Scheduler Soft Affinity: Dynamic Workload Partitioning

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Outline

1. CPU Resource Management
2. Dynamic Partitioning
3. Implementation
4. Results
5. Future Work

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CPU Resource Management

- Multiple instances of workload are consolidated in one system
  - Multiple VMs or Containers
  - Autonomous Database
    - Oracle Multitenant
    - Multiple Container Database/Pluggable Database instances

CPU Resource Management

- Instances can be hard partitioned
  - *sched_setaffinity(2)* or *cpusets* to e.g. a NUMA node
  - One instance can't use the CPUs of another
- Instances can be free inside the system
  - Can be scheduled on any CPU (no affinity)
  - *cpu.shares* for fair share
  - Cache interference and coherence

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Dynamic Partitioning

- Goal: Best of both worlds
  - Allow bursting out of partition
  - Minimize cache interference and coherence when busy
  - Have negligible overhead

AutoNuma Balancer?

- Can work for NUMA partitions (LLC)
- High reaction time
  - Periodic scanning
- Ineffective if memory is spread across NUMA nodes

AutoNuma Balancer?

- Motivational experiment
  - *numactl* used to bind memory (2 DB instances, 2 socket system)
  - AutoNuma Balancer not migrating threads
  - AutoNuma Balancer ON vs OFF did not make a difference

Dynamic Partitioning

- ”Soft” partition of *any* set of CPUs
  - LLC (NUMA) can be most effective on x86 Intel systems
  - L2/L1 can be beneficial for other platforms
  - APIs

CPU shares

- Soft Affinity is orthogonal to CPU shares
  - CPU shares decides *how many* cycles to consume
  - Soft affinity decides *where* to preferably consume those cycles
  - Can be used together

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Implementation

- Define a preferred set of CPUs
  - *cpu_preferred* in addition to *cpu_allowed*
- Use *cpu_preferred* for *want_affine*
- LLC search:

```
if (cpu_preferred == cpu_allowed)
        search cpu_allowed;
else
        search cpu_preferred;
        search (cpu_allowed – cpu_preferred);
```

Implementation

- Only changes the *push* side of the scheduler
  - Idle balancing unchanged
  - *Implicitly soft*
- Only implemented for CFS class
  - Child inheritance

Implementation

API

- New system call to specify soft partition
  - sched_setaffinity2
  - Extra parameter for affinity type
  - HARD_AFFINITY == sched_setaffinity
  - SOFT_AFFINITY == ”soft” affinity
- Other option: extending cpuset

Implementation

Example snippet

```
...
        cpu_set_t set;
        pid_t pid;
        CPU_ZERO(&set);
        for (i=0; i<=3; i++)
                CPU_SET(i, &set);
        pid = getpid();
        rc = sched_setaffinity2(pid, sizeof(cpu_set_t), &set, SOFT_AFFINITY);
...
```

