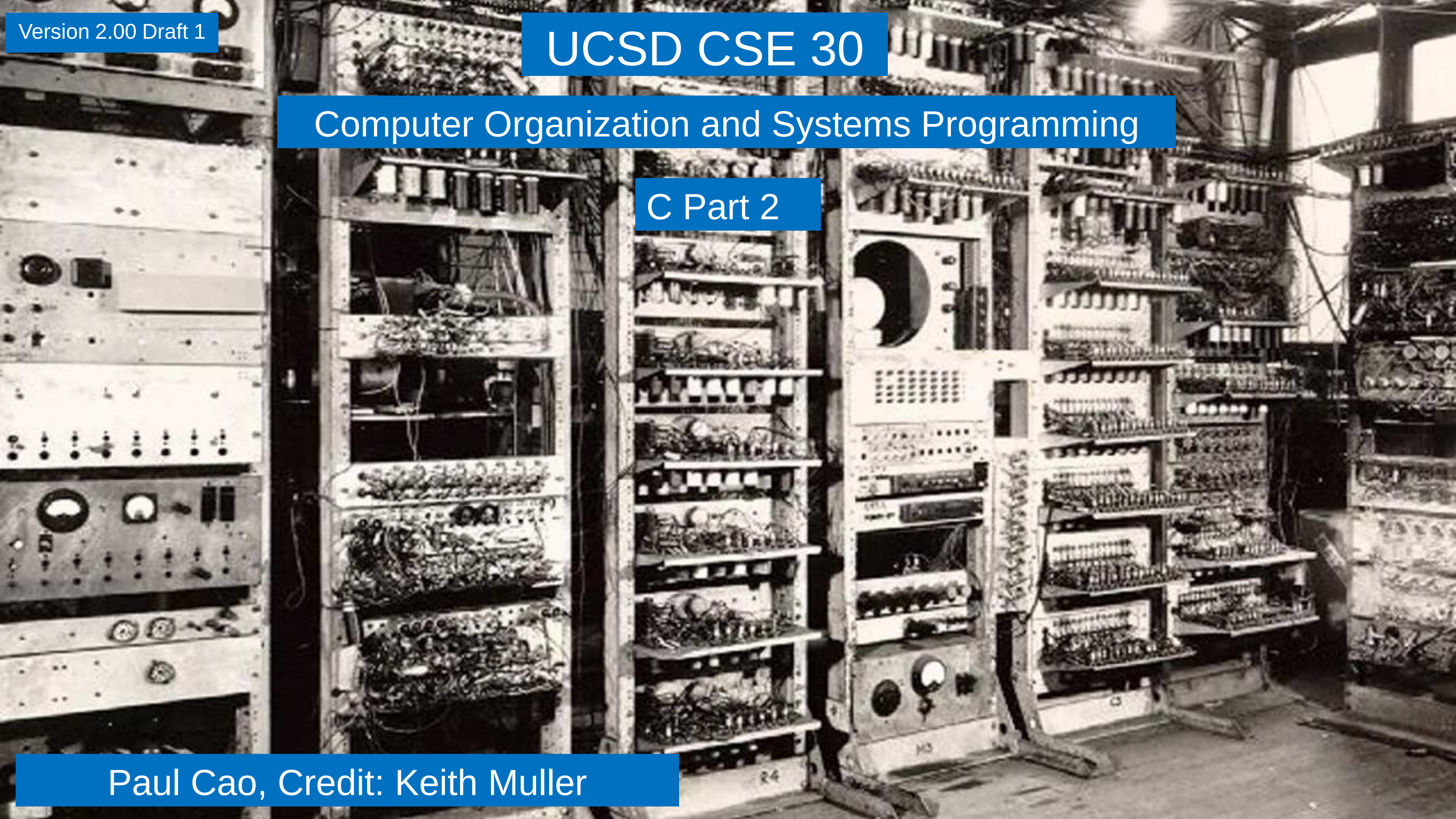


Version 2.00 Draft 1

UCSD CSE 30

Computer Organization and Systems Programming

C Part 2

Paul Cao, Credit: Keith Muller

Variables in C

- **Integer types**
  - `char` [default: unspecified!]
  - `int` [default: signed]
- **Floating Point**
  - `float`, `double` [always signed]
- **Optional Modifiers** for each base type
  - `short` [int]
  - `long` [int, double]
  - `signed` [char, int]
  - `unsigned` [char, int]
  - `const`: read only
- **char type**
  - **One byte** in a **byte addressable** memory
  - **Signed** vs **Unsigned** implementation dependent
  - **Be careful** char is unsigned on arm and signed on other HW like intel

C Data Type	AArch-32 contiguous Bytes	AArch-64 contiguous Bytes
%c char (arm unsigned)	1	1
short int	%hd 2	2
unsigned short int	%hu 2	2
int	4 %d	4
unsigned int	4 %u	4
long int	%ld 4	8
long long int	%lld 8	8
%f float	4	4
%lf double	8	8
long double	%llf 8	16
%p pointer *	4	8

word size is the size of the address (pointer)

X

sizeof(): Variable Size (number of bytes) *Operator*

```
#include <stddef.h>
/* size_t type may vary by system but is always unsigned */
```

sizeof() operator returns a value of type size_t:

the number of bytes used to store a variable or variable type

```
size_t size = sizeof(variable_type);
            or
size_t size = sizeof(variable_name); // preferred!
```

- The argument to `sizeof()` is often an expression:

```
size = sizeof(int * 10);
```

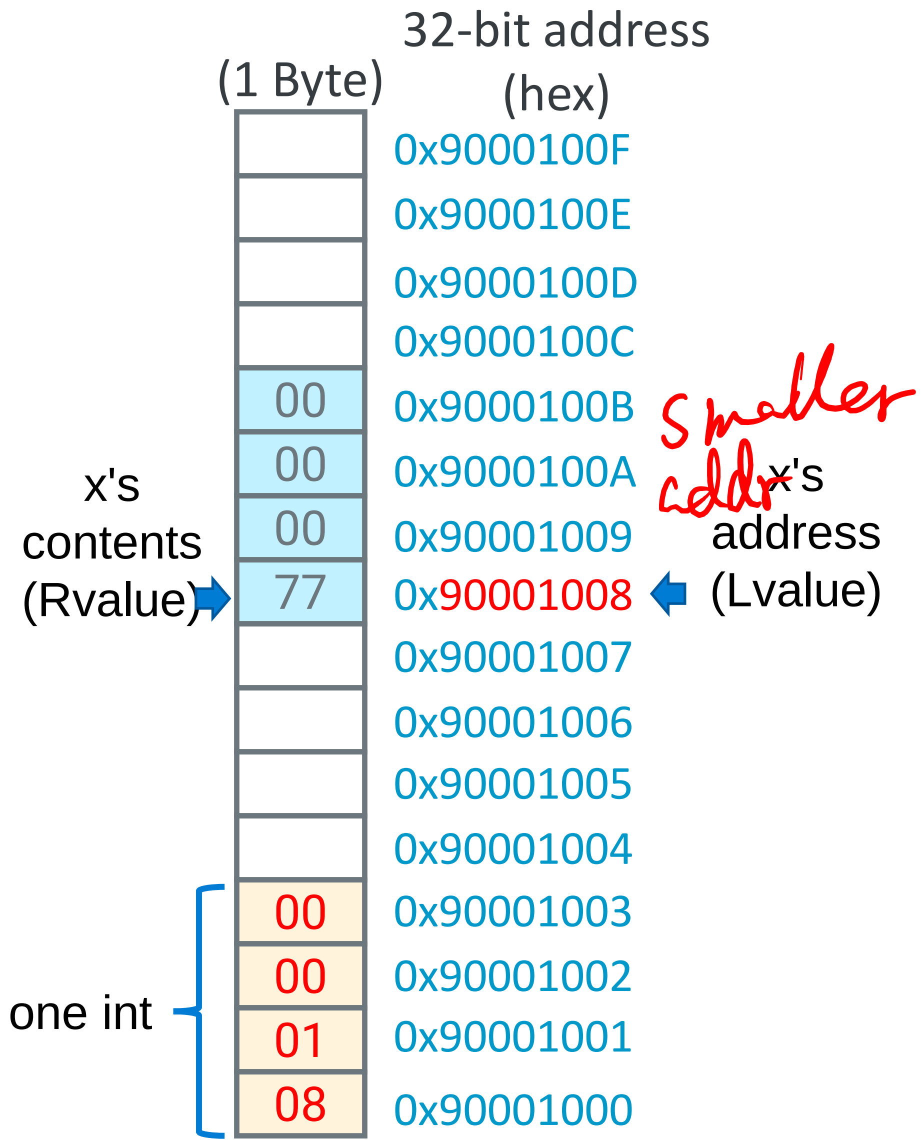
  - reads as:
    - number of bytes required to store **10 integers (an array of [10])**

X

Memory Addresses & Memory Content

```
Given int x, y;     // 4 bytes on pi cluster
x = x;              // Lvalue = Rvalue
```

- **Variable name** in a C statement evaluates to either:
  - **Lvalue:** when on the left side (Lside or Left value) of the = sign is the
    - address where it is stored in memory – a constant
    - Address assigned to a variable cannot be changed at runtime
  - **Rvalue:** when on the right side (Rside or Right value) of an = sign is the
    - contents or value stored in the variable (at its memory address)
    - requires a memory read to obtain



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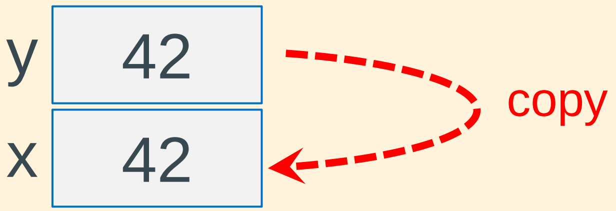
Memory Addresses & Memory Content

```
y = 42;

x = y;      // Lvalue = Rvalue
```



- **x** on left side (**Lside**) of the assignment operator = evaluates to:
  - The address of the memory assigned to the x – this is x's **Lvalue**
- **y** on right side (**Rside**) of the assignment operator = evaluates to:
  - READ the contents of the memory assigned to the variable y (type determines length – number of bytes) - this is y’s **Rvalue**
- So x = y; is:

Read memory at y (**Rvalue**); write it to memory at x's address (**Lvalue**)

x

Introduction: Address Operator: &

addr bit and

- Unary ***address operator*** (&) produces the **address** of where an identifier is in memory
- Requirement: **identifier must have a Lvalue**
  - Cannot be used with constants (e.g., 12) or expressions (e.g., x + y)
  - `&12` does not have an *Lvalue*, so &12 is **not** a legal expression
- How can I get an address for use on the **Rside**? Three ways:
  - **`&var`** (any variable identifier or name)
  - **function_name** (name of a function, not func()); **&funct_name** is equivalent
  - **array_name** (name of the array like array_name[5]); &array_name is equivalent

X

Introduction: Address Operator: &

- Unary ***address operator*** (&) produces the **address** of where an identifier is in memory

- Example: this might print:

  ***value** of g is: 42*

  ***address** of g is: 0x71a0a0*

  (the address will vary)

```
int g = 42;
int
main(void)
{
    printf("value of g is: %d\n", g);
    printf("address of g is: %p\n", &g);
    return EXIT_SUCCESS;
}
```

int *

- *Tip*: `printf()` format specifier to display an address/pointer (in hex) is "%p"

x

Introduction: Pointer Variables - 1

- In C, there is a *variable* ***type*** for **storing an address**: a ***pointer***
  - **Contents** of a pointer is an **unsigned** (0+, positive numbers) **memory address**

- When the **Rside of a variable** contains a **memory address**, (it **evaluates** to an **address**) the variable is called a **pointer variable**

- A pointer is defined by placing a ***star (***or ***asterisk) (*)*** ***before*** the identifier (name)

```
type *name;  // defines a pointer; name contains address of a variable of type
```

pointer

X

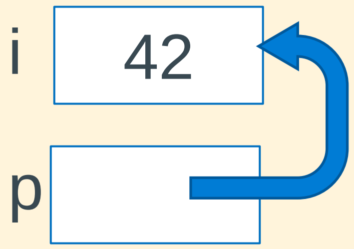
Introduction: Pointer Variables - 1

```
type *name;  // defines a pointer; name contains address of a variable of type
```

- You also must specify the type of variable to which the pointer points

```
int i = 42;
int *p;  /* p contains the address of an integer */
p = &i;  /* p "points at" i (assign address of i to p) */
```

int **ptr;



i

0x80

- Recommended: be careful when defining multiple pointers on the same line:

`int *p1, p2;` is not the same as: `int *p1, *p2;`

Use instead:

```
int *p1;
int *p2;
```

Introduction: Pointer Variables - 2

- **Pointers are typed**! Why?
  - The compiler needs the size (sizeof()) of the data **you are pointing at** (number of bytes to access)
- A pointer definition:

```
int *p = &i;  /* p points at i (assign address i to p) */
```

- Is the same as writing the following definition and assignment statements

```
int *p;        /* p is defined (not initialized) */
p = &i;        /* p points at i (assign address i to p */
```

- The * is part of the definition of p and is not part of the variable name
  - The name of the variable is simply p, not *p
- C mostly ignores whitespace, so these three definitions are equivalent

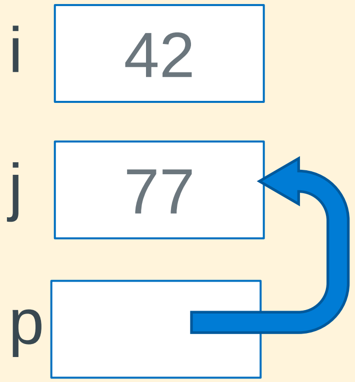
```
int  *p = &i;        /* Style A */
int * p = &i;        /* Style B */
int*  p = &i;        /* Style C */
```


