Scalability in the Clouds! A Myth or Reality?

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Programmer's Paradise?

- A programmer day-to-day task: *program compilation,* like Linux kernel compilation.
- Relies on Buildbot to complete the job ASAP!
- Expects the job to complete sooner with increasing core count.
  - With respect to vertical scalability, a parallel job with no sequential bottleneck should scale with increasing core count.

Programmer's Paradise?

- A programmer day-to-day task: *program compilation,* like Linux kernel compilation.

How about using Cloud providers for our fun and their profit?

increasing core count.

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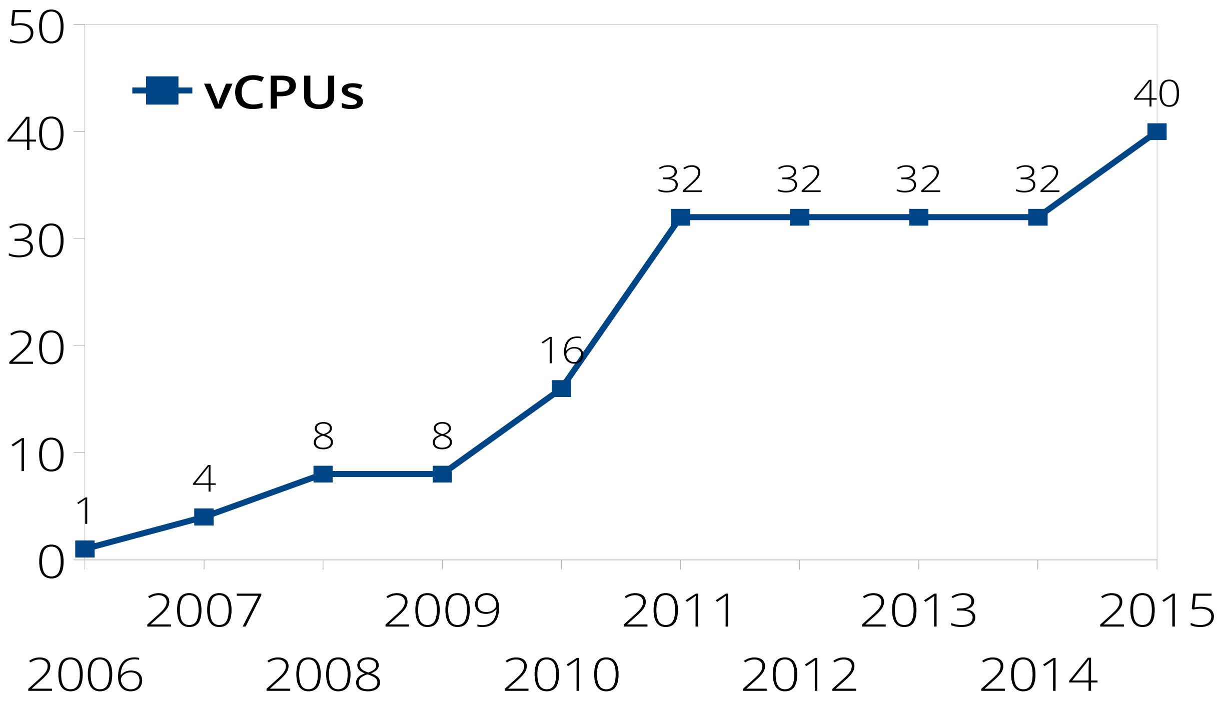
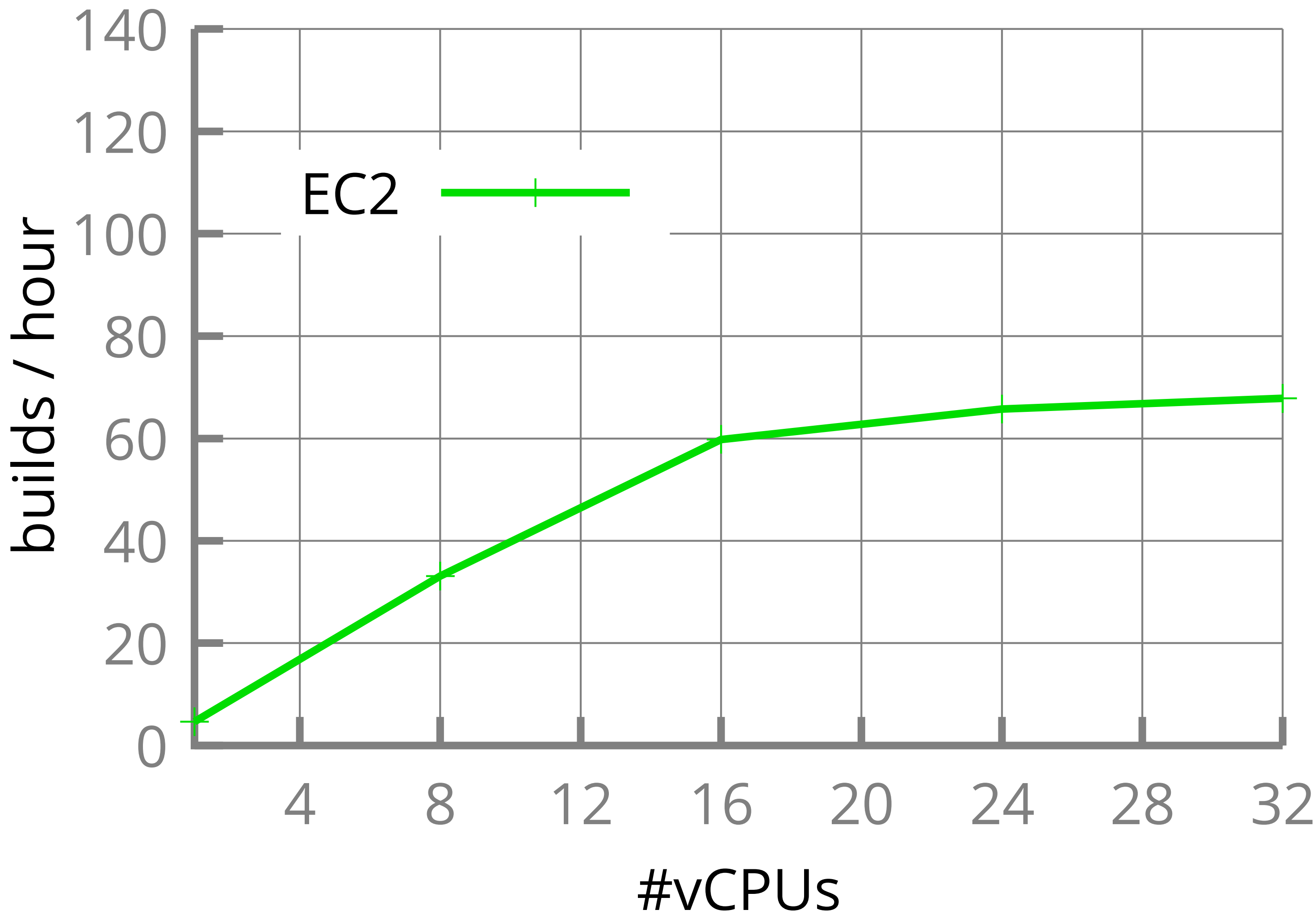
Clouds Trend

- Trend is changing → Larger instances (40 vCPUs) are available.
- Will Buildbot really scale?



Scalability Behavior in the Clouds



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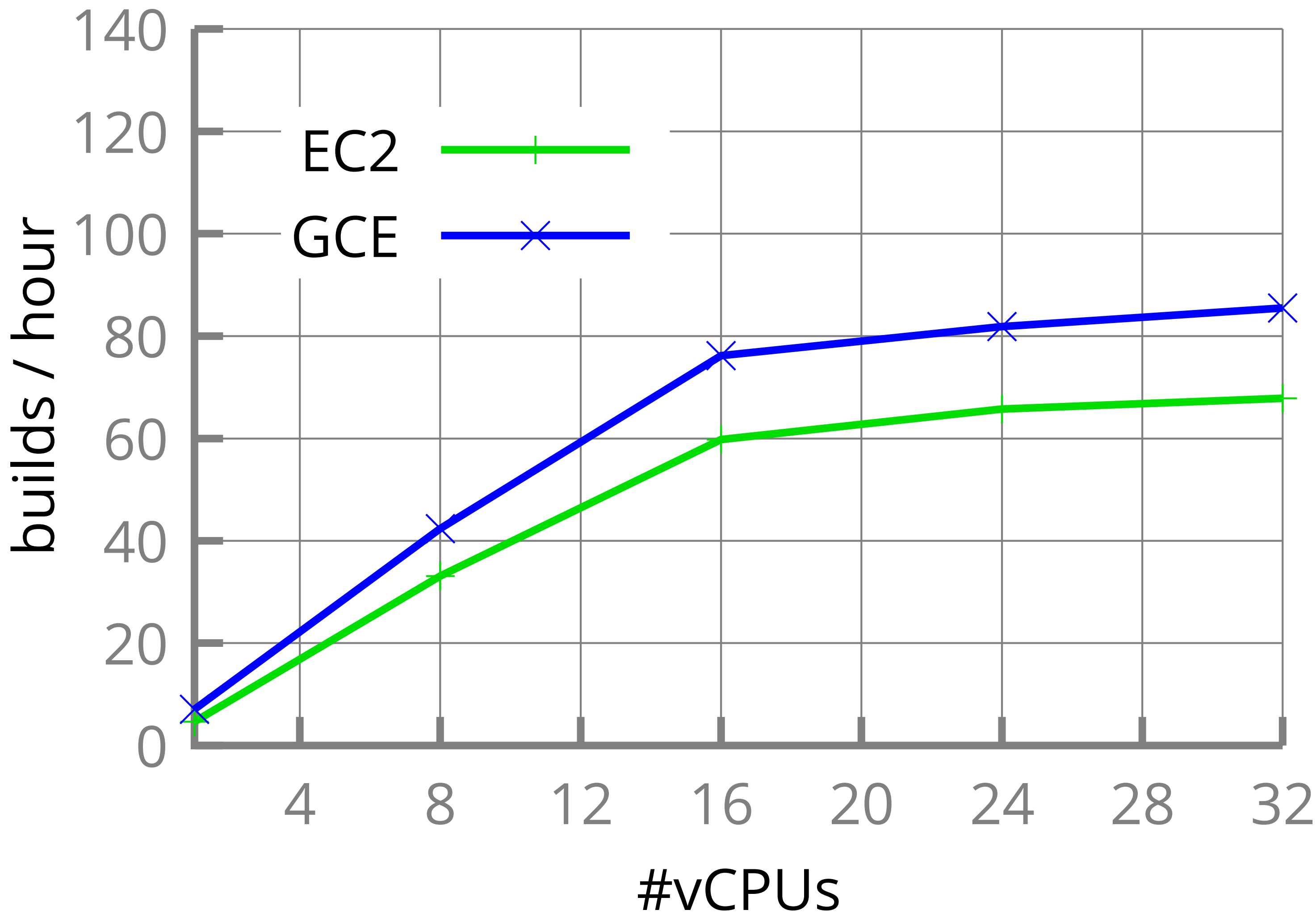

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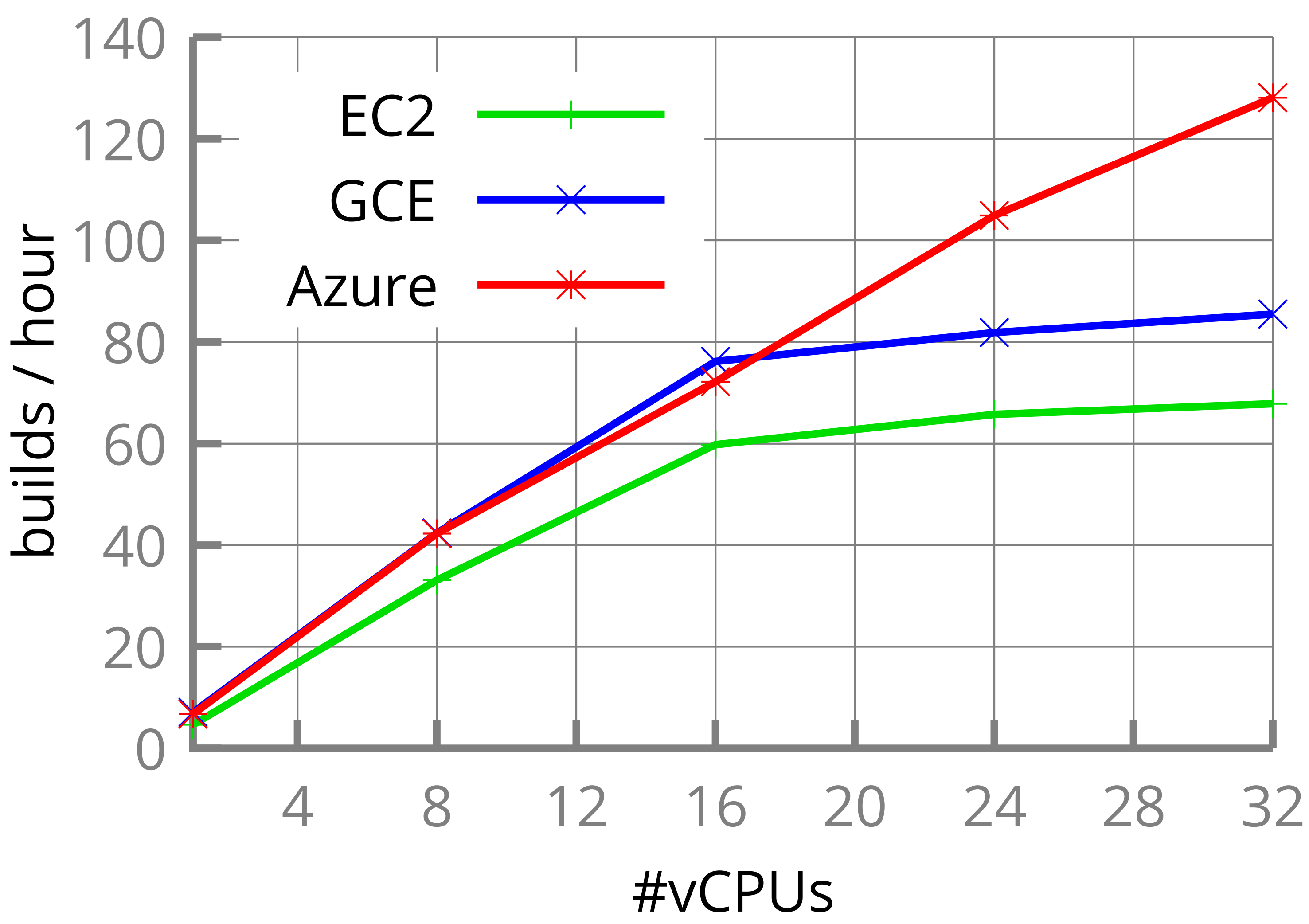

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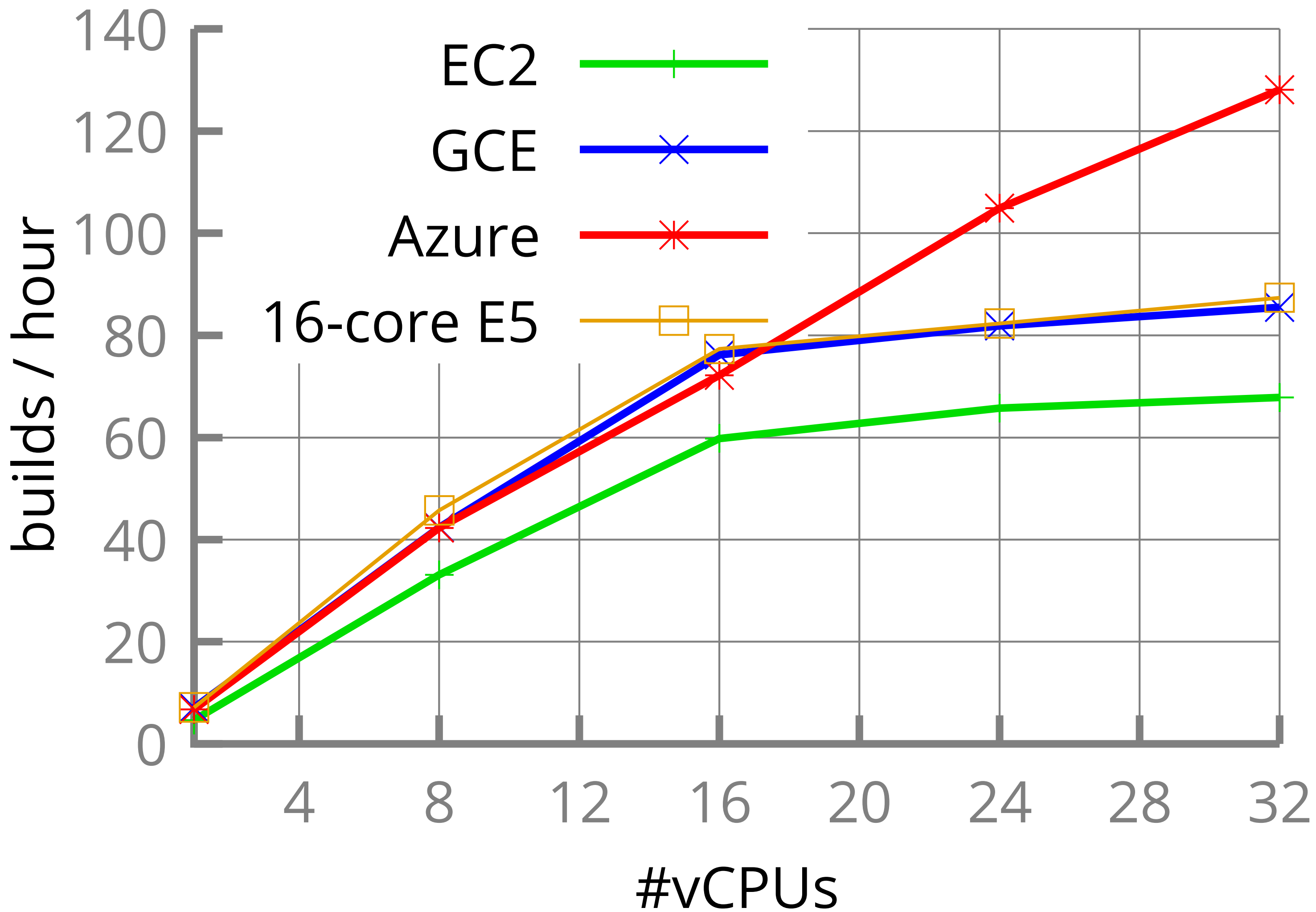

