

Understanding channels

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inner workings of
channels

concurrency features

goroutines

to execute tasks **independently**,
potentially in parallel.

channels

for **communication, synchronization**
between goroutines.

```
func main() {  
    tasks := getTasks()  
  
    // Process each task.  
    for _, task := range tasks {  
        process(task)  
    }  
  
    ...  
}
```

→ **helloTasks**

task queue

```
func main() {  
    // Buffered channel.  
    ch := make(chan Task, 3)
```

task queue

```
func main() {  
    // Buffered channel.  
    ch := make(chan Task, 3)  
  
    // Run fixed number of workers.  
    for i := 0; i < numWorkers; i++ {  
        go worker(ch)  
    }  
}
```

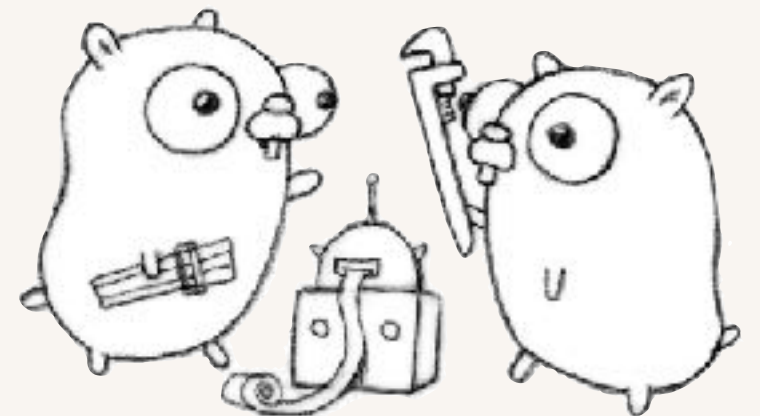
task queue

```
func main() {  
    // Buffered channel.  
    ch := make(chan Task, 3)  
  
    // Run fixed number of workers.  
    for i := 0; i < numWorkers; i++ {  
        go worker(ch)  
    }  
  
    // Send tasks to workers.  
    hellaTasks := getTasks()  
  
    for _, task := range hellaTasks {  
        taskCh <- task  
    }  
  
    ...  
}
```

```
func worker(ch) {  
    for {  
        // Receive task.  
        task := <-taskCh  
        process(task)  
    }  
}
```


channels are inherently interesting

- goroutine-safe.
- store and pass values between goroutines.
- provide **FIFO** semantics.
- can cause goroutines to block and unblock.



making channels

the hchan struct

sends and receives

goroutine scheduling

stepping back:

design considerations

making channels

make chan

buffered channel

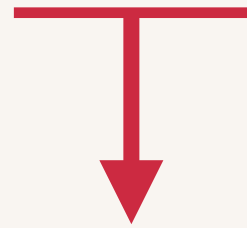
```
ch := make(chan Task, 3)
```

unbuffered channel

```
ch := make(chan int)
```

buffered channel

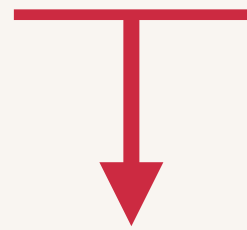
```
ch := make(chan Task, 3)
```



- **goroutine-safe**
- **stores up to capacity elements, and provides FIFO semantics**
- sends values between goroutines
- can cause them to block, unblock

buffered channel

```
ch := make(chan Task, 3)
```

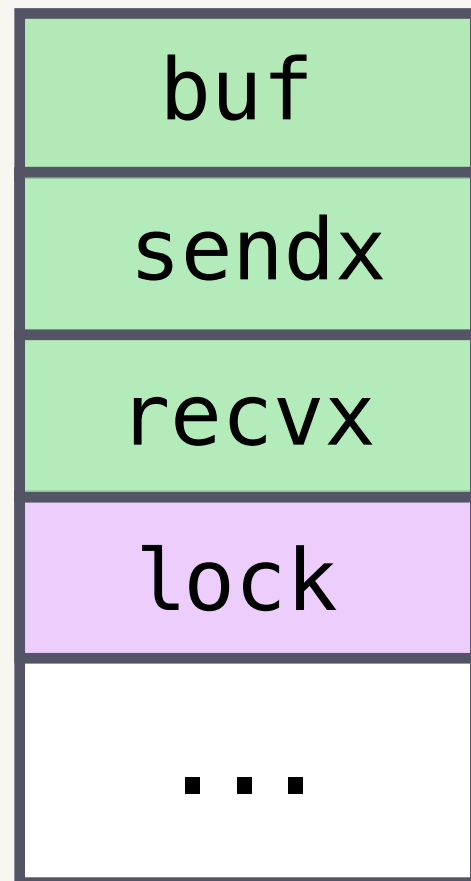


circular queue

send index

receive index

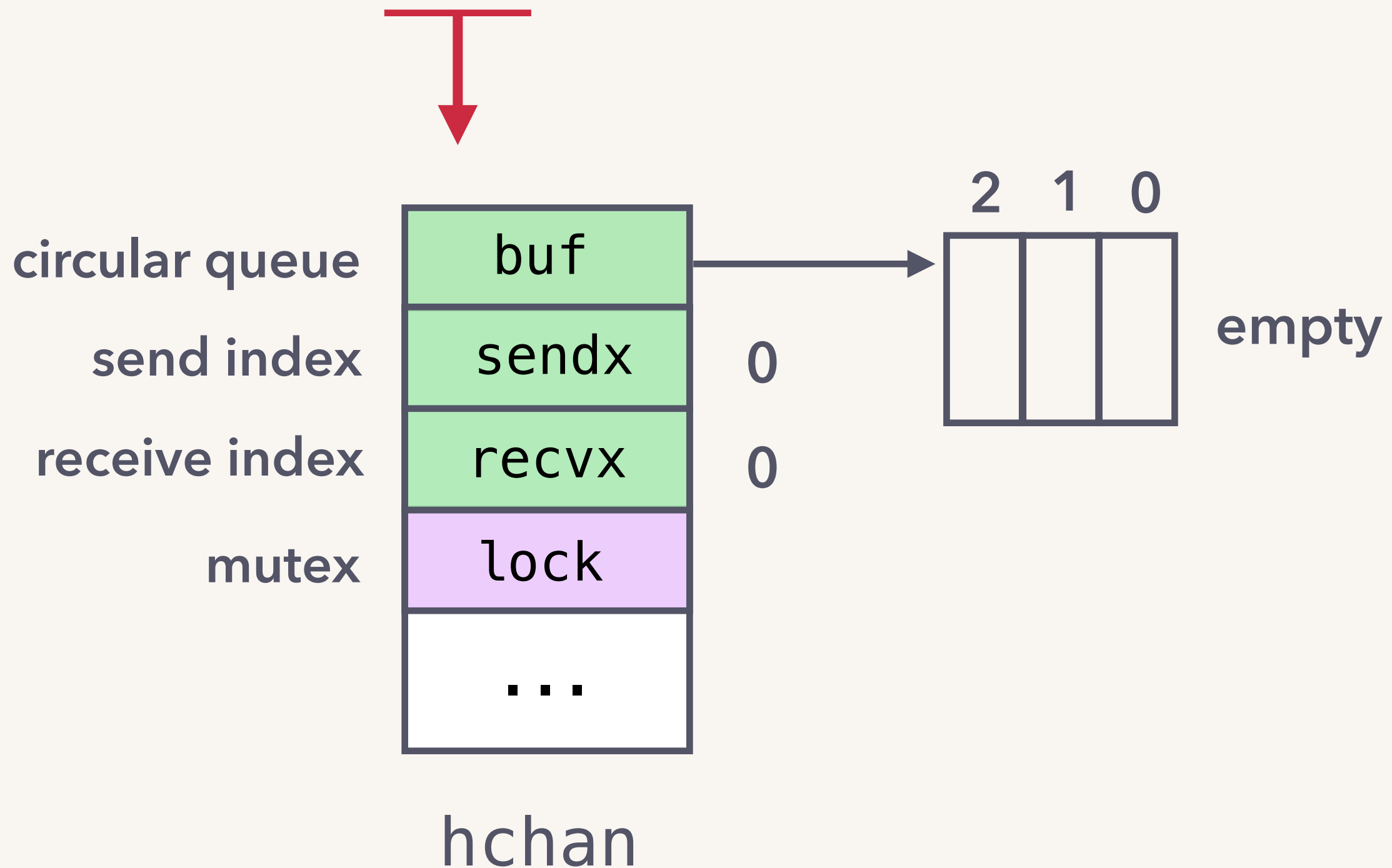
mutex



hchan

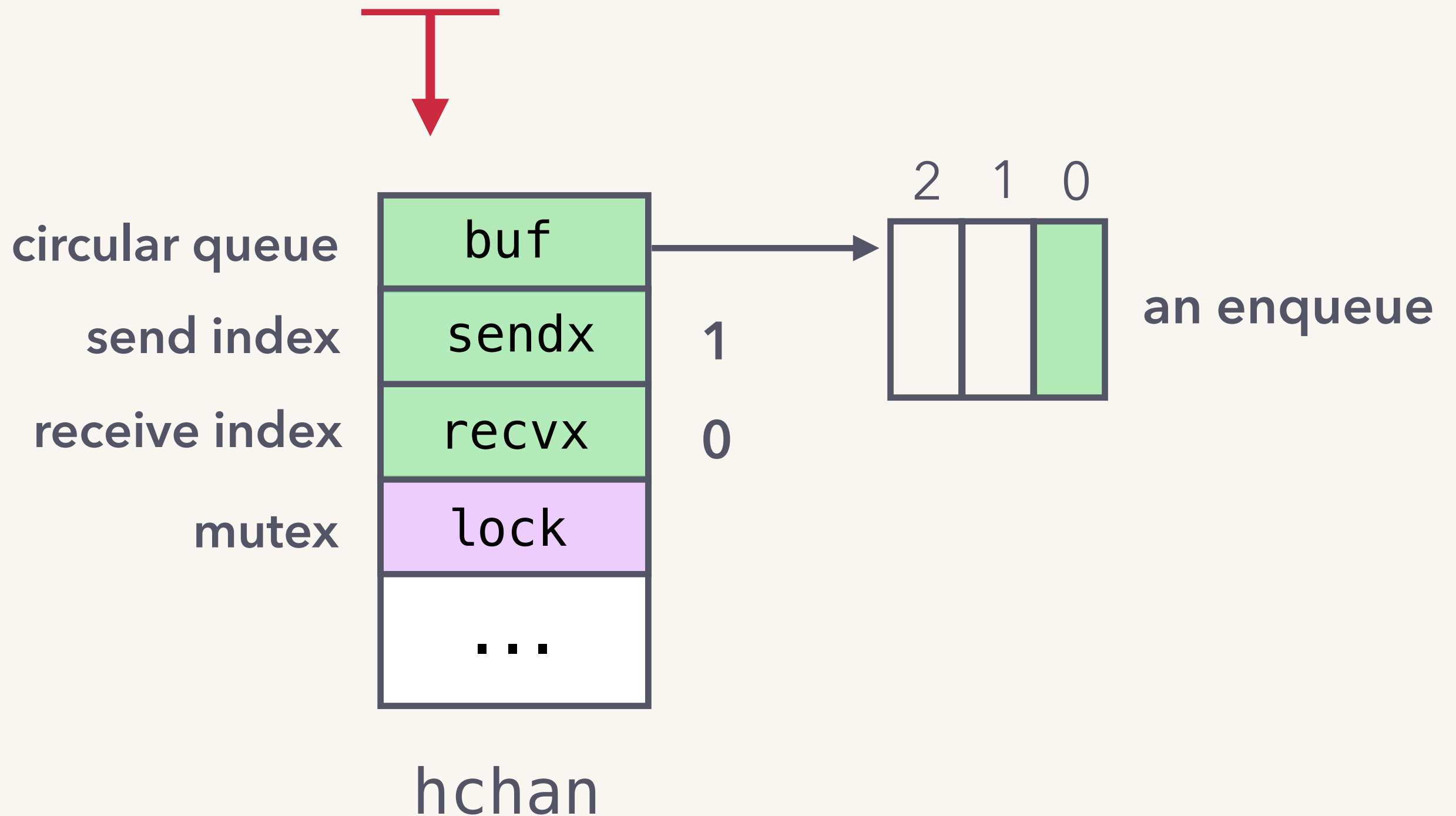
buffered channel

```
ch := make(chan Task, 3)
```



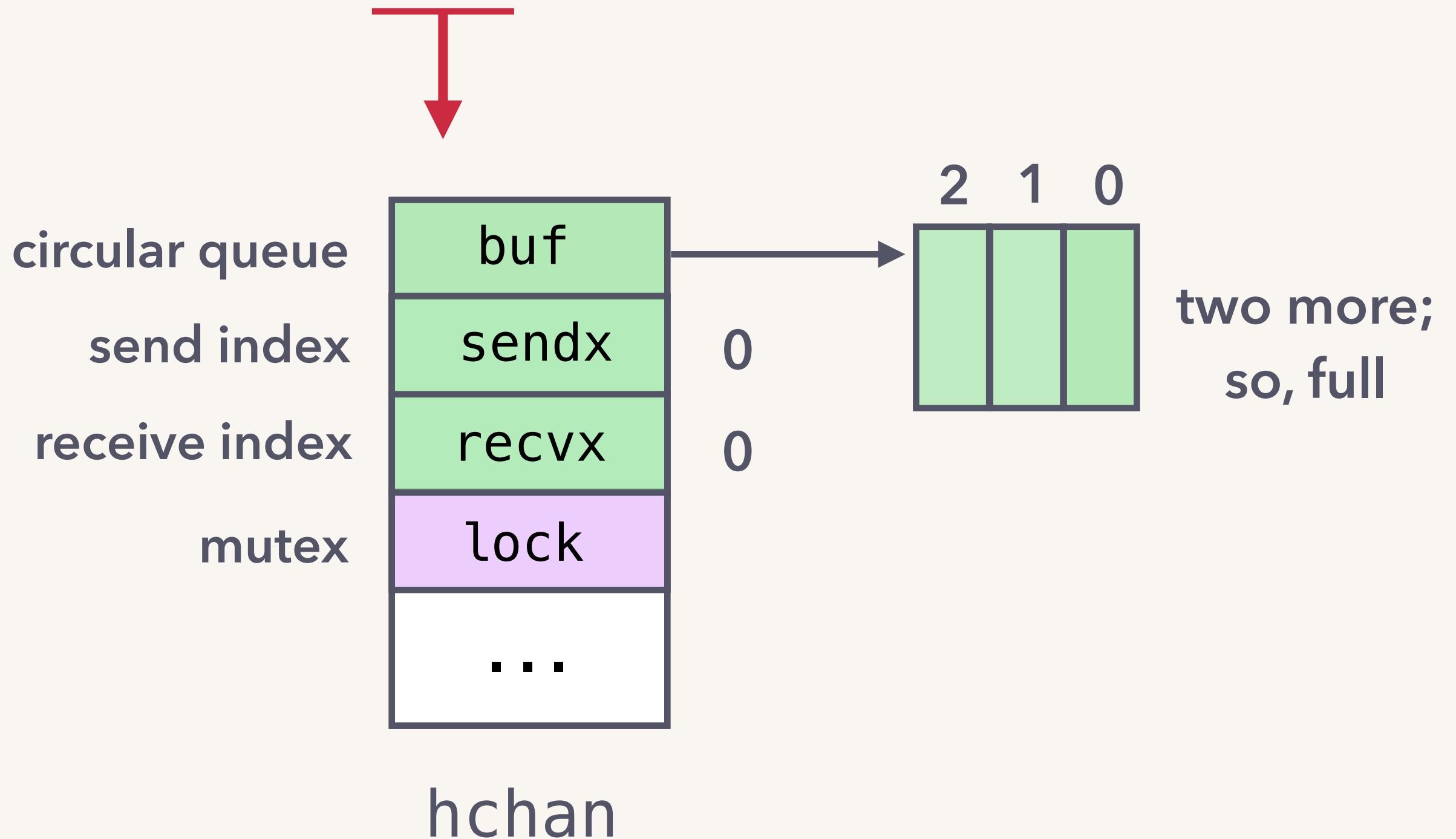
buffered channel

```
ch := make(chan Task, 3)
```



