Performance Analysis and Tuning – Part I

Containers are Linux, run/optimized and tuned just like Linux.

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Agenda: Performance Analysis Tuning Part I

- Part I - Containers are Linux, run/optimized and tuned just like Linux.
  - RHEL Evolution 5->6->7 – Hybrid Clouds Atomic / OSE / RHOP
    - System Performance/Tools Tuned profiles
  - NonUniform Memory Access (NUMA)
    - What is NUMA, RHEL Architecture, Auto-NUMA-Balance
  - Network Performance – noHZ, Throughput vs Latency-performance
    - Tuna – IRQ pinning, alter priorities, monitor
    - NFV w/ DPDK fastdata path
    - Perf advanced features, BW monitoring, Cache-line tears C-2-C
  - “Performance + Scale Experts” - 205C - 5:30-7 PM
  - Free - Soda/Beer/Wine

Red Hat Enterprise Linux Performance Evolution

- RHEL5
  - 1000 Hz, CFQ IO elevator, ktune to change to deadline
  - Numactl, taskset affinity, static hugepages, IRQ balance, oprofile
- RHEL 6
  - Tickless scheduler CFS, islocpus, userspace NUMAD tool
  - Transparent hugepages (THP), numa-IRQ balance, cGroups
  - Tuna, Perf, PCP ship w/ OS
- RHEL 7
  - NoHZ_full for CFQ, islocpu, realtime ship same RHEL7 kernel
  - AutoNuma balance, THP, systemd – Atomic containers

RHEL Performance Workload Coverage

(bare metal, KVM virt w/ RHEV and/or OSP, LXC Kube/OSEand Industry Standard Benchmarks)

Benchmarks – code path coverage

- CPU – linpack, lmbench
- Memory – lmbench, McCalpin STREAM
- Disk IO – iozone, fio – SCSI, FC, iSCSI
- Filesystems – iozone, ext3/4, xfs, gfs2, gluster
- Networks – netperf – 10/40Gbit, Infiniband/RoCE, Bypass
- Bare Metal, RHEL6/7 KVM, Atomic Containers
- White box AMD/Intel, with our OEM partners

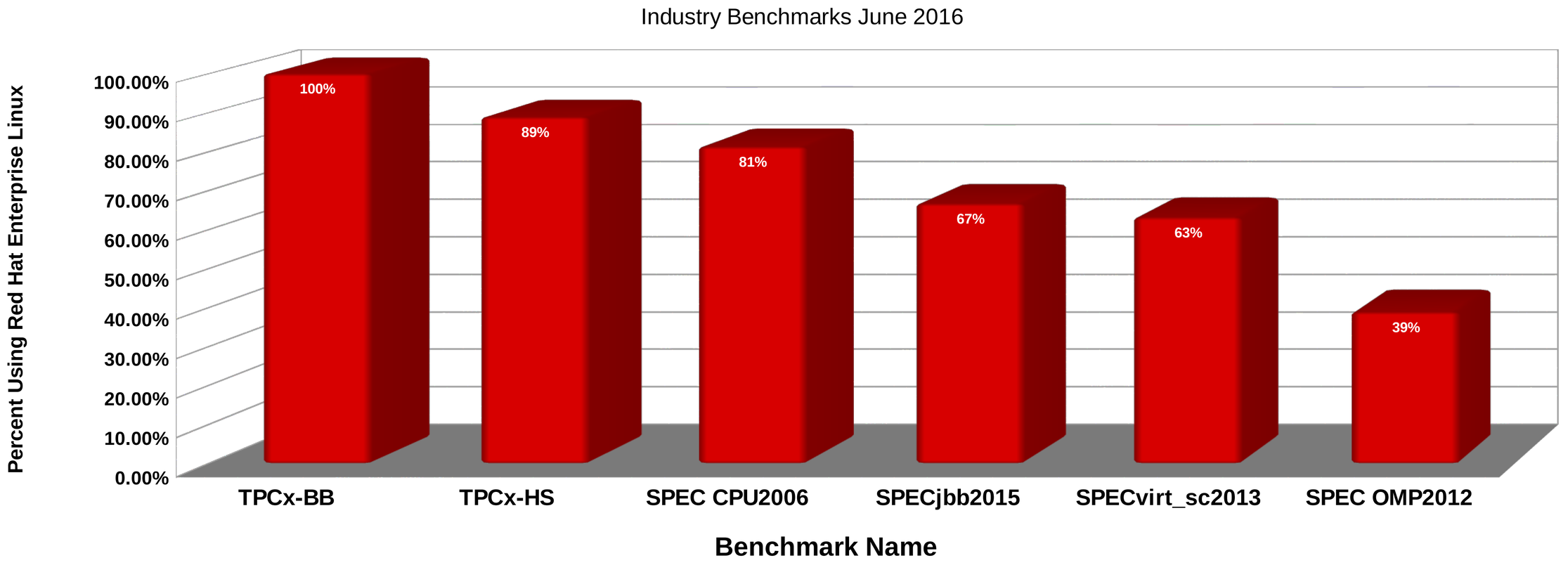
Application Performance

- Linpack MPI, HPC workloads
- AIM 7 – shared, filesystem, db, compute
- Database: DB2, Oracle 11/12, Sybase 15.x , MySQL, MariaDB, Postgrs, MongoDB
- OLTP – TPC-C, TPC-VMS
- DSS – TPC-H/xDS
- Big Data – TPCx-HS, Bigbench
- SPEC cpu, jbb, sfs, virt, cloud
- SAP – SLCS, SD, Hana
- STAC = FSI (STAC-N)
- SAS mixed Analytic, SAS grid (gfs2)

RHEL / Intel Benchmarks Broadwell EP/EX

red-hat-delivers-high-performance-on-critical-enterprise-workloads-with-the-latest-intel-xeon-e7-v4-processor-family

Benchmark publications using Red Hat Enterprise Linux over past 24 months



#1 performance and price/performance on non-clustered TPC-H@1000GB

HPE, Microsoft, and Red Hat deliver first-ever result with SQL Server 2017 Enterprise Edition

Winning partnerships!

HPE ProLiant DL380 Gen9

Microsoft

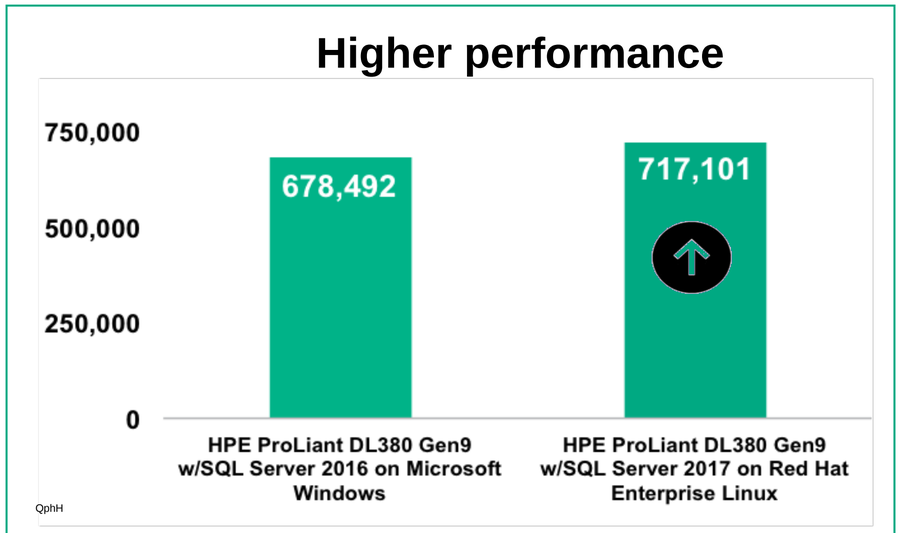
SQL Server 2017 Enterprise Edition

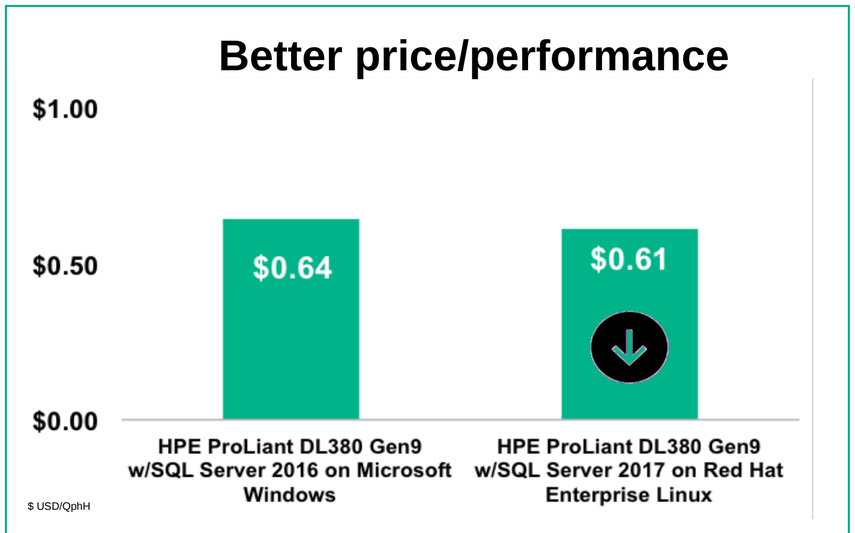
redhat.

Red Hat Enterprise Linux 7

Key performance takeaways

- –SQL Server 2017 on Red Hat Enterprise Linux surpasses the previous #1 TPC-H@1000GB result achieved with SQL Server 2016
  - –6% higher performance
  - –5% better price/performance
- –The first and only result with Microsoft SQL Server 2017 Enterprise Edition
- –Results achieved on similarly configured servers with two Intel® Xeon® E5-2699 v4 processors





Read the performance brief at hpe.com/servers/benchmarks.

Hewlett Packard Enterprise

Microsoft

redhat.

Pointers – Benchmarks / Partner Results

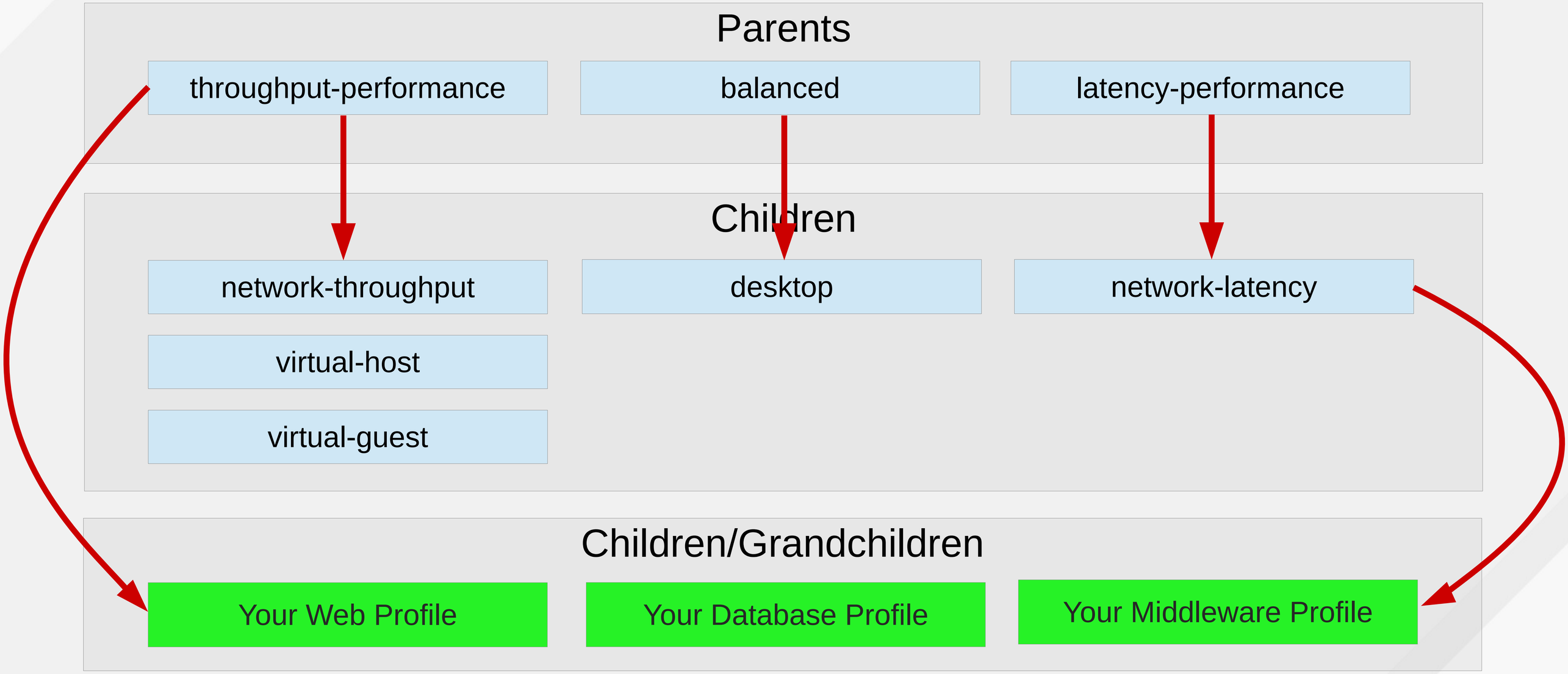
- SPEC – Systems Performance Evaluation Committee
  - http://www.spec.org
- TPC – Transaction Processing Council
  - http://www.tpc.org
- STAC – Security Technology Analysis Center
  - https://stacresearch.com/
- Intel - http://www.intel.com/content/www/us/en/benchmarks/
- HP
  - http://hpe.com/servers/benchmarks New World Record RH/SQLserver2017 http://h20195.www2.hpe.com/V2/GetDocument.aspx?docname=a00007695ENW

Performance Tools - Tuned

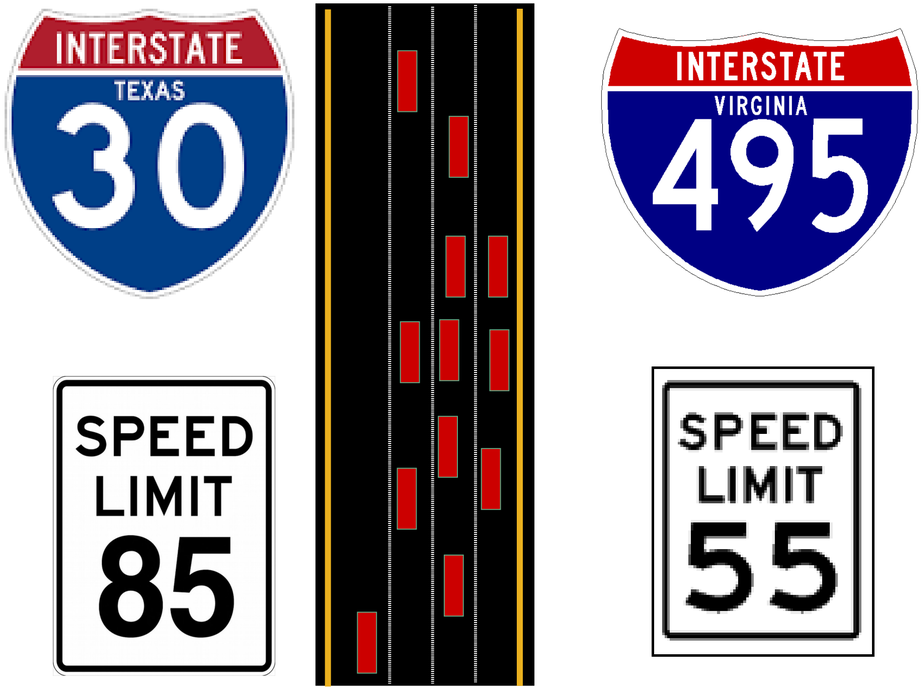
tuned is a tool to dynamically tune Red Hat Enterprise Linux.

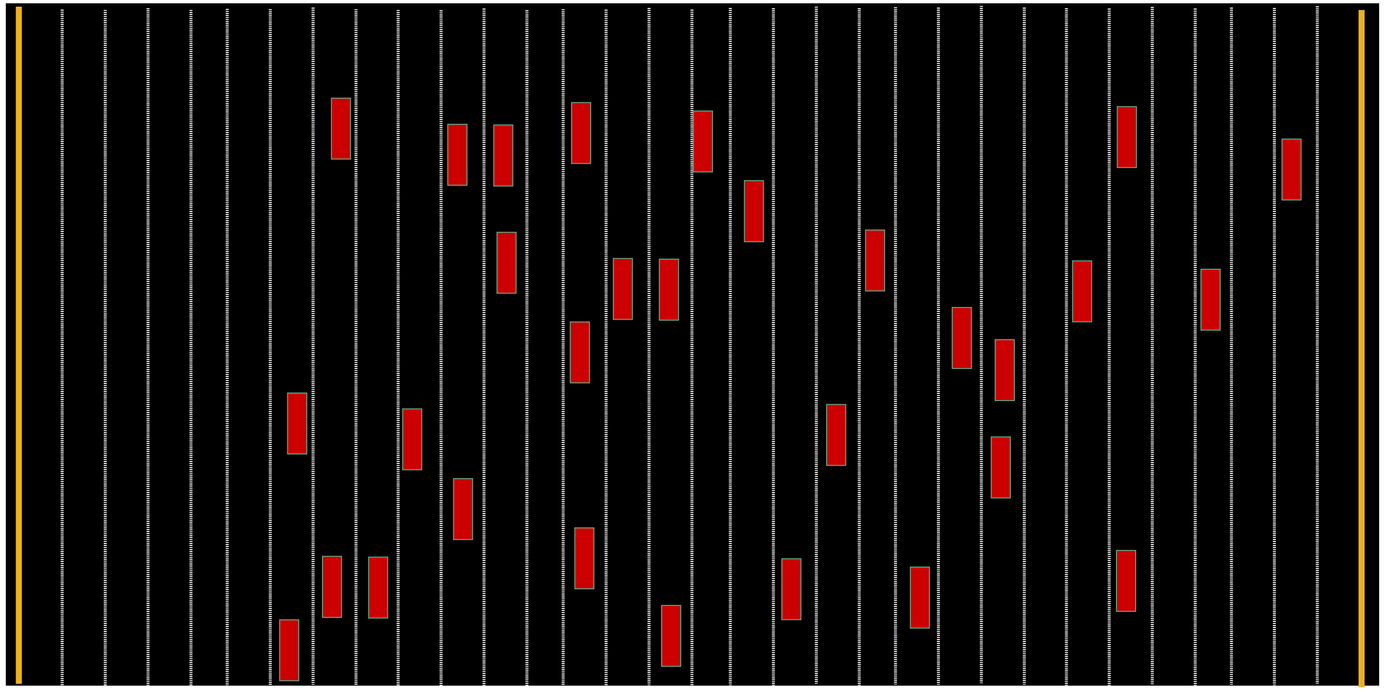
You could improve workload performance by applying one of the predefined profiles or use those that you've written yourself

Tuned: Your Custom Profiles



Performance Metrics - Latency==Speed - Throughput==Bandwidth





- **Latency – Speed Limit**
  - **Ghz of CPU, Memory PCI**
  - **Small transfers, disable aggregation – TCP nodelay**
  - **Dataplane optimization DPDK**

Throughput – Bandwidth - # lanes in Highway
- **Width of data path / cachelines**
- **Bus Bandwidth, QPI links, PCI 1-2-3**
- **Network 1 / 10 / 40 Gb – aggregation, NAPI**
- **Fiberchannel 4/8/16, SSD, NVME Drivers**

Tuned Profile Examples

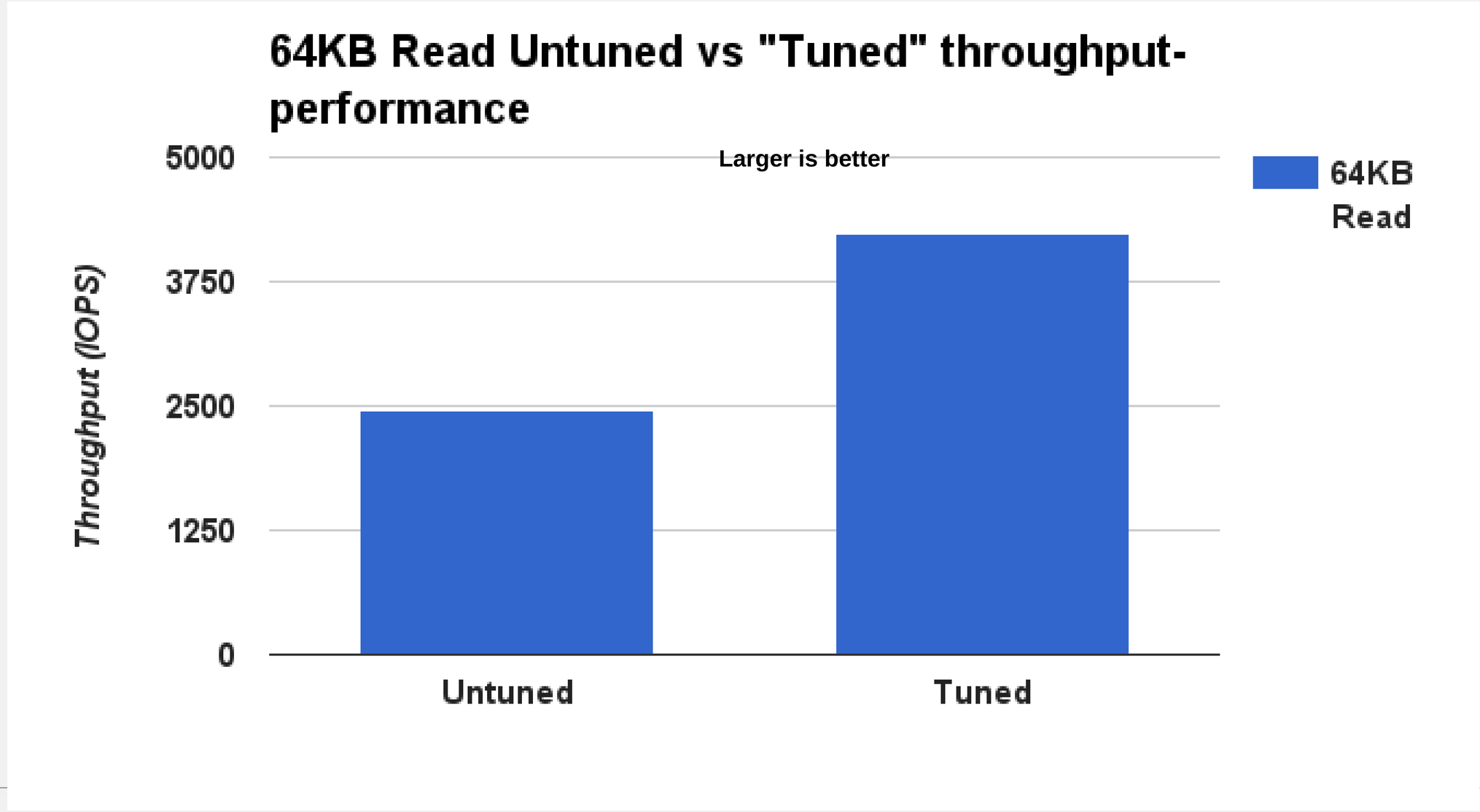
throughput-performance

governor=performance
energy_perf_bias=performance
min_perf_pct=100
transparent_hugepages=always
readahead=>4096
sched_min_granularity_ns = 10000000
sched_wakeup_granularity_ns = 15000000
vm.dirty_ratio = 40
vm.dirty_background_ratio = 10
vm.swappiness=10

latency-performance

force_latency=1
governor=performance
energy_perf_bias=performance
min_perf_pct=100
kernel.sched_min_granularity_ns=10000000
vm.dirty_ratio=10
vm.dirty_background_ratio=3
vm.swappiness=10
kernel.sched_migration_cost_ns=5000000

Tuned: Storage Performance Boost: throughput-performance (default in RHEL7)

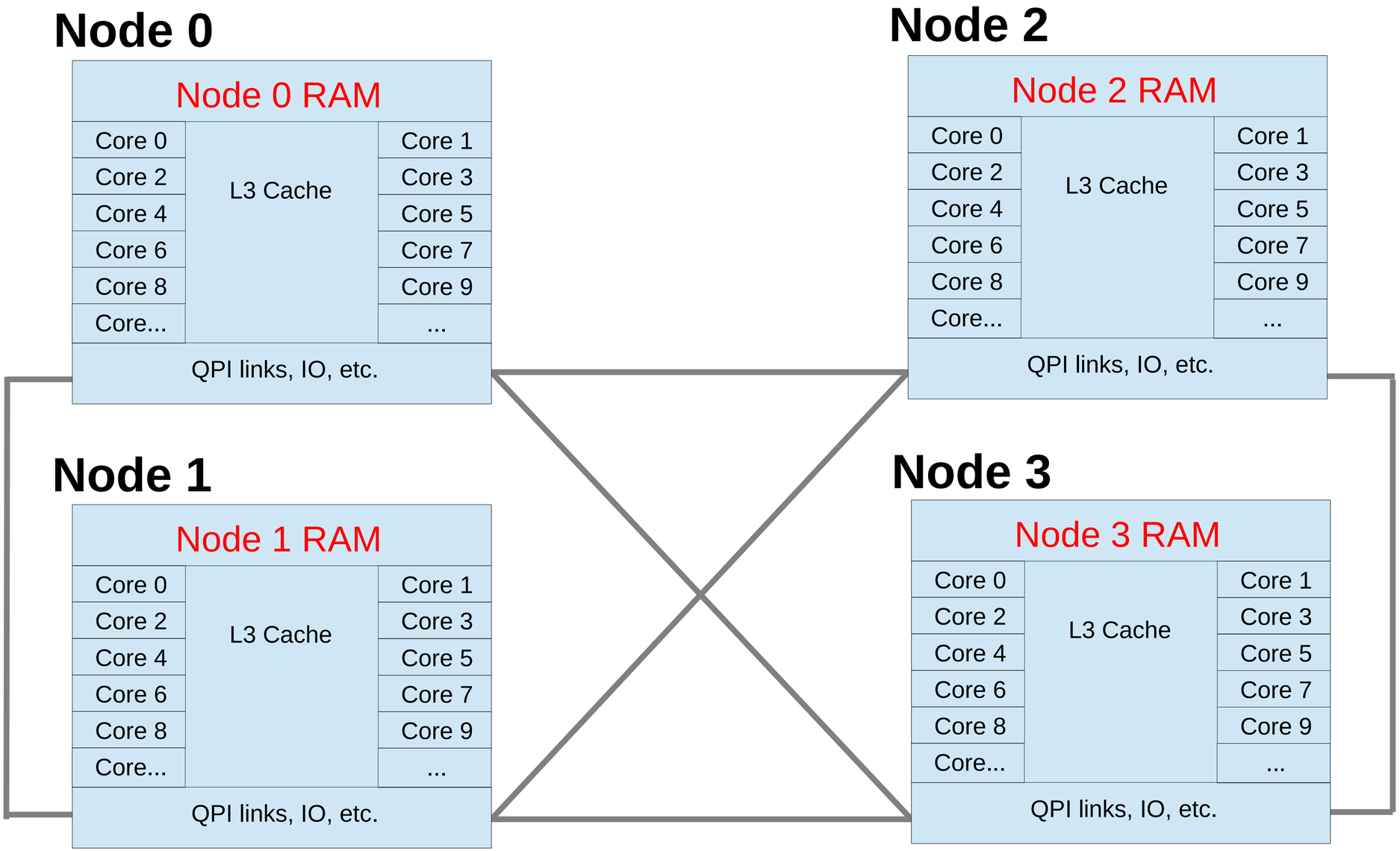


Mapping *tuned* profiles to Red Hat's product portfolio

RHEL Desktop/Workstation **balanced**	RHEL Server/HPC **throughput-performance**	RHEL for Real Time **realtime**
RHV Host, Guest **virtual-host/guest**	RHV **virtual-host**	RHEL for Real Time KVM/NFV **realtime-virtual-host/guest**
Red Hat Storage **rhs-high-throughput, virt**	RHOSP (compute node) **virtual-host**	RHEL + SAP **sap / sap-hana**
RHEL Atomic **atomic-host, atomic-guest**	OpenShift **openshift-master, node**	RHOP - NFV (compute node) **cpu-partitioning**

RHEL 6/7 Non-Uniform Memory Access (NUMA)

Typical Four-Node NUMA System

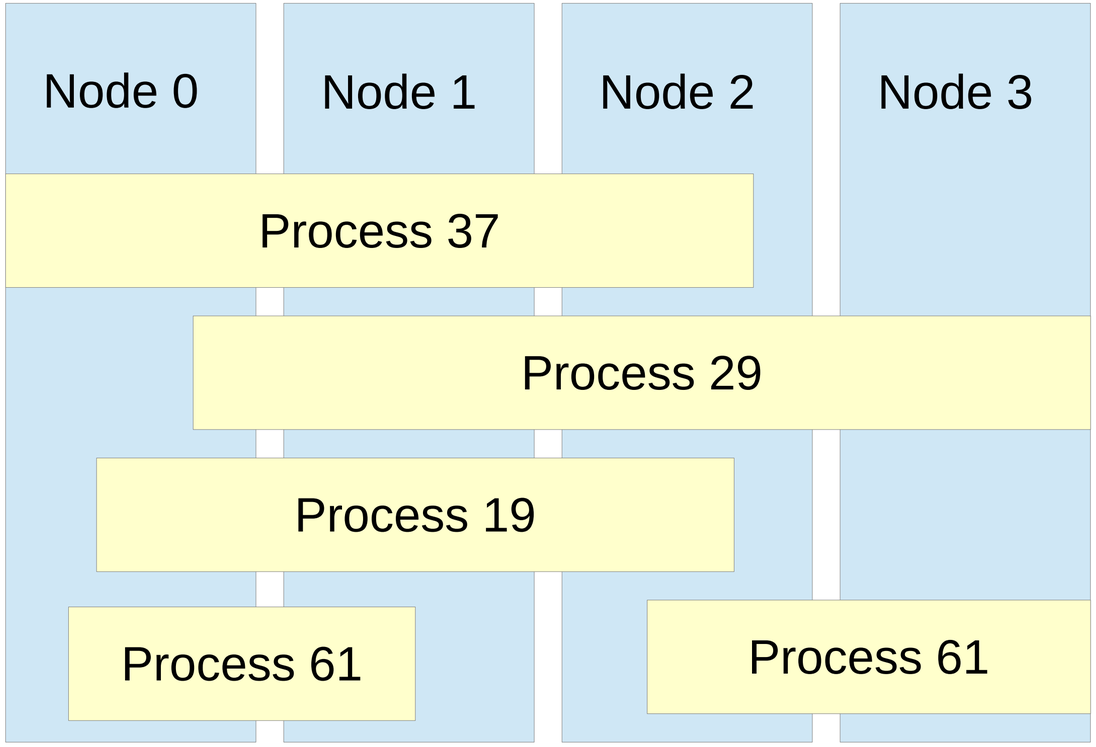


NUMA Especially Important When...

