C Programming

Computer Operating Systems, Spring 2024

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- What questions do you have for me?

Administrivia (pt. 1)

- HW00 Posted
  - Should have everything you need after this lecture
  - Autograder Posted over the weekend
  - Due: Friday 9/6 @ Midnight
  - Start ASAP since you need to setup the environment
  - Short HW00 Demo in a second

- Survey00: Pre-semester Survey
  - Anonymous Survey, live now
  - On Canvas (So that it can be anonymous)
  - Due Wednesday 9/11 @ midnight

Administrivia (pt. 2)

- Check-in 00
  - Short questions about C
  - Due before lecture on Tuesday
  - Releases tonight or sometime tomorrow
  - Will be on gradescope

HW00 Demo

- Demonstrate how to run it
- Compiling it is something you need to figure out

- **`clang-15`** is the compiler you should use for the assignment
  - If it is not installed, try running this in the terminal:

    ```
    apt-get install -y clang-15
    ```

Website & Infra Demo

- Website: https://www.seas.upenn.edu/~cis2400/current/
- Canvas site: https://canvas.upenn.edu/courses/1811752
- Docker: see setup doc on course website

Lecture Outline

- **C Intro**
  - **Cont. from last time:**
    - **Arrays**
    - **Command line args**
  - Pointers
    - Box & Arrow Diagrams
    - Arrays vs pointers
    - C Strings
  - ~~Structs~~
  - ~~The Stack & Pass-by-value~~
  - More on Compiling

Sample C program: sum evens

```
#include <stdio.h>
#include <stdlib.h>

int sum_evens(int n) {
  int sum = 0;
  for (int i = 0; i < n; i++) {
    if (i % 2 == 0) {
      sum += i;
    }
  }
  return sum;
}

int main() {
  int sum = sum_evens(5);
  printf("sum: %d\n", sum);
  return EXIT_SUCCESS;
}
```

Function declarations & parameters

Variables local to the function

For loops & if statements look similar

Print statements are different to format output. This replaces %d with the value of sum, more later in lecture

Another Similarity: Scope

- Variables declared inside of a function are local to that function and are not visible outside of that scope.

- Variables can also be declared outside of a function – these variables typically have global scope but there are some subtleties

C vs Java Similarities Overview

- C and Java are very similar syntactically

- Similarities:
  - Control Structures (if/else/for/while/…)
  - Variables and data types (int/char/float/double/…)
  - Arrays and strings exist in both
    (but are also different implementation wise)
  - Statements & Expressions
    x = (y + z) / 2

C vs Java

- C and Java are Syntactically Similar, but …
  - **do not assume everything in C is like Java**
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- From my experience, a common source for making mistakes in C is forgetting that things are not like Java

C vs Java: Differences

- C is functionally very different than Java

- Some differences:
  - C doesn’t default initialize anything
  - C doesn’t have objects
  - C compiles down to machine code
  - C runs really fast
  - C doesn’t check much in terms of safety, no nice error messages like Java has
  - C is “just above” assembly in terms of abstraction
  - C allows for direct memory access
  - **Java has implicit references, C is explicit with pointers**

More on this in a second

Arrays

- Definition: `type name[size]`
  - Allocates `size` *contiguous* elements of type `type`
  - Normal usage is a compile-time constant for `size` (*e.g.* `int scores[5];`)
  - Initially, array values are "garbage" == Random values

value	10	9	9	9	10

- Size of an array
  - **Not stored anywhere** – array does not know its own size!
  - The programmer will have to store the length in another variable or hard-code it in

Using Arrays

Optional when initializing

- Initialization: `type name[size] = {val0,…,valN};`
  - `{}` initialization can *only* be used at time of definition
  - If no size supplied, infers from length of array initializer

- Array name used as identifier for "collection of data"
  - `name[index]` specifies an element of the array and can be used as an assignment target or as a value in an expression
  - The array name cannot be assigned to / changed

```
int primes[6] = {2, 3, 5, 6, 11, 13};
primes[3] = 7;
primes[100] = 0;   // memory smash!
```

