Introductions, Pointers, Arrays

Computer Systems Programming, Spring 2023

Instructor: Travis McGaha

TAs:

Kevine Bernat	Jialin Cai
Mati Davis	Donglun He
Chandravaran Kunjeti	Heyi Liu
Shufan Liu	Eddy Yang

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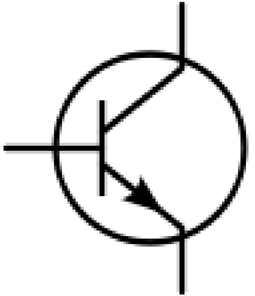
Lecture Outline

- **Introduction & Logistics**
  - **Course Overview**
  - **Assignments & Exams**
  - **Policies**
- Pointers
- Arrays

Instructor: Travis McGaha

- UPenn CIS faculty member since… August 2021
  - Currently my fourth semester at UPenn
  - Second Semester with CIT 595
- Education: University of Washington, Seattle
  - Masters in Computer Science in March 2021
  - Bachelors in Computer Engineering in June 2019
  - Instructed a course that covers very similar material
- More on my personal website: https://www.cis.upenn.edu/~tqmcgaha/

Course Overview



Course Overview

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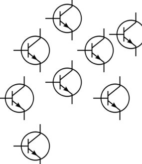

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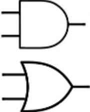

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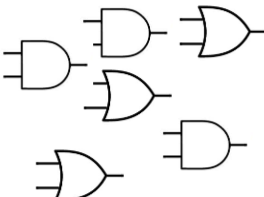