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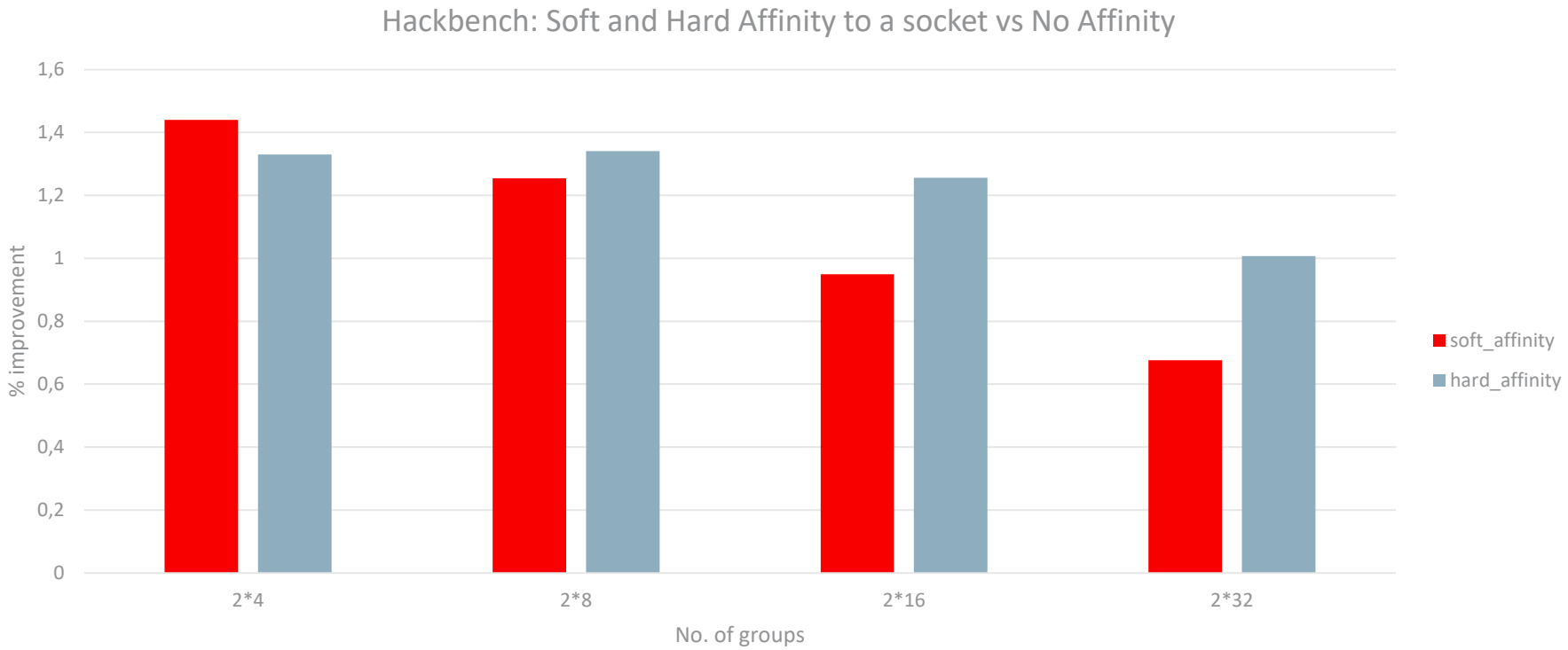
