Creative Fabrica

Smarter Locks

A deep dive on the Runtime Mutex Spin Optimisation

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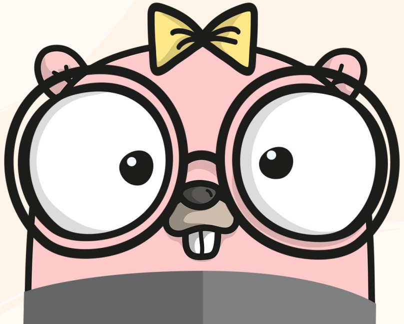

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A deep dive on the Runtime Mutex Spin Optimisation

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Overview:

- Motivation
- Behaviour before the optimization
- go1.24 runtime mutex optimization

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> Several performance improvements to the runtime have decreased CPU overheads by 2–3% on average across a suite of representative benchmarks.

https://tip.golang.org/doc/go1.24

- What was the mutex behaviour before?
- What was proposed and how does it improve CPU overhead?
- What benchmarks?

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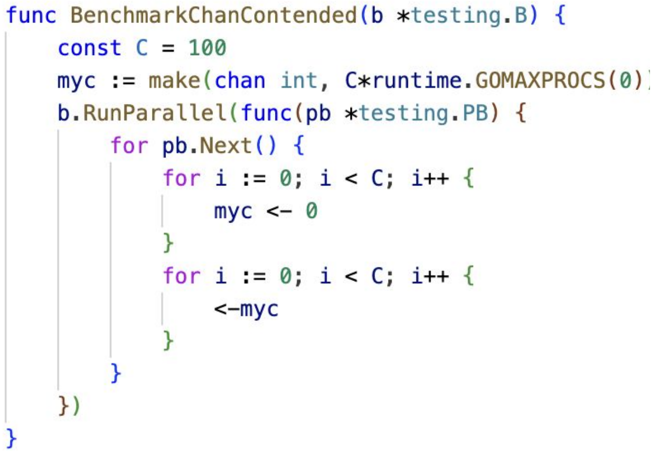
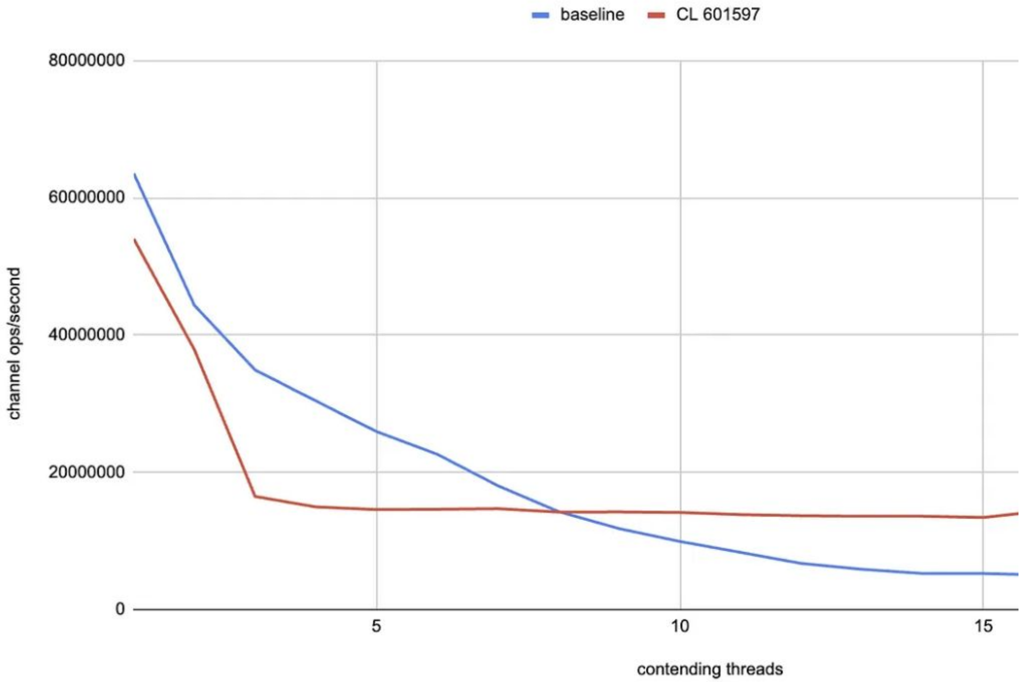


```go
func BenchmarkChanContended(b *testing.B) {
	const C = 100
	myc := make(chan int, C*runtime.GOMAXPROCS(0))
	b.RunParallel(func(pb *testing.PB) {
		for pb.Next() {
			for i := 0; i < C; i++ {
				myc <- 0
			}
			for i := 0; i < C; i++ {
				<-myc
			}
		}
	})
}
```

CL 601597 gives horizontal scaling

Versus baseline, where each additional thread makes the lock even slower



go test runtime -test.run='^$' -test.bench=ChanContended -test.cpu="$(seq 1 20 | tr '\n' ',')" -test.count=10

src/runtime/chan_test.go

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Go concurrency primitives

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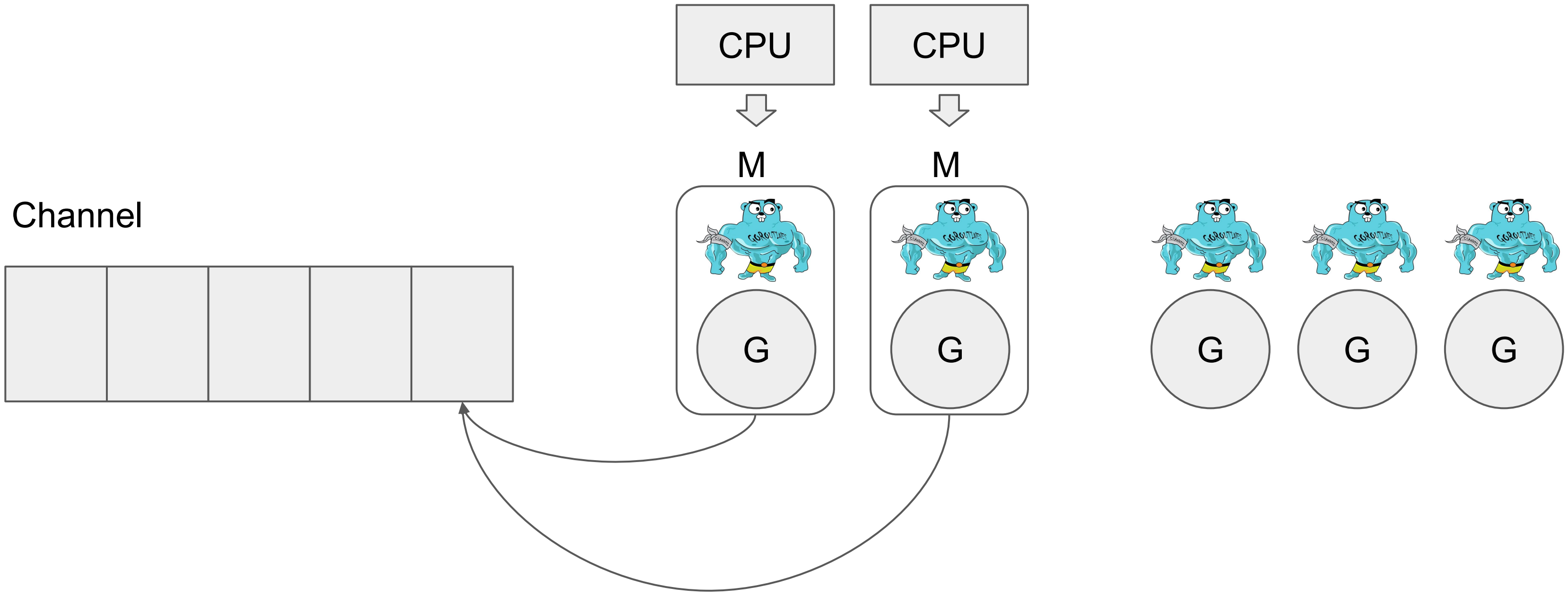

