The Future of Intel® Optane™ Persistent Memory

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Data is Fueling Digital Transformation

Growing and new workloads that are driving transformation

- Business intelligence
- Data security
- Artificial intelligence (AI) and machine learning (ML)
- Predictive analytics
- Massive datasets
- Transactional processing
- Real-time analytics

New capabilities from transformation

- Deliver business value in real time
- Minimize risk and increase future opportunities
- Highly parallel processing on large datasets
- Low latency for mission-critical transactions

175 ZB globally by 2025¹

²6% CAGR

Compound annual growth rate (CAGR)² in data

Adapting to the Changing Data Landscape

The data economy is fundamentally changing the workloads and infrastructure in the data center.

**Compute Demand Accelerating**

- Phase 1: Density increase ~4X/3 years
- Phase 2: Density increase ~2X/2 years
- Phase 3: Density increase ~2X/4 years

**DRAM is Not Scaling**

- **Phase 1**: Density increase ~4X/3 years
- **Phase 2**: Density increase ~2X/2 years
- **Phase 3**: Density increase ~2X/4 years

**Gap Between Data and Memory Capacity is Increasing**

- Memory Need Growth
- DRAM Scaling

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1. Source for “Compute Demand Accelerating” Intel Market Intelligence Group
2. Source for “DRAM is Not Scaling”: 3D NAND Technology – Implications for Enterprise Storage Applications” by J.Yoon (IBM), 2015 Flash Memory Summit
3. Source: Data Age 2025, sponsored by Seagate with data from IDC Global DataSphere, Nov 2018
Vision of 2-Tier Memory / Storage for PMem

Intel® Optane™ persistent memory can help memory and storage applications!
More to be Gained by Being on Memory Bus

Average Lightly Loaded Random Read Latency\(^1\)

<table>
<thead>
<tr>
<th>Storage</th>
<th>Hardware latency</th>
<th>Software latency</th>
</tr>
</thead>
<tbody>
<tr>
<td>With Intel® 3D NAND SSD P5600</td>
<td>~6μs for 4kB</td>
<td></td>
</tr>
<tr>
<td>With Intel® Optane™ SSD P5800X w/SPDK</td>
<td>~100ns to ~340ns for 64B(^2)</td>
<td></td>
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</tbody>
</table>

Memory Subsystem
Average ~100ns to ~340ns for 64B\(^2\)

Performance results are based on testing as of September 25, 2020. Performance varies by use, configuration and other factors, for details, see Slide 12. Learn more at www.Intel.com/PerformanceIndex.
A Strong Memory and Storage Future

2019
- 2nd Generation Intel® Xeon® Scalable processors
- Intel® Optane™ Persistent Memory 100 series

2020
- 3rd Generation Intel Xeon Scalable processors (Cooper Lake)
- Intel Optane Persistent Memory 200 series

2021
- 3rd Generation Intel Xeon Scalable processors (Ice Lake)

Future
- Future Intel Xeon Scalable processors (Sapphire Rapids)

- Future Intel Optane Persistent Memory (Crow Pass)

- Next Generation Intel Optane Persistent Memory
Intel® Optane™ Persistent Memory (PMem) 200 Series

Affordable memory capacity for many applications

Maximize capacity with new persistent memory tier

Intel® Optane™ Persistent Memory – a Solution on a DIMM

Supporting 3rd Gen Intel® Xeon® Scalable processors

- up to 6 TB Total memory per socket
- avg. 25% Higher memory bandwidth vs prior generation
- approx. 3 W Typical power reduction, watts per module
- with eADR Support to improve app performance

Memory Mode

- Unmodified Application
- Unmodified OS/VMM
- Intel Xeon Scalable Processors
- Cores
- Memory Controller
- DRAM as Cache
- Volatile Memory

App Direct Mode

- PMem Aware Software
- PMem Aware OS
- Intel Xeon Scalable Processors
- Cores
- Memory Controller
- DRAM Memory
- Persistent Memory

Enhanced Asynchronous DRAM Refresh (eADR)

Available on Intel® Optane™ persistent memory 200 series with 3rd Gen Intel® Xeon® Scalable processors

**System Level Optimization**

- eADR automatically flushes caches eliminating CLFlush runtime use/overhead (Requires: Barlow Pass, Energy Store, App support)