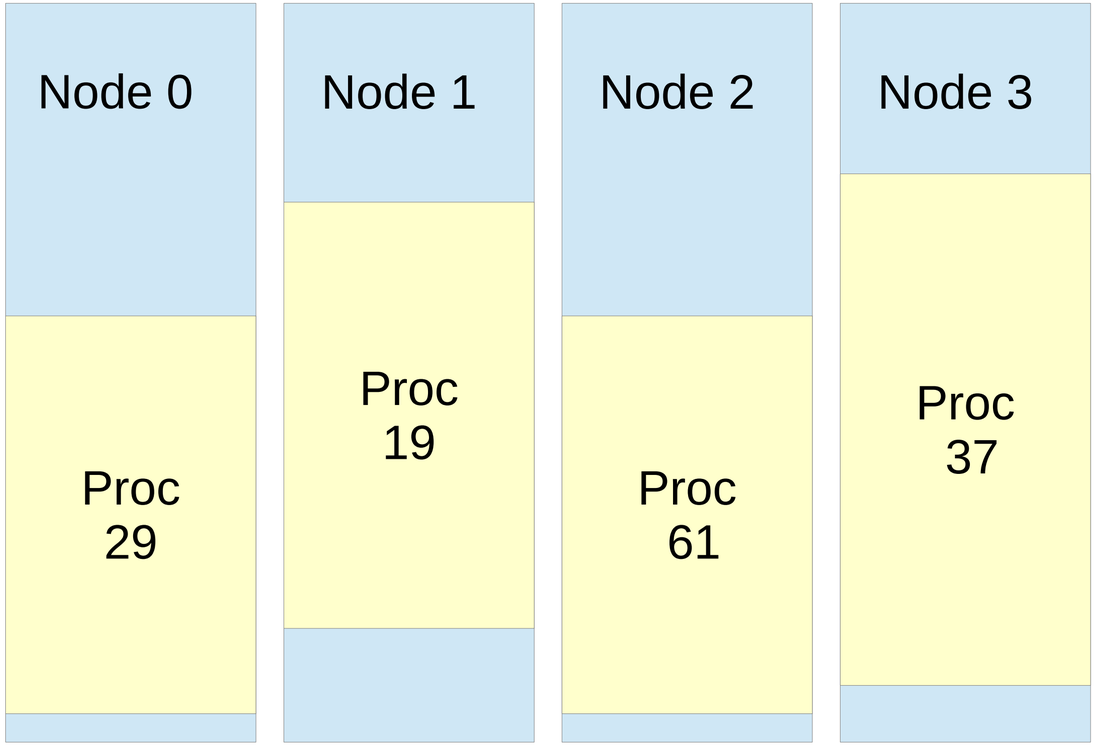
- Server consolidation / replicated processes / virtual guests / containers
  - Multiple processes (re)using mostly local data
  - Multiple workloads / threads consuming fractional subsets of system resources
  - Resource access patterns can be private, localized or contained
  - Ideally, these workloads / threads can be sized to fit within NUMA nodes!
  - Align CPUs, Memory, Devices, and Interrupts for workloads that can be localized to minimize latency, and isolated to avoid interference!
- System-wide monolithic processes with poor data locality are different...

Want to align process memory and CPU threads within NUMA nodes

No NUMA management

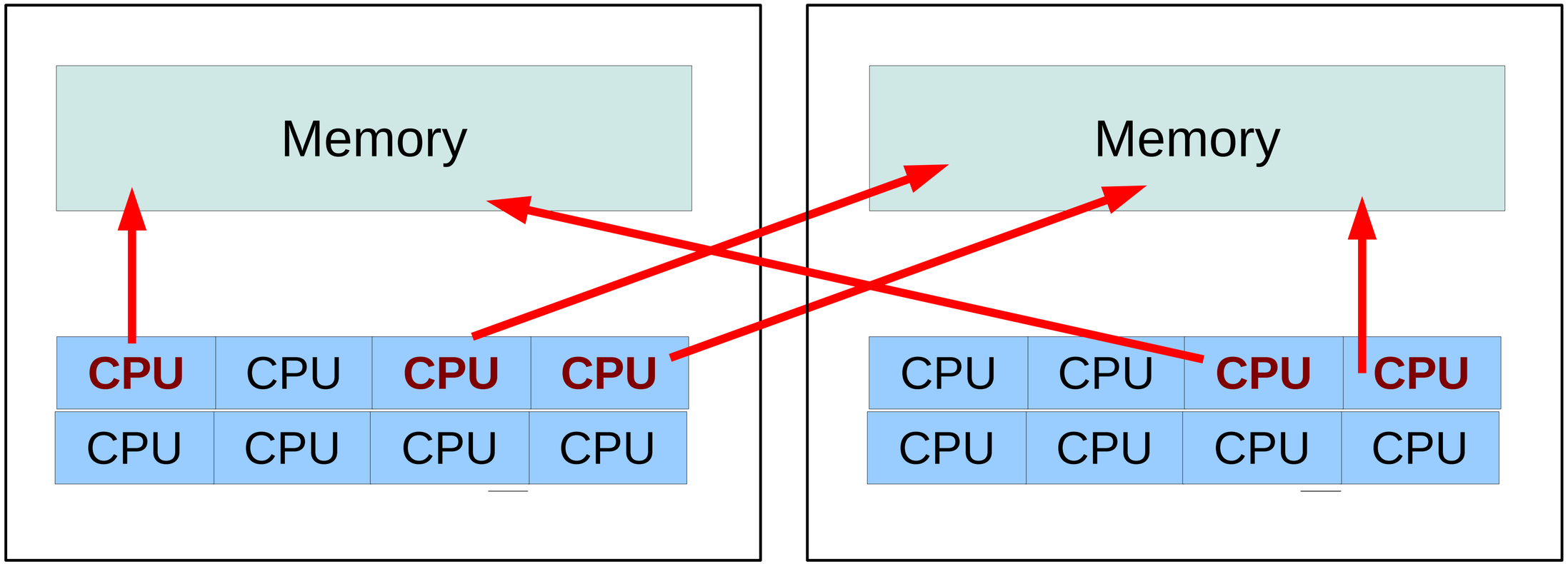


With NUMA management



Non-optimal numa setup

Process 1 in **red**, 5 threads

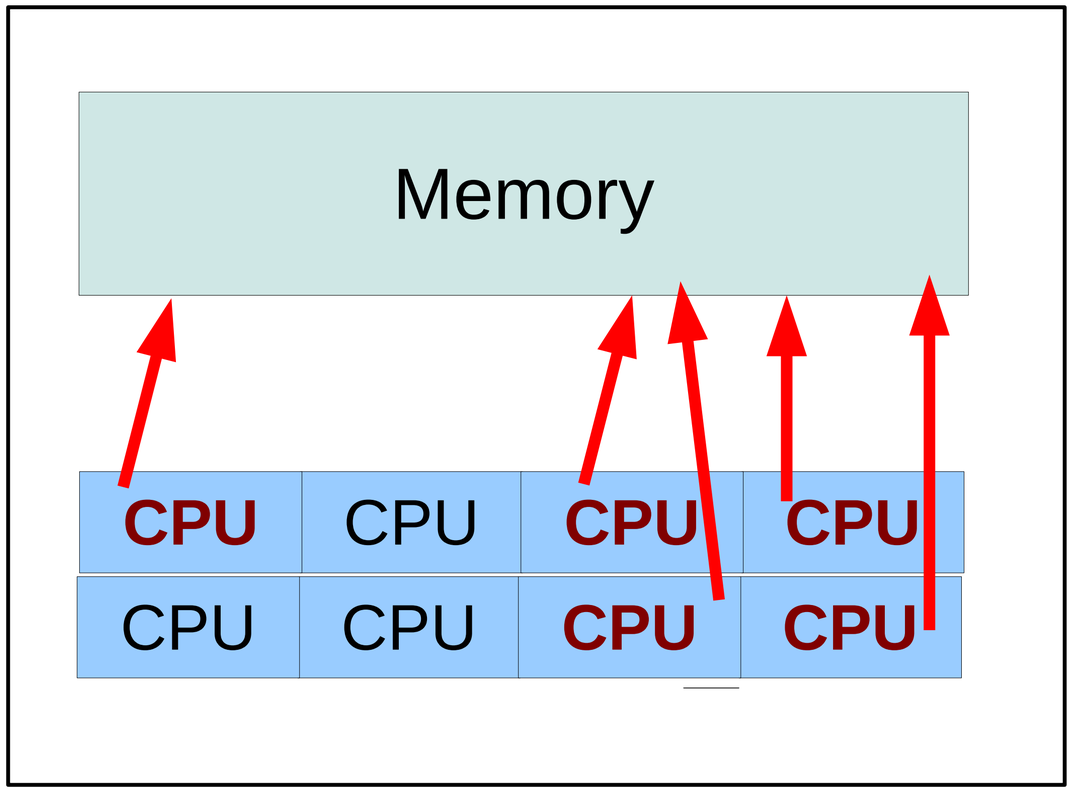


Numa node **0**

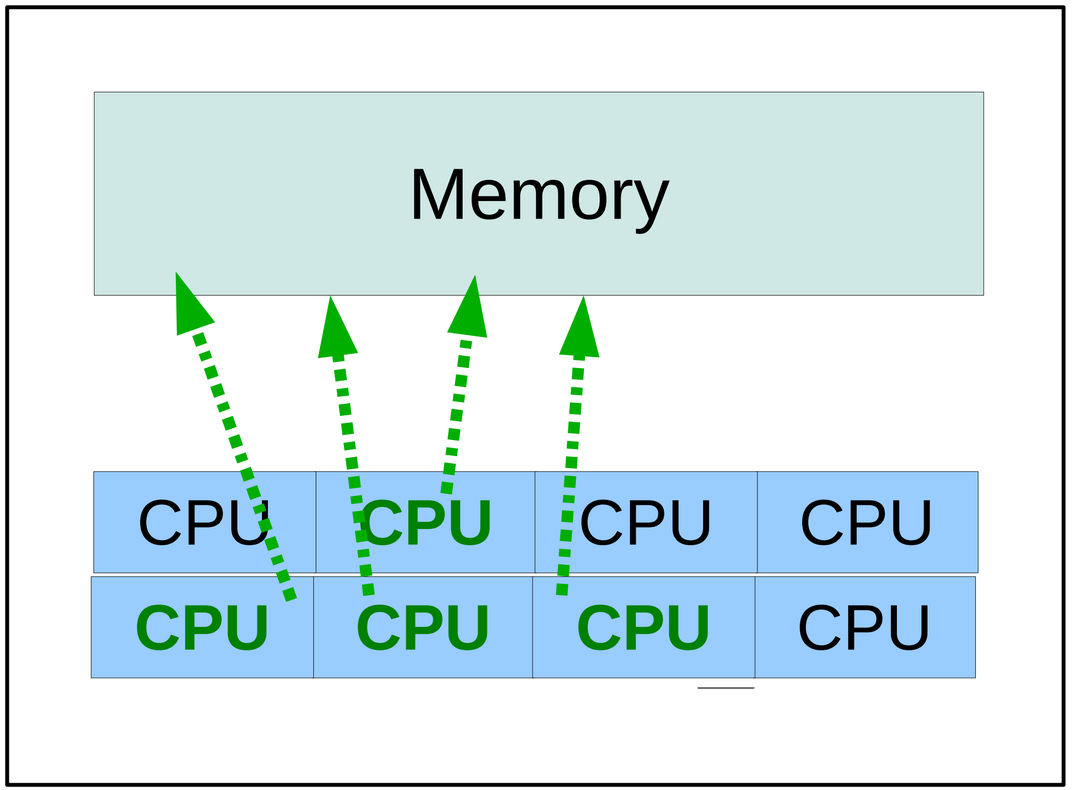
Numa node **1**

Optimal numa setup

Process 1 in **green**, 4 threads
Process 2 in **red**, 5 threads



Numa node 0



Numa node 1

Are my processes doing that?

- Variety of commands available to help:
  - lscpu
  - numactl
  - lstopo
  - numastat
  - ps
  - top

Tools to display CPU and Memory (NUMA)

```
# lscpu
Architecture:          x86_64
CPU op-mode(s):        32-bit, 64-bit
Byte Order:            Little Endian
CPU(s):                40
On-line CPU(s) list:   0-39
Thread(s) per core:    1
Core(s) per socket:    10
CPU socket(s):         4
NUMA node(s):          4
  . . . .
L1d cache:             32K
L1i cache:             32K
L2 cache:              256K
L3 cache:              30720K
NUMA node0 CPU(s):     0,4,8,12,16,20,24,28,32,36
NUMA node1 CPU(s):     2,6,10,14,18,22,26,30,34,38
NUMA node2 CPU(s):     1,5,9,13,17,21,25,29,33,37
NUMA node3 CPU(s):     3,7,11,15,19,23,27,31,35,39
```

cpu, core, socket, node info

The cpu numbers for each node

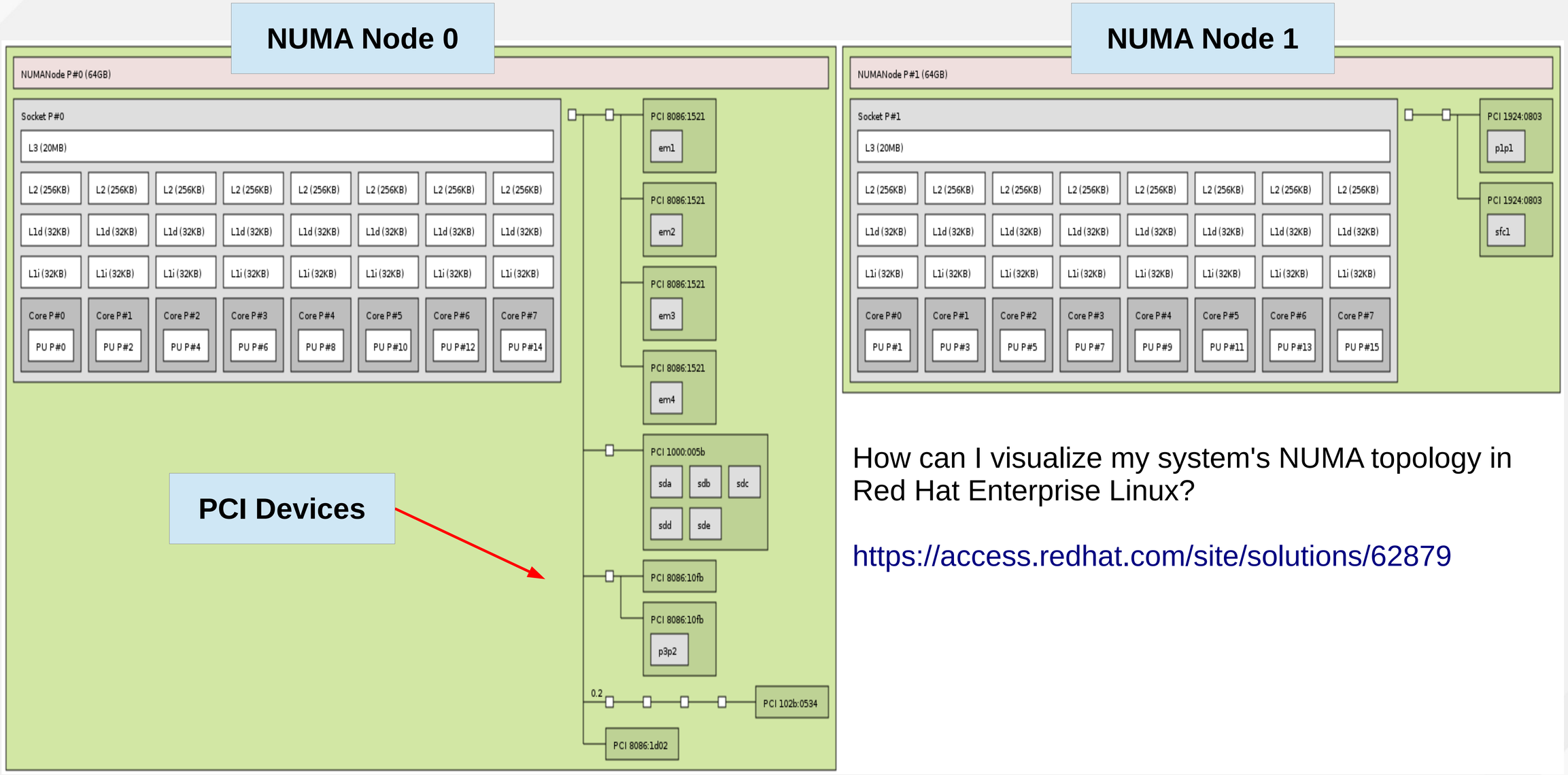
Tools to display CPU and Memory (NUMA)

```
# numactl --hardware
available: 4 nodes (0-3)
node 0 cpus: 0 4 8 12 16 20 24 28 32 36
node 0 size: 65415 MB
node 0 free: 63482 MB
node 1 cpus: 2 6 10 14 18 22 26 30 34 38
node 1 size: 65536 MB
node 1 free: 63968 MB
node 2 cpus: 1 5 9 13 17 21 25 29 33 37
node 2 size: 65536 MB
node 2 free: 63897 MB
node 3 cpus: 3 7 11 15 19 23 27 31 35 39
node 3 size: 65536 MB
node 3 free: 63971 MB
node distances:
node   0   1   2   3
  0:  10  21  21  21
  1:  21  10  21  21
  2:  21  21  10  21
  3:  21  21  21  10
```

cpus & memory for each node

Relative “node-to-node” latency costs.

Visualize NUMA Topology: lstopo



How can I visualize my system's NUMA topology in Red Hat Enterprise Linux?

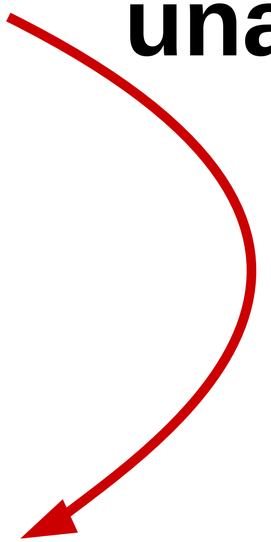
https://access.redhat.com/site/solutions/62879

Numastat Shows Process Memory Locations

- Enhanced by Red Hat (since Red Hat Enterprise Linux 6.4) with helpful and informative new memory display features.
- Numastat shows per-NUMA-node memory statistics for processes and the operating system.
- By default, numastat displays per-node kernel memory allocator hit and miss statistics.
- Any command line arguments to numastat will invoke enhanced behavior to show per-node distribution of memory.
- Typical usage: “numastat -cm <workload>

numastat shows need for NUMA management

```
# numastat -c qemu  Per-node process memory usage (in Mbs)

PID              Node 0 Node 1 Node 2 Node 3 Total
---------------  ------ ------ ------ ------ -----
10587 (qemu-kvm)   1216   4022   4028   1456 10722
10629 (qemu-kvm)   2108     56    473   8077 10714
10671 (qemu-kvm)   4096   3470   3036    110 10712
10713 (qemu-kvm)   4043   3498   2135   1055 10730
---------------  ------ ------ ------ ------ -----
Total             11462  11045   9672  10698 42877

# numastat -c qemu

Per-node process memory usage (in Mbs)

PID              Node 0 Node 1 Node 2 Node 3 Total
---------------  ------ ------ ------ ------ -----
10587 (qemu-kvm)      0  10723      5      0 10728
10629 (qemu-kvm)      0      0      5  10717 10722
10671 (qemu-kvm)      0      0  10726      0 10726
10713 (qemu-kvm)  10733      0      5      0 10738
---------------  ------ ------ ------ ------ -----
Total             10733  10723  10740  10717 42913
```



unaligned

aligned

What about my processes and threads? Two ways to see “where it last ran”.

1) *ps -T -o pid,tid,psr,comm <pid>*

```
# ps -T -o pid,tid,psr,comm  `pidof pig`
    PID     TID PSR COMMAND
3175391 3175391  73 pig
3175391 3175392   1 pig
3175391 3175393  25 pig
3175391 3175394  49 pig
3175391 3175395  74 pig
3175391 3175396   2 pig
3175391 3175397  26 pig
3175391 3175398  50 pig
3175391 3175399  75 pig
3175391 3175400   3 pig
```

”*Last Ran CPU*” column

2) *Run “**top**”, then enter “**f**”, then select “**Last used cpu**” field*

Tips for Good NUMA Performance

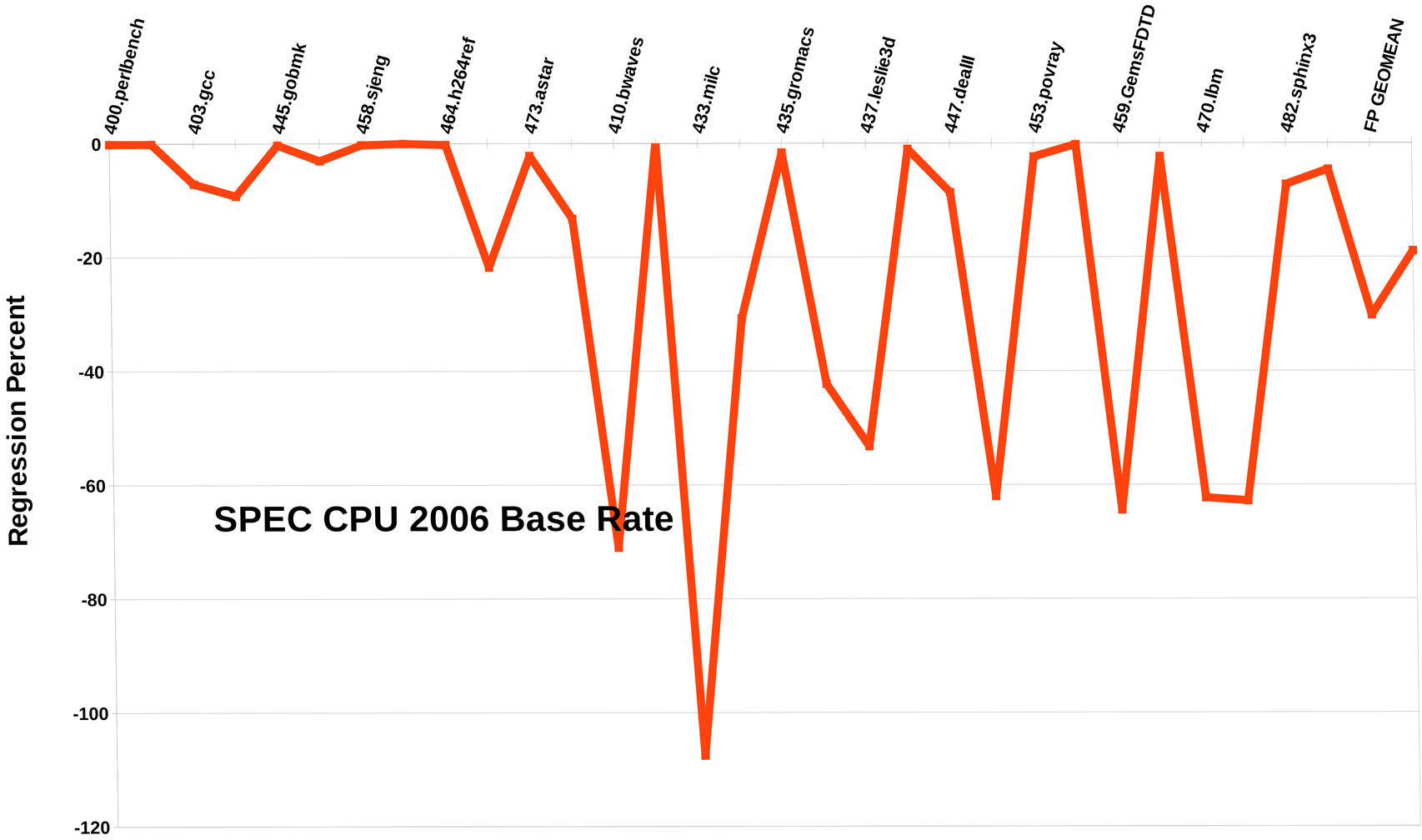
- Never disable NUMA in the BIOS. Keep BIOS interleaved memory OFF (which should be the system BIOS default)
  - Else OS will see only 1-NUMA node!
- Understand your system hardware NUMA topology, and basic operation and implications of NUMA
  - (e.g. per-node resources, and zone_reclaim_mode setting)
- Know your workload resource consumption. If possible, size parallel jobs to fit entirely in NUMA nodes.
- Use appropriate tuning if necessary to control placement.

zone_reclaim_mode

- Controls NUMA specific memory allocation policy
- To see current setting: cat /proc/sys/vm/zone_reclaim_mode
  - Turn ON: echo 1 > /proc/sys/vm/zone_reclaim_mode
    - Reclaim memory from local node rather than allocating from next node
  - Turn OFF: echo 0 > /proc/sys/vm/zone_reclaim_mode
    - Allocate from all nodes before reclaiming memory
- Default is set at boot time based on NUMA factor
- In Red Hat Enterprise Linux 6.6+ and 7+, the default is usually OFF – because this is better for many applications

zone_reclaim_mode (continued)

- Low-memory SPEC CPU loses huge performance with wrong zone reclaim mode setting! Several benchmarks off more than 40%.
- (BTW, Don't run SPEC CPU with low memory!!)



