ETH zürich

Decoupling Cores, Kernels and Operating Systems

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Outline

- Motivation
  Trends in hardware and software
- Booting and shutting down cores dynamically
  Decoupling the kernel state
- Evaluation
  Kernel updates, specialized kernels

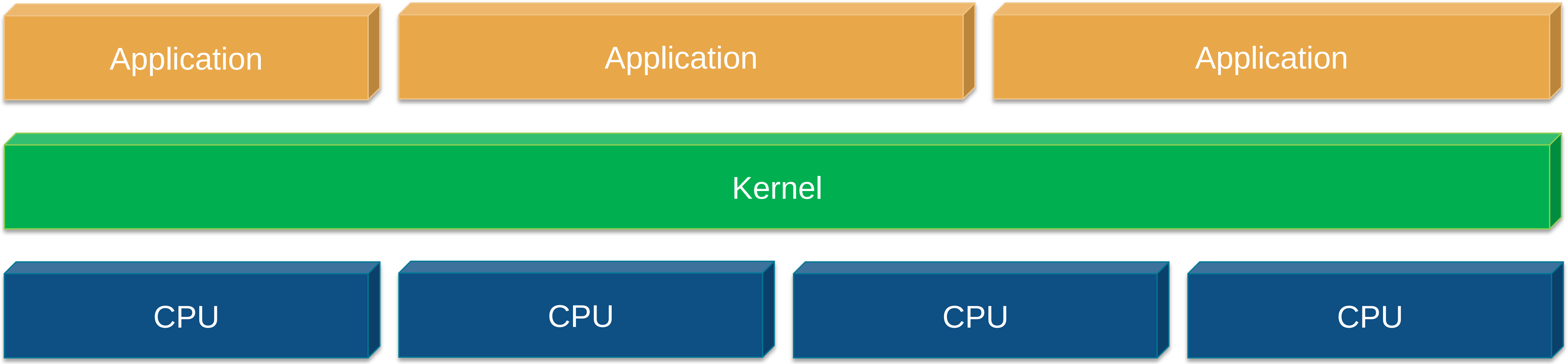
What's happening to hardware

- Constrained by power consumption

- Reconfigurable cores (dynamically changed behavior)
  - DVFS, Turbo Boost, SMT
  - Core Fusion [ISCA '07]
  - Dark silicon [ISCA '10]

- Heterogeneous cores
  - Fast and power hungry vs. slow and power efficient
  - Asymmetric multiprocessing
  - Conservation Cores [ASPLOS '10]

What current operating systems look like



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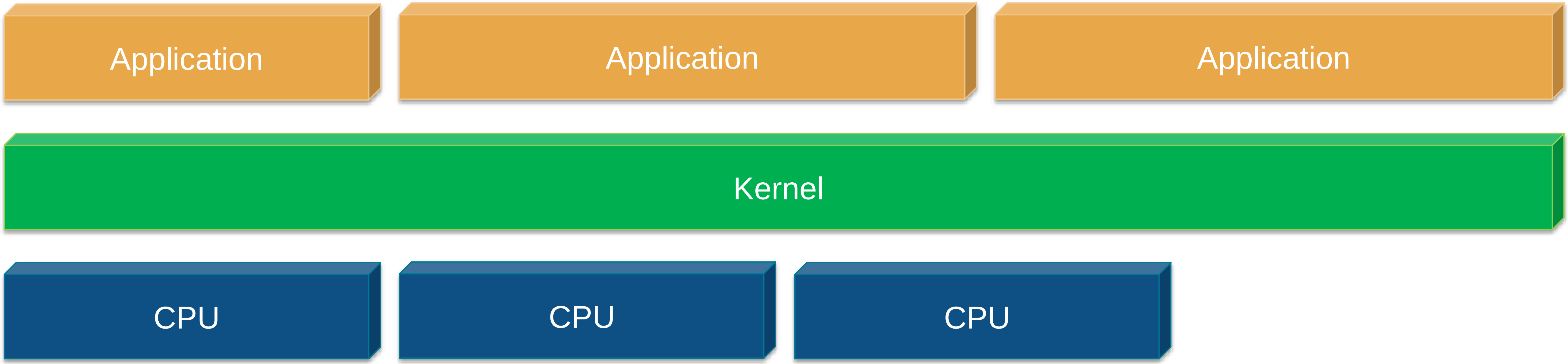

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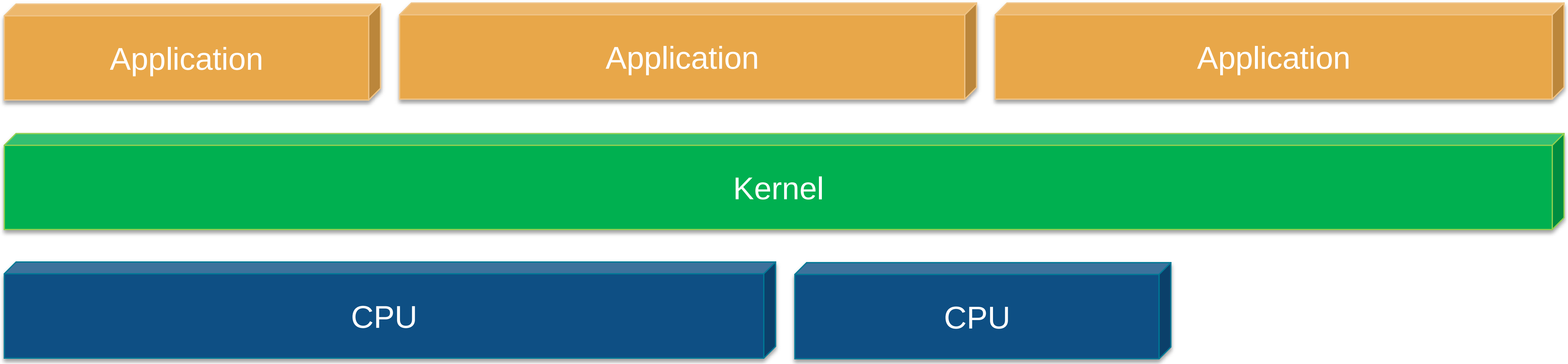


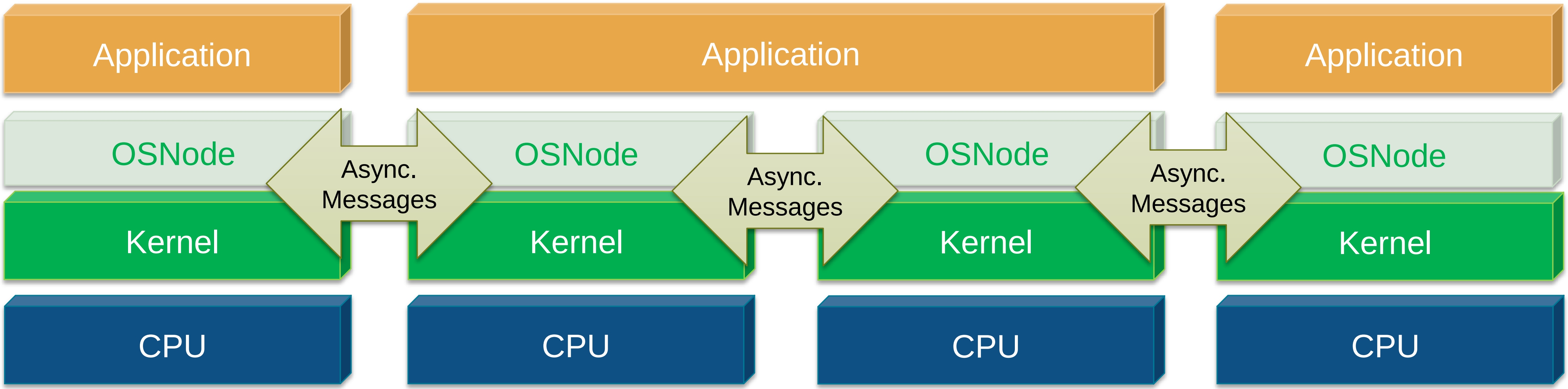
What’s happening to software

- OS needs to adapt to different workloads

- Adapting at build-, boot-, and run-time
  - Debugging support: profiling, tracing etc.
  - Real-time support

- On-the-fly kernel updates
  - KSplice (Linux) [EuroSys ‘09]
  - K42 [ATC ‘07]

Multikernel [SOSP '09]



Implementation

- Barrelfish OS

- Treating cores as pluggable devices
  - Booting a core dynamically with boot drivers
  - Shutting down a core

- Decoupling Cores, Kernels and the Operating System

  Externalizing kernel state

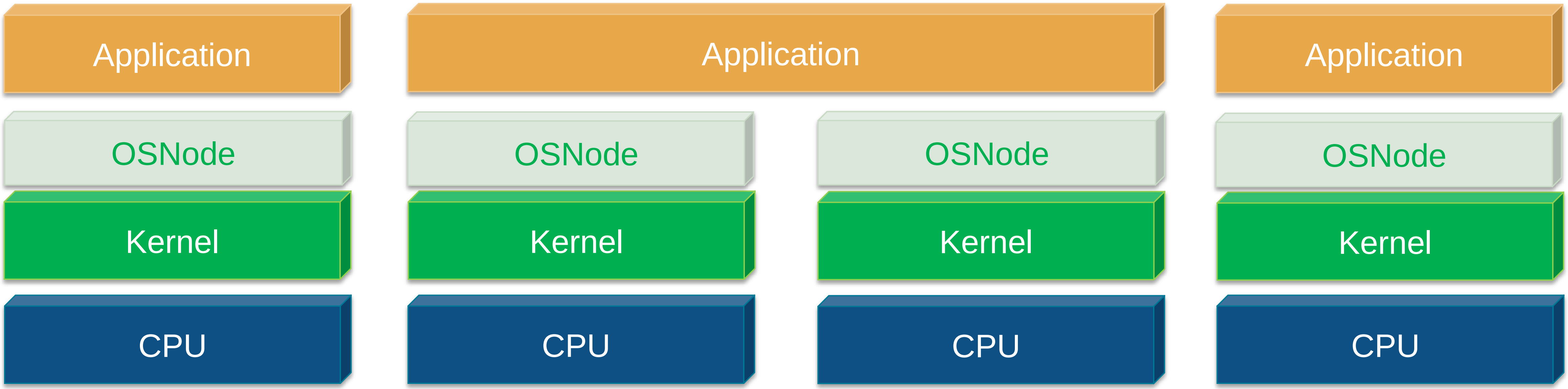
Booting a core with boot drivers

- OS service for target core management
- Dynamically chooses kernel for core based on runtime information
  - Boots any core with any suitable kernel
  - Run any OSNode on any compatible core
- Implements boot, shutdown, reboot protocol

Shutting down a core

- Harder than booting a core
  - Need to deal with per-core state: Scheduler queues, memory pools, page-tables…
  - Takes time (and energy)
- However, we want to remove the core as fast as possible
- General approach (cf. Chameleon [ASPLOS ’12])
  - Get state out of the way quickly
  - Dismantle it later, lazily (if needed)

