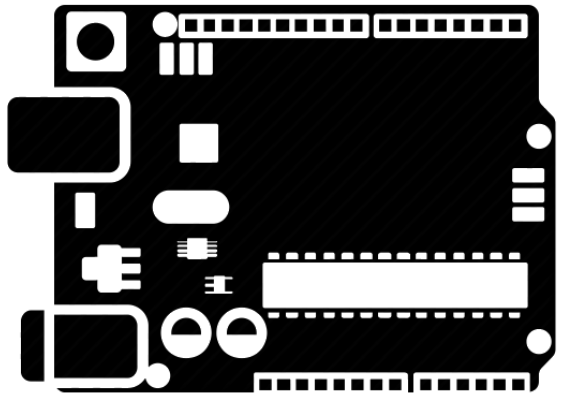
Scheduling

CS 161: Lecture 4

2/9/17


Where does the first process come from?
BRACE YOURSELVES...
STORY TIME IS COMING

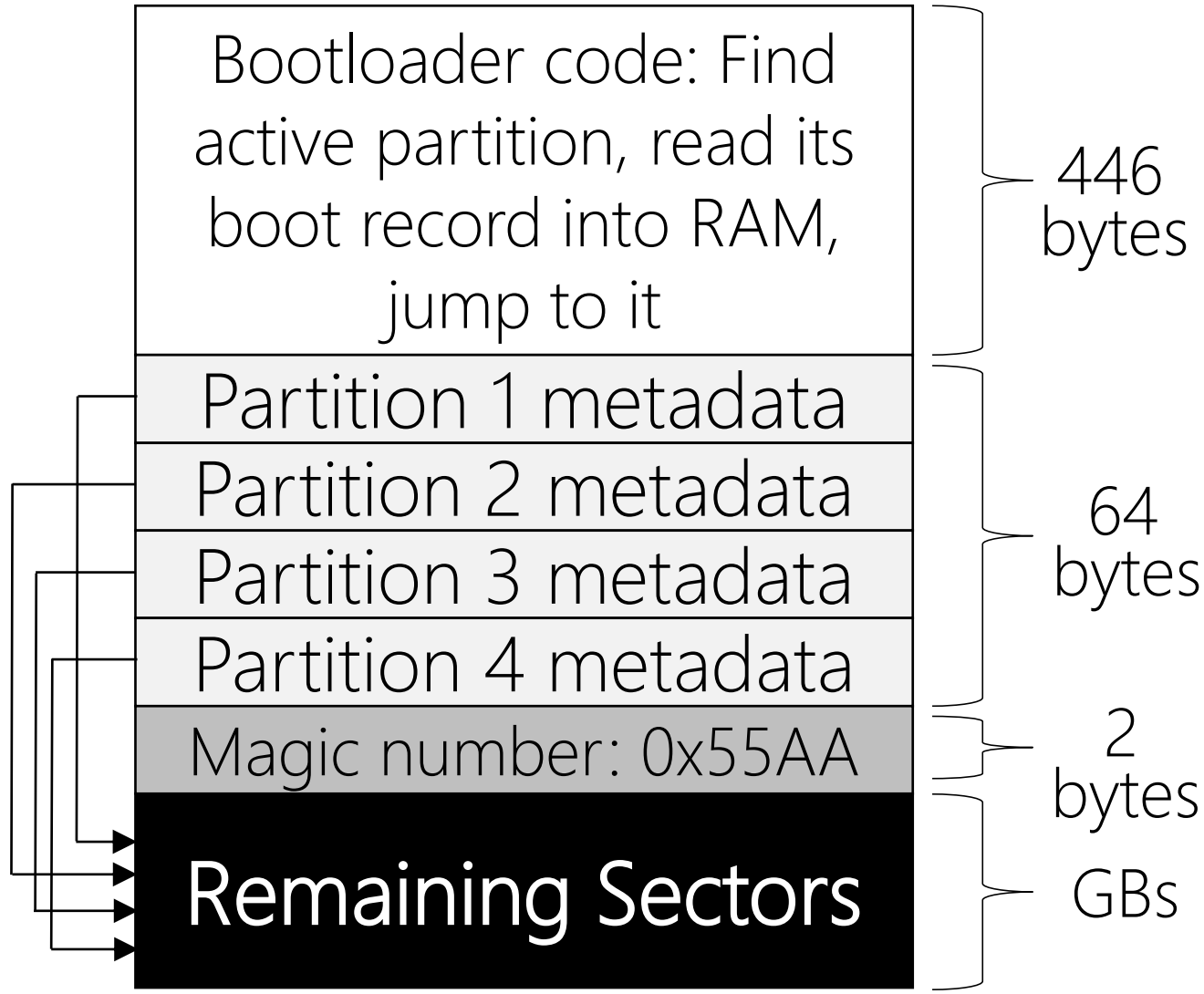
The Linux Boot Process



Machine turned on; BIOS runs

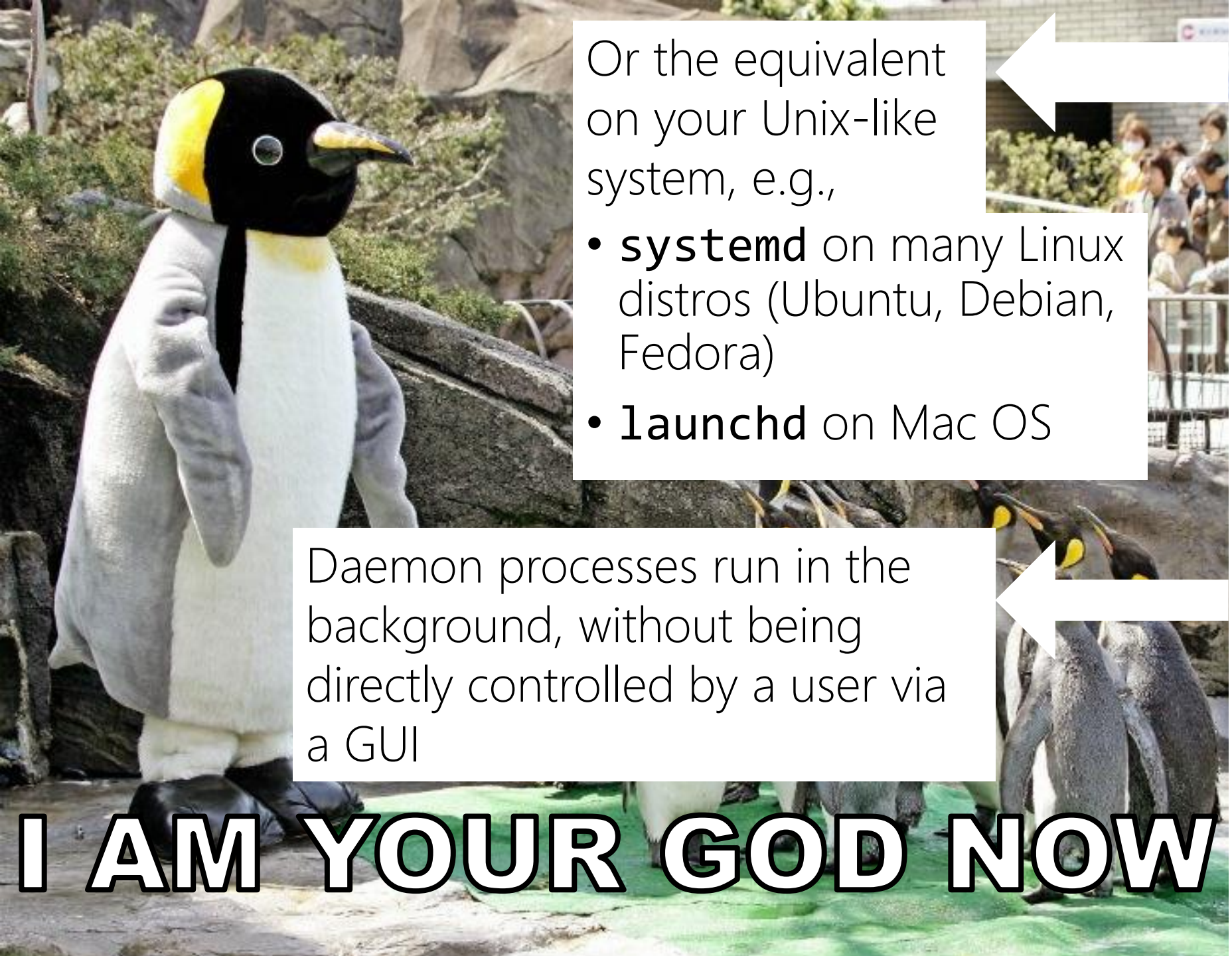
- BIOS: Basic Input/Output System
- Stored in flash memory on motherboard
- Determines which devices are available, loads Master Boot Record (MBR) of the bootable storage device into RAM, jumps to it

MBR: first sector on the storage device



The Linux Boot Process

- The stage 2 bootloader loads the OS kernel into RAM and then jumps to its first instruction
  - The stage 2 bootloader code is larger than a single sector, so it can do fancy things
  - Ex: Present user with a GUI for selecting one of several kernels to load
- The kernel starts running and does low-level system initialization, e.g.,
  - Setting up virtual memory hardware
  - Installing interrupt handlers
  - Loading device drivers
  - Mounting the file system
- But how do user-level processes get started?



