Universität Rostock

Traditio et Innovatio

The Pitfalls of Deploying Solid-State Drive RAIDs

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Motivation

- Solid-state drives (SSDs) have potential to replace hard disk drives (HDDs) in performance-critical applications
- Why do we need SSD RAIDs, if SSDs are that much superior to HDDs?
  - even higher performance and reliability for applications such as *Cloud Computing, OLTP*
  - larger storage capacity
- **Goal:** Deploy fast and reliable SSD RAIDs for performance-critical applications
- **Problem:** Deployment of SSD RAIDs reveals **pitfalls**

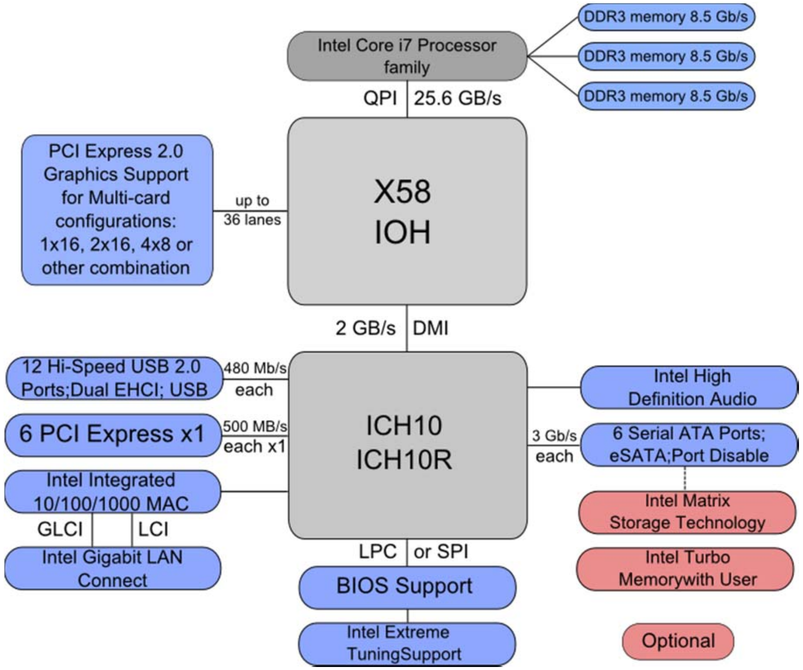
Outline of the Talk

> Pitfalls of deploying SSD RAIDs
> Random write performance of SSDs
> Parity-less SSD RAIDs
> Parity-based SSD RAIDs
> Conclusions

Pitfall – I/O Topology and Bottlenecks

> Problem
  > Most systems can handle throughput of single SSD
  > Throughput of multiple SSDs sums up in SSD RAID
  > Bottlenecks can occur along the path between processor cores and SSDs in a RAID

> Solution
  > Evaluate the I/O topology of the used machine and eliminate bottlenecks (e.g., distribute SSDs to multiple controllers)



Source: Wikipedia

Pitfall – RAID Implementation

Source: Adaptec

> Problem
  > Current hardware RAID controllers seem to be designed for HDDs
  > Even enterprise-class hardware RAID controllers can only handle total number of IOPS delivered by few SSDs

> Solution
  > Use software RAID to overcome the performance limitations of hardware RAID
  > Bottlenecks in software RAID implementations can still occur though at higher performance level

Pitfall – Asymmetry between Read/Write Speed

- Problem
  - Reading flash pages faster than writing
  - Writes in parity-based RAIDs slower than reads due to Read-Modify-Write operations
  - Effects can accumulate:
    Even faster reads and
    slower writes

Source: Winbond

- No simple solution
  - Property of flash memory

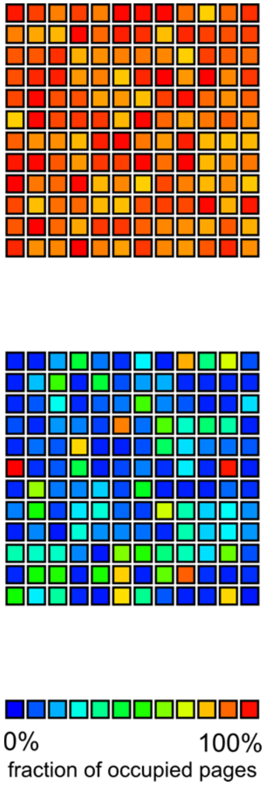
Pitfall – Synchronous SSD Aging

- Problem
  - SSDs have limited number of erase cycles
  - Lifespan of SSD depends on write workload
  - In RAIDs writes often distributed equally to all drives
    → Multiple drives may wear out at the same time