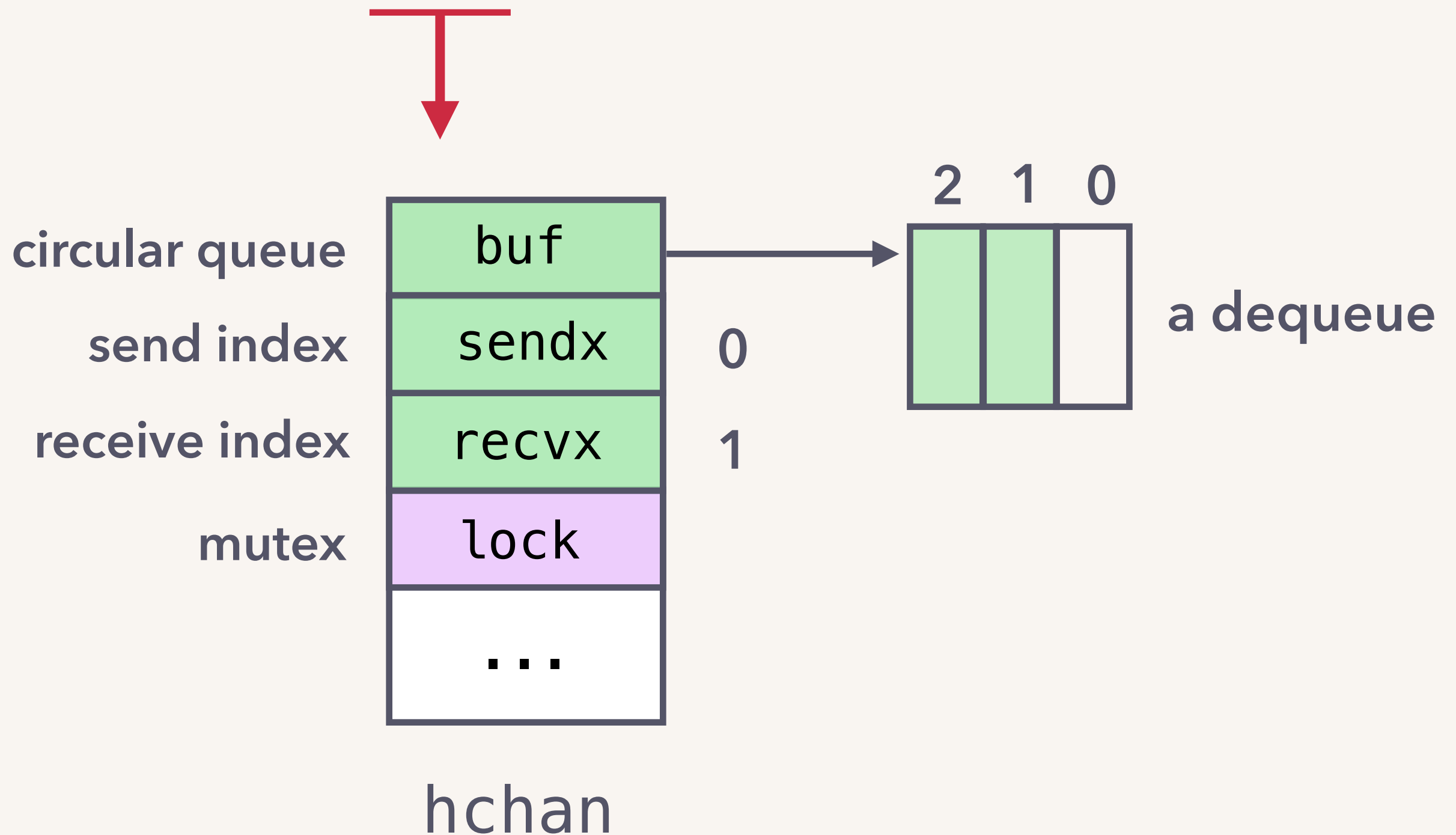
buffered channel

```
ch := make(chan Task, 3)
```



buffered channel

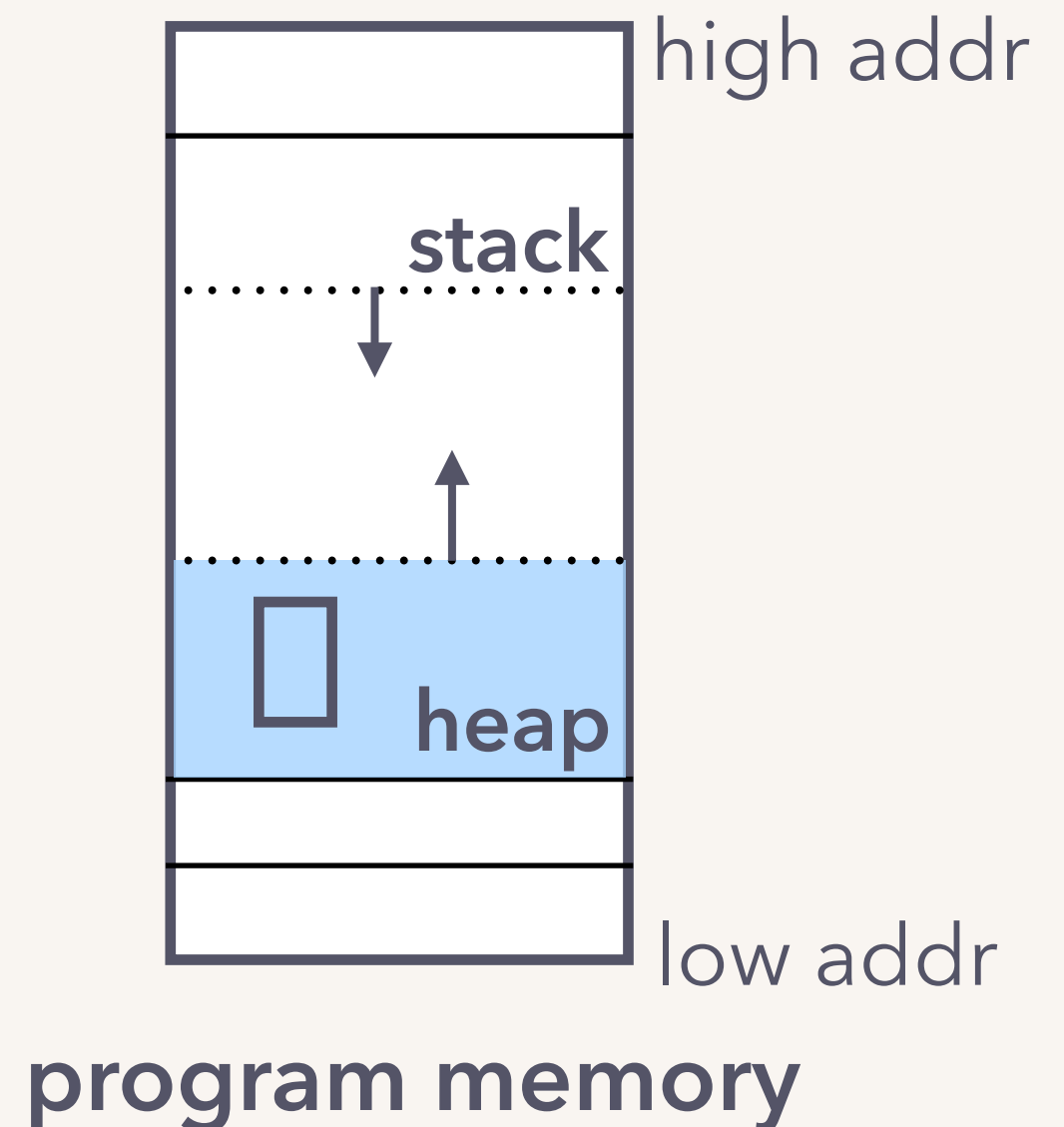
```
ch := make(chan Task, 3)
```



make chan

```
ch := make(chan Task, 3)
```

allocates an hchan struct **on the heap**.



make chan

```
ch := make(chan Task, 3)
```

allocates an hchan struct **on the heap**.

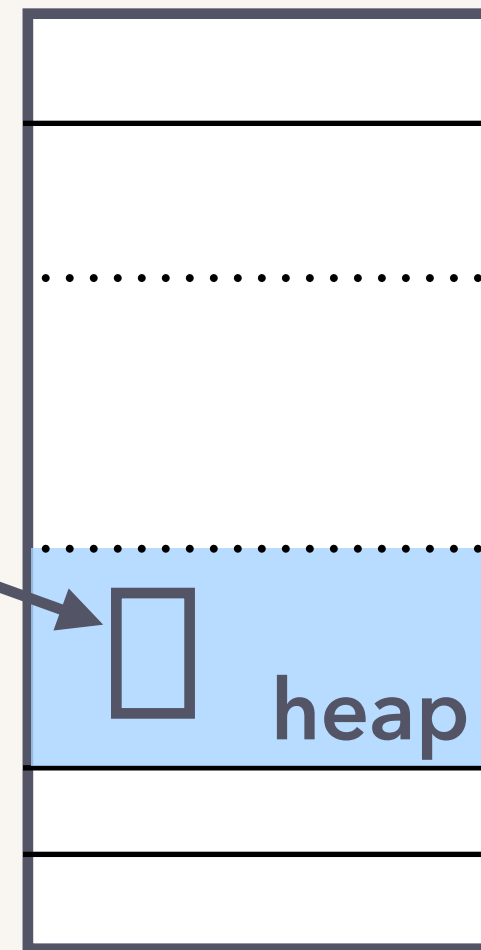
initializes it.

returns a pointer to it.



This is why we can pass channels between functions,
don't need to pass pointers to channels.

ch



sends and receives

task queue

G1

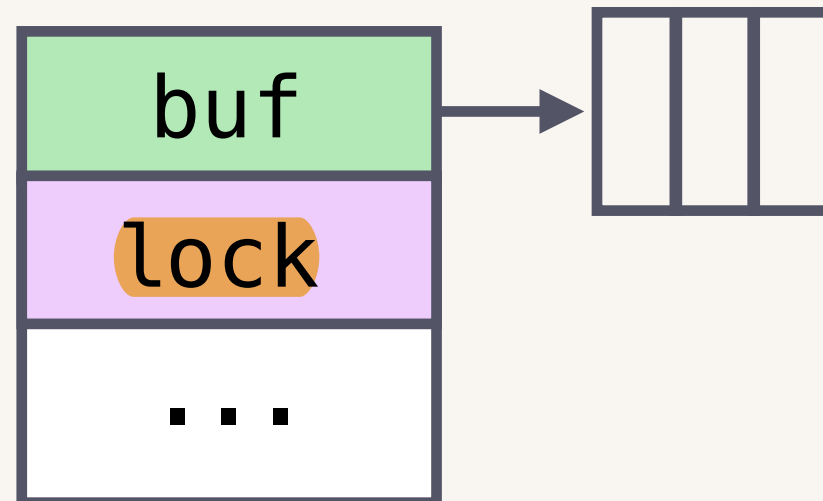
```
func main() {  
    ...  
    for _, task := range tasks {  
        taskCh <- task  
    }  
    ...  
}
```

G2

```
func worker() {  
    for {  
        task := <-taskCh  
        process(task)  
    }  
}
```

G1

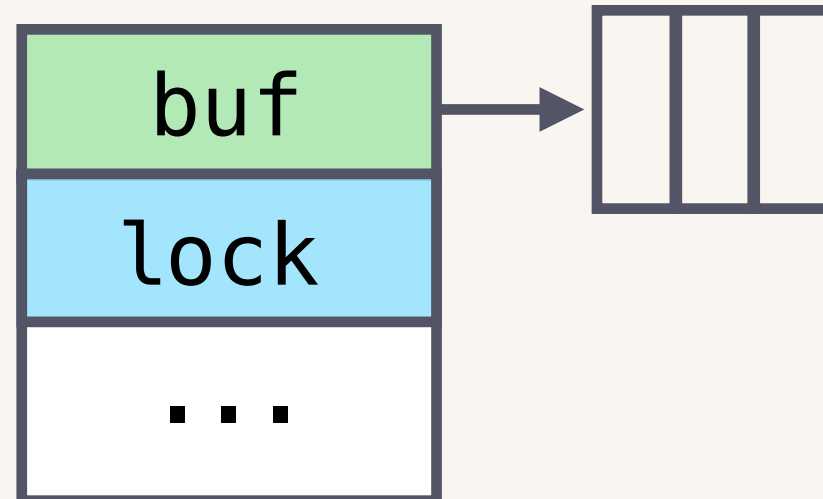
```
ch <- task0
```



G1

`ch <- task0`

1. acquire

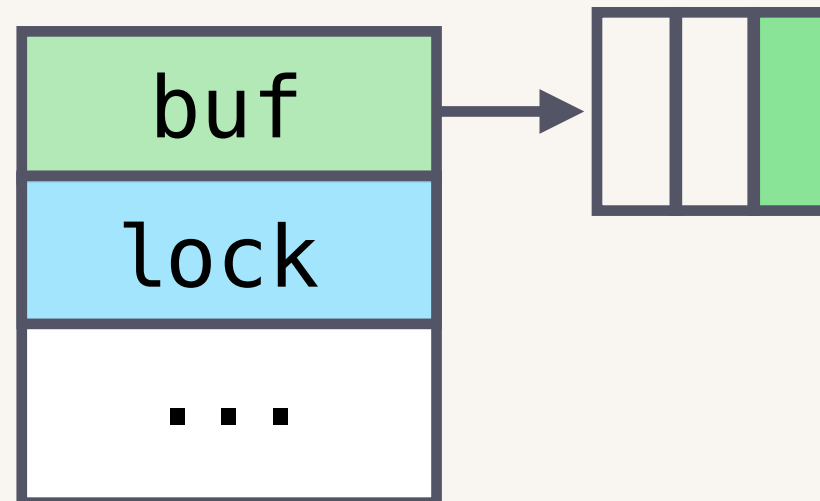


G1

`ch ← task0`

2. enqueue

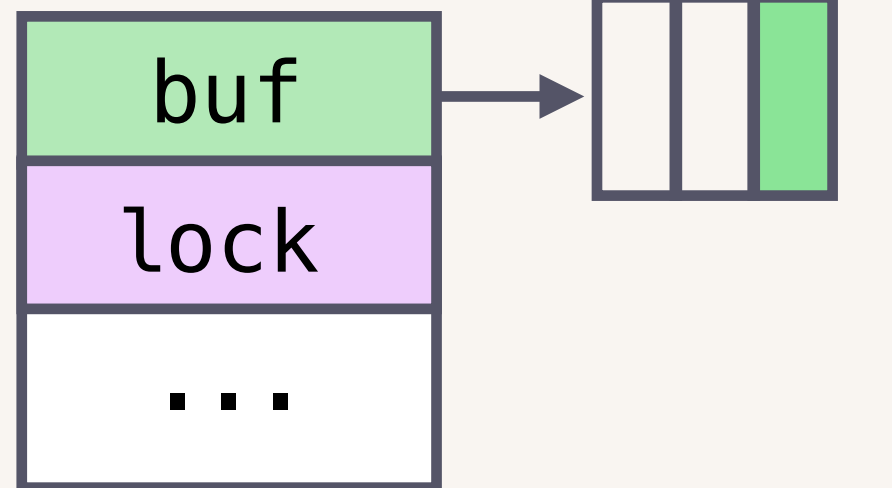
task₀
copy



G1

`ch <- task0`

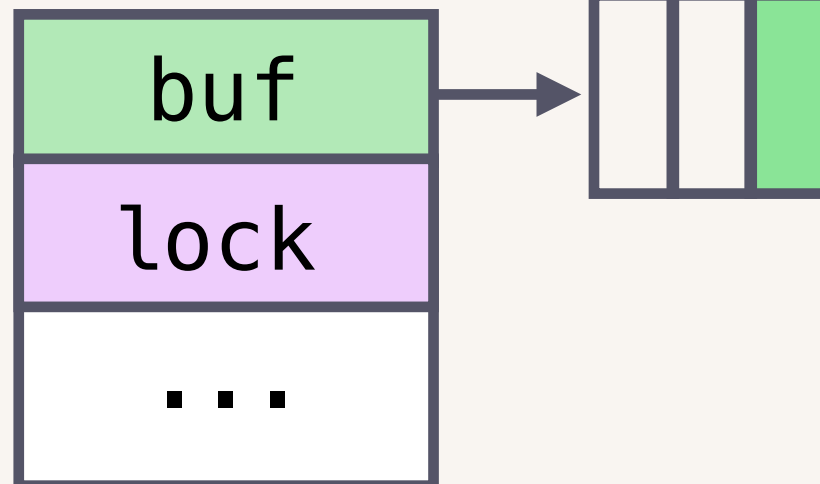
3. release



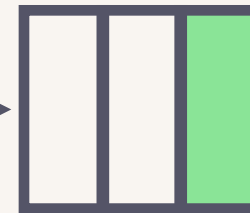
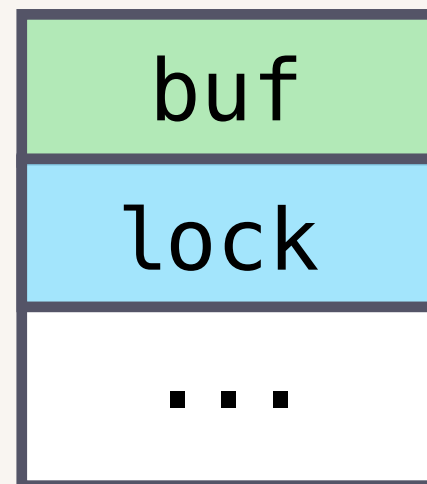
G2

task₀
copy

t := <-ch



1. acquire

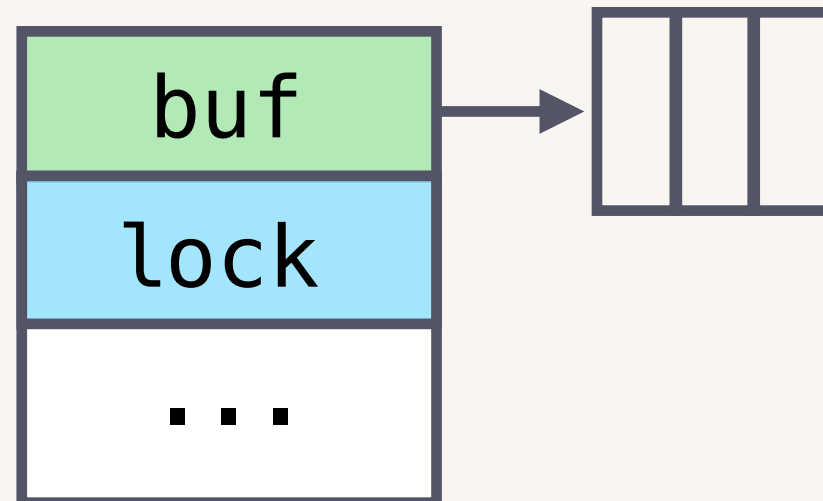


G2

t := <-ch

G2

2. dequeue

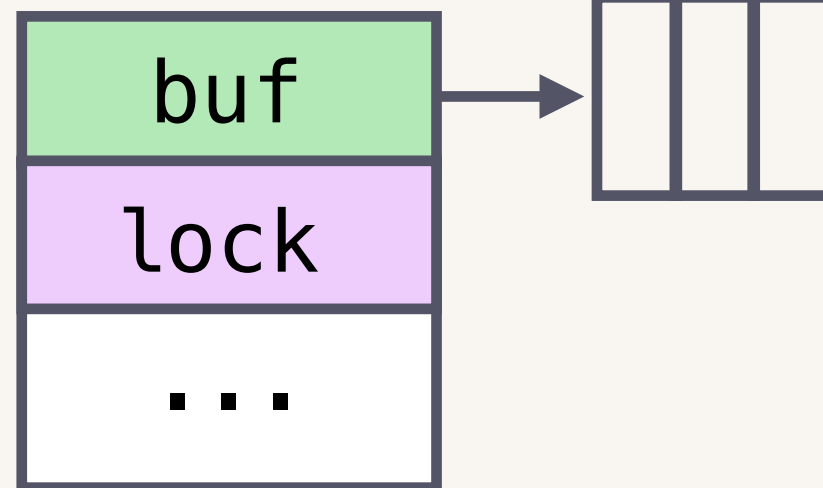


$t := \leftarrow ch$



$task_0$
copy'

3. release



G2

$t := \leftarrow ch$



task₀
copy'

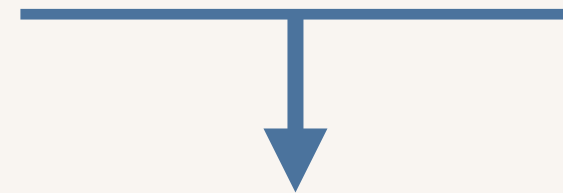
no shared memory
(except hchan)

copies

no shared memory
(except hchan)



