The multicore evolution and operating systems

Frans Kaashoek

Joint work with: Silas Boyd-Wickizer, Austin T. Clements, Yandong Mao, Aleksey Pesterev, Robert Morris, and Nickolai Zeldovich

MIT

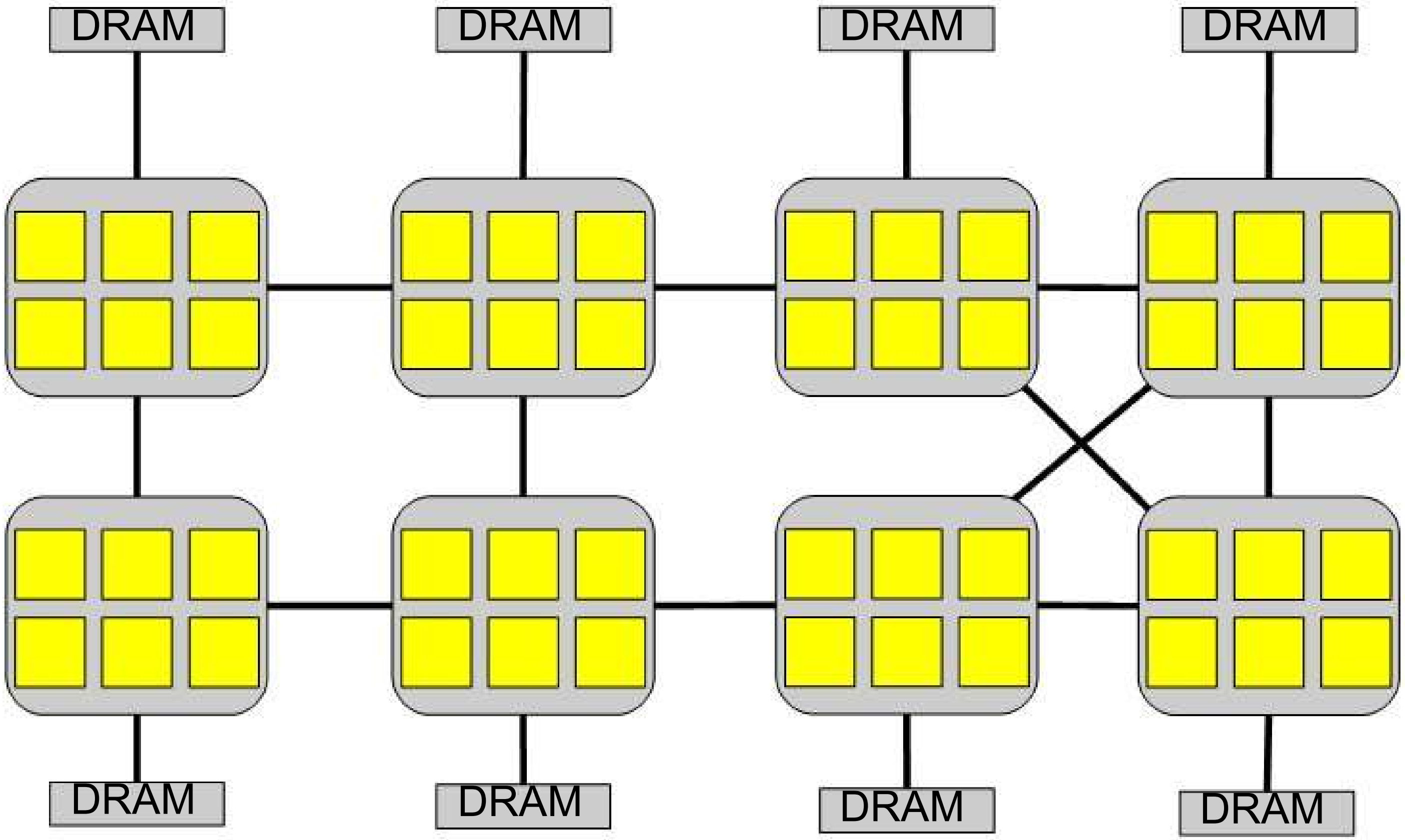
Non-scalable locks are dangerous.
Silas Boyd-Wickizer, M. Frans Kaashoek, Robert Morris, and Nickolai Zeldovich. *In the Proceedings of the Linux Symposium, Ottawa, Canada, July 2012.*

How well does Linux scale?

- Experiment:
  - Linux 2.6.35-rc5 (relatively old, but problems are representative of issues in recent kernels too)
  - Select a few inherent parallel system applications
  - Measure throughput on different # of cores
  - Use tmpfs to avoid disk bottlenecks

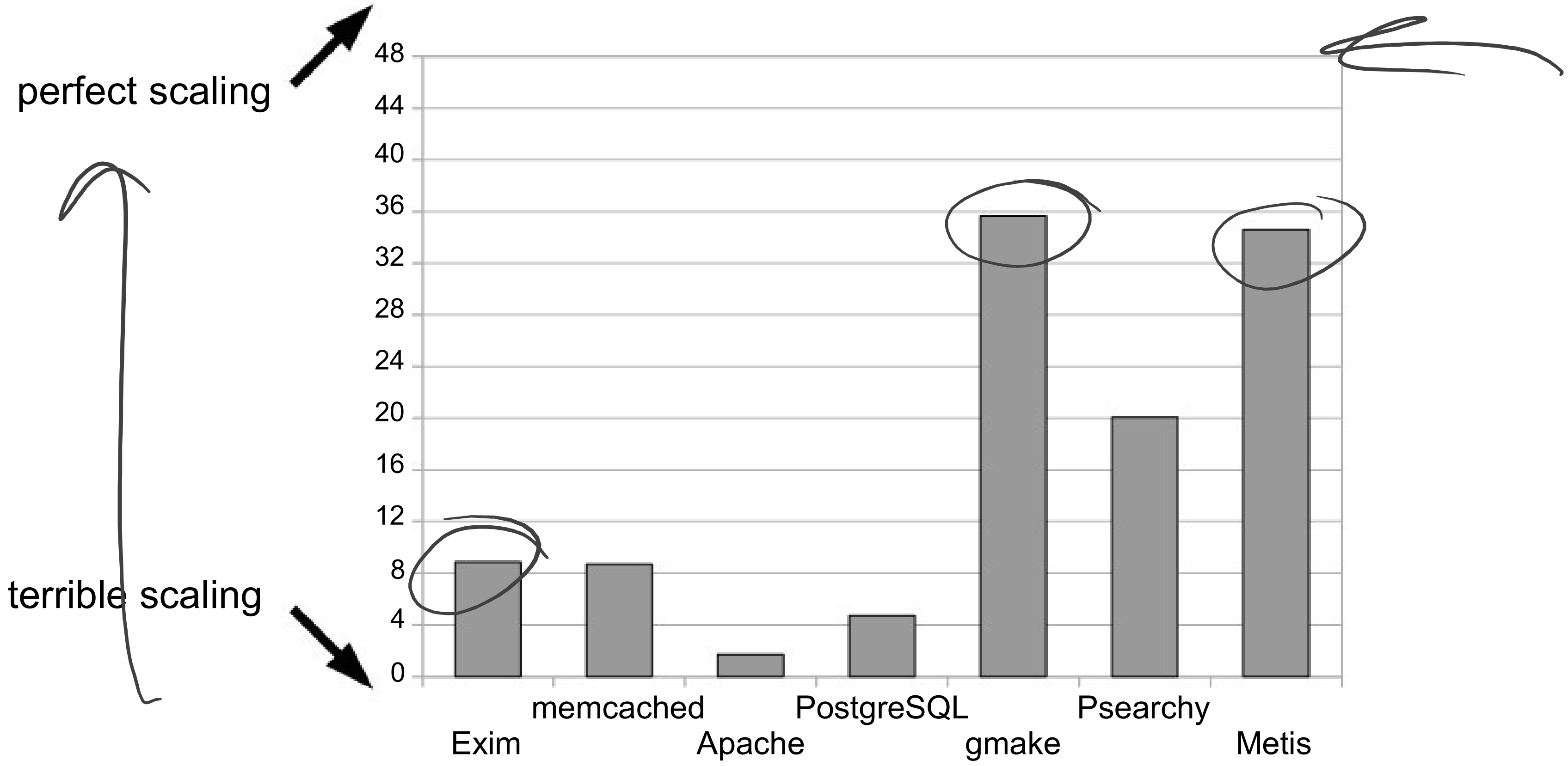
- Insight 1: Short critical sections can lead to sharp performance collapse