- Potential solution
  - Distribute parity unevenly to available drives
    (e.g., use dedicated parity drives)
  - Usefulness unclear as drives can actually fail after higher or lower number of erase cycles than expected/guaranteed

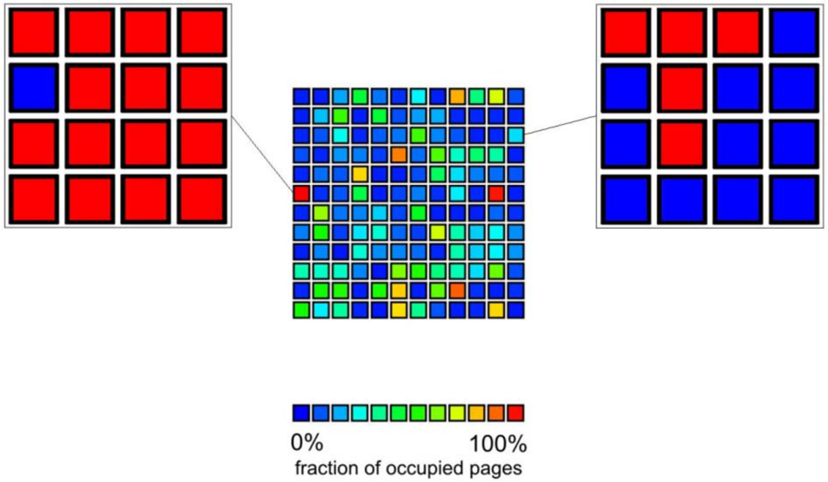
Pitfall – Workload History Dependency

> Problem
  > Flash memory requires out-of-place updates and block-wise erasure leading to fragmentation if spare capacity is rare
  > Fragmentation degrades performance especially for sustained random writes
  > Additionally random write dominated workloads maximize fragmentation
  > Fragmented drive contains mainly blocks with many occupied pages
  > Less fragmented drive contains several blocks that have only few occupied pages



Pitfall – Workload History Dependency

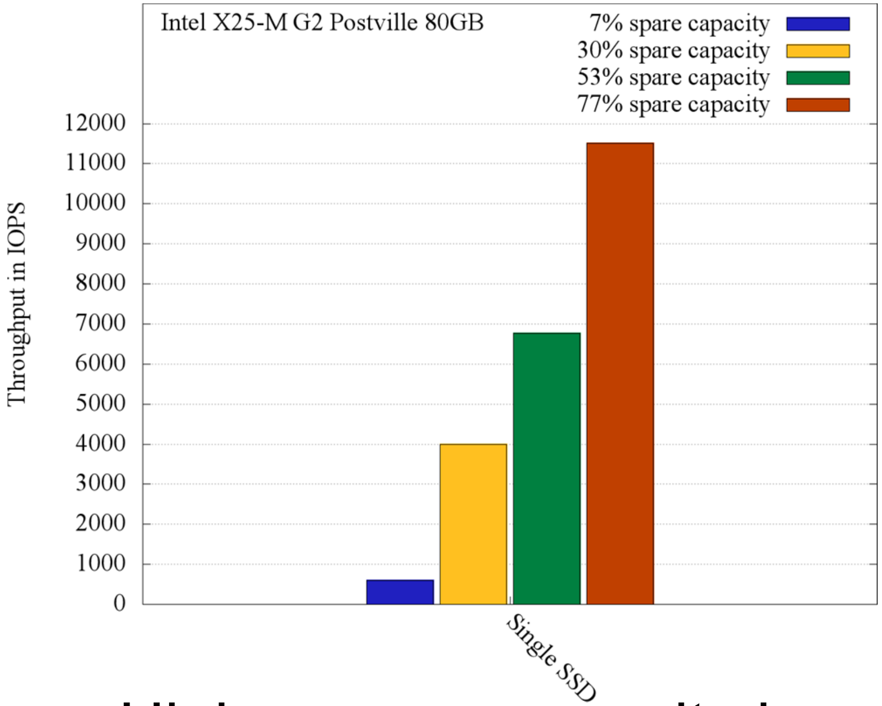
- Solution
  - Increase spare capacity to ensure that enough free flash blocks will be available anytime
  - Garbage collector has to reclaim less flash blocks lowering the number of writes to move valid data
  - Write amplification decreases substantially providing a much higher random write performance



