CS107 Spring 2019, Lecture 5
More C Strings

Reading: K&R (1.6, 5.5, Appendix B3) or Essential C section 3

Plan For Today

- **Recap:** String Operations
- **Demo:** Buffer Overflow and Valgrind
- Arrays of Strings
- **Practice:** Password Verification
- Pointers
- **Announcements**
- Strings in Memory
- Pointers to Strings

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C Strings

C strings are arrays of characters, ending with a **null-terminating character** '\0'.

index	*0*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*
value	`'H'`	`'e'`	`'l'`	`'l'`	`'o'`	`','`	`' '`	`'w'`	`'o'`	`'r'`	`'l'`	`'d'`	`'!'`	`'\0'`

String operations such as `strlen` use the null-terminating character to find the end of the string.

Common `string.h` Functions

Function	Description
`strlen(`***str***`)`	returns the # of chars in a C string (before null-terminating character).

`strcmp(`***str1, str2***`),`
`strncmp(`***str1, str2, n***`)`
	compares two strings; returns 0 if identical, <0 if ***str1*** comes before ***str2*** in alphabet, >0 if ***str1*** comes after ***str2*** in alphabet. ***strncmp*** stops comparing after at most ***n*** characters.

`strchr(`***str, ch***`)`
`strrchr(`***str, ch***`)`
	character search: returns a pointer to the first occurrence of ***ch*** in ***str***, or ***NULL*** if ***ch*** was not found in ***str***. `strrchr` find the last occurrence.

`strstr(`***haystack, needle***`)`	string search: returns a pointer to the start of the first occurrence of ***needle*** in ***haystack***, or ***NULL*** if ***needle*** was not found in ***haystack***.

`strcpy(`***dst, src***`),`
`strncpy(`***dst, src, n***`)`
	copies characters in ***src*** to ***dst***, including null-terminating character. Assumes enough space in ***dst***. Strings must not overlap. **`strncpy`** stops after at most ***n*** chars, and does not add null-terminating char.

`strcat(`***dst, src***`),`
`strncat(`***dst, src, n***`)`
	concatenate ***src*** onto the end of ***dst***. **`strncat`** stops concatenating after at most ***n*** characters. Always adds a null-terminating character.

`strspn(`***str, accept***`),`
`strcspn(`***str, reject***`)`
	`strspn` returns the length of the initial part of ***str*** which contains only characters in ***accept***. **`strcspn`** returns the length of the initial part of ***str*** which does not contain any characters in ***reject***.

C Strings As Parameters

When you pass a string as a parameter, it is passed as a **char ***. You can still operate on the string the same way as with a char[]. (*We'll see how today!)*.

```
int doSomething(char *str) {
    char secondChar = str[1];
    ...
}

// can also write this, but it is really a pointer
int doSomething(char str[]) { ...
```

Buffer Overflows

- It is your responsibility to ensure that memory operations you perform don’t improperly read or write memory.
  - E.g. don’t copy a string into a space that is too small!
  - E.g. don’t ask for the string length of an uninitialized string!
- The **Valgrind** tool may be able to help track down memory-related issues.
  - See cs107.stanford.edu/resources/valgrind
  - We’ll talk about Valgrind more when we talk about dynamically-allocated memory.

Demo: Memory Errors

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Arrays of Strings

You can make an array of strings to group multiple strings together:

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

You can also use the following shorthand to initialize a string array:

```
char *stringArray[] = {
     "my string 1",
     "my string 2",
     "my string 3"
};
```

Arrays of Strings

You can access each string using bracket syntax:

```
printf("%s\n", stringArray[0]);  // print out first string
```

When an array of strings is passed as a parameter, it is passed as a *pointer to the first element of the string array*. This is what **argv** is in **main**! This means you write the parameter type as:

```
void myFunction(char **stringArray) {

// equivalent to this, but it is really a double pointer
void myFunction(char *stringArray[]) {
```

Practice: Password Verification

Write a function **verifyPassword** that accepts a candidate password and certain password criteria, and returns whether the password is valid.

```
bool verifyPassword(char *password, char *validChars, char
*badSubstrings[], int numBadSubstrings);
```

password is valid if it contains only letters in **validChars**, and does not contain any substrings in **badSubstrings**.

Practice: Password Verification

```
bool verifyPassword(char *password, char *validChars, char
*badSubstrings[], int numBadSubstrings);
```

Example:

```
char *invalidSubstrings[] = { "1234" };

bool valid = verifyPassword("1572", "0123456789",
         invalidSubstrings, 1);      // true
bool valid = verifyPassword("141234", "0123456789",
         invalidSubstrings, 1);      // false
```

Practice: Password Verification

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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.

Pointers

```
int x = 2;

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

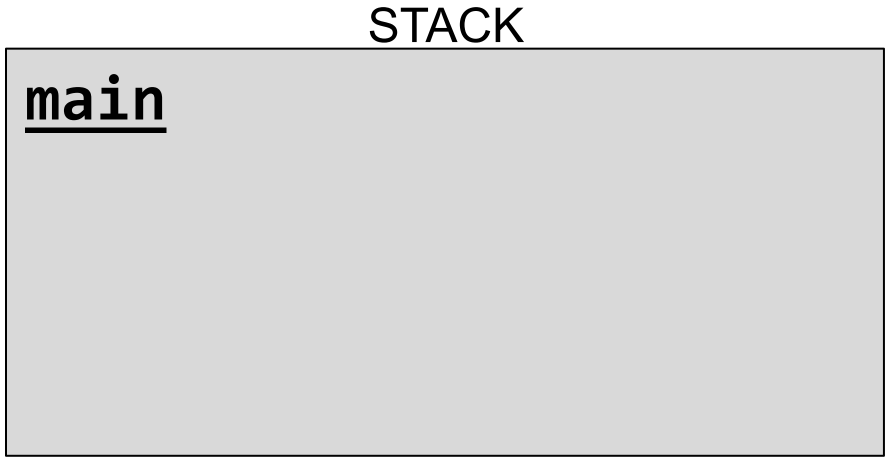
// Dereference the pointer to go to that address.
// (* means "dereference")
printf("%d", *xPtr);    // prints 2
```

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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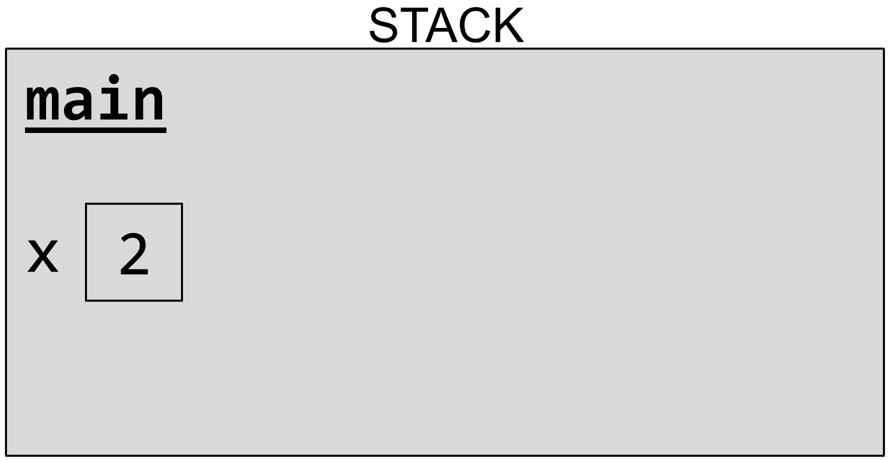
     ...
}
```



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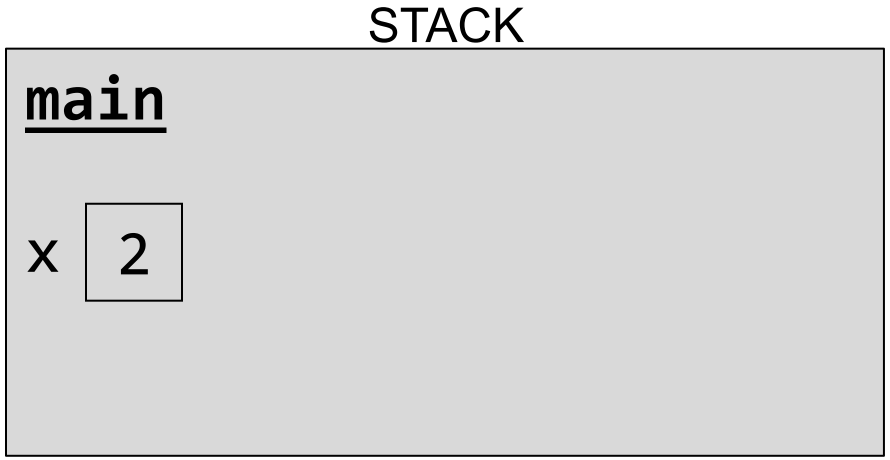
     ...
}
```



