Memory Management

Sections and memory map
Initializing memory
Heap memory allocation

All of Bare Metal

Processor and memory architecture

Peripherals: GPIO, timers, UART

Assembly language and machine code

From C to assembly language

Functions and stack frames

Serial communication and strings

Modules and libraries

Memory management: the memory map

data/

```c
// initialized variables
int x = 1;
const int x_const = 2;
static int x_static = 3;
static const int x_static_const = 4;

// uninitialized variables (equal to 0)
int y;
const int y_const;
static int y_static;
static const int y_static_const;
```

```
% arm-none-eabi-nm main.o
00000000 T main
         U tricky
         U x
         U x_const
         U y
         U y_const

% arm-none-eabi-nm tricky.o
00000000 T tricky
00000000 D x
00000000 R x_const
00000004 d x_static
00000004 C y
00000004 C y_const
00000000 b y_static
```

Guide to Symbols

T/t - text

D/d - read-write data

R/r - read-only data

B/b - bss (*Block Started by Symbol*)

C - common (instead of B)

lower-case letter means `static`

Data Symbols

Types

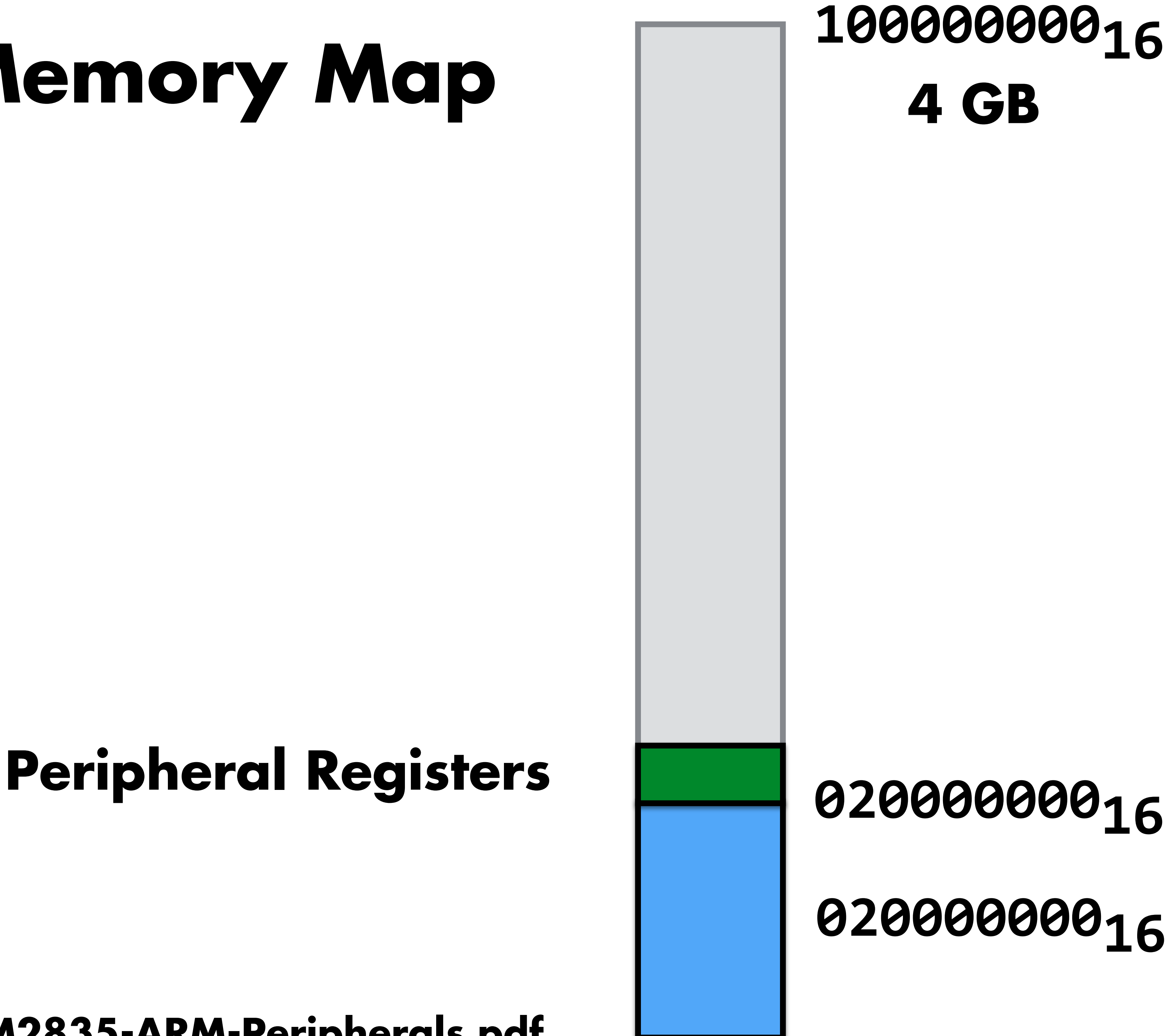
- global vs static
- read-only data vs data
- initialized vs uninitialized data
- common (shared data)

```
.text : {
    start.o (.text)
    *(.text*)
} > ram
.data : { *(.data*) } > ram
.rodata : { *(.rodata*) } > ram
__bss_start__ = .;
.bss : {
    *(.bss*)
    *(COMMON)
} > ram
. = ALIGN(8);
__bss_end__ = .;
```

```
% arm-none-eabi-nm -n main.elf
00008000 T _start
00008008 t hang
0000800c T _cstart
0000805c T tricky
000080a8 T main
00008108 D x
0000810c d x_static
00008110 R x_const
00008114 R __bss_start__
00008114 b y_static
00008118 B y_const
0000811c B y
00008120 B __bss_end__
```

