Overprovisioning in All-Flash Arrays

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Abstract

- Overprovisioning in All-Flash Arrays
  - This session will appeal to Data Center Managers, Development Managers, and those that are seeking a fundamental understanding of the performance and capacity tradeoffs involved in All-Flash arrays.
  - The session will look at how NAND operate, how overprovisioning effects that, and what optimal OP for different applications might be.
  - The presentation is intended to be high-level and is not intended for design engineers, but rather provides a overview of system operations appropriate for IT professionals.

Overprovisioning in All-Flash Arrays

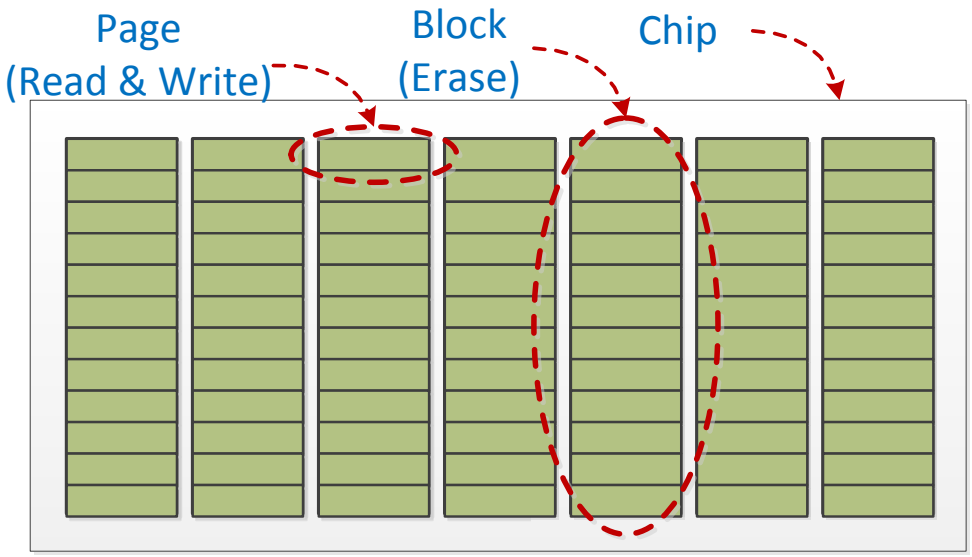
- NAND and Overprovisioning
  - NAND interfaces
  - Flash Translation Layer (FTL)
  - Block and Table Based Management
  - OP and Capacity
- OP's Effect on Performance
  - Garbage Collection and Write Amplification
  - Optimal OP
- All-Flash Arrays
  - AFA and Hybrid Arrays
  - Applications

NAND and Overprovisioning

- NAND are program/erase devices with read/write interfaces
  - SATA, SAS, PCIe, FC, IB, MMC are all read/write
- FTL's convert from one set of commands to another
  - FTL's manage conversion on block or page basis
- Overprovisioning makes that possible
  - More OP makes it more efficient

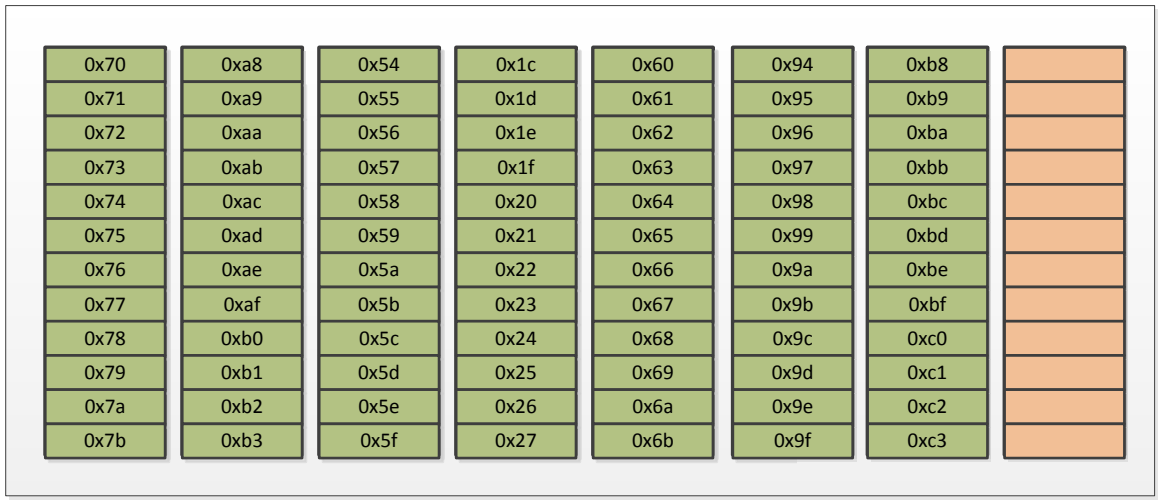
NAND and Overprovisioning: Program/Erase Devices

- Cannot overwrite data in place
- New data is written to empty blocks
- FTL notes invalidation of older entries



