Western Digital.

PRODUCT MANUAL

Ultrastar® DC ME200 Memory Extension Drive

Revision History

Revision	Date	Description	Reference
1.0	January 10, 2019	Initial release	
2.0	March 22, 2019	Added best practices for benchmarking and enhanced troubleshooting.	
3.0	May 07, 2019	Update to links within Sections 2.3, 2.4, and 8.1.	

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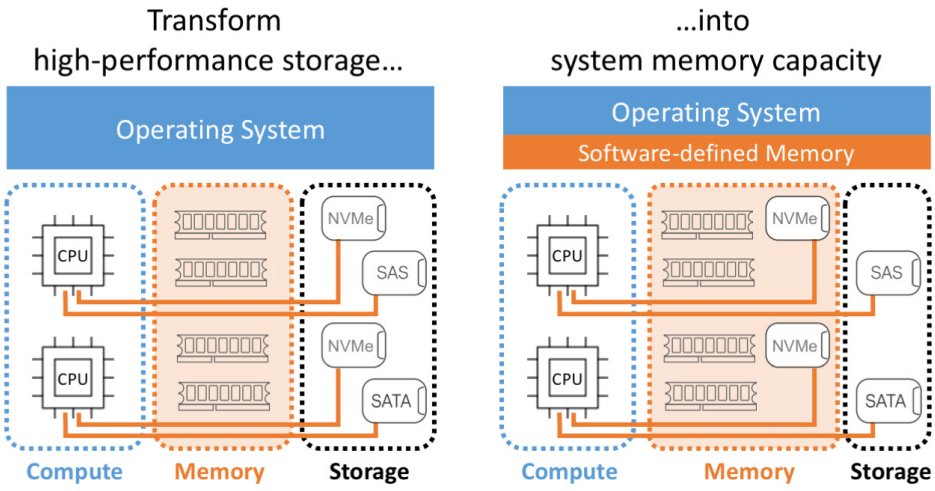
1.0 INTRODUCTION

The Ultrastar® DC ME200 Memory Extension Drive can be used to immediately scale existing system memory, promote server consolidation, and reduce the complexity of splitting large multi-TB data sets across multiple servers. The Ultrastar memory drive drives applications with large amounts of system memory at a fraction of the cost of DRAM by combining Ultrastar NVMe™ SSDs with Western Digital memory extension technology. Advanced software algorithms work to maintain DRAM-like performance across a variety of applications, especially targeting highly parallel workloads with high numbers of transactions. Once installed, the solution is transparent, requiring no changes to the existing OS and applications.

This document provides details for users and administrators on the design, installation, features, and specifications of Ultrastar memory drives.

As shown in Figure 1-1, the Ultrastar memory drive executes directly on the hardware, below the operating system, and creates a hybrid system memory from DRAM and NVM. This hybrid system memory operates transparently as volatile system memory, as if it were all DRAM.

Figure 1-1. Block Diagram of the Ultrastar Memory Drive



2.0 Installing Ultrastar Memory Drive

2.1 Operating System Prerequisites

- Linux® x86 64 bit, kernel versions 2.6.32 or higher.
- See **Release Notes** for supported Linux distributions.
- Ultrastar memory drives also supports Open Source hypervisors such as KVM, as shipped with the major Linux distributions.

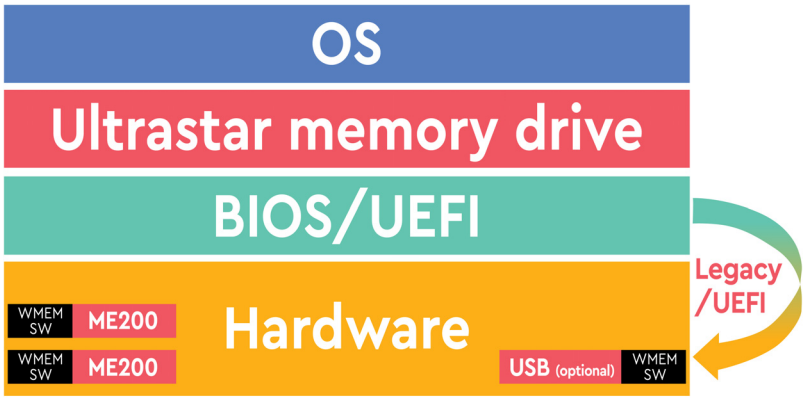
2.2 Preloaded Software

The Ultrastar memory drive is a bootable device, shipped with preloaded software to create software-defined memory. Booting a system directly from the Ultrastar memory drive requires the system to support a UEFI boot.

To setup the system from a different local bootable flash media, or if the system does not support UEFI boot, refer to Chapter 8 - *Reload the Ultrastar memory Software*.

If the preloaded software on the Ultrastar memory drive is accidentally deleted or corrupted, refer to Chapter 8 - *Reload the Ultrastar Memory Software*.

Figure 2-1. Preloaded Software



Installing the Ultrastar memory drive is as simple as physically connecting the Ultrastar memory device to the right slot within the system (refer to the system's manual for information on connecting NVMe devices to it).

- For optimal performance, it is highly recommended to install at least one Ultrastar memory drive per processor.
- Configure the system's BIOS to boot from one of the Ultrastar memory devices installed. Once setup is complete and changes, reboot the system.

NOTE: It is recommended to install a supported Linux OS; if Linux OS is pre-installed, continue with the boot process. Once prompted, select the device onto which the OS is installed as the boot device.

While it is recommended to have Linux OS pre-installed before installation, users may opt to install Linux OS before or after installing the Ultrastar memory drive.

2.3 Installing Ultrastar Memory Tools

If installing a system for purposes other than production use, such as software development, performance tuning, or quality assurance, it is recommended for users to also install the Ultrastar memory tools as it can provide valuable system information.

The software installer can be obtained from the download section of the product support page:

https://www.westerndigital.com/support/wdc/data-center-drives/ssd/ultrastar-dc-me200

> **NOTE:** The Ultrastar memory tools are installed by default within /usr/local/{bin,etc}.

Figure 2-2. Installing Ultrastar Memory Tools

```
#./wmem_installer-8.6.2535.77.sh in -t
Preparing installer...

Please take a moment to read the below
================================================================================
Welcome to WDC Ultrastar DC ME200 memory version 8.6.2535.77 !
--------------------------------------------------------------------------------
* By installing and/or using this software you acknowledge that you have read and
agreed to the agreement published at
https://www.get-wmen.com/EULA

* Parts if this program, as provided in binary form, include open source code under
one or more open source licenses. For further details and notices please see
https://www.scalemp.com/opensource.
================================================================================
Type “accept” to accept the terms and conditions above: accept
Terms and conditions accepted.

Installing WDC Ultrastar DC ME200 memory tools...
DC Ultrastar DC ME200 memory tools requires SUID permission to run as
non-root user.
Allow WDC Ultrastar DC ME200 memory tools to be run by all users (recommended)?
[N/Y] Y

WDC Ultrastar DC ME200 memory tools installation is complete.
```

2.4 Update Ultrastar Memory Software

A new software version of the Ultrastar memory drive is released periodically, which can include bug fixes, new features, and performance enhancements.

The latest software revision is available at:

https://www.westerndigital.com/support/wdc/data-center-drives/ssd/ultrastar-dc-me200

To update to the latest software version, proceed with the following:

1. Before starting the update, verify the Ultrastar memory drive is operating and supporting the installed OS.
2. Log into the system as *root*.
3. Download the latest software version to a directory on the target Linux server.
4. Make the installer file executable:

```
# chmod +x wmem_installer-x.x.x.x.sh
```

5. Launch the installer with the update flag, and follow on-screen instructions.

```
# ./wmem_installer-x.x.x.x.sh up

Please take a moment to read the following:
================================================================================
...
```

6. Press the **U** key to start the update process.

```
Writing part 1 out of 7: 100%
Writing part 2 out of 7: 100%
Writing part 3 out of 7: 100%
Writing part 4 out of 7: 100%
Writing part 5 out of 7: 100%
Writing part 6 out of 7: 100%
Writing part 7 out of 7: 100%

WDC Ultrastar DC ME200 memory installation is complete.

Installing WDC Ultrastar DC ME200 memory tools...
WDC Ultrastar DC ME200 memory tools requires SUID permission to run as non-root
user.

Allow Ultrastar DC ME200 memory tools to be run by all users (recommended)
[N/Y]? Y
```

7. Reboot the system.

The new version of the Ultrastar memory software will load and made available upon reboot of the system.

See Section 2.3 - *Installing Ultrastar Memory Tools*, for more information.

2.5 BIOS Configuration

The BIOS menus of the servers onto which they are installed may differ from the ones found below. Please verify the configuration of boot options in your systems' BIOS manual.

2.5.1 Configure Boot Device

1. Boot the machine and access the BIOS Setup Utility during system load.
2. Navigate via the **Menu** to **(Advanced) Boot Options**:
   If the system is capable of booting directly from the NVMe (using UEFI), set the **Boot mode** to **UEFI**.(See section 8.2 - *Installing Ultrastar Memory Drive Software to a Different Bootable Media*).

   In case the option of booting from the NVMe is not available, refer to the Chapter 8 - *Reload the Ultrastar Memory Software* of this publication.
3. Save changes in BIOS configuration and reboot the system.

