信息科学与技术学院
School of Information Science and Technology

CS 110 Computer Architecture C Pointers & Array

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Course website: https://toast-lab.sist.shanghaitech.edu.cn/courses/CS110@ShanghaiTech/Spring-2023/index.html

School of Information Science and Technology (SIST)

ShanghaiTech University

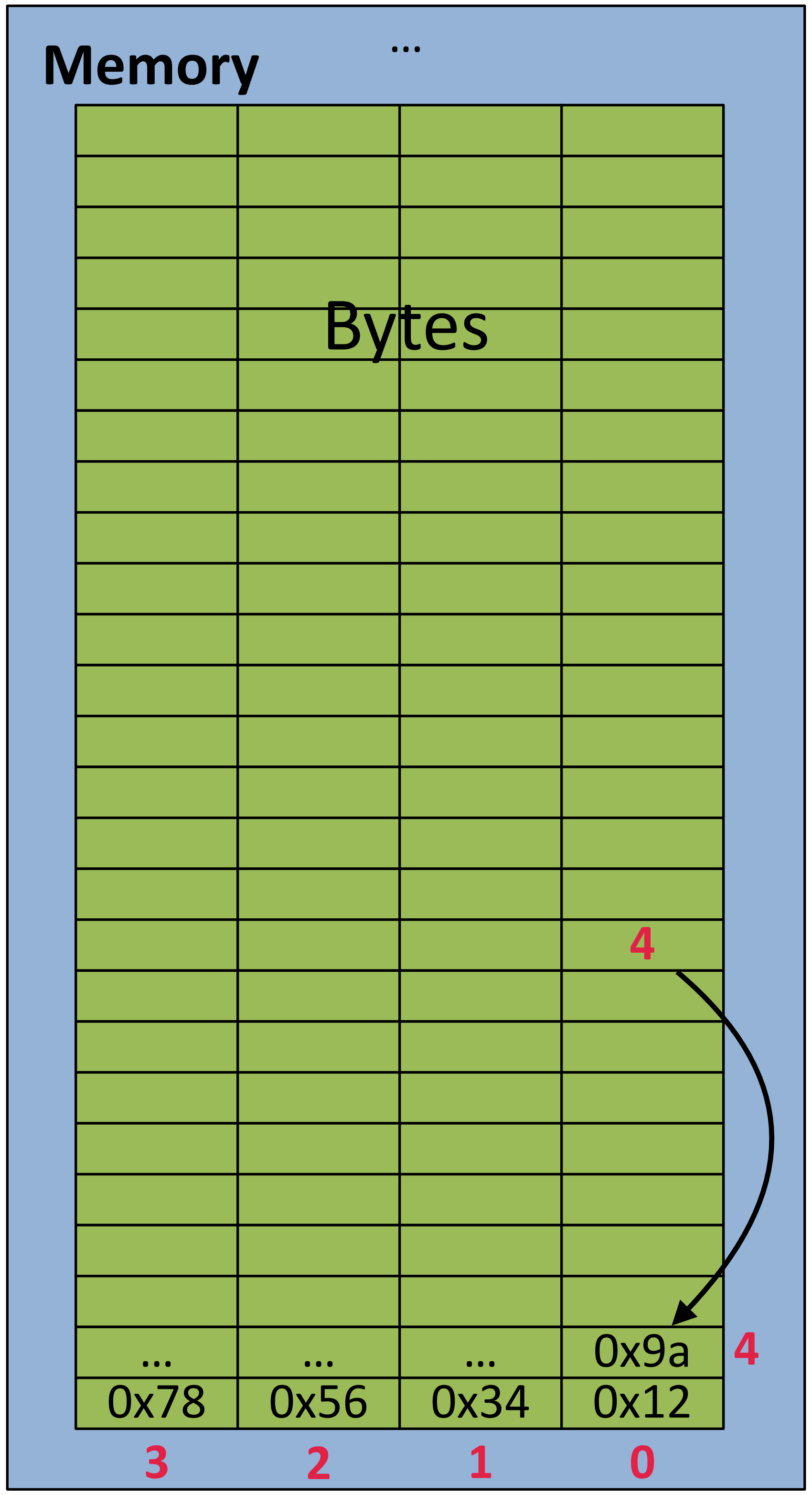
2023/2/6

Outline

- Pointer
- Array
- Memory Management

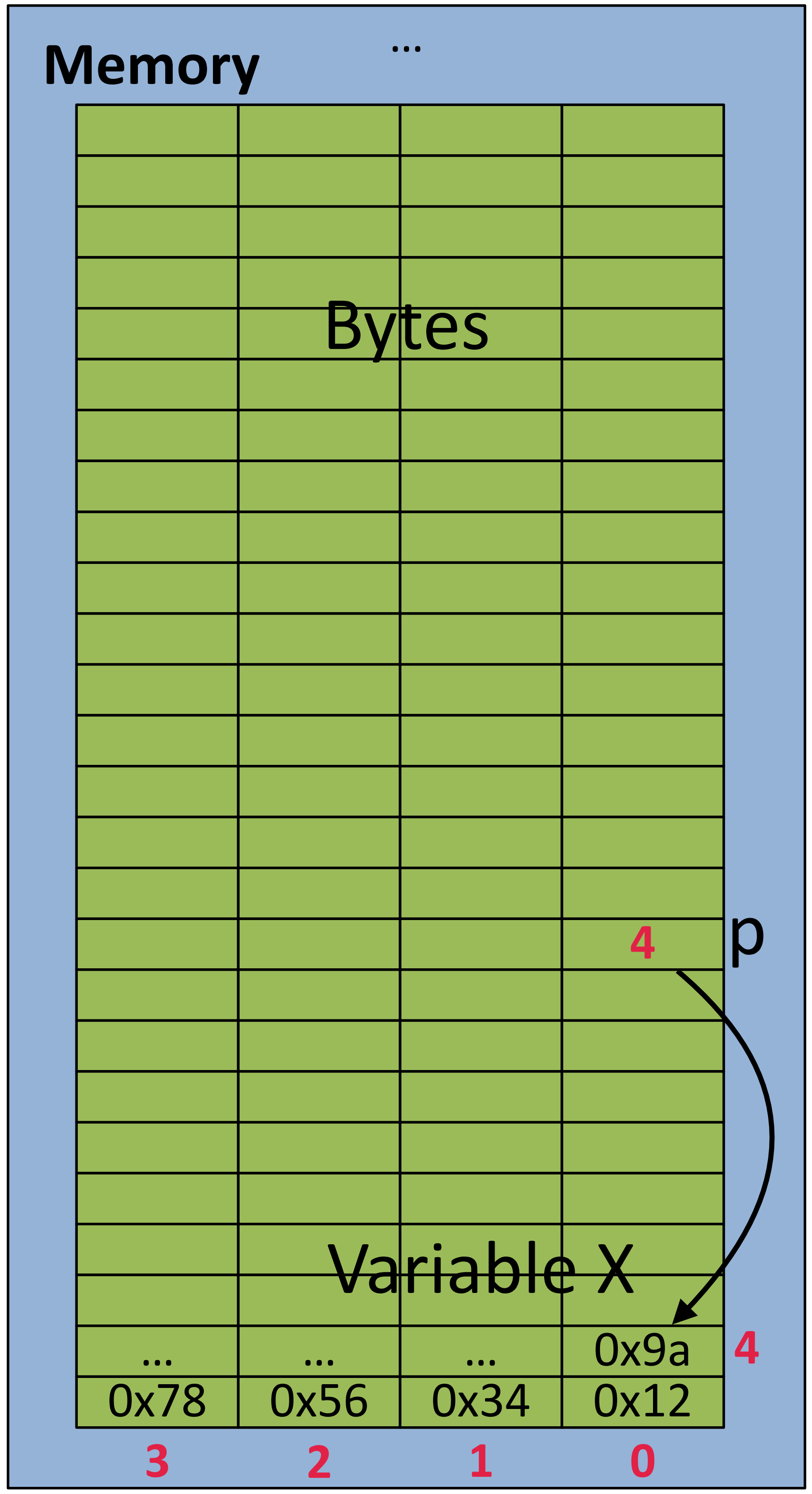
Address vs. Value

- Consider memory to be a single huge array
  - Each cell of the array has an address associated with it
  - Each cell also stores some value
  - For addresses do we use signed or unsigned numbers?
- Don't confuse the address referring to a memory location with the value stored there



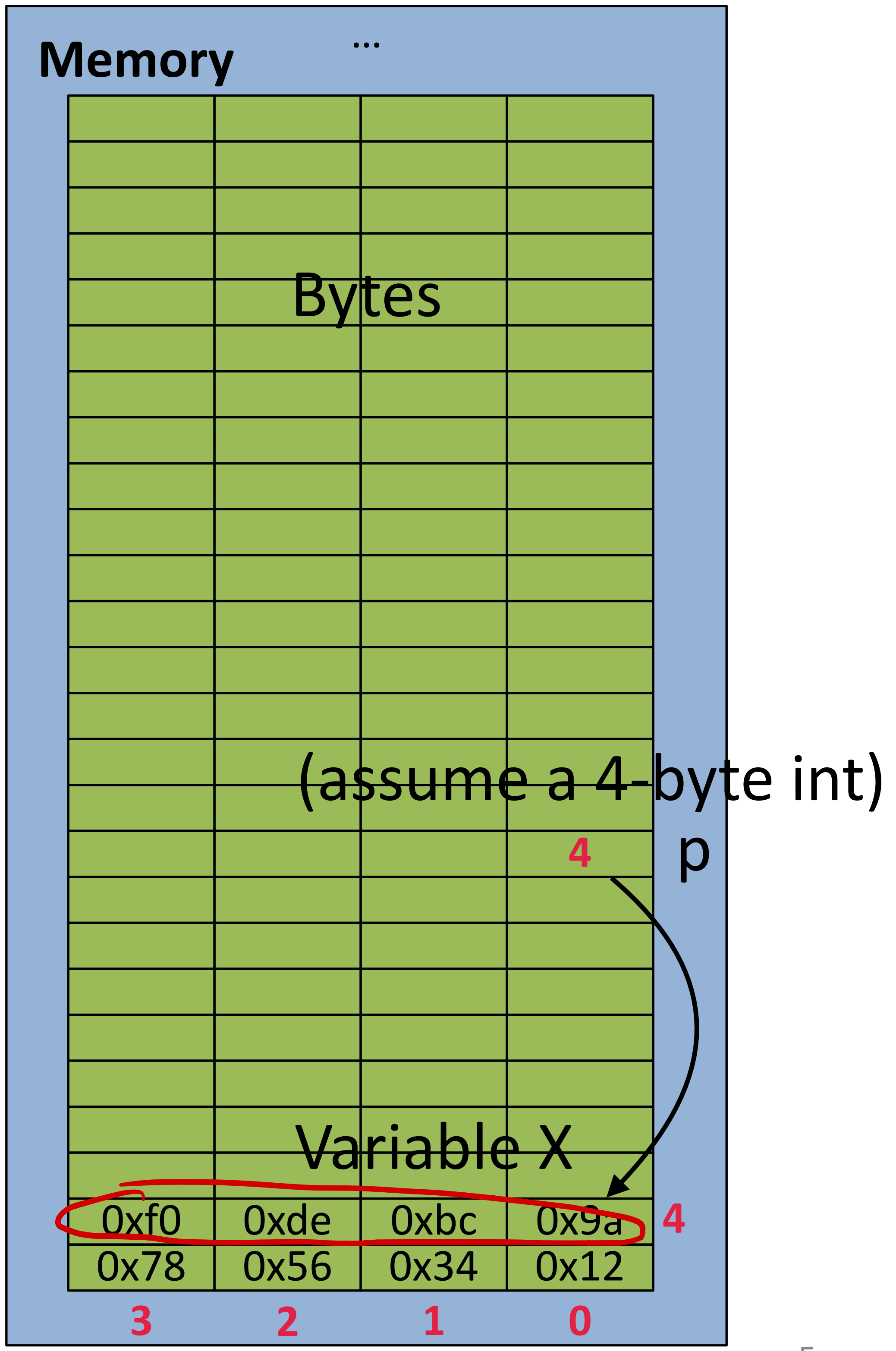
Pointers

- An address refers to a particular memory location; e.g., it points to a memory location
- Pointer: A variable that contains the address of a variable