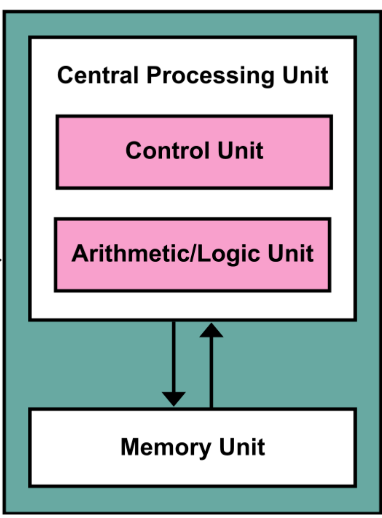
Course Overview

Adder

Mux/Demux

Latch/Flip-Flop

Course Overview



Course Overview

Course Overview

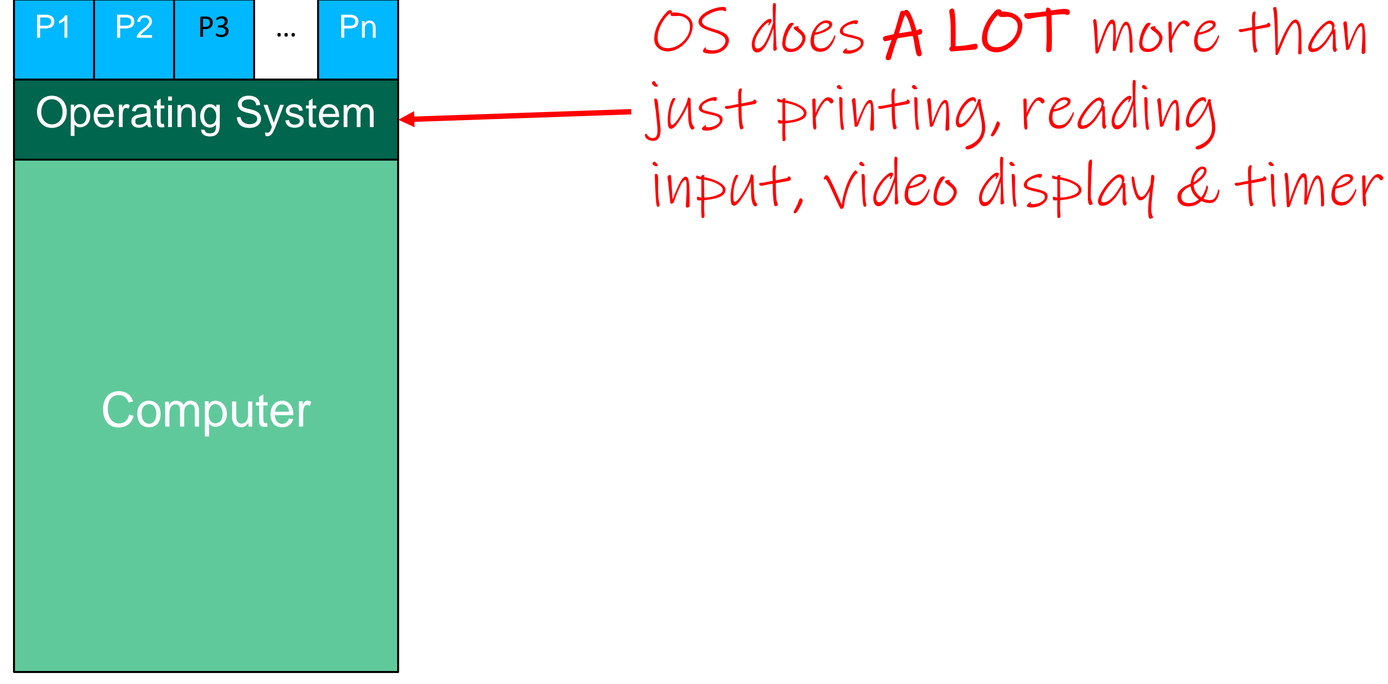
Course Overview

Process

Operating System

Computer

Course Overview



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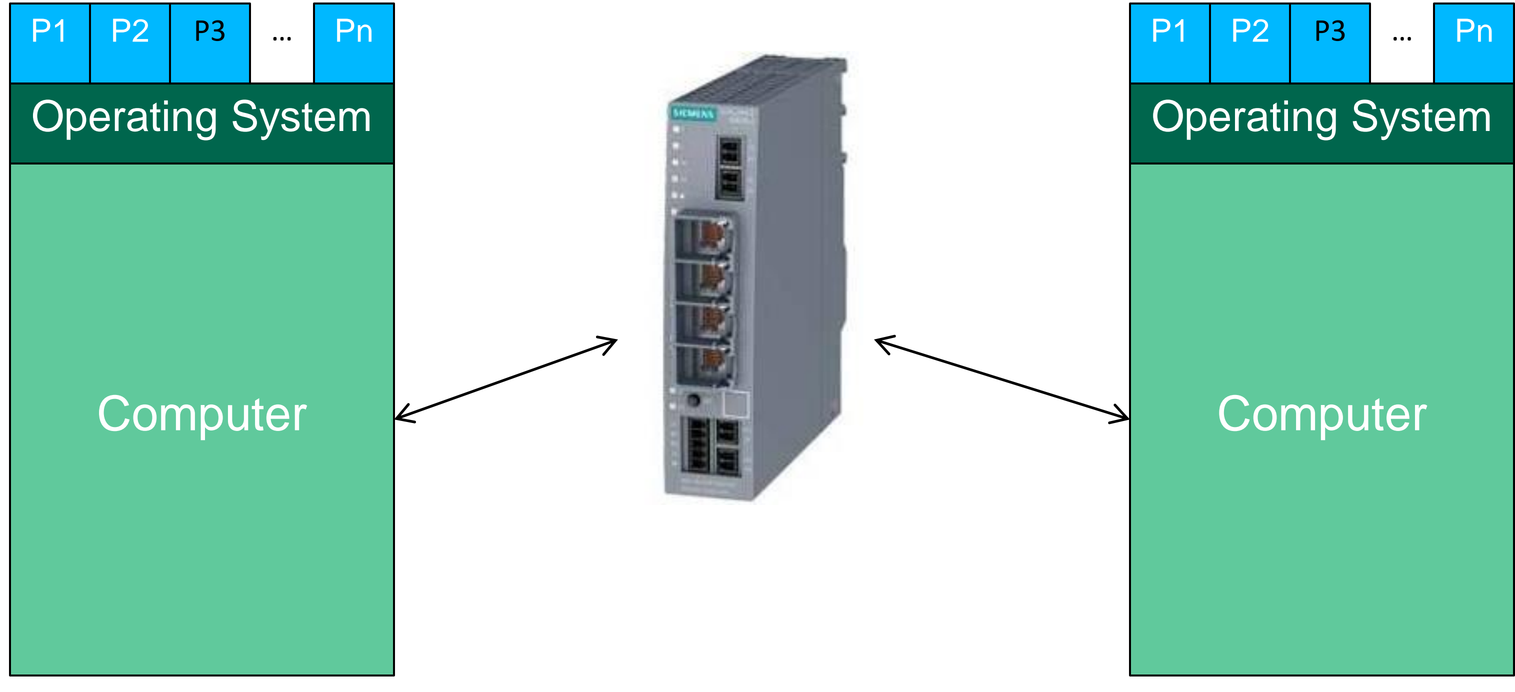