X

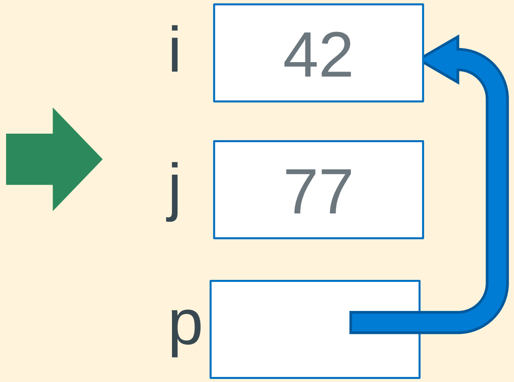
Introduction: Pointer Variables - 3

- As with any variable, its value can be changed

```
p = &j;      /* p now points at j */
```




```
p = &i;      /* p now points at i */
```



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Introduction: Pointer Variables - 4

- Pointer variables all use the **same amount of memory** no matter what they point at

```c
int *iptr;
char *cptr;

printf("iptr(%u) cptr(%u)\n", sizeof(iptr), sizeof(cptr));
```

- Above prints on a 32-raspberry pi

```
iptr(4) cptr(4)
```


X

Introduction: Indirection (or dereference) Operator: *

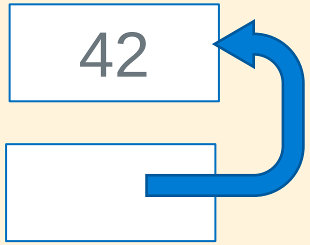
mul-ti deref define

- The ***indirection operator*** (*) or the *dereference operator to a variable* ptr is the **inverse** of the *address operator (&)*
- **address operator (&)** can be thought of as:

“get the address of this box”

i or (*p)

p = &i



- **indirection operator (*)** can be thought of as:

“follow the arrow to the next box and get its contents”

x

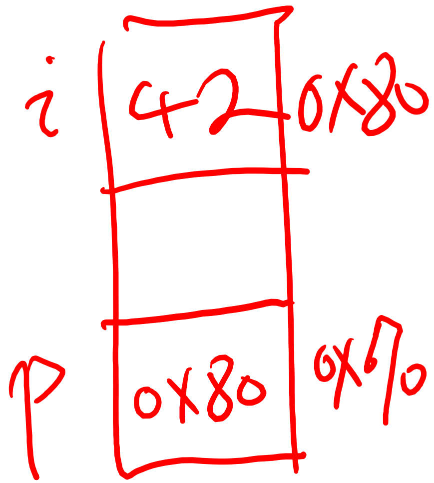
Introduction: Indirection (or dereference) Operator: *

*Contents of **p** is the address of **i** (p points at i)*

```
int i = 42;
int j = i;
int *p;
p = &i;

printf("*p is %d\n", *p);
```

```
% ./a.out
*p is 42
```



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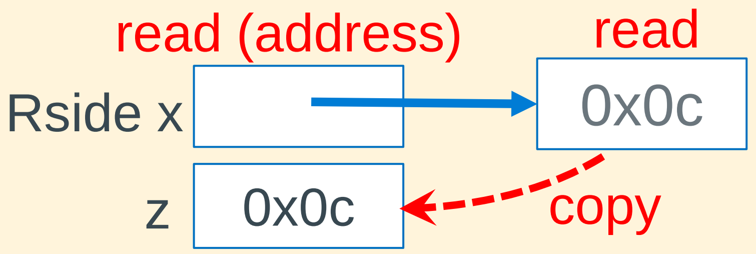
Introduction: Indirection Operator Rside

- Performs the following steps when the * is on the Rside:

1. read the contents of the variable to get an address
2. **read** and return the contents at that address
   - (requires two reads of memory on the Rside)

```
z = *x; // copy the contents of memory pointed at by x to z
```



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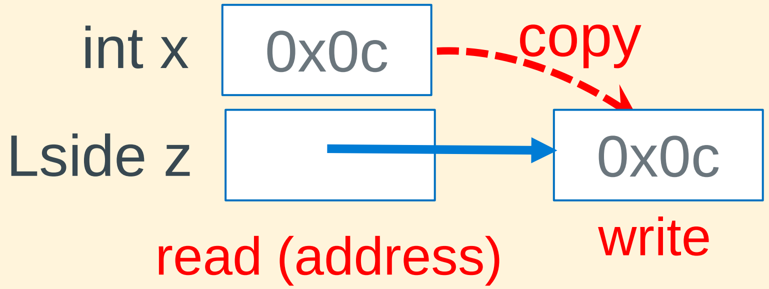
Introduction: Indirection Operator Lside

Performs the following steps when the * is on the Lside:

1. read the contents of the variable to get an address

2. **write** the evaluation of the Rside expression to that address
   - (requires one read of memory and one write of memory on the Lside)

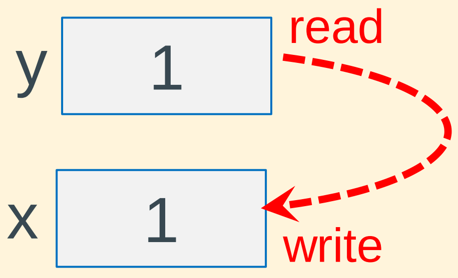
```
*z = x; // copy the value of x to the memory pointed at by z
```



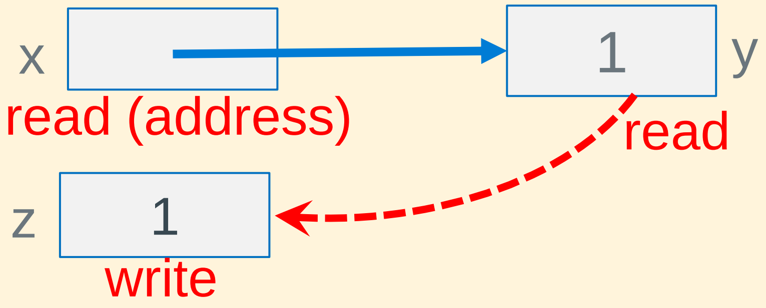
Each use of a * operator results in one additional read -1

Each * when used as a dereference operator in a statement (Lside and Rside) generates an additional read

```
int x = 2, y = 1;
x = y; // one read
```




```
int z = 2, y = 1;
int *x;
x = &y;
z = *x; // two reads
```



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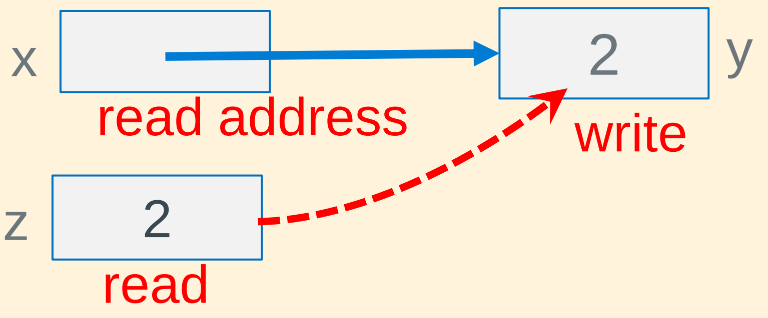
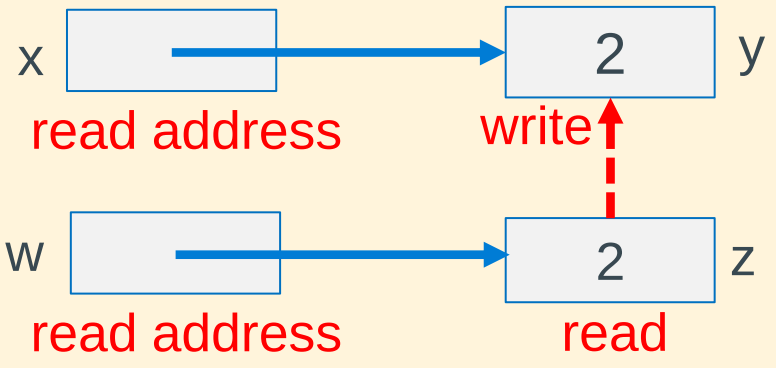
Each use of a * operator results in one additional read -2

- Each * when used as a dereference operator in a statement (Lside and Rside) generates an additional read

```
int z = 2, y = 1;
int *x;
x = &y;
*x = z;
```




```
int z = 2, y = 1;
int *x;
int *w;
x = &y;
w = &z;
*x = *w;
```



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Recap: Lside, Rside, Lvalue, Rvalue

```
int x = 2, y = 1;
x = y;
```

Constant Var Name	Lvalue address	Rvalue Contents	
y	0x108	0x1	read
x	0x104	0x1	write

```
int z = 2, y = 1;
int *x;
int *w;
x = &y;
w = &z;
*x = *w;
```

Constant Var Name	Lvalue address	Rvalue Contents	
x	0x10c	0x108	read (address)
y	0x108	0x2	write
z	0x104	0x2	read
w	0x100	0x104	read (address)

```
*x on Lside is   0x108
 w on Rside is   0x100
*w on Rside is   2
```


x

Pointer Practice

```c
int *ptr;
```

Declares a variable, `ptr`, which is a pointer to (*it* contains the address of) an `int` in memory

```c
int x = 5;
int y = 2;
```

Declares two variables, `x` and `y`, that contain `int`s, and *initializes* them to 5 and 2, respectively

```c
ptr = &x;
```

Sets `ptr` to contain the address of `x` ("`ptr` points to `x`")

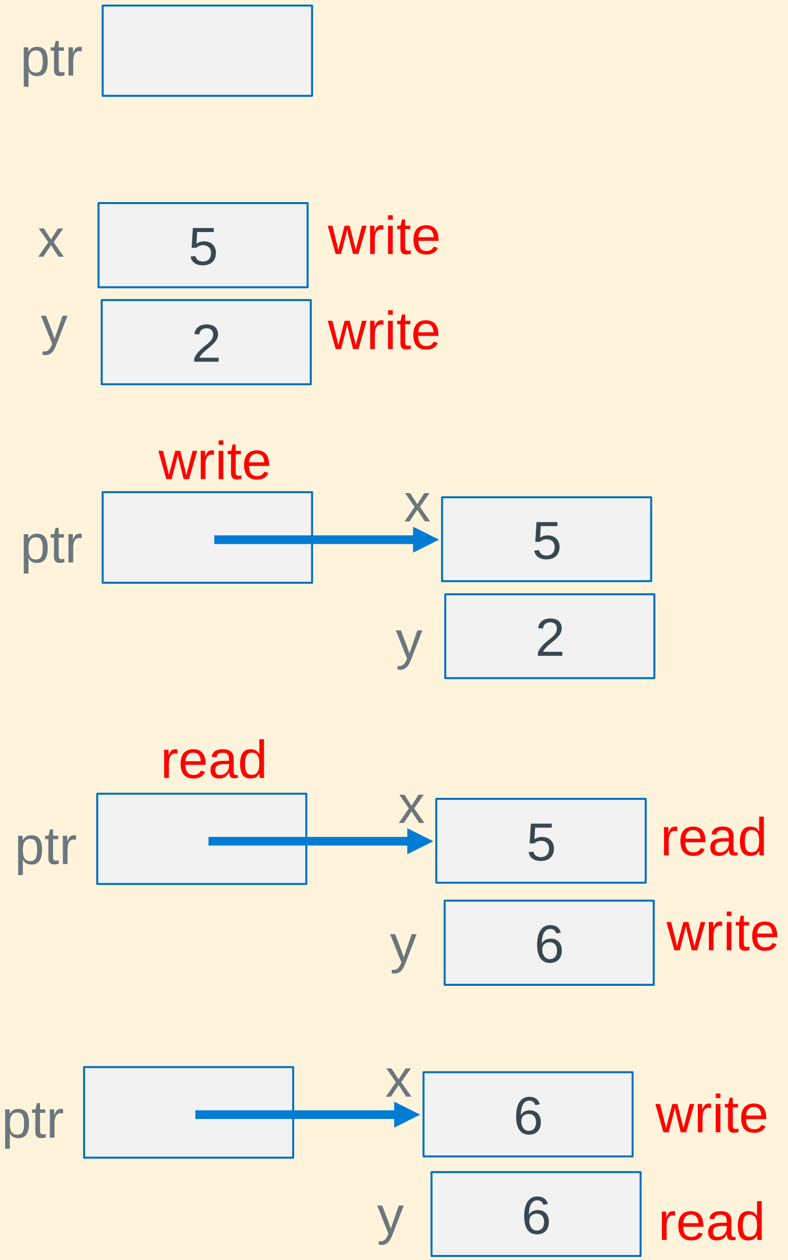
```c
y = 1 + *ptr;
```

"Dereference `ptr`"

Sets `y` to "1 plus the value stored at the address held by `ptr`. Because `ptr` points to `x`, this is equivalent to `y = 1 + x;`

```c
x = *(&y);
```

Sets x = y; The * and & cancel each other. get the address of y and then get the contents pointed by that address



The NULL Constant and Pointers

- **NULL is a constant** that **evaluates to zero (0)**
- You assign a pointer variable to contain NULL to indicate that the pointer does not point at anything
- A pointer variable with a value of NULL is called a "NULL pointer" (invalid address!)
- Memory location 0 (address is 0) is not a valid memory address in any C program
- Dereferencing NULL at runtime will cause a program fault (segmentation fault)!

```
p = NULL;
i = *p;                    /* segmentation fault! */
*(int *)900000 = 25;       /* cast 900000 to a pointer */
                           /* if writeable address space, it works */
                           /* that memory location just changed */
```


x

Using the NULL Pointer

- Many functions return NULL to indicate an error has occurred

```
/* these are all equivalent */
int *p = NULL;
int *p = (int *)0;    // cast 0 to a pointer type
int *p = (void *)0;  // automatically gets converted to the correct type
```

- NULL is considered "false" when used in a Boolean context
  - **Remember: false expressions** in C are defined to be zero *or* NULL
- The following two are equivalent (the second one is preferred for readability):

```
if (p) ...
if (p != NULL) ...
```

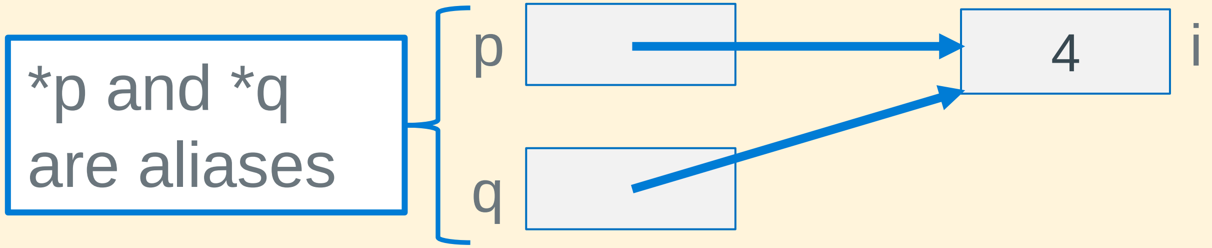

X

What is Aliasing?

