NUMA-aware scheduling

Red Hat, Inc.

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Author

- Software Engineer in Kernel Generalists team at Red Hat
- z-stream kernel maintainer
- interested in the latest news in sched/MM development
- credits to Jirka Hladky for providing many benchmark outputs

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Section 1

Introduce to NUMA

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What is NUMA?

- non-uniform memory access
- supported by most of modern OS
- logical follower of UMA architecture using SMP
- heavily used in HPC world

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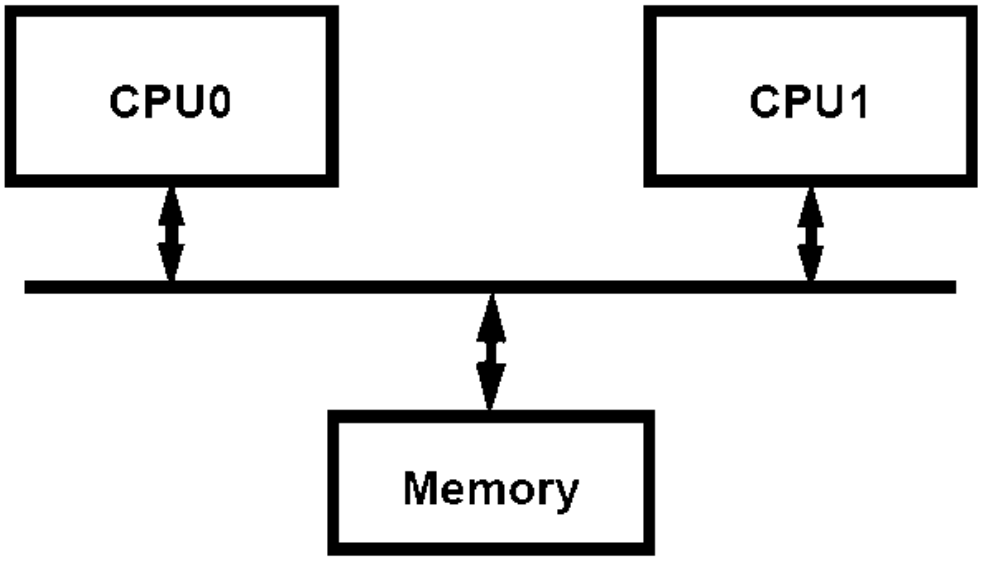
UMA

- uniform memory access
- typically based on SMP architecture with one bus
- memory bus is a bottleneck



Source: http://ixbtlabs.com/articles2/cpu/rmma-numa.html

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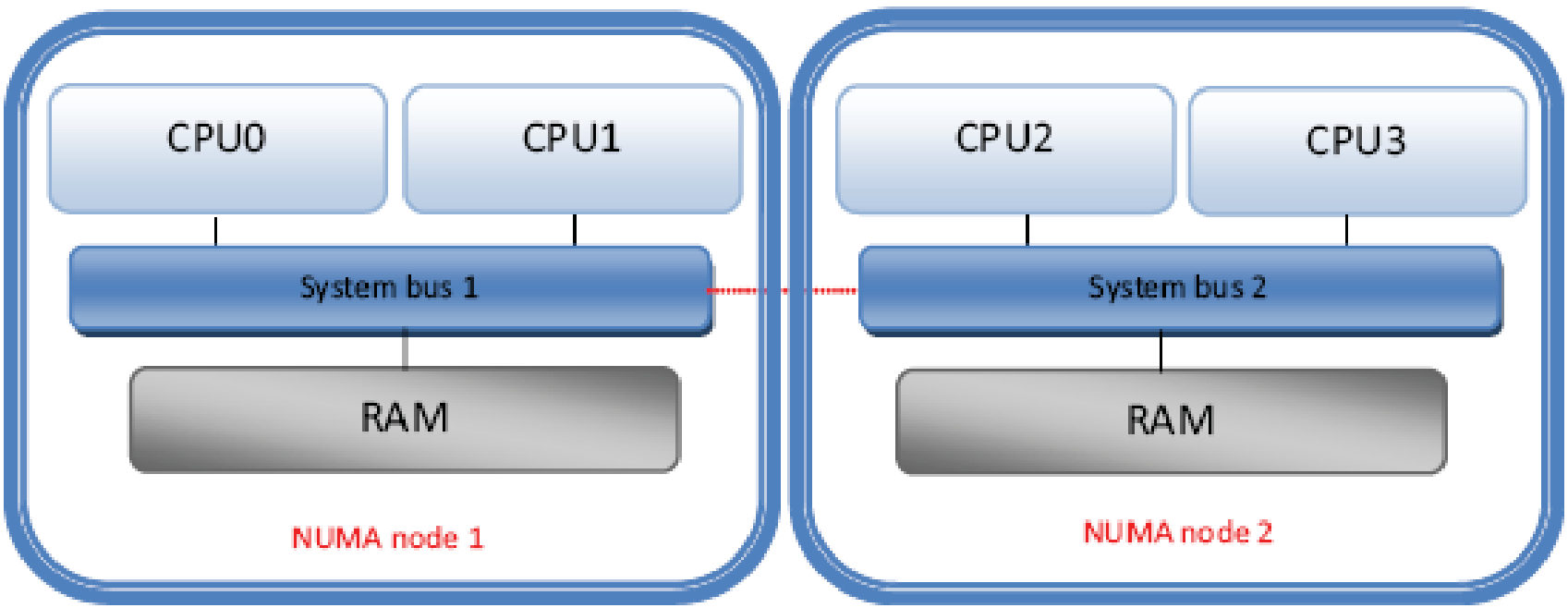
NUMA

