CS107 Spring 2019, Lecture 6
More Pointers and Arrays

Reading: K&R (5.2-5.5) or Essential C section 6

CS107 Topic 3: How can we effectively manage all types of memory in our programs?

Plan For Today

- Pointers and Parameters
- Arrays in Memory
- Arrays of Pointers
- **Announcements**
- Pointer Arithmetic
- Other topics: **const**, **struct** and ternary

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Pointers

- A *pointer* is a variable that stores a memory address.
- Because there is no pass-by-reference in C like in C++, pointers let us pass around the address of one instance of memory, instead of making many copies.
- One (8 byte) pointer can refer to any size memory location!
- Pointers are also essential for allocating memory on the heap, which we will cover later.
- Pointers also let us refer to memory generically, which we will cover later.

Memory

- Memory is a big array of bytes.
- Each byte has a unique numeric index that is commonly written in hexadecimal.
- A pointer stores one of these memory addresses.

Address	Value
	…
0x105	'\0'
0x104	'e'
0x103	'l'
0x102	'p'
0x101	'p'
0x100	'a'
	…

Memory

- Memory is a big array of bytes.
- Each byte has a unique numeric index that is commonly written in hexadecimal.
- A pointer stores one of these memory addresses.

Address	Value
	…
262	'\0'
260	'e'
259	'l'
258	'p'
257	'p'
256	'a'
	…

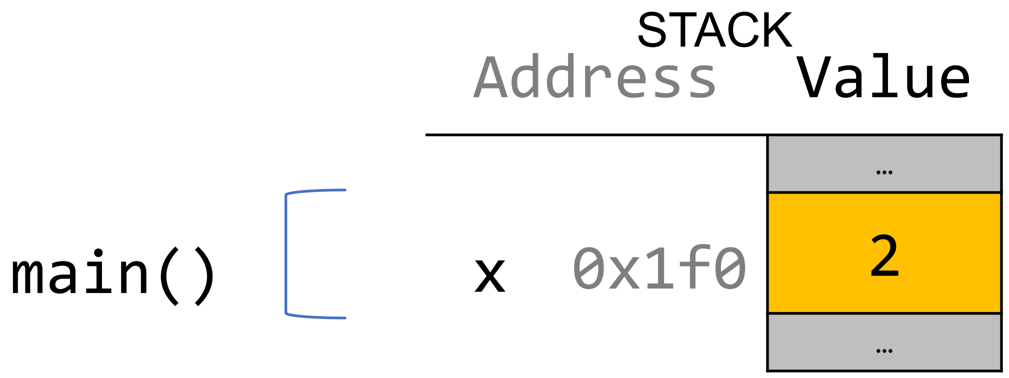
Pointers

```c
int x = 2;

// Make a pointer that stores the address of x.
// (& means "address of")
int *xPtr = &x;

// Dereference the pointer to get the data it points to.
// (* means "dereference")
printf("%d", *xPtr);    // prints 2
```

Pointers

A pointer is a variable that stores a memory address!

```
void myFunc(int *intPtr) {
    *intPtr = 3;
}

int main(int argc, char *argv[]) {
    int x = 2;
    myFunc(&x);
    printf("%d", x);    // 3!
    ...
}
```



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      myFunc(&x);
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      ...
}
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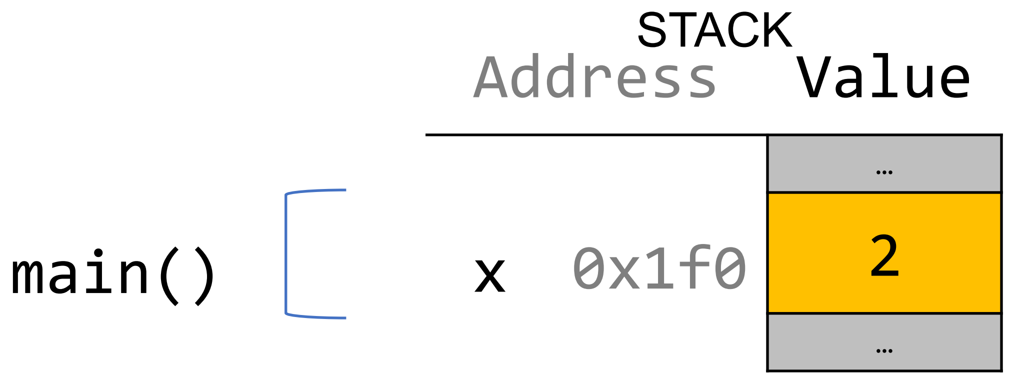

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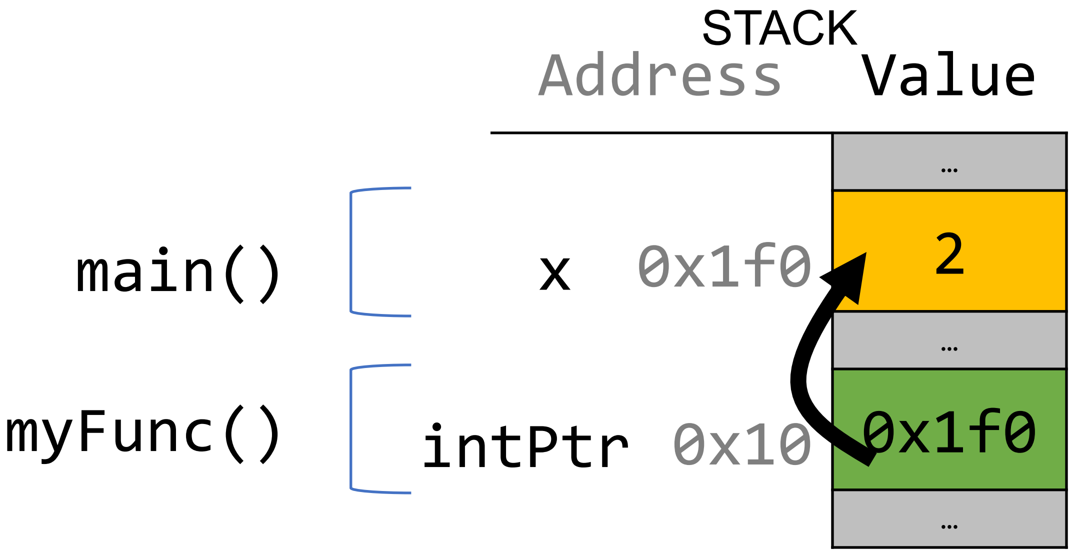

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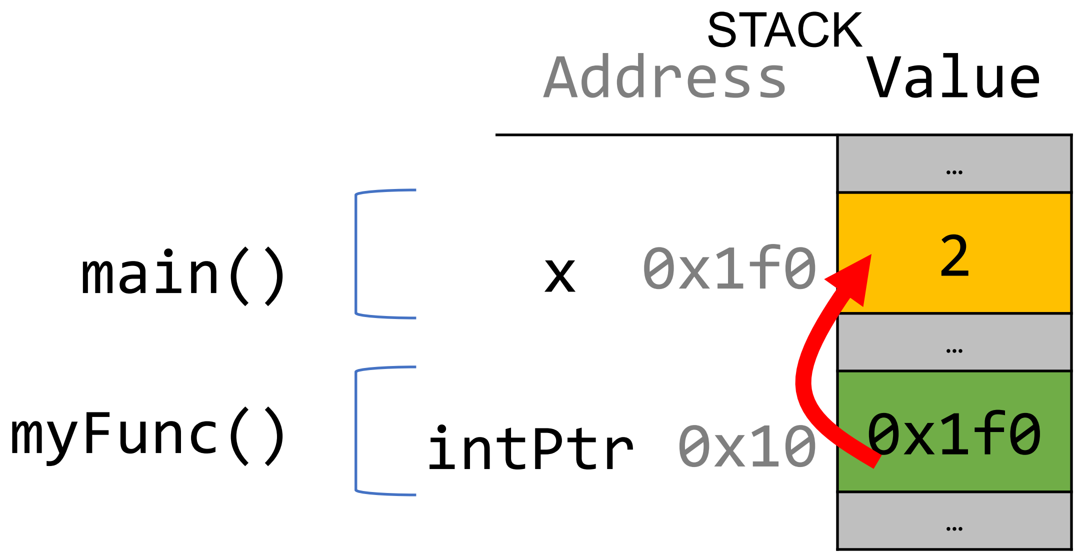