Techniques to control placement:

numactl:

- Control NUMA policy for processes or shared memory:

taskset:

- Retrieve or set a process's CPU affinity

*sched_**g**etaffinity(), sched_**s**etaffinity()*

- for process affinity from within program

*mbind(), **g**et_mempolicy(), **s**et_mempolicy()*

- set default NUMA memory policy for a process children.

Numactl

- The numactl command can launch commands with **static** NUMA memory and execution thread alignment
  - # numactl -m <NODES> -N <NODES> <Workload>
- Can specify devices of interest to process instead of explicit node list
- Numactl can interleave memory for large monolithic workloads
  - # numactl --interleave=all <Workload>

```
# numactl   -m 6-7 -N 6-7    numactl --show
policy: bind
preferred node: 6
physcpubind: 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79
cpubind: 6 7
nodebind: 6 7
membind: 6 7

# numactl   -m netdev:ens6f2 -N netdev:ens6f2    numactl --show
policy: bind
preferred node: 2
physcpubind: 20 21 22 23 24 25 26 27 28 29
cpubind: 2
nodebind: 2
membind: 2

# numactl   -m file:/data -N file:/data    numactl --show
policy: bind
preferred node: 0
physcpubind: 0 1 2 3 4 5 6 7 8 9
cpubind: 0
nodebind: 0
membind: 0

# numactl   --interleave=4-7  -N 4-7    numactl --show
policy: interleave
preferred node: 5 (interleave next)
interleavemask: 4 5 6 7
interleavenode: 5
physcpubind: 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59
60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79
cpubind: 4 5 6 7
nodebind: 4 5 6 7
membind: 0 1 2 3 4 5 6 7
```

Techniques to control placement (cont):

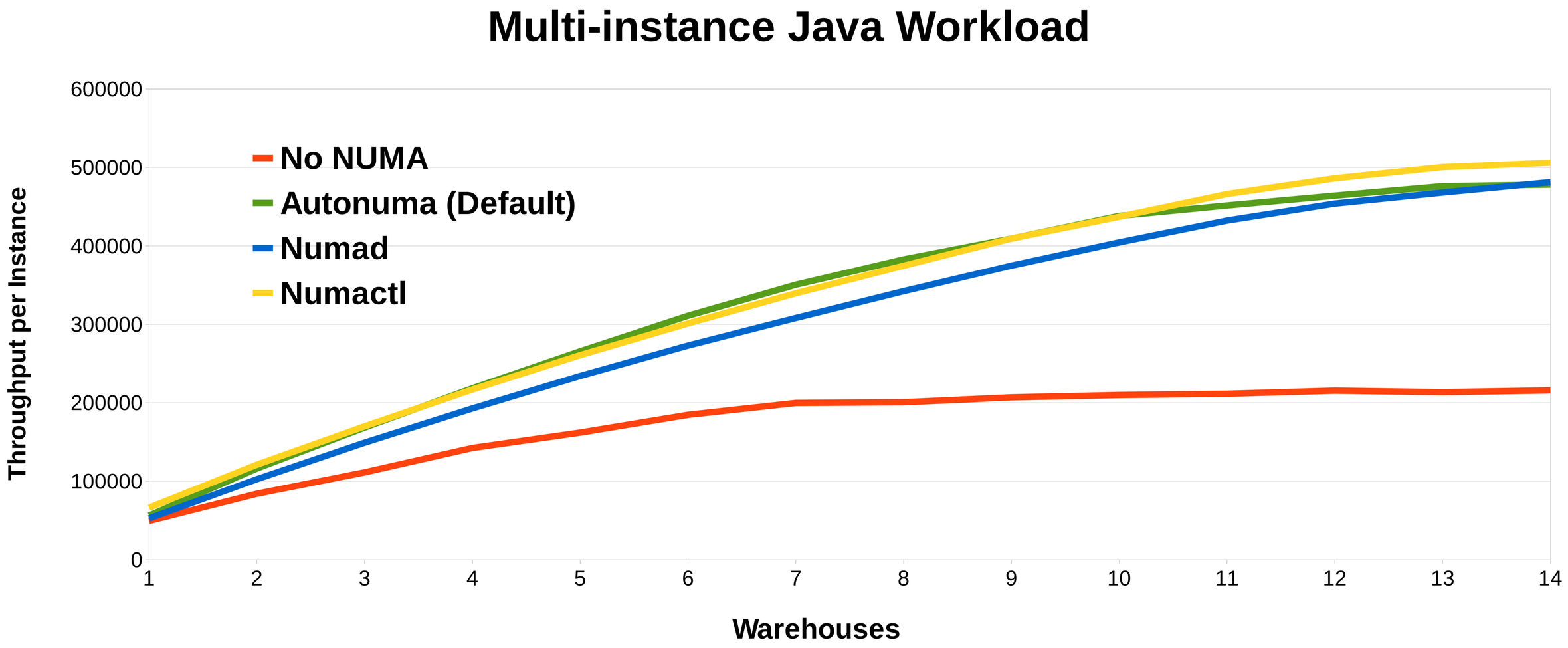
numad:

- User-mode daemon.
- Attempts to locate processes for efficient NUMA locality and affinity.
- Dynamically adjusting to changing system conditions.
- Available in RHEL 6 & 7.

Auto-Numa-Balance kernel scheduler:

- Automatically run programs near their memory, and moves memory near the programs using it.
- Default enabled. Available in RHEL 7+
- Great video on how it works:
  - https://www.youtube.com/watch?v=mjVw_oe1hEA

NUMA Alignment Makes SPECjbb2005 2x Faster



NUMA tuning for KVM / Containers is the same!

- Best performance is achieved if the size of the guest/container can fit into a single NUMA node.
  - In RHEL7, auto-numa kernel scheduler will try to move guest to one node.

- Great doc with numerous examples: See the NUMA chapter in:

  Red Hat Virtualization Tuning and Optimization Guide

RHEL Network Performance

Network Tuned Profiles

For throughput

Parents

throughput-performance

Children

network-throughput

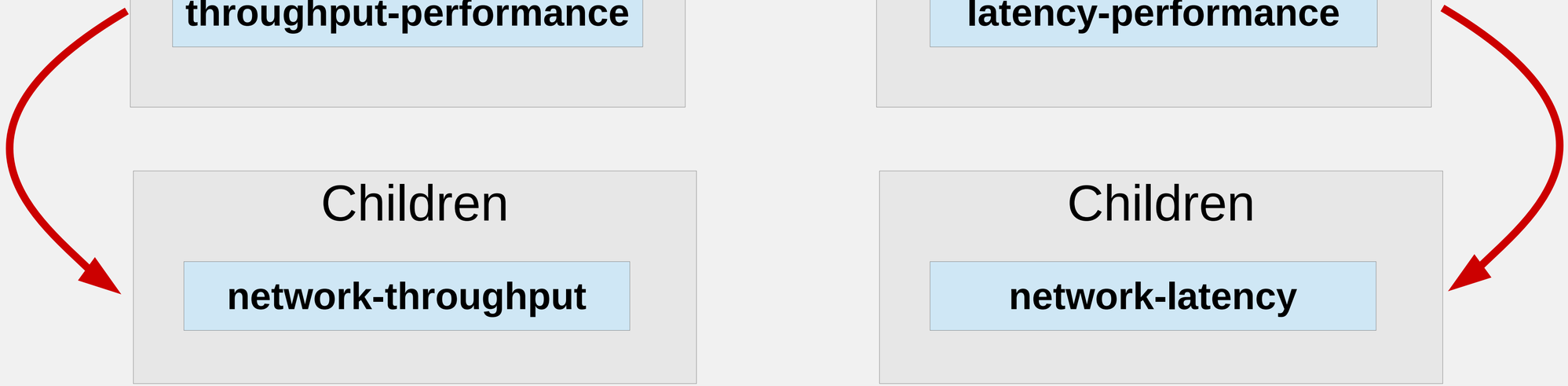
For latency

Parents

latency-performance

Children

network-latency



Network-throughput:

- Inherits system tunables for throughput.
- Bumps network tunables for increased network throughput.

Network-latency:

- Inherits system tunables for latency
- Bumps network tunables for latency
- Disables:
  - transparent hugepages
  - kernel numa balancing.

Network Performance Tuning Red Hat Enterprise Linux 7

- Tactical tuning overview for latency-sensitive workloads.
- Emphasizes impactful new features included in RHEL7:
  - CPU/power management
  - NUMA
  - tuned profiles
  - scheduling
  - network tunables
  - kernel timers.
  - "de-jittering" CPU cores
  - tracing techniques

https://access.redhat.com/articles/1323793

Performance Optimizations in RHEL7

- busy_poll – new default
- tcp_fastopen
  - Reduce 1 round trip of handshake setting up TCP connection.
- nohz_full (tickless while active)
  - Timer ticks only on boot cpu or selected cpus
- Byte Queue Limits
  - Control bufferbloat in network queues
  - Helps tune high prio packets to get delivered w/reasonable latency

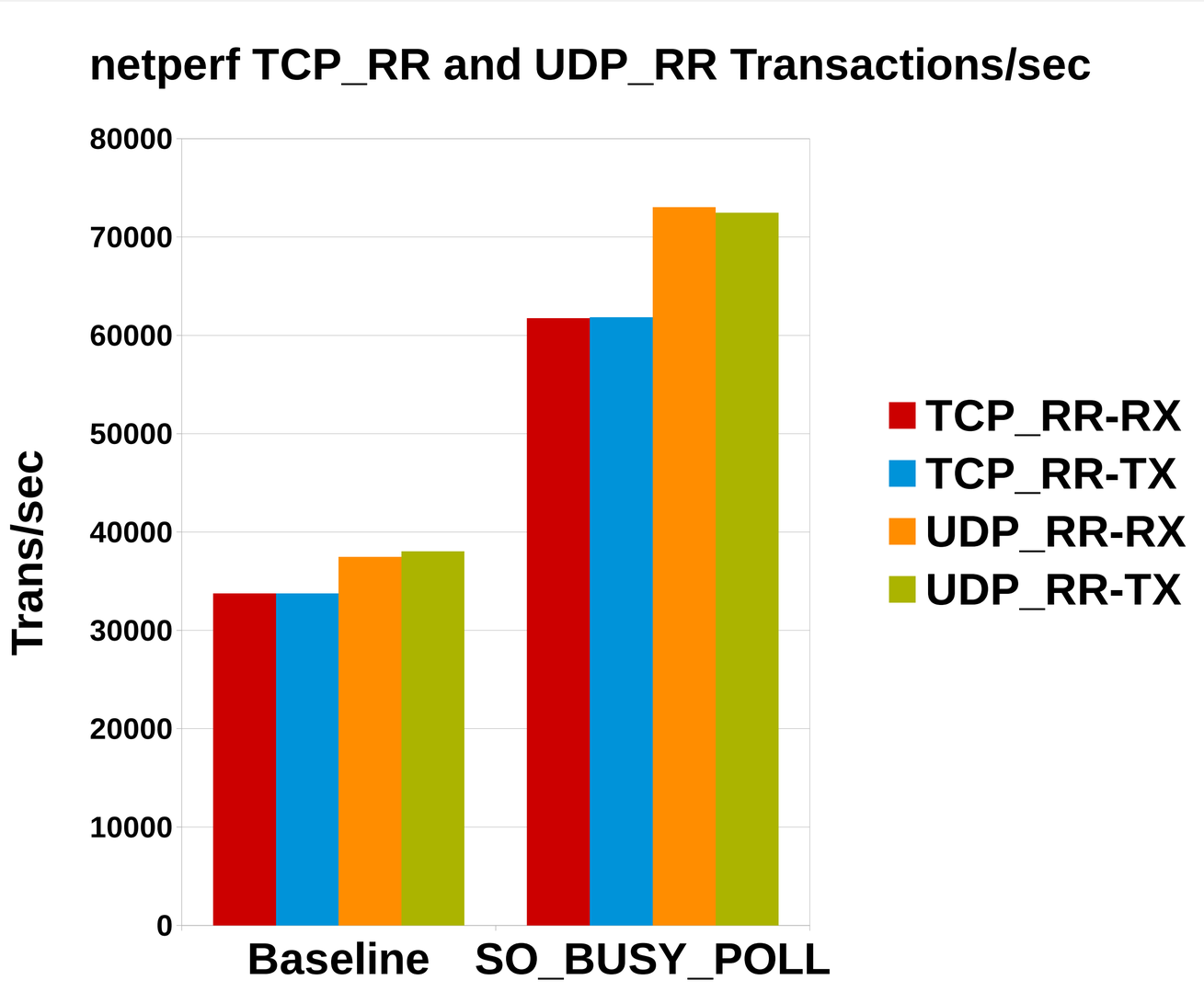
RHEL7 BUSY_POLL Socket Options

- Socket-layer code polls receive queue of NIC
- Replaces interrupts and NAPI
- Retains full capabilities of kernel network stack
- Set globally by tuned network-latency

To test if your device supports it:

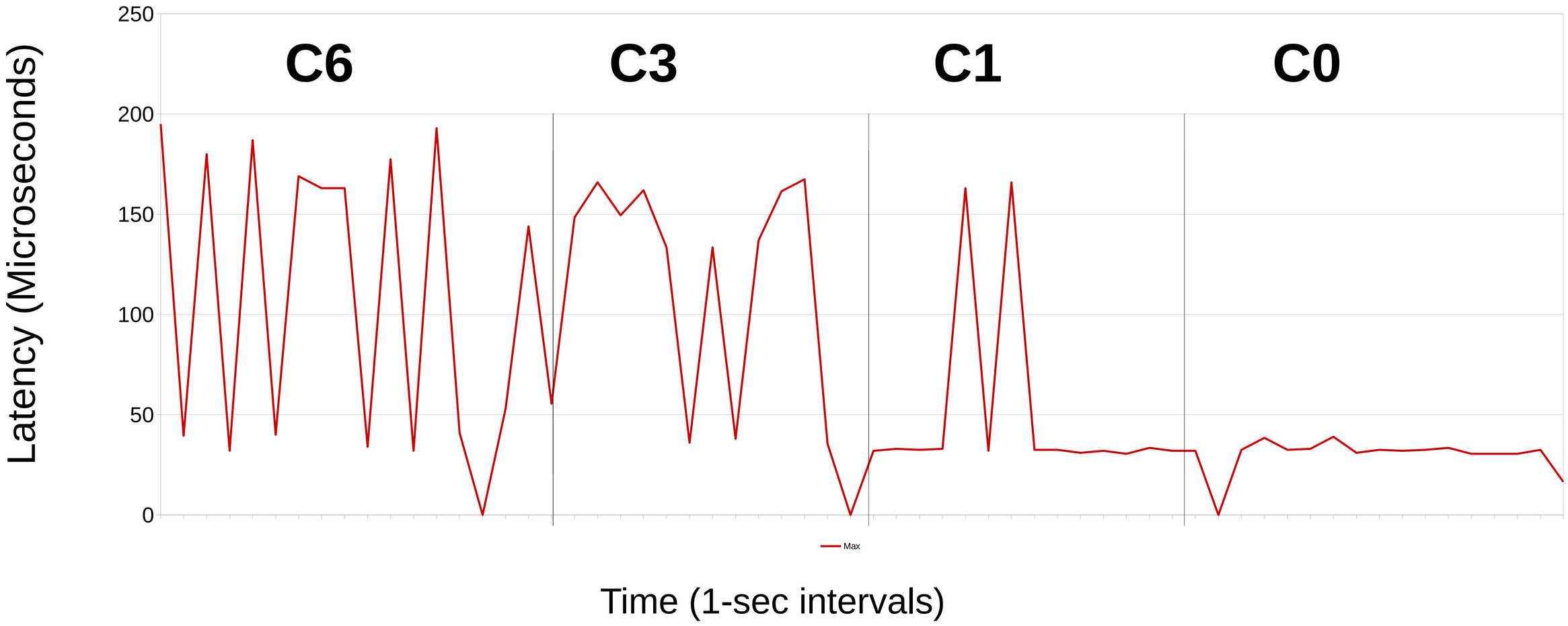
 # ethtool -k device | grep "busy-poll"

If this returns busy-poll: on [fixed], busy polling is available on the device.



Tuned: Network-Latency Performance Boost

C-state lock improves determinism, reduces jitter



Turbostat: Idle States and Frequencies on Intel CPUs

```
# tuned-adm profile throughput-performance
# turbostat sleep 5
```

Bzy_MHz	TSC_MHz	SMI	CPU%c1	CPU%c3	CPU%c6
1866	2600	0	0.22	0.01	99.71

```
# tuned-adm profile network-latency
# turbostat sleep 5
```

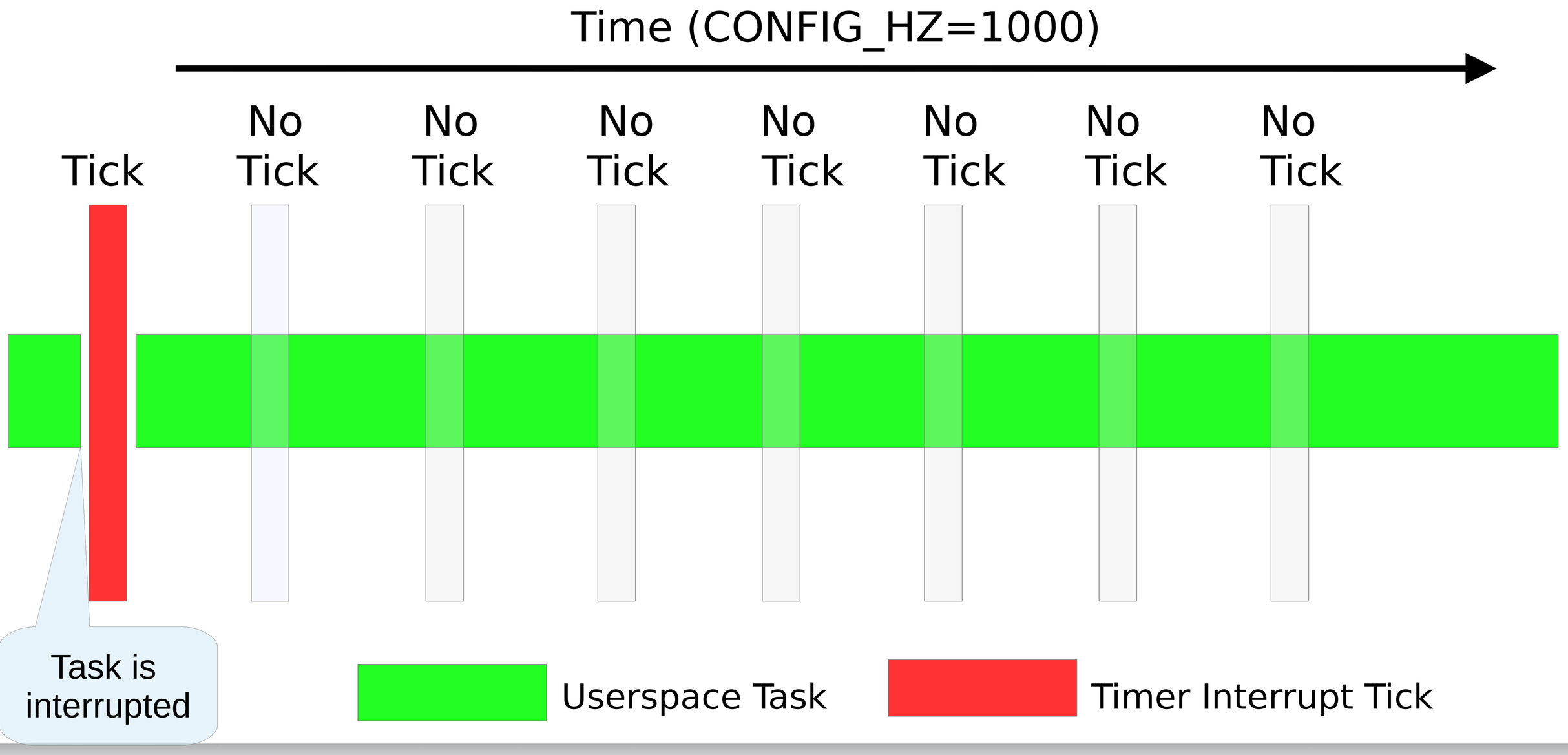
Bzy_MHz	TSC_MHz	SMI	CPU%c1	CPU%c3	CPU%c6
3108	2600	0	99.99	0.00	0.00

RHEL7 nohz_full

- Patchset Goal:
  - Stop interrupting userspace tasks
  - Move timekeeping to non-latency-sensitive cores
  -
- If nr_running=1, then scheduler/tick can avoid that core
- Default disabled...Opt-in via nohz_full cmdline option

- Kernel Tick:
- timekeeping (gettimeofday)
- Scheduler load balancing
- Memory statistics (vmstat)

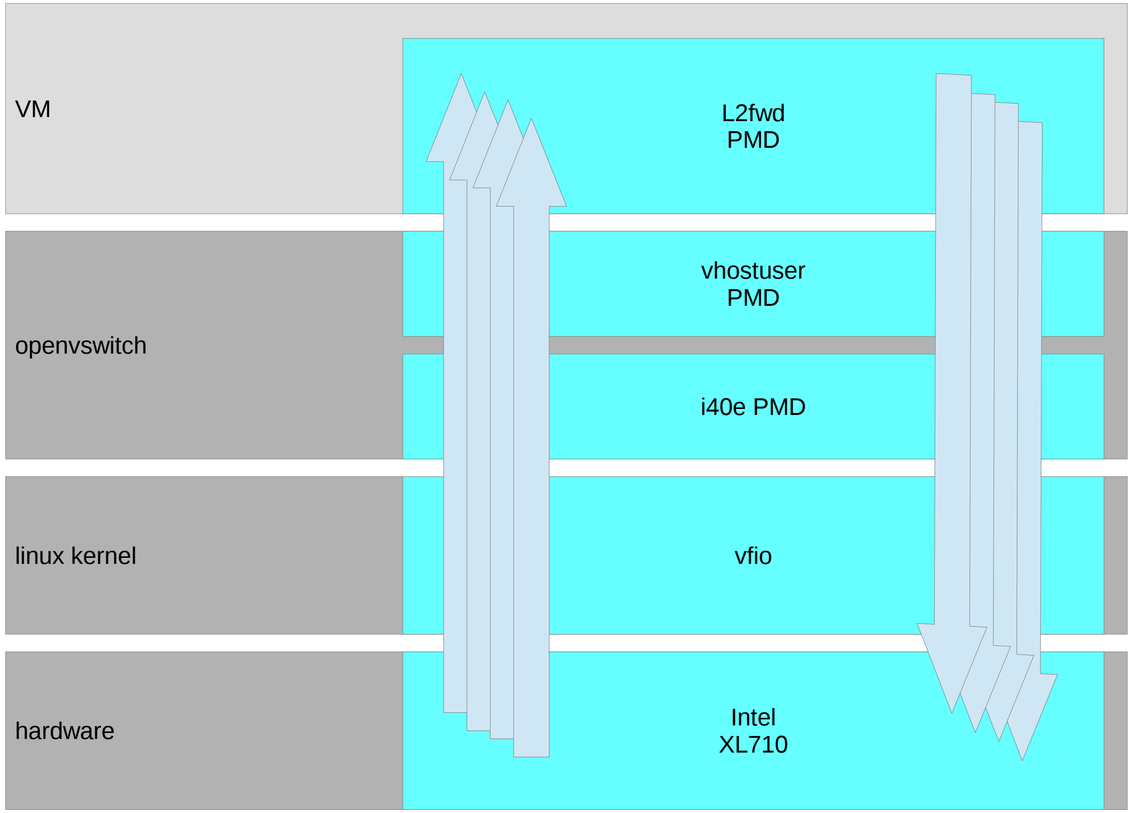
RHEL 7 nohz_full



RHEL Network NFV – DPDK + OVS

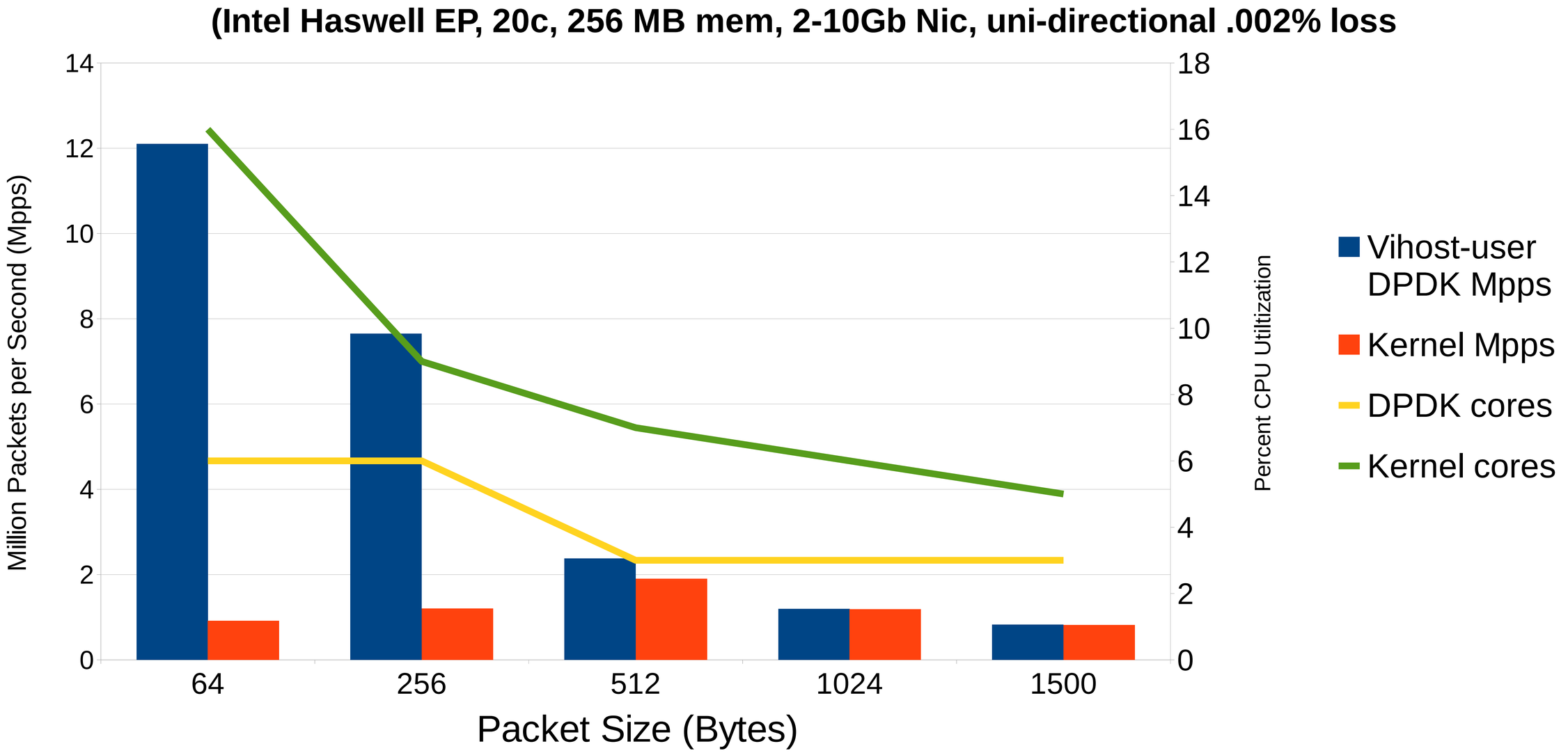
DPDK+OVS – kernel bypass, poll mode driver
RHEL 7.3 vhostuser – OVS 2.6 multi-queue