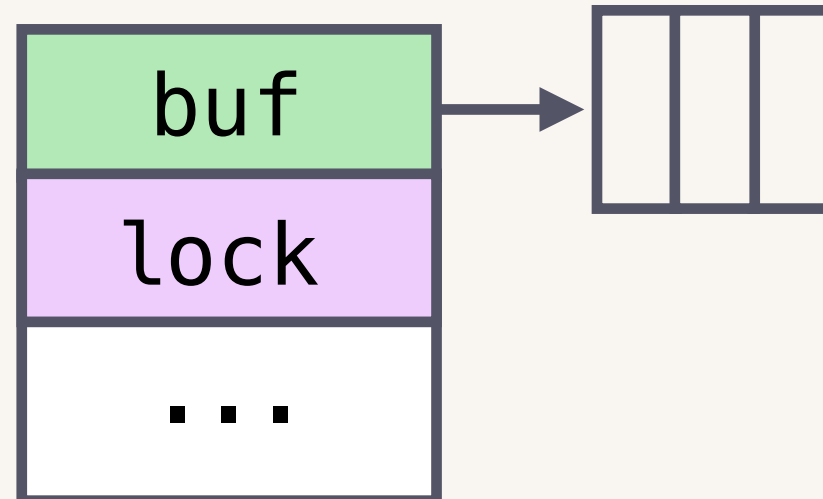
“Do not communicate by sharing memory;
instead, share memory by communicating.”



copies

G1

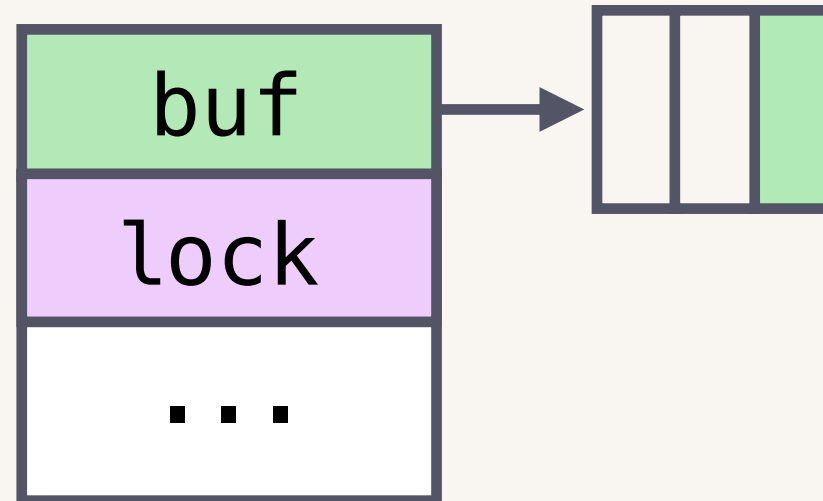
G2



G1

ch \leftarrow task₁

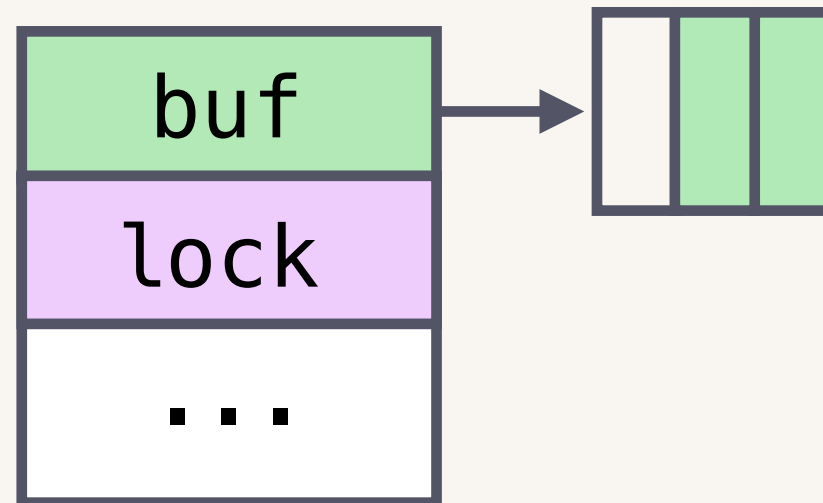
G2



G1

```
ch <- task1  
ch <- task2
```

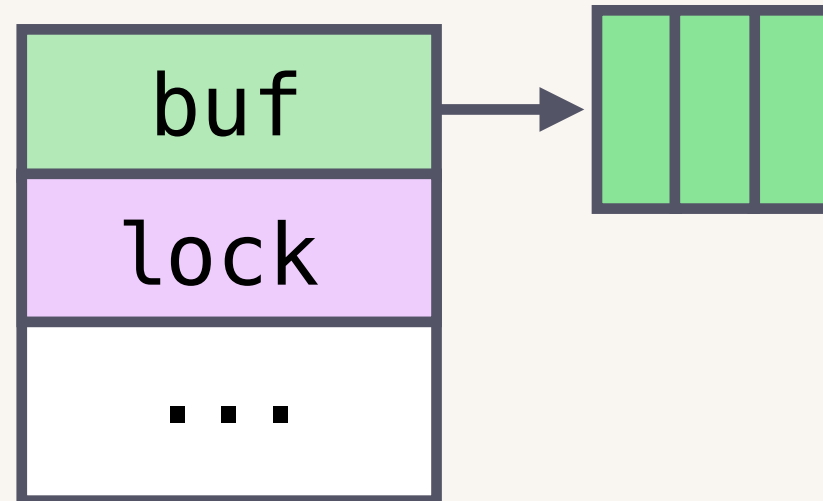
G2



G1

```
ch <- task1  
ch <- task2  
ch <- task3
```

G2



G1

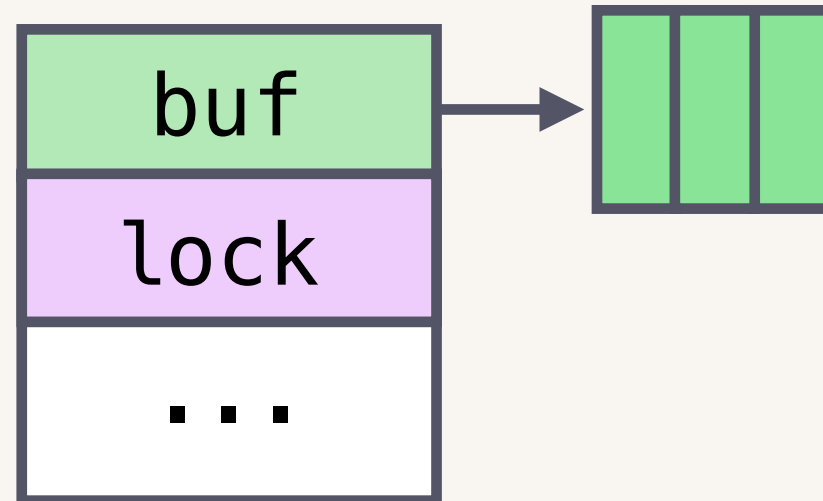
ch \leftarrow task₁

ch \leftarrow task₂

ch \leftarrow task₃

ch \leftarrow task₄

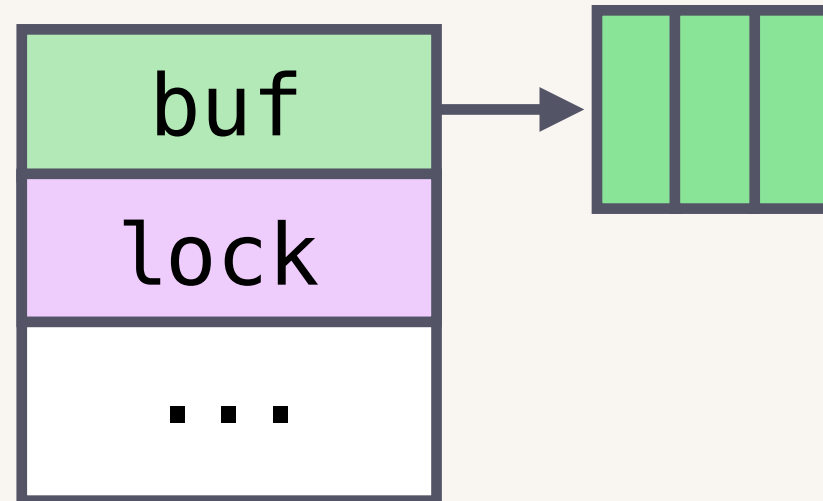
G2



G1

```
ch <- task1  
ch <- task2  
ch <- task3
```

```
ch <- task4
```



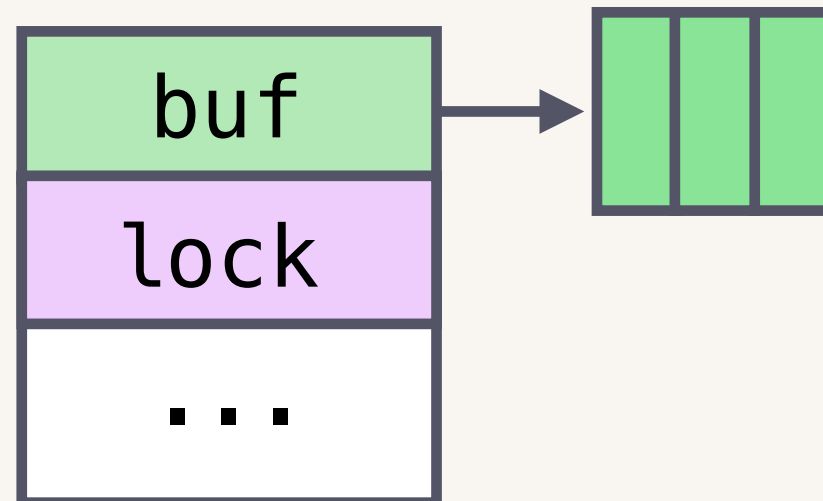
G2

ruh-roh, channel is **full**!
G1's execution is **paused**,
resumed after a receive.

G1

```
ch <- task1  
ch <- task2  
ch <- task3
```

```
ch <- task4
```



G2

ruh-roh, channel is **full**!
G1's execution is **paused**,
resumed after a receive.

?

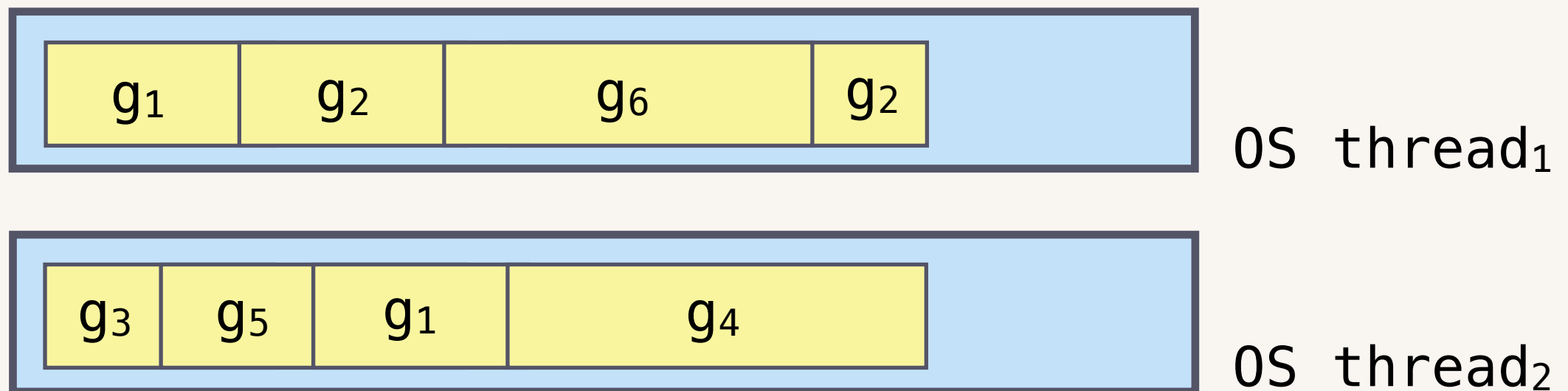
interlude: the runtime scheduler

goroutines are user-space threads.



created and managed by the Go runtime, not the OS.
lightweight compared to OS threads.

the runtime scheduler schedules them onto OS threads.



M:N scheduling

Go's M:N scheduling is described using three structures:

M: OS thread



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M: OS thread

G: goroutine

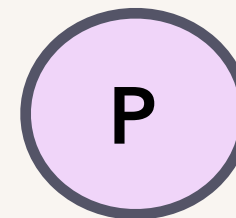


Go's M:N scheduling is described using three structures:

M: OS thread

G: goroutine

P: context for scheduling.



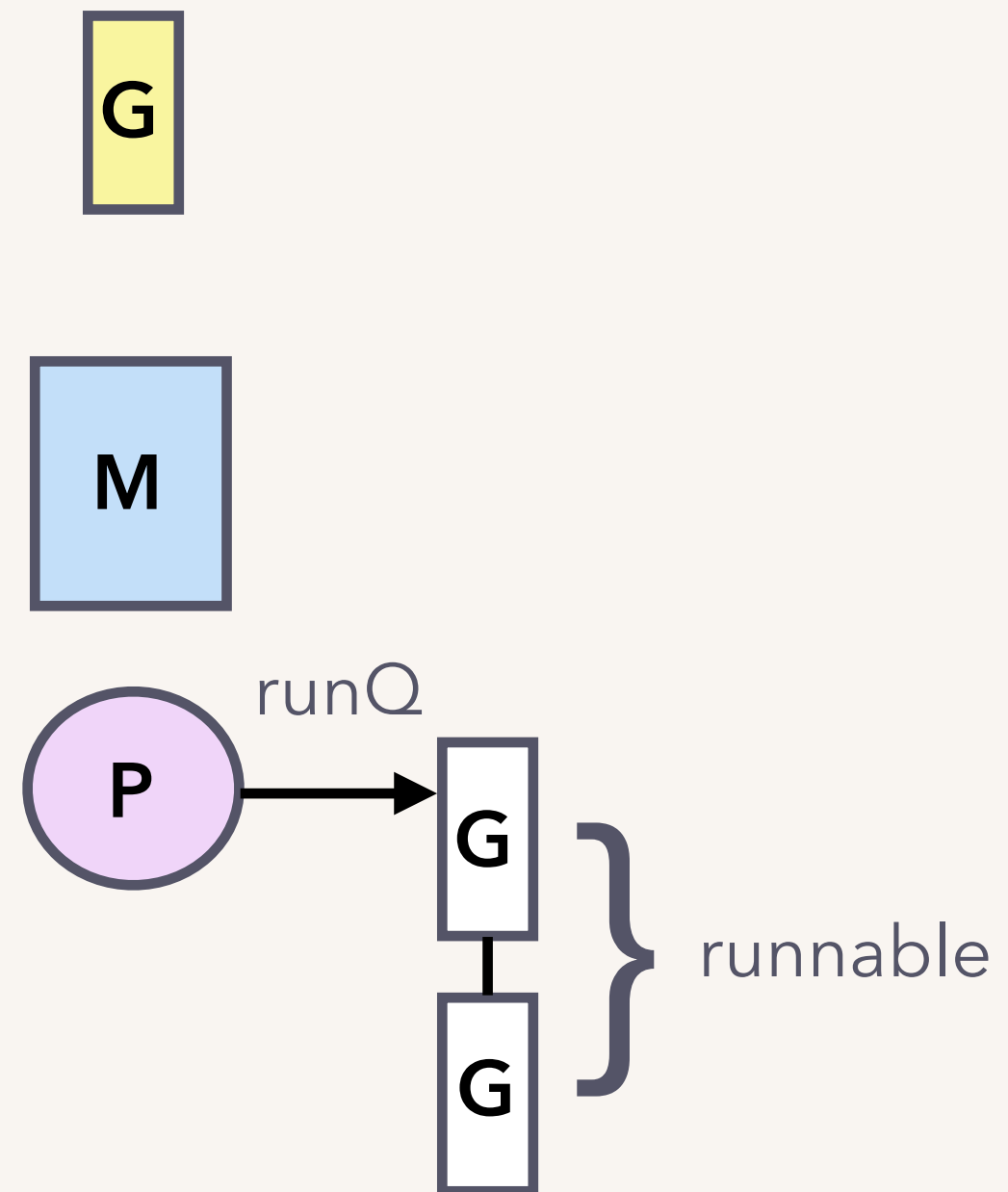
Go's M:N scheduling is described using three structures:

M: OS thread

G: goroutine

P: context for scheduling.

► Ps hold the runqueues.



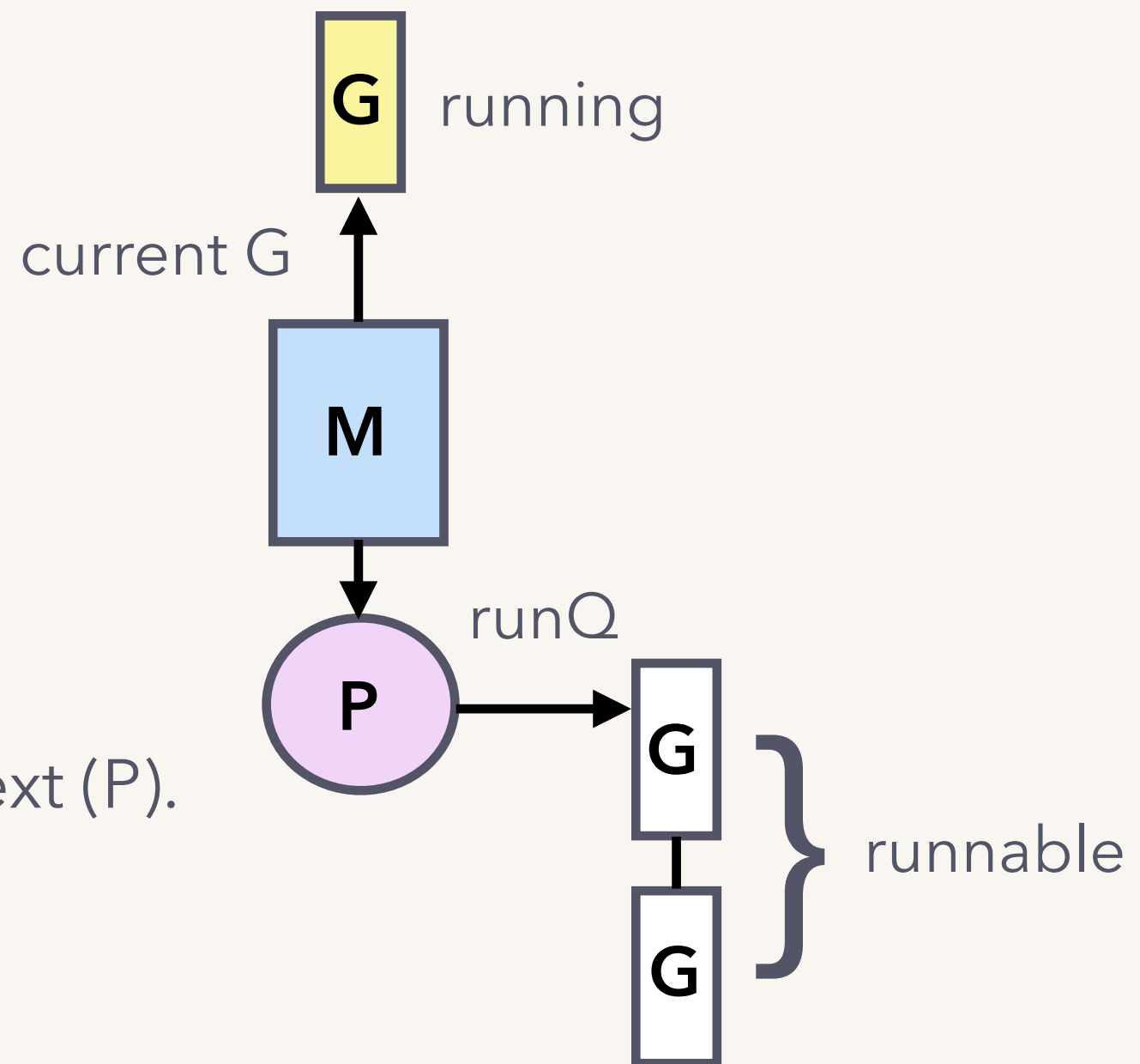
Go's M:N scheduling is described using three structures:

M: OS thread

G: goroutine

P: context for scheduling.

