The science behind the report:

Upgrade to better-performing storage without breaking the bank

This document describes what we tested, how we tested, and what we found. To learn how these facts translate into real-world benefits, read the report Upgrade to better-performing storage without breaking the bank.

On July 8, 2018, we finalized the hardware and software configurations we tested. Updates for current and recently released hardware and software appear often, so unavoidably these configurations may not represent the latest versions available when this report appears. For older systems, we chose configurations representative of typical purchases of those systems. We concluded hands-on testing on August 20, 2018.

Our results

The table below presents our findings in detail. We report the median, based on IOPS, of three Silly Little Oracle Benchmark (SLOB) runs.

Drives	Toshiba RM5 Series Value SAS SSDs (KRM51RUG960G)	Samsung PM863a Series Enterprise SATA SSDs (MZ-7LM960N)
IOPS		
Total IOPS	329,177.63	139,272.12
Read/sec	270,551.01	114,156.92
Write/sec	58,626.61	25,115.19
Throughput (MB/s)		
Read	2,113.81	894.80
Write	500.18	211.06
Latency (ms)		
Latency	1.16	2.91
Read latency	1.25	3.18
Write latency	0.76	1.72

System configuration information

The table below presents detailed information on the systems we tested.

Server configuration information	
BIOS name and version	U30 v1.36
Non-default BIOS settings	N/A
Operating system name and version/build number	Oracle® Enterprise Linux® 7.5 Kernel Version 4.1.12-124.16.4.el7uek.x86_64
Date of last OS updates/patches applied	07/08/18
Power management policy	Max Performance
Processor	
Number of processors	2
Vendor and model	Intel® Xeon® Platinum 8164
Core count (per processor)	26
Core frequency (GHz)	2.00
Stepping	H0
Memory module(s)	
Total memory in system (GB)	256
Number of memory modules	8
Vendor and model	Hynix HMA84GR7AFR4N-VK
Size (GB)	32
Type	PC4-2666
Speed (MHz)	2,666
Speed running in the server (MHz)	2,666
Storage controller	
Vendor and model	HPE Smart Array P408i-a SR Gen 10
Cache size (GB)	2
Firmware version	1.34
Local storage type 1 - boot drives	
Number of drives	2
Drive vendor and model	Toshiba THNSF8240PCSE
Drive size (GB)	240
Drive information (speed, interface, type)	6Gb/s SATA SSD

Server configuration information	
Local storage type 2	
Number of drives	4
Drive vendor and model	Samsung MZ-7LM960N
Drive size (GB)	960
Drive information (speed, interface, type)	6Gb/s SATA SSD
Local storage type 3	
Number of drives	4
Drive vendor and model	Toshiba KRM51RUG960G
Drive size (GB)	960
Drive information (speed, interface, type)	12Gb/s SAS SSD
Network adapter	
Vendor and model	HPE Ethernet 10/25Gb 2p 640FLR-SFP28 Adapter
Number and type of ports	2 x 10/25GbE
Cooling fans	
Vendor and model	AVC DBTA063B2S
Number of cooling fans	6
Power supplies	
Vendor and model	HPE HSTNS-PR62
Number of power supplies	2
Wattage of each (W)	1,600

How we tested

Our test bed consisted of one HPE ProLiant DL380 Gen10 server. We configured the server with 256 GB of RAM, and we installed the operating system (OS) and the automatic storage management (ASM) instance on individual, dedicated RAID 1 drive pairs. We configured the server with four of the SAS SSDs under test and four of the SATA SSDs under test. We then presented the raw SATA and SAS drives to the OS in respective Oracle ASM disk groups. We installed Oracle Grid and Database 12c and created an Oracle instance for each disk group. We then populated each database with SLOB and ran SLOB three times, recording the median score based on IOPS.

We used the following steps to configure the server and our Oracle environment.

