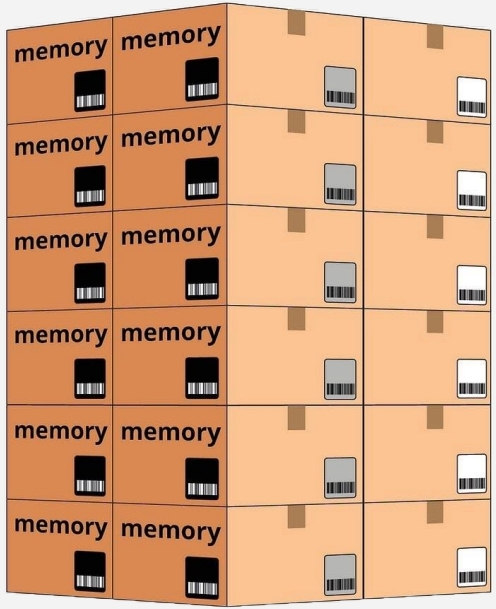
Go Memory Allocation Internals



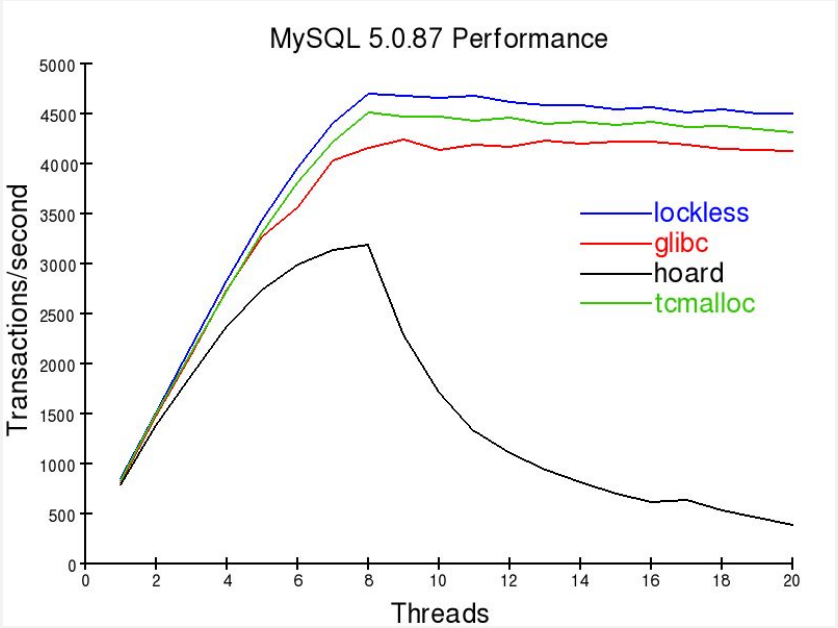
Renê Cardozo

- Formado em Ciência da Computação - USP
- 6 anos desenvolvendo em Go

Engine

@reneepc

O algoritmo de alocação faz diferença



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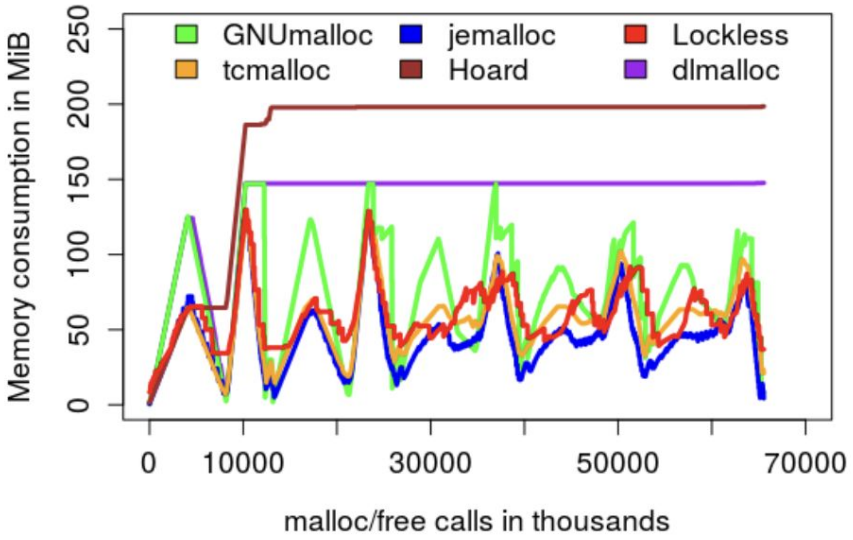
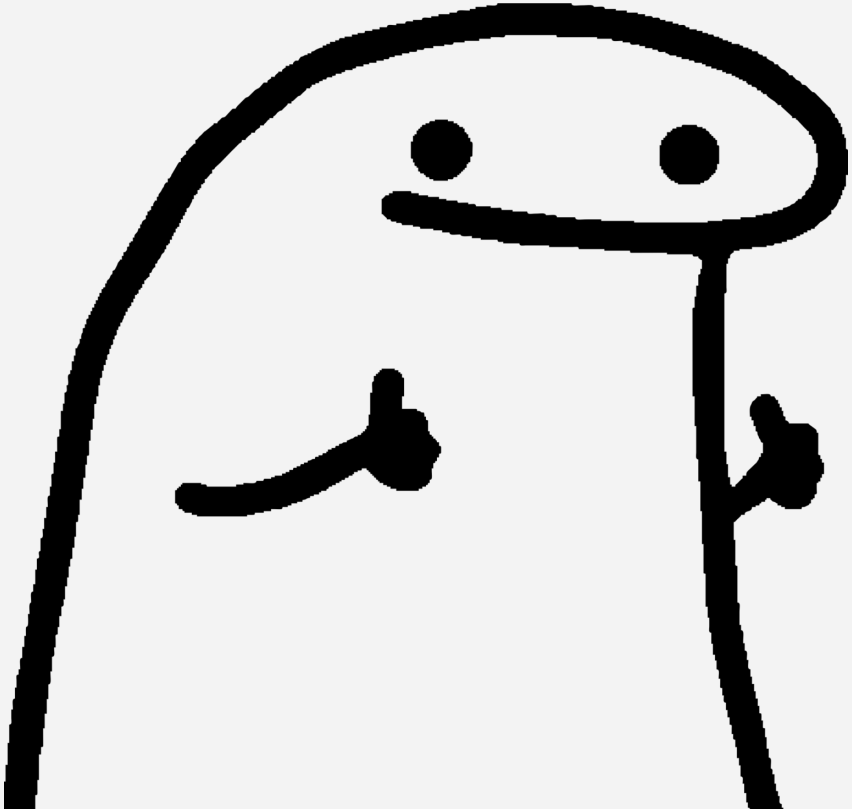


Figure 3: Memory usage over time.

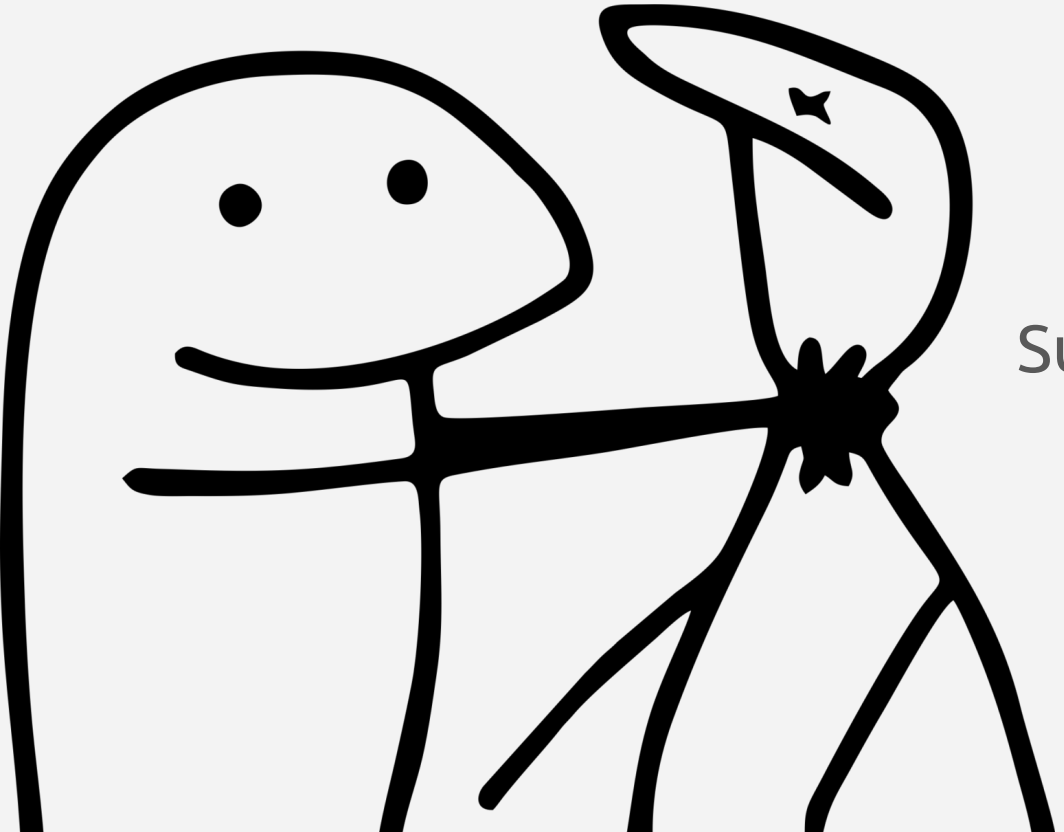
Zavrtanik, Matej & Mihelič, Jurij. (2017). Experimental Evaluation and Comparison of Memory Allocators in the GNU/Linux Operating System.

Mas o real motivo



~~Eu gosto~~
Não tinha ninguém melhor
para palestrar

Se você achar ruim



Submeta sua palestra para
o C4P da GolangSP

Panic

```
Starting charge of $49.99 for user user123
panic: runtime error: invalid memory address or nil pointer dereference
[signal SIGSEGV: segmentation violation code=0x2 addr=0x0
pc=0x100782e30]
goroutine 1 [running]:
main.(*PaymentGateway).Charge(0x0, "user123", 49.99)
    payment.go:34 +0x30

main.chargeCard("user123", 49.99)
    payment.go:26 +0xa4

main.processPayment("user123", 49.99)
    payment.go:14 +0x20

main.main()
    payment.go:6 +0x30

exit status 2
```

Stack

```go
package main

import "fmt"

func main() {
    userId := "user123"
    amount := 49.99

    processPayment(userId, amount)
}

func processPayment(userID string, amount float64) {
    if !validateUser(userID) {
        fmt.Println("Invalid user")
        return
    }
    chargeCard(userID, amount)
}

func validateUser(userID string) bool {
    // checa se usuário está presente no banco
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}

func chargeCard(userID string, amount float64) {
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    // Aciona o gateway de pagamentos
}
```

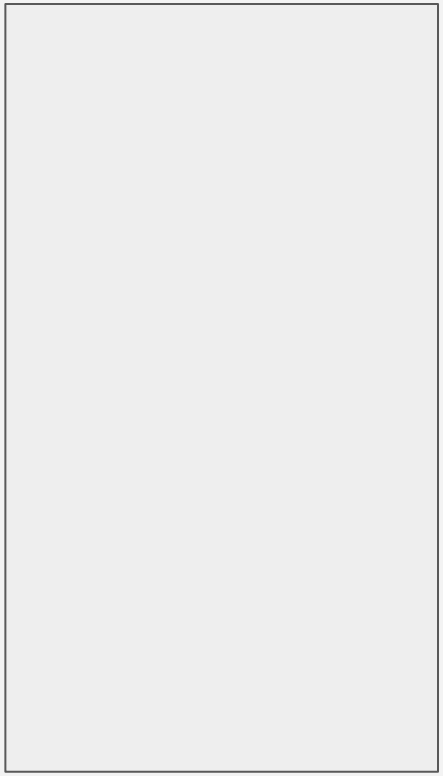

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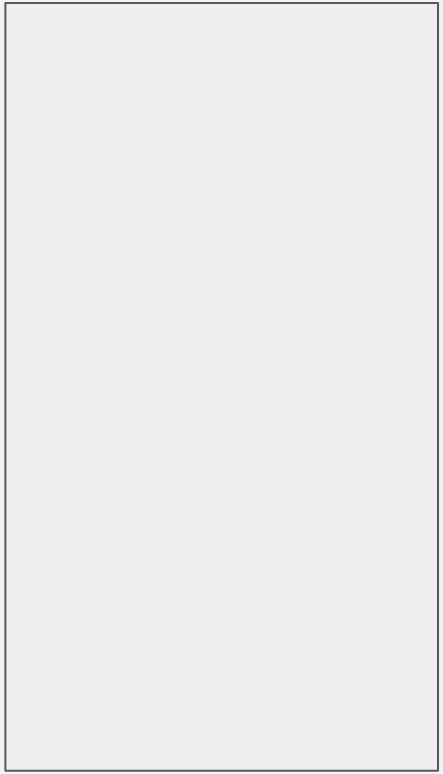
```

Para cada Goroutine uma Stack



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```
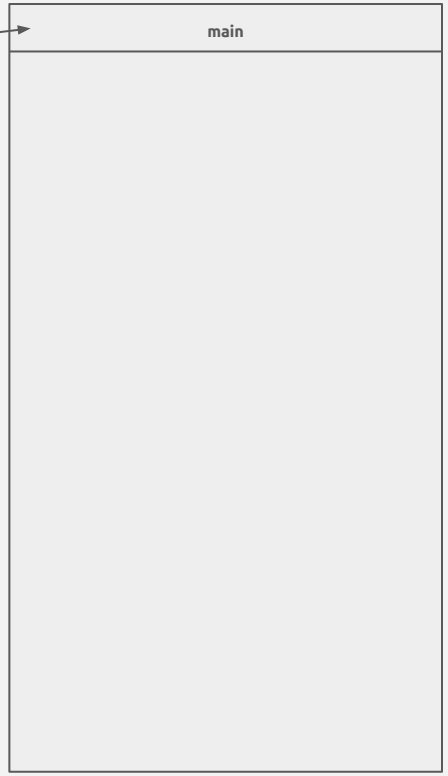

Cria um
stack frame



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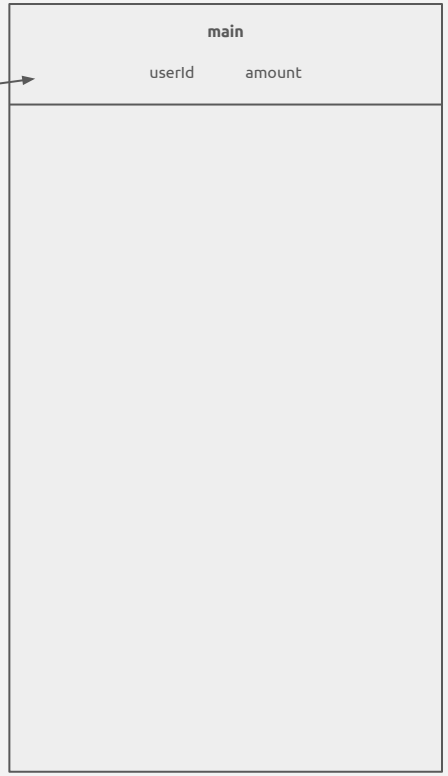
```

Variáveis locais são armazenadas na Stack



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```
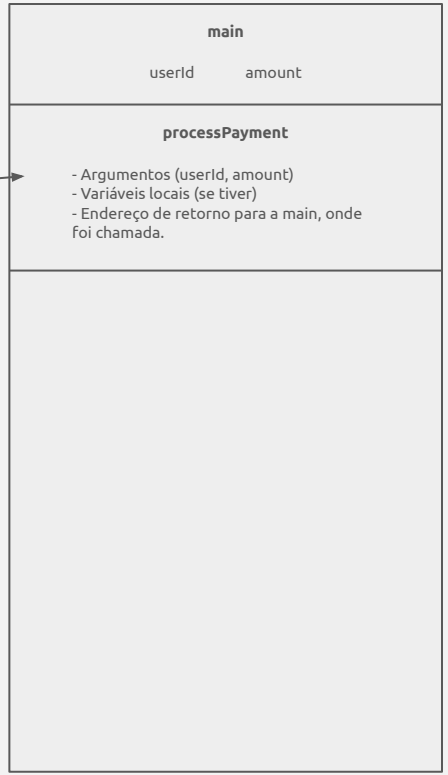

Cada stack frame mantém o **contexto de execução**.



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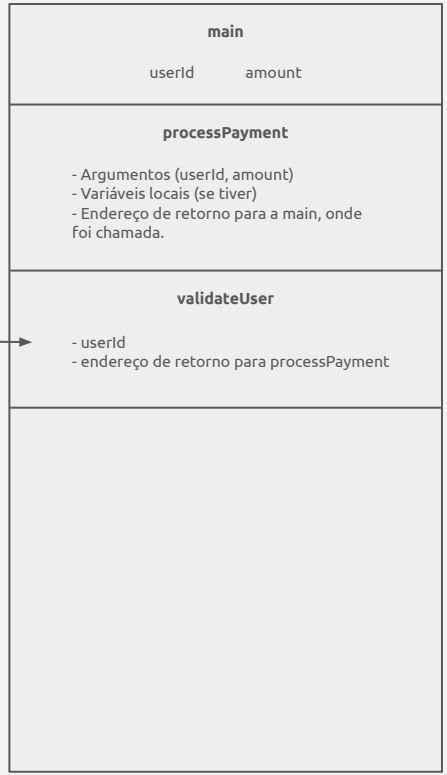

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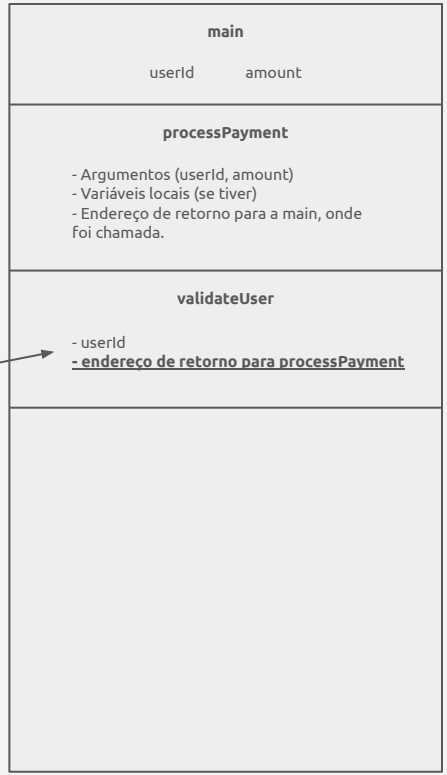

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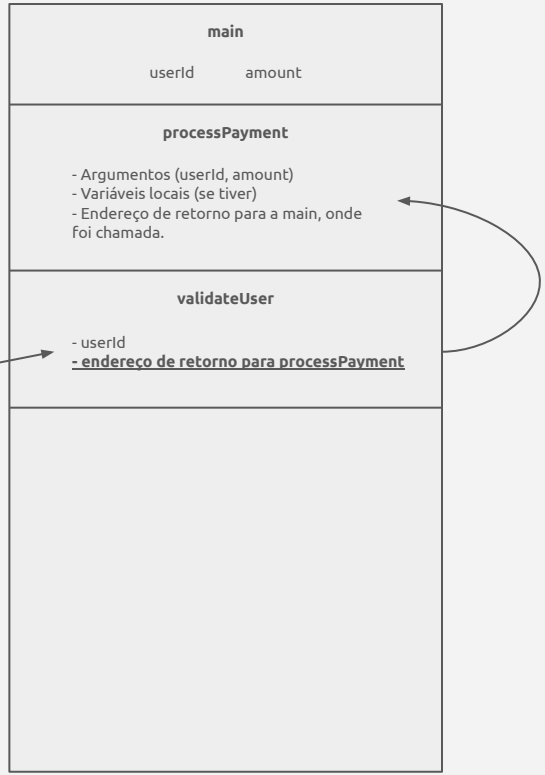

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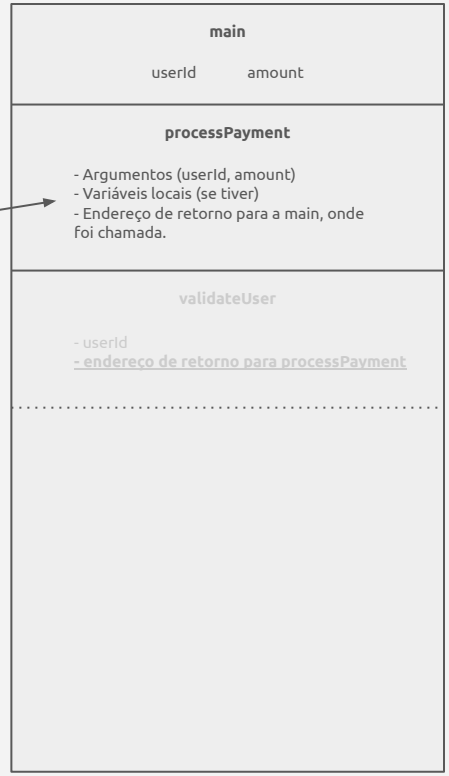

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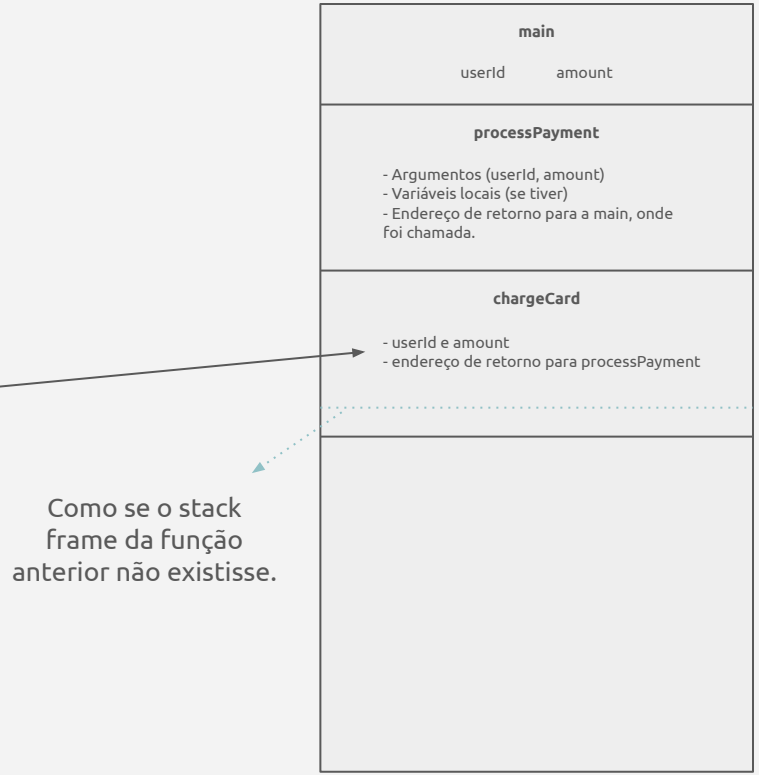

Como se o stack frame da função anterior não existisse.

Stack

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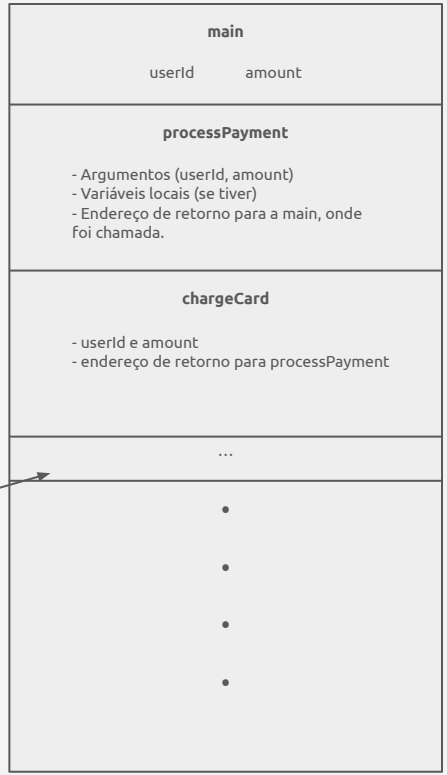

Stack

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Starting charge of $49.99 for user user123
panic: runtime error: invalid memory address or nil pointer dereference
[signal SIGSEGV: segmentation violation code=0x2 addr=0x0
pc=0x100782e30]
goroutine 1 [running]:
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    payment.go:34 +0x30

main.chargeCard("user123", 49.99)
    payment.go:26 +0xa4

main.processPayment("user123", 49.99)
    payment.go:14 +0x20

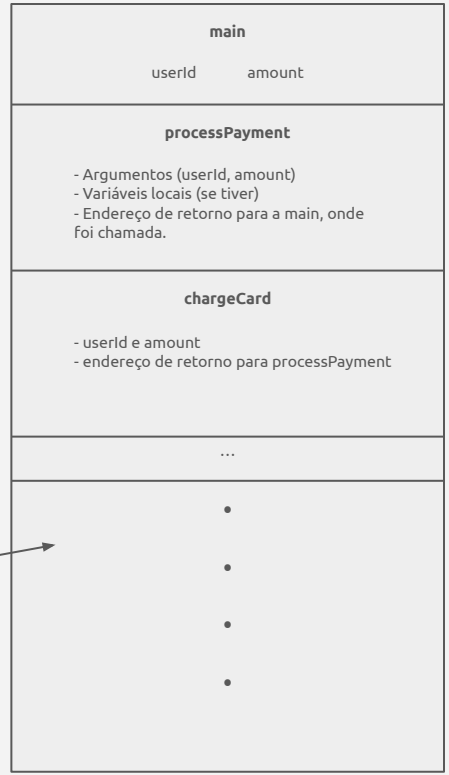
main.main()
    payment.go:6 +0x30

exit status 2
```

O runtime do Go caminha os endereços de retorno da stack para montar a stack trace.

runtime/traceback.go

```
userID)
    // Aciona o gateway de pagamentos
}
```



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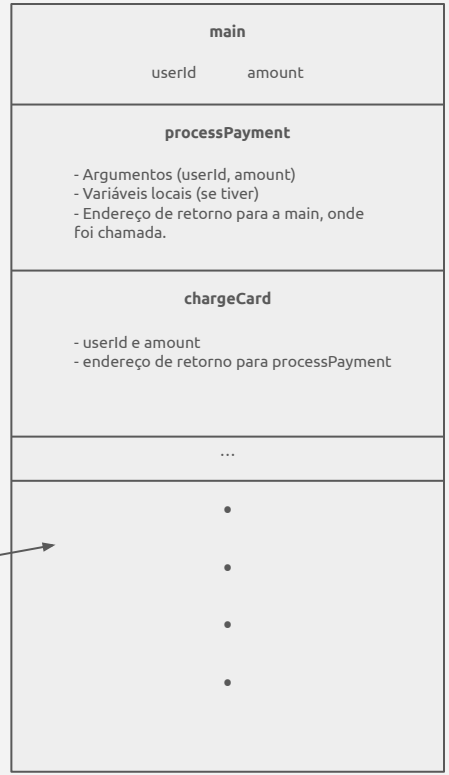

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exit status 2
```

```
userID)
    // Aciona o gateway de pagamentos
}
```

main

userId amount

processPayment

- Argumentos (userId, amount)
- Variáveis locais (se tiver)
- Endereço de retorno para a main, onde foi chamada.

chargeCard

- userId e amount
- endereço de retorno para processPayment

...

Quando a stack não é suficiente

```go
package main

import (
    "fmt"
)

type Notification struct {
    UserID  string
    Channel string
    Message string
}

func main() {
    // ...
    // processPayment
    // ...
    notifications := buildNotifications("user123", 49.99)

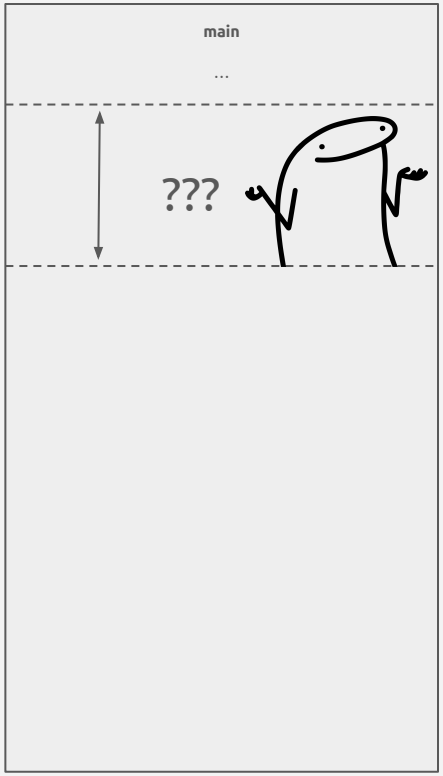
    for _, n := range notifications {
        // Persiste em outbox ou envia notificação
    }
}

func buildNotifications(userID string, amount float64) []Notification
{
    notifications := make([]Notification, 0)

    for _, channel = getUserNotificationChannels(userId) {
        notifications = append(notifications, Notification{
            UserID: userID,
            Channel: channel.Type,
            Message: channel.paymentNotification(amount)
        })
    }

    return notifications
}
```

Não é possível saber quantas notificações serão geradas, porque depende das configurações do usuário.



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```

Além disso, a stack também tem tamanho limitado.

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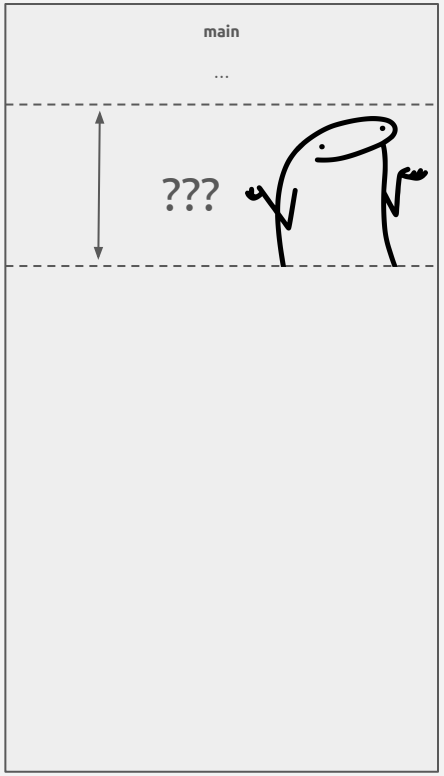

Heap

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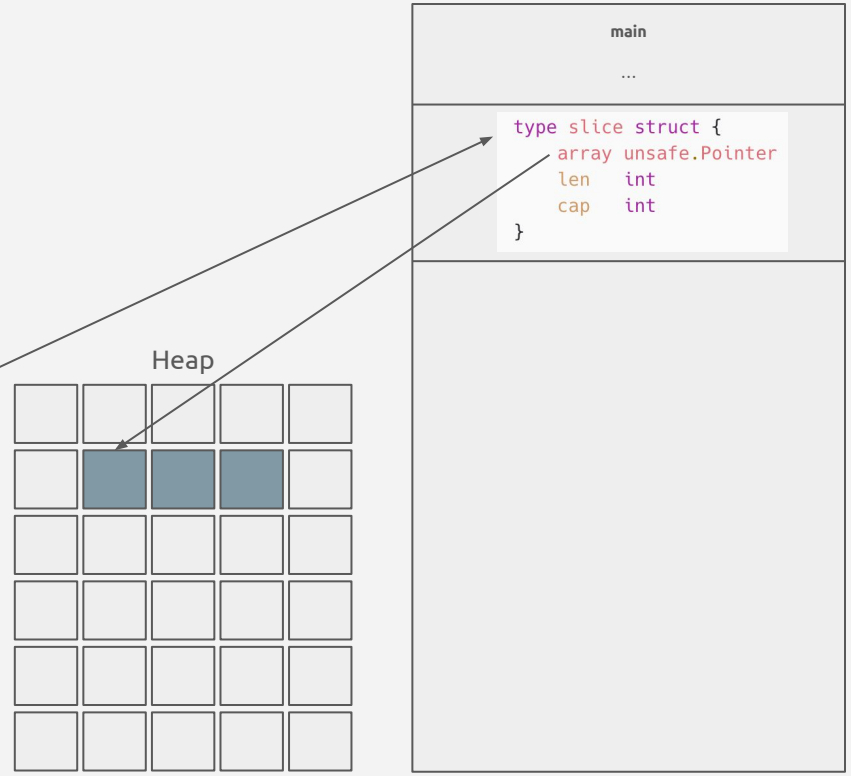

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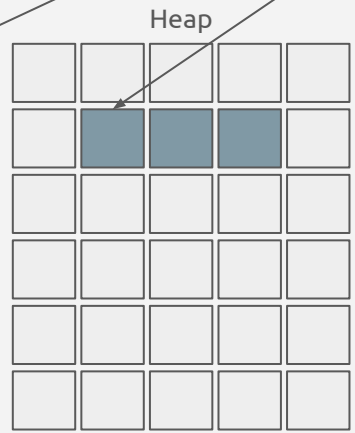
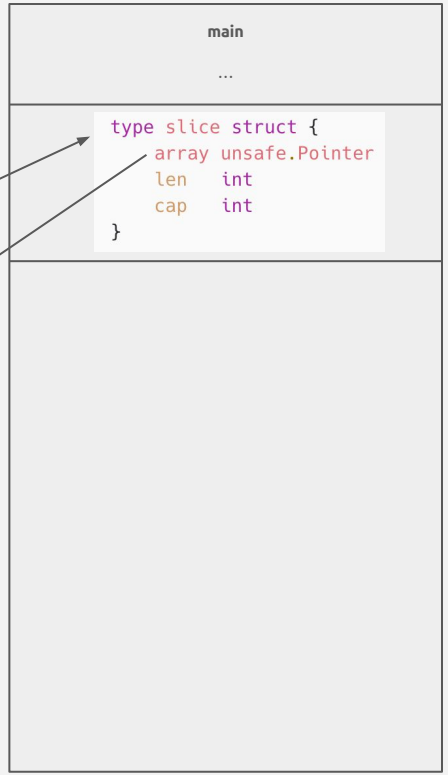
```

new()
make()





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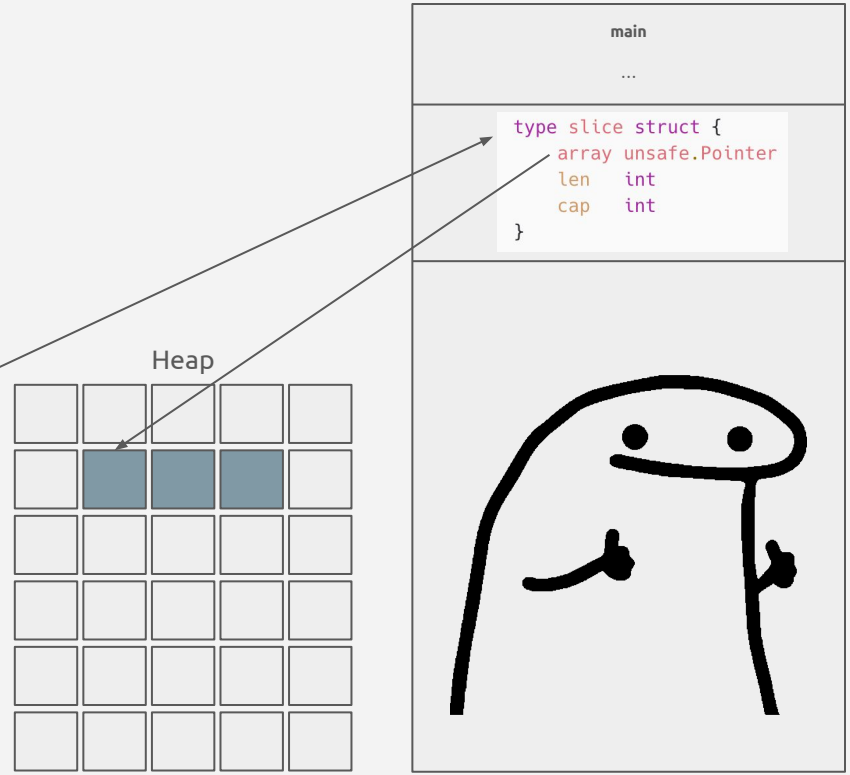
}

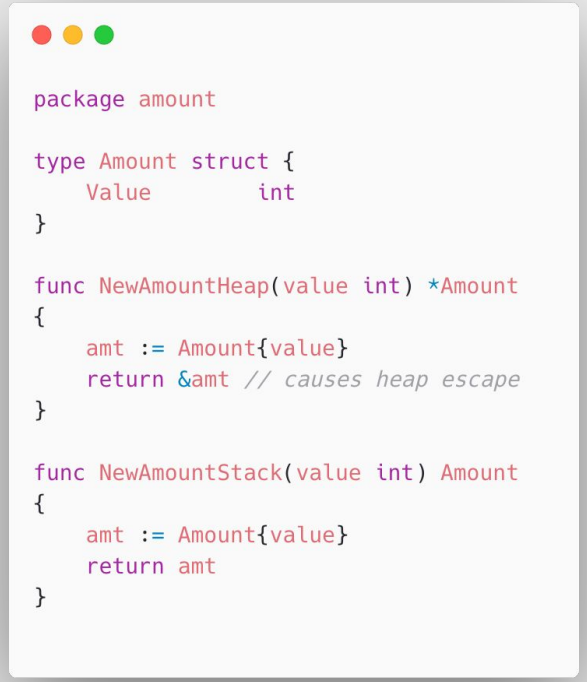
func buildNotifications(userID string, amount float64) []Notification
{
    notifications := make([]Notification, 0)

    for _, channel = getUserNotificationChannels(userId) {
        notifications = append(notifications, Notification{
            UserID: userID,
            Channel: channel.Type,
            Message: channel.paymentNotification(amount)
        })
    }

    return notifications
}
```



Heap



```
package amount

type Amount struct {
    Value        int
}

func NewAmountHeap(value int) *Amount
{
    amt := Amount{value}
    return &amt // causes heap escape
}

func NewAmountStack(value int) Amount
{
    amt := Amount{value}
    return amt
}
```

A heap também é usada para compartilhar referências a uma variável específica.

Heap

```go
package amount

type Amount struct {
    Value        int
}

func NewAmountHeap(value int) *Amount
{
    amt := Amount{value}
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}

func NewAmountStack(value int) Amount
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    return amt
}
```

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    amt := Amount{value}
    return amt
}
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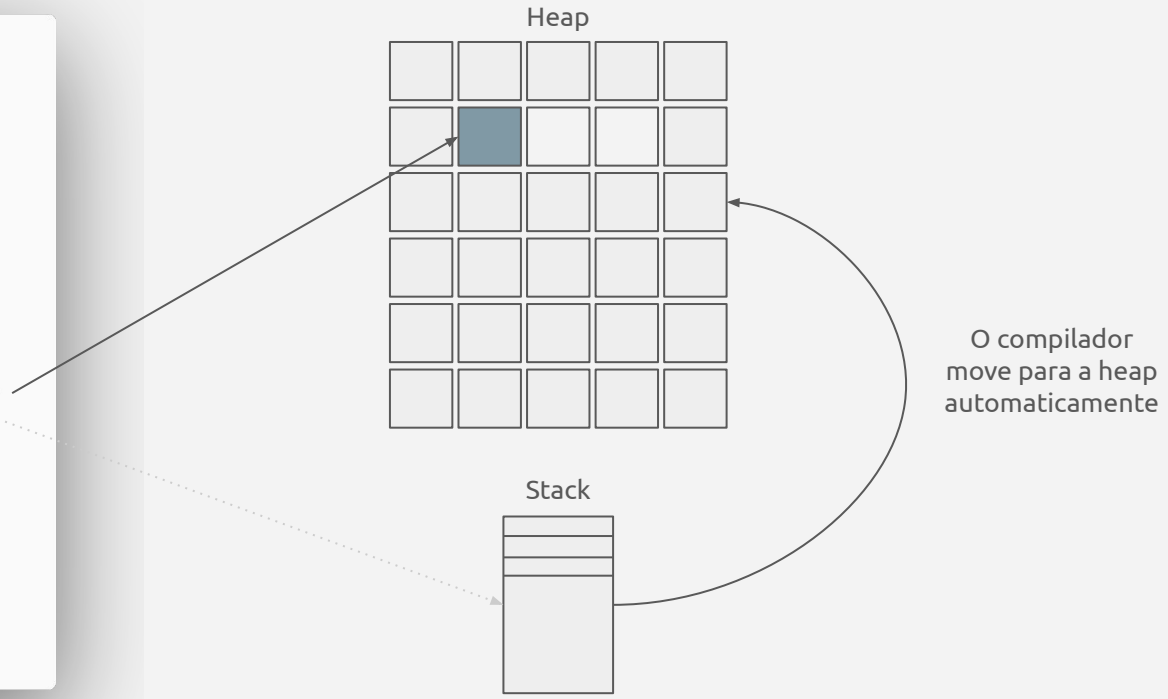
{
    amt := Amount{value}
    return amt
}
```



Heap

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package amount

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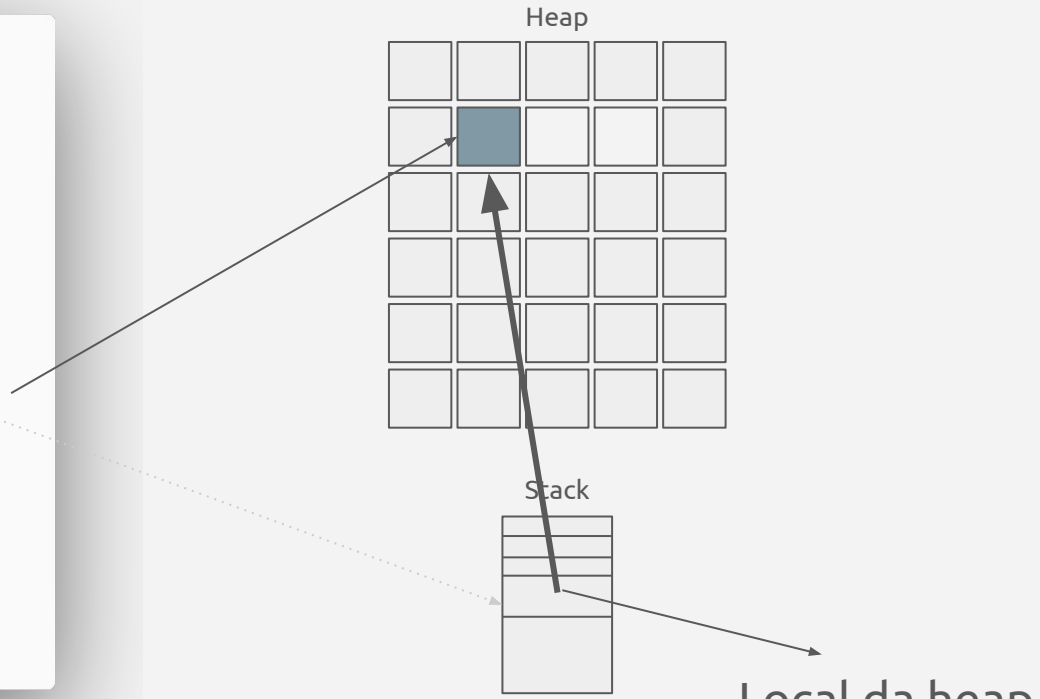
    Value        int
}

func NewAmountHeap(value int) *Amount
{
    amt := Amount{value}
    return &amt // causes heap escape
}

func NewAmountStack(value int) Amount
{
    amt := Amount{value}
    return amt
}
```



Heap

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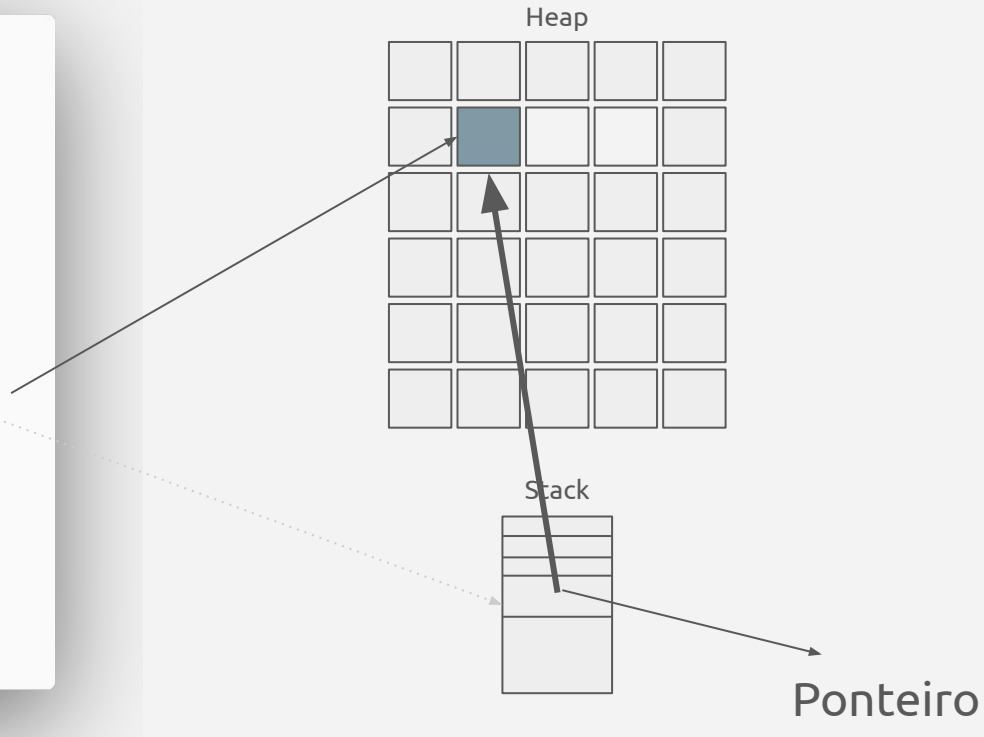
}

