# Read-Copy Update in a Garbage Collected Environment

By Harshal Sheth, Aashish Welling, and Nihar Sheth

# Overview

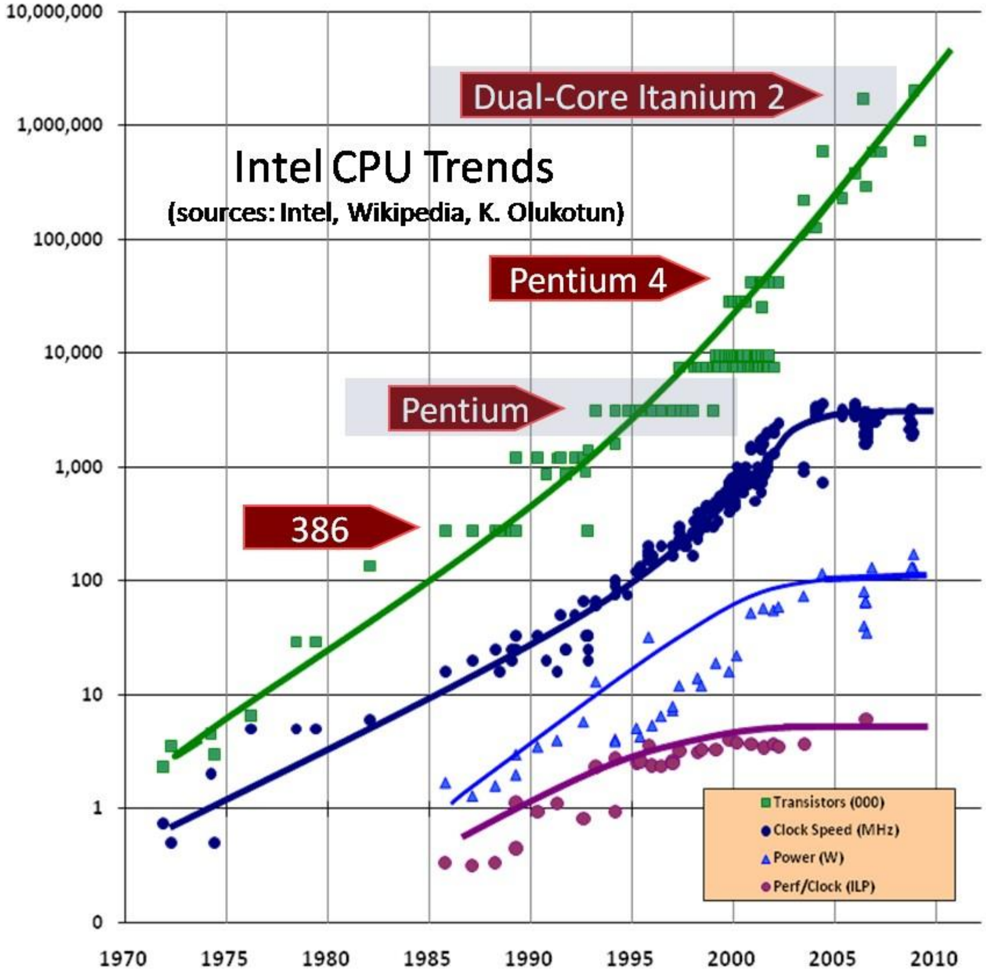
- Read-copy update (RCU)
  - Synchronization mechanism used in the Linux kernel
  - Mainly used in lower level languages such as C or C++
- Explored the viability of RCU in a garbage collected language: Go
- Go RCU provides similar performance to C++ RCU
- Code simpler and less error-prone in Go RCU

# Outline

- Problem
- RCU Background
- Experiment Design
- Results
- Conclusions
- Future Work
- Acknowledgements

# Introduction

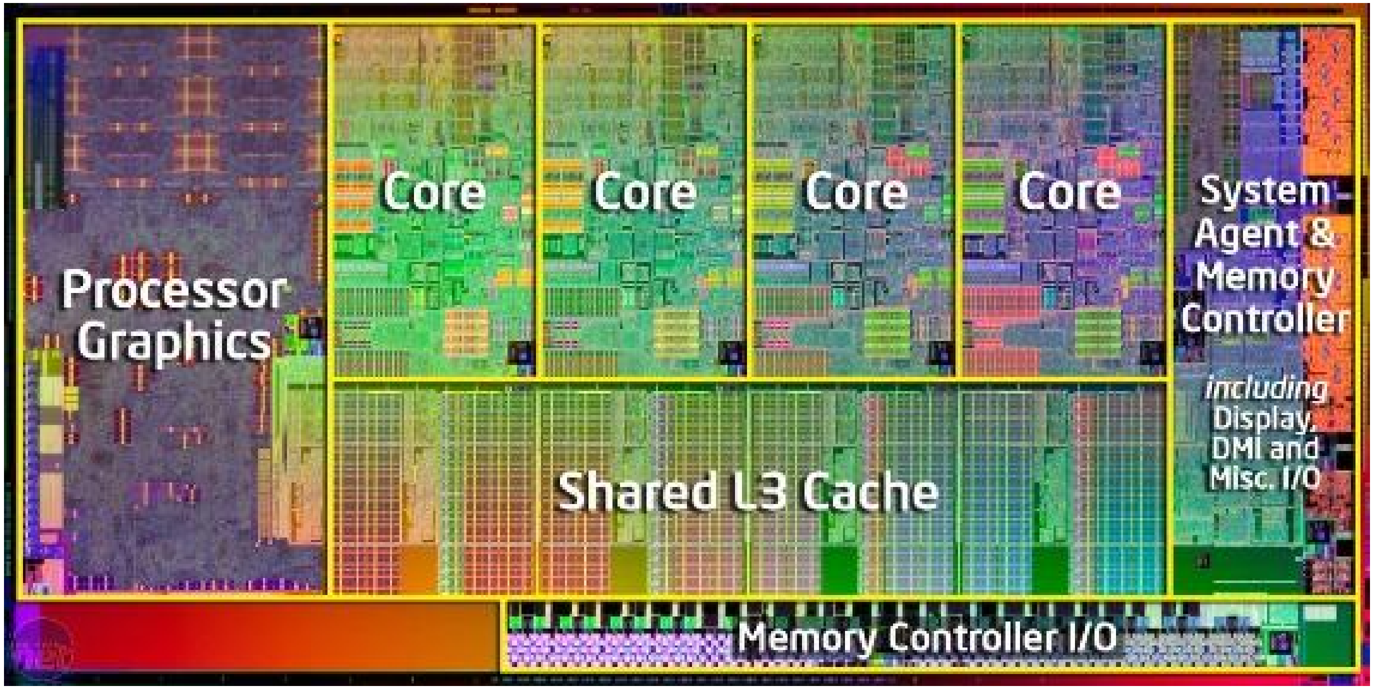
- Clock speeds are no longer increasing exponentially




http://www.extremetech.com/wp-content/uploads/2012/02/CPU-Scaling.jpg

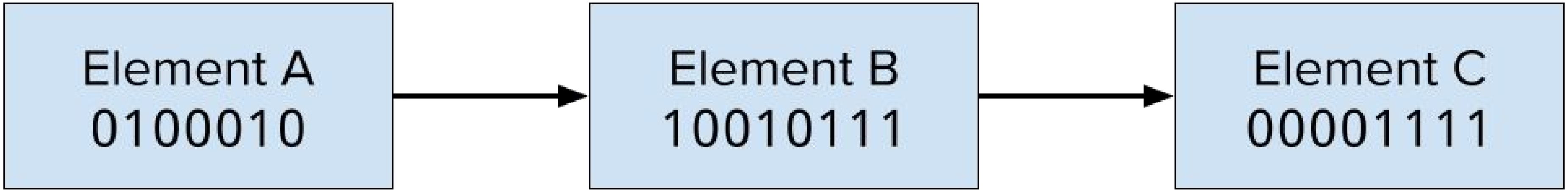
# Introduction

- Clock speeds are no longer increasing exponentially
- Computers have more cores
- Parallelization is becoming increasingly important