Pointer Syntax

- `int *p;`
  - Tells compiler that variable p is the address of an `int`
- `p = &X;`
  - Tells compiler to assign address of X to `p`
  - & called the “address operator” in this context
- `z = *p;`
  - Tells compiler to assign value at address p to `z`
  - `*` called the “dereference operator” in this context
- Can point to int/char/struct/function, etc.



小端 ← 0xf0debc9a

大端 → 0x9abcdef0

Creating and Using Pointers

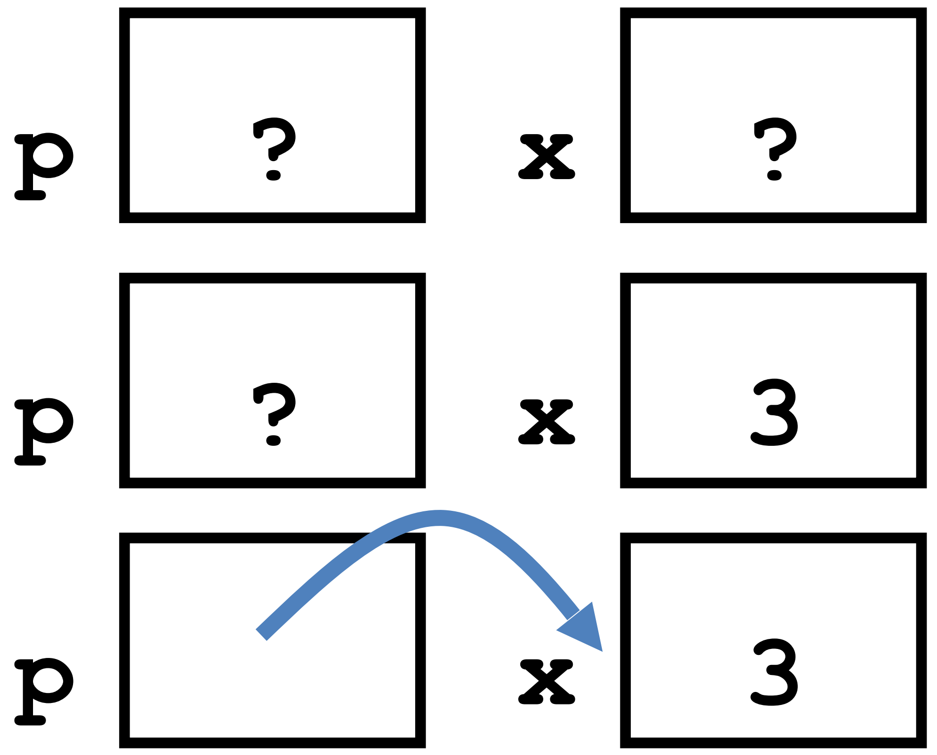
- How to create a pointer:

  `&` operator: get address of a variable

```
int *p, x;

 x = 3;

 p = &x;
```



Note the "`*`" gets used 2 different ways in this example. In the declaration to indicate that **`p`** is going to be a pointer, and in the **`printf`** to get the value pointed to by **`p`**.

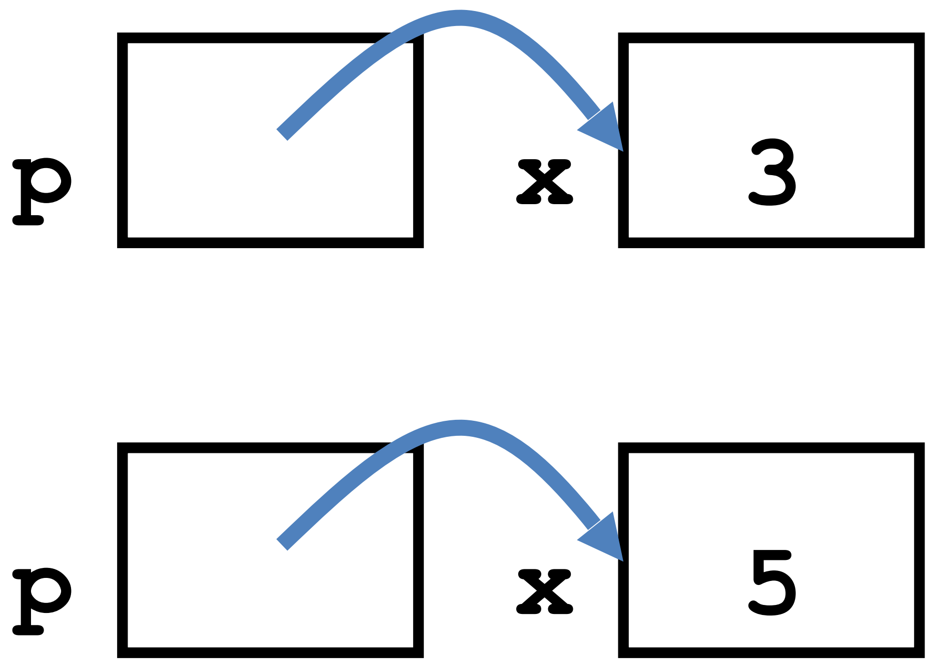
- How to get a value pointed to?

  "*" (dereference operator): get the value that the pointer points to

```
printf("p points to value %d\n",*p);
```

Using Pointer for Writes

- How to change a variable pointed to?
  - Use the dereference operator **`*`** on the left of assignment operator **`=`**



```
*p = 5;
```

Pointers and Parameter Passing

- C passes parameters "by value"
  - Procedure/function/method gets a copy of the parameter, *so changing the copy cannot change the original*

```
void add_one (int x) {
     x = x + 1;
  }
int y = 3;
add_one(y);
```

y remains equal to 3

Pointers and Parameter Passing

- How can we get a function to change the value held in a variable?

```
void add_one (int *p) {
    *p = *p + 1;
  }
int y = 3;

add_one(&y);
```

y is now equal to 4

Types of Pointers

- Pointers are used to point to any kind of data (**`int`**, **`char`**, a **`struct`**, etc.)
- Normally a pointer only points to one type (**`int`**, **`char`**, a **`struct`**, etc.).
  - **`void *`** is a type that can point to anything (generic pointer)
  - Be careful, use **`void *`** sparingly to help avoid program bugs, and security issues, and other bad things!

More C Pointer Dangers

- Declaring a pointer just allocates space to hold the pointer – it does not allocate the thing being pointed to!
- Local variables in C are not initialized, they may contain anything (a.k.a. "garbage")
- What does the following code do?

```
void f()
{
    int *ptr;
    *ptr = 5;
}
```

Undefined Behavior

Not even working in some environments

Pointers and Structures

```
typedef struct {
    int x;
    int y;
} Point;

Point p1;
Point p2;
Point *paddr;

p1 = {1,2};
```

```
/* dot notation */
int h = p1.x;
p2.y = p1.y;

/* arrow notation */
int h = paddr->x;
int h = (*paddr).x;

/* This works too */
p1 = p2;
```

Pointers in C

- Why use pointers?
  - If we want to pass a large struct or array, it's easier/faster/etc. to pass a pointer than the whole thing
  - In general, pointers allow cleaner, more compact code
- So what are the drawbacks?
  - Pointers are probably the single largest source of bugs in C, so be careful anytime you deal with them
    - Most problematic with dynamic memory management—coming up soon
    - Dangling references and memory leaks

Why Pointers in C?

- At time C was invented (early 1970s), compilers often didn't produce efficient code
  - Computers 100,000 times faster today, compilers better
- C designed to let programmer say what they want code to do without compiler getting in way
  - Even give compilers hints which registers to use!
- Today's compilers produce much better code, so may not need to use pointers in application code
- Low-level system code still needs low-level access via pointers

Course Info

- HW1 due today! HW2 will be available very soon (see piazza & course webpage). Lab 2 will be available this Friday.
- Find a lab-mate in the same lab session, two students in a group, and Sunday deadline approaching!
- Lab 1 is available and in this week's Lab session
- Lab & Discussion (see webpage, this Friday, VMware/ Ubuntu linux, etc.) starts this week.
- **Webpage: https://toast-lab.sist.shanghaitech.edu.cn/courses/CS110@ShanghaiTech/Spring-2023/index.html**
- Discussion next week: Venus (for RISC-V), Memory Management & debug

Outline

- Pointer
- Array
- Memory Management

C Arrays

- Declaration:

```
int ar[2];
```

declares a 2-element integer array: just a block of memory

```
int ar[] = {795, 635};
```

declares and initializes a 2-element integer array

- Must specify size (or provide info. that can infer the size)

C Strings

char *p = "abc"
p → static 区

- String in C is just an array of characters

  `char string[] = "abc";` ← sizeof( ) = 4

- How do you tell how long a string is?
  - Last character is followed by a $\boxed{\text{'\textbackslash 0'}}$ (NULL) byte (a.k.a. "null terminator") (RTFM) '\0' = 0

```
int strlength(char s[])
{
    int n = 0;
    while (s[n] != 0)
      n++;
    return n;
}
```

```
Finally, the declaration

        char s[] = "abc", t[3] = "abc";

defines ``plain'' char array objects s and t
whose members are initialized with character
string literals. This declaration is identical to

        char s[] = { 'a', 'b', 'c', '\0' },
                 t[] = { 'a', 'b', 'c' };
```

error →

无'\0'

sizeof(t)=3

Array Name/Pointer Duality

- Key Concept: Array variable is a "pointer" to the first (lowest addressed, i.e., 0th) element
- So, array variables almost identical to pointers
  - **`char *string`** and **`char string[]`** are nearly identical declarations
  - Differ in subtle ways: incrementing, declaration of filled arrays
- Consequences:
  - **`ar`** is an array variable, but works like a pointer
  - **`ar[0]`** is the same as **`*ar`**
  - **`ar[2]`** is the same as **`*(ar+2)`**
  - Can use pointer arithmetic to conveniently access arrays