Or the equivalent on your Unix-like system, e.g.,

- **`systemd`** on many Linux distros (Ubuntu, Debian, Fedora)
- **`launchd`** on Mac OS

Daemon processes run in the background, without being directly controlled by a user via a GUI

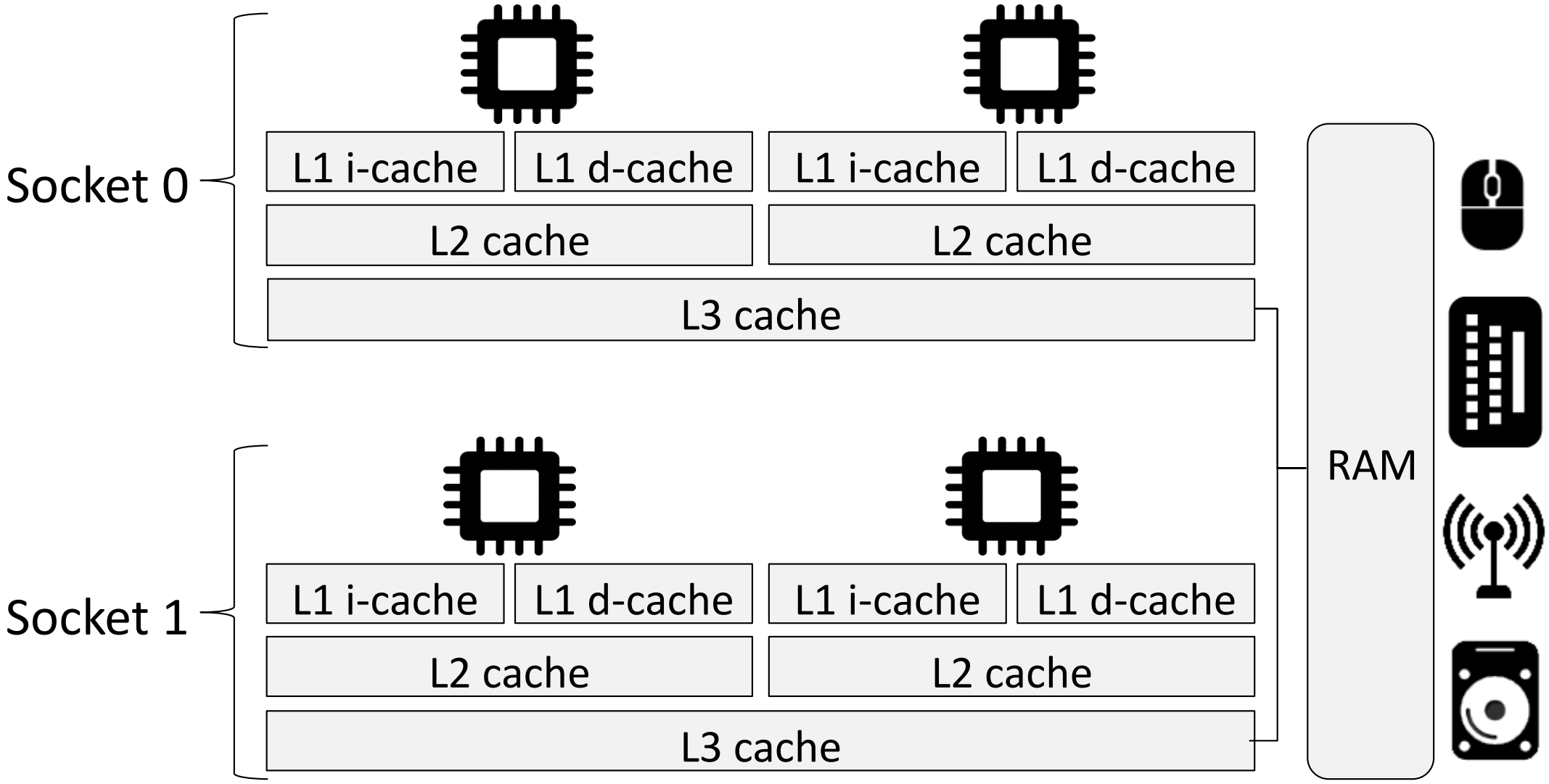
init

- The first process that runs
- Responsible for launching all other processes via fork()+exec()
  - Desktop window manager
  - **`sshd`**
  - Printer daemon
- Reaps all zombie processes whose parents did not wait() on them

Scheduling: Which Process Should Run Now?

- Different processes have different behaviors
  - IO-bound: A process mostly waits for IOs to complete
  - CPU-bound: A process issues few IOs, mostly does computation
  - A process may change its behavior throughout its execution—the scheduler must notice and adjust!
- Often a good idea to prioritize IO-bound processes
  - If IO comes from user (e.g., keyboard, mouse), we want interactive programs to feel responsive
  - Network IO may take tens or hundreds of milliseconds (Comcast! Verizon!)
  - IO is typically slow, so start it early!

Inside a Computer



IO Is Usually Slow: Start It Early!

1 CPU cycle (1 register access): 0.3 ns		
L1 cache access:	0.9 ns	
L2 cache access:	2.8 ns	1 OMag
L3 cache access:	12.9 ns	1 OMag
RAM access:	120 ns	3 OMags
SSD access:	50—150 µs	1—2 OMags
Disk access:	5—10 ms	1—2 OMags
Network RTT:	10—500 ms	1+ OMags
User input:	200 ms—seconds	