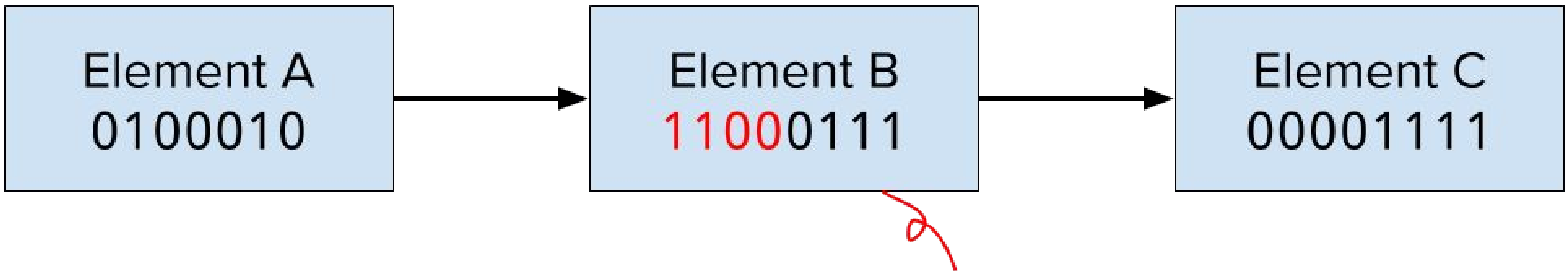



https://cnet3.cbsistatic.com/hub/i/2011/09/13/97506276-fdb9-11e2-8c7c-d4ae52e62bcc/21196cc0e9bf31954c21004a3c1ee115/inside_intel_sandy_bridge_quad_core_processor.jpg

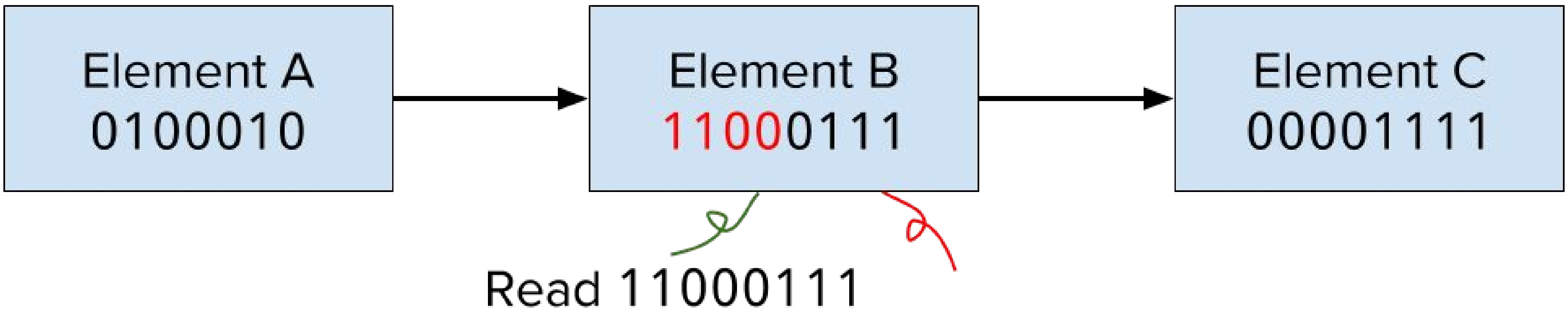
# Unprotected Data Access: Initial List



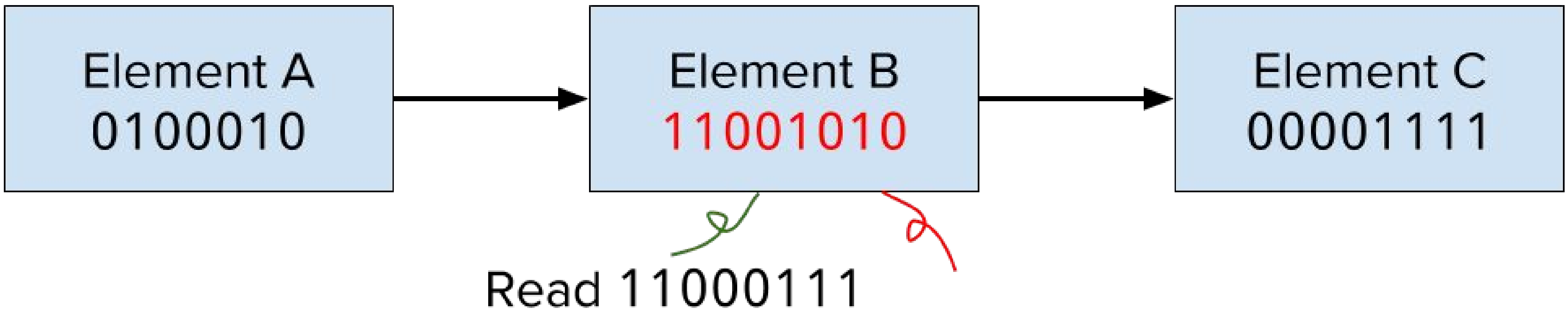
# Unprotected Data Access: Write Starts



# Unprotected Data Access: Read Occurs



# Unprotected Data Access: Write Finishes




- The reader has read a corrupted value from the list
- This could the program to crash

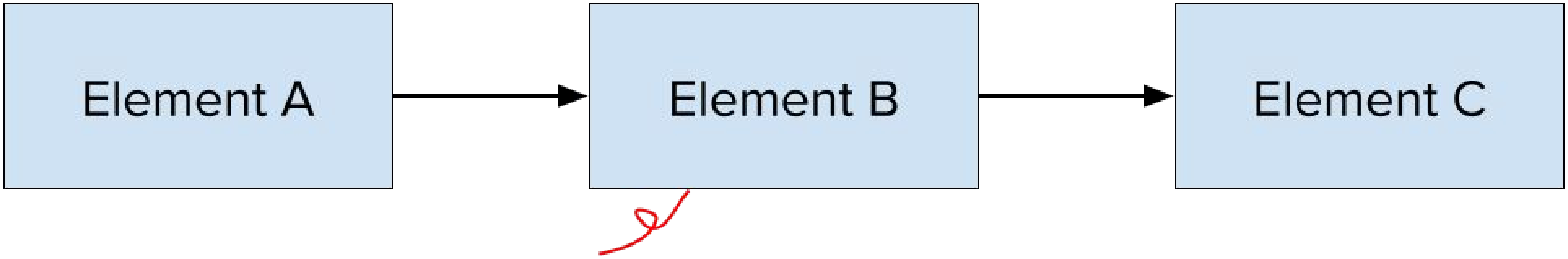
# Synchronizing Parallel Processes

- Multithreaded programs require synchronization
- Many different mechanisms to achieve such synchronization

