

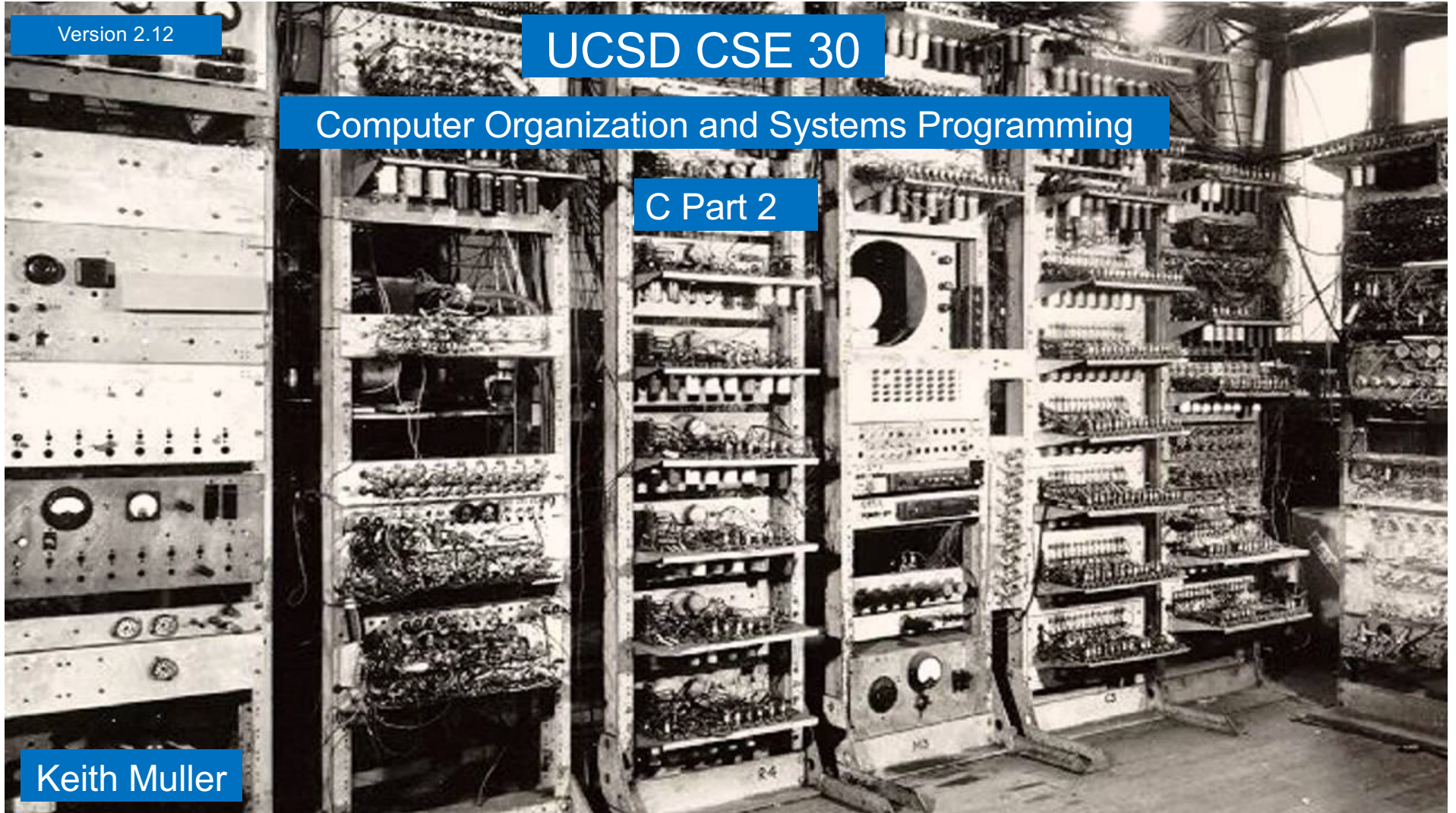
Version 2.12

UCSD CSE 30

Computer Organization and Systems Programming

C Part 2

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Review: Binary Numbering

- Binary is base 2
 - *adjective*: being in a state of one of two **mutually exclusive** conditions such as **on** or off, **true** or **false**, **molten** or **frozen**, **presence** or **absence** of a signal
 - From Late Latin *bīnārius* (“consisting of two”)
- **Two** symbols:
0 1
- Numbers in C that start with **0b** are binary
- Example: What is **0b110** in base 10?
 - $0b110 = 110_2 = (1 \times 2^2) + (1 \times 2^1) + (0 \times 2^0) = 6_{10}$
- A **bit** is a single binary digit
- A **byte** is an 8-bit value



powers of two

$$\text{Unsigned binary Number} = \sum_{i=0}^{n-1} b_i \times 2^i = b_{n-1}2^{N-1} + b_{n-2}2^{N-2} + \dots + b_12^1 + b_02^0$$

Review: Hexadecimal Numbering

- hexadecimal is base 16
 - From “hexa” (Ancient Greek ἑξά-) \Rightarrow six
 - and from “decem” (Latin) \Rightarrow ten

- **Sixteen** symbols

0 1 2 3 4 5 6 7 8 9 a b c d e f



- Numbers in C that start with **0x** are hexadecimal numbers
 - **16**₁₀ = **0x**10₁₆
- Example: What is **0xa5** in base 10?
 - **0xa5** = **a5**₁₆ = (**10** \times 16¹) + (**5** \times 16⁰) = 165₁₀
- **Hexadecimal** numbers are **very commonly used** in programming to express binary values
 - Imagine the difficulty in correctly expressing a 64-bit binary value in your code

$$\text{Unsigned Hex Number} = \sum_{i=0}^{n-1} b_i \times 16^i = b_{n-1}16^{n-1} + b_{n-2}16^{n-2} + \dots + b_116^1 + b_016^0$$

Binary <---> Hexadecimal Equivalences

- **Hex → Binary:** $16^1 = 2^4$ 1 digit hex = 4 digits binary
 1. Replace hex digits with binary digits
 2. Drop **leading zeros**
 - Example: 0x2d to binary
 - 0x2 is 0b0010, 0xd is 0b1101
 - Drop two leading zeros, answer is 0b101101
- **Binary → Hex:** $2^4 = 16^1$
 1. **Pad** with enough **leading zeros** until number of digits is a multiple of 4
 2. **Replace** each **group of 4** with the **HEX equivalent**
 - Example: 0b101101
 - **Pad on the left** to: 0b 0010 1101
 - Replace to get: 0x2d

Number Base Overview (as written in C)

- Decimal is base 10 and Hexadecimal is base 16,
- Hex digits have 16 values 0 - 9 a - f (written in C as 0x0 – 0xf)
- No standard prefix in C for binary (most use hex)
 - gcc (compiler) allows 0b prefix others might not

Hex digit	0x0	0x1	0x2	0x3	0x4	0x5	0x6	0x7
Decimal value	0	1	2	3	4	5	6	7
Binary value	0b0000	0b0001	0b0010	0b0011	0b0100	0b0101	0b0110	0b0111

Hex digit	0x8	0x9	0xa	0xb	0xc	0xd	0xe	0xf
Decimal value	8	9	10	11	12	13	14	15
Binary value	0b1000	0b1001	0b1010	0b1011	0b1100	0b1101	0b1110	0b1111

Hex to Binary (group 4 bits per digit from the right)

- Each Hex digit is 4 bits in base 2 $16^1 = 2^4$

0x f a 5 3

1111 1010 0101 0011

0b1111101001010011

↑ binary start with a 0b in C

Binary to Hex (group 4 bits per digit from the right)

- 4 binary bits is one Hex digit $2^4 = 16^1$

0b 0110 1010 0011 1111
 └──┘ └──┘ └──┘ └──┘
 6 a 3 f

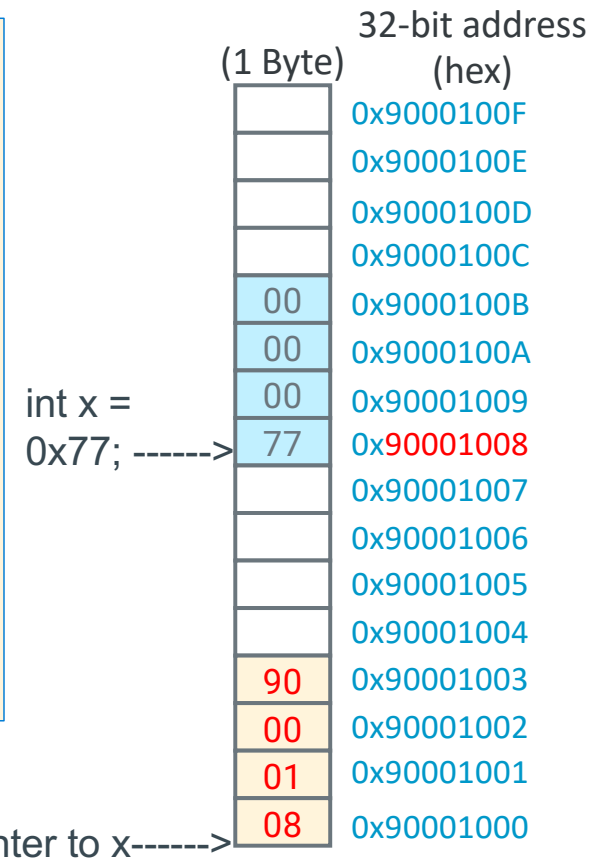
0x6a3f

hex start with 0x in C



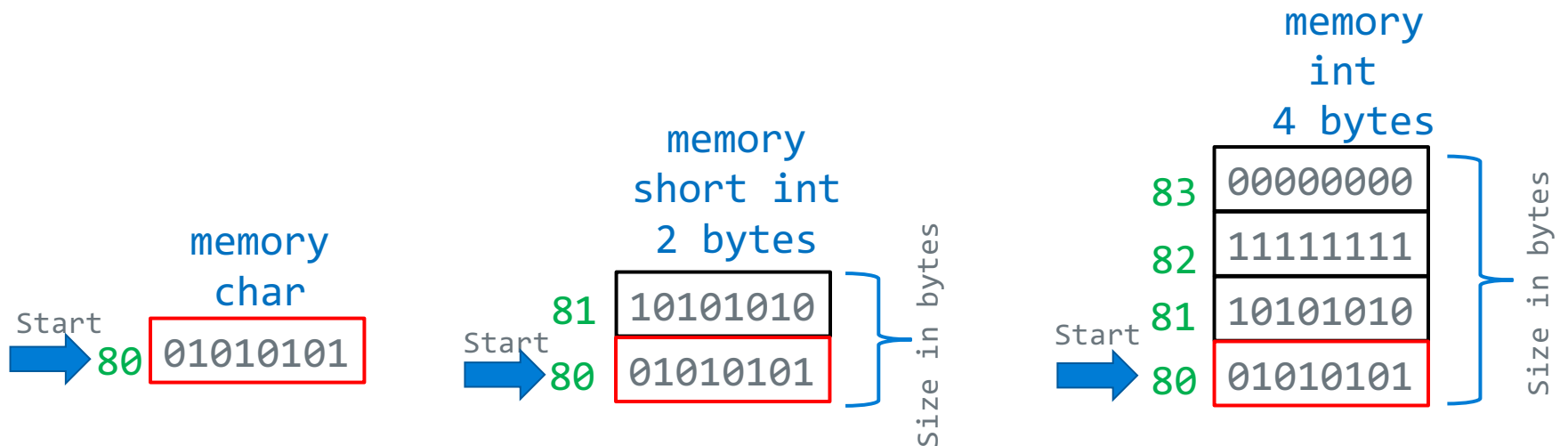
Address and Pointers

- An **address** refers to a location in memory, the **lowest** or **first byte** in a **contiguous sequence of bytes**
- A **pointer** is a **variable** whose **contents** (or value) can be properly used as an **address**
 - The **value in a pointer** *should* be a **valid address allocated to the process** by the **operating system**
- The **variable x** is at **memory address 0x90001008**
- The **variable pt** is at **memory location 0x90001000**
- The **contents** of **pt** is the **address of x 0x90001008**



Variables in Memory: Size and Address

- The number of contiguous bytes a variable uses is based on the *type* of the variable
 - Different variable types require different numbers of contiguous bytes
- **Variable names** map to a starting address in memory
- **Example Below:** Variables all starting at address 0x80, each box is a byte



Variables: Size

- Integer types

- `char`, `int`

- Floating Point

- `float`, `double`

- Modifiers for each base type

- `short` [int]
- `long` [int, double]
- `signed` [char, int]
- `unsigned` [char, int]
- `const`: variable read only

- char type

- One byte in a byte addressable memory
- **Signed** vs **Unsigned** Char implementations
- **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	printf specification
char (arm unsigned)	1	1	%c
short int	2	2	%hd
unsigned short int	2	2	%hu
int	4	4	%d / %i
unsigned int	4	4	%u
long int	4	8	%ld
long long int	8	8	%lld
float	4	4	%f
double	8	8	%lf
long double	8	16	%Lf
pointer *	4	8	%p

size of a pointer is the word size

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:

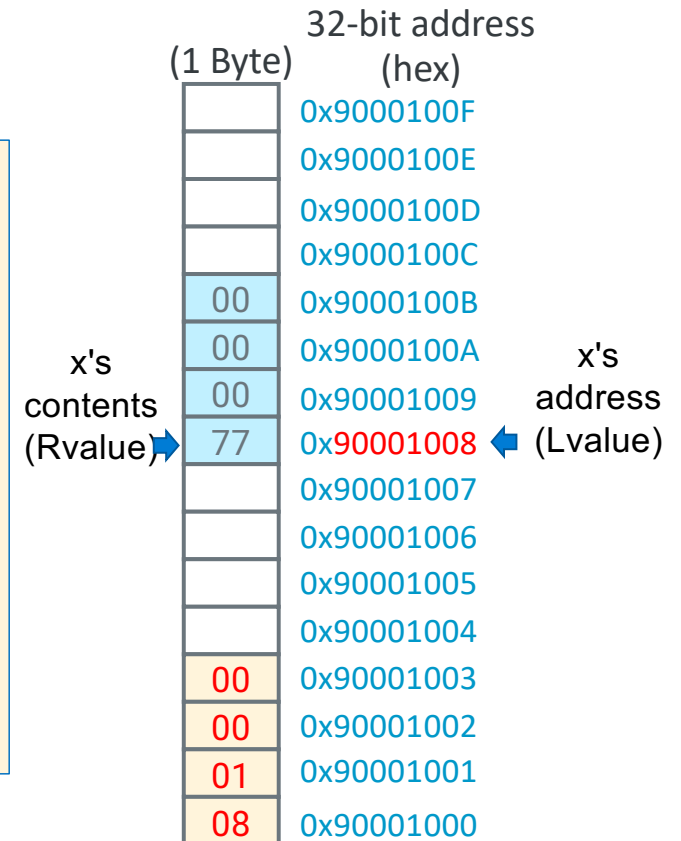
- number of bytes required to store **10 integers (an array of [10])**

Memory Addresses & Memory Content

Variable names in a C statement evaluation

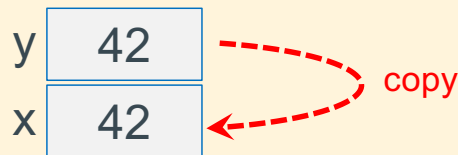
```
x = x + 1;    // Lvalue = Rvalue
```

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



Memory Addresses & Memory Content

`y = 42;` One memory write required
`x = y;` One memory read required
 // Lvalue = Rvalue



- `x` on left side (**Lside**) of the assignment operator = evaluates to:
 - **Address** of the memory assigned to the `x` – this is `x`'s **Lvalue**
- `y` on right side (**Rside**) of the assignment operator = evaluates to:
 - **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**)

Introduction: Address Operator: &

- Unary **address operator (&)** produces the **address** of where an **identifier** is in memory
 - Print assigned address to **g**
- **Example** this might print:
value of g is: 42
address of g is: 0x71a0a0
(the address will vary)
- **Tip:** printf() format specifier to display an address/pointer (in hex) is "%p"

```
int main(void)
{
    int g = 42;

    printf("value of g is: %d\n", g);
    printf("address of g is: %p\n", &g);
    return EXIT_SUCCESS;
}
```


Introduction: Address Operator: &

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

Pointer Variables

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

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

- A *pointer* is defined by placing a *star* (or *asterisk*) (*) before the identifier (name)
- You also must specify the *type of variable* to which the pointer points
- **Pointers are typed!** Why?
 - The compiler needs to know the *size* (sizeof()) of the data **you are pointing at** (number of consecutive bytes to access) to use (dereference) the pointer
- When the **Rside** of a **variable** contains a **memory address**, (it **evaluates** to an **address**) the variable is called a **pointer variable**

Pointer Variables - 2

- A pointer cannot point at itself, why?

```
int *p = &p; /* is not legal - type mismatch */
```

- `p` is defined as `(int *)`, a pointer to an int, but
- the type of `&p` is `(int **)`, a pointer to a pointer to an int
- Pointer variables all use the **same amount of memory** no matter what they point at

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

- Above prints on a 32-raspberry pi

```
% ./example  
iptr(4) cptr(4)
```

Defining Pointer Variables

- Assigning a value to a pointer:

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

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

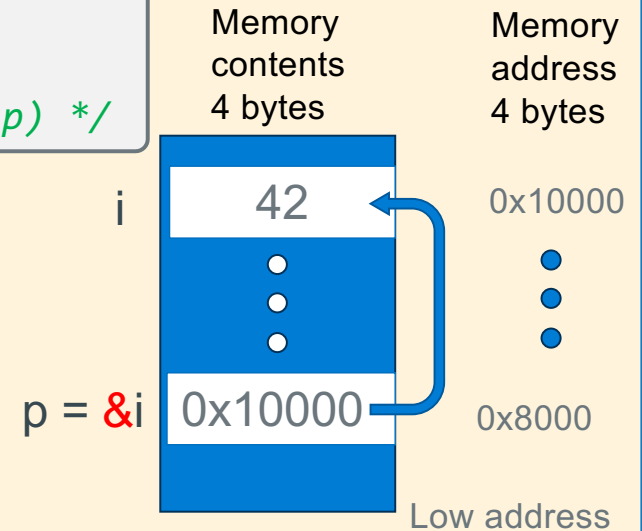
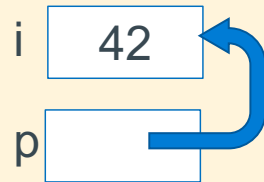
```
int *p;      /* p is defined (not initialized) */  
p = &i;      /* p points at i (assign address of i to p) */
```

- 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 */
```

Using Pointer Variables and the Address Operator & - 1

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



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

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

Some find this clearer instead:

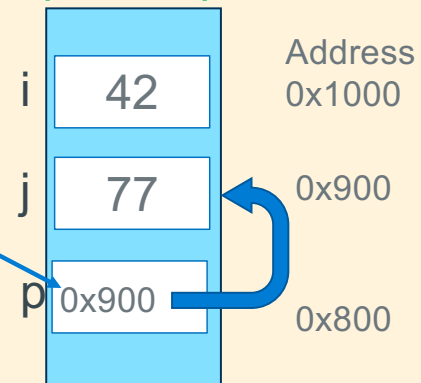
```
int *p1;  
int *p2;
```

Using Pointer Variables and the Address Operator & - 2

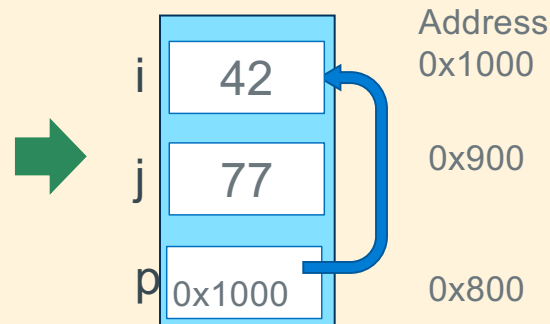
- As with any variable, you can change a pointers value (contents)

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

See that p's value
(contents) is the
address of i



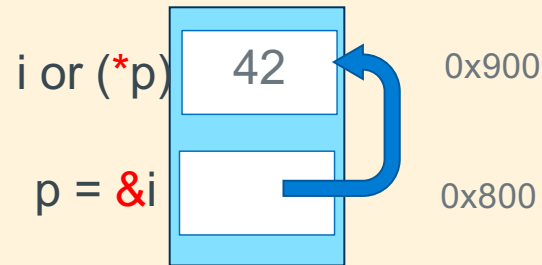
`p = &i;` */* p now points at i */*



Indirection (or dereference) Operator: *

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

"get the address of this box"

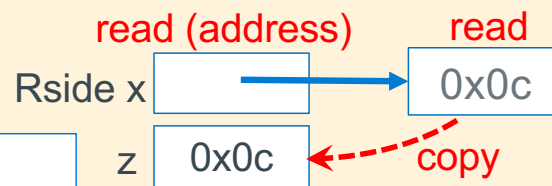


- **indirection operator** (*) can be thought of as:
- "follow the arrow to the next box and get its contents"*
- **Indirection operator causes an additional read to occur**, when on either the Rside or Lside of a statement

Rside Indirection (or dereference) Operator: *

- 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
```



Two reads here
(1) read to get an address
(2) read the address to get the value

Rside Indirection (or dereference) Operator: *

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

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

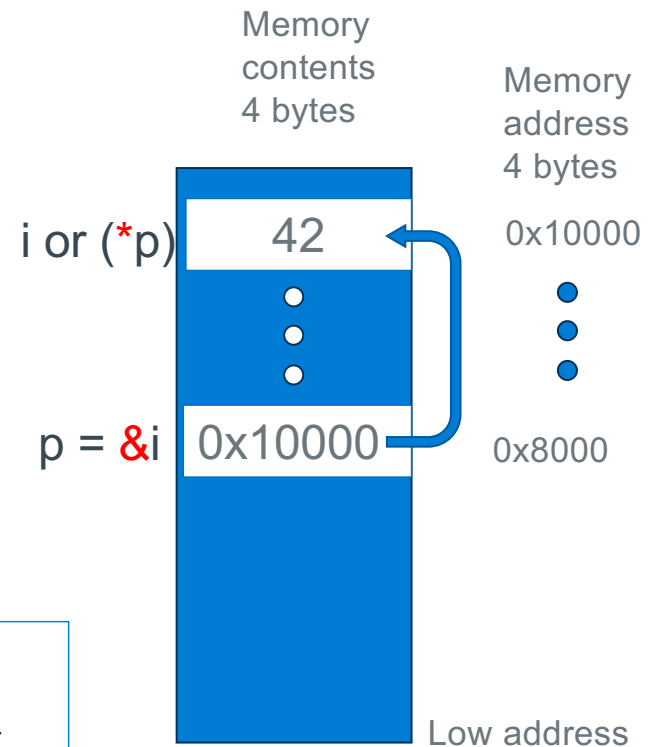
```
p = &i;
```

No reads here

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

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

Two reads here
(1) read to get an address
(2) read the address to get the value

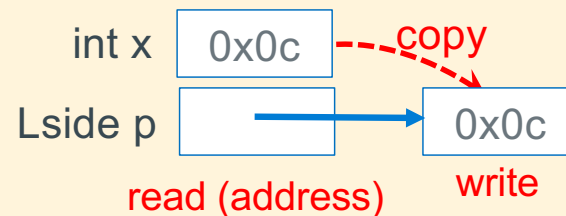


Lside Indirection Operator

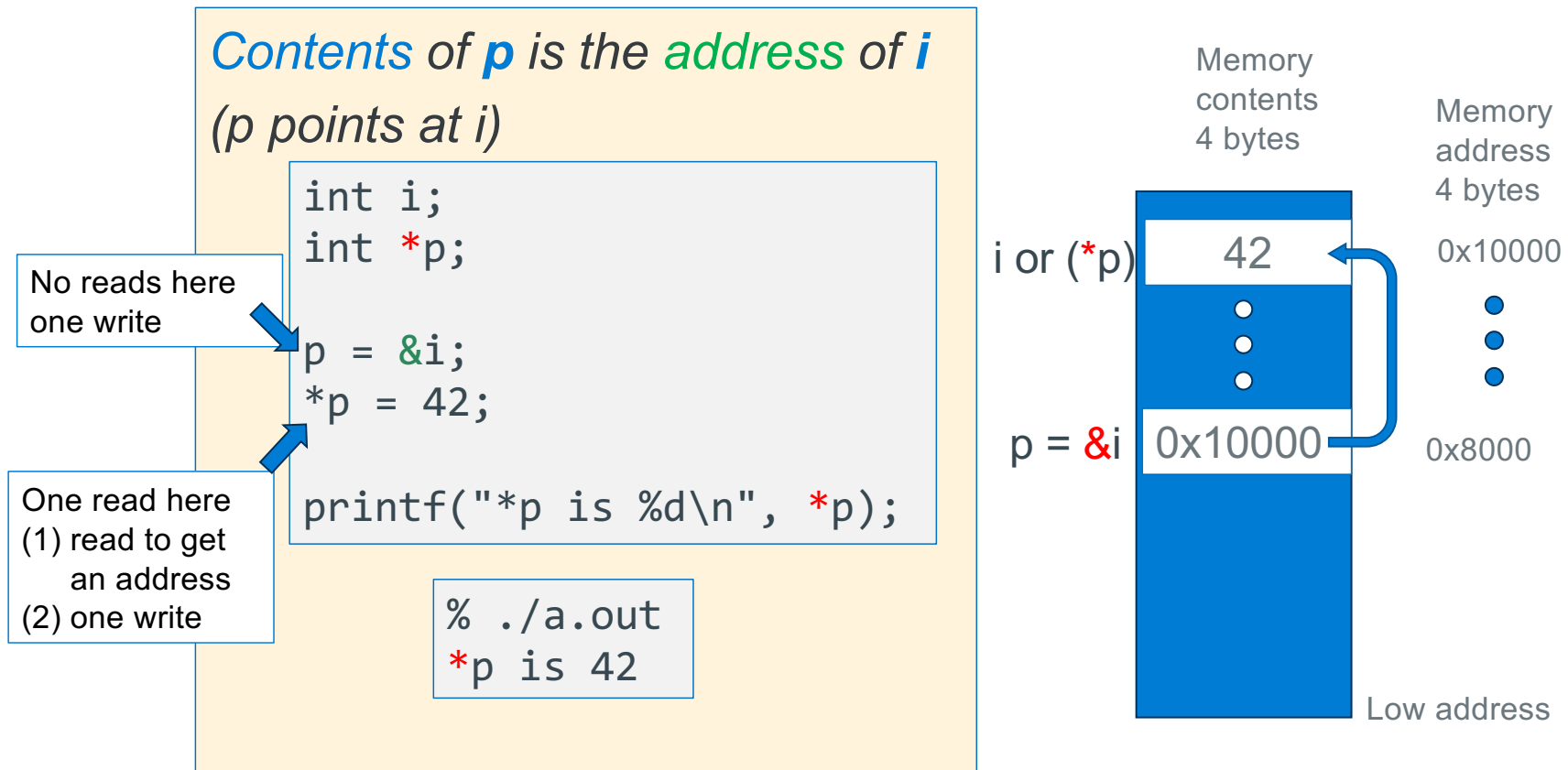
Performs the following steps when the ***** is on the Lside:

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**)

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

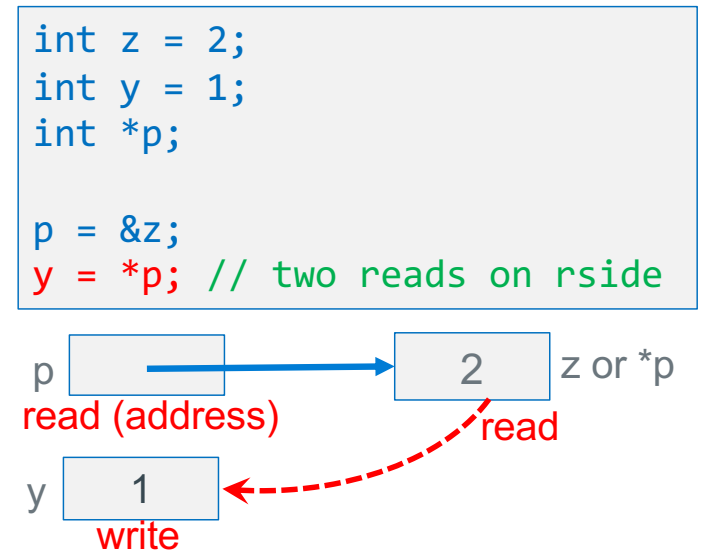
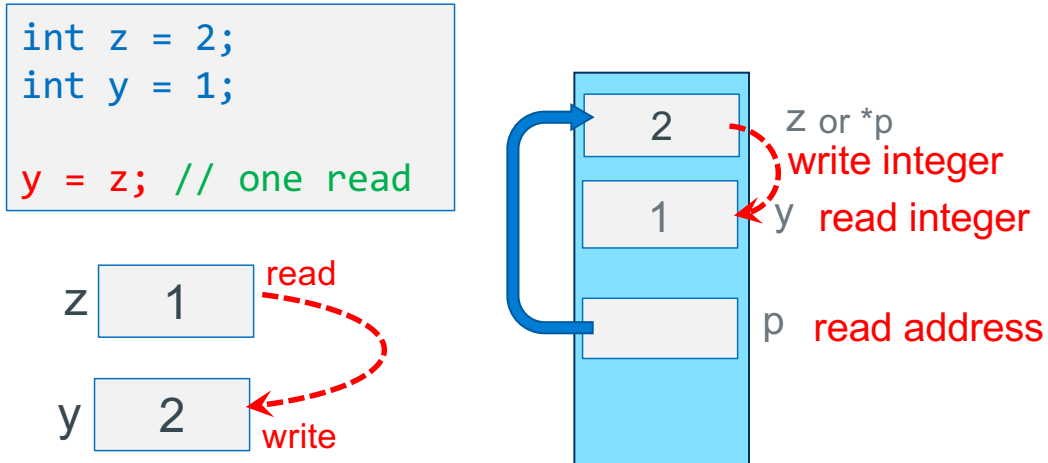


Left Side Indirection (or dereference) Operator: *



Each use of a * operator results in one additional read: Rside

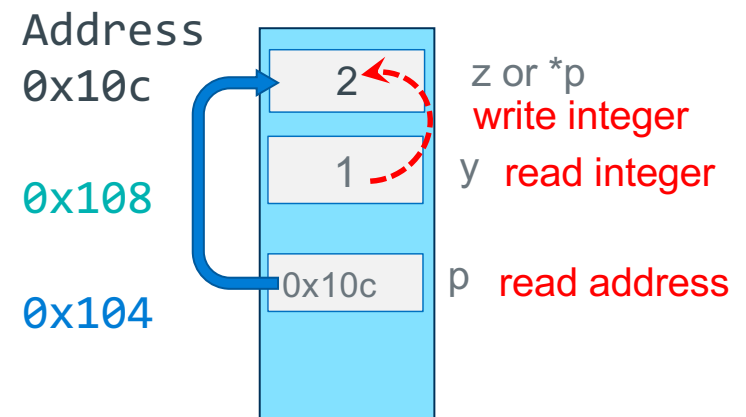
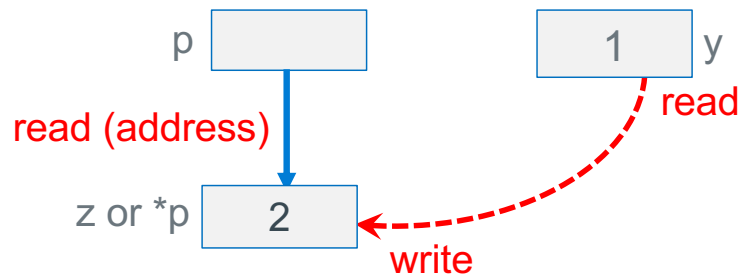
RULE: Each * when used as a dereference operator in a **statement** (either **Lside** or **Rside**) it causes an additional read to be performed



Aside: `y = *(&z);` // same as `y = z`

Each use of a * operator results in one additional read: Lside

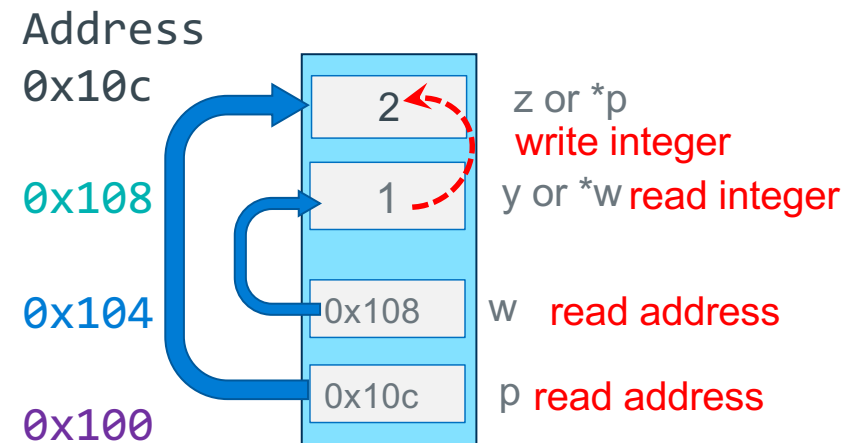
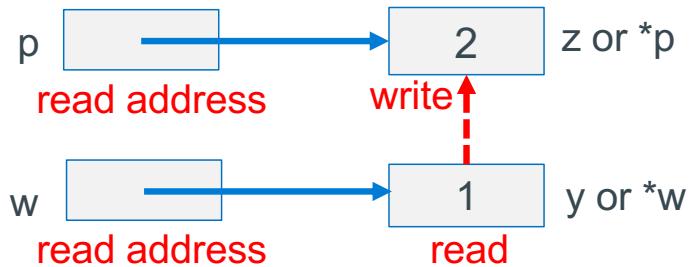
```
int z = 2;  
int y = 1;  
int *p;  
  
p = &z;  
*p = y;    // one read on lside
```



Each use of a * operator results in one additional read : both sides

```
int z = 2;  
int y = 1;  
int *w;  
int *p;
```

```
p = &z;  
w = &y;  
*p = *w;
```

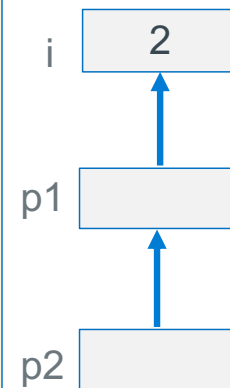


Pointer to Pointers (Double Indirection)

- Define a pointer to a pointer (p2 below)

```
int i = 2;  
int *p1;  
int **p2; // pointer to a pointer to an int  
  
p1 = &i;  
p2 = &p1;  
printf("%d\n", (**p2) * (**p2));
```

- C allows any number of pointer indirections
 - more than two levels is very uncommon in real applications as it reduces readability and generates a lot of memory reads
- RULE (important):** number of ***** in the variable definition tells you how many **reads** it takes to get to the **base type**
 $\text{\#reads to base type} = \text{number of } * \text{ (in the definition)} + 1$
- Example:
`int **p2;` // requires 3 reads to get to the int

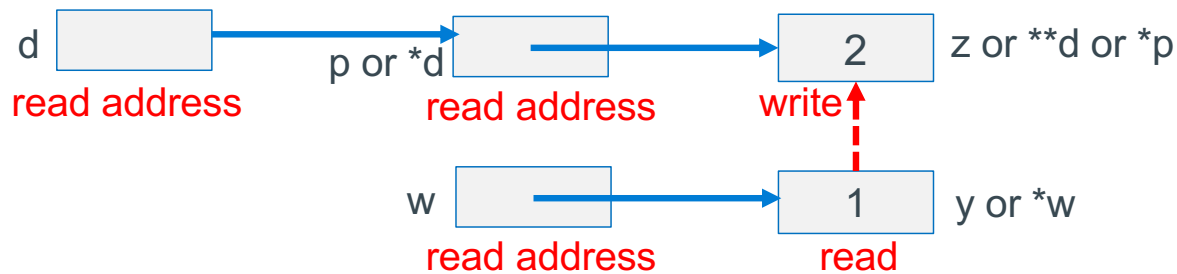
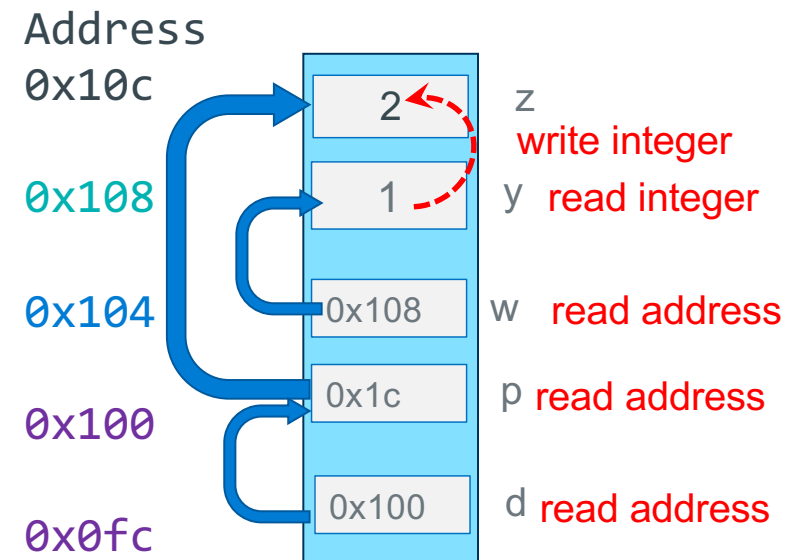


Double Indirection: Lside

```

int z = 2;
int y = 1;
int *w;
int *p;
int **d;

p = &z;
w = &y;
d = &p;
**d = *w;
    
```



