SDC

STORAGE DEVELOPER CONFERENCE

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# Andromeda: Building the Next-Generation High-Density Storage Interface for Successful Adoption


Laura Caulfield, Michael Xing, Zeke Tan, Robin Alexander

Cloud Server Infrastructure Engineering

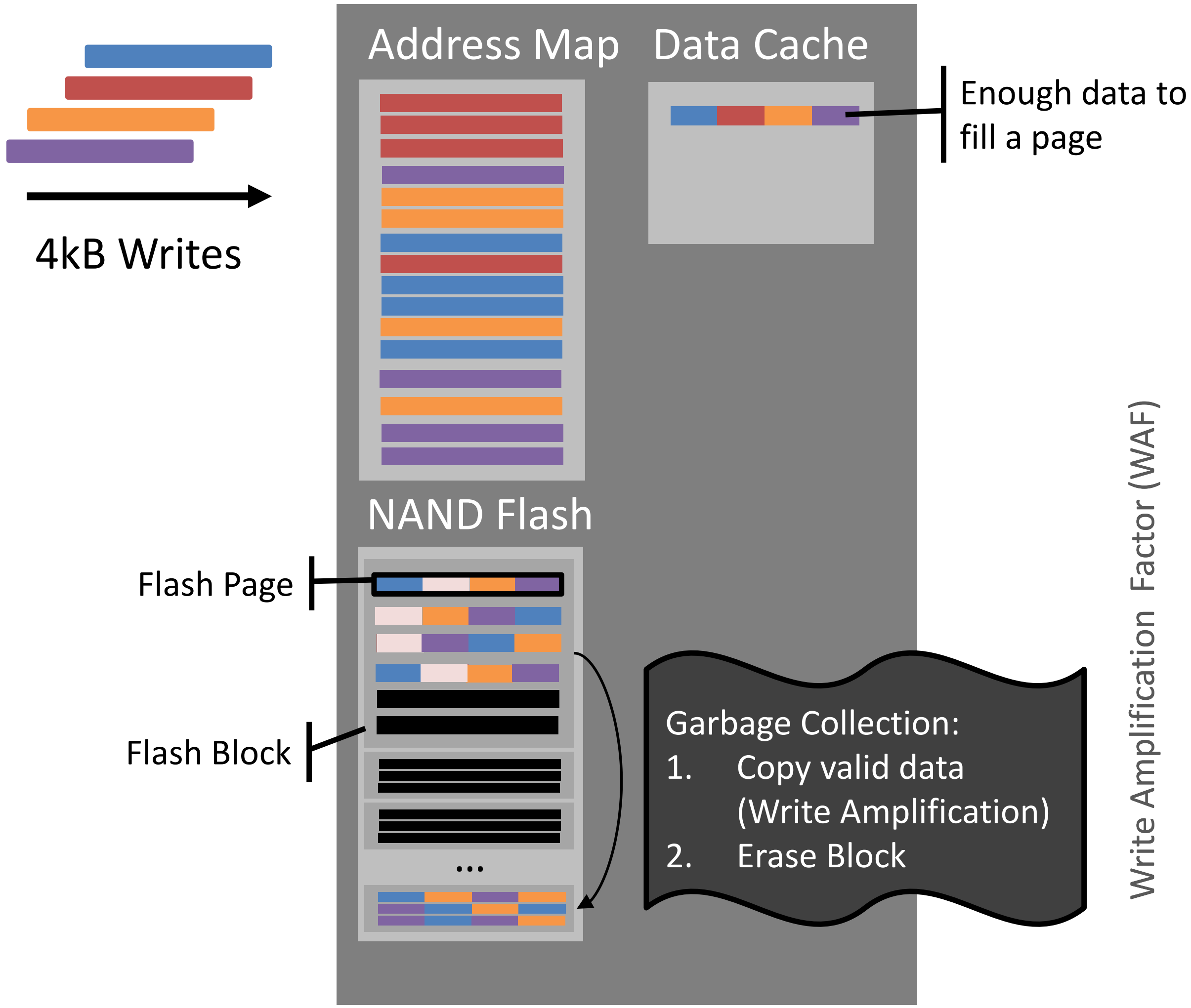
Microsoft Azure

# Design Principles For Cloud Hardware

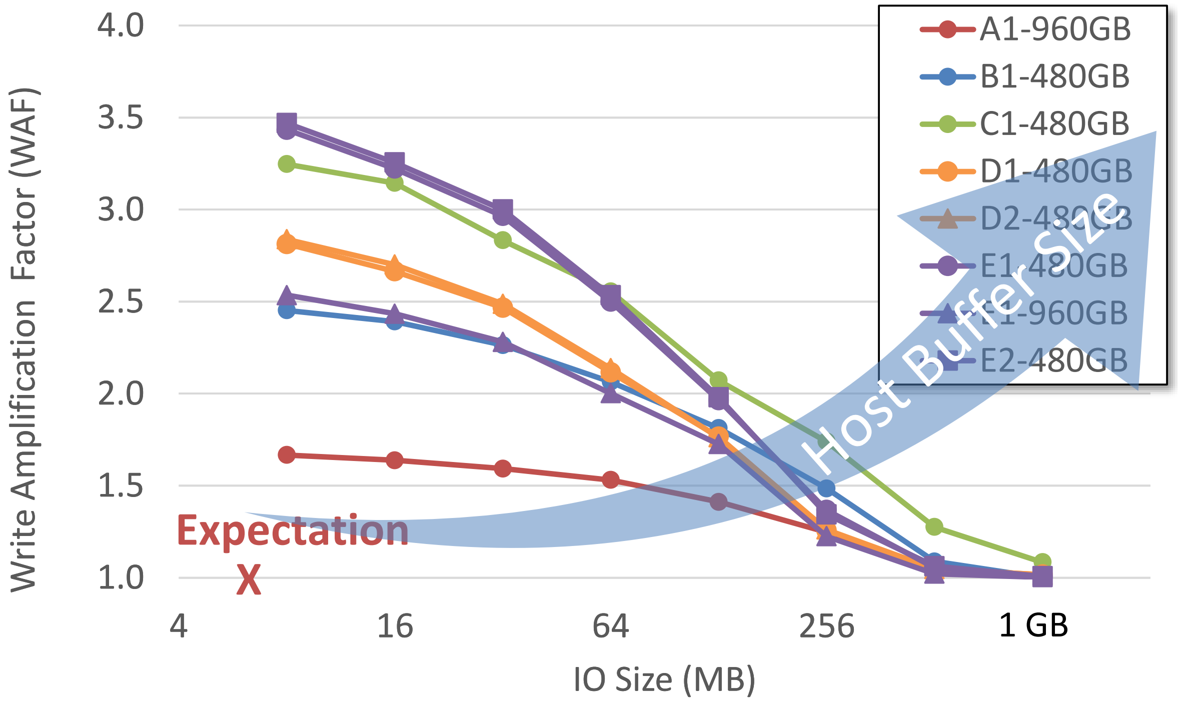
- Support a broad set of applications on shared hardware
  Azure (>600 services), Bing, Exchange, O365, others
- Scale requires vendor neutrality & supply chain diversity
  Azure operates in 38 regions globally, more than any other cloud provider
- Rapid enablement of new NAND generations
  New NAND every 18 months, hours to precondition, hundreds of workloads
- Flexible enough for software to evolve faster than hardware
  SSDs rated for 3-5 years, heavy process for FW update, software updated daily