Array Name/Pointer Duality

- Be really careful!

```
char string1[] = "abc";  <=> string1[]={'a','b','c','\0'}
char *string2 = "abc";   <=> const char string2[]
```

- **CAN** modify string1[*]
- **CANNOT** modify string2[*]
- **CAN** access string2 by string2[*]

Array Name/Pointer Duality

- Be really careful!

```
int arr[] = { 3, 5, 6, 7, 9 };
int *p = arr;                      int *p = &arr; X
int (*p1)[5] = &arr; ✓
    指向数组的指针
5个指针的数组 → int *p2[5];
int *p3(void);
    指向函数的指针
```

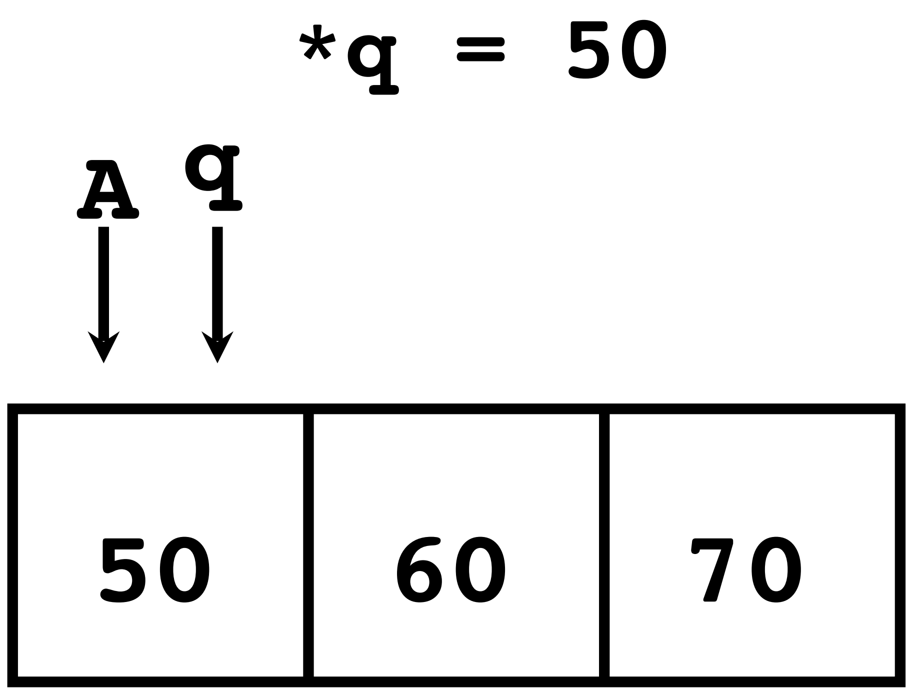
- Read More: C manual 3.5.5 Type names!

Changing a Pointer Argument?

- What if want function to change a pointer?
- What gets printed?

```
void inc_ptr(int *p)
{    p =  p + 1;    }
         无效

int A[3] = {50, 60, 70};
int *q = A;
inc_ptr( q);
printf( "q = %d\n",*q);
```



Pointer to a Pointer

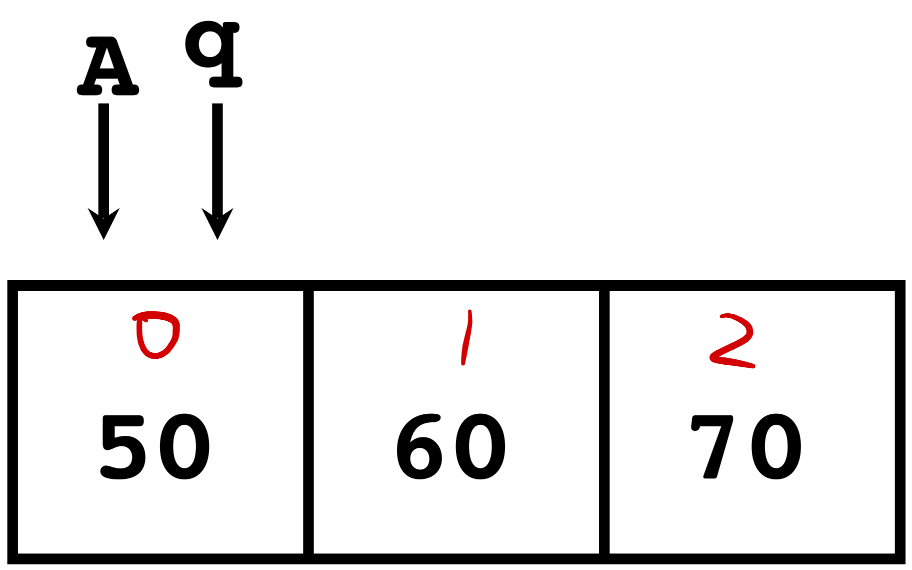
- Solution! Pass a pointer to a pointer, declared as `**h`
- Now what gets printed?

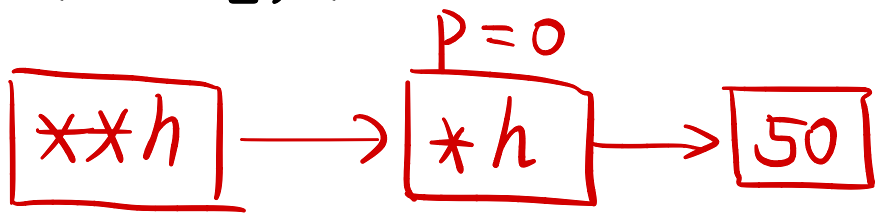
Pointer to pointer to an int

```
void inc_ptr(int **h)
{    *h = *h + 1;    }

int A[3] = {50, 60, 70};
int *q = A;
inc_ptr(&q);
printf("*q = %d\n", *q);
```

```
*q = 60
```





C Arrays are Very Primitive

- An array in C does not know its own length, and its bounds are not checked!
  - Consequence: We can accidentally access off the end of an array
  - Suggestion: We must pass the array and its size to any procedure that is going to manipulate it
- Out of boundary errors:
  - These are VERY difficult to find;
    Be careful!

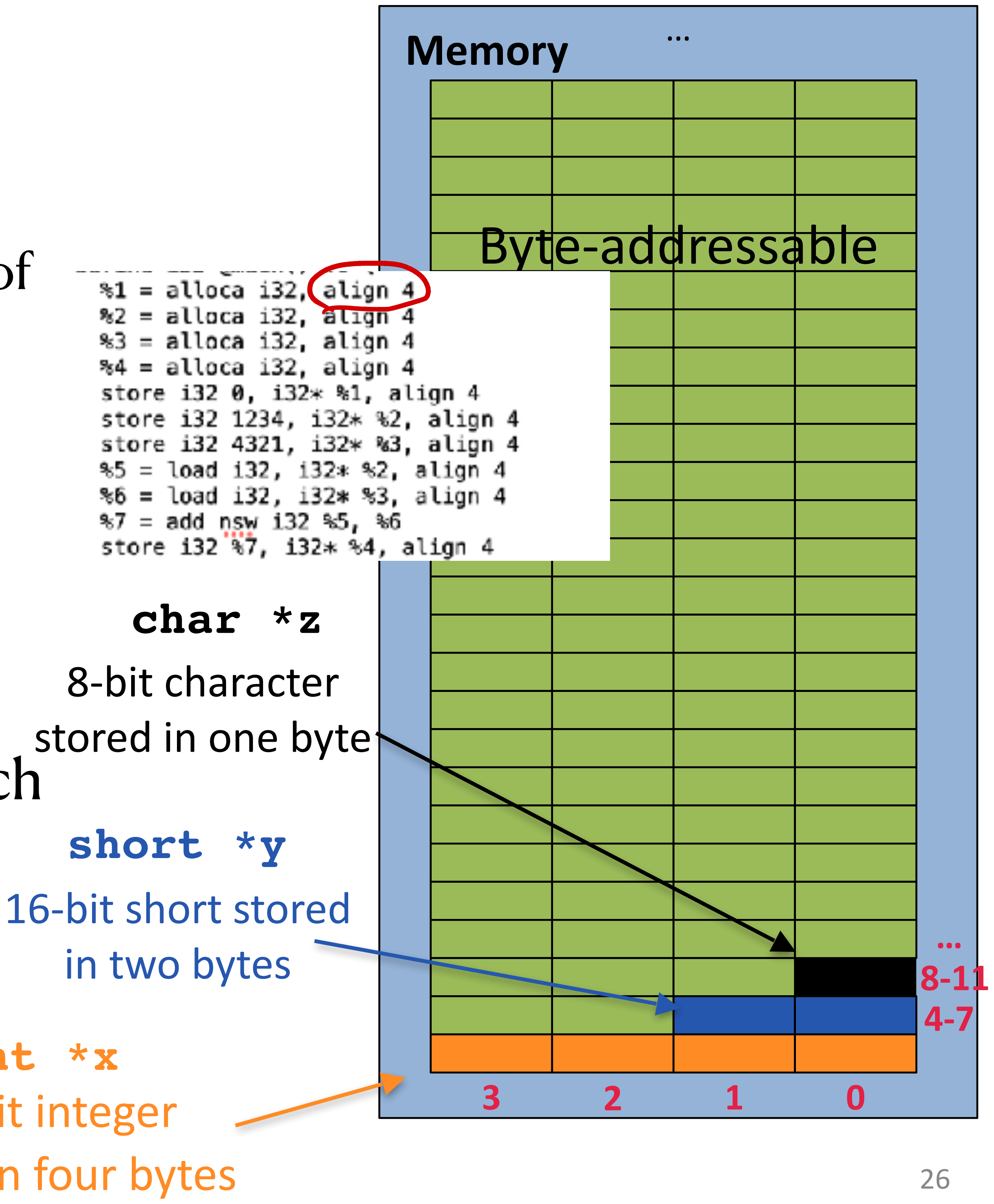
Use Defined Constants

- Array size *n*; want to access from 0 to *n*-1, so you should use counter AND utilize a variable for declaration & incrementation
  - Bad pattern
    ```
    int i, ar[10];
    for(i = 0; i < 10; i++){ ... }
    ```
  - Better pattern
    ```
    const int ARRAY_SIZE = 10;
    int i, a[ARRAY_SIZE];
    for(i = 0; i < ARRAY_SIZE; i++){ ... }
    ```