Off-the-shelf 48-core server (AMD)



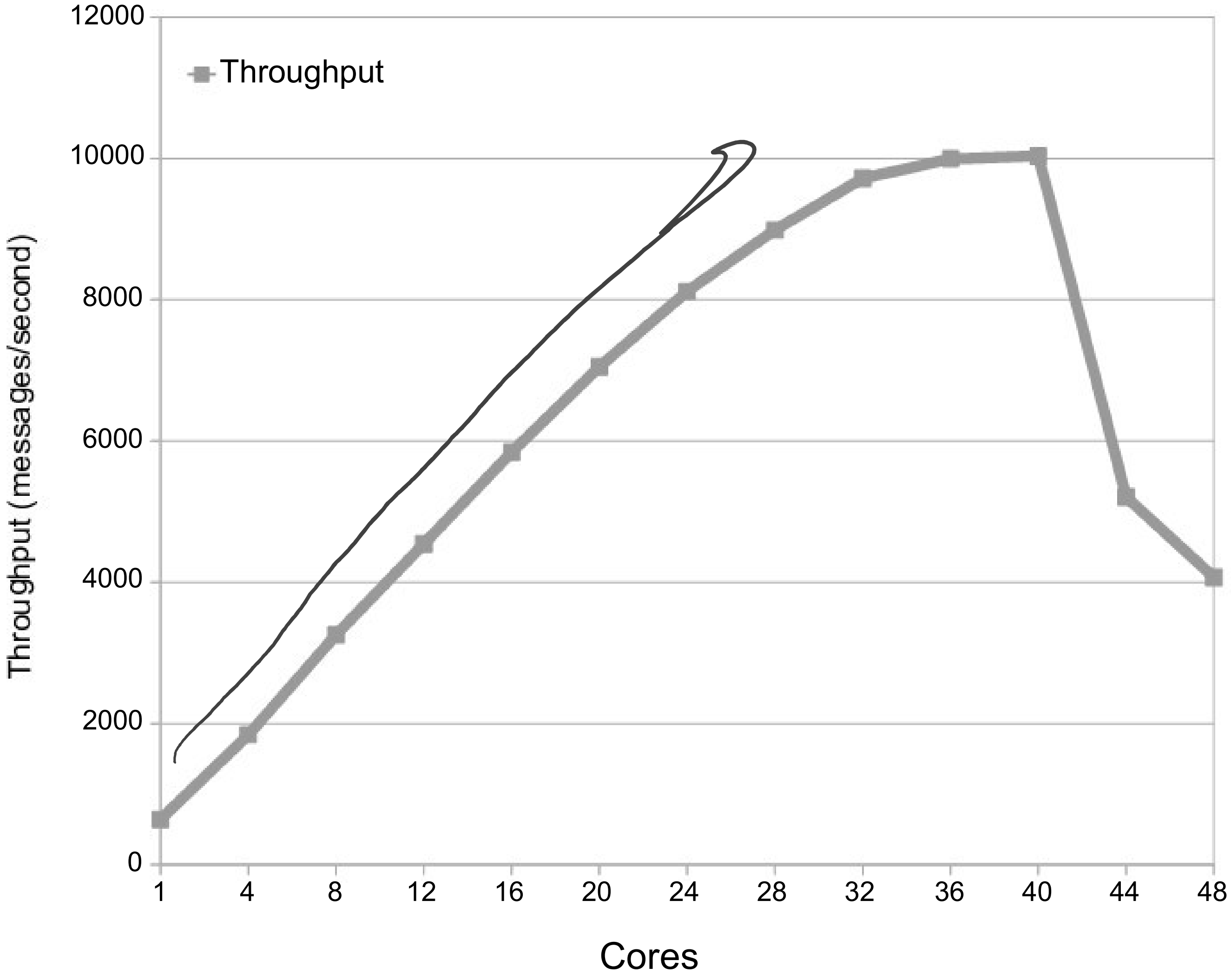
- Cache-coherent and non-uniform access
- An approximation of a future 48-core chip

Poor scaling on stock Linux kernel



Y-axis: (throughput with 48 cores) / (throughput with one core)

