



Understanding Real World Storage Workloads

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About the Instructor

- ◆ Eden Kim is CEO of Calypso Systems, Inc., a leader in SSD test and measurement equipment and services. Eden is also Chair of the SNIA Solid State Storage Technical Working Group

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◆ Storage Optimization for Data Center IT Professionals, Storage designers and Storage OEM/ODMs

This session will appeal to Data Center IT Managers, IT Professionals, Storage Designers, Storage OEM/ODMs and those that are seeking a fundamental understanding of Real World Storage Workloads. The session will explain what Real World Workloads are, how they are captured and why they are important. Not limited to developers, the session will also bring a clear understanding of the value of Real World Storage Workloads to the IT community and Systems Integrators. The audience will receive the fundamental understanding of how and why Real World Storage Workloads are important in Datacenter storage, server and storage device design, optimization and qualification.



Real World Storage Workloads

1. What are Real World Storage Workloads (RWSWs)?
2. Why are RWSWs Important?
3. What do RWSWs Look Like?
4. What can RWSWs Tell me?
5. How do I use RWSWs for Optimization, Design & Validation?
6. What is Next?
7. Questions & Answers

1. What are Real World Storage Workloads?



Real World Storage Workloads (RWSW) are:

- The collection of discrete IO Streams
- Observed at a specific level in the SW Stack
- That access physical or logical storage
- Over a given period of time

1.1 What is an IO Stream?

| Access Pattern | RND or SEQ | Block Size | Read/Write | Queue Depth Ave/Max | % Occurrence | Quantity (IOs) |
|----------------|------------|------------|------------|---------------------|--------------|----------------|
| SEQ 1.5K W | SEQ | 1536 | W | 1/111 | 1.34 | 69 |
| SEQ 1K W | SEQ | 1024 | W | 1/111 | 4.32 | 223 |
| SEQ 0.5K W | SEQ | 512 | W | 1/111 | 9.24 | 477 |
| SEQ 4K W | SEQ | 4096 | W | 1/111 | 22.31 | 1152 |
| SEQ 16K W | SEQ | 16384 | W | 1/111 | 14.25 | 736 |
| RND 4K W | RND | 4096 | W | 1/111 | 9.8 | 506 |
| RND 3.5K W | RND | 3584 | W | 1/111 | 0.62 | 32 |
| RND 3K W | RND | 3072 | W | 1/111 | 0.58 | 30 |
| RND 2.5K W | RND | 2560 | W | 1/111 | 0.74 | 38 |
| RND 8K R | RND | 8192 | R | 1/111 | 0.15 | 8 |
| RND 2K W | RND | 2048 | W | 1/111 | 0.93 | 48 |
| RND 1.5K W | RND | 1536 | W | 1/111 | 1.74 | 90 |
| RND 1K W | RND | 1024 | W | 1/111 | 3.21 | 166 |
| RND 0.5K W | RND | 512 | W | 1/111 | 1.99 | 103 |
| RND 8K W | RND | 8192 | W | 1/111 | 2.73 | 141 |
| RND 4K R | RND | 4096 | R | 1/111 | 0.91 | 47 |
| RND 12K W | RND | 12288 | W | 1/111 | 1.24 | 64 |
| RND 16K W | RND | 16384 | W | 1/111 | 15.63 | 807 |
| RND 20K W | RND | 20480 | W | 1/111 | 0.58 | 30 |
| RND 28K W | RND | 28672 | W | 1/111 | 2.03 | 105 |
| RND 36K W | RND | 36864 | W | 1/111 | 0.19 | 10 |

IO Stream Table: 2 Minute Capture Step showing IO Stream Statistics

An IO Stream¹ is an Input/Output Operation (IO) that has a unique:

- Random or Sequential Access
- Block Size or Data Transfer Size
- Read or Write IO
- Queue Depth (QD)

A single IO Stream can occur many times during an IO Capture Step

See Table where a single SEQ 1.5K W IO Stream occurs 69 times

¹ IO Stream definitions used here refer to Real World Storage Workloads which differ from Data Streams used in relation to SSD Endurance where similar write operations are associated with a given Data Stream.