New



Upstream ovs-dpdk (2.6), Intel 10Gb
64-byte frames
22.7 Million packets per second!
OVS: 8 cores (16 threads), 2 bridges, each using 4 i40e PMD threads + 4 vhostuser PMD threads
VM 4: cores (8 threads), 2 vhostuser interfaces, each using 4 virtio PMD thread

WHY DPDK+OVS ? RHEL7.3 KVM kernel vs DPDK

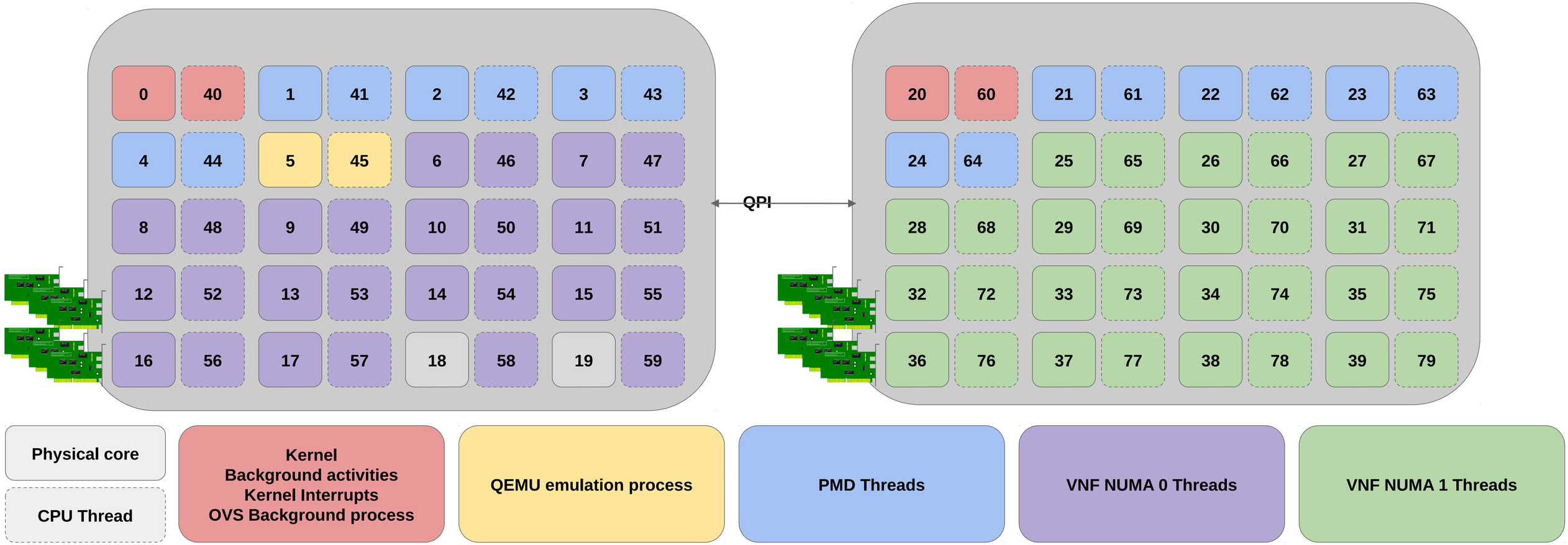


New “cpu-partitioning” tuned profile

- Do you have a latency sensitive application to tune for?
- If so:
  - Decide which cpus you want to allocated to it.
  - Add those cpus to a tuned configuration file.
  - Then reboot!
- A highly tuned low latency system with cores dedicated to your application.
- Numerous tedious tuning steps now handled by tuned!

VNF Mobile Network - Graphical CPU Partitioning

System Partitioning



redhat.

Cpu-partitioning – What the profile does for you.

- After reboot you have:
  1) Cpus dedicated to your application are isolated (not via the isolcpus boot flag)
  2) IRQs, RCU callbacks, kernel dirty page threads - all moved off the isolated cpus
  3) nohz_full set on the isolated cpus
  4) CPU frequency scaling set to maximum allowed
  5) MCE interrupts disabled
  6) Kernel workqueue requests moved off isolated cpus
  7) Kernel numa_balance and transparent hugepages disabled
  8) Various KVM options set to reduce latency and to remove unwanted VM Exits and interrupts
  9) Numerous SYSCTL parameters set to optimal low latency values

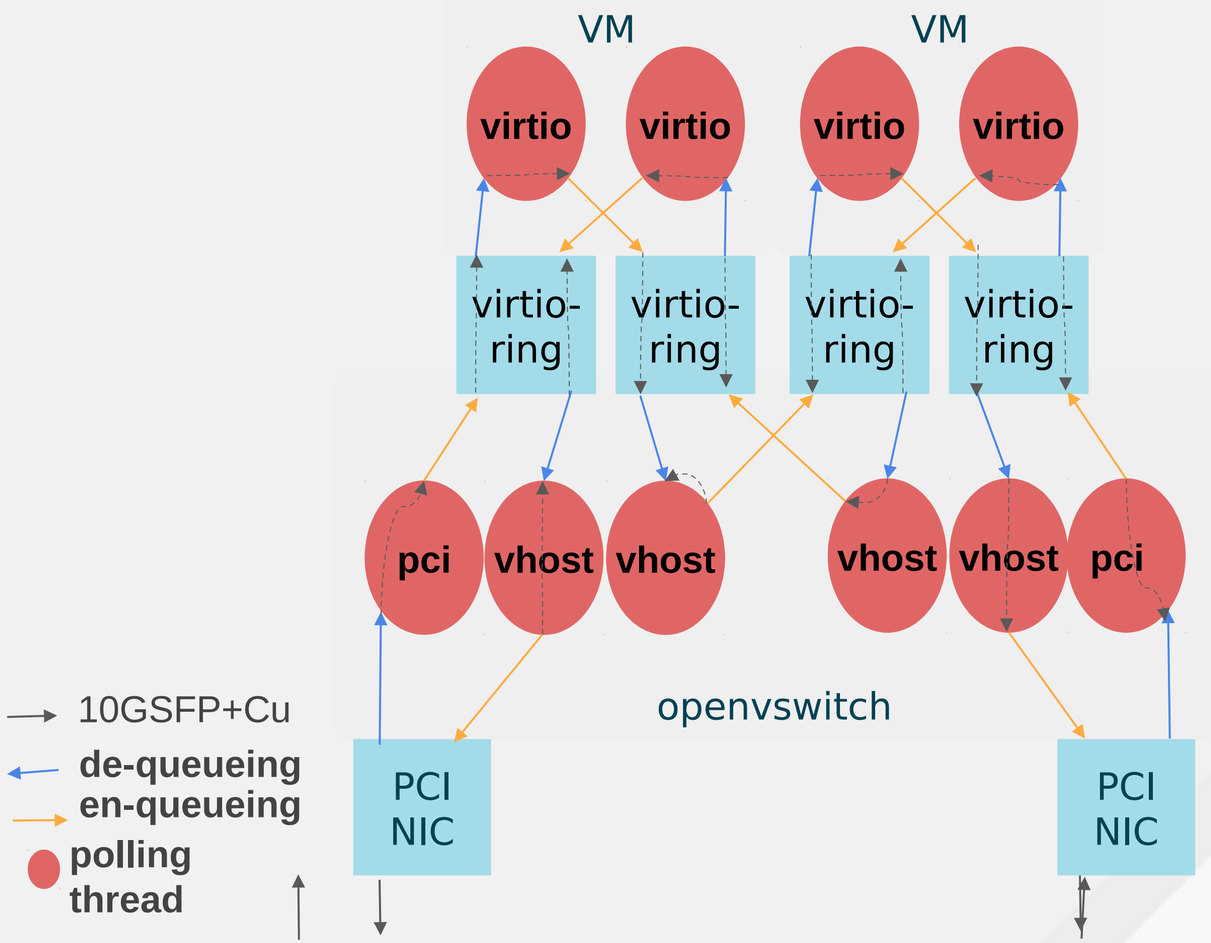
- Repeatable, automated, and very cool!

RHOP 10 w/ DPDK17.01 + OVS 2.6 L2 Forward tuned-adm profile=cpu-partitioning – 0.002% packet loss

(Intel Haswell EP, 20c, 256 MB mem, 2-10Gb Nic, uni-directional .002% loss

Frame size	Mpps @0.002% loss	Gbps @0.002% loss	Mpps/core @0.002% loss
64	22.93[1]	15.41	5.73
256	9.04	19.96	2.26
1024	2.39	19.96	0.59
1500	1.63	19.88	0.40

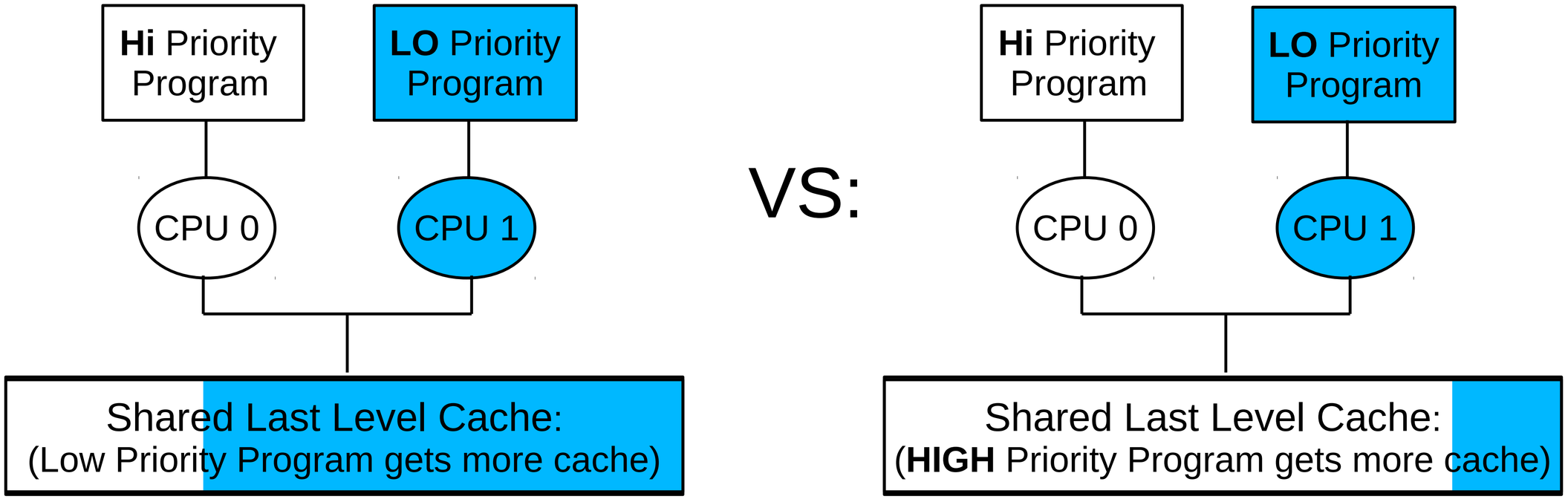
[1] Dual-port Intel 82599 based adapters are hardware limited to ~23Mpps



Noisy Cacheline Neighbor

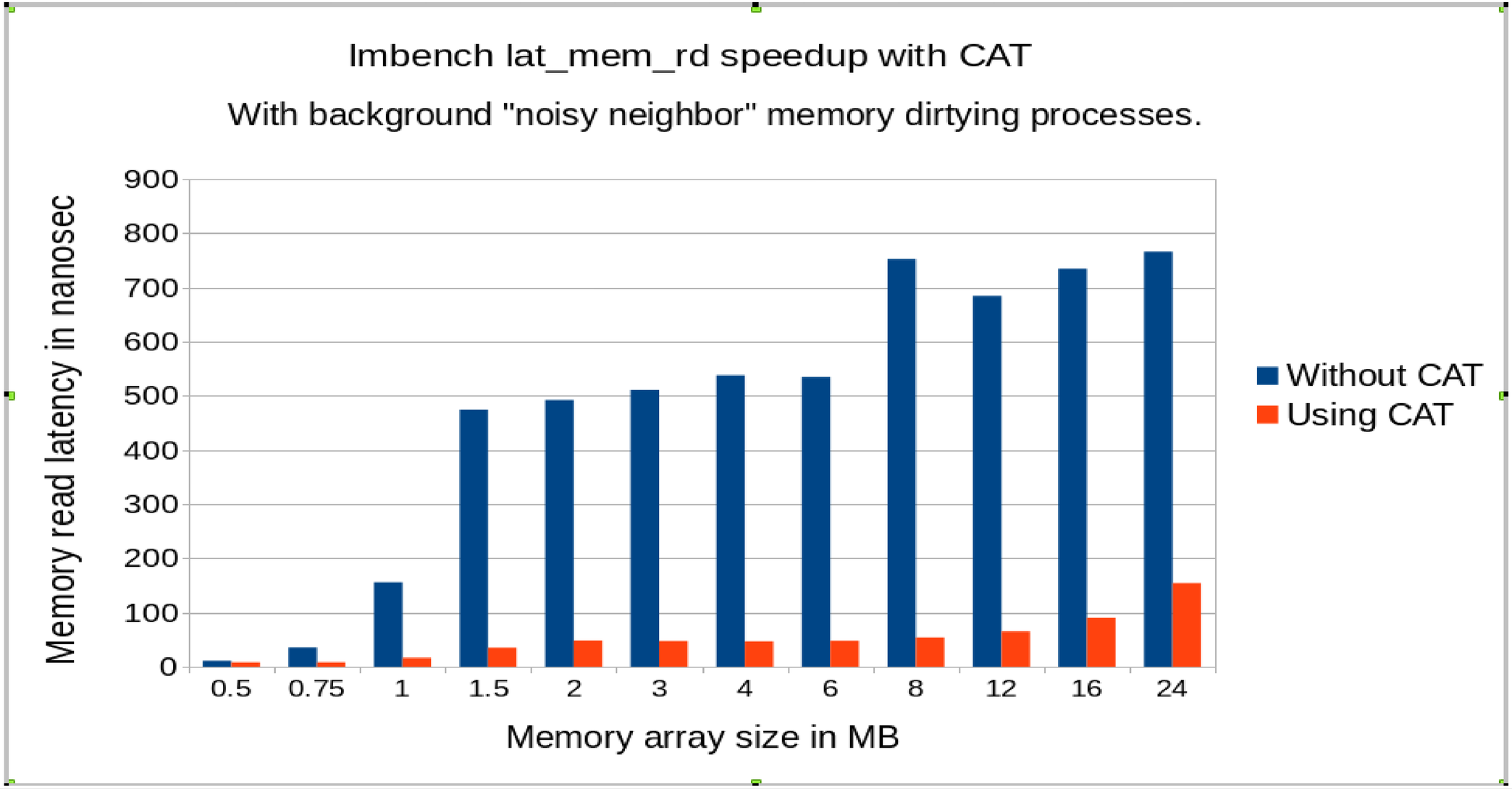
Cache Allocation & Cache Monitoring Technology

New in7.4



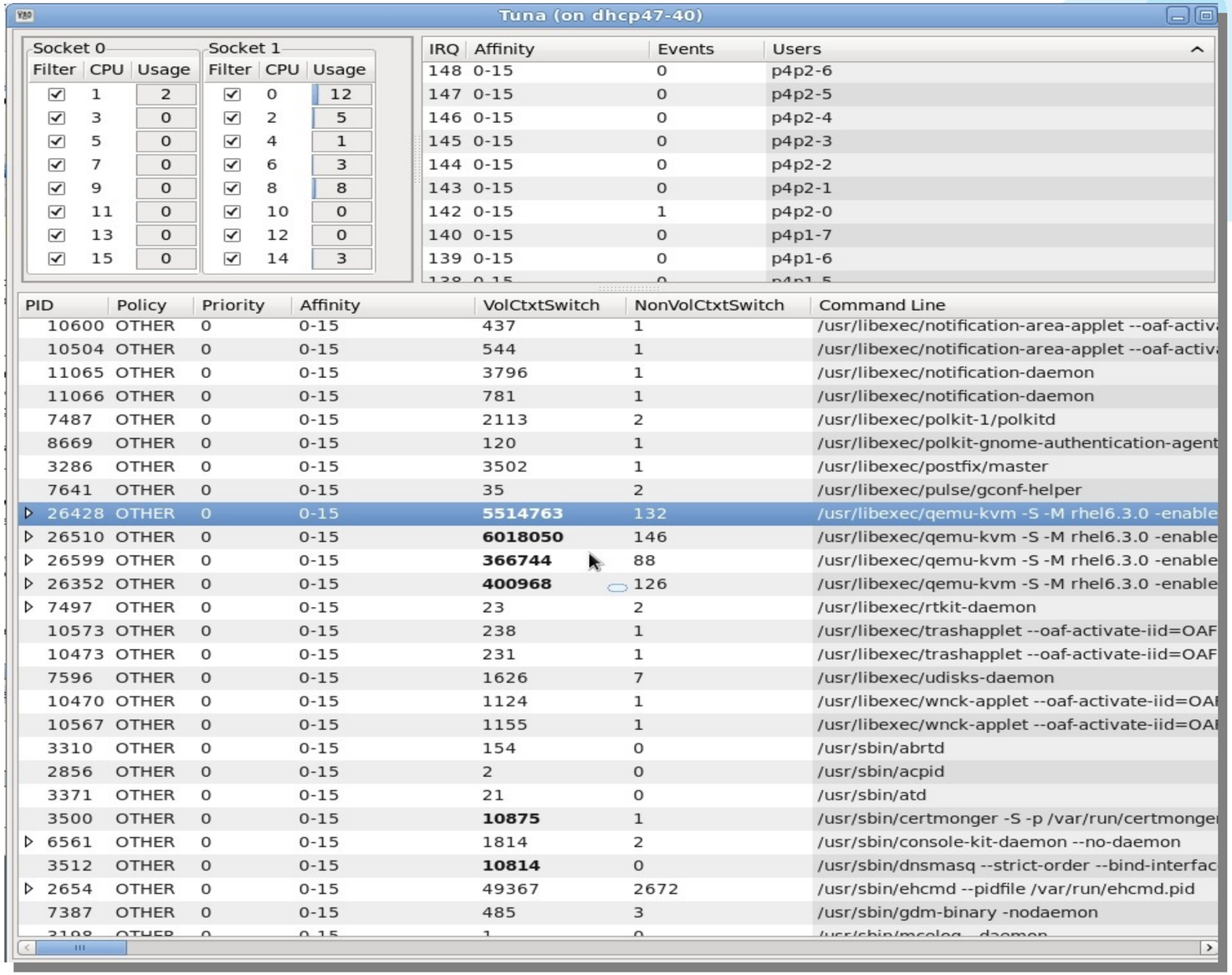
Available in RHEL 7.4 via the intel-cmt-cat-*.el7 package.
See ‘man pqos’
Intel only. Recent CPU models.

Memory latency testing using CAT



System Tuning Tool - tuna

- Tool for fine grained control
- Display applications / processes
- Displays CPU enumeration
- Socket (useful for NUMA tuning)
- Dynamic control of tuning
  - Process affinity
  - Parent & threads
  - Scheduling policy
  - Device IRQ priorities, etc



tuna command line

```
# tuna --help
    -h, --help                              Give this help list
    -a, --config_file_apply=profilename     Apply changes described in profile
    -l, --config_file_list                  List preloaded profiles
    -g, --gui                               Start the GUI
    -G, --cgroup                            Display the processes with the type of cgroups they
                                            are in
    -c, --cpus=CPU-LIST                     CPU-LIST affected by commands
    -C, --affect_children                   Operation will affect children threads
    -f, --filter                            Display filter the selected entities
    -i, --isolate                           Move all threads away from CPU-LIST
    -I, --include                           Allow all threads to run on CPU-LIST
    -K, --no_kthreads                       Operations will not affect kernel threads
    -m, --move                              Move selected entities to CPU-LIST
    -N, --nohz_full                         CPUs in nohz_full= kernel command line will be
                                            affected by operations
    -p, --priority=[POLICY:]RTPRIO          Set thread scheduler tunables: POLICY and RTPRIO
    -P, --show_threads                      Show thread list
    -Q, --show_irqs                         Show IRQ list
    -q, --irqs=IRQ-LIST                     IRQ-LIST affected by commands
    -r, --run=COMMAND                       fork a new process and run the COMMAND
    -s, --save=FILENAME                     Save kthreads sched tunables to FILENAME
    -S, --sockets=CPU-SOCKET-LIST           CPU-SOCKET-LIST affected by commands
    -t, --threads=THREAD-LIST               THREAD-LIST affected by commands
    -U, --no_uthreads                       Operations will not affect user threads
    -v, --version                           Show version
    -W, --what_is                           Provides help about selected entities
    -x, --spread                            Spread selected entities over CPU-LIST
```

Tuna – command line examples

Move an irq to cpu 5

- tuna -c5 -q eth4-rx-4 –move

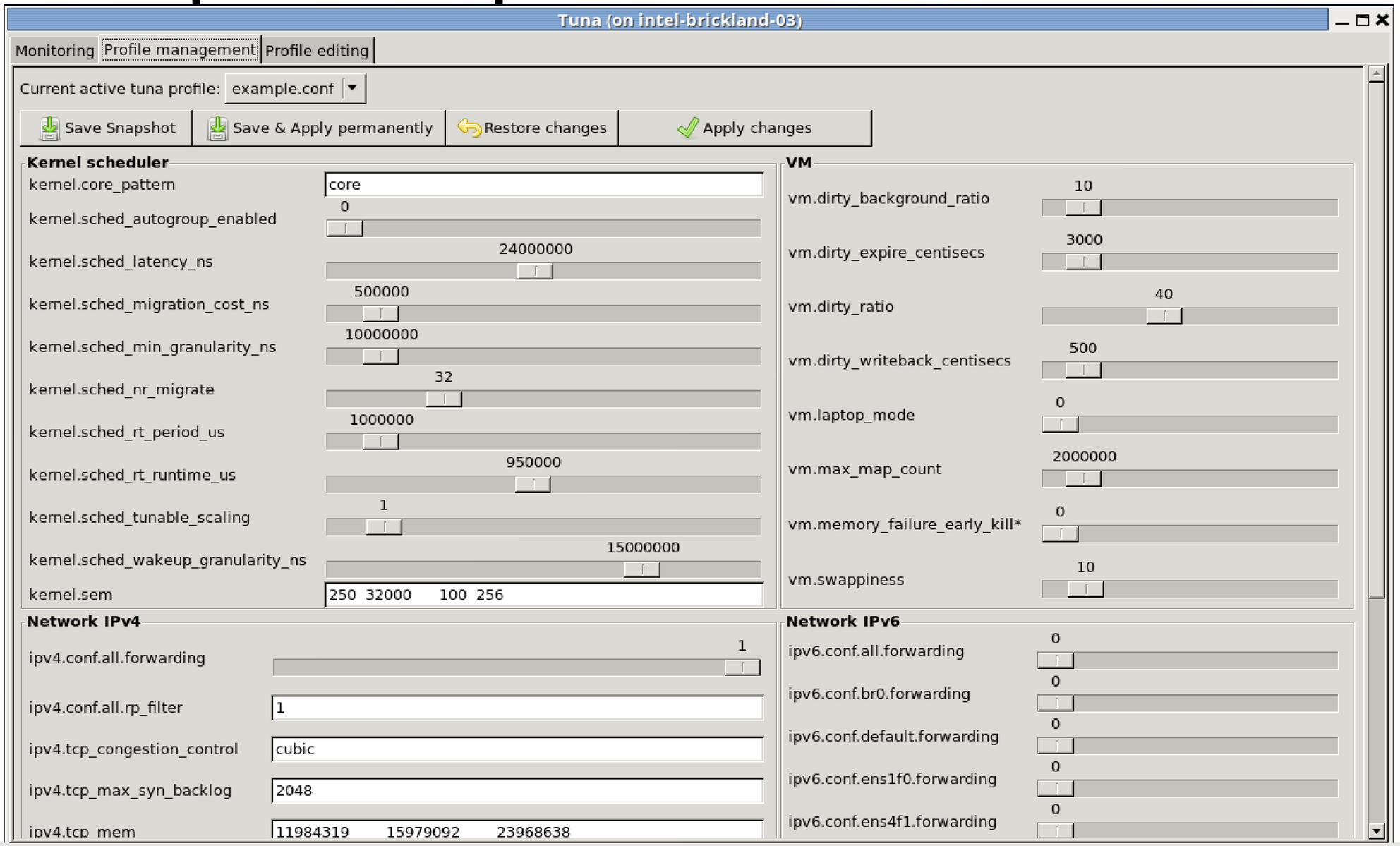
Move all irqs named “eth4*****” away from numa node 1

- tuna -S 1 -i -q ‘eth4*’