Shutting down a core



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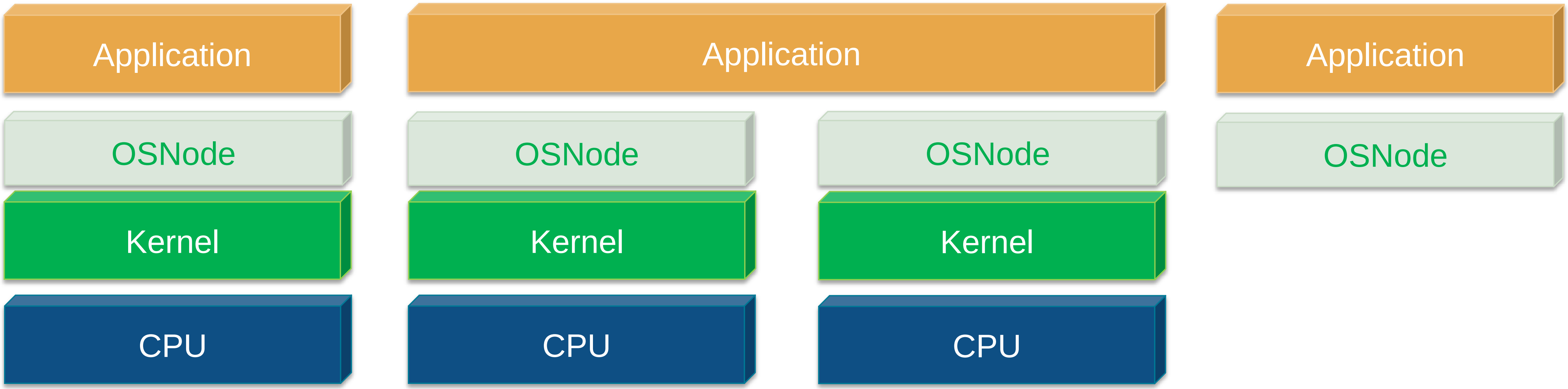

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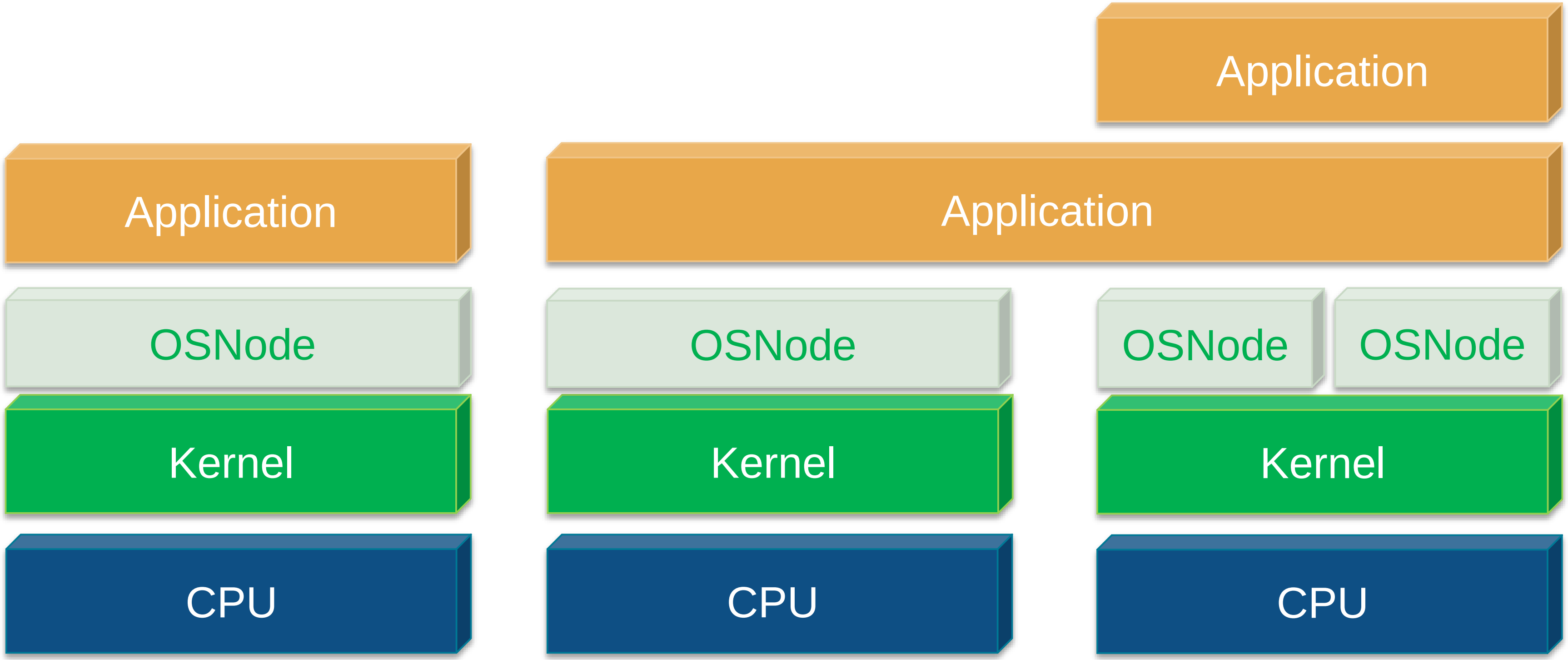

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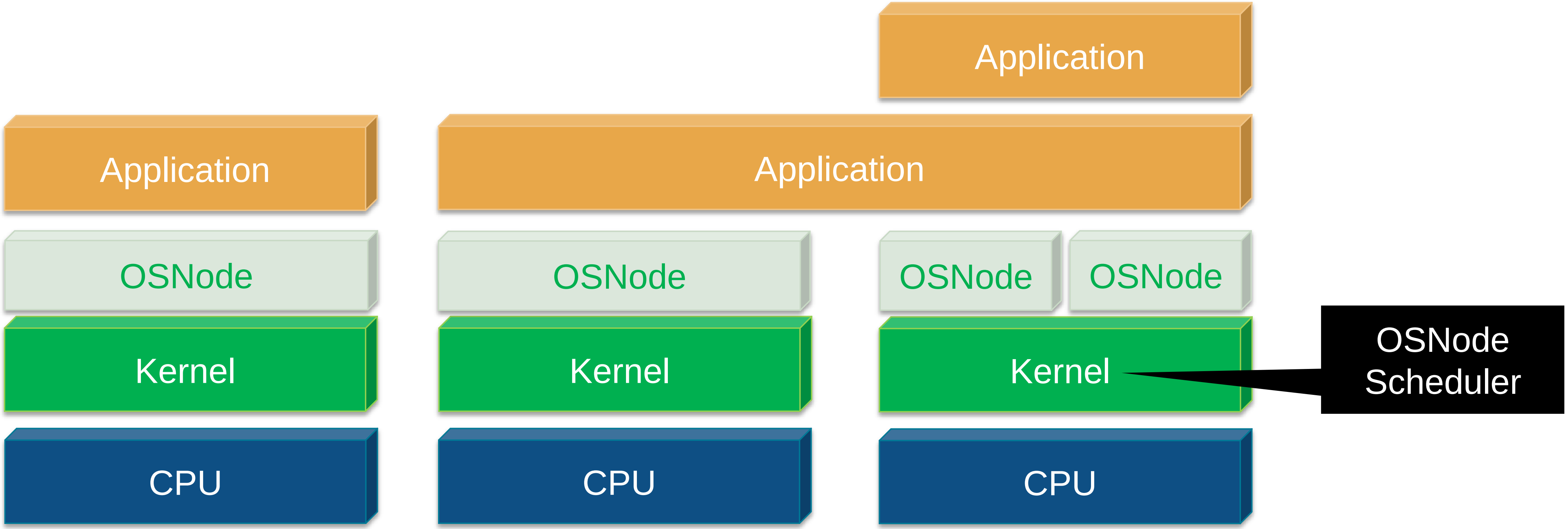

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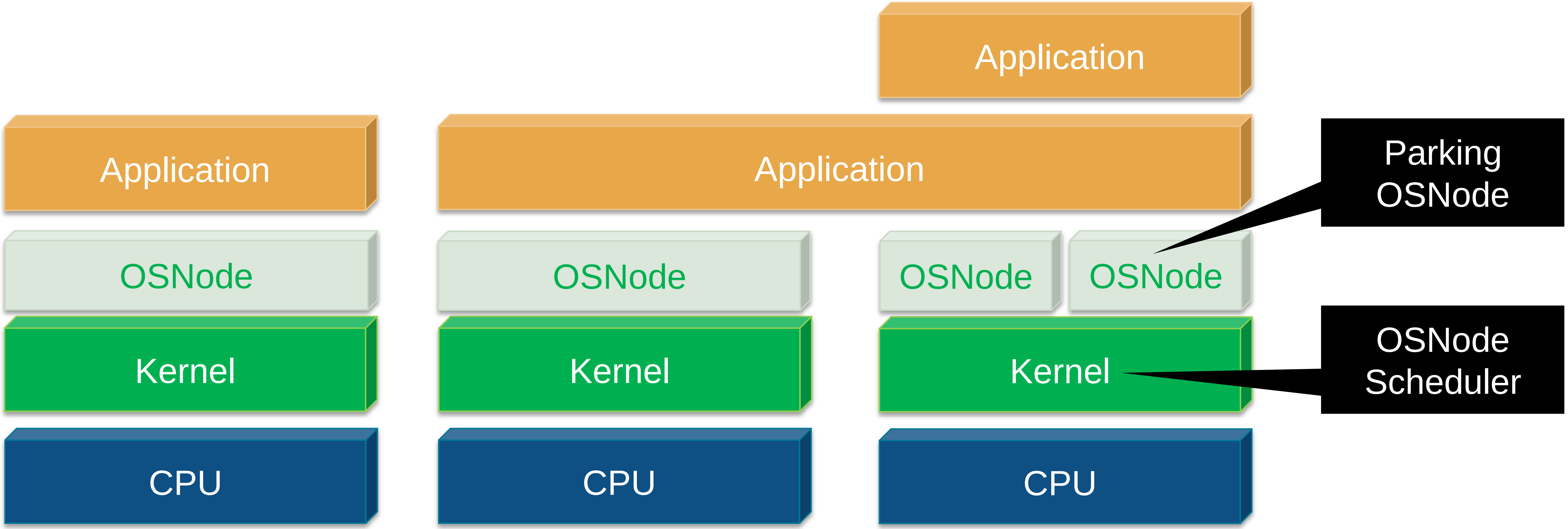

