Ipanema:
Safe multicore scheduling in a Linux cluster environment

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with :

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Work in Progress!

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- Linux-based software stack
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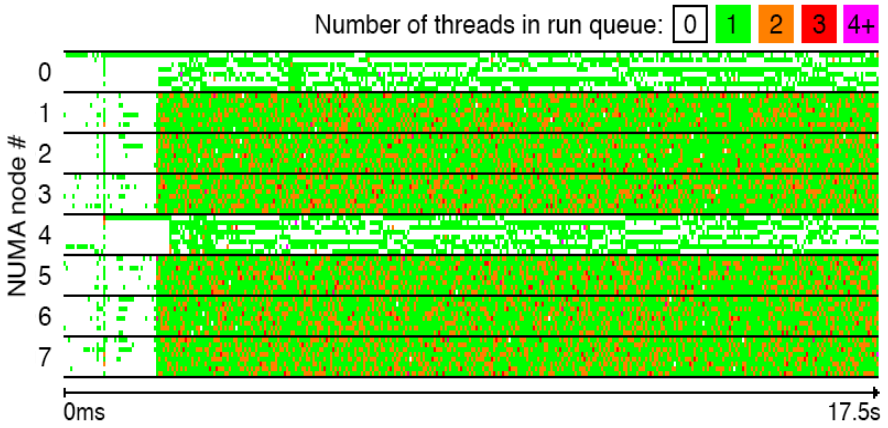
- Challenge: don’t waste cycles!
  - Reduces infrastructure and energy costs
  - Improves bandwidth and latency

The problem: perf bugs in scheduler

- The Linux scheduler has performance bugs!
- Showed this last year @EuroSys
  « The Linux Scheduler: A Decade of Wasted Cores »



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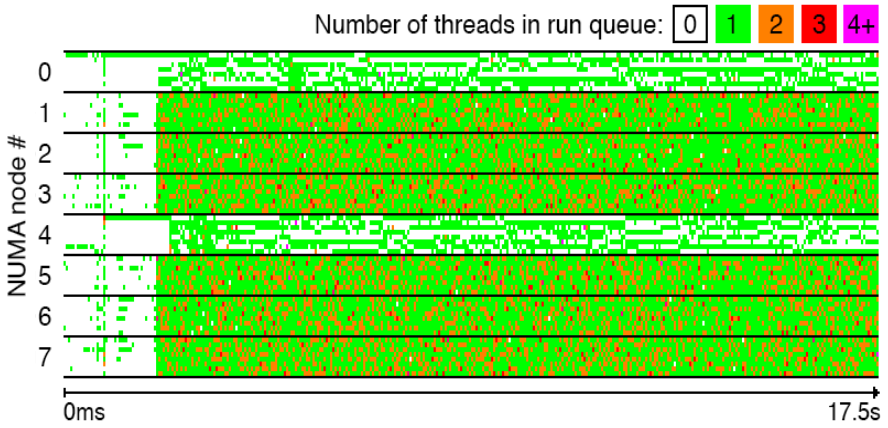

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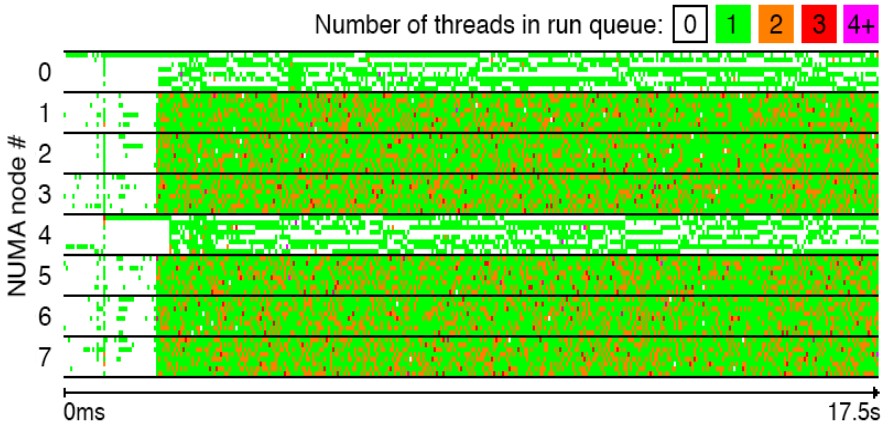

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  - Idle cores while several threads running on some cores
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- Consequences:
  - Wasted energy, infrastructure resources, lower bandwidth, higher latency...
  - Lack of predictability: harder to scale-out!