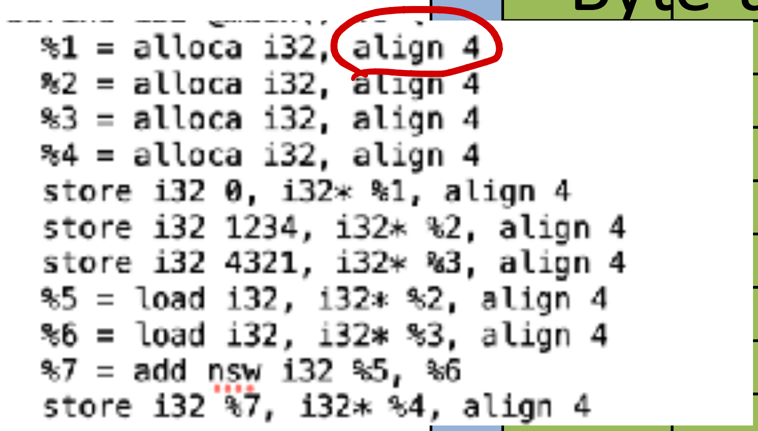
- SINGLE SOURCE OF TRUTH
  - You avoid maintaining two copies of the number 10
  - DRY: "Don't Repeat Yourself"

Pointing to Different Size Objects

- Modern machines are "byte-addressable"
  - Hardware's memory composed of 8-bit storage cells, each has a unique address
- A C pointer is just abstracted memory address
- Type declaration tells compiler how many bytes to fetch on each access through pointer
  - E.g., 32-bit integer stored in 4 consecutive 8-bit bytes
- Alignment



Memory
…
Byte-addressable
char *z
8-bit character stored in one byte
short *y
16-bit short stored in two bytes
int *x
32-bit integer stored in four bytes
…
8-11
4-7
3
2
1
0



```
%1 = alloca i32, align 4
%2 = alloca i32, align 4
%3 = alloca i32, align 4
%4 = alloca i32, align 4
store i32 0, i32* %1, align 4
store i32 1234, i32* %2, align 4
store i32 4321, i32* %3, align 4
%5 = load i32, i32* %2, align 4
%6 = load i32, i32* %3, align 4
%7 = add nsw i32 %5, %6
store i32 %7, i32* %4, align 4
```

sizeof() operator

不是 function

compile-time 完成

- sizeof(type) returns number of bytes in object
  - But number of bits in a byte is not standardized
    - In olden times, when dragons roamed the earth, bytes could be 5, 6, 7, 9 bits long
- By definition, sizeof(char)==1
- Can take sizeof(variable), or sizeof(type)
- We'll see more of sizeof when we look at dynamic memory management

Pointer Arithmetic

pointer + number   *pointer – number*

e.g., *pointer* `+ 1`   adds 1 to a pointer, used in array access

```
char   *p;
char    a;
char    b;

p = &a;
p += 1;
```

In each, p now points to b

(Assuming compiler doesn't reorder variables in memory. **Never code like this!!!!**)

```
int   *p;
int    a;
int    b;

p = &a;
p += 1;
```

Adds `1*sizeof(char)` to the memory address

Adds `1*sizeof(int)` to the memory address

Pointer arithmetic should be used cautiously

Arrays and Pointers

- Array ≈ pointer to the initial (0th) array element

  `a[i]` ≡ **`(*(a+(i)))`**

- An array is passed to a function as a pointer
  - The array size is lost!

- Usually bad style to interchange arrays and pointers
  - Avoid pointer arithmetic!

Passing arrays

Really **`int *array`**

Must explicitly pass the size

```
int
foo(int array[],
    unsigned int size)
{
   … array[size - 1] …
}

int
main(void)
{
   int a[10], b[5];
   … foo(a, 10)… foo(b, 5) …
}
```

Arrays and Pointers

```
int
foo(int array[],
    unsigned int size)
{
   …
   printf("%d\n", sizeof(array));
}

int
main(void)
{
   int a[10], b[5];
   … foo(a, 10)… foo(b, 5)  …
   printf("%d\n", sizeof(a));

}
```

指針的大小，不是array的

⇑

Compiler time operator

What does this print (32-bit address)? **4**

... because **`array`** is really a pointer (and a pointer is architecture dependent, but likely to be 8 on modern machines!)

What does this print (32-bit int)? **40**

Arrays and Pointers

```
int  i;
int  array[10];

for (i = 0; i < 10; i++)
{
  array[i] = …;
}
```

```
int *p;
int  array[10];

for (p = array; p < &array[10]; p++)
{
  *p = …;
}
```

These code sequences have the same effect!

Concise strlen()

```
int(long) strlen(char *s)
{   char *p = s;
    while (*p++)
            ; /* Null body of while */
    return (p - s - 1);
}
```

What happens if there is no zero character at end of string?

Point past end of array?

- Array size n; want to access from 0 to n-1, but test for exit by comparing to address one element past the last member of the array

ar[10] valid

```
int ar[10]={},*p, *q, sum=0;
p = &ar[0]; q = &ar[10];
while (p!=q) /* sum = sum+*p; p = p+1*/
    sum += *p++;
```

- C defines that one element past end of array must be a valid address, i.e., not causing an error

Valid Pointer Arithmetic

- Add an integer to a pointer.
- Subtract 2 pointers (pointed to the same array/object)
- Compare pointers (<, <=, ==, !=, >, >=)
- Compare pointer to NULL (indicates that the pointer 0x0)

Everything else illegal since makes no sense:

- adding two pointers
- multiplying pointers
- subtract pointer from integer
- etc.

Arguments in `main()`

- To get arguments to the main function, use: 字符串指针的数组
  - `int main(int argc, char *argv[])`
- What does this mean? 无操作系统时，可以没有 main
  - `argc` contains the number of strings on the command line (the executable counts as one, plus one for each argument). Here `argc` is 5:

    ```
    % clang -ansi introC_1_1.c -o introC_1_1.out
    ```

  - `argv` is a pointer to an array containing the arguments as strings

Example

% clang -ansi introC_1_1.c -o introC_1_1.out

- `argc = 5 /* number arguments */`

-
  ```
  argv[0] = "clang",
  argv[1] = “-ansi",
  argv[2] = “introC_1_1.c”,
  argv[3] = “-o”,
  argv[4] = “introC_1_1.out”,
  ```
  - Array of pointers to strings

指针

Summary

- "Lowest High-level language"
  - Use ANSI C89 in class
  - => closest to assembler
- Pointers: powerful but dangerous
- Pointer arithmetic and arrays useful but also dangerous

Summary

- Pointers and arrays are virtually same
- C knows how to increment pointers
- C is an efficient language, with little protection
    - Array bounds not checked
    - Variables not automatically initialized
- (Beware) The cost of efficiency is more overhead for the programmer.

  "C gives you a lot of extra rope but be careful not to hang yourself with it!"

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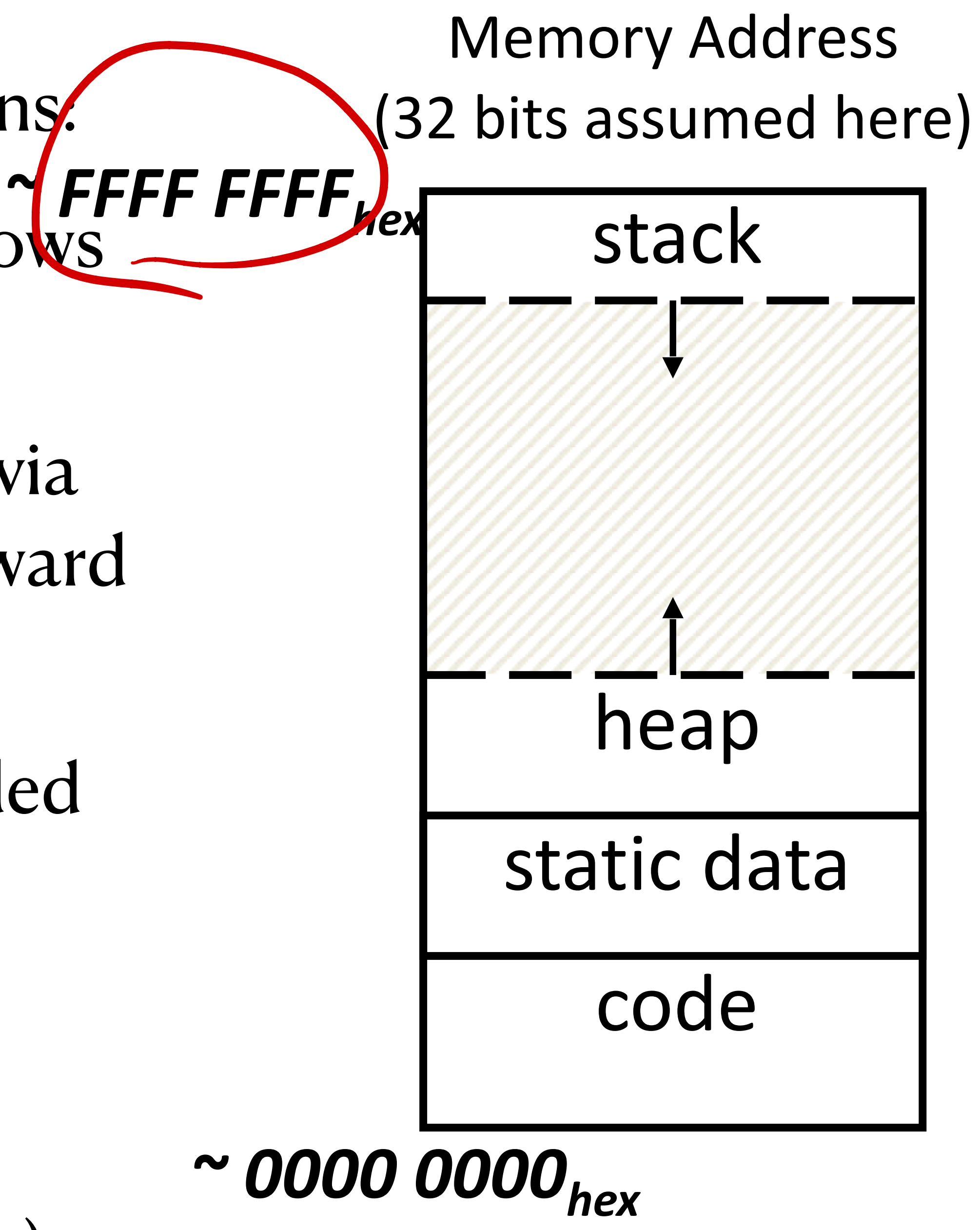
C Memory Management

- To simplify, assume one program runs at a time
- A program's address space contains 4 regions:
  - stack: local variables inside functions, grows downward
  - 可人为管理
  - heap: space requested for dynamic data via `malloc`(); resizes dynamically, grows upward
  - static data: variables declared outside functions, does not grow or shrink. Loaded when program starts, can be modified.
  - code (a.k.a. text): loaded when program starts, does not change
  - 0x0 unwritable/unreadable (NULL pointer)

static



Where are Variables Allocated?

