

# Affordably Accommodate the Next Wave of Data Demands

How to reach beyond DRAM and NAND limitations with the ROI-boosting benefits of Intel® Optane™ persistent memory and Intel® Optane™ SSDs



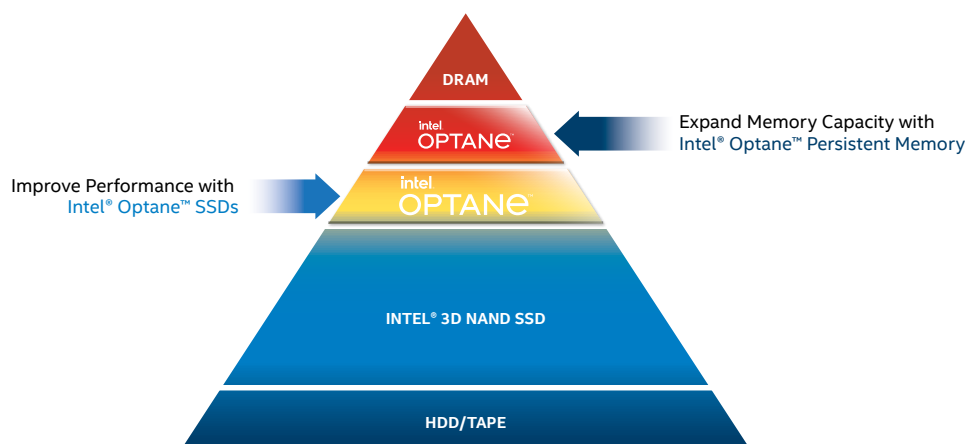
## Executive Summary

As the volume of global data continues to rise exponentially, the world's cloud infrastructures, where much of that data will reside, must either adapt or be overwhelmed. Traditional memory and storage architectures often prove too limited in capacity or performance for conventional real-time data demands.

Intel® Optane™ persistent memory and Intel® Optane™ SSDs help address the performance and capacity gap that exists between DRAM and NAND storage. By combining groundbreaking Intel® Optane™ technology media with new software, users can employ various configuration modes to achieve a range of benefits, including:

- Massively expanded total system memory capacities
- High virtual machine (VM) density, enabling more VMs per server and/or total server count consolidation
- High application performance partially due to less need for disk swapping
- New tiering possibilities from responsive storage
- Persistent memory for remarkably fast system recovery

Intel Optane persistent memory and SSDs provide an affordable, reliable solution for enabling data center and cloud applications with the capacity and performance needed to accommodate the coming generation of data demands.



**Figure 1.** Between fast memory and high-capacity storage, a broad gap has held back storage capabilities in core data applications. Intel® Optane™ technology solutions now address those needs.

## Business Challenge

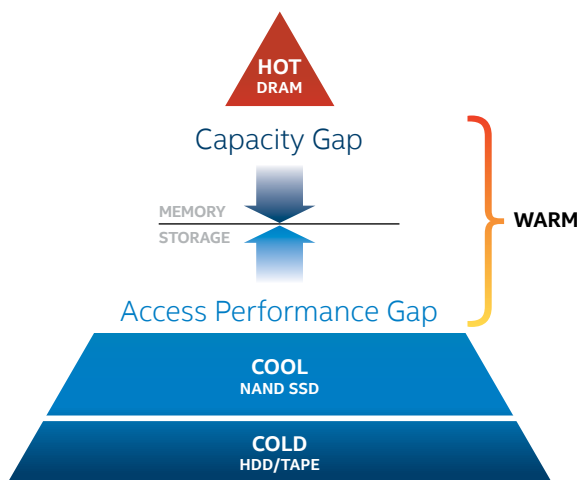
To paraphrase Einstein, the technologies that brought us to today will not solve the problems of tomorrow. Organizations need a fundamental improvement in how they process data to keep pace with the rising volume, speed, and complexity of workloads. This need stems from a range of macro-level, industry-defining trends, starting with the explosive growth of global data. According to IDC, the world will create more than three times more data over the next five years than in the previous five.<sup>1</sup> Within that rising tide, productivity/embedded data will comprise 29 percent of all global data by 2024, marking a compounded annual growth rate (CAGR) of 40 percent.<sup>2</sup> By 2025, nearly half of the world's data will be stored in the cloud, enabling 30 percent of all data to be available in real time as it is created.<sup>3</sup> Thus, global need focuses on both the capacity to store all this data as well as ensuring that storage has the speed to provide real-time responsiveness.

