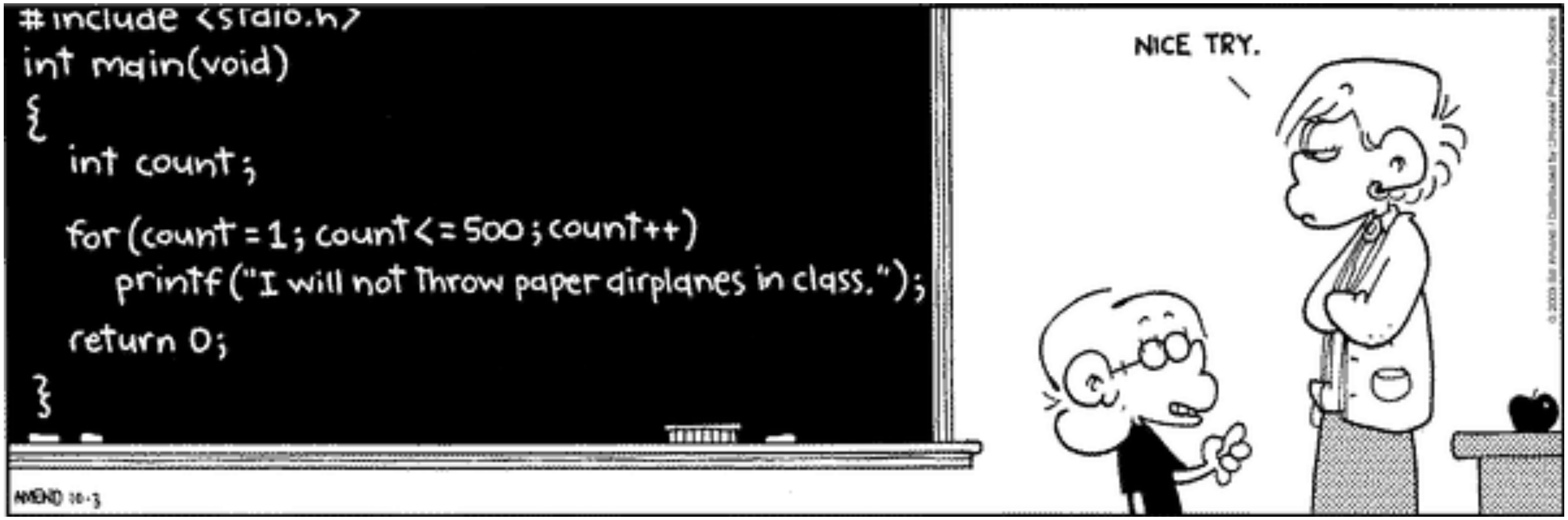
Admin

- printf perseverance and pride!!
- Let us know if you need help before we go much further



Today: Thanks for the memory!

