IBM Linux Technology Center

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The Linux Scheduler, today and looking forward

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Agenda

- Introduction
- Old Scheduler
- Need for the new scheduler
- CFS
- Group scheduling
- Load Balancing
- Future

The O(1) Scheduler

- Known as the ultra scalable scheduler
- The typical scheduling operations were O(1)
  - enqueue
  - dequeue
- Used rotating priority arrays
- Basically a Weighted Round Robin scheduler
  - Used nice values for determining time slice
  - Used two arrays, active and expired.
    - Task finishes its timeslice and goes to the expired array
    - When active is empty, the arrays are exchanged and expired becomes active and active, expired

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    - Was not
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    - Was not
    - Erratic scheduling patterns
  - Runtime Accounting
    - Was statistical
    - Or too coarse

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    - Need to get CPU fast
      - Otherwise noticeable effects, for example, audio stutters

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- Nice is now exponential and not linear

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- Two major “features”
  - ✔ Shorter time slices: On an average, the CFS has shorter time slices.
    - With the help of these, tasks which are further behind, get to run faster
  - ✔ Wakeup behavior
    - Typical interactive task -> sleeps for long, and then has a short burst
    - Waiting for CPU, not good. Shows up as stutters in amarok
    - So we queue up a newly woken up task to the head of the queue

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So how fair is the CFS?

