# When the OS gets in the way

(and what you can do about it)

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LMAX Exchange

# When the ~~OS~~ *Linux* gets in the way

(and what you can do about it)

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# It’s not the OS’s fault

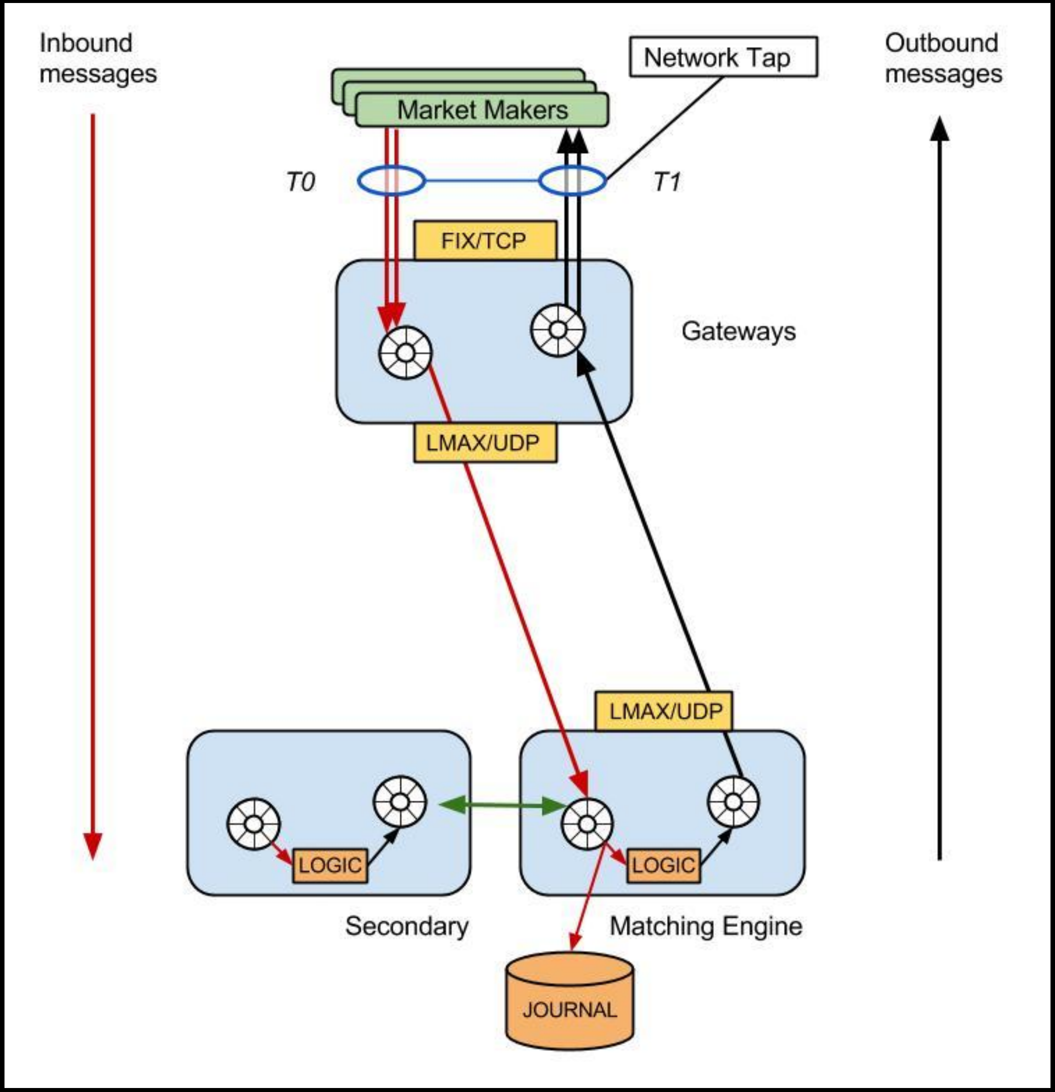
- Linux is an excellent general-purpose OS
- Many target platforms
- Scheduling is actually fairly complicated
- Low-latency is a special use-case
- We need to provide some hints

# Why should I care?

# Useful in some scenarios

- Low latency applications
- Response times < 1ms
- Compute-intensive workloads
- Long-running jobs

# A real-world scenario: LMAX




System Latency = T1 - T0

Before tuning:

250us / 10+ms

After tuning:

80us / <1ms

(mean / max)

# Jitter

- *“slight irregular movement, variation, or unsteadiness, especially in an electrical signal or electronic device”*
- Variation in response time latency
- Long-tail in response time

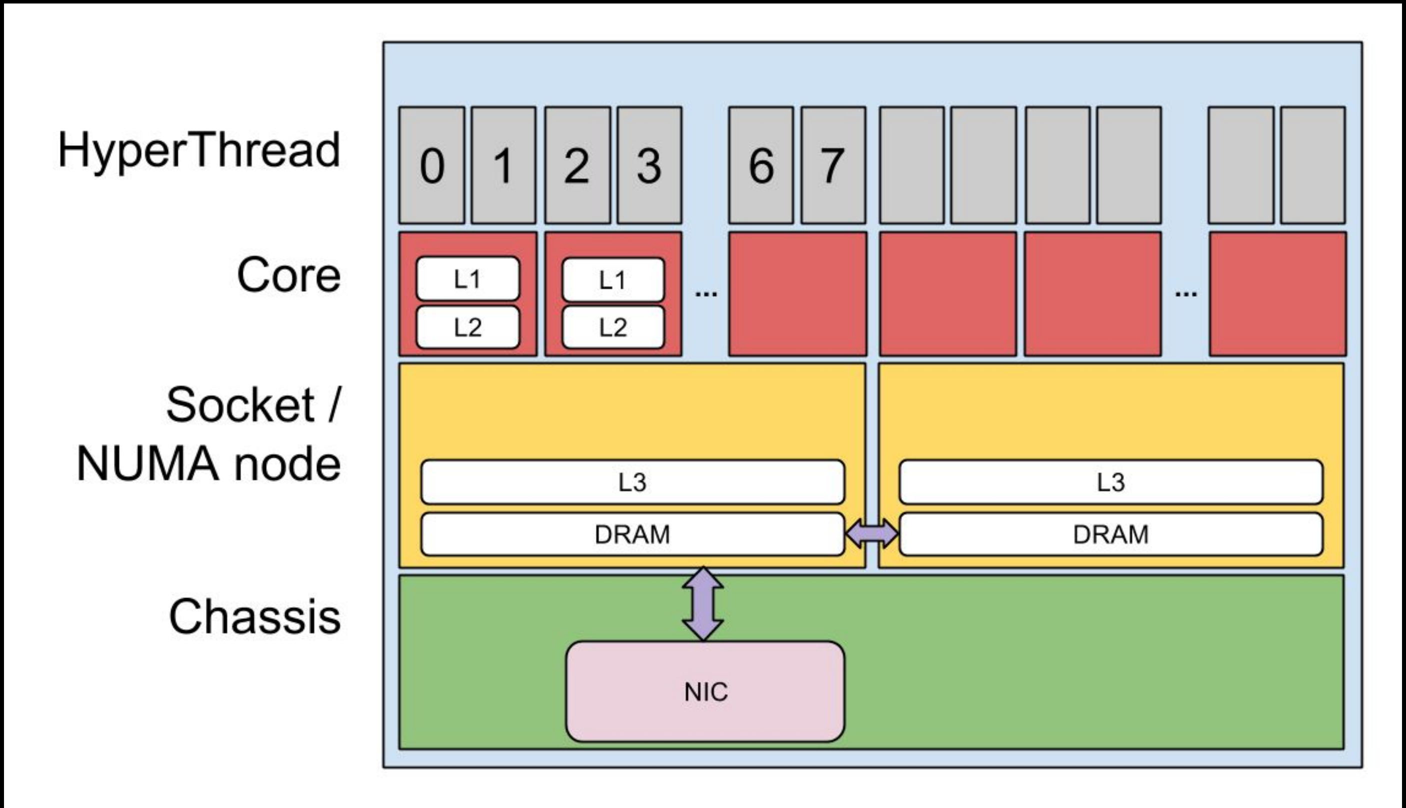
# Dealing with it

- First take care of the low-hanging fruit
  - e.g. Garbage collection (gc-free / Zing)
  - e.g. Slow I/O
- Once response times are < 10ms the fun begins
- Make sure your code is running!

