Technology Trends

3D Xpoint

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Business Brief

3D XPoint (pronounced: three dee cross point) is a new type of non-volatile memory storage technology that was jointly developed and released by Intel and Micron Technology Inc. in 2015. While both companies co-developed the product they have since ended their business cooperation and each now brands and markets their own specific 3D Xpoint product; Optane for Intel and QuantX for Micron.

In order to fully understand 3D Xpoint, a user must understand what computer memory (memory) is. The term memory refers to any information or data, often in binary format, that a machine or technology can recall and use. There are many different kinds of memory in conventional computers and devices, however they differ based on the complex design of the hardware in which they're stored.[1] Memory can be categorized as volatile (not-permanent) and non-volatile (permanent).

Volatile memory, also known as temporary memory, is a type of computer memory that requires power to preserve the stored data/information. If the computer is switched off, anything stored in the volatile memory is removed or deleted.[2] All Random Access Memory (RAM) is volatile (some exceptions exist e.g. the CMOS RAM used in the BIOS). RAM is typically used as a primary storage or acts as the main memory in computer systems. Since the primary storage demands extreme speed, it mainly uses volatile memory. Due to the volatile nature of RAM, users often need to save their work to a non-volatile permanent medium, such as a hard drive, in order to avoid data loss.[3]

Non-Volatile Memory (NVM), also known as non-volatile storage, is a type of computer memory that has the capability to hold/store saved data even if the computer's power is turned off. Unlike volatile memory, NVM does not require its memory data to be periodically refreshed. It is commonly used for secondary storage or long-term consistent storage.[4] NVM is highly popular among digital media and is widely used in memory chips for USB memory sticks (Flash Drives) and digital cameras. NVM eradicates the need for relatively slow types of secondary storage systems, for example hard disks/hard drives.[5]

3D Xpoint aims to fill a gap in the storage market between two types of memory storage technology. The first is a type of Random Access Memory (RAM) known as Dynamic Random Access Memory (DRAM) which is categorized as volatile memory and is typically used for data or program code that a computer processor needs to function. RAM is hardware that allows a computer to efficiently perform more than one task at a time (i.e., multi-task).[6]

The second storage technology is NAND Flash Memory, which is a type of non-volatile memory that does not require power in order to retain data. NAND Flash Memory's goal has been to reduce the cost-per-bit while increasing maximum chip capacity in order for flash memory to compete with magnetic storage devices, such as hard disks/hard drives. NAND Flash Memory has found a market in devices where large files are

frequently uploaded and replaced, such as in MP3 players, digital cameras, and USB (universal serial bus) flash drives.[7]

3D XPoint provides the non-volatile capabilities of NAND technology and low latency of DRAM. This means, 3D XPoint is able to retain its data even in the face of a power loss or reboot (it is a non-volatile technology) but it is also able to maintain the speed of DRAM and operate at lower latency compared to Flash technology.

In a nutshell, 3D Xpoint is an attempt to capture the strengths of both DRAM and NAND Flash Memory and provide an alternative to their limitations. 3D XPoint has unique attributes. Like all RAM chips, it is byte addressable and can thus be used as main memory or as a secondary RAM bank. Because it is non-volatile, it can also replace a Hard Disk Drive (HDD) or a Solid State Drive (SSD), or be used in conjunction with each.[8]

Technical Brief

The goal of 3D XPoint is to break the memory (SRAM, DRAM) / storage (NAND SSD, HDD) barrier by offering an in-between solution. Even though the technology is fairly new, the research does indicate better system performance. Benchmarks found performance of 2000MB/s sequential read and 900MB/s sequential write which isn't significantly faster than NAND SSD. Where the technology distinguishes itself is with its low latency of ~10μs which 100 times slower than DRAM but 1000 times faster than NAND SSD. (Malventano, 2017) This means the system remains responsive even under load because the CPU isn't wasting time waiting for the memory and so, CPU performance is increased. (Gangam, 2018) Furthermore, 3D XPoint offers better endurance and long term reliability due to its nature. The technology can be rewritten up to 20,000 cycles before degrading as opposed to 1,000-3,000 for traditional NAND SSD. This last technology holds data by storing electrical charges in cells, but it will slowly leak energy if left for long periods without power, which results in data loss. Therefore, they are not suited for archival storage. (Wikipedia, 2019) On the other hand, 3D XPoint would render the problem of replacing storage media a thing of the past as PCM keeps their atomic state regardless of an electrical source.