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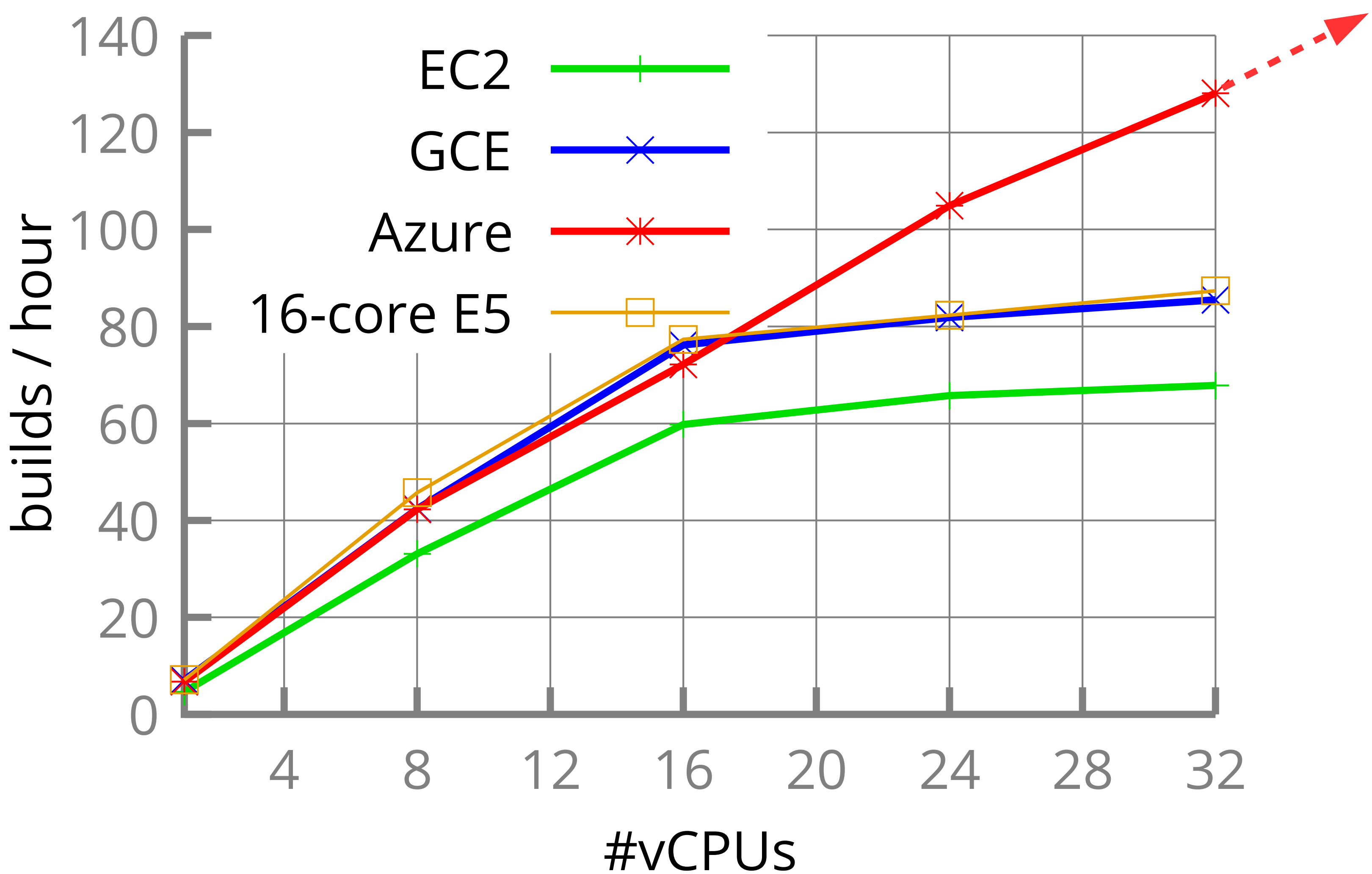

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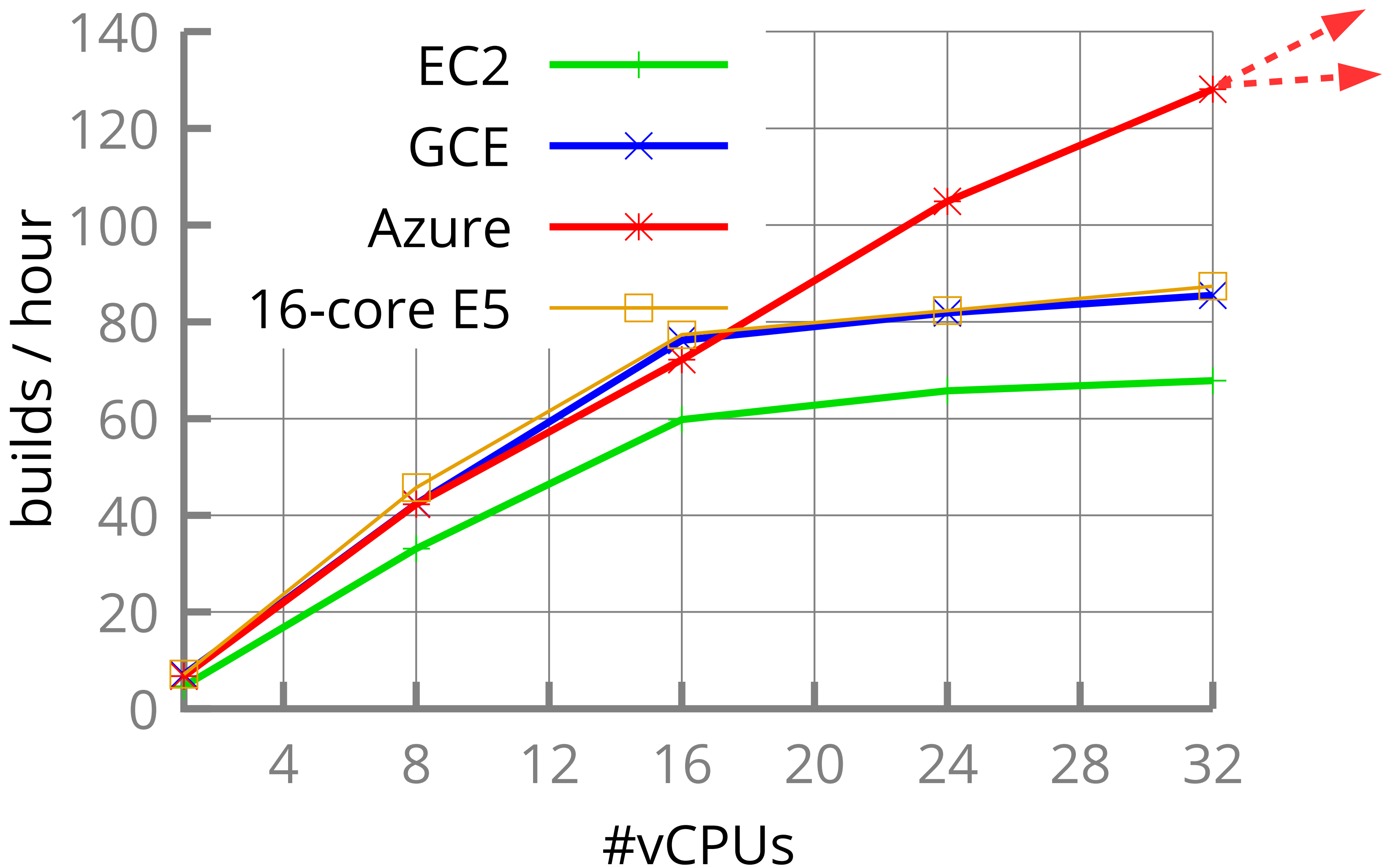

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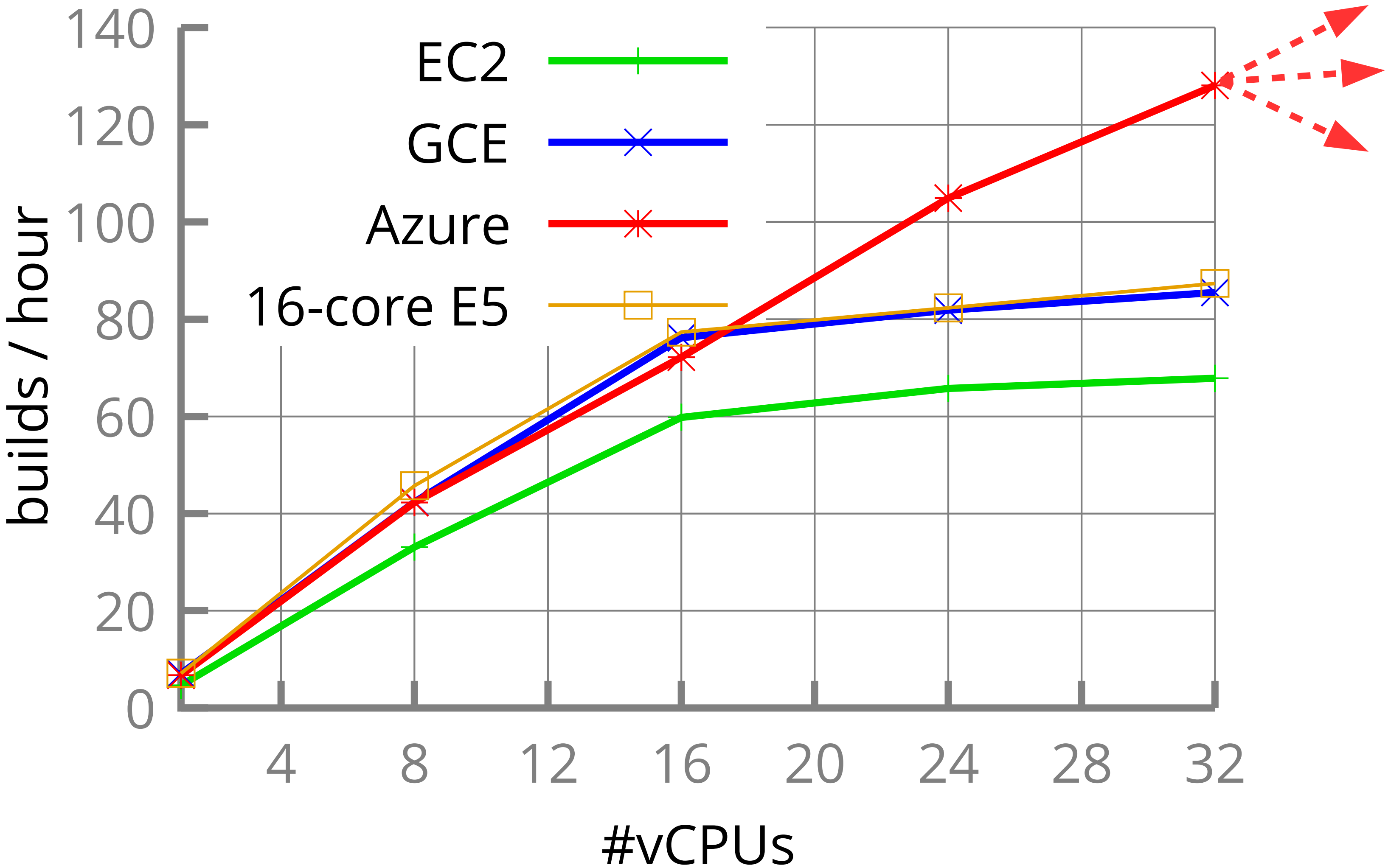

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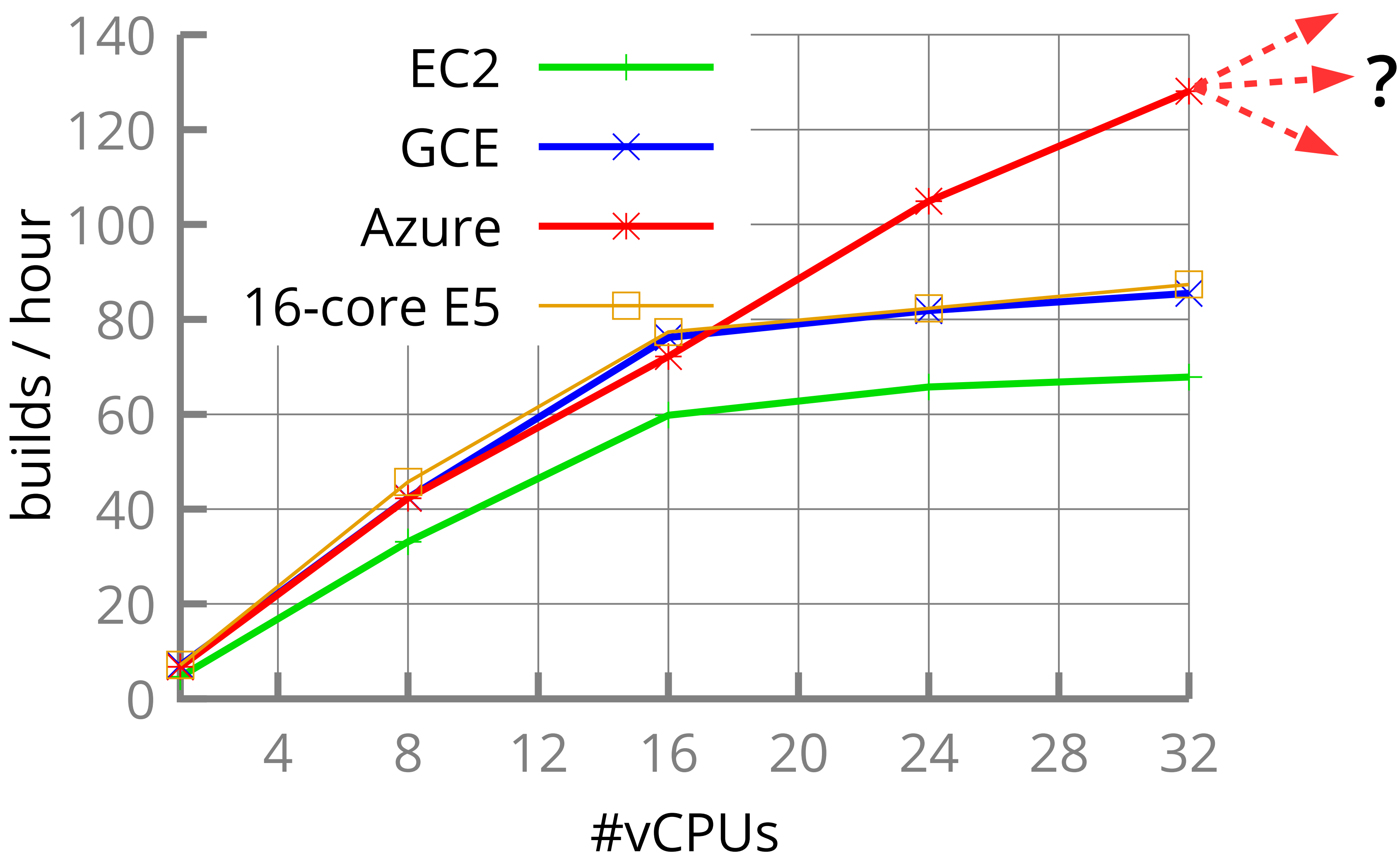
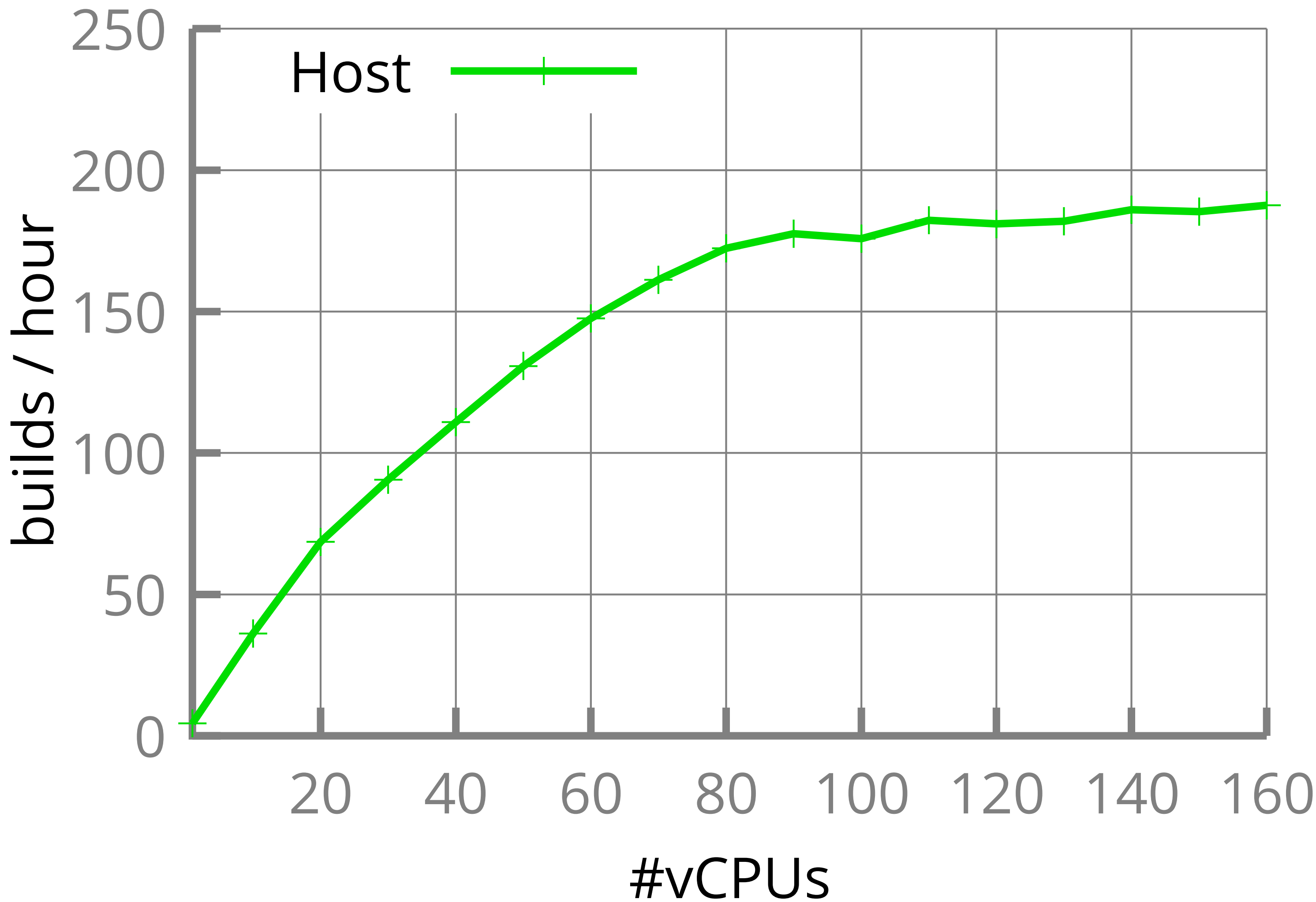