No IndexOutOfBounds
Hope for segfault

Arrays as Parameters

- It’s tricky to use arrays as parameters
  - What happens when you use an array name as an argument?
  - Arrays do not know their own size

```
int sumAll(int a[]) {
   int i, sum = 0;
   for (i = 0; i < ...???
}
```

Solution: Pass Size as Parameter

```
int sumAll(int[] a, int size) {
  int i, sum = 0;
  for (i = 0; i < size; i++) {
    sum += a[i];
  }
  return sum;
}
```

- Standard idiom in C programs

C command line args

```
#include <stdio.h>
#include <stdlib.h>

int main(int argc, char* argv[]) {
  for (int i = 0; i < argc; i++) {
    printf("%s\n", argv[i]);
  }
  return EXIT_SUCCESS;
}
```

- **argc** is the number of arguments given to the program.
  - **The name of the program is counts as an argument.**
- **argv is an array of char*'s** (strings) that are the arguments
  - **The name of the program is the first argument.**

C command line args [Live Demo]

```
#include <stdio.h>
#include <stdlib.h>

int main(int argc, char* argv[]) {
  for (int i = 0; i < argc; i++) {
    printf("%s\n", argv[i]);
  }
  return EXIT_SUCCESS;
}
```

- **Let’s see an example…**

- Note how everything arg is a string, will need to do conversion to other types if you want that.

Lecture Outline

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    - **Box & Arrow Diagrams**
    - **Arrays vs pointers**
    - **C Strings**
  - ~~Structs~~
  - ~~The Stack & Pass-by-value~~
  - More on Compiling

Pointers

POINTERS ARE EXTREMELY IMPORTANT IN C

- Variables that are explicit “references”
  - Holds the location to some data in computer memory
  - Must specify a type so the data being referred to can be interpreted

equivalent

- Generic definition: `type* name;` or `type *name;`
  - Example: `int *ptr;`
    - Declares a variable that can refer to an int
    - Trying to access that data at that address will treat the data there as an int

Pointer Operators

- *Dereference* a pointer using the unary `*` operator
  - Access the memory referred to by a pointer
  - Can be used to read or write the data
  - Example:

```
int *ptr = ...; // Assume initialized
int a = *ptr; // read the value
*ptr = a + 2; // write the value
```

- Get the “reference” of a variable with `&`
  - `&foo` gets a “reference” to foo in memory
  - Example:

```
int a = 240;
int *ptr = &a;
*ptr = 2; // 'a' now holds 2
```

Box and Arrow Diagrams

Red arrow is the next line to execute

- Really Really Really useful thing to visualize C code is to draw diagrams with boxes and arrows to visualize what is going on.

```
int main(int argc, char* argv[]) {
  int a, b, c;
  int* ptr;

  a = 5;
  b = 3;
  ptr = &a;

  *ptr = 7;
  c = a + b;

  return 0;
}
```

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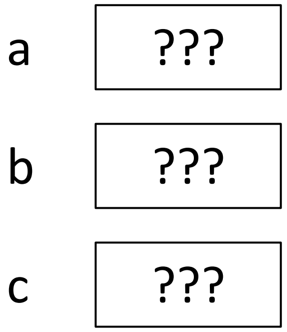

a	???
b	???
c	???

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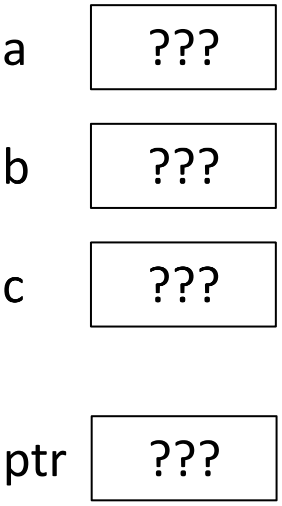

a ???

b ???

c ???

ptr ???