STACK

main

x 2

Pointers

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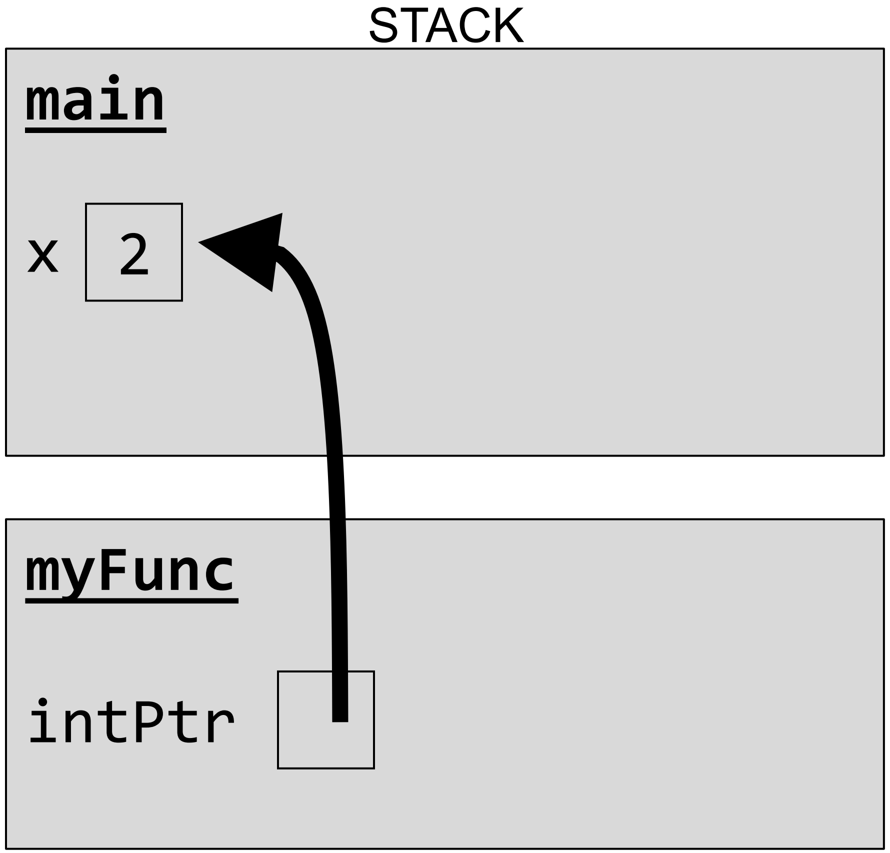
     ...
}
```



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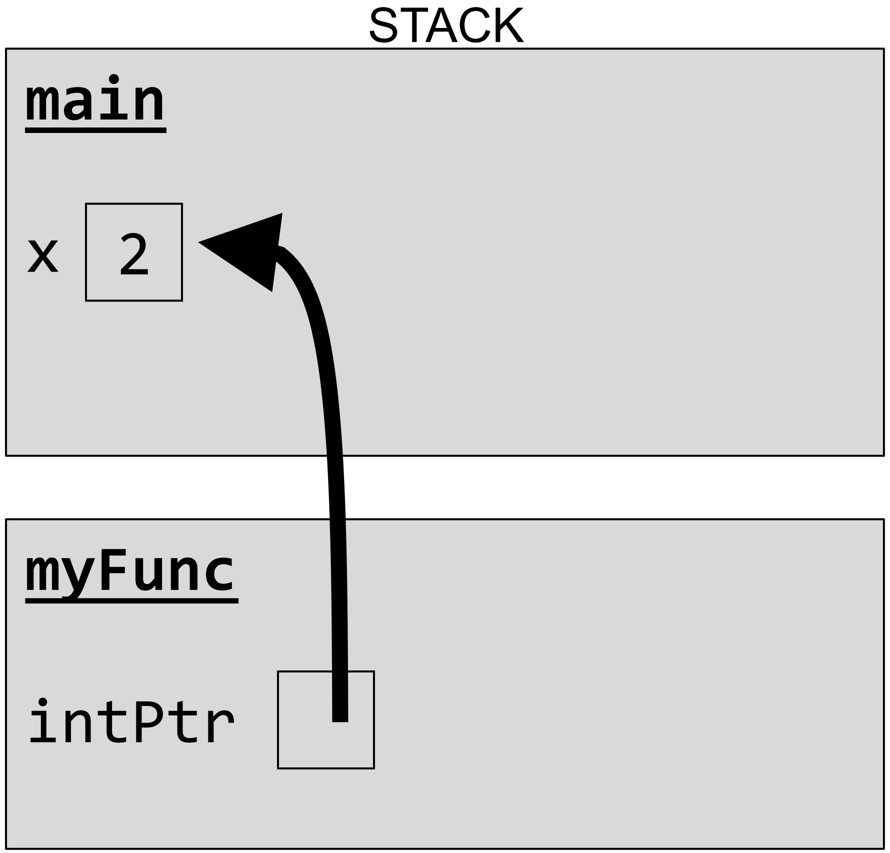

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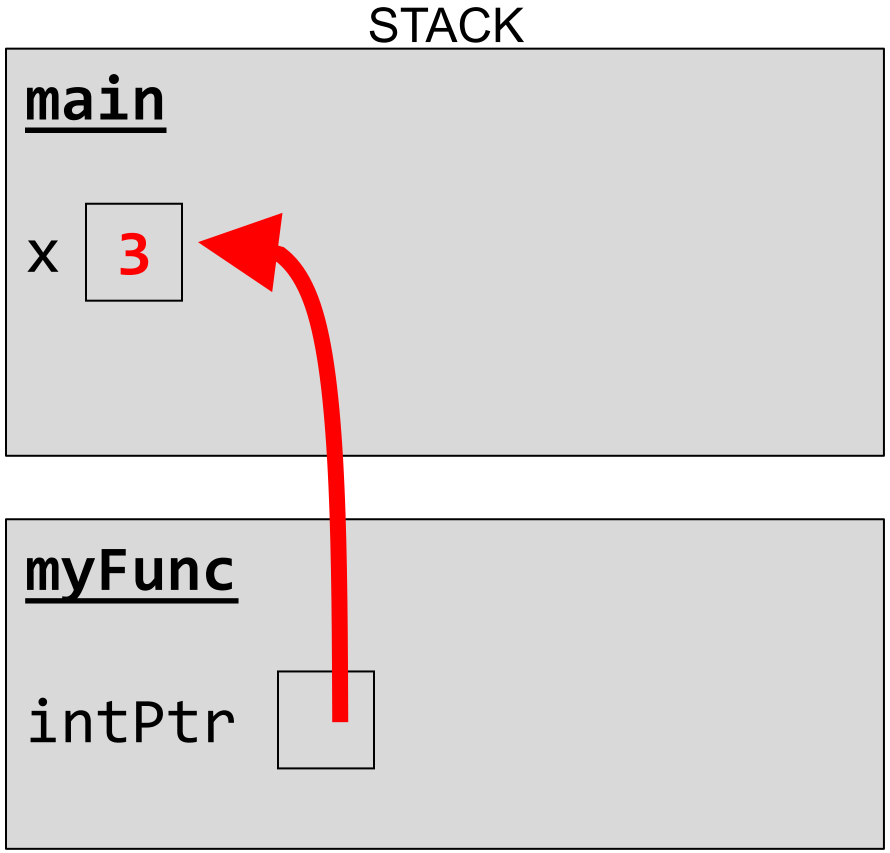

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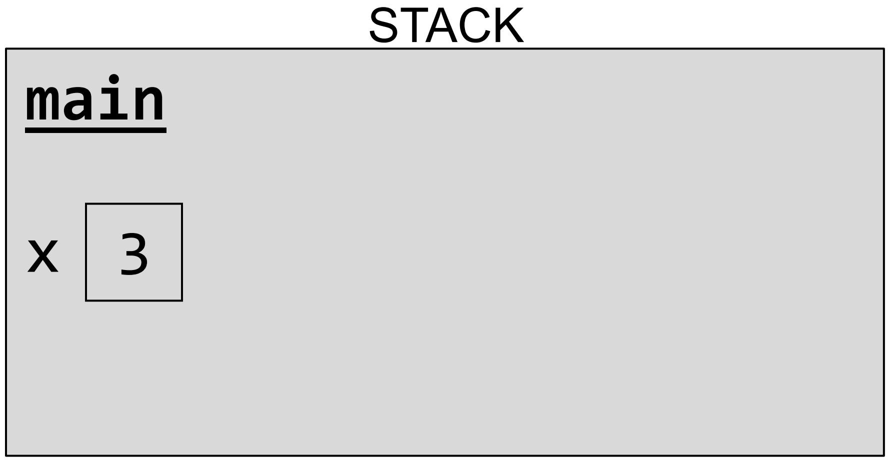

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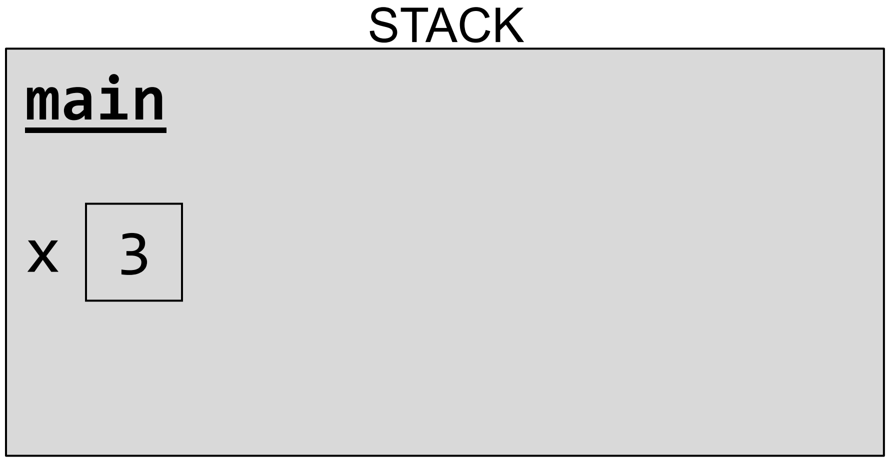

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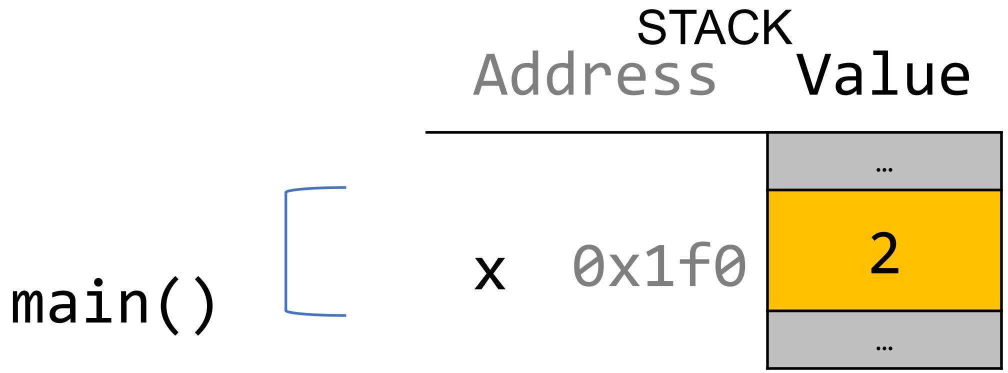

STACK

Address Value

…

main() x 0x1f0 2

…

Pointers

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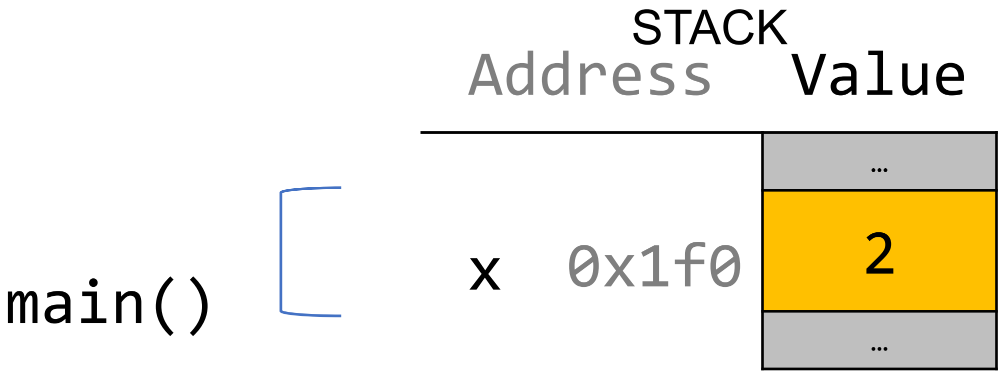
     ...
}
```