# Measure first

- Need to validate changes are good
- End-to-end tests
- Using realistic load
- Change one thing and observe
- A refresher...

# Modern hardware layout



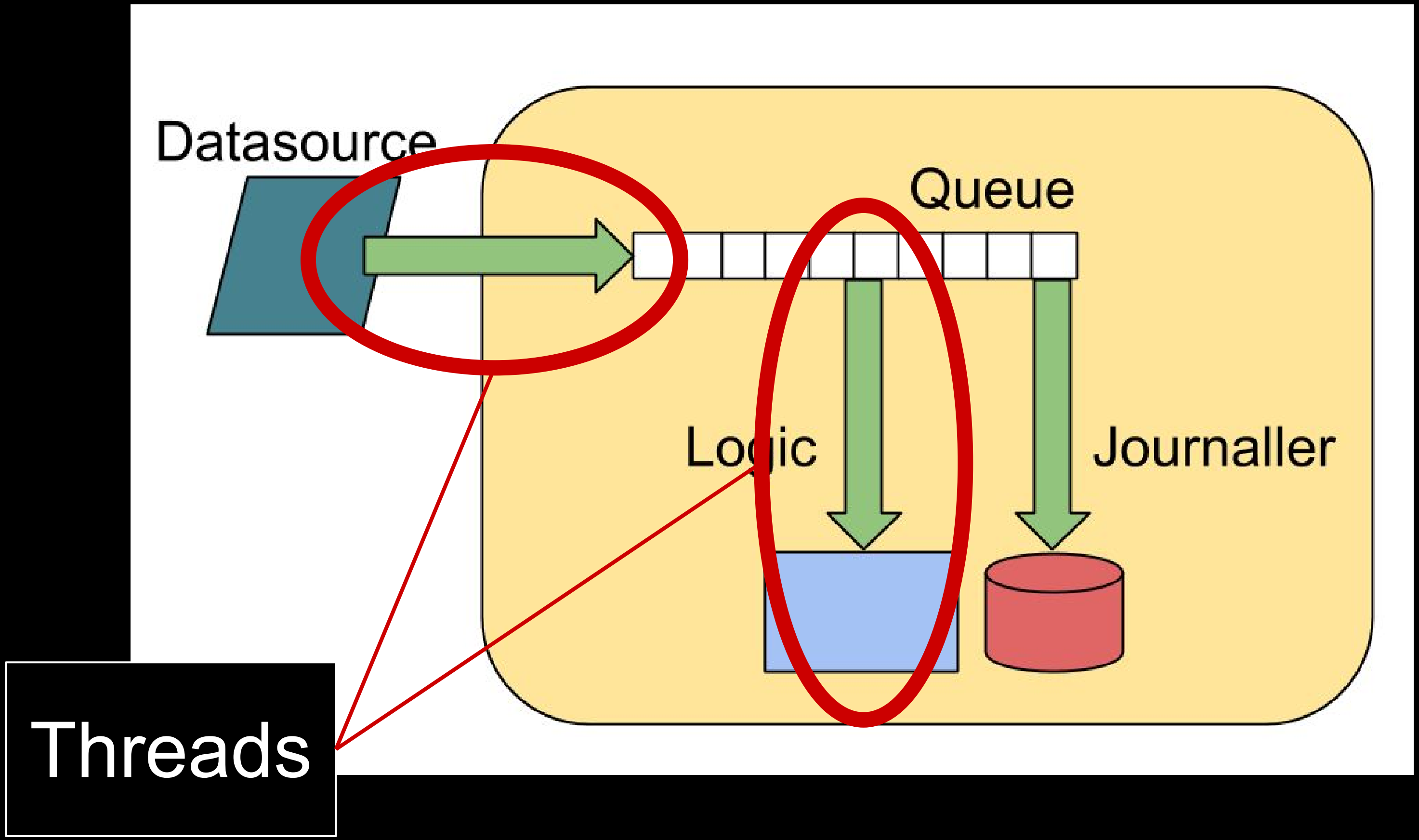
# Multi-tasking

- num(tasks) > num(HyperThreads)
- OS must share out hardware resources
- Clever? Dumb? Fast? Slow?
- Fair...