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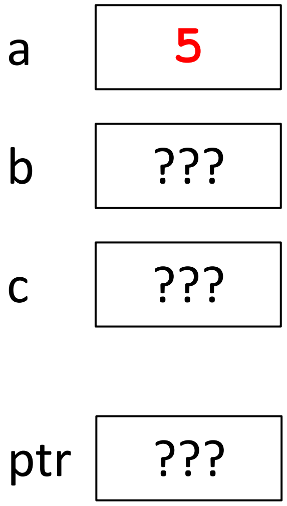

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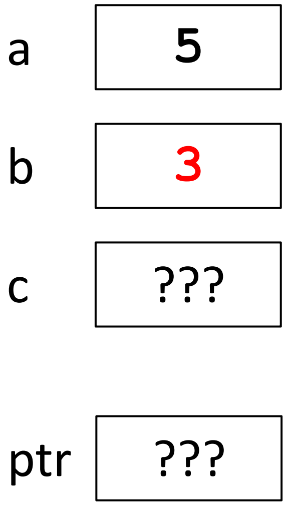

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b 3

c ???

ptr ???

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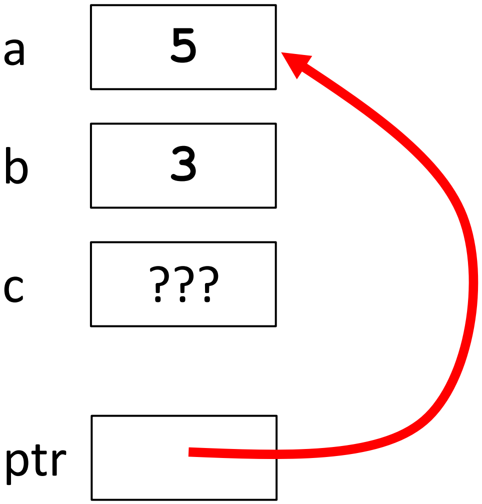
}
```



a 5

b 3

c ???

ptr

Box and Arrow Diagrams

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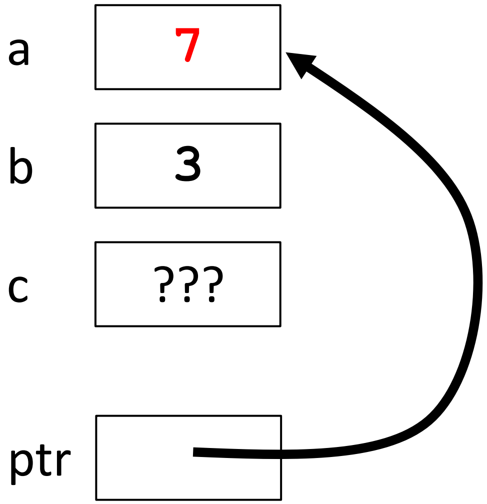

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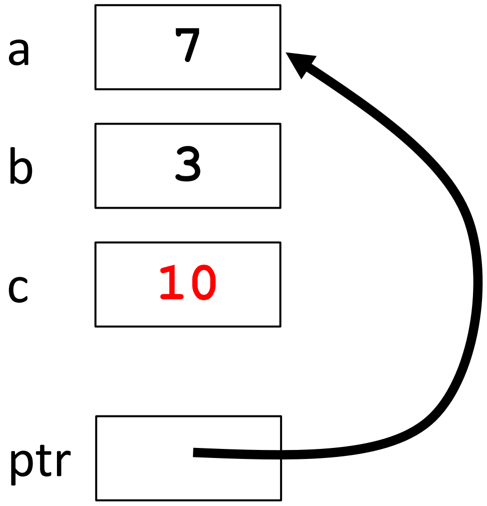
  *ptr = 7;
  c = a + b;

→ return 0;
}
```



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- What does this program print?

```
int main(int argc, char* argv[]) {
  int x = 3;
  int y = 10;
  int z = 2;

  int *ptr = &x;
  *ptr = z * *ptr;
  z = 4;
  ptr = &z;
  y = *ptr + 2;

  printf("%d %d %d \n", x, y, z);
  return 0;
}
```