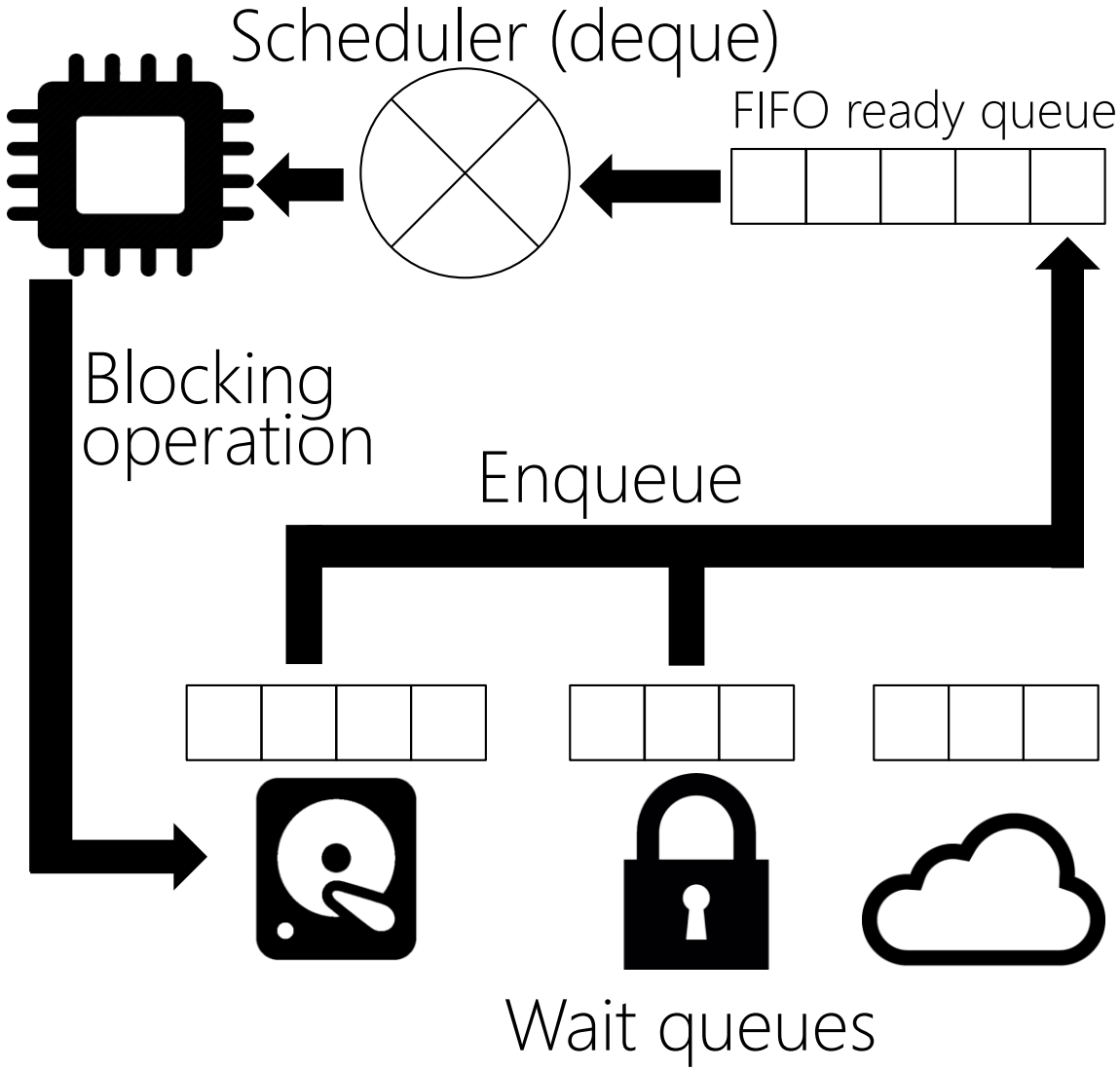
Mechanism versus Policy

- Policy: A high-level goal (e.g., “Prioritize IO-bound tasks”)
- Mechanism: The low-level primitives that are used to implement a policy
  - Ideally, a single set of mechanisms are sufficiently generic to support multiple policies
  - Designing a minimal (but expressive) set of mechanisms is often tricky!

- Basic scheduling mechanisms
  - Run queue: the set of threads that are ready to execute on the CPU
  - Wait channel: a set of threads that are waiting for an event to occur
  - Traps: opportunities for the OS to run and make a scheduling decision

First-Come, First-Serve (FCFS)

- Basic idea: Run a task until it's "finished"
  - "Finished" is typically defined as "willingly blocks" (e.g., due to an IO request)
  - The blocked task is placed in the relevant wait queue
  - When a task unblocks, it is placed at the end of a single FIFO ready queue
- Advantages
  - Enables parallel use of the CPU and IO devices
  - Simple!
- Disadvantages
  - Seems unfair AF: A single CPU task can monopolize the processor!

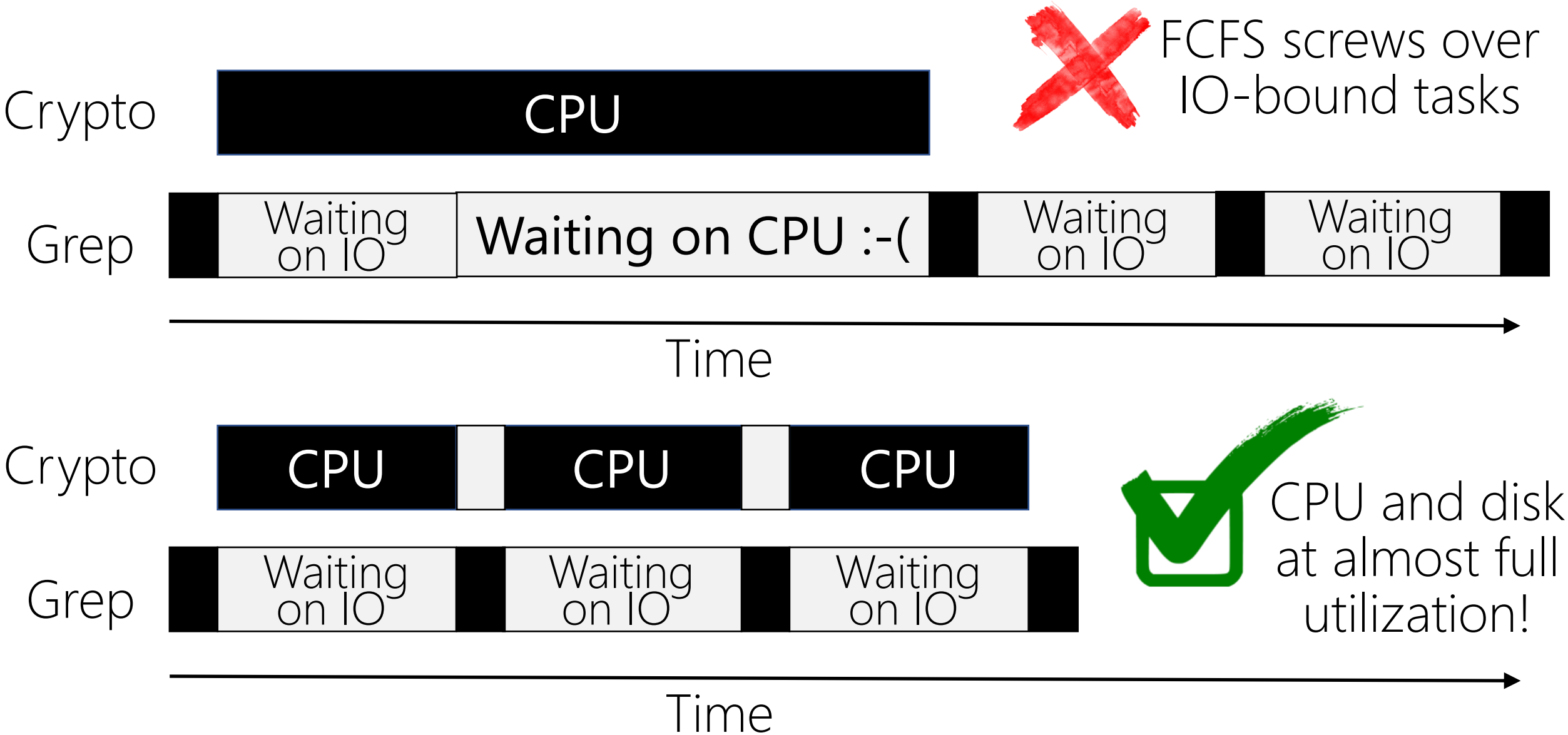


"AF" means "As Fuzz"
For example:

Response Times

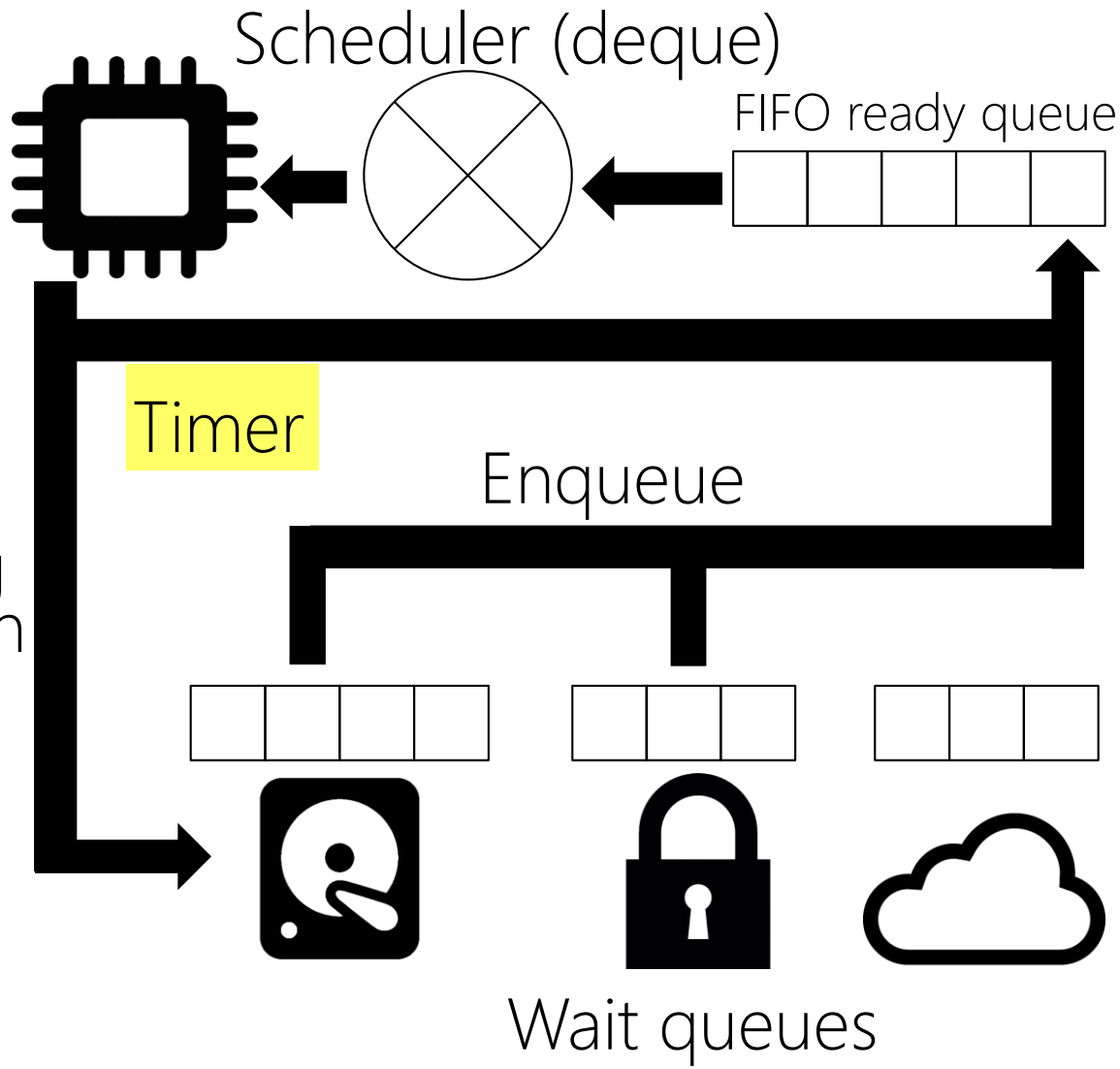
- Ideally, a scheduler would maximize both CPU utilization and IO device utilization
- So, we should overlap computation from CPU-bound jobs with IO from IO-bound jobs
  - Important consequence: When IO-bound jobs are ready to use the CPU, we should prioritize those jobs (i.e., minimize the response time needed to assign them to a core)
  - Otherwise, devices lay idle: a sadness

Ex: An IO-bound disk grep, and a CPU-bound crypto calculation on a single-core machine



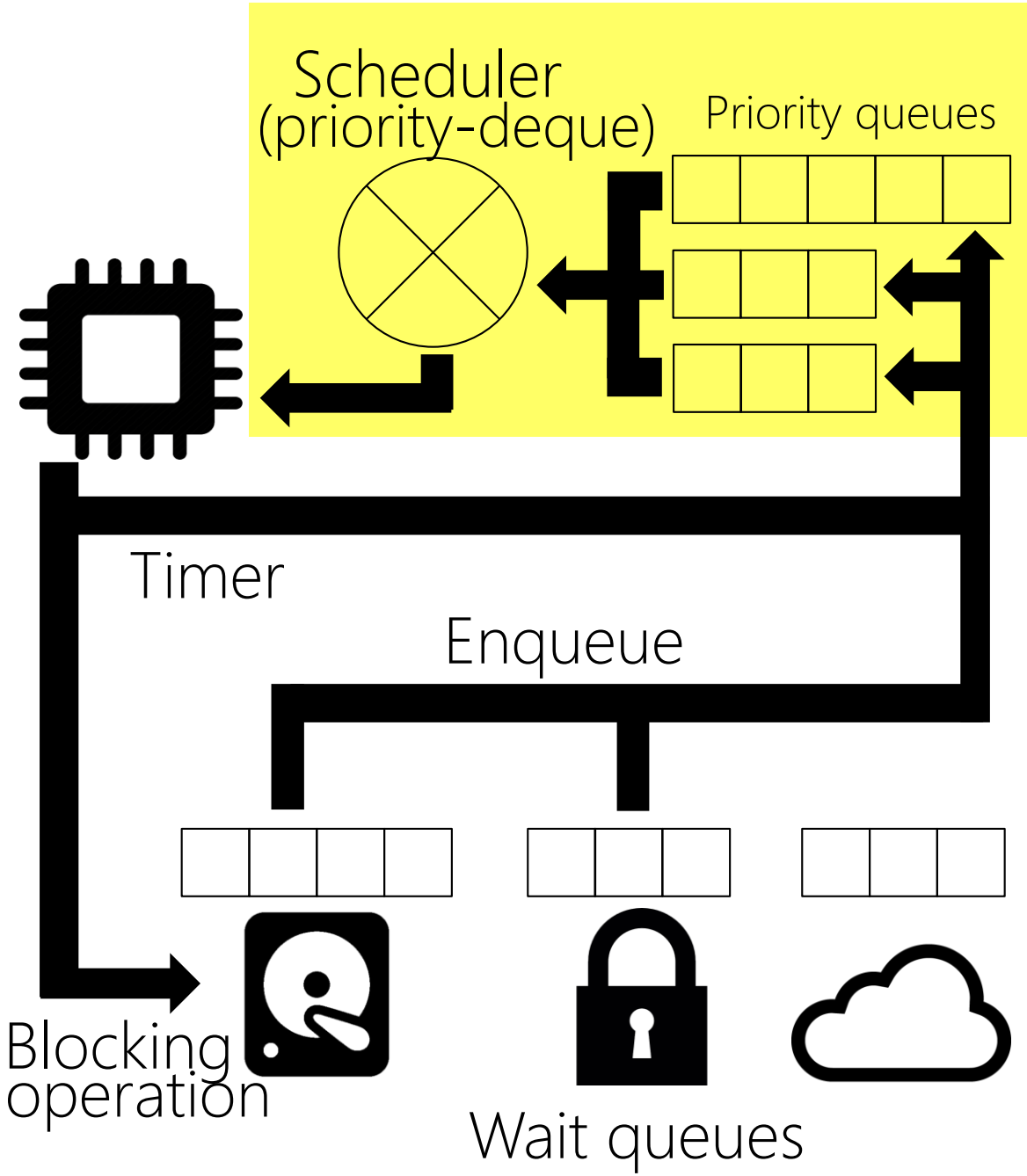
Round-Robin

- Insight: After a task has run for a while, the OS should forcibly preempt the task
  - Time slice: the maximum amount of time that a task can run before being taken off the CPU
  - Timer interrupts provide a convenient mechanism to enforce time slices
- If a task is forcibly preempted, it goes at the end of the ready queue
  - Voluntary blocking places the task in the appropriate wait queue
- Advantages:
  - CPU-bound tasks must share the processor
  - No starvation!
- Subtlety: What's the timer period?
- Problem: What if some tasks are more important than other tasks?



