Debugging concurrent programs in Go

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cat /etc/about_me

- From Ukraine :
- Gopher, OSS contributor
- father of 👧 👶
- debuggers fan
- Speaker at many conferences

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Concurrency Programming is Challenging!

[redacted]

Debugging concurrent programs is Hard!

8 stages of debugging

1. That can’t happen.
2. That doesn’t happen on my machine.
3. That shouldn’t happen.
4. Why does that happen?
5. Oh, I see 🤔
6. How did that ever work? 🤦
7. Who wrote this 💩 💩 💩
8. Oh wait, that was me. (From reddit)

Debugging sequential programs

```
dlv test -- -test.run TestFibonacciBig
(dlv) b main_test.go:6
Breakpoint 1 set at 0x115887f for github.com/andriisoldatenko/
debug_test.TestFibonacciBig() ./main_test.go:6
(dlv) c
> github.com/andriisoldatenko/debug_test.TestFibonacciBig() ./
main_test.go:6 (hits goroutine(17):1 total:1) (PC: 0x115887f)
     1:  package main
     2:
     3:  import "testing"
     4:
     5:  func TestFibonacciBig(t *testing.T) {
=>   6:    var want int64 = 55
     7:    got := FibonacciBig(10)
     8:    if got.Int64() != want {
     9:      t.Errorf("Invalid Fibonacci value for N: %d, got: %d,
want: %d", 10, got.Int64(), want)
    10:    }
    11:  }
(dlv)
```

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Debugging concurrent programs

```go
package main

import (
	"fmt"
	"time"
)

func say(s string) {
	for i := 0; i < 5; i++ {
		time.Sleep(100 * time.Millisecond)
		fmt.Println(s)
	}
}

func main() {
	go say("world")
	say("hello")
}
```

```
gowayfest git:(master) ✗ go run main.go
hello
world
world
hello
hello
world
world
hello
world
hello
gowayfest git:(master) ✗ go run main.go
world
hello
hello
world
hello
world
world
hello
hello
world
```

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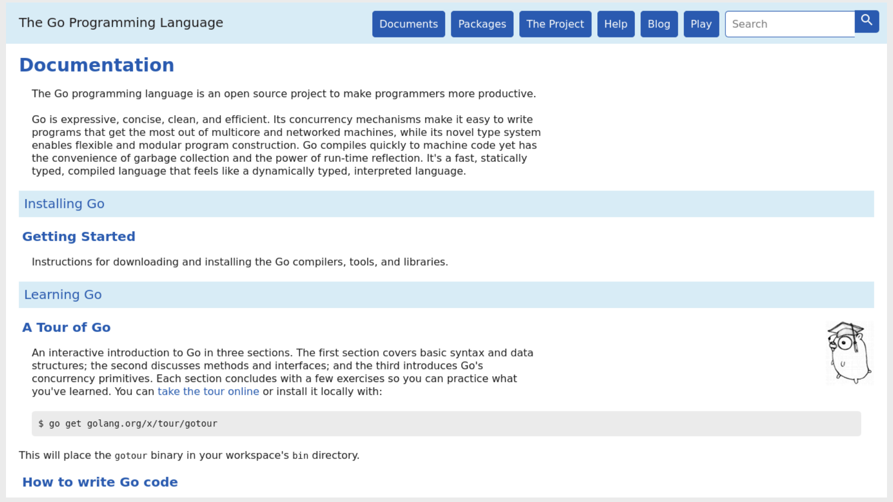

The Go Programming Language

Documents Packages The Project Help Blog Play Search

Documentation

The Go programming language is an open source project to make programmers more productive.

Go is expressive, concise, clean, and efficient. Its concurrency mechanisms make it easy to write programs that get the most out of multicore and networked machines, while its novel type system enables flexible and modular program construction. Go compiles quickly to machine code yet has the convenience of garbage collection and the power of run-time reflection. It's a fast, statically typed, compiled language that feels like a dynamically typed, interpreted language.

Installing Go

Getting Started

Instructions for downloading and installing the Go compilers, tools, and libraries.

Learning Go

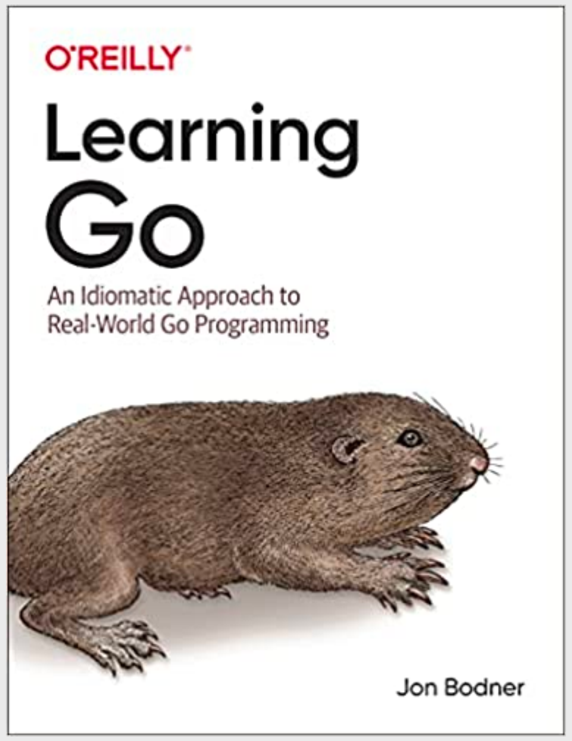
A Tour of Go

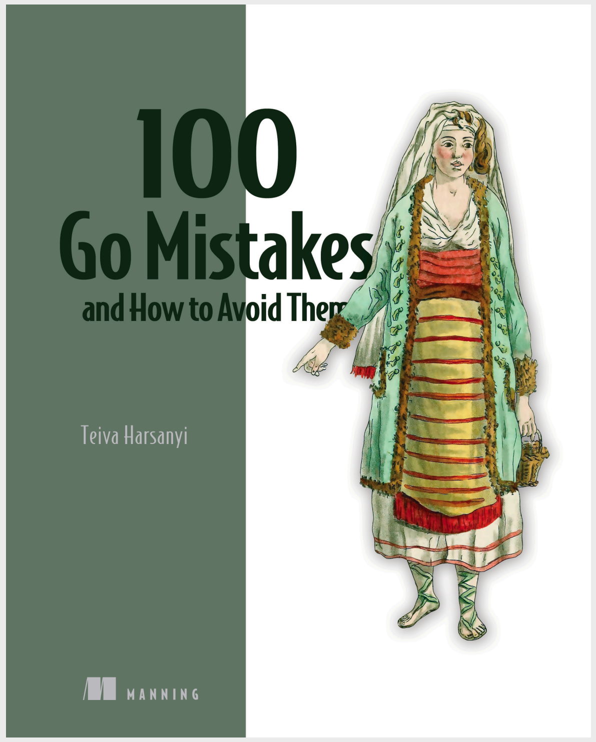
An interactive introduction to Go in three sections. The first section covers basic syntax and data structures; the second discusses methods and interfaces; and the third introduces Go's concurrency primitives. Each section concludes with a few exercises so you can practice what you've learned. You can take the tour online or install it locally with:

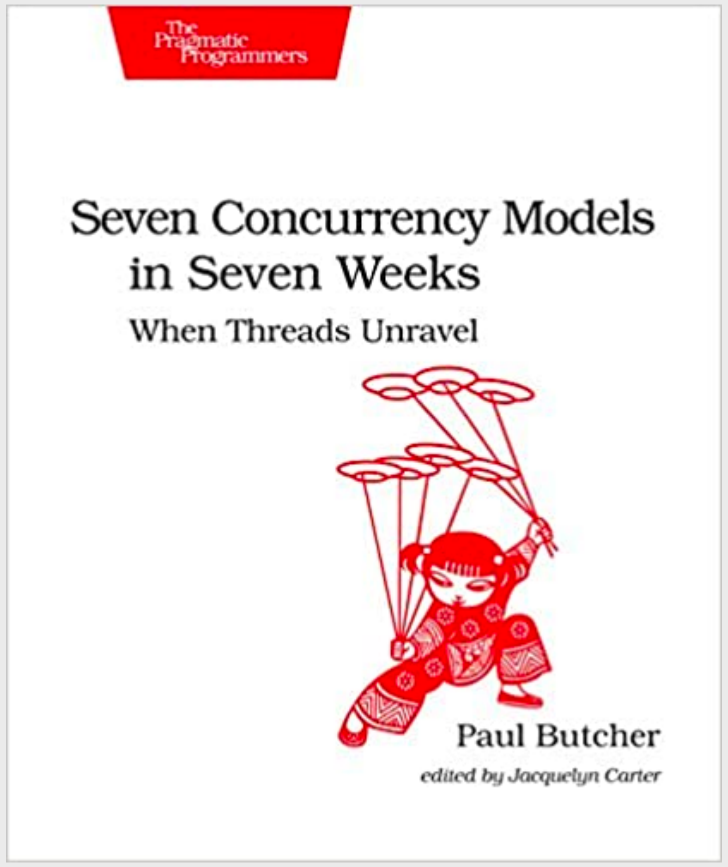
```
$ go get golang.org/x/tour/gotour
```

