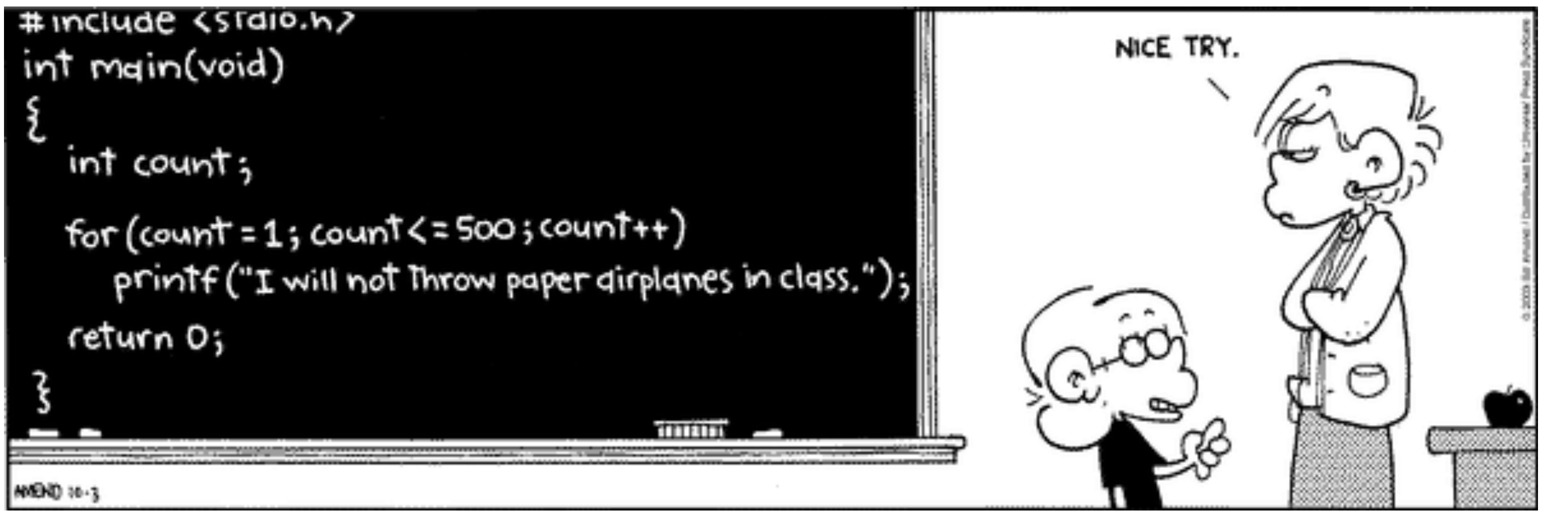
Admin

- Halfway there!
- A deep appreciation for printf -- and you'll appreciate having it!
- Project proposals due tomorrow (Saturday)



Today: Thanks for the memory!