**Persist the CPU caches**
- No cache flush; stores are considered persistent as soon as they are visible
- Free up resources, avoid waiting for flushes to complete

**Applications with mapped data in PMem will benefit**
- Databases
- Transactional processes
- Mission critical data handling
- High performance apps using lock-free or non-blocking algorithms

**Immediately available with PMDK**

Immediate availability with PMDK

Available on Intel® Optane™ persistent memory 200 series with 3rd Gen Intel® Xeon® Scalable processors
A Growing Ecosystem for Intel® Optane™ Technology

Software

CSPs & COSPS

OEMs & SIs

Other names and brands may be claimed as the property of others.
## Intel® Optane™ Persistent Memory
Delivering Real World Benefits

<table>
<thead>
<tr>
<th>Customer Traction Since Launch</th>
<th>Over 200 Fortune 500</th>
<th>Over 85% POC to Sale Conversion</th>
<th>Over 475 Production Wins</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TCO Savings</strong></td>
<td><strong>Increased Throughput</strong></td>
<td><strong>Faster Time to Insights</strong></td>
<td></td>
</tr>
<tr>
<td>1.3X improvement in TCO (Redis)</td>
<td>~3X improvement in jobs per physical host ratio</td>
<td>8X faster solver run compared to Lustre filesystem</td>
<td></td>
</tr>
<tr>
<td>30% reduction in recommendation system &amp; Redis service</td>
<td>2.78X increase in games hosted on a single server</td>
<td>80% latency reduction &amp; 3X accelerated indexing (Elasticsearch)</td>
<td></td>
</tr>
<tr>
<td>15X reduction in memory for image processing</td>
<td>1.1X increase in CPU utilization vs. DRAM-only</td>
<td>15X faster database data load startup (SAP HANA)</td>
<td></td>
</tr>
<tr>
<td>22.5%-48% improvement in TCO (Redis)</td>
<td>~2X VM instantiation for 5G Multi-access Edge (Redis)</td>
<td>13.7X accelerated database startup (SAP HANA)</td>
<td></td>
</tr>
<tr>
<td>41% reduction on infrastructure cost</td>
<td>~40% more VMs &amp; containers within same budget (Redis)</td>
<td>up to 17X faster storage applications (RocksDB, MongoDB, mySQL)</td>
<td></td>
</tr>
</tbody>
</table>

Performance results are based on testing as of dates in configuration. Performance varies by use, configuration and other factors, for details, see Slide 13 & Slide 14. Learn more at www.Intel.com/PerformanceIndex.
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Results have been estimated or simulated.

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Configuration details – Intel® Optane™ P5800x, Intel® SSD D7-P5600, Intel® Optane™ PMem


Intel Optane PMem 100 Series – Tested by Intel on single DIMM configuration; Test date 09/25/2020. Intel® 2nd Gen Xeon® Scalable Processor Platform; Chipset LBG B1; CPU CLX QRL1 BO 28 Core (28276), 1S; DDR speed 2666 MT/s; Intel Optane PMEM 256GB module, 15W Memory configuration 1 channel, 32GB DDR4 (6 per socket), Intel Optane PMEM FW 1.2.0.5435; BIOS 0601.D02: BKC version WW02 BKC, Linux OS Fedora release 31 5.5.7-200.fc31; Spectre/Meltdown patched (1,2,3,3a); Performance Tuning QoS Disabled IODC=5(AD). Intel® Optane PMem uses DDR memory interface and MLC for performance measurements.

Intel Optane PMem 200 Series – Tested by Intel on single DIMM configuration; Test date 09/25/2020. Intel® 3rd Gen Xeon® Scalable Processor Platform; Chipset LBG B1; CPU CPX-6 QUC9 26 Core, 1S; DDR speed 2666 MT/s; Intel Optane PMEM 256GB module, 15W Memory configuration 1 channel, 32GB DDR4 (6 per socket), Intel Optane PMEM FW 2.2.0.1516; BIOS 007.P23; BKC version WW38 BKC, Linux OS Fedora release 29 4.20.6-200.fc29.x86_64; Spectre/Meltdown patched (1,2,3a,4); Performance Tuning QoS Disabled IODC=5(AD). Intel® Optane PMem uses DDR memory interface and MLC for performance measurements.