- ▶ Ps hold the runqueues.
- ▶ In order to run goroutines (G), a thread (M) must hold a context (P).



pausing goroutines

`ch <- task4`  send on a full channel

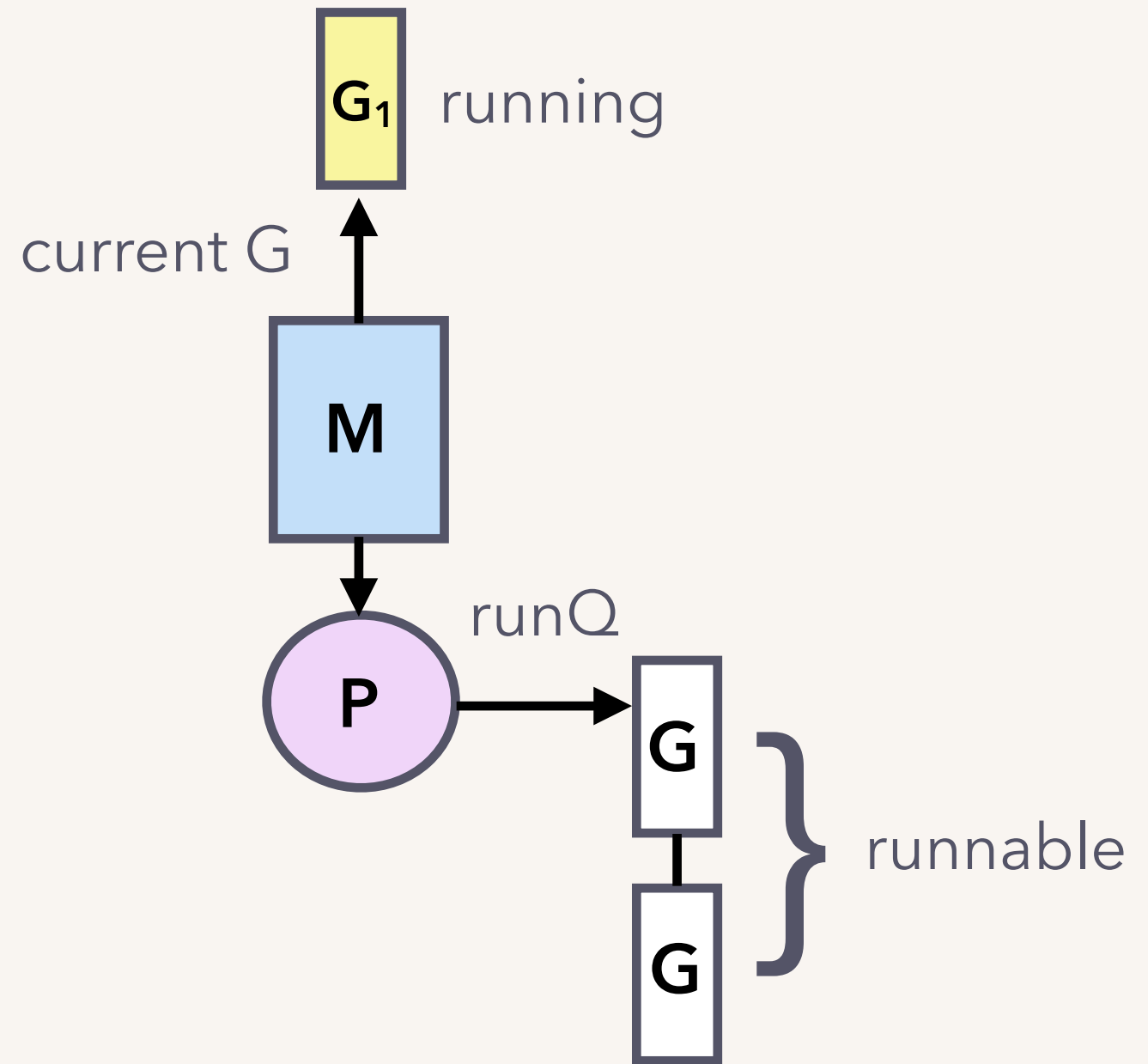
G1

`ch <- task4`

`gopark`



calls into the scheduler



G1

`ch <- task4`

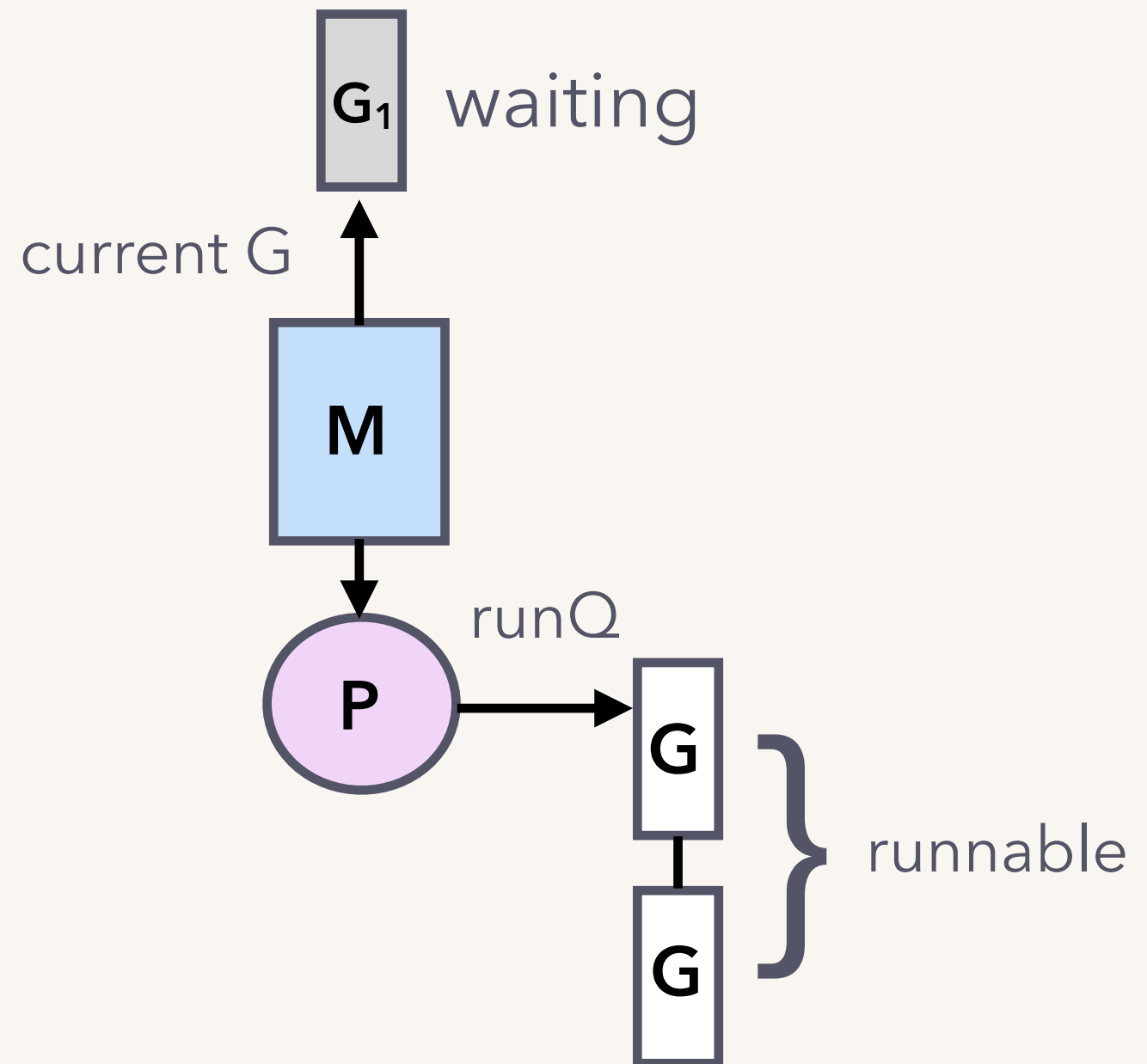
`gopark`



calls into the scheduler



sets **G1** to waiting



G1

`ch <- task4`

`gopark`



calls into the scheduler

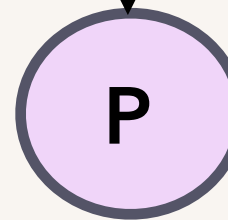


sets **G1** to waiting

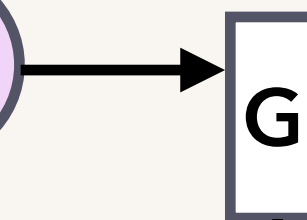
removes association
between **G1**, **M**



waiting



runQ



runnable

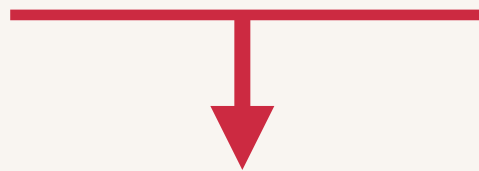
G1

ch ← task₄

gopark



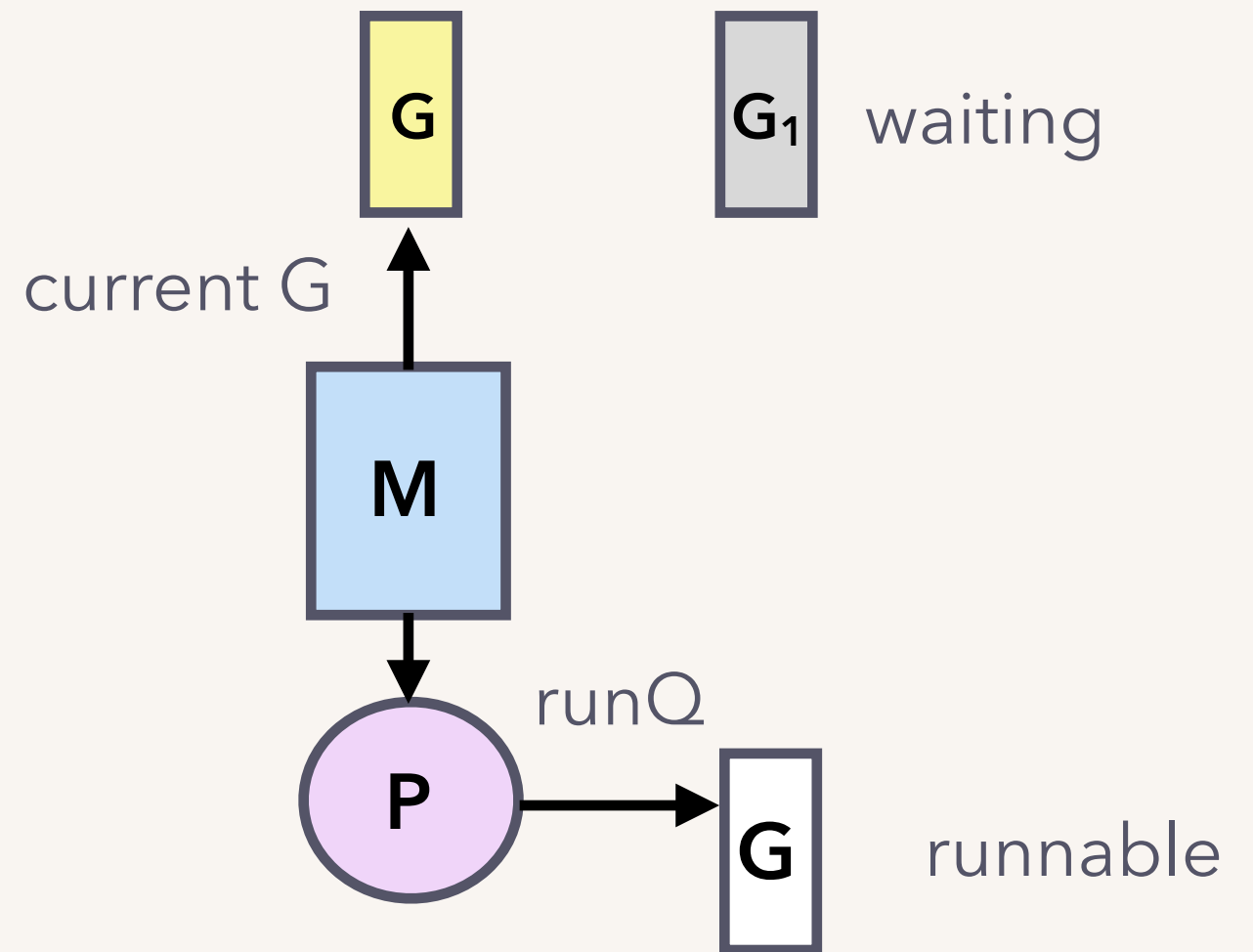
calls into the scheduler



sets **G1** to waiting

removes association
between **G1**, M

schedules a runnable G
from the runqueue



} "returns"
to a
different G

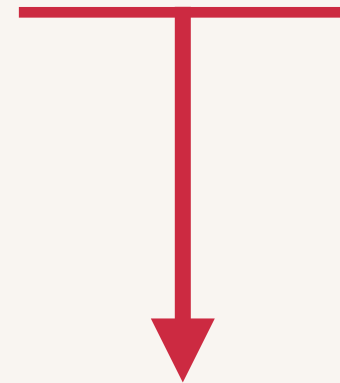
This is neat.

G1 is blocked as needed, but not the OS thread.

This is neat.

G1 is blocked as needed, but not the OS thread.

...great, but how do we **resume**
the blocked goroutine?



after a channel receive, and
the channel is no longer full

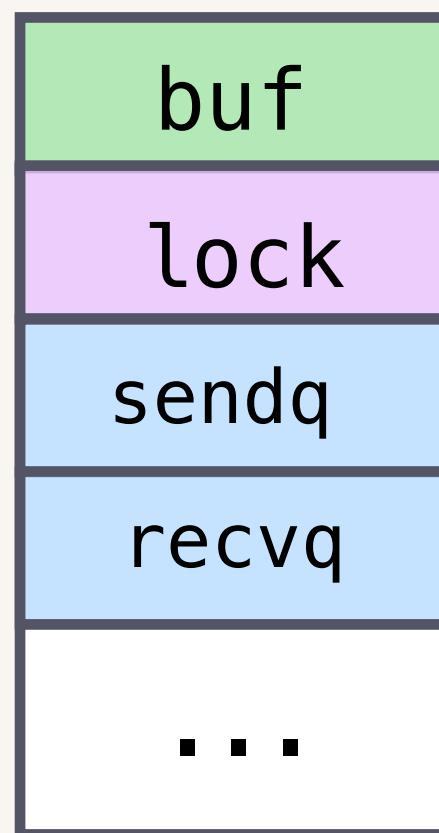
resuming goroutines

the hchan struct stores waiting senders, receivers as well.