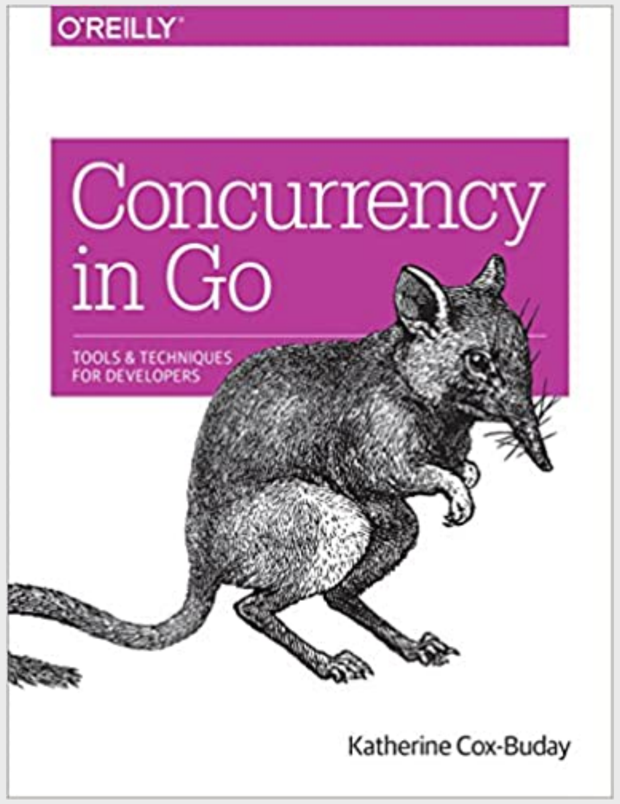
This will place the `gotour` binary in your workspace's `bin` directory.

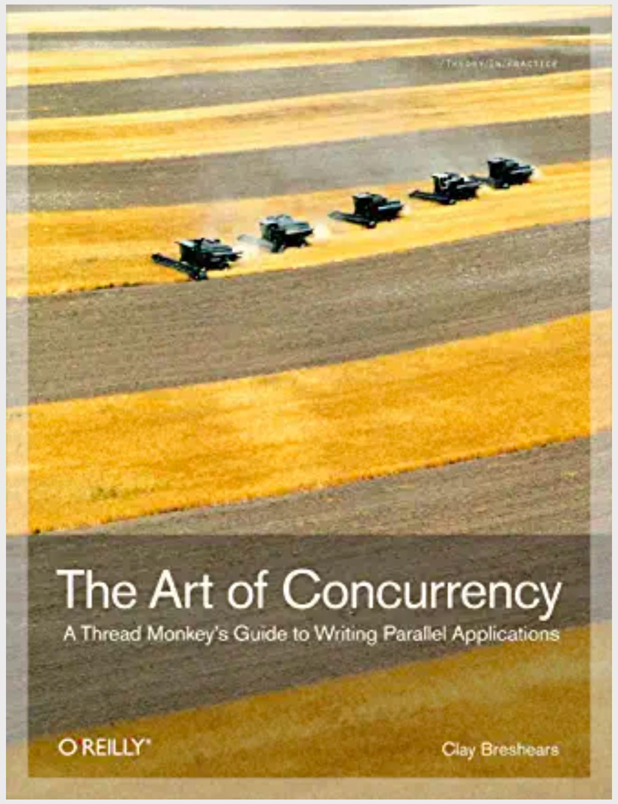
How to write Go code






The Pragmatic Programmers
Seven Concurrency Models in Seven Weeks
When Threads Unravel
Paul Butcher
edited by Jacquelyn Carter





What is a goroutine?

```
type g struct {
    stack            stack
    stackguard0      uintptr
    stackguard1      uintptr
    _panic           *_panic
    _defer           *_defer
    m                *m
    sched            gobuf
    syscallsp        uintptr
    syscallpc        uintptr
    stktopsp         uintptr
    param            unsafe.Pointer
    atomicstatus     uint32
    stackLock        uint32
    goid             int64
    schedlink        guintptr
    waitsince        int64
    waitreason       waitReason
    preempt          bool
    preemptStop      bool
    preemptShrink    bool
    asyncSafePoint   bool
    paniconfault     bool
    gcscandone       bool
    throwsplit       bool
    activeStackChans bool
    raceignore       int8
    sysblocktraced   bool
    sysexitticks     int64
    traceseq         uint64
    tracelastp       puintptr
    lockedm          muintptr
    sig              uint32
    writebuf         []byte
    sigcode0         uintptr
    sigcode1         uintptr
    sigpc            uintptr
    gopc             uintptr
    ancestors        *[]ancestorInfo
    startpc          uintptr
    racectx          uintptr
    waiting          *sudog
    cgoCtxt          []uintptr
    labels           unsafe.Pointer
    timer            *timer
    selectDone       uint32
    gcAssistBytes    int64
}
```

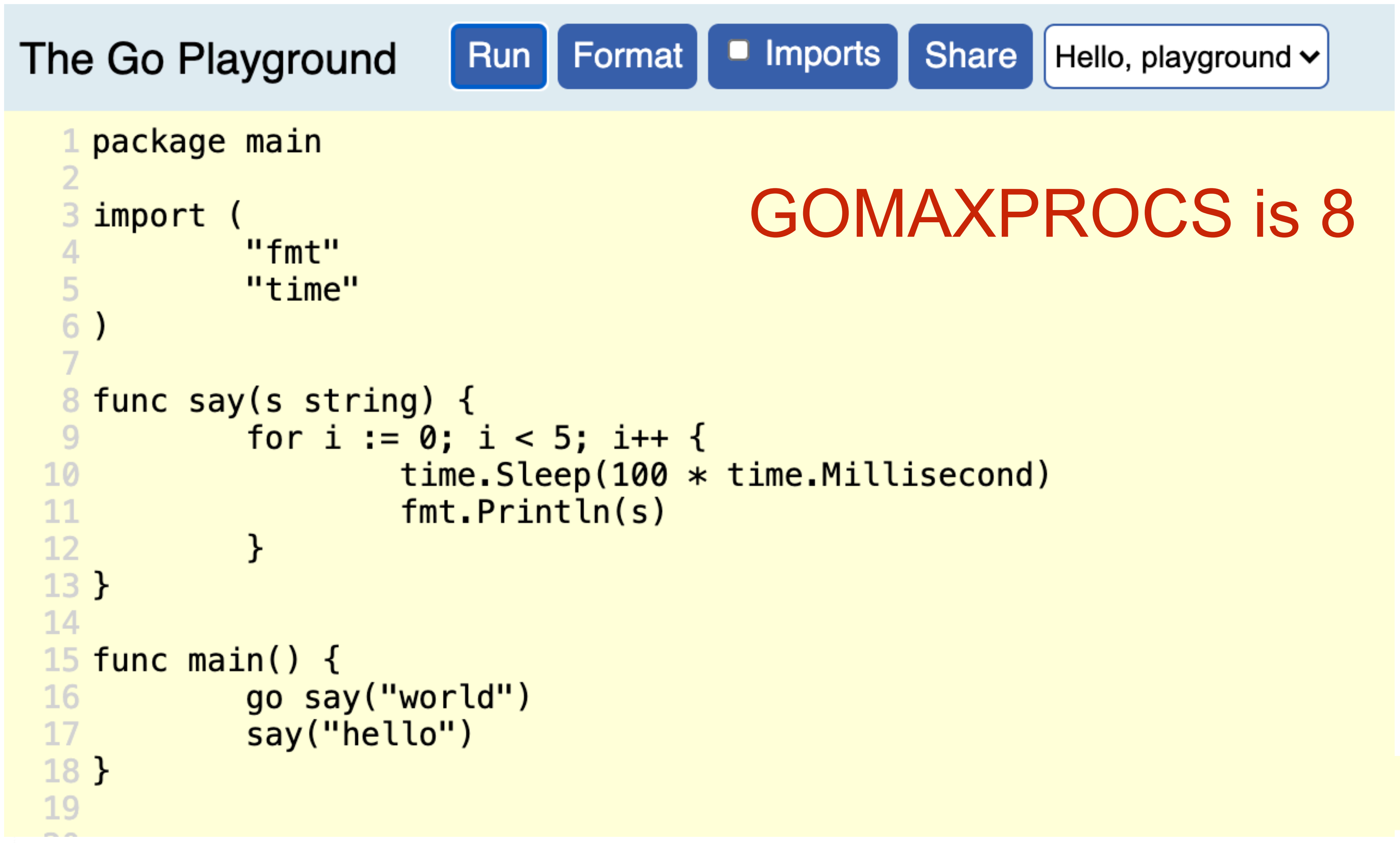
https://tpaschalis.github.io/goroutines-size/

Do you know why gorotines?

Question to audience!

How can I debug my concurrent Go program?