Exim on stock Linux: collapse



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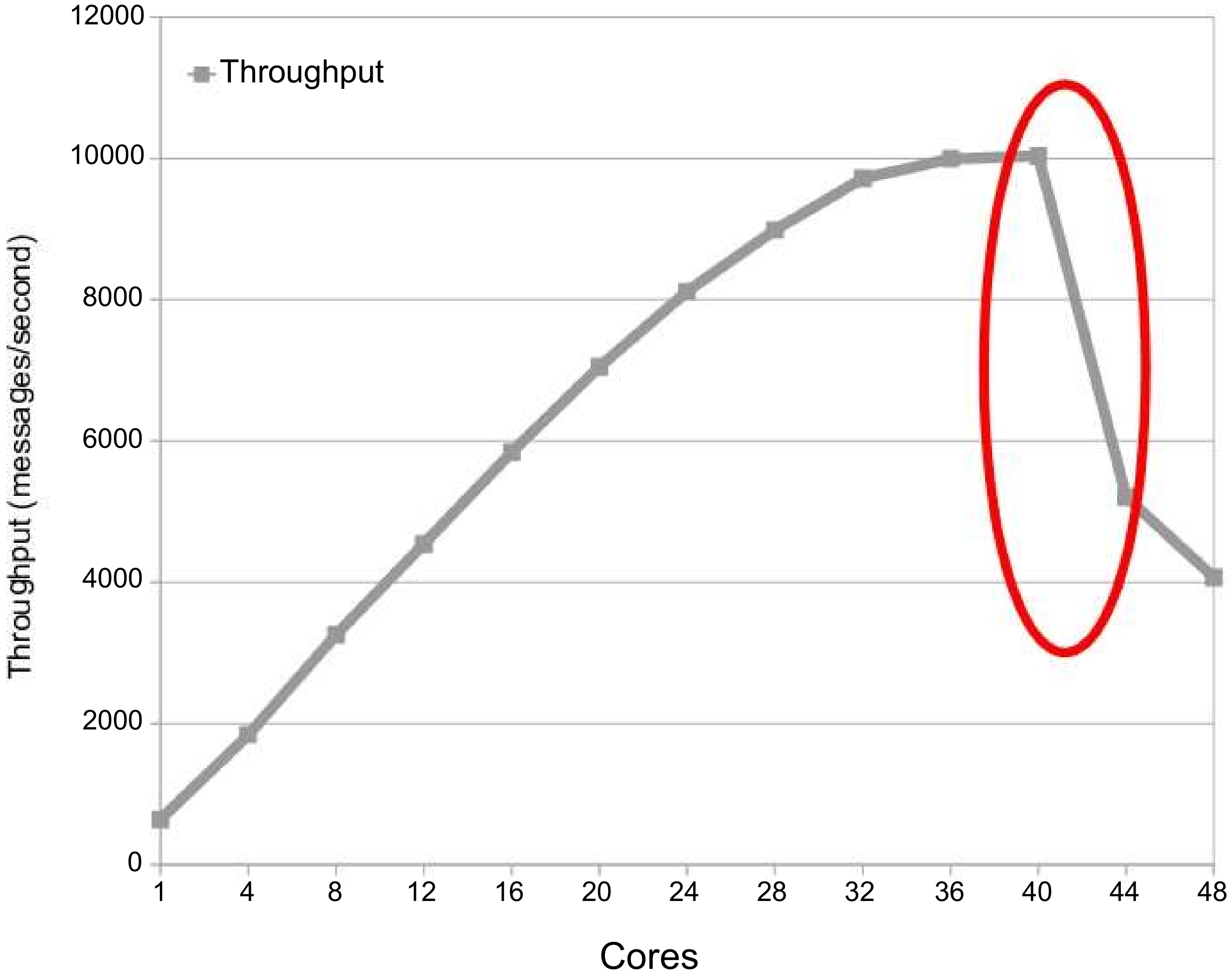

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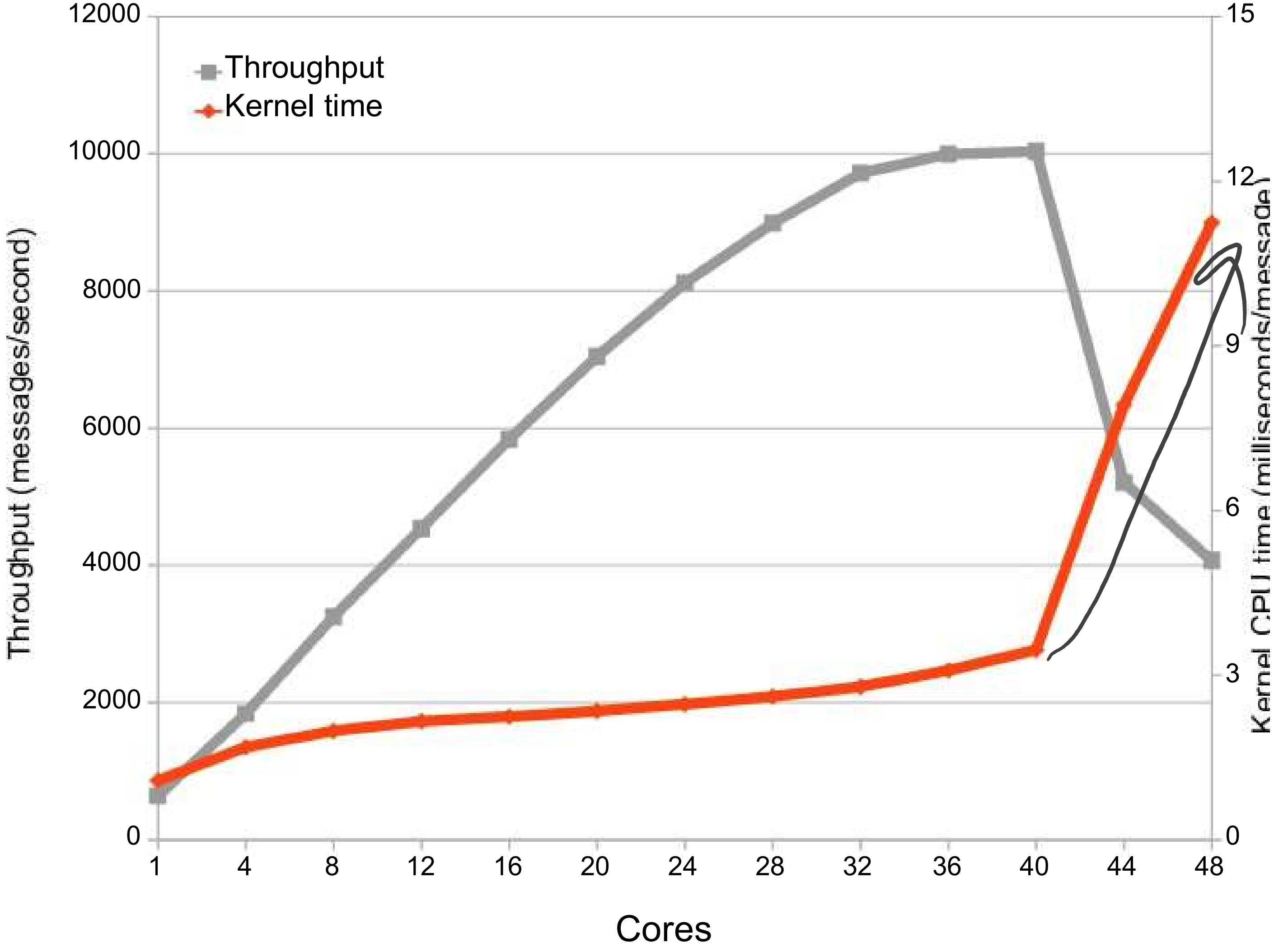