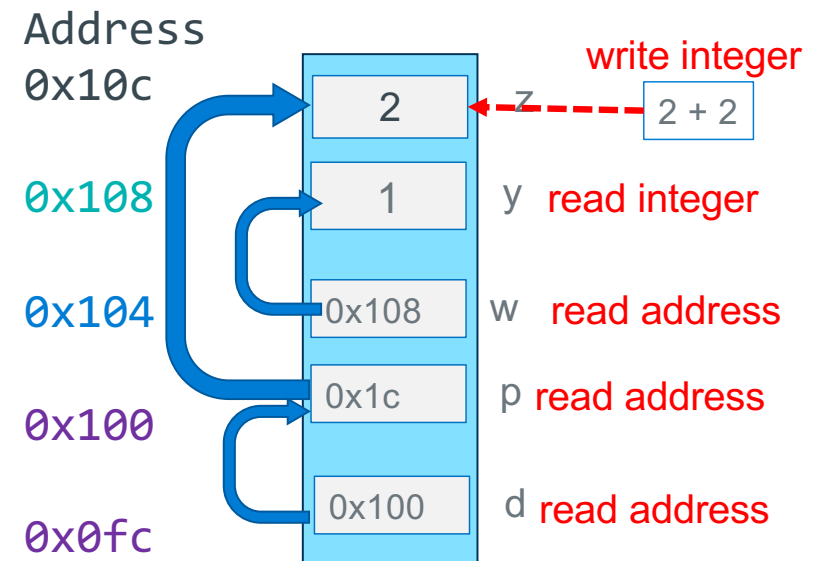
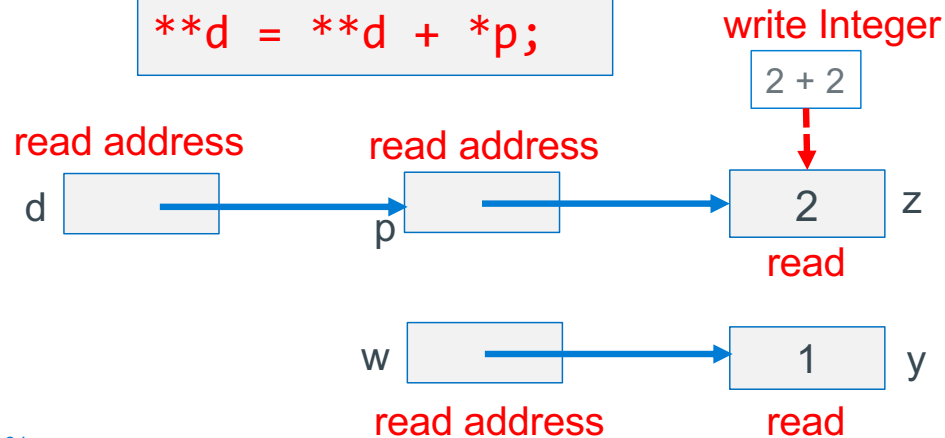
Double Indirection: Rside

```

int z = 2;
int y = 1;
int *w;
int *p;
int **d;

p = &z;
w = &y;
d = &p;

**d = **d + *p;
    
```



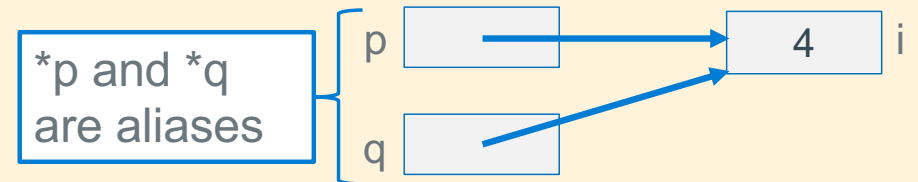
Important Observation
`**d` on Lside is two reads
`**d` on Rside is three reads

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)
- **Example:** 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 same 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 now aliases
*q = 4;   // changes i and *p
```



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

Defining Arrays

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 $(\text{count} * \text{sizeof}(\text{type}))$ bytes of *contiguous memory*
- Common usage is to specify a compile-time constant for `count`

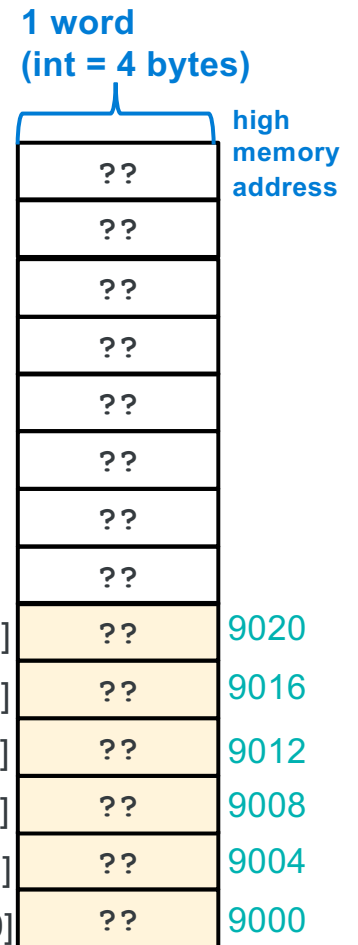
```
#define BSZ 6  
int b[BSZ];
```

BSZ is a macro replaced by the C preprocessor

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

```
int a [BSZ];  
a = b;          // invalid does not copy the array  
                // must copy arrays element by element
```

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



x

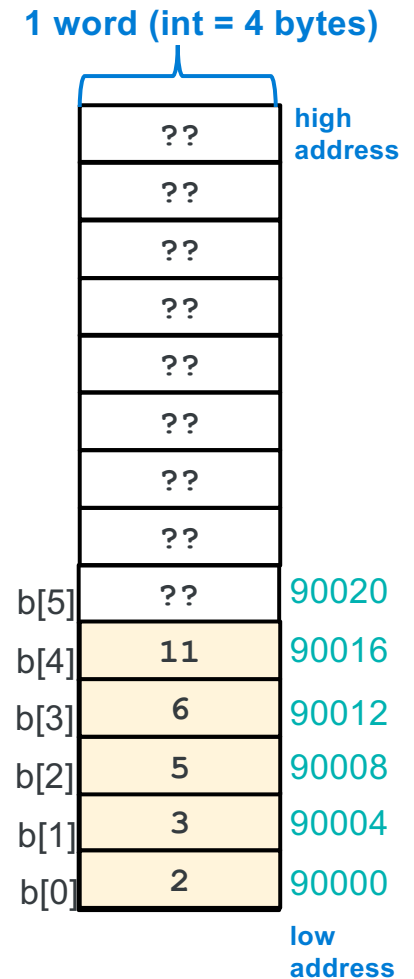
Array Initialization

- 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
 - 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**



X

Accessing Arrays Using Indexing

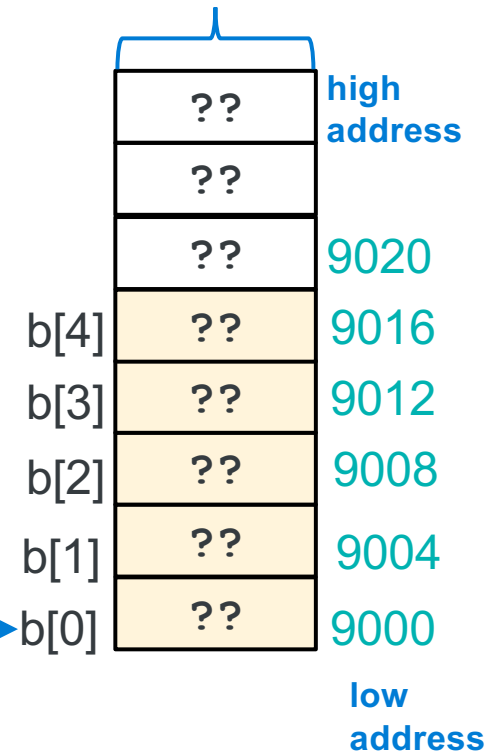
- **name** [**index**] selects the **index** element of the array
 - index **should be** unsigned
 - Elements range from: 0 to count – 1 (int x[count];)
- **name** [**index**] can be used as an **assignment target** or as a **value in an expression**

```
int a[2] = {1, 2};  
a[0] = a[1];
```
- **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;
```

p 9000

1 word
(int = 4 bytes)



How many elements are in an array?

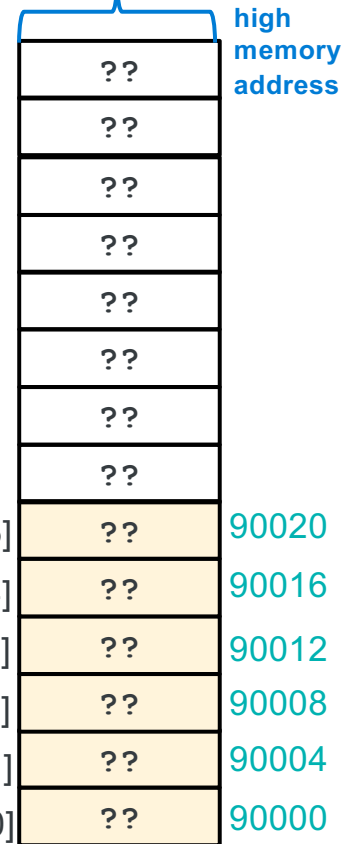
- The number of elements of space allocated to an array (called **element count**) and indirectly the total size in bytes of an array is not stored anywhere!!!!!!
- An **array name** is just the **address of the first element in a block of contiguous memory**
 - So, an array does not know its own size!

```
#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];
```

1 word
(int = 4 bytes)



Determining Element Count: compile time calculation

- 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** where the array variable was defined

```
#include <stddef.h>
int main()
{
    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;
```

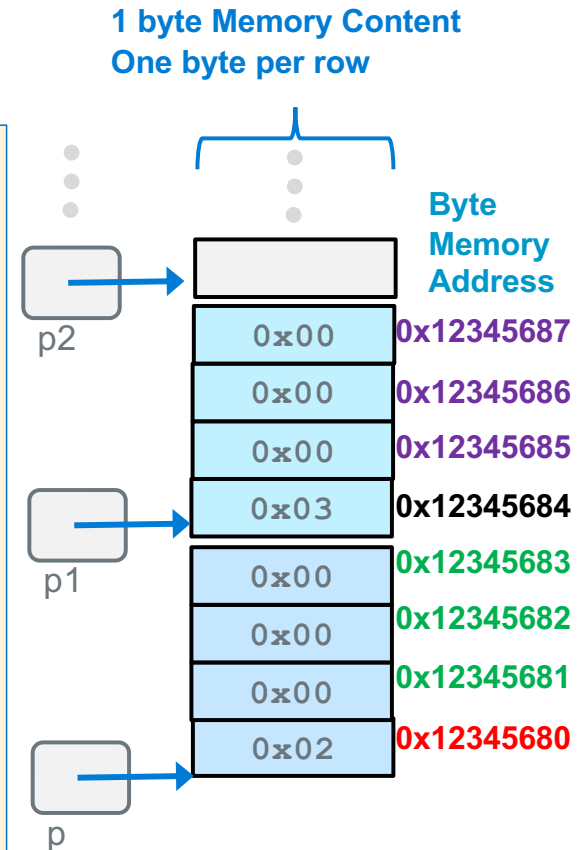
Pointers and Arrays - 1

- 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];
```



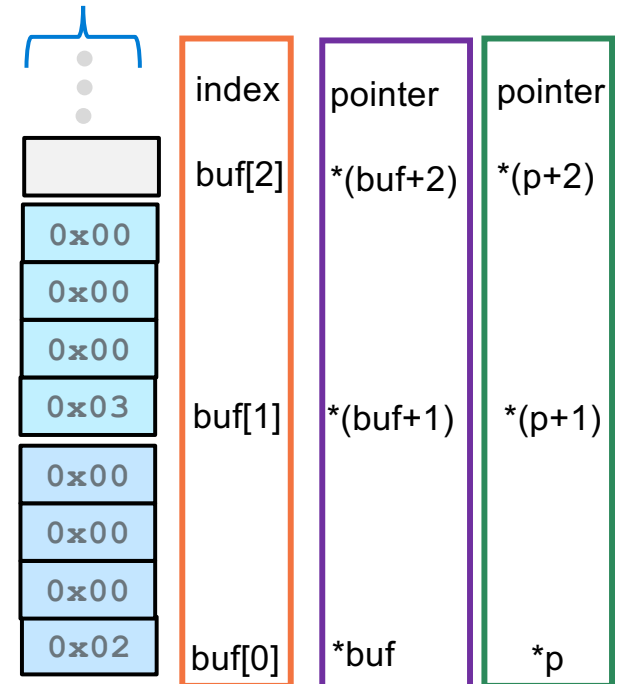
Pointers and Arrays - 2

- When `p` is a pointer, the actual evaluation of the address:
 - `(p+1)` depends on the base type the 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]`

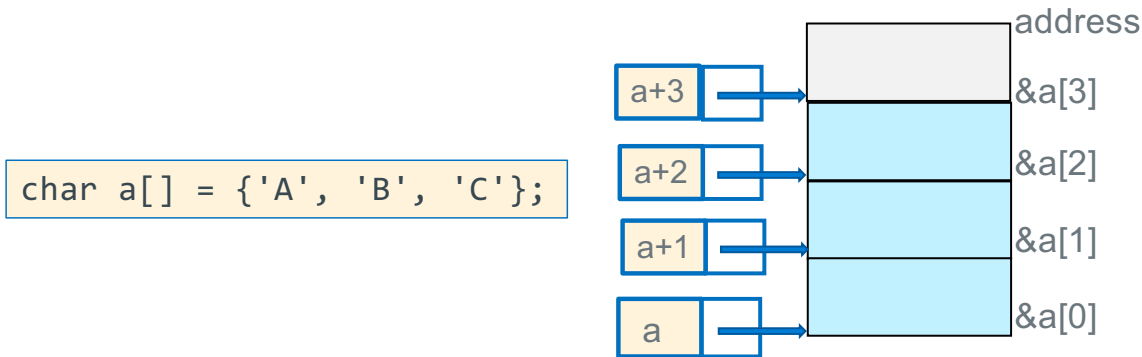
```
int buf[] = {2, 3, 5, 6, 11};
int *p;
p = buf;

