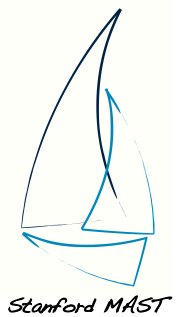
ReFlex: Remote Flash at the Performance of Local Flash

Ana Klimovic Heiner Litz
Christos Kozyrakis

Flash Memory Summit 2017
Santa Clara, CA



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Flash in Datacenters

- NVMe Flash
  - 1,000x higher throughput than disk (1MIOPS)
  - 100x lower latency than disk (50-70usec)

- But Flash is often underutilized due to imbalanced resource requirements

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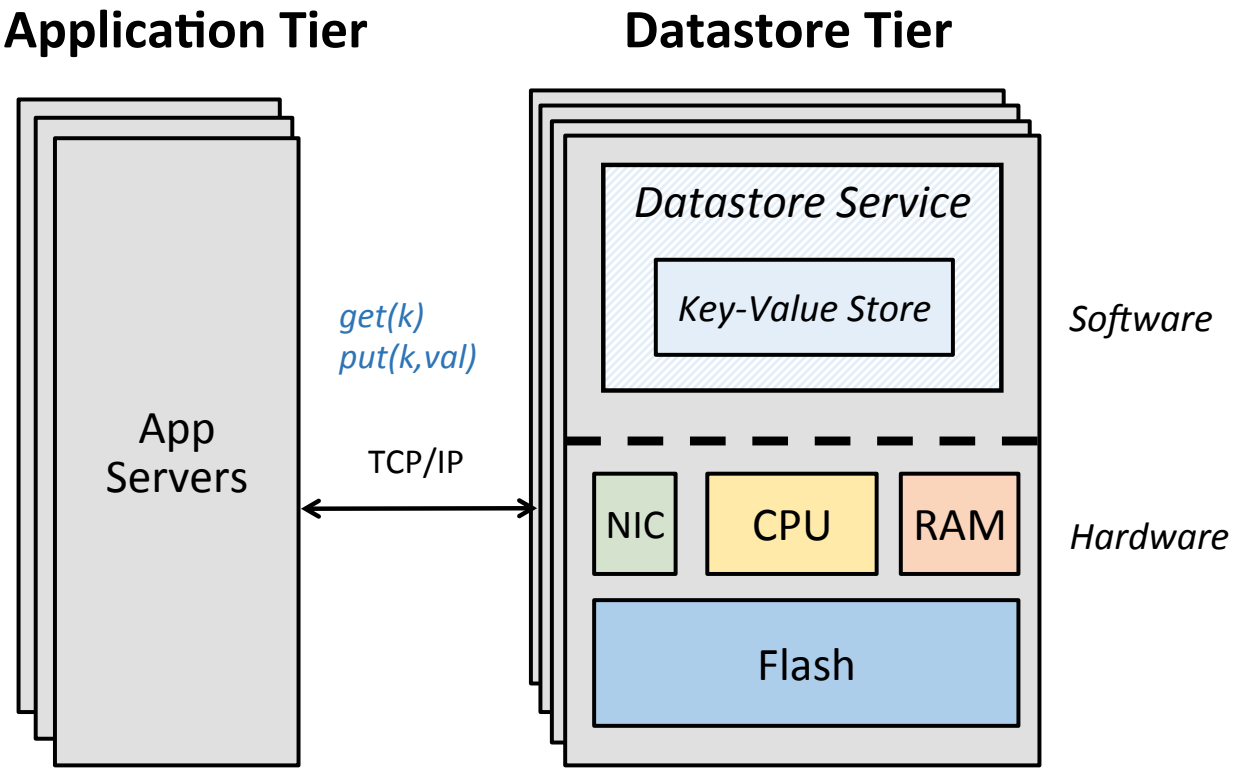
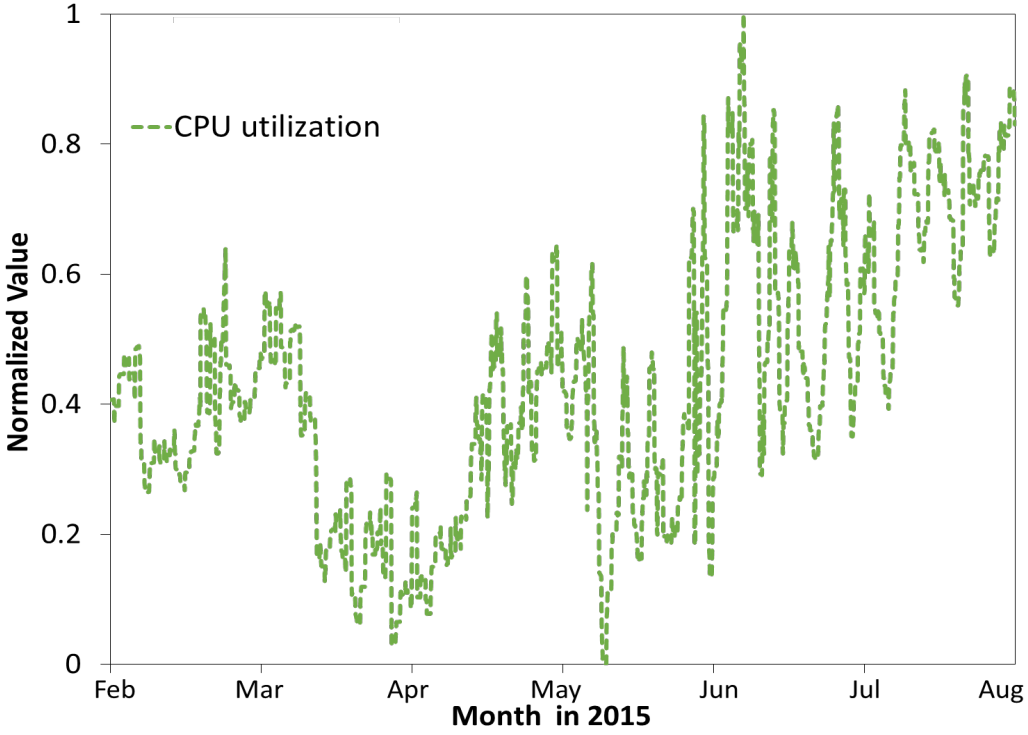
Example Datacenter Flash Use-Case



Imbalanced Resource Utilization

Sample utilization of Facebook servers hosting a Flash-based key-value store over 6 months



[EuroSys'16] *Flash storage disaggregation*. Ana Klimovic, Christos Kozyrakis, Eno Thereska, Binu John, Sanjeev Kumar.

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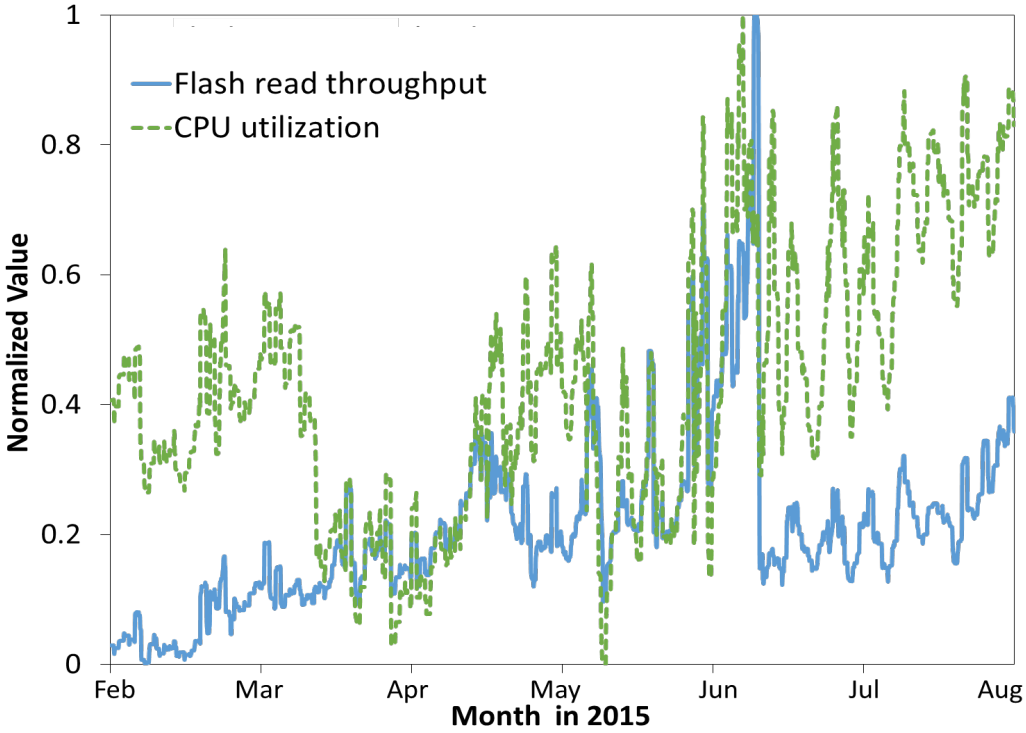

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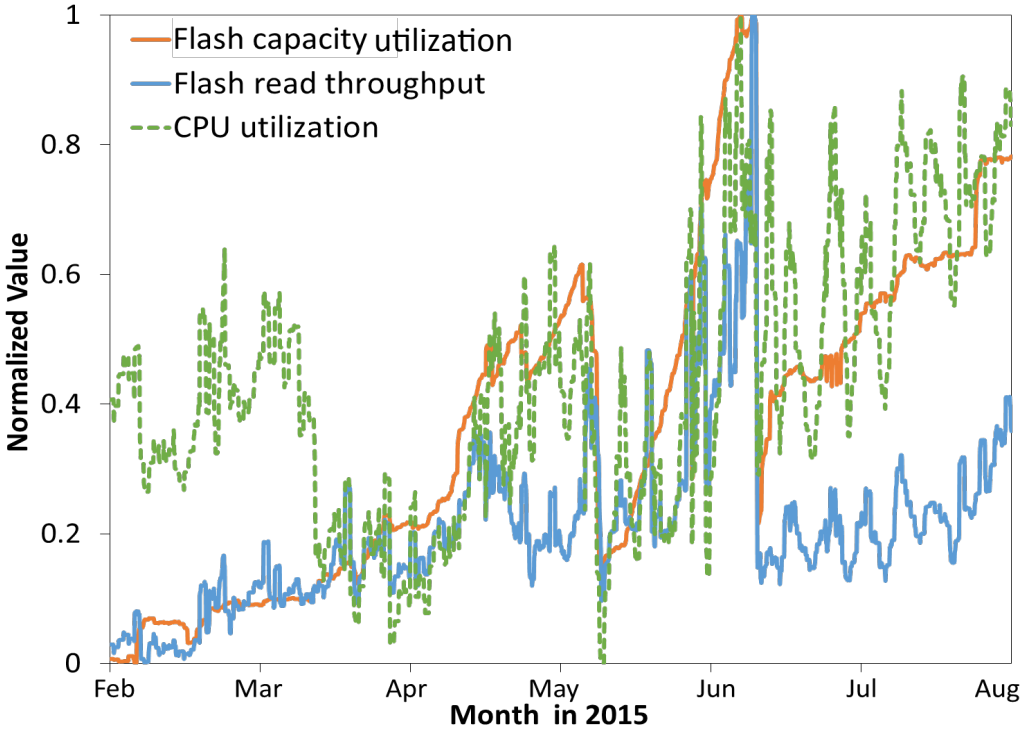

