# Scalable Concurrent Hash Tables via Relativistic Programming

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- 0.1 meters/cycle (4 inches/cycle)
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- Ignores propagation delay, ramp time, speed of signals
- One of the reasons CPUs stopped getting faster
- Physical limit on memory, CPU–CPU communication

# Throughput vs Latency

- CPUs can do a lot of independent work in 1 cycle
- CPUs can work out of their own cache in 1 cycle
- CPUs can't communicate and agree in 1 cycle

# How to scale?

- To improve scalability, work independently
- Agreement represents the bottleneck
- Scale by reducing the need to agree

# Classic concurrent programming

- Every CPU agrees on the order of instructions
- No tolerance for conflicts
- Implicit communication and agreement required
- Does not scale
- Example: mutual exclusion

# Relativistic programming

- By analogy with physics: no global reference frame
- Allow each thread to work with its observed "relative" view of memory
- Minimal constraints on instruction ordering
- Tolerance for conflicts: allow concurrent threads to access shared data at the same time, even when doing modifications.

# Why relativistic programming?

- Wait-free
- Very low overhead
- Linear scalability

# Concrete examples

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- Deferred destruction — Read-Copy Update (RCU)

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- Primitives for conflict-tolerant operations: `rcu_assign_pointer`, `rcu_deference`
- Working data structures you don't have to think hard about

# RCU data structures

- Linked lists
- Radix trees
- Hash tables, sort of

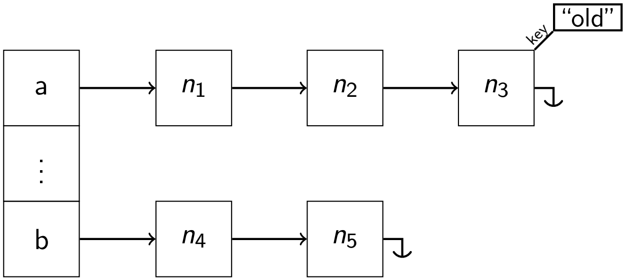
# Hash tables, sort of

- RCU linked lists for buckets
- Insertion and removal
- No other operations

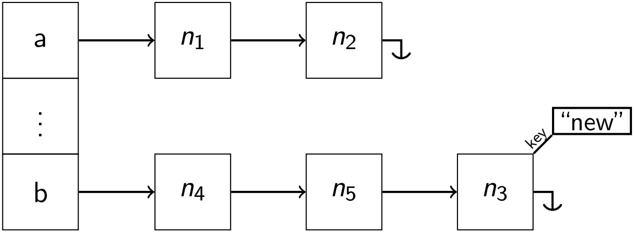
# New RCU hash table operations

- Move element
- Resize table

# Move operation



# Move operation



# Move operation semantics

- If a reader doesn't see the old item, subsequent lookups of the new item must succeed.
- If a reader sees the new item, subsequent lookups of the old item must fail.
- The move operation must not cause concurrent lookups for other items to fail
- Semantics based roughly on filesystems

# Move operation challenge

- Trivial to implement with mutual exclusion
  - Insert then remove, or remove then insert
  - Intermediate states don't matter
- Hash table buckets use linked lists
- RCU linked list implementations provide insert and remove
- Move semantics not possible using just insert and remove

# Current approach in Linux

- Sequence lock
- Readers retry if they race with a rename
- Any rename

# Solution characteristics

- Principles:
  - One semantically significant change at a time
  - Intermediate states must not violate semantics
- Need a new move operation specific to relativistic hash tables, making moves a single semantically significant change with no broken intermediate state
- Must appear to simultaneously move item to new bucket and change key

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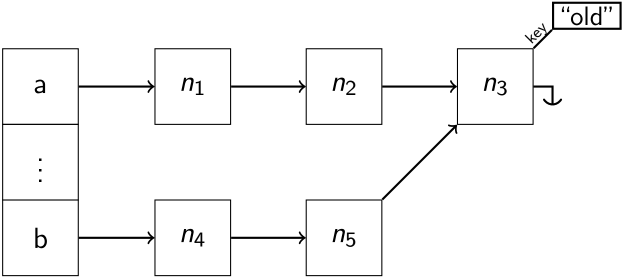
# Key idea

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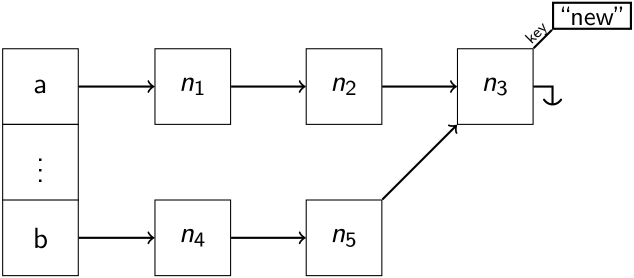