- If declared $\boxed{\text{outside a function}}$, allocated in "static" storage
- If declared inside function, allocated on the "stack" and freed when function returns
    - `main()` is treated like a function

全局变量在静态区

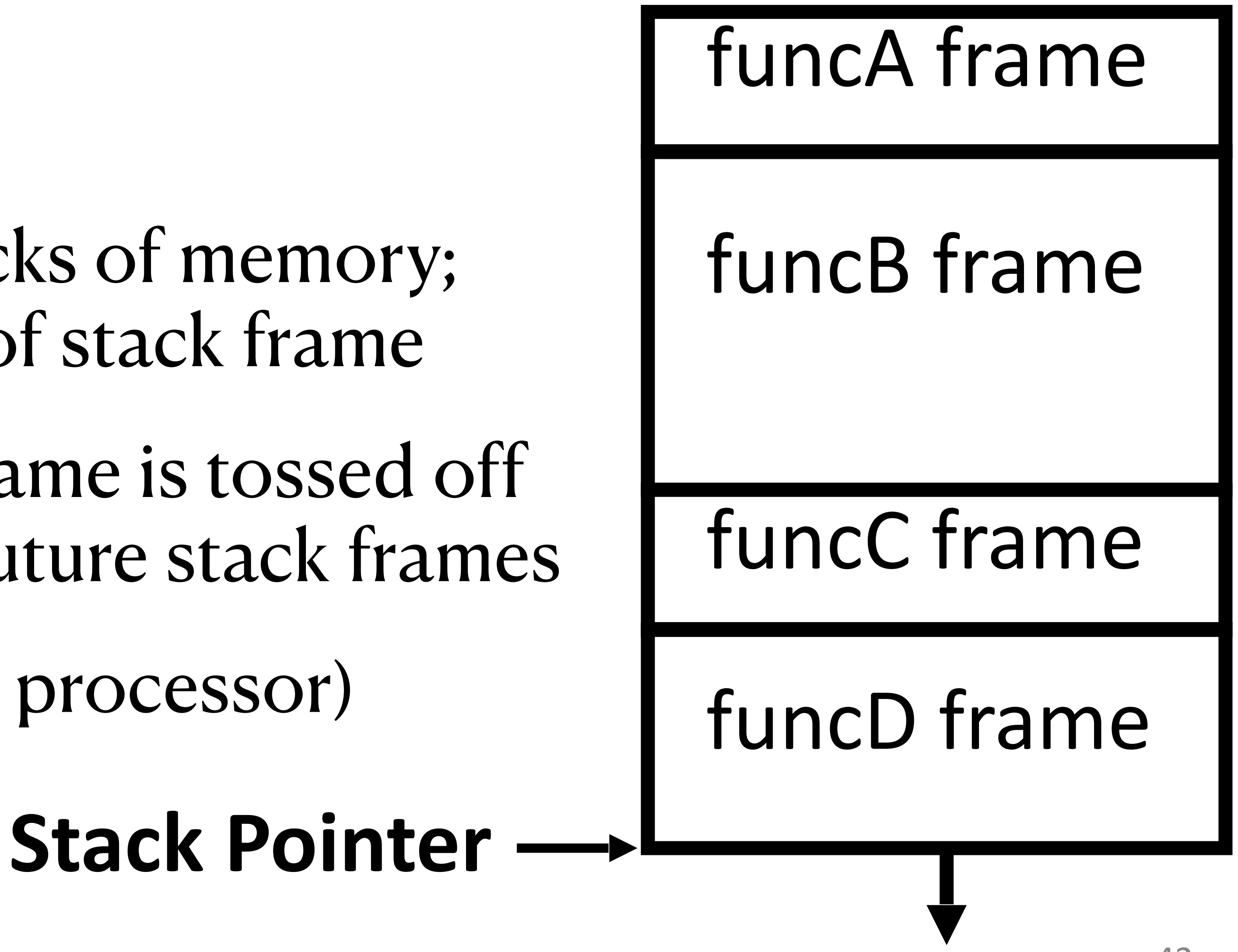
```
int myGlobal; static
main() {
    int myTemp; stack
}
```

- For the above two types, the memory management is automatic
    - Don't need to deallocating when no longer using them
    - A variable does not exist anymore once a function ends!

The Stack

- Every time a function is called, a new "stack frame" is allocated on the stack
- Stack frame includes:
  - Return address (who called me?)
  - Arguments
  - Space for local variables
- Stack frames contiguous blocks of memory; stack pointer indicates start of stack frame
- When function ends, stack frame is tossed off the stack; frees memory for future stack frames
- Details covered later (RISC-V processor)

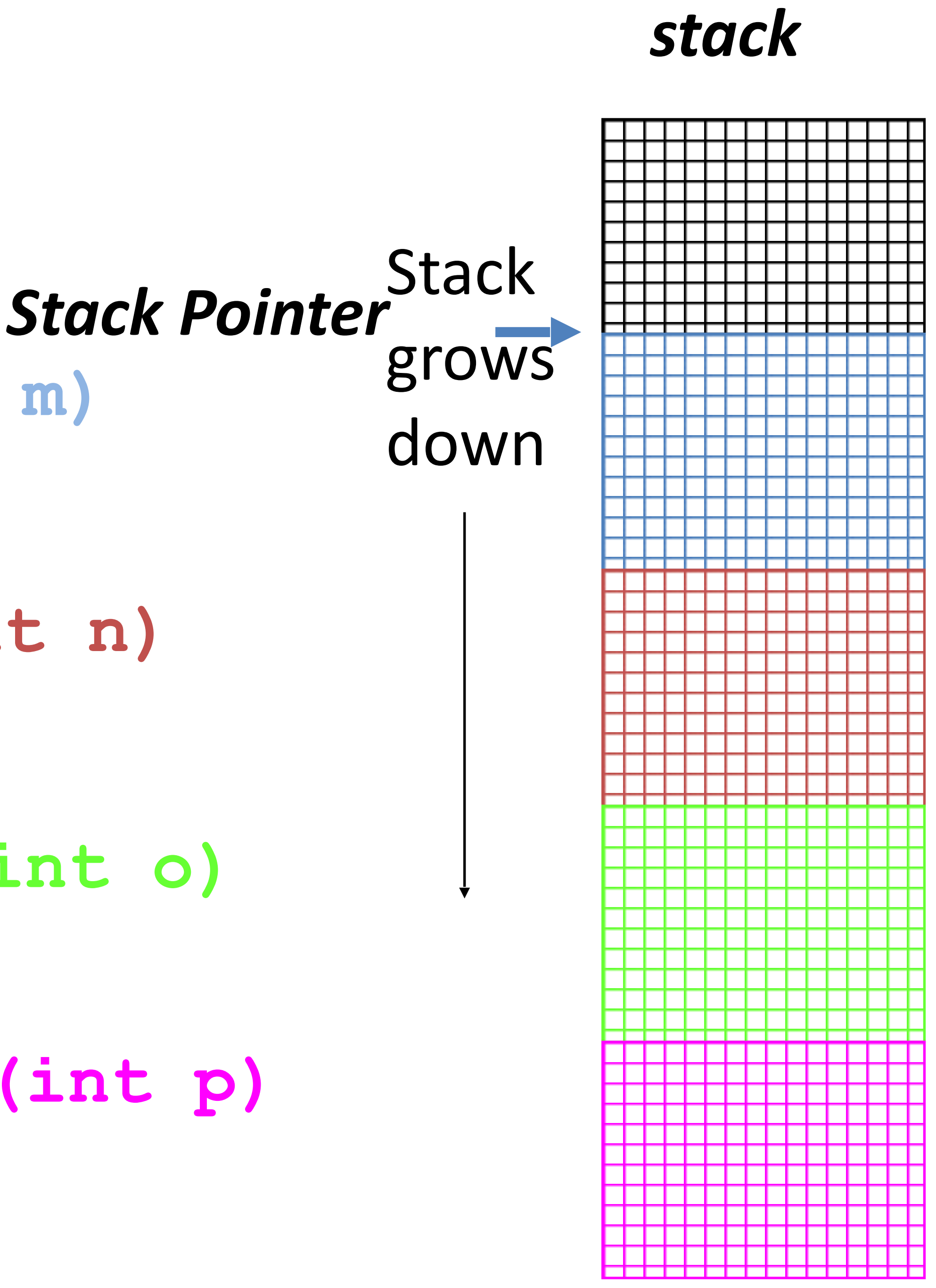
```
funcA() { funcB(); }
funcB() { funcC(); }
funcC() { funcD(); }
```



Stack Animation

- Last In, First Out (LIFO) data structure

```
main ()
{ a(0);
}
   void a (int m)
   { b(1);
   }
     void b (int n)
     { c(2);
     }
       void c (int o)
       { d(3);
       }
        void d (int p)
        {
        }
```

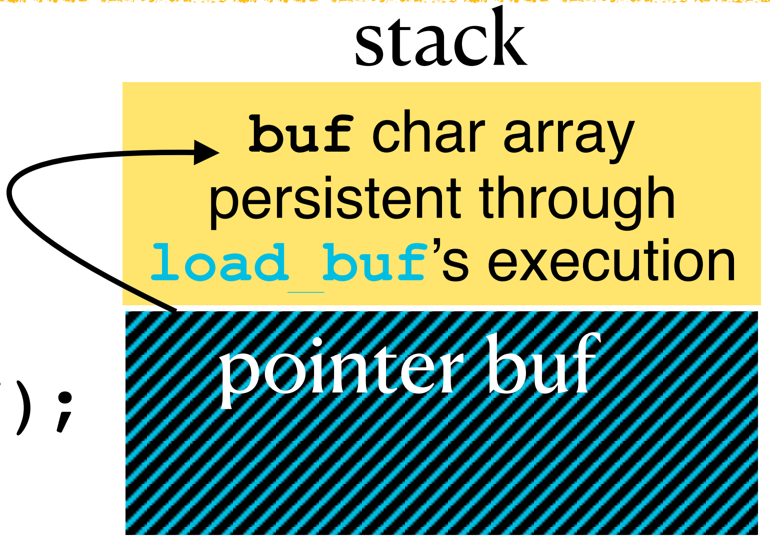


```
_main:
sub sp, sp, #48
… … …
mov w8, #1234
stur    w8, [x29, #-8]
mov w8, #4321
stur    w8, [x29, #-12]
ldur    w8, [x29, #-8]
ldur    w9, [x29, #-12]
add w8, w8, w9
… … …
add sp, sp, #48
ret
```

Passing Pointers into the Stack

- It is fine to pass a pointer to stack space further down.