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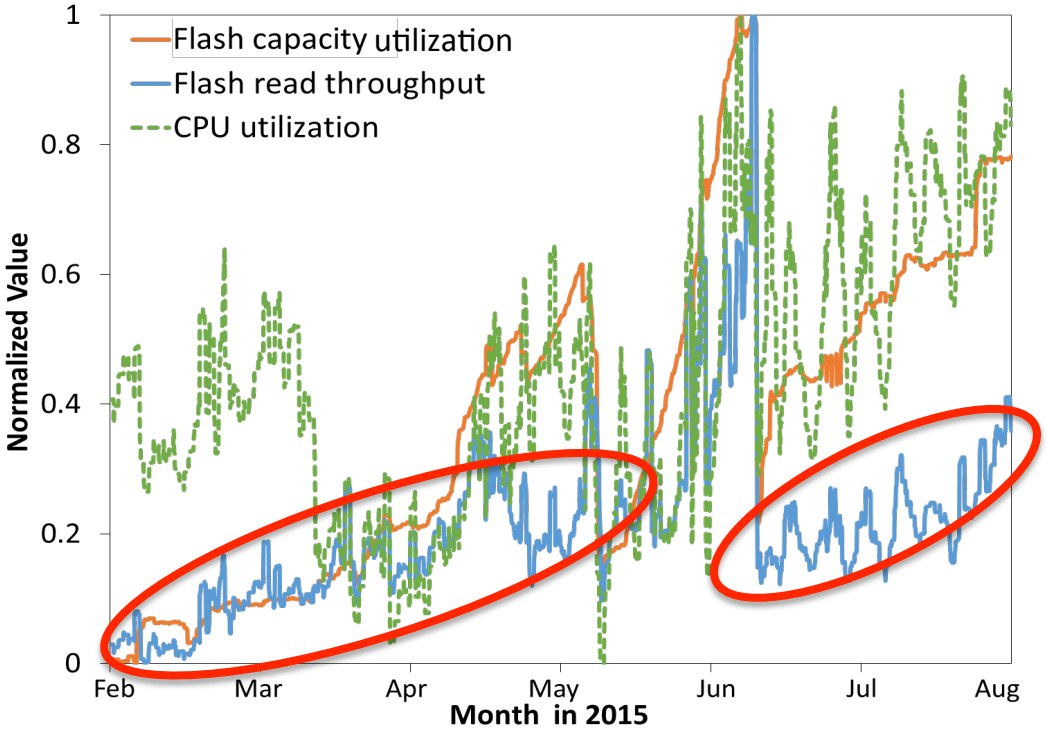
Imbalanced Resource Utilization

Flash capacity and bandwidth are underutilized for long periods of time



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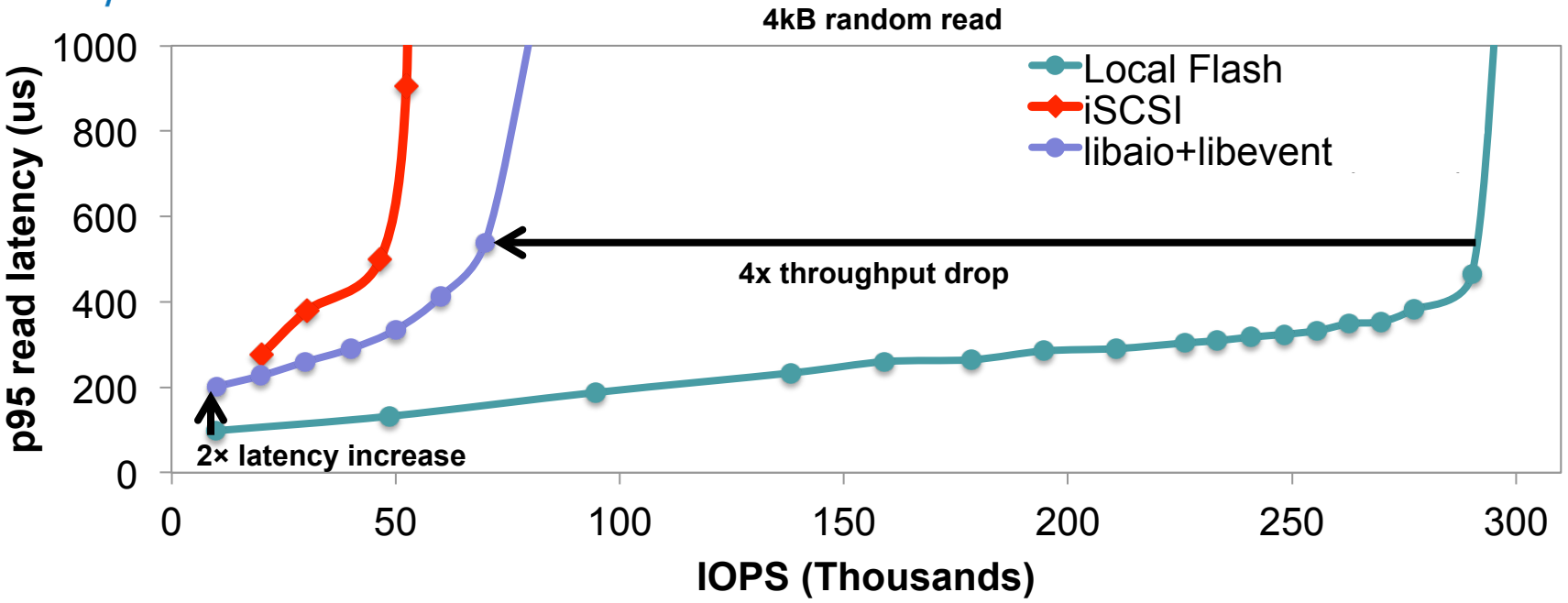
Solution: Remote Access to Storage

- Improve resource utilization by sharing NVMe Flash between remote tenants

- There are 3 main concerns:
  1. Performance overhead for remote access
  2. Interference on shared Flash
  3. Flexibility of Flash usage

Issue 1: Performance Overhead



- Traditional network/storage protocols and Linux I/O libraries (e.g. libaio, libevent) have high overhead

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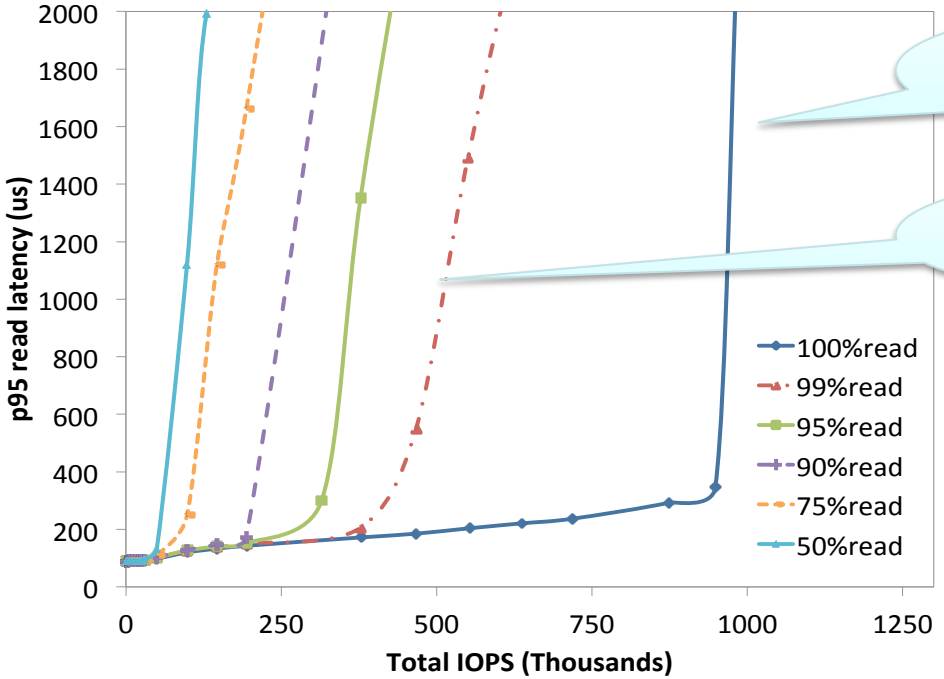
Issue 2: Performance Interference



Latency depends on IOPS load

Writes impact read tail latency

To share Flash, we need to enforce performance isolation

Issue 3: Flexibility

- Flexibility is key
- Want to allocate Flash capacity and bandwidth for applications:
  - On any machine in the datacenter
  - At any scale
  - Accessed using any network-storage protocol

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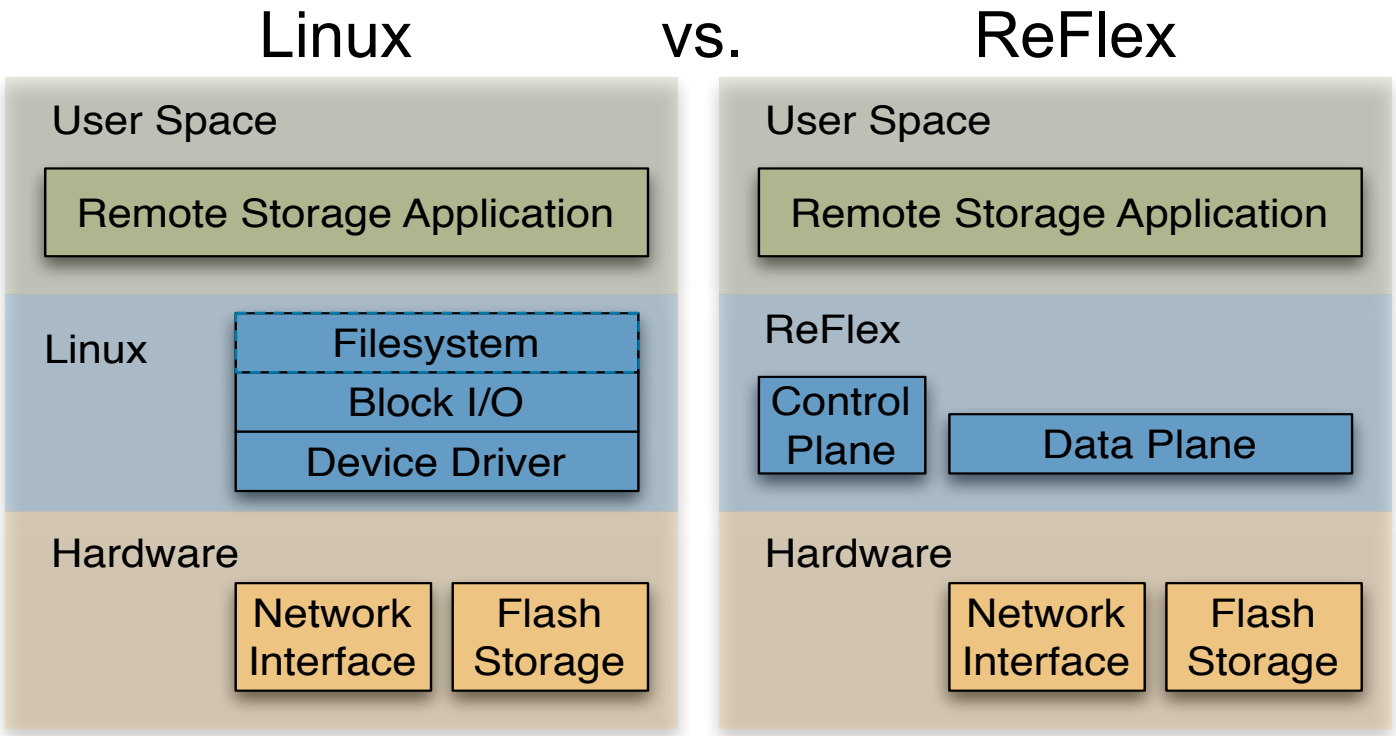
How does ReFlex achieve high performance?



[ASPLOS'17] *ReFlex: Remote Flash ≈ Local Flash*. Ana Klimovic, Heiner Litz, Christos Kozyrakis.