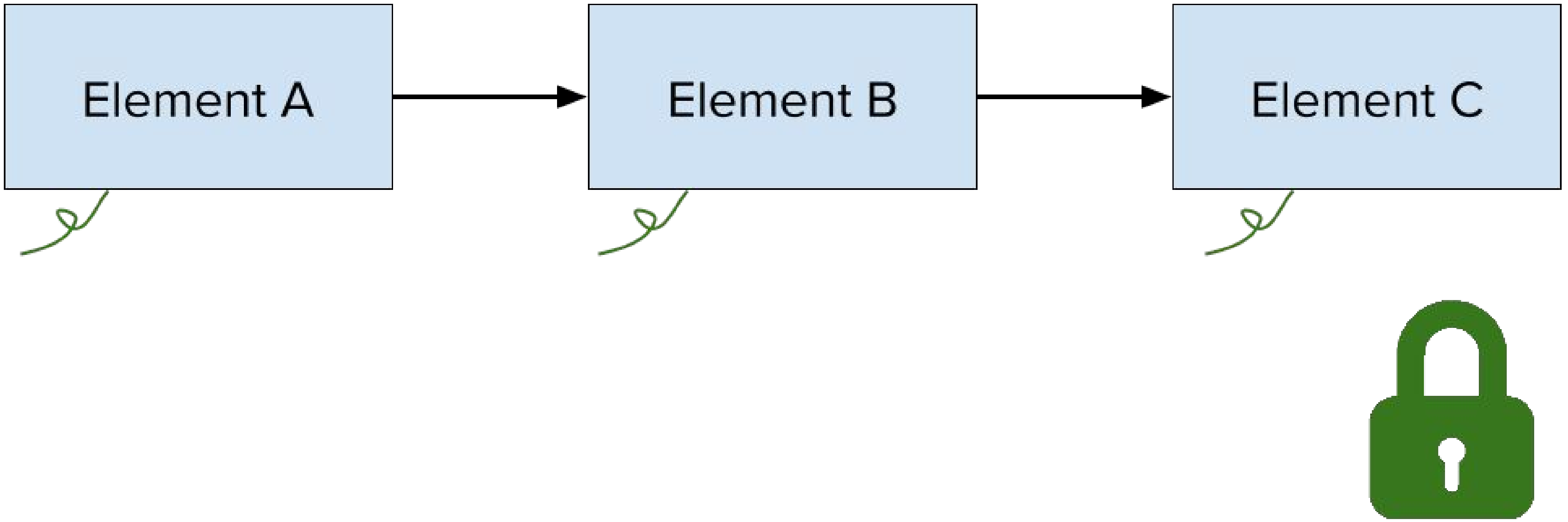
# Read-Write Mutexes

- Mutexes are the conventional method of synchronization
- “Locks” to prevent unsafe concurrent access to memory
- Writing and reading threads cannot operate concurrently

# Write Lock

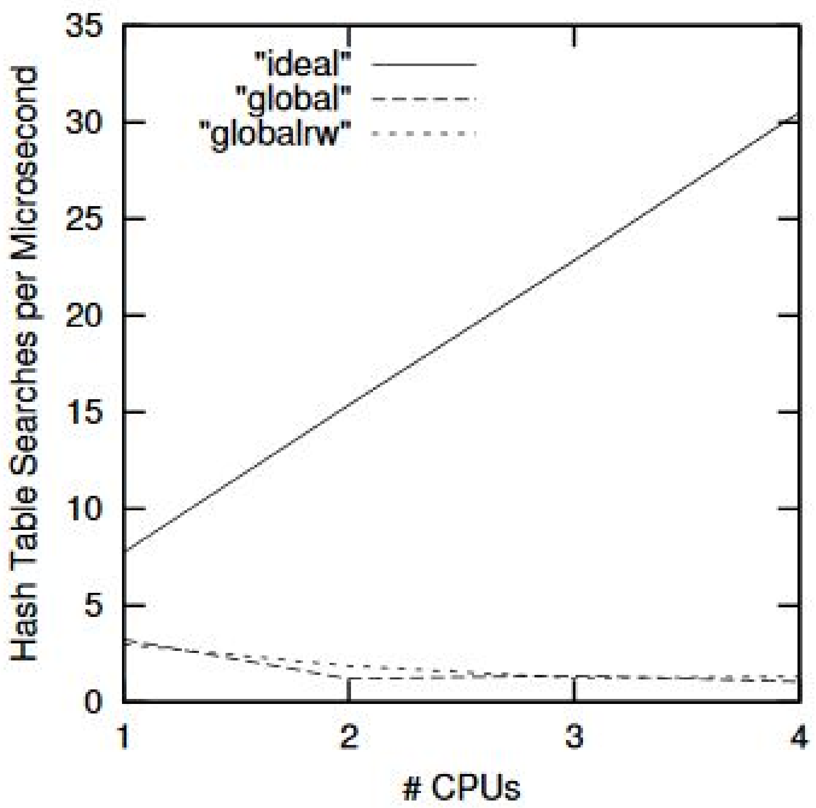



# Read Lock



# Problem: Locks Limit Scalability

- Ideally, performance should increase linearly with the number of cores
- If there is high contention, threads are essentially serialized




From Paul McKenney's dissertation

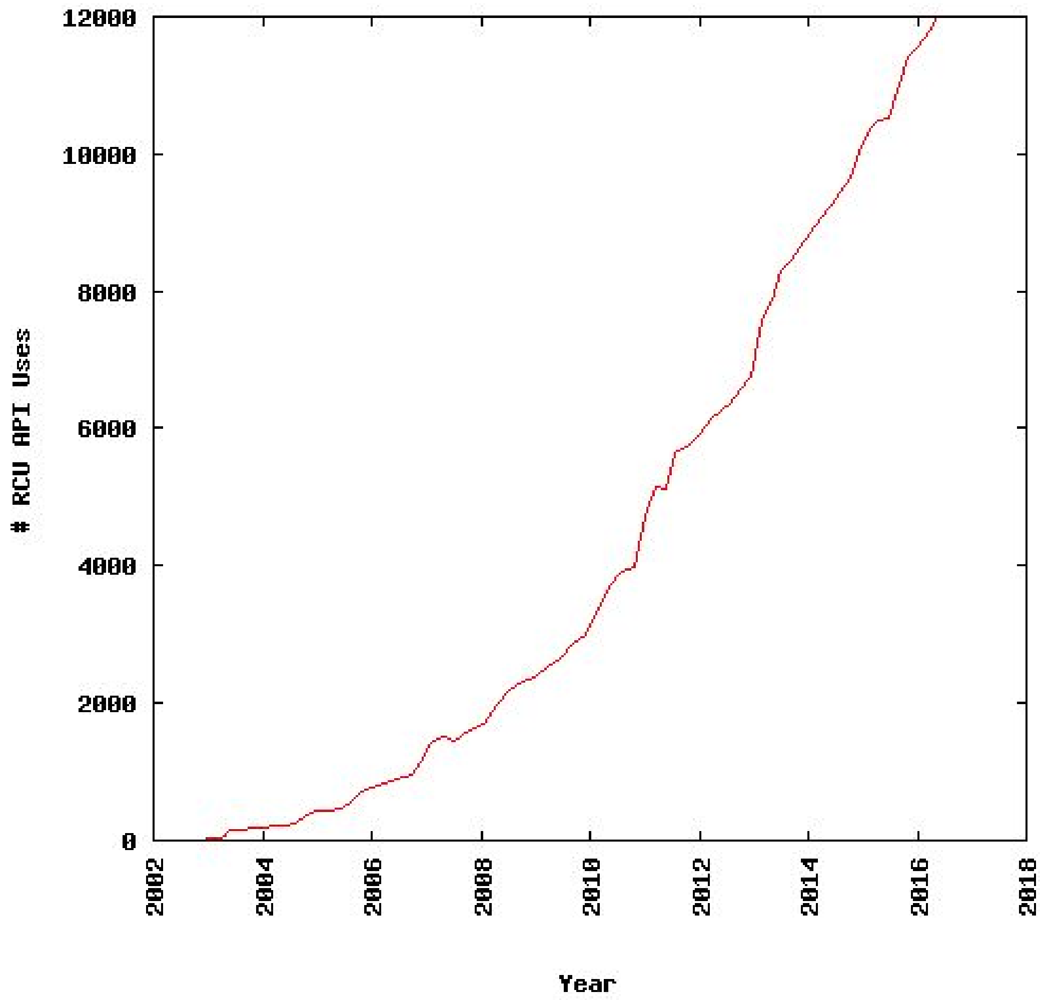
# Read-Copy Update

# Basic RCU Properties

- Prevents data corruption
- Never blocks readers
- Writers are still serialized and have higher overhead
- Good for high reading thread to writing thread ratios
    - This happens a lot in the Linux kernel

