THE OS SCHEDULER: A PERFORMANCE-CRITICAL COMPONENT IN LINUX CLUSTER ENVIRONMENTS

KEYNOTE FOR BPOE-9 *@ASPLOS2018*

THE NINTH WORKSHOP ON BIG DATA BENCHMARKS, PERFORMANCE, OPTIMIZATION AND EMERGING HARDWARE

By Jean-Pierre Lozi
Oracle Labs

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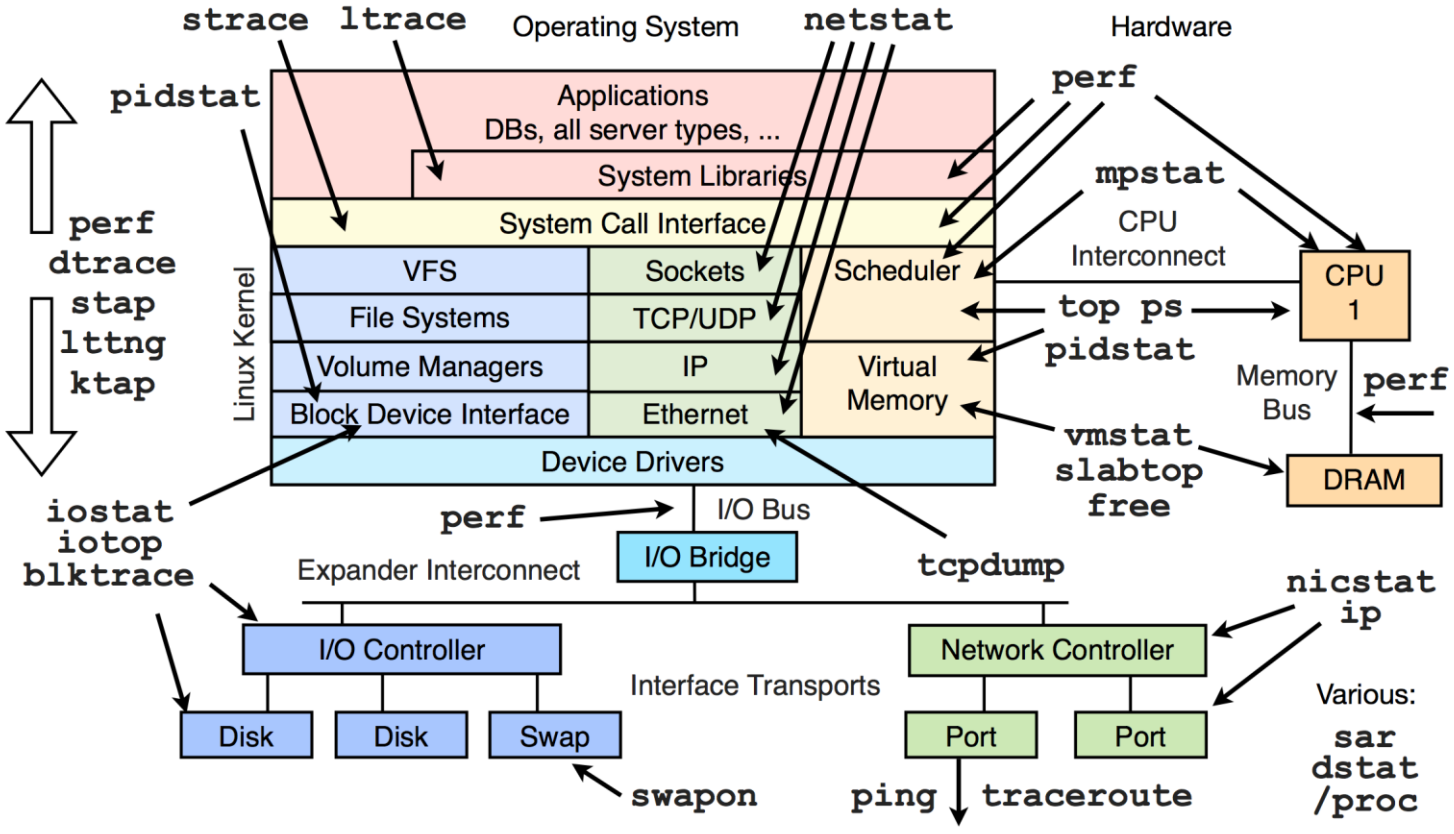
- **Challenge: don't waste cycles!**
  - Reduces infrastructure and energy costs
  - Improves bandwidth and latency

WHERE TO HUNT FOR CYCLES?



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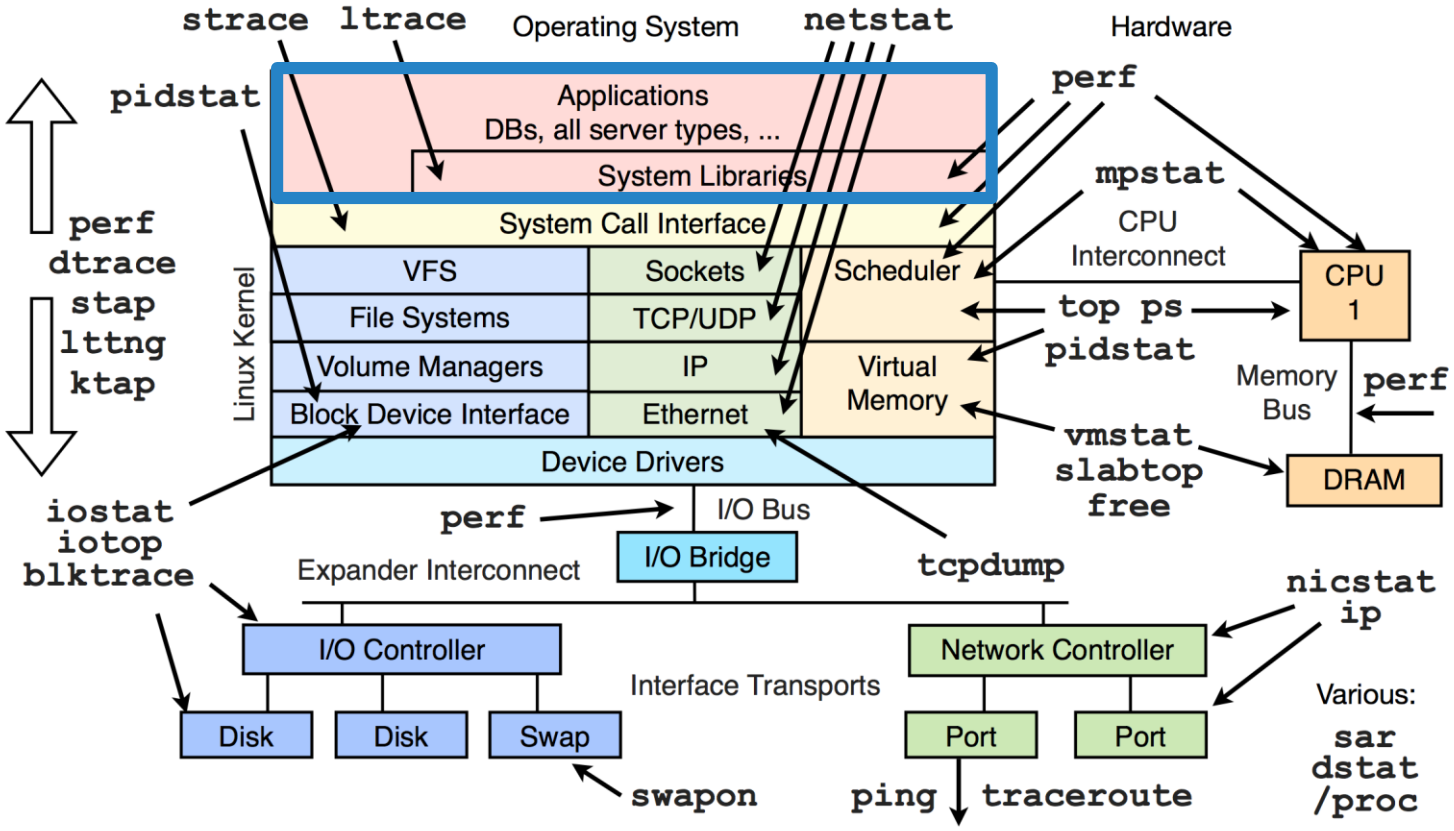

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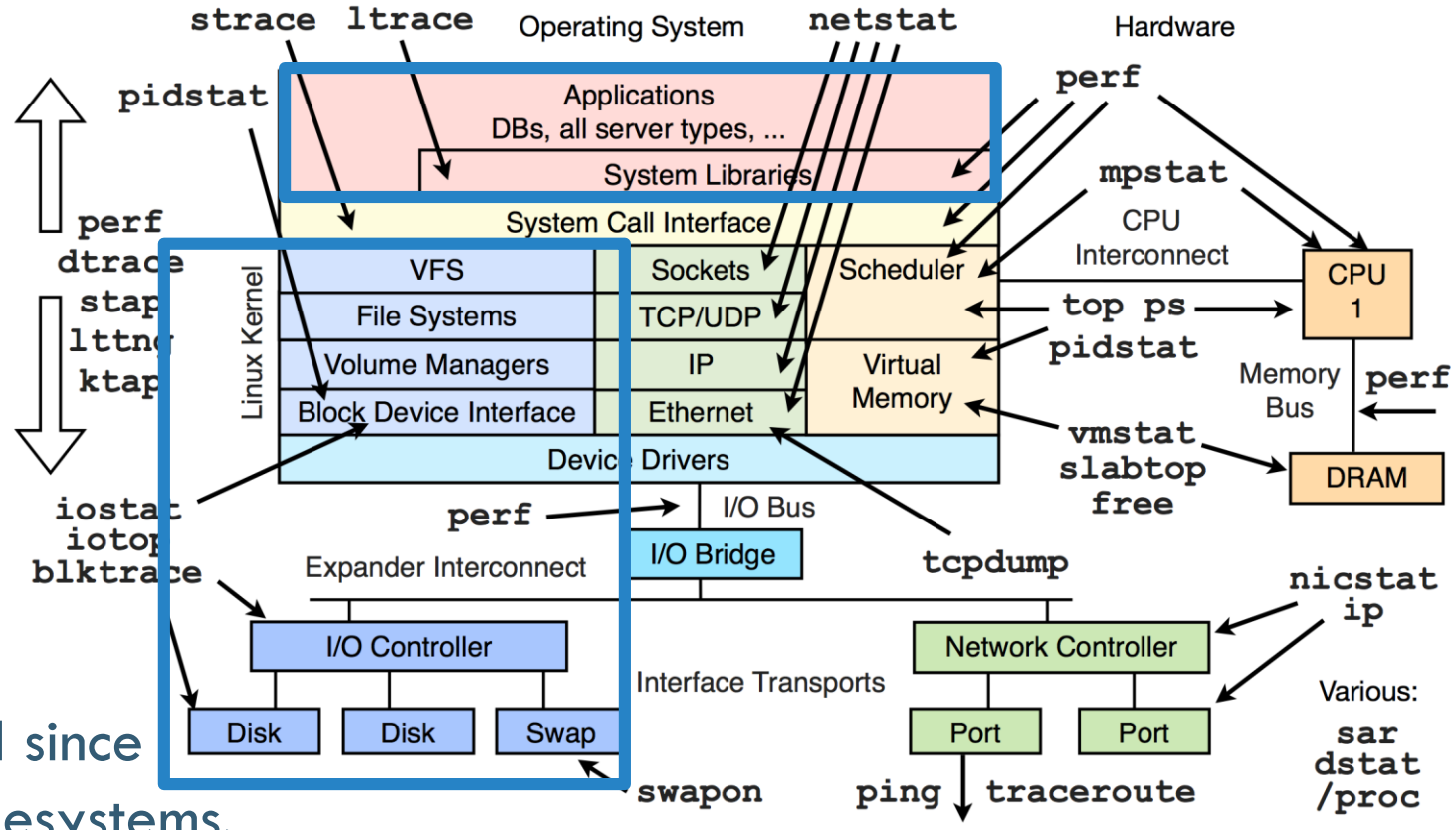

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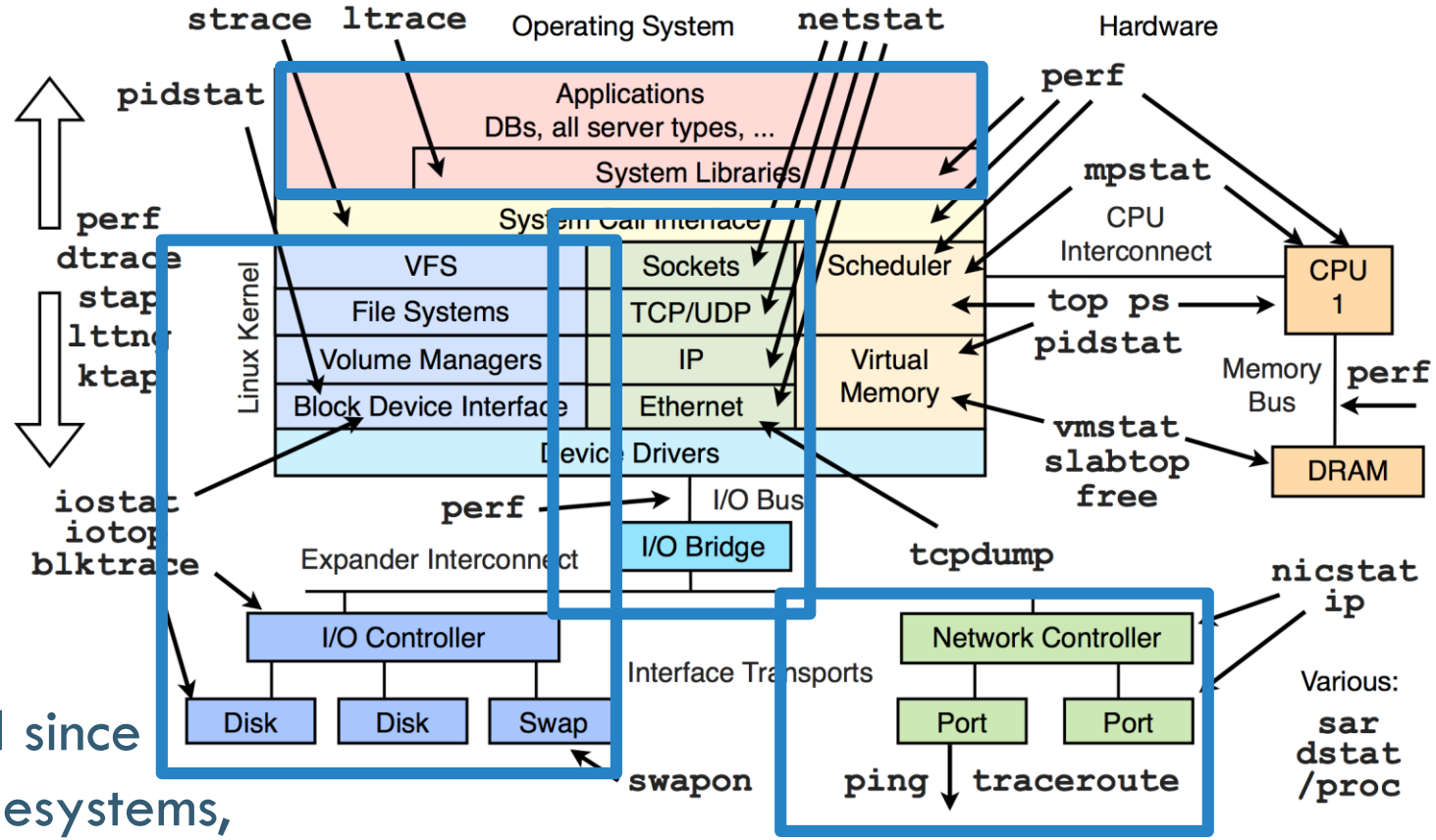

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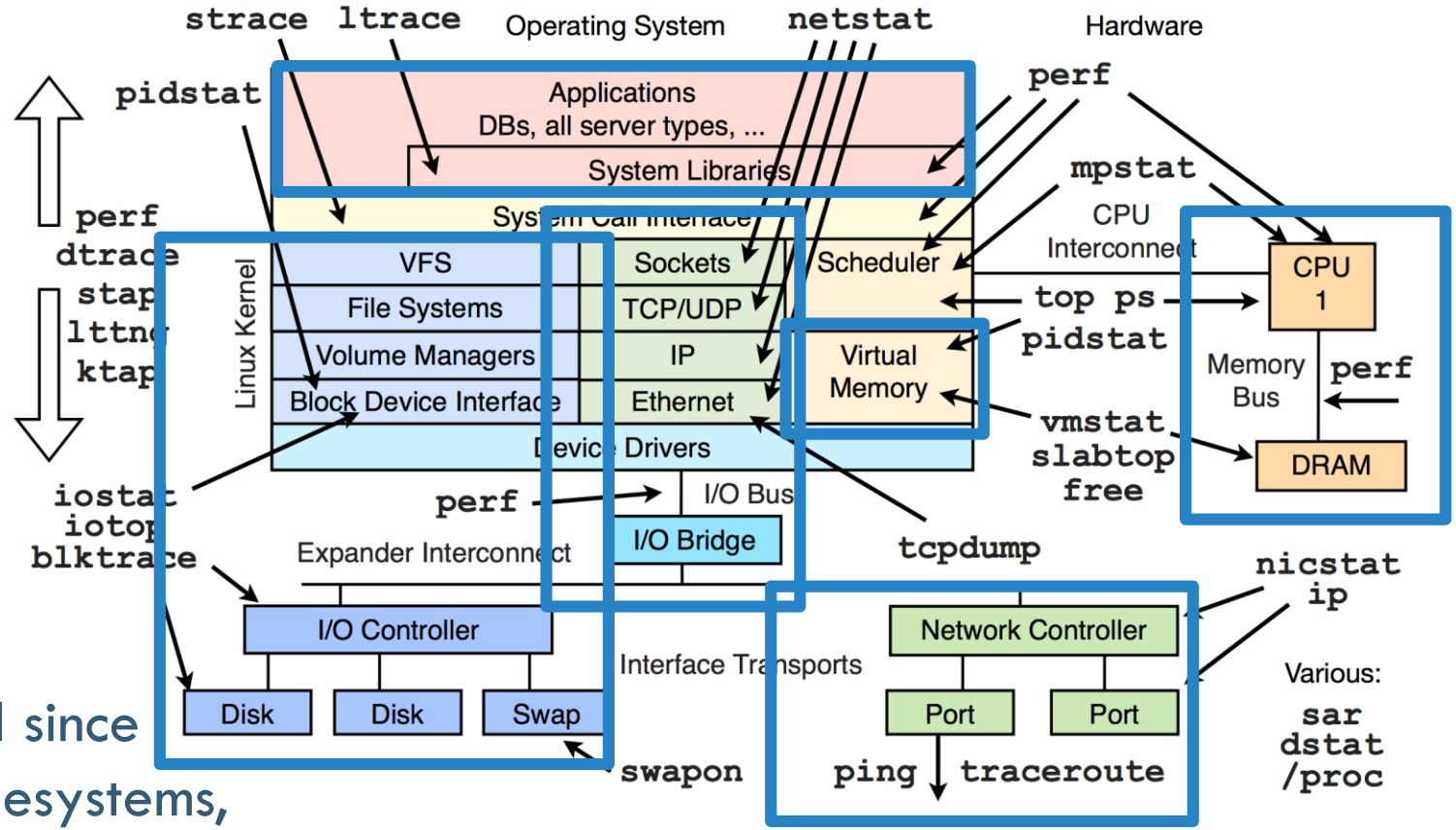

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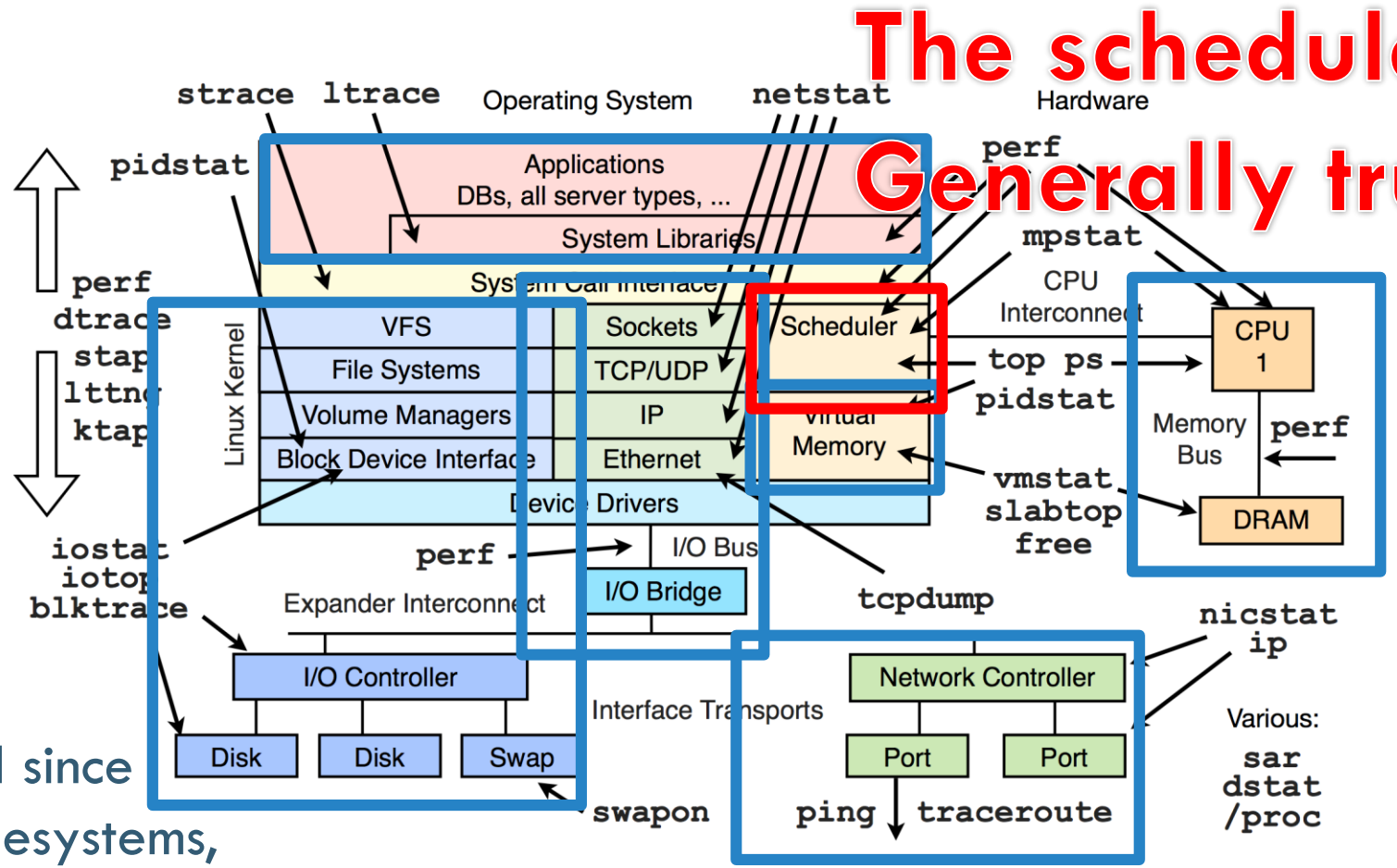

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  - **Would you ever suspect the scheduler?**

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  - ***We implemented high-resolution tracing tools and saw that some cores were idle while others overloaded…***

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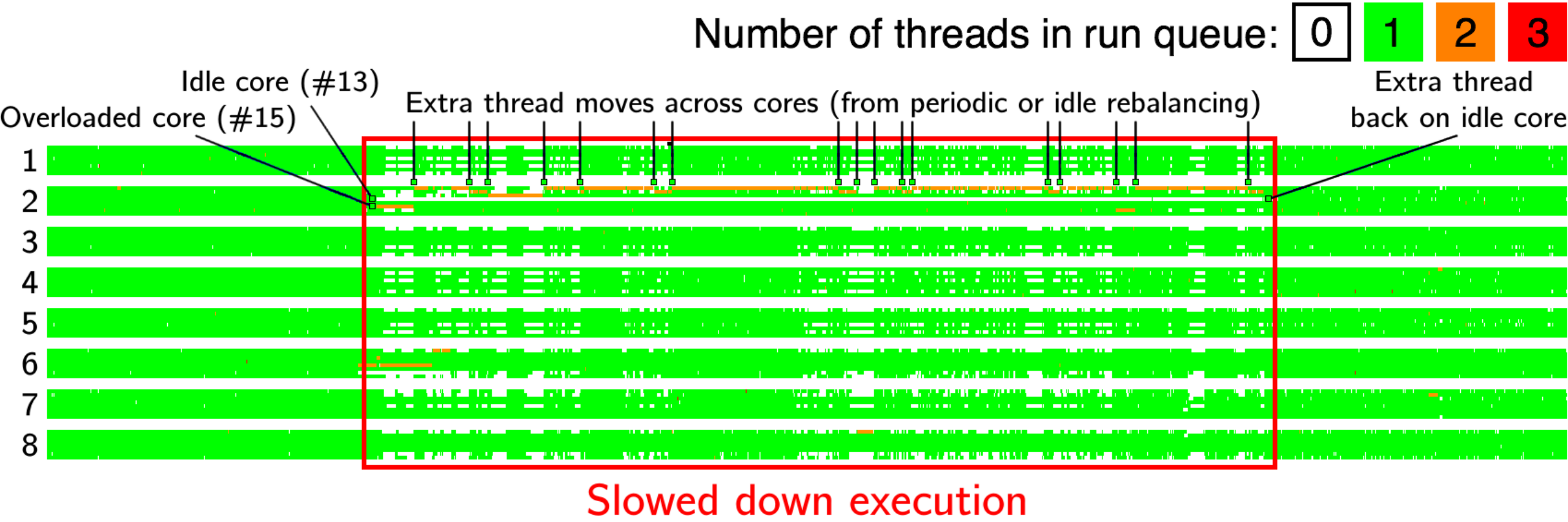

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- **Not always possible to provide a simple, working fix...**
  - Intrisic problems with the design of the scheduler?

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The Linux Scheduler: a Decade of Wasted Cores

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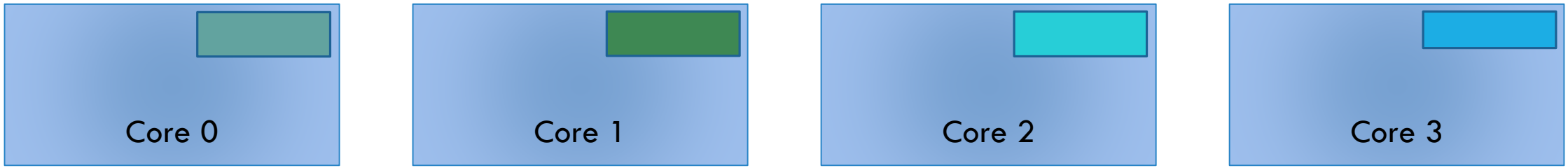

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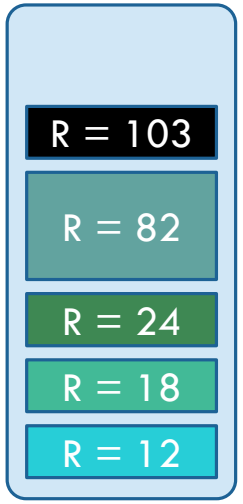

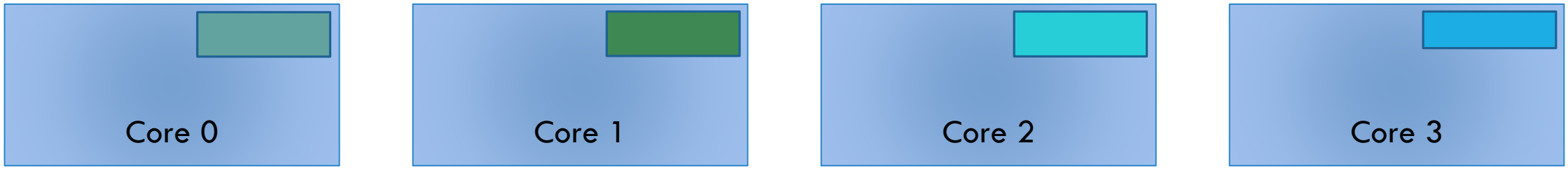

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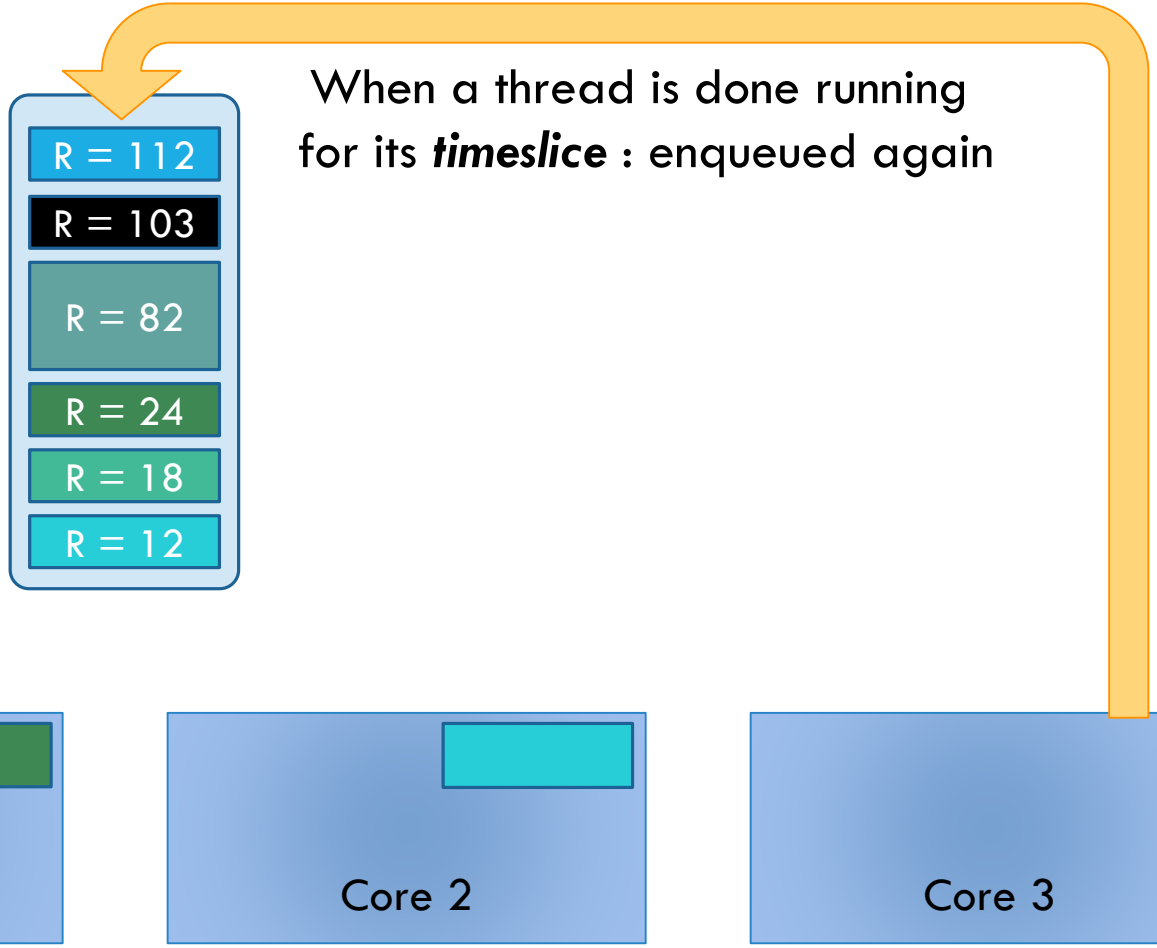

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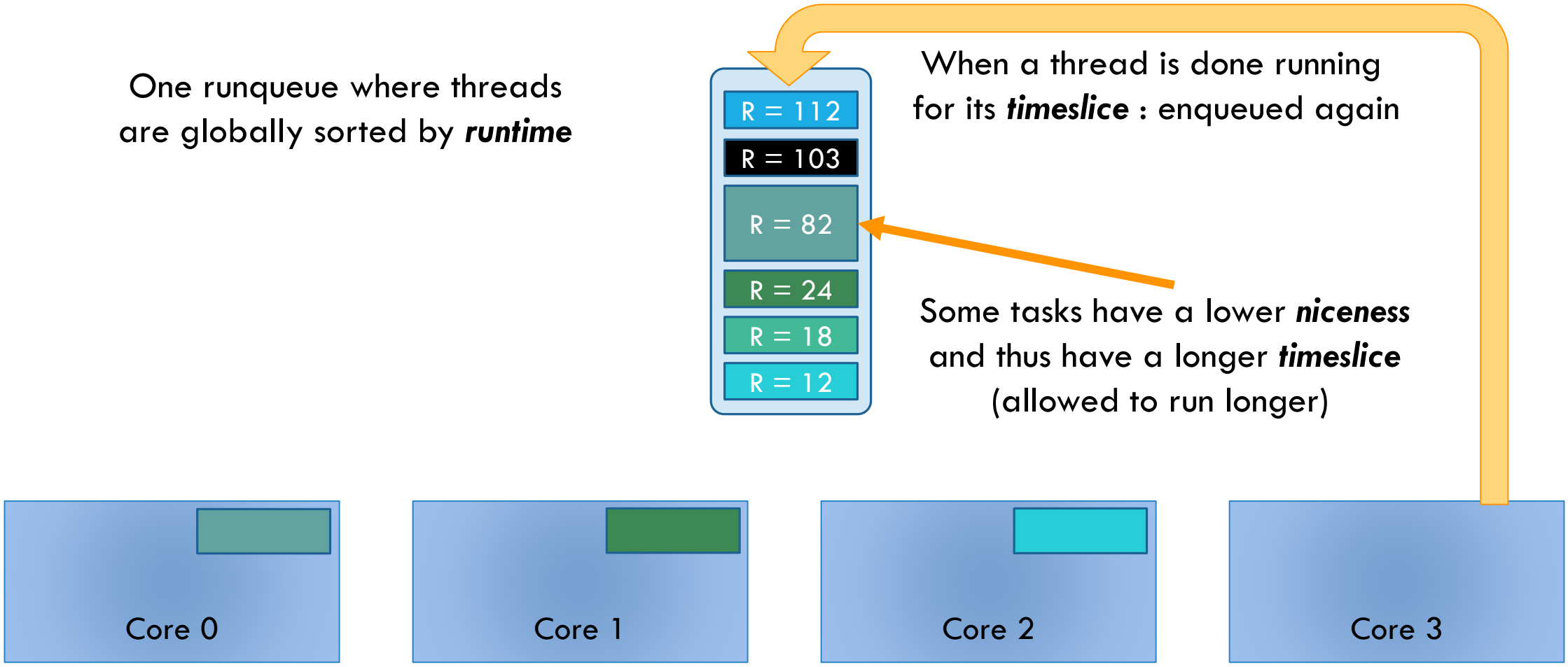

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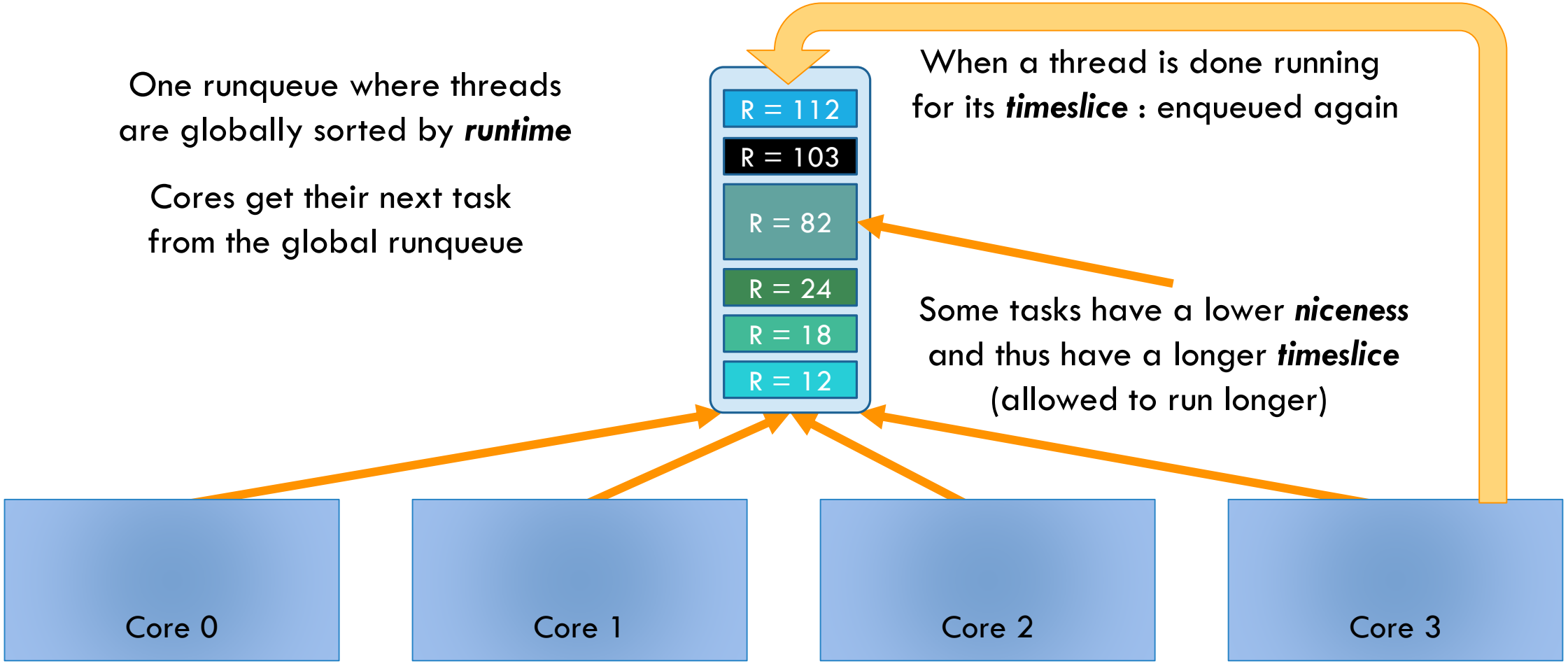

