Advanced Operating Systems (CS 202)

Read Copy Update (RCU)

UNIVERSITY OF CALIFORNIA, RIVERSIDE

Linux Synch. Primitives

Technique	Description	Scope
Per-CPU variables	Duplicate a data structure among CPUs	All CPUs
Atomic operation	Atomic read-modify-write instruction	All
Memory barrier	Avoid instruction re-ordering	Local CPU
Spin lock	Lock with busy wait	All
Semaphore	Lock with blocking wait (sleep)	All
Seqlocks	Lock based on access counter	All
Local interrupt disabling	Forbid interrupt on a single CPU	Local
Local softirq disabling	Forbid deferrable function on a single CPU	Local
Read-copy-update (RCU)	Lock-free access to shared data through pointers	All

Why are we reading this paper?

- Example of a synchronization primitive that is:
  - Lock free (mostly/for reads)
  - Tuned to a common access pattern
  - Making the common case fast
- What is this common pattern?
  - A lot of reads
  - Writes are rare
  - Prioritize writes
  - Ok to read a slightly stale copy
    - But that can be fixed too

Traditional OS locking designs

- complex
- poor concurrency
- Fail to take advantage of event-driven nature of operating systems

Motivation

- Locks have acquire and release cost
  - Each uses atomic operations which are expensive
  - Can dominate cost for short critical regions
  - Locks become the bottleneck
- Readers/writers lock is also expensive – uses atomic increment/decrement for reader count

Lock free data structures

- Do not require locks
- Good if contention is rare
- But difficult to create and error prone
- RCU is a mixture
  - Concurrent changes to pointers a challenge for lock-free
  - RCU serializes writers using locks
  - Win if most of our accesses are reads