- Two or more variables are aliases of each other when they all reference the same memory (so different names, same memory location)
- When one pointer is copied to another pointer it *creates an* ***alias***
- ***Side effect***: Changing one variables value (content) changes the value for other variables
  - Multiple variables all read and write the **<u>same</u>** memory location
  - Aliases occur either by accident (coding errors) or deliberate (careful: readability)

```
int i = 5;
int *p;
int *q;
p = &i;

q = p;    // *p & *q are aliases
*q = 4;  // changes i
```



Result *p, *q and i all have the value of 4

Defining Arrays

int n;
int arr[n]; → global X

Definition: `type name[count]`

- *"Compound"* data type where each value in an array is an element of type
- Allocates **name** with a *fixed* count array elements of type **type**
- Allocates (`count * sizeof(type)`) bytes of ***contiguous memory***
- Common usage is to specify a compile-time constant for **`count`**

```
#define BSZ   6
int b[BSZ];
```

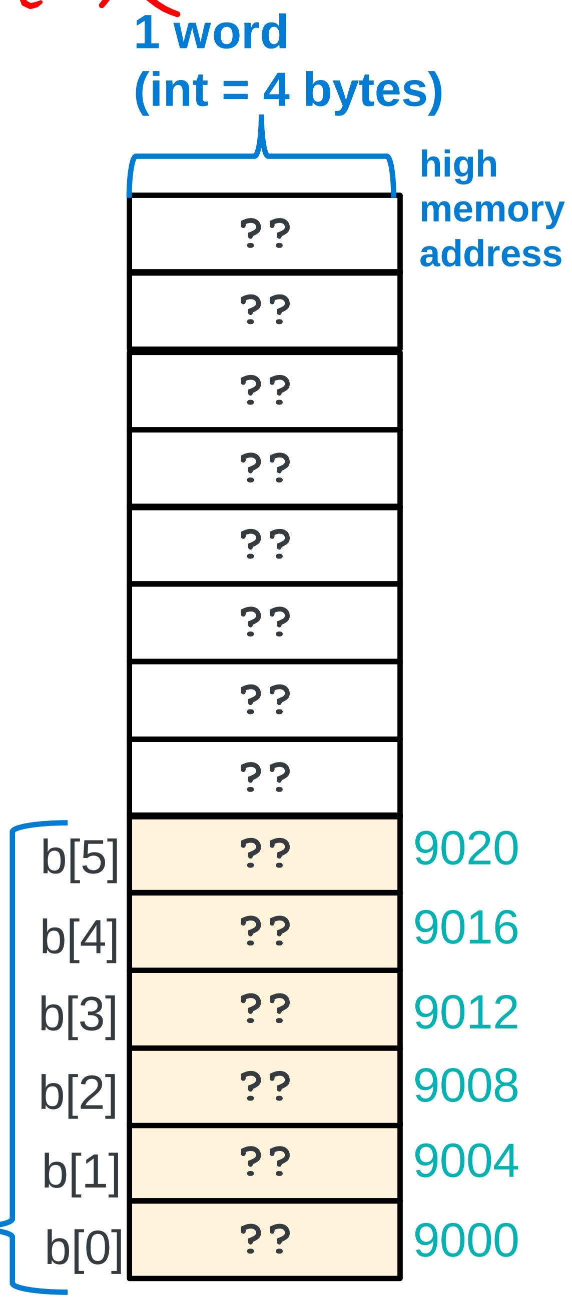
BSZ is a macro replaced by the C preprocessor at compile time

- Array **names are constants** and cannot be assigned (the name cannot appear on the Lside by itself)

```
a = b;        // invalid does not copy the array
              // copy arrays element by element
```

b : 0x5000

```
int b[6];
```



Array Initialization

- Initialization: `type name[count] = {val0,…,valN};`
  - **{ }** *(optional)* initialization list can *only* be used at **time** of **definition**
  - If no `count` supplied, `count` is determined by compiler using the number of array initializers

    no initialization values given; then elements are initialized to 0

  - `int block[20] = {}; //only works with constant size arrays`

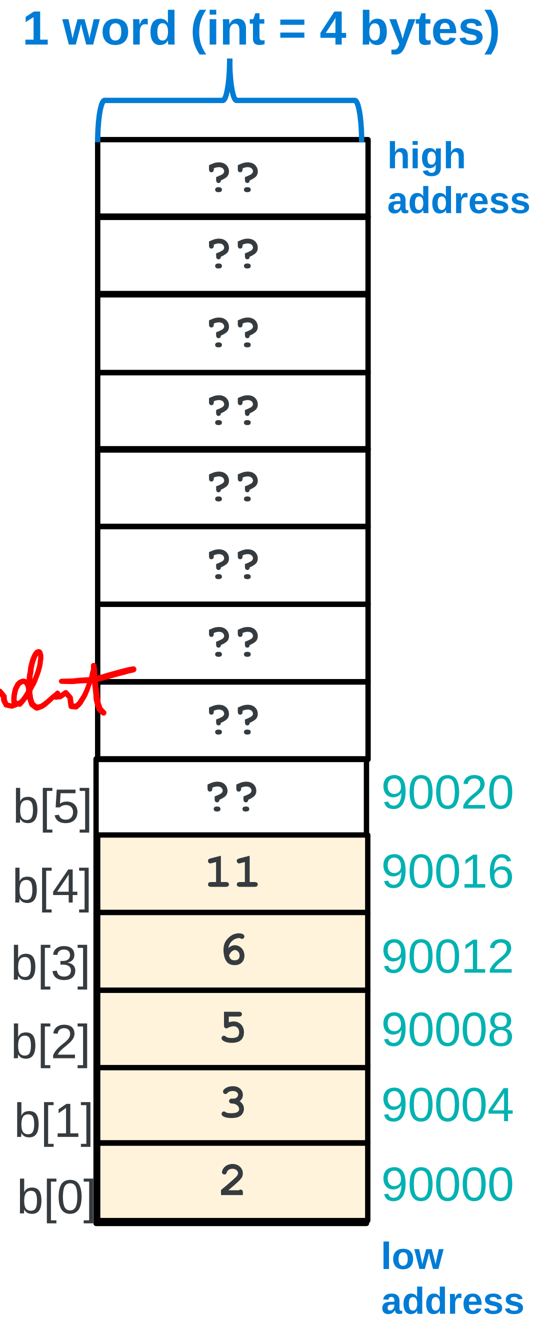
    compiler dependent

    - defines an **array of 20 integers** each element filled with zeros
    - Performance comment: do not zero automatic arrays unless really needed!
- When a **count** is given:
  - **extra** *initialization values* are **ignored**
  - **missing** *initialization values* are set to **zero**

```
int block[5] = {2, 3, 5, 6, 11, 13};
```

not needed and if used **may** truncate initialization list

6 initialization values given, **only 5 are used**



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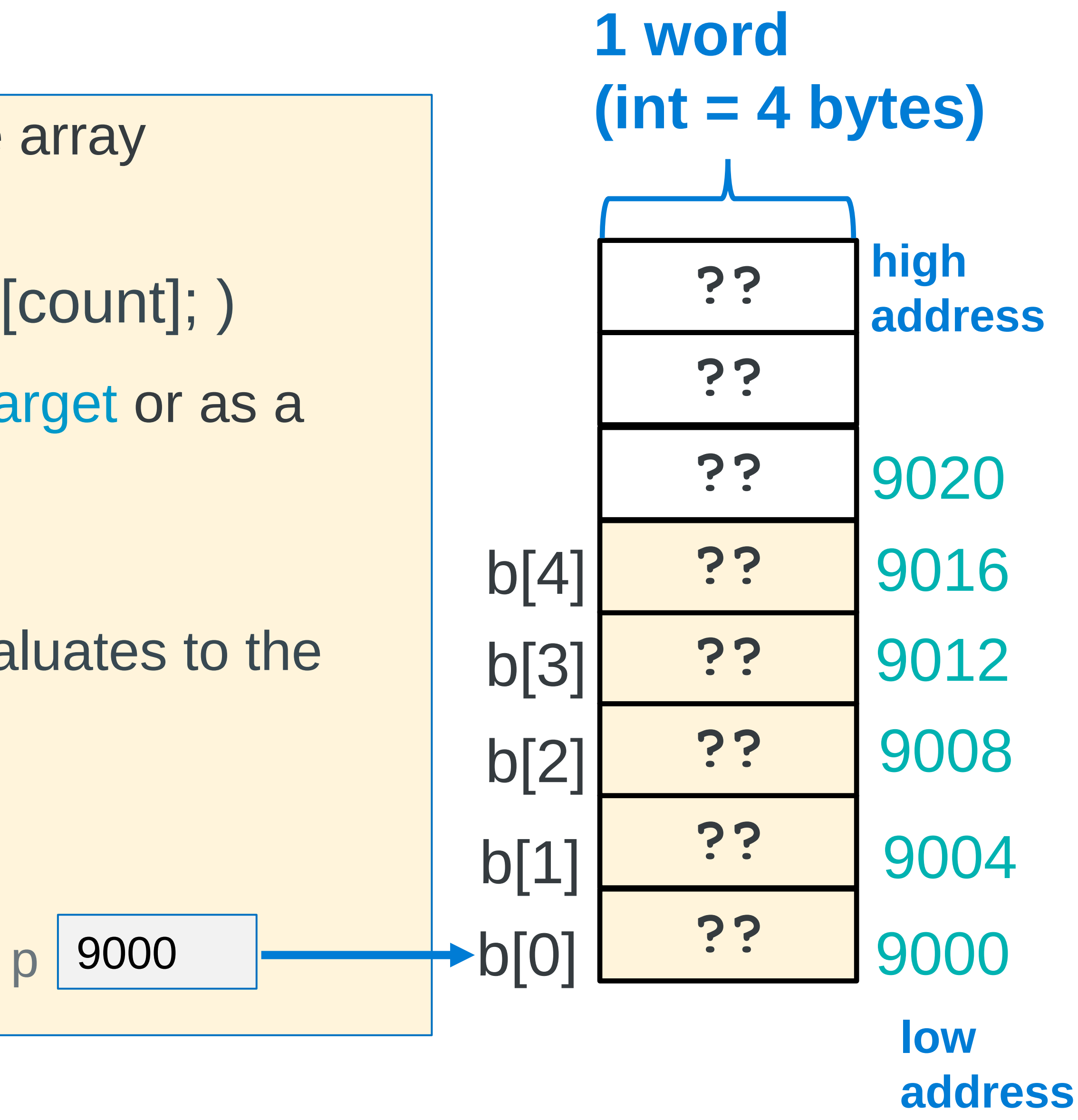
Accessing Arrays Using Indexing

- **name[index]** selects the **index** element of the array
  - index **should be** unsigned
  - Elements range from: 0 to count – 1 (int x[count];)
- **name[index]** can be used as an assignment target or as a value in an expression

```
int a[5];
int b[5];
```

- Array name (by itself with no [ ]) on the Rside evaluates to the address of the first element of the array

```
int b[5];
int *p = b;
```



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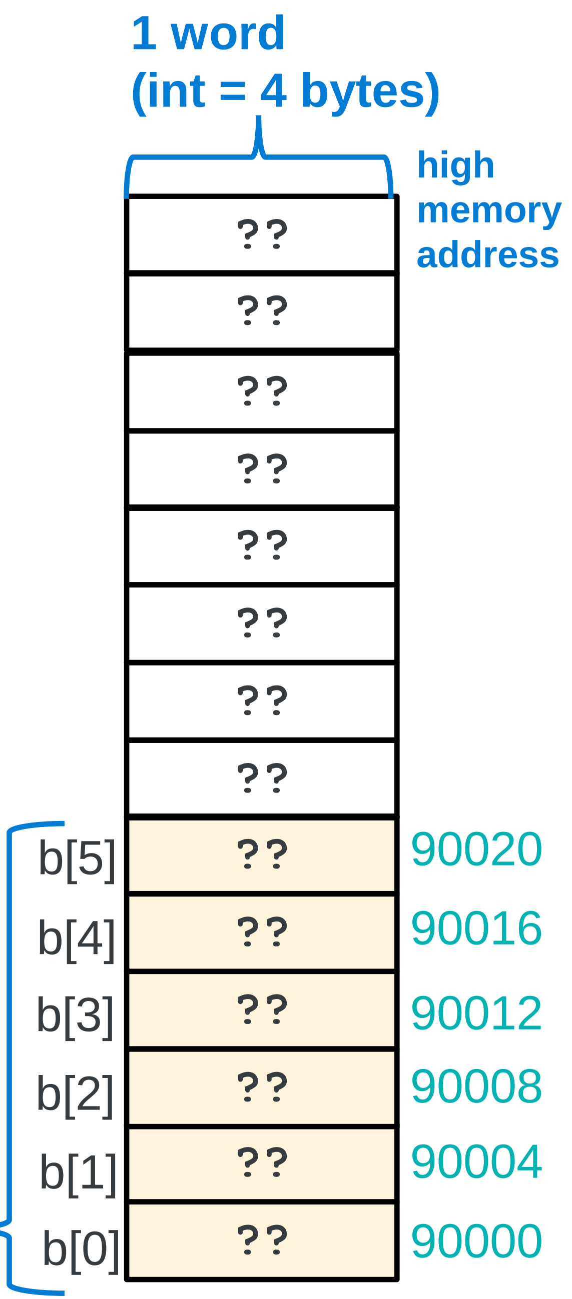
How many elements are in an array?

