Workload profiling and sizing

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The problem

- **Workload characterization**: Determining the IO pattern of an application (or suite of applications)
  - We do so by measuring it, known as *workload profiling*

- **Storage sizing**: Determining how much hardware you need to serve a given application (or suite of applications)

- The challenge of characterization and sizing
  - Storage is a complex system!
  - Danger: high penalty for underestimating needs...
Two kinds of metrics

• Inherent **access pattern metrics**:  
  • Based on the code

• Resulting **performance metrics**:  
  • The performance observed when those access patterns hit the storage system

• Sometimes difficult to separate:  
  • Common one that’s hard to tell: **IOPS**  
  • Did we see 50 IOPS because the workload only made that many requests, or because the storage system could only respond that fast?  
  • Was storage system mostly idle? Then IOPS was limited by workload.
Access pattern metrics

- Random vs. sequential IO
  - Often expressed as random%
  - Alternatives: average distance, seek distance histogram, etc.

- IO size

- IOPS
  - If controller/disk utilization was low, then IOPS represent storage demand (the rate the app asked for)
  - Alternative metric: inter-arrival time (average, histogram, etc.)

- Reads vs. writes
  - Often expressed as read%
  - May also split all of the above by read vs. write (read access pattern often different from write pattern)

- Breaking down application: can we identify separate threads?
  - Is it 50% random, or is there one 100% random thread and one 100% sequential thread?
Performance metrics

• IOPS (if storage system was bottleneck)
  • Alternative metric: IO latency (average, histogram, etc.)
  • Alternative metric: throughput (for sequential workloads)

• Queue length: number of IO operations outstanding at a time
  • A measure of IO parallelism
Example of metrics

- Metrics for “DVDStore”, a web store benchmark.
  - Random workload (seek distance ≠ 0)
  - IO size = 8k
  - Short read queue, long write queue
  - Reasonable latency (within usual seek time)
  - Seek distance for writes is biased positive (likely due to asynchronous write flushing doing writes in positive order to minimize write seek distance)

How to get these metrics?

- **Profiling:** *Run* the workload and *measure*

  - Two problems:
    1. How to “run”?
      - Most workloads interact with users
        - Need user behavior to get realistic access pattern!
      - Where to get users?
        - App already in production? Use actual users
        - If not, fake it: **synthetic load generation**
          (extra program pretends to be users)
        - What about so-called **benchmarks**?
    2. How to “measure”? We’ll see in a bit...
Benchmarks

- **Benchmark**: a program used to generate load in order to measure resulting performance. Various types:
  - **The application itself**: You literally run the real app with a synthetic load generator.
    - Example: Microsoft Exchange plus LoadGen
  - **Application-equivalent**: Implements a realistic task from scratch, often with synthetic load generation built in.
    - Example: DVDStore, an Oracle benchmark that literally implements a web-based DVD store.
  - **Task simulator**: Generate an access pattern commonly associated with a certain *type* of workload
    - Example: Swingbench DSS, which generates database requests consistent with computing long-running reports
  - **Synthetic benchmark**: Generate a mix of load with a specific pattern
    - Example: IOZone, which runs a block device at a given random%, read%, IO size, etc.
Methods of profiling

- **App instrumentation**
  - Requires code changes

- **Kernel instrumentation**
  - Can use kernel performance counters (e.g. `iostat`)
  - Can hook at system call level (e.g. `strace`) or block IO level (e.g. `blktrace`).
  - Can also do arbitrary kernel instrumentation, hook anything (e.g., `systemtap`)

- **Hypervisor instrumentation**
  - Hypervisor sees all I/O by definition
  - Example: `vsctrlStats` in VMware ESX

- **Storage controller instrumentation**
  - Use built-in performance counters
  - Basically this is kernel instrumentation on the storage controller kernel

- **User-level metrics (e.g. latency to load an email)**
  - These don’t directly help understand storage performance, but they *are* the metrics that users actually care about
• Now we know how workload acts; need to decide how much storage gear we need to buy

• Will present basic rules, but there are complicating factors:
  • Effects of storage efficiency features?
  • Effects of various caches?
  • CPU needs of the storage controller?
  • Result when multiple workloads are combined on one system?

• Real-world sizing of enterprise workloads:
  • For commercial apps, ask the vendor – companies with big, expensive, scalable apps have sizing teams that write sizing guides, tools, etc.
  • On the storage system side, ask the system vendor – companies with big, expensive, scalable storage systems have sizing teams too.
Disk array sizing

- Recall: In a RAID array, performance is proportional to number of disks; this includes IOPS
- Each disk “provides” some IOPS: $IOPS_{\text{disk}}$
- Our workload profile tells us: $IOPS_{\text{workload}}$
- Compute $\frac{IOPS_{\text{workload}}}{IOPS_{\text{disk}}}$: get number of disks needed
- Add overhead: RAID parity disks, hot spares, etc.
- Add safety margin: 20% minimum, >50% if active/active
- Note: this works for SSDs too, $IOPS_{\text{disk}}$ is just way bigger
Characterizing disks

- Use synthetic benchmark to find performance in the extremes (100% read, 100% write, 100% seq, 100% random, etc.)
- You did this on HW1...results for Samsung 850 Evo 2TB SSD:

From http://www.storagereview.com/samsung_850_evo_ssd_2tb_review
• What are these graphs missing?
  • **Error bars!**
  • What is the variance in these tests? Are the results significant??