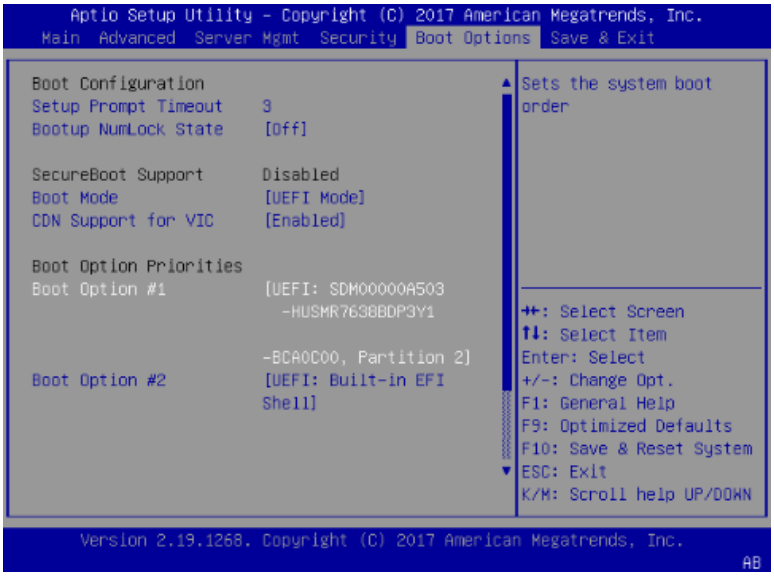
   NOTE: To enable boot device selection, save the BIOS configuration and reboot the system.

4. Re-enter the BIOS setup utility.
5. Navigate via the menu to **Boot Options**, then select **Change Boot Order/ Priorities**.

   If the system is capable of booting directly from the NVMe (using UEFI), assign to the UEFI Device and assign as the first/highest boot sequence priority.

   In case the option of booting from the NVMe is not available, assign to the USB Flash Drive highest boot sequence priority by moving it to the first position on the list.
6. Select menu option **Save & Exit** and press **Enter**.

Figure 2-3. Change Boot Order / Priorities



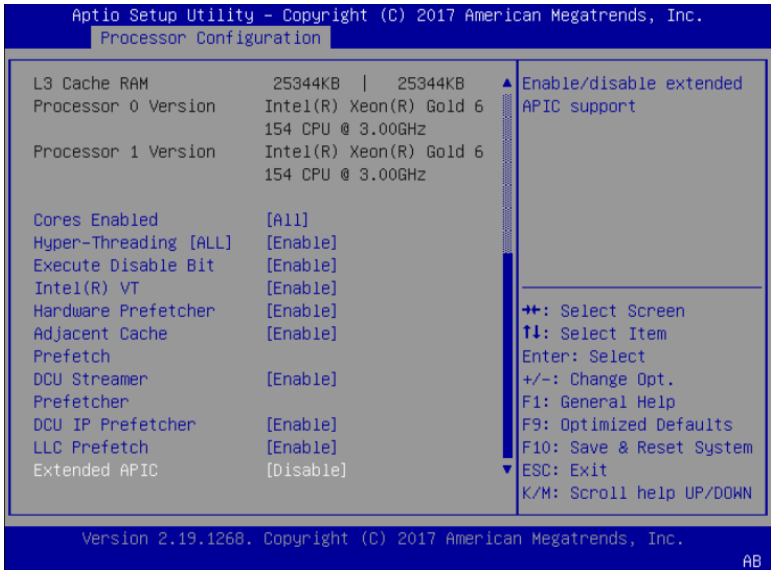
2.5.2 Configuring BIOS to Support Intel® Virtualization Technology

Note, in most systems this feature is a default setting.

To enable **Intel Virtualization Technology** (VT), navigate via the menu and proceed with the following steps:

1. Select **Advanced**, then select **Socket Configuration.**
2. Click on **Processor Configuration**, and set **Intel Virtualization Technology** to **Enabled**.

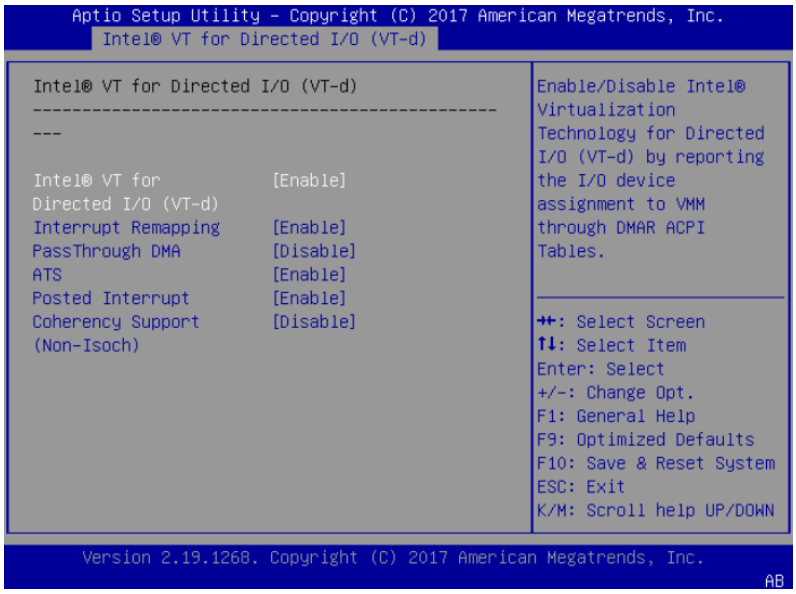
Figure 2-4. Intel Virtualization Technology Configuration



To enable VT-D, navigate via the menu and proceed with the following steps:

1. Select **Advanced**, then select **Socket Configuration**.
2. Click on **Integrated IO Configuration**, and set **Intel Virtualization Technology for Direct I/O** to **Enabled**.

Figure 2-5. Intel Virtualization Technology for Direct I/O Configuration



3.0 Ultrastar Memory Drive Boot, Settings and Diagnostics Menu

This chapter outlines the boot process of Ultrastar memory drives, as well as the interactive user setting and diagnostics options available during the boot process.

It is important to note that for data centers in which KVM console access is not available, the Ultrastar memory drive can be configured for those outputs and controls to be available via Serial over LAN (SOL).

3.1 Boot Process

The following screens are displayed during the loading process, directly after the Ultrastar memory drive system boot.

First visual the end-user sees after BIOS POST.

Figure 3-1. First Screen

Ultrastar memory drive boot start.

Figure 3-2. Ultrastar Memory Drive Boot

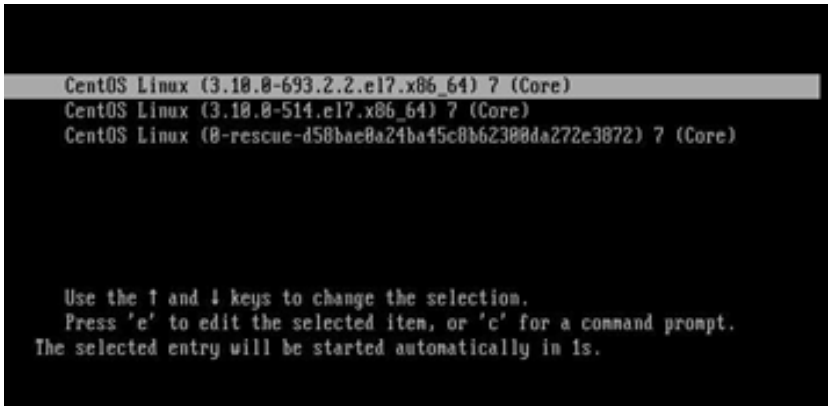
At this stage, the system displays configuration information. This specific example shows:

- 1 x 2 Processor System ("Board") with 768GiB RAM (of which 728GiB are available for use).
- 2 x NVMe SSDs ("Boards") with 1,788GiB each (of which 1,044GiB each are available for use).
- The system reports a total of 2,816GiB available for use.
- Warning messages, if any (displayed in yellow font), notify the user about deviations from best practices and recommendations.
- A prompt is displayed to optionally enter the Ultrastar memory drive settings and diagnostics menu (displayed in yellow font) by pressing <**F5**> key. If no action is taken, after timeout, the Linux OS will be booted from the device defined in the Ultrastar memory drive configuration.

Figure 3-3. Configuration Display

Guest OS Loads

Figure 3-4. Guest OS Loads



3.2 Guest OS

Once the guest operating system loads, it is possible to see all available system memory using standard **free** command:

Figure 3-5. Performance Data Collection

```
# free -g

          total    used    free    shared    buff/cache    available
Mem:       2771      21    2749         0             0         2746
```

Additionally, to check the Ultrastar memory drive version and configuration, users may see the **wmemversion** command (Note: this requires installation of Ultrastar memory tools; see Chapter 2 - *Installing Ultrastar Memory Drive Tools*):

Figure 3-6. Software Installer

```
# wmemversion --long
WDC Ultrastar DC ME200 memory: 8.6.2535.77 (Sep 20 2018 20:26:30)
System configuration:
       Boards:  3
         1 x Proc. + I/O + memory
         2 x NVM devices (HGST HUSMR7616BDP3M1)
       Processors:  2, Cores: 36, Threads: 72
         Intel(R) Xeon(R) Gold 6140 CPU @ 2.30GHz Stepping 04
       Memory (GB): 2816 (of 4343), Cache: 730, Private: 797
         1 x 728GB       [ 768/ 1/  39]
         1 x 1044GB      [1788/365/379]    86:00.0#1
         1 x 1044GB      [1788/365/379]    87:00.0#1
       Boot device: [HDD0] ATA VK000240GWCFD
```

Supported until: Unlimited this specific example shows the resources available for use:

- 1 x 2 Processor System ("Board") with 768GB RAM
  (of which 728GB are available for use)
- 2 x NVMe SSDs ("Boards") with 1,788GiB each
  (of which 1,044GiB each are available for use).