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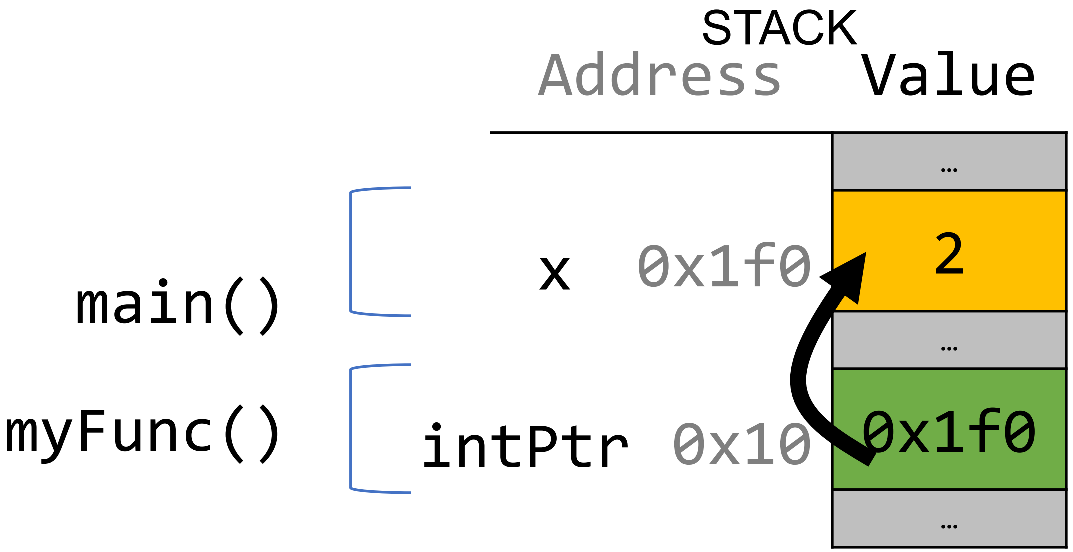

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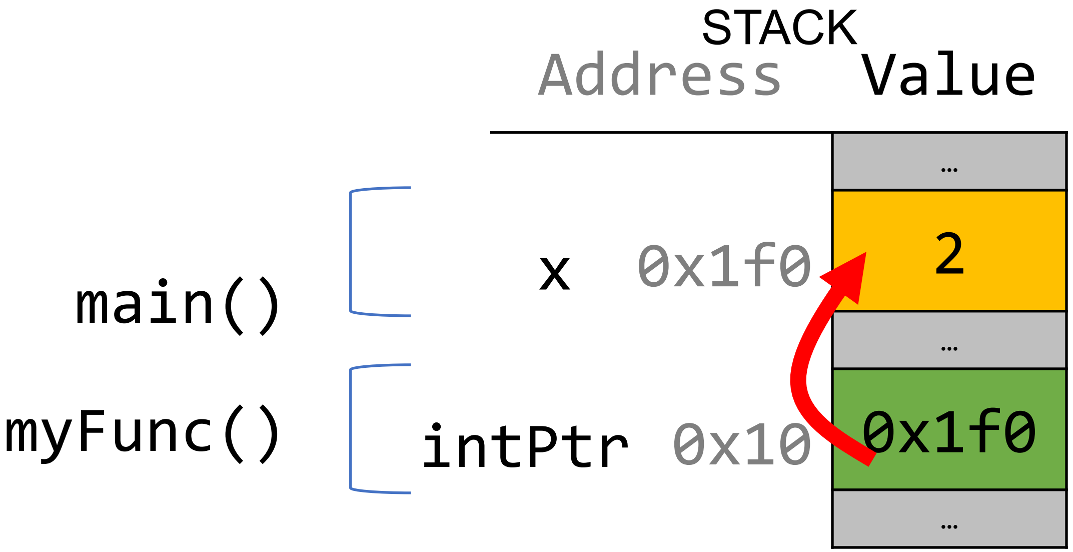
```



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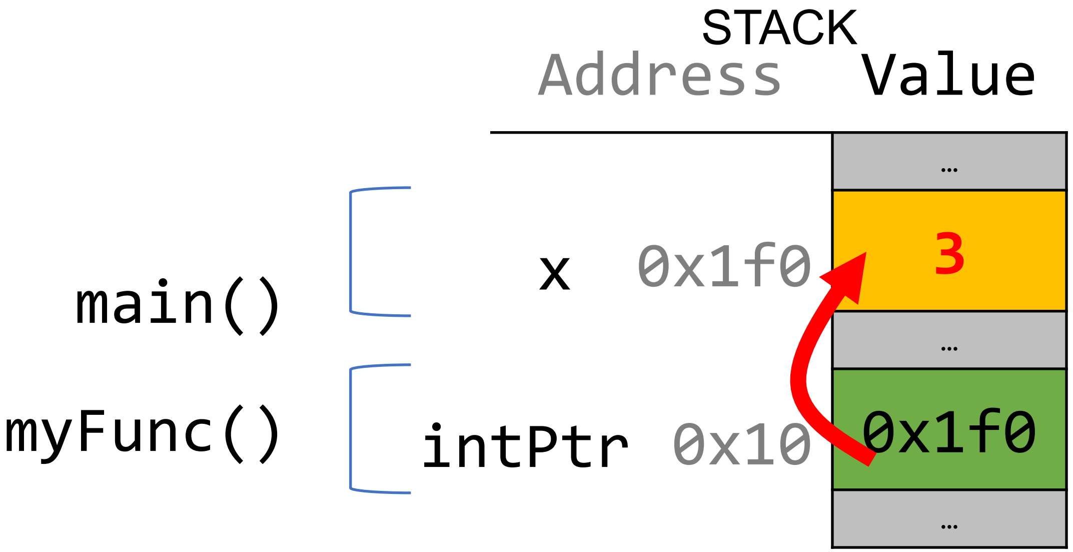

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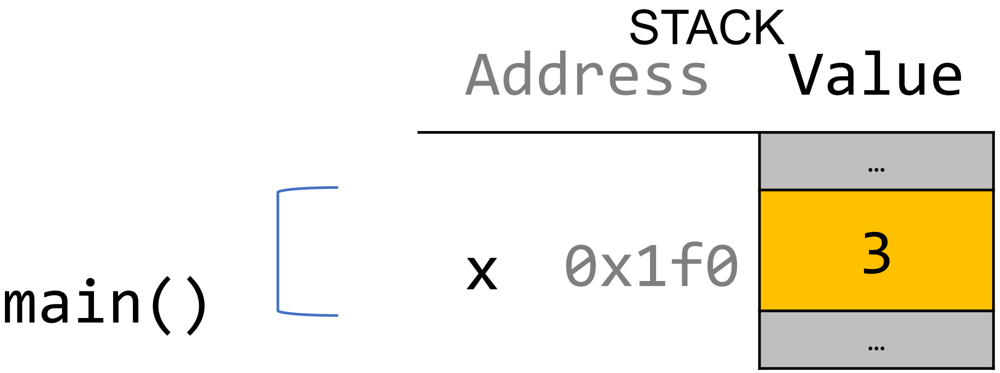

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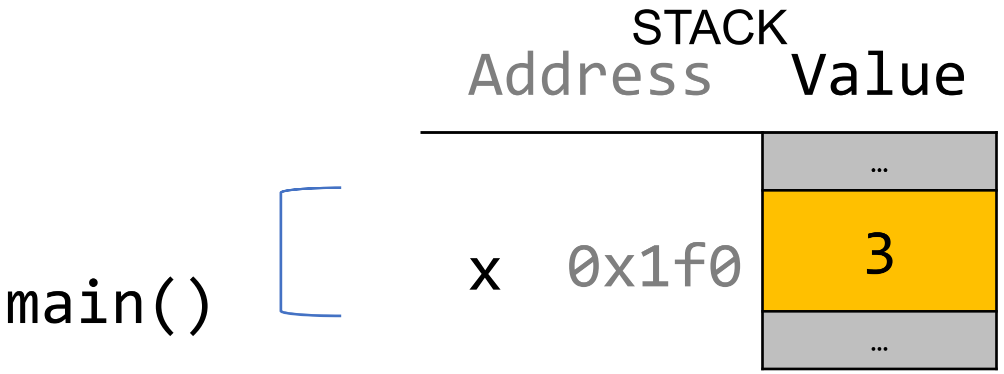


STACK

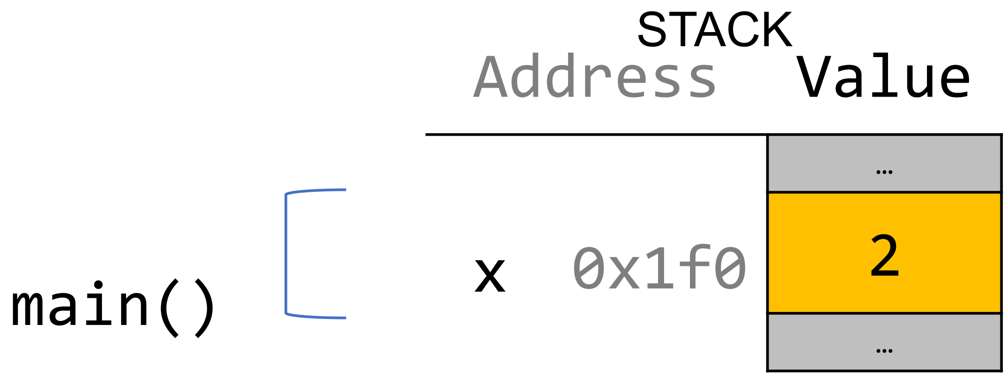
	Address	Value
		…
x	0x1f0	3
		…

Pointers

Without pointers, we would make copies.