Random Write Performance of SSDs (I)

> Visualization of SSD fragmentation

Random Write Performance of SSDs (II)

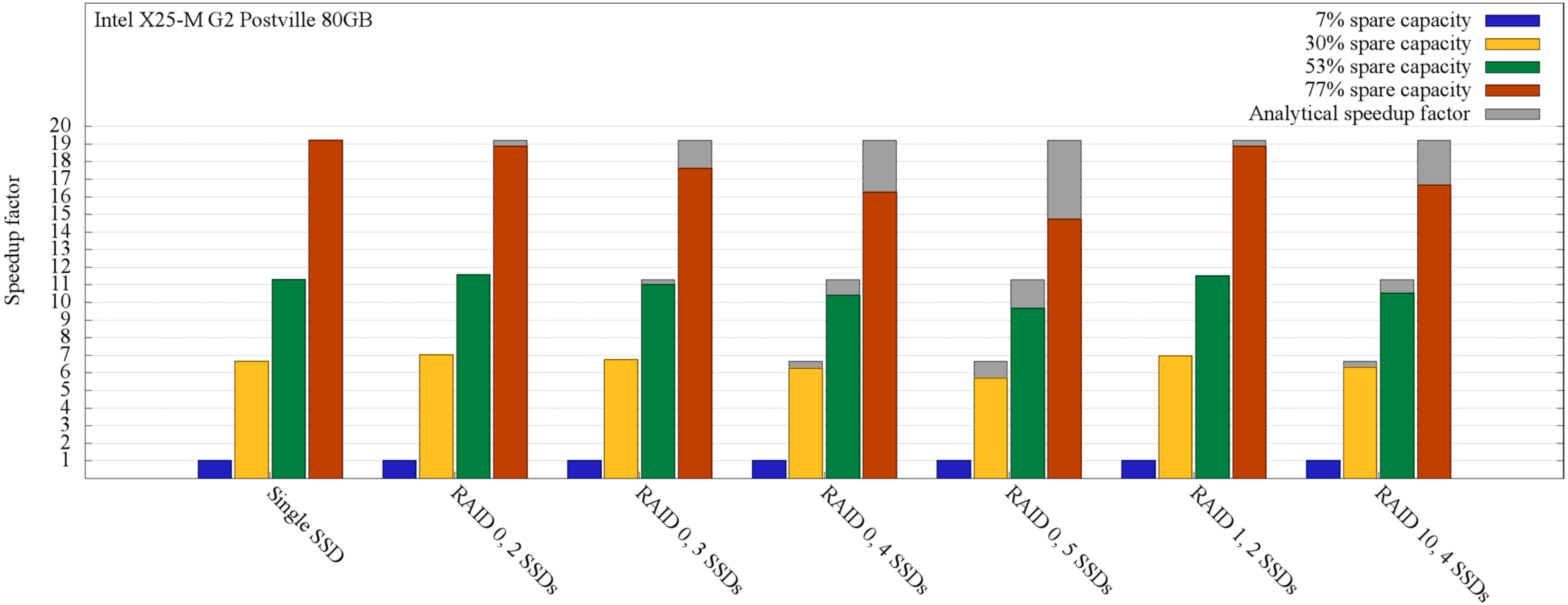


Source: Intel

Spare capacity	7%	30%	53%	77%
Speedup factor	1.00	6.67	11.29	19.22

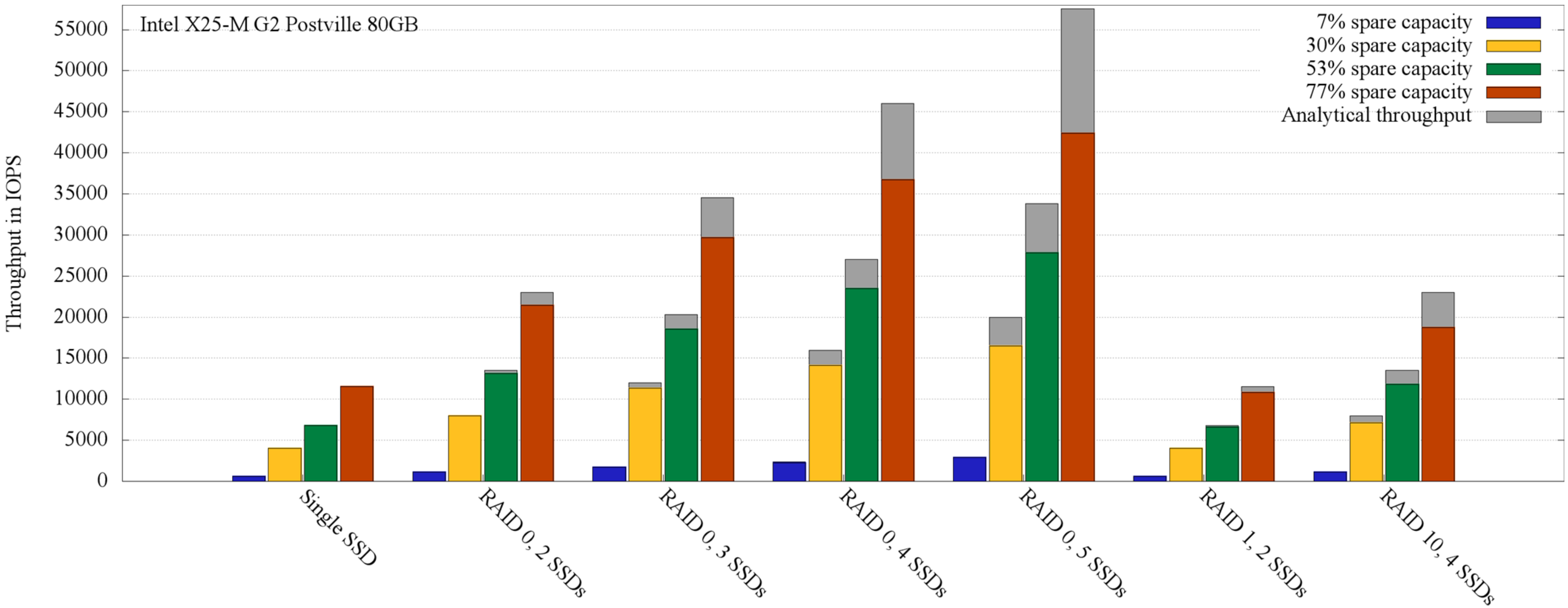
- Higher spare capacity improves sustained random write speed of a single SSD up to **19x**
- Throughput increases from **600 IOPS** to **11,500 IOPS**
- Will the situation be different for SSD RAIDs?

Parity-less SSD RAIDs: Random Write Performance (I)



- Speedup factor for parity-less RAIDs (0,1,10) should be same as for single SSD because writes are evenly distributed
- Random write performance increases up to **15x - 19x**
- Speedup factor slightly lower with more drives especially when combined with high spare capacity

Parity-less SSD RAIDs: Random Write Performance (II)



- Random write throughput increases up to **43,000 IOPS**
- Throughput scales almost straight proportional with the number of drives except for 5 drives

Parity-based SSD RAIDs: Random writes

- Prediction of random write performance more complex because random writes to RAID device incur reads
  - Speedup factor depends on number of write and read operations required to serve write request to RAID device
  - But spare capacity affects only write throughput
    $\longrightarrow$ Speedup factor will be different from single SSD

- Goals
  - Predict speedup factor without measurements for considered SSD RAID setups
  - Approximate speedup factor for RAID device based on speedup factor of single SSD