3D XPoint gets its name from its architecture of a stackable cross-gridded data access array. Submicroscopic columns of selectors and memory cells are meshed at the intersection of perpendicular wires. Each cell can be addressed individually by sending a current through the corresponding top and bottom wires. This design allows for several layers to be stacked in three dimensions to improve the scalability and it is reported by Intel to have a storage density up to 8 to 10 times greater than DRAM. (Jain, 2018)

The 3D XPoint technology is based on phase-change materials (PCM). The technology has an unspecified composition, but common phase-change alloy including Germanium, Antimony and Tellurium are likely candidates. These metalloids have the physical properties of holding multiple stable states with distinctive resistance

characteristic. Each cell's selector verifies a change operation and applies the appropriate voltage to the material to change its atomic structure between an amorphous insulator and a crystalline conductor. Each resistance level represents a value of 0 or 1 and will hold its values indefinitely. Therefore, it isn't affected by power loss because it doesn't use silicon to form energy dependant transistors like DRAM. Furthermore, there is no "erase" action required to program a PCM cell because it can be set regardless of its previous state, unlike NAND flash in which data is stored in blocks of 4KB and must be erased before new data can be written. This gives 3D XPoint a theoretical higher performance and lower power consumption than its counterpart. (Malventano, 2017)

Industry Use

The need to keep up with growing performance requirements and cost-effectiveness has prompted the development of an alternative to DRAM and NAND Flash, especially in the areas of real-time analytics and demanding cloud and virtualization envirnonments (Forrester, 2015). In 2018, Intel launched their second generation of the 3D XPoint brand called Optane that is commercially available for the consumer and enterprise market. Because it is an in-between technology, the tech giant offers distinct versions of their technology as either memory or storage for personal computing or enterprise data centers. Below are the various families of Optane products. (Intel, 2019)

- **Intel Optane Memory**: This series comes in an M.2 form factor and a PCIe NVMe 3.0x4 Interface with a capacity of 16GB, 32GB or 64GB. It works as a cache drive operating in parallel with a primary boot drive to turn a simple hard disk into a hybrid disk. The caching algorithm accelerates a computer's responsiveness by remembering and storing frequently used files to increase workflow productivity.
- **Intel Optane SSD:** This consumer family comes in an M.2 form factor with a capacity ranging from 58GB to 2TB and delivers high performance, stability and power efficiency. It is designed for application and file storage.
- **Intel Optane DC persistent memory:** This workload optimized technology will help businesses extract more actionable insights from data: from cloud and databases, to in-memory analytics, and content delivery networks.
- **Intel Optane DC SSDs:** This line of products has a U.2 and a M.2 form factor with a capacity ranging 100 GB to 1.5 TB. This data center solution eliminates storage bottlenecks and reduces transaction costs for latency-sensitive workloads to improve their overall quality and allow more affordable data sets.

As of 2019, the cost of 3D XPoint technologies is around 1$/GB while DRAM is 10 times more expensive and NAND SSD is 5 times less. The hardware requirements for Intel Optane memory are motherboards that supports 7th generation Intel processor or newer and that needs an M.2 Slot which most boards feature a single one. The technology is only compatible with Windows 10 version 1803 (April 2018 update) or

later. Although, it is possible to use the technology using an AMD chipset but requires the installation of a specialized software. (Walton, 2019)

CERN is an organization that runs the large hadron collider. Due to the nature of their research their organizational data demands are extensive. Current memory hierarchies are simply not suitable for the amount of data they need to collect. When surveyed by Intel, they reported that their current infrastructure is bottlenecked by DRAM. This is because they would require a large (and expensive) amount of DRAM but still need to port that data to their flash and SSD technology. Intel's Optane SSD would be a perfect fit for their current memory needs as it has the density they require, there is no loss of data in the case of power outages, and writing to it is still faster than NAND flash. CERN did remark their skepticism of the product. While they do think it meets all their requirements, the idea that all their existing drives would have to be changed and applications would potentially have to be re-written, there is a lot of risk, and potential cost associated with that risk.

Canadian Government Use

There is a significant lack of documented Government of Canada (GC) initiatives and programs regarding the analysis and deployment of 3D Xpoint. This is mainly due to the fact that the GC is currently grappling with the implementation of Cloud Services, and the majority of resources and efforts are occupied, including analyzing security concerns related to the protection of the information of Canadians.

Future in-depth interviews and research will need to be conducted with Shared Services Canada (SSC) Account Executives and with client departments in order to ascertain the business requirements for 3D Xpoint and its impact on the GC network.

Implications for Shared Services Canada (SSC)

Value Proposition

The amount of data created and used by the Government of Canada (GC) is escalating exponentially. The GC thrives on this data to make critical decisions, gain new insights, and improve services.