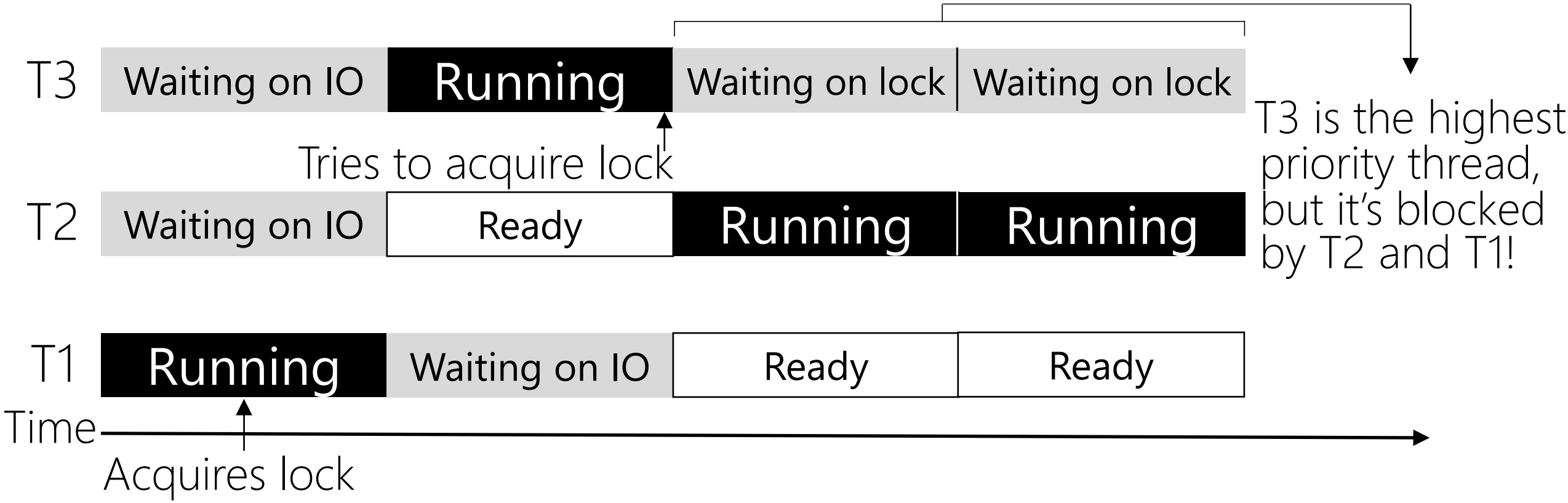
Priority-based Round-Robin

- Insight: Maintain several ready queues, one for each priority level
  - Each queue is FIFO
  - Scheduler finds highest-priority non-empty queue and runs the first task in that queue
- Advantage: Allows higher-priority tasks to receive more CPU time
- Problem: Low-priority tasks may starve!
  - Solution: aging (the longer a priority waits without getting the CPU, the higher its priority becomes)
  - We'll discuss specific aging approaches next lecture!
- Related problem: IO-bound tasks may suffer if not given high priorities
- Problem: priority inversion



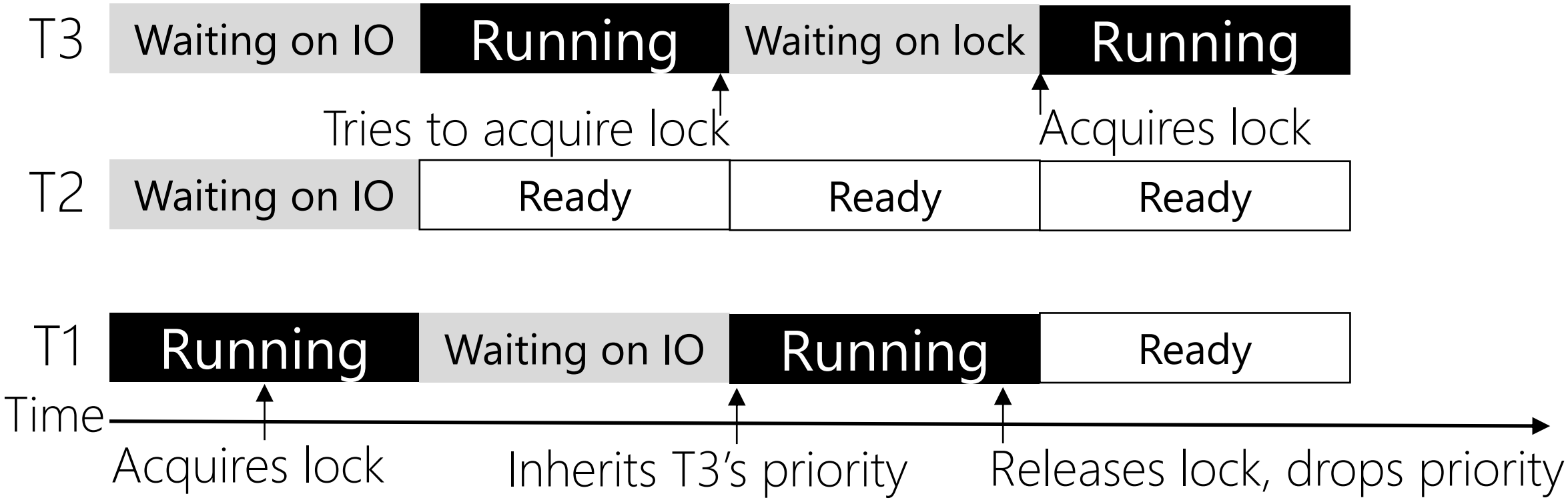
Priority Inversion

- Assume that a system has three tasks T1, T2, and T3
  - Priority: T3 > T2 > T1
- Imagine that T1 and T3 both use the same lock . . .



Priority Inheritance

A task which owns a lock inherits the highest priority of any task that wishes to acquire the lock

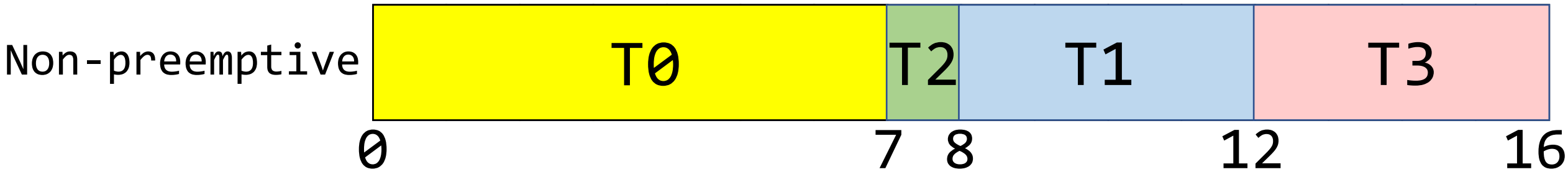


Shortest Time to Completion First (STCF)

- Goal: Minimize the amount of time that a runnable task has to wait before it actually runs
  - Define "completion time" as the length of a task's next CPU burst
  - Scheduler estimates each runnable task's completion time (e.g., using the average length of the task's recent CPU bursts)
  - Scheduler keeps a single run queue sorted by estimated completion time
  - The front of the queue gets to run next
- STCF can be used with or without preemption
  - Non-preemptive STCF: Once a task is running, it does not relinquish the CPU until the CPU burst is finished
  - Preemptive STCF: The currently-running task can be kicked off the CPU if a new task arrives with a shorter burst time

Shortest Time to Completion First (STCF)

Task	Arrival time	Burst time
T0	0	7
T1	2	4
T2	4	1
T3	5	4



Shortest Time to Completion First (STCF)

Task	Arrival time	Burst time
T0	0	7
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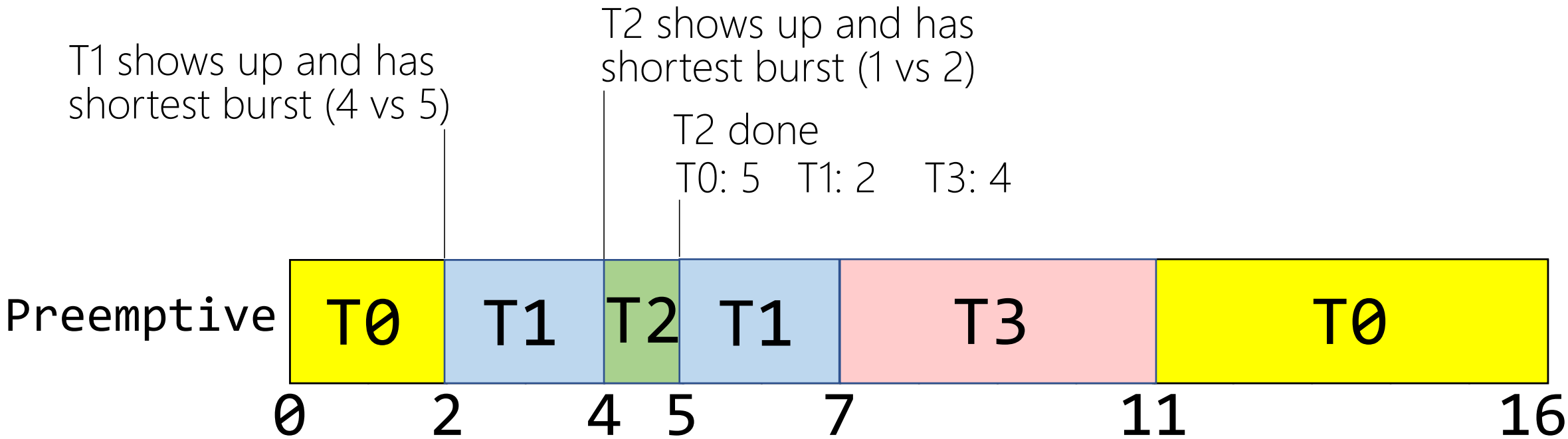
STCF minimizes average response time, but, unlike RR, does not prevent starvation! So, aging is necessary.