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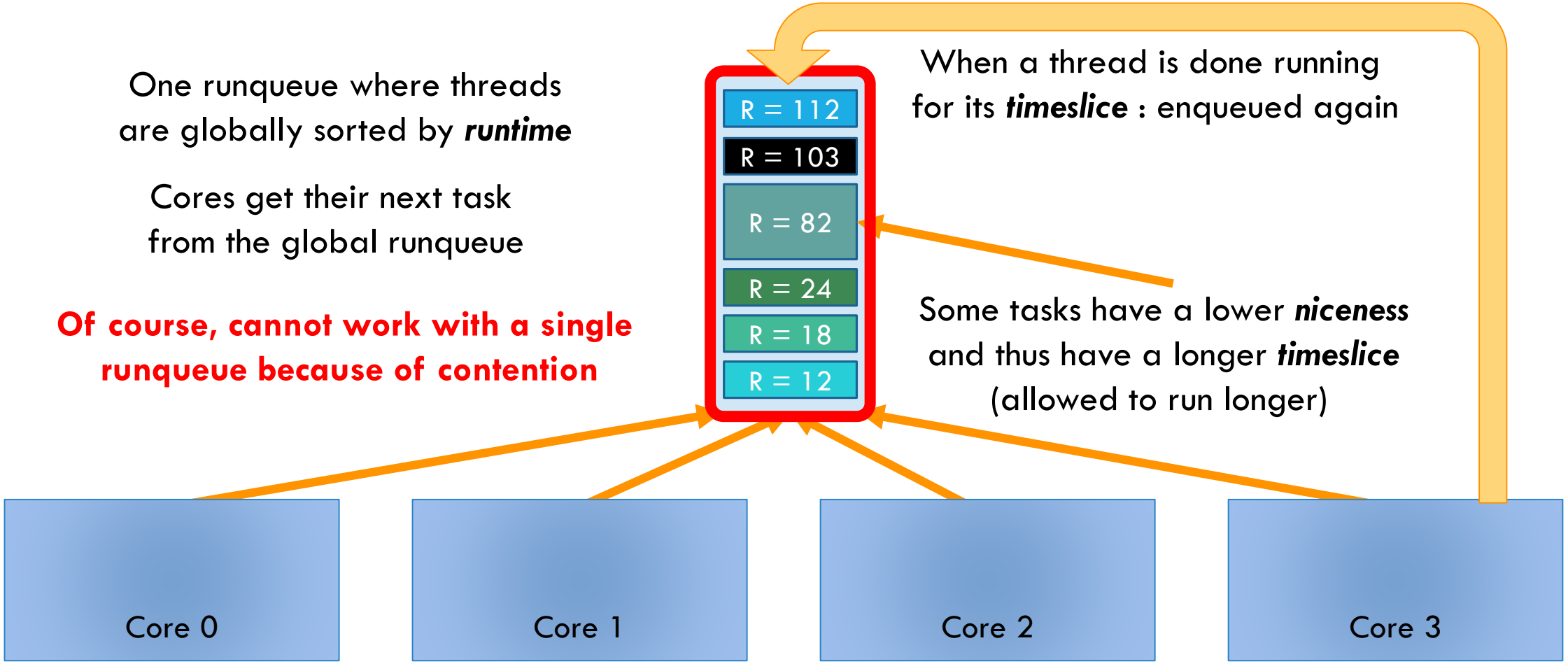
Of course, cannot work with a single runqueue because of contention



CFS: IN PRACTICE

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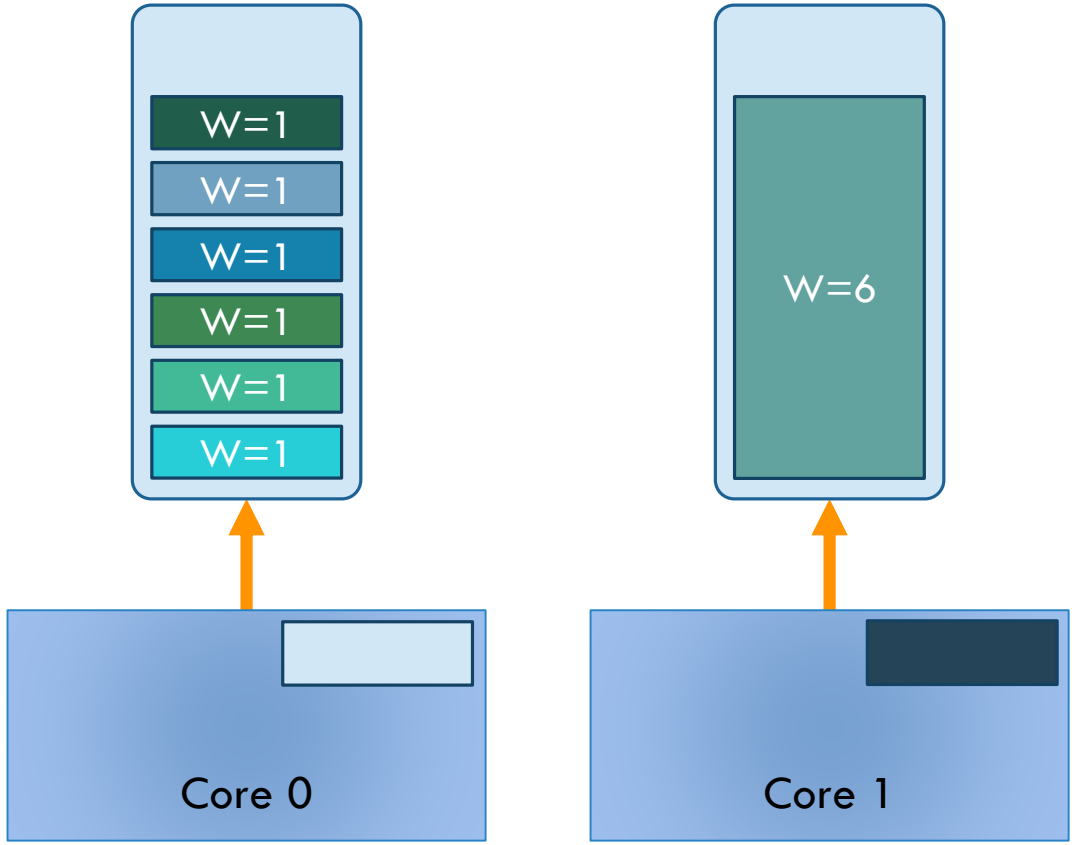

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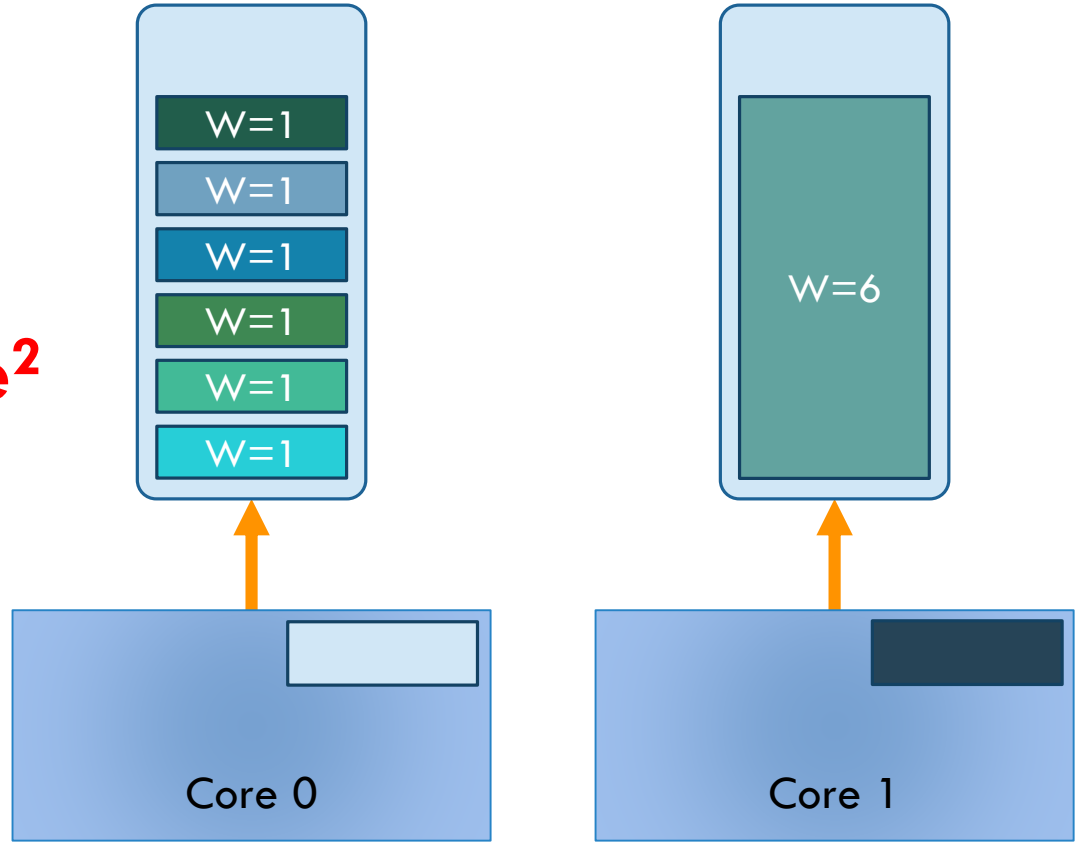

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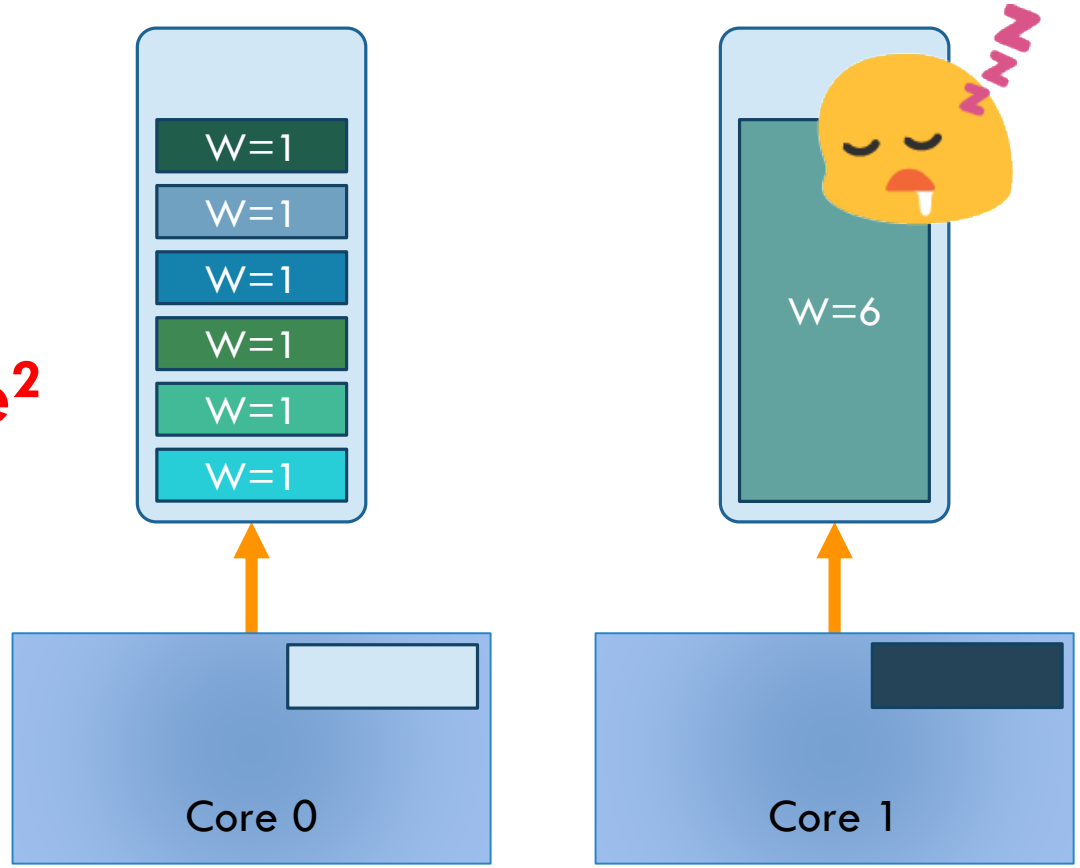

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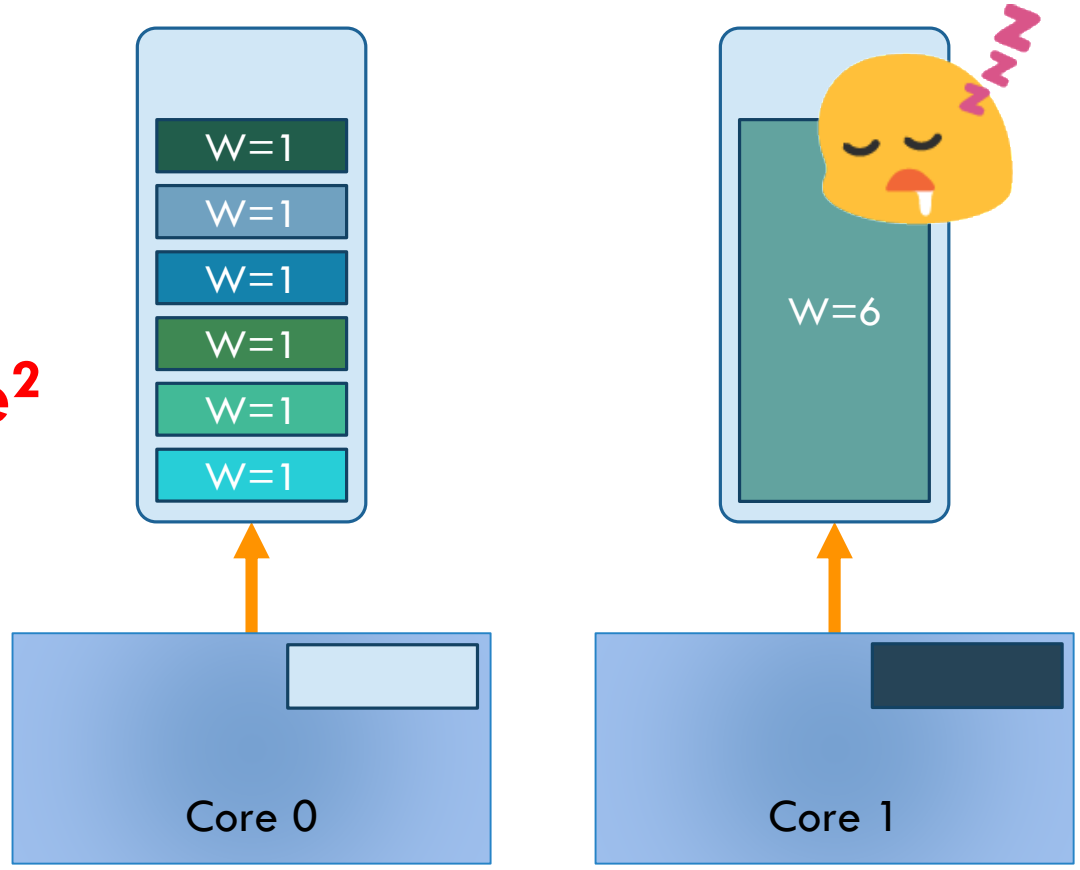

- **Since there can be many cores: hierarchical approach!**

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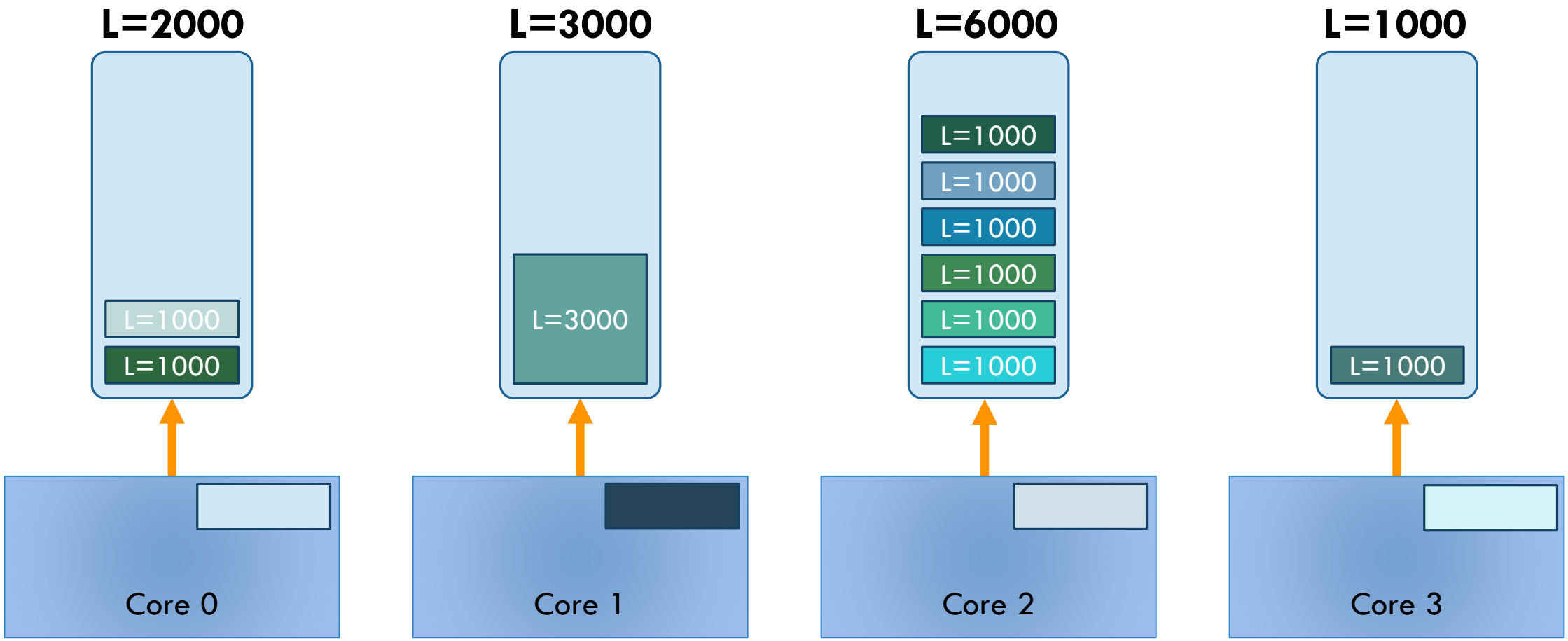

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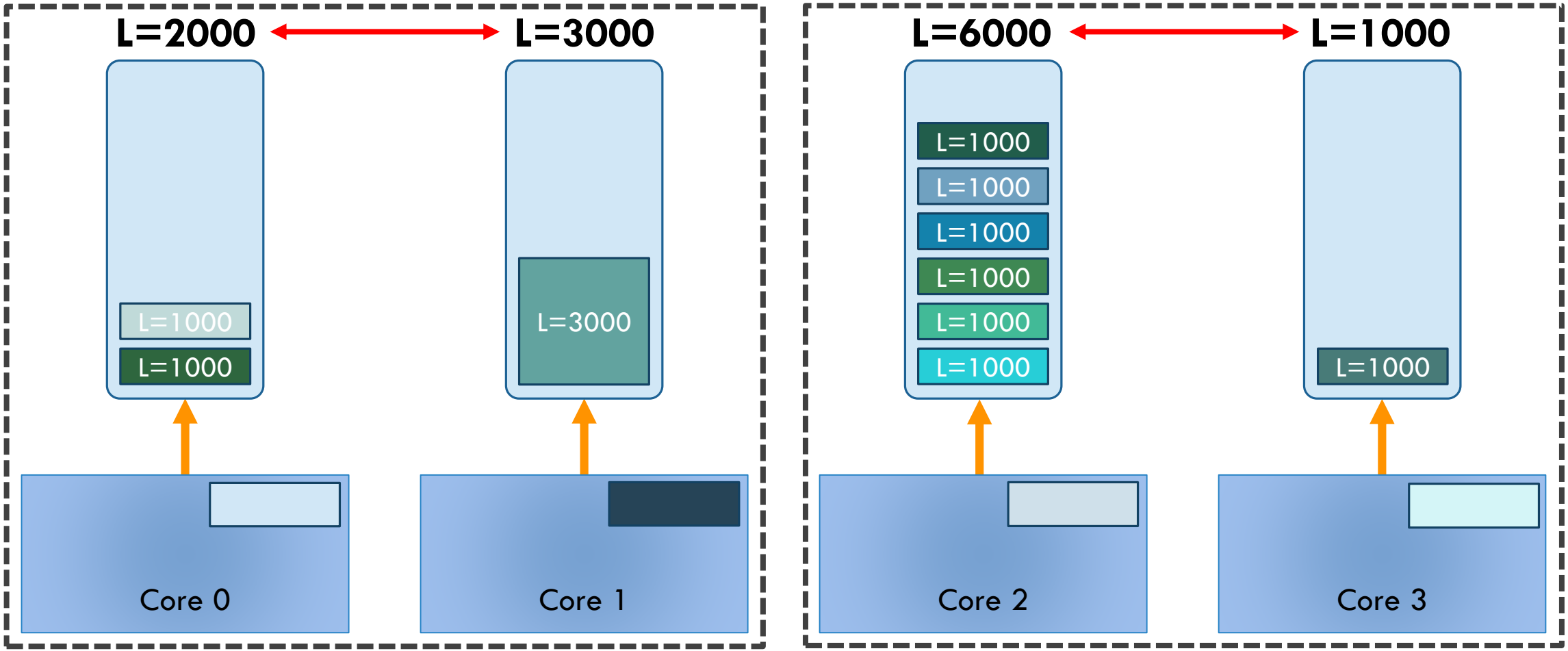

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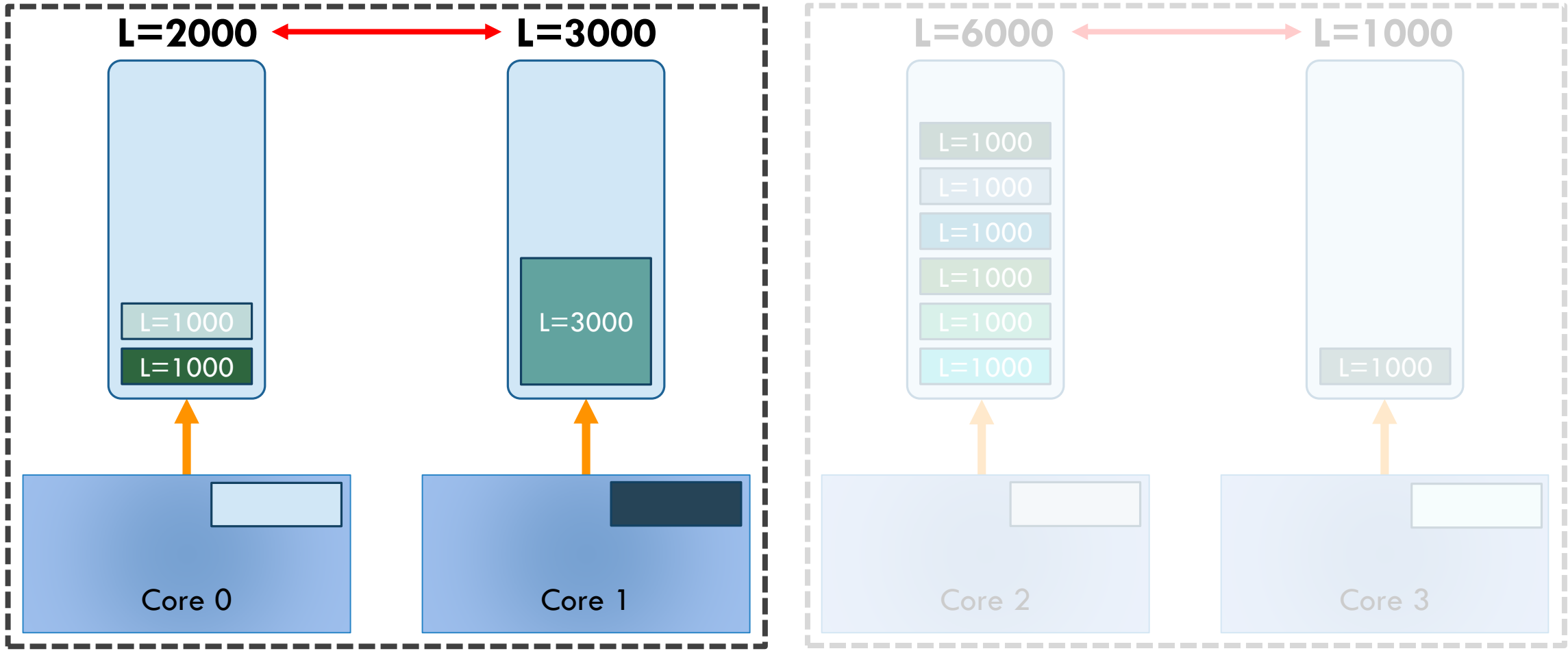

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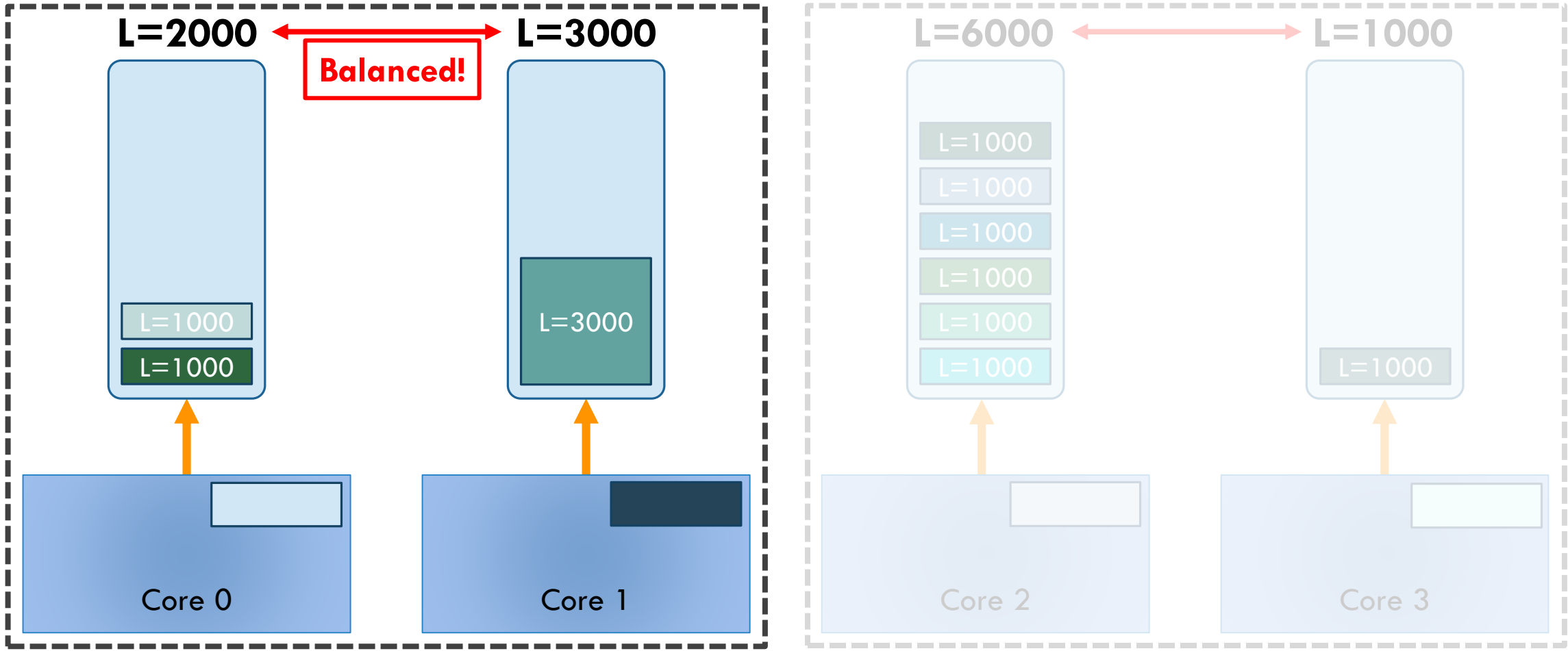

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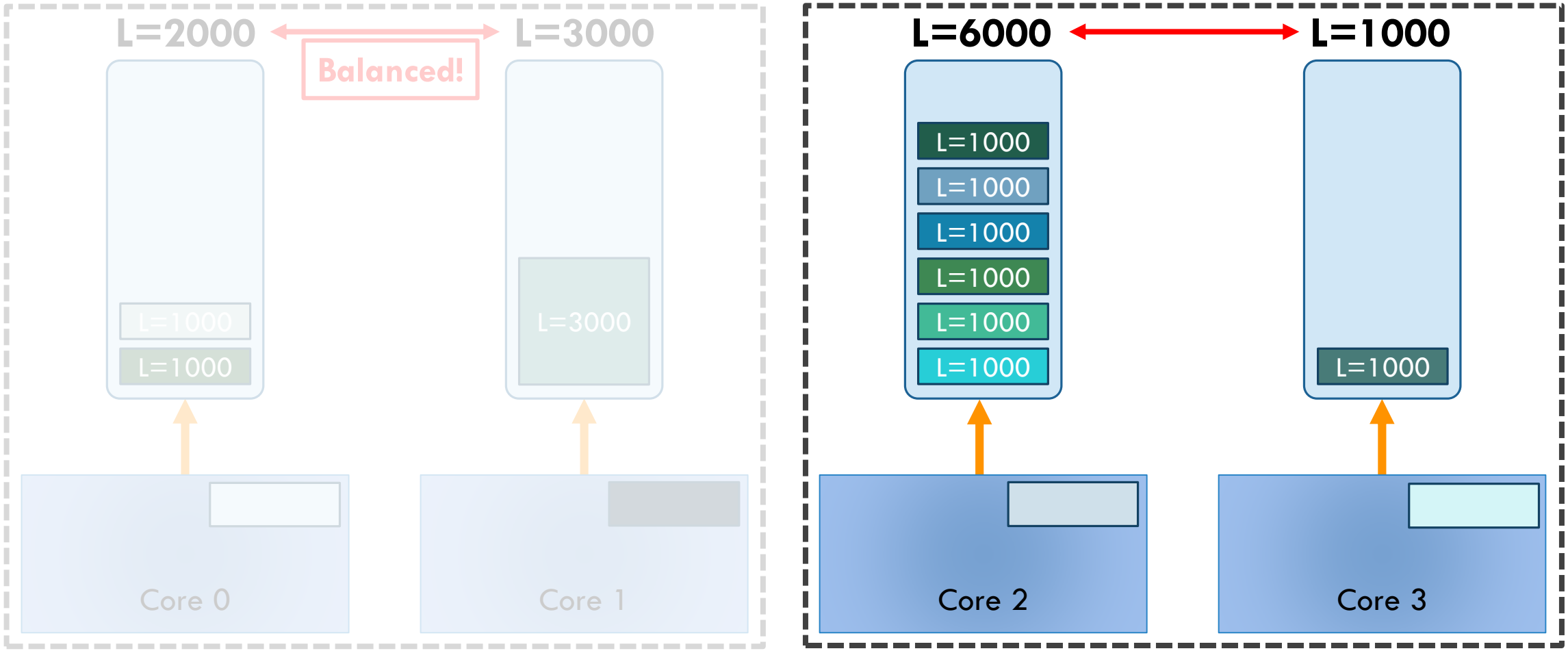

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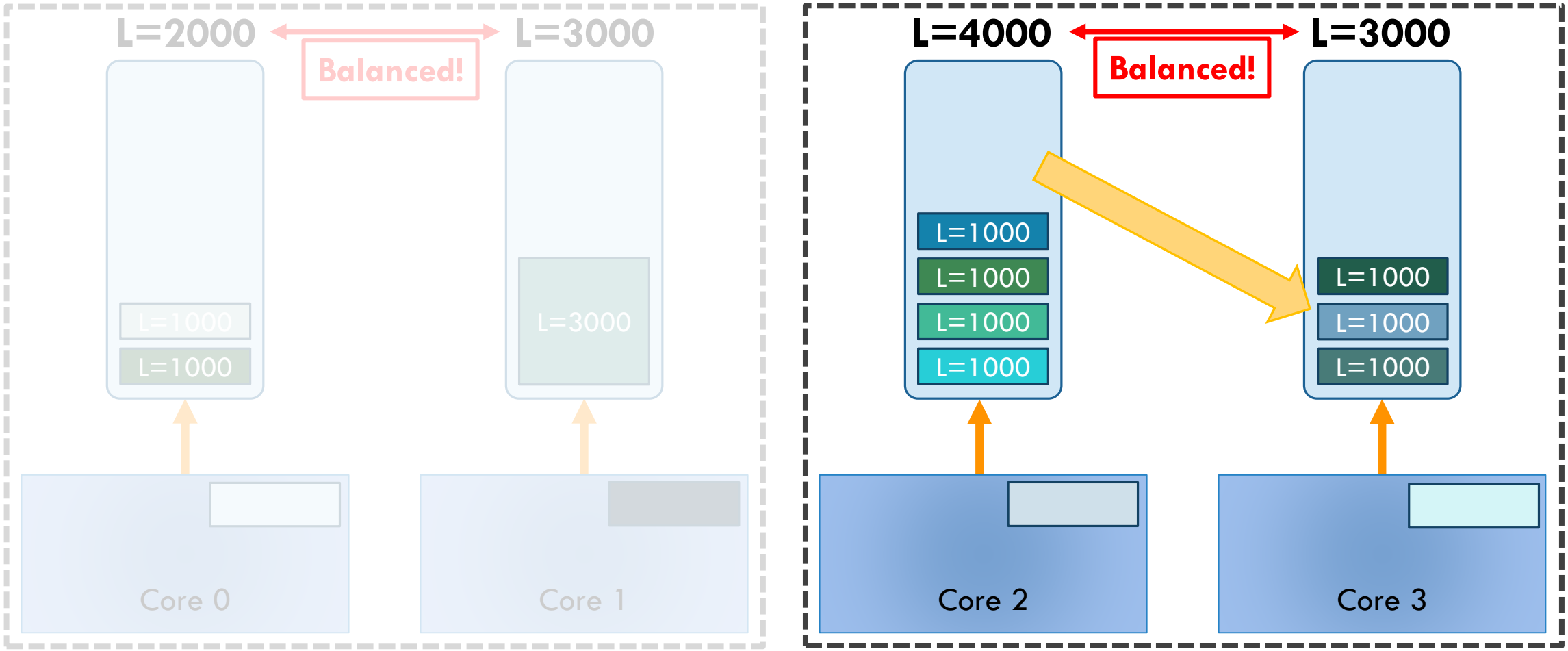

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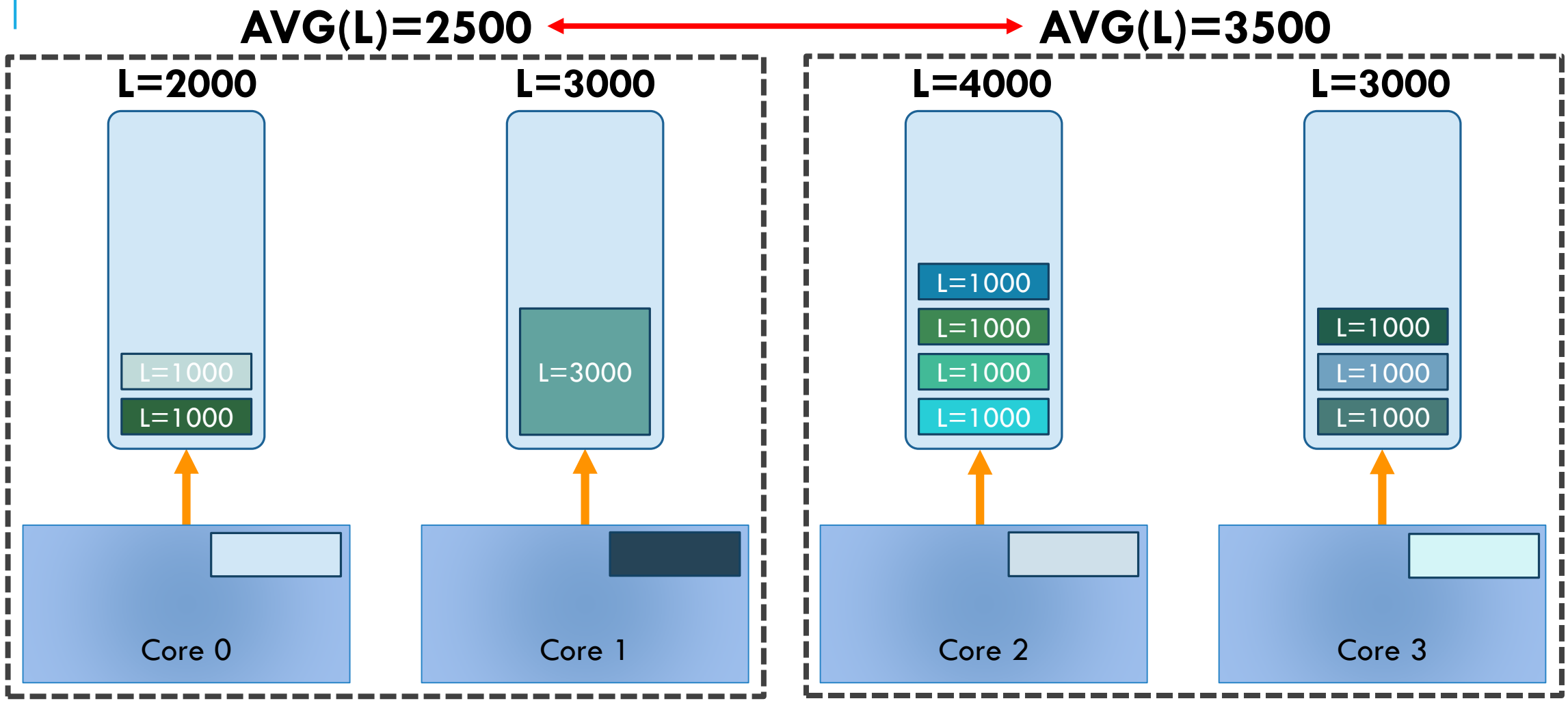

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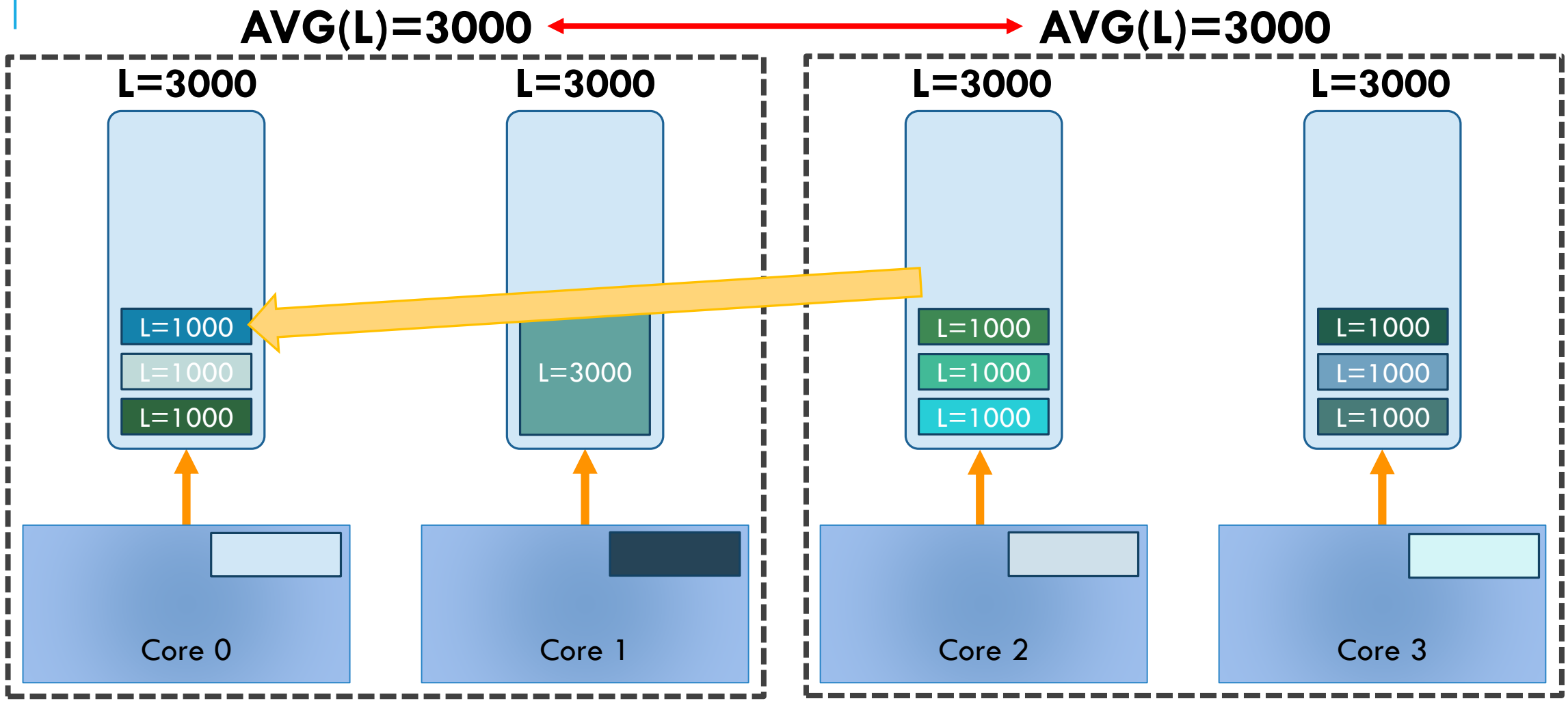