According to Cisco, many factors fuel this data explosion:<sup>4</sup>

- 5G rollouts beginning in 2020
- IoT connections will double (to 28.5 billion) by 2022
- Internet gaming traffic will expand by 9x from 2017 to 2022
- Video surveillance will grow by 7x from 2017 to 2022
- Virtual and augmented reality traffic will experience 65 percent CAGR over the same five years

From now until 2025 is startlingly little time to prepare the world to accommodate more than a quintupling of created and captured data. The strain on computing infrastructure will be significant. Imagine if the highways around your home needed to accommodate five times more traffic and, simultaneously, everyone wanted to drive much faster than before. Data centers now face this situation.

All that data will fuel rampant growth in data workloads, much of which will need real-time processing. Traditionally, addressing such speed demands meant costly measures, including moving to in-memory databases. However, in-memory systems are often prohibitively expensive, in part because per-gigabyte DRAM pricing tends to remain high while module capacities are limited.



**Figure 2.** The pressures being placed on data centers have resulted in a need for more affordable capacity in memory resources and higher performance from “warm” storage.

This “fast but expensive and capacity-limited” nature of DRAM has led to a fragmented memory/storage market represented by Figure 2. “Hot” or “active” data needs to reside in memory to provide performance, but organizations struggle to get all the data they want into DRAM. “Warm” (or nearline) data has more relaxed responsiveness requirements so it can reside in storage. However, the data explosion affects all levels. Low-latency demands on nearline storage keep increasing, sometimes beyond the limits of what NAND SSDs can fulfill. It's time for a new technology to fill the performance and capacity gap in today's market so the world can meet tomorrow's data needs.

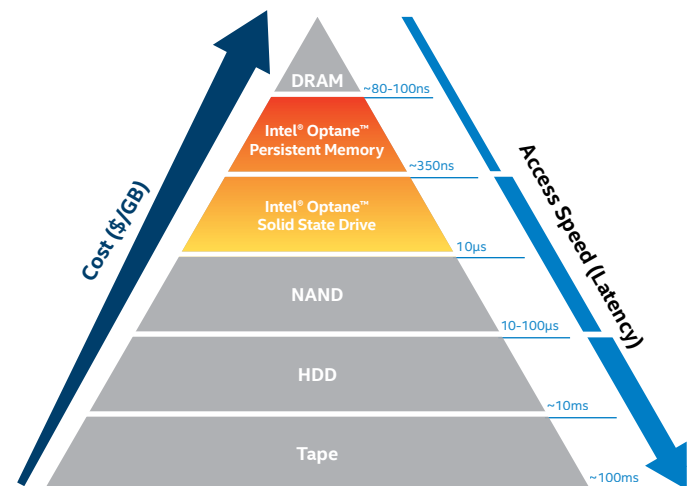
## The Intel® Optane™ Technology Solution

As Figure 2 implies, performance and capacity have traditionally been viewed as contrasting, almost opposing states, like black and white. In reality, they are more like frequency bands on a continuous spectrum. DRAM is not the fastest form of memory; we can peek inside the CPU at L1 through L3 caches, or even registers, to find faster memory. Similarly, hard drives and tape are not the slowest storage media. Memory and storage exist on a continuum. That continuum is typically viewed through two lenses, cost and latency, which usually have an inverse relationship. As cost per gigabyte increases, access latency decreases, as shown in Figure 3.

With DRAM, increasing amounts of active, high-performance memory is needed, but modern DRAM is prohibitively expensive in large quantities. Further, existing DRAM DIMM densities limit the capacities physically possible for system memory. This creates a gap in the continuum. NAND is too slow to serve as memory, and DRAM is both too expensive and not dense enough to feasibly extend memory capacities.

Additionally, there is a gap above NAND SSDs. NAND media provides adequate storage sizes and persistence, but it lacks performance and endurance. The market needs persistent storage that is closer in speed to DRAM but is less expensive, larger in size, and more enduring.

Intel Optane technology slots into the capacity and performance gaps on this memory/storage continuum and closes them. The unique memory medium uses a type



**Figure 3.** As the cost increases (cost per gigabyte), access latency decreases.

of resistive memory technology that delivers inherently fast performance and large capacities at the memory end of the continuum gap while also adding the qualities of performance, persistence, and endurance at the storage end of the gap. Intel Optane memory media is fast, near DRAM speeds,<sup>5</sup> byte-addressable, write-in-place, persistent, high endurance, and consistent in its low-latency responsiveness.<sup>6</sup>

With these characteristics, Intel Optane memory media can be packaged in two ways: In a DIMM form factor, as a persistent memory module that sits on the memory bus, or as an NVMe SSD storage device that sits on the PCIe bus. When configured as an Intel Optane persistent memory module, it can expand memory capacity at near-DRAM speeds and a lower cost<sup>7</sup> while also offering the ability to bring persistence to memory. When configured as an Intel Optane SSD, it can dramatically increase the access speeds of storage, deliver consistent performance, and exhibit high endurance not seen in conventional NAND SSDs.<sup>8</sup>

Whether this underlying media is packaged as memory modules or SSDs, Intel Optane technology possesses several characteristics that make it versatile and needed.