The system reports total 2,816GB available for use.

NVMe® SMART attributes are accessible in-band using the command below. SMART attributes are also accessible out-of-band using IPMI.

Figure 3-7. Software Installer

```
# wmemctl --pinfo
Device info:
       Board number:   0
       Device number:  0
       Device type:    0
       Device address: 0087:00.0#1
       PCI VID:DID:    1c58:0023
       PCI SVID:SDID:  1c58:0023
Controller ID:
       Serial number (SN):        CJH002000869
       Model number (MN):         HUSMR7632BHP301
       Firmware number (FN):      KNGNP090
       Number of namespaces (NN): 128
Namespace ID:
       Namespace size (NSZE):         543076758
       Namespace capacity (NCAP):     543076758
       Namespace utilization (NUSE):  543076758
SMART / HEALTH Information Log:
       Critical Warning:          0x0
       Composite Temperature:     48 C
       Available Spare:           191%
       Available Spare Threshold: 10%
       Percentage Used:           3%
       Data Units Read:           4021317382
       Data Units Written:        2177033579
       Host Read Commands:        452665252284
       Host Write Commands:       272541820061
       Controller Busy Time:      44577
       Power Cycles:              751
       Power On Hours:            2
       Unsafe Shutdowns:          140
       Media and Data
       Integrity Errors:          0
       Number of Error
       Information Log Entries:   2
License Info:
       Provisioned License
```

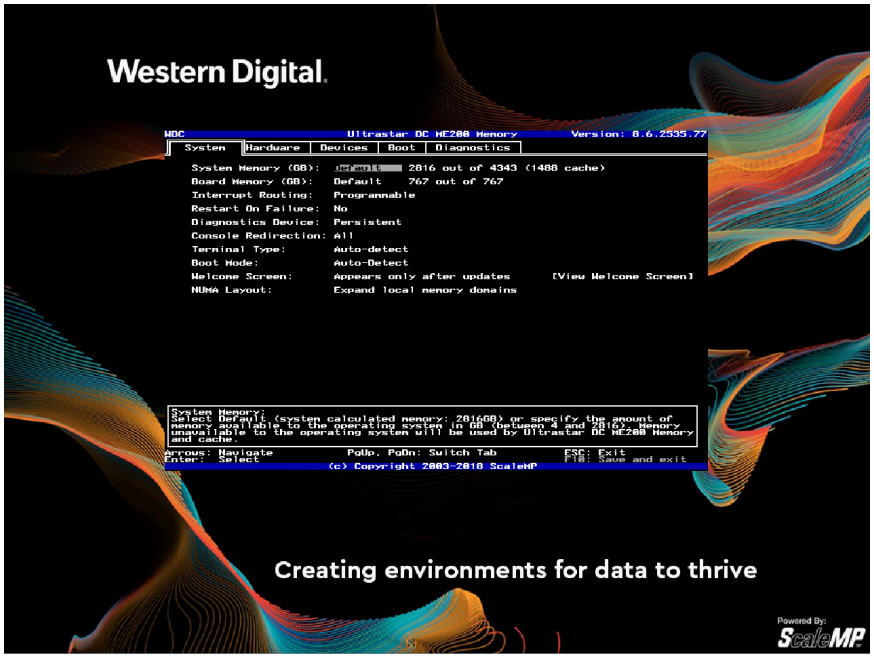
3.3 System Settings and Diagnostics

During the Ultrastar memory drive loading process, the user may go into the **Settings and Diagnostics** menu by pressing <**F5**> when prompted.

In the **System** tab, the following can be configured:

- The total system memory available to the operating system (use the default or set it manually).
- The physical board memory used (typically used in benchmarking, otherwise keep as Default).
- Set the system to auto-restart in case of critical failure of a system component (restarting without that component or stay frozen with the error message).
- Define the console redirection and terminal type.
- Toggle the display of the welcome screen between **Always** and **Only After Updates** options.
- Select the NUMA layout that Ultrastar memory drive will present to the operating system.

Figure 3-8. Systems Settings and Diagnostics (1)

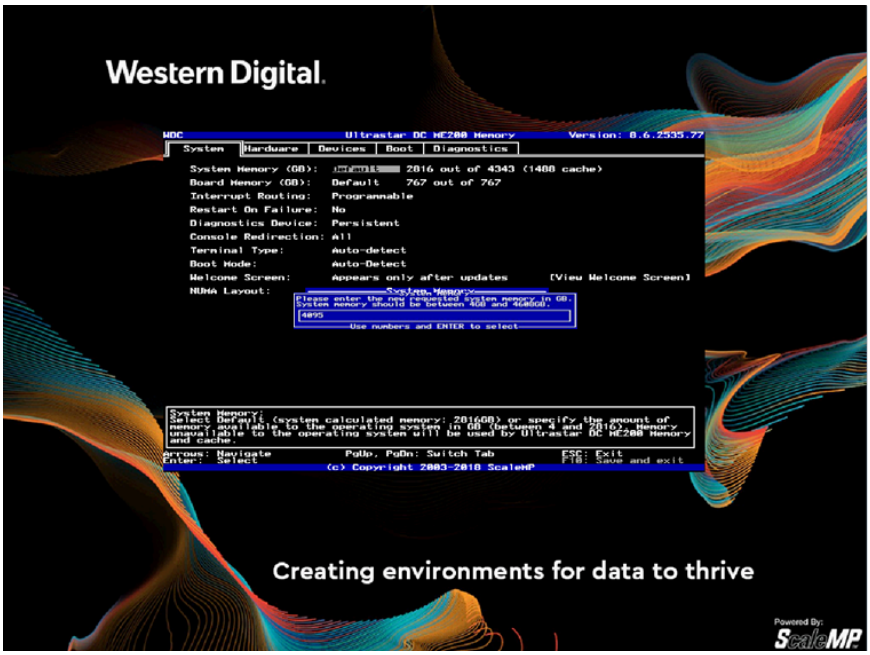


When setting the System Memory, the **Default** allows the Ultrastar memory drive to set the number to the optimal value for performance.

Switch this setting to **Manual** and set any other value from the range allowed by the system, if desired.

Setting a higher number than the default value would allow for larger system memory capacity at the expense of performance.

Figure 3-9. Systems Settings and Diagnostics (2)



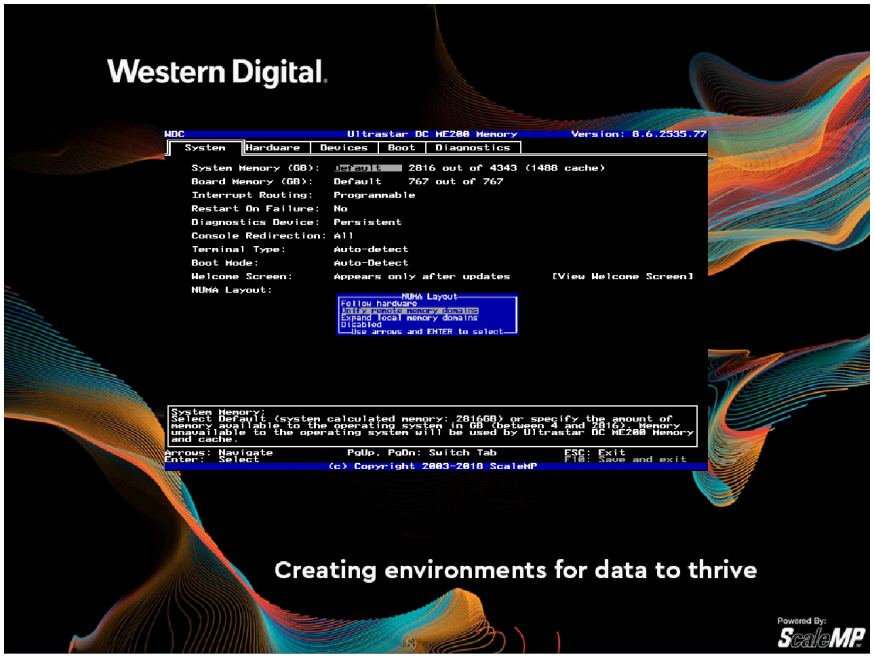
Ultrastar memory drives may present the added memory gain from the NVMe SSDs, as per the following:

- **Unifying Remote Memory Domains** - present a processor-less (memory-only) NUMA domain, which is the default setting.
- **Expand Local Memory Domains** - to expand each processor's memory domain with a portion of the memory made available by Ultrastar memory drive.

The **Expand Local Memory Domains** option is recommended for applications like the SAP HANA in-memory database.

Consult application-specific documentation for the right choice to a desired application.