Pointers

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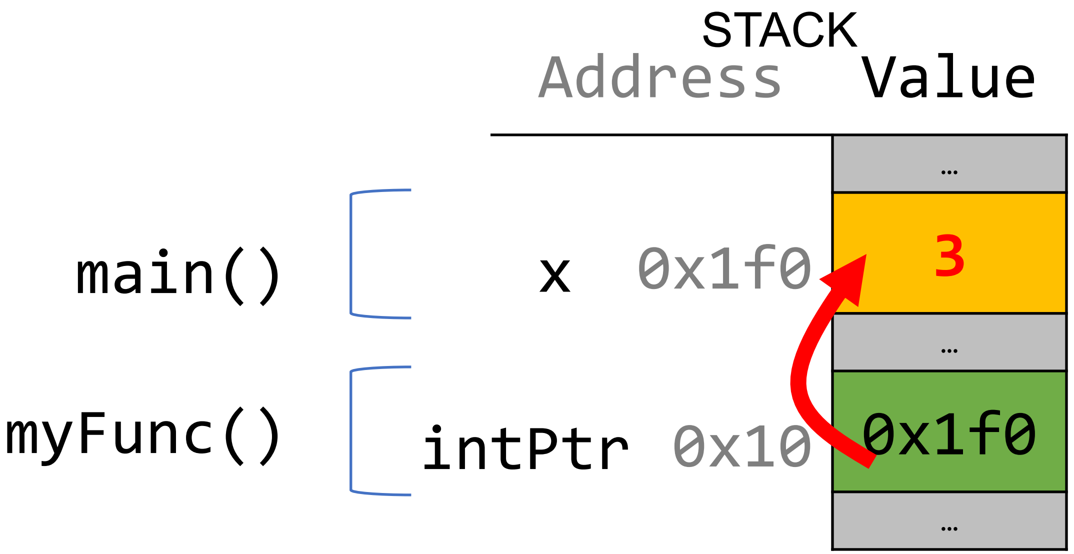
int main(int argc, char *argv[]) {
      int x = 2;
      myFunc(&x);
      printf("%d", x);     // 3!
      ...
}
```



Pointers

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void myFunc(int *intPtr) {
      *intPtr = 3;
}

int main(int argc, char *argv[]) {
      int x = 2;
      myFunc(&x);
      printf("%d", x);    // 3!
      ...
}
```
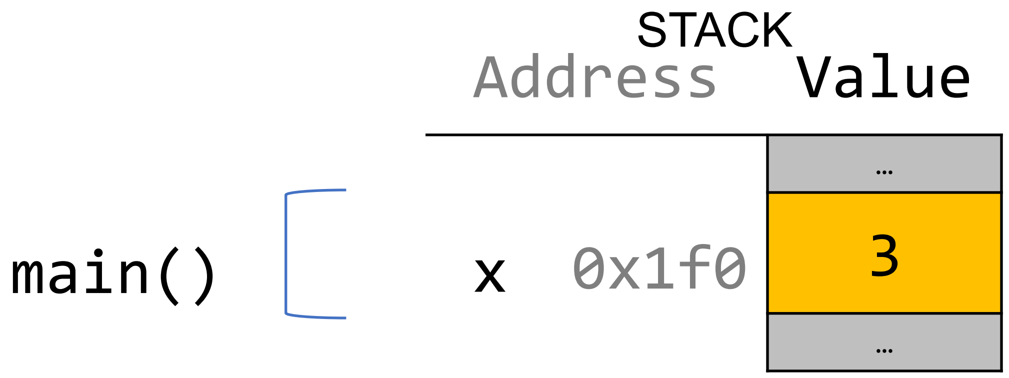
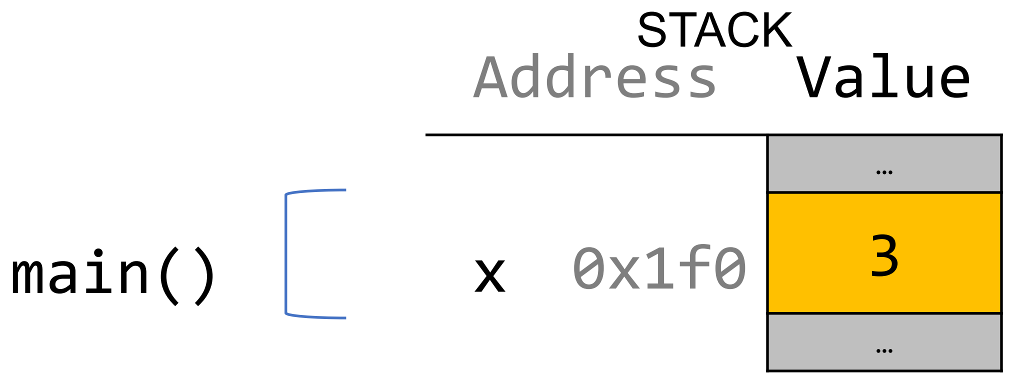



Pointers

A pointer is just a variable that stores a memory address!

```
void myFunc(int *intPtr) {
      *intPtr = 3;
}

int main(int argc, char *argv[]) {
      int x = 2;
      myFunc(&x);
      printf("%d", x);    // 3!
      ...
}
```



C Parameters

When you pass a value as a parameter, C passes a copy of that value.

```
void myFunction(int x) {
	…
}

int main(int argc, char *argv[]) {
	int num = 4;
	myFunction(num);		// passes copy of 4
}
```

C Parameters

When you pass a value as a parameter, C passes a copy of that value.

```
void myFunction(int *x) {
    …
}

int main(int argc, char *argv[]) {
    int num = 4;
    myFunction(&num);      // passes copy of e.g. 0xffed63
}
```

C Parameters

When you pass a value as a parameter, C passes a copy of that value.

```
void myFunction(char ch) {
	…
}

int main(int argc, char *argv[]) {
	char myStr[] = "Hello!";
	myFunction(myStr[1]);		// passes copy of 'e'
}
```

C Parameters

If you are performing an operation with some input and do not care about any changes to the input, pass the data type itself.

C Parameters

If you are performing an operation with some input and do not care about any changes to the input, pass the data type itself.

```
void myFunction(char ch) {
    printf("%c", ch);
}

int main(int argc, char *argv[]) {
    char myStr[] = "Hello!";
    myFunction(myStr[1]);        // prints 'e'
}
```

C Parameters

If you are performing an operation with some input and do not care about any changes to the input, pass the data type itself.

```
int myFunction(int num1, int num2) {
     return x + y;
}

int main(int argc, char *argv[]) {
     int x = 5;
     int y = 6;
     int sum = myFunction(x, y);      // returns 11
}
```

C Parameters

If you are modifying a specific instance of some value, pass the *location* of what you would like to modify.

Do I care about modifying *this* instance of my data? If so, I need to pass where that instance lives as a parameter so it can be modified.

Pointers

If you are modifying a specific instance of some value, pass the *location* of what you would like to modify.

```
void capitalize(char *ch) {
    // modifies what is at the address stored in ch
}

int main(int argc, char *argv[]) {
    char letter = 'h';
    /* We don’t want to capitalize any instance of 'h'.
     * We want to capitalize *this* instance of 'h'! */
    capitalize(&letter);
    printf("%c", letter);  // want to print 'H';
}
```

Pointers

If you are modifying a specific instance of some value, pass the *location* of what you would like to modify.

```
void doubleNum(int *x) {
    // modifies what is at the address stored in x
}

int main(int argc, char *argv[]) {
    int num = 2;
    /* We don’t want to double any instance of 2.
     * We want to double *this* instance of 2! */
    doubleNum(&num);
    printf("%d", num); // want to print 4;
}
```

Pointers

If a function takes an address (pointer) as a parameter, it can *go to* that address if it needs the actual value.

```
void capitalize(char *ch) {
     // *ch gets the character stored at address ch.
     char newChar = toupper(*ch);

     // *ch = goes to address ch and puts newChar there.
     *ch = newChar;
}
```

Pointers

If a function takes an address (pointer) as a parameter, it can *go to* that address if it needs the actual value.

```
void capitalize(char *ch) {
     /* go to address ch and put the capitalized version
      * of what is at address ch there. */
      *ch = toupper(*ch);
}
```

Pointers

If a function takes an address (pointer) as a parameter, it can *go to* that address if it needs the actual value.

```
void capitalize(char *ch) {
     // this capitalizes the address ch! ☹
     char newChar = toupper(ch);

     // this stores newChar in ch as an address! ☹
     ch = newChar;
}
```

Exercise 1

We want to write a function that prints out the square of a number. What should go in each of the blanks?

```
void printSquare(__?__) {
    int square = __?__ * __?__;
    printf("%d", square);
}

int main(int argc, char *argv[]) {
    int num = 3;
    printSquare(__?__);     // should print 9
}
```

Exercise 1

We want to write a function that prints out the square of a number. What should go in each of the blanks?

```
void printSquare(int x) {
	int square = x * x;
	printf("%d", square);
}

int main(int argc, char *argv[]) {
	int num = 3;
	printSquare(num);  // should print 9
}
```

We are performing a calculation with some input and do not care about any changes to the input, so we pass the data type itself.