```
void myFunc(int val) {
     val = 3;
}

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



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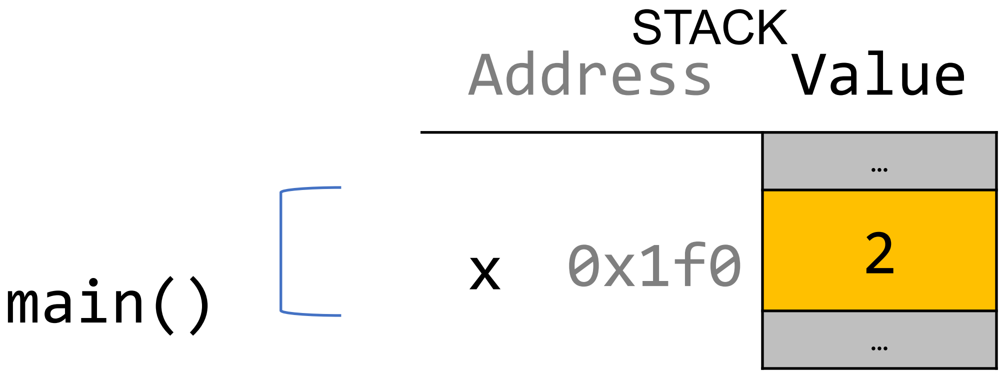

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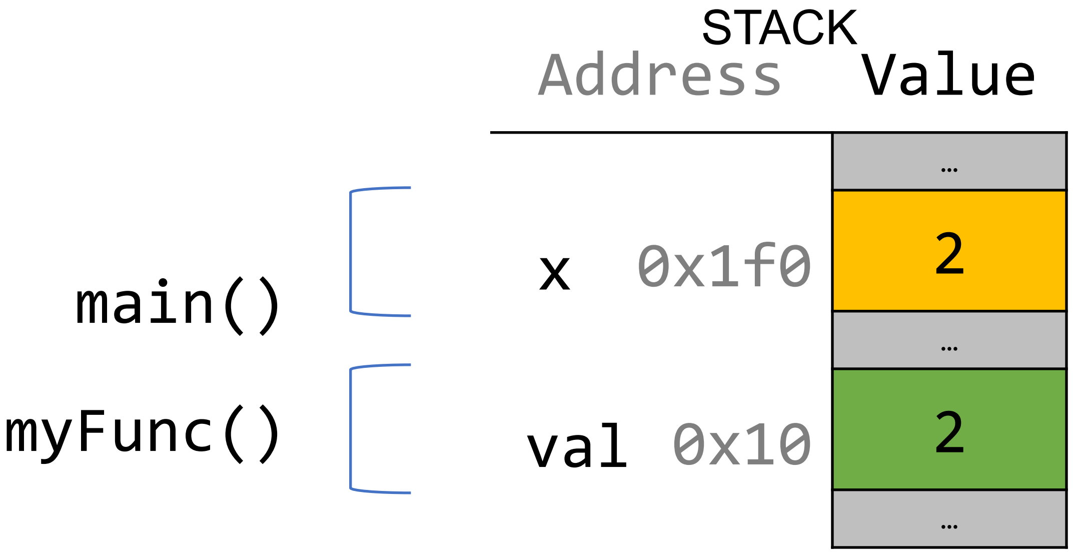
     ...
}
```



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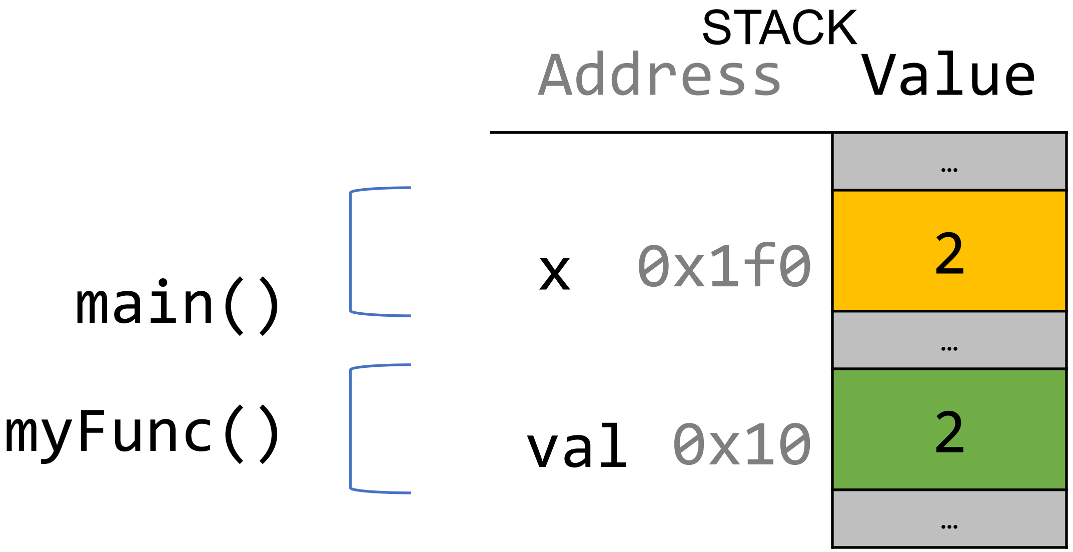

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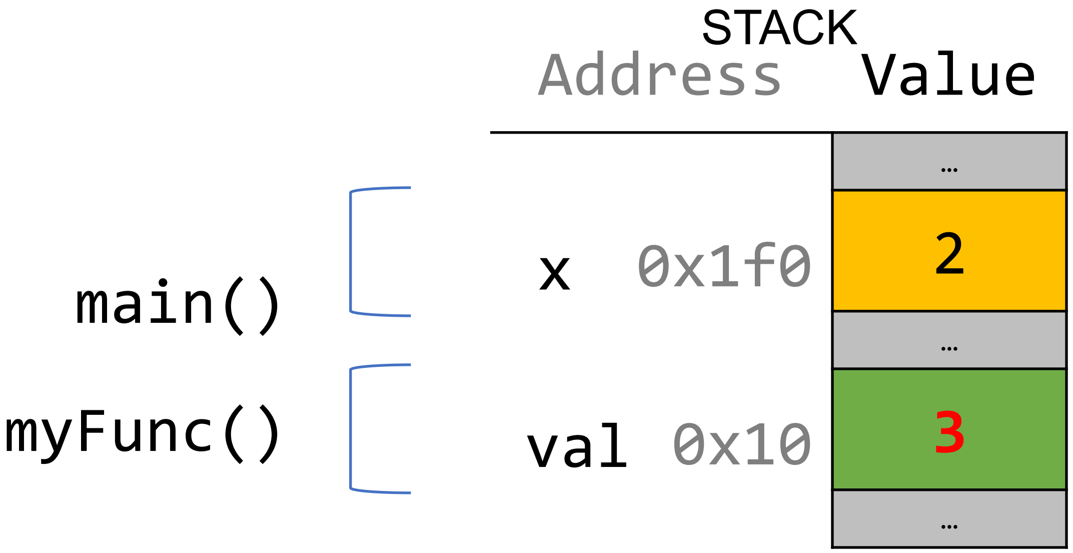
     ...
}
```



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}

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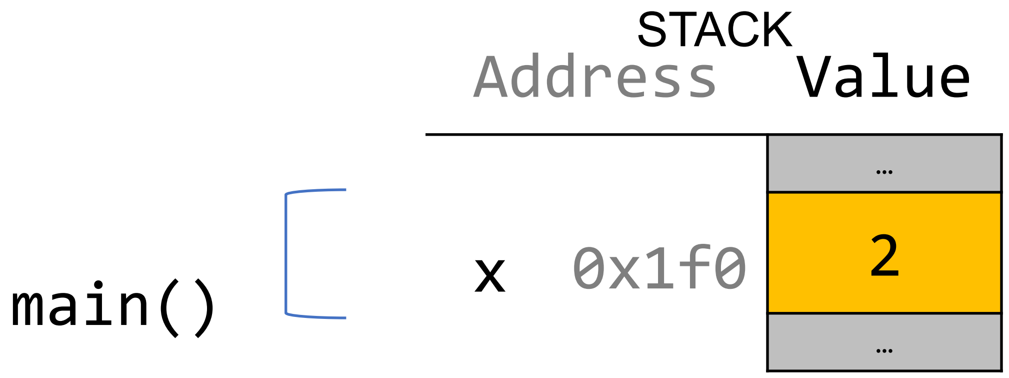
     myFunc(x);
     printf("%d", x);    // 2!
     ...
}
```



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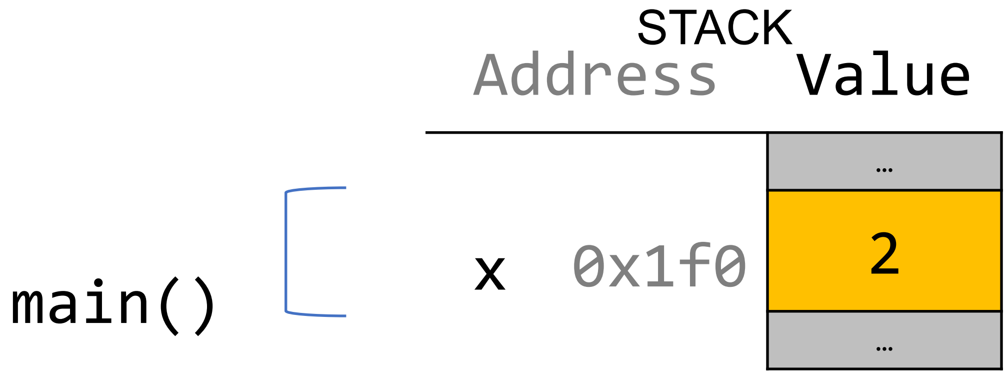
     printf("%d", x);    // 2!
     ...
}
```