Runtime stack, stack frame layout

Linker memory map, address space layout

Loading, how an executable file becomes a running program

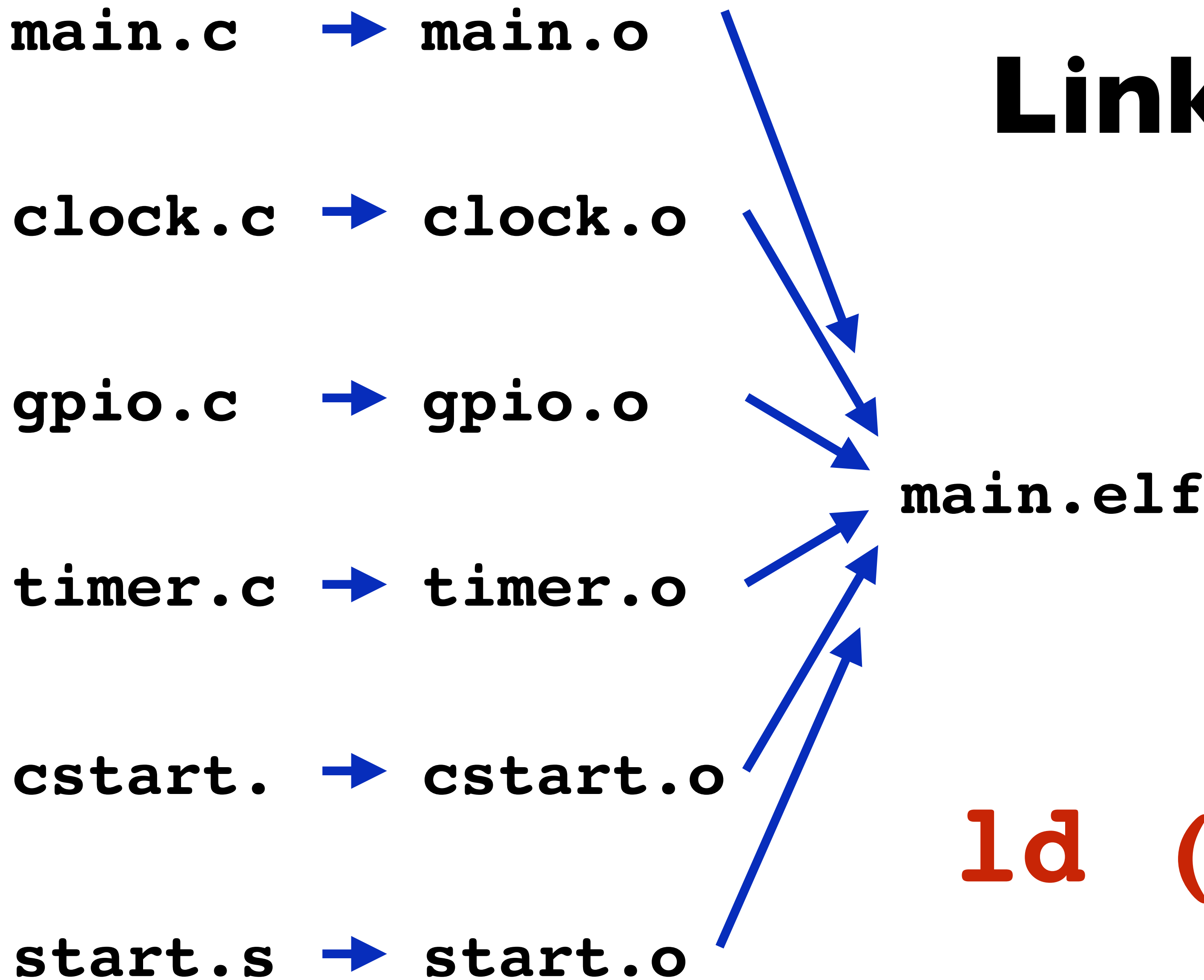
Heap allocation, malloc and free

gcc is all powerful

gpio.c	→	gpio.i	→	gpio.s	→	gpio.o
	cpp		cc1		as	
	gcc -E		gcc -S		gcc -c	

gcc –save-temps

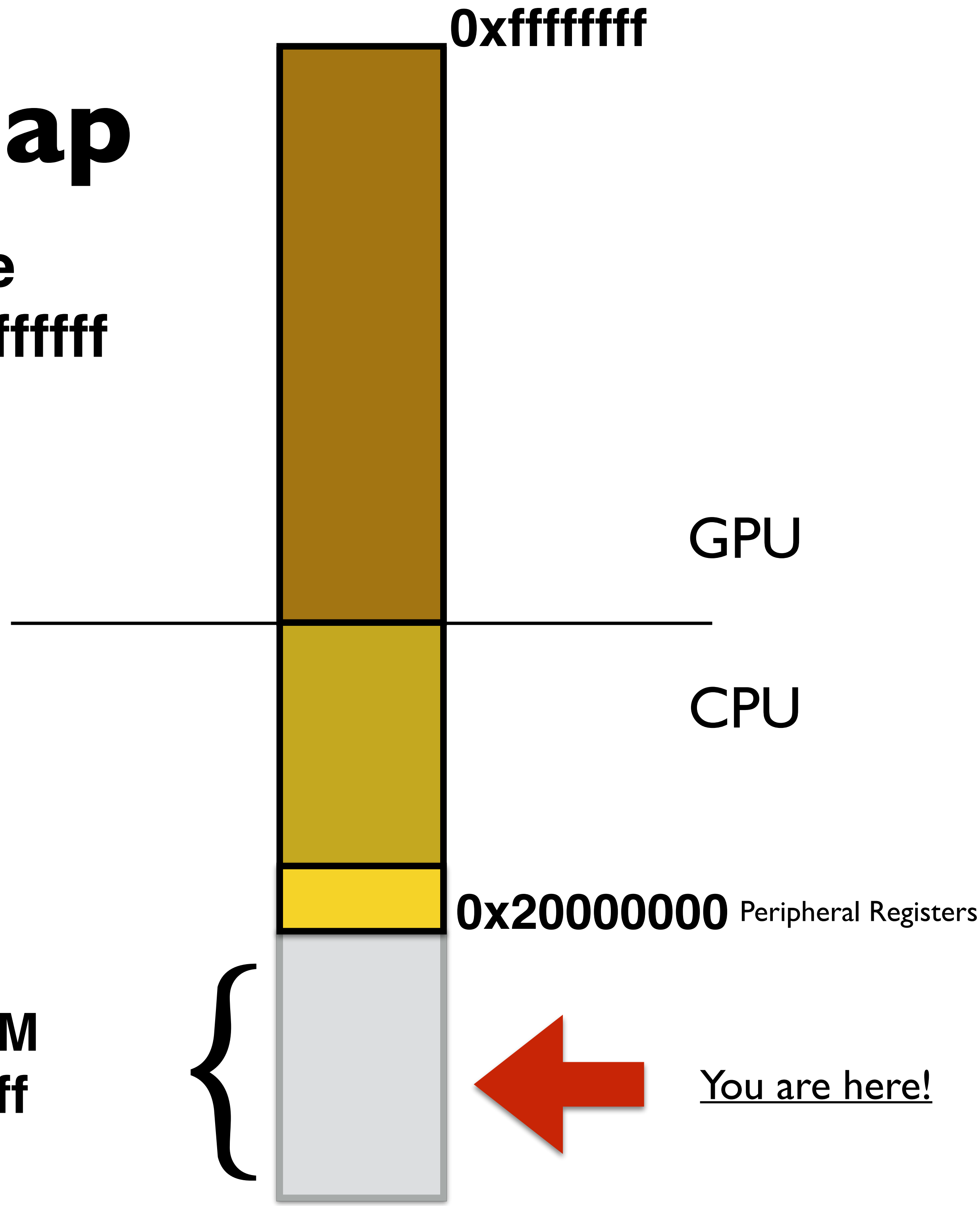
Linking



ld (gcc)

Memory Map

32-bit address space
Addresses 0 to 0xffffffff



512 MB of physical RAM
Addresses 0 - 0x1fffffff

Ref: BCM2835-ARM-Peripherals.pdf

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

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

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

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

0x8000000

Use this memory for heap☞

__bss_end__

(zeroed data) .bss

__bss_start__

(initialized data) .data

(read-only data) .rodata

blink.bin

.text

0x8000

Global allocation

+ **Convenient**

  Fixed location, shared across entire program

+ **Fast, 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 variables can address some issues

  Frowned upon stylistically (advanced systems reasons)

Stack allocation

+ **Convenient**

  Automatic alloc/dealloc on function entry/exit

+ **Fast**

  Fast to allocate/deallocate, good locality

- **Usually don't allocate large chunks (megabytes)**

- **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 also need a heap?