- Tried out massive_intr.c
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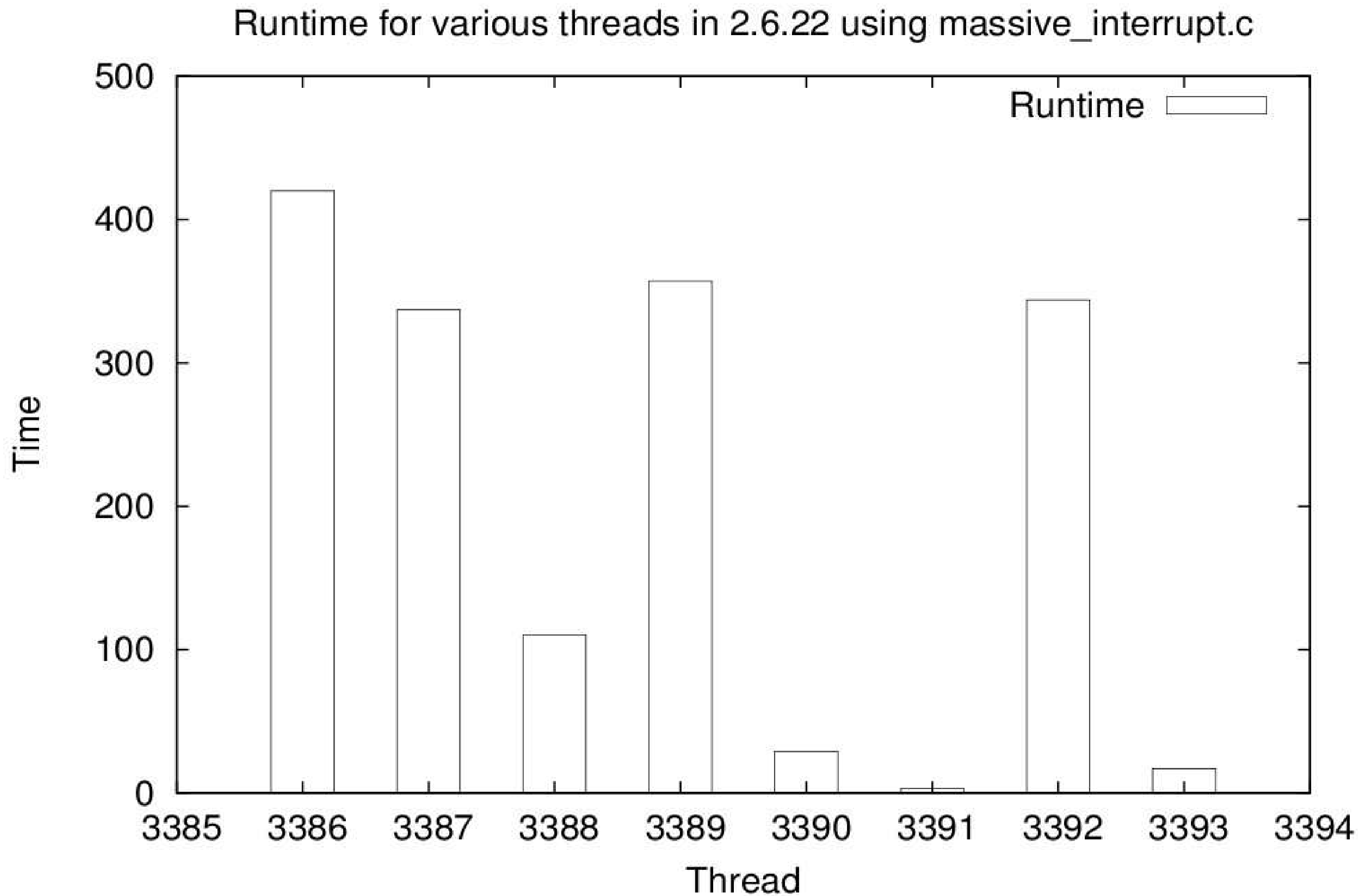
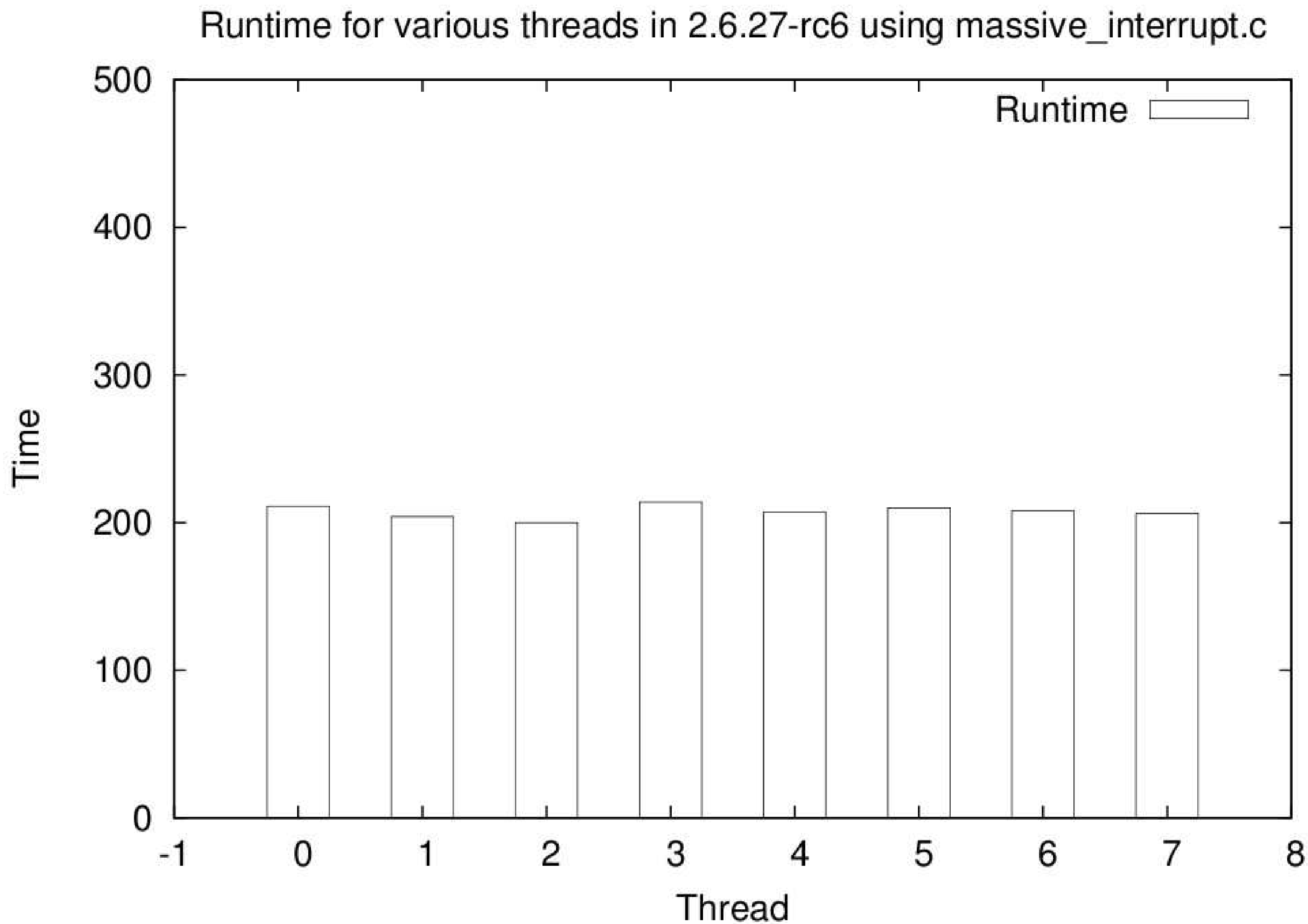
- Takes two arguments.
  - ✔ Number of threads
  - ✔ How long to run the program
- Very simple
  - ✔ Runs a thread for 8ms and then puts it to sleep for 1ms
  - ✔ At the end of the time, it kills all the threads, and prints out the time each thread got


