Lecture 16: more `malloc()` under the hood

CSE 29: Systems Programming and Software Tools

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Announcements

- Problem set 4 released

- Sign up for Exam 3 on prairietest.com

Implementation Issues

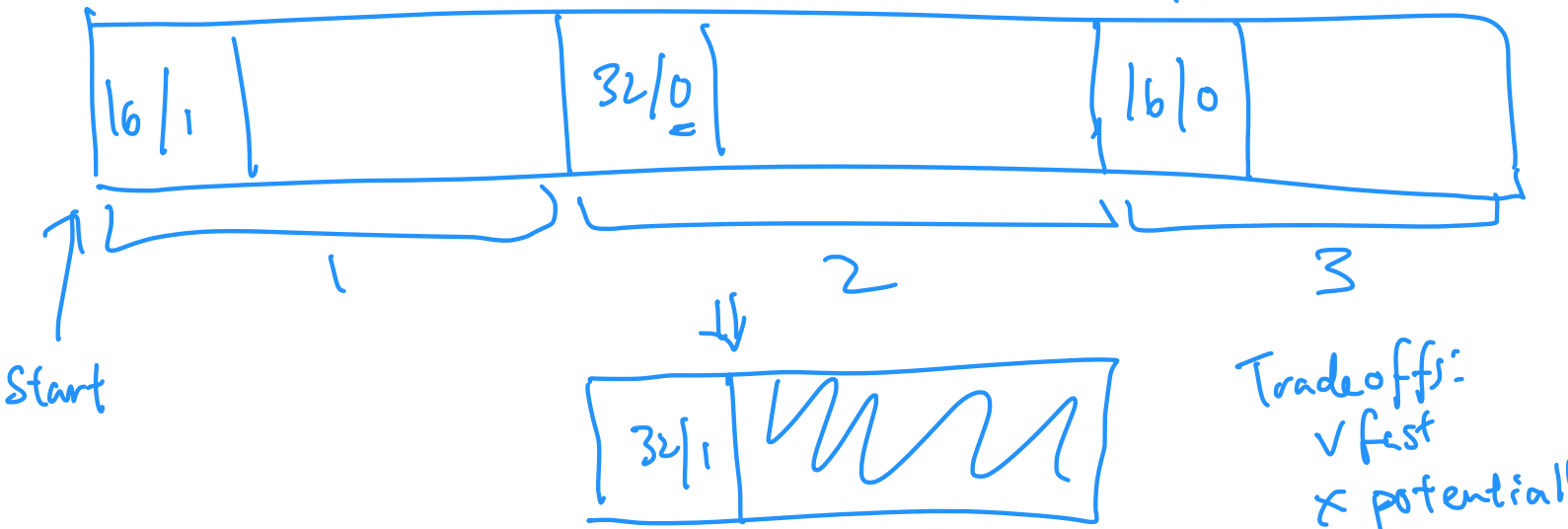
- How to know how much memory is being `free()`'d when we're only given a pointer (and no length)? **Use headers**
- How to keep track of free memory blocks? **Implicit list + is-allocated bit**
- How to pick which free memory chunks to use for allocation?
  - Many viable options
- What to do with extra space when allocating a block that is smaller than the free block it is placed in?

Implicit List: Finding a Free Block

4-byte aligned
4-byte headers

- First fit:
  - Search list from beginning, choose *first* free block that fits

p = malloc(6) – needs 12 bytes
→ 6 bytes payload
+ 4 bytes header
+ 2 bytes padding
12

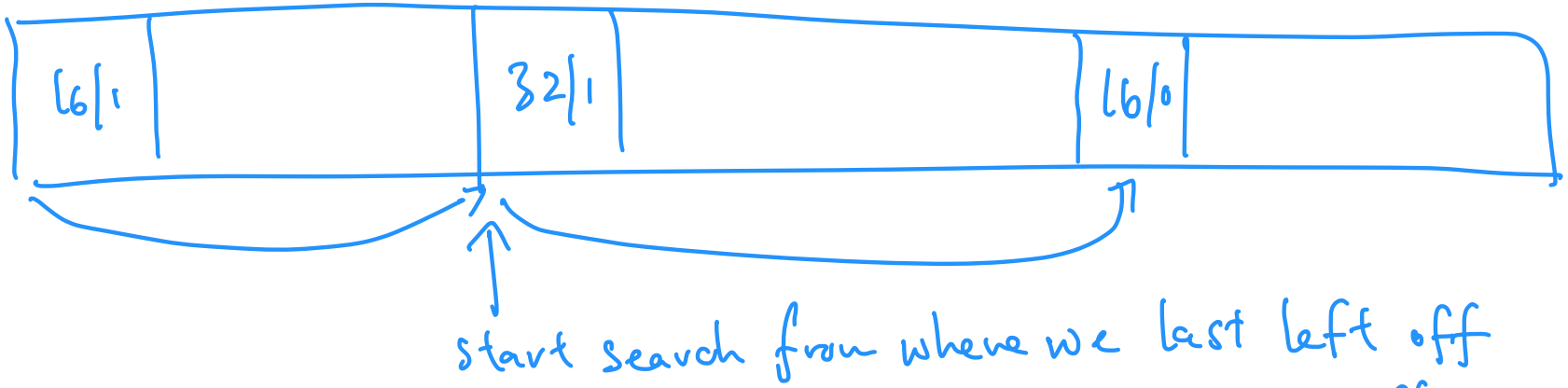


Tradeoffs:
✓ fast
✗ potentially wastes memory

Implicit List: Finding a Free Block

p = malloc(12)

