Enabling Cost-effective Data Processing with Smart SSD

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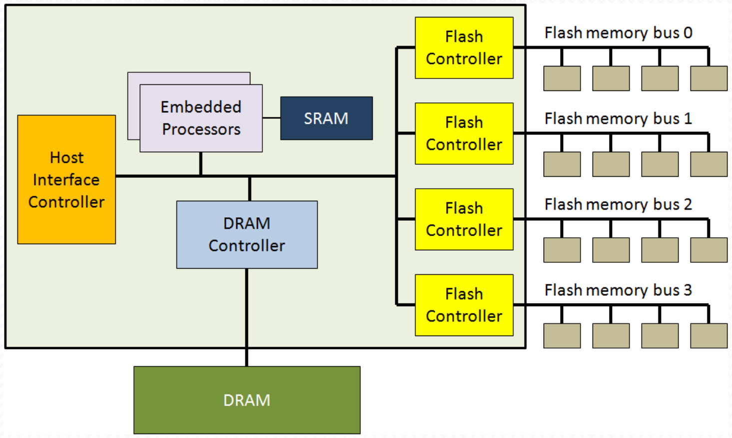
Efficient Use of Solid State Drives

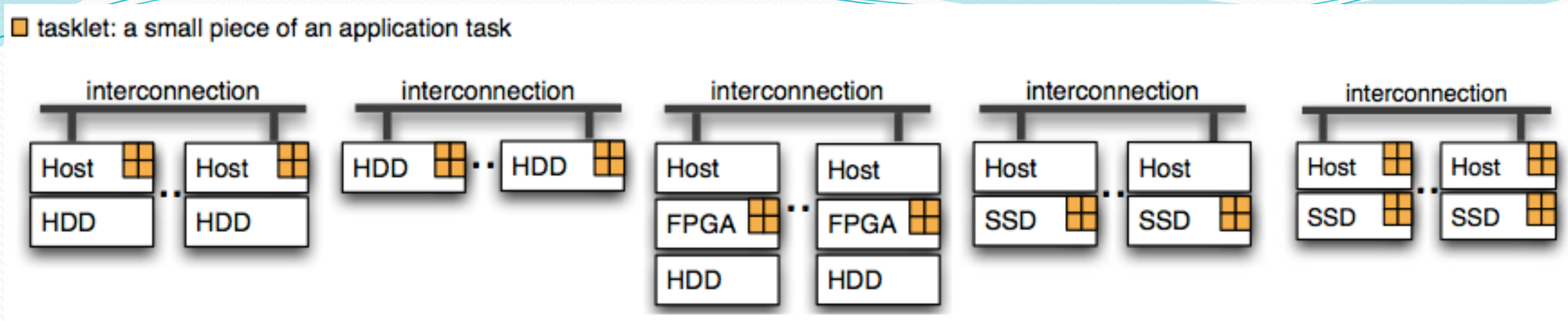
- Modern SSDs
  - Multiple processors / flash controllers
  - High internal bandwidth between Flash and DRAM
  - IOPS: 1k~85k 4K requests



- Assumptions on slow I/O devices are being challenged
  - OS storage stack is optimized for slow I/O devices
  - e.g. I/O schedulers, device queue management, I/O interrupts

- ***How can the system efficiently leverage the processing power and internal bandwidth of SSDs?***
  - *Alternative storage stack for SSDs*
  - *Offloading I/O tasks to SSDs*

