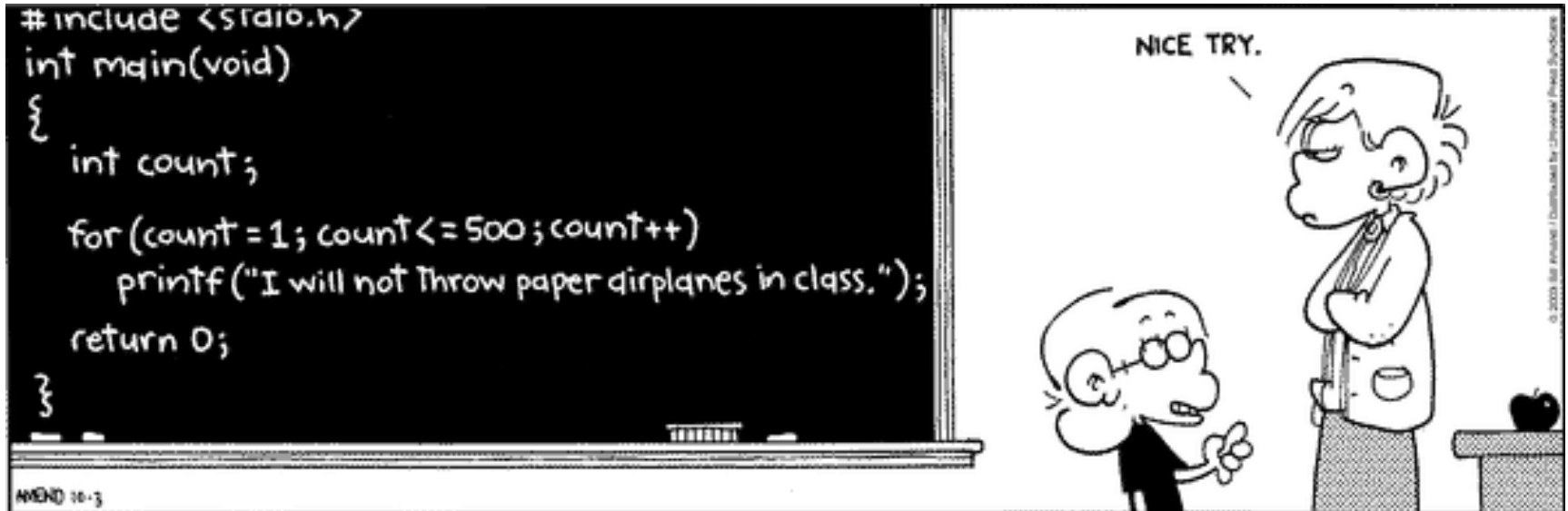


Admin

- Assign 2 issues posted, fix and resubmit
- printf perseverance and pride!!



Today: Thanks for the memory!