M: OS Threads
G: Goroutines

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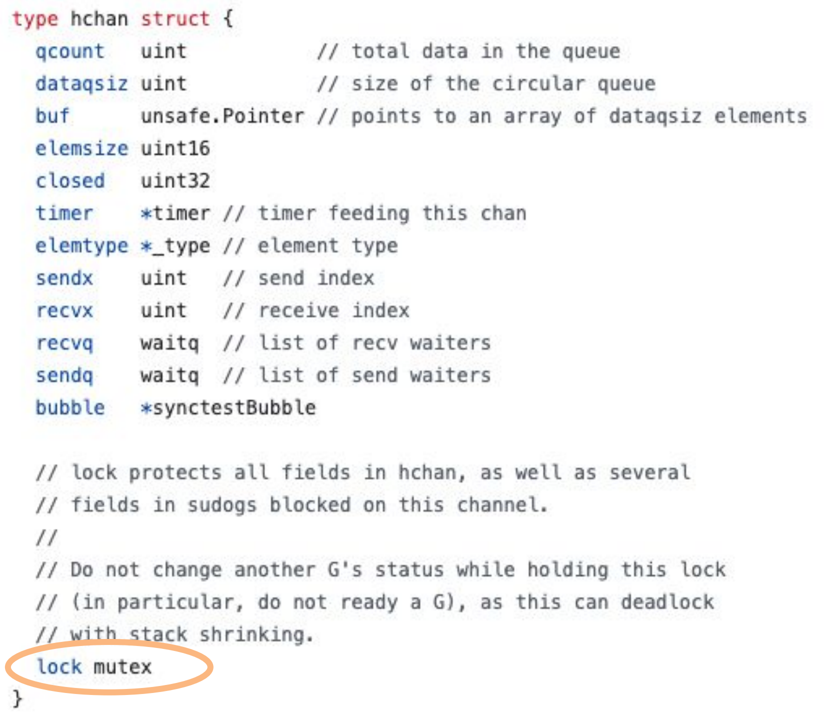

```go
type hchan struct {
  qcount   uint           // total data in the queue
  dataqsiz uint           // size of the circular queue
  buf      unsafe.Pointer // points to an array of dataqsiz elements
  elemsize uint16
  closed   uint32
  timer    *timer // timer feeding this chan
  elemtype *_type // element type
  sendx    uint   // send index
  recvx    uint   // receive index
  recvq    waitq  // list of recv waiters
  sendq    waitq  // list of send waiters
  bubble   *synctestBubble

  // lock protects all fields in hchan, as well as several
  // fields in sudogs blocked on this channel.
  //
  // Do not change another G's status while holding this lock
  // (in particular, do not ready a G), as this can deadlock
  // with stack shrinking.
  lock mutex
}
```

- This is where the optimization is 🎉
- What was happening before?

src/runtime/chan.go

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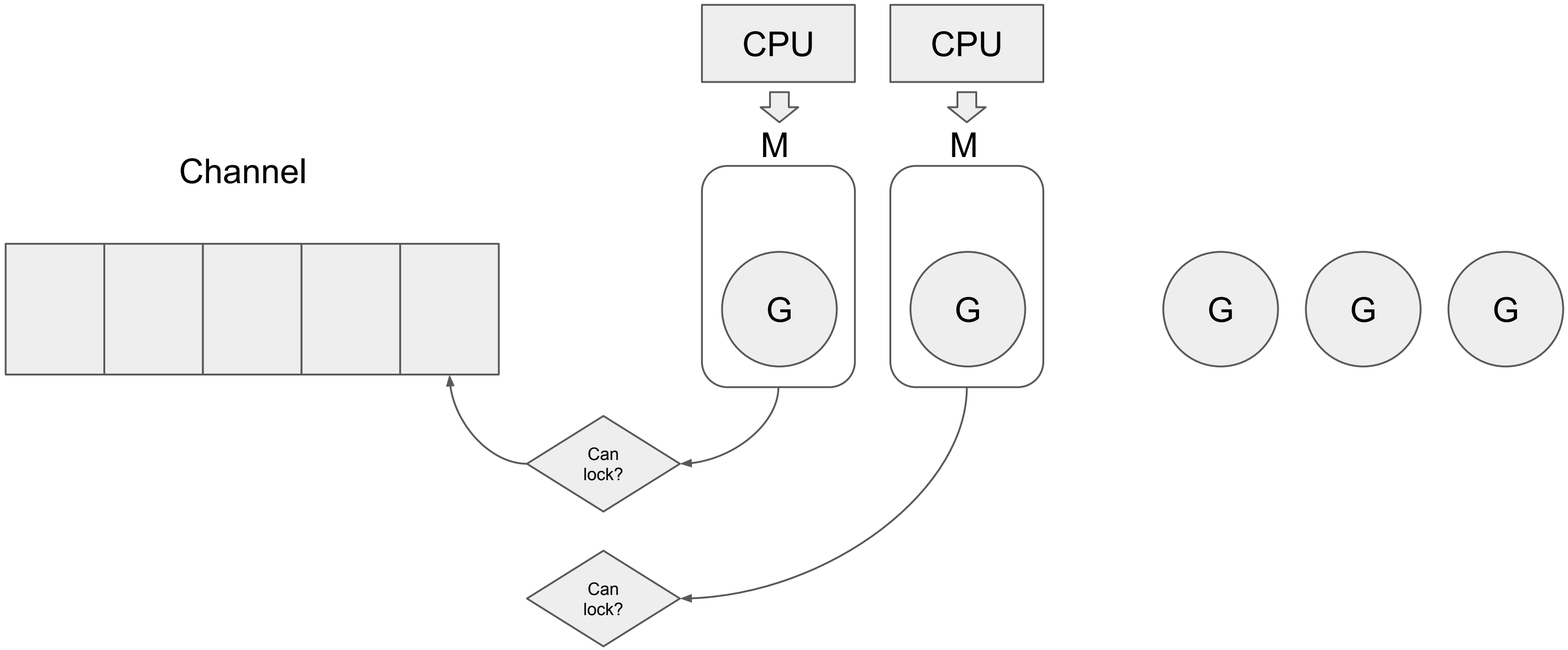

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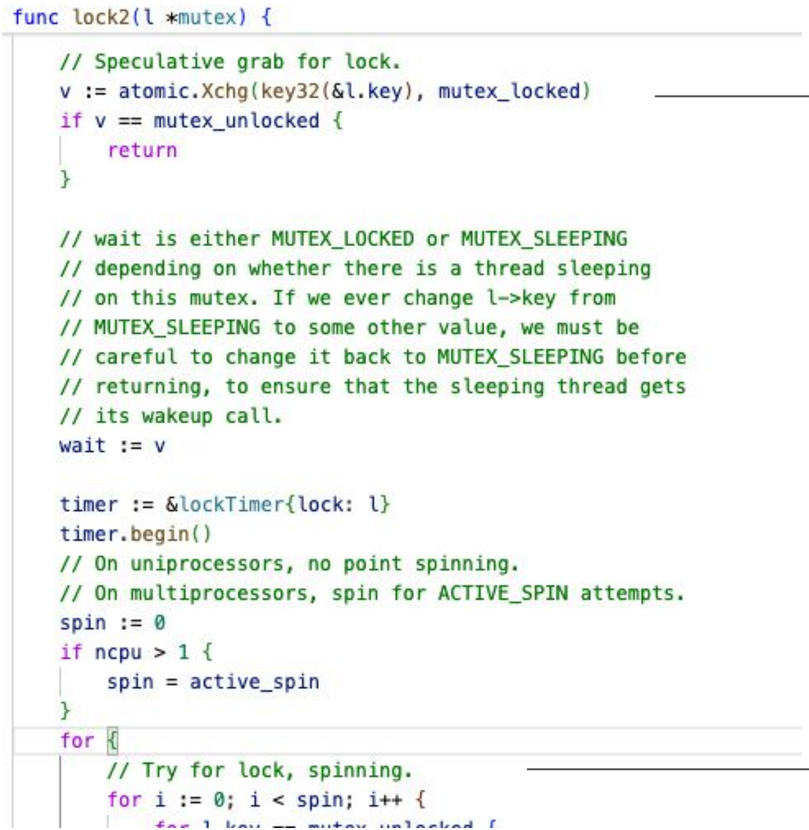

```go
func lock2(l *mutex) {
    // Speculative grab for lock.
    v := atomic.Xchg(key32(&l.key), mutex_locked)
    if v == mutex_unlocked {
        return
    }

    // wait is either MUTEX_LOCKED or MUTEX_SLEEPING
    // depending on whether there is a thread sleeping
    // on this mutex. If we ever change l->key from
    // MUTEX_SLEEPING to some other value, we must be
    // careful to change it back to MUTEX_SLEEPING before
    // returning, to ensure that the sleeping thread gets
    // its wakeup call.
    wait := v

    timer := &lockTimer{lock: l}
    timer.begin()
    // On uniprocessors, no point spinning.
    // On multiprocessors, spin for ACTIVE_SPIN attempts.
    spin := 0
    if ncpu > 1 {
        spin = active_spin
    }
    for {
        // Try for lock, spinning.
        for i := 0; i < spin; i++ {
            for l.key == mutex_unlocked {
```