Scalability Behavior in VMs with Higher-core count



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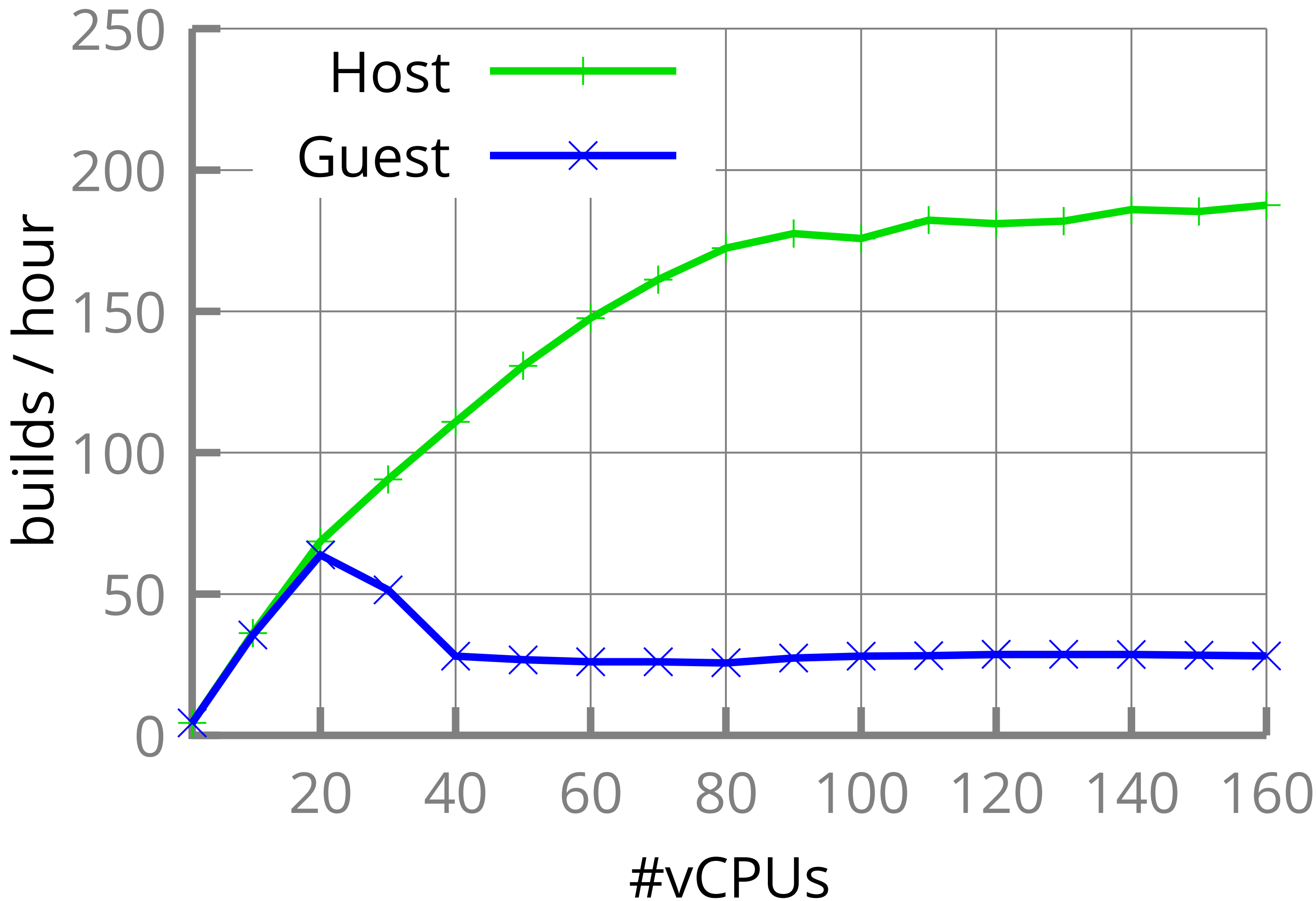

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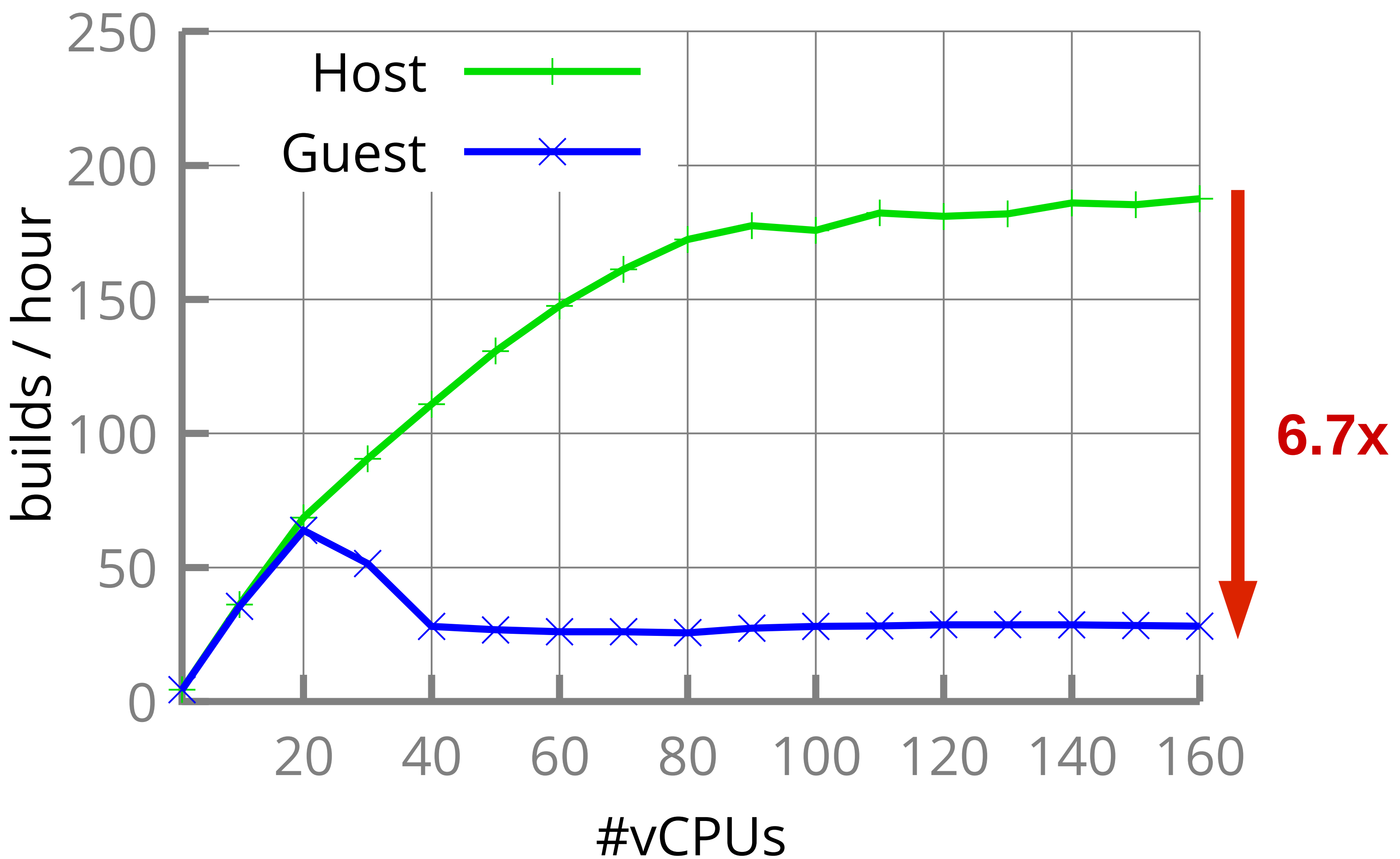

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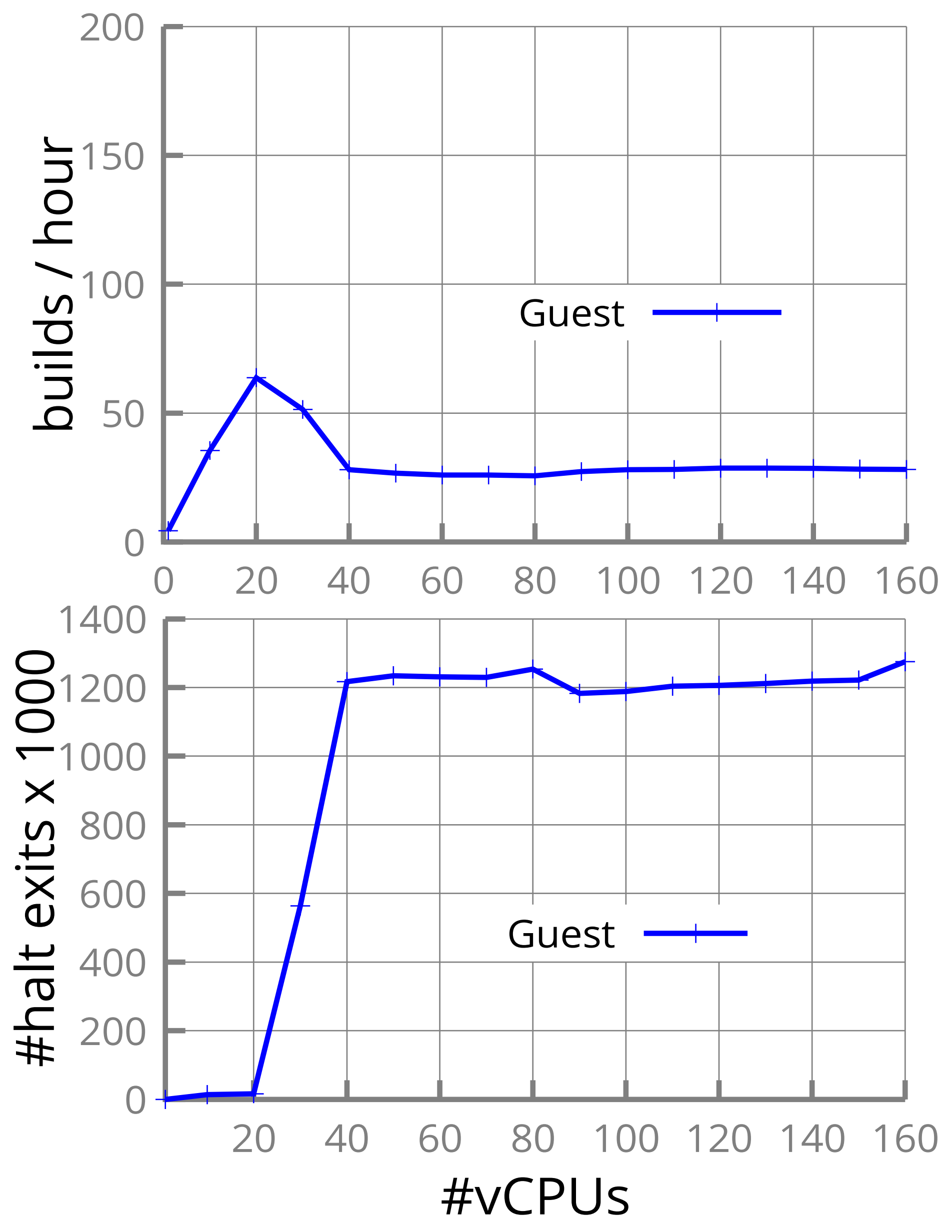

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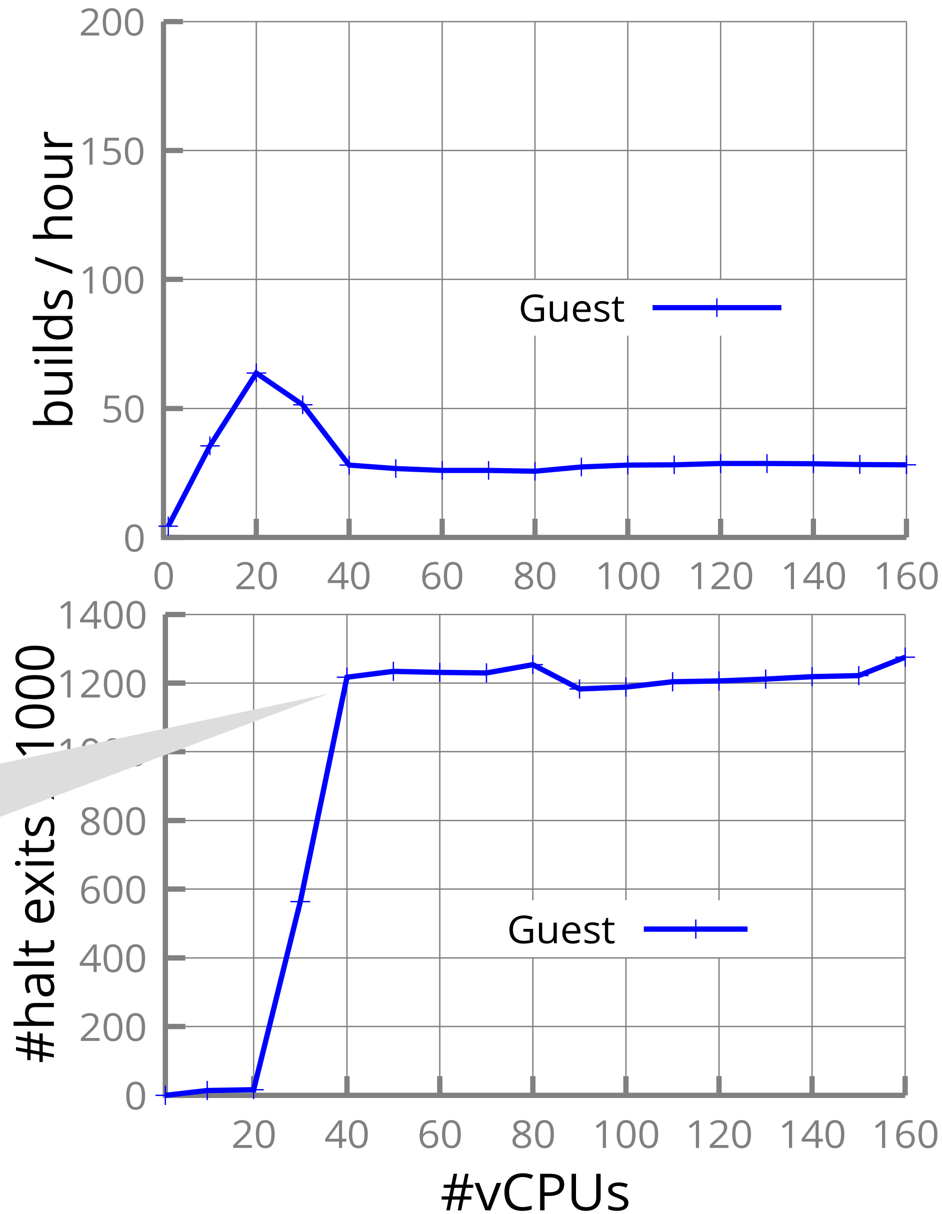

Spinlock is sleeping!

Spinlock Evolution in the Linux Kernel

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Test-and-
Test-And-Set
spinlock

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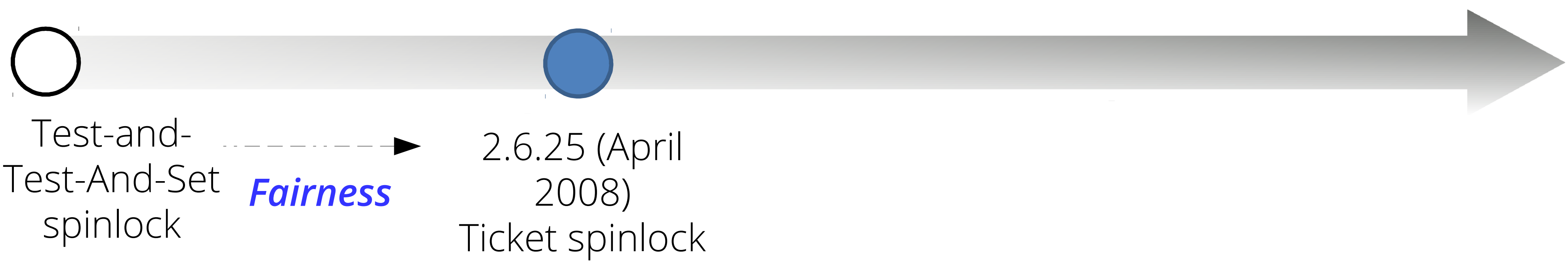

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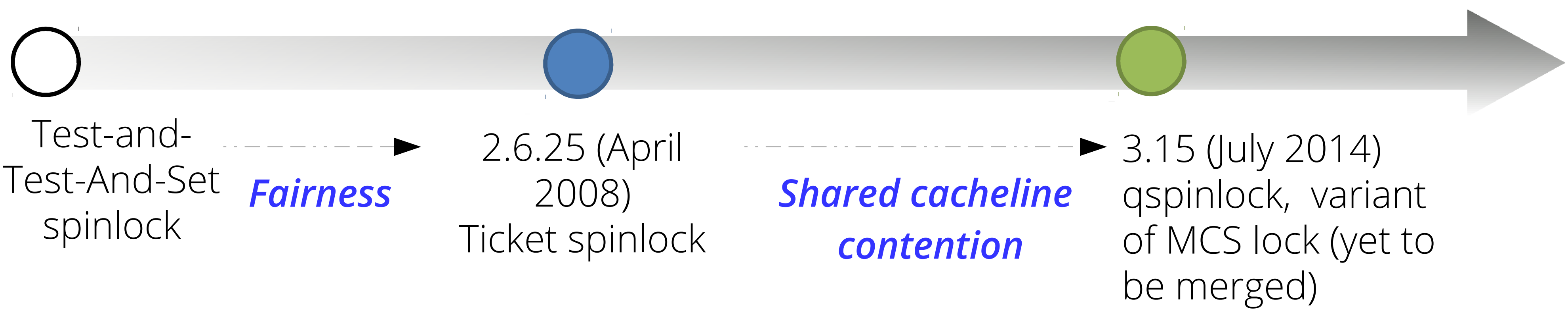

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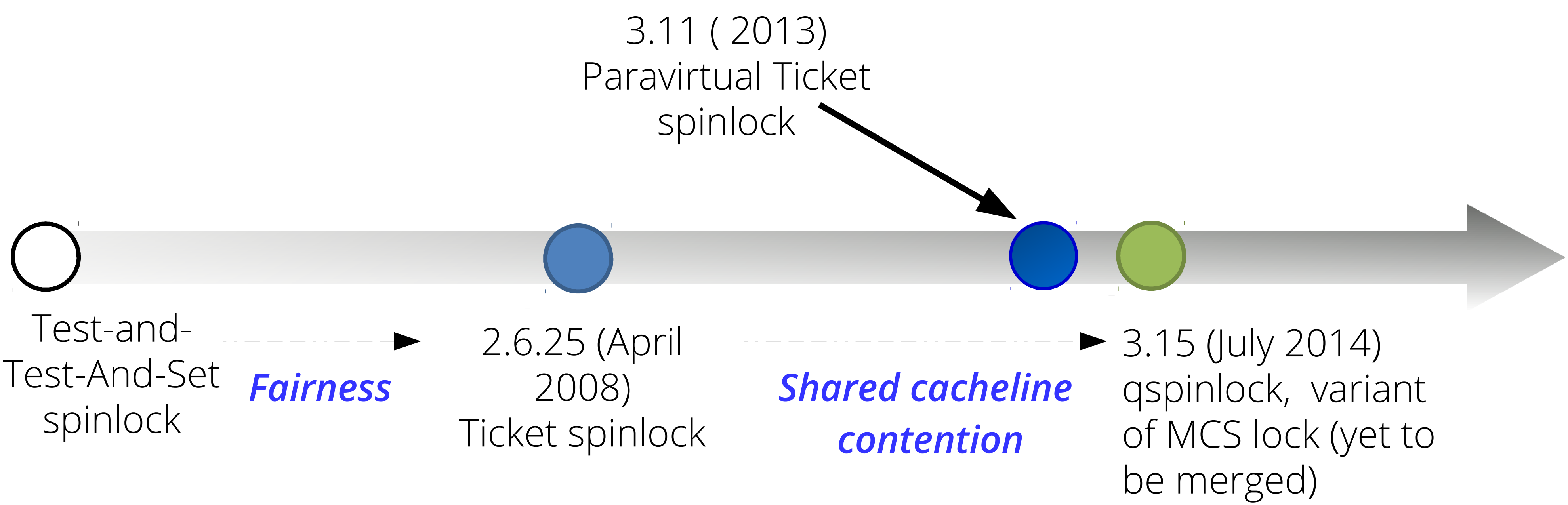

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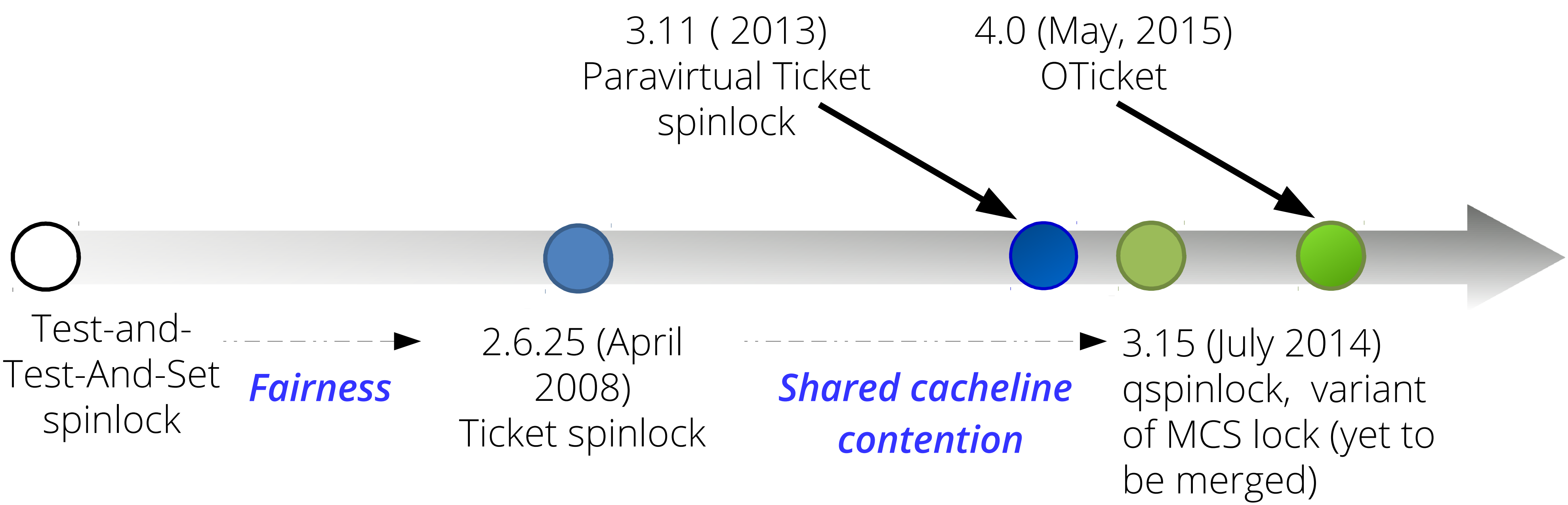

Ticket Spinlock

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- Guaranteed FIFO ordering.
- Mitigates starvation with increasing core count.

