Jericho: Achieving Scalability through Optimal Data Placement on Multicore Systems

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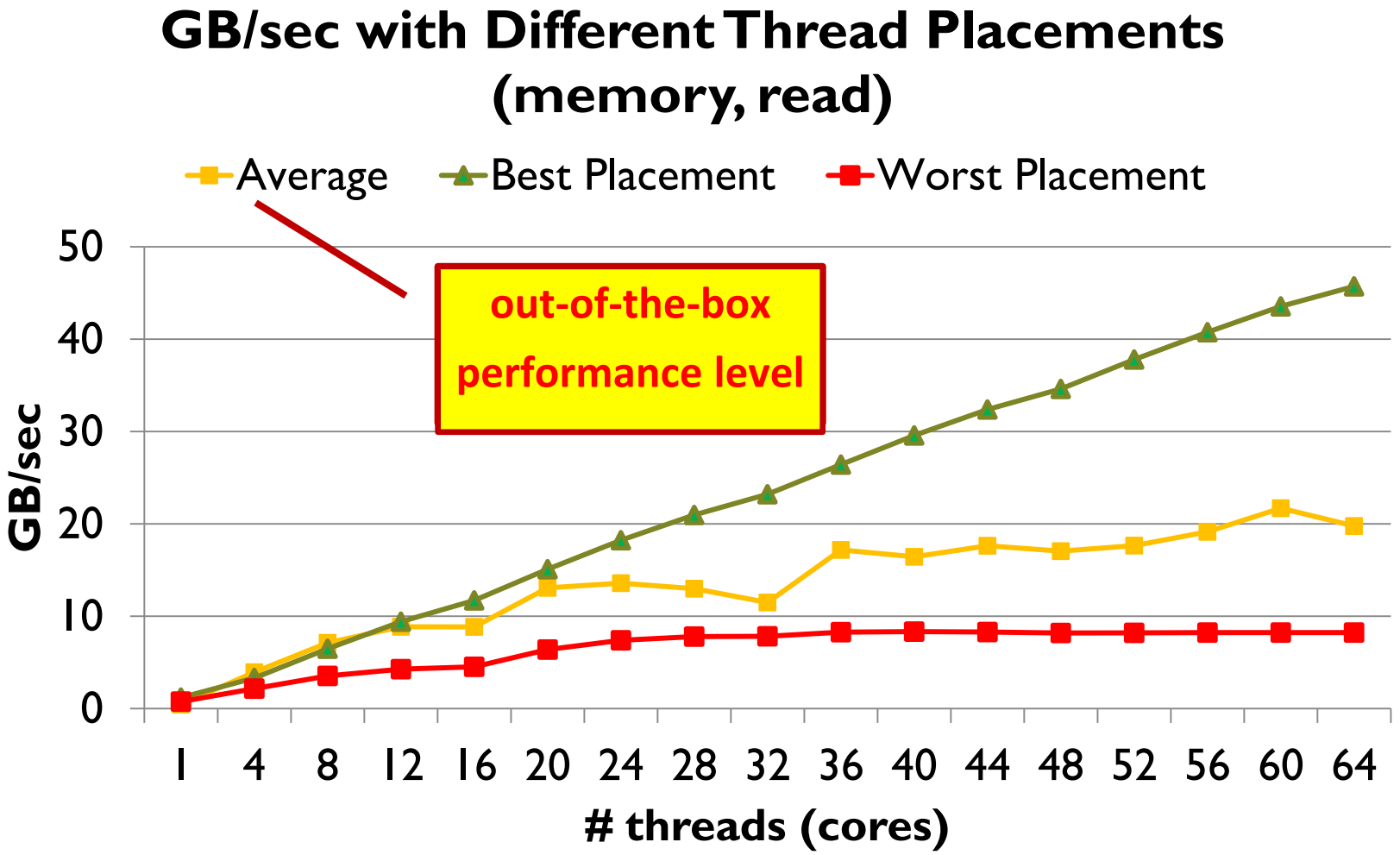
Outline of this talk

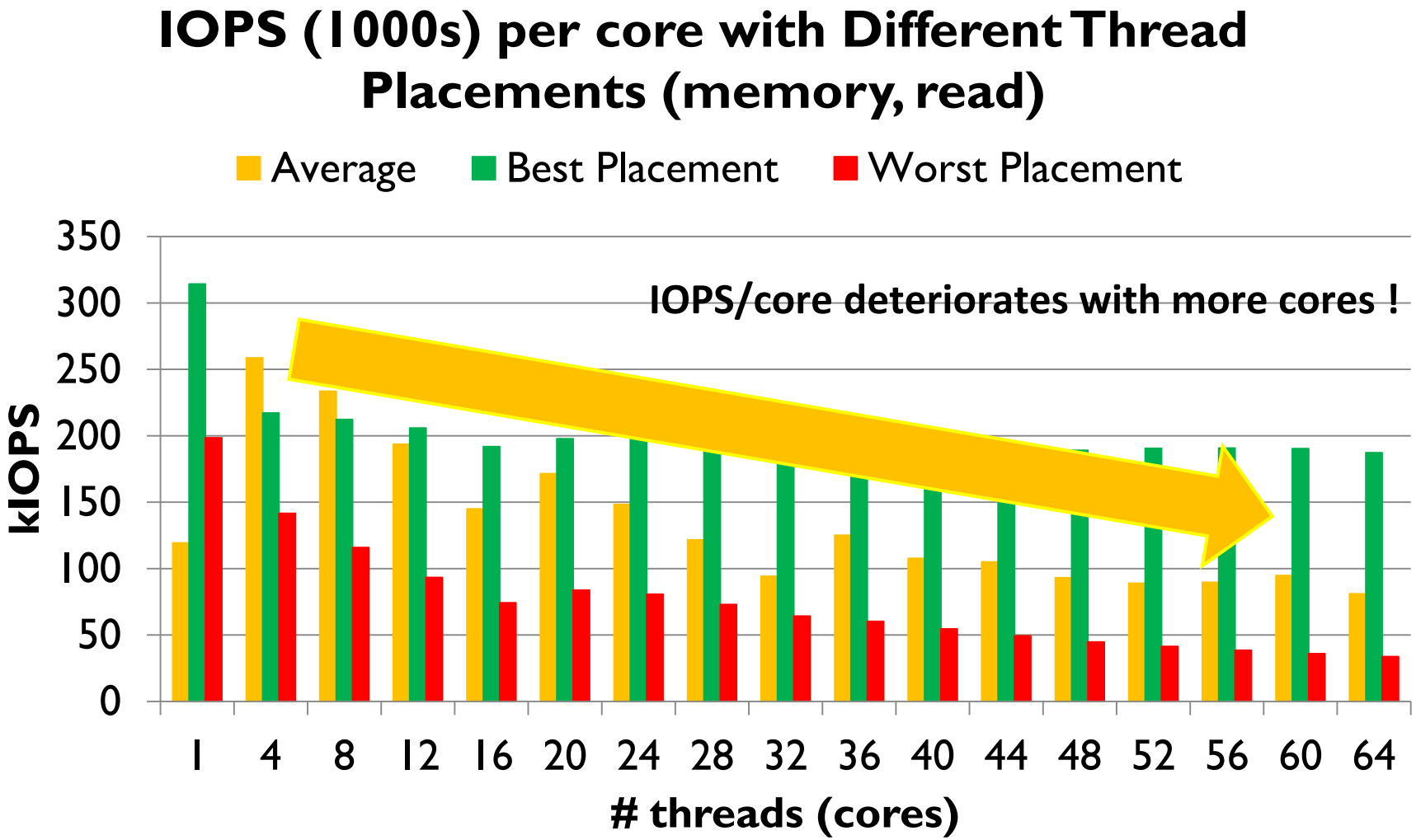
- Does thread/data affinity matter for I/O performance on NUMA multicore servers ?
- Jericho Design
- Evaluation
- Conclusions

Thread/Data affinity matters … a lot!

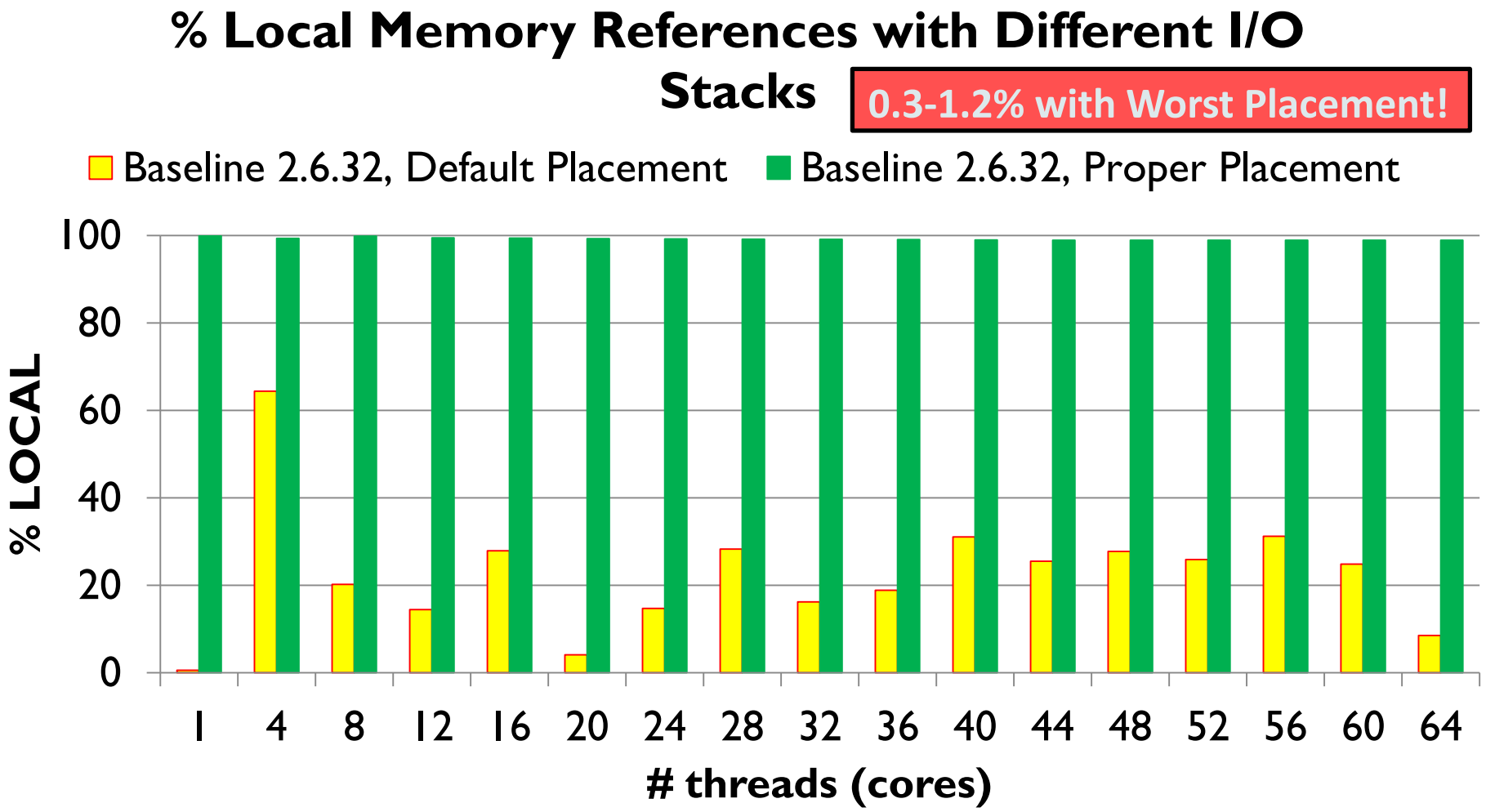


[fio, independent files, sequential reads, 4KB requests]

Impact of thread/data affinity [alt. view: IOPS/core]



% Local vs Remote memory references



What workloads are affected ?