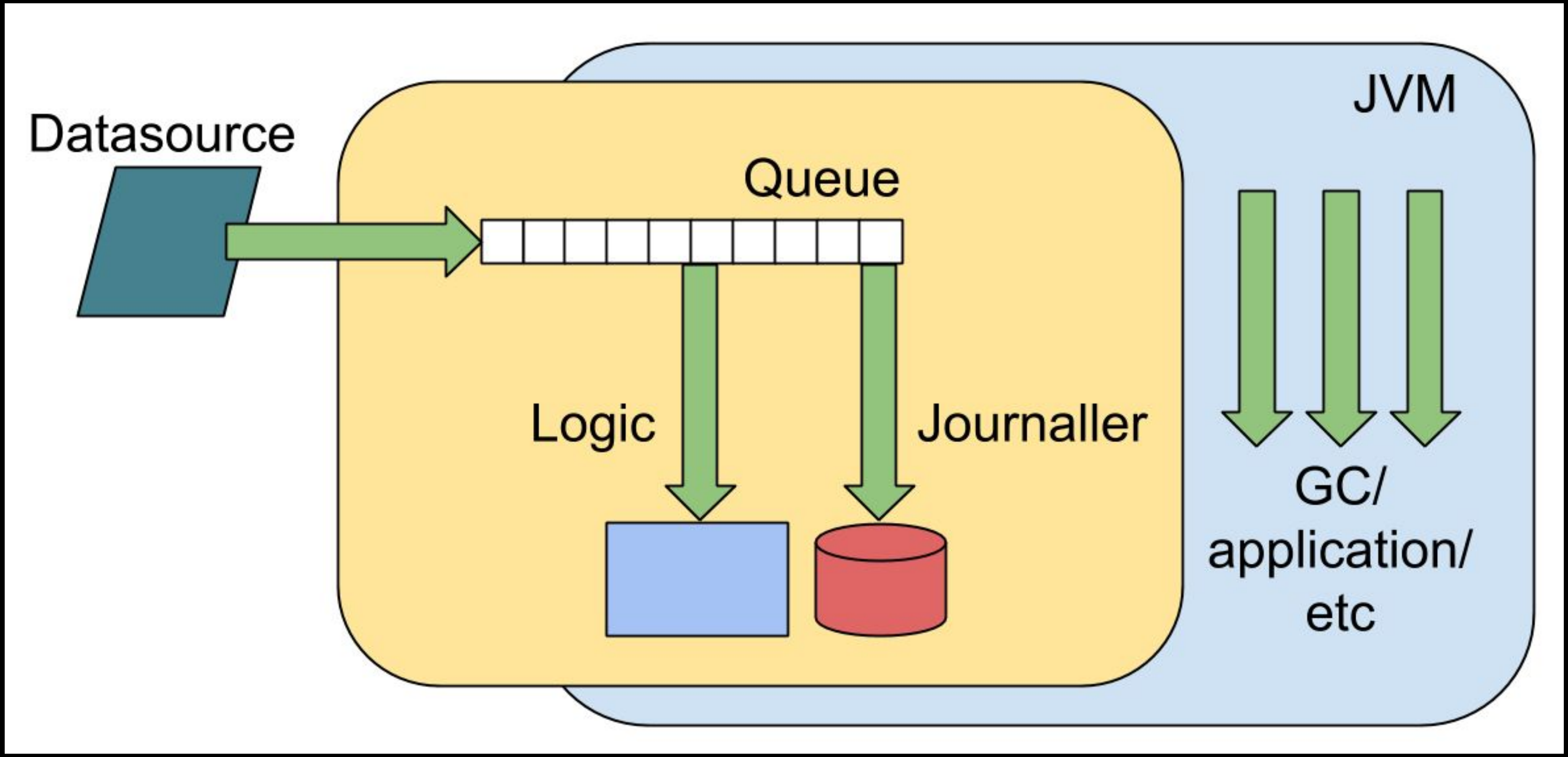
# Linux CFS

- Completely Fair Scheduler
- Maintains a task ‘queue’ per HT
- Runs the task with the lowest runtime
- Updates task runtime after execution
- Higher priority implies longer execution time
- Tasks are load-balanced across HTs

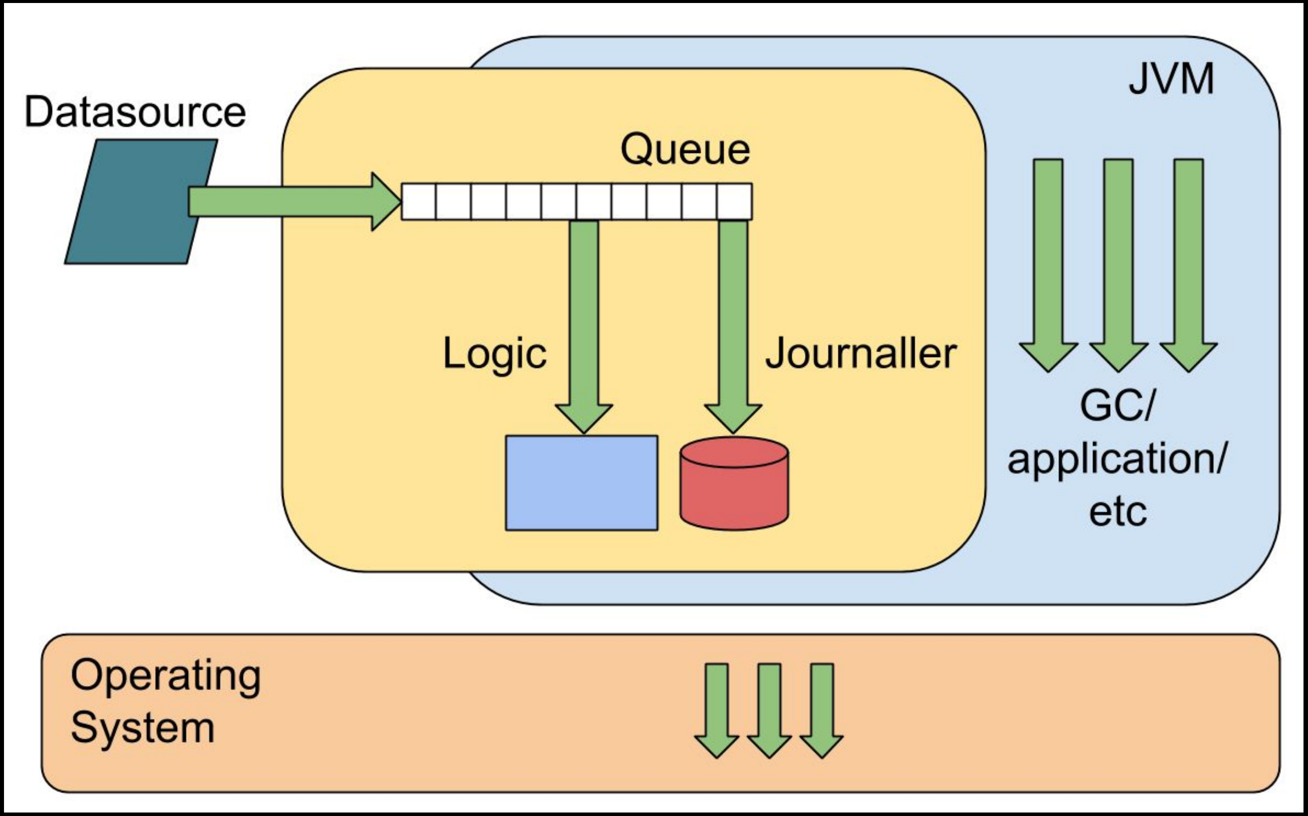
# An example application ...



