

Read-Copy Update (RCU)

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CSE 506

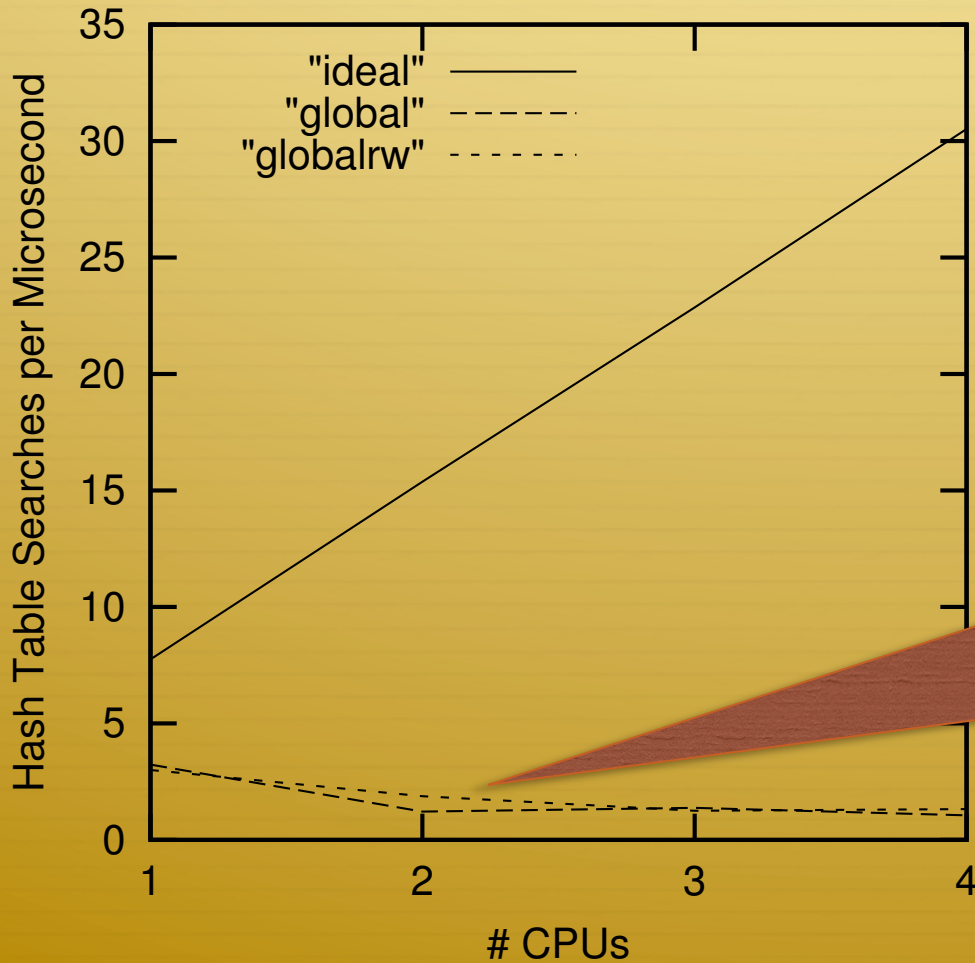
RCU in a nutshell



- ✦ Think about data structures that are mostly read, occasionally written
 - ✦ Like the Linux dcache
- ✦ RW locks allow concurrent reads
 - ✦ Still require an atomic decrement of a lock counter
 - ✦ Atomic ops are expensive
- ✦ Idea: Only require locks for writers; carefully update data structure so readers see consistent views of data

Motivation

(from Paul McKenney's Thesis)



Performance of RW lock only marginally better than mutex lock

Principle (1/2)



- ✦ Locks have an acquire and release cost
 - ✦ Substantial, since atomic ops are expensive
- ✦ For short critical regions, this cost dominates performance

Principle (2/2)