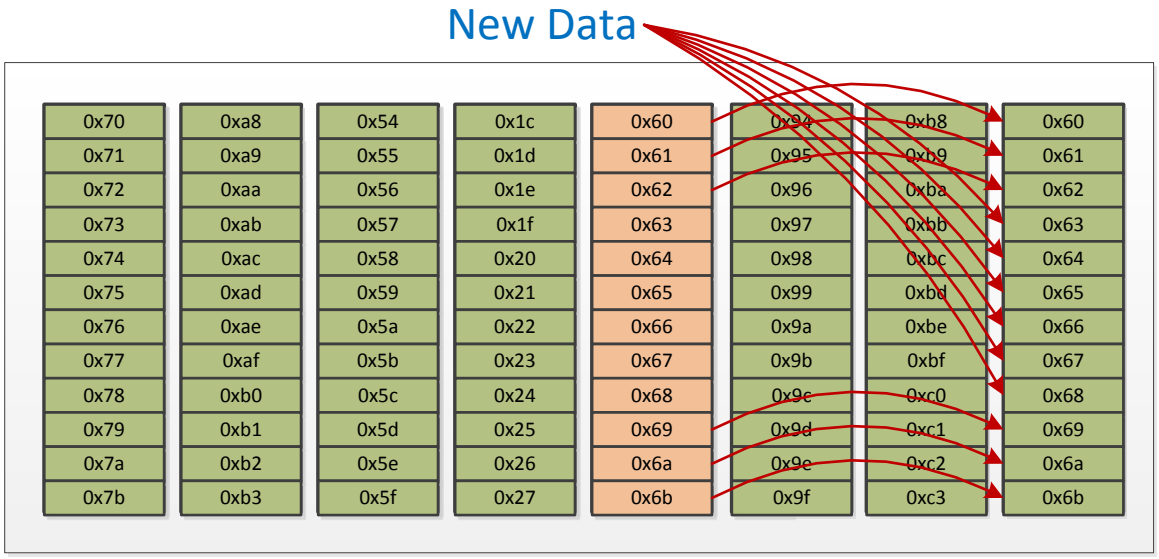
NAND and Overprovisioning: Block-based Management

- NAND can be managed on a block basis
  - Each block contains a region of addresses
  - Any update to a given block would cause the entire block to be rewritten
- Most useful if writes are at least the size of a block
  - Pictures and video, for example



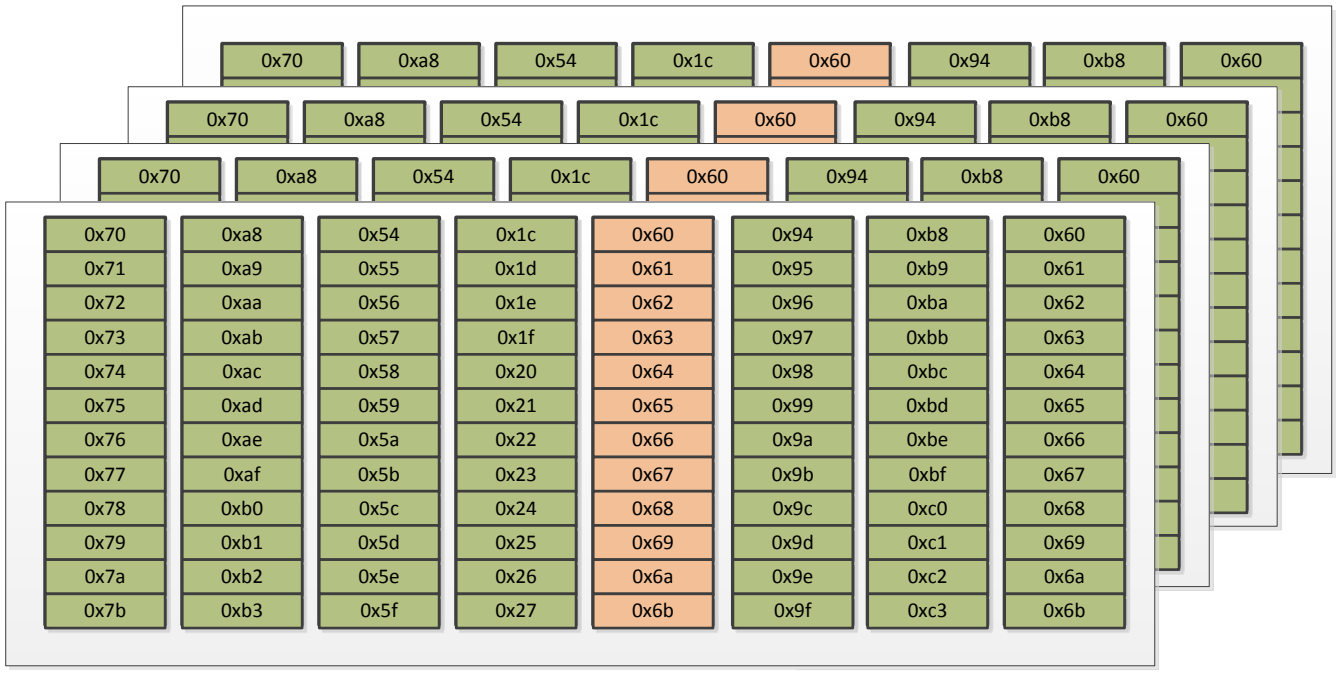
NAND and Overprovisioning: Block-based Management

- New and old data may have to be merged
  - Old data from old block, new data to be written
- Only requires 1 spare block for OP
- In this case, an equal amount of copying and writing



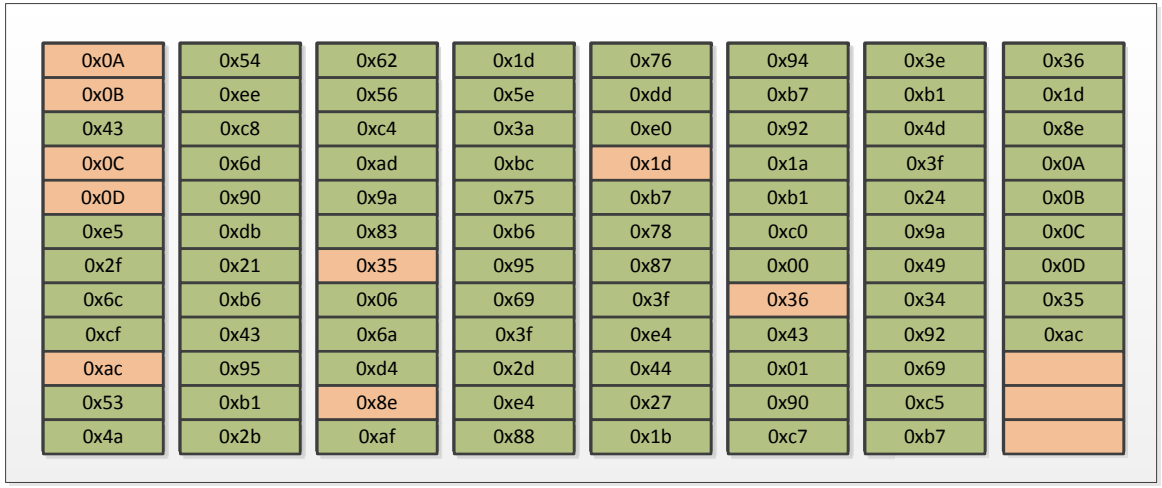
NAND and Overprovisioning: Block-based Management