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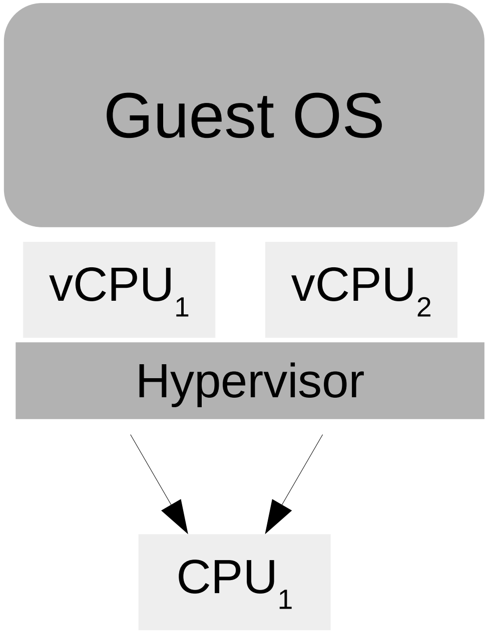
Complexity of Ticket Spinlock in Virtualized Environment

- vCPUs are scheduled by host scheduler.
- Semantic gap between the hypervisor and guest OS.



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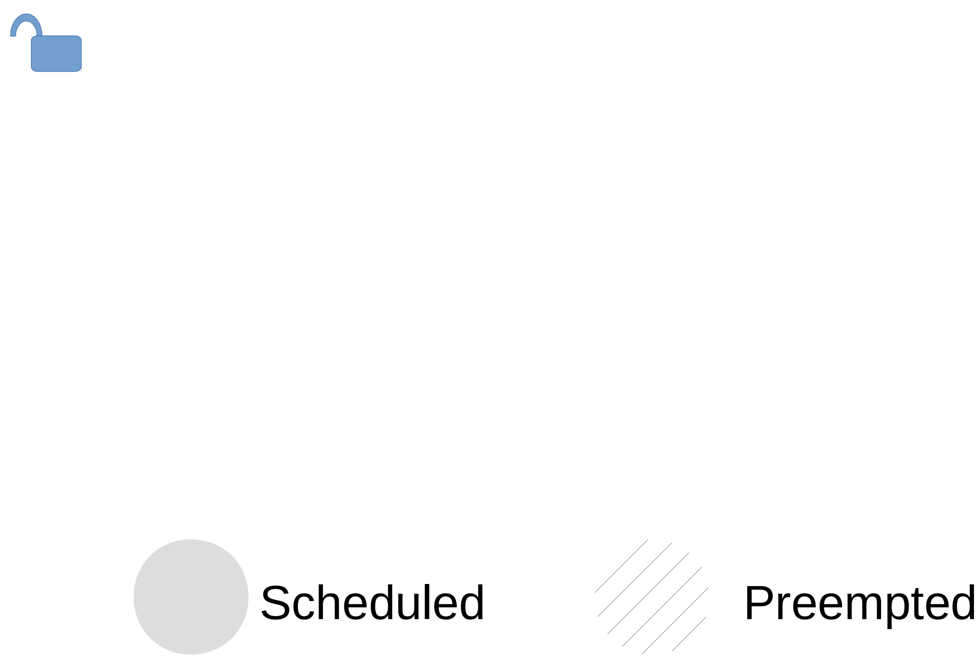

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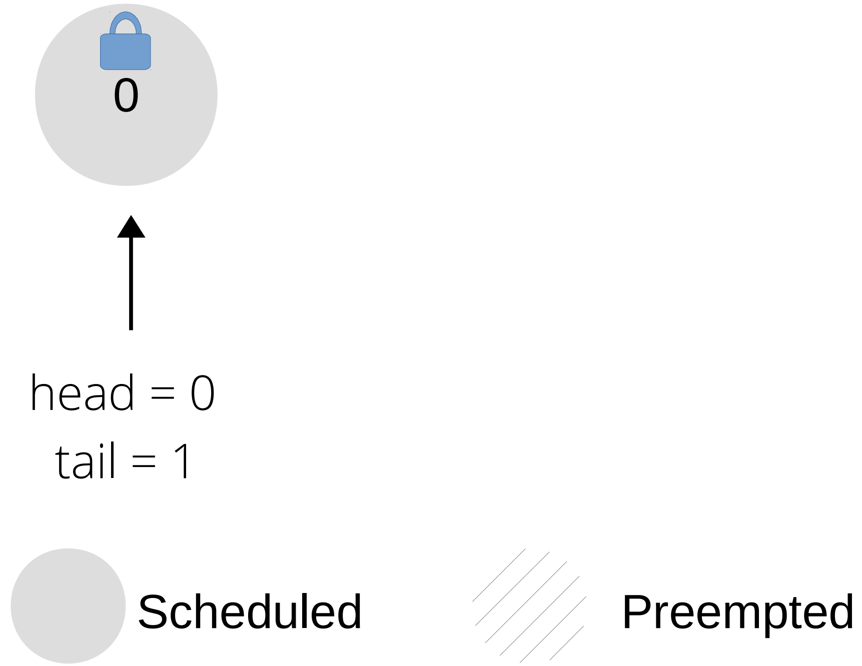

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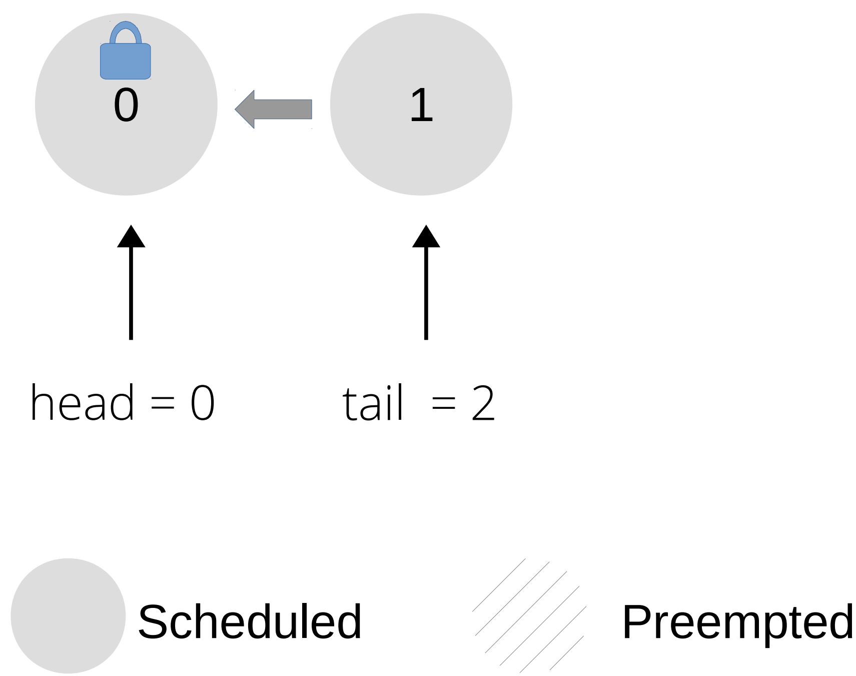

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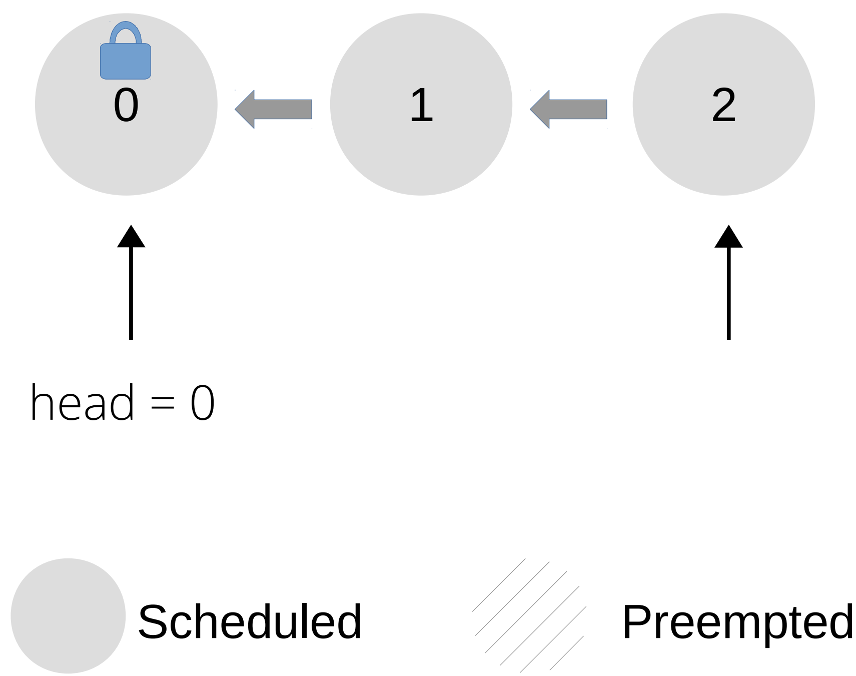

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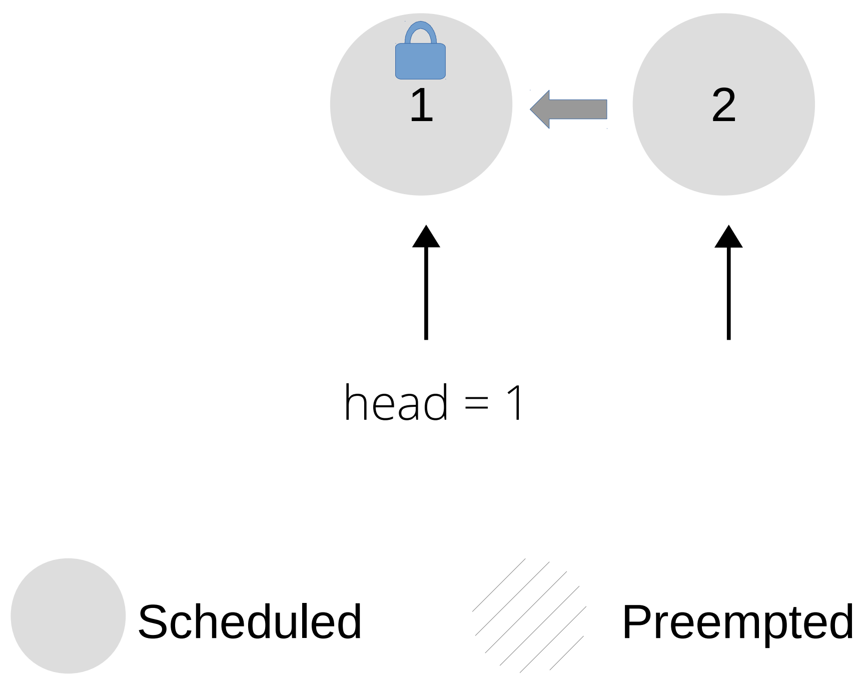

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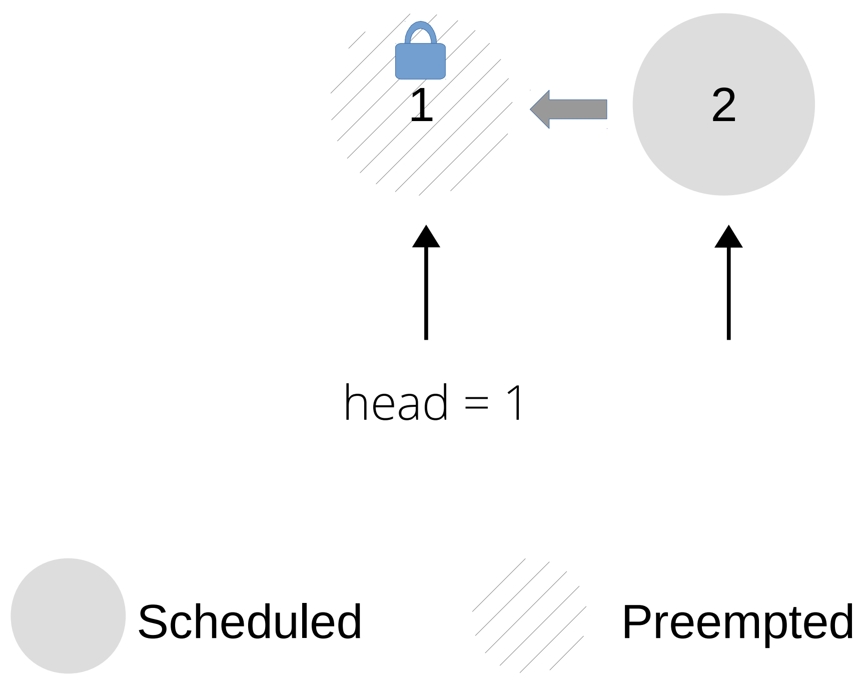

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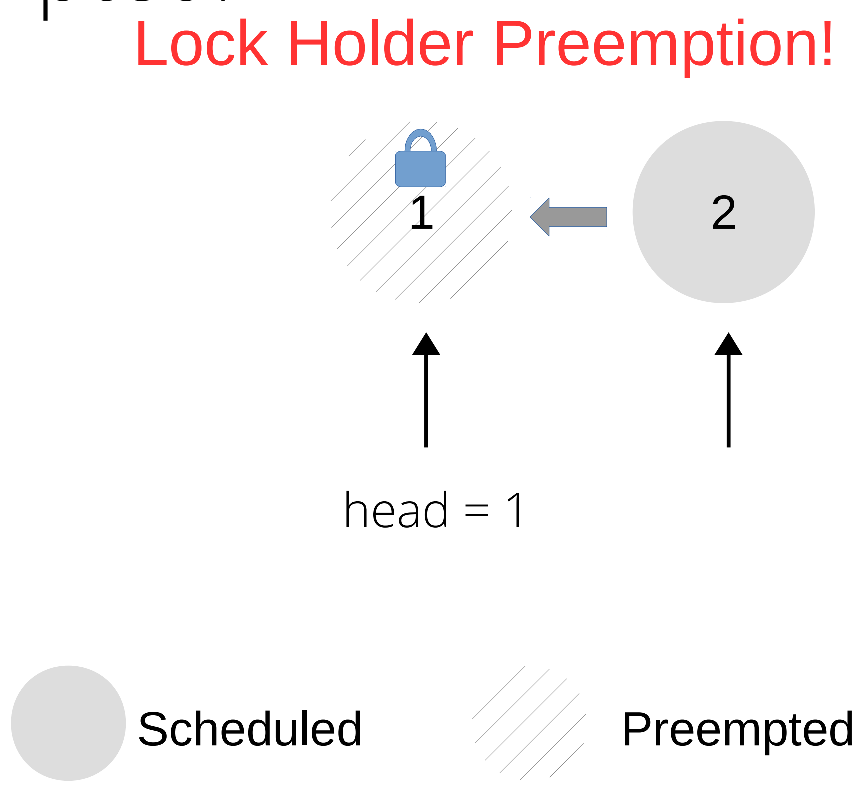

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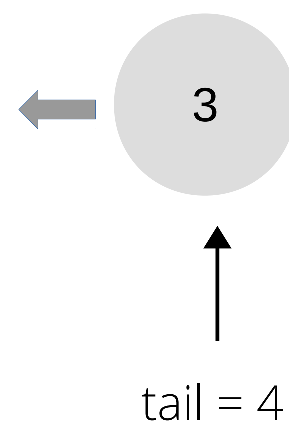

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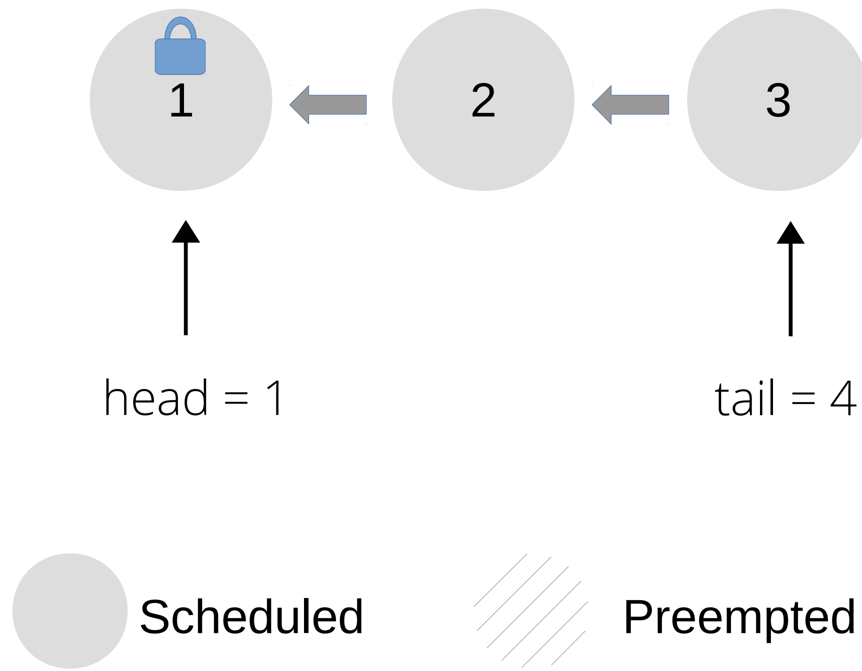