Oprofile shows an obvious problem

40 cores:
10000 msg/sec

samples	%	app name	symbol name
2616	7.3522	vmlinux	radix_tree_lookup_slot
2329	6.5456	vmlinux	unmap_vmas
2197	6.1746	vmlinux	filemap_fault
1488	4.1820	vmlinux	__do_fault
1348	3.7885	vmlinux	copy_page_c
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Bottleneck: reading mount table

- Delivering an email calls sys_open
- sys_open calls

```
struct vfsmount *lookup_mnt(struct path *path)
{
        struct vfsmount *mnt;
        spin_lock(&vfsmount_lock);
        mnt = hash_get(mnts, path);
        spin_unlock(&vfsmount_lock);
        return mnt;
}
```

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- sys_open calls:

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Serial section is short. Why does it cause a scalability bottleneck?

What causes the sharp performance collapse?

- Linux uses ticket spin locks, which are non-scalable
  - So we should expect collapse [Anderson 90]

- But why so sudden, and so sharp, for a short section?
  - Is spin lock/unlock implemented incorrectly?
  - Is hardware cache-coherence protocol at fault?

Ticket Lock

```
struct {
    int current_ticket;
    int next_ticket;
} spinlock_t
```

```
void spin_lock(spinlock_t *lock)
{
    t = atomic_inc(lock->next_ticket);
    while(t != lock->current_ticket)
          ; /* spin */
}
```

```
void spin_unlock(spinlock_t *lock)
{
    lock->current_ticket++;