Playground



GOMAXPROCS is 8

```go
package main

import (
	"fmt"
	"time"
)

func say(s string) {
	for i := 0; i < 5; i++ {
		time.Sleep(100 * time.Millisecond)
		fmt.Println(s)
	}
}

func main() {
	go say("world")
	say("hello")
}

```

```
hello                                     hello
world                                     world
world                                     world
hello                                     hello
world                                     world
hello                                     hello
hello                                     hello
world                                     world
world                                     world
hello                                     hello
```

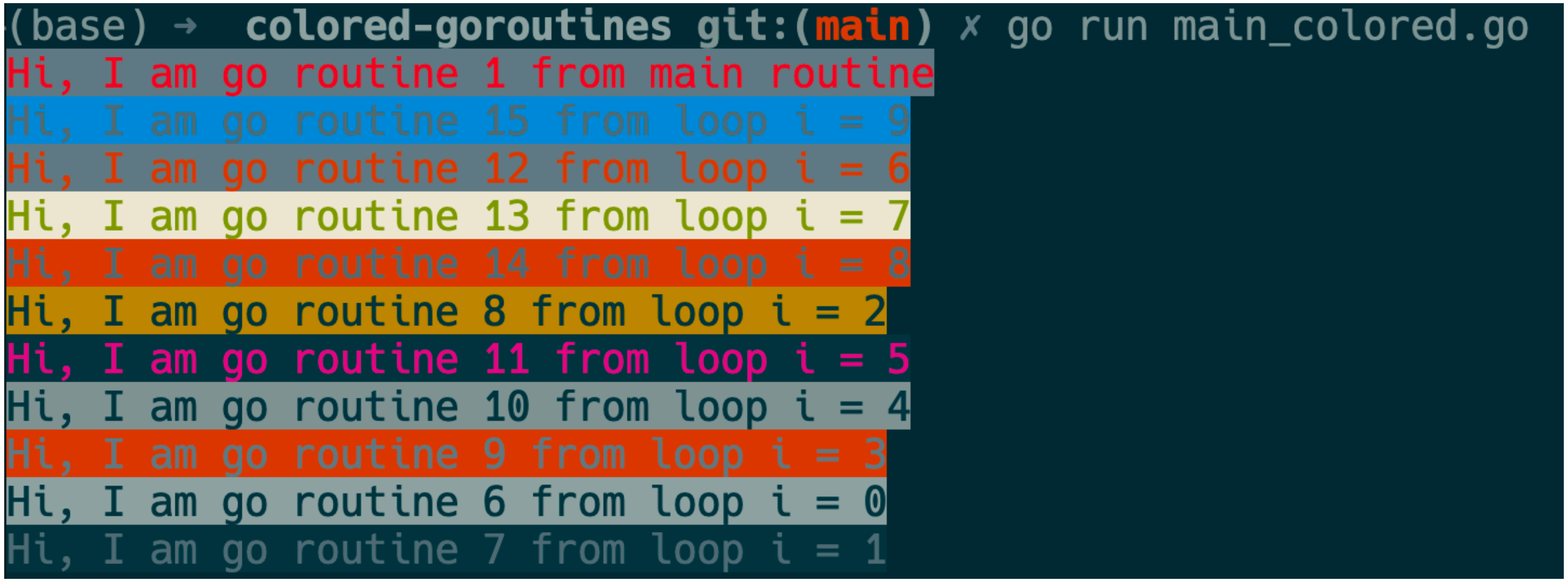
Developers which are using coloured logs

Developers which are using prints

visualize goroutines🐞 ?

```go
func main() {

        c := coloredgoroutine.Colors(os.Stdout)

        fmt.Fprintln(c, "Hi, I am go routine", goid.ID(), "from main routine")

        count := 10

        var wg sync.WaitGroup
        wg.Add(count)

        for i := 0; i < count; i++ {
                i := i
                go func() {
                        fmt.Fprintln(c, "Hi, I am go routine", goid.ID(), "from 
loop i =", i)
                        wg.Done()
                }()
        }
        wg.Wait()
}
```

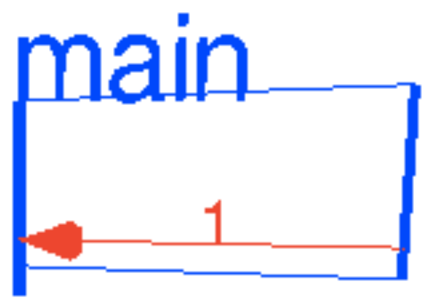
visualize goroutines🐞 ?



```
(base) ➜  colored-goroutines git:(main) ✗ go run main_colored.go
Hi, I am go routine 1 from main routine
Hi, I am go routine 15 from loop i = 9
Hi, I am go routine 12 from loop i = 6
Hi, I am go routine 13 from loop i = 7
Hi, I am go routine 14 from loop i = 8
Hi, I am go routine 8 from loop i = 2
Hi, I am go routine 11 from loop i = 5
Hi, I am go routine 10 from loop i = 4
Hi, I am go routine 9 from loop i = 3
Hi, I am go routine 6 from loop i = 0
Hi, I am go routine 7 from loop i = 1
```

https://github.com/xiegeo/coloredgoroutine

visualize goroutines🐞 ?



https://divan.dev/posts/go_concurrency_visualize/

scheduling events

Print scheduling events?

```
$ GODEBUG=schedtrace=5000 <binary>
```

```
SCHED 0ms: gomaxprocs=28 idleprocs=25 threads=4 spinningthreads=1 idlethreads=0 r
# command-line-arguments
SCHED 0ms: gomaxprocs=28 idleprocs=25 threads=5 spinningthreads=1 idlethreads=0 r
# command-line-arguments
SCHED 0ms: gomaxprocs=28 idleprocs=25 threads=5 spinningthreads=1 idlethreads=0 r
SCHED 0ms: gomaxprocs=28 idleprocs=25 threads=5 spinningthreads=1 idlethreads=0 r
hello
world
Channel 1: world
Channel 2: hello
```

using debuggers:

- delve
- gdb

How to set breakpoint inside goroutine?

```go
package main

import (
	"fmt"
)

func say(s string, r chan string) {
	fmt.Println(s)
	r <- s
}

func main() {
	chan1 := make(chan string)
	chan2 := make(chan string)

	go say("world", chan1)
	go say("hello", chan2)

	res1 := <-chan1
	res2 := <-chan2

	fmt.Printf("Channel 1: %s\nChannel 2: %s\n", res1, res2)
}
```

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How to set breakpoint inside goroutine?

```
> main.say() ./main.go:9 (hits goroutine(7):1 total:1) (PC:
0x10c46c9)
     4:         "fmt"
     5: )
     6:
     7: func say(s string, r chan string) {
     8:         fmt.Println(s)
=>   9:         r <- s
    10: }
    11:
    12: func main() {
    13:         chan1 := make(chan string)
    14:         chan2 := make(chan string)
```

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How to debug channel?

```go
package main


func main() {
  ch := make(chan int, 4)
  ch <- 1
  ch <- 2
  ch <- 3
  ch <- 4
  close(ch)
}
```