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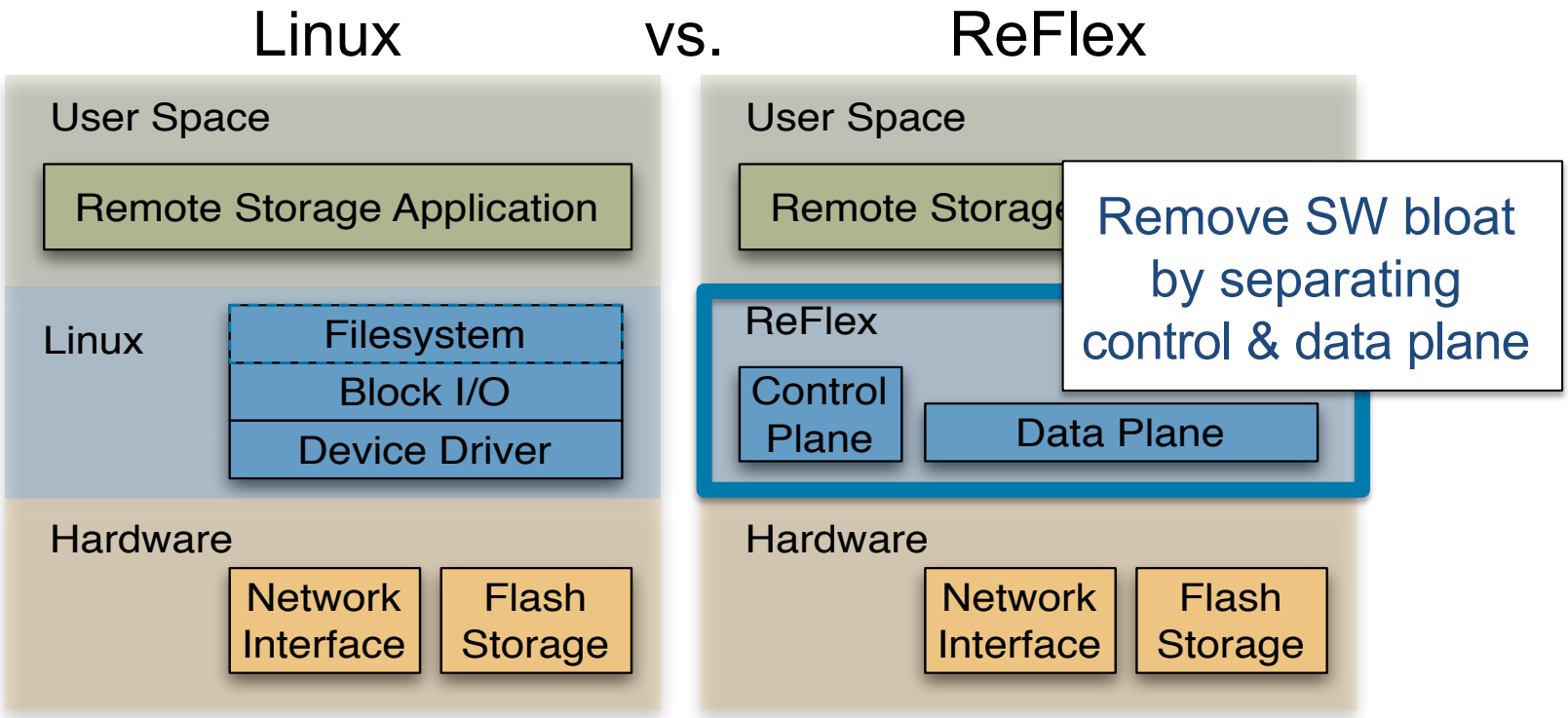

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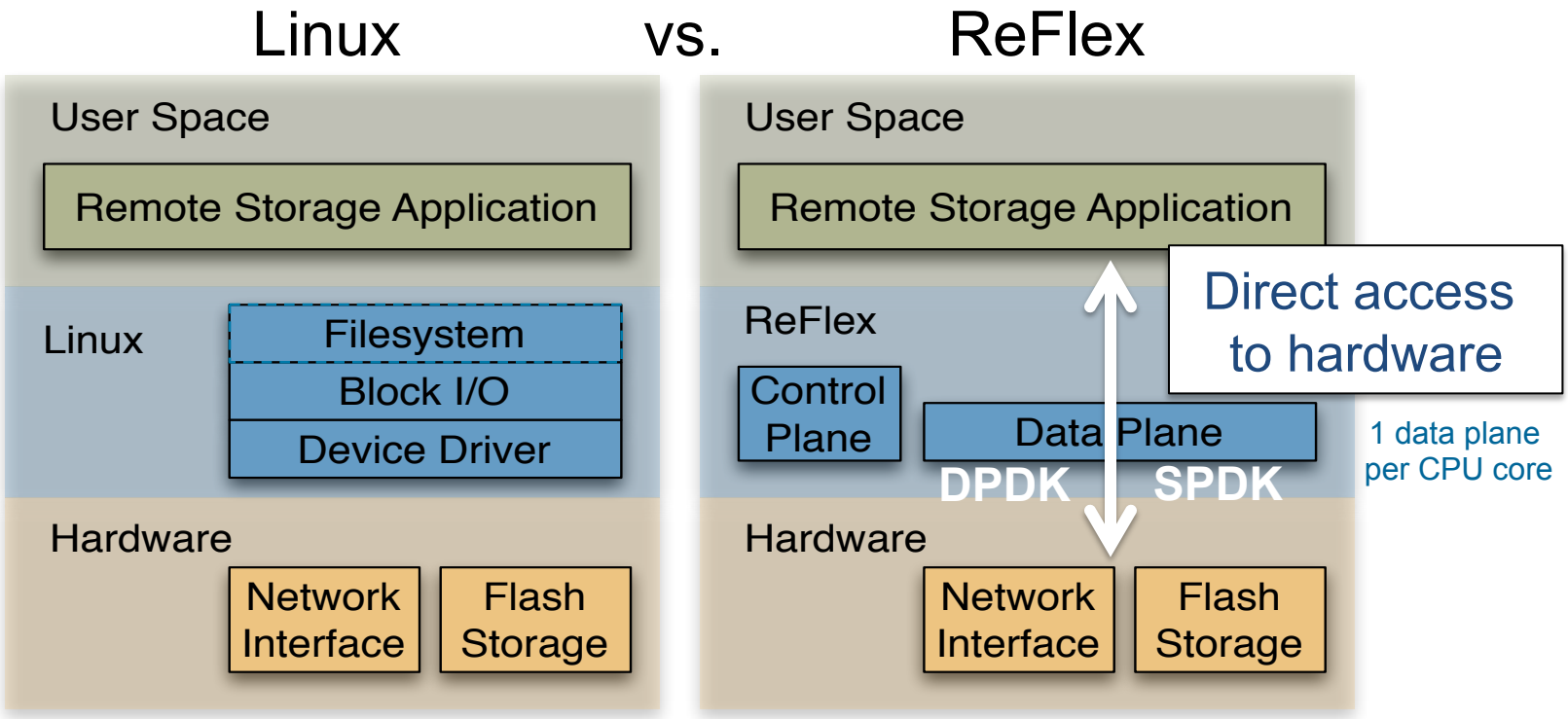

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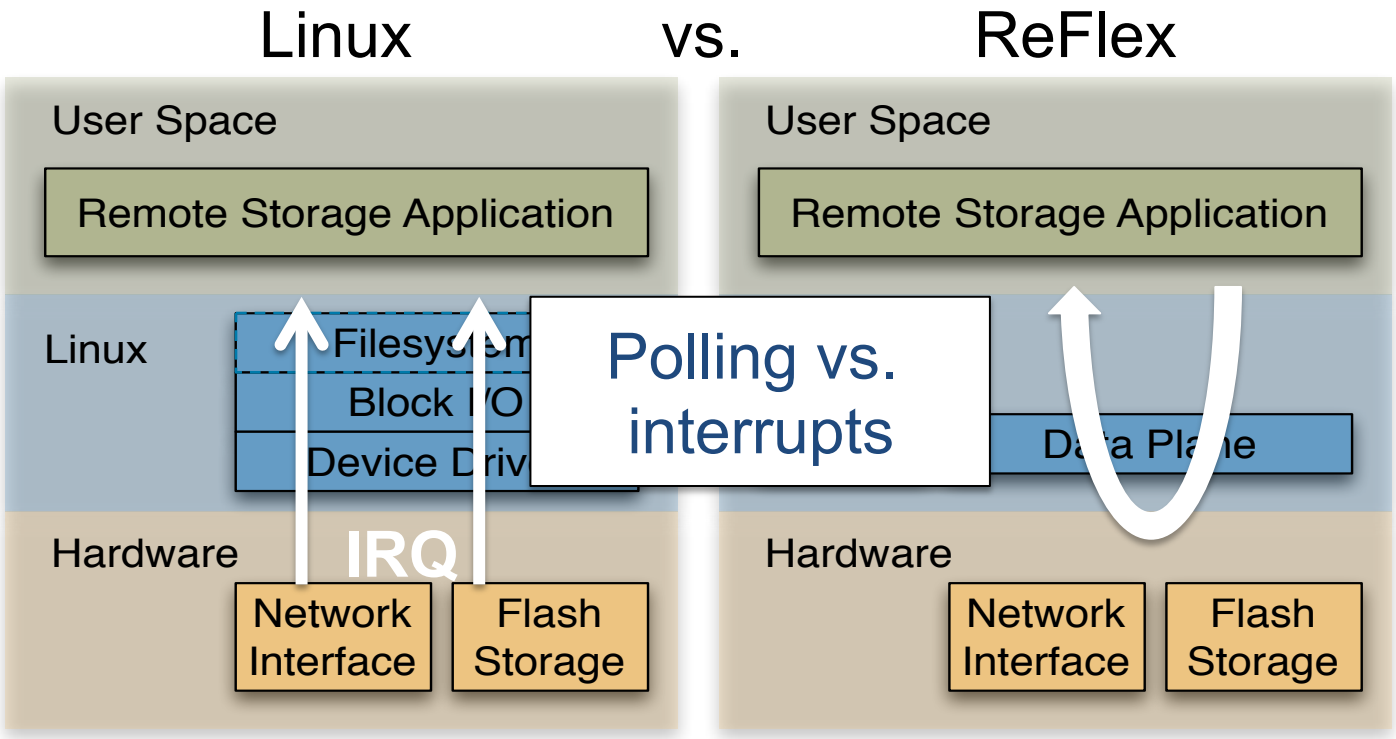

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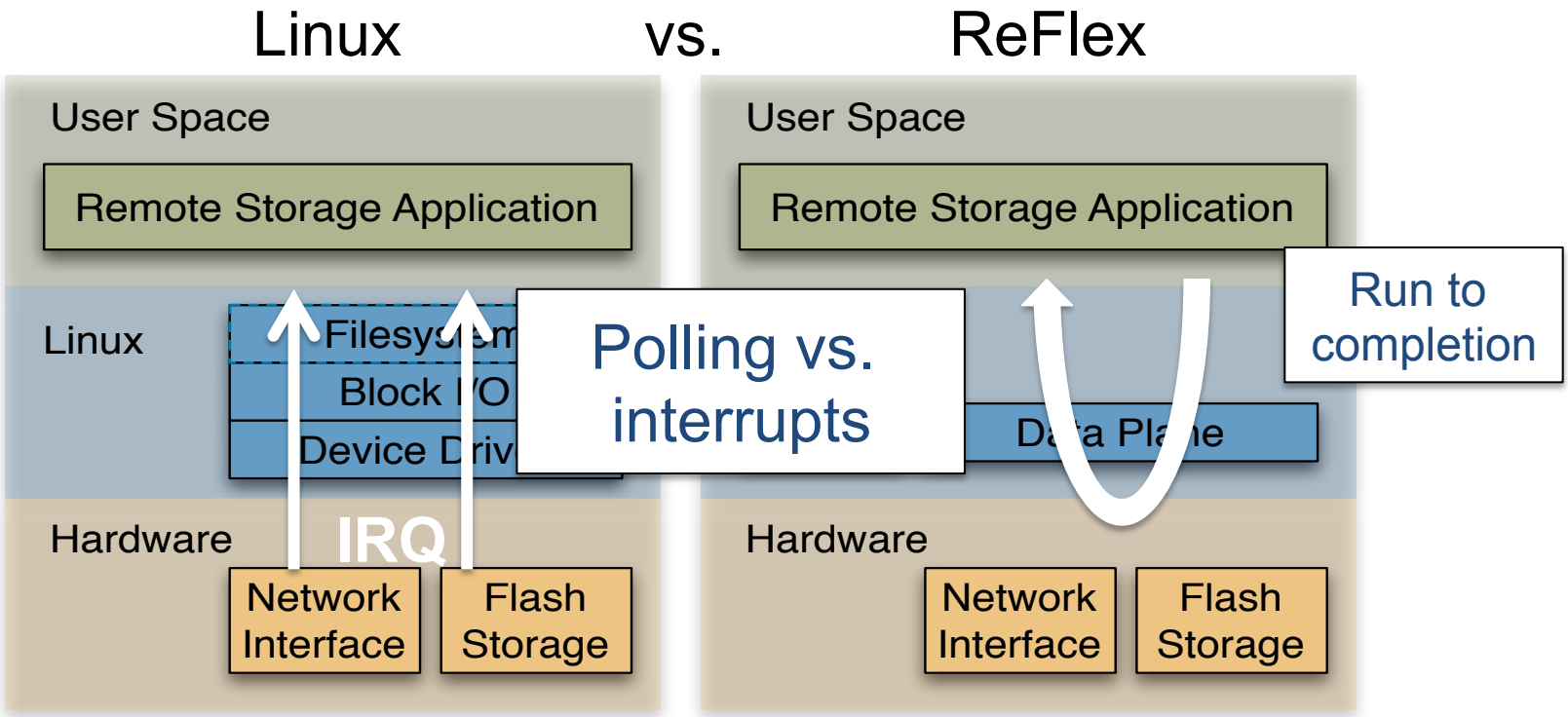