### Low Latency

DDR4 modules specify latencies in the 10 to 20 nanosecond (ns) range.<sup>9</sup> Using the same physical DDR4 packaging and memory bus, Intel Optane persistent memory offers latency of up to about 350 ns. This is a relatively narrow delta compared to the 10 to 100 microseconds ( $\mu$ s) of NAND SSDs. (Remember that 1,000 nanoseconds make one microsecond.) As shown in Figure 4, even across the chasm of a PCIe storage bus, Intel Optane SSDs still provide markedly faster access times than nearly all NAND SSDs.<sup>10</sup> In short, Intel Optane technology enables larger low-latency pools for “hot” data so users can reach and use the most-needed data faster.

### Data Persistence

Like NAND storage, Intel® Optane™ media deployed as storage does not lose data in the event of power failure or cycling. Depending on the mode in which it is configured, this data persistence can also apply to Intel Optane media deployed as system memory. Data persistence is a key facet

of Intel Optane technology, as having data persistence opens the way to a new programming model so developers can build simpler and more powerful applications faster.

### High Endurance

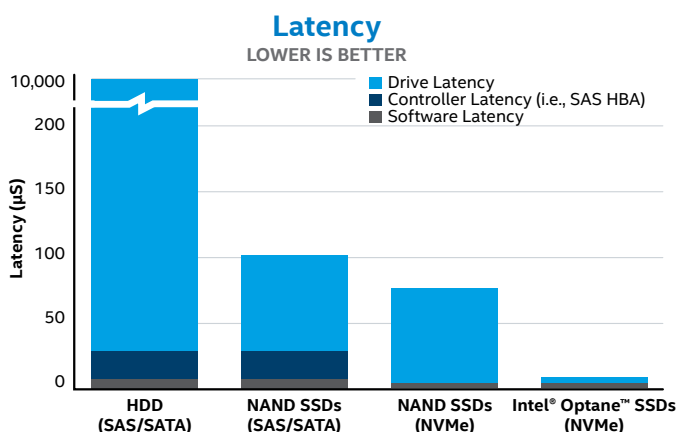
Unlike NAND, Intel Optane media is a write-in-place technology, which eliminates NAND's requirement for erasing a cell before writing to it. This dramatically increases endurance. For example, the 1.5 TB Intel® Optane™ SSD DC D4800X specifies 82.1 petabytes written (PBW) over the life of the drive, as opposed to the 1.6 TB Intel® SSD DC P4610, which specifies 12.25 PBW. The ROI benefits, especially for data centers with write-intensive workloads, can be compelling.

### Reliable Performance

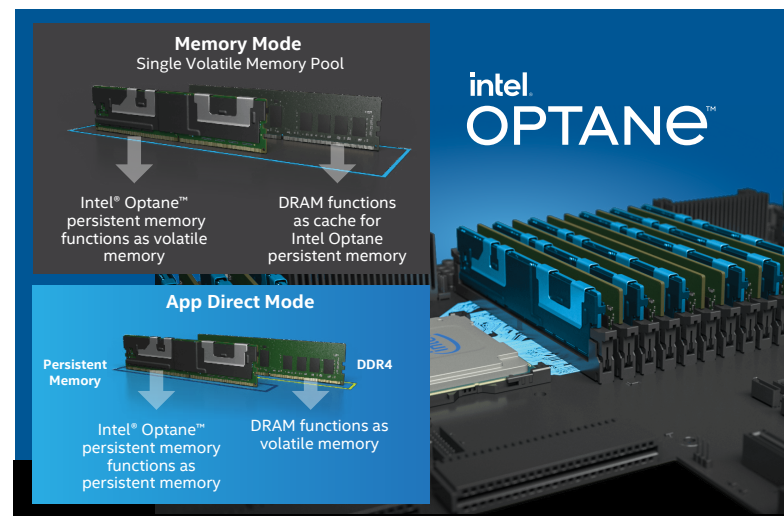
Intel Optane technology media exhibits consistent performance as workloads scale. For instance, NAND-based SSDs tend to slow in responsiveness (latency) as write pressure increases. When evaluated over time with a sustained, increasing workload, Intel Optane SSDs show a consistent, flat, fast responsiveness relative to NAND-based storage, which can ultimately slow to over 60x the latency of Intel Optane storage.<sup>12</sup> Thus, for heavy workloads and applications that depend on consistent storage performance, Intel Optane technology emerges as a far more reliable choice. This quality even applies at the initiation of work. Some media require a “ramp-up” time to achieve high IOPS performance at low queue depths, where the majority of enterprise workloads operate, but Intel Optane SSDs begin work at high IOPS levels and then stay there.<sup>13</sup>

