Towards High-Performance Application-Level Storage Management

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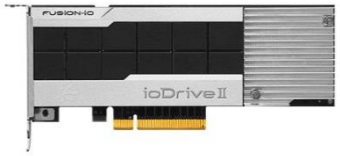
Talk Overview

- Dramatic increase in storage I/O performance
  - PCIe-attached flash
- **Problem:** OS storage stack becomes I/O bottleneck
  - Shared stack -> high overhead per I/O op
- **Solution:** Application-level storage architecture
  - Optimize storage stacks for each application
  - Assume storage devices remain on peripheral bus
- How to structure OS & hardware?

Problem: Storage I/O Performance

- Storage performance matters
  - Web servers
  - File servers
  - Key-value stores
  - Persistent lock managers
- Storage performance is improving 
  - PCIe attached flash
  - Flash-backed caching RAID controllers
- CPU frequencies have stalled
- **File system code expensive to run on CPU** 

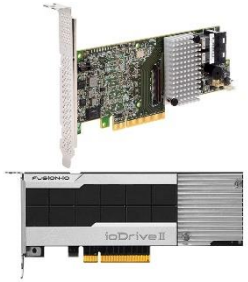


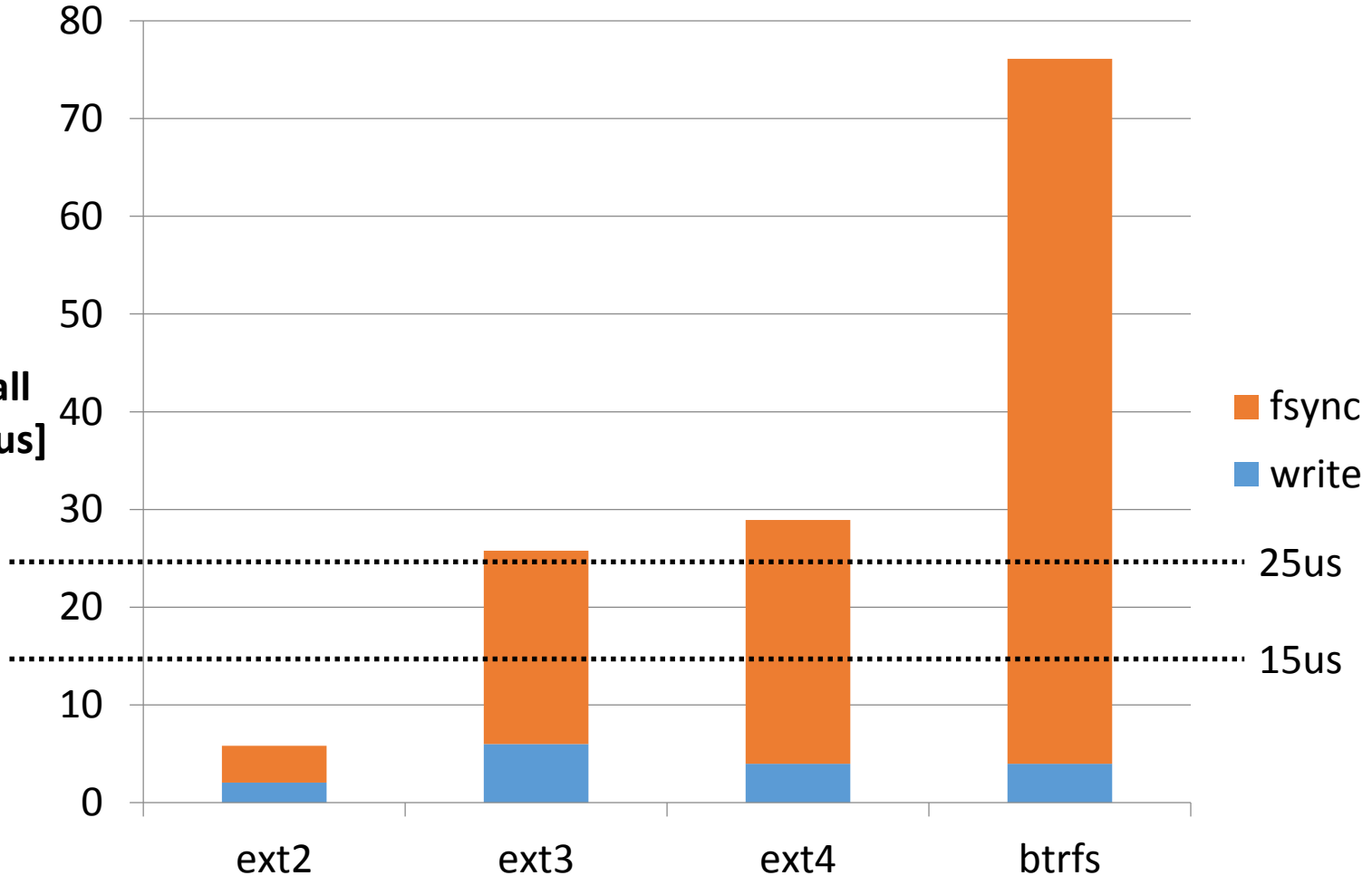
File system CPU overheads (writing 1K, then fsync)