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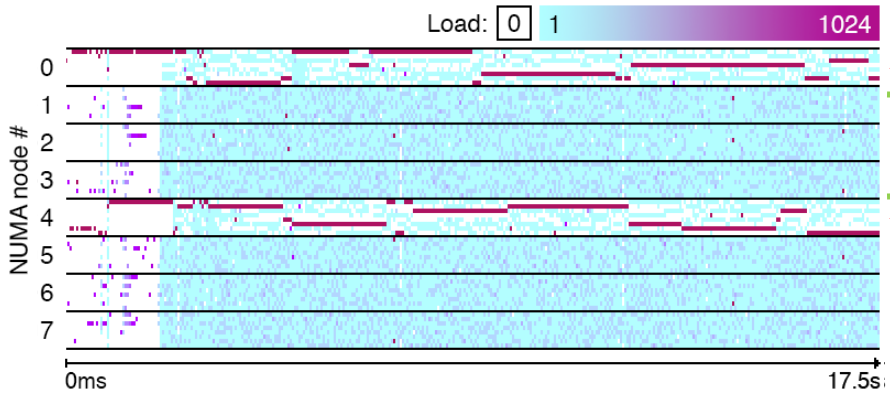
- **Not necessarily the case!**



Load 1 = avg(R thread with high load + a few make threads with low load)

Load 2 = avg(many make threads with low load)

Load 1 = Load 2: the scheduler thinks the load is balanced!

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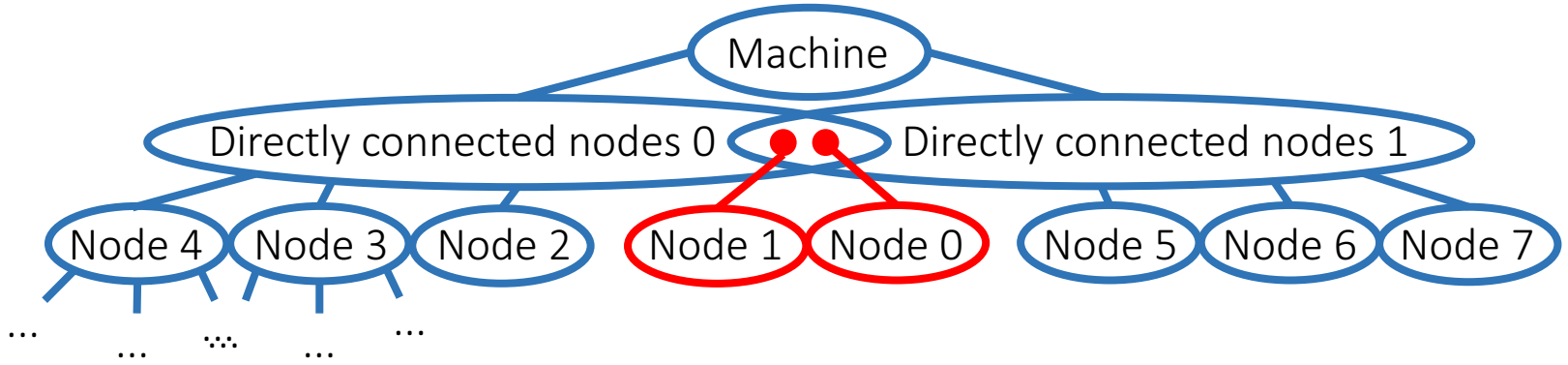
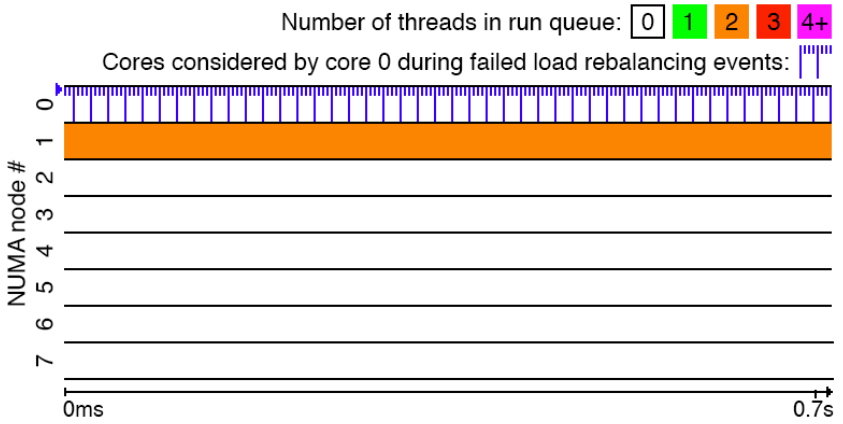
- **Threads on that core never balanced :** load of both groups equal