In today's technological climate, there is a gap in data storage tiers. DRAM is volatile memory and is too expensive to scale up. While NAND Flash Memory does have the capacity and cost-efficiency to scale and is a type of NVM; it lacks sufficient performance to function in the memory space. To address the gap, the GC needs a storage solution that behaves like system memory.

One of the core responsibilities of Shared Service Canada (SSC) is to provide modern, secure and reliable data centre services to customer organizations for the remote

storing, processing and distribution of data, including cloud storage and computing services. 3D XPoint technology will have to be incorporated into SSC's IT infrastructure to benefit the service delivery of other governmental departments.

It is speculated that 3D Xpoint technology could extend the apparent memory size and boost instance storage performance of data centers, enable bigger and more efficient database, overcome big data network bottlenecks, facilitate high-performance computing applications, provide the storage capacity and speed that hybrid clouds need and possibly serve as primary memory tiers in hyper-converged systems. (Rouse, 2016) 3D XPoint could also improve the GC's applications including AI training and machine learning, big data analytics, push software patches and updates faster, or reduces outage time. (Moorhead, 2018)

The manufacturing of Intel's Optane product family in particular, is said to go uninterrupted as Intel sees the potential of the technology can greatly benefit data centers by increasing system uptime, providing faster recovery from power outage, accelerating virtual machine storage, and delivering high performance for multimode and distributed cloud applications. (Tallis, 2019)

The structural design of this emerging technology significantly reduces the write cycles, making it more durable and having a longer lifespan. These technological properties could increase the breadth of enterprise data storage. Because the modern landscape of information is constantly in motion, the technology would greatly benefit an enterprise's ability to perform machine learning, business analytics and, possibly, edge computing. There are other emerging memory technology currently under development that share similar properties such as resistive RAM (reRAM) or memrister but 3D XPoint is said to use completely different physics.

3D XPoint Use Cases

3D XPoint is used as an additional layer of storage between flash and DRAM. It's a relatively common practice to tier storage between hard disk drives (HDDs) and flash. High-intensity data and applications that benefit more from high speeds are stored on the flash layer, while data and applications that are accessed less frequently are put on disk. 3D XPoint is another layer of storage above flash for data and applications that need even greater speeds.

The Optane SSD with 3D Xpoint technology would provide the greatest benefit to SSC in the memory hierarchy of its data centers. The common data center hierarchy is established with three tiers. The hot tier is comprised of cache memory and DRAM, the warm tier is NAND flash and SSD, and the cold tier is hard disks and tapes. The Optane SSD fits in somewhere in the middle of the hot tier and warm tier by providing hot-tier capabilities in terms of speed with the persistence of the warm tier. The first generation of Intel's Optane comes in a DIMM form factor with 128GB, 256GB and 512GB

capacities with hardware encryption for data security and error detection. (Mortillaro, 2018) Here are the main advantages of Optane technology.

- **Enterprise's application:** The emergence of 3D XPoint as a new storage tier is a major technological transition that will greatly impact the upcoming large cloud and hyperscale data centers as a dominating force in technology. Intel's Optane is aimed at servicing random, transactional data sets not optimized for in-memory processing. As such, the technology is going to service the highest end of warm and part of the hot tier in terms of storage or even to extend the memory size or space within that hottest tier. It could be used to perform limited real-time analytics on current data sets or store and update records in real time. (Mearian, 2017)
- **Data Center's Performance:** The Optane technology also provides greater system availability since system restarts can happen much quicker. Intel claims that the new memory will greatly increase the amount of memory available to the processor and eliminate the latency that occurs when moving data from memory to persistent storage. The advantages this persistency provides is that booting a computer doesn't require loading data into memory because it is already there. As a demonstration, Intel ran a restart of an Aerospike in-memory database server. Using simple DRAM and flash the server took 35 minutes to restart. With the Optane SSD this time was cut down to 16.9 seconds. This means that the technology would greatly reduce the time necessary to perform OS patching and updates. Also, Optane has a high endurance as it is design for high write environments making suitable for increasing the life expectancy of a server. (Kampman, 2017)

3D XPoint could also benefit workplace enablement where the technology increases the performance of workplace computers as Intel also targets the consumer electronics market with their Optane products. The Intel Optane caching solution enables a personal computer to boot-up in less than half the time and boost the overall system performance by 28%. (Mearian, 2017). The Intel Optane Memory cache drive works by watching data access patterns over time to predict what data the user will need in the future. Benchmarks of the technology show a significant difference in operating system boot time, application start time and data loading time. Intel stated that the new technology greatly increases the amount of memory available for processors. Because persistent memory has big implications for software developers, the tech giant will provide a remote access to machines using Optane Persistent Memory so that they can develop and test software that takes advantage of these capabilities. (Kampman, 2017)