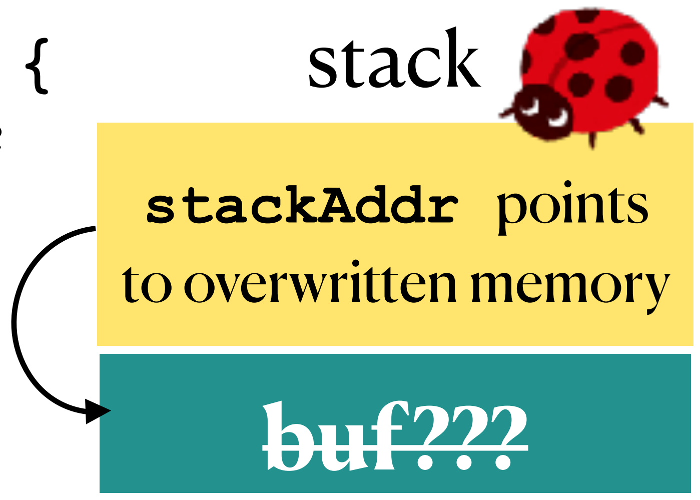
```
#define BUFLEN 256
int main() {
    …
    char buf[BUFLEN];
    load_buf(buf, BUFLEN);
    …
}
```



- However, it is bad to return a pointer to something in the stack!
  - Memory will be overwritten when other functions called!
  - So your data would no longer exist, and writes can overwrite key pointers, causing crashes!

```
char *make_buf() {
    char buf[50];
    return buf;
}

int main(){
    …
    char *stackAddr = \
        make_buf();
    foo();
    …
}
```



Carving on the moving boat to look for the sword

Solve with slides to come …

Managing the Heap

- The heap is dynamic memory – memory that can be allocated, resized, and freed during program runtime.
  - Useful for persistent memory across function calls
  - But biggest source of pointer bugs, memory leaks, …
- Large pool of memory, not allocated in contiguous order
  - Back-to-back requests for heap memory could result in blocks very far apart
- C supports four functions for heap management: 未被初始化

`malloc()`	allocate a block of uninitialized memory	memory allocate
`calloc()`	allocate a block of zeroed memory 清零	clear allocate
`free()`	free previously allocated block of memory	
`realloc()`	change size of previously allocated block (might move)	re-allocate

  - Read-more: http://web.archive.org/web/20030222051144/http://home.earthlink.net/~bobbitts/c89.txt section 4.10.3 memory management functions

Managing the Heap

- **`void *malloc(size_t n)`**:
  - Allocate a block of uninitialized memory
  - **`n`** is an integer, indicating size of allocated memory block in bytes
  - **`size_t`** is an unsigned integer type big enough to "count" memory bytes
  - **`sizeof`** returns size of given type in bytes, produces more portable code
  - Returns **`void*`** pointer to block; **`NULL`** return indicates no more memory; always check for return **`NULL`** (**`if (ip)`**)
  - Think of pointer as a handle that describes the allocated block of memory; Additional control information stored in the heap around the allocated block! (Including size, etc.)

"Cast" operation, changes type of a variable.

Here changes ***`(void *)`*** *to* ***`(int *)`***

- Examples:

```
int *ip1, *ip2;
ip1 = (int *) malloc(sizeof(int));
Ip2 = (int *) malloc(20*sizeof(int)); //allocate an array of 20 ints.


typedef struct { … } TreeNode;
TreeNode *tp = (TreeNode *) malloc(sizeof(TreeNode));
```

Assuming size of objects can lead to misleading, unportable code. Use **`sizeof()`**!

Managing the Heap

- **`void free(void *p):`**
  - Releases memory allocated by **`malloc()`**
  - **`p`** is pointer containing the address originally returned by **`malloc()`**

```
int *ip;
ip = (int *) malloc(sizeof(int));
... .. ..
free((void*) ip);  /* Can you free(ip) after ip++ ? */

typedef struct {… } TreeNode;
TreeNode *tp = (TreeNode *) malloc(sizeof(TreeNode));
    ... .. ..
free((void *) tp);
```

X

  - When you free memory, you must be sure that you pass the original address returned from **`malloc()`** to **`free()`**; Otherwise, system exception (or worse)!

Managing the Heap

- `void *realloc(void *p, size_t size):`
  - Returns new address of the memory block.
    - In doing so, it may need to copy all data to a new location.

```
realloc(NULL, size); // behaves like malloc
realloc(ptr,  0); // behaves like free, deallocates heap block
```

  - Always check for return NULL

Keep track of this, since it might change.

```
int *ip; ip = (int *) malloc(10*sizeof(int));
… … …                      /* check for NULL */
ip = (int *) realloc(ip, 20*sizeof(int));
/* contents of first 10 elements retained */
… … …                      /* check for NULL */
realloc(ip,0);             /* equivalent to free(ip); */
```

Summary

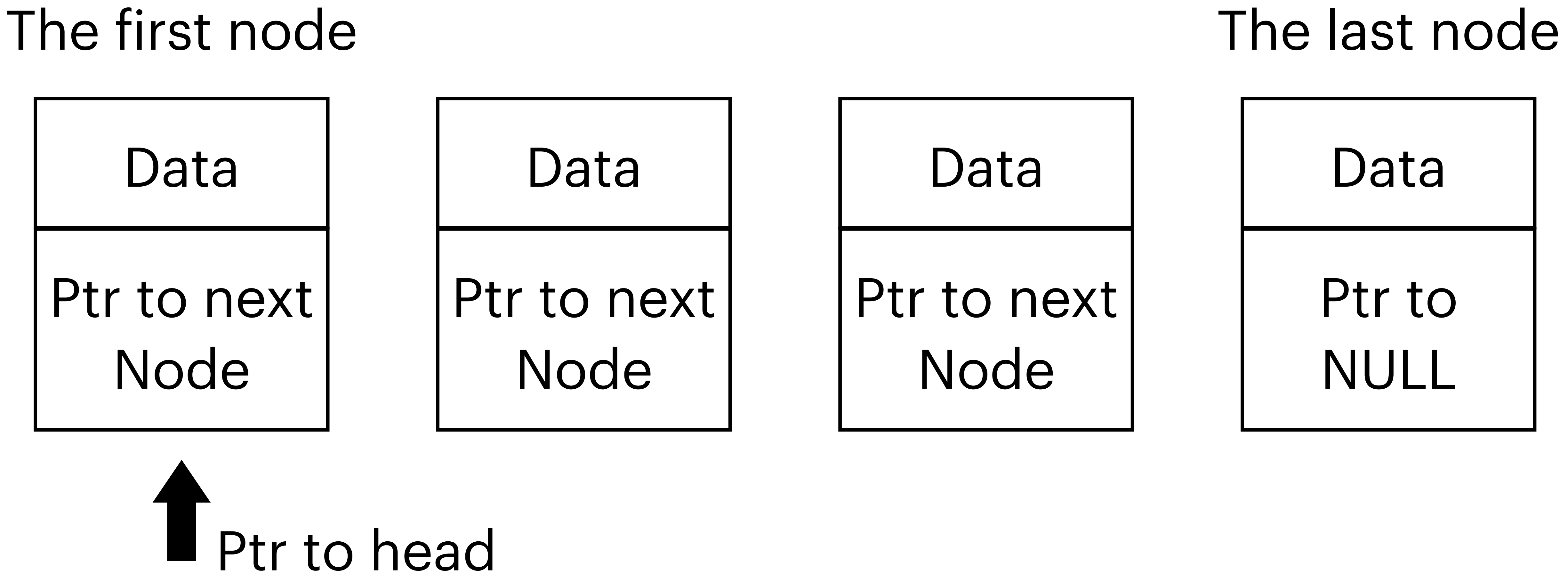
- Code, static storage are easy: they never grow or shrink
- Stack space is relatively easy: stack frames are created and destroyed in last-in, first-out (LIFO) order, avoid “dangling references"
- Managing the heap is tricky:
  - Memory can be allocated/deallocated at any time
  - “Memory leak”: If you forget to deallocate memory
  - “Use after free”: If you use data after calling free
  - “Double free”: If you call free 2x on same memory

Using Dynamic Memory—Linked List

```
typedef struct Node
{
  int val;
  struct Node *next;
} node;
```

```
node * head = NULL;
head = (node *) malloc(sizeof(node));
if(head == NULL){
  return 1;
}
head -> val = 1;
head -> next = NULL;
```

Create the first node

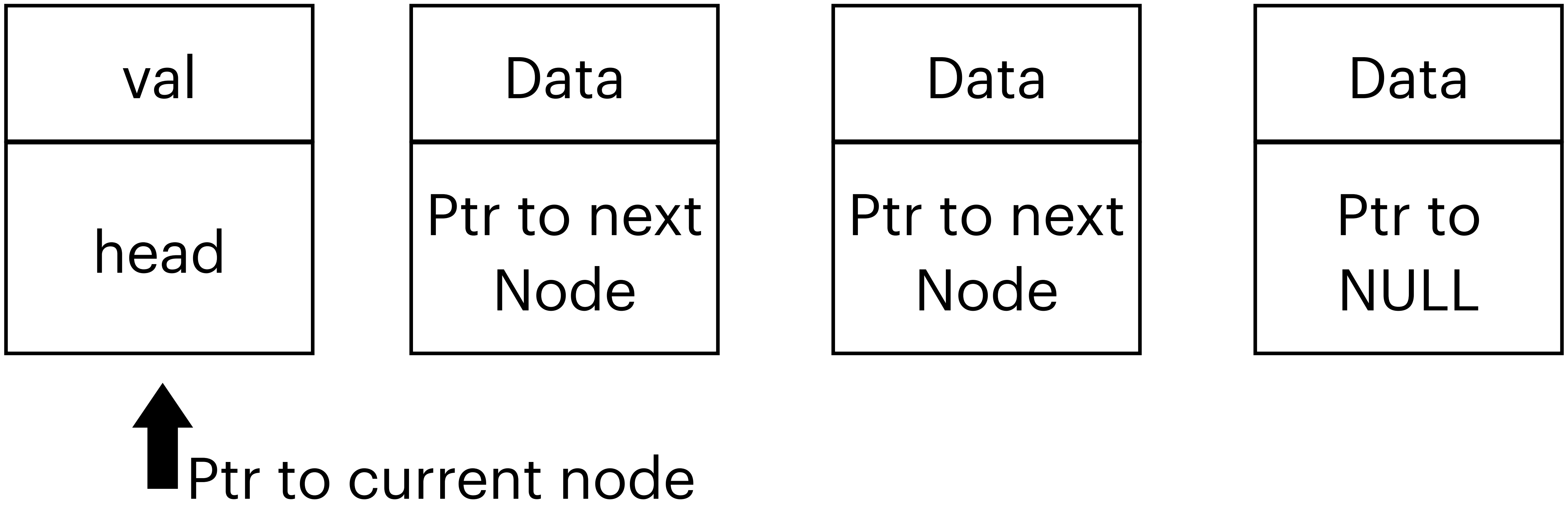


Using Dynamic Memory—Iterate

```
typedef struct Node
{
  int val;
  struct Node *next;
} node;
```

```
void print_list(node *head){
    node * current = head;
    while (current != NULL){
        printf("%d\t", current -> val);
        current = current -> next;
    }
    printf("\n");
}
```