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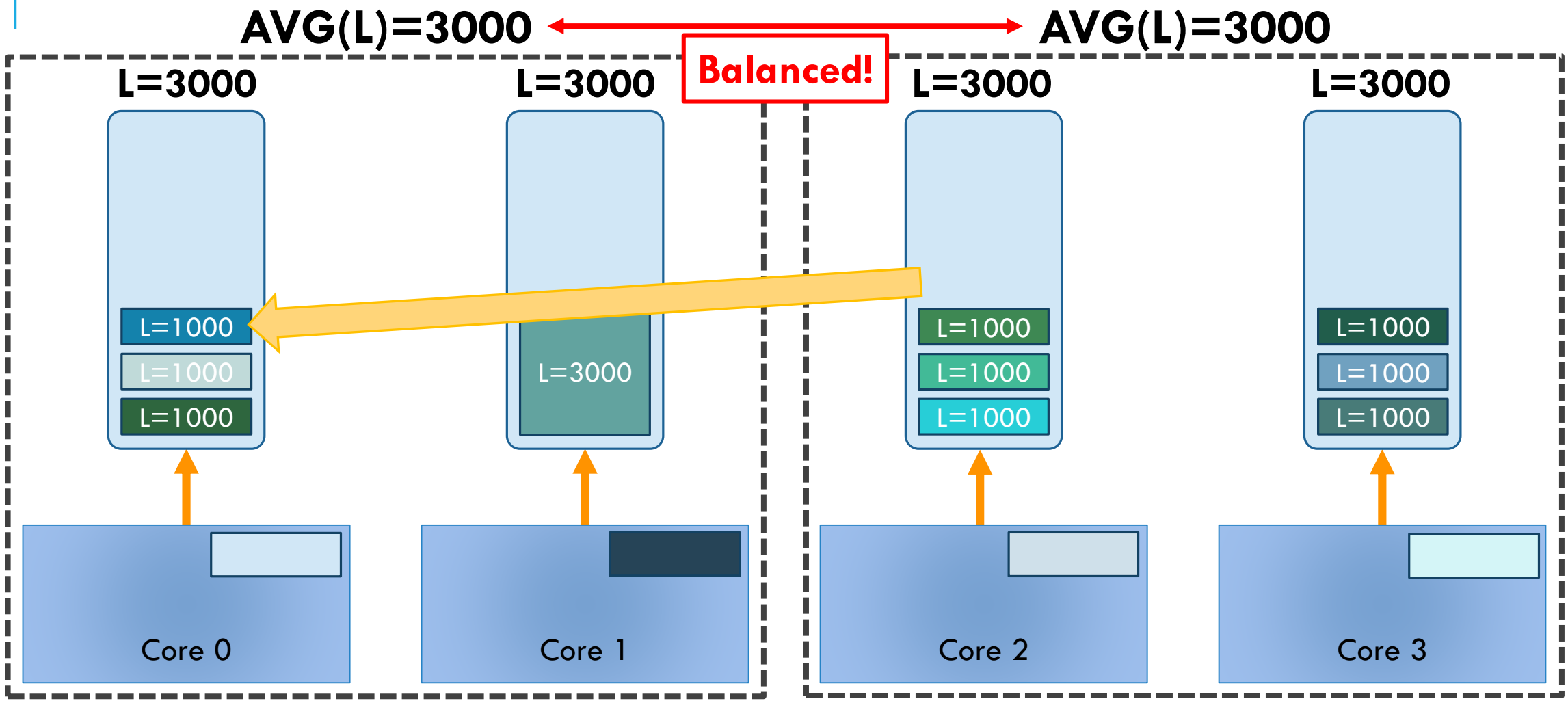

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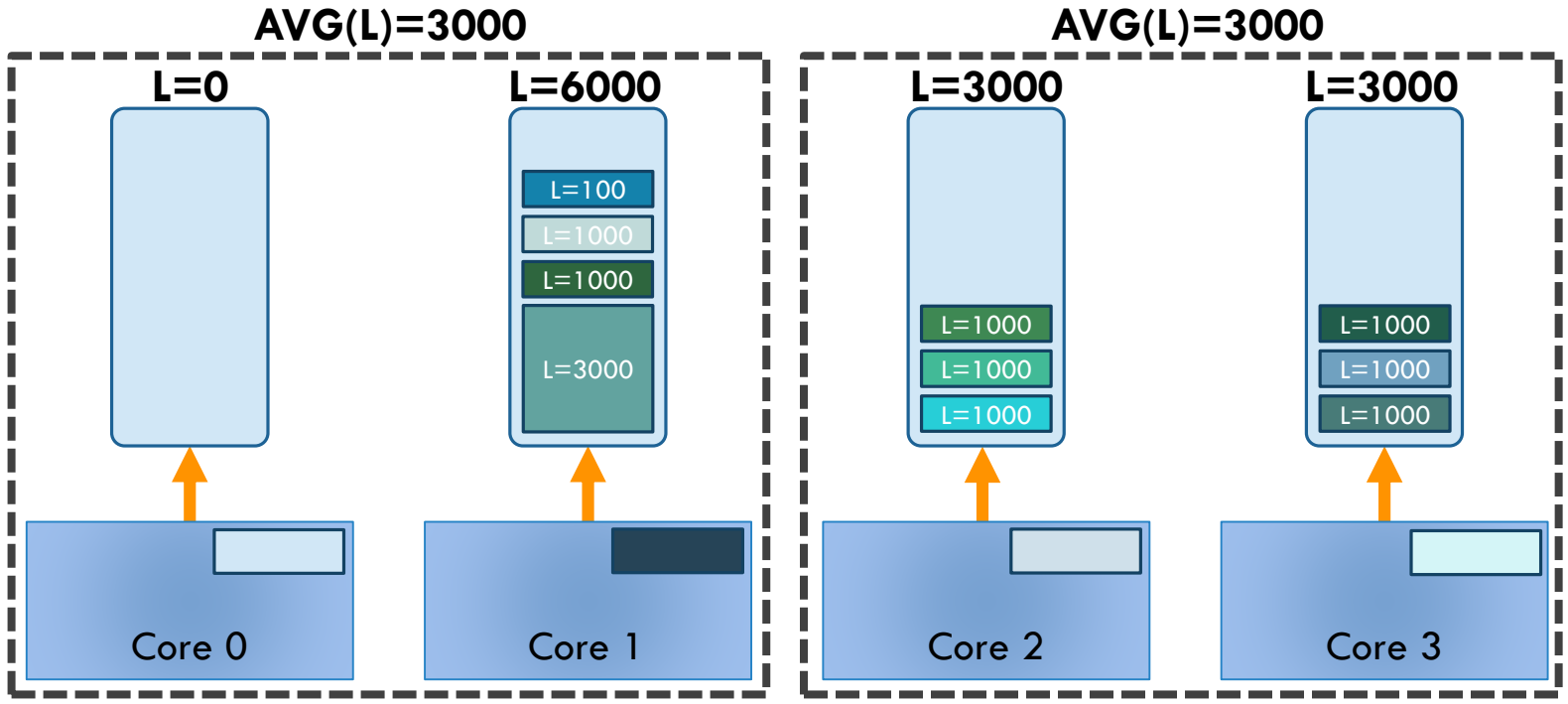

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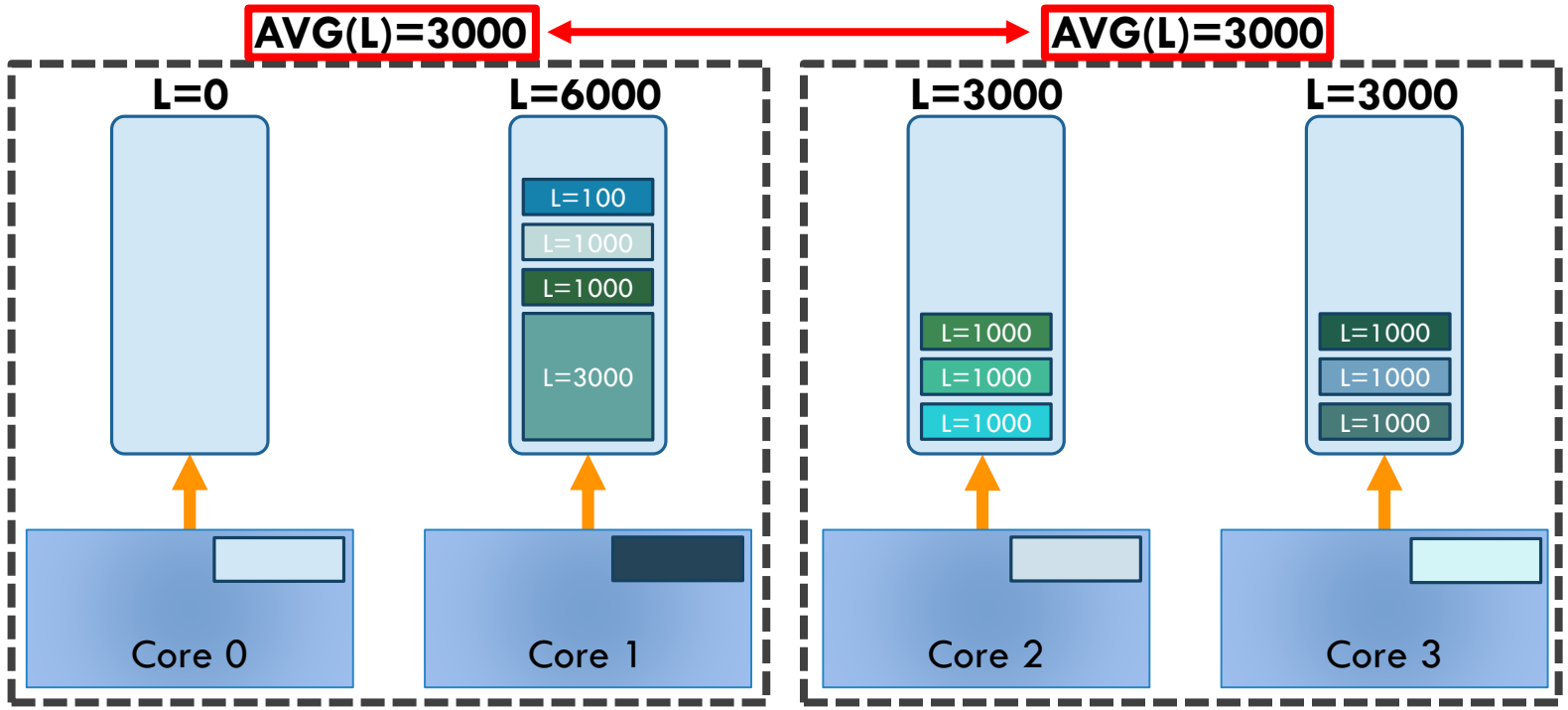

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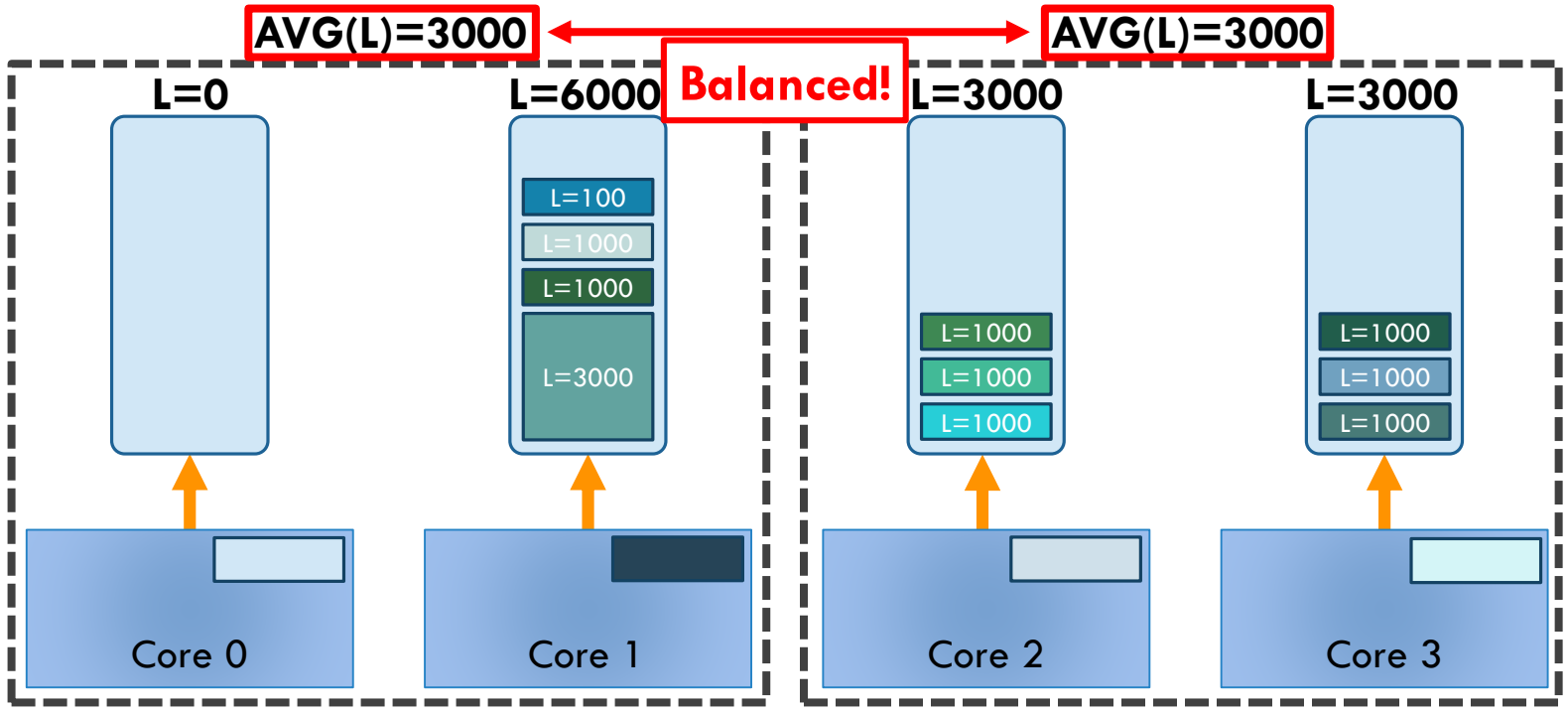

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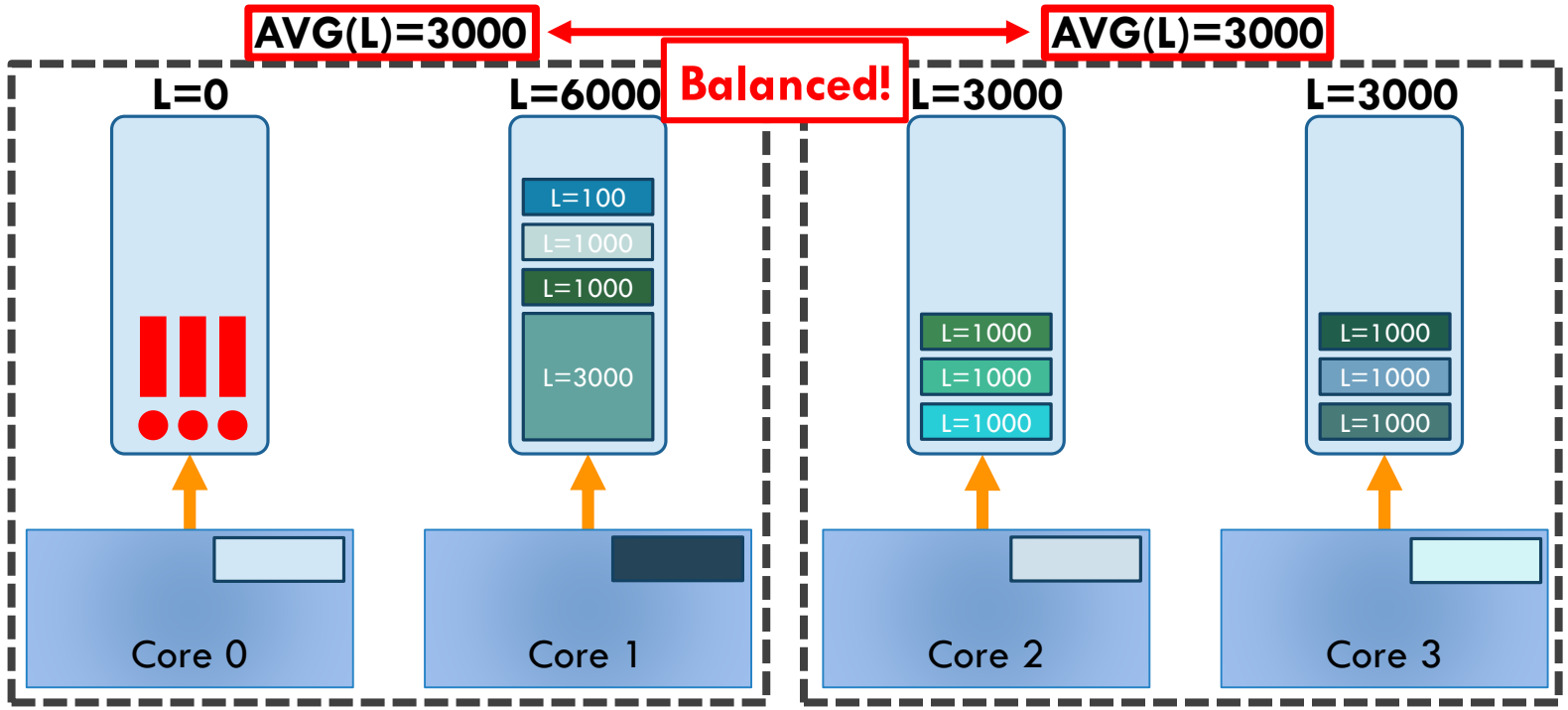

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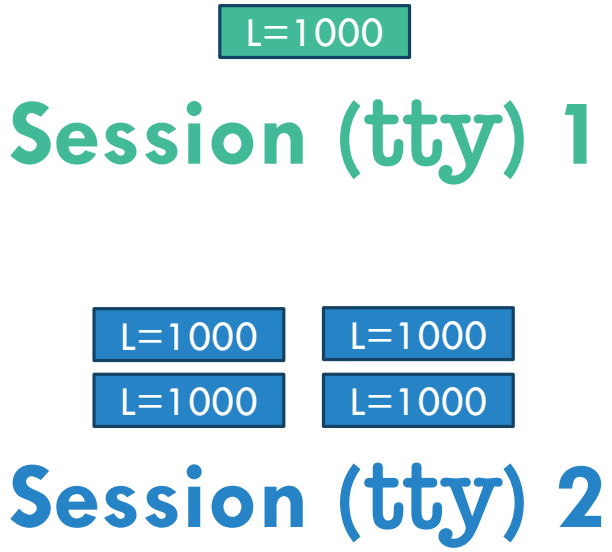

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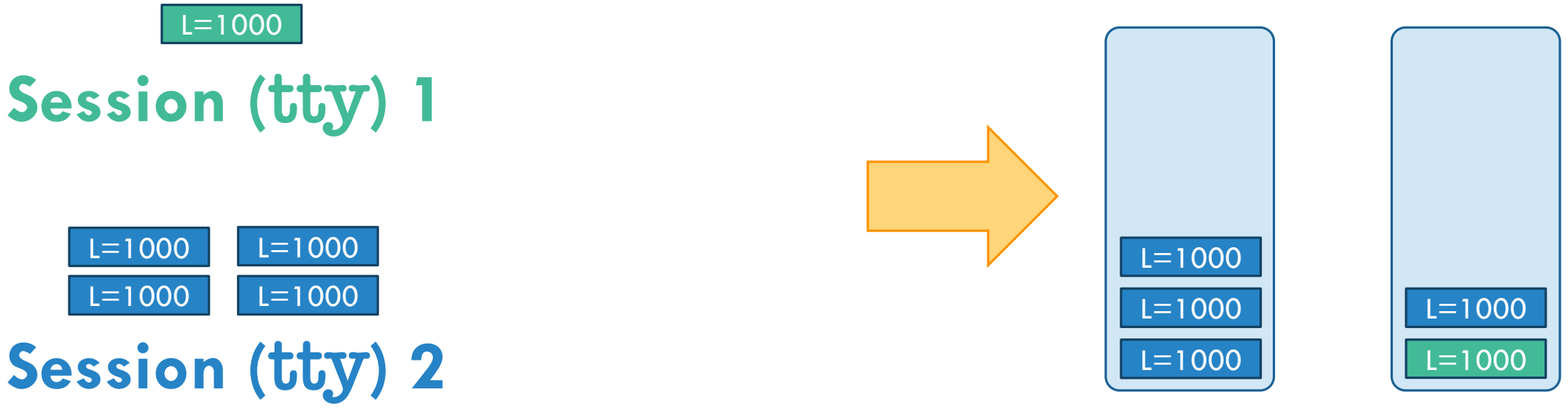

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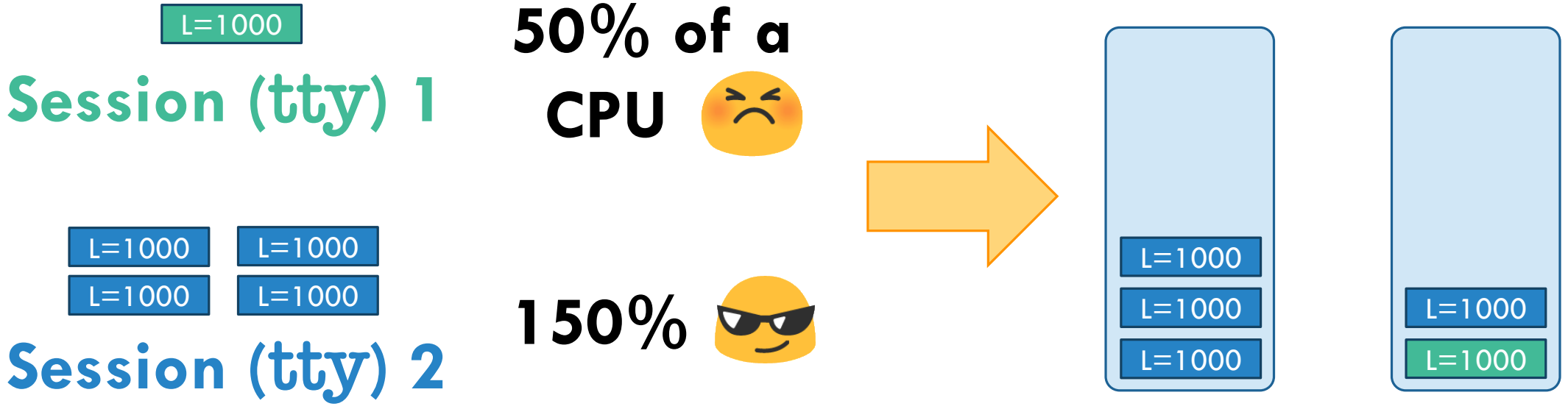

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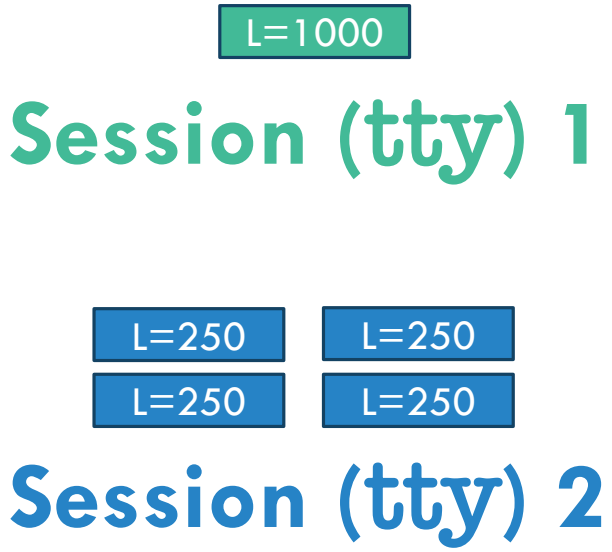

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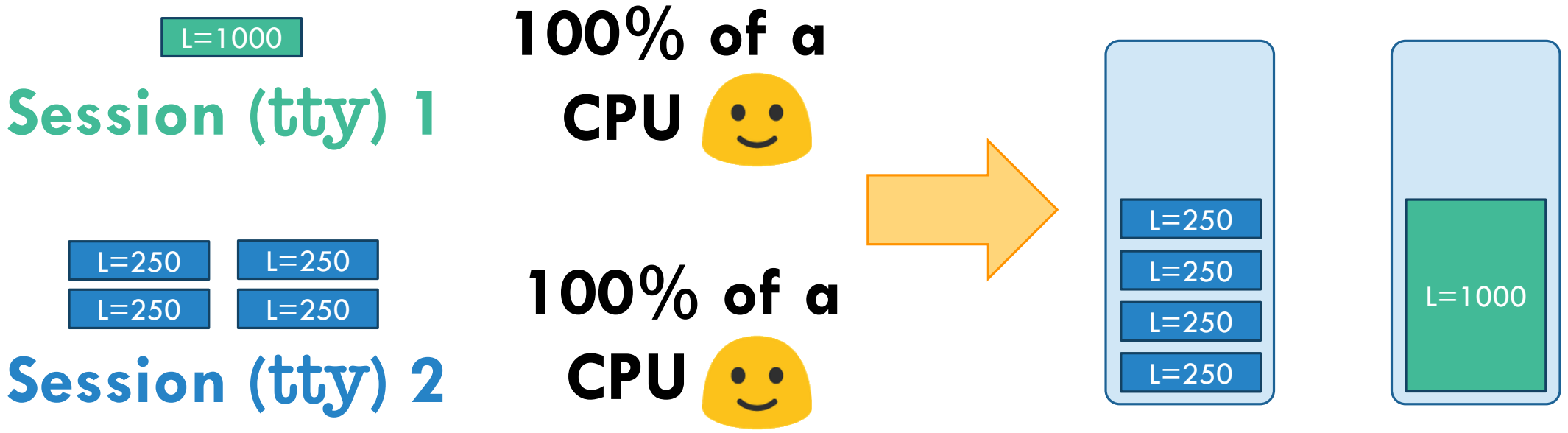

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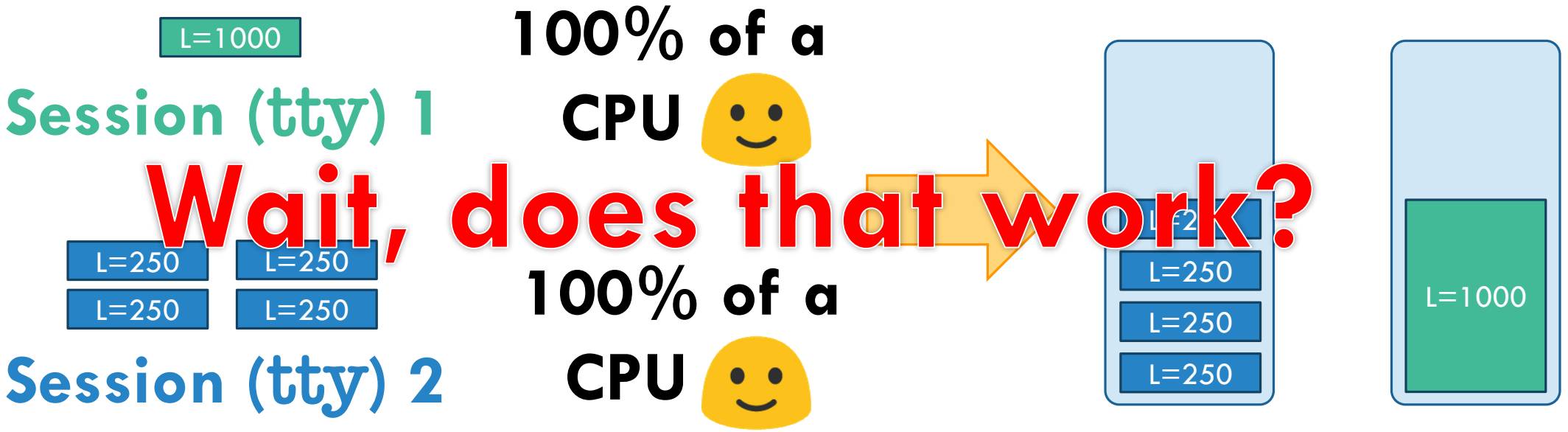
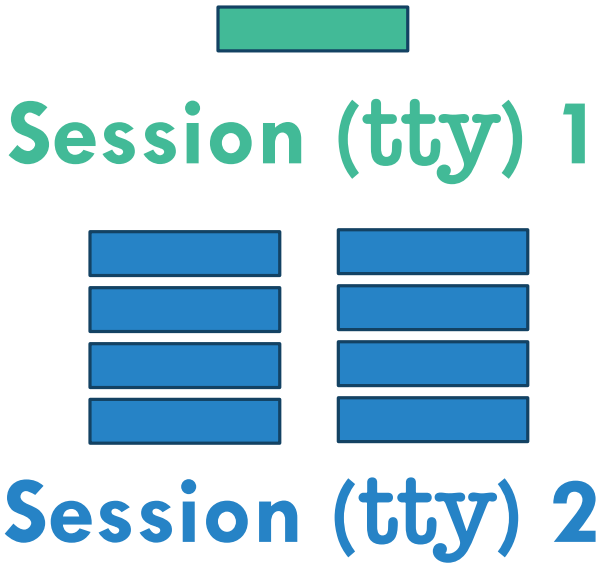


BUG 1/4: GROUP IMBALANCE



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Load(thread) = %cpu × weight / #threads
= 100 × 10 / 1
= 1000

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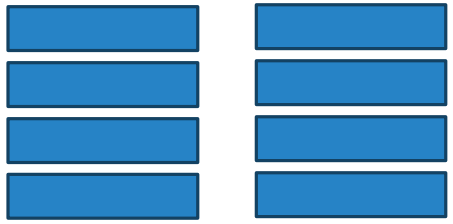

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= 125

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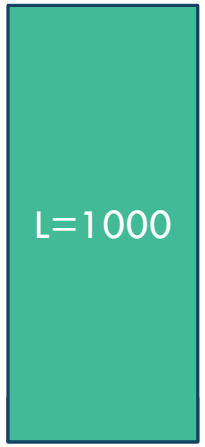

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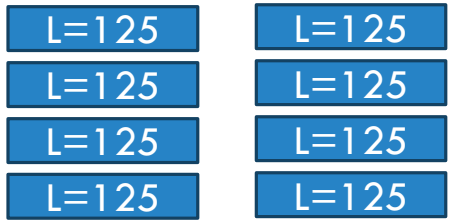

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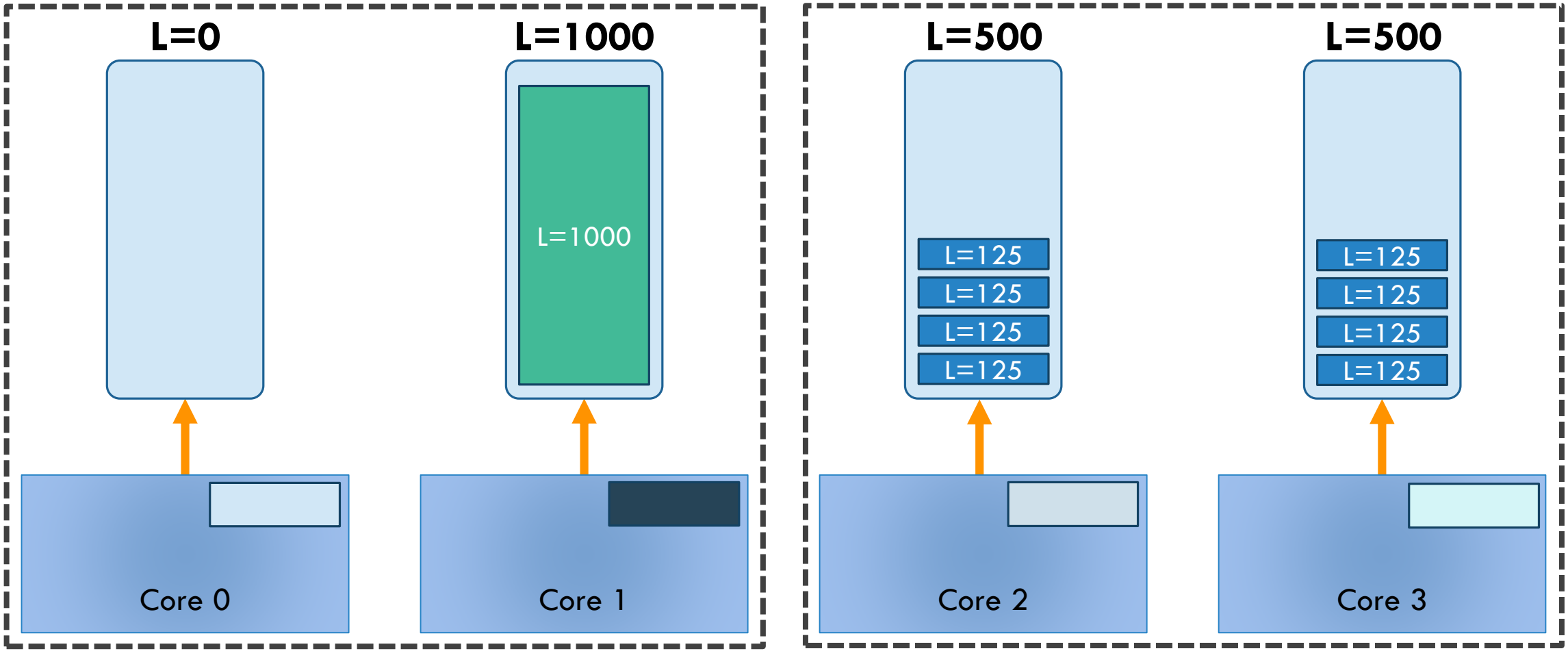

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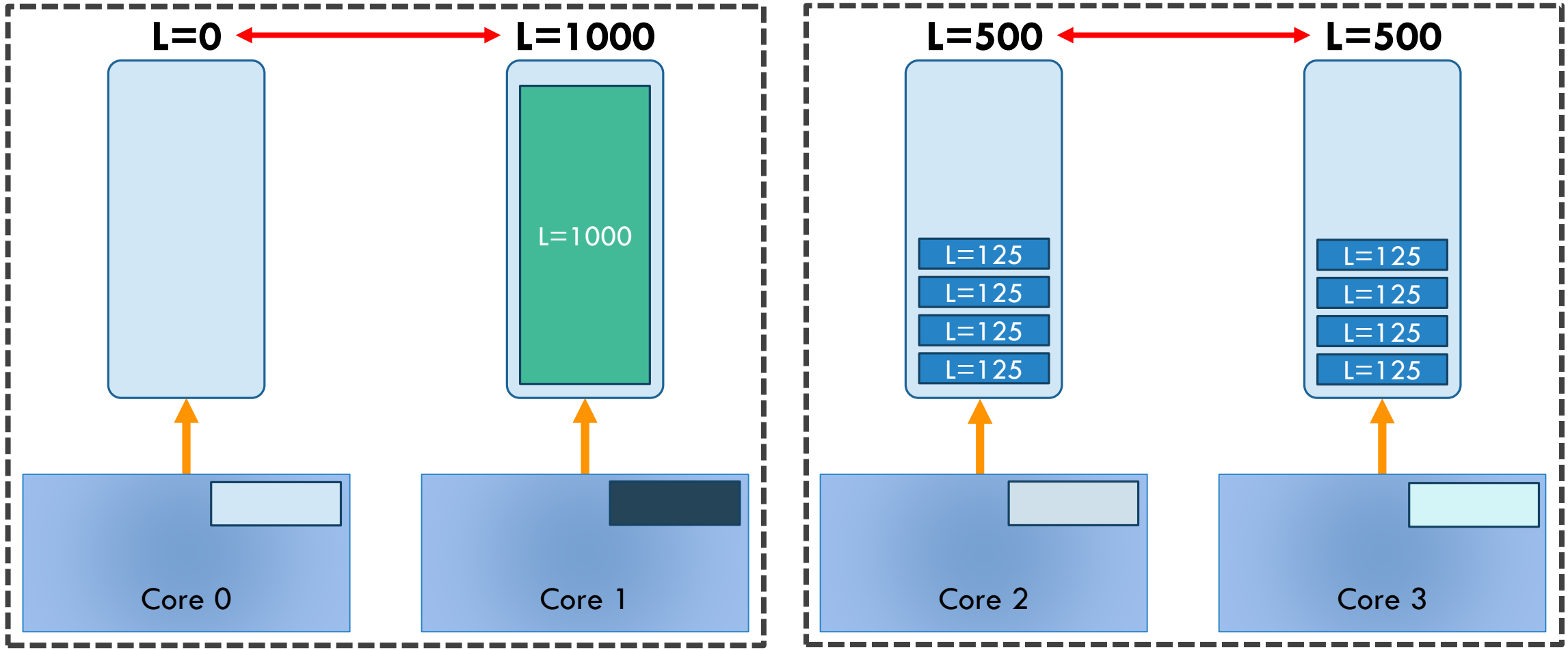

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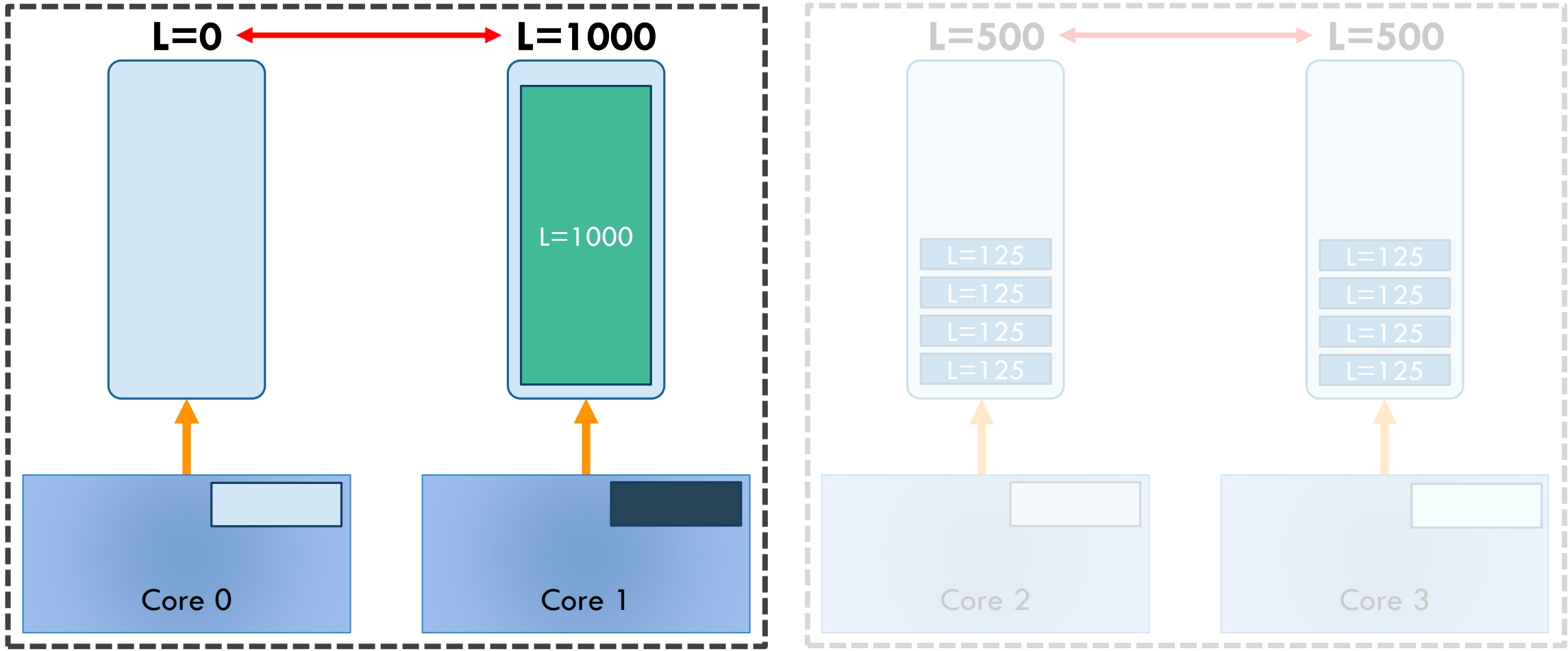