OS Atomic call:

- Check and Set

If lock was not acquired "spin" for a while

src/runtime/lock_futex.go

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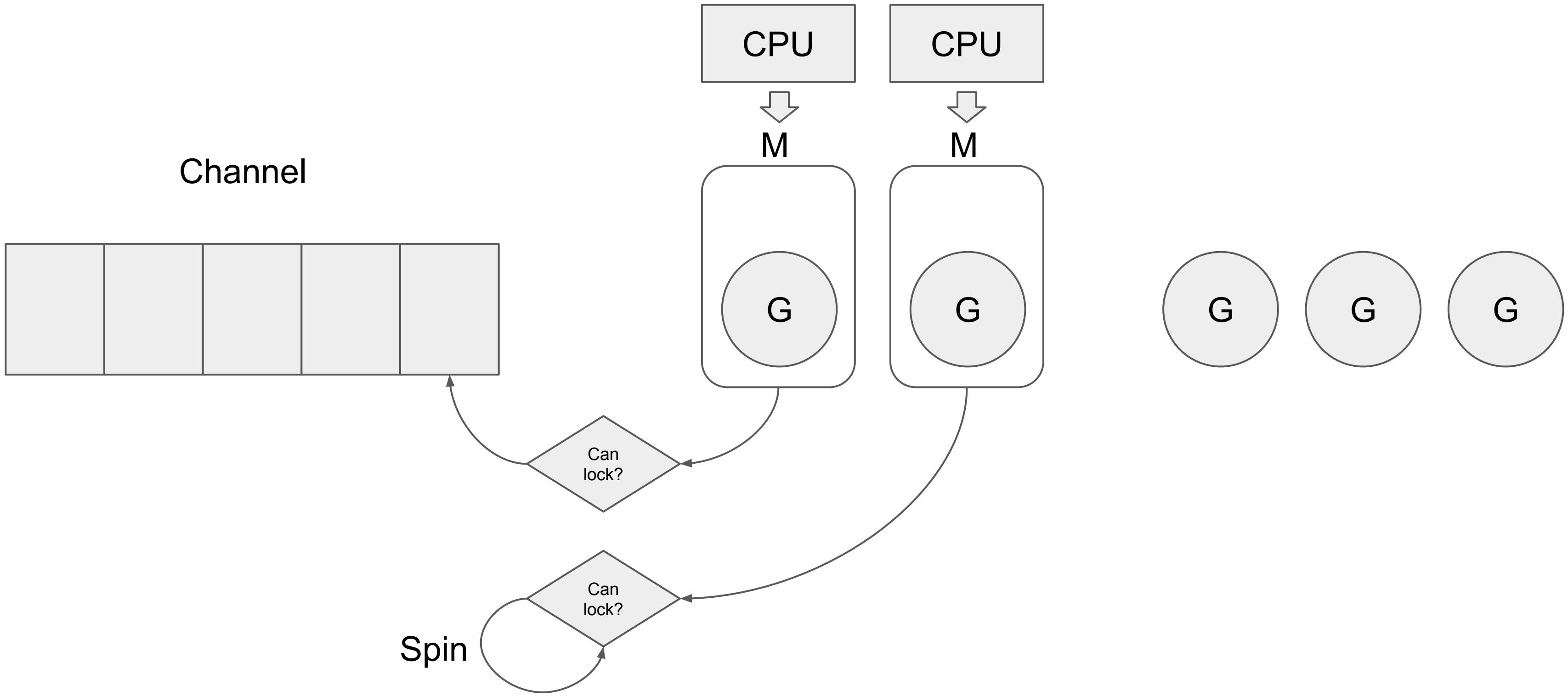

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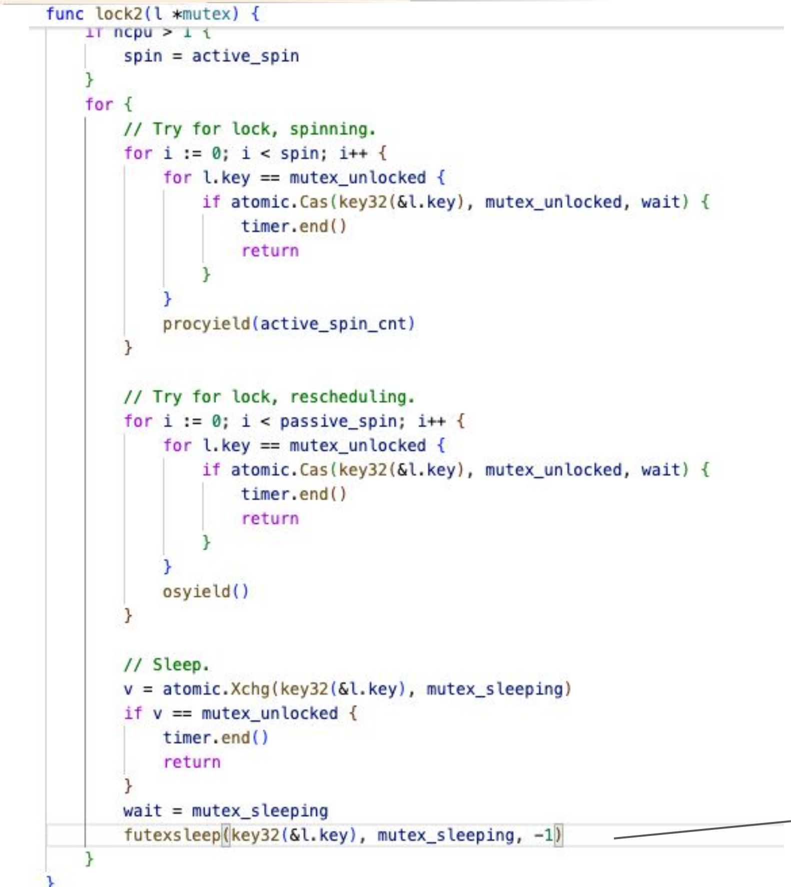

```go
func lock2(l *mutex) {
    if ncpu > 1 {
        spin = active_spin
    }
    for {
        // Try for lock, spinning.
        for i := 0; i < spin; i++ {
            for l.key == mutex_unlocked {
                if atomic.Cas(key32(&l.key), mutex_unlocked, wait) {
                    timer.end()
                    return
                }
            }
            procyield(active_spin_cnt)
        }

        // Try for lock, rescheduling.
        for i := 0; i < passive_spin; i++ {
            for l.key == mutex_unlocked {
                if atomic.Cas(key32(&l.key), mutex_unlocked, wait) {
                    timer.end()
                    return
                }
            }
            osyield()
        }

        // Sleep.
        v = atomic.Xchg(key32(&l.key), mutex_sleeping)
        if v == mutex_unlocked {
            timer.end()
            return
        }
        wait = mutex_sleeping
        futexsleep(key32(&l.key), mutex_sleeping, -1)
    }
}
```

