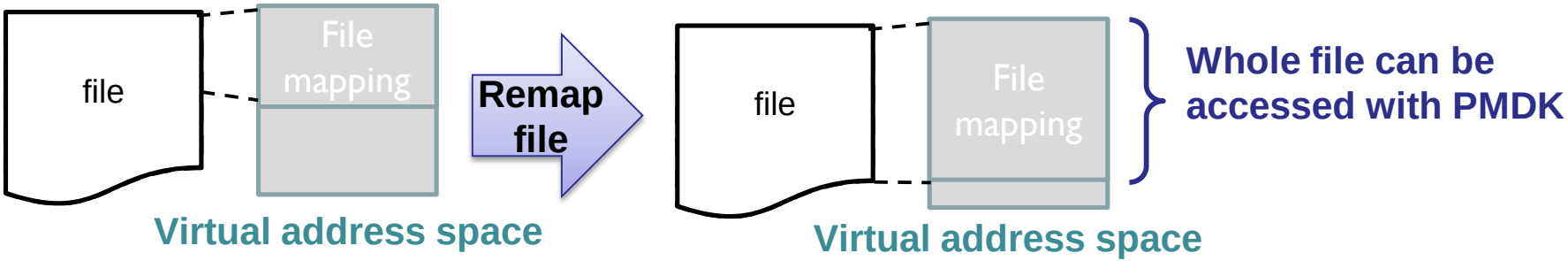
- PMDK provides APIs for mmap file
  - Difficult to resize mmap file without overhead
  - Best practice is to access only fixed-size file
    - We changed how to access only 1GB checkpoint file

How to resize mmap file

- Enlarge file



- Remap file



Implementation to enlarge file

- 3 function calls are added to use PMDK

	DAX FS	DAX FS and PMDK
Open	`fd = open(path, ...);`	`addr1 = pmem_map_file (path, len1, ...);`
Unmap		`pmem_unmap(addr1, len1);`
Extend		`truncate(path, len2);`
Remap		`addr2 = pmem_map_file (path, len2, ...);`
Close	`close(fd);`	`pmem_unmap(addr2, len2);`

Implementation to shrink file

- 2 function calls are added to use PMDK

	DAX FS	DAX FS and PMDK
Open	`fd = open(path, ...);`	`addr1 = pmem_map_file (path, len1, ...);`
Unmap		`pmem_unmap(addr1, len1)`
Shrink	`ftruncate(fd, len2);`	`truncate(path, len2);`
Remap		`addr2 = pmem_map_file (path, len2, ...);`
Close	`close(fd);`	`pmem_unmap(addr2, len2);`

Resizing file with PMDK

- Difficult to use PMDK unless file size is fixed
  - Repeating remapping many times degrades performance
    - Remapping file has large overhead
      - By using PMDK, munmap() /close()/open()/mmap() syscall is called again
  - Mapping large file may make file system full
- Best practice is to use fixed-size file only

4. Challenges for implementation

1. How to resize checkpoint file
2. **How to select sync function for WAL**

Selecting sync function for WAL

- How to write log to WAL file
  - Initialization – create file and fill file with zero
    - Necessary to flush file metadata
  - Synchronous logging - sequential synchronous write
    - Necessary to flush only written data

- PMDK sync APIs
  - pmem_msync() – file metadata and written data are flushed
  - pmem_drain() – only written data is flushed

PMDK sync function for WAL

- Initialization of WAL file
  - Necessary to flush WAL file metadata
  - pmem_msync()

- Synchronous logging
  - Necessary to flush only written data
  - pmem_drain() or pmem_msync()
    - pmem_drain() is faster than pmem_msync()
    - We selected pmem_drain()

Comparing PMDK sync functions

- I ran microbenchmark to compare pmem_msync() to pmem_drain()
  - Preprocessing
    - WAL initialization
    - Create file and fill file with zero and flush file metadata
  - Measurement processing
    - Synchronous logging
    - Overwrite data and flush written data