Exercise 1

We want to write a function that prints out the square of a number. What should go in each of the blanks?

```
void printSquare(int x) {
     x = x * x;
     printf("%d", x);
}

int main(int argc, char *argv[]) {
     int num = 3;
     printSquare(num);  // should print 9
}
```

We are performing a calculation with some input and do not care about any changes to the input, so we pass the data type itself.

Exercise 2

We want to write a function that flips the case of a letter. What should go in each of the blanks?

```
void flipCase(__?__) {
      if (isupper(__?__)) {
            __?__ = __?__;
      } else if (islower(__?__)) {
            __?__ = __?__;
      }
}

int main(int argc, char *argv[]) {
      char ch = 'g';
      flipCase(__?__);
      printf("%c", ch);     // want this to print ‘G’
}
```

Exercise 2

We want to write a function that flips the case of a letter. What should go in each of the blanks?

```
void flipCase(char *letter) {
      if (isupper(*letter)) {
            *letter = tolower(*letter);
      } else if (islower(*letter)) {
            *letter = toupper(*letter);
      }
}

int main(int argc, char *argv[]) {
      char ch = 'g';
      flipCase(&ch);
      printf("%c", ch);     // want this to print 'G'
```

We are modifying a specific instance of the letter, so we pass the *location* of the letter we would like to modify.

Pointers Summary

- If you are performing an operation with some input and do not care about any changes to the input, **pass the data type itself**.
- If you are modifying a specific instance of some value, **pass the location** of what you would like to modify.
- If a function takes an address (pointer) as a parameter, it can *go to* that address if it needs the actual value.

Pointers Summary

- **Tip:** setting a function parameter equal to a new value usually doesn't do what you want. Remember that this is setting the function's *own copy* of the parameter equal to some new value.

```
void doubleNum(int x) {
    x = x * x;     // modifies doubleNum's own copy!
}

void advanceStr(char *str) {
    str += 2;      // modifies advanceStr's own copy!
}
```

Exercise 3

We want to write a function that advances a string pointer past any initial spaces. What should go in each of the blanks?

```
void skipSpaces(__?__) {
     int numSpaces = strspn(__?__, " ");
     __?__ += numSpaces;
}

int main(int argc, char *argv[]) {
     char *str = "    hello";
     skipSpaces(__?__);
     printf("%s", str);       // should print "hello"
}
```

Exercise 3

We want to write a function that advances a string pointer past any initial spaces. What should go in each of the blanks?

```
void skipSpaces(char **strPtr) {
    int numSpaces = strspn(*strPtr, " ");
    *strPtr += numSpaces;
}

int main(int argc, char *argv[]) {
    char *str = "    hello";
    skipSpaces(&str);
    printf("%s", str);      // should print "hello"
}
```

We are modifying a specific instance of the string pointer, so we pass the *location* of the string pointer we would like to modify.

Exercise 3

We want to write a function that advances a string pointer past any initial spaces. What should go in each of the blanks?

```
void skipSpaces(char *strPtr) {
    int numSpaces = strspn(strPtr, " ");
    strPtr += numSpaces;
}

int main(int argc, char *argv[]) {
    char *str = "    hello";
    skipSpaces(str);
    printf("%s", str);      // should print "hello"
}
```

This advances skipSpace's own copy of the string pointer, not the instance in main.

Demo: SkipSpaces

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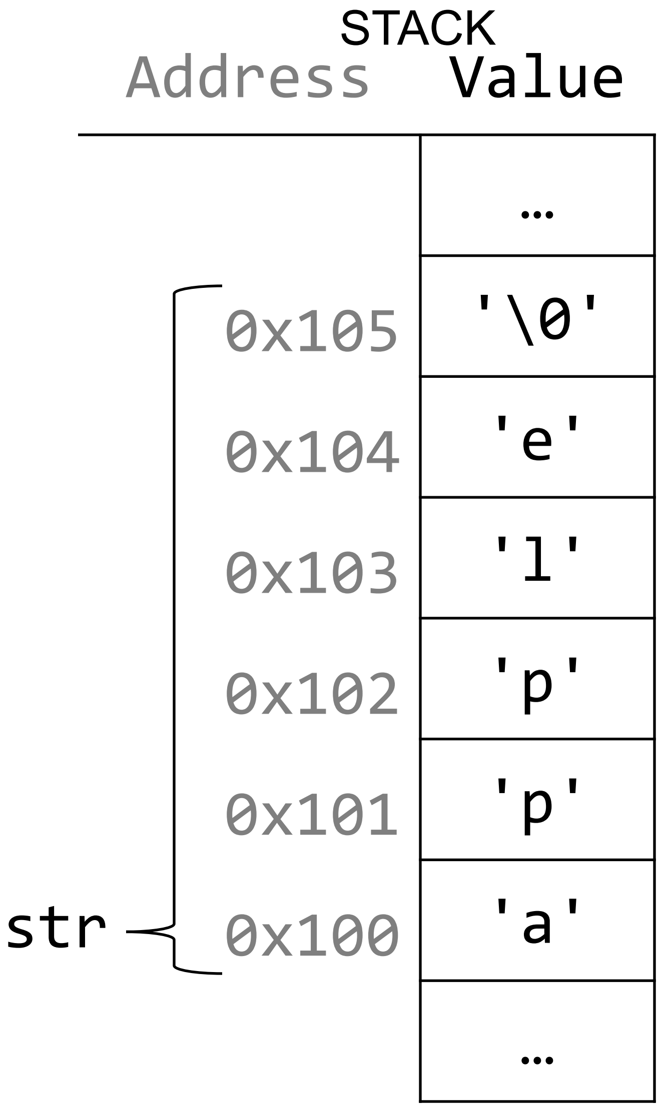
Arrays

When you declare an array, contiguous memory is allocated on the stack to store the contents of the entire array.

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

The array variable (e.g. **str**) is not a pointer; it refers to the entire array contents. In fact, **sizeof** returns the size of the entire array!

```
int arrayBytes = sizeof(str);    // 6
```



Arrays

An array variable refers to an entire block of memory. You cannot reassign an existing array to be equal to a new array.

```
int nums[] = {1, 2, 3};
int nums2[] = {4, 5, 6, 7};
nums = nums2; // not allowed!
```

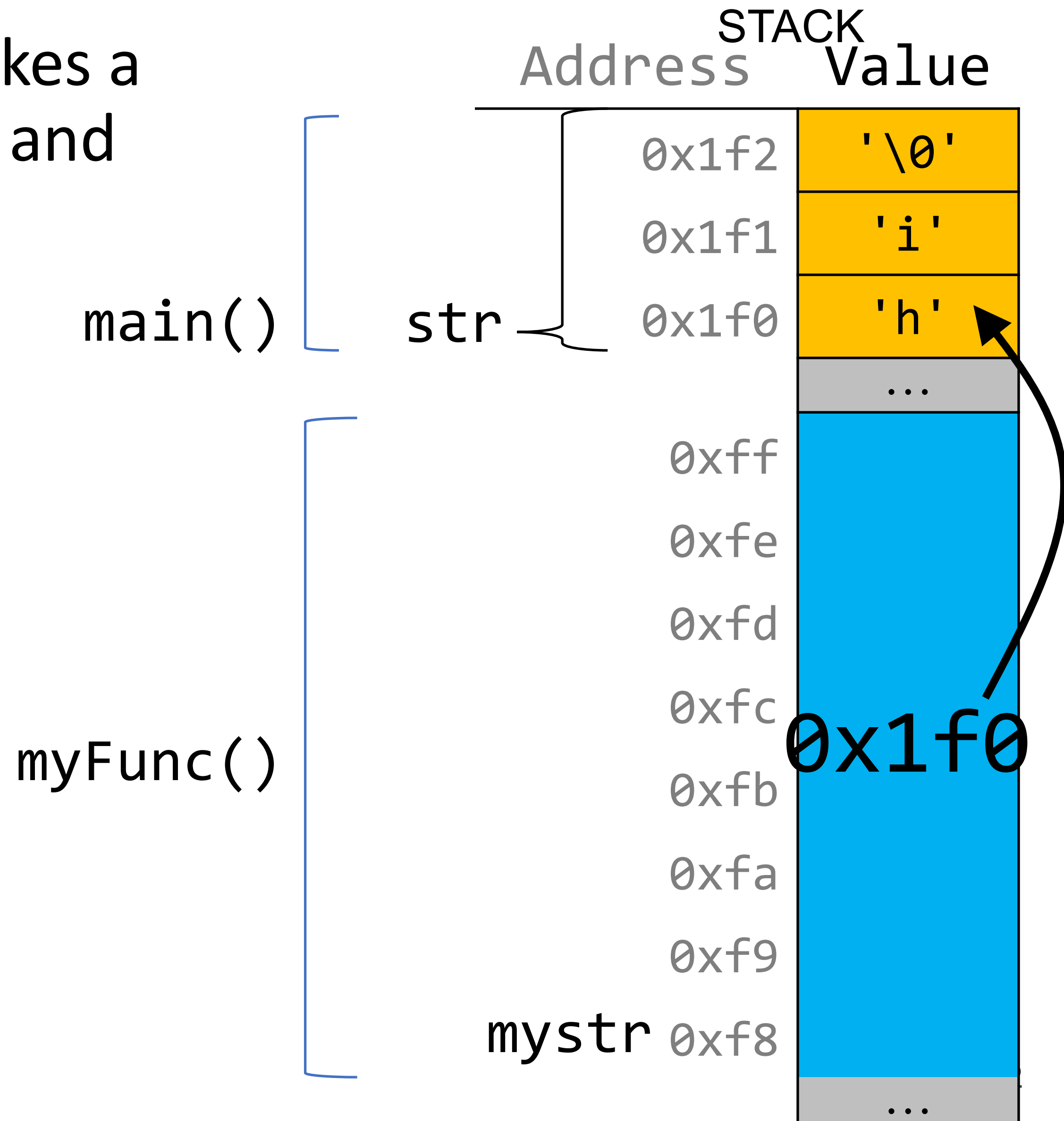
An array's size cannot be changed once you create it; you must create another new array instead.