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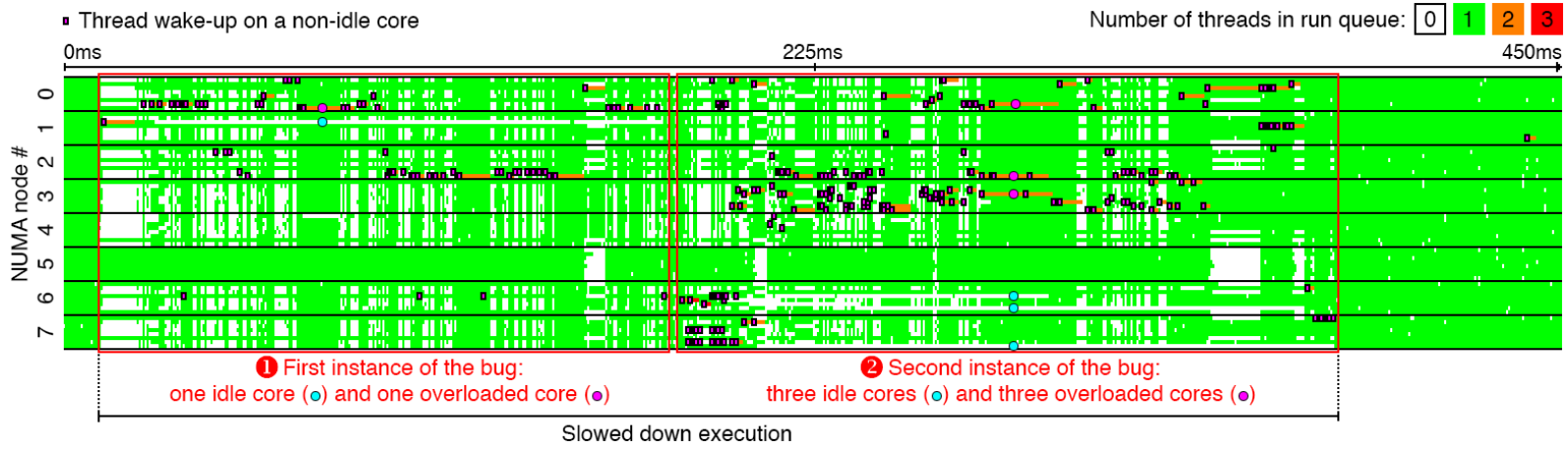
- **One makes mistakes the other can’t fix!**



Analysis: Linux scheduler too complex!