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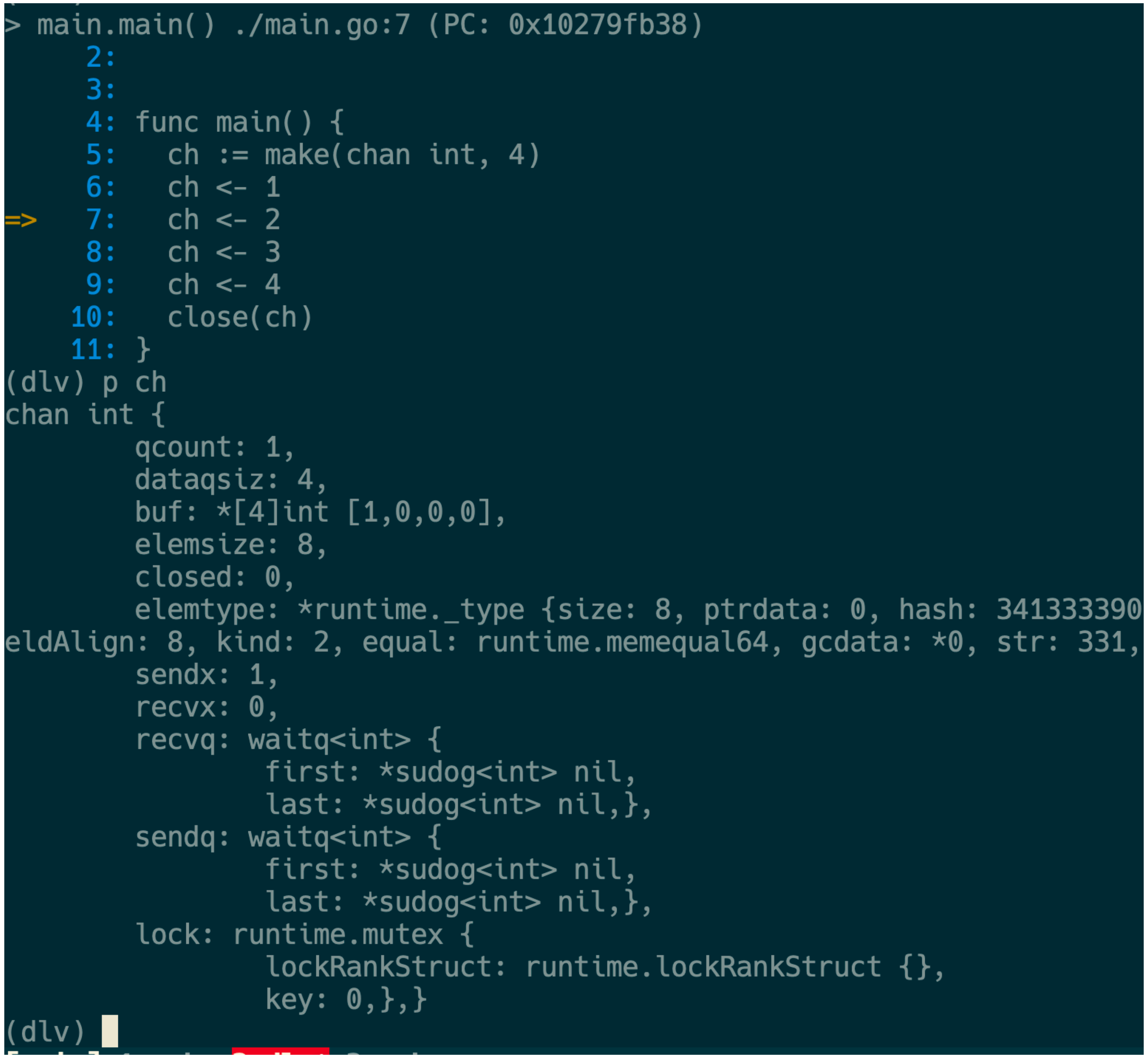
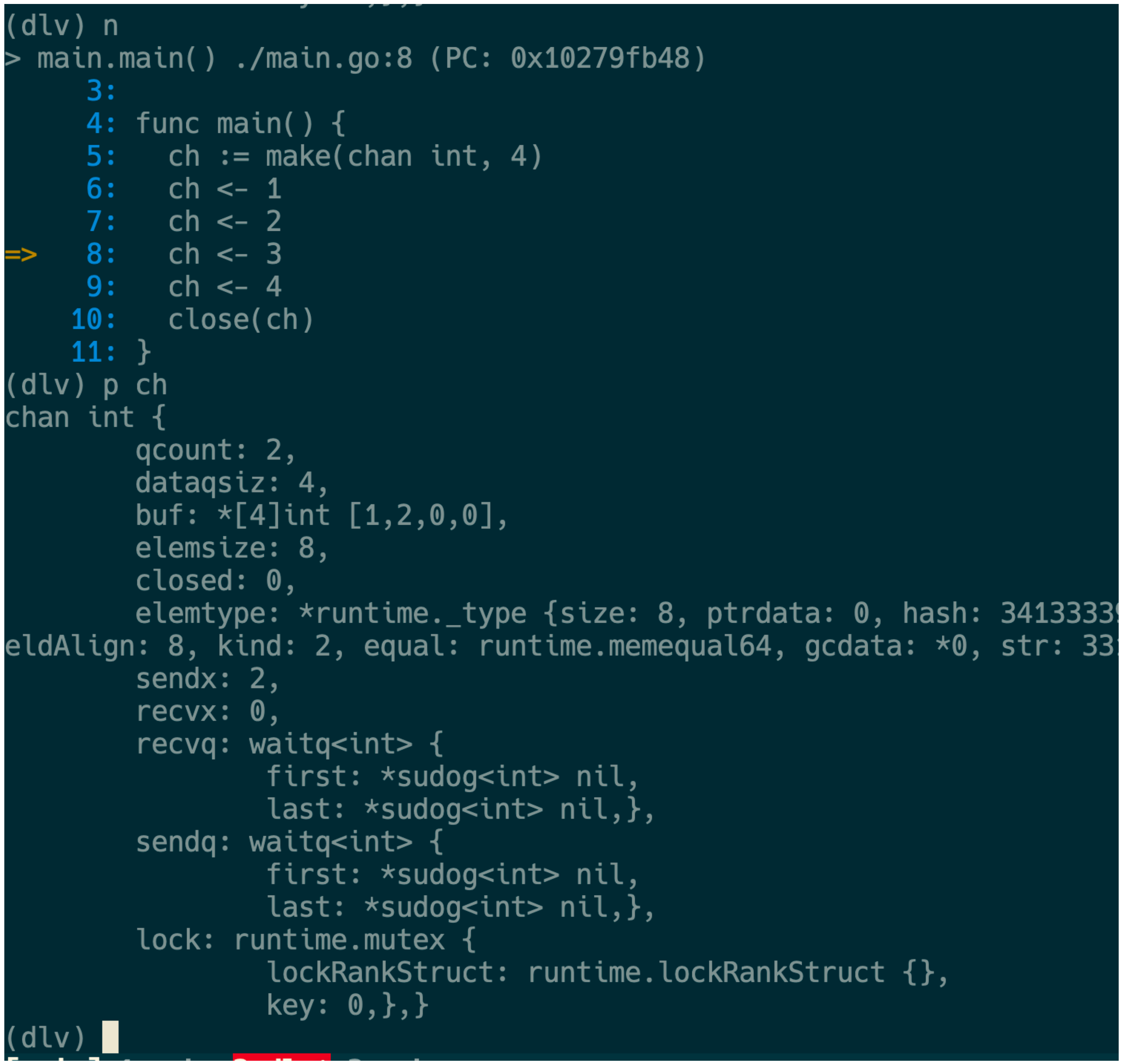
How to debug channel?



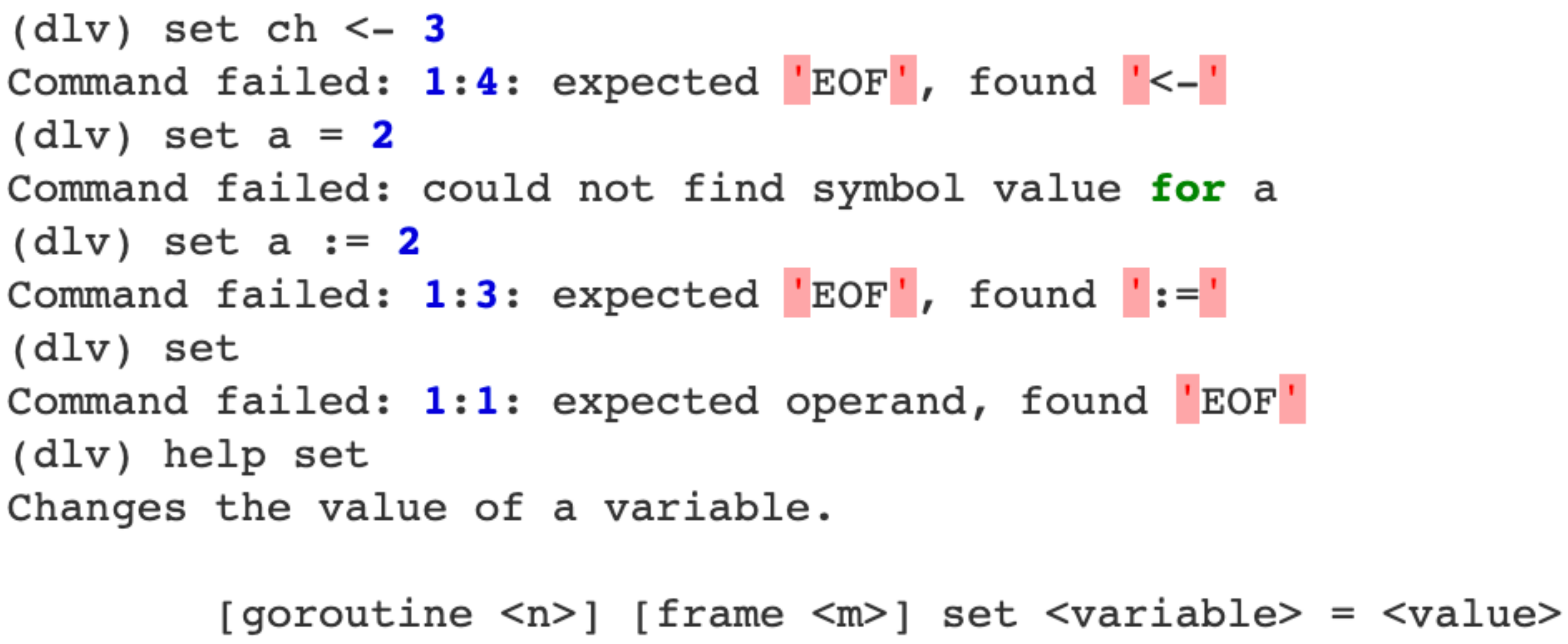
```
> main.main() ./main.go:7 (PC: 0x10279fb38)
     2:
     3:
     4: func main() {
     5:   ch := make(chan int, 4)
     6:   ch <- 1
=>   7:   ch <- 2
     8:   ch <- 3
     9:   ch <- 4
    10:   close(ch)
    11: }
(dlv) p ch
chan int {
        qcount: 1,
        dataqsiz: 4,
        buf: *[4]int [1,0,0,0],
        elemsize: 8,
        closed: 0,
        elemtype: *runtime._type {size: 8, ptrdata: 0, hash: 341333390
eldAlign: 8, kind: 2, equal: runtime.memequal64, gcdata: *0, str: 331,
        sendx: 1,
        recvx: 0,
        recvq: waitq<int> {
                first: *sudog<int> nil,
                last: *sudog<int> nil,},
        sendq: waitq<int> {
                first: *sudog<int> nil,
                last: *sudog<int> nil,},
        lock: runtime.mutex {
                lockRankStruct: runtime.lockRankStruct {},
                key: 0,},}
(dlv)
```

