Performance Analysis and Tuning – Part 1

D. John Shakshober (Shak) - Sr Consulting Eng / Director Performance Engineering

Larry Woodman - Senior Consulting Engineer / Kernel VM

Jeremy Eder – Senior Principal Performance Engineer / Network/Atomic

Joe Mario - Senior Principal Performance Engineer / RHEL / NUMA

Agenda: Performance Analysis Tuning Part I

- Part I
  - RHEL Evolution 5->6->7 – Hybrid Clouds Atomic / OSE / RHOP
  - NonUniform Memory Access (NUMA)
    - What is NUMA, RHEL Architecture, Auto-NUMA-Balance
  - Cgroups cpuset, memory, network and IO
    - Use to prevent IO from consuming 95% of memory
    - Used by RHEV w/ KVM and OSE w/ Atomic
  - System Performance/Tools
    - Tuned, Perf, and Tuna

  - “Meet The Experts” - 5:45-7 PM Free - Soda/Beer/Wine

Red Hat Enterprise Linux Performance Evolution

RHEL5

Static Hugepages

Ktune – on/off

CPU Affinity (taskset)

NUMA Pinning (numactl)

Irqbalance

RHEL6

Transparent HugePage

Tuned – choose profile

CPU Affinity (ts/numactl)

NUMAD – uerspace tool

Cgroups -

irqbalance – NUMA enhanced

RHEL7

Transparent Hugepages

Tuned – throughput-performance (default)

CPU Affinity (ts/numactl)

Autonuma-Balance

LXC – Container/Docker

irqbalance – NUMA enhanced

RH Cloud Suites

RHEV – out-of-the-box

virt-host/guest

RHEL OSP – blueprints

Tuned, Numa pining NIC – jumbo sriov

RHEL Atomic Host/Atomic Enterprise

RH OpenShift v3

Cloud Forms

RHEL Performance Workload Coverage

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

Benchmarks – code path coverage

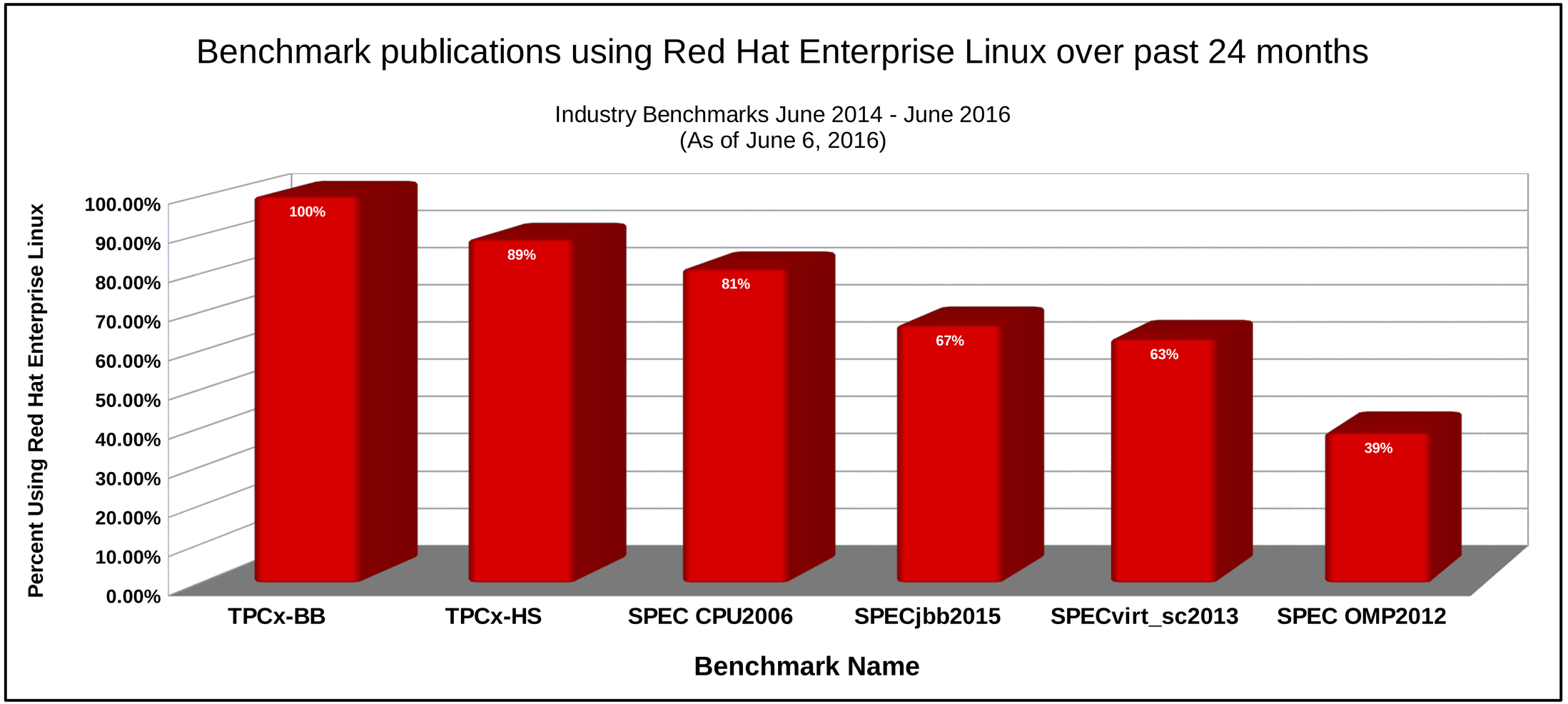
- CPU – linpack, lmbench
- Memory – lmbench, McCalpin STREAM
- Disk IO – iozone, fio – SCSI, FC, iSCSI
- Filesystems – iozone, ext3/4, xfs, gfs2, gluster
- Networks – netperf – 10/40Gbit, Infiniband/RoCE, Bypass
- Bare Metal, RHEL6/7 KVM, Atomic Containers
- White box AMD/Intel, with our OEM partners

Application Performance

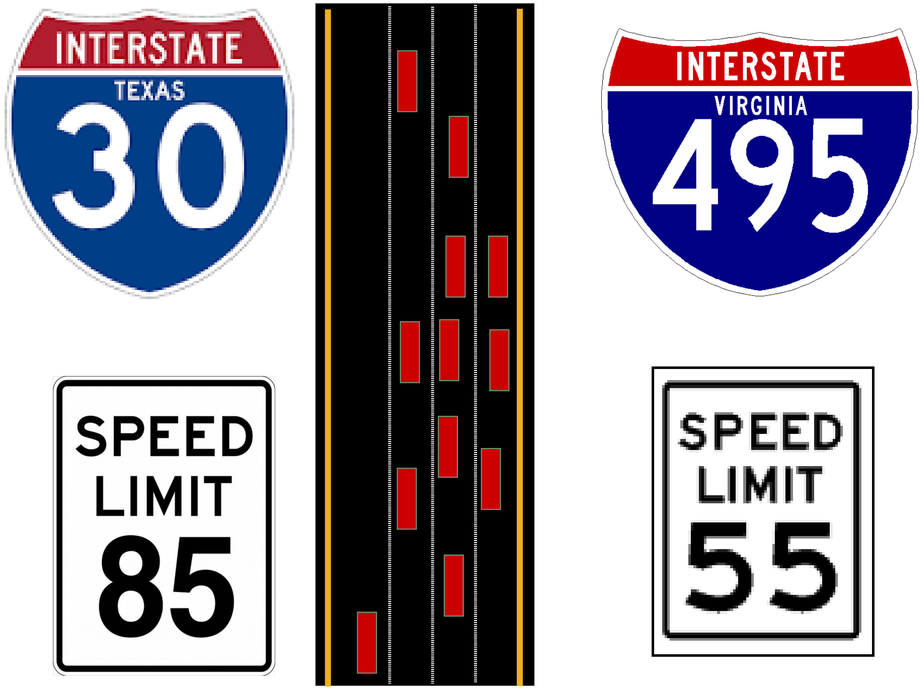
- Linpack MPI, HPC workloads
- AIM 7 – shared, filesystem, db, compute
- Database: DB2, Oracle 11/12, Sybase 15.x , MySQL, MariaDB, Postgrs, MongoDB
- OLTP – TPC-C, TPC-VMS
- DSS – TPC-H/xDS
- Big Data – TPCx-HS, Bigbench
- SPEC cpu, jbb, sfs, virt, cloud
- SAP – SLCS, SD
- STAC = FSI (STAC-N)
- SAS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

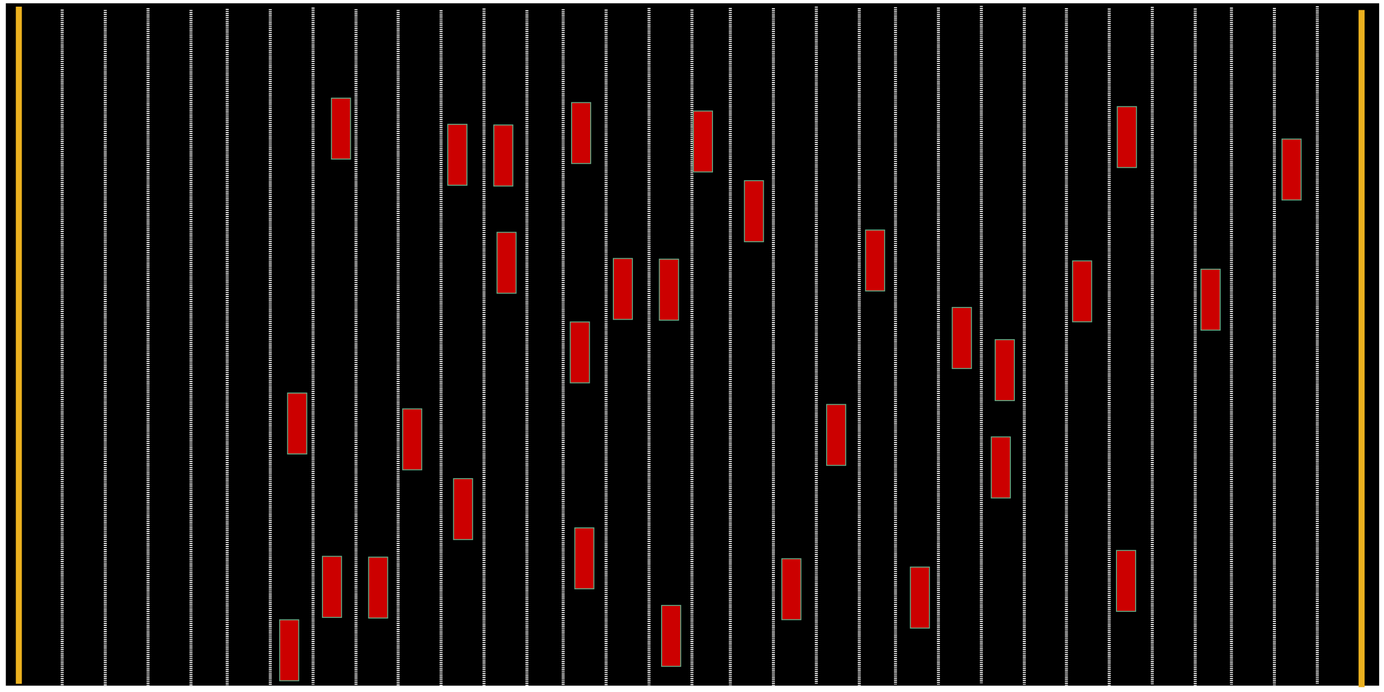
RHEL / Intel Benchmarks Broadwell EP/EX

(http://rhelblog.redhat.com/2016/06/06
/red-hat-delivers-high-performance-on-critical-enterprise-workloads-with-the-latest-intel-xeon-e7-v4-processor-family/)



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**

Subsystem Analysis: ALL

pmcollectl -s cdnm

```
#<--------CPU--------> <----------Disks----------> <----------Network---------> #<-----------Memory----------->

#cpu sys inter  ctxsw  KBRead  Reads KBWrit Writes  KBIn  PktIn  KBOut  PktOut #Free Buff Cach Inac Slab  Map

   0   0   210    179       0      0     64     18     2     17      0       1 32355M  13M  52M  91M  63M  44M
   0   0   150    150       0      0     40     10     1     14      0       1 32355M  13M  52M  92M  63M  44M
   4   1  1678   2073    6876      0      0     14    10     50      5      33 32346M  14M  57M  98M  63M  44M
  17   0  2348    183       0      0     36     10     2     14      0       3 32346M  14M  57M  98M  63M  44M
  17   0  2361    216       0      0     32     10     0      0      0       1 32346M  14M  57M  98M  63M  44M
   7   1  1760   1629     272     20  88356    282     6     46      0      46 32345M  14M  58M  96M  63M  44M
   3   2  1691   2526      40     10 795720   2330     0     11      0       2 32344M  14M  58M  96M  63M  44M
   3   2  1875   2859      28      7 924736   2714     2     18      0       3 32344M  14M  58M  96M  63M  44M
   2   1  5137   5383     460     40 288836    851 35127   2583    161    2473 32345M  15M  58M  96M  63M  44M
   4   3 16997  28627       0      0     56     10 245172  17629   1101   17038 32344M  15M  58M  96M  63M  44M
   3   2 15619  28062       0      0     44     12 242954  17508   1087   16871 32345M  15M  58M  96M  63M  44M
   6   2  4495   7098     104      3     80      9 51692   3781    240    3675 31804M  15M  58M  96M  63M  44M
  17   5  2380    187       0      0     20      5     1     12      0       3 28287M  15M  59M  96M  64M  44M
  17   5  2349    188       0      0     52     15     1     13      0       1 24805M  15M  59M  96M  64M  44M
  17   5  2356    214       0      0     32     10     2     16      0       1 21284M  15M  59M  96M  64M  44M
  17   5  2348    197       0      0     32     10     0      9      0       1 17436M  15M  59M  96M  64M  44M
   9   3  1366    225       0      0     32     10     2     20      0       4 24766M  15M  59M  96M  64M  44M
   1   0   465    516       8      2    992    169     2     25      1      15 32344M  15M  59M  96M  64M  44M
   1   0   236    205       0      0     32     10     1     10      0       1 32344M  15M  59M  96M  64M  44M
   0   0   217    185       0      0     32     10     1     14      0       1 32344M  15M  59M  96M  64M  44M
```