Microsoft

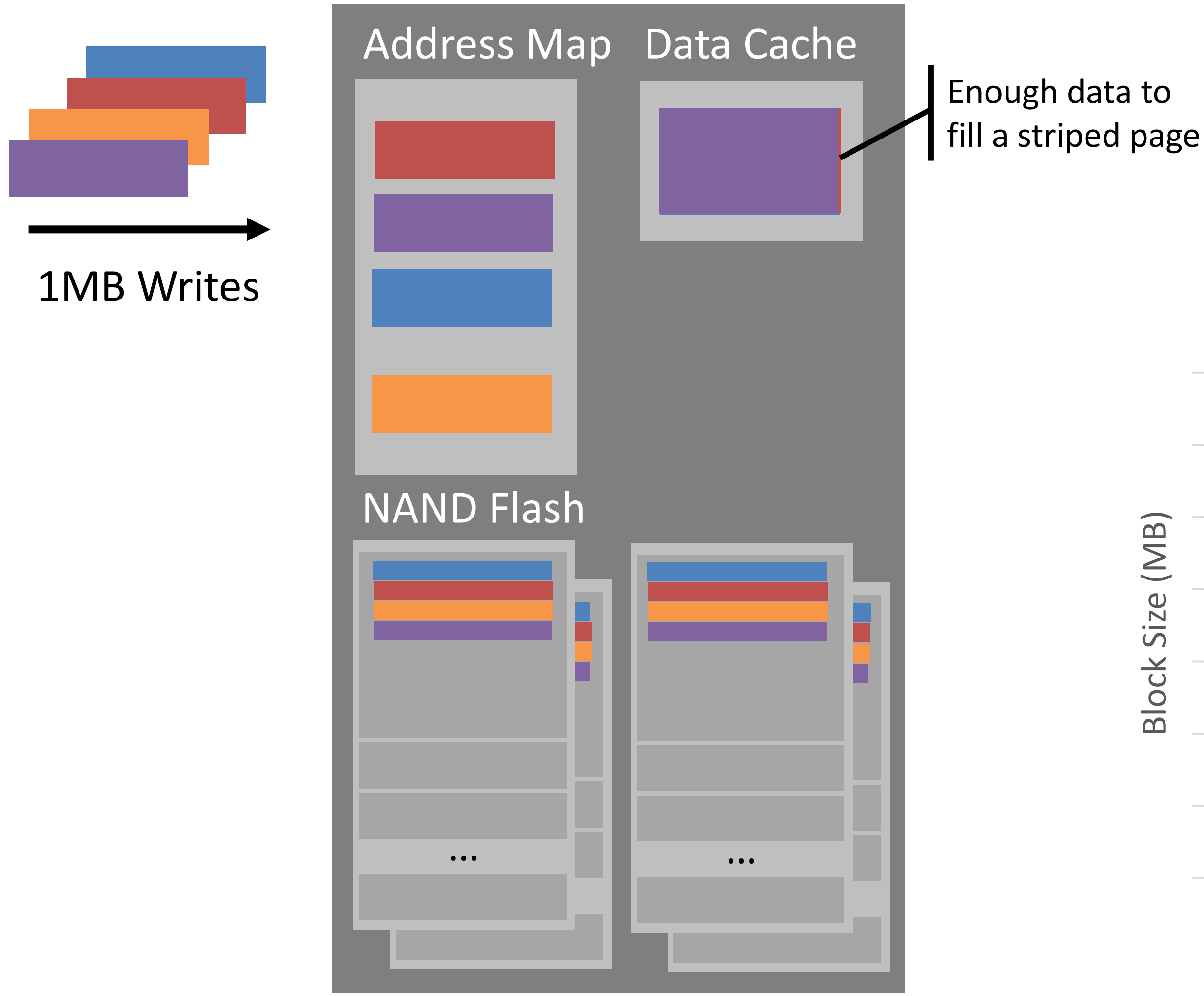
# SSD Architecture



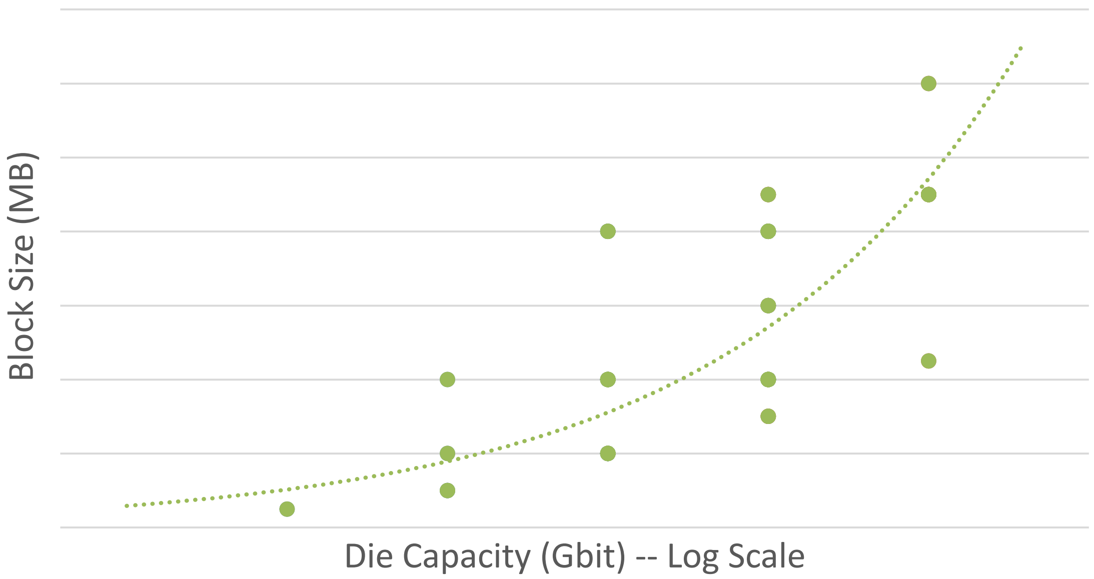

| Attribute | Size |
|---|---|
| Flash Page | 16kB |
| Flash Block | 4MB - 9MB |
| Map Granularity | 4kB |



# SSD Architecture




| Attribute | Size |
|---|---|
| Flash Page | ~~16kB~~ 1MB |
| Flash Block | ~~4MB - 9MB~~ 1GB |
| Map Granularity | 4kB |