- ✦ Reader/writer locks may allow critical regions to execute in parallel
- ✦ But they still serialize the increment and decrement of the read count with atomic instructions
 - ✦ Atomic instructions performance decreases as more CPUs try to do them at the same time
- ✦ **The read lock itself becomes a scalability bottleneck, even if the data it protects is read 99% of the time**

Lock-free data structures



- ✦ Some concurrent data structures have been proposed that don't require locks
- ✦ They are difficult to create if one doesn't already suit your needs; highly error prone
- ✦ Can eliminate these problems

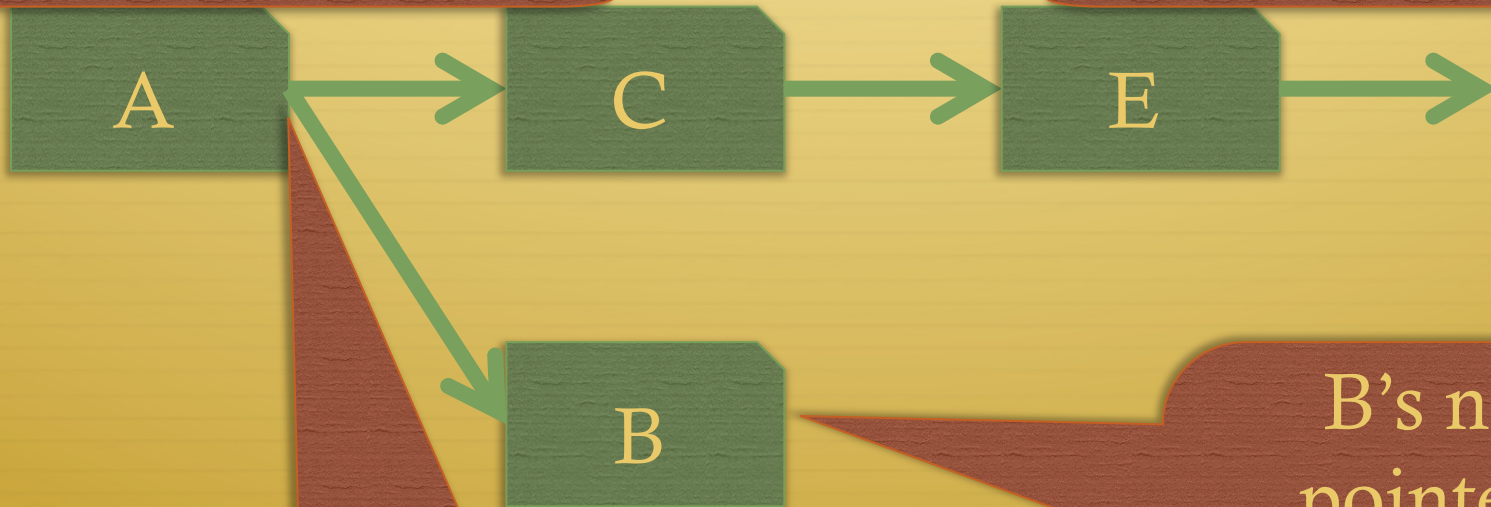
RCU: Split the difference



- ✦ One of the hardest parts of lock-free algorithms is concurrent changes to pointers
 - ✦ So just use locks and make writers go one-at-a-time
- ✦ But, make writers be a bit careful so readers see a consistent view of the data structures
- ✦ If 99% of accesses are readers, avoid performance-killing read lock in the common case