Move all rcu kernel threads to cpus 1 and 3

- tuna -c1,3 -t ‘*rcu*’ --move

Tuna GUI Capabilities Updated for RHEL7



Performance Tools - Perf

Partial list of available pre-defined perf events

```
# perf list
  branch-instructions OR branches                    [Hardware event]
  branch-misses                                      [Hardware event]
  cache-misses                                       [Hardware event]
  cpu-cycles OR cycles                               [Hardware event]
  instructions                                       [Hardware event]
  context-switches OR cs                             [Software event]
  page-faults OR faults                              [Software event]
  LLC-load-misses                                    [Hardware cache event]
  LLC-loads                                          [Hardware cache event]
  LLC-store-misses                                   [Hardware cache event]
  LLC-stores                                         [Hardware cache event]
  dTLB-load-misses                                   [Hardware cache event]
  dTLB-loads                                         [Hardware cache event]
  dTLB-store-misses                                  [Hardware cache event]
  dTLB-stores                                        [Hardware cache event]
  node-load-misses                                   [Hardware cache event]
  node-store-misses                                  [Hardware cache event]
  intel_cqm/llc_occupancy/                           [Kernel PMU event]
  mem-loads OR cpu/mem-loads/                        [Kernel PMU event]
  mem-stores OR cpu/mem-stores/                      [Kernel PMU event]
  power/energy-pkg/                                  [Kernel PMU event]
  tx-abort OR cpu/tx-abort/                          [Kernel PMU event]
  tx-capacity OR cpu/tx-capacity/                    [Kernel PMU event]
  tx-commit OR cpu/tx-commit/                        [Kernel PMU event]
  uncore_imc_0/cas_count_read/                       [Kernel PMU event]
  uncore_imc_0/cas_count_write/                      [Kernel PMU event]

  block:block_bio_backmerge                          [Tracepoint event]
  block:block_bio_bounce                             [Tracepoint event]
```

Most commonly used perf commands:

```
annotate        Read perf.data (created by perf record) and display annotated code
archive         Create archive with object files with build-ids found in perf.data file
bench           General framework for benchmark suites
buildid-cache   Manage build-id cache.
buildid-list    List the buildids in a perf.data file
config          Get and set variables in a configuration file.
data            Data file related processing
diff            Read perf.data files and display the differential profile
evlist          List the event names in a perf.data file
inject          Filter to augment the events stream with additional information
kmem            Tool to trace/measure kernel memory properties
kvm             Tool to trace/measure kvm guest os
list            List all symbolic event types
lock            Analyze lock events
mem             Profile memory accesses
record          Run a command and record its profile into perf.data
report          Read perf.data (created by perf record) and display the profile
sched           Tool to trace/measure scheduler properties (latencies)
script          Read perf.data (created by perf record) and display trace output
stat            Run a command and gather performance counter statistics
test            Runs sanity tests.
timechart       Tool to visualize total system behavior during a workload
top             System profiling tool.
probe           Define new dynamic tracepoints
trace           strace inspired tool
```

Example: **perf record**

- Record system-wide (-a)
  - perf record -a sleep 10
  - perf record -a // Hit ctrl-c when done.
- Or record a single command
  - perf record myapp.exe
- Or record an existing process (-p)
  - perf record -p <pid>
- Or add call-chain recording (-g)
  - perf record -g ls -rl /root
- *Or only record specific events (-e)*
  - *perf record -e branch-misses -p <pid>*

Followed by: ***perf report***

- *perf report [options]*

perf report

```
# Overhead   Command       Shared Object                      .....
# ........   .......   ..................   ..........................
#
    43.53%         dd   [kernel.kallsyms]   [k] __clear_user
                   |
                   --- __clear_user
                       |
                       |--99.75%--  read_zero.part.5
                       |            read_zero
                       |            vfs_read
                       |            sys_read
                       |            system_call_fastpath
                       |            __GI___libc_read
                       --0.25%--  [...]

     5.37%         dd   [kernel.kallsyms]   [k] do_blockdev_direct_IO
                   |
                   --- do_blockdev_direct_IO
                       __blockdev_direct_IO
                       xfs_vm_direct_IO
                       generic_file_direct_write
                       xfs_file_dio_aio_write
                       xfs_file_aio_write
                       do_sync_write
```

/dev/zero

oflag=direct

perf top

System-wide 'top' view of busy functions

```
Samples: 10K of event 'cycles', Event count (approx.): 5973713325
 34.35%          httpd  [kernel.kallsyms]    [k] avtab_search_node
 12.70%          httpd  [kernel.kallsyms]    [k] _spin_lock
  8.61%          httpd  [kernel.kallsyms]    [k] tg_load_down
  7.42%          httpd  [kernel.kallsyms]    [k] _spin_lock_irq
  5.79%           init  [kernel.kallsyms]    [k] intel_idle
  3.92%          httpd  [kernel.kallsyms]    [k] _spin_lock_irqsave
  1.75%          httpd  [kernel.kallsyms]    [k] sidtab_search_core
  1.74%          httpd  [kernel.kallsyms]    [k] load_balance_fair
  1.18%          httpd  [kernel.kallsyms]    [k] tg_nop
  1.13%           init  [kernel.kallsyms]    [k] _spin_lock
```

perf diff / sched

Compare 2 perf recordings

```
# perf diff

# Event 'cycles'
#
# Baseline    Delta             Shared Object                 Symbol
# ........  .......  ..............................  ......................
#
    12.88%  -12.27%  [kernel.kallsyms]                [k] __lookup_mnt
    11.97%  -11.17%  systemd                         [.] 0x0000000000064968
     4.32%   +6.43%  libdbus-1.so.3.7.4              [.] 0x0000000000029258
     4.06%   +4.72%  dbus-daemon                     [.] 0x000000000014a6e
     3.79%   -3.79%  libglib-2.0.so.0.3600.3         [.] 0x000000000088d6a
     3.72%   +0.25%  [kernel.kallsyms]                [k] seq_list_start
```

grep for something interesting, maybe to see what numabalance is doing ?

```
# perf list | grep sched: | grep numa
  sched:sched_move_numa                              [Tracepoint event]
  sched:sched_stick_numa                             [Tracepoint event]
  sched:sched_swap_numa                              [Tracepoint event]
```

perf c2c for cpu cacheline false sharing detection

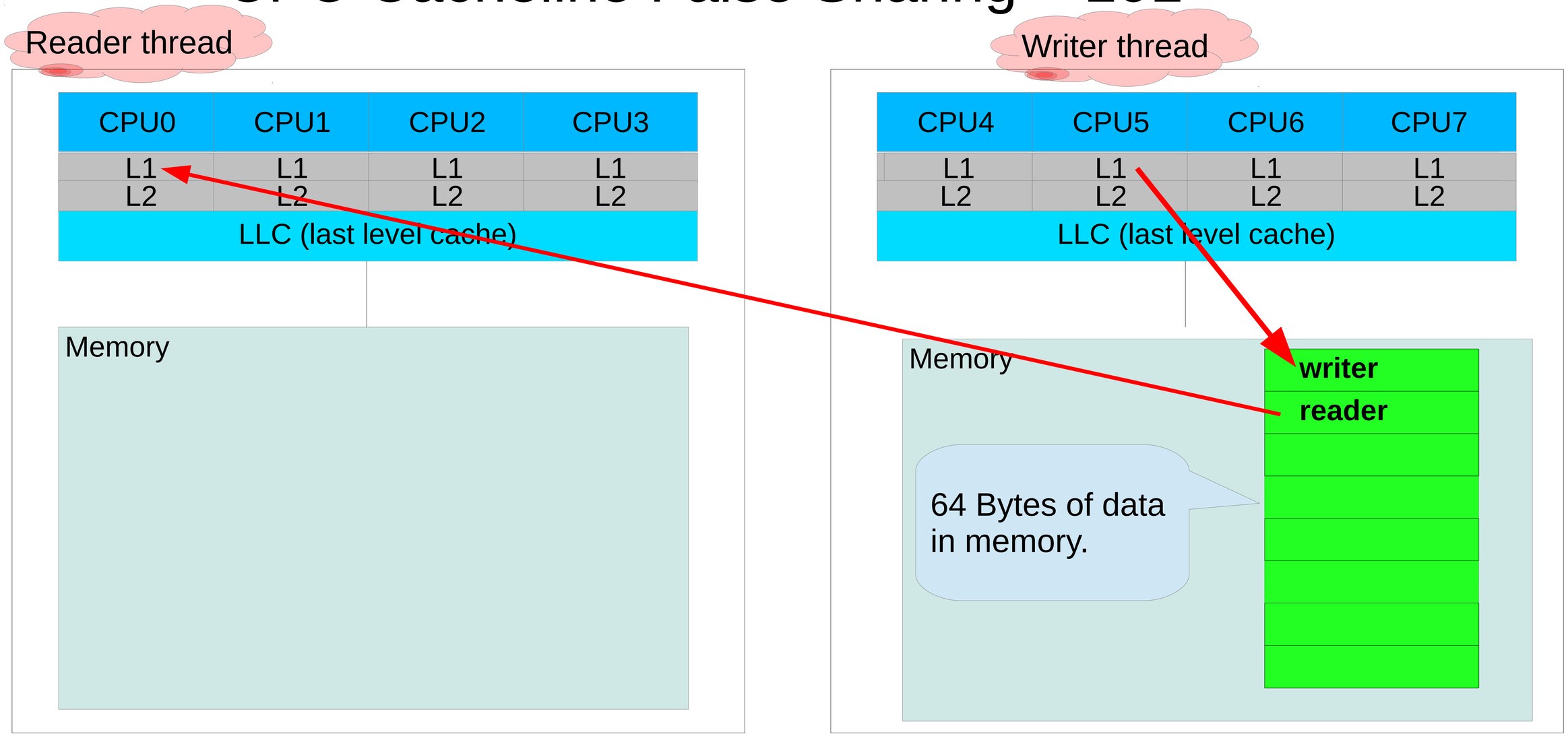
Shows everything needed to find false sharing problems.

- All readers and writers contending for the hottest cachelines.
  - The cpus and nodes they executed on.
- The process names, data addr, ip, pids, tids, src file and line number.
- Where hot variables are sharing cachelines, (like locks).
- Where hot structs are spanning cachelines, (like an unaligned mutex).

Tends to show up in shared memory and/or multi-threaded programs.

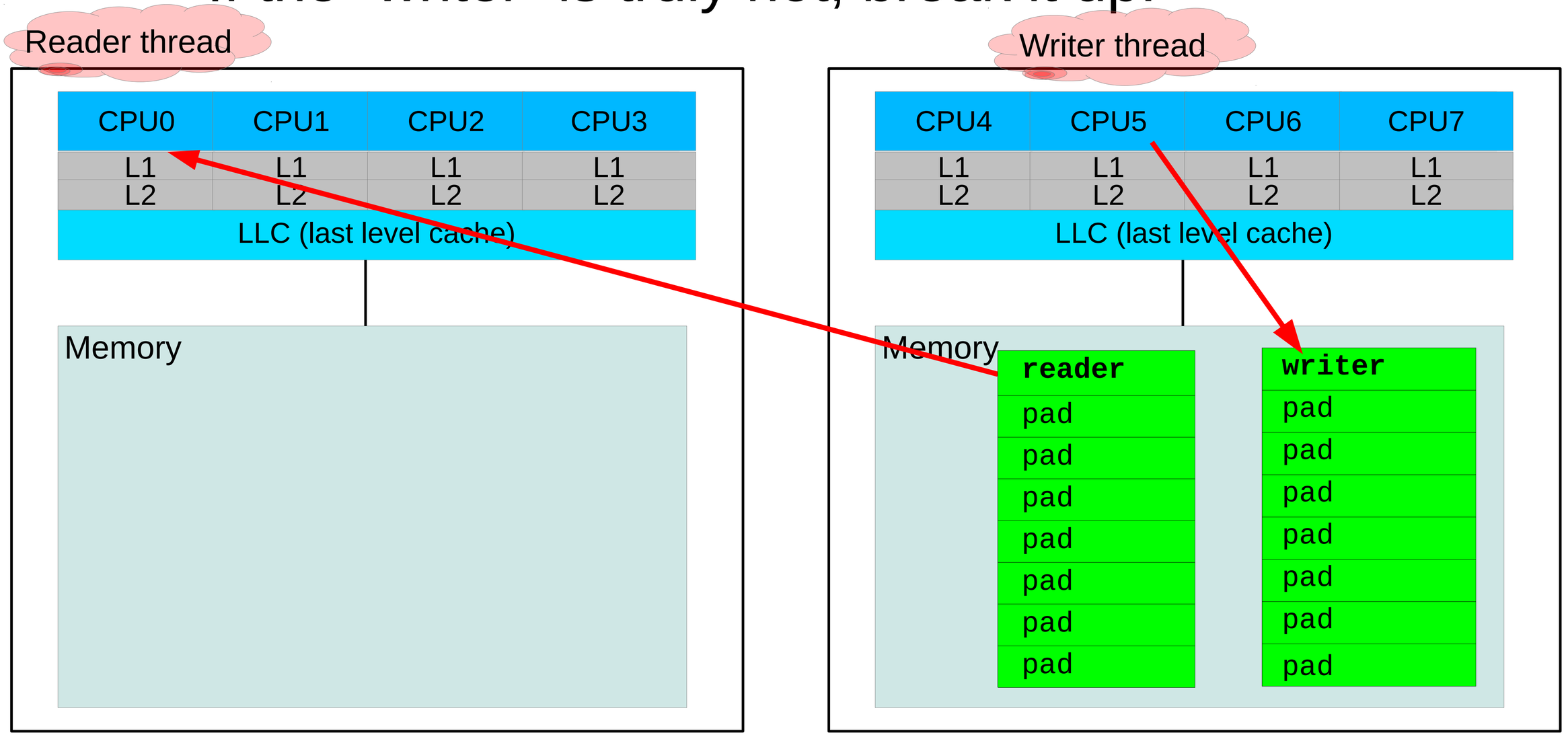
Detailed blog at: https://joemario.github.io/blog/2016/09/01/c2c-blog/

CPU Cacheline False Sharing – 101

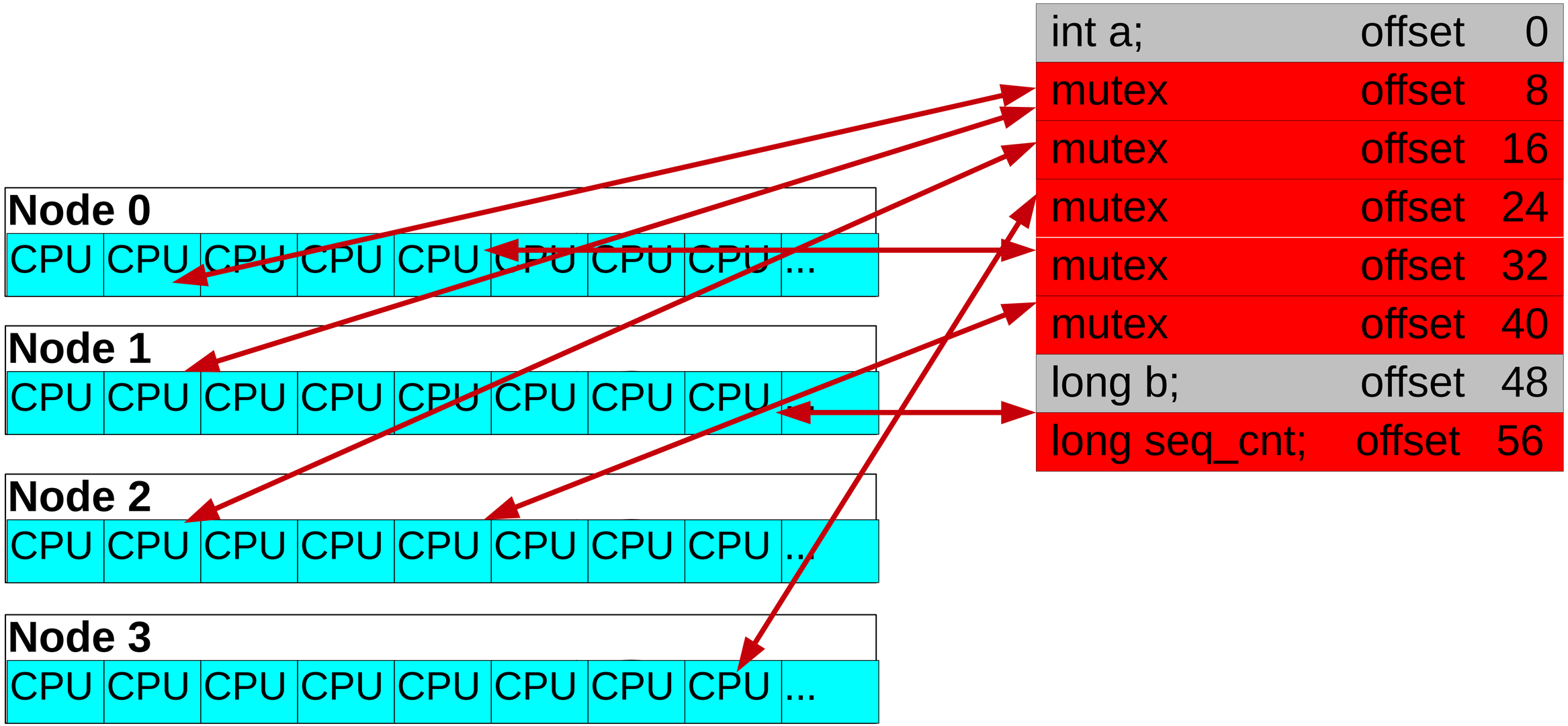


Two numa node system

If the “writer” is truly hot, break it up.



We often see this:



Summary - Red Hat Enterprise Linux – Part 1

- Red Hat Enterprise Linux – Containers are Linux
  - RHEL x86 evolution, autoNUMA, Hugepages, IRQ pin, tuned profiles
  - NonUniform Memory Access (NUMA), numactl, numad, autonuma
  - Network Performance
    - RHEL 7 Network tuning via tuned, try noHZ_full to reduce jitter
    - RHEL/KVM DPDK + OVS 2.6 multiQ, 0% packet loss in OSP10.
  - Tuna - IRQ placement, alter device affinities, process priorities
  - Perf – monitoring BW, cache-line tears, C-2-C analysis

- Q+A at “Meet The Experts” - Free as in Soda/Beer/Wine

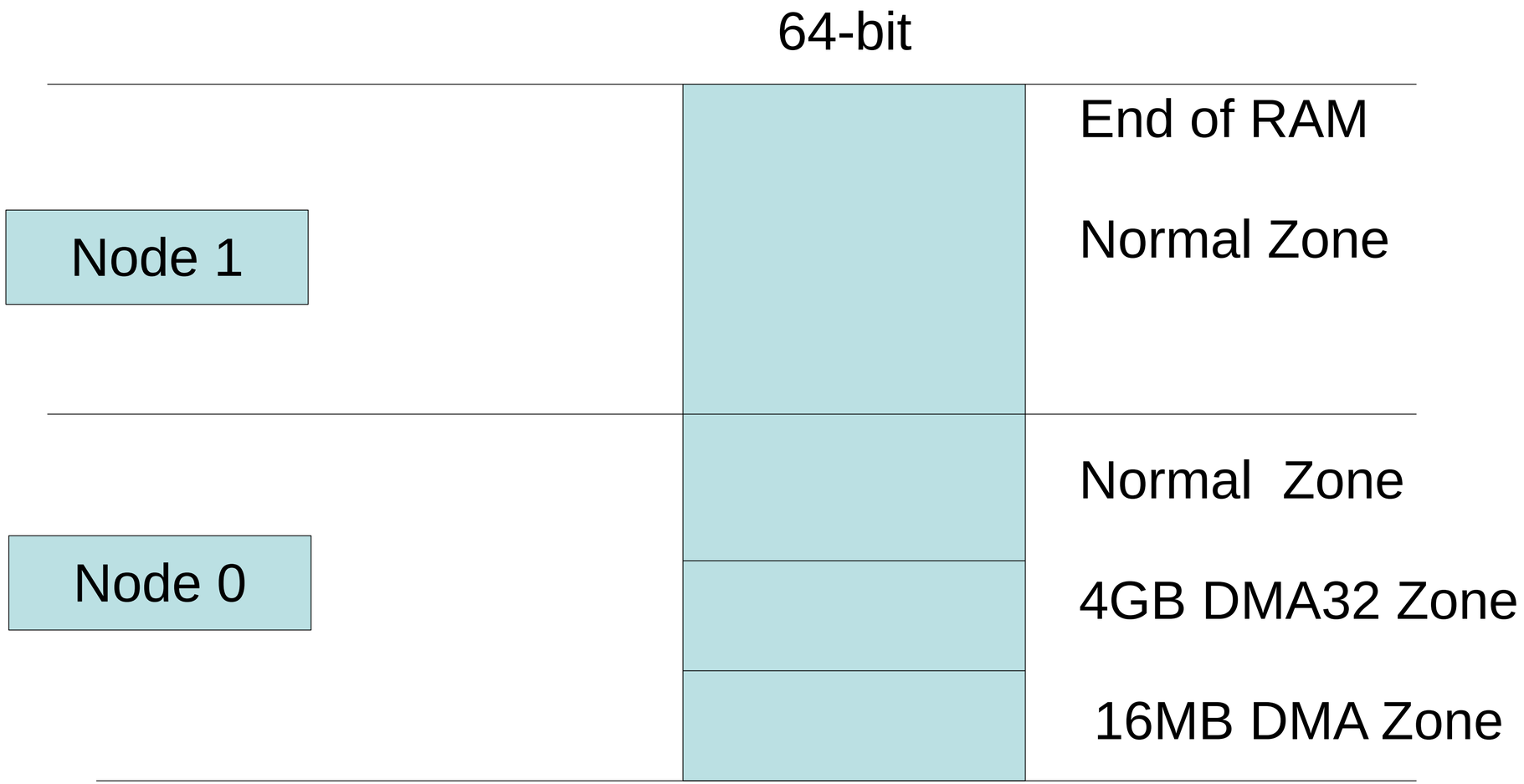
Agenda: Performance Analysis Tuning Part II

- Part II - Containers are Linux, run/optimized and tuned just like Linux.
  - What is NUMA, RHEL Architecture, Auto-NUMA-Balance
  - Disk IO – IO elevators, sawpiness, dirty ratios, readahead, multi-Q
  - Scheduler tunables – new features
  - HugePages - Static, Transparent, variable sized 4K/2MB/1GB
  - Cgroups cpuset, memory, network and IO
    - Use to prevent IO from consuming 95% of memory
  - R+D GPUoffload, OpenHPC, multi-arch – Bill
  - Containers / Other preso's
  - “Performance + Scale Experts” - Room 205C 5:30-7 PM
  - Free - Soda/Beer/Wine

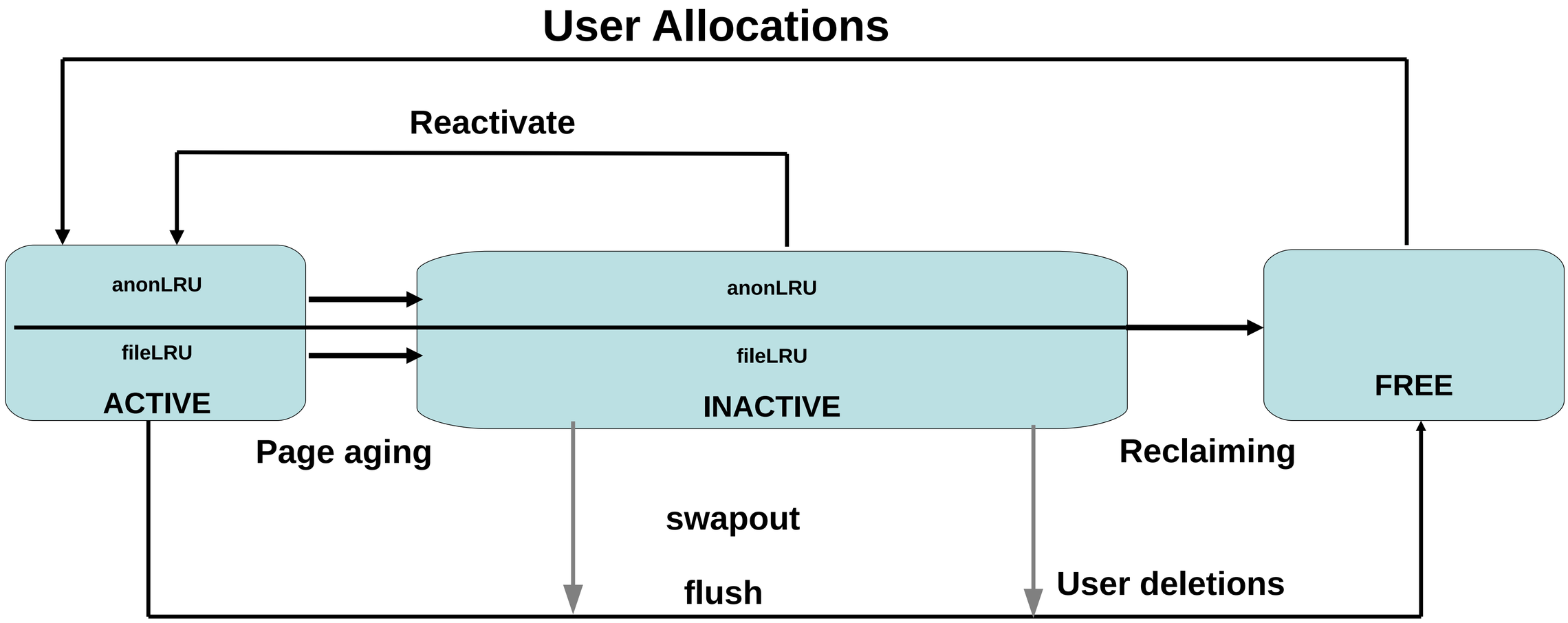
Mapping *tuned* profiles to Red Hat's product portfolio

RHEL Desktop/Workstation **balanced**	RHEL Server/HPC **throughput-performance**	RHEL for Real Time **realtime**
RHV Host, Guest **virtual-host/guest**	RHV **virtual-host**	RHEL for Real Time KVM-RT **realtime-virtual-host/guest**
Red Hat Storage **rhs-high-throughput, virt**	RHOSP (compute node) **virtual-host**	RHEL + SAP **sap / sap-hana**
RHEL Atomic **atomic-host, atomic-guest**	OpenShift **openshift-master, node**	RHOP - NFV (compute node) **cpu-partitioning**