Linker memory map, address space layout

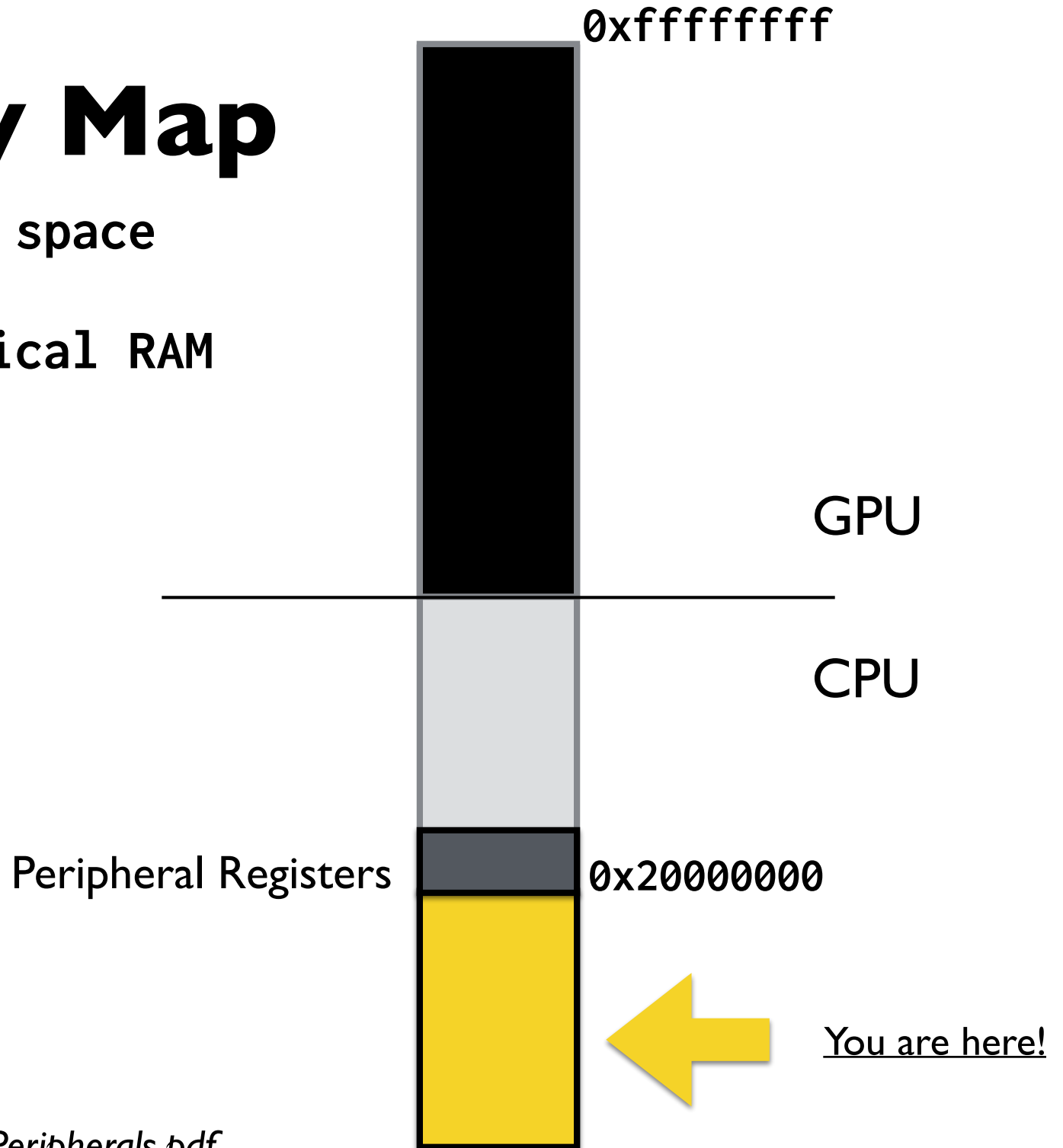
Loading, how an executable file becomes a running program

Heap allocation, malloc and free

Memory Map

32-bit address space

512 MB of physical RAM



SECTIONS

```
{
    .text 0x8000 : { start.o(.text*)
                    *(.text*)}
    .data :      { *(.data*) }
    .rodata :    { *(.rodata*) }

    __bss_start__ = .;
    .bss :        { *(.bss*)
                    *(COMMON) }
    __bss_end__ = ALIGN(8);
}
```

Use this memory for heap👉

(zeroed data) .bss

(read-only data) .rodata

(initialized data) .data

.text



0x8000000

```
_start:
    mov sp, #0x8000000
    mov fp, #0
    bl _cstart
```

```
void _cstart(void) {
    int *bss = &__bss_start__;
    while (bss < &__bss_end__)
        *bss++ = 0;
}
main();
}
```

__bss_end__

__bss_start__

} blink.bin

0x8000

Global allocation

- + **Convenient**

 - Fixed location, shared across entire program

- + **Fairly efficient, plentiful**

 - No explicit allocation/deallocation

 - But heavy user incurs cost to send over serial to bootloader

- + **Reasonable type safety**

- **Size fixed at declaration, no option to resize**

- +/- **Scope and lifetime is global**

 - No encapsulation, hard to track use/dependencies

 - One shared namespace, have to manually manage conflicts

 - Frowned upon stylistically

Stack allocation

- + **Convenient**

 - Automatic alloc/dealloc on function entry/exit

- + **Efficient, fairly plentiful**

 - Fast to allocate/deallocate, low consequence if large size

- + **Reasonable type safety**

- **Size fixed at declaration, no option to resize**

- +/- **Scope/lifetime dictated by control flow**

 - Private to stack frame

 - Does not persist after function exits

Heap allocation

- + **Moderately efficient**

 - Have to search for available space, update record-keeping

- + **Very plentiful**

 - Heap enlarges on demand to limits of address space

- + **Versatile, under programmer control**

 - Can precisely determine scope, lifetime

 - Can be resized

- **Low type safety**

 - Interface is raw void *, number of bytes

- **Lots of opportunity for error**

 - (allocate wrong size, use after free, double free)