- Next fit:
  - Like first fit, but start searching from *where previous search finished*
  - Often is *faster* than first fit: avoids re-scanning unhelpful blocks



Tradeoffs
✓ speed faster than first fit
✗ waste memory

Implicit List: Finding a Free Block

- Best fit:
  - Search the list, choosing the best free block: fits with fewest bytes leftover
  - Will typically run slower than first fit

The only way we know this block is the best is to search the whole heap.

Tradeoffs
- ✓ best memory util
- ✗ throughput / speed

Implicit List: Finding a Free Block

- First fit:
  - Search list from beginning, choose *first* free block that fits
- Next fit:
  - Like first fit, but start searching from *where previous search finished*
  - Often is *faster* than first fit: avoids re-scanning unhelpful blocks
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- Which one is better?

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Implicit List: Allocating in a Free Block

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```
p1 = malloc(4)
```



```
p2 = malloc(6)
```

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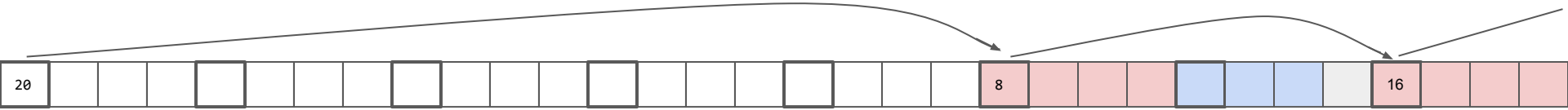
- Splitting a free block
  - Since object might be smaller than free space, we might want to split the free block



Header byte

Allocated byte

Padding byte

Free byte

Byte whose address % 4 == 0

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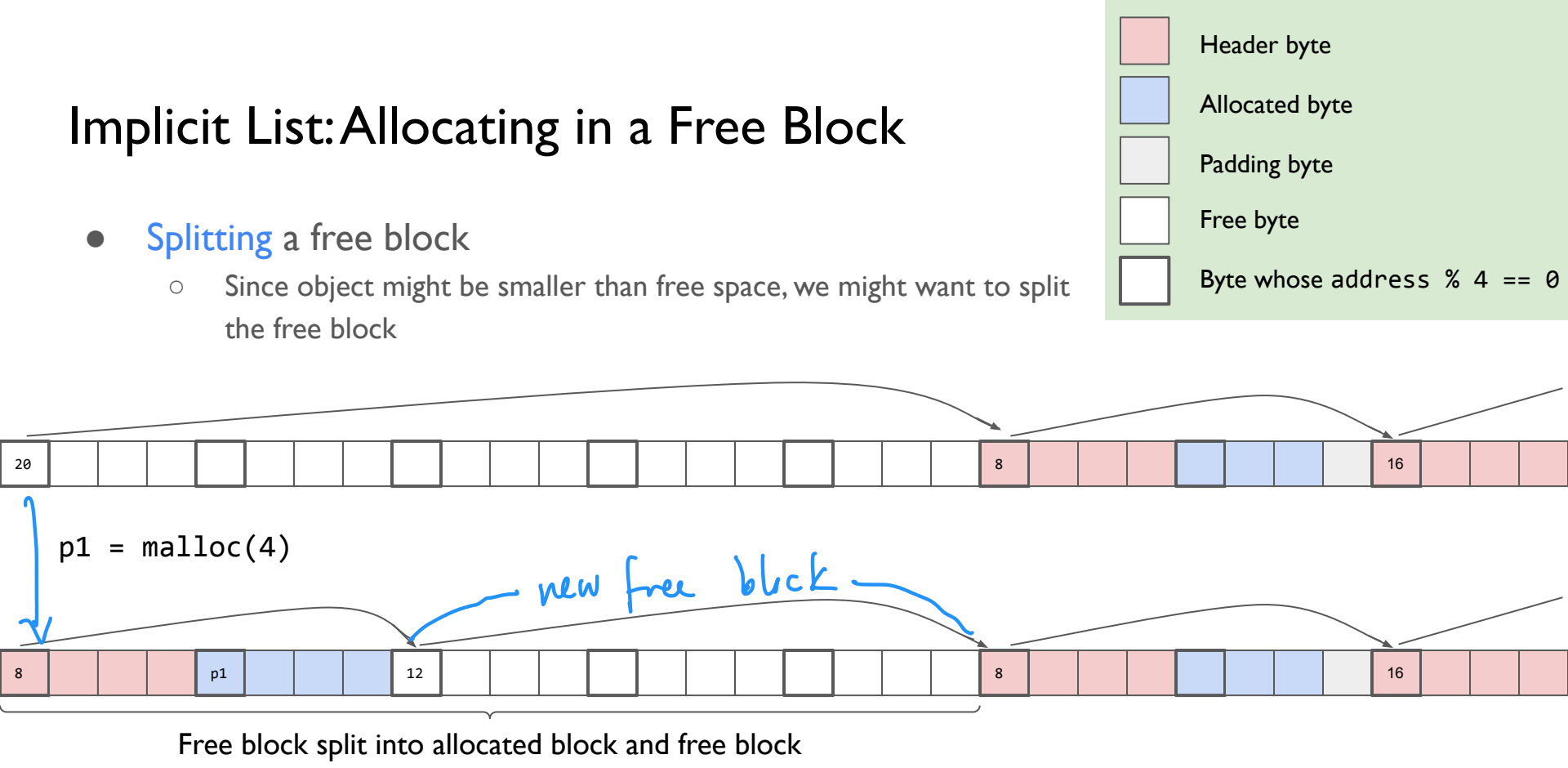

Implicit List: Allocating in a Free Block

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  - Improves memory utilization! *(Is this always true?)*


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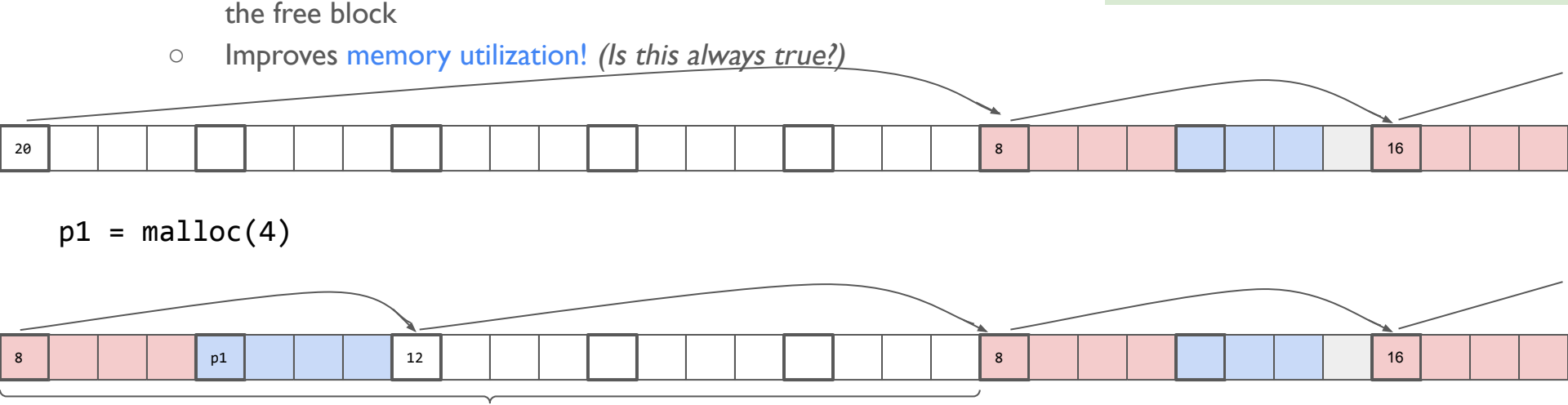

Free block split into allocated block and free block

