

Accelerating Vector Database Performance through Disk-based Indexes with KIOXIA CM7 Series SSDs

Introduction

Artificial intelligence (AI) is becoming omnipresent and the list of applications, use cases and benefits are growing continually. Large language models (LLMs) are an important generative AI use case and include vast deep learning models pre-trained on large datasets. These large datasets and each model's parameters are traditionally read into DRAM. The memory demand and requirements for LLMs can pose significant challenges and costs for systems with limited DRAM capacity.

LLMs are trained on large amounts of text data consisting of words and sentences that derive semantic meaning and context to generate a meaningful response. However, often times through just training on this data alone, the model can still generate irrelevant or factually incorrect responses. Vector databases (DBs) help to address these issues by functioning as the underlying storage layer for which the LLM can retrieve accurate and factual data. Unlike traditional databases, vector DBs use vectors to represent data that enables applications to be built with an LLM on top of a vector storage layer that contains the most up-to-date, factual and accurate data available.

A vector DB stores original data (i.e., images, audio, text), as well as encoded data known as embeddings. Vector data is stored in a vector DB through indexing which creates data structures and vector lookup tables, which narrow down searches quickly. Embedding models store vector data with high dimensionality, and Approximate Nearest Neighbor (ANN) algorithms capture data relationships through context or semantic meaning that can demonstrate how similar points of data are in relation to each other.

Popular vector indexes, such as Hierarchical Navigable Small Worlds (HNSW), require significant system memory that can become very expensive, as datasets and dimensionality grow. To counter the growing size of vector indexes, a new type of indexing was created that stores and searches the vector indexes using disk. More recent advances in vector DB indexing use Disk Approximate Nearest Neighbor¹ (DiskANN) algorithms that can offload the system memory footprint to disk without sacrificing performance. To support DiskANN algorithms, fast underlying storage is required.

This performance brief presents performance tests using DiskANN algorithms with a KIOXIA CM7-R Series SSD - E3.S form factor, enterprise-class, read-intensive, and compliant with the PCIe[®] 5.0 specification and NVMe[™] 2.0 protocol - that delivers high-read throughput and low latency in support of a broad range of applications and workloads. The KIOXIA CM7-R Series SSD deployed in a Dell[®] PowerEdge[™] R6615 rack server was used to hold a prepared [Cohere[™] dataset²](#) and a [LAION dataset](#) in a Milvus^{®3} vector DB. The Cohere datasets included 1 million and 10 million vectors while the LAION dataset included 100 million vectors. Both datasets utilized 768 dimensions per vector.

The tests determined whether the KIOXIA CM7-R Series SSD using DiskANN algorithms can deliver similar or improved performance when compared with system memory-based indexes, such as HSNW. The tests were performed through VectorDBBench software.

The test results show that a KIOXIA CM7-R Series SSD using DiskANN algorithms was able to outperform or match memory-based indexes using ANN algorithms in queries per second (QPS), QPS per dollar and recall, while effectively lowering the system memory footprint. The results also demonstrate that in order to support LLM vector DB applications, using SSDs can minimize system memory use. This enables DRAM resources to be freed for other tasks and is more efficient for processing large datasets, such as those used in data analytics, AI/ML and deep learning applications.

The test results presented include a brief description of each workload test, a graphical depiction of the test results and an analysis. Appendix A covers the hardware and software configuration – Appendix B covers the configuration set-up and test procedures.

Test Results Snapshot

A KIOXIA CM7-R Series SSD using disk-based indexes in a Dell[®] PowerEdge[™] R6615 server delivered the following vector DB performance results when compared with system memory-based indexes:

Queries per Second (QPS) *(higher is better)*

1M Vectors	10M Vectors	100M Vectors
+92%	+123%	Similar

Total System Memory Used *(lower is better)*

1M Vectors	10M Vectors	100M Vectors
-32%	-64%	-74%

QPS per Dollar *(higher is better)*

1M Vectors	10M Vectors	100M Vectors
+5x	+6x	+2x

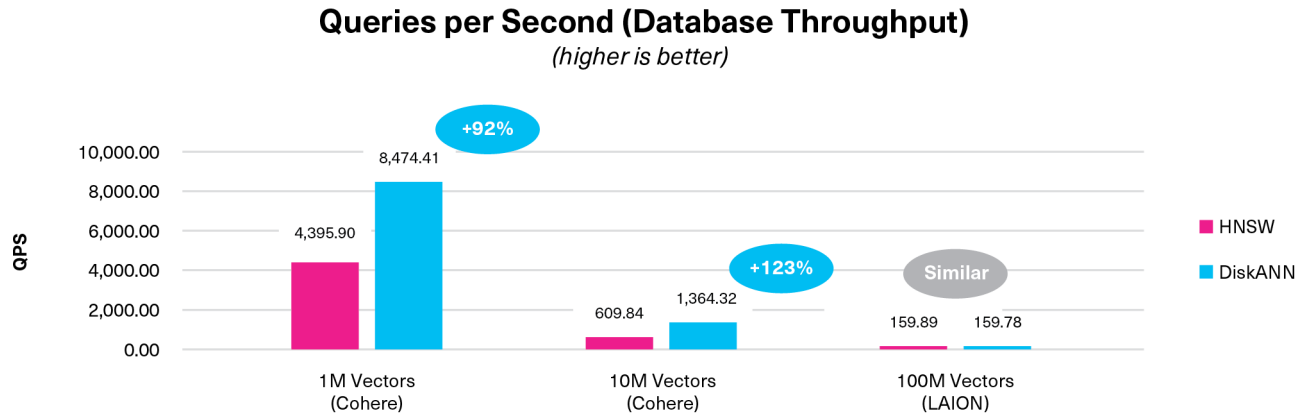
Recall *(higher is better)*

1M Vectors	10M Vectors	100M Vectors
Similar	Similar	Similar

Test Results⁴

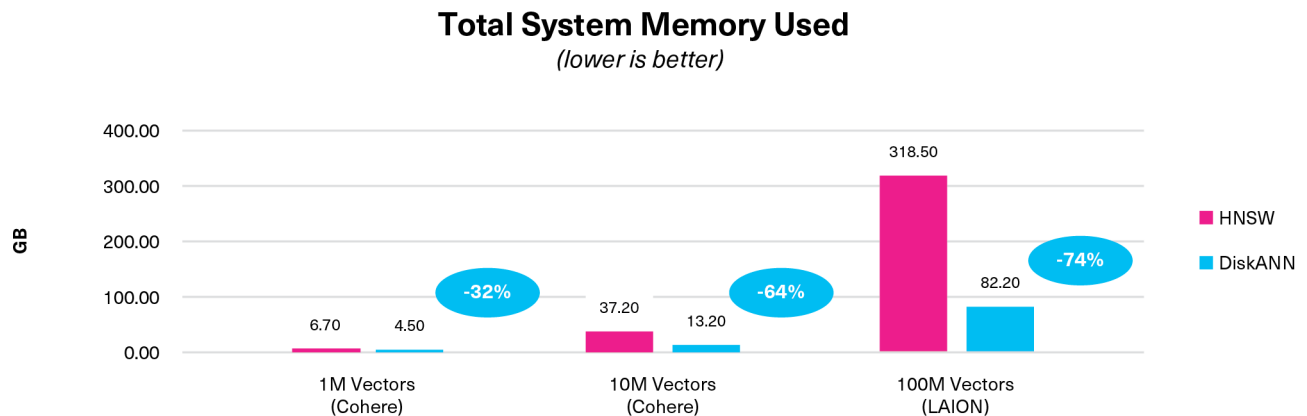
Metric 1: Queries per Second (Database Throughput)

This metric measured the number of queries per second that the Milvus[®] vector DB can achieve when querying the vector space for a similarity search. Higher database throughput indicates that the compute resources are working more efficiently, are able to scan through more vectors in the index, and are capable of returning the results of the similarity search faster. The DiskANN index, in conjunction with a KIOXIA CM7-R Series SSD, is able to outperform an HNSW index at lower dataset sizes and is able to match the performance of an HNSW index at higher dataset sizes. The database throughput results are in QPS and the higher result is better.