1.2 What is an IO Capture?

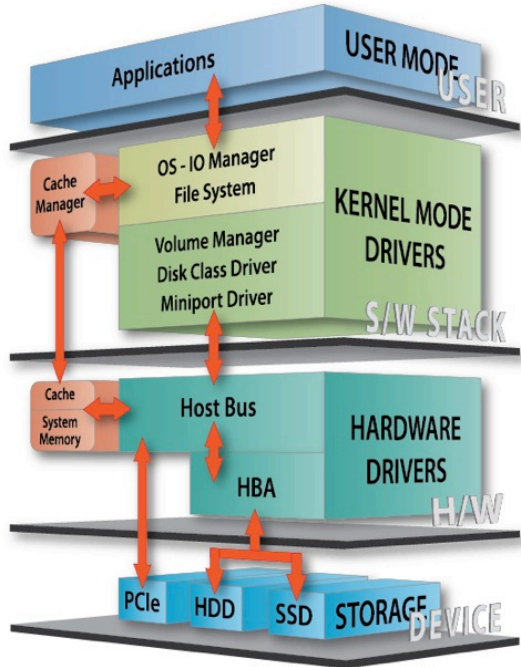


An IO Capture is the tabulation of statistics on IO Streams that are observed during a capture period.

- IO Capture Tools gather statistics and metrics on IO Streams
- An IO Capture is NOT an IO Trace
- No data or private information is collected, only binary numeric tables
- IO Capture Tools are Operating System (OS) specific
- Public and private IO Capture Tools are available²
- IO Capture Tools vary by: OS, Level in the SW Stack and Metrics taken

² Examples of public tools include `perfmon` for Windows and `blocktrace` for Linux. Private tools include `hiomon` for Windows by hyperIO and `IOProfiler` for Windows, Linux, FreeBSD and MacOS by Calypso. `IOProfiler` captures and results were used for the data presented herein and can be seen as Demo No. 3 at TestMyWorkload.com

1.3 What is the Software Stack?



Windows Software Stack

The Software (SW) Stack refers to the layers of software (OS, APIs, programs, drivers and abstractions) that exist between User space and storage.

- IO Streams are generated in User space by software applications
- IO Streams traverse the SW Stack to storage and back
- IO Stream composition is different at different levels in the SW Stack

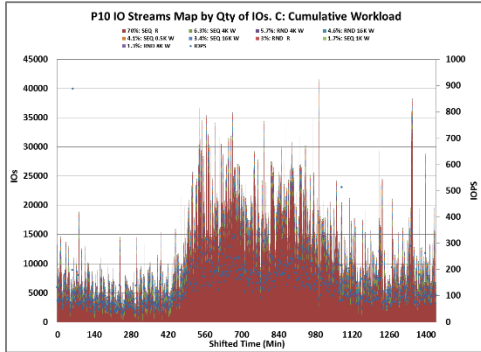
2. Why are RWSWs Important?



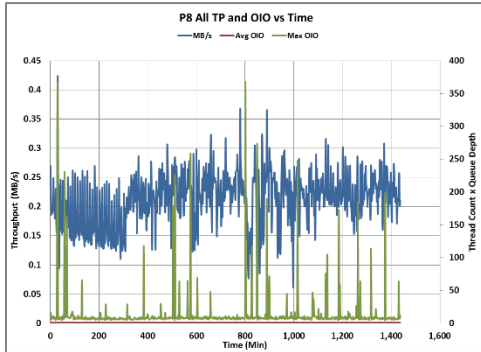
RWSWs are key determinants in storage performance and have a significant impact on SW and storage optimizations.

- Solid State Storage Performance depends, in large part, on RWSWs
- Unlike lab test workloads, RWSWs are comprised of dynamically changing combinations of IO Streams & Demand Intensity
- IO Streams change at each layer of software abstraction
- IO Stream content affects Optimization, Design, Validation & Failure Analysis

2.1 Why do RWSW Affect Storage Performance?



RWSW – IOPS & Changing Combinations of IO Streams



RWSW - Throughput & Changing Queue Depths

Solid State Storage Performance depends on how well storage responds to constantly changing combinations of IO Streams and Demand Intensity.