```
p2 = malloc(6)
```
Now possible!

Implicit List: Allocating in a Free Block

- Splitting a free block
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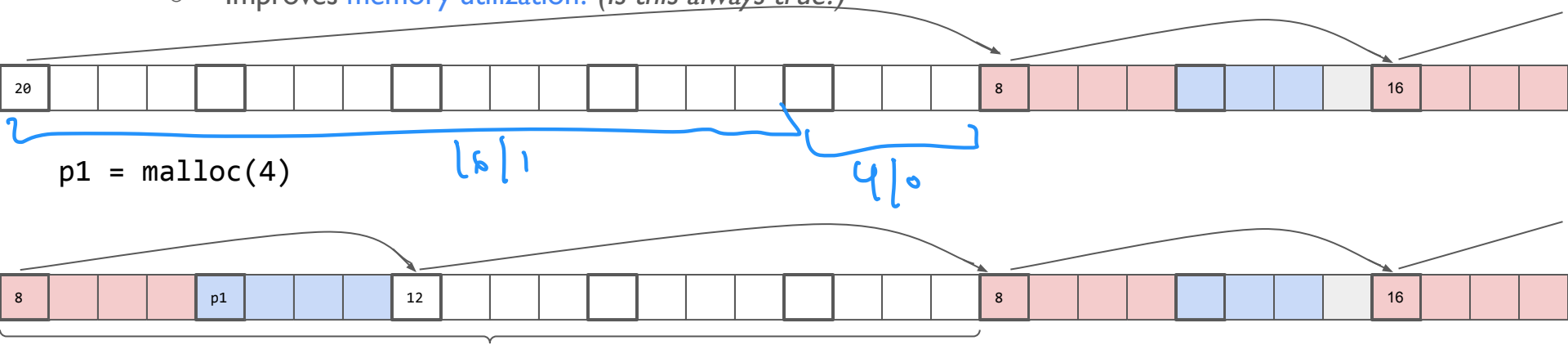

`p2 = malloc(6)` Now possible!

Is it always worth it to split your free blocks?

Implementation Issues

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- How to reinsert freed memory into the heap?

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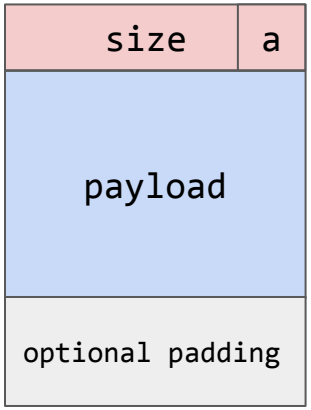
Implicit List: Freeing a Block

- Simplest implementation:
  - Need only set the "allocated" flag in header to 0



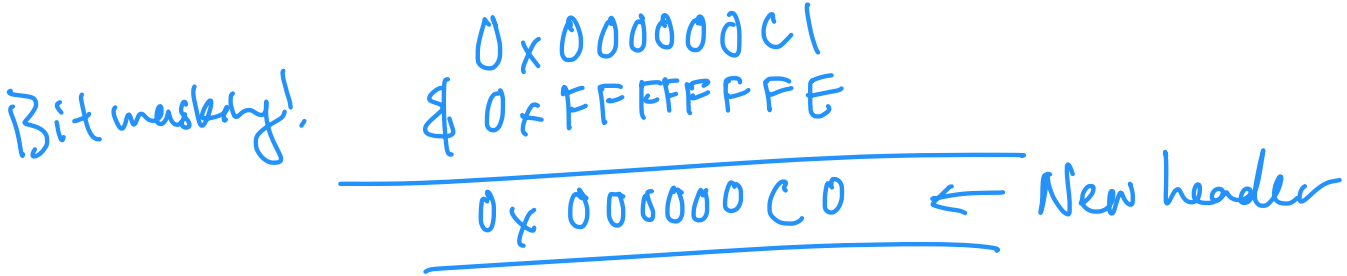
a = 1: allocated block
a = 0: free block

size = block size

payload: object data (allocated blocks only)

How to set the is-allocated bit to 0?

- Header: 0x000000C1
  - Assume 4 byte unsigned int



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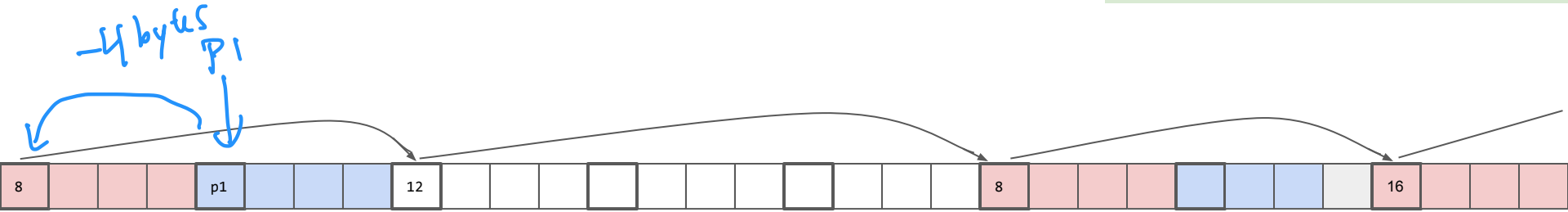


