Linux Kernel Abstractions for Open-Channel SSDs

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Market Specific FTLs

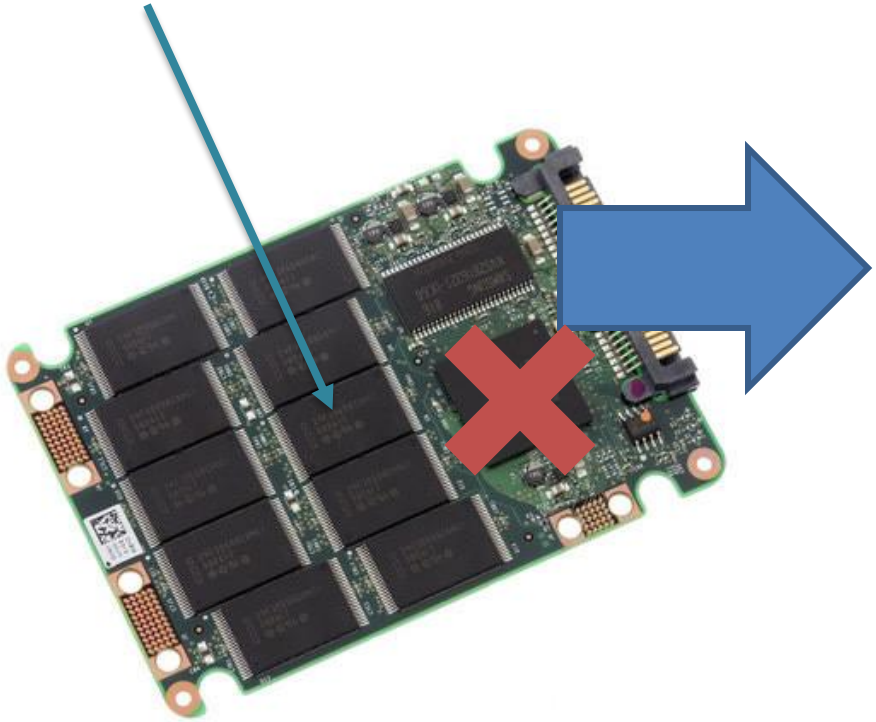
- SSDs on the market with embedded FTLs targeted at specific workloads (90% reads) or applications (SQL Server, KV store)
- FTL is no longer in the way of a given application
- What if the workload or application changes?
- What about the other workloads or applications?

Embedded FTLs: No Future

- Dealing with flash chip constraints is a necessity
  - No way around some form of FTL
- Embedded FTLs were great to guarantee adoption, but have critical limitations:
  - Hardwire design decisions about data placement, overprovisioning, scheduling, garbage collection and wear leveling
  - Based on more or less explicit assumptions about the application workload
  - Resulting in redundancies, missed optimizations and underutilization of resources

Open-Channel SSDs

Physical flash exposed to the host (Read, write, erase)



Host

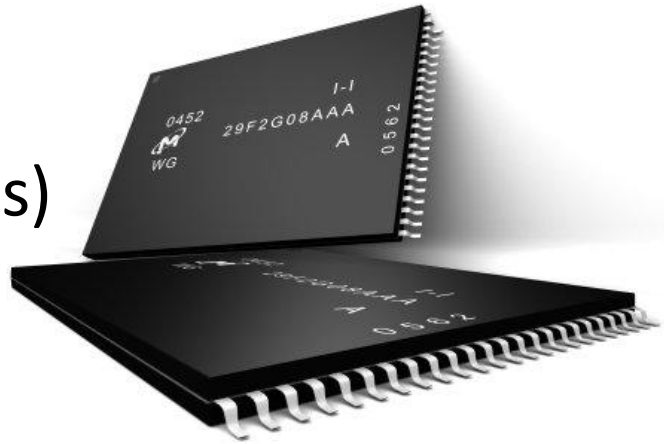
- Data placement
- IO Scheduling
- Over-provisioning
- Garbage collection
- Wear levelling

Where are Open-Channel SSDs useful?

- Data centers with multi-tenancy environments
- Software-defined SSDs
  - Managed storage centrally across open-channel SSDs.
  - NAND flash shared at fine-granularity
- Applications that have specific needs can be serviced by a FTL tailored to their needs (Application-driven FTLs).