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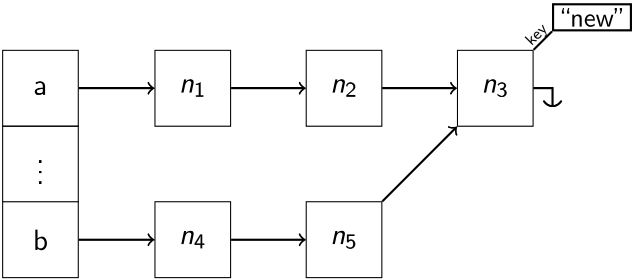
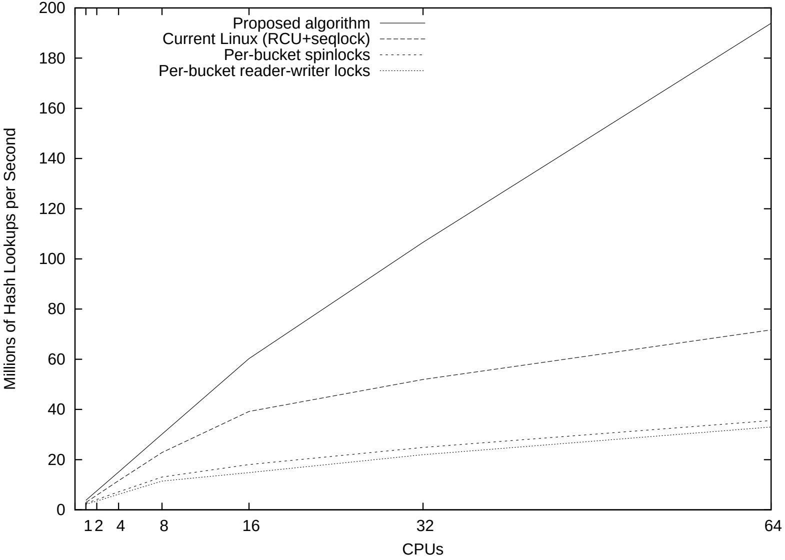



- Cross-link end of new bucket to node in old bucket
- While target node appears in both buckets, change the key
- Need to resolve cross-linking safely, even for readers looking at the target node
- First copy target node to the end of its bucket, so readers can't miss later nodes
- Memory barriers

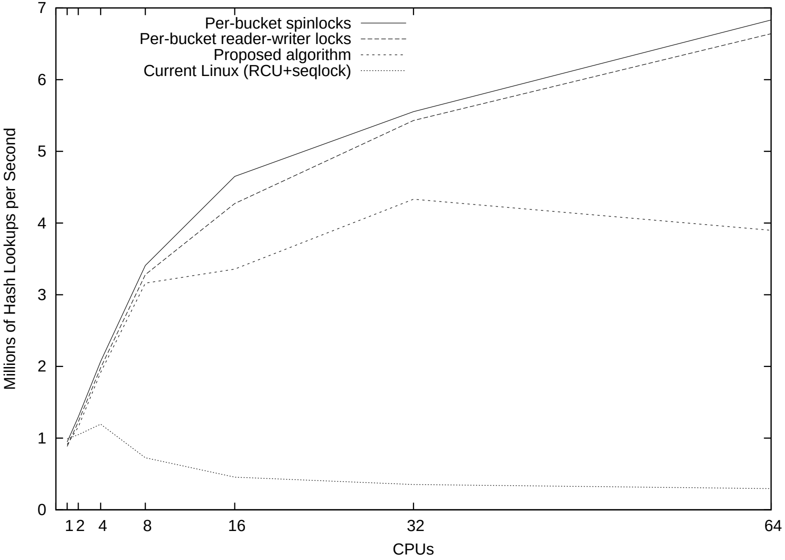
# Benchmarking with rcuhashbash

- Run one thread per CPU.
- Continuous loop: randomly lookup or move
- Configurable algorithm and lookup:move ratio
- Run for 30 seconds, count reads and writes
- Average of 10 runs
- Tested on 64 CPUs

# Results, 999:1 lookup:move ratio, reads



# Results, 1:1 lookup:move ratio, reads



# Resizing RCU-protected hash tables

- Disclaimer: work in progress
- Working on implementation and test framework in rcuhashbash
- No benchmark numbers yet
- Expect code and announcement soon

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- Cross-link tails of chains to second table in appropriate bucket
- Wait for current readers to finish before removing cross-links from primary table
- Repeat until primary table empty
- Make the secondary table primary
- Free the old primary table after a grace period

# For more information

- Code: `git://git.kernel.org/pub/scm/linux/kernel/git/josh/rcuhashbash` (Resize coming soon!)
- Relativistic programming: `http://wiki.cs.pdx.edu/rp/`
- Email: `josh@joshtriplett.org`