- **Leaks** (less critical, but annoying nonetheless)

Heap interface

```
void *malloc (size_t nbytes);  
void free (void *ptr);  
void *realloc (void *ptr, size_t nbytes);
```

void* pointer

"Generic" pointer, a memory address

Type of pointee is not specified, unknown

What you can do with a void*

Pass to/from function, pointer assignment

What you cannot do with a void*

Cannot dereference (must cast first)

Cannot do pointer arithmetic (cast to char * to manually control scaling)

Cannot use array indexing (size of pointee not known!)

Why do we need a heap?

Let's see an example!

`code/heap/names.c`

How to implement a heap

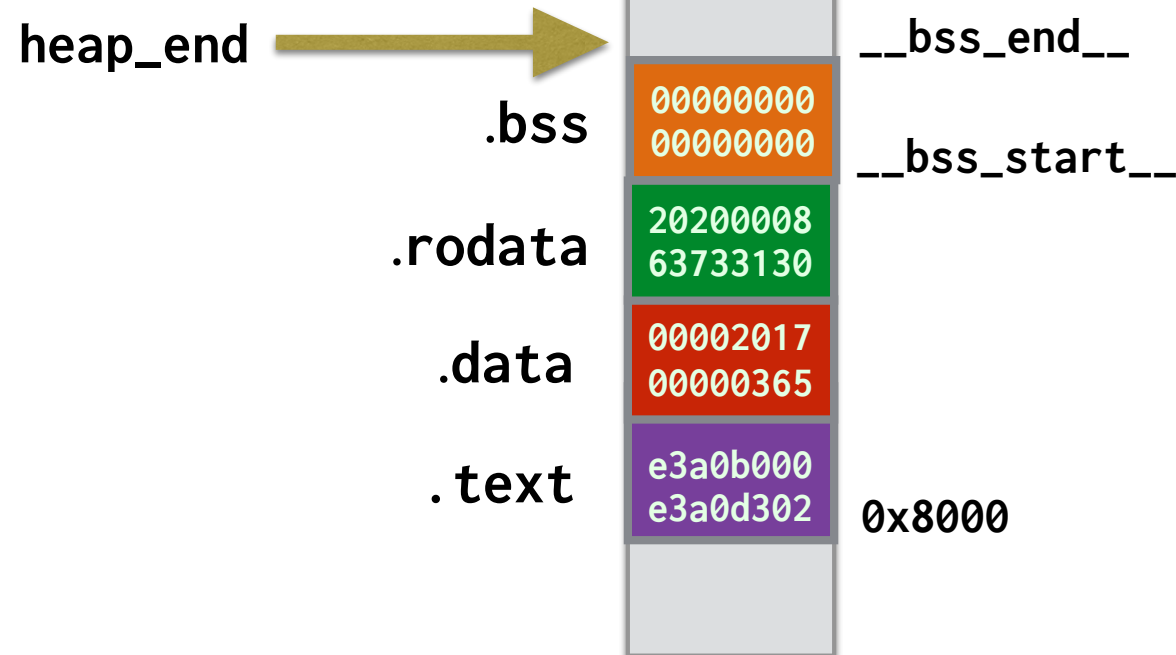


```

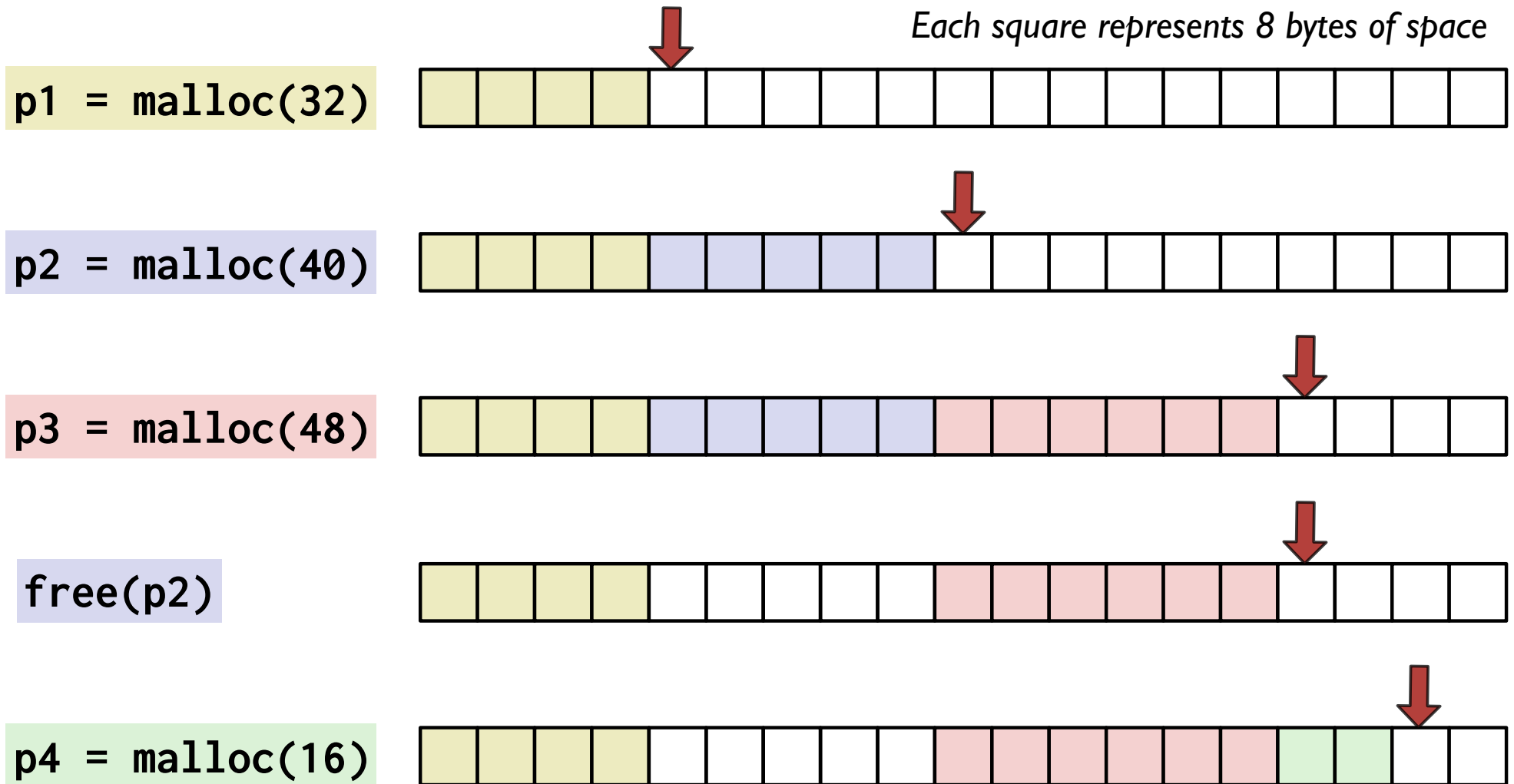
void *sbrk(int nbytes)
{
    static void *heap_end = &__bss_end__;

    void *prev_end = heap_end;
    heap_end = (char *)heap_end + nbytes;
    return prev_end;
}