STACK

Address Value

…

main() x 0x1f0 2

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Announcements

- Assignment 0 grades released this afternoon
- Assignment 1 due Monday 4/15 11:59PM PST
    - Grace period until Wed. 4/17 11:59PM PST
- Lab 2: C strings practice
- Assignment 2 released at Assignment 1 due date
    - Due Mon. 4/22 11:59PM PST, grace period until Wed. 4/24 11:59PM PST
    - Programs using C strings

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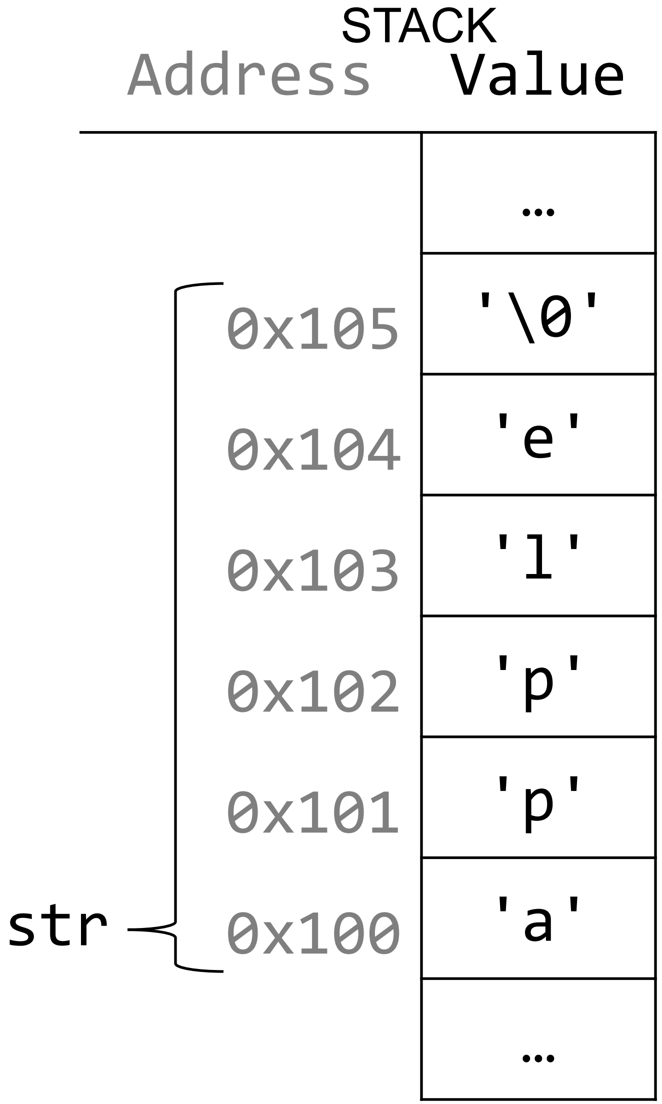
Character Arrays

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

```
char str[6] = "apple";
```



STACK

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

Character Arrays

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

```
char str[6] = "apple";
char str2[8] = "apple 2";
str = str2;   // not allowed!
```

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

char *

There is another convenient way to create a string if you do not need to modify it later. You can create a char * and set it directly equal to a string literal.

```
char *myString = "Hello, world!";
char *empty = "";

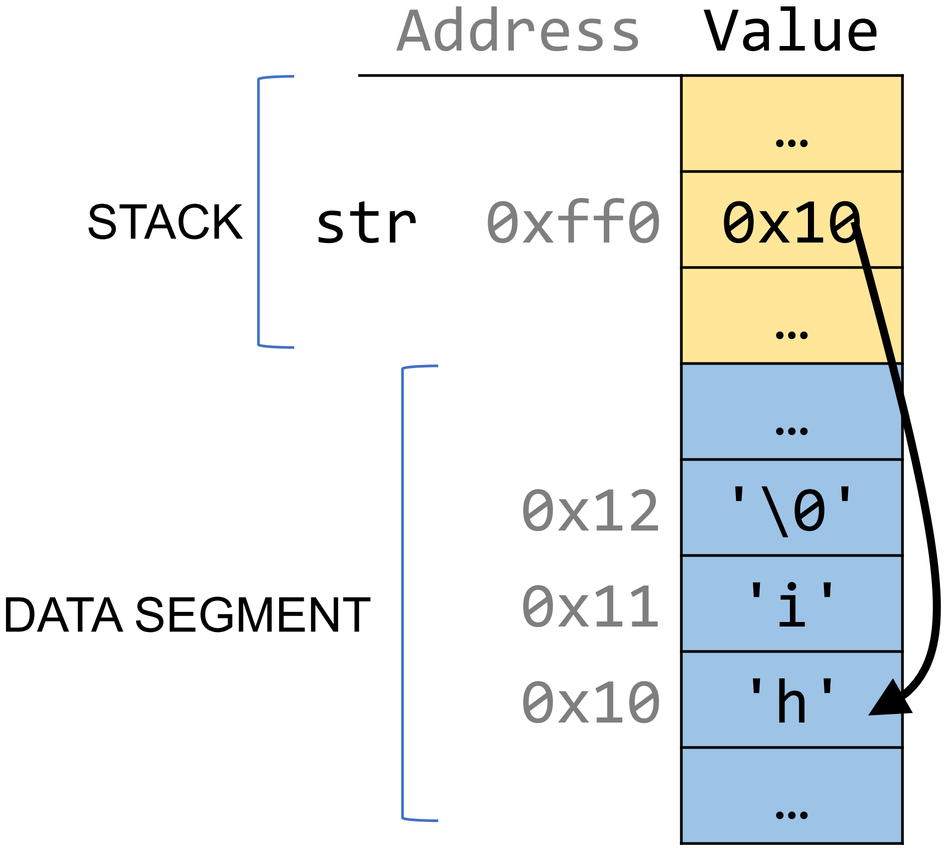
~~myString[0] = 'h';~~                 // crashes!
printf("%s", myString);            // Hello, world!
```

char *

When you declare a char pointer equal to a string literal, the characters are *not* stored on the stack. Instead, they are 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*.



char *

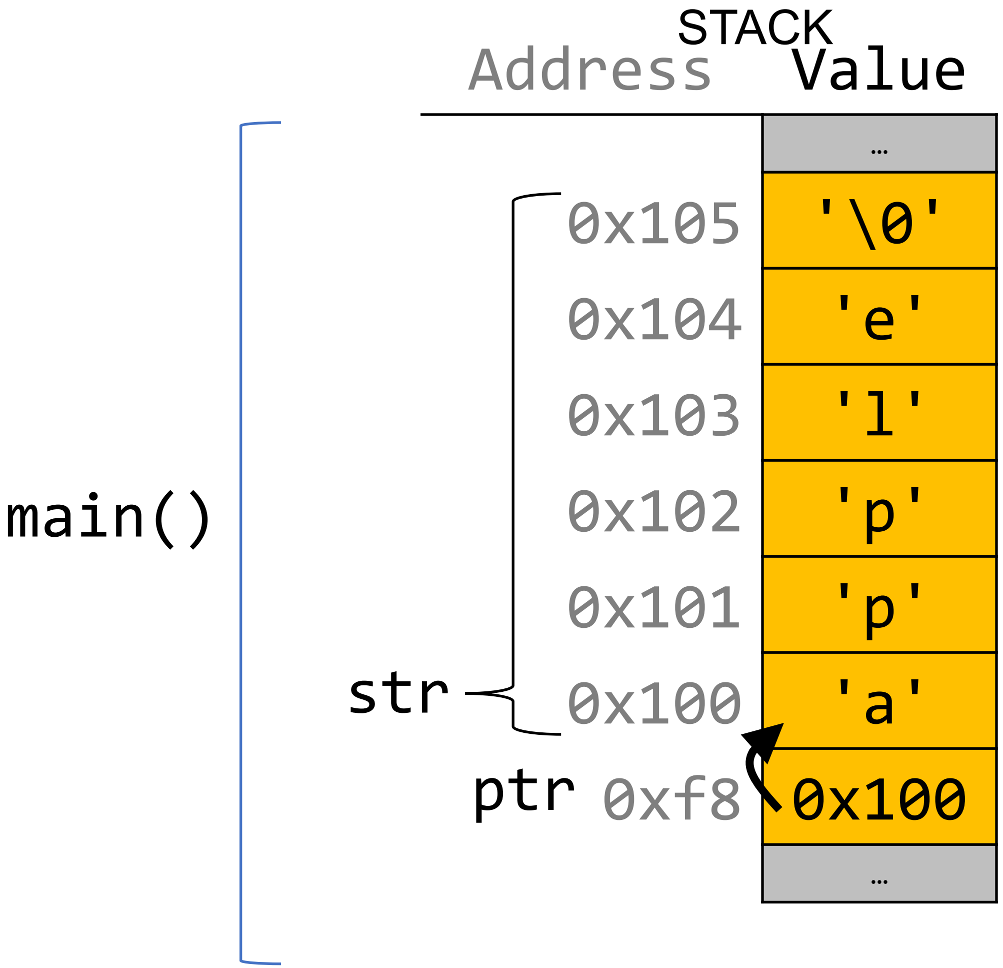
A **char *** variable refers to a single character. You can reassign an existing **char *** pointer to be equal to another **char *** pointer.

```
char *str = "apple";         // e.g. 0xfff0
char *str2 = "apple 2";      // e.g. 0xfe0
str = str2;   // ok!  Both store address 0xfe0
```