From http://www.storagereview.com/samsung_850_evo_ssd_2tb_review
Combining workloads

• Rare to have one storage system handle just ONE workload; shared storage on the rise

• Can we simply add workload demands together?
  • Sometimes...it’s complicated.

  • Example that works: two random workloads run on separate 3-disk RAIDs will get similar performance running together one 6-disk RAID

  • Example that doesn’t: a random workload plus a sequential workload wrecks performance of the sequential workload
    • Random IOs will “interrupt” big sequential reads that would otherwise be combined by OS/controller.

Workload combining

**OLTP** = “Online Transaction Processing” (normal user-activity-driven database)

**DSS** = “Decision Support System” (long-running report on a database)

Table 1. Comparison of DVDStore and OLTP when run in isolation and shared mode

<table>
<thead>
<tr>
<th>Workload</th>
<th>LUN configuration</th>
<th>Throughput</th>
<th>95% tile latency</th>
<th>Application Metric</th>
</tr>
</thead>
<tbody>
<tr>
<td>DVDStore</td>
<td>2+1</td>
<td>130 IOPS</td>
<td>100</td>
<td>6132 TPM</td>
</tr>
<tr>
<td>OLTP</td>
<td>2+1</td>
<td>141</td>
<td>30</td>
<td>5723 TPM</td>
</tr>
<tr>
<td>DVDStore (Shared)</td>
<td>5+1</td>
<td>144</td>
<td>30</td>
<td>7630 TPM</td>
</tr>
<tr>
<td>OLTP (Shared)</td>
<td>5+1</td>
<td>135</td>
<td>-29%</td>
<td>5718 TPM</td>
</tr>
</tbody>
</table>

Table 2. Comparison of DVDStore and DSS when run in isolation and shared mode

<table>
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<tr>
<td>DSS</td>
<td>2+1</td>
<td>44 MB/s</td>
<td>30</td>
<td>6 completed transactions</td>
</tr>
<tr>
<td>DVDStore (Shared)</td>
<td>5+1</td>
<td>164 IOPS</td>
<td>+26%</td>
<td>7630 TPM</td>
</tr>
<tr>
<td>DSS (Shared)</td>
<td>5+1</td>
<td>31 MB/s</td>
<td>-29%</td>
<td>3 completed transactions</td>
</tr>
</tbody>
</table>

- “OLTP” = “Online Transaction Processing” (normal user-activity-driven database)
- “DSS” = “Decision Support System” (long-running report on a database)

Table 2: DVDStore benefits from twice as many disks to help with latency, but DSS’s sequential IO gets wrecked by the random interruptions to its stream.

Effects of aging on performance

• A storage system can get worse over time due to aging effects – changes in storage layout over time as data is added/removed.

• Can complicate testing and require much longer tests

• Can come from on-disk data structures (filesystem) and the device itself (especially for SSD)...
Sources of aging effects

- The **filesystem** makes placement decisions.
  - Example: write of blocks A,B,C,D,E,F,G:
    - Later, we delete B,D,F and write X,Y:

    | A | B | C | D | E | F | G |
    |---|---|---|---|---|---|---|
    | A | X | C | Y | E |   | (free) | G |

  - This is classic external fragmentation
  - Also occurs in metadata of filesystem (e.g. inode tables)

- An **SSD** will indirect the location of objects
  - An SSD never actually overwrites a page! Always writes elsewhere, compacts later, etc.
  - Effects most pronounced when SSD is near full; controller has fewest choices it can make to place new data!
    - Side note: “Full” here means “not TRIM’d”
  - Can mean slower writes, worse internal cache effects on reads
  - Worst case: if SSD has to block a write to do an erase cycle (~3ms!)
Dealing with aging in benchmarking

- Result: Have to subject storage system to **realistic** workload for a sufficient number of IOs to get long-term measurements
  - Tests might have to run for days/weeks/months...

- Test realism is important here:
  - Real workloads typically follow various 80/20 rules (e.g., 80% of writes to 20% of locations)
  - Therefore, naïve synthetic workloads will be either hugely optimistic (repeated full-device sequential write) or hugely pessimistic (repeated full-device random write)
  - Accuracy is achieved with a test workload that mirrors the intended use case
Conclusion

• To **characterize** a workload, we must **profile** it
  • Run it (generating user input if needed)
  • Measure IO metrics in app/kernel/hypervisor/controller

• Can use workload profile for **sizing**: to identify storage gear needed
  • Basic rule: provision enough disks for the IOPS you need
  • Past that, look for published guidance from software/hardware vendor
  • Failing that, use successive experiments with differing gear to identify performance trends