= 25ms

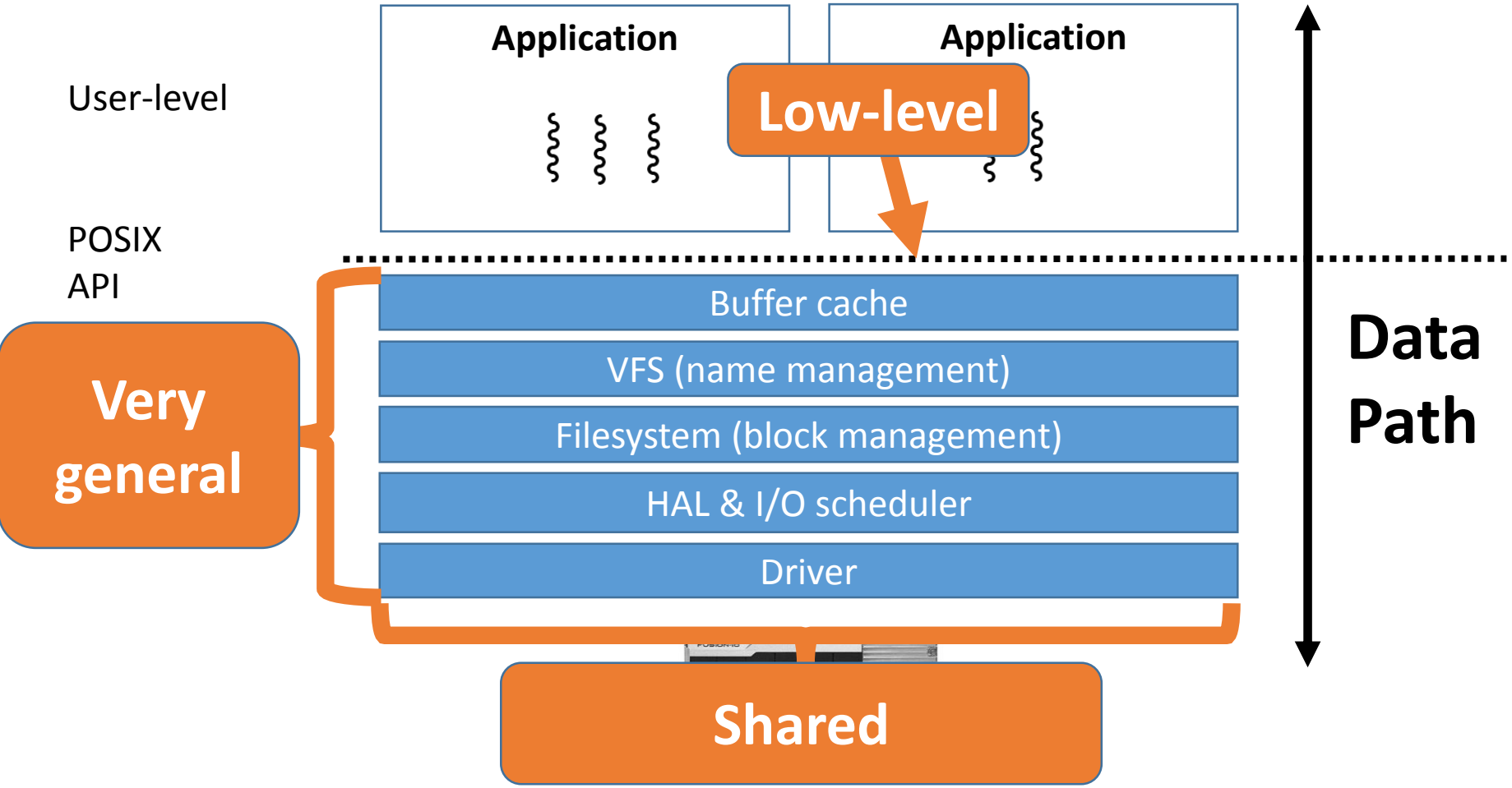
= 1ms

System call duration [us]