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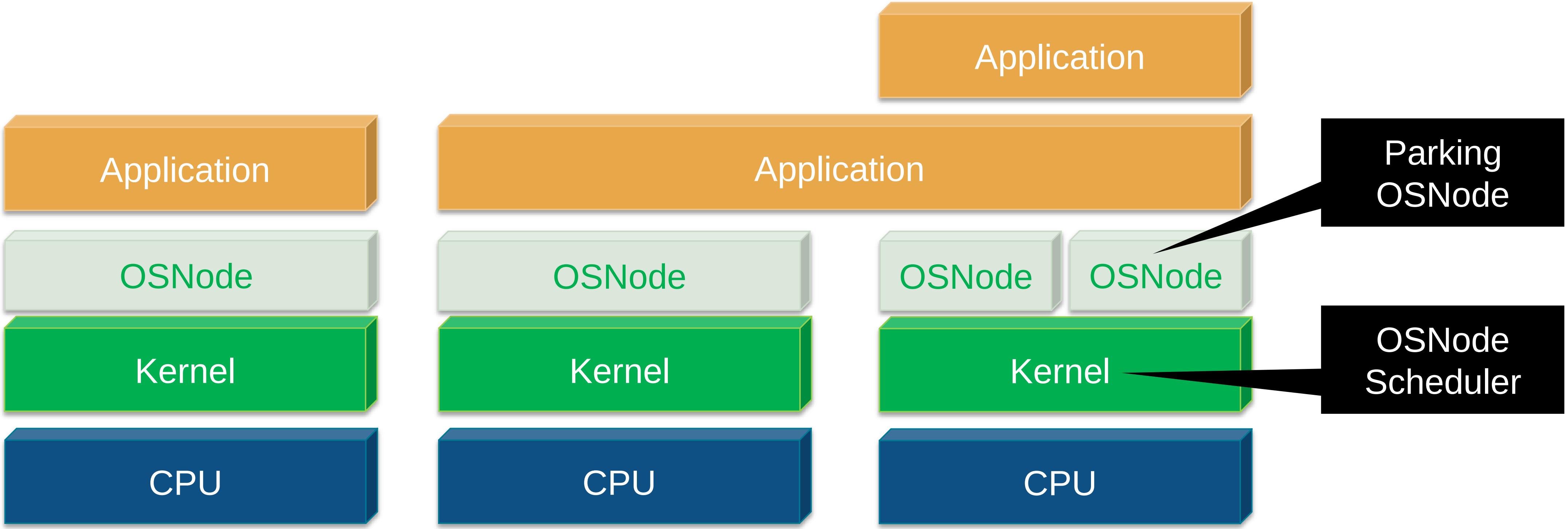


Highly scalable, only two cores involved

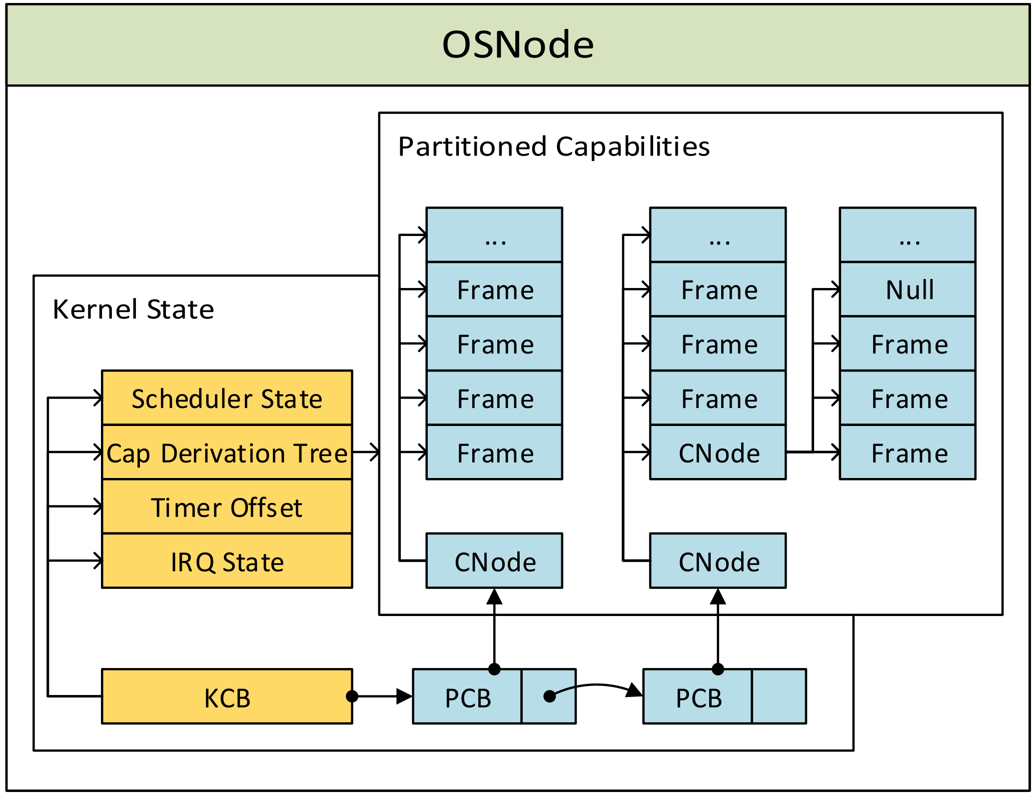
What is the OSNode?

OSNode: All state for a single core and kernel

How do we capture this OSNode?

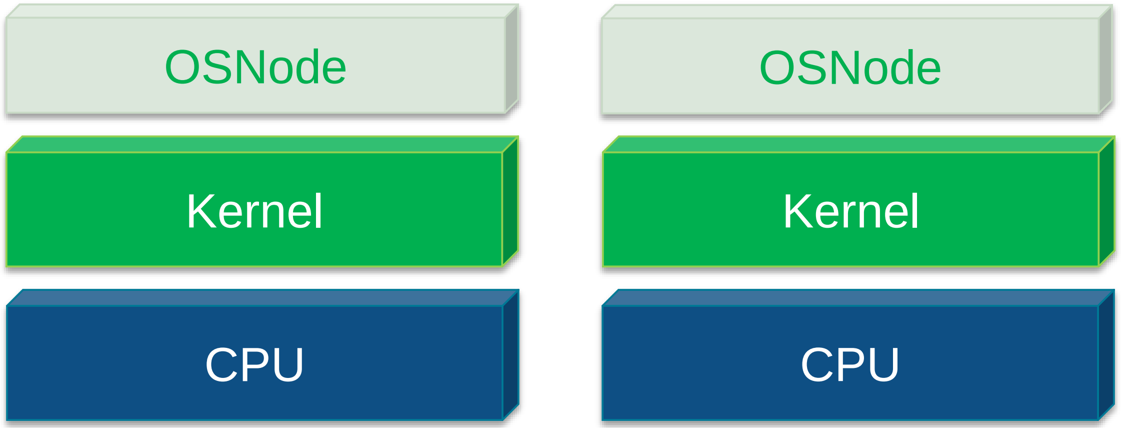
- **Capabilities:**
  - Tracks all application state
  - Tracks all OS state

  cf. seL4, EROS, KeyKOS
- **KCB (Kernel control block)**
  - Hardware specific state
  - Entry point to capability tree
  - Represented as a capability itself



Decoupling Cores, Kernels and Operating Systems

State externalization & dynamic core booting is a much more general mechanism



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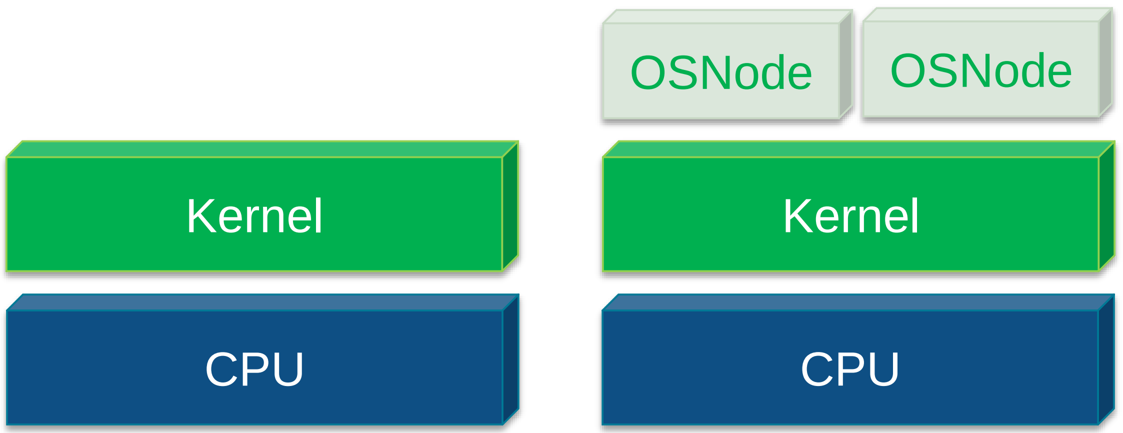

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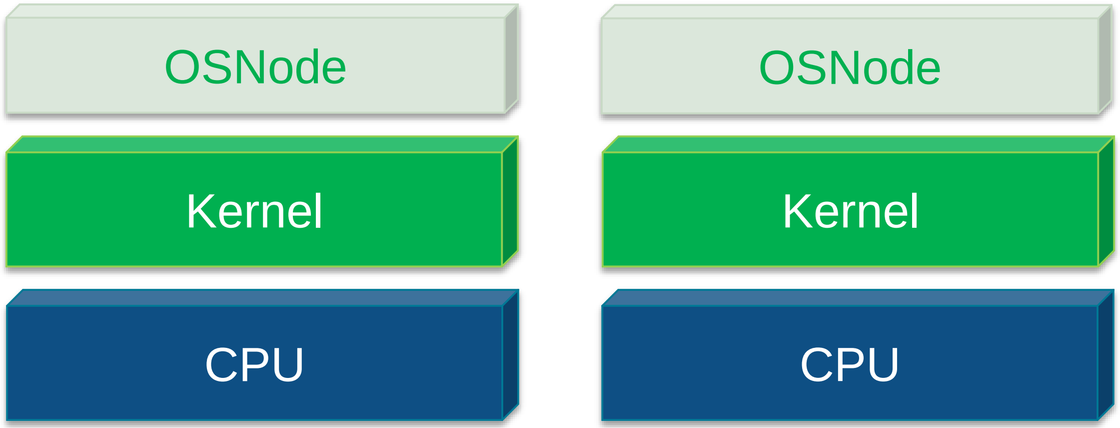

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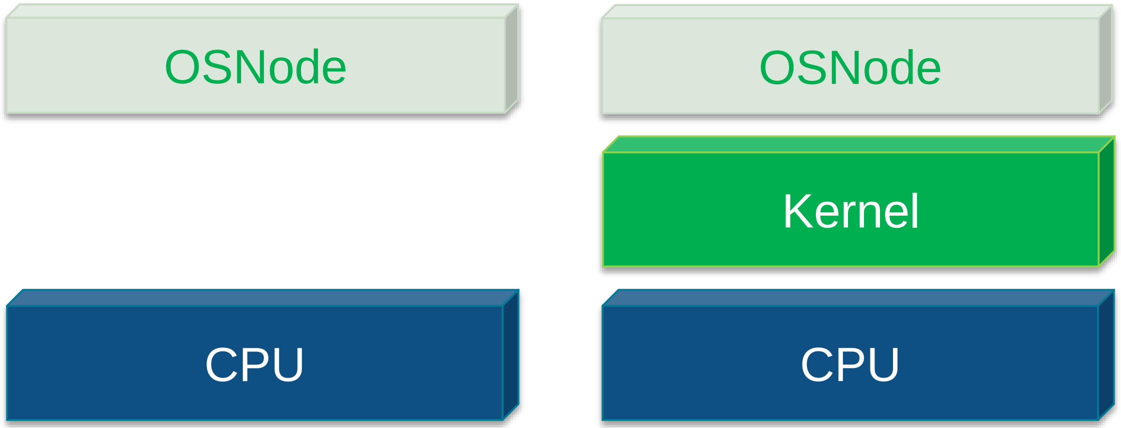