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int main(int argc, char* argv[]) {
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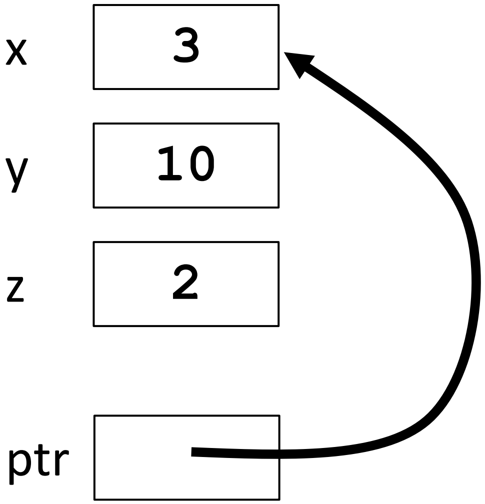

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  printf("%d %d %d \n", x, y, z);
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}
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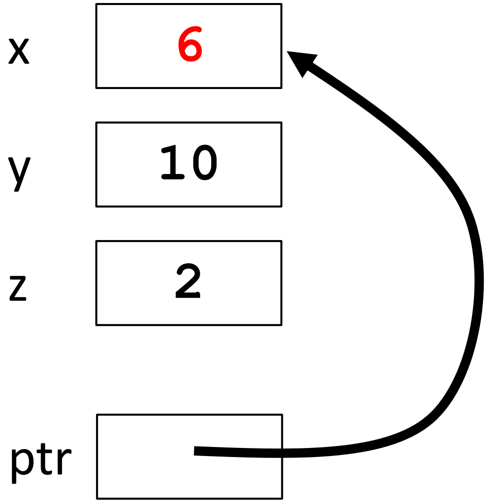

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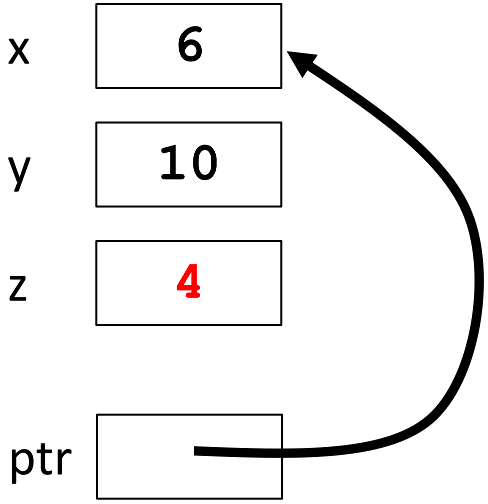

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  ptr = &z;
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  printf("%d %d %d \n", x, y, z);
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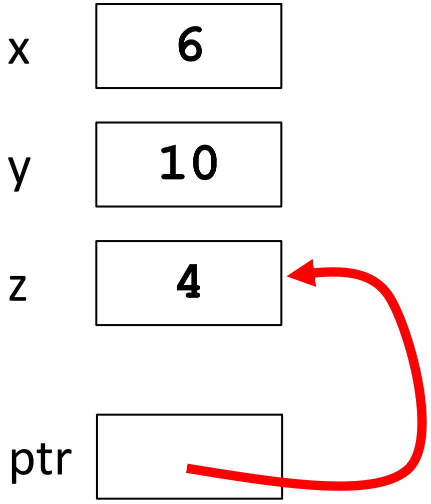

x 6

y 10

z 4

ptr

Poll Solution

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int main(int argc, char* argv[]) {
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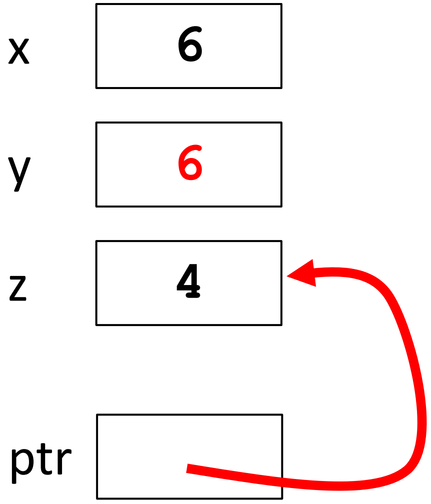