- Becomes less efficient as data size becomes smaller
- Becomes less efficient as blocks become bigger
  - Grouping Flash together has higher performance, and higher effective block size
- All-Flash Arrays cannot use Block-based Management



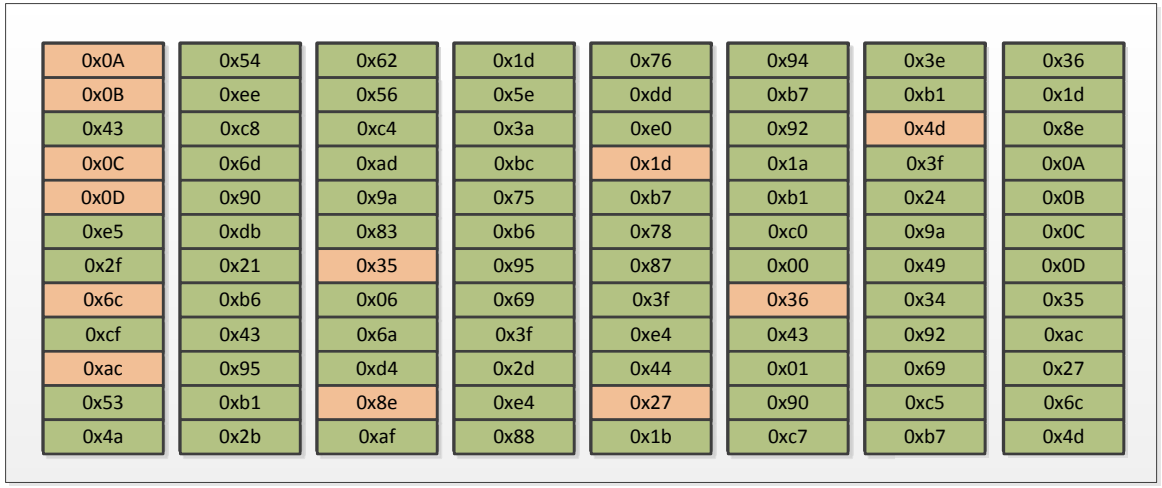
NAND and Overprovisioning: Page-based Management

- Each page of user data is tracked by the FTL
- A single block may contain many different files
  - Usually written at the same time
- New data writes invalidate older data
  - Invalid data shown in orange: some locations unwritten



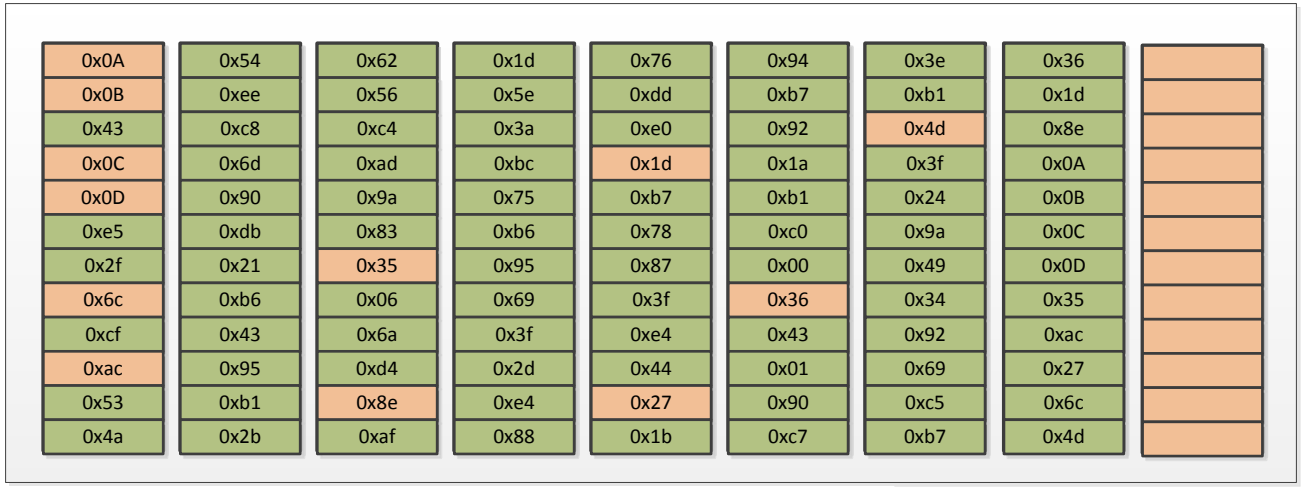
NAND and Overprovisioning: Garbage Collection

- As data is overwritten or trimmed, blocks become empty
- When a block is needed, the remaining data from the most-empty block is copied
- That block can then be erased and reused