- **Linux used for many classes of applications**
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- Result: a very complex monolithic scheduler, supposed to work in all situations!
  - 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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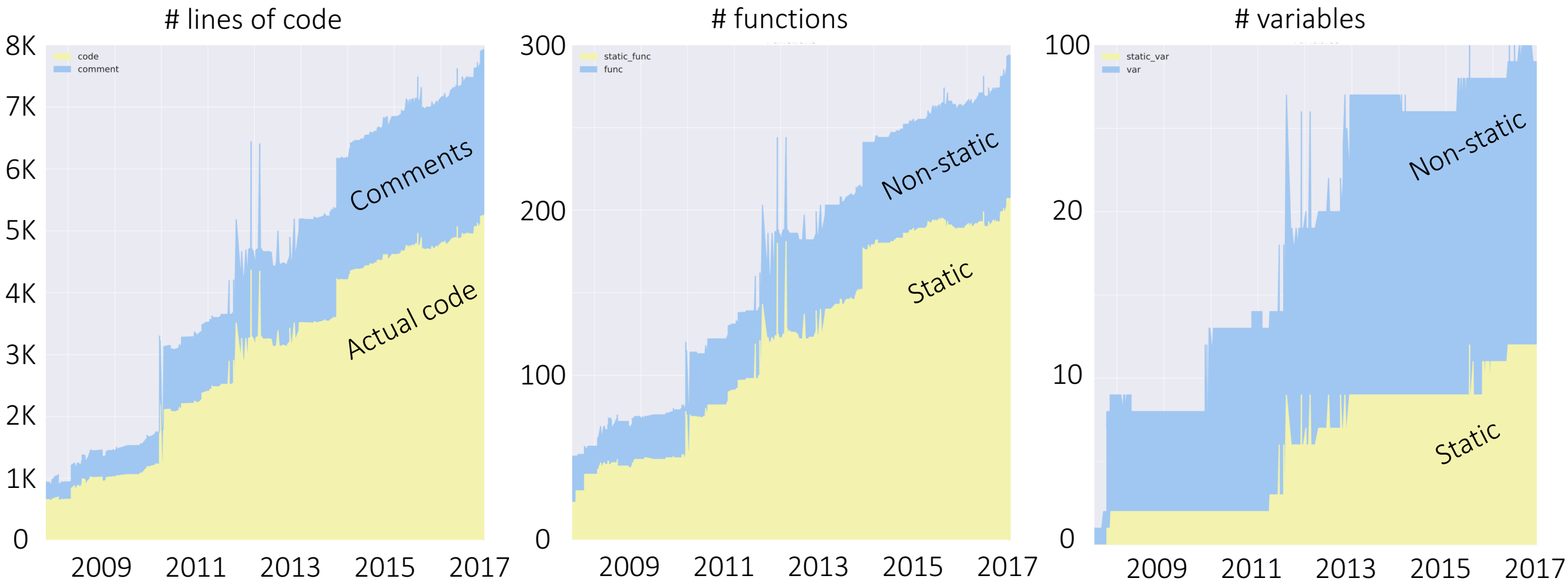
For instance, `fair.c`:



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- Not doable! We need another approach…

Our solution: Ipanema

- A scheduler is tailored to a (class of) parallel application(s)
  - Specific thread election criterion
    - *E.g., more preemption for more interactive applications…*
  - Specific load balancing criterion
    - *EDF for real-time apps, locality-aware balancing…*
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- Scheduler deployed together with an application on a partition

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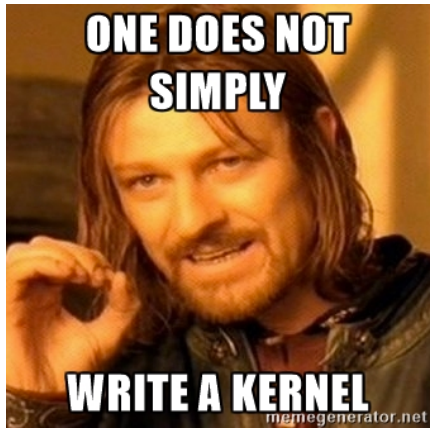

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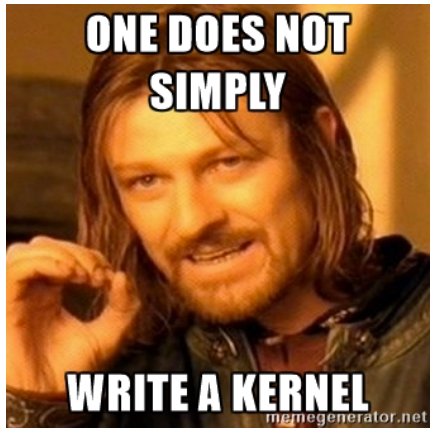

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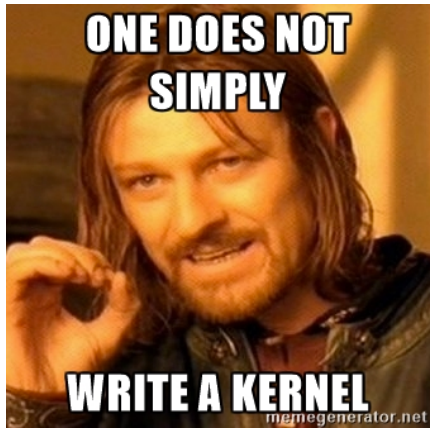

