GoBench: A Benchmark Suite of Real-World Go Concurrency Bugs

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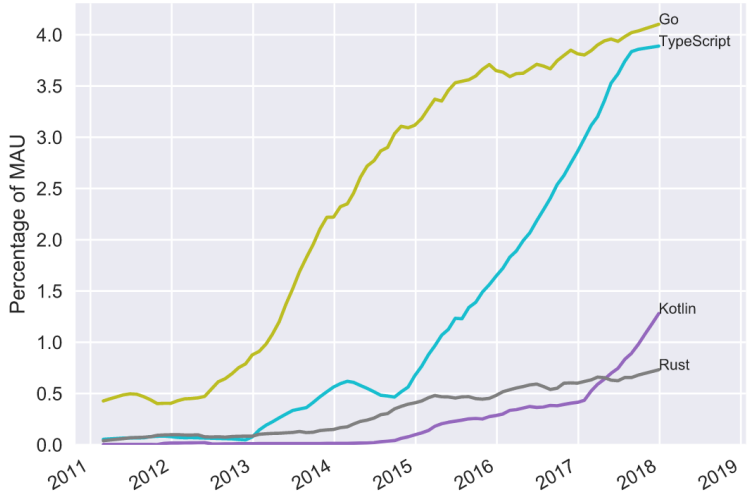
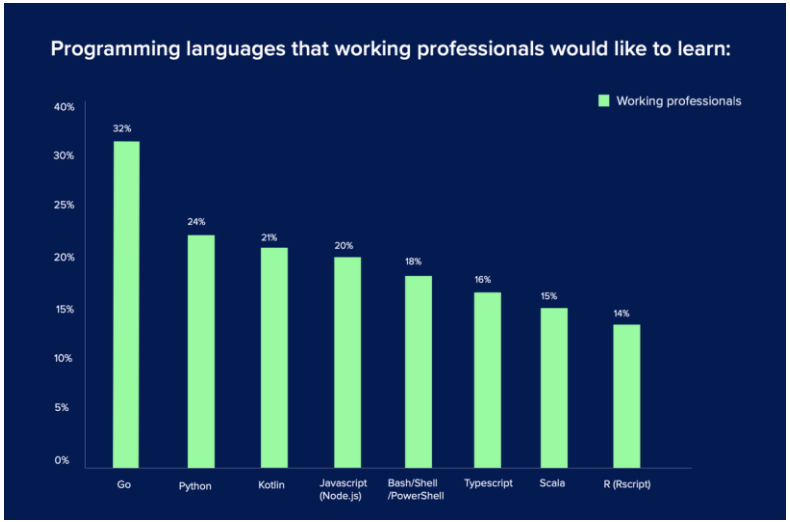
Go is popular

- Go is a language with the fastest-growing user base since 2011.



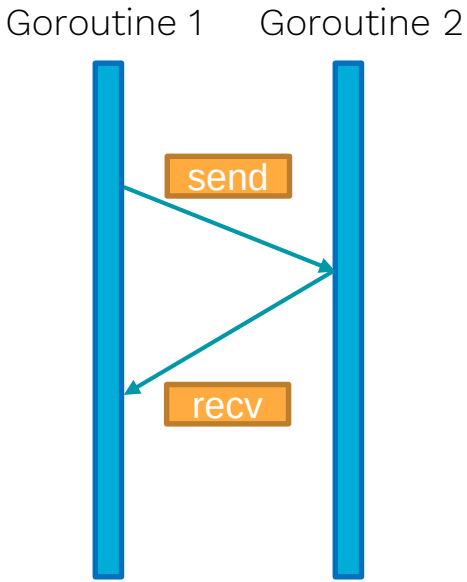


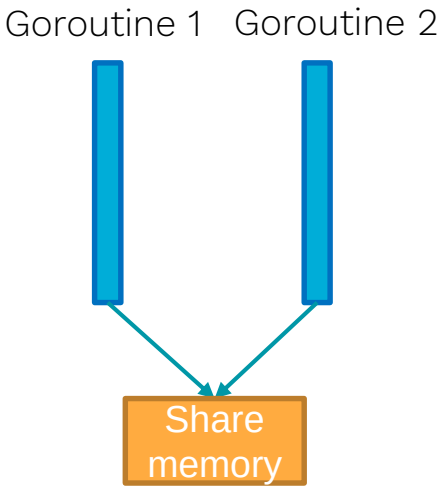
[1] Ranking Programming Languages by GitHub Users

