Introducing Optane DC Persistent Memory

Technical Solution Specialist
Fumiyasu Ishibashi
MEMORY AND STORAGE HIERARCHY GAPS

THE CAPACITY GAP
Big and Affordable Memory
- 128, 256, 512GB Modules
- DDR4 Pin Compatible

Byte Addressable
- Direct Load/Store Access

High Performance Storage
- Native Persistence

High Reliability and Security

Two Operational Modes
INTEL® OPTANE™ MEDIA TECHNOLOGY

Cross-Point Structure
Selectors allow dense packing
And individual access to bits

High Resistivity – ‘0’
Low Resistivity – ‘1’

Attributes
+ Non-volatile
+ Potentially fast write
+ High density
+ Non-destructive fast read
+ Low voltage
+ Integratable w/ logic
+ Bit alterable

Breakthrough Material Advances
Compatible switch and memory cell materials

Scalable
Memory layers can be stacked in a 3D manner

First Generation Capacities:
128 GB
256 GB
512 GB

High Performance
Cell and array architecture that can switch fast

Intel® Optane™ Media Technology
MORE TO BE GAINED BY BEING ON MEMORY BUS

IDLE AVERAGE RANDOM READ LATENCY

- Hardware latency
- Software latency

IDLE AVG. IS ABOUT 10µS FOR 4KB

MEMORY SUBSYSTEM IDLE AVG. IS ABOUT ~100ns TO ~340ns FOR 64B²

MEMORY SUBSYSTEM WITH INTEL® OPTANE™ DC PERSISTENT MEMORY

Performance results are based on testing as of July 24, 2018 set forth in the configurations and may not reflect all publicly available security updates. See configuration disclosure for details. No product can be absolutely secure. For more complete information about performance and benchmark results, visit www.intel.com/benchmarks.
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For more complete information about performance and benchmark results, visit www.intel.com/benchmarks.

Measurement notes:
- For SSDs Random 4KB Accesses over entire SSD, Read latency measured per 4kB access
- For Intel® Optane™ DC Persistent Memory Random 256B accesses Over entire module 256B random accesses w/ read latency measured per 64B access
• Intel® Optane™ DC persistent memory is programmable for different power limits for power/performance optimization
  • 12W – 18W, in 0.25 watt granularity - for example: 12.25W, 14.75W, 18W
• Higher power settings give best performance
• Performance varies based on traffic pattern
• Contiguous 4 cacheline (256B) granularity vs. single random cacheline (64B) granularity
• Read vs. writes

### PERFORMANCE DETAILS

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<th>Granularity</th>
<th>Traffic</th>
<th>Module</th>
<th>Bandwidth</th>
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<tr>
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COMPLETE SYSTEM ON A MODULE

- **PMIC**: Generates all the rails for media and controller
- **SPI Flash**: Where FW is saved
- **Intel® Optane™ media**: 11 parallel devices for data + ECC + spare
- **DQ buffers**: Need for high bit rate signal integrity
- **AIT DRAM**: Where address indirection table lies
- **Energy store caps**: Ensures flushing of all module queues at power fail

**Intel® Optane™ DC Persistent Memory Controller**

- **Media Access**
- **Media Interface**
- **Microcontroller**
  - AES-XTS 256 encryption
  - ECC engine
  - Buffers
  - Scheduler
  - AIT management
- **DDR-T Interface**
- **SMBus, SPI GPIO**
- **Power and Thermal Control**
- **AIT DRAM I/F**
- **DRAM**
- **C&A Bus**
- **64B Transfers**
- **DQ Buffers**
- **SPI**
- **SMBus**
- **PMIC**
- **2nd Generation Intel® Xeon® Scalable Processor Gold & Platinum SKUs**
DESIGNED TO PROVIDE DATA AT REST SECURITY

HARDWARE-ENCRYPTED MEMORY

- Full module protection using 256b AES-XTP encryption engine on board
- Security keys are stored on module in hardware
- Secure cryptographic erase and module over-write for secure repurposing or discard
- Firmware authentication and integrity
MEMORY LEVEL ENDURANCE

Endurance targets are spec'd in Petabytes Written (PBW)

Example Intel® Optane™ DC Persistent Memory

Endurance in PBW @15W (4 CL) 256GB

Let's do the math:
PBW for 100%wr
= BW*%write*3600s/hr*24hr*356days/yr*5years/1e6
= 2.3*3600*24*356*5
= 353.72PBW

ENDURANCE FOR THE ENTERPRISE

Usage reporting through SMART registers
5-year product warranty

From Datasheet

<table>
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<th>Bandwidth</th>
<th>Bandwidth 100% READ 15W 256B</th>
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TWO OPERATIONAL MODES

MEMORY MODE

- Load/Store
- CORE
  - L1I
  - L1D
  - L2 Cache
- L3 CACHE
- DDR4 Cache
  - DDR4 Cache Hit
  - DDR4 Cache Miss