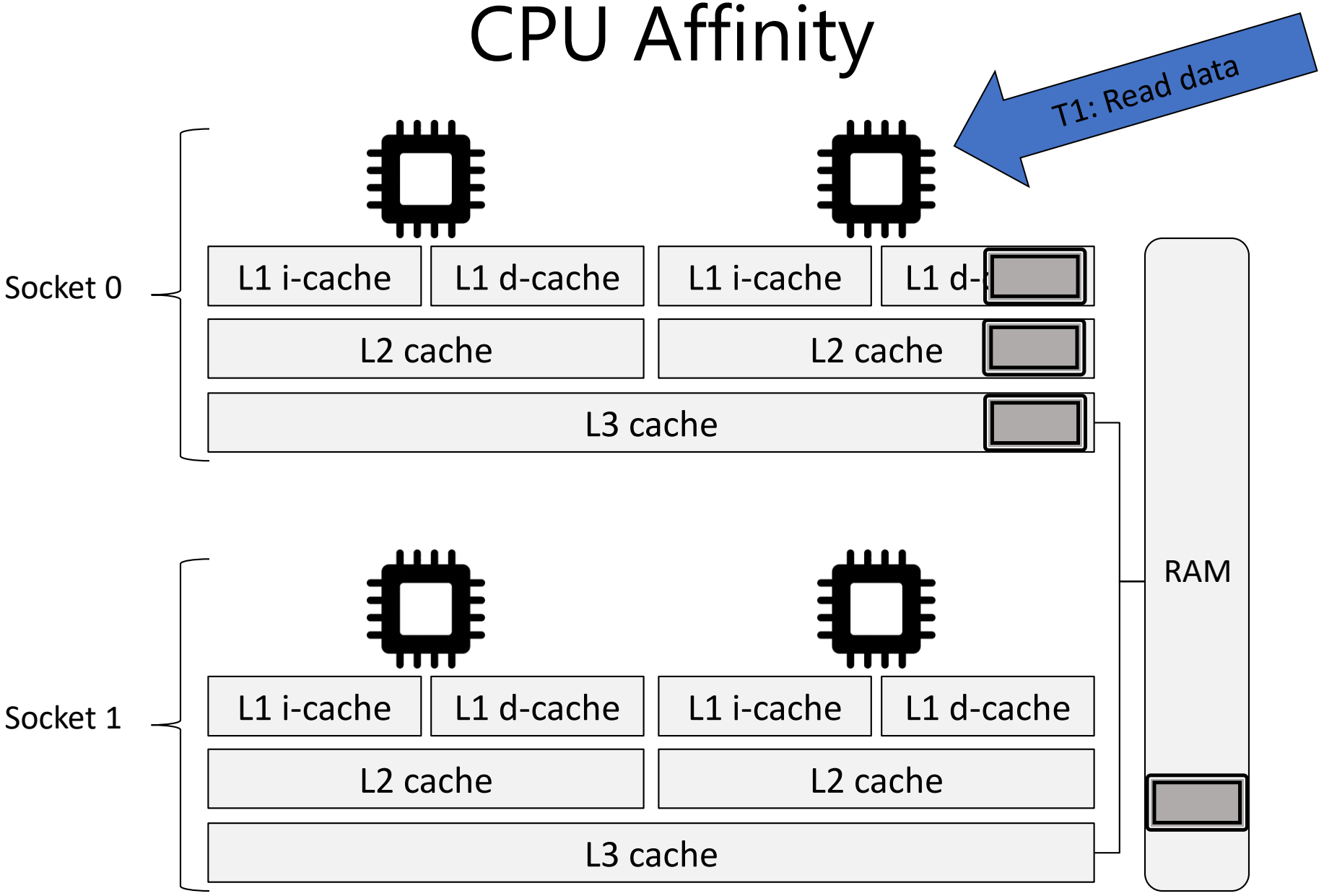
Context switches are pure overhead!

- Direct cost: CPU cycles devoted to bookkeeping
  - Save and restore registers
  - Invoke scheduler logic
  - Switch address spaces from old process to new process
- Indirect costs
  - L1/L2/L3 caches are polluted by kernel code and data; new task must warm the caches with its code and data
  - TLB entries become invalid

CPU Affinity

```
struct task_struct{ //From the Linux kernel
    volatile long state; //TASK_RUNNING,
                         //TASK_ZOMBIE,
                         //etc.
    void *stack;         //Kernel stack
    int exit_code;
    struct mm_struct *mm;//Address space info
    unsigned long cpus_allowed;
        //Bitmask representing which
        //cpus the task can run on
    ...
};
```

CPU Affinity



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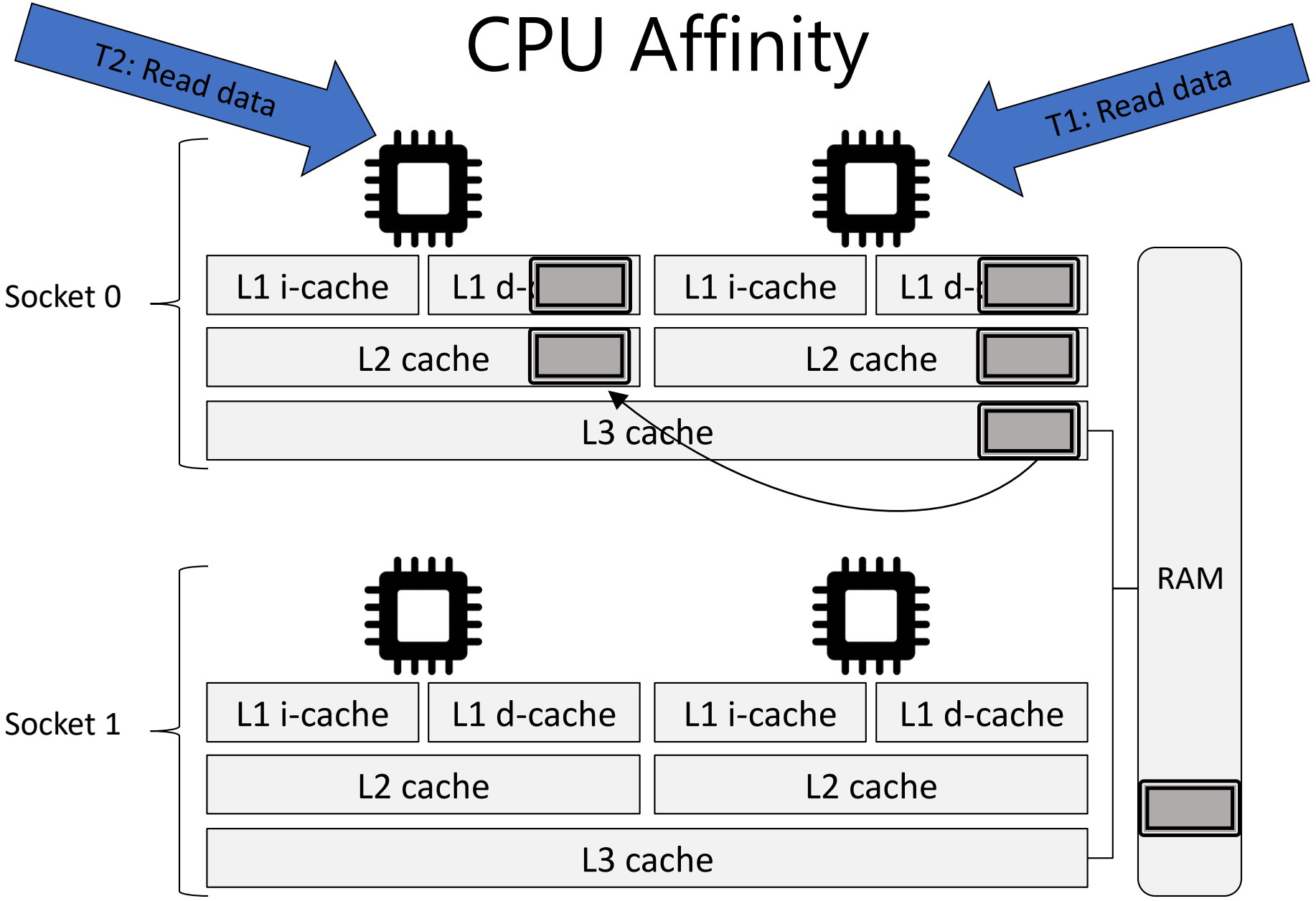