CPU

DISK IO

NET

MEM

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

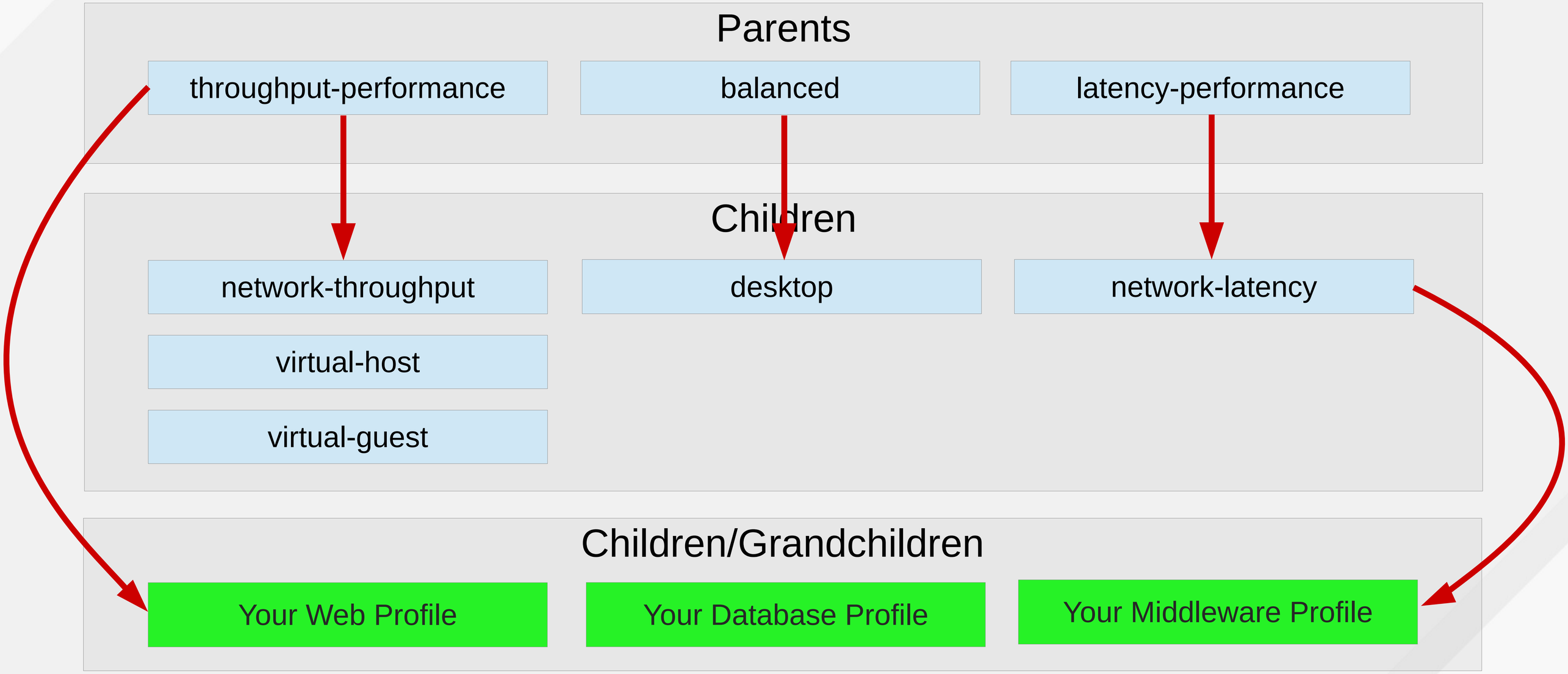
Tuned Overview

- Installed by default
- Auto-set Profiles
- Single config file
- Inheritance/Hooks
- bootloader/cmdline configs

- New Profiles since last yea
  - Realtime
  - NFV
  - RHEL Atomic Host
  - OpenShift
  - Oracle

See `man tuned-profiles` for profile definitions

Tuned: Your Custom Profiles



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

RHEL Desktop/Workstation **balanced**	RHEL Server/HPC **throughput-performance**	
RHEL KVM Host, Guest **virtual-host/guest**	RHEV **virtual-host**	RHEL for Real Time **realtime**
Red Hat Storage **rhs-high-throughput, virt**	RHEL OSP (compute node) **virtual-host**	RHEL for Real Time KVM/NFV **realtime-virtual-host/guest**
RHEL Atomic **atomic-host, atomic-guest**	OpenShift **openshift-master, node**	

Tuned Profile Examples

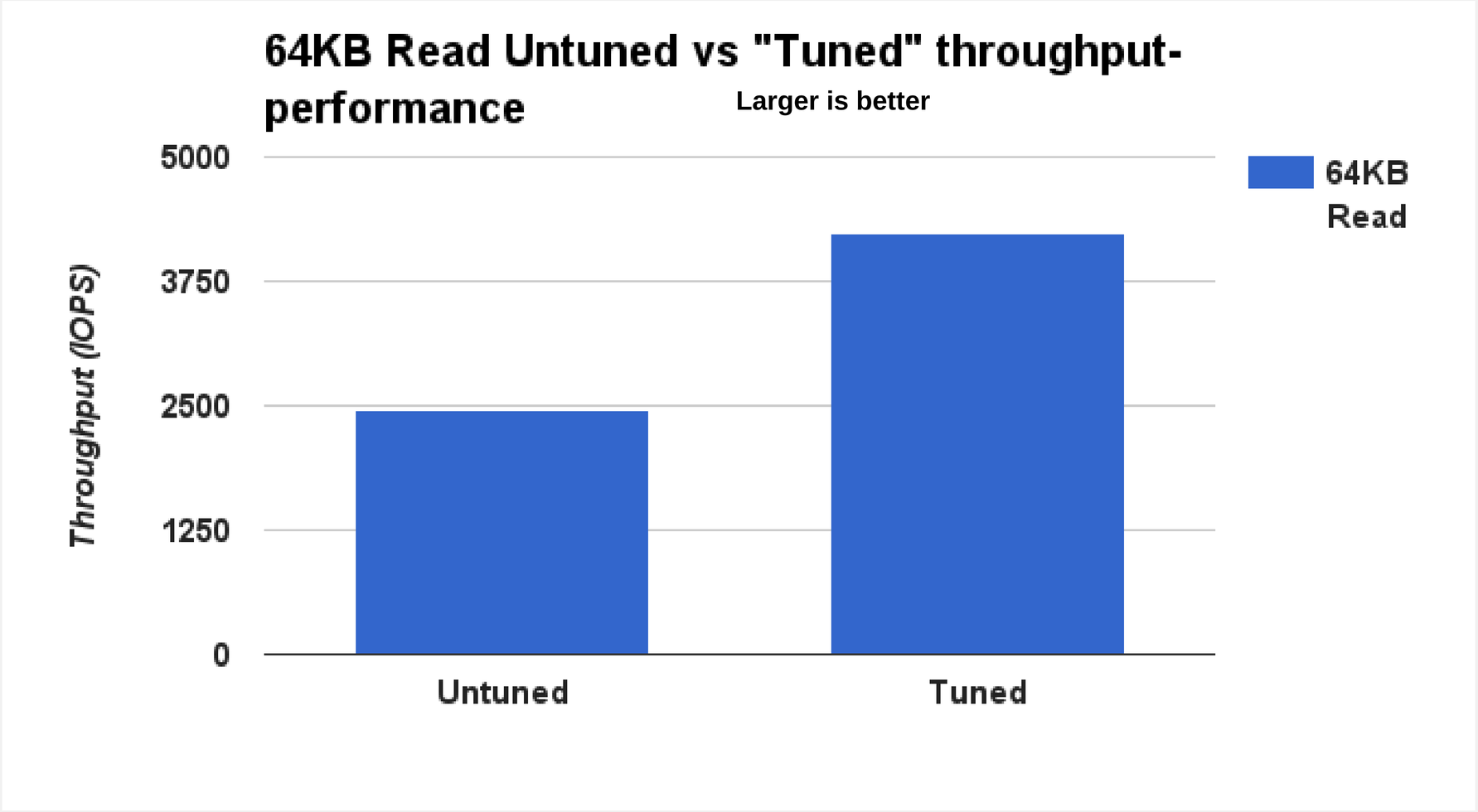
throughput-performance

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

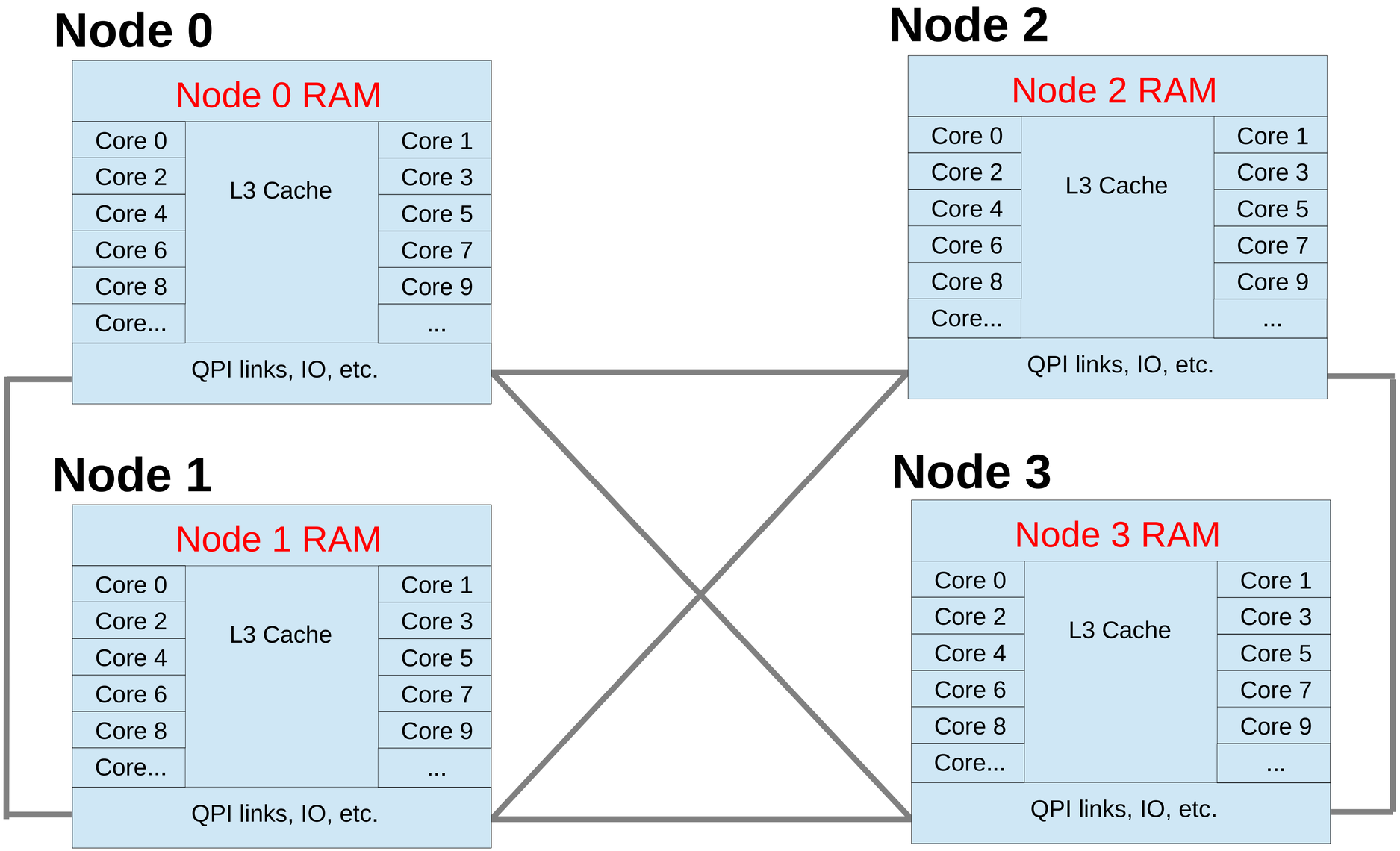
force_latency=1
governor=performance
energy_perf_bias=performance
min_perf_pct=100
kernel.sched_min_granularity_ns=10000000
vm.dirty_ratio=10
vm.dirty_background_ratio=3
vm.swappiness=10
kernel.sched_migration_cost_ns=5000000