Race Between Teardown and Use of Service

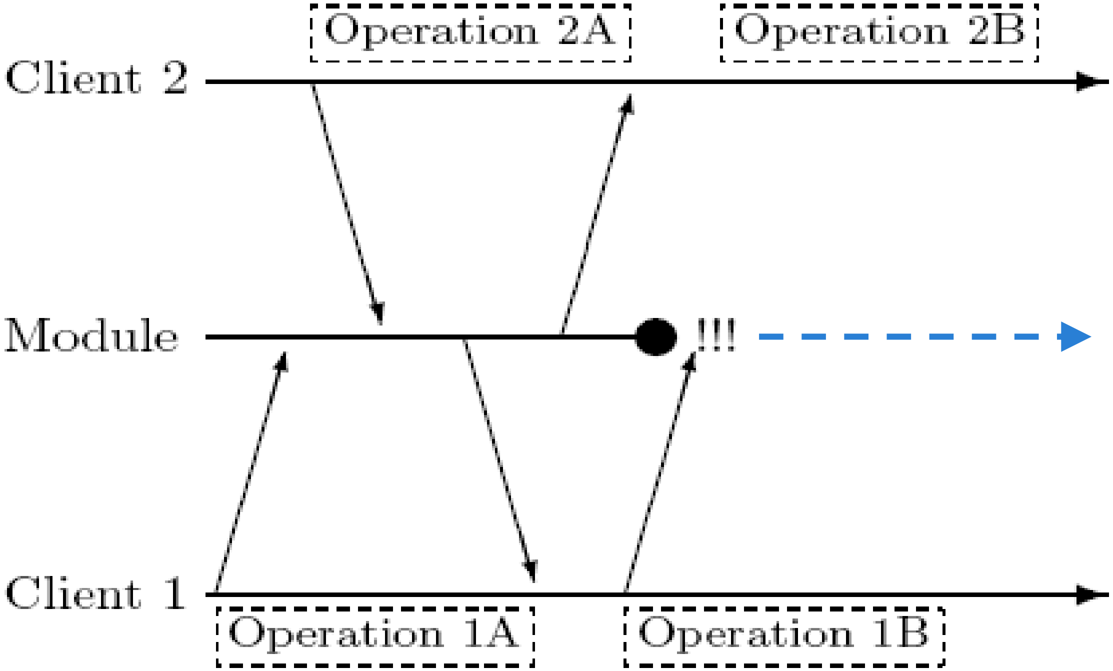


Figure 1: Race Between Teardown and Use of Service

Read-Copy Update Handling Race

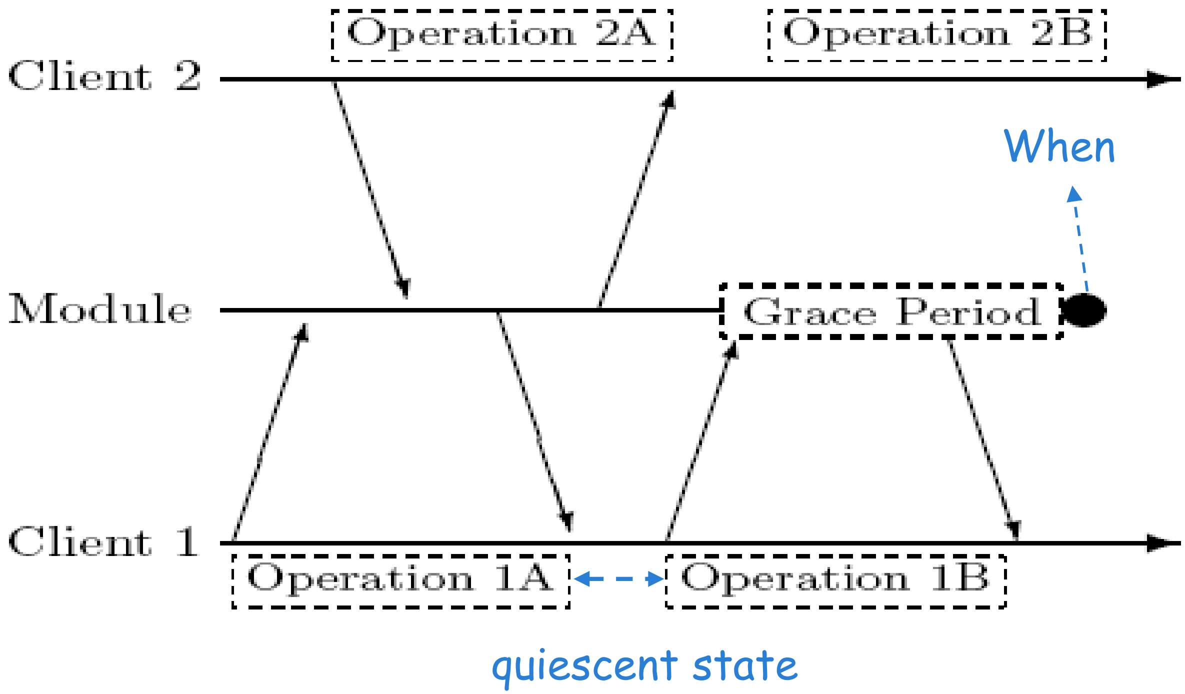


Figure 2: Read-Copy Update Handling Race

Typical RCU update sequence

- Replace pointers to a data structure with pointers to a new version
  - Is this replacement atomic?
- Wait for all previous reader to complete their RCU read-side critical sections.
- At this point, there cannot be any readers who hold reference to the data structure, so it now may safely be reclaimed.

Read-Copy Search

```
struct el search(long addr)
{
    read_lock(&list_lock);
    p = head->next;
    while (p != head) {
        if (p->address == addr) {
            atomic_inc(&p->refcnt)
            read_unlock(&list_lock);
            return (p);
        }
        p = p->next;
    }
    read_unlock(&list_lock);
    return (NULL);
}
```

Reference-Counted Search

```
struct el *search(long addr)
{
    struct el *p;
    p = head->next;
    while (p != head) {
        if (p->address == addr) {
            return (p);
        }
        p = p->next;
    }
    return (NULL);
}
```