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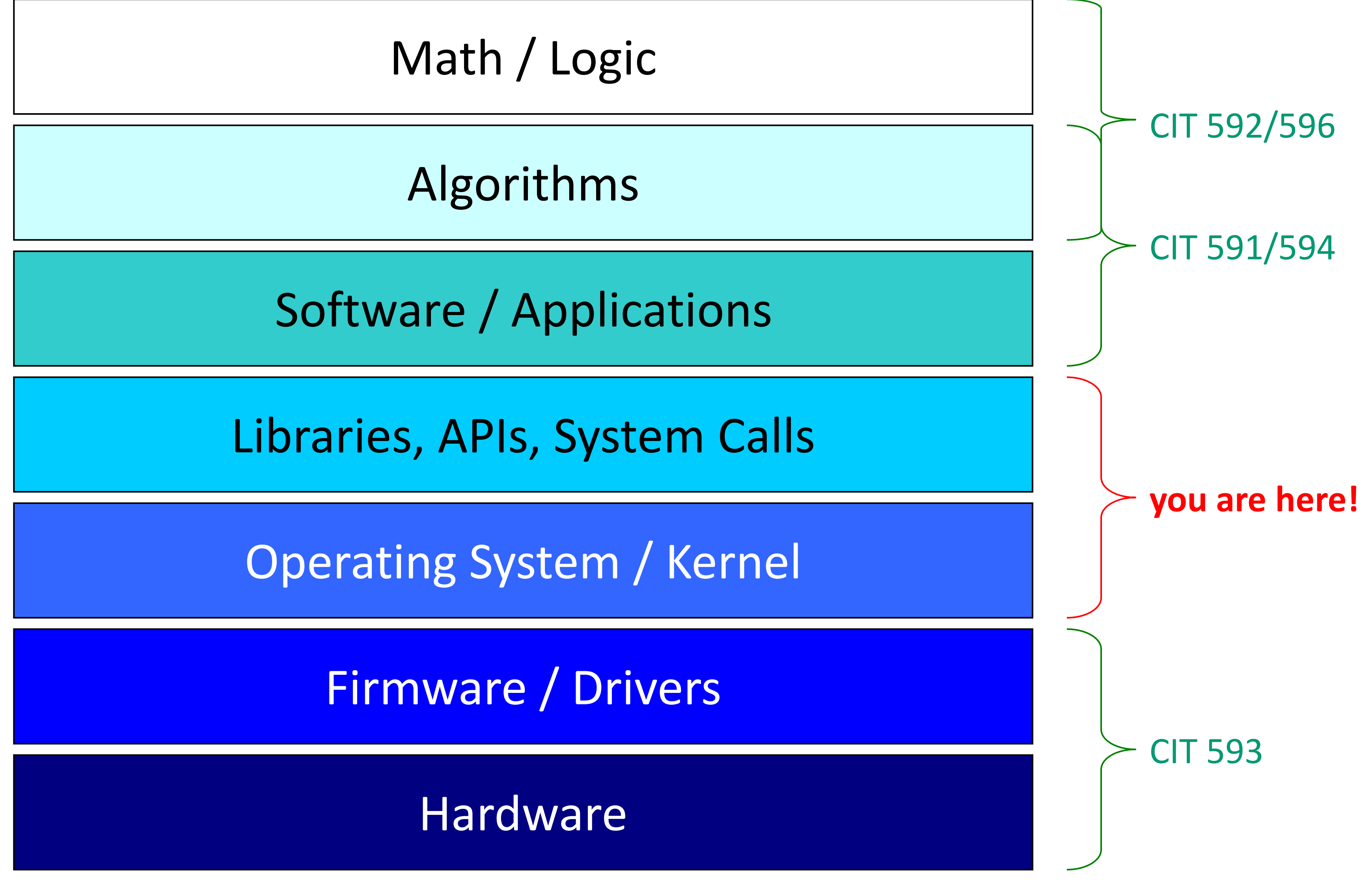


Prerequisites

- Course Prerequisites:
  - CIT 5930
- What you should be familiar with already:
  - C programming
  - C Memory Model
  - Computer Architecture Model
  - Basic UNIX command line skills
- Will still cover some of these lightly with the beginning of the semester ☺

CIT 5950 Learning Objectives

- To leave the class with a better understanding of:
  - How software "interfaces" with Operating System
  - How a computer runs/manages multiple programs
  - Various system resources and how to apply those to code
    - Threads, networking, file I/O
  - C++

- Topics list/schedule can be found on course website
  - Note: These may be slightly tweaked

Disclaimer

- This is a digest, **READ THE SYLLABUS**
  - https://www.seas.upenn.edu/~cit5950/23sp/documents/syllabus

Course Components pt. 1

- Lectures (28)
  - Introduces concepts, slides & recordings available on canvas
  - In lecture polling. Polls remain open until the next lecture
- Sections (12)
  - Reiterates lecture content, lecture clarifications, assignment & exam preparation
- Programming Projects (5)
  - Due every ~2 weeks
  - Applications of course content
- Check-ins “Quizzes” (12)
  - Unlimited attempt low-stake quizzes on canvas to make sure you are caught up with material
  - Lowest two are dropped

Course Components pt. 2

- Final Project (1)
  - Due at the end of the semester
  - Can be done solo or in partners (tentatively)
  - Further Details TBD
- Take home Exams (2)
  - Two virtual take-home exams
  - Midterm will be the week before spring break
  - Final will be the week of finals
- Textbook (0)
  - No Textbook, but using a C++ reference would probably be useful
  - https://cplusplus.com/
  - https://en.cppreference.com/w/

Course Policies

- HW Late Policy
  - Late days given on request
    - (Request usually granted)
  - No cap on the number of late days per assignment
    - More than 3 on an assignment requires approval from Travis

- Midterm Clobber Policy
  - Final is cumulative
  - If you do better on the “midterm section” of the final, your midterm grade can be overwritten.