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



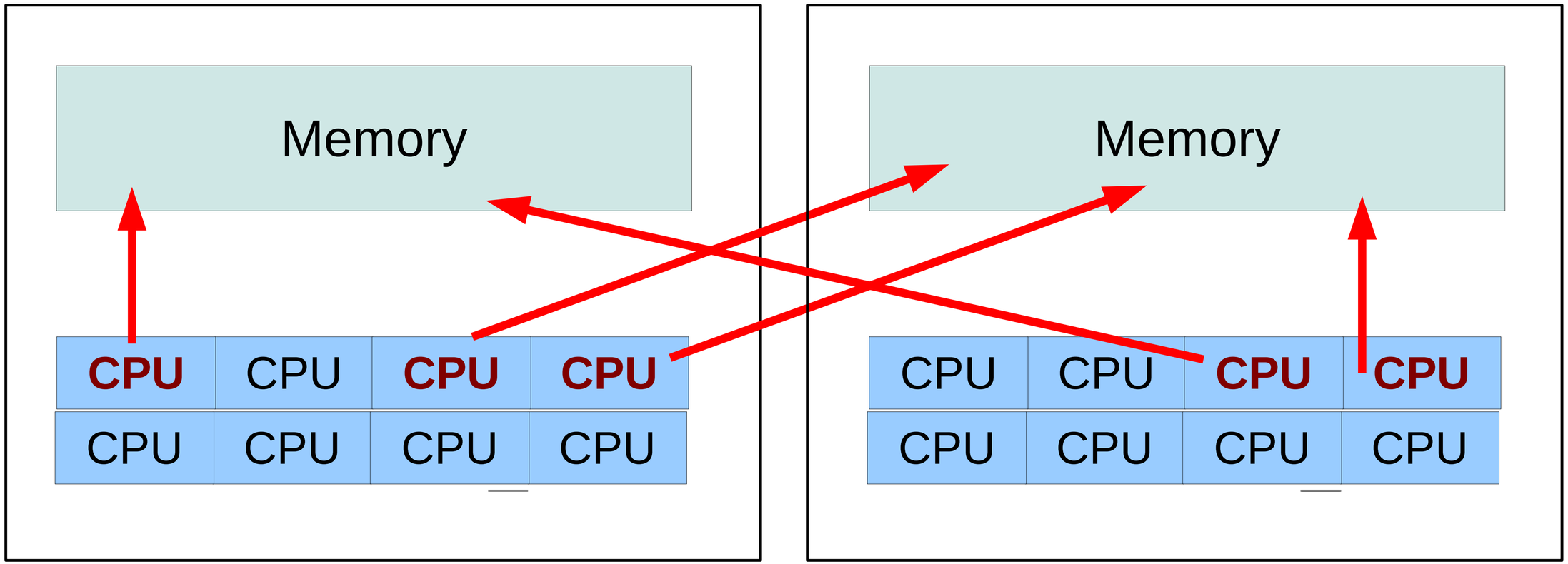
RHEL 6/7 Non-Uniform Memory (NUMA)

Typical Four-Node NUMA System



Non-optimal numa setup

Process 1 in **red**, 5 threads

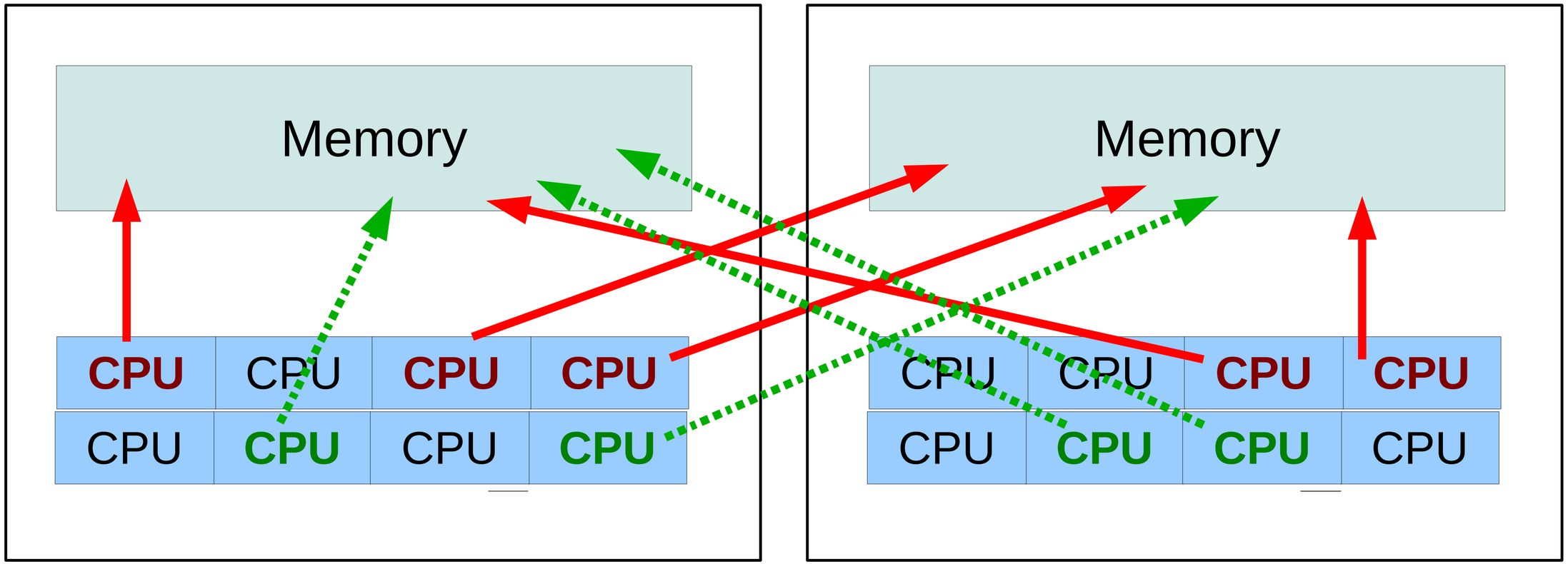


Numa node **0**

Numa node **1**

Add in more processes: non-optimal

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

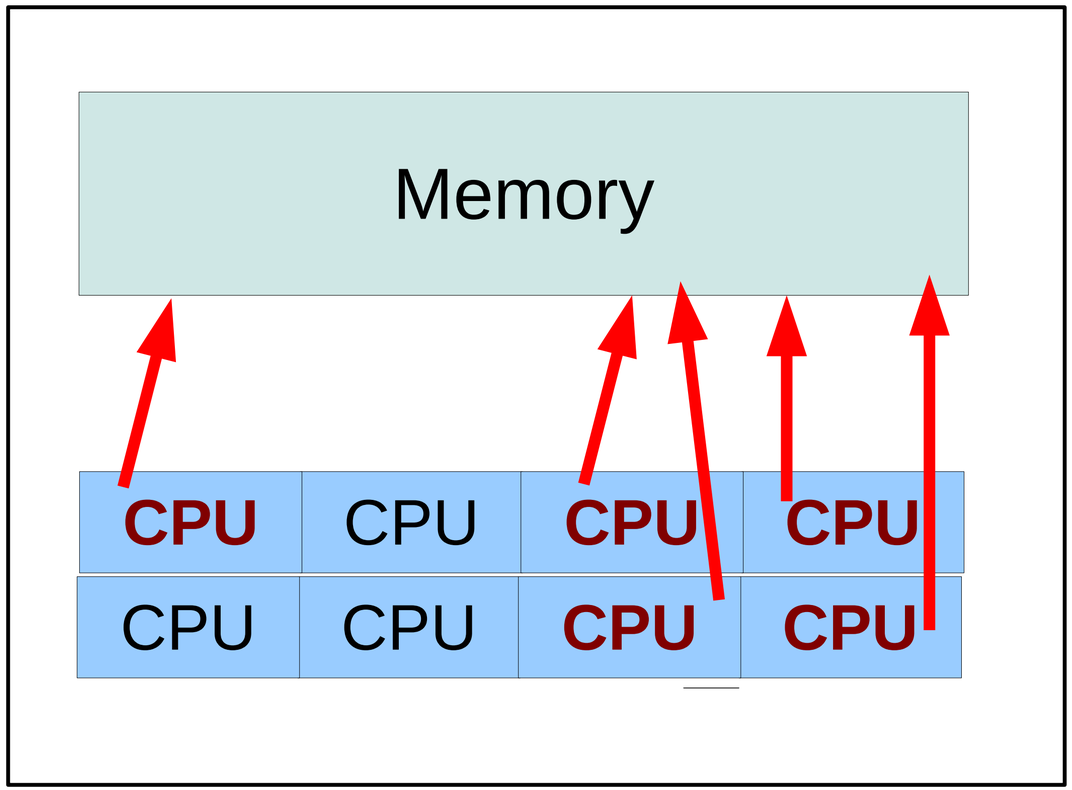


Numa node 0

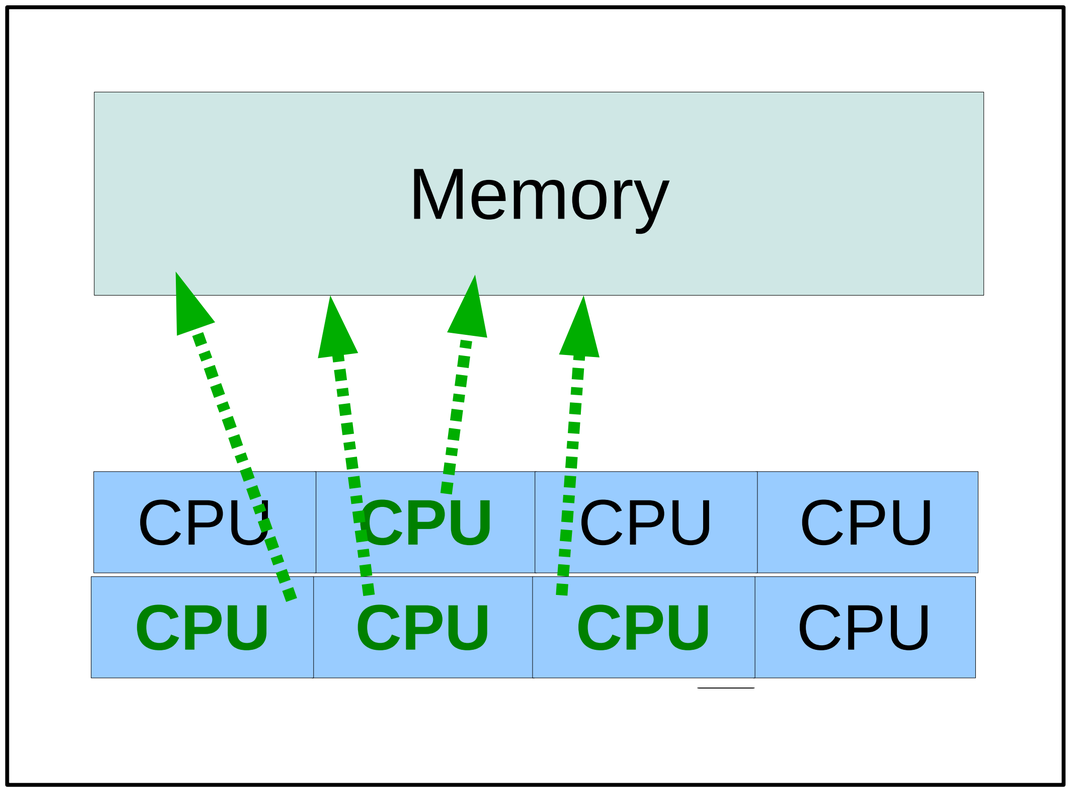
Numa node 1

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 CPUs via lstopo (hwloc-gui rpm)