- **The number of elements of space allocated to an array (called element count) and indirectly the total size in bytes of an array** is <u>not stored anywhere</u>!!!!!!
- An **array name** is just the **address of the first element in a block of contiguous memory**
  - So an array does not know its own size!

```
#define SZ 6
int block[SZ];        // you specify the array has SZ elements
int indx;             // use when SZ is defined

for (indx = 0; indx < SZ; indx++)
      block[indx] = 0;
```

```
int b[6];
```



Determining Element Count for a compiler calculated array

- Programmatically determining the element count in a compiler calculated array

  `sizeof(array) / sizeof(of just one element in the array)`

- `sizeof(array)` **only works** when used in the SAME **scope** as where the array variable was defined

```
#include <stddef.h>

int block[] = {2, 3, 5, 6, 11, 13};     // automatic: compiler calculates array size

int cnt = (int)(sizeof(block) / sizeof(block[0])); // in this case cnt = 6

for (int indx = 0; indx < cnt; indx++)
        block[indx] = 0;
```


X

Pointer and Arrays - 1

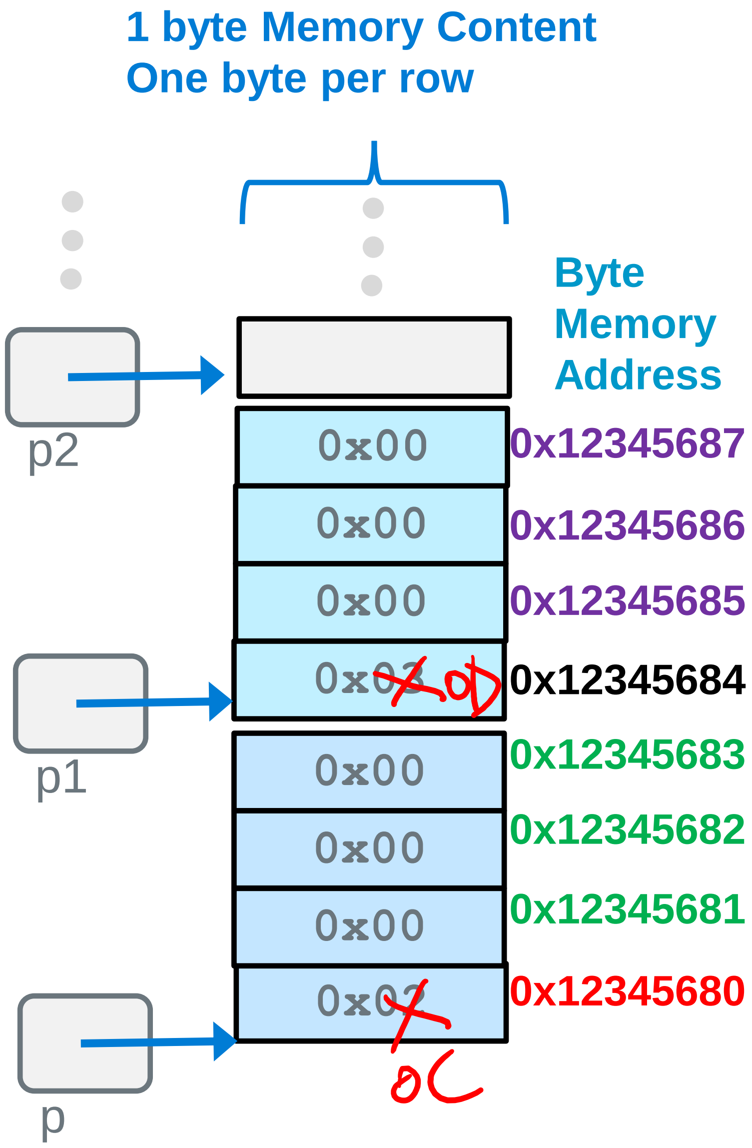
- A few slides back we stated: Array name (by itself) on the Rside evaluates to the address of the first element of the array

```
int buf[] = {2, 3, 5, 6, 11};
```

- Array indexing syntax ([ ]) an operator that performs *pointer arithmetic*

- **buf and &buf[0]** on the **Rside are equivalent**, ***both evaluate*** to the address of the first array element

```
int *p = buf;         // or int *p = &buf[0];
int *p1 = &buf[1];
int *p2 = &buf[2];
int *p3 = &buf[3];

*p = *p + 10;
*p1 = *p1 + 10;       // {12, 13, 5, 6, 11}
```



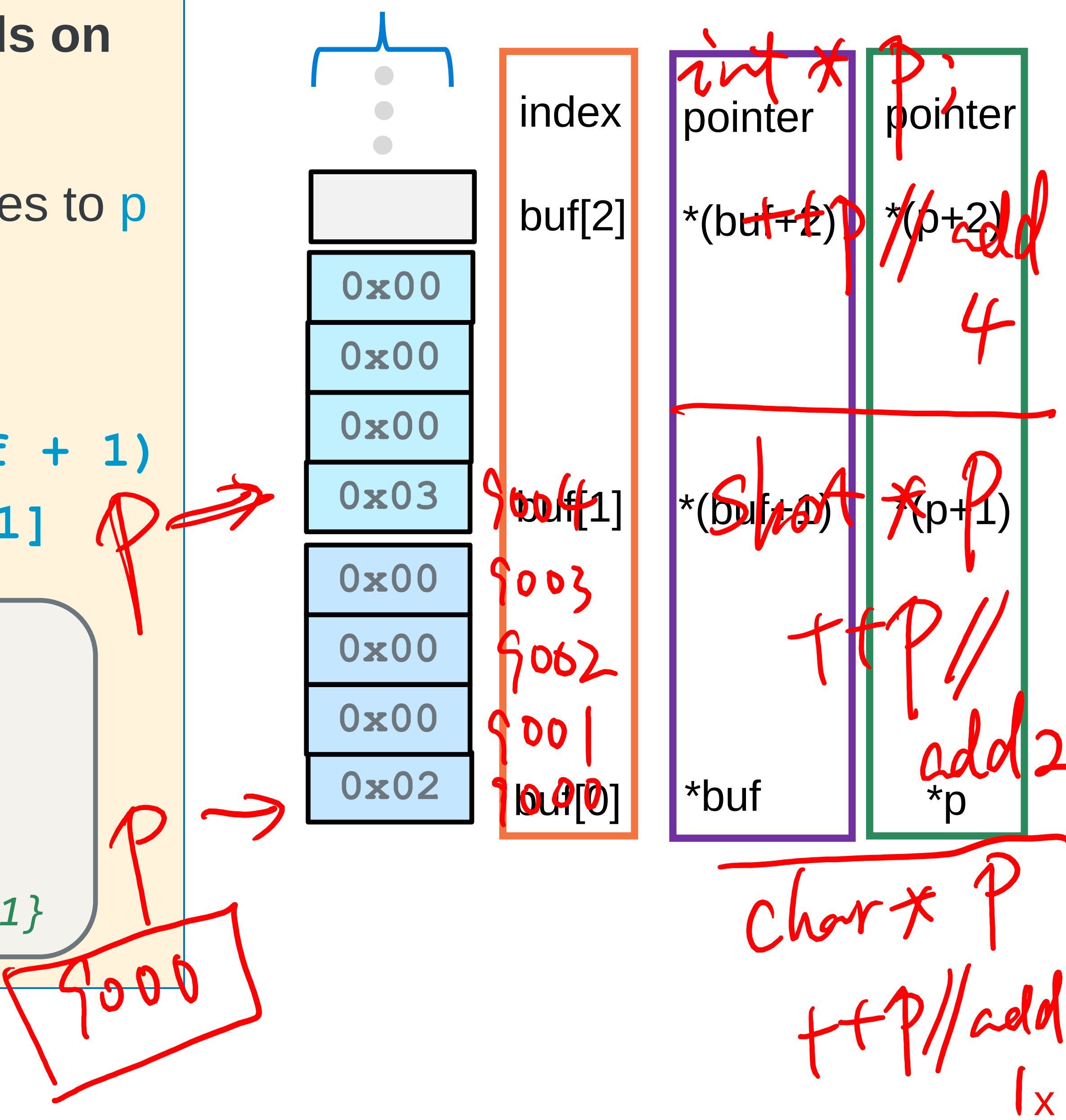
Pointer and Arrays - 2

When p is a pointer, the actual value of `(p+1)` **depends on the type** that pointer p points at

- `(p+1)` adds `1 x sizeof(what p points at)` bytes to p
  - `++p` is equivalent to `p = p + 1`
- Using pointer arithmetic to find array elements:
  - Address of the second element `&buf[1]` is `(buf + 1)`
  - It can be referenced as `*(buf + 1)` or `buf[1]`

```
int buf[] = {2, 3, 5, 6, 11};
int *p;
p = buf;

*p = *p + 10;
*(p + 1) = *(p + 1) + 10; // {12, 13, 5, 6, 11}
```

1 byte Memory Content
One byte per row



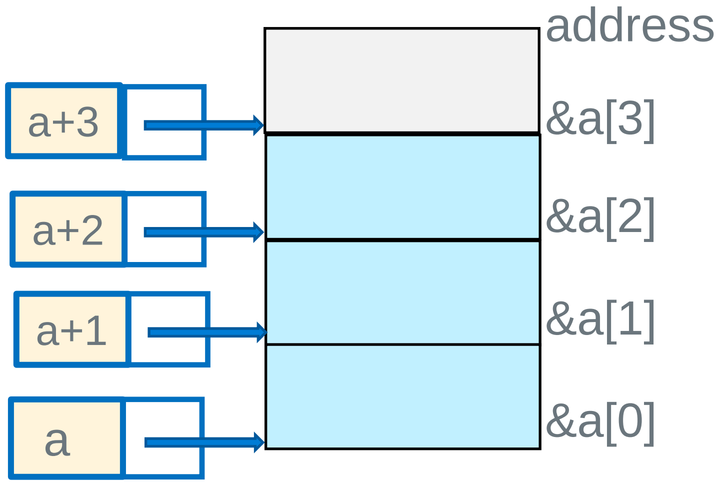
Pointer Arithmetic In Use – C's Performance Focus

char * p = a;

++p; ✓

```
char a[] = {'A', 'B', 'C'};
```

~~++a~~ ✗



a[1] ⟺ a+1

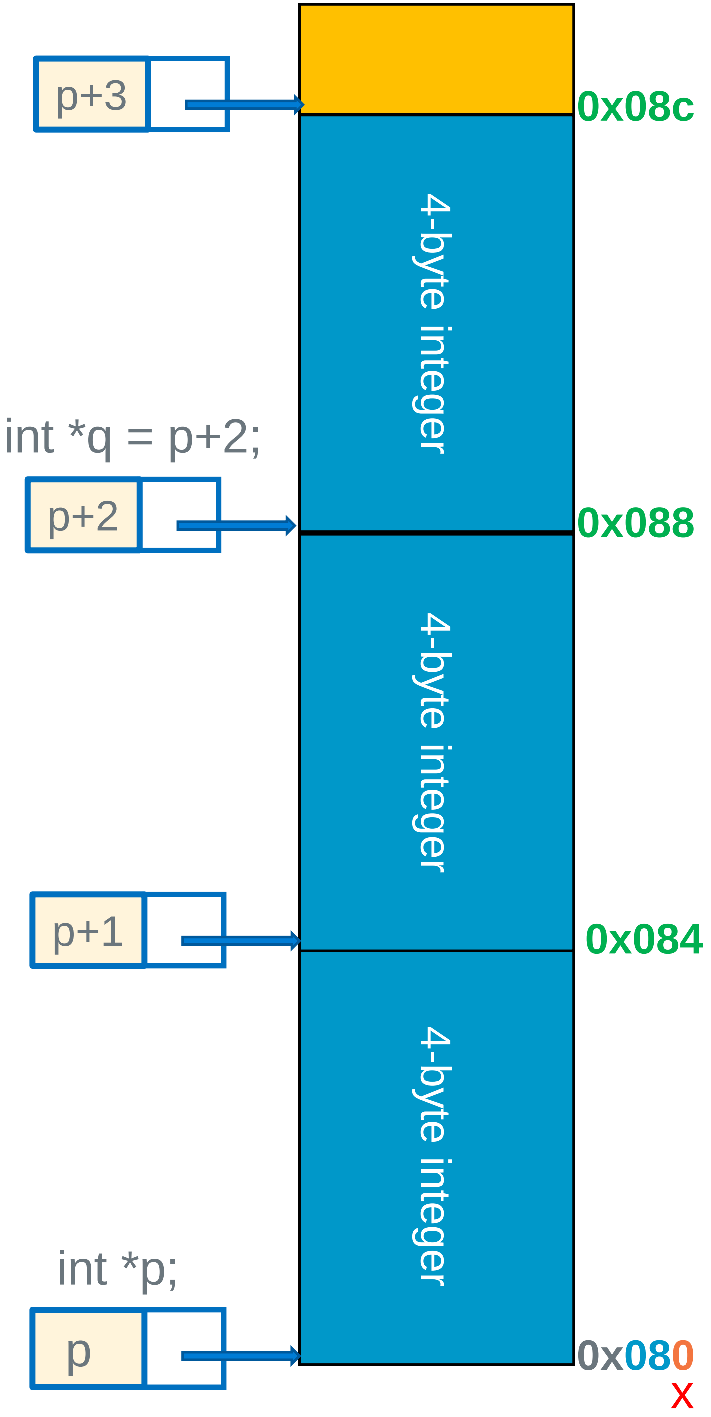
- **Alert!:** C performance focus <u>**does**</u> <u>**not**</u> perform any array "bounds checking"
- **Performance by Design**: *bound checking* <u>***slows down execution***</u> *of a properly written program*
- Example: array **a** of length i, C <u>**does**</u> <u>**not**</u> <u>**verify**</u> that **a[j] or *(a + j)** is valid (does not check: 0 ≤ j < i)
  - C simply *"translates"* and accesses the memory specified from: `a[j]` to be `*(a + j)` which may be *outside the bounds* of the array
  - OS only ***"faults"*** for an incorrect <u>access</u> to memory (read-only or <u>not</u> assigned to your process)
    - It does not fault for out of bound indexes or out of scope
- **lack of bound checking** is a common source of **errors** and **bugs** and is a common criticism of C

x

Pointer Arithmetic

- **You <u>cannot</u> add two pointers** *(what is the reason?)*
- A pointer q <u>can be subtracted</u> from another pointer p when the pointers are the same type – best done only within arrays!
- The value of **`(p-q)`** is the number of **elements between** the two pointers
  - Using memory address arithmetic (p and q Rside are both byte addresses):

```
distance in elements = (p - q) / sizeof(*p)

(p + 3) - p = 3 = (0x08c - 0x080)/4 = 3
```