APPLICATION DIRECT MODE

- Load/Store
- CORE
  - L1I
  - L1D
  - L2 Cache
- L3 CACHE
- DDR4

DATA PLACEMENT

- HW MANAGED
- SW MANAGED

PERSISTENCY

- VOLATILE
- PERSISTENT
**PERSISTENCY: EARLY ENGAGEMENT WITH INDUSTRY**

PERSISTENT MEMORY PROGRAMING MODEL
developed through SNIA

PERSISTENT MEMORY DESIGN KIT (PMDK)
available on [http://pmem.io](http://pmem.io)

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**Diagram Description:**
- **Management UI** connected to **Application** via **Management Library**.
- **File System** and **Pmem-Aware File System** with **Load/Store**.
- **Generic NVDIMM Driver** connects to **Persistence Memory**.
- **User Space** and **Kernel Space** interactions through **File** and **Memory**.
- **DAX** (Direct Access eXtension) file system API.
## SECOND GENERATION INTEL® XEON® SCALABLE PROCESOR

### OPTIMIZED FOR HIGHEST PER-CORE SCALABLE PERFORMANCE

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### FEATURING INTEL® SPEED SELECT TECHNOLOGY PROFILE (SST-PP, 3 IN 1)

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### NETWORKING/NFV SPECIALIZED (INTEL® SPEED SELECT-TP)

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### VIRTUAL MACHINE DENSITY VALUE SPECIALIZED

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### LONG-LIFE CYCLE AND HEATSINK-THERMAL FRIENDLY

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### SEARCH APPLICATION VALUE SPECIALIZED

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## Intel Persistent Memory Recommendations

### Population Guidelines

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<thead>
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<th>Population</th>
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<th>DRAM</th>
<th>AD</th>
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- **All Modes:**
  - Max 1 DCPMM per channel
- **Memory Mode (MM):**
  - Min 1 DRAM DIMM + 1 DCPMM per IMC
  - 8:1; 5.3:1; 4:1 DCPMM to DRAM populated
  - DCPMM total capacity counted ONLY. DRAM used as cache.
- **App Direct Mode (AD):**
  - Min 1 DCPMM anywhere on platform
  - DRAM and DCPMM additive for total capacity.

---

Sample Cascade Lake (CLX) Platinum/Gold Socket with Apache Pass (DCPMM)
A STRONG MEMORY & STORAGE FUTURE

**TODAY**

- **2ND GEN INTEL XEON SCALABLE (CASCADE LAKE)**
  - APACHE PASS
  - Intel® SSD DC P4800X (COLDSTREAM)
  - INTEL® 3D NAND SSD P46XX/P45XX

**FUTURE**

- **3RD GEN DC PERSISTENT MEMORY**
  - BARLOW PASS
  - ALDER STREAM
  - CLIFFDALE-R/ARBORDALE + (96-L, 144-L)

- **4TH GEN DC PERSISTENT MEMORY**
  - 3RD GEN DC PERSISTENT MEMORY
  - NEXT GENERATION
  - NEXT GENERATION

For each processor above, Intel® Optane™ DC Persistent Memory will be supported on select SKUs.
Growing Global Ecosystem for

Software

CSPs & COSPs

OEMS & SIs
USECASE-DATABASE
SAP HANA controls what is placed in Persistent Memory and what remains in DRAM

- Volatile data structures remain in DRAM
- Column Store Main moves to Persistent Memory
  - DIMM form-factor, replacing DRAM
  - Could be configured for each table, partition, or column
  - Loading of tables into memory at startup becomes obsolete
  - Lower TCO, larger capacity
- No changes to the persistence

SAP HANA Main Store relocated to larger persistent memory to achieve lower TCO

**FASTER RESTART TIMES**

**INCREASED MEMORY CAPACITY**
**Oracle Exadata: Persistent Memory Accelerator for OLTP**

- Exadata Storage Servers will add Persistent Memory Accelerator in front of Flash memory
- **RDMA** bypasses the software stack, giving 10X faster access latency to remove Persistent Memory
- Persistent Memory mirrored across storage servers for fault-tolerance
- Persistent memory used as a shared cache effectively increases its capacity 10X vs using it directly as expensive storage
- Log Writes will use RDMA to achieve super fast commits

*10X lower latency*
USECASE- STORAGE
**NetApp MAX Data**

- **NetApp MAX Data** runs on servers equipped with 2nd Generation Intel® Xeon® Scalable processors and Intel Optane DC persistent memory.
- **NetApp MAX File System** (FS) for Optane and auto tiering.
- Your applications don’t require any changes (App Direct mode).

---

**Application Server**

- Application
  - NetApp MAX Data* with NetApp Max FS*

**Memory Tier**

- Intel® Optane DC Persistent Memory
- DRAM

**Storage Tier**

- NetApp AFF A-Series* and NetApp AFF8000* Series All Flash Arrays
MAX Recovery enables memory-to-memory replication between the MAX Data Server and the MAX Recovery server.

MAX Recovery enables recovery in minutes instead of hours.