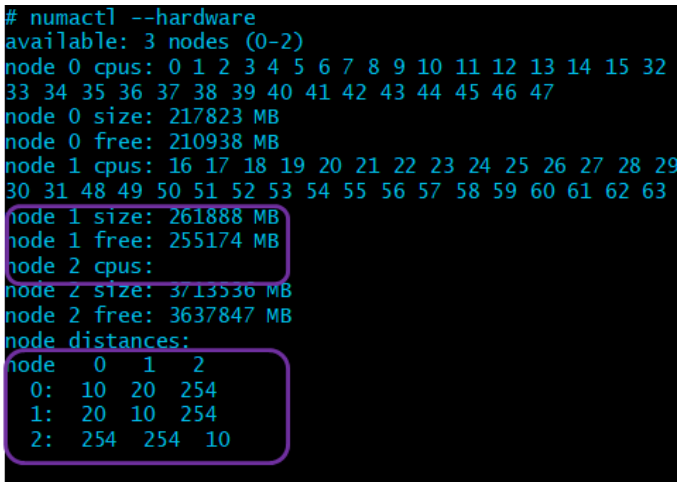
Figure 3-10. Systems Settings and Diagnostics (3)



Unify Remote Memory Domains

Memory from Ultrastar memory drive is a single additional numa-node without CPUs.

Figure 3-11. Unify Remote Memory Domains



Expand Local Memory Domains

Memory from Ultrastar memory drive is divided between the processor-oriented numa-nodes.

Figure 3-12. Expand Local Memory Domains

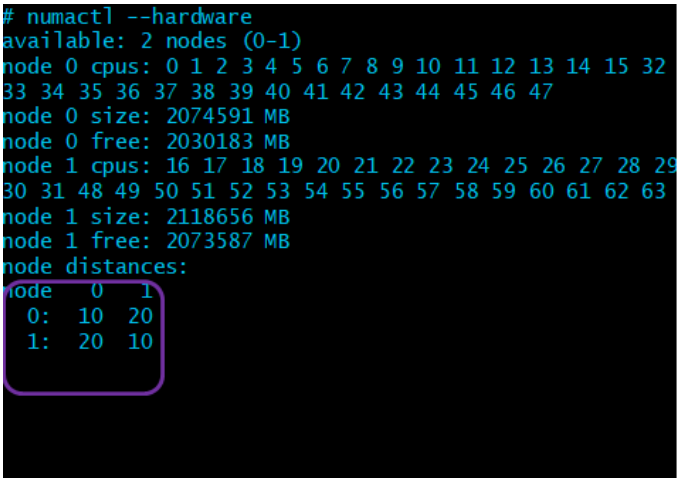
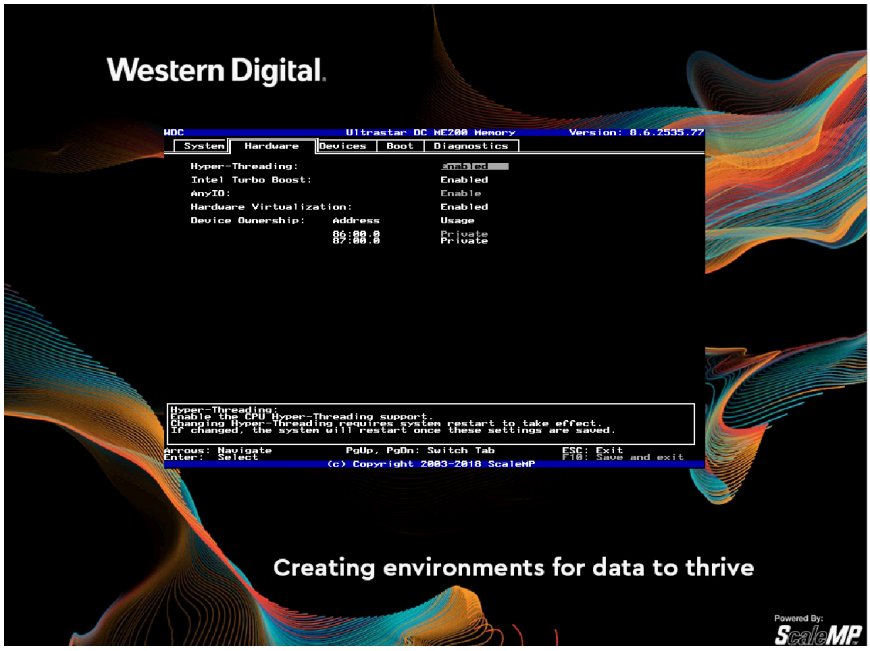


Figure 3-13. Hardware Tab

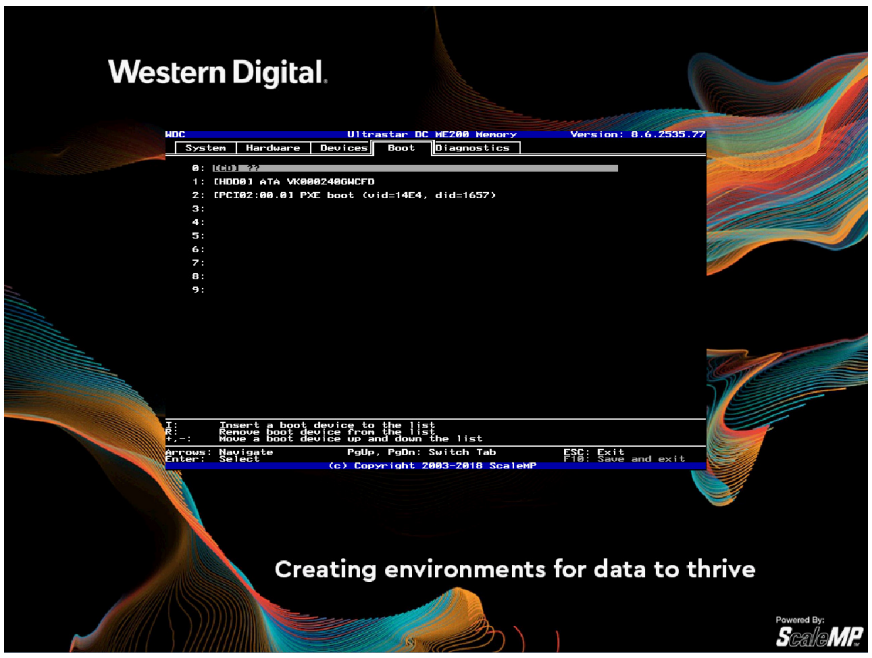


In the **Hardware** tab, the following can be set:

1. Intel processor: Hyper-threading
2. Turbo-boost
3. Hardware virtualization support.
4. Enable or disable the use of Ultrastar memory devices as storage devices.

To enable the use of untested PCI-Express cards as I/O and compute devices, use the **Devices** tab.

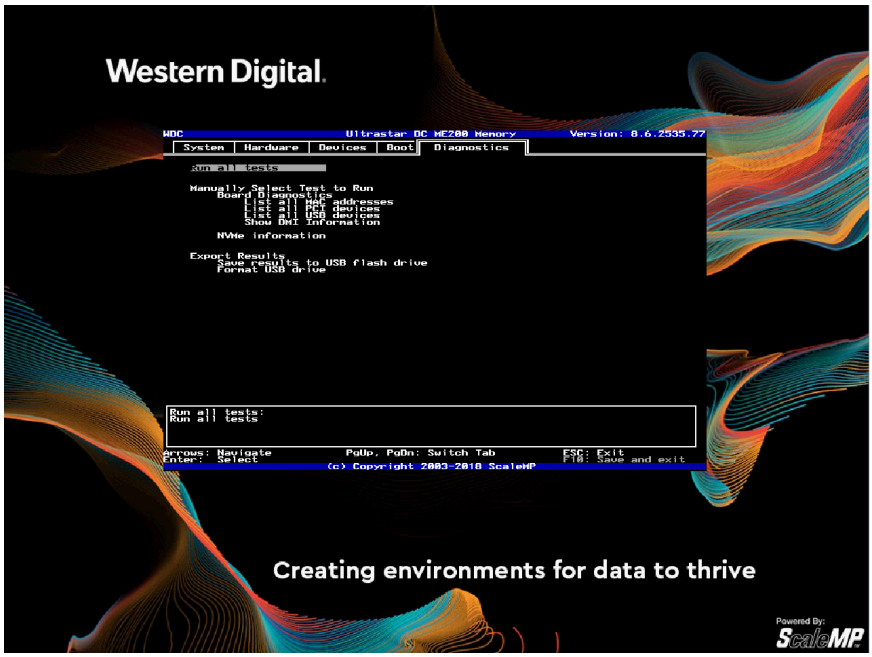
Figure 3-14. Boot Tab



In the **Boot** tab, select the device containing the desired operating system.

The boot device can be an optical device or a disk connected directly to the system, a SAN-connected device, a NIC if booting the OS over PXE, etc.

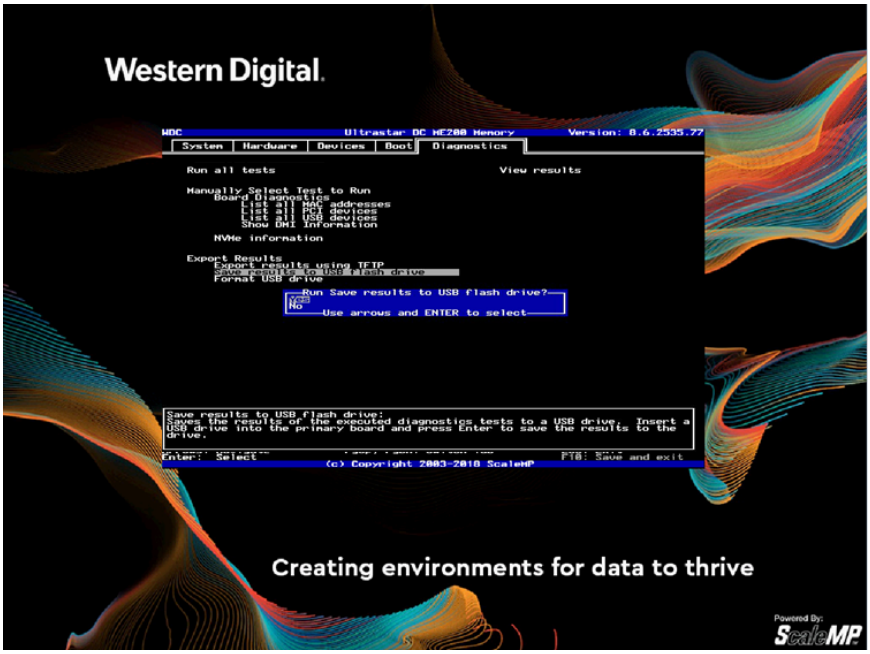
Figure 3-15. Diagnostics Tab



In the **Diagnostic** tab, select which diagnostics tests to run (or run **All Tests**).