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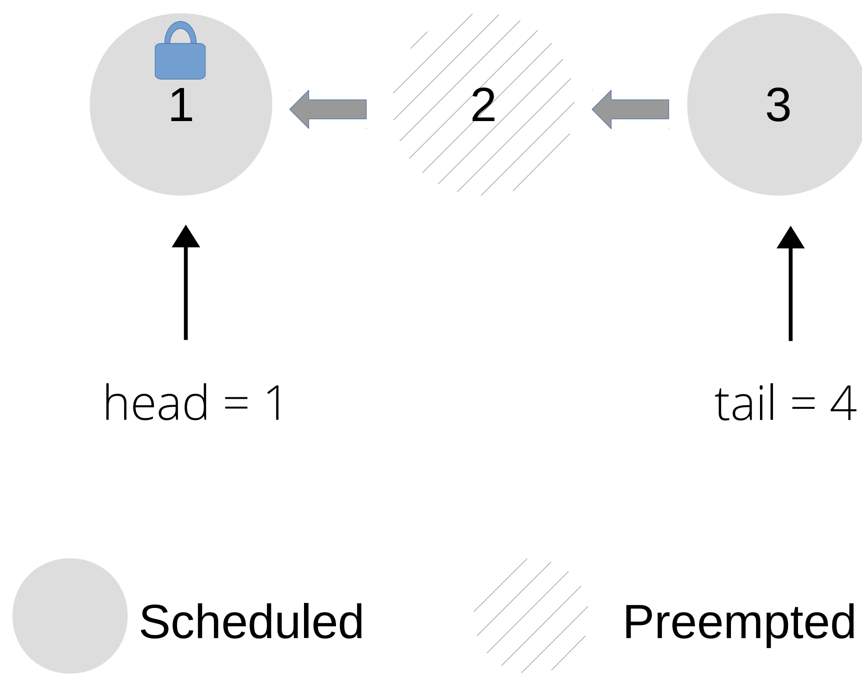

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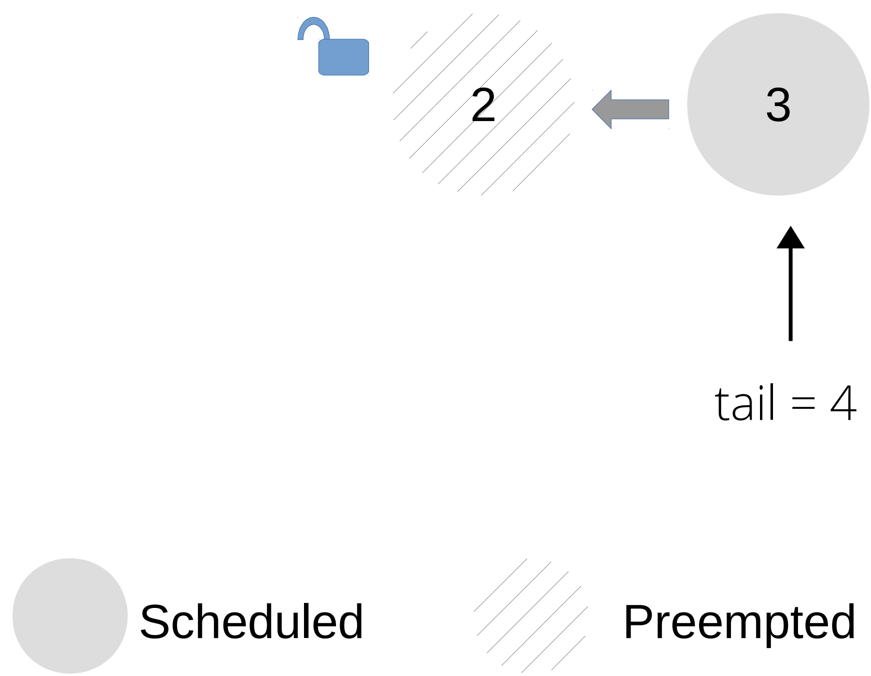

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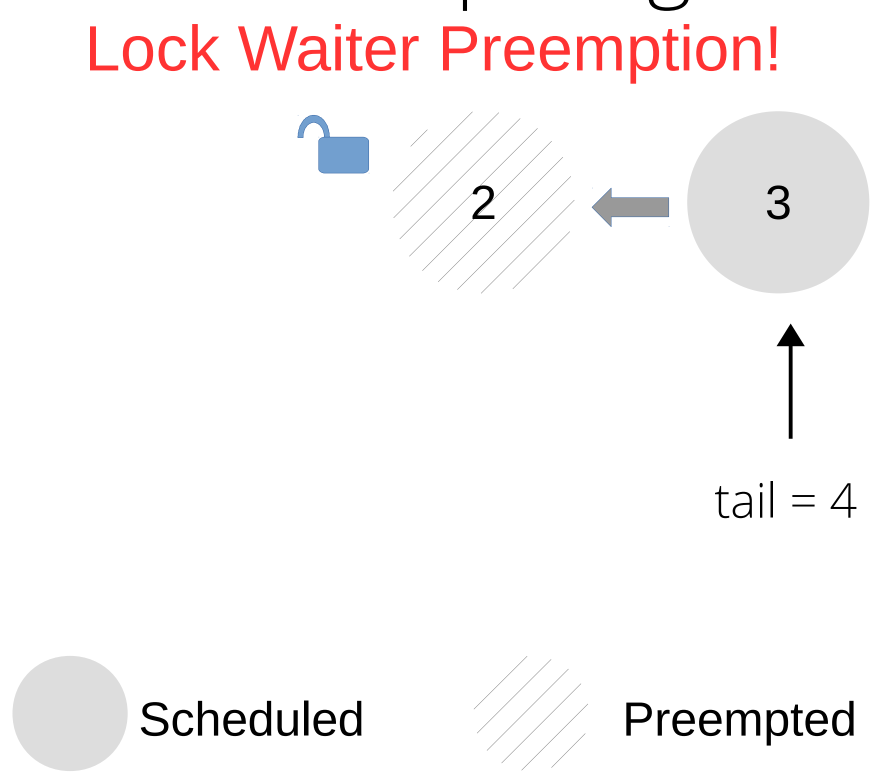

Current Solution to LHP and LWP

- Handling lock requests depending on the lock state.
  - **Lock**: yield if long wait.
  - **Unlock**: wake up the preempted waiter.
- A paravirtual interface to track state change.

Paravirtual Ticket Spinlock

- Lock:
  - **Fast path**: spin till a certain threshold value.
  - **Slow path**: notify the hypervisor to de-schedule the thread.
- Unlock:
  - Wake-up procedure to re-schedule the next waiting thread.

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 void lock() {
        my_ticket = F&I(tail);
        for( ; ; ) {
                int count = threshold;
                do {
                        if(my_ticket == head);
                                goto out;
                } while(--count);
+               slowpath_spin(tail);
        }
 out: ;
 }
 void unlock() {
+       wakeup_cpu(head + 1);
        head++;
 }
```

Paravirtual Ticket Spinlock

- Lock:
  - **Fast path**: spin till a certain threshold value.
  - **Slow path**: notify the hypervisor to de-schedule the thread.
- Unlock:
  - Wake-up procedure to re-schedule the next waiting thread.

```
#define SPIN_THRESHOLD  (1 << 15)
 int head = 0;
 int tail = 0;
 int threshold = SPIN_THRESHOLD;
 void lock() {
        my_ticket = F&I(tail);
        for( ; ; ) {
               int count = threshold;
               do {
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               } while(--count);
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 }
```

Problem: The Mechanism to Annotate the Slow Behavior

The **slowpath_spin** issues the hlt instruction

↓

The hypervisor traps the instruction

↓

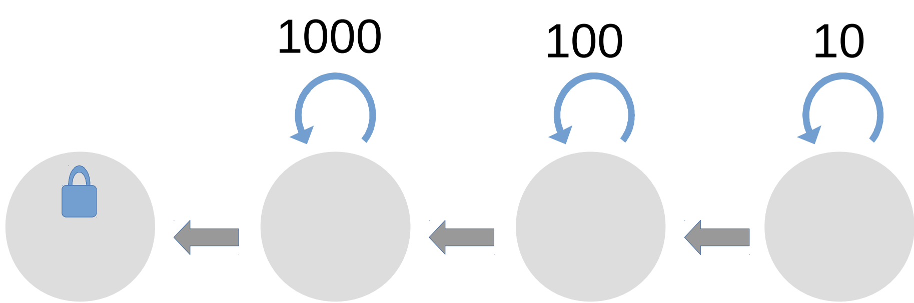
Then it de-schedules the vCPU.

- Probable cause of degradation:
  - Most vCPUs trap to the hypervisor
  - Switching overhead between guest and host + communication cost to wake-up other vCPUs increases

Key idea: Ordering

- OTicket tries to exploit the ordering.
- **Lock**:
  - Lower ticket distance → longer spin.
  - Allows more spinning to nearby waiters.
- **Unlock**:
  - Wake-up multiple waiters.
  - Reduces latency for the upcoming waiters.

OTicket: Opportunistic Spinning

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        my_ticket = F&I(tail);
+       if(my_ticket - head < TICKET_QUEUE) {
+               threshold = SPIN_MAX_THRESHOLD
+                                   >> (dist – 1);
+       }
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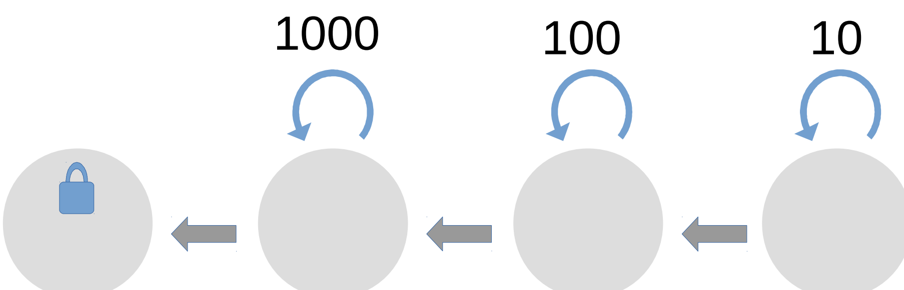


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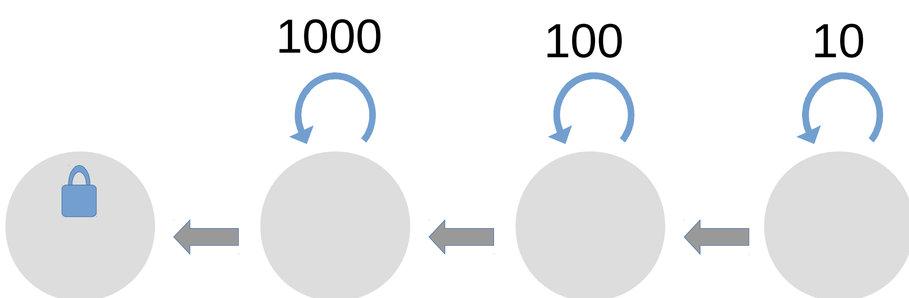


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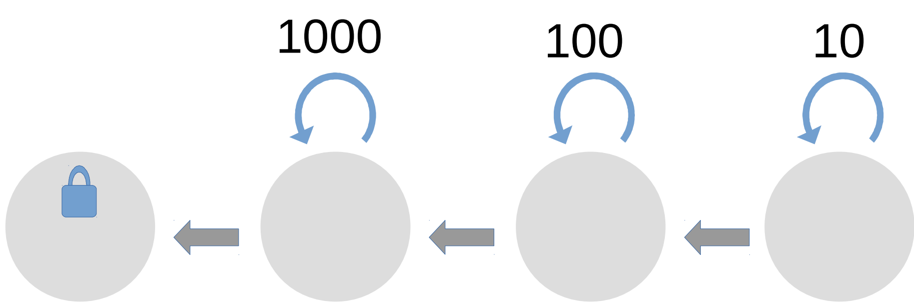


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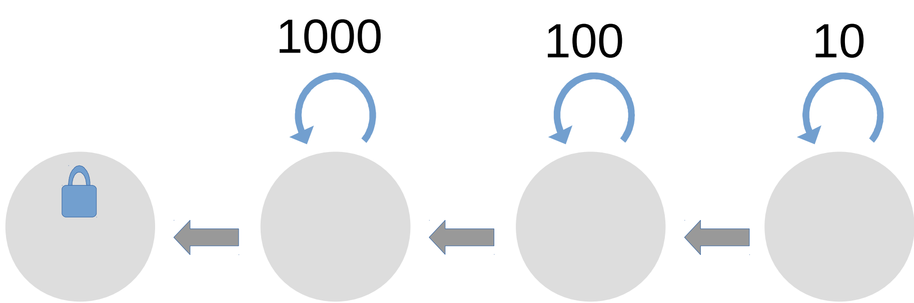


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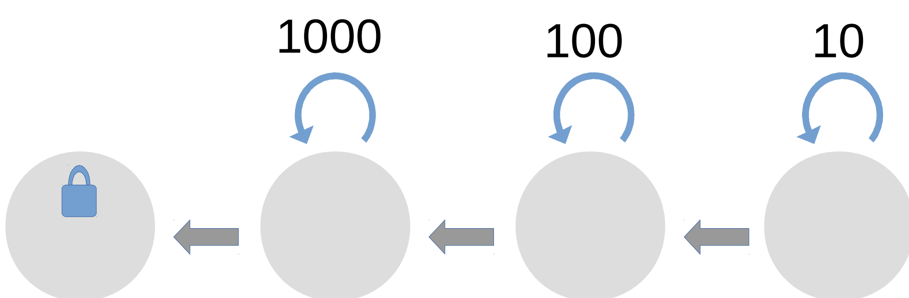


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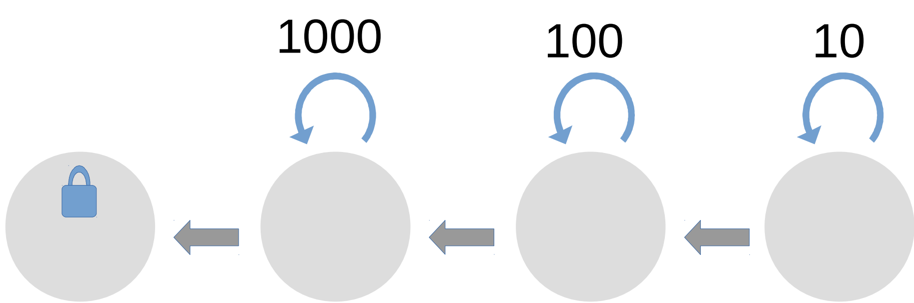


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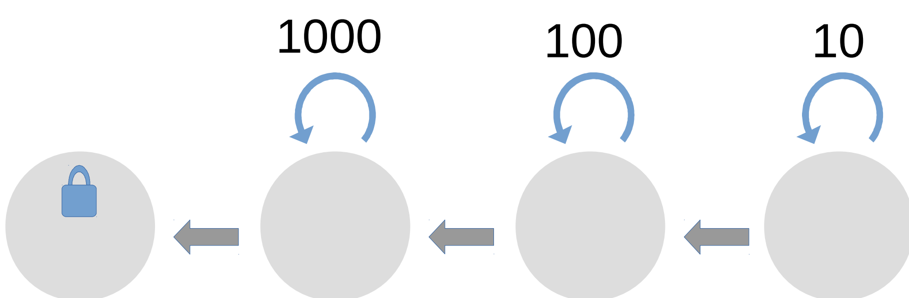


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OTicket: Opportunistic Wake-up

```
 void unlock() {
+      for(count = 1; count <= EAGER_WAITERS;
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+            wakeup_cpu(head + count);
       }
       head++;
 }
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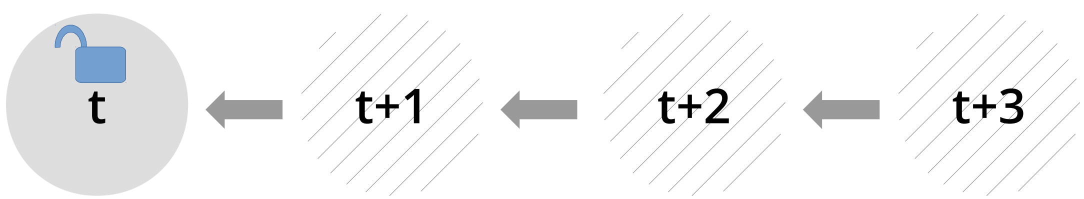

Wake-up sleeping waiters

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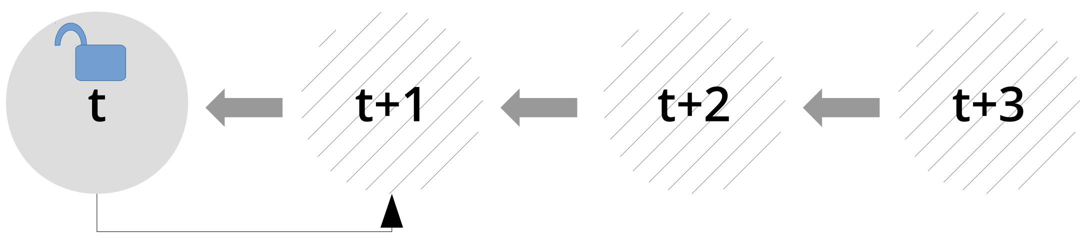

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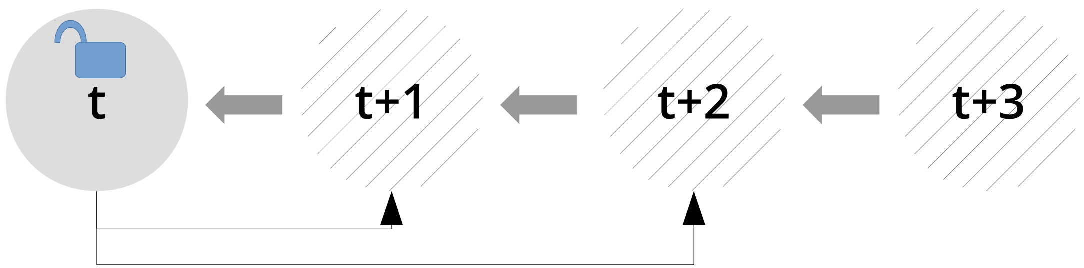

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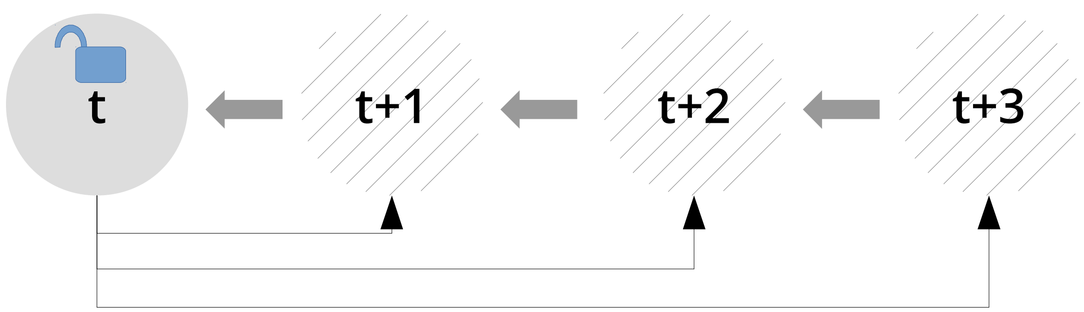