Read-Copy Search

Read-Copy Deletion

```
struct el delete(struct el *p)
{
    write_lock(&list_lock);
    p->next->prev = p->prev;
    p->prev->next = p->next;
    release(p);
    write_unlock(&list_lock);
}
```

Reference-counted Deletion

```
void delete(struct el *p)
{
    spin_lock(&list_lock);
    p->next->prev = p->prev;
    p->prev->next = p->next;
    spin_unlock(&list_lock);
    kfree_rcu(p, NULL);
}
```

Read-Copy Deletion

Read-Copy Deletion (delete B)

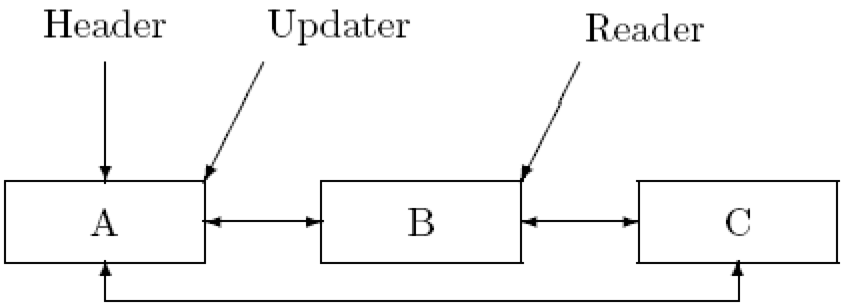


Figure 11: List Initial State

the first phase of the update

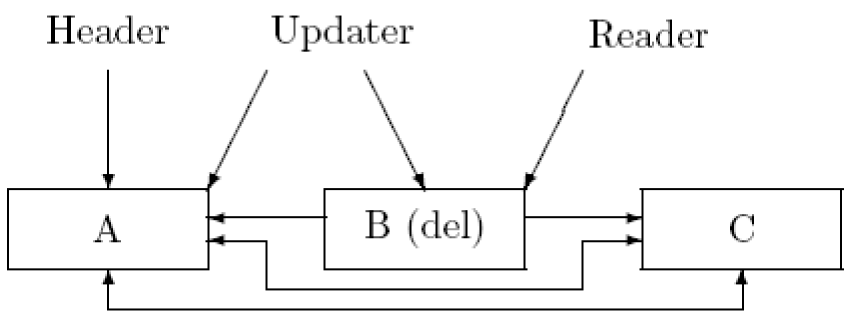


Figure 12: Element B Unlinked From List

Read-Copy Deletion

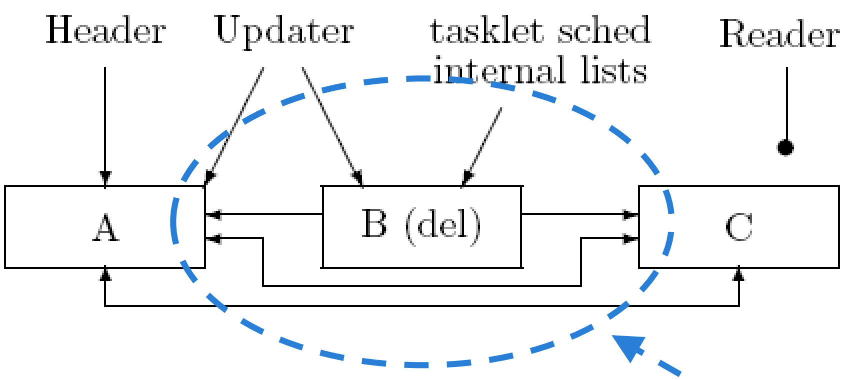