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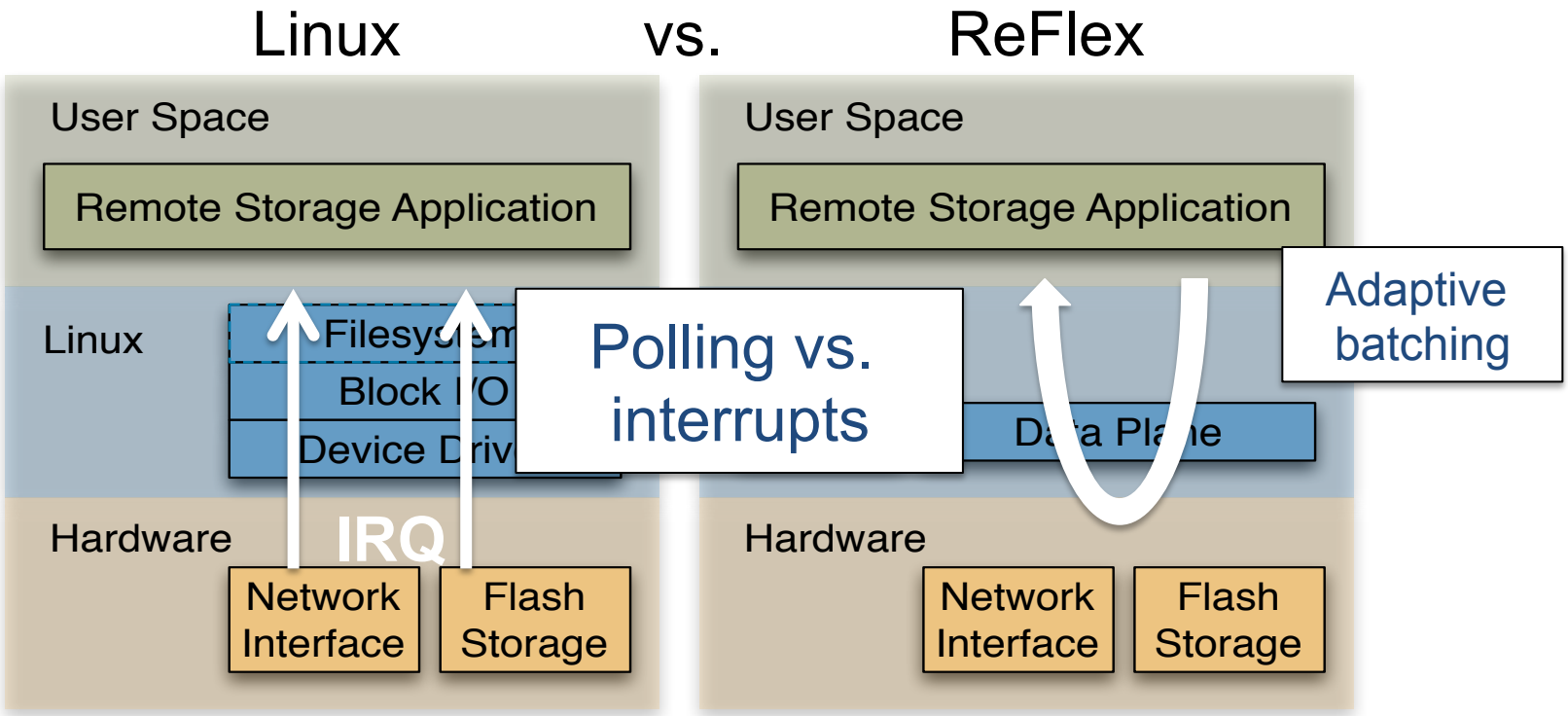

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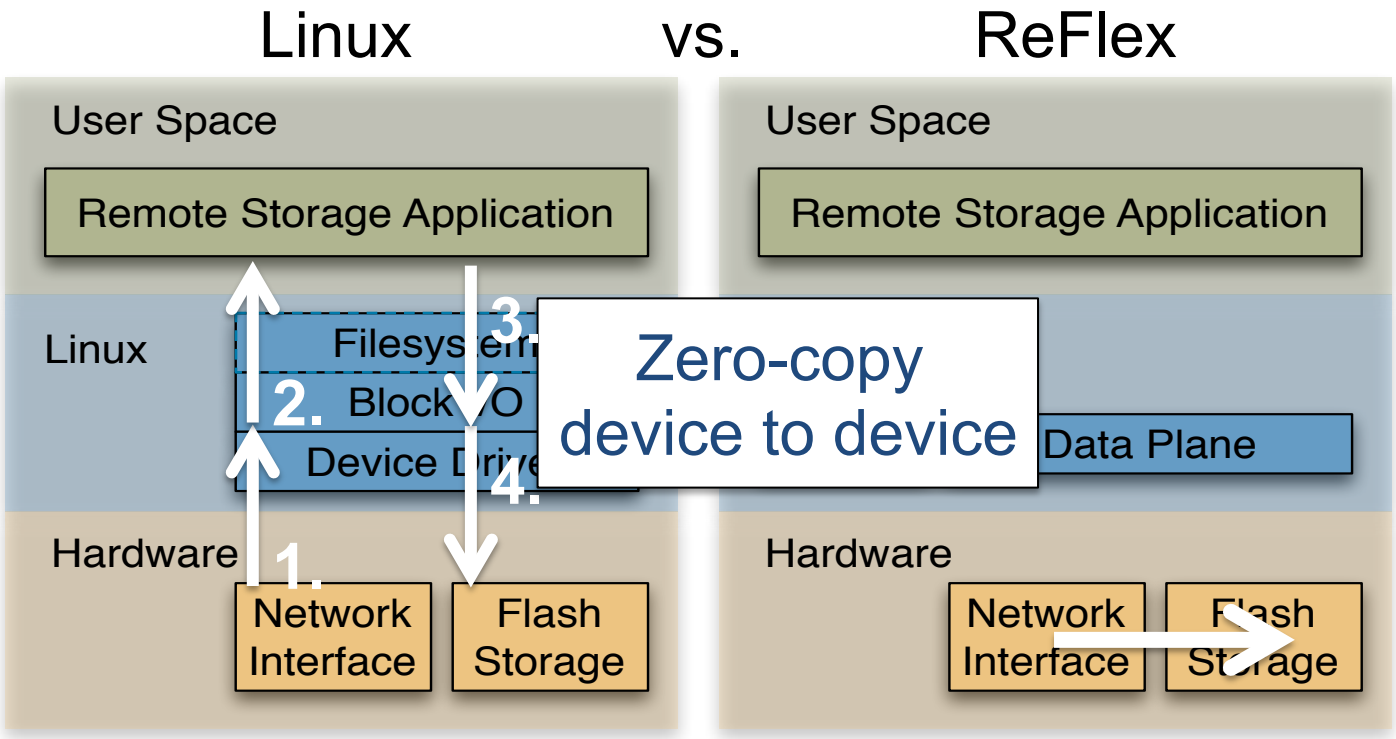


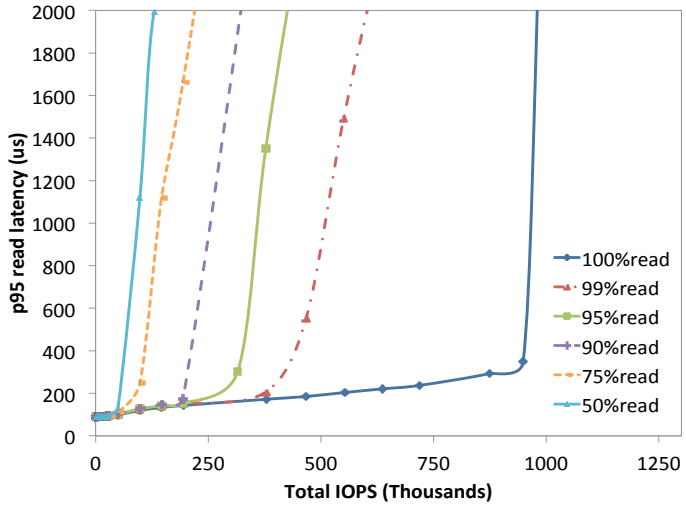
How does ReFlex enable performance isolation?

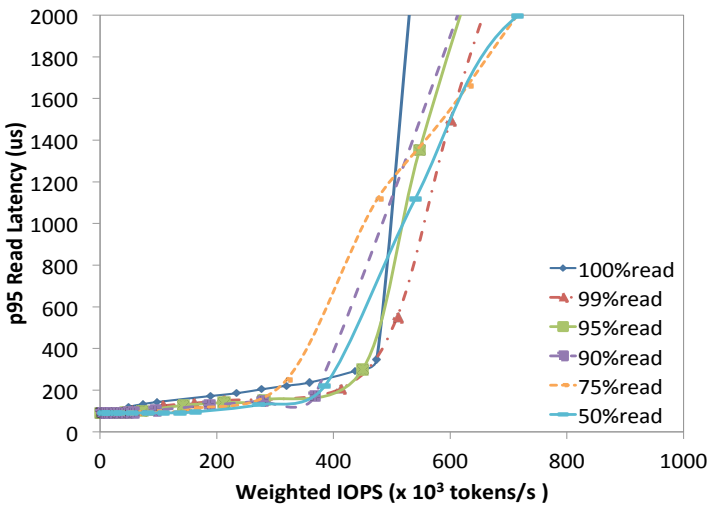
- Request cost based scheduling
- Determine the impact of tenant A on the **tail latency** and **IOPS** of tenant B
- Control plane assigns tenants with a **quota**
- Data plane enforces quotas through throttling