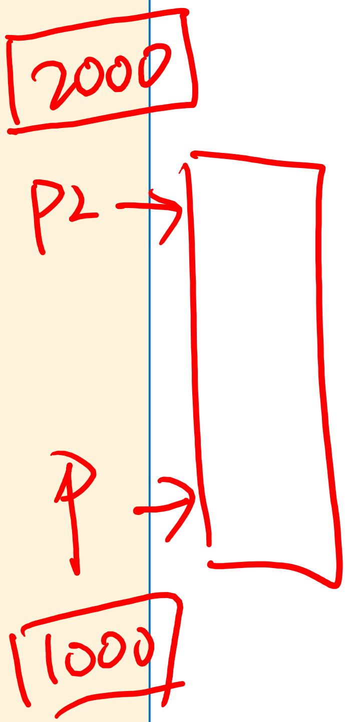
Pointer Comparisons

- Pointers (**same type**) can be compared with the comparison operators:

  `<, <=, ==, !=, >=, >`

```
int numb[] = {9, 8, 1, 9, 5};
int *end;
int *a;
end = numb + (int) (sizeof(numb)/sizeof(*numb));
a = numb;
while (a < end)  // compares two pointers (address)
      /* rest of code including doing an a++ */
```

num[0]



- Invalid, Undefined, or **risky** pointer arithmetic (some examples)
  - Add, multiply, divide on two pointers
  - Subtract two pointers of different types or pointing at different arrays
  - Compare two pointers of different types
  - Subtract a pointer from an integer

Fast Ways to "Walk" an Array: Use a Limit Pointer

```
int x[] = {0xd4c3b2a1, 0xd4c3b200, 0x12345684};
int cnt = (int)(sizeof(x) / sizeof(*x));

int *ptr;
int *xpt;
ptr = x; //or &x[0]
xptr = ptr + cnt;
```

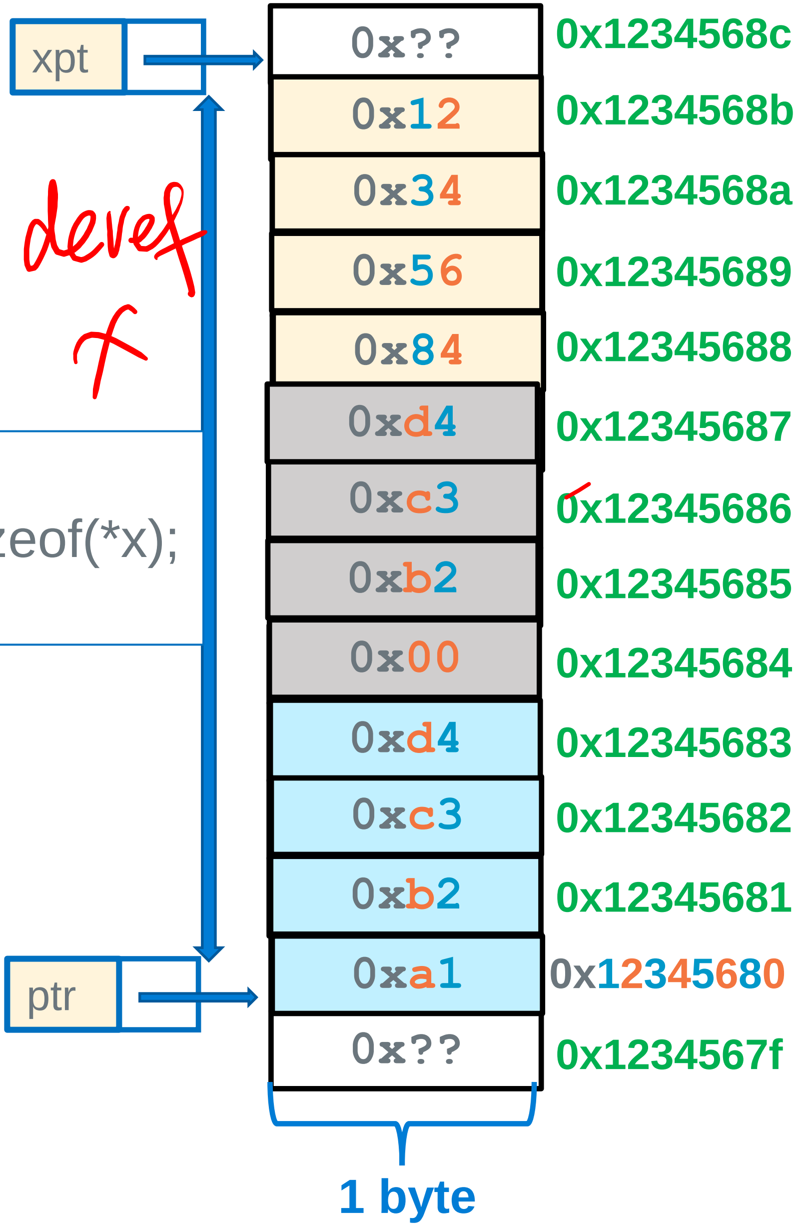
*x : deref

xpt is a loop **limit pointer**
it points 1 element past
the end of the array

```
cnt   = 3;
bytes = cnt * sizeof(*x);
      = 12
```

```
while (ptr < xpt) {
    printf("%#x\n", *ptr);
    ptr++;
}
```

```
% ./a.out
0xd4c3b2a1
0xd4c3b200
0x12345684
```



C Precedence and Pointers

- ++ -- pre and post increment combined with pointers can create code that is complex, hard to read and difficult to maintain
- Use () to help readability

common	With Parentheses	Meaning
`*p++`	`*(p++)`	(1)The Rvalue is the object that p points at (2)increment pointer p to next element ++ is higher than *
`(*p)++`		(1)Rvalue is the object that p points at (2)increment the object
`*++p`	`*(++p)`	(1)Increment pointer p first to the next element (2)Rvalue is the object that the incremented pointer points at
`++*p`	`++(*p)`	Rvalue is the incremented value of the object that p points at

Operator	Description	Associativity
() [] . -> ++ --	Parentheses or function call Brackets or array subscript Dot or Member selection operator Arrow operator Postfix increment/decrement	left to right
++ -- + - ! ~ (type) * & sizeof	Prefix increment/decrement Unary plus and minus not operator and bitwise complement type cast Indirection or dereference operator Address of operator Determine size in bytes	right to left
* / %	Multiplication, division and modulus	left to right
+ -	Addition and subtraction	left to right
<< >>	Bitwise left shift and right shift	left to right
< <= > >=	relational less than/less than equal to relational greater than/greater than or equal to	left to right
== !=	Relational equal to or not equal to	left to right
&&	Bitwise AND	left to right
^	Bitwise exclusive OR	left to right
|	Bitwise inclusive OR	left to right
&&	Logical AND	left to right
||	Logical OR	left to right
?:	Ternary operator	right to left
= += -= *= /= %= &= ^= |= <<= >>=	Assignment operator Addition/subtraction assignment Multiplication/division assignment Modulus and bitwise assignment Bitwise exclusive/inclusive OR assignment	right to left
,	comma operator	left to right

X

C Strings - 1

- **C <u>does not</u>** have a **dedicated type** for strings
- **Strings are** an **array of characters terminated by** a sentinel termination **character**
- `'\0'` is the **Null termination character;** has the **value of zero (do not confuse with '0')**
- An **array of chars** contains **a string only <u>when</u>** it is terminated by a '\0'
- **Length of a string** is the number of characters in it, <u>not including</u> the '\0'
- Strings in C are **<u>not</u>** objects
  - No embedded information about them, you just have a name and a memory location
  - You cannot use + or += to concatenate strings in C
  - For example, you must **calculate string length** using code at runtime looking for the end

length of the string: number of char (= 5)

index	*0*	*1*	*2*	*3*	*4*	*5*
char	`'H'`	`'e'`	`'l'`	`'l'`	`'o'`	`'\0'`

length (size) of the array in number of char (= 6)

C Strings - 2

- **First `'\0'` <u>encountered</u> from the start of the string** always indicates the end of a string
- The **'\0' does not have to be** in the **last element in the space allocated to the array**
  - But, String length is always less than the size of the array it is contained in
- In the example below, the array buf contains <u>two strings</u>
  - One string starts at &(buf[0]) is "cat" with a string length of 3
  - The other string starts at &(b[4]) is "o" with a string length of 1
  - "o" has two bytes: 'o' and '\0'

string length: number of char (= 3)

string length: number of char (= 1)

index	0	1	2	3	4	5
buf	`'c'`	`'a'`	`'t'`	`'\0'`	`'o'`	`'\0'`
	`0x63`	`0x61`	`0x74`	`0x00`	`0x6f`	`0x00`

length (size) of the array in number of char (= 6)

X

Defining Strings: Initialization

- When you combine the automatic length definition for arrays with double quote(") **initialization**
  - Compiler automatically adds the null terminator '\0' for you

```
char a[4] = {'c', 'a', 't', '\0'};
char b[] = "cat";                         // compiler calculates size, adds '\0'
char c[] = {'c', 'a', 't', '\0', 'a, 'b'}; // array size 6, string length 3
char empty[] = "";                        // empty string – contains '\0'
                                          // string length = 0
```


X

Defining Strings: Initialization Equivalents

- Following definitions create **equivalent** 4-character arrays
  - These are all strings as they all include a null ('\0') terminator

```
char a[4] = {'c', 'a', 't', '\0'};
char b[4] = {'c', 'a', 't', 0};
char c[4] = {'c', 'a', 't'};       // missing initial value defaults to 0
char d[4] = { 99, 97, 116, 0};     // 99 = 'c', 97 = 'a', 116 = 't'
char e[4] = "cat";
char f[4] = "cat\0";               // literal has 5 chars; array f string
                                   // length is 3
```


X

Background: Different Ways to Pass Parameters

- **Call-by-reference (or pass by reference)**
  - Parameter in the called function is an ***alias*** (references the same memory location) for the supplied argument
  - Modifying the parameter modifies the calling argument

Call-by-value (or pass by value) (C)

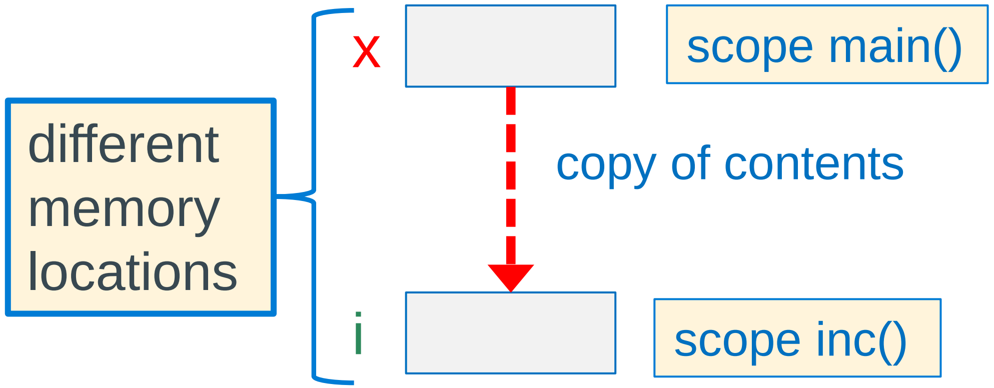
- What **Called** Function Does
  - Passed Parameters are used like local variables
  - Modifying the passed parameter in the function is allowed just like a local variable
  - So, writing to the parameter, ***only*** changes the ***copy***
- The return value from a function in C is **by value**

x

Passing Parameters – Call by Value Example

```
int main(void)
{
    int x = 5;
    inc(x);                 // makes a copy of x
    printf("%d\n", x); // 5 or 6 ?
}

void inc(int i)         // i is local to inc
{
    ++i;
}
```

if this was an expression like inc(x+1) it evaluates and stores the result in the memory allocated for the copy



- when `inc(x)` is called, a copy of x is made to another memory location
  - `inc()` cannot change the variable x since `inc()` does not have the address of x, it is local to `main()` so, 5 is printed
- The `inc()` function is free to change it's copy of the argument (just like any local variable) remember it does <u>NOT</u> change the parameter in `main()`

x

Output Parameters

- Passing a pointer parameter with the **intent** that the called function will use the address it to store values for use by the calling function, then pointer parameter is called an **output parameter**
- To pass the address of a variable x use the **address operator** (&x) **or** the contents of a pointer variable that points at x, or the name of an array (the arrays address)
- To be receive an address in the called function, define the corresponding parameter type to be a pointer (add *)
  - It is common to describe this method as: “pass a pointer to x
- C is still using “*pass by value*”
  - we pass the **value** of the address/pointer in a **parameter copy**
  - **The called routine** uses the address to change a variable in the caller's scope

```
void inc(int *p);
int
main(void)
{
    int x = 5;
    inc(&x);
    printf("%d\n", x);
    return EXIT_SUCCESS;
}

void
inc(int *p)
{
    if (p != NULL)
        *p += 1; // or (*p)++
}
```