Runtime for various threads in 2.6.22 using massive_interrupt.c
Runtime
Time
Thread
500
400
300
200
100
0
3385
3386
3387
3388
3389
3390
3391
3392
3393
3394


Runtime for various threads in 2.6.27-rc6 using massive_interrupt.c
Runtime
Time
Thread
0
100
200
300
400
500
-1
0
1
2
3
4
5
6
7
8

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- Administrator finds it easier to control groups
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- Control Groups provided the ability to group threads arbitrarily
  - So, group "blog", *could* consist of webserver and database threads
- Srivatsa Vaddagiri extended the CFS to provide group scheduling, which would give control over groups such as "blog"
  - Merged in v2.6.24

Scheduler Entity

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- Group scheduling requires scheduler to deal with “task groups”
- Enter sched_entity
  - ✔ Helped with reuse of the code
  - ✔ Can mean either a task or a task group. Basically something that can be “scheduled”
  - ✔ Keeps track of vital scheduling data, such vruntime
  - ✔ Scheduler core modified to work entities rather than tasks

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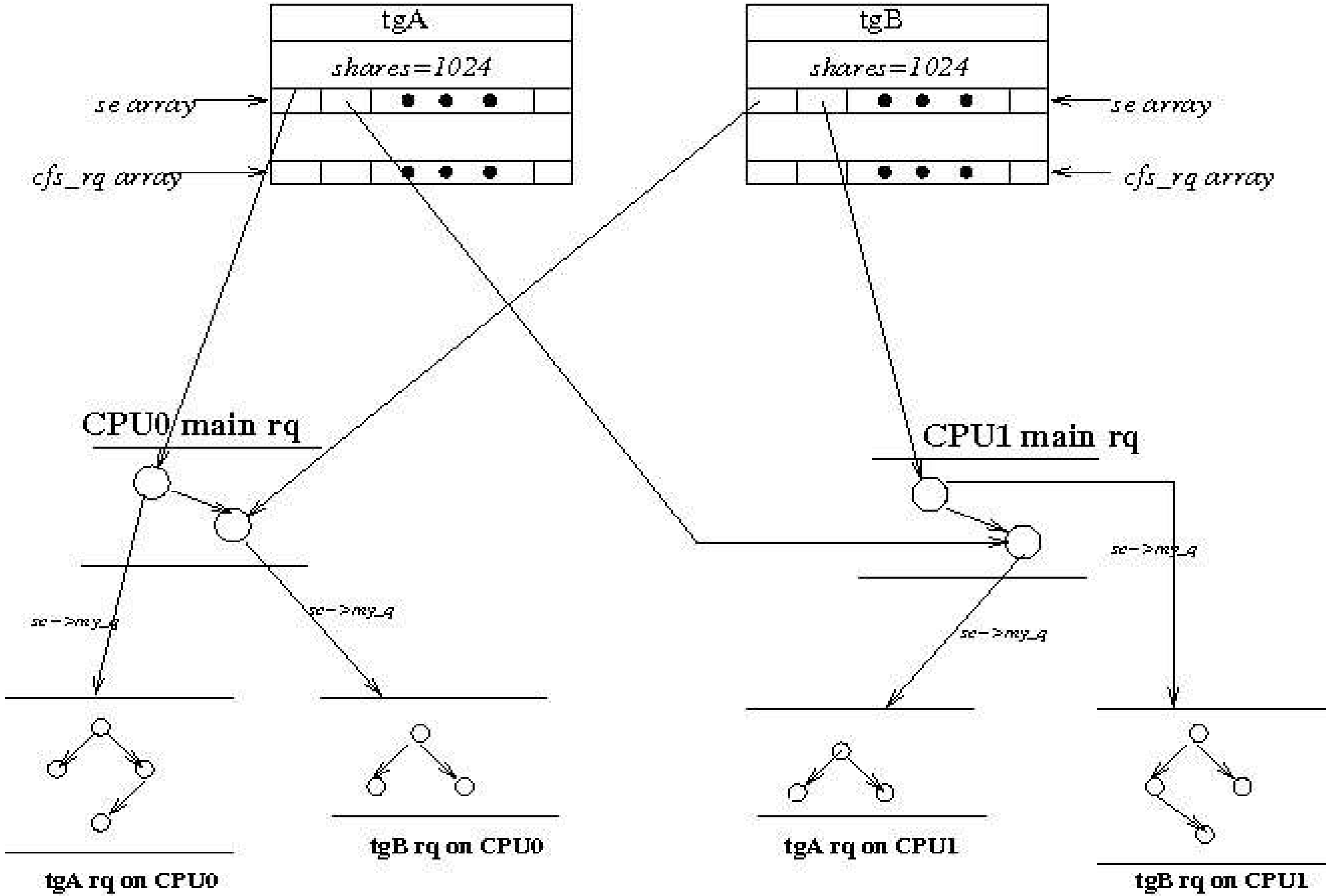
  - Those which are not grouped, form a group :-)