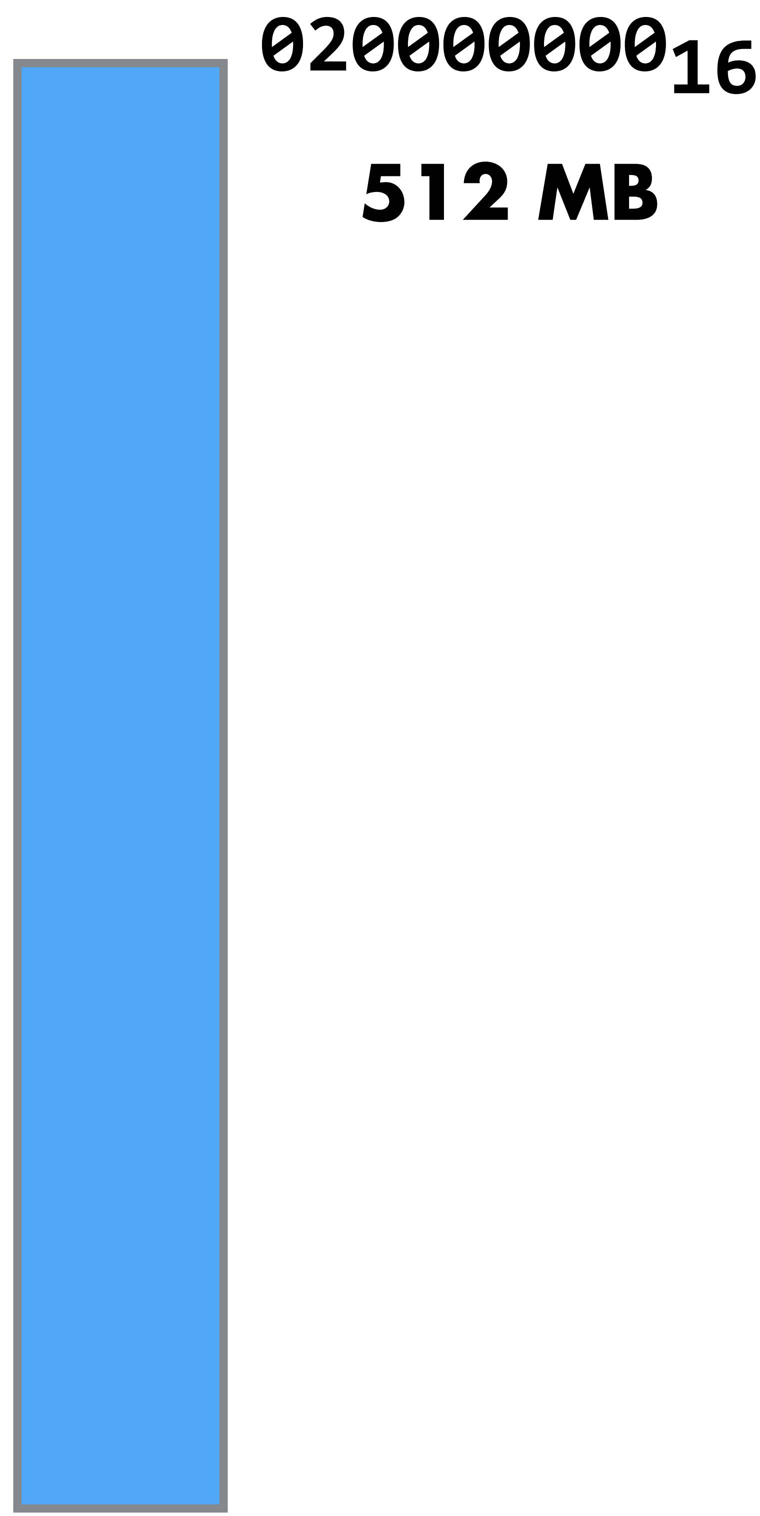
```c
// cstart.c - initializes bss to 0
extern int __bss_start__;
extern int __bss_end__;

void main();

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

Memory Map

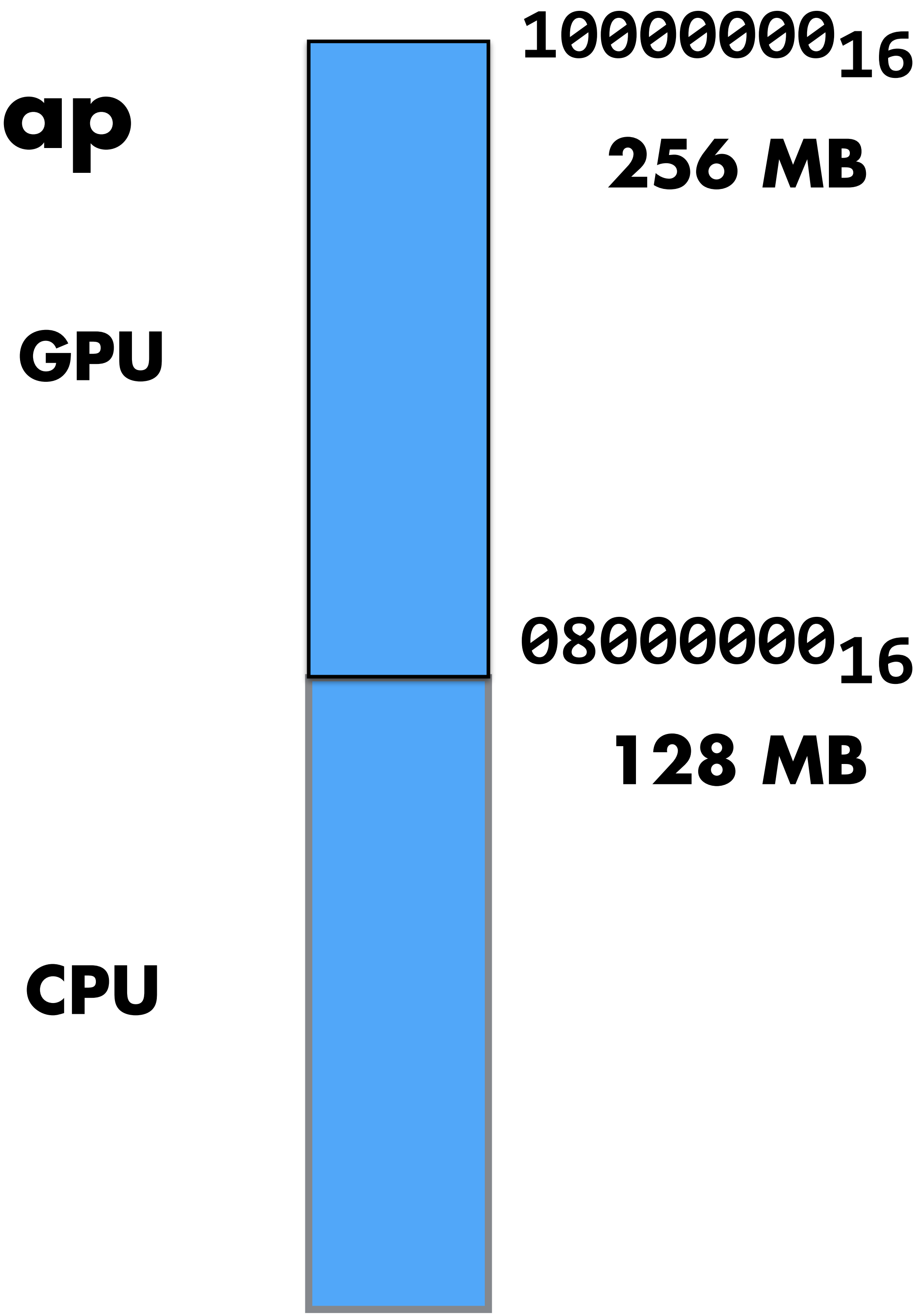