Four MAX Data servers can replicate to a single MAX Recovery server.
ORACLE*®, INTEL® OPTANE™ DC PERSISTENT MEMORY, AND NETAPP MAX DATA* PERFORMANCE SUMMARY

IOPS 2X HIGHER THROUGHPUT

Oracle 18c—75% Select
Without MAX DATA: 205,000
MAX DATA: 415,000

LATENCY 16X LOWER

Oracle 18c—75% Select
Without MAX DATA: 810
MAX DATA: 50
DAOS: DISTRIBUTED ASYNCHRONOUS OBJECT STORAGE

A new open-source, high-performance storage software solution architected for DCPMM

- Small I/Os are stored in Intel Optane DC persistent memory
- Bulk I/Os go straight to the NVMe SSDs
- Built entirely in userspace

DAOS Storage Engine

- Low-latency, high-message-rate communications
- Collective operations & in-storage computing

- Metadata, low-latency I/Os & indexing/query
- Persistent Memory Development Kit
- NVMe Interface
- Bulk data
- Storage Performance Development Kit

- Intel Optane DCPMM
- 3D NAND/ XPoint™ Storage
Customer: Argonne National Laboratory supports about 3,500 researchers with a billion-dollar budget each year and spearheads scientific research in disciplines like physics, chemistry, genomics and more.

Challenge: Deploying Aurora, the first exascale supercomputer in the United States, represents an enormous undertaking. The complexity of next-generation research and engineering requires a system offering the prowess to tackle workloads involving massive data sets like advanced simulation and modeling, artificial intelligence and data science.

Solution: Working closely with Intel and Cray, the Argonne team collaborated to design and implement Aurora's exascale architecture. Scheduled for deployment in 2021, Aurora will feature future Generation Intel® Xeon® Scalable processors, Intel's Xe compute architecture, future Intel® Optane™ DC persistent memory and Intel® One API.

“What excites me most about exascale systems like Aurora is the fact that we now have, in one platform and one environment, the ability to mix simulation and artificial intelligence. This idea of mixing simulation and data-intensive science will give us an unprecedented capability, and open doors in research which were inaccessible before, like cancer research, materials science, climate science, and cosmology.”

Rick Stevens, associate laboratory director for computing, environment and life sciences at Argonne National Laboratory and professor of computer science at the University of Chicago
USECASE-VIRTUALIZATION
## When Is VM Memory Expansion a Good Fit for Your Customer?

<table>
<thead>
<tr>
<th>GOOD FIT</th>
<th>NOT A GOOD FIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>When CPU utilizations are low, to use untapped server potential</td>
<td>If DRAM capacity not limiting app density (i.e. small VM size)</td>
</tr>
<tr>
<td>Read versus Write ratios are high</td>
<td>Workloads that require ultimate performance</td>
</tr>
<tr>
<td>Where cost for performance is a primary motivation</td>
<td>If higher VM density (or more VM's) is not required</td>
</tr>
</tbody>
</table>
# VMware ESXi VMMark for Incremental Memory

## Workload – Increase VMs per Node

<table>
<thead>
<tr>
<th>DDR4 DRAM ONLY</th>
<th>DDR4 DRAM + Intel® Optane™ DC Persistent Memory</th>
<th>Memory Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DO MORE</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>768 GB DDR4 DRAM</td>
<td>192 GB DDR4 DRAM + 1 TB Intel® Optane™ DC Persistent Memory</td>
<td>up to 33% more memory&lt;sup&gt;1&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>152 VMs</strong></td>
<td><strong>190 VMs</strong></td>
<td>up to 25% more VMs per node&lt;sup&gt;1,2&lt;/sup&gt;</td>
</tr>
<tr>
<td>~$80 USD</td>
<td>~$69 USD</td>
<td>up to 14% lower estimated HW cost per VM</td>
</tr>
</tbody>
</table>

**CPU:** 2x Intel® Xeon® Gold 6252 Processor  
**Memory:** 768 GB DDR4 DRAM Memory

**SAVE MORE**

<table>
<thead>
<tr>
<th>DDR4 DRAM ONLY</th>
<th>DDR4 DRAM + Intel® Optane™ DC Persistent Memory</th>
<th>Memory Mode</th>
</tr>
</thead>
</table>
| **CPU:** 2x Intel® Xeon® Gold 6252 Processor  
**Memory:** 768 GB DDR4 DRAM Memory | **CPU:** 2x Intel® Xeon® Gold 6252 Processor  
**Memory:** 192 GB DDR4 DRAM Memory + 1 TB Intel® Optane™ DC Persistent Memory |              |

## More, Affordable Memory = Lower Cost per VM

Performance results are based on testing as of 4/02/2019 and may not reflect all publicly available security updates. See configuration disclosure for details. No product can be absolutely secure. For more complete information about performance and benchmark results, visit www.intel.com/benchmarks. Configuration: See VMware VMMark config slide.
A COMPLETE HIERARCHY

- Intel® OPTANE™ PERSISTENT MEMORY
  - Brings more data into memory
- Intel® OPTANE™ SSDs
  - Bring storage closer to the processor
- Intel® QLC 3D NAND SSDs
  - Brings more data into solid state storage

Compute Cache

In Package Memory

DRAM

Persistent Memory

Performance Storage

NAND SSD

Intel® 3D NAND

HDD-TAPE
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