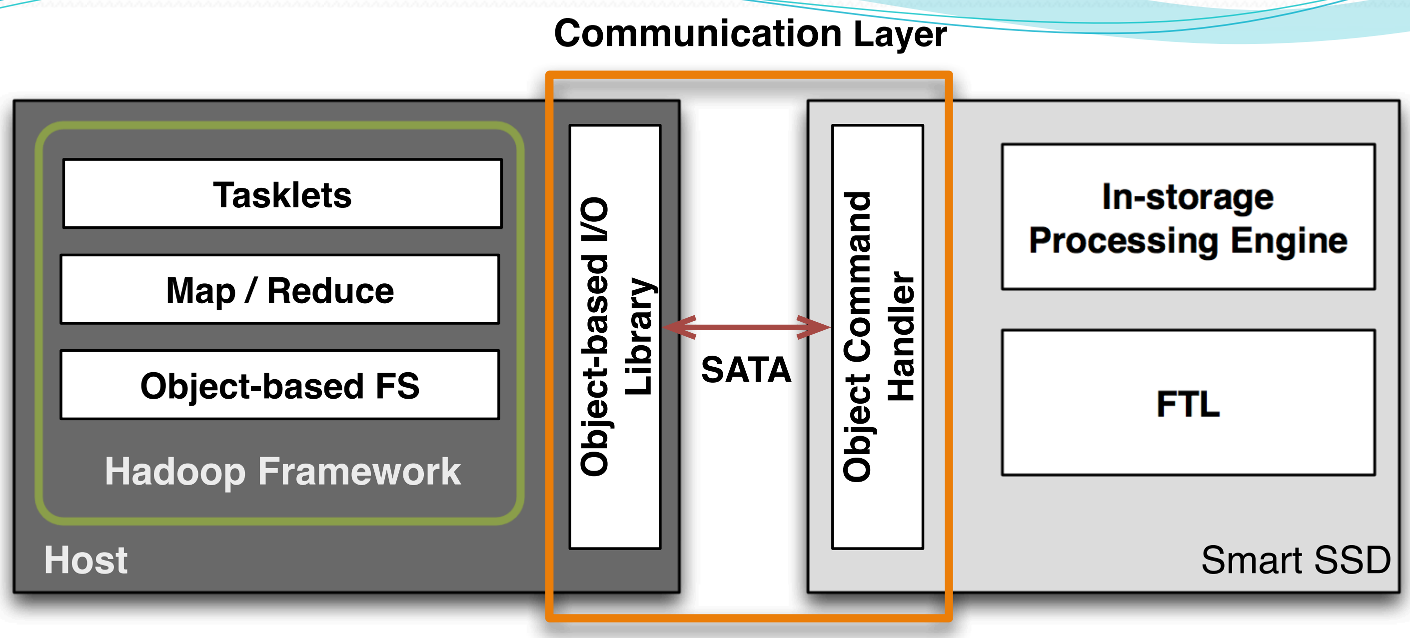
Intelligent Storage Devices



Host-only | Active Disks | FPGA-aided HDDs | Flash controller-based in-storage processing | Smart SSDs

- Problems with HDD-based in-storage processing
  - Limited processing capabilities
  - Requires additional hardware components such as memory and FPGA (commodity hard drives could not be used)
  - Reduces traffic between a host and a device but provides little I/O performance improvements
- Smart SSD
  - Designed to use embedded processors and DRAM in SSDs to process I/O tasks
  - Uses devices' internal knowledge to optimize an execution plan
  - Achieve low energy consumption by not using power-hungry host resources

Smart SSDs



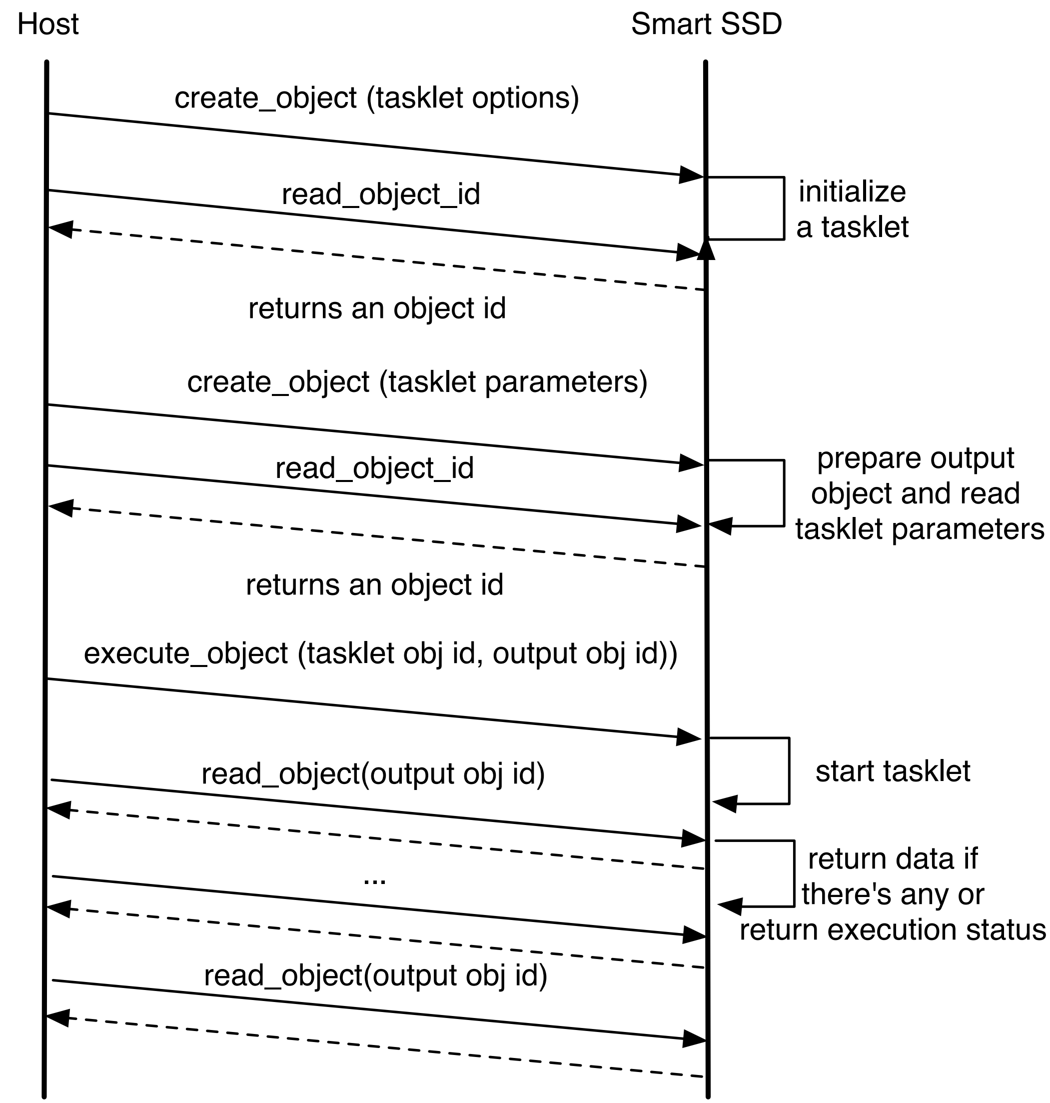
- In-Storage Processing Engine
  - Uses existing hardware and SATA protocols
  - Allows hosts and devices to work together on the same job
- Object-based Communication Layer
  - Designed to provide an universal interface to applications and operating systems, independent to the underlying protocols such as SAS, SATA, and PCI-e
- Application Interface
  - Map/Reduce programming interface for user applications