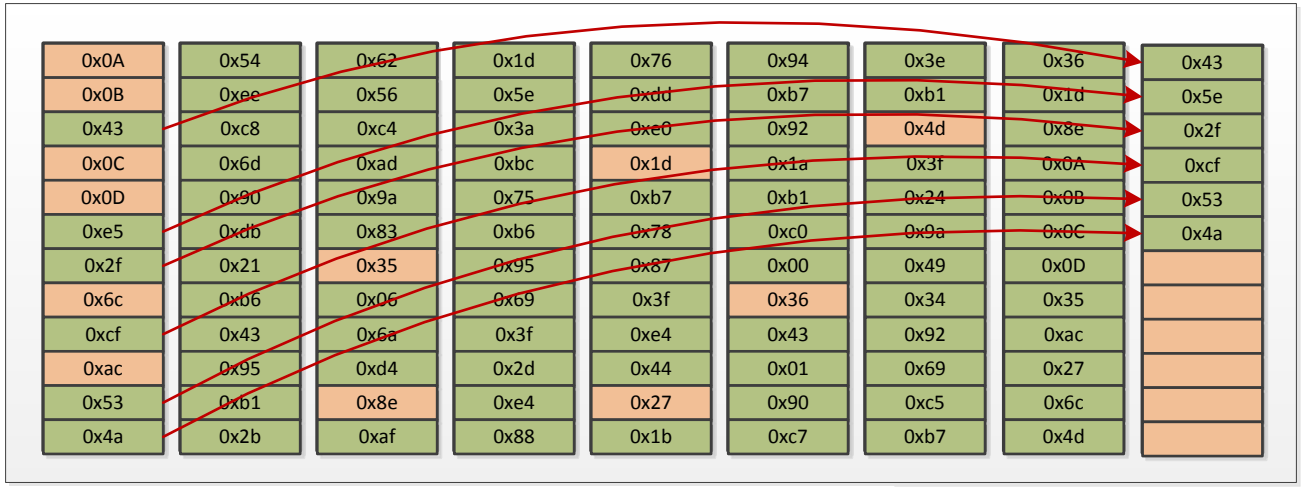
NAND and Overprovisioning: Garbage Collection

- When the data region is full, another block must be found
  - Kept in reserve during the write operations
- Orange blocks are counted as Overprovisioning
  - Both unused blocks, and portion of blocks with invalid data



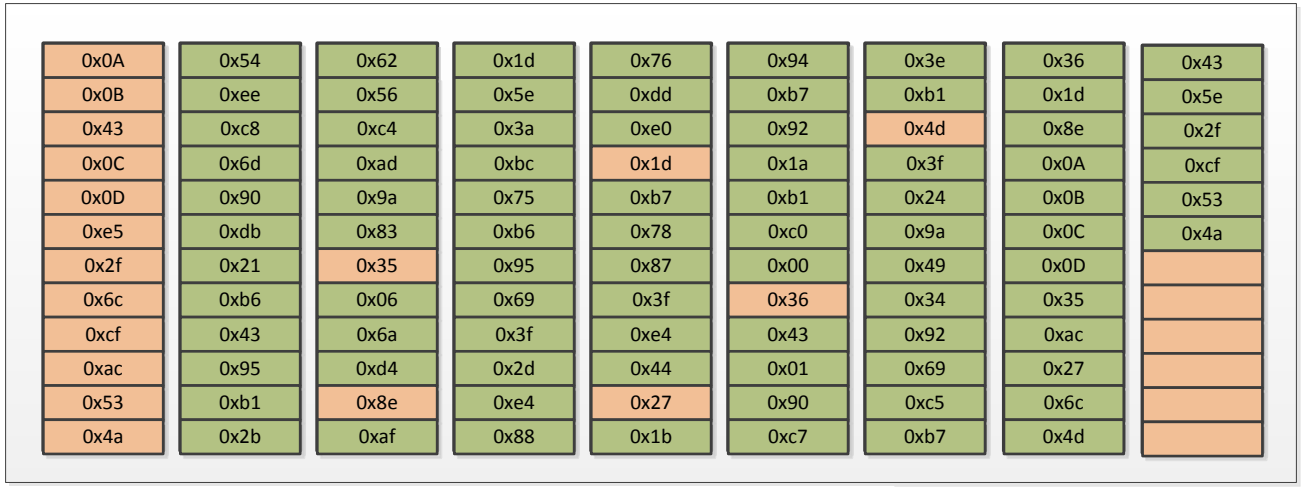
NAND and Overprovisioning: Garbage Collection

- Remaining valid data from least-valid block is copied to the previously empty block
  - This process leads to security issues
- FTL must update the location of the valid copy



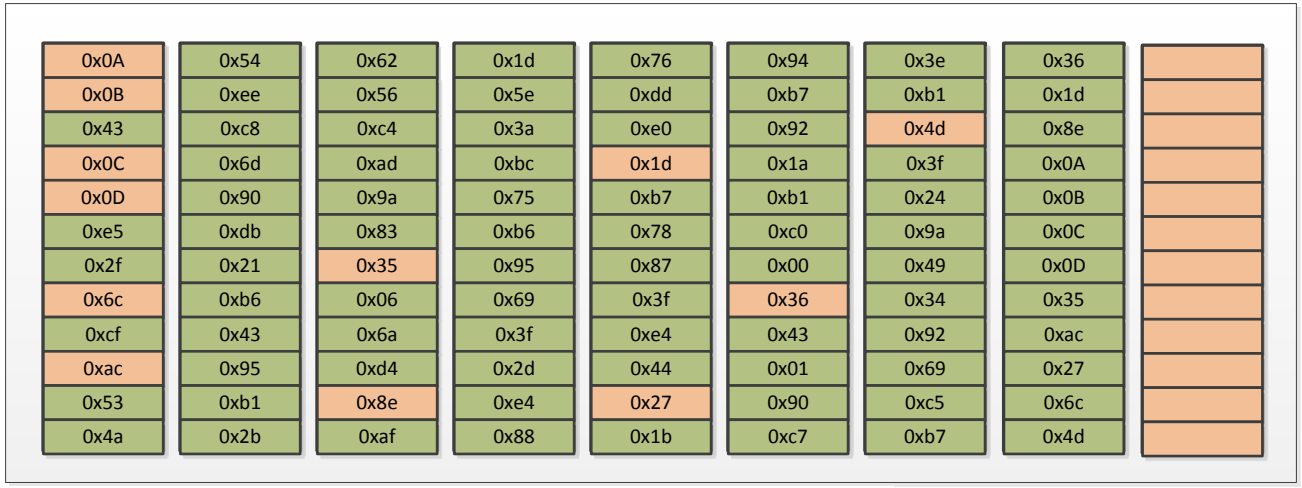
NAND and Overprovisioning: Garbage Collection