*p = *p + 10; // {12, 3, 5, 6, 11}
*(p + 1) = *(buf + 1) + 10; // {12, 13, 5, 6, 11}
```

1 byte Memory Content
One byte per row



Pointer Arithmetic In Use – C's Performance Focus



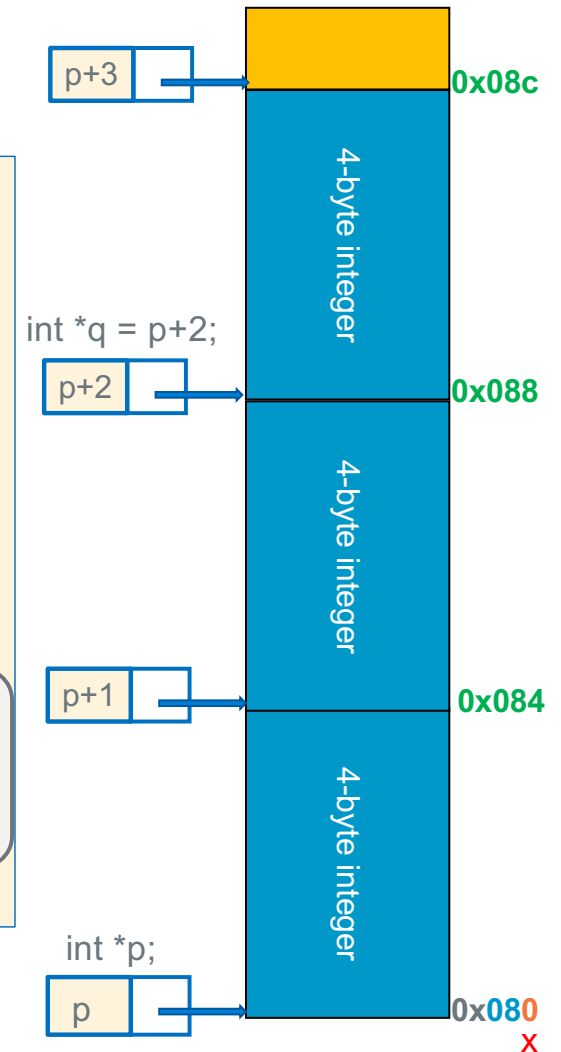
- **Alert!**: C performance focus does not perform any array “bounds checking”
- **Performance by Design**: bound checking slows down execution of a properly written program
- **Example**: array `a` of length `i`, C does not verify that `a[j]` or `*(a + j)` is valid (does not check: $0 \leq j < i$)
 - 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 access to memory (read-only or not 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

Pointer Arithmetic

- You cannot add two pointers (*what is the reason?*)
- A pointer *q* can be subtracted 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* are both **byte addresses**):

distance in elements = $(p - q) / \text{sizeof}(*p)$

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



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++ */
```

- 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

Using Pointers to Traverse an array

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

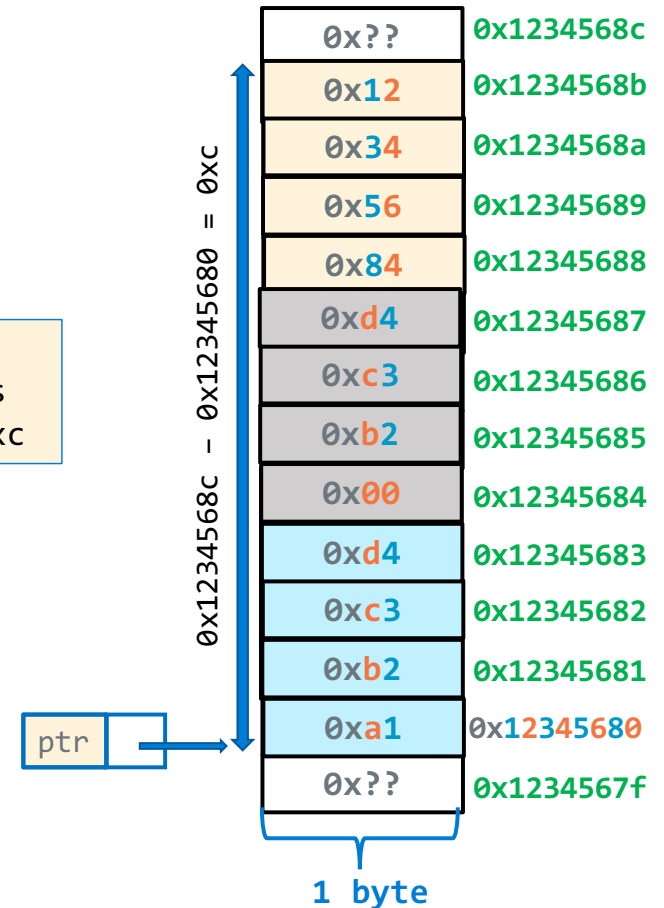
for (int j = 0; j < cnt; j++)
    printf("%#x\n", x[j]);
}
```

cnt = 3;
 actual space used by x is cnt * sizeof(*x); = 12 bytes
 Calculating by addresses: 0x1234568c - 0x12345680 = 0xc

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

for (int j = 0; j < cnt; j++)
    printf("%#x\n", *(ptr + j));
}
```

Brute force translation to pointers



x

Fast Ways to Traverse an Array: Use a Limit Pointer

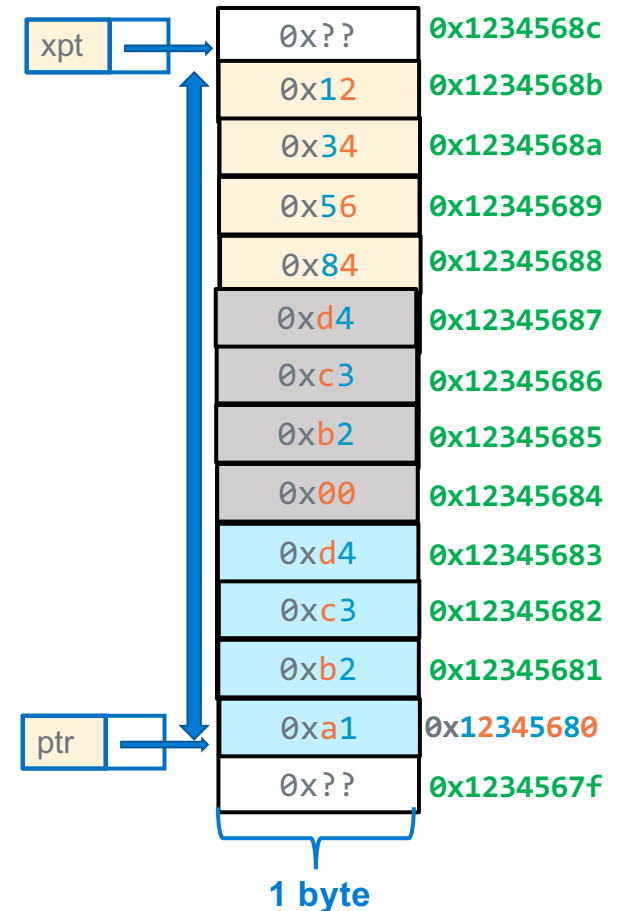
```
int x[] = {0xd4c3b2a1, 0xd4c3b200, 0x12345684};
int cnt = (int)(sizeof(x) / sizeof(*x));
```

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

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

```
while (ptr < xptr) {
    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

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

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

Example of a hard-to-understand pointer statement

```
int array[] = {2, 5, 7, 9, 11, 13};
int *ptr = array;
int x;
```

```
x = 1 + (*ptr++)++; // yuck!!
```

```
/* Same as the one line above */
x = 1 + *ptr;      // x = 1 + 2 = 3;
*ptr = *ptr + 1;   // (*ptr)++ is array[0]=2+1=3;
ptr = 1 + ptr;     // ptr = &array[1] = ptr points at 5
```

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

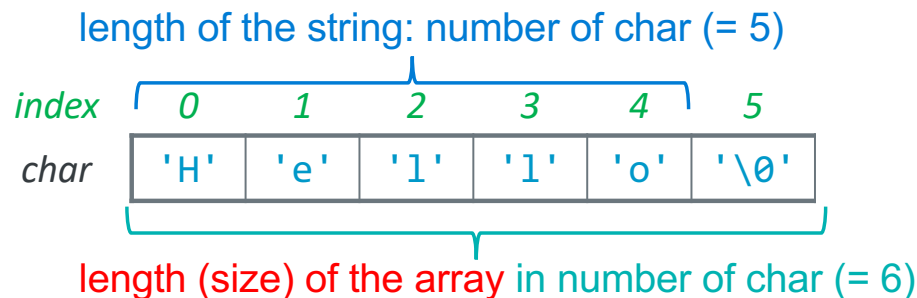
```
x = 1 + ++(*ptr++);
```

```
*ptr = *ptr + 1;   // (*ptr)++ is array[0]=2+1=3
x = 1 + *ptr;      // x = 1 + 3 = 4;
ptr = 1 + ptr;     // ptr = &array[1]; ptr -> 5
```

x

C Strings - 1

- C does not 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 when** it is terminated by a `'\0'`
- **Length of a string** is the **number of characters** in it, not including the `'\0'`
- Strings in C are **not** 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 sentinel



C Strings - 2

- First '`\0`' encountered 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 two strings (but only `cat` is seen as the string)
 - 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)

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

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)

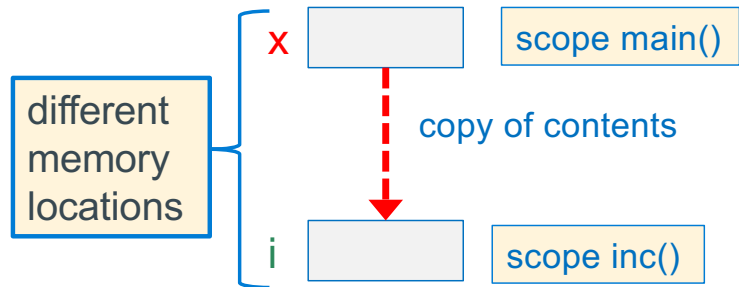
- What **Called** Function Does
 - Passed Parameters are used like local variables
 - **Modifying** the **passed parameter** in the **function** is **allowed** just like a **local variable**
 - So, writing to the parameter, **only** **changes** the **copy**
- The **return value** from a function in C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

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

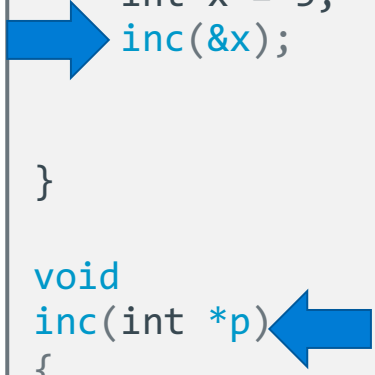


- when `inc(x)` is called, a copy of `x` is made to another memory location
 - `inc()` cannot change the variable `x` since `inc()` does not have the address of `x`, it is local to `main()` so, 5 is printed
- The `inc()` function is free to change its copy of the argument (just like any local variable)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

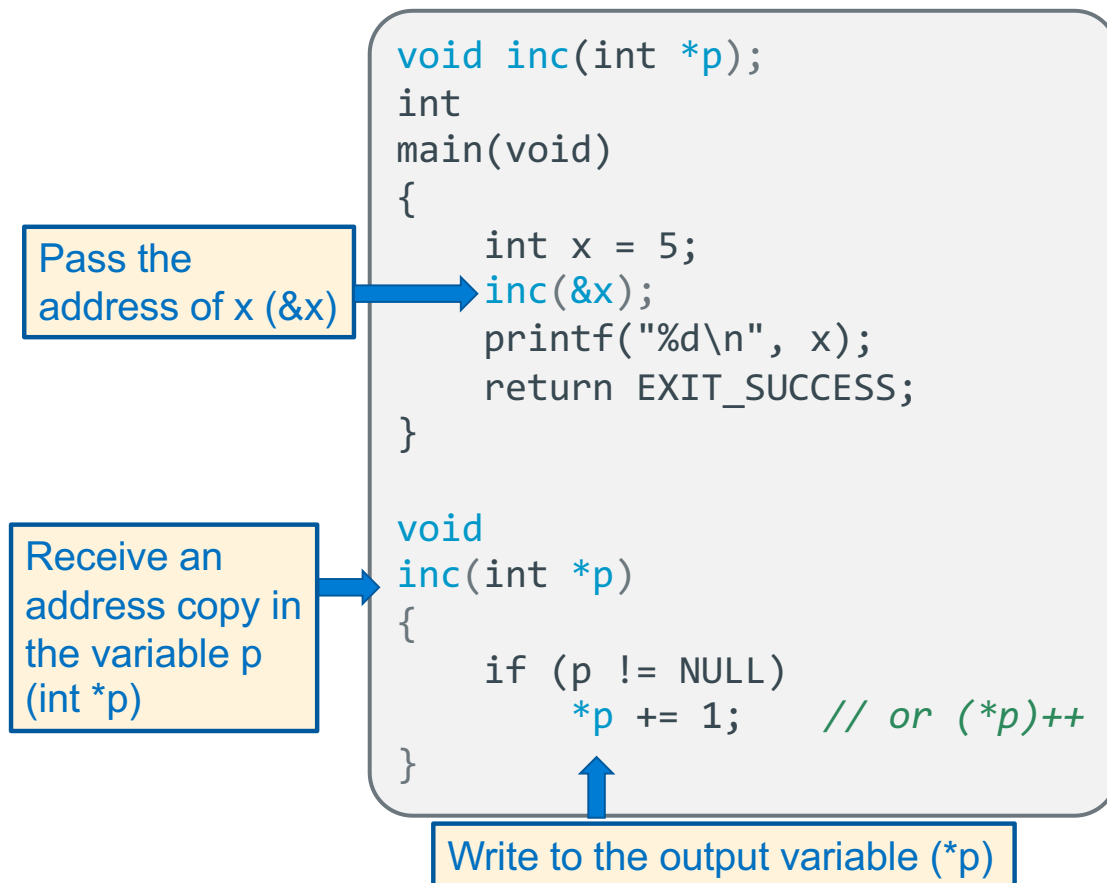
Output Parameters (Mimics Call by Reference)

- 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);  
}  
  
void  
inc(int *p)  
{  
  
}  
}
```