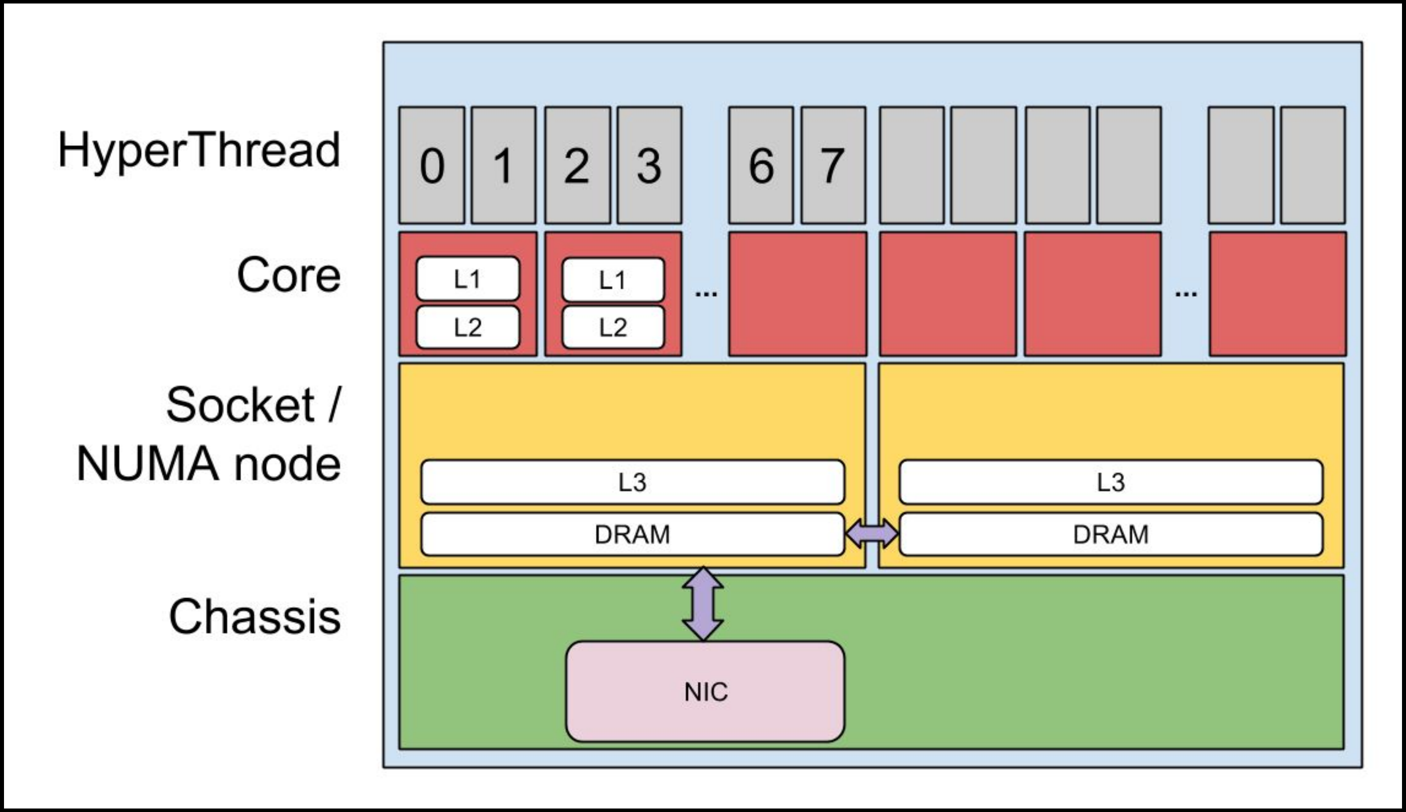
# … running on a language runtime



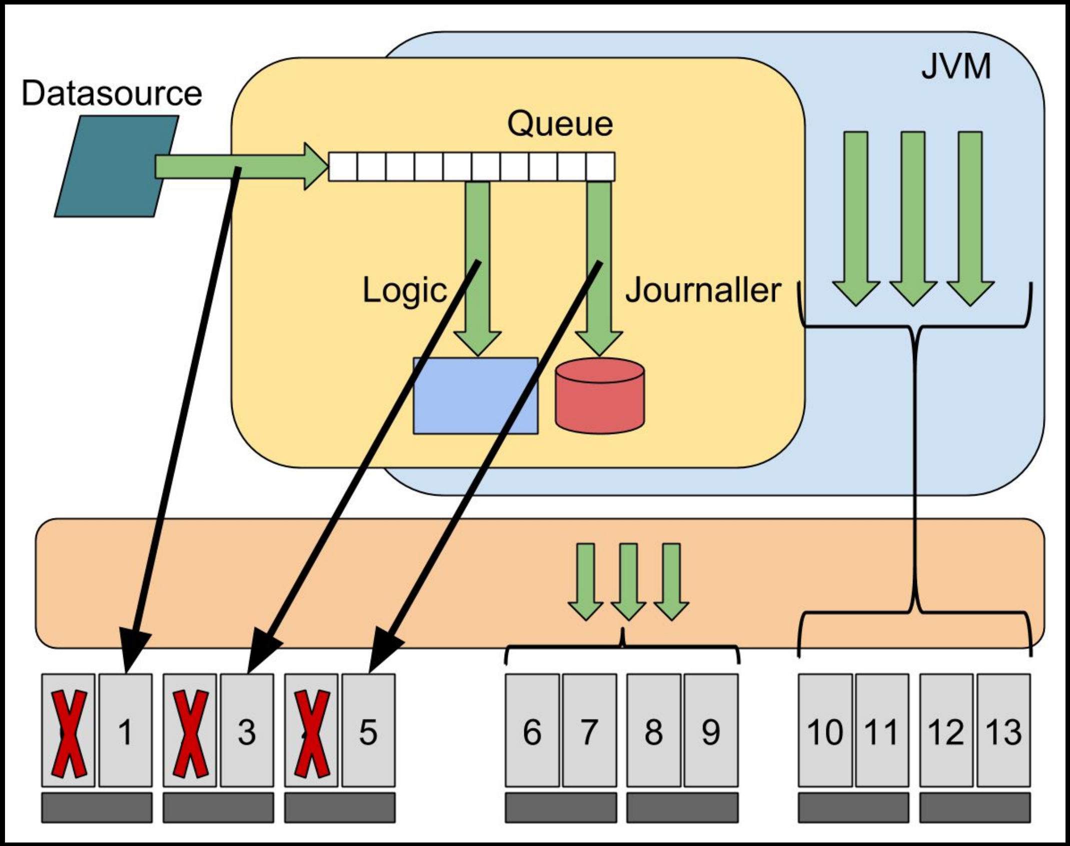
# … running on an operating system



# Optimise for locality - PCI/memory



# Target deployment



# How do I start?

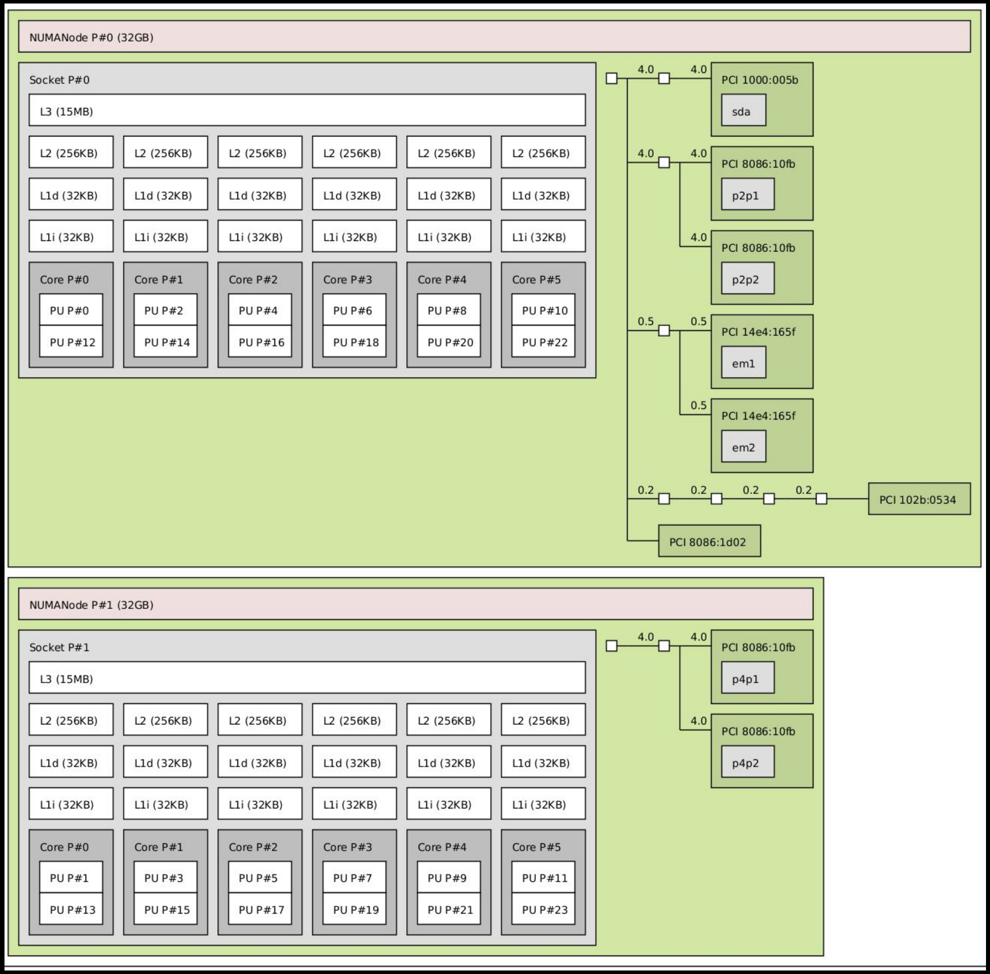
# Start with the metal

- BIOS settings for maximum performance
- That’s a whole other talk...