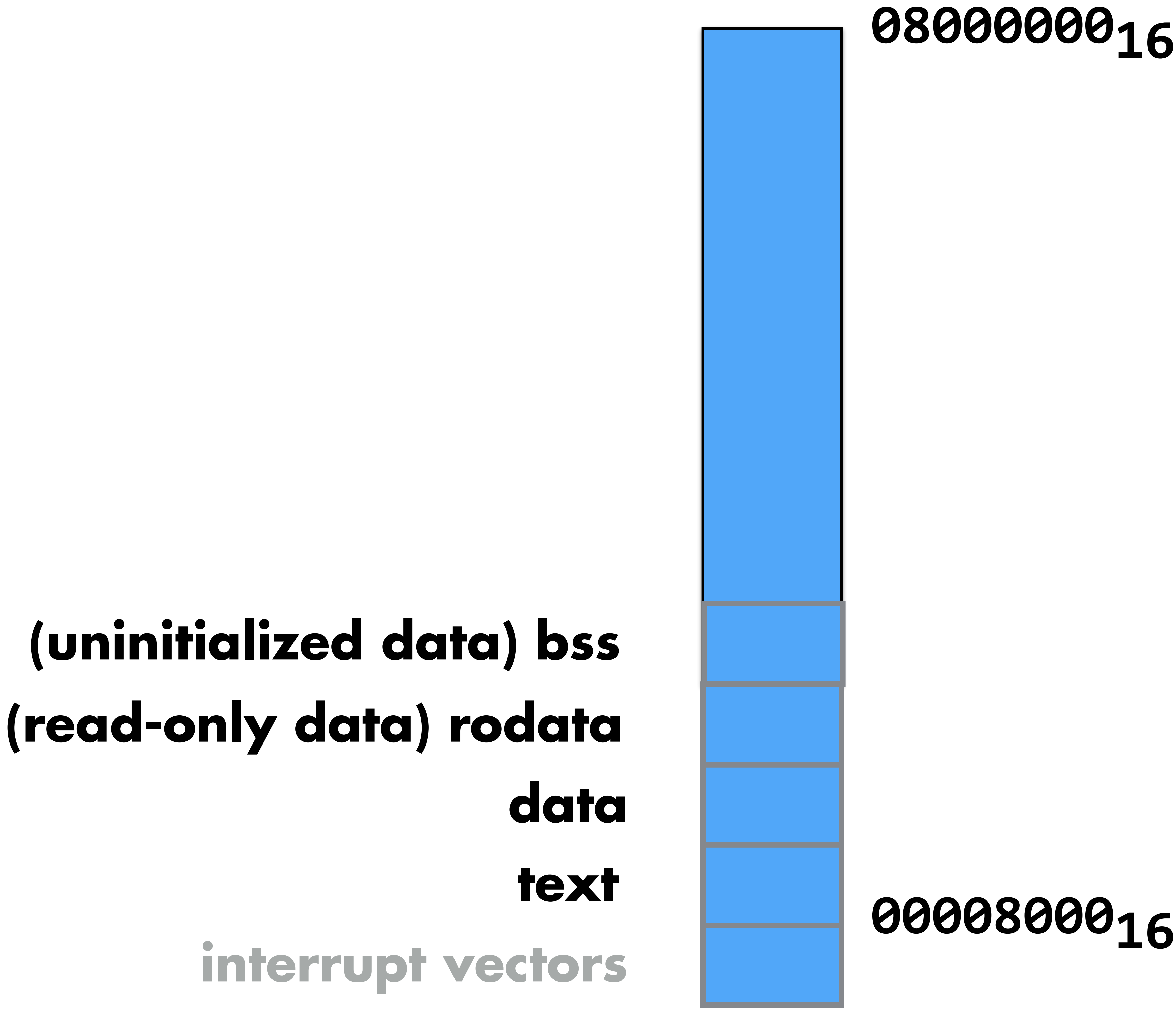
Ref: BCM2835-ARM-Peripherals.pdf

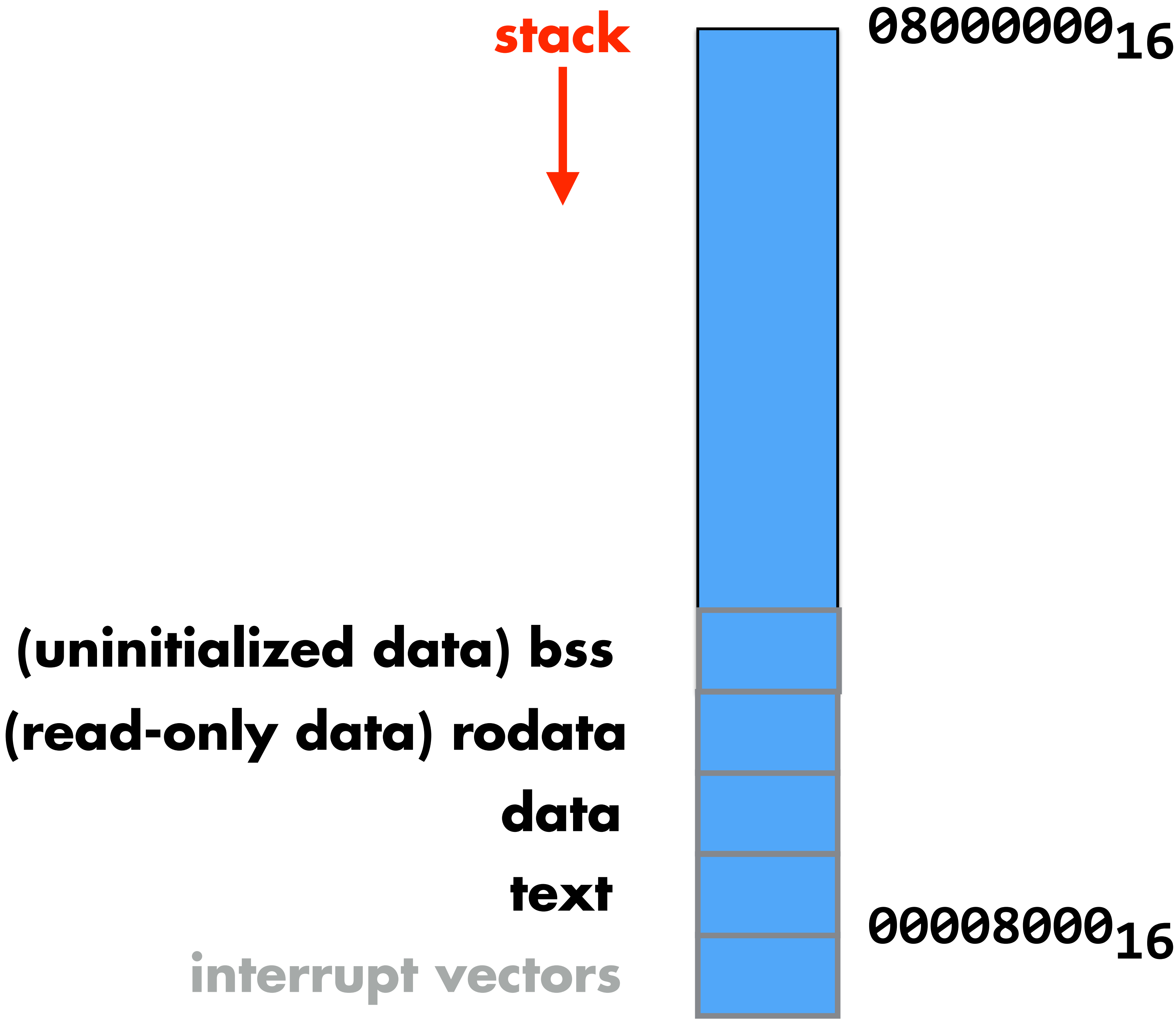
Memory Map

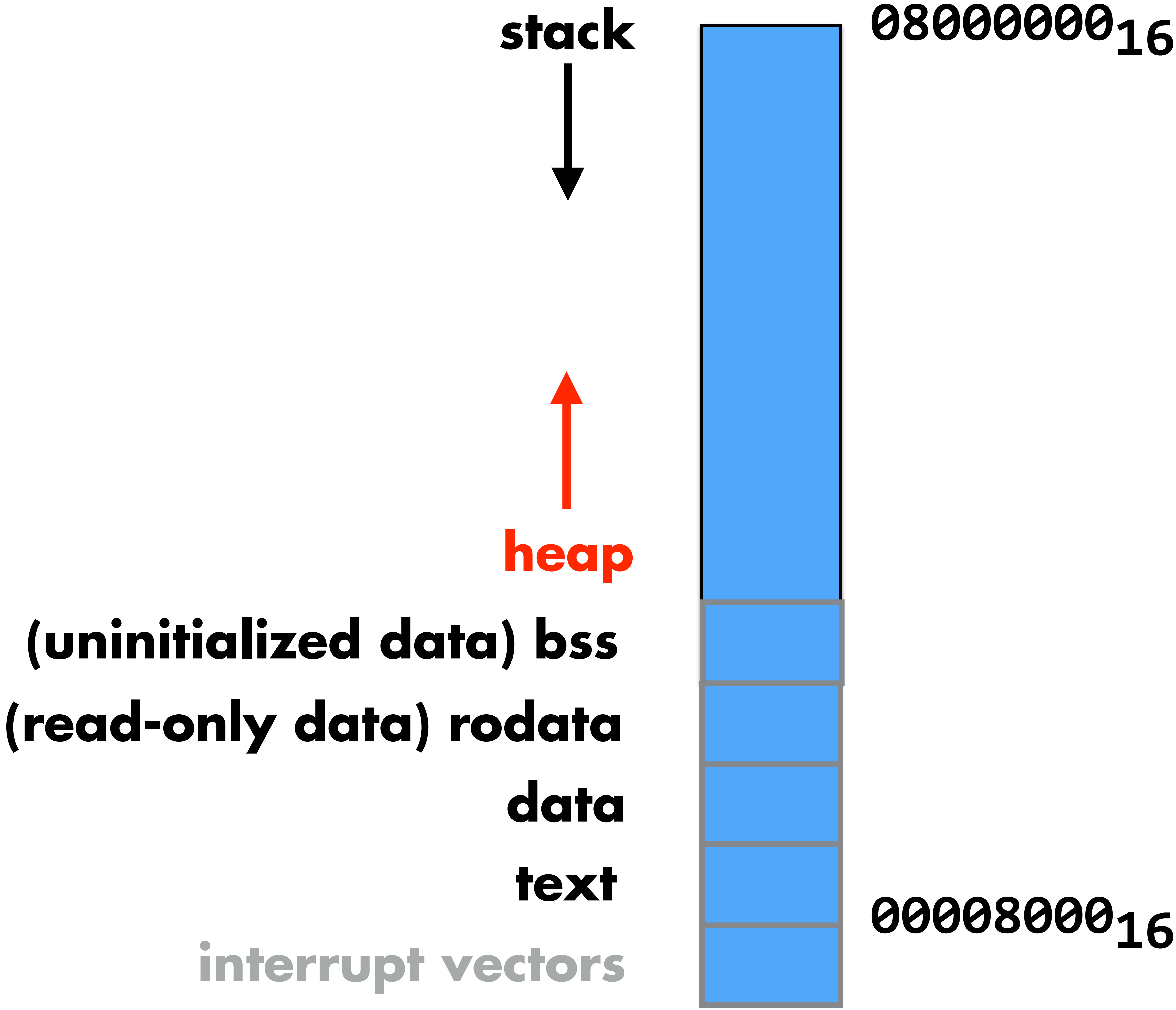


Memory Map




08000000$_{16}$
(uninitialized data) bss
(read-only data) rodata
data
text
00008000$_{16}$
interrupt vectors


stack
08000000₁₆
(uninitialized data) bss
(read-only data) rodata
data
text
00008000₁₆
interrupt vectors



stack
08000000_{16}
heap
(uninitialized data) bss
(read-only data) rodata
data
text
00008000_{16}
interrupt vectors

Heap Memory Allocation

Memory Allocation

Compile-time vs. run-time memory allocation

Why run-time memory allocation?

1. Don't know the size of an array when compiling

2. Dynamic data structures such as strings, lists and trees

Strings

`strings.c`

Bump Memory Allocator

`malloc.c`

API