```



Tracing the bump allocator



Bump Memory Allocator

`code/heap/malloc.c`

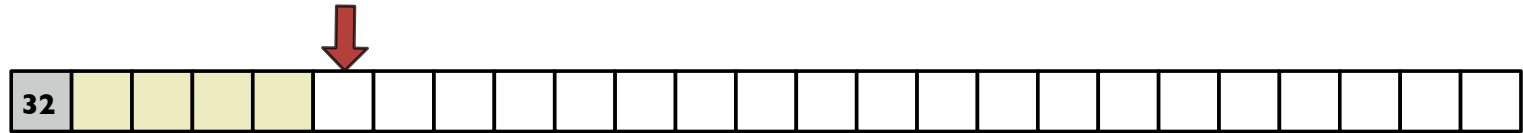
Evaluate bump allocator

- + Operations super-fast
- + Very simple code, easy to verify, test, debug
- No recycling/re-use
 - (in what situations will this be problematic?)
- Sad consequences when `sbrk()` advances into stack
 - (what can we do about that?)

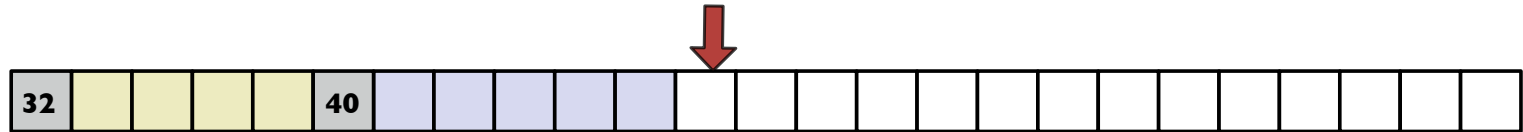
Pre-block header, implicit list

Each square represents 8 bytes of space, size recorded as total byte count

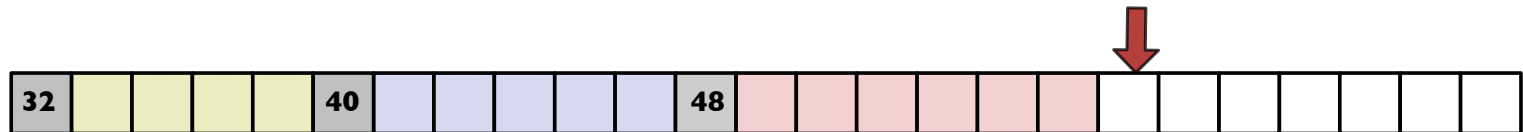
`p1 = malloc(32)`



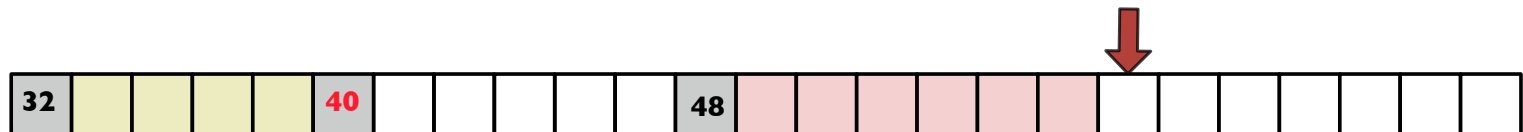
`p2 = malloc(40)`



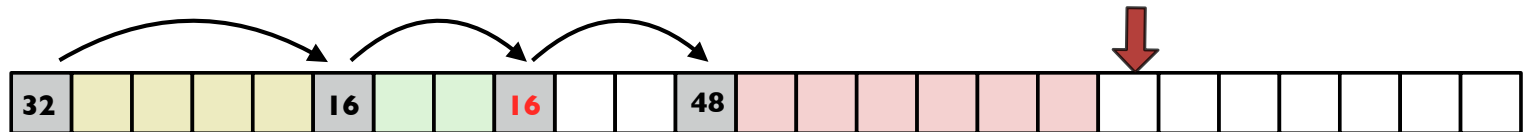
`p3 = malloc(48)`



`free(p2)`



`p4 = malloc(16)`



Header struct

```
struct header {
    unsigned int size;
    unsigned int status;
};                                     // sizeof(struct header) = 8 bytes

enum { IN_USE = 0, FREE = 1};

void *malloc(size_t nbytes)
{
    nbytes = roundup(nbytes, 8);
    size_t total_bytes = nbytes + sizeof(struct header);

    struct header *hdr = sbrk(total_bytes);
    hdr->size = nbytes;
    hdr->status = IN_USE;
    return hdr + 1;    // return address at start of payload
}
```

Challenges for malloc client

- **Correct allocation (size in bytes)**
- **Correct access to block (within bounds, not freed)**
- **Correct free (once and only once, at correct time)**

What happens if you...

- forget to free a block after you are done using it?
- access a memory block after you freed it?
- free a block twice?
- free a pointer you didn't malloc?
- access outside the bounds of a heap-allocated block?

Challenges for malloc implementor

just malloc is easy 😎

malloc with free is hard 🤔

Efficient malloc with freeYikes! 😓

Complex code (pointer math, typecasts)

Thorough testing is challenge (more so than usual)

Critical system component

correctness is non-negotiable, ideally fast and compact

Survival strategies:

draw pictures

printf (you've earned it!!)

early tests use examples small enough to trace by hand if need be

build up to bigger, more complex tests