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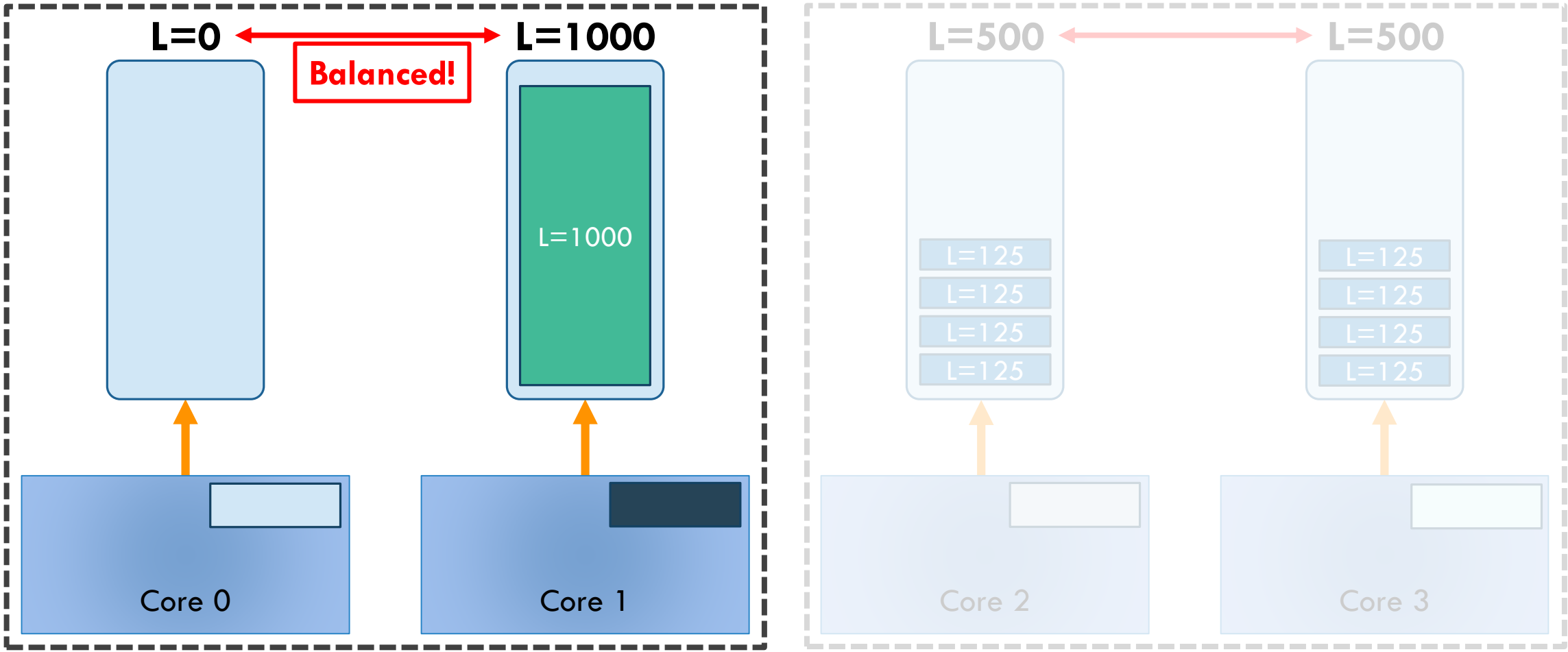

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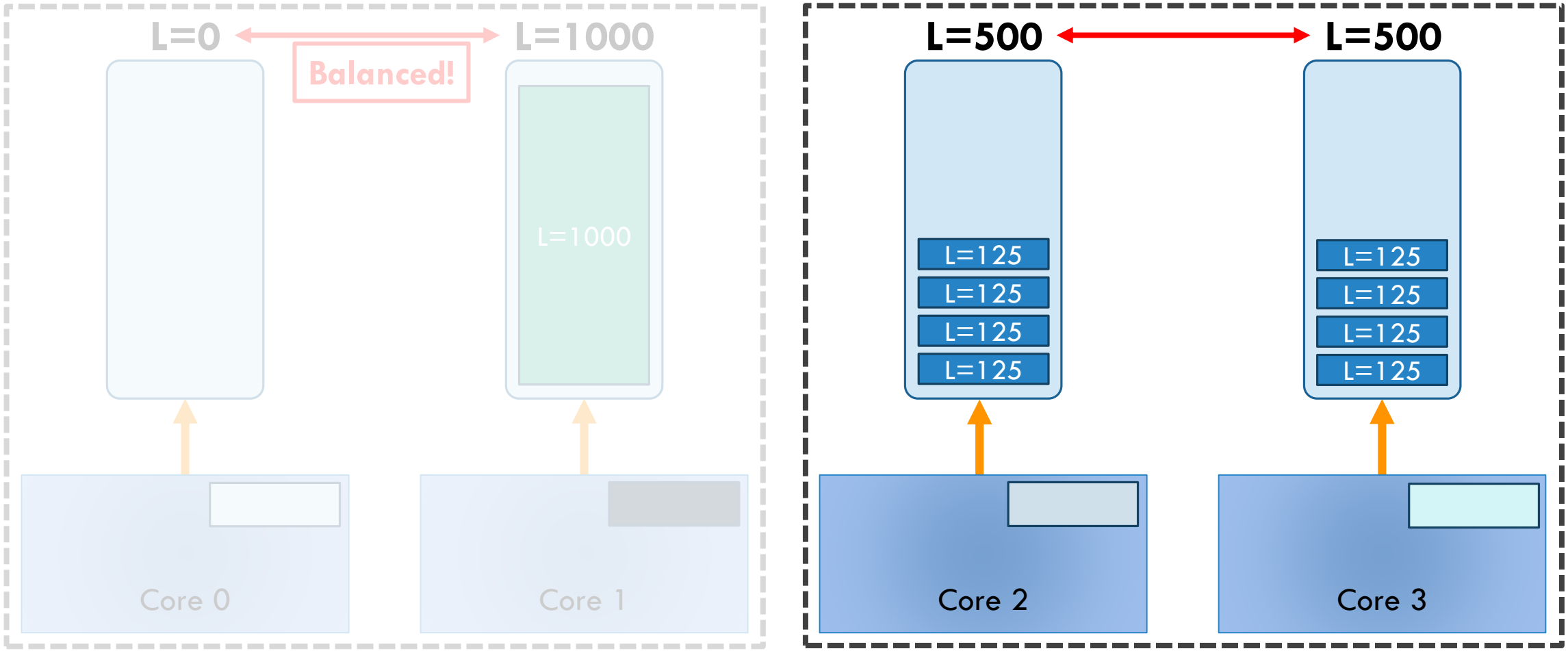

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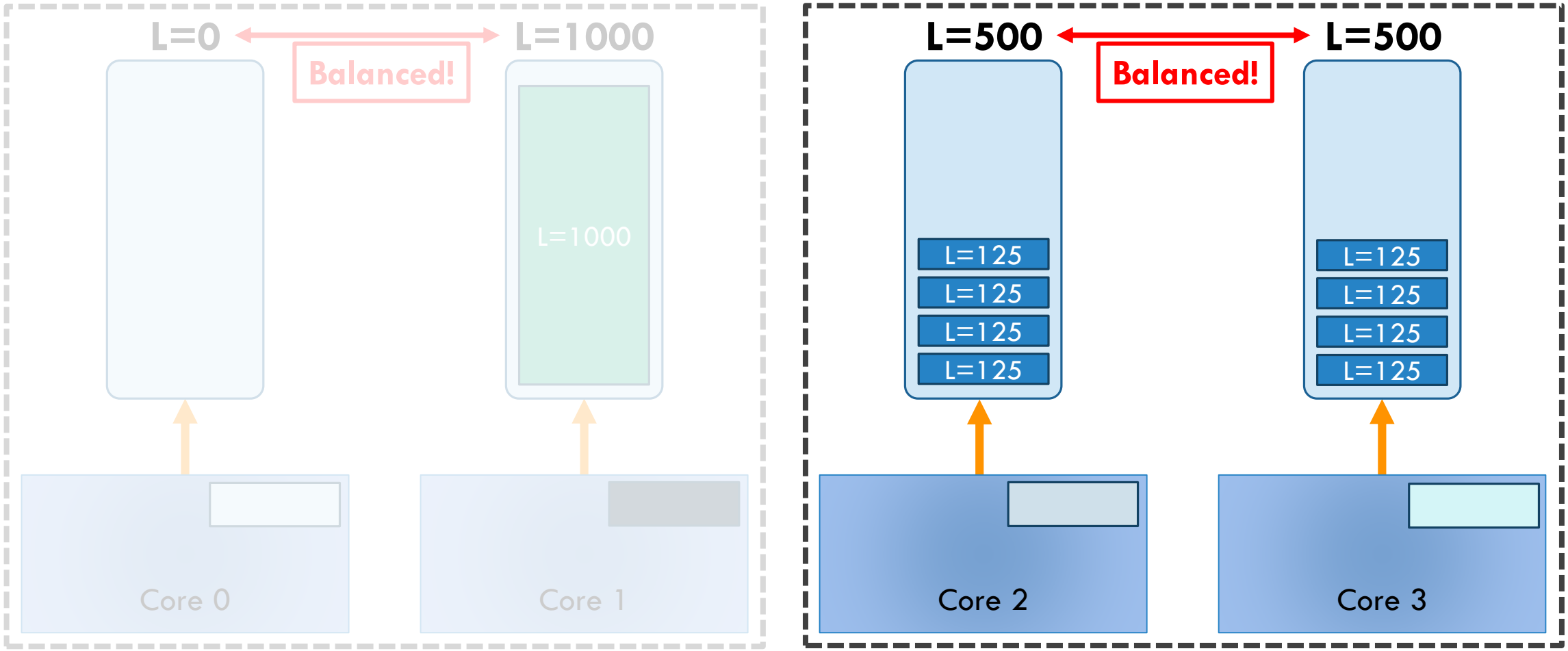

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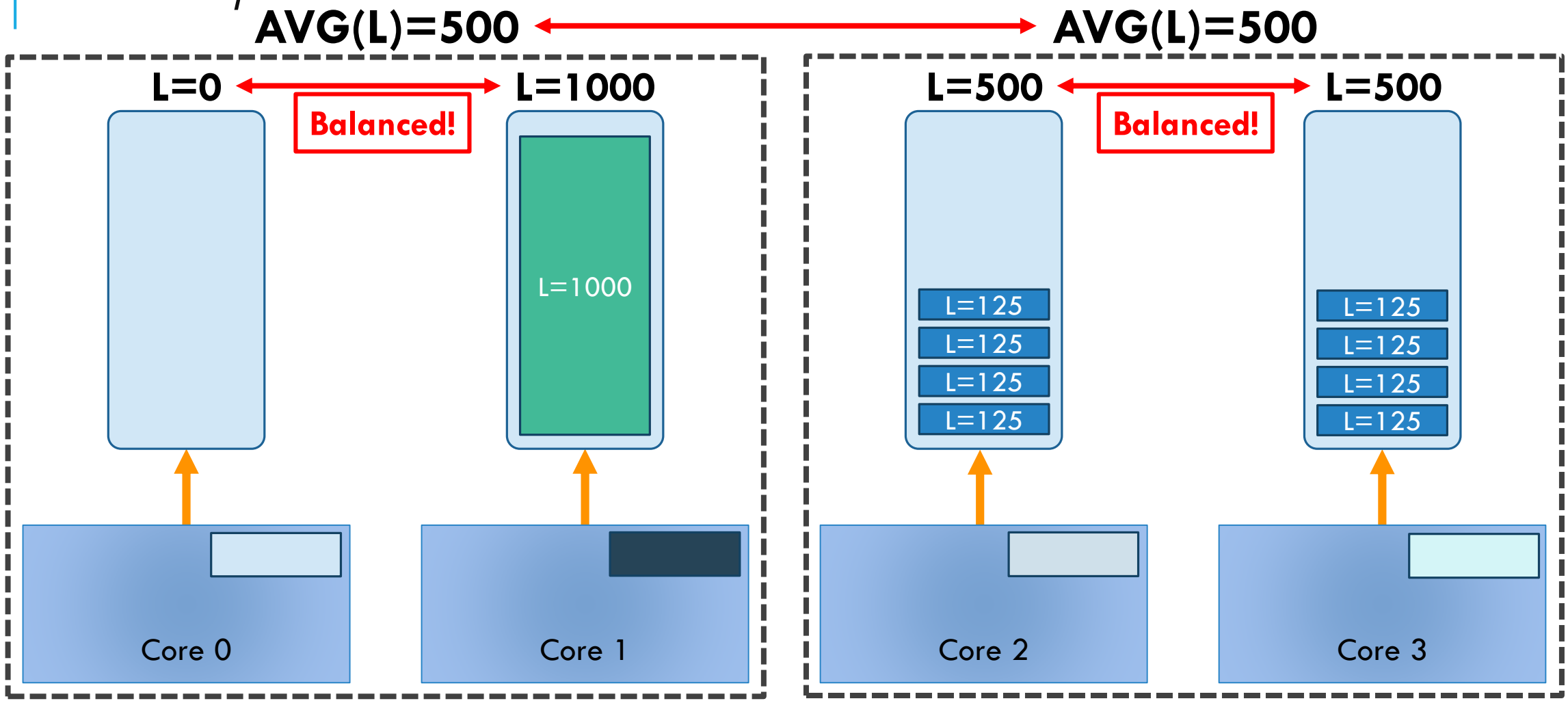

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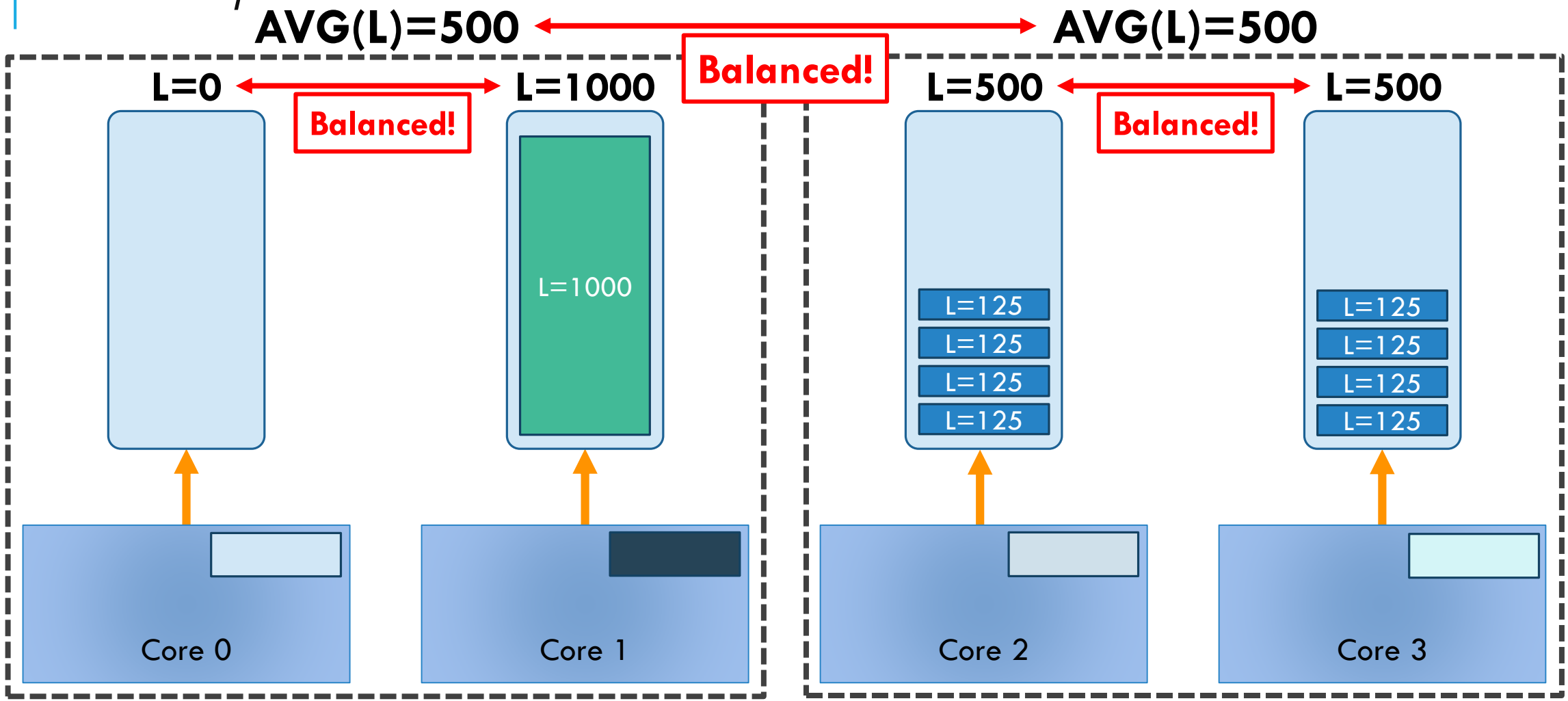

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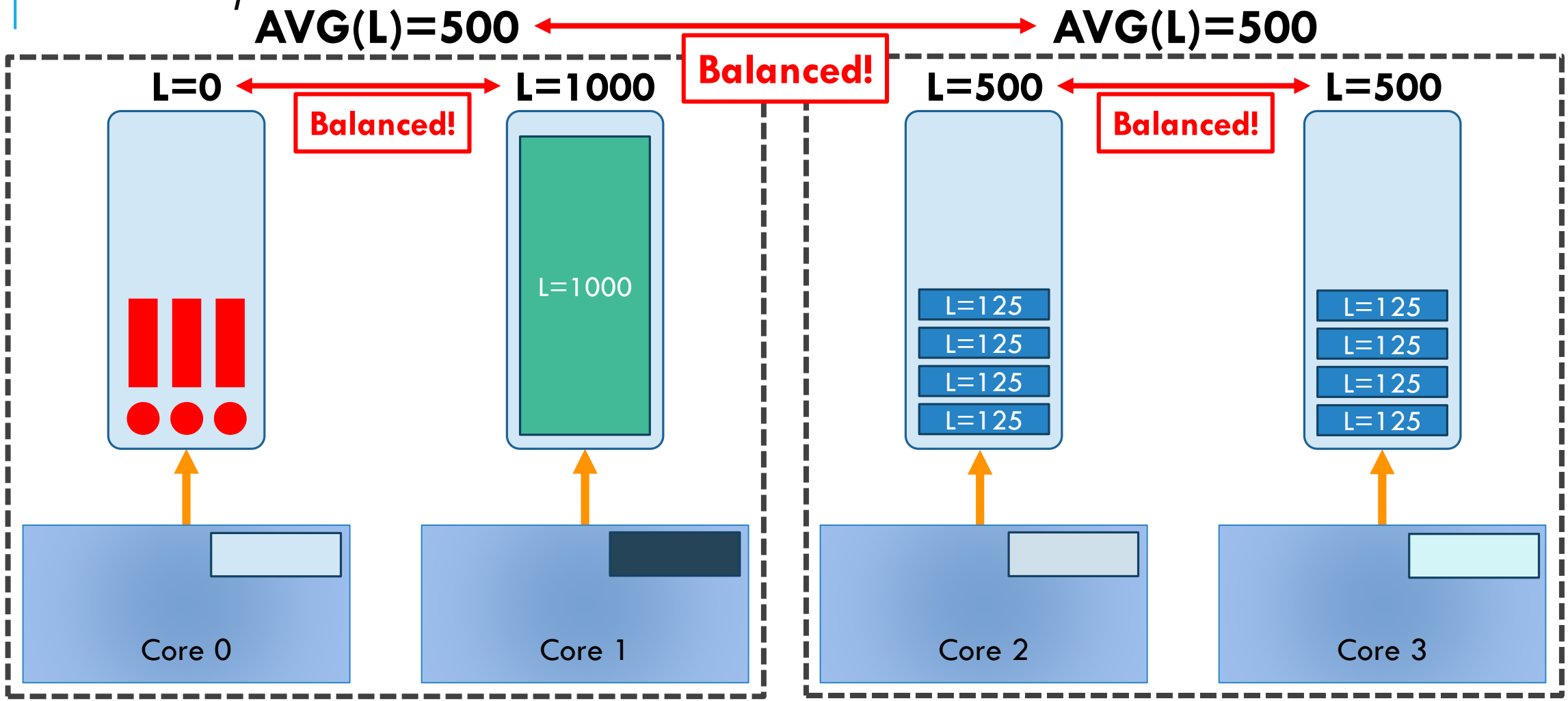

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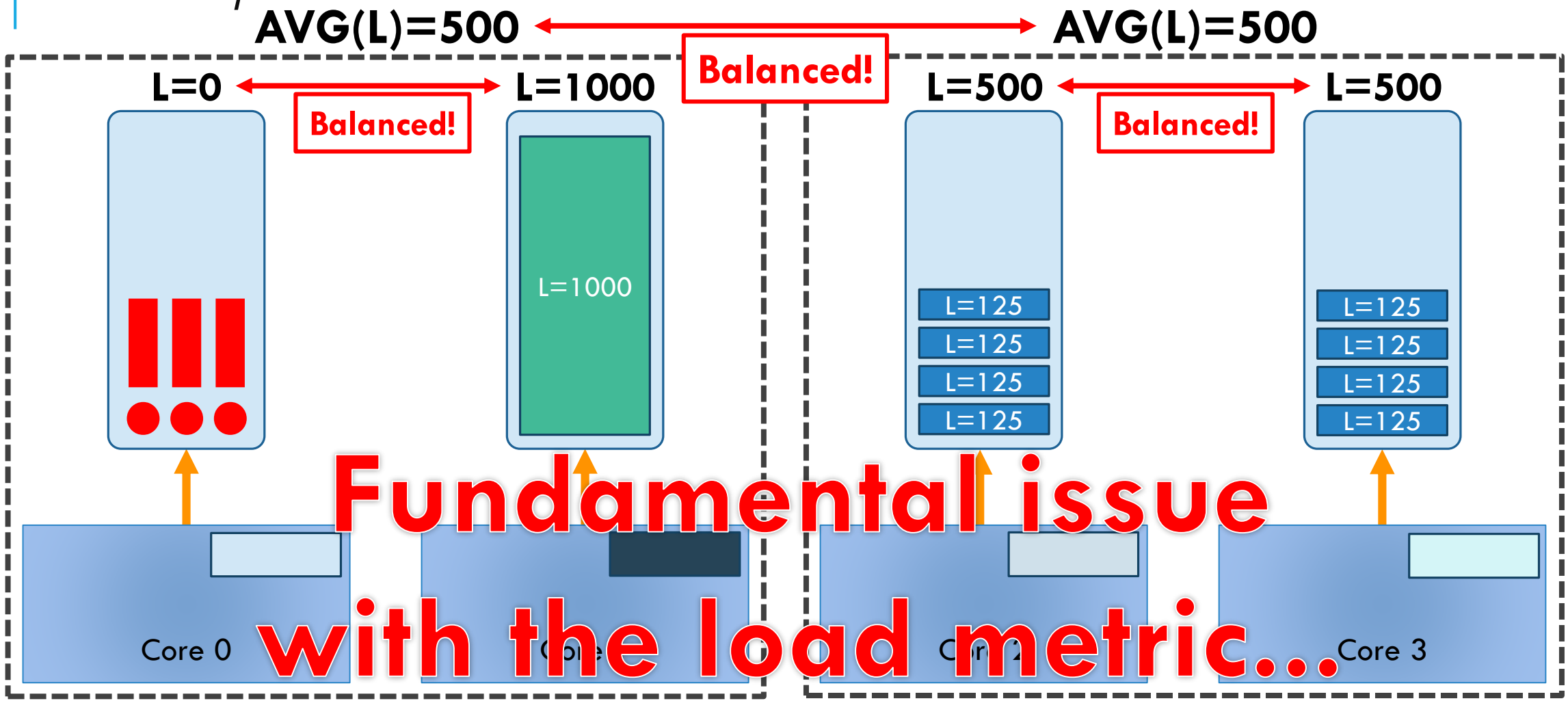

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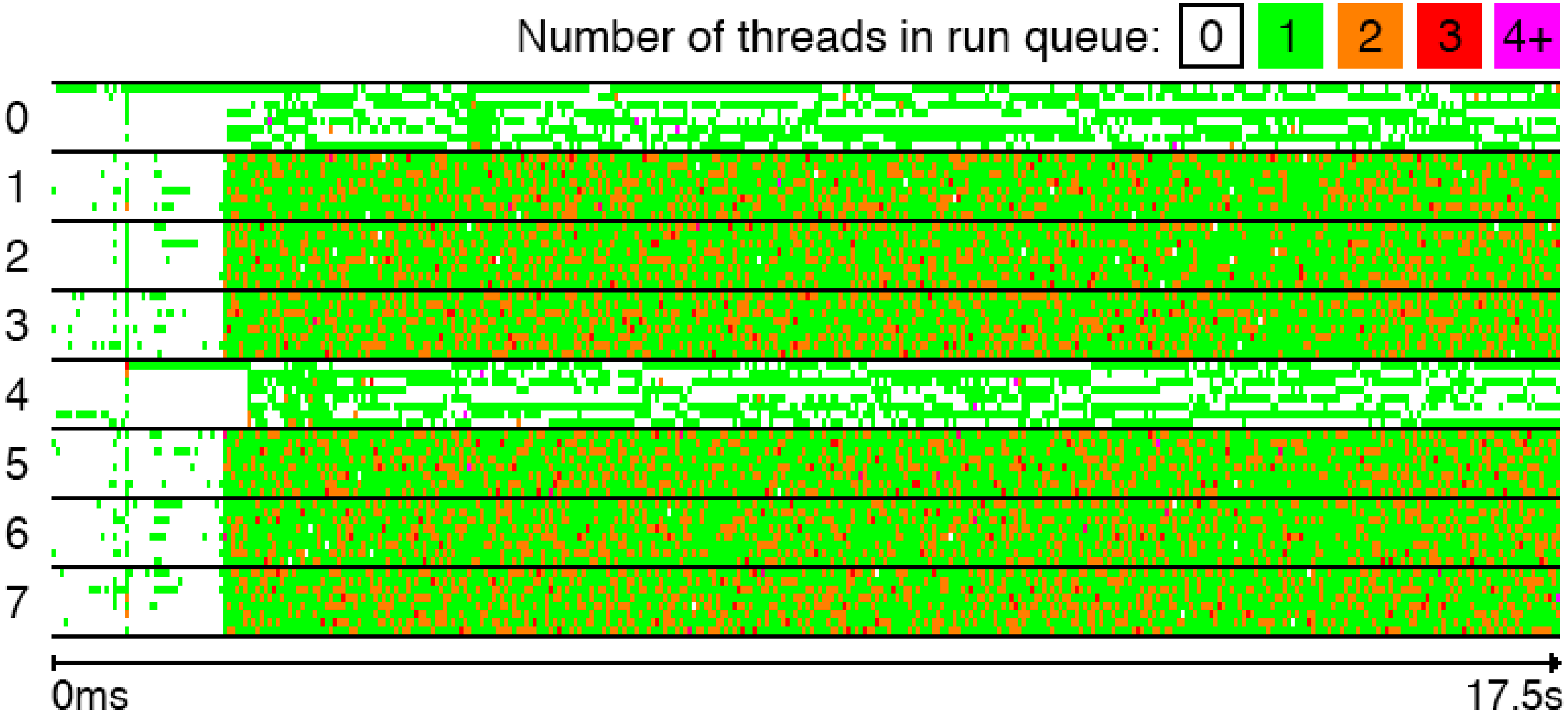

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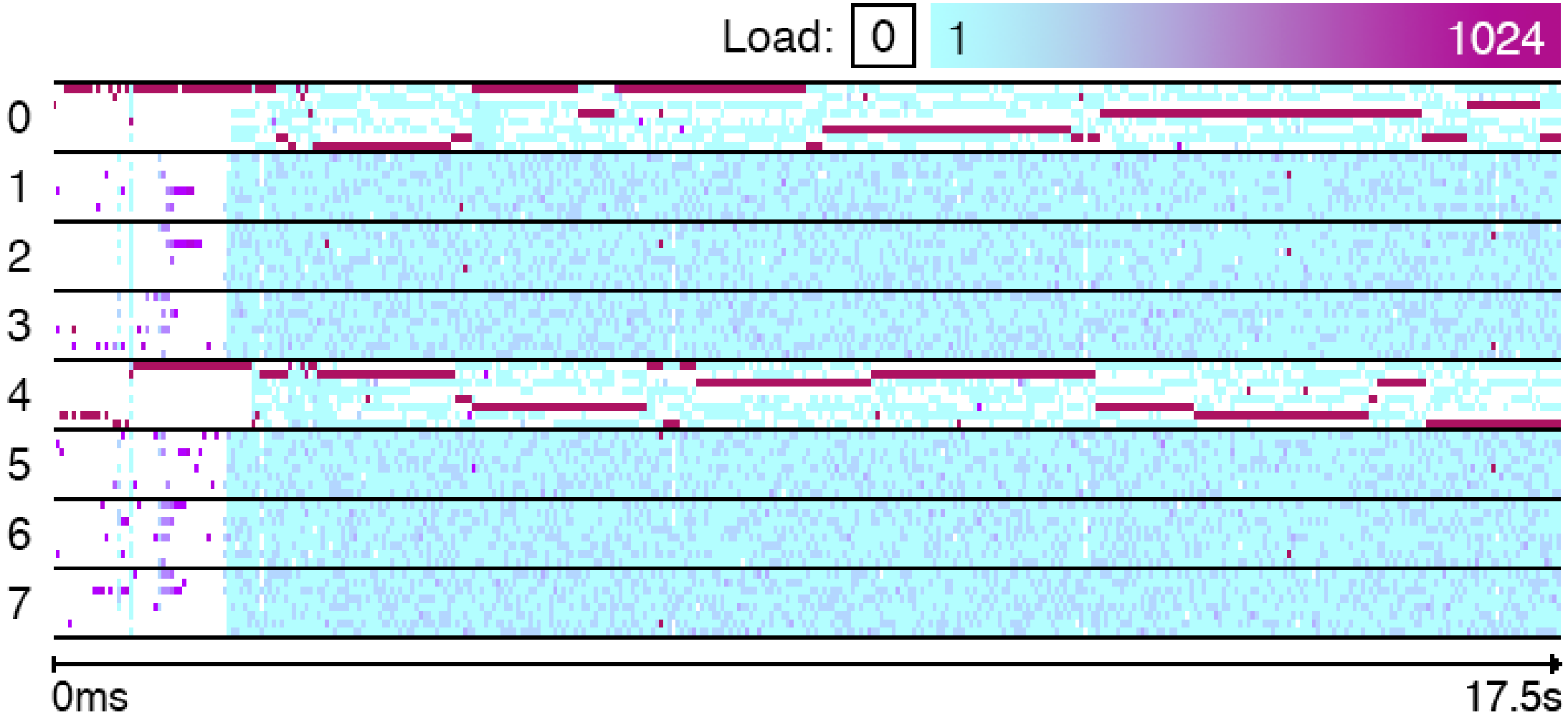

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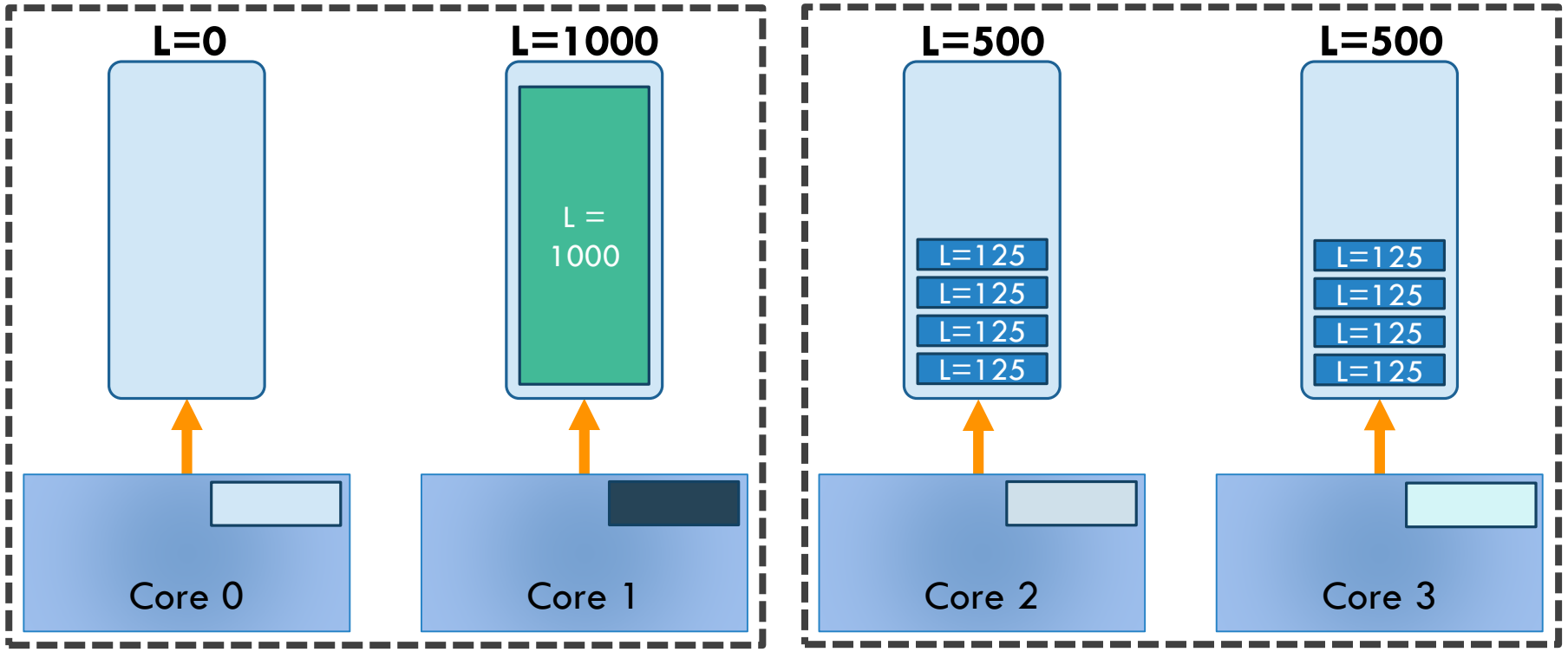

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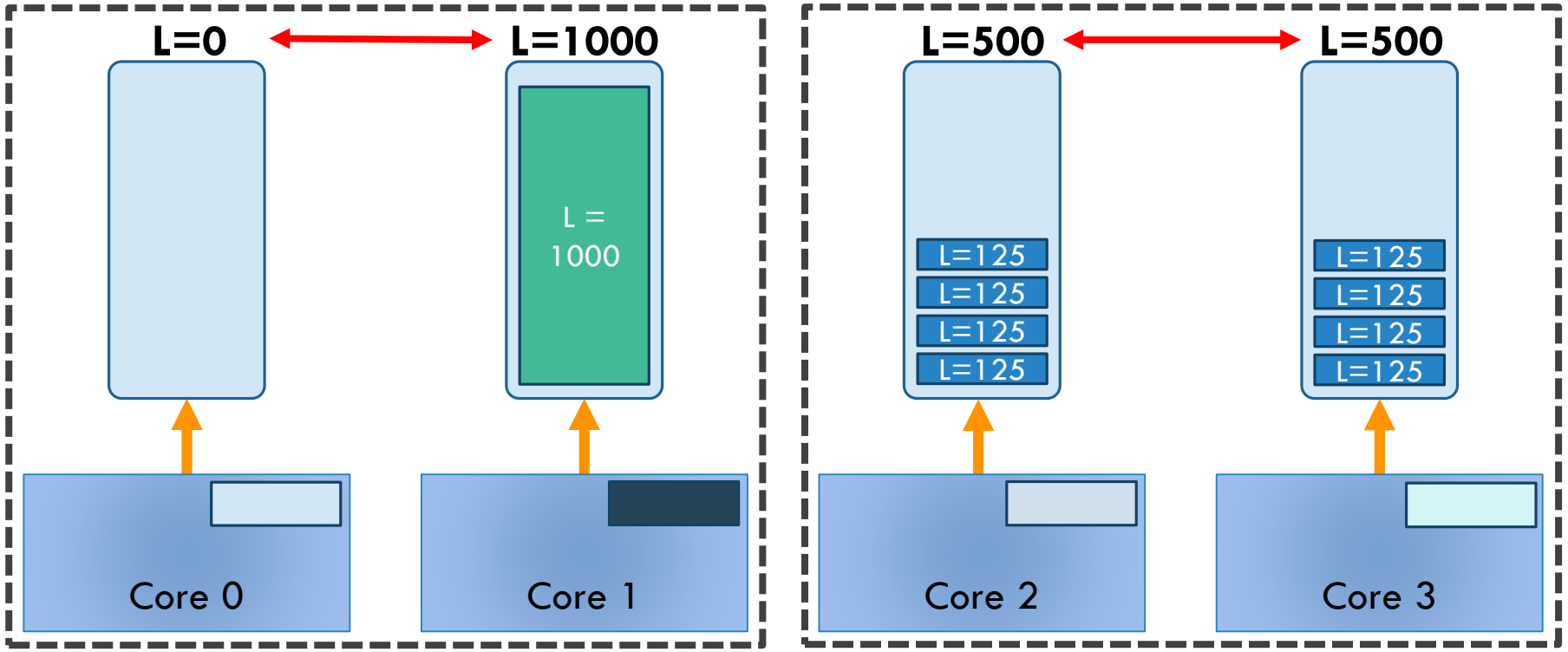

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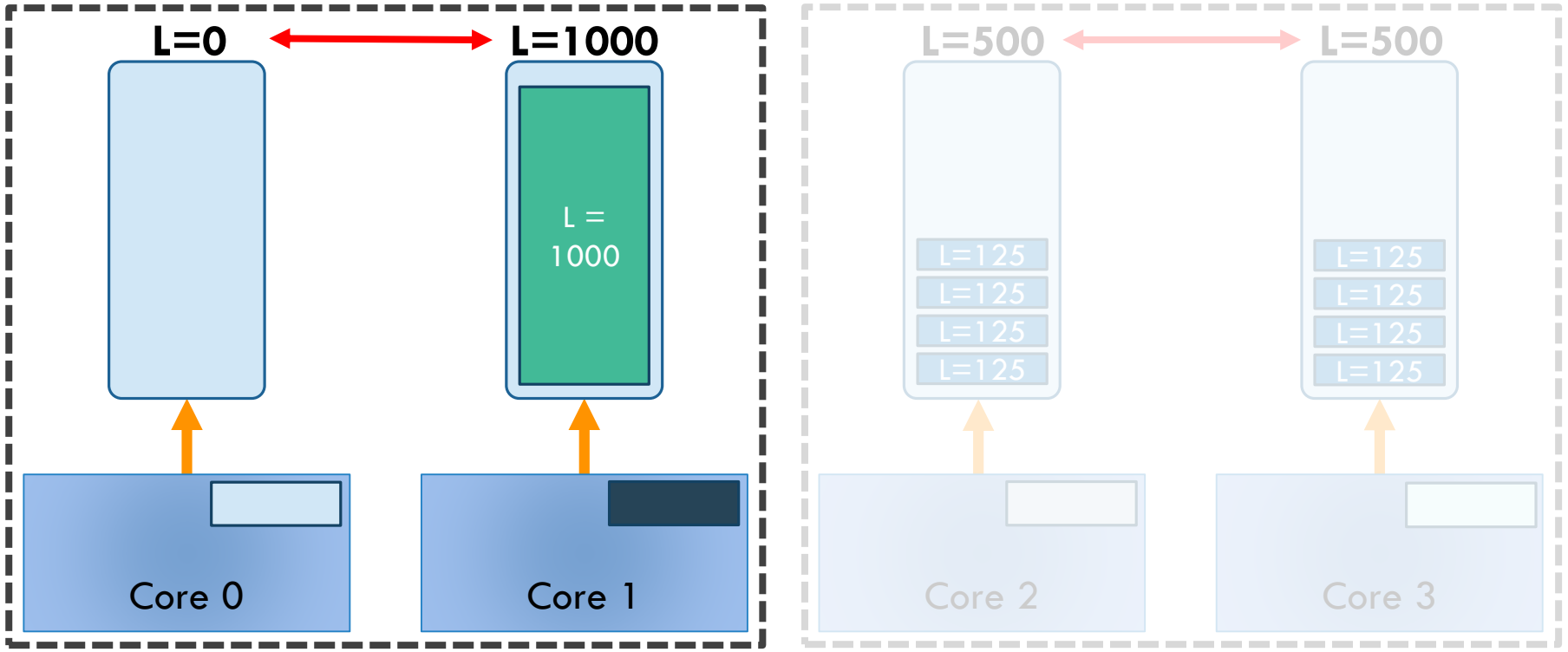