[2] Developers say Google's Go is 'most sought after' programming language of 2020

Concurrency in Go

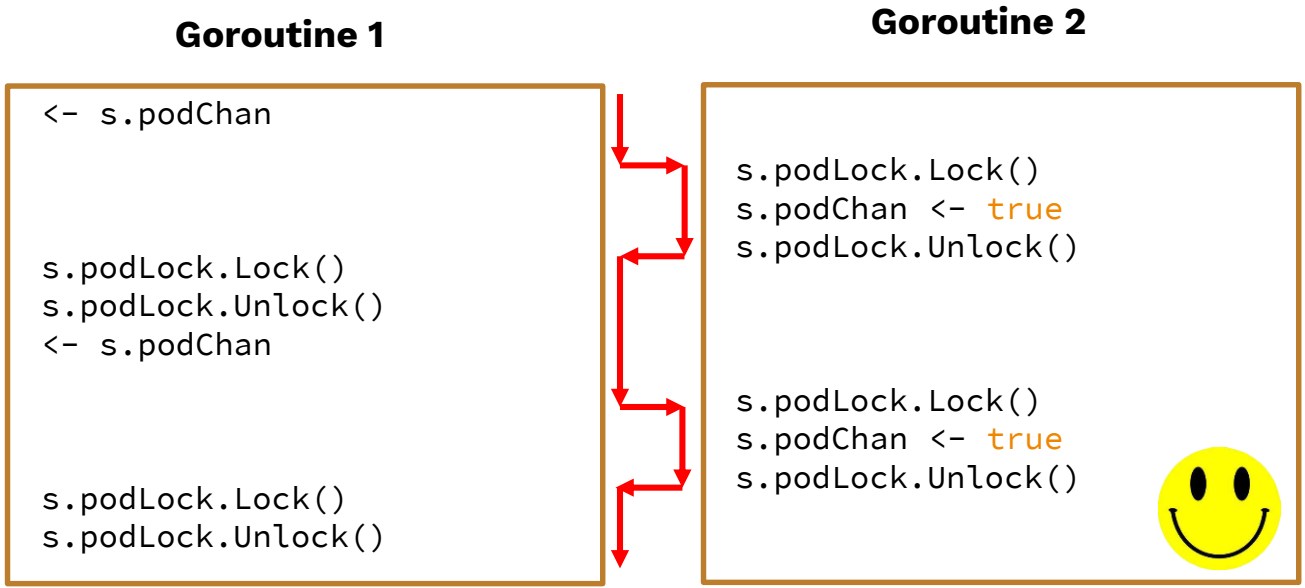
- Message passing and shared memory are widely used in real world Go applications.





Concurrency in Go

- However, using the two mechanisms together may easily lead to mistakes.