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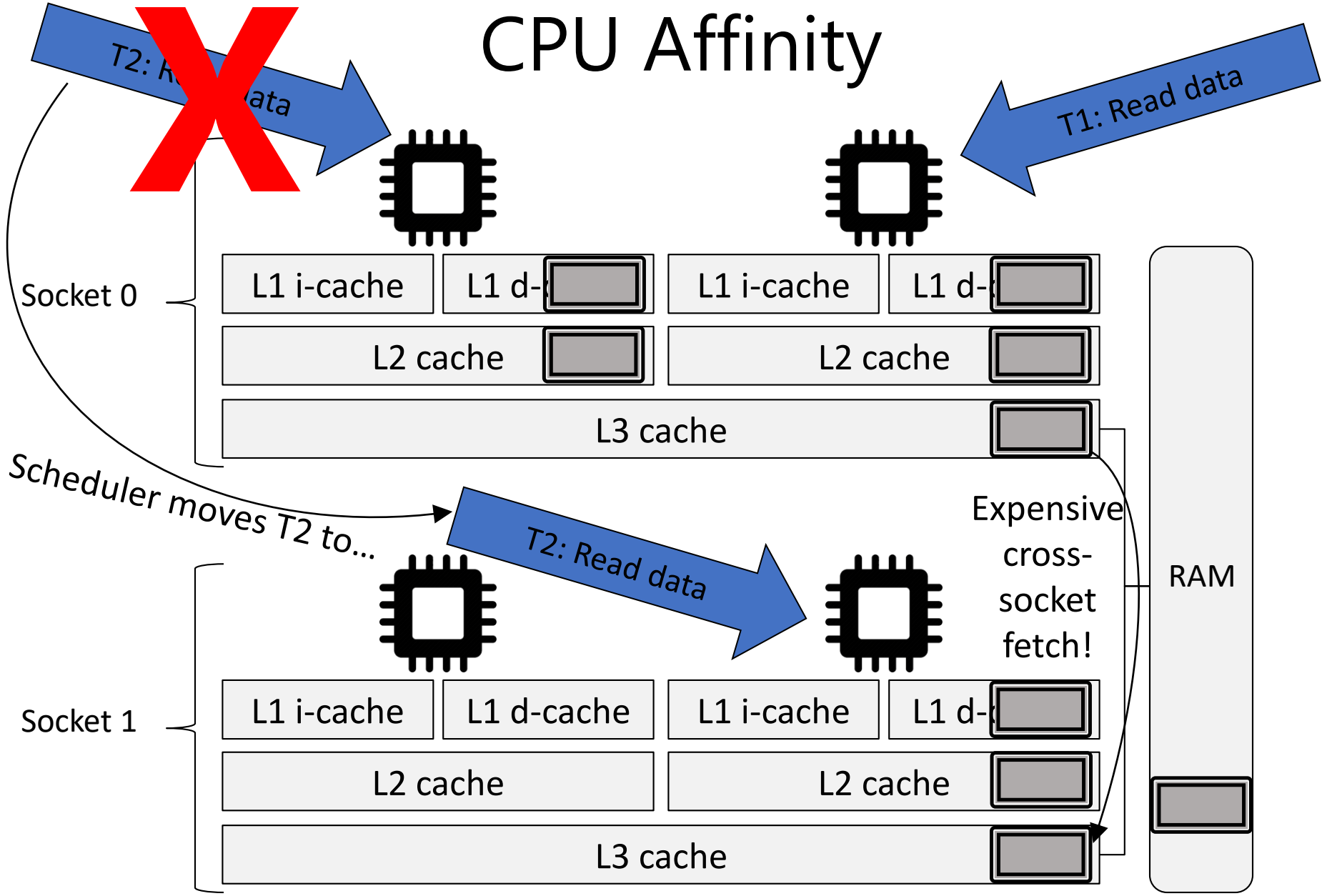

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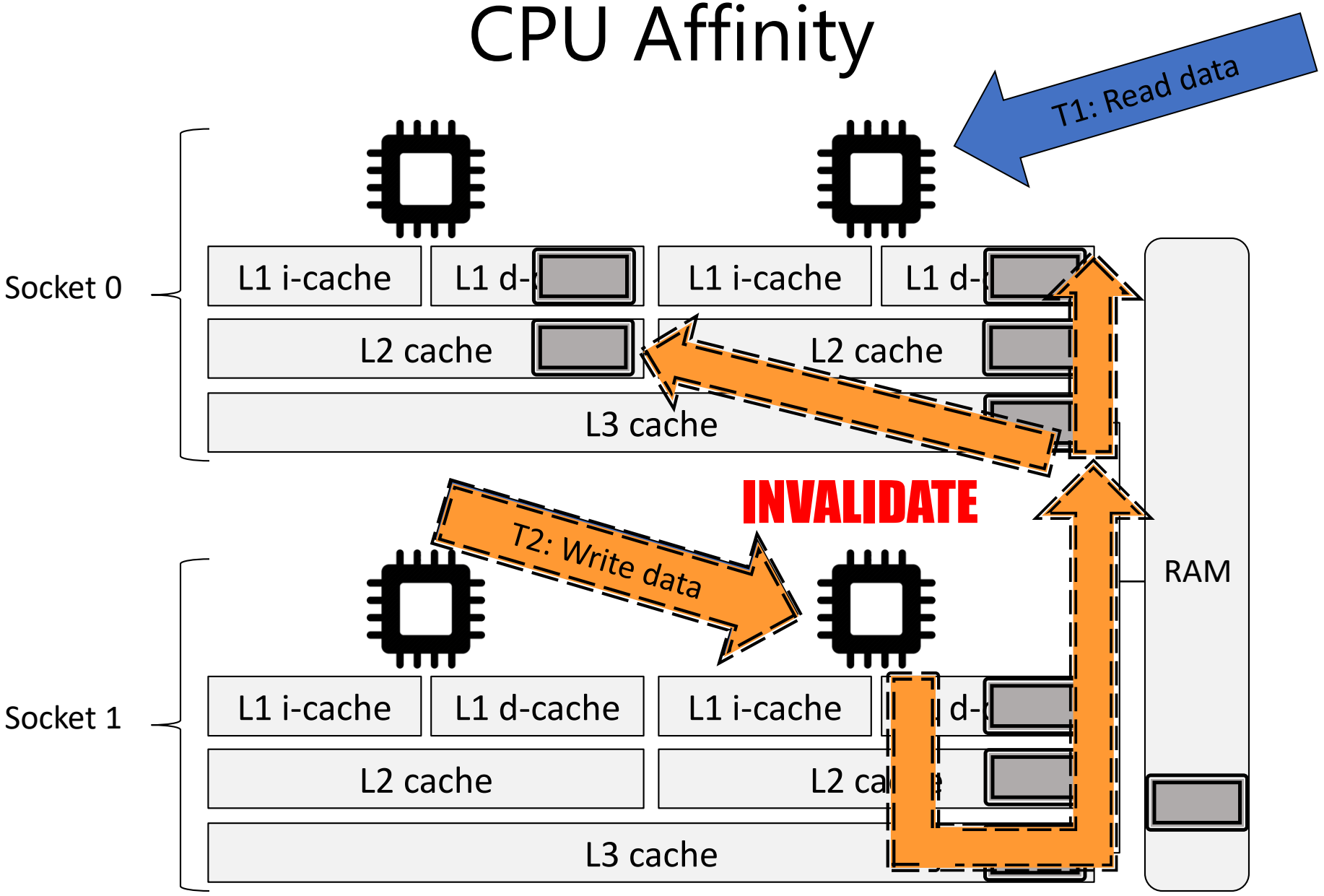