# Cloud-Scale Workloads

**What is the most efficient placement of their data in an SSD's NAND Flash Array?**

**Azure Storage Backend** (SOSP '11)
- Lowest tier in hierarchy ("streaming")
- Write Perf. ↑, Stream Count ↑
- Read QoS via small reclaim unit

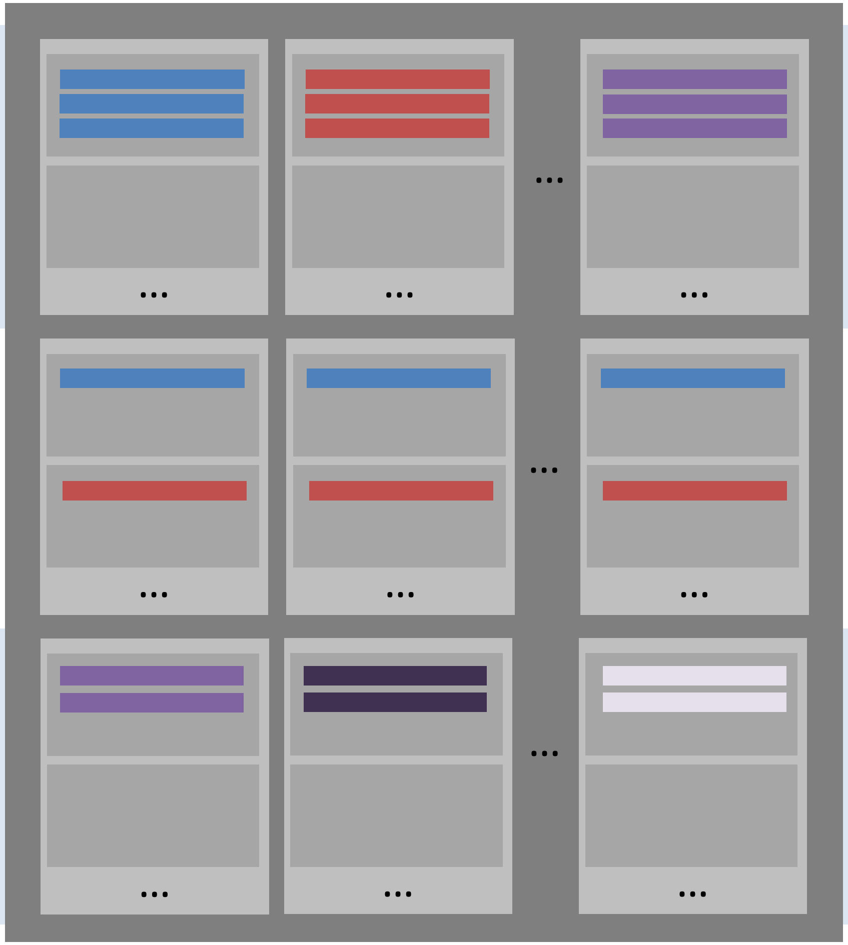
**Vertical Stripe**
- High throughput through aggregation
- Smallest possible effective block size