Installing Oracle Enterprise Linux 7.5

1. Insert an Oracle Enterprise Linux 7.4 bootable USB stick into the server, and boot to it.
2. Select Install or upgrade an existing system.
3. Choose the language you wish to use, and click Continue.
4. Select Installation Destination.
5. Select the desired disk for the OS.
6. Under Other Storage Options, select I will configure partitioning.
7. Click Done.
8. Select Click here to create them automatically.
9. Remove the /home partition.
10. Expand the swap partition to 16 GB.
11. Assign all remaining free space to the / partition.
12. Click Done.
13. Click Accept Changes.
14. Select Kdump.
15. Uncheck Enable kdump, and click Done.
16. Select Network & Hostname.
17. Enter the desired hostname for the VM.
18. Turn on the desired network port, and click Configure.
19. On the General tab, select Automatically connect to this network when it is available.
20. Under Method on the IPv4 Settings tab, select Manual.
21. Under Addresses, click Add, and enter the desired static IP information for the server.
22. Enter the desired DNS information.
23. Click save, and click Done.
24. Select Date & Time, and ensure the correct date, time, and timezone is set.
25. To add your NTP server, click the cog for the Network Time On/Off switch.
26. Add the IP address of your NTP server, and click +.
27. Uncheck all other NTP servers.
28. Click OK.
29. Click Done.
30. Click Begin Installation.
31. Select Root Password.
32. Enter the desired root password, and click Done.
33. To restart the server after completing the installation, select Reboot.

Configuring Oracle Enterprise Linux 7.5 for Oracle

1. Log onto the server as root.
2. Disable the firewall:

```
systemctl stop firewalld
systemctl disable firewalld
```

3. Disable SELinux:

```
vi /etc/selinux/config
SELINUX=disabled
```

4. Install the Oracle 12*c* preinstall RPM:

```
yum install oracle-database-server-12cR2-preinstall
```

5. Update OEL 7.5

```
yum update
```

6. Using yum, install the following prerequisite packages for Oracle Database:

```
yum install compat-libstdc++-33.i686
yum install glibc-devel.i686
yum install libstdc++-devel.i686
yum install libaio.i686
yum install libaio-devel.i686
yum install libXext.i686
yum install libXtst.i686
yum install unixODBC
yum install unixODBC-devel
yum install zlib-devel
yum install zlib-devel.i686
yum install xhost
```

7. Disable auditd:

```
systemctl disable auditd
```

8. Create Oracle users and groups:

```
groupadd -g 54327 asmdba
groupadd -g 54328 asmoper
groupadd -g 54329 asmadmin
usermod -g 54321 -g oinstall -G dba,oper,backupdba,dgdba,kmdba,asmdba,asmoper,asmadmin oracle
```

9. For the Oracle account, create passwords with passwd.
10. Create the following directories, and assign the following permissions.

```
mkdir -p /u01/app/12.2.0.1/grid
mkdir -p /u01/app/oracle/product/12.2.0.1/db_1
chown -R oracle:oinstall /u01
chmod -R 775 /u01/
```

11. Append the following to the /etc/security/limits.conf:

```
oracle - nofile 65536
oracle - nproc 16384
oracle - stack 32768
oracle - memlock 134217728
soft memlock unlimited
hard memlock unlimited
```

12. Modify the system's kernel parameters by appending the following to /etc/systctl.conf:

```
vm.nr_hugepages = 98304
vm.hugetlb_shm_group = 54321
```

13. Add the following lines to the .bash_profile for the Oracle user:

```
export TMP=/tmp
export TMPDIR=$TMP

export ORACLE_HOSTNAME= <HOSTNAME>
export ORACLE_UNQNAME=orcl
export ORACLE_BASE=/u01/app/oracle
export GRID_HOME=/u01/app/12.2.0.1/grid
export DB_HOME=$ORACLE_BASE/product/12.2.0.1/db_1
```

```
export ORACLE_HOME=$DB_HOME
export ORACLE_SID=orcl
export ORACLE_TERM=xterm
export BASE_PATH=/usr /sbin:$PATH
export PATH=$ORACLE_HOME/bin:$BASE_PATH

export LD_LIBRARY_PATH=$ORACLE_HOME/lib:/lib:/usr/lib
export CLASSPATH=$ORACLE_HOME/JRE:$ORACLE_HOME/jlib:$ORACLE_HOME/rdbms/jlib

alias grid_env='. /home/oracle/grid_env'
alias db_env='.    /home/oracle/db_env'
alias sas_db_env='.       /home/oracle/sas_db_env'

alias sata_db_env='.      /home/oracle/sata_db_env'
```