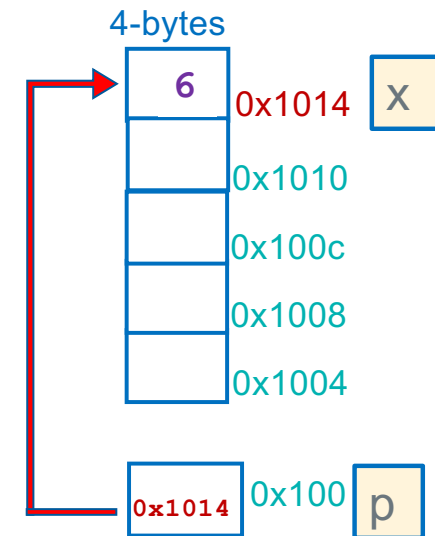


Example Using Output Parameters



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

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*

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

```
void passa(int []);
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) on pi-cluster and 8 on ieng6

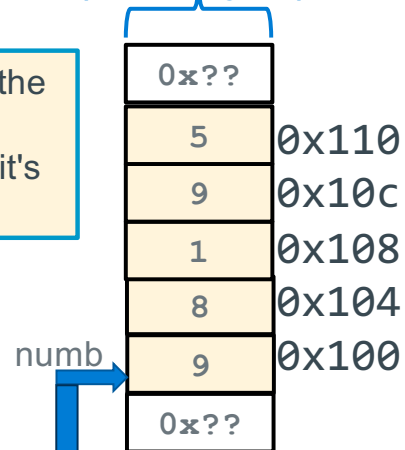
- Call-by-value pointer (callee can change the pointer parameter to point to something else!)
- Acts like call-by-reference (called function can change the contents caller's array)

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

Observe numb is the name of an array (whose Rvalue is it's starting address)

1 word content
(int = 4 bytes)



Remember a is parameter copy so is a separate variable that contains a pointer to num

```
int sumAll(int *);
```

```
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];
```

```
}
```

```
}
```

this is a POINTER to the first element.....
so sizeof(a) is the size of a pointer, not the array it points at
Net result: sz is a 1 on picluster

Arrays As Parameters, Approach 1: Pass the size

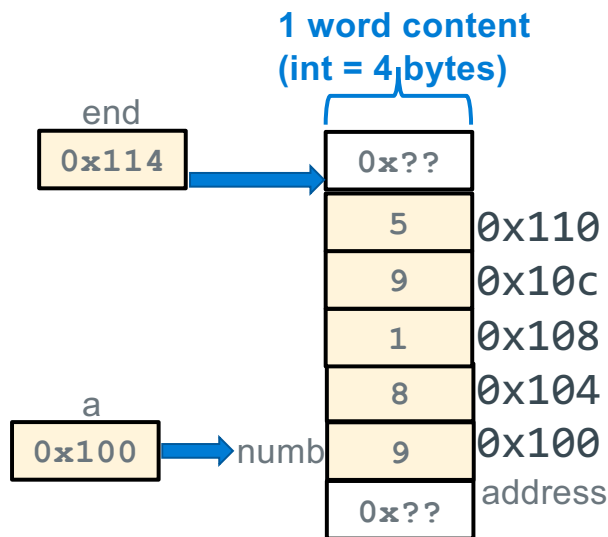
Two ways to pass array size

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 defined

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

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



```
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++;

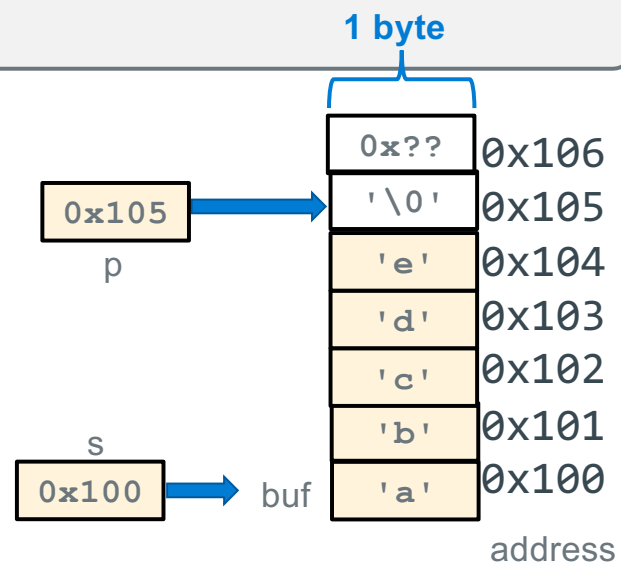
Arrays As Parameters, Approach 2: Use a sentinel element

- 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

```
int strlen(char *a); // returns number of chars in string, not counting \0
int main(void)
{
    char buf[] = {'a', 'b', 'c', 'd', 'e', '\0'}; // or buf[] = "abcde";

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

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



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

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

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) //  $O(n^2)$  !!!
{
    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 ;
}
```

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 */
```

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) ...
```

Simple String IO - Reading

Task	Example Function Calls
Read a string	<pre>#include <stdio.h> char *strptr; char myStr[BFSZ]; strptr = fgets(myStr, BFSZ, stdin);</pre> <div>must pass the size of the array so fgets() knows how much space there is</div>

`char *fgets(char array[], int size, FILE *stream)`

- **char *** is a pointer (address) to an **array of char**
- reads in at most **one less than size** characters from **stream** and stores them into **array**
- Reading stops after an **EOF** or a newline '\n'
 - If a newline ('\n') is read, it is stored into the buffer
 - **A terminating null byte ('\0') is always stored after the last character in the buffer**

t	h	i	s		i	s		a	s	t	r	i	n	g	\n	\0
---	---	---	---	--	---	---	--	---	---	---	---	---	---	---	----	----

- Returns a **NULL at end of file** (or a read failure), otherwise a pointer to array (pointers later...)
- See `man 3 fgets`

Pointer returns from a function call (NULL Examples)

This function returns a pointer to the character that follows the first comma ','

```
char *next(char *ptr)
{
    if (ptr == NULL)
        return NULL;

    while ((*ptr != '\0') && (*ptr != ','))
        ptr++;

    if (*ptr == ',')
        return ++ptr;
    return NULL;
}
```

```
#include <stdlib.h>
#include <stdio.h>
#define BUFSZ 512
char *next(char *);

int main()
{
    char buf[BUFSZ];
    char *ptr;

    while (fgets(buf, BUFSZ, stdin) != NULL) {
        printf("buf: %s\n", buf);

        if ((ptr = next(buf)) != NULL)
            printf("after: %s\n", ptr);
        else
            printf("no comma found\n");
    }
    return EXIT_SUCCESS;
}
```

Returning a Pointer To a Local Variable (Dangling Pointer)

- There are many situations where a function will return a pointer, but a function must never return a pointer to a memory location that is **no longer valid** such as:
 - Address of a **passed parameter copy** as the caller may or will deallocate it after the call
 - Address of a **local variable (automatic)** that is invalid on function return
- These errors are called a **dangling pointer**

n is a parameter with the scope of bad_idea it is no longer valid after the function returns

```
int *bad_idea(int n)
{
    return &n; // NEVER do this
}
```

a is an automatic (local) with a scope and **lifetime** within bad_idea2 a is no longer a valid location after the function returns

```
int *bad_idea2(int n)
{
    int a = n * n;
    return &a; // NEVER do this
}
```

```
/*
 * this is ok to do
 * it is NOT a dangling
 * pointer
 */

int *ok(int n)
{
    static int a = n * n;
    return &a; // ok
}
```


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

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

```
// strncpy adds a length limit on copy
char str1[6];
int cnt = (int)(sizeof(str1) / sizeof(str1[0]));

strncpy(str1, "hello", cnt); // \0 copied
strncpy(str1, "hello", cnt - 1); // \0 not copied
```

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

    while ((*s0++ = *s1++) && --len) //watch short circuit here
        ;
    return str;
}
```

String Literals (Read-Only) in Expressions

- When strings in quotations (e.g., "string") are **part of** an **expression** (i.e., *not part of an array initialization*) they are called **string literals**

```
printf("literal\n");  
printf("literal %s\n", "another literal");
```

- What is a **string literal**:
 - Is a **null-terminated string** in a **const char array**
 - Located in the **read-only data segment of memory**
 - Is **not assigned a variable name** by the compiler, so it is only accessible by the location in memory where it is stored
- **String literals** are a type of **anonymous variable**
 - Memory containing **data without a name bound** to them (only the address is known)
- The **string literal in the printf()'s**, are replaced with the **starting address of the corresponding array** (first or [0] element) when the code is compiled

String Literals, Mutable and Immutable arrays - 1

- `mess1` is a **mutable** array (type is `char []`) with enough space to hold the string + `'\0'`

```
char mess1[] = "Hello World";  
*(mess1 + 5) = '\0'; // shortens string to "Hello"
```

`mess1[]` Hello World\0

- `mess2` is a **pointer** to an **immutable** array with space to hold the string + `'\0'`

```
char *mess2 = "Hello World"; // "Hello World" read only string literal  
// mess2 is a pointer NOT an array!  
*(mess2 + 1) = '\0'; // Not OK (bus error)
```

`mess2` → Hello World\0 ← read only string literal

- `mess3` is a **pointer** to a mutable array

```
char *mess3 = (char []) {"Hello World"}; // mutable string  
*(mess3 + 1) = '\0'; // ok
```

using the cast `(char [])`
makes it mutable

`mess3` → Hello World\0 ← mutable string

2D Arrays

- Generic (uniform) 2D array format:

```
type name[rows][cols] = {{values}, ..., {values}};
```

- allocates a single, contiguous block of memory
- The array is organized in **row-major** format

```
// a 2-row, 3-column array of char
```

```
char matrix[2][3];
```

```
// a 2-row, 5-column (row length) array of ints
```

```
// Must specify row length, compiler counts rows
```

```
int grid[][5] = {  
    {0, 1, 2, 3, 4},  
    {5, 6, 7, 8, 9}  
};
```

[1][0]	[1][1]	[1][2]	[1][3]	[1][4]
[0][0]	[0][1]	[0][2]	[0][3]	[0][4]

```
grid[1][2] using pointers is *( *(grid + 1) + 2)
```

1 word (int = 4 bytes)

	?	high memory
grid[1][4]	9	0x0024
grid[1][3]	8	0x0020
grid[1][2]	7	0x001c
grid[1][1]	6	0x0018
grid[1][0]	5	0x0014
grid[0][4]	4	0x0010
grid[0][3]	3	0x000c
grid[0][2]	2	0x0008
grid[0][1]	1	0x0004
grid[0][0]	0	0x0000
		low memory

X

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 (fills rest with zeros '\0')

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

high
memory

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

low
memory

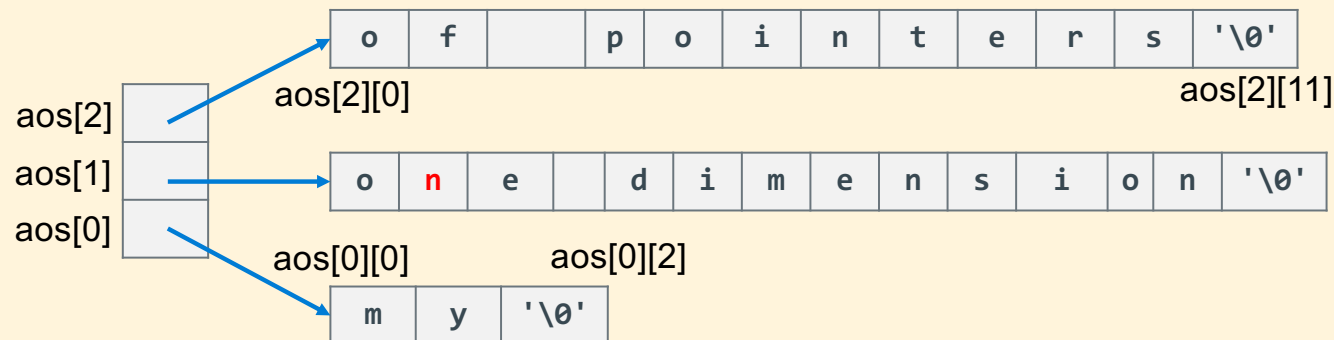
```
#define ROWS 3
char aos[ROWS][22] = { "my", "two dimensional", "char array"};
char (*ptc)[22] = aos; // ptc points at a row of 22 chars