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[6] = "apple";
     char *ptr = str;
     ...
}
```



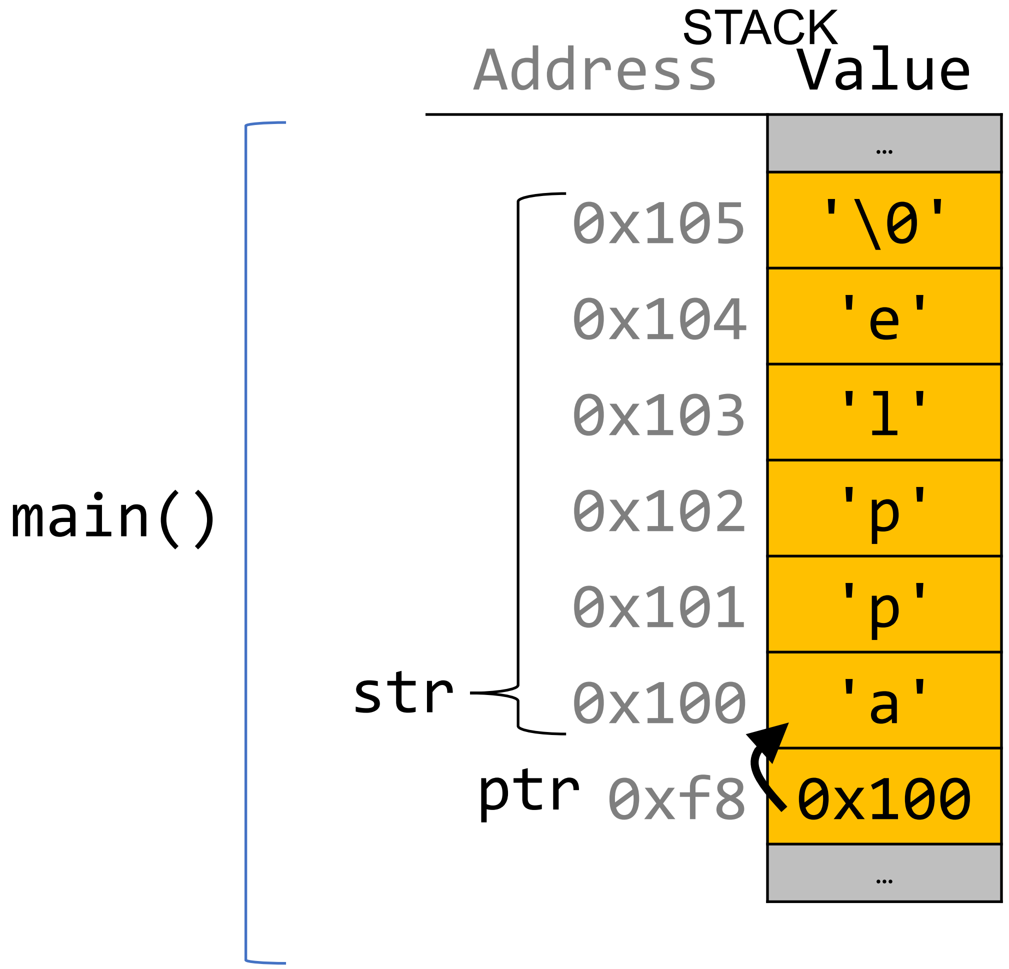
Arrays and Pointers

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[6] = "apple";
      char *ptr = str;

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

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



STACK

		Address	Value
main()			…
		0x105	'\0'
		0x104	'e'
		0x103	'l'
		0x102	'p'
		0x101	'p'
	str	0x100	'a'
	ptr	0xf8	0x100
			…

sizeof

- A char **array** is not a pointer; it refers to the entire array contents. In fact, **sizeof** returns the size of the entire array!

```
char str[] = "Hello";
int arrayBytes = sizeof(str);    // 6
```

- A char **pointer** refers to the address of a single character. Since this variable is just a pointer, **sizeof** returns 8, no matter the total size of the string!

```
char *str = "Hello";
int stringBytes = sizeof(str);   // 8
```

Pointer Arithmetic

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

```
char *str = "apple";    // e.g. 0xff0
char *str2 = str + 1;   // e.g. 0xff1
char *str3 = str + 3;   // e.g. 0xff3

printf("%s", str);      // apple
printf("%s", str2);     // pple
printf("%s", str3);     // le
```

TEXT SEGMENT

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

Pointer Arithmetic

Pointer arithmetic does *not* add bytes. Instead, it adds the *size of the type it points to*.

```
// nums points to an int array
int *nums = …             // e.g. 0xff0
int *nums2 = nums + 1;  // e.g. 0xff4
int *nums3 = nums + 3;  // e.g. 0xffc

printf("%d", *nums);    // 52
printf("%d", *nums2);   // 23
printf("%d", *nums3);   // 34
```

STACK

Address	Value
	…
0x1004	1
0x1000	16
0xffc	34
0xff8	12
0xff4	23
0xff0	52
	…

char *

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 three places to str,
// and then dereference to get the char there.
// E.g. get memory at 0xff3.
char thirdLetter = str[3];       // 'l'
char thirdLetter = *(str + 3);   // 'l'
```

TEXT SEGMENT

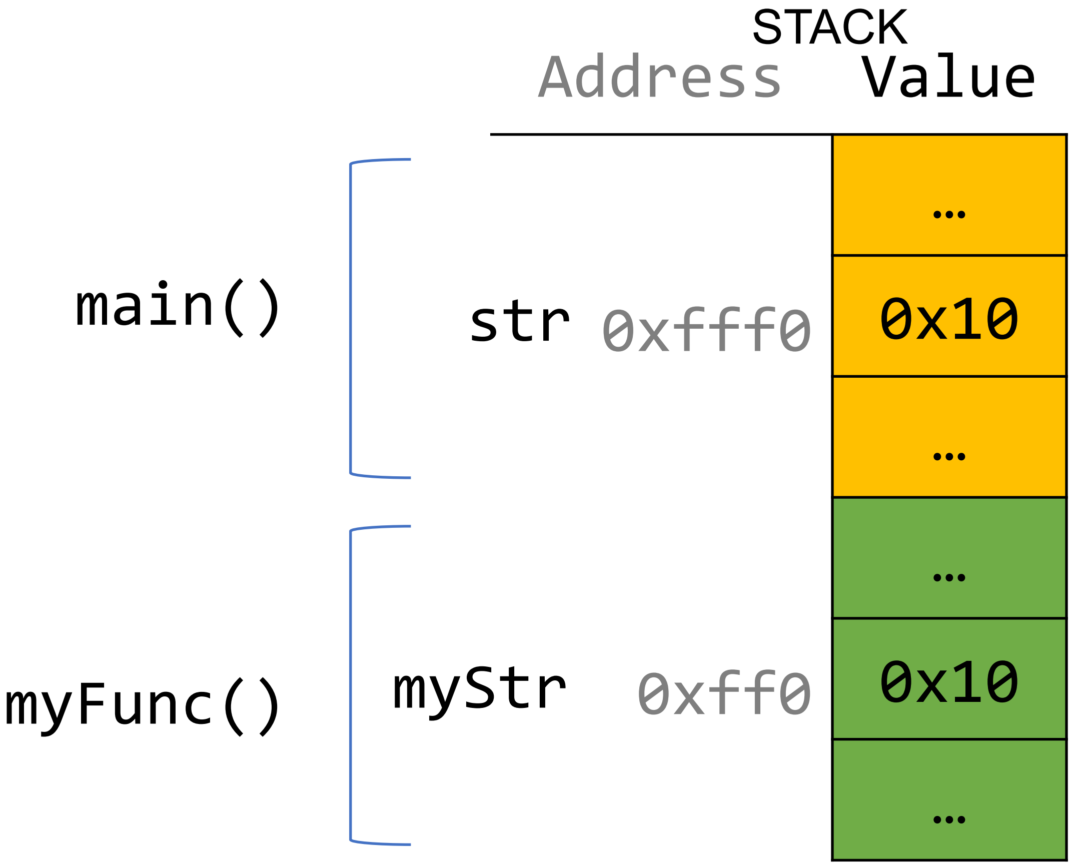
Address	Value
	…
0xff5	'\0'
0xff4	'e'
0xff3	'l'
0xff2	'p'
0xff1	'p'
0xff0	'a'
	…

Strings as Parameters

When you pass a **char *** string as a parameter, C makes a *copy* of the address stored in the **char ***, and passes it to the function. This means they both refer to the same memory location.