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```

Scalability collapse caused by non-scalable locks [Anderson 90]

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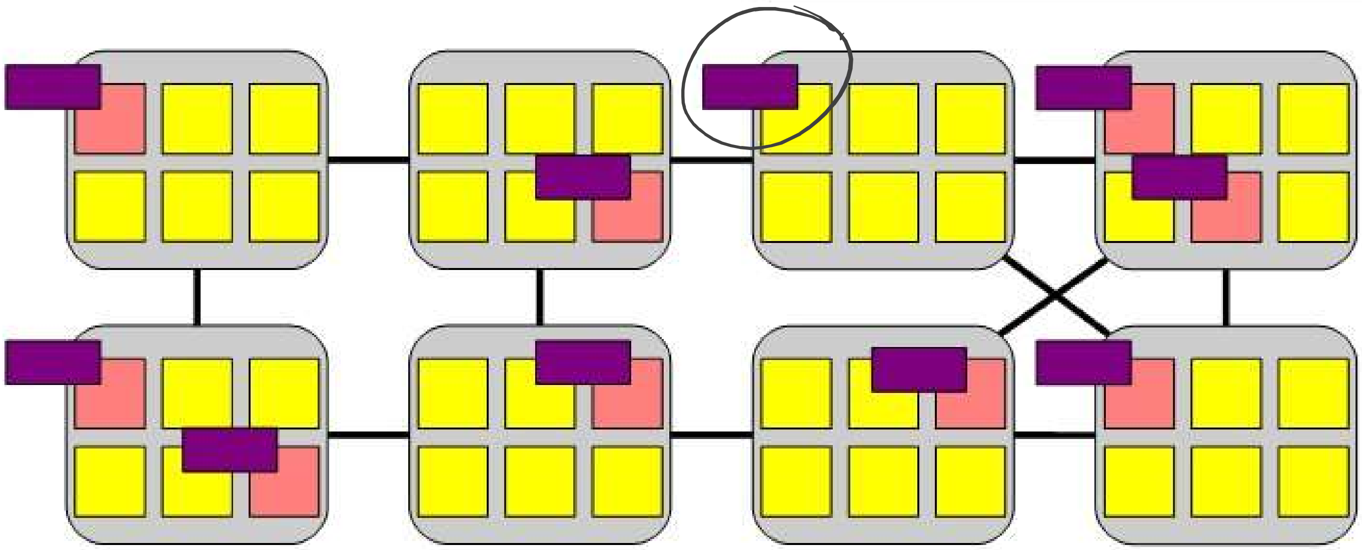

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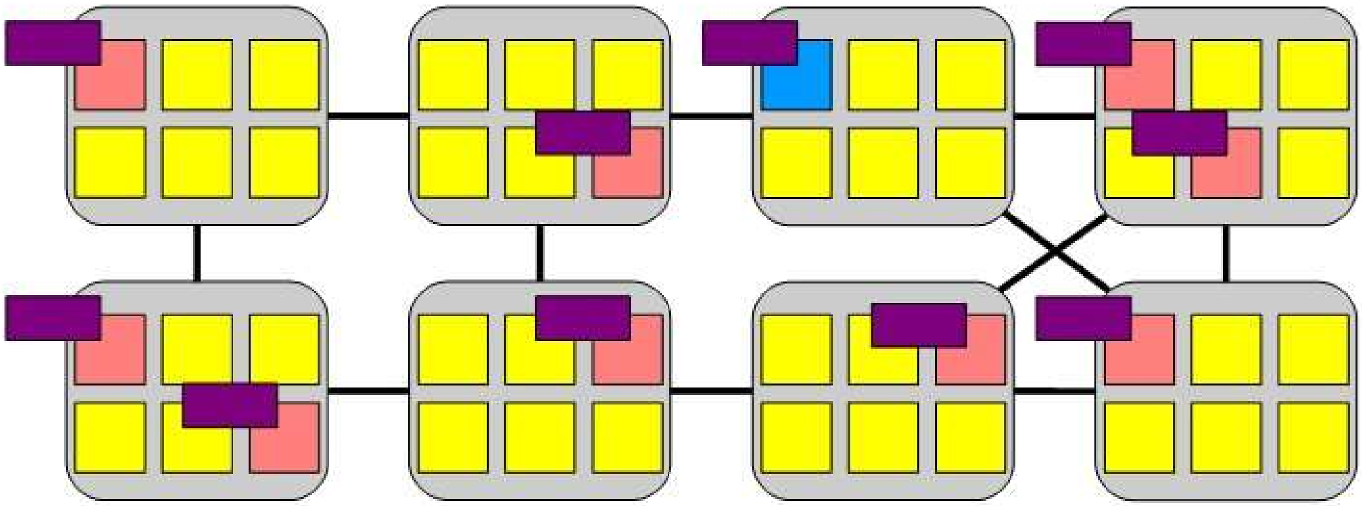

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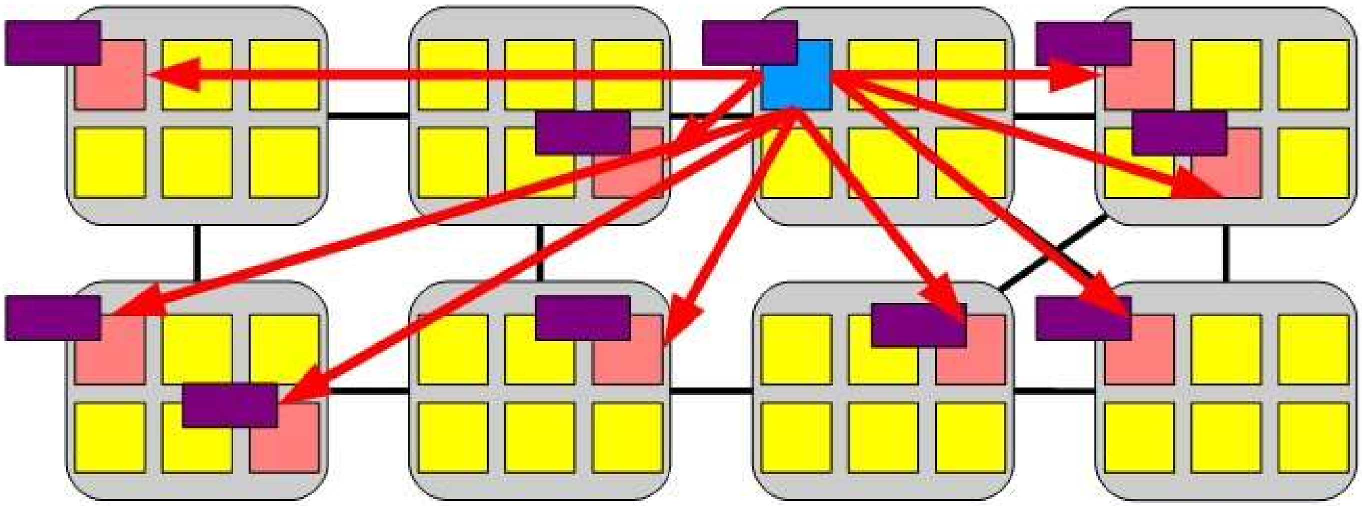

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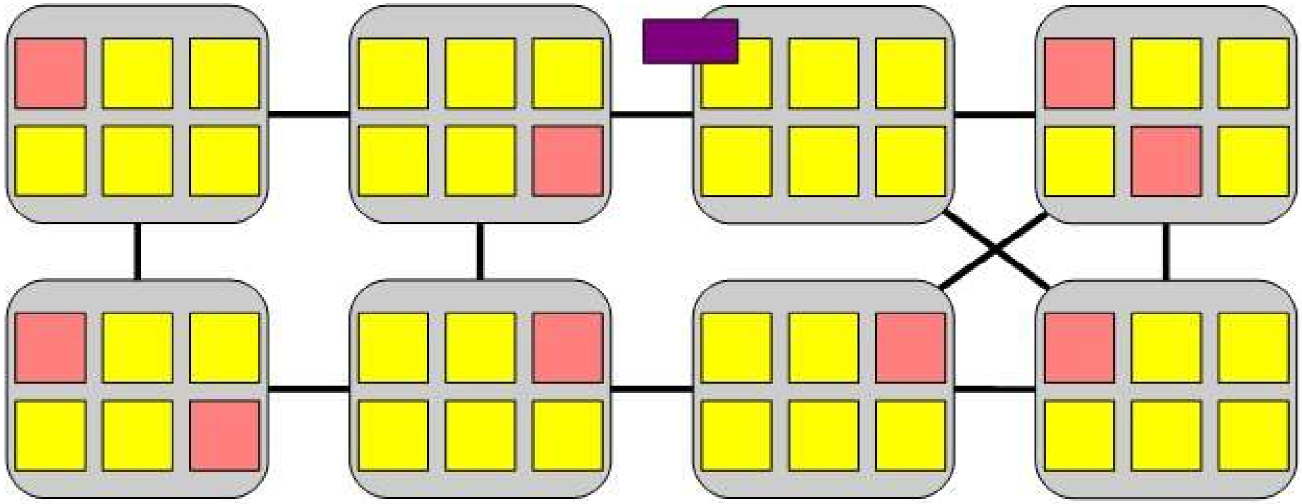

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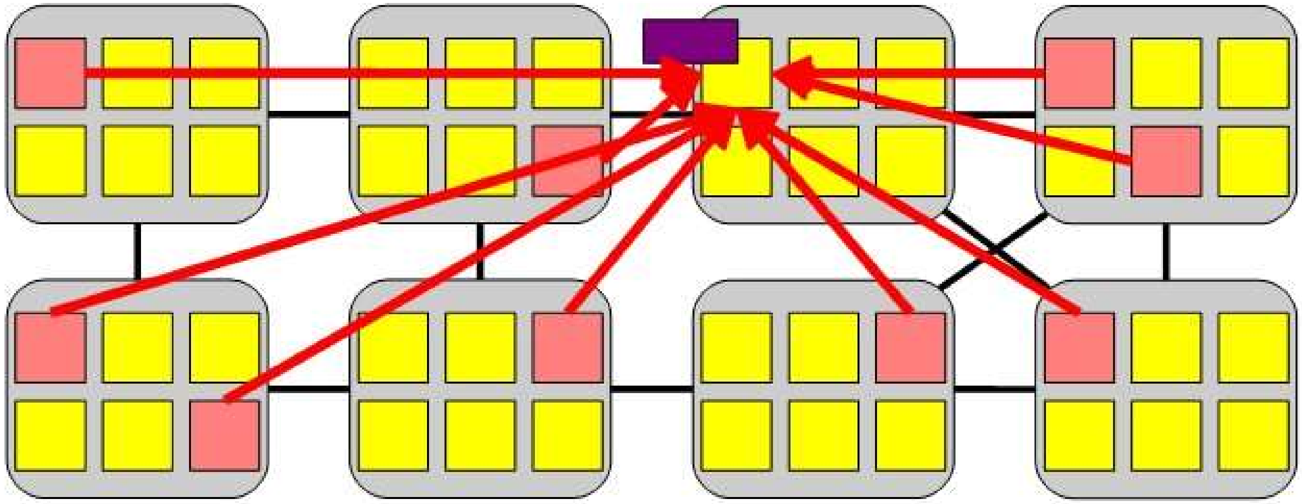

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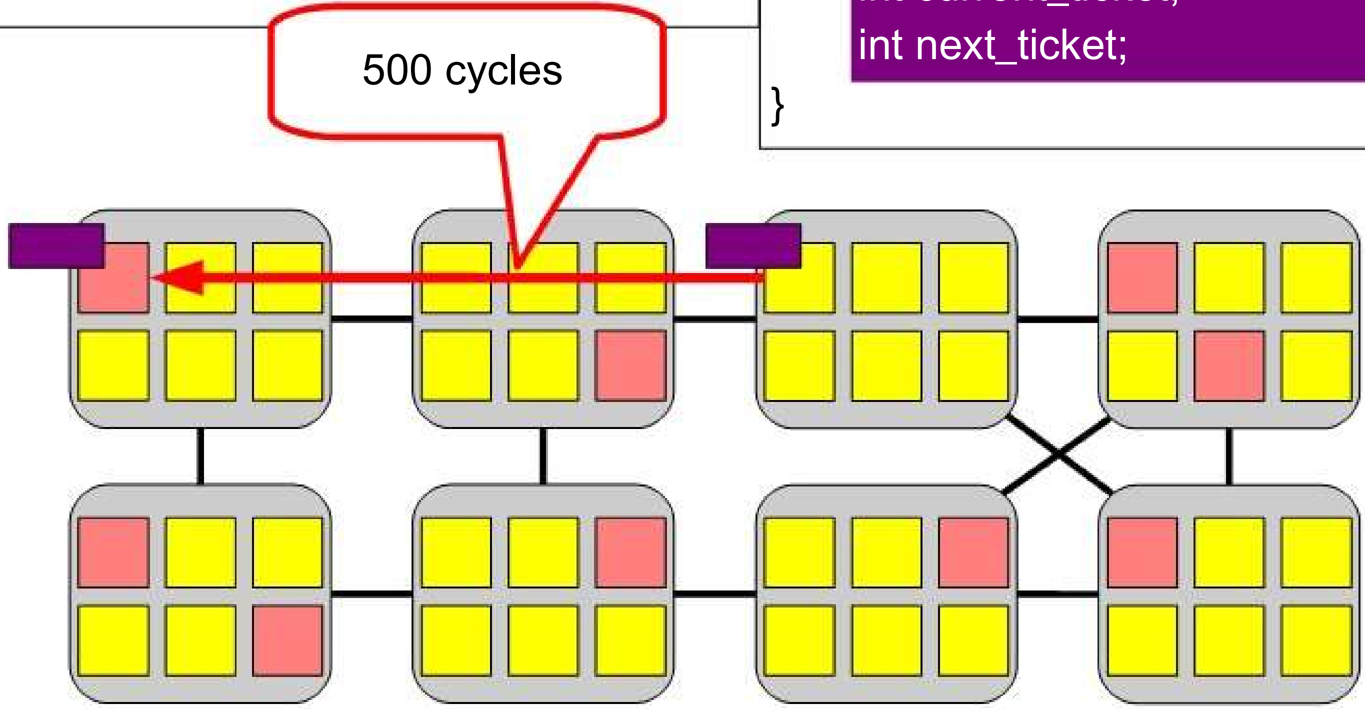

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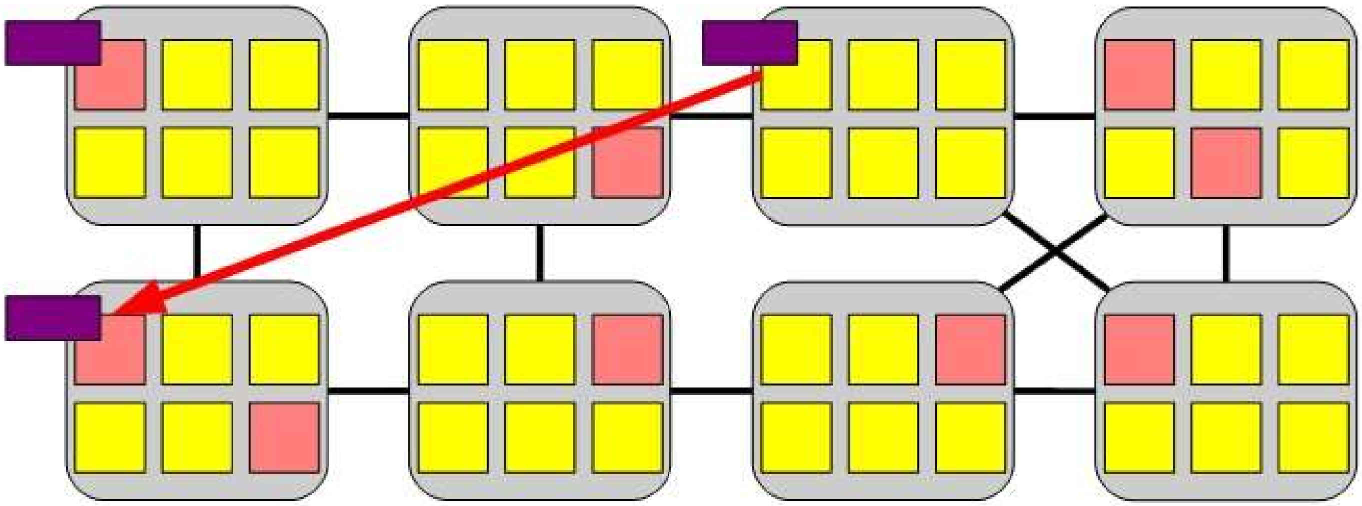