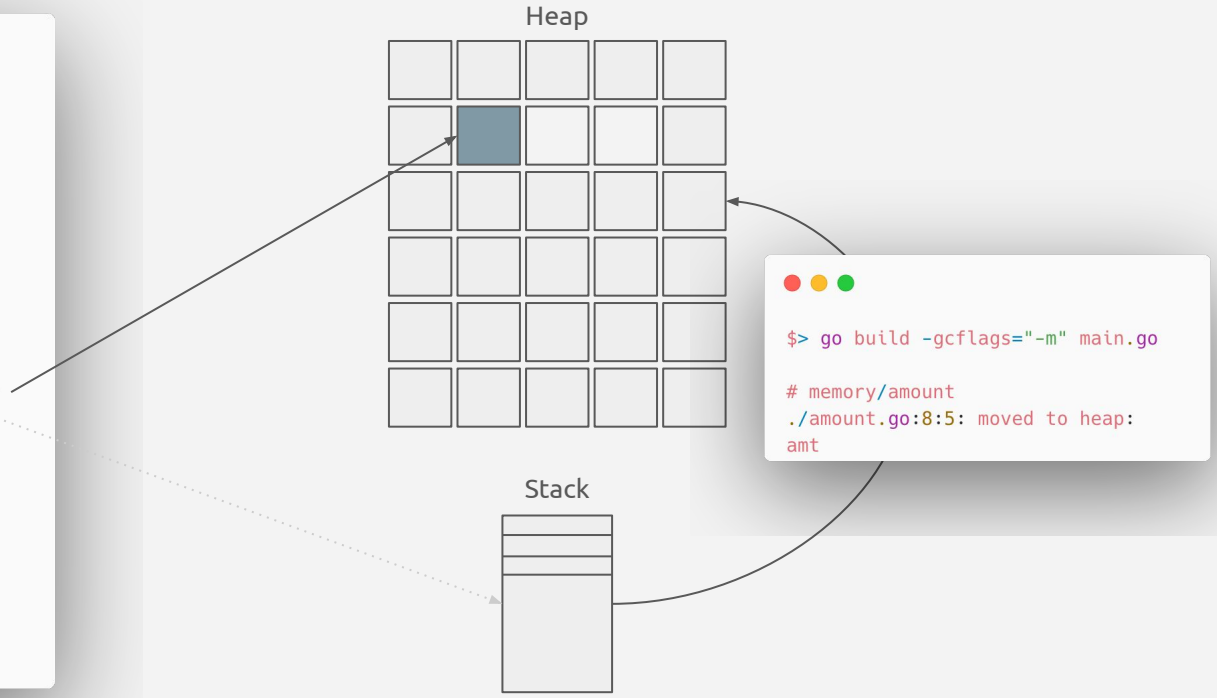
func NewAmountHeap(value int) *Amount
{
    amt := Amount{value}
    return &amt // causes heap escape
}

func NewAmountStack(value int) Amount
{
    amt := Amount{value}
    return amt
}
```



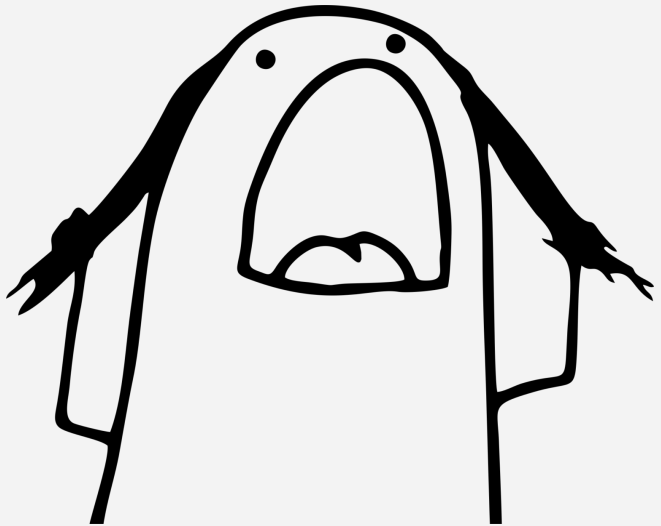
Escape analysis

```go
package amount

type Amount struct {
    Value        int
}

func NewAmountHeap(value int) *Amount
{
    amt := Amount{value}
    return &amt // causes heap escape
}

func NewAmountStack(value int) Amount
{
    amt := Amount{value}
    return amt
}
```



Escape analysis

```
TEXT memory.NewAmountStack(SB)
  // amount.go:13
  MOVD.W R30, -48(RSP)
  MOVD R29, -8(RSP)
  SUB $8, RSP, R29
  MOVD R0, 56(RSP)
  MOVD R1, 64(RSP)
  MOVD R2, 72(RSP)
  STP (ZR, ZR), 16(RSP)
  MOVD ZR, 32(RSP)

  // amount.go:14
  STP (ZR, ZR), 16(RSP)
  MOVD ZR, 32(RSP)
  MOVD 56(RSP), R0
  MOVD R0, 16(RSP)
  MOVD 64(RSP), R1
  MOVD 72(RSP), R2
  MOVD R1, 24(RSP)
  MOVD R2, 32(RSP)
  ADD $40, RSP, R29
  ADD $48, RSP, RSP
  RET
```



Escape analysis

```
TEXT memory.NewAmountStack(SB)
  // amount.go:13
  MOVD.W R30, -48(RSP)
  MOVD R29, -8(RSP)
  SUB $8, RSP, R29
  MOVD R0, 56(RSP)
  MOVD R1, 64(RSP)
  MOVD R2, 72(RSP)
  STP (ZR, ZR), 16(RSP)
  MOVD ZR, 32(RSP)

  // amount.go:14
  STP (ZR, ZR), 16(RSP)
  MOVD ZR, 32(RSP)
  MOVD 56(RSP), R0
  MOVD R0, 16(RSP)
  MOVD 64(RSP), R1
  MOVD 72(RSP), R2
  MOVD R1, 24(RSP)
  MOVD R2, 32(RSP)
  ADD $40, RSP, R29
  ADD $48, RSP, RSP
  RET
```

```
TEXT memory.NewAmountHeap(SB)
  // amount.go:8
  MOVD 16(R28), R16
  CMP R16, RSP
  BLS 39(PC)
  MOVD.W R30, -80(RSP)
  MOVD R29, -8(RSP)
  SUB $8, RSP, R29
  MOVD R0, 88(RSP)
  MOVD R1, 96(RSP)
  MOVD R2, 104(RSP)
  MOVD ZR, 32(RSP)

  // amount.go:9
  ADRP type:memory.Amount, R0
  ADD $0, R0, R0
  CALL runtime.newobject
  MOVD R0, 64(RSP)
  STP (ZR, ZR), 40(RSP)
  MOVD ZR, 56(RSP)
  MOVD 88(RSP), R1
  MOVD R1, 40(RSP)
  MOVD 96(RSP), R2
  MOVD 104(RSP), R3
  MOVD R2, 48(RSP)
  MOVD R3, 56(RSP)
  MOVD 64(RSP), R4
  MOVD R1, (R4)
  MOVD R3, 16(R4)
  ADRP runtime.writeBarrier, R27
  MOVWU (R27), R1
  CBZW R1, 2(PC)
  JMP 2(PC)
  JMP 6(PC)
  CALL runtime.gcWriteBarrier2
  MOVD R2, (R25)
  MOVD 8(R4), R1
  MOVD R1, 8(R25)
  JMP 1(PC)
  MOVD R2, 8(R4)

  // amount.go:10
  MOVD 64(RSP), R0
  MOVD R0, 32(RSP)
  LDP -8(RSP), (R29, R30)
  ADD $80, RSP, RSP
  RET
  MOVD R0, 8(RSP)
  MOVD R1, 16(RSP)
  MOVD R2, 24(RSP)
  MOVD R30, R3
  CALL runtime.morestack_noctxt
  MOVD 8(RSP), R0
  MOVD 16(RSP), R1
  MOVD 24(RSP), R2
  JMP memory.NewAmountHeap(SB)
```

Escape analysis

```
TEXT memory.NewAmountStack(SB)
  // amount.go:13
  MOVD.W R30, -48(RSP)
  MOVD R29, -8(RSP)
  SUB $8, RSP, R29
  MOVD R0, 56(RSP)
  MOVD R1, 64(RSP)
  MOVD R2, 72(RSP)
  STP (ZR, ZR), 16(RSP)
  MOVD ZR, 32(RSP)

  // amount.go:14
  STP (ZR, ZR), 16(RSP)
  MOVD ZR, 32(RSP)
  MOVD 56(RSP), R0
  MOVD R0, 16(RSP)
  MOVD 64(RSP), R1
  MOVD 72(RSP), R2
  MOVD R1, 24(RSP)
  MOVD R2, 32(RSP)
  ADD $40, RSP, R29
  ADD $48, RSP, RSP
  RET
```

Chamada para o alocador

Tracking pelo garbage collector

```
TEXT memory.NewAmountHeap(SB)
  // amount.go:8
  MOVD 16(R28), R16
  CMP R16, RSP
  BLS 39(PC)
  MOVD.W R30, -80(RSP)
  MOVD R29, -8(RSP)
  SUB $8, RSP, R29
  MOVD R0, 88(RSP)
  MOVD R1, 96(RSP)
  MOVD R2, 104(RSP)
  MOVD ZR, 32(RSP)

  // amount.go:9
  ADRP type:memory.Amount, R0
  ADD $0, R0, R0
  CALL runtime.newobject
  MOVD R0, 64(RSP)
  STP (ZR, ZR), 40(RSP)
  MOVD ZR, 56(RSP)
  MOVD 88(RSP), R1
  MOVD R1, 40(RSP)
  MOVD 96(RSP), R2
  MOVD 104(RSP), R3
  MOVD R2, 48(RSP)
  MOVD R3, 56(RSP)
  MOVD 64(RSP), R4
  MOVD R1, (R4)
  MOVD R3, 16(R4)
  ADRP runtime.writeBarrier, R27
  MOVWU (R27), R1
  CBZW R1, 2(PC)
  JMP 2(PC)
  JMP 6(PC)
  CALL runtime.gcWriteBarrier2
  MOVD R2, (R25)
  MOVD 8(R4), R1
  MOVD R1, 8(R25)
  JMP 1(PC)
  MOVD R2, 8(R4)