What should the host know?

- SSD Geometry
  - NAND idiosyncrasies
  - Die geometry (Blocks & Pages)
  - Channels, Timings, Etc.
  - Bad blocks
  - Error-Correcting Codes (ECC)
- Features and Responsbilities



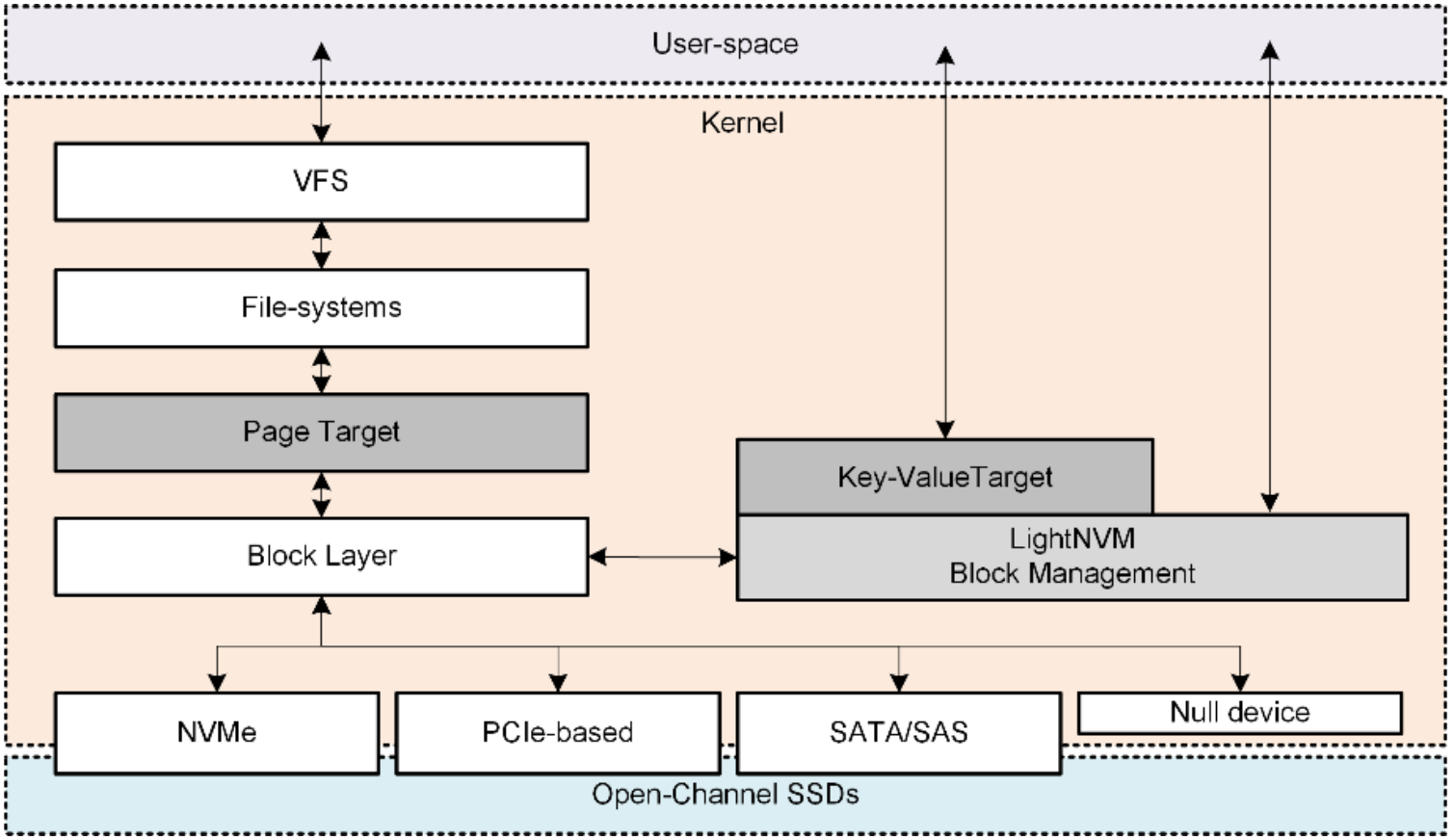
New Logical Abstractions

- How is flash exposed to the host?
  - Traditional Flash Translation Layer
    - Both metadata and data are managed by the host
  - New interfaces
    - LUNs (The parallel unit of SSDs)
    - Key-value database (e.g. LevelDB and RocksDB)
    - Object-store (OSSD)
    - Application-driven (New research area)
    - File-system (DirectFS)
    - Hybrid FTL (Traditional FTL is expensive, offload metadata consistency to device)
  - Manage multiple devices under a single address space
    - Including garbage collection (Global FTL)