- The least-valid block can now be erased
- After GC, we have 1 ½ empty blocks
  - Started GC with 1 empty block
  - Using two blocks of OP



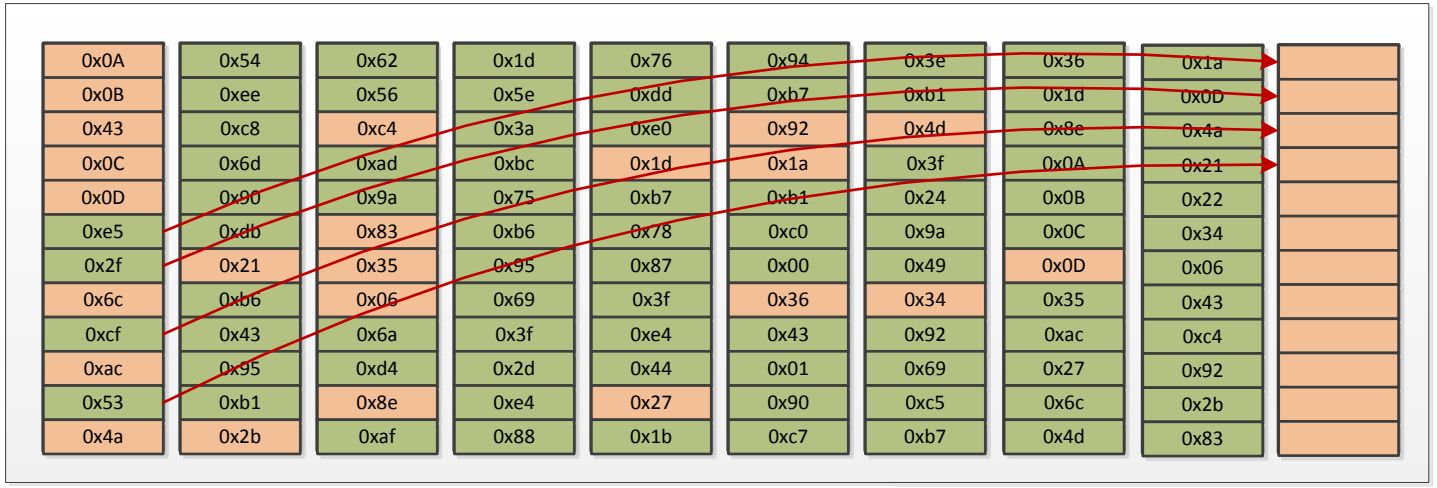
NAND and Overprovisioning: GC Overhead

- If more blocks are available, garbage collection may be delayed
- Instead of copying into empty block, allow host to write data to it
- Decreases the amount of valid data in the least-valid block



NAND and Overprovisioning: GC Overhead

- After one more block is written, less copying is required
  - There are 1 2/3 free blocks after GC
- Adding another is likely to decrease copying further
- Generally, more OP means less GC



NAND and Overprovisioning: Capacity

- Extra space is the difference between NAND and user capacity
- This space comes from a number of sources
  - NAND page and die sizes slightly larger than Po2
  - Difference between base-2 and base-10
  - Extra chips or blades
  - Lowering the stated capacity
- Extra space is consumed by ECC, bad blocks, RAID, FW, tables, and OP
  - Several layers of CRC, ECC, and RAID may be present
  - Space can be reallocated unexpectedly

NAND and Overprovisioning: Capacity

- State capacity could mean one of several things
  - User capacity, with or without compression
  - User capacity and OP, usually if OP is configurable
  - NAND capacity, requiring understanding of ECC overheads
- 100 TB of “raw” capacity
  - After ECC (5%), RAID-5 (3%), RAID-5 (12%), Overprovisioning (30%), and FW & Tables (5%): 60 TB of formatted capacity
- 100 TB of “unformatted” capacity
  - After Overprovisioning (20-40%) and FW & Tables: 79-68 TB of formatted capacity
- 100 TB of “compressed” capacity
  - Must remove compression factor from capacity: 20-50 TB of formatted capacity

NAND and Overprovisioning: Capacity

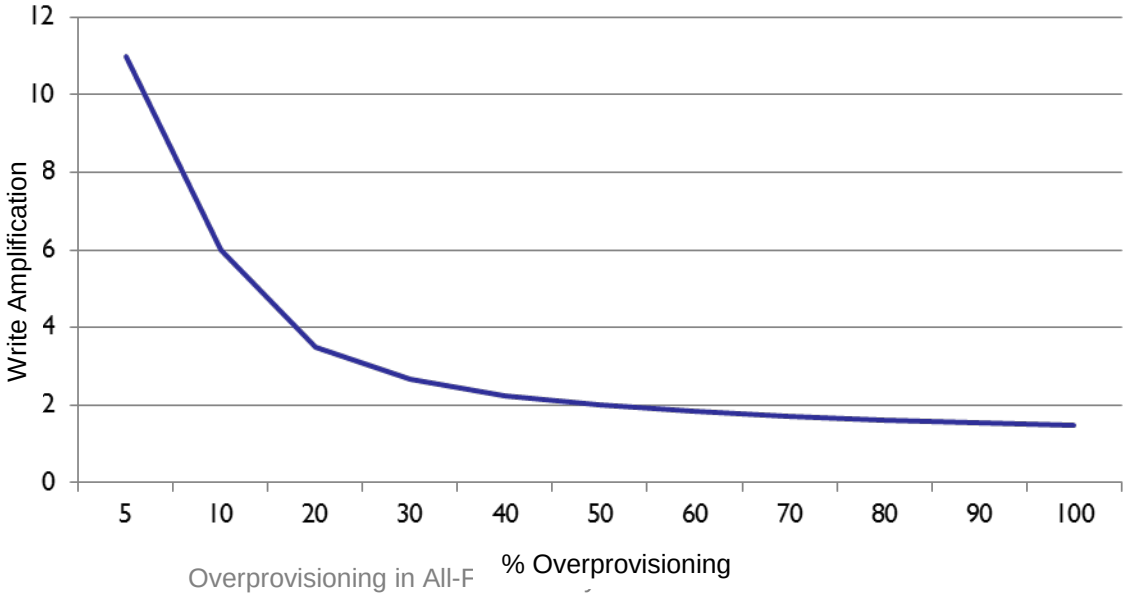
- Device vendors are paid for the user capacity
  - Previous values all estimates: your mileage may vary
  - Memory dedicated to other purposes should be hidden
  - If not, cost must be recomputed
- Goal is to maintain performance with minimal cost
  - Need to meet MB/s goal
  - Need to meet product lifetime goal
- OP is expensive