  // amount.go:10
  MOVD 64(RSP), R0
  MOVD R0, 32(RSP)
  LDP -8(RSP), (R29, R30)
  ADD $80, RSP, RSP
  RET
  MOVD R0, 8(RSP)
  MOVD R1, 16(RSP)
  MOVD R2, 24(RSP)
  MOVD R30, R3
  CALL runtime.morestack_noctxt
  MOVD 8(RSP), R0
  MOVD 16(RSP), R1
  MOVD 24(RSP), R2
  JMP memory.NewAmountHeap(SB)
```

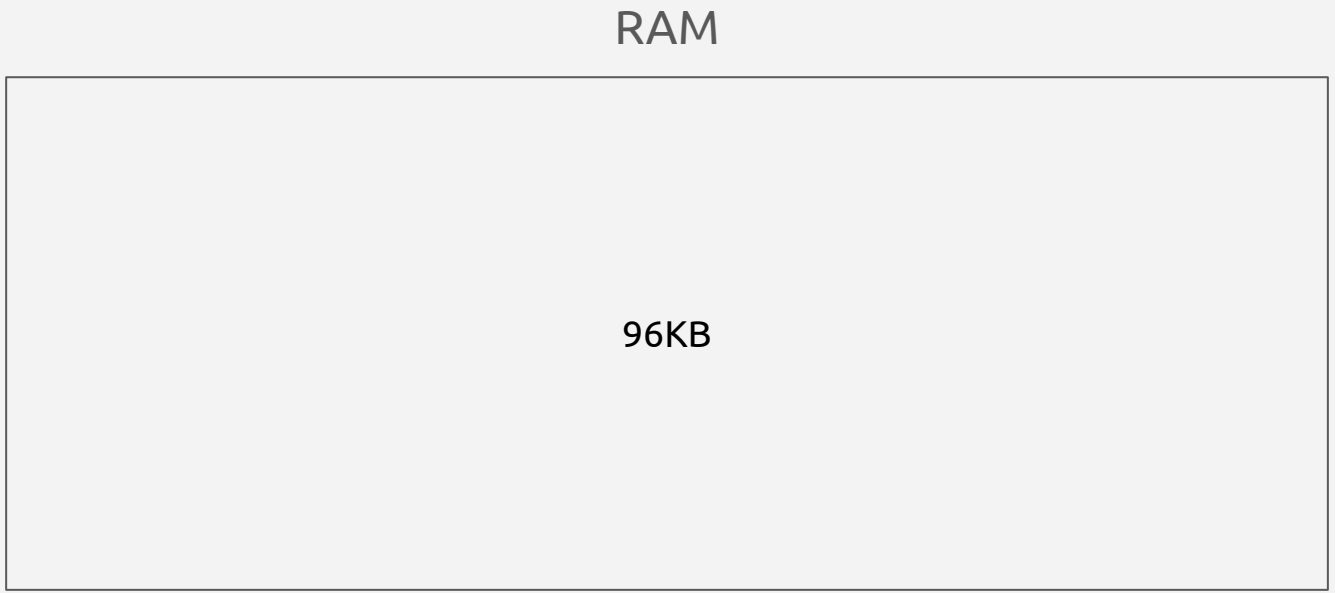
If the closure outlives the stack frame of the variables it references, the variable must be allocated on the heap

Functions that return interfaces also escape to the heap.

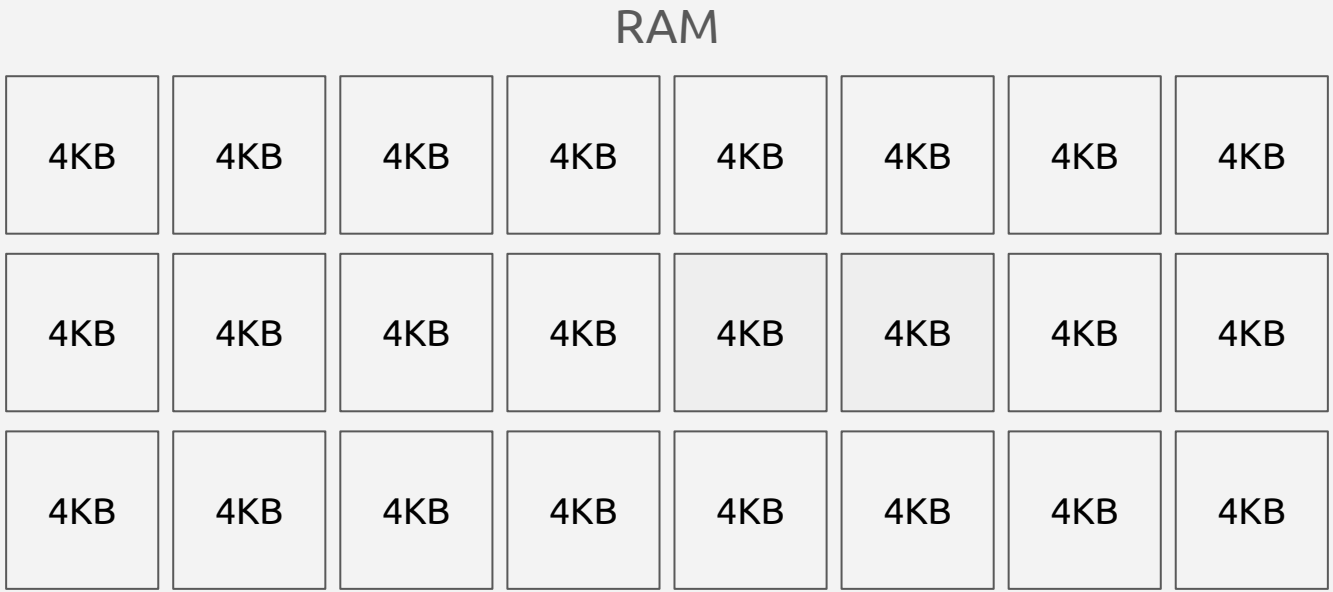
O trabalho do alocador

- Como lidar com a paginação do SO
- Como lidar com a fragmentação

O trabalho do alocador



O SO divide a memória em páginas



Hierarquia de memória

Operação	Latência
Clock da CPU (4GHz)	0.25ns
Acesso Cache L1	0,75ns
Acesso Cache L2	7ns
Lock/Unlock de um Mutex	25ns
Acesso à memória RAM	100ns
Leitura de 4KB do SSD	150.000ns

Hierarquia de memória

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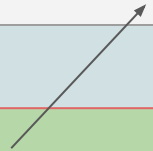
Leitura de 4KB do SSD	150.000ns

Hierarquia de memória

40x mais rápido que um Pentium (1995) 100Mhz



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Hierarquia de memória

40x mais rápido que um Pentium (1995) 100Mhz

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Clock da CPU (4GHz)	0.25ns
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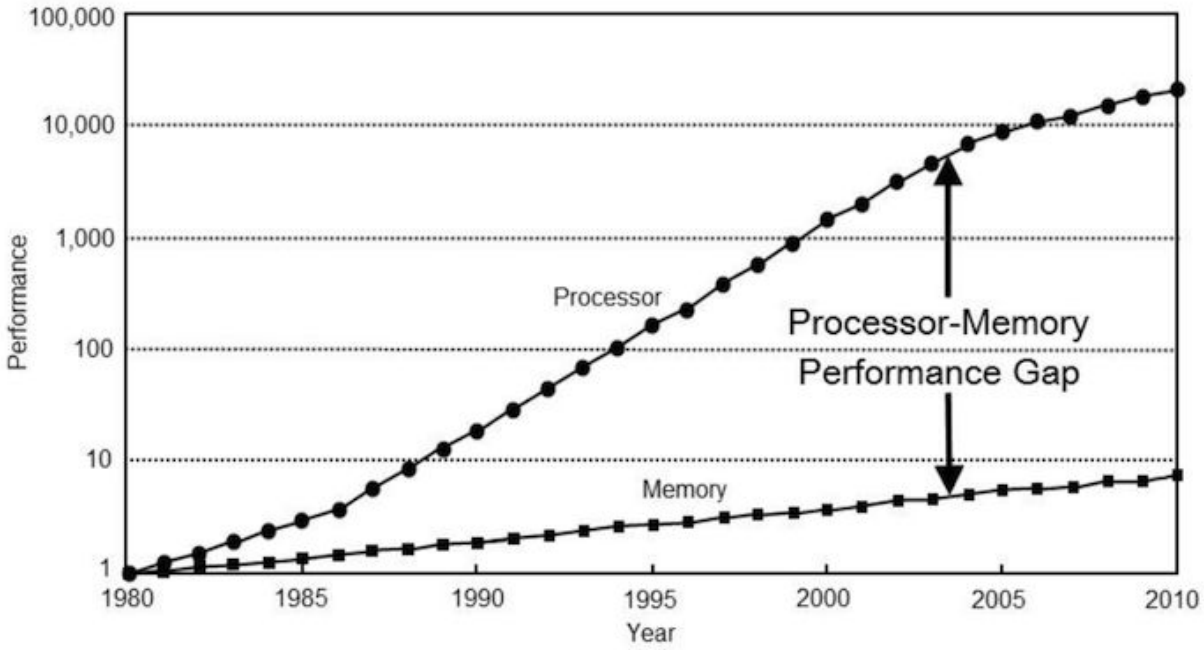
Leitura de 4KB do SSD	150.000ns

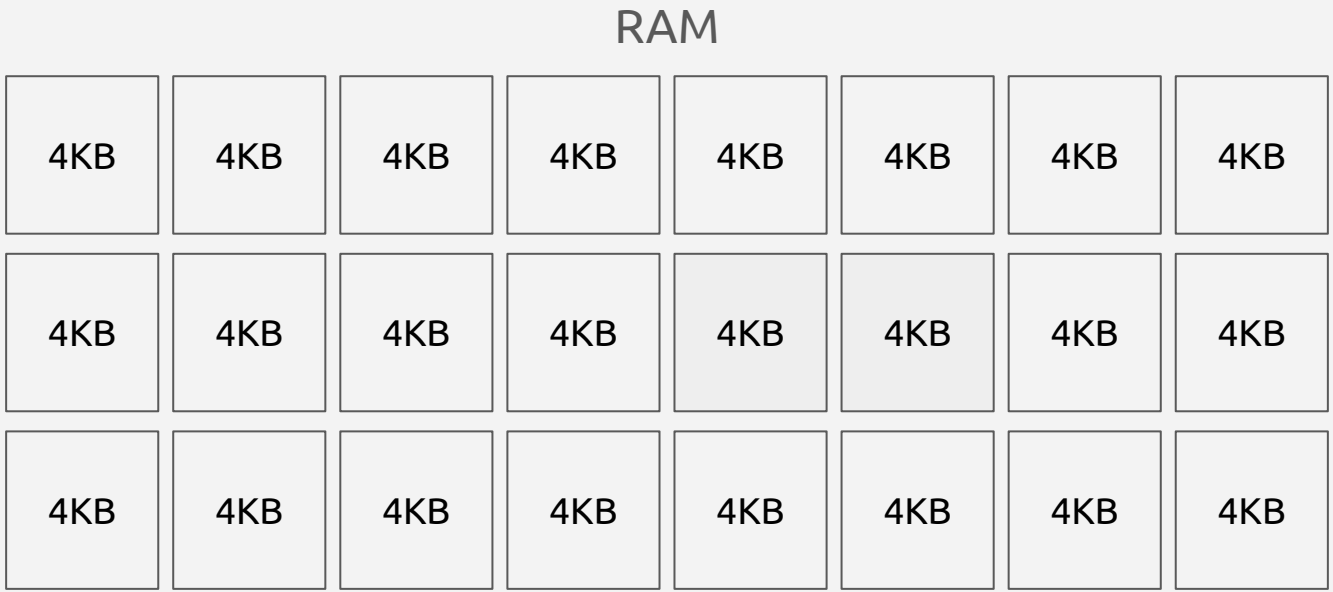
Melhorou menos de 2x-3x nos últimos 30 anos

Memory Wall



Computer Architecture: A Quantitative Approach by John L. Hennessy, David A. Patterson, Andrea C. Arpaci-Dusseau

O SO divide a memória em páginas

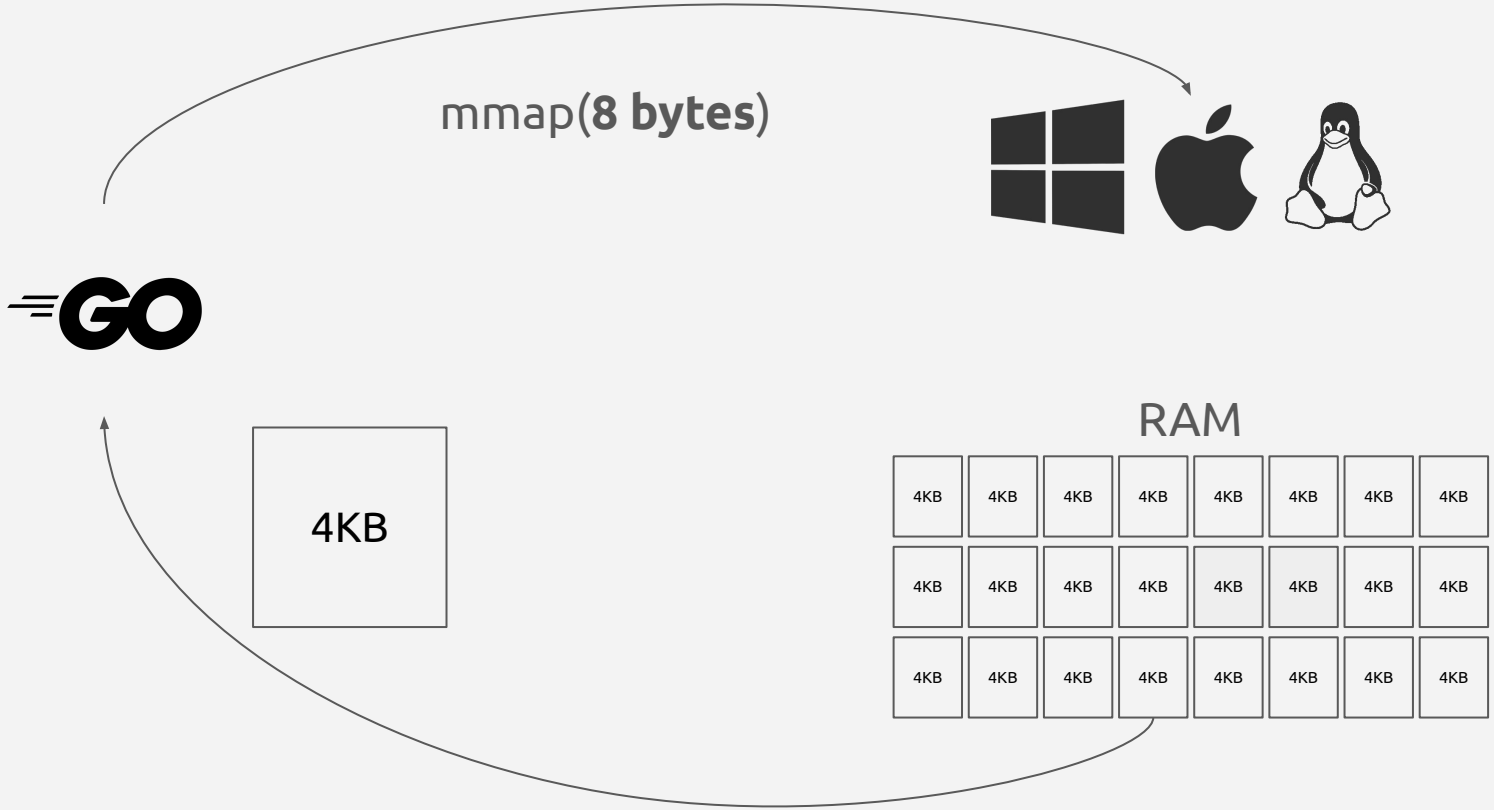


Paginação

mmap(**8 bytes**)

RAM

Paginação


mmap(8 bytes)
4KB
RAM
4KB
4KB
4KB
4KB
4KB
4KB
4KB
4KB
4KB
4KB
4KB
4KB
4KB
4KB
4KB
4KB
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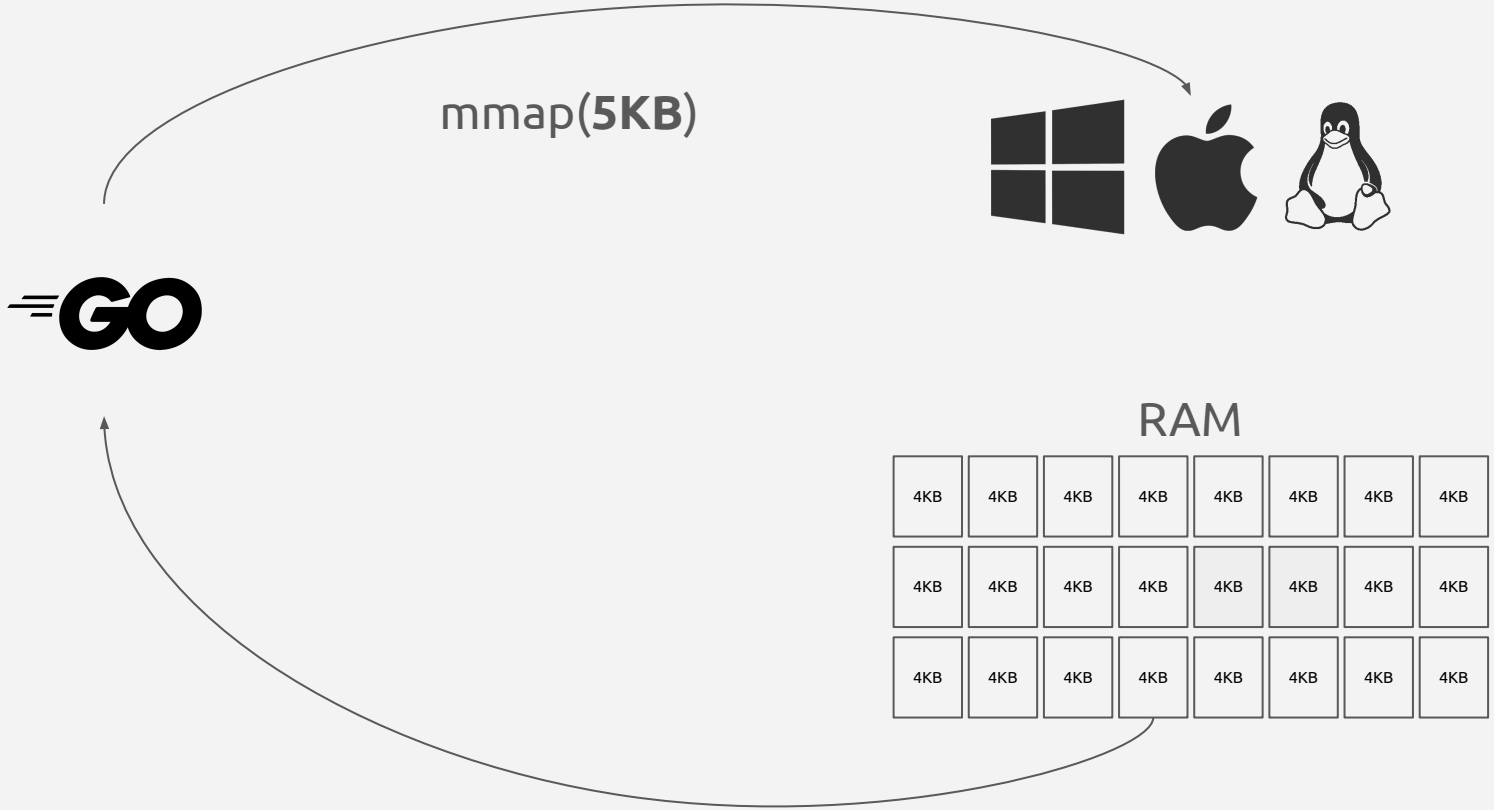
4KB
4KB

Paginação


mmap(5KB)
GO
RAM
4KB
4KB
4KB
4KB
4KB
4KB
4KB
4KB
4KB
4KB
4KB
4KB
4KB
4KB
4KB
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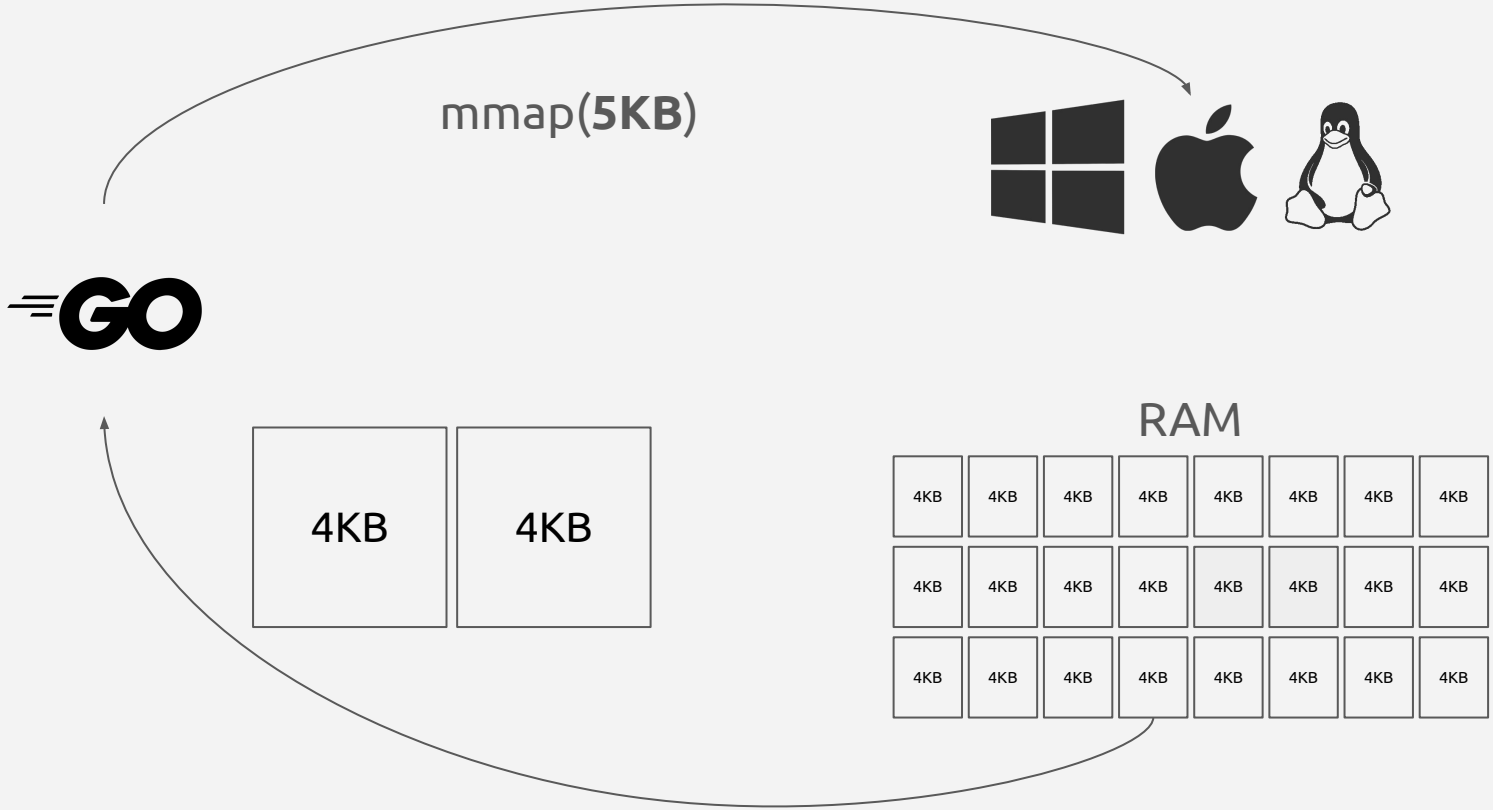
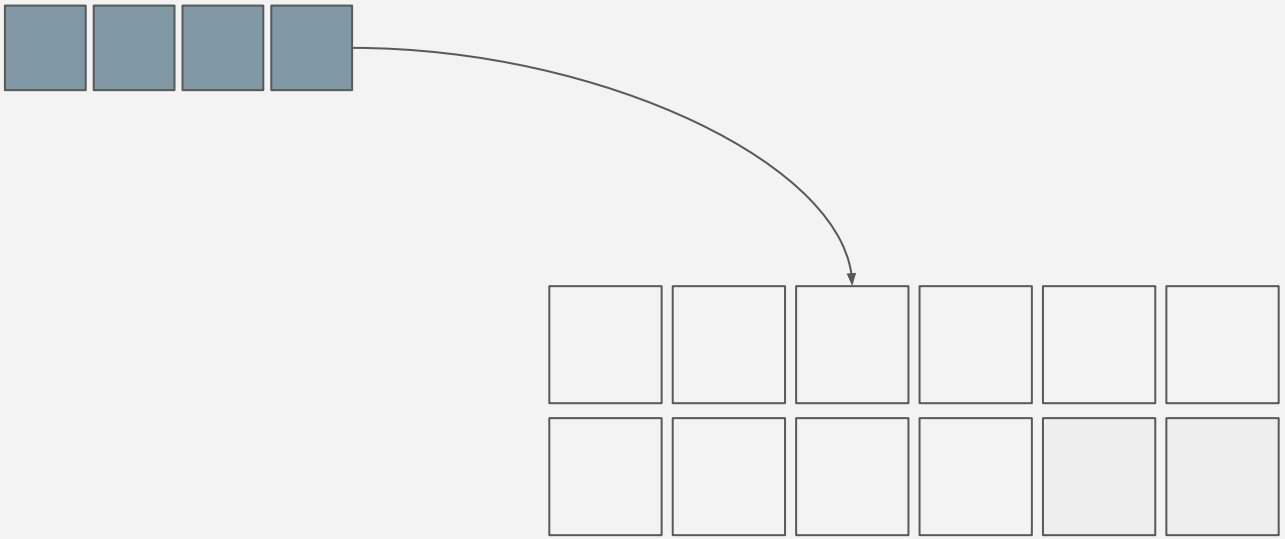
4KB

Paginação

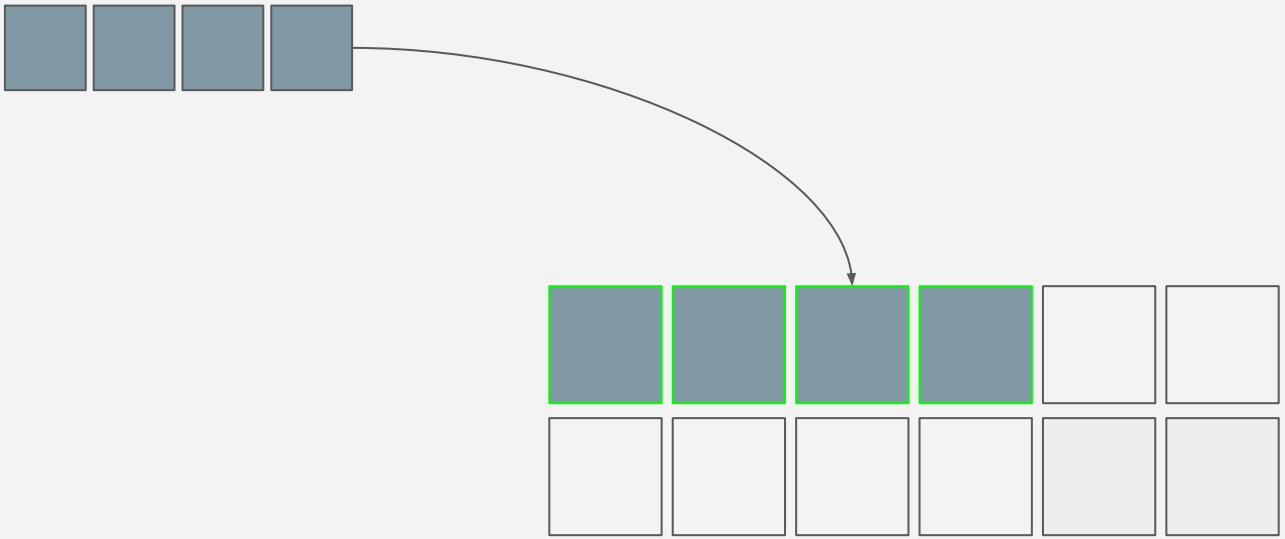

mmap(5KB)
4KB
4KB
RAM
4KB 4KB 4KB 4KB 4KB 4KB 4KB 4KB
4KB 4KB 4KB 4KB 4KB 4KB 4KB 4KB
4KB 4KB 4KB 4KB 4KB 4KB 4KB 4KB

O trabalho do alocador



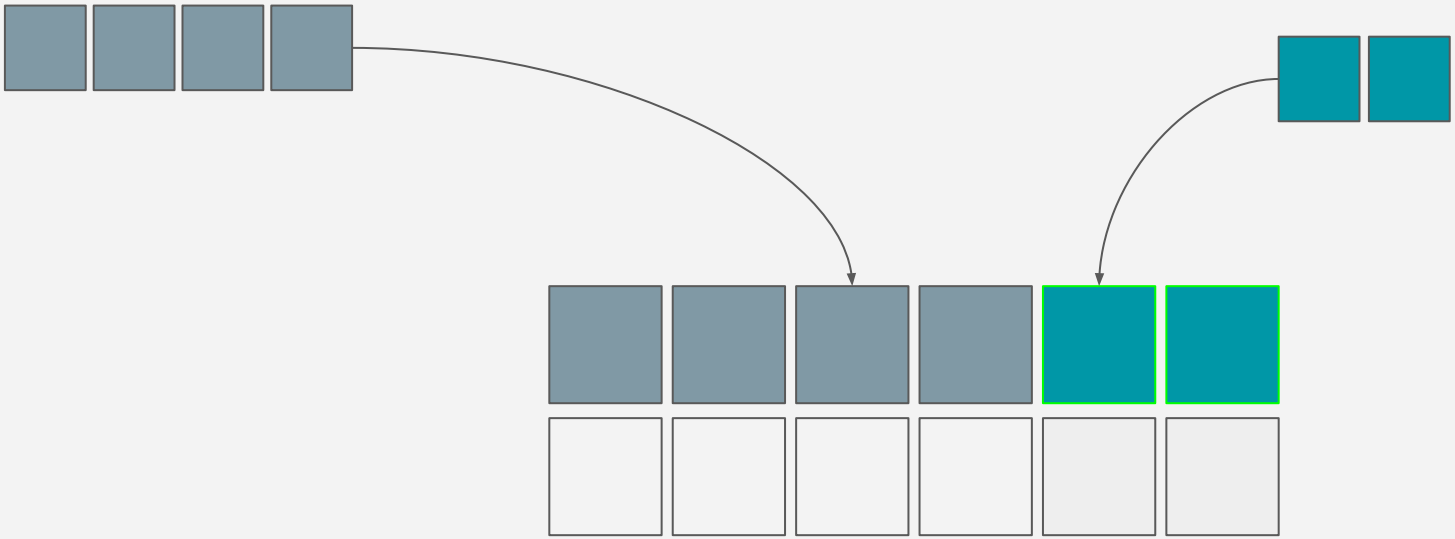
Disponível: 12

O trabalho do alocador



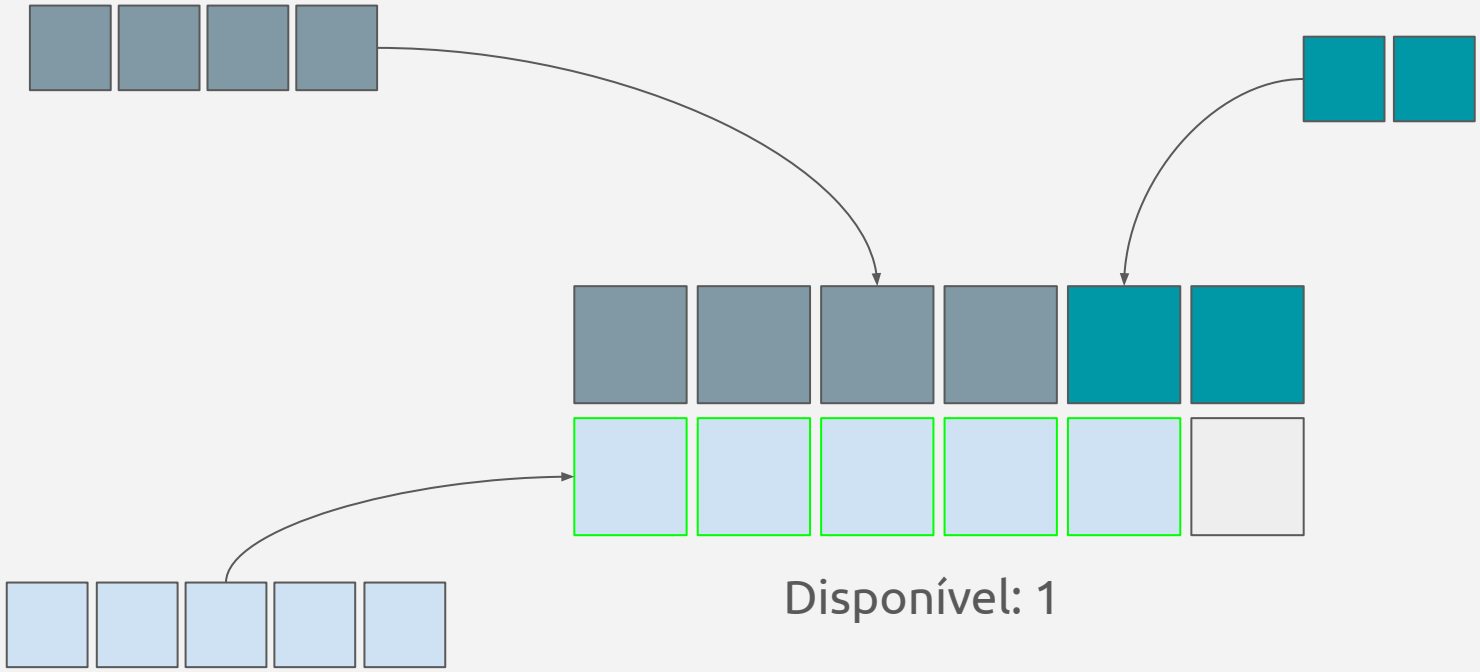
Disponível: 8

O trabalho do alocador



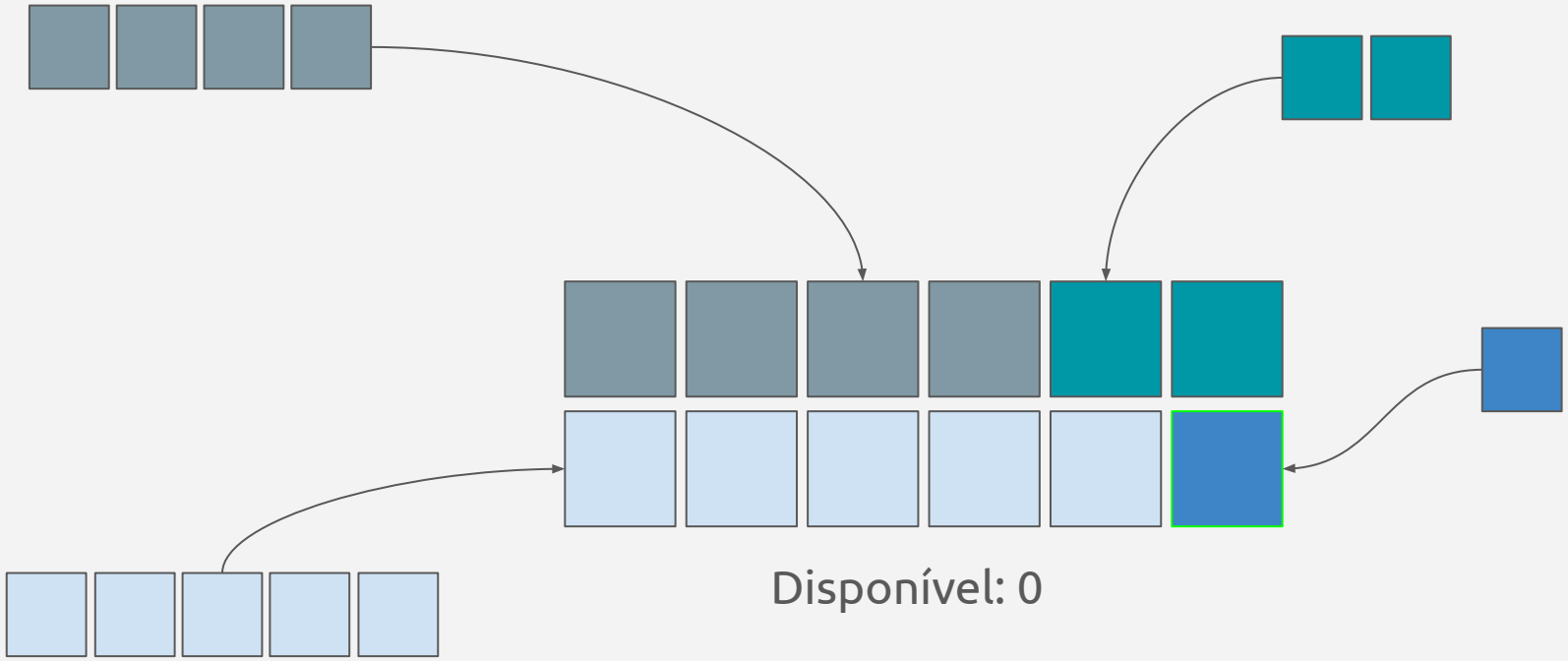
Disponível: 6

O trabalho do alocador

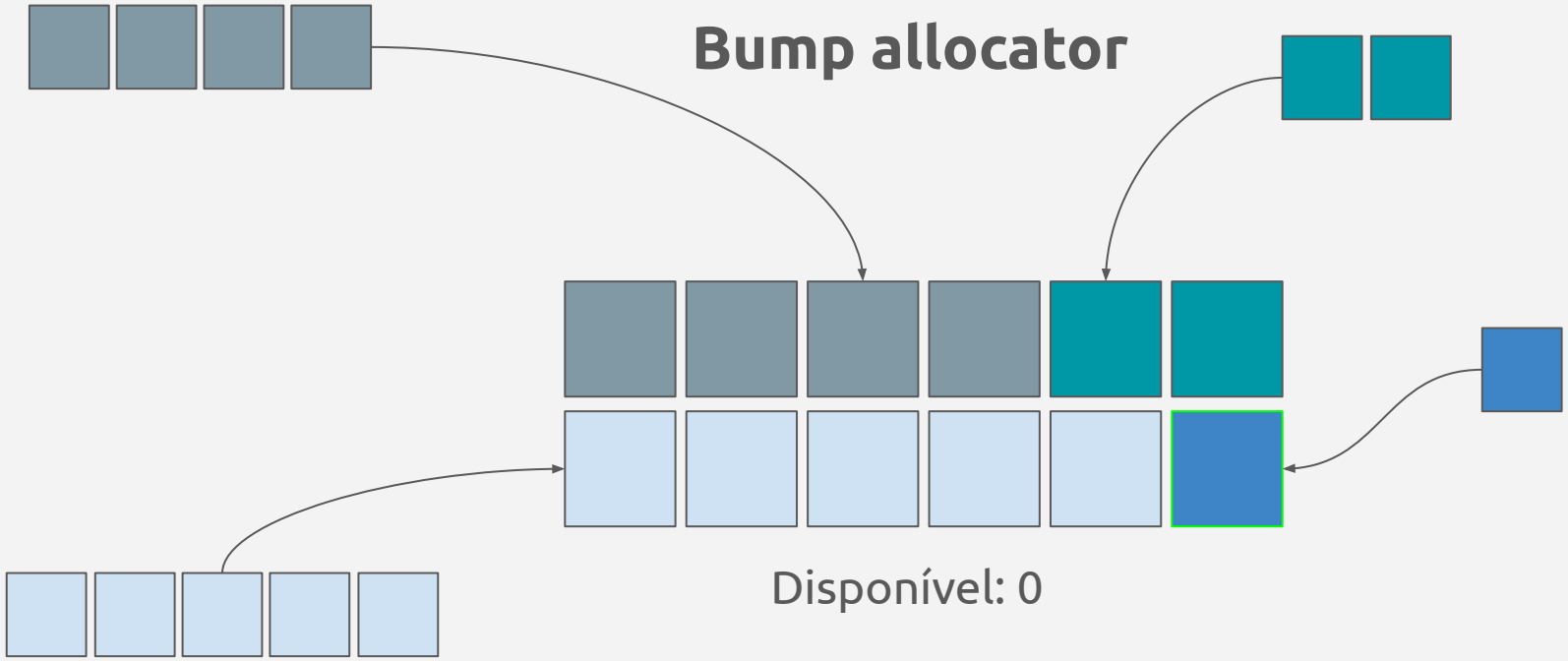


Disponível: 1

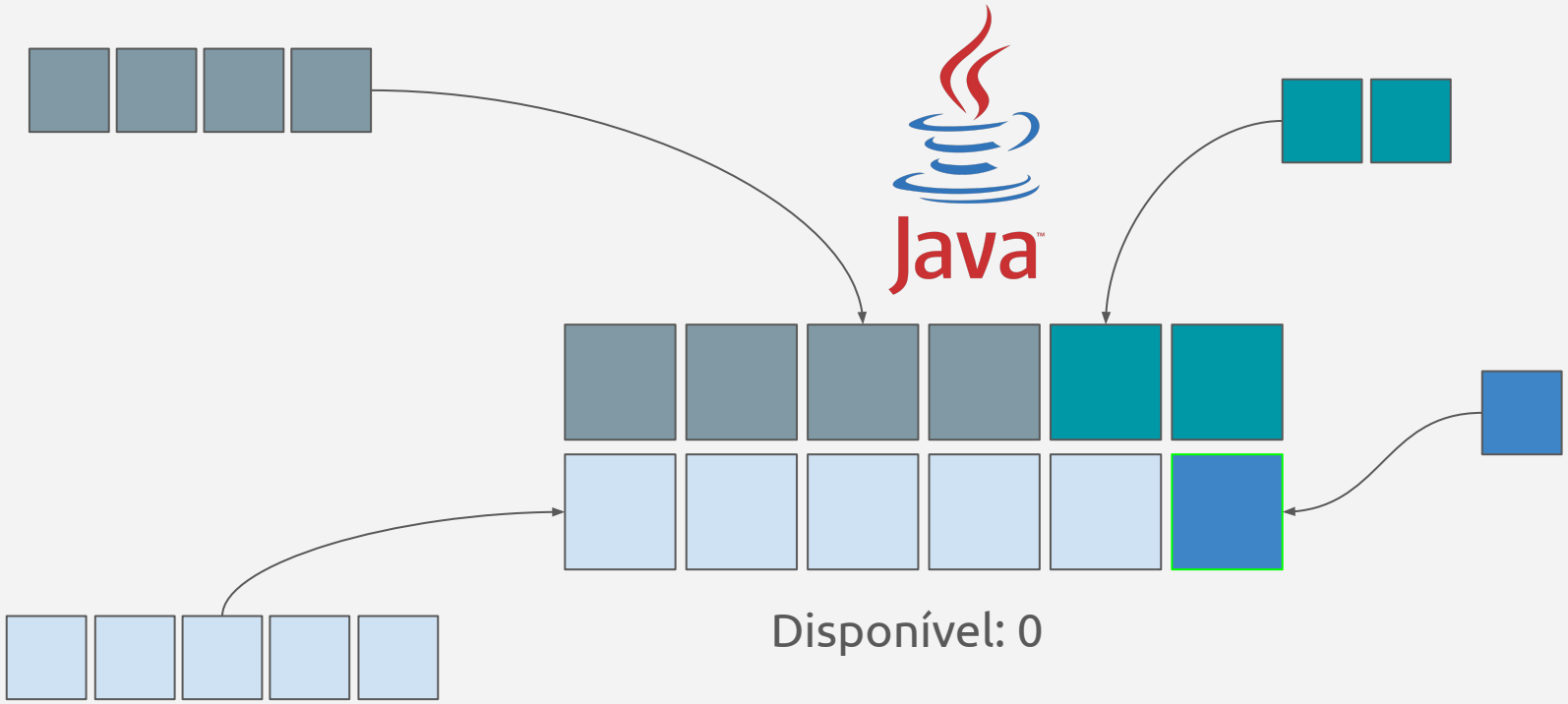
O trabalho do alocador



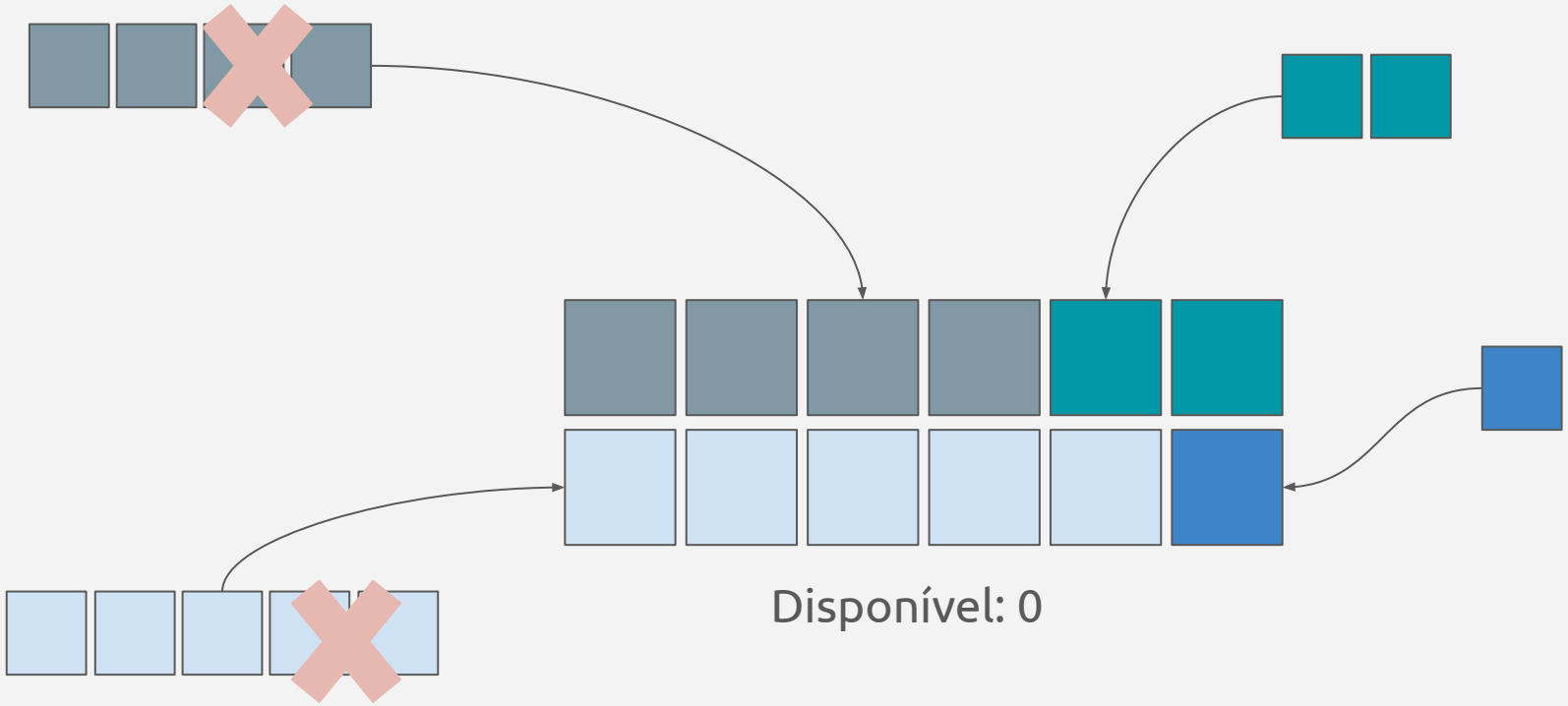
O trabalho do alocador



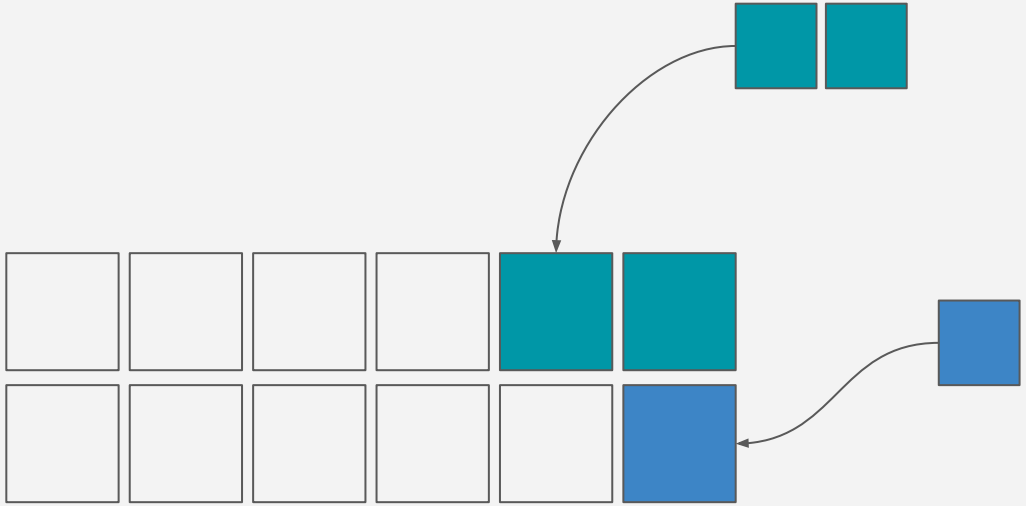
O trabalho do alocador



O trabalho do alocador

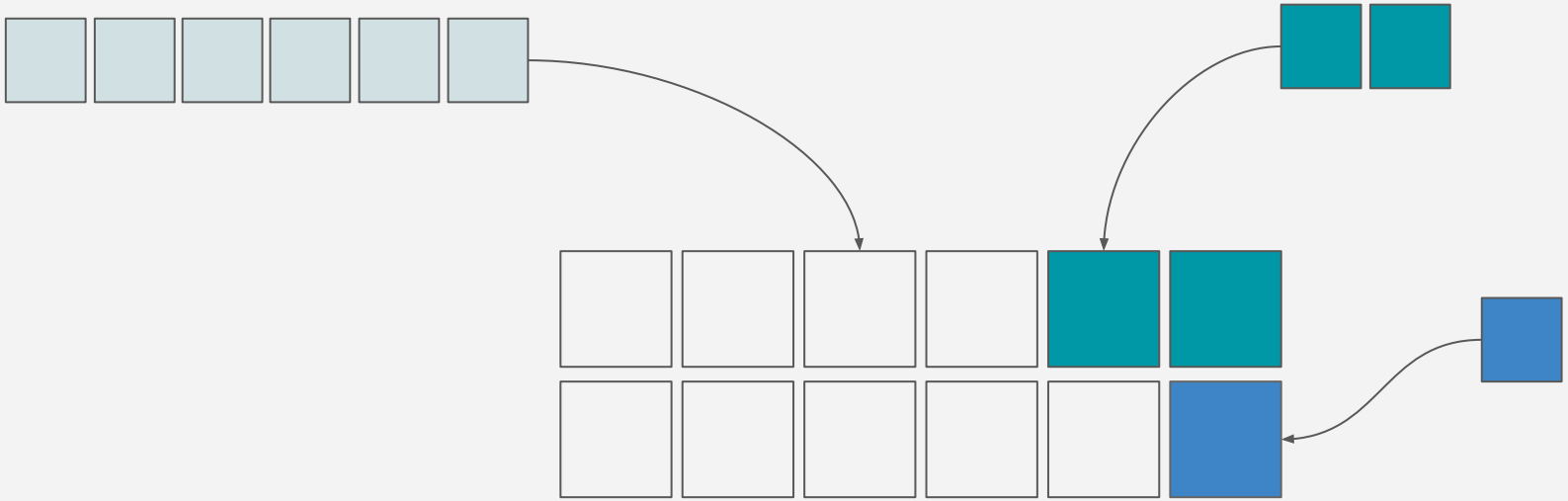


O trabalho do alocador



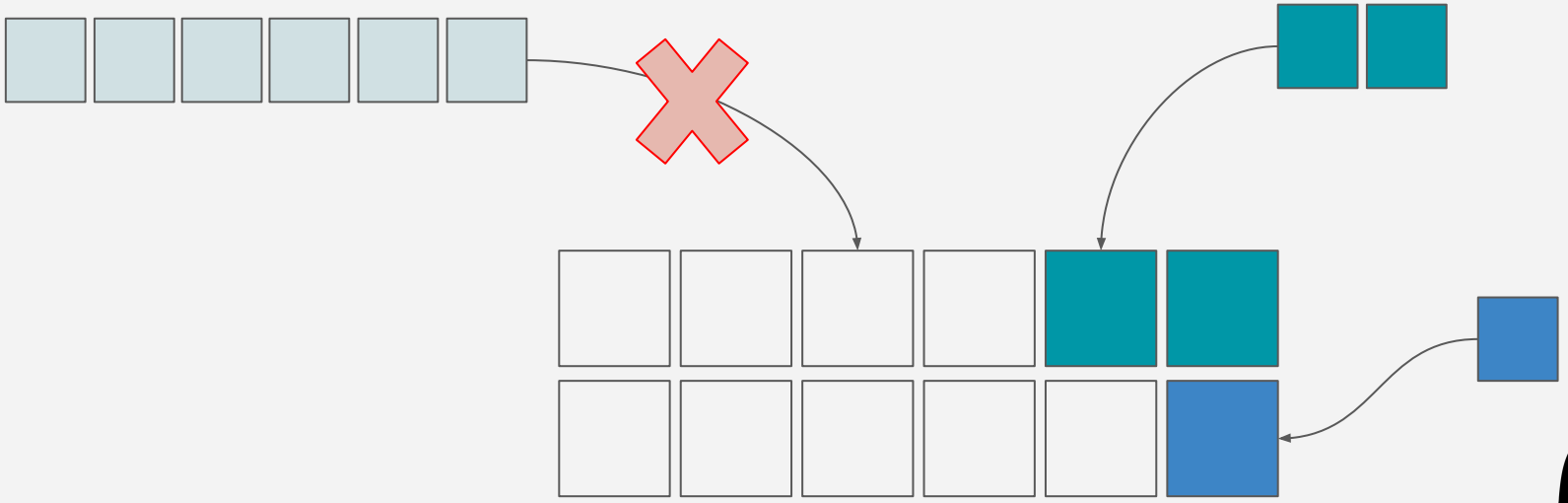
Disponível: 9

O trabalho do alocador

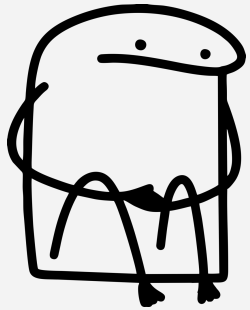


Disponível: 9

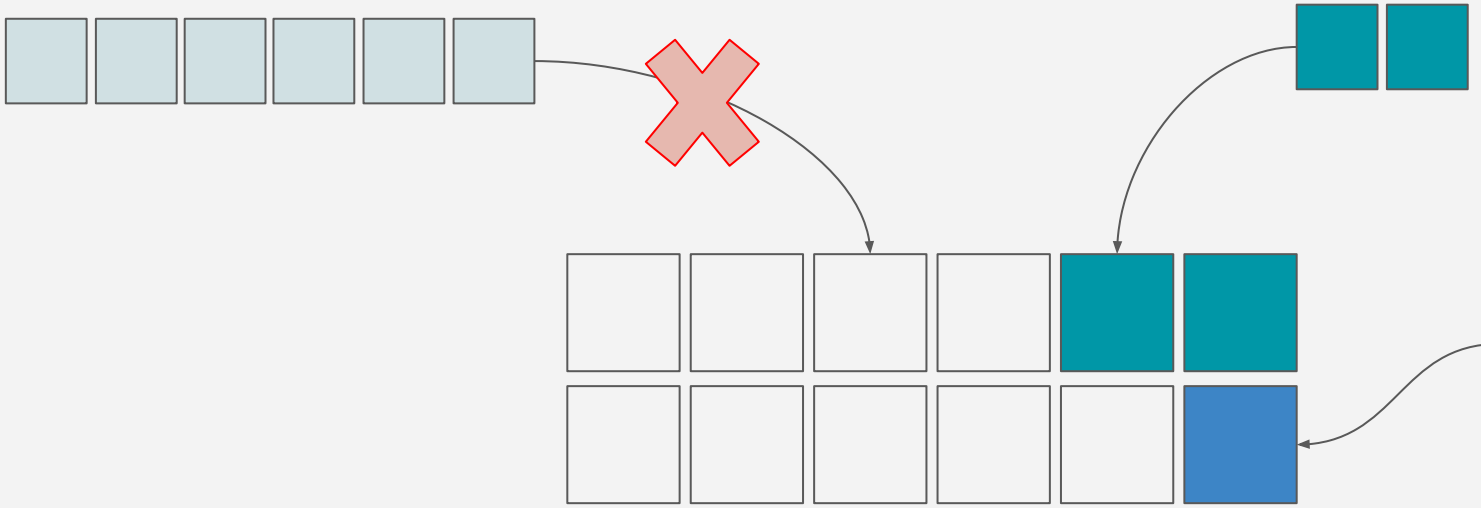
O trabalho do alocador



Disponível: 9



Fragmentação

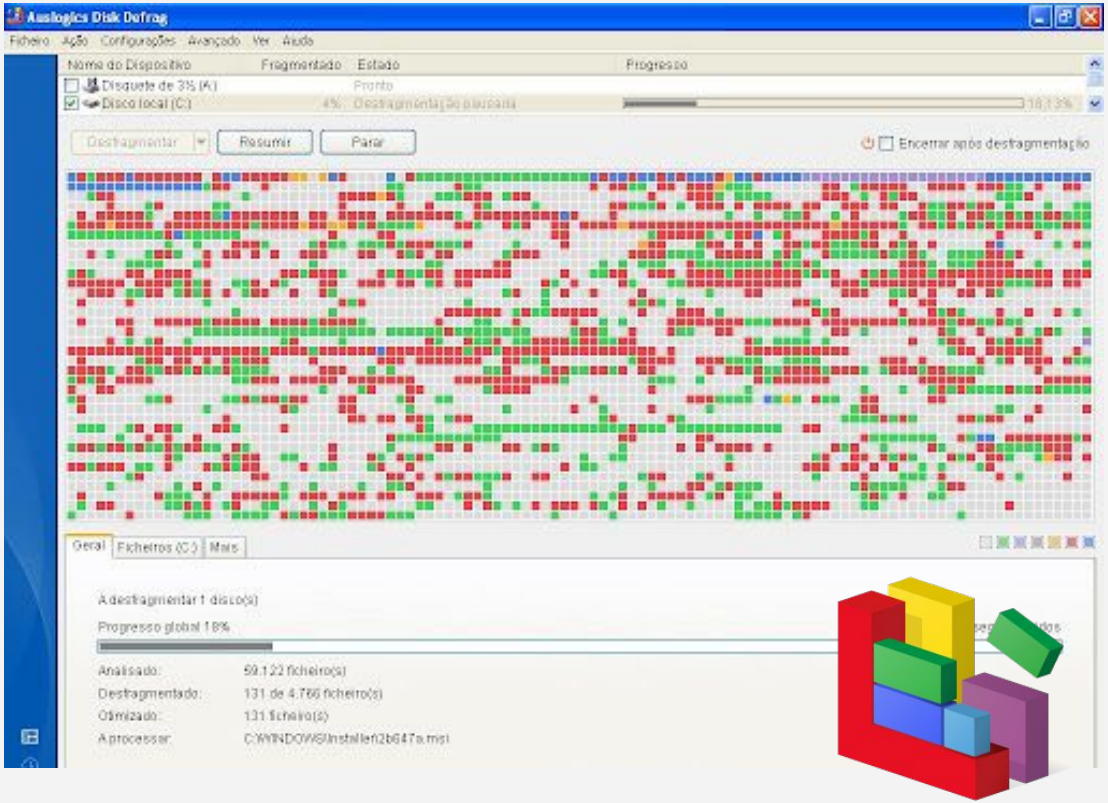


Disponível: 9

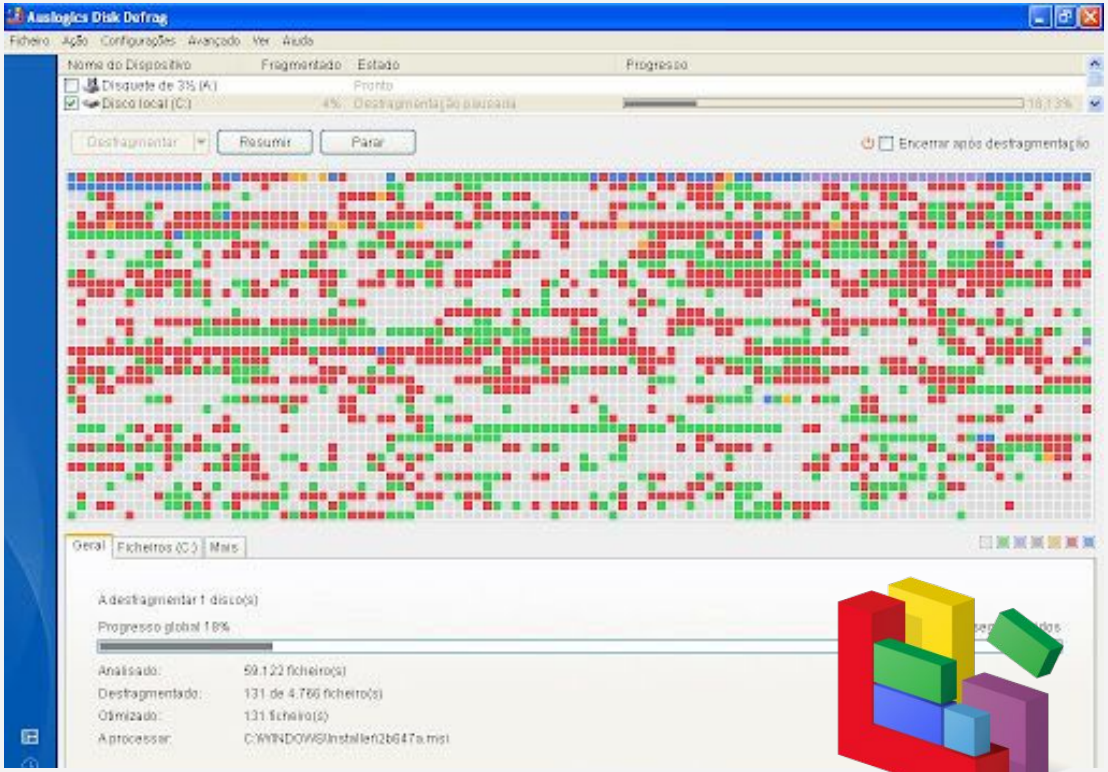
Fragmentação

Disponível: 9

(des)Fragmentação



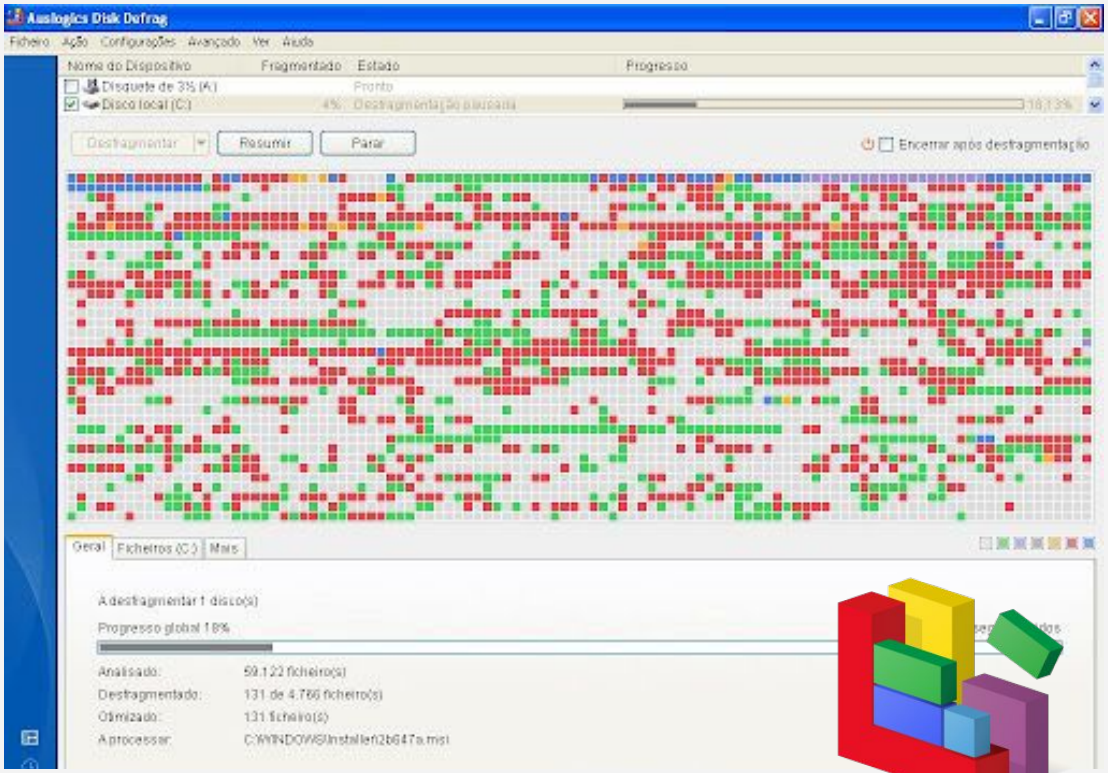
(des)Fragmentação



Move os dados para regiões contíguas de memória e elimina espaços vazios.

Compactação

(des)Fragmentação

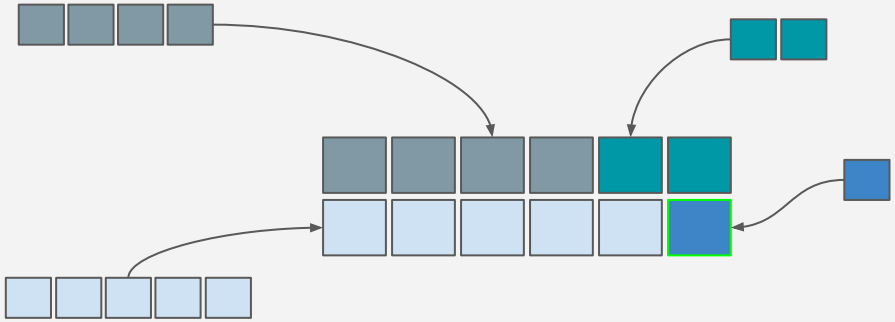


Java

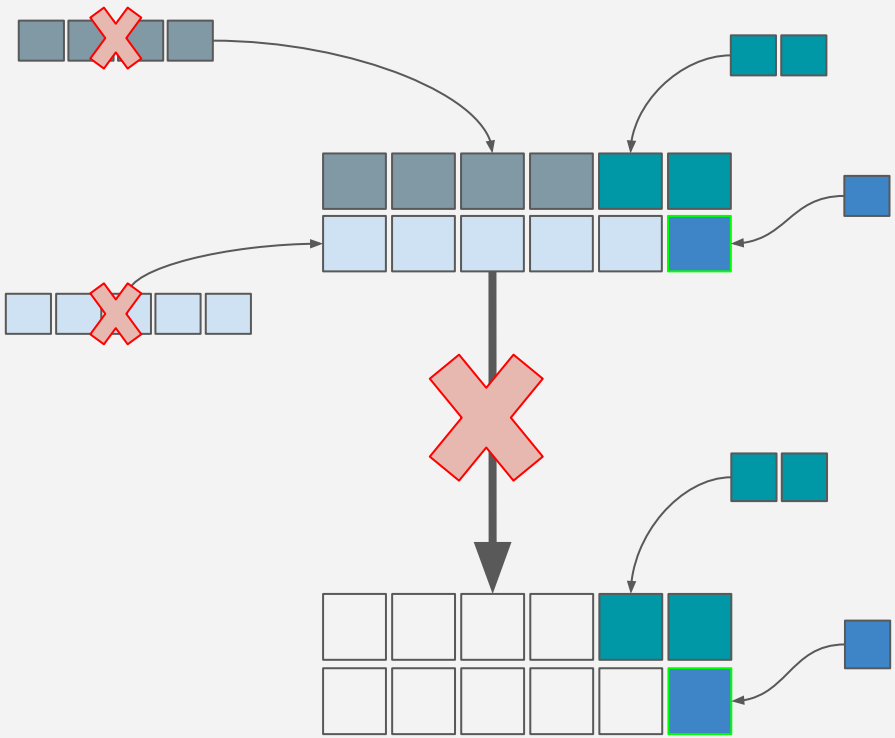
Kotlin

JS

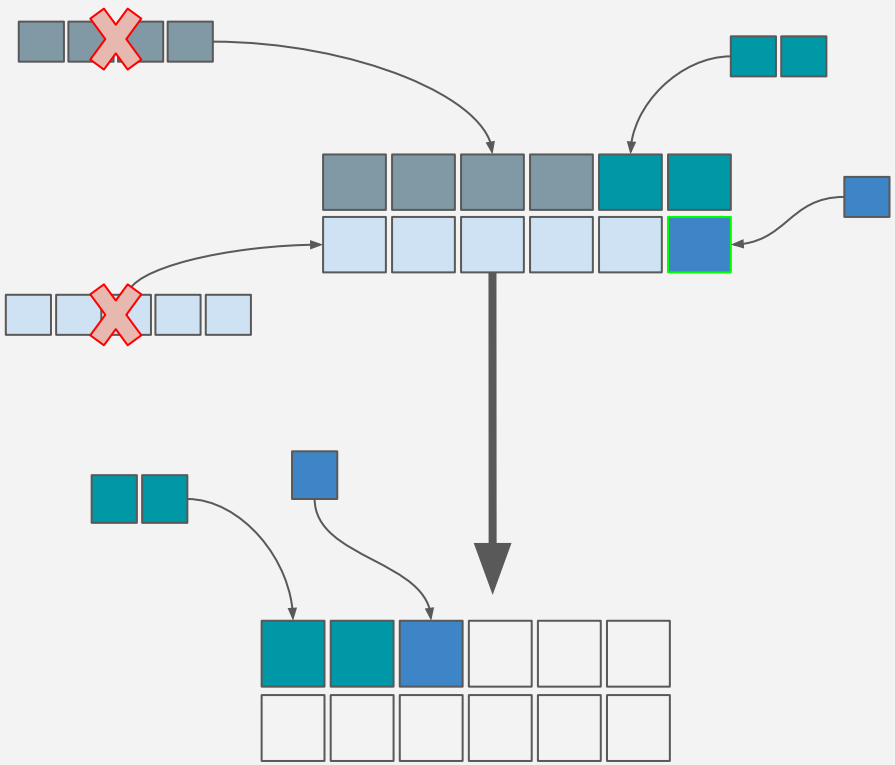
Moving Garbage Collectors



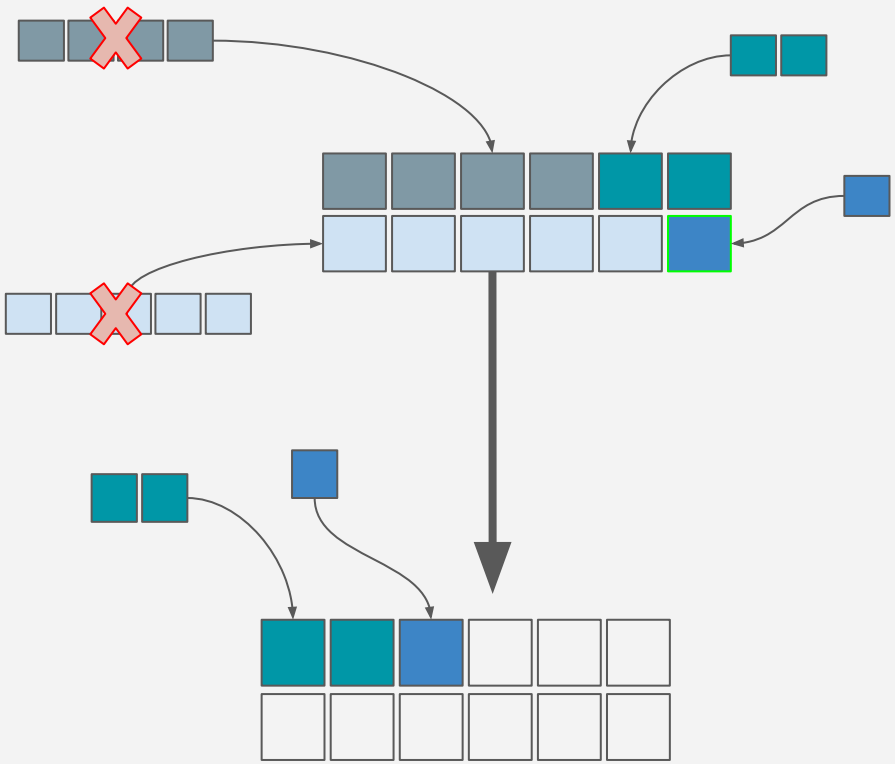
Moving Garbage Collectors

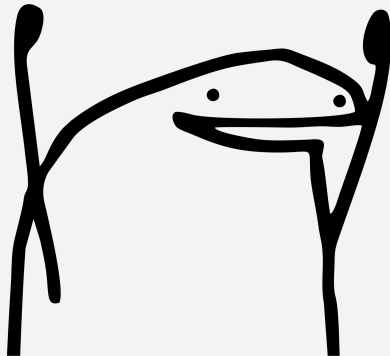


Moving Garbage Collectors

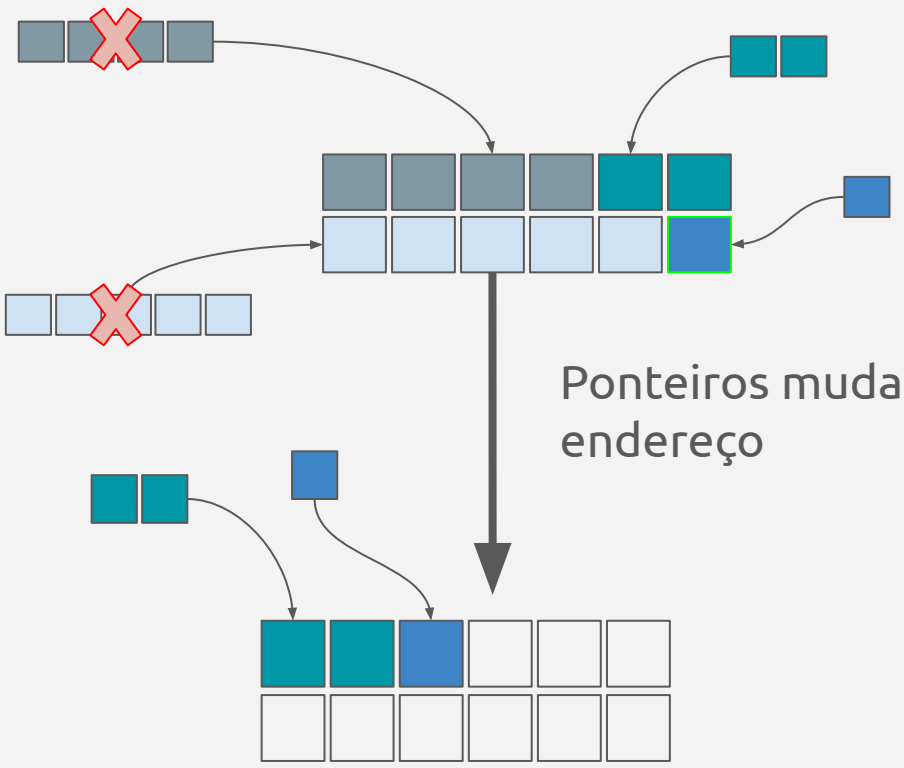


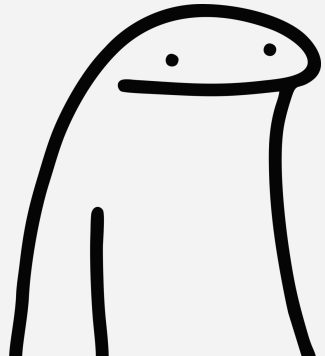
Moving Garbage Collectors



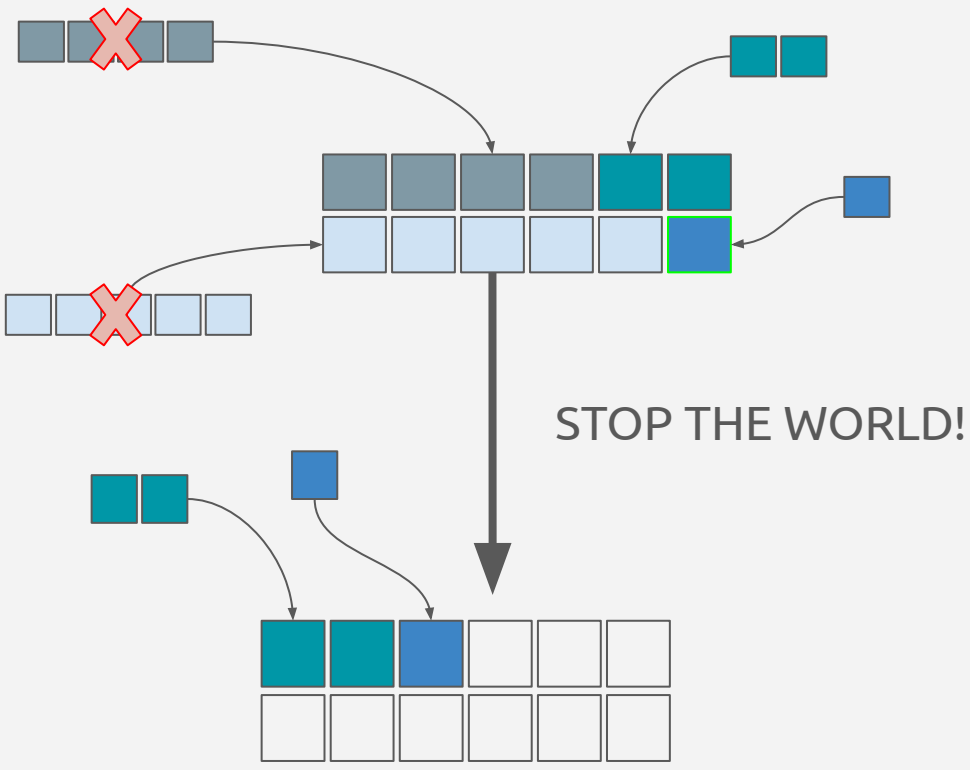


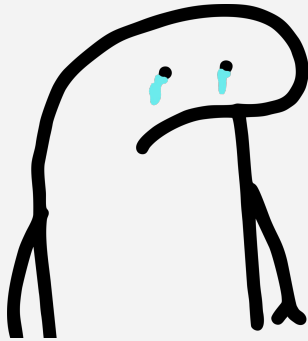
Moving Garbage Collectors



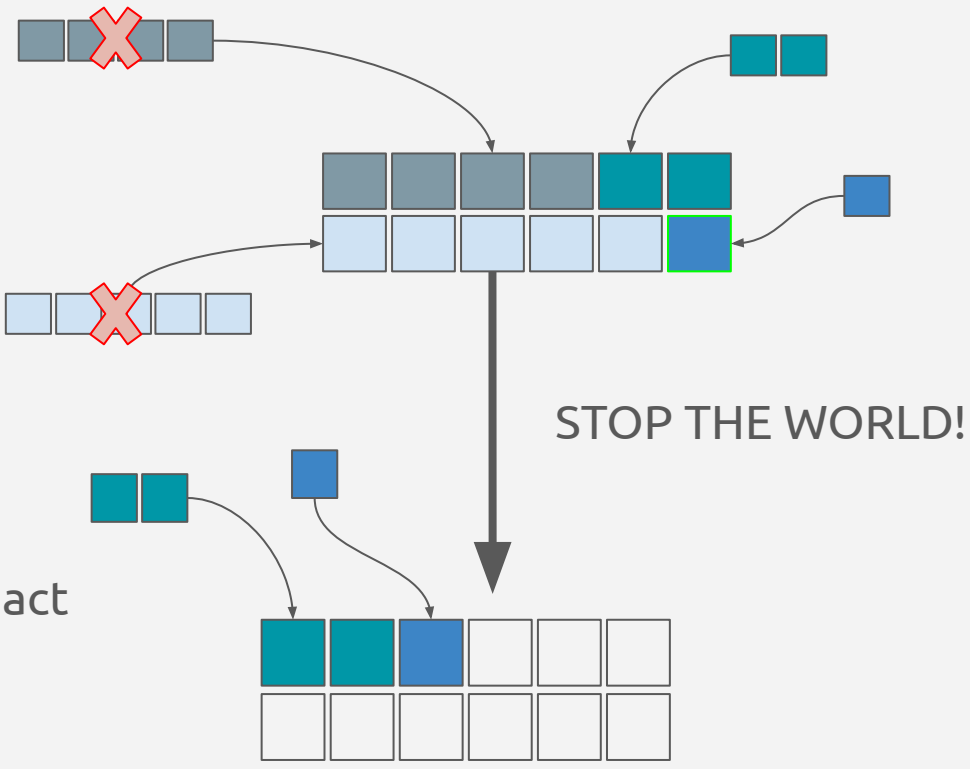


Moving Garbage Collectors

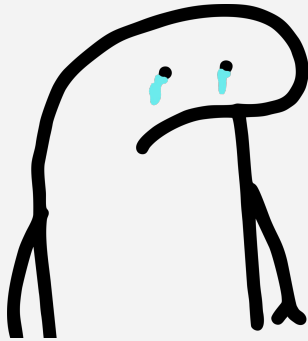




Moving Garbage Collectors



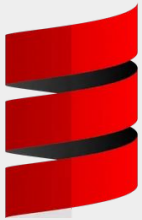
- Geracional
- Mark-and-Copy
- Mark-and-Compact
- …



Moving Garbage Collectors

JVM






CLR



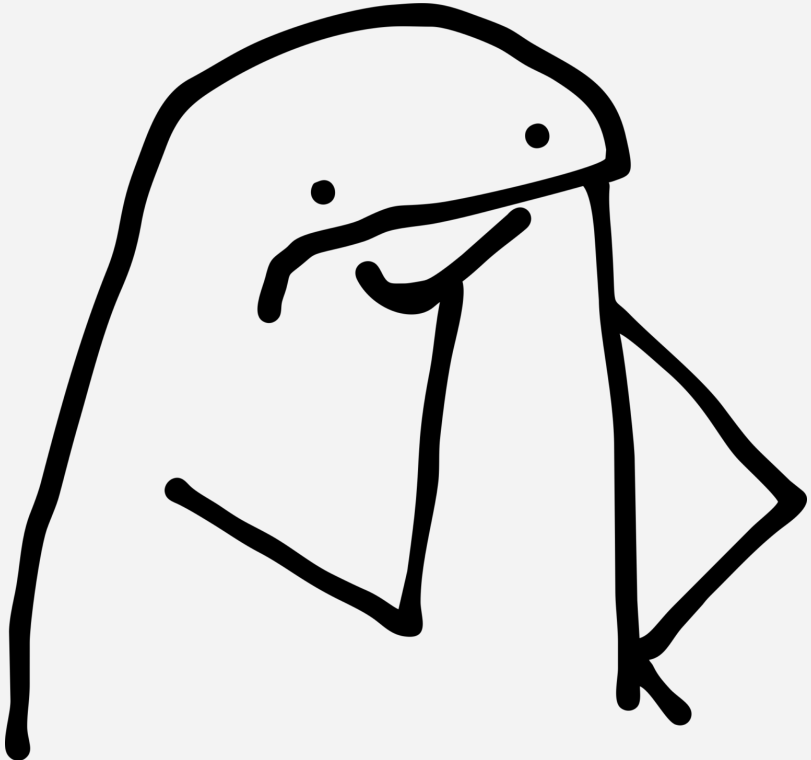






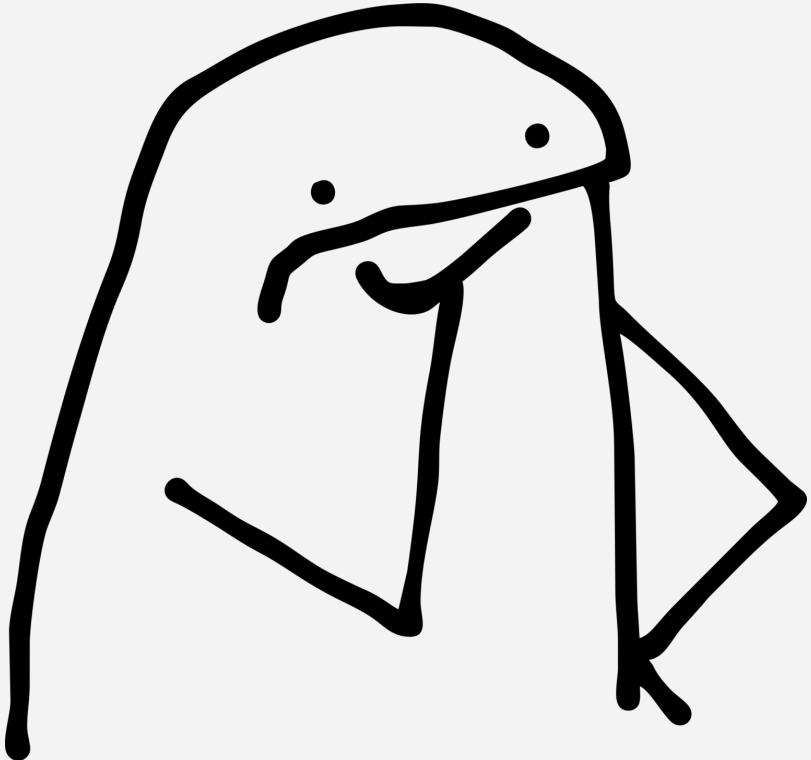
Como eliminar a fragmentação?

Sem mover objetos…



Como eliminar a fragmentação?

Existe algum algoritmos para fazer isso direto na alocação?



A fragmentação é inevitável

An Estimate of the Store Size Necessary for Dynamic Storage Allocation

J. M. ROBSON

Oxford University, Oxford, England*

ABSTRACT. Dynamic storage allocation using fixed blocks is usually inefficient in its use of store. The amount of store needed depends on the al
for any strategy the amount of store needed is boun
arithmically with the size of blocks used. A certain st
factor of at most 13/4. The exact amount of store need
sizes 1 and 2 only.

Worst case fragmentation of first fit and best fit storage allocation strategies

J. M. Robson

Department of Computer Studies, University of Lancaster, Bailrigg, Lancaster LA1 4YN

The worst possible storage fragmentation is analysed for two commonly used allocation strategies. In the case of the first fit system, fragmentation is not much worse than is inevitable but for the best fit system, it is almost as bad as it could be for any system.

(Received January 1975)

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Realizar uma alocação ótima de memória é um problema **NP-hard**.

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Heurísticas

- Um palpite fundamentado

Heurísticas

- Um palpite fundamentado
- Troca a perfeição ou o algoritmos ótimo por velocidade

Heurísticas relacionadas a alocação de memória

1. **Objetos pequenos são alocados mais frequentemente** do que objetos grandes.

Heurísticas relacionadas a alocação de memória

1. **Objetos pequenos são alocados mais frequentemente** do que objetos grandes.
2. O tempo de vida de um objeto geralmente é **proporcional ao tamanho** do mesmo.
    a. Objetos menores tem ciclos de vida menores.
    b. Objetos maiores tendem a permanecer mais tempo na memória.

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Alocações pequenas são fundamentalmente diferentes de alocações grandes.

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Alocações pequenas são fundamentalmente diferentes de alocações grandes.

Merecem diferentes estratégias

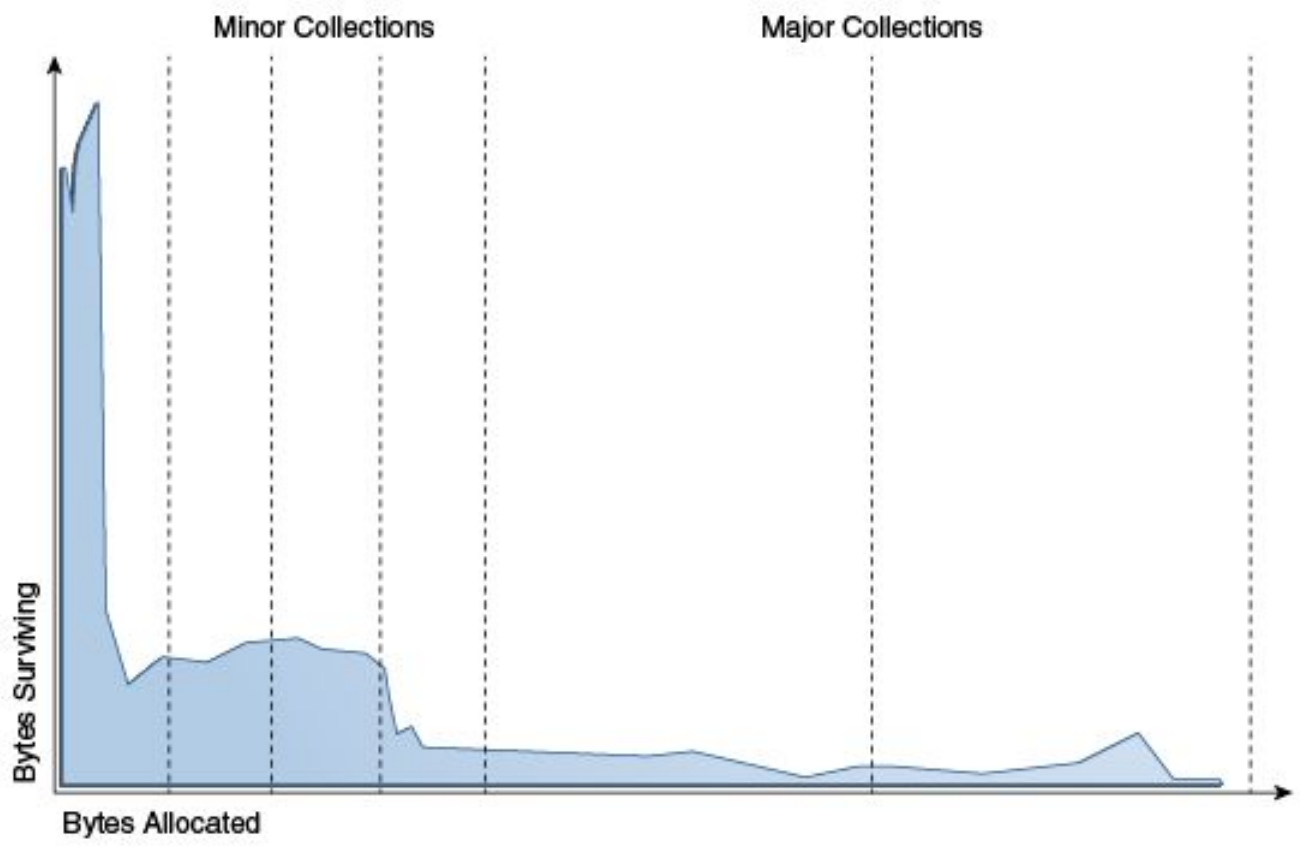
Weak Generational Hypothesis

Generation Scavenging: A Non-disruptive High Performance Storage Reclamation Algorithm

David Ungar

Computer Science Division
Department of Electrical Engineering and Computer Sciences
University of California
Berkeley, California 94720

Weak Generational Hypothesis



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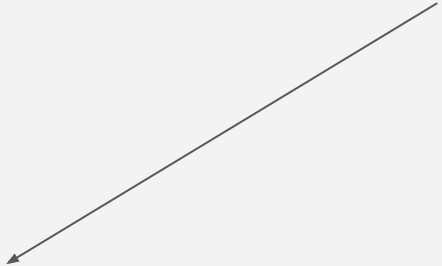
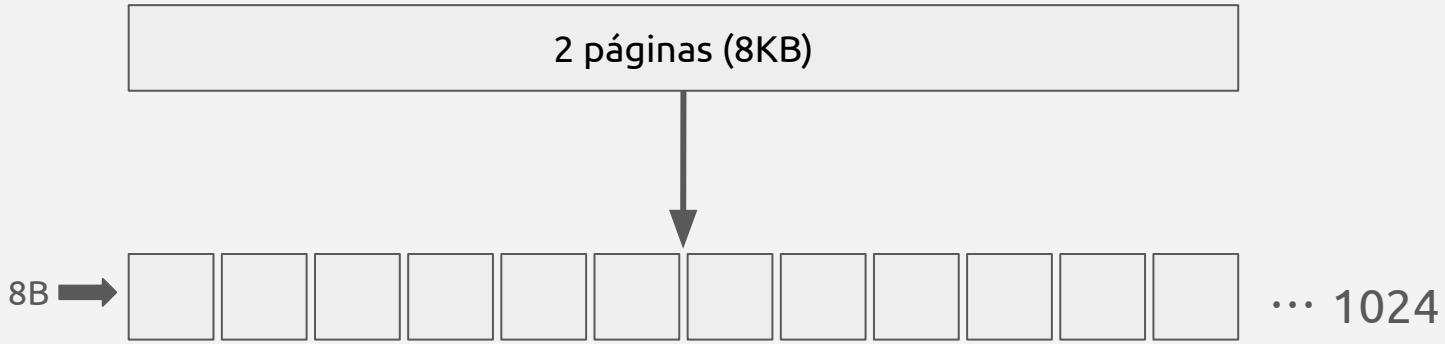
Estratégia para alocações pequenas

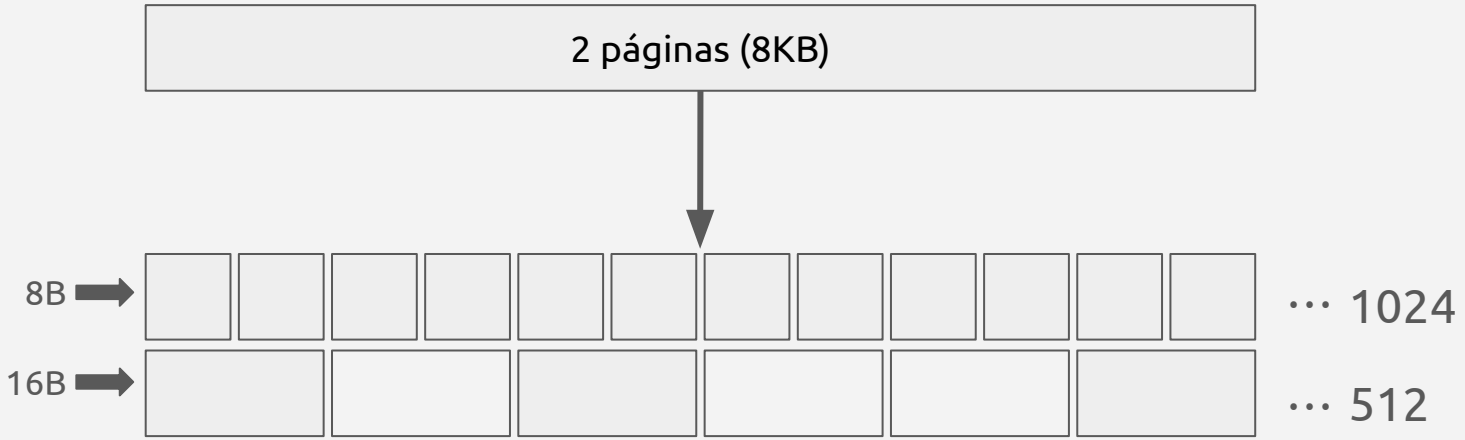


De 1B à 32KB

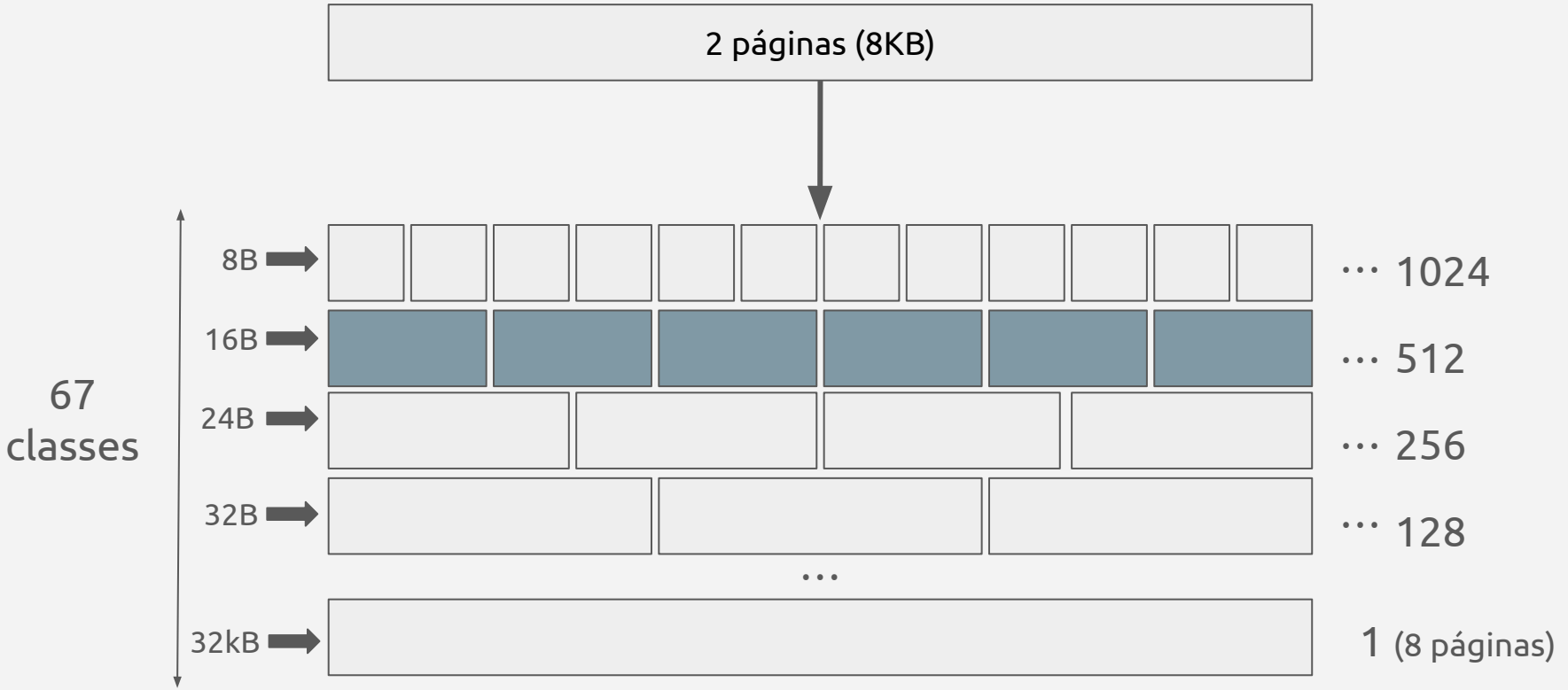
Estratégia para alocações pequenas



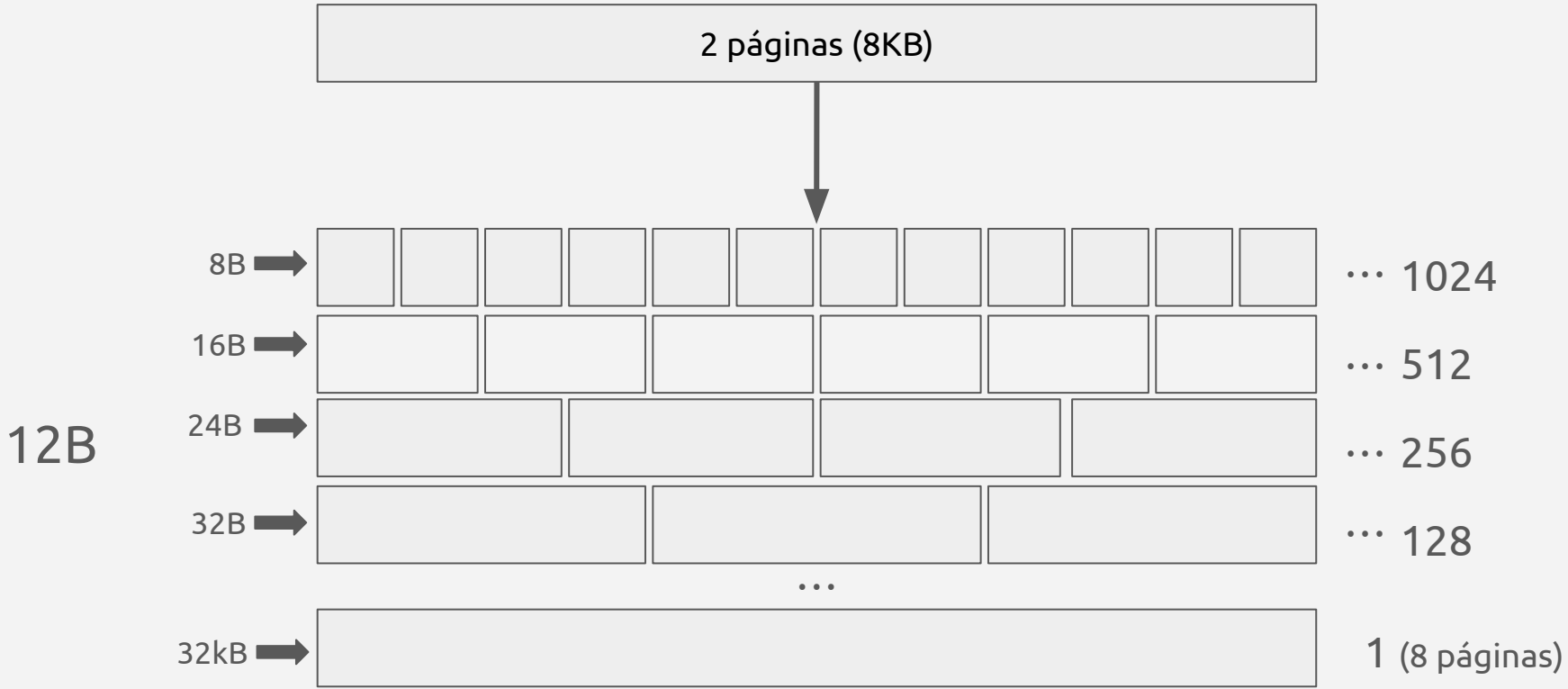
Estratégia para alocações pequenas



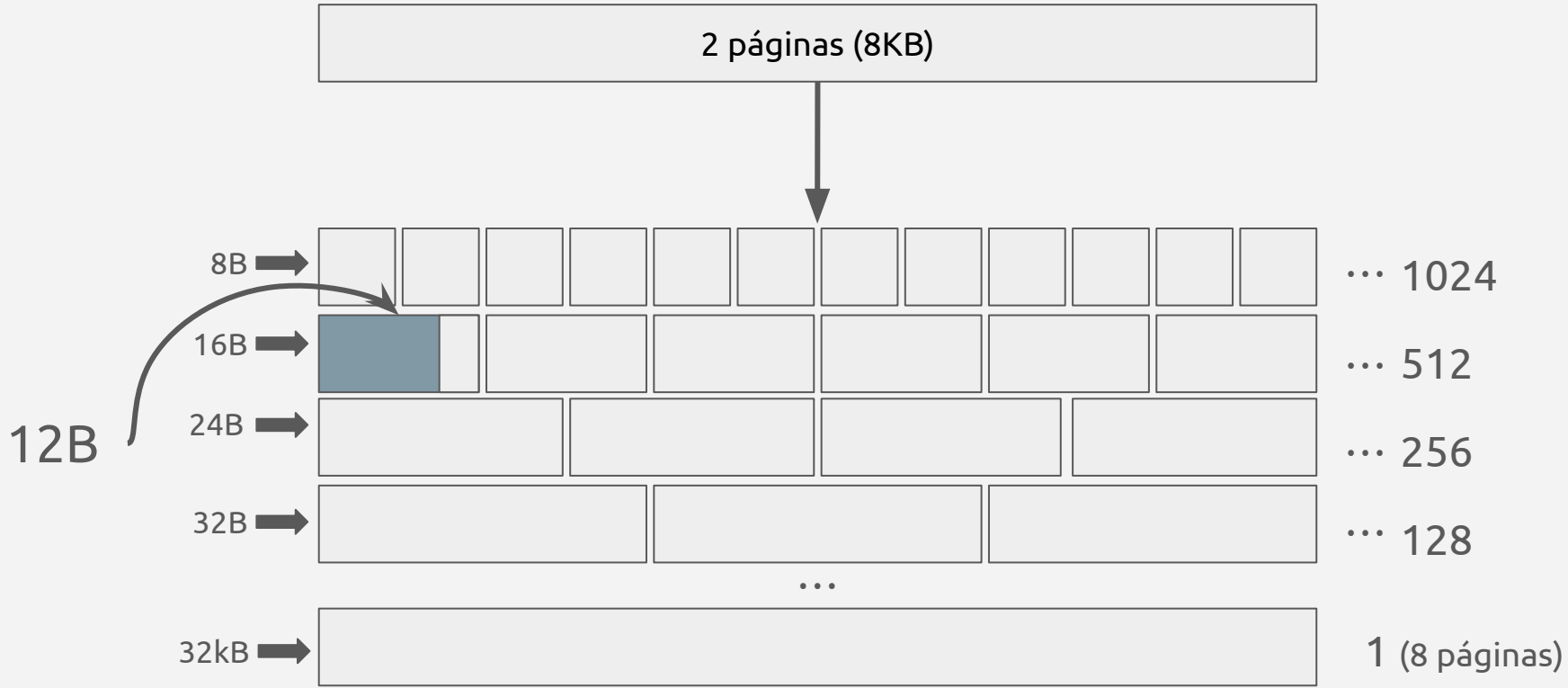
mspan


2 páginas (8KB)
8B
16B
24B
32B
32kB
67 classes
… 1024
… 512
… 256
… 128
1 (8 páginas)

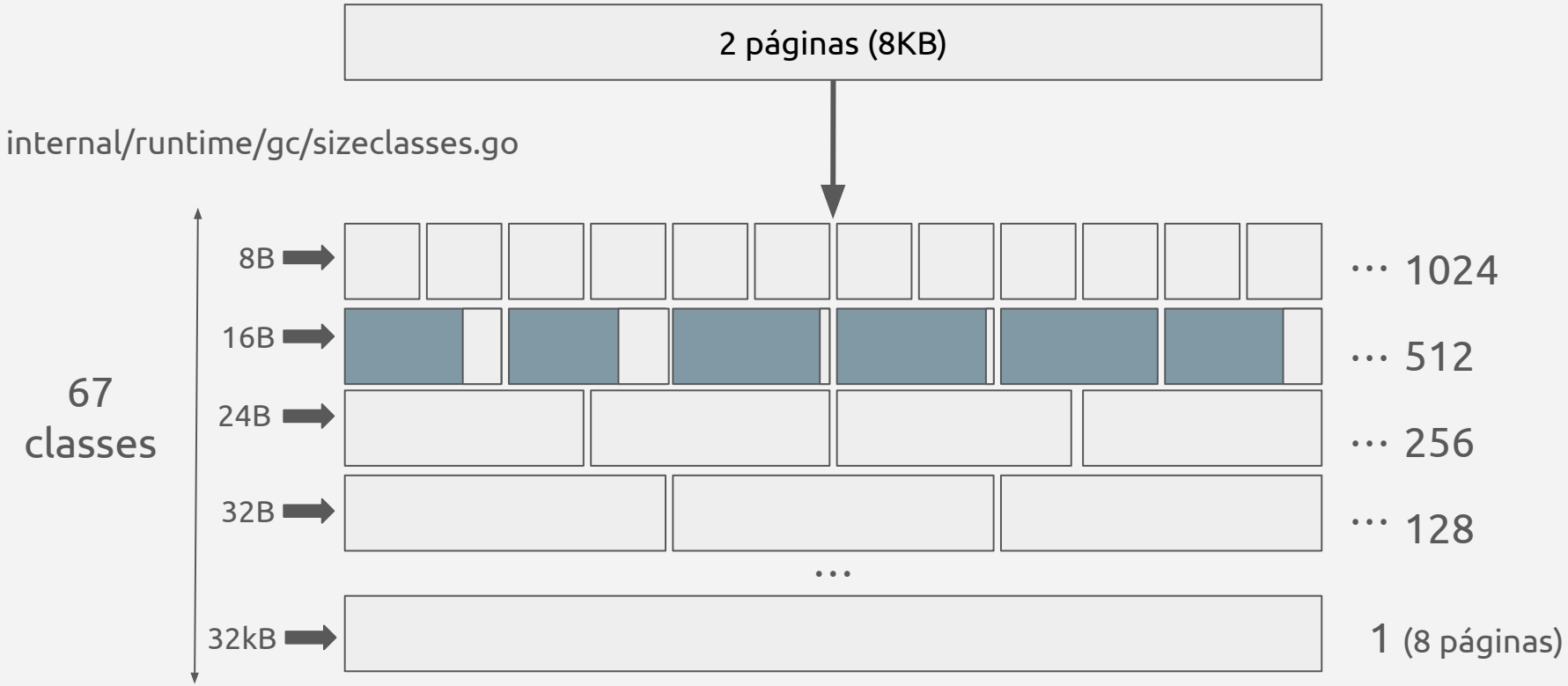
Para tamanhos intermediários



Para tamanhos intermediários



mspan


2 páginas (8KB)
internal/runtime/gc/sizeclasses.go
67 classes
8B
16B
24B
32B
32kB
… 1024
… 512
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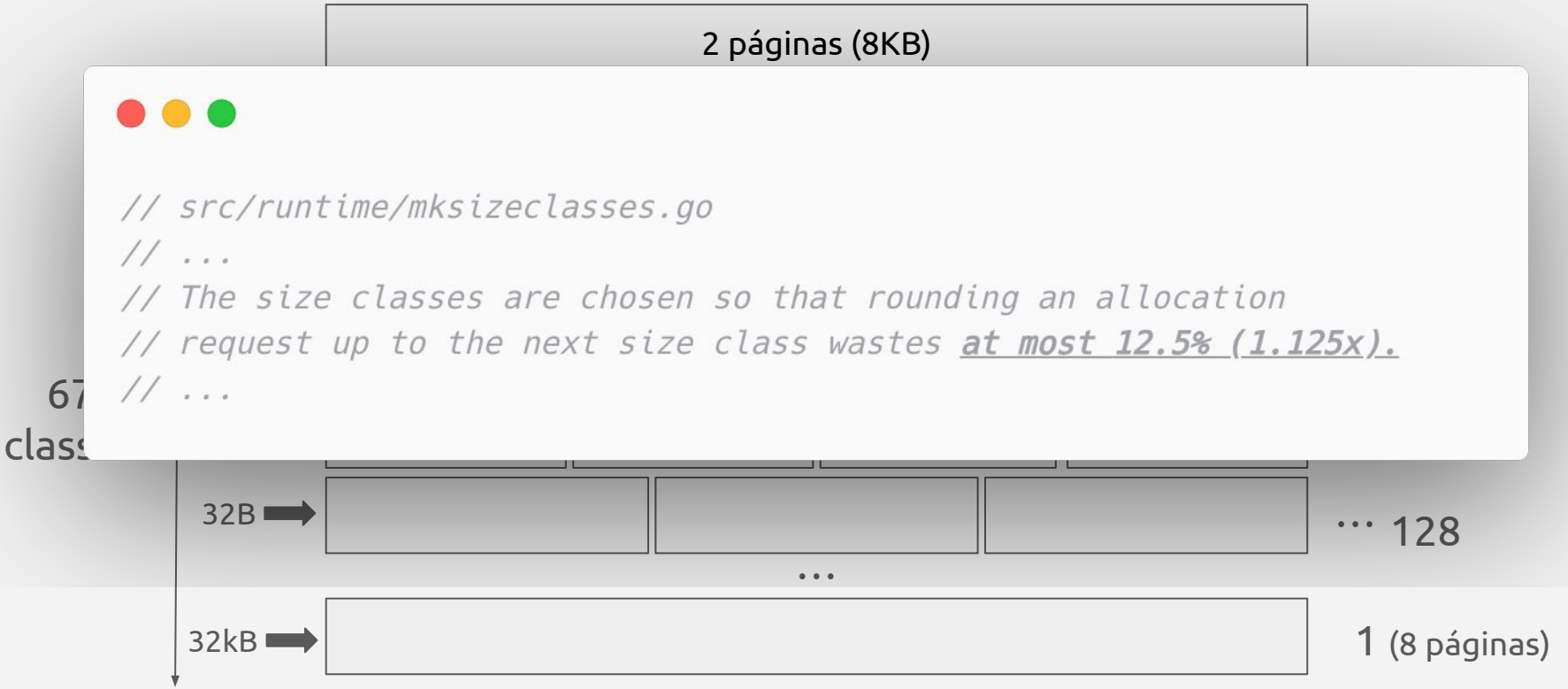
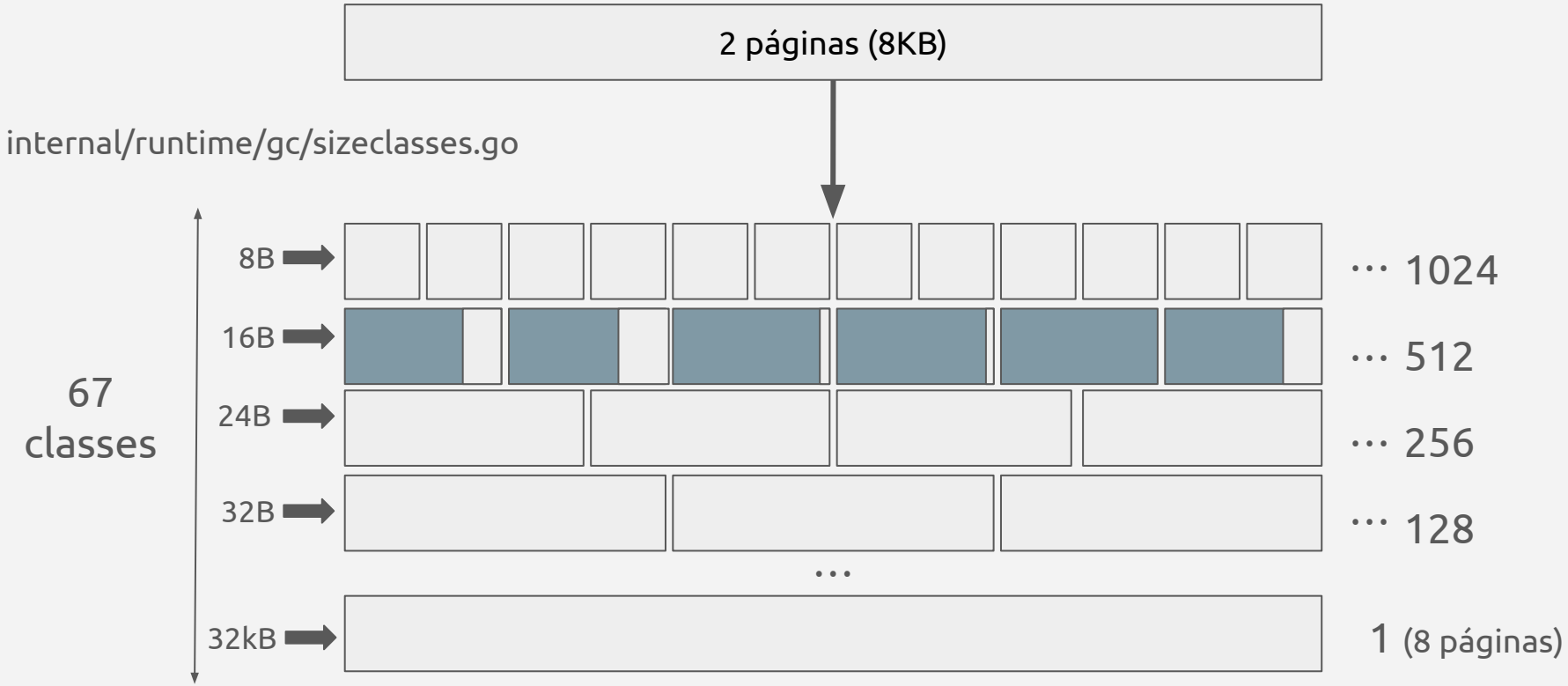
… 128
1 (8 páginas)

mspan


2 páginas (8KB)
// src/runtime/mksizeclasses.go
// ...
// The size classes are chosen so that rounding an allocation
// request up to the next size class wastes at most 12.5% (1.125x).
// ...
67
class
32B
... 128
...
32kB
1 (8 páginas)

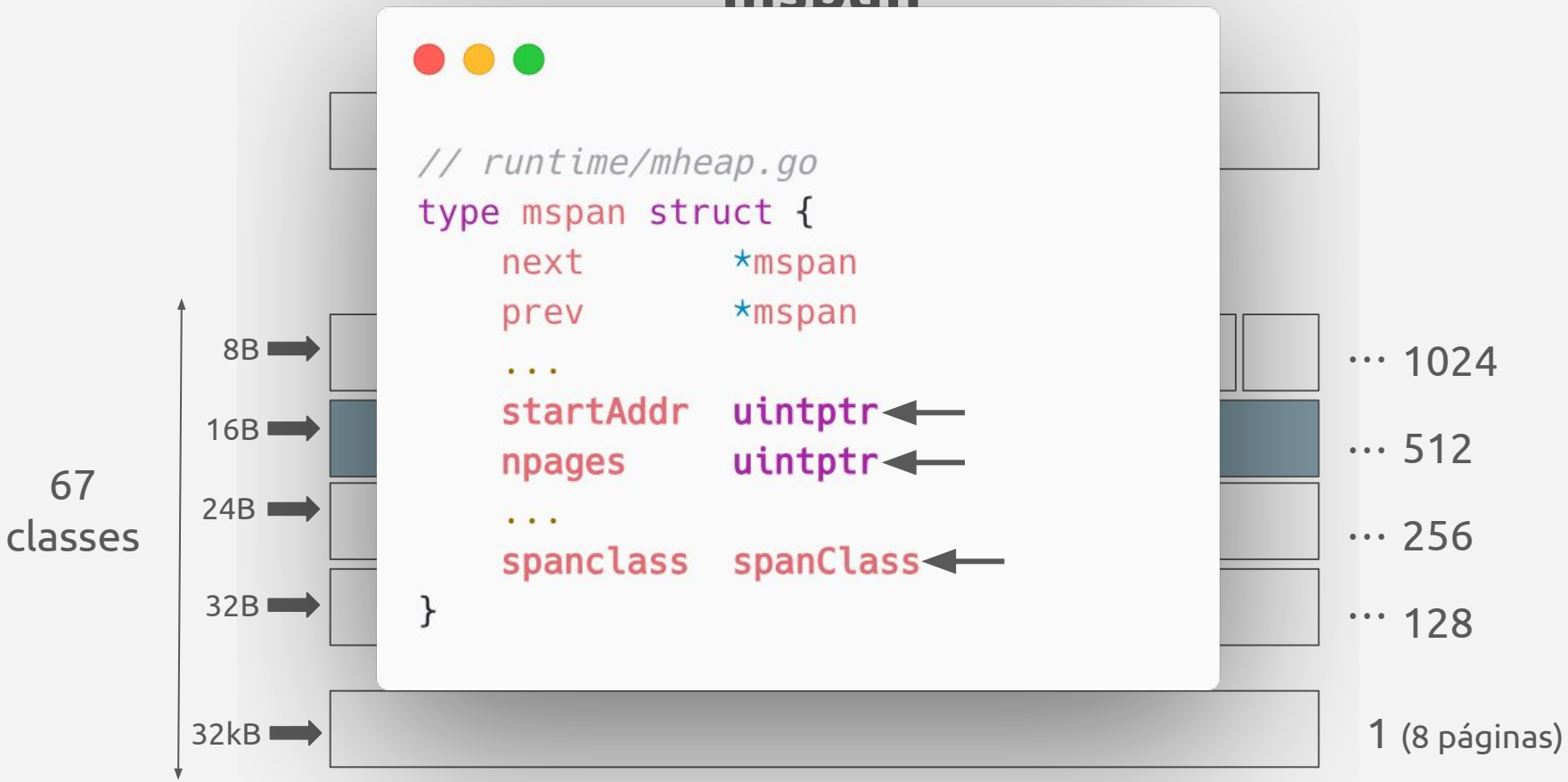
mspan


2 páginas (8KB)
internal/runtime/gc/sizeclasses.go
67 classes
8B
16B
24B
32B
32kB
… 1024
… 512
… 256
… 128
1 (8 páginas)

mspan


// runtime/mheap.go
type mspan struct {
next *mspan
prev *mspan
...
startAddr uintptr
npages uintptr
...
spanclass spanClass
}
67 classes
8B
16B
24B
32B
32kB
... 1024
... 512
... 256
... 128
1 (8 páginas)

mspan


// runtime/mheap.go
type mspan struct {
next *mspan
prev *mspan
...
startAddr uintptr
npages uintptr
...
spanclass spanClass
}
67 classes
8B
16B
24B
32B
32kB
... 1024
... 512
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1 (8 páginas)

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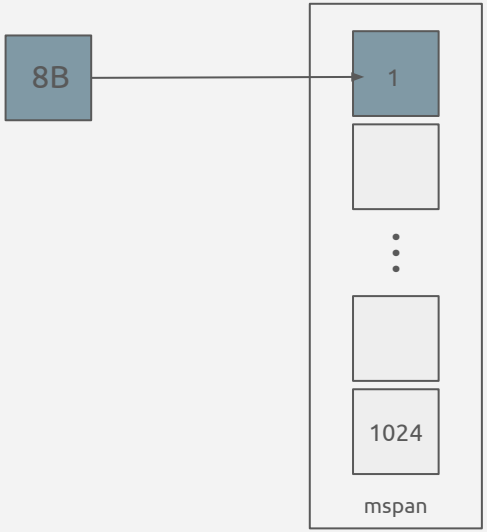
67 classes
8B
16B
24B
32B
32kB
... 1024
... 512
... 256
... 128
1 (8 páginas)

Para cada classe, uma lista de mspans



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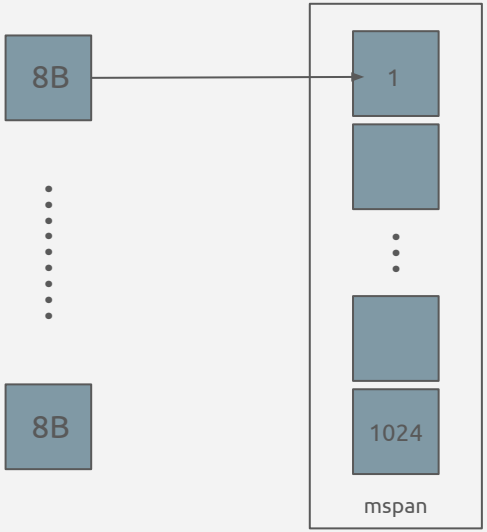

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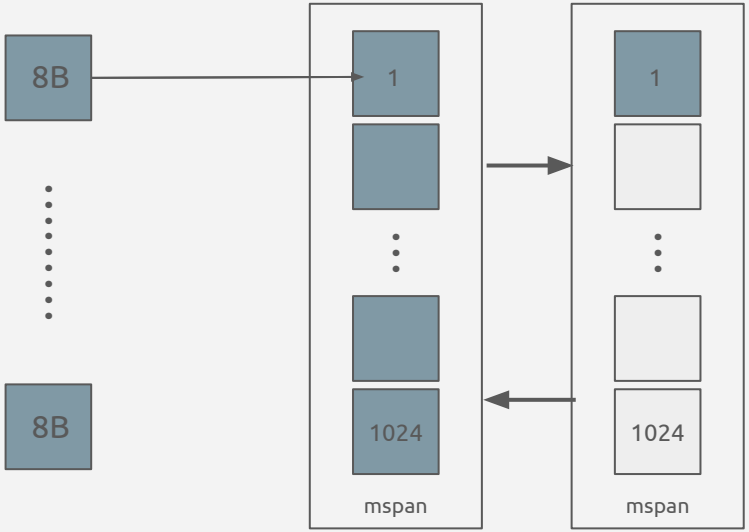
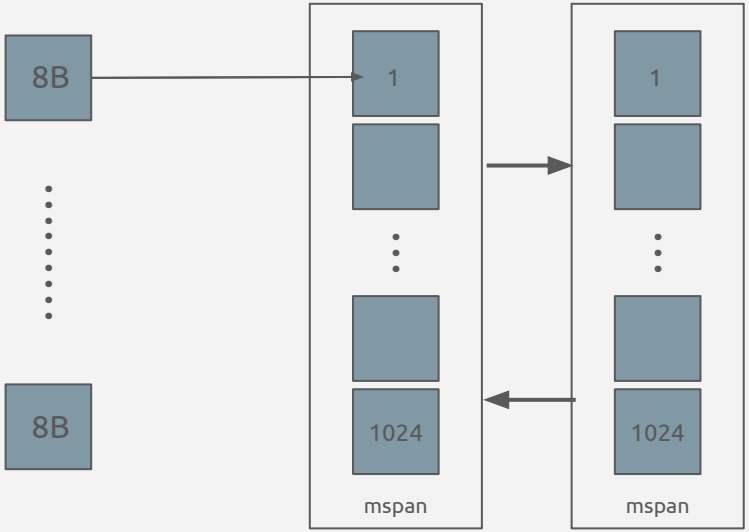


Para cada classe, uma lista de mspans



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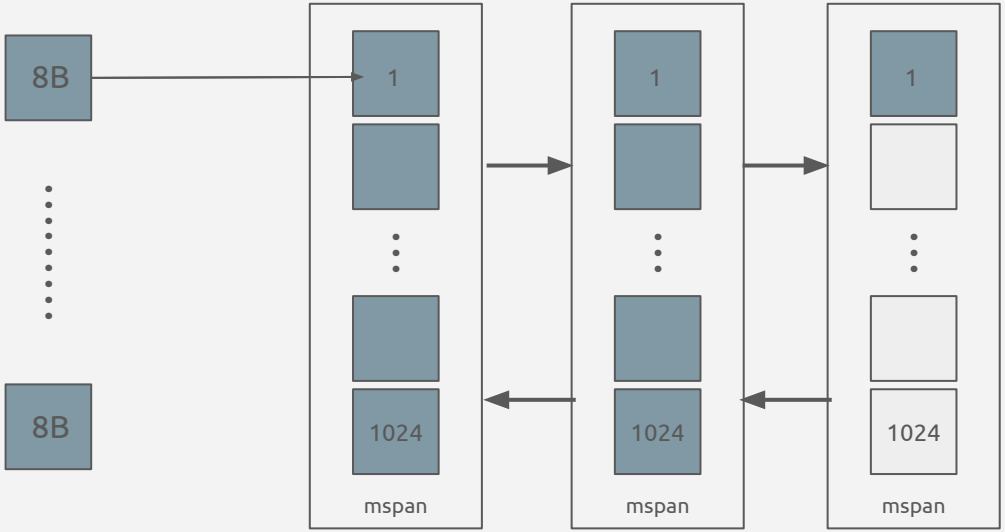

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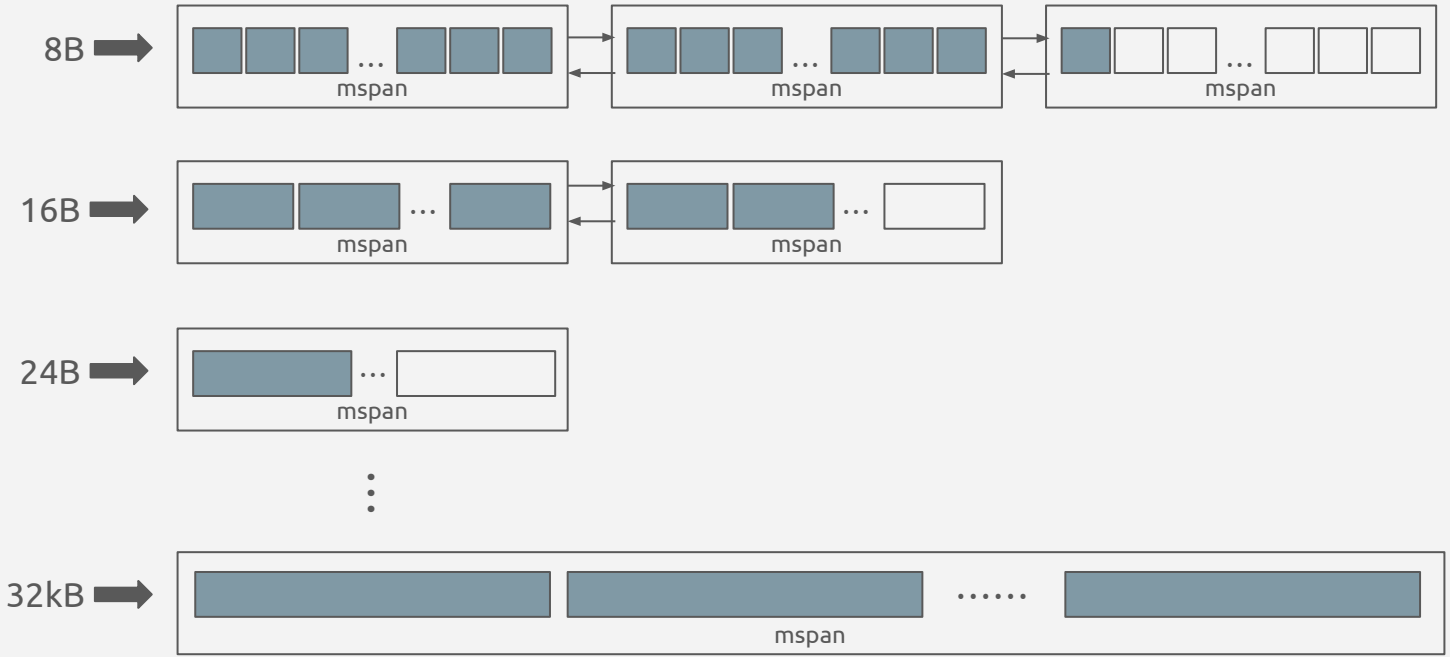
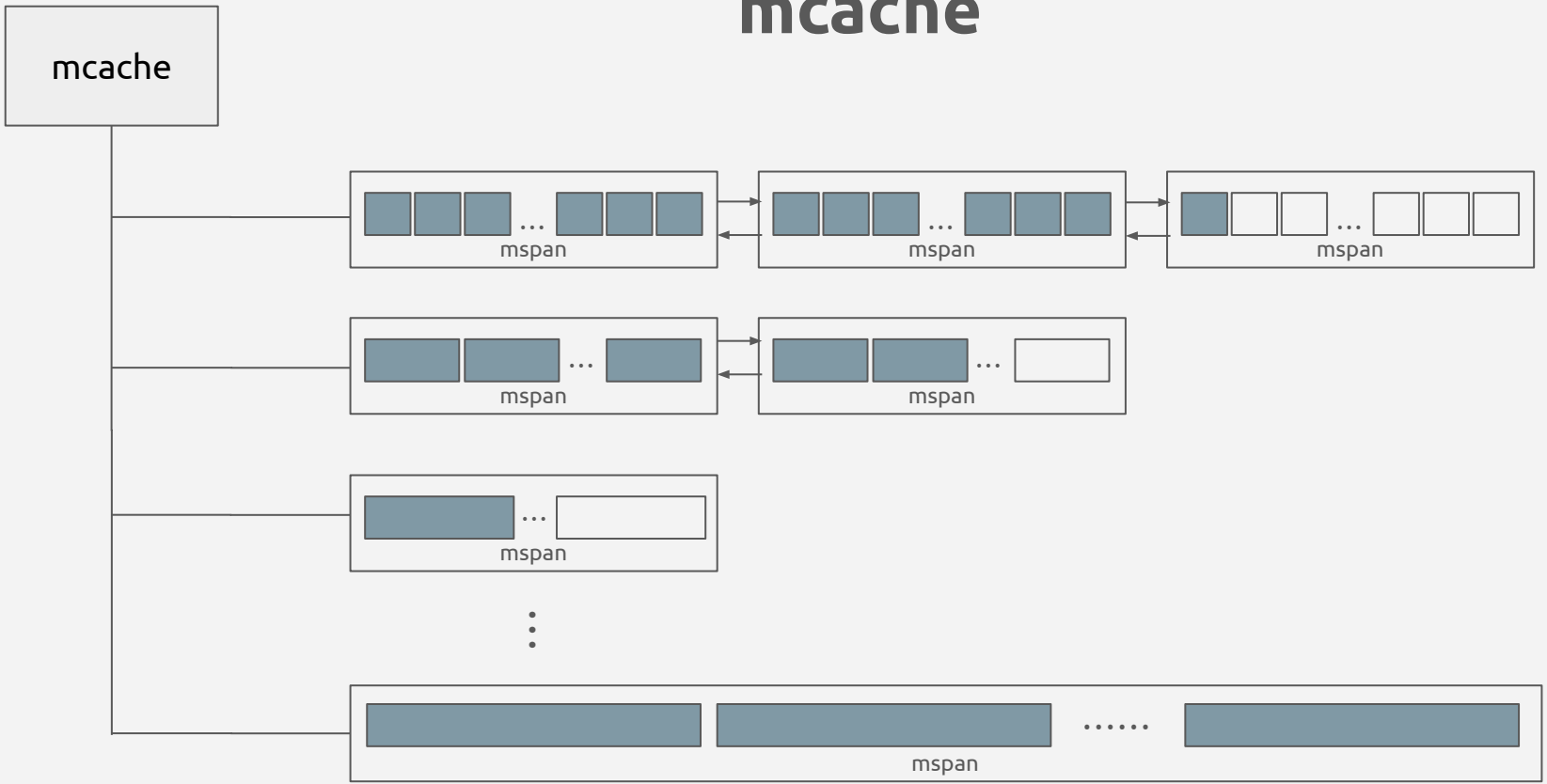
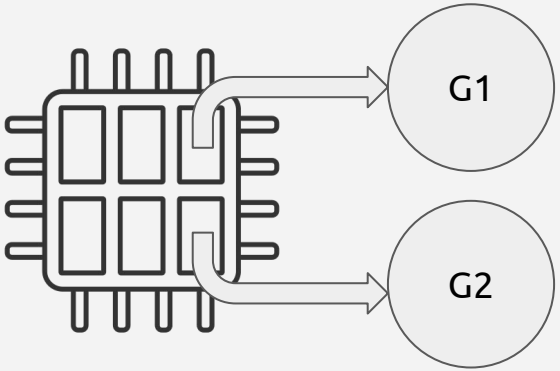


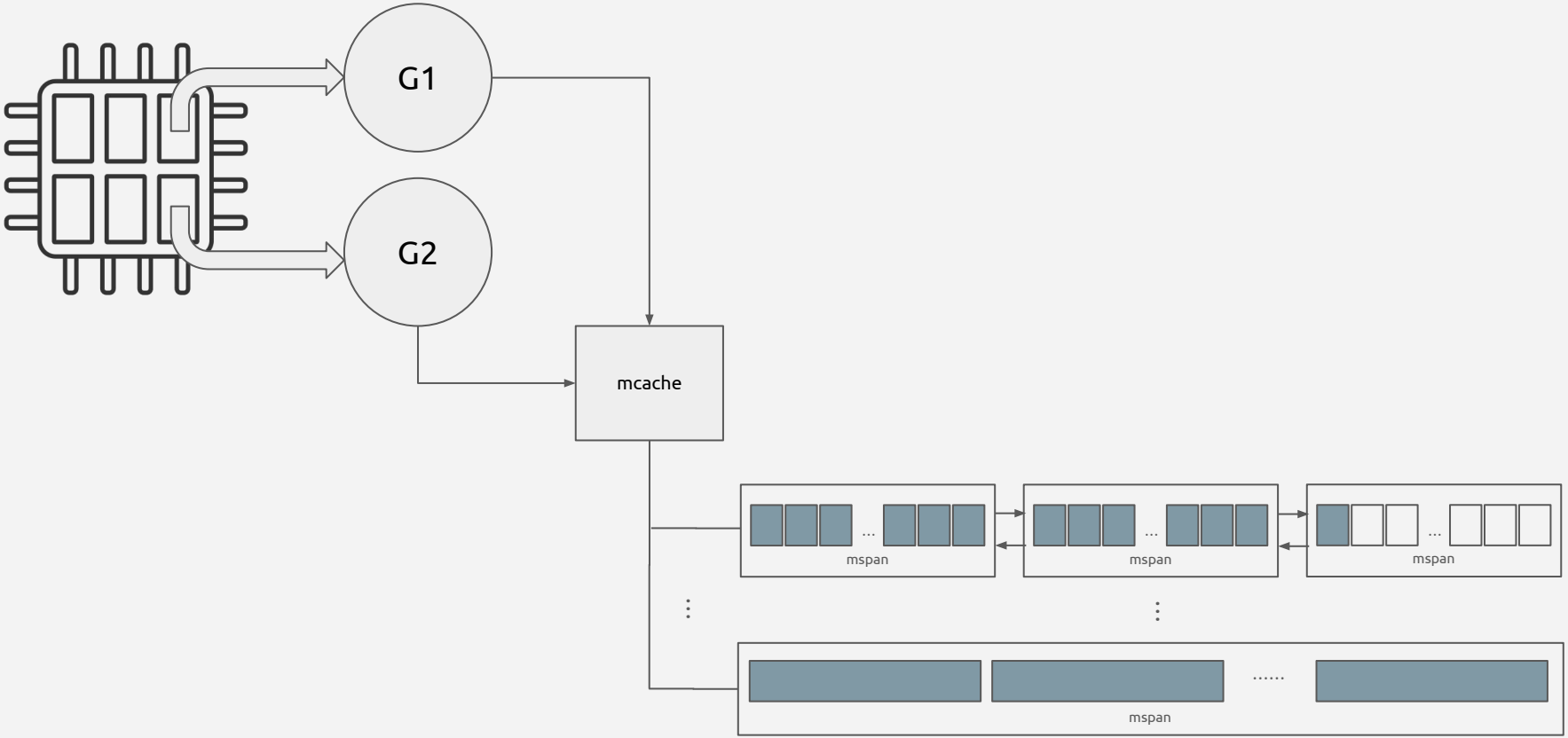
mcache



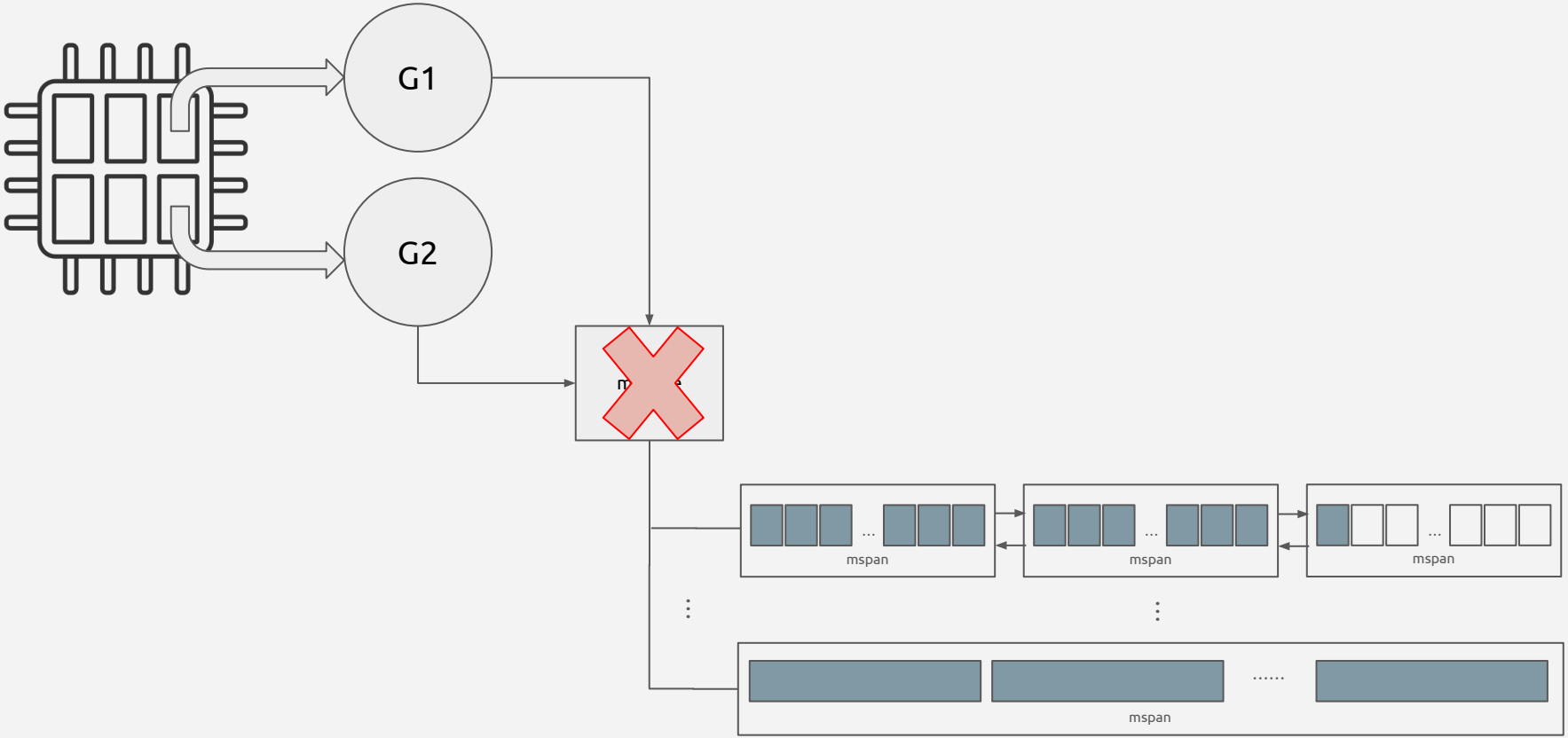
Concorrência



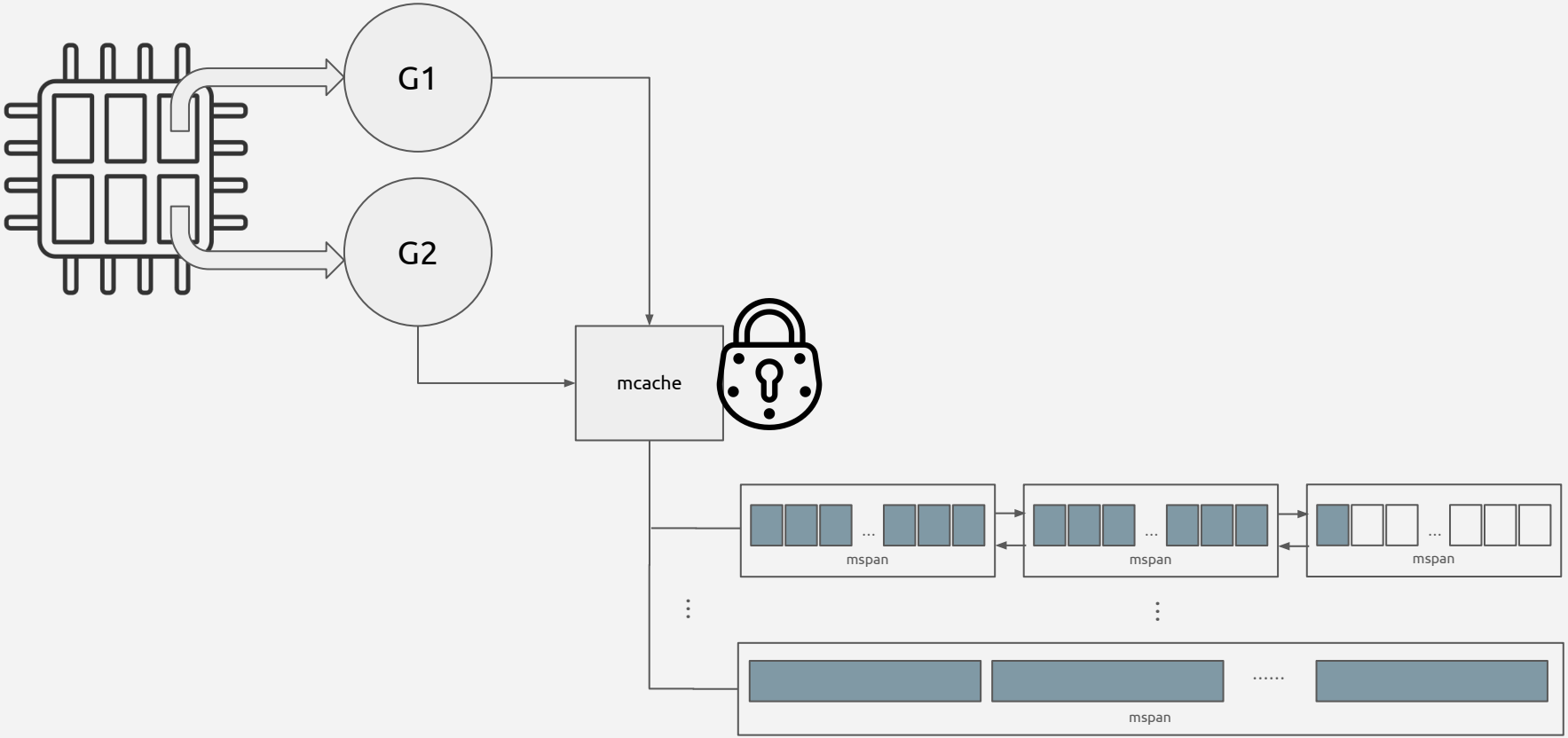
Concorrência



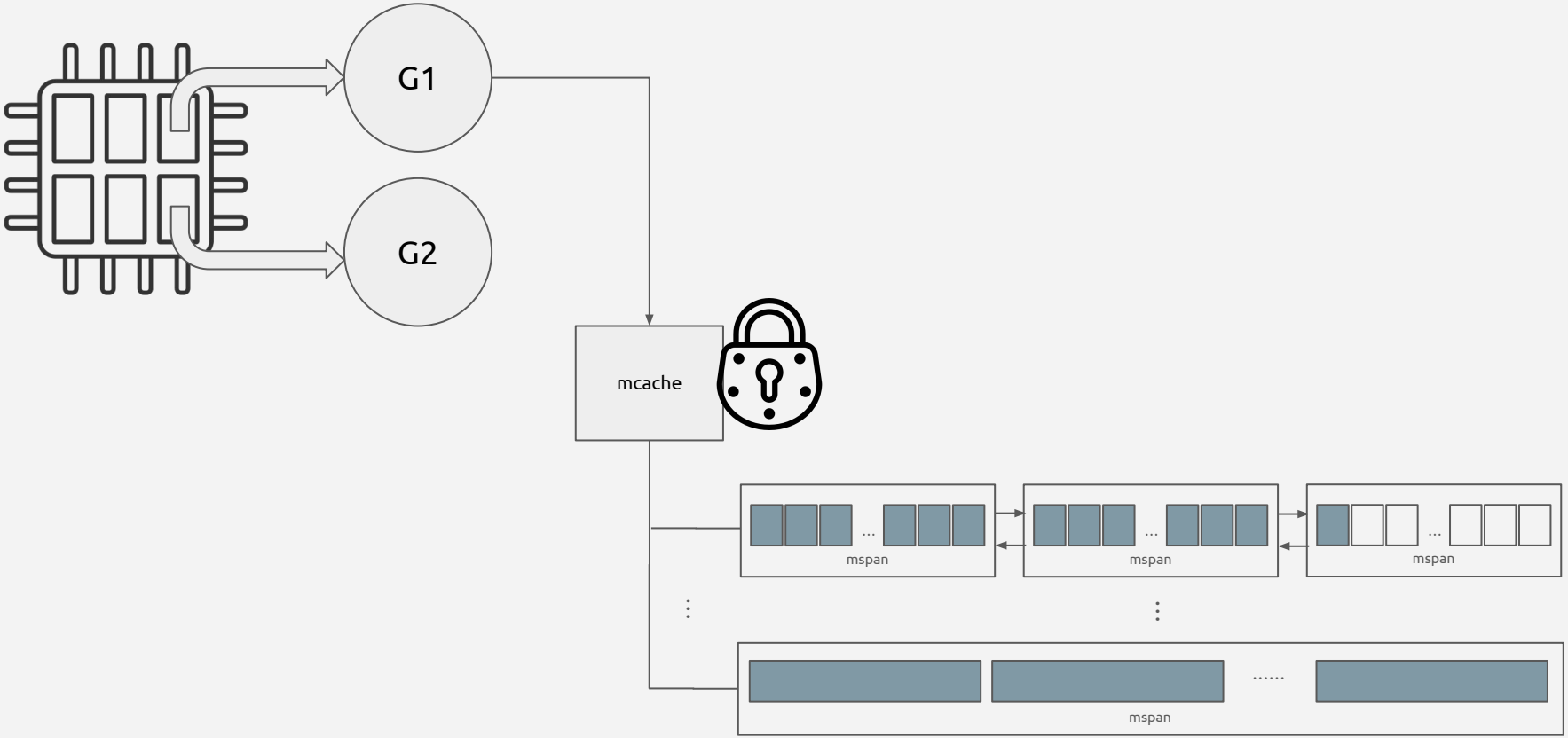
Concorrência



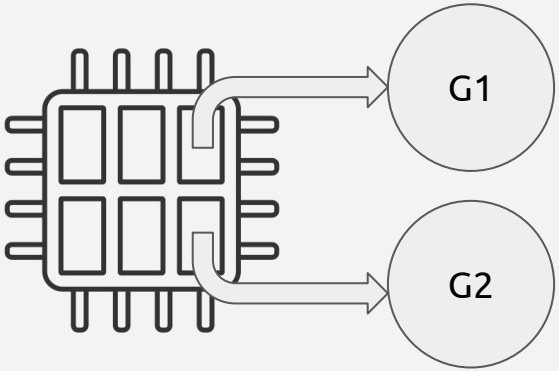
Concorrência

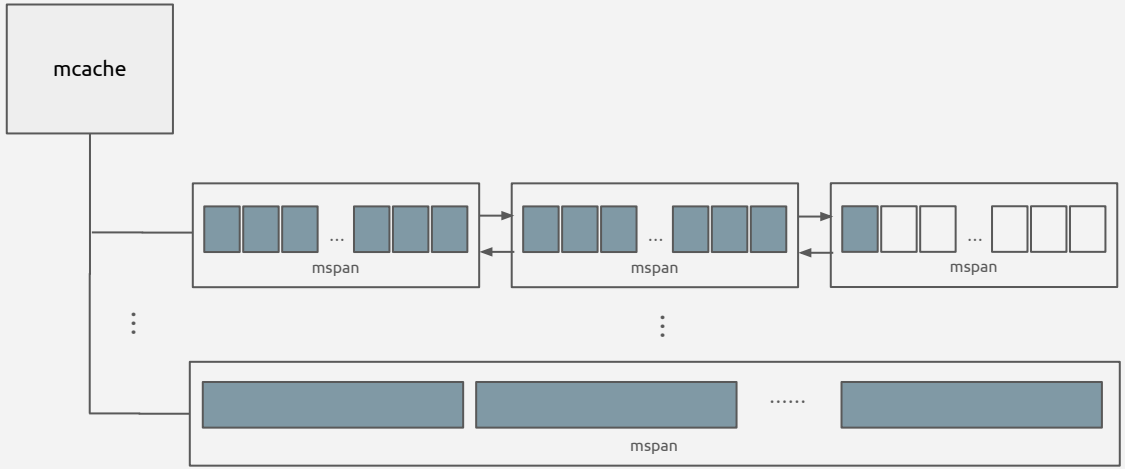


Concorrência

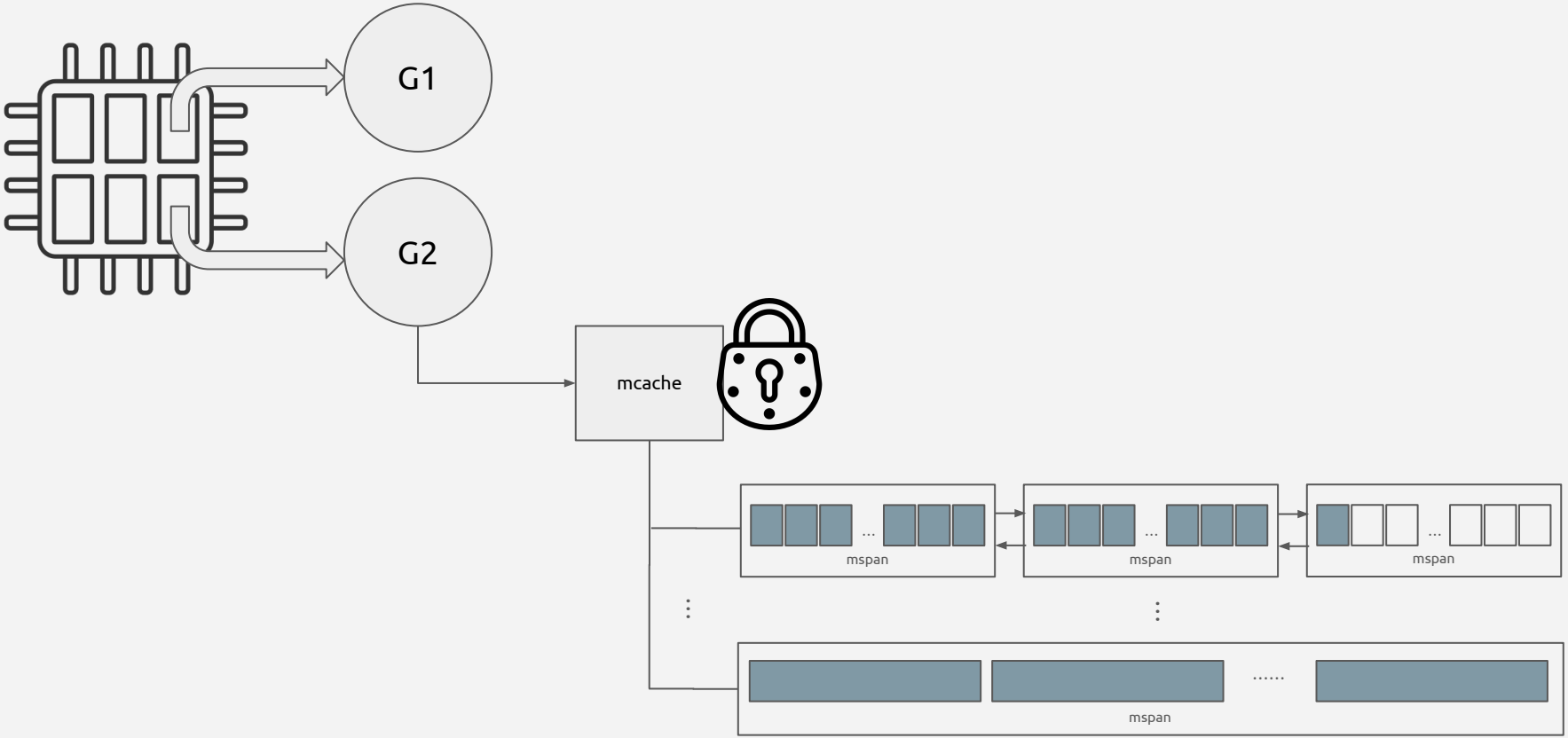


Concorrência

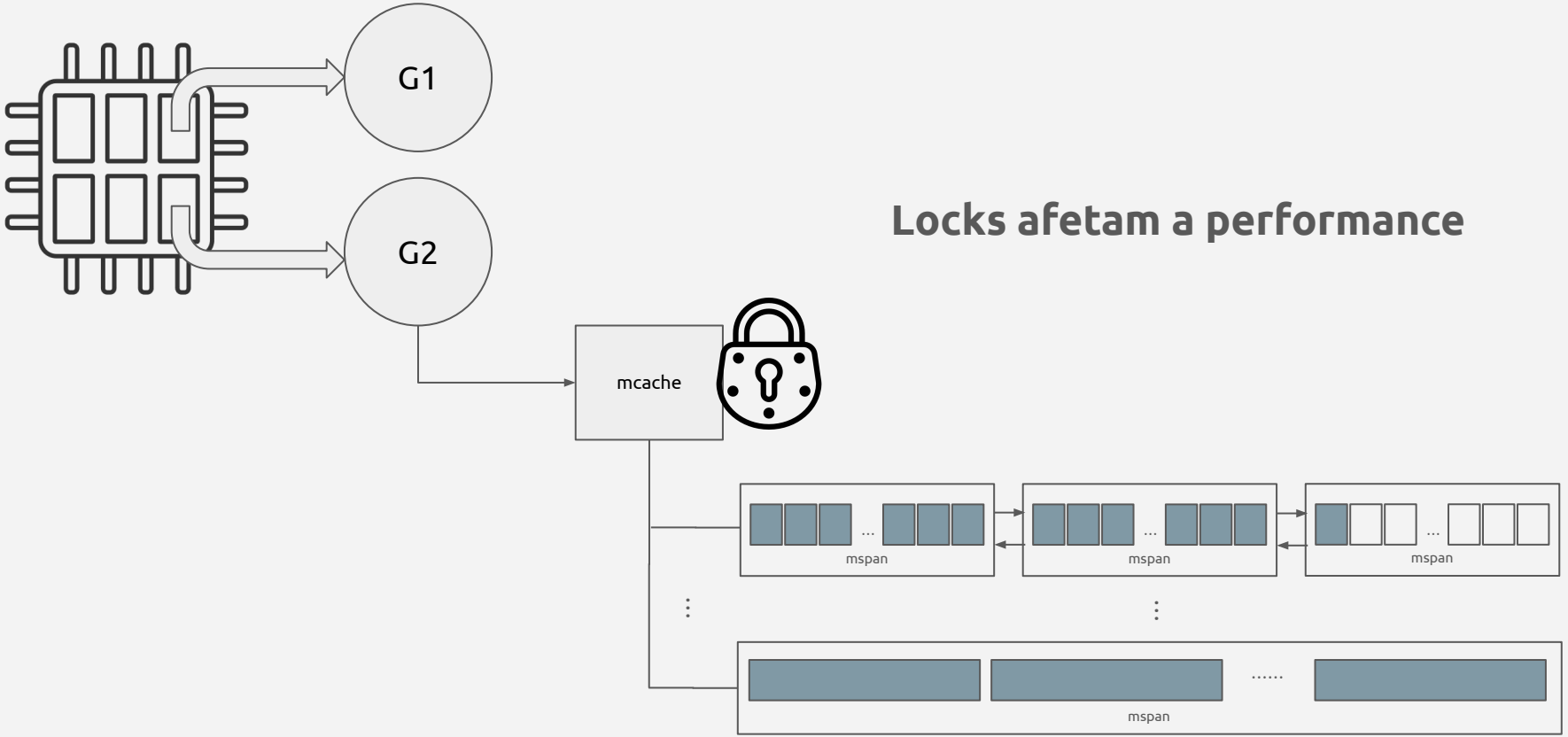




Concorrência

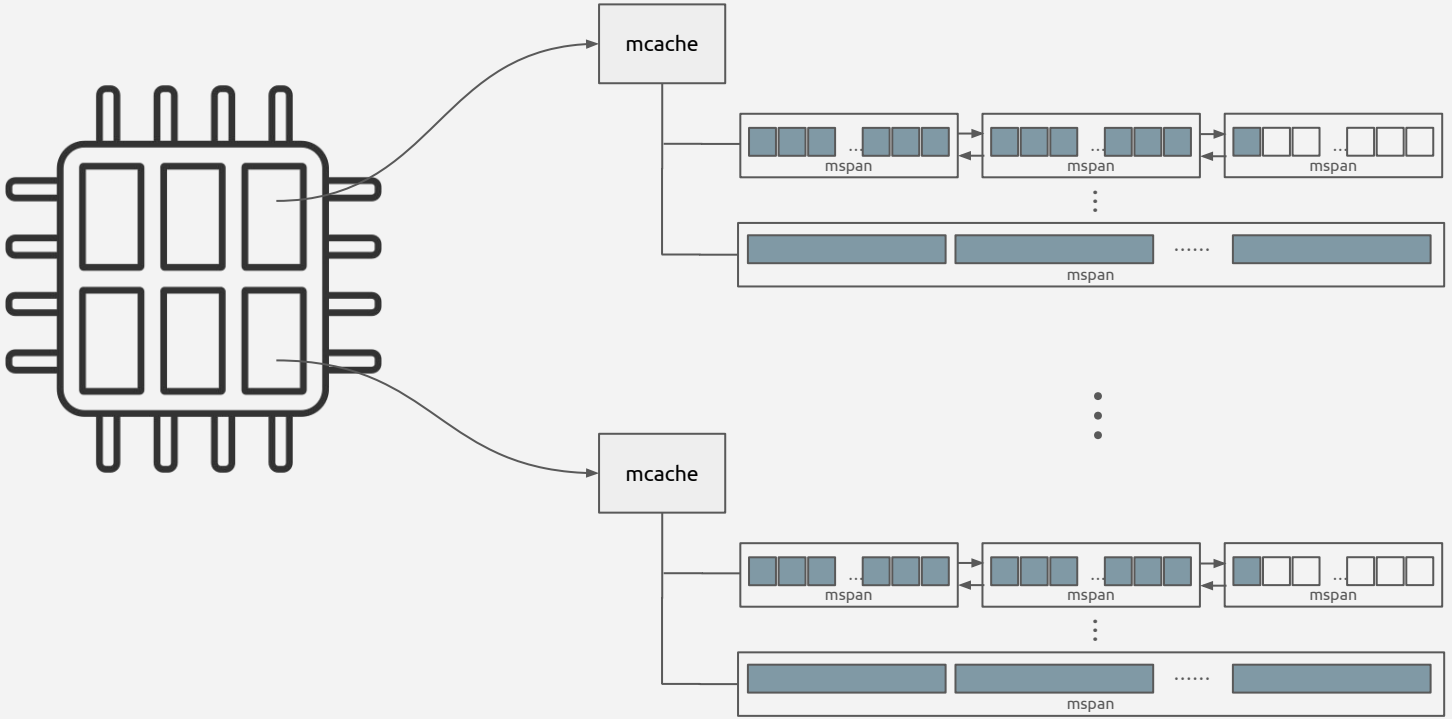


Concorrência



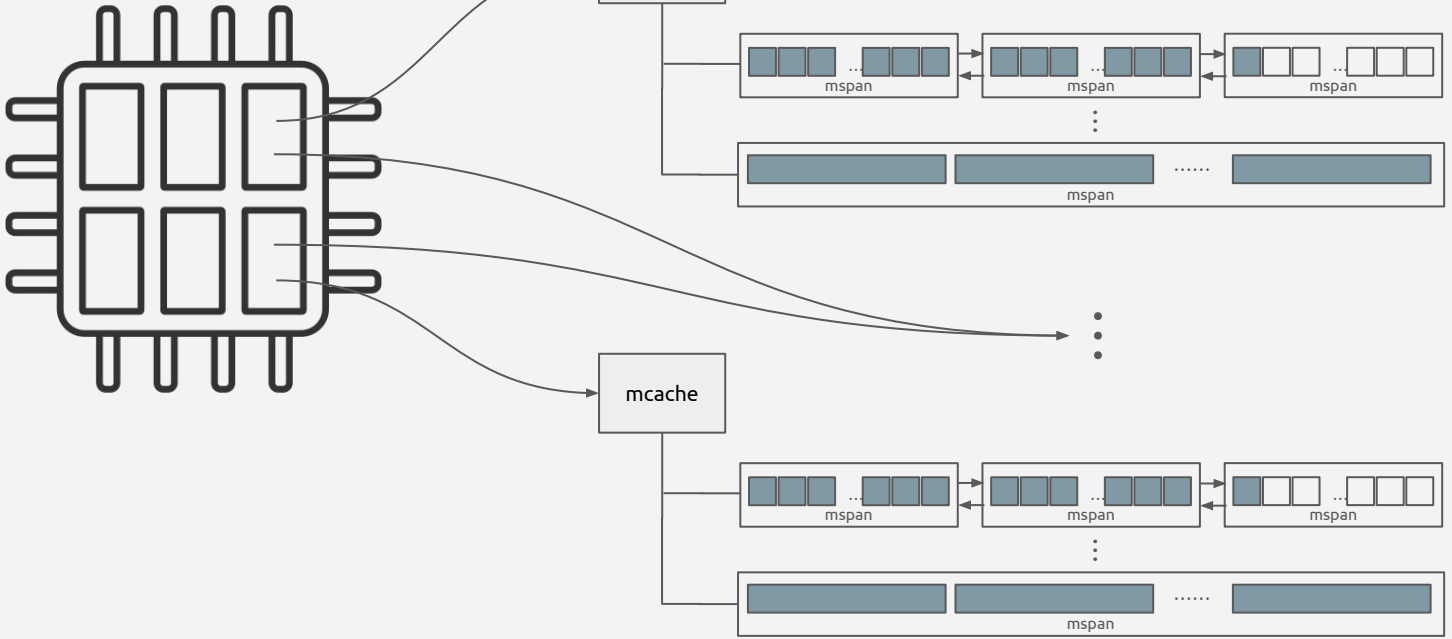
Locks afetam a performance

mcache


mcache
mspan
mspan
mspan
mspan
mcache
mspan
mspan
mspan
mspan

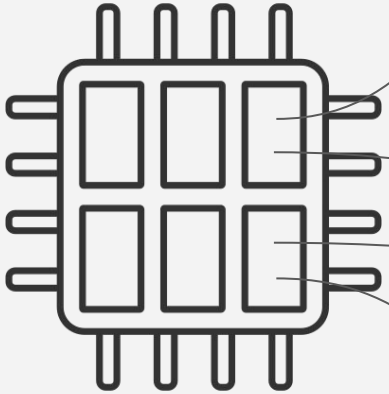
mcache

Thread de execução da CPU

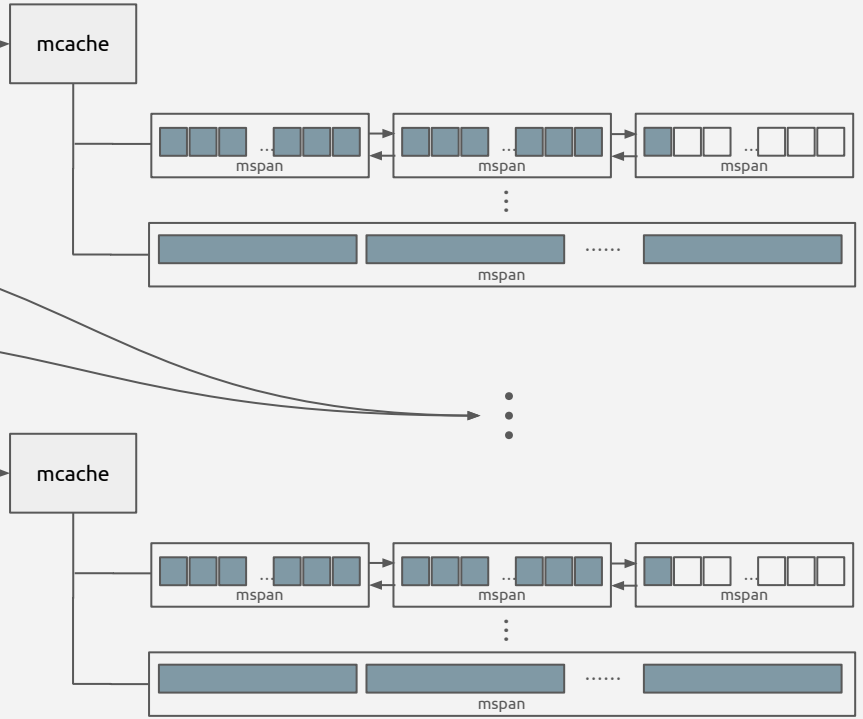


mcache

Thread de execução
da CPU

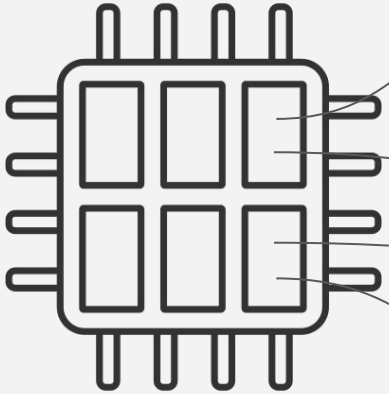


6 núcleos
12 threads

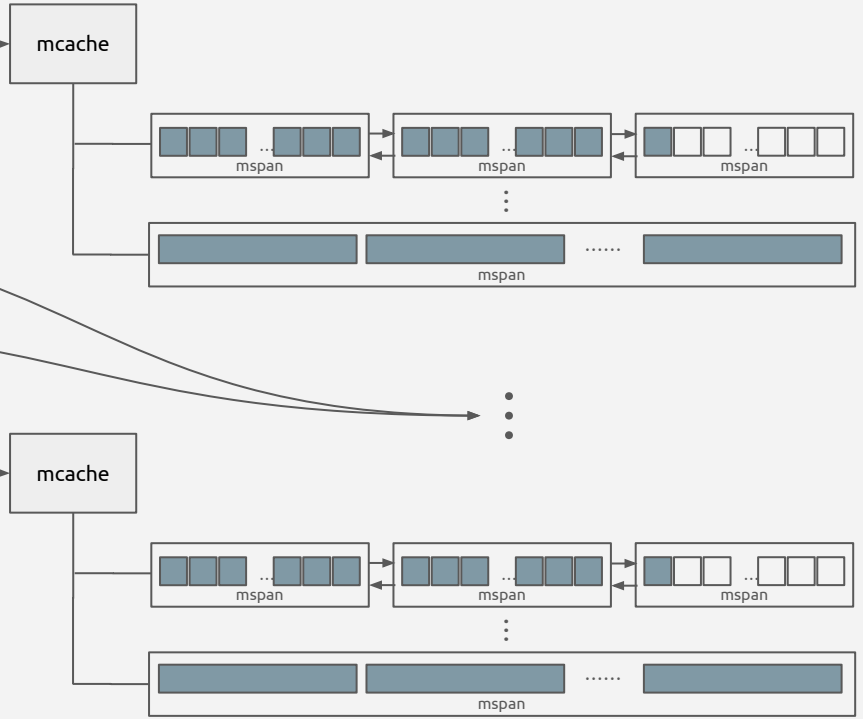


mcache

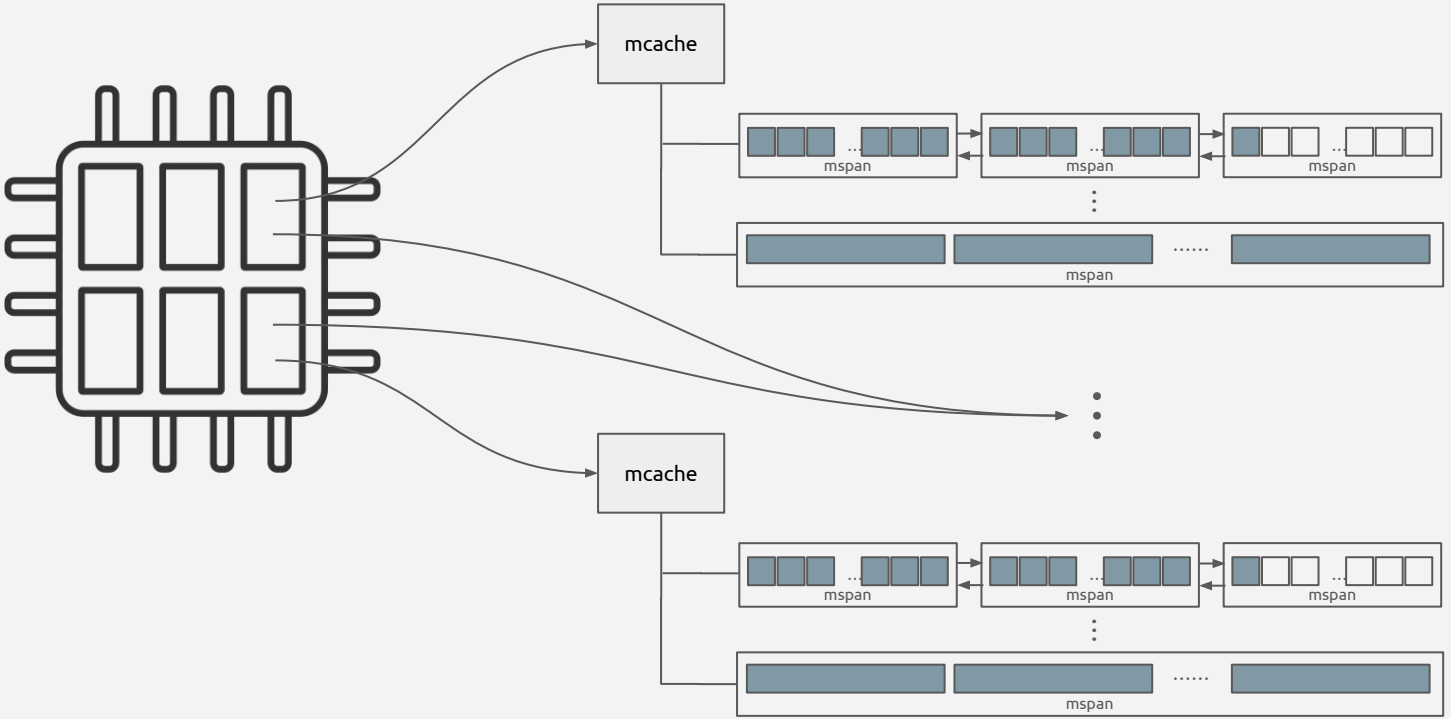
Processador lógico
(P)



6 núcleos
12 threads



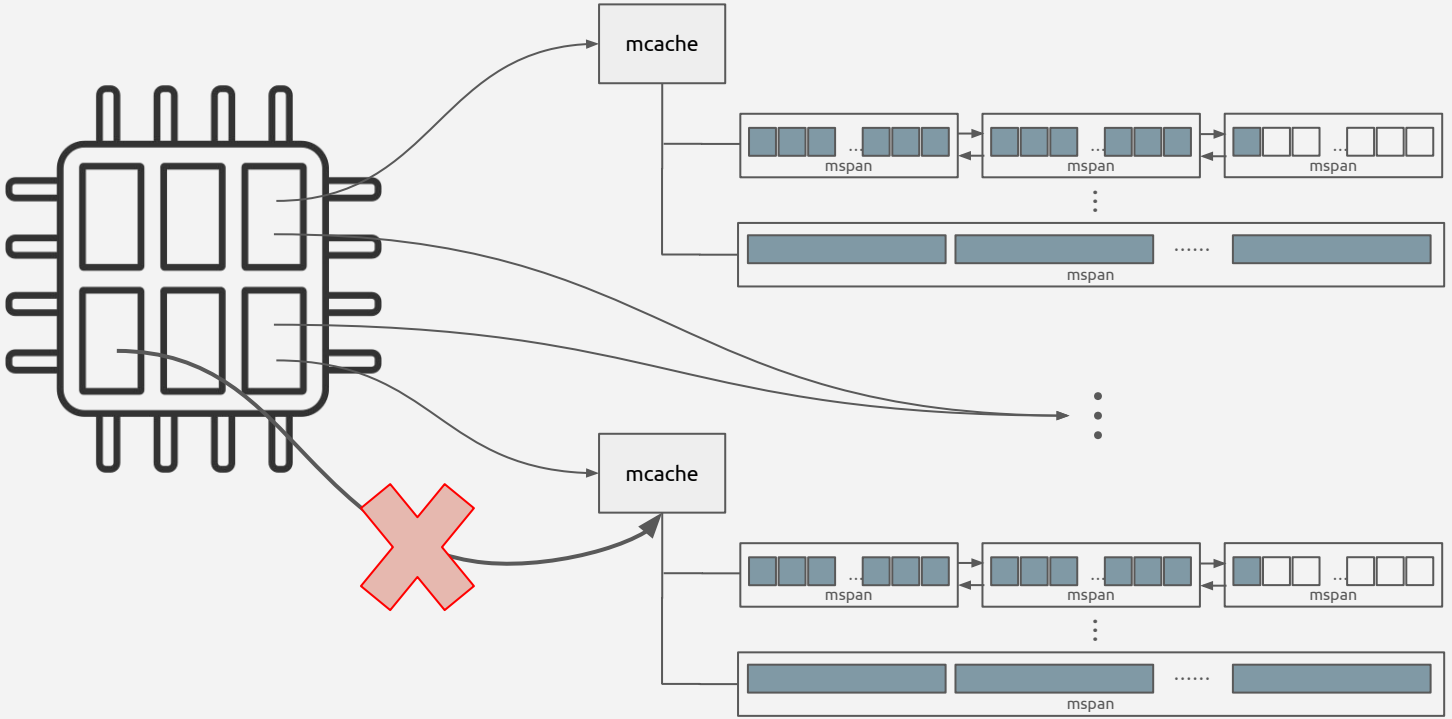
mcache


mcache
mspan
mspan
mspan
mspan
mcache
mspan
mspan
mspan
mspan

Preserva os valores no cache da CPU

Operação	Latência
Clock da CPU (4GHz)	0.25ns
Acesso Cache L1	0,75ns
Acesso Cache L2	7ns
Lock/Unlock de um Mutex	25ns
Acesso à memória RAM	100ns
Leitura de 4KB do SSD	150.000ns

mcache


mcache
mspan
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mspan
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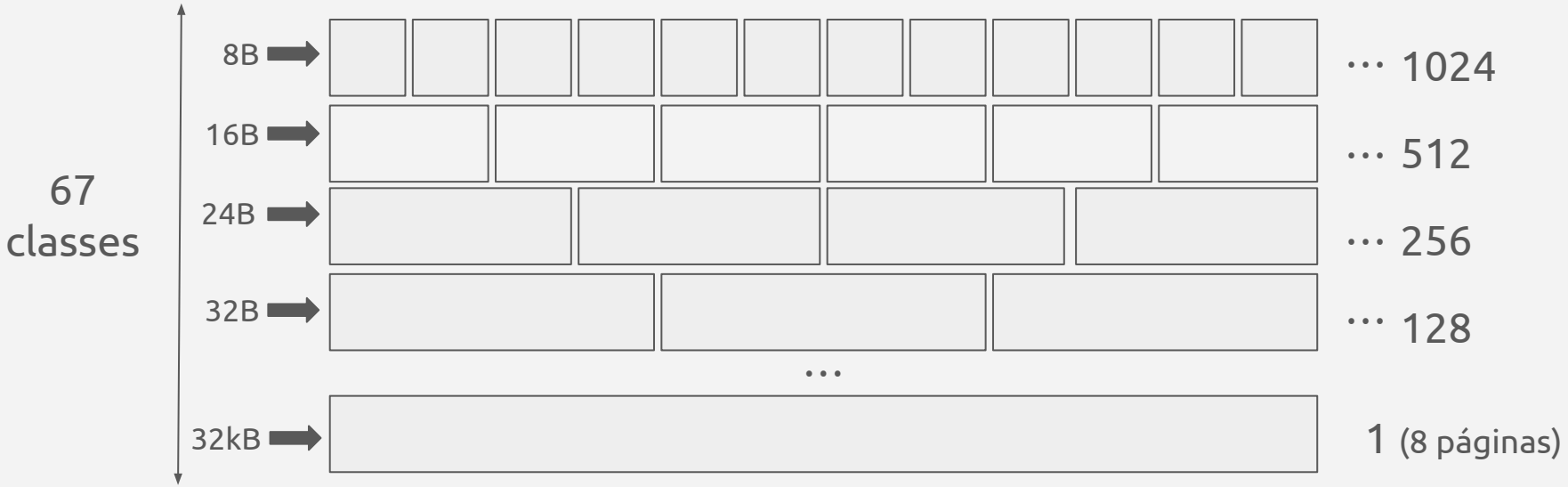
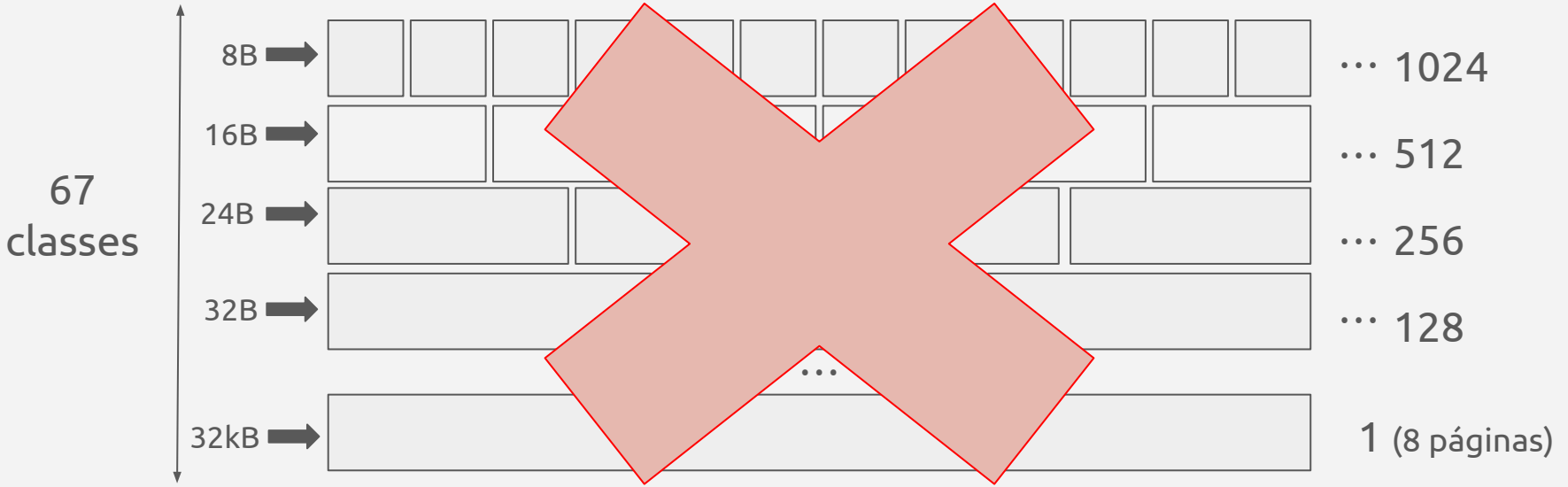
mspan

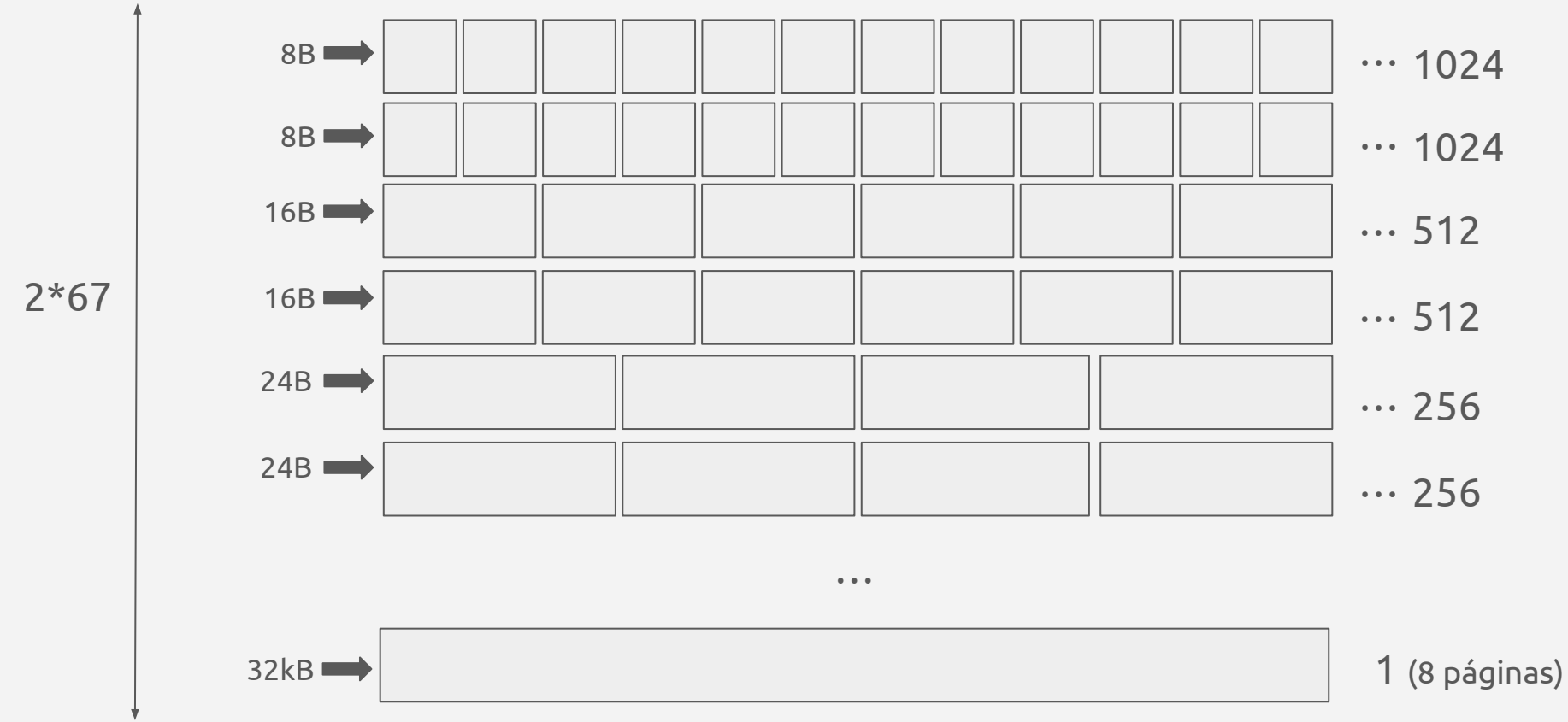
Cada mcache tem 67 classes



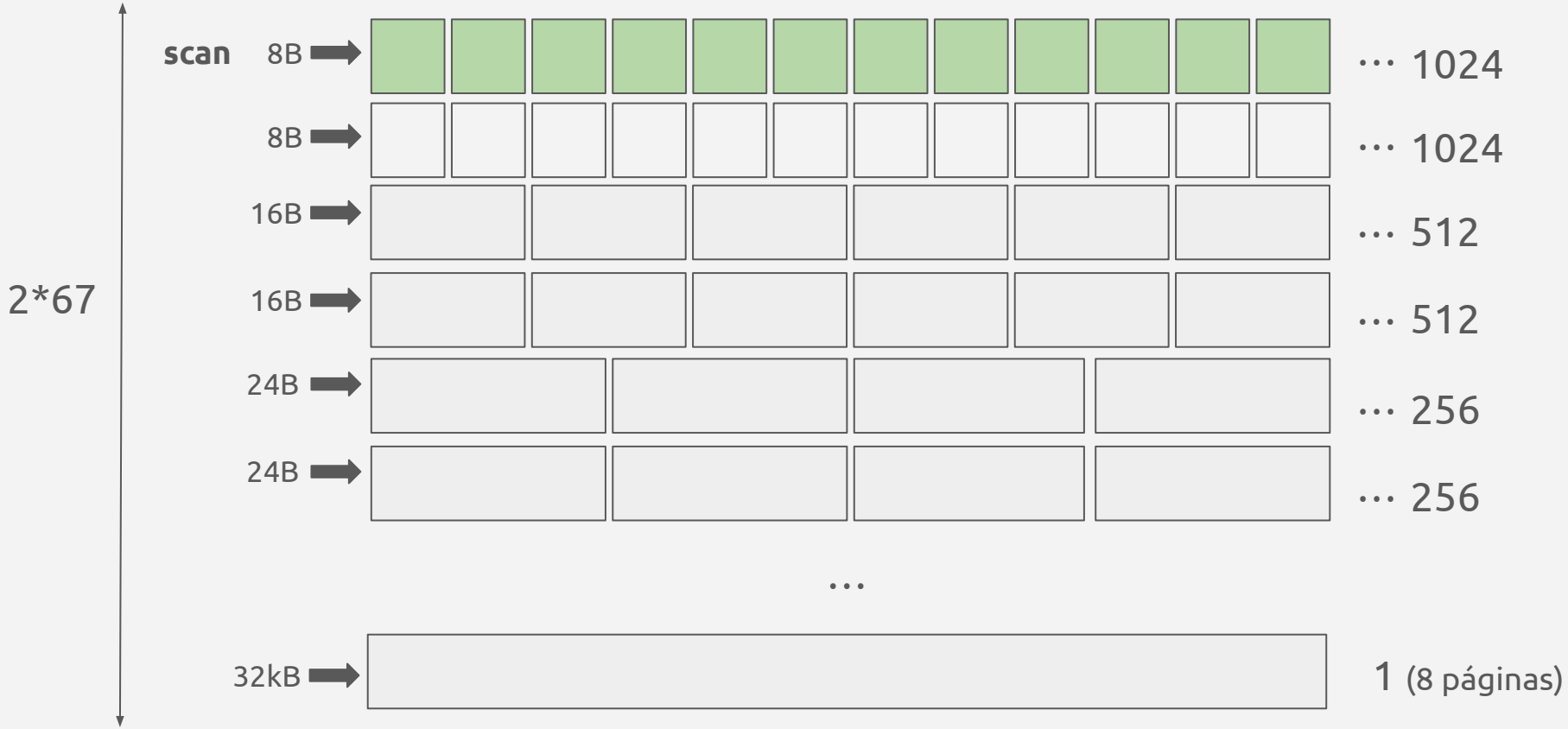
Cada mcache tem 67 classes



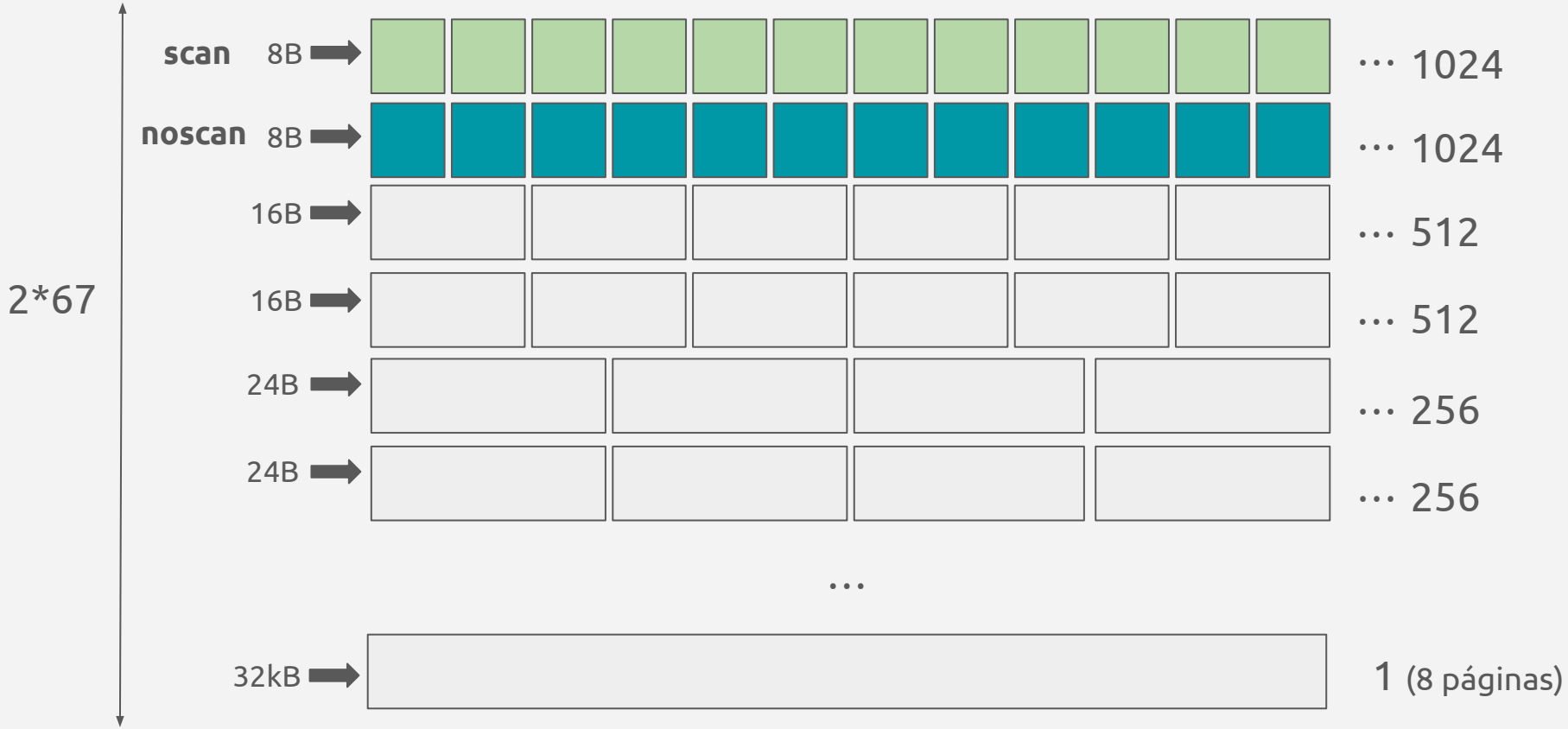
Cada mcache tem 134 classes



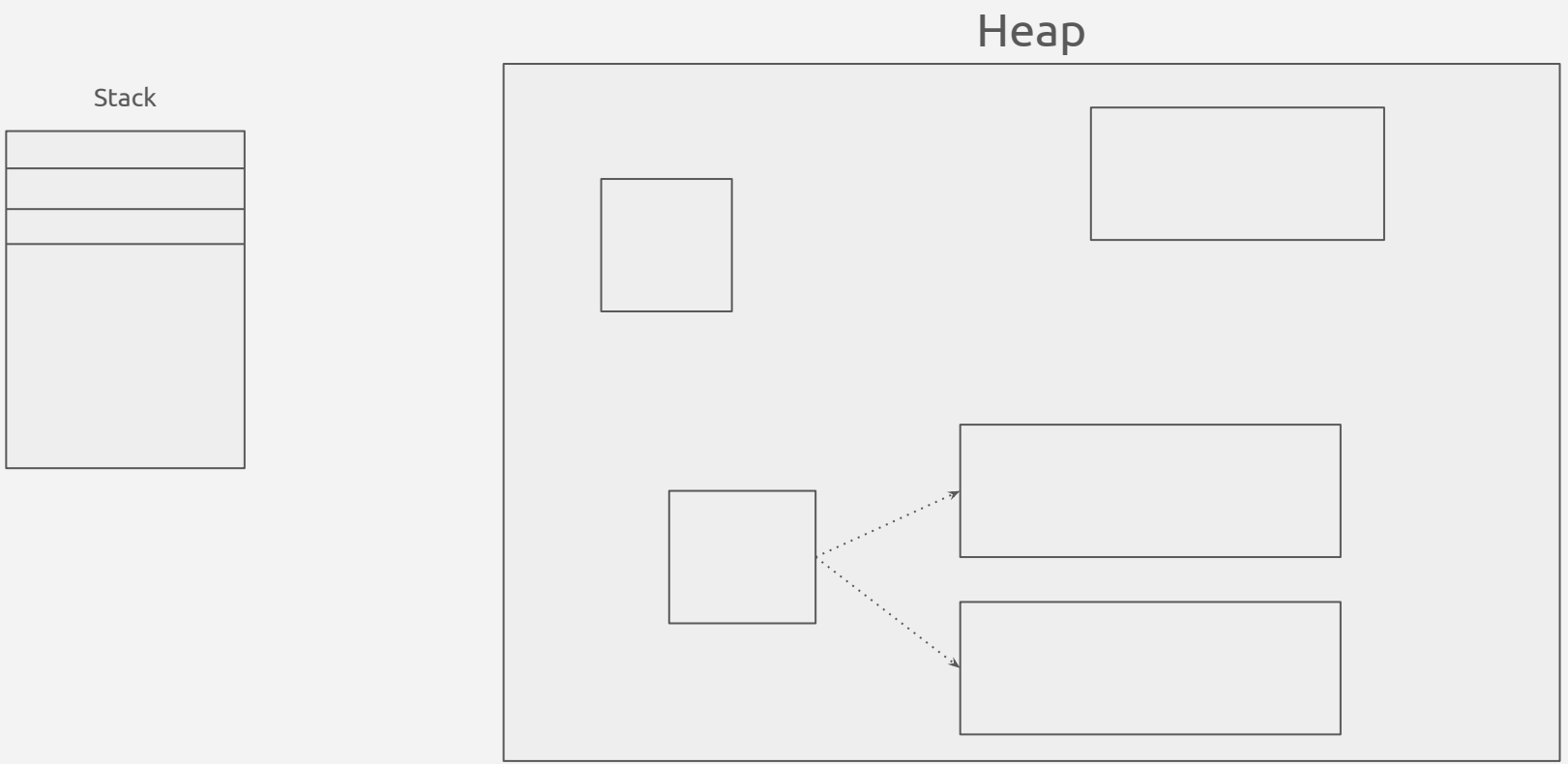
Cada mcache tem 134 classes



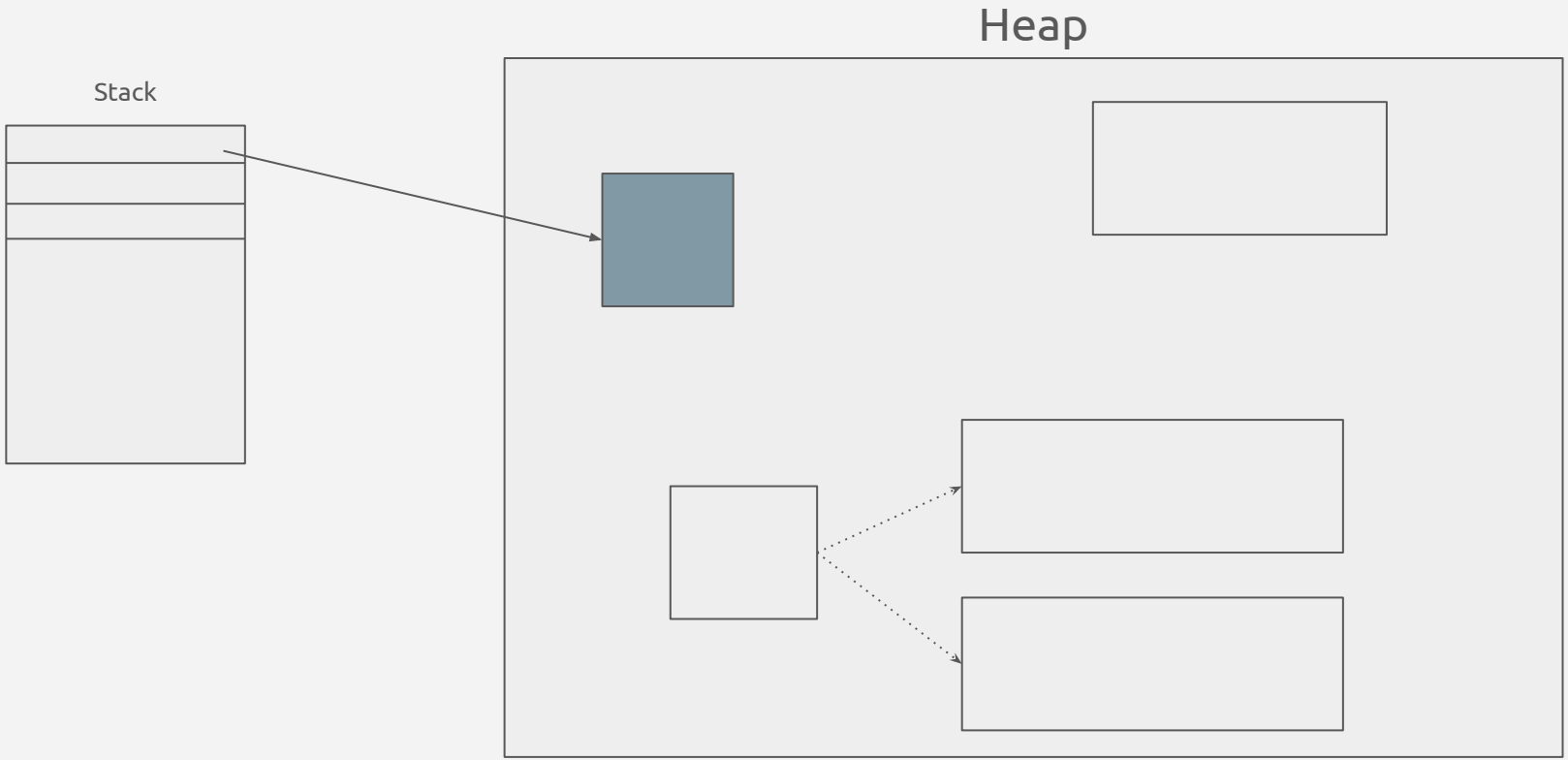
Cada mcache tem 134 classes



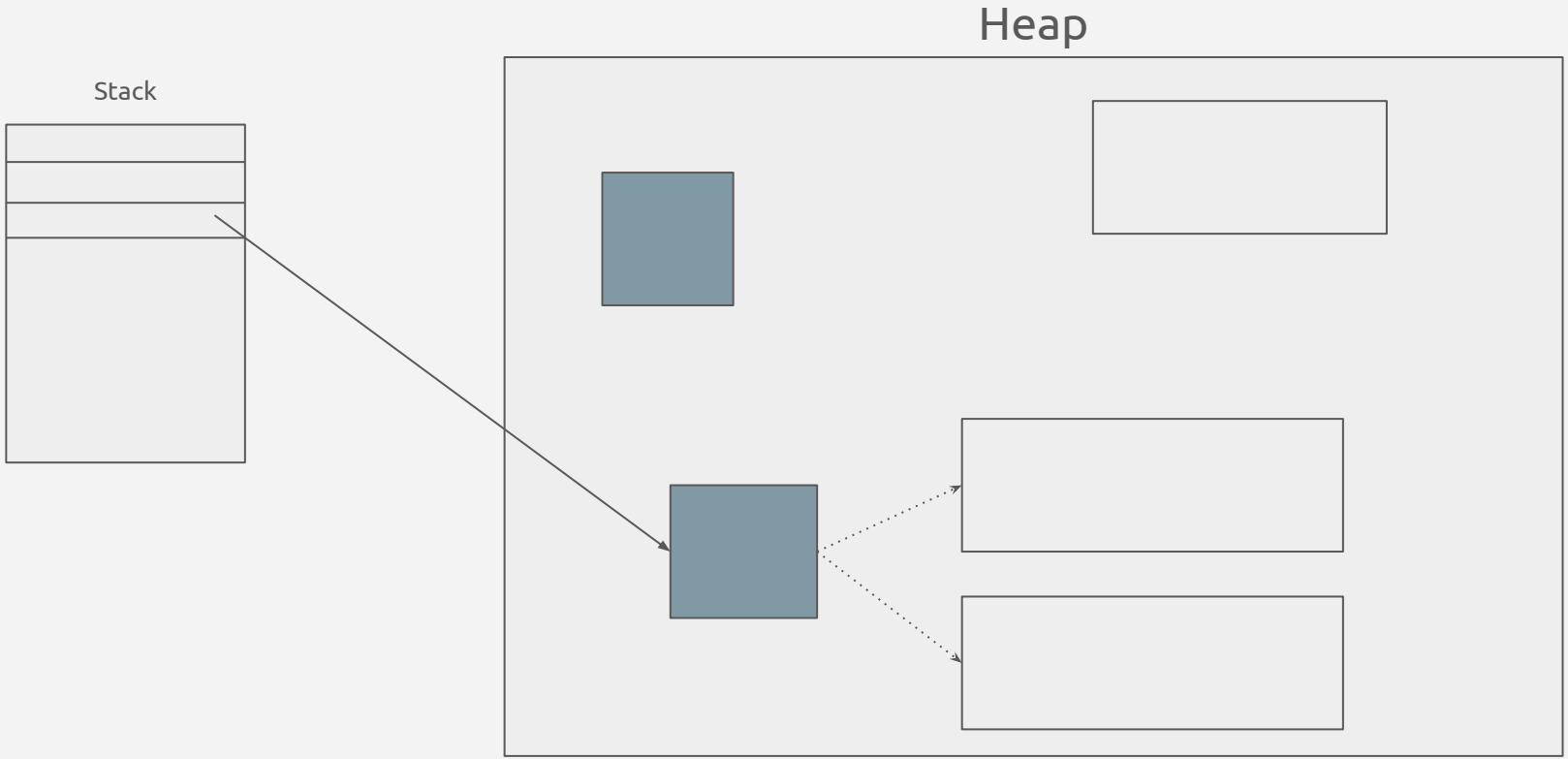
Como o GC funciona



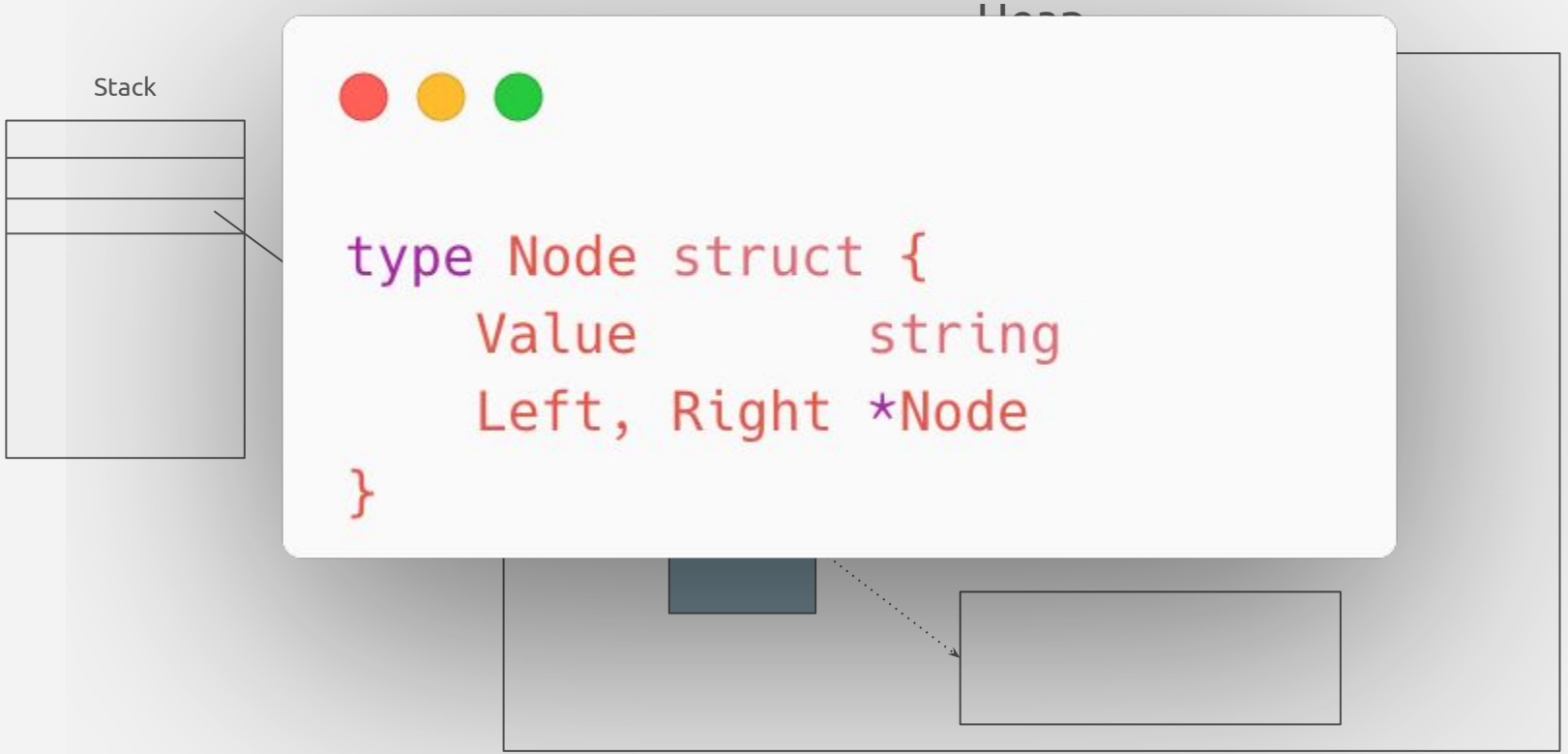
Como o GC funciona



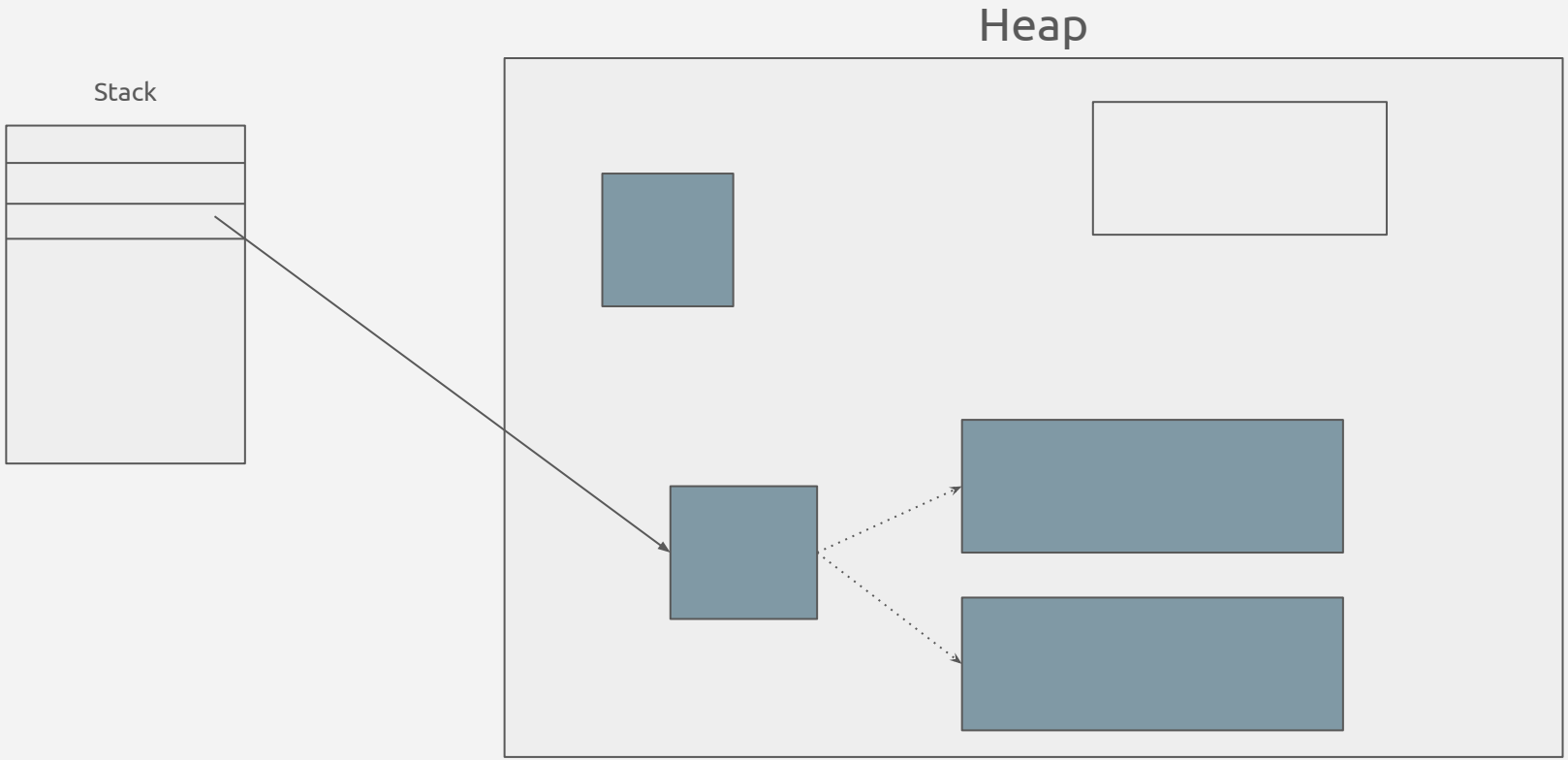
Como o GC funciona



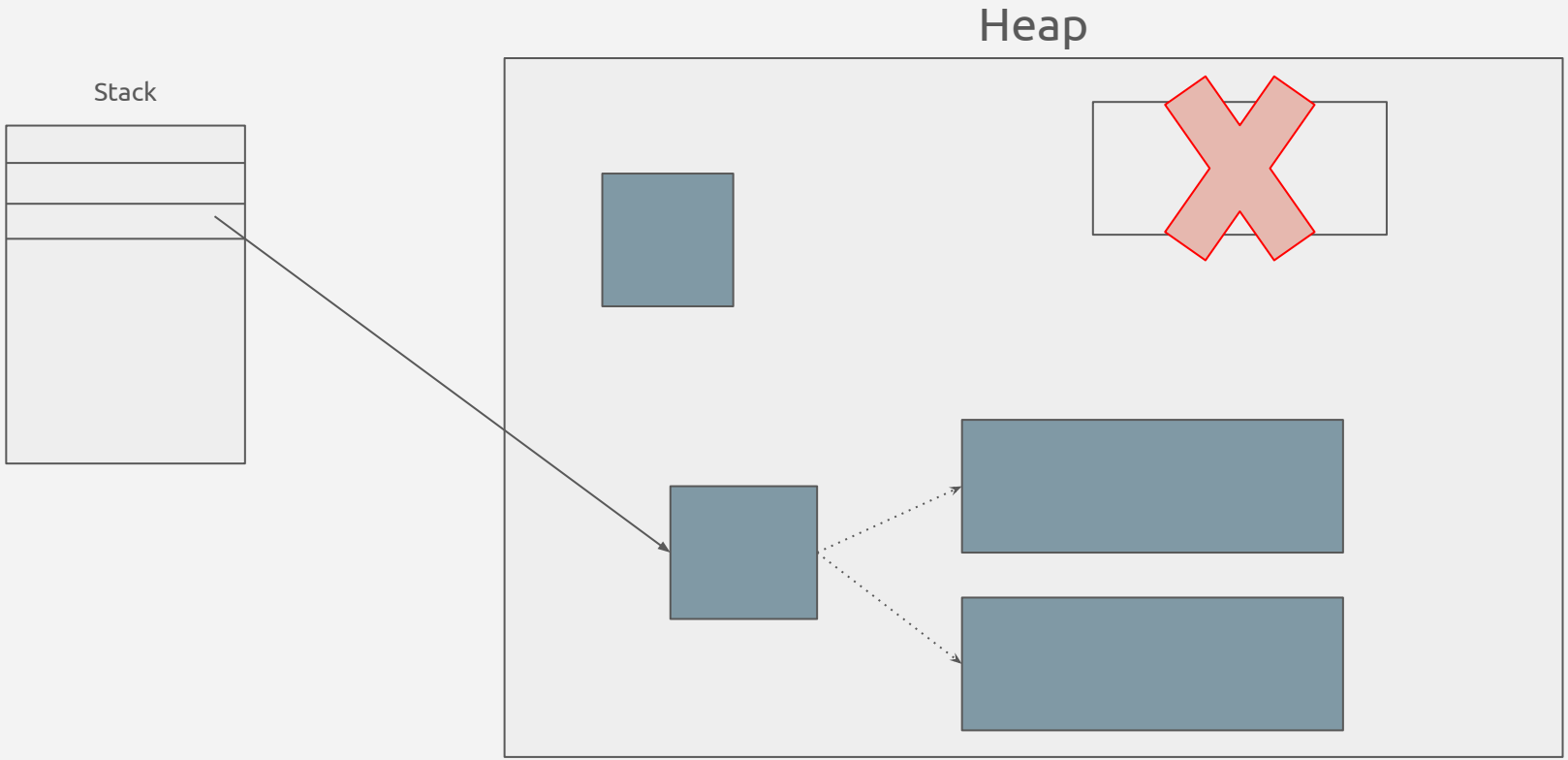
Se a variável tem ponteiros...



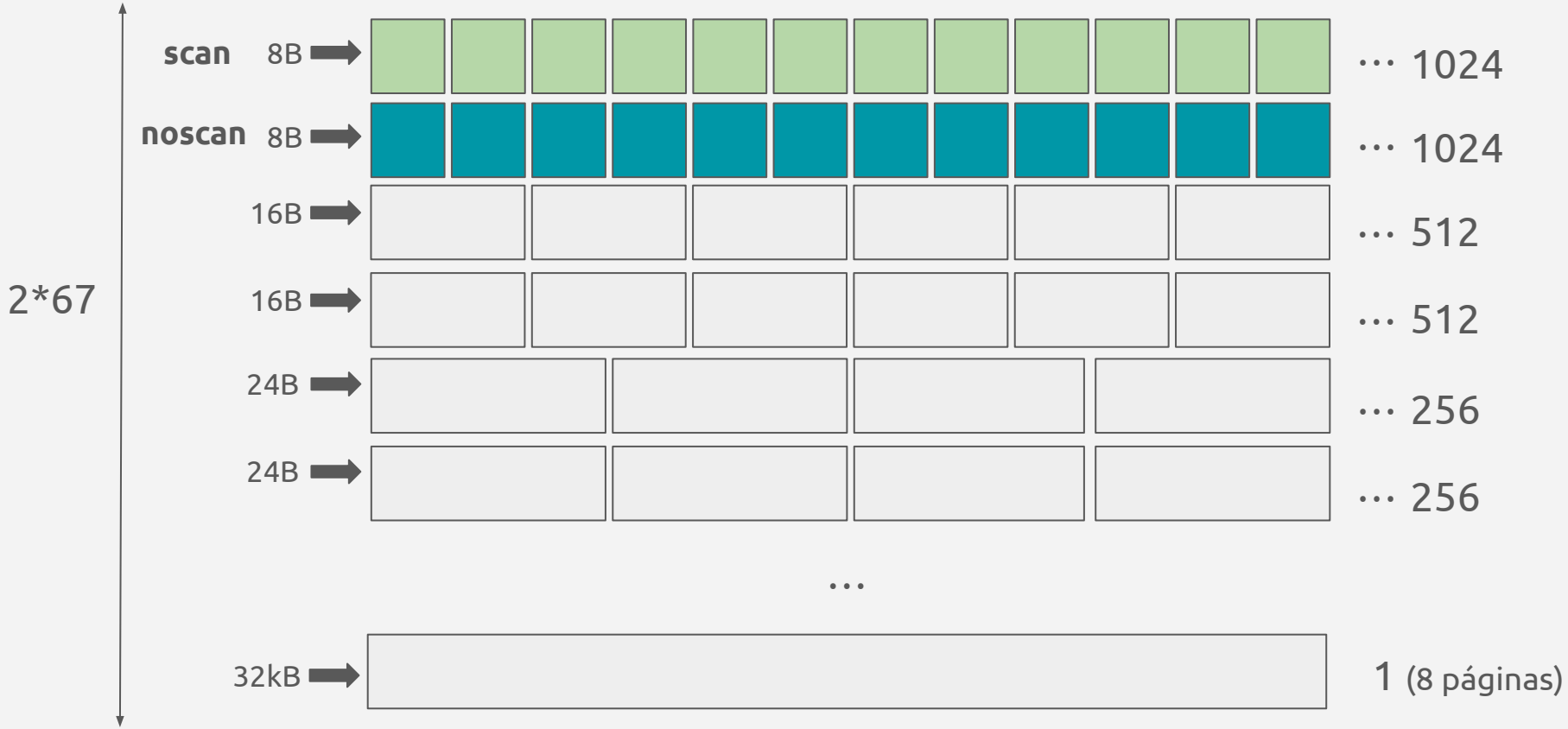
Persegue os ponteiros



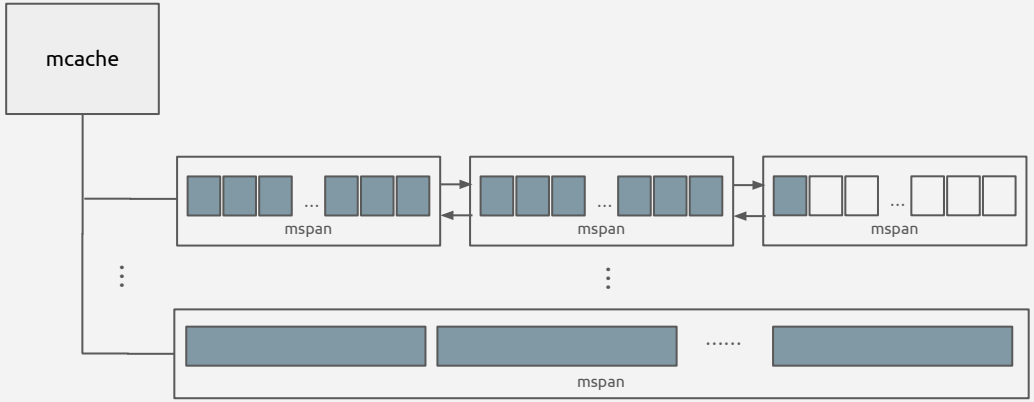
Elimina o que não foi marcado



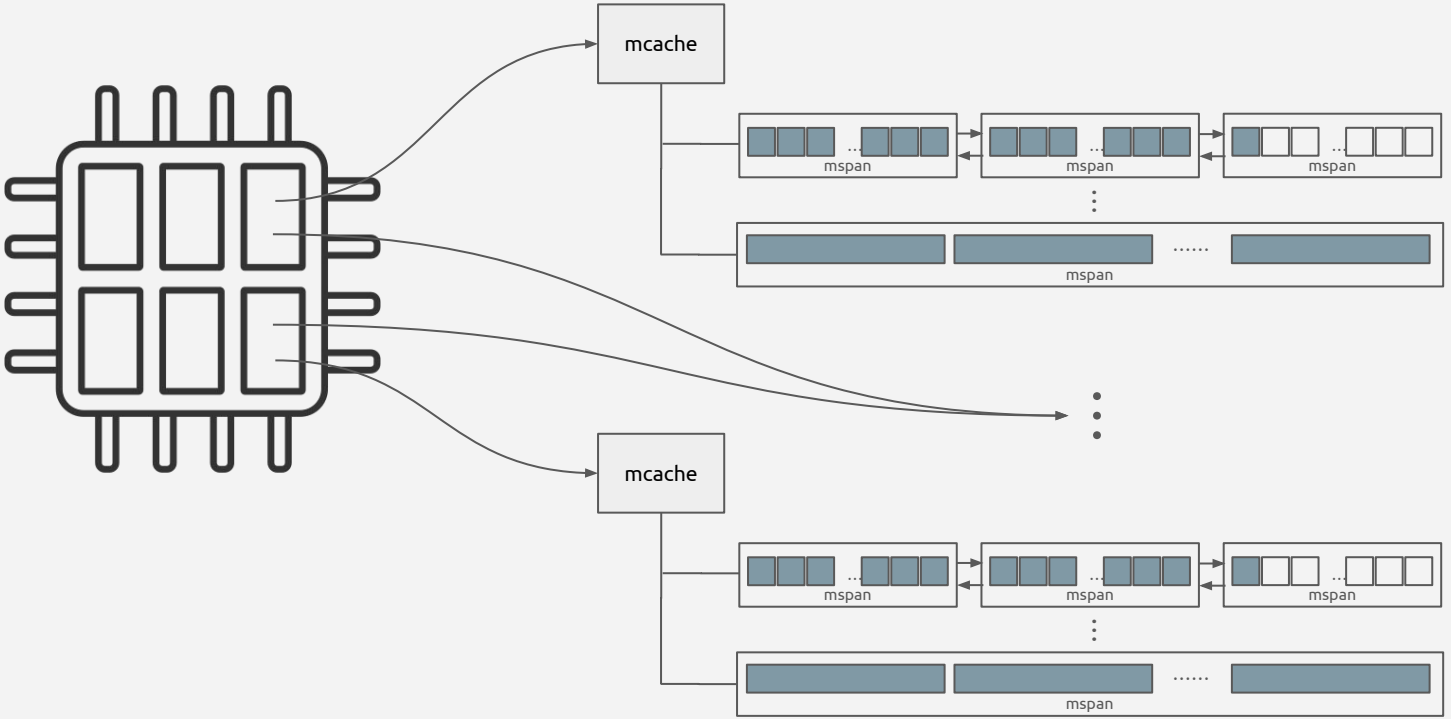
Cada mcache tem 134 classes



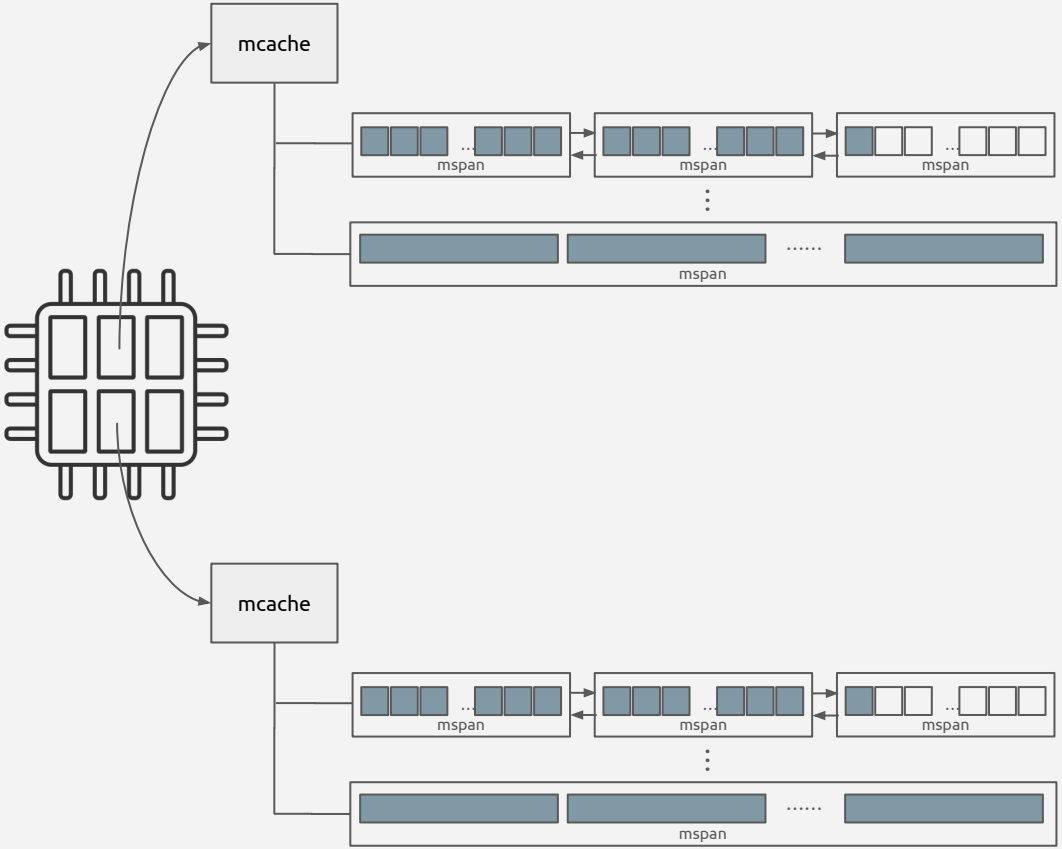
mcache

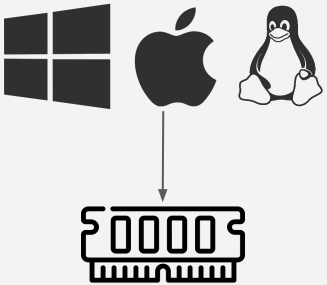


mcache para cada processador lógico

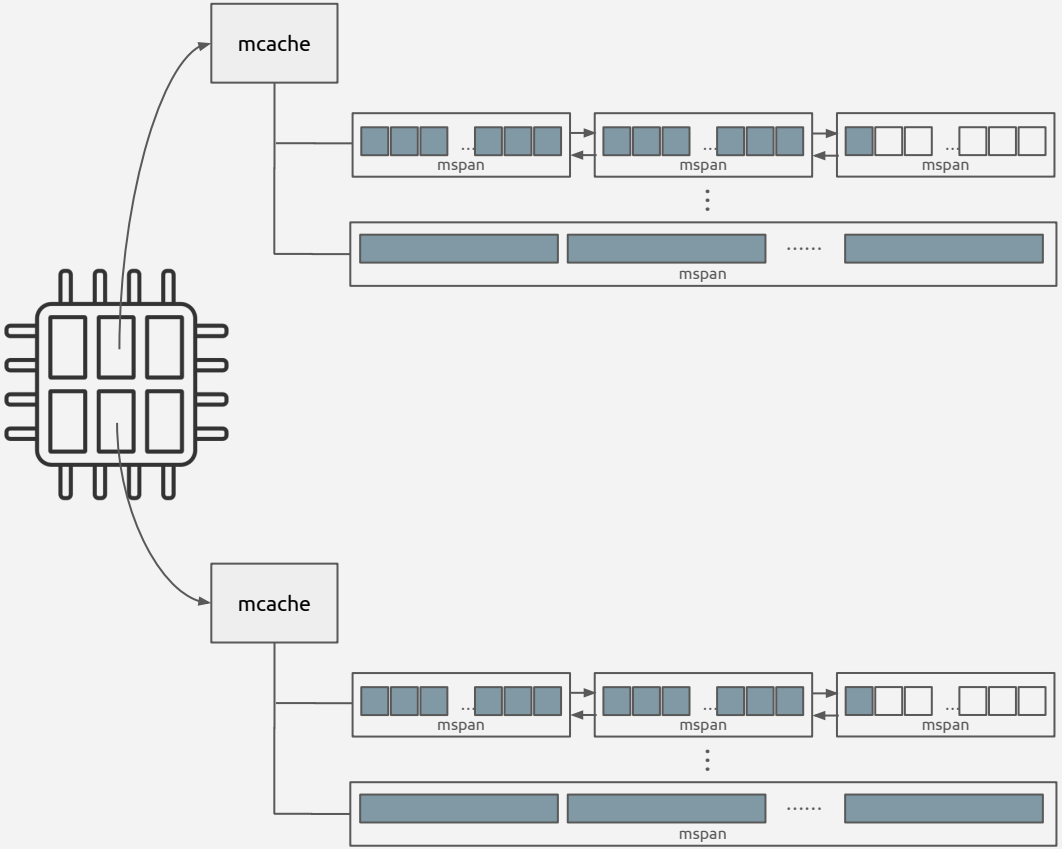


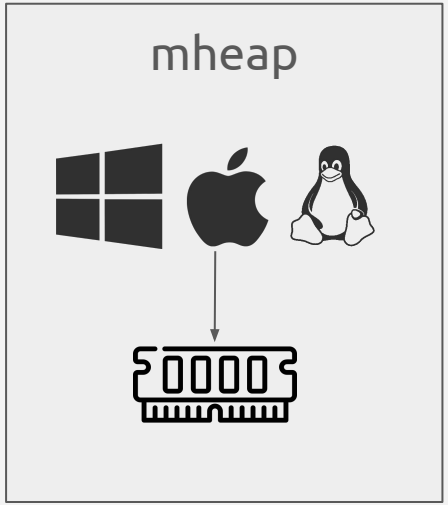
No fim, a memória é uma só



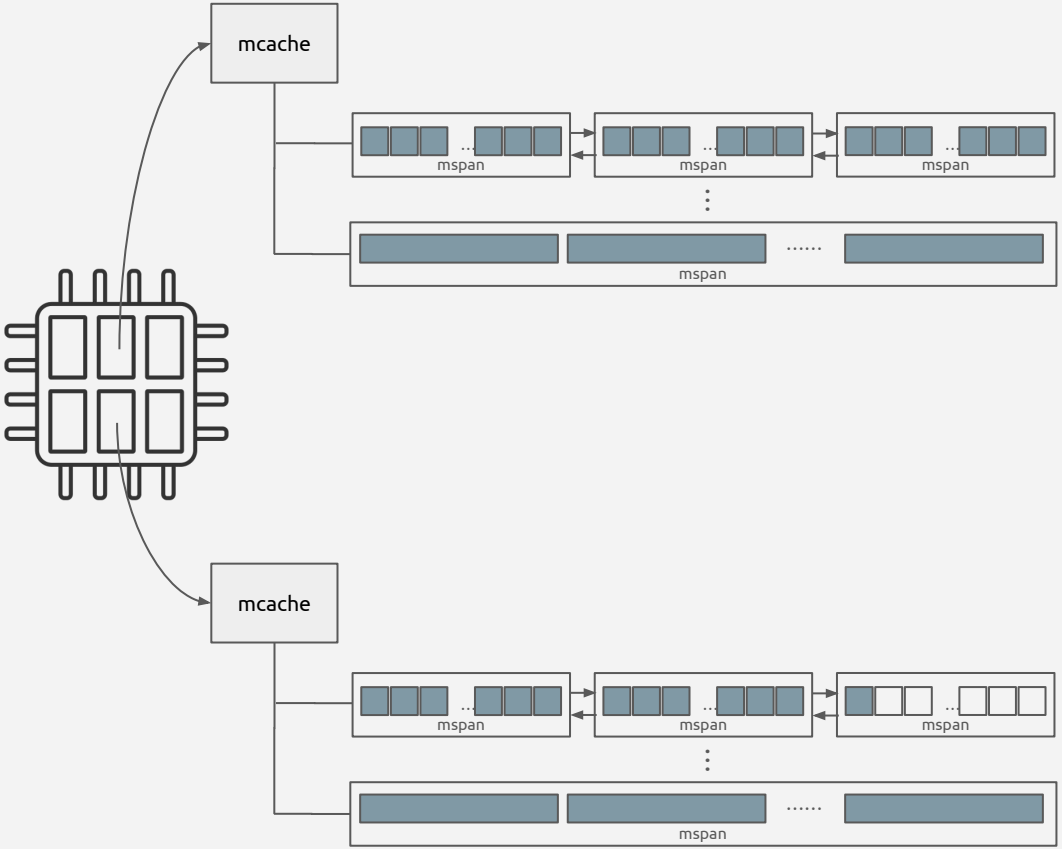


mheap


mcache
mspan
mspan
mspan
mspan
mcache
mspan
mspan
mspan
mspan


mheap

mheap


mcache
mspan
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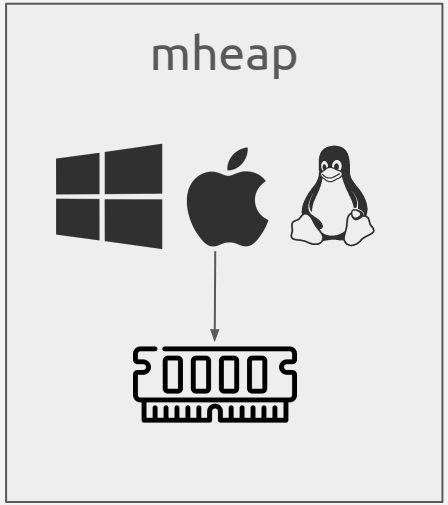
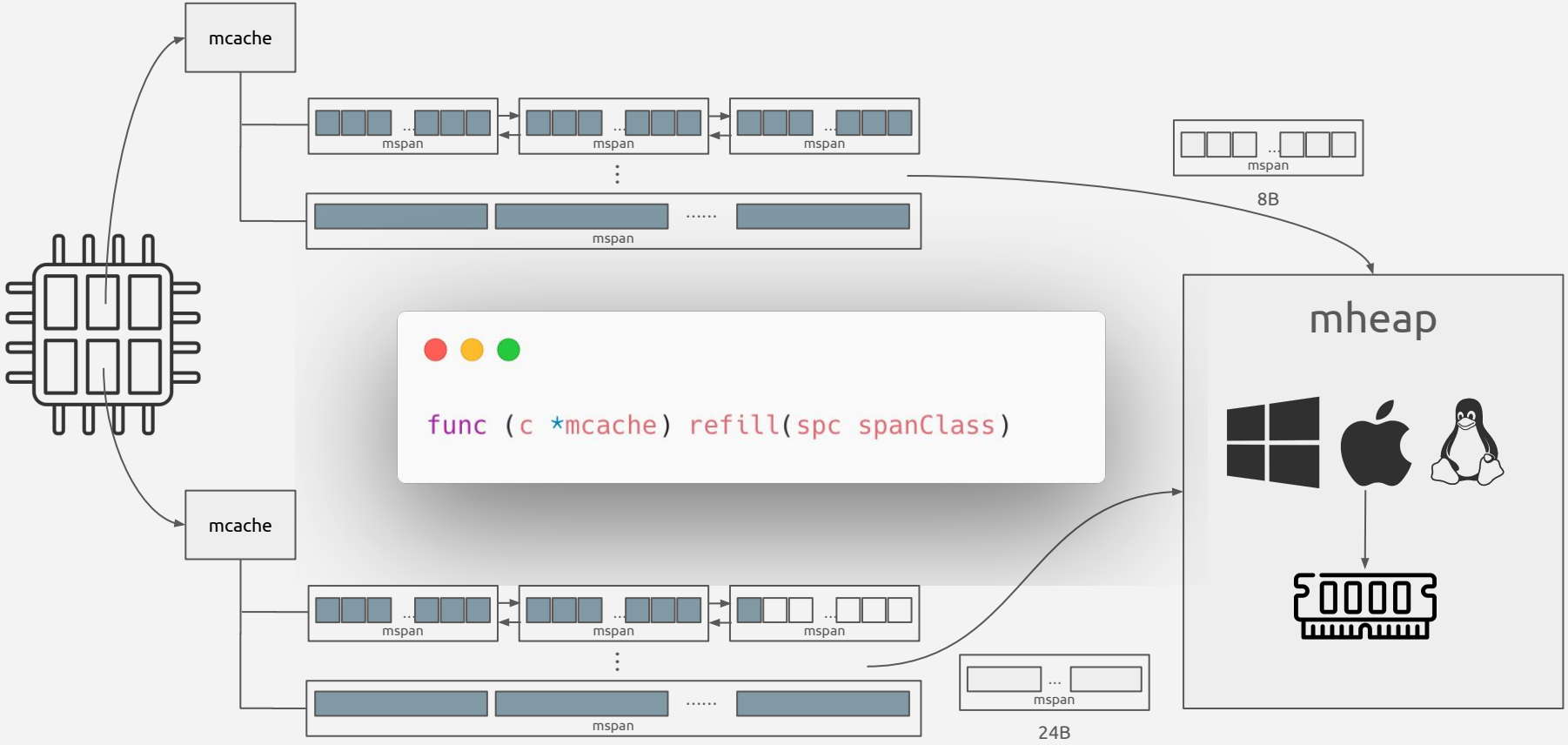
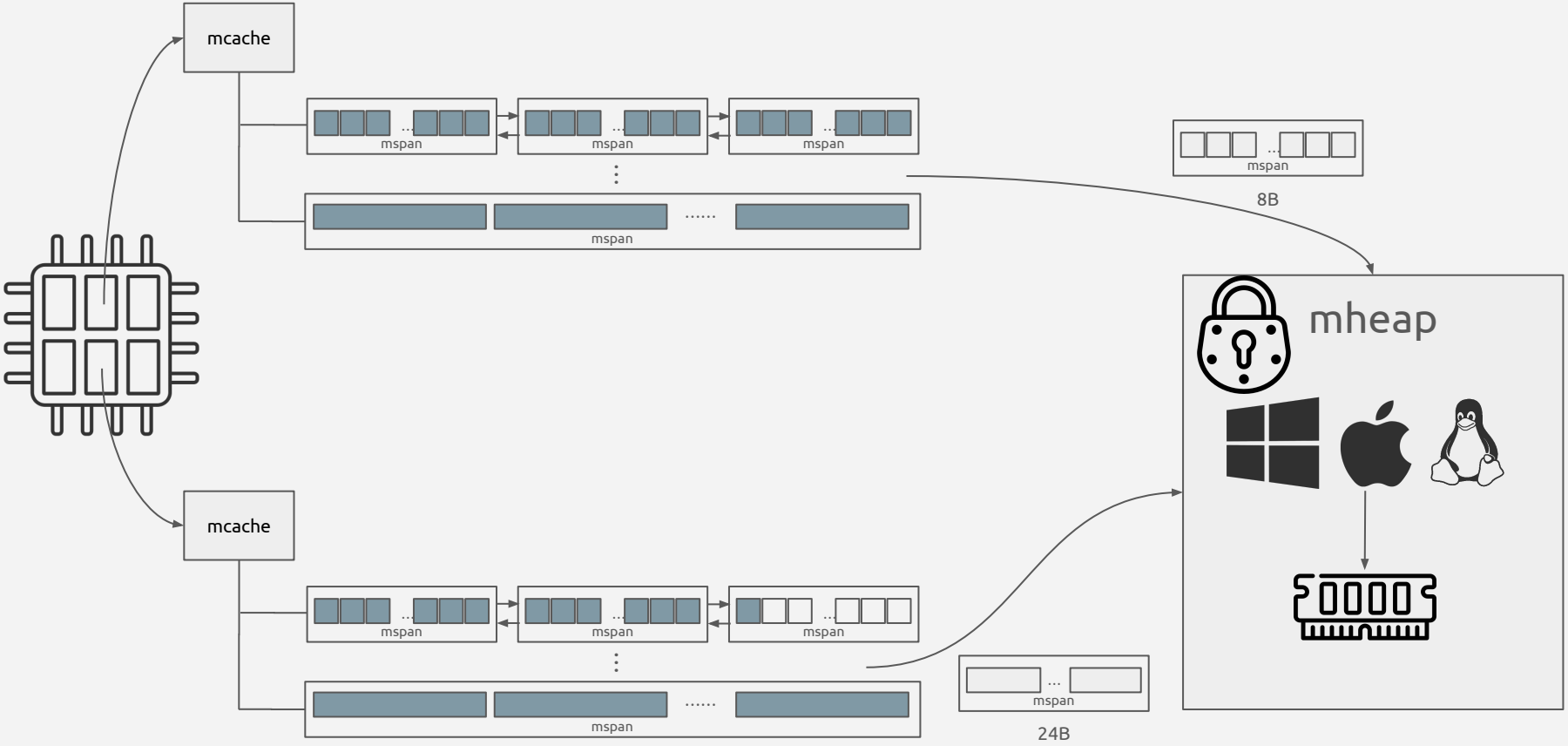
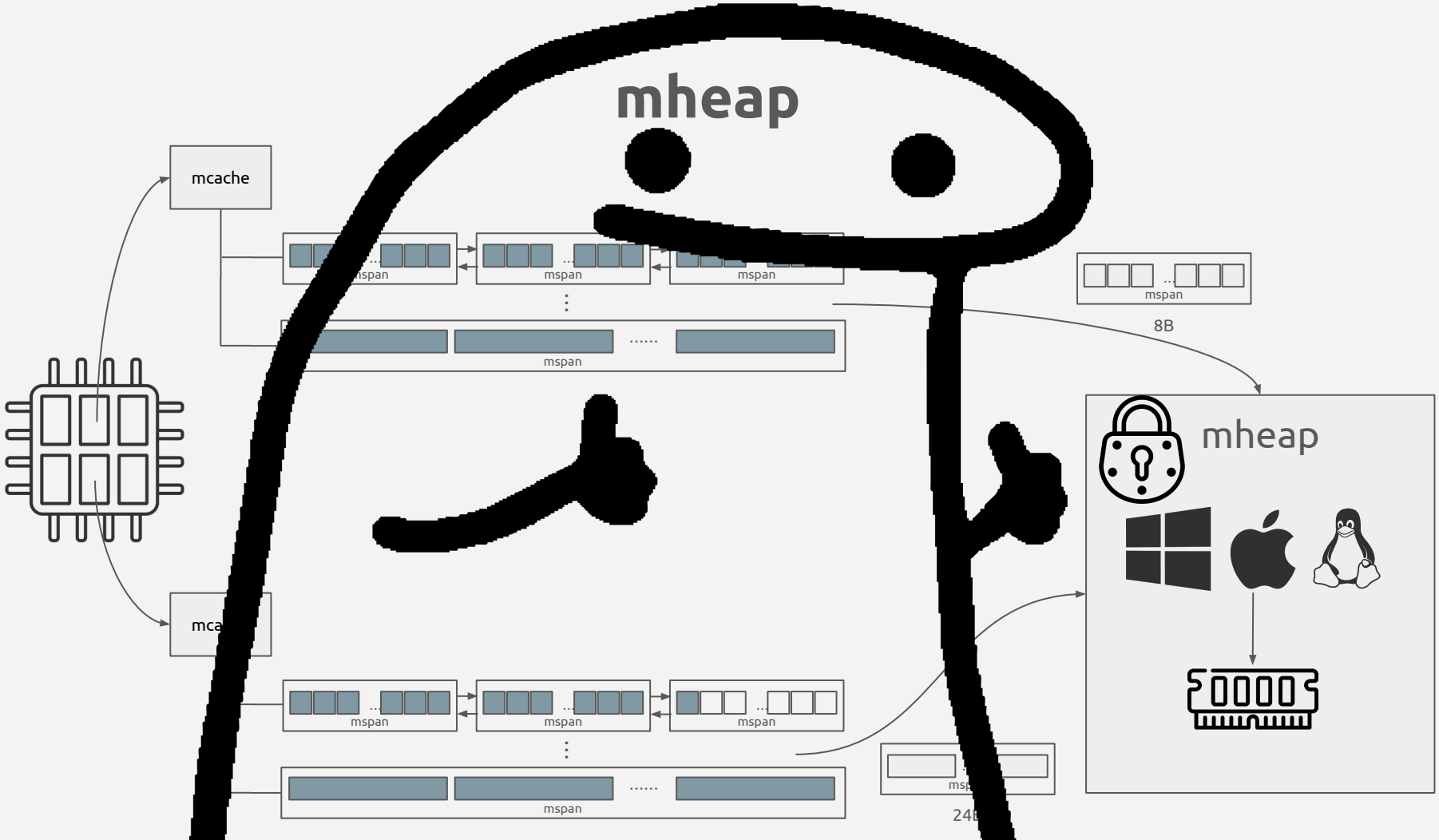

mheap

mheap

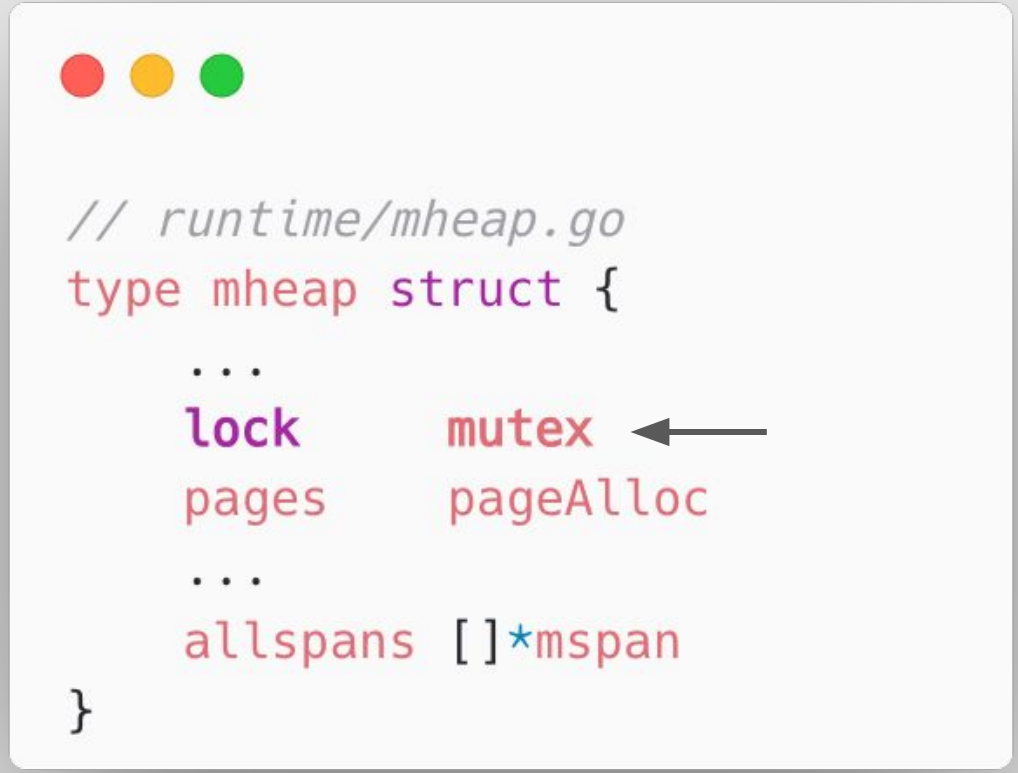

mcache
mspan
mspan
mspan
mspan
8B
mheap
func (c *mcache) refill(spc spanClass)
mcache
mspan
mspan
mspan
mspan
mspan
24B

mheap

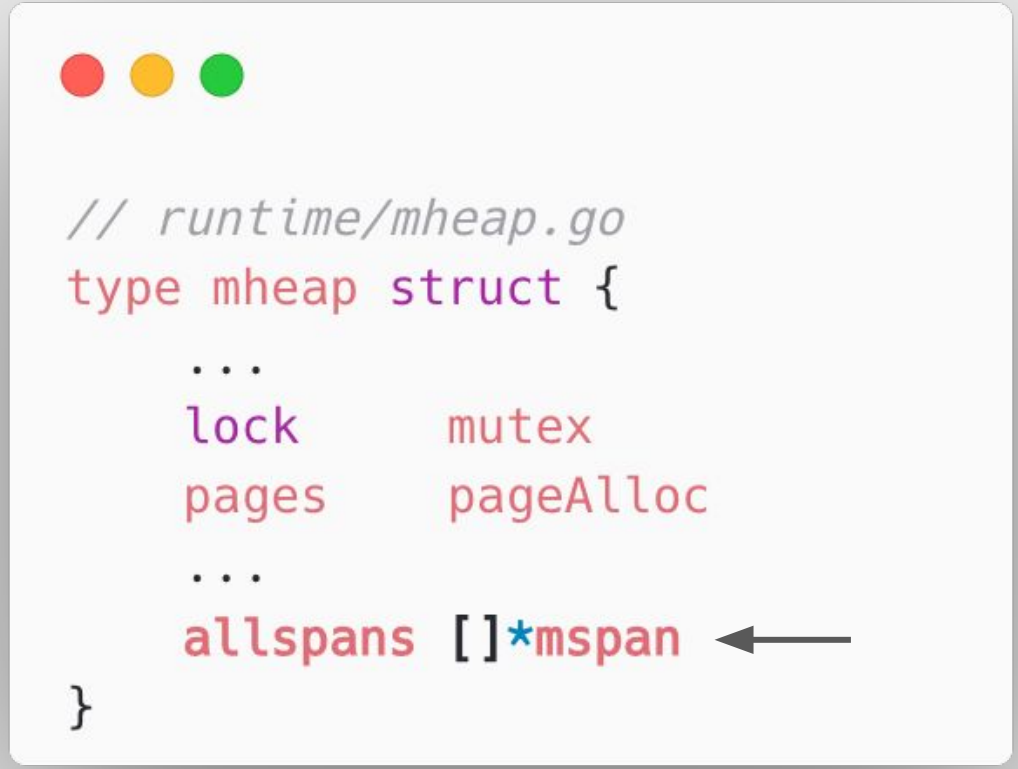

mcache
mspan
mspan
mspan
mspan
8B
mheap
mcache
mspan
mspan
mspan
mspan
24B


mheap
mcache
mspan
mspan
mspan
mspan
8B
mheap
mspan
mspan
mspan
mspan
24B

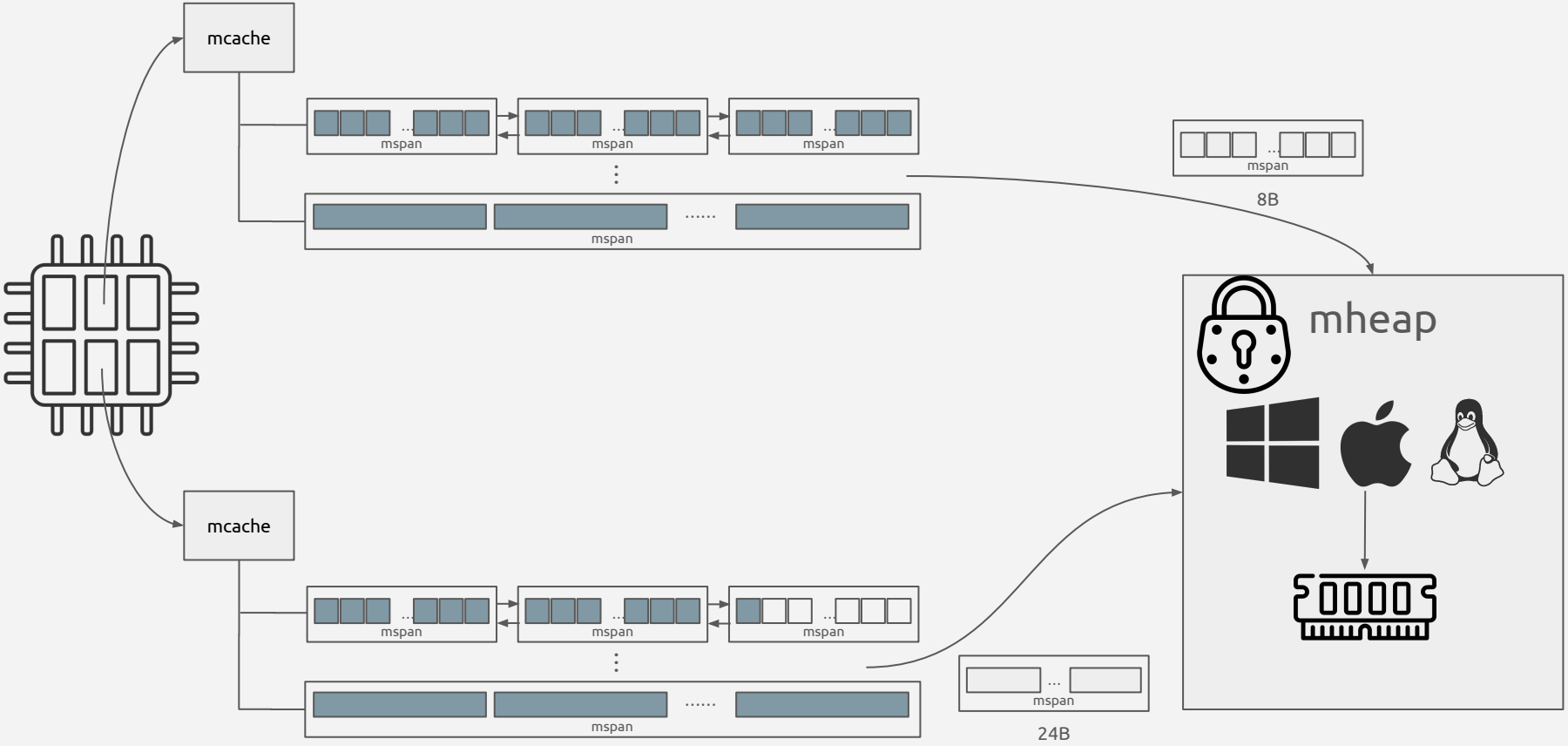
mheap


// runtime/mheap.go
type mheap struct {
...
lock mutex
pages pageAlloc
...
allspans []*mspan
}

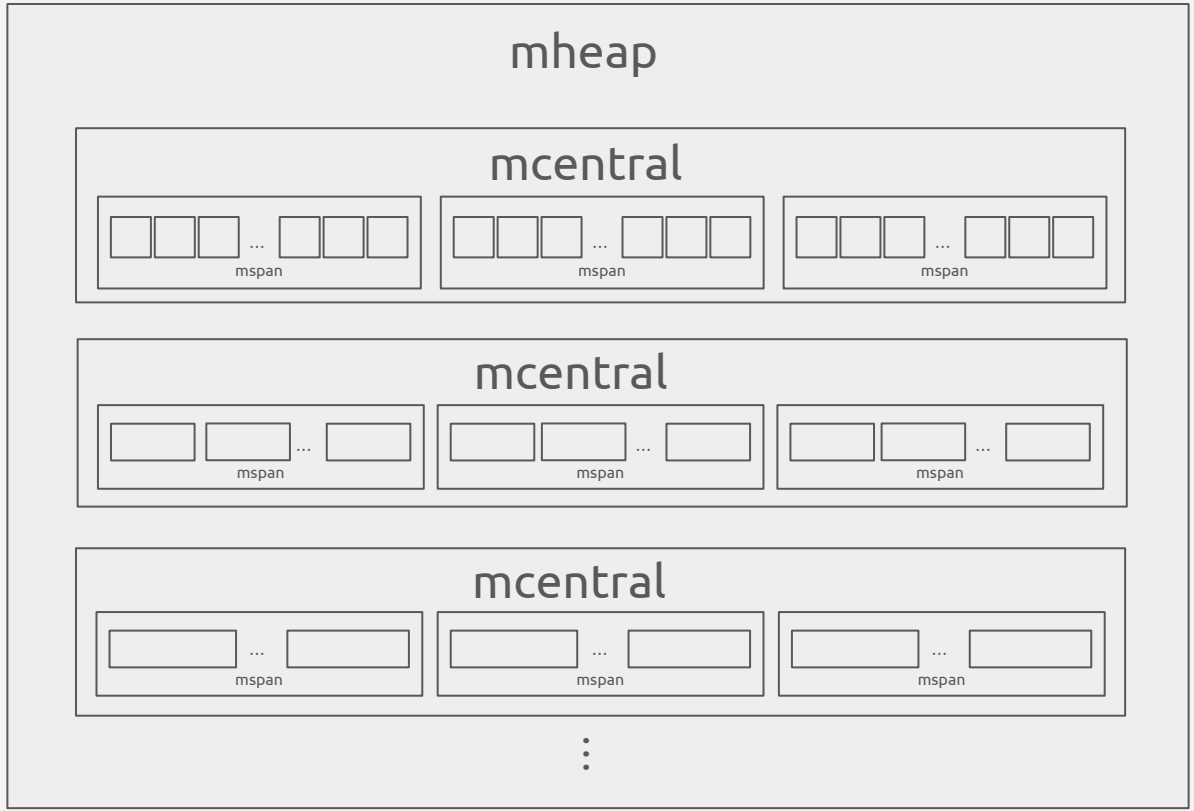
mheap


// runtime/mheap.go
type mheap struct {
...
lock mutex
pages pageAlloc
...
allspans []*mspan
}

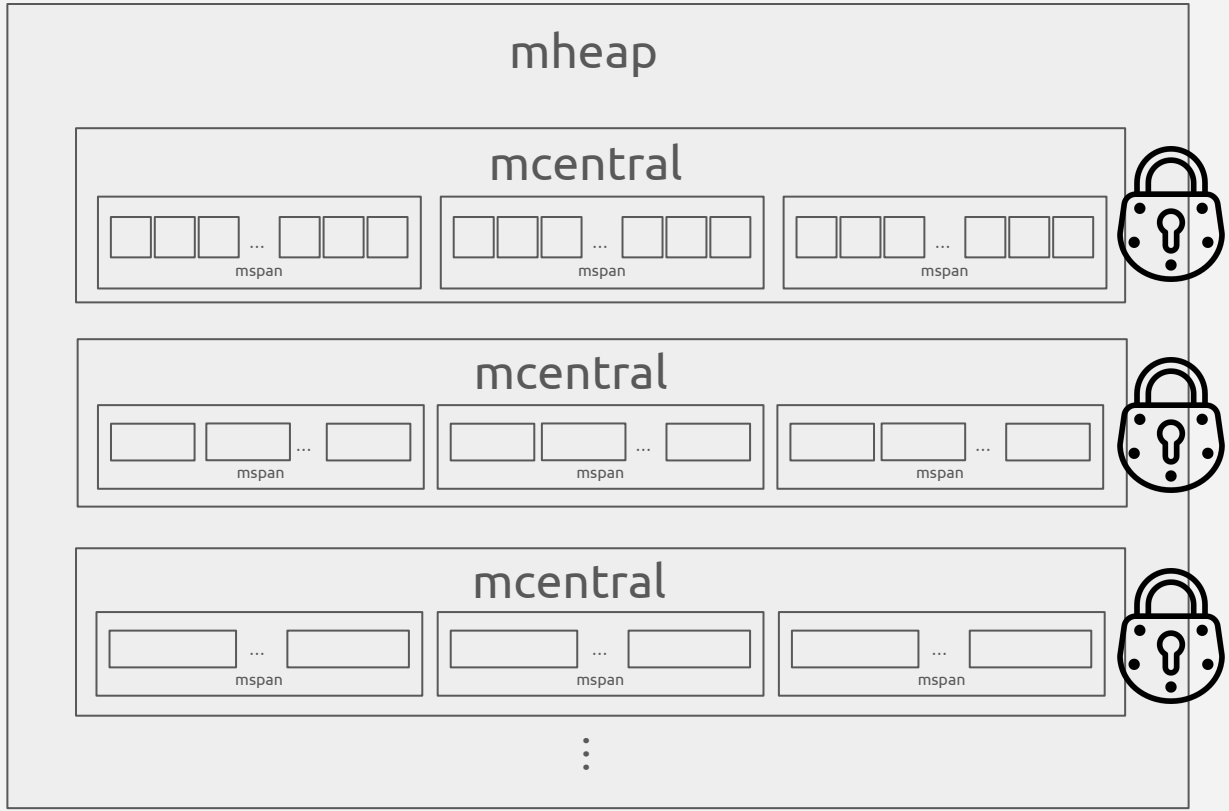
Nem todas as alocações na heap são iguais



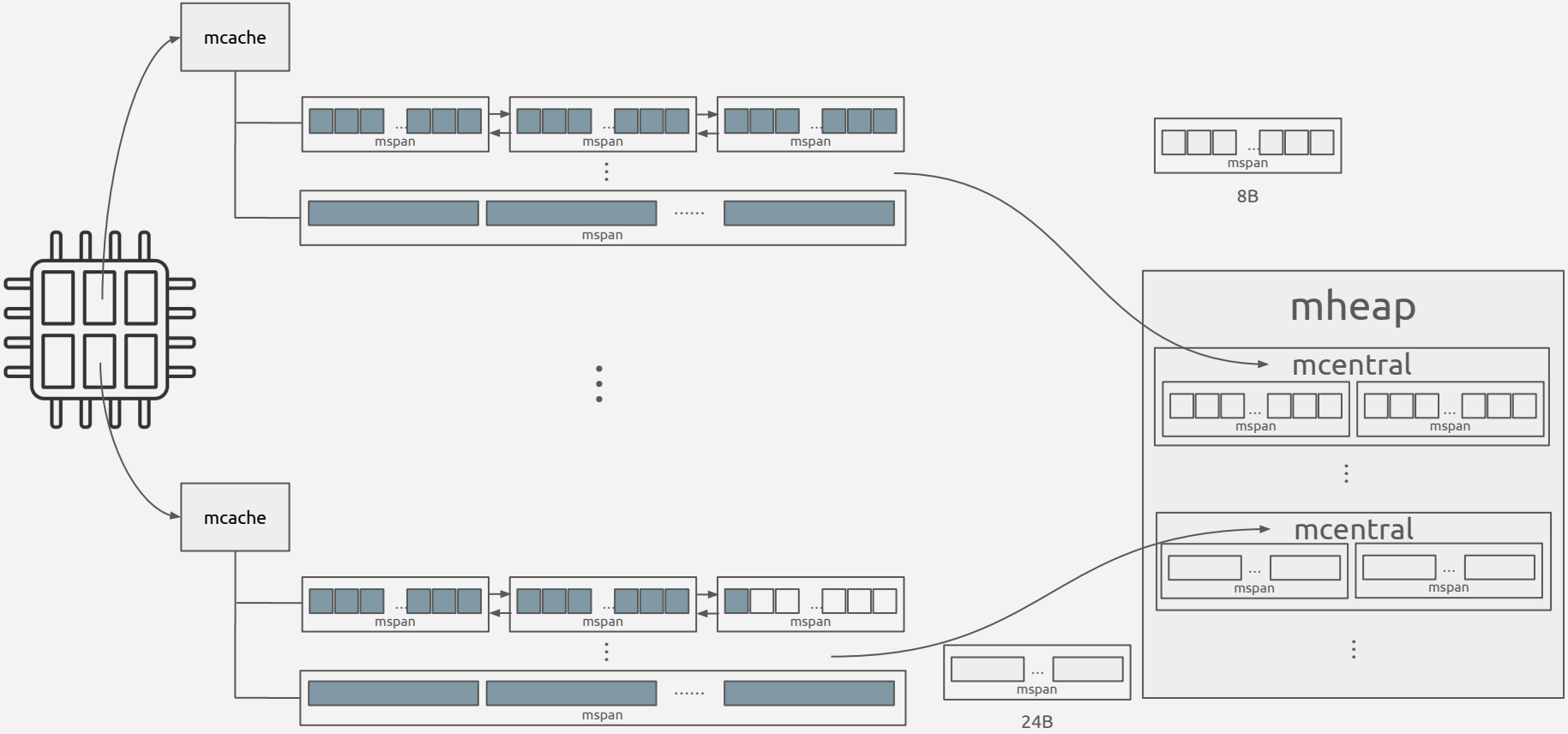
mcentral


mheap
mcentral
mspan
mspan
mspan
mcentral
mspan
mspan
mspan
mcentral
mspan
mspan
mspan

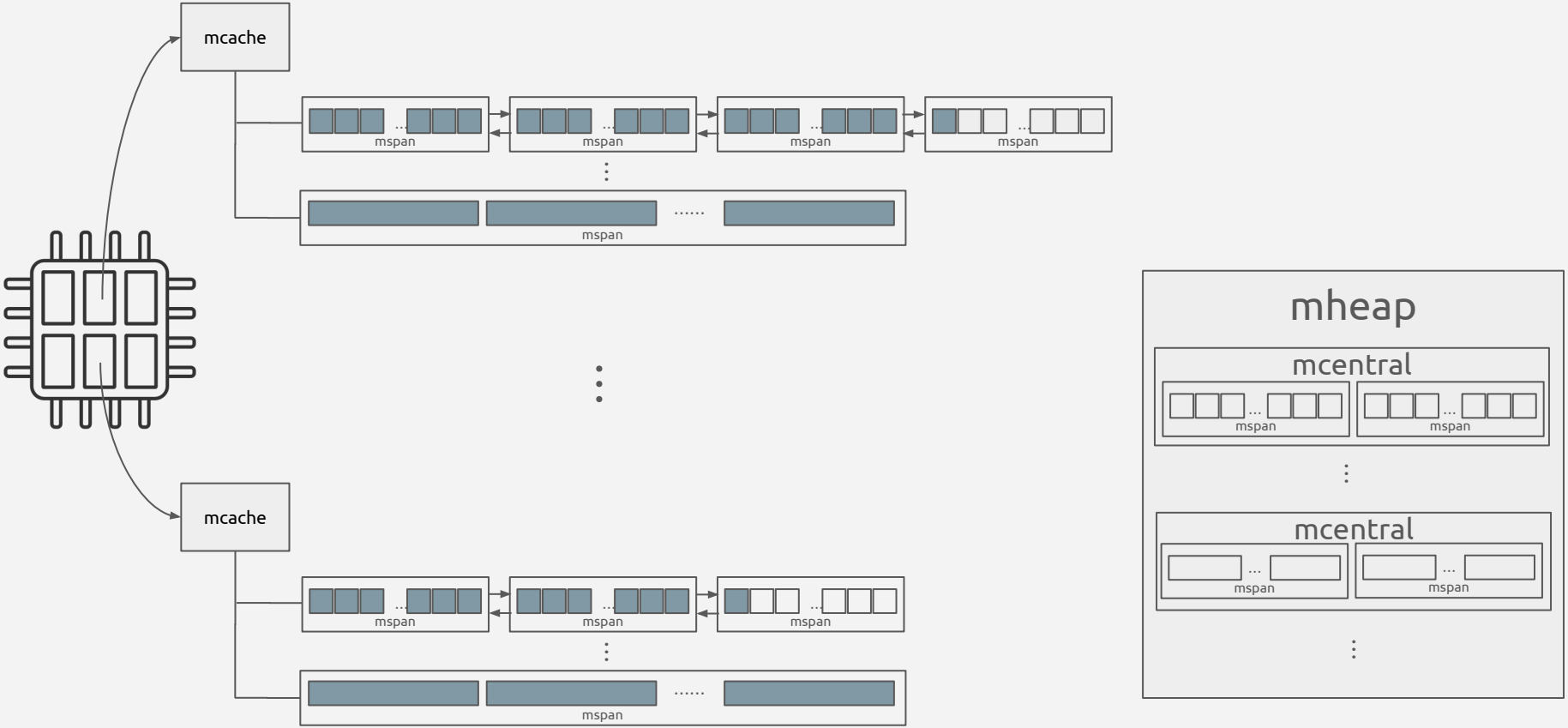
mcentral


mheap
mcentral
mspan
mspan
mspan
mcentral
mspan
mspan
mspan
mcentral
mspan
mspan
mspan

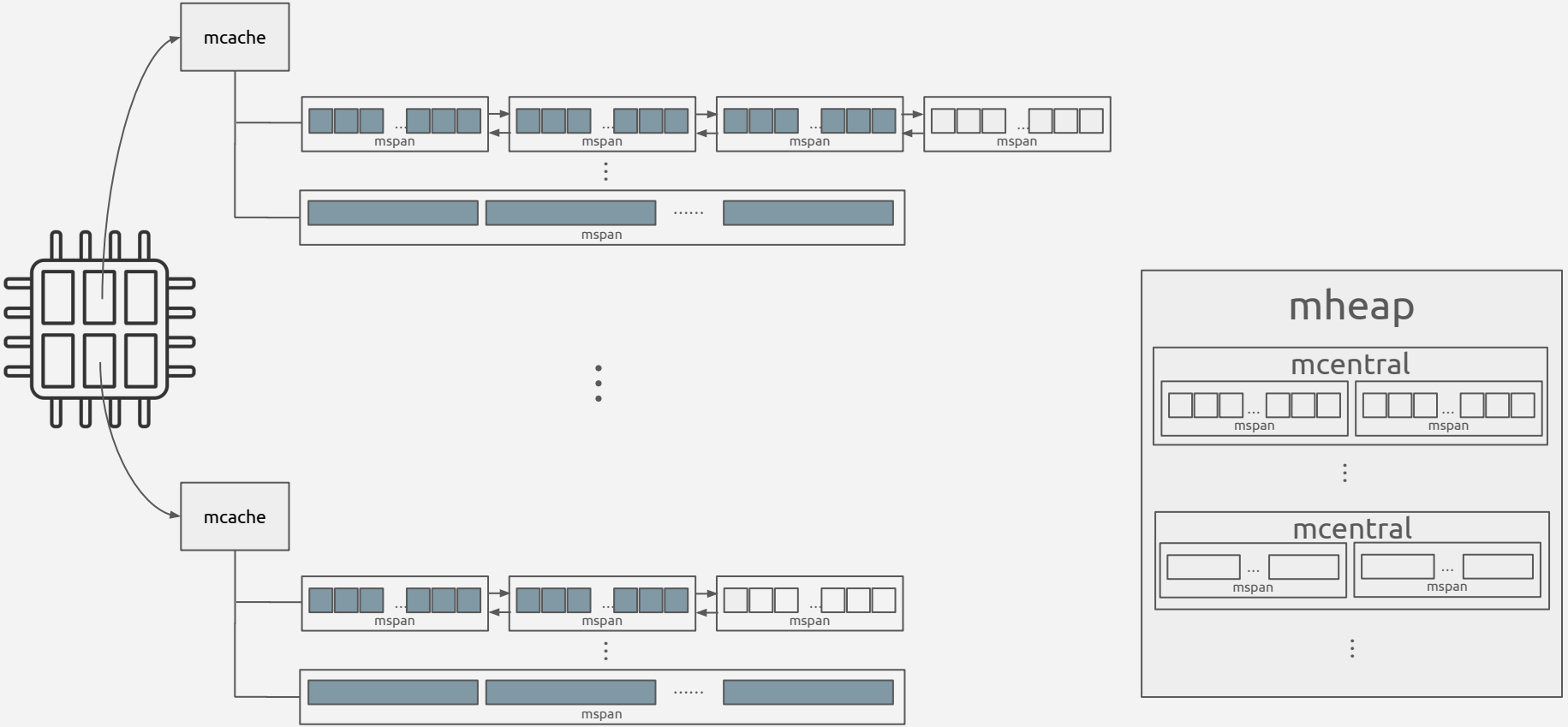
Layout final para alocações pequenas



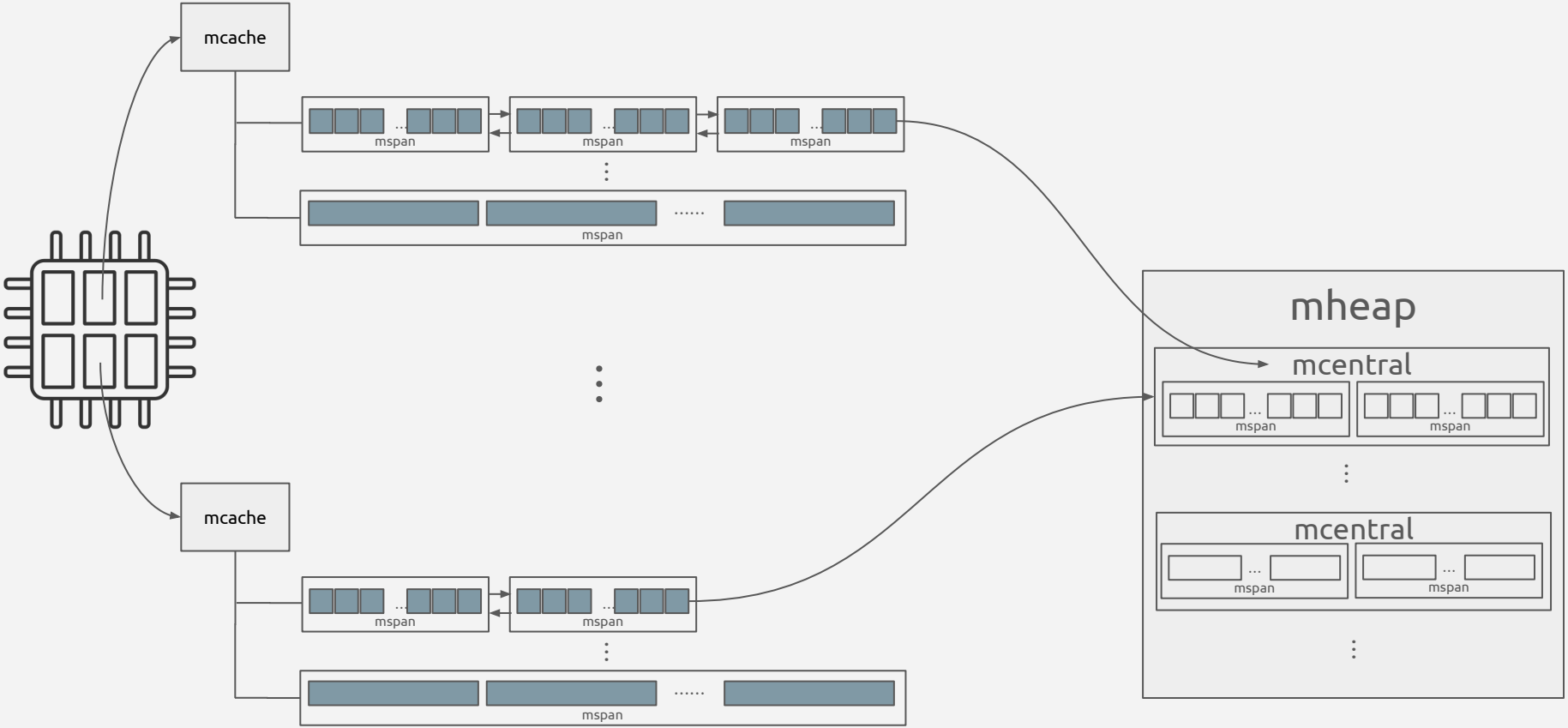
Layout final para alocações pequenas



Spans desalocados retornam para mcentral



Spans desalocados retornam para mcentral

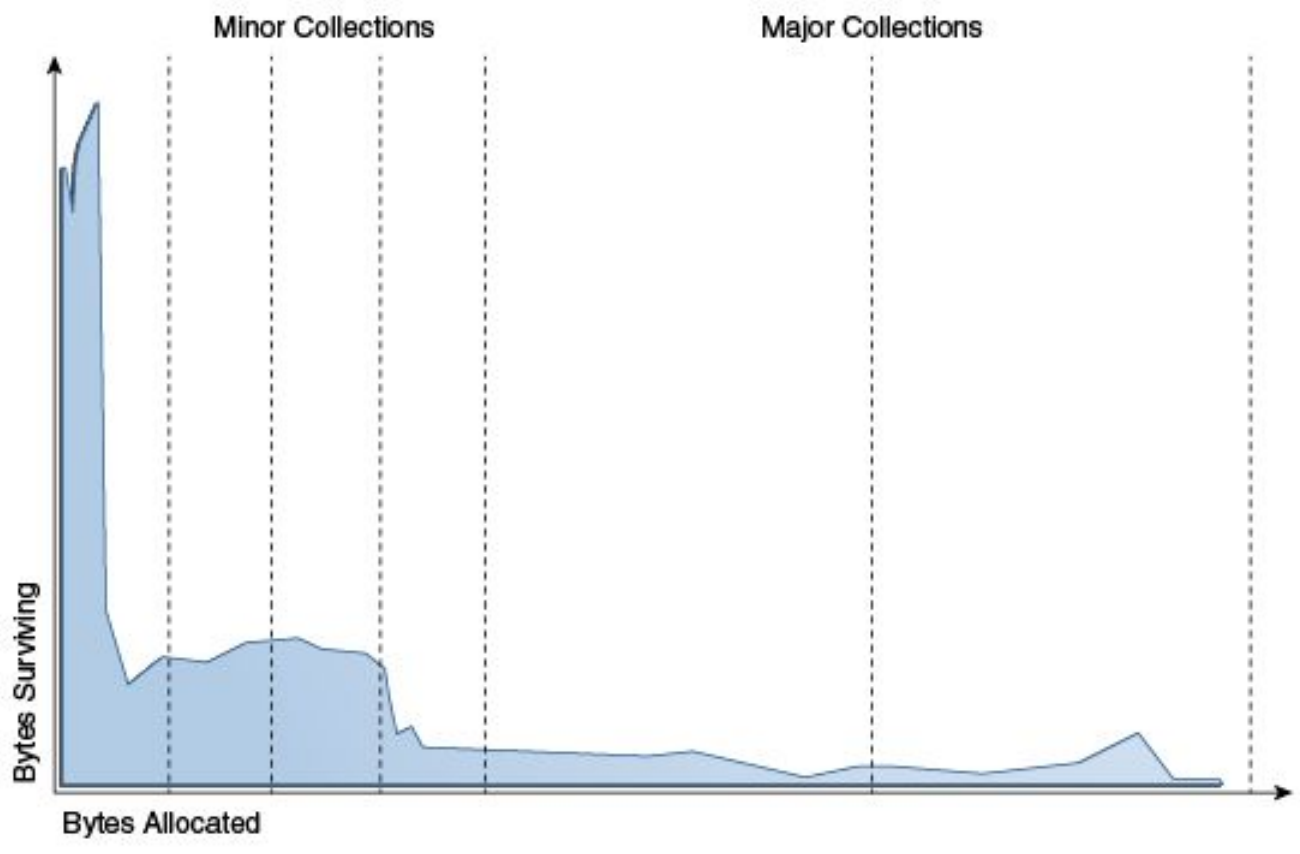


Alocações grandes