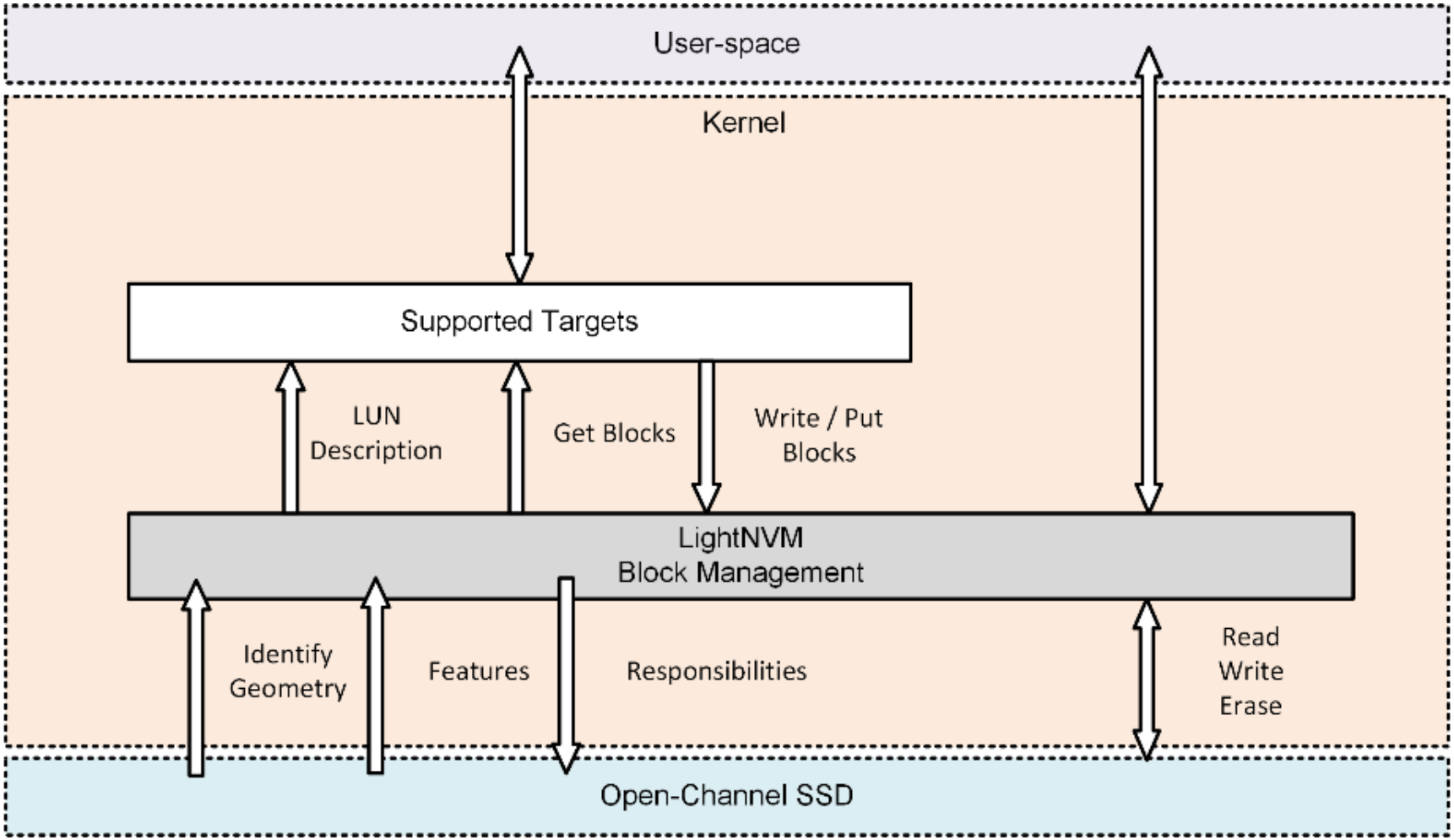
Introducing LightNVM

- Open, Extensible, and Scalable Layer for Open-Channel SSDs in the Linux kernel
- Generic core features for flash-based SSD management such as:
  - List of free and in-use blocks, handling of flash characteristics, and global state.
- Targets that expose a logical address space, possibly tailored for the needs of a class of applications (e.g., key-value stores or file systems)