Request Cost Modeling

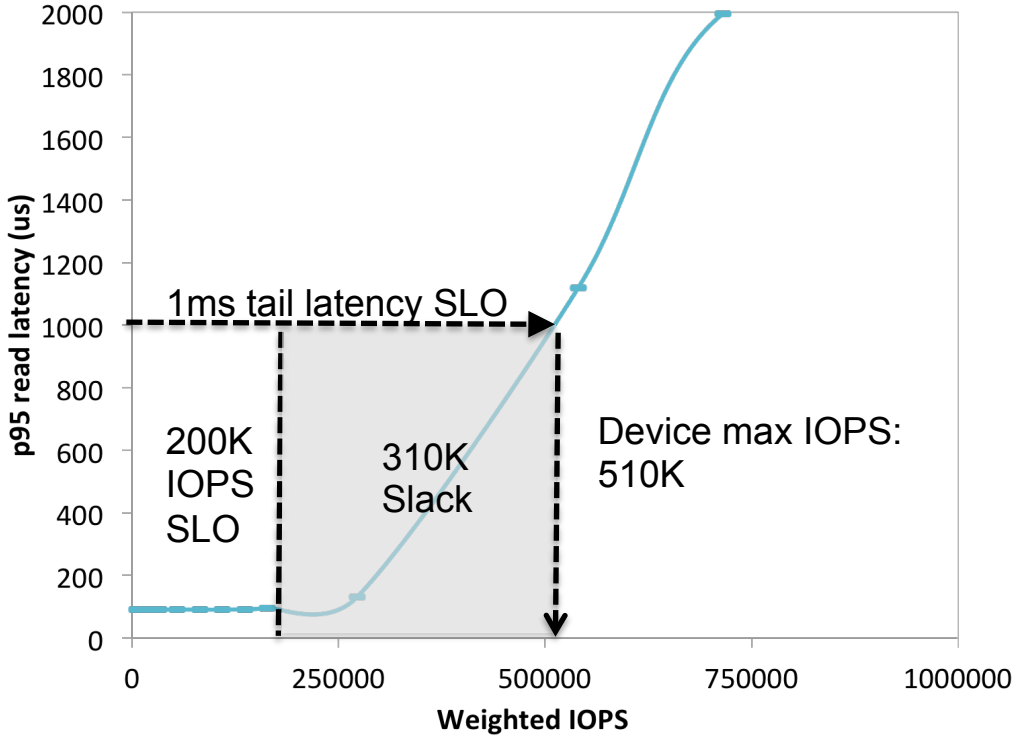
Compensate for read-write asymmetry

For this device:
Write == 10x Read





Request Cost Based Scheduling



Tenant A SLO:

- 1ms tail latency
- 200K IOPS

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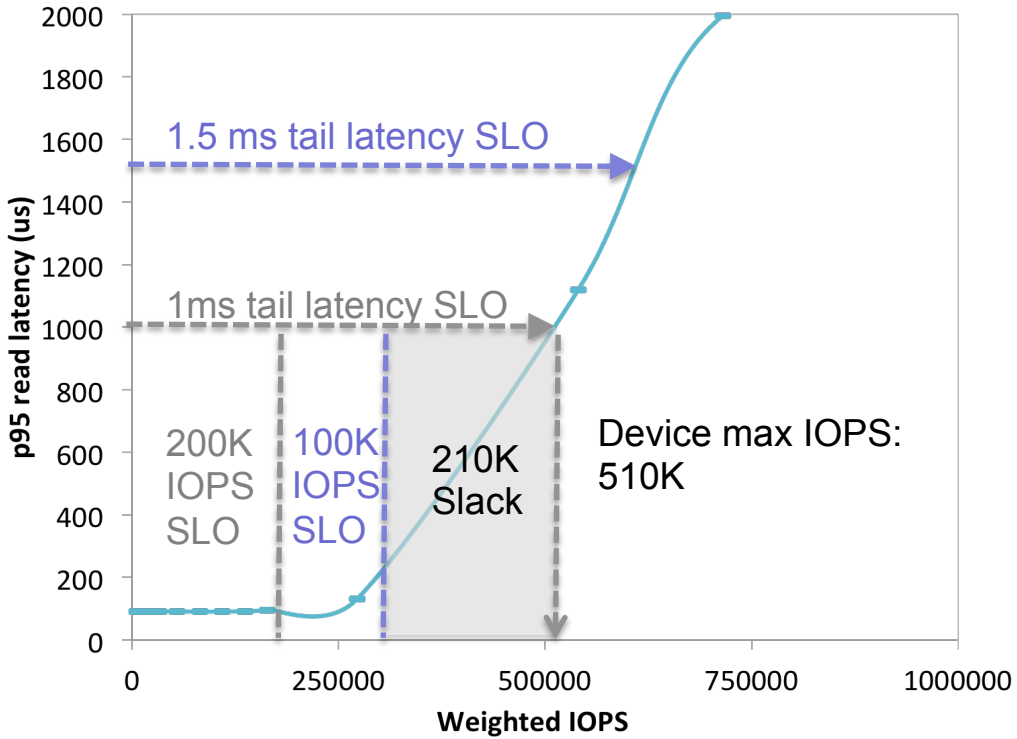
Request Cost Based Scheduling



Tenant A SLO:
- 1ms tail latency
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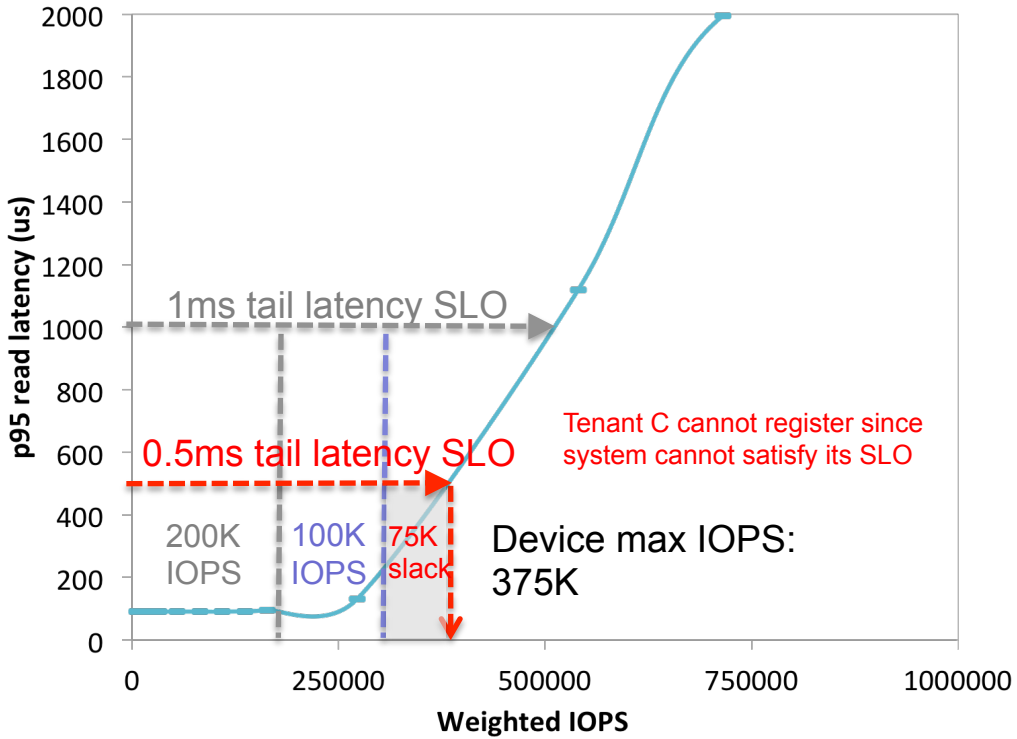
Tenant B SLO:
- 1.5ms tail latency
- 100K IOPS