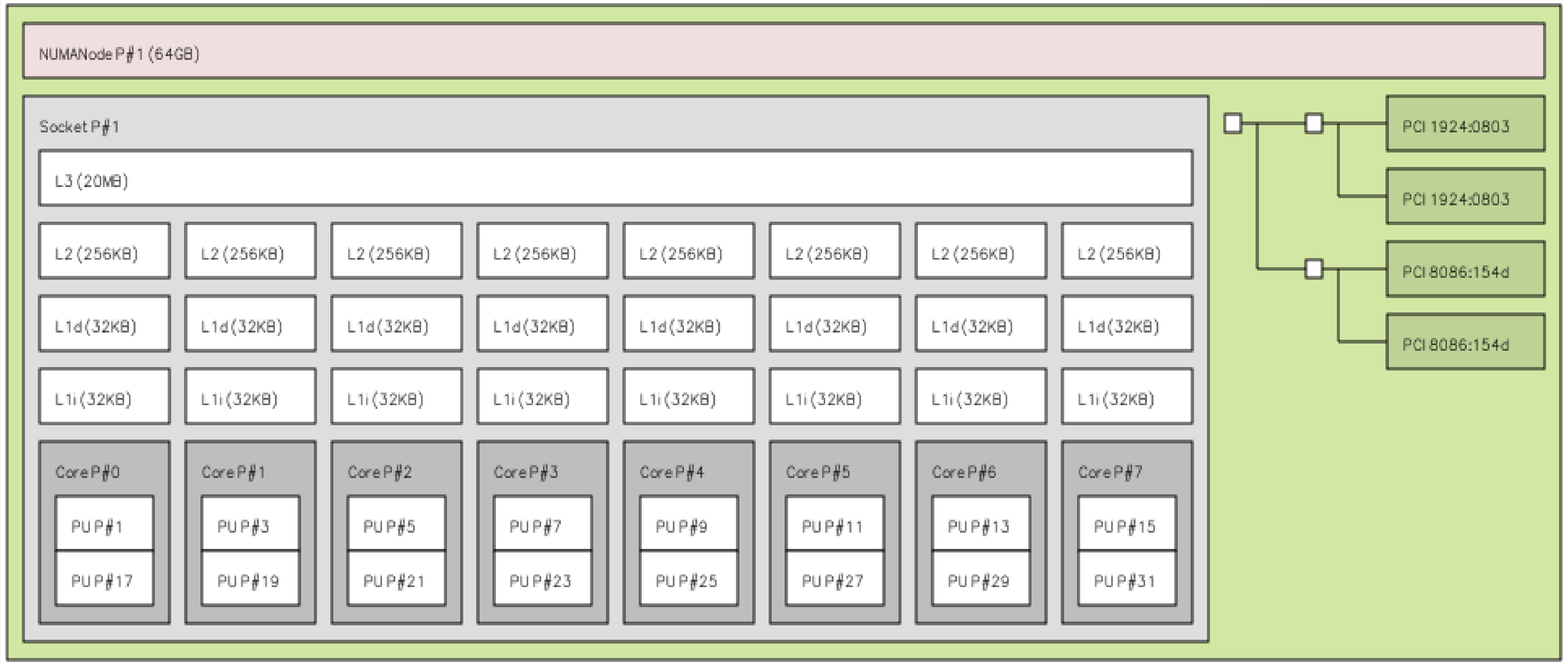
```
# lstopo
```

PCIe

NUMA

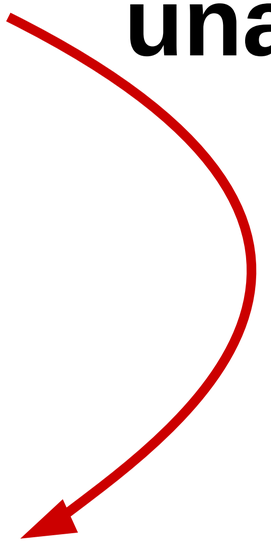
CACHE

cores
cpus
HT



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

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
```

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*

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.

Techniques to control placement (cont):

numad:

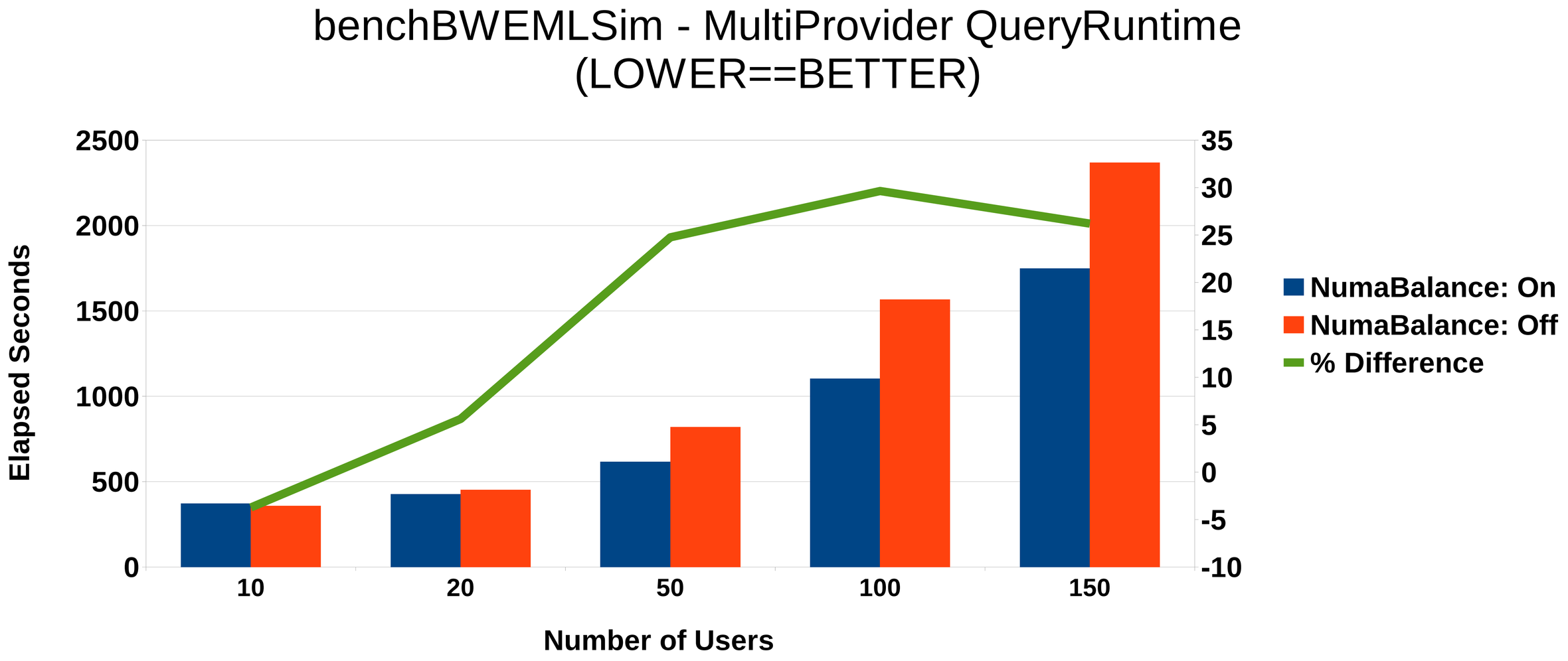
- User-mode daemon.
- Attempts to locate processes for efficient NUMA locality and affinity.
- Dynamically adjusting to changing system conditions.
- Available in RHEL 6 & 7.

Auto-Numa-Balance kernel scheduler:

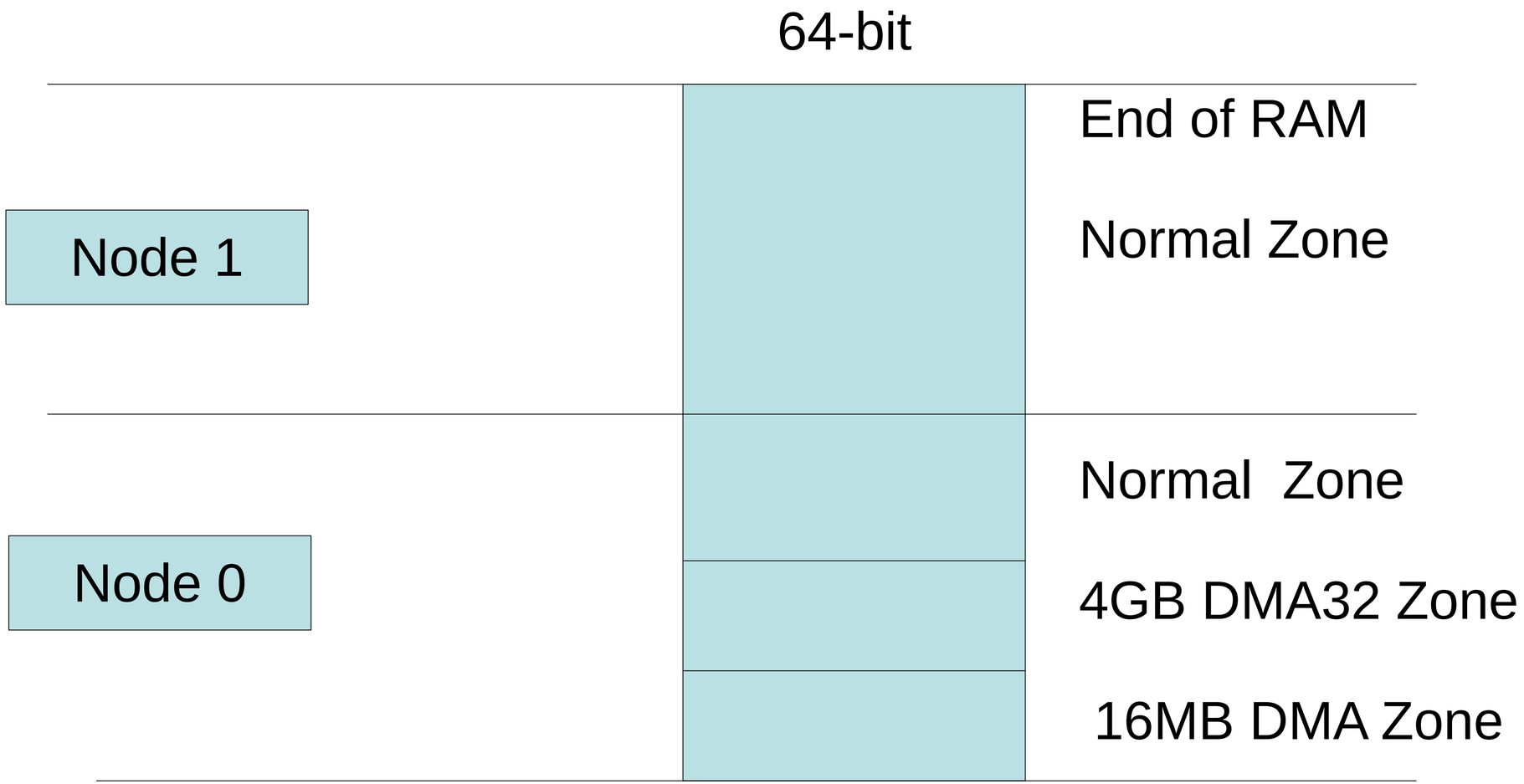
- Automatically run programs near their memory, and moves memory near the programs using it.
- Default enabled. Available in RHEL 7+
- Great video on how it works:
  - https://www.youtube.com/watch?v=mjVw_oe1hEA

Early SAP HANA benefit from Auto-Numa-Balance

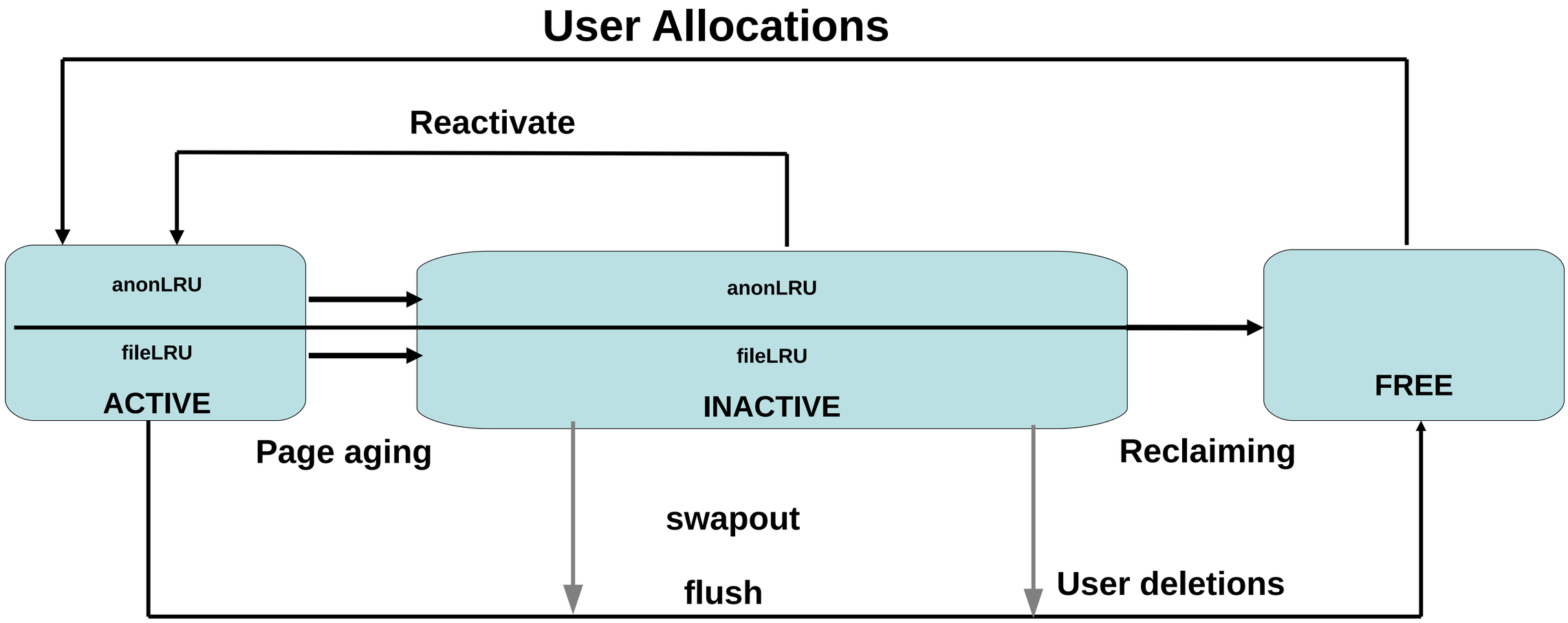
25+% gain. [Recent HANA numa-aware binary closed gap.]



NUMA Nodes and Zones



Per Node / Zone split LRU Paging Dynamics



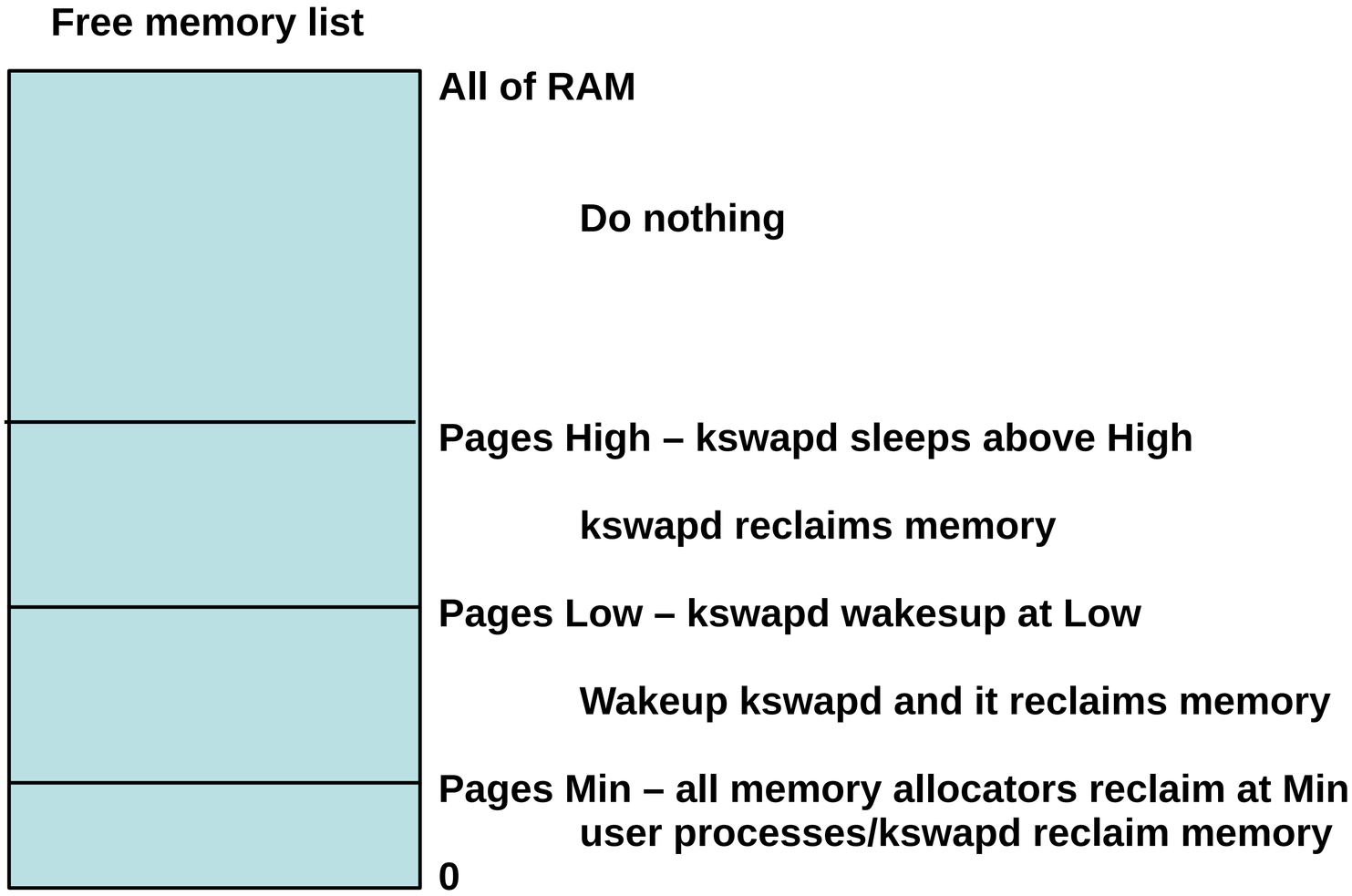
Interaction between VM Tunables and NUMA

- 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

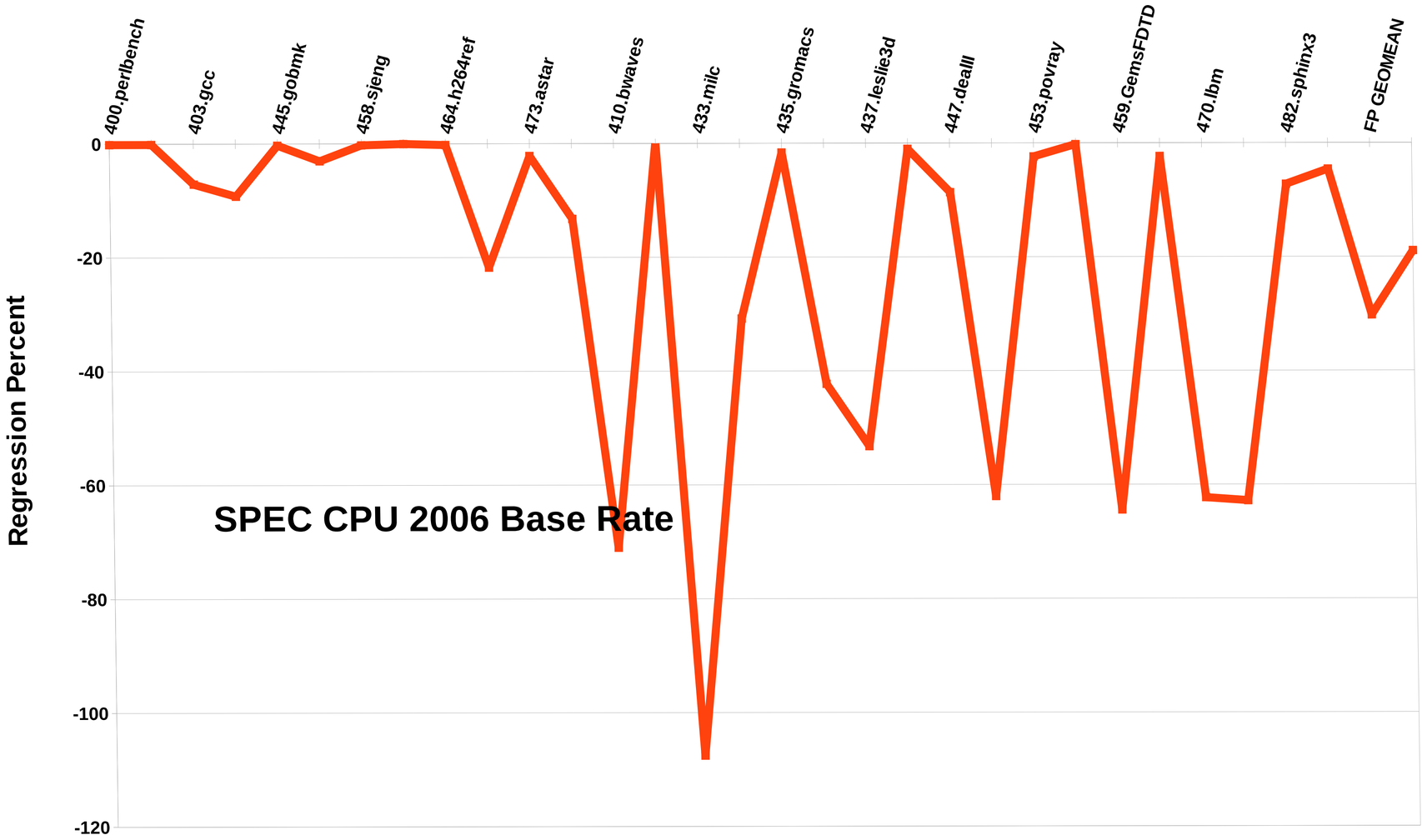
```
# cat /proc/sys/vm/min_free_kbytes
90100
------------------------------------------------------------
Node 0 DMA    min:80 low:100kB high:120kB
Node 0 DMA32 min:15312kB low:19140kB high:22968kB
Node 0 Normal min:29600kB low:37000kB high:44400kB
Node 1 Normal min:45108kB low:56384kB high:67660kB
------------------------------------------------------------