Course Grading

- Breakdown:
  - Homeworks (55%)
  - Final Project (15%)
  - Exams (25%)
    - Midterm 10%
    - Final 15%
  - Check in Quizzes (5%)

- Final Grade Calculations:
  - I would LOVE to give everyone an A+ if it is earned
  - Final grade cut-offs will be decided privately at the end of the Semester

Course Infrastructure

- Course Website
  - Schedule, syllabus, materials …
- Codio
  - Coding environment for hw's
- Gradescope
  - Used for exams & HW submissions
- Poll Everywhere
  - Used for lecture polls
- Ed
  - Course discussion board
- Canvas
  - grades, lecture recordings, surveys & quizzes

Getting Help

- Ed
  - Announcements will be made through here
  - Ask and answer questions
  - Sign up if you haven't already!
- Office Hours:
  - Can be found on calendar on front page of canvas page
  - Starts next week
- 1-on-1's:
  - Can schedule 1-on-1's with Travis
  - Should attend OH and use Ed when possible, but this is an option for when OH and Piazza can't meet your needs

We Care

- We care about you and your experience with the course
  - There is a pre-semester survey available on canvas now. Please fill this out honestly and we will do our best to incorporate people's answers
  - There are pretty much unlimited extensions
  - Please reach out to course staff if something comes up and you need help

- PLEASE DO NOT CHEAT OR VIOLATE ACADEMIC INTEGRITY
  - We know that things can be tough, but please reach out if you feel tempted. We want to help
  - Read more on academic integrity in the syllabus

Questions?

- Any questions for me about ANYTHING?

Lecture Outline

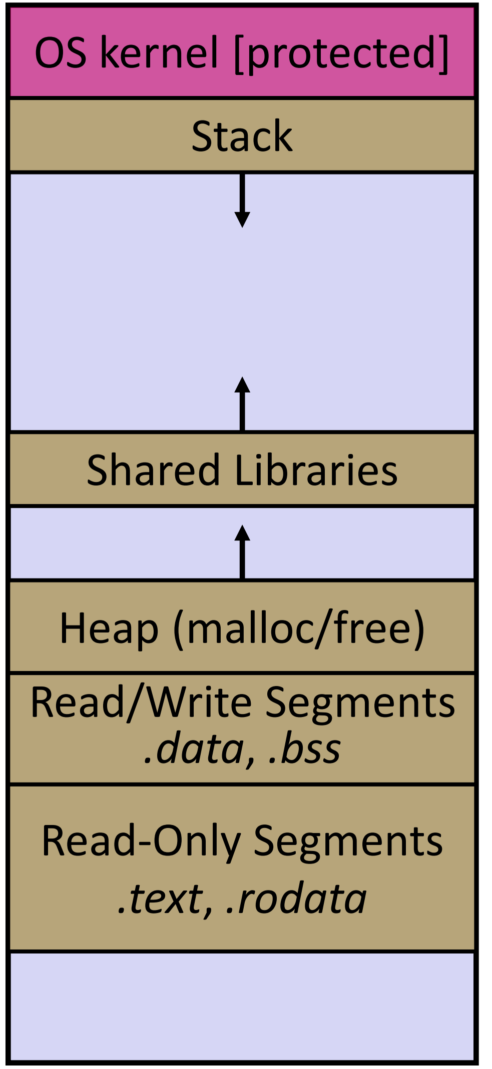
- Introduction & Logistics
  - Course Overview
  - Assignments & Exams
  - Policies
- **Pointers**
- Arrays

Aside: Memory

- Where all data, code, etc are stored for a program

- Broken up into several segments:
  - The stack
  - The heap
  - The kernel
  - Etc.

- Each "unit" of memory has an address



Pointers

POINTERS ARE EXTREMELY IMPORTANT IN C & C++

- Variables that store addresses
  - It stores the address to somewhere in memory
  - Must specify a type so the data at that address can be interpreted

equivalent

- Generic definition: `type* name;` or `type *name;`
  - Example: `int *ptr;`
    - Declares a variable that can contain an address
    - 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 memory at the address
  - Example:

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

- Get the address of a variable with `&`
  - `&foo` gets the address of foo in memory
  - Example:

```
int a = 595;
int *ptr = &a;
*ptr = 2; // 'a' now holds 2
```

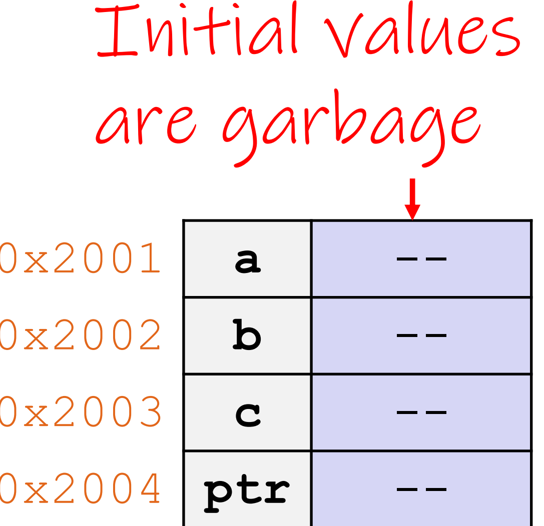
Pointer Example

```
int main(int argc, char** argv) {
  int a, b, c;
  int* ptr;    // ptr is a pointer to an int

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

  *ptr = 7;
  c = a + b;

  return 0;
}
```