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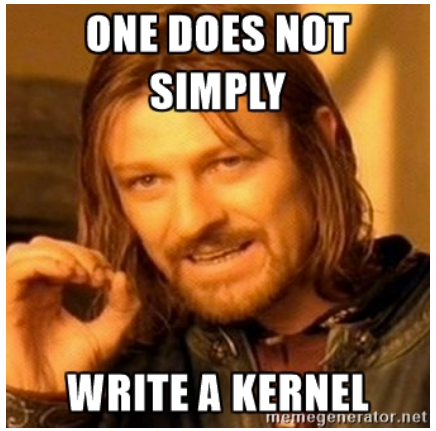

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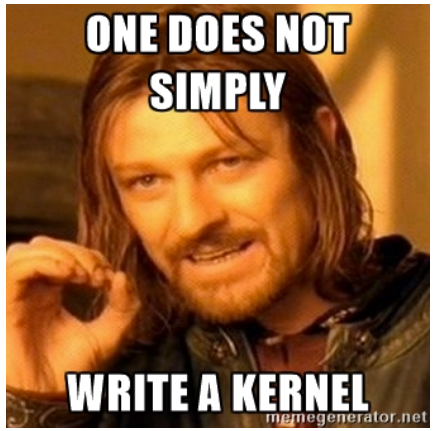

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- More issues, e.g., optimizations hinder code maintenance
  - Target-specific implementation of mechanisms ⇒ policy obfuscated!

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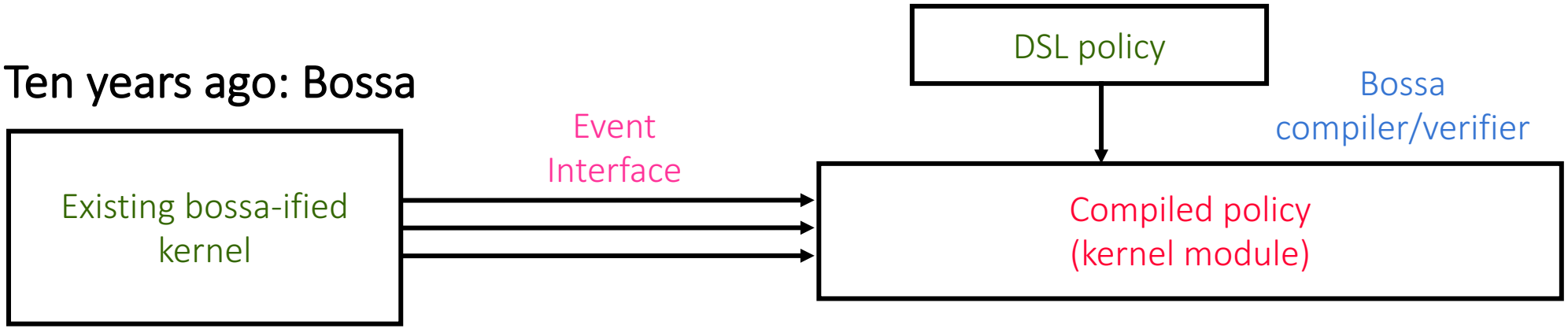
DSL: A programming language dedicated to a family of programs that offers specific abstractions and notations.

-Trade expressiveness for expertise/knowledge:

- Productivity: easier and safer programming
- Robustness: (static) verification of properties
- Performance: efficient compilation

Bossa

- **Ten years ago: Bossa**



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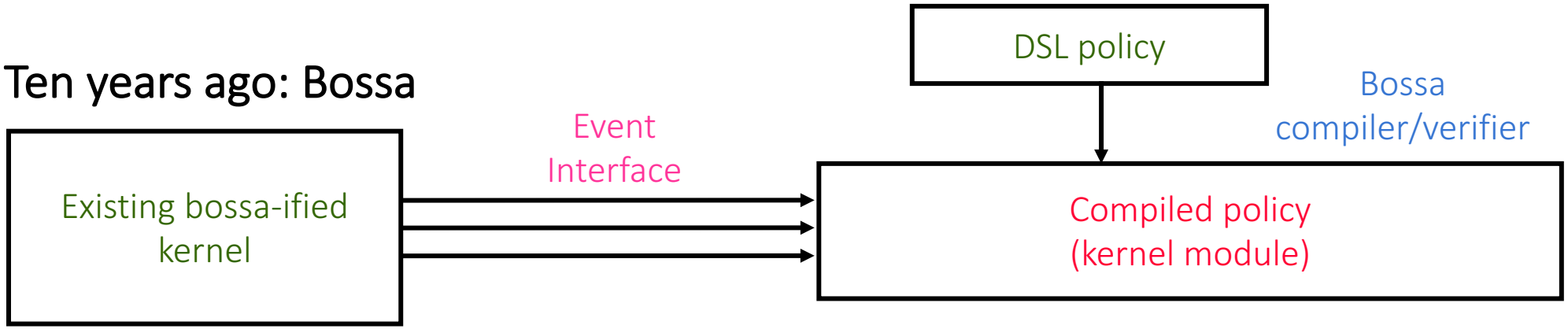