```
big1 := make([]byte, 10*1024*1024)
```

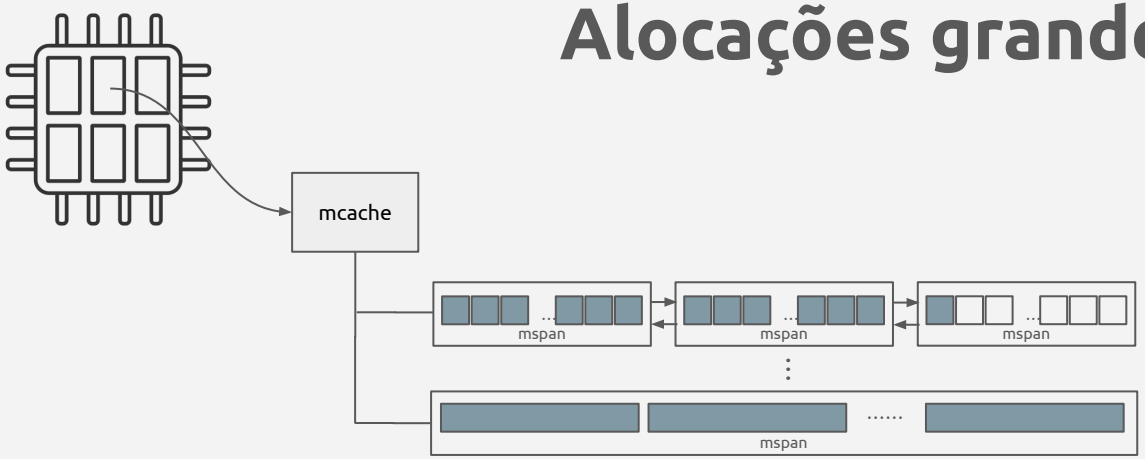
10MB

Weak Generational Hypothesis

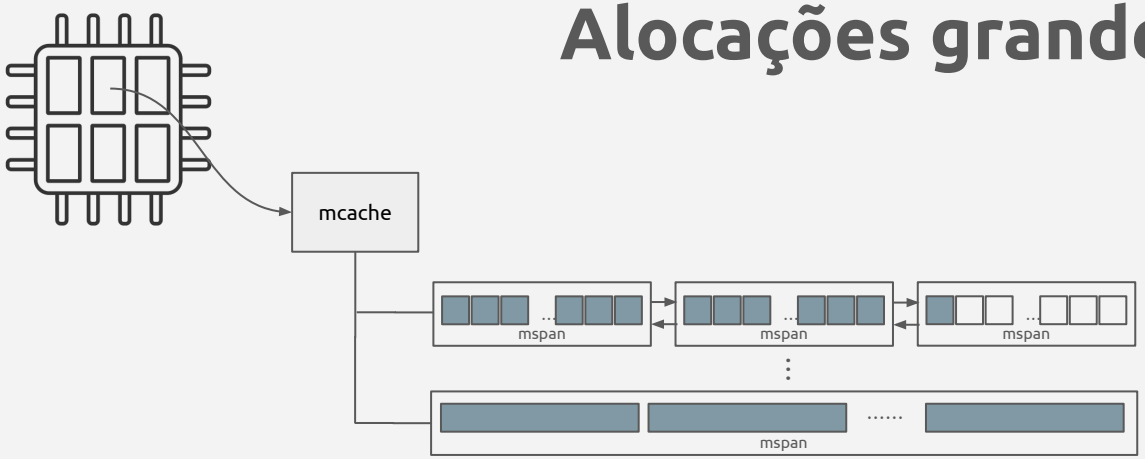


docs.oracle.com

Alocações grandes

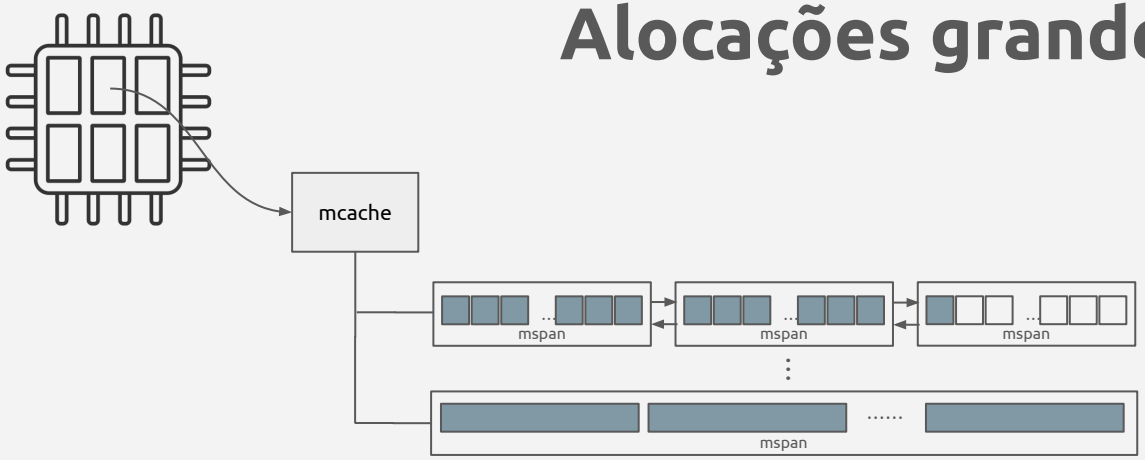


Alocações grandes



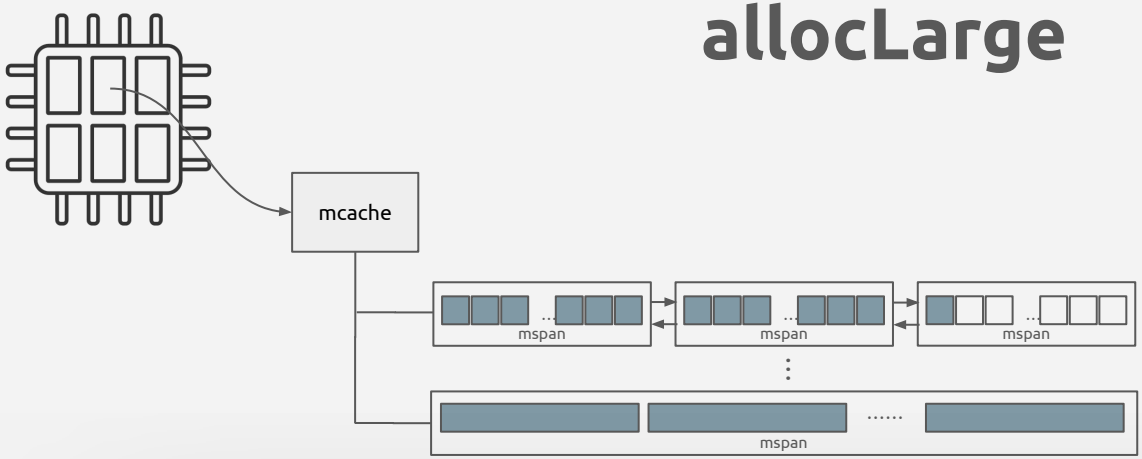