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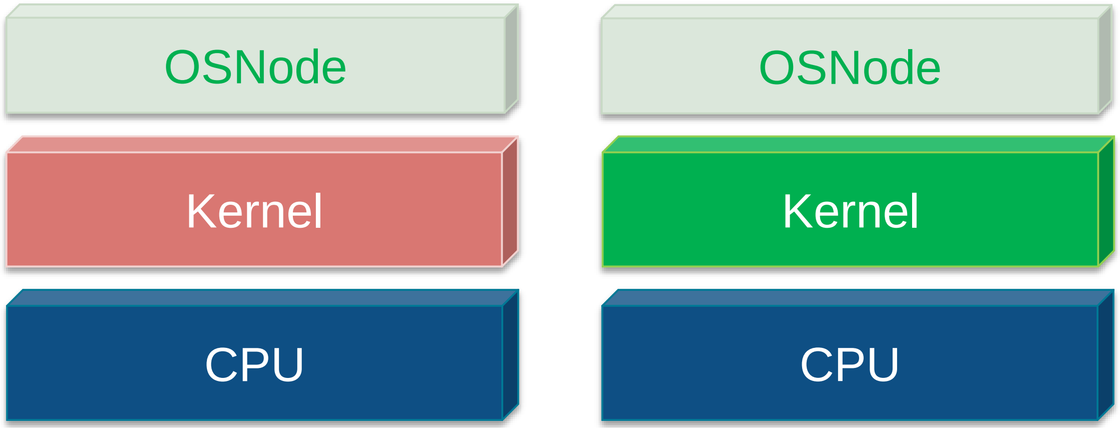


Evaluation

- Core management
  Adding and removing cores in the system
- Kernel updates
  Hot-swapping the kernel
- Specialized kernels
  e.g., eliminate OS jitter

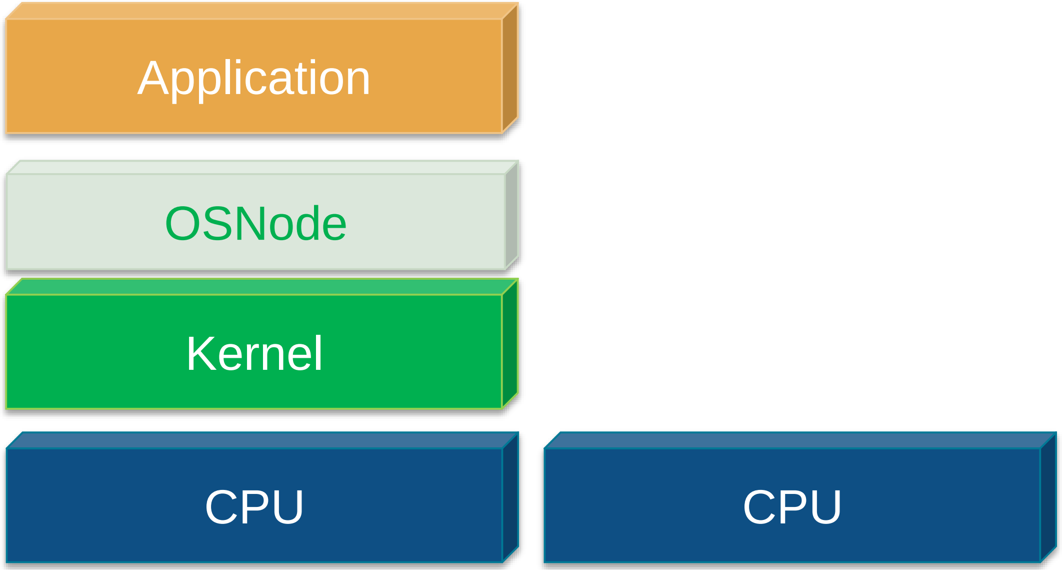
Core management (Haswell, 1x4 cores, no HT)

Booting a core	No Load	Load
Linux 3.13	14 ms	20 ms
Barrelfish/DC	7.5 ms	7.5 ms

Removing a core	No Load	Load
Linux 3.13	46 ms	2542 ms
Barrelfish/DC	0.0008 ms	0.0008 ms

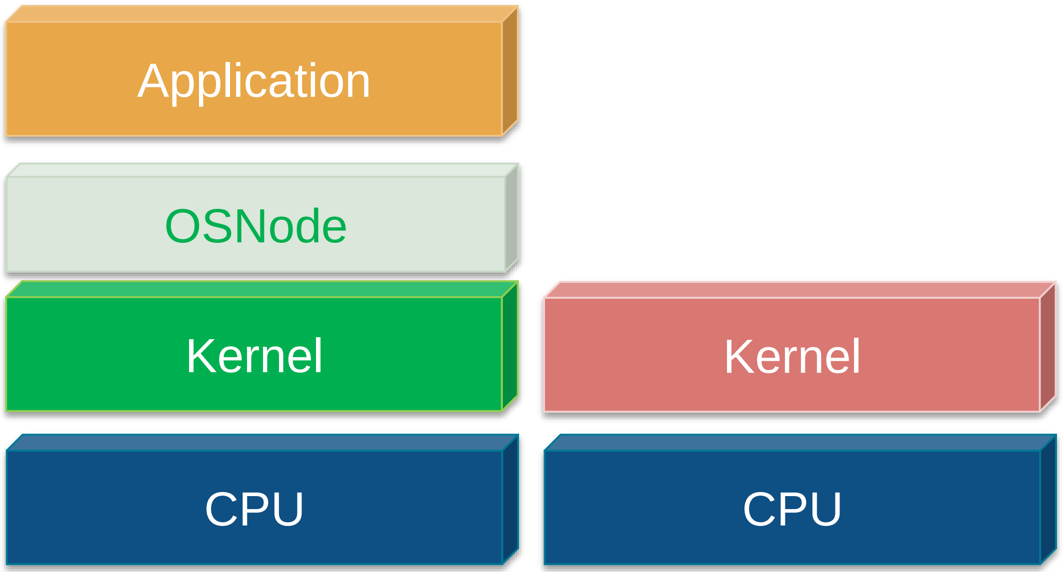
Use-case: Kernel Updates

- Shut-down target core



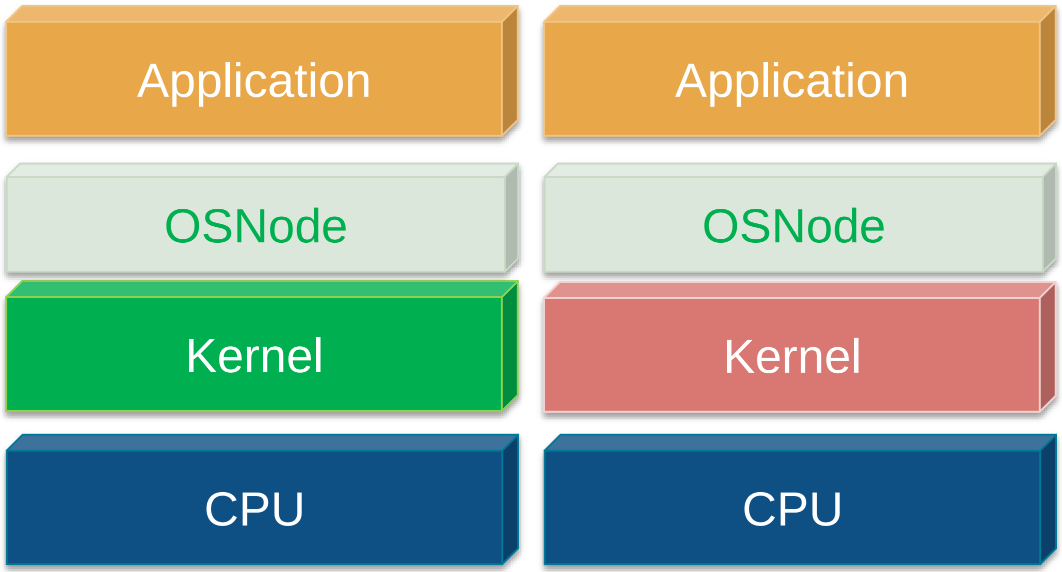
Use-case: Kernel Updates

- Shut-down target core
- Reboot core with a new kernel image

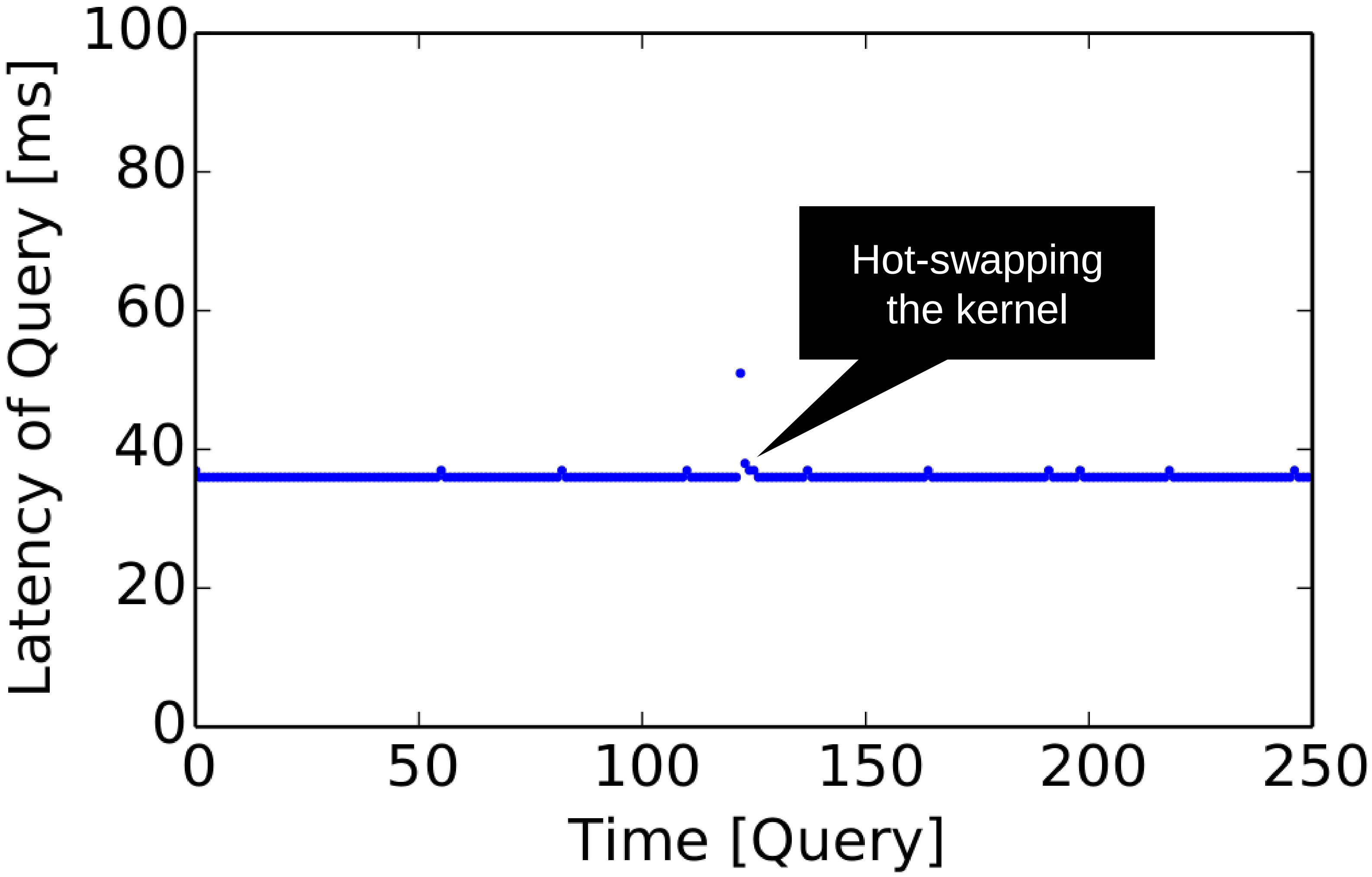


Use-case: Kernel Updates

- Shut-down target core
- Reboot core with a new kernel image
- Dispatch previous OSNode