## Intel® Optane™ Persistent Memory

Intel Optane persistent memory adheres to DDR4 physical module specifications. Thus, when used on existing platforms supporting 2nd or 3rd Gen Intel® Xeon® Scalable processors, Intel Optane persistent memory modules simply drop in alongside conventional DDR4 memory, allowing more data to remain close to CPUs with near-DRAM latency. Intel Optane persistent memory is available in high-capacity (128 GB, 256 GB, and 512 GB), non-volatile DIMMs at an affordable price, yielding better overall price-performance ratios.<sup>14</sup> How the modules operate within the server depends on which mode they are configured with Intel® software.



**Figure 4.** Moving to NVMe helps eliminate latencies caused by controller overhead, but most of the performance benefit seen in Intel® Optane™ SSDs derives from the media itself.<sup>11</sup>



**Memory Mode** enables higher total system memory because Intel Optane persistent memory modules feature much larger capacities than their DRAM counterparts. Intel Optane persistent memory modules run alongside DDR4 modules, with the latter functioning as a large L4 cache while the Intel Optane memory modules provide the single memory area accessible by users. Note that Intel® Optane™ memory is volatile in this mode. Memory Mode is ideal for memory-constrained applications and situations, such as very large database workloads or virtualized environments that need higher VM and/or container counts. Memory Mode works with all applications and requires no programming or code modification.

**App Direct Mode** configures Intel Optane persistent memory such that data stays persistent within the modules. DRAM memory, however, remains volatile. Memory capacities are cumulative, enabling even higher system memory counts, although users will need software compatible with App Direct Mode, and some additional programming may be needed for optimization. Under App Direct Mode, the operating system recognizes Intel Optane persistent memory and RAM as separate memory pools and can treat them differently. Memory can be persistent like storage, byte-addressable like memory, and cache coherent for supporting persistent memory beyond the local node. Because data persists, there is no need to reload data, which can yield benefits in cases such as fast database restarts and accelerated real-time analytics. Under App Direct Mode, DRAM and Intel Optane persistent memory can be allocated as needed so applications can use whichever medium is optimal for a given task.

**Storage Over App Direct (AD) Mode** does not require applications to be modified. It uses the same operating-system NVDIMM driver as App Direct Mode, but Storage Over AD allows users to configure their Intel Optane persistent memory pool as non-volatile storage while still on the memory bus. This eliminates I/O bus latencies, allows DRAM to serve in its typical volatile memory role, and provides a greatly accelerated caching layer for performance-sensitive applications.

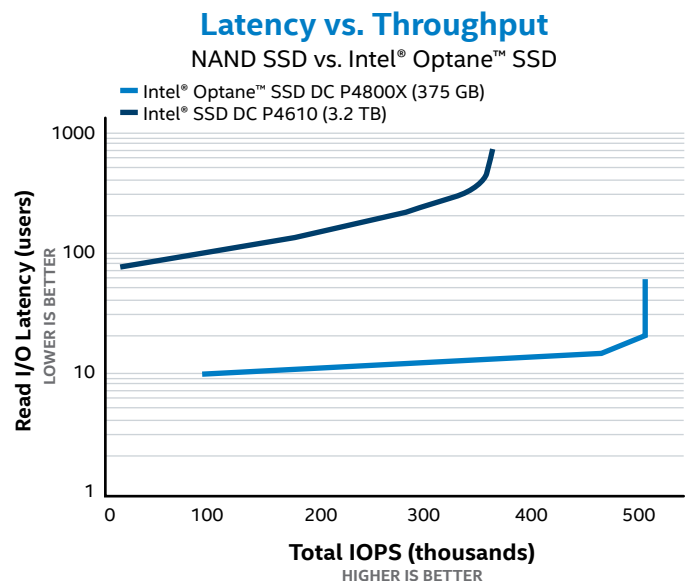
Intel Optane persistent memory does not replace DRAM; it complements DRAM. Intel Optane persistent memory significantly expands system memory and brings persistence to data that would have otherwise been relegated to slower storage media. Both facets of Intel Optane persistent memory can bring substantial ROI benefits. For example,

memory-constrained VMs tend to underutilize CPUs. By expanding the memory available to constrained VMs, CPU utilization can increase for each VM, leading to higher total utilization. Alternatively, higher memory capacity can allow more VMs on each physical system, allowing organizations to run fewer total servers. By increasing VM density on fewer resources, the solution price-performance ratio improves.