NUMA Nodes and Zones



Per Node / Zone split LRU Paging Dynamics



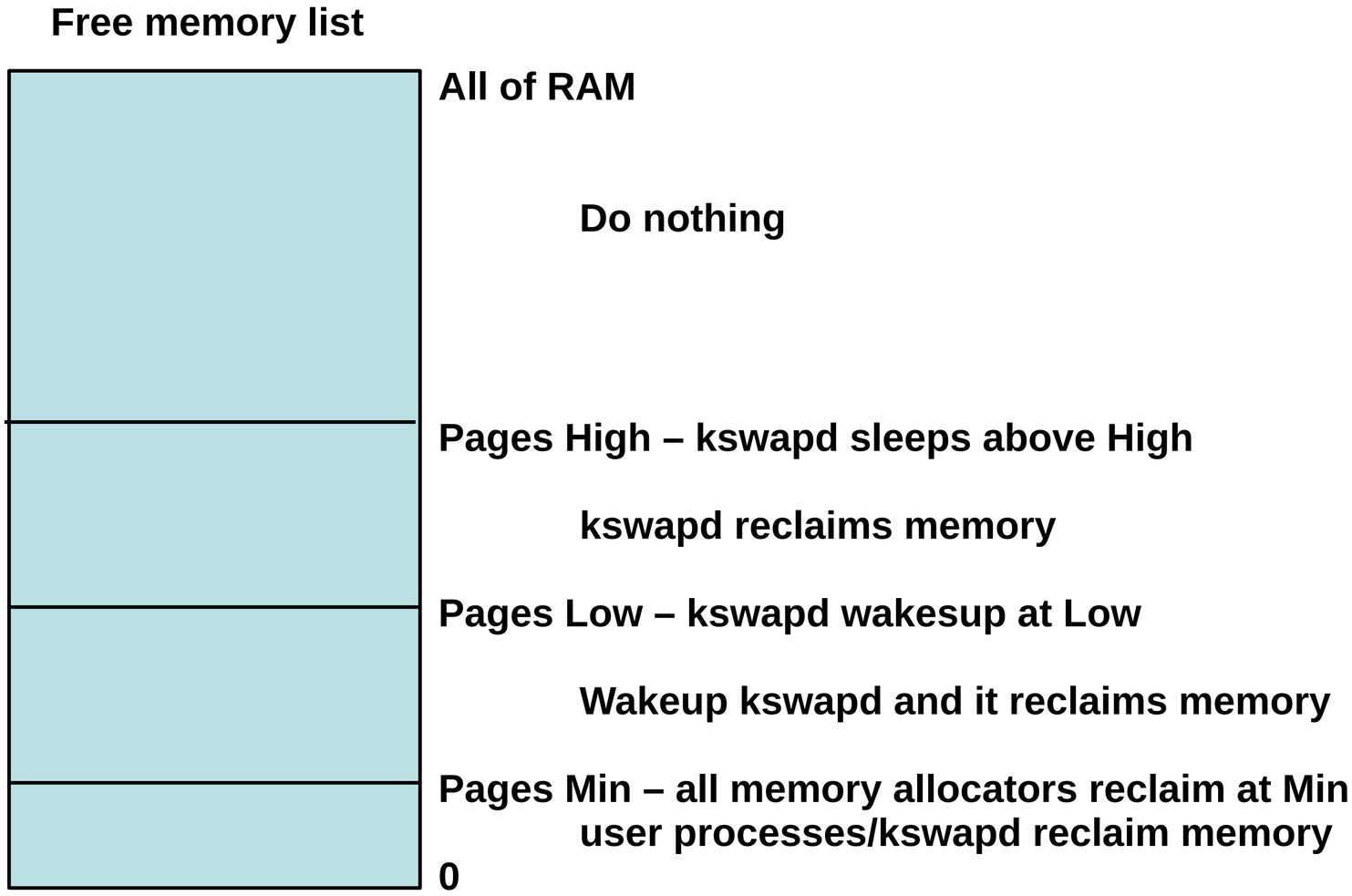
Interaction between VM Tunables and NUMA

- Dependent on NUMA: Reclaim Ratios
  - /proc/sys/vm/swappiness
  - /proc/sys/vm/min_free_kbytes
  - /proc/sys/vm/zone_reclaim_mode
- Independent of NUMA: Reclaim Ratios
  - /proc/sys/vm/vfs_cache_pressure
- Writeback Parameters
  - /proc/sys/vm/dirty_background_ratio
  - /proc/sys/vm/dirty_ratio
- Readahead parameters
  - /sys/block/<bdev>/queue/read_ahead_kb

swappiness

- Controls how aggressively the system reclaims anonymous memory versus pagecache memory:
  - Anonymous memory – swapping and freeing
  - File pages – writing if dirty and freeing
  - System V shared memory – swapping and freeing
- Default is 60
- Decrease: more aggressive reclaiming of pagecache memory
- Increase: more aggressive swapping of anonymous memory
- Can effect Numa nodes differently.
- Tuning not as necessary on RHEL7 than RHEL6 and even less than RHEL5

Memory reclaim Watermarks



min_free_kbytes

Directly controls the page reclaim watermarks in KB

Distributed between the Numa nodes

Defaults are higher when THP is enabled

```
# cat /proc/sys/vm/min_free_kbytes
90100
------------------------------------------------------------
Node 0 DMA    min:80 low:100kB high:120kB
Node 0 DMA32 min:15312kB low:19140kB high:22968kB
Node 0 Normal min:29600kB low:37000kB high:44400kB
Node 1 Normal min:45108kB low:56384kB high:67660kB
------------------------------------------------------------

echo 180200 > /proc/sys/vm/min_free_kbytes
------------------------------------------------------------2
Node 0 DMA    min:160kB low:200kB high:240kB
Node 0 DMA32 min:30624kB low:38280kB high:45936kB
Node 0 Normal min:59200kB low:74000kB high:88800kB
Node 1 Normal min:90216kB low:112768kB high:135320kB
------------------------------------------------------------
```

RHEL Disk IO

I/O Tuning – Understanding I/O Elevators

- Deadline – new RHEL7 default for all profiles
  - Two queues per device, one for read and one for writes
  - I/Os dispatched based on time spent in queue
- CFQ – used for system disks off SATA/SAS controllers
  - Per process queue
  - Each process queue gets fixed time slice (based on process priority)
- NOOP – used for high-end SSDs (Fusion IO etc)
  - FIFO
  - Simple I/O Merging
  - Lowest CPU Cost

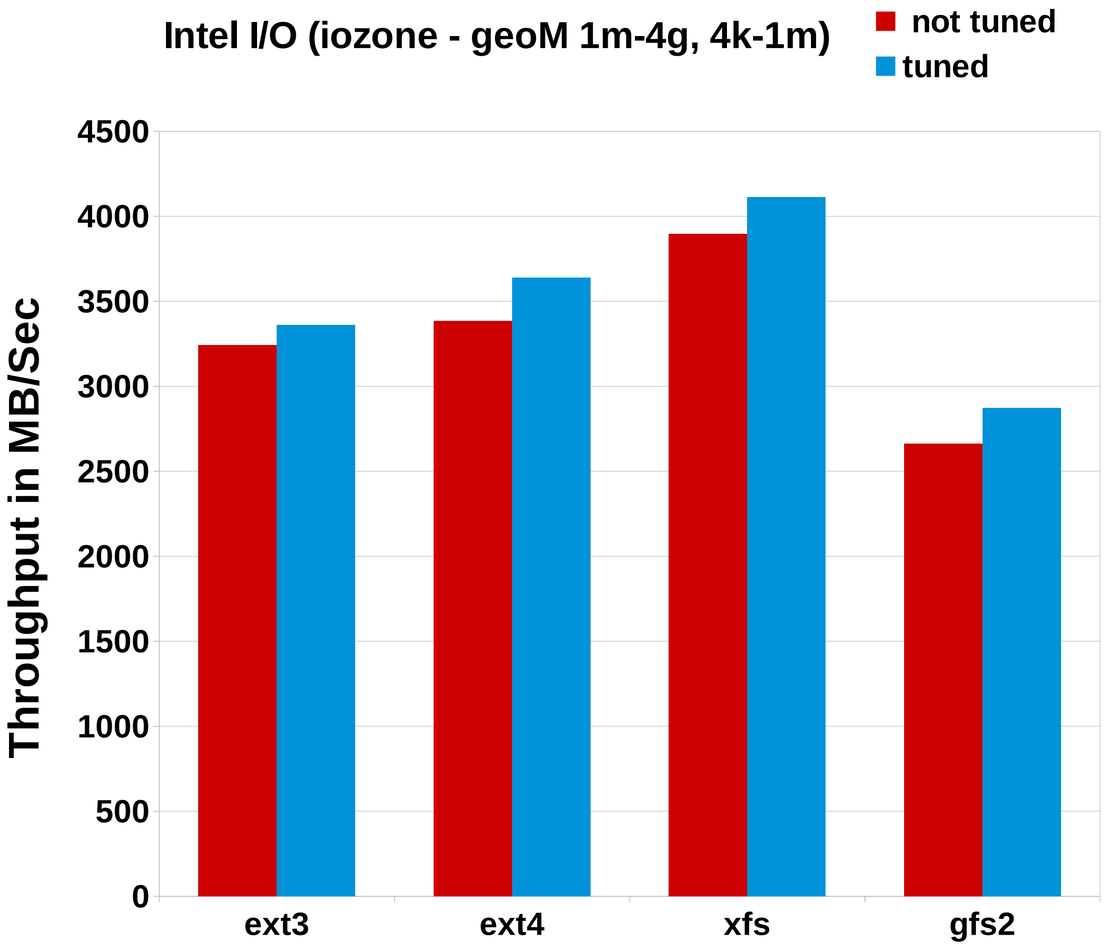
Tuned: Profile throughput-performance (RHEL7 default)

throughput-performance

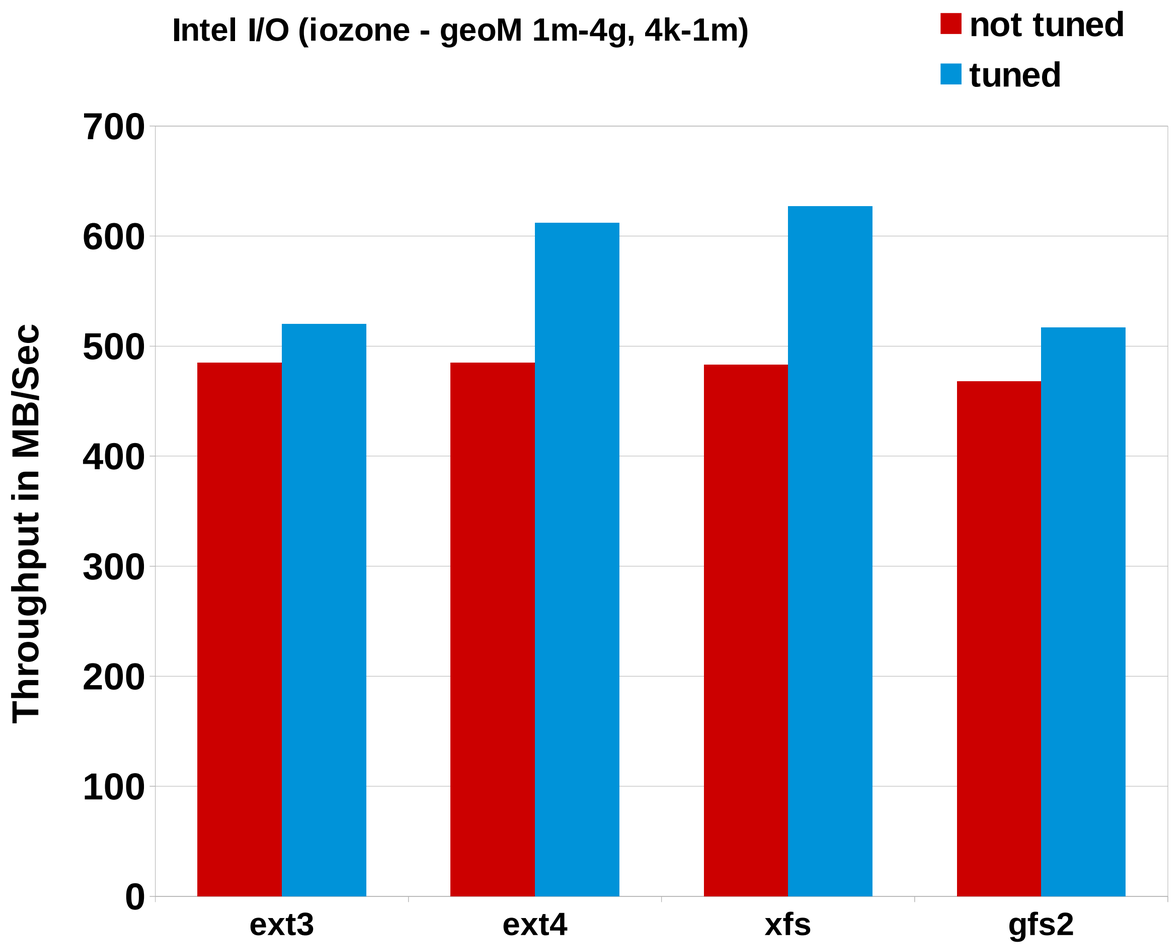
```
governor=performance
energy_perf_bias=performance
min_perf_pct=100
readahead=4096
kernel.sched_min_granularity_ns = 10000000
kernel.sched_wakeup_granularity_ns = 15000000
vm.dirty_background_ratio = 10
vm.swappiness=10
```

Iozone Performance effect of “tuned” EXT4/XFS/GFS

RHEL 7.1 3.10.0-253 File System In Cache Performance



RHEL7 3.10.0-253 File System Out of Cache Performance



SAS Application on Standalone Systems

RHEL 7 limits

xfs **most** recommended

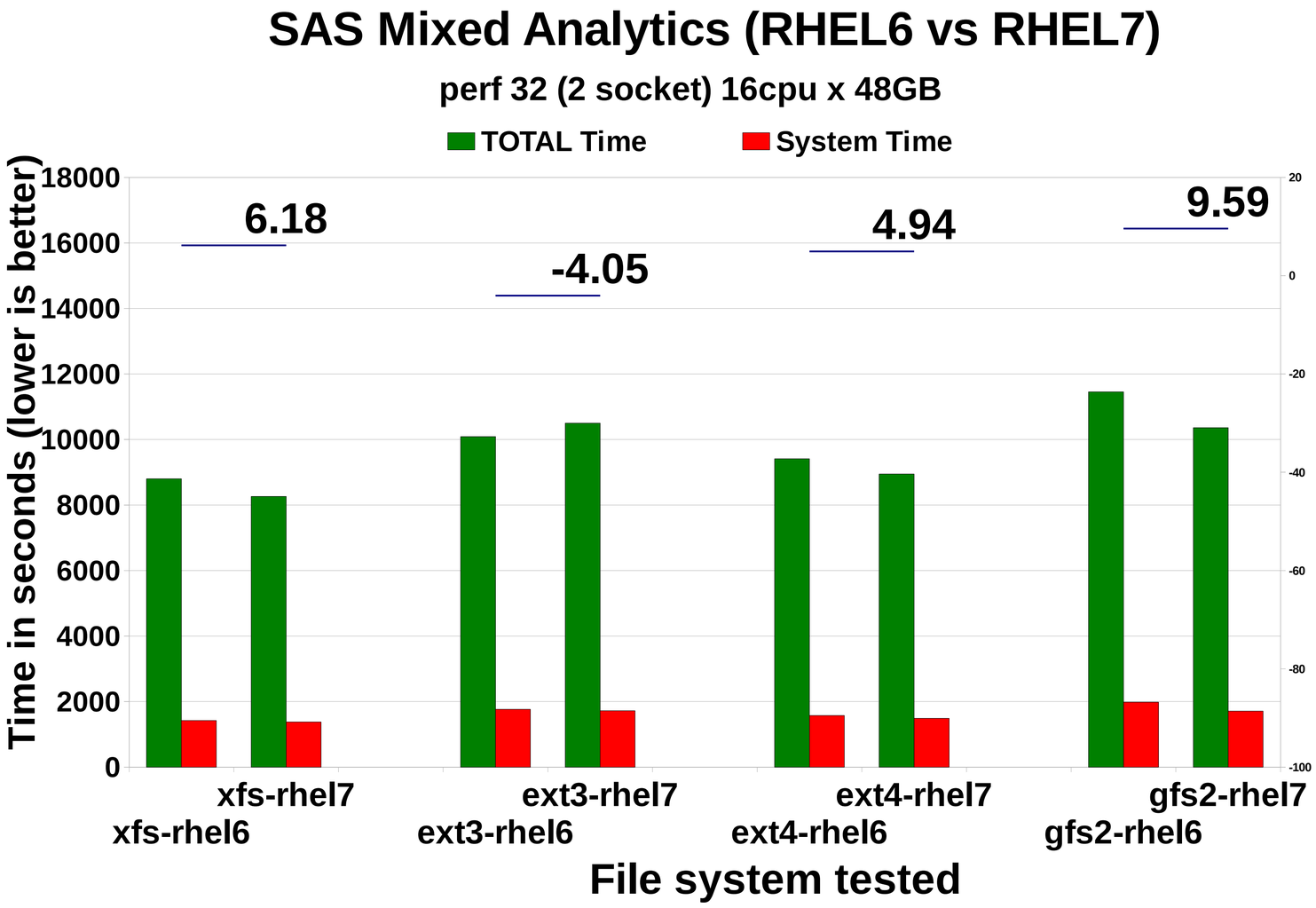
- Max file system size 500TB
- Max file size 100 TB
- Best performing

ext4 recommended

- Max file system size 50 TB
- Max file size 16 TB

ext3 not recommended

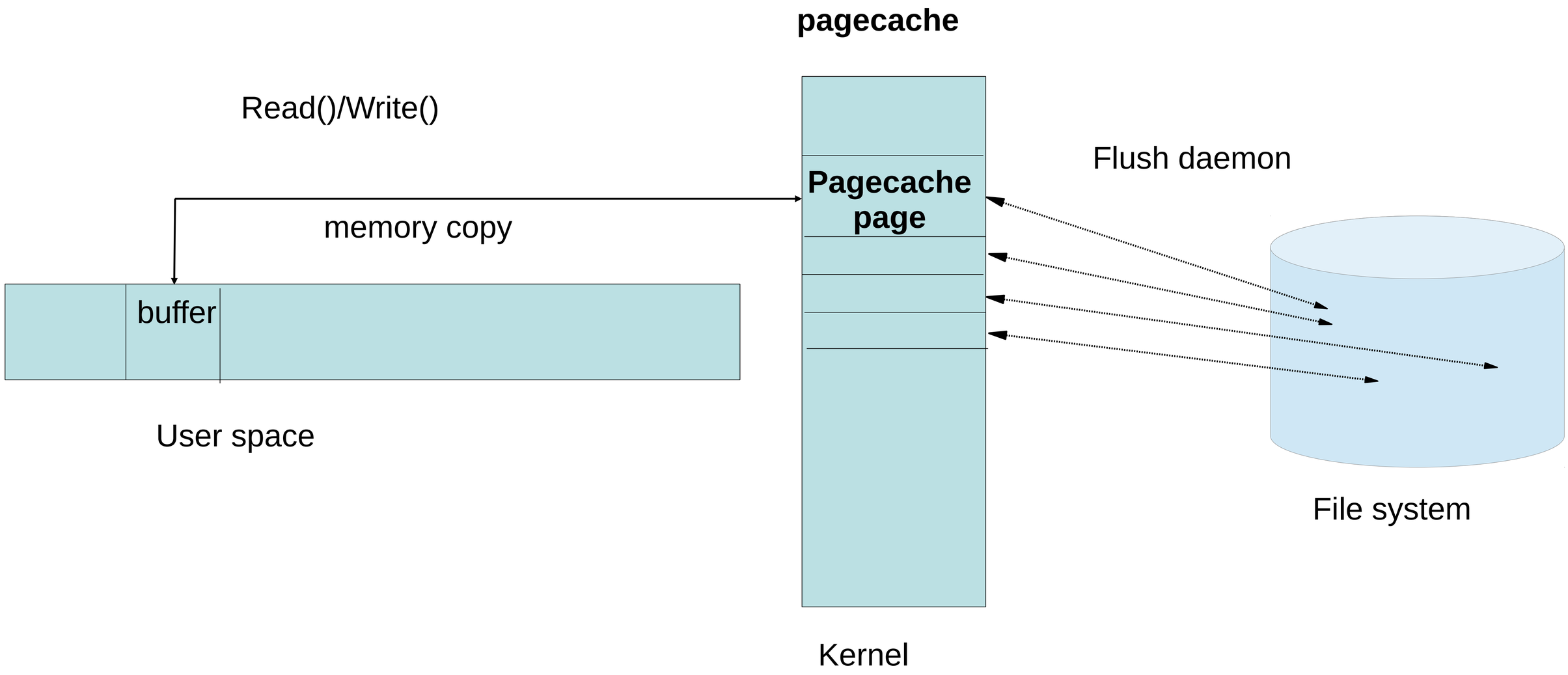
- Max file system size 16TB
- Max file size 2TB



Tuning Memory – Flushing Caches

- Drop unused Cache – to control pagecache dynamically
  - ✔Frees most pagecache memory
  - ✔File cache
  - ✗If the DB uses cache, may notice slowdown
- NOTE: Use for benchmark environments.
- **Free pagecache**
  - **# sync;** echo 1 > /proc/sys/vm/drop_caches
- **Free slabcache**
  - # sync; echo 2 > /proc/sys/vm/drop_caches
- **Free pagecache and slabcache**
  - # sync; echo 3 > /proc/sys/vm/drop_caches

Per file system flush daemon



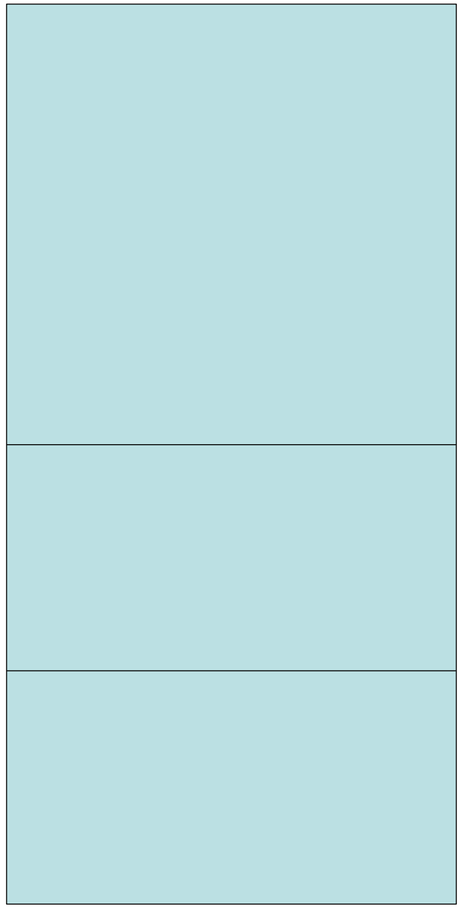
Virtual Memory Manager (VM) Tunables

- **Reclaim Ratios**
  - /proc/sys/vm/swappiness
  - /proc/sys/vm/vfs_cache_pressure
  - /proc/sys/vm/min_free_kbytes
- **Writeback Parameters**
  - /proc/sys/vm/dirty_background_ratio
  - /proc/sys/vm/dirty_ratio
- **Readahead parameters**
  - /sys/block/<bdev>/queue/read_ahead_kb

dirty_background_ratio, dirty_background_bytes

- Controls when dirty pagecache memory starts getting written.
- Default is 10%
- Lower
  - flushing starts earlier
  - less dirty pagecache and smaller IO streams
- Higher
  - flushing starts later
  - more dirty pagecache and larger IO streams
- **dirty_background_bytes over-rides when you want < 1%**

dirty_ratio and dirty_background_ratio



100% of pagecache RAM dirty

flushd and write()'ng processes write dirty buffers

dirty_ratio(20% of RAM dirty) – processes start synchronous writes

flushd writes dirty buffers in background

dirty_background_ratio(10% of RAM dirty) – wakeup flushd

do_nothing

0% of pagecache RAM dirty

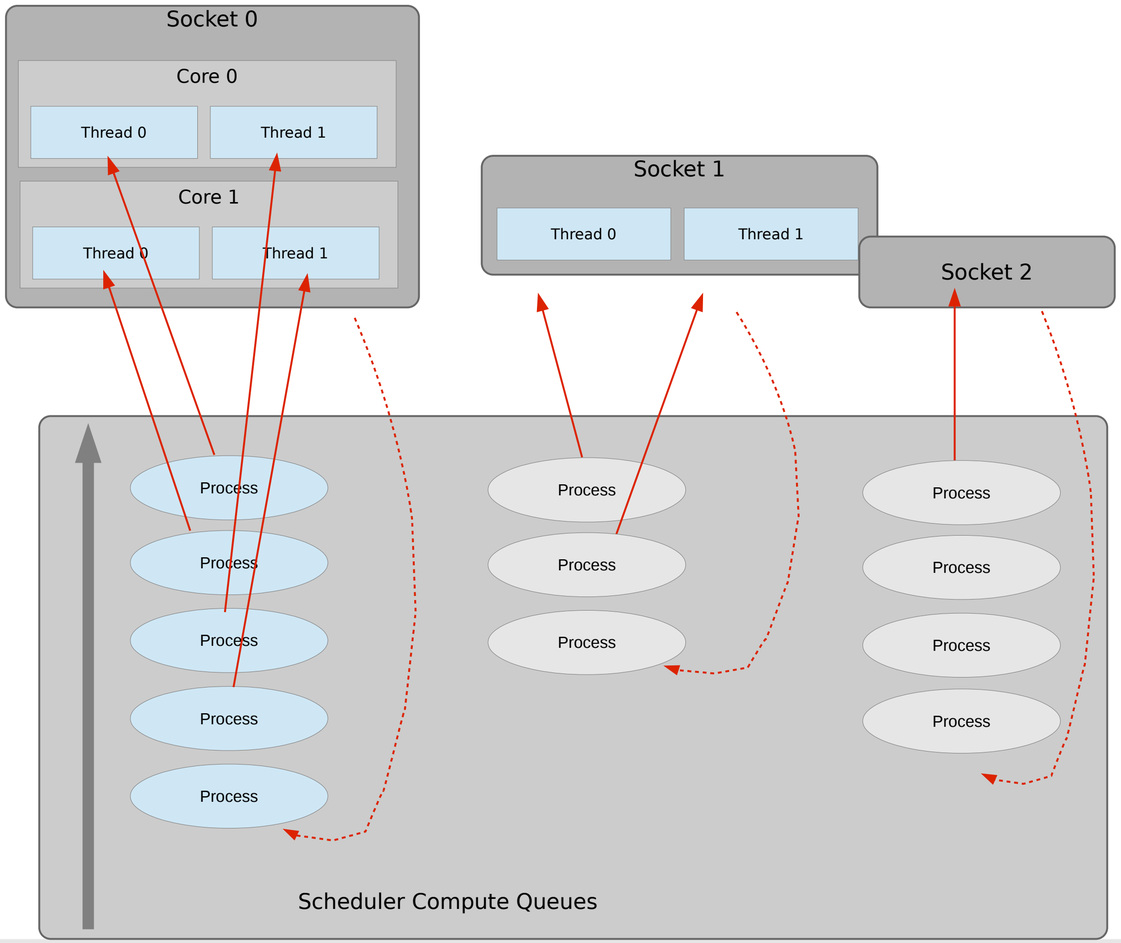
RHEL CFS Scheduler

RHEL Scheduler Tunables

Implements multiple red/black trees as run queues for sockets and cores (as opposed to one run queue per processor or per system)

RHEL tunables

- sched_min_granularity_ns
- sched_wakeup_granularity_ns
- sched_migration_cost
- sched_child_runs_first
- sched_latency_ns



Finer Grained Scheduler Tuning

- RHEL6/7 Tuned-adm will increase quantum on par with RHEL5
  - echo 10000000 > /proc/sys/kernel/sched_min_granularity_ns
    - Minimal preemption granularity for CPU bound tasks. See sched_latency_ns for details. The default value is 4000000 (ns).
  - echo 15000000 > /proc/sys/kernel/sched_wakeup_granularity_ns
    - The wake-up preemption granularity.
    - Increasing this variable reduces wake-up preemption, reducing disturbance of compute bound tasks.
    - Decreasing it improves wake-up latency and throughput for latency critical tasks, particularly when a short duty cycle load component must compete with CPU bound components. The default value is 5000000 (ns).