Request Cost Based Scheduling

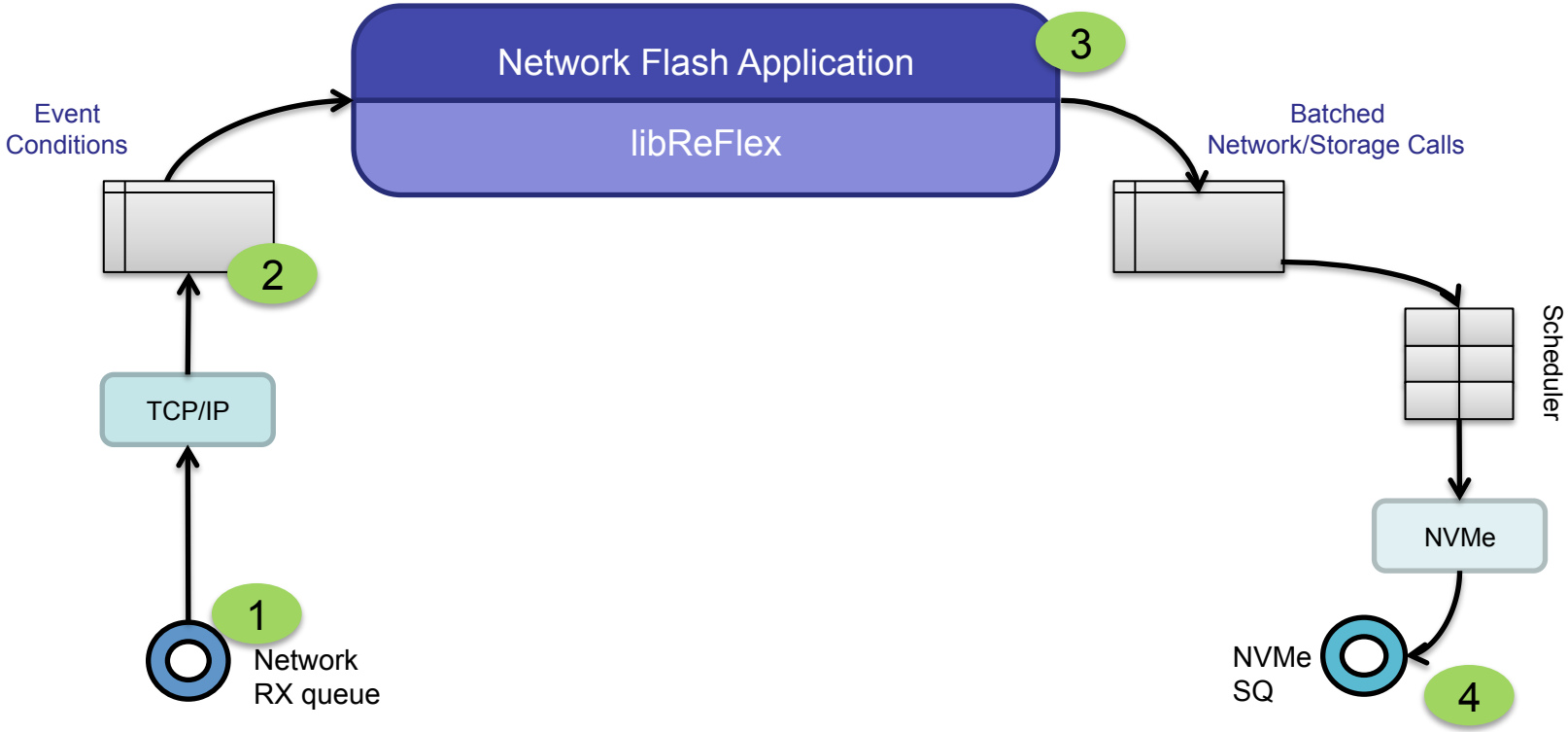


Tenant A SLO:
- 1ms tail latency
- 200K IOPS

Tenant B SLO:
- 1.5ms tail latency
- 100K IOPS

Tenant C SLO:
- 0.5ms tail latency
- 200K IOPS

Summary: Life of a Packet in ReFlex



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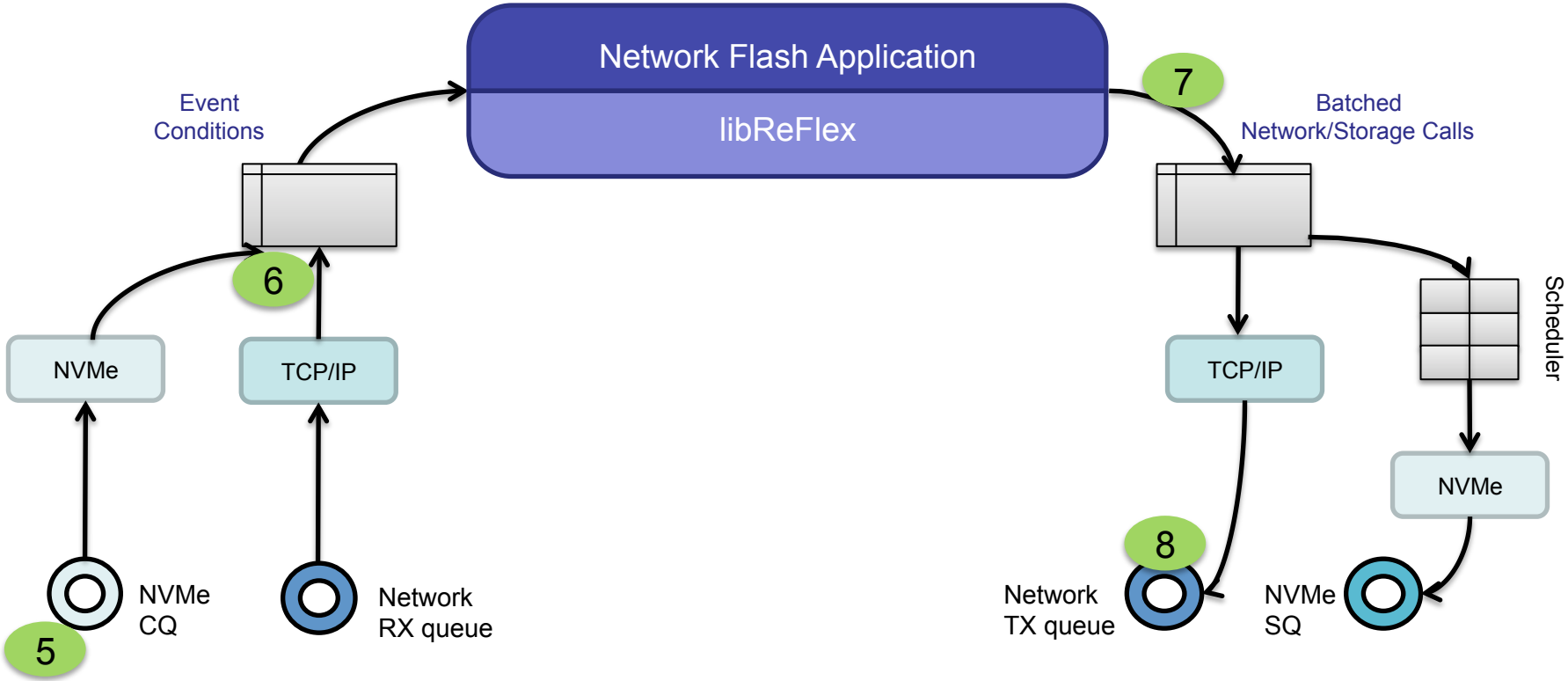

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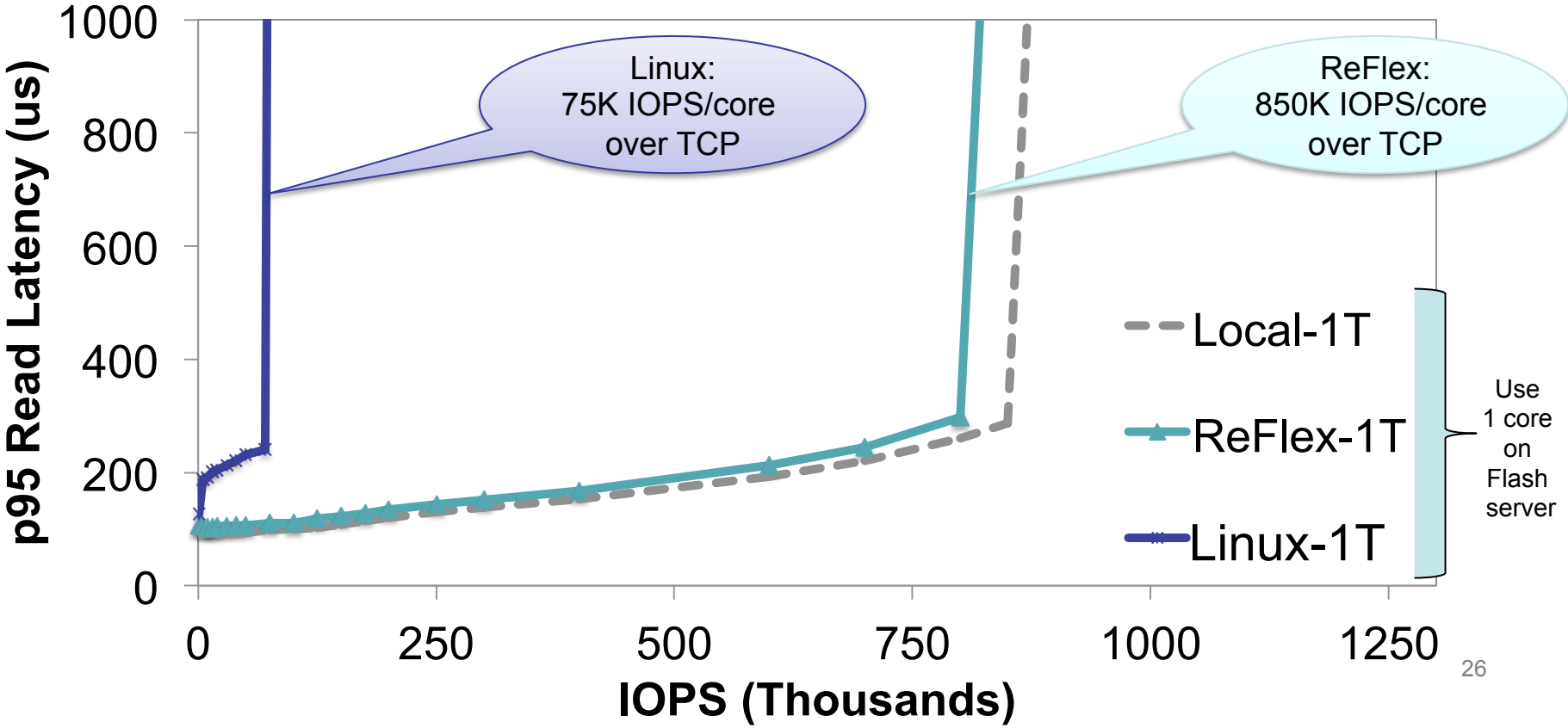
Results: Local ≈ Remote Latency



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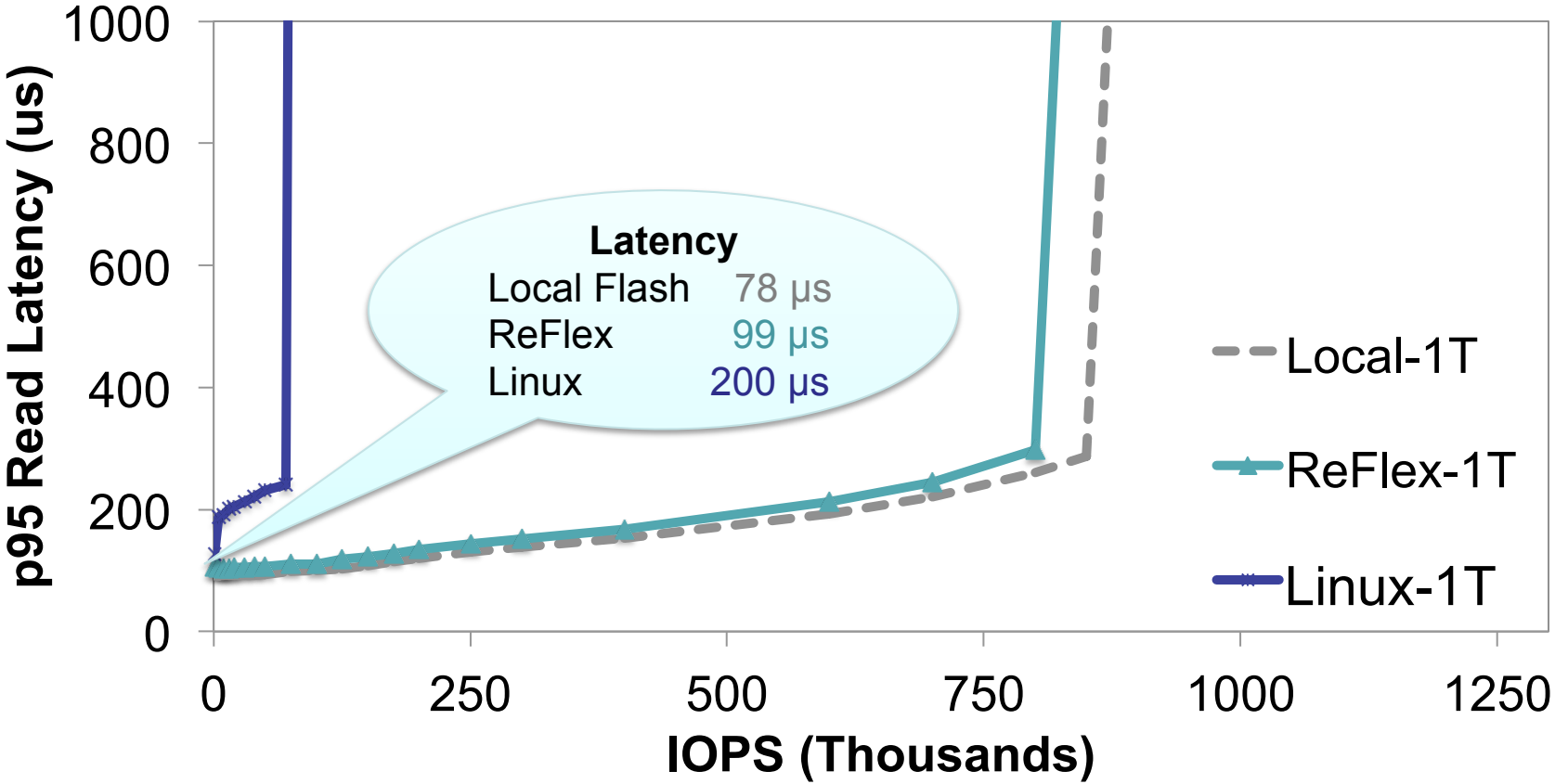