Assuming that integers and pointers each fit into a single memory location

Pointer Example

```
int main(int argc, char** argv) {
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  c = a + b;

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}
```

Address	Name	Value
0x2001	a	5
0x2002	b	3
0x2003	c	--
0x2004	ptr	--

Assuming that integers and pointers each fit into a single memory location

Pointer Example

```
int main(int argc, char** argv) {
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  a = 5;
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  return 0;
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```

Address	Name	Value
0x2001	**a**	5
0x2002	**b**	3
0x2003	**c**	--
0x2004	**ptr**	**0x2001**

Assuming that integers and pointers each fit into a single memory location

Pointer Example

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int main(int argc, char** argv) {
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0x2001	a	7
0x2002	b	3
0x2003	c	--
0x2004	ptr	0x2001

Assuming that integers and pointers each fit into a single memory location

Pointer Example

```
int main(int argc, char** argv) {
  int a, b, c;
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  a = 5;
  b = 3;
  ptr = &a;

  *ptr = 7;
  c = a + b;

  return 0;
}
```

0x2001	**a**	7
0x2002	**b**	3
0x2003	**c**	10
0x2004	**ptr**	0x2001

Assuming that integers and pointers each fit into a single memory location

Output Parameters

- Pointers can be used to “return” more than one value from a function

```
int solve_quadratic(double a, double b, double c,
                    double* soln1, double* soln2){
  double d = b*b - 4 * a * c;
  if (d >= 0) {
    *soln1 = (-b + sqrt(d)) / (2*a);
    *soln2 = (-b - sqrt(d)) / (2*a);
    return 1;
  } else {
    return 0;
  }
}

int main(int argc, char** argv) {
  double soln1, soln2; // populated by function call
  solve_quadratic(2.0, 4.0, 0.0, &soln1, &soln2);
  // ...
}
```

Output Parameters

PRO TIP: Draw out the addresses with "Boxes & Arrows" to visualize what is going on

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  // ...
}
```

main

soln1	?
soln2	?

Output Parameters

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  solve_quadratic(2.0, 4.0, 0.0, &soln1, &soln2);
  // ...
}
```

main

soln1	?
soln2	?

solve_quad

a	2.0
b	4.0
c	0.0
soln1	
soln2	
d	16.0

Output Parameters

PRO TIP: Draw out the addresses with "Boxes & Arrows" to visualize what is going on

- Pointers can be used to "return" more than one value from a function

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  // ...
}
```

main

soln1	0
soln2	?

solve_quad

a	2.0
b	4.0
c	0.0
soln1	
soln2	
d	16.0

Output Parameters

PRO TIP: Draw out the addresses with "Boxes & Arrows" to visualize what is going on

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  double soln1, soln2; // populated by function call
  solve_quadratic(2.0, 4.0, 0.0, &soln1, &soln2);
  // ...
}
```

main

soln1	0.0
soln2	-2.0

solve_quad

a	2.0
b	4.0
c	0.0
soln1	
soln2	
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  // ...
}
```

main

soln1	0.0
soln2	-2.0

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- What is printed in this program?

```
void foo(int *x, int *y, int z) {
  int temp = *y;
  *y = z;
  z = *x;
  y = x;
  x = &temp;
}

int main() {
  int a = 10, b = 24, c = 33;
  foo(&a, &b, c);
  printf("%d, %d, %d\n", a, b, c);
  return EXIT_SUCCESS;
}
```

A. 10, 24, 33

B. 10, 33, 33

C. 24, 10, 10

D. 24, 33, 33

E. I’m not sure

Poll Everywhere

pollev.com/tqm

- What is printed in this program?

Red arrow indicates the NEXT line to execute

```
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  int temp = *y;
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  z = *x;
  y = x;
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}

int main() {
  int a = 10, b = 24, c = 33;
  foo(&a, &b, c);
  printf("%d, %d, %d\n", a, b, c);
  return EXIT_SUCCESS;
}
```