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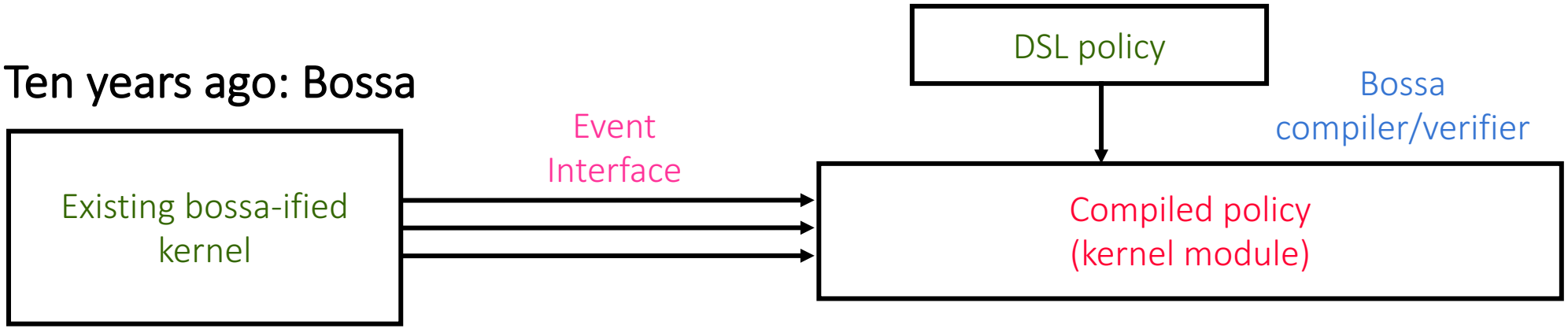

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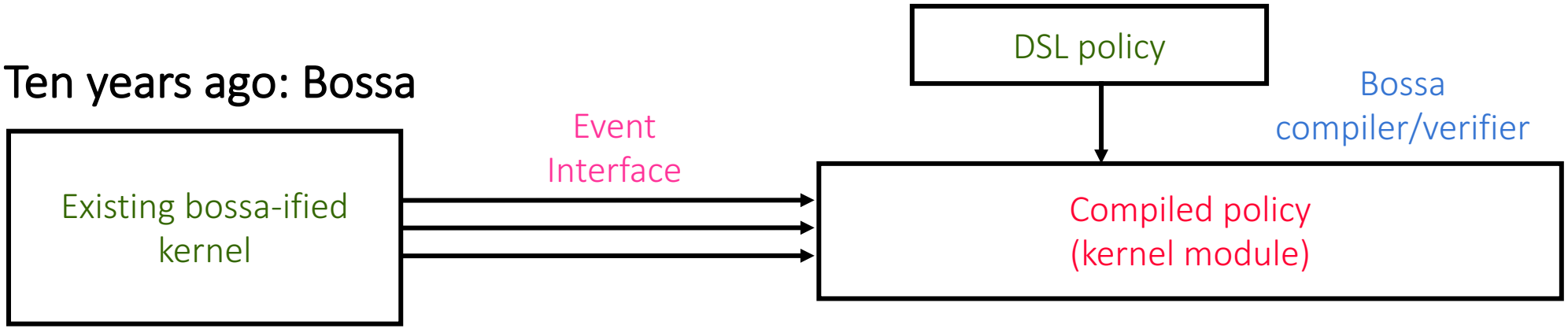

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- Used for teaching scheduling
- Related publications [ASE 2003, EW 2004, HASE 2006]
- Target: single-core systems only!