How to debug channel?



```
(dlv) n
> main.main() ./main.go:8 (PC: 0x10279fb48)
     3:
     4: func main() {
     5:   ch := make(chan int, 4)
     6:   ch <- 1
     7:   ch <- 2
=>   8:   ch <- 3
     9:   ch <- 4
    10:   close(ch)
    11: }
(dlv) p ch
chan int {
        qcount: 2,
        dataqsiz: 4,
        buf: *[4]int [1,2,0,0],
        elemsize: 8,
        closed: 0,
        elemtype: *runtime._type {size: 8, ptrdata: 0, hash: 3413333
eldAlign: 8, kind: 2, equal: runtime.memequal64, gcdata: *0, str: 33
        sendx: 2,
        recvx: 0,
        recvq: waitq<int> {
                first: *sudog<int> nil,
                last: *sudog<int> nil,},
        sendq: waitq<int> {
                first: *sudog<int> nil,
                last: *sudog<int> nil,},
        lock: runtime.mutex {
                lockRankStruct: runtime.lockRankStruct {},
                key: 0,},}
(dlv)
```

dlv send to channel value similar to set variable.

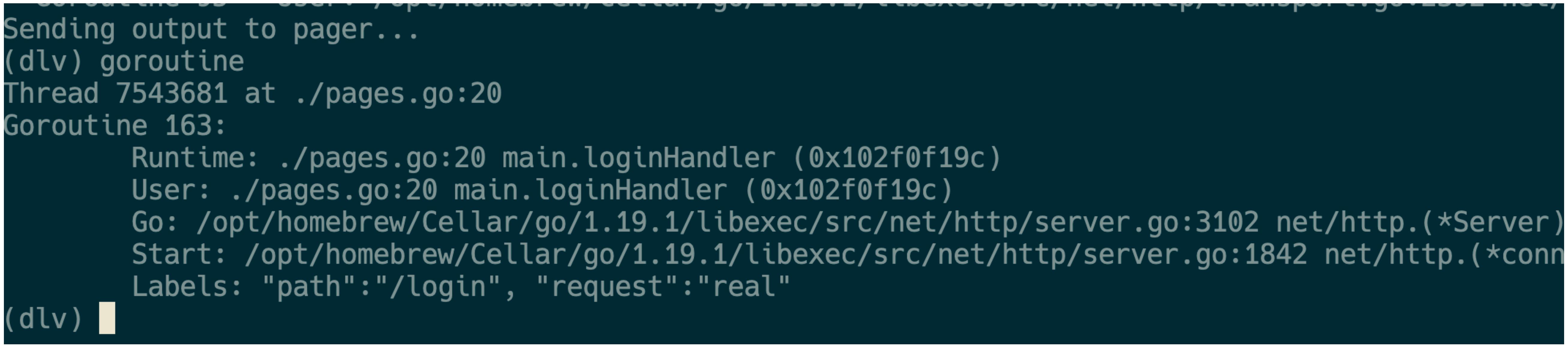


```
(dlv) set ch <- 3
Command failed: 1:4: expected 'EOF', found '<-'
(dlv) set a = 2
Command failed: could not find symbol value for a
(dlv) set a := 2
Command failed: 1:3: expected 'EOF', found ':='
(dlv) set
Command failed: 1:1: expected operand, found 'EOF'
(dlv) help set
Changes the value of a variable.

        [goroutine <n>] [frame <m>] set <variable> = <value>
```

https://github.com/go-delve/delve/issues/2117

dlv goroutine



```
Sending output to pager...
(dlv) goroutine
Thread 7543681 at ./pages.go:20
Goroutine 163:
        Runtime: ./pages.go:20 main.loginHandler (0x102f0f19c)
        User: ./pages.go:20 main.loginHandler (0x102f0f19c)
        Go: /opt/homebrew/Cellar/go/1.19.1/libexec/src/net/http/server.go:3102 net/http.(*Server)
        Start: /opt/homebrew/Cellar/go/1.19.1/libexec/src/net/http/server.go:1842 net/http.(*conn
        Labels: "path":"/login", "request":"real"
(dlv) 
```

Profile labels

```
labels := pprof.Labels("worker", "purge")
pprof.Do(ctx, labels, func(ctx context.Context) {
    // Do some work...

    go update(ctx) // propagates labels in ctx.
})
```

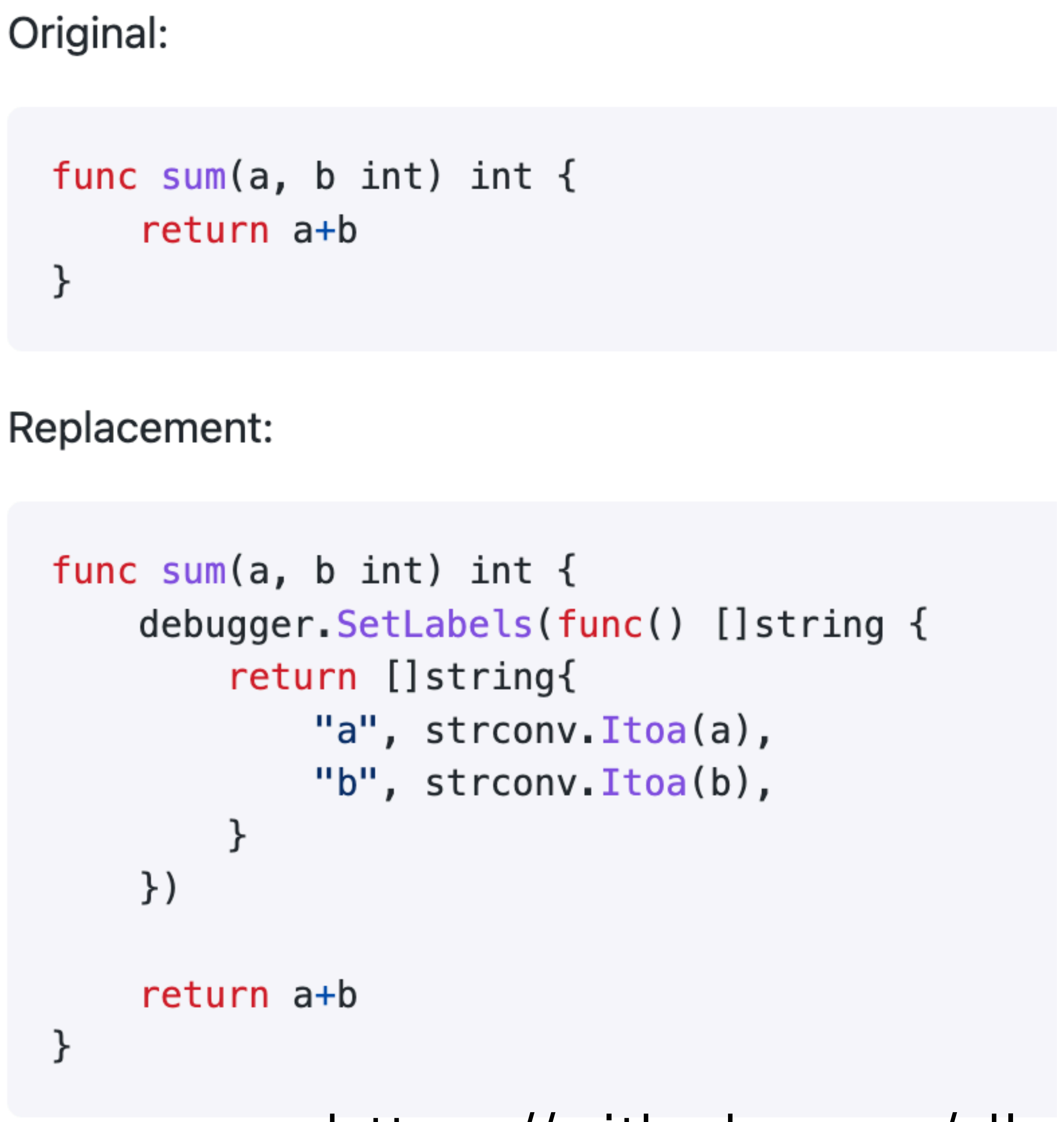
goroutines labels

```go
go func(p string, rid int64) {
    labels := pprof.Labels("request", "automated", "page", p, "rid", str
    pprof.Do(context.Background(), labels, func(_ context.Context) {
        makeRequest(activeConns, c, p, rid)
    })
}(page, i)
```

Or you can use Debugger Middleware

```
router.HandleFunc("/", debugger.Middleware(homeHandler, func(r *http.Request) []string {
    return []string{
        "path", r.RequestURI,
    }
}))
```