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

high
memory

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

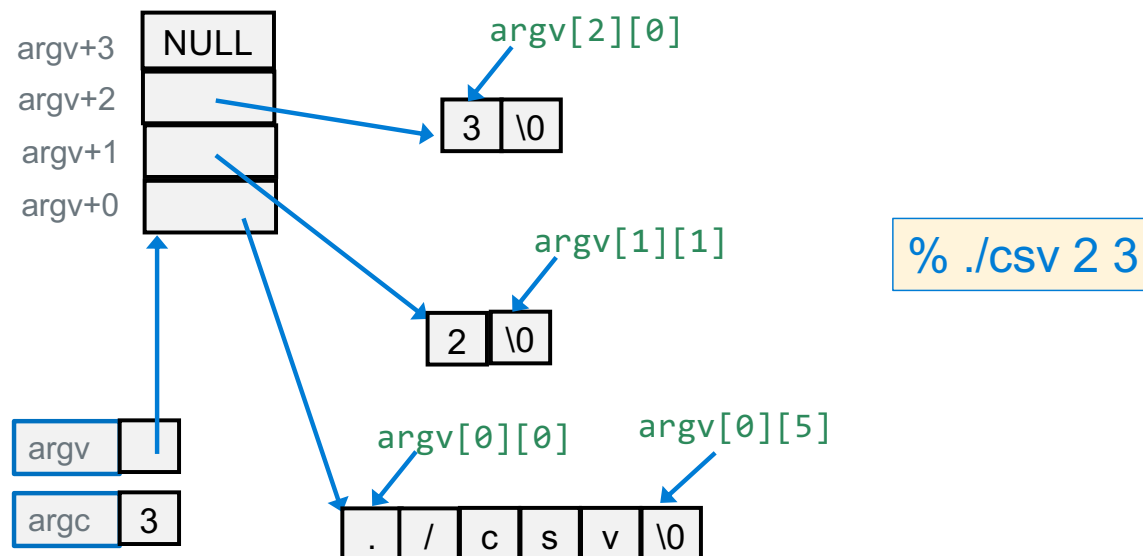
- 2D char arrays are an inefficient way to store strings (wastes memory) unless all the strings are similar lengths, so 2D char arrays *are rarely used* with string elements
- **An array of pointers** is common for strings as "rows" can vary in length
- `char *aos[3];`



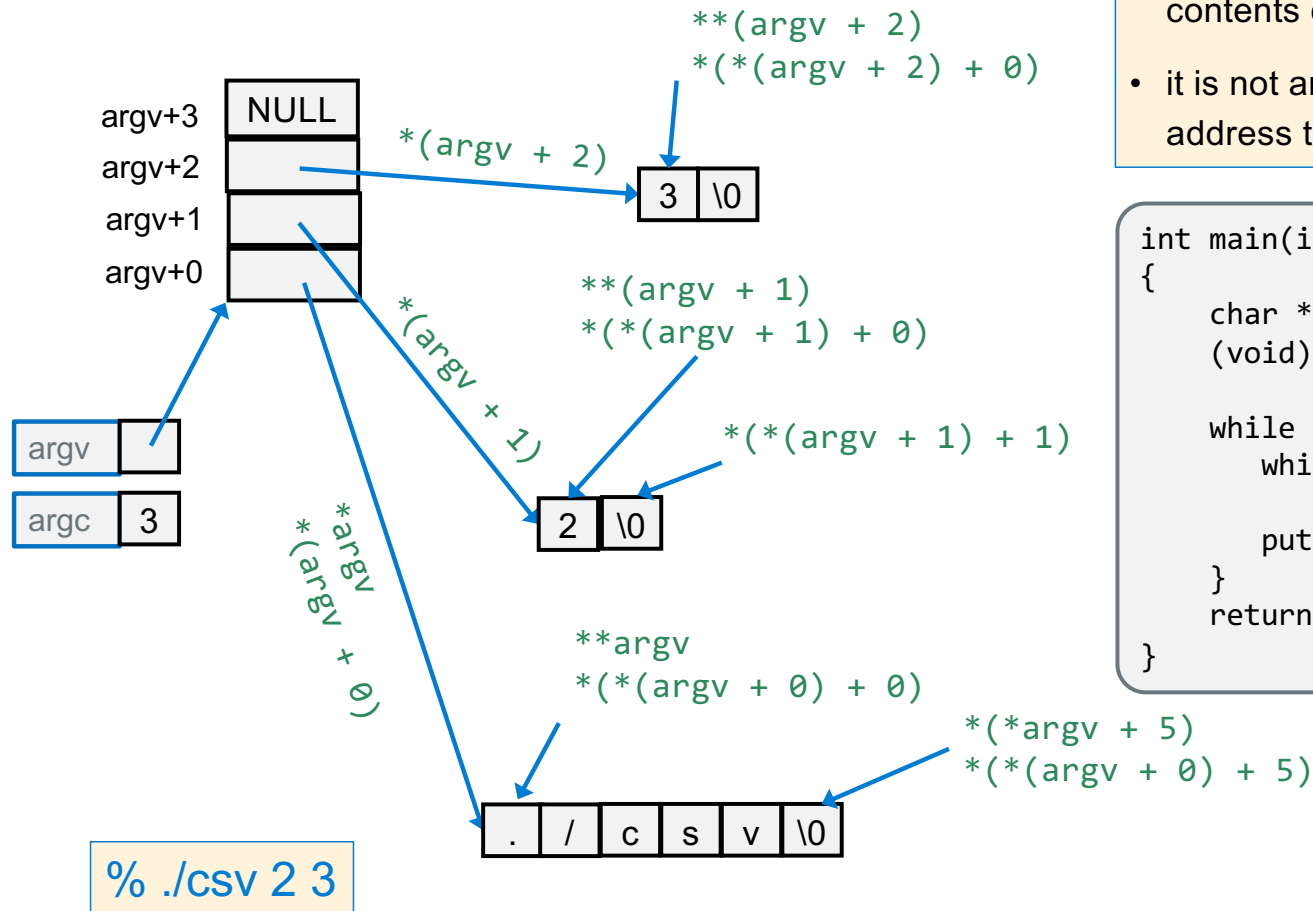
- `aos` is an array of pointers; each pointer points at a character array (also a string here)
- **Not a 2D array**, but any char can be accessed as if it was in a 2D array of chars
 - When I was learning, this was the most confusing syntax aspects of C

main() Command line arguments: argc, argv

- Arguments are passed to main() as a pointer to an array of pointers to char arrays (strings)(**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] or *(argv + argc) always contains a NULL (0) sentinel
- argv elements point at **mutable strings!**



Accessing argv char at a time



- `argv` is a pointer variable, whose contents can be changed
- it is not an array name, which is just an address that cannot be changed

```
int main(int argc, char **argv)
{
    char *pt;
    (void)argc; // shut up the compiler

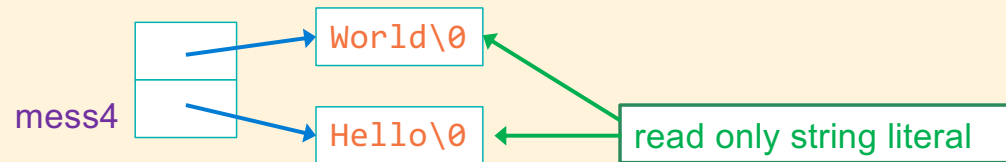
    while ((pt = *argv++) != NULL) {
        while (*pt != '\0')
            putchar(*pt++);
        putchar('\n');
    }
    return EXIT_SUCCESS;
}
```


Defining an Array of Pointers to Strings

- `mess4` is an array of pointers to immutable arrays

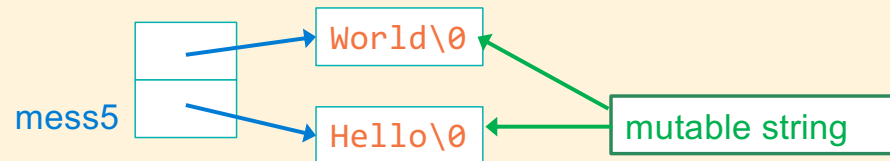
```
char *mess4[] = {"Hello", "World"}; // immutable string  
*(*mess4 + 1) = '\0'; // bus error
```

Bus error: writing
read only memory
Seg fault: writing
unallocated memory



- `mess5` is an array of pointers to mutable arrays

```
char *mess5[] = { (char []){"Hello"}, (char []){"World"}};  
*(*mess5 + 1) = '\0'; // OK!
```

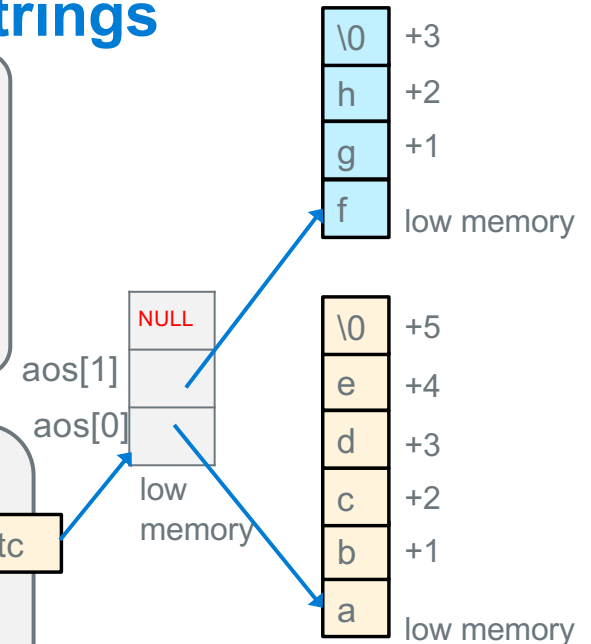


Defining an Array of Pointers to Mutable Strings

- Make an **array of pointers** to **mutable strings** requires using a **cast to an array (char [])**
- Add a NULL sentinel at the end to indicate the end of the array

```
char *aos[] = {  
    (char []) {"abcde"},  
    (char []) {"fgh"},  
    (char *) {NULL}  
};  
char **ptc = aos;
```

```
printf("%c\n", (*(aos + 1) + 1));  
  
while (*ptc != NULL) {  
    printf("%s\n", *ptc);    // prints string  
  
    for (int j = 0; *(*ptc + j); j++)  
        putchar(*(*ptc + j)); // char in string  
  
    putchar('\n');  
    ptc++;  
}
```



```
%./a.out  
abcde  
abcde  
fgh  
fgh
```

Pointers to Functions (Function Pointers)

- Similar in concept to an array name, a **function name ends up being the address of the first instruction in a function**

- A function pointer variable contains the address of a function

- Generic format: `returnType (*name)(type1, ..., typeN)`

- Looks like a function prototype with extra * in front of name
- Why are parentheses around (*name) needed?

`returnType *name(type1, ..., typeN) //wrong`

- Above says name is a function returning a pointer to returnType

- Using the function:

`(*name)(arg1, ..., argN)`

`name(arg1, ..., argN)`

Calls the pointed-to function with the given arguments and returns the return value

Pointers to Function Example

```
int add1(int);
int sqr(int);
void array_update(int (*)(int), int *, int);
void print_array(int *, int);

int main(void)
{
    int array[] = {4, 8, 15, 16, 23, 42};
    int cnt = sizeof(array)/sizeof(array[0]);

    print_array(array, cnt);
    array_update(add1, array, cnt);
    print_array(array, cnt);
    array_update(sqr, array, cnt);
    print_array(array, cnt);
    return EXIT_SUCCESS;
}
```

```
void array_update(int (*f)(int), int *a, int cnt)
{
    while (a < endpt) {
        *a = f(*a);
        a++;
    }
}
```

```
void print_array(int *a, int cnt)
{
    int *endpt = a + cnt;

    while (a < endpt)
        printf("%d ", *a++);
    printf("\n");
}
```