OS Call to sleep M

src/runtime/lock_futex.go

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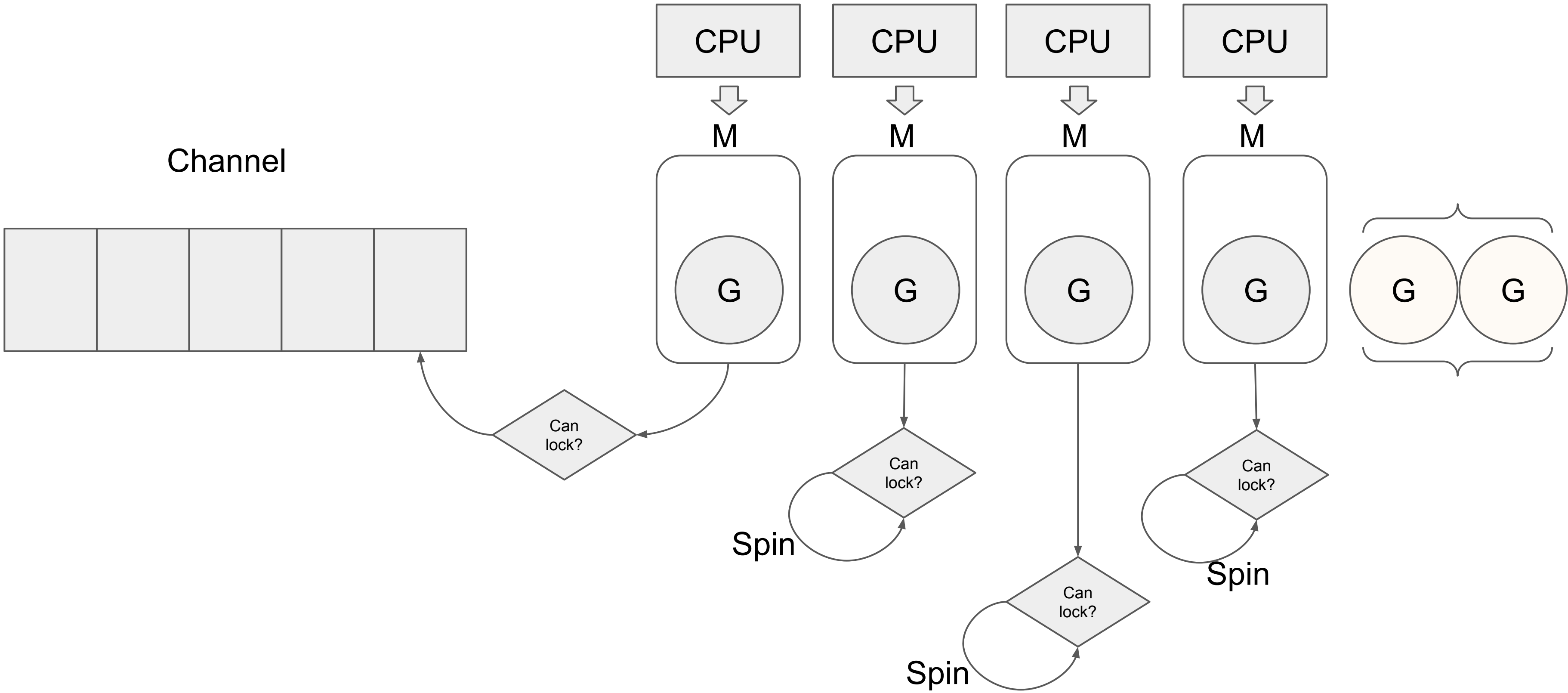

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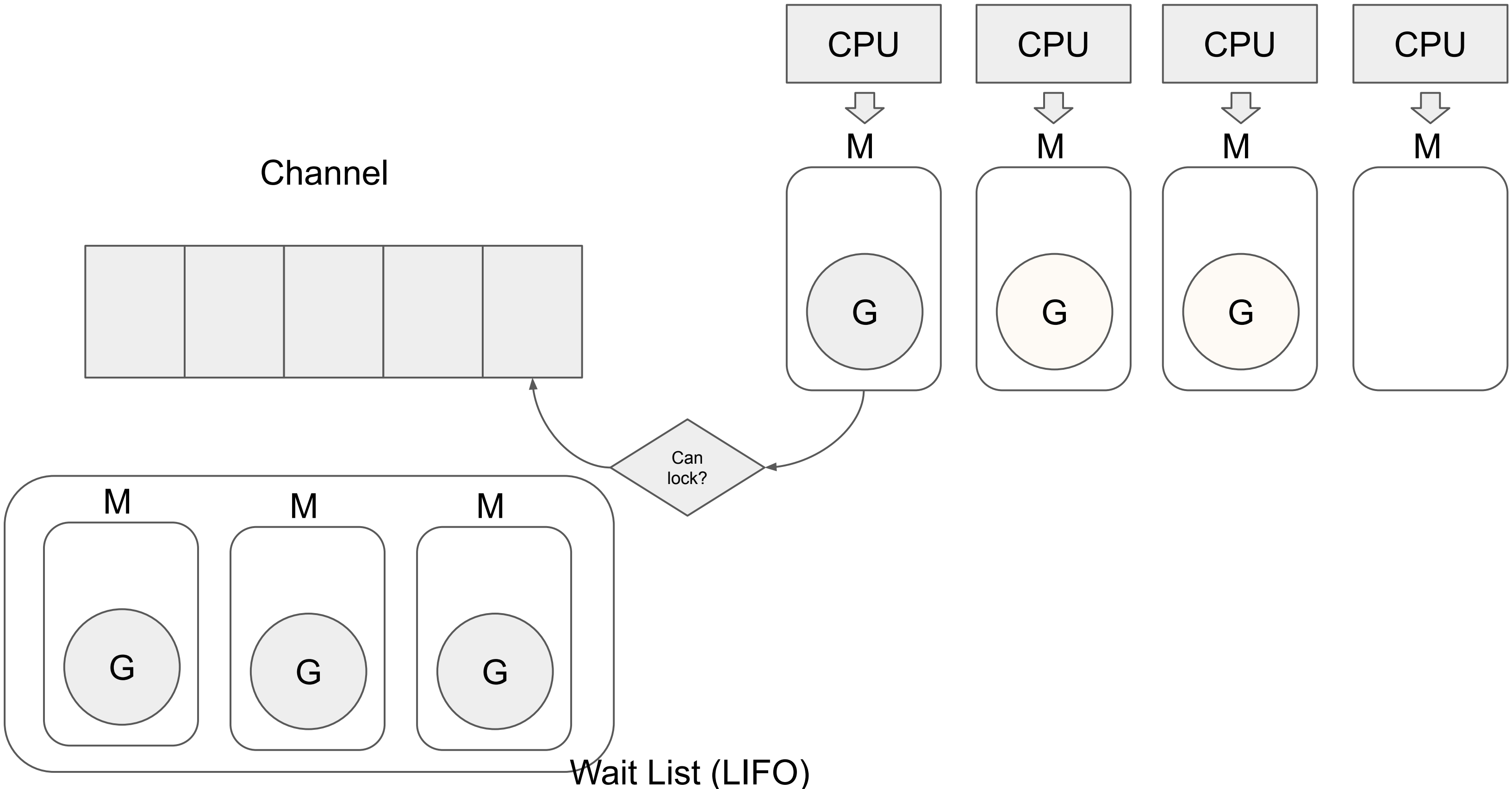

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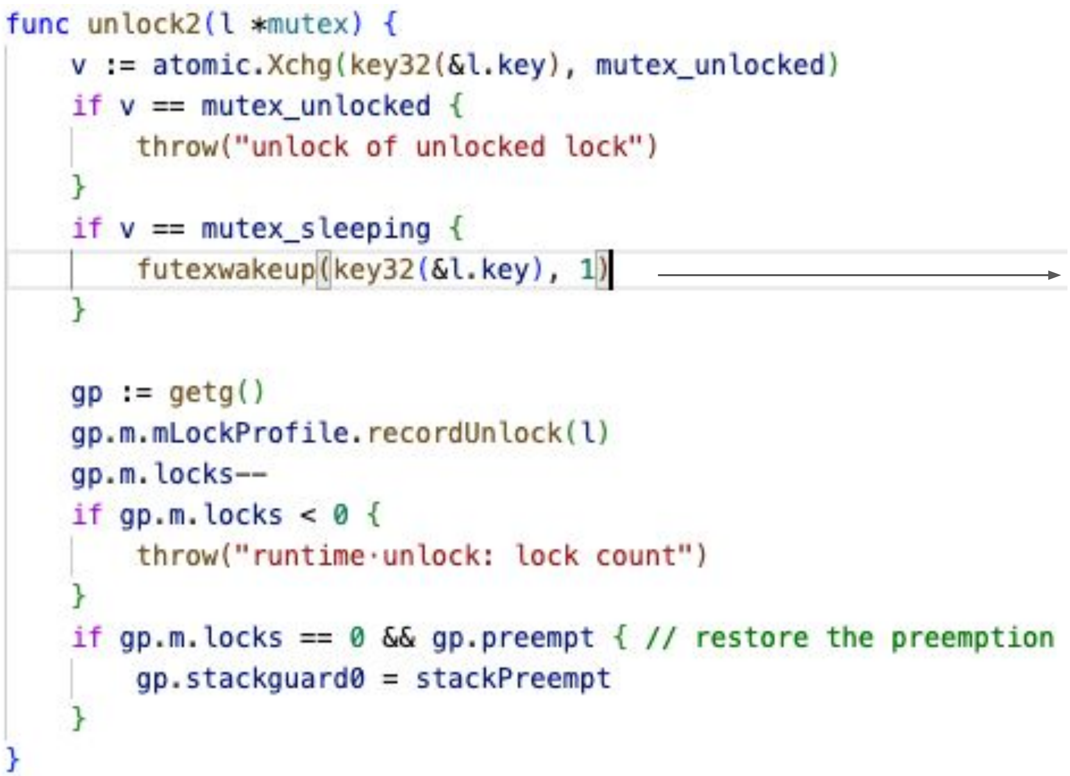

```go
func unlock2(l *mutex) {
	v := atomic.Xchg(key32(&l.key), mutex_unlocked)
	if v == mutex_unlocked {
		throw("unlock of unlocked lock")
	}
	if v == mutex_sleeping {
		futexwakeup(key32(&l.key), 1)
	}

	gp := getg()
	gp.m.mLockProfile.recordUnlock(l)
	gp.m.locks--
	if gp.m.locks < 0 {
		throw("runtime·unlock: lock count")
	}
	if gp.m.locks == 0 && gp.preempt { // restore the preemption
		gp.stackguard0 = stackPreempt
	}
}
```