14. Create the following files in the Oracle user home folder:

```
>>>grid_env<<<
export ORACLE_SID=+ASM
export ORACLE_HOME=$GRID_HOME
export PATH=$ORACLE_HOME/bin:$BASE_PATH

export LD_LIBRARY_PATH=$ORACLE_HOME/lib:/lib:/usr/lib
export CLASSPATH=$ORACLE_HOME/JRE:$ORACLE_HOME/jlib:$ORACLE_HOME/rdbms/jlib
>>>db_env<<<
export ORACLE_SID=orcl
export ORACLE_HOME=$DB_HOME
export PATH=$ORACLE_HOME/bin:$BASE_PATH

export LD_LIBRARY_PATH=$ORACLE_HOME/lib:/lib:/usr/lib
export CLASSPATH=$ORACLE_HOME/JRE:$ORACLE_HOME/jlib:$ORACLE_HOME/rdbms/jlib
>>>sas_db_env<<<
export ORACLE_SID=sas
export ORACLE_HOME=$DB_HOME
export PATH=$ORACLE_HOME/bin:$BASE_PATH

export LD_LIBRARY_PATH=$ORACLE_HOME/lib:/lib:/usr/lib
export CLASSPATH=$ORACLE_HOME/JRE:$ORACLE_HOME/jlib:$ORACLE_HOME/rdbms/jlib
>>>sata_db_env<<<
export ORACLE_SID=sata
export ORACLE_HOME=$DB_HOME
export PATH=$ORACLE_HOME/bin:$BASE_PATH

export LD_LIBRARY_PATH=$ORACLE_HOME/lib:/lib:/usr/lib
export CLASSPATH=$ORACLE_HOME/JRE:$ORACLE_HOME/jlib:$ORACLE_HOME/rdbms/jlib
```

15. Install the oracleasmlib packages:

```
yum install -y oracleasm-support-*
```

16. Create a partition on all disks using fdisk.

```
Edit /etc/sysconfig/oracleasm to contain the following:
# ORACLEASM_ENABLED: 'true' means to load the driver on boot.
ORACLEASM_ENABLED=true

# ORACLEASM_UID: Default UID owning the /dev/oracleasm mount point.
ORACLEASM_UID=oracle

# ORACLEASM_GID: Default GID owning the /dev/oracleasm mount point.
ORACLEASM_GID=oinstall

# ORACLEASM_SCANBOOT: 'true' means fix disk perms on boot
ORACLEASM_SCANBOOT=true

# ORACLEASM_USE_LOGICAL_BLOCK_SIZE: 'true' means use the logical block
# size reported by the underlying disk instead of the physical. The
# default is 'false' ORACLEASM_USE_LOGICAL_BLOCK_SIZE=false

Initialize oracleasm:
oracleasm init
```

17. Configure all disks for Oracle ASM:

```
oracleasm createdisk SAS1 /dev/sdc1
oracleasm createdisk SAS2 /dev/sdd1
oracleasm createdisk SAS3 /dev/sde1
oracleasm createdisk SAS4 /dev/sdf1
oracleasm createdisk SATA1 /dev/sdg1
oracleasm createdisk SATA2 /dev/sdh1
oracleasm createdisk SATA3 /dev/sdi1
oracleasm createdisk SATA4 /dev/sdj1
```

Installing Oracle Grid Infrastructure 12*c*

1. Log in as the Oracle user.
2. Unzip linuxx64_12201_grid_home.zip.
3. Open a terminal to the unzipped database directory.
4. To set the Oracle Grid environment, type `grid_env`.
5. To start the installer, type `./gridSetup`.
6. In the Select Installation Option screen, select Install and Configure Grid Infrastructure for a Standalone Server, and click Next.
7. Choose the language, and click Next.
8. In the Create ASM Disk Group screen, choose the Disk Group Name, and change redundancy to Normal.
9. Change the path to /dev/oracleasm/disks, and select the two disks that you are planning to use for the ASM instance.
10. In the Specify ASM Password screen, choose Use same password for these accounts, write the passwords for the ASM users, and click Next.
11. At the Management Options screen, click Next.
12. Leave the default Operating System Groups, and click Next.
13. Leave the default installation, and click Next.
14. Leave the default inventory location, and click Next.
15. Under Root script execution, select Automatically run configuration scripts, and enter root credentials.
16. In the Prerequisite Checks screen, make sure there are no errors.
17. In the Summary screen, verify that everything is correct, and to install Oracle Grid Infrastructure, click Finish.
18. At one point during the installation, the installation prompts you to execute two configuration scripts as root. To run the scripts, follow the instructions.
19. At the Finish screen, click Close.
20. To run the ASM Configuration Assistant, type `asmca`.
21. In the ASM Configuration Assistant, click Create.
22. In the Create Disk Group window, name the new disk group SAS, choose redundancy Normal Redundancy, and select the four SAS disks for SAS diskgroup.
23. Click Advanced Options.
24. Set the database compatibility level to 12.2.0.1.0, and click OK.
25. Complete steps 9 through 11 for the SATA diskgroup.
26. Exit the ASM Configuration Assistant.