- Application threads accessing independent file sets
- Batch-style processing of independent files
  - e.g. Map-Reduce on Hadoop
- Virtual machines
  - running from (private) device images

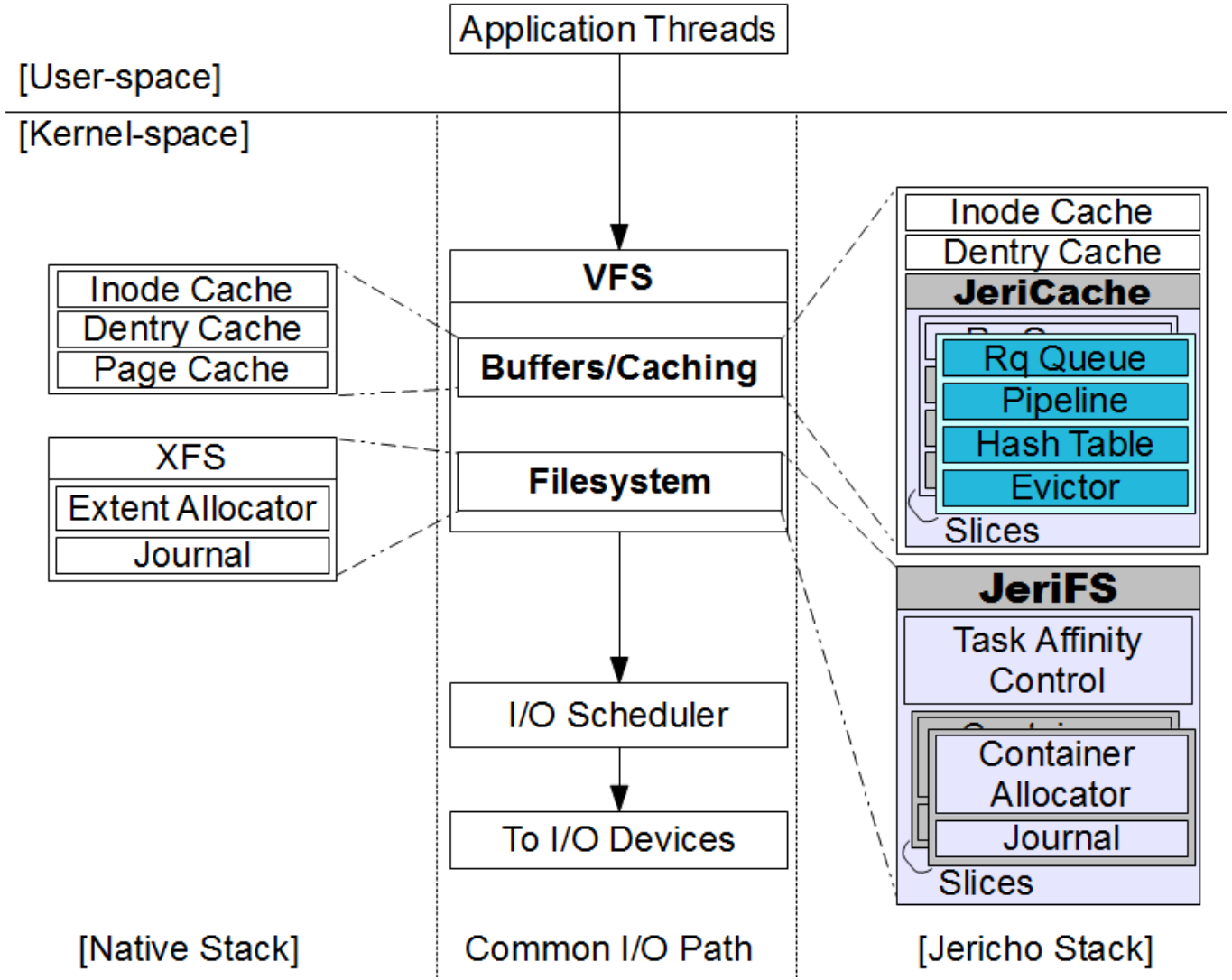
Contributions

- A simple locality management scheme for proper affinity with negligible overhead
- Page-cache capable of controlling page placement
  - Cache organized as slices, mapped to NUMA memory nodes
- NUMA-aware filesystem to enforce task placement
  - Based on the location of file buffers

Why a custom I/O stack ?

- Local access by a simple and fast check (upon I/O access)
- … via pre-arranged division of buffers
- … via placement rule implemented in the filesystem
- No need to track the location of individual buffers

Jericho: Custom I/O stack in the Linux kernel



Testbed Machine Architecture (NUMA)