An example:

code/heap/names.c

Dynamic storage

+ Programmer controls scope/lifetime

Versatile, precise

Works for situations where global/stack do not

- Needs software runtime support

Library routines manage the heap memory and

Process allocation/deallocation requests

- C version is low on safety

No type safety (raw void *, number of bytes)

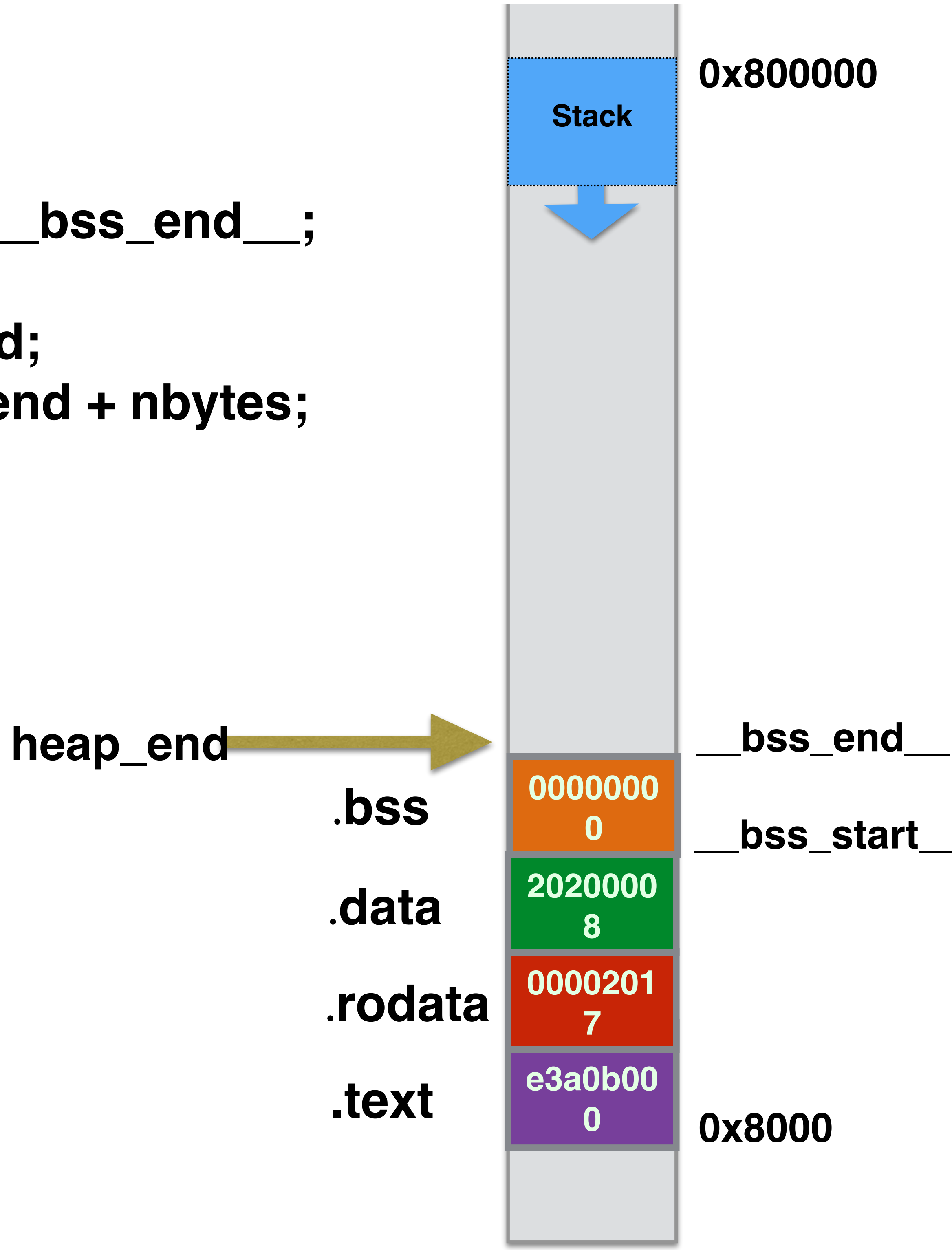
Much opportunity for error