The test results will be presented on-screen (see next screen-shot). Go back to the **Diagnostics** tab and select to save the test results to a USB Flash Drive or make them available for download using TFTP (this option requires a DHCP server on your network to assign an IP address to the diagnostics utility).

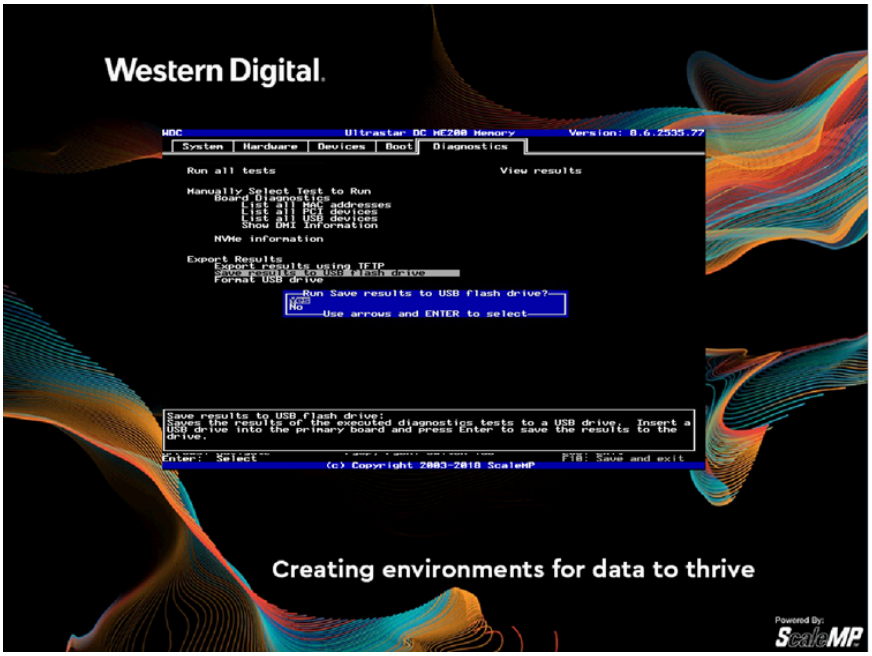
Figure 3-16. Review Diagnostic Test



Review the diagnostic test results on-screen and navigate using the keyboard arrows and page-up/page-down keys.

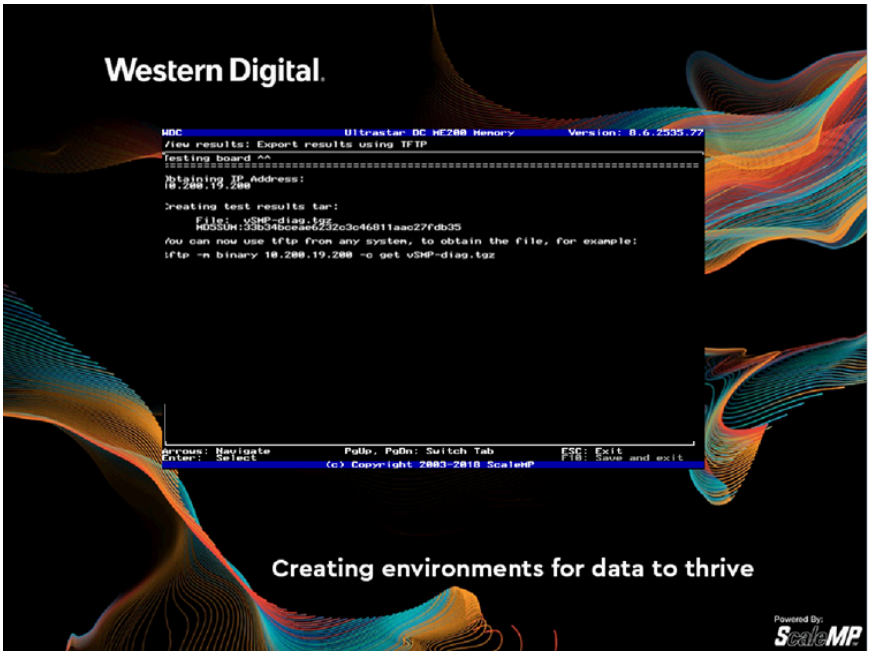
To save the diagnostics results, press <**ESC**> to go back to the **Diagnostics** tab and choose the option desired under **Export Results** tab.

Figure 3-17. Diagnostics Results



Diagnostics results can be saved to a USB Flash Drive.

Figure 3-18. TFTP Option



Alternatively, **Diagnostics** results can also be obtained via TFTP (this option requires a DHCP server on your network to assign an IP address to the diagnostics utility).

4.0 Hardware Configuration

4.1 Recommended Configuration

1. **Strongly recommended**: Attach equal number of Ultrastar memory devices between the sockets (consult your system manual for PCIe-to-socket mapping). Less than one Ultrastar memory device per socket will result in inferior performance.
2. Multiple Ultrastar memory devices can be installed and are aggregated to improve performance; optimize for the highest aggregated 4K IOPS across all Ultrastar memory devices.
3. A smaller capacity Ultrastar memory drive for each processor/socket will yield better performance than a single larger capacity device attached to only one of multiple sockets. For example, in a dual socket system, two Ultrastar memory devices with capacity of 1TiB, attached one to each socket, would perform better than a single 2TiB Ultrastar memory device attached to only one of the sockets. The same holds true for multiple devices per socket: Two smaller capacity Ultrastar memory devices per each processor/socket will yield better performance than a single larger capacity device attached to each socket. For example, in a dual socket system, four Ultrastar memory devices with capacity of 1TiB attached two to each socket, would perform better than a two 2TiB Ultrastar memory device attached one to each socket.

4.2 DRAM to Ultrastar Memory Drive Ratio

Ultrastar memory drive uses part of the overall capacity (DRAM + NVM) for caching, prefetching, and endurance protection. Thus, adding capacity in either DRAM or Ultrastar memory drives may result in lower increase or no increase at all in the system memory available for the OS. This can be overridden by changing Ultrastar memory drive system memory settings at boot time (<F5>, system settings) from Automatic to Manual.

For example, when set to Automatic, with 512GiB of DRAM on a system with four 1024GiB Ultrastar memory devices, an increase in number of drives to six will result in improved performance. However, the system memory available for the OS will not be increased (it will remain 4TiB).

Tables 4-1 and 4-2 indicate the total SDM capacity for a specific DRAM and Ultrastar memory drive configurations, optimized for performance. Using a higher number of devices for the same total capacity increases performance. Actual system memory capacity may vary by ±3% compared to the tables below. Some valid, but less frequent, configurations are not listed. For example, it is allowed to have a quad-socket system with less than 2TiB system memory, or an octa-socket system with less than 8TiB system memory.

Table 4-1. Performance-optimized Software-defined Memory (SDM) Capacity

Optimized	DRAM	Sockets	2	2	2	2	2	2	4	4	4	4
		Channels	6	6	6	6	6	6	6	6	6	6
		DPC	1	2	2	2	2	2	1	2	2	2
		DIMM Size (GiB)	8	8	16	32	64	128	32	32	64	128
NAND Devices	Device Size (GiB)	Total Size (GiB)	96	192	384	768	1536	3072	768	1536	3072	6144
2	1024	2048	768	1536	**2432**	**2816**	**3584**	**5120**	**2816**	**3584**	**5120**	**8192**
3	1024	3072	768	1536	3072	**3840**	**4608**	**6144**	**3840**	**4608**	**6144**	**9216**
4	1024	4096	768	1536	3072	**4864**	**5632**	**7168**	**4864**	**5632**	**7168**	**10240**
5	1024	5120	768	1536	3072	**5888**	**6656**	**8192**	**5888**	**6656**	**8192**	**11264**
6	1024	6144	768	1536	3072	6144	**7680**	**9216**	6144	**7680**	**9216**	**12288**
7	1024	7168	768	1536	3072	6144	**8704**	**10240**	6144	**8704**	**10240**	**13312**
8	1024	8192	768	1536	3072	6144	**9728**	**11264**	6144	**9728**	**11264**	**14336**
2	2048	4096	768	1536	3072	**4864**	**5632**	**7168**	**4864**	**5632**	**7168**	**10240**
3	2048	6144	768	1536	3072	6144	**7680**	**9216**	6144	**7680**	**9216**	**12288**
4	2048	8192	768	1536	3072	6144	**9728**	**11264**	6144	**9728**	**11264**	**14336**
5	2048	10240	768	1536	3072	6144	**11776**	**13312**	6144	**11776**	**13312**	**16384**
6	2048	12288	768	1536	3072	6144	12288	**15360**	6144	12288	**15360**	**18432**
7	2048	14336	768	1536	3072	6144	12288	**17408**	6144	12288	**17408**	**20480**
8	2048	16384	768	1536	3072	6144	12288	**19456**	6144	12288	**19456**	**22528**
2	4096	8192	768	1536	3072	6144	**9728**	**11264**	6144	**9728**	**11264**	**14336**
3	4096	12288	768	1536	3072	6144	12288	**15360**	6144	12288	**15360**	**18432**
4	4096	16384	768	1536	3072	6144	12288	**19456**	6144	12288	**19456**	**22528**
5	4096	20480	768	1536	3072	6144	12288	**23552**	6144	12288	**23552**	**26624**
6	4096	24576	768	1536	3072	6144	12288	24576	6144	12288	24576	**30720**
7	4096	28672	768	1536	3072	6144	12288	24576	6144	12288	24576	**34816**
8	4096	32768	768	1536	3072	6144	12288	24576	6144	12288	24576	**38912**

NOTE: Figures in bold and underlined indicate that the full capacity of DRAM and NAND can be used.