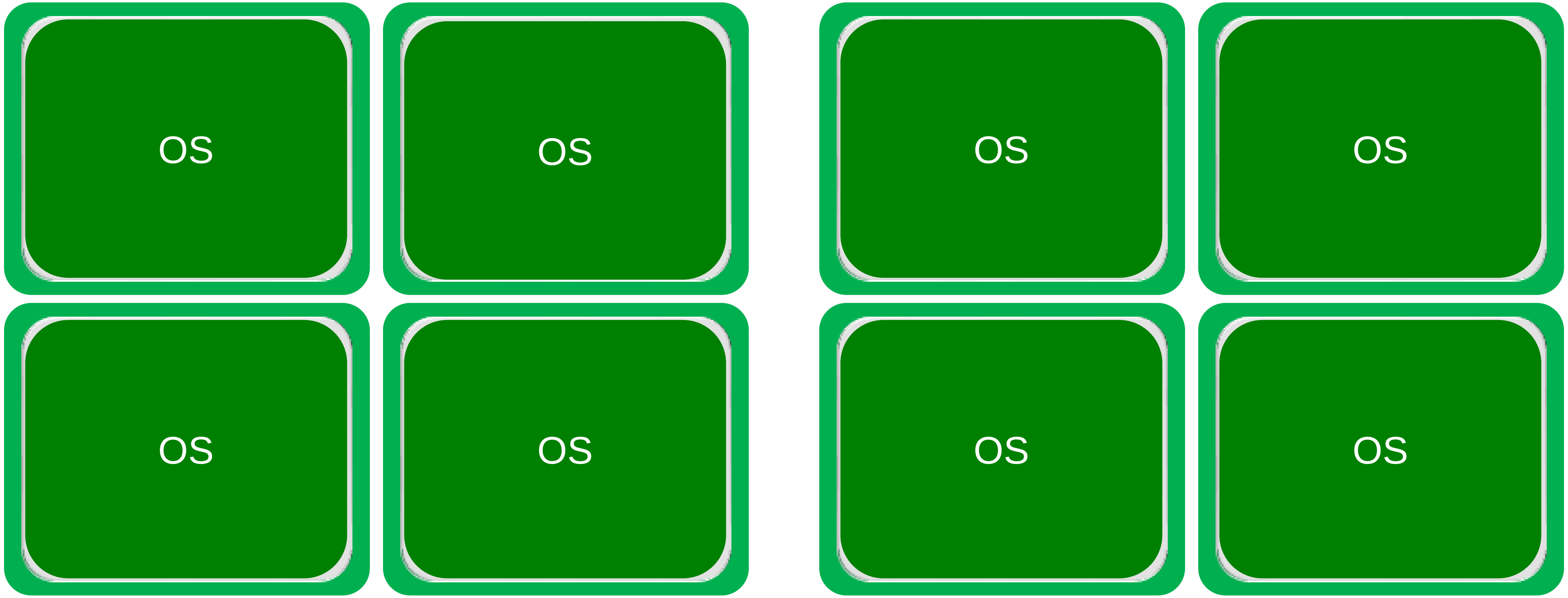
Kernel updates: PostgreSQL & TPC-H



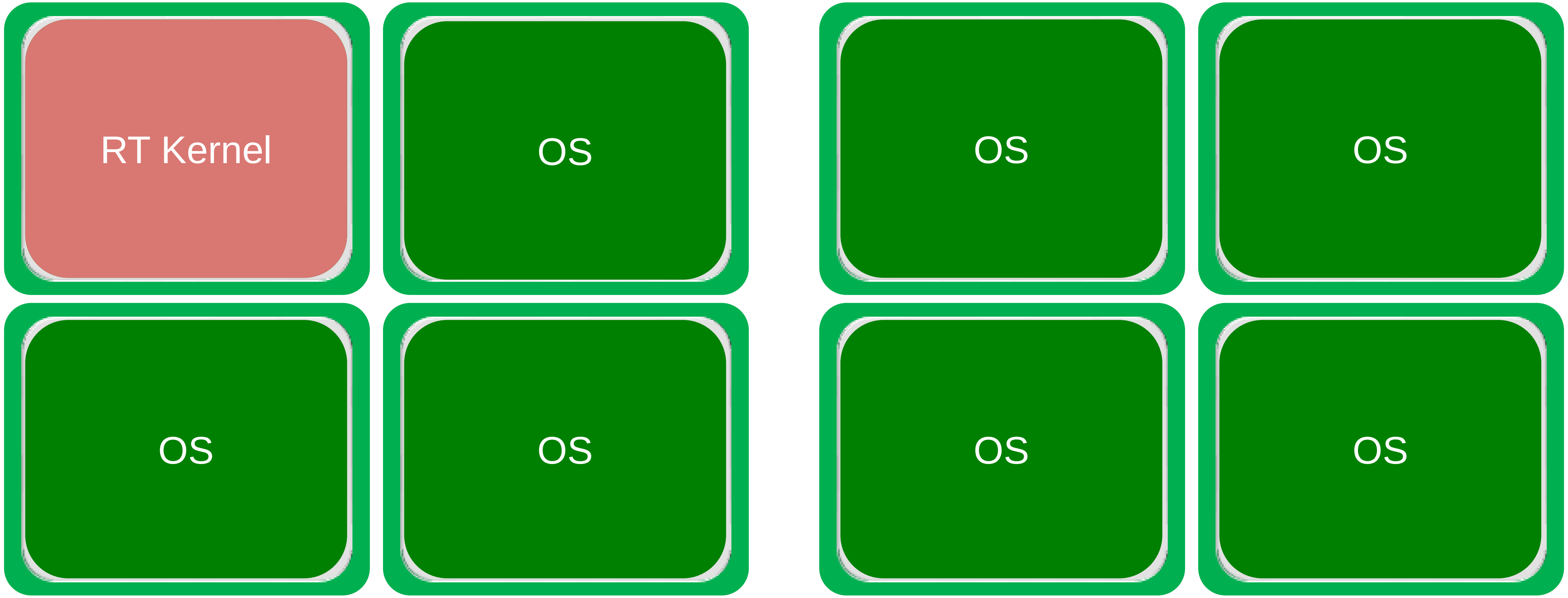
Use-case: Temporary real time task

- A thread that needs to run with hard real time performance
  - E.g., phone baseband stack, control application, robotics etc.
- A lot of effort spent to make this work in a general purpose OS
- Many real time OS for embedded systems (RTLinux, LynxOS, QNX, …)

Use-case: Real time application



Use-case: Real time application



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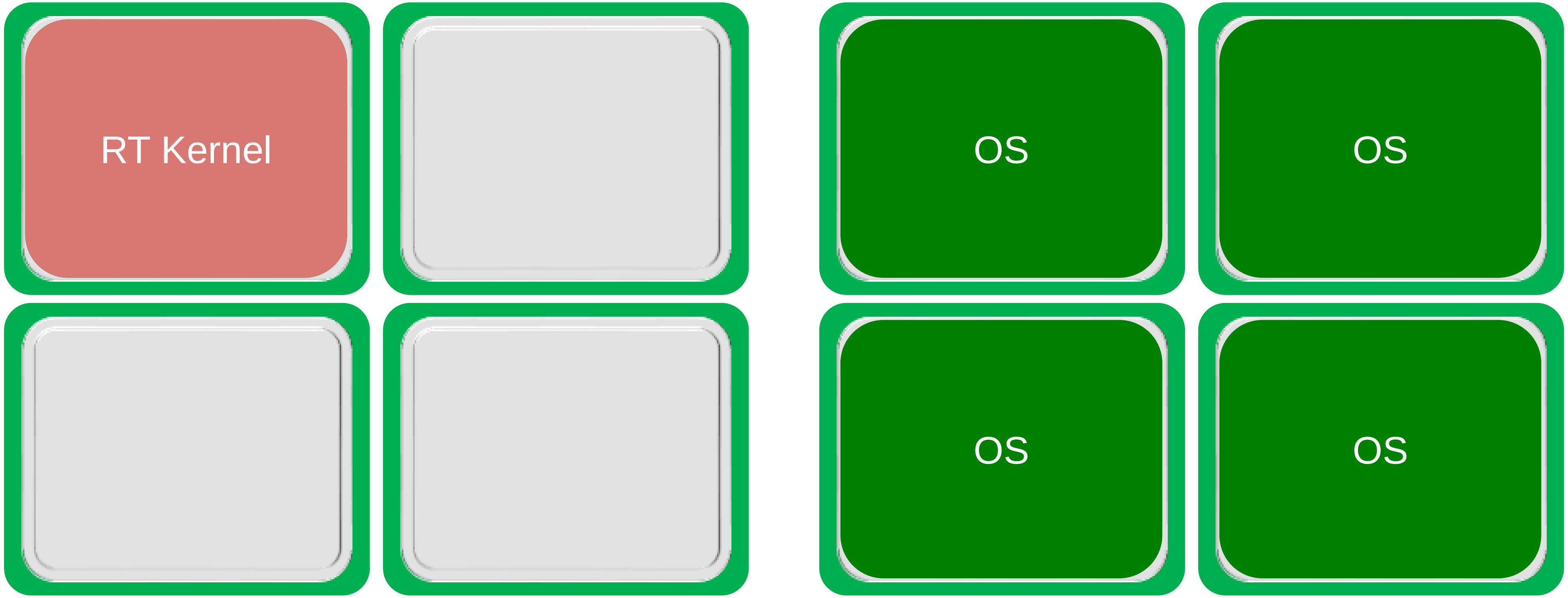
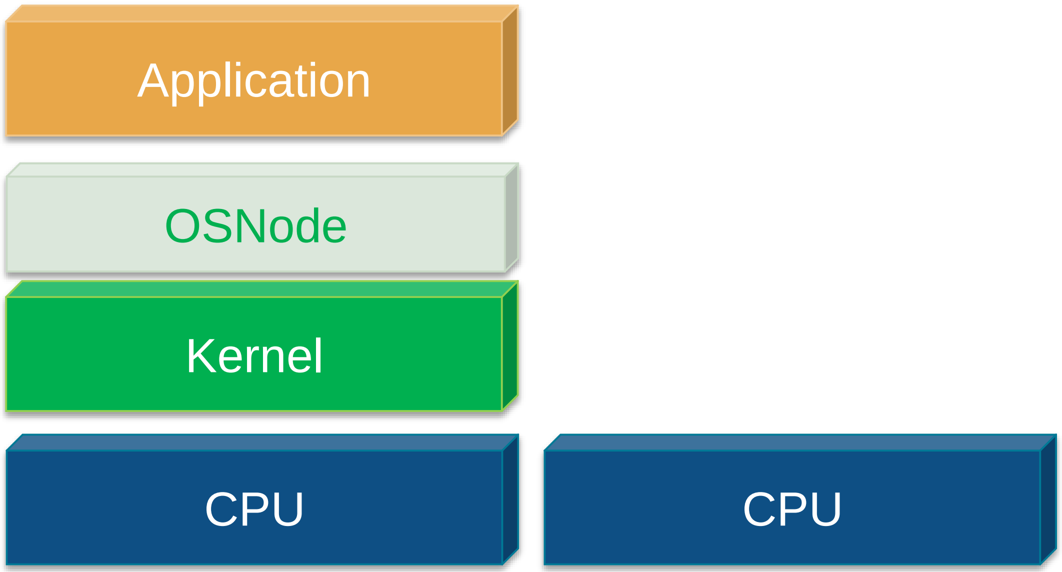