Average of 25% higher memory bandwidth vs prior gen:
Baseline: 1-node, 1x Intel® Xeon® B280L 28C @ 2.7GHz processor on Neon City with Single Pmem module config (6x32GB DRAM; 1x{128GB,256GB,512GB} Intel Optane Pmem 100 Series module at 15W) ucode Rev: 04002F00 running Fedora 29 kernel 5.18-200.fc29.x86_64, and MLC ver 3.8 with App-Direct. Source: 2020ww18_CPX_BPS_D1. Tested by Intel, on 27 Apr 2020. New configuration: 1-node, 1x Intel® Xeon® pre-production CPX6 28C @ 2.9GHz processor on Cooper City with Single PMem module config (6x32GB DRAM; 1x{128GB,256GB,512GB} Intel Optane Pmem 200 Series module at 15W), ucode pre-production running Fedora 29 kernel 5.18-200.fc29.x86_64, and MLC ver 3.8 with App-Direct. Source: 2020ww18_CPX_BPS_BG. Tested by Intel, on 31 Mar 2020.

Typical power reduction of approximately 3 Watts per module:
**Intel Optane Persistent Memory: Delivering Real World Benefits**

**Kingsoft Cloud REDIS service** *(self-defined workload)*: OS: Red Hat Enterprise Linux® 7.5 4.18.8-x86_64. Testing by Intel and Kingsoft Cloud completed on Jan 10, 2019. Security Mitigations for Variants 1, 2, 3 and L1TF in place. BASELINE: 2nd Gen Intel® Xeon® Platinum 8260 processor, 2.3 GHz, 24 cores, turbo, and HT on, BIOS 101B, 1536GB total memory, 12 slots / 64GB / 2666 MT/s / DDR4 LRDIMM, 1x 480GB / Intel® SSD DC S4500 + 1x 1TB / Intel® SSD DC P4500. NEW: 2nd Gen Intel® Xeon® Platinum 8260 processor, 2.3GHz, 24 cores, turbo and HT on, BIOS 101B, 1536GB total memory, 12 slots / 16GB / 2933 MT/s / DDR4 LRDIMM and 12 slot / 128 GB / Intel® Optane™ DC persistent memory, 1x 480GB / Intel® SSD DC S4500 + 1x 1TB / Intel® SSD DC P4500. For more complete information about performance and benchmark results, visit: https://www.intel.com/content/www/us/en/processors/optane/scalable/software-solutions/kingsoft-cloud-redis-service.html.

**Kuaishou Technology:** Test results are based on Kuaishou’s internal tests and evaluation. For more details, please contact Kuaishou https://www.intel.cn/content/www/cn/zh/architecture-and-technology/kuaishou-recommendation-system-and-redis-services-storage-upgrade.html.

**Max Planck:** 2x 6248 CPUs with 2-2-21256GB Apache Pass modules configured in memory mode. 32GBx12 DDR4 2666MHz RAM, CentOS® 7.6. For more complete information about performance and benchmark results, visit: https://www.intel.com/content/www/us/en/customer-spotlight/stories/max-planck-institute-customer-story.html.

**Ping An Cloud:** Total Cost of Ownership (TCO): This cost reduction data is derived from the joint calculation by of Ping An Cloud and Intel. For more complete information about performance and benchmark results, visit: https://www.intel.com/content/www/us/en/customer-spotlight/stories/ping-an-cloud-customer-story.html.

**SoftBank:** Results of the validation at SoftBank: Intel® Xeon® Silver 4114 processor: 40 cores with Intel® Hyper-Threading Technology enabled, 512 GB 1VM resource at 30VM capacity: 1.3 cores, 17.0 GB. Intel® Xeon® Gold 6222V processor: 80 cores with Intel® Hyper-Threading Technology enabled, 1536 GB 1VM resource at 60VM capacity: 1.3 cores, 25.6 GB. The information was described as of 13th December 2019. For more complete information about performance and benchmark results, visit: https://www.intel.com/content/www/us/en/customer-spotlight/stories/softbank-customer-story.html.

**CDW Canada StudioCloud:** Test results are based on StudioCloud internal tests and evaluation as of December 2019. For more complete information about performance and benchmark results, visit: https://www.cdw.ca/content/cdwca/en/industries/studiocloud.html.