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
------------------------------------------------------------
```

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!!)



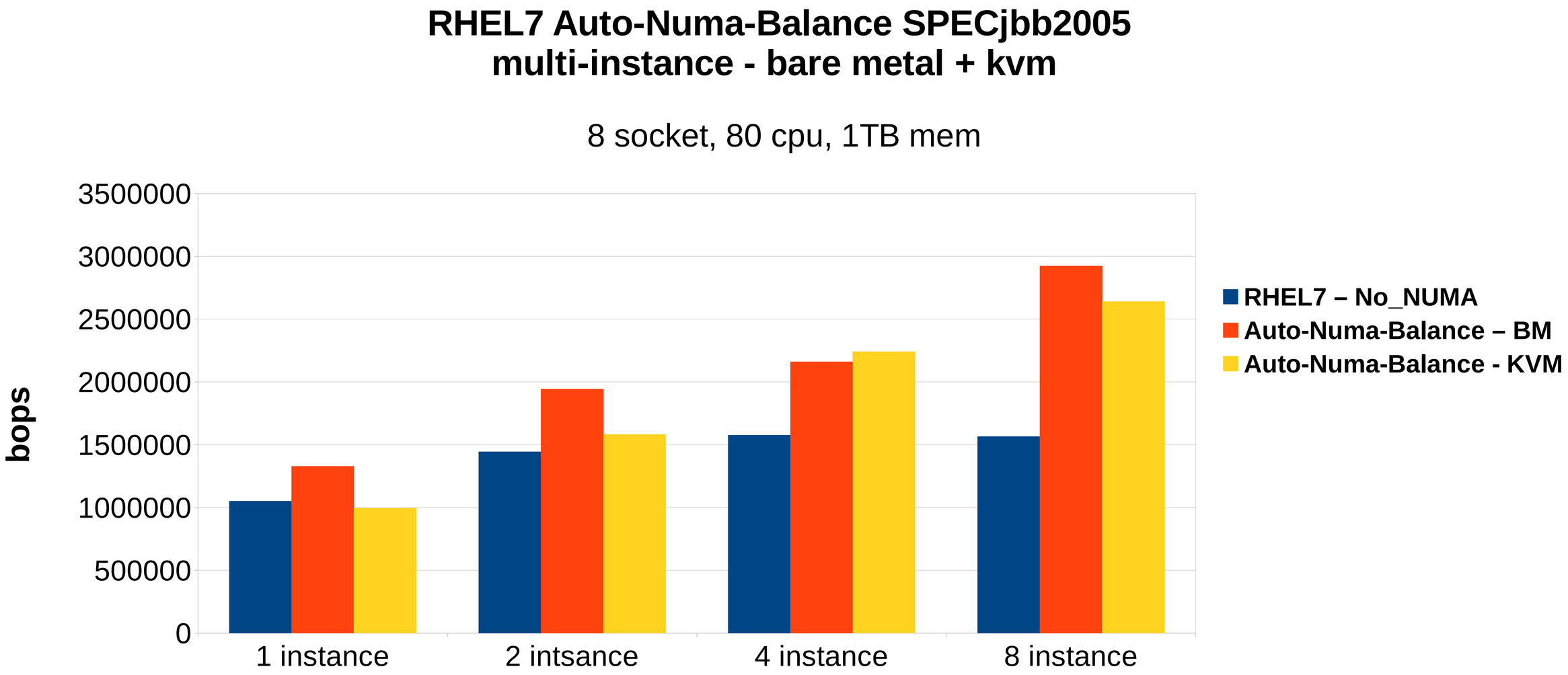
NUMA tuning for KVM / Atomic is the same!

- 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

NUMA Performance – SPECjbb2005 on DL980 Westmere EX



Red Hat Enterprise Linux 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**

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

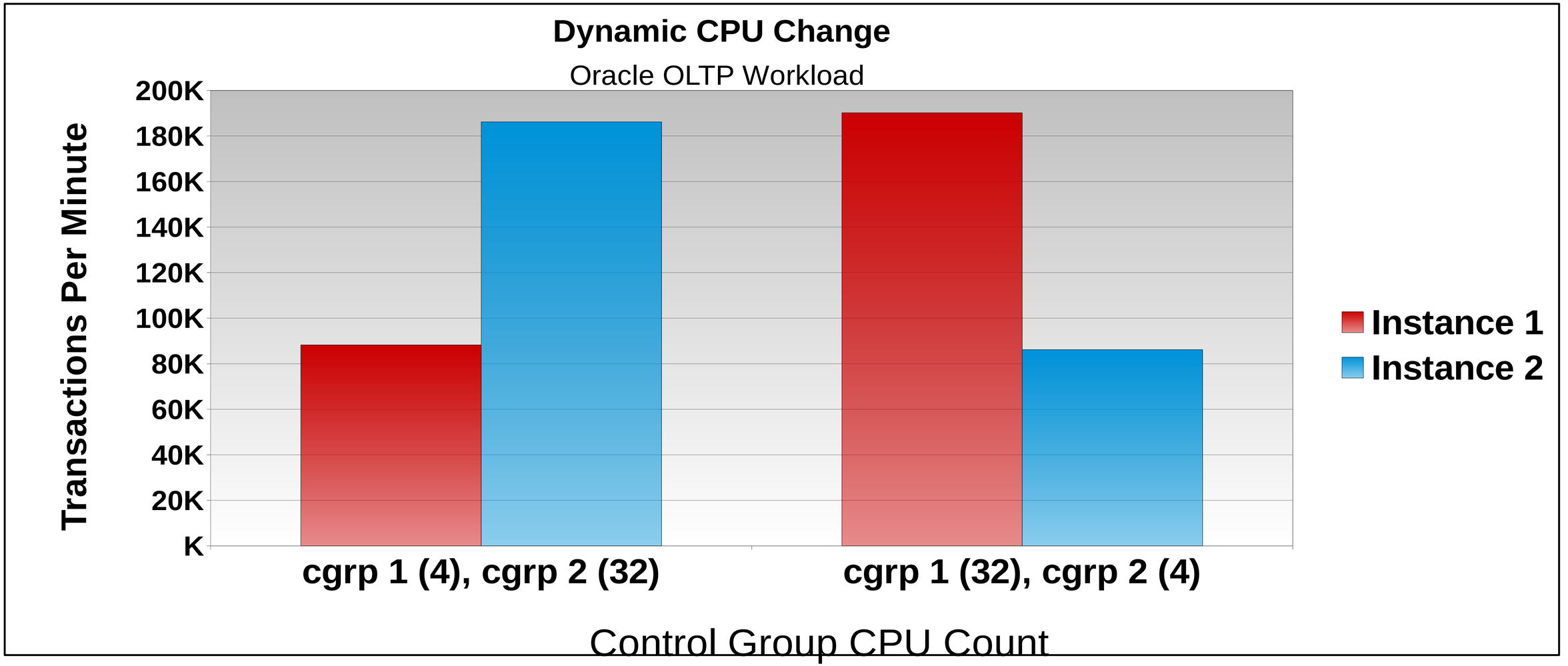
```
# mkdir -p /sys/fs/cgroup/memory/test
# echo 1G > /sys/fs/cgroup/memory/test/memory.limit_in_bytes
# echo 2G > /sys/fs/cgroup/memory/test/memory.memsw.limit_in_bytes
# echo $$ > /sys/fs/cgroup/memory/test/tasks