OP's Effect on Performance

- Write performance is dependent upon amount of Garbage Collection
  - With 10% OP, a system may copy 5B of GC data for every byte of write
  - This corresponds to a Write Amplification of 6
- Large Write Amp can cause endurance problems
  - NAND can be worn down by extra writes
- More OP decreases Garbage Collection writes
  - Expensive way to increase write rate
  - Other factors also influence GC
- OP does not effect read performance

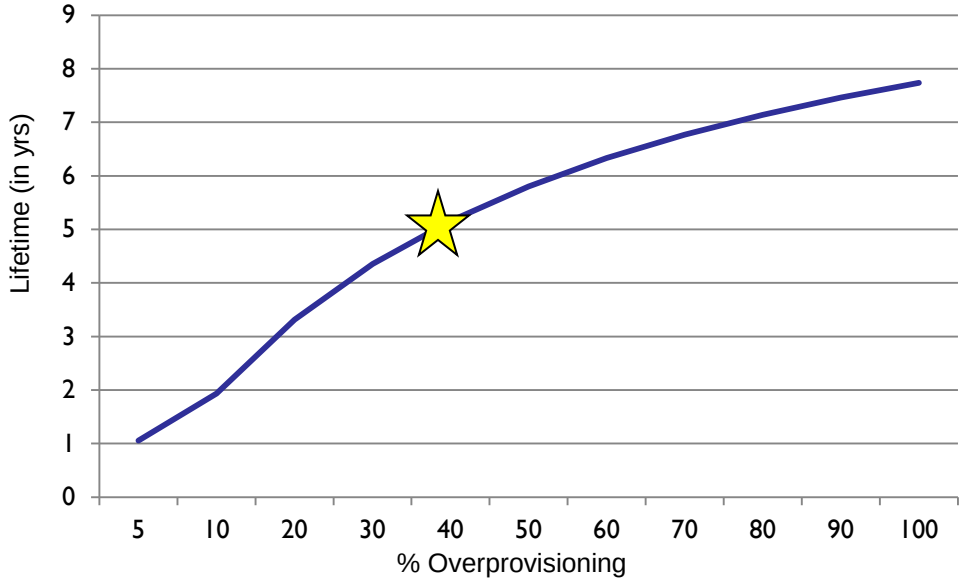
OP's Effect on Performance: Write Amplification

- Until about 50% OP, most writes are caused by Garbage Collection
  - With small OP (5%-10%), 90% of writes can be GC
- These are worst-case benchmark results
  - Small-sized, random writes



OP's Effect on Performance: Lifetime

- A flash can be cycled to death without careful system management
  - Graphs shows an example 1MIOPS system with 50 TB capacity using high-endurance NAND
- A five-year life would require 40% OP

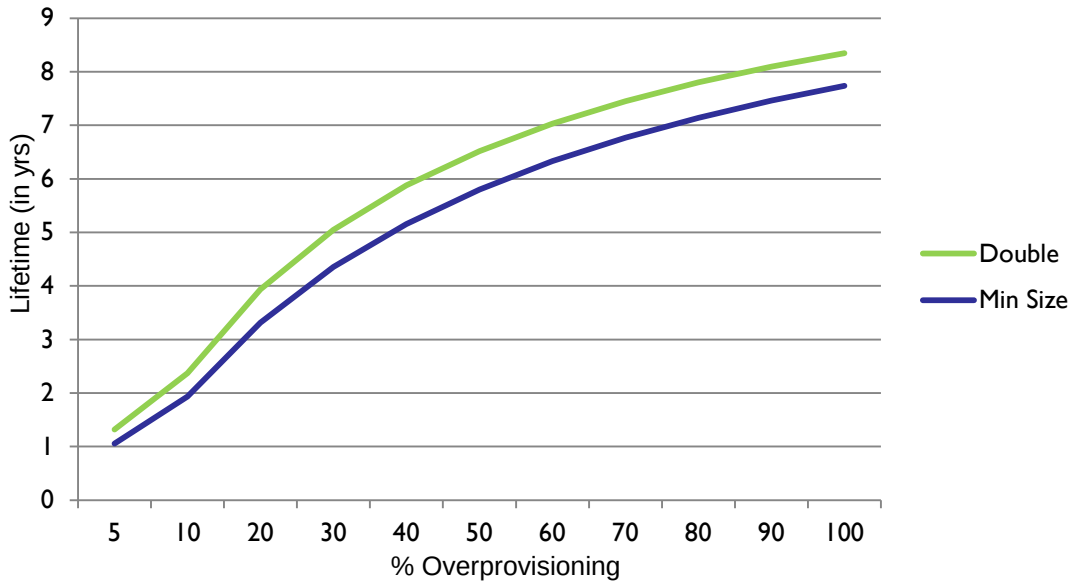


OP's Effect on Performance: Data Size

- Larger data sizes make page-based GC more efficient
  - Increases the chances of an entire block being invalid
- Many applications use larger than minimal data sizes
  - Most operations are small
  - Most data is transferred during large operations
- The toughest case is isolated, page-sized operations
  - Random operations over a limited range are similar to large blocks