```
func (c *mcache) refill(spc spanClass)
```

Alocações grandes



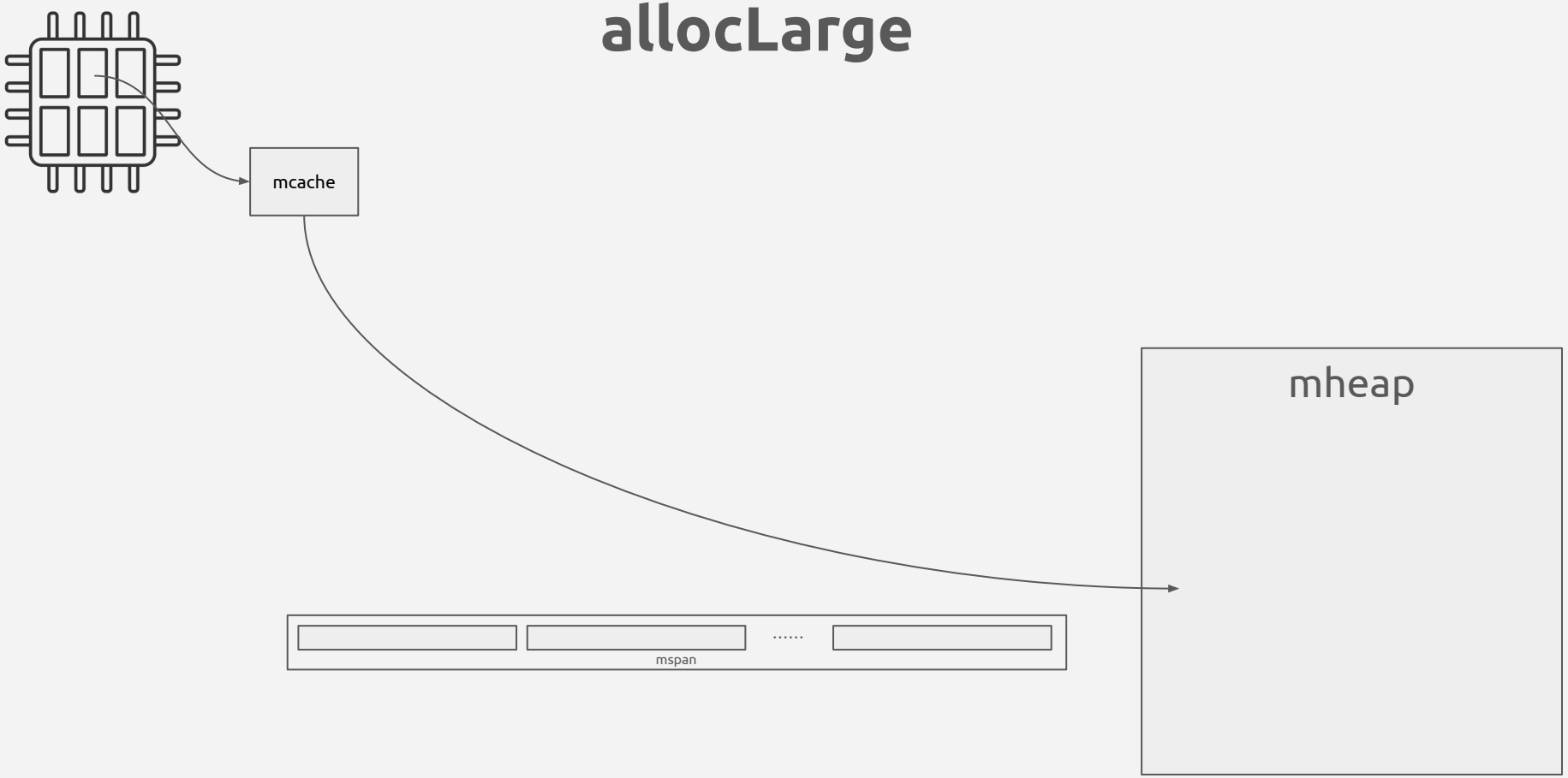