```
free(p1)
```

Header byte

Allocated byte

Padding byte

Free byte

Byte whose address % 4 == 0

Implicit List: Freeing a Block

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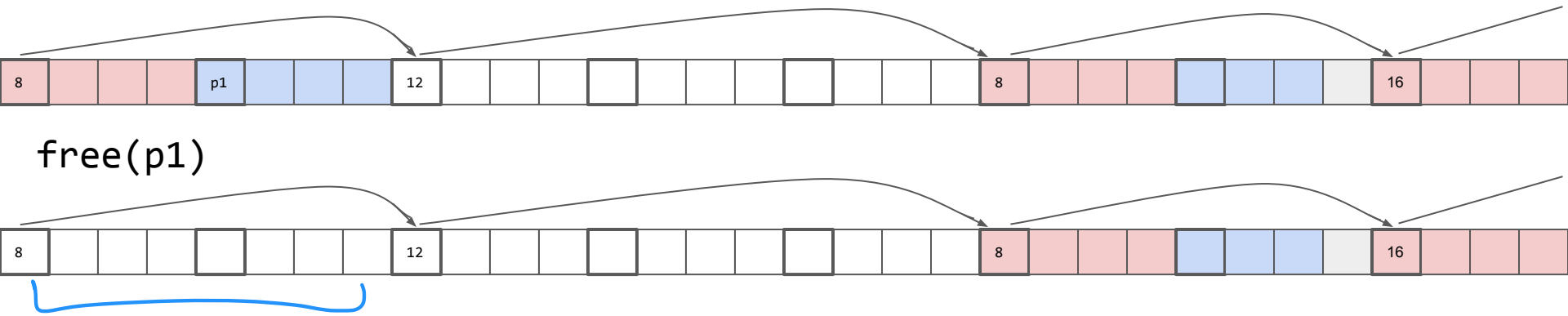

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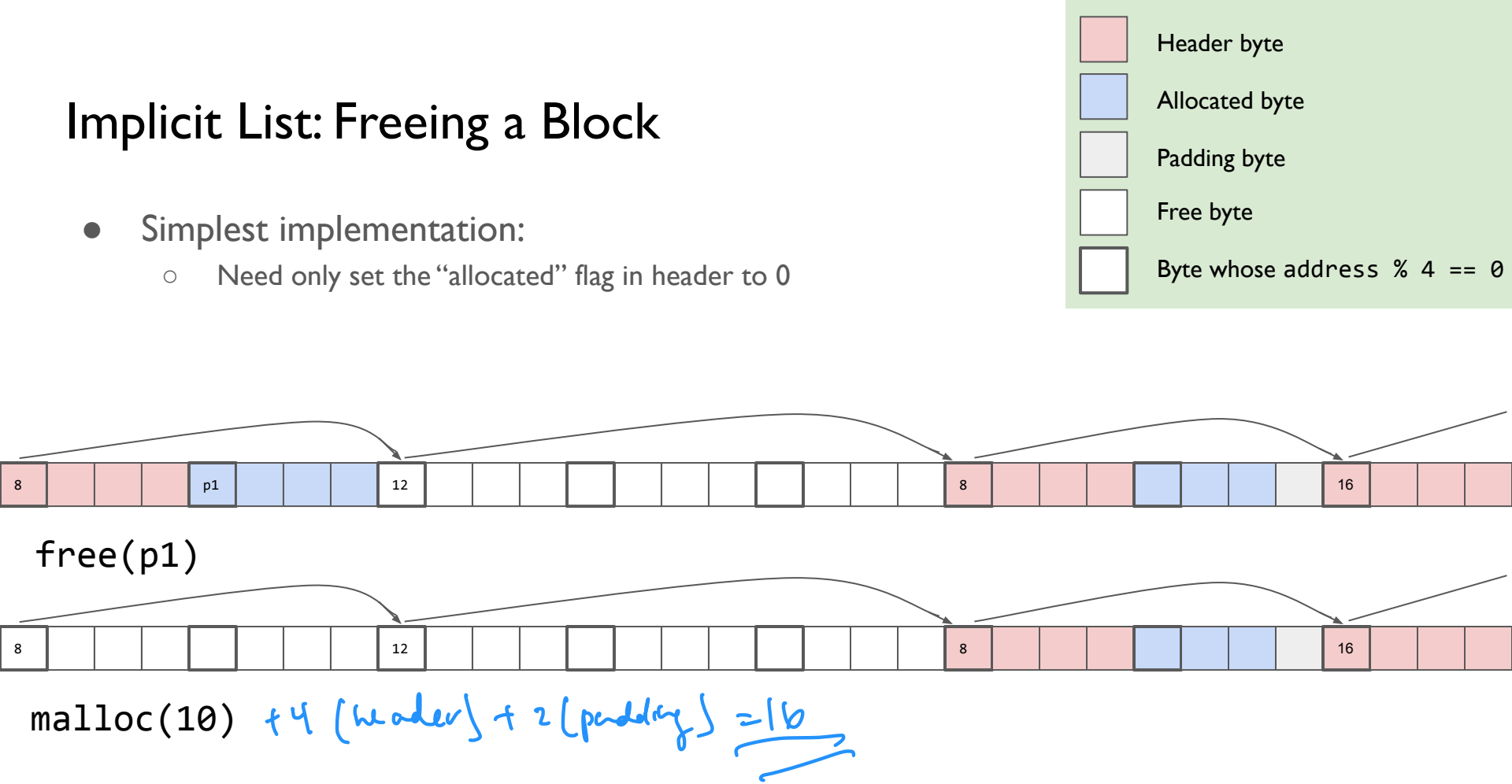
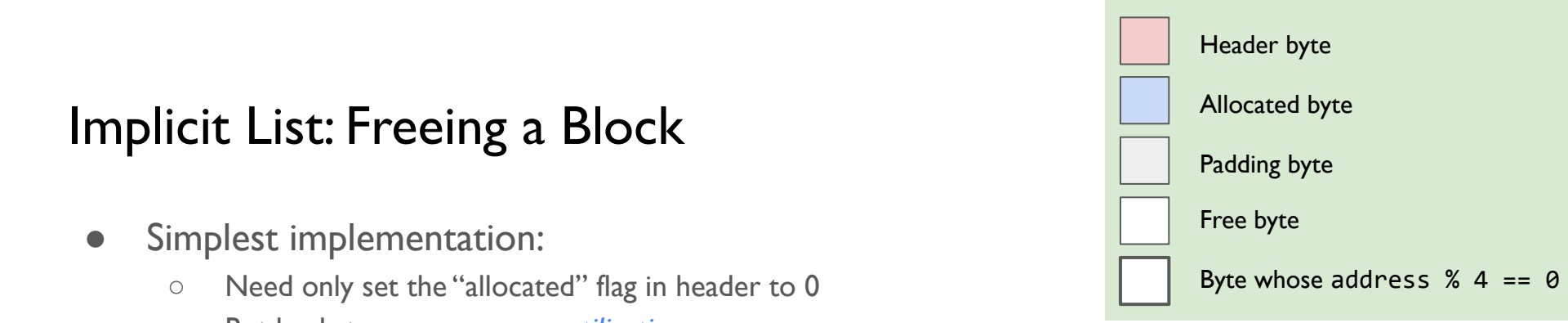


Implicit List: Freeing a Block

- Simplest implementation:
  - Need only set the "allocated" flag in header to 0
  - But leads to *poor memory utilization*



There is enough free space, but the allocator won't be able to find it!

Implicit List: Coalescing

- When freeing a block, join (coalesce) it with next/previous blocks, if they are free

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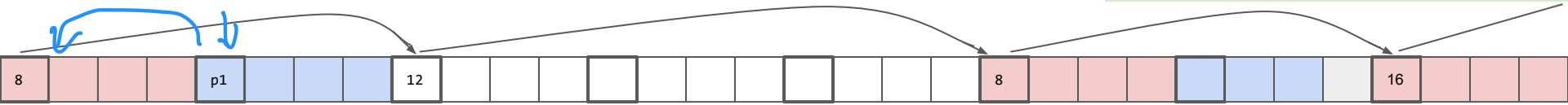


`free(p1)`

Header byte

Allocated byte

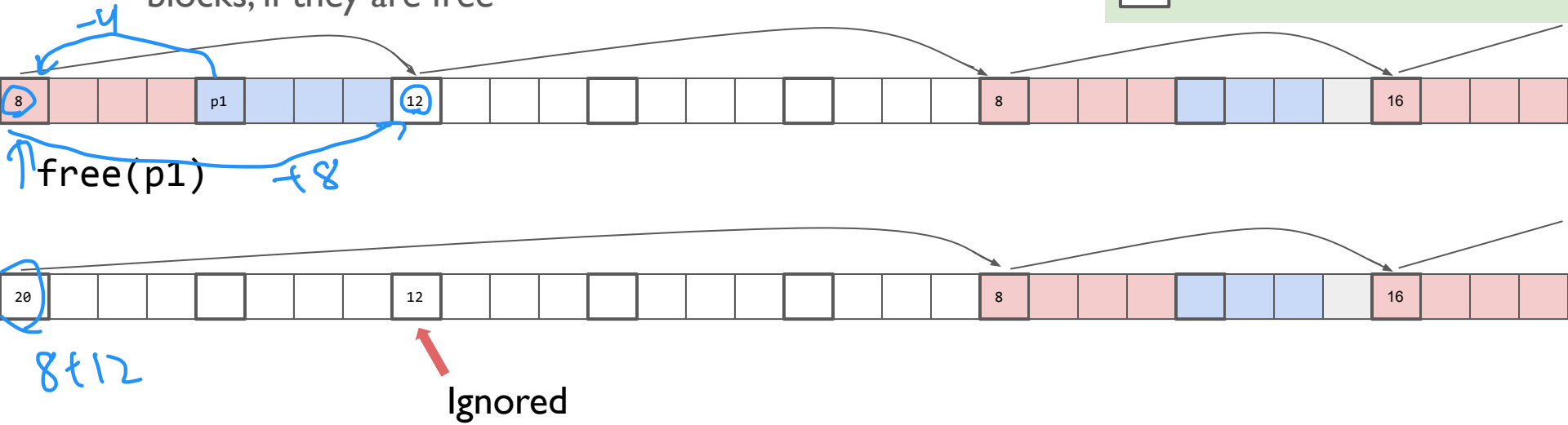