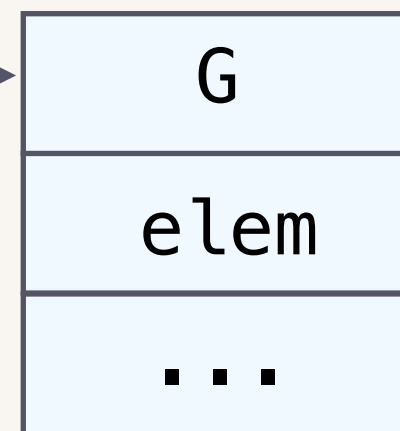
stored as a sudog

represents a G
in a waiting list

waiting senders
waiting receivers



hchan



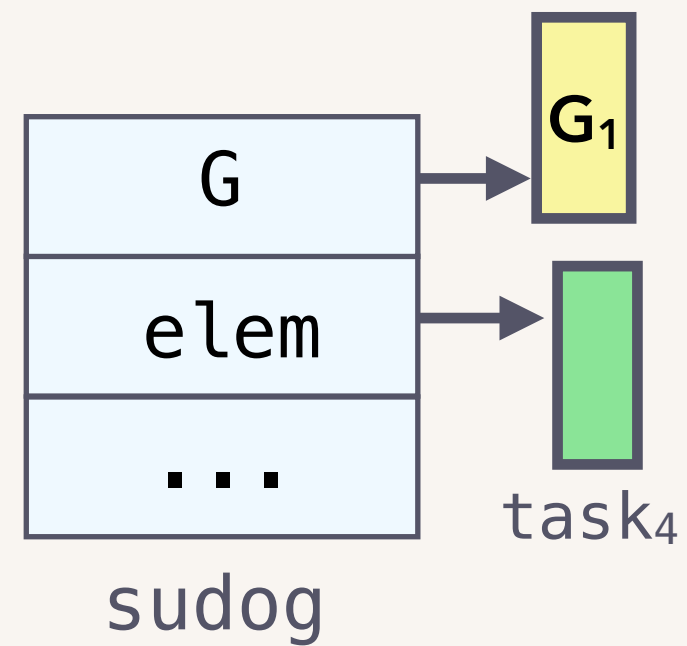
sudog

waiting G
elem to send/recv

G1

```
ch <- task4
```

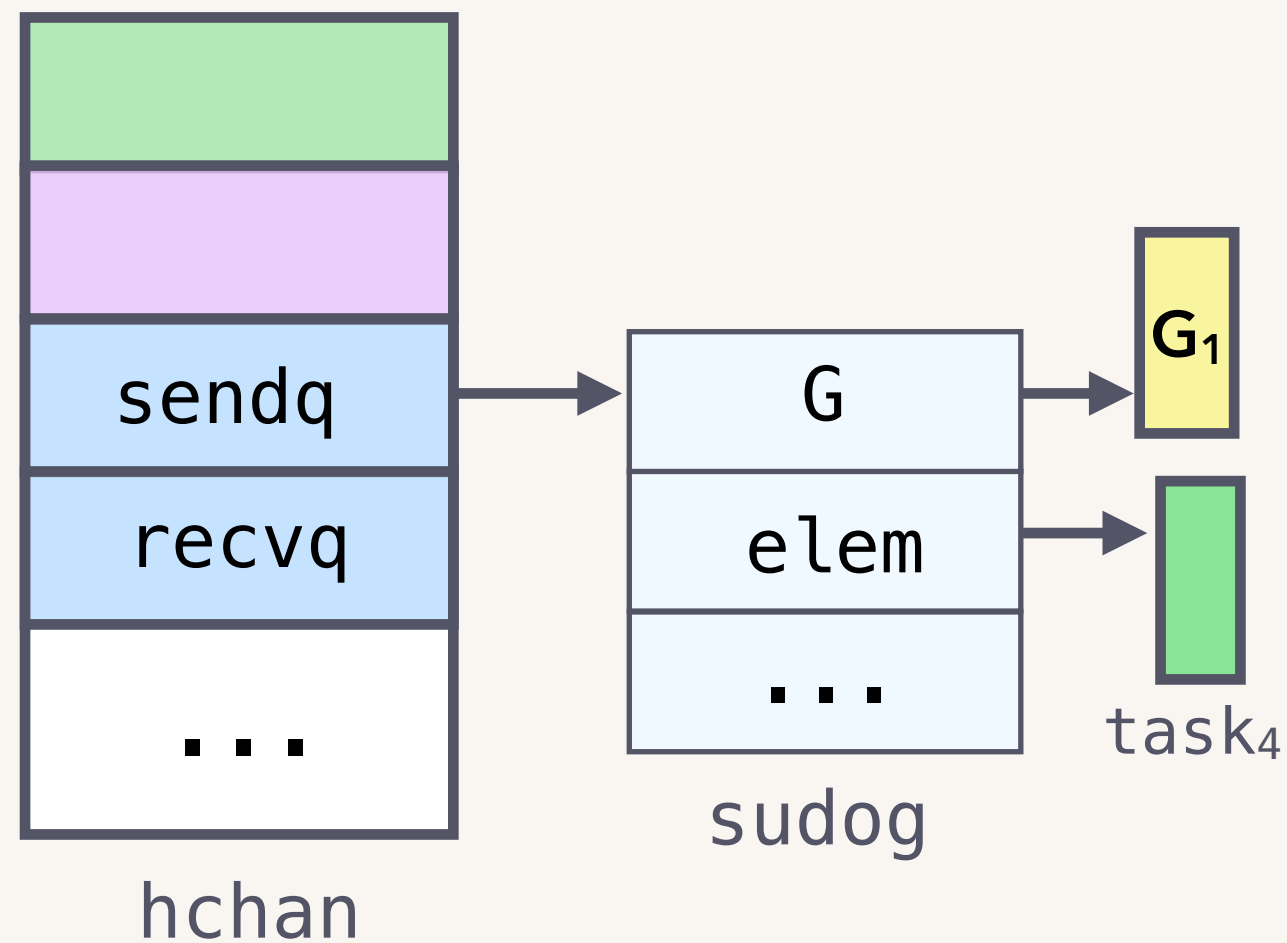
creates a **sudog** for itself



G1

ch ← task₄

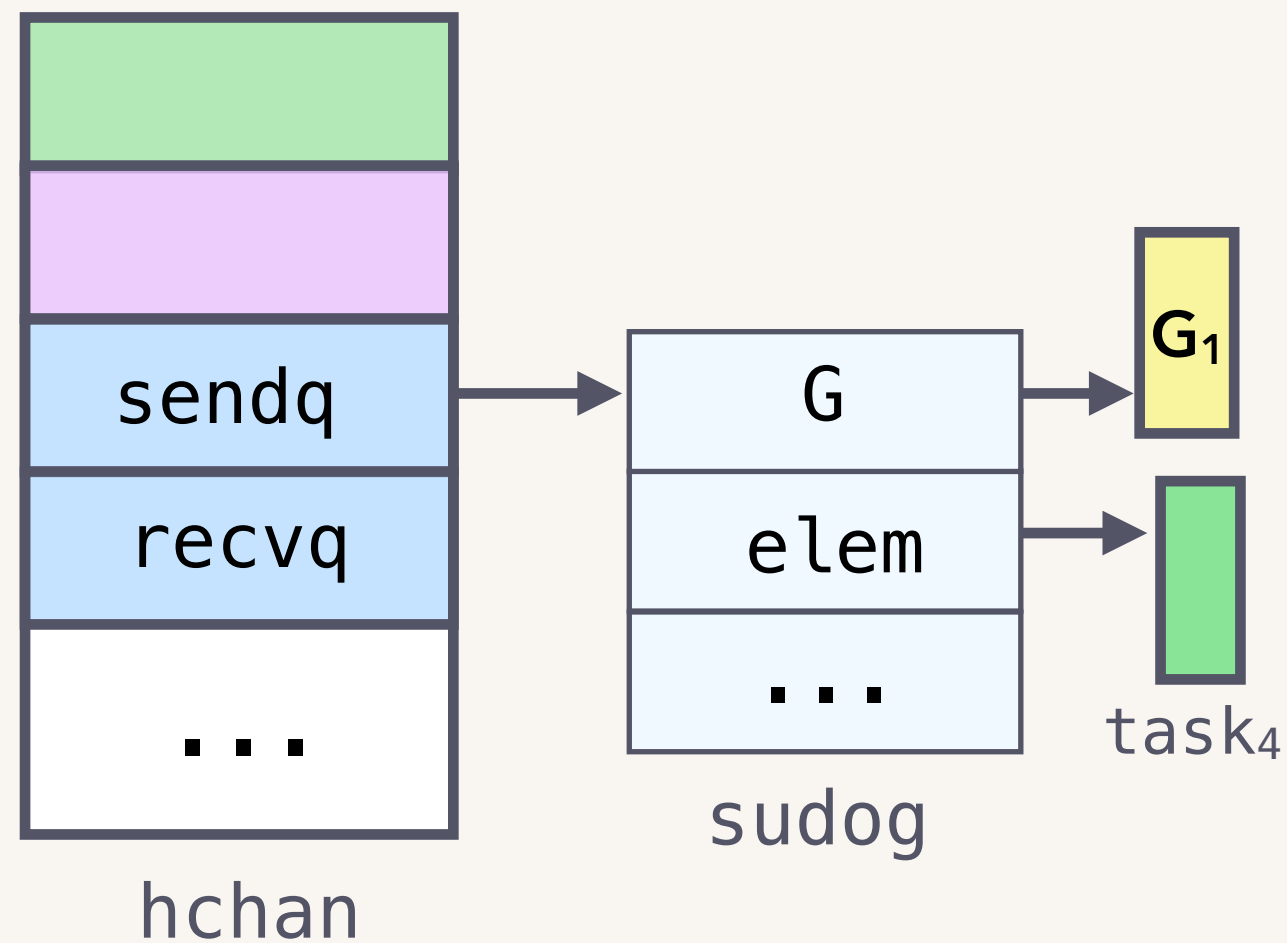
creates a **sudog** for itself, puts it in the **sendq** → **receiver**
uses it to
resume G1.



G1

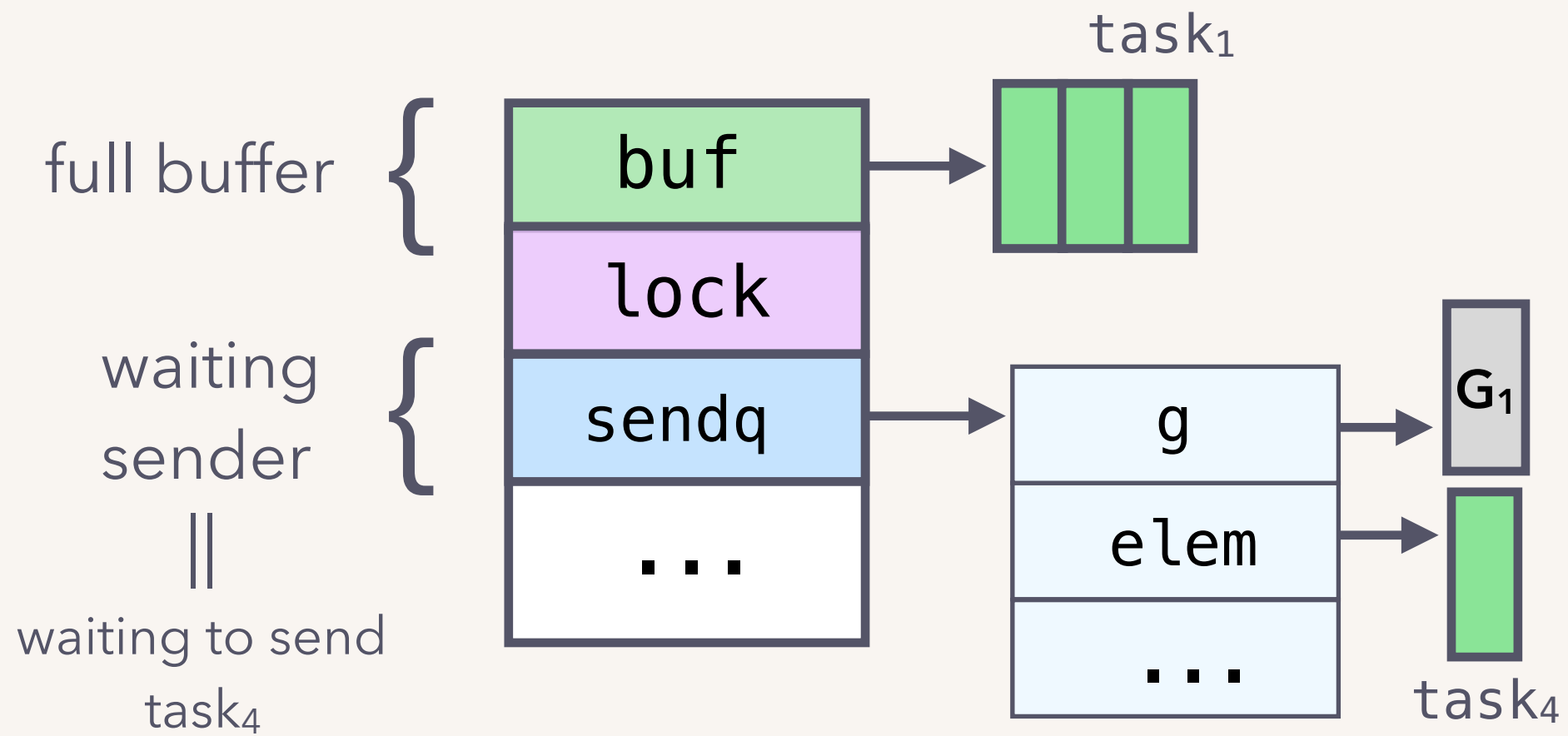
ch <- task₄

creates a **sudog** for itself, puts it in the **sendq** → **receiver**
happens **before** calling into the scheduler. **uses it to**
resume G1.