Installing Oracle Database 12*c*

1. Unzip linux_12201_database.zip.
2. Open a terminal to the unzipped database directory.
3. To set the first Oracle database environment, type `db_env`.
4. Run ./runInstaller.sh.
5. Wait for the GUI installer to load.
6. On the Configure Security Updates screen, enter the credentials for My Oracle Support. If you do not have an account, uncheck I wish to receive security updates via My Oracle Support, and click Next.
7. At the warning, click Yes.
8. On the Download Software Updates screen, enter the desired update option, and click Next.
9. On the Select Installation Option screen, select Install database software only, and click Next.
10. On the Grid Installation Options screen, select Single instance database installation, and click Next.
11. On the Select Product Languages screen, leave the default setting of English, and click Next.
12. On the Select Database Edition screen, select Enterprise Edition, and click Next.
13. On the Specify Installation Location, leave the defaults, and click Next.
14. On the Create Inventory screen, leave the default settings, and click Next.

15. On the Privileged Operating System groups screen, keep the defaults, and click Next.
16. Allow the prerequisite checker to complete.
17. On the Summary screen, click Install.
18. Once the Execute Configuration scripts prompt appears, ssh into the server as root, and run the following command:

    ```
    # /u01/app/oracle/product/12.2.0.1/db_1/root.sh
    ```
19. Return to the prompt, and click OK.
20. Once the installer completes, click Close.

Creating and configuring the SAS database

1. Using Putty with X11 forwarding enabled, SSH to the VM.
2. To switch to the first database environment, type `sas_db_env`.
3. To open the Database configuration assistant, type `dbca`, and press Enter.
4. At the Database Operation screen, select Create Database, and click Next.
5. Under Creation Mode, select Advanced Mode, and click Next.
6. At the Deployment Type screen, select General Purpose or Transaction Processing. Click Next.
7. Enter a Global database name and the appropriate SID, and uncheck Create as Container database. Click Next.
8. At the storage option screen, select Use following for the database storage attributes.
9. In the drop down, select Automatic Storage Management (ASM), and select +SAS for the file location.
10. At the Network Configuration screen, select the listener, and click Next.
11. At the Data Vault Option screen, leave default, and click Next.
12. At the Configuration Options screen, set the SGA size to 98304 and the PGA size to 32768, and click Next.
13. At the Management Options screen, select Configure Enterprise Manager (EM) Database Express, and click Next.
14. At the User Credentials screen, select Use the same administrative password for all accounts, enter and confirm the desired password, and click Next.
15. At the Creation Options screen, select Create Database, and click Next.
16. At the summary screen, click Finish.
17. Close the Database Configuration Assistant.
18. To open the database manager in a Web browser, browse to `https://host.ip.address:5500/em`.
19. Log in as system with the password you specified.
20. Go to Storage→Tablespaces.
21. Click Create.
22. Type `SLOB` as the Name.
23. Select Big File, and click Add Data File.
24. Set the file size to 1228G, and click OK.
25. Go to Storage→Redo Log Groups.
26. Click Actions→Switch file… until you get one of the groups to go inactive.
27. Highlight the inactive group, and click Actions→Drop group.
28. Create two redo log groups, each with a single 10GB file on the +SAS ASM volume.
29. Repeat steps 26 and 27, removing the remaining default redo logs.
30. To enter SQLPlus, run the following command:

    ```
    sqlplus / as sysdba
    ```
31. To shut down the database, type `shutdown`.
32. After the database has shut down, type `exit`.