# ./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)

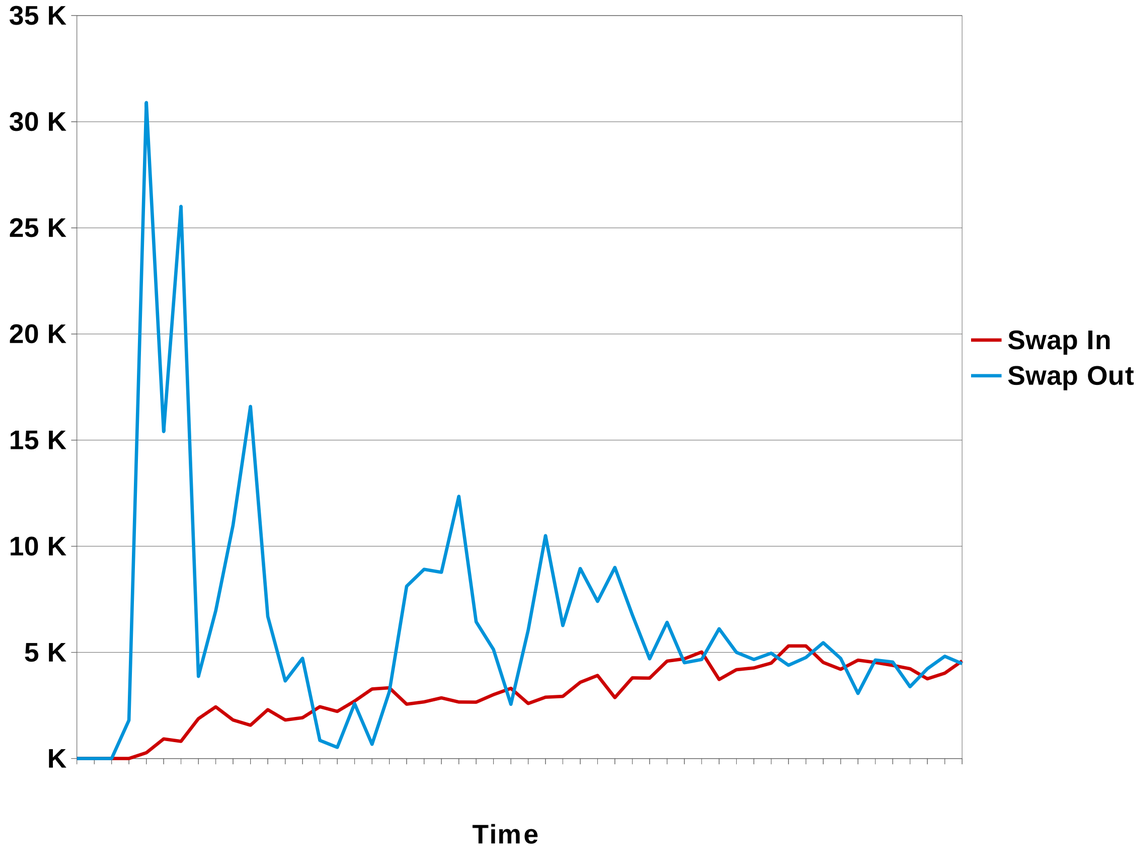
```
# vmstat 1
...
 0  0  52224 1640116       0 3676924    0    0       0      0   202  487  0  0 100  0  0
 1  0  52224 1640116       0 3676924    0    0       0      0   162  316  0  0 100  0  0
 0  1 248532 587268        0 3676948   32 196312      32 196372   912  974  1  4 88   7  0
 0  1 406228 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
...
```

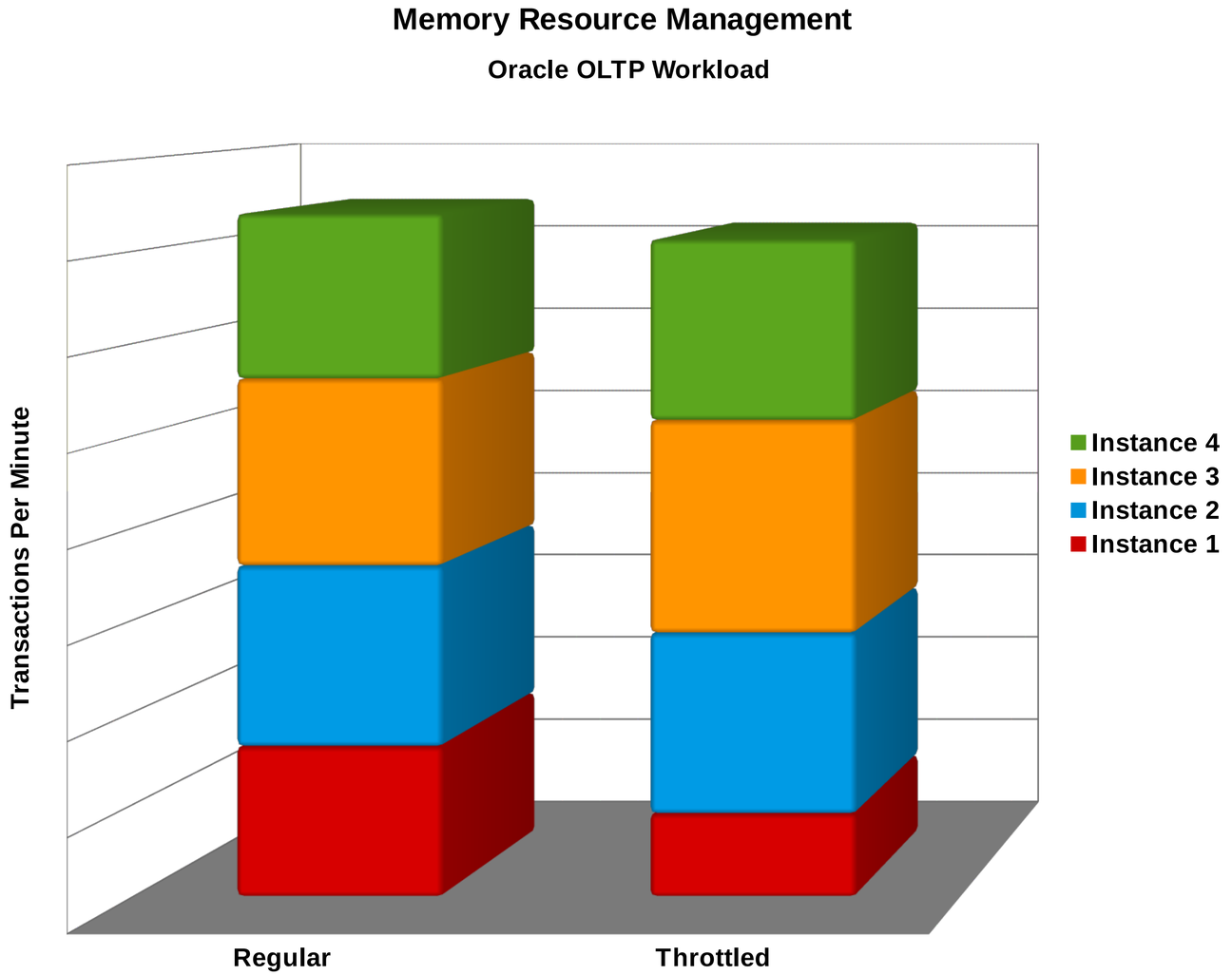
```
# dmesg
...
[506858.413341] Task in /test killed as a result of limit of /test
[506858.413342] memory: usage 1048460kB, limit 1048576kB, failcnt 295377
[506858.413343] memory+swap: usage 2097152kB, limit 2097152kB, failcnt 74
[506858.413344] kmem: usage 0kB, limit 9007199254740991kB, failcnt 0
[506858.413345] 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
```

C-group Dynamic resource control



Cgroup – Application Isolation





Even though one application does not have resources and starts swapping, other applications are not affected

Summary - Red Hat Enterprise Linux NUMA

- RHEL6 – NUMAD - With Red Hat Enterprise Linux 6.5
  - NUMAD can significantly improve performance and automate NUMA management on systems with server consolidation or replicated parallel workloads.
- RHEL7, Auto-NUMA-Balance works well for most applications out of the box!
- Use NUMAstat and NUMActl tools to measure and/or fine control your application on RHEL.
- App Developers – use perf to check for false sharing, advise padding
- **Q+A at “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
- RHEL OSP 7: Cinder Volume Performance on RHCS 1.3 (Ceph) https://access.redhat.com/articles/2061493
- RHGS 3.1 Performance Brief (Gluster) https://access.redhat.com/articles/1982243

- Red Hat Performance Tuning Guide
- Red Hat Low Latency Tuning Guide
- Red Hat Virtualization Tuning Guide
- RHEL Blog / Developer Blog

Performance Utility Summary

Supportability

- redhat-support-tool
- sos
- kdump
- perf
- psmisc
- strace
- sysstat
- systemtap
- trace-cmd
- Util-linux-ng
- pcp

NUMA

- hwloc
- Intel PCM
- numactl
- numad
- numatop (01.org)

Networking

- dropwatch
- ethtool
- netsniff-ng (EPEL6)
- tcpdump
- wireshark/tshark

Power/Tuning

- cpupowerutils (R6)
- kernel-tools (R7)
- powertop
- tuna
- tuned

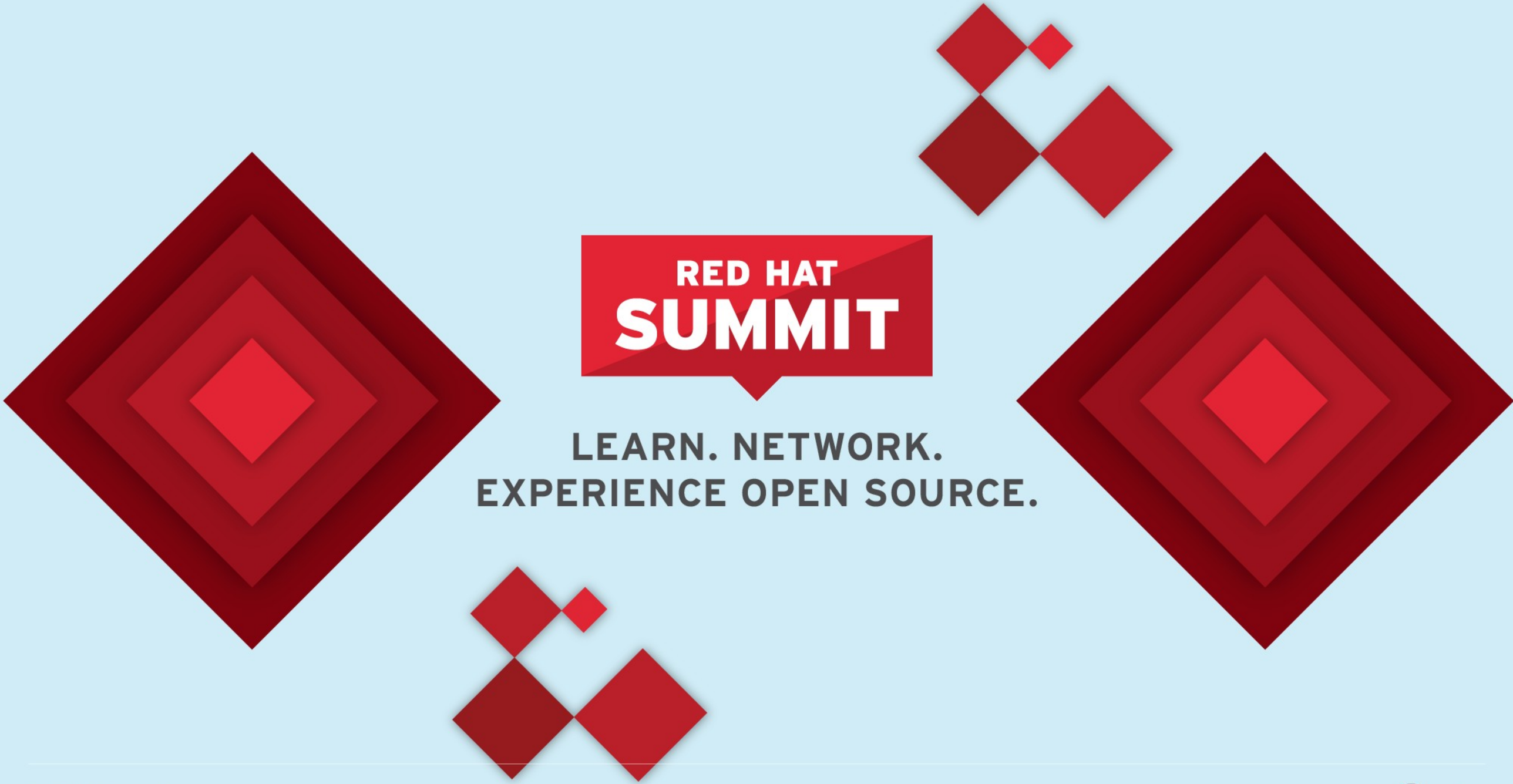
Storage

- blktrace
- iotop
- iostat

Agenda: Performance Analysis Tuning Part II

- Part II
  - Scheduler tunables
  - Transparent Hugepages, Static Hugepages 4K/2MB/1GB
  - Disk and Filesystem IO - Throughput-performance - RHS / Cloud
  - Network Performance and Latency-performance noHZ_full
  - NFV Kernel vs offload DPDK, w/ Virt, Container
  - Demo – low latency profile