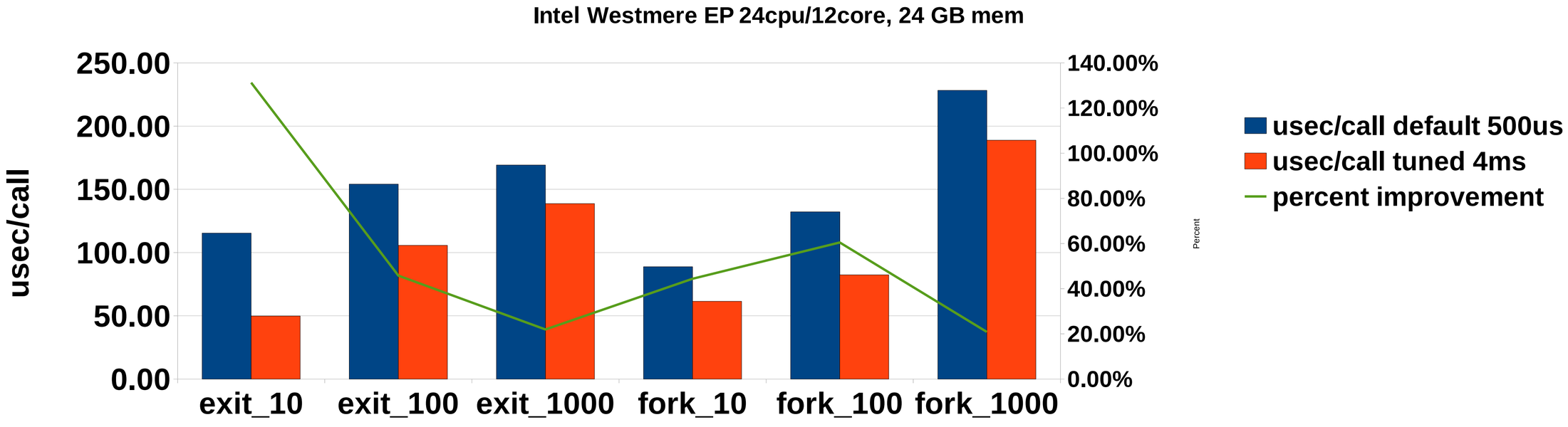
Load Balancing

- Scheduler tries to keep all CPUs busy by moving tasks form overloaded CPUs to idle CPUs
- Detect using “perf stat”, look for excessive “migrations”
- **/proc/sys/kernel/sched_migration_cost**
  - Amount of time after the last execution that a task is considered to be “cache hot” in migration decisions. A “hot” task is less likely to be migrated, so increasing this variable reduces task migrations. The default value is 500000 (ns).
  - If the CPU idle time is higher than expected when there are runnable processes, try reducing this value. If tasks bounce between CPUs or nodes too often, try increasing it.
- Rule of thumb – increase by **2-10x** to reduce load balancing (tuned does this)
- Use 10x on large systems when many CGROUPs are actively used (ex: RHEV/KVM/RHOS)

fork() behavior

sched_child_runs_first
- Controls whether parent or child runs first
- Default is 0: parent continues before children run.
- Default is different than RHEL5

RHEL6 Effect of sched_migration cost on fork/exit



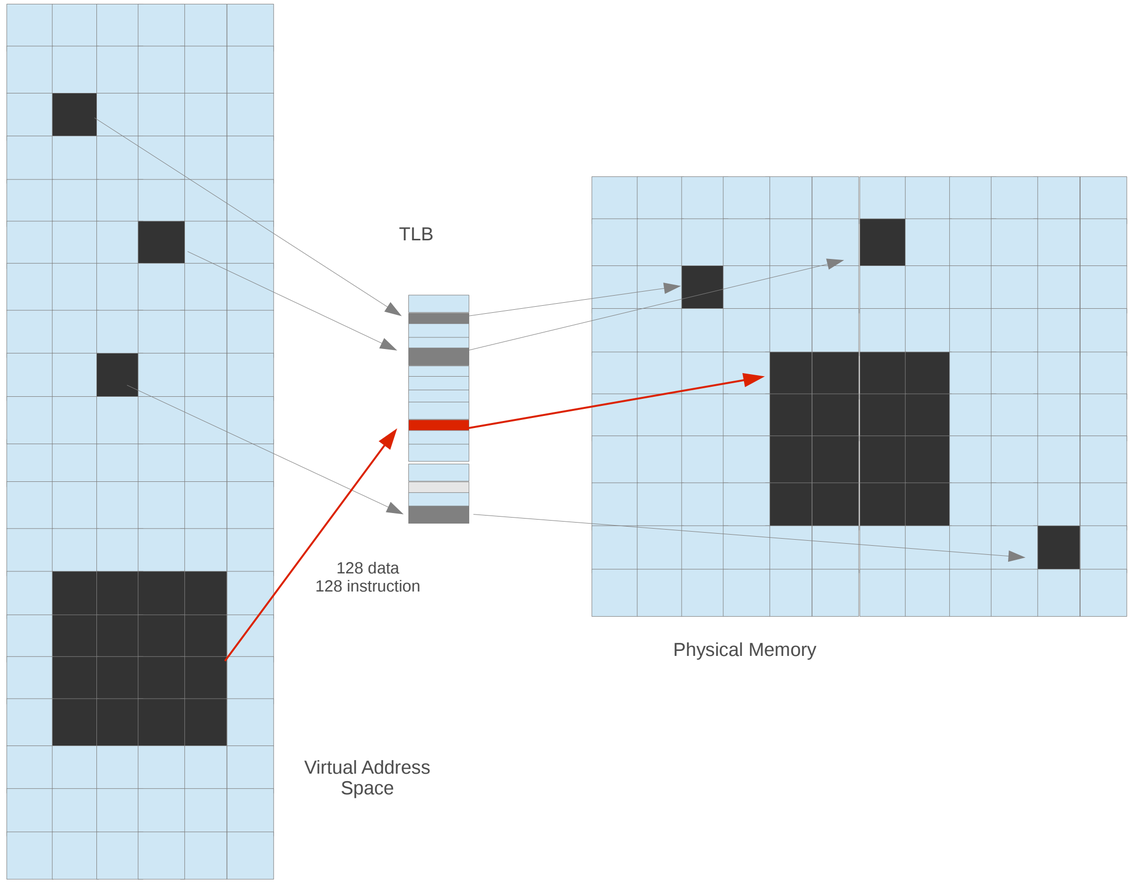
RHEL7.4 Core Kernel Features

- Deadline Scheduler
  - allows process to define when it must run.
- Persistent Memory
  - supports huge amounts of non-volitle RAM
- Qspinlock
  - prevents cacheline contention causes locking contention
- RWsemaphore locking
  - performance improvement to kernel r/w semaphores
- KASLR
  - kernel addr space randomization provide better security

RHEL VM HugePages

RHEL Hugepages/ VM Tuning

- Standard HugePages 2MB
  - Reserve/free via
    - /proc/sys/vm/nr_hugepages
    - /sys/devices/node/* /hugepages/*/nrhugepages
  - Used via hugetlbfs
- GB Hugepages 1GB
  - Reserved at boot time/no freeing
  - RHEL7 allows runtime allocation & freeing
  - Used via hugetlbfs
- Transparent HugePages 2MB
  - On by default via boot args or /sys
  - Used for anonymous memory



Transparent Hugepages

- Disable transparent_hugepages

```
#echo never > /sys/kernel/mm/transparent_hugepages=never

#time ./memory 15 0
real    0m12.434s
user    0m0.936s
sys     0m11.416s

 # cat /proc/meminfo
 MemTotal:       16331124 kB
 AnonHugePages:  0 kB
```

- Boot argument: transparent_hugepages=always (enabled by default)

```
#echo always > /sys/kernel/mm/redhat_transparent_hugepage/enabled

#time ./memory 15GB
real    0m7.024s
user    0m0.073s
sys     0m6.847s

#cat /proc/meminfo
MemTotal:       16331124 kB
AnonHugePages:  15590528 kB
```

SPEEDUP 12.4/7.0 = 1.77x, 56%

2MB standard Hugepages

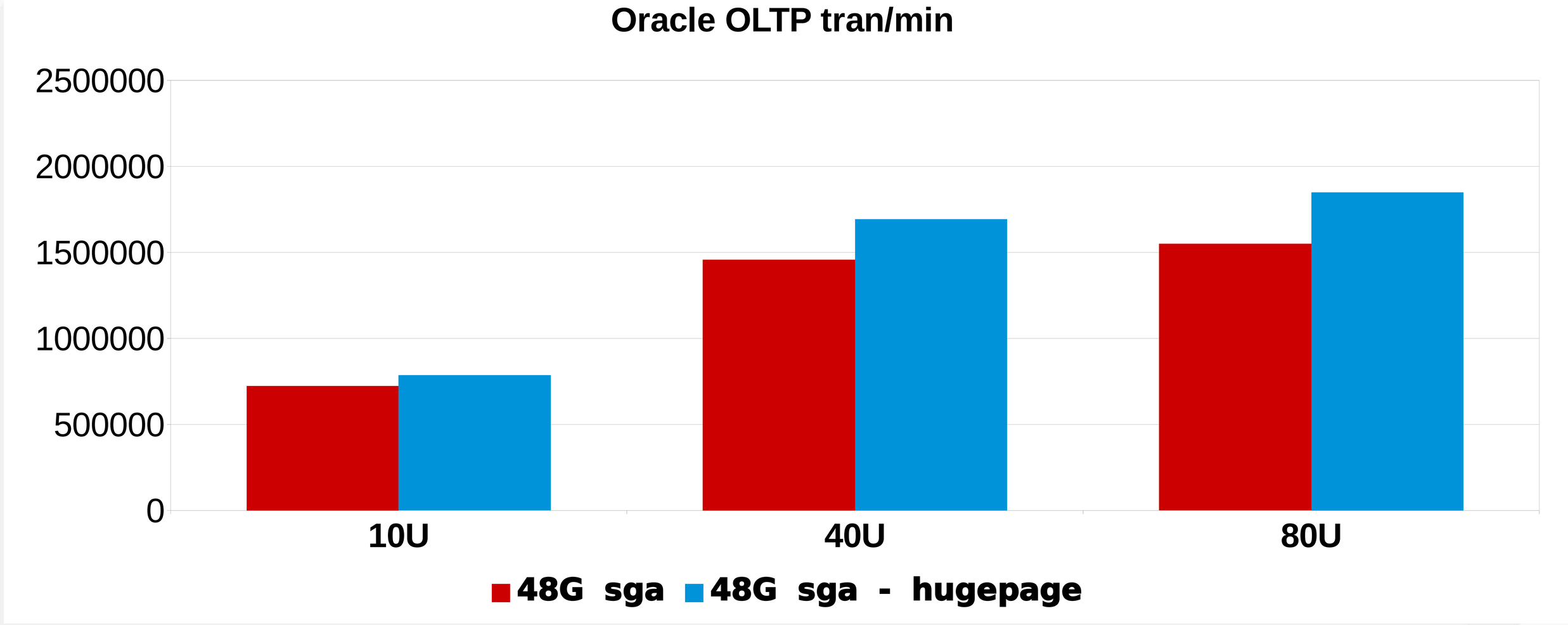
```
# echo 2000 > /proc/sys/vm/nr_hugepages
# cat /proc/meminfo
MemTotal:       16331124 kB
MemFree:        11788608 kB

HugePages_Total:    2000
HugePages_Free:     2000
HugePages_Rsvd:        0
HugePages_Surp:        0
Hugepagesize:       2048 kB

# ./hugeshm 1000

# cat /proc/meminfo
MemTotal:       16331124 kB
MemFree:        11788608 kB

HugePages_Total:    2000
HugePages_Free:     1000
HugePages_Rsvd:     1000
HugePages_Surp:        0
Hugepagesize:       2048 kB
```

2MB Hugepages - specific node allocation

```
# echo 0 > /proc/sys/vm/nr_hugepages
# cat /proc/meminfo | grep HugePages_Free
HugePages_Free:     0

# echo 1000 > /proc/sys/vm/nr_hugepages
# cat /proc/meminfo | grep HugePages_Free
HugePages_Free:     1000
# cat /sys/devices/system/node/node*/hugepages/hugepages-2048kB/nr_hugepages
500
500

# echo 0 > /proc/sys/vm/nr_hugepages
# echo 1000 > /sys/devices/system/node/node0/hugepages/hugepages-2048kB/nr_hugepages
# cat /proc/meminfo | grep HugePages_Free
HugePages_Free:     1000
# cat /sys/devices/system/node/node*/hugepages/hugepages-2048kB/nr_hugepages
1000
0
```

Database Performance OLTP (Higher = Better)

huge pages on Bare Metal



The effect of hugepages are more pronounced as system drive to saturaton

Boot-time allocated 1GB Hugepages

Boot arguments

- default_hugepagesz=1G, hugepagesz=1G, hugepages=8

```
# cat /proc/meminfo | grep HugePages
HugePages_Total:       8
HugePages_Free:        8
HugePages_Rsvd:        0
HugePages_Surp:        0
```

```
#mount -t hugetlbfs none /mnt
# ./mmapwrite /mnt/junk 33
writing 2097152 pages of random junk to file /mnt/junk
wrote 8589934592 bytes to file /mnt/junk
```

```
# cat /proc/meminfo | grep HugePages
HugePages_Total:       8
HugePages_Free:        0
HugePages_Rsvd:        0
HugePages_Surp:        0
```

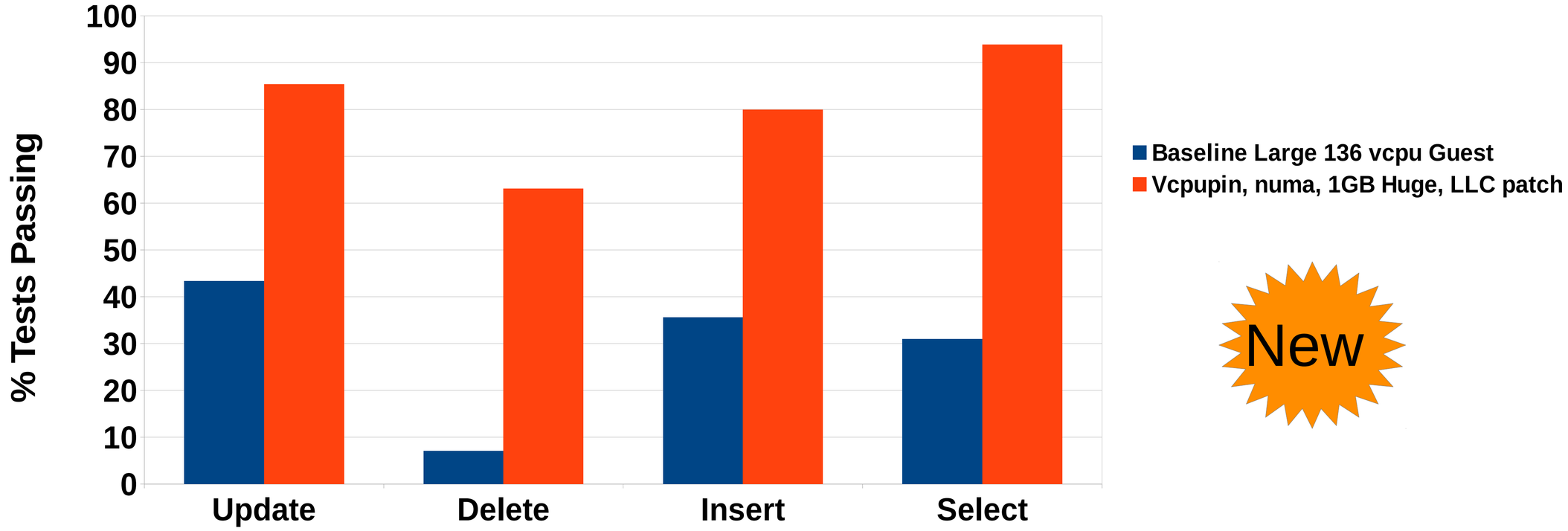
Dynamic per-node allocation/deallocation of 1GB Hugepages

```
# cat /sys/devices/system/node/node*/hugepages/hugepages-1048576kB/nr_hugepages
0
0

# echo 8 >  /sys/devices/system/node/node0/hugepages/hugepages-1048576kB/nr_hugepages
# cat /proc/meminfo | grep HugePages_Free
HugePages_Free:     8
# cat /sys/devices/system/node/node*/hugepages/hugepages-1048576kB/nr_hugepages
8
0

# echo 0 >  /sys/devices/system/node/node0/hugepages/hugepages-1048576kB/nr_hugepages
# cat /proc/meminfo | grep HugePages_Free
HugePages_Free:     0
# cat /sys/devices/system/node/node*/hugepages/hugepages-1048576kB/nr_hugepages
0
0
```

SAP Performance w/ Hana

RHEL7.3 RHV4.x - SAP HANA OLTP Cert (250 test) - Baseline vs. Tuned Guest

Intel Haswell EX, 144 CPU, 4 socket, 512 GB memory, 2 PCI NVME cards



RHEL Control Group - Cgroups

Cgroup default mount points

RHEL6

```
# cat /etc/cgconfig.conf

mount {
    cpuset= /cgroup/cpuset;
    cpu  = /cgroup/cpu;
    cpuacct  = /cgroup/cpuacct;
    memory  = /cgroup/memory;
    devices  = /cgroup/devices;
    freezer   = /cgroup/freezer;
    net_cls   = /cgroup/net_cls;
    blkio    = /cgroup/blkio;
 }
```

RHEL7

/sys/fs/cgroup/

```
# ls -l /cgroup
drwxr-xr-x 2 root root 0 Jun 21 13:33 blkio
drwxr-xr-x 3 root root 0 Jun 21 13:33 cpu
drwxr-xr-x 3 root root 0 Jun 21 13:33 cpuacct
drwxr-xr-x 3 root root 0 Jun 21 13:33 cpuset
drwxr-xr-x 3 root root 0 Jun 21 13:33 devices
drwxr-xr-x 3 root root 0 Jun 21 13:33 freezer
drwxr-xr-x 3 root root 0 Jun 21 13:33 memory
drwxr-xr-x 2 root root 0 Jun 21 13:33 net_cls
```

RHEL7

```
#ls -l /sys/fs/cgroup/
drwxr-xr-x. 2 root root  0 Mar 20 16:40 blkio
drwxr-xr-x. 2 root root  0 Mar 20 16:40 cpu,cpuacct
drwxr-xr-x. 2 root root  0 Mar 20 16:40 cpuset
drwxr-xr-x. 2 root root  0 Mar 20 16:40 devices
drwxr-xr-x. 2 root root  0 Mar 20 16:40 freezer
drwxr-xr-x. 2 root root  0 Mar 20 16:40 hugetlb
drwxr-xr-x. 3 root root  0 Mar 20 16:40 memory
drwxr-xr-x. 2 root root  0 Mar 20 16:40 net_cls
drwxr-xr-x. 2 root root  0 Mar 20 16:40 perf_event
drwxr-xr-x. 4 root root  0 Mar 20 16:40 systemd
```

Cgroup how-to

Create a 2GB/4CPU subset of a 16GB/8CPU system

```
# numactl --hardware
# mount -t cgroup xxx /cgroups
# mkdir -p /cgroups/test
# cd /cgroups/test
# echo 0 > cpuset.mems
# echo 0-3 > cpuset.cpus
# echo 2G > memory.limit_in_bytes
# echo $$ > tasks
```

cgroups

```
# echo 0-3 > cpuset.cpus
# runmany 20MB 110procs &
# top -d 5
top - 12:24:13 up  1:36,  4 users,  load average: 22.70, 5.32, 1.79
Tasks: 315 total,  93 running, 222 sleeping,   0 stopped,   0 zombie
Cpu0  : 100.0%us,  0.0%sy,  0.0%ni,  0.0%id,  0.0%wa,  0.0%hi,  0.0%si,  0.0%st
Cpu1  : 100.0%us,  0.0%sy,  0.0%ni,  0.0%id,  0.0%wa,  0.0%hi,  0.0%si,  0.0%st
Cpu2  : 100.0%us,  0.0%sy,  0.0%ni,  0.0%id,  0.0%wa,  0.0%hi,  0.0%si,  0.0%st
Cpu3  : 100.0%us,  0.0%sy,  0.0%ni,  0.0%id,  0.0%wa,  0.0%hi,  0.0%si,  0.0%st
Cpu4  :  0.4%us,  0.6%sy,  0.0%ni, 98.8%id,  0.0%wa,  0.0%hi,  0.2%si,  0.0%st
Cpu5  :  0.4%us,  0.0%sy,  0.0%ni, 99.2%id,  0.0%wa,  0.0%hi,  0.4%si,  0.0%st
Cpu6  :  0.0%us,  0.0%sy,  0.0%ni,100.0%id,  0.0%wa,  0.0%hi,  0.0%si,  0.0%st
Cpu7  :  0.0%us,  0.0%sy,  0.0%ni, 99.8%id,  0.0%wa,  0.0%hi,  0.2%si,  0.0%st
```

Correct NUMA bindings

```
# echo 0 > cpuset.mems
# echo 0-3 > cpuset.cpus
# numastat
                           node0           node1
numa_hit                1648772          438778
numa_miss                 23459         2134520
local_node              1648648          423162
other_node                23583         2150136

# /common/lwoodman/code/memory 4G
faulting took 1.616062s
touching took 0.364937s

# numastat
                           node0           node1
numa_hit                2700423          439550
numa_miss                 23459         2134520
local_node              2700299          423934
other_node                23583         2150136
```

Incorrect NUMA bindings

```
# echo 1 > cpuset.mems
# echo 0-3 > cpuset.cpus
# numastat
                           node0           node1
numa_hit                1623318          434106
numa_miss                 23459         1082458
local_node              1623194          418490
other_node                23583         1098074

# /common/lwoodman/code/memory 4G
faulting took 1.976627s
touching took 0.454322s

# numastat
                           node0           node1
numa_hit                1623341          434147
numa_miss                 23459         2133738
local_node              1623217          418531
other_node                23583         2149354
```

cpu.shares default

 # cat cpu.shares
1024

top - 10:04:19 up 13 days, 17:24, 11 users, load average: 8.41, 8.31, 6.17

PID	USER	PR	NI	VIRT	RES	SHR	S	%CPU	%MEM	TIME
20104	root	20	0	4160	360	284	R	99.4	0.0	12:35.83 useless
20103	root	20	0	4160	356	284	R	91.4	0.0	12:34.78 useless
20105	root	20	0	4160	360	284	R	90.4	0.0	12:33.08 useless
20106	root	20	0	4160	360	284	R	88.4	0.0	12:32.81 useless
20102	root	20	0	4160	360	284	R	86.4	0.0	12:35.29 useless
20107	root	20	0	4160	356	284	R	85.4	0.0	12:33.51 useless
20110	root	20	0	4160	360	284	R	84.8	0.0	12:31.87 useless
20108	root	20	0	4160	360	284	R	82.1	0.0	12:30.55 useless
20410	**root**	**20**	**0**	**4160**	**360**	**284**	**R**	**91.4**	**0.0**	**0:18.51 useful**

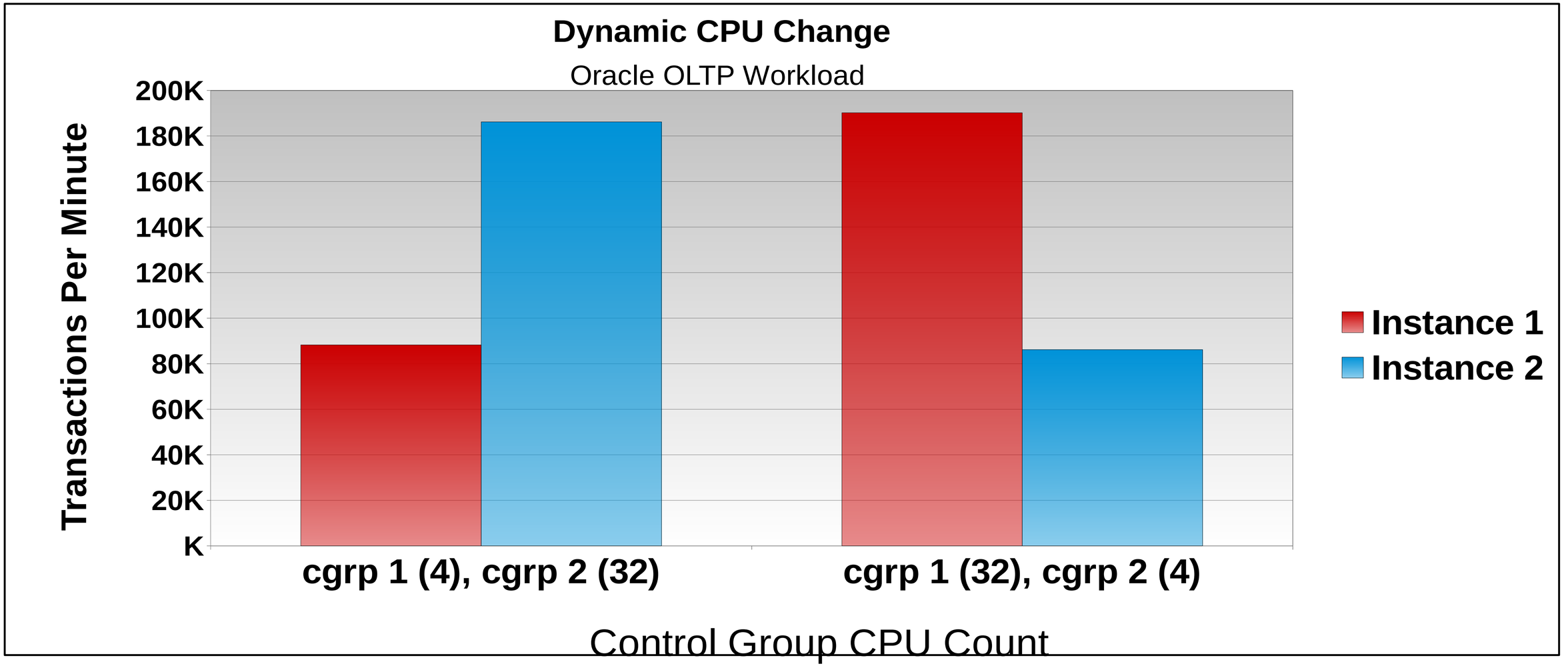
cpu.shares throttled

 # echo 10 > cpu.shares

top - 09:51:58 up 13 days, 17:11, 11 users, load average: 7.14, 5.78, 3.09

PID	USER	PR	NI	VIRT	RES	SHR	S	%CPU	%MEM	TIME
20102	root	20	0	4160	360	284	R	100.0	0.0	0:17.45 useless
20103	root	20	0	4160	356	284	R	100.0	0.0	0:17.03 useless
20107	root	20	0	4160	356	284	R	100.0	0.0	0:15.57 useless
20104	root	20	0	4160	360	284	R	99.8	0.0	0:16.66 useless
20105	root	20	0	4160	360	284	R	99.8	0.0	0:16.31 useless
20108	root	20	0	4160	360	284	R	99.8	0.0	0:15.19 useless
20110	root	20	0	4160	360	284	R	99.4	0.0	0:14.74 useless
20106	root	20	0	4160	360	284	R	99.1	0.0	0:15.87 useless
20111	**root**	**20**	**0**	**4160**	**356**	**284**	**R**	**1.0**	**0.0**	**0:00.08 useful**

