Is Co-scheduling Too Expensive for SMP VMs?

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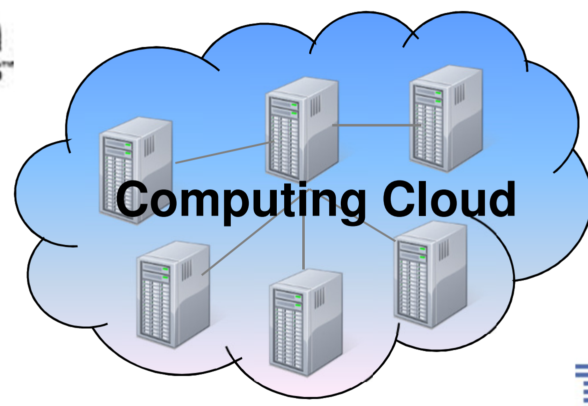
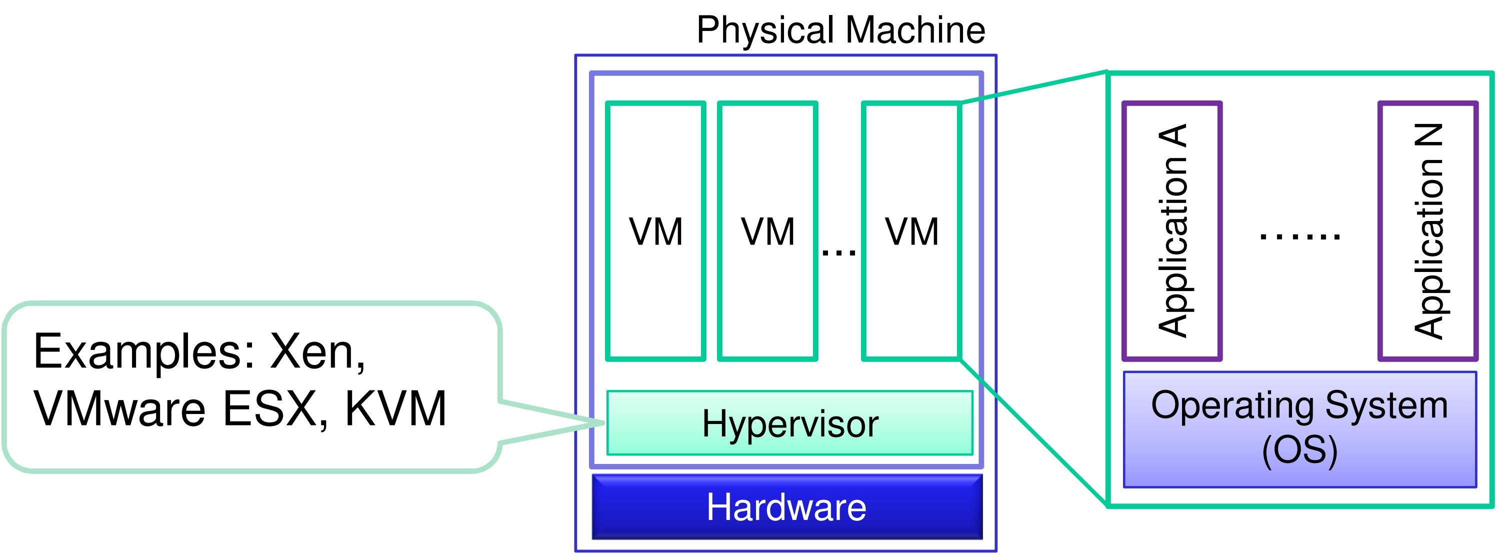
EuroSys 2011 - April 12, 2011

Cloud & Virtualization



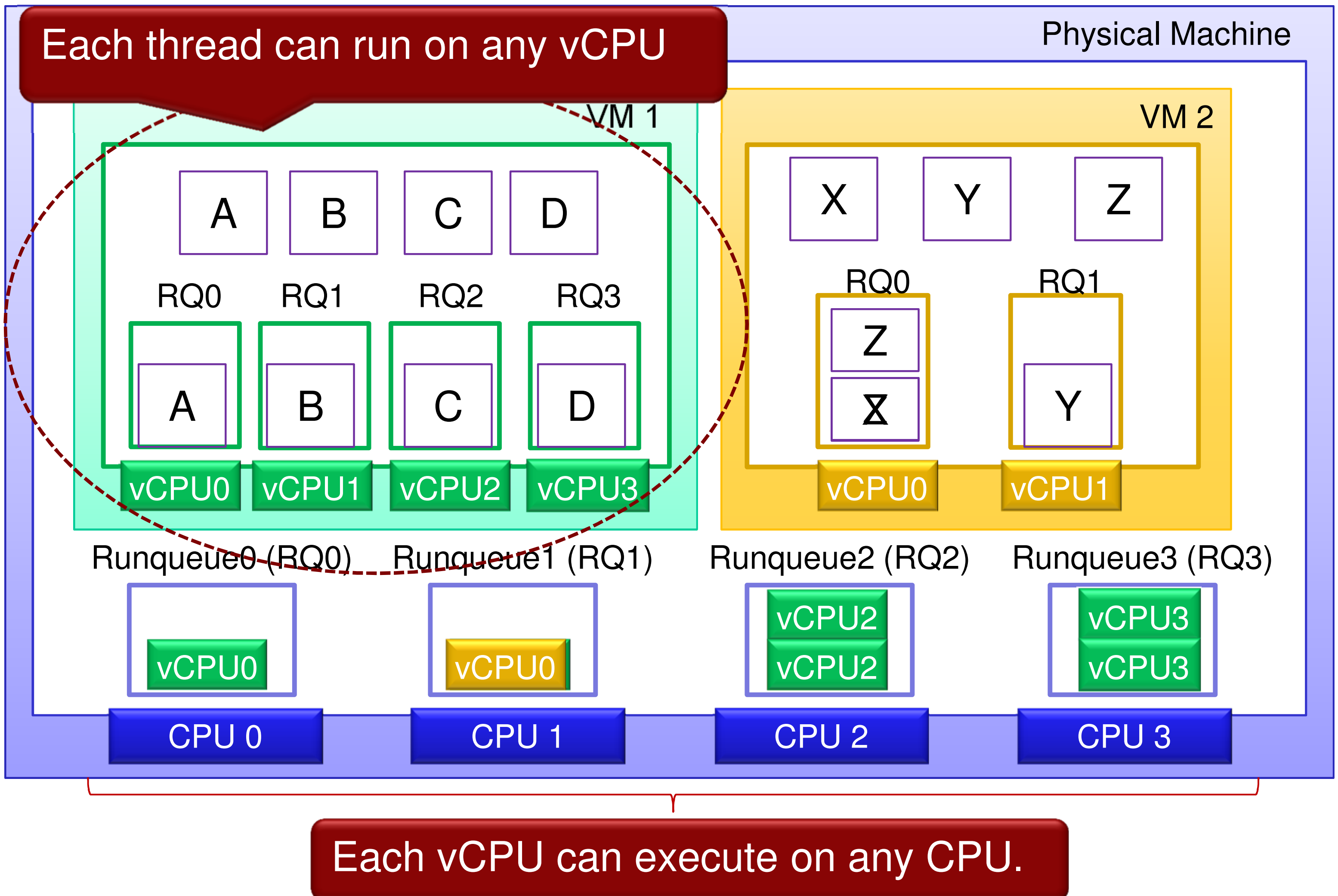
- Virtualization
  - Allow multiple servers to share the same physical machine
  - Achieve higher utilization of physical machines
  - Ease infrastructure management