Linker memory map, address space layout

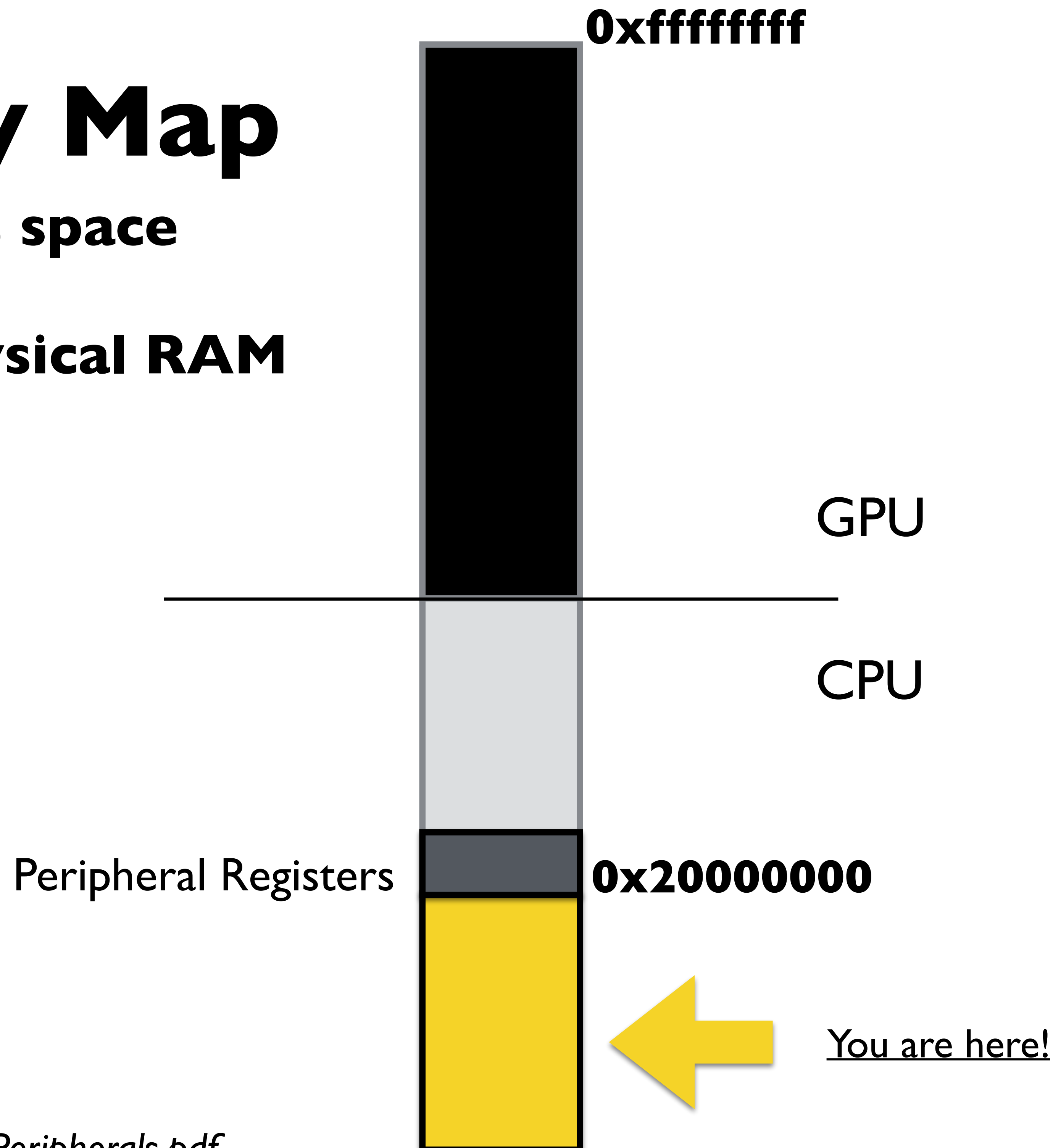
Loading, how an executable file becomes a running program

Heap allocation, malloc and free

Memory Map

32-bit address space

512 MB of physical RAM



Ref: BCM2835-ARM-Peripherals.pdf

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

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

0x8000000

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

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

Use this memory for heap☞

__bss_end__

(zeroed data) .bss

__bss_start__

(read-only data) .rodata

(initialized data) .data

.text

0x8000

blink.bin

Global allocation

+ **Convenient**

    Fixed location, shared across entire program

+ **Fairly efficient, plentiful**

    No explicit allocation/deallocation

    But have to send over serial to bootloader (can be slow)

- **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

    Static can be address some issues

    Frowned upon stylistically (advanced systems reasons)

Stack allocation

+ **Convenient**

  Automatic alloc/dealloc on function entry/exit

+ **Efficient, fairly plentiful**

  Fast to allocate/deallocate, good locality

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

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

  Private to stack frame

  Does not persist after function exits

- **Memory bug can corrupt execution**

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 (can't access by value)**

  Interface is raw void *, number of bytes

- **Lots of opportunity for error**

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

- **Leaks**
- **Hard to track down sources of corruption**

Heap interface

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

void* pointer

"Generic" pointer, a memory adddress

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)

Why do we need a heap?