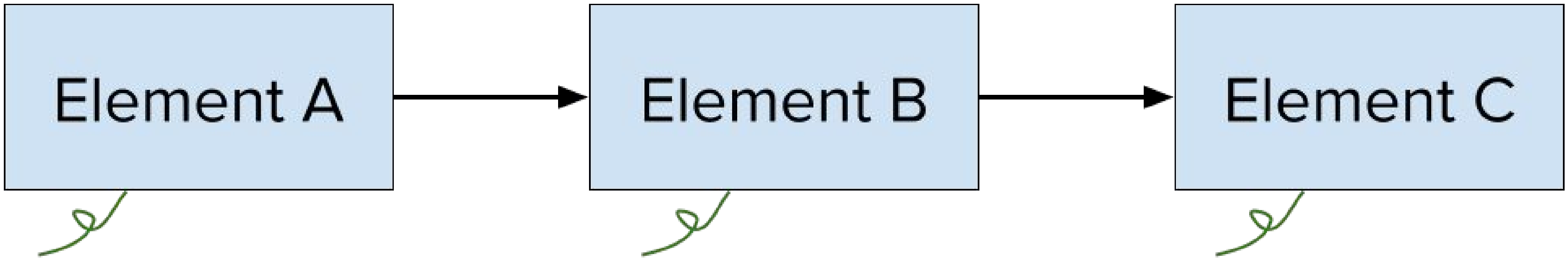
# RCU Use in Linux Kernel

- Used commonly in Linux kernel and normally implemented in C
- Linux is used everywhere
  - Android
  - Servers
  - etc.