Or you can use Directly



Original:

```go
func sum(a, b int) int {
	return a+b
}
```

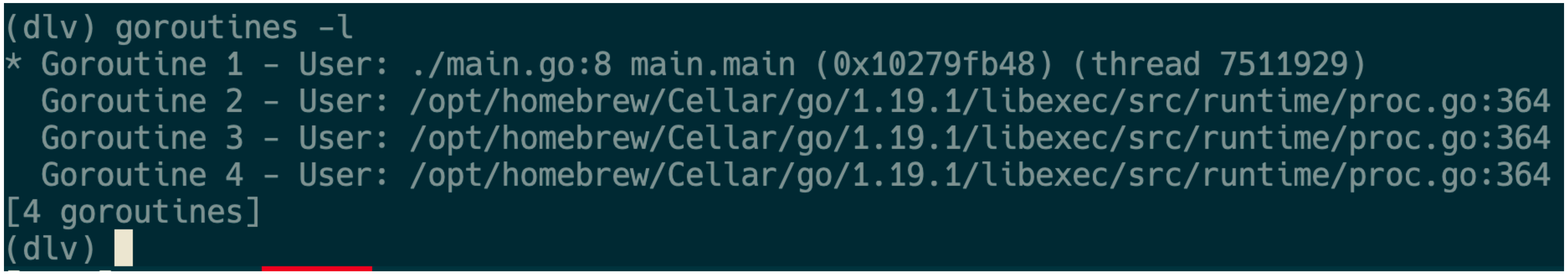
Replacement:

```go
func sum(a, b int) int {
	debugger.SetLabels(func() []string {
		return []string{
			"a", strconv.Itoa(a),
			"b", strconv.Itoa(b),
		}
	})

	return a+b
}
```

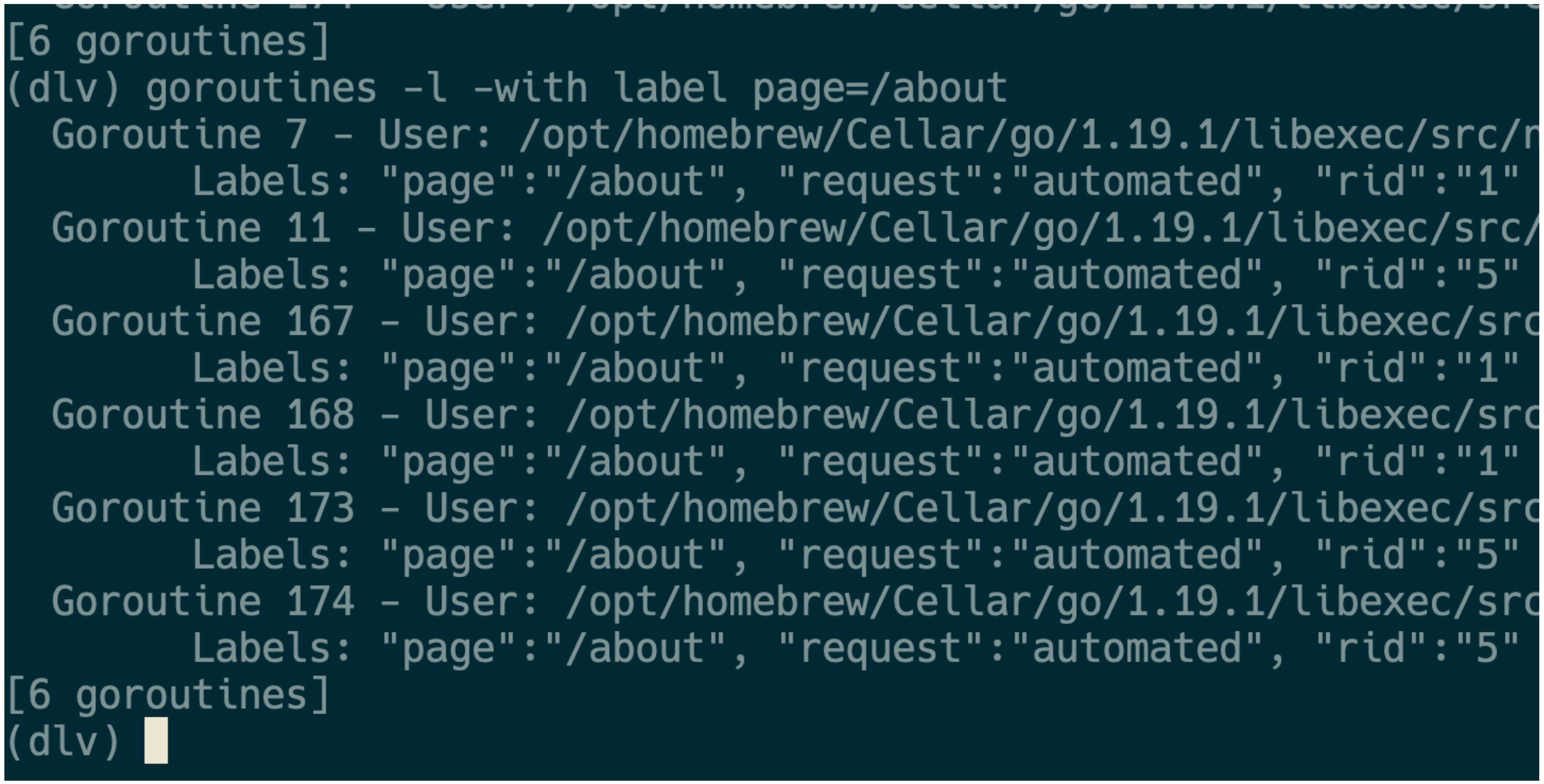
https://github.com/dlsniper/debugger

goroutines dlv



```
(dlv) goroutines -l
* Goroutine 1 - User: ./main.go:8 main.main (0x10279fb48) (thread 7511929)
  Goroutine 2 - User: /opt/homebrew/Cellar/go/1.19.1/libexec/src/runtime/proc.go:364
  Goroutine 3 - User: /opt/homebrew/Cellar/go/1.19.1/libexec/src/runtime/proc.go:364
  Goroutine 4 - User: /opt/homebrew/Cellar/go/1.19.1/libexec/src/runtime/proc.go:364
[4 goroutines]
(dlv) 
```

goroutines labels golang

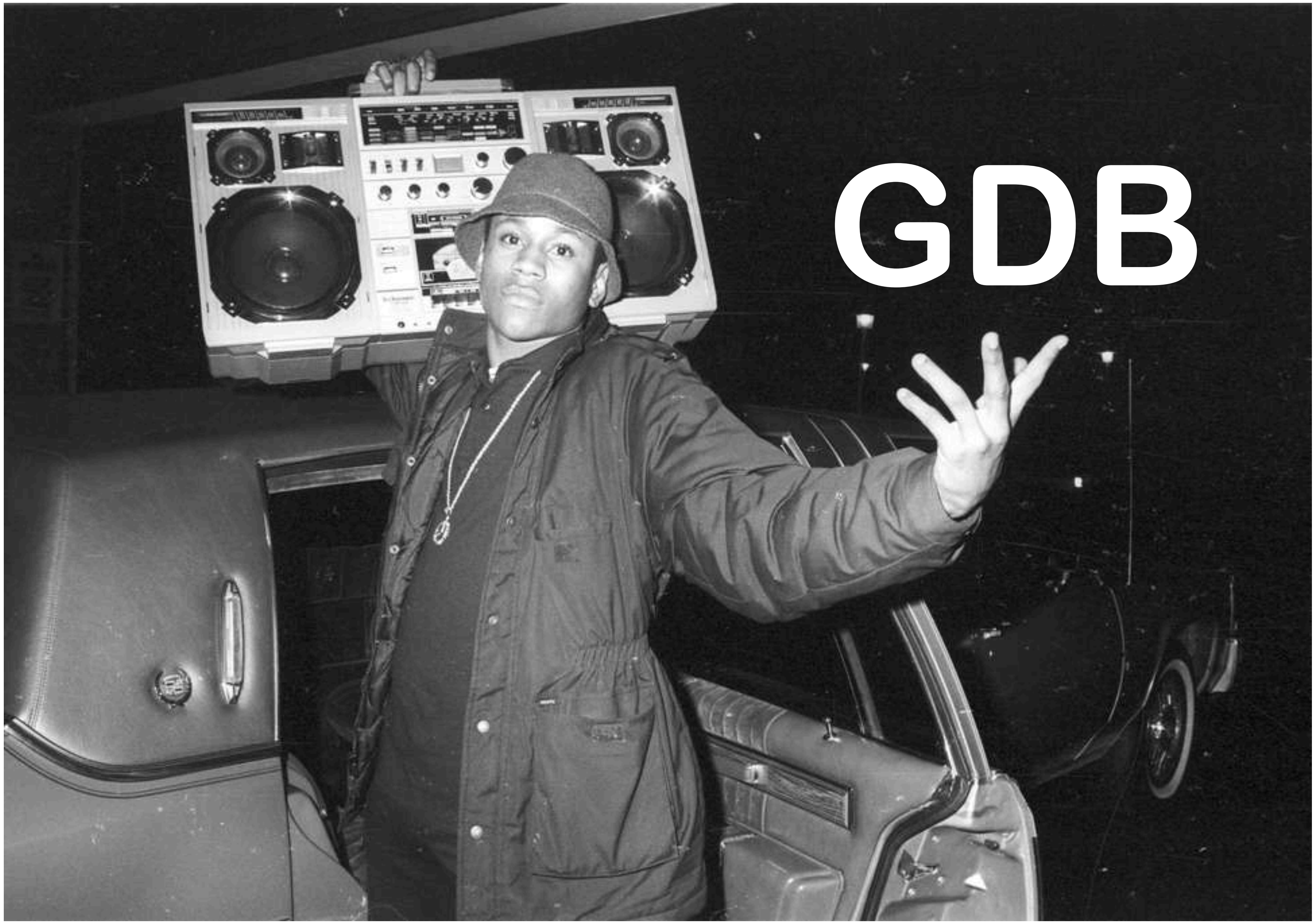


```
[6 goroutines]
(dlv) goroutines -l -with label page=/about
  Goroutine 7 - User: /opt/homebrew/Cellar/go/1.19.1/libexec/src/r
        Labels: "page":"/about", "request":"automated", "rid":"1"
  Goroutine 11 - User: /opt/homebrew/Cellar/go/1.19.1/libexec/src/
        Labels: "page":"/about", "request":"automated", "rid":"5"
  Goroutine 167 - User: /opt/homebrew/Cellar/go/1.19.1/libexec/src
        Labels: "page":"/about", "request":"automated", "rid":"1"
  Goroutine 168 - User: /opt/homebrew/Cellar/go/1.19.1/libexec/src
        Labels: "page":"/about", "request":"automated", "rid":"1"
  Goroutine 173 - User: /opt/homebrew/Cellar/go/1.19.1/libexec/src
        Labels: "page":"/about", "request":"automated", "rid":"5"
  Goroutine 174 - User: /opt/homebrew/Cellar/go/1.19.1/libexec/src
        Labels: "page":"/about", "request":"automated", "rid":"5"
[6 goroutines]
(dlv) 
```