```
func (c *mcache
c spanClass)
```

allocLarge

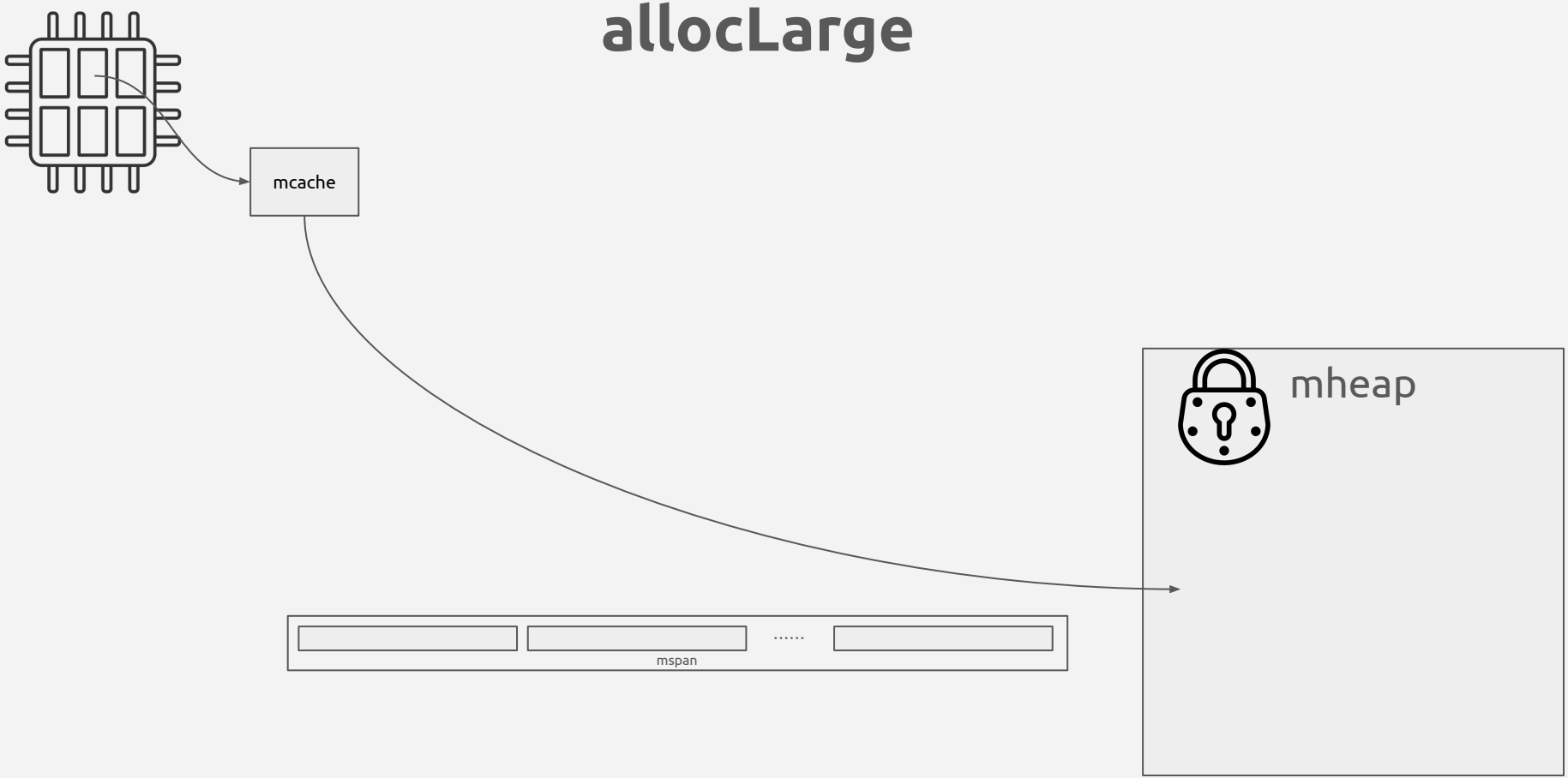