Parity-based SSD RAIDs: Model

- Speedup factor for RAID device derived from speedup factor of single SSD and scalability factor

Speedup factor of RAID device

Speedup factor of single SSD

$$\boxed{\frac{w_2}{w_1}} = \boxed{s_f} \cdot \boxed{\frac{w_{max,2}}{w_{max,1}}}$$

- Scalability factor for RAID device for RAID 5 with 4+ and RAID 6 with 6+ drives

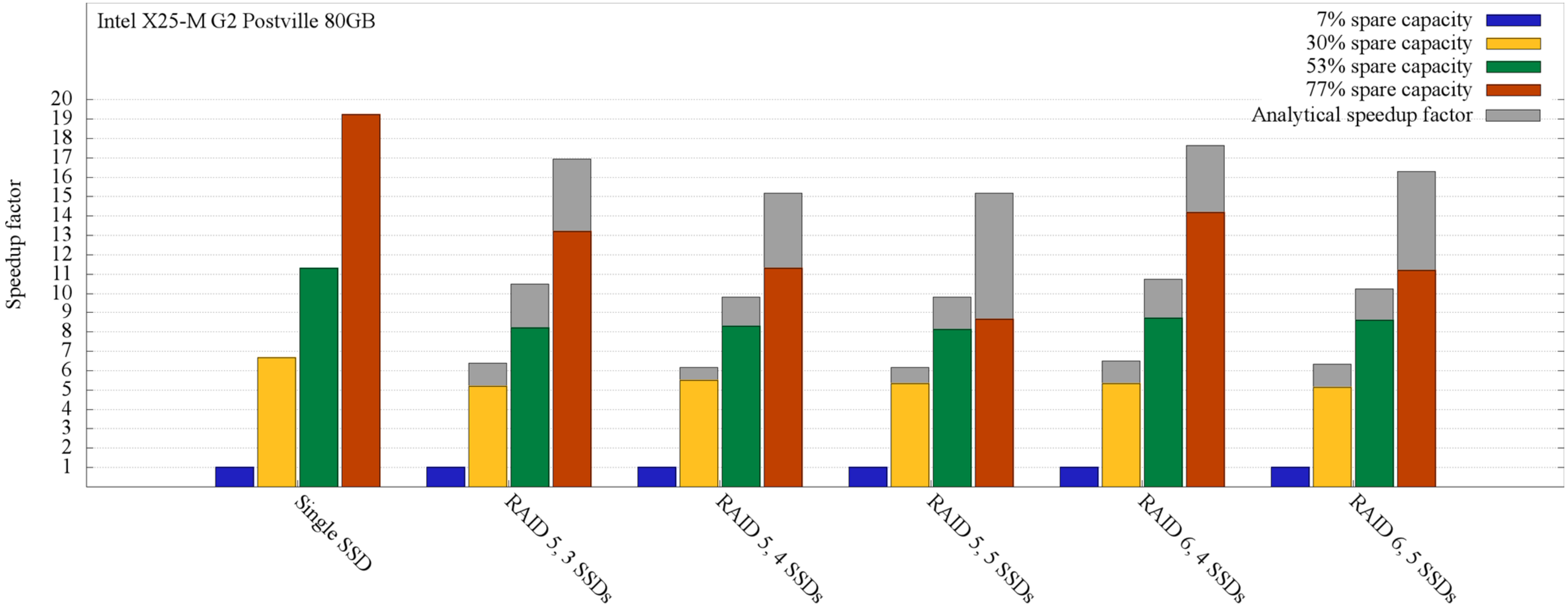
$i = 1$: Old spare capacity

$i = 2$: New spare capacity

$$s_f = \frac{1+f_1}{1+f_2}, f_i = \frac{w_{max,i}}{r_{max}}$$

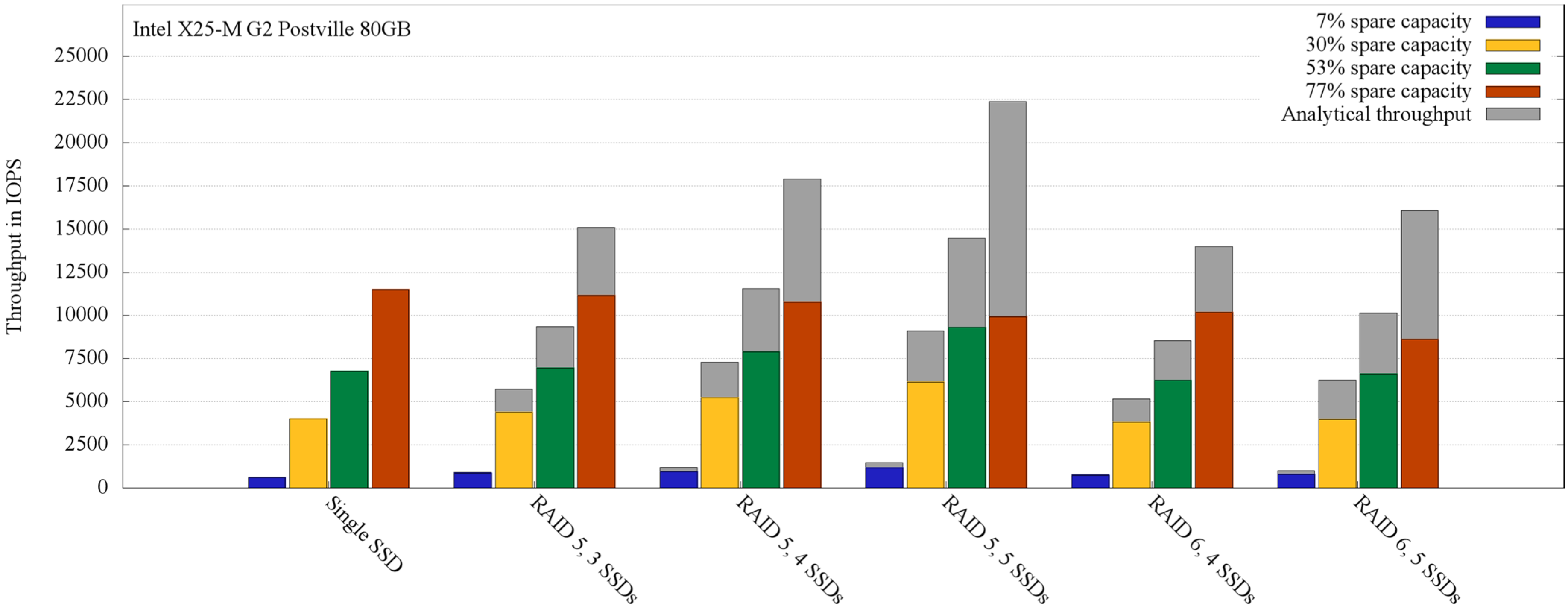
- Scalability factor for RAIDs with less drives detailed in paper

Parity-based SSD RAIDs: Evaluation (I)



- Random write performance increases up to **9x - 14x**
- Measured speedup factor 20% lower than expected
- Scaling problem for 4+ drives with high spare capacity

Parity-based SSD RAIDs: Evaluation (II)



> Random write performance increases up to **11,000 IOPS**

> Scaling problems with high spare capacity

Conclusions

> Several pitfalls can prevent SSD RAIDs from exploiting their full potential

> Spare capacity increase improves sustained random write performance in SSD RAIDs significantly

> Parity-less SSD RAIDs superior to parity-based

> Scalability issues can arise for higher number of drives in combination with large spare capacity

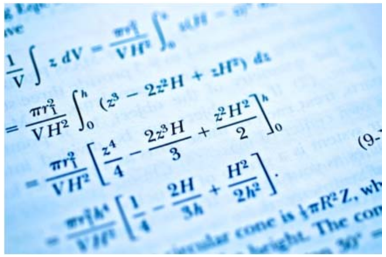
Future Work

- Improve our performance prediction model
  - Consider interaction between reads and writes
  - Extend model to
    - predict sequential write performance
    - predict read performance
- Investigate performance issues
- Explore properties of hybrid RAID setups (SSD & HDD)

Discussion

SSD RAID

Pitfalls



Model

Evaluation

Thank you for your attention!

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