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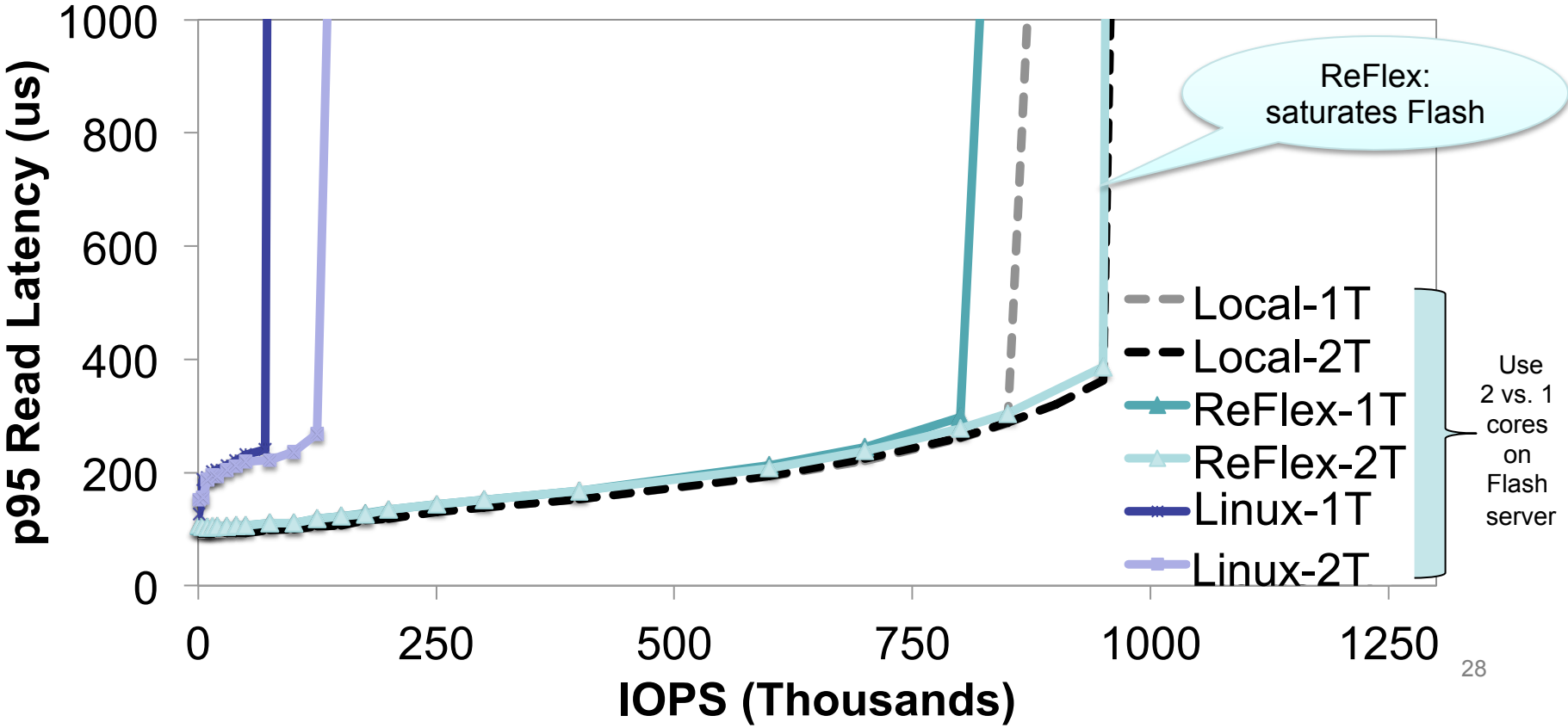
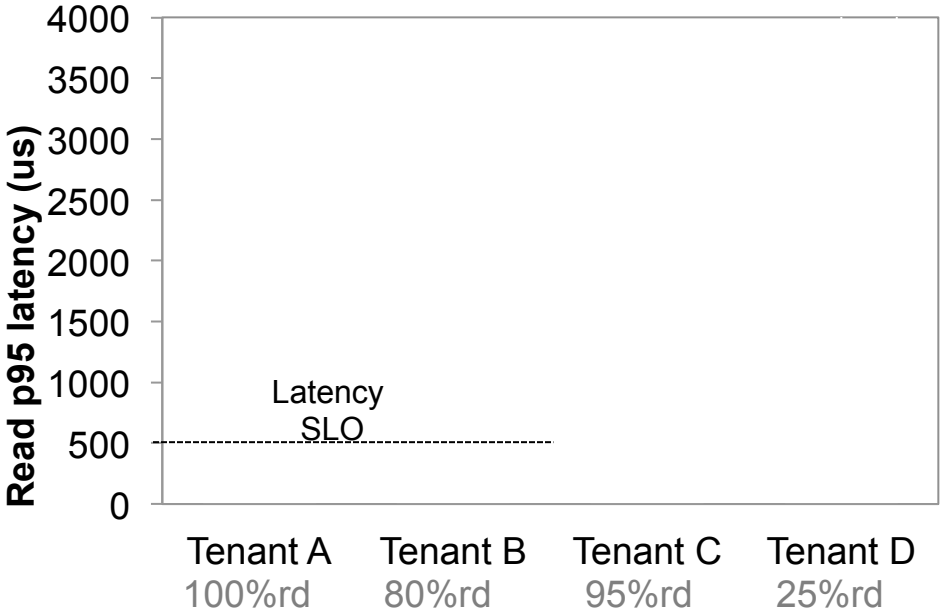
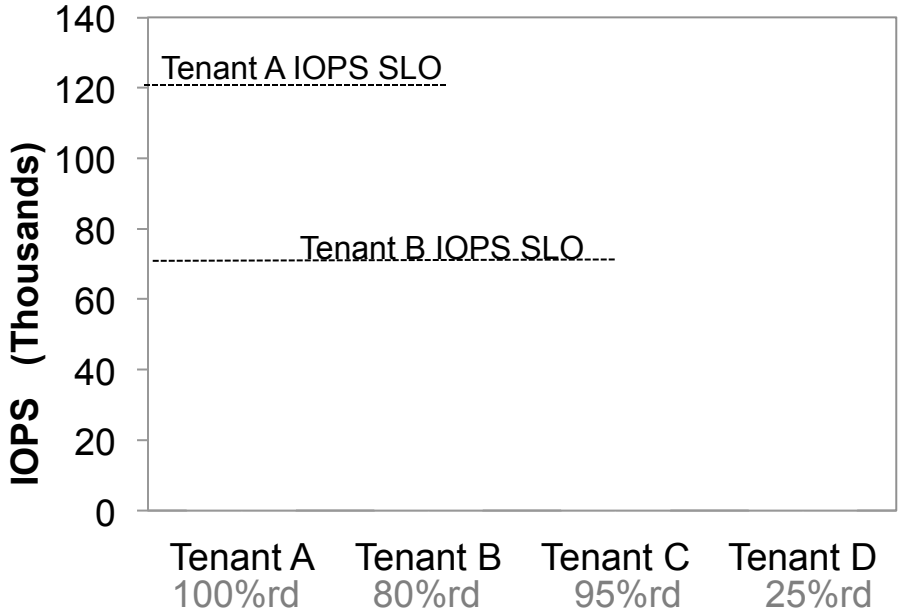


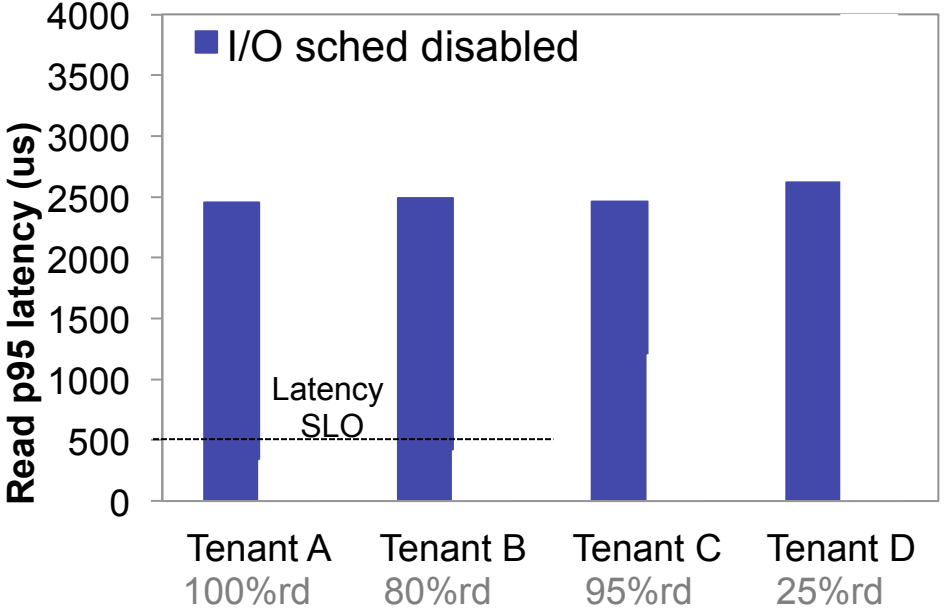
Results: Performance Isolation

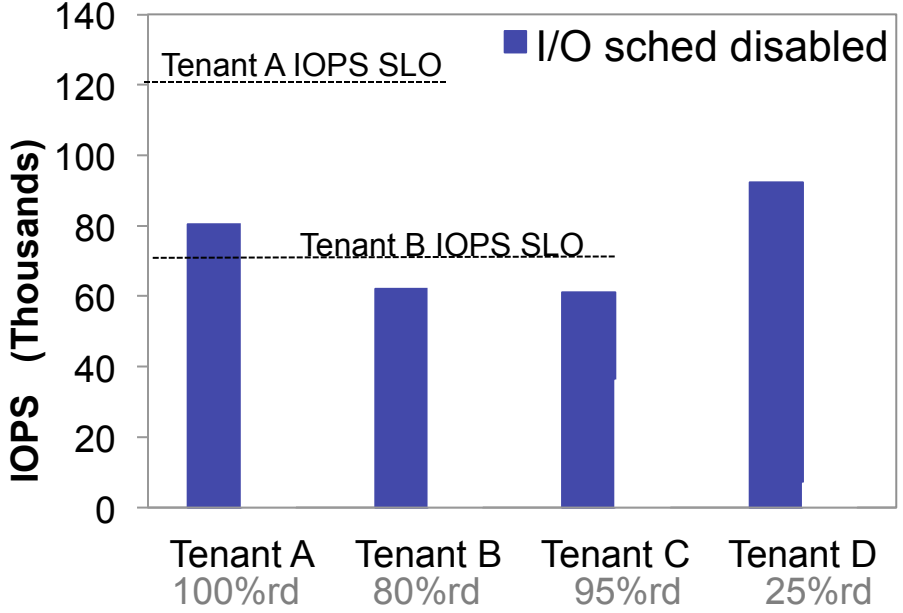




- Tenants A & B: latency-critical; Tenant C + D: best effort

Results: Performance Isolation





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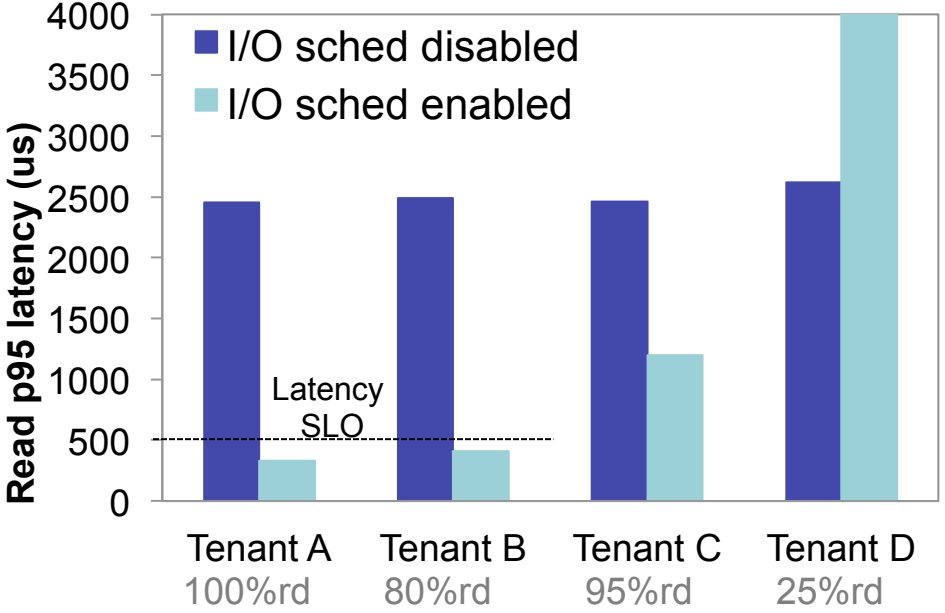
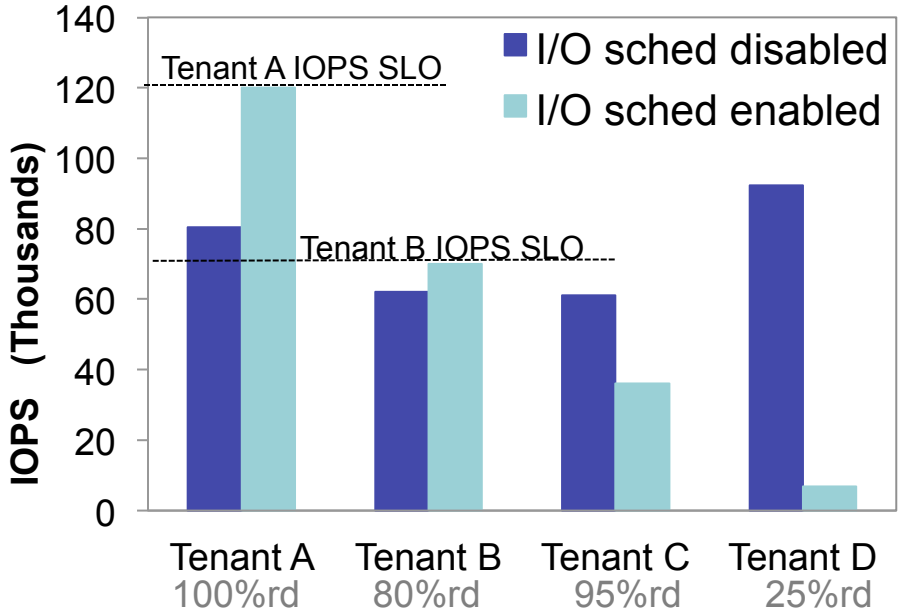