Arrays as Parameters

When you pass an **array** as a parameter, C makes a *copy of the address of the first array element*, and passes it (a pointer) to the function.

```
void myFunc(char *myStr) {
      …
}

int main(int argc, char *argv[]) {
      char str[] = "hi";
      myFunc(str);
      ...
}
```

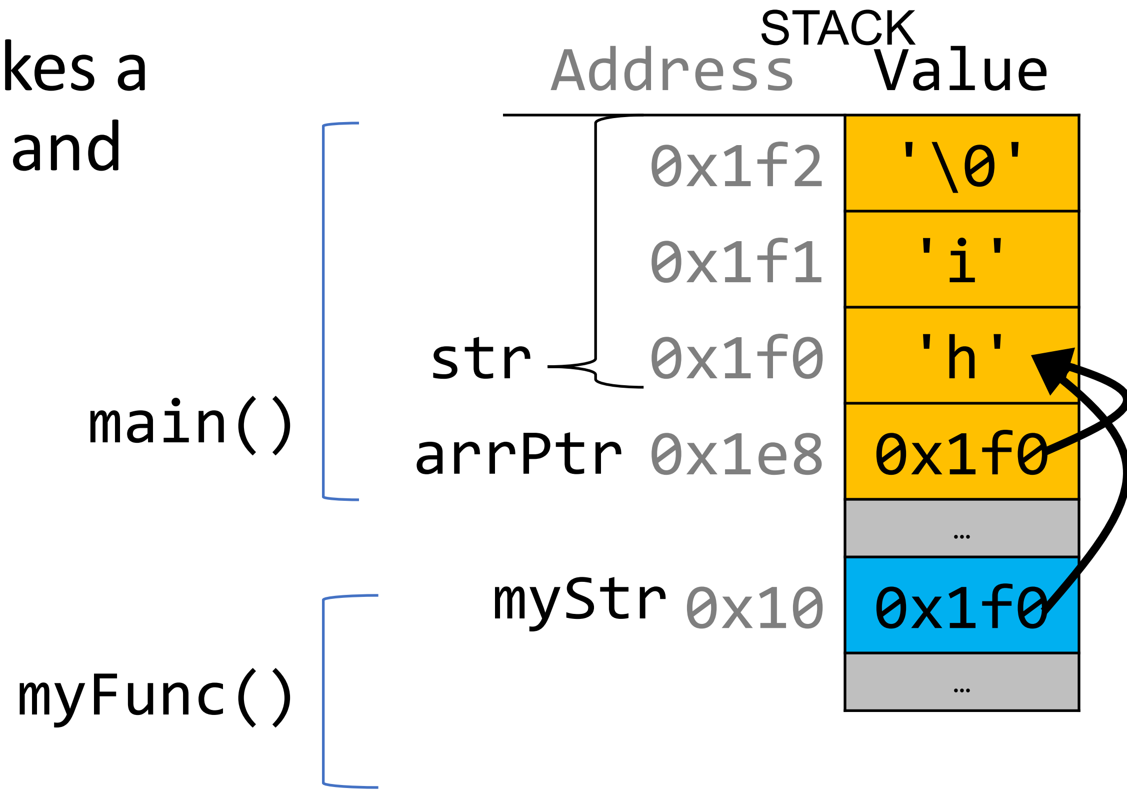


Arrays as Parameters

When you pass an **array** as a parameter, C makes a *copy of the address of the first array element*, and passes it (a pointer) to the function.

```
void myFunc(char *myStr) {
	…
}

int main(int argc, char *argv[]) {
	char str[] = "hi";
	// equivalent
	char *arrPtr = str;
	myFunc(arrPtr);
	...
}
```

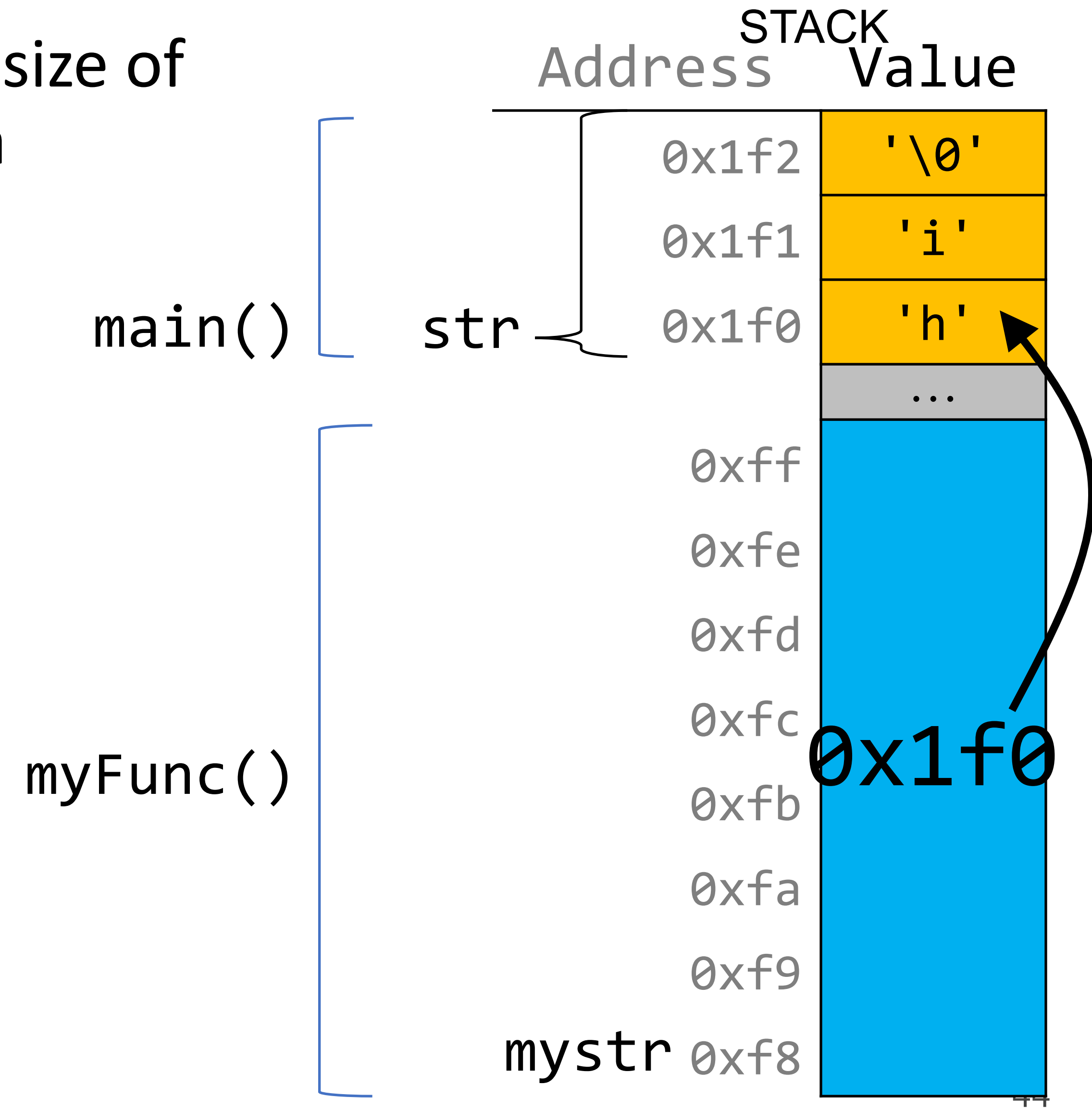


Arrays as Parameters

This also means we can no longer get the full size of the array using **sizeof**, because now it is just a pointer.

```
void myFunc(char *myStr) {
      int size = sizeof(myStr); // 8
}

int main(int argc, char *argv[]) {
      char str[] = "hi";
      int size = sizeof(str);    // 3
      myFunc(str);
      ...
}
```