Table 4-2. Maximum Software-defined Memory (SDM) capacity for Ultrastar Memory

Optimized	DRAM	Sockets	2	2	2	2	2	2	4	4	4	4
		Channels	6	6	6	6	6	6	6	6	6	6
		DPC	1	2	2	2	2	2	1	2	2	2
		DIMM Size (GiB)	8	8	16	32	64	128	32	32	64	128
NAND Devices	Device Size (GiB)	Total Size (GiB)	96	192	384	768	1536	3072	768	1536	3072	6144
2	1024	2048	**2144**	**2240**	**2432**	**2816**	**3584**	**5120**	**2816**	**3584**	**5120**	**8192**
3	1024	3072	**3168**	**3264**	**3456**	**3840**	**4608**	**6144**	**3840**	**4608**	**6144**	**9216**
4	1024	4096	**4192**	**4288**	**4480**	**4864**	**5632**	**7168**	**4864**	**5632**	**7168**	**10240**
5	1024	5120	**5216**	**5312**	**5504**	**5888**	**6656**	**8192**	**58888**	**6656**	**8192**	**11264**
6	1024	6144	6048	**6336**	**6528**	**6912**	**7680**	**9216**	**6912**	**7680**	**9216**	**12288**
7	1024	7168	6048	**7360**	**7552**	**7936**	**8704**	**10240**	**7936**	**8704**	**10240**	**13312**
8	1024	8192	6048	**8384**	**8576**	**8960**	**9728**	**11264**	**8960**	**9728**	**11264**	**14336**
2	2048	4096	**4192**	**4288**	**4480**	**4864**	**5632**	**7168**	**4864**	**5632**	**7168**	**10240**
3	2048	6144	6048	**6336**	**6528**	**6912**	**7680**	**9216**	**6912**	**7680**	**9216**	**12288**
4	2048	8192	6048	**8384**	**8576**	**8960**	**9728**	**11264**	**8960**	**9728**	**11264**	**14336**
5	2048	10240	6048	**10432**	**10624**	**11008**	**11776**	**13312**	**11008**	**11776**	**13312**	**16384**
6	2048	12288	6048	1296	**12672**	**13056**	**13824**	**15360**	**13056**	**13824**	**15360**	**18432**
7	2048	14336	6048	12096	**14720**	**15104**	**15872**	**17408**	**15104**	**15872**	**17408**	**20480**
8	2048	16384	6048	12096	**16768**	**17152**	**17920**	**19456**	**17152**	**17920**	**19456**	**22528**
2	4096	8192	6048	**8384**	**8576**	**8960**	**9728**	**11264**	**8960**	**9728**	**11264**	**14336**
3	4096	12288	6048	12096	**12672**	**13056**	**13824**	**15360**	**13056**	**13824**	**15360**	**18432**
4	4096	16384	6048	12096	**16768**	**17152**	**17920**	**19456**	**17152**	**17920**	**19456**	**22528**
5	4096	20480	6048	12096	**20864**	**21248**	**22016**	**23552**	**21248**	**22016**	**23552**	**26624**
6	4096	24576	6048	12096	24192	**25344**	**26112**	**27648**	24576	**26112**	**27648**	**30720**
7	4096	28672	6048	12096	24192	**29440**	**30208**	**31744**	24576	**30208**	**31744**	**34816**
8	4096	32768	6048	12096	24192	**33536**	**34304**	**35840**	24576	**34304**	**35840**	**38912**

NOTE: Figures in bold and underlined indicate that the full capacity of DRAM and NAND can be used.

5.0 Workloads Performance & Optimizations

5.1 Target Workloads for Ultrastar Memory

The Ultrastar memory drive can take advantage of one or more of the following workload characteristics to achieve DRAM-like performance, which can be associated with the sample relevant applications:

Table 5-1. Workloads and Applications

Probability-based memory access pattern [pre-fetch]	**High concurrency access pattern [asynchronous memory load]**	**CPU intensive [placement]**
Predictable workloads: Analytics, DBMS, etc.	Many processes, or highly multi-threaded.	CAE, HPC
Memory access can be predicted by: ■ Frequently similar access pattern (sequential, structured, etc.) ■ Application code analysis ■ Memory block associativity Examples can be: ■ Databases tuples ■ In-memory columnar database ■ Reading database indexes ■ Large in-core matrices Block of memory stored from a disk through DMA. While relevant application workloads can be row- or column-store in-memory databases used in analytics workloads, such as SAP® HANA®, Oracle®, 12c, or MySQL™	Concurrency can be due to: ■ Many threads ■ Throughput (many independent jobs) ■ Multi-tenants Relevant application workloads can be: ■ Multi-tenant workloads like container-based virtual-shared web-hosting server with Docker™, or Virtualization-based partitioning for example with KVM. ■ Multi-threaded key-value cache such as memcached. ■ Distributed/shared data grids and frameworks such as Apache Spark®, Apache Ignite®, Aerospike, or Redis™.	Those are workloads which are heavy on compute vs. memory access. Relevant applications and workloads can be: ■ Multi-threaded linear algebra workloads with large matrices. ■ Parallel statistics calculations on large data.

5.1.1 Workloads That Do Not Benefit From Ultrastar Memory Drive

As with any architecture, there are certain workloads that are not an ideal fit and would not benefit from running with Ultrastar memory drive.

Examples:

1. Workloads with low-concurrency workloads (e.g. serial workloads):
   As there is only one execution thread, even though Ultrastar memory drives can prefetch the memory, the wait-time for memory will reduce the compute efficiency of the workload.
2. Workloads bound by memory bandwidth
   As we rely on Ultrastar memory devices with bandwidth of approximately 2.2GB/s (70%R/30%W), even if four Ultrastar memory drives are installed, the total aggregate bandwidth would be approx. 8.8GB/s. This would be much lower than two Xeon processors memory bandwidth of >100GB/s total on their memory controllers' link to DRAM.
   An example for that is a program constantly accessing memory and doing little compute on the fetched memory before moving over to consume new memory.
3. Workloads with a high frequency of system calls may suffer from virtualization overhead (Ultrastar memory drives uses Intel Virtualization Technology).

5.2 Optimized Workload Settings

This section lists generic recommendations for software stack setup in an environment using Ultrastar memory drive. Western Digital may publish application-specific execution and configuration guidelines; consult the support library for the same.

5.2.1 Operating System

1. Western Digital recommends using recent builds of supported popular Linux distributions (or clones) such as Red Hat® Enterprise Linux® 7.x/CentOS 7.x or SLES 12.x, at the time of writing this manual.
2. Ultrastar memory drives also support Open Source hypervisors such as KVM, as shipped with the major Linux distributions.

5.2.2 Memory Settings and Memory Allocators

It is recommended that memory allocators be configured to use large pages (as example THP - the Linux Transparent Huge Pages), while correctly configuring them to (1) save on memory use, and (2) avoid memory fragmentation. For example, if the application was pre-compiled with the default libc allocator or with jemalloc, or links to one of them using the OS dynamic linker, please use the following guidelines:

1. For jemalloc, ensure THP operation is maintained by running the command:

Figure 5-1. Performance Data Collection

```
# ln -sf 'lg_dirty_mult:-1' /etc/malloc.conf
```

2. For libc, the following environment variables may be useful to increase memory allocation size by the application, and to reduce virtualization overheads:

Figure 5-2. Performance Data Collection

```
# export MALLOC_TOP_PAD_=$((16777216))
# export MALLOC_TRIM_THRESHOLD_=$((16777216))
```

5.2.3 Application Settings

Application parallelism or concurrency yields great benefits with Ultrastar memory drive. Make sure your application is configured to use many threads in order to process data, where available. CPU over-subscription increases the throughput of Ultrastar memory drive.

6.0 Benchmarking Methodology and Performance Collection

The Ultrastar memory drive is designed to provide DRAM-like functionality and performance. As such, the following benefits and use cases are aimed for, which derive the benchmarks and comparisons to be performed:

- **Memory Expansion**: The goal of benchmarking such cases is to make sure that a workload with more memory than DRAM available in a server can successfully execute (along with some performance measurement, e.g. complete execution within a required amount of time, or enable a required transaction throughput per second, etc.).
- **Memory Replacement**: The goal of benchmarking such cases is to perform apples-to-apples comparison of the desired workload on identical environments, where the Native system would have a certain amount of DRAM. While the system with Ultrastar memory drive would be using a lower amount of DRAM, aggregated with Ultrastar memory drive to create the same memory foot-print. In many cases, due to the limitation of obtaining a comparable system with sufficient amount of DRAM, a scaled-down version of the workload may be used (as described below).