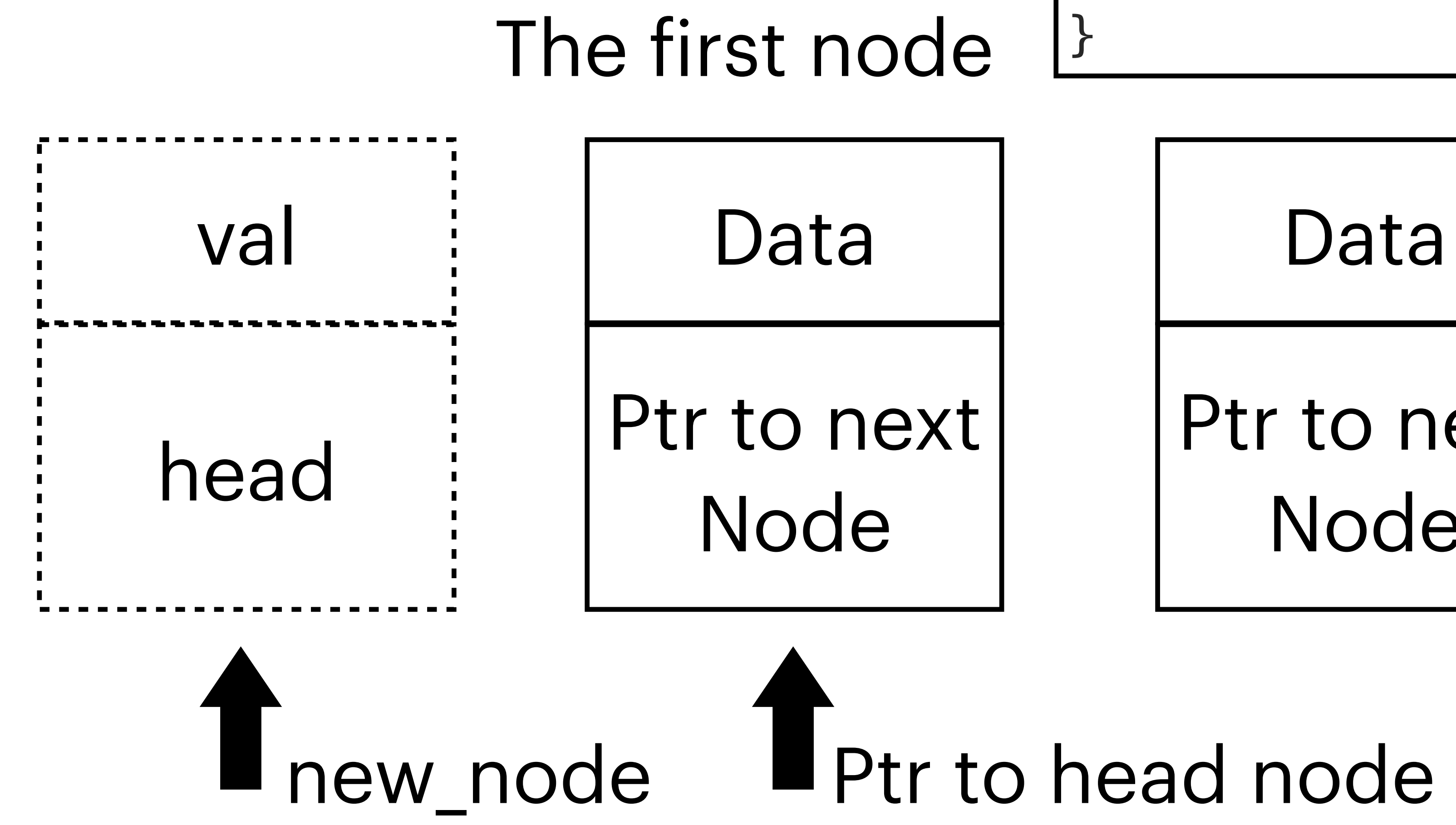
The first node



Using Dynamic Memory—Push

```
typedef struct Node
{
  int val;
  struct Node *next;
} node;
```

```
void push_node(node ** head, int val){
    node * new_node;
    new_node = (node *) malloc (sizeof
(node));
    new_node -> val = val;
    new_node -> next = *head;
    *head = new_node;
    printf("Node %d push succeeds!\n",
(*head) -> val);
}
```



Using Dynamic Memory—Remove

```c
typedef struct Node
{
  int val;
  struct Node *next;
} node;
```

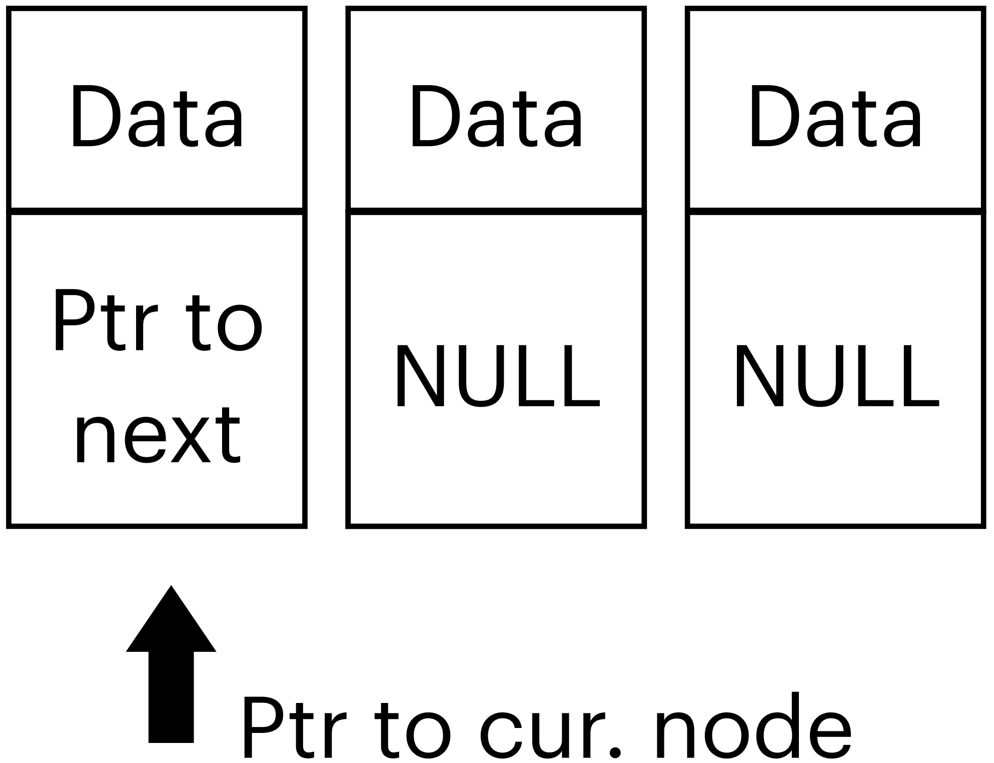
```c
int remove_last(node * head) {
    int retval = 0;

    if (head->next == NULL) {
        retval = head->val;
        free(head);
        return retval;
    }

    node * current = head;
    while (current->next->next != NULL) {
        current = current->next;
    }

    retval = current->next->val;
    free(current->next);
    current->next = NULL;
    printf("%d is removed.\n",retval);
    return retval;
}
```

The first node

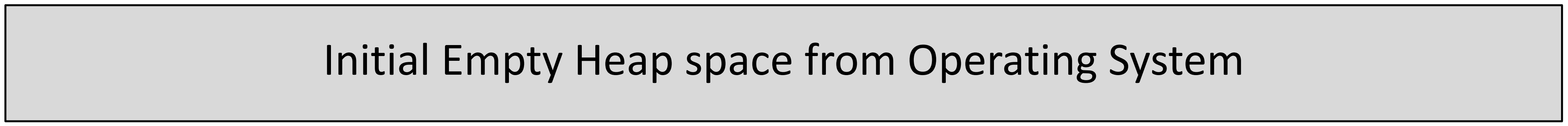


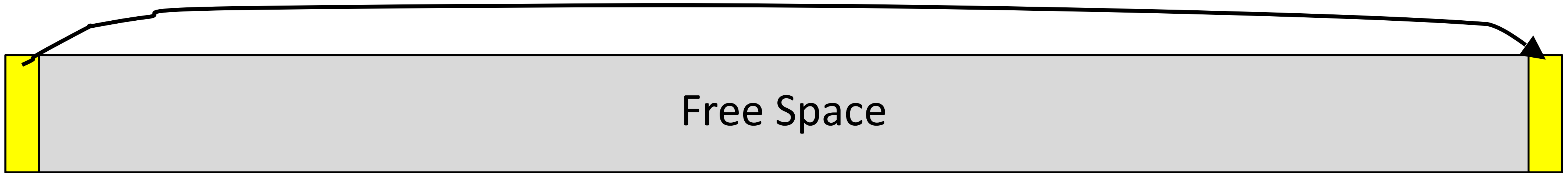
Ptr to cur. node

How are Malloc/Free implemented?

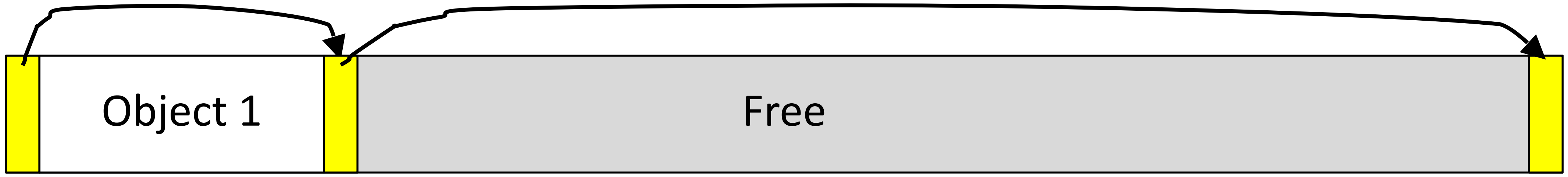
- Underlying operating system allows **`malloc`** library to ask for large blocks of memory to use in heap (e.g., using Unix **`sbrk()`** call)
- C standard **`malloc`** library creates data structure inside unused portions to track free space

Simple Slow Malloc Implementation

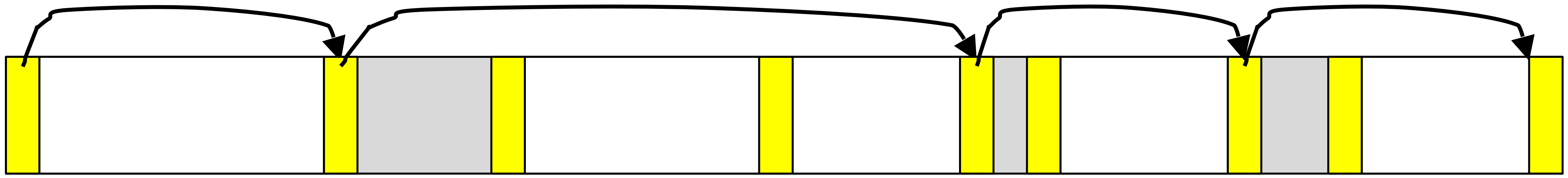




Malloc library creates linked list of empty blocks (one block initially)