Creating and configuring the SATA database

1. To switch to the first database environment, type `sata_db_env`.
2. Type `dbca`, and to open the Database configuration assistant, press Enter.
3. At the Database Operation screen, select Create Database, and click Next.
4. Under Creation Mode, select Advanced Mode, and click Next.
5. At the Deployment Type screen, select General Purpose or Transaction Processing. Click Next.
6. Enter a Global database name and the appropriate SID, and uncheck Create as Container database. Click Next.
7. At the storage option screen, select Use following for the database storage attributes.
8. In the drop down, select Automatic Storage Management (ASM), and select +SATA for the file location.
9. At the Network Configuration screen, select the listener, and click Next.
10. At the Data Vault Option screen, leave default, and click Next.
11. At the Configuration Options screen, set the SGA size to 98304 and the PGA size to 32768, and click Next.
12. At the Management Options screen, select Configure Enterprise Manager (EM) Database Express, and click Next.
13. At the User Credentials screen, select Use the same administrative password for all accounts, enter and confirm the desired password, and click Next.
14. At the Creation Options screen, select Create Database, and click Next.
15. At the summary screen, click Finish.
16. Close the Database Configuration Assistant.
17. To open the database manager in a Web browser, browse to `https://host.ip.address:5501/em`.
18. Log in as system with the password you specified.
19. Go to Storage→Tablespaces.
20. Click Create.
21. Type `SLOB` as the Name.
22. Select Big File, and click Add Data File.
23. Set the file size to 1228G, and click OK.
24. Go to Storage→Redo Log Groups.
25. Click Actions→Switch file… until you get one of the groups to go inactive.
26. Highlight the inactive group, and click Actions→Drop group.
27. Create two redo log groups, each with a single 10GB file on the +SATA ASM volume.
28. Repeat steps 26 and 27, removing the remaining default redo logs.
29. To enter SQLPlus, run the following command:

    `sqlplus / as sysdba`

30. To shut down the database, type `shutdown`.
31. After the database has shut down, type `exit`.

Installing SLOB and populating the databases

1. Download the SLOB kit from http://kevinclosson.net/slob/.
2. Copy and untar the files to /home/oracle/SLOB.
3. Edit the slob.conf file to match Appendix D.
4. To switch to the first database environment, type `sas_db_env`.
5. To enter SQLPlus, run the following command:

    `sqlplus / as sysdba`

6. To start the database, type `startup`.
7. Once the database is up, type `exit`.
8. To start the data population to the SLOB tablespace you created earlier, type `./setup.sh SLOB 128`. When the setup is complete, the database is populated.
9. Once the database is populated, shut down the SAS database.
10. To switch to the SATA database environment, type `sata_db_env`.
11. To populate and shut down the SATA database, complete steps 5 through 10.

Running SLOB on SAS

1. Log in as the Oracle user.
2. To switch back to the first database environment, type `sas_db_env`.
3. Start the database.
4. Navigate to /home/oracle/SLOB.
5. To start the test, type `./runit.sh 64`.
6. Repeat step 5 two more times.
7. Shut down the database.

Running SLOB on SATA

1. Log in as the Oracle user.
2. To switch back to the first database environment, type `sata_db_env`.
3. Start the database.
4. Navigate to /home/oracle/SLOB.
5. To start the test, type `./runit.sh 64`.
6. Repeat step 5 two more times.
7. Shut down the database.

Oracle SPFILE

SAS database

```
sas.__data_transfer_cache_size=0
sas.__db_cache_size=79993765888
sas.__inmemory_ext_roarea=0
sas.__inmemory_ext_rwarea=0
sas.__java_pool_size=1879048192
sas.__large_pool_size=10468982784
sas.__oracle_base='/u01/app/oracle'#ORACLE_BASE set from environment
sas.__pga_aggregate_target=34359738368
sas.__sga_target=103079215104
sas.__shared_io_pool_size=536870912
sas.__shared_pool_size=9932111872
sas.__streams_pool_size=0
*.audit_file_dest='/u01/app/oracle/admin/sas/adump'
*.audit_trail='db'
*.compatible='12.2.0'
*.control_files='+ORACLE_SAS/SAS/CONTROLFILE/current.258.983963989'
*.db_block_size=8192
*.db_create_file_dest='+ORACLE_SAS'
*.db_name='sas'
*.diagnostic_dest='/u01/app/oracle'
*.dispatchers='(PROTOCOL=TCP) (SERVICE=sasXDB)'
*.local_listener='LISTENER_SAS'
*.lock_sga=TRUE
*.nls_language='AMERICAN'
*.nls_territory='AMERICA'
*.open_cursors=300
*.pga_aggregate_target=32768m
*.processes=8320
*.remote_login_passwordfile='EXCLUSIVE'
*.sga_target=98304m
*.undo_tablespace='UNDOTBS1'
*.use_large_pages='only'
```