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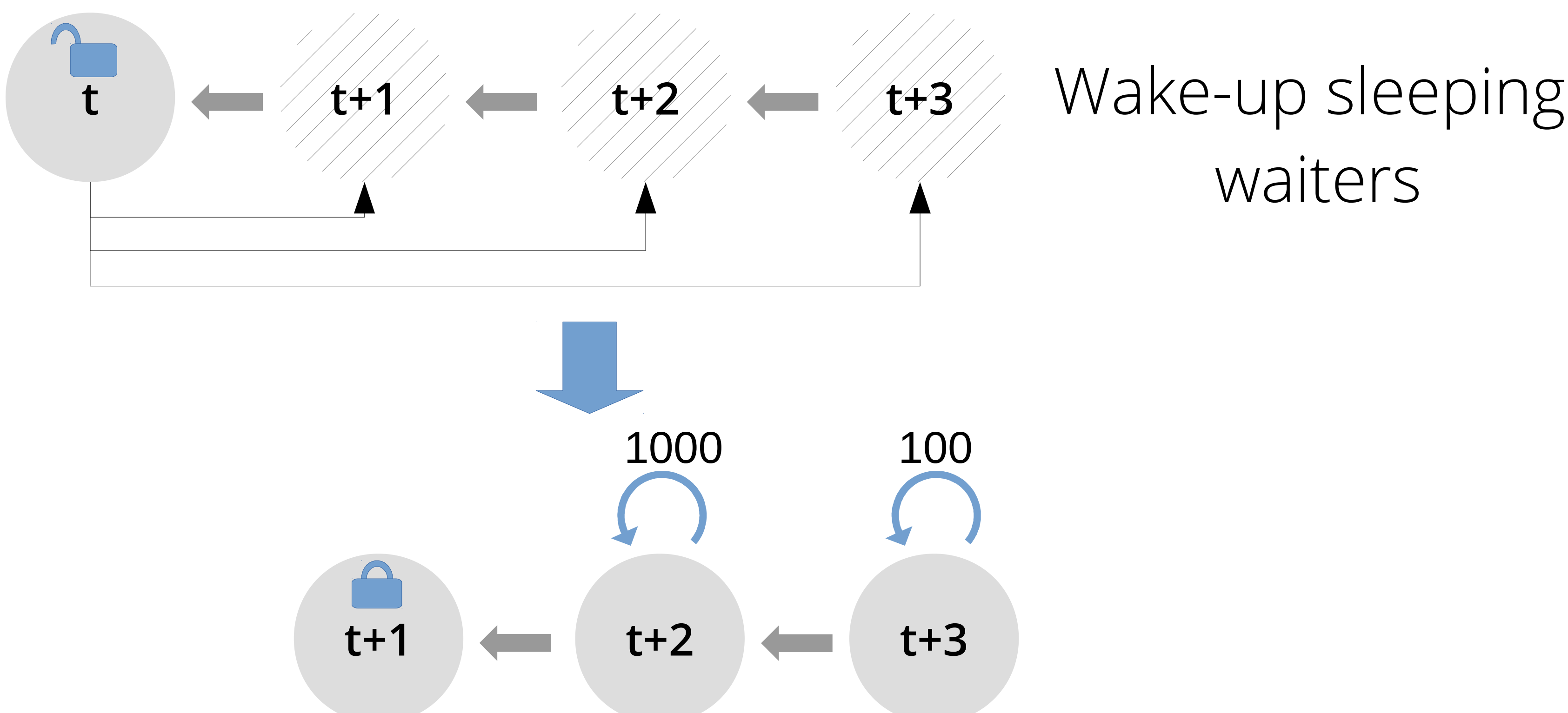

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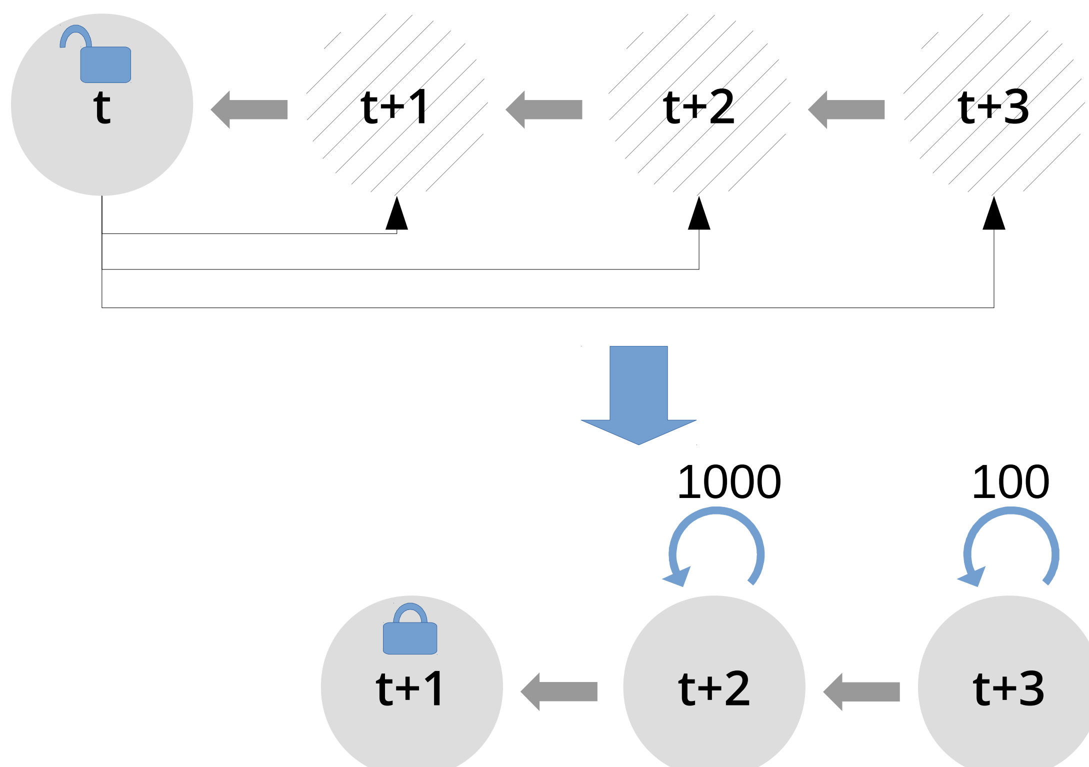

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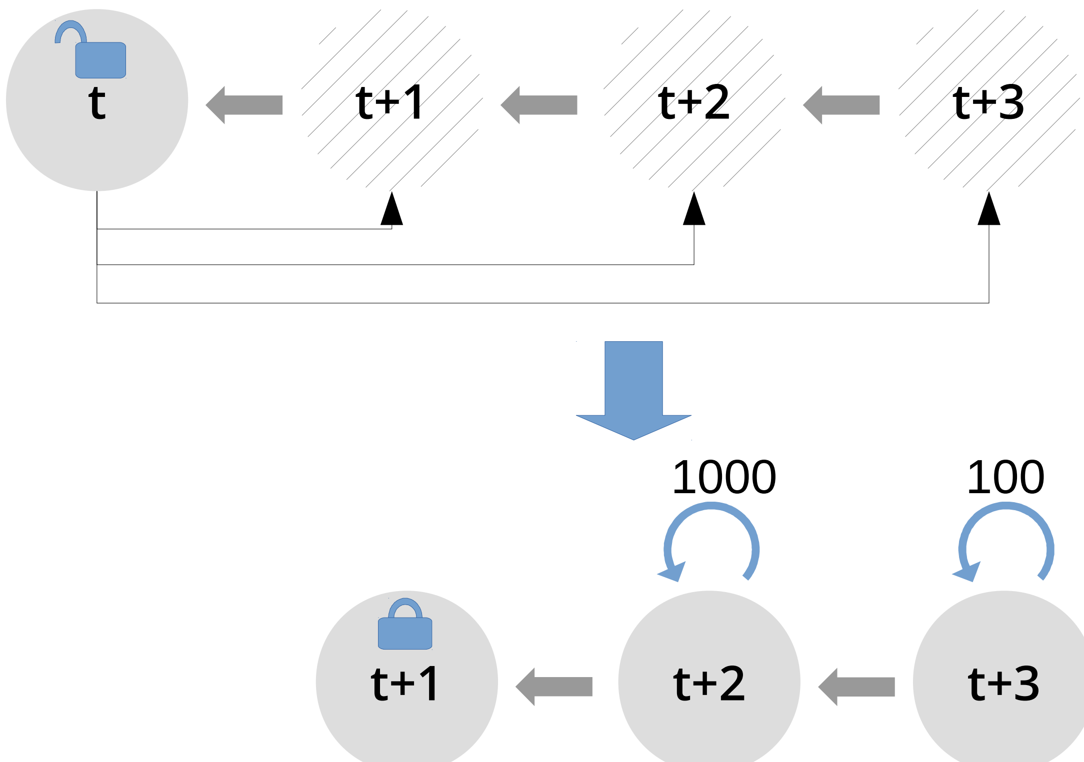

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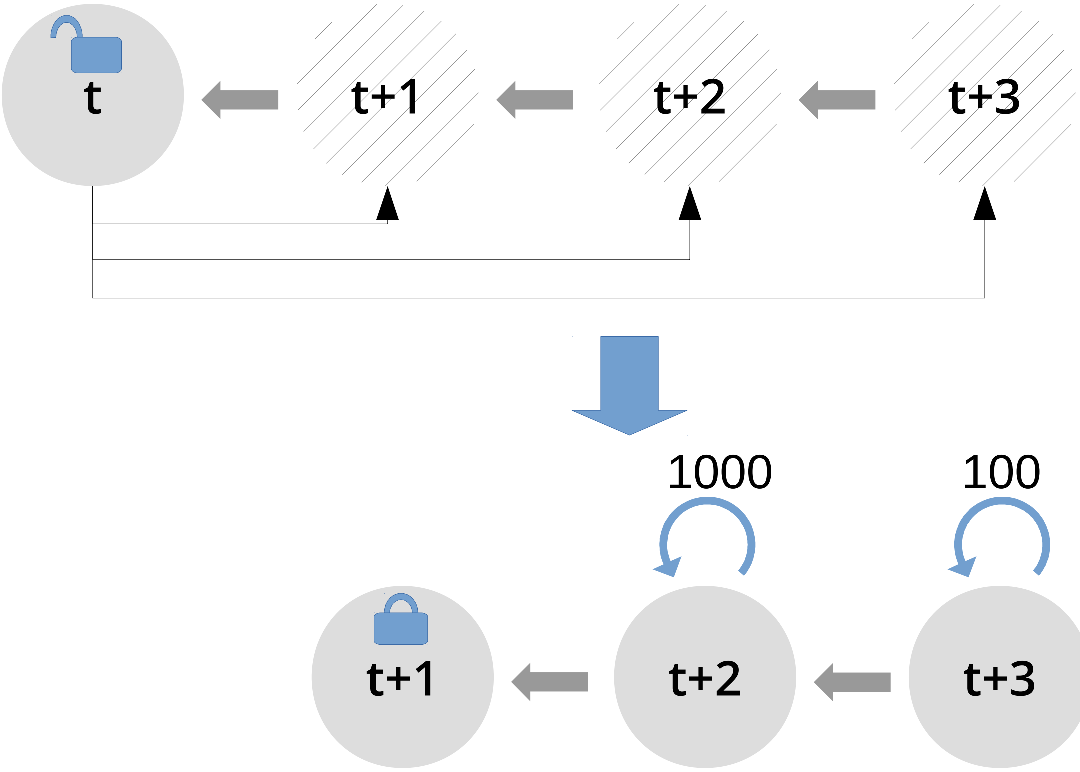


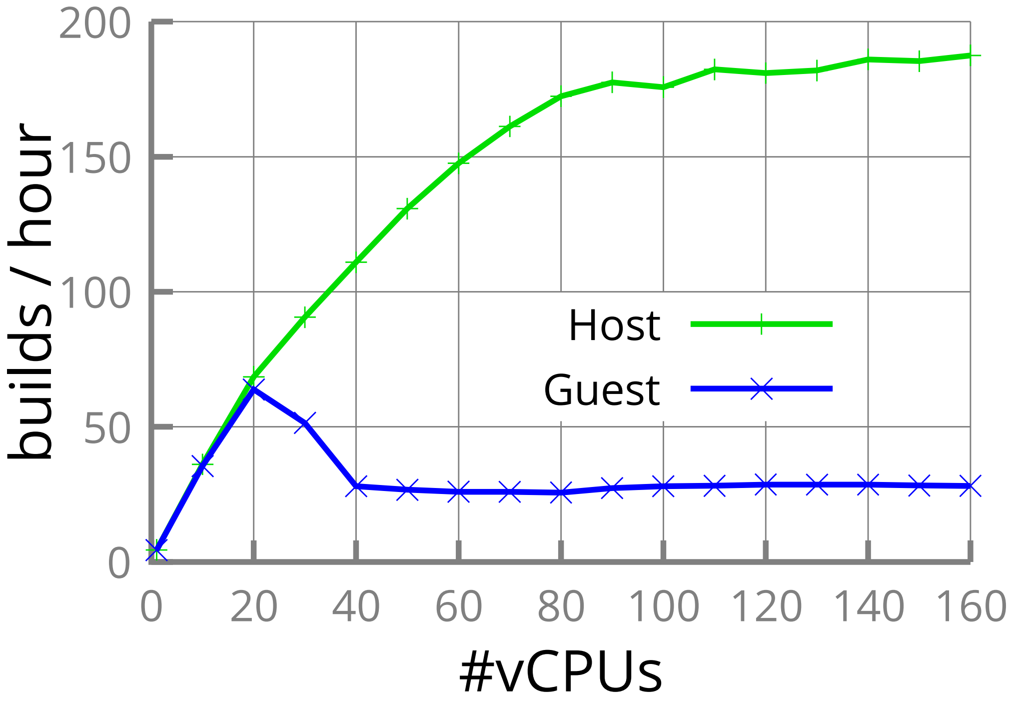
Wake-up sleeping waiters

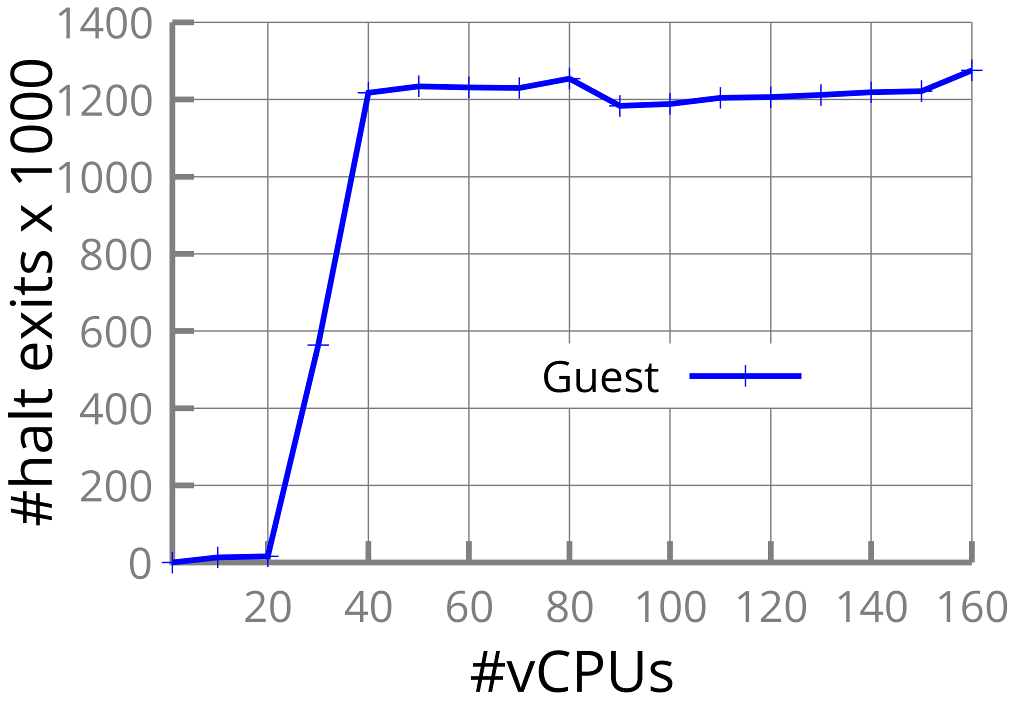
Outline

- Scalability issue in the Clouds
- Scalability issue in VMs with higher core count
- OTicket design
- **Evaluation**
- Conclusion

OTicket: Guest vs Host

- Improves guest performance by almost **5x**.
- Reduces **halt exits** by 6x.