# Discover what’s available

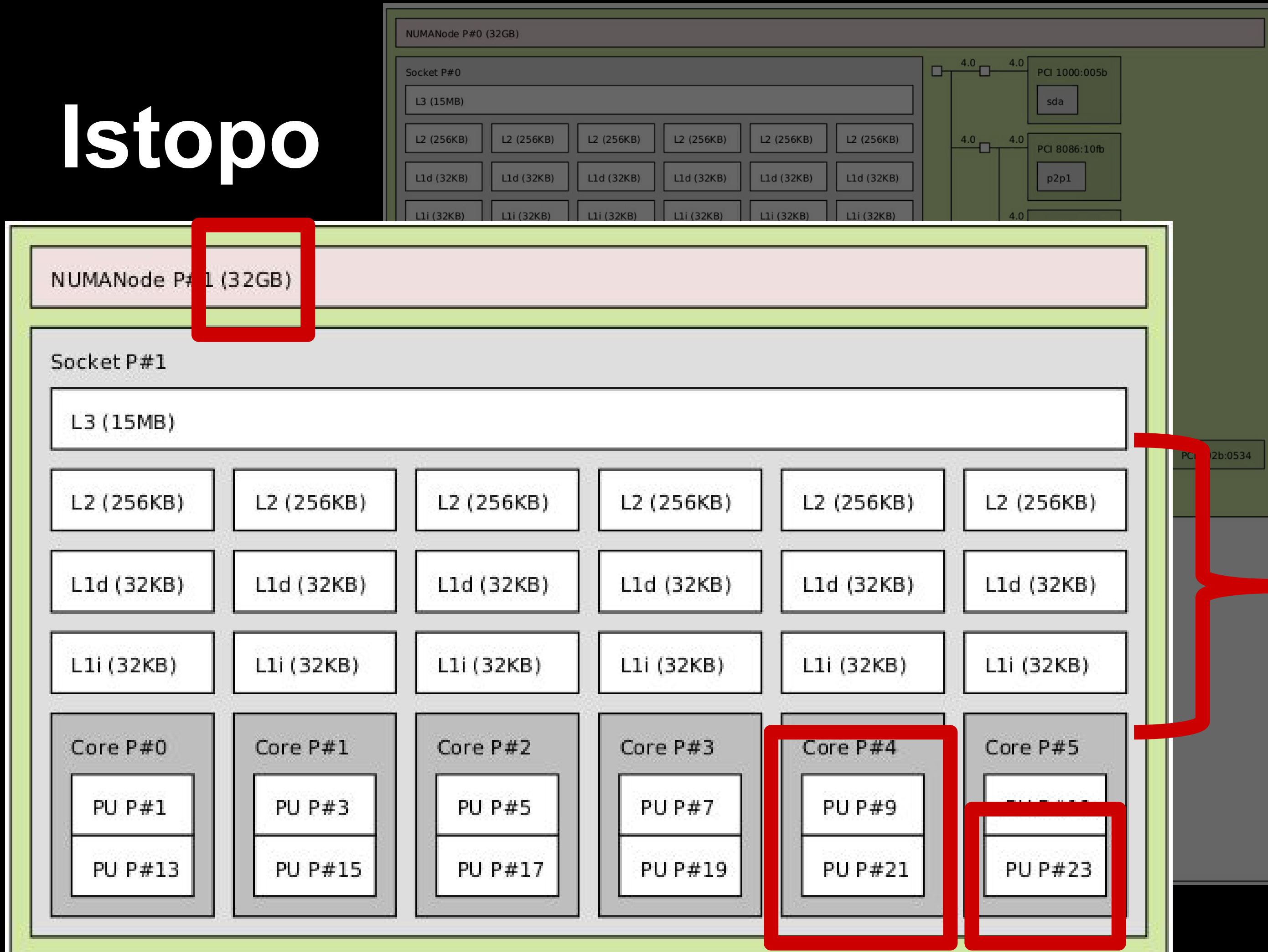
- *lstopo* is a useful tool for looking at hardware
- Provided by the hwloc package
- Displays:
  - HyperThreads
  - Physical cores
  - NUMA nodes
  - PCI locality

# lstopo



NUMANode P#0 (32GB)
Socket P#0
L3 (15MB)
L2 (256KB)
L1d (32KB)
L1i (32KB)
Core P#0
PU P#0
PU P#12
Core P#1
PU P#2
PU P#14
Core P#2
PU P#4
PU P#16
Core P#3
PU P#6
PU P#18
Core P#4
PU P#8
PU P#20
Core P#5
PU P#10
PU P#22
4.0
PCI 1000:005b
sda
PCI 8086:10fb
p2p1
PCI 8086:10fb
p2p2
0.5
PCI 14e4:165f
em1
PCI 14e4:165f
em2
0.2
PCI 102b:0534
PCI 8086:1d02
NUMANode P#1 (32GB)
Socket P#1
L3 (15MB)
Core P#0
PU P#1
PU P#13
Core P#1
PU P#3
PU P#15
Core P#2
PU P#5
PU P#17
Core P#3
PU P#7
PU P#19
Core P#4
PU P#9
PU P#21
Core P#5
PU P#11
PU P#23
PCI 8086:10fb
p4p1
PCI 8086:10fb
p4p2