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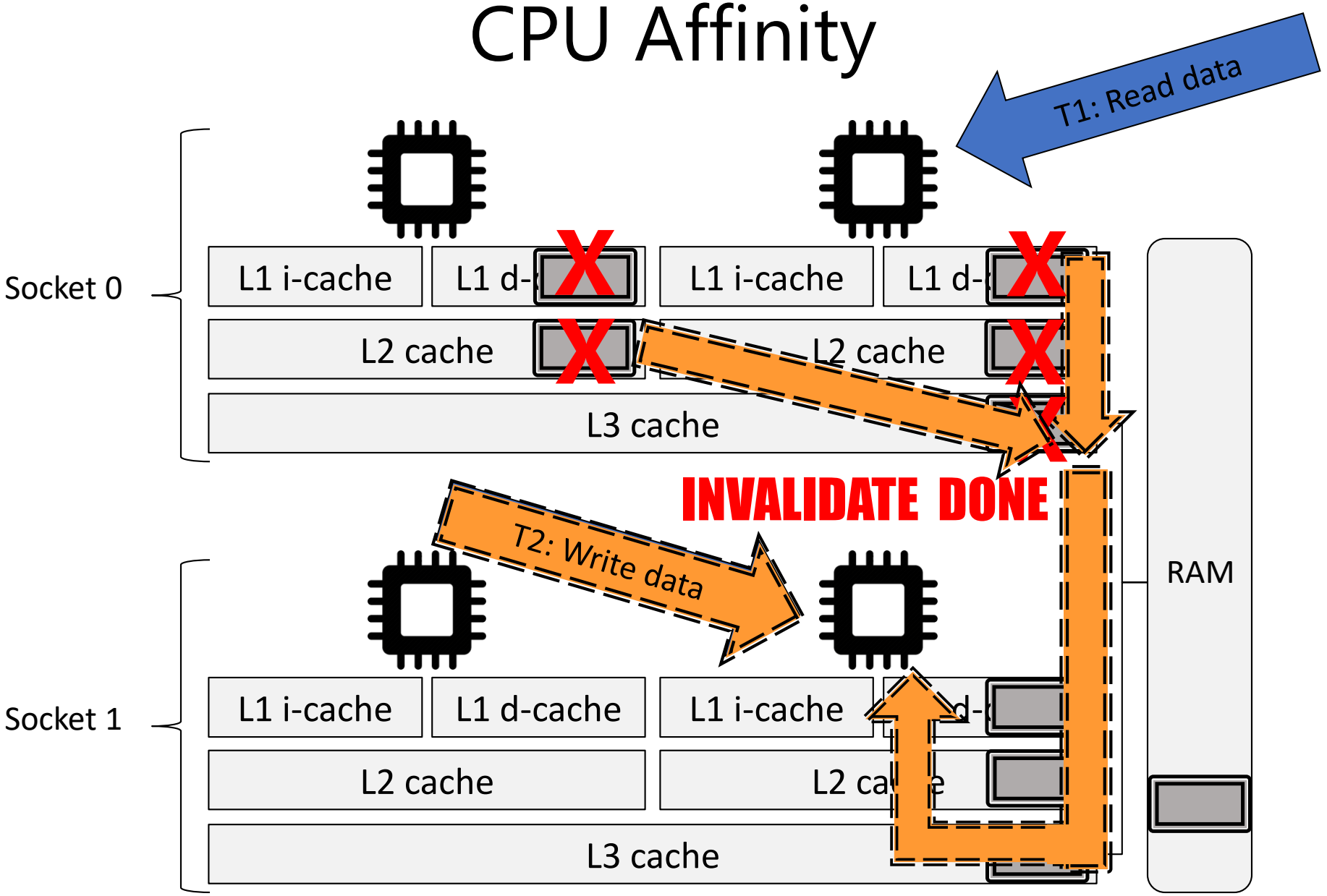

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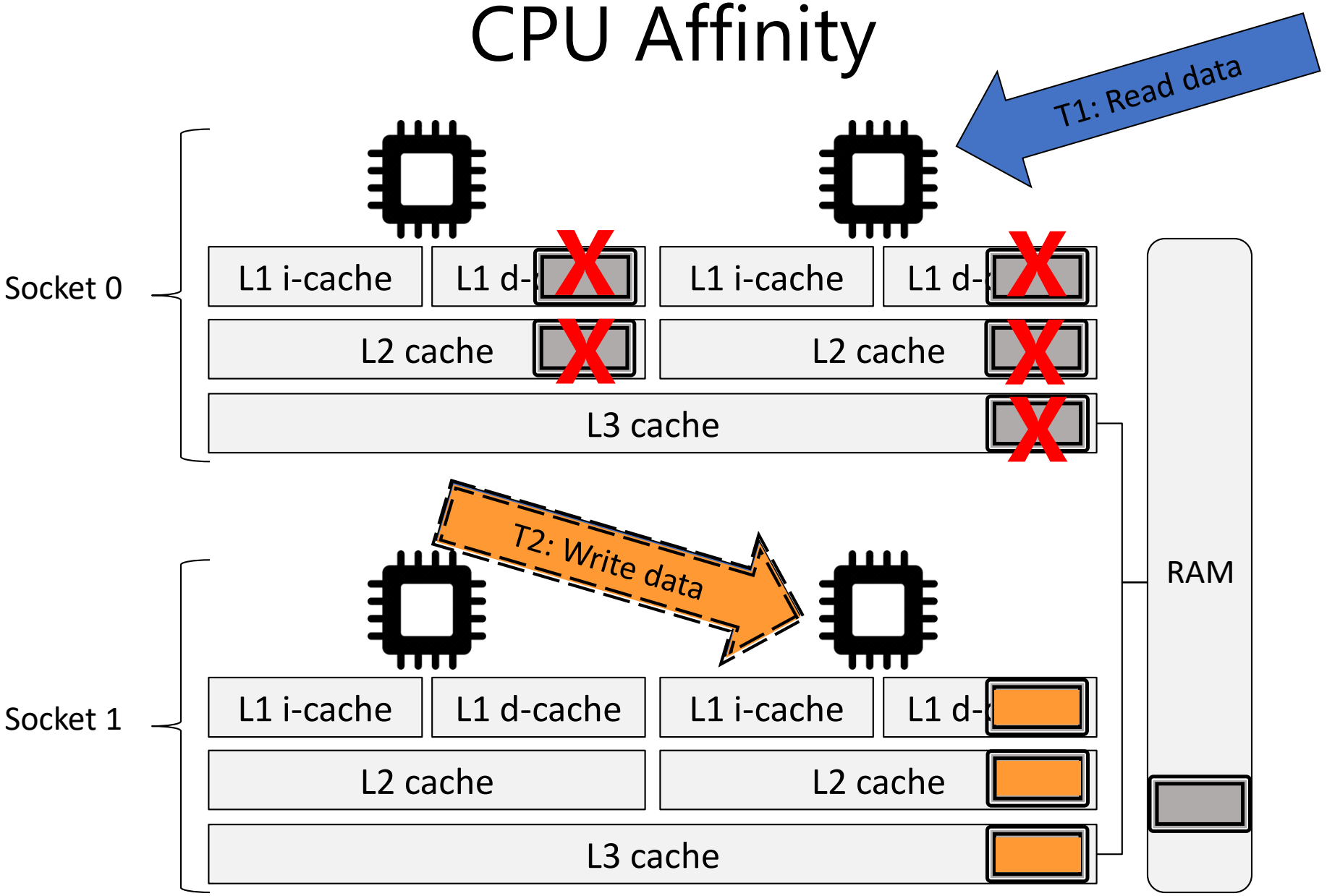

Your Machine is a Distributed System!

- Components are connected by a network
  - Some components talk directly (e.g., core/registers)
  - Others require multiple hops to communicate (e.g., core and L3 cache; two cores on different sockets)
  - More hops = more communication latency!
- Ideally, the OS scheduler can:
  - Avoid network latencies by co-locating related threads on the same subset of cores (or at least on the same socket)
  - Keep all of the cores utilized (to avoid convoy effects on a small set of highly-utilized cores)