OS Call to wake the thread up

src/runtime/lock_futex.go

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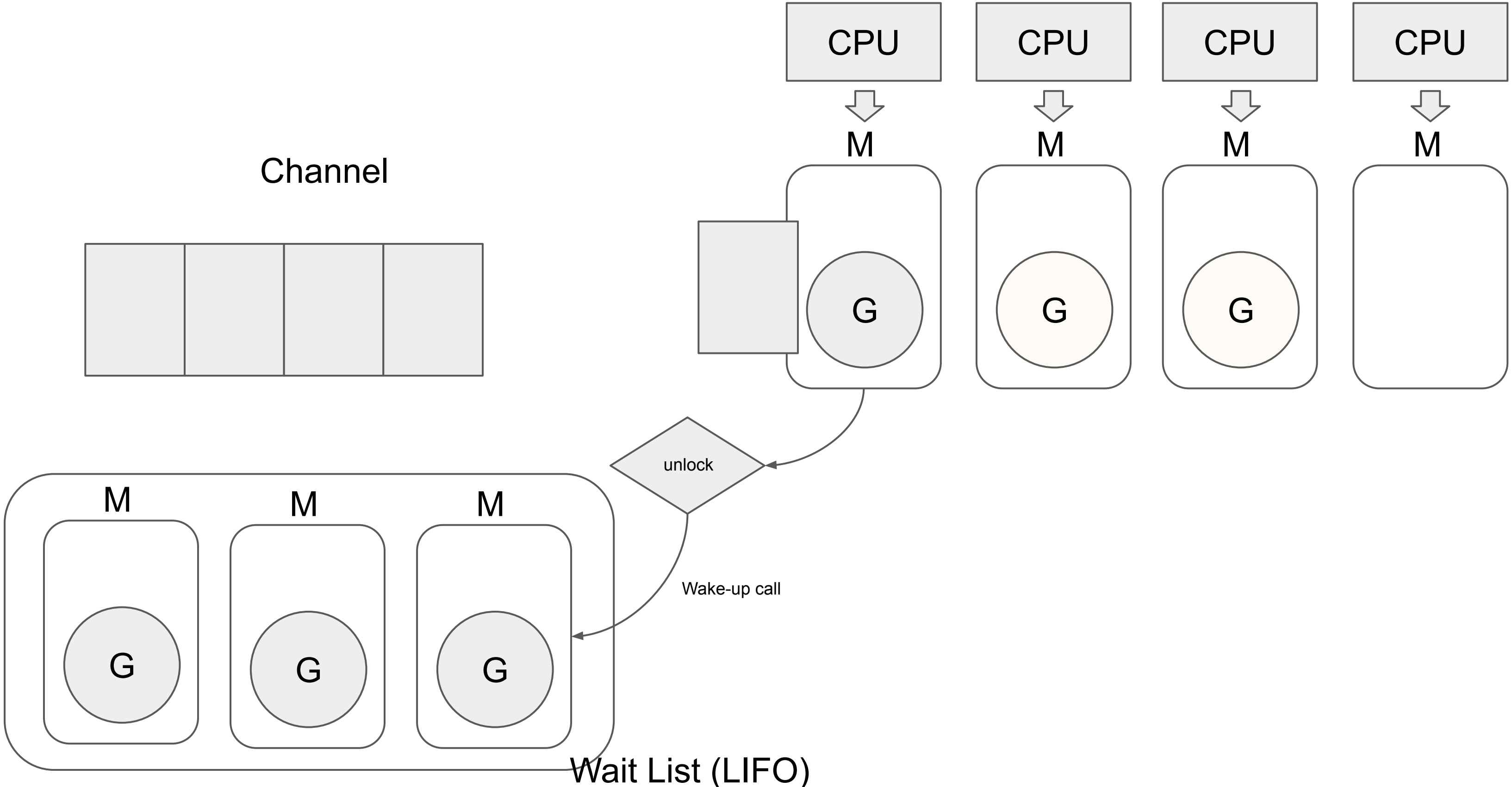

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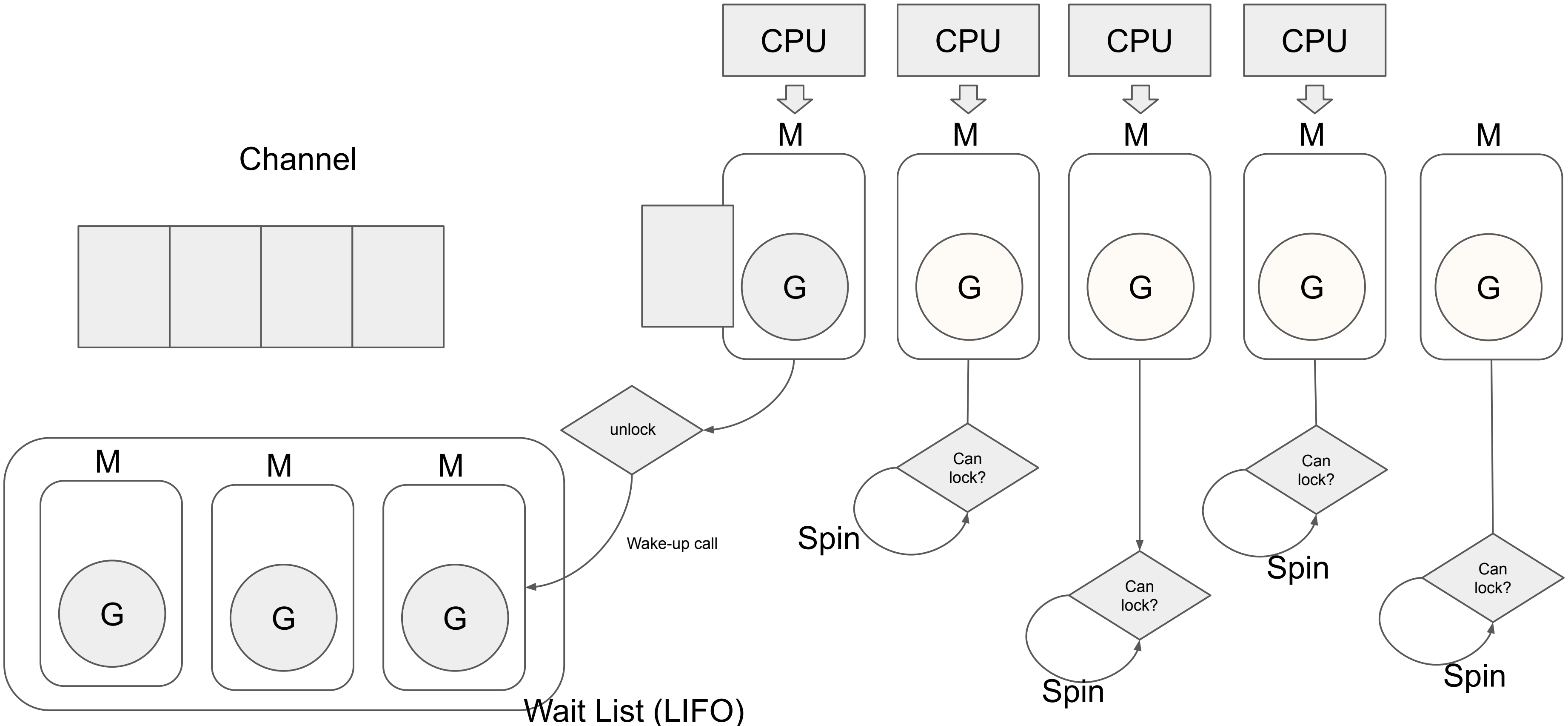