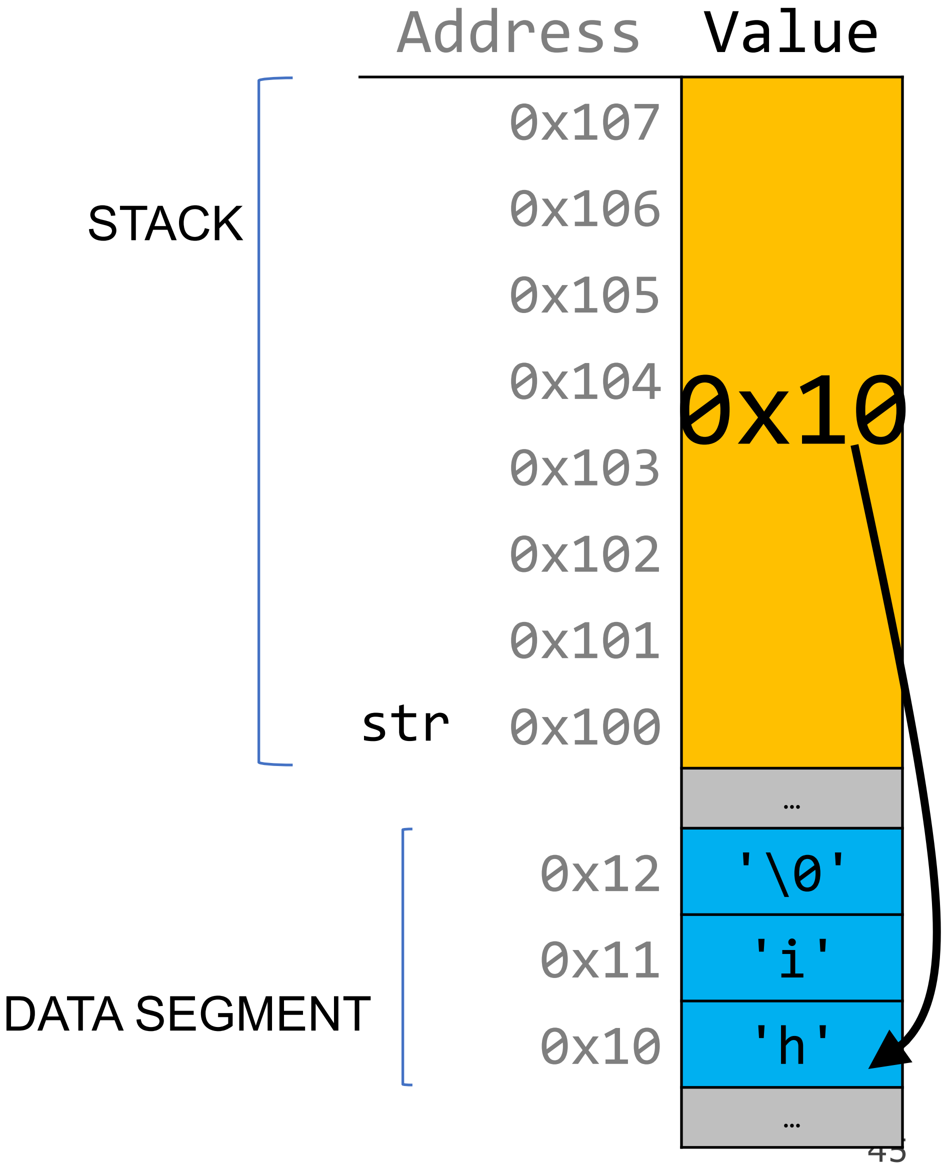
char *

When you declare a char pointer equal to a string literal, the string literal is *not* stored on the stack. Instead, it's stored in a special area of memory called the "Data segment". You *cannot modify memory in this segment*.

```
char *str = "hi";
```

The pointer variable (e.g. **str**) refers to the *address of the first character of the string in the data segment*. Since this variable is just a pointer, **sizeof** returns 8, no matter the total size of the string!

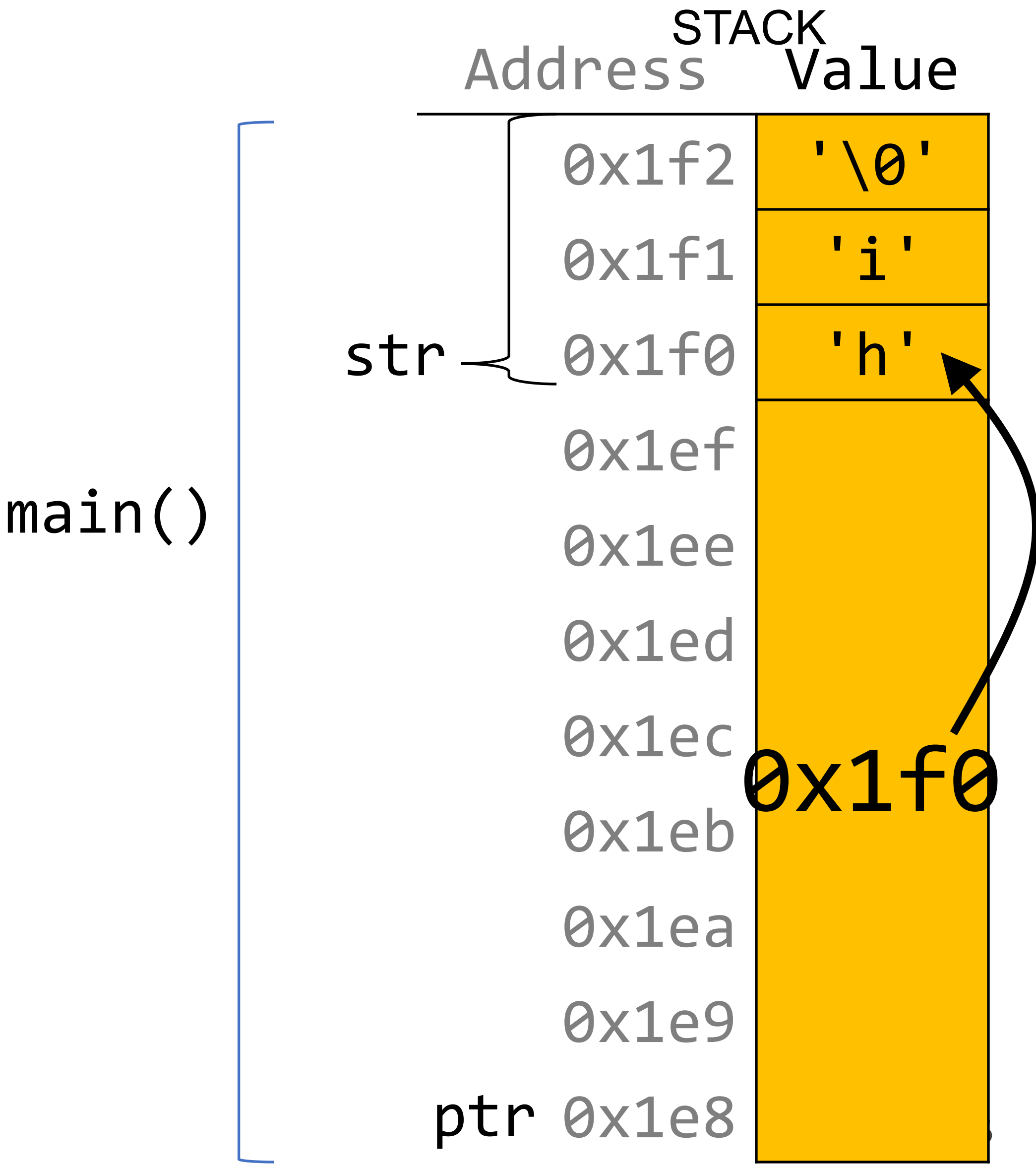
```
int stringBytes = sizeof(str);    // 8
```



Arrays and Pointers

You can also make a pointer equal to an array; it will point to the first element in that array.

```
int main(int argc, char *argv[]) {
     char str[] = "hi";
     char *ptr = str;
     ...
}
```