11.9 GBytes/sec per memory channel

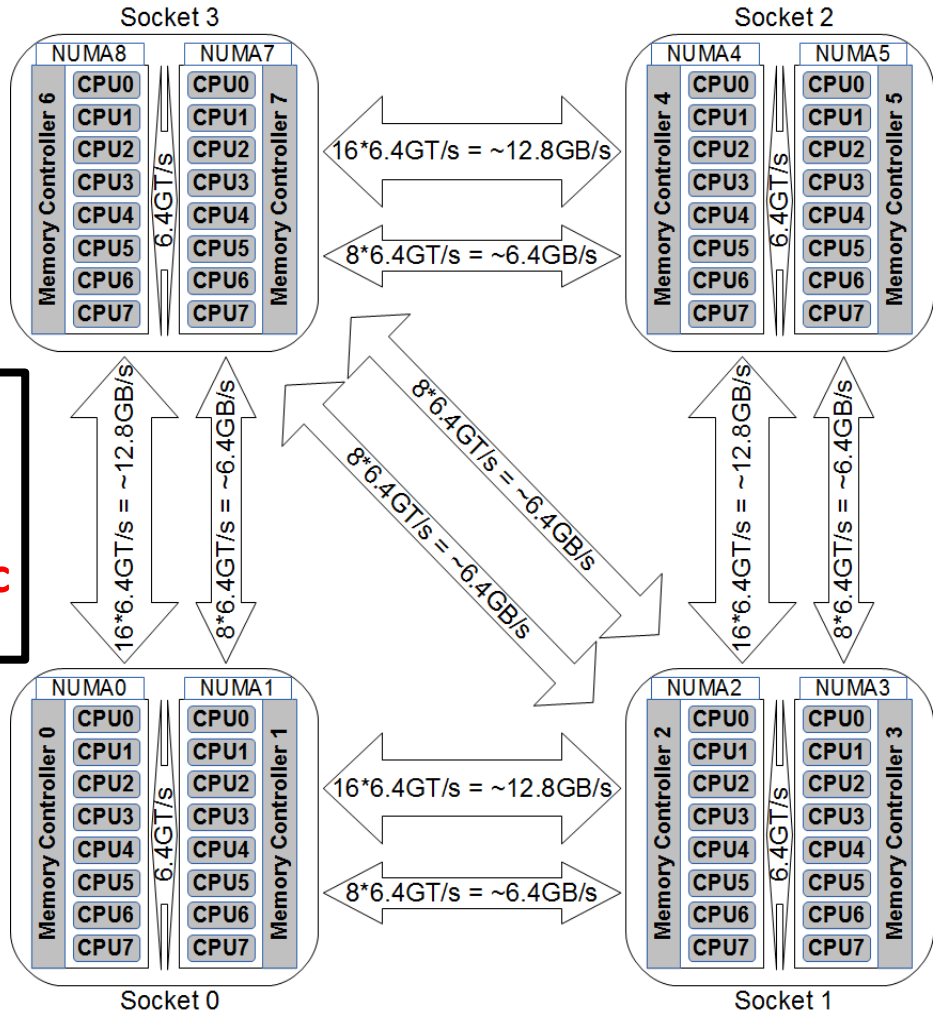
23.8 GBytes/sec per memory controller

47.6 GBytes/sec per socket

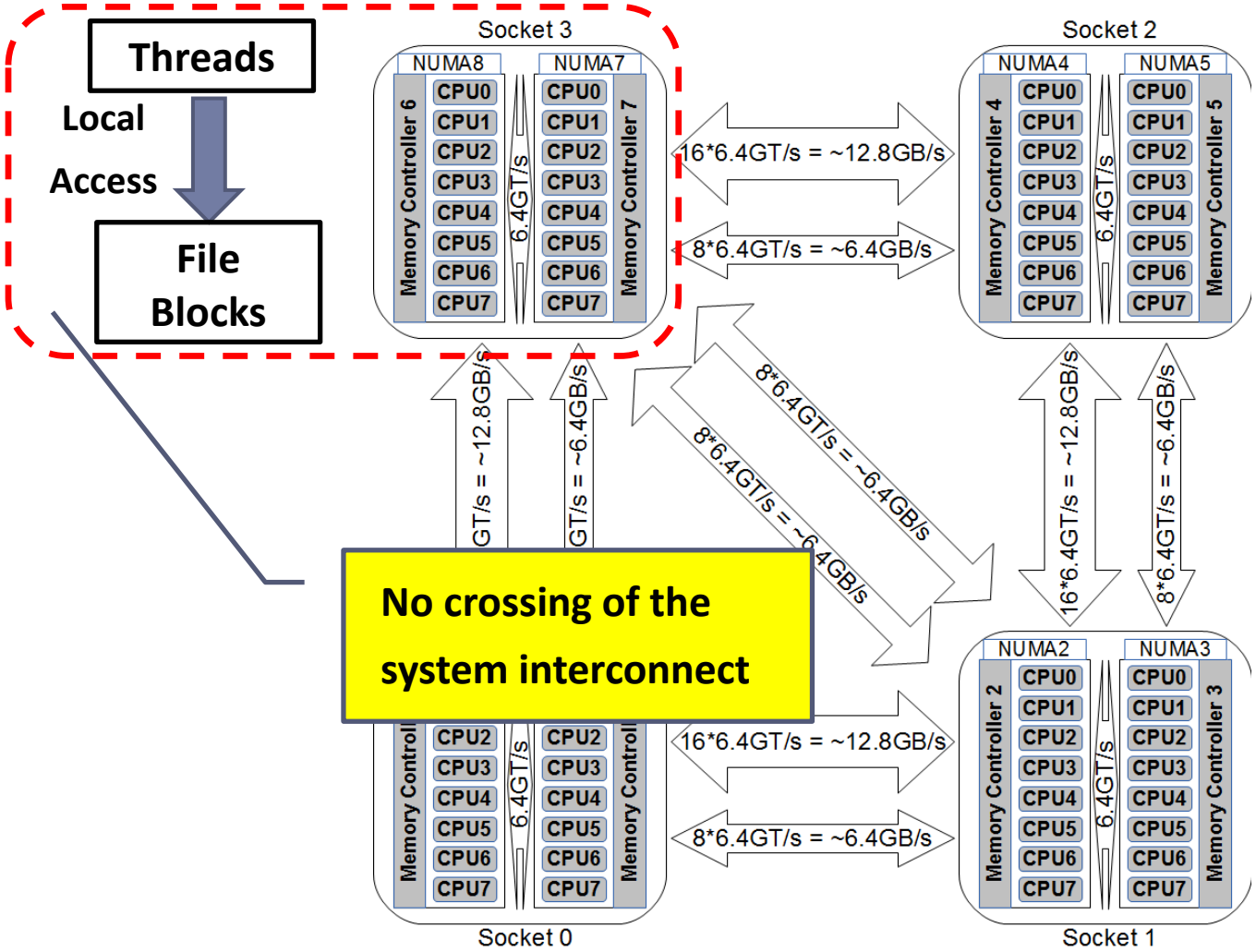
1-2 hops on system interconnect for remote memory accesses

… over **paths capable of <= 12.8 GBytes/sec**

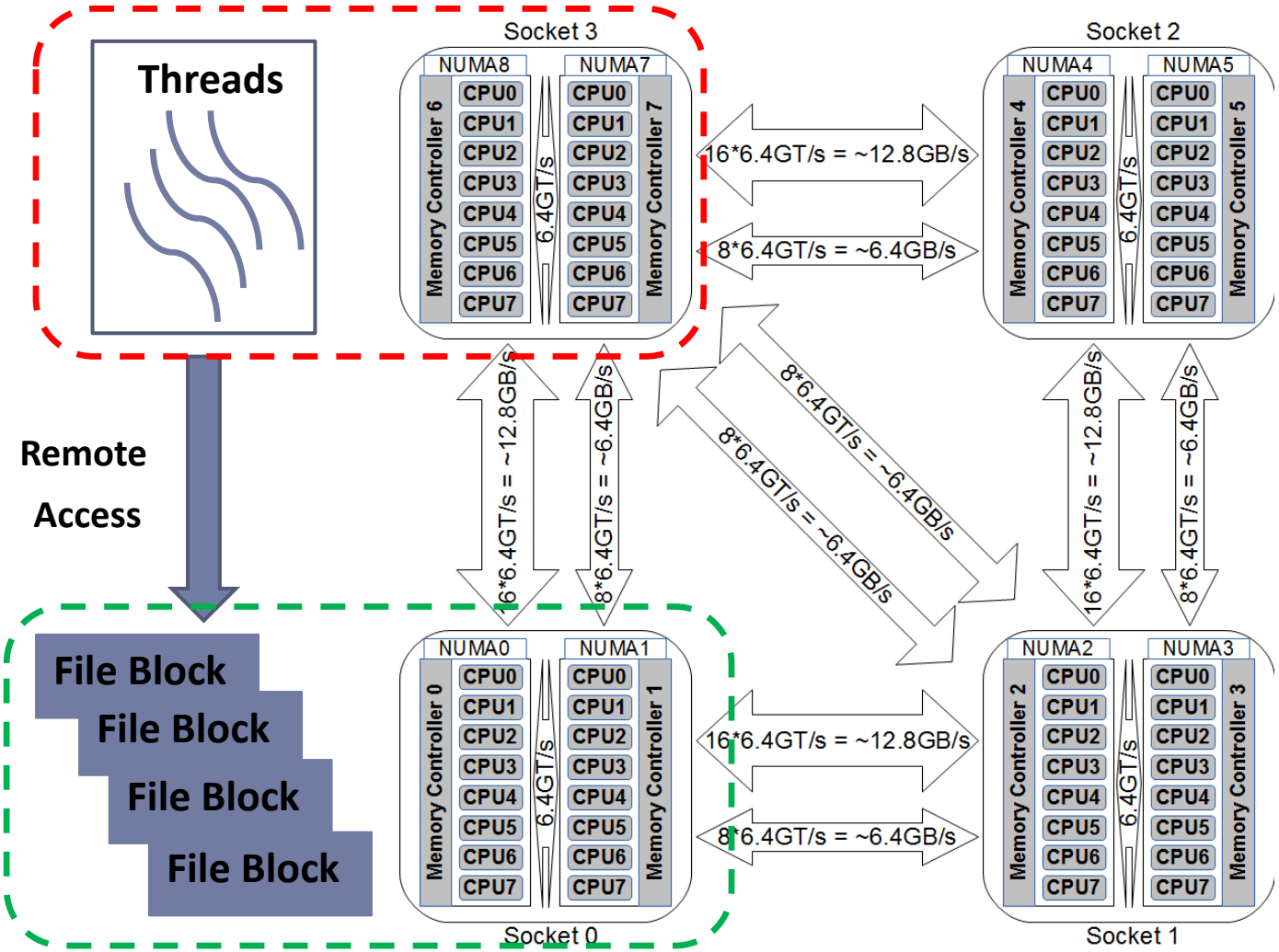
Estimation of local vs remote memory accesses with the **likwid** tool (via H/W performance counters)



Thread/Data Affinity : Local Access Case



Thread/Data Affinity : Remote Access Case



Jericho := JeriCache + JeriFS

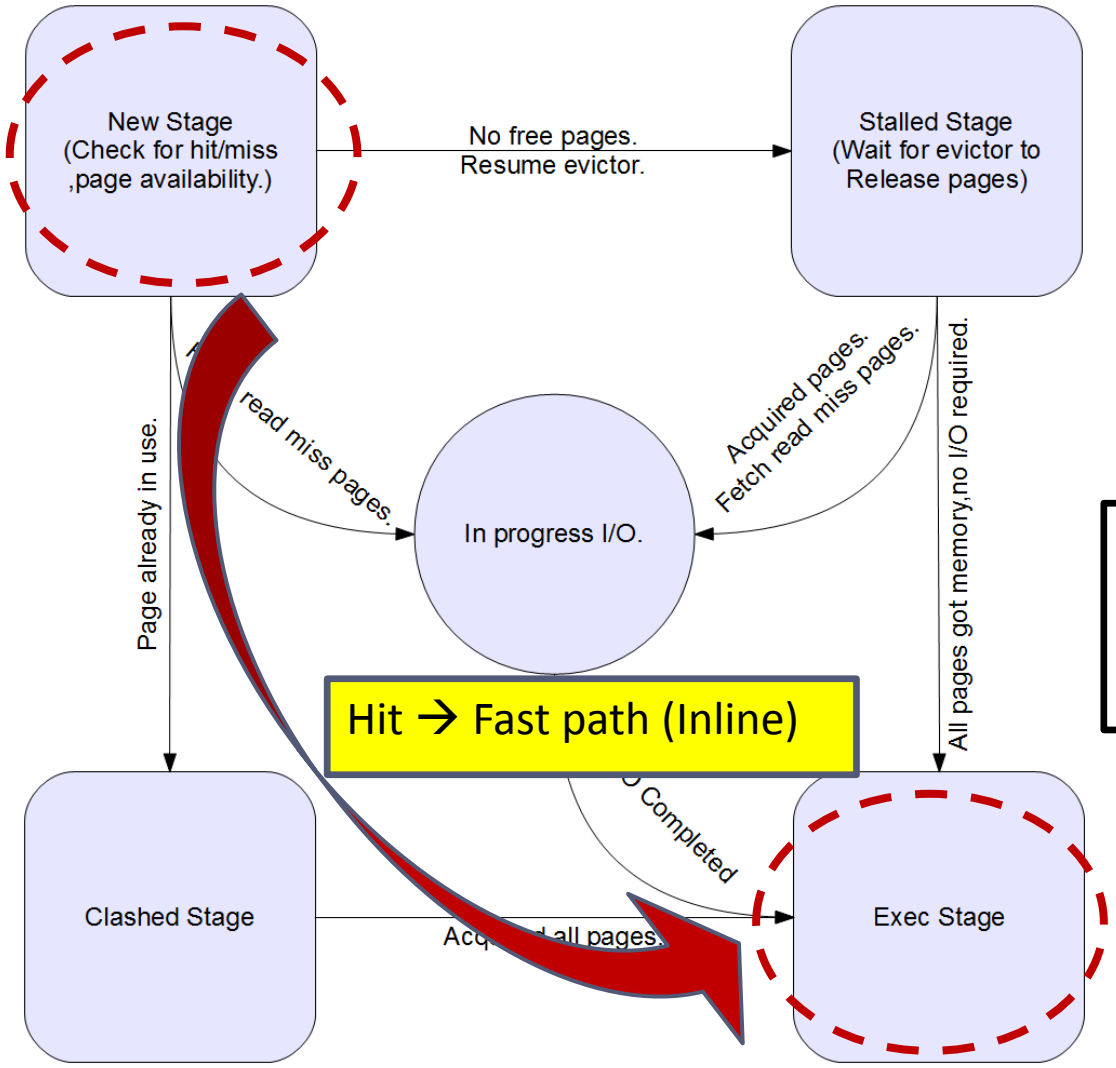
- JeriCache: Mapping of storage block ranges to NUMA nodes
  - Implement policies based on the actual data set of each application
  - Simpler than tracking I/O requests & I/O buffers in Linux kernel
  - **Slice**: a cache instance limited to memory of single NUMA node
  - Caches a specified range of blocks from underlying storage device