Virtualization

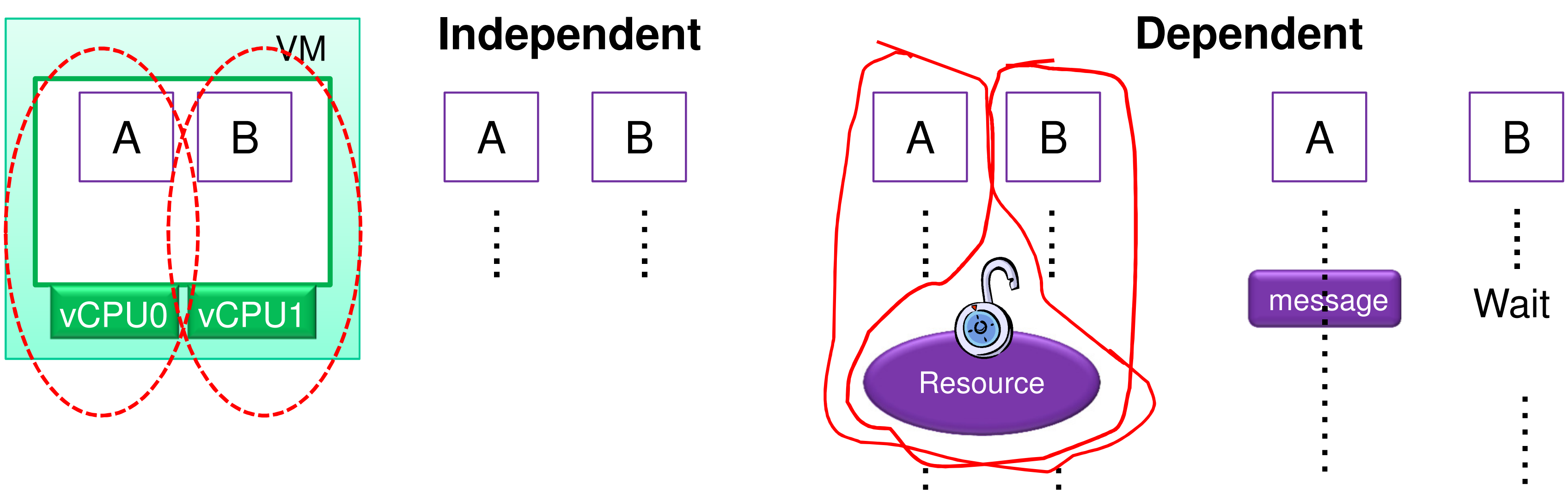


- A symmetric multiprocessing (SMP) VM/guest
  - A VM with > 1 virtual CPU (vCPU)
  - Each vCPU behaves identically
- vCPU siblings = vCPUs belonging to the same VM

VM Scheduling



Synchronization in SMP VMs



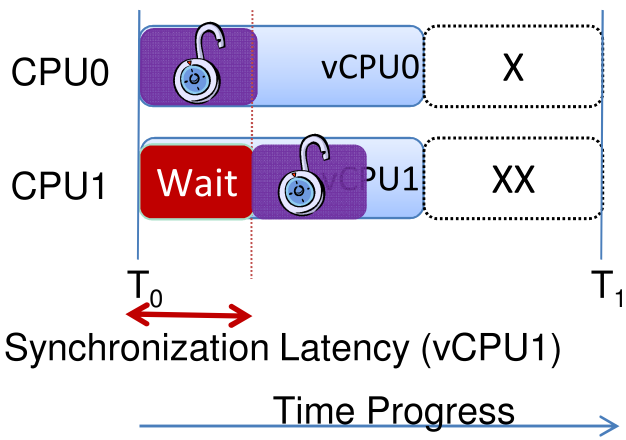
- Assuming that *vCPU0* runs *A* and *vCPU1* runs *B*
- If *A* and *B* are dependent, *vCPU0* and *vCPU1* are also dependent

Synchronization Latency Problem

- Recall: each thread can run on any CPU

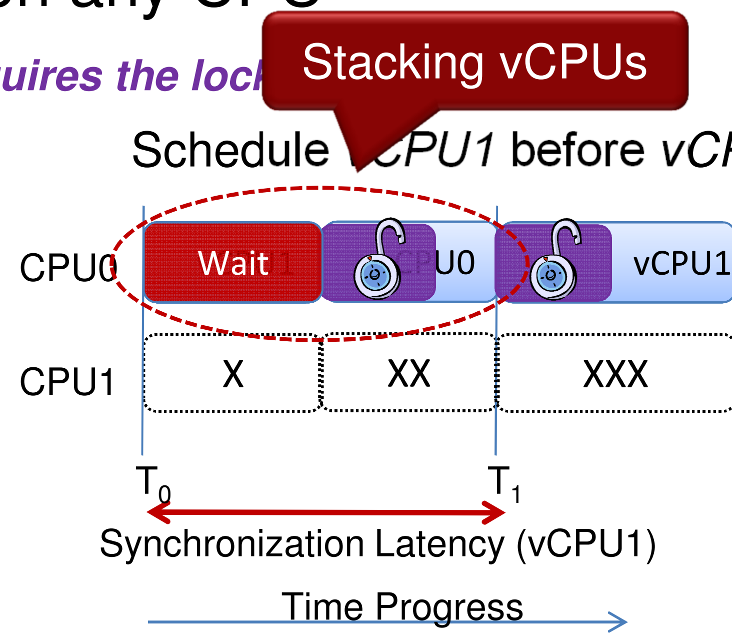
Assume vCPU0 successfully acquires the lock