- CPUs are divided into groups
- NUMA reduces number of CPUs competing for shared memory bus
- better parallelism



Source: http://www.networkcomputing.com/virtualization/harnessing-vsphere-performance-benefits/2295022

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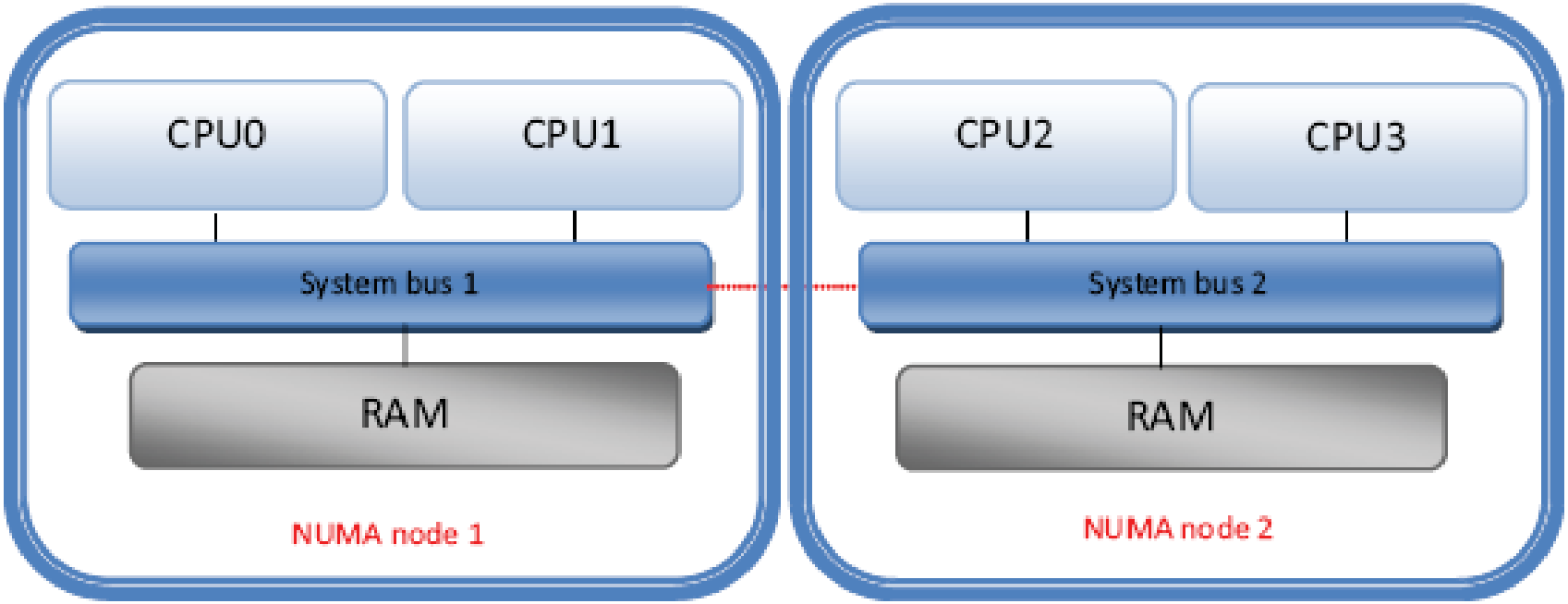
Disadvantages of NUMA

- local memory access vs. remote memory access
- remote node access is ~2 times slower
- placement of tasks for balanced load