X

Example Using Output Parameters

```
void inc(int *p);
int
main(void)
{
    int x = 5;
    inc(&x);
    printf("%d\n", x);
    return EXIT_SUCCESS;
}

void
inc(int *p)
{
    if (p != NULL)
        *p += 1;    // or (*p)++
}
```

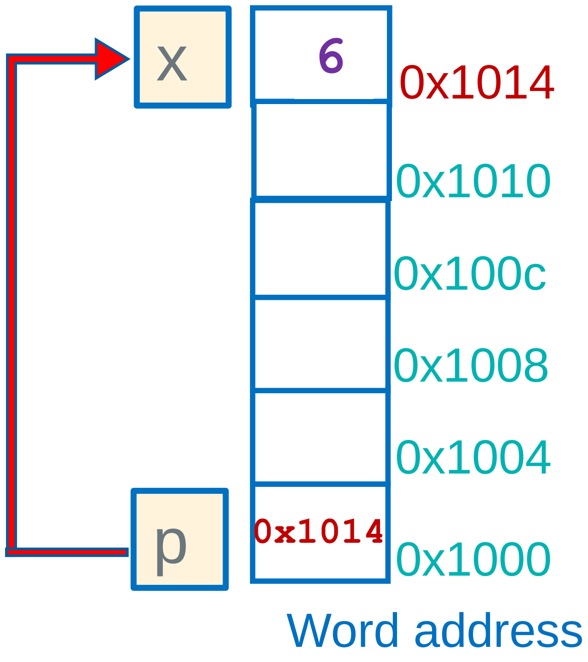
Pass the address of x (&x)

Receive an address copy (int *p)

Write to the output variable (*p)

At the Call to inc() in main()

1. Allocate space for p
2. Copy x's address into p



With a pointer to X,

inc() can change x in main()

this is called a side effect

p just like any other local variable

X

Array Parameters: Call-By-Value or Call-By-Reference?

- **`Type[]`** array parameter is automatically "**promoted**" to a pointer of type **`Type *`**, and a **copy** of the ***pointer*** is ***passed by value***

```
int main(void)
{
  int numbers[] = {9, 8, 1, 9, 5};

  passa(numbers);
  printf("numbers size:%lu\n", sizeof(numbers)); // 20
  return EXIT_SUCCESS;
}
```

```
void passa(int a[])
{
    printf("a size:%lu\n", sizeof(a)); // 4
    return;
}
```

IMPORTANT:
See the size difference 20 in main() in passa() is 4 bytes (size of a pointer)

- Call-by-value pointer (callee can change the pointer parameter to point to something else!)
- Acts like call-by-reference (called function can change the contents caller's array)

X

Arrays As Parameters: What is the size of the array?

- It's tricky to use arrays as parameters, as **they are passed as pointers to the start of the array**
  - In C, **Arrays do not know their own size** and at runtime there is no "bounds" checking on indexes

```
int sumAll(int a[]);

int main(void)
{
  int numb[] = {9, 8, 1, 9, 5};
  int sum = sumAll(numb);

  return EXIT_SUCCESS;
}

int sumAll(int a[])
{
  int i, sum = 0;
  int sz = (int) (sizeof(a)/sizeof(*a));
  for (i = 0; i < sz; i++) // this does not work
      sum += a[i];
  }
}
```

the name is the address, so this is passing a pointer to the start of the array

"inside" the body of sumAll(), the question is: how big is that array? all I have is a POINTER to the first element…..
sz is a 1 on 32 bit arm

X

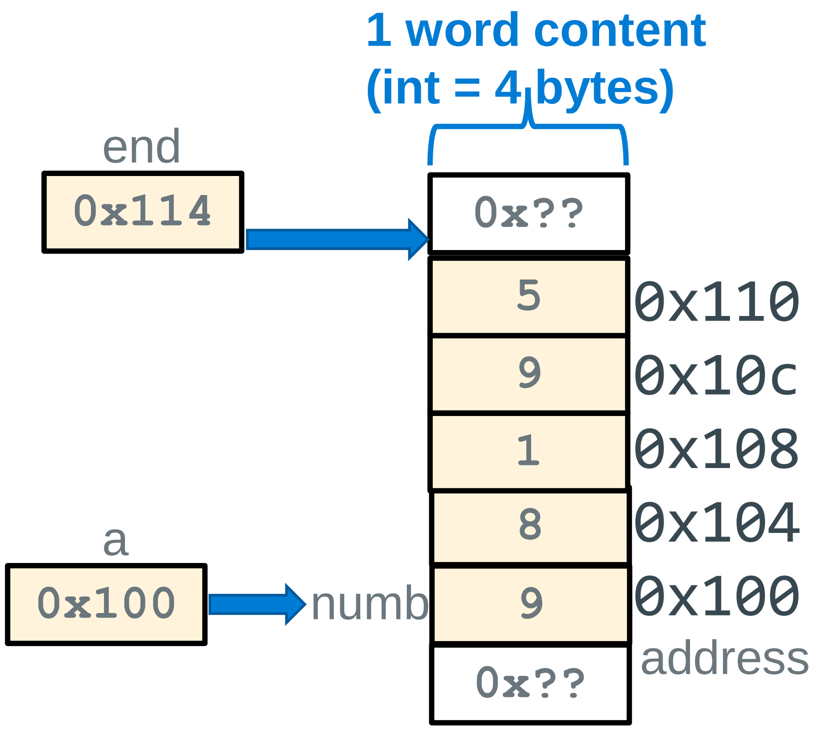
Arrays As Parameters, Approach 1: Pass the size

Two ways to pass array size

1. pass the count as an additional argument
2. add a sentinel element as the last element

remember you can only use sizeof() to calculate element count where the array is <u>defined</u>

```c
int sumAll(int *a, int size);
int main(void)
{
  int numb[] = {9, 8, 1, 9, 5};
  int cnt = sizeof(numb)/sizeof(numb[0]);

  printf("sum is: %d\n", sumAll(numb, cnt););
  return EXIT_SUCCESS;
}
```




```c
int sumAll(int *a, int size)
{
  int sum = 0;
  int *end;
  end = a + size;

  while (a < end)
    sum += *a++;
  return sum;
}
```

same as:
sum = sum + *a;
a++;

X

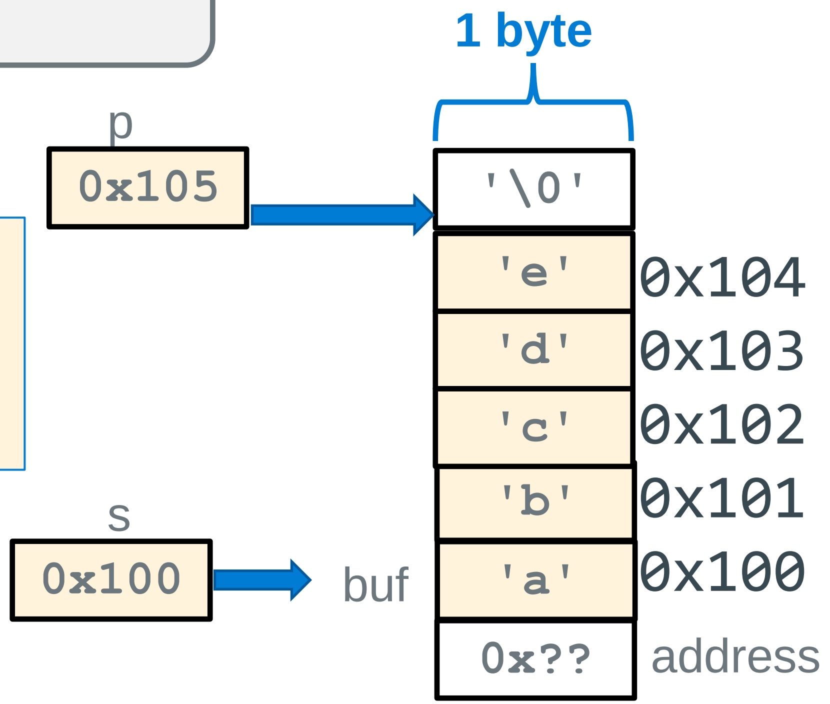
Arrays As Parameters, Approach 2: Use a sentinel element

- A sentinel is an element that contains a value that is not part of the normal data range
  - Forms of 0 are often used (like with strings). Examples: '\0', NULL

```c
int strlen(char *a);
int main(void)
{
  char buf[] = {'a', 'b', 'c', 'd', 'e', '\0'}; // string

  printf("Number of chars is: %d\n", strlen(buf));
  return EXIT_SUCCESS;
}
```

```c
/* Assumes parameter is a terminated string */
int strlen(char *s)
{
   char *p = s;
   if (p == NULL)
       return 0;
   while (*p++)
       ;
    return (p - s - 1);
}
```

```c
same as:
while (*p != '\0')
    p = p + 1;
return (p - s);
```



Do not overuse strlen()

- C string library function **`strlen()`** calculates string length **at runtime**
- **Do not overuse strlen(), as it walks the array each time called**

```
int count_e(char *s)  // o(n²) !!!
{
   int count = 0;
   if (s == NULL)
       return 0;
   for (int j = 0; j < strlen(s); j++) {
       if (s[j] == 'e')
           count++
   }
   return count ;
}
```

```
int count_e(char *s)  // o(n) !!!
{
   int count = 0;
   if (s == NULL)
       return 0;
   while (*s) {
       if (*s++ == 'e')
           count++
   }
   return count ;
}
```

```
same as:
while (*s != '\0') {
    if (*s == 'e')
        count++;
    s++;
}
```


X

Comparing stings

- Characters can be easily compared (c1 < c2) as they are numbers, so the **character order** is determined by the ASCII values assigned to each character
  - 65 = A   66 = B   67 = C   68 = D   69 = E   70 = F   71 = G, and so on.
- Example: the following strings are in lexicographical (alphabetical) order:

  ""   "a" "az"   "c"   "cab"   "cabin"   "cat"   "catastrophe"

- Compare two strings lexicographically (i.e., comparing ASCII values), subtract one from the other

Return Value	Comparison
< 0	s1 < s2
> 0	s1 > s2
= 0	s1 == s2

```
int strcmp(char *s1, char *s2)
{
    while (*s1 == *s2) {
        if ((*s1 == '\0') || (*s2 == '\0'))
            break;
        s1++;
        s2++;
    }
    return *s1 - *s2;  // character difference
}
```

Copying Strings: Use the Sentinel; libc: strcpy(), strncpy()

- To copy an array, you must copy each character from source to destination array
- Watch overwrites: strcpy assumes the target array size is equal or larger than source array

index	*0*	*1*	*2*	*3*	*4*	*5*
char	'H'	'e'	'l'	'l'	'o'	'\0'

```
char str1[80];
strcpy(str1, "hello");
```

```
// strncpy adds a length limit on copy
char str1[6];
strncpy(str1, "hello", 5); // \0 not copied
str1[5] = '\0'; // make sure \0 terminated
```

```
char *strcpy(char *s0, char *s1)
{
    char *str = s0;

    if ((s0 == NULL) || (s1 == NULL))
       return NULL;
    while (*s0++ = *s1++)
       ;
    return str;
}
```

```
char *strncpy(char *s0, char *s1, int len)
{
    char *str = s0;
    if ((s0 == NULL) || (s1 == NULL))
       return NULL;

    while ((*s0++ = *s1++) && --len)
       ;
    return str;
}
```


X

Reference: Some String Routines in libc (#include <string.h>)

Function	Description
`strlen(str)`	returns the # of chars in a C string (before null-terminating character).
`strcmp(str1, str2)`, `strncmp(str1, str2, n)`	compares two strings; returns 0 if identical, <0 if ***str1*** comes before ***str2*** in alphabet, >0 if ***str1*** comes after ***str2*** in alphabet. ***strncmp*** stops comparing after at most ***n*** characters.
`strchr(str, ch)` `strrchr(str, ch)`	character search: returns a pointer to the first occurrence of ***ch*** in ***str***, or ***NULL*** if ***ch*** was not found in ***str***. strrchr find the last occurrence.
`strstr(haystack, needle)`	string search: returns a pointer to the start of the first occurrence of ***needle*** in ***haystack***, or ***NULL*** if ***needle*** was not found in ***haystack***.
`strcpy(dst, src)`, `strncpy(dst, src, n)`	copies characters in ***src*** to ***dst***, including null-terminating character. Assumes enough space in ***dst***. Strings must not overlap. **strncpy** stops after at most ***n*** chars, and does not add null-terminating char.
`strcat(dst, src)`, `strncat(dst, src, n)`	concatenate ***src*** onto the end of ***dst***. **strncat** stops concatenating after at most ***n*** characters. Always adds a null-terminating character.
`strspn(str, accept)`, `strcspn(str, reject)`	**strspn** returns the length of the initial part of ***str*** which contains only characters in ***accept***. **strcspn** returns the length of the initial part of ***str*** which does not contain any characters in ***reject***.