- RWSWs are constantly changing combinations of IO Streams and QDs
- IO Streams will have different Block Sizes, Accesses and Read or Write IOs
- Synthetic Lab tests are a fixed and constant workload
- Solid State Storage responds differently to the type of access (RND or SEQ), the Block Size, and whether the IO is a Read or a Write
- The type and combination of RWSW IO Streams and the Demand Intensity determines, in large part, the storage performance that is provided

2.2 RWSW - Key for Optimization, Validation & Qualification

| Cumulative Workload | | mysql sqservr | | GPS Apps | |
|---|-----------------|---|--------------|---|--------------|
| <input checked="" type="checkbox"/> SEQ 128b R | 60.3% 6,949,694 | <input checked="" type="checkbox"/> SEQ 102b W | 38.7% 91,941 | <input checked="" type="checkbox"/> SEQ 102b W | 30.2% 92,133 |
| <input checked="" type="checkbox"/> SEQ 4K W | 5.5% 630,734 | <input checked="" type="checkbox"/> RND 102b W | 10.0% 23,798 | <input checked="" type="checkbox"/> RND 46b W | 10.8% 32,967 |
| <input checked="" type="checkbox"/> RND 4K W | 4.9% 585,924 | <input checked="" type="checkbox"/> RND 1b W | 5.9% 14,124 | <input checked="" type="checkbox"/> RND 102b W | 7.8% 23,838 |
| <input checked="" type="checkbox"/> RND 16K W | 4.0% 460,547 | <input checked="" type="checkbox"/> RND 80b W | 3.8% 9,144 | <input checked="" type="checkbox"/> RND 47b W | 6.7% 20,359 |
| <input checked="" type="checkbox"/> SEQ 0.5K W | 3.8% 404,127 | <input checked="" type="checkbox"/> RND 67b W | 3.3% 7,763 | <input checked="" type="checkbox"/> RND 1b W | 4.7% 14,176 |
| <input checked="" type="checkbox"/> SEQ 16K W | 2.9% 339,821 | <input checked="" type="checkbox"/> RND 64b W | 3.2% 7,707 | <input checked="" type="checkbox"/> RND 45b W | 4.0% 12,041 |
| <input checked="" type="checkbox"/> RND 128b R | 2.6% 301,351 | <input checked="" type="checkbox"/> RND 79b W | 2.9% 6,992 | <input checked="" type="checkbox"/> RND 80b W | 3.0% 9,171 |
| <input checked="" type="checkbox"/> SEQ 1K W | 1.4% 164,959 | <input checked="" type="checkbox"/> RND 103b W | 2.7% 6,324 | <input checked="" type="checkbox"/> RND 57b W | 2.5% 7,763 |
| <input checked="" type="checkbox"/> RND 8K W | 1.1% 125,819 | <input checked="" type="checkbox"/> RND 56b W | 2.7% 6,322 | <input checked="" type="checkbox"/> RND 64b W | 2.5% 7,707 |
| <input type="checkbox"/> SEQ 102b W | 0.80% 92,729 | <input checked="" type="checkbox"/> RND 83b W | 2.7% 6,321 | <input checked="" type="checkbox"/> RND 79b W | 2.3% 7,001 |
| <input type="checkbox"/> RND 1K W | 0.66% 76,324 | <input checked="" type="checkbox"/> SEQ 116b W | 2.4% 5,634 | <input checked="" type="checkbox"/> RND 56b W | 2.1% 6,374 |
| Total IOs of 7,109 streams: 11,526,799 Selected 9 streams: 9,942,976 (86%) E | | Total IOs of 218 streams: 237,778 Selected 17 streams: 208,966 (88%) E | | Total IOs of 222 streams: 304,725 Selected 18 streams: 269,260 (88%) E | |