Schedule *vCPU0* & *vCPU1* simultaneously



vCPU1 waits **< (T_1 - T_0)** for the lock

Schedule *vCPU1* before *vCPU0*



vCPU1 waits **(T_1 - T_0)** for the lock

- Synchronization latency can increase significantly, depending on scheduling order

How Often Does Scheduler Stack vCPUs?

- Run 4-vCPU VMs on a 4-CPU physical host
- Run the CPU-bound workload inside the VMs
  - 100% utilization on each vCPU

# VMs	≥ 2 vCPU siblings stacking on the same CPU
1	5.564%
2	**43.127%**
3	**45.932%**

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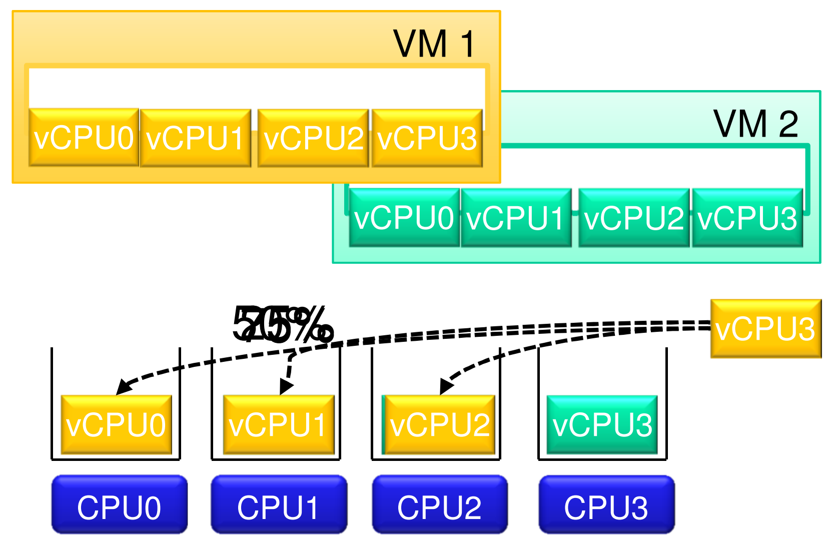
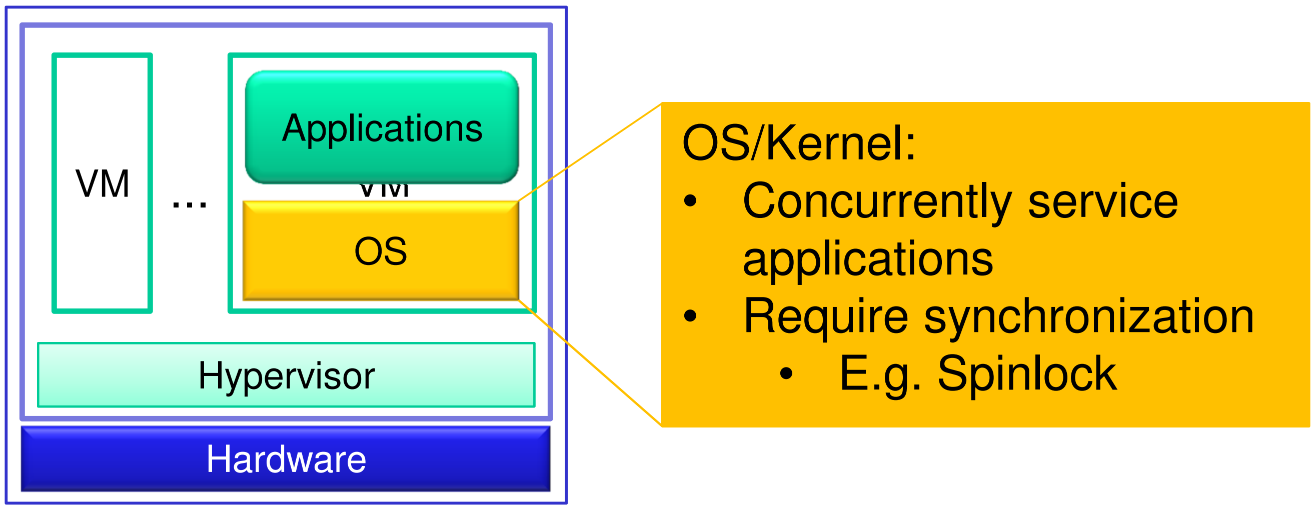


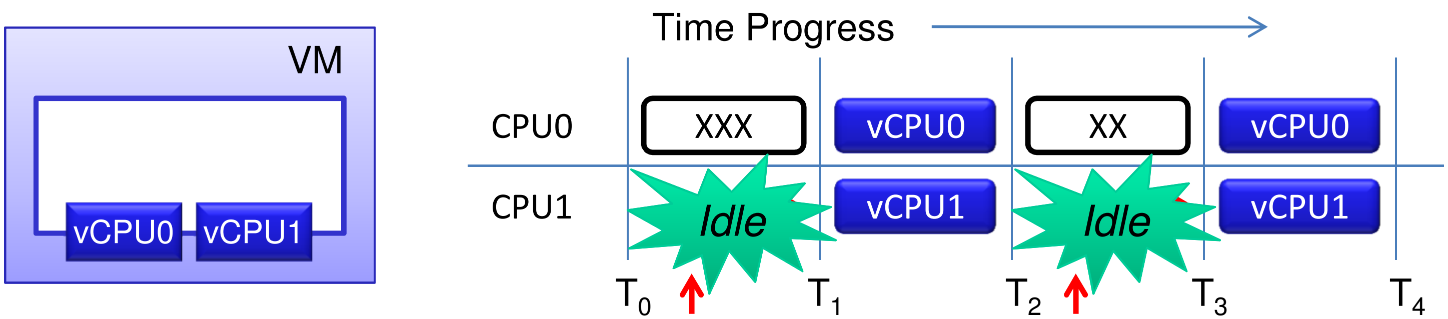
What if running non-concurrent application?