6.1 Benchmarking Methodology

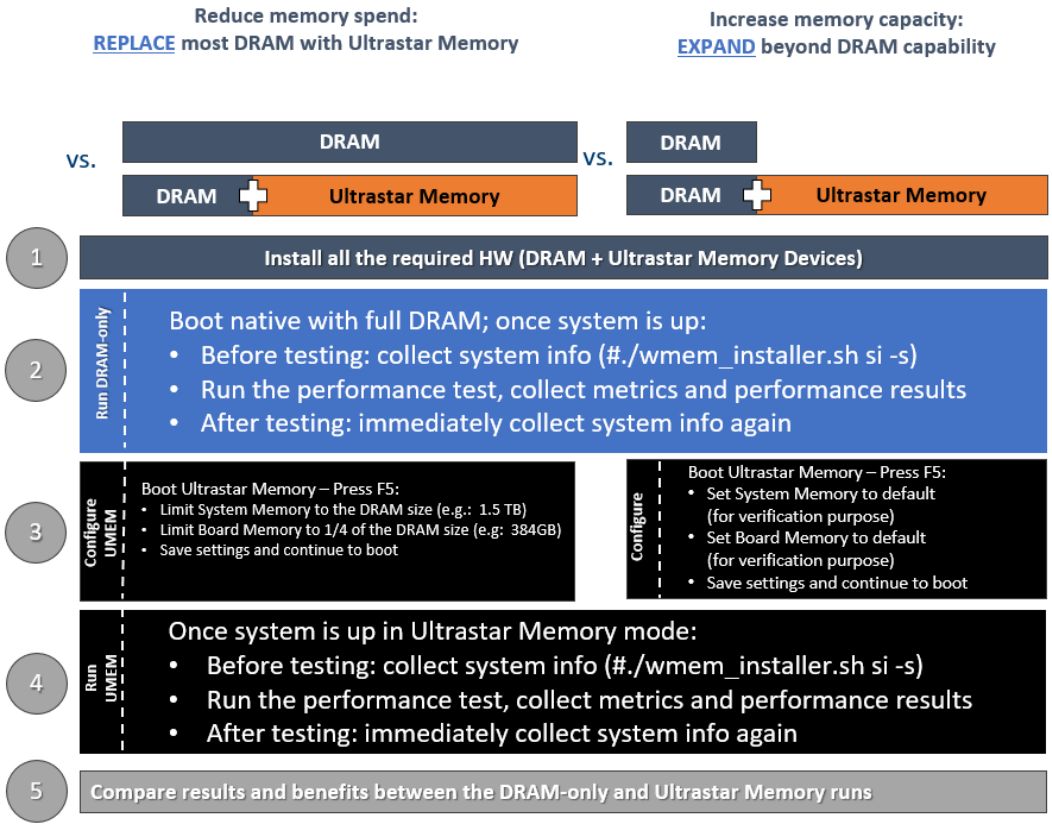
Start with apples-to-apples comparison: Use the same machine for Native and Ultrastar memory drive comparison:

- Native: Use maximum available memory (in optimal configuration).
- Ultrastar memory drive:
  - Keep same number of DIMMs, with reduced capacity.
  - Use Ultrastar memory drive configuration switch to reduce the used DRAM capacity (See section **System Settings and Diagnostics**, under **Board Memory** settings).
- Tune workload configuration for execution environment: Native vs. Ultrastar memory drive.
  - Example: Optimal thread count may be different between Ultrastar memory drive and Native; use the optimal configuration of the workload for each machine setup to represent "the best possible" for that setup.

Scale for larger memory foot-print (especially for memory expansion use case).

- For applicable workloads, expand memory beyond DRAM capacity:

Figure 6-1. Figure 1 Type



6.2 Expected Results and Demonstrated Value

The Ultrastar memory drive is designed to provide DRAM-like performance.

The Native system (with "all-DRAM" used and no software-defined memory) results serve as a **reference point** and Ultrastar memory drive is expected to deliver at least 75% of that performance for fitting workloads (as described in Ultrastar memory drive documentation).

In addition, it is common to review the overall demonstrated value-based price/performance, enhanced capabilities and overall cost reduction/savings:

- DRAM expansion by up to 8x.
- DRAM-like performance (not more than 25% difference).
- Memory cost reduction by 30-60%.

6.3 Performance Data Collection

Ultrastar memory drives provide tools for collecting performance-related statistics. The tools are installed by default into **/usr/local/{etc,bin}**.

To activate periodic statistics data collection, use the following command in Figure 6-1, which records the counters every 60 seconds into /tmp/stats. Note, it is strongly recommended to ensure that this directory is neither network-based nor ramfs/tmpfs, but rather a directory located on a direct-attached storage device.

Figure 6-2. Performance Data Collection

```
# cd /tmp/stats; /usr/local/bin/wmemstat --outfile 60
```

To start the performance collection at boot, add the following to your crontab file (with crontab -e):

Figure 6-3. Performance Data Collection

```
@reboot   (cd /tmp/stats && /usr/local/bin/wmemstat --outfile 60)
```

After the workload execution is complete, if you wish to have the statistics reviewed, create a zipped/tar archive of the files collected, or the complete target directory (/tmp/stats in the example above), and share it with the Ultrastar memory drive support team to receive expert advice about the execution of your workload.

6.4 Out-of-the-Box Large Memory Benchmark

To easily test the performance of the system, a large memory workload, demonstrating multiplication of very large matrices, which is the corner stone of many algorithms, leveraging Intel® Math Kernel Library (MKL) is provided.

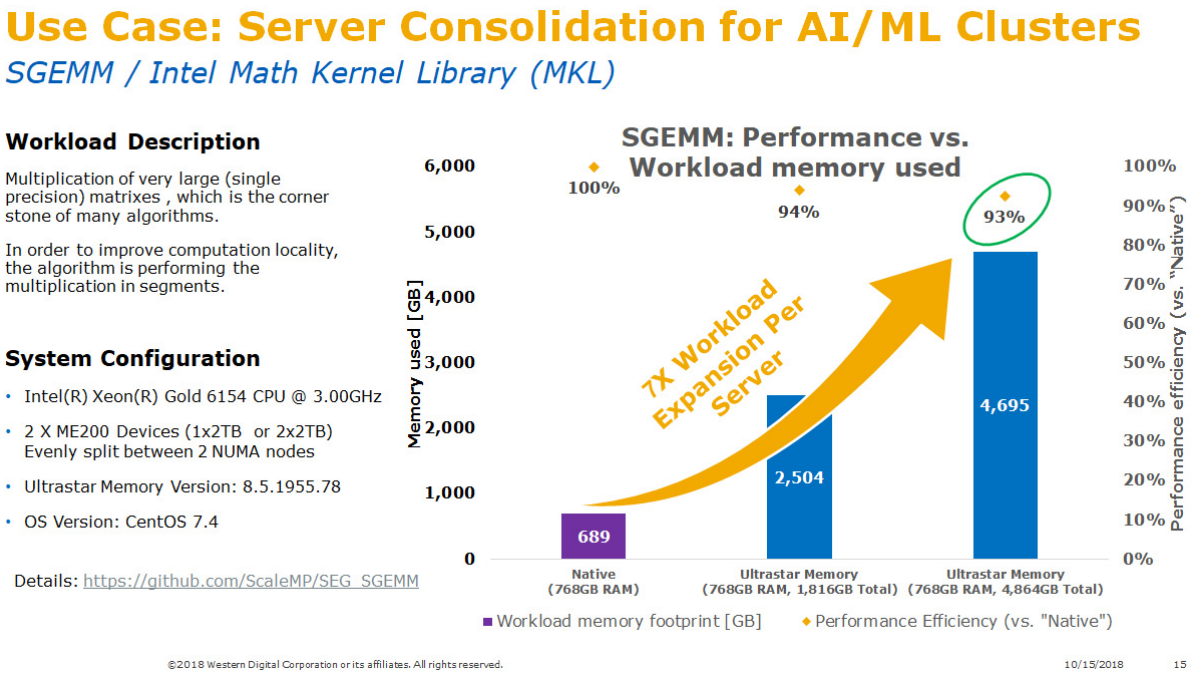
The workload can be used to test system performance for:

- **Memory Replacement**: Performing an apples-to-apples comparison of (1) a Native (i.e. DRAM only) system, with (2) a system using lower DRAM augmented with Ultrastar memory, where (2) would be a cost-effective alternative to DRAM.
- **Memory Expansion**: Validate that a workload with a memory footprint higher than DRAM capacity can successfully execute with near-DRAM performance by expanding the system memory with Ultrastar memory.

To perform the test:

1. If using version 9.0 or newer, run the test embedded in the installer:
   `# ./wmem_installer-9.0.3365.2.sh si -p s`
2. Otherwise, a publicly available workload can be obtained and configured per the following: github.com/ScaleMP/SEG_SGEMM
3. Run the workload on a Native (i.e. DRAM only) system, and collect the results.
4. Run the workload on a system with Ultrastar memory drive configured, and collect the results.