C-group Dynamic resource control



cpu.cfs_quota_us unlimited

 # cat cpu.cfs_period_us
100000
 # cat cpu.cfs_quota_us
-1

top - 10:11:33 up 13 days, 17:31, 11 users, load average: 6.21, 7.78, 6.80

PID	USER	PR	NI	VIRT	RES	SHR	S	%CPU	%MEM	TIME+	COMMAND
20614	root	20	0	4160	360	284	R	**100.0**	0.0	0:30.77	useful

 # echo 1000 > cpu.cfs_quota_us

top - 10:16:55 up 13 days, 17:36, 11 users, load average: 0.07, 2.87, 4.93

PID	USER	PR	NI	VIRT	RES	SHR	S	%CPU	%MEM	TIME+	COMMAND
20645	root	20	0	4160	360	284	R	**1.0**	0.0	0:01.54	useful

Cgroup OOMkills

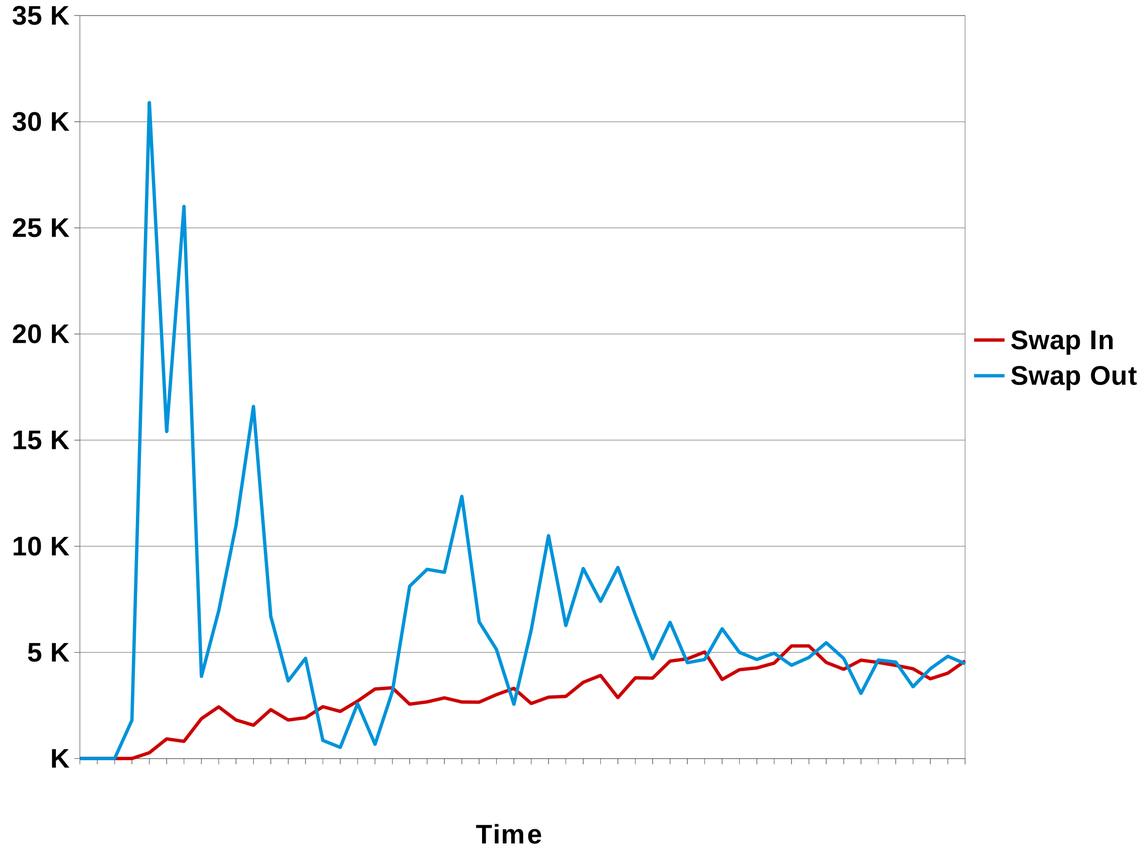
```
# mkdir -p /sys/fs/cgroup/memory/test
# echo 1G > /sys/fs/cgroup/memory/test/memory.limit_in_bytes
# echo 2G > /sys/fs/cgroup/memory/test/memory.memsw.limit_in_bytes
# echo $$ > /sys/fs/cgroup/memory/test/tasks

# ./memory 16G
size = 10485760000
touching 2560000 pages
Killed
# vmstat 1
...
 0  0  52224 1640116      0 3676924    0    0     0     0  202  487  0  0 100  0  0
 1  0  52224 1640116      0 3676924    0    0     0     0  162  316  0  0 100  0  0
 0  1 248532 587268       0 3676948   32 196312    32 196372  912  974  1  4 88   7  0
 0  1 406228 586572       0 3677308    0 157696     0 157704  624  696  0  1 87  11  0
 0  1 568532 585928       0 3676864    0 162304     0 162312  722 1039  0  2 87  11  0
 0  1 729300 584744       0 3676840    0 160768     0 160776  719 1161  0  2 87  11  0
 1  0 885972 585404       0 3677008    0 156844     0 156852  754 1225  0  2 88  10  0
 0  1 1042644 587128      0 3676784    0 156500     0 156508  747 1146  0  2 86  12  0
 0  1 1169708 587396      0 3676748    0 127064     4 127836  702 1429  0  2 88  10  0
 0  0  86648 1607092      0 3677020  144    0     148     0   491 1151  0  1 97   1  0
```

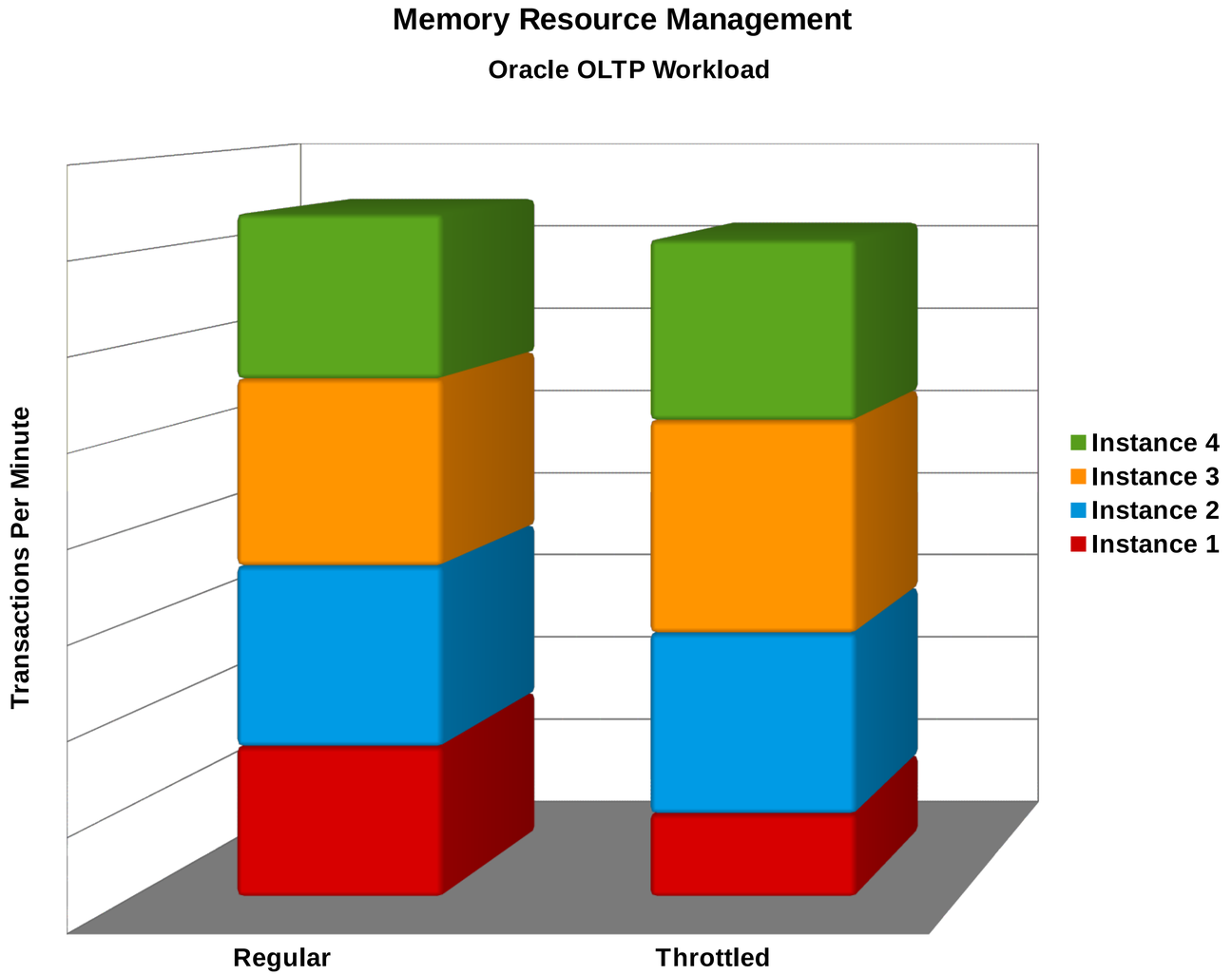
Cgroup OOMkills (continued)

```
# vmstat 1
...
 0  0  52224 1640116       0 3676924    0    0       0      0   202  487  0  0 100  0  0
 1  0  52224 1640116       0 3676924    0    0       0      0   162  316  0  0 100  0  0
 0  1 248532 587268        0 3676948   32 196312      32 196372   912  974  1  4 88   7  0
 0  1 406228 586572        0 3677308    0 157696       0 157704   624  696  0  1 87  11  0
 0  1 568532 585928        0 3676864    0 162304       0 162312   722 1039  0  2 87  11  0
 0  1 729300 584744        0 3676840    0 160768       0 160776   719 1161  0  2 87  11  0
 1  0 885972 585404        0 3677008    0 156844       0 156852   754 1225  0  2 88  10  0
 0  1 1042644 587128       0 3676784    0 156500       0 156508   747 1146  0  2 86  12  0
 0  1 1169708 587396       0 3676748    0 127064       4 127836   702 1429  0  2 88  10  0
 0  0  86648 1607092       0 3677020  144    0      148      0   491 1151  0  1 97   1  0
...
```

```
# dmesg
...
[506858.413341] Task in /test killed as a result of limit of /test
[506858.413342] memory: usage 1048460kB, limit 1048576kB, failcnt 295377
[506858.413343] memory+swap: usage 2097152kB, limit 2097152kB, failcnt 74
[506858.413344] kmem: usage 0kB, limit 9007199254740991kB, failcnt 0
[506858.413345] Memory cgroup stats for /test: cache:0KB rss:1048460KB rss_huge:10240KB
mapped_file:0KB swap:1048692KB inactive_anon:524372KB active_anon:524084KB inactive_file:0KB
active_file:0KB unevictable:0KB
```

Cgroup – Application Isolation





Even though the “RED” application does not have resources and starts swapping,
The other applications are not affected.

Red Hat R+D HPC, GPU, Multi-Arch

HPC R&D: OpenHPC

- A Linux Foundation project to collect and distribute a standardized set of HPC tools and libraries
- OpenHPC Mission: to provide a reference collection of open-source HPC software components and best practices, lowering barriers to deployment, advancement, and use of modern HPC methods and tools.
- Red Hat joined OpenHPC in 2016
- Would like to hear from any of you interested in this topic.

Multiple-Architecture R&D:

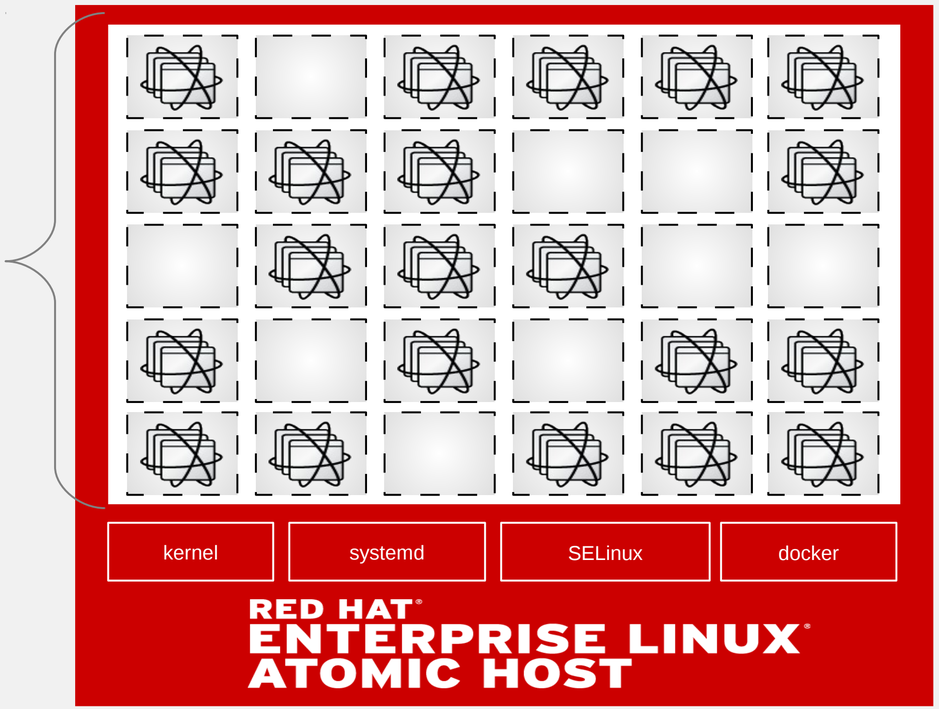
- Red Hat Enterprise Linux: multiple architectures, one experience.
- Driving standardized interfaces and consistent user experiences
- Open, flexible, familiar across common architectures
- Would like to hear from any of you interested in this topic.

GPU / Accelerator R&D:

- Various research efforts exploring offloading and acceleration technologies spanning bare metal, virtualization, and containers
- Looking for input to prioritize important use cases such as:
  - AI / ML (Tensorflow, Theano, Torch, etc.)
  - Image analysis
  - Scientific applications
  - Accelerated libraries
  - Software development tools for accelerated applications
  - Other applications

RHEL Atomic Containers

RED HAT ENTERPRISE LINUX ATOMIC HOST



MINIMAL, SECURE FOOTPRINT

- Minimal host provides “just enough” to support apps.

RAPID PROVISIONING

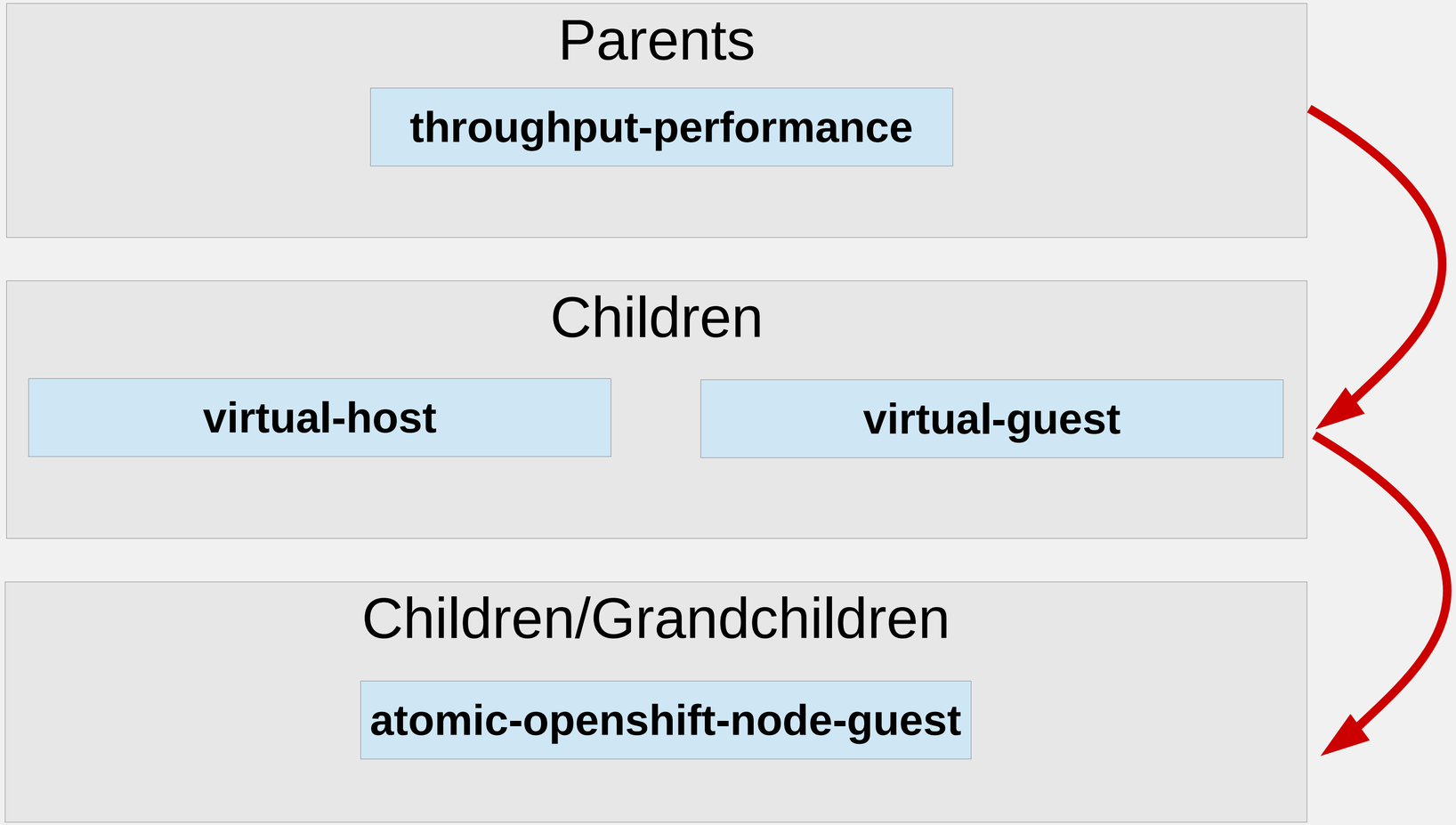
- Apps can be provisioned and started in milliseconds.

SIMPLIFIED MAINTENANCE

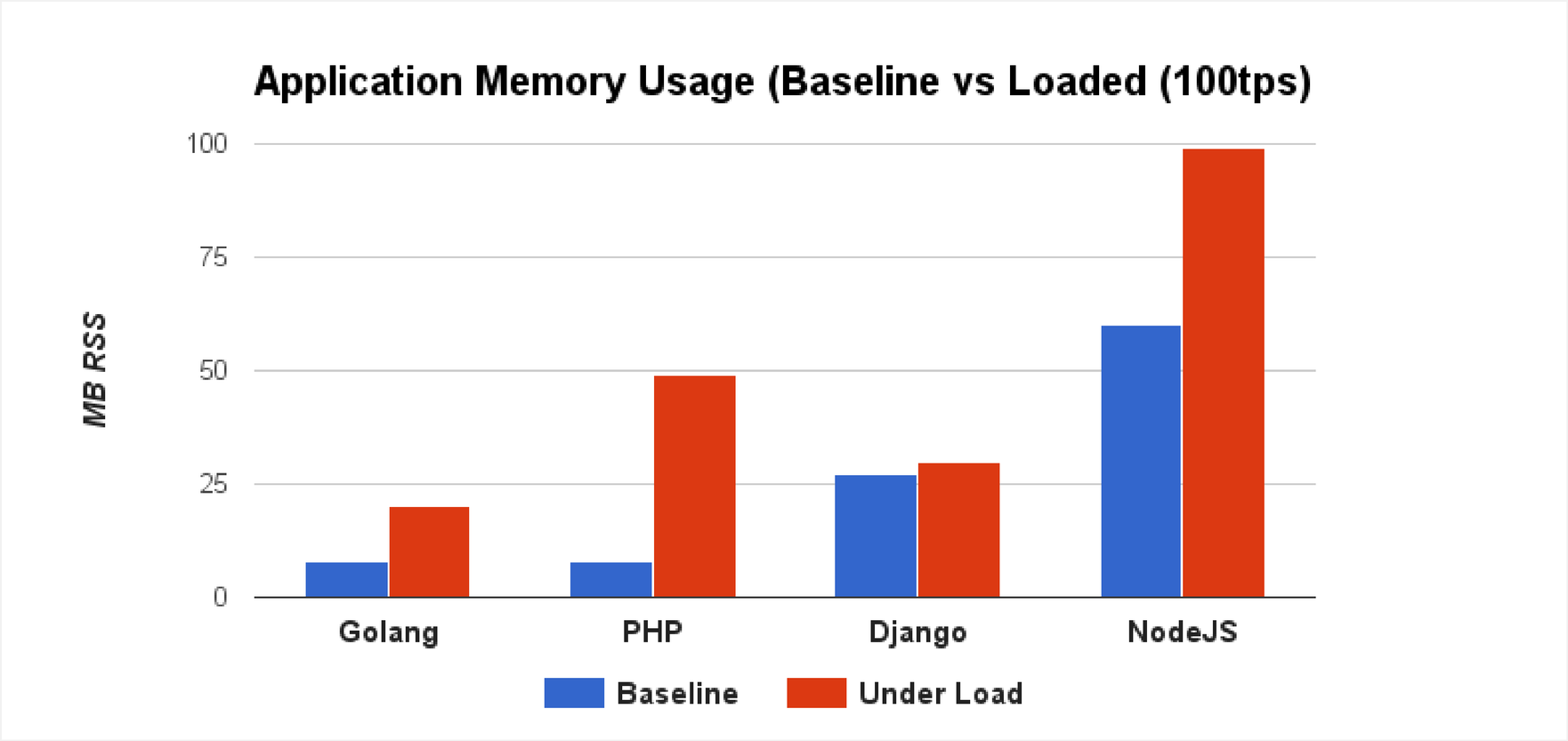
- Atomic updates are quick, reliable, and can be rolled back.

[1] Red Hat Enterprise Linux Atomic Host is not generally available. Visit http://www.redhat.com/about/news/press-archive/2014/4/linux-container-innovations for additional information.

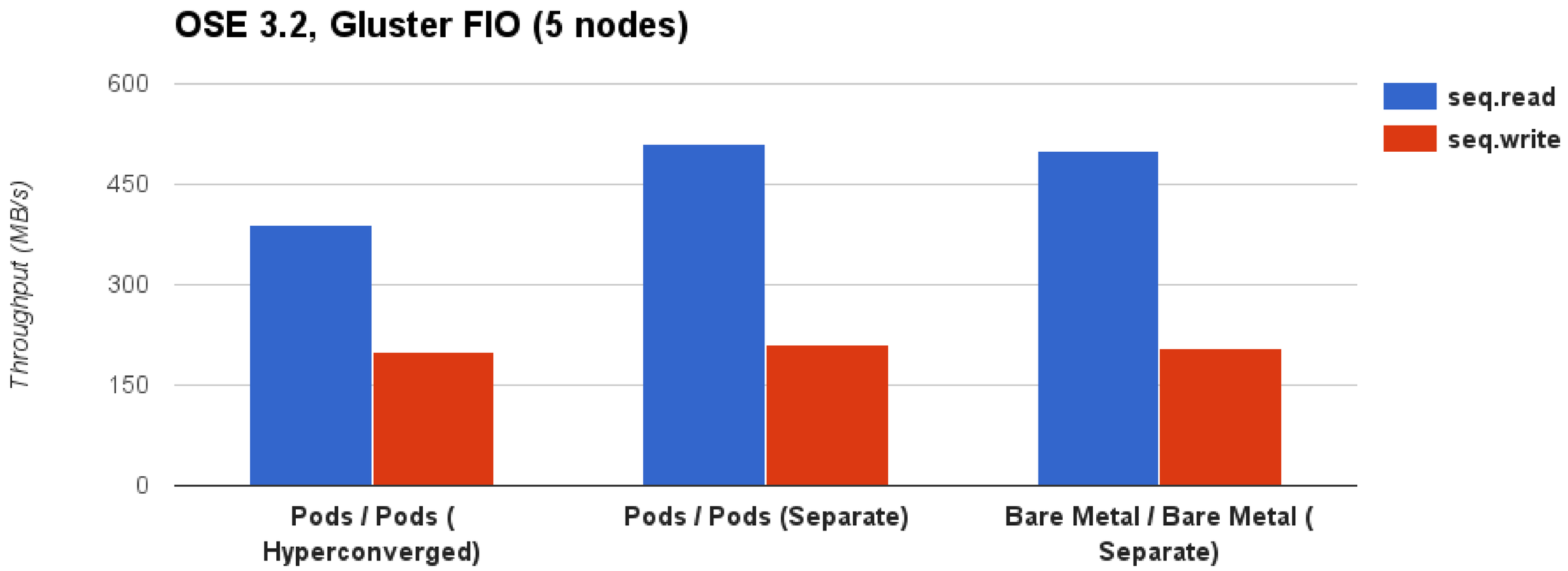
Atomic Tuned Profile Inheritance



Capacity Planning / Memory Usage



OSE 3.4 Cloud Native Storage w/ Gluster



Using Cgroups – Docker, Kubernetes

```
/sys/fs/cgroup/blkio/system.slice/docker-0d4aeda3.scope
/sys/fs/cgroup/cpu,cpuacct/system.slice/docker-0d4aeda3.scope
/sys/fs/cgroup/cpuset/system.slice/docker-0d4aeda3.scope
/sys/fs/cgroup/devices/system.slice/docker-0d4aeda3.scope
/sys/fs/cgroup/freezer/system.slice/docker-0d4aeda3.scope
/sys/fs/cgroup/hugetlb/system.slice/docker-0d4aeda3.scope
/sys/fs/cgroup/memory/system.slice/docker-0d4aeda3.scope
/sys/fs/cgroup/net_cls,net_prio/system.slice/docker-0d4aeda3.scope
/sys/fs/cgroup/perf_event/system.slice/docker-0d4aeda3.scope
```

Using Cgroups – cgconfig.conf

```
group app1 {

    cpuset {
        cpuset.cpus = "2,4,6,8,10";
        cpuset.mems = 0;
```

```
group app2 {

    cpuset {
        cpuset.cpus = "1,3,5,7,9;
        cpuset.mems = 1;
```

RHEL7 Performance Tuning Summary – Part II

- NonUniform Memory Access (NUMA) – kernel details / tuning
- Scheduler tunables adjust quantum, forking, migration cost, new deadline scheduler in 7.x
- HugePages - static, THP, variable sized 4K/2MB/1GB
- Cgroups cpuset, memory, network and IO
  - use to prevent IO from consuming 95% of memory
- Disk IO - IO elevators, sawpiness, dirty ratios, readahead, multi-Q
- R+D GPUoffload, OpenHPC, multi-arch
- Containers
  - Containers are Linux, run/optimized and tuned just like Linux.

- Q+A in “Meet The Experts” - Free as in Soda/Beer/Wine

Performance Whitepapers

- Performance Tuning of Satellite 6.1 and Capsules
  https://access.redhat.com/articles/2356131
- OpenShift v3 Scaling, Performance and Capacity Planning
  https://access.redhat.com/articles/2191731
- Performance and Scaling your RHEL OSP 7 Cloud
  https://access.redhat.com/articles/2165131
  - Update guides to perf / virt to rhel7, add containers
- Red Hat Enterprise Linux Tuning Guide RHEL7
- Red Hat Virtualization Tuning Guide
- Comprehensive Overview of Storage Scalability in Docker
- RHEL Blog / Developer Blog

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