Architecture



Responsibilities



Hybrid Target

- Host-side Translation table and reverse mapping table (for GC) in host
- Device maintains metadata consistency
  - Offloads metadata overhead at the cost of disk also maintaining translation table
- Sequential mapping of pages within a block
- Cost-based garbage collection
- Inflight tracking
  - Guarantee atomicity of writes

Hybrid Target per Request

Component	Description	Native Latency(us)		LightNVM Latency(us)	
		Read	Write	Read	Write
Kernel and fio overhead	Submission and completion	1.18	1.21	1.34 (+0.16)	1.44 (+0.23)
Completion time for devices	High-performance SSD	10us (2%)			
	Null NVMe hardware device	35us (0.07%)			
	Common SSD	100us (0.002%)			

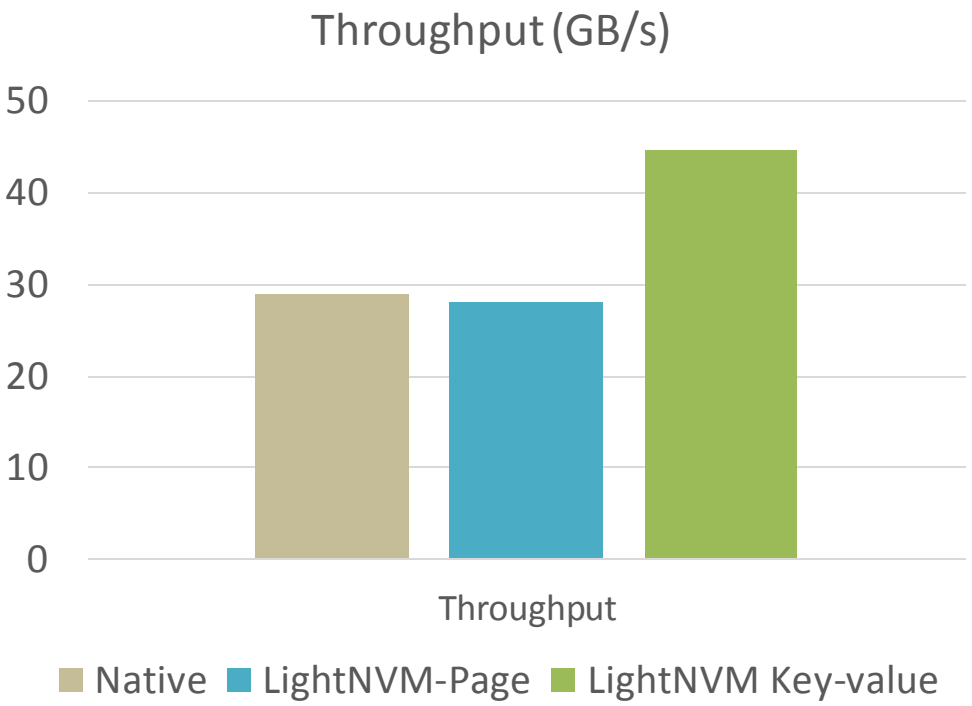
System: i7-3960K, 32GB 1600Mhz – 4K IOs

Low overhead compared to hardware overhead
0.16us on reads and 0.23us on writes