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

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

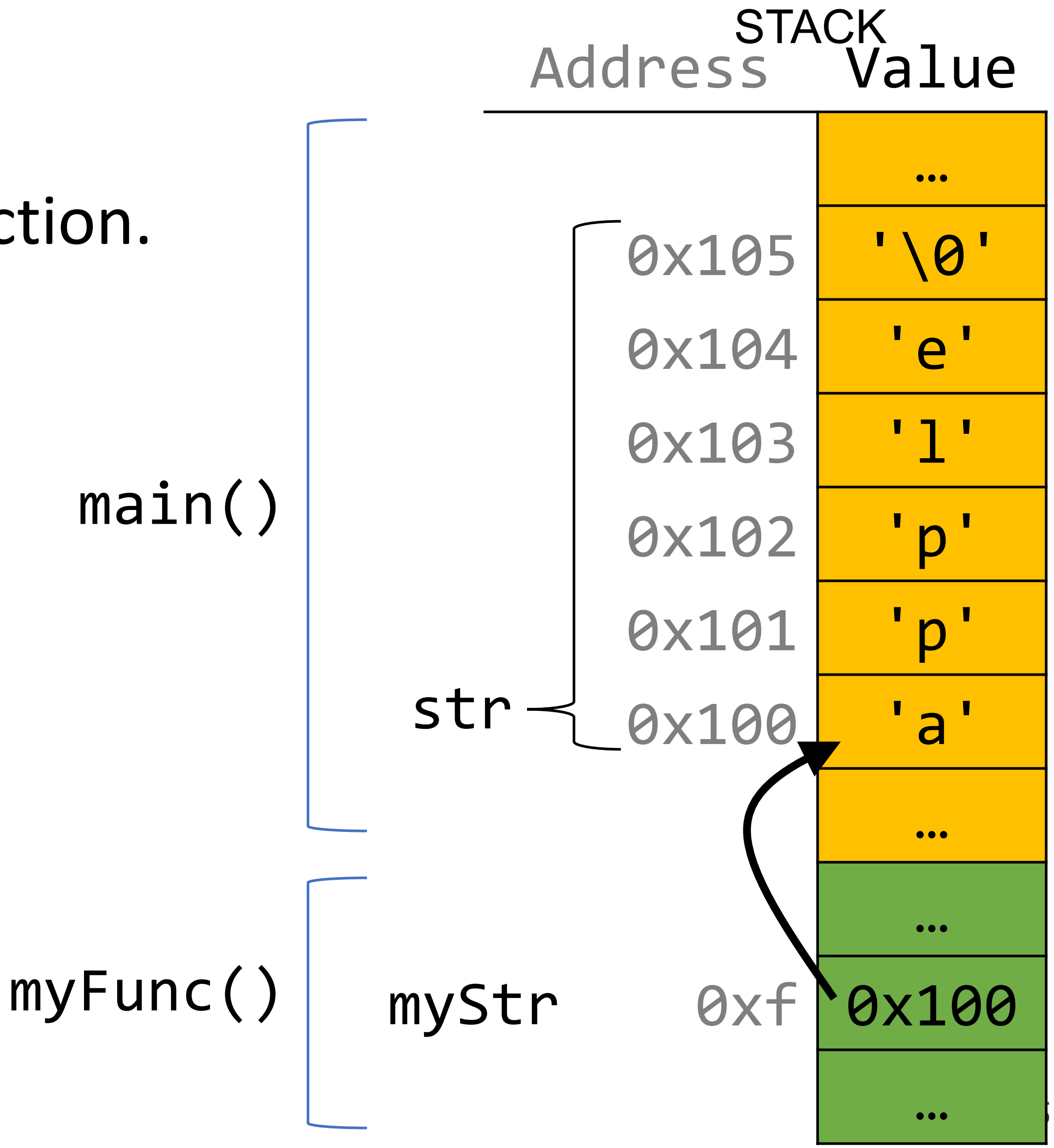


Strings as Parameters

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

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

int main(int argc, char *argv[]) {
     char str[6] = "apple";
     myFunc(str);
     ...
}
```

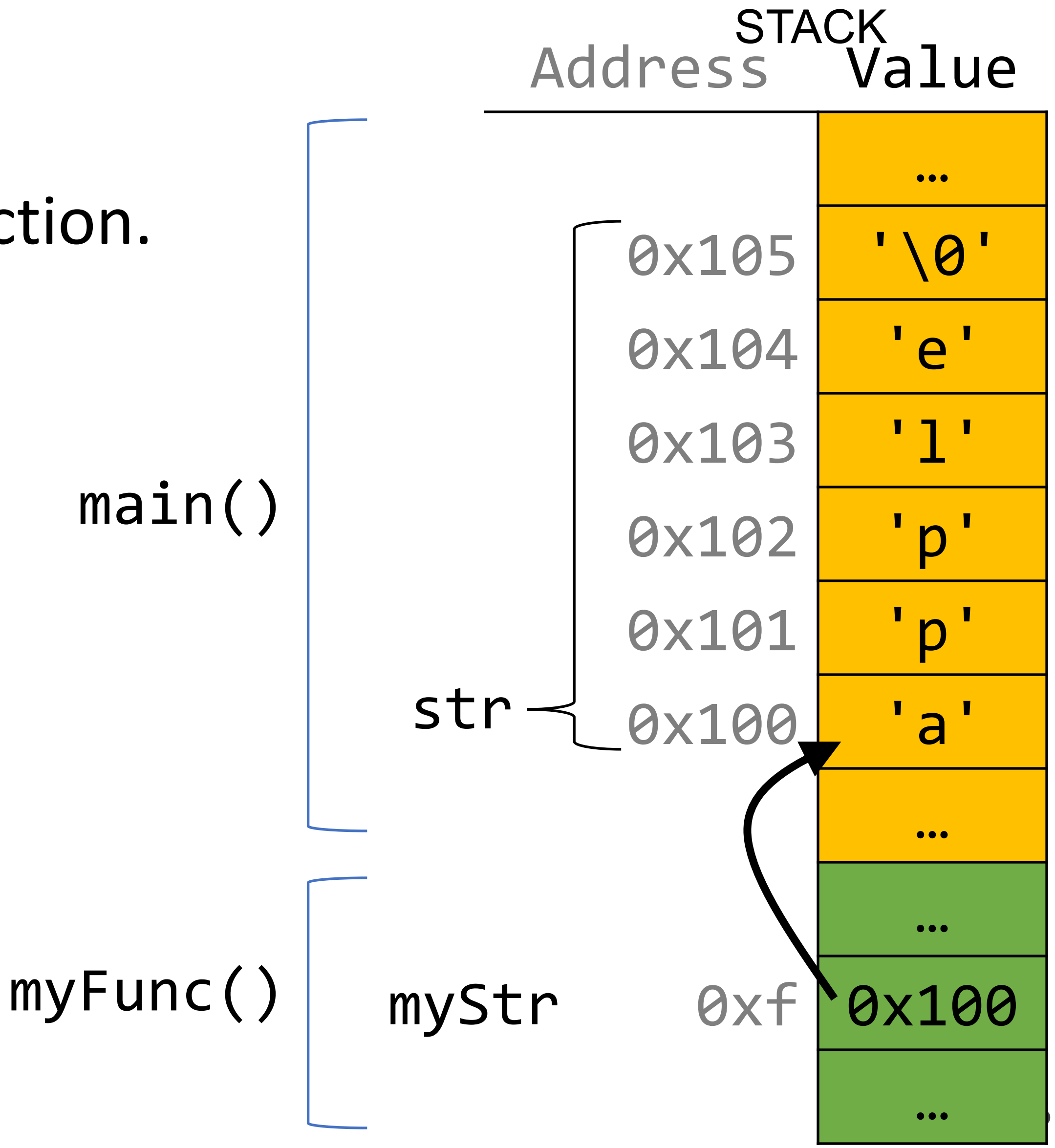


Strings as Parameters

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

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

int main(int argc, char *argv[]) {
     char str[6] = "apple";
     // equivalent
     char *arrPtr = str;
     myFunc(arrPtr);
     ...
}
```



STACK

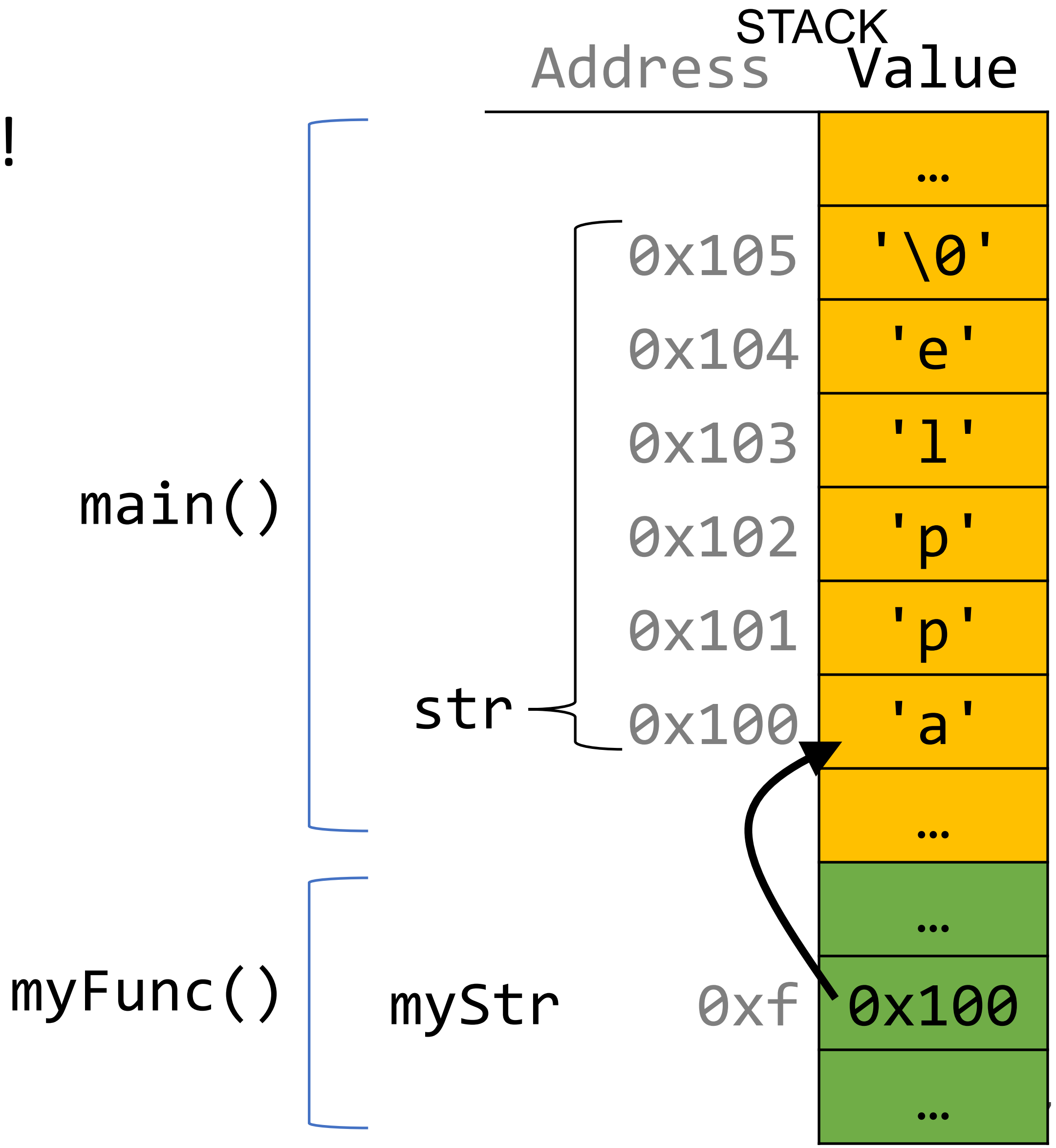
		Address	Value
main()			…
		0x105	'\0'
		0x104	'e'
		0x103	'l'
		0x102	'p'
		0x101	'p'
	str	0x100	'a'
			…
myFunc()			…
	myStr	0xf	0x100
			…