# lstopo




NUMA-local RAM

Caches

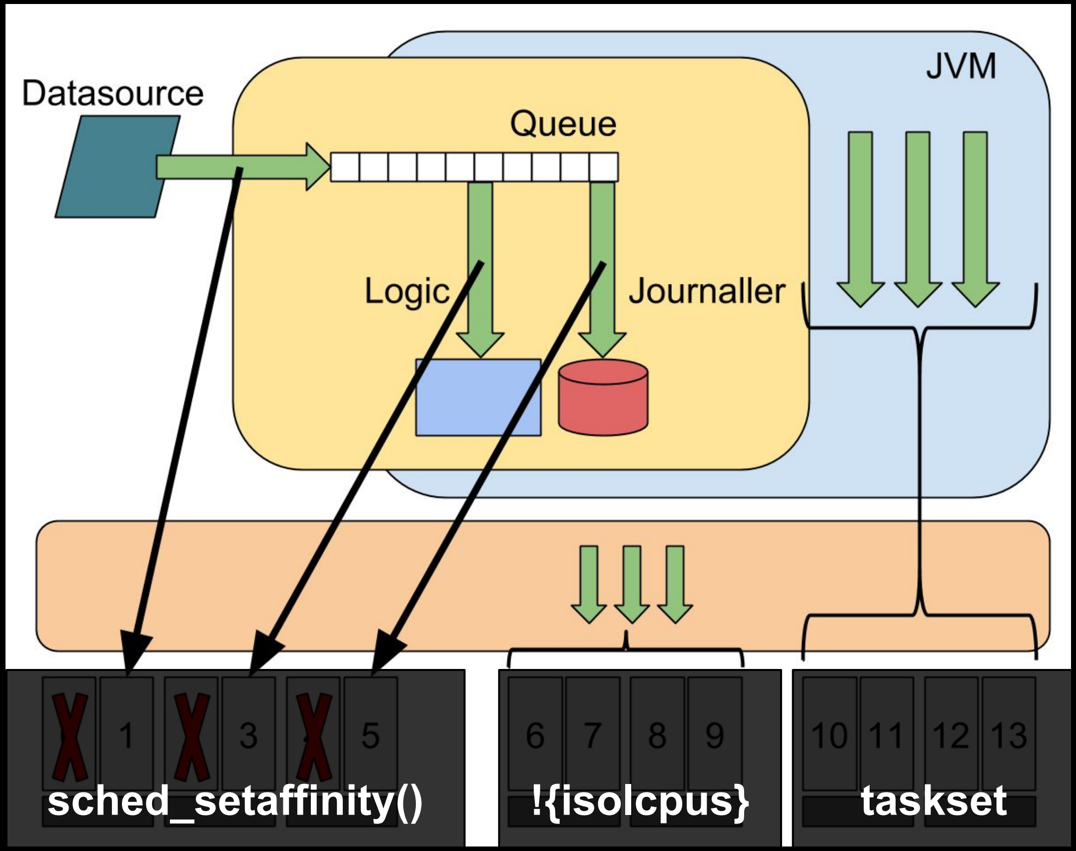
Core

HyperThread

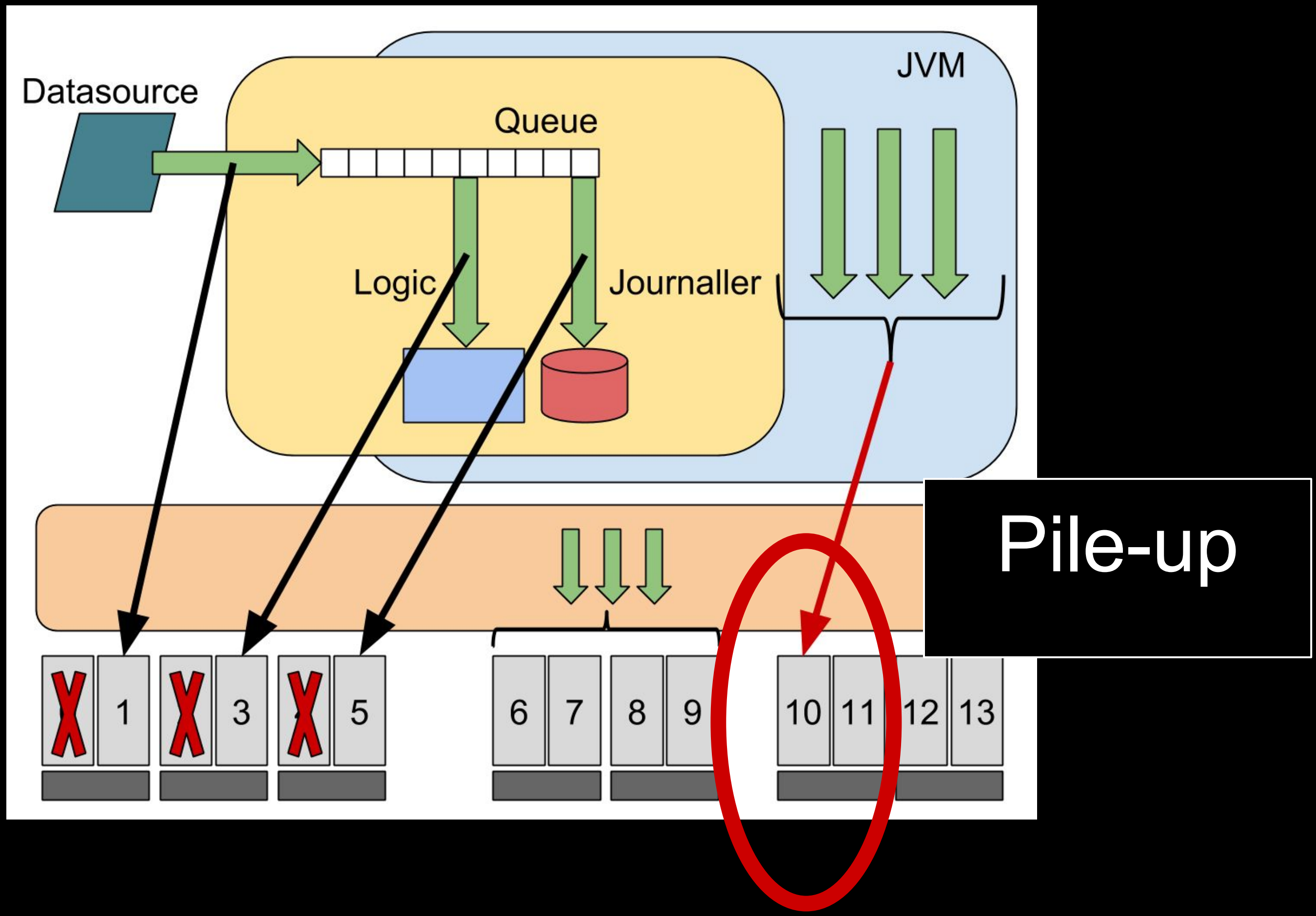
# Reserve & use specific resource

- Use *isolcpus* to reserve cpu resource
- kernel boot parameter
- isolcpus=0-5,10-13
- Use *taskset* to pin your application to cpus:
- taskset -c 10-13 *java …*
- Set affinity of hot threads:
- *sched_setaffinity(...)*

# Deploy the application



# You have no load-balancer



# A solution: cpusets

- Create hierarchical sets of reserved resource
- CPU, memory
- Userland tools: cset (SUSE)

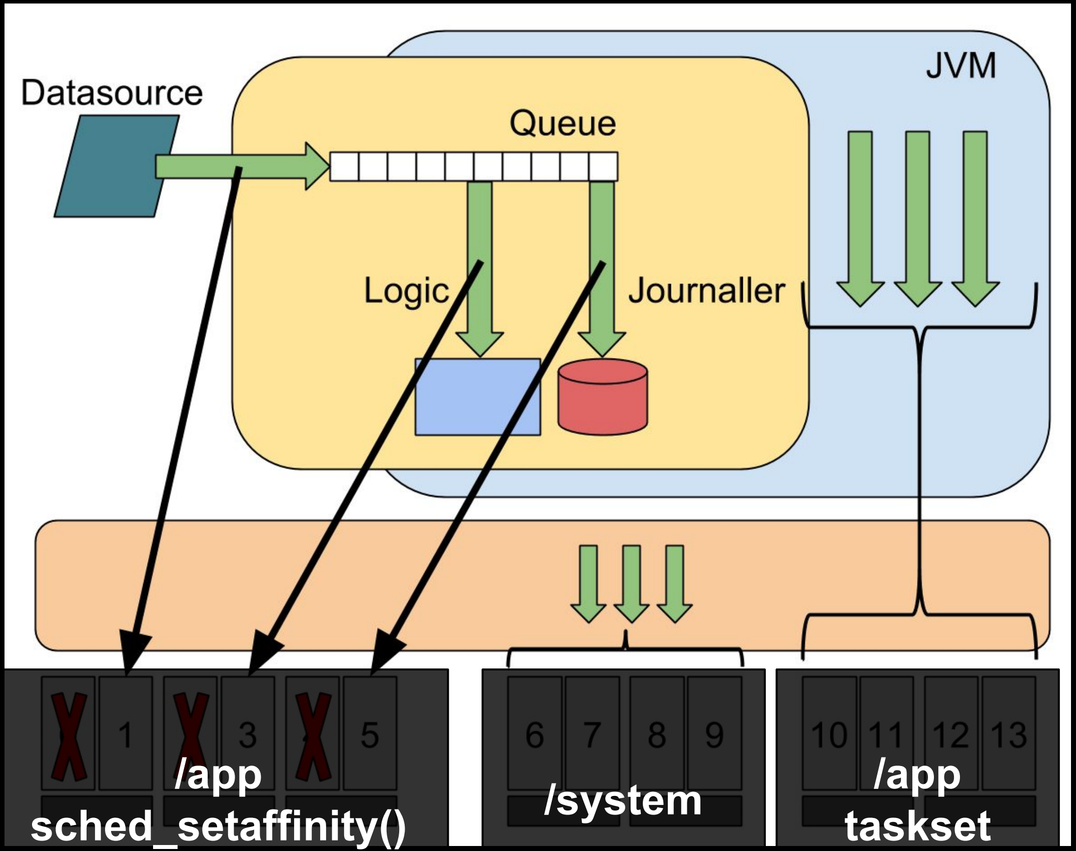
# Isolate OS processes

- cset set --set=/system --cpu=6-9
  - *create a cpuset with cpus 6-9*
  - *create it at the path /system*
- cset proc --move --from-set=/ --to-set=/system
  - *move all processes from / to /system*
  - *-k => move unbound kernel threads*
  - *--threads => move child threads*
  - *--force => erm... force*