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

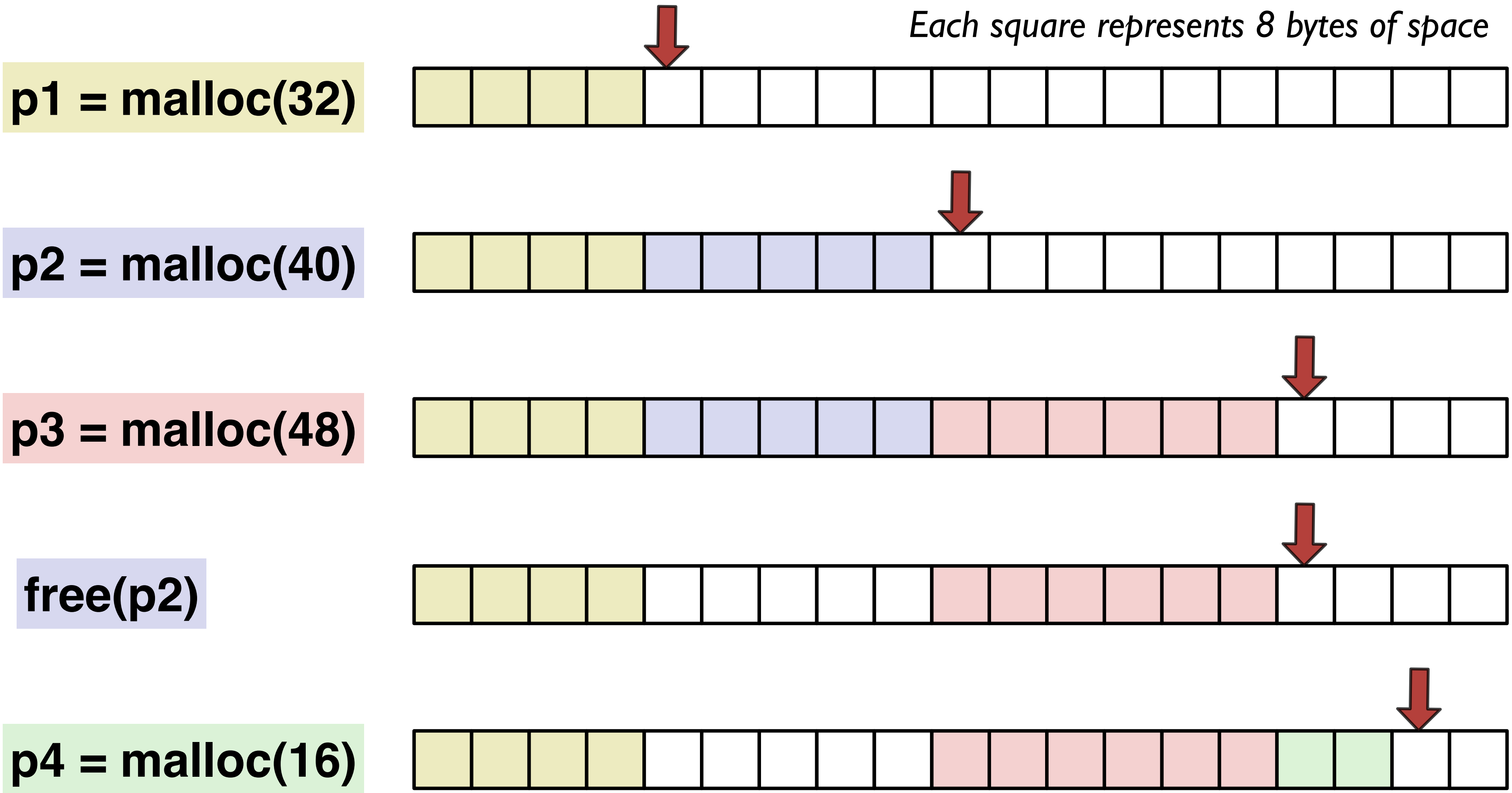
How to implement a heap

```
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?)

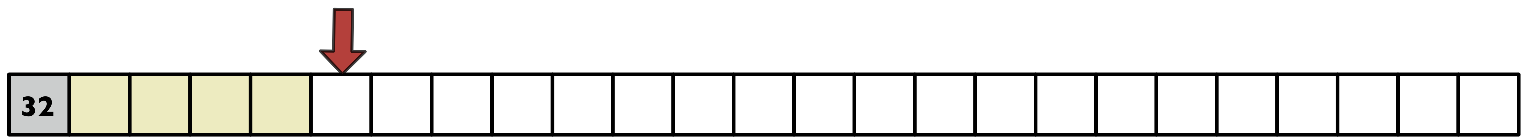
- Sad consequences when **sbrk()** advances into stack

    (what can we do about that?)

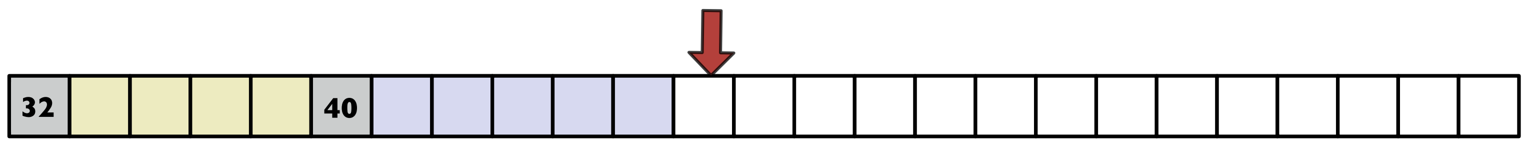
Pre-block header, implicit list

Each square represents 8 bytes, header records size of payload in bytes