## Intel® Optane™ SSDs

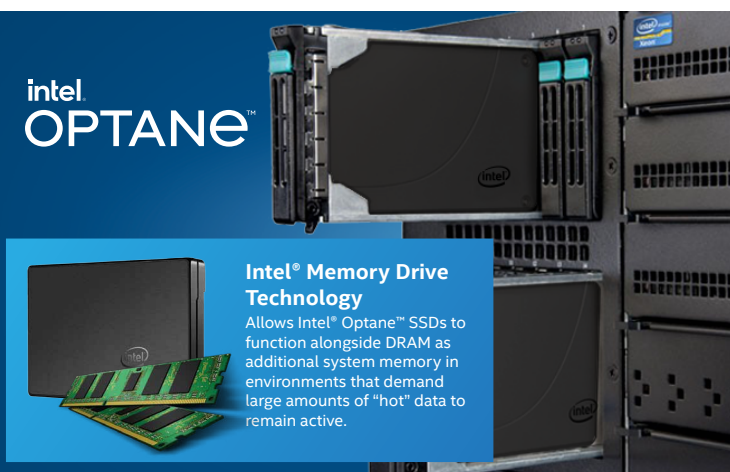
By placing the same Intel Optane technology media on x4 AIC, U.2, or M.2 form factor devices, a similar range of opportunities opens for storage. As noted earlier, the PCI Express storage bus introduces additional latencies and overhead, but read/write performance (typically under 10µs) remains more than sufficient to enable a high storage tier with benefits that are either costly or impossible to reach with NAND SSDs.

How Intel Optane media exhibits far greater endurance than NAND was previously described. Intel Optane storage also shows significantly faster and more reliable performance than NAND under a sustained load. To show this point, Figure 5 illustrates the relationship between latency and IOPS, comparing Intel® 3D NAND SSDs and Intel Optane SSDs.



**Figure 5.** Intel® Optane™ SSDs maintain their low latency performance much more consistently than NAND alternatives as load levels increase.

Interestingly, some of Intel Optane persistent memory's benefits can be realized by pairing Intel Optane SSDs with Intel® Memory Drive Technology (currently available for Linux). This solution uses software to create an extension of memory capacity by bonding Intel Optane SSDs with the DRAM pool, much like in Memory Mode with Intel Optane persistent memory modules. Intel Optane SSDs with Intel Memory Drive Technology provide a cost-effective way to massively expand system memory beyond regular DRAM limits. The technology enables very large workloads while maintaining relatively low DRAM capacities, potentially saving on hardware procurement and operations costs. Like Intel Optane persistent memory, combining Intel Optane SSDs





with Intel Memory Drive Technology is another way to get “hot” data cached for fast, low-latency availability to the CPU.

Because the SSD(s) communicate across the PCIe bus, some inevitable I/O latencies remain, which is why Intel Optane persistent memory remains preferable in performance-sensitive environments. However, Intel Optane SSDs with Intel Memory Drive Technology not only provide the outsized system memory sizes needed for many applications and environments, it is also supported by a larger number of today's CPUs.

As with all Intel Optane SSDs in general, Intel Memory Drive Technology works with Intel Xeon Scalable processors, Intel® Xeon® processor E5-x6xx v2 or later,<sup>15</sup> and Intel Xeon processor E7-x8xx v2 or later models. Note that data remains volatile under Intel Memory Drive Technology.

## More System Memory for All Workloads

Many use cases and target applications exist for Intel Optane persistent memory and SSDs, and more will continue to arrive as adoption continues. Both implementations of Intel Optane technology build on the foundation laid by Intel 3D NAND capacity storage in previous- and current-generation Intel Xeon processor-based servers. Intel 3D NAND SSDs establish a baseline for good data performance and reliability across a variety of enterprise workloads (see Table 1).


On platforms running applications that would benefit from lower latency access to storage, adding Intel Optane SSDs

can provide better performance compared to 3D NAND SSDs. Intel Optane SSDs can provide more than enough capacity and speed to serve in a buffer/caching role. Frequently accessed storage data can reside in Intel Optane SSDs and realize markedly faster response rates while also sparing main SSD capacity storage from unnecessary use and wear. This helps Intel Optane SSDs deliver higher total system performance and lower costs as the storage subsystem reaps the benefits of Intel Optane media's long endurance characteristics.

Additionally, select Intel Xeon processor-based platforms<sup>16</sup> can use Intel Optane SSDs to optimize total system memory capacities. By using Intel Memory Drive Technology, even previous platforms can jump from gigabytes to several terabytes of available memory. This can markedly increase efficiency of memory-constrained applications and workloads, enabling benefits such as larger datasets, higher virtual machine density, and physical server consolidation.