**Application in Virtual Machine** (VM)
- Small updates
- Unaligned Peak Traffic (Bursty)

**Horizontal Stripe**
- Each write receives peak performance
- Erase blocks when VM closes

**New Application in VM**
- Same resources as any VM guest
- Adaptable to flash sizes

**Hybrid Stripe**
- VM Host allocates horizontal stripe
- VM Guest partitions it further



**Allow these and other stripe dimensions simultaneously in the same SSD**

# Key Observations

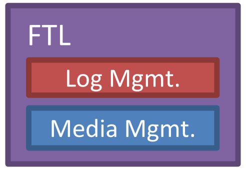
- Block abstraction is showing its age
  - Forces expensive reserve of flash and DRAM
  - Mixes distinct streams of data, increasing WAF
  - Even HDDs are host-managed (SMR)

Baidu first to propose in ASPLOS '14
Increase Raw BW from 40% to 95%
Increase capacity from 50% to 99%

- Reliability should be near media
  - Warranty & Production-scale quality are essential
  - Tuning the host to different NANDs is not practical
  - Expertise is in-house at SSD companies
- Data placement policy should be near applications
  - Trade-off between reclaim size & throughput
  - Each application has a different place on spectrum
  - Expertise is in-house at software companies

Fundamental requirements
of the general purpose cloud

# What do you mean by "Open Channel"?




## FTL (Flash Translation Layer):

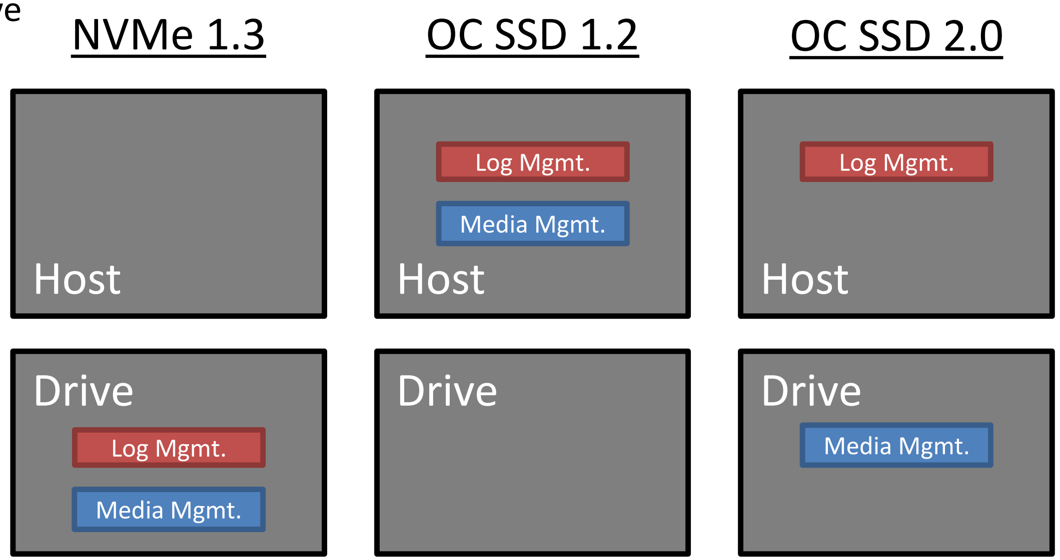
Algorithms which allow flash to replace conventional HDDs
Conventional systems contain the entire FTL in the Drive's controller
Target design divides the log and media mgmt. between host and drive


## Log Managers:

Receive random writes
Transmit one or more streams of sequential writes
Maintains address map, performs garbage collection


## Media Managers:

Tuned to a specific generation of media
(such as Toshiba A19nm or Micron L95)
Implement error correction such as ECC, RAID and read-retry
Prevent media-specific errors through scrubbing, mapping out bad blocks, etc.



✓ Available
● Incomplete
✗ Not planned

# Existing Proposals

| | Log Abstraction | In-Host Placement Policy | In-Drive Reliability |
|---|---|---|---|
| LightNVM / OCSSD 2.0 (FAST '17) | ✓ | ✓ | ✓ |
| Software Defined Flash (ASPLOS '14) | ✓ | ✓ | ✗ |
| IO Determinism (Fall '16) | ✗ | ● | ✓ |
| Multi-Streamed SSD (HotStor '14) | ✗ | ● | ✓ |
| Nameless Writes (FAST '12) | ✗ | ✗ | ✓ |
| Programmable Flash (ADMS '11) | ✗ | ✗ | ✓ |

Next: Iterate on OCSSD 2.0 Spec. to create production-ready system (manufacturable, warrantable, etc.)