**GPORTAL:** Baseline Configuration: Dell EMC PowerEdge R640 server; 2x Intel® Xeon® Gold 6154 processor @ 3.0 GHz (18 cores/36 threads); 768 GB DDR4; BIOS = 2.3.10; OS = Linux. Results: 180 Minecraft game instances DUT Configuration: Dell EMC PowerEdge R640 server; 2x Intel® Xeon® Platinum 8268 processor @ 2.90 GHz (24 cores/48 threads); 12 x 32 GB DDR4 + 12 x 128 GB Intel® Optane™ DC persistent memory modules; BIOS = 2.3.10; OS = Linux. Results: 500 Minecraft game instances. Testing by GPORTAL as of 5 December 2019.

**Nitrodo:** Testing by Nitrodo as of February 7, 2019. All-DRAM configuration: dual-socket Intel® Xeon® Gold 6148 processor (8x 64 GB DDR4-2666 DRAM), total memory installed = 512 GB. System memory available = 512 GB. Number of Minecraft instances: 182. CPU utilization: 40%. DRAM + Intel® Optane™ DC persistent memory configuration: dual-socket Intel® Xeon® Gold 6252 processor (12x 128 GB (1.5TB) Intel® Optane™ OC persistent memory plus 12x 16 GB (192 GB) DDR4-2400 DRAM), total memory installed = 1,692 GB. System memory available = 1,536 GB. Number of Minecraft instances: 500. CPU utilization: 85%. Results were extrapolated from Nitrodo’s testing data. For more complete information about performance and benchmark results, visit: https://www.intel.com/content/www/us/en/customer-spotlight/stories/nitrodo-online-gaming-customer-story.html.


**EFC:** Performance results provided by EFC and may not reflect all released security updates. No product can provide absolute security. For more complete information about performance and benchmark results, visit: https://www.intel.com/content/www/us/en/customer-spotlight/stories/edinburgh-parallel-computing-center-customer-story.html.

Intel Optane Persistent Memory: Delivering Real World Benefits (CONT)

**Siemens:** 15X faster database data load at startup performance results are based Siemens testing in April 2019 and may not reflect all released security updates. No product can provide absolute security. For more complete information about performance and benchmark results, visit https://www.intel.com/content/www/us/en/customer-spotlight/stories/siemens-in-memory-processing-customer-story.html.

**T-Systems:** Testing by T-Systems as of March 18, 2019. Baseline Configuration Hardware: HPE Superdome Flex* server with 4x CPU sockets (Intel® Xeon® Platinum processor Beta 8276M 2.20 GHz ; Memory = 4x6 256 GB Intel® Optane™ DC persistent memory (6 TB) - DEACTIVATED and 4x6 64 GB DDR4 Memory (1.5 TB) for a total memory configuration of 1.5 TB Software: Database: SAP S/4HANA* 2.0 SPS4 rev. 40 installation with BW-Benchmark workload Re-start time: 10,248 seconds (approximately 2.85 hours) Proof of Concept Configuration Hardware: HPE Superdome Flex* server with 4x CPU sockets (Intel® Xeon® Platinum processor Beta 8276M 2.20 GHz ; Memory = 4x6 256 GB Intel® Optane™ DC persistent memory (6 TB) and 4x6 64 GB DDR4 Memory (1.5 TB) for a total memory configuration of 7.5 TB Software: Database: 4 TB SAP S/4HANA* database in App Direct Mode; OS: Standard SUSE Linux Enterprise Server* 12 Service Pack 4 microcode = 0xb00002e; kernel = Linux 4.12.14-95.16, standard NetApp cDot*-based storage used for persistence; SAP HANA 2.0 SPS4 rev. 40 installation with BW-Benchmark workload Re-start Time: 748 seconds (approximately 12.47 minutes). For more complete information about performance and benchmark results, visit https://www.intel.com/content/www/us/en/customer-spotlight/stories/t-systems-in-memory-database-customer-story.html.

**UC San Diego:** Testing conducted by UC San Diego as of August 8, 2019. For more complete information about performance and benchmark results, visit https://arxiv.org/pdf/1903.05714.pdf.