2D Array of Char (where elements may contain strings)

- 2D array of chars (where rows may include strings)
- Each row has the same fixed number of memory allocated
- All the rows are the same length regardless of the actual string length)
- The column size must be large enough for the longest string

high memory

```
char aos2d[3][22] = {"my", "two dimensional", "char array"};
```

aos2d[2]	c	h	a	r		a	r	r	a	y	'\0'											
aos2d[1]	t	w	o		d	i	m	e	n	s	i	o	n	a	l		a	r	r	a	y	'\0'
aos2d[0]	m	y	'\0'																			

low memory

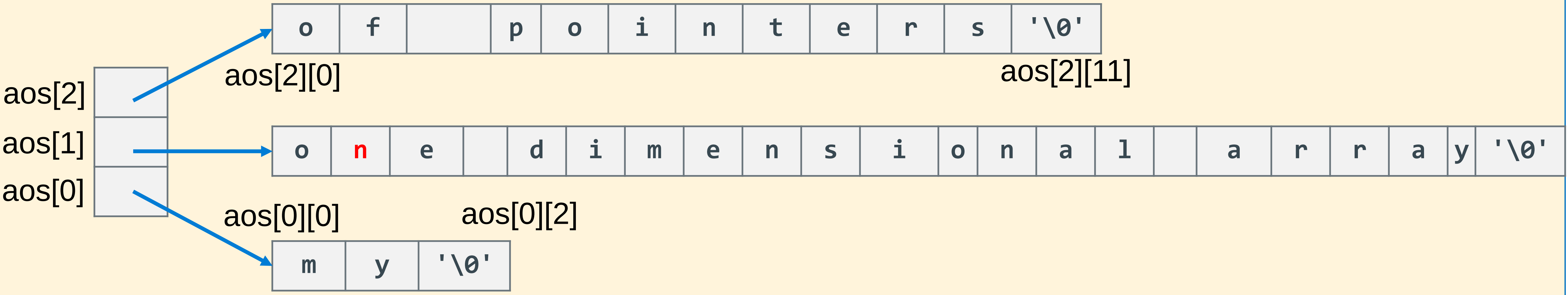
high memory

```
#define ROWS 3
char aos[ROWS][22] = { "my", "two dimensional", "char array"};
char (*ptc)[22] = aos;  // ptr points at a row of 22 chars

for (int i = 0; i < ROWS; i++)
    printf("%s\n", *(ptc + i));
```


X

Pointer Array to Strings (This is NOT a 2D array)

- 2D char arrays are an inefficient way to store strings (wastes memory) unless all the strings are similar lengths, so 2D char arrays *are rarely used* with string elements
- **An array of pointers** is common for strings as *"rows"* can very in length



- **`aos`** is an array of pointers; each pointer points at a character array (also a string here)
- Not a 2D array, but any char can be accessed as if it was in a 2D array of chars

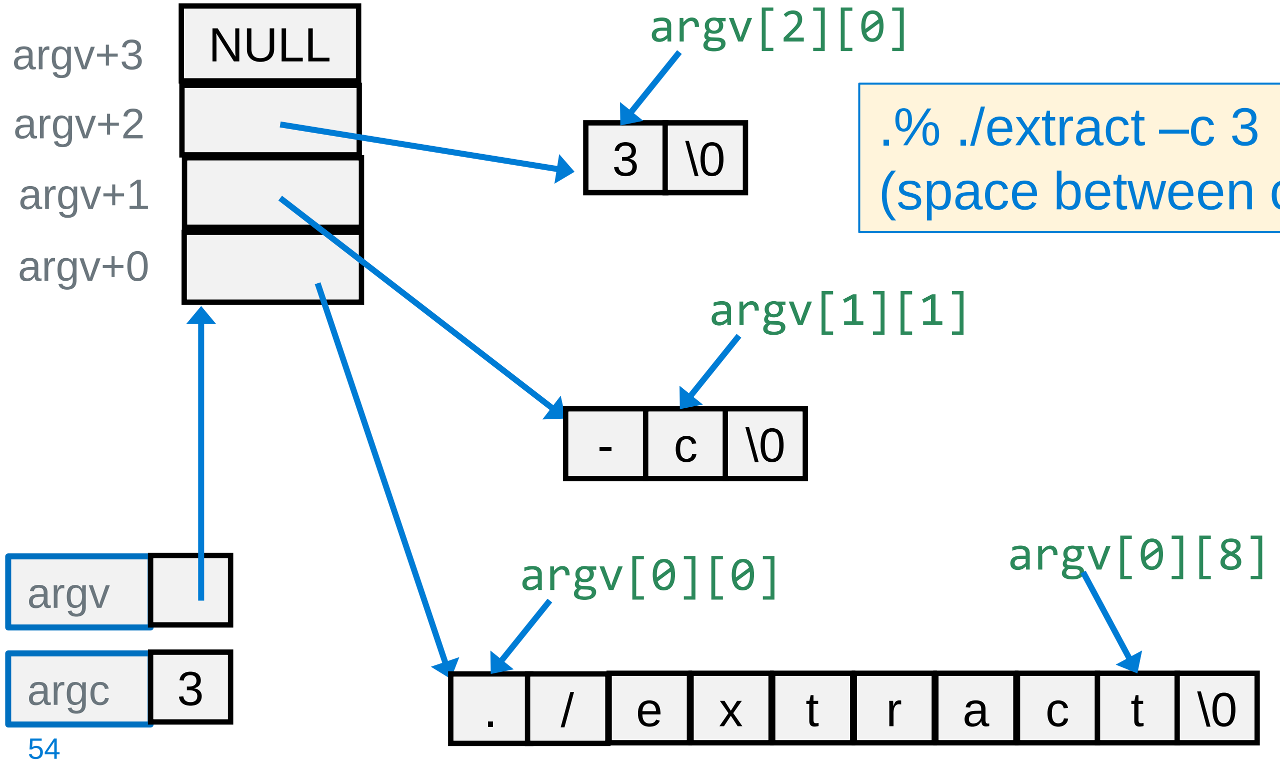
X

main() Command line arguments: argc, argv

- Arguments are passed to main() as a pointer to an array of pointers `(**argv or *argv[])`

  `Conceptually: % *argv[0] *argv[1] *argv[2] ….`

- `argc` is the number of VALID elements (they point at something)
- `*argv (argv[0]) is` **usually** is the name of the executable file (% ./vim file.c)
- `*(argv + argc)` always contains a NULL (0) sentinel
- `*argv[] (or **argv)` elements point at **mutable strings**!

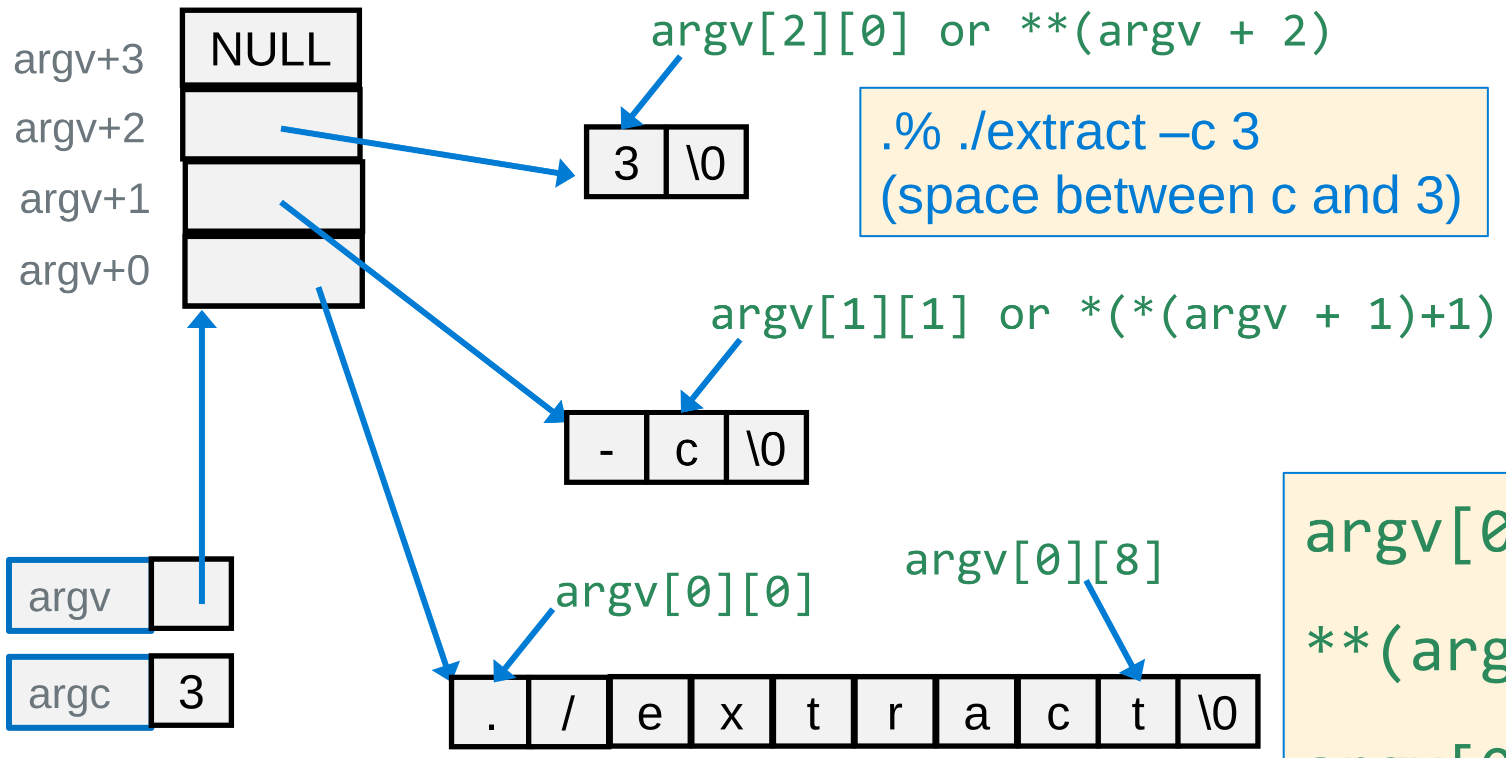


.% ./extract –c 3
(space between c and 3)

```
printf("%s\n", *(argv+0));
printf("%s\n", *(argv+1));
printf("%s\n", *(argv+2));
```


x

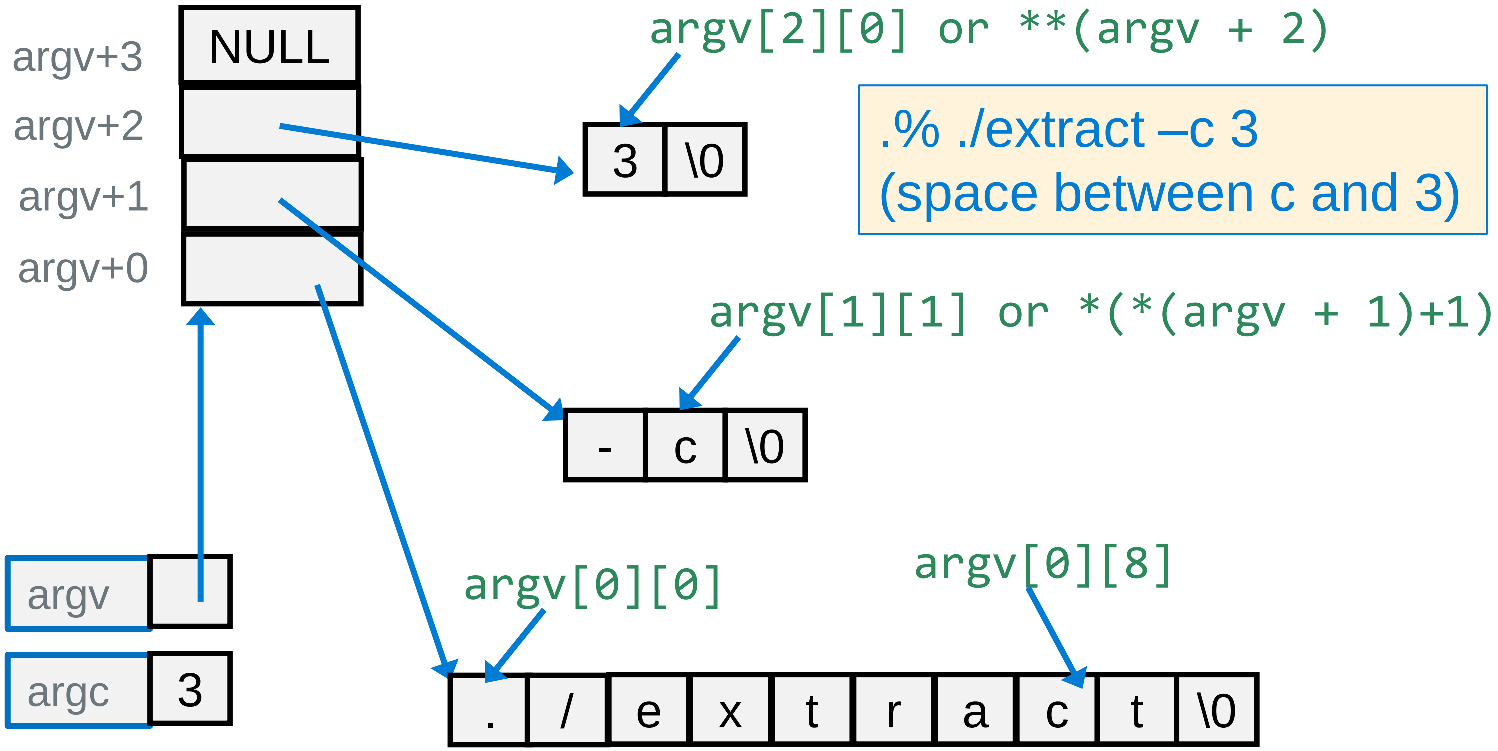
main() Command line arguments: argc, argv




```
argv[0][0] equiv to **(argv+0)
**(argv+0) equiv **argv
argv[0][8] equiv *(*argv + 8)


char *pt = *argv;
*pt equiv to **(argv+0)
*(pt+8) equiv to *(*argv + 8)
```