File System Level – Dominant IO Streams

| Cumulative Workload | | mysql sqservr | | GPS Apps | |
|--|---------------|---|-------------|---|-------------|
| <input checked="" type="checkbox"/> SEQ 4K W | 21.6% 757,697 | <input checked="" type="checkbox"/> RND 32K R | 39.7% 2,466 | <input checked="" type="checkbox"/> RND 32K R | 39.0% 2,469 |
| <input checked="" type="checkbox"/> RND 16K W | 12.0% 422,999 | <input checked="" type="checkbox"/> RND 4K R | 16.3% 1,012 | <input checked="" type="checkbox"/> RND 4K R | 16.9% 1,066 |
| <input checked="" type="checkbox"/> SEQ 0.5K W | 11.7% 409,357 | <input checked="" type="checkbox"/> RND 16K R | 14.2% 885 | <input checked="" type="checkbox"/> RND 16K R | 14.1% 889 |
| <input checked="" type="checkbox"/> SEQ 16K W | 10.7% 376,211 | <input checked="" type="checkbox"/> RND 28K R | 5.1% 319 | <input checked="" type="checkbox"/> RND 28K R | 5.1% 320 |
| <input checked="" type="checkbox"/> RND 4K W | 9.6% 336,424 | <input checked="" type="checkbox"/> RND 12K R | 4.6% 287 | <input checked="" type="checkbox"/> RND 12K R | 4.6% 290 |
| <input checked="" type="checkbox"/> SEQ 1K W | 4.9% 173,343 | <input checked="" type="checkbox"/> RND 8K R | 4.2% 260 | <input checked="" type="checkbox"/> RND 8K R | 4.3% 270 |
| <input checked="" type="checkbox"/> RND 8K W | 3.5% 121,532 | <input checked="" type="checkbox"/> RND 24K R | 2.8% 175 | <input checked="" type="checkbox"/> RND 24K R | 2.8% 179 |
| <input checked="" type="checkbox"/> RND 1K W | 2.4% 84,592 | <input checked="" type="checkbox"/> RND 20K R | 2.2% 135 | <input checked="" type="checkbox"/> RND 20K R | 2.2% 137 |
| <input checked="" type="checkbox"/> SEQ 1.5K W | 2.1% 72,871 | <input type="checkbox"/> SEQ 32K R | 1.43% 89 | <input type="checkbox"/> SEQ 32K R | 1.41% 89 |
| <input type="checkbox"/> RND 28K W | 1.95% 68,618 | <input type="checkbox"/> SEQ 4K R | 1.08% 67 | <input type="checkbox"/> SEQ 4K R | 1.30% 82 |
| <input type="checkbox"/> RND 0.5K W | 1.76% 61,862 | <input type="checkbox"/> RND 0.5K R | 1.05% 65 | <input type="checkbox"/> RND 0.5K R | 1.04% 66 |
| Total IOs of 1,033 streams: 3,512,860 Selected 9 streams: 2,755,026 (78%) E | | Total IOs of 59 streams: 6,219 Selected 8 streams: 5,539 (89%) E | | Total IOs of 60 streams: 6,324 Selected 8 streams: 5,620 (89%) E | |

Block IO Level – Dominant IO Streams

RWSW characterization is essential for software optimization, firmware validation, storage qualification & Failure Analysis.

- Each layer of abstraction in the SW Stack can change IO Streams
- Abstractions include metadata, data compression, encryption, data de-duplication, storage virtualization, storage tiers, back-up, snapshots and more
- IO Streams can be appended, fragmented, coalesced or written to cache
- File System level IO Streams tend to include smaller byte accesses to cache
- Block IO level IO Streams tend to include larger KB accesses to storage
- Understanding the IO Stream composition at different SW Stack layers is key to Software and Storage optimization

3. What do RWSWs look like?

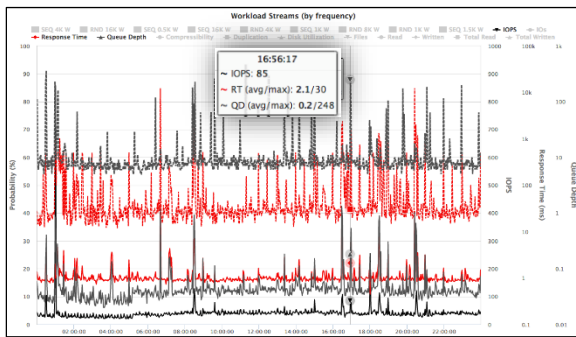
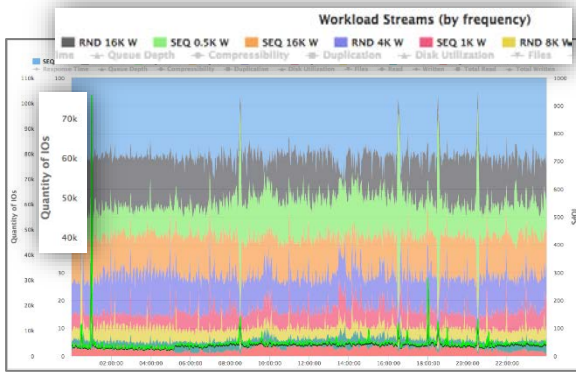