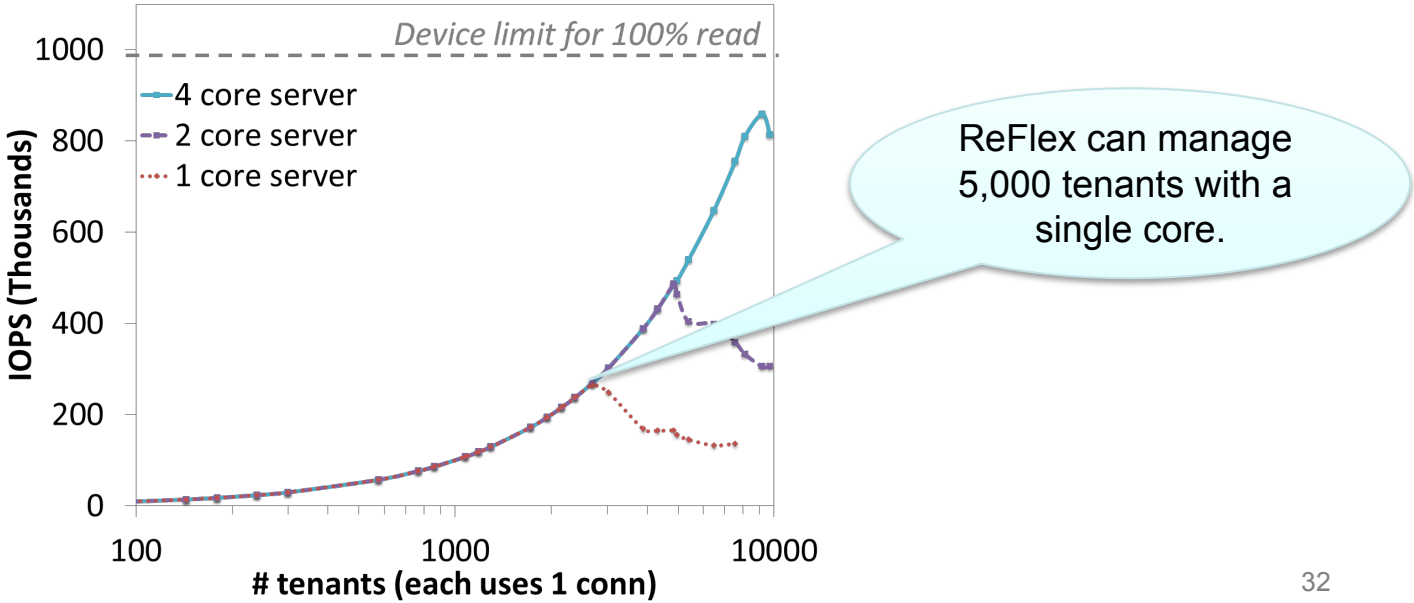


- Tenants A & B: latency-critical; Tenant C + D: best effort
- Without scheduler: latency and bandwidth QoS for A/B are violated
- Scheduler rate limits best-effort tenants to enforce SLOs

Results: Scalability

- ReFlex scales to multiple cores (we tested with up to 12 cores)
- ReFlex scales to thousands of tenants and connections

Each tenant issues
100 1kB reads/sec



How can I use ReFlex?

- ReFlex is open source:
  www.github.com/stanford-mast/reflex

- Two versions of ReFlex available:
  1. Kernel implementation:
     - Provides a protected network-storage data plane (user application not trusted)
     - Builds on hardware support for virtualization
     - Requires Dune kernel module for direct access to hardware and memory management in Linux
  2. User space implementation:
     - Network-storage data plane runs as user space application; kernel-bypass
     - Portable implementation, tested on Amazon Web Services i3 instance

ReFlex Clients

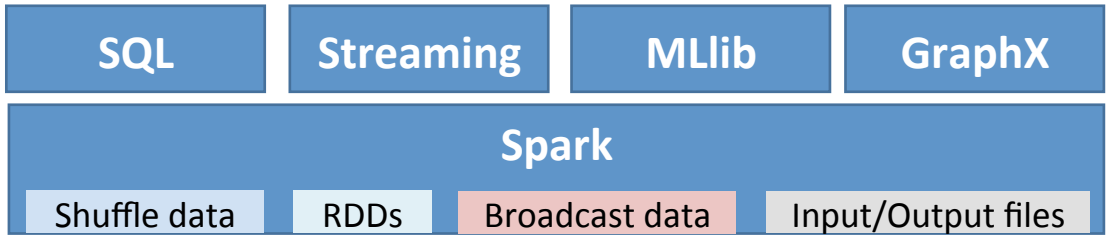
- ReFlex exposes a logical block interface
- ReFlex client implementations available:
  1. Block I/O client
     → For issuing raw network block I/O requests to ReFlex
  2. Remote block device driver
     → For legacy Linux applications

Control Plane for ReFlex

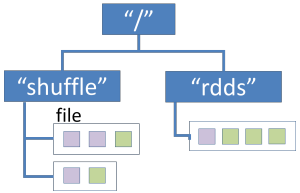
- ReFlex provides an efficient data plane for remote access
- Bring your own control plane or distributed storage system:
  - Global control plane allocates Flash capacity & bandwidth in cluster
  - Control plane can be a cluster manager or a distributed storage system (e.g. distributed file system or database)
- Example: ReFlex storage tier for Crail distributed file system
  - Spark applications can use ReFlex as a remote Flash storage tier, managed by the Crail distributed data store

Example Use-Case

- Big data analytics frameworks such as Spark store a variety of data types in memory, Flash and disk



- Crail is a distributed storage system that manages and provides high-performance access to data across multiple storage tiers

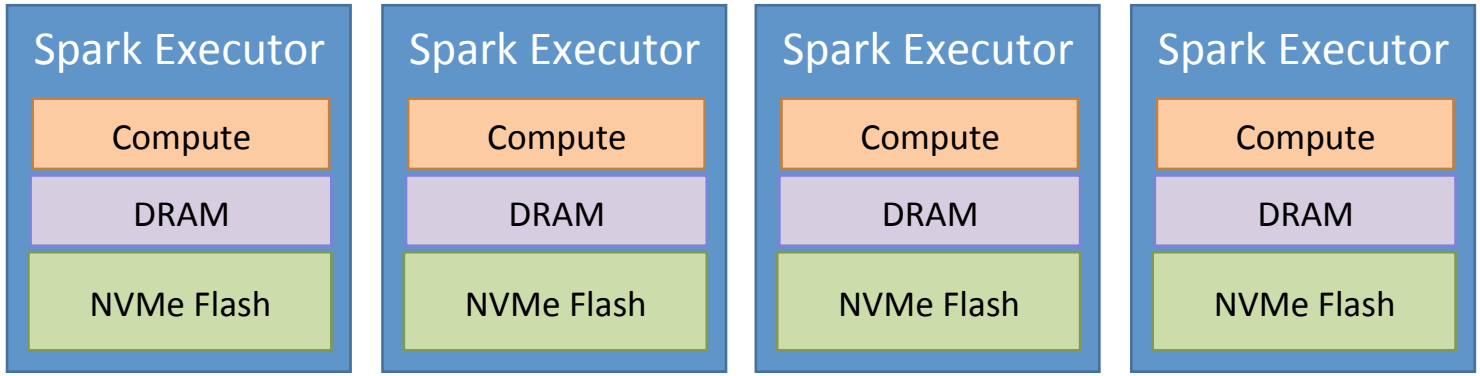


crail

www.crail.io

Example Use-Case

- Spark executors often use (local) Flash to store temporary data (e.g. shuffle)

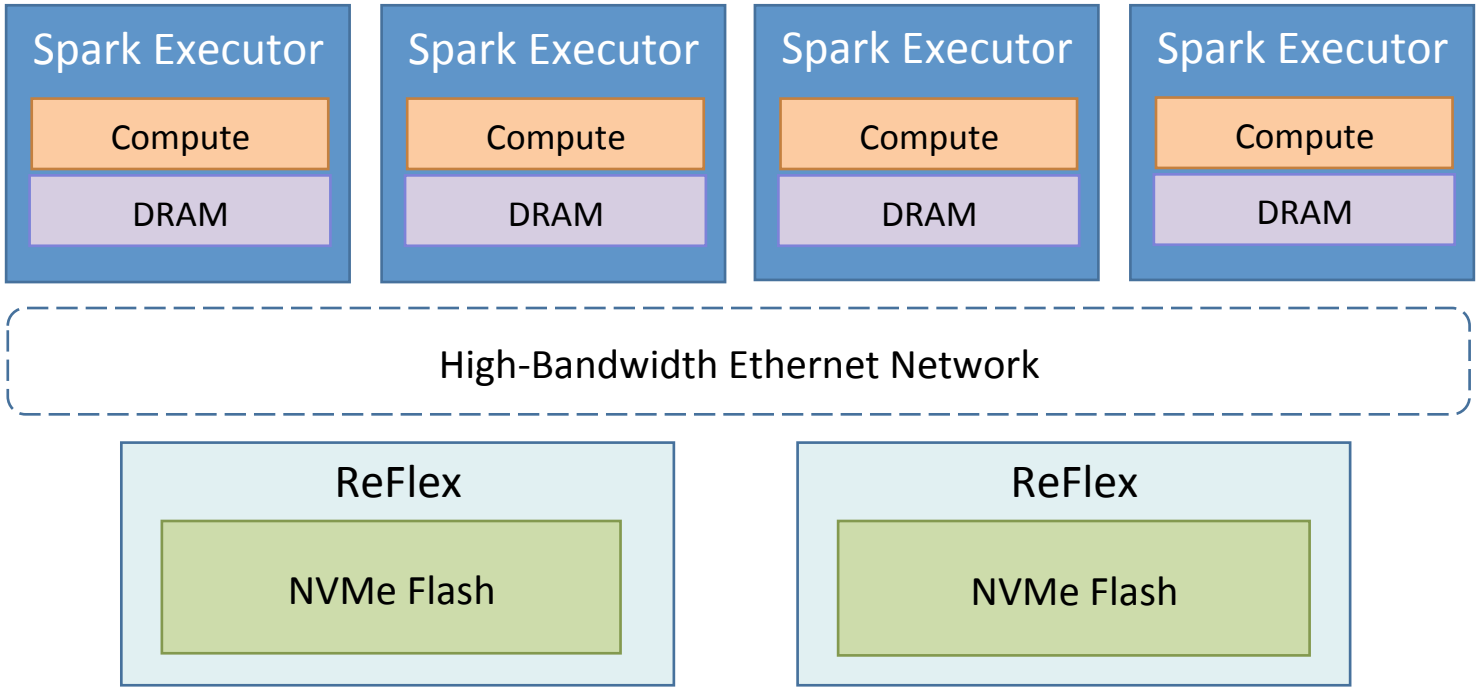


- Spark applications often saturate CPU resources before they can saturate NVMe Flash IOPS

  → Local Flash bandwidth is underutilized

Example Use-Case

- ReFlex provides a shared remote Flash tier for big data analytics
  - Improves resource utilization while offering local Flash performance



Summary

- ReFlex enables Flash disaggregation
- Performance: *remote* ≈ *local*
- Commodity networking, low CPU overhead
- QoS on shared Flash with I/O scheduler

Thank You!

ReFlex is available at:

https://github.com/stanford-mast/reflex