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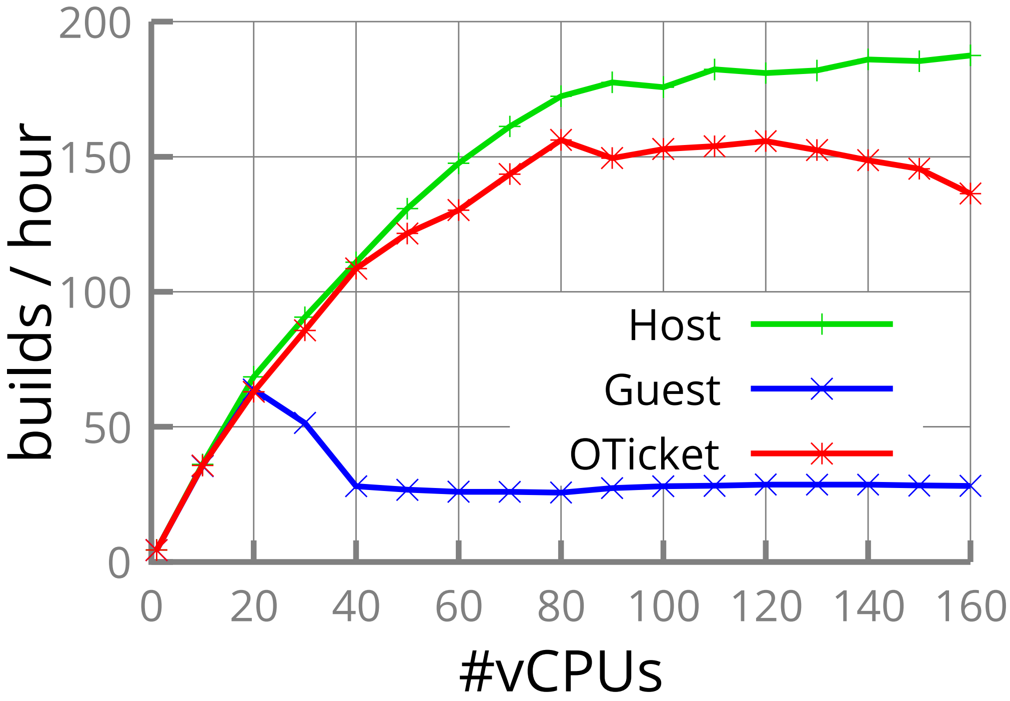
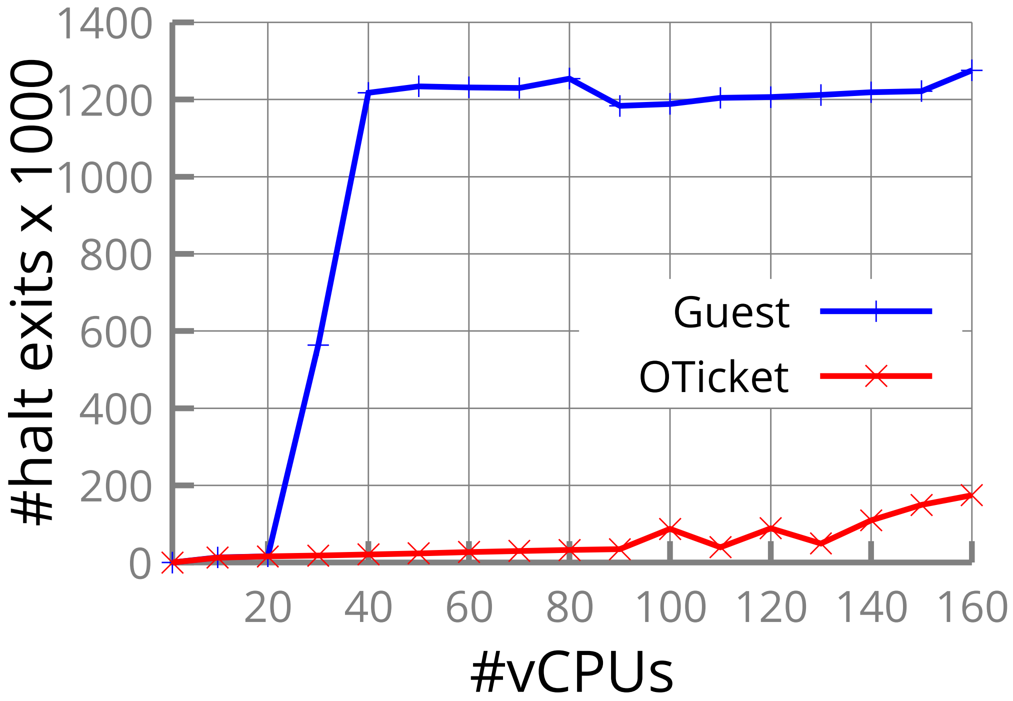
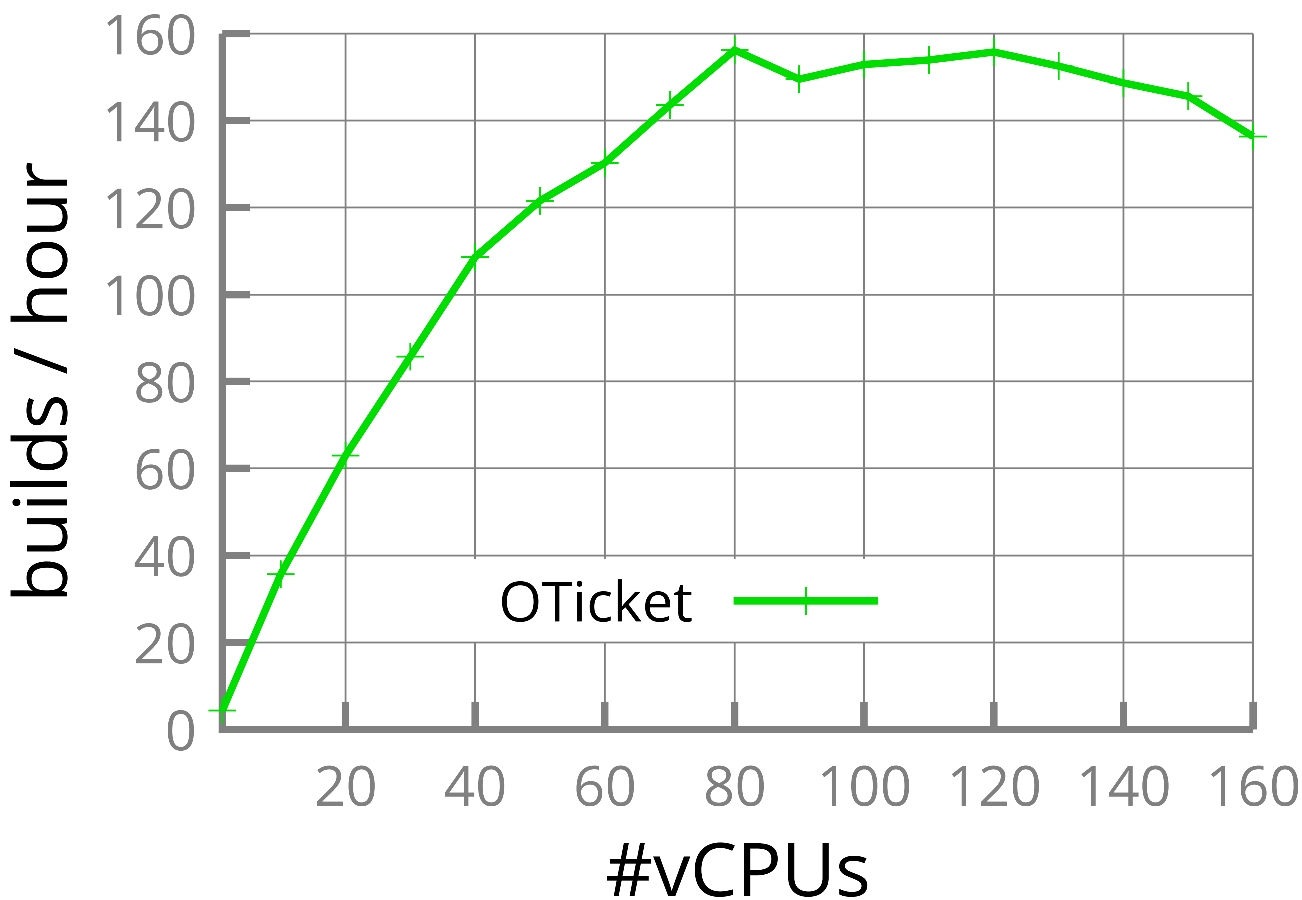




OTicket Performance Breakdown

- Opportunistic spinning prohibits sleeping.



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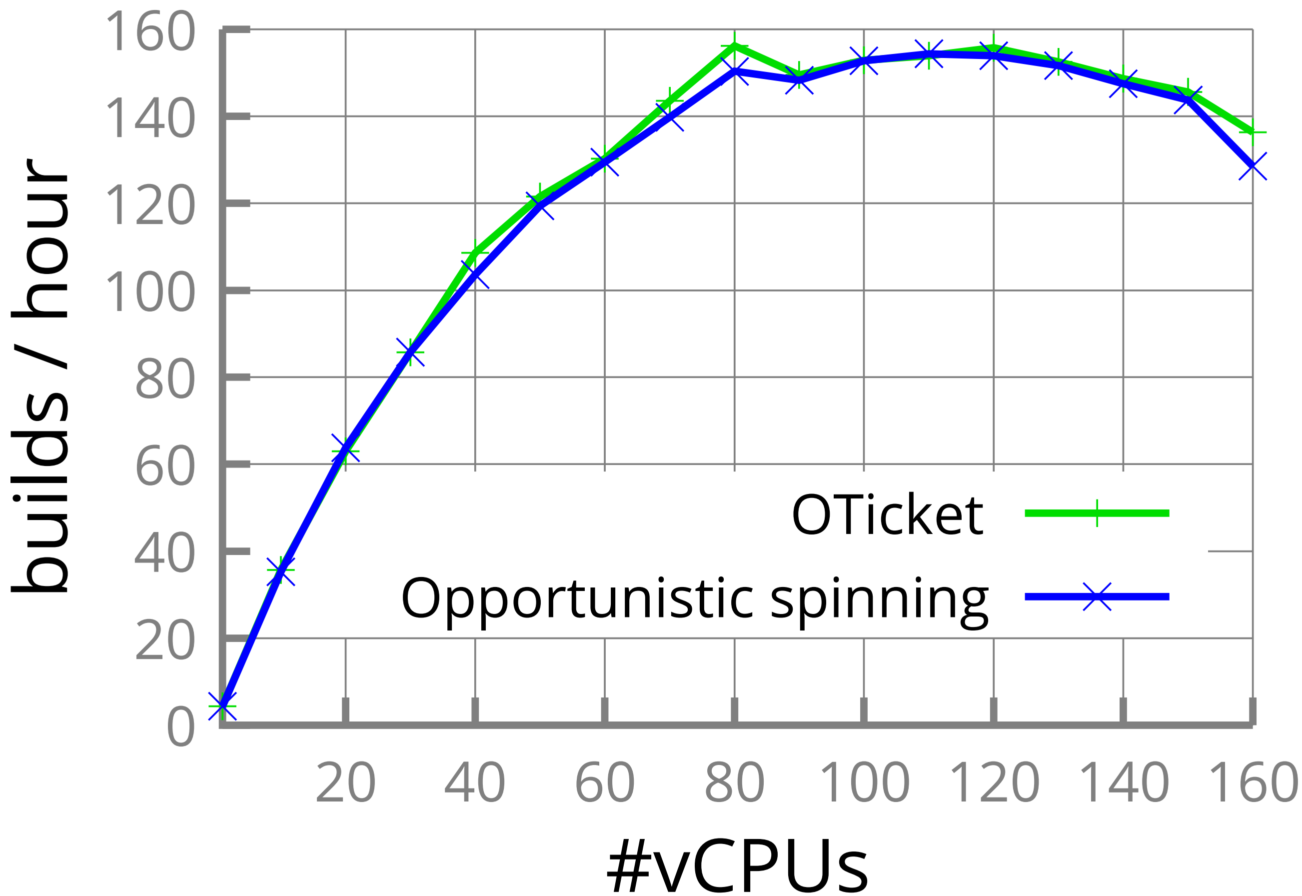

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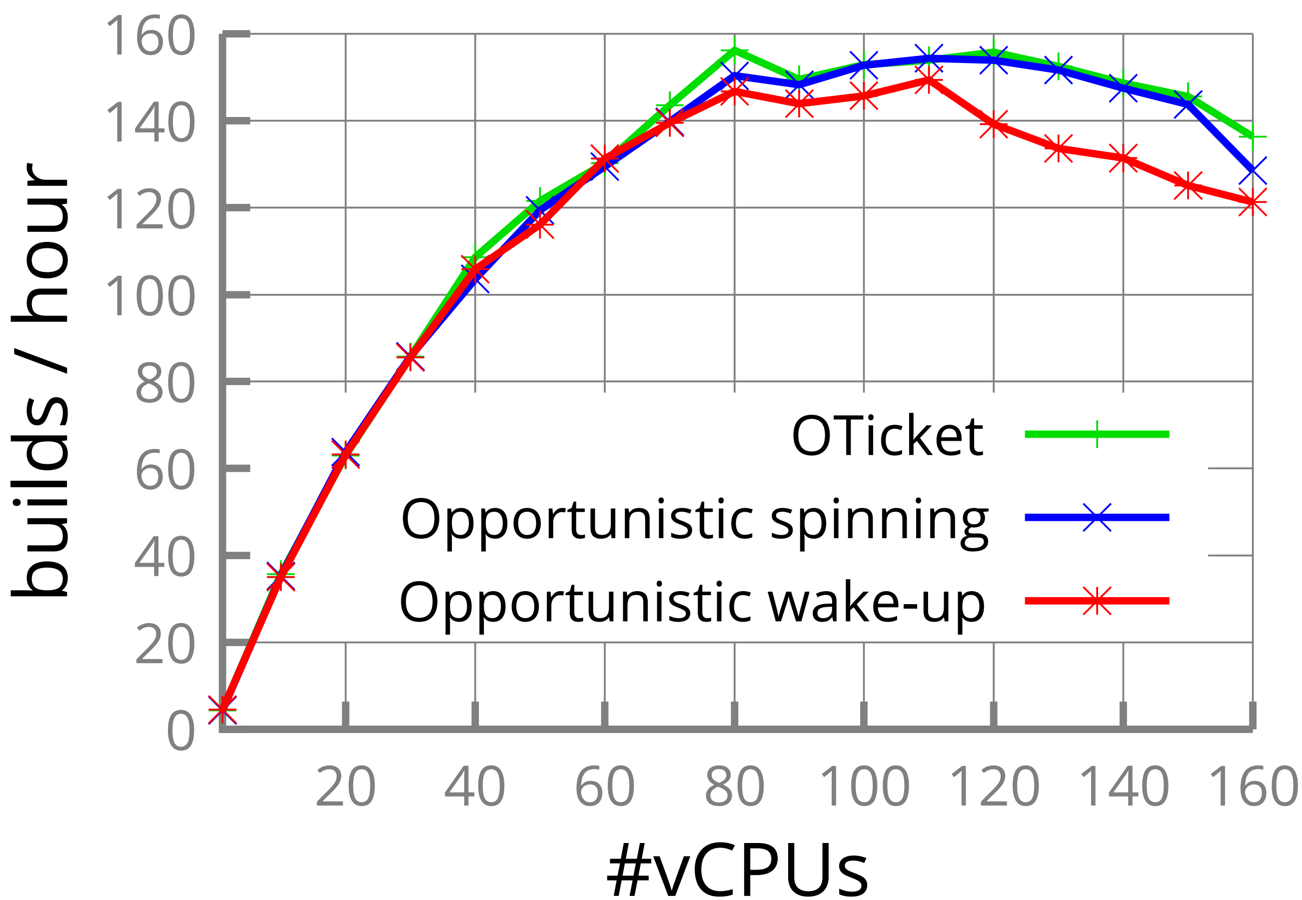
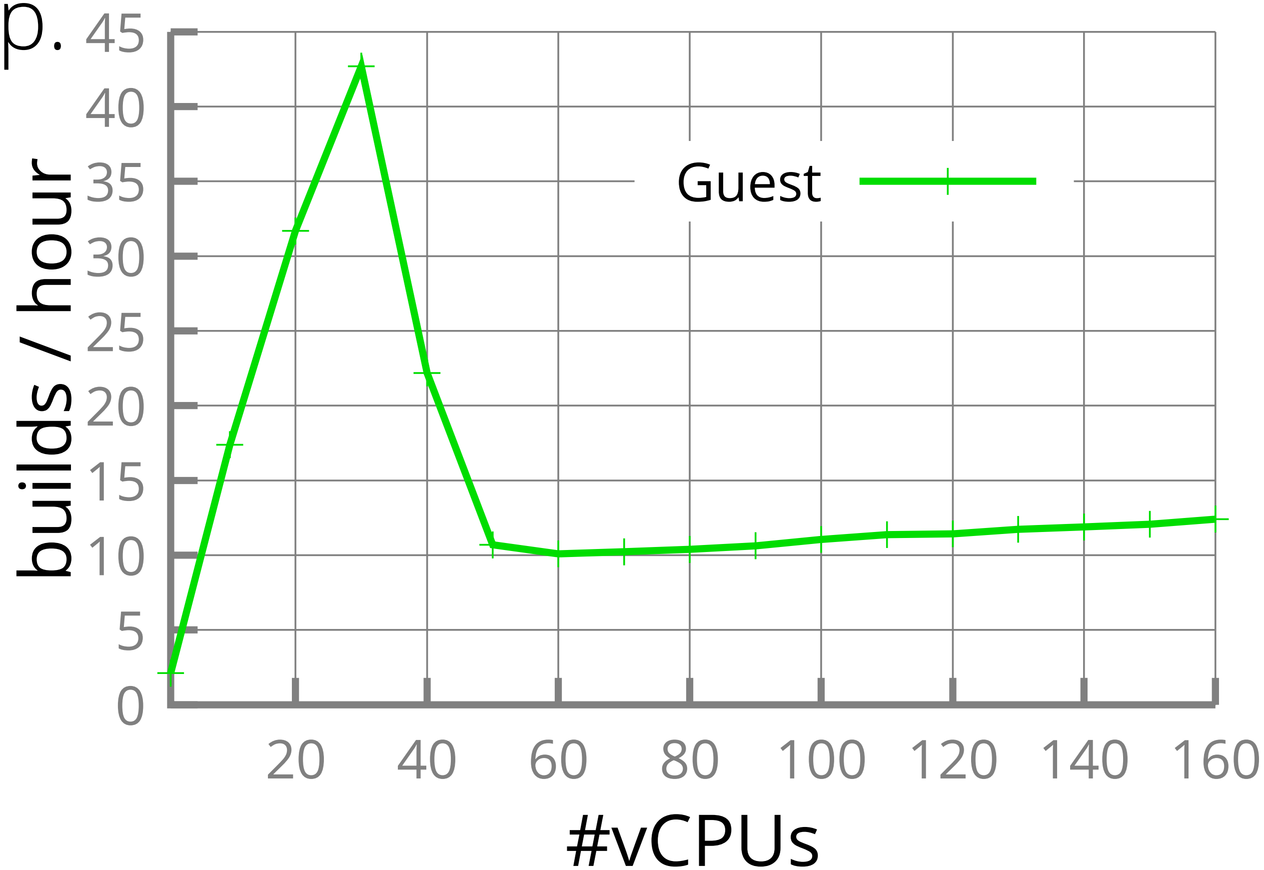


Importance of Wake-ups

- Oversubscribed tenants.
- OTicket performs better due to opportunistic wake-up.



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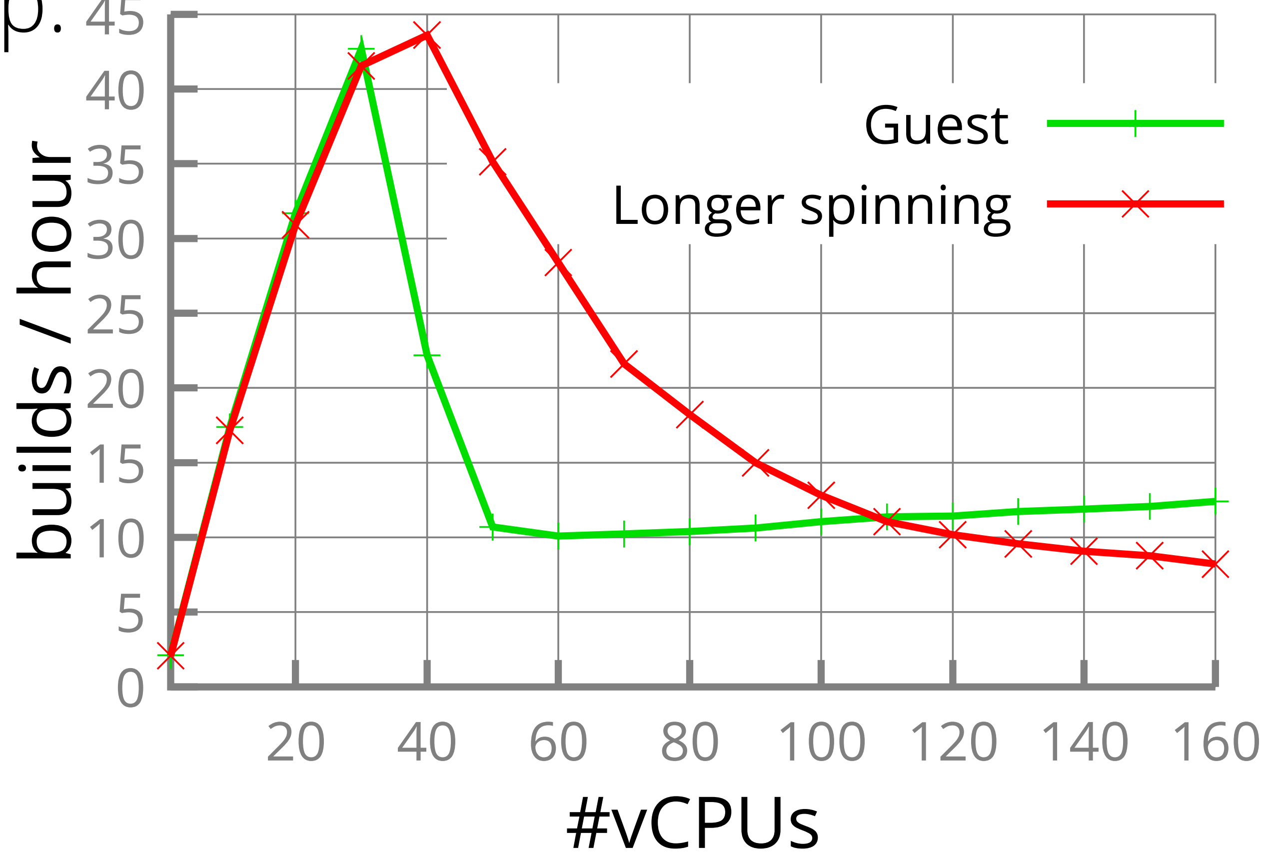