In-Storage Processing Engine

- An event-driven processing framework to execute tasklets
- Each tasklet implements the following event functions
  - On_Create
  - On_Execute
  - On_DataAvailable
  - On_Read
- Internal read requests:
  - have a lower priority than normal read operations
  - are divided into multiple smaller read requests based on the current load.
  - On_DataAvailable is called whenever each read request is done, to generate partial results

Host-Device Interface
Object Interface on SATA

- Designed to provide an universal APIs regardless of the underlying protocols
- Tasklets are executable objects
- 3 commands are provided
  - create_object
  - execute_object
  - read_object
- Implementation issues
  - No bi-directional communication
  - Device-initiated connection

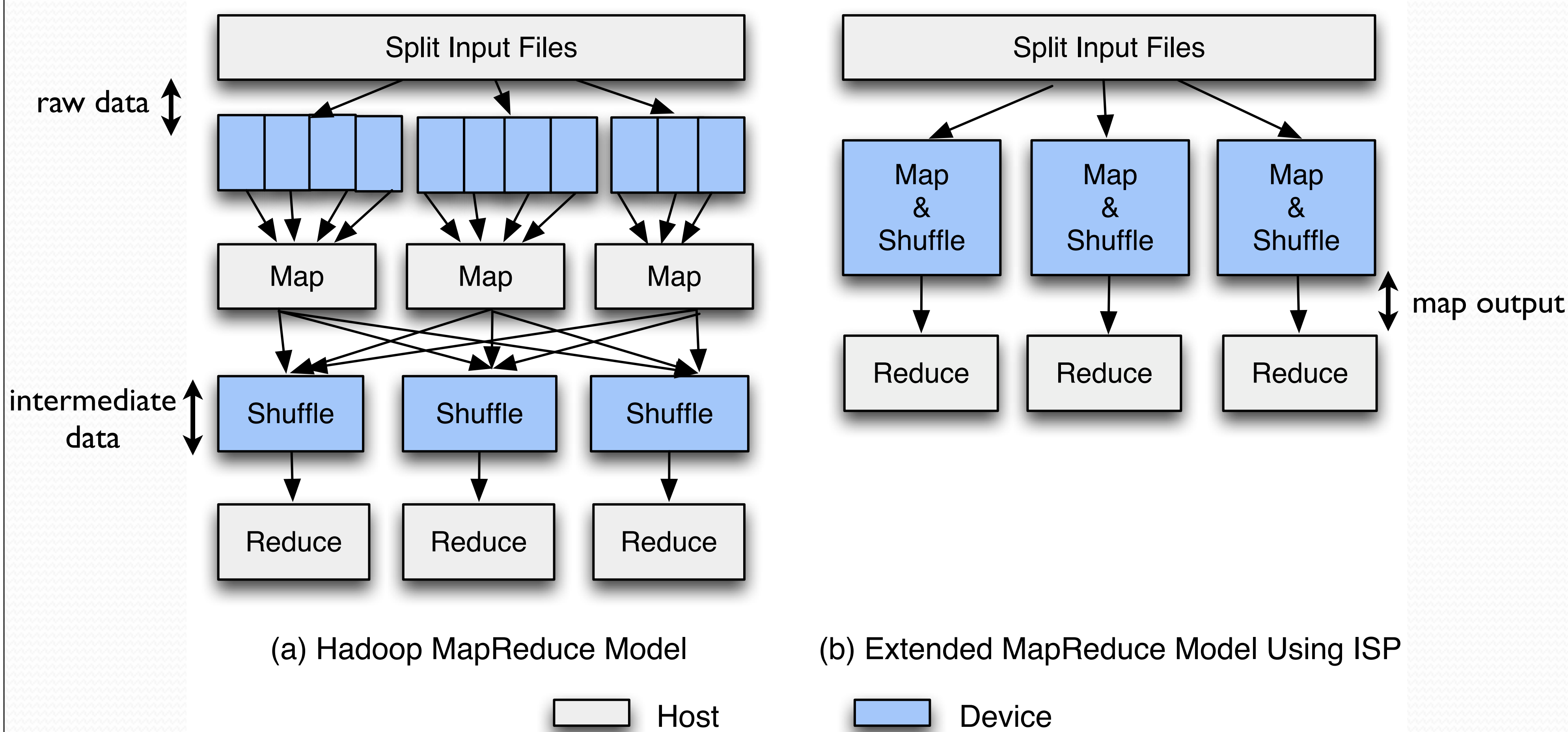


Application Interface for Smart SSD

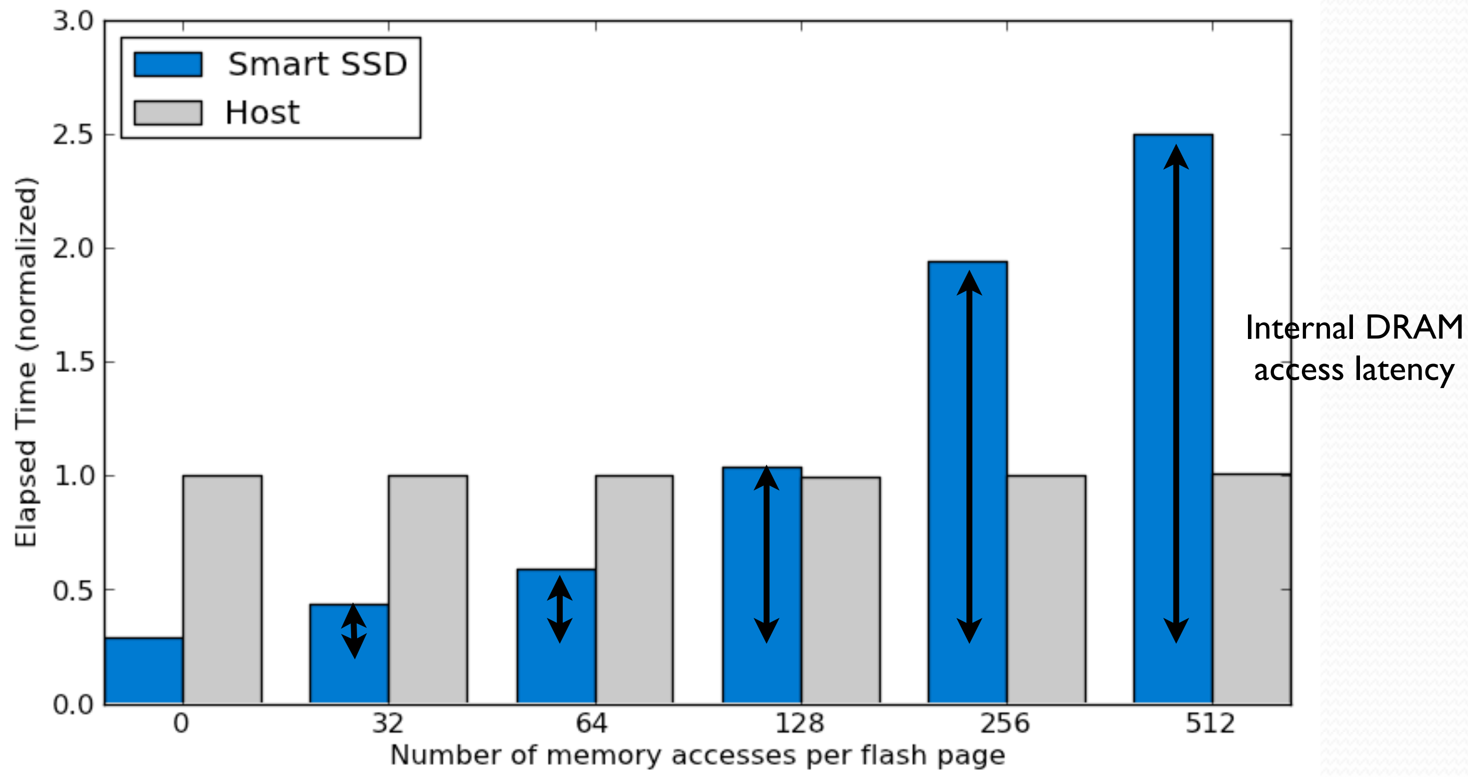
- Direct access
  - Use the low-level protocol directly
  - can be used by SSD-aware storage(file) systems

- MapReduce Model
  - Simple programming interface to applications
  - Hide the detailed communication from applications
  - Generate independent sets of data that can be assigned to multiple Smart SSDs / tasklets concurrently
  - Tasklets can be mappers, reducers or both