First allocation chews up space from start of free space

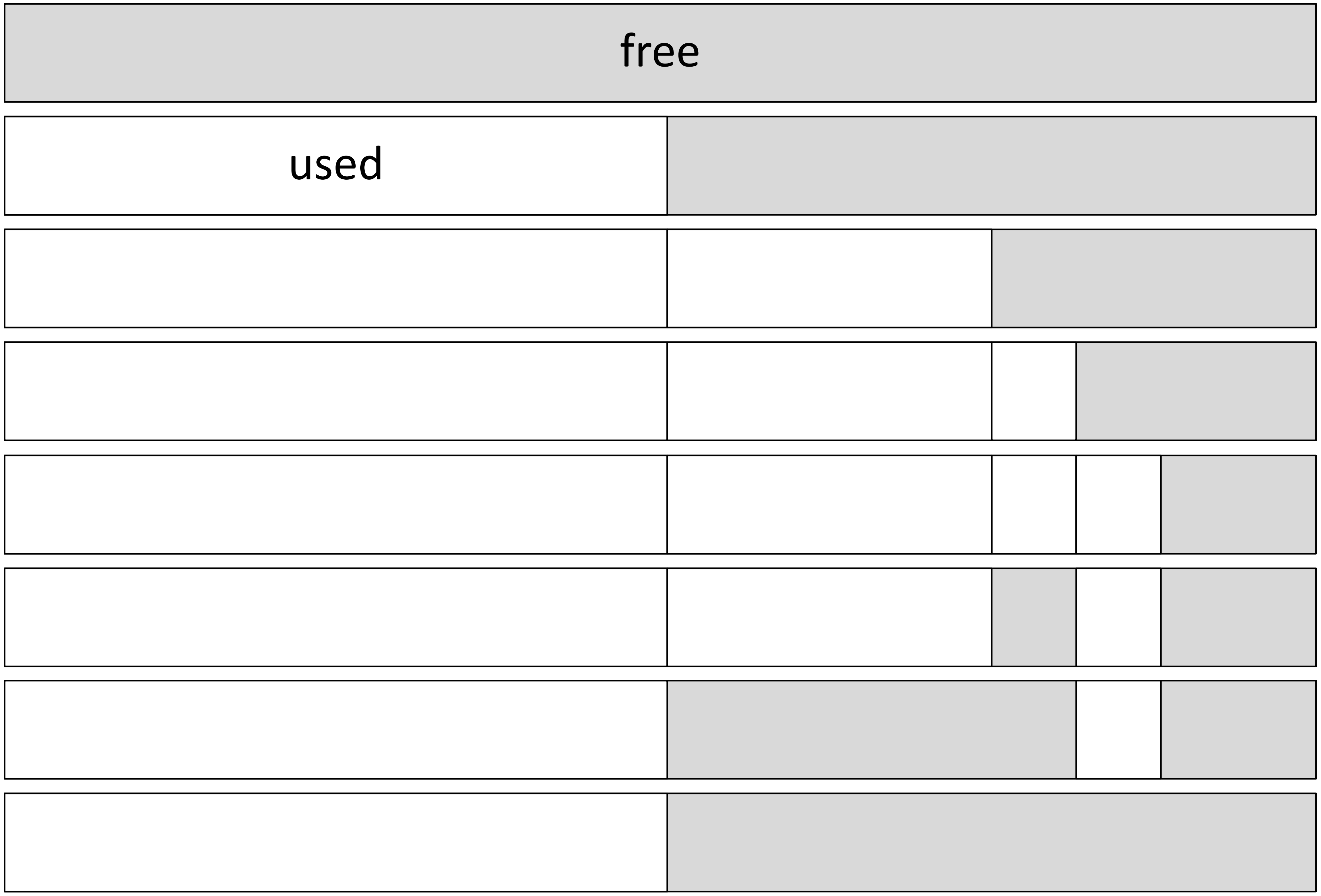


After many mallocs and frees, have potentially long linked list of odd-sized blocks
Frees link block back onto linked list – might merge with neighboring free space

Faster malloc implementations

- Keep separate pools of blocks for different sized objects
- "Buddy allocators" always round up to power-of-2 sized chunks to simplify finding correct size and merging neighboring blocks:

Power-of-2 "Buddy Allocator"



Malloc Implementations

- All provide the same library interface, but can have radically different implementations
- Uses headers at start of allocated blocks and space in unallocated memory to hold **`malloc`**'s internal data structures
- Rely on programmer remembering to free with same pointer returned by **`malloc`**
- Rely on programmer not messing with internal data structures accidentally!

Agenda

- C Memory Management
- C Bugs

Common Memory Problems

- Using uninitialized values
- Using memory that you don't own
  - Deallocated stack or heap variable
  - Out-of-bounds reference to stack or heap array
  - Using NULL or garbage data as a pointer
- Improper use of free/realloc by messing with the pointer handle returned by malloc/calloc
- Memory leaks (you allocated something you forgot to later free)

Using Memory You Don't Own

- What is wrong with this code?
- Using pointers beyond the range that had been malloc'd
  - –May look obvious, but what if mem refs had been result of pointer arithmetic that erroneously took them out of the allocated range?

```
int *ipr, *ipw;
void ReadMem() {
     int i, j;
     ipr = (*int) malloc(4 * sizeof(int));
      i = *(ipr - 1000); j = *(ipr + 1000);
     free(ipr);
   }

   void WriteMem() {
     ipw = (*int) malloc(5 * sizeof(int));
     *(ipw - 1000) = 0; *(ipw + 1000) = 0;
     free(ipw);
   }
```

Faulty Heap Management

- What is wrong with this code?

```
int *pi;
void foo() {
  pi = malloc(8*sizeof(int));
  …
  free(pi);
}

void main() {
  pi = malloc(4*sizeof(int));
  foo();
  …
}
```

Faulty Heap Management

- Memory leak: more mallocs than frees

```
int *pi;
void foo() {
   pi = malloc(8*sizeof(int));
   /* Allocate memory for pi */
   /* Oops, leaked the old memory pointed to by pi */
   …
   free(pi); /* foo() is done with pi, so free it */
}

void main() {
   pi = malloc(4*sizeof(int));
   foo(); /* Memory leak: foo leaks it */
  …
}
```

Faulty Heap Management

- What is wrong with this code?

```
int *plk = NULL;
void genPLK() {
   plk = malloc(2 * sizeof(int));
  … … …
   plk++;
}
```

Faulty Heap Management

- Potential memory leak – handle has been changed, do you still have copy of it that can correctly be used in a later free?

```
int *plk = NULL;
void genPLK() {
   plk = malloc(2 * sizeof(int));
  … … …
   plk++;
}
```

Faulty Heap Management

- What is wrong with this code?

```
void FreeMemX() {
   int fnh = 0;
   free(&fnh);
}

void FreeMemY() {
   int *fum = malloc(4 * sizeof(int));
   free(fum+1);
   free(fum);
   free(fum);
}
```

Faulty Heap Management

- Can’t free non-heap memory; Can’t free memory that hasn’t been allocated

```
void FreeMemX() {
   int fnh = 0;
   free(&fnh);
}

void FreeMemY() {
   int *fum = malloc(4 * sizeof(int));
   free(fum+1);
   free(fum);
   free(fum);
}
```

Using Memory You Haven’t Allocated

- What is wrong with this code?

```
void StringManipulate() {
   const char *name = “Safety Critical";
   char *str = malloc(10);
   strncpy(str, name, 10);
   str[10] = '\0';
   printf("%s\n", str);
}
```

Using Memory You Haven’t Allocated

- Reference beyond array bounds

```
void StringManipulate() {
   const char *name = “Safety Critical";
   char *str = malloc(10);
   strncpy(str, name, 10);
   str[10] = '\0';
  /* Write Beyond Array Bounds */
   printf("%s\n", str);
}
```

Using Memory You Don't Own

- What's wrong with this code?

```
char *append(const char* s1, const char *s2) {
   const int MAXSIZE = 128;
   char result[128];
   int i=0, j=0;
   for (j=0; i<MAXSIZE-1 && j<strlen(s1); i++,j++) {
    result[i] = s1[j];
   }
   for (j=0; i<MAXSIZE-1 && j<strlen(s2); i++,j++) {
    result[i] = s2[j];
   }
   result[++i] = '\0';
   return result;
}
```

Using Memory You Don't Own

- Beyond stack read/write

```
char *append(const char* s1, const char *s2) {
   const int MAXSIZE = 128;
   char result[128];
   int i=0, j=0;
   for (j=0; i<MAXSIZE-1 && j<strlen(s1); i++,j++) {
    result[i] = s1[j];
   }
   for (j=0; i<MAXSIZE-1 && j<strlen(s2); i++,j++) {
    result[i] = s2[j];
   }
   result[++i] = '\0';
   return result;
}
```

result is a local array name – stack memory allocated

Function returns pointer to stack memory – won't be valid after function returns

Using Memory You Don't Own

- What is wrong with this code?

```
typedef struct node {
      struct node* next;
      int val;
   } Node;

   int findLastNodeValue(Node* head) {
      while (head->next != NULL) {
          head = head->next;
      }
      return head->val;
   }
```

Using Memory You Don't Own

- Following a NULL pointer to mem addr 0!

```
typedef struct node {
        struct node* next;
        int val;
    } Node;

    int findLastNodeValue(Node* head) {
        while (head->next != NULL) {
            head = head->next;
        }
        return head->val;
    }
```

Using Memory You Don't Own

- What is wrong with this code?

```
int* init_array(int *ptr, int new_size) {
   ptr = realloc(ptr, new_size*sizeof(int));
   memset(ptr, 0, new_size*sizeof(int));
   return ptr;
}

int* fill_fibonacci(int *fib, int size) {
   int i;
   init_array(fib, size);
   /* fib[0] = 0; */ fib[1] = 1;
   for (i=2; i<size; i++)
    fib[i] = fib[i-1] + fib[i-2];
   return fib;
}
```

Using Memory You Don't Own

- Improper matched usage of mem handles

```
int* init_array(int *ptr, int new_size) {
   ptr = realloc(ptr, new_size*sizeof(int));
   memset(ptr, 0, new_size*sizeof(int));
   return ptr;
}
```

Remember: realloc may move entire block

```
int* fill_fibonacci(int *fib, int size) {
   int i;
   /* oops, forgot: fib = */ init_array(fib, size);
   /* fib[0] = 0; */ fib[1] = 1;
   for (i=2; i<size; i++)
    fib[i] = fib[i-1] + fib[i-2];
   return fib;
}
```

What if array is moved to new location?

Summary

- All data/program is in memory
  - Each memory location has an address to use to refer to it and a value stored in it
- Pointer is a C version (abstraction) of a data address
  - * "follows" a pointer to its value
  - & gets the address of a value
  - Arrays and strings are implemented as variations on pointers
- C is an efficient language, but leaves safety to the programmer
  - Variables not automatically initialized
  - Use pointers with care: they are a common source of bugs in programs

Summary

- C has three main memory segments in which to allocate data:
  - Static Data: Variables outside functions
  - Stack: Variables local to function
  - Heap: Objects explicitly malloc-ed/free-d.
- Heap data is biggest source of bugs in C code