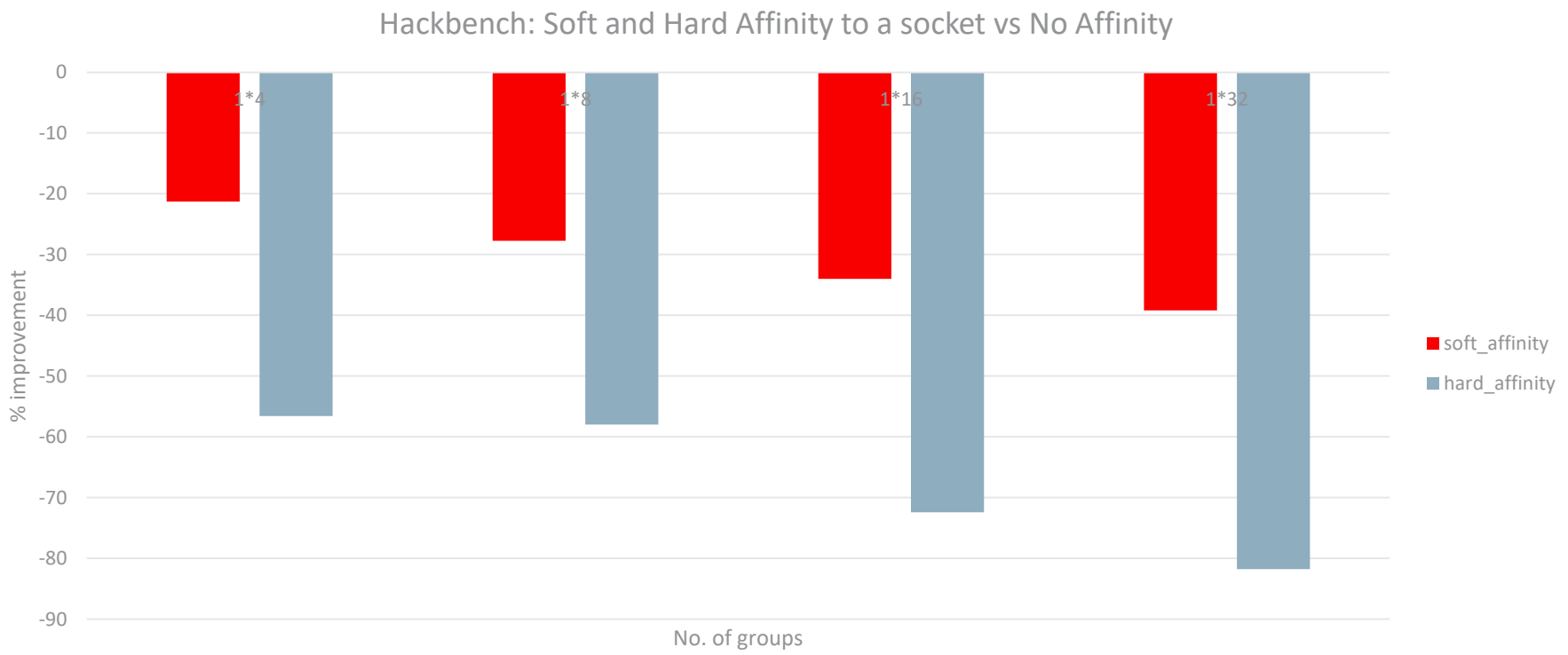
Hackbench: 2 instances, 2 socket NUMA system, 22 cores per socket