Pointers to Pointers to Pointers to Pointers

- You can have pointers to pointers:
- A pointer to a pointer to an int:

```
int x = 3;
int *ptr = &x;
int **ptr_ptr = &ptr;
```

- Can dereference more than one at a time:
  - Deference's twice: `**ptr = 3;`

- Can have pointers to pointers to pointers to pointers to pointers… `int ********************ptr;`

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- What does this program print?

```
int main(int argc, char* argv[]) {
  int x = 3;
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  int z = 2;

  int *p = &x;
  int **pp = &p; // ptr to a ptr

  *p = 10;
  *pp = &y;
  y = 3;
  p = &z;
  **pp = *p + 3;

  printf("%d %d %d \n", x, y, z);
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```

Poll Solution

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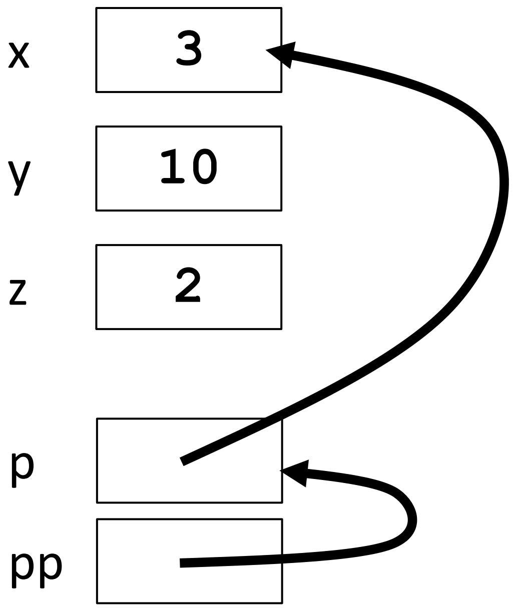
}
```



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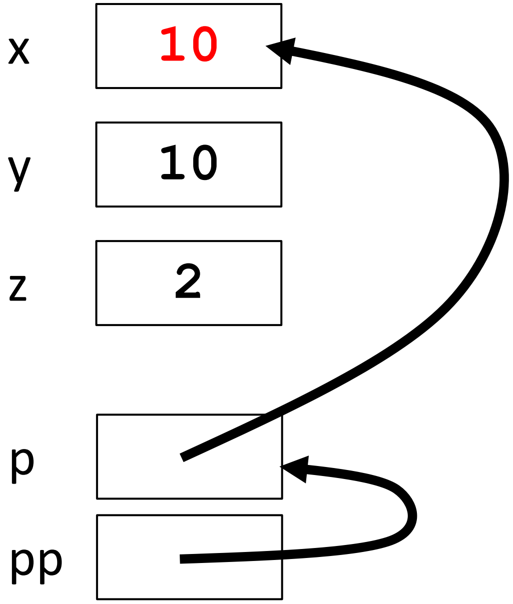

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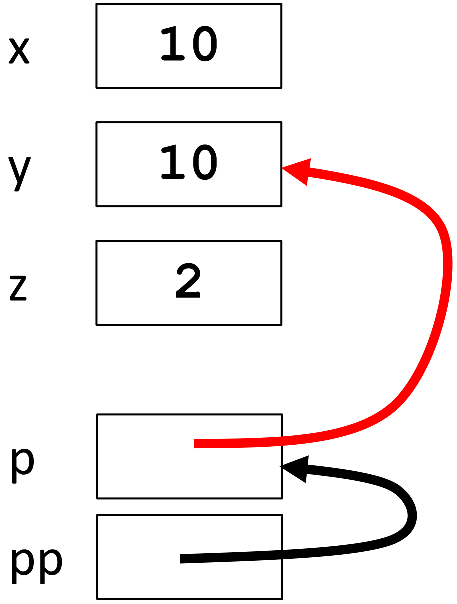