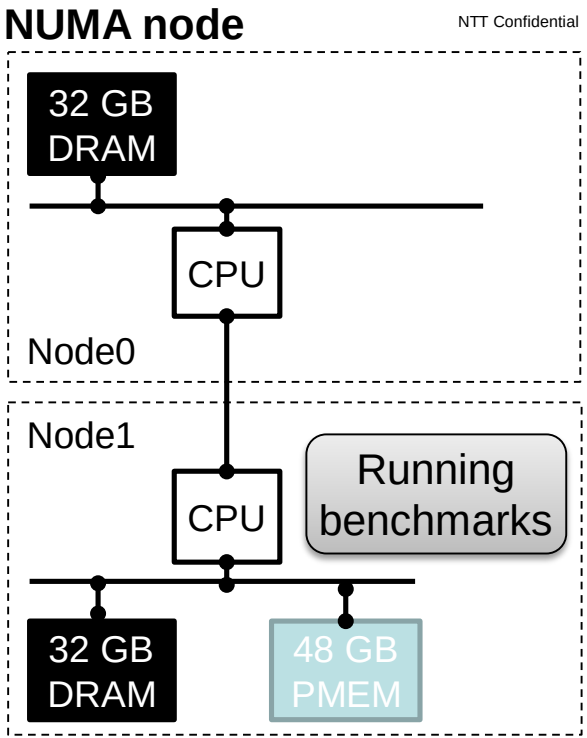
Microbenchmark

- Synchronous logging

	1. DAX FS fdatasync()	2. DAX FS and PMDK pmem_msync()	3. DAX FS and PMDK pmem_drain()
Open	open()	**pmem_map_file()**	**pmem_map_file()**
	while () {	while () {	while() {
Write	write()	**pmem_memcpy_nodrain()**	**pmem_memcpy_nodrain()**
Sync	**fdatasync()**	**pmem_msync()**	**pmem_drain()**
Loop N	}	}	}
Close	close()	**pmem_unmap()**	**pmem_unmap()**

Evaluation setup

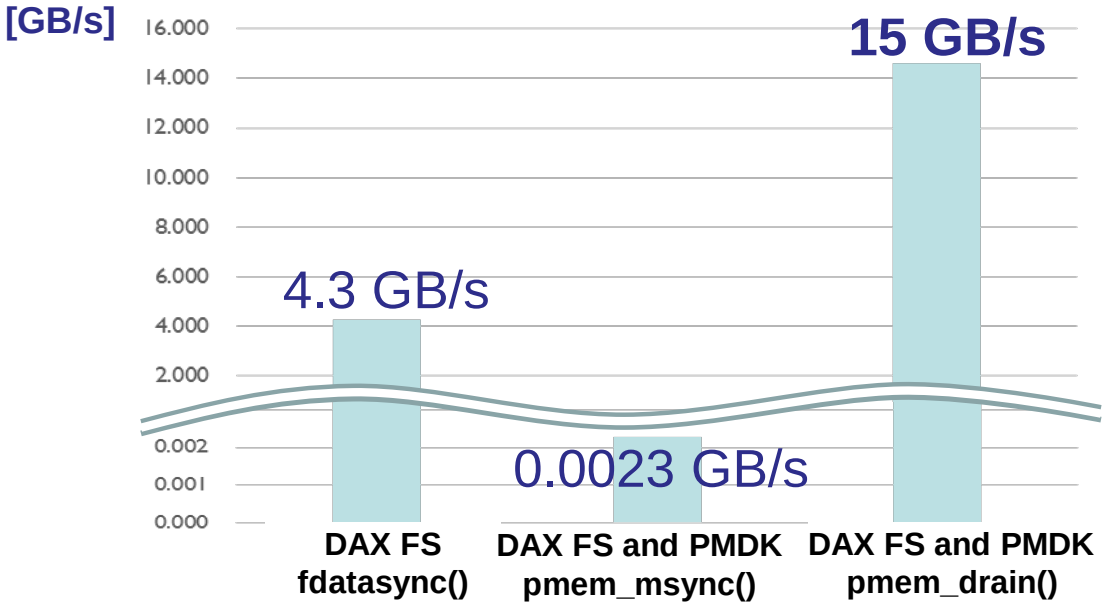
Hardware	
CPU	E5-2667 v4 x 2 (8 cores per node)
DRAM	[Node0/1] 32 GB each
PMEM (NVDIMM-N)	[Node1] 48 GB (HPE 8GB NVDIMM x 6)
Software	
Distro	Ubuntu 16.04
Linux kernel	4.17.9*
PMDK	1.4.1
Filesystem	ext4 (DAX available)



*: git://git.kernel.org/pub/scm/linux/kernel/git/stable/linux.git

Performance evaluation - microbenchmark

- pmem_drain() is fastest of 3 patterns as expected



- Total written data is 10 GB
- Block is 8 KB

PMDK sync functions

- pmem_drain() greatly improves performance of I/O-intensive workload

- You should use pmem_drain() with caution
  - pmem_drain() can’t flush file metadata
    - pmem_msync() should be called by application that uses file metadata such as
      - Time of last modification
      - Time of last access
  - pmem_drain() doesn’t work without pmem_memcpy_nodrain()

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5. Challenges for performance evaluation