OP's Effect on Performance: Data Size

- Larger data sizes make page-based GC more efficient
  - Increases the chances of an entire block being invalid
- Optimal OP for 5 year life decreases from 40% to 30%
  - Relatively small decrease in data size

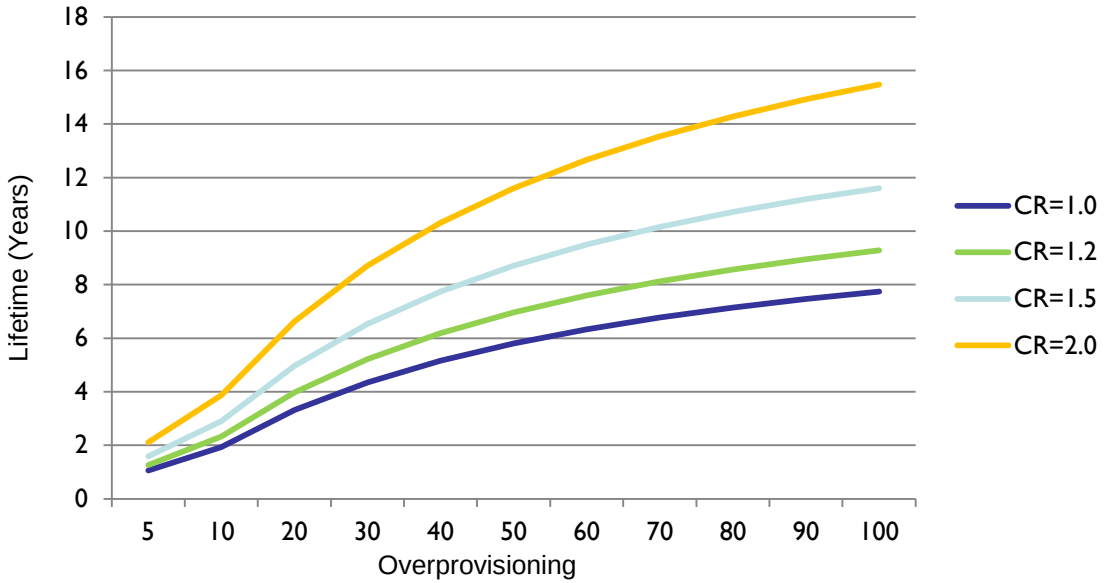


OP's Effect on Performance: Compression & Dedup

- Decreases the amount of written user data
  - Correspondingly decreases the GC
- Radically increases the system complexity
  - Hardware required for comp, dedup
  - Firmware to track byte locations, sizes
  - Lots of nasty edge cases for both
- Effectively increases the capacity of the device
  - Depending upon the compression ratio

OP's Effect on Performance: Compression & Dedup

- Decreased NAND traffic from Compression & Dedup decreases cycling and wear
  - Our hypothetical 40% goes to 15%
- Dangerous to base OP reduction on compression
  - Overprovisioning usually based on worst-case expected traffic

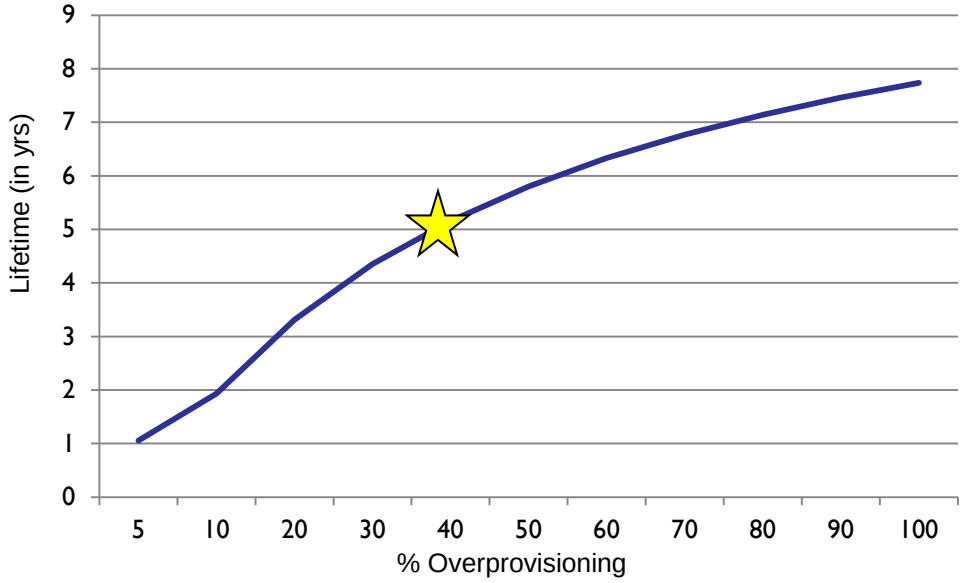


OP's Effect on Performance: Data Organization

- GC cost can be significantly decreased if data is not random
  - Many benchmarks are random
- If data which is invalidated together is grouped, less copying is needed
- Many heuristics exist to improve performance
  - Based on traffic patterns of applications

OP's Effect on Performance

- For a given lifetime or performance, certain OP is necessary
  - That value can be based on worst-case scenario
- The necessary value can be informed by average transfer size, compression and compressibility, and organization