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Bossa provides: 1, 2, and 5

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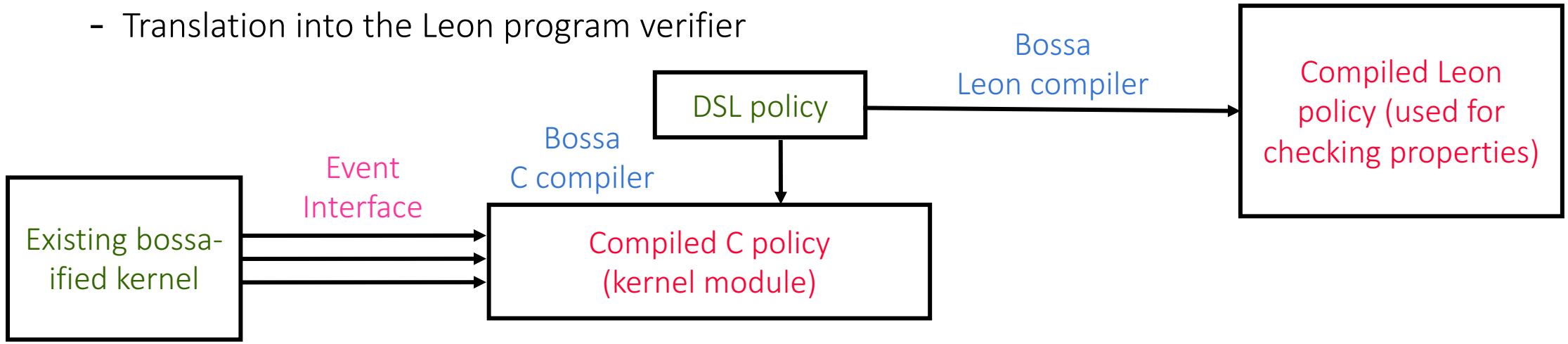
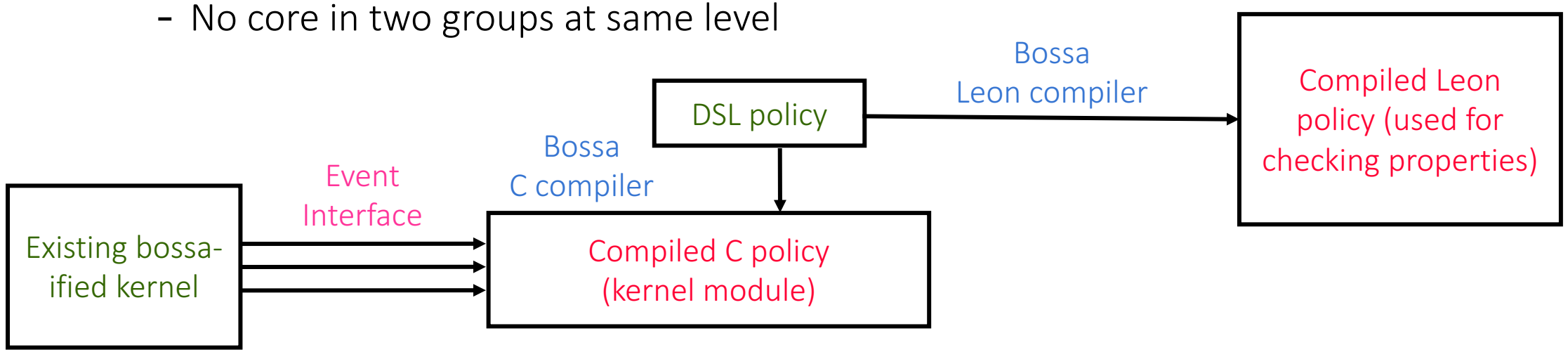


The Ipanema DSL

- Properties checked with Leon:
  - Load-balancing is work-conserving (can ensure it on « reasonable » policies)
  - Load is balanced in finite number of rounds of load-balancing (assuming « stable » system)
  - Load-balancing hierarchy is valid:
    - Top level contains all cores
    - No core in two groups at same level



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Ipanema also provides: 3 and 4

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- **Abstractions:**
  - Thread attributes
  - Ordering criteria
  - Thread states
  - Event handlers
  - A few more things (interface functions...)