- Difficult to get valid results in PG performance evaluation

- What is valid result?
  - Avoid Non-Uniform Memory Access (NUMA) effects
  - Avoid CPUs becoming hotspots
    - tuning application for PMEM

5. Challenges for performance evaluation

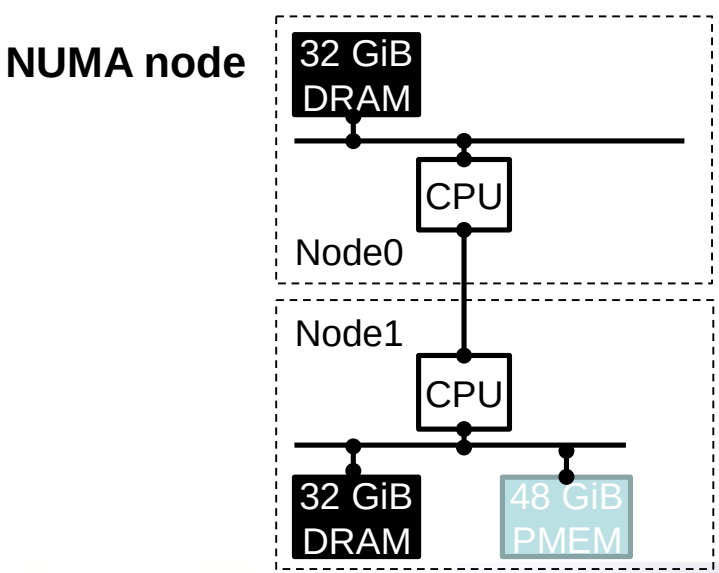
1. NUMA effect
2. Tuning application for PMEM

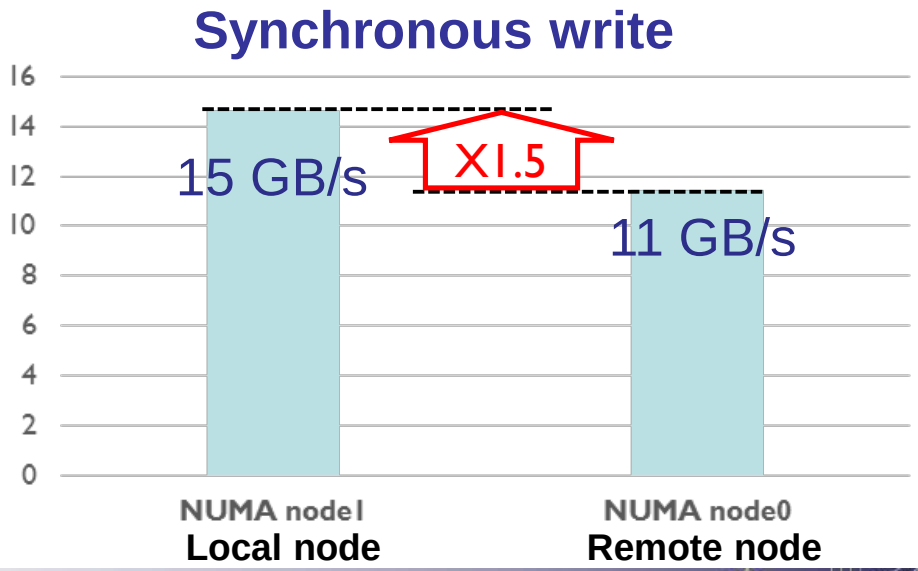
5. Challenges for performance evaluation

1. **NUMA effect**
2. Tuning application for PMEM

NUMA effect

- Synchronous write is about 1.5 times faster on local NUMA node than on remote NUMA node





5. Challenges for performance evaluation

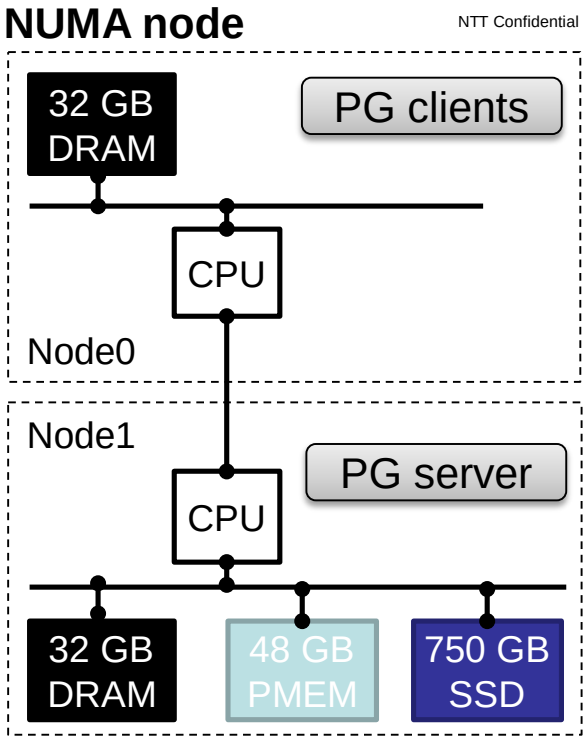
1. NUMA effect
2. **Tuning application for PMEM**