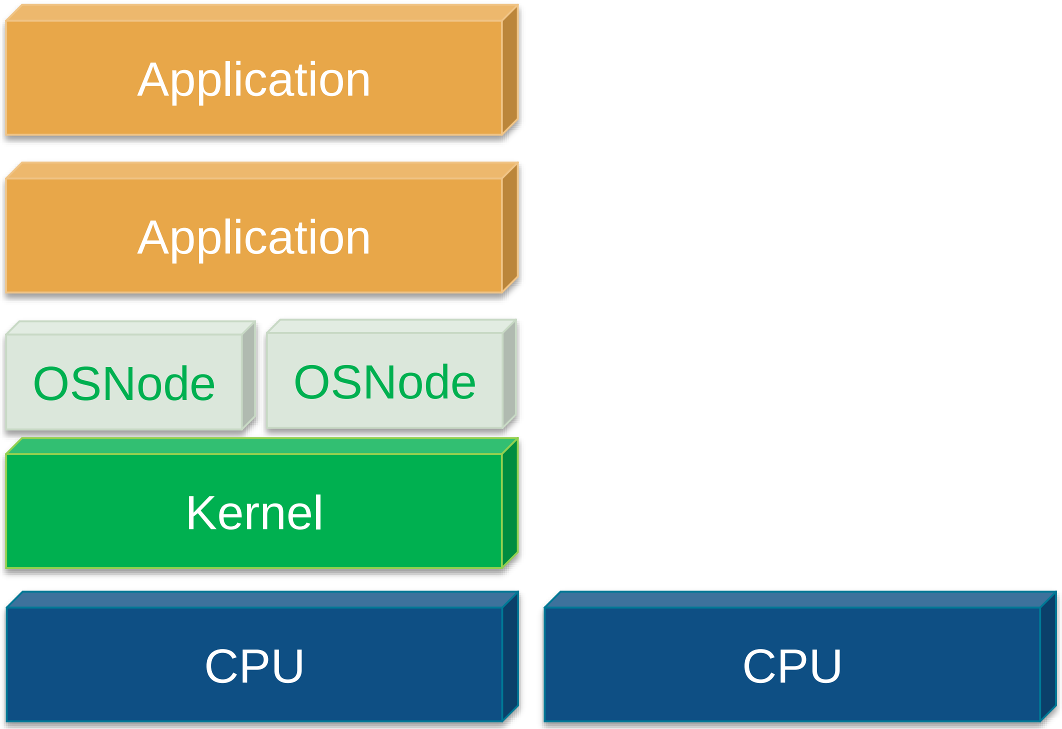
Use-case: Specialized kernels

- Shut-down target core

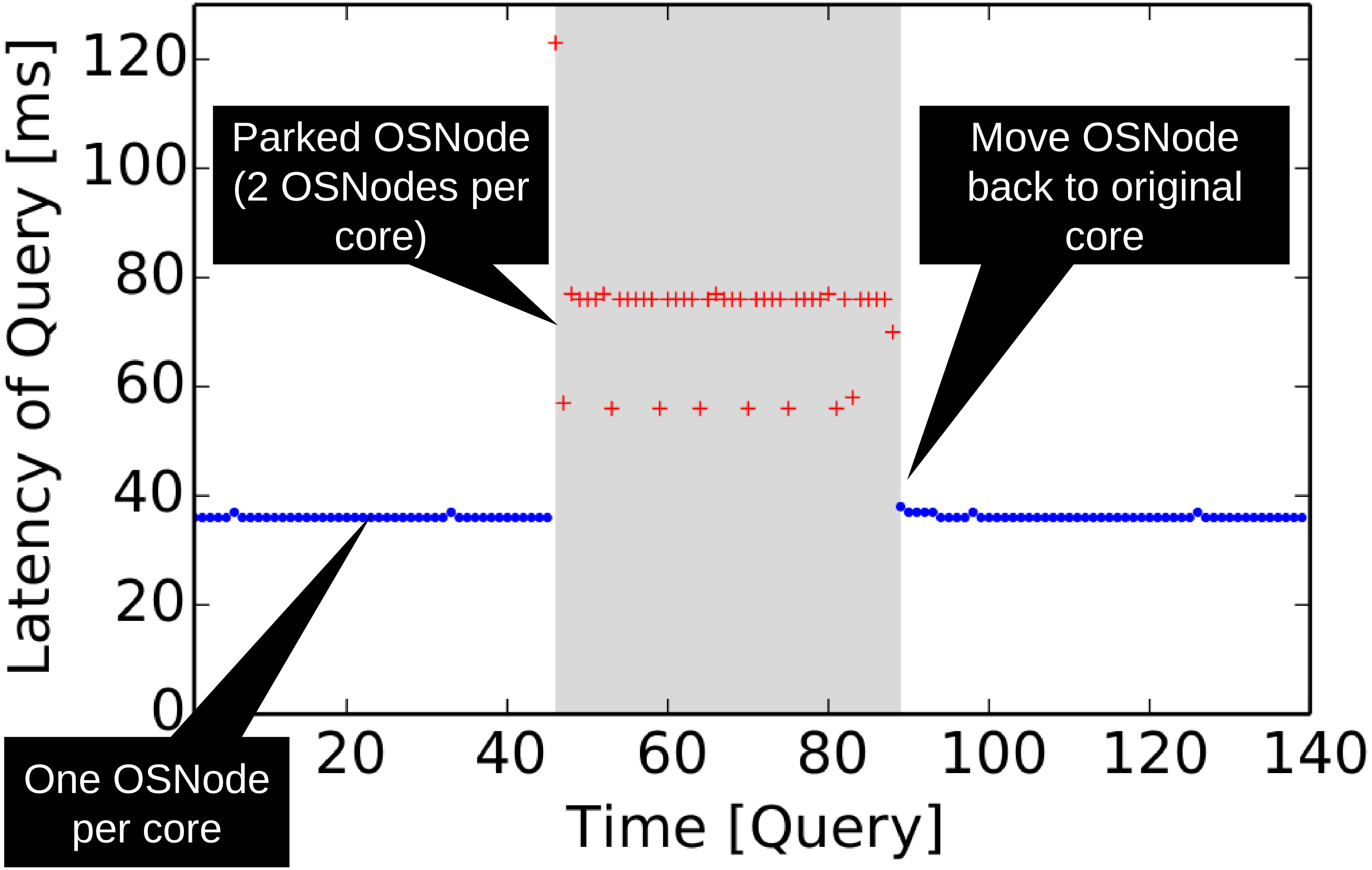


Use-case: Specialized kernels

- Shut-down target core
- Temporarily park the target OSNode

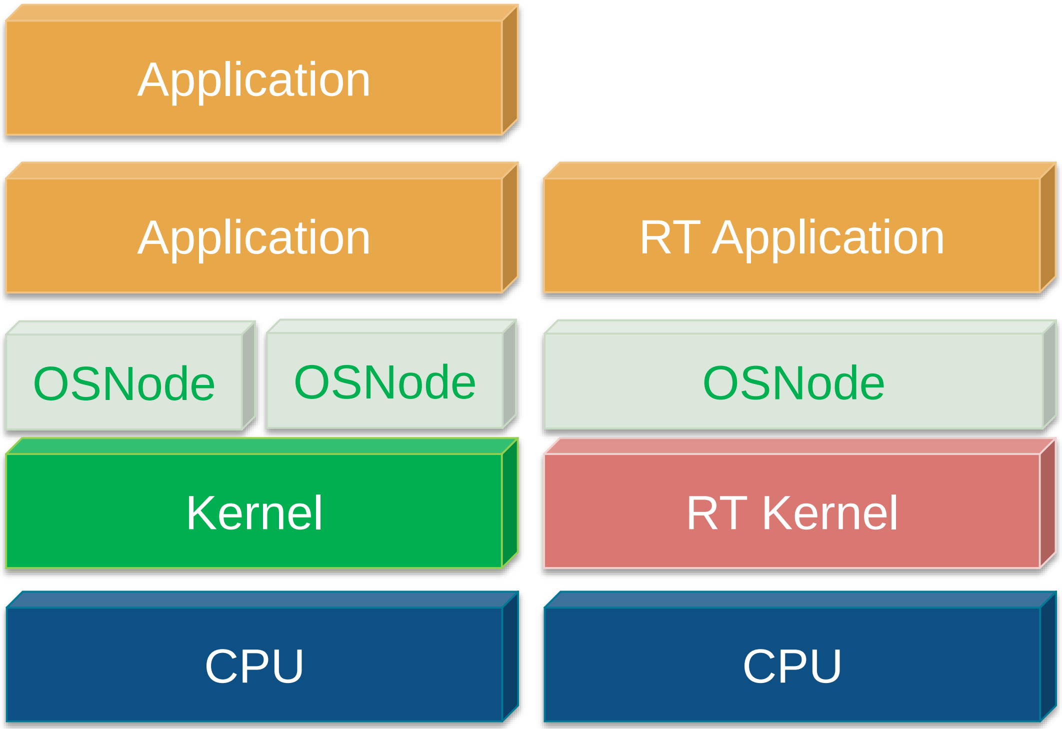


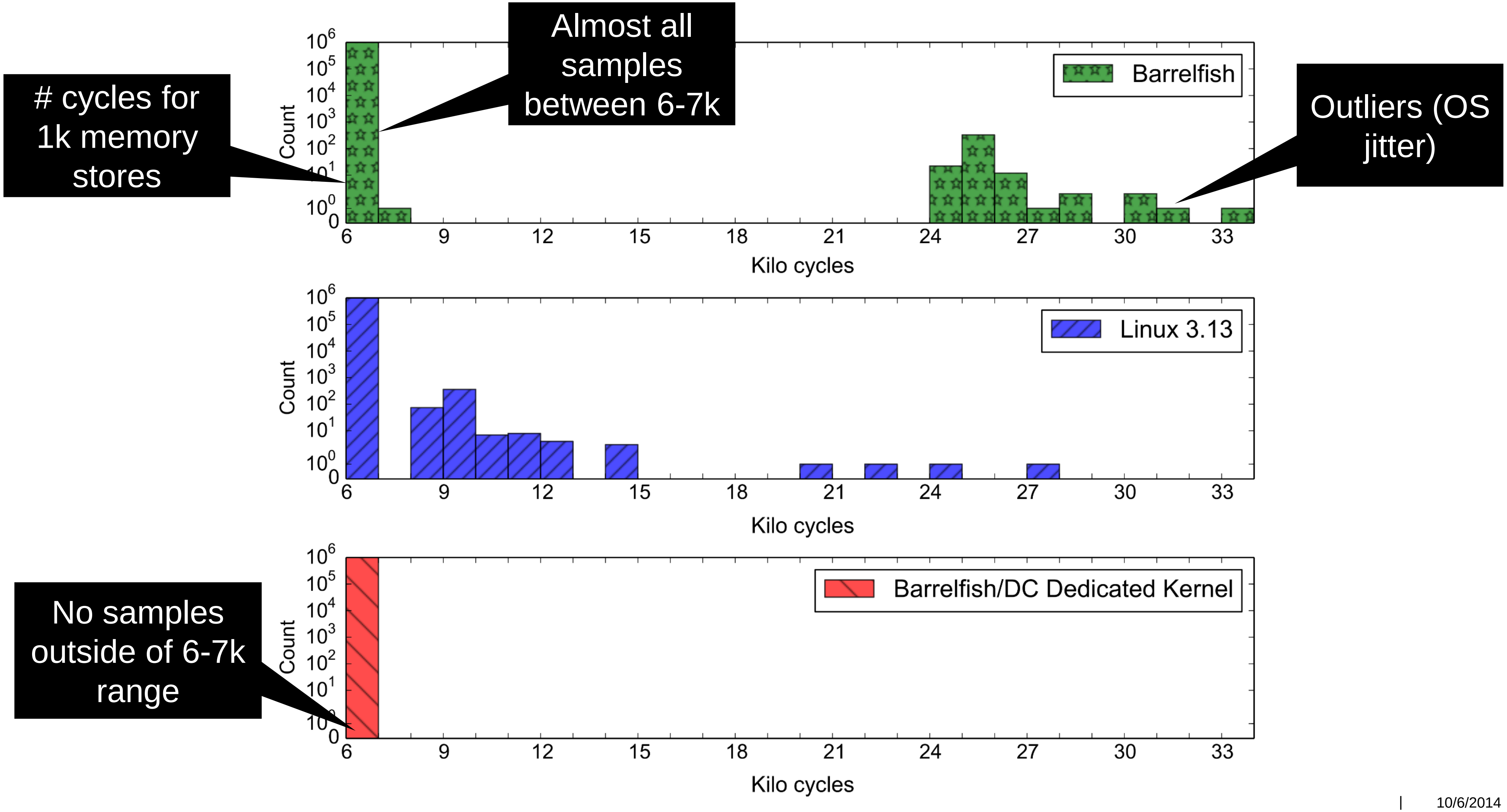
Evaluation: PostgreSQL & TPC-H



Use-case: Specialized kernels

- Shut-down target core
- Temporarily park the target OSNode
- Boot simple real-time kernel that runs just one application
  - Does not take interrupts
  - No timers
  - No scheduler
- Temporarily provides task with hard real time guarantees




cycles for 1k memory stores
Almost all samples between 6-7k
Outliers (OS jitter)
No samples outside of 6-7k range
Barrelfish
Linux 3.13
Barrelfish/DC Dedicated Kernel
Count
Kilo cycles
6
9
12
15
18
21
24
27
30
33

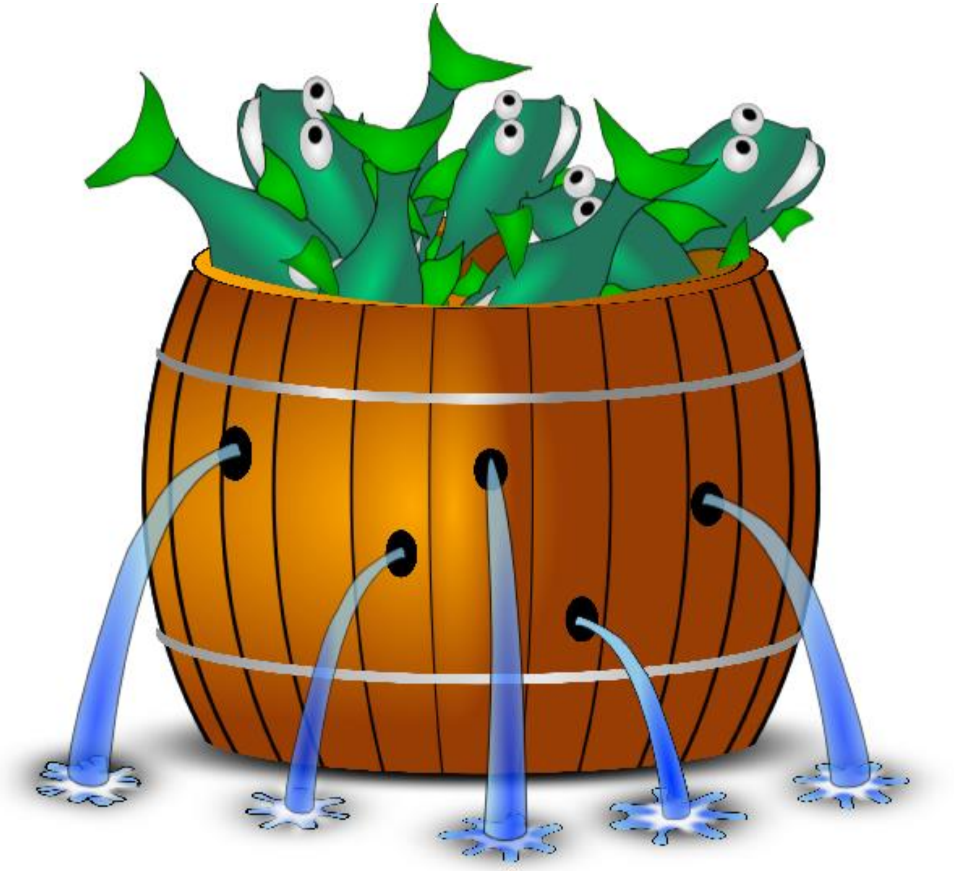