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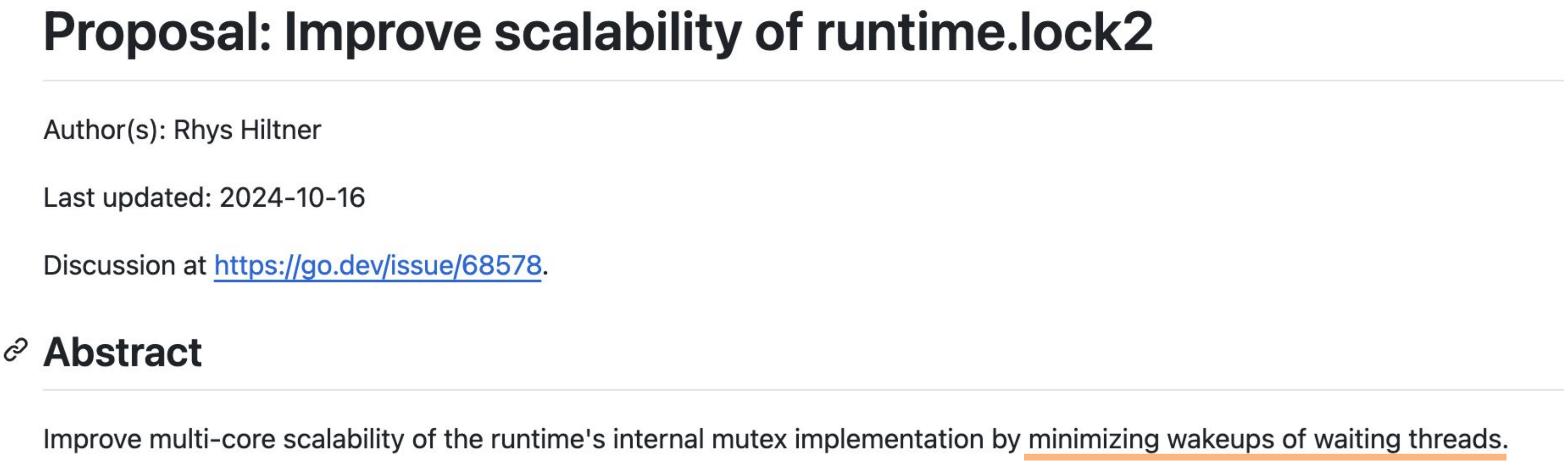

Proposal: Improve scalability of runtime.lock2

Author(s): Rhys Hiltner

Last updated: 2024-10-16

Discussion at https://go.dev/issue/68578.

Abstract

Improve multi-core scalability of the runtime's internal mutex implementation by minimizing wakeups of waiting threads.

https://github.com/golang/proposal/blob/master/design/68578-mutex-spinbit.md

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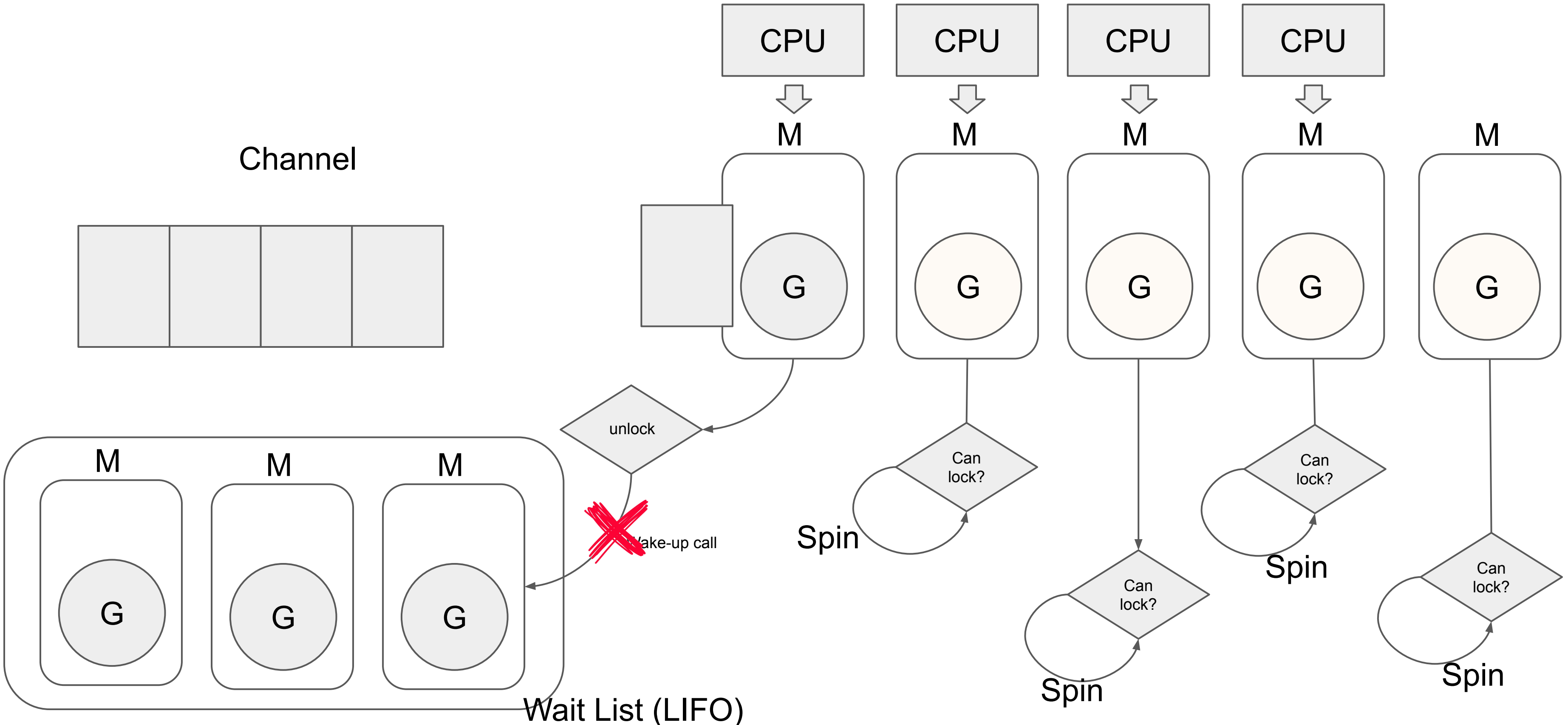