You can play on you own using example project:

https://github.com/dlsniper/serverdemo

```
dlv debug --build-flags="-ldflags=-s -tags=debugger" *.go
```


GDB

Gdb and golang

```
go build -ldflags=-compressdwarf=false
-gcflags=all="-N -l" -o main main.go
```

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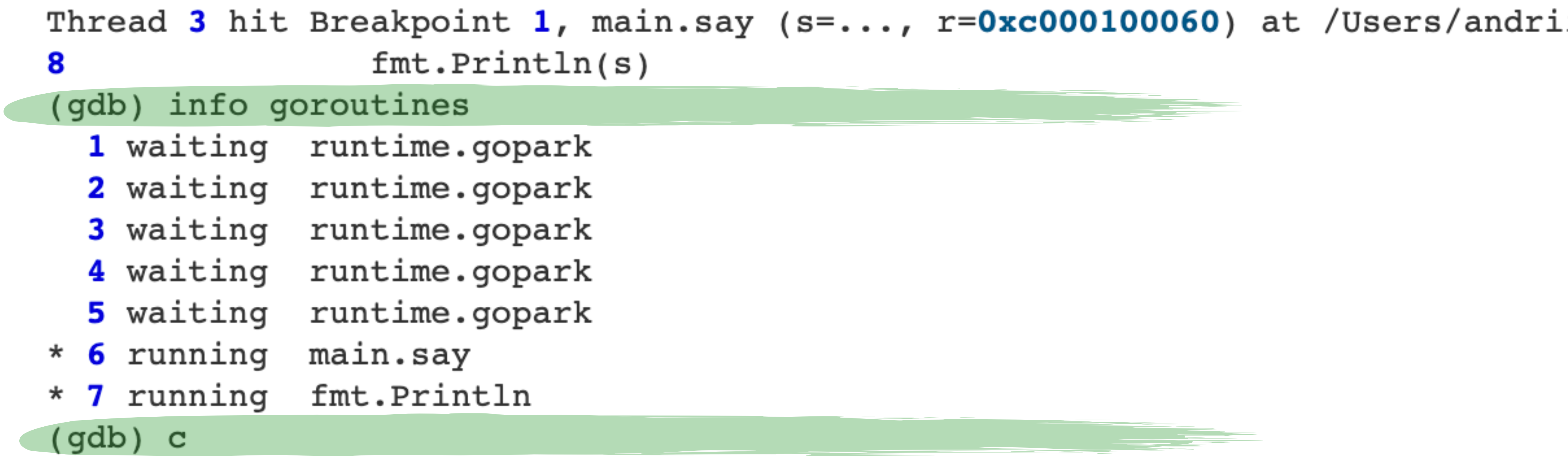
Gdb and goroutines



```
Thread 3 hit Breakpoint 1, main.say (s=..., r=0xc000100060) at /Users/andri
8                       fmt.Println(s)
(gdb) info goroutines
  1 waiting  runtime.gopark
  2 waiting  runtime.gopark
  3 waiting  runtime.gopark
  4 waiting  runtime.gopark
  5 waiting  runtime.gopark
* 6 running  main.say
* 7 running  fmt.Println
(gdb) c
```

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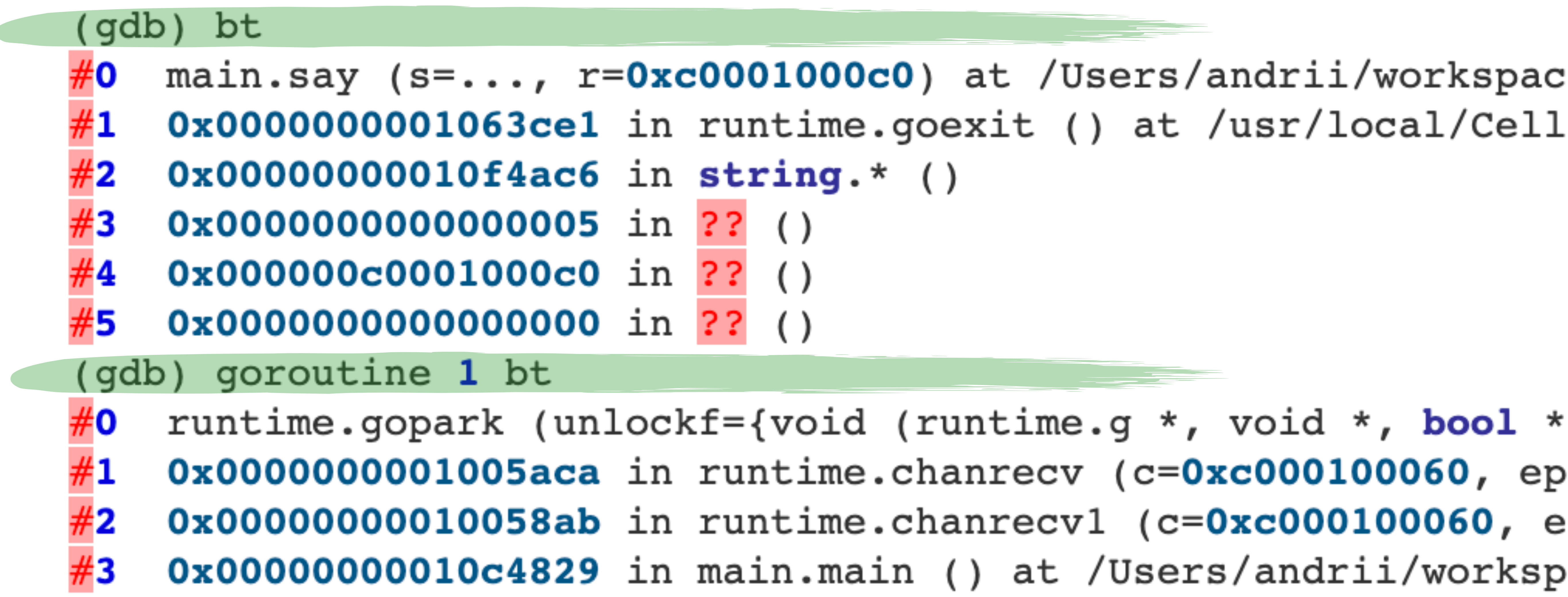
Gdb and goroutines



```
(gdb) bt
#0  main.say (s=..., r=0xc0001000c0) at /Users/andrii/workspac
#1  0x0000000001063ce1 in runtime.goexit () at /usr/local/Cell
#2  0x00000000010f4ac6 in string.* ()
#3  0x0000000000000005 in ?? ()
#4  0x000000c0001000c0 in ?? ()
#5  0x0000000000000000 in ?? ()
(gdb) goroutine 1 bt
#0  runtime.gopark (unlockf={void (runtime.g *, void *, bool *
#1  0x0000000001005aca in runtime.chanrecv (c=0xc000100060, ep
#2  0x00000000010058ab in runtime.chanrecv1 (c=0xc000100060, e
#3  0x00000000010c4829 in main.main () at /Users/andrii/worksp
```

@a_soldatenko

Deadlocks happen and are painful to debug.