Future Work & Applications

- Transfer OSNodes between power efficient and high performance cores
- Dynamic OS instrumentation
  - Profiling, tracing kernels
- A/B kernel testing
- Specialized kernel to run applications in guest ring 0

  cf. Arrakis

Conclusion

- Decoupling the kernel state
- Result: highly dynamic OS architecture
  - Kernels can be rebooted, updated and specialized
  - Cores can be allocated and de-allocated arbitrarily
- For many versions of the “dark silicon” hardware, this may be the only way for system software



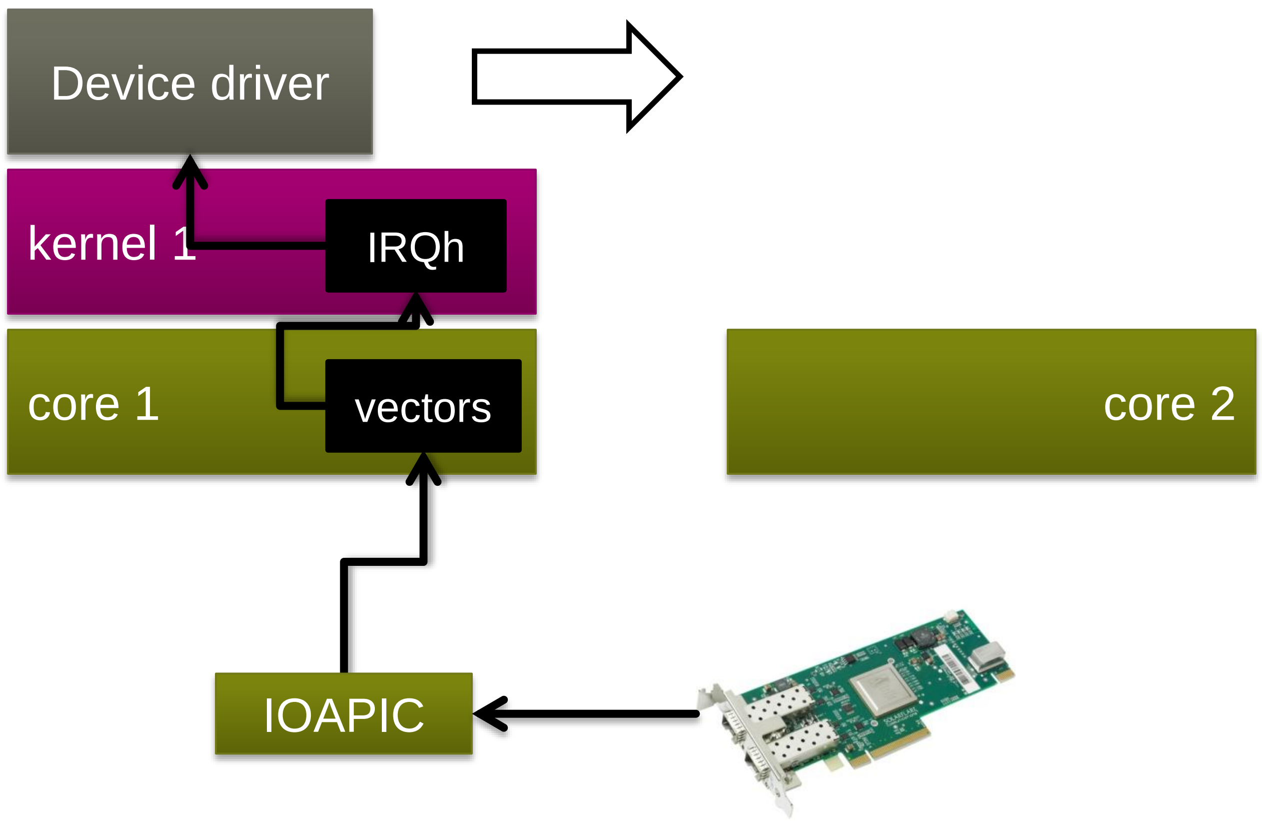
www.barrelfish.org

Backup

Dealing with interrupts

1. Timers, etc. local to core and CPU driver
   - Handled internally to CPU driver
2. Inter-processor interrupts (IPIs)
   - Indirection table of OSNodes → physical cores
3. Device interrupts
   - Must be re-routed to new core