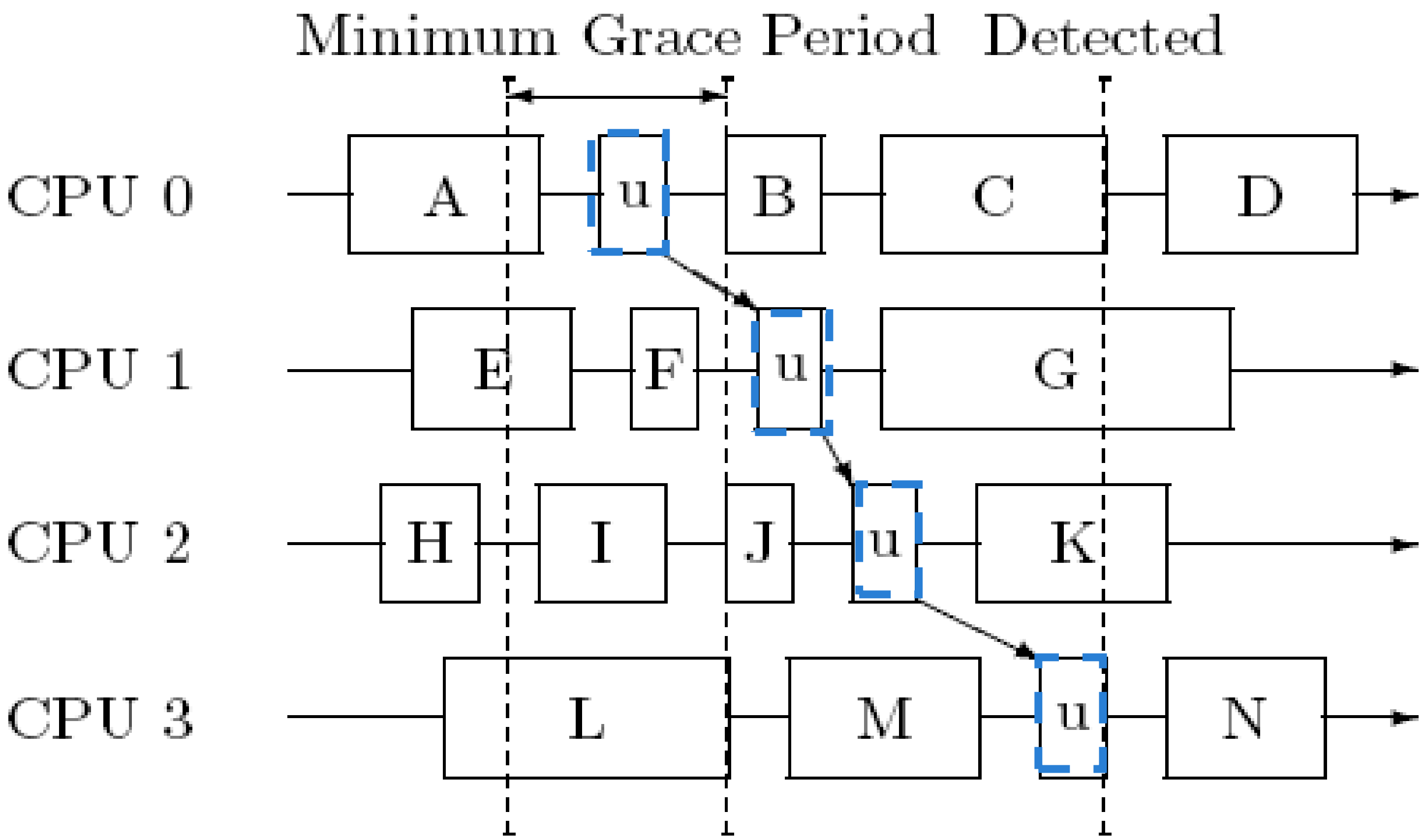
Figure 13: List After Grace Period

When

Read-Copy Deletion

Figure 14: List After Element B Returned to Freelist

Simple Grace-Period Detection



wait_for_rcu() I

```
void wait_for_rcu(void)
{
    unsigned long cpus_allowed;
    unsigned long policy;
    unsigned long rt_priority;
    /* Save current state */
    cpus_allowed = current->cpus_allowed;
    policy = current->policy;
    rt_priority = current->rt_priority;
    /* Create an unreal time task. */
    current->policy = SCHED_FIFO;
    current->rt_priority = 1001 +
    sys_sched_get_priority_max(SCHED_FIFO);
    /* Make us schedulable on all CPUs. */
    current->cpus_allowed =
                (1UL<<smp_num_cpus)-1;