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How to detect deadlocks

```go
package main

func main() {
        ch := make(chan string)
        ch <- "hello deadlock"
}
```

```
fatal error: all goroutines are asleep - deadlock!

goroutine 1 [chan send]:
main.main()
        /Users/andrii/workspace/src/github.com/andriisoldatenko/
gowayfest/main_deadlock.go:5 +0x50
exit status 2
```

Real world examples complicated scenario & tools

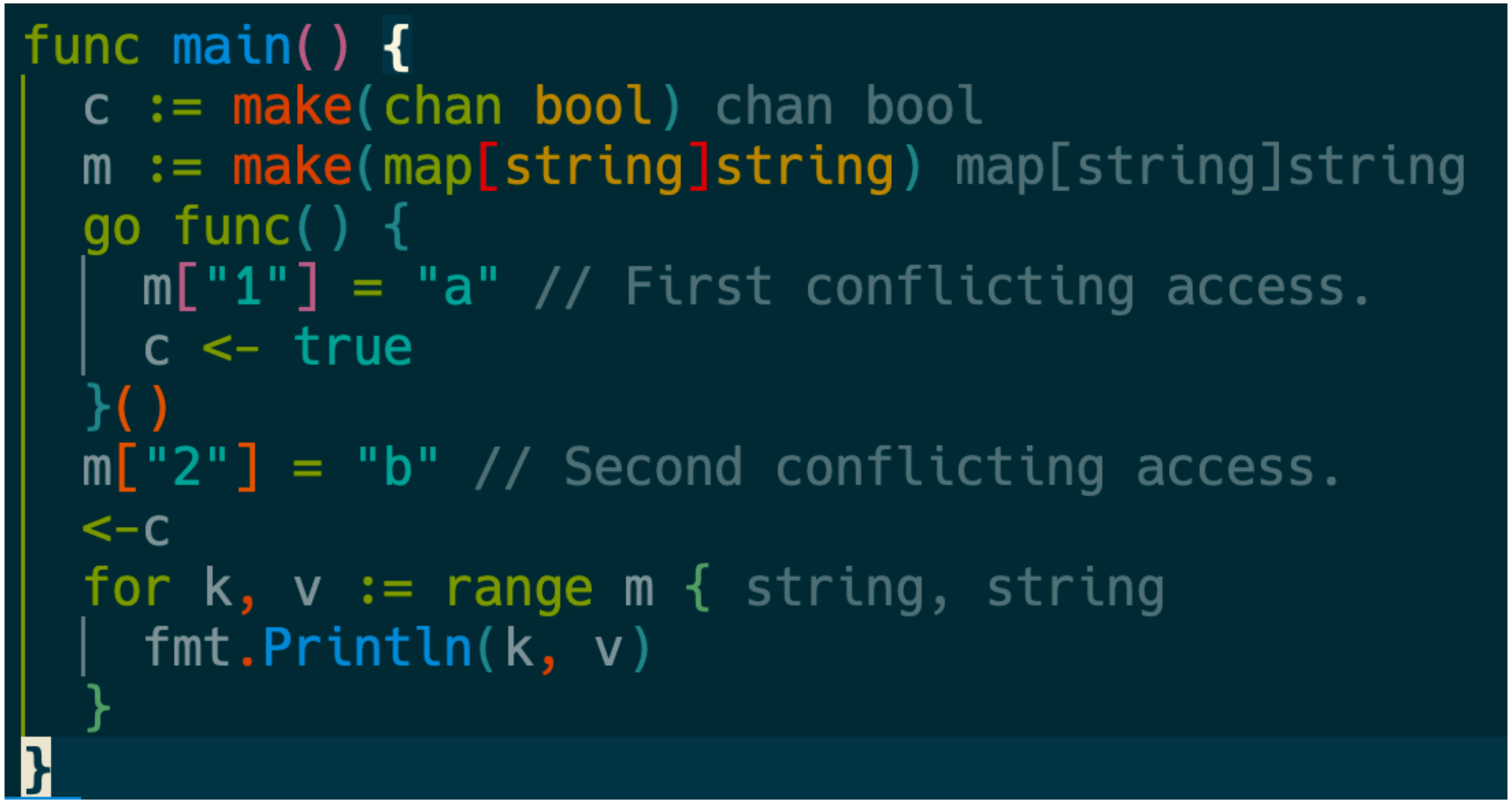
https://github.com/sasha-s/go-deadlock

↓

CockroachDB

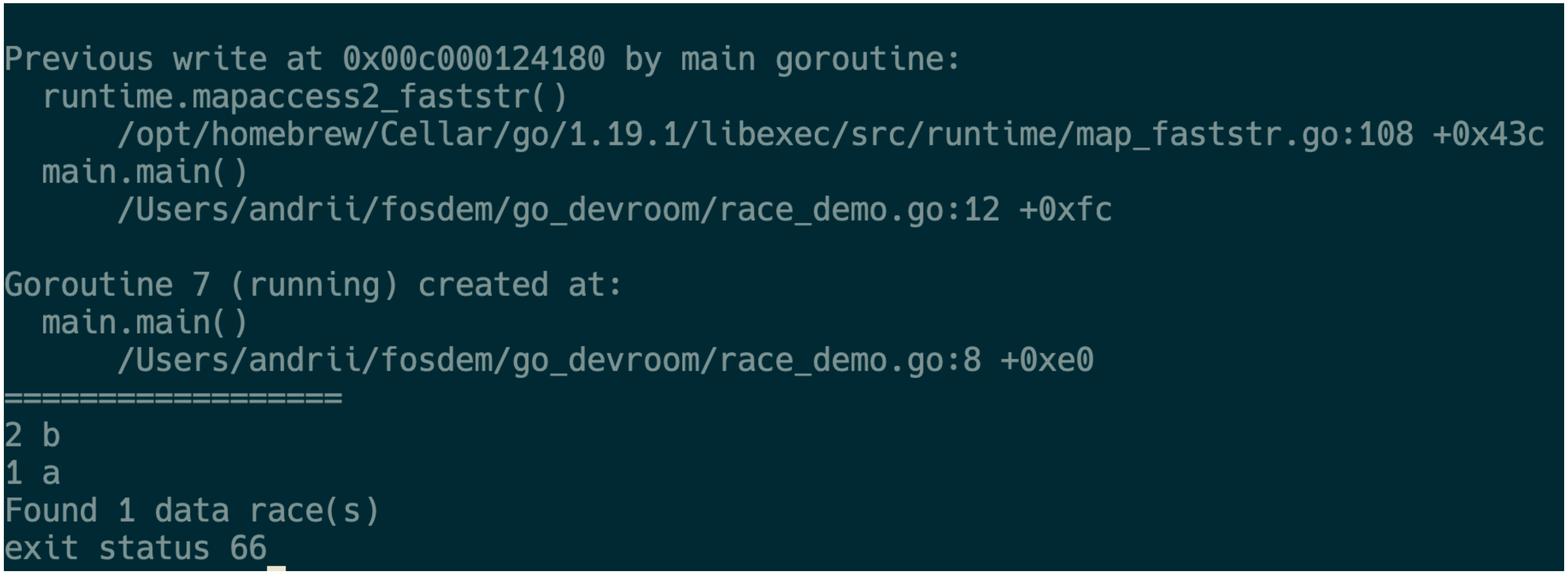
https://github.com/cockroachdb/cockroach/issues/7972

Data races:
go run -race race_demo.go



```go
func main() {
  c := make(chan bool) chan bool
  m := make(map[string]string) map[string]string
  go func() {
    m["1"] = "a" // First conflicting access.
    c <- true
  }()
  m["2"] = "b" // Second conflicting access.
  <-c
  for k, v := range m { string, string
    fmt.Println(k, v)
  }
}
```

Data races:
go run -race race_demo.go



```
Previous write at 0x00c000124180 by main goroutine:
  runtime.mapaccess2_faststr()
      /opt/homebrew/Cellar/go/1.19.1/libexec/src/runtime/map_faststr.go:108 +0x43c
  main.main()
      /Users/andrii/fosdem/go_devroom/race_demo.go:12 +0xfc

Goroutine 7 (running) created at:
  main.main()
      /Users/andrii/fosdem/go_devroom/race_demo.go:8 +0xe0
==================
2 b
1 a
Found 1 data race(s)
exit status 66
```

7 simple rules for debugging concurrency applications

- Never assume a particular order of execution
- Implement concurrency at the highest level possible
- Don’t forget Go only detects when the program as a whole freezes, not when a subset of goroutines get stuck.
- STRACE

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7 simple rules for debugging concurrency applications

- conditional breakpoints your best friend
- DEBUG=schedtrace=5000
- go-deadlock
- And last but not least use Debugger!

References 1

- https://github.com/golang/go/blob/release-branch.go1.14/src/runtime/HACKING.md
- https://github.com/golang/go/wiki/LearnConcurrency
- https://rakyll.org/go-cloud/
- https://yourbasic.org/golang/detect-deadlock/

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- https://blog.minio.io/debugging-go-routine-leaks-a1220142d32c
- https://golang.org/src/cmd/link/internal/ld/dwarf.go
- https://golang.org/src/runtime/runtime-gdb.py
- https://cseweb.ucsd.edu/~yiying/GoStudy-ASPLOS19.pdf
- https://golang.org/doc/articles/race_detector.html

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Slides:

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Thank You

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Questions ?