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



Performance Tools - Perf

perf list

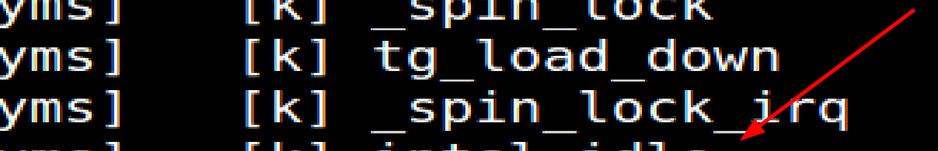
List counters/tracepoints available on your system

```
# perf list

List of pre-defined events (to be used in -e):
  cpu-cycles OR cycles                               [Hardware event]
  instructions                                       [Hardware event]
  cache-references                                   [Hardware event]
  cache-misses                                       [Hardware event]
  branch-instructions OR branches                    [Hardware event]
  branch-misses                                      [Hardware event]
  cpu-clock                                          [Software event]
  task-clock                                         [Software event]
  page-faults OR faults                              [Software event]
  context-switches OR cs                             [Software event]
  cpu-migrations OR migrations                       [Software event]
  minor-faults                                       [Software event]
  major-faults                                       [Software event]
```

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 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>*

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 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
```

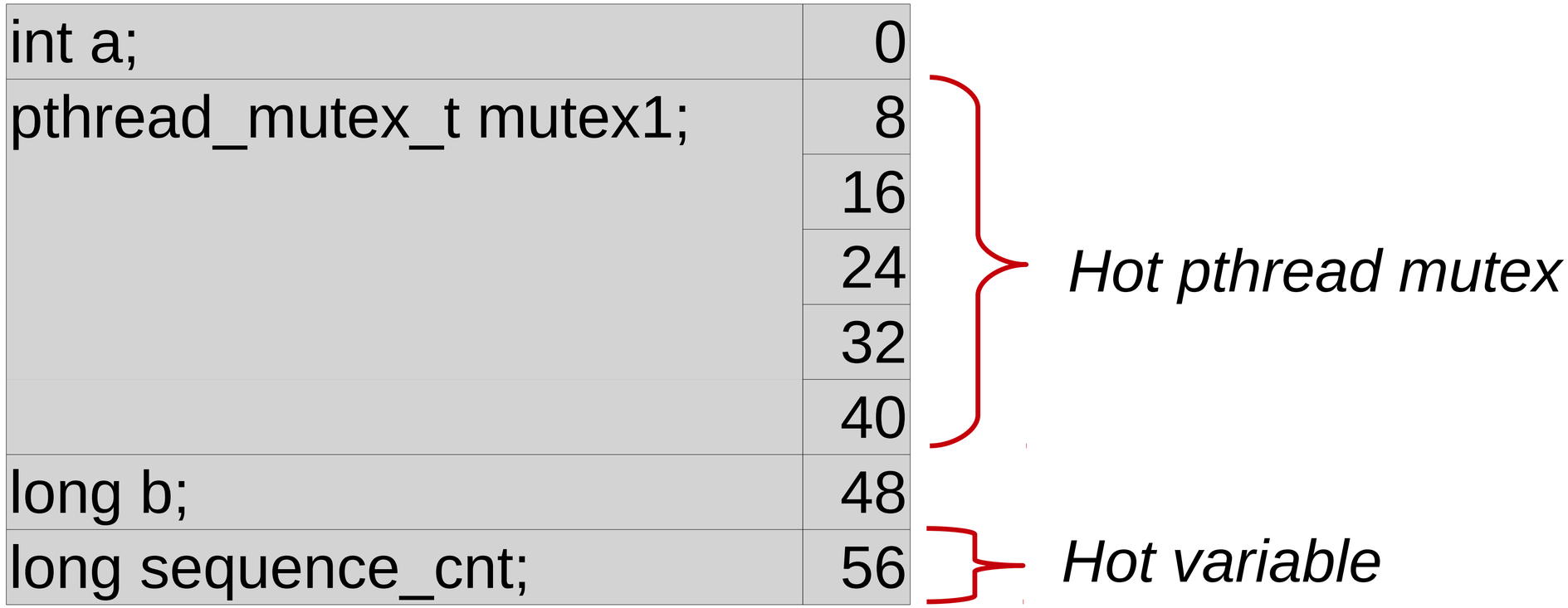
grep for something interesting, maybe to see what numabalance is doing ?

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

False Sharing

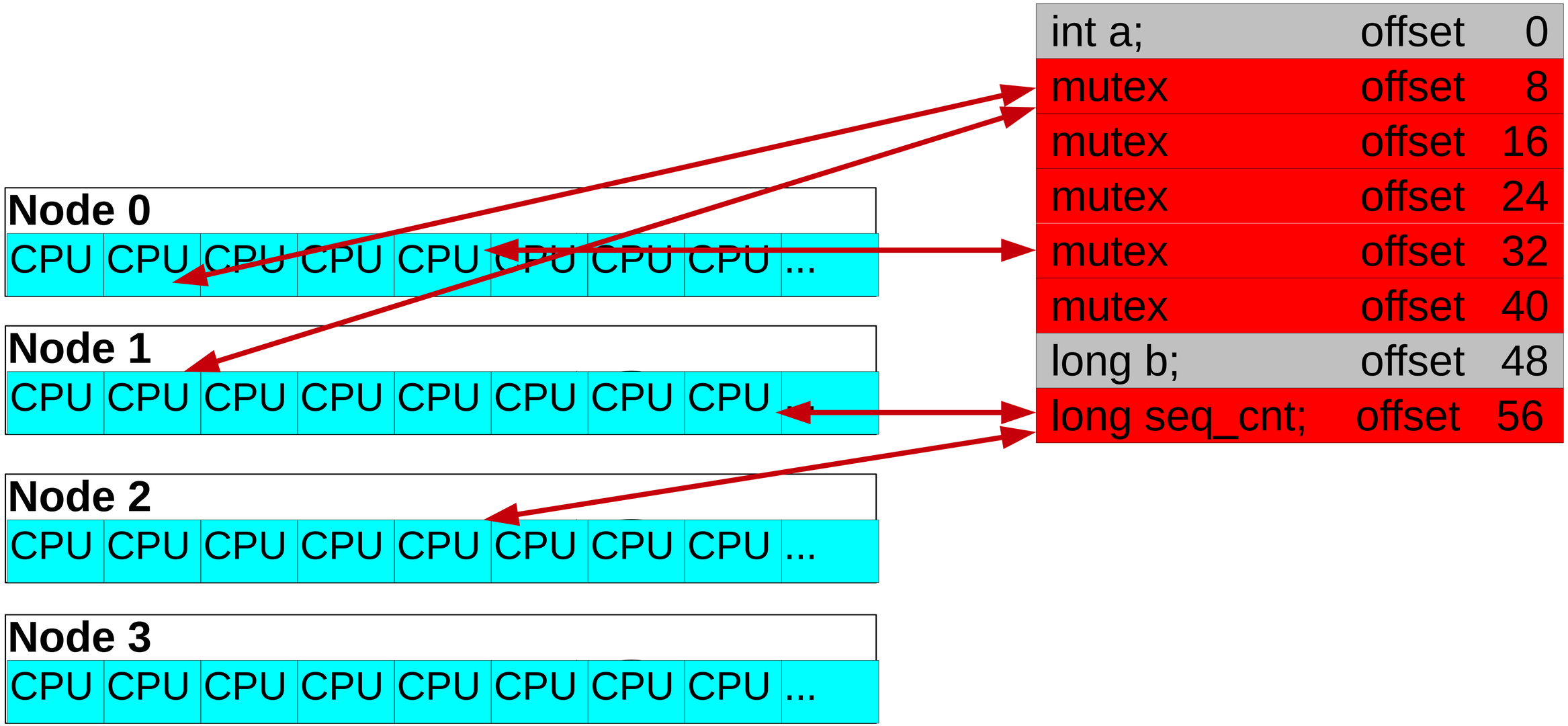
- Different threads sharing common data struct
- Different processes sharing common shared memory.

Ex: Two hotly contended data items sharing a 64-byte cacheline.

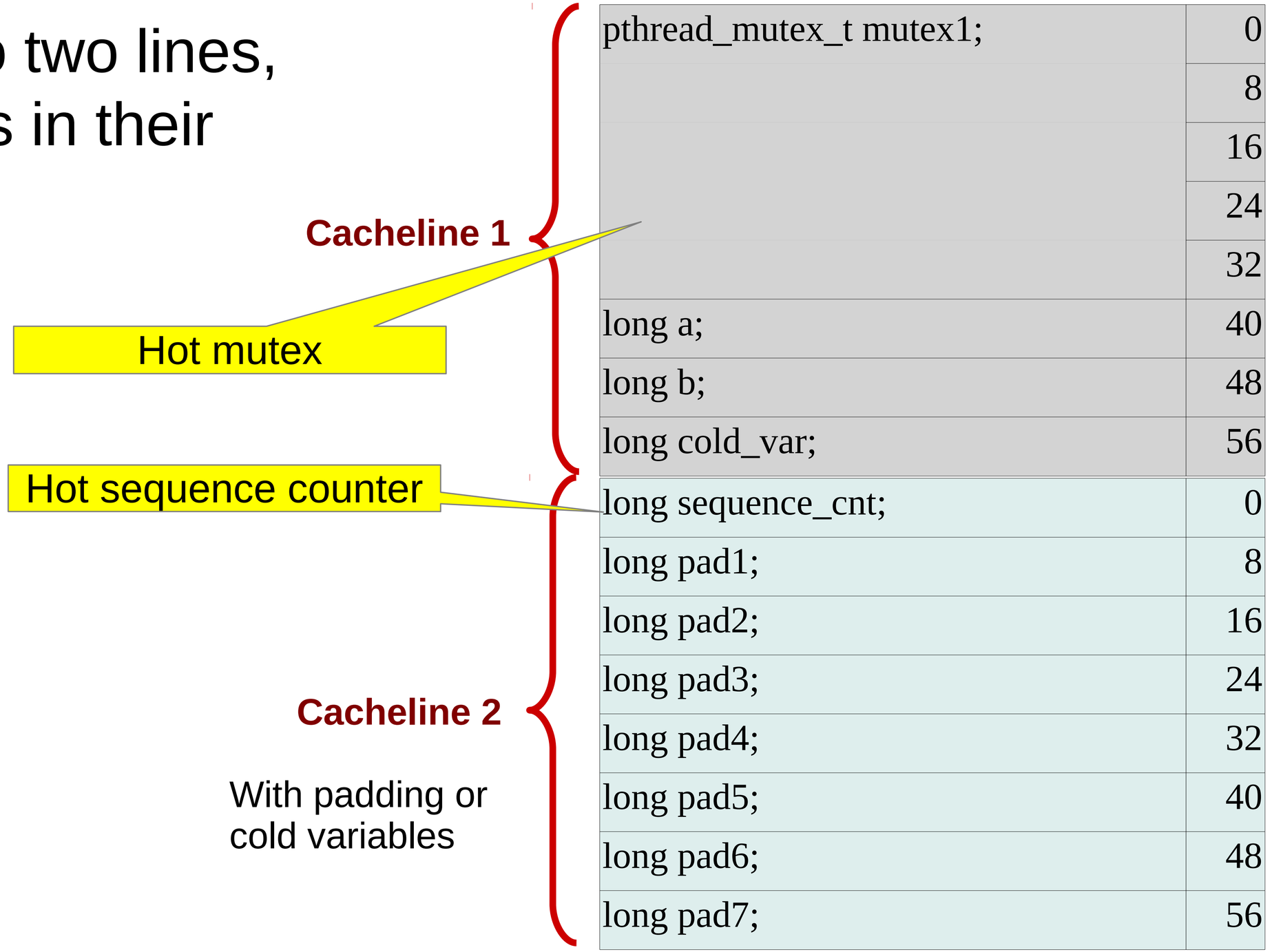


Gets you contention like this:

- Can be quite painful



Split it up into two lines, with hot items in their own lines:



pthread_mutex_t mutex1;	0
	8
	16
	24
	32
long a;	40
long b;	48
long cold_var;	56
long sequence_cnt;	0
long pad1;	8
long pad2;	16
long pad3;	24
long pad4;	32
long pad5;	40
long pad6;	48
long pad7;	56

Future Red Hat update to perf: “c2c data sharing” tool

Cache #	Refs	Stores	Data Address	Pid	Tid	Inst Address	Symbol	Object	CPU Participants
0	118789	273709	0x602380	37878					
	17734	136078	0x602380	37878	37878	0x401520	read_wrt_thread	a.out	0{0}
	13452	137631	0x602388	37878	37883	0x4015a0	read_wrt_thread	a.out	0{1}
	15134	0	0x6023a8	37878	37882	0x4011d7	reader_thread	a.out	1{5}
	14684	0	0x6023b0	37878	37880	0x4011d7	reader_thread	a.out	1{6}
	13864	0	0x6023b8	37878	37881	0x4011d7	reader_thread	a.out	1{7}