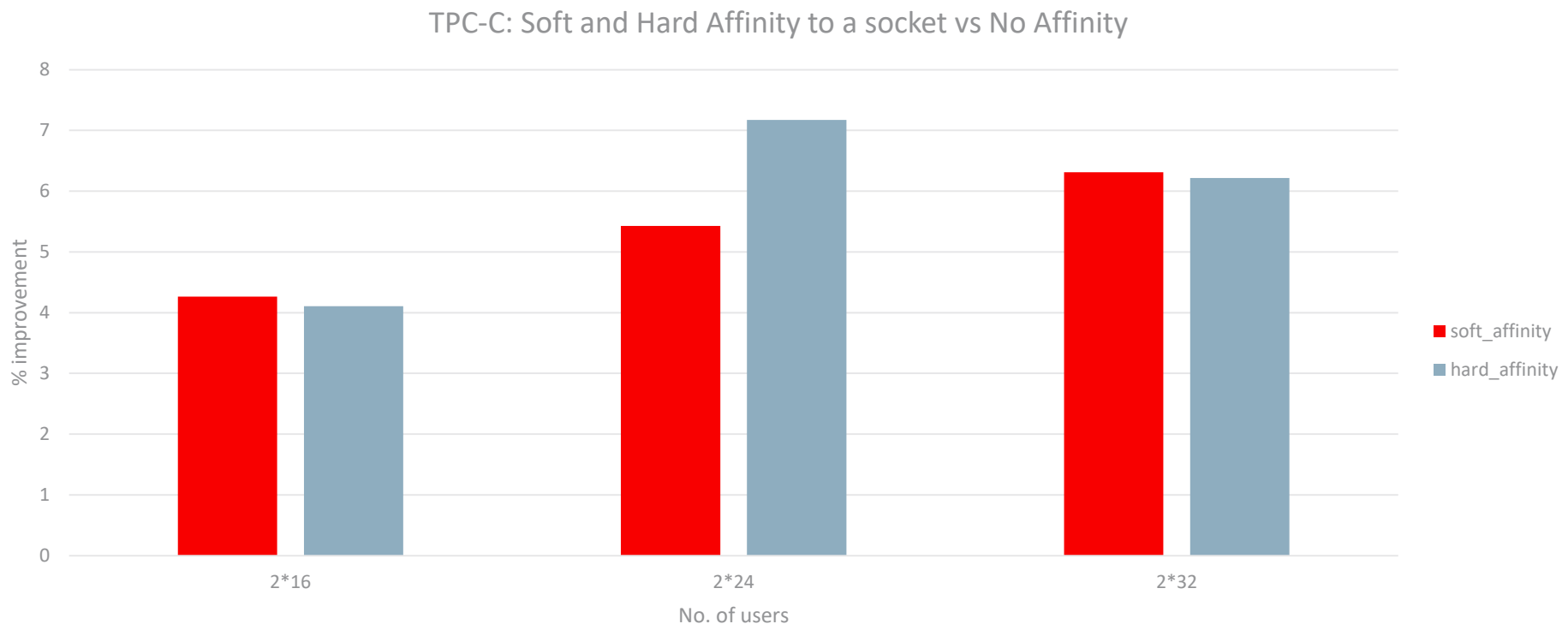
Hackbench: 1 instance, 2 socket NUMA system, 22 cores per socket