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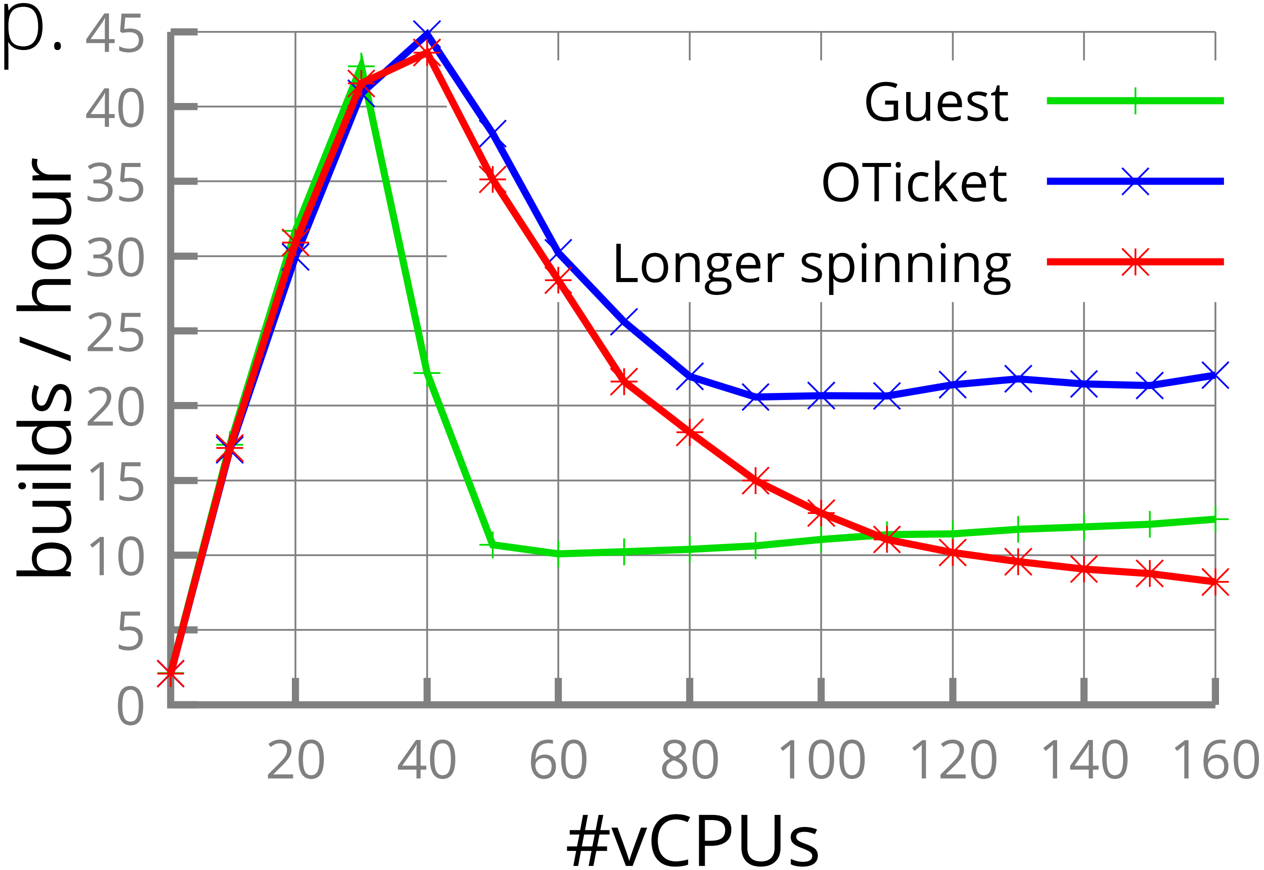
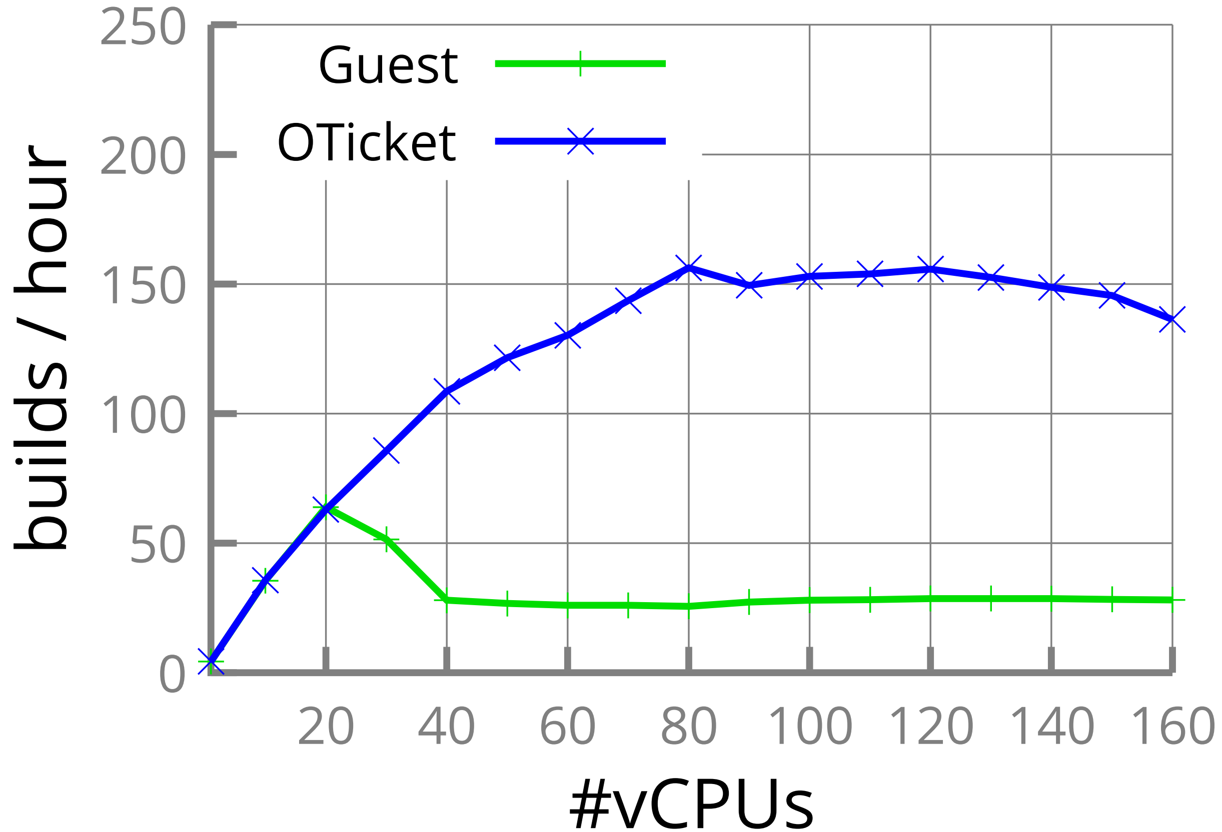


Other Spinlock Alternatives

- Two spinlock implementaions:
  - Current ticket spinlock
  - Fast-queue spinlock



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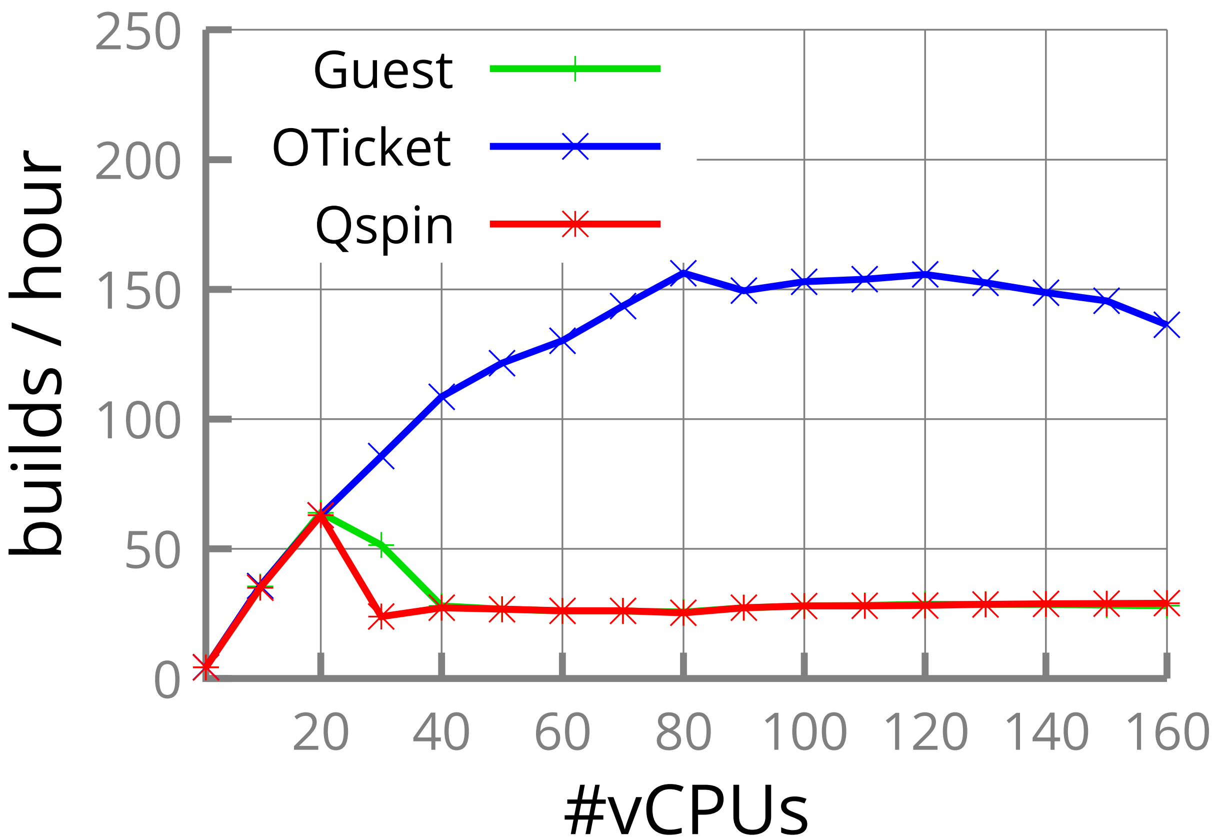

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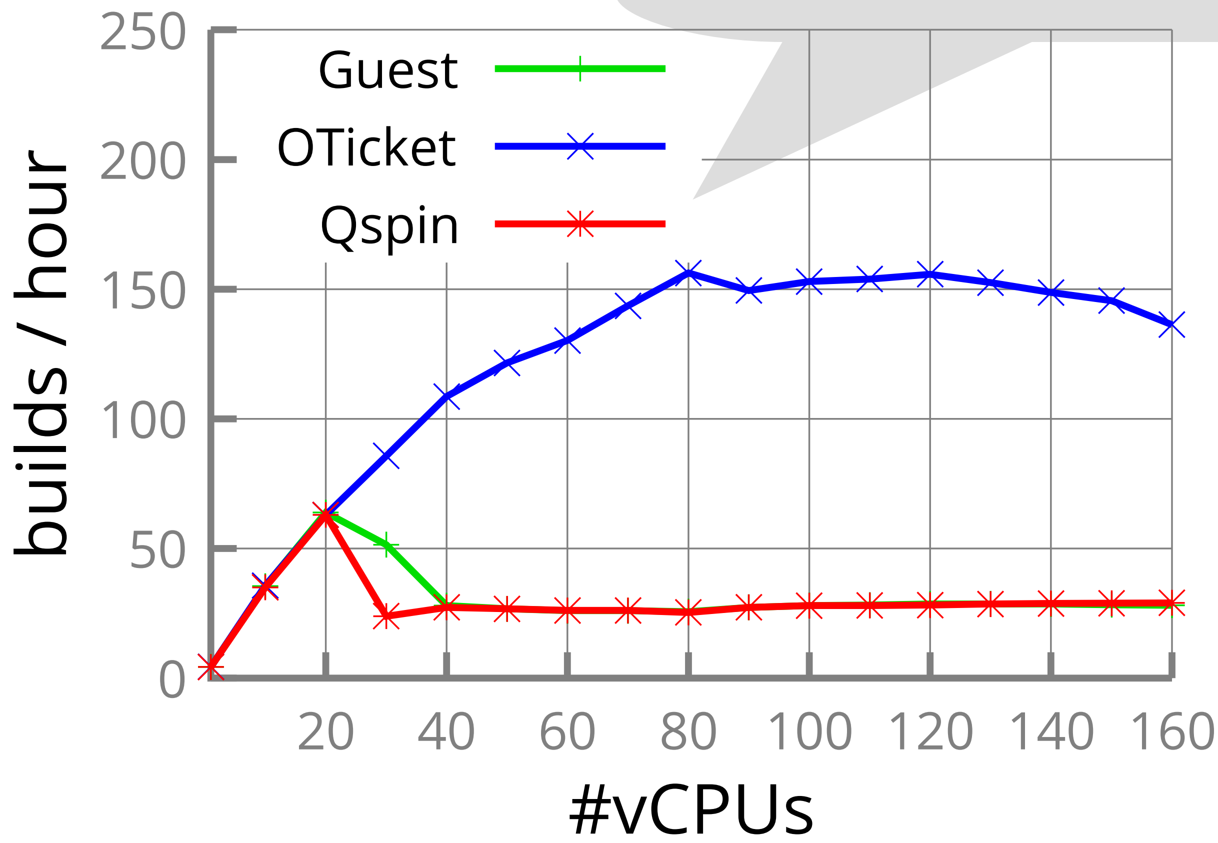
Qspinlock has the same issue.

Our design has been already acknowledged!



Conclusion

- **Identified a new class of problem.**
  - not *cacheline contention.*
  - *sleepy spinlock anomaly.*
- Carefully utilized the ordering property can scale the spinlock:
  - Opportunistic spinning.
  - Opportunistic wake-up.

Conclusion

locking/qspinlock: Enhance pvqspinlock & introduce queued unfair lock

From: Waiman Long <Waiman.Long@hp.com>
To: Peter Zijlstra <peterz@infradead.org>, Ingo Molnar <mingo@redhat.com>, Thomas Gleixner <tglx@linutronix.de>, "H. Peter Anvin" <hpa@zytor.com>
Subject: [PATCH 0/7] locking/qspinlock: Enhance pvqspinlock & introduce queued unfair lock
Date: Sat, 11 Jul 2015 16:36:51 -0400
Message-ID: <1436647018-49734-1-git-send-email-Waiman.Long@hp.com>
Cc: x86@kernel.org, linux-kernel@vger.kernel.org, Scott J Norton <scott.norton@hp.com>, Douglas Hatch <doug.hatch@hp.com>, Waiman Long <Waiman.Long@hp.com>
Archive-link: Article, Thread

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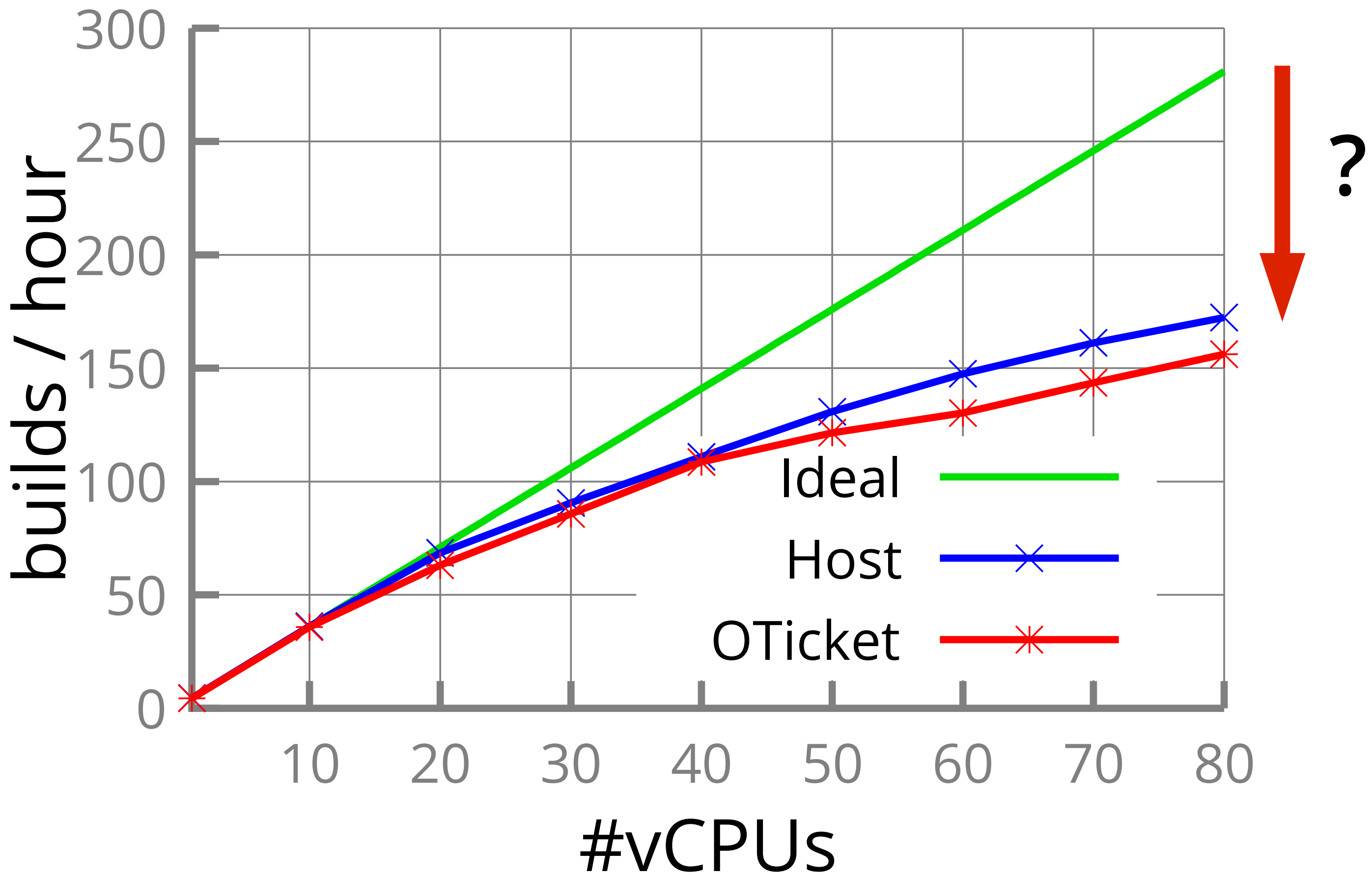
Recent Features

```
This patchset consists of two parts:

 1) Patches 1-5 enhance the performance of PV qspinlock especially for
    overcommitted guest. The first patch moves all the CPU kicking to
    the unlock code. The 2nd and 3rd patches implement a kick-ahead
    and wait-early mechanism that was shown to improve performance for
    overcommitted guest. They are inspired by the "Do Virtual Machines
    Really Scale?" blog from Sanidhya Kashyap.  The 4th patch adds
    code to collect PV qspinlock statistics. The last patch adds the
    pending bit support to PV qspinlock to improve performance at
    light load. This is important as the PV queuing code has even
    higher overhead than the native queuing code.
```

Future Work

- Scalability of other synchronization primitives in virtualized environment?
-



Thank you!

Sanidhya Kashyap
sanidhya@gatech.edu
Changwoo Min, Taesoo Kim
Georgia Institute of Technology

Questions?

https://github.com/sslab-gatech/vbench