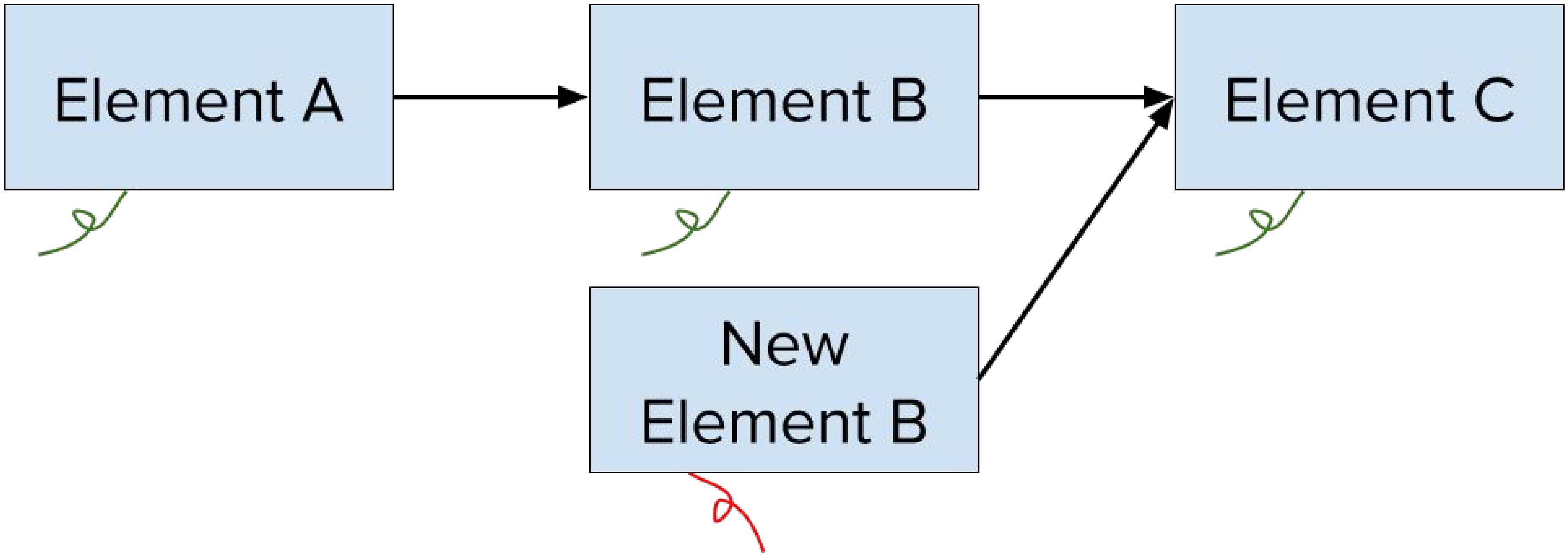



From http://www.rdrop.com/~paulmck/RCU/linuxusage/linux-RCU.png

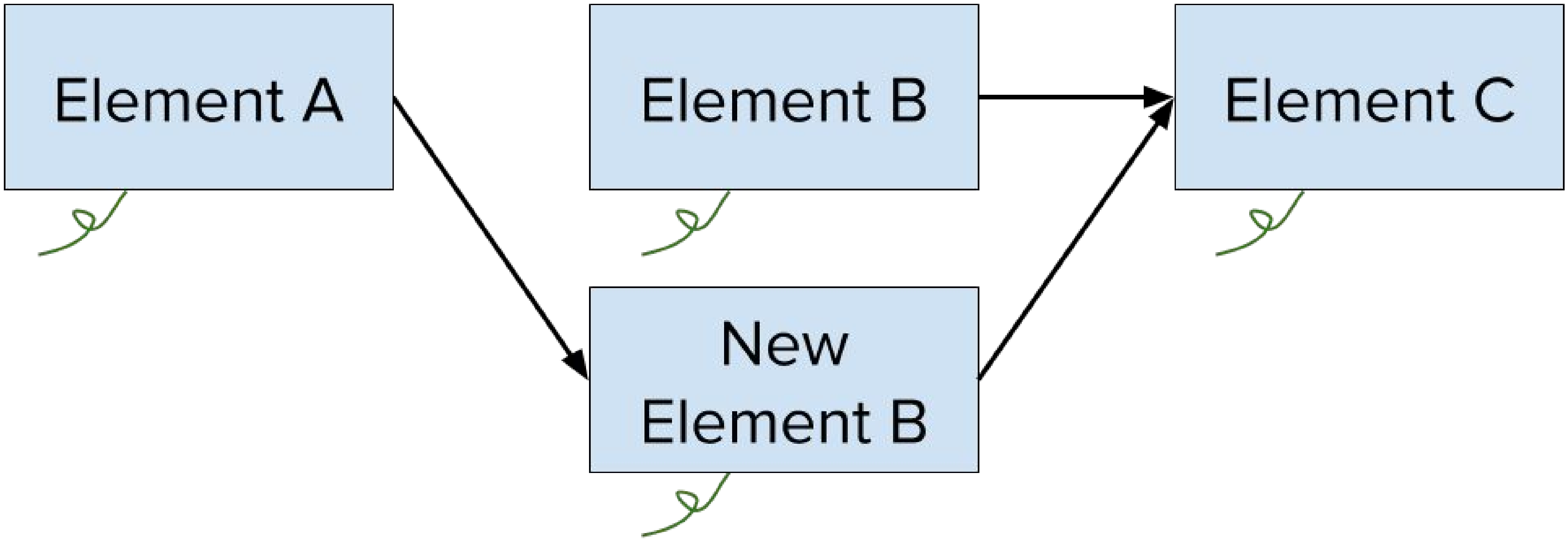
# Example: Initial Linked List



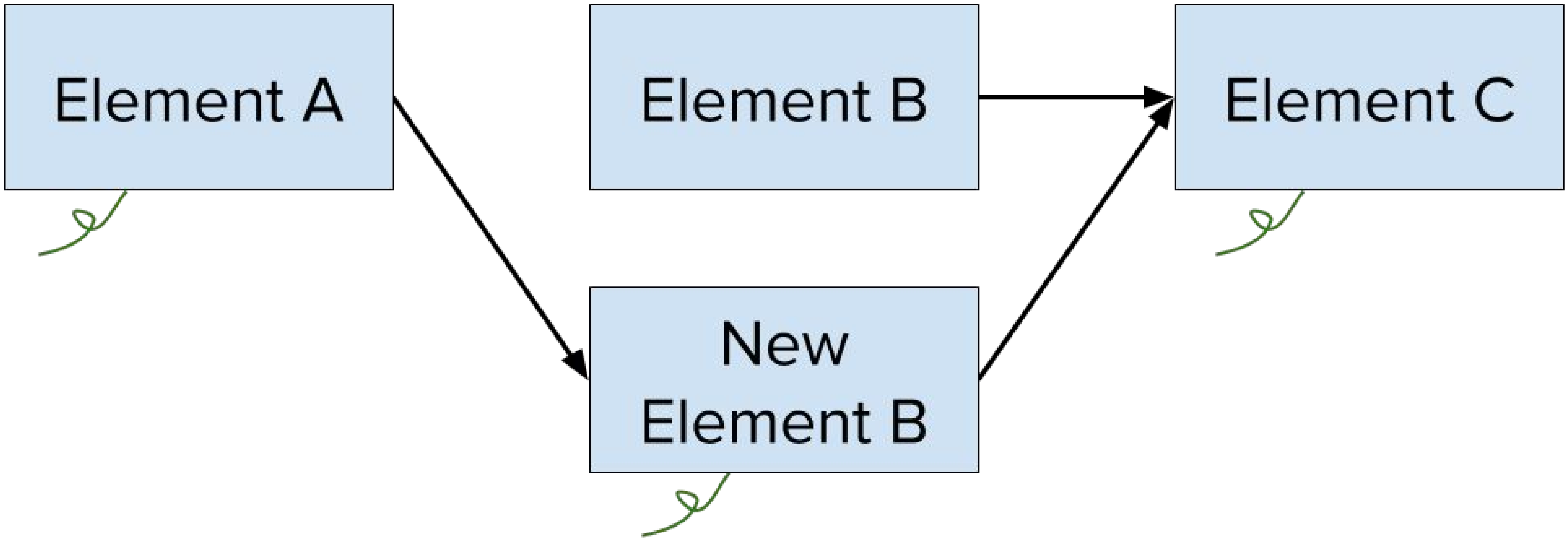
# Example: Copy Element



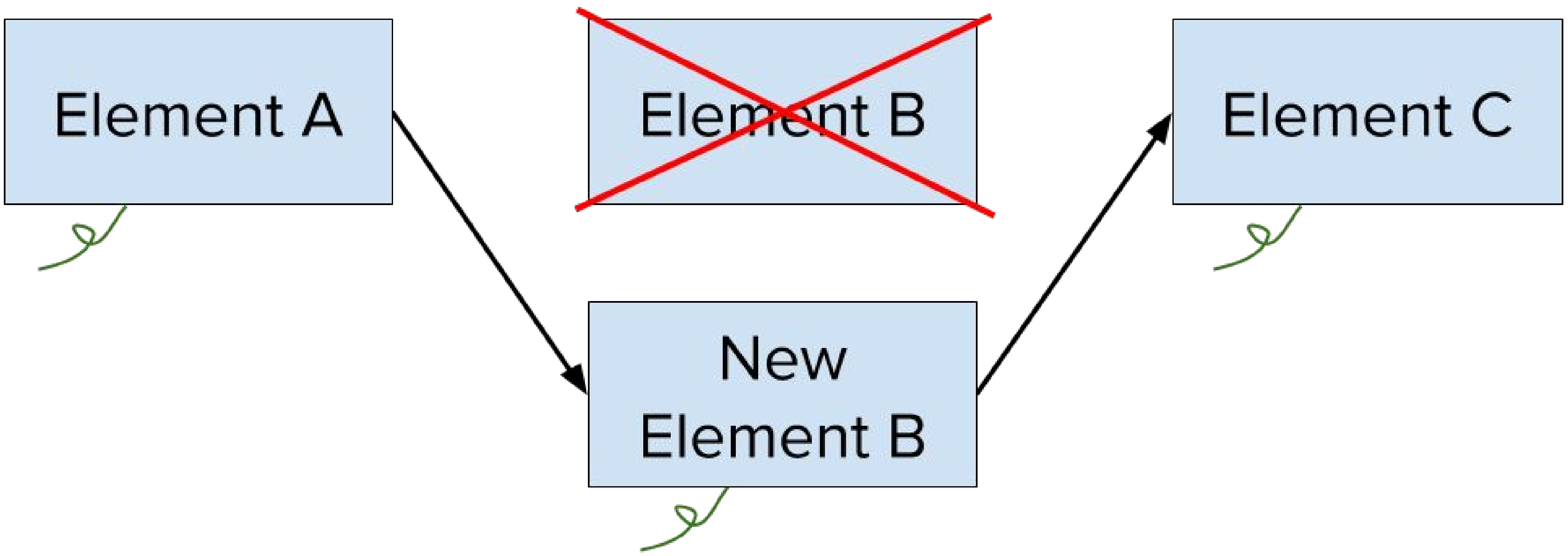
# Example: Update List Atomically



# Example: All Previous Readers Finish

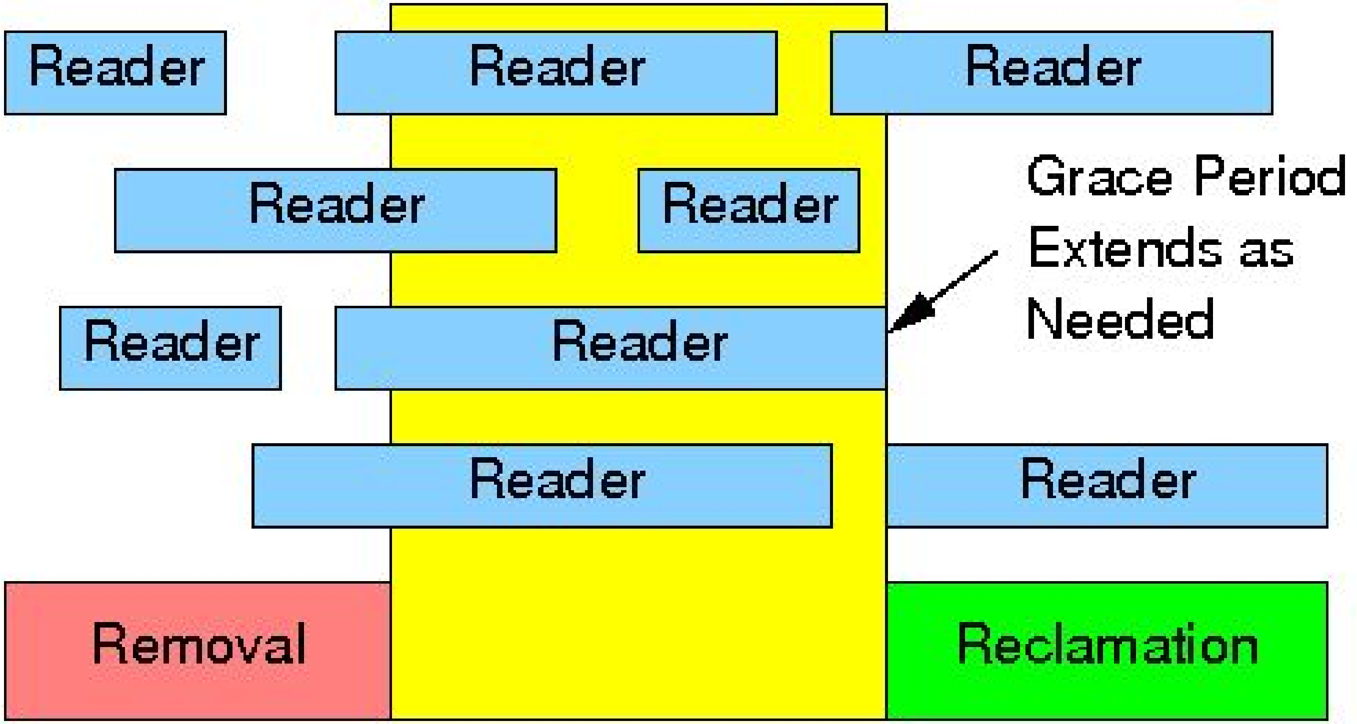


# Example: Free Old Element



# When Can We Free Memory?

- Quiescent state: any time period during which a thread is not reading
- Grace period: time it takes for all threads to go through at least one quiescent state




http://lwn.net/Articles/323929/

# RCU in the Linux Kernel

- Linux kernel written in C
- No garbage collector in C
  - Old copies need to be manually freed
  - Need to wait until a grace period has passed until freeing
  - Difficulty of implementation leads to bugs
  - For example, a recent Linux kernel bug (#102291) dealt with RCU accidentally taking a write lock during a read-side critical section
    - Avoiding bugs is very important in widely used systems
- "RCU is a poor man's garbage collector"