Extended MapReduce Model for In-storage Processing

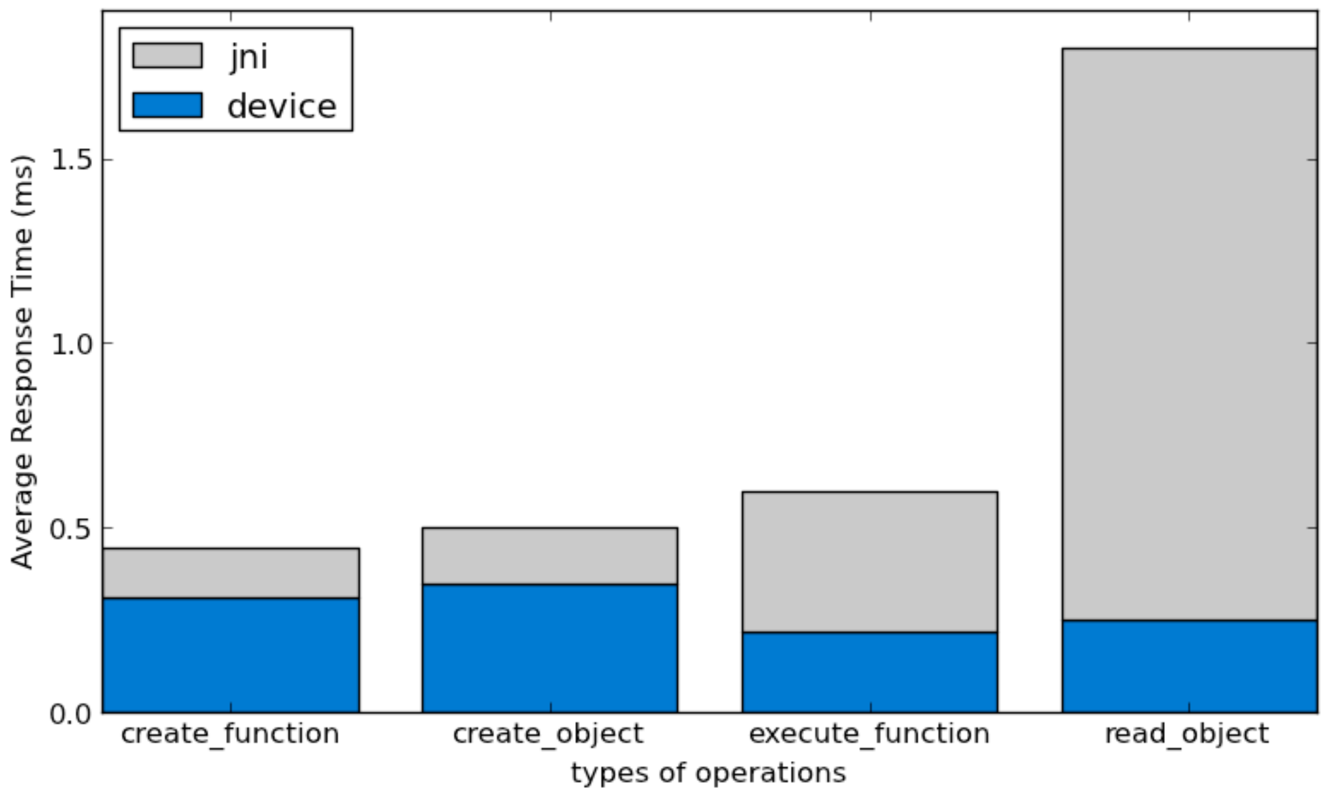


Evaluation
Tasklet Execution Performance



- Internal read performance - *1.6x faster* than the host-device bandwidth
- For each access, it reads one integer, and does one integer comparison
- However, the performance degrades as the number of DRAM accesses and comparisons increase

Evaluation
Host-Device Communication Overhead



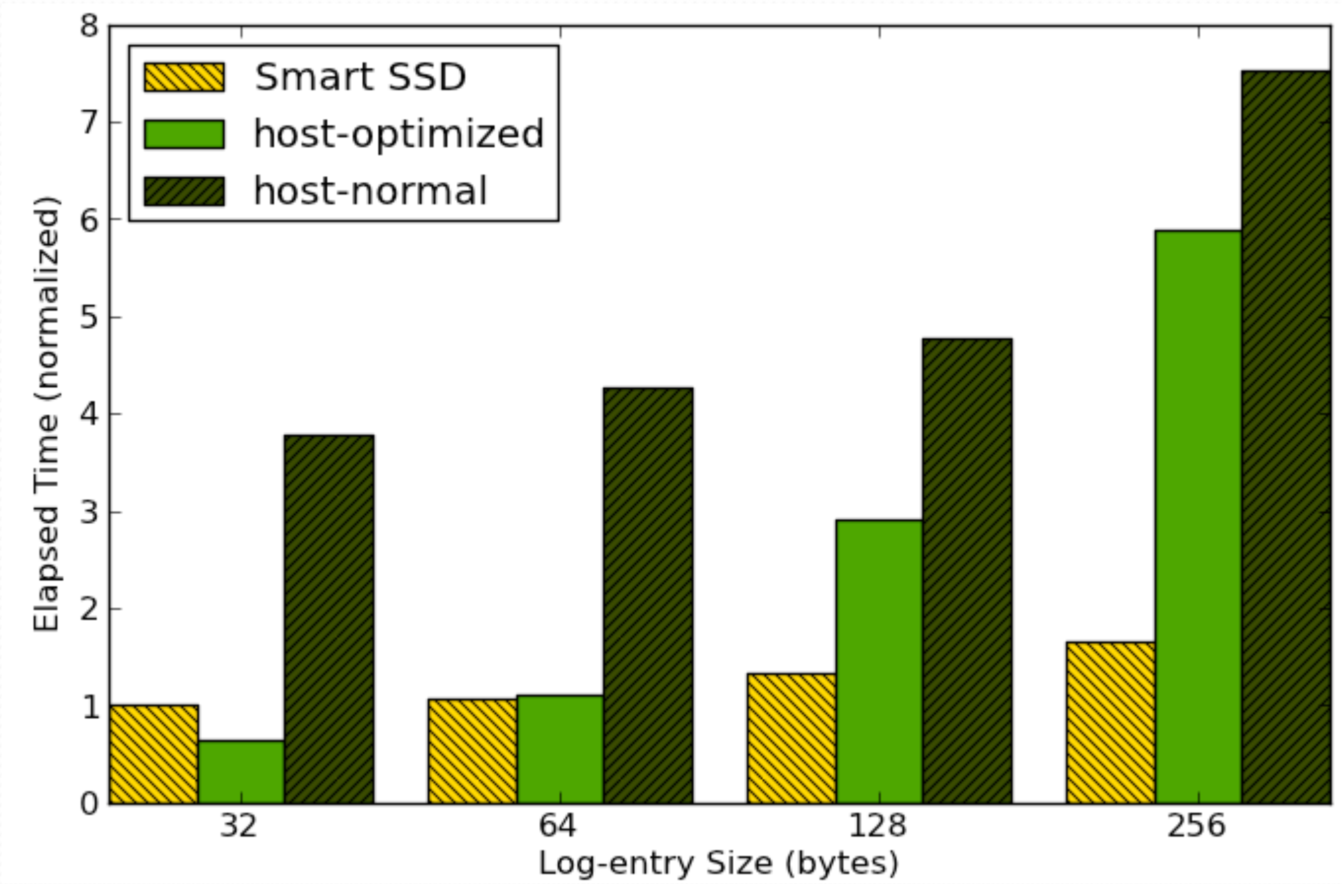
- create_function, create_output_object takes more time than other functions, because it consists of two separate commands
- read_object takes more time in JNI part, due to the memory copy between c and java and algorithms for determining the polling interval