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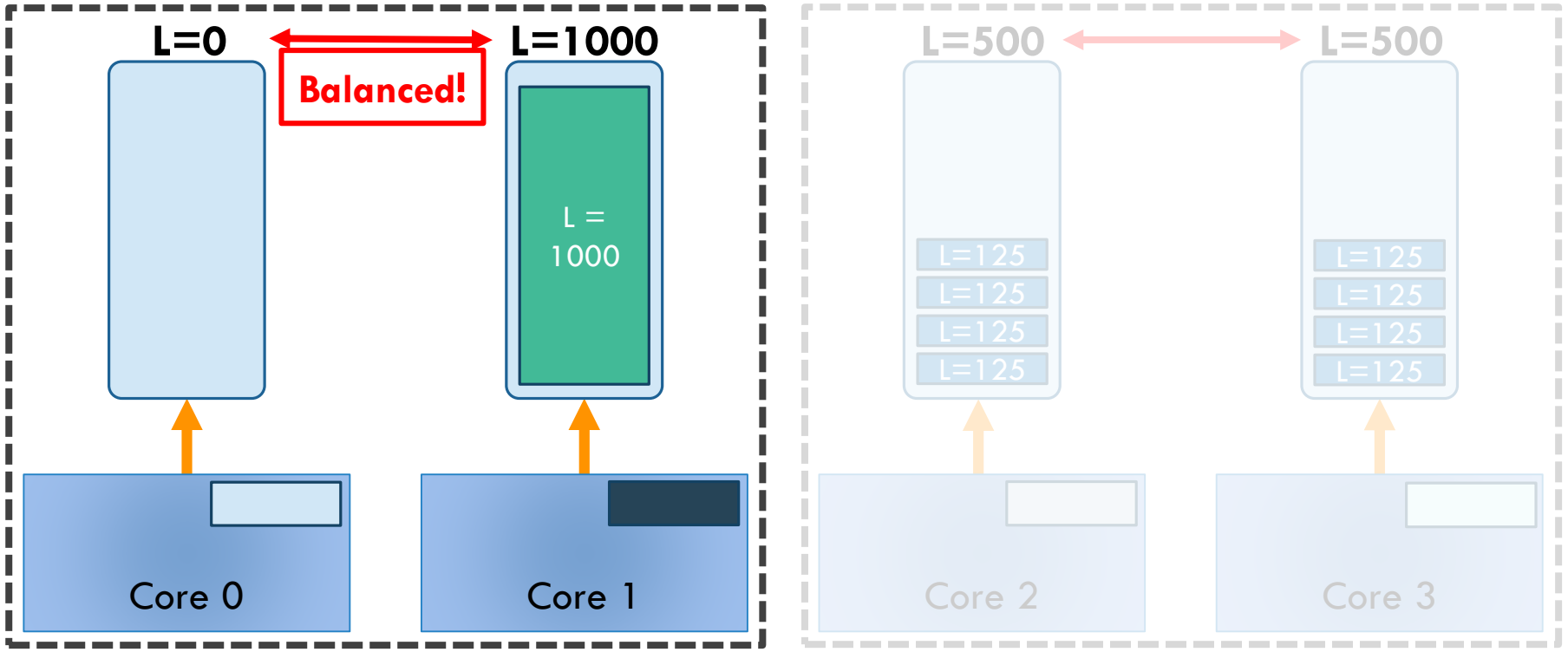

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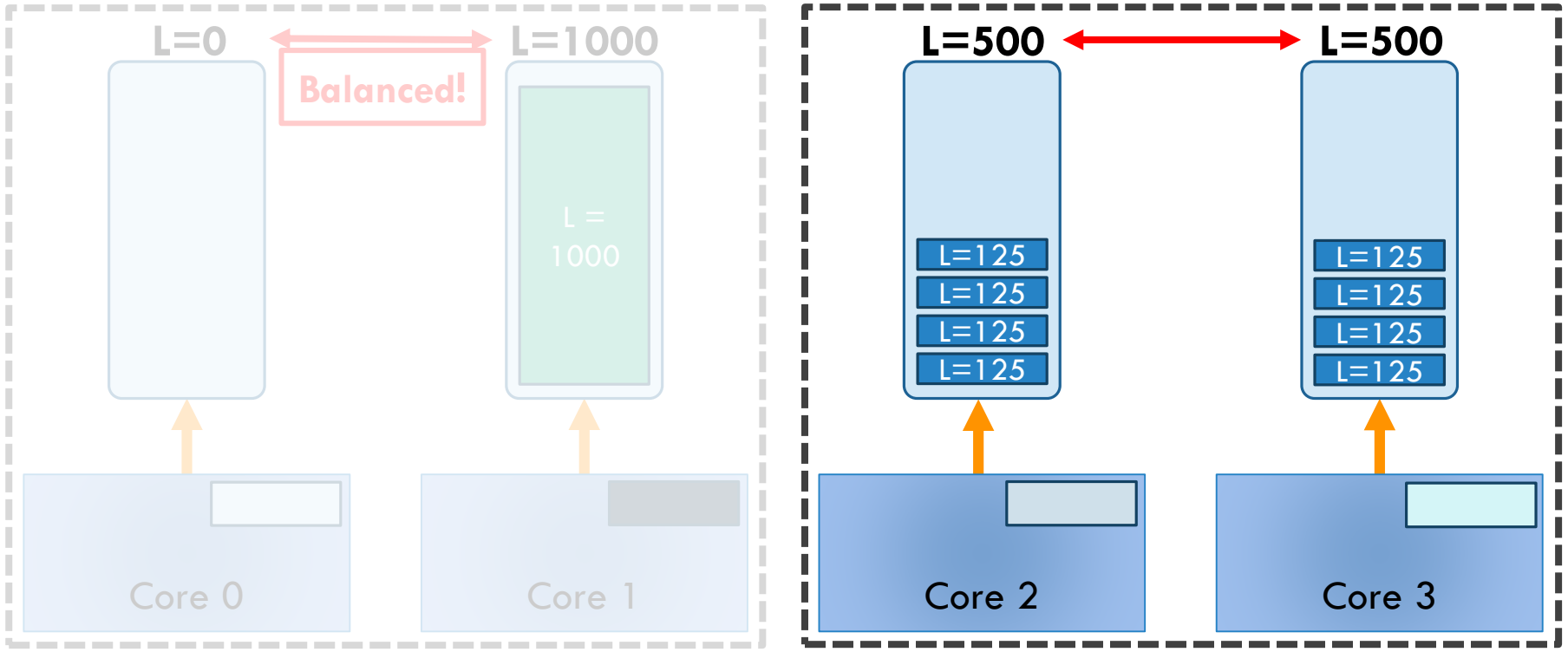

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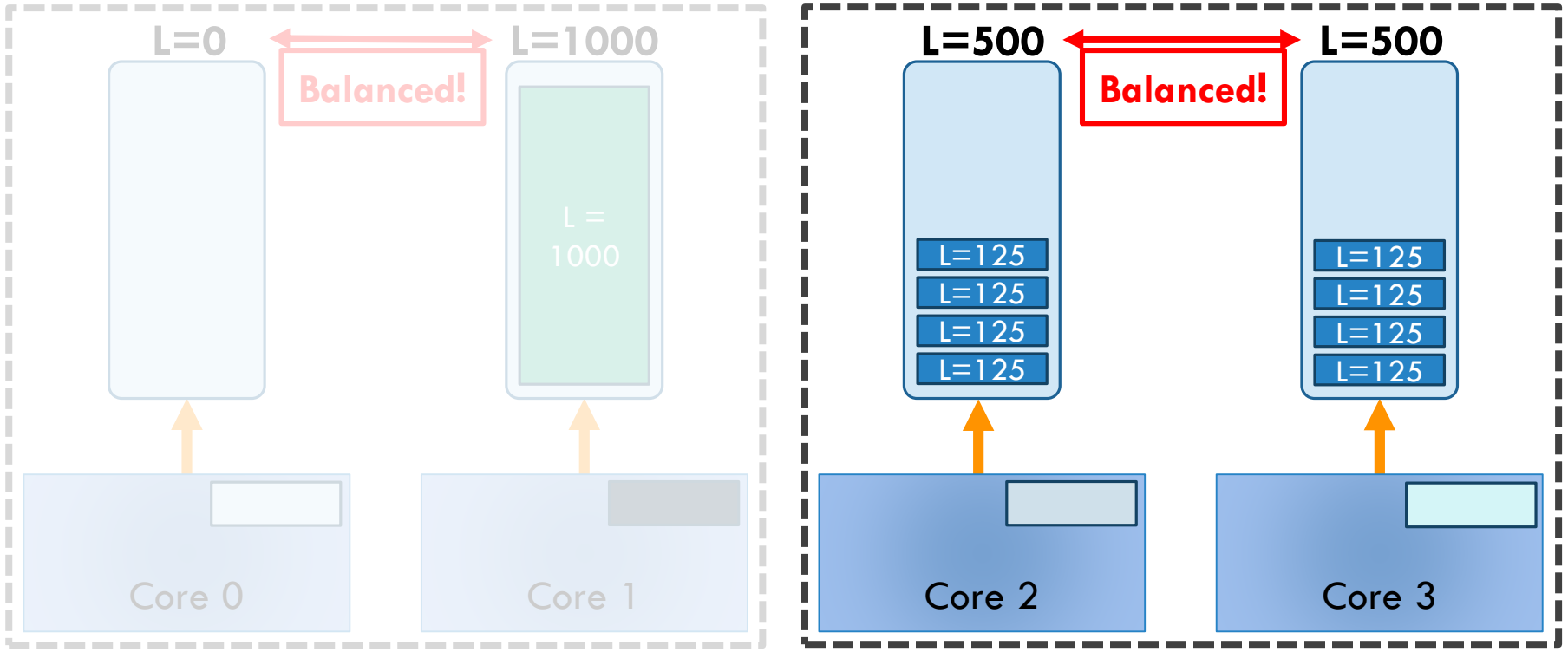

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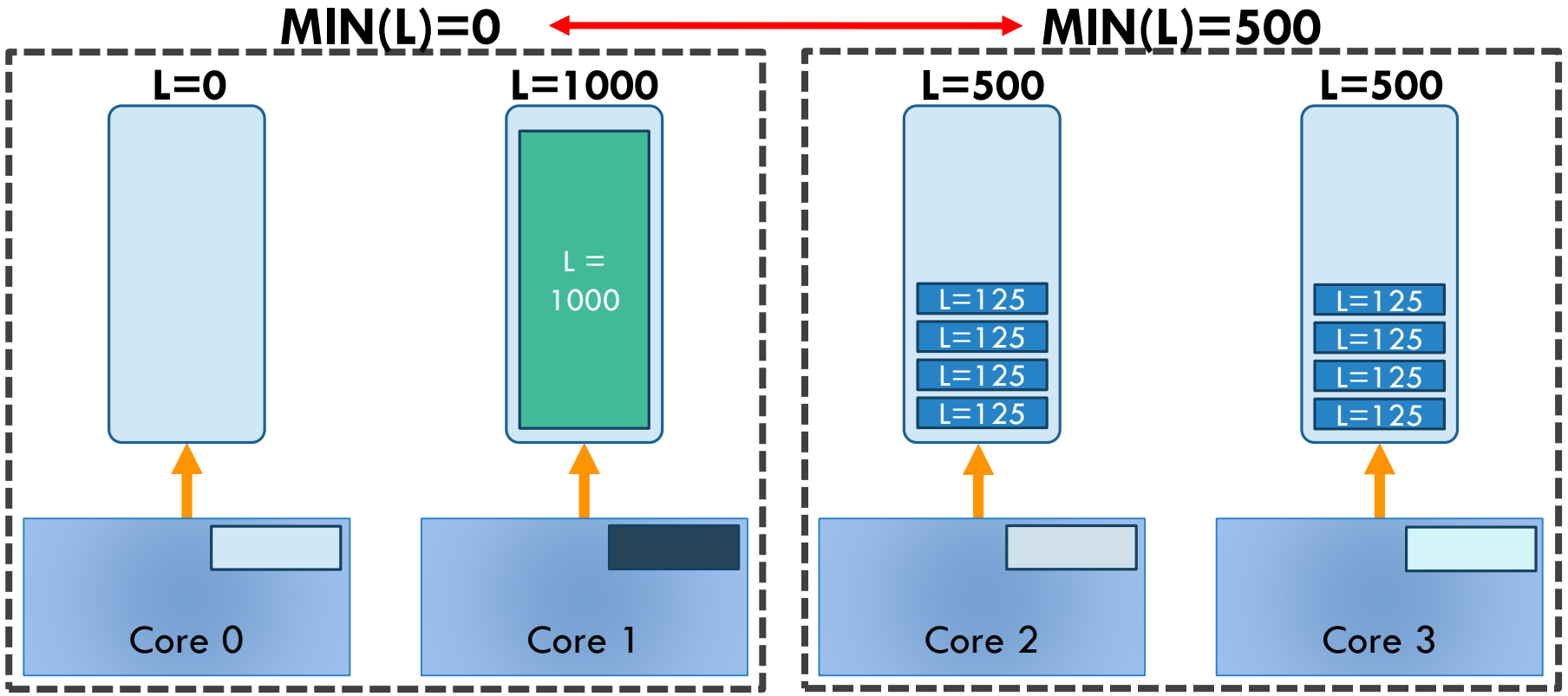

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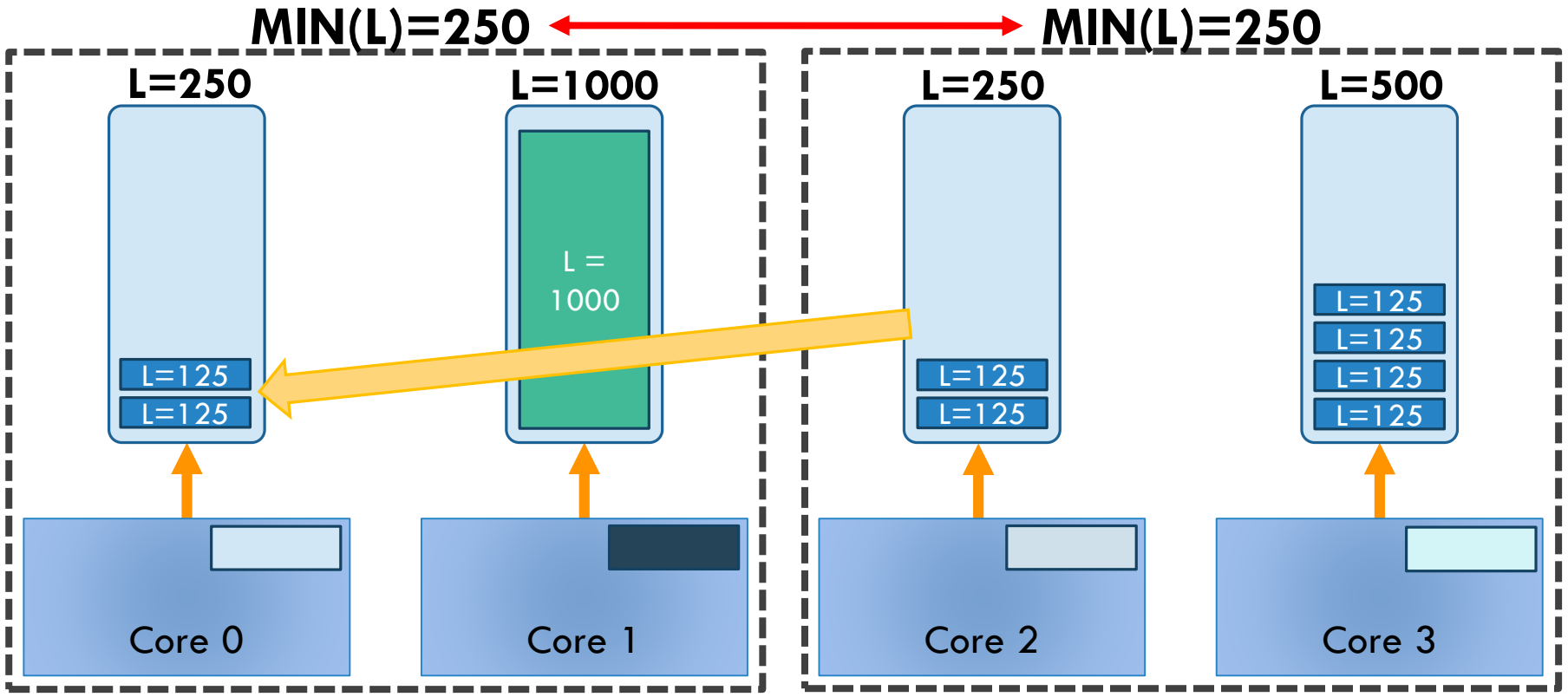

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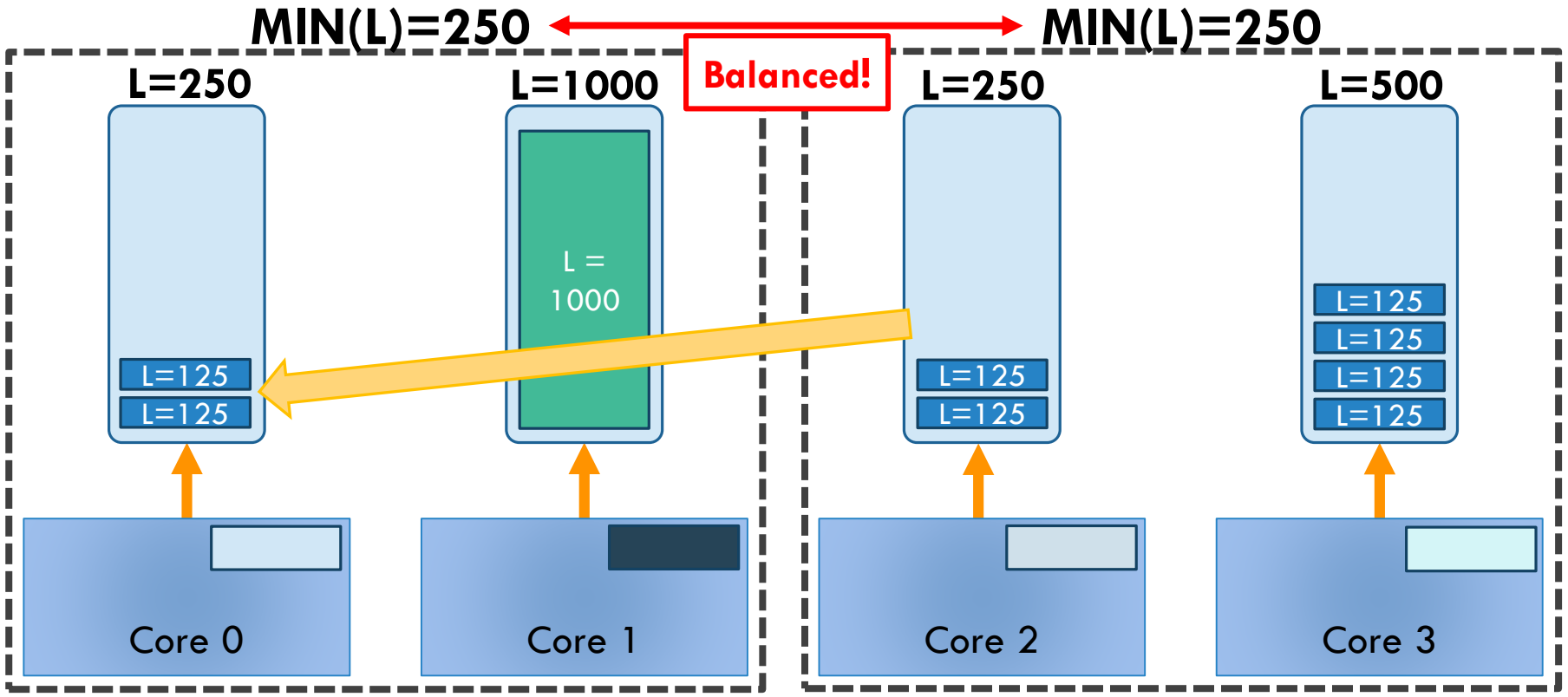

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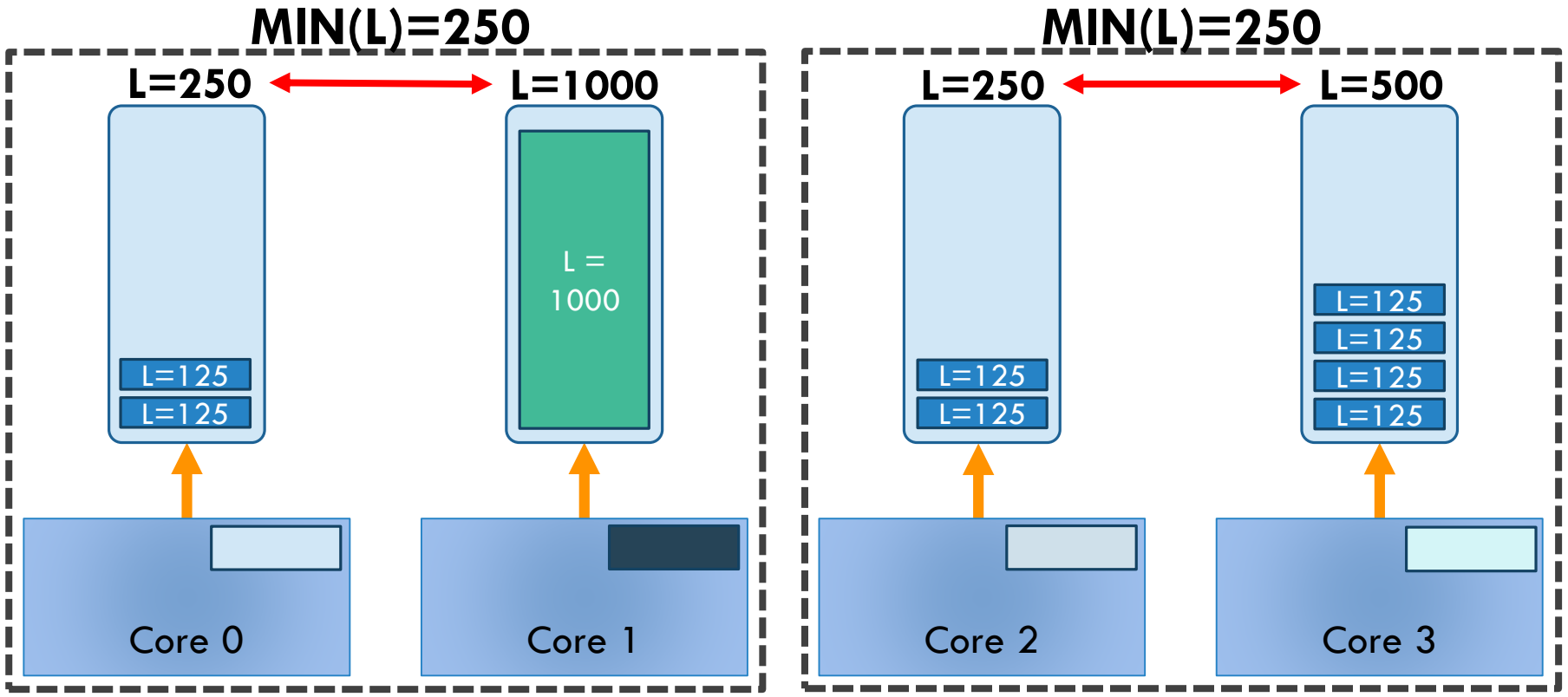

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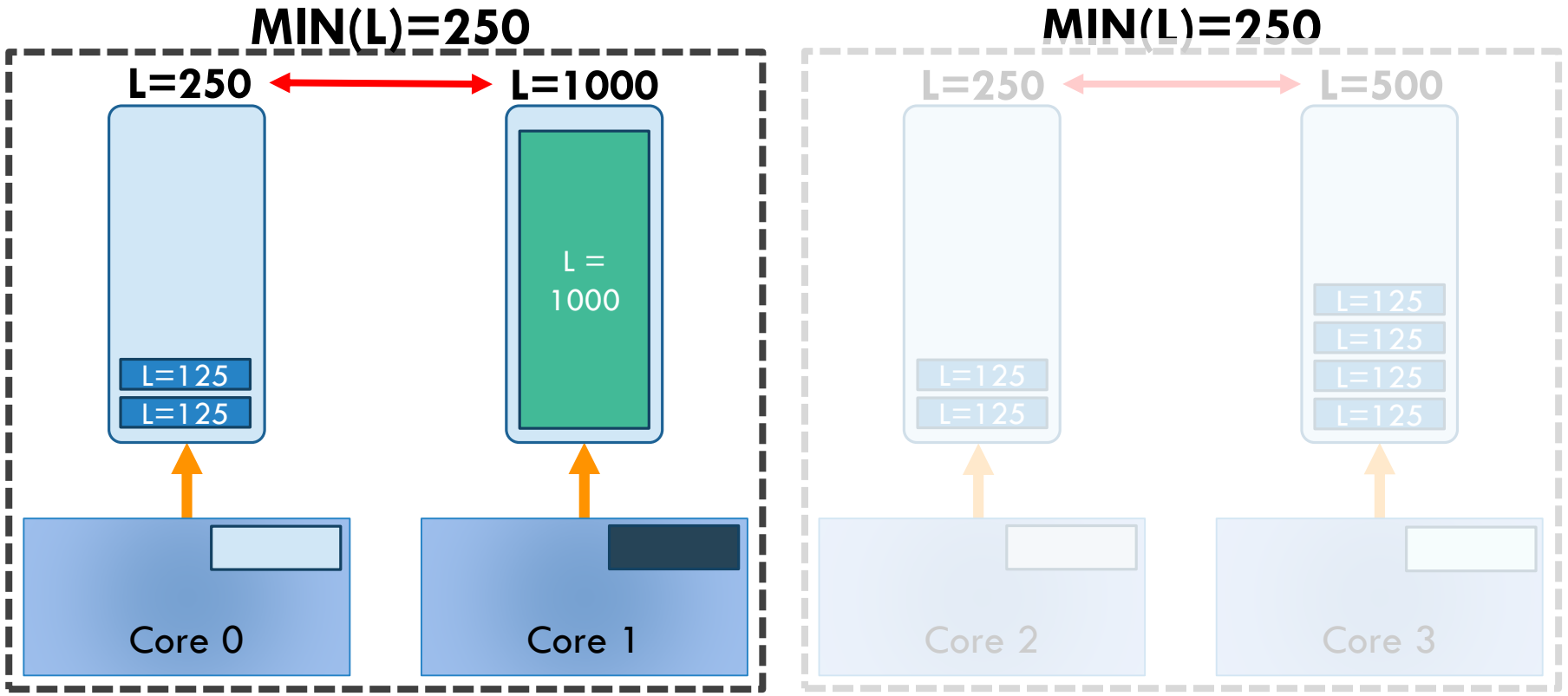

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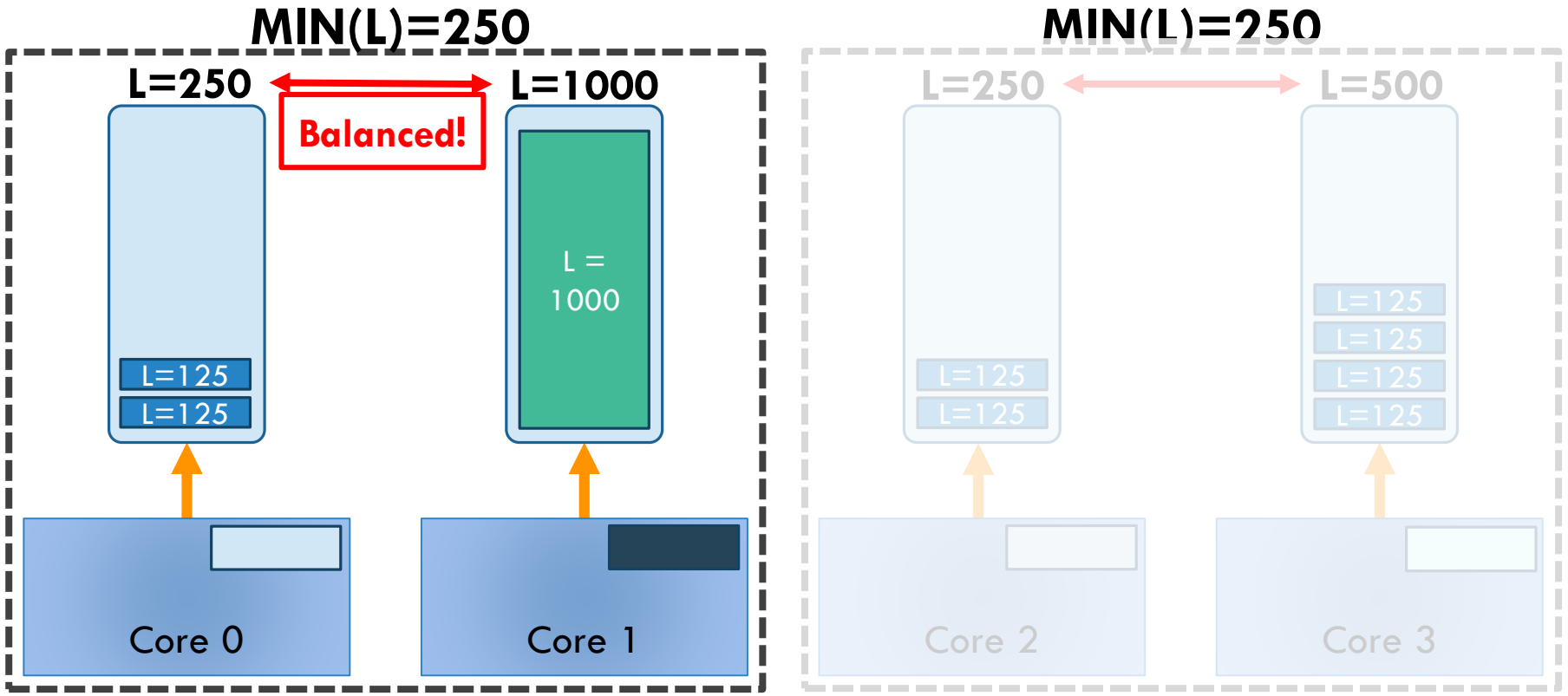

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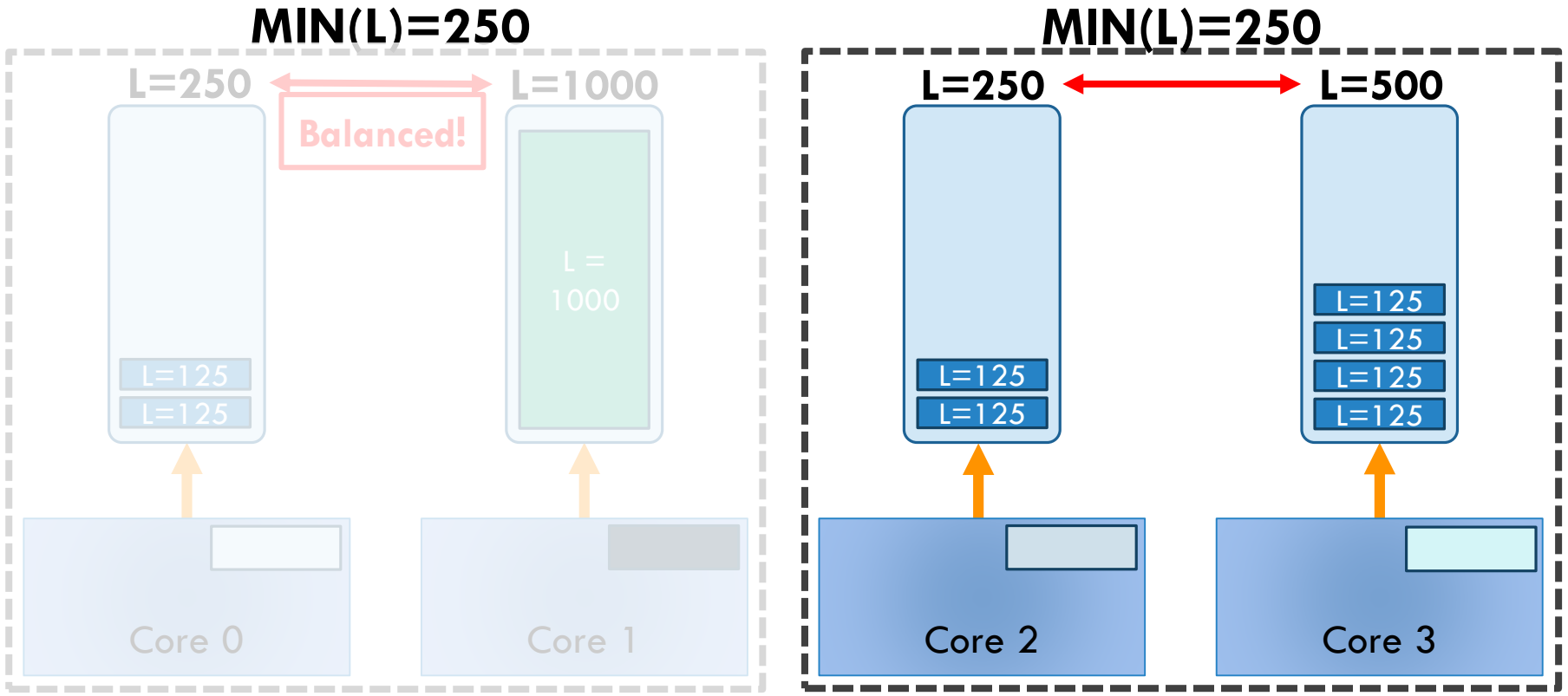

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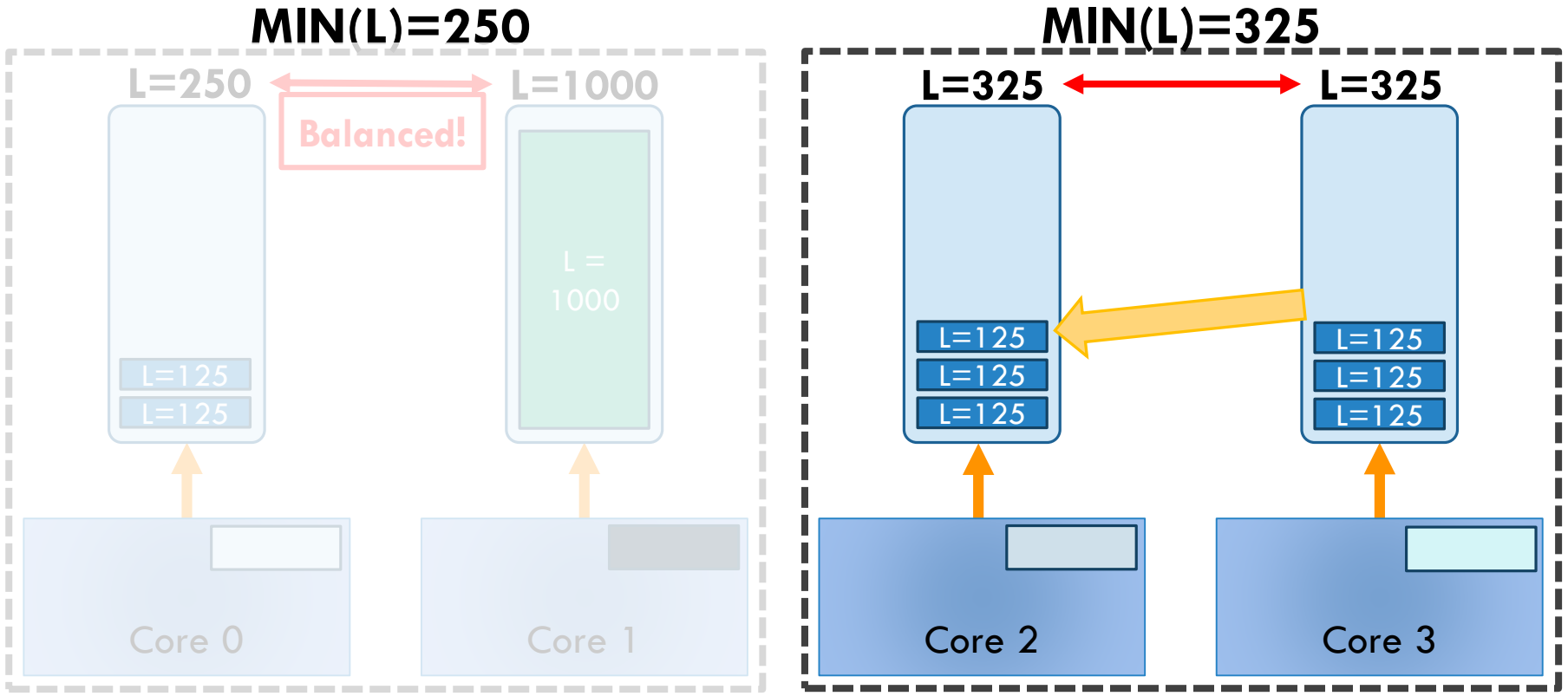