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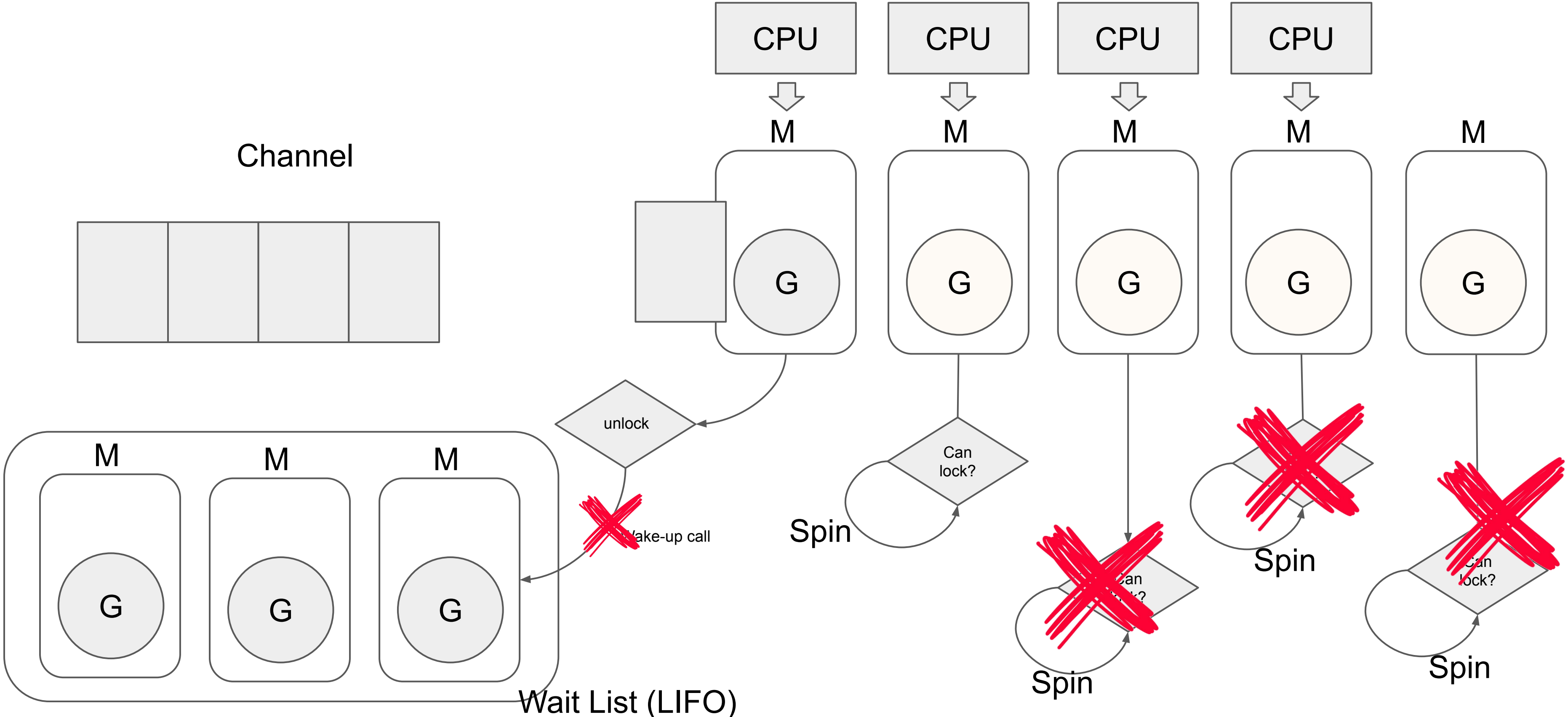

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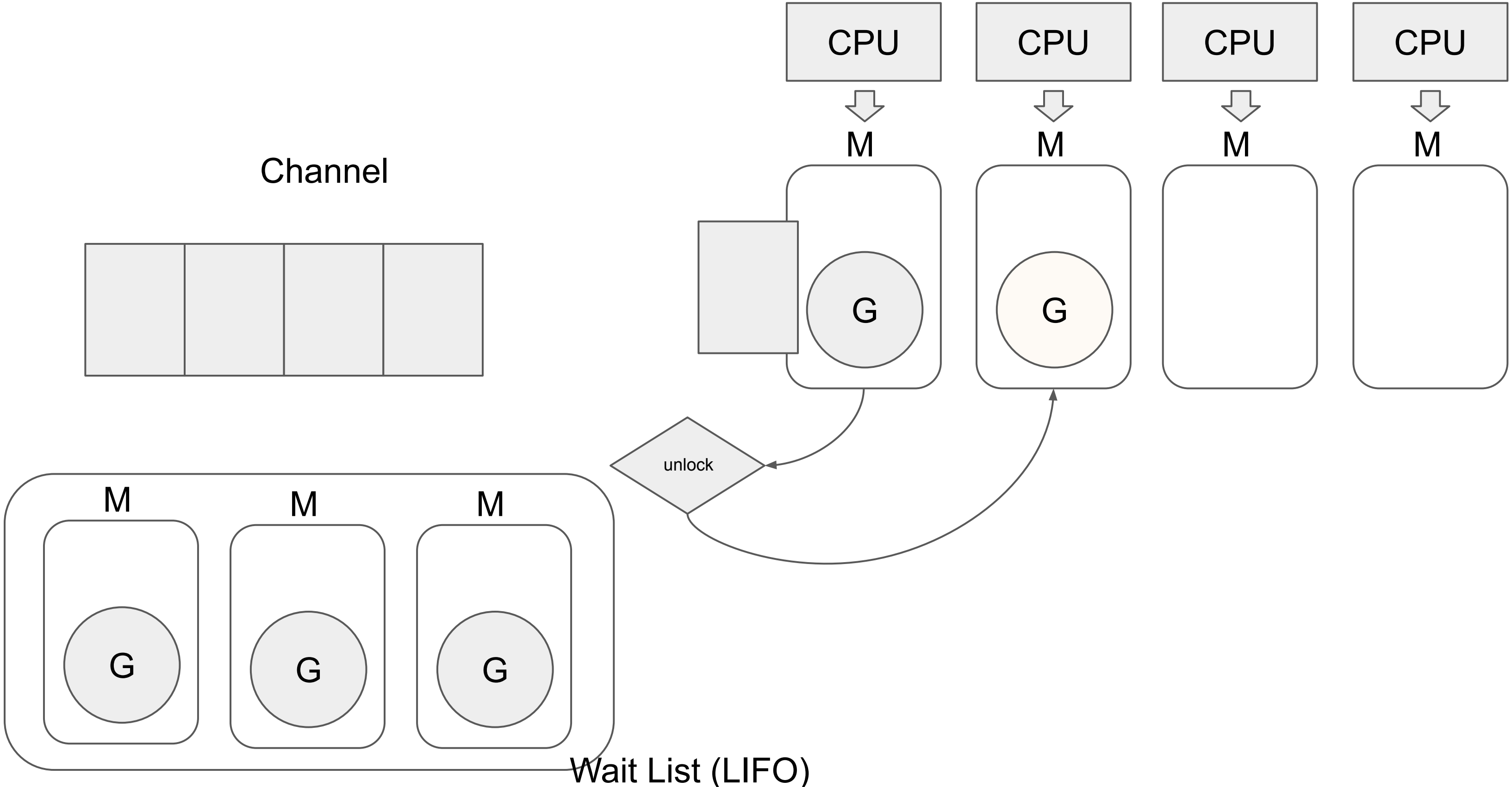

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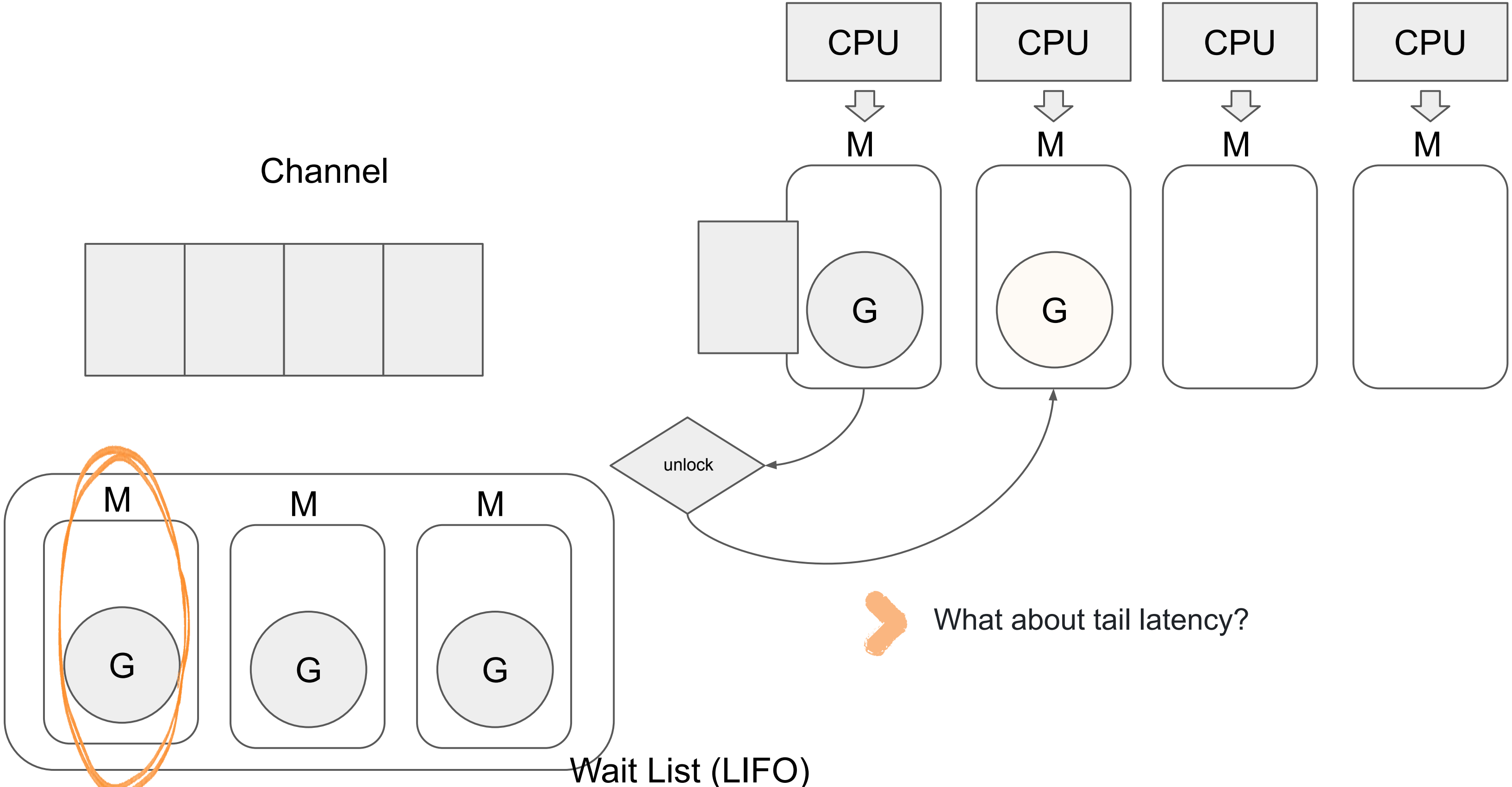