- JeriFS filesystem: Manage set of block ranges
  - Determines on the fly, for each I/O, location of issuing task & data
  - Space is divided in block ranges, each mapped to a JeriCache slice
  - Allows files to use specific locations on devices and NUMA nodes
  - + allocator (per-slice)
  - + atomic updates (one journal per-slice + cross-slice coordination)

Locality Management

- Exploit the fact that filesystem code runs in same context (albeit in kernel space) as the user
- Migrate user context without modifying the OS scheduler
- At every IO access, FS checks affinity of issuing thread
  - Migrate threads, not buffers
  - At remote buffer access, FS alters thread's affinity
  - Run only on CPU core of NUMA node where buffer is placed
  - Force a context switch, effectively migrating the process
- When process resumes execution, I/O is guaranteed to only cause local memory references **in JerichoCache**

Design Highlights: JeriCache



Contexts:

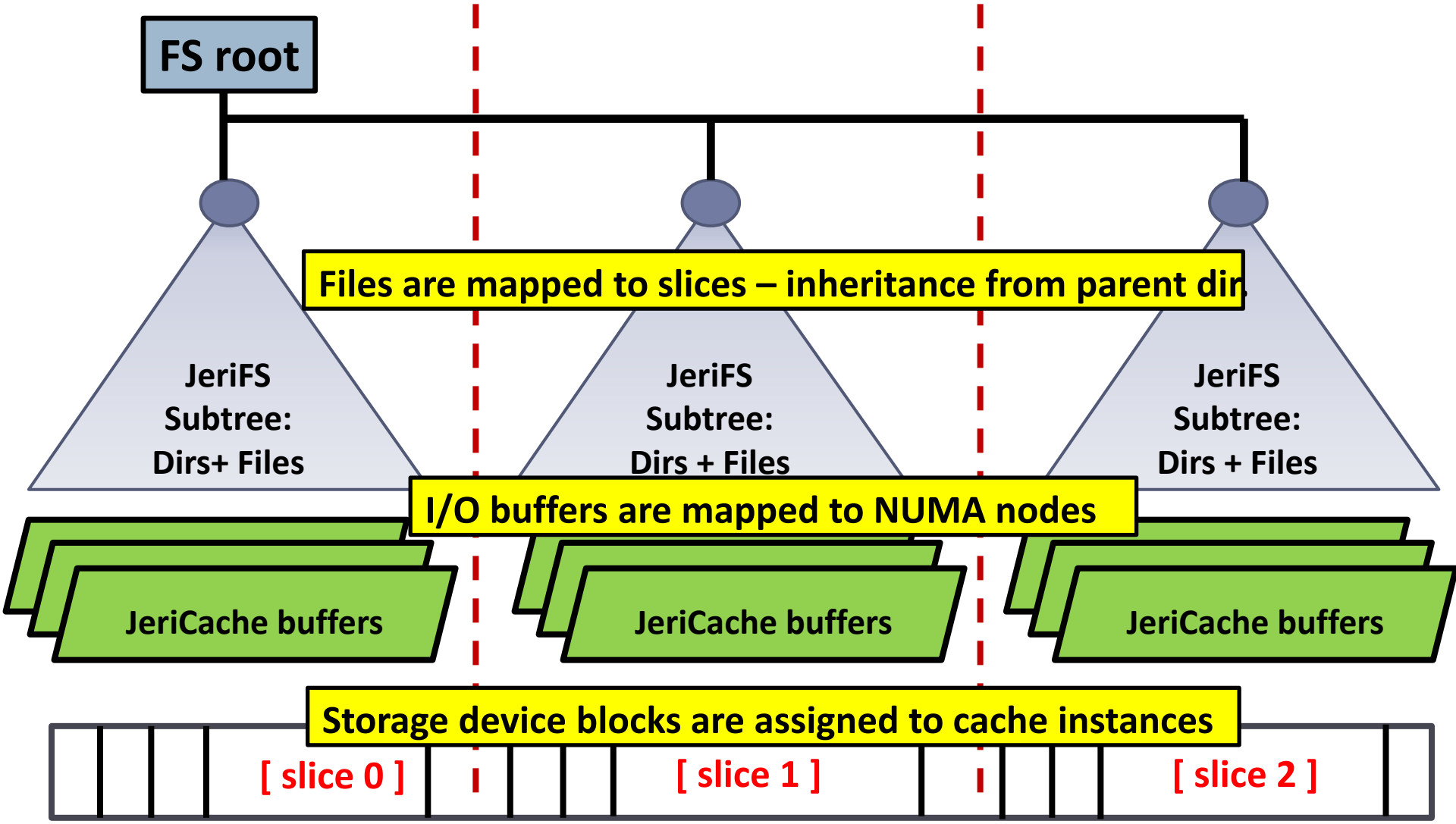
- I/O issuer
- Pipeline thread (one per cache)
- Evictor (one per cache)

Inlining optimization:

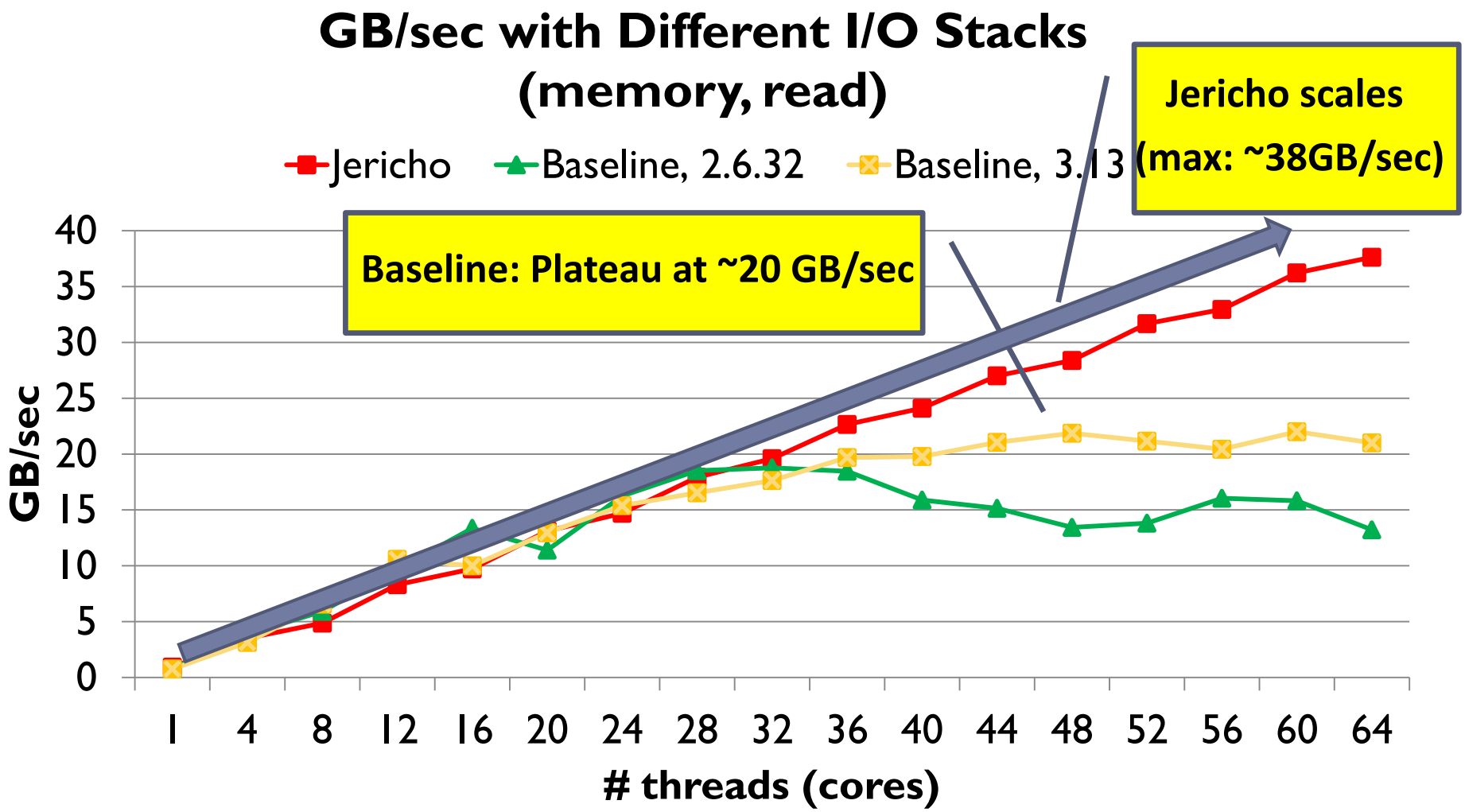
No context switch "Issuer → Pipeline" needed in the case of a cache hit

Eviction proceeds concurrently with request processing (LRU approximation)