Figure 6-4. Figure 1 Type



7.0 TROUBLESHOOTING

7.1 Ultrastar Memory Drive Fails to Start

Ensure use of supported OS distribution and correctly configured BIOS to boot from Ultrastar memory drive (see specifications in Chapter 5).

7.1.1 Common Installation Error Codes

During the boot process, the Ultrastar memory drive may issue warnings and errors to the console, in many cases using error codes.

Table 7-1 (see below) lists the most common error codes, their explanations, and suggested path to resolution.

Table 7-1. Common Installation Error Codes

Error Code or Symptom	System State / Diagnosis	Proposed Resolution
System does not load Ultrastar memory software	BIOS is not set to boot form the Ultrastar memory device.	Configure the BIOS to boot form Ultrastar memory drive.
	Ultrastar memory drive software erased or mis-configured.	Follow manual steps to recover erased Ultrastar memory drive software (see User Manual).
Ultrastar memory loads, but OS fails to boot	OS installation is erroneous.	■ Make sure a supported Linux OS is installed ■ Collect information; report to L2
Ultrastar memory drive reports error 279 or 700	The boot device is not detected.	Collect information; report to L2.
Ultrastar memory reports error 70x	Ultrastar memory drive software installed to other bootable device. (e.g. USB drive).	Remove bootable media that contains Ultrastar memory software - except for Ultrastar memory devices.
Ultrastar memory hangs during boot	Ultrastar memory drive software error.	■ Have user take a screenshot of the error ■ Collect error code ■ Report to L2
Ultrastar memory drive crashed	A Blue Screen on the console title Ultrastar memory drive error with details in white text.	■ Have user take a screenshot of the error ■ Collect information including screenshot ■ Report to L2
Ultrastar memory is exhibiting low performance	Workload mis-configured or unfit for use with Ultrastar memory drives.	■ Make sure user followed performance guidelines from the manual ■ Collect information ■ Collect periodic statistics while workload is running ■ Report to L2

7.2 Collecting Information for Escalating to Support

Table 7-2. Workloads and Applications

Error Type	Proposed Resolution
Ultrastar memory drive fails to boot.	▪ Take a console screenshot depicting the point when the Ultrastar memory drive boot stops. ▪ Boot to native and run the installer per the following: `./wmem_installer-x.x.x.x.sh si -s`
Ultrastar memory drive successfully boots; but OS fails to boot.	▪ In addition to the above instructions, boot the Ultrastar memory drive. ▪ Press F5 to access the Ultrastar memory drive menu settings and run diagnostic tests.
Ultrastar memory drive and OS successfully boots; problems arise after booting process	▪ In addition to the above instructions and after the successful boot of the Ultrastar memory drive and operating system, execute the following: `./wmem_installer-x.x.x.x.sh si -s`

NOTE: The collection of the above information should be filed when escalating the case to Level2 Support, including but not limited to:

- Description of user actions leading to the error,
- Output .tgz file generated by **# ./wmem_installer-x.x.x.x.sh si -s**,
- Related screenshots,
- Diagnostic results, etc.

8.0 Reload the Ultrastar Memory Drive Software

The Ultrastar memory drives were shipped pre-installed with software. If the software was removed, deleted, or became corrupted, or if it is required to install the software on a different bootable device, follow the steps listed in the below sections.

8.1 Reload to Ultrastar Memory Device

> **NOTE:** Back up all data before beginning the software setup. Ultrastar memory drive software configures the PCIe-based devices as a part of main (volatile) memory pool.

The software installer can be obtained from the download section of the product support page:

https://www.westerndigital.com/support/wdc/data-center-drives/ssd/ultrastar-dc-me200

Install the Ultrastar memory drive software to the Ultrastar memory device.

1. If the system is capable of booting directly from the Ultrastar memory device (using UEFI), set the system BIOS to boot from one of the Ultrastar memory devices (if not, skip to the next section).
2. Software reload is complete. Reboot the system to expand system DRAM with Ultrastar memory drive.
3. If your system fails to boot, you may try booting from a different bootable media as is described in the following section.

Figure 8-1. Software Installer

```
chmod +x wmen_installer-8.6.2535.77.sh

#./wmem_installer-8.6.2535.77.sh in -n
Preparing installer ............

Please take a moment to read the below
=========================================================================
Welcome to WDC Ultrastar DC ME200 memory version 8.6.2535.77 !
-------------------------------------------------------------------------
* By installing and/or using this software you acknowledge that you have read and
agreed to the agreement published at
https://www.get-wmem.com/EULA.

*  Parts of this program, as provided in binary form, include open source
code under one or more open source licenses. For further details and
notices please see https://www.scalemp.com/opensource.
=============================================================================
Type “accept” to accept the terms and conditions above:

Accept terms and conditions accepted.

WDC Ultrastar DC ME200 NVMe SSD licensing status:

##  Block Device  Vendor and Model Number  Serial Number  Size (GB/GiB)
01 /dev/nvme0n1   HGST HUSMR7616BDP3M1     SDM0000237D8   1920 / 1788  Available
02 /dev/nvme1n1   HGST HUSMR7616BDP3M1     SDM00001BC43   1920 / 1788  Available

Install WDC Ultrastar DC ME200 memory and its licenses on devices #01, #02? Y/N
Starting license and software installation...

---------------------- Installation Status -----------------------------------
---------------------- Installation Status -----------------------------------

/dev/nvme0n1   [==================================================](100%)  DONE
/dev/nvme1n1   [==================================================](100%)  DONE

Installing WDC Ultrastar DC ME200 memory tools...
WDC Ultrastar DC ME200 memory tools requires SUID permission to run as non-root
user.

Allow WDC Ultrastar DC ME200 memory tools to be run by all users (recommended)?
[N/Y]


WDC Ultrastar DC ME200 memory tools installation is complete.
```

8.2 Installing Ultrastar Memory Drive Software to a Different Bootable Media

After following the steps mentioned above to load the Ultrastar memory drive software on the NVMe device, proceed with the following steps:

1. Insert a bootable flash media to the system (such as USB flash drive).
2. Ensure the bootable flash media is unmounted.
3. Install the Ultrastar memory drive software to the bootable flash media (See Figure 8.2, found below).
4. Set the system BIOS to boot from the bootable flash media.
5. Software reload is complete. Reboot the system to expand system DRAM with Ultrastar memory drives.

Figure 8-2. Software Installer

```
# ./wmem_installer-8.6.2535.77.sh in -b
Preparing installer.............

Please take a moment to read the below
================================================================================
Welcome to WDC Ultrastar DC ME200 memory version 8.6.2535.77 !
--------------------------------------------------------------------------------
*  By installing and/or using this software you acknowledge that you have
read and agreed to the agreement published at
https://www.get-wmem.com/EULA.

*  Parts of this program, as provided in binary form, include open source
code under one or more open source licenses. For further details and
notices please see https://www.scalemp.com/opensource.
================================================================================
Type “accept” to accept the terms and conditions above: accept
Terms and conditions accepted.

WDC Ultrastar DC ME200 memory version 8.6.2535.77 found the following bootable
media:

##  Block Device  Vendor and Model Number   Serial Number       Size (GB/GiB)
01  /dev/sdb      USB DISK 2.0              07A70E13754EFEA4    1.003 / 0.979


Please select devices to install WDC Ultrastar DC ME200 memory:
- device list (1, 3, 4 or 1-3 or combination of both e.g. 1, 2-4, 5)
- all devices (a)
Devices (q or <ENTER> to quit): 01

/dev/sdb (USB DISK 2.0 07A70E13754EFEA4): installing...
/dev/sdb (USB DISK 2.0 07A70E13754EFEA4): done.

Installing WDC Ultrastar DC ME200 memory tools...
WDC Ultrastar DC ME200 memory tools to be run by all users (recommended)? [N/Y]Y

Please enter absolute install path for Ultrastar DC ME200 memory wmem tools [/usr/
local]:


WDC Ultrastar DC ME200 memory tools installation is complete.
```

9.0 SPECIFICATIONS

Table 9-1. Specifications

Capacity[1,2,3]	U.2: 1TiB, 2TiB, 4TiB AIC: 1TiB, 2TiB, 4TiB
Form Factors	U.2: 2.5" 15mm dual-port NVMe AIC: HH-HL NVMe
Operating Systems	For an updated list of operating systems, please refer to the latest release notes. Ultrastar memory extension software supports UEFI boot, or alternatively requires a bootable media. Supported protocols: IDE, UHCI, and EHCI
Supported Processors	Intel Xeon® E5-x6xx v3 or later, E7-x8xx v3 or later Intel Xeon Bronze, Silver, Gold, or Platinum
Maximum Processor Sockets	8
Maximum Software-defined Memory	64 TiB[1]
Recommended DRAM Expansion	Up to 8x[4]
Case Temperature Specification	Operating: 0-70C (U.2), 0-55C (HHHL)
Hot-plug	Hot-plug is not supported
Certifications and Declarations	UL*, CE*, C-Tick*, BSMI*, KCC*, VCCI*, CAN/CSA*
Product Ecological Compliance	RoHS*, WEEE*

1. GiB = 1,073,741,824 bytes, TiB = 1,099,511,627,776 bytes
2. Total usable capacity towards memory is lower than total physical capacity of the media in the Ultrastar DC ME200 Memory Extension Drive.
3. Ultrastar memory drives may be offered with higher capacities at a later date.
4. For example: 1024GiB DRAM can be expanded up to 8096GiB based on the capacity of memory extension drives installed. Higher expansion ratios may be supported, with possibly suboptimal performance.

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