- A VM runs both applications and OS
- Even though running synchronization-free applications inside the VM, the VM may still encounter the synchronization latency problem.

Co-scheduling

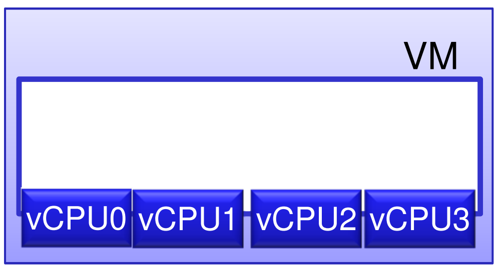
- Schedule vCPU siblings simultaneously

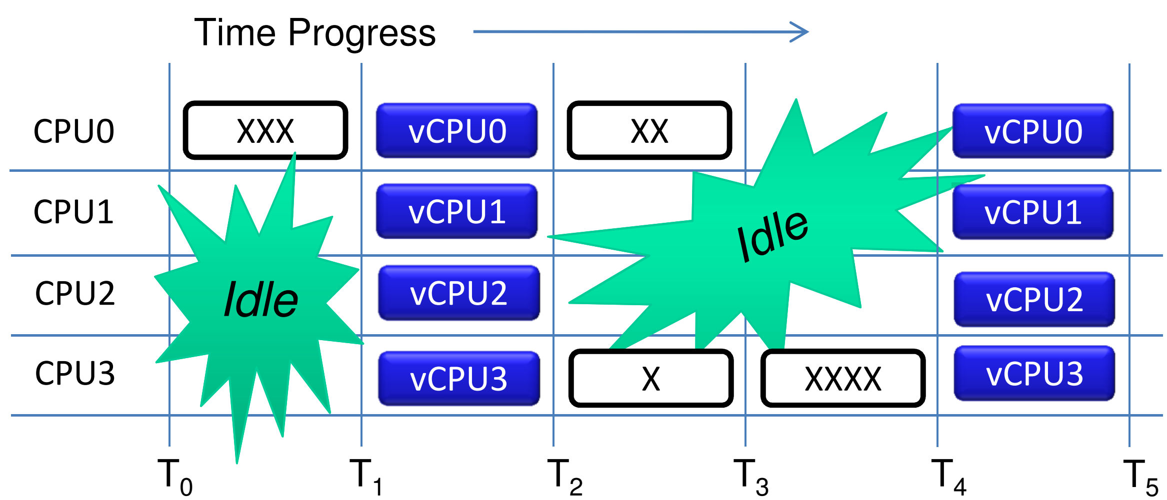


- Drawback
  - CPU fragmentation
    - Lower utilization and delay vCPU execution

Co-scheduling

- Schedule vCPU siblings simultaneously





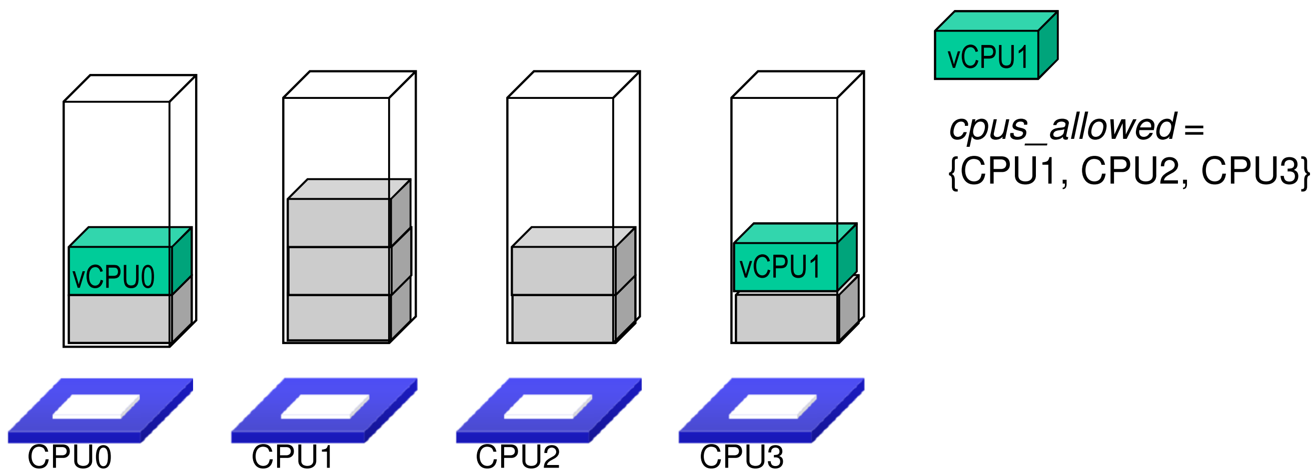
- Drawback
  - CPU fragmentation
    - *Significantly* lower utilization and delay vCPU execution