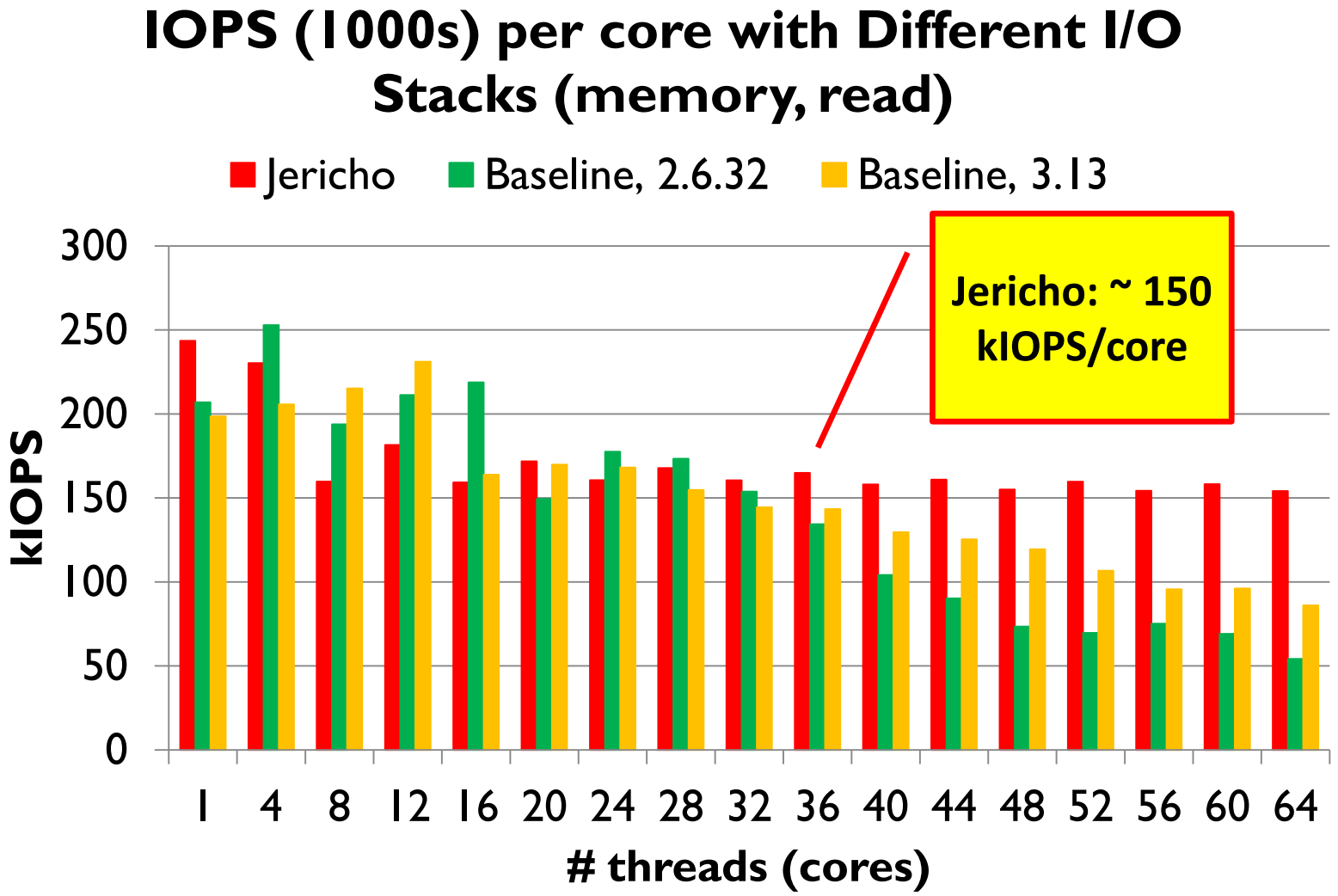
Design Highlights: JeriFS



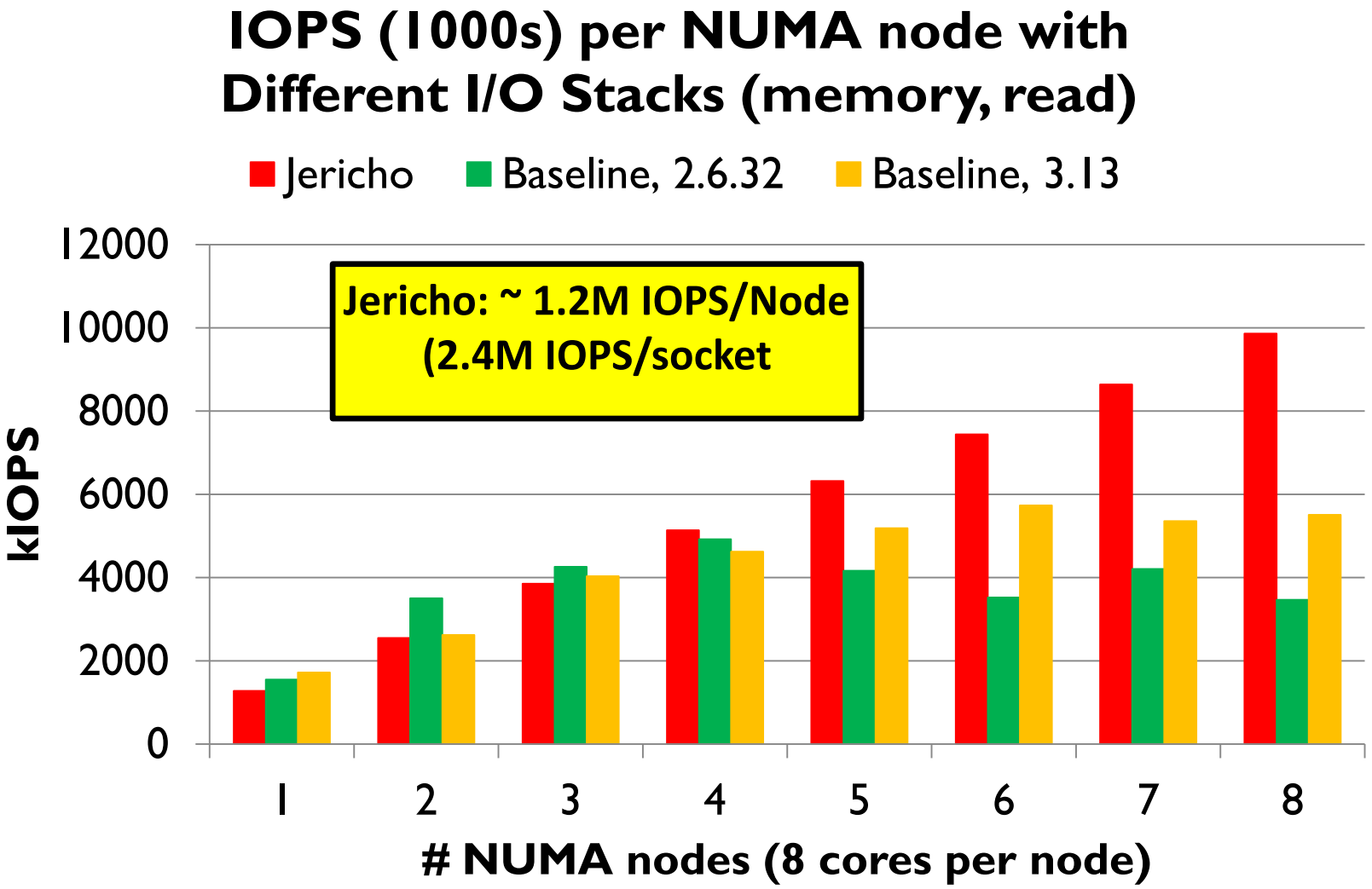
fio, 4KB Random Reads



fio, 4KB Random Reads [alt. view: IOPS/core]



fio, 4KB Random Reads [alt. view: IOPS/node]

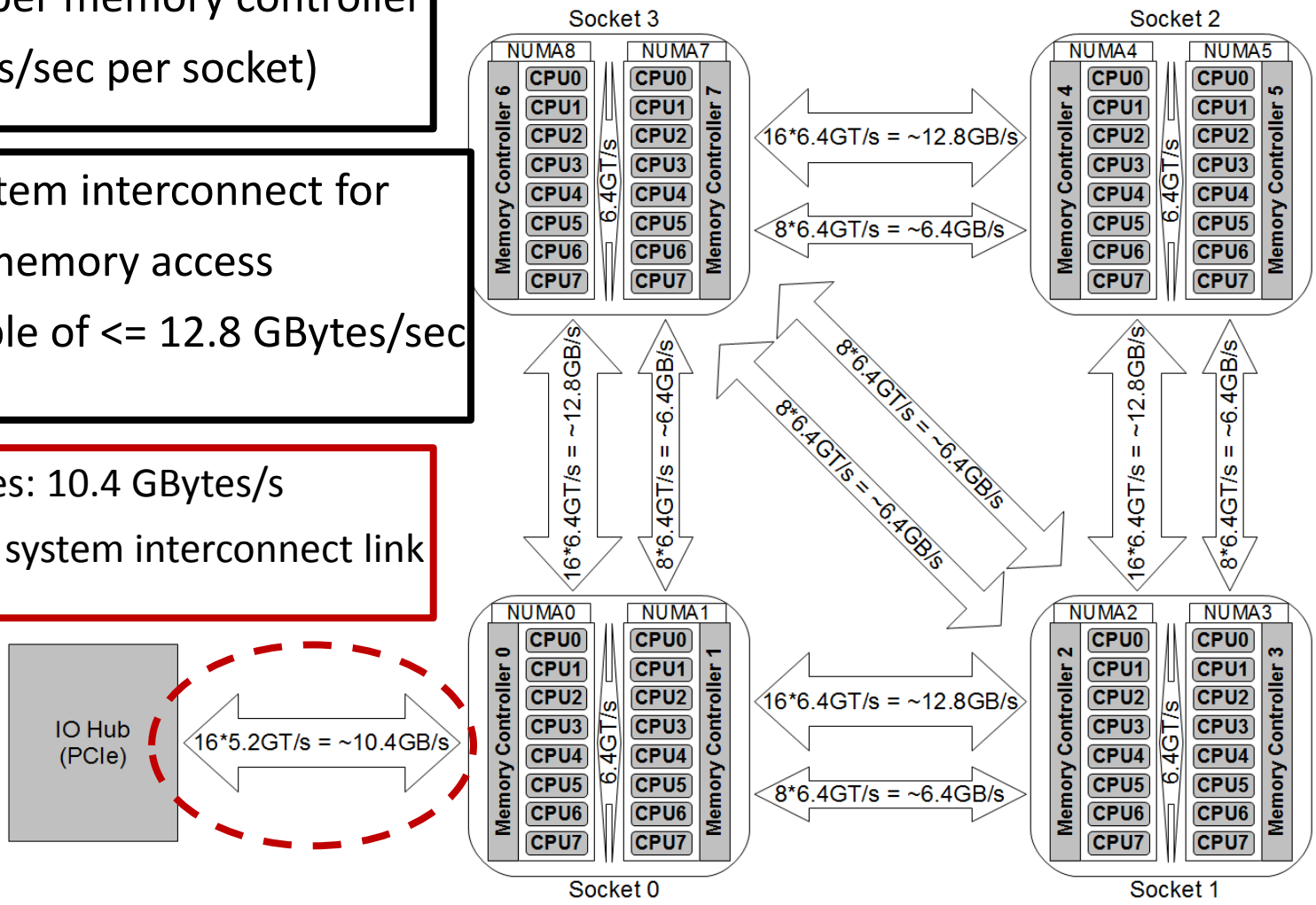


Testbed Machine Architecture (with device I/O)