```
void *malloc( size_t size );
void free( void *pointer );

// Note that void* is a generic pointer
// Note that size_t is for sizes
```

Questions

What happens if you forget to free a pointer after you are done using it?

Can you refer to a pointer after it has been freed?

What is stored in the memory that you malloc?

Calling free with a pointer that you didn't malloc?

Can you free the same pointer twice?

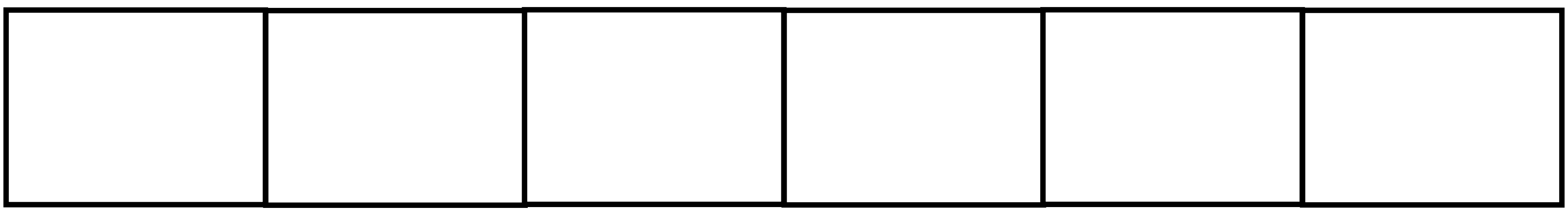