Related Work

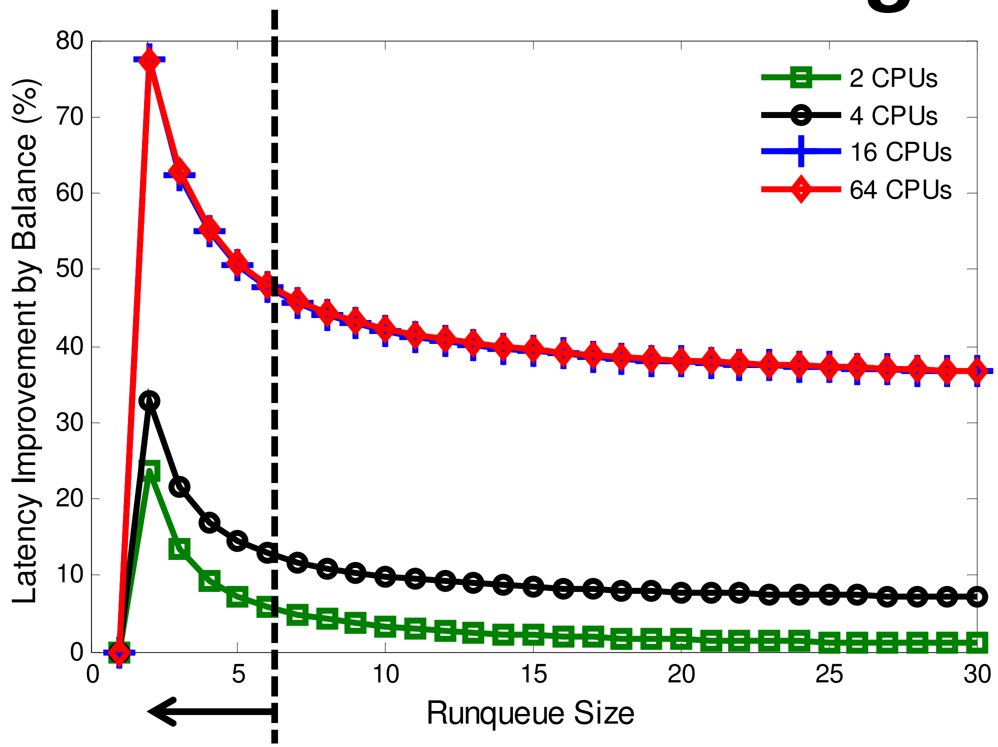
- Co-scheduling
  - VMware => *Relax co-scheduling to mitigate CPU fragmentation*
    - Strict co-scheduling (ESX 2.x)
    - Relaxed co-scheduling (ESX 3.x)
    - Further relaxed co-scheduling (ESX 4.x)
  - Xen => *Selectively apply co-scheduling to the concurrent VMs*
    - Weng2009, Bai2010
- Affinity-based scheduling
  - *Statically* bind a vCPU to a set of CPUs
  - *Carefully* bind vCPUs to avoid overloading particular CPUs

Our Balance Scheduling

- Simple idea: *Balance* vCPU siblings across CPUs
  - Never put any two vCPU siblings into the same RQ
  - No need to force vCPU siblings to be scheduled simultaneously
- Cause no CPU fragmentation and improve the performance of SMP VMs as well as co-scheduling does
- Easy to implement
  - Modify each vCPU's *cpus_allowed* field before selecting a RQ



Synchronization Latency Improvement By Balance Scheduling



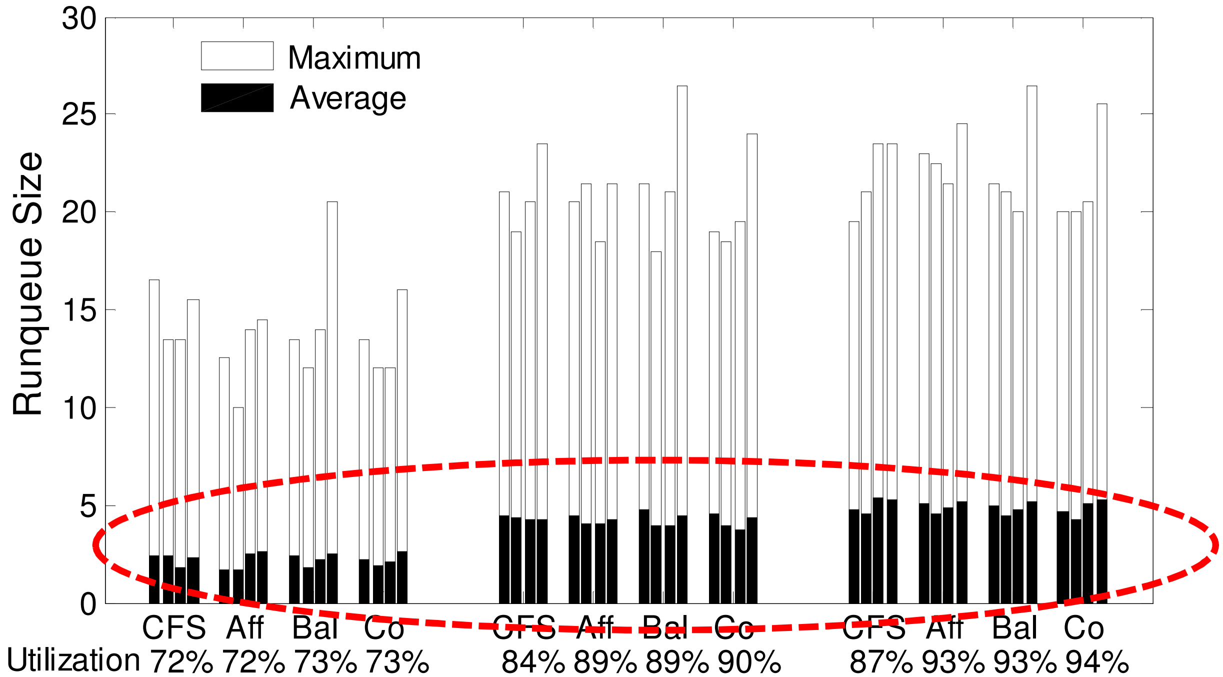
- The improvement decreases as the runqueue size grows
- The empirical results show that the runqueue size is *≤ 6* on average

Evaluate Scheduling Algorithms

- Completely Fair Scheduler (CFS)
  - Default scheduler in KVM
  - Treat each vCPU the same
- Affinity-based algorithm (Aff)
  - Statically bind each vCPU to a CPU before running an experiment
    - # vCPUs per physical CPU is relatively the same
    - Do not assign any two vCPU siblings to the same physical CPU
- Co-scheduling algorithm (Co)
  - Implement on top of CFS
  - No longer have CPU fragmentation problem but may incur additional context switching
- Our balance scheduling algorithm (Bal)