SATA database

```
sata.__data_transfer_cache_size=0
sata.__db_cache_size=79993765888
sata.__inmemory_ext_roarea=0
sata.__inmemory_ext_rwarea=0
sata.__java_pool_size=1879048192
sata.__large_pool_size=10468982784
sata.__oracle_base='/u01/app/oracle'#ORACLE_BASE set from environment
sata.__pga_aggregate_target=34359738368
sata.__sga_target=103079215104
sata.__shared_io_pool_size=536870912
sata.__shared_pool_size=9932111872
sata.__streams_pool_size=0
*.audit_file_dest='/u01/app/oracle/admin/sata/adump'
*.audit_trail='db'
*.compatible='12.2.0'
*.control_files='+ORACLE_SATA/SATA/CONTROLFILE/current.258.983980125'
*.db_block_size=8192
*.db_create_file_dest='+ORACLE_SATA'
*.db_name='sata'
*.diagnostic_dest='/u01/app/oracle'
*.dispatchers='(PROTOCOL=TCP) (SERVICE=sataXDB)'
*.local_listener='LISTENER_SATA'
*.lock_sga=TRUE
*.nls_language='AMERICAN'
```

```
*.nls_territory='AMERICA'
*.open_cursors=300
*.pga_aggregate_target=32768m
*.processes=8320
*.remote_login_passwordfile='EXCLUSIVE'
*.sga_target=98304m
*.undo_tablespace='UNDOTBS1'
*.use_large_pages='only'
```

Benchmark parameters

```
#### SLOB 2.4.0 slob.conf

UPDATE_PCT=10
SCAN_PCT=0
RUN_TIME=3600
WORK_LOOP=0
SCALE=8G
SCAN_TABLE_SZ=1M
WORK_UNIT=64
REDO_STRESS=LITE
LOAD_PARALLEL_DEGREE=8

THREADS_PER_SCHEMA=2

DATABASE_STATISTICS_TYPE=awr    # Permitted values: [statspack|awr]

#### Settings for SQL*Net connectivity:
#### Uncomment the following if needed:
#ADMIN_SQLNET_SERVICE="if needed, replace with a valid tnsnames.ora service"
#SQLNET_SERVICE_BASE="if needed, replace with a valid tnsnames.ora service"
#SQLNET_SERVICE_MAX="if needed, replace with a non-zero integer"
#
#### Note: Admin connections to the instance are, by default, made as SYSTEM
#          with the default password of "manager". If you wish to use another
#          privileged account (as would be the cause with most DBaaS), then
#          change DBA_PRIV_USER and SYSDBA_PASSWD accordingly.
#### Uncomment the following if needed:
DBA_PRIV_USER="system"
SYSDBA_PASSWD="password"

#### The EXTERNAL_SCRIPT parameter is used by the external script calling feature of runit.sh.
#### Please see SLOB Documentation at https://kevinclosson.net/slob for more information

EXTERNAL_SCRIPT=''


#########################
#### Advanced settings:
#### The following are Hot Spot related parameters.
#### By default Hot Spot functionality is disabled (DO_HOTSPOT=FALSE).

DO_HOTSPOT=FALSE
HOTSPOT_MB=8
HOTSPOT_OFFSET_MB=16
HOTSPOT_FREQUENCY=3


#### The following controls operations on Hot Schema
#### Default Value: 0. Default setting disables Hot Schema

HOT_SCHEMA_FREQUENCY=0

#### The following parameters control think time between SLOB
#### operations (SQL Executions).
#### Setting the frequency to 0 disables think time.

THINK_TM_FREQUENCY=0
THINK_TM_MIN=.01
THINK_TM_MAX=.01
```

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