Compared to 3D NAND SSDs, organizations that deploy server platforms based on 2nd or 3rd Gen Intel Xeon processors can realize the best range of benefits. Rather than expand system memory across the NVMe bus, high-capacity Intel Optane persistent memory modules enable system memory capacities that are several times larger than what is possible with DRAM alone. All this memory coexists on the DDR4 bus and reaps that channel's access time benefits, providing outsized capacity for very large datasets and higher performance (compared to reaching to

**Table 1.** Any Intel® Xeon® processor-based server can benefit from the advantages of integrating Intel® Optane™ SSDs. However, for servers based on 2nd or 3rd Generation Intel Xeon Scalable processors, an increasing number of applications can achieve the best range of benefits by using Intel Optane persistent memory.



## For Expanded Memory Capacity

Recommend Intel® Optane™ Persistent Memory

### Infrastructure

VM Density

- Linux KVM
- VDI
- Microsoft Hyper-V
- VMware vSphere

File System Tiering

- NetApp MAX Data

### Database

IMDb/NoSQL/RDBMS

- SAP HANA
- Redis Labs/Redis
- Aerospike
- KX
- Oracle Exadata

### AI/Analytics


Real-Time Analytics

- SAS VIYA
- Apache Spark

### Communication

Content Delivery Network

- Live Stream/Hot VoD



## For Improved Storage Performance

Recommend Intel® Optane™ SSD

### HPC

Scratch & I/O Nodes

- Flex Storage Node

### Storage

SDS


- Ceph Block/Object
- Red Hat Ceph
- Hadoop YARN temp

Traditional (dual port)

- PureStorage Flash Array//X
- Dell EMC Powermax


Appliance

- VAST Data



## For Combined Memory and Storage Benefits

Recommend Intel Optane Persistent Memory and Intel Optane SSDs



### HCI

VMare/vSAN

Expanded Memory (ESXi)

+

Caching (vSAN)

Azure Stack HCI

Expanded Memory

+

Caching

Cisco HyperFlex

Intel PMem (Under Evaluation)

+

Caching

Nutanix

Intel PMem Support in v5.19

+

Caching

### Database

MySQL

Expanded Memory

+

Caching

MS-SQL

Expanded Memory

+

Caching

Oracle DB

Expanded Memory

+

Accelerating or Tiering

Intel Optane media across the NVMe bus) for demanding applications that have been enhanced to be Intel Optane persistent memory-aware.

As a case in point, Hewlett Packard Enterprise (HPE) realized a 48 percent performance/price advantage for a GraphX pharmaceutical workload by using 1.5 TB of Intel Optane persistent memory when compared against using all DRAM.<sup>17</sup>

Intel Optane persistent memory modules on 2nd or 3rd Gen Intel Xeon processors provide additional benefits through the use of App Direct Mode. With App Direct, organizations can optimize configurations for both performance and system memory capacity as workloads dictate. Ultimately, businesses that use 2nd or 3rd Gen Intel Xeon processor-based servers and that need to expand memory capacities and/or use fast, non-volatile memory should add Intel Optane persistent memory.

Intel Optane SSDs target usage models and workloads with widespread presence in the data center marketplace, including hyper-converged and software-defined storage workloads such as vSAN, Ceph, and Microsoft Storage Spaces Direct. In fact, hyper-converged infrastructure is a key focus area and one of the early adopters of Intel Optane SSDs because their low-latency characteristics help to minimize I/O wait times. Reducing I/O wait helps to recover CPU cycles, which in turn can help to increase workload density. Ultimately, increasing density can enable a reduction in node count. Fewer nodes facilitate smaller hardware investment and can lead to reduced software licensing costs.

Alternatively, data centers can use Intel Optane SSDs to increase virtual machine density on existing systems. A hyper-converged platform study conducted by Evaluator Group found performance and price/performance benefits

from integrating Intel Xeon Scalable processors and Intel Optane SSDs into a hyper-converged platform running VMware vSAN. Results showed that the improved platform could support 1.6x more VMs while still meeting service-level agreement (SLA) performance requirements for each VM.<sup>18</sup>

In the infrastructure space, database workloads such as memcached and Redis are used as a database. Extending memory with a cost-effective solution like Intel Optane persistent memory can do well since networking, rather than the memory subsystem, is the typical bottleneck. With more memory, users can achieve better cache hit rates and thus improve the overall SLA in an affordable manner.

For database uses, SAP/HANA is the current market leader. Intel Optane persistent memory not only delivers high performance at a comparatively low cost, but it also allows for larger memory capacities than possible with DRAM alone. The other unique advantage for this market is persistence in database memory.