  \- Paul E. McKenney, Inventor of RCU

# Our Idea: RCU in a Garbage Collected Language

- Why make a “poor man’s garbage collector” when a full garbage collector is available?
- Garbage collection makes usage significantly easier
  - Garbage collector automatically decides when to free memory - no need to keep track of grace periods manually!
  - Bug 102291 would be avoided in GC environment
- Decided to use Go
  - Designed by Google

# Why Go?

- For system-level programming
  - Could be used to write a kernel
- Good garbage collector
  - Is it good enough?

# Experiment Design

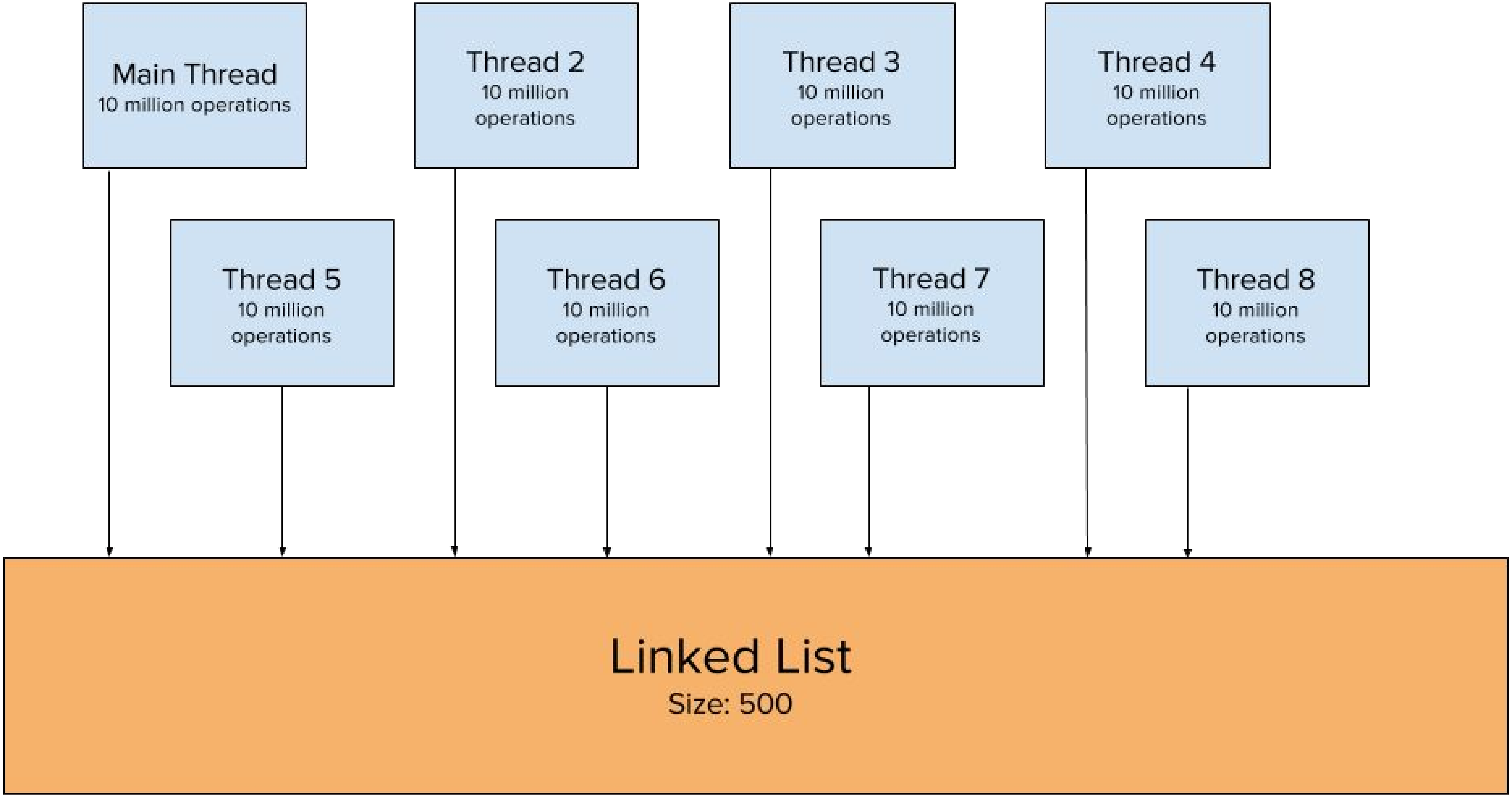
# Goals

- Is RCU in a garbage collected language a viable option?
    a. Is it easier to implement and/or use?
    b. Does it provide performance benefits similar to RCU in manual memory management languages?

# Our Approach

- Implemented RCU in Go
- Compared amount of code that had to be written
- Compared RCU performance in Go to performance in C++

# Benchmark Setup




We vary the number of operations that are writes. The % writes is the mix. We used mixes up to 30%.