An example from Kubernetes

Concurrency in Go

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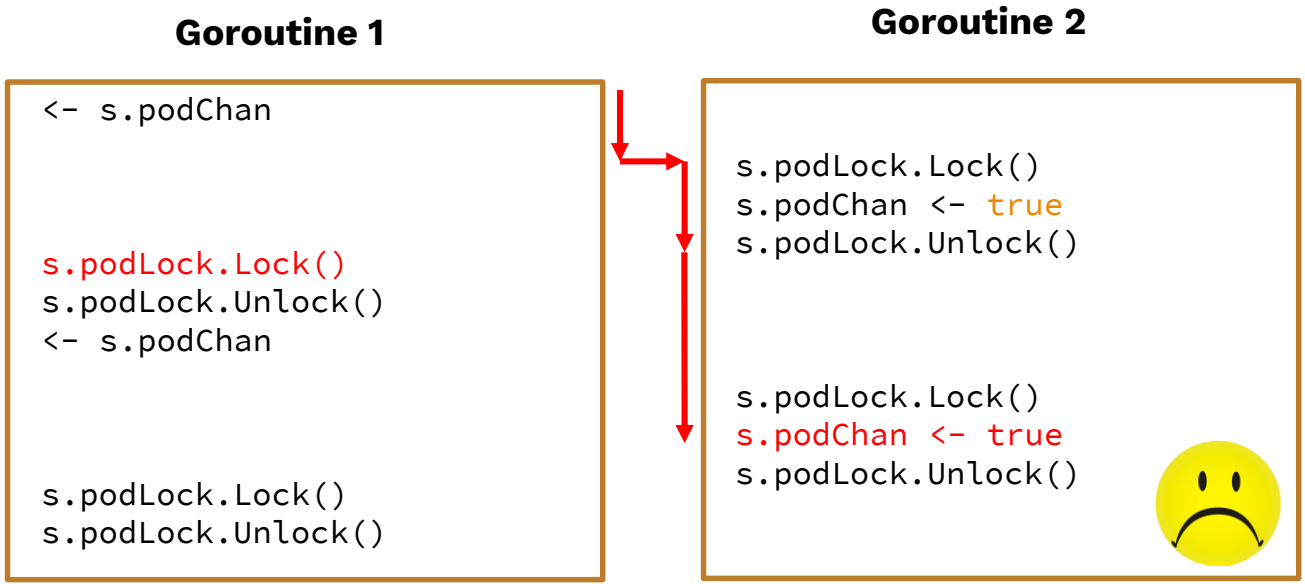


An example from Kubernetes

Concurrency in Go

- And there are also many Go specific non-blocking bugs

Goroutine 1

```
select {
    case <- s.donec:
        return
    default:
}
```

Goroutine 2

```
close(s.donec)
s.donec = nil
```

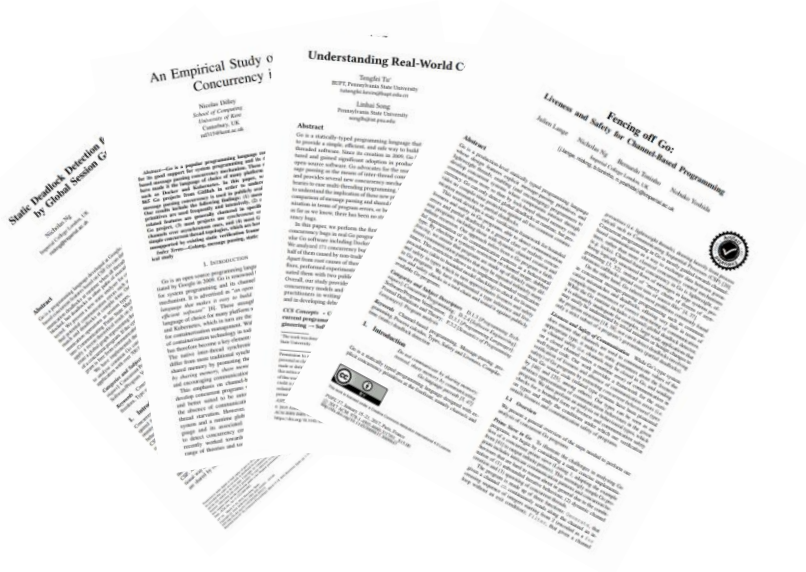
Channel misuse in Istio

```
for _, c := range checks {
    go func() {
        CheckInTxn(&c.Name)
    }
}
```

Anonymous function misuse in CockroachDB

Motivation

- Researches on *Go concurrency bugs* gradually rise



- Open source detectors:
  - goleak
  - go-deadlock
  - dingo-hunter
  - ... ...
- But so far there is no measurement to evaluate concurrency bug detectors on Go!