main

a	b	c
10	24	33

pollev.com/tqm

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void foo(int *x, int *y, int z) {
→ int temp = *y;
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  foo(&a, &b, c);
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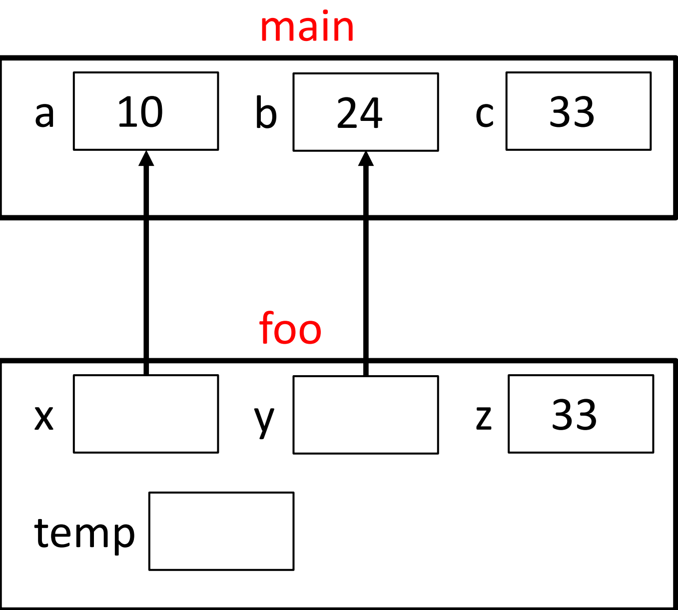
}
```



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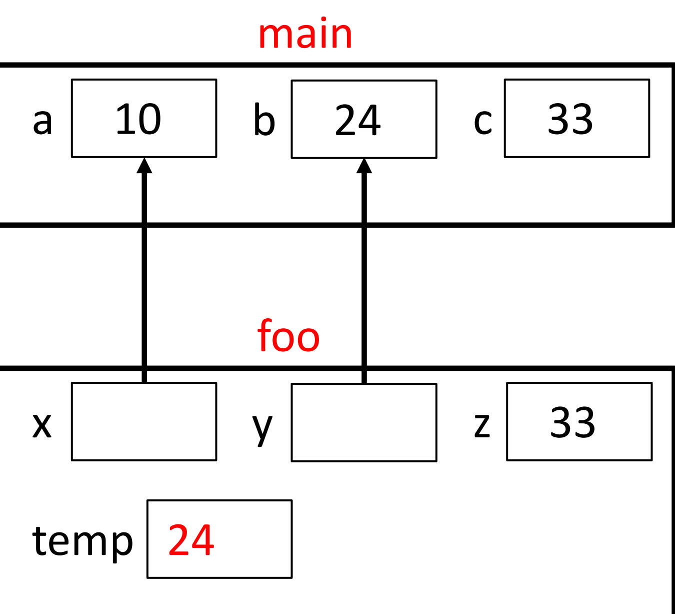

Poll Everywhere

pollev.com/tqm

- What is printed in this program?

Red arrow indicates the NEXT line to execute

```
void foo(int *x, int *y, int z) {
  int temp = *y;
  *y = z;
  z = *x;        <-- (red arrow)
  y = x;
  x = &temp;
}

int main() {
  int a = 10, b = 24, c = 33;
  foo(&a, &b, c);
  printf("%d, %d, %d\n", a, b, c);
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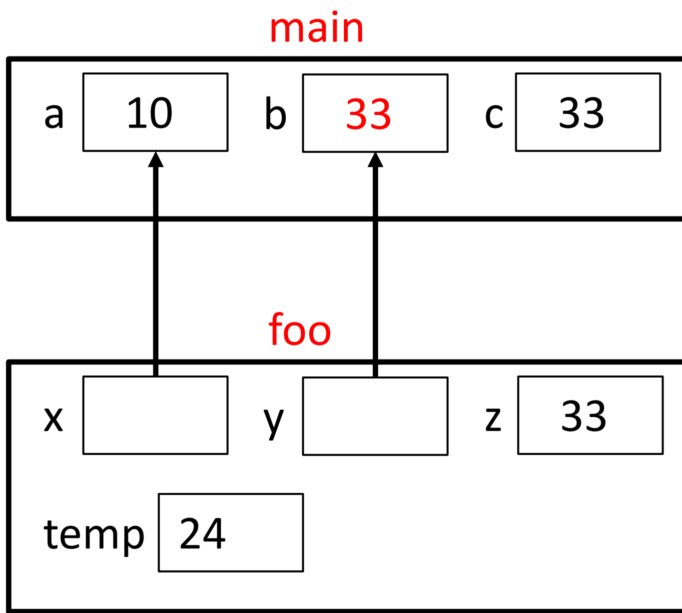

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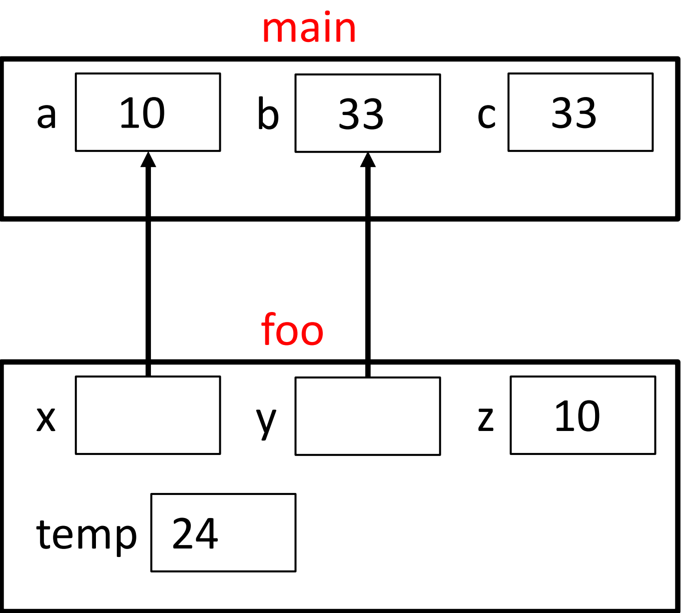