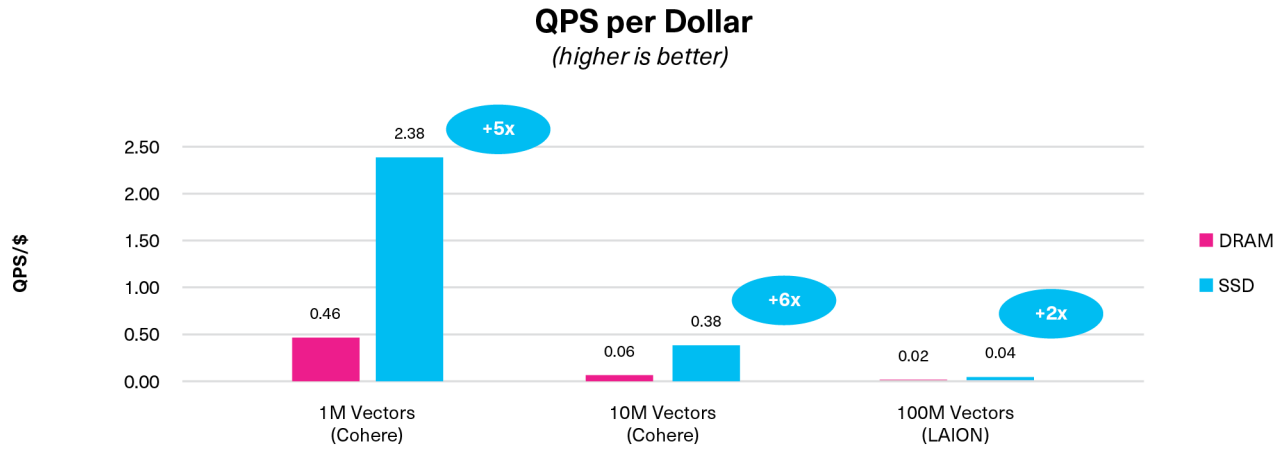
Metric 2: Total System Memory Used

This metric measured the amount of system memory that was utilized by the Milvus process when the vector DB test cases were run. Algorithms that use disk instead of DRAM can lower or offload the system memory footprint, enabling system memory resources to be utilized for other processes or trainings on much larger dataset sizes. This delivers cost-effectiveness since DRAM can be expensive as datasets grow. System design and associated purchases can be altered so that less DRAM is required to run large vector DB datasets by storing the indexes on fast SSDs. The results are in gigabytes⁵ (GB) and the lower result is better.



Metric 3: QPS per Dollar

This metric measured⁶ the amount of costs that can be saved by switching to a disk-based index and SSD as opposed to a memory-intensive index in system memory without sacrificing vector DB throughput performance. With more expensive DRAM costs, coupled with larger datasets, it becomes inefficient to store all of this content into system memory. With KIOXIA CM7-R Series SSDs, large capacities are available to provide a cost-effective solution. The results are in queries per second per dollar (QPS/\$) and the higher result is better.



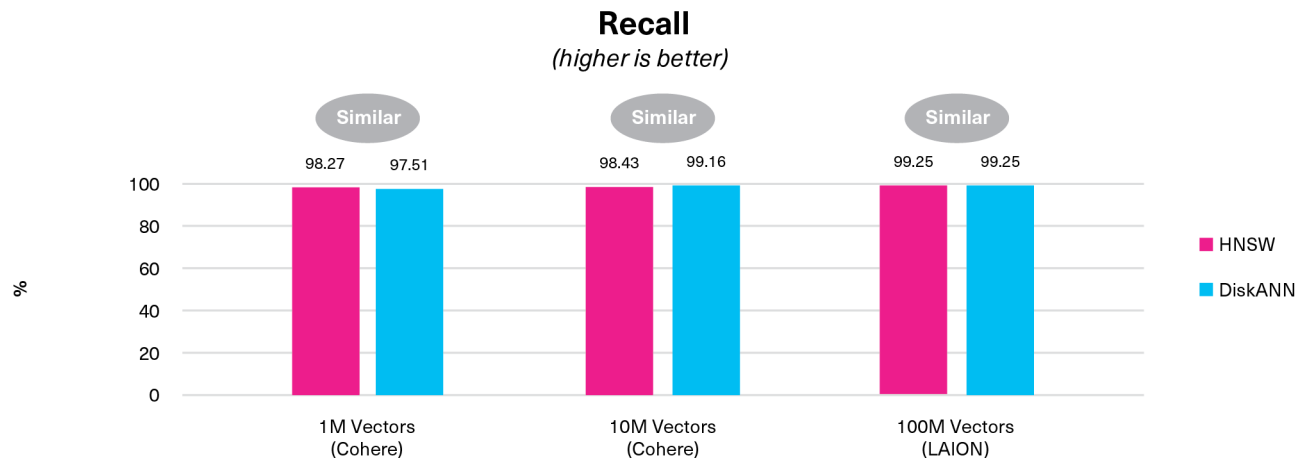
Metric 4: Recall

This metric measured the ability of the Milvus[®] vector DB to find all relevant cases (true positives) within a vector space when conducting a similarity search. The results are then calculated using the following formula:

$$\frac{\text{True Positives}}{\text{True Positives} + \text{False Negatives}}$$

The recall shows what proportion of actual positives were identified correctly. From these calculations, the higher the recall, the more precise and similar the results will be when vector data is returned back to the Milvus vector DB.