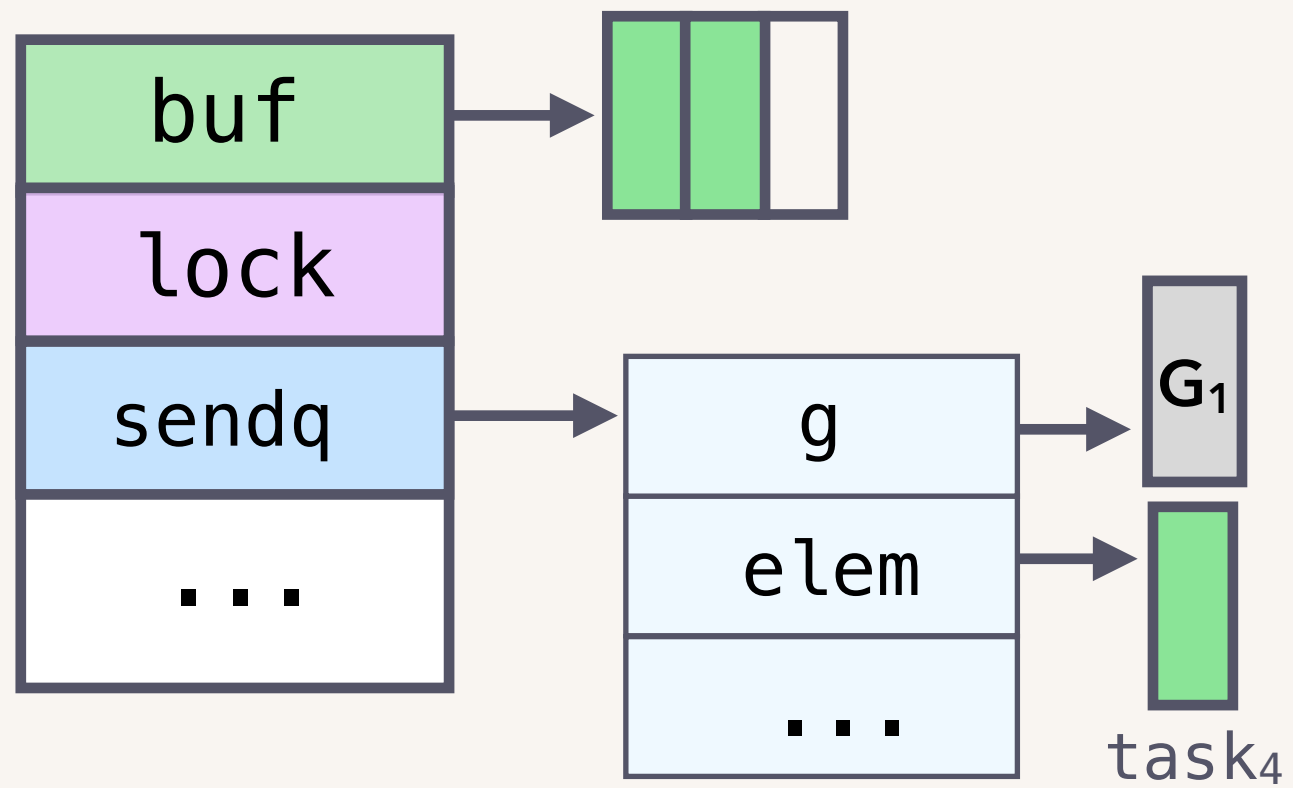


G2

$t := \leftarrow ch$



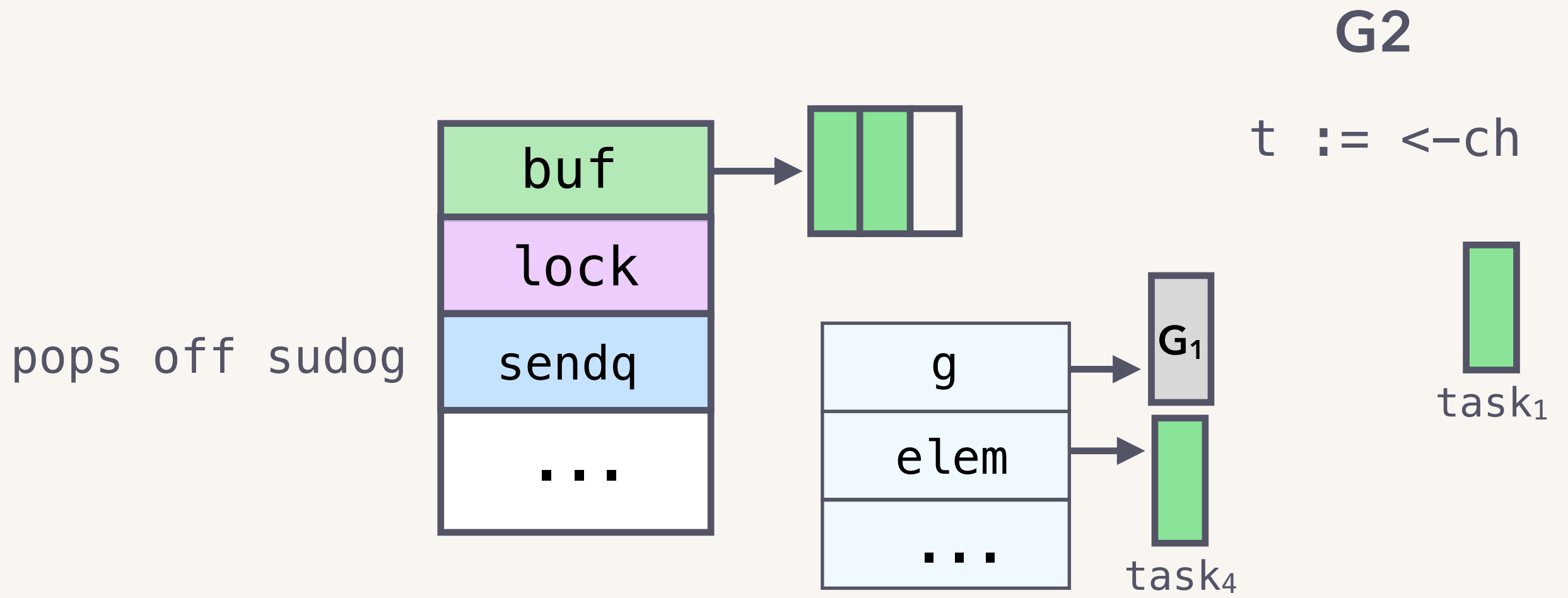
dequeue



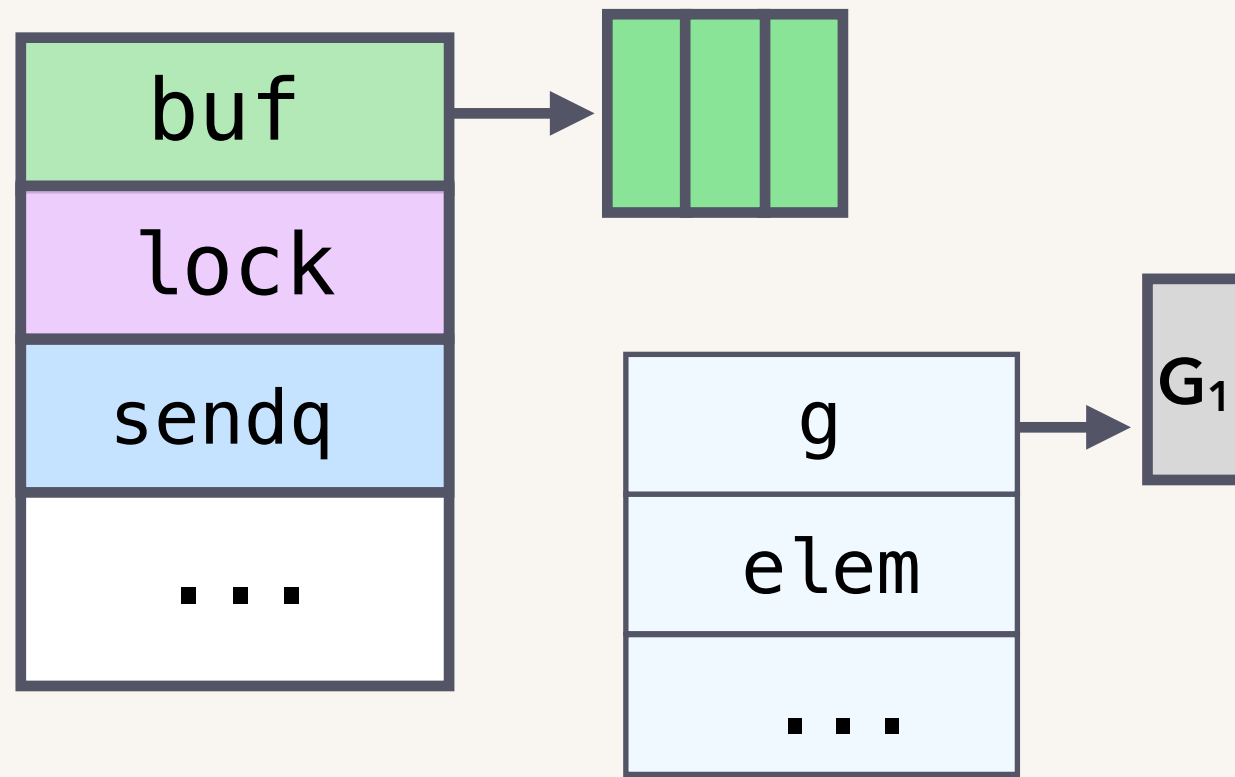
G2

$t := \leftarrow ch$





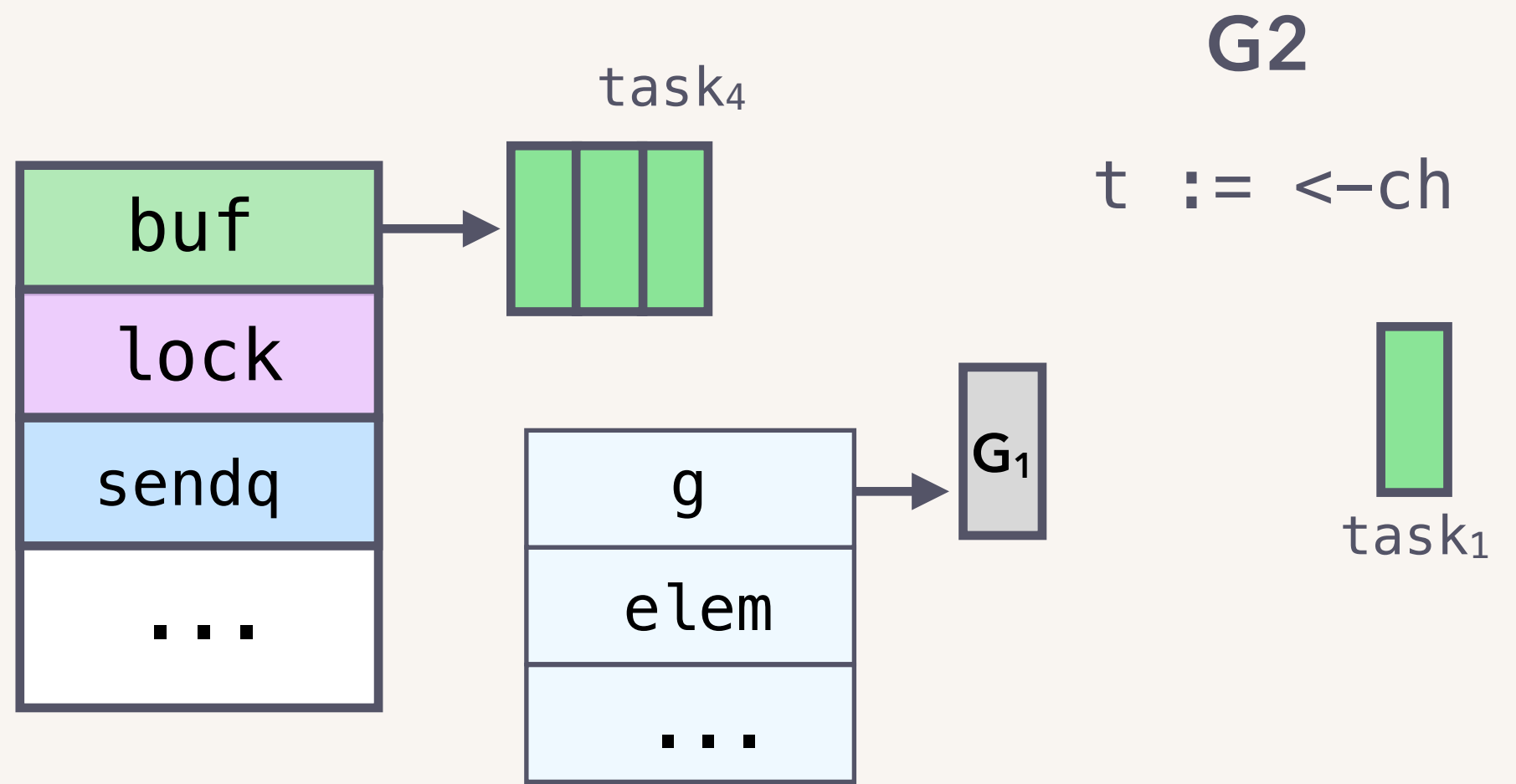
enqueues the sudog's elem: task₄



G2

t := <-ch





need to set G1 to runnable

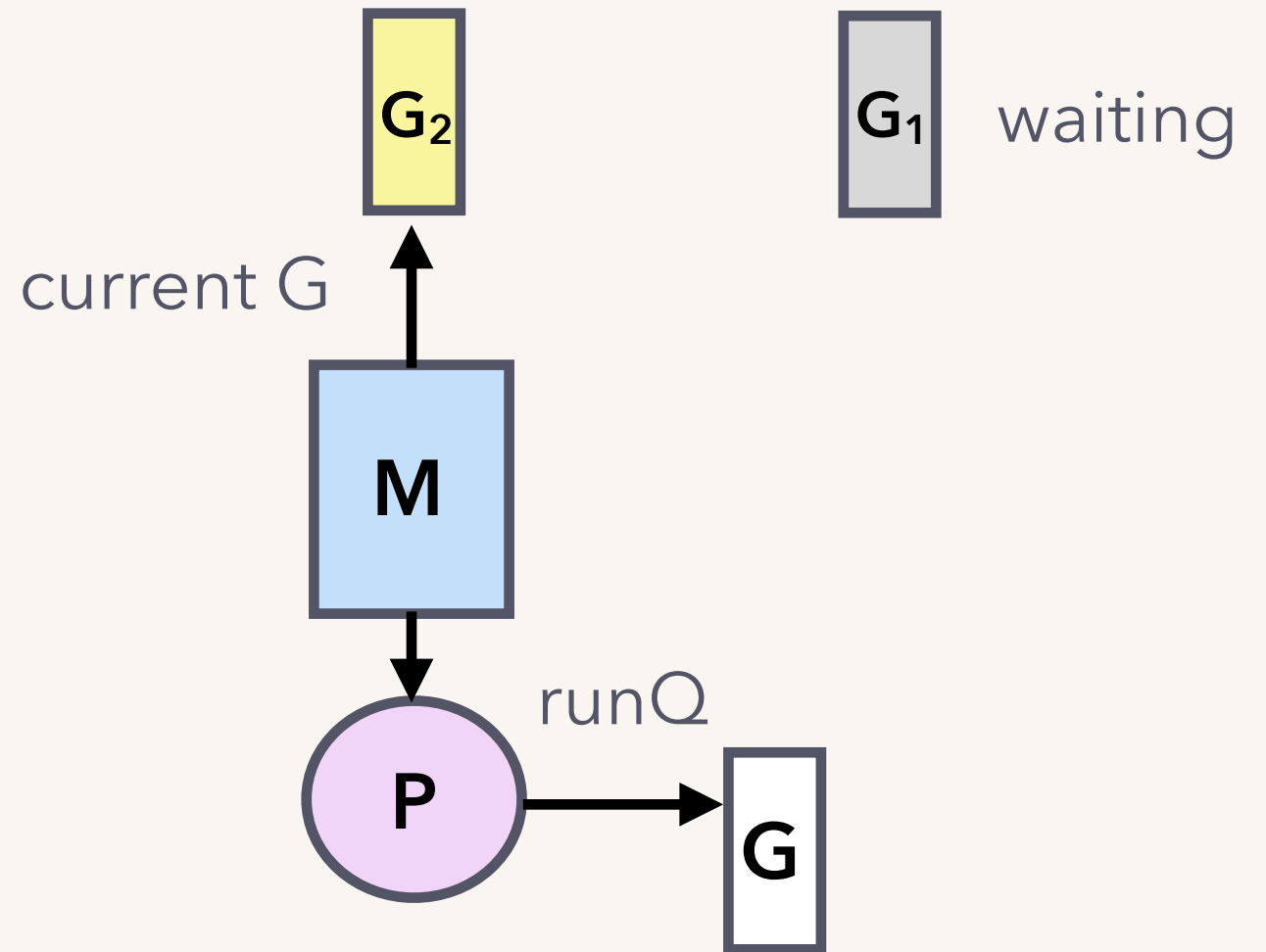
G2

`t := <-ch`

goready
(G1)



calls into the scheduler



G2

`t := <-ch`

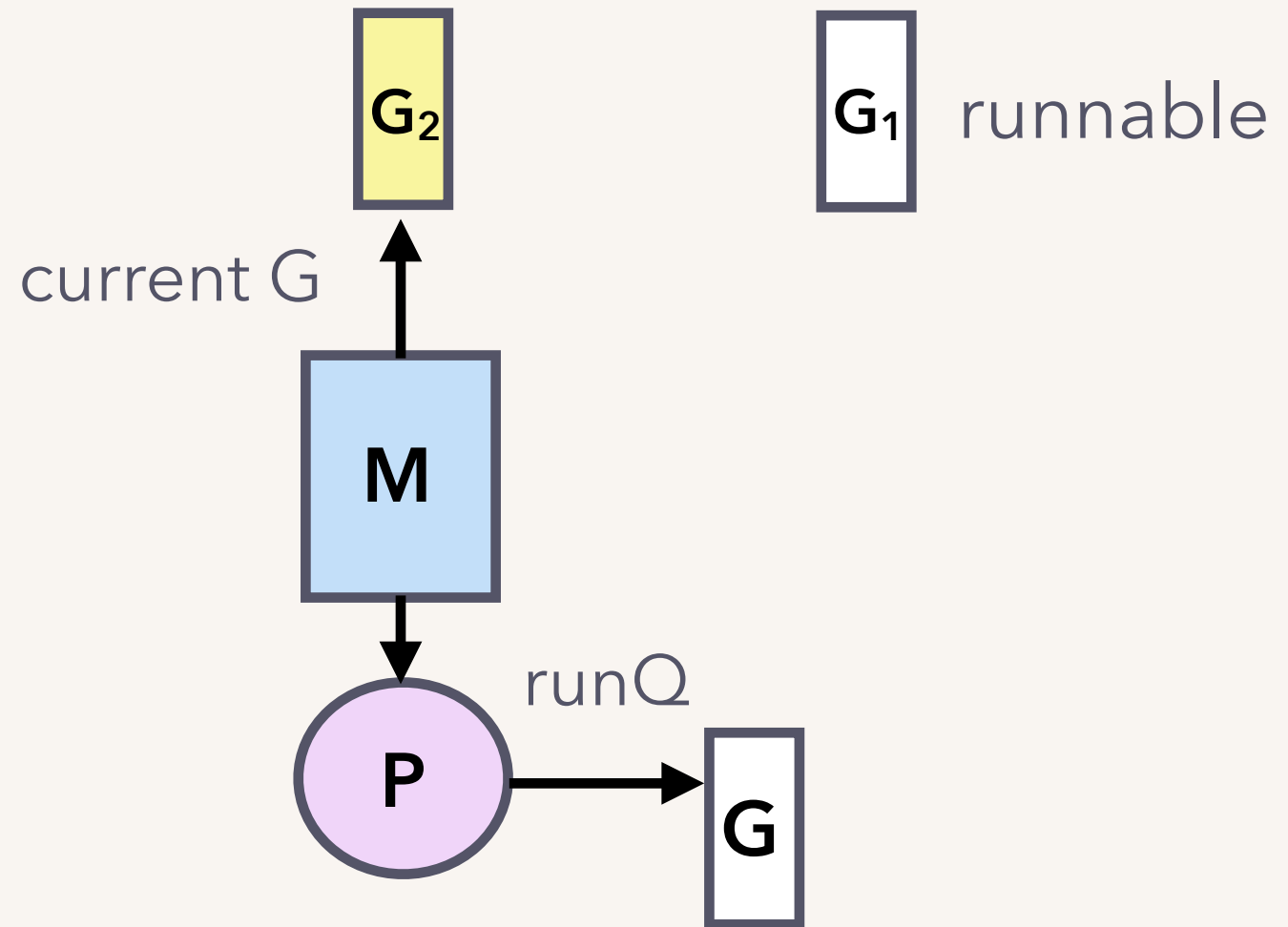
goready
(G1)



calls into the scheduler



sets **G1** to runnable



G2

`t := <-ch`

goready
(G1)