Runqueue Size

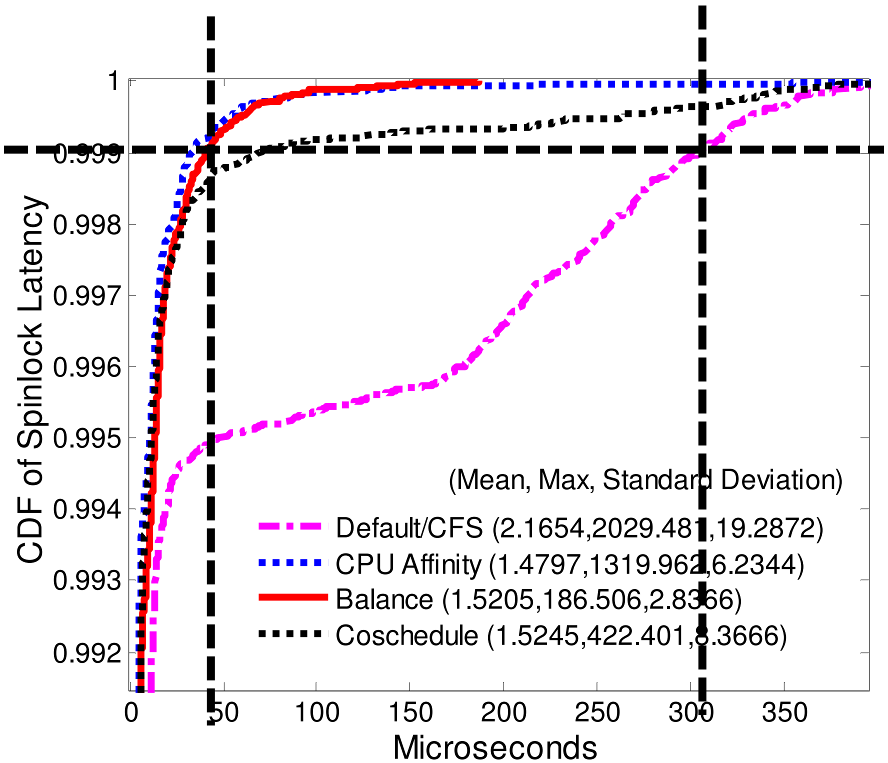
- Run 14 VMs on a 4-CPU physical machine
- Expect 56 vCPU threads + I/O QEMU threads

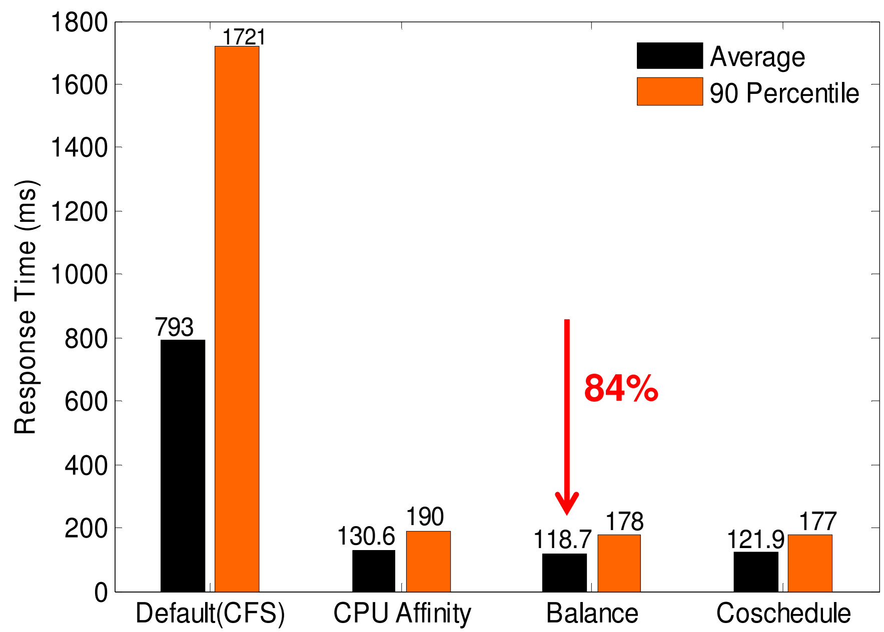


- Runqueue size is about *4-6* on average

TPC-W

- Run 3 four-vCPU VMs for a proxy server, an application server, and a database server on a 4-CPU host.