Results

- Small improvement for Hackbench 2 instances
  - some benefit of islolating LLC
  - Little room for improvement
- Big regressions for Hackbench 1 instance
  - Not using all CPUs efficiently
  - Soft Affinity better than Hard Affinity

TPC-C: 2 instances, 2 socket NUMA system, 22 cores per socket



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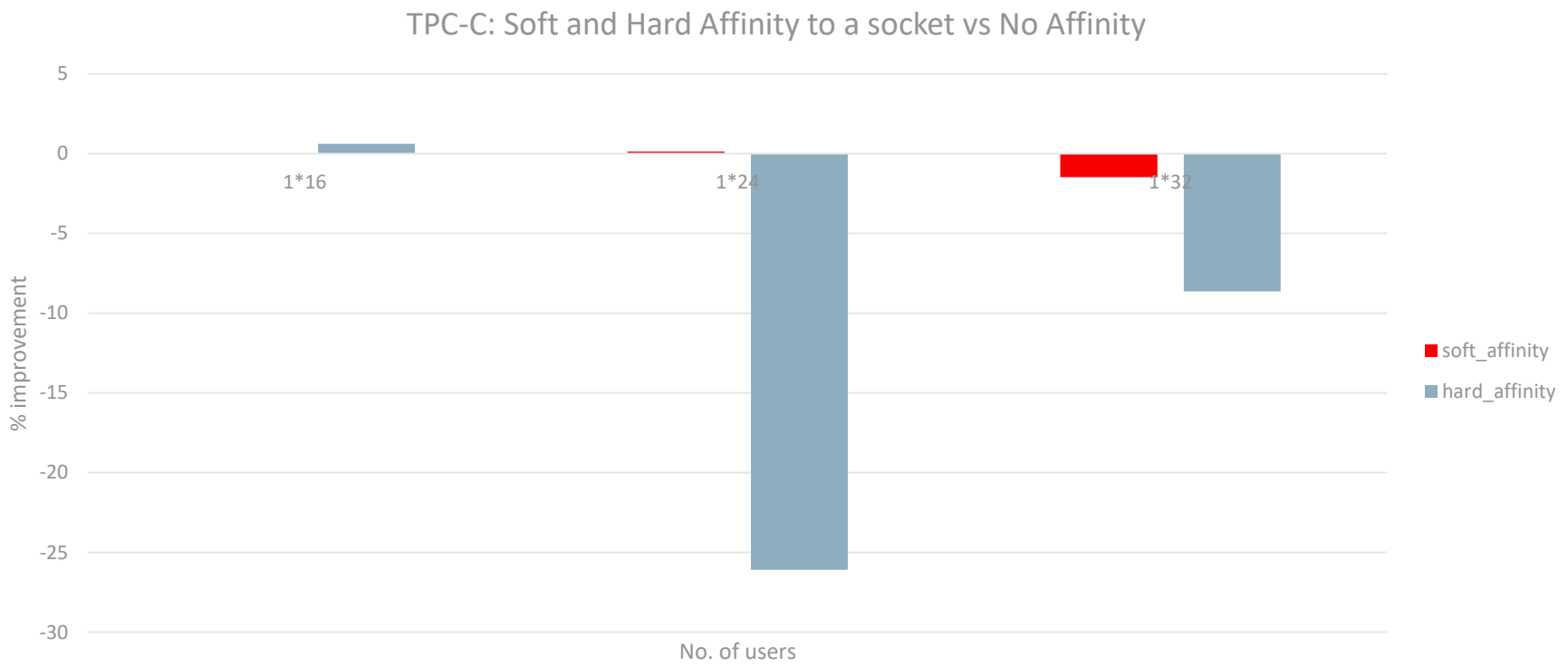
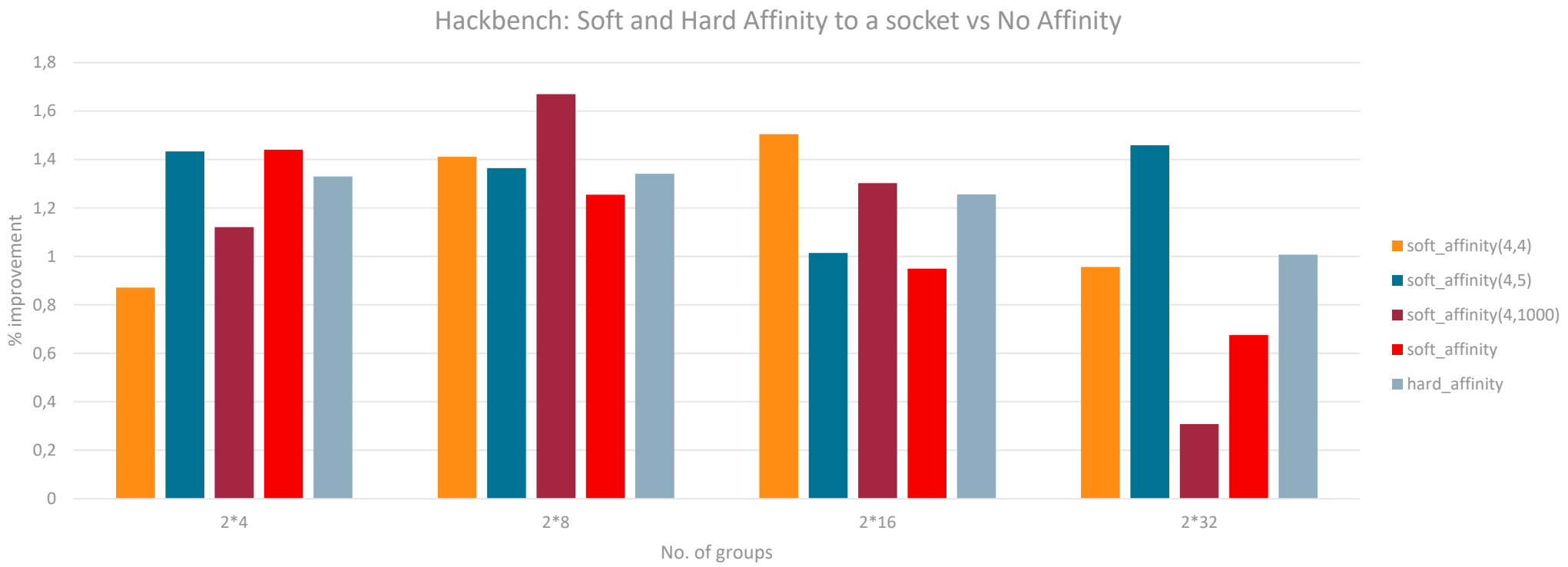