Example: Linked lists

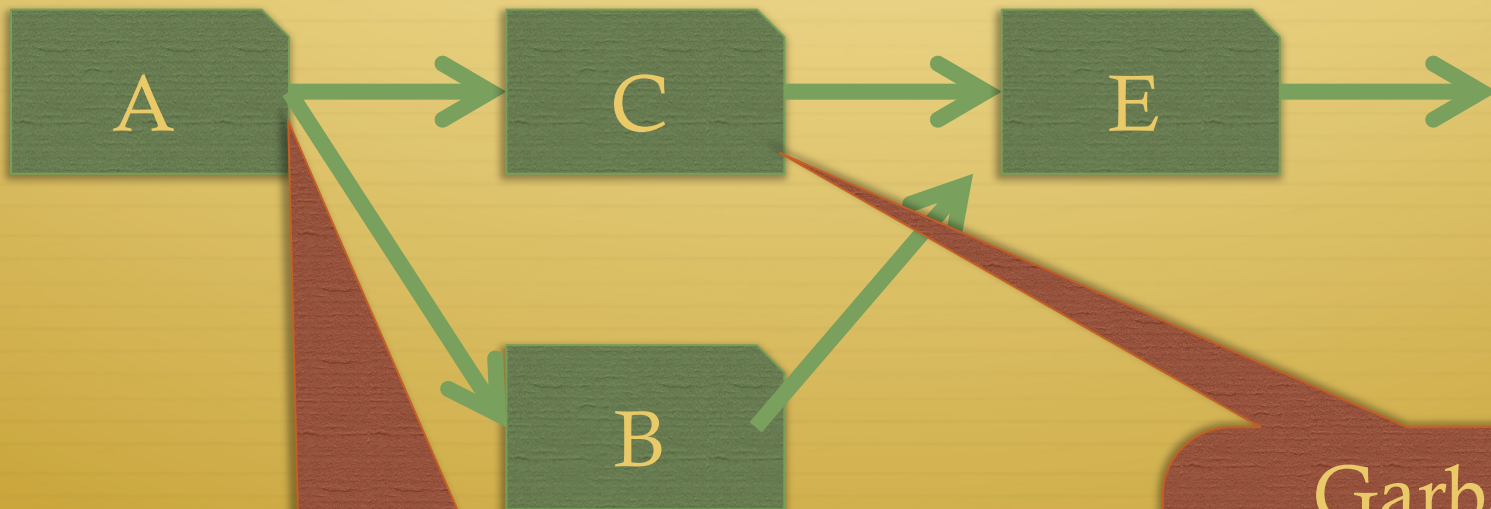
This implementation
needs a lock



Reader goes to B

B's next
pointer is
uninitialized;
Reader gets a
page fault

Example: Linked lists



Reader goes to C or B---either is ok

Garbage collect C after all readers finished

Example recap



- ✦ Notice that we first created node B, and set up all outgoing pointers
- ✦ Then we overwrite the pointer from A
 - ✦ No atomic instruction needed
 - ✦ Either traversal is safe
 - ✦ In some cases, we may need a memory barrier
- ✦ Key idea: Carefully update the data structure so that a reader can never follow a bad pointer

Garbage collection



- ✦ Part of what makes this safe is that we don't immediately free node C
 - ✦ A reader could be looking at this node
 - ✦ If we free/overwrite the node, the reader tries to follow the 'next' pointer
 - ✦ Uh-oh
- ✦ How do we know when all readers are finished using it?
 - ✦ Hint: No new readers can access this node: it is now unreachable

Quiescence



- ✦ Trick: Linux doesn't allow a process to sleep while traversing an RCU-protected data structure
 - ✦ Includes kernel preemption, I/O waiting, etc.
- ✦ Idea: If every CPU has called `schedule()` (quiesced), then it is safe to free the node
 - ✦ Each CPU counts the number of times it has called `schedule()`
 - ✦ Put a to-be-freed item on a list of pending frees
 - ✦ Record timestamp on each CPU
 - ✦ Once each CPU has called `schedule`, do the free

Quiescence, cont



- ✦ There are some optimizations that keep the per-CPU counter to just a bit
 - ✦ Intuition: All you really need to know is if each CPU has called `schedule()` once since this list became non-empty
 - ✦ Details left to the reader

Limitations



- ✦ No doubly-linked lists
- ✦ Can't immediately reuse embedded list nodes
 - ✦ Must wait for quiescence first
 - ✦ So only useful for lists where an item's position doesn't change frequently
- ✦ Only a few RCU data structures in existence

Nonetheless



- ✦ Linked lists are the workhorse of the Linux kernel
- ✦ RCU lists are increasingly used where appropriate
- ✦ Improved performance!