Source: http://www.networkcomputing.com/virtualization/harnessing-vsphere-performance-benefits/2295022

Section 2

Recent NUMA-aware scheduling changes

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Development

- first patchset merged in Oct 2013 - kernel 3.12
- based on work of many people during years 2012 and 2013
- still under active development
- this feature is fully automatic and requires only NUMA enabled in BIOS

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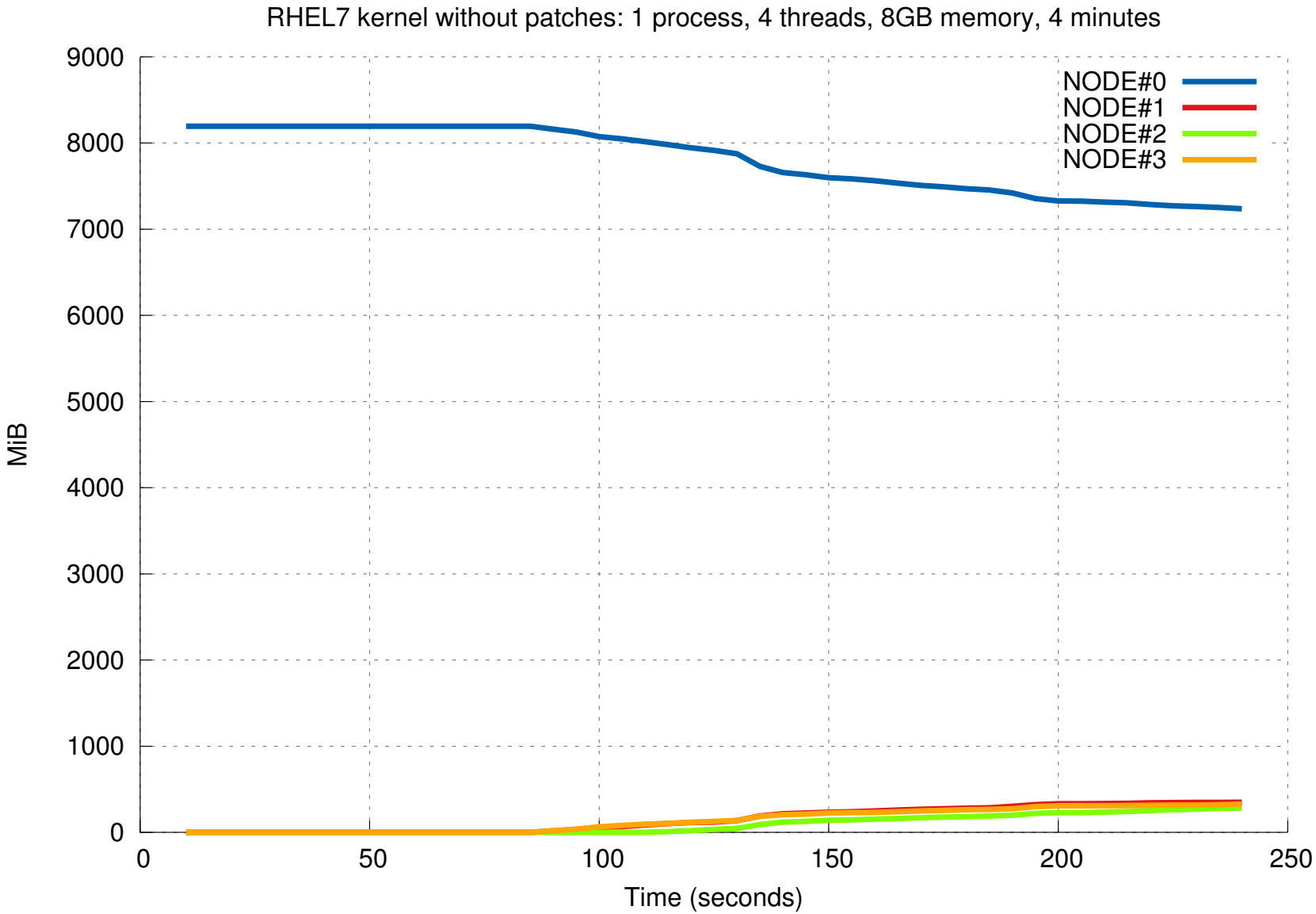
How older kernels migrated tasks and memory