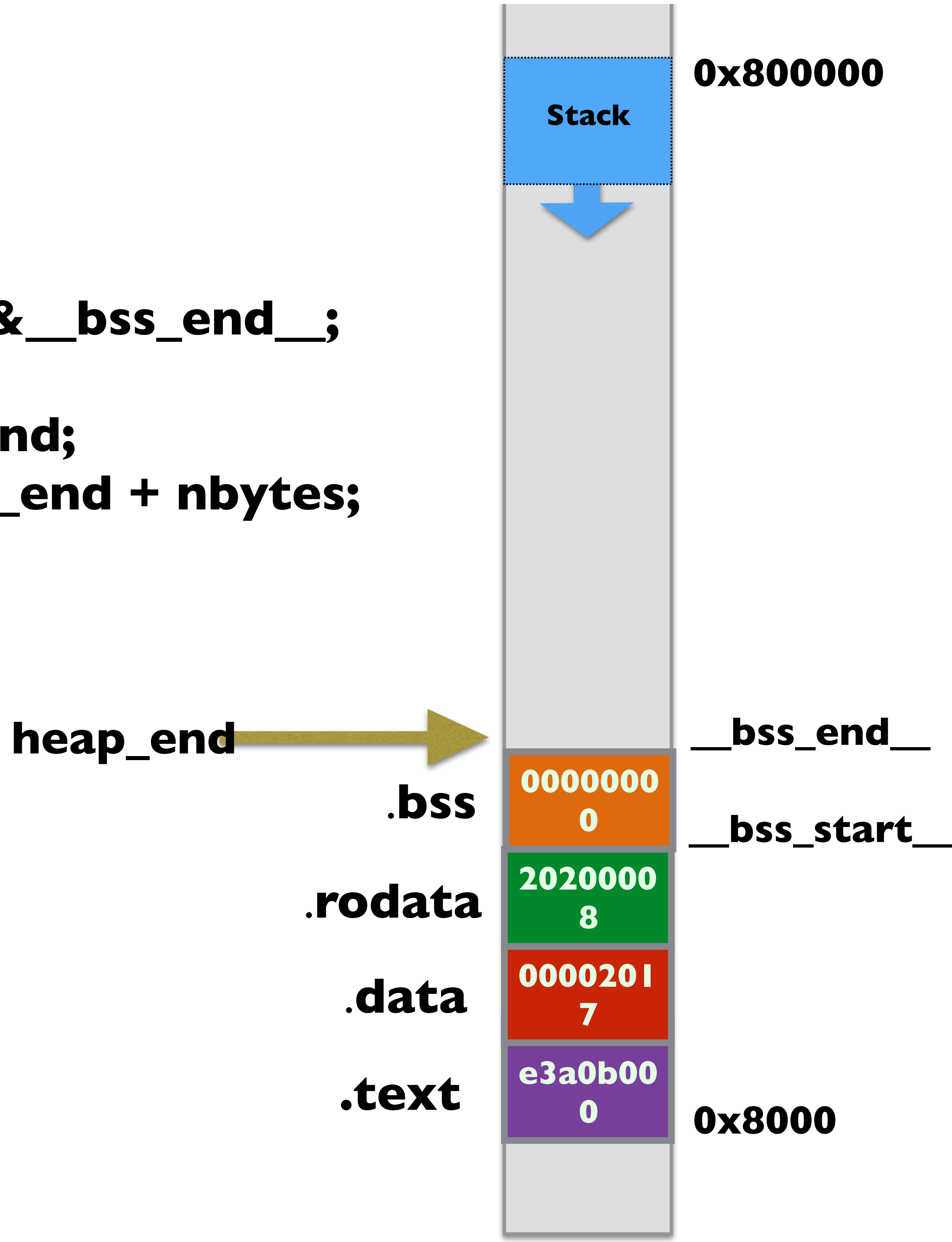
Let's see an example!