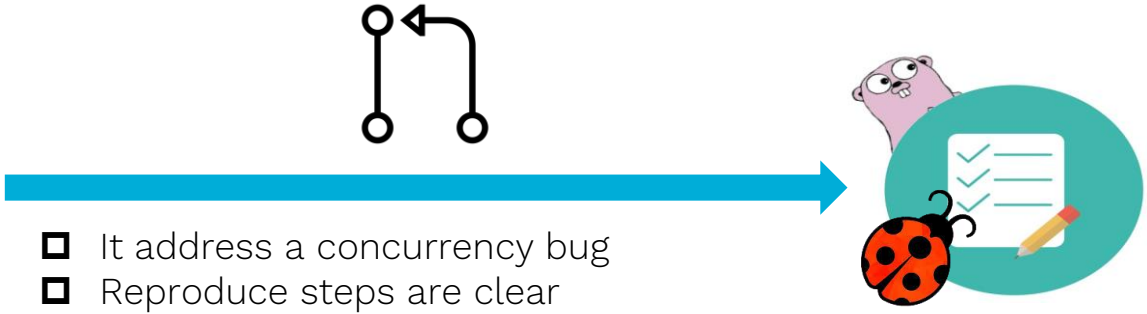
Overview of $GoBench$

- A benchmark suite of real-world $Go\ concurrency\ bugs$
- $GoBench$ is composed of $GoReal$ and $GoKer$
- $GoReal$: 82 representative bugs found in 9 popular open source applications
- $GoKer$: 103 bug kernels extracted from $GoReal$ and a recent study [1]

[1] Tu, Tengfei, et al. “Understanding real-world concurrency bugs in Go”. ASPLOS 2019.

GoReal: Real world bugs

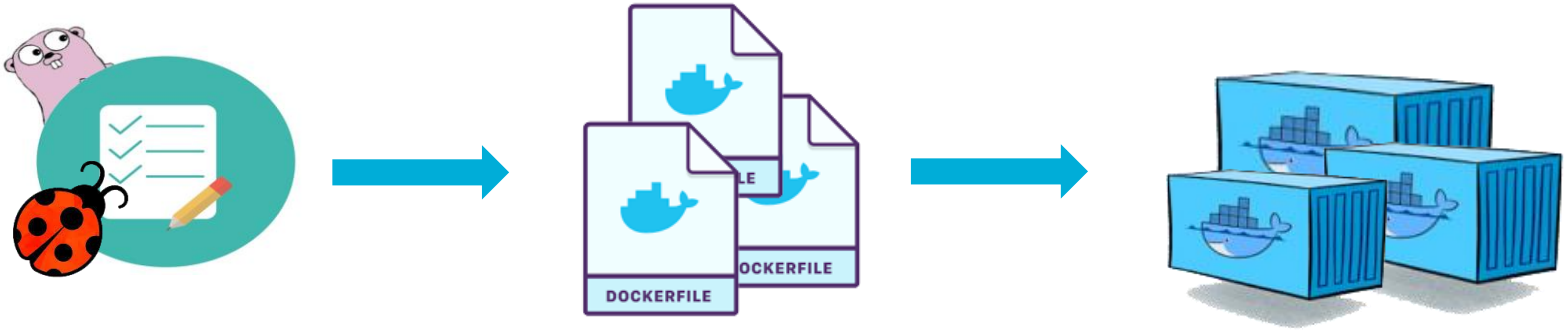
- Collect concurrency bugs in pull requests



- It address a concurrency bug
- Reproduce steps are clear
- There is a test function as the entry point

GoReal: Real world bugs

- Package those bugs into Dockerfiles



GoReal: Real world bugs

- Bug classification

Bug Type (#Bugs)	
Blocking Bugs (40)	Resource Deadlock (9)
	Communication Deadlock (21)
	Mixed Deadlock (10)
Non-blocking Bugs (42)	Traditional Bugs (24)
	Go-specific Bugs (18)