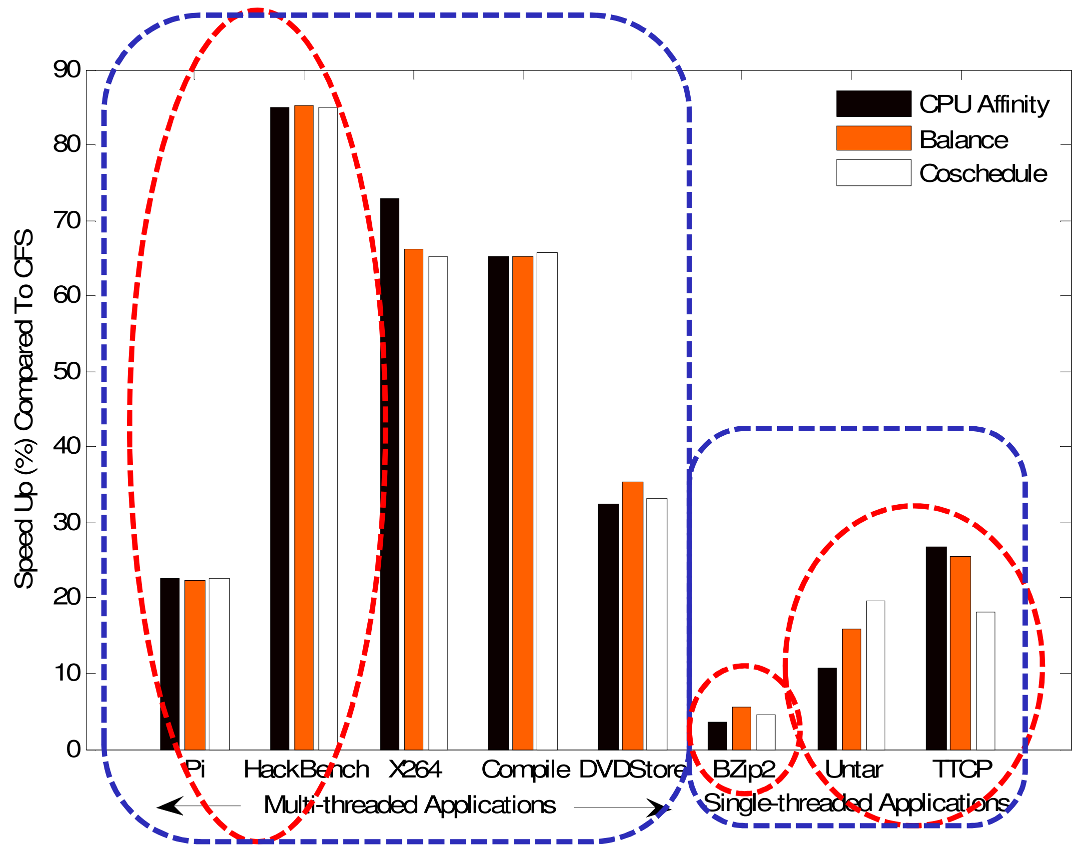




Spinlock Latency ↑ → TCP Retransmission ↑ → Response Time ↑

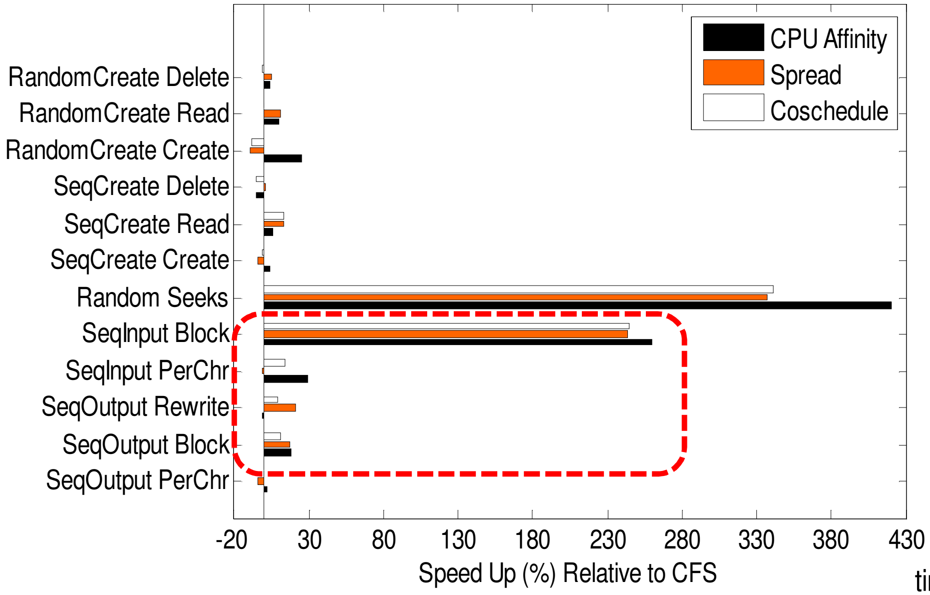
Different Applications

Run 2 VMs in the host
- One 4-vCPU VM
  - Run an application
- One 2-vCPU VM
  - Run the CPU-bound workload



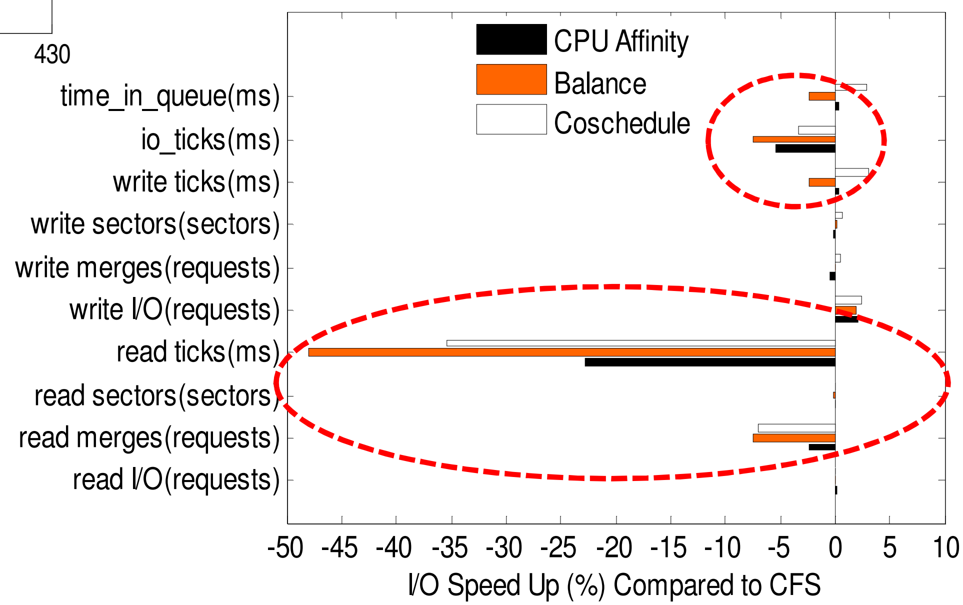
- *Improvement depends on the synchronization degree in VMs*
- *Balance scheduling can improve application performance as much as co-scheduling*