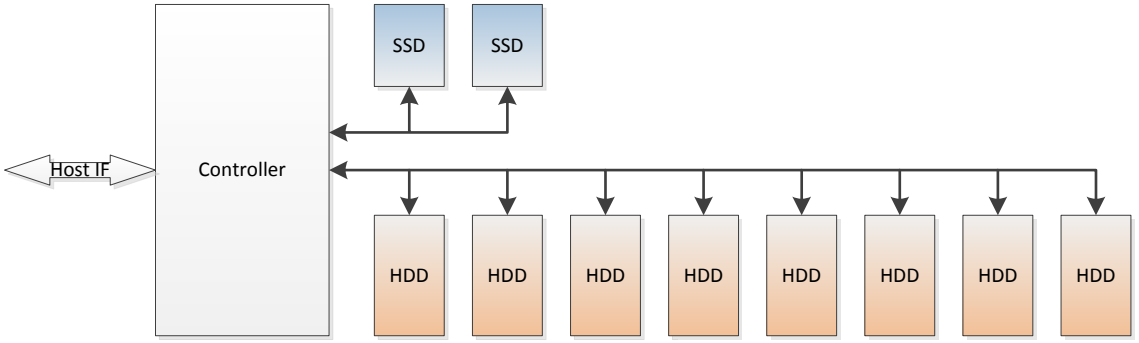


All-Flash Arrays

- Traditionally Enterprise-SSD's have been used for caches in hybrid system
  - Caches are very high traffic
  - Traffic is filtered before caching
- AFA are structurally different from Hybrid-Caching systems
  - Allowing for higher performance and density at the same cost
- All-Flash Arrays see more of the traffic
  - There is (almost) always patterns which can be exploited

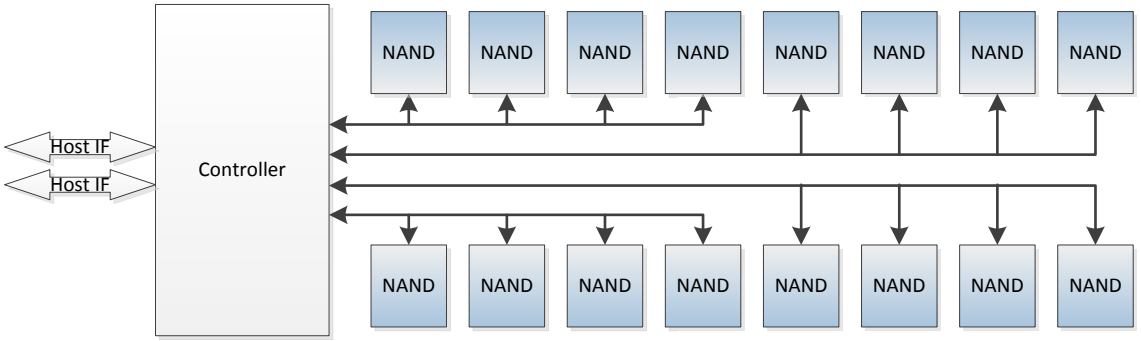
All-Flash Arrays: Hybrid-Caches and AFA

- Traditionally SSD's have been used for caches in hybrid system
  - SSD's high speed used to offset long HDD latency
  - Small SSD capacity has small cost impact
  - SSD as percentage of total capacity grew over time
- Controller firmware responsible for moving data into SSD's
  - Trying to keep as much data as possible in fast SSD's



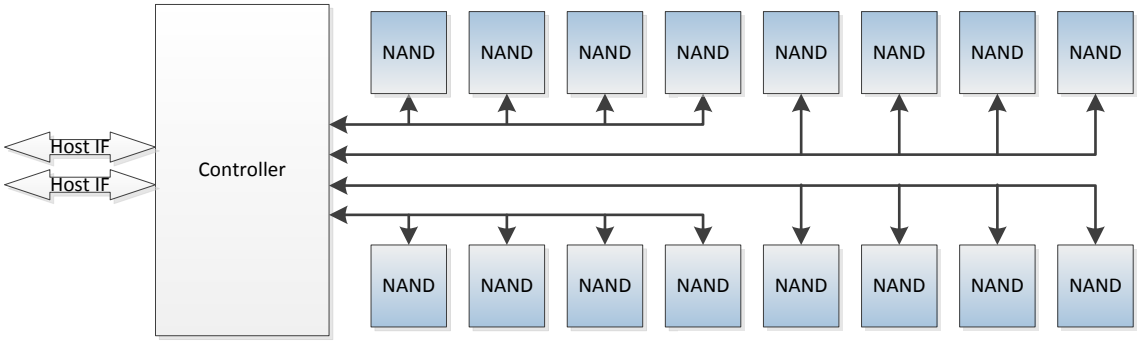
All-Flash Arrays: Hybrid-Caches and AFA

- Hybrid systems easily transitioned to SSD Arrays
  - As the percent in SSD approached 100%
- Transition increased simplicity and performance
- AFA can manage Flash directly or using SSD's
  - Performance and density limited by using HDD-based standards



All-Flash Arrays: Hybrid-Caches and AFA

- All-Flash Arrays see more of the traffic
  - Can take advantage of differences in traffic patterns
- AFA are much faster than HDD or hybrid drives
  - Have achieved price parity with HDD
- Cost of AFA is dominated by the cost of Flash



All-Flash Arrays: Traffic Considerations

- Most applications do not require maximal OP
- Some hybrid-caching applications would be worst-case

Application	Xfer Size	Writes	Comp
Hybrid Caching	Small	High	Medium
Video Streaming	Large	Low	Low
Web Search	Medium	Medium	Medium
Database Processing	Small	Medium	Medium

All-Flash Arrays: Performance Tradeoffs

- The amount of OP should be kept as small as necessary
  - For both performance and endurance goals
  - Flash cost is paramount
- That necessary amount is smaller in All-Flash Arrays than in hybrid caches
  - No longer subject to worst-case traffic, except benchmarks
- There are effects which are not captured here
  - Underlying NAND technology and handling
  - Efficiency of firmware

Conclusion

- Overprovisioning is a necessary response to NAND die architecture
  - Part of the structure used to convert to Flash protcol
- More is better, if everything else is equal
  - Improves performance and reduces wear
  - More OP is more expensive
- Price of OP may be hidden in system cost
  - Need to be careful about capacity and cost
- Know your application
  - Optimal OP depends upon data size, compression, access pattern, and firmware behaviour

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Authorship History

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