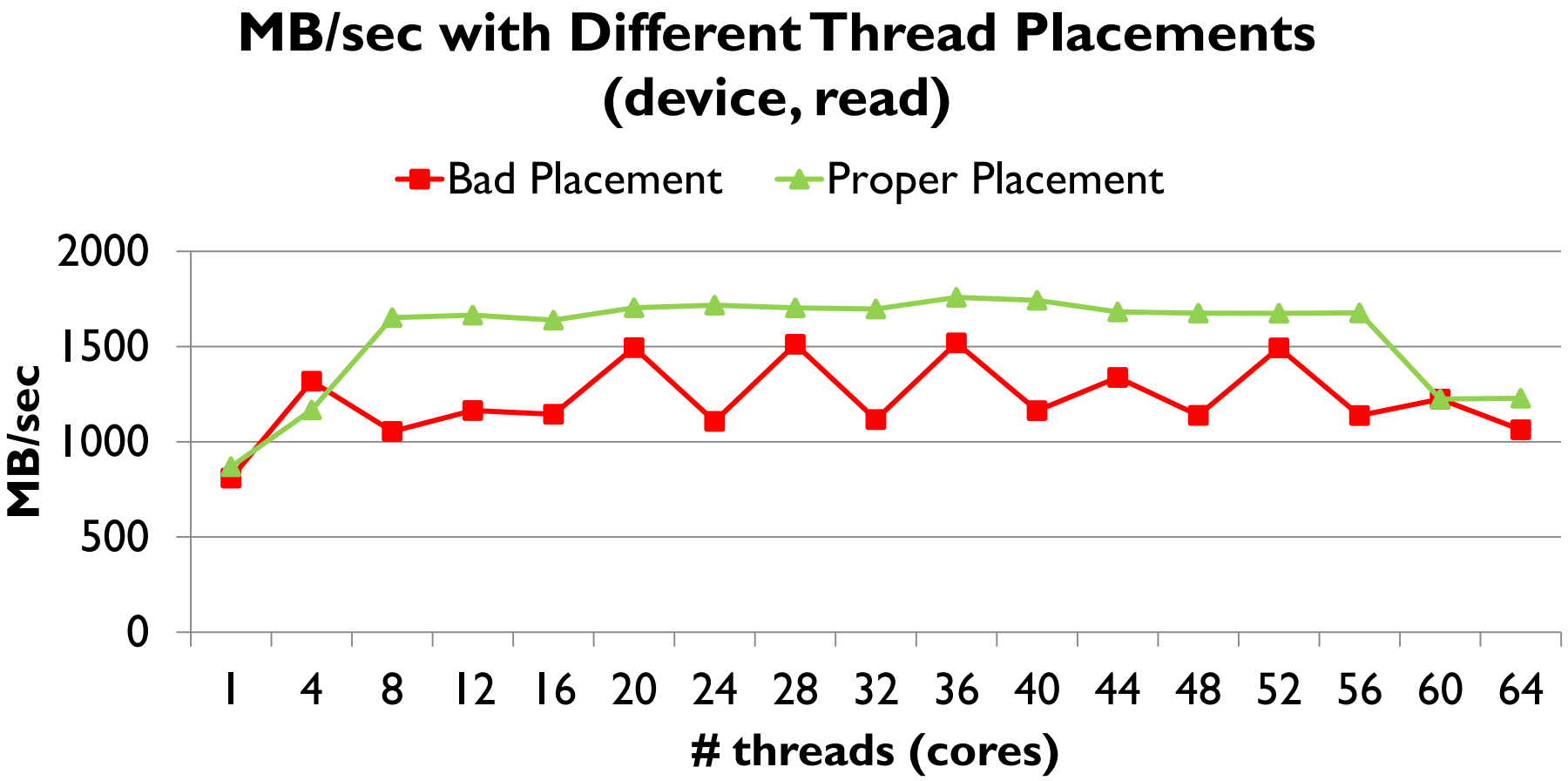
21.3 Gbytes/sec per memory controller
(42.6 Gbytes/sec per socket)

1-2 hops on system interconnect for
remote memory access
… over paths capable of <= 12.8 GBytes/sec

PCIe path to devices: 10.4 GBytes/s
… comparable to a system interconnect link



Is affinity an issue when we have device I/O ?



Affinity is already an issue, and fast devices are becoming more prevalent …

Conclusions

- Scalability limitations of the Linux kernel due to NUMA effects, with 24+ cores
- Thread/data affinity is a major issue for workloads accessing data from memory and fast storage devices
- Improvements achieved with Jericho I/O stack (64 cores):
  - 2.9x for seq. reads, 3.4x for seq. writes
  - (similar results for random IOPS)

Questions ?

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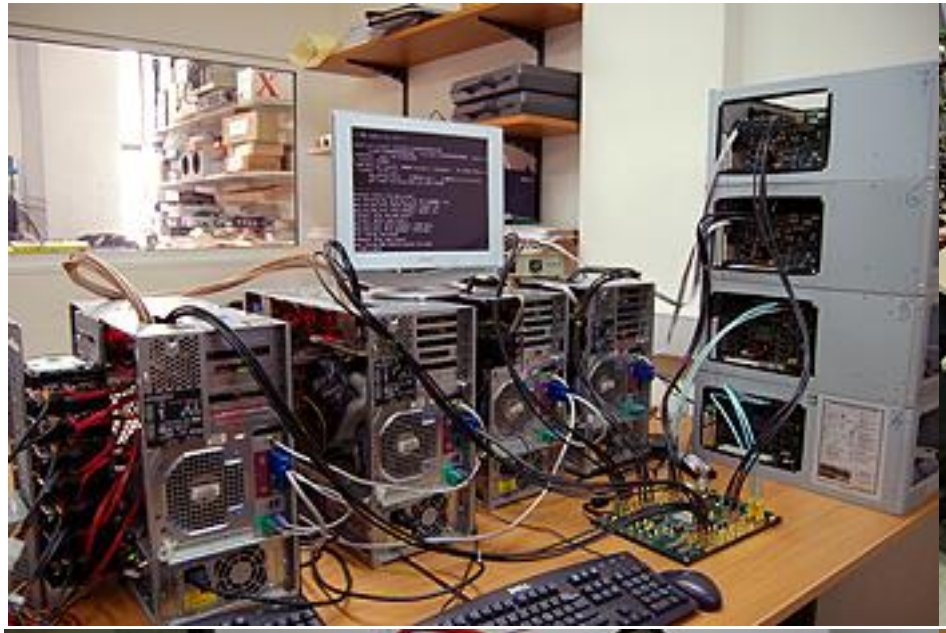
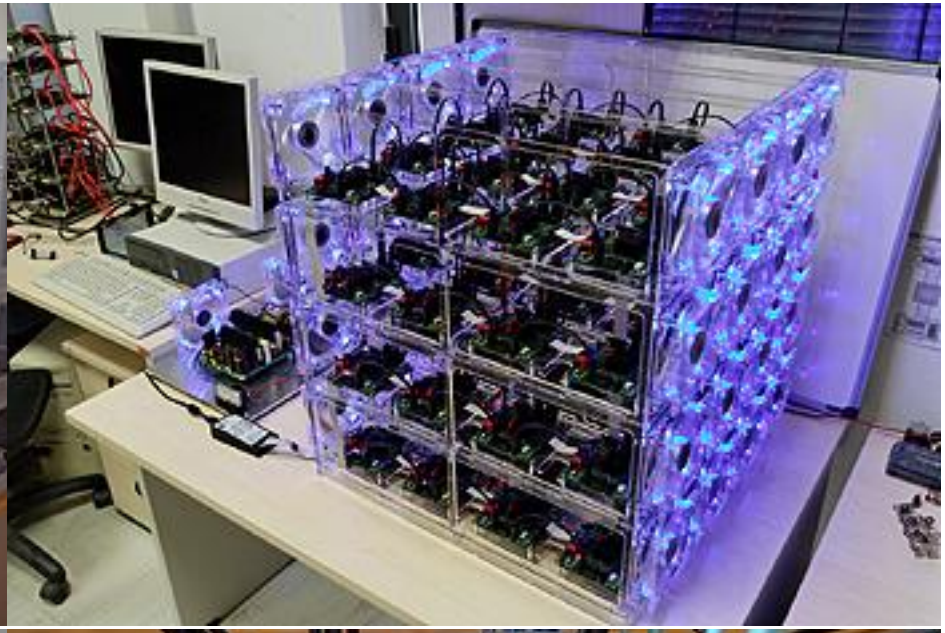
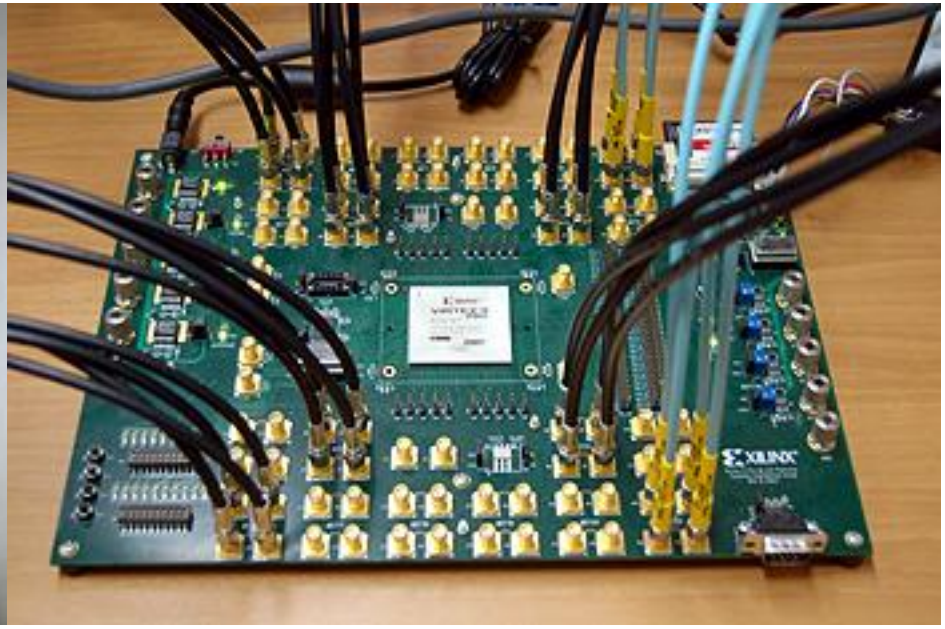