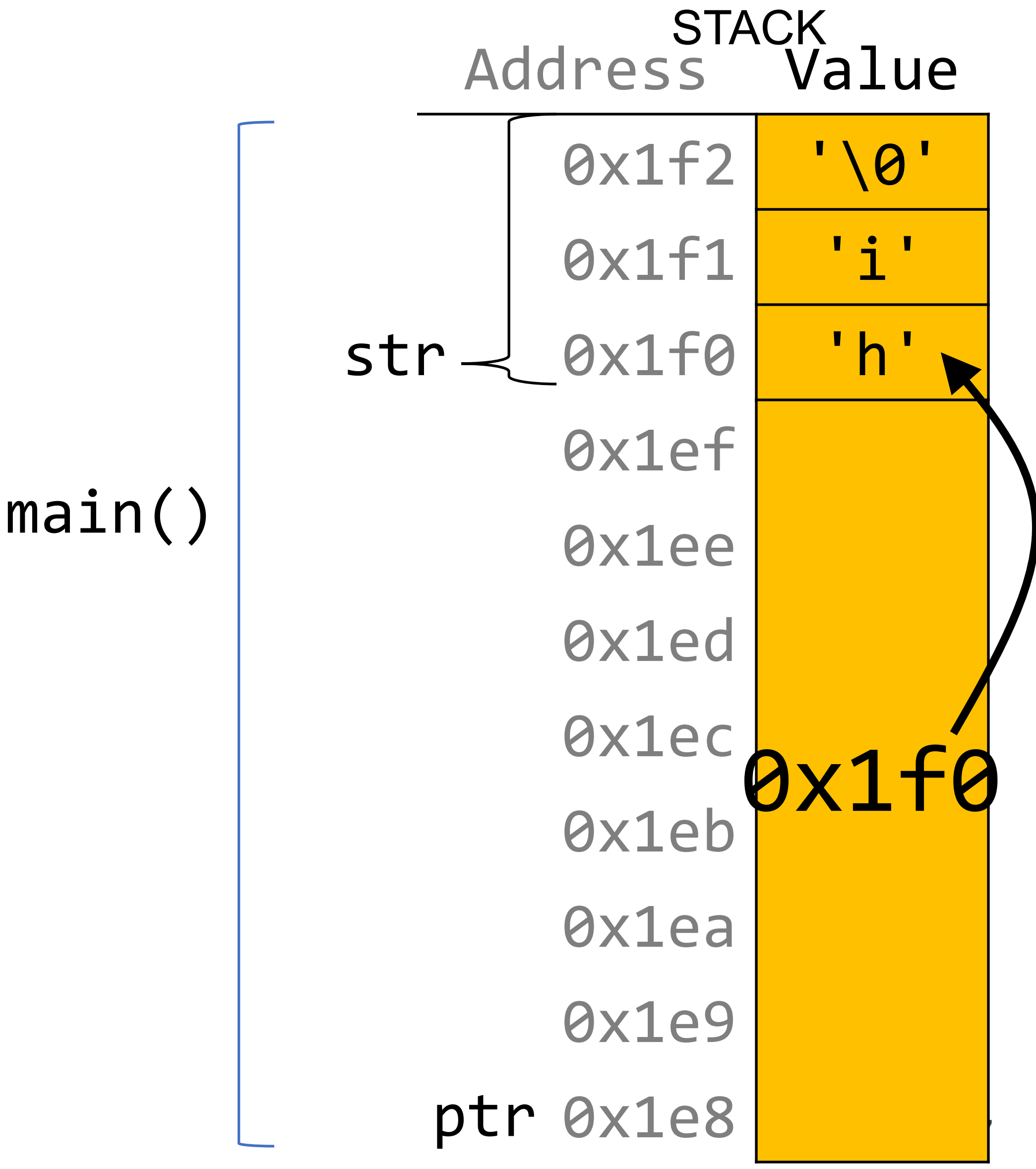
Arrays and Pointers

You can also make a pointer equal to an array; it will point to the first element in that array.

```
int main(int argc, char *argv[]) {
     char str[] = "hi";
     char *ptr = str;

     // equivalent
     char *ptr = &str[0];

     // equivalent, but avoid
     char *ptr = &str;
     ...
}
```



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Arrays Of Pointers

You can make an array of pointers to e.g. group multiple strings together:

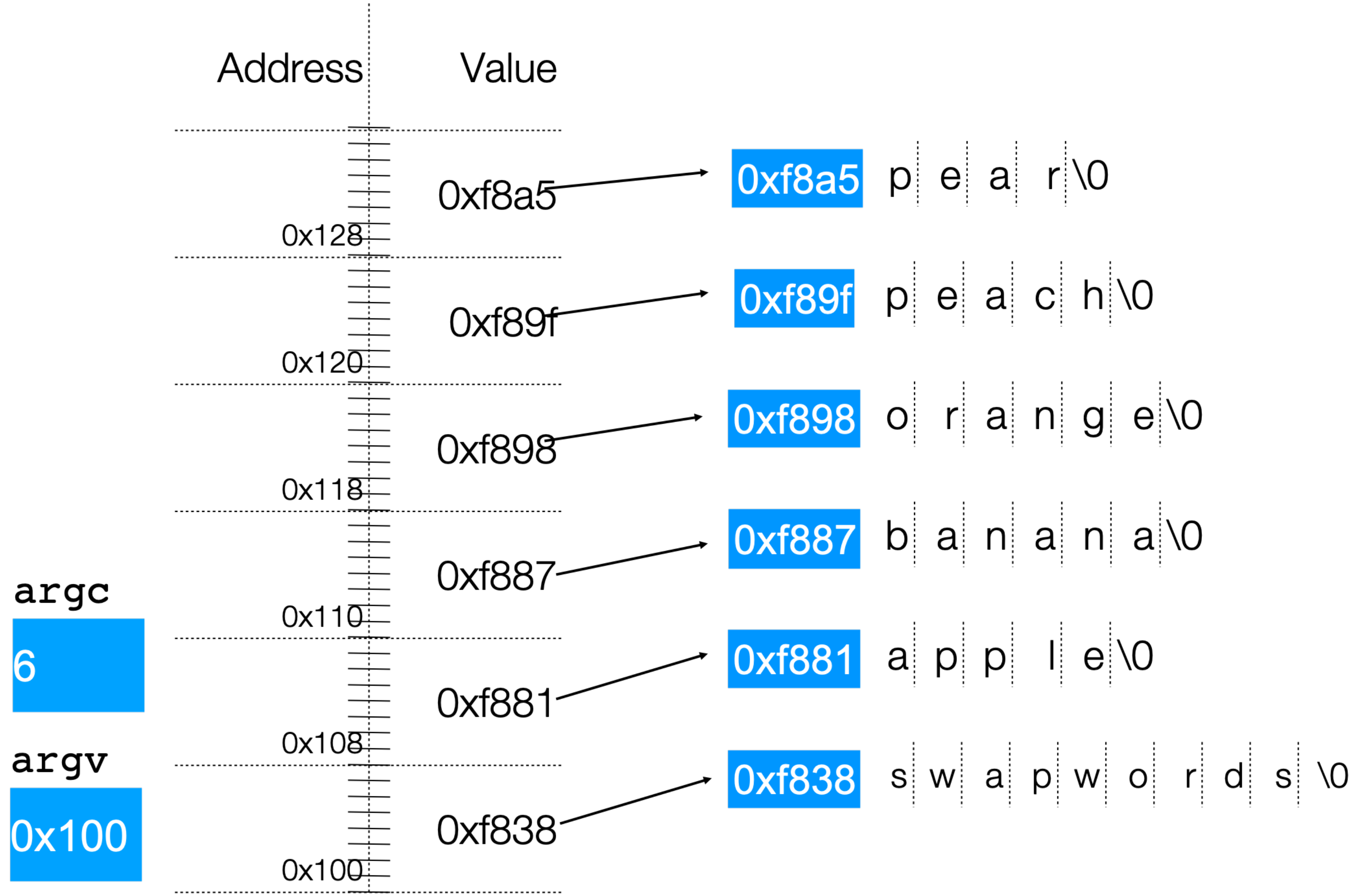
```
char *stringArray[5];   // space to store 5 char *s
```

This stores 5 **char *s**, *not* all of the characters for 5 strings!

```
char *str0 = stringArray[0];     // first char *
```