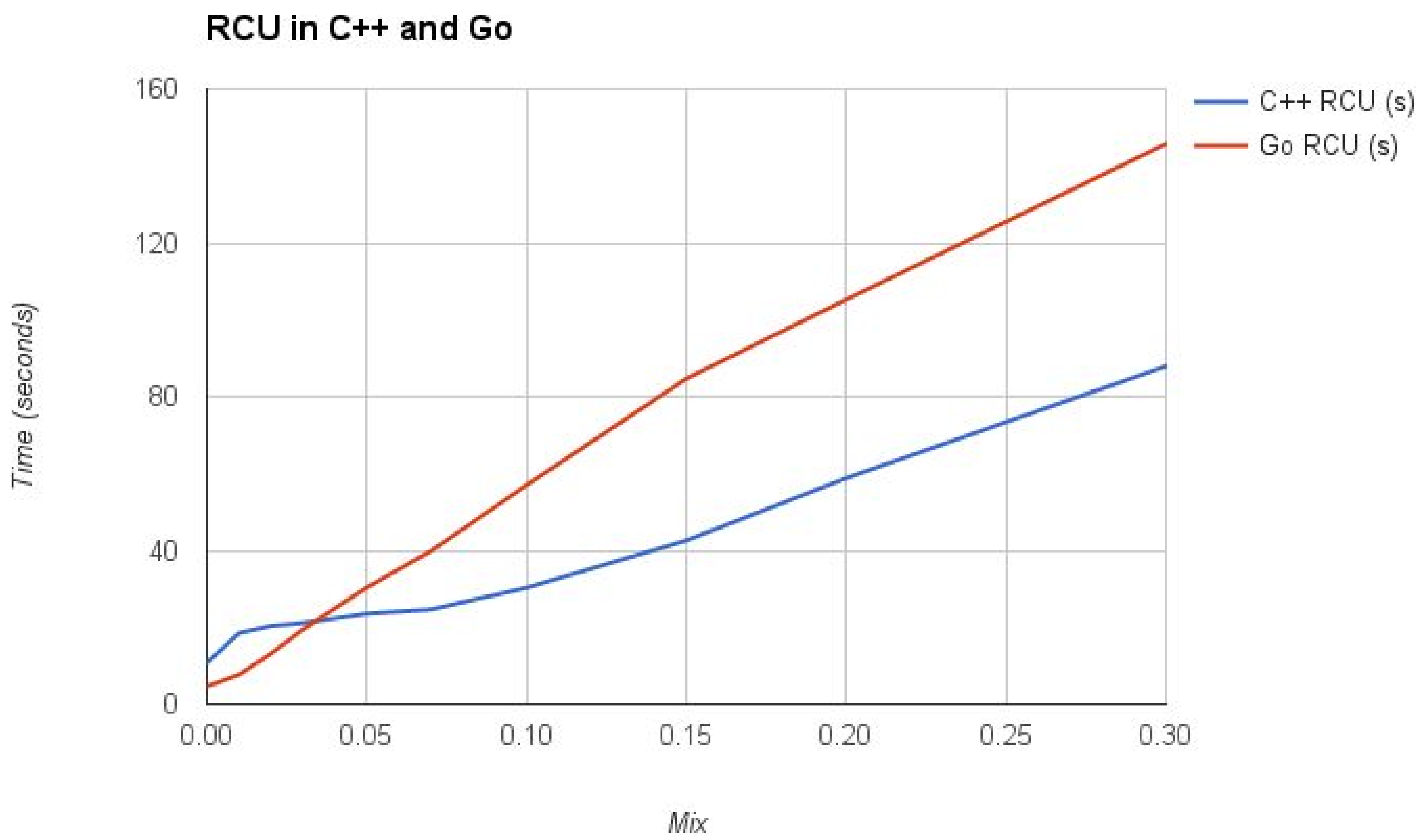
# Results

# Go RCU is Indeed Simpler

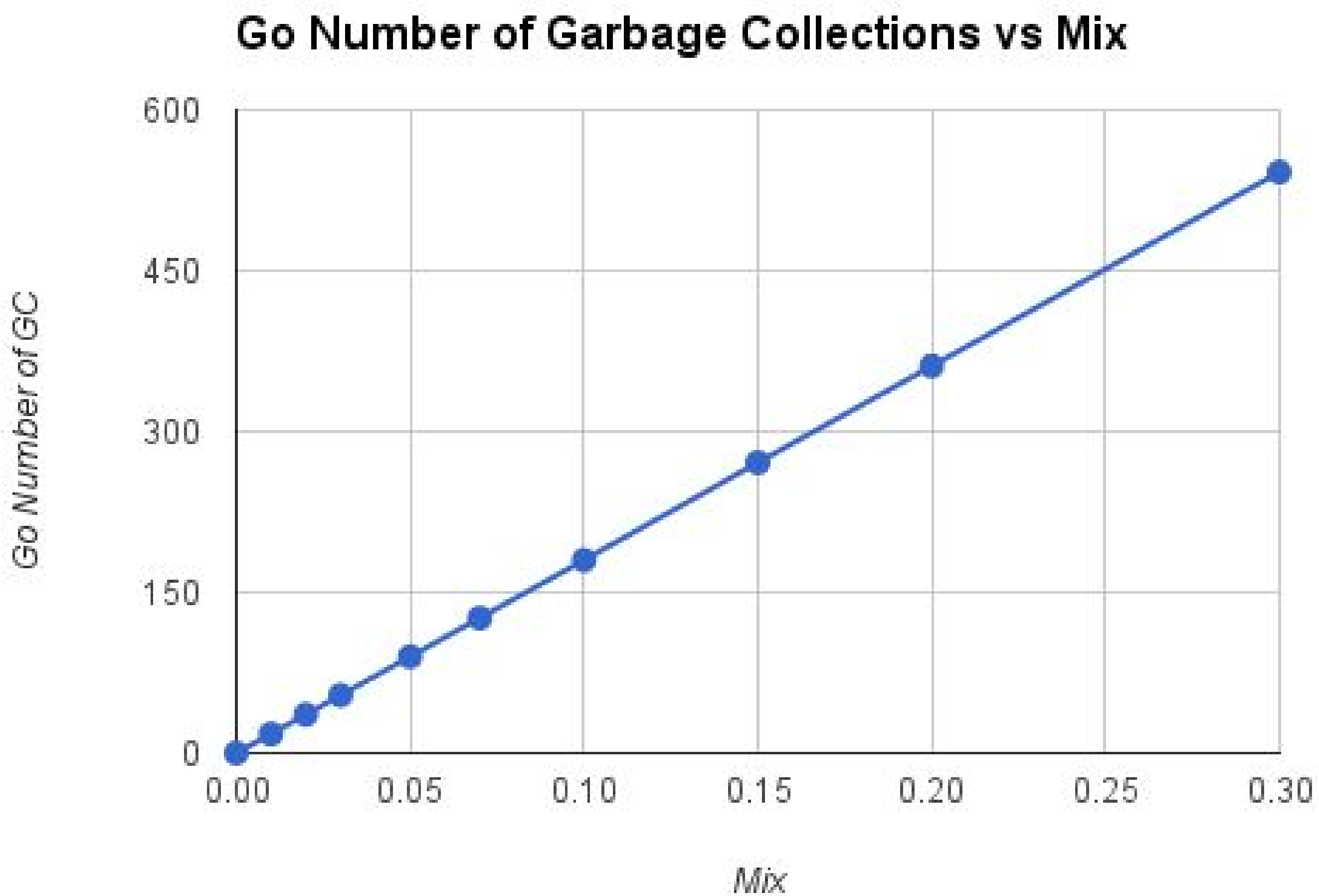
| API Function | C++ Necessary | Go Necessary |
| --- | --- | --- |
| rcu_read_lock() | Yes | No |
| rcu_read_unlock() | Yes | No |
| synchronize_rcu() | Yes | No |
| call_rcu() | Yes | No |
| rcu_assign_pointer() | Yes | No |
| rcu_dereference() | Yes | No |