Finally, in high-performance computing, Intel Optane SSDs with Intel Memory Drive Technology can be flexibly configured on the fly as either memory or storage. This can bring tremendous versatility to HPC cluster budgeting and design, reducing reliance on high-cost DRAM in large-capacity memory nodes.

All of this innovation and enterprise capability expansion arrives in part due to the many years Intel has participated in industry standards bodies, including PCI-SIG (which governs PCIe), NVM Express, and the Enterprise & Datacenter SSD Form Factor (EDSFF) Working Group. Intel's foundational work in these and similar standards bodies help ensure that solutions based on new technologies, such as Intel Optane persistent memory and Intel Optane SSDs, arrive amply validated, optimized, and ready for wide, successful deployment.

## Use Cases and Related Applications

For a deeper dive into some of these use cases and related applications, investigate these Intel solution briefs:

- [Ceph](#): Accelerate Ceph Clusters with Intel Optane SSDs.
- [SAP HANA](#): SAP HANA 2.0 SPS 03 contains numerous innovations to the SAP HANA platform—and it is the first major database solution to support Intel Optane persistent memory.
- [VMware vSAN](#): Agile storage systems rapidly enhance analysis and insight from stored data.
- [Vexata Systems and Intel Optane SSDs](#): Vexata delivers enterprise storage arrays based on Intel Optane SSDs and NVMe/PCIe Intel® SSDs to enable transformative application performance for database and analytics workloads.
- [Exploiting Intel Optane SSD for Microsoft SQL Server](#): New NVM-based devices provide unparalleled performance than Flash-based SSDs.

## Related Content

If you liked this paper, you may also be interested in these related resources:

- [Intel Optane Technology for Data Centers](#)
- [Intel Optane Technology FAQ](#)
- [Memory and Storage Technical Series](#): These resources can help system architects, engineers, and IT administrators better understand the limitations of traditional memory and storage options; how those limitations lead to performance and capacity gaps in your data center; and finally how Intel Optane technology is helping to fill those gaps with a new industry-disrupting architecture.
- [Overview of the Intel Optane Persistent Memory Video](#)
- [Overview of the Intel Optane Persistent Memory Performance Video](#)
- [Configuring Intel Optane Persistent Memory for Best Performance Video](#)

## Conclusion

A 2019 Flexera survey revealed that 64 percent of organizations will focus on optimizing their existing cloud use for cost savings in 2019.<sup>19</sup> (Note that the #2 cloud priority for organizations, at 58 percent, was moving more workloads to the cloud.) Many of these organizations running cloud applications could benefit from having the memory capacity to host larger data sets, but the high cost of DRAM and limited DRAM capacities impose barriers. Concurrently, organizations could offer more value and service variety to customers if their applications' storage was more responsive, but NAND SSD latency has been largely capped by inherent media limitations that could only be—in some cases—surmounted by pushing data into DRAM. Of course, that approach entails high cost per gigabyte.

Intel Optane persistent memory and Intel Optane SSD technologies give businesses a way to cost-effectively break beyond these barriers using product classes that never existed before. By enabling previously unattainable system memory capacities and introducing new levels of responsiveness and endurance to high-performance storage, Intel Optane technology delivers the affordable solutions data centers and cloud applications need to accommodate the coming generation of data demands.

For more information on Intel Optane technology, visit [intel.com/optane](https://intel.com/optane).



<sup>1</sup> IDC "IDC's Global DataSphere Forecast Shows Continued Steady Growth in the Creation and Consumption of Data." May 2020. [idc.com/getdoc.jsp?containerId=prUS46286020](https://www.idc.com/getdoc.jsp?containerId=prUS46286020)

<sup>2</sup> See endnote 1.

<sup>3</sup> IDC/Seagate "Data Age 2025" white paper. November 2018. [seagate.com/www-content/our-story/trends/files/idc-seagate-dataage-whitepaper.pdf](https://www.seagate.com/www-content/our-story/trends/files/idc-seagate-dataage-whitepaper.pdf)

<sup>4</sup> Cisco Visual Networking Index: Forecast and Trends, 2017–2022. [cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/white-paper-c11-741490.html](https://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/white-paper-c11-741490.html)

<sup>5</sup> Intel-tested as of November 15, 2018. 4K 70/30 read/write performance at low QD. Measured using FIO 3.1. Common configuration: Intel 2U Server System, OS: CentOS 7.5, kernel 4.17.6-1.el7.x86\_64, 2 x Intel® Xeon® Gold 6154 processor at 3.0 GHz (18 cores), 256 GB DDR4 RAM at 2666 MHz. Configuration: 375 GB Intel® Optane™ SSD DC P4800X compared to 1.6 TB Intel SSD DC P4600. Intel microcode: 0x2000043; system BIOS: 00.01.0013; Intel ME firmware: 04.00.04.294; BMC firmware: 1.43.91f76955; FRUSDR: 1.43. The benchmark results may need to be revised as additional testing is conducted.