Key-value Target

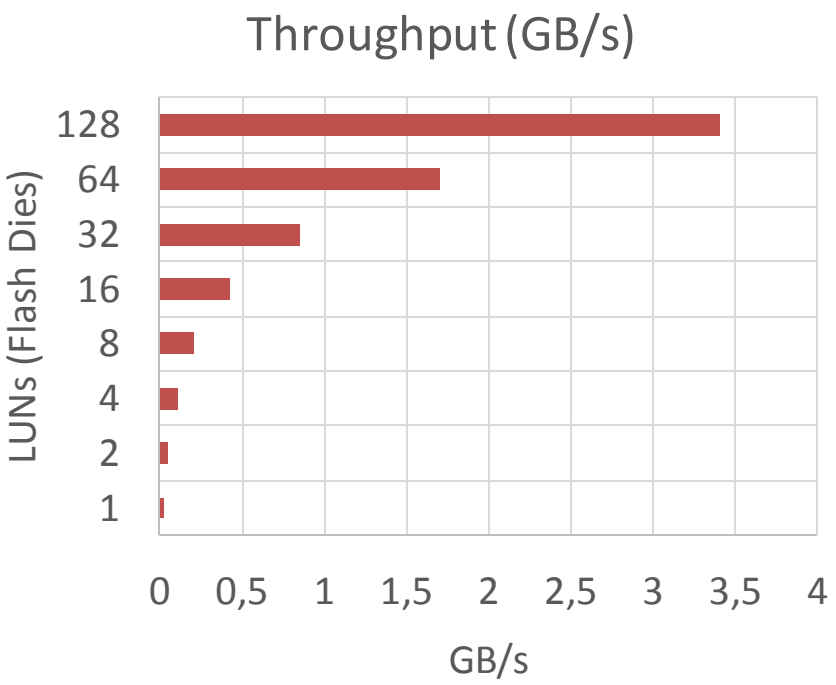
1 MB Writes

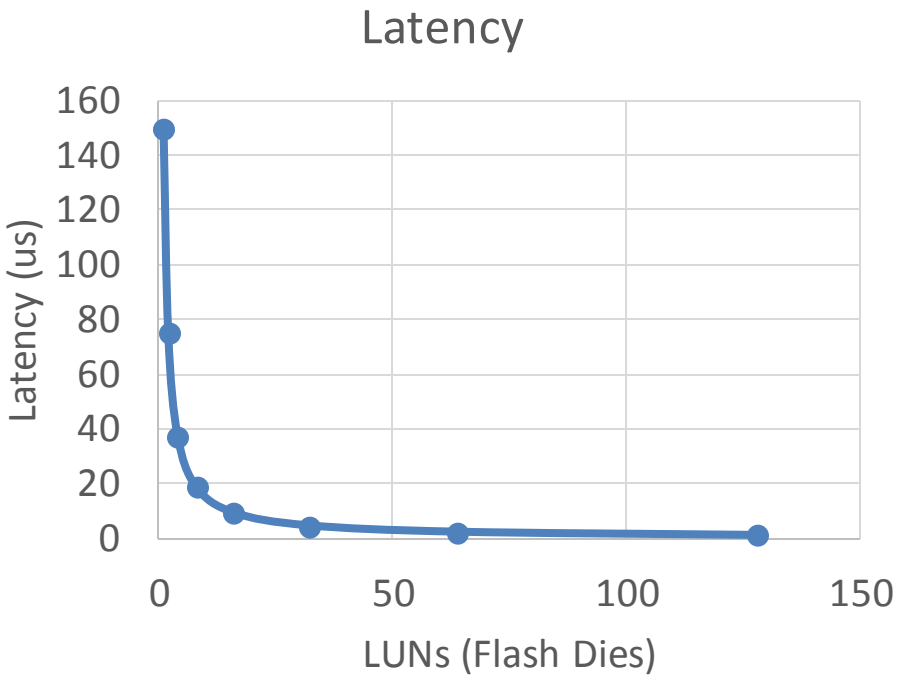
Metric	Native	LightNVM -Page	LightNVM Key-value
Throughput	29GB/s	28.1GB/s	44.7GB/s
Latency	32.04µs	33.02µs	21.20µs
Kernel Time	66.03%	67.20%	50.01%



Kernel time overhead 30% serving 1MB writes.
Opportunities for application-driven FTLs (NVMKV, ...)

Performance Guarantees





Configuration

4K IO Request, Buffered, flash page size 32K, Write timing 1200us

Writes can be buffered, Reads take full time

Conclusion

- Enable data placement and garbage collection on host
- Enable global garbage collection
- Enable application-driven FTLs
- Industry traction
  - MemBlaze, IIT Madras, Stealth startups, and others
- Soon to be submitted to the Linux kernel
- Source and interface specification available at https://github.com/OpenChannelSSD