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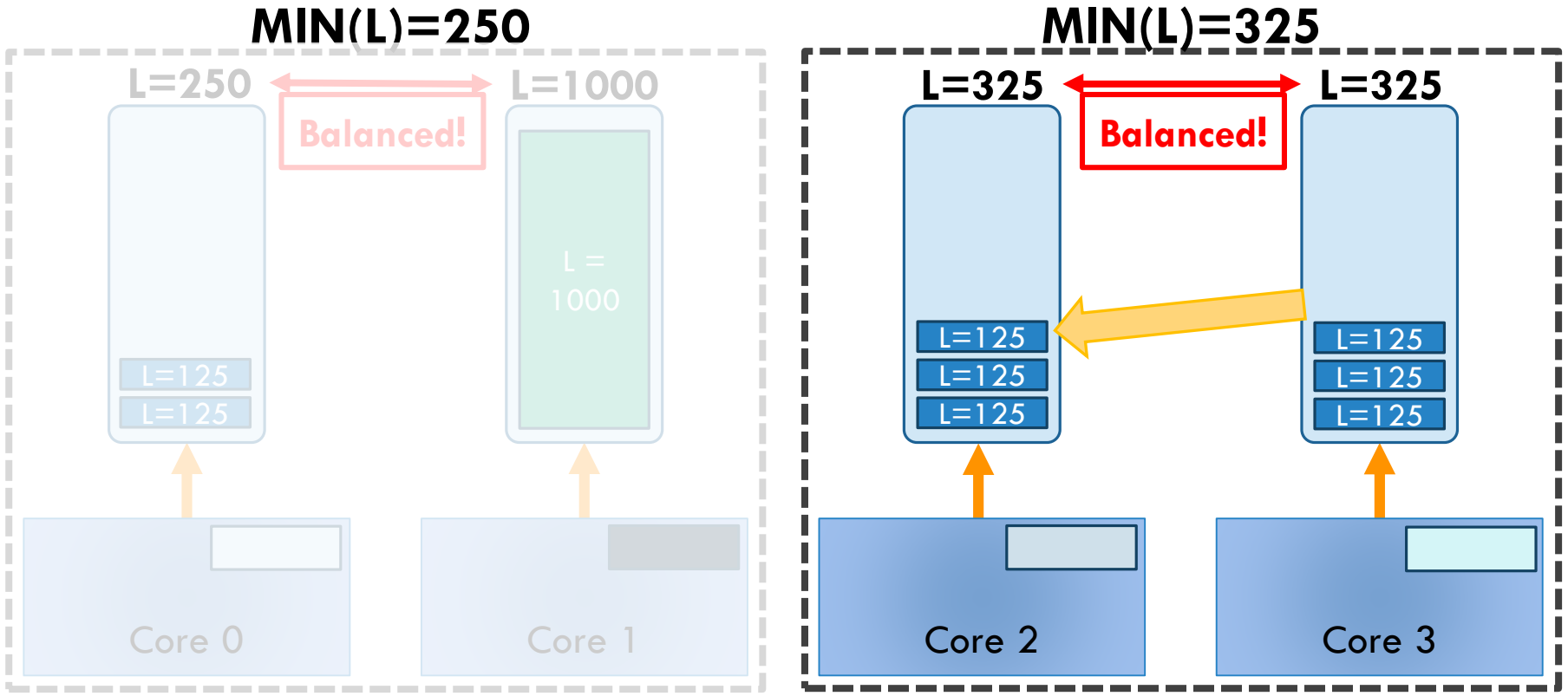

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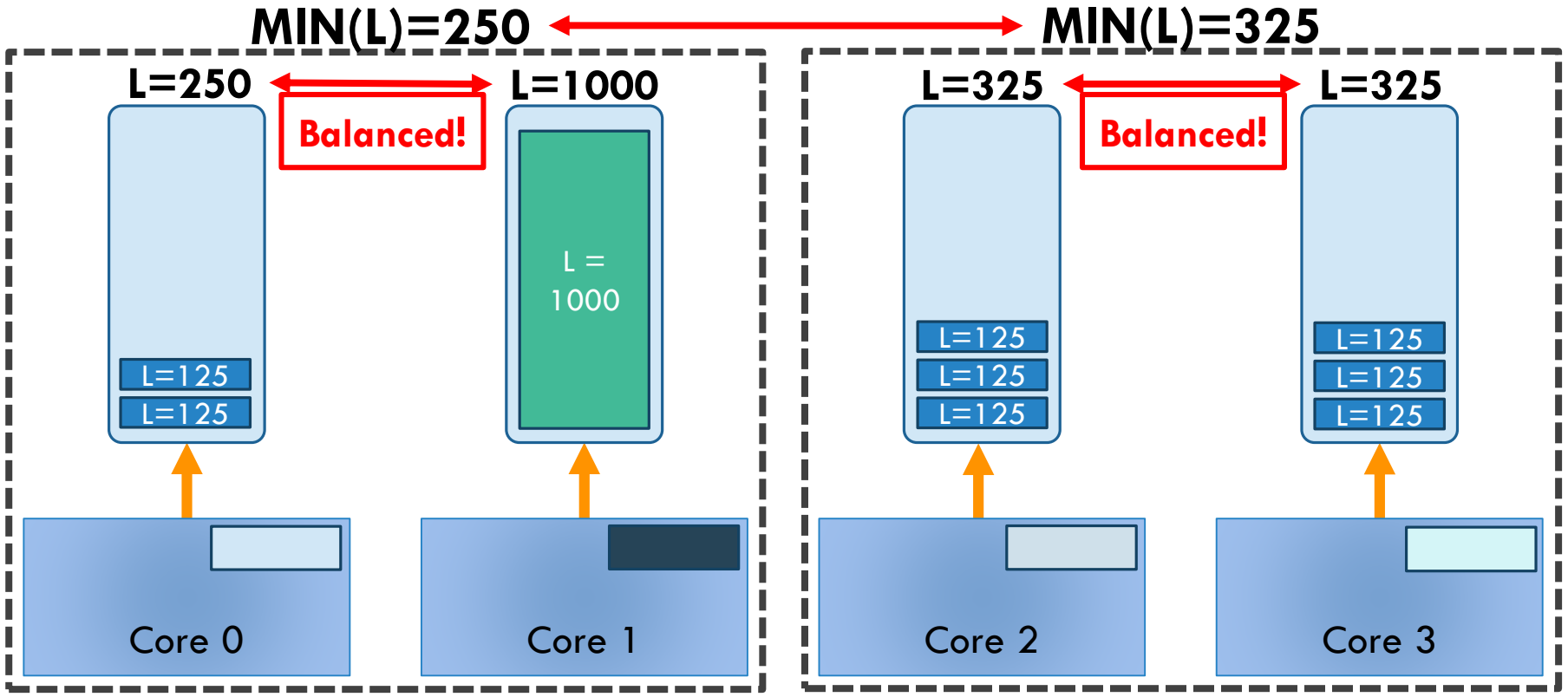

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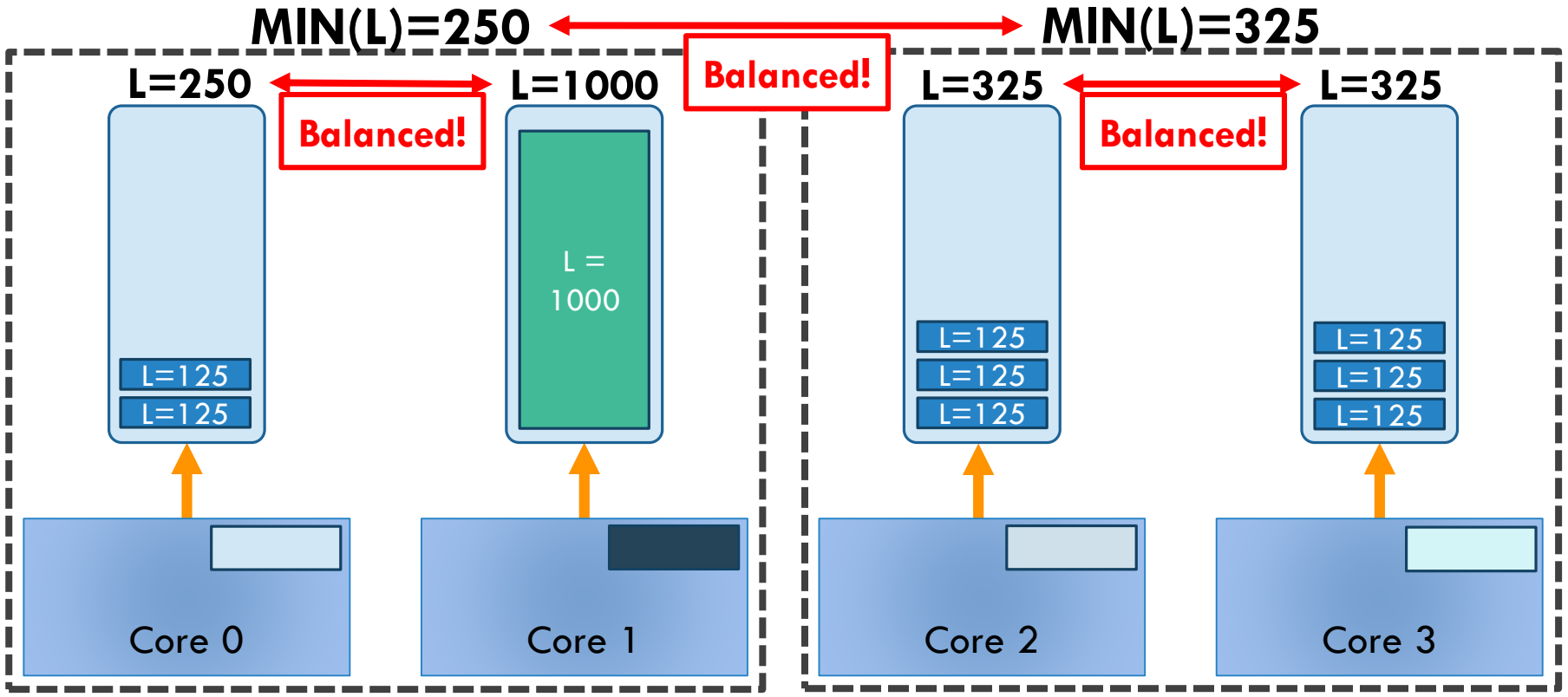

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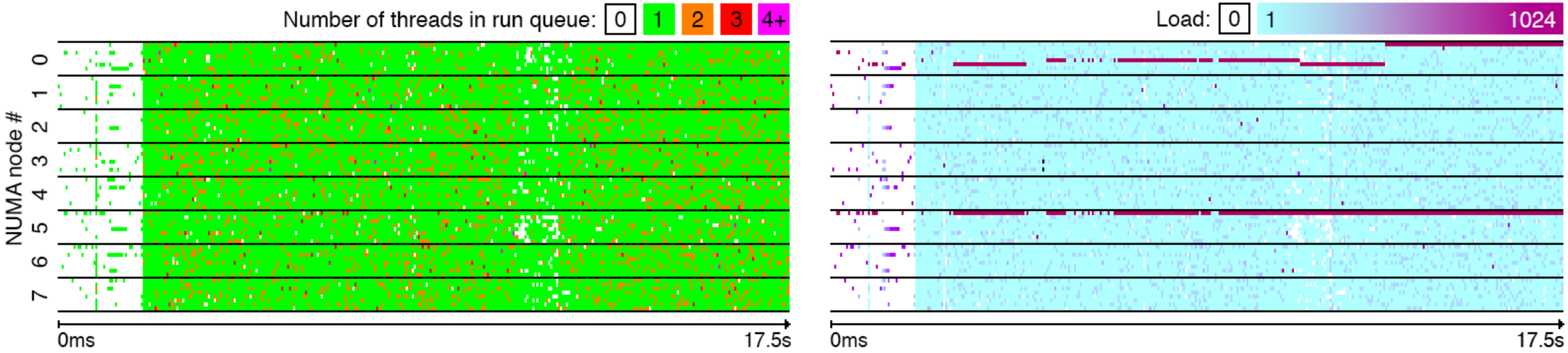

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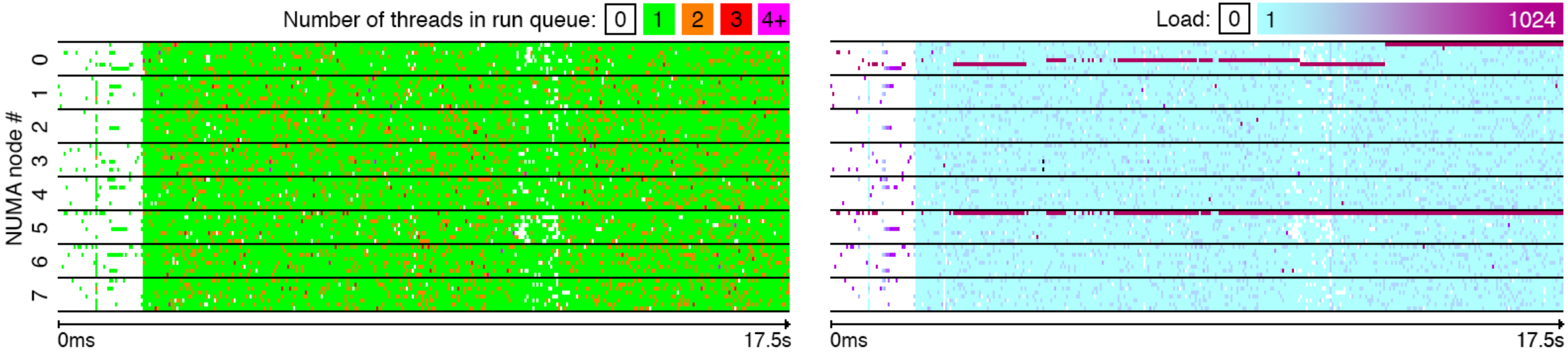

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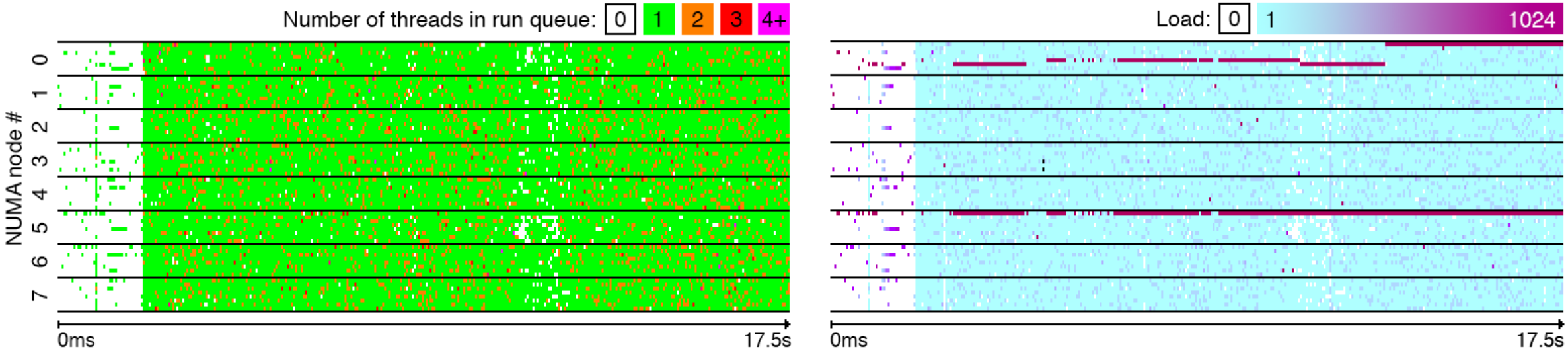

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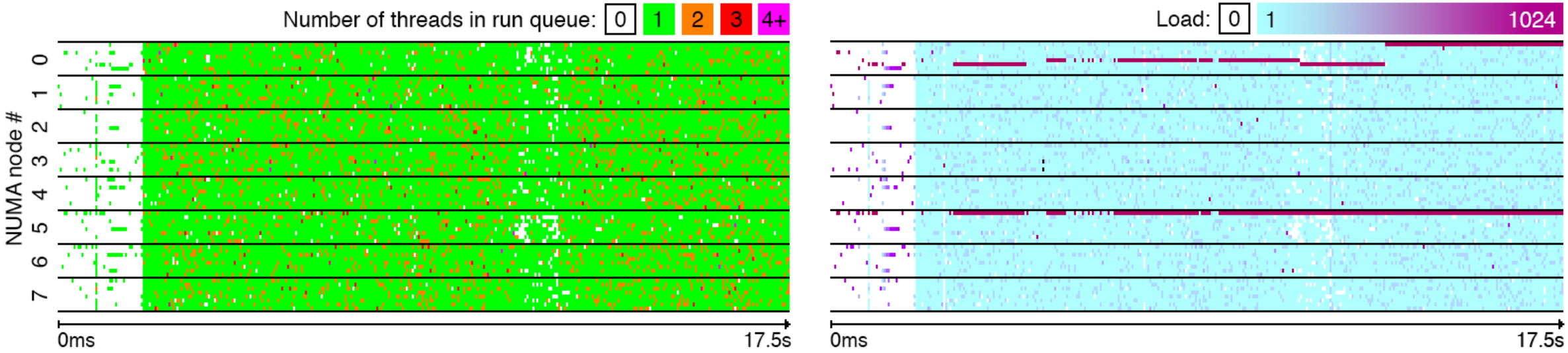

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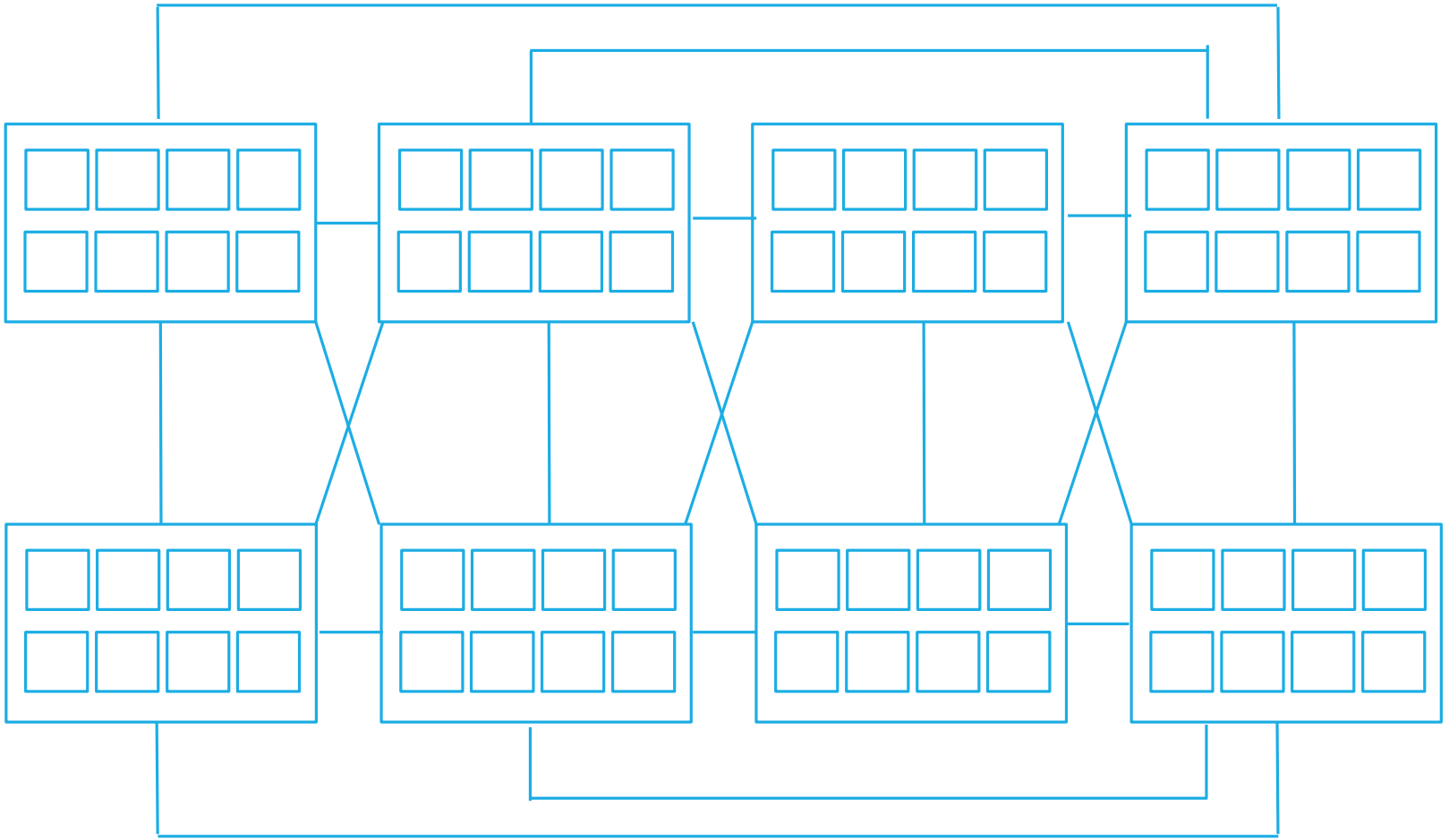
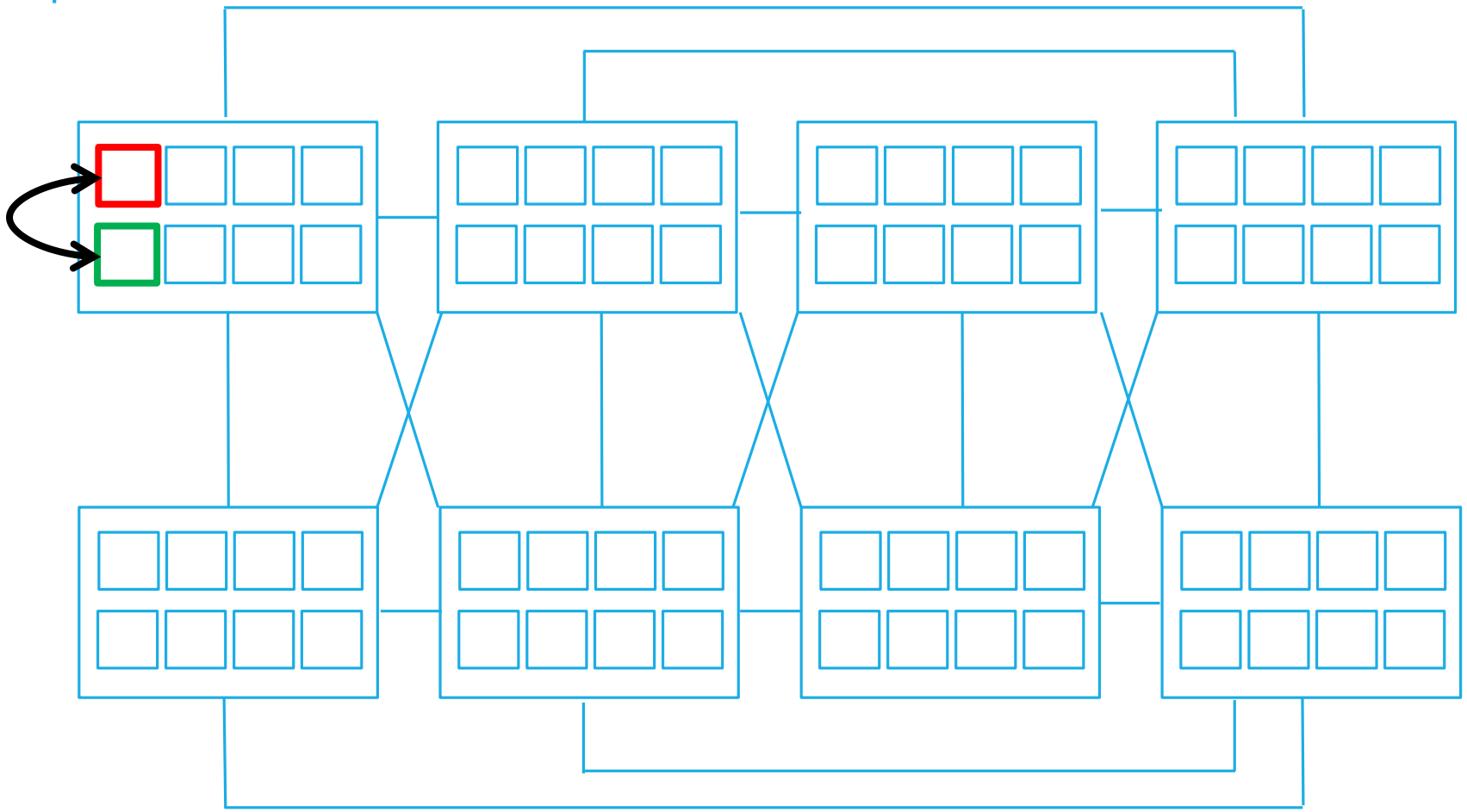
  - At level 4, the whole machine (s.d.) contains group of directly connected CPUs (s.g.)

BUG 2/4: SCHEDULING GROUP CONSTRUCTION



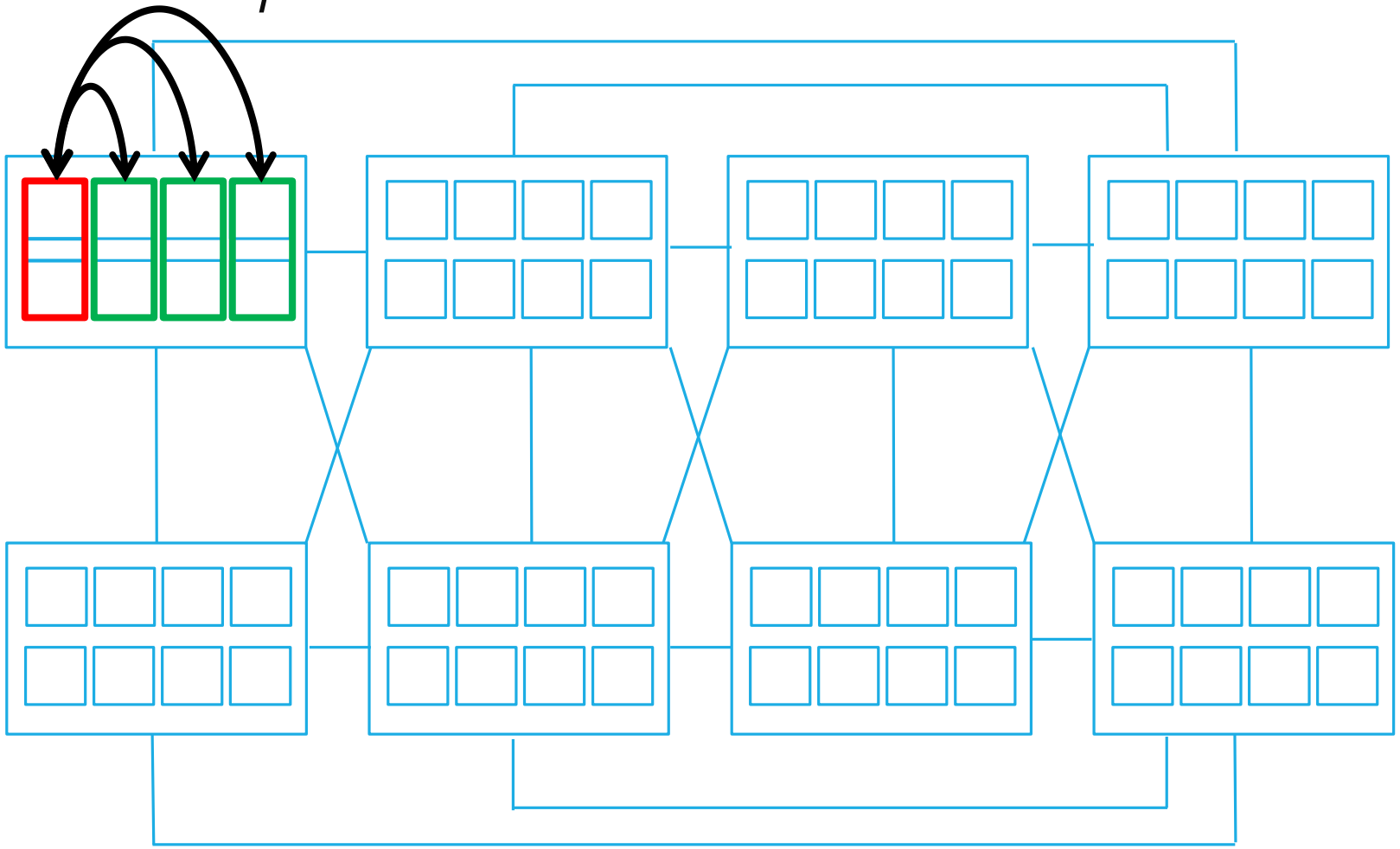
Bulldozer 64-core:
Eight CPUs, with
8 cores each,
non-complete interconnect graph!

BUG 2/4: SCHEDULING GROUP CONSTRUCTION



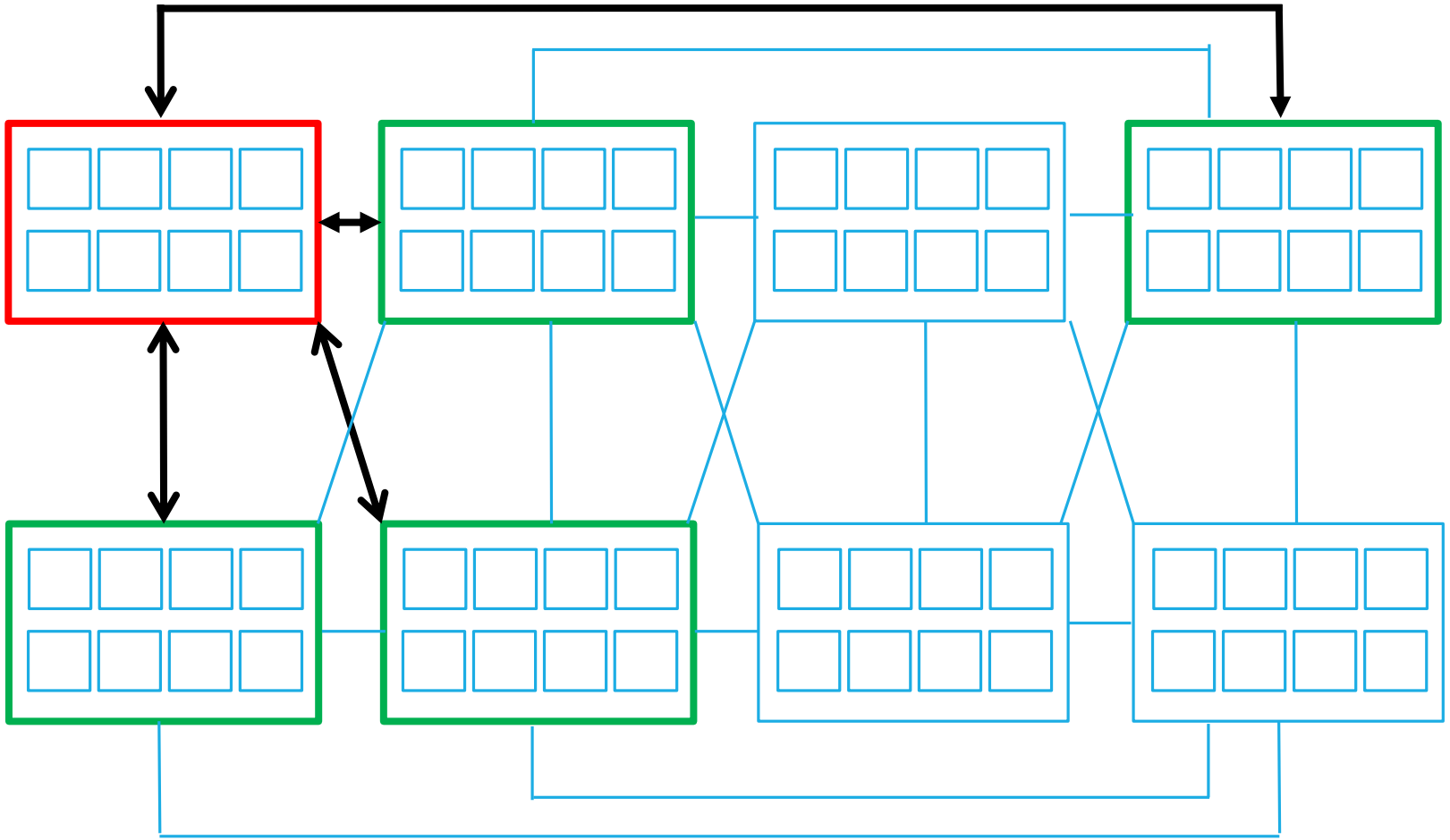
At the **first level**, the **first core** balances load with the other core **on the same pair** (because they share resources, high affinity)

BUG 2/4: SCHEDULING GROUP CONSTRUCTION



At the **2nd level,** the **first pair** balances load with other pairs **on the same CPU**

BUG 2/4: SCHEDULING GROUP CONSTRUCTION



At the **3rd level**, the **first CPU** balances load with **directly connected CPUS**

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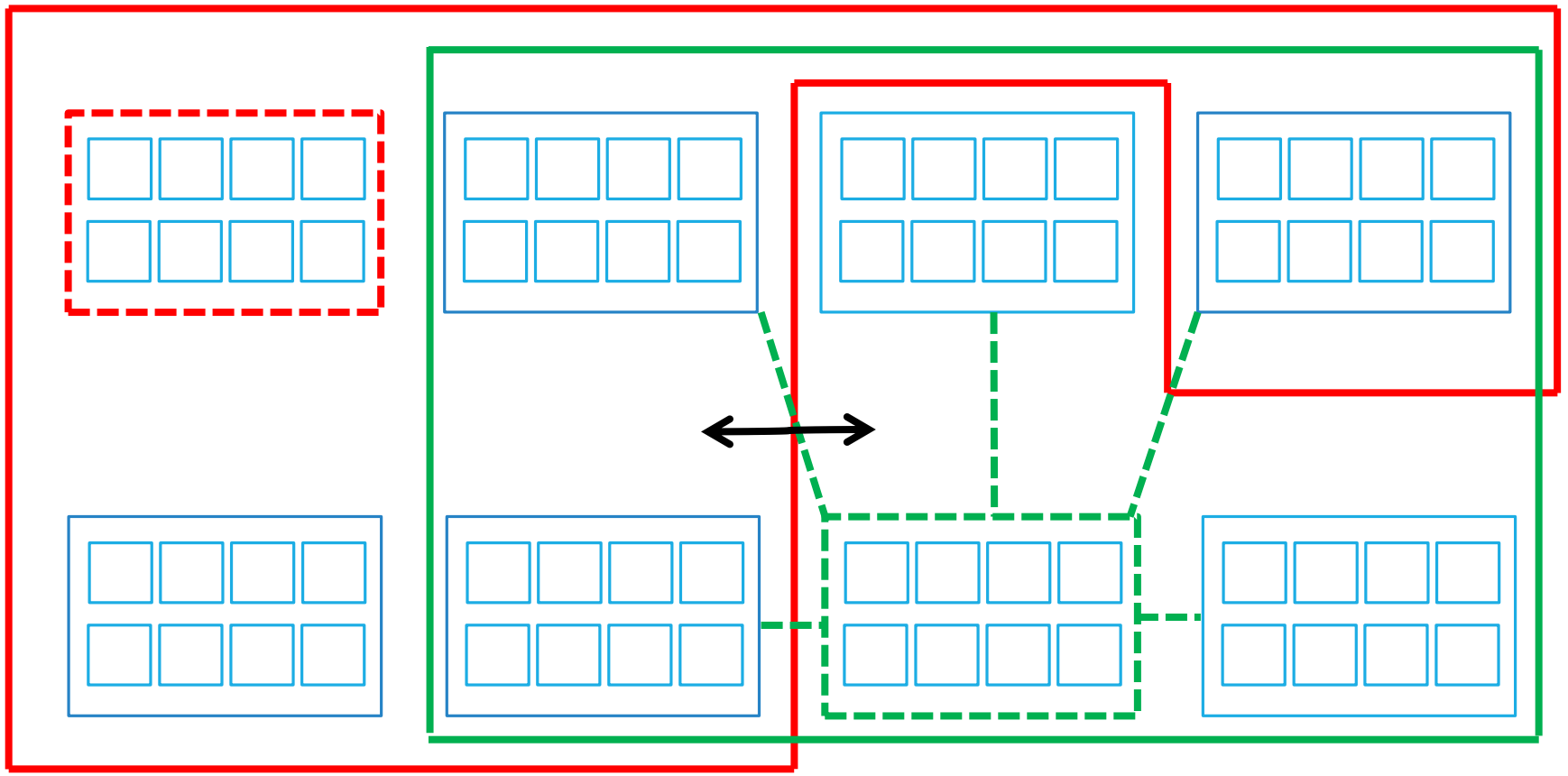

At the **4th level**, the **first group of directly connected CPUs** balances load with **the other groups of directly connected CPUs**

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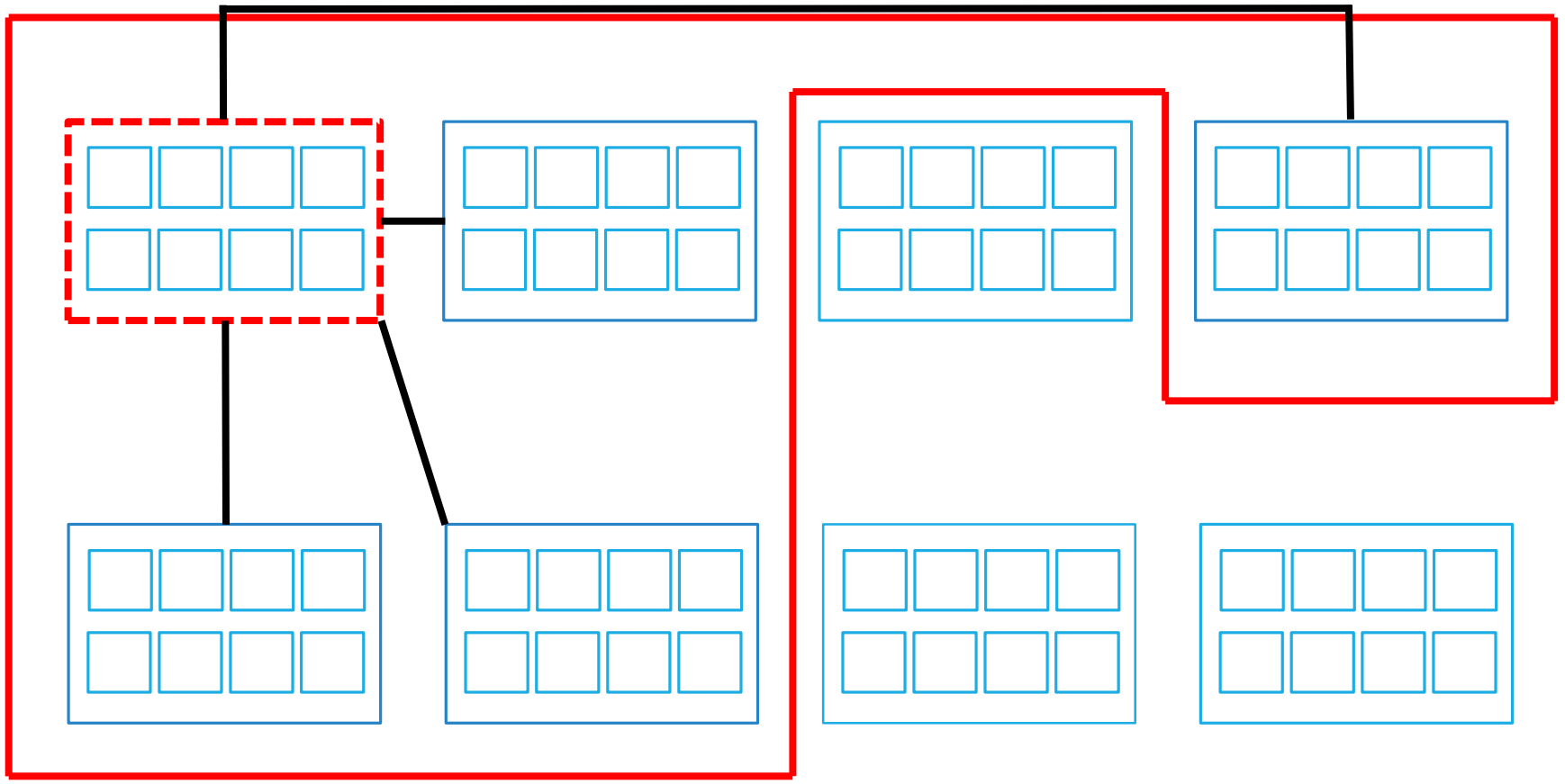

Groups of CPUs built by:

(1) picking first CPU and looking for all directly connected CPUs

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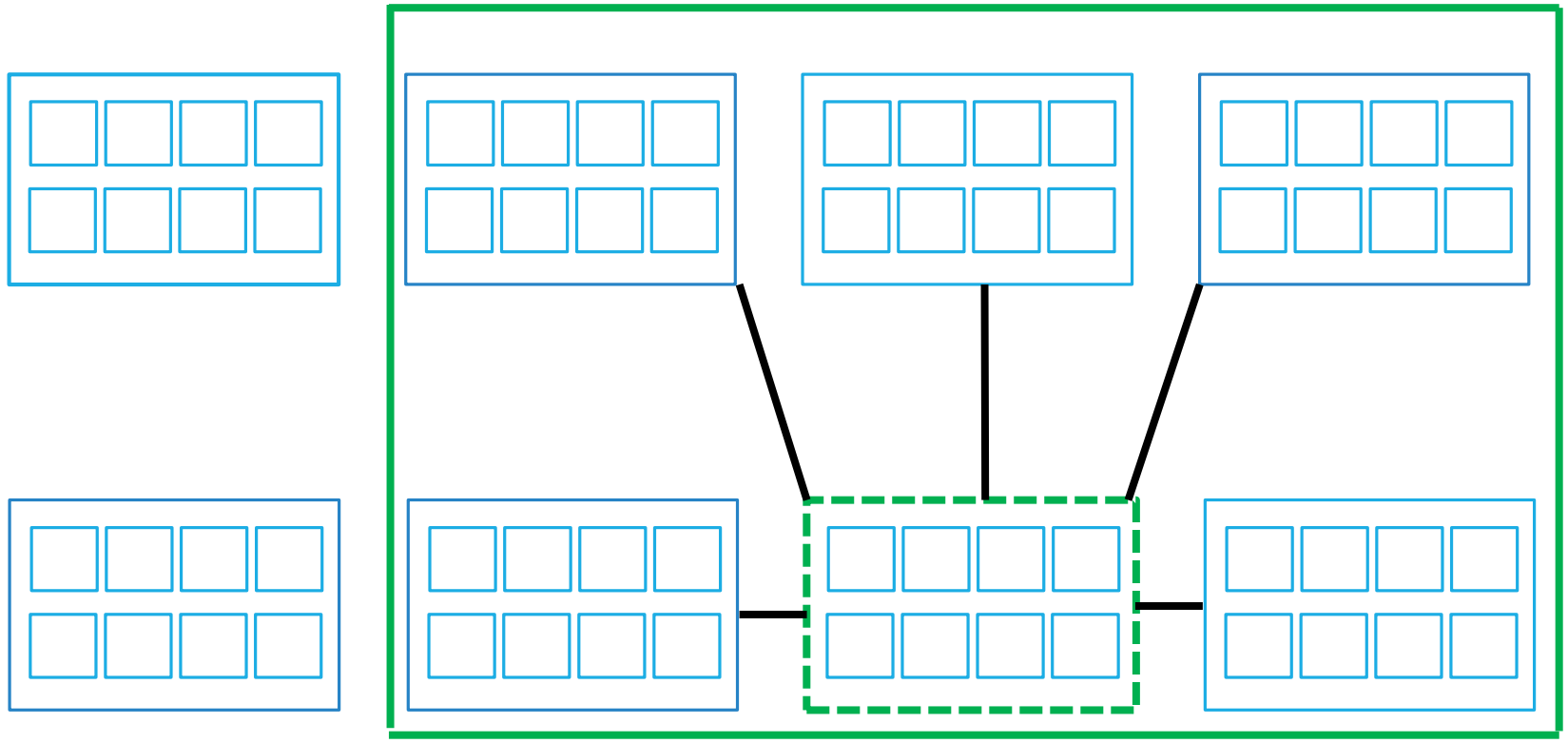
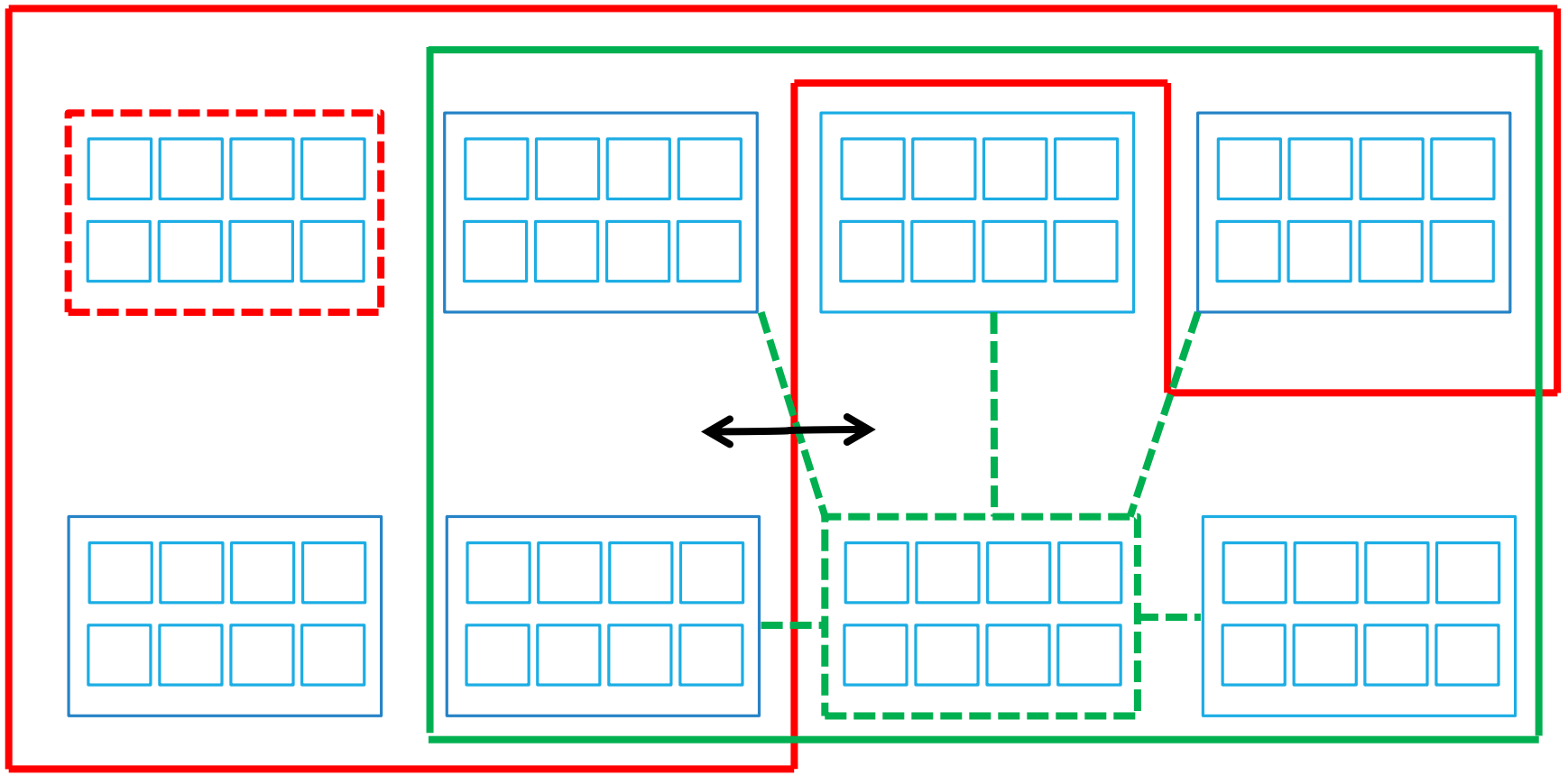


Groups of CPUs built by:

(2) picking first CPU not in a group and looking for all directly connected CPUs

BUG 2/4: SCHEDULING GROUP CONSTRUCTION



And then stop,
because all CPUs are in a group

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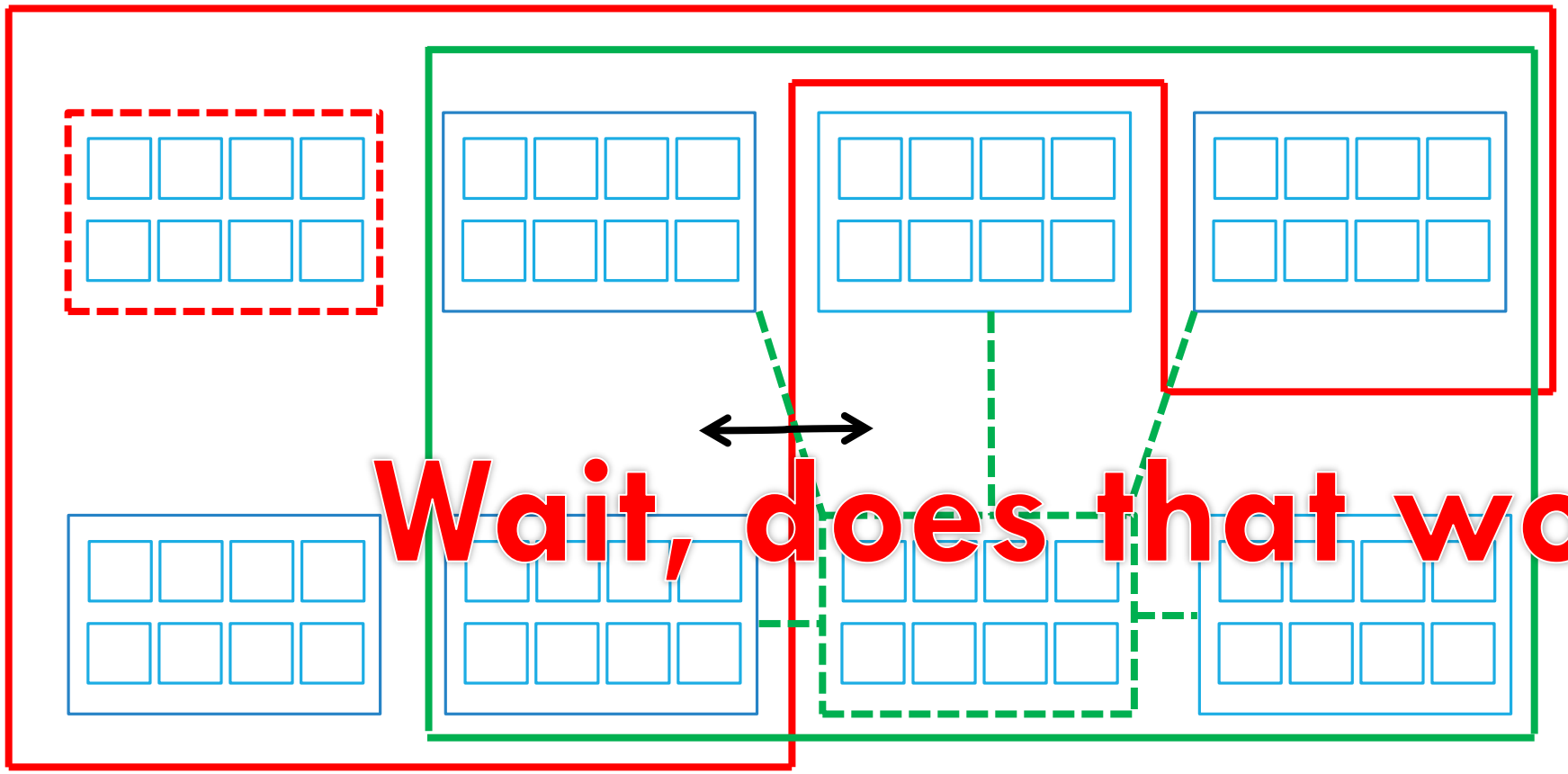

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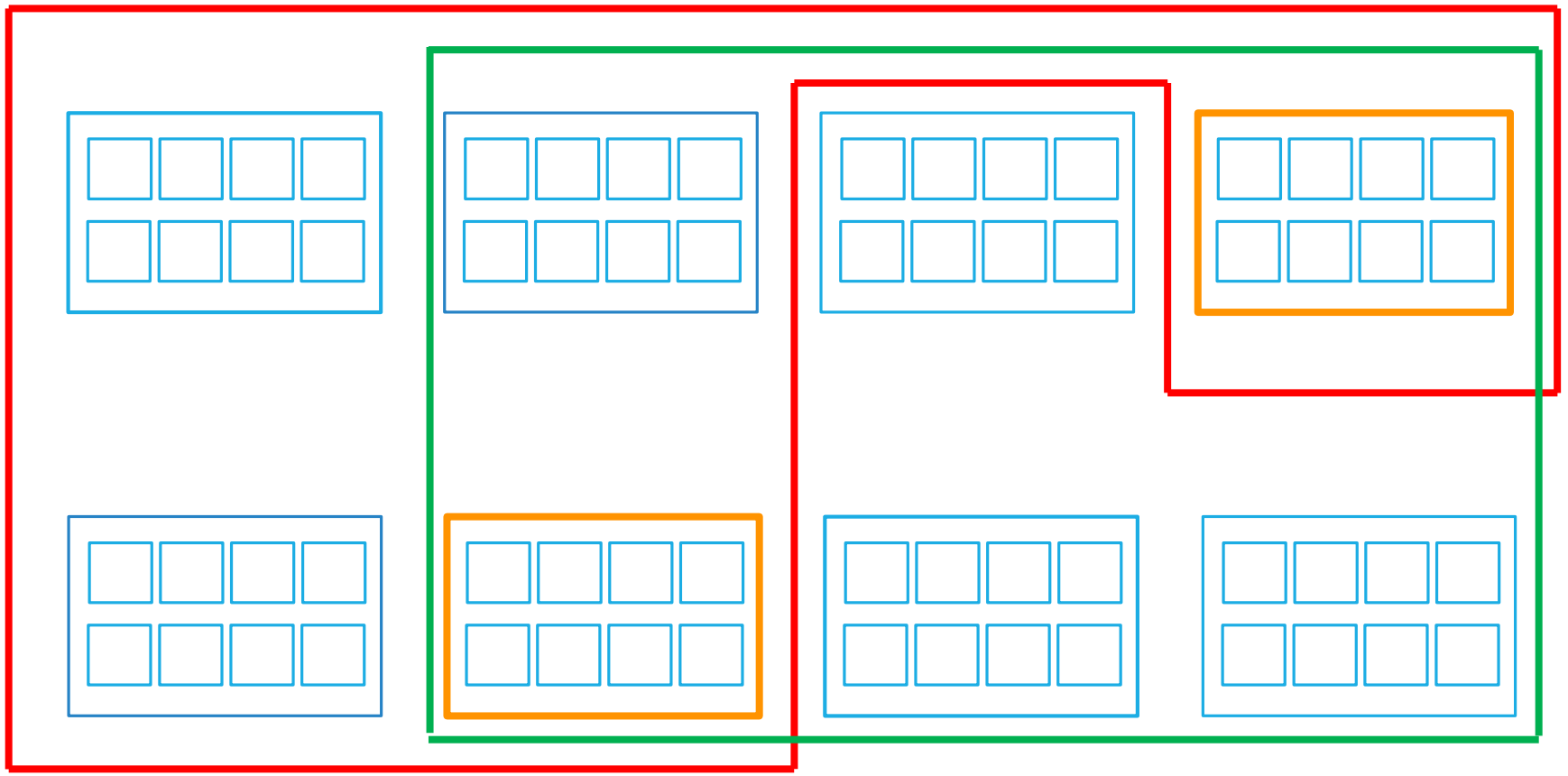

Suppose we taskset an application on **these two CPUs,** two hops apart (16 threads)

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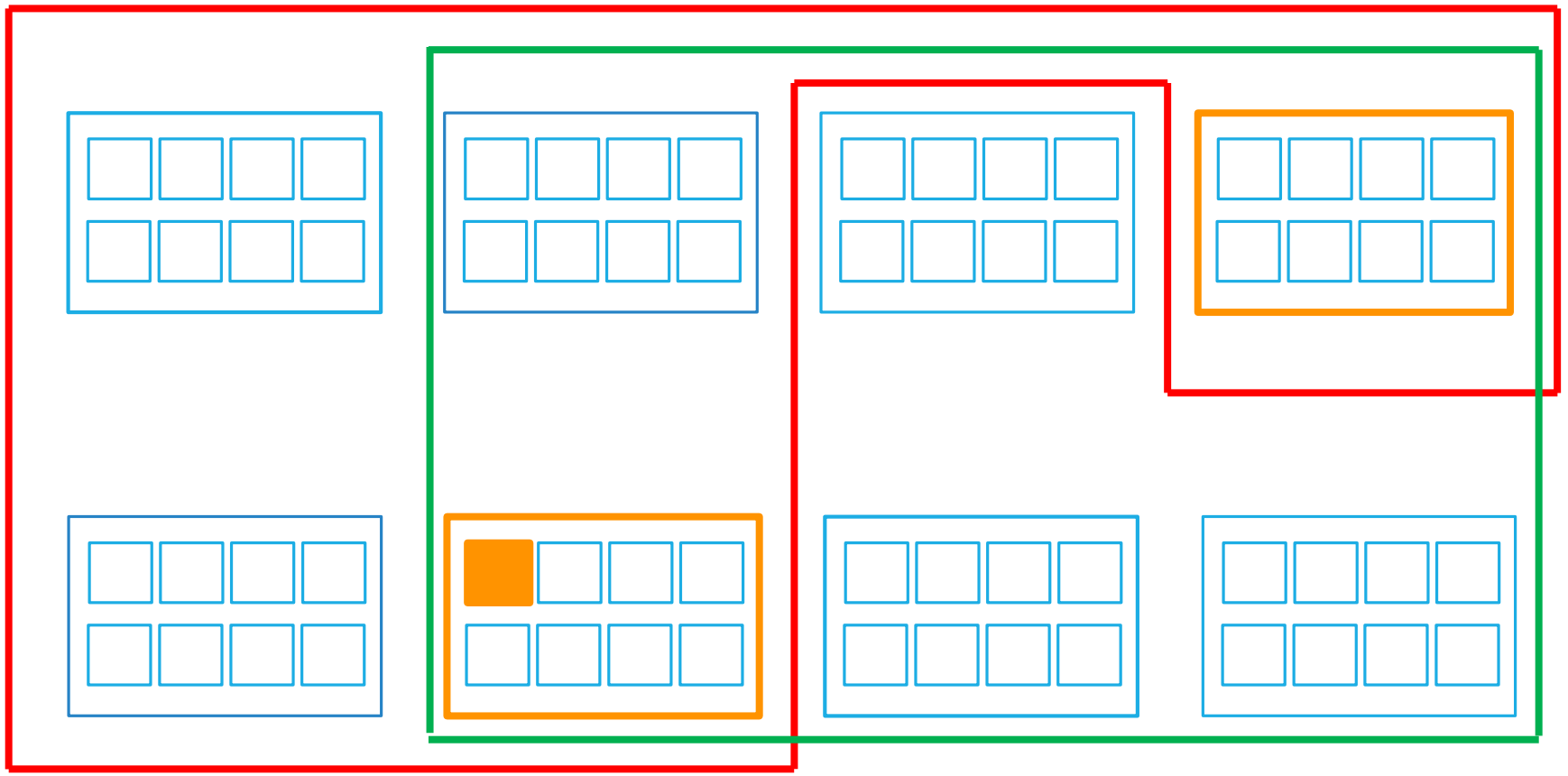

And threads are created **on this core**

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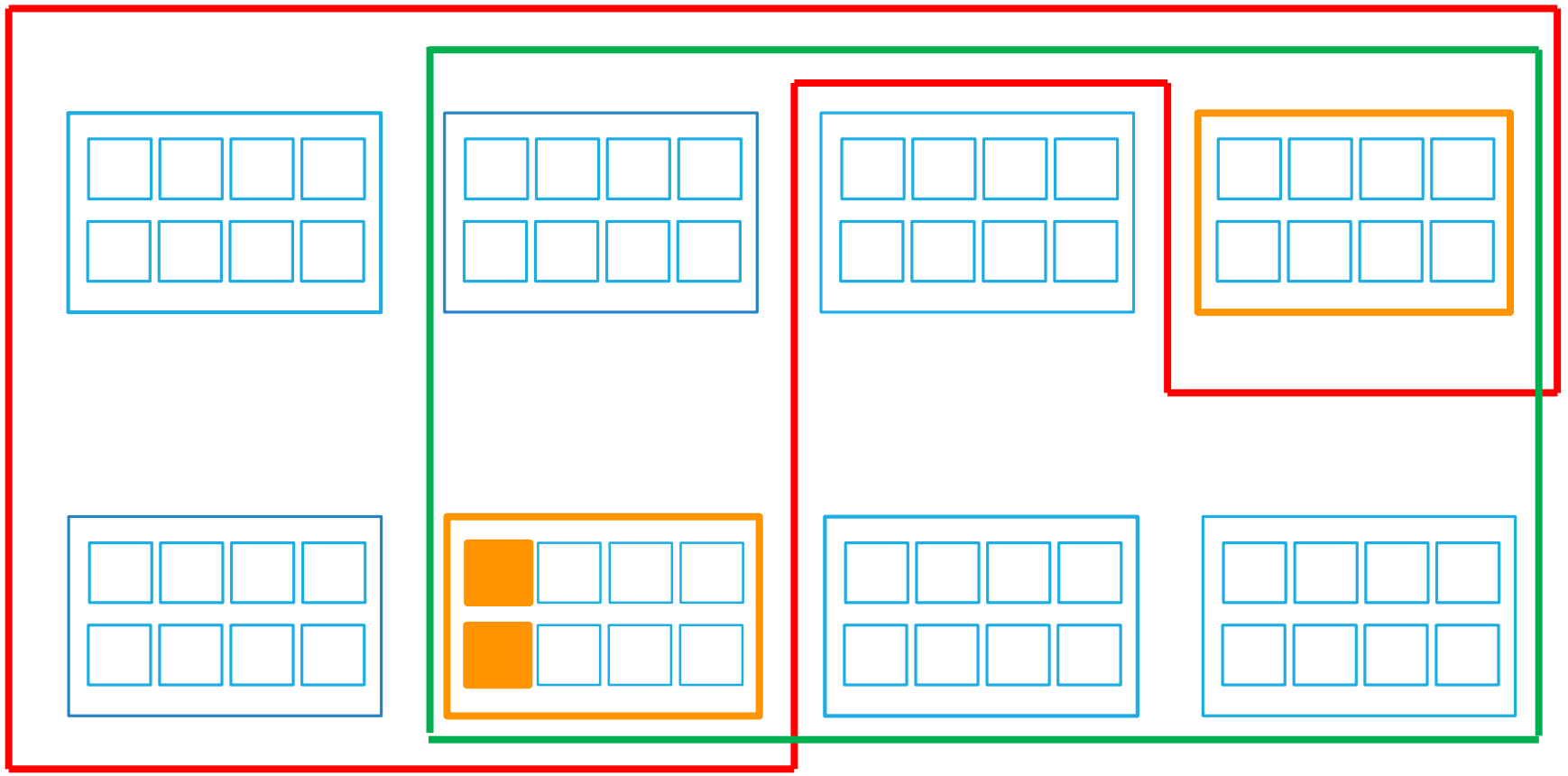

Load gets correctly balanced **on the pair of cores**

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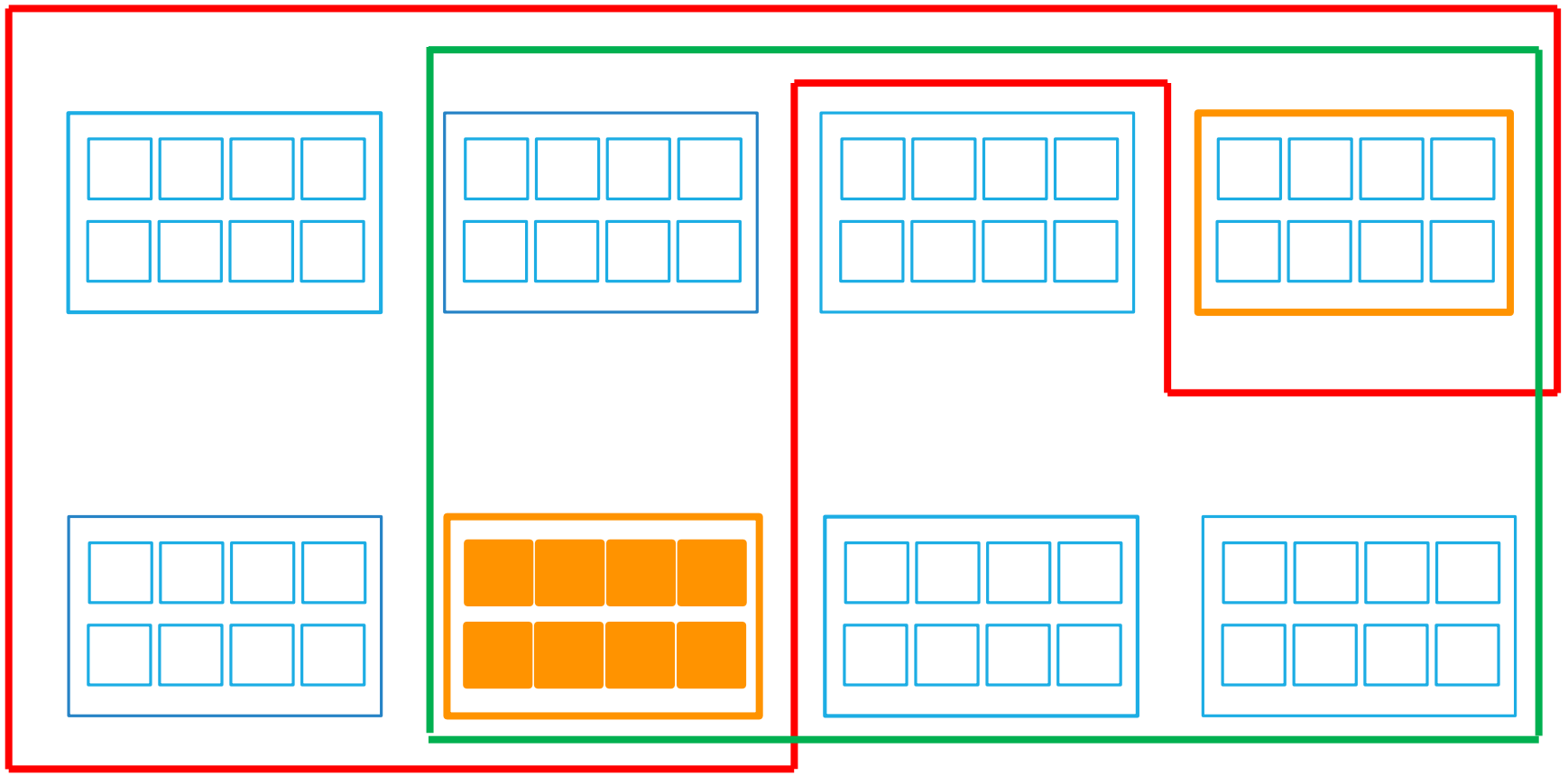

Load gets correctly balanced **on the CPU**

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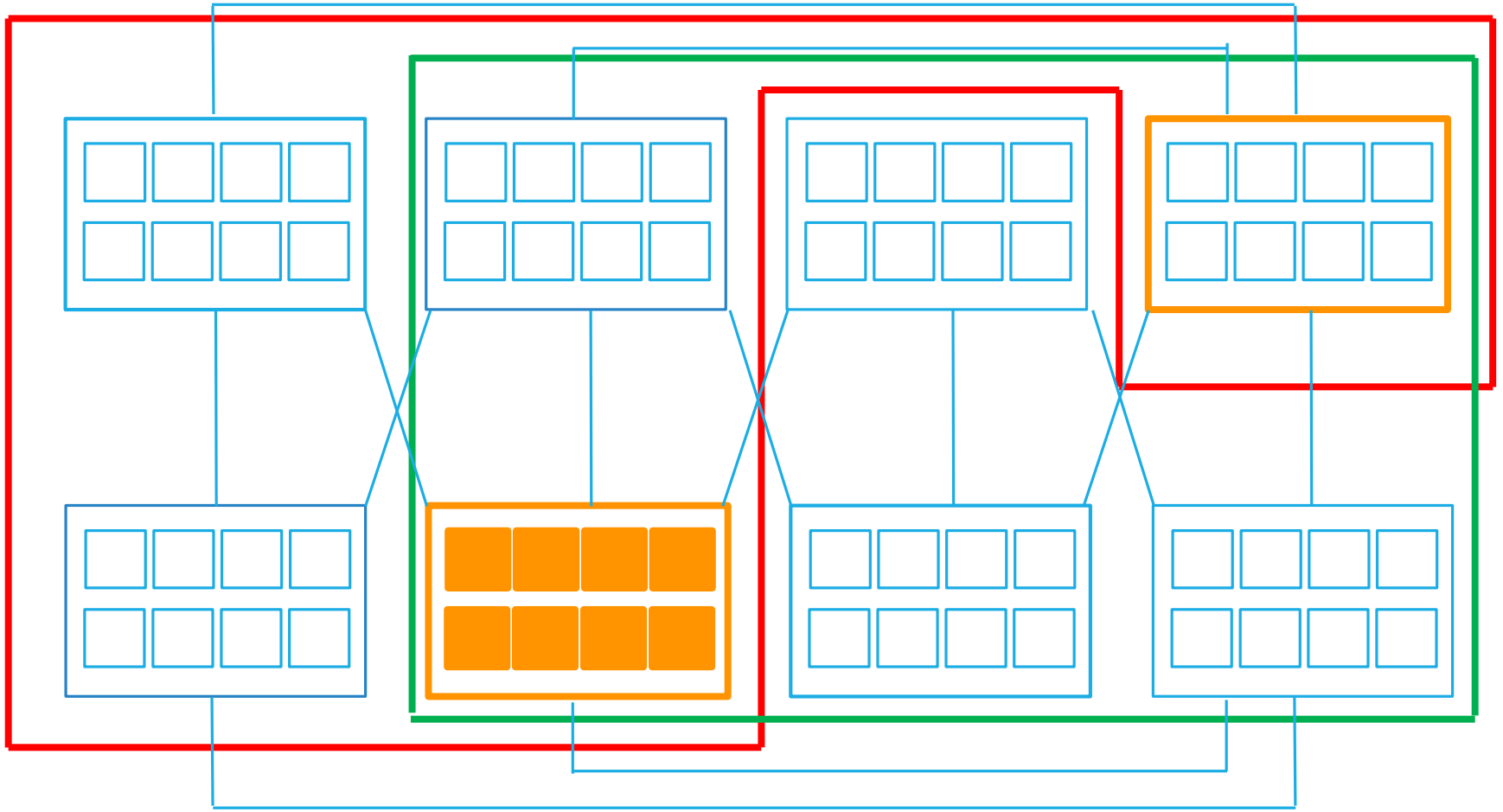

No stealing at level 3, because nodes not directly connected (1 hop apart)

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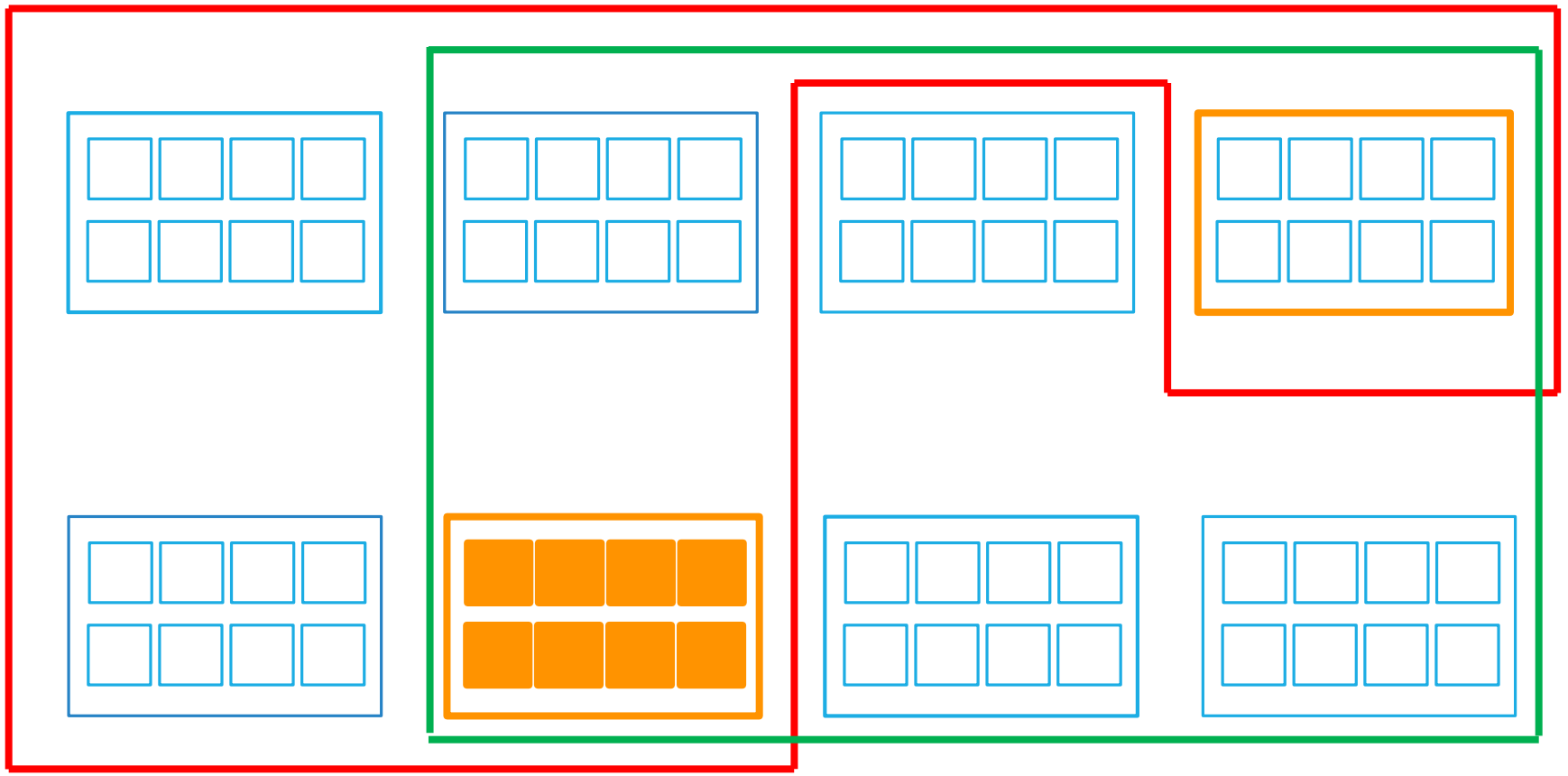

At level 4, stealing between the red and green groups...

Overloaded node in both groups!

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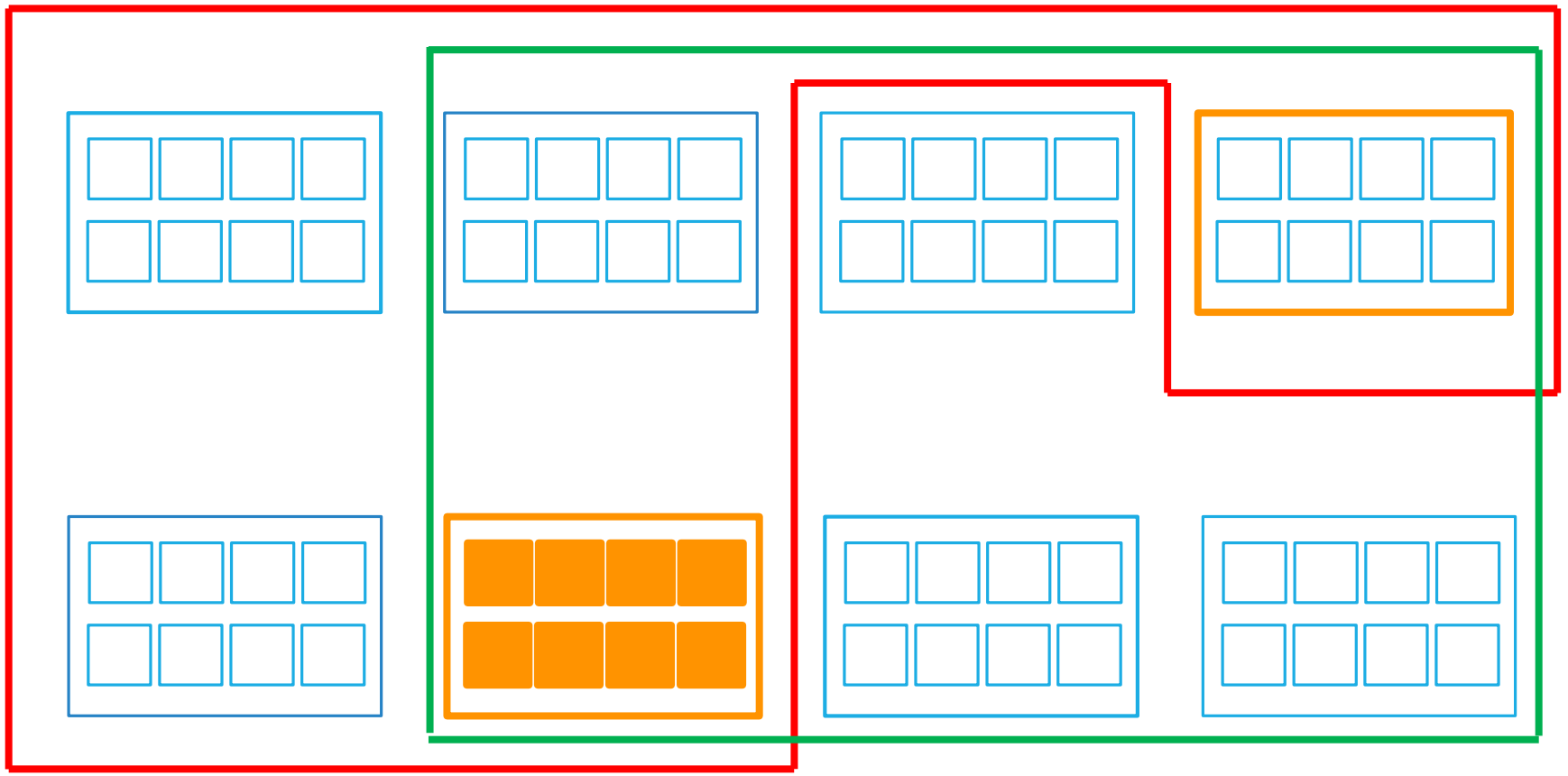

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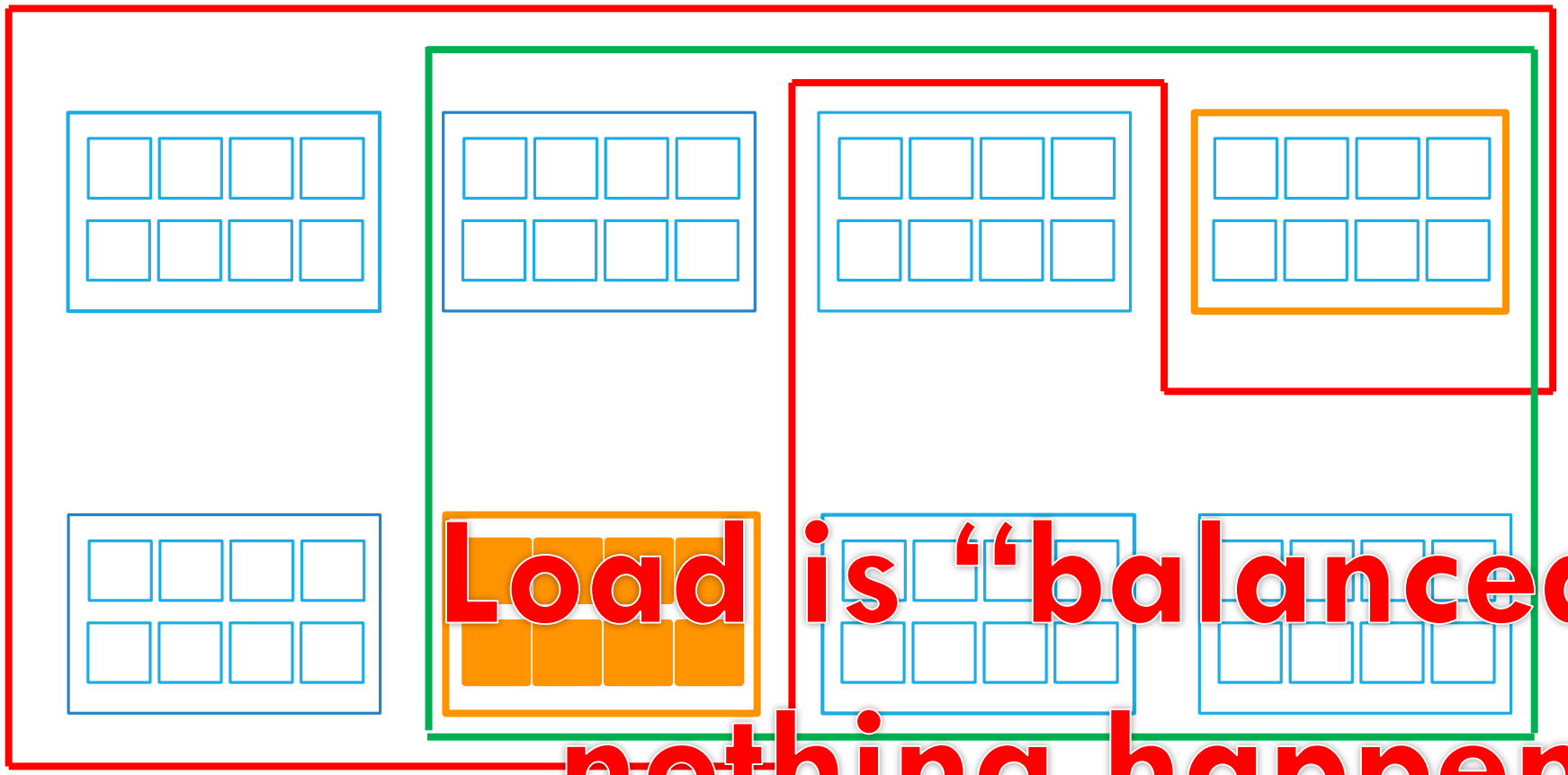