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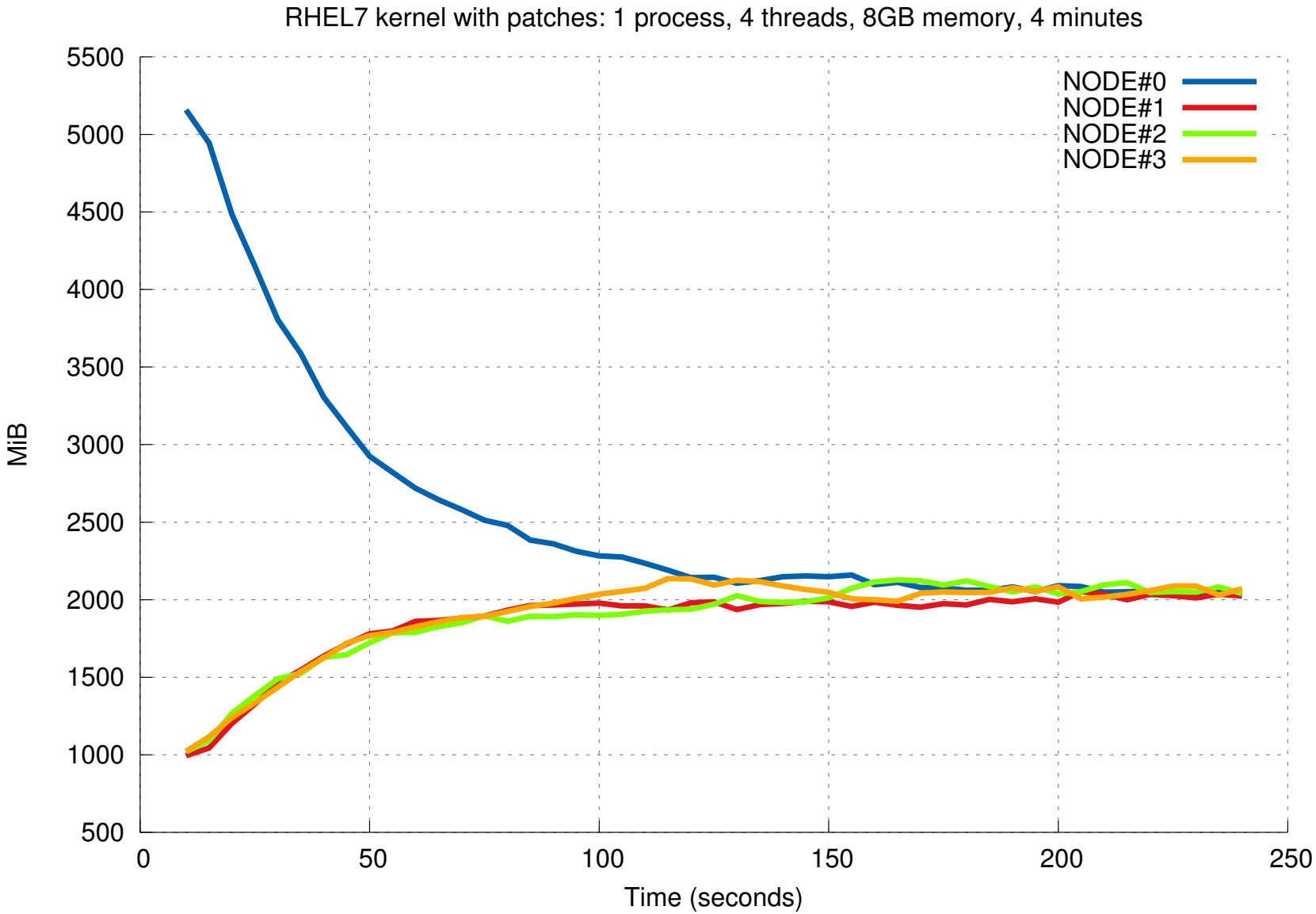
How recent kernels migrate tasks and memory