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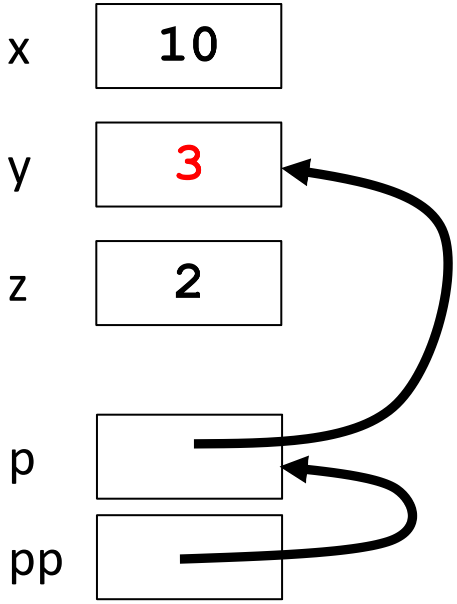
  int x = 3;
  int y = 10;
  int z = 2;

  int *p = &x;
  int **pp = &p; // ptr to a ptr

  *p = 10;
  *pp = &y;
  y = 3;
  p = &z;
  **pp = *p + 3;

  printf("%d %d %d \n", x, y, z);
  return 0;
}
```



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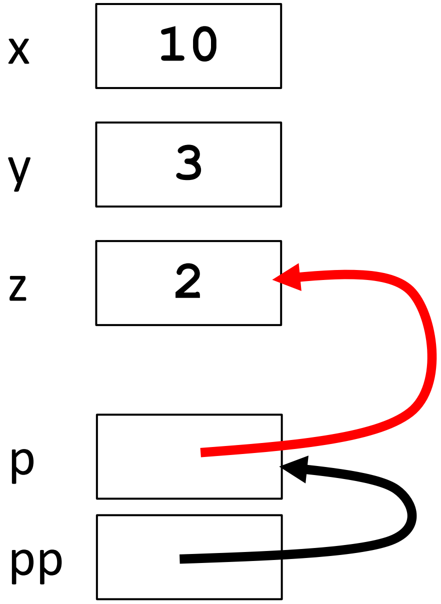

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- What does this program print?

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  int z = 2;

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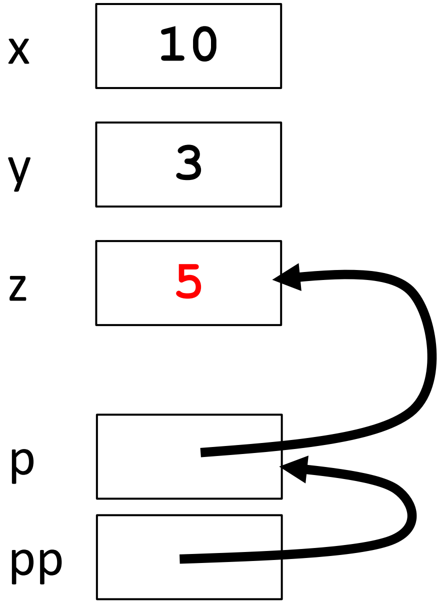
  return 0;
}
```



NULL

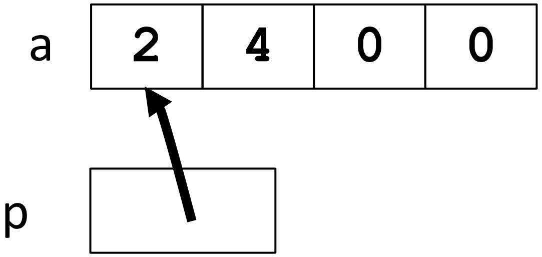
- NULL is a reference that is guaranteed to be invalid
  - an attempt to dereference NULL *causes a segmentation fault*
- Useful as an indicator of an uninitialized (or currently unused) pointer
  - It's better to cause a segfault than to allow the corruption of memory!
  - If you can't give a pointer an initial value yet, give it NULL!

```
int main(int argc, char* argv[]) {
  int* p = NULL;
  *p = 1;  // causes a segmentation fault
  return EXIT_SUCCESS;
}
```