```

wait_for_rcu() II

```
    /* Eliminate current cpu, reschedule */
    while ((current->cpus_allowed &= ~(1 <<
                cpu_number_map(
                 smp_processor_id()))) != 0)
        schedule();
    /* Back to normal. */
    current->cpus_allowed = cpus_allowed;
    current->policy = policy;
    current->rt_priority = rt_priority;
}
```

Implementations of Quiescent State

1. simply execute onto each CPU in turn.

2. use context switch, execution in the idle loop, execution in user mode, system call entry, trap from user mode as the quiescent states.

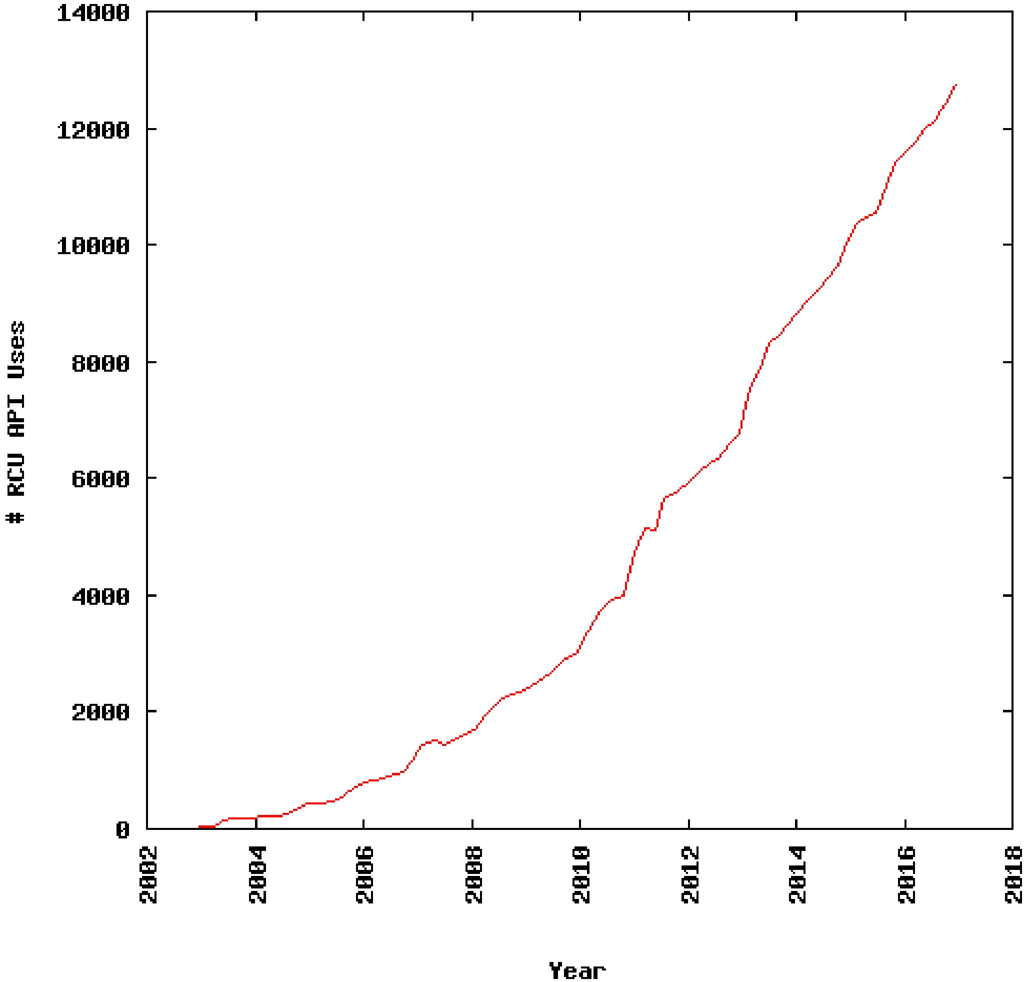
3. voluntary context switch as the sole quiescent state