# Physical Page Addressing (PPA) Interface

*Host and drive communicate with physical addresses*

- Terminology
  - Channel: SSD Channel
  - Parallel Unit (PU): NAND Die
  - Chunk: multi-plane block
  - Sector: 512B or 4k region of NAND page

Address Format:


- All addresses map to a fixed physical location

- Host IO Requirements:
  - Erase a chunk before writing any sectors
  - Write sectors within the chunk sequentially
  - Read any sector that is not within “cache minimum write size”



“Open-Channel Solid State Drives NVMe Specification” Matias Bjørling, Oct 2016 https://aka.ms/i9my03

Microsoft

# Chunk Address: Logical or Physical?

*Host requires no resource guarantees rooted in physical location for chunk – option to make chunk address logical*

**If Chunk Address Remains Physical**

- Host manages all wear leveling
  - Monitors erase count on every block
  - Uses vector copy command
- Drive monitors wear, provides backup
  - Low water mark: notifies host of uneven wear
  - High water mark: moves data and notifies host of new address

**If Chunk Address Were Logical**

- Drive guarantees even wear within die
- Wear leveling integrated with scrubbing
- Simple wear leveling
  - Full, block-granular map
  - Swap most/least worn block at regular period
- Start-gap style wear-leveling
  - No map (equation-based)
  - Move 1 block of data at regular period
- Host issues maintenance “go” and “stop”

Remapping the block number within the drive has much lower performance and space overheads vs. current SSD designs

Microsoft

# Reliability and QoS

## Tight QoS Guarantees

- OCSSD 2.0
  - Read and write times include ECC
  - “Heroic ECC” is binary
- Future Enhancement
  - Use reported times as “base” performance
  - Table to select reliability/latency
  - Selectable per chunk? Per stripe?