Challenges

Although Intel and Micron have marketed their 3D Xpoint products as bringing significant changes to the IT industry, the technology as failed to live up to its expectations. Intel is adamant about 1000x faster speed but, in reality, third party benchmarks only show a 10x latency reduction. Many consider that the performance benefits from the transition of NAND Flash Memory to 3D XPoint aren't as great as the switch from HDD to SSD. Since Intel's credibility regarding the technology is being questioned, SSC should analyze its requirements before delving into the technology. (Mortillaro, 2018) The primary concerns for Intel's Optane memory in particular are:

- **Production:** The production of the Optane products presents many complications. One of the strong points of the technology is its density related to its stackable layered 3 dimensional structure. However, the first generation of 3D XPoint features only 2 stacked layers of single bit cells with a 20nm process and a 128GB die. On the other hand, NAND technology is currently transitioning from 64 to 96 layers. However, there's a big difference in the layering process of NAND and 3D XPoint. This last one needs a more advanced and costly lithography resulting from vertical and horizontal conductors. This complicates the process that some experts doubt that it will ever be economically viable to scale the technology to multiple layers. (Mellor, 2019)
- **System Requirement:** The Optane Memory cache drive for desktop specifically present software and hardware limitations. The technology is only officially supports systems with a Windows 10 with the April 2018 patch. Therefore, MacOS and Linux systems aren't eligible for using the technology. As for the hardware requirements, Optane only comes with an M.2 form factor that is only available on newer motherboards with at least a 7th generation Intel processor socket. Furthermore, the Government of Canada is inclined to having their civil servants using laptops for work, most of which don't have an M.2 expansion slot at the moment. These requirements means that the Optane caching drive won't work on most of the available laptops. (Yamada, 2017)
- **Applications:** Applications and storage systems will need to be redesign to fit the new architecture. The current process of retrieving data requires too many CPU cycles when a miss occurs in the first two tiers. There is also the need for major kernel involvement with the current way. With Intel's system applications can essentially talk to the hardware directly, almost the same as a DMA performed by I/O devices contacting RAM. Giving applications this kind of ability presents a risk of data corruption. Applications also need to be written using a persistent memory development kit to support persistent memory replication.

- **Price:** As of Q2 of 2019, the data center targeted Optane is too expensive, but it is still a cheaper alternative to the Non-Volatile DIMM (RAM) and it's usages is restricted mainly to data caching and tiering mechanism. As for the

> consumer caching options, Intel provides a 16GB for $23, 32GB for $59 and a new 64GB option for $80. However, users are confused as to how it is meant to be used. There is not enough memory to put an instance of Windows 10 on it and applications meant to use its potential are too large for anything else. The scenario Intel envisions is to combine it an HDD to give it "SSD" level of performance. But why not just buy an SSD for less and the same level of performance. Optane is currently trying to solve a problem that has already been solved. (Kampman, 2017)

Considerations

There are two main considerations that should be given to the use of Optane SSD and 3D Xpoint technology. (Branscombe, 2018)

- **Data Center Architecture:** The re-architecting of application and storage systems needs to be considered. Without this the full effect of this technology will not be felt. This is true for both the application and protocol stack. Intel has tried to mitigate this issue by providing software which allows a 3D Xpoint PCIe card to be addressed as part of a memory pool. This means the operating system does not have to be changed significantly to accommodate the technology. However, this is not a permanent solution to the issue and thus it should still be considered.
- **Cost:** Cost is the second major consideration. If measured by production the cost should be lower than that of DRAM. However based on production volume the cost associated with 3D Xpoint is much higher than DRAM. The volume will increase as the industry begins to transition to adopting the technology. For the moment however, the cost DRAM has also been decreasing since the demand is so high. As a result this is preventing Intel from increasing their production volume.

Lastly, SSC may wish to consider evaluating the current Service Catalogue and Infrastructure plans in order to determine where 3D Xpoint can be leveraged to improve efficiencies, reduce costs, and improve processing as well as how the introduction of this new technology will impact the size and complexity of the GC network. Any new procurement of devices that are 3D Xpoint or platforms should have high market value and can be on-boarded easily onto the GC network.

References

Baltazar, H. & R. Fichera. (2015, Oct 1). *Brief: New Memory Innovations Will Power Extreme Service Performance*. Retrieved from Forrester paper.