IO Stream Map: 24-hour Block IO Level (Drive0) Capture showing IOPS & IO Streams

RWSW can be visualized by creating an IO Stream Map that shows the changing combinations of IOs and metrics over Time.

- IO Stream % probability of occurrence is shown as different color data series and plotted against the Y-axis
- IOPS are shown by the dominant black line and are plotted against the secondary Y-axis
- Time is shown along the X-axis: 24-hour capture at 2 minute steps
- Secondary metrics captured by the Capture tool can be displayed

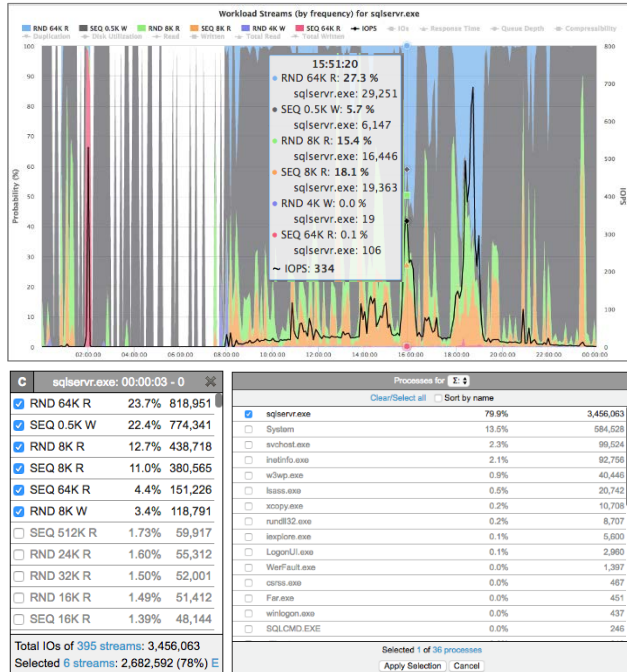
3.1 Viewing Secondary IO Metrics



Secondary IO Metrics that are captured by the IO Capture tool can be viewed on an IO Stream Map.

- IO Capture tools can capture various Secondary IO Metrics
- IO Streams can be listed by RND/SEQ access, Block Size & R/W IO
- Average & Maximum Response Times and QDs can be shown
- Additional IO Metrics can be shown for IO Count, Duplication Ratio, Compression Ratio, Disk Utilization, Reads, Writes and more

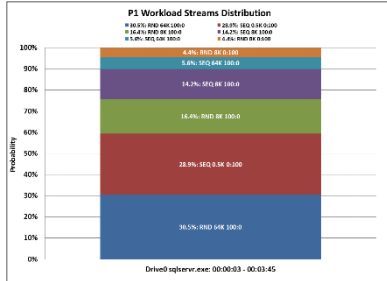
3.2 Viewing IO Streams by Application / Process



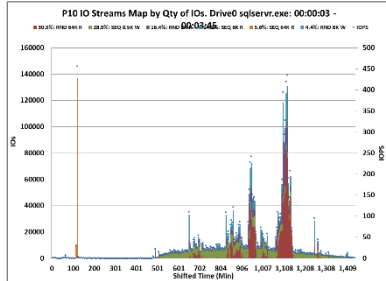
IO Streams can be filtered, extracted or presented by Application or Process IDs (PIDs)