4. tracks beginnings and ends of operations

Implementation (option 4)

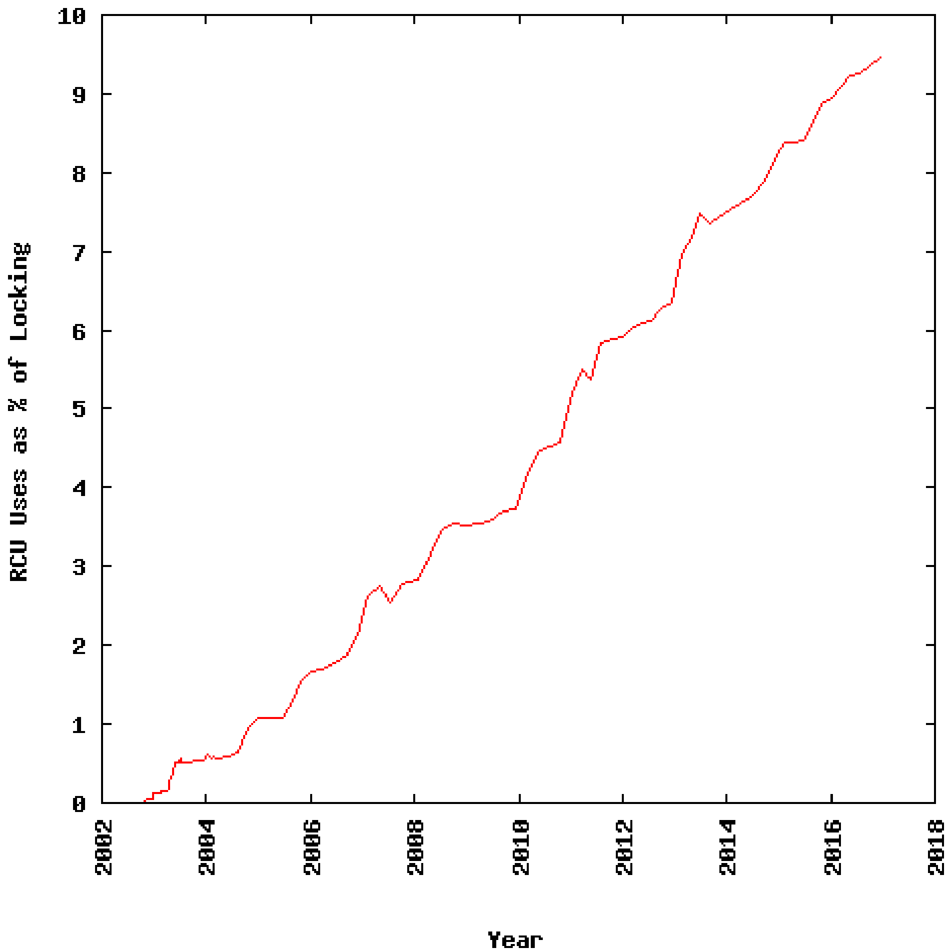
- Generation counter for each RCU region
- Generation updated on write
- Every read increments generation counter going in
  - And decrements it going out
- Quiescence = counter is zero

RCU usage in Linux



Source: http://www.rdrop.com/users/paulmc/RCU/linuxusage.html

RCU as percentage of all locking in linux



Source: http://www.rdrop.com/users/paulmc/RCU/linuxusage.html

SeqLock

- Another special synchronization primitive
- Goal is to avoid writer starvation in reader writer locks
- Has a lock and a sequence number
  - Lock for writers only
  - Writer increments sequence number after acquiring lock and before releasing lock
- Readers do not block
  - But can check sequence number