The DiskANN index using the KIOXIA CM7-R Series SSD was able to deliver similar recall when compared with the HNSW index. The results ensure that the similarity search returned a high percentage of relevant content without sacrificing performance. The results are in percentage (%) of recall and the higher result is better.



Analysis

Using DiskANN algorithms to offload the system memory footprint to the KIOXIA CM7-R Series SSD enabled the DRAM resource to be utilized for other processes and tasks, delivering cost-effectiveness especially since system memory can be expensive. The KIOXIA CM7-R Series SSD with DiskANN algorithms used 32% less system memory at 1 million vectors, 64% less at 10 million vectors and 74% less at 100 million vectors when compared with a system memory-based index.

For queries per second (database throughput), the KIOXIA CM7-R Series SSD with DiskANN algorithms performed better at lower dataset sizes (1 million and 10 million vectors). At the higher LAION 100 million vector dataset size, the performance of the SSD DiskANN-based index was roughly equivalent to a system memory-based index. This means that IT personnel can substitute higher cost DRAM with less expensive SSDs without sacrificing performance. The KIOXIA CM7-R Series SSD with DiskANN algorithms delivered 92% more queries per second at 1 million vectors, 123% more at 10 million vectors and similar throughput at 100 million vectors when compared with a system memory-based index.

These performance results translate into cost savings as evident from the QPS per dollar results⁶. The KIOXIA CM7-R Series SSD with DiskANN algorithms delivered 5x higher QPS per dollar at 1 million vectors, 6x higher QPS per dollar at 10 million vectors and 2x higher QPS per dollar at 100 million vectors.

The recall results demonstrate comparable accuracy percentages of the KIOXIA CM7-R Series SSD and DiskANN index when compared with a system memory-based index. This enables IT personnel to save on operating costs and cost of ownership by using SSDs to gain accurate vector DB performance metrics instead of investing/reinvesting in relatively more expensive DRAM system memory.

Summary

The KIOXIA CM7-R Series E3.S SSD and DiskANN index performed better than a system memory-based index at various vector DB sizes with regards to queries per second (database throughput) and also delivered comparable recall performance for accuracy. These drives are well-suited to support vector DBs that use DiskANN vector indexes as showcased by the test results. System design and associated purchases can be altered so that less DRAM is required to run large vector DB datasets by storing the indexes on fast SSDs.

KIOXIA CM7-R Series SSD Product Info

The latest generation KIOXIA CM7-R Series SSDs support the Enterprise and Datacenter Standard Form Factor (EDSFF) E3.S form factor which is compliant with the PCIe[®] 5.0 specification and the NVMe™ 2.0 protocol. The E3.S SSDs are available with 1 DWPD⁷ endurance and capacities up to 15.36 terabytes⁵ (TB). Additional features include a dual-port design for high availability applications, flash die failure protection to maintain reliability in case of a die failure and security options⁸.



KIOXIA CM7 Series E3.S SSD¹⁰

Performance Overview (single port (1x4) mode):

Sequential Read: up to 14,000 megabytes per second (MB/s); up to 13,000 MB/s for the 15.36 TB model
 Sequential Write: up to 6,750 MB/s; up to 5,300 MB/s for the 15.36 TB model
 Random Read: up to 2,700,000 input/output operations per second (IOPS); up to 2,000,000 IOPS for the 15.36 TB model
 Random Write: up to 310,000 IOPS; up to 260,000 IOPS for the 15.36 TB model

KIOXIA CM7 Series SSDs are also available for higher endurance mixed-use applications in both 2.5-inch⁹ and E3.S form factors, and include 3 DWPD endurance and capacities up to 12.8 TB.

Additional KIOXIA CM7 Series SSD information is available [here](#).

Appendix A

Hardware/Software Test Configuration

Server Information	
Model	Dell® PowerEdge™ R6615
No. of Servers	1
No. of CPU Sockets	1
CPU	AMD EPYC™ 9454P
No. of CPU Cores	48
CPU Frequency	2.75 GHz
Total Memory	384 GB ⁴ DDR5 DRAM
Memory Frequency	DDR5-4800
Operating System Information	
Operating System	Ubuntu®
Version	22.04.4 LTS
Kernel	5.15.0-97-generic
File System Information	
File System	XFS®
Mount Options	noatime, nodiratime
Vector Database Software Information	
Vector Database	Milvus®
Version	2.3.10
Test Software Information	
Test Software	VectorDBBench
Version	0.0.7
Vector Dimensions	768
Dataset #1	Cohere™
No. of Vectors (Dataset #1)	1M / 10M
Dataset #2	LAION
No. of Vectors (Dataset #2)	100M
HNSW Parameters	
M Vectors	30
efConstruction	360
ef	100
DiskANN Parameters	
search_list	100
SSD Information	
Model	KIOXIA CM7-R Series
Interface	PCIe® 5.0 x4
Protocol	NVMe™ 2.0
No. of Drives	1
Form Factor	EDSFF E3.S
Capacity	3.84 TB
DWPD	1 (5 years)