```
func (c *mcache) allocLarge(size uintptr, noscan bool) *mspan
```

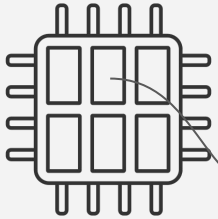
allocLarge



allocLarge



allocLarge



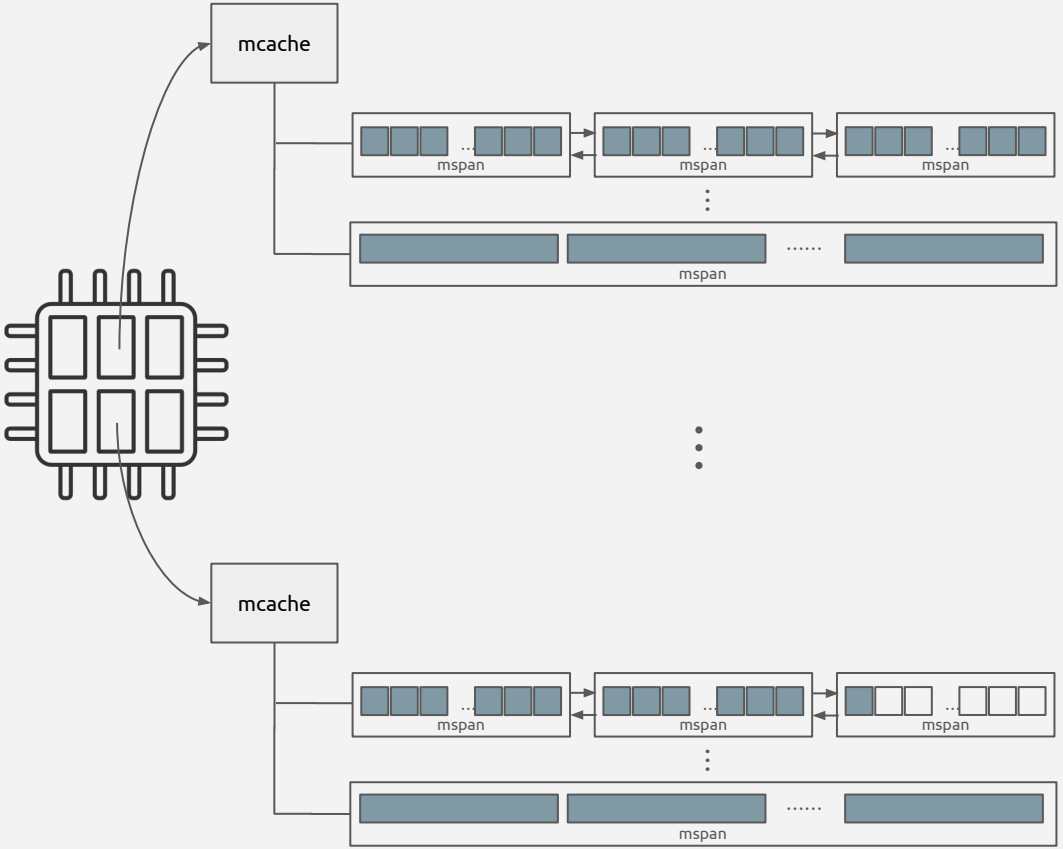
mcache

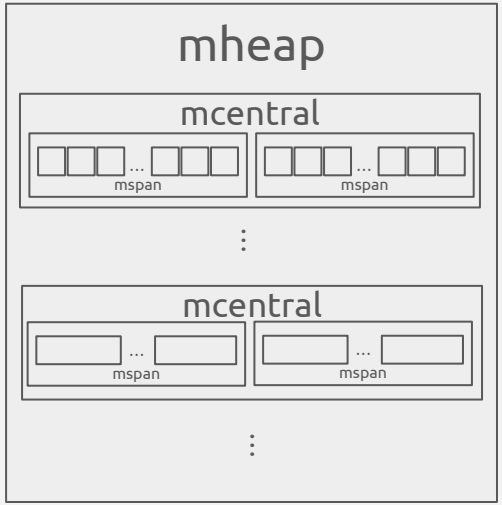
Menos frequentes = menos contenção

mheap

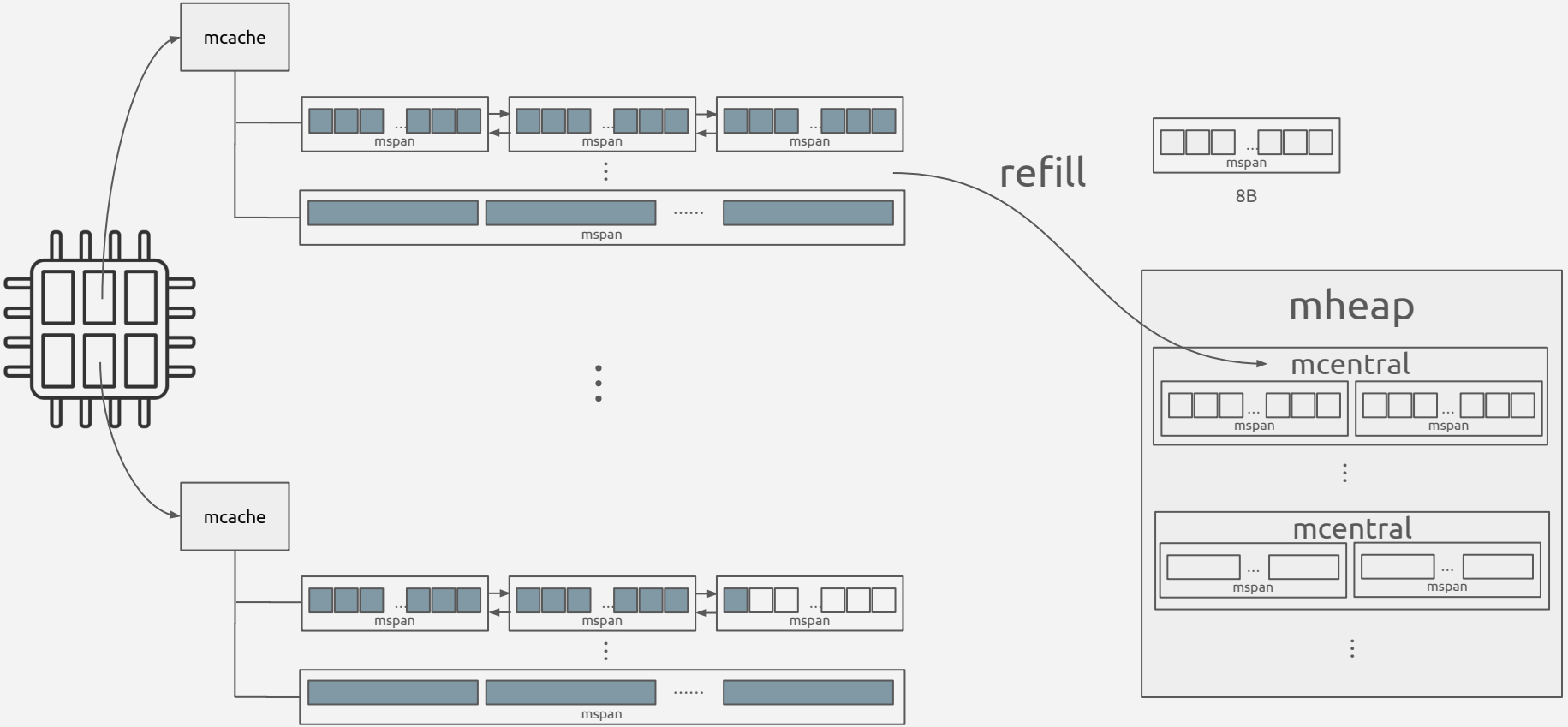
mspan

Memory Zoo

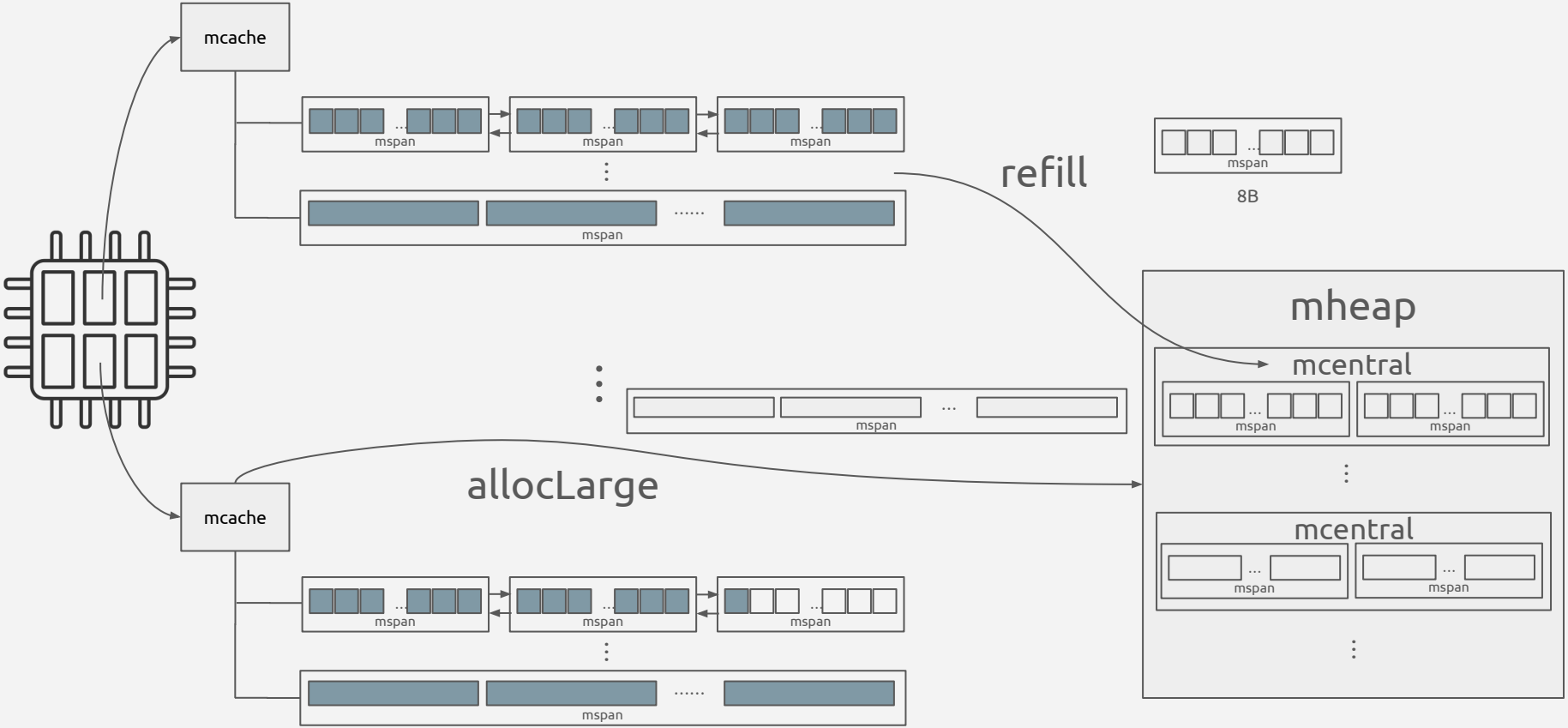

mcache
mspan
mspan
mspan
mspan
mcache
mspan
mspan
mspan
mspan


mheap
mcentral
mspan
mspan
mcentral
mspan
mspan

Memory Zoo


mcache
mspan
mspan
mspan
mspan
refill
mspan
8B
mheap
mcentral
mspan
mspan
mcentral
mspan
mspan
mcache
mspan
mspan
mspan
mspan

Memory Zoo


mcache
mspan
mspan
mspan
mspan
refill
mspan
8B
mheap
mcentral
mspan
mspan
mspan
allocLarge
mcache
mcentral
mspan
mspan
mspan
mspan
mspan

Arenas