<sup>6</sup> See endnote 5.

<sup>7</sup> Intel. "Breakthrough Performance Expands Datasets, Eliminates Bottlenecks." January 2019. [intel.com/content/www/us/en/products/docs/memory-storage/solid-state-drives/data-center-ssds/optane-ssd-dc-p4800x-p4801x-brief.html](https://www.intel.com/content/www/us/en/products/docs/memory-storage/solid-state-drives/data-center-ssds/optane-ssd-dc-p4800x-p4801x-brief.html).

<sup>8</sup> See endnote 7.

<sup>9</sup> [wikipedia.org/wiki/DDR4\\_SDRAM#JEDEC\\_standard\\_DDR4\\_module](https://en.wikipedia.org/wiki/DDR4_SDRAM#JEDEC_standard_DDR4_module)

<sup>10</sup> Average read latency measured at queue depth 1 during 4K random write workload. Measured using FIO 3.1. Common Configuration – Intel® 2U Server System, OS CentOS 7.5, kernel 4.17.6-1.el7.x86\_64, CPU 2 x Intel® Xeon® 6154 Gold processor @ 3.0 GHz (18 cores), RAM 256 GB DDR4 @ 2666 MHz. Configuration – Intel® Optane™ SSD DC P4800X 375 GB and Intel® SSD DC P4600 1.6 TB. Latency – Average read latency measured at QD1 during 4K random write operations using FIO 3.1. Intel® Microcode: 0x2000043; System BIOS: 00.01.0013; ME Firmware: 04.00.04.294; BMC Firmware: 1.43.91f76955; FRUSDR: 1.43. SSDs tested were commercially available at time of test. Intel performance test results as of July 24, 2018 may not reflect all publicly available security updates.

<sup>11</sup> See endnote 9.

<sup>12</sup> Intel. "EMR Optimized on CISCO HyperFlex All NMve with Intel® Optane™ Technology". [itpeernetwork.intel.com/emr-optimized-on-cisco-hyperflex-all-nmve-with-intel-optane-technology/#gs.h1oo20](https://itpeernetwork.intel.com/emr-optimized-on-cisco-hyperflex-all-nmve-with-intel-optane-technology/#gs.h1oo20)

<sup>13</sup> See endnote 10.

<sup>14</sup> Hewlett Packard Enterprise. "Major Performance/Price Advantage, Scalability Gains with Intel® Optane™ Persistent Memory 100 Series for HPE on GraphX Workload." June 2019. <https://h20195.www2.hpe.com/v2/getdocument.aspx?docname=a00074594enw>.

<sup>15</sup> See the Features At-a-Glance chart at [intel.com/content/www/us/en/products/docs/memory-storage/solid-state-drives/optane-ssd-dc-p4800x-mdt-brief.html](https://www.intel.com/content/www/us/en/products/docs/memory-storage/solid-state-drives/optane-ssd-dc-p4800x-mdt-brief.html)

<sup>16</sup> See endnote 10.

<sup>17</sup> Hewlett Packard Enterprise. "Major Performance/Price Advantage, Scalability Gains with Intel® Optane™ Persistent Memory 100 Series for HPE on GraphX Workload." June 2019. <https://h20195.www2.hpe.com/v2/getdocument.aspx?docname=a00074594enw>.

<sup>18</sup> Evaluator Group. "Lab Insight: Latest Intel® Technologies Power New Performance Levels on VMware vSAN – 2018 Update." October 2018.

<sup>19</sup> [www.evaluatorgroup.com/document/lab-insight-latest-intel-technologies-power-new-performance-levels-vmware-vsan-2018-update](https://www.evaluatorgroup.com/document/lab-insight-latest-intel-technologies-power-new-performance-levels-vmware-vsan-2018-update)

<sup>19</sup> Flexera blog (formerly RightScale), February 27, 2019, "2019 State of the Cloud Survey." [flexera.com/blog/cloud/2019/02/cloud-computing-trends-2019-state-of-the-cloud-survey/#The%20#1%20Priority%20in%202019%20is%20Cloud%20Cost%20Optimization](https://flexera.com/blog/cloud/2019/02/cloud-computing-trends-2019-state-of-the-cloud-survey/#The%20#1%20Priority%20in%202019%20is%20Cloud%20Cost%20Optimization)

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