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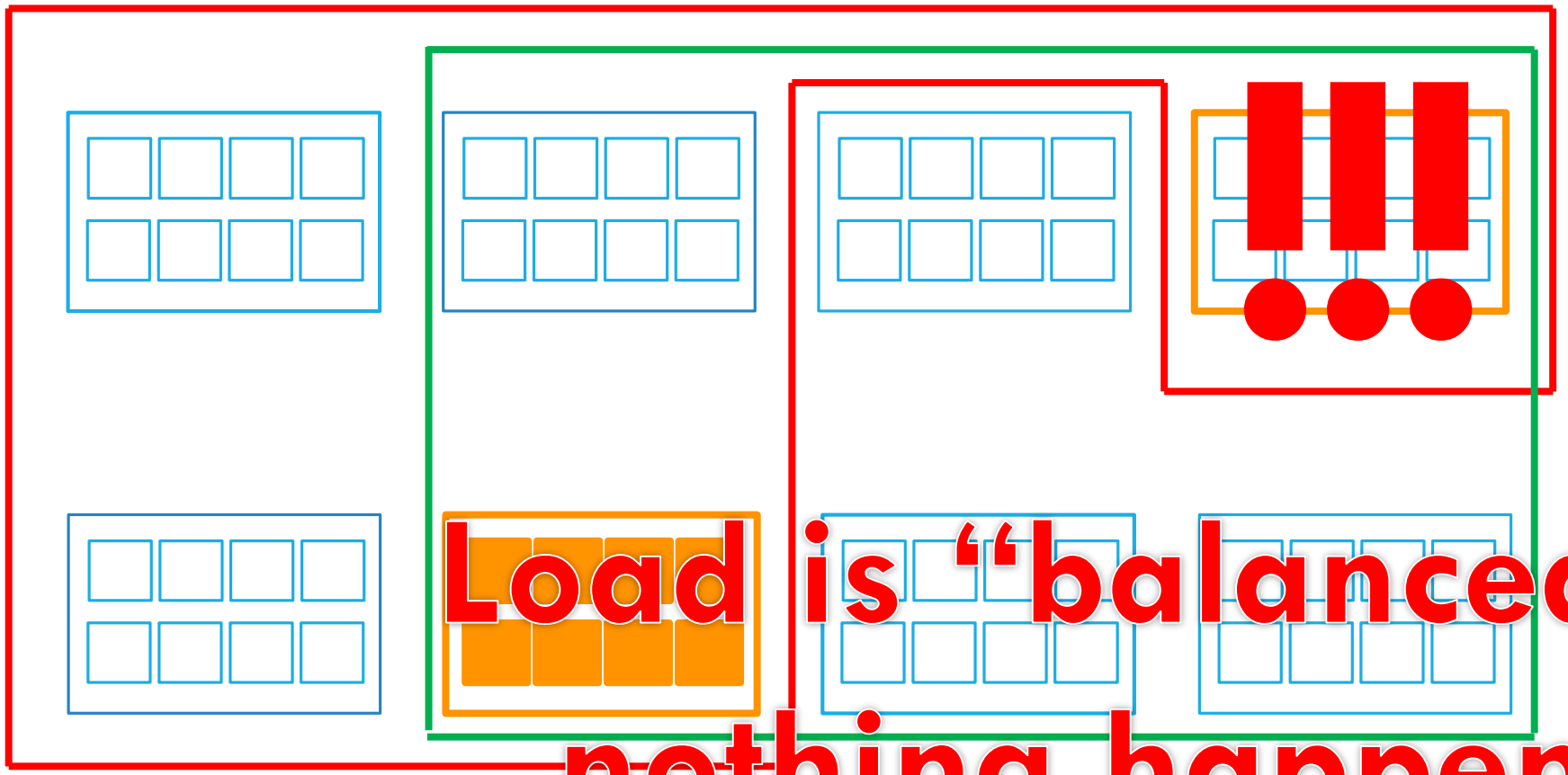

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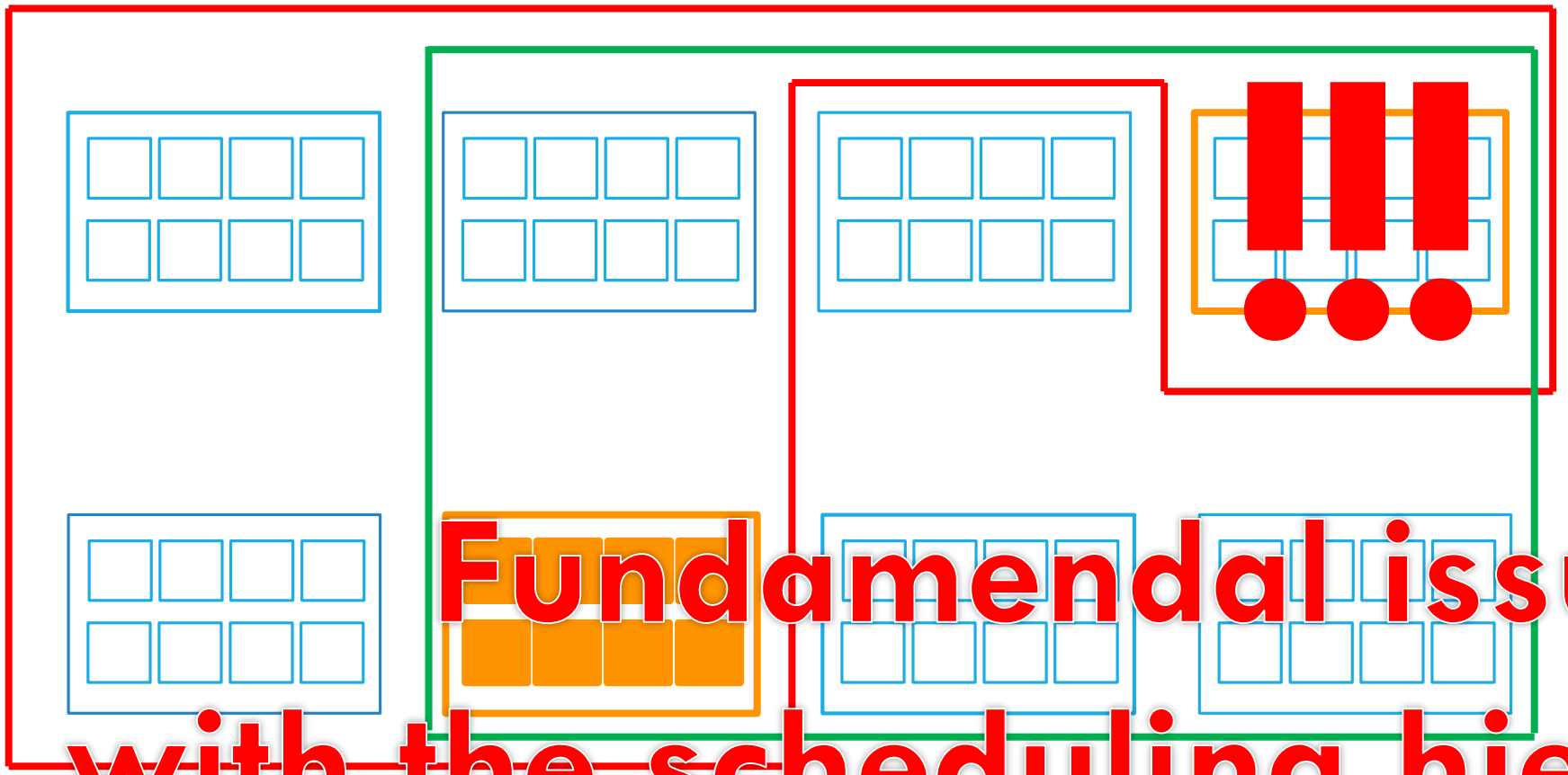

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Fundamendal issue with the scheduling hierarchy !

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- **Very good improvement for LU because more threads than cores if can't use 16 cores**
  - Solves spinlock issues (incl. potential convoys)

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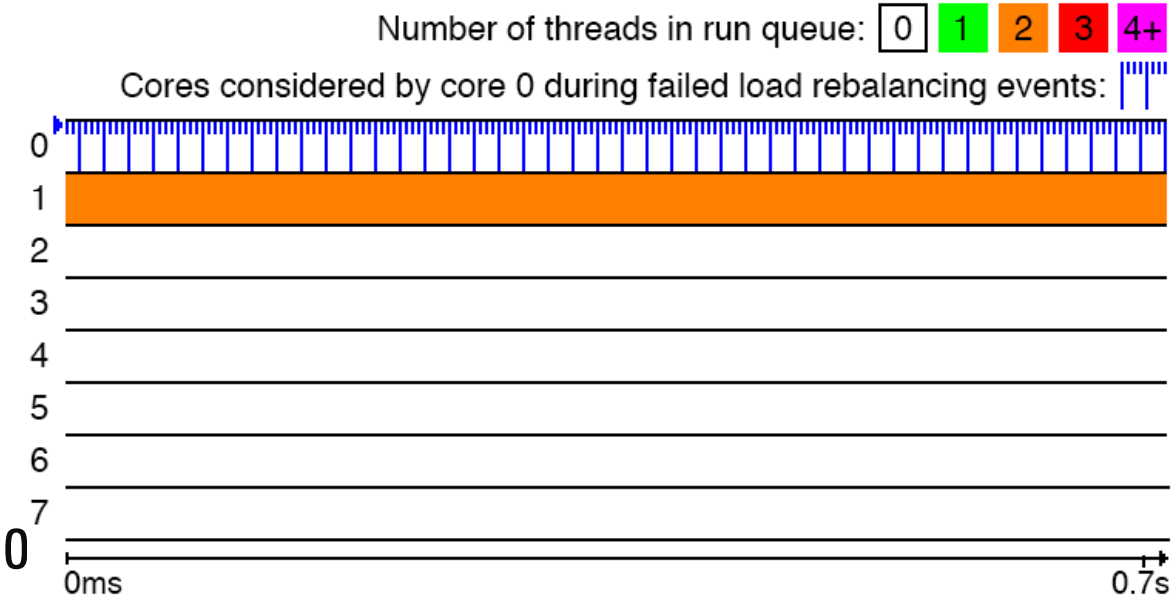

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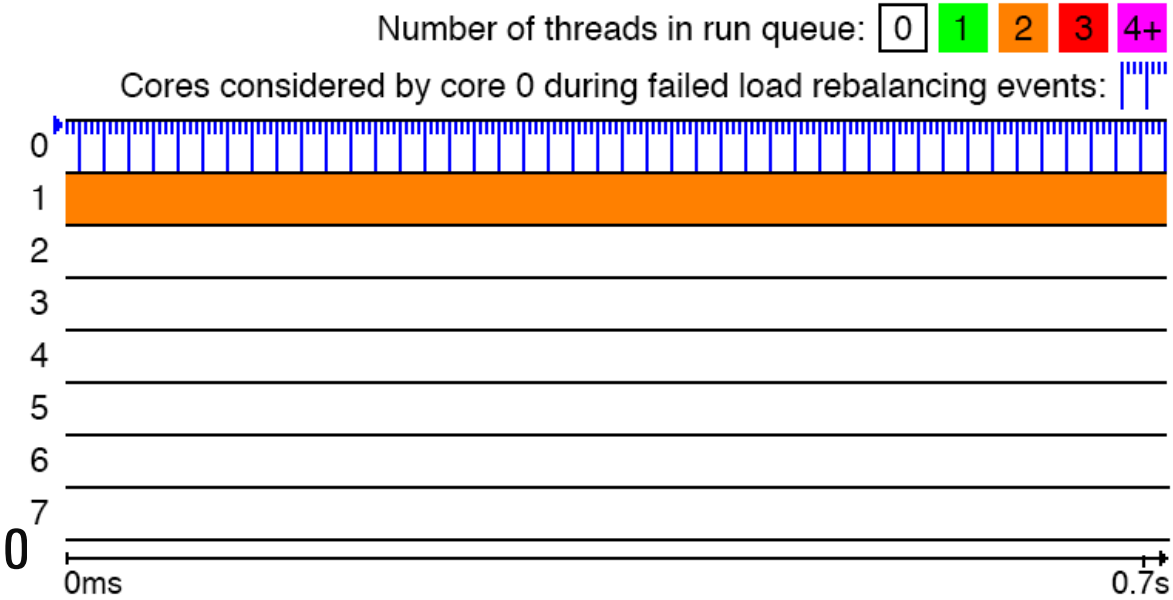
CG	134	5.4	25x
EP	72	18	4x
LU	2196	16	137x



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Wait, does that work?

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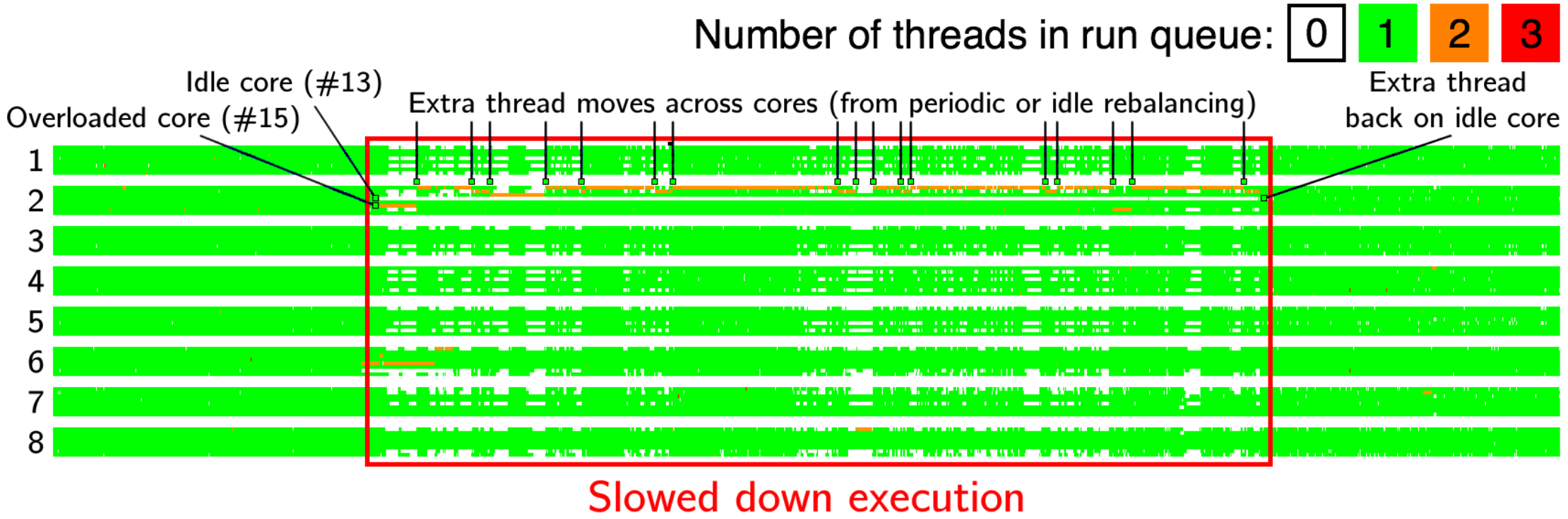

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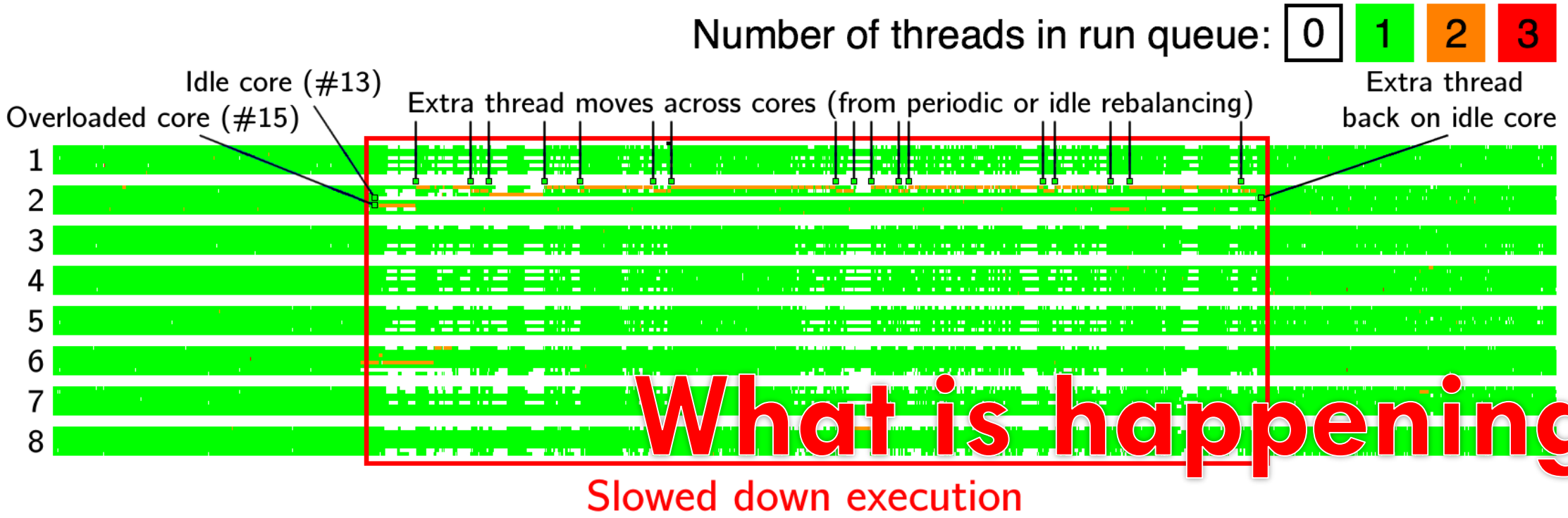

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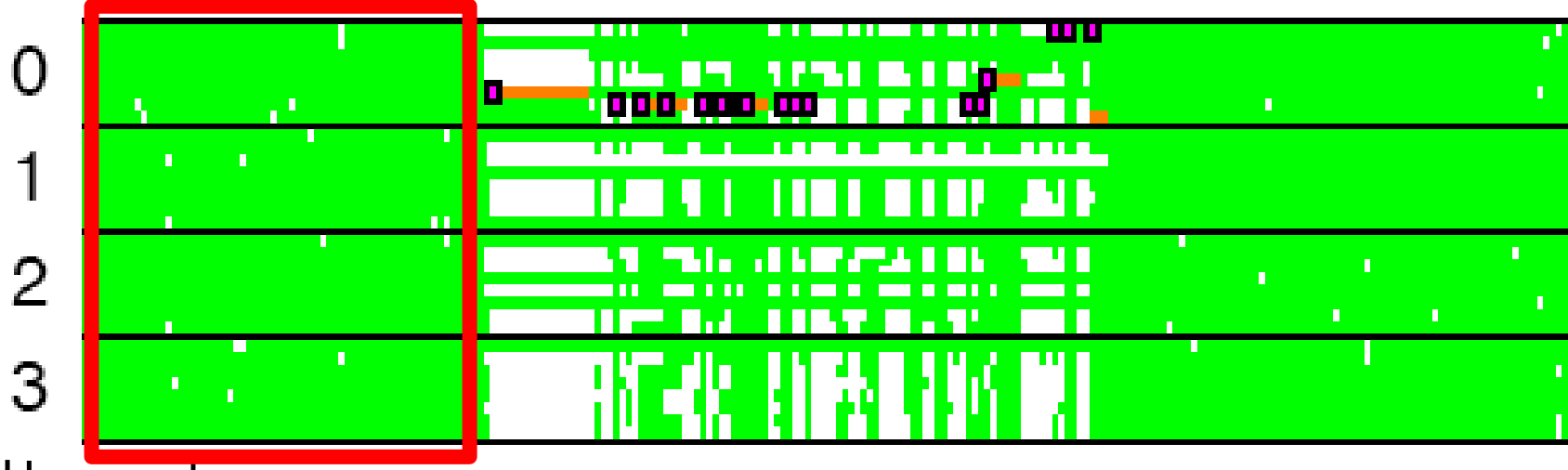

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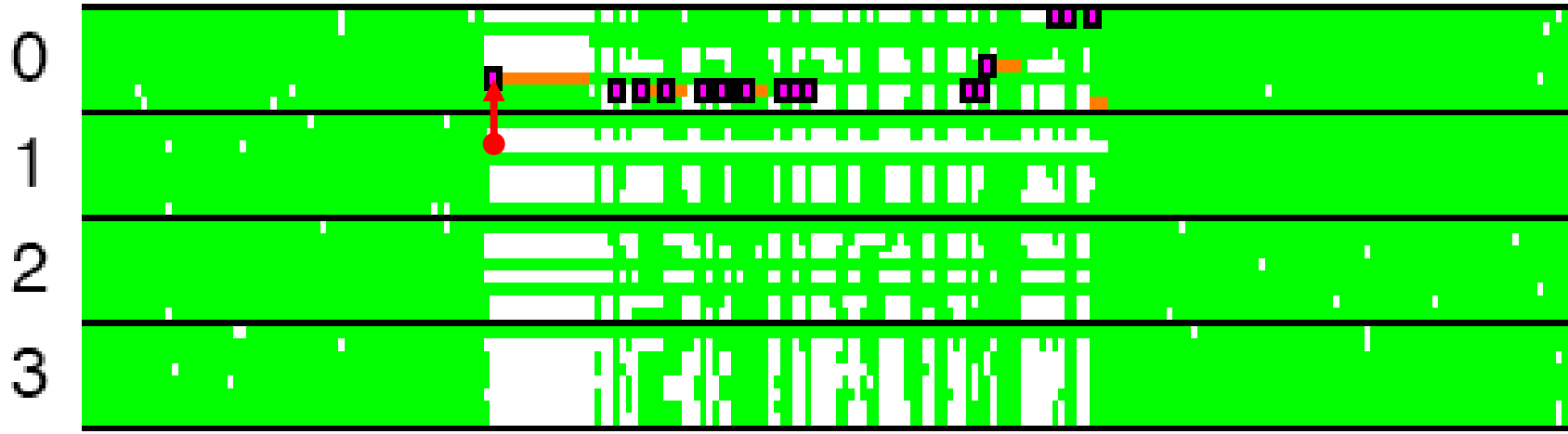

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Bug fixes	TPC-H request #18	Full TPC-H benchmark
None	55.9s	542.9s
Group Imbalance	48.6s (–13.1%)	513.8s (–5.4%)
Overload-on-Wakeup	43.5s (–22.2%)	471.1s (–13.2%)
Both	43.3s (–22.6%)	465.6s (–14.2%)

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  - Hierarchical rebalancing uses a metric named ***load***,
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  - In addition to this, threads balance load by ***selecting core where to wake up***.

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Wait, was anything working at all? ☺

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- **Model checking, formal proofs**
  - Complex, parallel code: so far, nobody knows how to do it...

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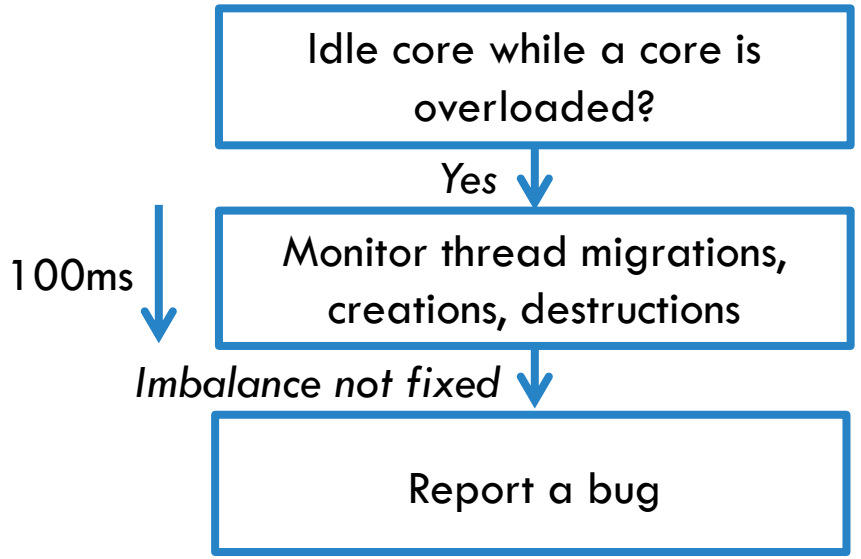

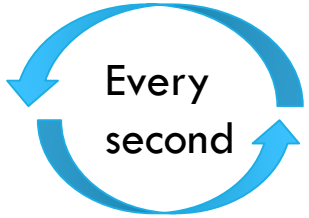

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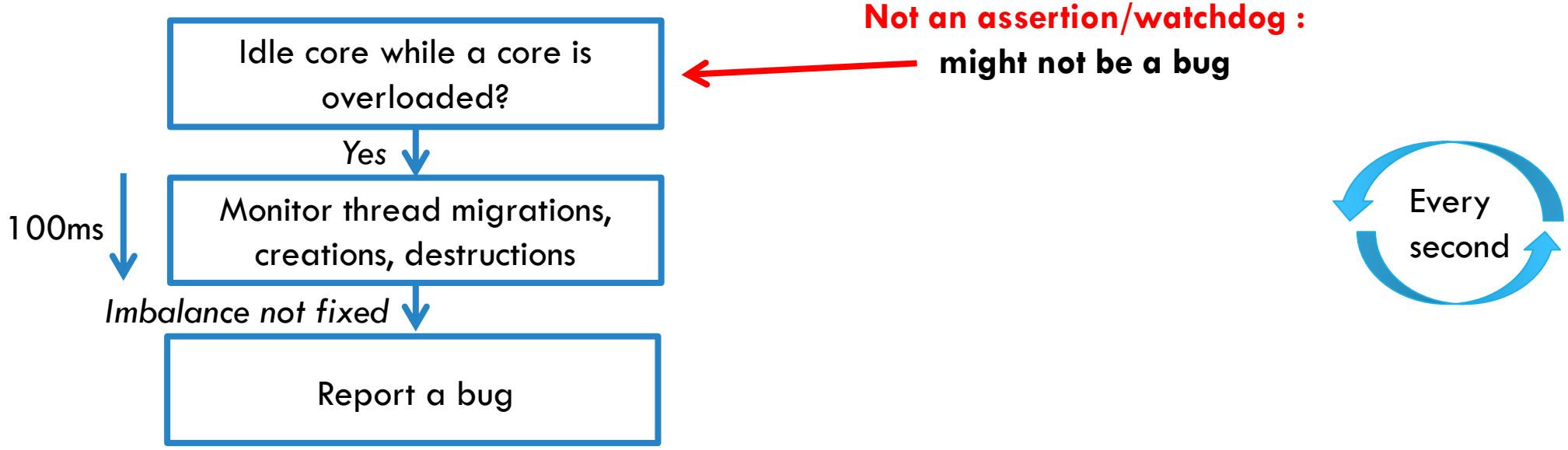

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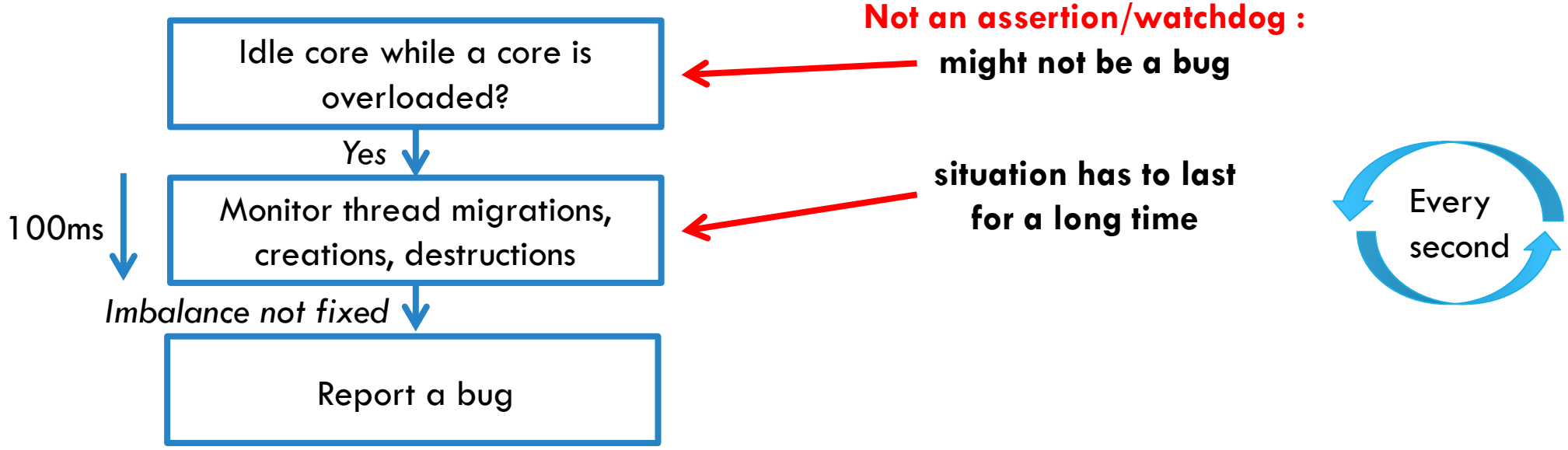

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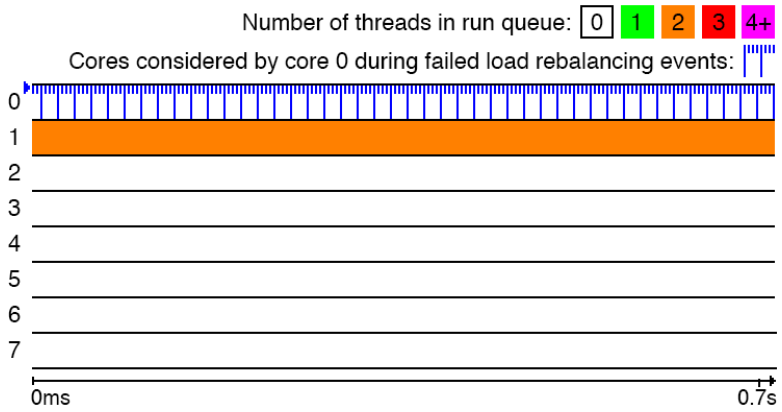

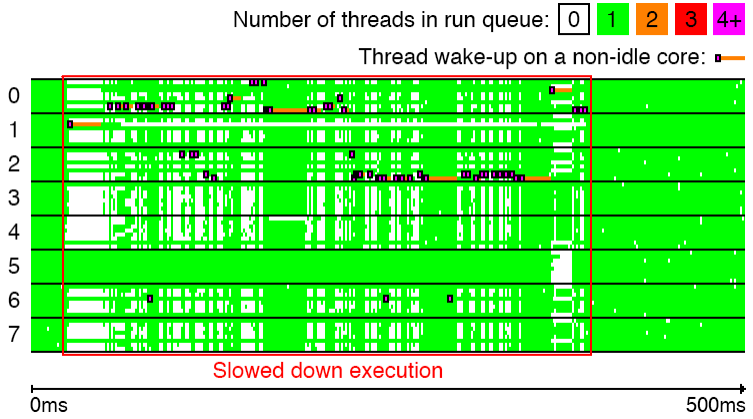

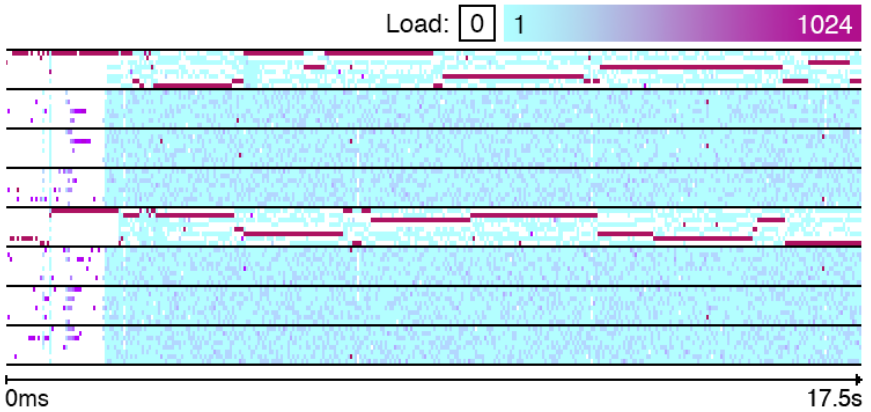

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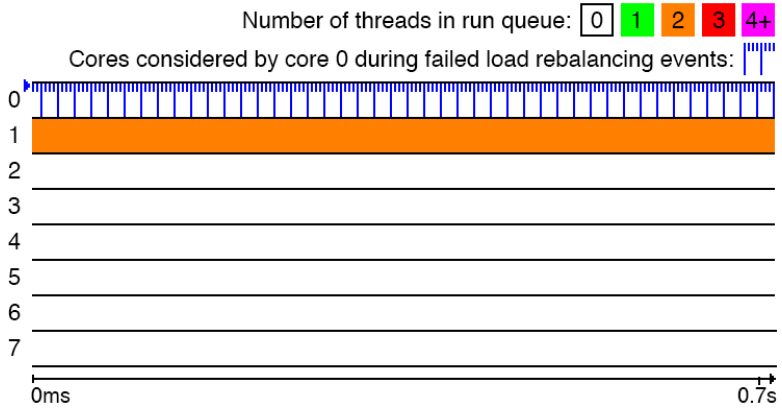

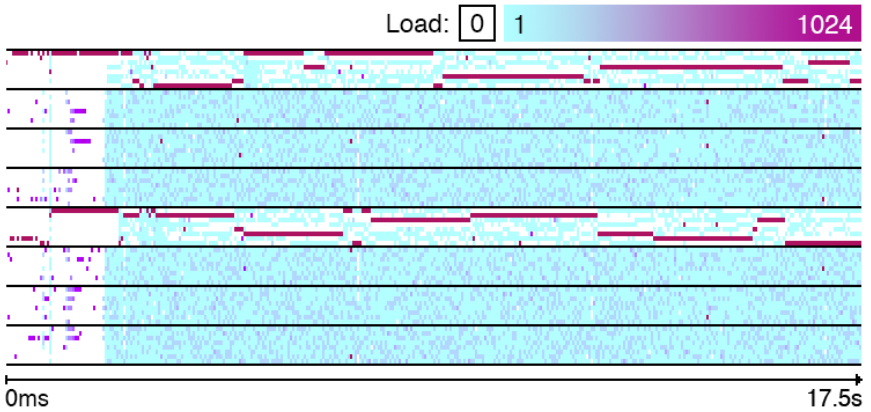

- **Could really be improved!**

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  - Follow threads, and see if often on overloaded cores when shouldn't have?
  - Detect if threads unnecessarily moved to core/node that leads to many cache misses?

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  - **Using combination of many real applications:** configuration nightmare!
  - Simulated workloads?
    - Have to do **elaborate work**: spinning and sleeping not efficient
    - Have to be **representative of reality**, have to **cover corner cases**
      - *Use machine learning? Genetic algorithms?*

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  - Many heuristics interact in complex, unpredictable ways
  - Some features greatly complexify, e.g., load balancing (tasksets, cgroups/autogroups...)
- Keeps getting worse!
  - **E.g., task_struct:** 163 fields in Linux 3.0 (07/2011), 215 fields in 4.6 (05/2016)
  - **20,000 lines of C!**

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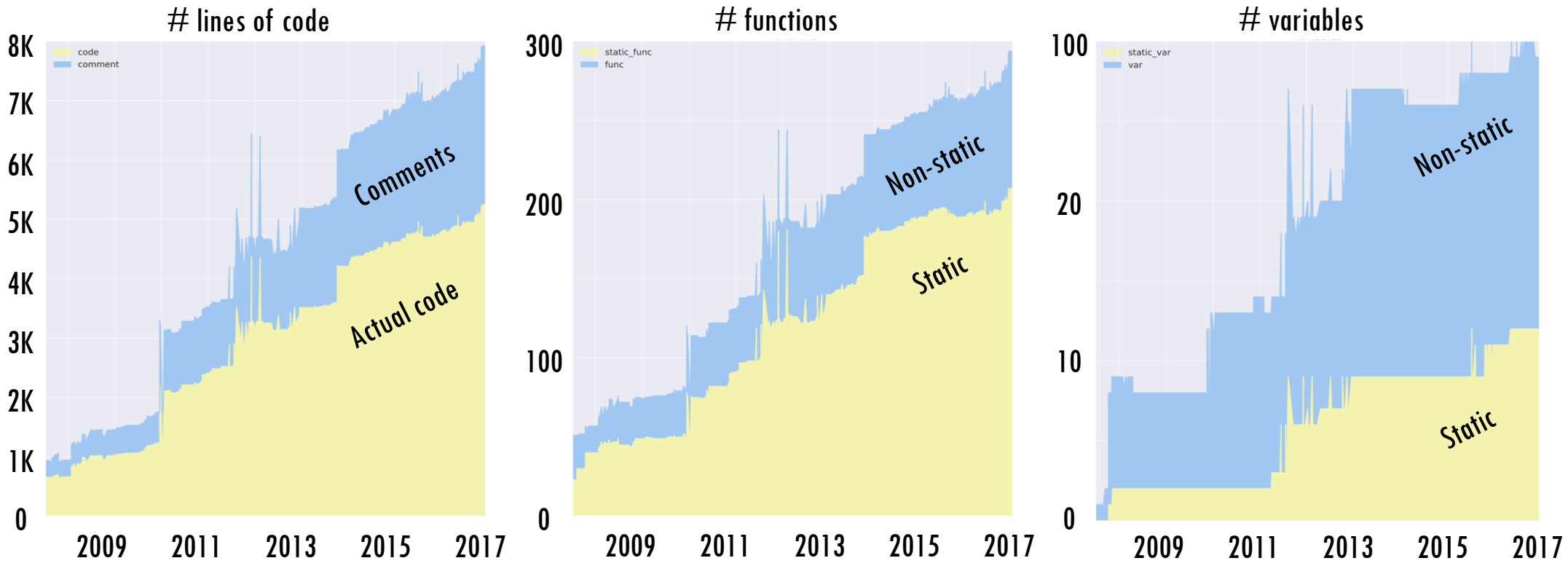

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  - *We need another approach…*

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- **Idea 5:** switch to simpler schedulers, easier to reason about!
- **Write simple, schedulers with proven properties !**
  - A scheduler is tailored to a (class of) parallel application(s)
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    - *Work conservation, load balancing live and in finite # or rounds, valid hierarchy…*

Towards Proving Optimistic Multicore Schedulers

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- **Idea 6:** ???
- Any other ideas?

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Your turn!