Arrays vs Pointers

- Arrays and pointers are very similar:
  - A pointer can refer “point to “ the first element in an array

```
int a[] = {2, 4, 0, 0};
int *p = a;
```



  - Because of this, we can access the “index of” a pointer

```
int a[] = {2, 4, 0, 0};
int *p = a;

printf("%d\n", p[1]); // prints 4
```

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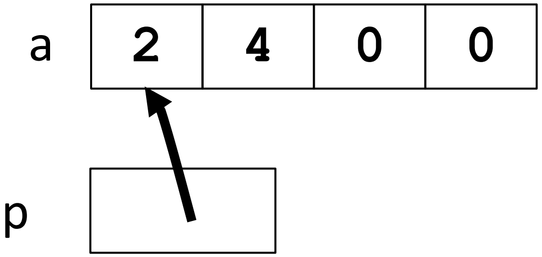
int *p = a;
```



  - Pointers can be reassigned, arrays cannot

```
int a[] = {2, 4, 0, 0};
int *p = a;
int x = 3;

p = &x;
// a = &x;  // does not compile
p = &(a[1]);

printf("%d\n", p[1]); // prints ???
```

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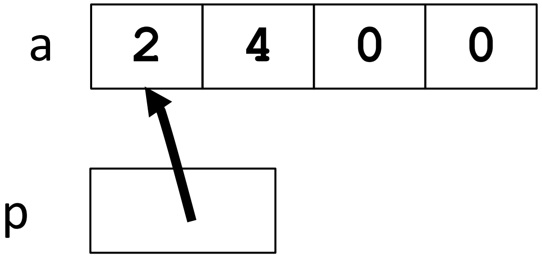
int *p = a;
```



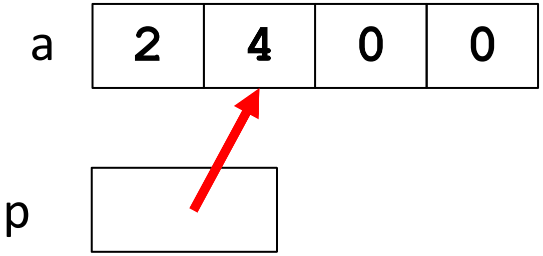
  - Pointers can be reassigned, arrays cannot

```
int a[] = {2, 4, 0, 0};
int *p = a;
int x = 3;

p = &x;
// a = &x;  // does not compile
p = &(a[1]);

printf("%d\n", p[1]); // prints ???
```

pollev.com/tqm



Prints "0"

Arrays as Parameters (Pointer Decay)

- It's tricky to use arrays as parameters
  - What happens when you use an array name as an argument?
  - Arrays do not know their own size
  - **Arrays are secretly passed as pointers to the array**

```
int sumAll(int a[]) {
  int i, sum = 0;
  for (i = 0; i < ...???
}
```

```
int sumAll(int* a) {
  int i, sum = 0;
  for (i = 0; i < ...???
}
```

Equivalent

- Note: Array syntax works on pointers using pointer arithmetic
  - E.g.

```
ptr[3] = ...;
```

Strings without Objects

- Strings are central to C, very important for I/O
- In C, we don’t have Objects but we need strings
- If a string is just a sequence of characters, we can use an array of characters as a string

- Example:

```
char str_arr[] = "Hello World!";
char *str_ptr = "Hello World!";
```

Null Termination

DO NOT FORGET THIS. THIS IS THE CAUSE OF MANY BUGS

- Arrays don’t have a length, but we **mark the end of a string with the null terminator character.**
  - The null terminator has value **`0x00`** or `'\0'`
  - Well formed strings ***MUST*** be null terminated
  - How else would printf know how to stop printing?

```
char str[] = "Hello";
```