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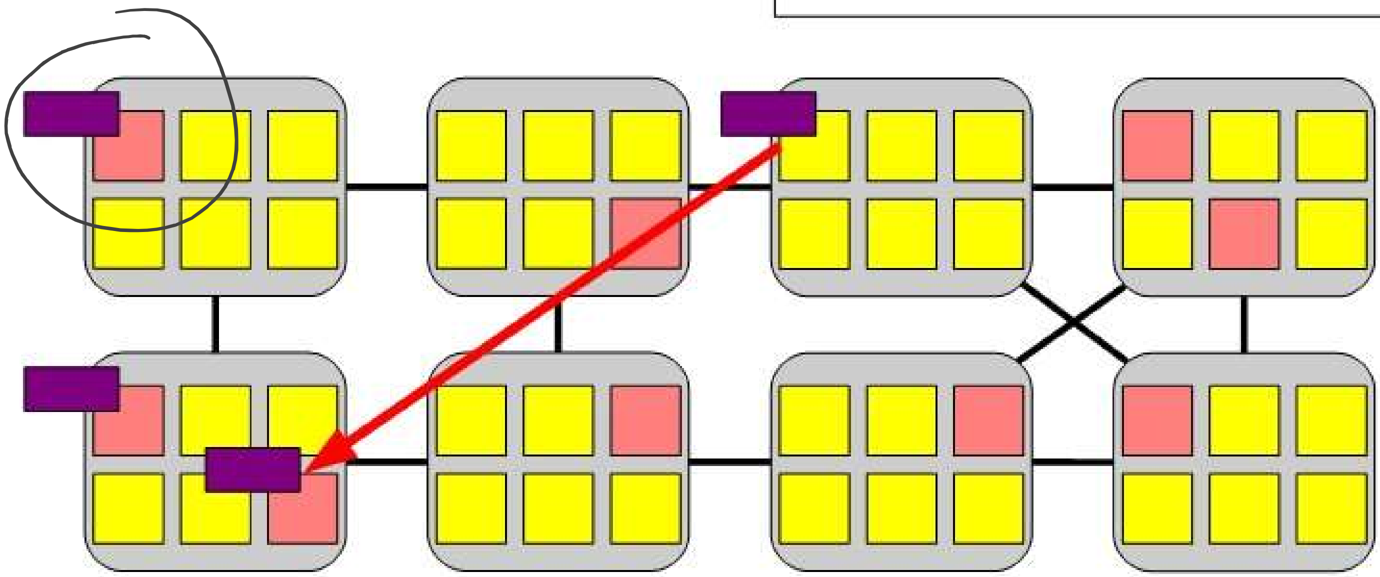

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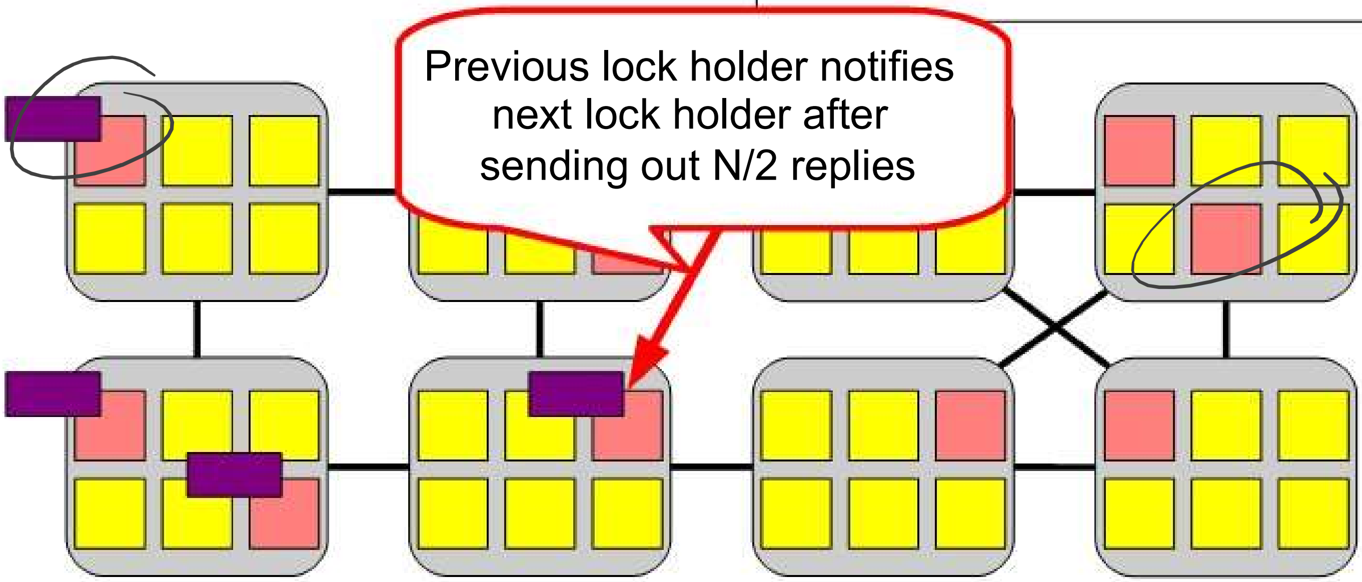
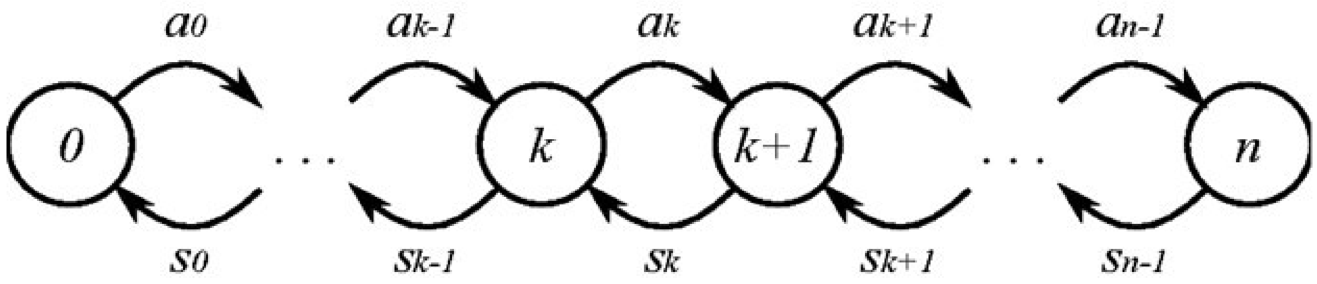
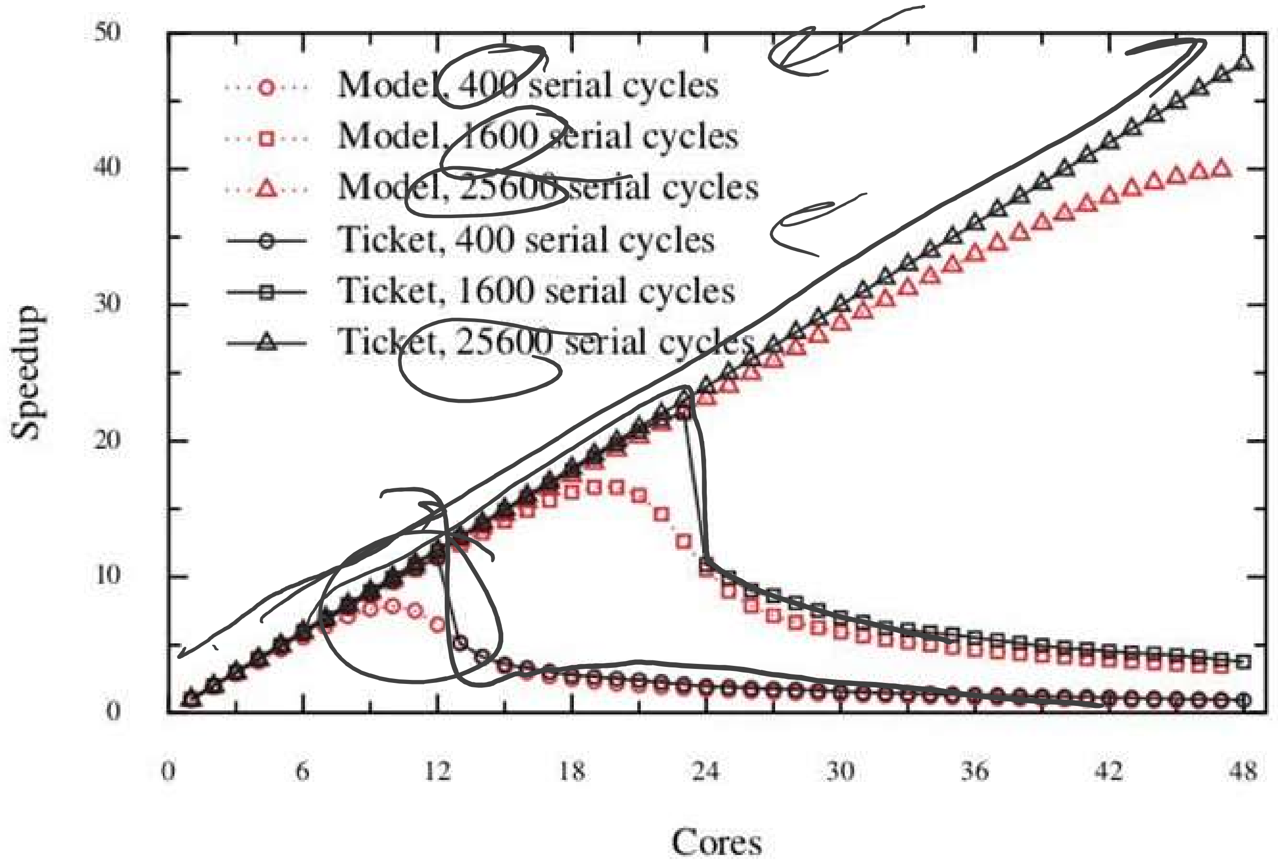


Why collapse with short sections?



- Arrival rate is proportional to # non-waiting cores
- Service time is proportional to # cores waiting (*k*)
  - As *k* increases, waiting time goes up
  - As waiting time goes up, *k* increases
- System gets stuck in states with many waiting cores

Short sections result in collapse

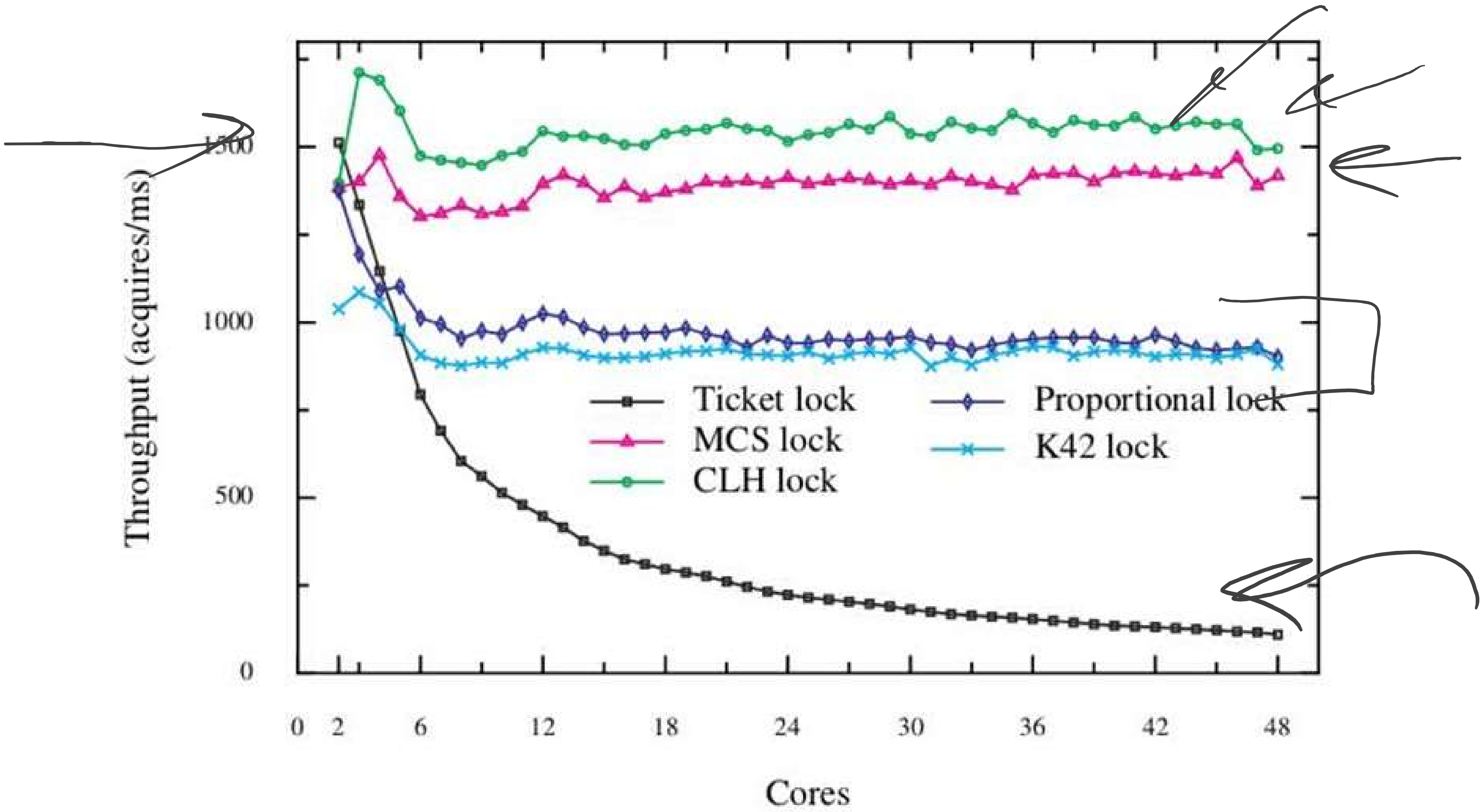


- Experiment: 2% of time spent in critical section
- Critical sections become “longer” with more cores
- Lesson: non-scalable locks fine for long sections

Avoiding lock collapse

- Unscalable locks are fine for long sections
- Unscalable locks collapse for short sections
  - Sudden sharp collapse due to “snowball” effect
- Scalable locks avoid collapse altogether
  - But requires interface change

Scalable lock scalability



- It doesn't matter much which one
- But all slower in terms of latency

Avoiding lock collapse is not enough to scale

- “Scalable” locks don't make the kernel scalable
  - Main benefit is avoiding collapse: total throughput will not be lower with more cores
  - But, usually want throughput to keep increasing with more cores