Padding byte

Free byte

Byte whose `address % 4 == 0`

Implicit List: Coalescing

- When freeing a block, join (coalesce) it with next/previous blocks, if they are free



Four cases for coalescing

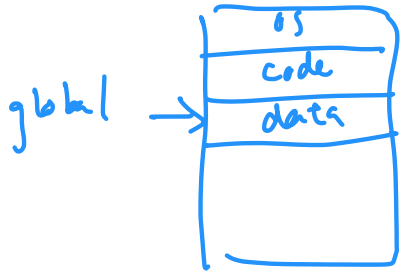
1. Previous and next blocks are both allocated Cannot coalesce

Four cases for coalescing

2. Next block is free

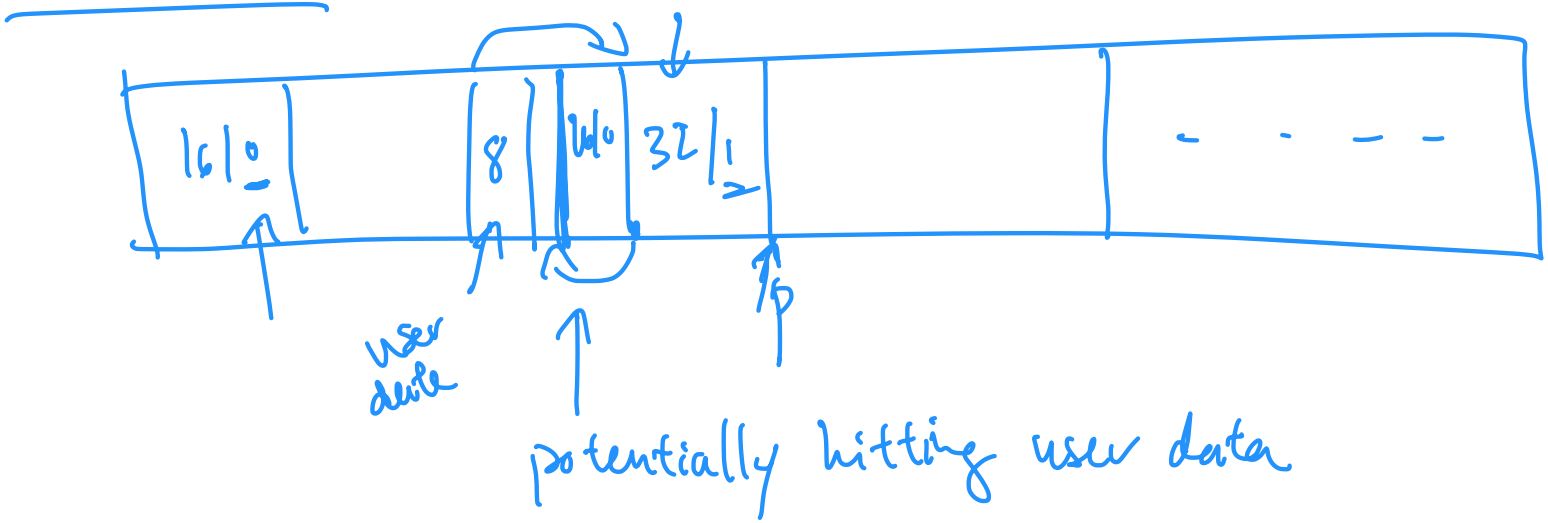
similar to last example

Four cases for coalescing



free(p)

3. Previous block is free



Four cases for coalescing

4. Previous and next blocks are free

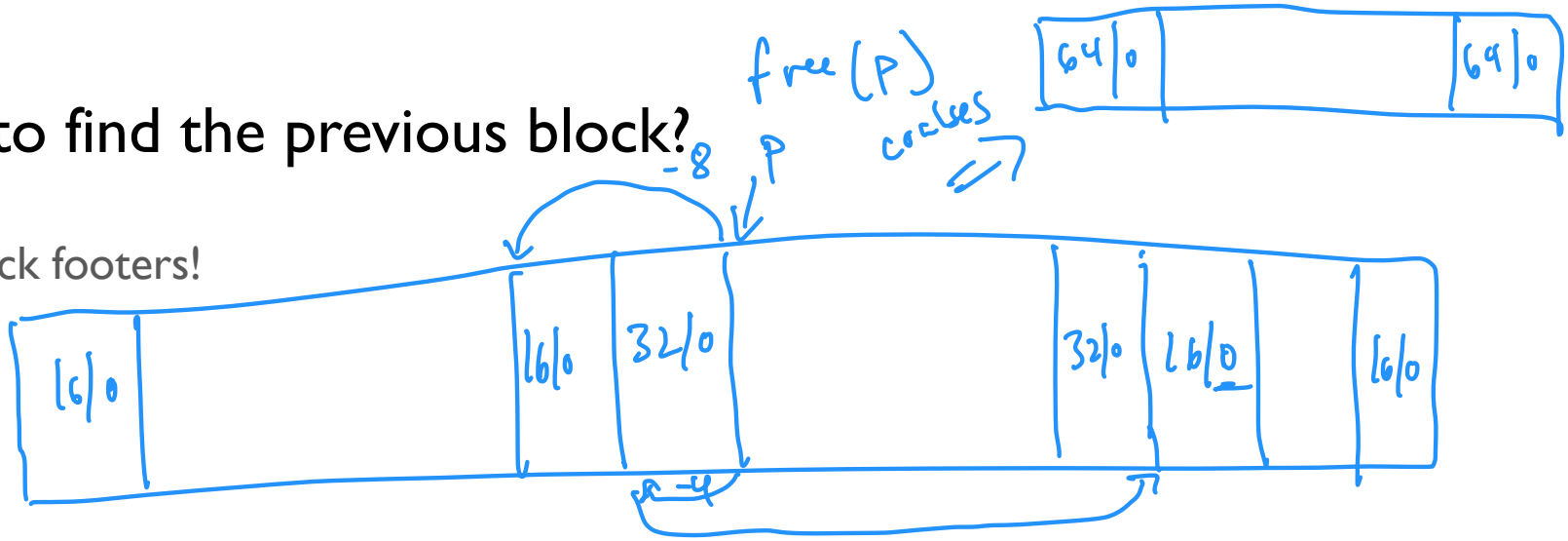
How to find the previous block?

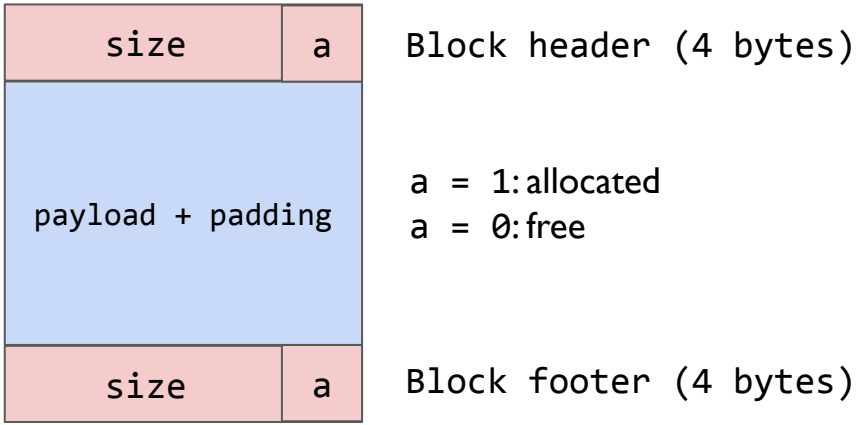
- Search again from the start of the heap to find previous block

- Problem: Time-consuming
  - How can we save time?

How to find the previous block?

- Block footers!





What tradeoffs do block footers introduce?