API



- ✦ Drop in replacement for `read_lock`:
 - ✦ `rcu_read_lock()`
- ✦ Wrappers such as `rcu_assign_pointer()` and `rcu_dereference_pointer()` include memory barriers
- ✦ Rather than immediately free an object, use `call_rcu(object, delete_fn)` to do a deferred deletion

From McKenney and Walpole, Introducing Technology into the Linux Kernel: A Case Study

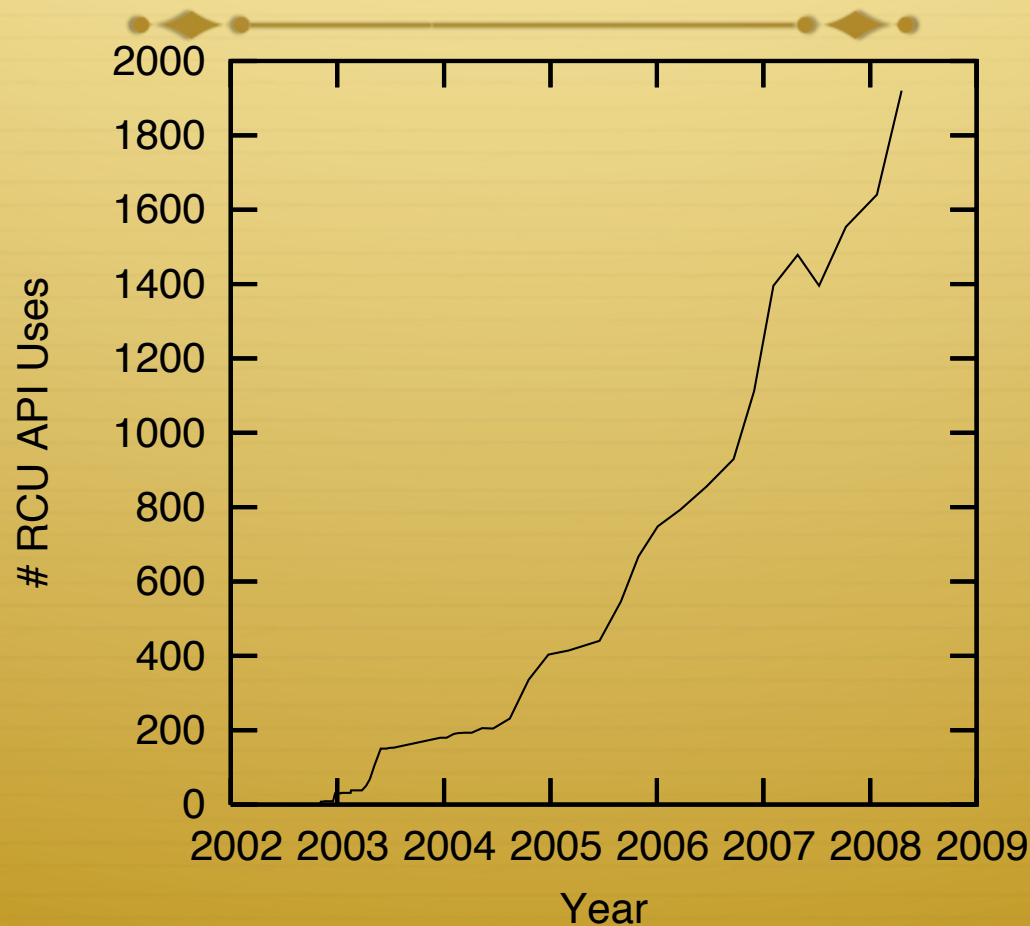


Figure 2: RCU API Usage in the Linux Kernel

Summary



- ✦ Understand intuition of RCU
- ✦ Understand how to add/delete a list node in RCU
- ✦ Pros/cons of RCU