1	31	69	0xffff88023960df40	37878					
	13	69	0xffff88023960df70	37878	***	0xffffffff8109f8e5	update_cfs_rq_blocked_load	vmlinux	**0{0,1,2}; 1{14,16}**
	17	0	0xffff88023960df60	37878	***	0xffffffff8109fc2e	__update_entity_load_avg_contrib	vmlinux	**0{0,1,2}; 1{14,16}**
	1	0	0xffff88023960df78	37878	37882	0xffffffff8109fc4e	__update_entity_load_avg_contrib	vmlinux	0{2}

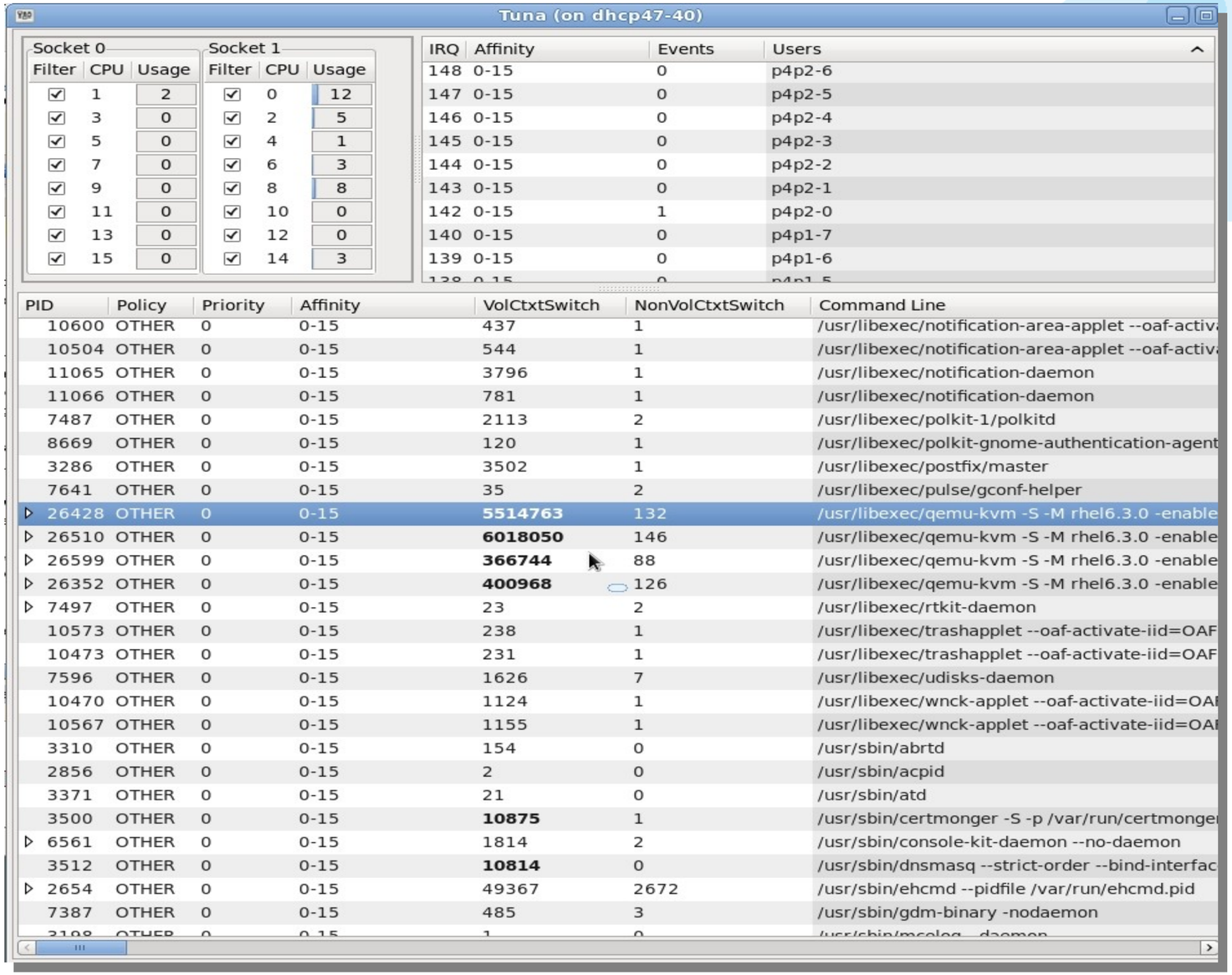
This shows who is contributing to the false sharing:

- The hottest contended cachelines
- The process names, data addr, ip, pids, tids
- The node and CPU numbers they ran on,
- And how the cacheline is being accessed (read or write)
- Disassemble the binary to find the ip, and track back to the sources.

Performance Tools - Tuna

System Tuning Tool - tuna

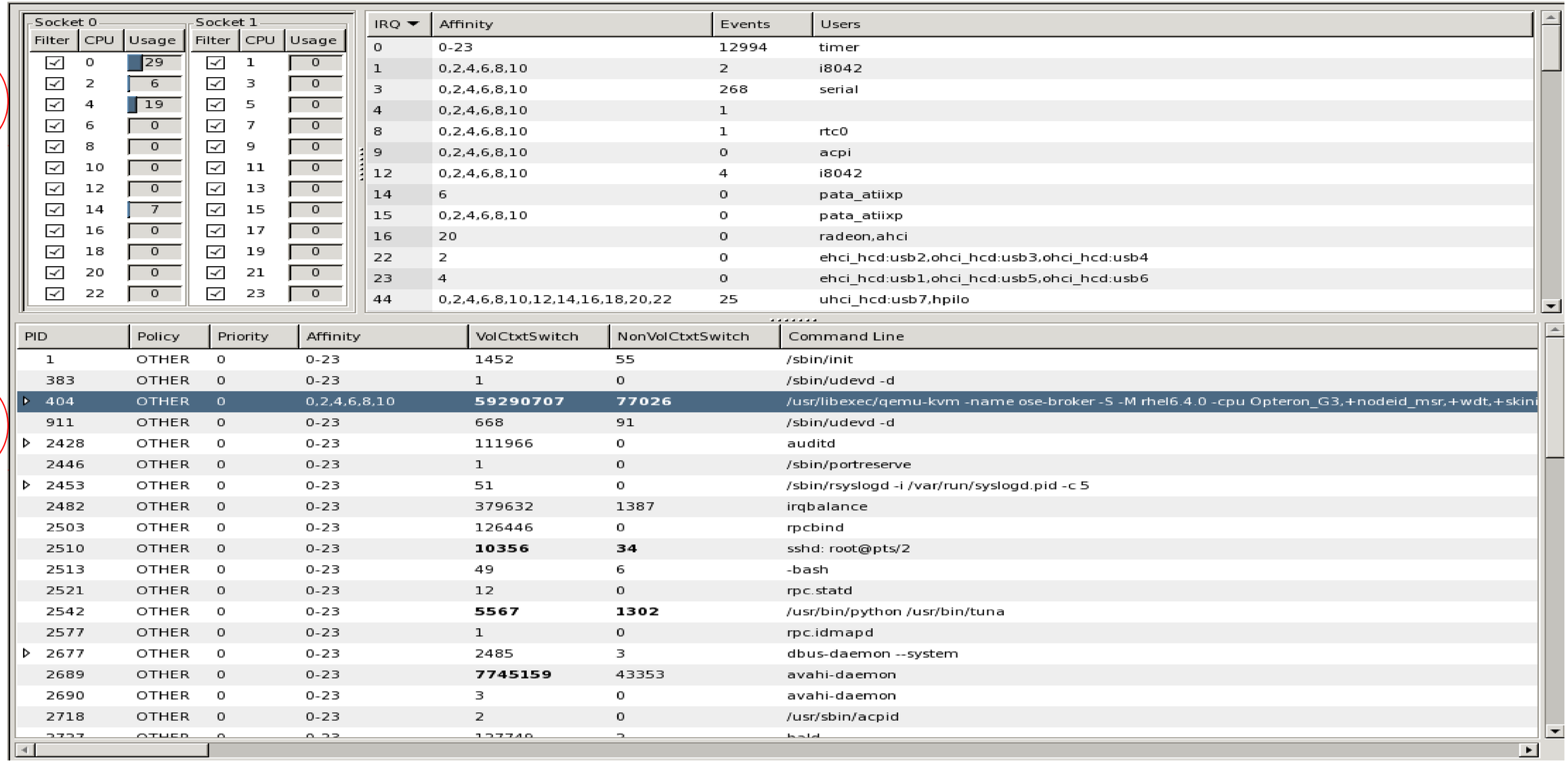
- Tool for fine grained control
- Display applications / processes
- Displays CPU enumeration
- Socket (useful for NUMA tuning)
- Dynamic control of tuning
  - Process affinity
  - Parent & threads
  - Scheduling policy
  - Device IRQ priorities, etc



Tuna (RHEL6/7)

1

3



Socket 0

Filter	CPU	Usage
☑	0	29
☑	2	6
☑	4	19
☑	6	0
☑	8	0
☑	10	0
☑	12	0
☑	14	7
☑	16	0
☑	18	0
☑	20	0
☑	22	0

Socket 1

Filter	CPU	Usage
☑	1	0
☑	3	0
☑	5	0
☑	7	0
☑	9	0
☑	11	0
☑	13	0
☑	15	0
☑	17	0
☑	19	0
☑	21	0
☑	23	0

IRQ	Affinity	Events	Users
0	0-23	12994	timer
1	0,2,4,6,8,10	2	i8042
3	0,2,4,6,8,10	268	serial
4	0,2,4,6,8,10	1	
8	0,2,4,6,8,10	1	rtc0
9	0,2,4,6,8,10	0	acpi
12	0,2,4,6,8,10	4	i8042
14	6	0	pata_atiixp
15	0,2,4,6,8,10	0	pata_atiixp
16	20	0	radeon,ahci
22	2	0	ehci_hcd:usb2,ohci_hcd:usb3,ohci_hcd:usb4
23	4	0	ehci_hcd:usb1,ohci_hcd:usb5,ohci_hcd:usb6
44	0,2,4,6,8,10,12,14,16,18,20,22	25	uhci_hcd:usb7,hpilo

PID	Policy	Priority	Affinity	VolCtxtSwitch	NonVolCtxtSwitch	Command Line
1	OTHER	0	0-23	1452	55	/sbin/init
383	OTHER	0	0-23	1	0	/sbin/udevd -d
▸ 404	OTHER	0	0,2,4,6,8,10	**59290707**	**77026**	/usr/libexec/qemu-kvm -name ose-broker -S -M rhel6.4.0 -cpu Opteron_G3,+nodeid_msr,+wdt,+skini
911	OTHER	0	0-23	668	91	/sbin/udevd -d
▸ 2428	OTHER	0	0-23	111966	0	auditd
2446	OTHER	0	0-23	1	0	/sbin/portreserve
▸ 2453	OTHER	0	0-23	51	0	/sbin/rsyslogd -i /var/run/syslogd.pid -c 5
2482	OTHER	0	0-23	379632	1387	irqbalance
2503	OTHER	0	0-23	126446	0	rpcbind
2510	OTHER	0	0-23	**10356**	**34**	sshd: root@pts/2
2513	OTHER	0	0-23	49	6	-bash
2521	OTHER	0	0-23	12	0	rpc.statd
2542	OTHER	0	0-23	**5567**	**1302**	/usr/bin/python /usr/bin/tuna
2577	OTHER	0	0-23	1	0	rpc.idmapd
▸ 2677	OTHER	0	0-23	2485	3	dbus-daemon --system
2689	OTHER	0	0-23	**7745159**	43353	avahi-daemon
2690	OTHER	0	0-23	3	0	avahi-daemon
2718	OTHER	0	0-23	2	0	/usr/sbin/acpid

Tuna GUI Capabilities Updated for RHEL7