GoKer: Kernels extracted from real world bugs

- 36 bug kernels are reconstructed from a recent study.[1]
- 67 bug kernels are extracted from *GoReal*

There's a deadlock in `assignSimpleTokenToUser`. The function acquires lock `as.simpleTokensMu` and posts to `addSimpleTokenCh` (suppose that the channel is full so it blocks). If the goroutine `simpleTokenTTL-Keeper.run` happens to hit `<-tokenTicker.C`, it will try to acquire `simpleTokensMu` while calling `delete-TokenFunc`. Since only the goroutine `simpleToken-TTLKeeper.run` can drain `addSimpleTokenCh`, the lock is never released.

```
G1 [semacquire]:
.../auth.newDeleter.func1(...)
.../auth.(*simpleTokenTTLKeeper).run(...)
created by .../etcd/auth.NewSimpleTokenTTLKeeper

G4 [chan send]:
.../auth.(*simpleTokenTTLKeeper).addSimpleToken(...)
.../auth.(*tokenSimple).assignSimpleTokenToUser(...)
.../auth.(*tokenSimple).assign(...)
.../auth.(*authStore).Authenticate(...)
created by .../etcd/auth.TestHammerSimpleAuthenticate
```

[1] Tu, Tengfei, et al. "Understanding real-world concurrency bugs in Go". ASPLOS 2019.

GoKer: Kernels extracted from real world bugs

- We manually extract the code snippets into a separate test function.

```
func newDeleterFunc(t *tokenSimple) func(string) {
    return func(tk string) {
        t.simpleTokensMu.Lock()
        defer t.simpleTokensMu.Unlock()
-       if username, ok := t.simpleTokens[tk]; ok {
-           plog.Infof("deleting token %s for user %s", tk, username)
-           delete(t.simpleTokens, tk)
-       }
    }
}
type simpleTokenTTLKeeper struct {
    tokens              map[string]time.Time
-   addSimpleTokenCh    chan string
+   addSimpleTokenCh    chan struct{}
-   resetSimpleTokenCh  chan string
-   deleteSimpleTokenCh chan string
-   stopCh              chan chan struct{}
    deleteTokenFunc     func(string)
}
```

```
func TestEtcd7492(t *testing.T) {
    ... ...
    as := setupAuthStore()    // Fork G1
    var wg sync.WaitGroup
-   wg.Add(len(users))
+   wg.Add(3)
-   for u := range users {
+   for i := 0;i < 3; i ++ {
-       go func(user string) {
+       go func() {    // Fork G2, G3, and G4
            defer wg.Done()
-           ... ...
-           _, err := as.AuthInfoFromCtx(ctx)
-           if err != nil {
-               t.Fatal(err)
-           }
-       }(u)
+           as.Authenticate()
+       }()
    }
-   time.Sleep(time.Millisecond)
    wg.Wait()
    ... ...
}
```

GoKer: Kernels extracted from real world bugs

- Bug classification

Bug Type (#Bugs)	
Blocking Bugs (68)	Resource Deadlock (23)
	Communication Deadlock (29)
	Mixed Deadlock (16)
Non-blocking Bugs (35)	Traditional Bugs (21)
	Go-specific Bugs (14)