Evaluation Log-Analysis Example

- Trace
  - 1998 World Cup website access log
  - 7,000,000 entries with different sizes ranging from 32 bytes to 256 bytes
- Scenarios
  - Number of accesses per region (requires 4 byte read per log entry and sum)
  - Top 5 file types accessed per region (requires 8 byte read per log entry and sorting)
- Applications
  - host-normal: normal log-analyzer using MapReduce
  - host-optimized: modified version of host-normal, not generating the intermediate results
  - Smart SSD: in-storage processing

Evaluation
Log-Analysis Example

- Scenario 1. counting the number of accesses per region



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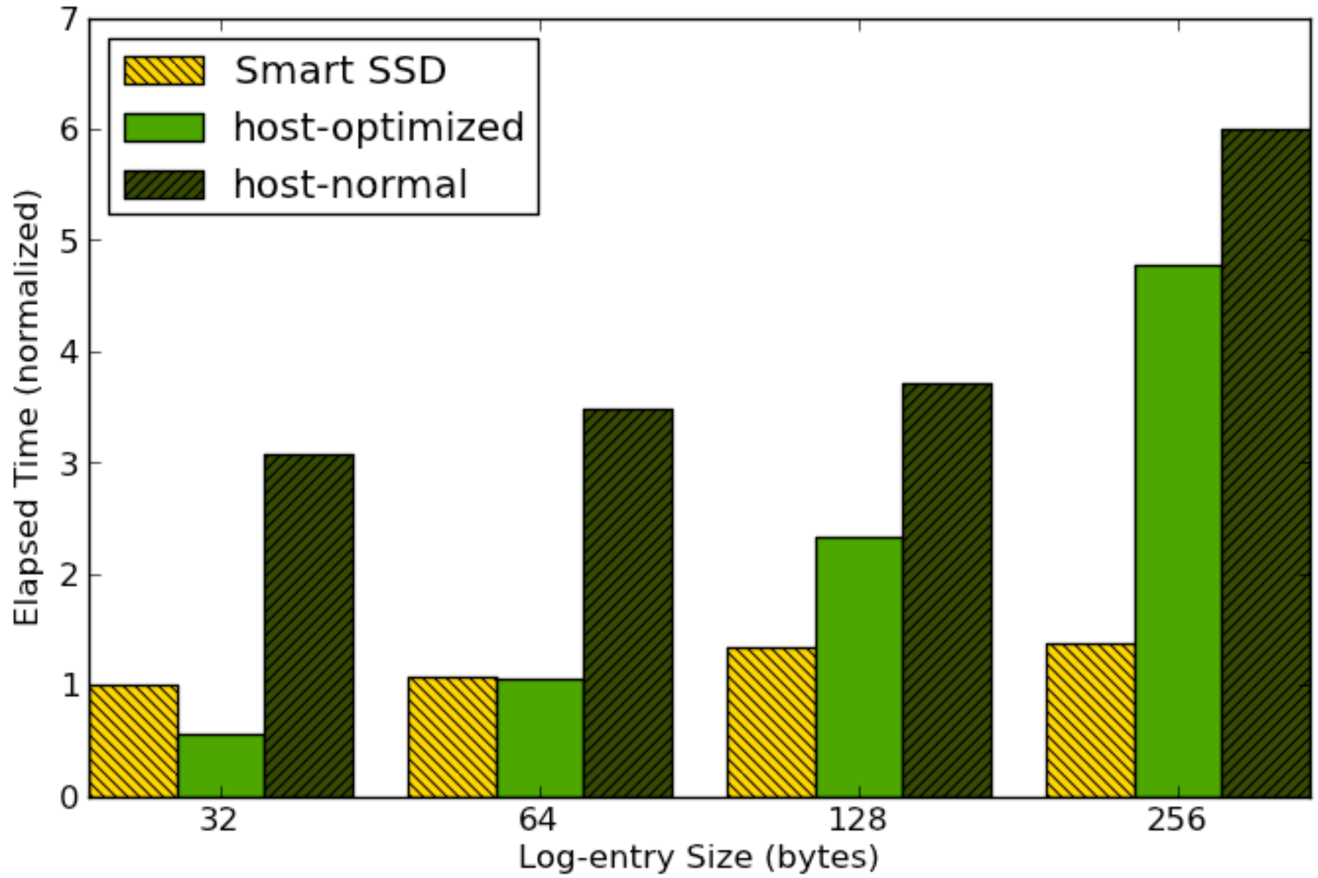
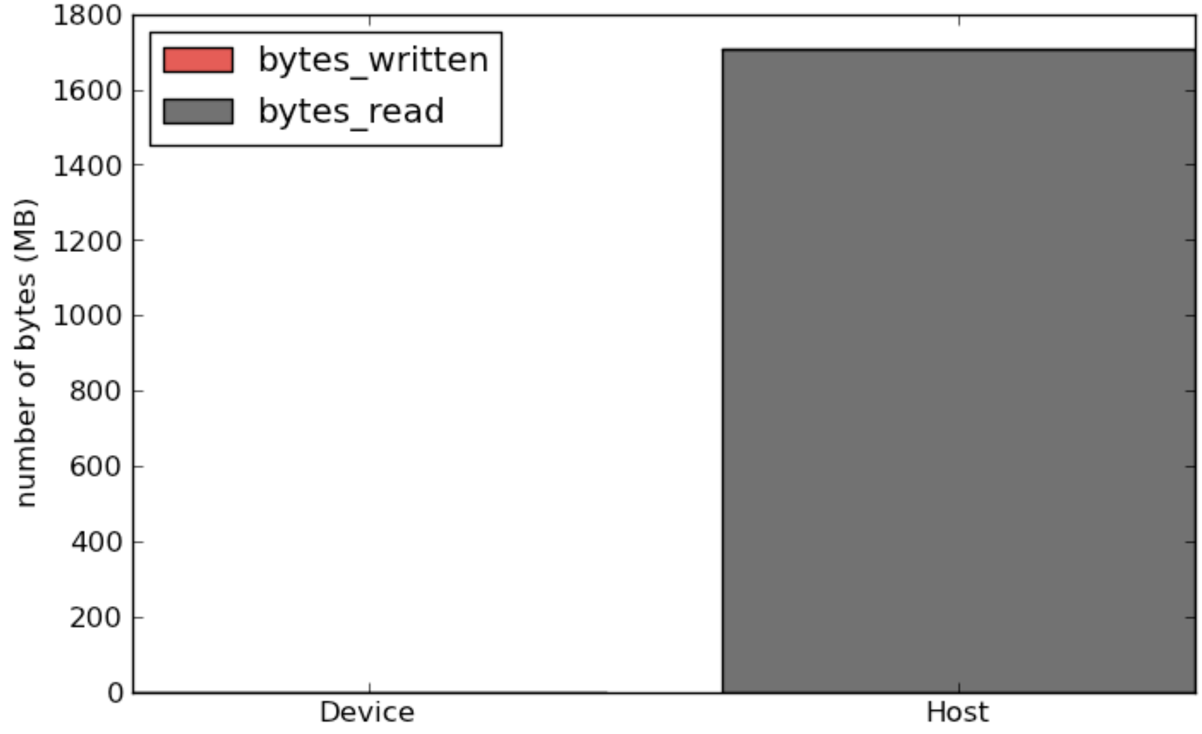
Evaluation
Log-Analysis Example