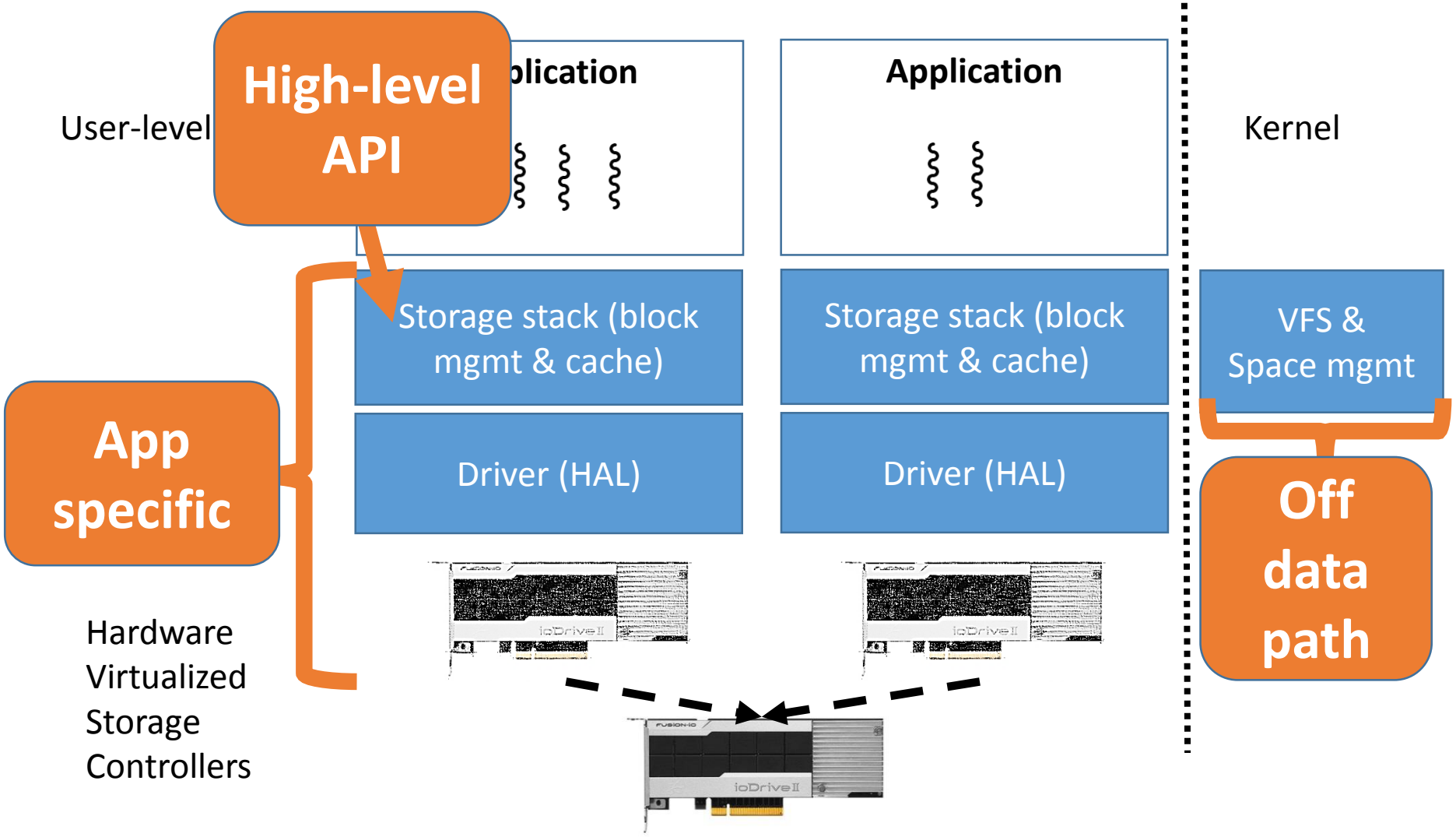




Today's Storage Stack



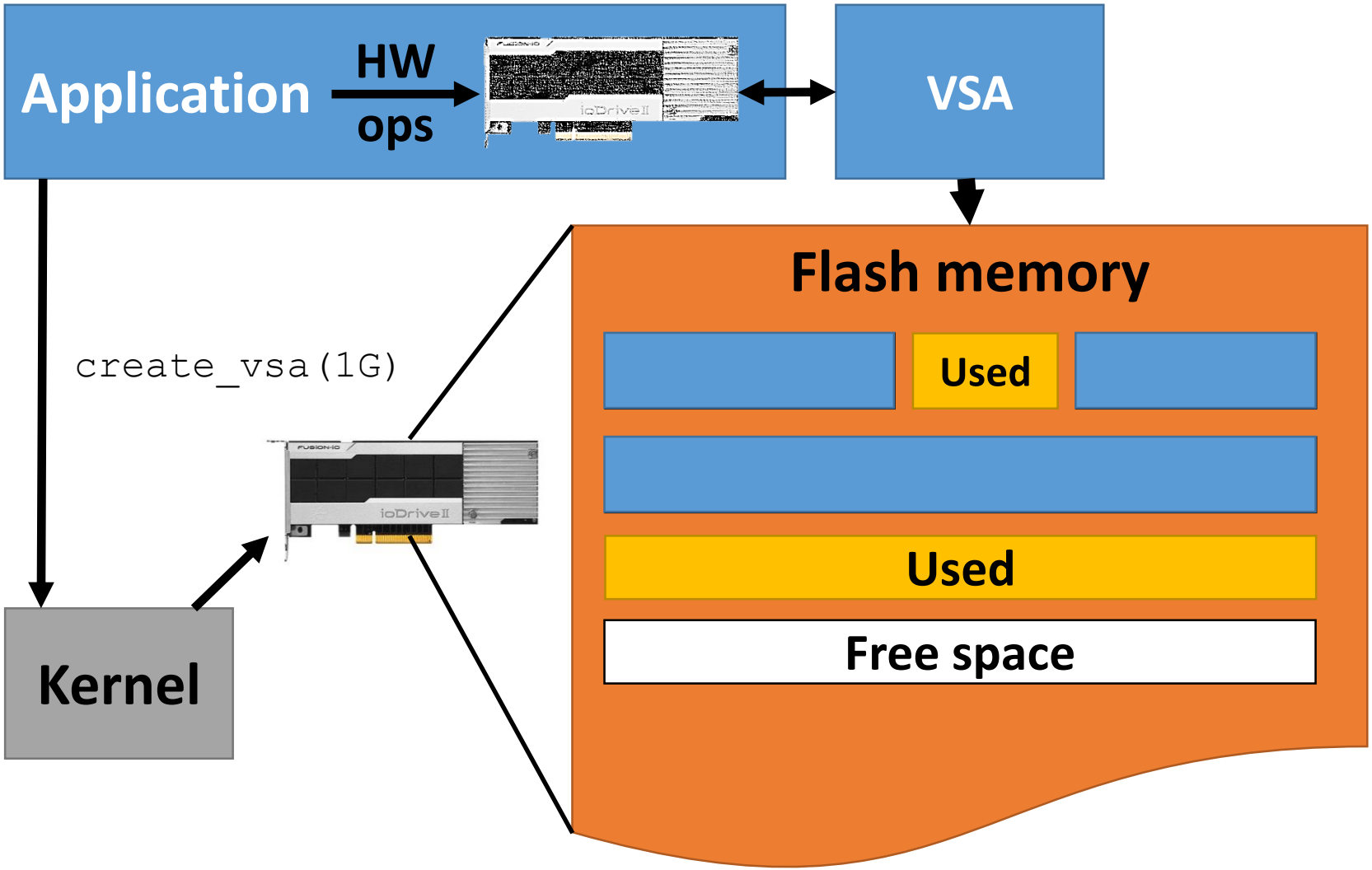
Our Storage Architecture



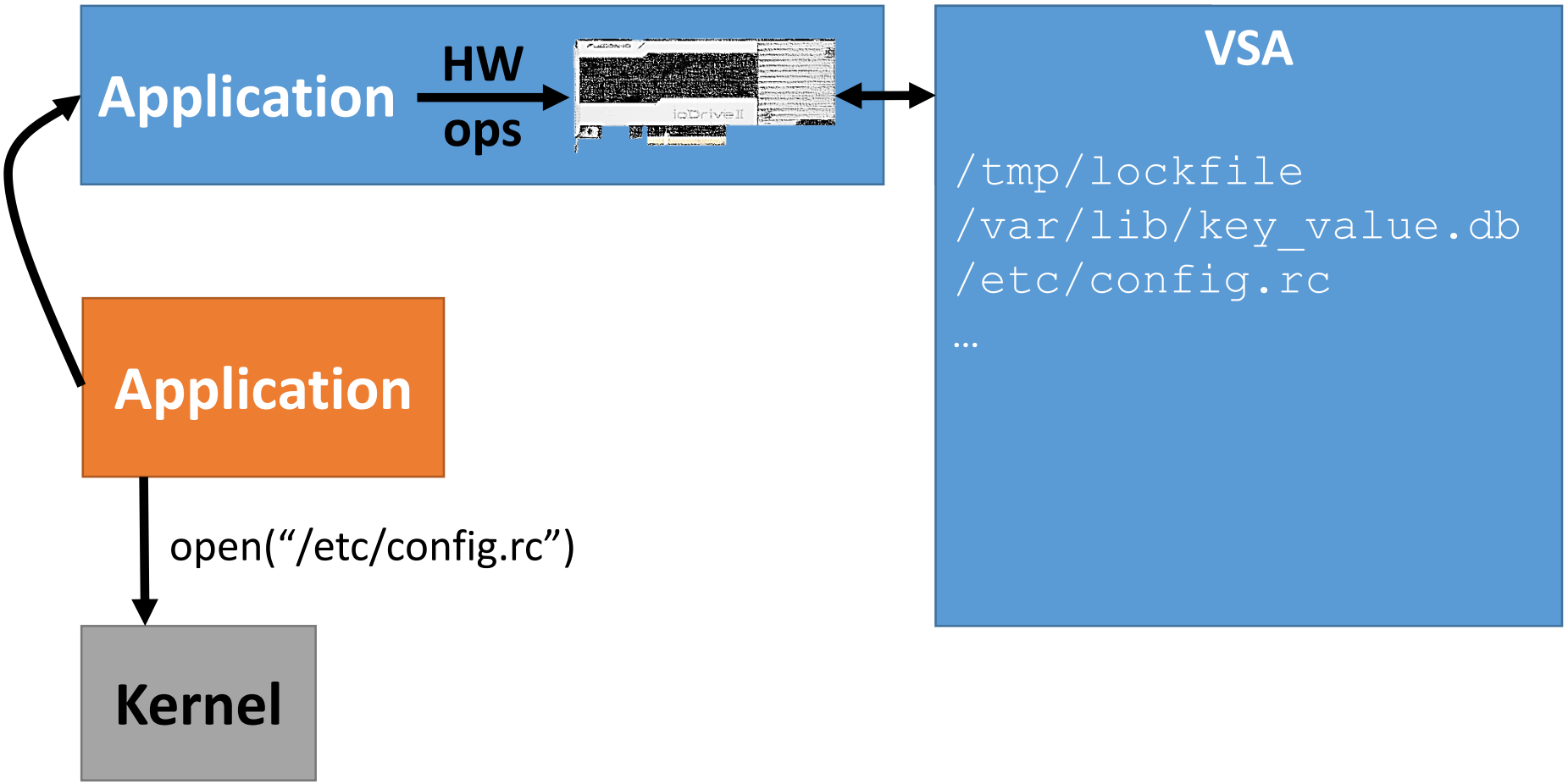
Storage Hardware Model

- Virtual storage devices
  - Protected command/DMA queues, interrupts
  - Can be provided by current technology
- Virtual storage areas (VSAs)
  - At least 1 per application
  - Map to physical storage extents
  - Protected in hardware
- Both managed by kernel

Storage Hardware Model: Example



Global File Name Resolution



High-Level API: Persistent Data Structures

- Examples: log, queue, hash table, tree
- Operations immediately persistent
  - To flash memory on storage peripheral

Goals:

- Scalability
- Robustness vs. crashes
- Low operation latency

Prototype Implementation

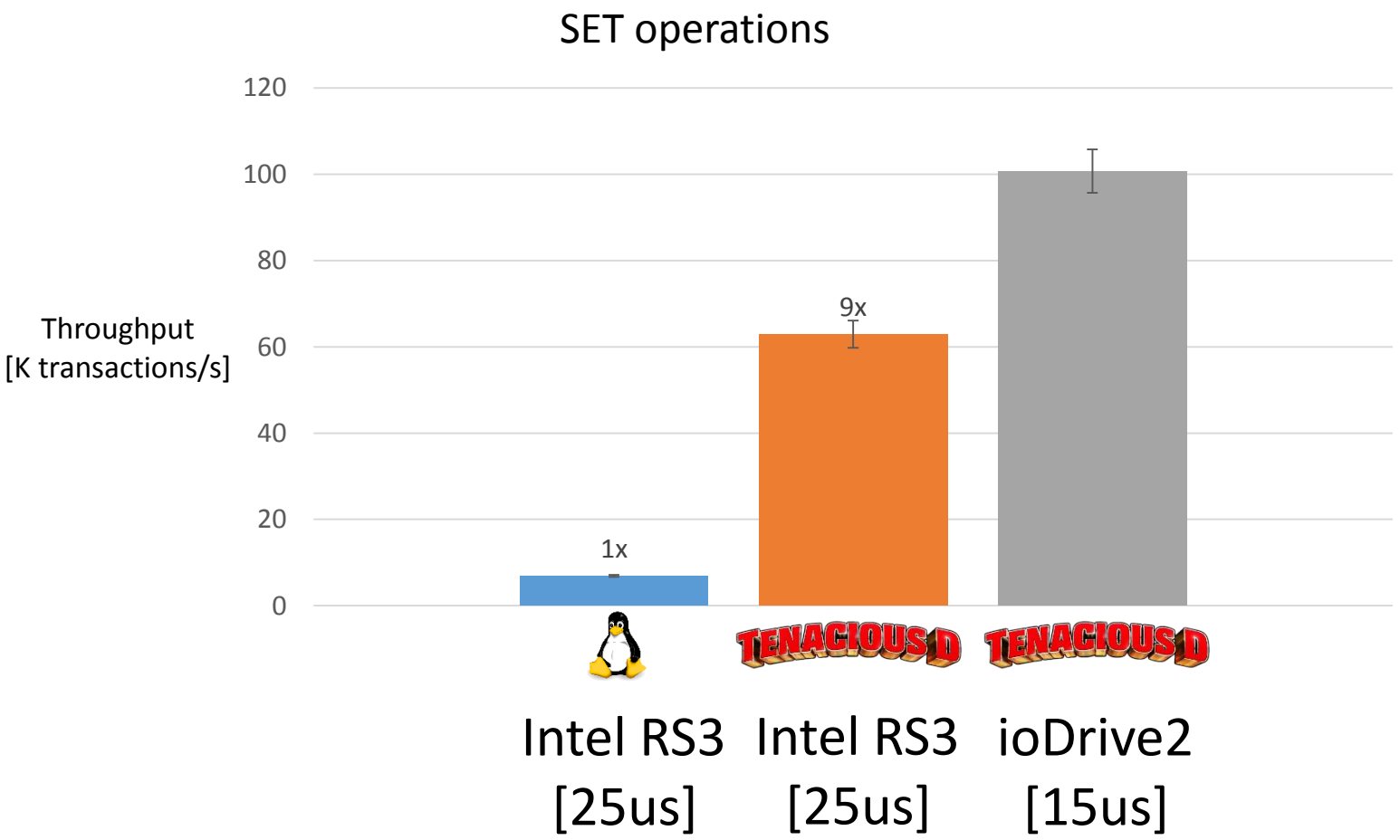
- In **Arrakis** OS
  - Has similar architecture for the network
- User-level device driver for Intel RS3 RAID controller
- Library of persistent data-structures
  - Persistent log

Evaluation: Redis NoSQL Store

- Redis logs operations to disk
- Modified to use **TenaciousD log**
  - 109 LOC changed
- Redis-benchmark
  - SET workload
  - 64K keys
  - 1K value size
- Compare to Linux on ext4
  - Server-sided performance

Evaluation: Redis NoSQL Store

- Cut SET latency by 81% (163 -> 31 us)



Summary

- New low-latency storage hardware
- **Problem:** Shared storage stack becomes bottleneck
- **Arrakis:** New OS storage architecture
  - HW/SW co-design
- Application-level storage eliminates I/O bottleneck
  - 9x speedup for Redis
  - Scales with CPUs & storage HW performance

http://arrakis.cs.washington.edu