- Programmers are likely to write fewer bugs since it is simpler

# Performance of C++ RCU vs. Go RCU



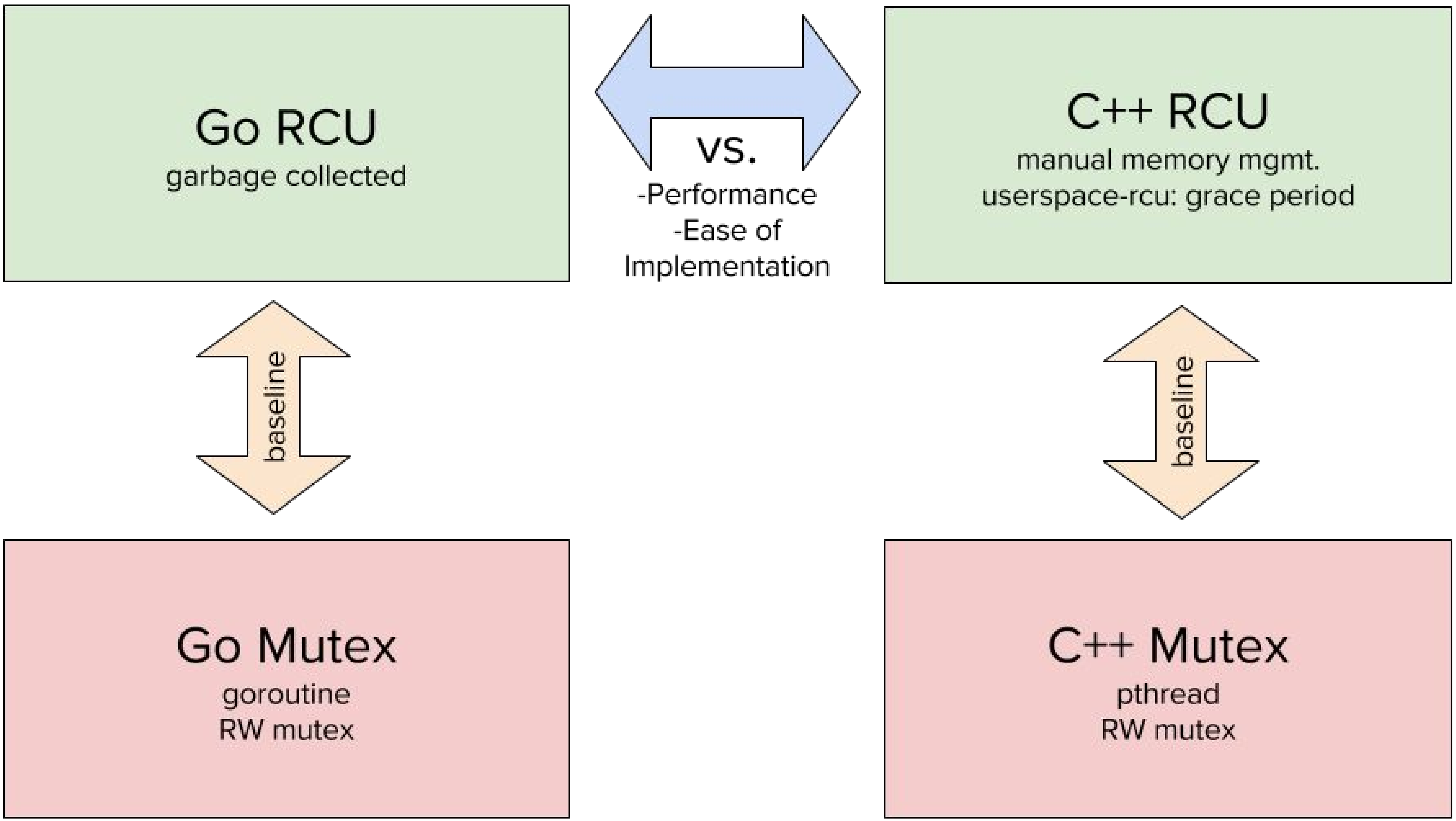
# Garbage Collection Counts



# Factoring Out the Programming Language

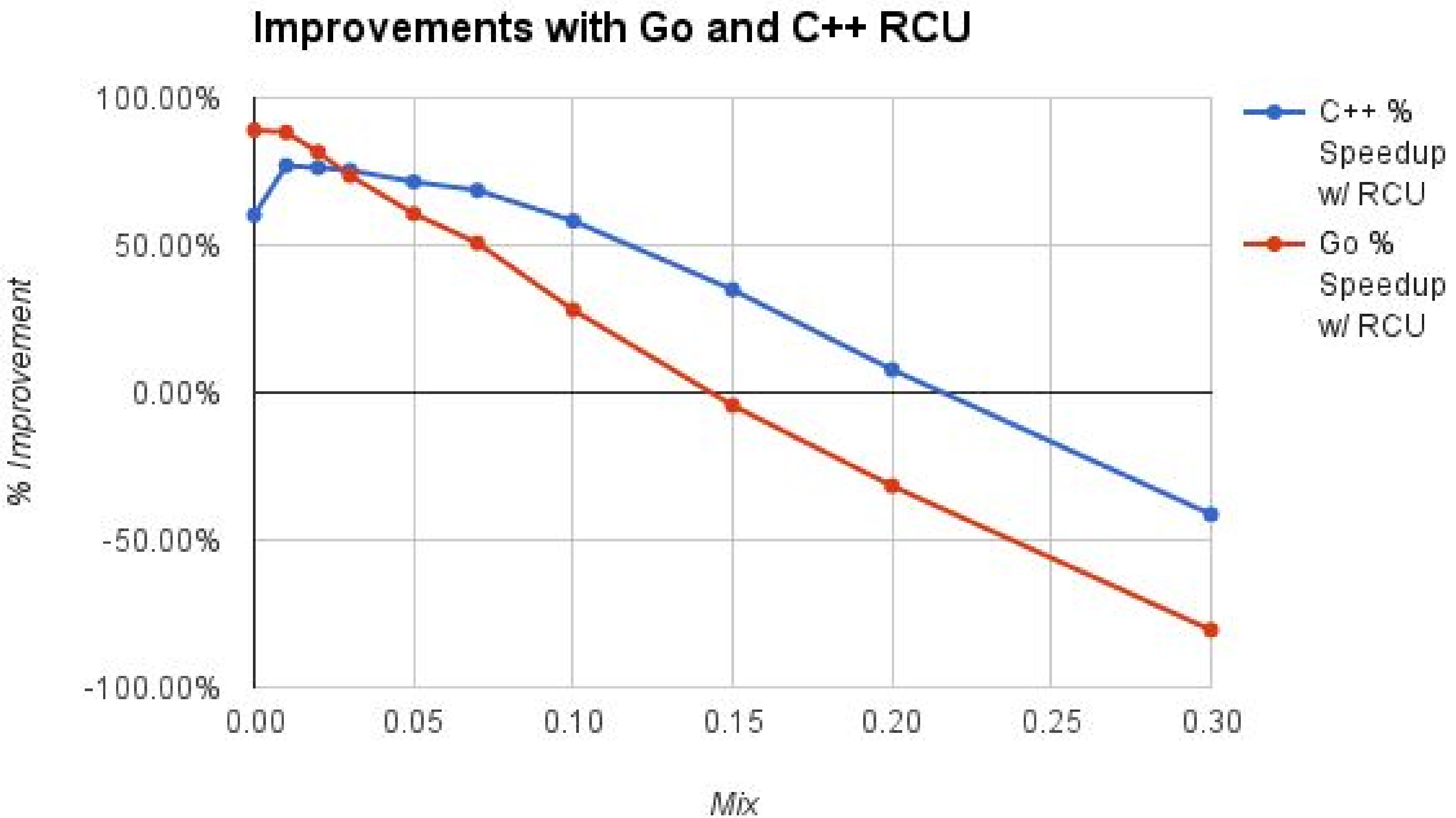
- Benchmark has RCU portions and non-RCU portions
  - Need to focus on RCU portion

# Evaluating RCU




Benchmarked each implementation with same test parameters

# Speedups over RW Mutex



# Conclusions

# Conclusions

- RCU in a garbage collected environment is promising
- Performance improvement vs. RW mutex is similar if not better than improvement in C++
- Don’t need to worry about freeing old copies because of garbage collector
  - Many functions simply not necessary
  - Fewer opportunities for bugs

# Future Work

- Integrate Go RCU into an actual application (i.e. cache) to see its real-world performance
- Use Go RCU inside an OS kernel to see how it would perform in kernel space

# Acknowledgements

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- Our mentor Cody Cutler for his guidance and insight
- Prof. Frans Kaashoek for suggesting this project
- Our parents for their constant support and encouragement
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