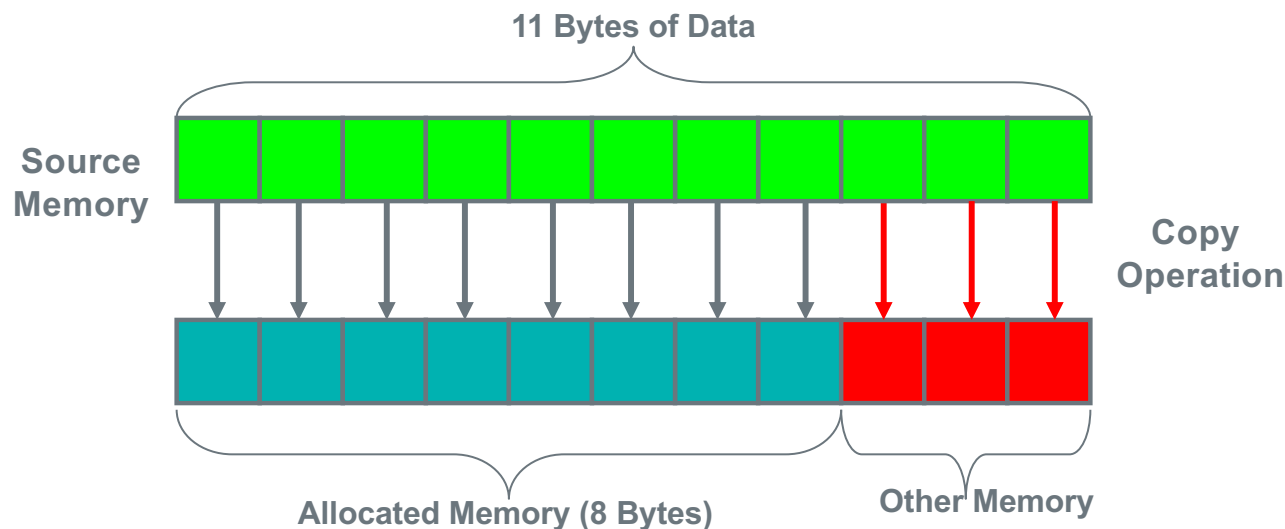
```
int add1(int i)
{
    return i + 1;
}

int sqr(int i)
{
    return i * i;
}
```

```
./a.out
4 8 15 16 23 42
5 9 16 17 24 43
25 81 256 289 576 1849
```

string buffer overflow: common security flaw

- A **buffer overflow** occurs when data is written **outside the boundaries** of the **memory allocated to target variable** (or target buffer)
- **strcpy()** is a very *common source of buffer overrun security flaws*:
 - always ensure that the **destination array is large enough** (and don't forget the null terminator)
- **strcpy()** can cause **problems** when the **destination** and **source regions overlap**



strcpy() buffer overflow: over-write of an adjacent variable

```
int main(void)
{
    char s1[] = "before";
    char r2[] = "xyz";
    char s2[] = "after";

    printf("s2: %s\nr2: %s\nr2: %s\n", s2, r2, s1);

    strcpy(r2, "hello");

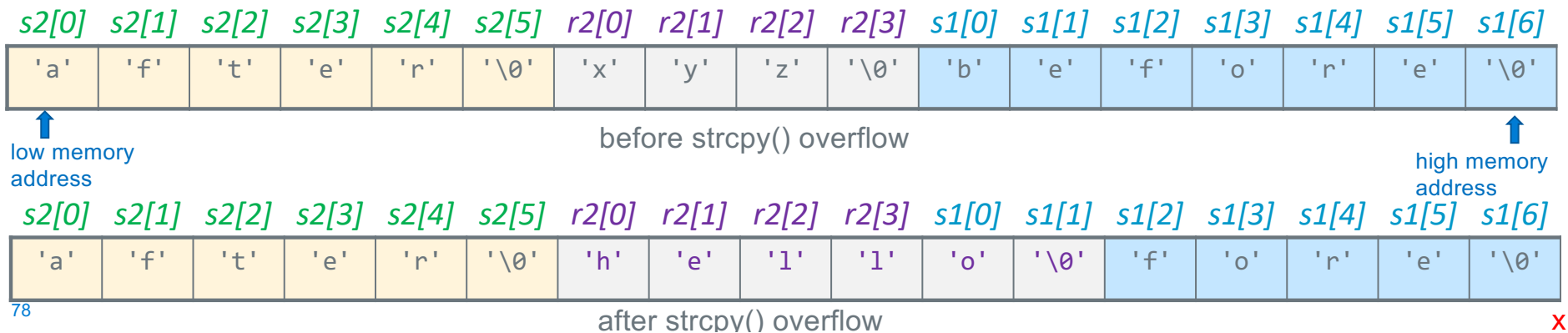
    printf("\ns2: %s\nr2: %s\nr2: %s\n", s2, r2, s1);
    return EXIT_SUCCESS;
}
```

these are mutable
arrays, not literals

compile on pi-cluster with
gcc test.c

```
./a.out
s2: after
r2: xyz
s1: before

s2: after
r2: hello
s1: o
```

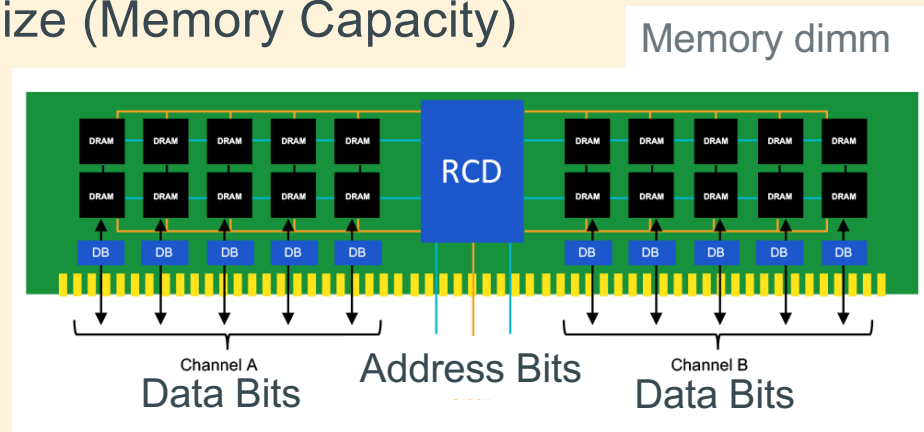


Extra Slides

-

Memory Size

- Since memory addresses are implemented in hardware using binary
 - The **Size (number of byte sized cells)** of Memory is specified in **powers of 2**
- Memory size/capacity in **bytes** is specified by the “**Number of bits**” in an address
 - 32 bits of address = $2^{32} = 4,294,967,296$
 - Address Range is 0 to $2^{32} - 1$ (unsigned)
- Shorthand notation for address size (Memory Capacity)
 - KB = 2^{10} (K=1024) kilobyte
 - MB = 2^{20} megabyte
 - GB = 2^{30} gigabyte
 - TB = 2^{40} terabyte
 - PB = 2^{50} petabyte



Fixed size types in C (later addition to C)

- Sometimes programs need to be written for a particular range of integers or for a particular size of storage, regardless of what machine the program runs on
- In the file `<stdint.h>` the following fixed size types are defined for use in these situations:

Signed Data types	Unsigned Data types	Exact Size
<code>int8_t</code>	<code>uint8_t</code>	8 bits (1 byte)
<code>int16_t</code>	<code>uint16_t</code>	16 bits (2 bytes)
<code>int32_t</code>	<code>uint32_t</code>	32 bits (4 bytes)
<code>int64_t</code>	<code>uint64_t</code>	64 bits (8 bytes)

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
```

Pointer Practice

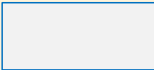
`int *ptr;` Declares a variable, `ptr`, which is a pointer to (it contains the address of) an `int` in memory

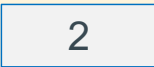
`int x = 5;`
`int y = 2;` Declares two variables, `x` and `y`, that contain `ints`, and *initializes* them to 5 and 2, respectively

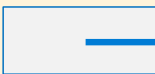


`ptr = &x;` Sets `ptr` to contain the address of `x` ("`ptr` points to `x`")

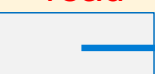
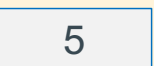

`y = 1 + *ptr;` Sets `y` to "1 plus the value stored at the address held by `ptr`. Because `ptr` points to `x`, this is equivalent to `y = 1 + x;`
"Dereference `ptr`"

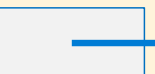


`x = *(&y);` Sets `x = y`; The `*` and `&` cancel each other. get the address of `y` and then get the contents pointed by that address

`ptr` 

`x`  write
`y`  write

`ptr`  `x`  5
`y`  2

`ptr`  `x`  5 read
`y`  6 write

`ptr`  `x`  6 write
`y`  6 read

strtol() and strtoul() examples of passing a pointer to a pointer

```
long int strtol(const char *str, char **endptr, int base);
```

```
unsigned long int strtoul(const char *str, char **endptr, int base);
```

reruns the string converted to a long or unsigned long

str pointer to the string to convert

endptr pass the address of a variable that is a char pointer (output variable)

base: number base used by the string

- **Example**: string is to contain just positive numbers ≥ 0 (in ascii) with no extra stuff
- If the string is not valid, then
 - ***endptr** **!=** **'\0'** then string contains more than just numbers (bad input)
 - ***endptr** stores the address of the first invalid character found in the buffer pointed (**str**)
- How to use **endptr** when it does not contain NULL:
 - If there are other conversion errors (you can read the man page) then **errno** **!=** 0
 - When conversion is ok, **errno** is unaltered (always clear it before calling these routines)

strtol() and strtoul() examples of passing a pointer to a pointer

```
#include <stdlib.h>
#include <errno.h>
char *endptr;
char buf[] = "33"; // test buffer string
int number;

errno = 0; // set errno to 0 (zero) before each call
number = (int)strtol(buf, &endptr, 10)
// check if the string was a proper number
// *entpr should be at the end of the string == '\0'

if ((*endptr != '\0') || (errno != 0)) {
    // handle the error
}
printf("%d\n", number);
```

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

- 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

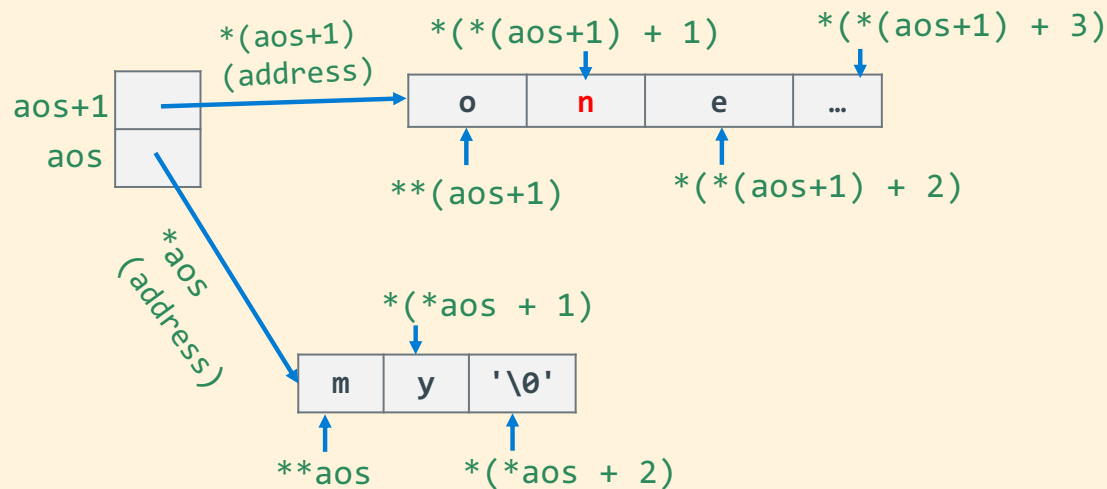
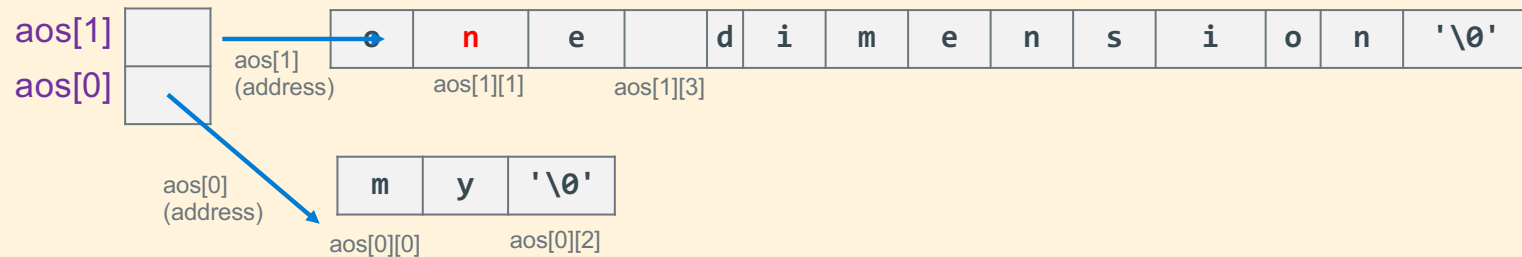
<i>index</i>	0	1	2	3	4	5
<i>char</i>	'H'	'e'	'l'	'l'	'o'	'\0'

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

```
char *strcpy(char *s0, char *s1)  
{  
    char *str = s0;  
  
    if ((s0 == NULL) || (s1 == NULL))  
        return NULL;  
    while (*s0++ = *s1++)  
        ;  
    return str; // address of dest string  
}
```

Accessing Characters in an Array of Pointers to Strings

`aos[1][1]` is `*(*aos + 1) + 1` which contains 'n'; address is `(*aos + 1) + 1`



```
char *ptr;

ptr = *aos;

if (*ptr == ',')
    or
if (**aos) == ','
```

You cannot write to an immutable literal

- You can use & to get the address of an anonymous variable as shown
 - Though the Rvalue of "Hello" is the address
- You cannot write to an immutable literal

```
char *pt;  
  
// pt = "Hello";  
pt = (char *) &"Hello";  
*pt = 'a'; // bus error  
printf("%s\n", pt);
```