Branscombe, M. (2018, June 4). *How Intel's New Optane Persistent Memory Will Change Your Data Center*. Retrieved from datacenterknowledge: https://www.datacenterknowledge.com/storage/how-intel-s-new-optane-persistent-memory-will-change-your-data-center

Cutress, I. (2018, July 16). *Intel and Micron To Dissolve 3D XPoint Partnership After 2019*. Retrieved from anandtech: https://www.anandtech.com/show/13083/intel-and-micron-update-3d-xpoint-roadmap-combined-effort-2nd-gen-3rd-gen-separate

Gangam, V. (2018, July 24). *Solve the Most Demanding Storage and MemoryChallenges with Intel Optane*. Retrieved from lanworks: https://lanworks.com/solve-the-most-demanding-storage-and-memory-challenges-with-intel-optane/

Intel. (2019, July 31). *Intel Optane Technology*. Retrieved from Intel: https://www.intel.com/content/www/us/en/architecture-and-technology/intel-optane-technology2.html

Jain, A. (2018, August 16). *Is 3D Xpoint a phase change memory?* Retrieved from Quora: https://www.quora.com/Is-3D-Xpoint-a-phase-change-memory

Kampman, J. (2017, April 24). *Intel's 32GB Optane Memory storage accelerator reviewed*. Retrieved from Tech Report: https://techreport.com/review/31784/intels-32gb-optane-memory-storage-accelerator-reviewed/

Malventano, A. (2017, June 2). *How 3D XPoint Phase-Change Memory Works*. Retrieved from pcper: https://pcper.com/2017/06/how-3d-xpoint-phase-change-memory-works/

Mearian, L. (2017, May 4). *FAQ: 3D XPoint memory – NAND flash killer or DRAM replacement?* Retrieved from computerworld.com: https://www.computerworld.com/article/3194147/faq-3d-xpoint-memory-nand-flash-killer-or-dram-replacement.html

Mellor, C. (2019, January 22). *3D XPoint needs to be bigger and cheaper. But how will it get there?* Retrieved from blocksandfiles.com: https://blocksandfiles.com/2019/01/22/great-expectations-xpoint-evolution-envisaged/

Moorhead, P. (2018, August 8). *Intel Makes Storage Integral To Data Center Architecture, And That's Smart*. Retrieved from forbes: https://www.forbes.com/sites/patrickmoorhead/2018/08/08/intel-makes-storage-integral-to-data-center-architecture-and-thats-smart/#7a2aa09278b3

Morra, J. (2018, July 24). *Intel Winds Down 3D XPoint Development with Micron*. Retrieved from electronicdesign: https://www.electronicdesign.com/embedded-revolution/intel-winds-down-3d-xpoint-development-micron

Mortillaro, M. (2018, November 5). *What Future for Intel Optane?* Retrieved from Kamshin: https://www.kamshin.com/2018/11/what-future-for-intel-optane/

Rouse, M. (2016, April 29). *3D XPoint*. Retrieved from searchstorage.techtarget: https://searchstorage.techtarget.com/definition/3D-XPoint

Tallis, B. (2019, January 14). *Micron Exercises Option to Buyout Intel's Share of IMFT*. Retrieved from anandtech: https://www.anandtech.com/show/13862/micron-exercises-option-to-buyout-intels-share-of-imft

Walton, J. (2019, May 6). *Intel Optane Memory: everything you need to know*. Retrieved from pcgamer: https://www.pcgamer.com/intel-optane-memory-everything-you-need-to-know/

Wikipedia. (2019, July 27). *3D XPoint*. Retrieved from Wikipedia: https://en.wikipedia.org/wiki/3D_XPoint

Wikipedia. (2019, July 20). *Solid-state drive*. Retrieved from Wikipedia: https://en.wikipedia.org/wiki/Solid-state_drive

Yamada, K. (2017, May 2). *10 Reasons Why Intel's Bleeding-Edge Optane Drive Is a Rip-Off*. Retrieved from makeuseof.com: https://www.makeuseof.com/tag/reasons-why-intel-optane-drive-rip-off/

[1] https://www.techopedia.com/definition/2787/memory
[2] https://www.techopedia.com/definition/9966/volatile-storage
[3] https://www.techopedia.com/definition/9966/volatile-storage

[4] https://courses.lumenlearning.com/collegesuccess2x48x115/chapter/volatile-and-non-volatile-computer-memory-session-6/
[5] https://www.techopedia.com/definition/2793/non-volatile-memory-nvm
[6] https://kb.iu.edu/d/ahtx
[7] https://searchstorage.techtarget.com/definition/NAND-flash-memory
[8] https://www.pcmag.com/encyclopedia/term/69459/3d-xpoint