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- Abstractions:
  - Thread attributes
  - Ordering criteria
  - Thread states
  - Event handlers
  - A few more things (interface functions...)
- Properties (mandatory):
  - Termination of events, bounded loops
  - Valid state transitions
  - No loss of a thread

The Ipanema DSL: a very basic example

Process/thread and core-local abstractions:

```
process = {
   int quanta;
   int load;
}

core = {
   processes = {
      RUNNING process current;
      shared READY set<process> ready : order = {lowest quanta};

      BLOCKED set<process> blocked;
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List of blocked processes (on an I/O, a lock).

The Ipanema DSL: a very basic example

Process/thread and core-local abstractions:

```
process = {
   int quanta;
   int load;
}

core = {
   processes = {
      RUNNING process current;
      shared READY set<process> ready : order = {lowest quanta};

      BLOCKED set<process> blocked;
      TERMINATED terminated;
   }
...
}
```

Process/thread-local variables.

Number of quanta the process has been running for.

Core-local, process-related variables.

Process currently running on the core.

List of processes, ordered by quantum (lazy evaluation), can be accessed by other processes (**shared** keyword).

List of blocked processes (on an I/O, a lock).

No reference kept (pseudo-state).

The Ipanema DSL: a very basic example

Process events:

```
handler (process_event e) {
   on tick {
      e.target.quanta++;
      if (e.target.quanta % 5 == 0) {
         e.target => ready;
      }
   }
   on yield {
      e.target => ready;
   }
   on block {
      e.target => blocked;
   }
   on unblock {
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   on schedule {
      first(ready) => current;
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Handlers for all events regarding a process (or thread).

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Context switch (will trigger schedule). Implicit list management.

Valid state transitions checked at compile-time.

Uses **`ready`**'s ordering criterion.

The Ipanema DSL

What's new? Mostly multicore stuff.

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- Abstractions:
  - Core attributes
  - Load criteria
  - Groups of cores
  - Core handlers
  - Load balancing functions

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What's new? Mostly multicore stuff.

- Abstractions:
  - Core attributes
  - Load criteria
  - Groups of cores
  - Core handlers
  - Load balancing functions
- Performance/synchronization properties:
  - Locking/sychronization handled by the framework
  - Mostly trylocks: if unable to lock a runqueue, give up on stealing thread (best effort)
  - Ensure no performance bugs

The Ipanema DSL: a very basic example

Multicore abstractions:

```
domain = {
   set<group> groups;
}

group = {
   set<core> cores;
   lazy int load = sum(cores.load);
   int capacity = count(cores);

   lazy bool is_stealable = or(cores.is_stealable);
}
```

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Stealing from this group won't cause load conservation issues.

Group stealable iff one of its cores is.

The Ipanema DSL: a very basic example

Core abstractions:

```
core = {

   ...

   system int id;
   lazy int load = sum(current.load, ready.load);
   lazy bool is_stealable = count(current, ready) > 1;
   set<domain> scheduling_domains;

   domains (core self) to scheduling_domains = {
      foreach (dist in distances starting_at 1) {
         domain (c | distance(c, self) <= dist) to groups = {
            group (c1,c2 | distance(c1, c2) <= dist - 1) to cores;
         }
      }
   }
}
```

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Obtained from the kernel.

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Be work-conserving (basic).

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```

Obtained from the kernel.

Be work-conserving (basic).

Hierarchy-building functions co-designed with proofs: Leon code checks good properties (top domain contains all cores, no core in two groups at the same level...).

The Ipanema DSL: a very basic example

Load balancing: who steals whom?

```
handler (core_event e) {

   on balancing_select {

      foreach (sd in e.target.scheduling_domains) {
         group busiest = max(sd.groups order = { highest load / capacity } filter = { is_stealable });

         if (valid(busiest)) {
            core busiest_core = max(busiest.core order = { highest load } filter = { ready.size >= 1 });
            balancing_steal(e.target, busiest_core);
         }
      }

   }

}
```

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```

Load-balancing logic similar to Linux (simplified).

The Ipanema DSL: a very basic example

Load balancing: stealing processes

```
try void balancing_steal(core self, core busiest) {

      int imbalance = (busiest.load - self.load) / 2;
      if (imbalance <= 0)
        return;

      foreach (p in busiest.ready) {
         if (imbalance < p.load)
            continue;

          p => self.ready;

          imbalance -= p.load;
          if (imbalance <= 0)
             break;
      }
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The Ipanema DSL: a very basic example

Load balancing: stealing processes

Acquires locks automatically and may quietly fail (best effort).

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