Arrays Of Pointers

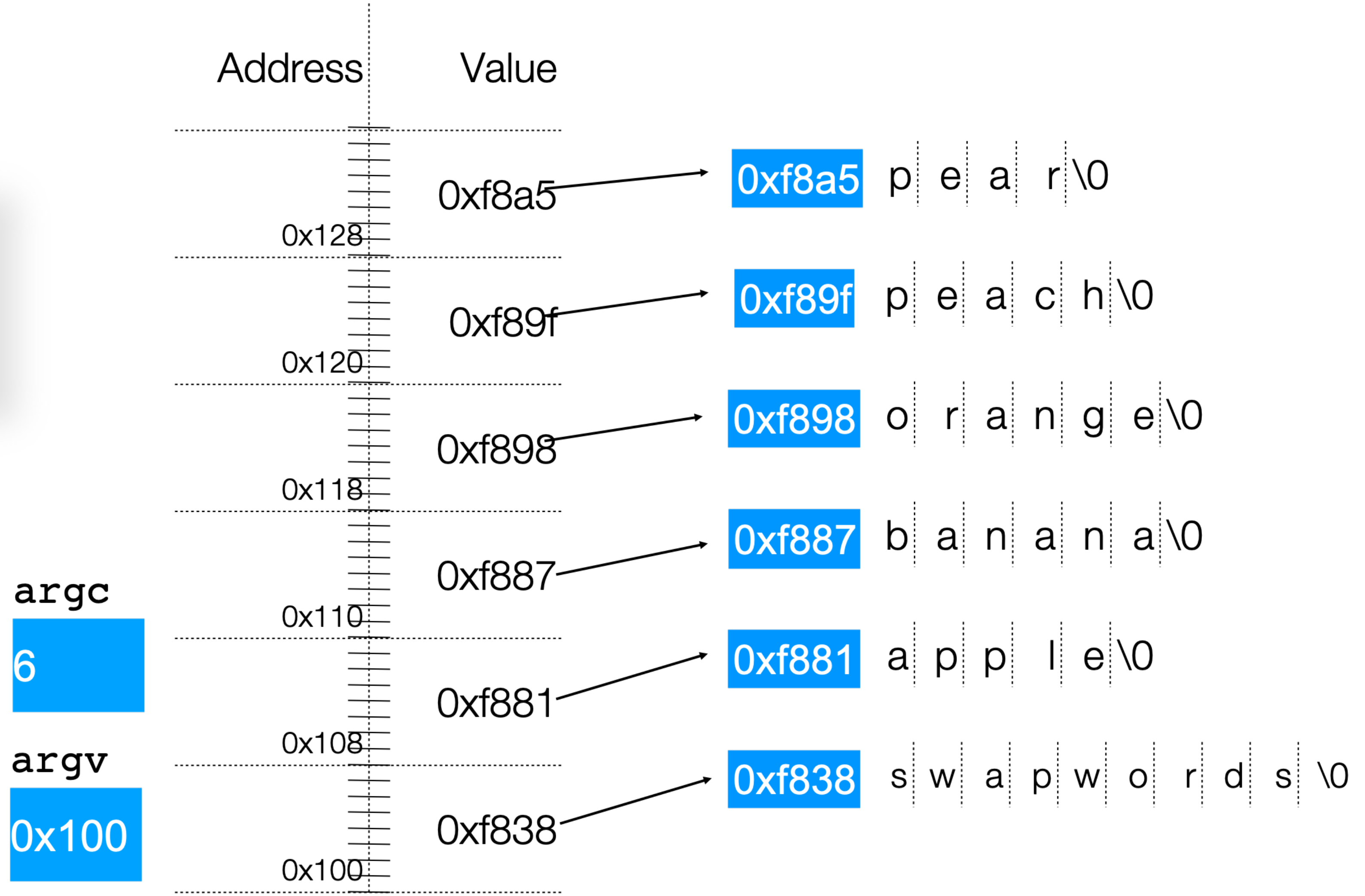
```
./swapwords apple banana orange peach pear
```



Arrays Of Pointers

```
./swapwords apple banana orange peach pear
```

What is the value of argv[2] in this diagram?



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Announcements

- Lab 2
- GPS Rollover Event

GPS Rollover

- GPS is linked to the US Naval Observatory clock for timekeeping by tracking the number of weeks since the beginning of August 21, 1999
- The “week number” counter is 10 bits long
- On April 6, 2019, it overflowed to 0!
- Not the first time this has happened – it happens every 1,024 weeks
- Most newer GPS receivers are programmed to handle this overflow, but old ones were not. Also, other old un-updated systems such as cell networks, electrical utilities, etc. use GPS receivers for timing. Uh oh!
- Modernization plan: increase the week counter to 13 bits (157.5 year max)
- More info: https://arstechnica.com/information-technology/2019/04/gps-rollover-event-on-april-6-could-have-some-side-effects/

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Pointer Arithmetic

When you do pointer arithmetic, you are adjusting the pointer by a certain *number of places* (e.g. characters).

```
char *str = "apple";    // e.g. 0xff0
char *str1 = str + 1;   // e.g. 0xff1
char *str3 = str + 3;   // e.g. 0xff3

printf("%s", str);      // apple
printf("%s", str1);     // pple
printf("%s", str3);     // le
```

DATA SEGMENT

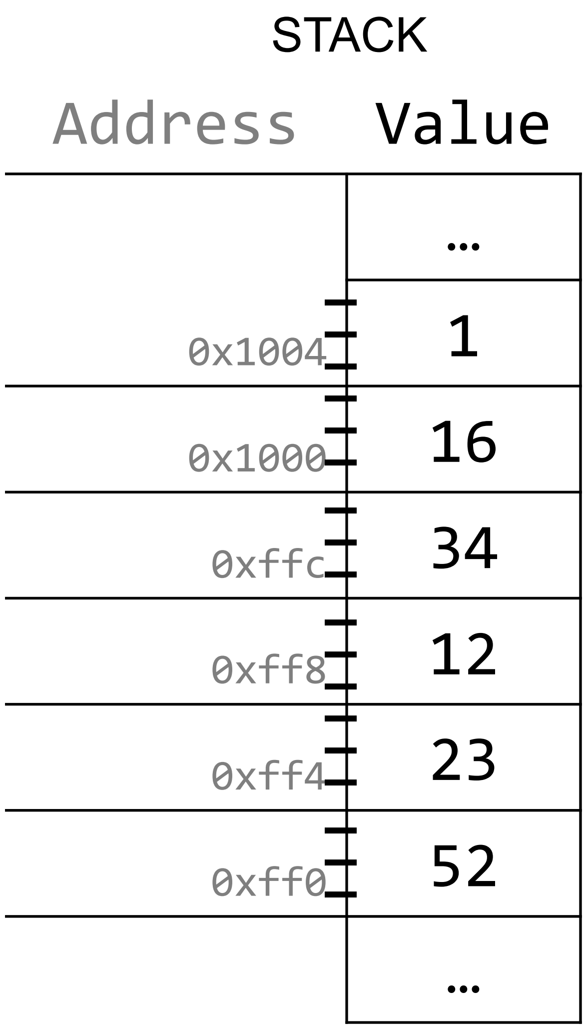
Address	Value
	…
0xff5	'\0'
0xff4	'e'
0xff3	'l'
0xff2	'p'
0xff1	'p'
0xff0	'a'
	…

Pointer Arithmetic

Pointer arithmetic does *not* work in bytes. Instead, it works in the *size of the type it points to*.

```
// nums points to an int array
int *nums = …             // e.g. 0xff0
int *nums1 = nums + 1;  // e.g. 0xff4
int *nums3 = nums + 3;  // e.g. 0xffc

printf("%d", *nums);    // 52
printf("%d", *nums1);   // 23
printf("%d", *nums3);   // 34
```

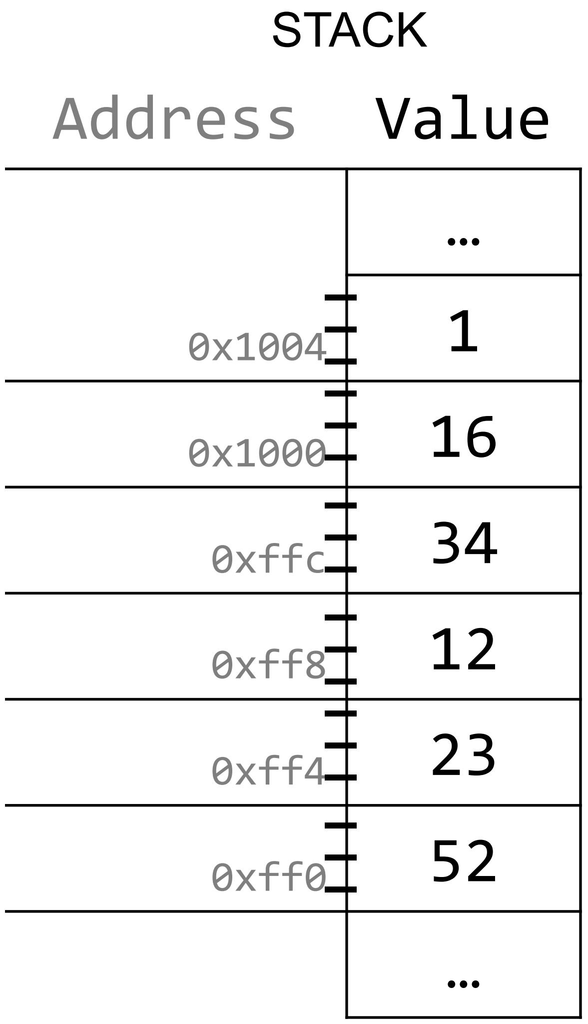


Pointer Arithmetic

Pointer arithmetic does *not* work in bytes. Instead, it works in the *size of the type it points to*.

```c
// nums points to an int array
int *nums = …               // e.g. 0xff0
int *nums3 = nums + 3; // e.g. 0xffc
int *nums2 = nums3 - 1;// e.g. 0xff8

printf("%d", *nums);    // 52
printf("%d", *nums2);   // 12
printf("%d", *nums3);   // 34
```