Device interrupts



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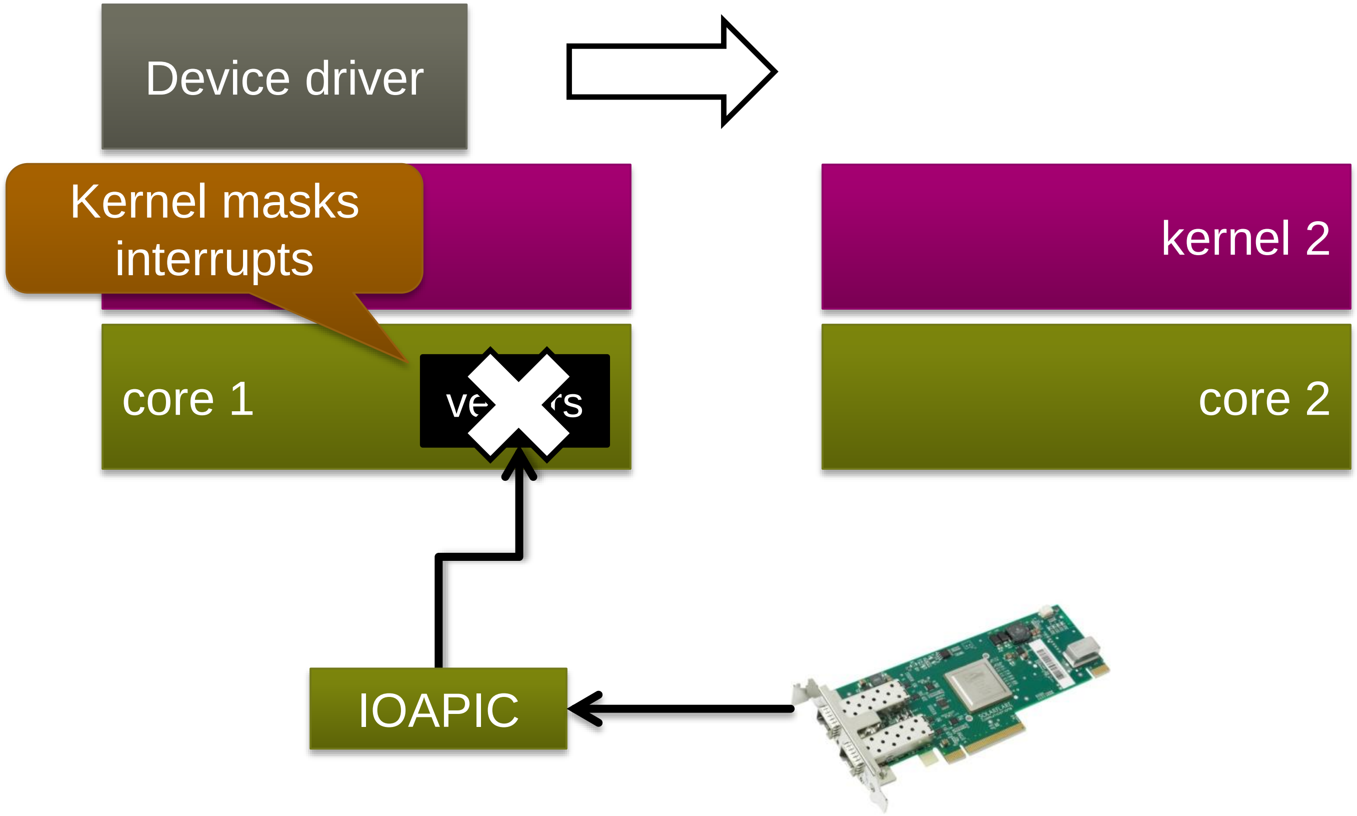

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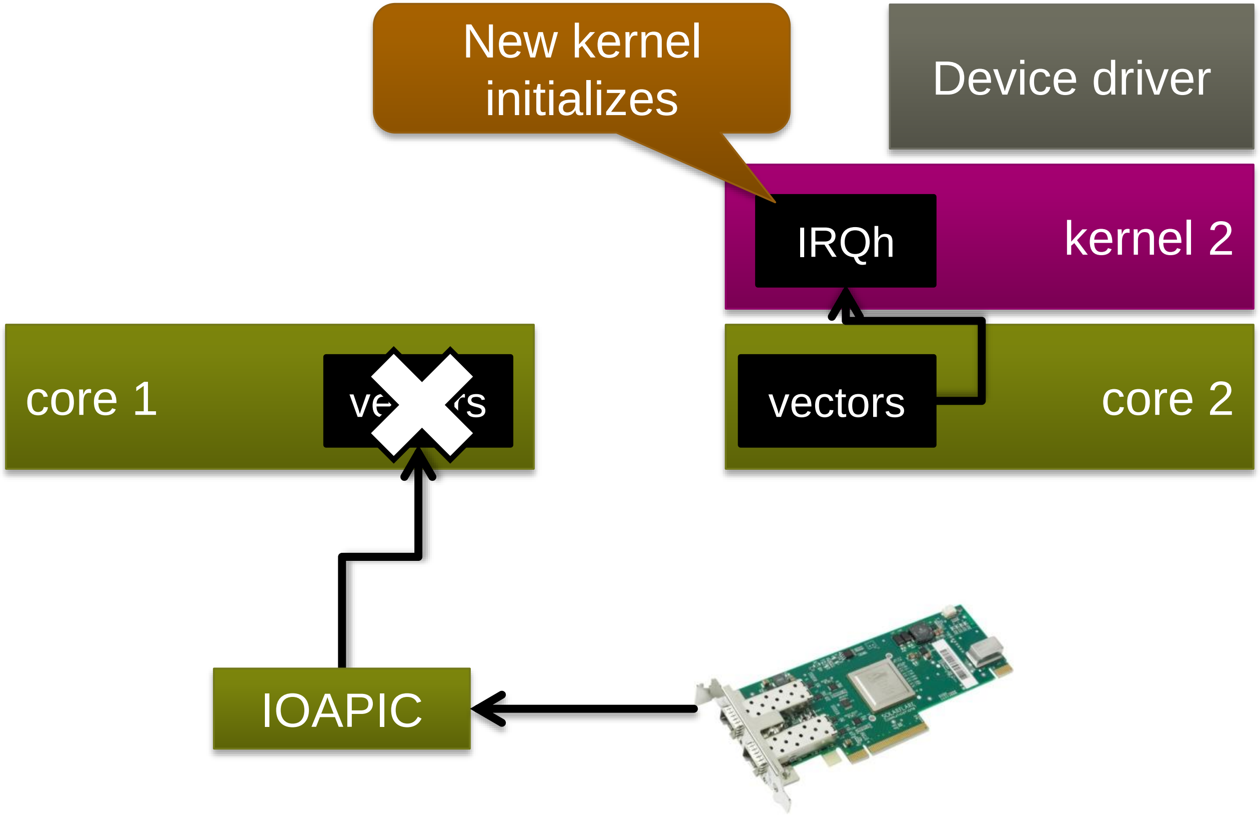

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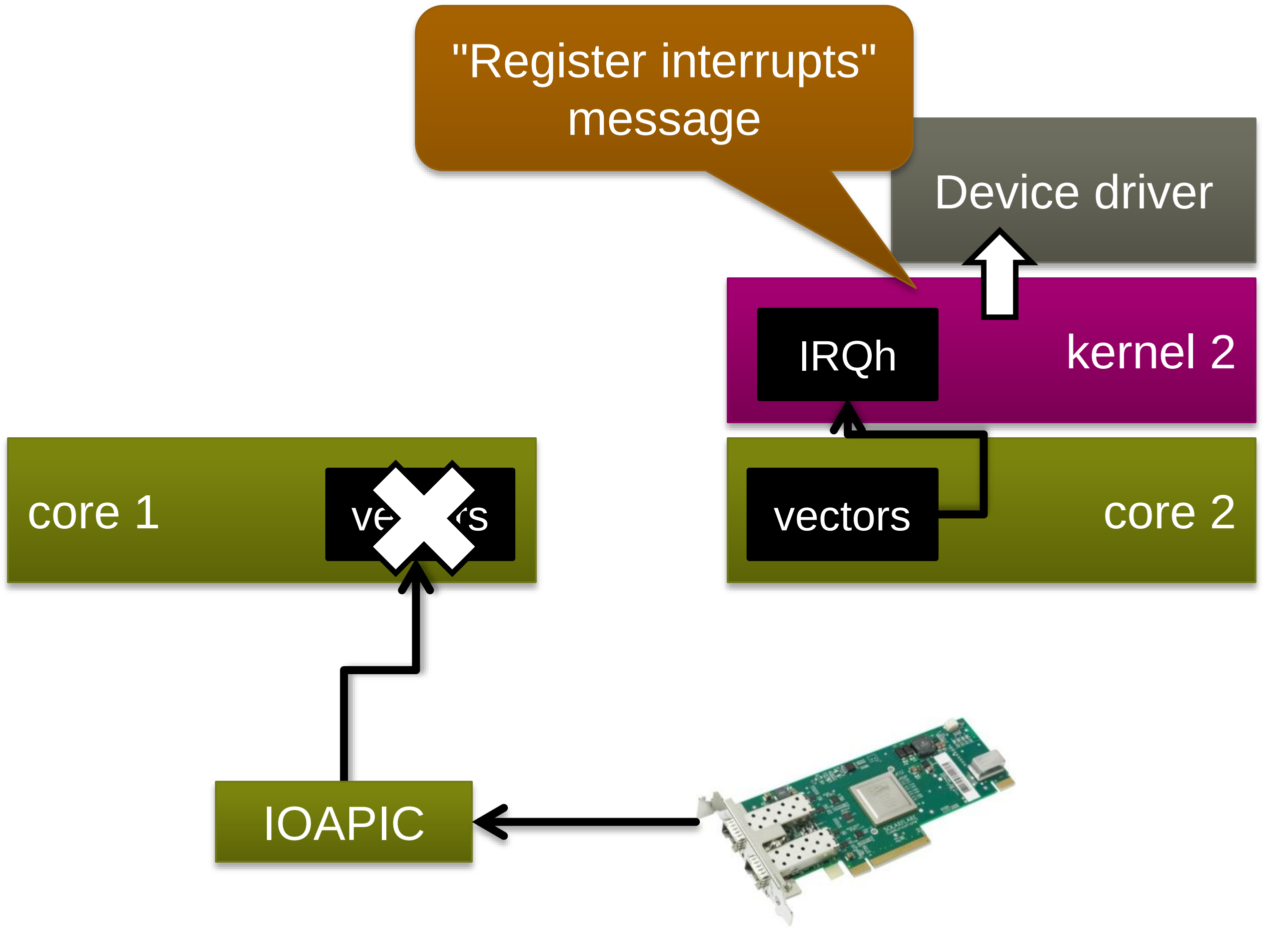

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