code/heap/names.c

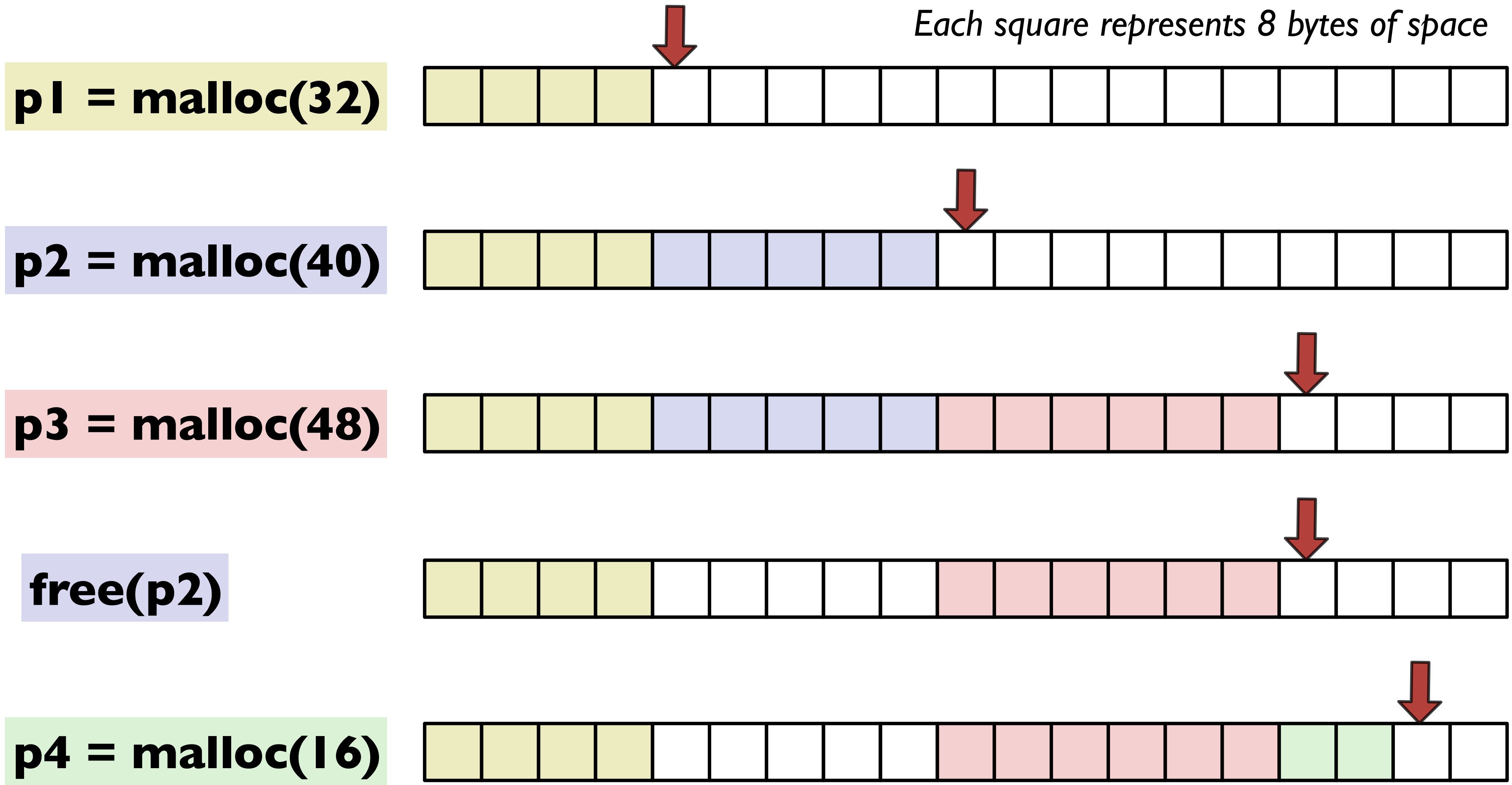
How to implement a heap

```
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

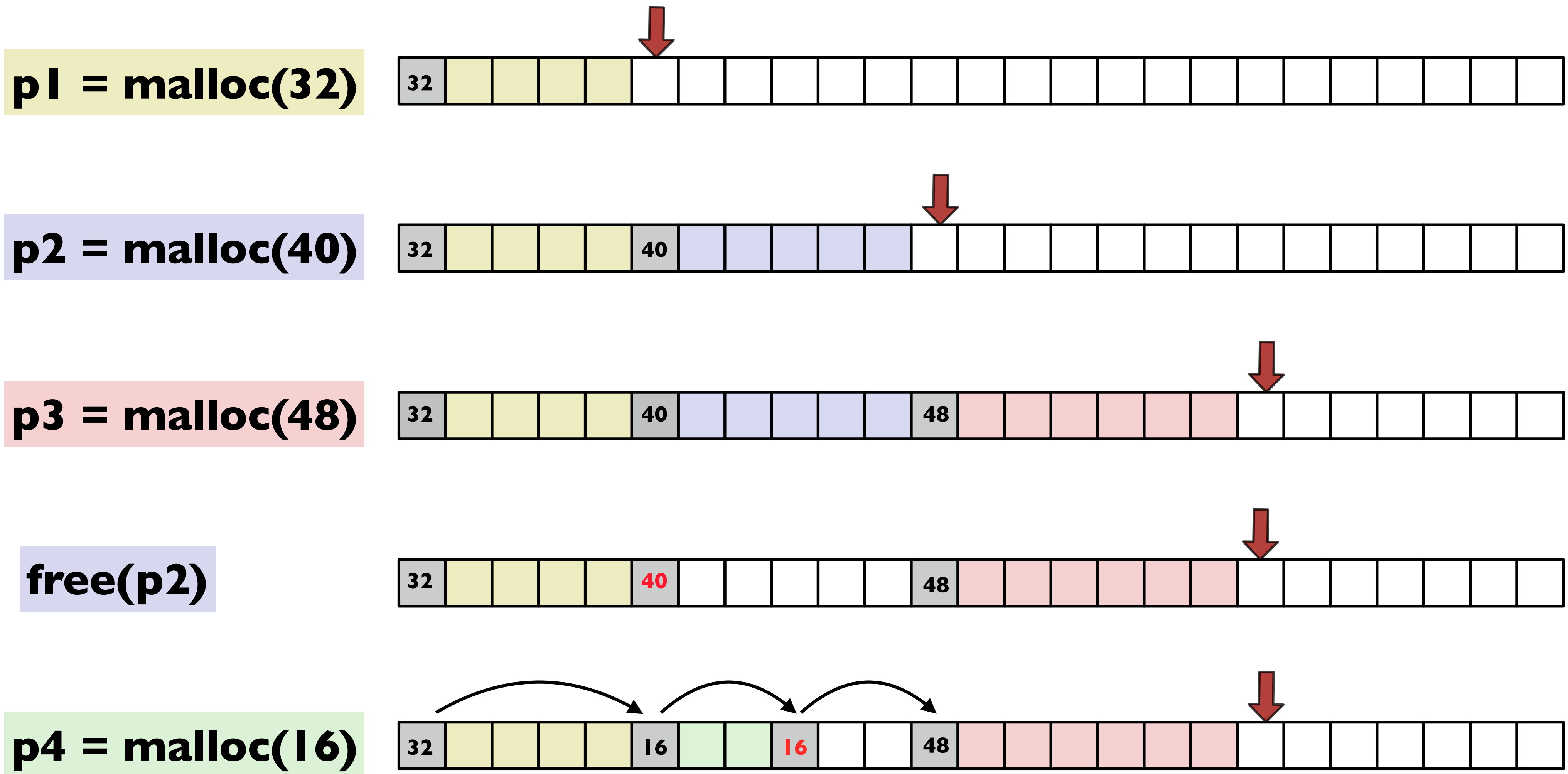
    (in what situations will this be problematic?)

- 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



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 **free** ….Yikes! [?]

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