Wouldn't it be nice to not have to worry about freeing memory?

Lists

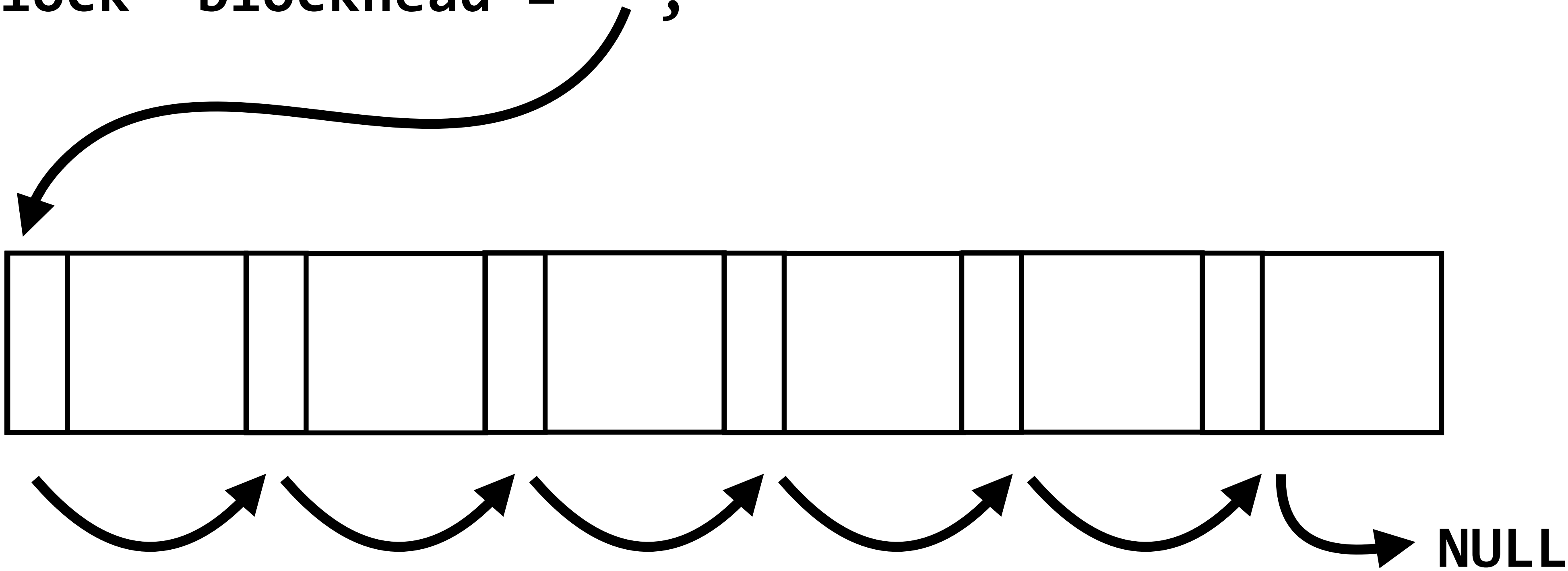
`list.c`

block.c

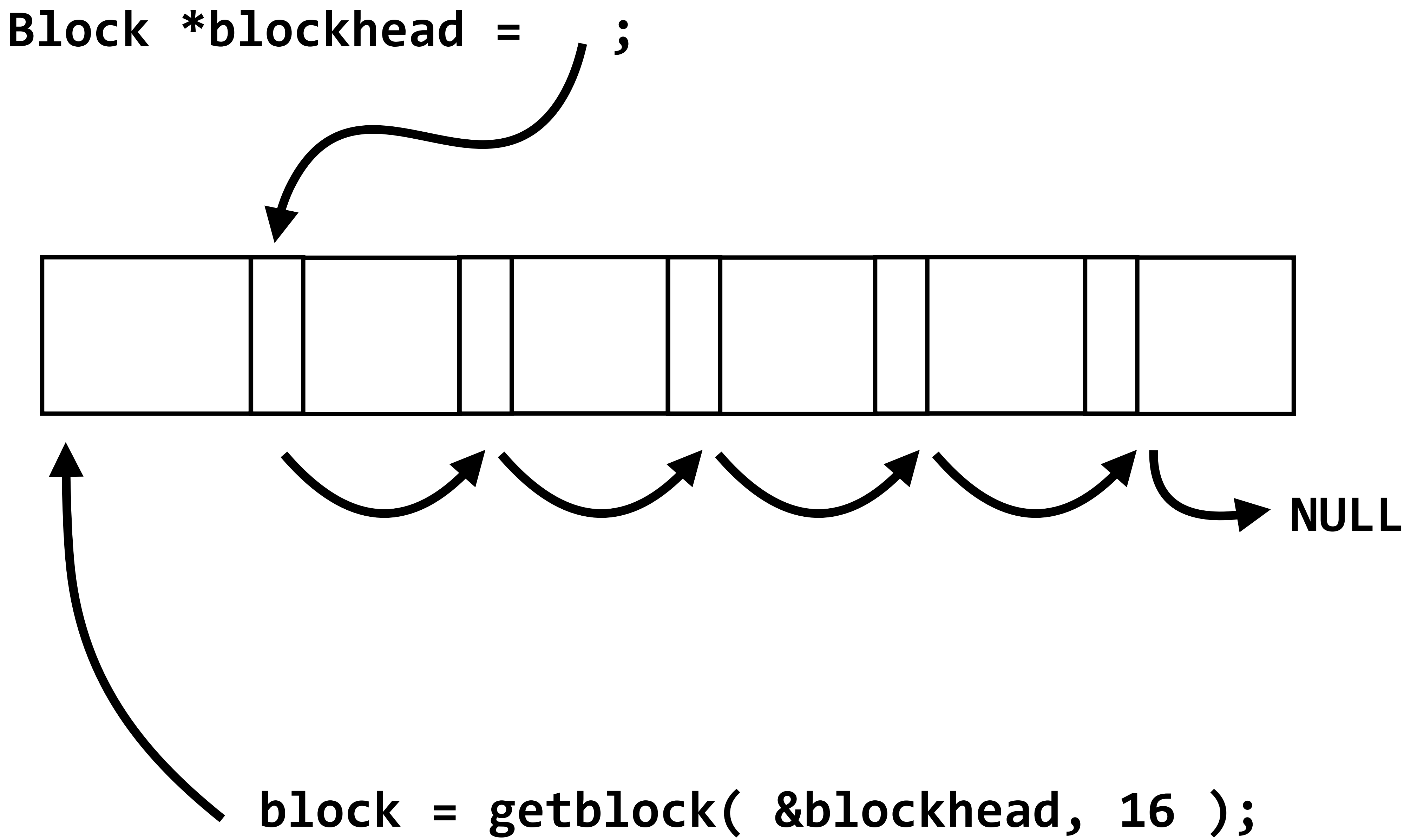
```
newblock( nelements=6, nsize=16 );
```



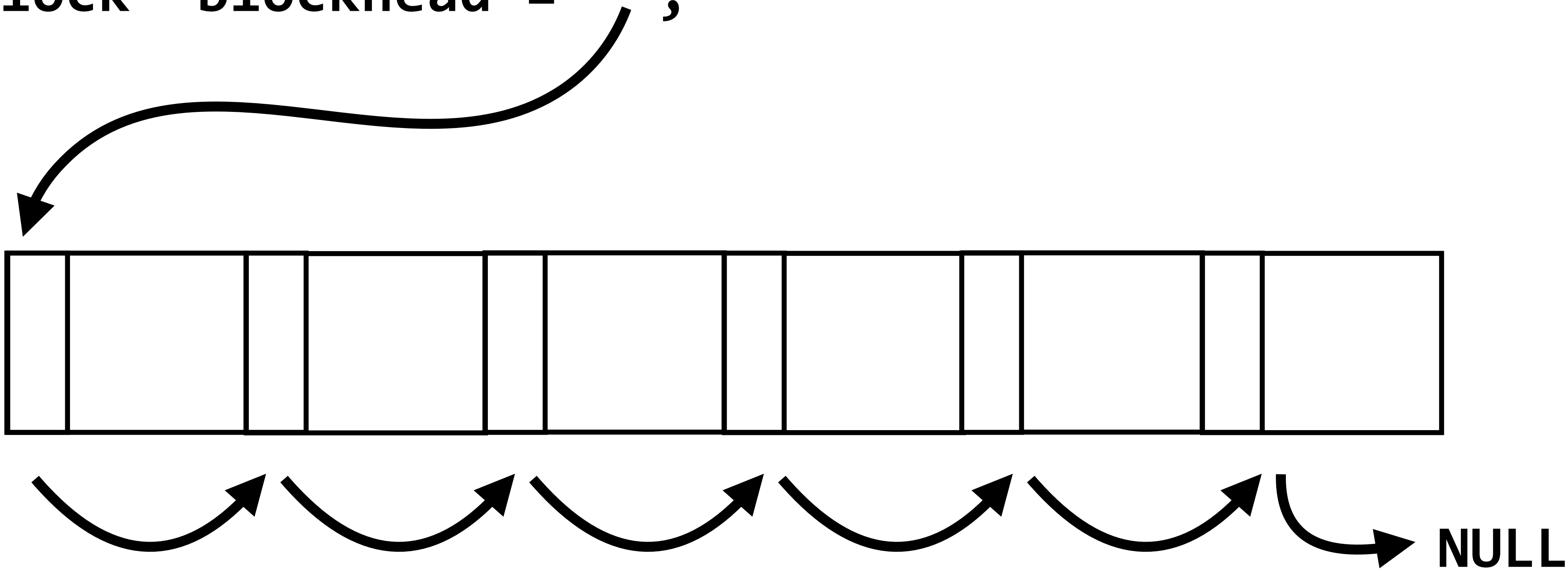
```c
Block *blockhead = ;
```




```c
typedef struct b {
    struct b *next;
} Block;
```


Block *blockhead = ;
NULL
block = getblock(&blockhead, 16);

```
Block *blockhead =   ;
```




```
getblock( &blockhead, block );
```

Variable Size `malloc/free`

just `malloc` is easy 🙂

`malloc` with `free` is hard 🙁

- `free` **returns blocks that can be re-allocated**
- `malloc` **should search to see if there is a block of sufficient size. Which block should it choose (best-fit, first-fit, largest)?**
- `malloc` **may use only some of the block. It splits the block into two sub-blocks of smaller sizes**
- **splitting blocks causes fragmentation**