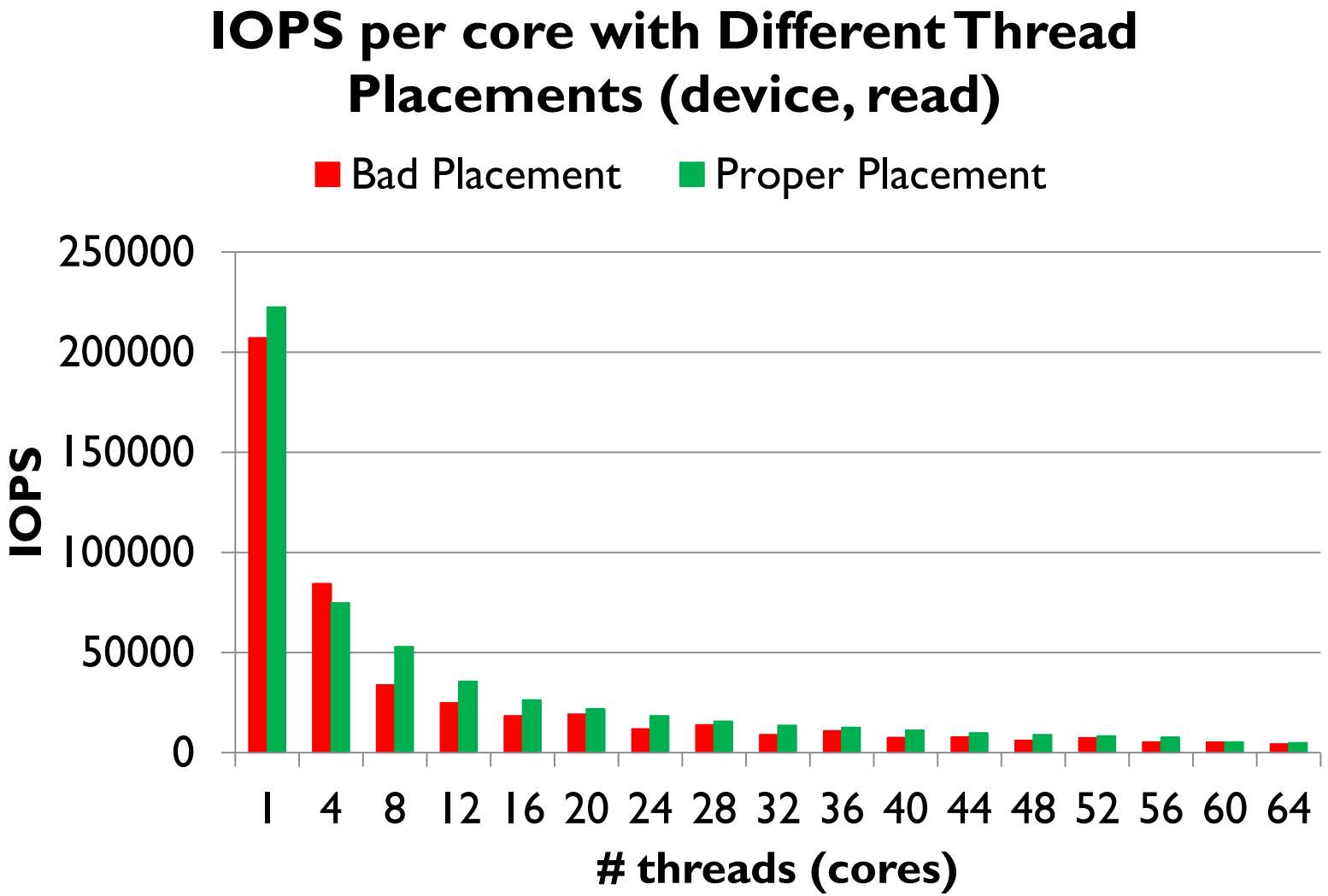


Backup Slides

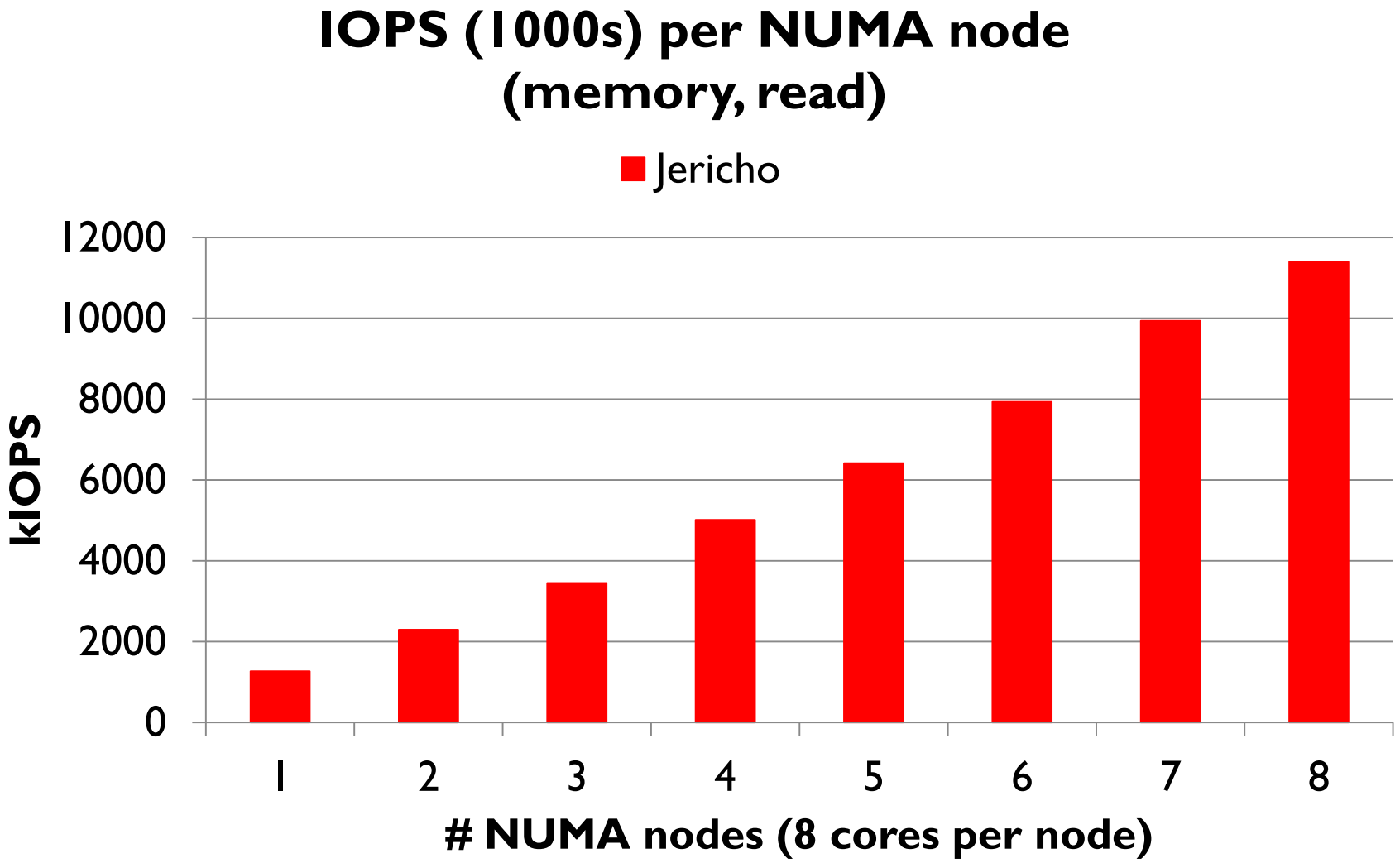
Testbed specifications

Processor socket count	4
Cores/processor socket	16
Motherboard	Tyan S8812
Processor type	AMD Opteron 6272 (2.1GHz)
Processor core caches	L1: 2x32KB (code - per 2 cores), 16KB (data) L2: 4x2MB (per 2 cores) L3: 2x8MB (per 4 cores)
DRAM (DDR3, # DIMMs)	Up to 16 (up to 512 GB, currently 256 GB)
Interconnect type	HyperTransport 3.1
Interconnect topology	Point-to-Point, asymmetric
Storage Devices	16 Solid State Disks (Samsung 830 Series) in RAID0 configuration
Storage Controllers	2x LSI MegaRAID SAS 9265-8i controllers, each with 8 Solid State Disks attached