Poll Everywhere

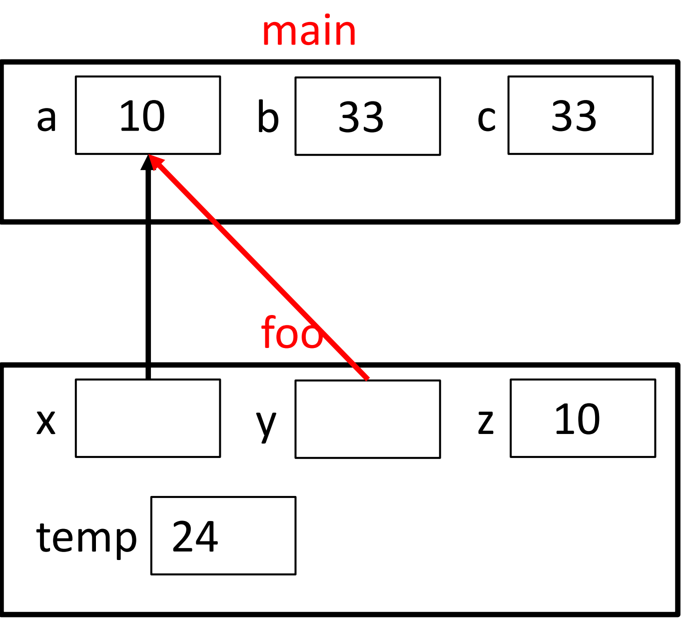
pollev.com/tqm

- What is printed in this program?

Red arrow indicates the NEXT line to execute

```c
void foo(int *x, int *y, int z) {
  int temp = *y;
  *y = z;
  z = *x;
  y = x;
  x = &temp;    // <- next line to execute
}

int main() {
  int a = 10, b = 24, c = 33;
  foo(&a, &b, c);
  printf("%d, %d, %d\n", a, b, c);
  return EXIT_SUCCESS;
}
```



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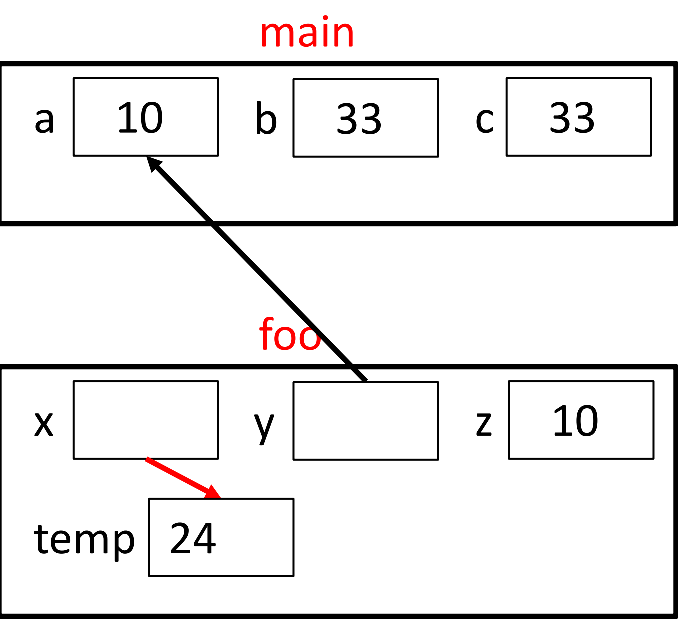

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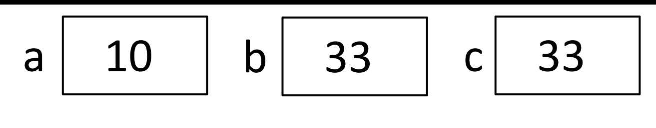
}
```

main



B. 10, 33, 33

Lecture Outline

- Introduction & Logistics
  - Course Overview
  - Assignments & Exams
  - Policies
- Pointers
- **Arrays**

Arrays

- Definition: `type name[size]`
  - Allocates `size*sizeof(type)` bytes of *contiguous* memory
  - Normal usage is a compile-time constant for `size` (*e.g.* `int scores[175];`)
  - Initially, array values are "garbage"

- 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
  - Array name (by itself) produces the address of the start of the array
    - 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

Multi-dimensional Arrays

- Generic 2D format:

  `type name[rows][cols];`

  - Still allocates a single, contiguous chunk of memory
  - C is *row-major*
  - Can access elements with multiple indices
    - **`A[0][1] = 7;`**
    - **`my_int = A[1][2];`**

  - The entries in this array are stored in memory in row major order as follows:
    - A[0][0], A[0][1], A[0][2], A[1][0], A[1][1], A[1][2]

  - 2-D arrays normally only useful if size known in advance. Otherwise use dynamically-allocated data and pointers (later)

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

Passes in address of start of 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
  - E.g. `ptr[3] = ...;`

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

Pointer Arithmetic

- We can do arithmetic on addresses to iterate through arrays.
  - ```
    double my_array[10]; // create an array of 10 doubles
    double *ptr = my_array; // ptr has the address of the
                            // first element
    ptr = ptr + 1; // increment ptr to point to
                   // the next elemetnt
    ptr[2] = 3.14; // equivalent to *(ptr + 2) = 3.14
    ```
- Pointers are *typed*
  - Tells the compiler the size of the data you are pointing to
- Pointer arithmetic is scaled by `sizeof(*ptr)`
  - Sometimes a single array element can span multiple addresses
  - Works nicely for arrays