Evaluation

- Blocking bugs

Static tools: *dingo-hunter*
Dynamic tools: *go-leak, go-deadlock*

- Non-blocking bugs

Dynamic tools: *built-in race detector (Go-rd)*

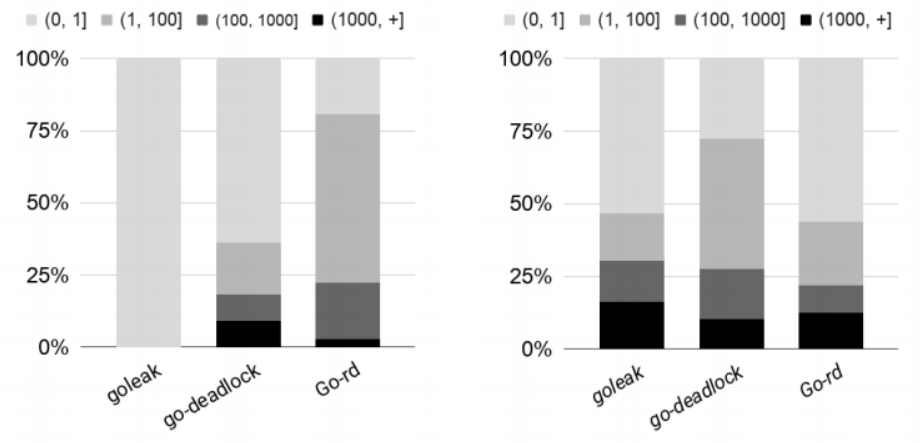
Blocking bugs

Suite	Bug Type	*goleak*	*go-deadlock*	*dingo-hunter*
		# TP/FN/FP	# TP/FN/FP	# TP/FN/FP
GoReal	Resource Deadlock	1/8/1	7/2/0	-/-/-
	Communication Deadlock	8/13/0	1/20/4	-/-/-
	Mixed Deadlock	3/7/1	4/6/3	-/-/-
	Total	12/28/2	12/28/7	-/-/-
GoKer	Resource Deadlock	14/9/0	23/0/0	0/23/0
	Communication Deadlock	20/9/0	0/29/0	1/28/0
	Mixed Deadlock	9/7/0	6/10/0	0/16/0
	Total	43/25/0	29/39/0	1/67/0

Non-blocking bugs

Suite	Bug Type	*Go-rd*		
		#TP	#FN	#FP
GoReal	Traditional	23	1	0
	Go-specific	13	5	0
	Total	36	6	0
GoKer	Traditional	21	0	0
	Go-specific	11	3	0
	Total	32	3	0

Efficiency of dynamic tools

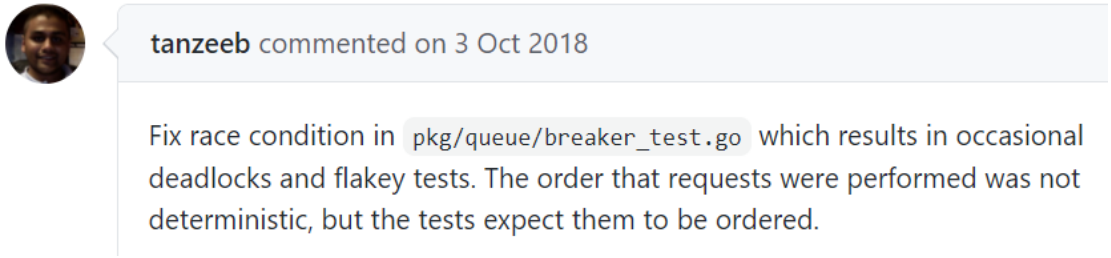


(a) GoReal (b) GoKer

Fig. 10. Percentage distribution for the (average) number of runs falling into each of the four given intervals that is needed by a tool in finding a bug.

A case study (serving#2137)

- A mixed deadlock bug reported in Knative/serving



https://github.com/knative/serving/pull/2137

A case study (serving#2137)

- Goroutines in this case are spawn within a for loop. Multiple buffered channels are involved in the mixed deadlock, and their buffer sizes are different.

- Currently, there is no static tool that can detect it. Dynamic tools require tens of thousands of times to trigger the bug.

- You can try its bug kernel: https://github.com/timmyyuan/gobench/blob/master/gobench/goker/blocking/serving/2137/serving2137_test.go

Conclusion

- $GoBench$ is the first benchmark suite of real-world $Go\ concurrency\ bugs$.
- Static tools need to improve the effectiveness of finding concurrency bugs in Go.
- Dynamic tools need to improve the efficiency of finding concurrency bugs in Go.

Conclusion

- We publish $GoBench$ at https://github.com/timmyyuan/gobench
- We believe $GoBench$ will be instrumental in helping researchers understand concurrency bugs in Go and develop effective tools for their detection.

THANK YOU

Q&A

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