Load Based Soft Affinity

- Conditionally use *cpu_preferred* for *want_affine*
  - Compare two CPUs from *cpu_preferred* and (*cpu_allowed – cpu_preferred)* in O(1)
  - Scheduler tunables: *sched_preferred* and *sched_allowed*

```
cpu_x = cpumask_any(cpu_preferred);
cpu_y = cpumask_any(cpu_allowed – cpu_preferred);
If (sched_preferred * cpu_x utilization > sched_allowed * cpu_y utilization)
        want_affine = 0;
else
        want_affine = 1;
```

Hackbench: 2 instances, 2 socket NUMA system, 22 cores per socket



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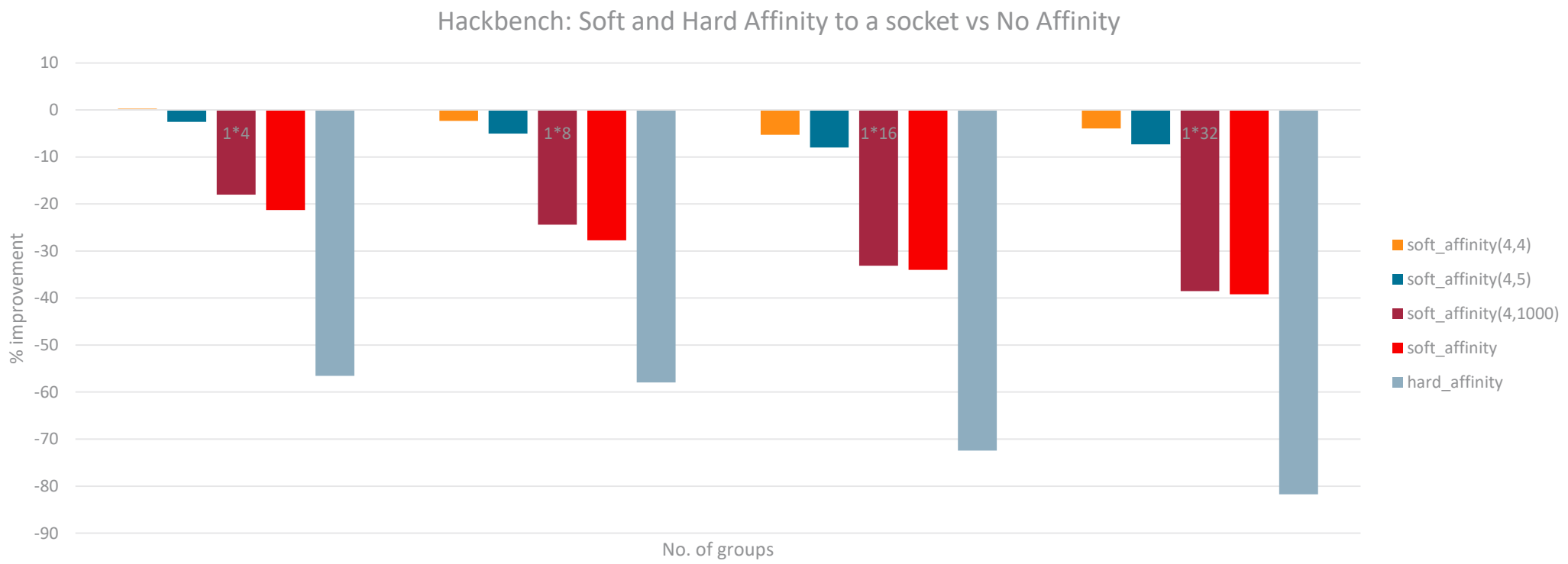

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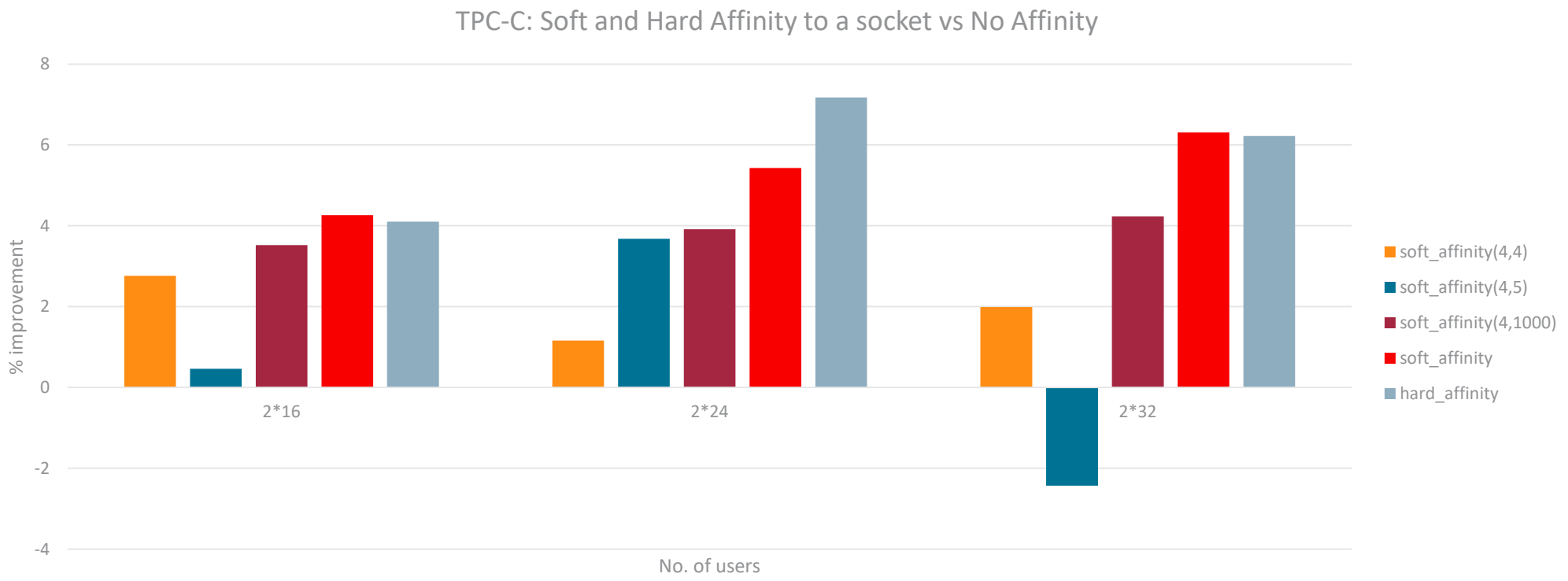