Pointer Arithmetic

When you use bracket notation with a pointer, you are actually *performing pointer arithmetic and dereferencing*:

```
char *str = "apple";    // e.g. 0xff0

// both of these add two places to str,
// and then dereference to get the char there.
// E.g. get memory at 0xff2.
char thirdLetter = str[2];        // 'p'
char thirdLetter = *(str + 2);   // 'p'
```

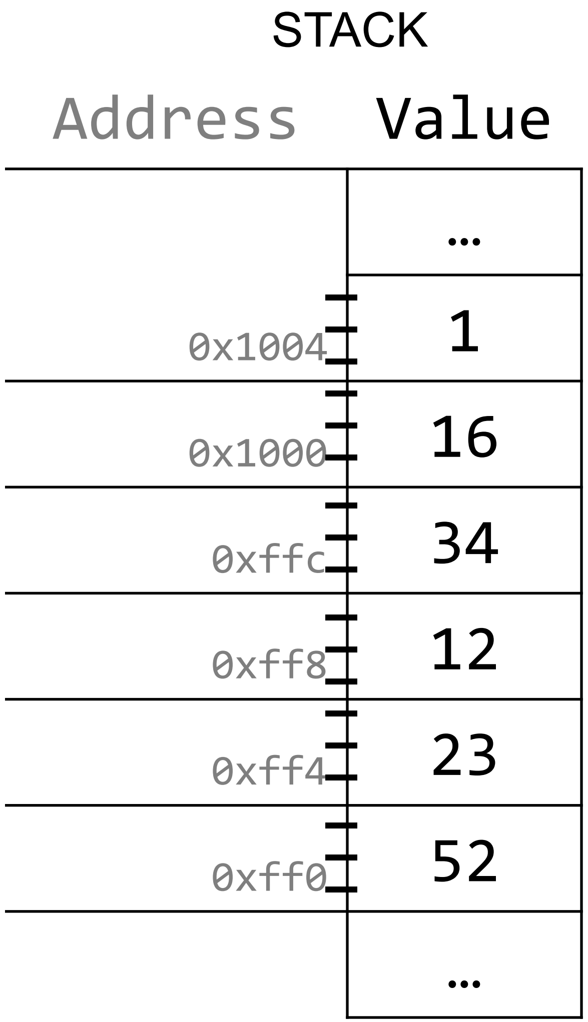
DATA SEGMENT

Address	Value
	…
0xff5	'\0'
0xff4	'e'
0xff3	'l'
0xff2	'p'
0xff1	'p'
0xff0	'a'
	…

Pointer Arithmetic

Pointer arithmetic with two pointers does *not* give the byte difference. Instead, it gives the number of *places* they differ by.

```
// nums points to an int array
int *nums = …                 // e.g. 0xff0
int *nums3 = nums + 3;        // e.g. 0xffc
int diff = nums3 - nums;      // 3
```



Pointer Arithmetic

How does the code know how many bytes it should look at once it visits an address?

```
int x = 2;
int *xPtr = &x;           // e.g. 0xff0

// How does it know to print out just the 4 bytes at xPtr?
printf("%d", *xPtr);     // 2
```

Pointer Arithmetic

How does the code know how many bytes it should add when performing pointer arithmetic?

```
int nums[] = {1, 2, 3};

// How does it know to add 4 bytes here?
int *intPtr = nums + 1;

char str[] = "CS107";

// How does it know to add 1 byte here?
char *charPtr = str + 1;
```

Pointer Arithmetic

- At compile time, C can figure out the sizes of different data types, and the sizes of what they point to.
- For this reason, when the program runs, it knows the correct number of bytes to address or add/subtract for each data type.

Plan For Today

- Pointers and Parameters
- Arrays in Memory
- Arrays of Pointers
- **Announcements**
- Pointer Arithmetic
- Other topics: **const**, **struct** and ternary

Const

- Use **const** to declare global constants in your program. This indicates the variable cannot change after being created.

```
const double PI = 3.1415;
const int DAYS_IN_WEEK = 7;

int main(int argc, char *argv[]) {
    …
    if (x == DAYS_IN_WEEK) {
        …
    }
    …
}
```

Const

- Use **const** with pointers to indicate that the data that is pointed to cannot change.

```
char str[] = "Hello";
const char *s = str;

// Cannot use s to change characters it points to
s[0] = 'h';
```

Const

Sometimes we use **const** with pointer parameters to indicate that the function will not / should not change what it points to. The actual pointer can be changed, however.

```
// This function promises to not change str's characters
int countUppercase(const char *str) {
	int count = 0;
	for (int i = 0; i < strlen(str); i++) {
		if (isupper(str[i])) {
			count++;
		}
	}
	return count;
}
```

Const

By definition, C gets upset when you set a **non-const** pointer equal to a **const** pointer. You need to be consistent with **const** to reflect what you cannot modify.

```
// This function promises to not change str's characters
int countUppercase(const char *str) {
	// compiler warning and error
	char *strToModify = str;
	strToModify[0] = …
}
```

Const

By definition, C gets upset when you set a **non-const** pointer equal to a **const** pointer. You need to be consistent with **const** to reflect what you cannot modify. **Think of const as part of the variable type**.

```
// This function promises to not change str’s characters
int countUppercase(const char *str) {
    const char *strToModify = str;
    strToModify[0] = …
}
```

Const

const can be confusing to interpret in some variable types.

```
// cannot modify this char
const char c = 'h';

// cannot modify chars pointed to by str
const char *str = …

// cannot modify chars pointed to by *strPtr
const char **strPtr = …
```

Structs

A *struct* is a way to define a new variable type that is a group of other variables.

```
struct date {            // declaring a struct type
    int month;
    int day;             // members of each date structure
};
…

struct date today;                      // construct structure instances
today.month = 1;
today.day = 28;

struct date new_years_eve = {12, 31};   // shorter initializer syntax
```

Structs

Wrap the struct definition in a **typedef** to avoid having to include the word **struct** every time you make a new variable of that type.

```
typedef struct date {
    int month;
    int day;
} date;
…

date today;
today.month = 1;
today.day = 28;

date new_years_eve = {12, 31};
```

Structs

If you pass a struct as a parameter, like for other parameters, C passes a **copy** of the entire struct.

```
void advance_day(date d) {
	d.day++;
}

int main(int argc, char *argv[]) {
	date my_date = {1, 28};
	advance_day(my_date);
	printf("%d", my_date.day); // 28
	return 0;
}
```

Structs

If you pass a struct as a parameter, like for other parameters, C passes a **copy** of the entire struct.   **Use a pointer to modify a specific instance.**

```
void advance_day(date *d) {
      (*d).day++;
}

int main(int argc, char *argv[]) {
      date my_date = {1, 28};
      advance_day(&my_date);
      printf("%d", my_date.day); // 29
      return 0;
}
```

Structs

The **arrow** operator lets you access the field of a struct pointed to by a pointer.

```
void advance_day(date *d) {
	d->day++;
}

int main(int argc, char *argv[]) {
	date my_date = {1, 28};
	advance_day(&my_date);
	printf("%d", my_date.day); // 29
	return 0;
}
```

Structs

C allows you to return structs from functions as well. It returns whatever is contained within the struct.

```
date create_new_years_date() {
     date d = {1, 1};
    return d;         // or return (date){1, 1};
}

int main(int argc, char *argv[]) {
     date my_date = create_new_years_date();
     printf("%d", my_date.day); // 1
     return 0;
}
```

Structs

sizeof gives you the entire size of a struct, which is the sum of the sizes of all its contents.

```
typedef struct date {
      int month;
      int day;
  } date;

int main(int argc, char *argv[]) {
      int size = sizeof(date);   // 8
      return 0;
}
```

Arrays of Structs

You can create arrays of structs just like any other variable type.

```
typedef struct my_struct {
    int x;
    char c;
} my_struct;

…

my_struct array_of_structs[5];
```

Arrays of Structs

To initialize an entry of the array, you must use this special syntax to confirm the type to C.

```
typedef struct my_struct {
     int x;
     char c;
} my_struct;

…

my_struct array_of_structs[5];
array_of_structs[0] = (my_struct){0, 'A'};
```

Arrays of Structs

You can also set each field individually.

```
typedef struct my_struct {
    int x;
    char c;
} my_struct;

…
my_struct array_of_structs[5];
array_of_structs[0].x = 2;
array_of_structs[0].c = 'A';
```

Ternary Operator

The ternary operator is a shorthand for using if/else to evaluate to a value.

```
condition ? expressionIfTrue : expressionIfFalse
```

```
int x;
if (argc > 1) {
     x = 50;
} else {
     x = 0;
}

// equivalent to
int x = argc > 1 ? 50 : 0;
```

Recap

- Pointers and Parameters
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- Arrays of Pointers
- **Announcements**
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Next time: dynamically allocated memory