X

main() Command line arguments: argc, argv

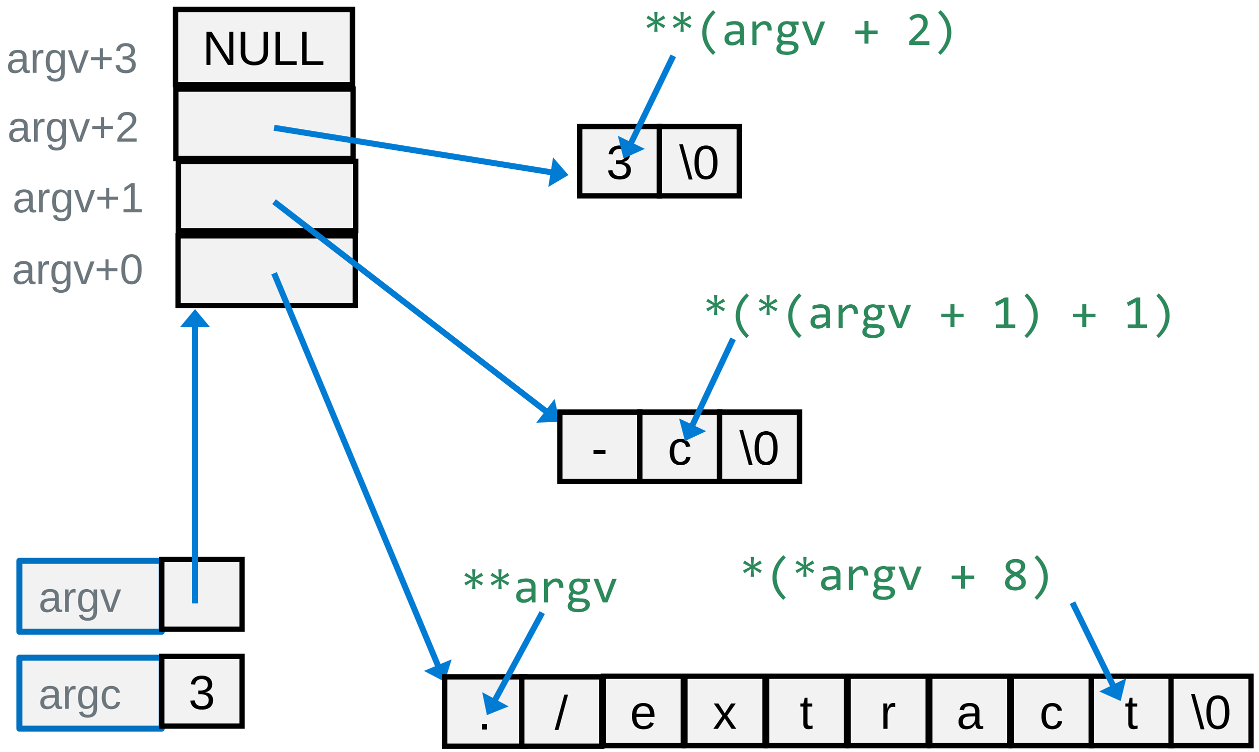



```c
int main(int argc, char *argv[])
{
    for (int i = 0; argv[i] != NULL; i++) {
        for (int j = 0; argv[i][j] != '\0'; j++)
           putchar(argv[i][j]);
       putchar('\n');
    }
    return EXIT_SUCCESS;
}
```

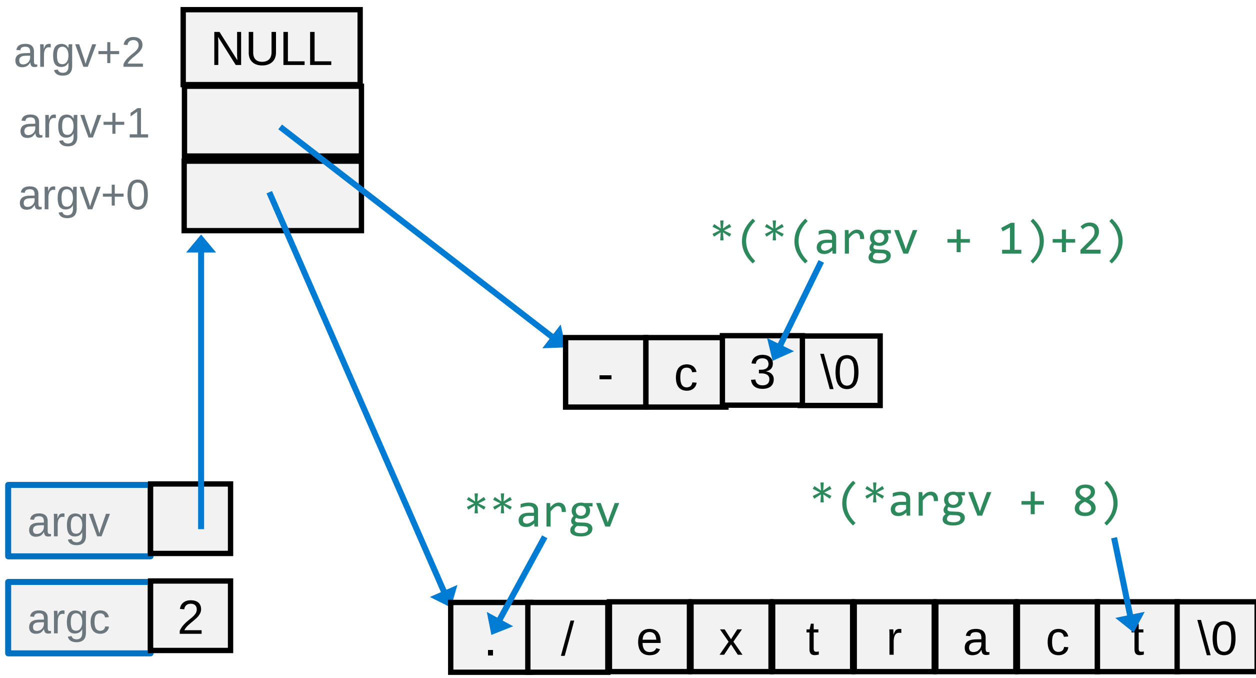
```c
int main(int argc, char **argv)
{
    char *pt;
    while ((pt = *argv++) != NULL) {
       while (*pt != '\0')
           putchar(*pt++);
       putchar('\n');
    }
    return EXIT_SUCCESS;
}
```


X

main() Command line arguments: argc, argv



.% ./extract –c 3
(space between c and 3)

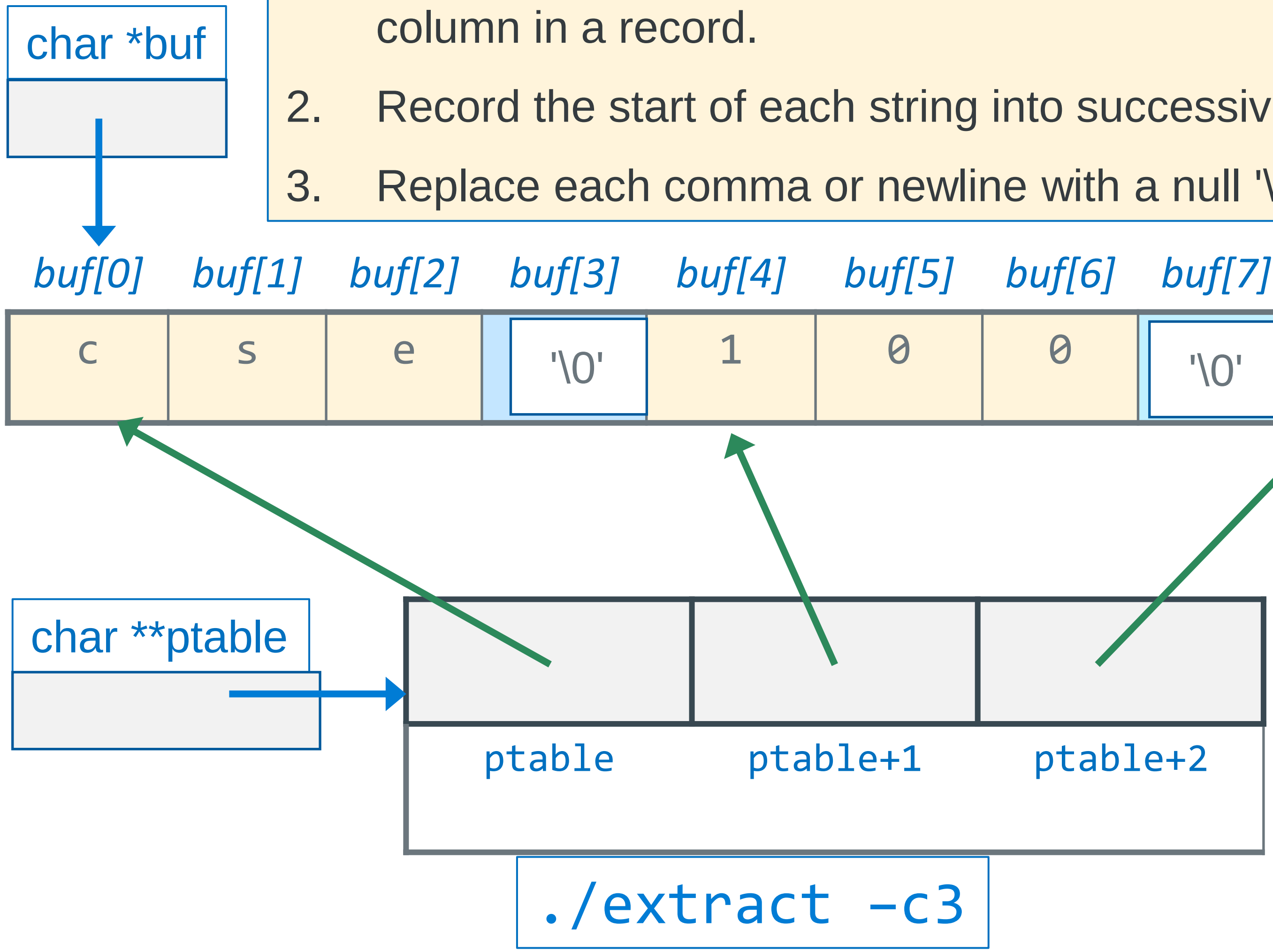


.% ./extract –c3
(No space between c and 3)

X

PA4: Creating a 2D Array of Mutable String Pointers

1. Break a string of comma separated words into individual strings without copying. Do This by walking the string until you see an either a comma , or a newline \n. Each points at a field or column in a record.
2. Record the start of each string into successive elements in an array of pointers
3. Replace each comma or newline with a null '\0'



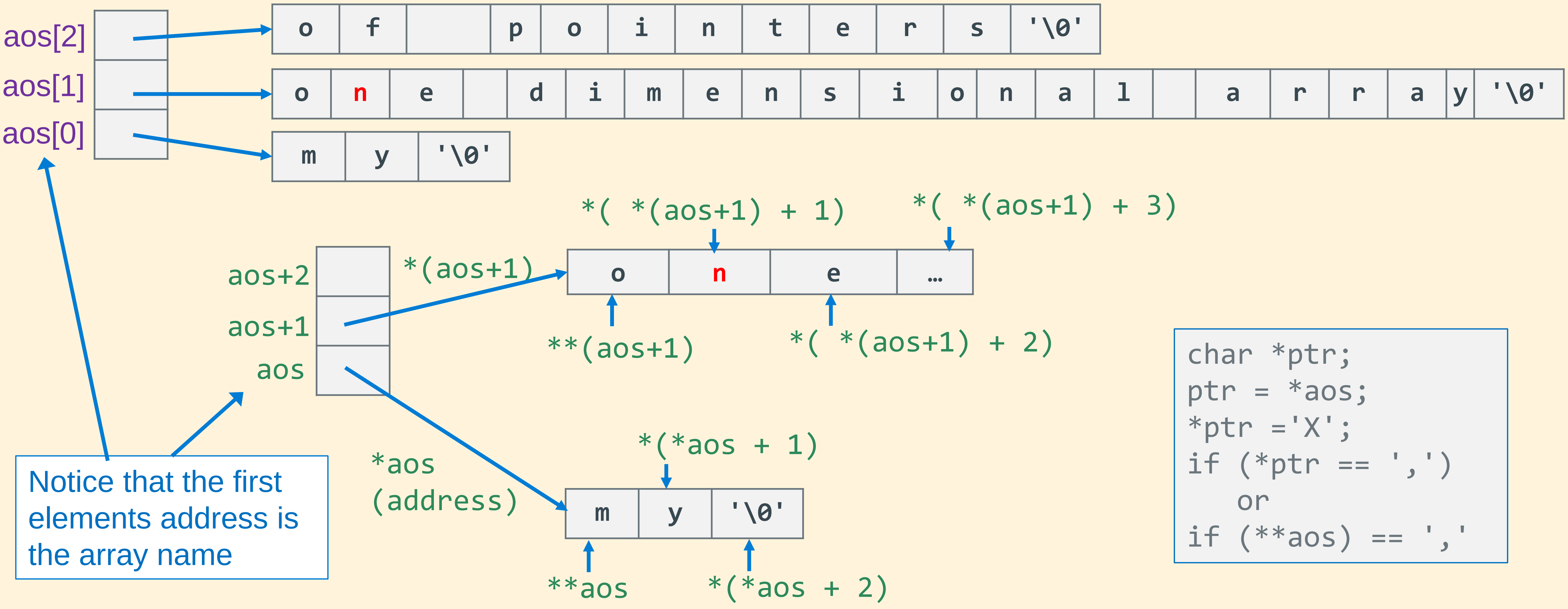

```
// extrack of token(), passed buf, ptable
and cnt

char **endptr = ptable + cnt;
*ptable = buf;
while ((ptable < endpt) && (*buf != '\0'))
{
    *ptable++ = buf;
    while (*buf != '\0') {
        /* process chars including buf++ */
    }
}
// check for too many or too few fields
```

Review: Pointer Array to Strings

How to access: `aos[1][1]` is `*(*(aos + 1) + 1)` which contains '**n**'

its address is `(*(aos + 1) + 1)`

aos+2 is not shown due to space limits on the slide




```
char *ptr;
ptr = *aos;
*ptr ='X';
if (*ptr == ',')
   or
if (**aos) == ','
```


X