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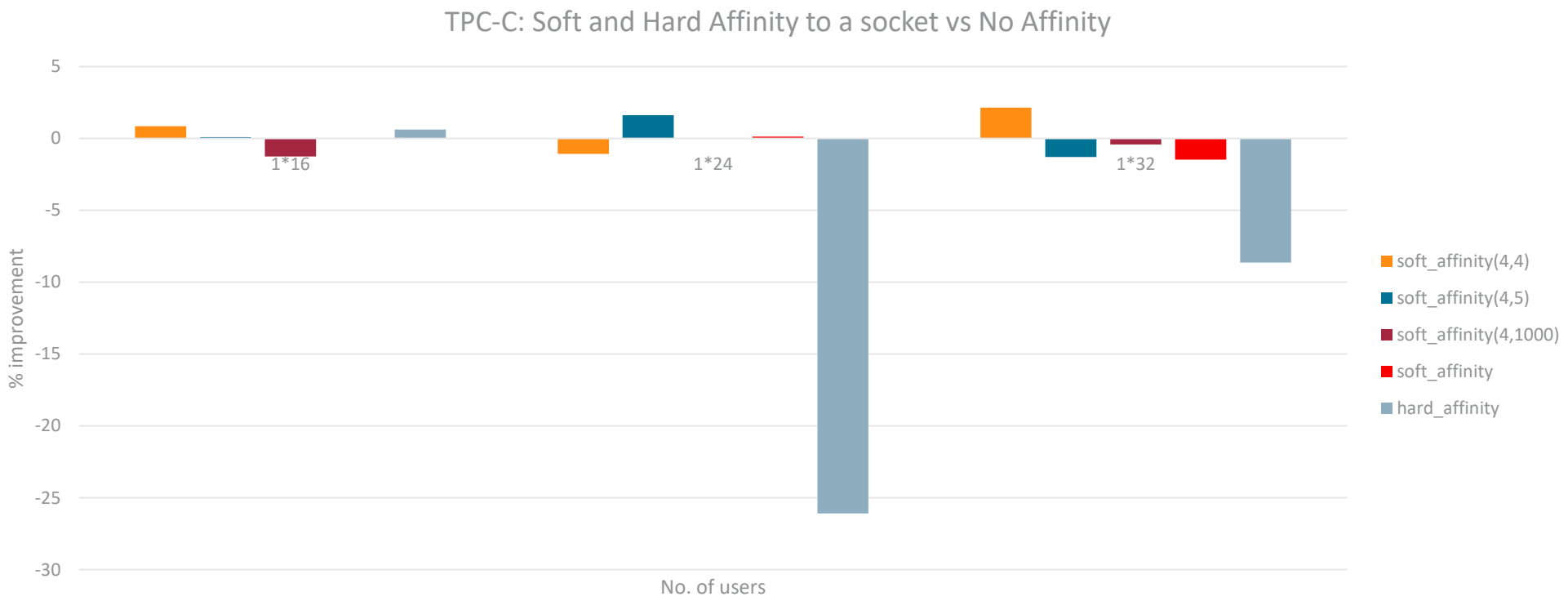

No overhead when Soft Affinity *not* used

Hackbench	No_Affinity % change	Hard_Affinity % change
2x4	0.10590459	0.30898275
2x8	0.128548	0.55474365
2x16	0.61016786	0.90104716
2x32	0.86854058	1.01481597
1x4	0.47585608	0.43398421
1x8	0.45468479	0.33351682
1x16	0.61327776	0.64039494
1x32	0.11759902	0.62852034

Results

- *numactl* used for each DB instance
- For TPC-C load based Soft Affinity (4,1000) works best
  - *harder* Soft Affinity similar to basic implementation
  - Improvements are more (~4% for 2 DB instance) than regressions (~-0.5% 1 DB instance)
- Other experiments
  - Spreading memory across NUMA nodes has *similar* results
  - Sub-NUMA partitions (soft or hard) had no benefit

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Future Work

- Testing on bigger (4 and 8 socket) systems, more DB instances
  - Find right tunable values
- Get rid of tunables?
  - Heterogeneous workload consolidation: per process tunables
  - Kernel does not have enough information of workload
    - cache sharing between threads
    - working set size
    - producer-consumer pattern

Questions?


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