- Scenario 2. top 5 file types accessed per region

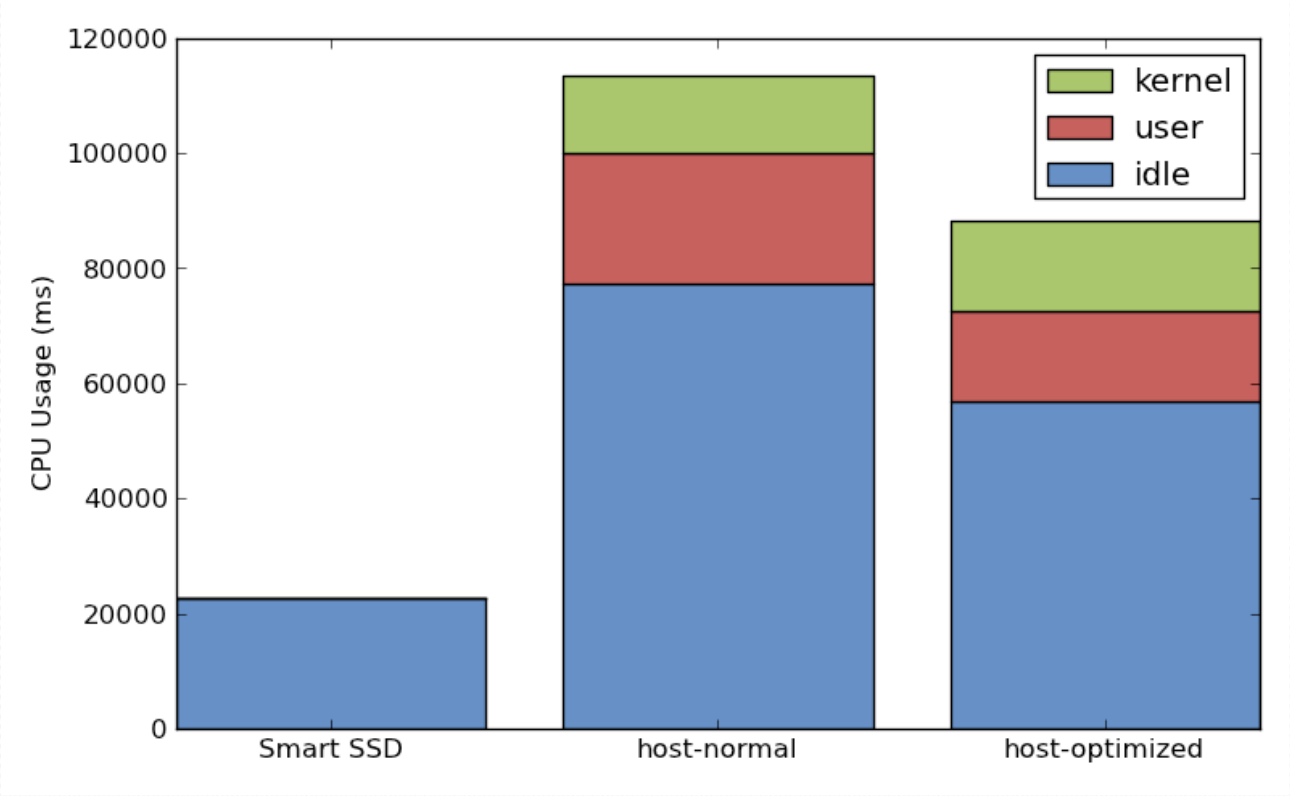


Evaluation
Disk I/Os



- Smart SSDs do not transfer any raw data to the host

Evaluation
CPU Usage

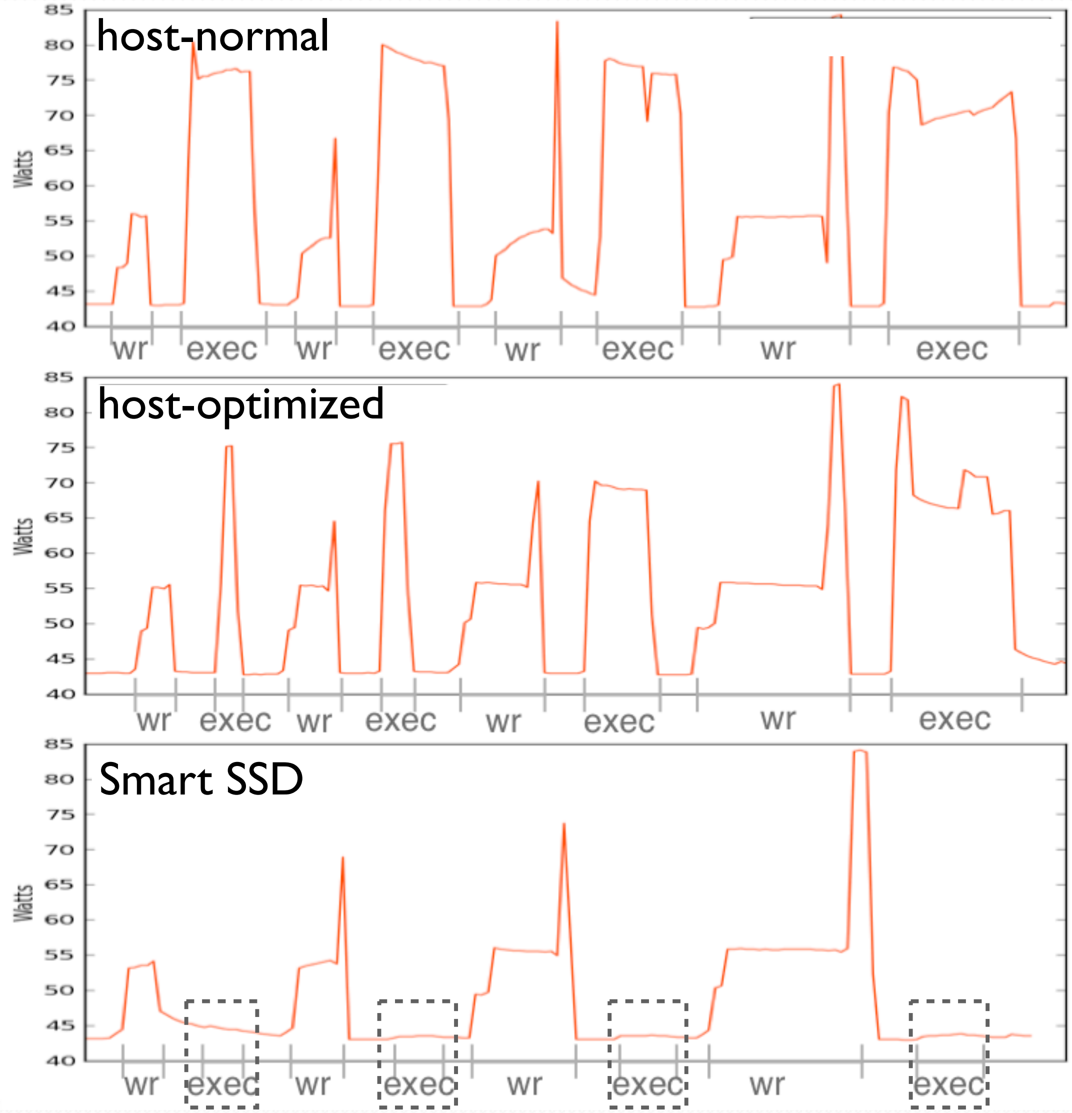


- With Smart SSDs, CPUs are mostly in the idle state waiting for the results
- In host-normal and host-optimized, CPUs wait for I/O requests (kernel time), and then process the data (user time)

Evaluation
Energy Efficiency

- Host-normal and host-optimized:
  - host system uses 35 ~ 40 Watts
- Smart SSD:
  - consumes 0.9 Watts to 1.2 Watts

50% reduction in overall energy consumption



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Evaluation
Data Filtering

- Problem of long DRAM read latencies can be alleviated by using filtering instead of searching
  - Stop processing after the first match
- Host systems can assign data filtering tasks to the device before entering long computations
  - taking advantage of energy-efficient ISP
- Data filtering with 1GB data, 60% selectivity, 256 accesses per page => 40% faster than searching

Suggestions for Future Smart SSD Architecture

- Reduce DRAM Access Latency
  - High bandwidth between DRAM and CPU
  - L1/L2 caches for embedded processors

- I/O Latency
  - Use application processors to enable background processing

- Tasklet Programming
  - Define a general set of APIs that expose the functionality of the firmware and hardware to tasklets
  - Add support for a script language and Sandboxing

Summary

- Explored the potentials and limitations of the Smart SSD model on the current SSD architecture
- Based on a prototype on a real SSD hardware and firmware, we measured performance and energy consumption of a Smart SSD
- Smart SSDs can help achieve both high performance and energy efficiency at a low cost through in-storage data processing
- Problems with the current SSD architecture
  - High DRAM access latency
  - Lack of cpu caches
  - No dynamic memory allocations

Thank you

Questions?

Extended Hadoop Framework

- Object File System
  - A Hadoop file system that supports Smart SSDs
    - Provides open/read/write to a raw Smart SSD
    - Directory support
  - ISP Support
    - Internally handles object-based communication with a device
  - Block management
    - Manages logical block numbers (unlike pure Object-based file systems)
- MapReduce Framework
  - ‘DeviceMapper’ and ‘DeviceJobClient’ are added