# Run the application

- cset set --cpu=0-5,10-13 --set=/app
- cset proc --exec /app *taskset -cp 10-13 java …*
    - *start a process in the /app cpuset*
    - *run the program on cpus 10-13*
- sched_setaffinity() to pin the hot threads to cpus 1,3,5

# Isolated threads



# No more jitter?

## perf_events

- Sampling tracer
- Static/dynamic trace points
- Very low overhead
- A good starting point for digging deeper
- *perf list* to view available trace points
- network, file-system, scheduler, etc

# What’s happening CPU?

- perf record -e "sched:sched_switch" -C 3
  - Sample task switches on CPU 3
- perf report (best for multiple events)
- perf script (best for single events)

# Rogue process

java

36049 [003] 3011858.780856: sched:sched_switch: java:
36049 [110] R ==> kworker/3:1:13991 [120]

kworker/3:1

13991 [003] 3011858.780861: sched:sched_switch:
kworker/3:1:13991 [120] S ==> java:36049 [110]

# ftrace

- Function tracer
- Static/dynamic trace points
- Higher overhead
- But captures everything
- Can provide function graphs
- trace-cmd is the usable front-end

# So what is that kernel thread doing?

- trace-cmd record -P <pid> -p function_graph
  - Trace functions called by process <pid>
- trace-cmd report
  - Display captured trace data

# Some things can't be deferred

```
kworker/3:1-13991 [003] 3013287.180771: funcgraph_entry:             |  process_one_work() {
kworker/3:1-13991 [003] 3013287.180772: funcgraph_entry:             |    cache_reap() {
kworker/3:1-13991 [003] 3013287.180772: funcgraph_entry: 0.137 us    |      mutex_trylock();
kworker/3:1-13991 [003] 3013287.180772: funcgraph_entry: 0.289 us    |      drain_array();
kworker/3:1-13991 [003] 3013287.180773: funcgraph_entry: 0.040 us    |      _cond_resched();
.........
.........
kworker/3:1-13991 [003] 3013287.180859: funcgraph_exit: +86.735 us |  }
```

+86.735 us

# Things to look out for

- cache_reap() - SLAB allocator
- vmstat_update() - kernel stats
- other workqueue events
  - perf record -e “workqueue:*” -C 3
- Interrupts - set affinity in /proc/irq
- Timer ticks - tickless mode
- CPU governor - set to performance
  - /sys/devices/system/cpu/cpuN/cpufreq/scaling_governor

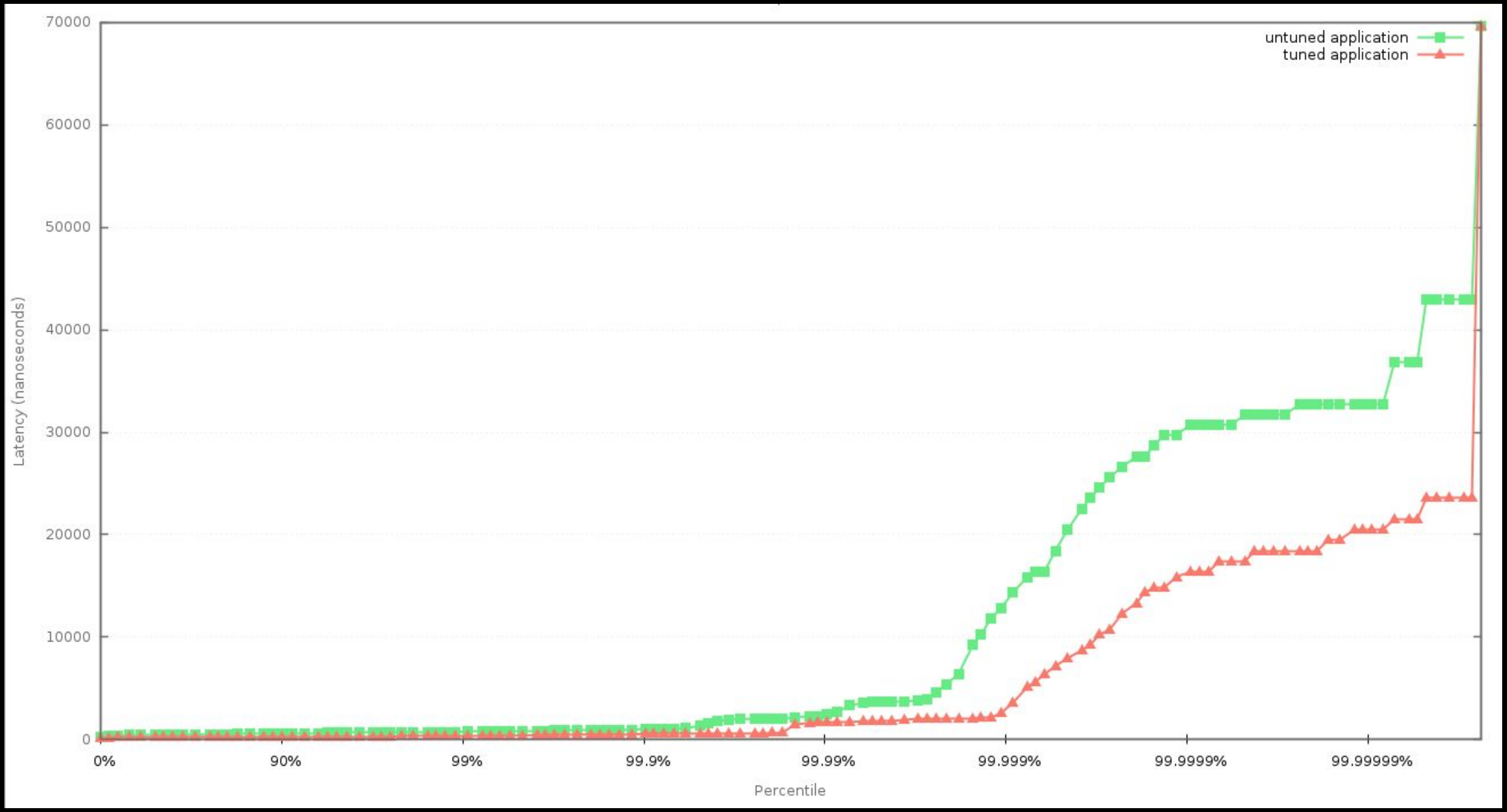
# Some numbers

- Inter-thread latency is a good proxy
- 2 busy-spinning threads passing a message
- Time taken between producer & consumer
- Record times over several seconds
- Compare tuned/untuned