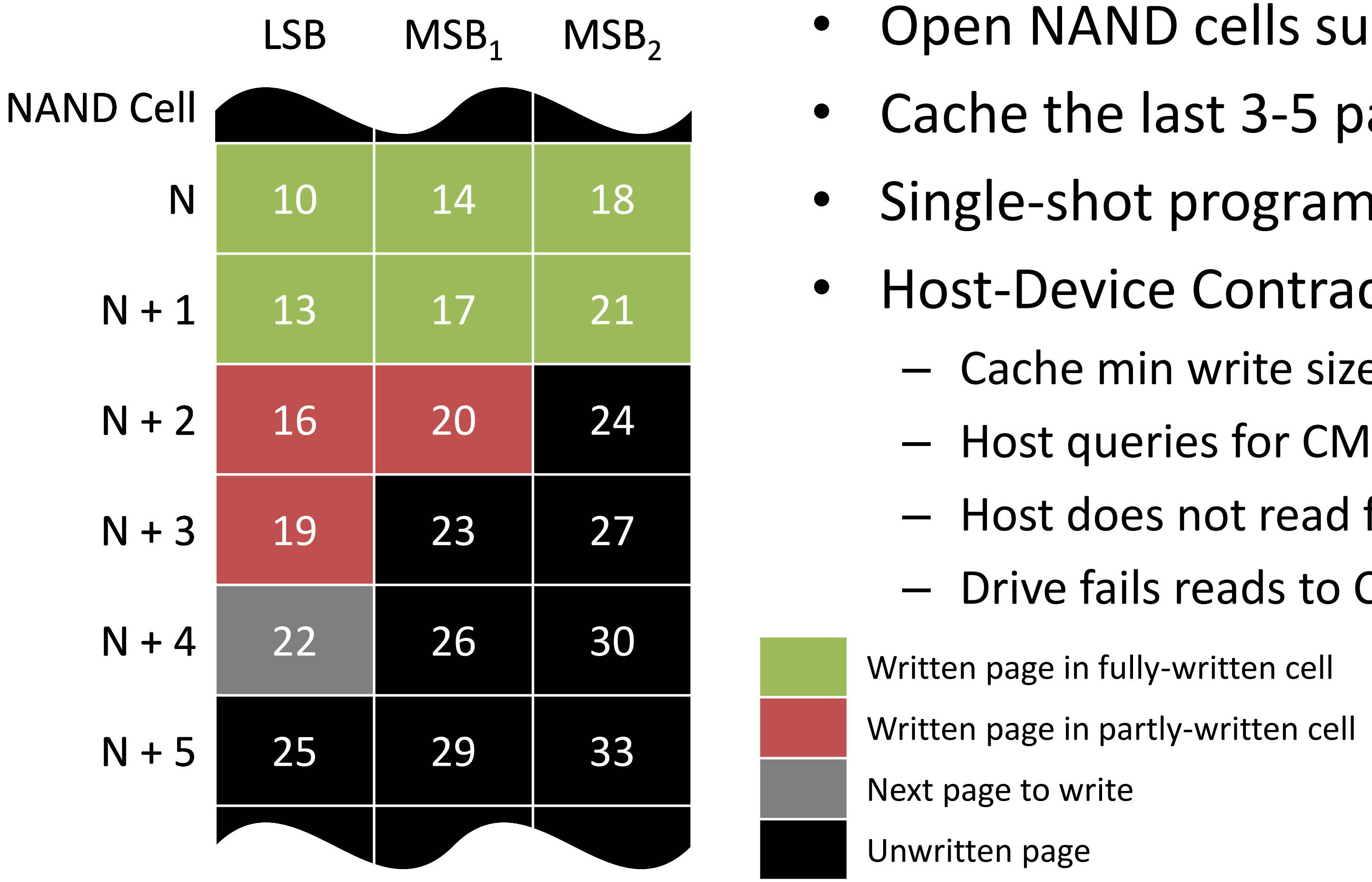
## RAID

- RAID and isolation are at odds
  - Independent work scheduled to each die
  - Must build parity and decode on all dies
- Higher level replication
  - RAID within drive is *sometimes* redundant
  - Require information & mechanisms for host to selectively us in-drive RAID
  - Leverage vector reads/writes

# Cache Minimum Write Size

*Mitigating Open Memory Cell Read Disturb, defining the right abstraction for the "open block timer"*

- Open NAND cells susceptible to read disturb
- Cache the last 3-5 pages written to any write point
- Single-shot programming is not susceptible
- Host-Device Contract:
  - Cache min write size (CMWS) = max kB in open cells
  - Host queries for CMWS (0kB if drive caches enough)
  - Host does not read from last CMWS of data
  - Drive fails reads to CMWS region




"Vulnerabilities in MLC NAND Flash Memory Programming." Yu Cai et al. HPCA 2017

# Telemetry for Physical Addressing

- OCSSD 2.0: “Chunk Report”
  - Enhancement: use an NVMe log page
  - Supported only in open channel drives
  - Include additional telemetry (at right)
- Vendor-specific log page
  - Standard address
  - Vendor-specific content
  - May be temporary, used only while the open channel interface matures

**Additional Standard Telemetry**

- Erase count per PU

  Host may use this to determine which PUs to swap during cross-die wear leveling.

- Erase count per chunk

  If chunk addressing is logical, host may use this to reduce drive activity by freeing little-worn chunks.

- Read disturb count per sector

  Host may use this to reduce drive activity by scrubbing or distributing reads.

# Conclusions

- Storage interface is changing, let's architect it for the long term
  - Correct division of responsibilities between Host and SSD
  - Control to define heterogeneous block stripes
  - HyperScale: Hundreds or thousands of workers per TB
- Final solution must include expertise from community
  - Currently working through the division between host and SSD
  - Contact me to discuss (Laura.Caulfield@microsoft.com)
  - Read more in our FAST 2017 paper: FlashBlox

# References


- Azure Storage Backend (SOSP '11)
  Windows Azure Storage: A Highly Available Cloud Storage Service with Strong Consistency
- FlashBlox (FAST '17)
  FlashBlox: Achieving Both Performance Isolation and Uniform Lifetime for Virtualized SSDs
- LightNVM (FAST '17)
  LightNVM: The Linux Open-Channel SSD Subsystem
- Read Determinism (SDC '16)
  Standards for improving SSD performance and endurance
- Software-Defined Flash (ASPLOS '14)
  SDF: Software-Defined Flash for Web-Scale Internet Storage Systems
- Multi-Streamed SSD (HotStor '14)
  The Multi-streamed Solid-State Drive
- De-Indirection (FAST '12)
  De-Indirection for Flash-based SSDs with Nameless Writes
- Programmable Flash (ADMS '11)
  Fast, Energy Efficient Scan inside Flash Memory SSDs