Bonnie++



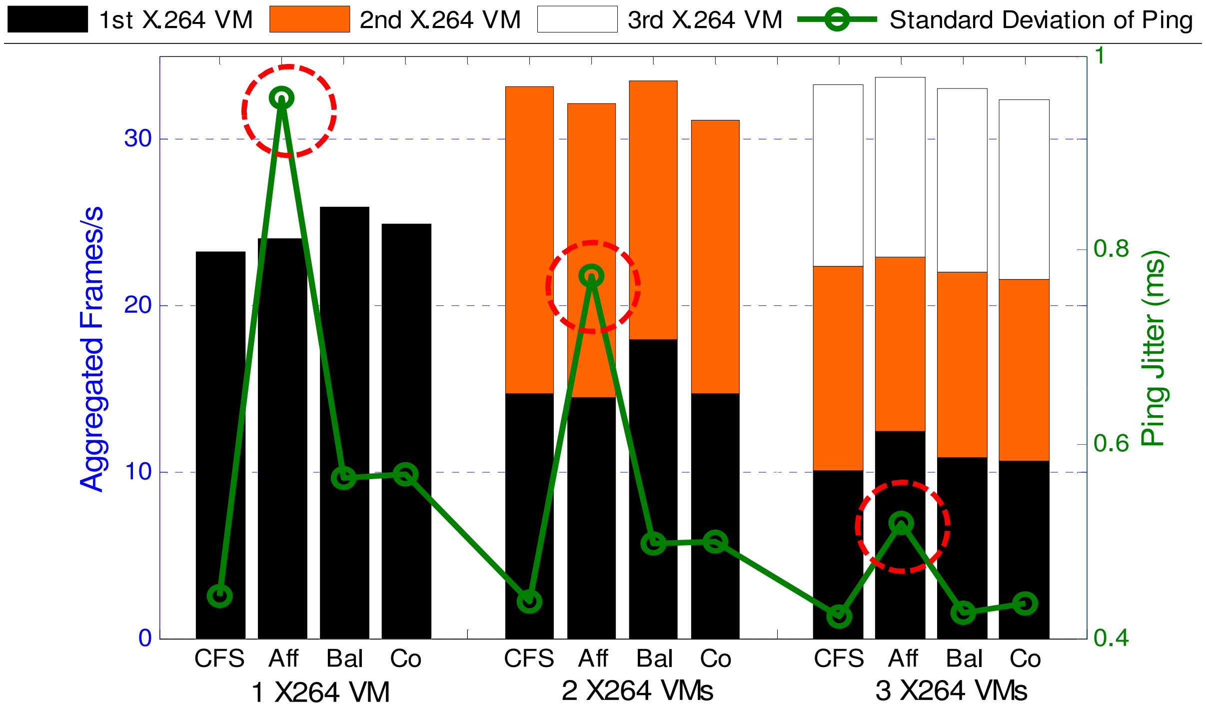
- Run Bonnie++ in a 4-vCPU VM with a 2-vCPU VM running the CPU-bound workload
- Bonnie++ => single-threaded, I/O-intensive

- Running a *single-threaded* application can also benefit from co-scheduling, balance scheduling and affinity-based scheduling



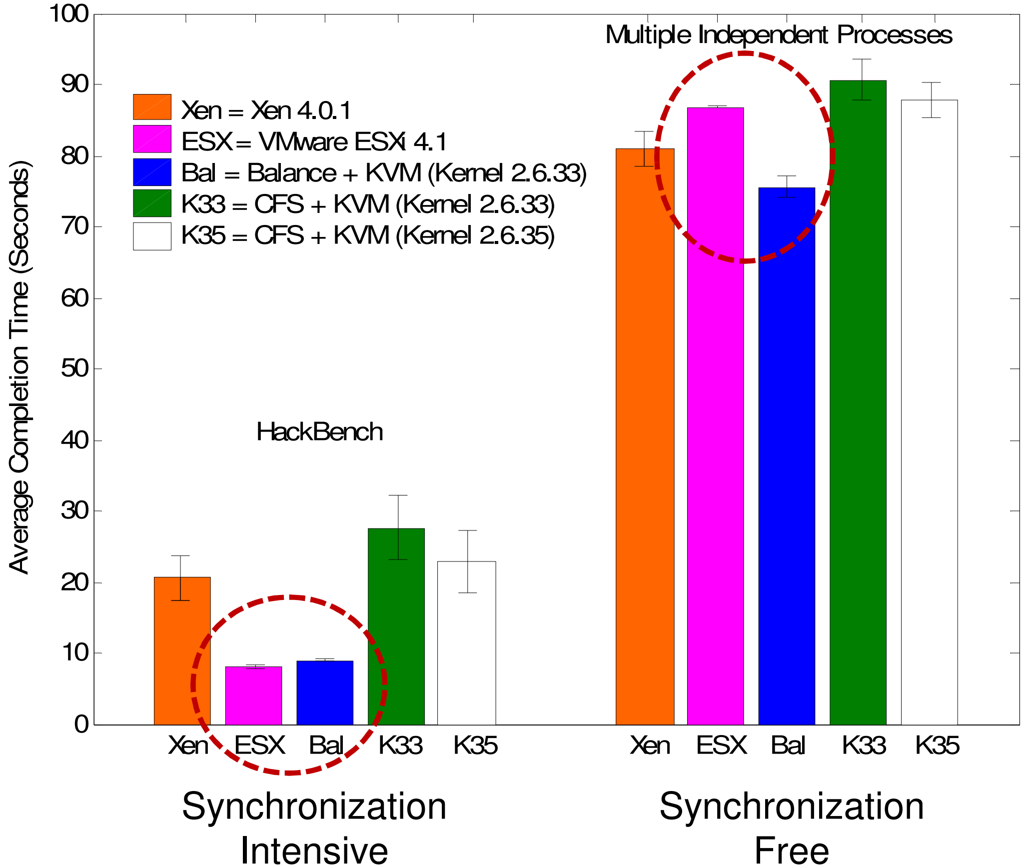
X264 & Ping

- 3 four-vCPU VMs run X.264 and 1 one-vCPU VM runs Ping



- In *affinity-based scheduling*, the Ping vCPU may get stuck in the *busiest* CPU. With *balance scheduling*, the Ping vCPU can choose the *idlest* CPU.

Different Hypervisors



Our *balance scheduling* works well with both *synchronization-intensive* and *synchronization-free* applications

Discussion

- What are most applications?
  - Synchronization-intensive? Synchronization-free?
- Many legacy applications are still single-threaded.
- A good number of applications are concurrent programs to take advantage of multi-core architecture
- A rule of thumb of concurrent programming is using minimal synchronization to promote parallelism
- We believe that future parallel programs should be leaning toward the minimal usage of synchronization

=> Our balance scheduling should be a way to go!

Conclusion

- Synchronization latency problem can significantly degrade application performance
  - Even if running synchronization-free applications due to the synchronization in the guest OS
- Co-scheduling can be too expensive for SMP VMs with minimal synchronization
  - CPU fragmentation
    - Reduce the host-CPU utilization and delay vCPU execution
- Our balance scheduling can
  - Perform similarly to co-scheduling given concurrent SMP VMs
  - Work well with minimal-synchronization VMs