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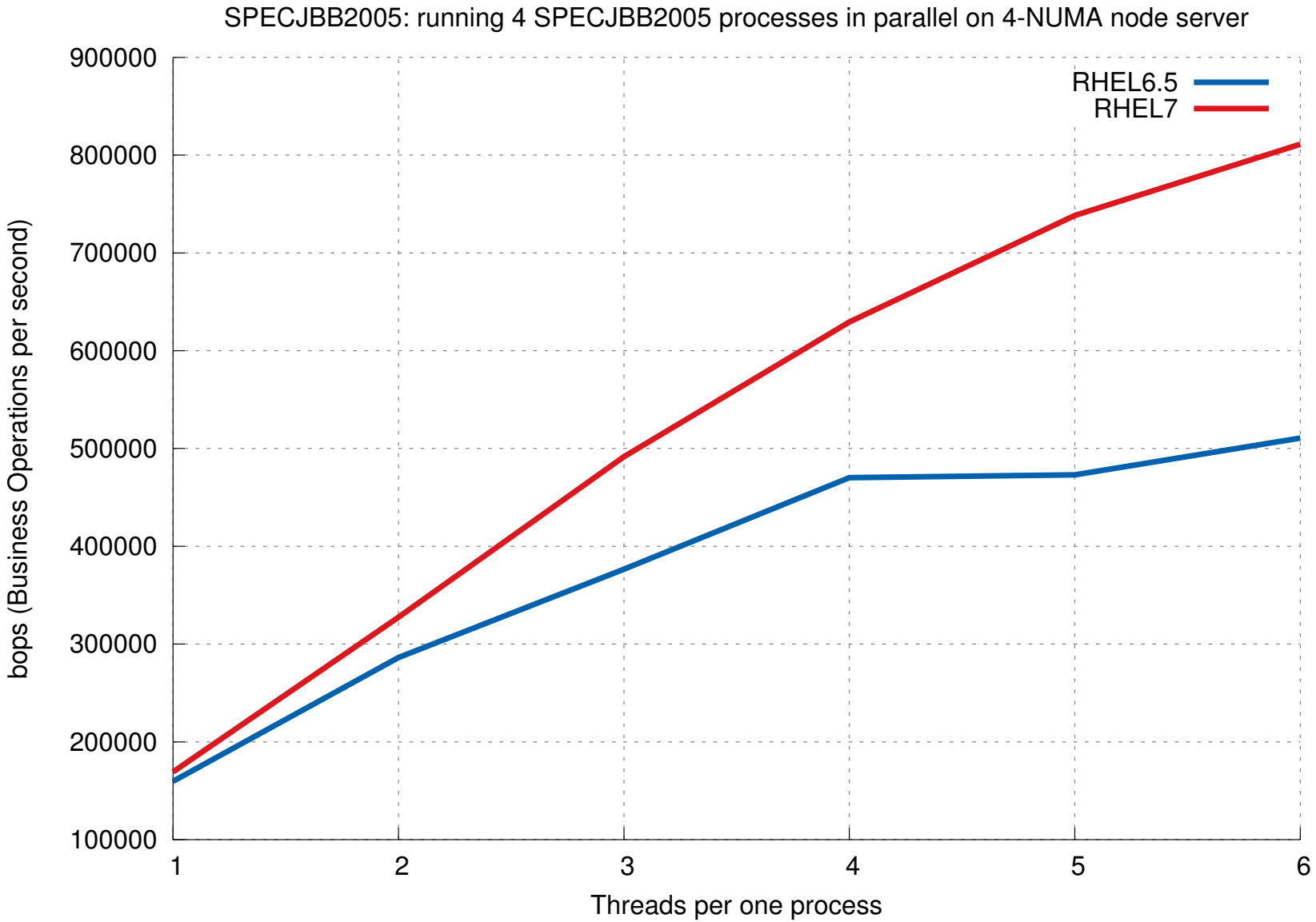
Results of SPECjbb2005



Section 3

Implementation

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Preferred node

- node with the most accessed memory
- every task has assigned preferred node
- kernel attempts to move task towards its preferred node

```
--- a/include/linux/sched.h
+++ b/include/linux/sched.h
@@ -1344,6 +1344,7 @@ struct task_struct {
struct callback_head numa_work;

+ unsigned long *numa_faults;
+ int numa_preferred_nid;

#endif /* CONFIG_NUMA_BALANCING */
```

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Tracking of page accesses

- kernel periodically unmaps memory of processes
- resulting pagefaults then provide access metadata
- not all types of pages are watched
- last `cpupid` encoded into `struct page` flags

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Migrating of memory

- memory is also migrated towards tasks
- kernel did it also before, but now it is better
- more conditions, e.g. tasks pinned to node

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NUMA groups

- groups of tasks accessing same shared pages
- shared page accesses are tracked at the group level
- shared pages accesses are preferred over private pages accesses

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How can I tune it?

- `cat /sys/kernel/debug/sched_features`
- `echo NO_NUMA > /sys/kernel/debug/sched_features`
- `echo NUMA > /sys/kernel/debug/sched_features`

Section 4

Summary

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Summary

- tasks and memory are migrated to each other
- performance gains upto ∼40% compared to RHEL6.5 on 4 nodes NUMA systems
- this feature **will be** included in RHEL7

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Sources

- https://lkml.org/lkml/2013/9/27/211
- http://lwn.net/Articles/568870/
- http://www.spec.org/jbb2005/
- http://kernel.org

The end.

Any questions?