- Example:
  - Takes up 6 characters, 5 for “Hello” and 1 for the null terminator

value	'H'	'e'	'l'	'l'	'o'	'\0'

Poll Everywhere

Discuss

- What are all the bugs in this code?

```
int main(int argc, char* argv[]) {
  // TODO
  char str[] = "Ho";
  char* str_two = "Hi";

  printf("%s and %s\n", str, str_two);

  str = str_two;
  str_two = "Hey";

  printf("%s and %s\n", str, str_two);

  char arr[2];
  arr[0] = 'y';
  arr[1] = 'a’;
  printf("%s\n", arr);

  return 0;
}
```

Lecture Outline

- C Intro
  - Cont. from last time:
    - Arrays
    - Command line args
  - Pointers
    - Box & Arrow Diagrams
    - Arrays vs pointers
    - C Strings
  - ~~Structs~~
  - ~~The Stack & Pass-by-value~~
  - **More on Compiling**

Compilation: Basics & Running

- As we saw last time, we need to compile our code in this class.

- We use **`clang-15`** in this class
- Simplest Compilation: `clang-15 example.c`
  - By default produces an executable called `a.out`

- If we want to run the executable, we type: `./a.out`
  - If it was in a directory (called "test" for example)

```
./test/a.out
```

  - The first `.` is used to say "start looking in the current directory"

Compilation: Options

- a.out is not what we usually want to call our programs

- Can use the compiler flag `-o`
  to specify what the output should be called
  - After the –o, (letter o) need to specify what we want the output to be called

- If we want to compile the file `hello.c` into an executable called `hello`, we can do:

```
clang-15 -o hello hello.c
```

Compilation: More Options

- We will eventually use a debugger, covered more in a later class. Add the `-g3` flag to have the compiler output have the maximum debugging info

- Compiler is pretty good at telling us when something looks wrong. To turn on "all" warnings, use `-Wall`
  - Not "all" warnings.
  - Wall stands for **W**arnings **all**

- If we want to compile the file `hello.c` into an executable called `hello`, with these options we can do:

```
clang-15 -g3 -Wall -o hello hello.c
```

How to Read (warnings)

- You should fix all warnings you have during compilation, autograder will deduct for warnings AND errors

- Some warnings may have "cascading effects"
  - Try fixing them top to bottom
  - If you fix one error and still have more errors, try recompiling and see if the first error fixed others

- Demo: missing_semi.c

How to Read (warnings)

- Demo: missing_semi.c

```
missing_semi.c:22:18: error: expected ';' at end of declaration
  album copy = *a
                 ^

                 ;
missing_semi.c:42:23: error: use of undeclared identifier 'a1'
  printf("a1 = %s\n", a1);
                      ^
missing_semi.c:45:50: error: no member named 'title' in 'album'
  printf("madvillainy.title = %s\n", madvillainy.title.data);
                                     ~~~~~~~~~~~ ^

3 errors generated.
```

- General Structure:

```
file_name.c  :  line num : column num : error/warning description
      line from source code
```

Poll Everywhere

Discuss

- What’s this trying to say? How do you think we should fix it?

```
mystery.c:7:9: error: expected ';' after top level declarator
} string
        ^

        ;
mystery.c:19:8: warning: missing terminating '"' character [-
Winvalid-pp-token]
  mf = "DOOM;
       ^
mystery.c:19:8: error: expected expression
mystery.c:23:5: warning: expression result unused [-Wunused-value]
  x + 2;
  ~ ^ ~
mystery.c:29:1: warning: type specifier missing, defaults to 'int';
ISO C99 and later do not support implicit int [-Wimplicit-int]
weird_func() {
^
int
3 warnings and 2 errors generated.
```

Action Items

- Get things setup
- HW00
- Check-in00
- Pre-semester Survey