- IO Capture Tools can associate PIDs to specific IO Streams
- The Cumulative IO Capture shows 395 Total Streams and 36 Total PIDs
- IOs can be filtered by Application, Process IDs and by IO Stream % of occurrence over the capture duration
- The IO Stream Map here shows sqlservr.exe PIDs that occur > 3% of the time over the course of the 24-hour IO Capture
- (6) sqlservr.exe Streams are 78% of the Total IO Streams
- (1) sqlservr.exe PIDs is 79.9% of the Total PID IO Streams

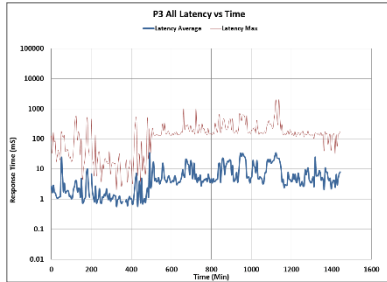
4. What can RWSWs tell me?



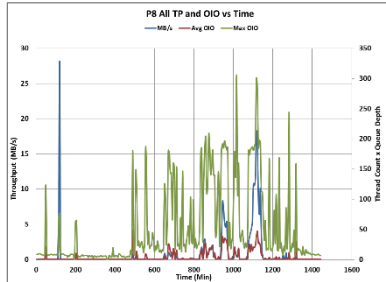
IO Stream Composition of Selected Processes



Changing Combinations of IO Streams



Application Process Response Times



Throughput and Queue Depths v Time

RWSWs let you extract specific application IOs to analyze the IO Composition, Metrics and Performance that occur on the target server during the IO Capture. You can see:

- IO Stream Distribution of the selected Process(es)
- Changing combinations of IO Streams over time
- IO Process Average & Maximum Response Times
- IO Process Throughput and Average & Maximum Queue Depth
- Secondary IO Metrics gathered by the IO Capture tool

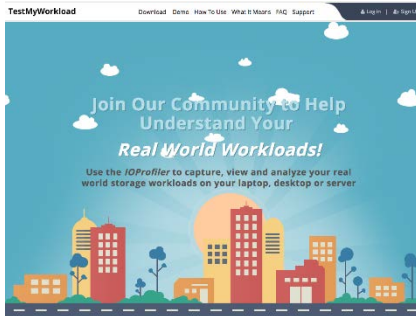
5. How do I use RSWs for Optimization, Design & Validation?



RSWs let you isolate/extract IO Stream workloads at different SW Stack levels to confirm the efficacy of software designs, the impact of abstractions and the content of workloads at the storage level.

- File System or Block IO level Captures
- Extract Application specific processes
- Examine in-situ server performance
- Evaluate Total Storage, Logical Units or Devices
- Replay for Failure Analysis or Storage Qualification

6. What's Next?



RWSWs make a difference! SNIA urges the Storage Community to actively participate in the capture and analysis of RWSWs. You can help to:

- Improve IO Capture Tools: Support OSES & IO Storage Metrics
- Increase Capture Database: Utilize Free Capture & Analysis at TestMyWorkload.com³
- Create Data Analytics: Analysis of Captures & SW Stack IO Streams
- Develop Methodologies: For Storage Qualification & Evaluation
- Establish Industry Standards: Participate in SNIA Technical Works

³ IO Capture tools, images, analytics and data presented herein were taken using the Free tools available at www.TestMyWorkload.com - a SNIA SSSI collaborative site with Calypso Systems, Inc. The sample capture can be viewed as Demonstration Capture No. 3 'Corporate Web Portal - 24 hr capture' on the TestMyWorkload site at <http://testmyworkload.com/info/demo/#exampleKB24hr>

7. Questions & Answers



Contact SNIA for more information.

- SNIA Education: snia.org/education
- Solid State Storage Initiative: asksssi@snia.org
- SSSI TechDev Committee: sssi_techdev@snia.org
- Solid State Storage Technical Working Group: ssstwg@snia.org



Check out SNIA Tutorial:

**Enterprise Applications:
How to Create a Synthetic Workload Test**

감사합니다 Natick
Danke Ευχαριστίες Dalu
Thank You Köszönöm
Спасибо Dank Gracias
谢谢 Merci Seé
ありがとう

Grazie

Obrigado

Attribution & Feedback

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