Problem with footers

- Problem: High memory overhead to have footers for ALL blocks

Problem with footers

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Why don't need footers in alloc'd blocks?

↳ Cannot coalesce w/ alloc'd block

- Solution: Only free blocks have footers

How to check if previous block is free or not?

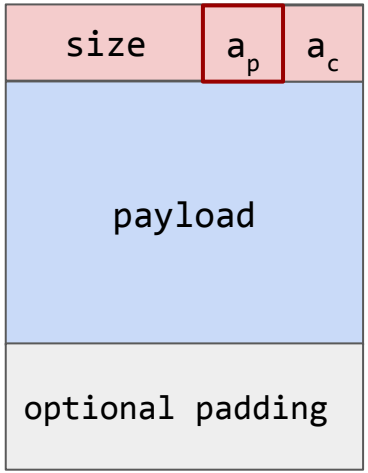
- Problem: pointer arithmetic insufficient!
  - If previous block is free: all good!

How to check if previous block is free or not?

- Problem: pointer arithmetic insufficient!
  - If previous block is free: all good!
  - If previous block is allocated: bad!

Storing more metadata in the header

- Structure of allocated block
  - Since memory is 4-byte aligned, the 2 lowest-order address bits are always 0
  - LSB = current block status
  - 2nd LSB = previous block status



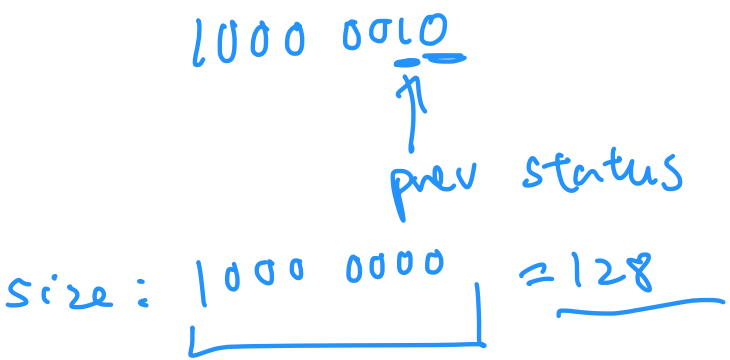
a_c = 1: current block alloc'd
a_c = 0: current block free

a_p = 1: previous block alloc'd
a_p = 0: previous block free

What is the size, current status, and previous status?

- Header = 0x82 => 0x00000082
  - Assume 4-byte unsigned int

Current status = free
previous status = allocated
size: 128 bytes



Coalescing with the previous block

- Steps:
  - check previous block status in my header
  - if free: look at footer and use info to update previous block's header (pointer arithmetic!)

When to coalesce?

- Immediate coalescing: coalesce each time `free()` is called
- Deferred coalescing: try to improve performance of `free()` by deferring coalescing until needed.
  - Ex:
    - Coalesce as you scan the heap for malloc()
    - Coalesce when the memory utilization reaches some threshold

- Which one is better?
  - Remember throughput vs. memory utilization tradeoff