Size (number of bytes) of thing being pointed at
    ```

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- What are the final values of nums?

```
int nums[4] = {2, 3, 5, 6};
int *ptr = nums;

ptr[1] = 0;
ptr++;
ptr[0] = 38;
ptr++;
ptr[1] = nums[0];
```

A. 2, 3, 5, 6

B. 38, 38, 5, 6

C. 2, 38, 5, 2

D. 2, 38, 5, 5

E. I'm not sure

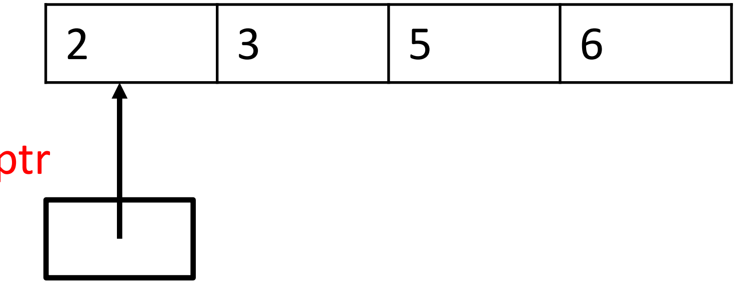
pollev.com/tqm

- What are the final values of nums?

Red arrow indicates the NEXT line to execute

```
int nums[4] = {2, 3, 5, 6};
int *ptr = nums;

ptr[1] = 0;
ptr++;
ptr[0] = 38;
ptr++;
ptr[1] = nums[0];
```



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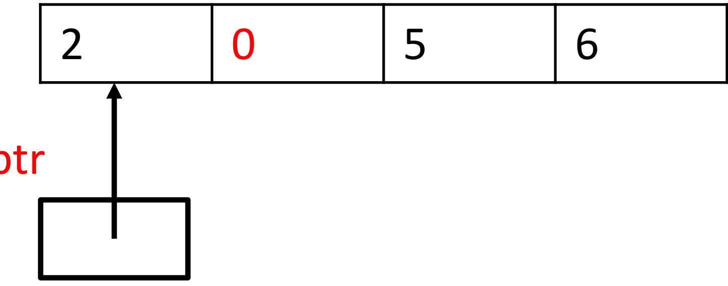

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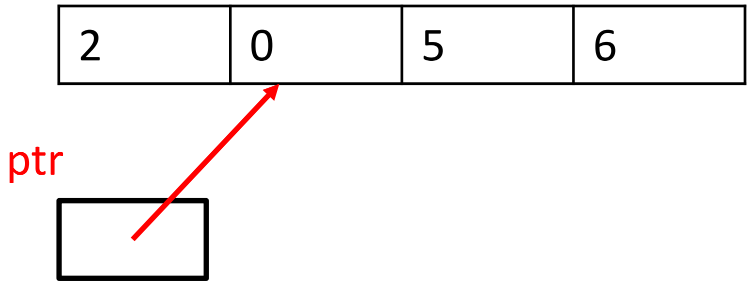

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- What are the final values of nums?

Red arrow indicates the NEXT line to execute

```
int nums[4] = {2, 3, 5, 6};
int *ptr = nums;

ptr[1] = 0;
ptr++;
ptr[0] = 38;
ptr++;          <- (red arrow: next line)
ptr[1] = nums[0];
```

nums

2	38	5	6

ptr (points to nums[1])

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- What are the final values of nums?

Red arrow indicates the NEXT line to execute

```
int nums[4] = {2, 3, 5, 6};
int *ptr = nums;

ptr[1] = 0;
ptr++;
ptr[0] = 38;
ptr++;
ptr[1] = nums[0];   ← (next line)
```

nums

2	38	5	6

ptr (points to nums[2])

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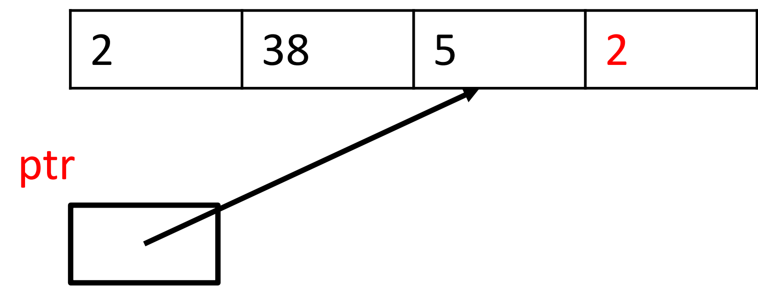
- What are the final values of nums?

Red arrow indicates the NEXT line to execute

```
int nums[4] = {2, 3, 5, 6};
int *ptr = nums;

ptr[1] = 0;
ptr++;
ptr[0] = 38;
ptr++;
ptr[1] = nums[0];
```



C. 2, 38, 5, 2