tgA
shares=1024
tgB
shares=1024
se array
cfs_rq array
se array
cfs_rq array
CPU0 main rq
CPU1 main rq
se->my_q
se->my_q
se->my_q
se->my_q
tgA rq on CPU0
tgB rq on CPU0
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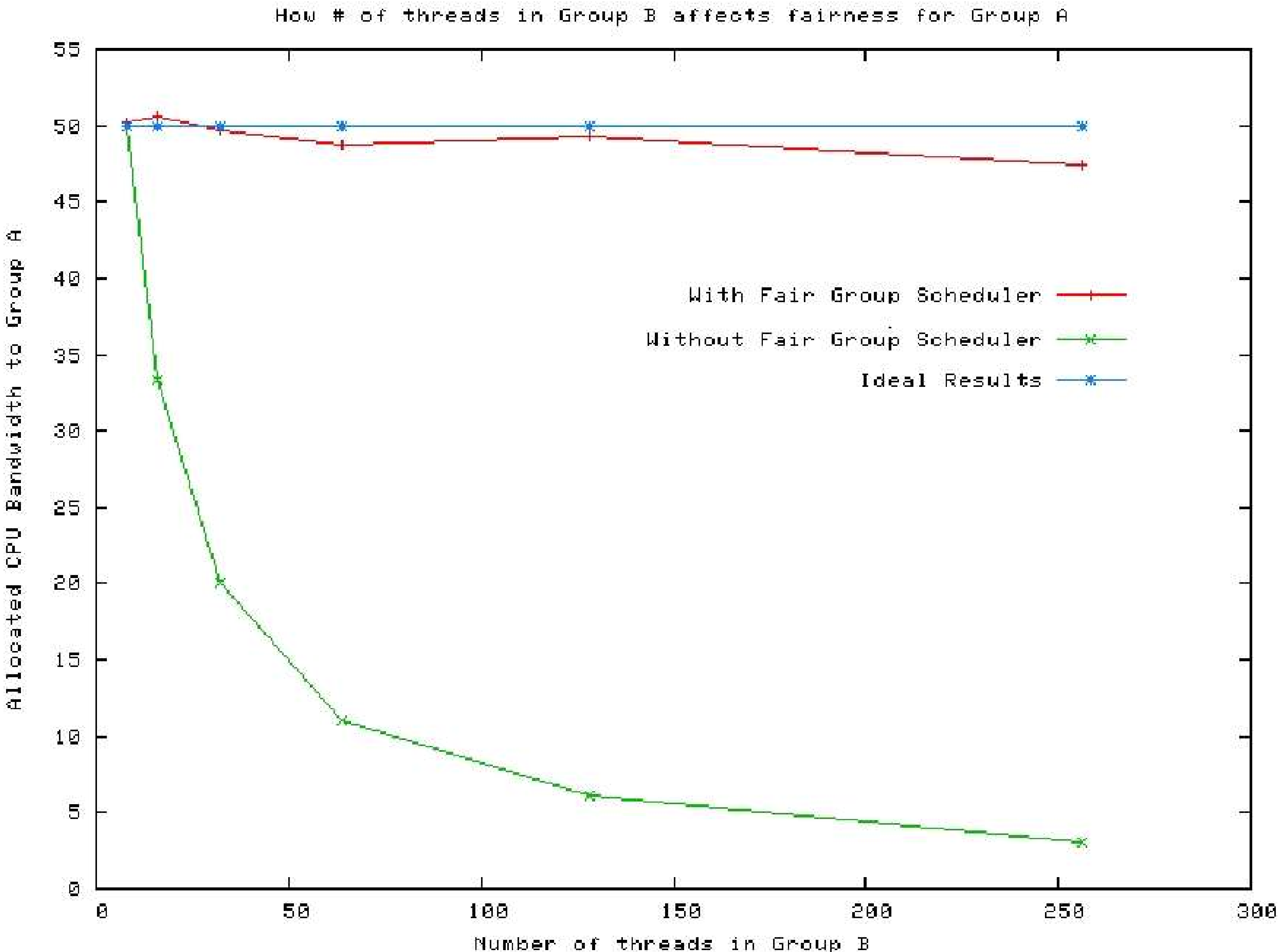
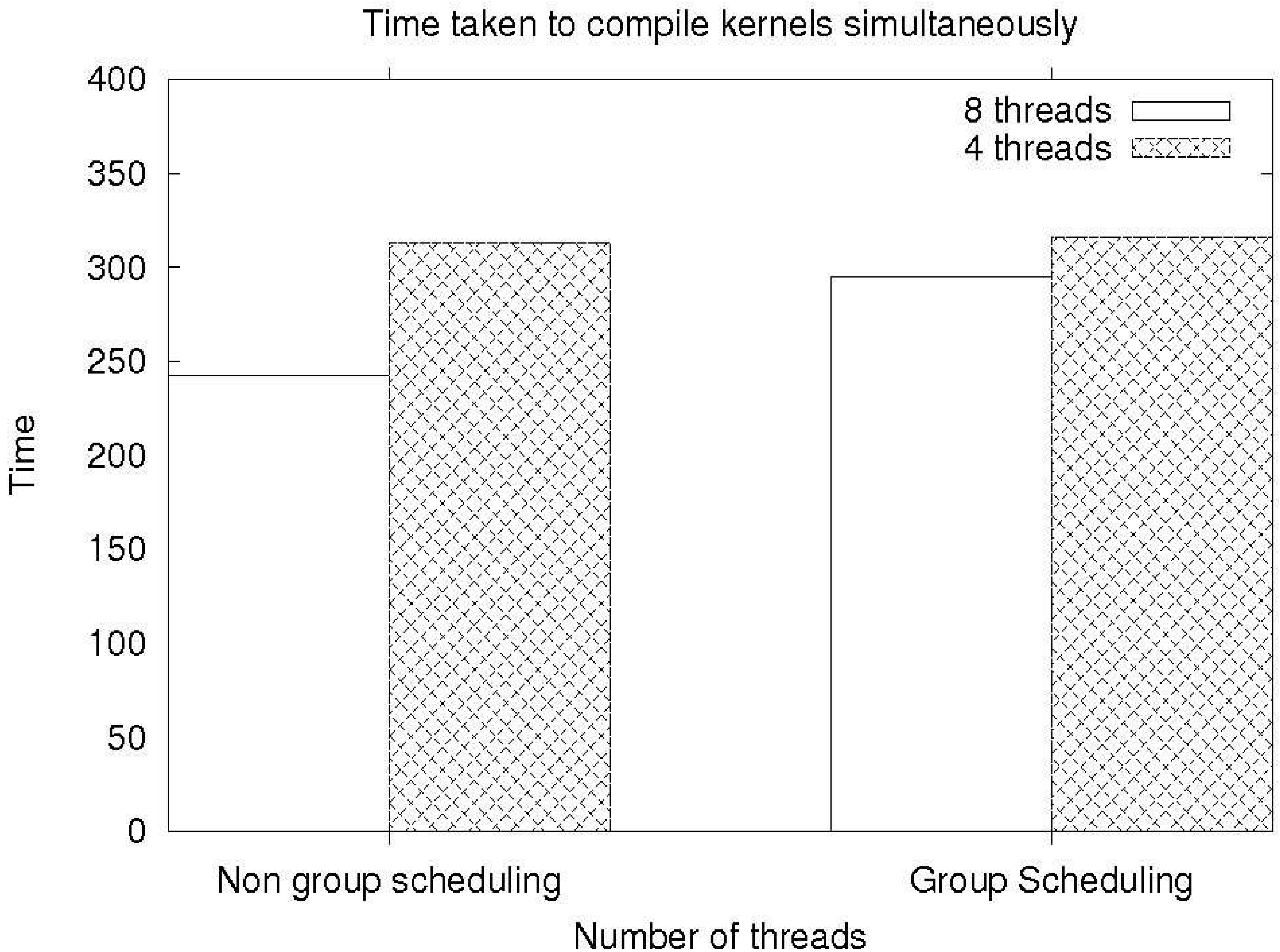
  - ✔ Available since v2.6.26