```
import "arena"

func main() {
    a := arena.New()
    defer a.Free()

    x := a.New((*MyType)(nil)).(*MyType)
    s := a.NewSlice((*[]int)(nil), 100).([]int)
}
```

Go 1.20

Feature
experimental

Arenas

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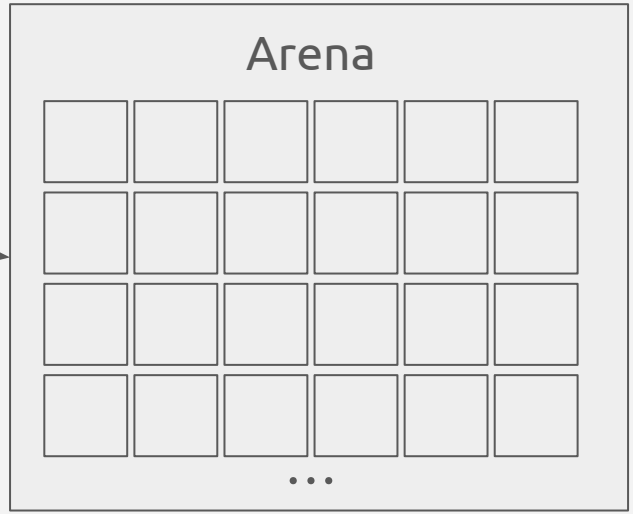

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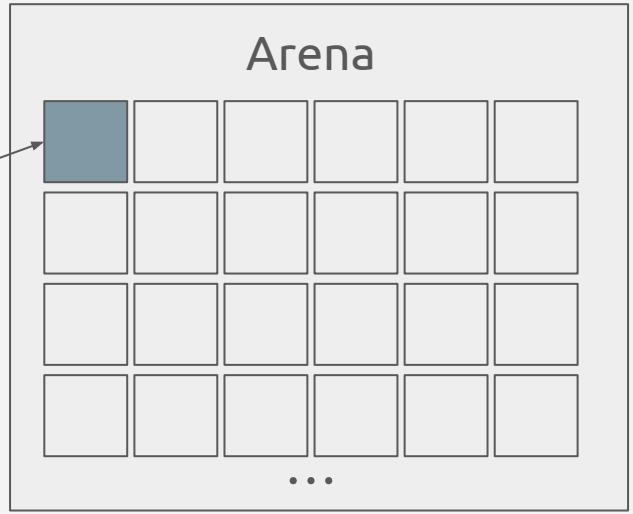

Arenas

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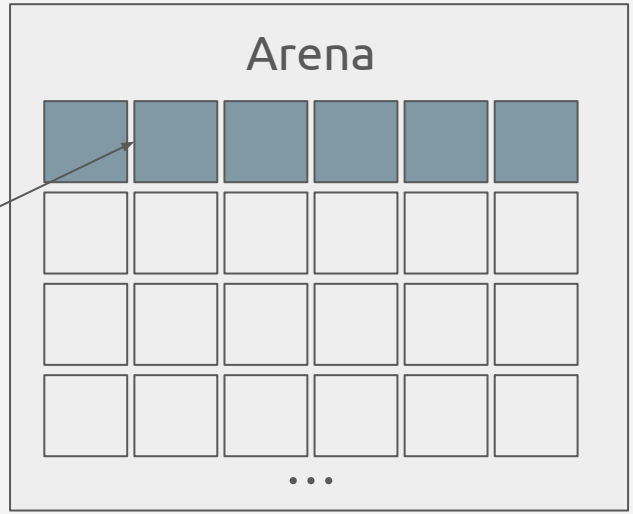

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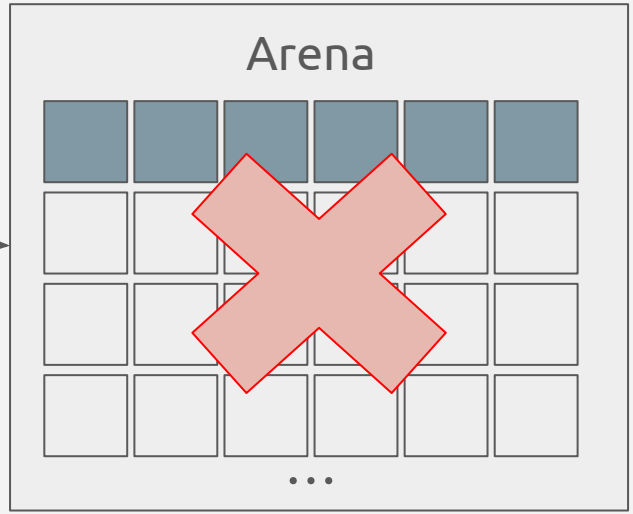
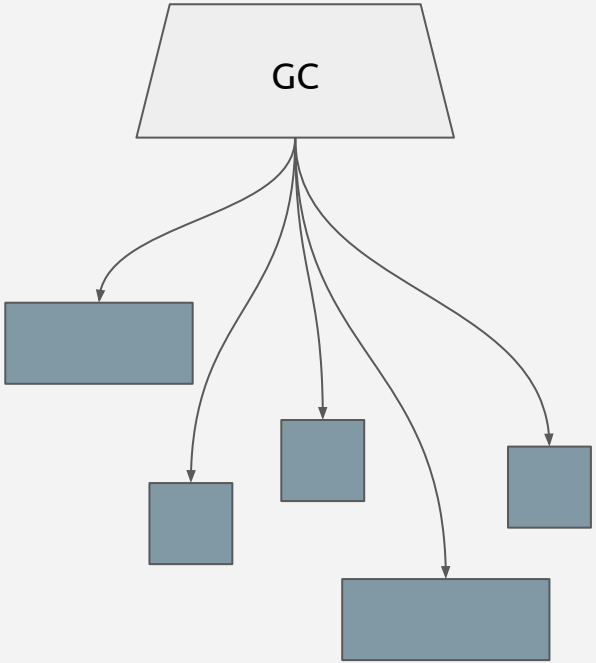
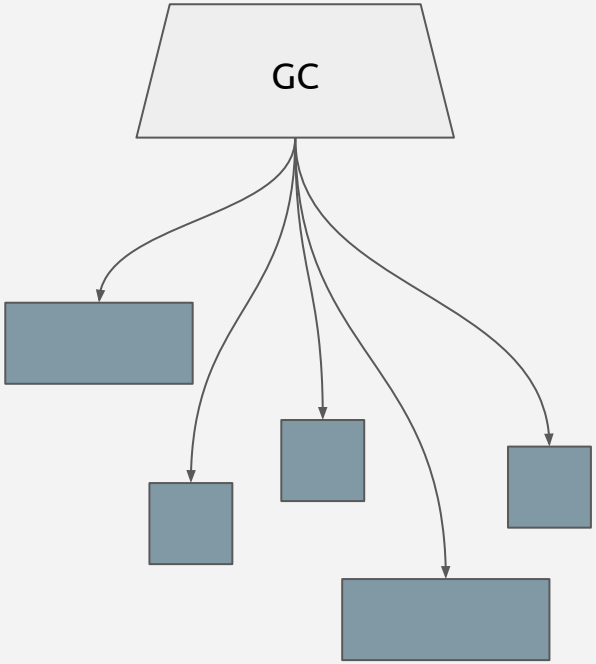


Alivia o garbage collector

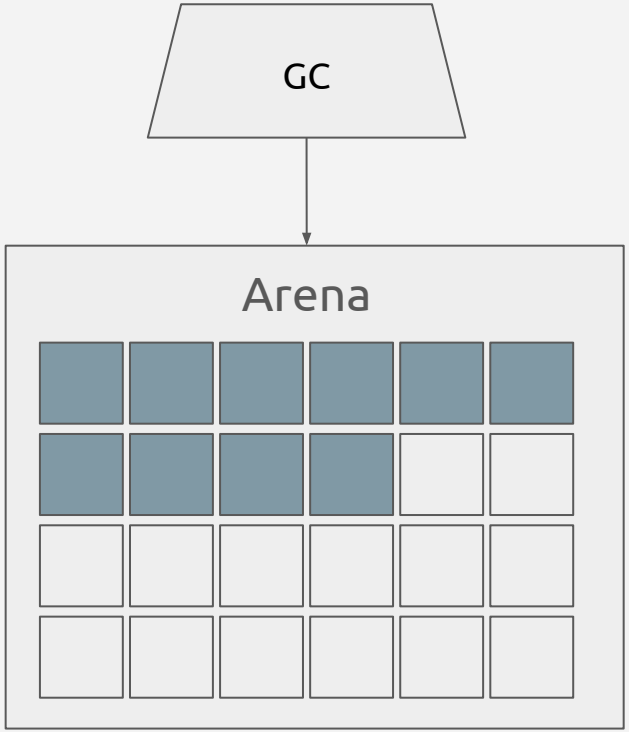


Sem arenas

Alivia o garbage collector



Sem arenas



Com arenas

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