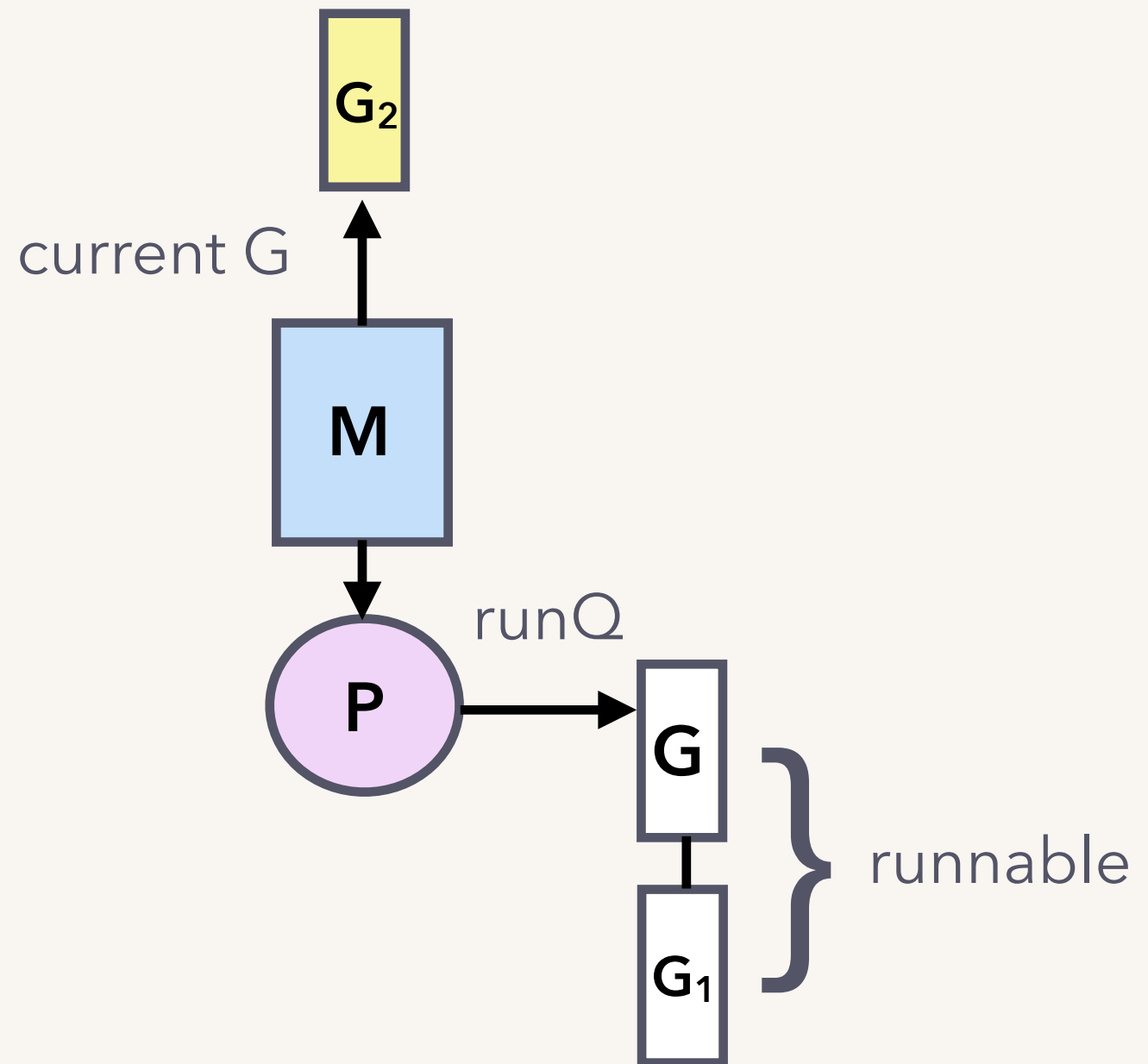
calls into the scheduler



sets **G1** to runnable

puts it on runqueue

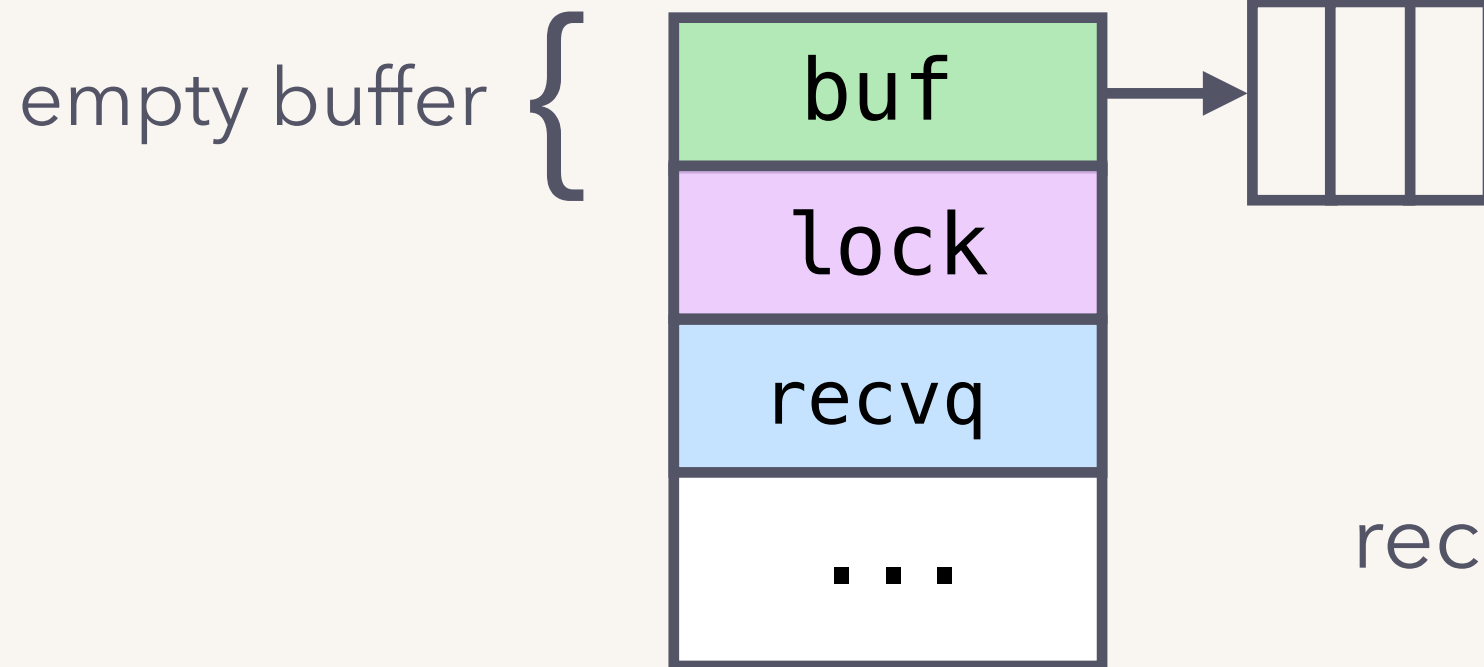
returns to **G2**



sends and receives
when the **receiver**
comes first

G2

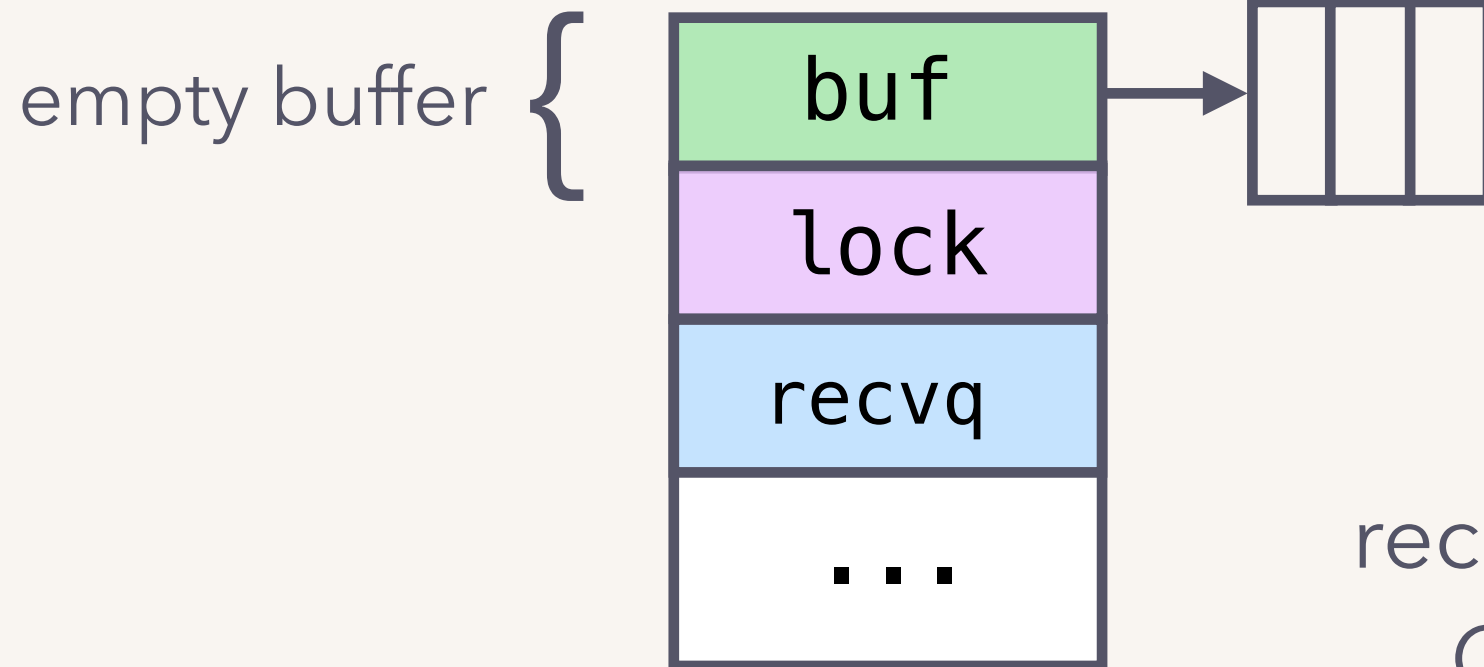
$t := \leftarrow \text{ch}$



receive on an **empty** channel:

G2

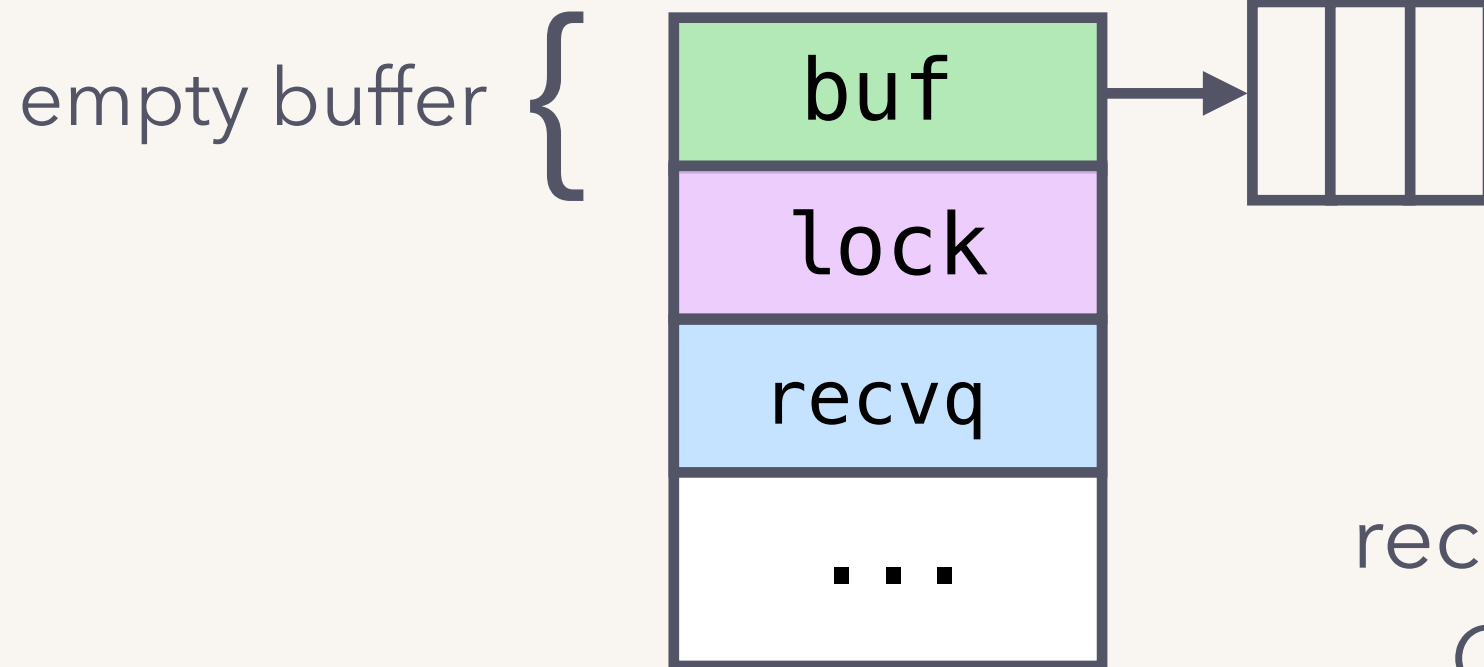
$t := \leftarrow \text{ch}$



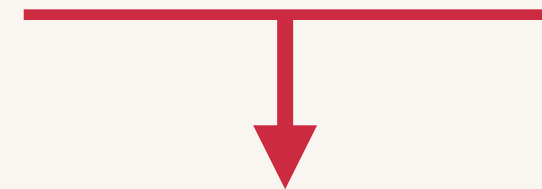
receive on an **empty** channel:
G2's execution is **paused**
resumed after a send.

G2

$t := \leftarrow \text{ch}$



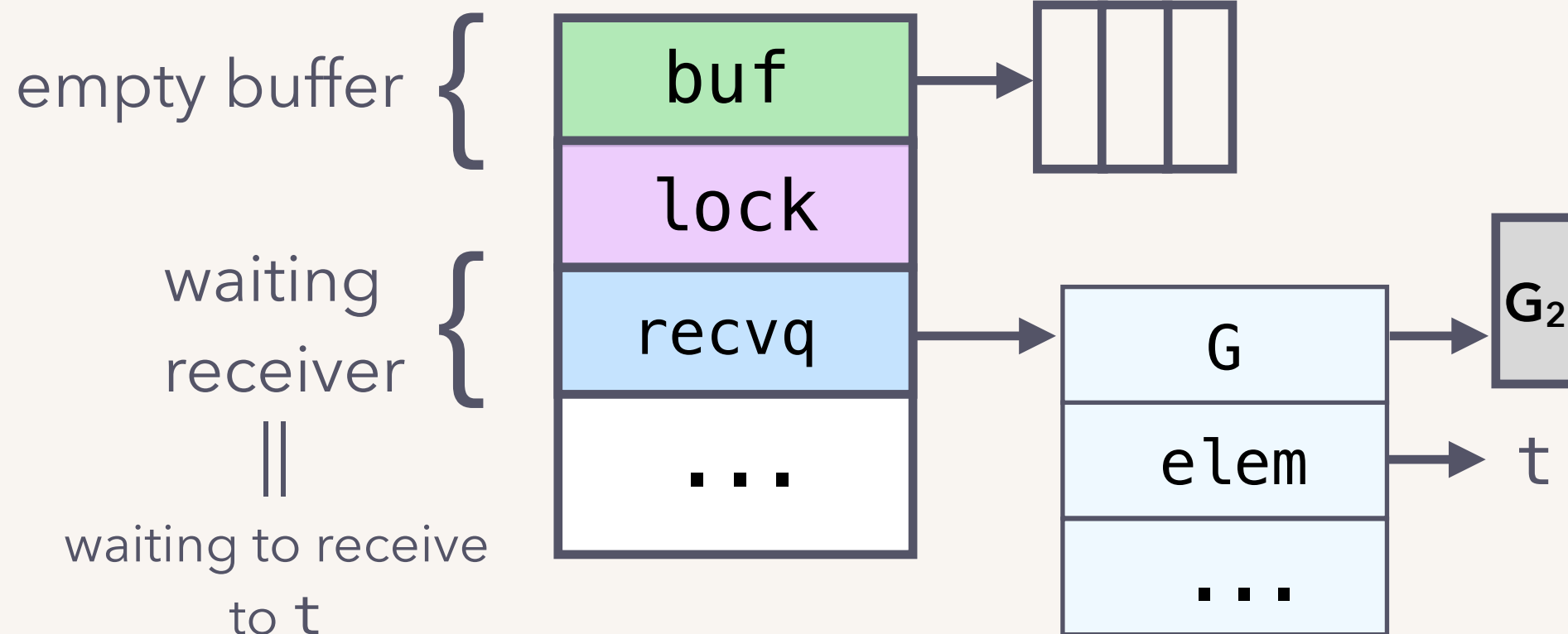
receive on an **empty** channel:
G2's execution is **paused**
resumed after a send.



set up state for resumption, and pause
put a **sudog** in the **recvq** gopark G2.

G2

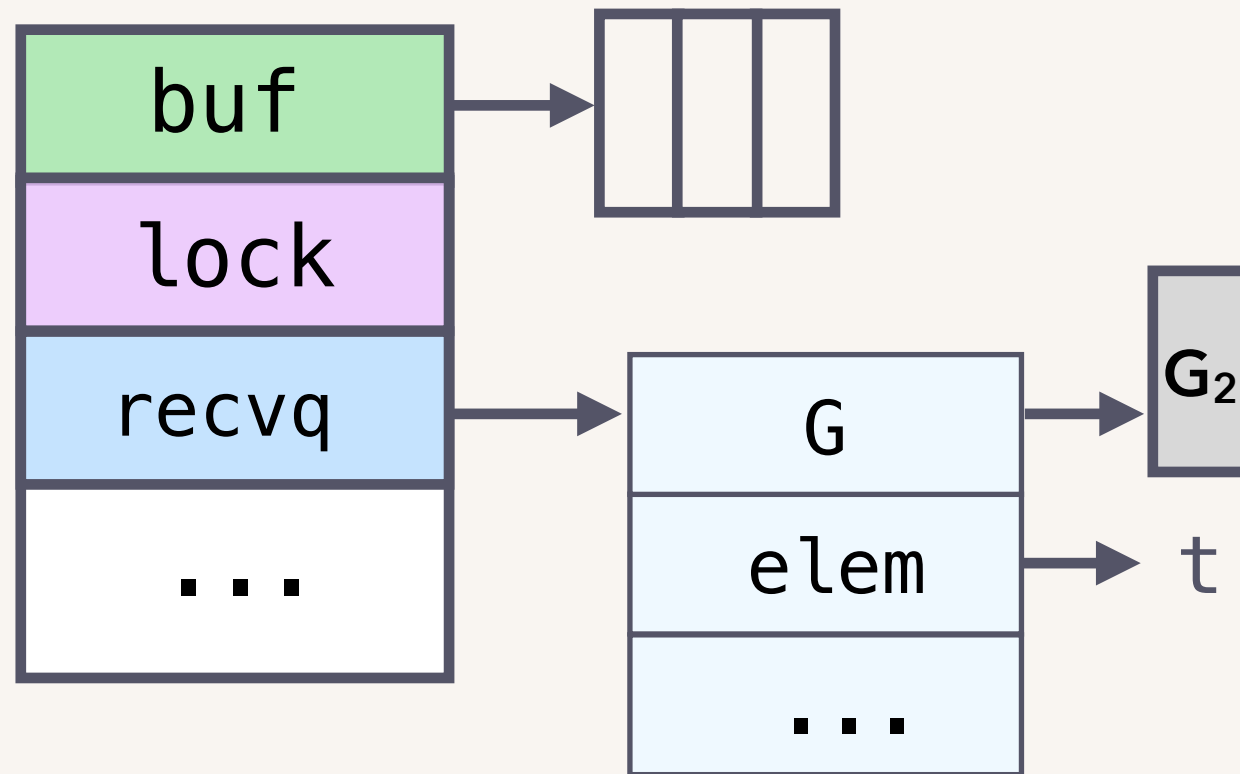
$t := \leftarrow \text{ch}$



set up state for resumption, and pause
put a **sudog** in the **recvq** **gopark** G2.