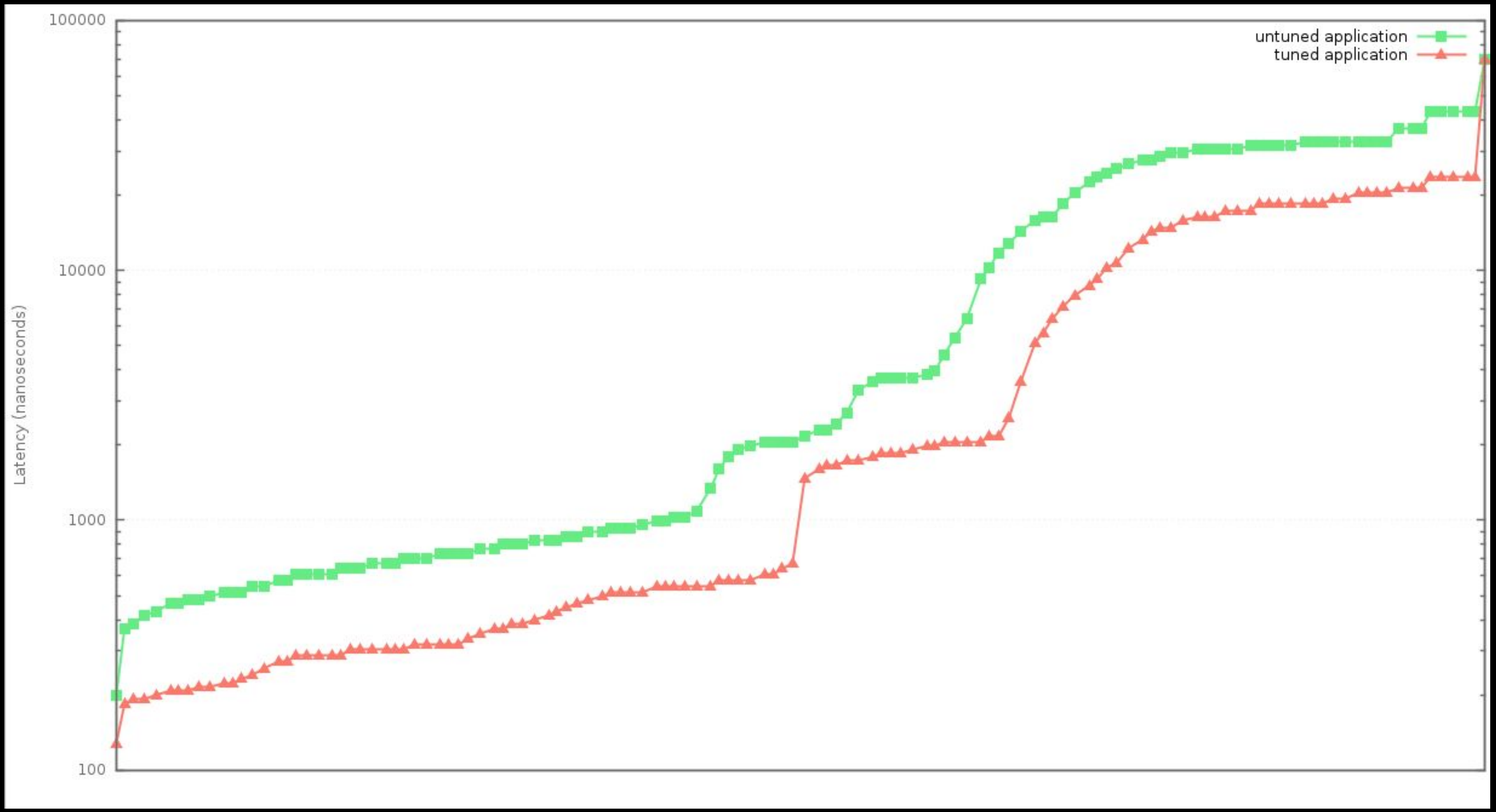
# Results

| == Latency (ns) == | untuned | tuned |
|---|---|---|
| mean | 466 | 216 |
| min | 200 | 128 |
| 50.00% | 464 | 208 |
| 90.00% | 608 | 288 |
| 99.00% | 768 | 336 |
| 99.90% | 992 | 544 |
| 99.99% | 2432 | 1664 |
| max | 69632 | 69632 |

# tuned vs untuned



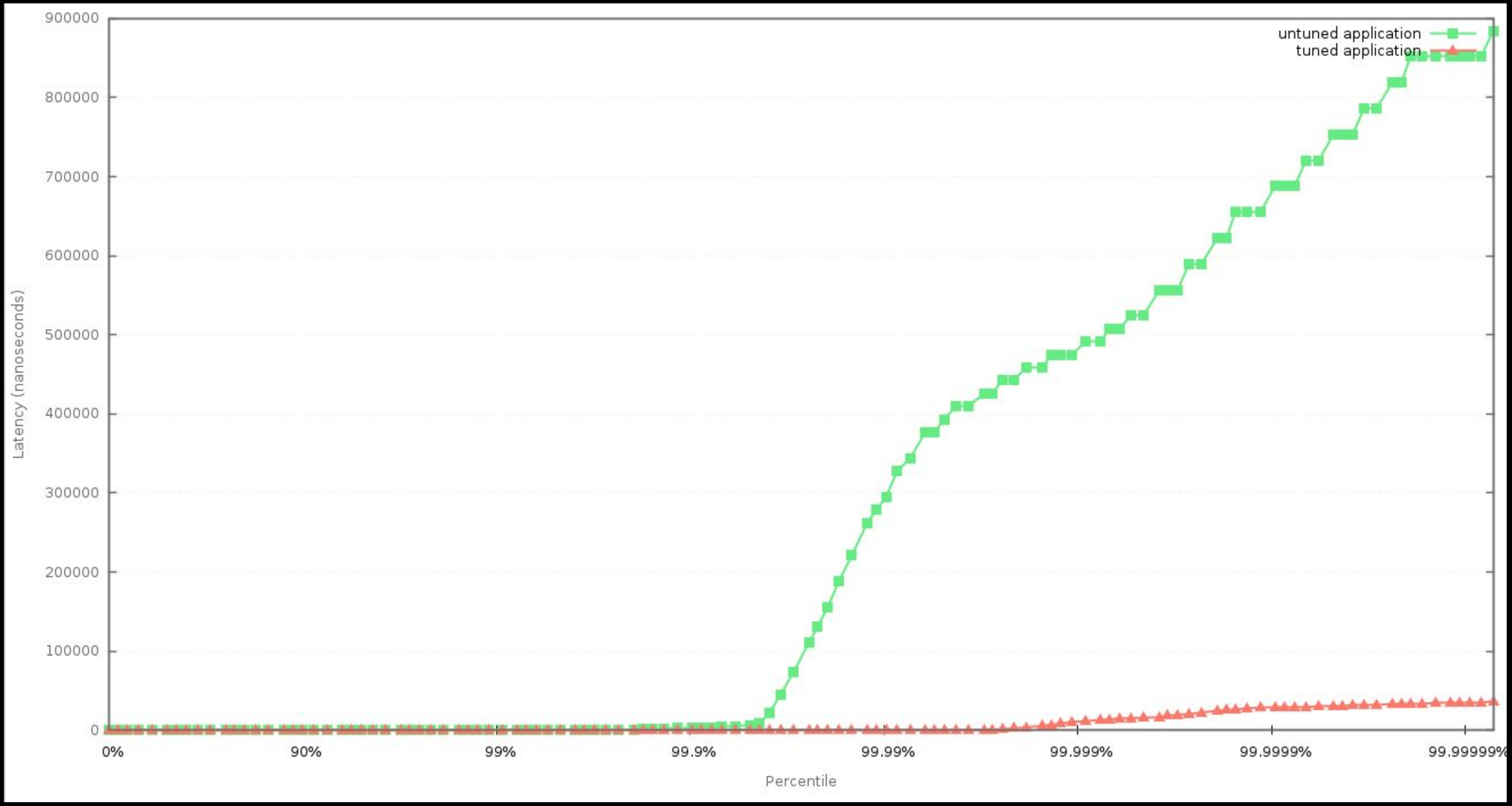
# tuned vs untuned (log scale)



# Results (loaded system)

| == Latency (ns) == | untuned | tuned |
|---|---|---|
| mean | 545 | 332 |
| min | 144 | 216 |
| 50.00% | 464 | 336 |
| 90.00% | 544 | 352 |
| 99.00% | 736 | 448 |
| 99.90% | 2944 | 544 |
| 99.99% | 294913 | 704 |
| max | 884739 | 36864 |

# tuned vs untuned (loaded system)



# Summary

- Select threads that need access to CPU
- Isolate CPUs from the OS
- Pin important threads to isolated CPUs
- Don’t forget interrupts
- There will be more things…
- Always test assumptions!
- Run validation tests to ensure tunings are as expected

# Thank you

- lmax.com/blog/staff-blogs/
- epickrram.blogspot.com
- github.com/epickrram/perf-workshop
- @epickrram