How # of threads in Group B affects fairness for Group A
Allocated CPU Bandwidth to Group A
Number of threads in Group B
0
5
10
15
20
25
30
35
40
45
50
55
0
50
100
150
200
250
300
With Fair Group Scheduler
Without Fair Group Scheduler
Ideal Results


Time taken to compile kernels simultaneously
400
350
300
250
200
150
100
50
0
Time
8 threads
4 threads
Non group scheduling
Group Scheduling
Number of threads

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  - ✔ sched_rt_period_us -> The refresh rate
  - ✔ Prevents RT tasks from taking over the system

RT Group Scheduling

- sched_rt_entity introduced
  - ✔ An abstraction similar to sched_entity

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  - An abstraction similar to sched_entity
- Two tunables
  - rt_period_us
  - rt_runtime_us

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- Linux uses distributed scheduling

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  - Based on various properties such as shared pipelines, shared caches
- CPUsets allow the user to carve up CPUs into sets
  - Also used for load balancing decisions

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  - ✔ Pick the busiest group and try to pull from there as long as we don't pull too much

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  - ✔ Bad for scalability

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- Use sched domains
  - ✔ Re-compute shares as we walk up the tree.

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    - Expensive. Arrival and departure of tasks is quite frequent
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    - Has some short term unfairness, but not more than what was already present, due to rebalancing

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- Faster convergence to fairness for group scheduling
- Looking at RT scheduling function, independent of PI
  - ✔ Allows us to experiment with more advanced RT scheduling
  - ✔ Possibly allow us to extend PI for SCHED_OTHER

Thank You!

Questions?

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- IBM is a registered trademark of International Business Machines Corporation in the United States and/or other countries.
- Linux is a registered trademark of Linus Torvalds.
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BACKUP

Scheduler Classes

- Scheduler Classes, a definition,

  An extensible hierarchy of scheduler modules which encapsulate scheduling policy details and are handled by the scheduler core without the core code assuming about them too much

  Ingo Molnar

- Essentially what he said, with a few custom changes :)

The CFS

- More vruntime love

$$vruntime = runtime\frac{runqueue\_weight}{weight}$$

- Calculated as follows
  - When a task forks, vruntime set so that it comes as the rightmost
    - Ensures that it does not affect the fairness promised to tasks already existing
  - When a task runs, the it runs is normalized to its weight, and is added to its vruntime
  - CFS tracks a variable known as cfs_rq->min_vruntime

Being nice

- CFS changed the definition of how nice worked
  - ✔ O(1) had liner values for nice
  - ✔ CFS has a exponential scale
  - ✔ $Nice_0 = 1024$
  - ✔ $Nice_{i-1} = 1.25Nice_i$
- Time slice dependent on weight
- Weight dependent on nice
- Therefore, nice has a much stronger effect on time slices now.

Some basic definitions

- We have tasks Ti of weight wi running on CPU Pj such that its runqueue has weight

$$rw_j = \sum_{i|\tau_i \in P_j} w_i$$

  - ✔ Each task gets w_i/rw_j runtime

- A task can be a supertask with weight w_i with subtasks spread across every CPU
  - ✔ Gives rise to the concept of shares, which is per CPU weight of the supertask

$$w_i = \sum_j s_{i,j} \qquad s_{i,j} = \frac{w_i rw_{i,j}}{rw_i}$$

Some basic definitions

- Another concept
  - Task weight as viewed from the root group

$$W_i = \prod_{\gamma} \frac{w_{k_\gamma}}{rw_{l_\gamma}} | k \in T_l, l_\gamma = k_{\gamma-1}$$

  - Which gives rise to

$$\sum_{i|i \in T_0} w_i = \sum_{k|k \in P_j, !super(k)} W_k$$

Sched Features

- Some key features,
- NEW_FAIR_SLEEPERS: Provides a bonus to tasks that just wake up.
- NORMALIZED_SLEEPERS: Normalizes the aforementioned bonus
- START_DEBIT: Demotes a newly forked task to the right of the runqueue

Distributed Load Balancing

- Wake Affine
  - Requires precise re-calculation
    - Not good!
  - We know,

$$s_{i,j} = \frac{w_i rw_{i,j}}{rw_i}$$

  - So we add in a delta

$$s'_{i,j} = \frac{w_i(rw_{i,j} + \delta w)}{(rw_i + \delta w)}$$

  - Express s'-s as a function of delta(w)