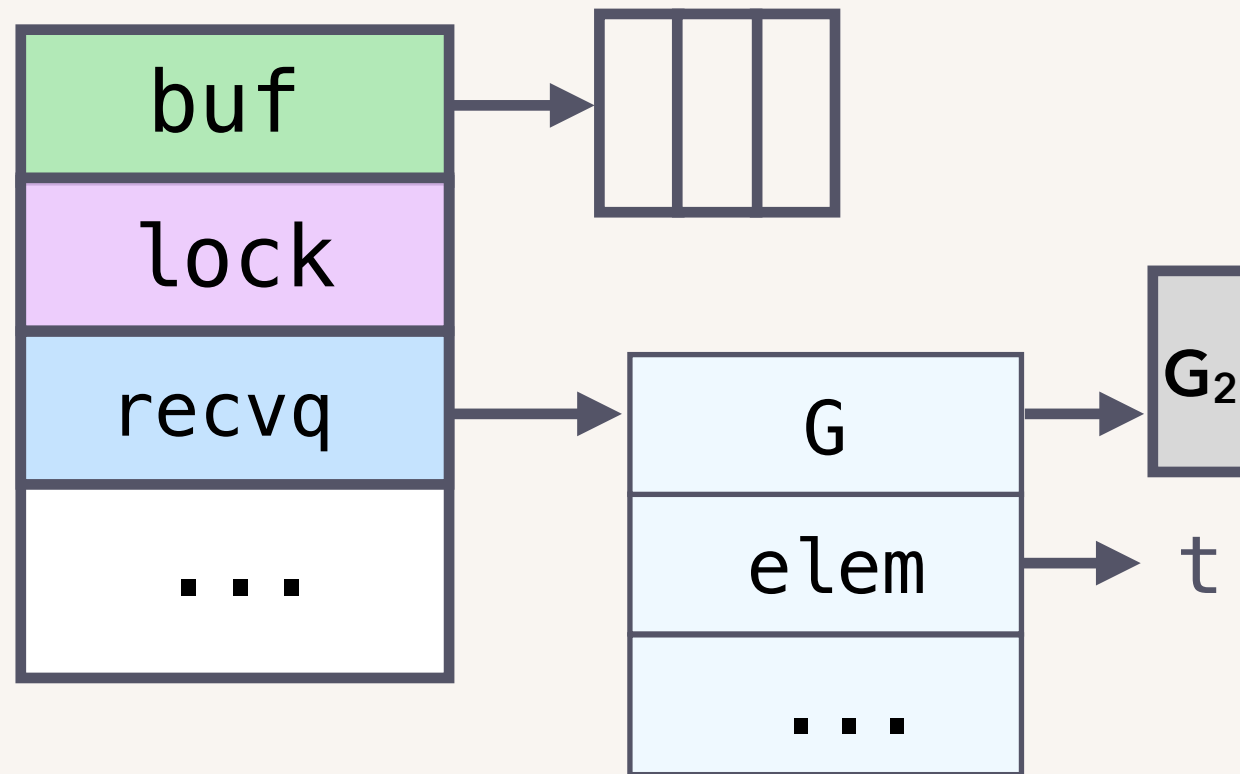
G1

ch <- task



G1

ch <- task

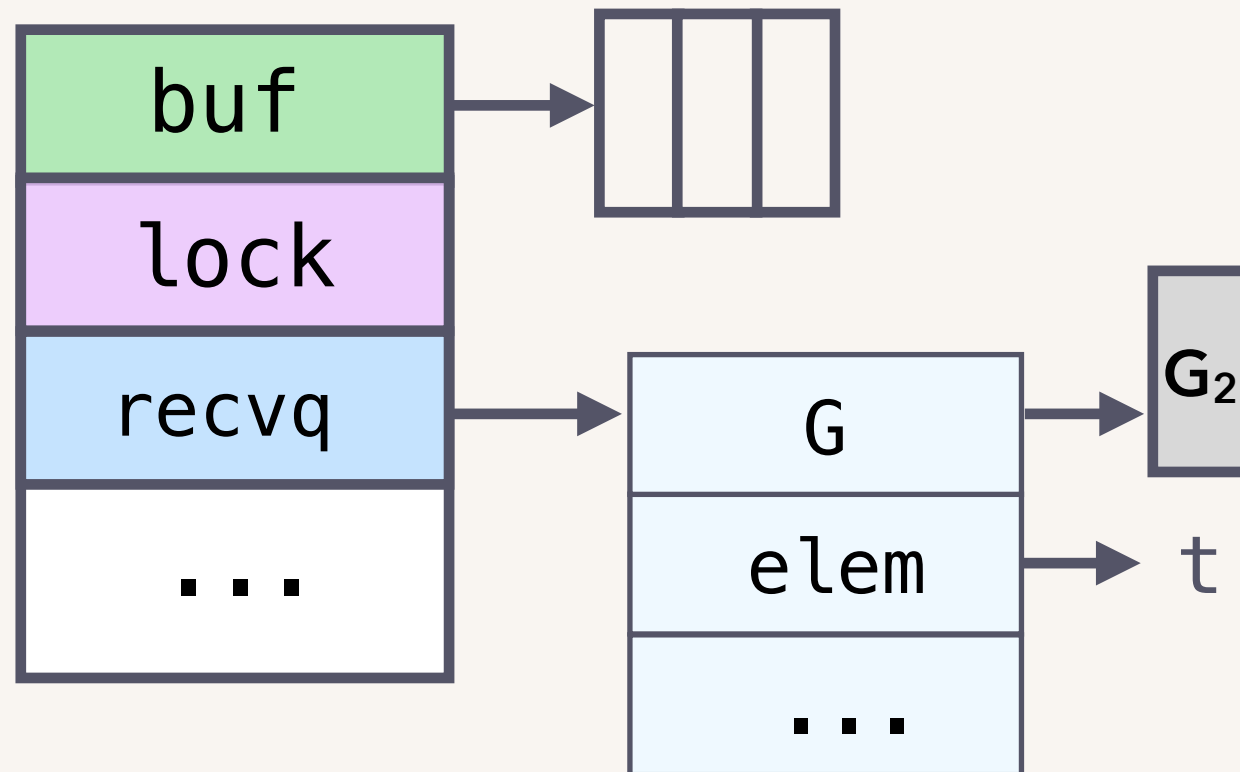


could:

- ▶ enqueue task in the buffer,
- ▶ goroutine(G₂)

G1

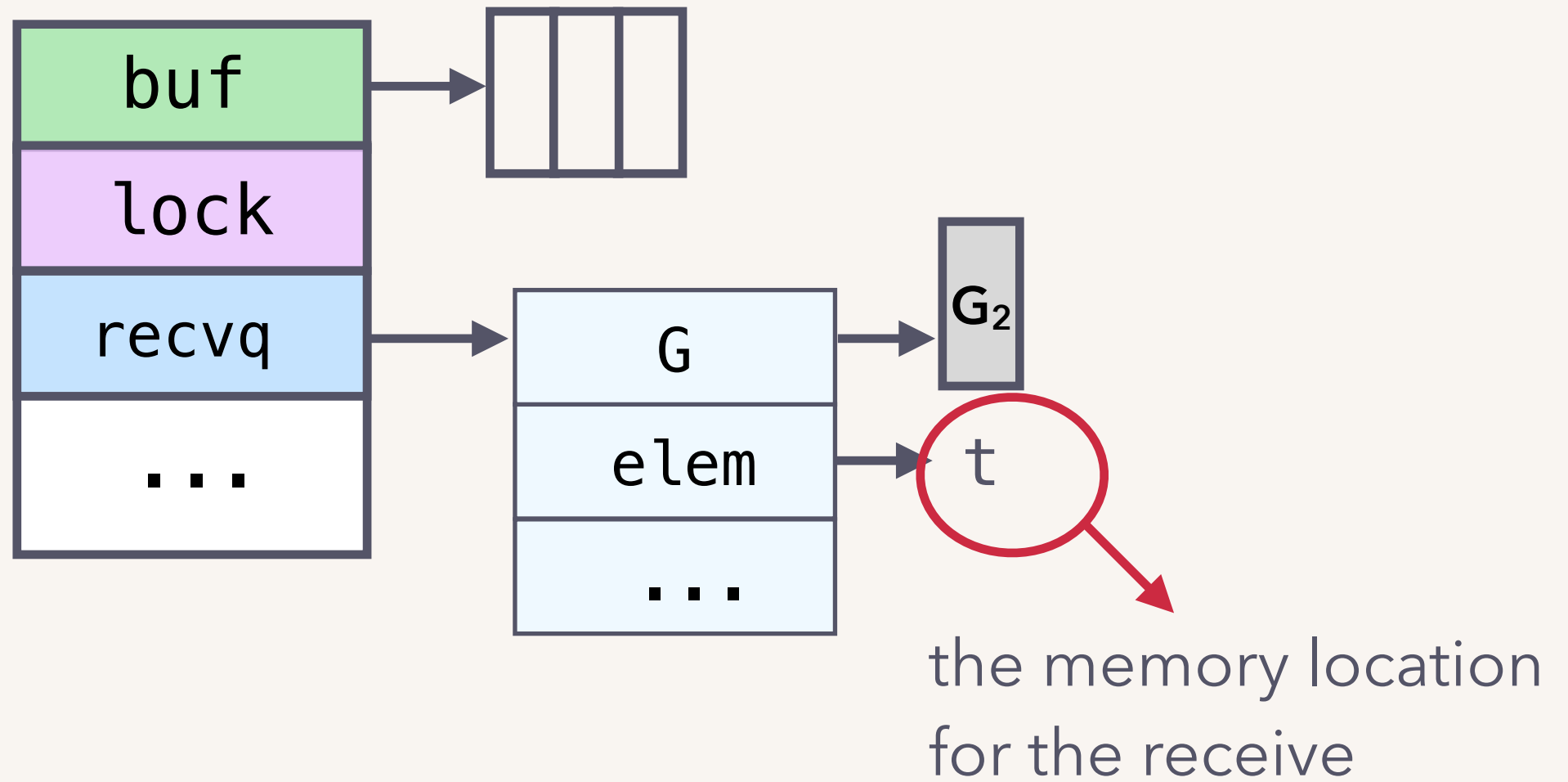
ch <- task



or we can be **smarter**.

G1

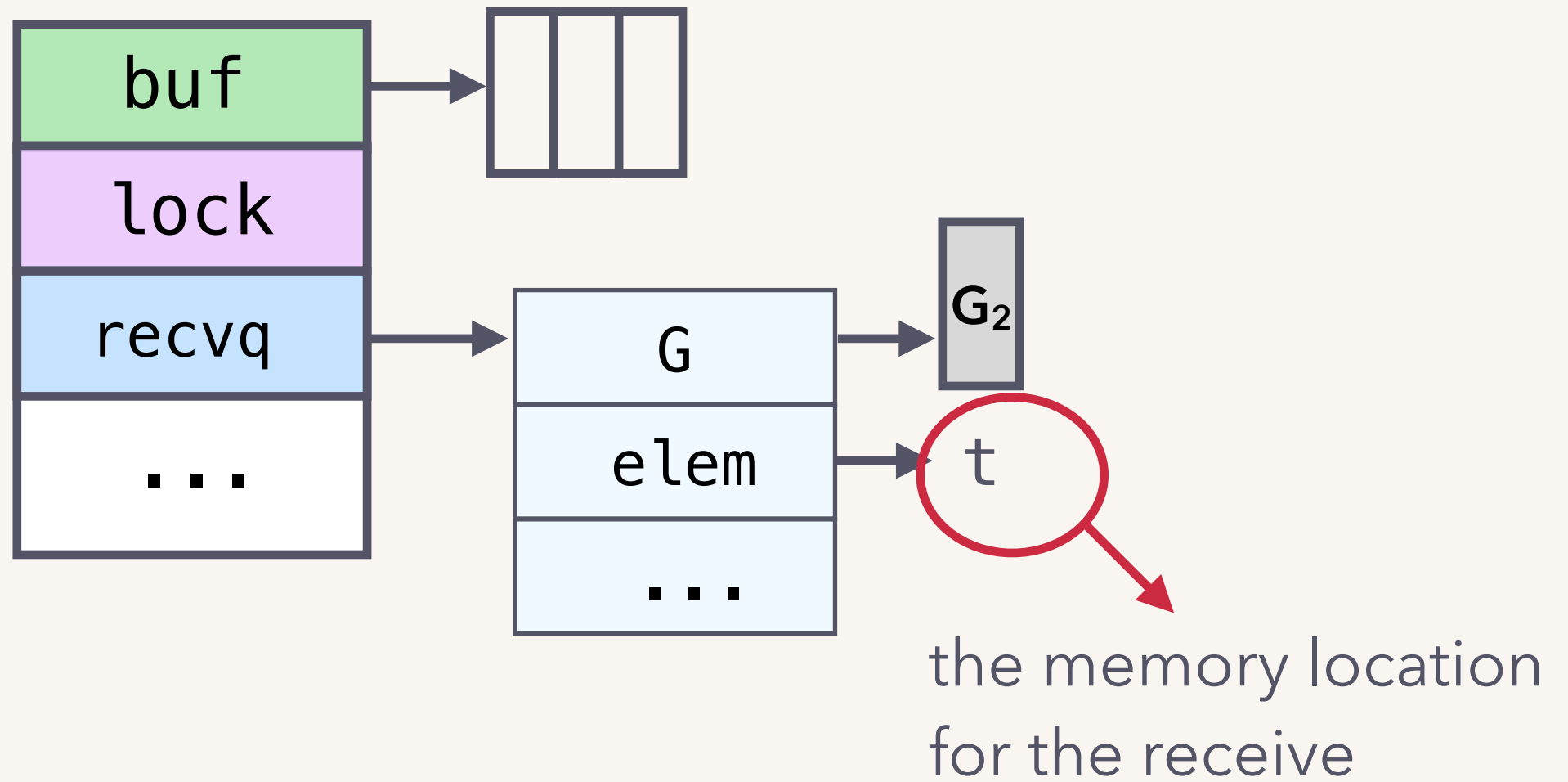
ch <- task



or we can be **smarter**.

G1

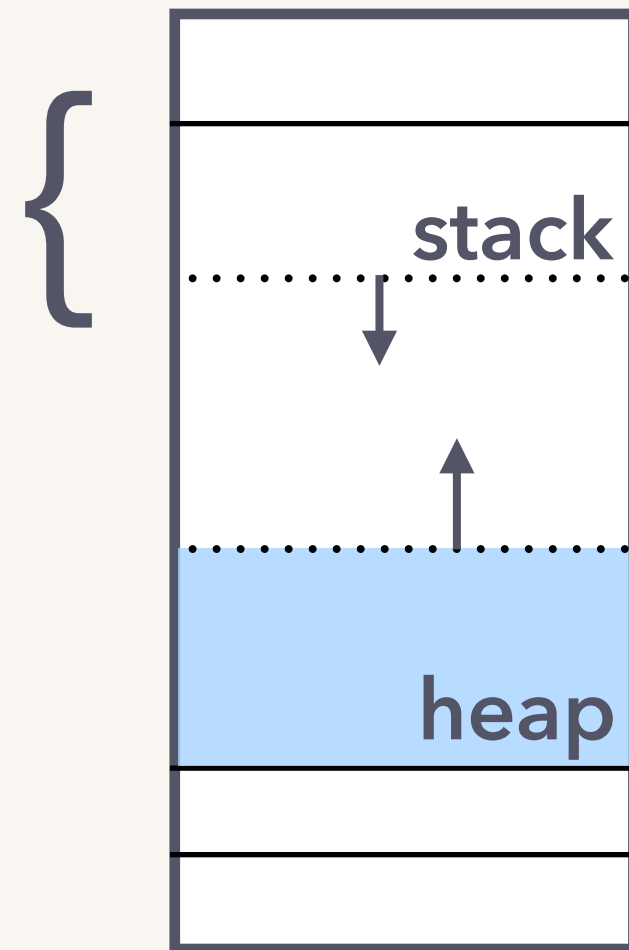
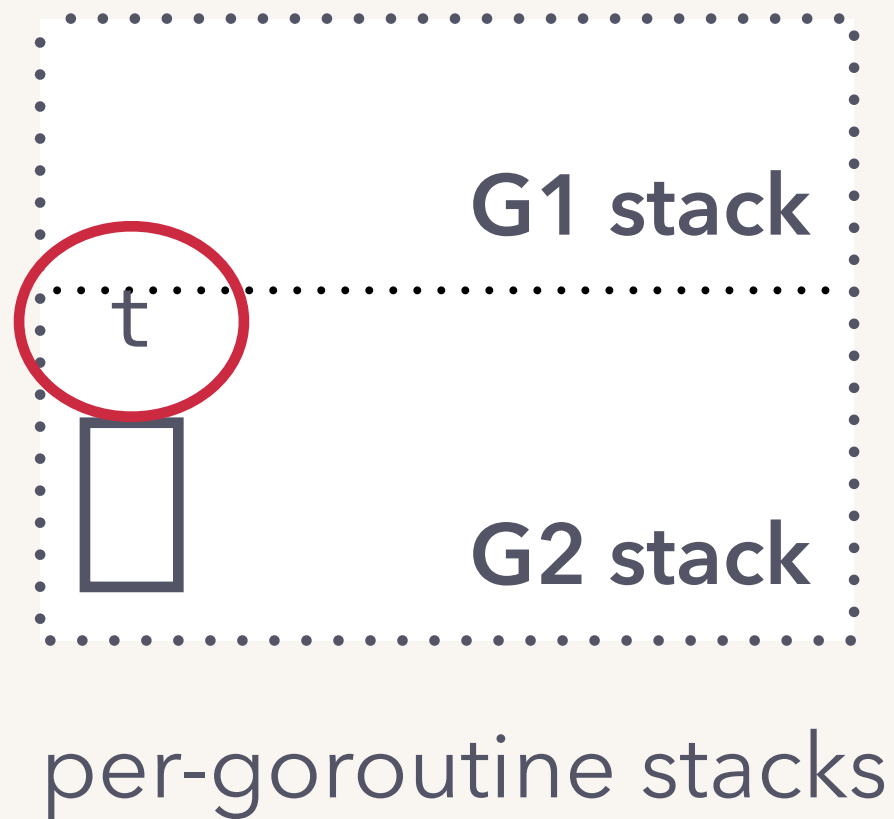
ch <- task



G1 writes to `t` directly.



direct send



G1 writes to G2's stack!

only operations in runtime where this happens.

This is clever.

On resuming, G2 does not need to acquire channel lock and manipulate the buffer.

Also, one fewer memory copy.

we now understand channels (sorta)...

goroutine-safe

► hchan **mutex**

store values, pass in FIFO.

► copying into and out of hchan **buffer**

can cause goroutines to pause and resume.

► hchan **sudog queues**

► calls into the **runtime scheduler**
(gopark, goready)

a note (or two)...

unbuffered channels

unbuffered channels always work like the “**direct send**” case:

- ▶ receiver first → sender writes to receiver's stack.
- ▶ sender first → receiver receives directly from the sudog.

select (general-case)

- ▶ all channels locked.
- ▶ a sudog is put in the sendq /recvq queues of all channels.
- ▶ channels unlocked, and the **select**-ing G is **paused**.
- ▶ CAS operation so there's one winning case.
- ▶ **resuming** mirrors the pause sequence.

stepping back...

simplicity and **performance**

simplicity

queue with a lock preferred to lock-free implementation:

“The **performance improvement** does not materialize from the air,
it comes with **code complexity increase**.” – dvyokov

performance

calling into the runtime **scheduler**:

- ▶ OS thread remains unblocked.

cross-goroutine stack reads and writes.

- ▶ goroutine wake-up path is lockless,
- ▶ potentially fewer memory copies

} need to account for
memory management:

} garbage collection,
stack-shrinking

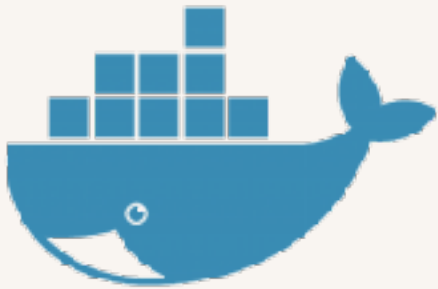
astute trade-offs
between
simplicity and **performance**

“The noblest pleasure is
the joy of understanding.”

- Leonardo da Vinci

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speakerdeck.com/kavya719/understanding-channels



Docker: software container platform

...Go is geared for distributed computing.
It has many built-in features to support concurrency...



Railgun: CloudFlare's web proxy

We chose to use Go because Railgun is inherently highly concurrent...

Railgun makes extensive use of goroutines and channels.



Doozer: Heroku's distributed data store

Fortunately, Go's concurrency primitives made the task much easier.



Kubernetes: Google's container orchestration platform

Built in concurrency. Building distributed systems in Go is helped tremendously by being able to fan out ...

unbuffered channels

```
unbuffered channel  
ch := make(chan int)
```

That's how unbuffered channels (always) work too.

If receiver is first:

- > puts a sudog on the recvq and is paused.
- > subsequent sender will "send directly", and resume the receiver.

If sender is first:

- > puts a sudog for itself on the sendq and is paused.
- > receiver then "receives directly" from the sudog and resumes the sender.

selects

```
var taskCh = make(chan Task, 3)
```

```
var cmdCh = make(chan Command)
```

```
func worker() {  
    for {  
        select {  
            case task := <-taskCh:  
                process(task)  
            case cmd := <-cmdCh:  
                execute(cmd)  
        }  
    }  
}
```