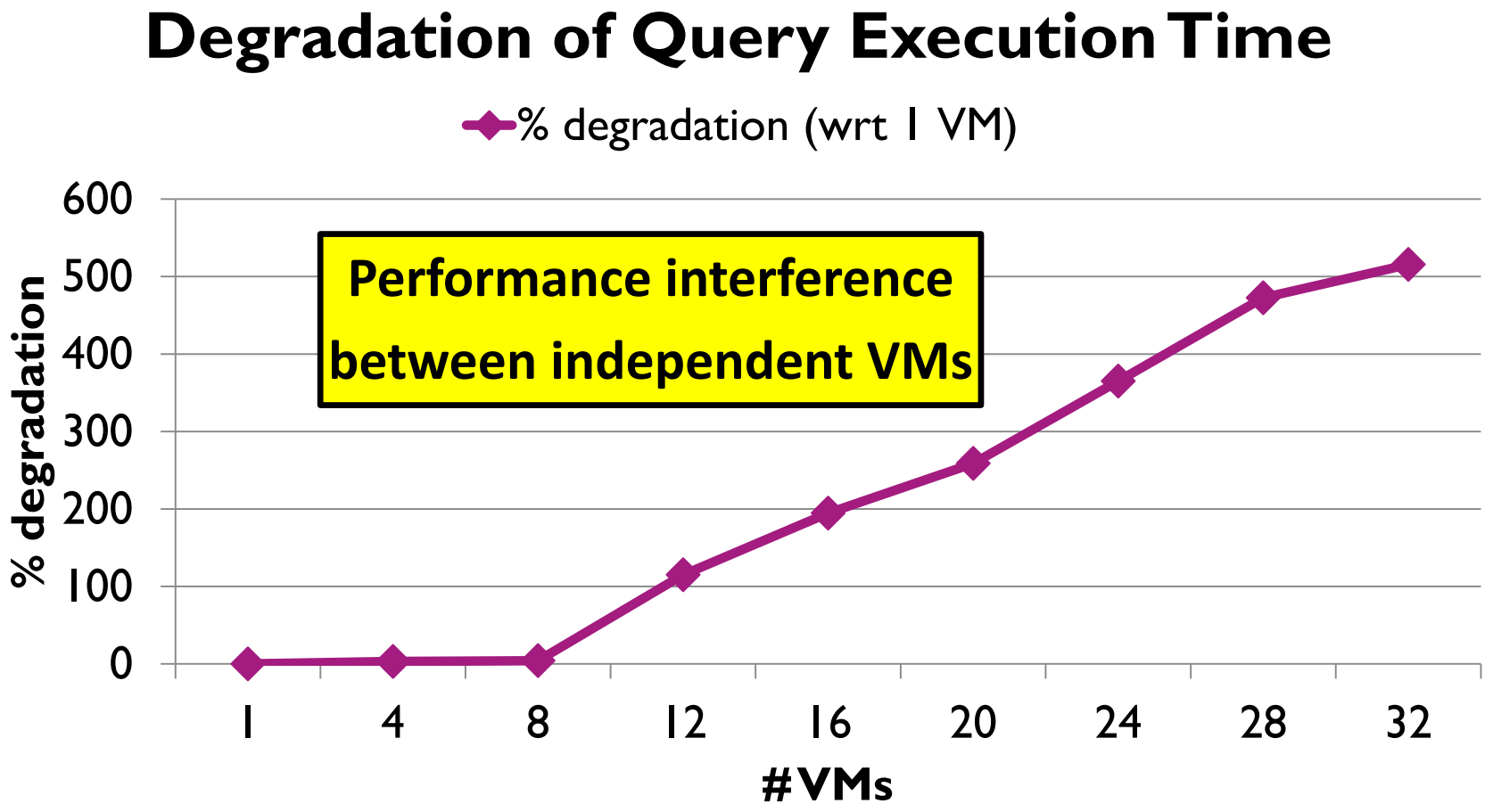
Is affinity an issue when we have device I/O ?
[alt. view: IOPS / core]



Scaling with the number of NUMA nodes

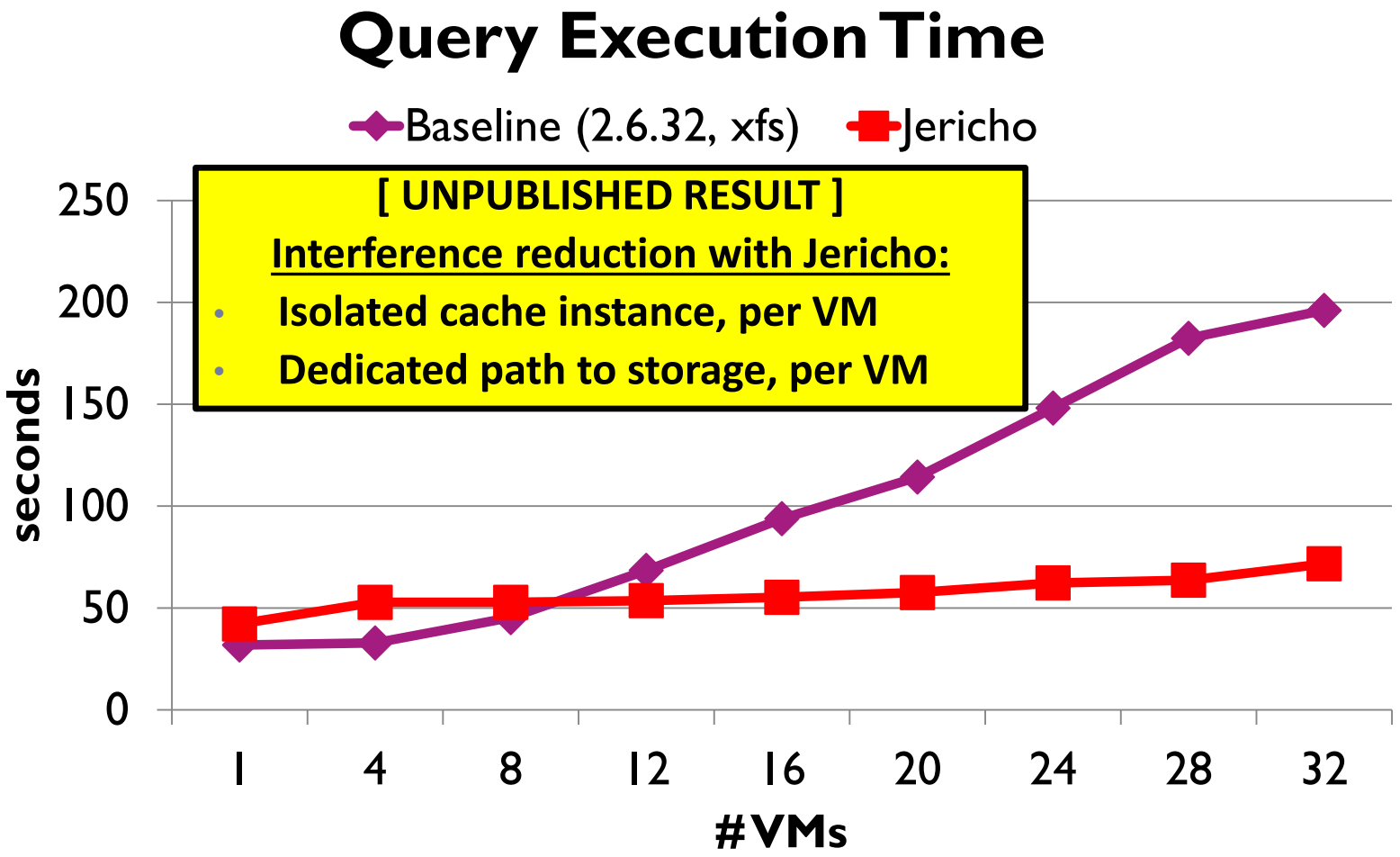


Independent Virtual Machines (no device I/O)

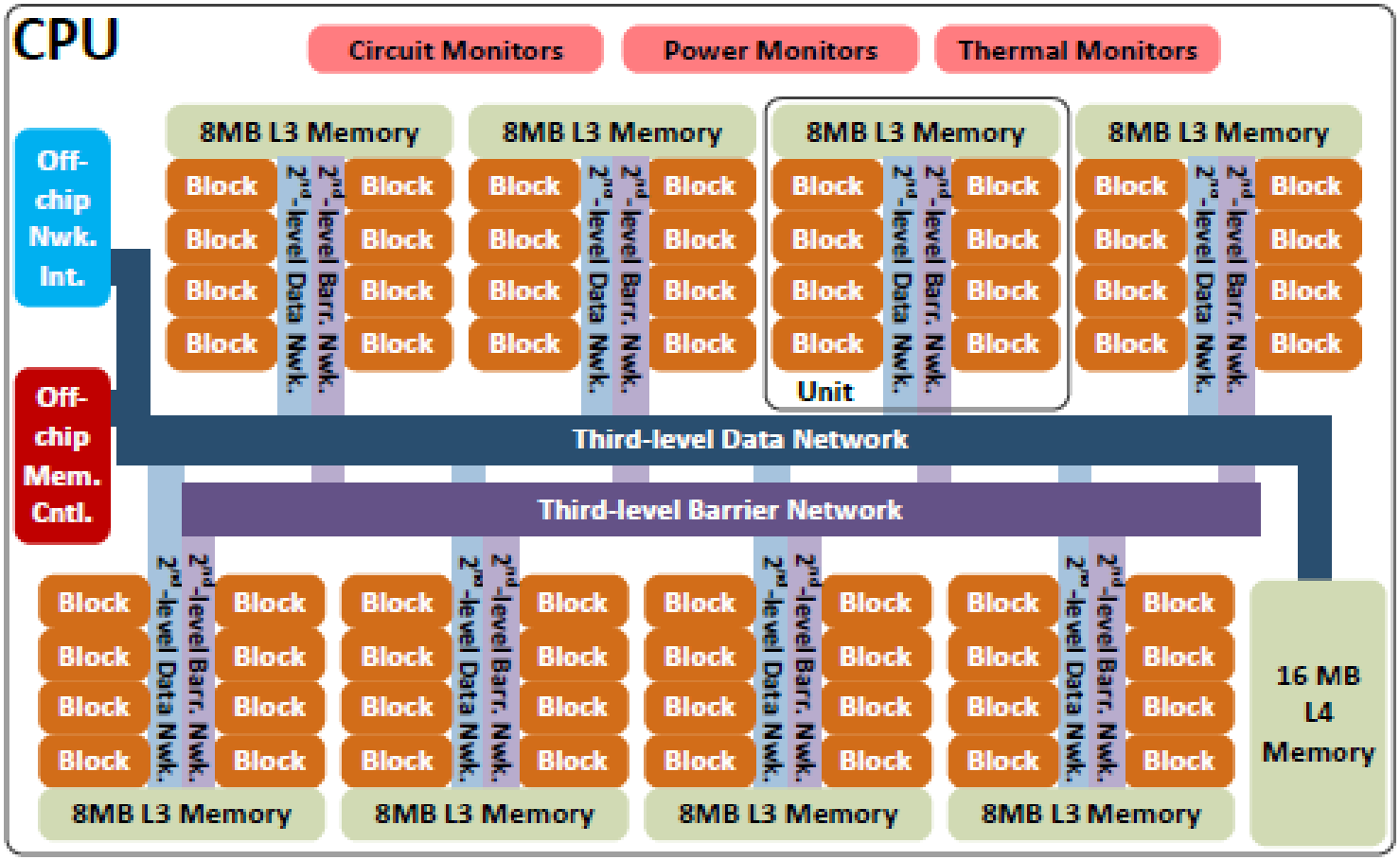


[TPC-H/Q5, 7GB database (PostgreSQL), kvm, Linux 2.6.32]

Independent Virtual Machines (no device I/O)



NUMA effects will become even more pronounced



- N. Carter, et al: **Runnemede: An Architecture for Ubiquitous High-Performance Computing**
  - In Proceedings of the IEEE International Symposium on High Performance Computer Architecture (HPCA), 2013