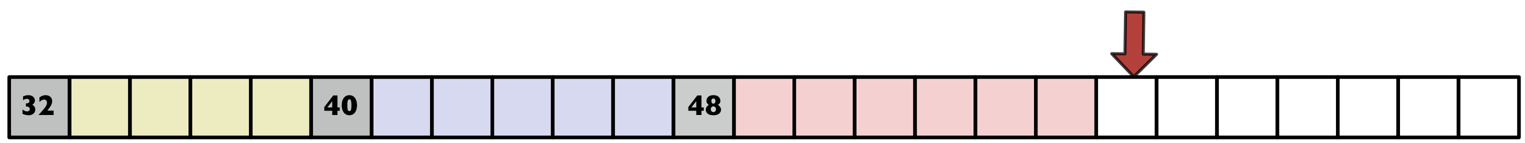
p1 = malloc(32)



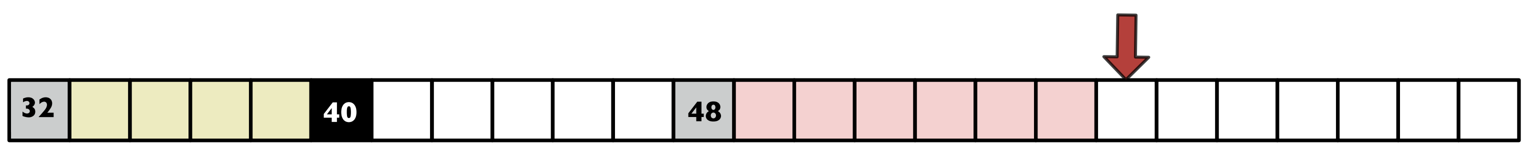
p2 = malloc(40)



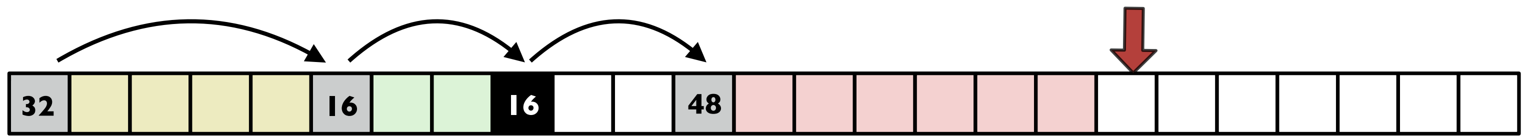
p3 = malloc(48)



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
}
```

Header struct on each block

```
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); // extend end of heap
   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!

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