Tuning application for PMEM

- Important to avoid calculation processing becoming hotspot
  - Better to use Stored Procedure in PG
    - Stored Procedure improves PG performance since user-defined functions are pre-compiled and stored in PG serve
    - pgbench -c 16 -j 16 -T 1800 -r [db_name] **-M prepared**

Evaluation setup

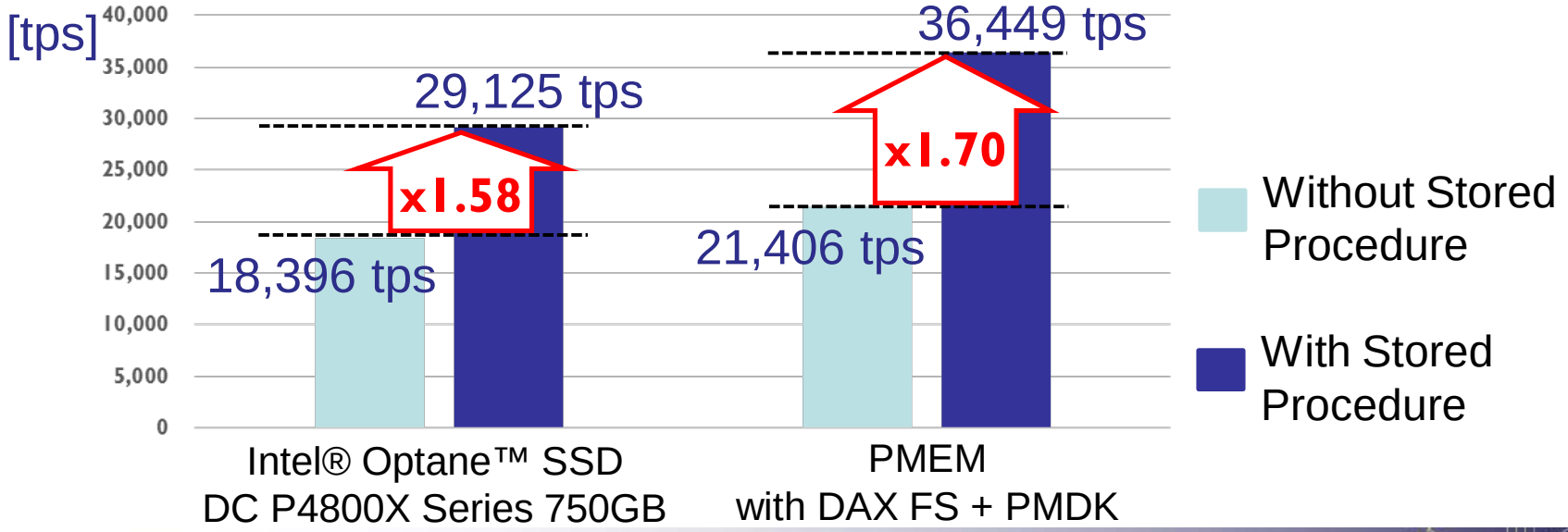
Hardware	
CPU	E5-2667 v4 x 2 (8 cores per node)
DRAM	[Node0/1] 32 GB each
PMEM (NVDIMM-N)	[Node1] 48 GB (HPE 8GB NVDIMM x 6)
SSD	Intel® Optane™ SSD DC P4800X Series 750GB
Software	
Distro	Ubuntu 16.04
Linux kernel	4.17.9
PMDK	1.4.1
Filesystem	ext4 (DAX available)
PostgreSQL	10.4 Beta*



*: https://www.postgresql.org/message-id/C20D38E97BCB33DAD59E3A1%40lab.ntt.co.jp

Stored Procedure

- Improvement ratio using PMEM is improved by 12% compared with using SSD



Conclusion

- Difficult to implement PMEM aware applications
  - Resizing file with overhead
    - Best practice is to access only fixed-size file
  - Selecting inappropriate sync function seriously degrades performance or durability

- Difficult to get valid results in performance evaluation
  - Avoiding NUMA effect
  - Avoiding CPUs becoming hotspots