Strings as Parameters

This means if you modify characters in **myFunc**, the changes will persist back in **main**!

```
void myFunc(char *myStr) {
     myStr[4] = 'y';
}

int main(int argc, char *argv[]) {
     char str[6] = "apple";
     myFunc(str);
     printf("%s", str);  // apply
     ...
}
```

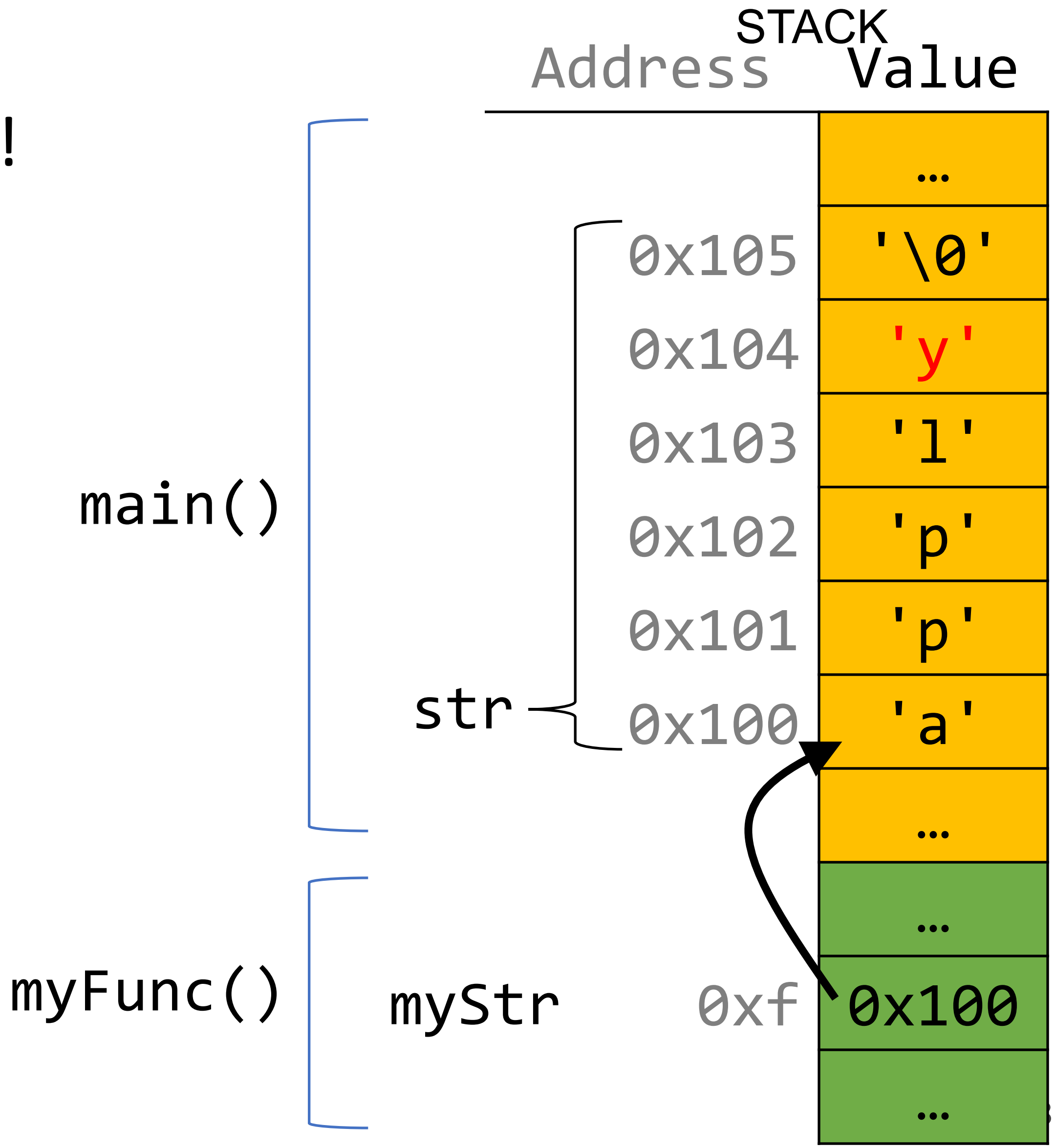


Strings as Parameters

This means if you modify characters in **myFunc**, the changes will persist back in **main**!

```c
void myFunc(char *myStr) {
      myStr[4] = 'y';
}

int main(int argc, char *argv[]) {
      char str[6] = "apple";
      myFunc(str);
      printf("%s", str);  // apply
      ...
}
```



STACK

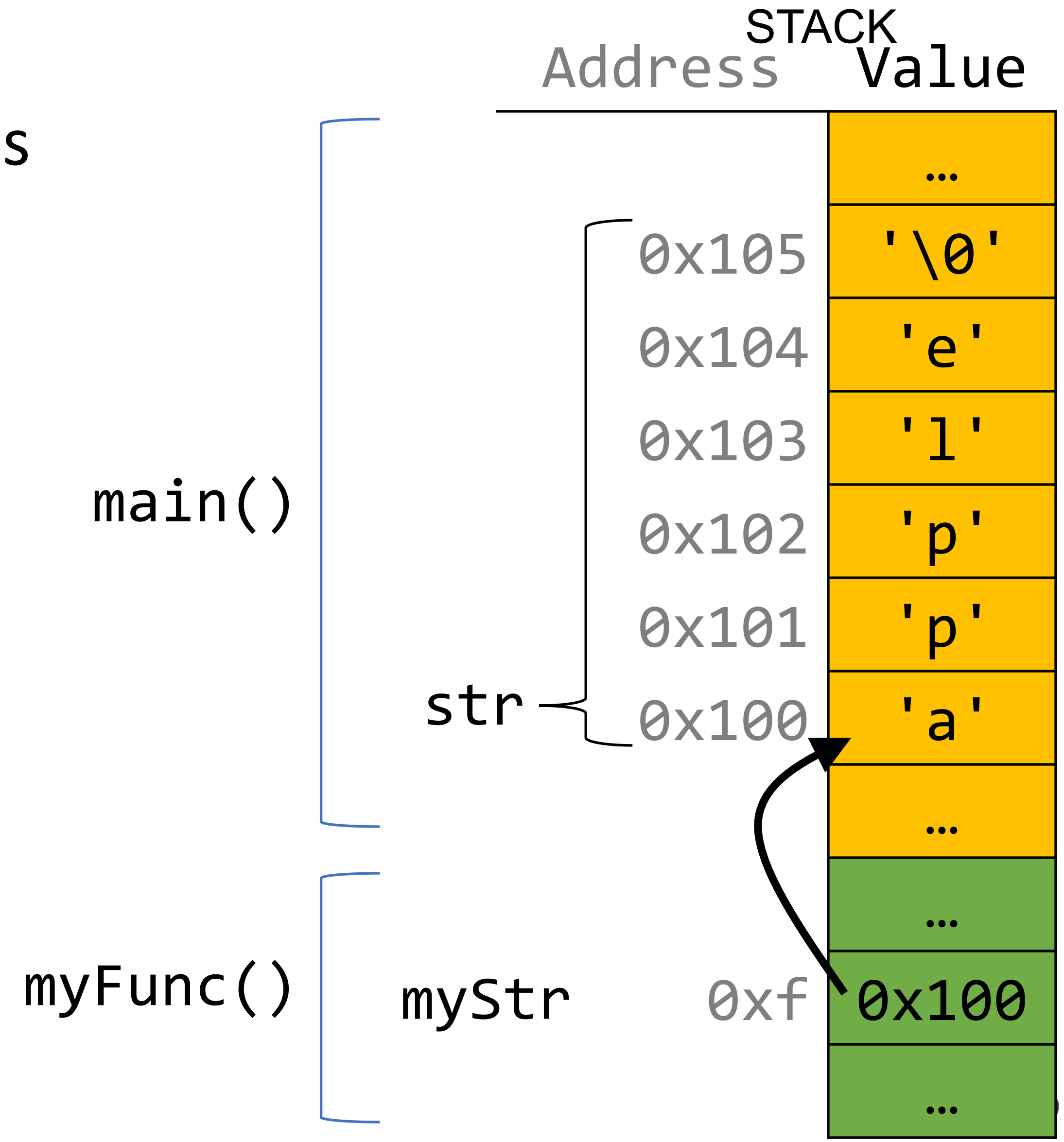
		Address	Value
main()			…
	str	0x105	'\0'
		0x104	'y'
		0x103	'l'
		0x102	'p'
		0x101	'p'
		0x100	'a'
			…
myFunc()			…
	myStr	0xf	0x100
			…

Strings as Parameters

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

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

int main(int argc, char *argv[]) {
	char str[6] = "apple";
	int size = sizeof(str);   // 6
	myFunc(str);
	...
}
```



Strings and Memory

These memory behaviors explain why strings behave the way they do:

1. If we make a variable to store a string literal that is a **char[]**, we can modify the characters because its memory lives in our stack space.
2. If we make a variable to store a string literal that is a **char ***, we cannot modify the characters because its memory lives in the data segment.
3. We can set a **char*** equal to another value, because it is just a pointer.
4. We cannot set a **char[]** equal to another value, because it is not a pointer; it refers to the block of memory reserved for the original array.
5. If we change characters in a string passed to a function, these changes will persist outside of the function.
6. When we pass a char array as a parameter, we can no longer use **sizeof** to get its full size.

Recap

- **Recap:** String Operations
- **Demo:** Buffer Overflow and Valgrind
- Arrays of Strings
- **Practice:** Password Verification
- Pointers
- **Announcements**
- Strings in Memory

Next time: Arrays and Pointers