Appendix B

Configuration Set-up/Test Procedures

Configuration Set-up

A Dell® PowerEdge™ R6615 rack server was setup with an Ubuntu® 22.04.4 LTS operating system.

One 3.84 TB KIOXIA CM7 Series E3.S SSD was installed into the server.

The SSD was setup with an XFS® file system and mounted with noatime and nodiratime flags.

The Milvus® vector DB was downloaded and configured so that raw data, vectors and indexes would be stored onto the SSD.

The VectorDBBench load generator was installed to run a search performance test for various vector DB sizes.

The Cohere™ and LAION datasets were downloaded and inserted into the Milvus vector DB. The Cohere datasets consisted of 1 million and 10 million vectors with 768 dimensions, while the LAION dataset consisted of 100 million vectors with 768 dimensions.

Test Procedures

The VectorDBBench benchmark test was run utilizing an HNSW index and the following metrics were gathered:

- *Total System Memory Used (in GB)*
- *Queries per Second (in QPS)*
- *QPS per Dollar (in QPS/\$)*
- *Recall (in %)*

The tests above were then repeated with a DiskANN index.

The metrics were compared between the two indexes.

NOTES:

¹ The DiskANN repository requests the following citation:

@misc{diskann-github;

authors = Simhadri, Harsha Vardhan and Krishnaswamy, Ravishankar and Srinivasa, Gopal and Subramanya, Suhas Jayaram and Antonijevic, Andrija and Pryce, Dax and Kaczynski, David and Williams, Shane and Gollapudi, Siddarth and Sivashankar, Varun and Karia, Neel and Singh, Aditi and Jaiswal, Shikhar and Mahapatro, Neelam and Adams, Philip and Tower, Bryan and Patel, Yash;

title = DiskANN: Graph-structured Indices for Scalable, Fast, Fresh and Filtered Approximate Nearest Neighbor Search;

urls = <https://github.com/Microsoft/DiskANN>;

version = 0.6.1;

year = 2023;

² Cohere™ dataset is part of the Cohere platform used to generate high-quality vector DB embeddings. The Cohere Embed API endpoint is used to generate language embeddings, and then those embeddings are indexed into the Pinecone™ vector DB for fast and scalable vector searches.

³ Milvus® is an open-source vector database built to power embedding similarity search and AI applications, and makes unstructured data searches more accessible.

⁴ Read and write speed may vary depending on the host device, read and write conditions, and file size.

⁵ Definition of capacity: KIOXIA Corporation defines a megabyte (MB) as 1,000,000 bytes, a gigabyte (GB) as 1,000,000,000 bytes, a terabyte (TB) as 1,000,000,000,000 bytes and a petabyte (PB) as 1,000,000,000,000,000 bytes. A computer operating system, however, reports storage capacity using powers of 2 for the definition of 1Gbit = 2³⁰ bits = 1,073,741,824 bits, 1GB = 2³⁰ bytes = 1,073,741,824 bytes, 1TB = 2⁴⁰ bytes = 1,099,511,627,776 bytes and 1PB = 2⁵⁰ bytes = 1,125,899,906,842,624 bytes and therefore shows less storage capacity. Available storage capacity (including examples of various media files) will vary based on file size, formatting, settings, software and operating system, and/or pre-installed software applications, or media content. Actual formatted capacity may vary.

⁶ The QPS per Dollar metric was calculated by dividing the QPS metric reported in Metric 1 from the pricing available on public sources as of this publication date for the total amount of DRAM or SSDs used in the server solution for HNSW and DiskANN algorithms, respectively.

⁷ DWPD: Drive Write(s) Per Day: One full drive write per day means the drive can be written and re-written to full capacity once a day, every day, for the specified lifetime. Actual results may vary due to system configuration, usage, and other factors.

⁸ Optional security feature compliant drives are not available in all countries due to export and local regulations.

⁹ 2.5-inch indicates the form factor of the SSD and not its physical size.

¹⁰ The product image shown is a representation of the design model and not an accurate product depiction.

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