What about tail latency?

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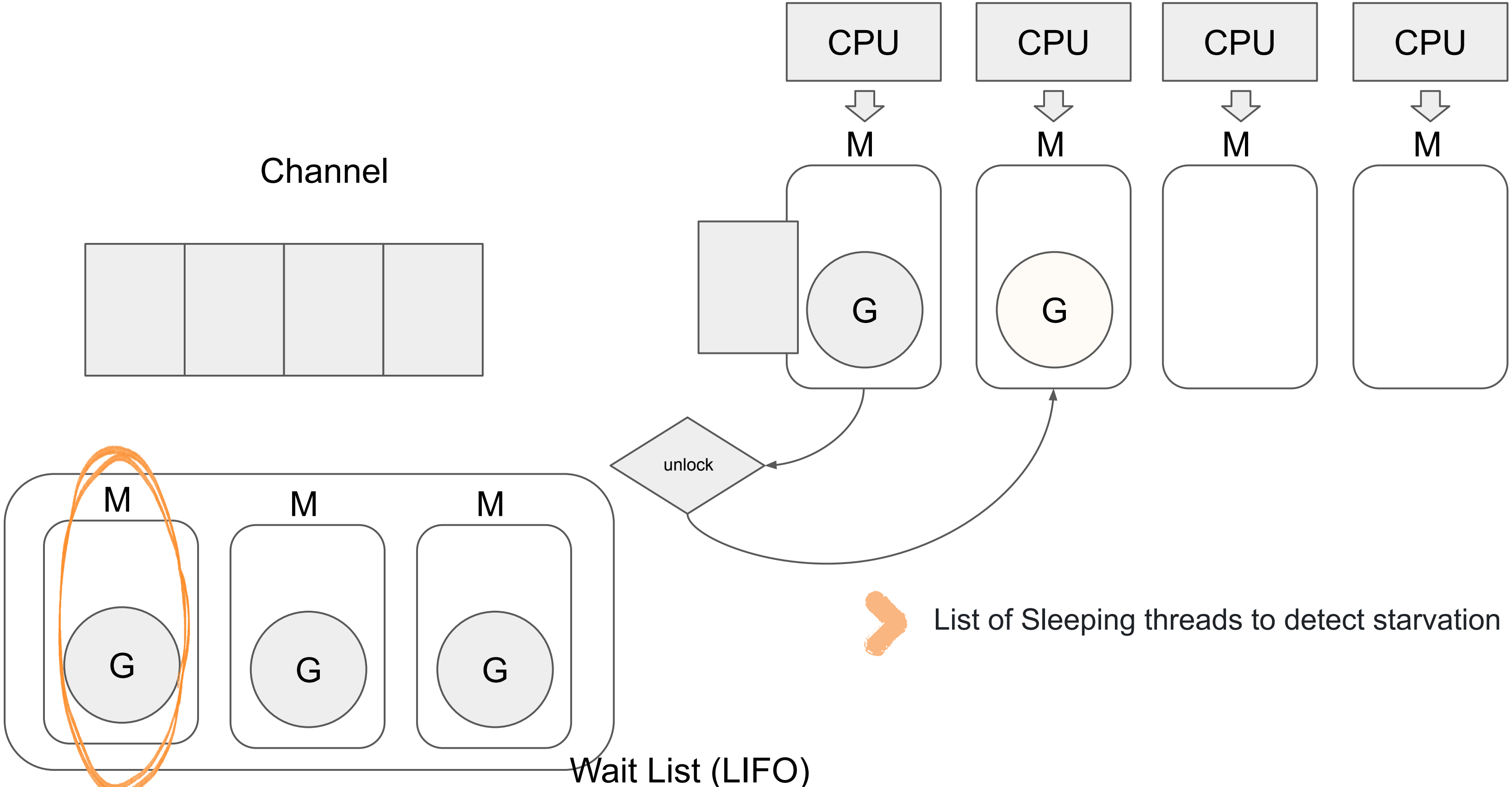

- List of Sleeping threads to detect starvation

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- "Minimizing wakeups of waiting threads".
- "Expand the mutex state word to include a new flag: spinning".
- "If there is one thread spinning, other threads needing the lock go immediately to sleep state".
- "If a thread is sleeping for too long wake it up so it starts to spin or reposition itself on the waiting stack"

https://github.com/golang/proposal/blob/master/design/68578-mutex-spinbit.md

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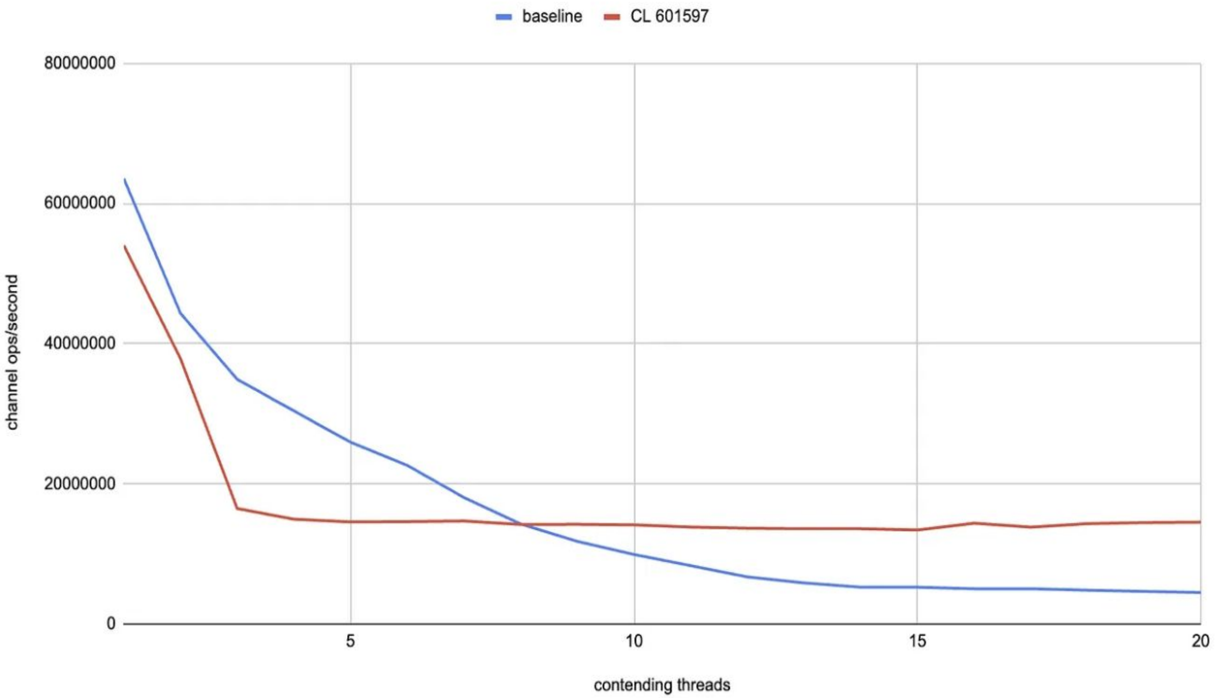

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THANK YOU